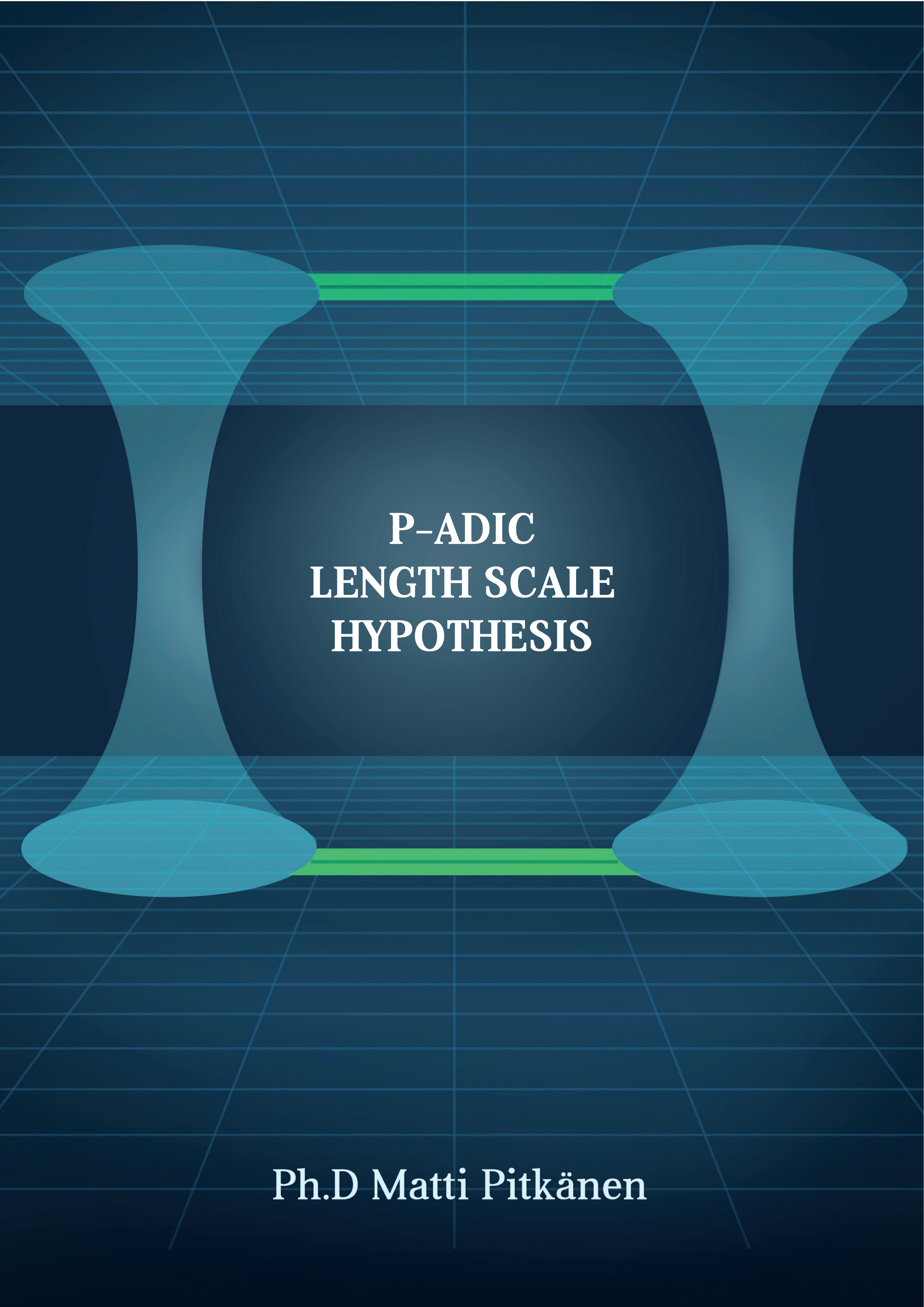

P-ADIC LENGTH SCALE HYPOTHESIS

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Preface

This book belongs to a series of online books summarizing the recent state Topological Geometrodynamics (TGD) and its applications. TGD can be regarded as a unified theory of fundamental interactions but is not the kind of unified theory as so called GUTs constructed by graduate students at seventies and eighties using detailed recipes for how to reduce everything to group theory. Nowadays this activity has been completely computerized and it probably takes only a few hours to print out the predictions of this kind of unified theory as an article in the desired format. TGD is something different and I am not ashamed to confess that I have devoted the last 37 years of my life to this enterprise and am still unable to write The Rules.

If I remember correctly, I got the basic idea of Topological Geometrodynamics (TGD) during autumn 1977, perhaps it was October. What I realized was that the representability of physical space-times as 4-dimensional surfaces of some higher-dimensional space-time obtained by replacing the points of Minkowski space with some very small compact internal space could resolve the conceptual difficulties of general relativity related to the definition of the notion of energy. This belief was too optimistic and only with the advent of what I call zero energy ontology the understanding of the notion of Poincare invariance has become satisfactory. This required also the understanding of the relationship to General Relativity.

It soon became clear that the approach leads to a generalization of the notion of space-time with particles being represented by space-time surfaces with finite size so that TGD could be also seen as a generalization of the string model. Much later it became clear that this generalization is consistent with conformal invariance only if space-time is 4-dimensional and the Minkowski space factor of imbedding space is 4-dimensional. During last year it became clear that 4-D Minkowski space and 4-D complex projective space CP_2 are completely unique in the sense that they allow twistor space with Kähler structure.

It took some time to discover that also the geometrization of also gauge interactions and elementary particle quantum numbers could be possible in this framework: it took two years to find the unique internal space (CP_2) providing this geometrization involving also the realization that family replication phenomenon for fermions has a natural topological explanation in TGD framework and that the symmetries of the standard model symmetries are much more profound than pragmatic TOE builders have believed them to be. If TGD is correct, main stream particle physics chose the wrong track leading to the recent deep crisis when people decided that quarks and leptons belong to same multiplet of the gauge group implying instability of proton.

There have been also longstanding problems.

- Gravitational energy is well-defined in cosmological models but is not conserved. Hence the conservation of the inertial energy does not seem to be consistent with the Equivalence Principle. Furthermore, the imbeddings of Robertson-Walker cosmologies turned out to be vacuum extremals with respect to the inertial energy. About 25 years was needed to realize that the sign of the inertial energy can be also negative and in cosmological scales the density of inertial energy vanishes: physically acceptable universes are creatable from vacuum. Eventually this led to the notion of zero energy ontology (ZEO) which deviates dramatically from the standard ontology being however consistent with the crossing symmetry of quantum field theories. In this framework the quantum numbers are assigned with zero energy states located at the boundaries of so called causal diamonds defined as intersections of future and past directed light-cones. The notion of energy-momentum becomes length scale dependent since one has a scale hierarchy for causal diamonds. This allows to understand the non-conservation of energy as apparent.

  Equivalence Principle as it is expressed by Einstein's equations follows from Poincare invariance once it is realized that GRT space-time is obtained from the many-sheeted space-time of TGD by lumping together the space-time sheets to a regionof Minkowski space and endowing it with an effective metric given as a sum of Minkowski metric and deviations of the metrices of space-time sheets from Minkowski metric. Similar description relates classical gauge potentials identified as components of induced spinor connection to Yang-Mills gauge potentials in GRT space-time. Various topological inhomogenities below resolution scale identified as particles are described using energy momentum tensor and gauge currents.

- From the beginning it was clear that the theory predicts the presence of long ranged classical electro-weak and color gauge fields and that these fields necessarily accompany classical electromagnetic fields.

  It took about 26 years to gain the maturity to admit the obvious: these fields are classical correlates for long range color and weak interactions assignable to dark matter. The only possible conclusion is that TGD physics is a fractal consisting of an entire hierarchy of fractal copies of standard model physics. Also the understanding of electro-weak massivation and screening of weak charges has been a long standing problem, and 32 years was needed to discover that what I call weak form of electric-magnetic duality gives a satisfactory solution of the problem and provides also surprisingly powerful insights to the mathematical structure of quantum TGD.

  The latest development was the realization that the well- definedness of electromagnetic charge as quantum number for the modes of the induced spinors field requires that the CP_2 projection of the region in which they are non-vanishing carries vanishing W boson field and is 2-D. This implies in the generic case their localization to 2-D surfaces: string world sheets and possibly also partonic 2-surfaces. This localization applies to all modes except covariantly constant right handed neutrino generating supersymmetry and mplies that string model in 4-D space-time is part of TGD. Localization is possible only for Kähler-Dirac assigned with Kähler action defining the dynamics of space-time surfaces. One must however leave open the question whether W field might vanish for the space-time of GRT if related to many-sheeted space-time in the proposed manner even when they do not vanish for space-time sheets.

I started the serious attempts to construct quantum TGD after my thesis around 1982. The original optimistic hope was that path integral formalism or canonical quantization might be enough to construct the quantum theory but the first discovery made already during first year of TGD was that these formalisms might be useless due to the extreme non-linearity and enormous vacuum degeneracy of the theory. This turned out to be the case.

- It took some years to discover that the only working approach is based on the generalization of Einstein's program. Quantum physics involves the geometrization of the infinite-dimensional "world of classical worlds" (WCW) identified as 3-dimensional surfaces. Still few years had to pass before I understood that general coordinate invariance leads to a more or less unique solution of the problem and in positive energyontology implies that space-time surfaces are analogous to Bohr orbits. This in positive energy ontology in which space-like 3-surface is basic object. It is not clear whether Bohr orbitology is necessary also in ZEO in which space-time surfaces connect space-like 3-surfaces at the light-like boundaries of causal diamond CD obtained as intersection of future and past directed light-cones (with CP_2 factor included). The reason is that the pair of 3-surfaces replaces the boundary conditions at single 3-surface involving also time derivatives. If one assumes Bohr orbitology then strong correlations between the 3-surfaces at the ends of CD follow. Still a couple of years and I discovered that quantum states of the Universe can be identified as classical spinor fields in WCW. Only quantum jump remains the genuinely quantal aspect of quantum physics.

- During these years TGD led to a rather profound generalization of the space-time concept. Quite general properties of the theory led to the notion of many-sheeted space-time with sheets representing physical subsystems of various sizes. At the beginning of 90s I became dimly aware of the importance of p-adic number fields and soon ended up with the idea that p-adic thermodynamics for a conformally invariant system allows to understand elementary particle massivation with amazingly few input assumptions. The attempts to understand p-adicity from basic principles led gradually to the vision about physics as a generalized number theory as an approach complementary to the physics as an infinite-dimensional spinor geometry of WCW approach. One of its elements was a generalization of the number concept obtained by fusing real numbers and various p-adic numbers along common rationals. The number theoretical trinity involves besides p-adic number fields also quaternions and octonions and the notion of infinite prime.

- TGD inspired theory of consciousness entered the scheme after 1995 as I started to write a book about consciousness. Gradually it became difficult to say where physics ends and consciousness theory begins since consciousness theory could be seen as a generalization of quantum measurement theory by identifying quantum jump as a moment of consciousness and by replacing the observer with the notion of self identified as a system which is conscious as long as it can avoid entanglement with environment. The somewhat cryptic statement "Everything is conscious and consciousness can be only lost" summarizes the basic philosophy neatly.

The idea about p-adic physics as physics of cognition and intentionality emerged also rather naturally and implies perhaps the most dramatic generalization of the space-time concept in which most points of p-adic space-time sheets are infinite in real sense and the projection to the real imbedding space consists of discrete set of points. One of the most fascinating outcomes was the observation that the entropy based on p-adic norm can be negative. This observation led to the vision that life can be regarded as something in the intersection of real and p-adic worlds. Negentropic entanglement has interpretation as a correlate for various positively colored aspects of conscious experience and means also the possibility of strongly correlated states stable under state function reduction and different from the conventional bound states and perhaps playing key role in the energy metabolism of living matter.

If one requires consistency of Negentropy Mazimization Proncible with standard measurement theory, negentropic entanglement defined in terms of number theoretic negentropy is necessarily associated with a density matrix proportional to unit matrix and is maximal and is characterized by the dimension n of the unit matrix. Negentropy is positive and maximal for a p-adic unique prime dividing n.

- One of the latest threads in the evolution of ideas is not more than nine years old. Learning about the paper of Laurent Nottale about the possibility to identify planetary orbits as Bohr orbits with a gigantic value of gravitational Planck constant made once again possible to see the obvious. Dynamical quantized Planck constant is strongly suggested by quantum classical correspondence and the fact that space-time sheets identifiable as quantum coherence regions can have arbitrarily large sizes. Second motivation for the hierarchy of Planck constants comes from bio-electromagnetism suggesting that in living systems Planck constant could have large values making macroscopic quantum coherence possible. The interpretation of dark matter as a hierarchy of phases of ordinary matter characterized by the value of Planck constant is very natural.

  During summer 2010 several new insights about the mathematical structure and interpretation of TGD emerged. One of these insights was the realization that the postulated hierarchy of Planck constants might follow from the basic structure of quantum TGD. The point is that due to the extreme non-linearity of the classical action principle the correspondence between canonical momentum densities and time derivatives of the imbedding space coordinates is one-to-many and the natural description of the situation is in terms of local singular covering spaces of the imbedding space. One could speak about effective value of Planck constant $h_{eff} = n \times h$ coming as a multiple of minimal value of Planck constant. Quite recently it became clear that the non-determinism of Kähler action is indeed the fundamental justification for the hierarchy: the integer n can be also interpreted as the integer characterizing the dimension of unit matrix characterizing negentropic entanglement made possible by the many-sheeted character of the space-time surface.

  Due to conformal invariance acting as gauge symmetry the n degenerate space-time sheets must be replaced with conformal equivalence classes of space-time sheets and conformal transformations correspond to quantum critical deformations leaving the ends of space-time surfaces invariant. Conformal invariance would be broken: only the sub-algebra for which conformal weights are divisible by n act as gauge symmetries. Thus deep connections between conformal invariance related to quantum criticality, hierarchy of Planck constants, negentropic entanglement, effective p-adic topology, and non-determinism of Kähler action perhaps reflecting p-adic non-determinism emerges.

  The implications of the hierarchy of Planck constants are extremely far reaching so that the significance of the reduction of this hierarchy to the basic mathematical structure distinguishing between TGD and competing theories cannot be under-estimated.

From the point of view of particle physics the ultimate goal is of course a practical construction recipe for the S-matrix of the theory. I have myself regarded this dream as quite too ambitious taking into account how far reaching re-structuring and generalization of the basic mathematical structure of quantum physics is required. It has indeed turned out that the dream about explicit formula is unrealistic before one has understood what happens in quantum jump. Symmetries and general physical principles have turned out to be the proper guide line here. To give some impressions about what is required some highlights are in order.

- With the emergence of ZEO the notion of S-matrix was replaced with M-matrix defined between positive and negative energy parts of zero energy states. M-matrix can be interpreted as a complex square root of density matrix representable as a diagonal and positive square root of density matrix and unitary S-matrix so that quantum theory in ZEO can be said to define a square root of thermodynamics at least formally. M-matrices in turn bombine to form the rows of unitary U-matrix defined between zero energy states.

- A decisive step was the strengthening of the General Coordinate Invariance to the requirement that the formulations of the theory in terms of light-like 3-surfaces identified as 3-surfaces at which the induced metric of space-time surfaces changes its signature and in terms of space-like 3-surfaces are equivalent. This means effective 2-dimensionality in the sense that partonic 2-surfaces defined as intersections of these two kinds of surfaces plus 4-D tangent space data at partonic 2-surfaces code for the physics. Quantum classical correspondence requires the coding of the quantum numbers characterizing quantum states assigned to the partonic 2-surfaces to the geometry of space-time surface. This is achieved by adding to the modified Dirac action a measurement interaction term assigned with light-like 3-surfaces.

- The replacement of strings with light-like 3-surfaces equivalent to space-like 3-surfaces means enormous generalization of the super conformal symmetries of string models. A further generalization of these symmetries to non-local Yangian symmetries generalizing the recently discovered Yangian symmetry of $\mathcal{N} = 4$ supersymmetric Yang-Mills theories is highly suggestive. Here the replacement of point like particles with partonic 2-surfaces means the replacement of conformal symmetry of Minkowski space with infinite-dimensional super-conformal algebras. Yangian symmetry provides also a further refinement to the notion of conserved quantum numbers allowing to define them for bound states using non-local energy conserved currents.

- A further attractive idea is that quantum TGD reduces to almost topological quantum field theory. This is possible if the Kähler action for the preferred extremals defining WCW Kähler function reduces to a 3-D boundary term. This takes place if the conserved currents are so called Beltrami fields with the defining property that the coordinates associated with flow lines extend to single global coordinate variable. This ansatz together with the weak form of electric-magnetic duality reduces the Kähler action to Chern-Simons term with the condition that the 3-surfaces are extremals of Chern-Simons action subject to the constraint force defined by the weak form of electric magnetic duality. It is the latter constraint which prevents the trivialization of the theory to a topological quantum field theory. Also the identification of the Kähler function of WCW as Dirac determinant finds support as well as the description of the scattering amplitudes in terms of braids with interpretation in terms of finite measurement resolution coded to the basic structure of the solutions of field equations.

- In standard QFT Feynman diagrams provide the description of scattering amplitudes. The beauty of Feynman diagrams is that they realize unitarity automatically via the so called Cutkosky rules. In contrast to Feynman's original beliefs, Feynman diagrams and virtual particles are taken only as a convenient mathematical tool in quantum field theories. QFT approach is however plagued by UV and IR divergences and one must keep mind open for the possibility that a genuine progress might mean opening of the black box of the virtual particle.

  In TGD framework this generalization of Feynman diagrams indeed emerges unavoidably. Light-like 3-surfaces replace the lines of Feynman diagrams and vertices are replaced by 2-D partonic 2-surfaces. Zero energy ontology and the interpretation of parton orbits as light-like "wormhole throats" suggests that virtual particle do not differ from on mass shell particles only in that the four- and three- momenta of wormhole throats fail to be parallel. The two throats of the wormhole contact defining virtual particle would contact carry on mass shell quantum numbers but for virtual particles the four-momenta need not be parallel and can also have opposite signs of energy.

The localization of the nodes of induced spinor fields to 2-D string world sheets (and possibly also to partonic 2-surfaces) implies a stringy formulation of the theory analogous to stringy variant of twistor formalism with string world sheets having interpretation as 2-braids. In TGD framework fermionic variant of twistor Grassmann formalism leads to a stringy variant of twistor diagrammatics in which basic fermions can be said to be on mass-shell but carry non-physical helicities in the internal lines. This suggests the generalization of the Yangian symmetry to infinite-dimensional super-conformal algebras.

What I have said above is strongly biased view about the recent situation in quantum TGD. This vision is single man's view and doomed to contain unrealistic elements as I know from experience. My dream is that young critical readers could take this vision seriously enough to try to demonstrate that some of its basic premises are wrong or to develop an alternative based on these or better premises. I must be however honest and tell that 32 years of TGD is a really vast bundle of thoughts and quite a challenge for anyone who is not able to cheat himself by taking the attitude of a blind believer or a light-hearted debunker trusting on the power of easy rhetoric tricks.

Matti Pitkänen

Hanko,
September 16, 2014

Acknowledgements

Neither TGD nor these books would exist without the help and encouragement of many people. The friendship with Heikki and Raija Haila and their family have been kept me in contact with the everyday world and without this friendship I would not have survived through these lonely 32 years most of which I have remained unemployed as a scientific dissident. I am happy that my children have understood my difficult position and like my friends have believed that what I am doing is something valuable although I have not received any official recognition for it.

During last decade Tapio Tammi has helped me quite concretely by providing the necessary computer facilities and being one of the few persons in Finland with whom to discuss about my work. I have had also stimulating discussions with Samuli Penttinen who has also helped to get through the economical situations in which there seemed to be no hope. The continual updating of fifteen online books means quite a heavy bureaucracy at the level of bits and without a systemization one ends up with endless copying and pasting and internal consistency is soon lost. Pekka Rapinoja has offered his help in this respect and I am especially grateful for him for my Python skills. Also Matti Vallinkoski has helped me in computer related problems.

The collaboration with Lian Sidorov was extremely fruitful and she also helped me to survive economically through the hardest years. The participation to CASYS conferences in Liege has been an important window to the academic world and I am grateful for Daniel Dubois and Peter Marcer for making this participation possible. The discussions and collaboration with Eduardo de Luna and Istvan Dienes stimulated the hope that the communication of new vision might not be a mission impossible after all. Also blog discussions have been very useful. During these years I have received innumerable email contacts from people around the world. In particualr, I am grateful for Mark McWilliams and Ulla Matfolk for providing links to possibly interesting web sites and articles. These contacts have helped me to avoid the depressive feeling of being some kind of Don Quixote of Science and helped me to widen my views: I am grateful for all these people.

In the situation in which the conventional scientific communication channels are strictly closed it is important to have some loop hole through which the information about the work done can at least in principle leak to the publicity through the iron wall of the academic censorship. Without any exaggeration I can say that without the world wide web I would not have survived as a scientist nor as individual. Homepage and blog are however not enough since only the formally published

result is a result in recent day science. Publishing is however impossible without a direct support from power holders- even in archives like arXiv.org.

Situation changed for five years ago as Andrew Adamatsky proposed the writing of a book about TGD when I had already got used to the thought that my work would not be published during my life time. The Prespacetime Journal and two other journals related to quantum biology and consciousness - all of them founded by Huping Hu - have provided this kind of loop holes. In particular, Dainis Zeps, Phil Gibbs, and Arkadiusz Jadczyk deserve my gratitude for their kind help in the preparation of an article series about TGD catalyzing a considerable progress in the understanding of quantum TGD. Also the viXra archive founded by Phil Gibbs and its predecessor Archive Freedom have been of great help: Victor Christianto deserves special thanks for doing the hard work needed to run Archive Freedom. Also the Neuroquantology Journal founded by Sultan Tarlaci deserves a special mention for its publication policy. And last but not least: there are people who experience as a fascinating intellectual challenge to spoil the practical working conditions of a person working with something which might be called unified theory: I am grateful for the people who have helped me to survive through the virus attacks, an activity which has taken roughly one month per year during the last half decade and given a strong hue of grey to my hair.

For a person approaching his sixty year birthday it is somewhat easier to overcome the hard feelings due to the loss of academic human rights than for an inpatient youngster. Unfortunately the economic situation has become increasingly difficult during the twenty years after the economic depression in Finland which in practice meant that Finland ceased to be a constitutional state in the strong sense of the word. It became possible to depose people like me from the society without fear about public reactions and the classification as dropout became a convenient tool of ridicule to circumvent the ethical issues. During last few years when the right wing has held the political power this trend has been steadily strengthening. In this kind of situation the concrete help from individuals has been and will be of utmost importance. Against this background it becomes obvious that this kind of work is not possible without the support from outside and I apologize for not being able to mention all the people who have helped me during these years.

Matti Pitkänen

Hanko,
September 15, 2010

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Chapter 1

Introduction

1.1 Basic Ideas of Topological Geometrodynamics (TGD)

Standard model describes rather successfully both electroweak and strong interactions but sees them as totally separate and contains a large number of parameters which it is not able to predict. For about four decades ago unified theories known as Grand Unified Theories (GUTs) trying to understand electroweak interactions and strong interactions as aspects of the same fundamental gauge interaction assignable to a larger symmetry group emerged. Later superstring models trying to unify even gravitation and strong and weak interactions emerged. The shortcomings of both GUTs and superstring models are now well-known. If TGD - whose basic idea emerged 37 years ago - would emerge now it would be seen as an attempt trying to solve the difficulties of these approaches to unification.

The basic physical picture behind TGD corresponds to a fusion of two rather disparate approaches: namely TGD as a Poincare invariant theory of gravitation and TGD as a generalization of the old-fashioned string model. The CMAP files at my homepage provide an overview about ideas and evolution of TGD and make easier to understand what TGD and its applications are about (`http://www.tgdtheory.fi/cmaphtml.html` [L20]).

1.1.1 Basic vision very briefly

T(opological) G(eometro)D(ynamics) is one of the many attempts to find a unified description of basic interactions. The development of the basic ideas of TGD to a relatively stable form took time of about half decade [K2].

The basic vision and its relationship to existing theories is now rather well understood.

1. Space-times are representable as 4-surfaces in the 8-dimensional imbedding space $H = M^4 \times CP_2$, where M^4 is 4-dimensional (4-D) Minkowski space and CP_2 is 4-D complex projective space (see Appendix).

2. Induction procedure allows to geometrize various fields. Space-time metric characterizing gravitational fields corresponds to the induced metric obtained by projecting the metric tensor of H to the space-time surface. Electroweak gauge potentials are identified as projections of the components of CP_2 spinor connection to the space-time surface, and color gauge potentials as projections ofCP_2 Killing vector fields representing color symmetries. Also spinor structure can be induced: induced spinor gamma matrices are projections of gamma matrices of H and induced spinor fields just H spinor fields restricted to space-time surface.

3. Geometrization of quantum numbers is achieved. The isometry group of the geometry of CP_2 codes for the color gauge symmetries of strong interactions. Vierbein group codes for electroweak symmetries, and explains their breaking in terms of CP_2 geometry so that standard model gauge group results. There are also important deviations from standard model: color quantum numbers are not spin-like but analogous to orbital angular momentum: this difference is expected to be seen only in CP_2 scale. In contrast to GUTs, quark and

lepton numbers are separately conserved and family replication has a topological explanation in terms of topology of the partonic 2-surface carrying fermionic quantum numbers.

M^4 and CP_2 are unique choices for many other reasons. For instance, they are the unique 4-D space-times allowing twistor space with Kähler structure. M^4 light-cone boundary allows a huge extension of 2-D conformal symmetries. Imbedding space H has a number theoretic interpretation as 8-D space allowing octonionic tangent space structure. M^4 and CP_2 allow quaternionic structures. Therefore standard model symmetries have number theoretic meaning.

4. Induced gauge potentials are expressible in terms of imbedding space coordinates and their gradients and general coordinate invariance implies that there are only 4 field like variables locally. Situation is thus extremely simple mathematically. The objection is that one loses linear superposition of fields. The resolution of the problem comes from the generalization of the concepts of particle and space-time.

   Space-time surfaces can be also particle like having thus finite size. In particular, space-time regions with Euclidian signature of the induced metric (temporal and spatial dimensions in the same role) emerge and have interpretation as lines of generalized Feynman diagrams. Particle in space-time can be identified as a topological inhomogenuity in background space-time surface which looks like the space-time of general relativity in long length scales.

   One ends up with a generalization of space-time surface to many-sheeted space-time with space-time sheets having extremely small distance of about 10^4 Planck lengths (CP_2 size). As one adds a particle to this kind of structure, it touches various space-time sheets and thus interacts with the associated classical fields. Their effects superpose linearly in good approximation and linear superposition of fields is replaced with that for their effects.

   This resolves the basic objection. It also leads to the understanding of how the space-time of general relativity and quantum field theories emerges from TGD space-time as effective space-time when the sheets of many-sheeted space-time are lumped together to form a region of Minkowski space with metric replaced with a metric identified as the sum of empty Minkowski metric and deviations of the metrics of sheets from empty Minkowski metric. Gauge potentials are identified as sums of the induced gauge potentials. TGD is therefore a microscopic theory from which standard model and general relativity follow as a topological simplification however forcing to increase dramatically the number of fundamental field variables.

5. A further objection is that classical weak fields identified as induced gauge fields are long ranged and should cause large parity breaking effects due to weak interactions. These effects are indeed observed but only in living matter. The resolution of problem is implied by the condition that the modes of the induced spinor fields have well-defined electromagnetic charge. This forces their localization to 2-D string world sheets in the generic case having vanishing weak gauge fields so that parity breaking effects emerge just as they do in standard model. Also string model like picture emerges from TGD and one ends up with a rather concrete view about generalized Feynman diagrammatics.

The great challenge is to construct a mathematical theory around these physically very attractive ideas and I have devoted the last thirty seven years for the realization of this dream and this has resulted in eight online books about TGD and nine online books about TGD inspired theory of consciousness and of quantum biology.

1.1.2 Two manners to see TGD and their fusion

As already mentioned, TGD can be interpreted both as a modification of general relativity and generalization of string models.

TGD as a Poincare invariant theory of gravitation

The first approach was born as an attempt to construct a Poincare invariant theory of gravitation. Space-time, rather than being an abstract manifold endowed with a pseudo-Riemannian structure, is regarded as a surface in the 8-dimensional space $H = M^4_\times CP_2$, where M^4 denotes Minkowski space and $CP_2 = SU(3)/U(2)$ is the complex projective space of two complex dimensions [A39, A31, A37, A29].

The identification of the space-time as a sub-manifold [A26, A38] of $M^4 \times CP_2$ leads to an exact Poincare invariance and solves the conceptual difficulties related to the definition of the energy-momentum in General Relativity.

It soon however turned out that sub-manifold geometry, being considerably richer in structure than the abstract manifold geometry, leads to a geometrization of all basic interactions. First, the geometrization of the elementary particle quantum numbers is achieved. The geometry of CP_2 explains electro-weak and color quantum numbers. The different H-chiralities of H-spinors correspond to the conserved baryon and lepton numbers. Secondly, the geometrization of the field concept results. The projections of the CP_2 spinor connection, Killing vector fields of CP_2 and of H-metric to four-surface define classical electro-weak, color gauge fields and metric in X^4.

The choice of H is unique from the condition that TGD has standard model symmetries. Also number theoretical vision selects $H = M^4 \times CP_2$ uniquely. M^4 and CP_2 are also unique spaces allowing twistor space with Kähler structure.

TGD as a generalization of the hadronic string model

The second approach was based on the generalization of the mesonic string model describing mesons as strings with quarks attached to the ends of the string. In the 3-dimensional generalization 3-surfaces correspond to free particles and the boundaries of the 3- surface correspond to partons in the sense that the quantum numbers of the elementary particles reside on the boundaries. Various boundary topologies (number of handles) correspond to various fermion families so that one obtains an explanation for the known elementary particle quantum numbers. This approach leads also to a natural topological description of the particle reactions as topology changes: for instance, two-particle decay corresponds to a decay of a 3-surface to two disjoint 3-surfaces.

This decay vertex does not however correspond to a direct generalization of trouser vertex of string models. Indeed, the important difference between TGD and string models is that the analogs of string world sheet diagrams do not describe particle decays but the propagation of particles via different routes. Particle reactions are described by generalized Feynman diagrams for which 3-D light-like surface describing particle propagating join along their ends at vertices. As 4-manifolds the space-time surfaces are therefore singular like Feynman diagrams as 1-manifolds.

Fusion of the two approaches via a generalization of the space-time concept

The problem is that the two approaches to TGD seem to be mutually exclusive since the orbit of a particle like 3-surface defines 4-dimensional surface, which differs drastically from the topologically trivial macroscopic space-time of General Relativity. The unification of these approaches forces a considerable generalization of the conventional space-time concept. First, the topologically trivial 3-space of General Relativity is replaced with a "topological condensate" containing matter as particle like 3-surfaces "glued" to the topologically trivial background 3-space by connected sum operation. Secondly, the assumption about connectedness of the 3-space is given up. Besides the "topological condensate" there could be "vapor phase" that is a "gas" of particle like 3-surfaces and string like objects (counterpart of the "baby universes" of GRT) and the non-conservation of energy in GRT corresponds to the transfer of energy between different sheets of the space-time and possibly existence vapour phase.

What one obtains is what I have christened as many-sheeted space-time (see fig. `http://www.tgdtheory.fi/appfigures/manysheeted.jpg` or fig. 9 in the appendix of this book). One particular aspect is topological field quantization meaning that various classical fields assignable to a physical system correspond to space-time sheets representing the classical fields to that particular system. One can speak of the field body of a particular physical system. Field body consists of topological light rays, and electric and magnetic flux quanta. In Maxwell's theory system does not possess this kind of field identity. The notion of magnetic body is one of the key players in TGD inspired theory of consciousness and quantum biology.

This picture became more detailed with the advent of zero energy ontology (ZEO). The basic notion of ZEO is causal diamond (CD) identified as the Cartesian product of CP_2 and of the intersection of future and past directed light-cones and having scale coming as an integer multiple of CP_2 size is fundamental. CDs form a fractal hierarchy and zero energy states decompose to products of positive and negative energy parts assignable to the opposite boundaries of CD defining the ends of the space-time surface. The counterpart of zero energy state in positive energy ontology is the pair of initial and final states of a physical event, say particle reaction.

At space-time level ZEO means that 3-surfaces are pairs of space-like 3-surfaces at the opposite light-like boundaries of CD. Since the extremals of Kähler action connect these, one can say that by holography the basic dynamical objects are the space-time surface connecting these 3-surfaces. This changes totally the vision about notions like self-organization: self-organization by quantum jumps does not take for a 3-D system but for the entire 4-D field pattern associated with it.

General Coordinate Invariance (GCI) allows to identify the basic dynamical objects as space-like 3-surfaces at the ends of space-time surface at boundaries of CD: this means that space-time surface is analogous to Bohr orbit. An alternative identification is as light-like 3-surfaces at which the signature of the induced metric changes from Minkowskian to Euclidian and interpreted as lines of generalized Feynman diagrams. Also the Euclidian 4-D regions would have similar interpretation. The requirement that the two interpretations are equivalent, leads to a strong form of General Coordinate Invariance. The outcome is effective 2-dimensionality stating that the partonic 2-surfaces identified as intersections of the space-like ends of space-time surface and light-like wormhole throats are the fundamental objects. That only effective 2-dimensionality is in question is due to the effects caused by the failure of strict determinism of Kähler action. In finite length scale resolution these effects can be neglected below UV cutoff and above IR cutoff. One can also speak about strong form of holography.

1.1.3 Basic objections

Objections are the most powerful tool in theory building. The strongest objection against TGD is the observation that all classical gauge fields are expressible in terms of four imbedding space coordinates only- essentially CP_2 coordinates. The linear superposition of classical gauge fields taking place independently for all gauge fields is lost. This would be a catastrophe without many-sheeted space-time. Instead of gauge fields, only the effects such as gauge forces are superposed. Particle topologically condenses to several space-time sheets simultaneously and experiences the sum of gauge forces. This transforms the weakness to extreme economy: in a typical unified theory the number of primary field variables is countered in hundreds if not thousands, now it is just four.

Second objection is that TGD space-time is quite too simple as compared to GRT space-time due to the imbeddability to 8-D imbedding space. One can also argue that Poincare invariant theory of gravitation cannot be consistent with General Relativity. The above interpretation allows to understand the relationship to GRT space-time and how Equivalence Principle (EP) follows from Poincare invariance of TGD. The interpretation of GRT space-time is as effective space-time obtained by replacing many-sheeted space-time with Minkowski space with effective metric determined as a sum of Minkowski metric and sum over the deviations of the induced metrices of space-time sheets from Minkowski metric. Poincare invariance suggests strongly classical EP for the GRT limit in long length scales at least. One can consider also other kinds of limits such as the analog of GRT limit for Euclidian space-time regions assignable to elementary particles. In this case deformations of CP_2 metric define a natural starting point and CP_2 indeed defines a gravitational instanton with very large cosmological constant in Einstein-Maxwell theory. Also gauge potentials of standard model correspond classically to superpositions of induced gauge potentials over space-time sheets.

Topological field quantization

Topological field quantization distinguishes between TGD based and more standard - say Maxwellian - notion of field. In Maxwell's fields created by separate systems superpose and one cannot tell which part of field comes from which system except theoretically. In TGD these fields correspond to different space-time sheets and only their effects on test particle superpose. Hence physical systems have well-defined field identifies - field bodies - in particular magnetic bodies.

The notion of magnetic body carrying dark matter with non-standard large value of Planck constant has become central concept in TGD inspired theory of consciousness and living matter, and by starting from various anomalies of biology one ends up to a rather detailed view about the role of magnetic body as intentional agent receiving sensory input from the biological body and controlling it using EEG and its various scaled up variants as a communication tool. Among other thins this leads to models for cell membrane, nerve pulse, and EEG.

1.1.4 p-Adic variants of space-time surfaces

There is a further generalization of the space-time concept inspired by p-adic physics forcing a generalization of the number concept through the fusion of real numbers and various p-adic number fields. Also the hierarchy of Planck constants forces a generalization of the notion of space-time but this generalization can be understood in terms of the failure of strict determinism for Kähler action defining the fundamental variational principle behind the dynamics of space-time surfaces.

A very concise manner to express how TGD differs from Special and General Relativities could be following. Relativity Principle (Poincare Invariance), General Coordinate Invariance, and Equivalence Principle remain true. What is new is the notion of sub-manifold geometry: this allows to realize Poincare Invariance and geometrize gravitation simultaneously. This notion also allows a geometrization of known fundamental interactions and is an essential element of all applications of TGD ranging from Planck length to cosmological scales. Sub-manifold geometry is also crucial in the applications of TGD to biology and consciousness theory.

1.1.5 The threads in the development of quantum TGD

The development of TGD has involved several strongly interacting threads: physics as infinite-dimensional geometry; TGD as a generalized number theory, the hierarchy of Planck constants interpreted in terms of dark matter hierarchy, and TGD inspired theory of consciousness. In the following these threads are briefly described.

The theoretical framework involves several threads.

1. Quantum T(opological) G(eometro)D(ynamics) as a classical spinor geometry for infinite-dimensional WCW, p-adic numbers and quantum TGD, and TGD inspired theory of consciousness and of quantum biology have been for last decade of the second millenium the basic three strongly interacting threads in the tapestry of quantum TGD.

2. The discussions with Tony Smith initiated a fourth thread which deserves the name 'TGD as a generalized number theory'. The basic observation was that classical number fields might allow a deeper formulation of quantum TGD. The work with Riemann hypothesis made time ripe for realization that the notion of infinite primes could provide, not only a reformulation, but a deep generalization of quantum TGD. This led to a thorough and extremely fruitful revision of the basic views about what the final form and physical content of quantum TGD might be. Together with the vision about the fusion of p-adic and real physics to a larger coherent structure these sub-threads fused to the "physics as generalized number theory" thread.

3. A further thread emerged from the realization that by quantum classical correspondence TGD predicts an infinite hierarchy of macroscopic quantum systems with increasing sizes, that it is not at all clear whether standard quantum mechanics can accommodate this hierarchy, and that a dynamical quantized Planck constant might be necessary and strongly suggested by the failure of strict determinism for the fundamental variational principle. The identification of hierarchy of Planck constants labelling phases of dark matter would be natural. This also led to a solution of a long standing puzzle: what is the proper interpretation of the predicted fractal hierarchy of long ranged classical electro-weak and color gauge fields. Quantum classical correspondences allows only single answer: there is infinite hierarchy of p-adically scaled up variants of standard model physics and for each of them also dark hierarchy. Thus TGD Universe would be fractal in very abstract and deep sense.

The chronology based identification of the threads is quite natural but not logical and it is much more logical to see p-adic physics, the ideas related to classical number fields, and infinite primes as sub-threads of a thread which might be called "physics as a generalized number theory". In the following I adopt this view. This reduces the number of threads to four.

TGD forces the generalization of physics to a quantum theory of consciousness, and represent TGD as a generalized number theory vision leads naturally to the emergence of p-adic physics as physics of cognitive representations. The eight online books [K72, K55, K46, K83, K64, K82, K81, K62] about TGD and nine online books about TGD inspired theory of consciousness and of quantum biology [K68, K10, K51, K9, K28, K33, K35, K61, K79] are warmly recommended to the interested reader.

Quantum TGD as spinor geometry of World of Classical Worlds

A turning point in the attempts to formulate a mathematical theory was reached after seven years from the birth of TGD. The great insight was "Do not quantize". The basic ingredients to the new approach have served as the basic philosophy for the attempt to construct Quantum TGD since then and have been the following ones:

1. Quantum theory for extended particles is free(!), classical(!) field theory for a generalized Schrödinger amplitude in the configuration space CH ("world of classical worlds",WCW) consisting of all possible 3-surfaces in H. "All possible" means that surfaces with arbitrary many disjoint components and with arbitrary internal topology and also singular surfaces topologically intermediate between two different manifold topologies are included. Particle reactions are identified as topology changes [A35, A40, A41]. For instance, the decay of a 3-surface to two 3-surfaces corresponds to the decay $A \rightarrow B+C$. Classically this corresponds to a path of WCW leading from 1-particle sector to 2-particle sector. At quantum level this corresponds to the dispersion of the generalized Schrödinger amplitude localized to 1-particle sector to two-particle sector. All coupling constants should result as predictions of the theory since no nonlinearities are introduced.

2. During years this naive and very rough vision has of course developed a lot and is not anymore quite equivalent with the original insight. In particular, the space-time correlates of Feynman graphs have emerged from theory as Euclidian space-time regions and the strong form of General Coordinate Invariance has led to a rather detailed and in many respects unexpected visions. This picture forces to give up the idea about smooth space-time surfaces and replace space-time surface with a generalization of Feynman diagram in which vertices represent the failure of manifold property. I have also introduced the word "world of classical worlds" (WCW) instead of rather formal "configuration space". I hope that "WCW" does not induce despair in the reader having tendency to think about the technicalities involved!

3. WCW is endowed with metric and spinor structure so that one can define various metric related differential operators, say Dirac operator, appearing in the field equations of the theory [1]. The most ambitious dream is that zero energy states correspond to a complete solution basis for the Dirac operator of WCW so that this classical free field theory would dictate M-matrices defined between positive and negative energy parts of zero energy states which form orthonormal rows of what I call U-matrix as a matrix defined between zero energy states. Given M-matrix in turn would decompose to a product of a hermitian density matrix and unitary S-matrix.

   M-matrix would define time-like entanglement coefficients between positive and negative energy parts of zero energy states (all net quantum numbers vanish for them) and can be regarded as a hermitian square root of density matrix multiplied by a unitary S-matrix. Quantum theory would be in well-defined sense a square root of thermodynamics. The orthogonality and hermiticity of the complex square roots of density matrices commuting with S-matrix means that they span infinite-dimensional Lie algebra acting as symmetries of the S-matrix. Therefore quantum TGD would reduce to group theory in well-defined sense: its own symmetries would define the symmetries of the theory. In fact the Lie algebra of Hermitian M-matrices extends to Kac-Moody type algebra obtained by multiplying hermitian

[1] There are four kinds of Dirac operators in TGD. WCW Dirac operator appearing in Super-Virasoro conditions, imbedding space Dirac operator whose modes define the ground states of Super-Virasoro representations, Kähler-Dirac operator at space-time surfaces, and the algebraic variant of M^4 Dirac operator appearing in propagators

square roots of density matrices with powers of the S-matrix. Also the analog of Yangian algebra involving only non-negative powers of S-matrix is possible.

4. By quantum classical correspondence the construction of WCW spinor structure reduces to the second quantization of the induced spinor fields at space-time surface. The basic action is so called modified Dirac action (or Kähler-Dirac action) in which gamma matrices are replaced with the modified (Kähler-Dirac) gamma matrices defined as contractions of the canonical momentum currents with the imbedding space gamma matrices. In this manner one achieves super-conformal symmetry and conservation of fermionic currents among other things and consistent Dirac equation. The modified gamma matrices define as anti-commutators effective metric, which might provide geometrization for some basic observables of condensed matter physics. One might also talk about bosonic emergence in accordance with the prediction that the gauge bosons and graviton are expressible in terms of bound states of fermion and anti-fermion.

5. An important result relates to the notion of induced spinor connection. If one requires that spinor modes have well-defined em charge, one must assume that the modes in the generic situation are localized at 2-D surfaces - string world sheets or perhaps also partonic 2-surfaces - at which classical W boson fields vanish. Covariantly constant right handed neutrino generating super-symmetries forms an exception. The vanishing of also Z^0 field is possible for Kähler-Dirac action and should hold true at least above weak length scales. This implies that string model in 4-D space-time becomes part of TGD. Without these conditions classical weak fields can vanish above weak scale only for the GRT limit of TGD for which gauge potentials are sums over those for space-time sheets.

   The localization simplifies enormously the mathematics and one can solve exactly the Kähler-Dirac equation for the modes of the induced spinor field just like in super string models.

   At the light-like 3-surfaces at which the signature of the induced metric changes from Euclidian to Minkowskian so that $\sqrt{g_4}$ vanishes one can pose the condition that the algebraic analog of massless Dirac equation is satisfied by the nodes so that Kähler-Dirac action gives massless Dirac propagator localizable at the boundaries of the string world sheets.

The evolution of these basic ideas has been rather slow but has gradually led to a rather beautiful vision. One of the key problems has been the definition of Kähler function. Kähler function is Kähler action for a preferred extremal assignable to a given 3-surface but what this preferred extremal is? The obvious first guess was as absolute minimum of Kähler action but could not be proven to be right or wrong. One big step in the progress was boosted by the idea that TGD should reduce to almost topological QFT in which braids would replace 3-surfaces in finite measurement resolution, which could be inherent property of the theory itself and imply discretization at partonic 2-surfaces with discrete points carrying fermion number.

1. TGD as almost topological QFT vision suggests that Kähler action for preferred extremals reduces to Chern-Simons term assigned with space-like 3-surfaces at the ends of space-time (recall the notion of causal diamond (CD)) and with the light-like 3-surfaces at which the signature of the induced metric changes from Minkowskian to Euclidian. Minkowskian and Euclidian regions would give at wormhole throats the same contribution apart from coefficients and in Minkowskian regions the $\sqrt{g_4}$ factorc coming from metric would be imaginary so that one would obtain sum of real term identifiable as Kähler function and imaginary term identifiable as the ordinary Minkowskian action giving rise to interference effects and stationary phase approximation central in both classical and quantum field theory.

   Imaginary contribution - the presence of which I realized only after 33 years of TGD - could also have topological interpretation as a Morse function. On physical side the emergence of Euclidian space-time regions is something completely new and leads to a dramatic modification of the ideas about black hole interior.

2. The manner to achieve the reduction to Chern-Simons terms is simple. The vanishing of Coulomb contribution to Kähler action is required and is true for all known extremals if one makes a general ansatz about the form of classical conserved currents. The so called weak

form of electric-magnetic duality defines a boundary condition reducing the resulting 3-D terms to Chern-Simons terms. In this manner almost topological QFT results. But only "almost" since the Lagrange multiplier term forcing electric-magnetic duality implies that Chern-Simons action for preferred extremals depends on metric.

TGD as a generalized number theory

Quantum T(opological)D(ynamics) as a classical spinor geometry for infinite-dimensional configuration space ("world of classical worldss", WCW), p-adic numbers and quantum TGD, and TGD inspired theory of consciousness, have been for last ten years the basic three strongly interacting threads in the tapestry of quantum TGD. The fourth thread deserves the name 'TGD as a generalized number theory'. It involves three separate threads: the fusion of real and various p-adic physics to a single coherent whole by requiring number theoretic universality discussed already, the formulation of quantum TGD in terms of hyper-counterparts of classical number fields identified as sub-spaces of complexified classical number fields with Minkowskian signature of the metric defined by the complexified inner product, and the notion of infinite prime.

1. p-Adic TGD and fusion of real and p-adic physics to single coherent whole

The p-adic thread emerged for roughly ten years ago as a dim hunch that p-adic numbers might be important for TGD. Experimentation with p-adic numbers led to the notion of canonical identification mapping reals to p-adics and vice versa. The breakthrough came with the successful p-adic mass calculations using p-adic thermodynamics for Super-Virasoro representations with the super-Kac-Moody algebra associated with a Lie-group containing standard model gauge group. Although the details of the calculations have varied from year to year, it was clear that p-adic physics reduces not only the ratio of proton and Planck mass, the great mystery number of physics, but all elementary particle mass scales, to number theory if one assumes that primes near prime powers of two are in a physically favored position. Why this is the case, became one of the key puzzles and led to a number of arguments with a common gist: evolution is present already at the elementary particle level and the primes allowed by the p-adic length scale hypothesis are the fittest ones.

It became very soon clear that p-adic topology is not something emerging in Planck length scale as often believed, but that there is an infinite hierarchy of p-adic physics characterized by p-adic length scales varying to even cosmological length scales. The idea about the connection of p-adics with cognition motivated already the first attempts to understand the role of the p-adics and inspired 'Universe as Computer' vision but time was not ripe to develop this idea to anything concrete (p-adic numbers are however in a central role in TGD inspired theory of consciousness). It became however obvious that the p-adic length scale hierarchy somehow corresponds to a hierarchy of intelligences and that p-adic prime serves as a kind of intelligence quotient. Ironically, the almost obvious idea about p-adic regions as cognitive regions of space-time providing cognitive representations for real regions had to wait for almost a decade for the access into my consciousness.

In string model context one tries to reduces the physics to Planck scale. The price is the inability to say anything about physics in long length scales. In TGD p-adic physics takes care of this shortcoming by predicting the physics also in long length scales.

There were many interpretational and technical questions crying for a definite answer.

1. What is the relationship of p-adic non-determinism to the classical non-determinism of the basic field equations of TGD? Are the p-adic space-time region genuinely p-adic or does p-adic topology only serve as an effective topology? If p-adic physics is direct image of real physics, how the mapping relating them is constructed so that it respects various symmetries? Is the basic physics p-adic or real (also real TGD seems to be free of divergences) or both? If it is both, how should one glue the physics in different number field together to get *the* Physics? Should one perform p-adicization also at the level of the WCW? Certainly the p-adicization at the level of super-conformal representation is necessary for the p-adic mass calculations.

2. Perhaps the most basic and most irritating technical problem was how to precisely define p-adic definite integral which is a crucial element of any variational principle based formulation of the field equations. Here the frustration was not due to the lack of solution but due to the too large number of solutions to the problem, a clear symptom for the sad fact that

clever inventions rather than real discoveries might be in question. Quite recently I however learned that the problem of making sense about p-adic integration has been for decades central problem in the frontier of mathematics and a lot of profound work has been done along same intuitive lines as I have proceeded in TGD framework. The basic idea is certainly the notion of algebraic continuation from the world of rationals belonging to the intersection of real world and various p-adic worlds.

The notion of p-adic manifold [K85] identified as p-adic space-time surface solving p-adic analogs of field equations and having real space-time sheets as chart maps provides a possible solution of the basic challenge. One can also speak of real space-time surfaces having p-adic space-time surfaces as chart maps (cognitive maps, "thought bubbles"). Discretization required having interpretation in terms of finite measurement resolution is unavoidable in this approach.

Despite various uncertainties, the number of the applications of the poorly defined p-adic physics has grown steadily and the applications turned out to be relatively stable so that it was clear that the solution to these problems must exist. It became only gradually clear that the solution of the problems might require going down to a deeper level than that represented by reals and p-adics.

The key challenge is to fuse various p-adic physics and real physics to single larger structures. This has inspired a proposal for a generalization of the notion of number field by fusing real numbers and various p-adic number fields and their extensions along rationals and possible common algebraic numbers. This leads to a generalization of the notions of imbedding space and space-time concept and one can speak about real and p-adic space-time sheets. The quantum dynamics should be such that it allows quantum transitions transforming space-time sheets belonging to different number fields to each other. The space-time sheets in the intersection of real and p-adic worlds are of special interest and the hypothesis is that living matter resides in this intersection. This leads to surprisingly detailed predictions and far reaching conjectures. For instance, the number theoretic generalization of entropy concept allows negentropic entanglement central for the applications to living matter (see fig. `http://www.tgdtheory.fi/appfigures/cat.jpg` or fig. 21 in the appendix of this book).

The basic principle is number theoretic universality stating roughly that the physics in various number fields can be obtained as completion of rational number based physics to various number fields. Rational number based physics would in turn describe physics in finite measurement resolution and cognitive resolution. The notion of finite measurement resolution has become one of the basic principles of quantum TGD and leads to the notions of braids as representatives of 3-surfaces and inclusions of hyper-finite factors as a representation for finite measurement resolution. The braids actually co-emerge with string world sheets implied by the condition that em charge is well-defined for spinor modes.

2. The role of classical number fields

The vision about the physical role of the classical number fields relies on certain speculative questions inspired by the idea that space-time dynamics could be reduced to associativity or co-associativity condition. Associativity means here associativity of tangent spaces of space-time region and co-associativity associativity of normal spaces of space-time region.

1. Could space-time surfaces X^4 be regarded as associative or co-associative ("quaternionic" is equivalent with "associative") surfaces of H endowed with octonionic structure in the sense that tangent space of space-time surface would be associative (co-associative with normal space associative) sub-space of octonions at each point of X^4 [K67]. This is certainly possible and an interesting conjecture is that the preferred extremals of Kähler action include associative and co-associative space-time regions.

2. Could the notion of compactification generalize to that of number theoretic compactification in the sense that one can map associative (co-associative) surfaces of M^8 regarded as octonionic linear space to surfaces in $M^4 \times CP_2$ [K67]? This conjecture - $M^8 - H$ duality - would give for $M^4 \times CP_2$ deep number theoretic meaning. CP_2 would parametrize associative planes of octonion space containing fixed complex plane $M^2 \subset M^8$ and CP_2 point would thus characterize the tangent space of $X^4 \subset M^8$. The point of M^4 would be obtained

by projecting the point of $X^4 \subset M^8$ to a point of M^4 identified as tangent space of X^4. This would guarantee that the dimension of space-time surface in H would be four. The conjecture is that the preferred extremals of Kähler action include these surfaces.

3. M^8-H duality can be generalized to a duality $H \rightarrow H$ if the images of the associative surface in M^8 is associative surface in H. One can start from associative surface of H and assume that it contains the preferred M^2 tangent plane in 8-D tangent space of H or integrable distribution $M^2(x)$ of them, and its points to H by mapping M^4 projection of H point to itself and associative tangent space to CP_2 point. This point need not be the original one! If the resulting surface is also associative, one can iterate the process indefinitely. WCW would be a category with one object.

4. G_2 defines the automorphism group of octonions, and one might hope that the maps of octonions to octonions such that the action of Jacobian in the tangent space of associative or co-associative surface reduces to that of G_2 could produce new associative/co-associative surfaces. The action of G_2 would be analogous to that of gauge group.

5. One can also ask whether the notions of commutativity and co-commutativity could have physical meaning. The well-definedness of em charge as quantum number for the modes of the induced spinor field requires their localization to 2-D surfaces (right-handed neutrino is an exception) - string world sheets and partonic 2-surfaces. This can be possible only for Kähler action and could have commutativity and co-commutativity as a number theoretic counterpart. The basic vision would be that the dynamics of Kähler action realizes number theoretical geometrical notions like associativity and commutativity and their co-notions.

The notion of number theoretic compactification stating that space-time surfaces can be regarded as surfaces of either M^8 or $M^4 \times CP_2$. As surfaces of M^8 identifiable as space of hyper-octonions they are hyper-quaternionic or co-hyper-quaternionic- and thus maximally associative or co-associative. This means that their tangent space is either hyper-quaternionic plane of M^8 or an orthogonal complement of such a plane. These surface can be mapped in natural manner to surfaces in $M^4 \times CP_2$ [K67] provided one can assign to each point of tangent space a hyper-complex plane $M^2(x) \subset M^4 \subset M^8$. One can also speak about $M^8 - H$ duality.

This vision has very strong predictive power. It predicts that the preferred extremals of Kähler action correspond to either hyper-quaternionic or co-hyper-quaternionic surfaces such that one can assign to tangent space at each point of space-time surface a hyper-complex plane $M^2(x) \subset M^4$. As a consequence, the M^4 projection of space-time surface at each point contains $M^2(x)$ and its orthogonal complement. These distributions are integrable implying that space-time surface allows dual slicings defined by string world sheets Y^2 and partonic 2-surfaces X^2. The existence of this kind of slicing was earlier deduced from the study of extremals of Kähler action and christened as Hamilton-Jacobi structure. The physical interpretation of $M^2(x)$ is as the space of non-physical polarizations and the plane of local 4-momentum.

Number theoretical compactification has inspired large number of conjectures. This includes dual formulations of TGD as Minkowskian and Euclidian string model type theories, the precise identification of preferred extremals of Kähler action as extremals for which second variation vanishes (at least for deformations representing dynamical symmetries) and thus providing space-time correlate for quantum criticality, the notion of number theoretic braid implied by the basic dynamics of Kähler action and crucial for precise construction of quantum TGD as almost-topological QFT, the construction of WCW metric and spinor structure in terms of second quantized induced spinor fields with modified Dirac action defined by Kähler action realizing the notion of finite measurement resolution and a connection with inclusions of hyper-finite factors of type II_1 about which Clifford algebra of WCW represents an example.

The two most important number theoretic conjectures relate to the preferred extremals of Kähler action. The general idea is that classical dynamics for the preferred extremals of Kähler action should reduce to number theory: space-time surfaces should be either associative or co-associative in some sense.

Associativity (co-associativity) would be that tangent (normal) spaces of space-time surfaces associative (co-associative) in some sense and thus quaternionic (co-quaternionic). This can be formulated in two manners.

1. One can introduce octonionic tangent space basis by assigning to the "free" gamma matrices octonion basis or in terms of octonionic representation of the imbedding space gamma matrices possible in dimension $D = 8$.

2. Associativity (quaternionicity) would state that the projections of octonionic basic vectors or induced gamma matrices basis to the space-time surface generates associative (quaternionic) sub-algebra at each space-time point. Co-associativity is defined in analogous manner and can be expressed in terms of the components of second fundamental form.

3. For gamma matrix option induced rather than modified gamma matrices must be in question since modified gamma matrices can span lower than 4-dimensional space and are not parallel to the space-time surfaces as imbedding space vectors.

3. Infinite primes

The discovery of the hierarchy of infinite primes and their correspondence with a hierarchy defined by a repeatedly second quantized arithmetic quantum field theory gave a further boost for the speculations about TGD as a generalized number theory.

After the realization that infinite primes can be mapped to polynomials possibly representable as surfaces geometrically, it was clear how TGD might be formulated as a generalized number theory with infinite primes forming the bridge between classical and quantum such that real numbers, p-adic numbers, and various generalizations of p-adics emerge dynamically from algebraic physics as various completions of the algebraic extensions of rational (hyper-)quaternions and (hyper-)octonions. Complete algebraic, topological and dimensional democracy would characterize the theory.

What is especially interesting is that p-adic and real regions of the space-time surface might aso emerge automatically as solutions of the field equations. In the space-time regions where the solutions of field equations give rise to in-admissible complex values of the imbedding space coordinates, p-adic solution can exist for some values of the p-adic prime. The characteristic non-determinism of the p-adic differential equations suggests strongly that p-adic regions correspond to 'mind stuff', the regions of space-time where cognitive representations reside. This interpretation implies that p-adic physics is physics of cognition. Since Nature is probably a brilliant simulator of Nature, the natural idea is to study the p-adic physics of the cognitive representations to derive information about the real physics. This view encouraged by TGD inspired theory of consciousness clarifies difficult interpretational issues and provides a clear interpretation for the predictions of p-adic physics.

1.1.6 Hierarchy of Planck constants and dark matter hierarchy

By quantum classical correspondence space-time sheets can be identified as quantum coherence regions. Hence the fact that they have all possible size scales more or less unavoidably implies that Planck constant must be quantized and have arbitrarily large values. If one accepts this then also the idea about dark matter as a macroscopic quantum phase characterized by an arbitrarily large value of Planck constant emerges naturally as does also the interpretation for the long ranged classical electro-weak and color fields predicted by TGD. Rather seldom the evolution of ideas follows simple linear logic, and this was the case also now. In any case, this vision represents the fifth, relatively new thread in the evolution of TGD and the ideas involved are still evolving.

Dark matter as large $\hbar$ phases

D. Da Rocha and Laurent Nottale [E4] have proposed that Schrödinger equation with Planck constant $\hbar$ replaced with what might be called gravitational Planck constant $\hbar_{gr} = \frac{GmM}{v_0}$ ($\hbar = c = 1$). v_0 is a velocity parameter having the value $v_0 = 144.7 \pm .7$ km/s giving $v_0/c = 4.6 \times 10^{-4}$. This is rather near to the peak orbital velocity of stars in galactic halos. Also subharmonics and harmonics of v_0 seem to appear. The support for the hypothesis coming from empirical data is impressive.

Nottale and Da Rocha believe that their Schrödinger equation results from a fractal hydrodynamics. Many-sheeted space-time however suggests that astrophysical systems are at some levels of the hierarchy of space-time sheets macroscopic quantum systems. The space-time sheets in question would carry dark matter.

Nottale's hypothesis would predict a gigantic value of h_{gr}. Equivalence Principle and the independence of gravitational Compton length on mass m implies however that one can restrict the values of mass m to masses of microscopic objects so that h_{gr} would be much smaller. Large h_{gr} could provide a solution of the black hole collapse (IR catastrophe) problem encountered at the classical level. The resolution of the problem inspired by TGD inspired theory of living matter is that it is the dark matter at larger space-time sheets which is quantum coherent in the required time scale [K59] .

It is natural to assign the values of Planck constants postulated by Nottale to the space-time sheets mediating gravitational interaction and identifiable as magnetic flux tubes (quanta) possibly carrying monopole flux and identifiable as remnants of cosmic string phase of primordial cosmology. The magnetic energy of these flux quanta would correspond to dark energy and magnetic tension would give rise to negative "pressure" forcing accelerate cosmological expansion. This leads to a rather detailed vision about the evolution of stars and galaxies identified as bubbles of ordinary and dark matter inside magnetic flux tubes identifiable as dark energy.

Hierarchy of Planck constants from the anomalies of neuroscience and biology

The quantal ELF effects of ELF em fields on vertebrate brain have been known since seventies. ELF em fields at frequencies identifiable as cyclotron frequencies in magnetic field whose intensity is about 2/5 times that of Earth for biologically important ions have physiological effects and affect also behavior. What is intriguing that the effects are found only in vertebrates (to my best knowledge). The energies for the photons of ELF em fields are extremely low - about 10^{-10} times lower than thermal energy at physiological temperatures- so that quantal effects are impossible in the framework of standard quantum theory. The values of Planck constant would be in these situations large but not gigantic.

This inspired the hypothesis that these photons correspond to so large a value of Planck constant that the energy of photons is above the thermal energy. The proposed interpretation was as dark photons and the general hypothesis was that dark matter corresponds to ordinary matter with non-standard value of Planck constant. If only particles with the same value of Planck constant can appear in the same vertex of Feynman diagram, the phases with different value of Planck constant are dark relative to each other. The phase transitions changing Planck constant can however make possible interactions between phases with different Planck constant but these interactions do not manifest themselves in particle physics. Also the interactions mediated by classical fields should be possible. Dark matter would not be so dark as we have used to believe.

The hypothesis $h_{eff} = h_{gr}$ - at least for microscopic particles - implies that cyclotron energies of charged particles do not depend on the mass of the particle and their spectrum is thus universal although corresponding frequencies depend on mass. In bio-applications this spectrum would correspond to the energy spectrum of bio-photons assumed to result from dark photons by h_{eff} reducing phase transition and the energies of bio-photons would be in visible and UV range associated with the excitations of bio-molecules.

Also the anomalies of biology (see for instance [K52, K53, K77]) support the view that dark matter might be a key player in living matter.

Does the hierarchy of Planck constants reduce to the vacuum degeneracy of Kähler action?

This starting point led gradually to the recent picture in which the hierarchy of Planck constants is postulated to come as integer multiples of the standard value of Planck constant. Given integer multiple $\hbar = n\hbar_0$ of the ordinary Planck constant $\hbar_0$ is assigned with a multiple singular covering of the imbedding space [K22]. One ends up to an identification of dark matter as phases with non-standard value of Planck constant having geometric interpretation in terms of these coverings providing generalized imbedding space with a book like structure with pages labelled by Planck constants or integers characterizing Planck constant. The phase transitions changing the value of Planck constant would correspond to leakage between different sectors of the extended imbedding space. The question is whether these coverings must be postulated separately or whether they are only a convenient auxiliary tool.

The simplest option is that the hierarchy of coverings of imbedding space is only effective. Many-sheeted coverings of the imbedding space indeed emerge naturally in TGD framework. The huge vacuum degeneracy of Kähler action implies that the relationship between gradients of the imbedding space coordinates and canonical momentum currents is many-to-one: this was the very fact forcing to give up all the standard quantization recipes and leading to the idea about physics as geometry of the "world of classical worlds". If one allows space-time surfaces for which all sheets corresponding to the same values of the canonical momentum currents are present, one obtains effectively many-sheeted covering of the imbedding space and the contributions from sheets to the Kähler action are identical. If all sheets are treated effectively as one and the same sheet, the value of Planck constant is an integer multiple of the ordinary one. A natural boundary condition would be that at the ends of space-time at future and past boundaries of causal diamond containing the space-time surface, various branches co-incide. This would raise the ends of space-time surface in special physical role.

A more precise formulation is in terms of presence of large number of space-time sheets connecting given space-like 3-surfaces at the opposite boundaries of causal diamond. Quantum criticality presence of vanishing second variations of Kähler action and identified in terms of conformal invariance broken down to to sub-algebras of super-conformal algebras with conformal weights divisible by integer n is highly suggestive notion and would imply that n sheets of the effective covering are actually conformal equivalence classes of space-time sheets with same Kähler action and same values of conserved classical charges (see fig. `http://www.tgdtheory.fi/appfigures/planckhierarchy.jpg`, which is also in the appendix of this book). n would naturally correspond the value of h_{eff} and its factors negentropic entanglement with unit density matrix would be between the n sheets of two coverings of this kind. p-Adic prime would be largest prime power factor of n.

Dark matter as a source of long ranged weak and color fields

Long ranged classical electro-weak and color gauge fields are unavoidable in TGD framework. The smallness of the parity breaking effects in hadronic, nuclear, and atomic length scales does not however seem to allow long ranged electro-weak gauge fields. The problem disappears if long range classical electro-weak gauge fields are identified as space-time correlates for massless gauge fields created by dark matter. Also scaled up variants of ordinary electro-weak particle spectra are possible. The identification explains chiral selection in living matter and unbroken $U(2)_{ew}$ invariance and free color in bio length scales become characteristics of living matter and of biochemistry and bio-nuclear physics.

The recent view about the solutions of Kähler- Dirac action assumes that the modes have a well-defined em charge and this implies that localization of the modes to 2-D surfaces (right-handed neutrino is an exception). Classical W boson fields vanish at these surfaces and also classical Z^0 field can vanish. The latter would guarantee the absence of large parity breaking effects above intermediate boson scale scaling like h_{eff}.

1.2 Bird's eye of view about the topics of the book

The book is devoted to the applications of p-adic length scale hypothesis and dark matter hierarchy.

1. p-Adic length scale hypothesis states that primes $p \simeq 2^k$, k integer, in particular prime, define preferred p-adic length scales. Physical arguments supporting this hypothesis are based on the generalization of Hawking's area law for blackhole entropy so that it applies in case of elementary particles.

2. A much deeper number theory based justification for this hypothesis is based on the generalization of the number concept fusing real number fields and p-adic number fields among common rationals or numbers in their non-trivial algebraic extensions. This approach also justifies the notion of multi-p-fractality and allows to understand scaling law in terms of simultaneous $p \simeq 2^k$- and 2-fractality.

3. Certain anomalous empirical findings inspire in TGD framework the hypothesis about the existence of entire hierarchy of phases of matter identifiable as dark matter. The levels of dark matter hierarchy are labeled by the values of dynamical quantized Planck constant. The justification for the hypothesis provided by quantum classical correspondence and the fact the sizes of space-time sheets identifiable as quantum coherence regions can be arbitrarily large.

The organization of the book is following.

1. The first part of the book is devoted to the description of elementary particle massivation in terms of p-adic thermodynamics.
2. In second part is devoted to the detailed calculation of masses of elementary particles and hadrons, and to various new physics suggested or predicted by the resulting scenario.

1.3 Sources

The eight online books about TGD [K72, K55, K83, K64, K46, K82, K81, K62] and nine online books about TGD inspired theory of consciousness and quantum biology [K68, K10, K51, K9, K28, K33, K35, K61, K79] are warmly recommended for the reader willing to get overall view about what is involved.

My homepage (`http://www.tgdtheory.com/curri.html`) contains a lot of material about TGD. In particular, there is summary about TGD and its applications using CMAP representation serving also as a TGD glossary [L20, L21] (see `http://www.tgdtheory.fi/cmaphtml.html` and `http://www.tgdtheory.fi/tgdglossary.pdf`).

I have published articles about TGD and its applications to consciousness and living matter in *Journal of Non-Locality* (`http://journals.sfu.ca/jnonlocality/index.php/jnonlocality` founded by Lian Sidorov and in *Prespacetime Journal* (`http://prespacetime.com`), *Journal of Consciousness Research and Exploration* (`https://www.createspace.com/4185546`), and *DNA Decipher Journal* (`http://dnadecipher.com`), all of them founded by Huping Hu. One can find the list about the articles published at `http://www.tgdtheory.com/curri.html`. I am grateful for these far-sighted people for providing a communication channel, whose importance one cannot overestimate.

1.4 The contents of the book

1.4.1 Part I: p-Adic description of particle massivation

In the first part of the book a p-adic description of particle massivation using p-adic thermodynamics and TGD variant of Higgs mechanism is developed.

Overall view about TGD from particle physics perspective

Topological Geometrodynamics is able to make rather precise and often testable predictions. In this and two other articles I want to describe the recent over all view about the aspects of quantum TGD relevant for particle physics.

In the first chapter I concentrate the heuristic picture about TGD with emphasis on particle physics.

- First I represent briefly the basic ontology: the motivations for TGD and the notion of many-sheeted space-time, the concept of zero energy ontology, the identification of dark matter in terms of hierarchy of Planck constant which now seems to follow as a prediction of quantum TGD, the motivations for p-adic physics and its basic implications, and the identification of space-time surfaces as generalized Feynman diagrams and the basic implications of this identification.

- Symmetries of quantum TGD are discussed. Besides the basic symmetries of the imbedding space geometry allowing to geometrize standard model quantum numbers and classical fields there are many other symmetries. General Coordinate Invariance is especially powerful in TGD framework allowing to realize quantum classical correspondence and implies effective 2-dimensionality realizing strong form of holography. Super-conformal symmetries of super string models generalize to conformal symmetries of 3-D light-like 3-surfaces and one can understand the generalization of Equivalence Principle in terms of coset representations for the two super Virasoro algebras associated with lightlike boundaries of so called causal diamonds defined as intersections of future and past directed lightcones (CDs) and with light-like 3-surfaces. Super-conformal symmetries imply generalization of the space-time supersymmetry in TGD framework consistent with the supersymmetries of minimal supersymmetric variant of the standard model. Twistorial approach to gauge theories has gradually become part of quantum TGD and the natural generalization of the Yangian symmetry identified originally as symmetry of $\mathcal{N} = 4$ SYMs is postulated as basic symmetry of quantum TGD.

- The so called weak form of electric-magnetic duality has turned out to have extremely far reaching consequences and is responsible for the recent progress in the understanding of the physics predicted by TGD. The duality leads to a detailed identification of elementary particles as composite objects of massless particles and predicts new electro-weak physics at LHC. Together with a simple postulate about the properties of preferred extremals of Kähler action the duality allows also to realized quantum TGD as almost topological quantum field theory giving excellent hopes about integrability of quantum TGD.

- There are two basic visions about the construction of quantum TGD. Physics as infinite-dimensional Kähler geometry of world of classical worlds (WCW) endowed with spinor structure and physics as generalized number theory. These visions are briefly summarized as also the practical constructing involving the concept of Dirac operator. As a matter fact, the construction of TGD involves three Dirac operators. The Kähler Dirac equation holds true in the interior of space-time surface and its solutions havea natural interpretation in terms of description of matter, in particular condensed matter. Chern-Simons Dirac action is associated with the light-like 3-surfaces and space-like 3-surfaces at ends of space-time surface at light-like boundaries of CD. One can assign to it a generalized eigenvalue equation and the matrix valued eigenvalues correspond to the the action of Dirac operator on momentum eigenstates. Momenta are however not usual momenta but pseudo-momenta very much analogous to region momenta of twistor approach. The third Dirac operator is associated with super Virasoro generators and super Virasoro conditions define Dirac equation in WCW. These conditions characterize zero energy states as modes of WCW spinor fields and code for the generalization of S-matrix to a collection of what I call M-matrices defining the rows of unitary U-matrix defining unitary process.

- Twistor approach has inspired several ideas in quantum TGD during the last years and it seems that the Yangian symmetry and the construction of scattering amplitudes in terms of Grassmannian integrals generalizes to TGD framework. This is due to ZEO allowing to assume that all particles have massless fermions as basic building blocks. ZEO inspires the hypothesis that incoming and outgoing particles are bound states of fundamental fermions associated with wormhole throats. Virtual particles would also consist of on mass shell massless particles but without bound state constraint. This implies very powerful constraints on loop diagrams and there are excellent hopes about their finiteness. Twistor approach also inspires the conjecture that quantum TGD allows also formulation in terms of 6-dimensional holomorphic surfaces in the product $CP_3 \times CP_3$ of two twistor spaces and general arguments allow to identify the partial different equations satisfied by these surfaces.

1.4.2 The recent vision about preferred extremals and solutions of the modified Dirac equation

During years several approaches to what preferred extremals of Kähler action and solutions of the modified Dirac equation could be have been proposed and the challenge is to see whether at least some of these approaches are consistent with each other. It is good to list various approaches first.

1. For preferred extremals generalization of conformal invariance to 4-D situation is very attractive approach and leads to concrete conditions formally similar to those encountered in string model. The approach based on basic heuristics for massless equations, on effective 3-dimensionality, and weak form of electric magnetic duality is also promising. An alternative approach is inspired by number theoretical considerations and identifies space-time surfaces as associative or co-associative sub-manifolds of octonionic imbedding space.

2. There are also several approaches for solving the modified Dirac equation. The most promising approach is assumes that other than right-handed neutrino modes are restricted on 2-D stringy world sheets and/or partonic 2-surfaces. This strange looking view is a rather natural consequence of number theoretic vision. The conditions stating that electric charge is conserved for preferred extremals is an alternative very promising approach.

In this chapter the question whether these various approaches are mutually consistent is discussed. It indeed turns out that the approach based on the conservation of electric charge leads under rather general assumptions to the proposal that solutions of the modified Dirac equation are localized on 2-dimensional string world sheets and/or partonic 2-surfaces. Einstein's equations are satisfied for the preferred extremals and this implies that the earlier proposal for the realization of Equivalence Principle is not needed. This leads to a considerable progress in the understanding of super Virasoro representations for super-symplectic and super-Kac-Moody algebra. In particular, the proposal is that super-Kac-Moody currents assignable to string world sheets define duals of gauge potentials and their generalization for gravitons: in the approximation that gauge group is Abelian - motivated by the notion of finite measurement resolution - the exponents for the sum of KM charges would define non-integrable phase factors. One can also identify Yangian as the algebra generated by these charges. The approach allows also to understand the special role of the right handed neutrino in SUSY according to TGD.

Elementary particle vacuum functionals

Genus-generation correspondence is one of the basic ideas of TGD approach. In order to answer various questions concerning the plausibility of the idea, one should know something about the dependence of the elementary particle vacuum functionals on the vibrational degrees of freedom for the partonic 2-surface.

The construction of the elementary particle vacuum functionals based on Diff invariance, 2-dimensional conformal symmetry, modular invariance plus natural stability requirements indeed leads to an essentially unique form of the vacuum functionals and one can understand why $g > 0$ bosonic families are experimentally absent and why lepton numbers are conserved separately.

An argument suggesting that the number of the light fermion families is three, is developed. The crux of the argument is that the partonic 2-surfaces coding for quantum states are for the maxima of Kähler action hyper-elliptic, that is possess Z_2 conformal symmetry, which for $g > 2$ implies that elementary particle vacuum functional vanishes.

Massless states and particle massivation

This chapter represents the most recent view about elementary particle massivation in TGD framework. This topic is necessarily quite extended since many several notions and new mathematics is involved. Therefore the calculation of particle masses involves five chapters. In the following my goal is to provide an up-to-date summary whereas the chapters are unavoidably a story about evolution of ideas.

The identification of the spectrum of light particles reduces to two tasks: the construction of massless states and the identification of the states which remain light in p-adic thermodynamics. The latter task is relatively straightforward. The thorough understanding of the massless spectrum requires however a real understanding of quantum TGD. It would be also highly desirable to understand why p-adic thermodynamics combined with p-adic length scale hypothesis works. A lot of progress has taken place in these respects during last years.

Zero energy ontology providing a detailed geometric view about bosons and fermions, the generalization of S-matrix to what I call M-matrix, the notion of finite measurement resolution characterized in terms of inclusions of von Neumann algebras, the derivation of p-adic coupling constant evolution and p-adic length scale hypothesis from the first principles, the realization that the counterpart of Higgs mechanism involves generalized eigenvalues of the modified Dirac operator: these are represent important steps of progress during last years with a direct relevance for the understanding of particle spectrum and massivation although the predictions of p-adic thermodynamics are not affected.

During 2010 a further progress took place. These steps of progress relate closely to zero energy ontology, bosonic emergence, the realization of the importance of twistors in TGD, and to the discovery of the weak form of electric-magnetic duality. Twistor approach and the understanding of the Chern-Simons Dirac operator served as a midwife in the process giving rise to the birth of the idea that all particles at fundamental level are massless and that both ordinary elementary particles and string like objects emerge from them. Even more, one can interpret virtual particles as being composed of these massless on mass shell particles assignable to wormhole throats so that four-momentum conservation poses extremely powerful constraints on loop integrals and makes them manifestly finite.

The weak form of electric-magnetic duality led to the realization that elementary particles correspond to bound states of two wormhole throats with opposite Kähler magnetic charges with second throat carrying weak isospin compensating that of the fermion state at second wormhole throat. Both fermions and bosons correspond to wormhole contacts: in the case of fermions topological condensation generates the second wormhole throat. This means that altogether four wormhole throats are involved with both fermions, gauge bosons, and gravitons (for gravitons this is unavoidable in any case). For p-adic thermodynamics the mathematical counterpart of string corresponds to a wormhole contact with size of order CP_2 size with the role of its ends played by wormhole throats at which the signature of the induced 4-metric changes. The key observation is that for massless states the throats of spin 1 particle must have opposite three-momenta so that gauge bosons are necessarily massive, even photon and other particles usually regarded as massless must have small mass which in turn cancels infrared divergences and give hopes about exact Yangian symmetry generalizing that of $\mathcal{N} = 4$ SYM. Besides this there is weak "stringy" contribution to the mass assignable to the magnetic flux tubes connecting the two wormhole throats at the two space-time sheets.

1.4.3 Part II: New physics predicted by TGD

Higgs or something else?

The question whether TGD predicts Higgs or not has been one of the longstanding issues of TGD. For 10 years ago I would not have hesitated to tell that TGD does not predict Higgs and had good looking arguments for my claim. During years my views have been alternating between Higgs and no-Higgs option. In the light of after wisdom the basic mistake has been the lack of a conscious attempt to localize precisely the location of the problem and suggest a minimal modification of standard theory picture to solve it.

Now the situation is settled experimentally: Higgs is there. It is however somewhat too light so that Higgs mechanism is not stable against radiative corrections. SUSY cannot take care of this problem since LHC demonstrated that SUSY mass scale is too high. One has the problem known as loss of "naturalness". Hence Higgs is not yet a fully written page in the history of physics. Furthermore, the experiments demonstrate the existence of Higgs, not the reality of Higgs mechanism. Higgs mechanism in fermionic sector is indeed an ugly duckling: the dimensionless couplings of fermions to Higgs vary in huge range: 12 orders of magnitude between neutrinos and top quark.

1. In TGD framework Higgs mechanism is replaced by p-adic thermodynamics. The couplings of Higgs to fermions are by dimensional arguments very naturally gradient couplings with coupling constant, which has dimensions of inverse mass. This dimensional coupling is same for all fermions so that naturalness is achieved.

2. Massivation of gauge bosons combines Higgs components and weak gauge bosons to massive particles in unitary gauge but leaves photon massless apart from small higher order corrections form p-adic thermodynamics. Unitary gauge is in TGD uniquely fixed by CP_2

geometry. This trivial observation means that there is no need for Higgs vacuum expectation value to define the em neutral direction in gauge algebra. Furthermore, the absence of covariantly constant holomorphic CP_2 vector fields strongly suggests that Higgs vacuum expectation does not make sense. This does not exclude the existence of Higgs like particle as the original wrong conclusion was.

3. W/Z mass squared ratio - the source of troubles in p-adic thermodynamics based approach - is expressible in terms of corresponding gauge coupling strengths g_i^2, $i = W, Z$, if the string tension of the flux tube connecting the two wormhole contacts assignable to gauge boson is proportional to g_i^2. This is definitely a new element in the physical picture and replaces Higgs vacuum energy with the energy of string.

4. p-Adic thermodynamics relying on super-conformal invariance can describe in its recent form only the contributions of wormhole contacts to the particle masses [K34]. The contributions from "long strings" connecting different wormhole contacts cannot be calculated. To achieve this one must generalize conformal invariance to include two conformal weights: the conformal weight assignable to the conformal weight for the light-like radial coordinate of light-cone boundary and the spinorial conformal weight assignable to the induced spinor fields at string world sheets. It seems that also an extension to Yangian algebra containing poly-local generators with locus defined as partonic 2-surface is needed: the number of partonic 2-surface would define a quantum number. p-Adic thermodynamics for the representations of Yangian with states labeled by these three integers could provide the complete description of the states.

   The recent construction of WCW geometry indeed leads to a picture allowing interpretation in terms of Yangian extension of super-conformal invariance. The matrix elements of WCW metrix are labelled by two conformal weights assignable to the light-like radial coordinate of light-cone boundary and to the coordinate along string defining the boundary of string world sheet at which fermions are located from the condition that spinor modes have a well-defined value of em charge.

In this chapter the recent view about Higgs is described and reader is saved from the many alternatives that I have considered during last years.

SUSY in TGD Universe

The view about space-time supersymmetry differs from the standard view in many respects. First of all, the super symmetries are not associated with Majorana spinors. Super generators correspond to the fermionic oscillator operators assignable to leptonic and quark-like induced spinors and there is in principle infinite number of them so that formally one would have $\mathcal{N} = \infty$ SUSY.

Quite recent developments in the understanding of the modified Dirac equation (I am writing this 2012) have led to a considerable understanding of the special role of right-handed neutrino. Whereas all other fermions are localized to 2-D string world sheets and partonic 2-surfaces by the condition that electromagnetic charge defined in spinorial sense is conserved, right-handed neutrino is delocalized at entire space-time surface and there is unbroken 4-dimensional counterpart of 2-D super-conformal symmetry associated with it. The rapid experimental progress at LHC during 2011-2012 has more or less eliminated standard SUSY and this gives a powerful constraint in the attempts to understand what TGD SUSY could be.

As conjectured earlier, TGD indeed has also 2-D badly broken SUSY generated by all fermion modes of the modified Dirac equation and labelled by conformal weight. This SUSY could be also interpreted super-conformal symmetry. It also gives rise to extension of 2-D super-conformal symmetry to 4-D super-conformal symmetry much larger than the ordinary super-conformal symmetry: this space-time SUSY applies at the level of space-time surfaces but what about TGD counteraprt of conventional space-time SUSY at the level of M^4 and imbedding space? Could covariantly constant right-handed neutrino generate it?

What remains to be understood is the role of the covariantly constant right-handed neutrino spinor carrying no momentum: it behaves like Majorana spinor and its helicity is not constrained by Dirac equation. It is not clear whether the states defined by 2-D parton and by parton plus 4-D delocalized right-handed neutrino can be distinguished experimentally if right-handed neutrino does not carry four-momentum. This would be a trivial explanation for the failure to find evidence for SUSY at LHC. In fact, this argument can be developed to a more precise one: both fermions and sfermions exists and form representations of SUSY with second state having zero norm. Therefore fermion and sfermion candidates exist but belong to different representations of SUSY, and right-handed neutrinos remain invisible in the dynamics and the characteristic spin and momentum dependent vertex factors distinguishing between particle and sparticle are absent. The loss of space-time SUSY is not a catastrophe since it is not needed to stabilize Higgs in TGD framework since the variant of Higgs mechanism based on Higgs like pseudo-scalar is based conformally covariant Higgs potential containing no tachyonic Higgs mass term and is free of the problems related to radiative instability of the tachyonic Higgs mass term.

In this chapter I discuss the evolution of the vision about SUSY in TGD framework. There is no attempt to represent a final outcome in a concise form because I do not have such a final view yet. I represent the arguments developed during years in roughly chronological order so that reader can see how the development has taken place. The arguments are not necessarily internally consistent and can be inaccurate.

p-Adic Particle Massivation: New Physics: part I

TGD predicts a lot of new physics and it is quite possible that this new physics becomes visible at LHC. Although the calculational formalism is still lacking, p-adic length scale hypothesis allows to make precise quantitative predictions for particle masses by using simple scaling arguments.

The basic elements of quantum TGD responsible for new physics are following.

1. The new view about particles relies on their identification as partonic 2-surfaces (plus 4-D tangent space data to be precise). This effective metric 2-dimensionality implies generalizaton of the notion of Feynman diagram and holography in strong sense. One implication is the notion of field identity or field body making sense also for elementary particles and the Lamb shift anomaly of muonic hydrogen could be explained in terms of field bodies of quarks.

2. The topological explanation for family replication phenomenon implies genus generation correspondence and predicts in principle infinite number of fermion families. One can however develop a rather general argument based on the notion of conformal symmetry known as hyper-ellipticity stating that only the genera $g = 0, 1, 2$ are light. What "light" means is however an open question. If light means something below CP_2 mass there is no hope of observing new fermion families at LHC. If it means weak mass scale situation changes.

   For bosons the implications of family replication phenomenon can be understood from the fact that they can be regarded as pairs of fermion and antifermion assignable to the opposite wormhole throats of wormhole throat. This means that bosons formally belong to octet and singlet representations of dynamical SU(3) for which 3 fermion families define 3-D representation. Singlet would correspond to ordinary gauge bosons. Also interacting fermions suffer topological condensation and correspond to wormhole contact. One can either assume that the resulting wormhole throat has the topology of sphere or that the genus is same for both throats.

3. The view about space-time supersymmetry differs from the standard view in many respects. First of all, the super symmetries are not associated with Majorana spinors. Super generators correspond to the fermionic oscillator operators assignable to leptonic and quark-like induced spinors and there is in principle infinite number of them so that formally one would have $\mathcal{N} = \infty$ SUSY. I have discussed the required modification of the formalism of SUSY theories and it turns out that effectively one obtains just $\mathcal{N} = 1$ SUSY required by experimental constraints. The reason is that the fermion states with higher fermion number define only short range interactions analogous to van der Waals forces. Right handed neutrino generates this super-symmetry broken by the mixing of the M^4 chiralities implied by the mixing of M^4 and CP_2 gamma matrices for induced gamma matrices. The simplest assumption is that particles and their superpartners obey the same mass formula but that the p-adic length scale can be different for them.

4. The new view about particle massivation involves besides p-adic thermodynamics also Higgs but there is no need to assume that Higgs vacuum expectation plays any role. The most natural option favored by the assumption that elementary bosons are bound states of massless elementary fermions, by twistorial considerations, and by the fact that both gauge bosons and Higgs form SU(2) triplet and singlet, predicts that also photon and other massless gauge bosons develop small mass so that all Higgs particles and their colored variants would disappear from spectrum. Same could happen for Higgsinos.

5. One of the basic distinctions between TGD and standard model is the new view about color.

   (a) The first implication is separate conservation of quark and lepton quantum numbers implying the stability of proton against the decay via the channels predicted by GUTs. This does not mean that proton would be absolutely stable. p-Adic and dark length scale hierarchies indeed predict the existence of scale variants of quarks and leptons and proton could decay to hadons of some zoomed up copy of hadrons physics. These decays should be slow and presumably they would involve phase transition changing the value of Planck constant characterizing proton. It might be that the simultaneous increase of Planck constant for all quarks occurs with very low rate.

   (b) Also color excitations of leptons and quarks are in principle possible. Detailed calculations would be required to see whether their mass scale is given by CP_2 mass scale. The so called leptohadron physics proposed to explain certain anomalies associated with both electron, muon, and τ lepton could be understood in terms of color octet excitations of leptons.

6. Fractal hierarchies of weak and hadronic physics labelled by p-adic primes and by the levels of dark matter hierarchy are highly suggestive. Ordinary hadron physics corresponds to $M_{107} = 2^{107} - 1$ One especially interesting candidate would be scaled up hadronic physics which would correspond to $M_{89} = 2^{89} - 1$ defining the p-adic prime of weak bosons. The corresponding string tension is about 512 GeV and it might be possible to see the first signatures of this physics at LHC. Nuclear string model in turn predicts that nuclei correspond to nuclear strings of nucleons connected by colored flux tubes having light quarks at their ends. The interpretation might be in terms of M_{127} hadron physics. In biologically most interesting length scale range 10 nm-2.5 μm there are four Gaussian Mersennes and the conjecture is that these and other Gaussian Mersennes are associated with zoomed up variants of hadron physics relevant for living matter. Cosmic rays might also reveal copies of hadron physics corresponding to M_{61} and M_{31}

7. Weak form of electric magnetic duality implies that the fermions and antifermions associated with both leptons and bosons are Kähler magnetic monopoles accompanied by monopoles of opposite magnetic charge and with opposite weak isospin. For quarks Kähler magnetic charge need not cancel and cancellation might occur only in hadronic length scale. The magnetic flux tubes behave like string like objects and if the string tension is determined by weak length scale, these string aspects should become visible at LHC. If the string tension is 512 GeV the situation becomes less promising.

In this chapter some aspects of the predicted new physics and possible indications for it are discussed. The evolution of the TGD based view about possible existing Higgs like particle and about space-time SUSY are discussed in separate chapters.

p-Adic Particle Massivation: New Physics: part II

In this chapter the focus is on the hadron physics. The applications are to various anomalies discovered during years.

1. *Application of the many-sheeted space-time concept in hadron physics*

The many-sheeted space-time concept involving also the notion of field body can be applied to hadron physics to explain findings which are difficult to understand in the framework of standard model.

1. The spin puzzle of proton is a two decades old mystery with no satisfactory explanation in QCD framework. The notion of hadronic space-time sheet which could be imagined as string like rotating object suggests a possible approach to the spin puzzle. The entanglement between valence quark spins and the angular momentum states of the rotating hadronic space-time sheet could allow natural explanation for why the average valence quark spin vanishes.

2. The notion of Pomeron was invented during the Bootstrap era preceding QCD to solve difficulties of Regge approach. There are experimental findings suggesting the reincarnation of this concept. The possibility that the newly born concept of Pomeron of Regge theory might be identified as the sea of perturbative QCD in TGD framework is considered. Geometrically Pomeron would correspond to hadronic space-time sheet without valence quarks.

3. The discovery that the charge radius of proton deduced from the muonic version of hydrogen atom is about 4 per cent smaller than from the radius deduced from hydrogen atom is in complete conflict with the cherished belief that atomic physics belongs to the museum of science. The title of the article *Quantum electrodynamics-a chink in the armour?* of the article published in Nature expresses well the possible implications, which might actually go well extend beyond QED. TGD based model for the findings relies on the notion of color magnetic body carrying both electromagnetic and color fields and extends well beyond the size scale of the particle. This gives rather detailed constraints on the model of the magnetic body.

4. The soft photon production rate in hadronic reactions is by an average factor of about four higher than expected. In the article soft photons assignable to the decays of Z^0 to quark-antiquark pairs. This anomaly has not reached the attention of particle physics which seems to be the fate of anomalies quite generally nowadays: large extra dimensions and black-holes at LHC are much more sexy topics of study than the anomalies about which both existing and speculative theories must remain silent. TGD based model is based on the notion of electric flux tube.

2. Quark gluon plasma

QCD predicts that at sufficiently high collision energies de-confinement phase transitions for quarks should take place leading to quark gluon plasma. In heavy ion collisions at RHIC something like this was found to happen. The properties of the quark gluon plasma were however not what was expected. There are long range correlations and the plasma seems to behave like perfect fluid with minimal viscosity/entropy ratio. The lifetime of the plasma phase is longer than expected and its density much higher than QCD would suggest. The experiments at LHC for proton proton collisions suggest also the presence of quark gluon plasma with similar properties.

TGD suggests an interpretation in terms of long color magnetic flux tubes containing the plasma. The confinement to color magnetic flux tubes would force higher density. The preferred extremals of Kähler action have interpretation as defining a flow of perfect incompressible fluid and the perfect fluid property is broken only by the many-sheeted structure of space-time with smaller space-time sheets assignable to sub-CDs representing radiative corrections. The phase in question corresponds to a non-standard value of Planck constant: this could also explain why the lifetime of the phase is longer than expected.

3. Breaking of discrete symmetries

Zero energy ontology provides a fresh approach to discrete symmetries and provides also a general mechanism for their breaking. A general vision about breaking of discrete symmetries relies on quantum measurement theory: the quantum jump selecting the quantization axes induces localization to a single CD and therefore induces breaking of discrete symmetries due to the choice of quantization axes. The time scale of CD is excellent candidate for defining mass and time scales characterizing the symmetry breaking. Entropic gravity idea has a variant in TGD framework resulting from the fact that in ZEO quantum theory is a square root of thermodynamics in a well-defined sense. Thermodynamical stability could force the generation of the arrow of time and also force it to be different for matter and antimatter inducing in this manner matter antimatter asymmetry and breaking of discrete symmetries like CP. Also CPT could be broken spontaneously and there are experimental indications that this takes place for top quark with mass difference which is surprisingly large- few per cent of top mass.

4. Are exotic Super Virasoro representations relevant for hadron physics?

In p-adic context exotic representations of Super Virasoro with $M^2 \propto p^k,\ k = 1, 2, ..m$ are possible. For $k = 1$ the states of these representations have same mass scale as elementary particles although in real context the masses would be gigantic. This inspires the question whether non-perturbative aspects of hadron physics could be assigned to the presence of these representations. Some intriguing numerical co-incidences suggest that the exotic representations of Super-Virasoro should be assigned with hadron and whereas ordinary Virasoro representations would be assigned with the quark-gluon plasma or possibly sea quarks.

Part I

P-ADIC DESCRIPTION OF PARTICLE MASSIVATION

Chapter 2

Overall View About TGD from Particle Physics Perspective

2.1 Introduction

Topological Geometrodynamics is able to make rather precise and often testable predictions. In this and two other articles I want to describe the recent over all view about the aspects of quantum TGD relevant for particle physics.

During these 32 years TGD has become quite an extensive theory involving also applications to quantum biology and quantum consciousness theory. Therefore it is difficult to decide in which order to proceed. Should one represent first the purely mathematical theory as done in the articles in Prespace-time Journal [L5, L6, L10, L11, L8, L4, L9, L12]? Or should one start from the TGD inspired heuristic view about space-time and particle physics and represent the vision about construction of quantum TGD briefly after that? In this and other two chapters I have chosen the latter approach since the emphasis is on the applications on particle physics.

Second problem is to decide about how much material one should cover. If the representation is too brief no-one understands and if it is too detailed no-one bothers to read. I do not know whether the outcome was a success or whether there is any way to success but in any case I have been sweating a lot in trying to decide what would be the optimum dose of details.

In the first chapter I concentrate the heuristic picture about TGD with emphasis on particle physics.

- First I represent briefly the basic ontology: the motivations for TGD and the notion of many-sheeted space-time, the concept of zero energy ontology, the identification of dark matter in terms of hierarchy of Planck constant which now seems to follow as a prediction of quantum TGD, the motivations for p-adic physics and its basic implications, and the identification of space-time surfaces as generalized Feynman diagrams and the basic implications of this identification.

- Symmetries of quantum TGD are discussed. Besides the basic symmetries of the imbedding space geometry allowing to geometrize standard model quantum numbers and classical fields there are many other symmetries. General Coordinate Invariance is especially powerful in TGD framework allowing to realize quantum classical correspondence and implies effective 2-dimensionality realizing strong form of holography. Super-conformal symmetries of super string models generalize to conformal symmetries of 3-D light-like 3-surfaces associated with light-like boundaries of so called causal diamonds defined as intersections of future and past directed light-cones (CDs) and with light-like 3-surfaces. Super-conformal symmetries imply generalization of the space-time supersymmetry in TGD framework consistent with the supersymmetries of minimal supersymmetric variant of the standard model. Twistorial approach to gauge theories has gradually become part of quantum TGD and the natural generalization of the Yangian symmetry identified originally as symmetry of $\mathcal{N} = 4$ SYMs is postulated as basic symmetry of quantum TGD.

- The understanding of the relationship between TGD and GRT and quantum and classical variants of Equivalence Principle (EP) in TGD have develope rather slowly but the recent picture is rather feasible.

  1. The recent view is that EP at quantum level reduces to Quantum Classical Correpondence (QCC) in the sense that Cartan algebra Noether charges assignable to 3-surface in case of Kähler action (inertial charges) are identical with eigenvalues of the quantal variants of Noether charges for Kähler-Dirac action (gravitational charges). The well-definedness of the latter charges is due to the conformal invariance assignable to 2-D surfaces (string world sheets and possibly partonic 2-surfaces) at which the spinor modes are localized in generic case. This localization follows from the condition that em charge has well defined value for the spinor modes. The localization is possibly only for the Kähler-Dirac action and key role is played by the modification of gamma matrices to Kähler-Dirac gamma matrices. The gravitational four-momentum is thus completely analogous to stringy four-momentum.
  2. At classical level EP follows from the interpretation of GRT space-time as effective space-time obtained by replacing many-sheeted space-time with Minkowski space with effective metric determined as a sum of Minkowski metric and sum over the deviations of the induced metrices of space-time sheets from Minkowski metric. Poincare invariance suggests strongly classical EP for the GRT limit in long length scales at least. Similar procedure applies to induced gauge fields.

- The so called weak form of electric-magnetic duality has turned out to have extremely far reaching consequences and is responsible for the recent progress in the understanding of the physics predicted by TGD. The duality leads to a detailed identification of elementary particles as composite objects of massless particles and predicts new electro-weak physics at LHC. Together with a simple postulate about the properties of preferred extremals of Kähler action the duality allows also to realized quantum TGD as almost topological quantum field theory giving excellent hopes about integrability of quantum TGD.

- There are two basic visions about the construction of quantum TGD. Physics as infinite-dimensional Kähler geometry of world of classical worlds (WCW) endowed with spinor structure and physics as generalized number theory. These visions are briefly summarized as also the practical constructing involving the concept of Dirac operator. As a matter fact, the construction of TGD involves three Dirac operators. The Kähler Dirac equation holds true in the interior of space-time surface and its solutions have a natural interpretation in terms of description of matter, in particular condensed matter. Chern-Simons Dirac action is associated with the light-like 3-surfaces and space-like 3-surfaces at ends of space-time surface at light-like boundaries of CD. One can assign to it a generalized eigenvalue equation and the matrix valued eigenvalues correspond to the the action of Dirac operator on momentum eigenstates. Momenta are however not usual momenta but pseudo-momenta very much analogous to region momenta of twistor approach. The third Dirac operator is associated with super Virasoro generators and super Virasoro conditions define Dirac equation in WCW. These conditions characterize zero energy states as modes of WCW spinor fields and code for the generalization of S-matrix to a collection of what I call M-matrices defining the rows of unitary U-matrix defining unitary process.

- Twistor approach has inspired several ideas in quantum TGD during the last years and it seems that the Yangian symmetry and the construction of scattering amplitudes in terms of Grassmannian integrals generalizes to TGD framework. This is due to ZEO allowing to assume that all particles have massless fermions as basic building blocks. ZEO inspires the hypothesis that incoming and outgoing particles are bound states of fundamental fermions associated with wormhole throats. Virtual particles would also consist of on mass shell massless particles but without bound state constraint. This implies very powerful constraints on loop diagrams and there are excellent hopes about their finiteness.

The discussion of this chapter is rather sketchy and the reader interesting in details can consult the books about TGD [K72, K55, K46, K40, K56, K64, K69] .

The appendix of the book gives a summary about basic concepts of TGD with illustrations. There are concept maps about topics related to the contents of the chapter prepared using CMAP realized as html files. Links to all CMAP files can be found at http://www.tgdtheory.fi/cmaphtml.html [L20]. Pdf representation of same files serving as a kind of glossary can be found at http://www.tgdtheory.fi/tgdglossary.pdf [L21]. The topics relevant to this chapter are given by the following list.

- Overall view about TGD [L36]
- What TGD is [L54]
- TGD as unified theory of fundamental interactions [L48]
- Key notions and ideas of TGD [L31]
- Basic TGD [L22]
- Space-time as 4-surface in $M^4 \times CP_2$ [L42]
- Classical TGD [L23]
- Manysheeted space-time [L35]
- Geometrization of fields [L27]
- TGD and GRT [L45]
- Zero Energy Ontology (ZEO) [L55]
- Vacuum functional in TGD [L52]
- Quantum Classical Correspondence [L40]
- Quantum criticality [L41]
- Symmetries of WCW [L44]
- TGD as ATQFT [L46]
- KD equation [L30]
- Kaehler-Dirac action [L29]
- The unique role of twistors in TGD [L50]
- Twistors and TGD [L51]

2.2 Some aspects of quantum TGD

In the following I summarize very briefly those basic notions of TGD which are especially relevant for the applications to particle physics. The representation will be practically formula free. The article series published in Prespace-time Journal [L5, L6, L10, L11, L8, L4, L9, L12] describes the mathematical theory behind TGD. The seven books about TGD [K72, K55, K46, K83, K64, K82, K81, K62] provide a detailed summary about the recent state of TGD.

2.2.1 New space-time concept

The physical motivation for TGD was what I have christened the energy problem of General Relativity. The notion of energy is ill-defined because the basic symmetries of empty space-time are lost in the presence of gravity. The way out is based on assumption that space-times are imbeddable as 4-surfaces to certain 8-dimensional space by replacing the points of 4-D empty Minkowski space with 4-D very small internal space. This space -call it S- is unique from the requirement that the theory has the symmetries of standard model: $S = CP_2$, where CP_2 is complex projective space with 4 real dimensions [L12] , is the unique choice.

The replacement of the abstract manifold geometry of general relativity with the geometry of surfaces brings the shape of surface as seen from the perspective of 8-D space-time and this means additional degrees of freedom giving excellent hopes of realizing the dream of Einstein about geometrization of fundamental interactions.

The work with the generic solutions of the field equations assignable to almost any general coordinate invariant variational principle led soon to the realization that the space-time in this framework is much more richer than in general relativity.

1. Space-time decomposes into space-time sheets (see fig. **??** in the appendix of this book) with finite size: this lead to the identification of physical objects that we perceive around us as space-time sheets. For instance, the outer boundary of the table is where that particular space-time sheet ends. Besides sheets also string like objects and elementary particle like objects appear so that TGD can be regarded also as a generalization of string models obtained by replacing strings with 3-D surfaces.

2. Elementary particles are identified as topological inhomogenuities glued to these space-time sheets (see figs. `http://www.tgdtheory.fi/appfigures/particletgd.jpg`, `http://www.tgdtheory.fi/appfigures/elparticletgd.jpg`, which are also in the appendix of this book). In this conceptual framework material structures and shapes are not due to some mysterious substance in slightly curved space-time but reduce to space-time topology just as energy- momentum currents reduce to space-time curvature in general relativity.

3. Also the view about classical fields changes. One can assign to each material system a field identity since electromagnetic and other fields decompose to topological field quanta. Examples are magnetic and electric flux tubes and flux sheets and topological light rays representing light propagating along tube like structure without dispersion and dissipation making em ideal tool for communications [K47] . One can speak about field body or magnetic body of the system.

Field body indeed becomes the key notion distinguishing TGD inspired model of quantum biology from competitors but having applications also in particle physics since also leptons and quarks possess field bodies. The is evidence for the Lamb shift anomaly of muonic hydrogen [C12] and the color magnetic body of u quark whose size is somethat larger than the Bohr radius could explain the anomaly [K37] .

2.2.2 Zero energy ontology

In standard ontology of quantum physics physical states are assumed to have positive energy. In zero energy ontology physical states decompose to pairs of positive and negative energy states such that all net values of the conserved quantum numbers vanish. The interpretation of these states in ordinary ontology would be as transitions between initial and final states, physical events. By quantum classical correspondences zero energy states must have space-time and imbedding space correlates.

1. Positive and negative energy parts reside at future and past light-like boundaries of causal diamond (CD) defined as intersection of future and past directed light-cones and visualizable as double cone (see ig. **??** in the appendix of this book)). The analog of CD in cosmology is big bang followed by big crunch. CDs for a fractal hierarchy containing CDs within CDs. Disjoint CDs are possible and CDs can also intersect.

2. p-Adic length scale hypothesis [K41] motivates the hypothesis that the temporal distances between the tips of the intersecting light-cones come as octaves $T = 2^n T_0$ of a fundamental time scale T_0 defined by CP_2 size R as $T_0 = R/c$. One prediction is that in the case of electron this time scale is .1 seconds defining the fundamental biorhythm. Also in the case u and d quarks the time scales correspond to biologically important time scales given by 10 ms for u quark and by and 2.5 ms for d quark [K7] . This means a direct coupling between microscopic and macroscopic scales.

Zero energy ontology conforms with the crossing symmetry of quantum field theories meaning that the final states of the quantum scattering event are effectively negative energy states. As long as one can restrict the consideration to either positive or negative energy part of the state ZEO is consistent with positive energy ontology. This is the case when the observer characterized by a particular CD studies the physics in the time scale of much larger CD containing observer's CD as a sub-CD. When the time scale sub-CD of the studied system is much shorter that the time scale of sub-CD characterizing the observer, the interpretation of states associated with sub-CD is in terms of quantum fluctuations.

ZEO solves the problem which results in any theory assuming symmetries giving rise to to conservation laws. The problem is that the theory itself is not able to characterize the values of conserved quantum numbers of the initial state. In ZEO this problem disappears since in principle any zero energy state is obtained from any other state by a sequence of quantum jumps without breaking of conservation laws. The fact that energy is not conserved in general relativity based cosmologies can be also understood since each CD is characterized by its own conserved quantities. As a matter fact, one must be speak about average values of conserved quantities since one can have a quantum superposition of zero energy states with the quantum numbers of the positive energy part varying over some range.

For thermodynamical states this is indeed the case and this leads to the idea that quantum theory in ZEO can be regarded as a "complex square root" of thermodynamics obtained as a product of positive diagonal square root of density matrix and unitary S-matrix. M-matrix defines time-like entanglement coefficients between positive and negative energy parts of the zero energy state and replaces S-matrix as the fundamental observable. In standard quantum measurement theory this time-like entanglement would be reduced in quantum measurement and regenerated in the next quantum jump if one accepts Negentropy Maximization Principle (NMP) [K36] as the fundamental variational principle. Various M-matrices define the rows of the unitary U matrix characterizing the unitary process part of quantum jump. From the point of view of consciousness theory the importance of ZEO is that conservation laws in principle pose no restrictions for the new realities created in quantum jumps: free will is maximal.

2.2.3 The hierarchy of Planck constants

The motivations for the hierarchy of Planck constants come from both astrophysics and biology [K54, K19] . In astrophysics the observation of Nottale [E4] that planetary orbits in solar system seem to correspond to Bohr orbits with a gigantic gravitational Planck constant motivated the proposal that Planck constant might not be constant after all [K59, K48] .

This led to the introduction of the quantization of Planck constant as an independent postulate. It has however turned that quantized Planck constant in effective sense could emerge from the basic structure of TGD alone. Canonical momentum densities and time derivatives of the imbedding space coordinates are the field theory analogs of momenta and velocities in classical mechanics. The extreme non-linearity and vacuum degeneracy of Kähler action imply that the correspondence between canonical momentum densities and time derivatives of the imbedding space coordinates is 1-to-many: for vacuum extremals themselves 1-to-infinite (see fig. **??** in the appendix of this book).

A convenient technical manner to treat the situation is to replace imbedding space with its n-fold singular covering. Canonical momentum densities to which conserved quantities are proportional would be same at the sheets corresponding to different values of the time derivatives. At each sheet of the covering Planck constant is effectively $\hbar = n\hbar_0$. This splitting to multi-sheeted structure can be seen as a phase transition reducing the densities of various charges by factor $1/n$ and making it possible to have perturbative phase at each sheet (gauge coupling strengths are proportional to

$1/\hbar$ and scaled down by $1/n$). The connection with fractional quantum Hall effect [D1] is almost obvious. At the more detailed level one finds that the spectrum of Planck constants would be given by $\hbar = n_a n_b \hbar_0$ [K22] .

This has many profound implications, which are welcome from the point of view of quantum biology but the implications would be profound also from particle physics perspective and one could say that living matter represents zoome up version of quantum world at elementary particle length scales.

1. Quantum coherence and quantum superposition become possible in arbitrary long length scales. One can speak about zoomed up variants of elementary particles and zoomed up sizes make it possible to satisfy the overlap condition for quantum length parameters used as a criterion for the presence of macroscopic quantum phases. In the case of quantum gravitation the length scale involved are astrophysical. This would conform with Penrose's intuition that quantum gravity is fundamental for the understanding of consciousness and also with the idea that consciousness cannot be localized to brain.

2. Photons with given frequency can in principle have arbitrarily high energies by $E = hf$ formula, and this would explain the strange anomalies associated with the interaction of ELF em fields with living matter [J1] . Quite generally the cyclotron frequencies which correspond to energies much below the thermal energy for ordinary value of Planck constant could correspond to energies above thermal threshold.

3. The value of Planck constant is a natural characterizer of the evolutionary level and biological evolution would mean a gradual increase of the largest Planck constant in the hierarchy characterizing given quantum system. Evolutionary leaps would have interpretation as phase transitions increasing the maximal value of Planck constant for evolving species. The space-time correlate would be the increase of both the number and the size of the sheets of the covering associated with the system so that its complexity would increase.

4. The phase transitions changing Planck constant change also the length of the magnetic flux tubes. The natural conjecture is that biomolecules form a kind of Indra's net connected by the flux tubes and $\hbar$ changing phase transitions are at the core of the quantum bio-dynamics. The contraction of the magnetic flux tube connecting distant biomolecules would force them near to each other making possible for the bio-catalysis to proceed. This mechanism could be central for DNA replication and other basic biological processes. Magnetic Indra's net could be also responsible for the coherence of gel phase and the phase transitions affecting flux tube lengths could induce the contractions and expansions of the intracellular gel phase. The reconnection of flux tubes would allow the restructuring of the signal pathways between biomolecules and other subsystems and would be also involved with ADP-ATP transformation inducing a transfer of negentropic entanglement [K25] (see fig. **??** in the appendix of this book). The braiding of the magnetic flux tubes could make possible topological quantum computation like processes and analog of computer memory realized in terms of braiding patterns [K21] .

5. p-Adic length scale hypothesis and hierarchy of Planck constants suggest entire hierarchy of zoomed up copies of standard model physics with range of weak interactions and color forces scaling like $\hbar$. This is not conflict with the known physics for the simple reason that we know very little about dark matter (partly because we might be making misleading assumptions about its nature). One implication is that it might be someday to study zoomed up variants particle physics at low energies using dark matter.

   Dark matter would make possible the large parity breaking effects manifested as chiral selection of bio-molecules [C39] . The classical Z^0 and possibly also W fields responsible for parity breaking effects must be experienced by fundamental fermions in cellular length scale. This is not possible for ordinary value of Planck constant above weak scale since the induced spinor modes are restricted on string world sheets at which W and Z^0 fields vanish: this follows from the well-definedness of em charge. If the value of Planck constant is so large that weak scale is some biological length scale, weak fields are effectively massless below this scale and large parity breaking effects become possible.

For the solutions of field equations which are almost vacuum extremals Z^0 field is non-vanishing and proportional to electromagnetic field. The hypothesis that cell membrane corresponds to a space-time sheet near a vacuum extremal (this corresponds to criticality very natural if the cell membrane is to serve as an ideal sensory receptor) leads to a rather successful model for cell membrane as sensory receptor with lipids representing the pixels of sensory qualia chart. The surprising prediction is that bio-photons [I2] and bundles of EEG photons can be identified as different decay products of dark photons with energies of visible photons. Also the peak frequencies of sensitivity for photoreceptors are predicted correctly [K54] .

2.2.4 p-Adic physics and number theoretic universality

p-Adic physics [K40, K67] has become gradually a key piece of TGD inspired biophysics. Basic quantitative predictions relate to p-adic length scale hypothesis and to the notion of number theoretic entropy. Basic ontological ideas are that life resides in the intersection of real and p-adic worlds and that p-adic space-time sheets serve as correlates for cognition and intentionality. Number theoretical universality requires the fusion of real physics and various p-adic physics to single coherent whole. On implication is the generalization of the notion of number obtained by fusing real and p-adic numbers to a larger structure.

p-Adic number fields

p-Adic number fields Q_p [A23] -one for each prime p- are analogous to reals in the sense that one can speak about p-adic continuum and that also p-adic numbers are obtained as completions of the field of rational numbers. One can say that rational numbers belong to the intersection of real and p-adic numbers. p-Adic number field Q_p allows also an infinite number of its algebraic extensions. Also transcendental extensions are possible. For reals the only extension is complex numbers.

p-Adic topology defining the notions of nearness and continuity differs dramatically from the real topology. An integer which is infinite as a real number can be completely well defined and finite as a p-adic number. In particular, powers p^n of prime p have p-adic norm (magnitude) equal to p^{-n} in Q_p so that at the limit of very large n real magnitude becomes infinite and p-adic magnitude vanishes.

p-Adic topology is rough since p-adic distance $d(x,y) = d(x-y)$ depends on the lowest pinary digit of $x-y$ only and is analogous to the distance between real points when approximated by taking into account only the lowest digit in the decimal expansion of $x-y$. A possible interpretation is in terms of a finite measurement resolution and resolution of sensory perception. p-Adic topology looks somewhat strange. For instance, p-adic spherical surface is not infinitely thin but has a finite thickness and p-adic surfaces possess no boundary in the topological sense. Ultra-metricity is the technical term characterizing the basic properties of p-adic topology and is coded by the inequality $d(x-y) \leq Min\{d(x), d(y)\}$. p-Adic topology brings in mind the decomposition of perceptive field to objects.

Motivations for p-adic number fields

The physical motivations for p-adic physics came from the observation that p-adic thermodynamics -not for energy but infinitesimal scaling generator of so called super-conformal algebra [A15] acting as symmetries of quantum TGD [K55] - predicts elementary particle mass scales and also masses correctly under very general assumptions [K40] . The calculations are discussed in more detail in the second article of the series. In particular, the ratio of proton mass to Planck mass, the basic mystery number of physics, is predicted correctly. The basic assumption is that the preferred primes characterizing the p-adic number fields involved are near powers of two: $p \simeq 2^k$, k positive integer. Those nearest to power of two correspond to Mersenne primes $M_n = 2^n - 1$. One can also consider complex primes known as Gaussian primes, in particular Gaussian Mersennes $M_{G,n} = (1+i)^n - 1$.

It turns out that Mersennes and Gaussian Mersennes are in a preferred position physically in TGD based world order. What is especially interesting that the length scale range 10 nm-5 μm contains as many as four scaled up electron Compton lengths $L_e(k) = \sqrt{5}L(k)$ assignable to Gaussian Mersennes $M_k = (1+i)^k - 1$, $k = 151, 157, 163, 167$, [K54] . This number theoretical miracle supports the view that p-adic physics is especially important for the understanding of living matter.

The philosophical for p-adic numbers fields come from the question about the possible physical correlates of cognition and intention [K44] . Cognition forms representations of the external world which have finite cognitive resolution and the decomposition of the perceptive field to objects is an essential element of these representations. Therefore p-adic space-time sheets could be seen as candidates of thought bubbles, the mind stuff of Descartes. One can also consider p-adic space-time sheets as correlates of intentions. The quantum jump in which p-adic space-time sheet is replaced with a real one could serve as a quantum correlate of intentional action (see fig. **??** in the appendix of this book). This process is forbidden by conservation laws in standard ontology: one cannot even compare real and p-adic variants of the conserved quantities like energy in the general case. In zero energy ontology the net values of conserved quantities for zero energy states vanish so that conservation laws allow these transitions.

Rational numbers belong to the intersection of real and p-adic continua. An obvious generalization of this statement applies to real manifolds and their p-adic variants. When extensions of p-adic numbers are allowed, also some algebraic numbers can belong to the intersection of p-adic and real worlds. The notion of intersection of real and p-adic worlds has actually two meanings.

1. The intersection could consist of the rational and possibly some algebraic points in the intersection of real and p-adic partonic 2-surfaces at the ends of CD. This set is in general discrete. The interpretation could be as discrete cognitive representations.

2. The intersection could also have a more abstract meaning. For instance, the surfaces defined by rational functions with rational coefficients have a well-defined meaning in both real and p-adic context and could be interpreted as belonging to this intersection. There is strong temptation to assume that intentions are transformed to actions only in this intersection. One could say that life resides in the intersection of real and p-adic worlds in this abstract sense.

Additional support for the idea comes from the observation that Shannon entropy $S = -\sum p_n log(p_n)$ allows a p-adic generalization if the probabilities are rational numbers by replacing $log(p_n)$ with $-log(|p_n|_p)$, where $|x|_p$ is p-adic norm. Also algebraic numbers in some extension of p-adic numbers can be allowed. The unexpected property of the number theoretic Shannon entropy is that it can be negative and its unique minimum value as a function of the p-adic prime p it is always negative. Entropy transforms to information!

In the case of number theoretic entanglement entropy there is a natural interpretation for this. Number theoretic entanglement entropy would measure the information carried by the entanglement whereas ordinary entanglement entropy would characterize the uncertainty about the state of either entangled system. For instance, for p maximally entangled states both ordinary entanglement entropy and number theoretic entanglement negentropy are maximal with respect to R_p norm. Negentropic entanglement carries maximal information. The information would be about the relationship between the systems, a rule. Schrödinger cat would be dead enough to know that it is better to not open the bottle completely (see fig. **??** in the appendix of this book).

Negentropy Maximization Principle [K36] coding the basic rules of quantum measurement theory implies that negentropic entanglement can be stable against the effects of quantum jumps unlike entropic entanglement. Therefore living matter could be distinguished from inanimate matter also by negentropic entanglement possible in the intersection of real and p-adic worlds. In consciousness theory negentropic entanglement could be seen as a correlate for the experience of understanding or any other positively colored experience, say love.

Negentropically entangled states are stable but binding energy and effective loss of relative translational degrees of freedom is not responsible for the stability. Therefore bound states are not in question. The distinction between negentropic and bound state entanglement could be compared to the difference between unhappy and happy marriage. The first one is a social jail but in the latter case both parties are free to leave but do not want to. The special characterics of negentropic entanglement raise the question whether the problematic notion of high energy phosphate bond [I1] central for metabolism could be understood in terms of negentropic entanglement. This would also allow an information theoretic interpretation of metabolism since the transfer of metabolic energy would mean a transfer of negentropy [K25] .

2.3 Symmetries of quantum TGD

2.4 Symmetries of TGD

Symmetry principles play key role in the construction of WCW geometry have become and deserve a separate explicit treatment even at the risk of repetitions. Symmetries of course manifest themselves also at space-time level and space-time supersymmetry - possibly present also in TGD - is the most non-trivial example of this.

2.4.1 General Coordinate Invariance

General coordinate invariance is certainly of the most important guidelines and is much more powerful in TGD framework thanin GRT context.

1. General coordinate transformations as a gauge symmetry so that the diffeomorphic slices of space-time surface equivalent physically. 3-D light-like 3-surfaces defined by wormhole throats define preferred slices and allows to fix the gauge partially apart from the remaining 3-D variant of general coordinate invariance and possible gauge degeneracy related to the choice of the light-like 3-surface due to the Kac-Moody invariance. This would mean that the random light-likeness represents gauge degree of freedom except at the ends of the light-like 3-surfaces.
2. GCI can be strengthened so that the pairs of space-like ends of space-like 3-surfaces at CDs are equivalent with light-like 3-surfaces connecting them. The outcome is effective 2-dimensionality because their intersections at the boundaries of CDs must carry the physically relevant information.

2.4.2 Generalized conformal symmetries

One can assign Kac-Moody type conformal symmetries to light-like 3-surfaces as isometries of H localized with respect to light-like 3-surfaces. Kac Moody algebra essentially the Lie algebra of gauge group with central extension meaning that projective representation in which representation matrices are defined only modulo a phase factor. Kac-Moody symmetry is not quite a pure gauge symmetry.

One can assign a generalization of Kac-Moody symmetries to the boundaries of CD by replacing Lie-group of Kac-Moody algebra with the group of symplectic (contact-) transformations [A24, A18, A17] of H_+ provided with a degenerate Kähler structure made possible by the effective 2-dimensionality of δM^4_+. The light-like radial coordinate of δM^4_+ plays the role of the complex coordinate of conformal transformations or their hyper-complex analogs. The basic hypothesis is that these transformations define the isometry algebra of WCW.

p-Adic mass calculations require also second super-conformal symmetry. It is defined by Kac-Moody algebra assignable to the isometries of the imbedding space or possibly those of δCD. This algebra must appear together with symplectic algebra as a direct sum. The original guess was that Kac-Moody algebra is associated with light-like 3-surfaces as a local algebra localized by hand with respect to the internal coordinates. A more elegant identification emerged in light of the wisdom gained from the solutions of the modified Dirac equation. Neutrino modes and symplectic Hamiltonians generate symplectic algebra and the remaining fermion modes and Hamiltonians of symplectic isometries generate the Kac-Moody algebra and the direct sum of these algebras acts naturally on physical states.

A further physically well-motivated hypothesis inspired by holography and extended GCI is that these symmetries extend so that they apply at the entire space-time sheet and also at the level of imbedding space.

1. The extension to the entire space-time surface requires the slicing of space-time surface by partonic 2- surfaces and by stringy world sheets such that each point of stringy world sheet defines a partonic 2-surface and vice versa. This slicing has deep physical motivations since it realizes geometrically standard facts about gauge invariance (partonic 2-surface defines the space of physical polarizations and stringy space-time sheet corresponds to non-physical

polarizations) and its existence is a hypothesis about the properties of the preferred extremals of Kähler action.

There is a similar decomposition also at the level of CD and so called Hamilton-Jacobi coordinates for M^4_+ [K8] define this kind of slicings. This slicing can induced the slicing of the space-time sheet. The number theoretic vision gives a further justification for this hypothesis and also strengthens it by postulating the presence of the preferred time direction having interpretation in terms of real unit of octonions. In ZEO this time direction corresponds to the time-like vector connecting the tips of CD.

2. The simplest extension of the symplectic algebra at the level of imbedding space is by parallel translating the light-cone boundary. This would imply duality of the formulations using light-like and space-like 3-surfaces and Equivalence Principle (EP) might correspond to this duality in turn implied by strong form of general coordinate invariance (GCI).

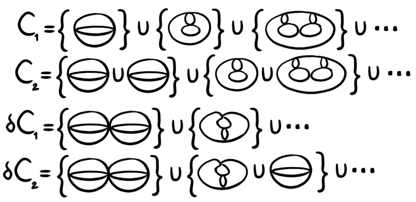

Figure 2.1: Conformal symmetry preserves angles in complex plane

Conformal symmetries would provide the realization of WCW as a union of symmetric spaces. Symmetric spaces are coset spaces of form G/H. The natural identification of G and H is as groups of symplectic transformations and its subroup leaving preferred 3-surface invariant (acting as diffeomorphisms for it). Quantum fluctuating (metrically non-trivial) degrees of freedom would correspond to symplectic transformations of H_+ and fluxes of the induced Kähler form would define a local representation for zero modes: not necessarily all of them.

2.4.3 Equivalence Principle and super-conformal symmetries

Equivalence Principle (EP) is a second corner stone of General Relativity and together with GCI leads to Einstein's equations. What EP states is that inertial and gravitational masses are identical. In this form it is not well-defined even in GRT since the definition of gravitational and inertial four-momenta is highly problematic because Noether theorem is not available. Therefore the realization is in terms of local equations identifying energy momentum tensor with Einstein tensor.

Thinking EP in terms of scattering amplitudes for graviton exchange, it seems obvious that EP is true in TGD since all particles are string like objects. How EP is realized in TGD has been a longstanding open question [K71]. The problem has been that at the classical level EP in its GRT form can hold true only in long enough length scales and it took long to time to realize that only the stringy form of this principle is required. The first question is how to identify the gravitational and inertial four-momenta. I have considered very many proposals in this regard!

The first idea was that one could associate to the two types super-conformal algebras g and h assigned with light-like 3-surfaces and space-like 3-surfaces four-momenta to both. EP would state that these four-momenta are identical and is equivalent with the generalization of GCI and effective 2-dimensionality. The condition generalizes so that it applies to the generators of super-conformal algebras associated with the two super-conformal symmetries. Ironically, this idea is rather compelling if the two super-conformal algebras correspond to symplectic symmetries acting at space-like *resp.* light-like 3-surfaces and both decompose to direct sums of representations of super-symplectic and super Kac-Moody algebras. Here I however made mis-identification and was led to a wrong track. The rediscovery of the correct (really?) interpretation took almost twenty years!

The imbeddings of Robertson-Walker cosmologies to $M^4 \times CP_2$ are vacuum extremals [K71] . Gravitational mass density does not however vanish for vacuum extremals. This forces to ask whether Equivalence Principle (EP) fails in TGD Universe. General arguments at the level of representations of super-conformal algebras however suggest that EP holds in generalised sense. Also GRT identified as limiting theory lumping many-sheeted space-time to M^4 endowed with an effective metric with Einstein's equations reflecting underlying Poincare invariance supports this intuition.

One could argue that Equivalence Principle (EP) reduces to a mere tautology in TGD framework since stringy picture implies stringy scattering amplitudes for graviton exchanges. This might be the case at quantum level. There are however problems: how the exact Poincare invariance can be consistent with the non-conservation of four-momentum in GRT based cosmologies? What EP could mean at quantum level? Does EP reduce at classical level to Einstein's equations in some sense. How to take into account the many-sheetedness of TGD space-time? The following represents the latest vision about EP in TGD.

1. ZEO and non-conservation of Poincare charges in Poincare invariant theory of gravitation

In positive energy ontology the Poincare invarance of TGD is in sharpt contrast with the fact that GRT based cosmology predicts non-conservation of Poincare charges (as a matter fact, the definition of Poincare charges is very questionable for general solutions of field equations).

In zero energy ontology (ZEO) all conserved (that is Noether-) charges of the Universe vanish identically and their densities should vanish in scales below the scale defining the scale for observations and assignable to causal diamond (CD). This observation allows to imagine a ways out of what seems to be a conflict of Poincare invariance with cosmological facts.

ZEO would explain the local non-conservation of average energies and other conserved quantum numbers in terms of the contributions of sub-CDs analogous to quantum fluctuations. Classical gravitation should have a thermodynamical description if this interpretation is correct. The average values of the quantum numbers assignable to a space-time sheet would depend on the size of CD and possibly also its location in M^4. If the temporal distance between the tips of CD is interpreted as a quantized variant of cosmic time, the non-conservation of energy-momentum defined in this manner follows. One can say that conservation laws hold only true in given scale defined by the largest CD involved.

2. Equivalence Principle at quantum level

The interpretation of EP at quantum level has developed slowly and the recent view is that it reduces to quantum classical correspondence meaning that the classical charges of Kähler action can be identified with eigen values of quantal charges associated with Kähler-Dirac action.

1. At quantum level I have proposed coset representations for the pair of super-symplectic algebras assignable to the light-like boundaries of CD and the Super Kac-Moody algebra assignable to the light-like 3-surfaces defining the orbits of partonic 2-surfaces as realization of EP. For coset representation the differences of super-conformal generators would annihilate the physical states so that one can argue that the corresponding four-momenta are identical. One could even say that one obtains coset representation for the "vibrational" parts of the super-conformal algebras in question. It is now clear that this idea does not work. Note however that coset representations occur naturally for the subalgebras of symplectic algebra and Super Kac-Moody algebra and are naturally induced by finite measurement resolution.

2. The most recent view (2014) about understanding how EP emerges in TGD is described in [K71] and relies heavily on superconformal invariance and a detailed realisation of ZEO at quantum level. In this approach EP corresponds to quantum classical correspondence (QCC): four-momentum identified as classical conserved Noether charge for space-time sheets associated with Käbler action is identical with quantal four-momentum assignable to the representations of super-symplectic and super Kac-Moody algebras as in string models and having a realisation in ZEO in terms of wave functions in the space of causal diamonds (CDs).

3. The latest realization is that the eigenvalues of quantal four-momentum can be identified as eigenvalues of the four-momentum operator assignable to the modified Dirac equation.

This realisation seems to be consistent with the p-adic mass calculations requiring that the super-conformal algebra acts in the tensor product of 5 tensor factors.

3. Equivalence Principle at classical level

How Einstein's equations and General Relativity in long length scales emerges from TGD has been a long-standing interpretational problem of TGD.

The first proposal making sense even when one does not assume ZEO is that vacuum extremals are only approximate representations of the physical situation and that small fluctuations around them give rise to an inertial four-momentum identifiable as gravitational four-momentum identifiable in terms of Einstein tensor. EP would hold true in the sense that the average gravitational four-momentum would be determined by the Einstein tensor assignable to the vacuum extremal. This interpretation does not however take into account the many-sheeted character of TGD space-time and is therefore questionable.

The resolution of the problem came from the realization that GRT is only an effective theory obtained by endowing M^4 with effective metric.

1. The replacement of superposition of fields with superposition of their effects means replacing superposition of fields with the set-theoretic union of space-time surfaces. Particle experiences sum of the effects caused by the classical fields at the space-time sheets.

2. This is true also for the classical gravitational field defined by the deviation from flat Minkowski metric instandard M^4 coordinates for the space-time sheets. One can define effective metric as sum of M^4 metric and deviations. This effective metric would correspond to that of General Relativity. This resolves long standing issues relating to the interpretation of TGD.

3. Einstein's equations could hold true for the effective metric. They are motivated by the underlying Poincare invariance which cannot be realized as global conservation laws for the effective metric. The conjecture vanishing of divergence of Khler energy momentum tensor can be seen as the microscopic justification for the claim that Einstein's equations hold true for the effective space-time.

4. The breaking of Poincare invariance could have interpretation as effective breaking in zero energy ontology (ZEO), in which various conserved charges are length dependent and defined separately for each causal diamond (CD).

One can of course consider the possibility that Einstein's equations generalize for preferred extremals of Kähbler action. This would actually represent at space-time level the notion of QCC rather than realise QCC interpreted as EP. The condition that the energy momentum tensor for Kähler action has vanishing covariant divergence would be satisfied in GRT if Einstein's equations with cosmological term hold true. This is the case also now but one can consider also more general solutions in which one has two cosmological constants which are not genuine constants anymore [K84].

An interesting question is whether inertial-gravitational duality generalizes to the case of color gauge charges so that color gauge fluxes would correspond to "gravitational" color charges and the charges defined by the conserved currents associated with color isometries would define "inertial" color charges. Since the induced color fields are proportional to color Hamiltonians multiplied by Kähler form they vanish identically for vacuum extremals in accordance with "gravitational" color confinement.

2.4.4 Extension of super-conformal symmetries

The original idea behind the extension of conformal symmetries to super-conformal symmetries was the observation that isometry currents defining infinitesimal isometries of WCW have natural super-counterparts obtained by contracting the Killing vector fields with the complexified gamma matrices of the imbedding space.

This vision has generalized considerably as the construction of WCW spinor structure in terms of modified Dirac action has developed. The basic philosophy behind this idea is that WCW spinor structure must relate directly to the fermionic sector of quantum physics. In particular, modified gamma matrices should be expressible in terms of the fermionic oscillator operators associated with the second quantized induced spinor fields. The explicit realization of this program leads to an identification of rich spectrum of super-conformal symmetries and generalization of the ordinary notion of space-time supersymmetry. What happens that all fermionic oscillator operator generate broken super-symmetries whereas in SUSYs there is only finite number of them. One can however identify sub-algebra of super-conformal symmetries associated with right handed neutrino and this gives $\mathcal{N} = 1$ super-symmetry [B7] of SUSYs [K24] .

2.4.5 Does TGD allow the counterpart of space-time super-symmetry

It has been clear from the beginning that the notion of super-conformal symmetry crucial for the successes of super-string models generalizes in TGD framework. The answer to the question whether space-time SUSY makes sense in TGD framework has not been obvious at all but it seems now that the answer is affirmative. The evolution of the ideas relevant for the formulation of SUSY in TGD framework is summarized in the chapters of [K56] . The chapters devoted to the notion of bosonic emergence [K49] , to the SUSY QFT limit of TGD [K24] , to twistor approach to TGD [K73] , and to the generalization of Yangian symmetry of $\mathcal{N} = 4$ SYM manifest in the Grassmannian twistor approach [B17] to a multi-local variant of super-conformal symmetries [K75] represent a gradual development of the ideas about how super-symmetric M-matrix could be constructed in TGD framework. A warning to the reader is in order. In their recent form these chapters do not represent the final outcome but just an evolution of ideas proceeding by trial and error. There are however good reasons to believe that the chapter about Yangian symmetry is nearest to the correct physical interpretation and mathematical formulation.

Contrary to the original expectations, TGD seems to allow a generalization of the space-time super-symmetry. This became clear with the increased understanding of the modified Dirac action [K12, K23, K16] . It is possible to define SUSY algebra at fundamental level as anti-commutation relations of fermionic oscillator operators. Depending on the situation $\mathcal{N} = 2N$ SUSY algebra (an inherent cutoff on the number of fermionic modes at light-like wormhole throat) or fermionic part of super-conformal algebra with infinite number of oscillator operators results. The addition of fermion in particular mode would define particular super-symmetry. This super-symmetry is badly broken due to the dynamics of the modified Dirac operator which also mixes M^4 chiralities inducing massivation. Since right-handed neutrino has no electro-weak couplings the breaking of the corresponding super-symmetry should be weakest.

Zero energy ontology combined with the analog of the twistor approach to $\mathcal{N} = 4$ SYMs and weak form of electric-magnetic duality has actually led to this kind of formulation [K75] . What is new that also virtual particles have massless fermions as their building blocks. This implies manifest finiteness of loop integrals so that the situation simplifies dramatically. What is also new element that physical particles and also string like objects correspond to bound states of massless fermions.

The question is whether this SUSY has a realization as a SUSY algebra at space-time level and whether the QFT limit of TGD could be formulated as a generalization of SUSY QFT. There are several problems involved.

1. In TGD framework super-symmetry means addition of fermion to the state and since the number of spinor modes is larger states with large spin and fermion numbers are obtained. This picture does not fit to the standard view about super-symmetry. In particular, the identification of theta parameters as Majorana spinors and super-charges as Hermitian operators is not possible.

2. The belief that Majorana spinors are somehow an intrinsic aspect of super-symmetry is however only a belief. Weyl spinors meaning complex theta parameters are also possible. Theta parameters can also carry fermion number meaning only the supercharges carry fermion number and are non-hermitian. The general classification of super-symmetric theories indeed demonstrates that for $D = 8$ Weyl spinors and complex and non-hermitian super-charges are possible. The original motivation for Majorana spinors might come from MSSM assuming that right handed neutrino does not exist. This belief might have also led to string theories in $D = 10$ and $D = 11$ as the only possible candidates for TOE after it turned out that chiral

anomalies cancel. It indeed turns out that TGD view about space-time SUSY is internally consistent. Even more, the separate conservation of quark and lepton number is essential for the internal consistency of this view [K24] .

3. The massivation of particles is the basic problem of both SUSYs and twistor approach. I have discussed several solutions to this problem [K73, K75] . The simplest and most convincing solution of the problem is following and inspired by twistor Grassmannian approach to $\mathcal{N} = 4$ SYM and the generalization of the Yangian symmetry of this theory. In zero energy ontology one can construct physical particles as bound states of massless particles associated with the opposite wormhole throats. If the particles have opposite 3-momenta the resulting state is automatically massive. In fact, this forces massivation of also spin one bosons since the fermion and anti-fermion must move in opposite directions for their spins to be parallel so that the net mass is non-vanishing: note that this means that even photon, gluons, and graviton have small mass. This mechanism makes topologically condensed fermions massive and padic thermodynamics allows to describe the massivation in terms of zero energy states and M-matrix. Bosons receive to their mass besides the small mass coming from thermodynamics also a contribution which is counterpart of the contribution coming from Higgs vacuum expectation value and Higgs gives rise to longitudinal polarizations. No Higgs potential is however needed. The cancellation of infrared divergences necessary for exact Yangian symmetry and the observation that even photon receives small mass suggest that scalar Higgs would disappear completely from the spectrum.

Basic data bits

Let us first summarize the data bits about possible relevance of super-symmetry for TGD before the addition of the 3-D measurement interaction term to the modified Dirac action [K12, K23] .

1. Right-handed covariantly constant neutrino spinor ν_R defines a super-symmetry in CP_2 degrees of freedom in the sense that Dirac equation is satisfied by covariant constancy and there is no need for the usual ansatz $\Psi = D\Psi_0$ giving $D^2\Psi = 0$. This super-symmetry allows to construct solutions of Dirac equation in CP_2 [A39, A31, A37, A29] .

2. In $M^4 \times CP_2$ this means the existence of massless modes $\Psi = \not{p}\Psi_0$, where Ψ_0 is the tensor product of M^4 and CP_2 spinors. For these solutions M^4 chiralities are not mixed unlike for all other modes which are massive and carry color quantum numbers depending on the CP_2 chirality and charge. As matter fact, covariantly constant right-handed neutrino spinor mode is the only color singlet. The mechanism leading to non-colored states for fermions is based on super-conformal representations for which the color is neutralized [K34, K42] . The negative conformal weight of the vacuum also cancels the enormous contribution to mass squared coming from mass in CP_2 degrees of freedom.

3. Right-handed covariantly constant neutrino allows to construct the gamma matrices of the world of classical worlds (WCW) as fermionic counterparts of Hamiltonians of WCW. This gives rise super-symplectic symmetry algebra having interpretation also as a conformal algebra. Also more general super-conformal symmetries exist.

4. Space-time (in the sense of Minkowski space M^4) super-symmetry in the conventional sense of the word is impossible in TGD framework since it would require require Majorana spinors. In 8-D space-time with Minkowski signature of metric Majorana spinors are definitely ruled out by the standard argument leading to super string model. Majorana spinors would also break separate conservation of lepton and baryon numbers in TGD framework.

Could one generalize super-symmetry?

Could one then consider a more general space-time super-symmetry with "space-time" identified as space-time surface rather than Minkowski space?

1. The TGD variant of the super-symmetry could correspond quite concretely to the addition to fermion and boson states right-handed neutrinos. Since right-handed neutrinos do not

have electro-weak interactions, the addition might not appreciably affect the mass formula although it could affect the p-adic prime defining the mass scale.

2. The problem is to understand what this addition of the right-handed neutrino means. To begin with, notice that in TGD Universe fermions reside at light-like 3-surfaces at which the signature of induced metric changes. Bosons correspond to pairs of light-like wormhole throats with wormhole contact having Euclidian signature of the induced metric. The long standing problem has been that for bosons with parallel light-like four-momenta with same sign of energy the spins of fermion and anti-fermion are opposite so that one would obtain only scalar bosons!

   I have considered several solutions to the problem but the final solution came from the basic problem of twistor approach to $\mathcal{N} = 4$ SUSY. This theory is believed to be UV finite but has IR divergences spoiling the Yangian SUSY. These infinities cancel if the physical particles are bound states of pairs of wormhole throats with light-like momenta. Just the requirement that spin is equal to one forces massivation. This is true for all spin 1 particles, also those regarded as massless. Massivation of the photon is not a problem if the mass corresponds to the IR cutoff determined by the largest causal diamond (CD) defining the measurement resolution. For electron the size of CD corresponds to the size scale of Earth. The basic prediction is that Higgs disappears completely from the spectrum so that this mechanism is testable at LHC.

   The first proposal to the solution of problem was that either fermion or anti-fermion in the boson state carries what might be called un-physical polarization in the standard conceptual framework. This means that it has negative energy but three-momentum parallel to that of the second wormhole throat. The assumption that the bosonic wormhole throats correspond to positive and negative energy space-time sheets realizes this constraint in the framework of zero energy ontology. It however turned out that for light-like momenta these states have more natural interpretation in terms of virtual bosons able to have space-like momenta. This means that one can realize virtual particles as pairs of on mass shell wormhole throats with either sign of energy and 3-momentum so that the basic condition of twistorial approach is satisfied. The conservation of 4-momentum at vertices gives extremely powerful kinematical constraints so that there are excellent hopes about cancellation of UV divergences of loop integrals.

3. The super-symmetry as an addition to the fermion state a second wormhole throats carrying right handed neutrino quantum numbers does not make sense since the resulting state cannot be distinguished from gauge boson or Higgs type particle. The light-like 3-surfaces can however carry fermion numbers up to the number of modes of the induced spinor field, which is expected to be infinite inside string like objects having wormhole throats at ends and finite when one has space time sheets containing the throats [K23] . In very general sense one could say that each mode defines a very large broken N-super-symmetry with the value of N depending on state and light-like 3-surface. The breaking of this super-symmetry would come from electro-weak - , color - , and gravitational interactions. Right-handed neutrino would by its electro-weak and color inertness define a minimally broken super-symmetry.

4. What this addition of the right handed neutrinos or more general fermion modes could precisely mean? One cannot assign fermionic oscillator operators to right handed neutrinos which are covariantly constant in both M^4 and CP_2 degrees of freedom since the modes with vanishing energy (frequency) cannot correspond to fermionic oscillator operator creating a physical state since one would have $a = a^\dagger$. The intuitive view is that all the spinor modes move in an exactly collinear manner -somewhat like quarks inside hadron do approximately.

Modified Dirac equation briefly

The answer to the question what "collinear motion" means mathematically emerged from the recent progress in the understanding of the modified Dirac equation.

1. The modified Dirac action involves two terms. Besides the original 4-D modified Dirac action there is measurement interaction which can be localized to wormhole throat or to any light-like 3-surfaces "parallel" to it in the slicing of space-time sheet by light-like 3-surfaces. This

term correlates space-time geometry with quantum numbers assignable to super-conformal representations and is also necessary to obtain almost- stringy propagator.

2. The modified Dirac equation with measurement action added reads as

$$\begin{aligned} D_K\Psi &= 0 \ , \\ D_3\Psi &= (D_{C-S} + Q\times O)\Psi = 0 \ , \\ [D_3, D_K]\,\Psi &= 0 \ . \end{aligned} \tag{2.4.1}$$

   (a) D_K corresponds formally to 4-D massless Dirac equation in X^4. D_3 realizes measurement interaction. D_{C-S} is the 3-D modified Dirac action defined by Chern-Simons action.

   (b) Q is linear in Cartan algebra generators of the isometry algebra of imbedding space (color isospin and hypercharge plus four-momentum or two components of four momentum and spin and boost in direction of 3-momentum). Q is expressible as

$$Q = Q_A \partial_\alpha h^k g^{AB} j_{Bk} \hat{\Gamma}^\alpha_{CS} \ . \tag{2.4.2}$$

   Here Q_A is Cartan algebra generator acting on physical states. Physical states must be eigen states of Q_A since otherwise the equations do not make sense. g^{AB} is the inverse of the matrix defined by the imbedding space inner product of Killing vector fields j^k_A and j^l_B: its existence allows only Cartan algebra charges. $\hat{\Gamma}^\alpha_{CS}$ is the modified gamma matrix associated with the Chern-Simons action.

   (c) In general case the modified gamma matrices are defined in terms of action density L as

$$\hat{\Gamma}^\alpha = \frac{\partial L}{\partial_\alpha h^k}\gamma^k \ . \tag{2.4.3}$$

   γ^k denotes imbedding space gamma matrices.

   (d) The operator O characterizes the conserved fermionic current to which Cartan algebra generators of isometries couple. The simplest conserved currents correspond to quark or lepton currents and corresponding vectorial isospin- and spin currents [K23]. Besides this there is an infinite hierarchy of conserved currents relating to quantum criticality and in one-one correspondence with vanishing second variations of Kähler action for preferred extremal. These couplings allow to represent measurement interaction for any observable.

3. The equation $D_3\nu_R = 0$ would reduce for vanishing color charges and covariantly constant spinor to the analog of algebraic fermionic on mass shell condition $p_A\gamma^A\nu_R = 0$ since Q is obtained by projecting the total four-momentum of the parton state interpreted as a vector-field of H to the space-time surface and by replacing ordinary gamma matrices with the modified ones. This equation cannot be exact since Q depends on the point of the light-like 3-surface so that covariant constancy fails and D_{C-S} cannot annihilate the state. This is the space-time correlate for the breaking of super-symmetry. The action of the Cartan algebra generators is purely algebraic and on the state of super-conformal representations rather than that of a differential operator on spinor field. The modified equation implies that all spinor modes represent fermions moving collinearly in the sense an equation with the same total four-momentum and total color quantum numbers is satisfied by all of them. Note that p_A represents the total four-momentum of the state rather than individual four-momenta of fermions.

TGD counterpart of space-time super-symmetry

This picture allows to define more precisely what one means with the approximate super-symmetries in TGD framework.

1. One can in principle construct many-fermion states containing both fermions and anti-fermions at given light-like 3-surface. The four-momenta of states related by super-symmetry need not be same. Super-symmetry breaking is present and has as the space-time correlate the deviation of the modified gamma matrices from the ordinary M^4 gamma matrices. In particular, the fact that $\hat{\Gamma}^\alpha$ possesses CP_2 part in general means that different M^4 chiralities are mixed: a space-time correlate for the massivation of the elementary particles.

2. For right-handed neutrino super-symmetry breaking is expected to be smallest but also in the case of the right-handed neutrino mode mixing of M^4 chiralities takes place and breaks the TGD counterpart of super-symmetry.

3. The fact that all helicities in the state are physical for a given light-like 3-surface has important implications. For instance, the addition of a right-handed antineutrino to right-handed (left-handed) electron state gives scalar (spin 1) state. Also states with fermion number two are obtained from fermions. For instance, for e_R one obtains the states $\{e_R, e_R\nu_R\overline{\nu}_R, e_R\overline{\nu}_R, e_R\nu_R\}$ with lepton numbers $(1, 1, 0, 2)$ and spins $(1/2, 1/2, 0, 1)$. For e_L one obtains the states $\{e_L, e_L\nu_R\overline{\nu}_R, e_L\overline{\nu}_R, e_L\nu_R\}$ with lepton numbers $(1, 1, 0, 2)$ and spins $(1/2, 1/2, 1, 0)$. In the case of gauge boson and Higgs type particles -allowed by TGD but not required by p-adic mass calculations- gauge boson has 15 super partners with fermion numbers $[2, 1, 0, -1, -2]$.

The cautious conclusion is that the recent view about quantum TGD allows the analog of super-symmetry which is necessary broken and for which the multiplets are much more general than for the ordinary super-symmetry. Right-handed neutrinos might however define something resembling ordinary super-symmetry to a high extent. The question is how strong prediction one can deduce using quantum TGD and proposed super-symmetry.

1. For a minimal breaking of super-symmetry only the p-adic length scale characterizing the super-partner differs from that for partner but the mass of the state is same. This would allow only a discrete set of masses for various super-partners coming as half octaves of the mass of the particle in question. A highly predictive model results.

2. The quantum field theoretic description should be based on QFT limit of TGD formulated in terms of bosonic emergence [K49] . This formulation should allow to calculate the propagators of the super-partners in terms of fermionic loops.

3. This TGD variant of space-time super-symmetry resembles ordinary super-symmetry in the sense that selection rules due to the right-handed neutrino number conservation and analogous to the conservation of R-parity hold true. The states inside super-multiplets have identical electro-weak and color quantum numbers but their p-adic mass scales can be different. It should be possible to estimate reaction reaction rates using rules very similar to those of super-symmetric gauge theories.

4. It might be even possible to find some simple generalization of standard super-symmetric gauge theory to get rough estimates for the reaction rates. There are however problems. The fact that spins $J = 0, 1, 2, 3/2, 2$ are possible for super-partners of gauge bosons forces to ask whether these additional states define an analog of non-stringy strong gravitation. Note that graviton in TGD framework corresponds to a pair of wormhole throats connected by flux tube (counterpart of string) and for gravitons one obtains 2^8-fold degeneracy.

2.4.6 What could be the generalization of Yangian symmetry of $\mathcal{N} = 4$ SUSY in TGD framework?

There has been impressive steps in the understanding of $\mathcal{N} = 4$ maximally sypersymmetric YM theory possessing 4-D super-conformal symmetry. This theory is related by AdS/CFT duality to certain string theory in $AdS_5 \times S^5$ background. Second stringy representation was discovered by

Witten and is based on 6-D Calabi-Yau manifold defined by twistors. The unifying proposal is that so called Yangian symmetry is behind the mathematical miracles involved.

The notion of Yangian symmetry would have a generalization in TGD framework obtained by replacing conformal algebra with appropriate super-conformal algebras. Also a possible realization of twistor approach and the construction of scattering amplitudes in terms of Yangian invariants defined by Grassmannian integrals is considered in TGD framework and based on the idea that in zero energy ontology one can represent massive states as bound states of massless particles. There is also a proposal for a physical interpretation of the Cartan algebra of Yangian algebra allowing to understand at the fundamental level how the mass spectrum of n-particle bound states could be understood in terms of the n-local charges of the Yangian algebra.

Twistors were originally introduced by Penrose to characterize the solutions of Maxwell's equations. Kähler action is Maxwell action for the induced Kähler form of CP_2. The preferred extremals allow a very concrete interpretation in terms of modes of massless non-linear field. Both conformally compactified Minkowski space identifiable as so called causal diamond and CP_2 allow a description in terms of twistors. These observations inspire the proposal that a generalization of Witten's twistor string theory relying on the identification of twistor string world sheets with certain holomorphic surfaces assigned with Feynman diagrams could allow a formulation of quantum TGD in terms of 3-dimensional holomorphic surfaces of $CP_3 \times CP_3$ mapped to 6-surfaces dual $CP_3 \times CP_3$, which are sphere bundles so that they are projected in a natural manner to 4-D space-time surfaces. Very general physical and mathematical arguments lead to a highly unique proposal for the holomorphic differential equations defining the complex 3-surfaces conjectured to correspond to the preferred extremals of Kähler action.

Background

I am outsider as far as concrete calculations in $\mathcal{N} = 4$ SUSY are considered and the following discussion of the background probably makes this obvious. My hope is that the reader had patience to not care about this and try to see the big pattern.

The developments began from the observation of Parke and Taylor [B26] that n-gluon tree amplitudes with less than two negative helicities vanish and those with two negative helicities have unexpectedly simple form when expressed in terms of spinor variables used to represent light-like momentum. In fact, in the formalism based on Grassmanian integrals the reduced tree amplitude for two negative helicities is just "1" and defines Yangian invariant. The article *Perturbative Gauge Theory As a String Theory In Twistor Space* [B29] by Witten led to so called Britto-Cachazo-Feng-Witten (BCFW) recursion relations for tree level amplitudes [B27, B18, B27] allowing to construct tree amplitudes using the analogs of Feynman rules in which vertices correspond to maximally helicity violating tree amplitudes (2 negative helicity gluons) and propagator is massless Feynman propagator for boson. The progress inspired the idea that the theory might be completely integrable meaning the existence of infinite-dimensional un-usual symmetry. This symmetry would be so called Yangian symmetry [K75] assigned to the super counterpart of the conformal group of 4-D Minkowski space.

Drumond, Henn, and Plefka represent in the article *Yangian symmetry of scattering amplitudes in $\mathcal{N} = 4$ super Yang-Mills theory* [B21] an argument suggesting that the Yangian invariance of the scattering amplitudes ins an intrinsic property of planar $\mathcal{N} = 4$ super Yang Mills at least at tree level.

The latest step in the progress was taken by Arkani-Hamed, Bourjaily, Cachazo, Carot-Huot, and Trnka and represented in the article *Yangian symmetry of scattering amplitudes in $\mathcal{N} = 4$ super Yang-Mills theory* [B17] . At the same day there was also the article of Rutger Boels entitled *On BCFW shifts of integrands and integrals* [B10] in the archive. Arkani-Hamed *et al* argue that a full Yangian symmetry of the theory allows to generalize the BCFW recursion relation for tree amplitudes to all loop orders at planar limit (planar means that Feynman diagram allows imbedding to plane without intersecting lines). On mass shell scattering amplitudes are in question.

Yangian symmetry

The notion equivalent to that of Yangian was originally introduced by Faddeev and his group in the study of integrable systems. Yangians are Hopf algebras which can be assigned with Lie algebras as the deformations of their universal enveloping algebras. The elegant but rather cryptic looking definition is in terms of the modification of the relations for generating elements [K75] . Besides ordinary product in the enveloping algebra there is co-product Δ which maps the elements of the enveloping algebra to its tensor product with itself. One can visualize product and co-product is in terms of particle reactions. Particle annihilation is analogous to annihilation of two particle so single one and co-product is analogous to the decay of particle to two. Δ allows to construct higher generators of the algebra.

Lie-algebra can mean here ordinary finite-dimensional simple Lie algebra, Kac-Moody algebra or Virasoro algebra. In the case of SUSY it means conformal algebra of M^4- or rather its super counterpart. Witten, Nappi and Dolan have described the notion of Yangian for super-conformal algebra in very elegant and and concrete manner in the article *Yangian Symmetry in D=4 superconformal Yang-Mills theory* [B23] . Also Yangians for gauge groups are discussed.

In the general case Yangian resembles Kac-Moody algebra with discrete index n replaced with a continuous one. Discrete index poses conditions on the Lie group and its representation (adjoint representation in the case of $\mathcal{N} = 4$ SUSY). One of the conditions conditions is that the tensor product $R \otimes R^*$ for representations involved contains adjoint representation only once. This condition is non-trivial. For $SU(n)$ these conditions are satisfied for any representation. In the case of $SU(2)$ the basic branching rule for the tensor product of representations implies that the condition is satisfied for the product of any representations.

Yangian algebra with a discrete basis is in many respects analogous to Kac-Moody algebra. Now however the generators are labelled by non-negative integers labeling the light-like incoming and outgoing momenta of scattering amplitude whereas in in the case of Kac-Moody algebra also negative values are allowed. Note that only the generators with non-negative conformal weight appear in the construction of states of Kac-Moody and Virasoro representations so that the extension to Yangian makes sense.

The generating elements are labelled by the generators of ordinary conformal transformations acting in M^4 and their duals acting in momentum space. These two sets of elements can be labelled by conformal weights $n = 0$ and $n = 1$ and and their mutual commutation relations are same as for Kac-Moody algebra. The commutators of $n = 1$ generators with themselves are however something different for a non-vanishing deformation parameter h. Serre's relations characterize the difference and involve the deformation parameter h. Under repeated commutations the generating elements generate infinite-dimensional symmetric algebra, the Yangian. For $h = 0$ one obtains just one half of the Virasoro algebra or Kac-Moody algebra. The generators with $n > 0$ are $n + 1$-local in the sense that they involve $n + 1$-forms of local generators assignable to the ordered set of incoming particles of the scattering amplitude. This non-locality generalizes the notion of local symmetry and is claimed to be powerful enough to fix the scattering amplitudes completely.

How to generalize Yangian symmetry in TGD framework?

As far as concrete calculations are considered, I have nothing to say. I am just perplexed. It is however possible to keep discussion at general level and still say something interesting (as I hope!). The key question is whether it could be possible to generalize the proposed Yangian symmetry and geometric picture behind it to TGD framework.

1. The first thing to notice is that the Yangian symmetry of $\mathcal{N} = 4$ SUSY in question is quite too limited since it allows only single representation of the gauge group and requires massless particles. One must allow all representations and massive particles so that the representation of symmetry algebra must involve states with different masses, in principle arbitrary spin and arbitrary internal quantum numbers. The candidates are obvious: Kac-Moody algebras [A6] and Virasoro algebras [A15] and their super counterparts. Yangians indeed exist for arbitrary super Lie algebras. In TGD framework conformal algebra of Minkowski space reduces to Poincare algebra and its extension to Kac-Moody allows to have also massive states.

2. The formal generalization looks surprisingly straightforward at the formal level. In zero energy ontology one replaces point like particles with partonic two-surfaces appearing at the ends of light-like orbits of wormhole throats located to the future and past light-like boundaries of causal diamond ($CD \times CP_2$ or briefly CD). Here CD is defined as the intersection of future and past directed light-cones. The polygon with light-like momenta is naturally

replaced with a polygon with more general momenta in zero energy ontology and having partonic surfaces as its vertices. Non-point-likeness forces to replace the finite-dimensional super Lie-algebra with infinite-dimensional Kac-Moody algebras and corresponding super-Virasoro algebras assignable to partonic 2-surfaces.

3. This description replaces disjoint holomorphic surfaces in twistor space with partonic 2-surfaces at the boundaries of $CD \times CP_2$ so that there seems to be a close analogy with Cachazo-Svrcek-Witten picture. These surfaces are connected by either light-like orbits of partonic 2-surface or space-like 3-surfaces at the ends of CD so that one indeed obtains the analog of polygon.

What does this then mean concretely (if this word can be used in this kind of context;-)?

1. At least it means that ordinary Super Kac-Moody and Super Virasoro algebras associated with isometries of $M^4 \times CP_2$ annihilating the scattering amplitudes must be extended to a co-algebras with a non-trivial deformation parameter. Kac-Moody group is thus the product of Poincare and color groups. This algebra acts as deformations of the light-like 3-surfaces representing the light-like orbits of particles which are extremals of Chern-Simon action with the constraint that weak form of electric-magnetic duality holds true. I know so little about the mathematical side that I cannot tell whether the condition that the product of the representations of Super-Kac-Moody and Super-Virasoro algebras ontains adjoint representation only once, holds true in this case. In any case, it would allow all representations of finite-dimensional Lie group in vertices whereas $\mathcal{N} = 4$ SUSY would allow only the adjoint.

2. Besides this ordinary kind of Kac-Moody algebra there is the analog of Super-Kac-Moody algebra associated with the light-cone boundary which is metrically 3-dimensional. The finite-dimensional Lie group is in this case replaced with infinite-dimensional group of symplectomorphisms of $\delta M^4_{+/-}$ made local with respect to the internal coordinates of partonic 2-surface. A coset construction is applied to these two Virasoro algebras so that the differences of the corresponding Super-Virasoro generators and Kac-Moody generators annihilate physical states. Contrary to the original belief, this construction does not provide a realization of Equivalence Principle at quantum level. The proper realization of EP at quantum level seems to be based on the identification of classical Noether charges in Cartan algebra with the eigenvalues of their quantum counterparts assignable to Kähler-Dirac action. At classical level EP follows at GRT limit obtained by lumping many-sheeted space-time to M^4 with effective metric satisfying Einstein's equations as a reflection of the underlying Poincare invariance.

3. The construction of TGD leads also to other super-conformal algebras and the natural guess is that the Yangians of all these algebras annihilate the scattering amplitudes.

4. Obviously, already the starting point symmetries look formidable but they still act on single partonic surface only. The discrete Yangian associated with this algebra associated with the closed polygon defined by the incoming momenta and the negatives of the outgoing momenta acts in multi-local manner on scattering amplitudes. It might make sense to speak about polygons defined also by other conserved quantum numbers so that one would have generalized light-like curves in the sense that state are massless in 8-D sense.

Is there any hope about description in terms of Grassmannians?

At technical level the successes of the twistor approach rely on the observation that the amplitudes can be expressed in terms of very simple integrals over sub-manifolds of the space consisting of k-dimensional planes of n-dimensional space defined by delta function appearing in the integrand. These integrals define super-conformal Yangian invariants appearing in twistorial amplitudes and the belief is that by a proper choice of the surfaces of the twistor space one can construct all invariants. One can construct also the counterparts of loop corrections by starting from tree diagrams and annihilating pair of particles by connecting the lines and quantum entangling the states at the ends in the manner dictated by the integration over loop momentum. These operations can be defined as operations for Grassmannian integrals in general changing the values of n and

k. This description looks extremely powerful and elegant and nosta importantly involves only the external momenta.

The obvious question is whether one could use similar invariants in TGD framework to construct the momentum dependence of amplitudes.

1. The first thing to notice is that the super algebras in question act on infinite-dimensional representations and basically in the world of classical worlds assigned to the partonic 2-surfaces correlated by the fact that they are associated with the same space-time surface. This does not promise anything very practical. On the other hand, one can hope that everything related to other than M^4 degrees of freedom could be treated like color degrees of freedom in $\mathcal{N} = 4$ SYM and would boil down to indices labeling the quantum states. The Yangian conditions coming from isometry quantum numbers, color quantum numbers, and electroweak quantum numbers are of course expected to be highly non-trivial and could fix the coefficients of various singlets resulting in the tensor product of incoming and outgoing states.

2. The fact that incoming particles can be also massive seems to exclude the use of the twistor space. The following observation however raises hopes. The Dirac propagator for wormhole throat is massless propagator but for what I call pseudo momentum. It is still unclear how this momentum relates to the actual four-momentum. Could it be actually equal to it? The recent view about pseudo-momentum does not support this view but it is better to keep mind open. In any case this finding suggests that twistorial approach could work in in more or less standard form. What would be needed is a representation for massive incoming particles as bound states of massless partons. In particular, the massive states of super-conformal representations should allow this kind of description.

Could zero energy ontology allow to achieve this dream?

1. As far as divergence cancellation is considered, zero energy ontology suggests a totally new approach producing the basic nice aspects of QFT approach, in particular unitarity and coupling constant evolution. The big idea related to zero energy ontology is that all virtual particle particles correspond to wormhole throats, which are pairs of on mass shell particles. If their momentum directions are different, one obtains time-like continuum of virtual momenta and if the signs of energy are opposite one obtains also space-like virtual momenta. The on mass shell property for virtual partons (massive in general) implies extremely strong constraints on loops and one expect that only very few loops remain and that they are finite since loop integration reduces to integration over much lower-dimensional space than in the QFT approach. There are also excellent hopes about Cutkoski rules.

2. Could zero energy ontology make also possible to construct massive incoming particles from massless ones? Could one construct the representations of the super conformal algebras using only massless states so that at the fundamental level incoming particles would be massless and one could apply twistor formalism and build the momentum dependence of amplitudes using Grassmannian integrals.

   One could indeed construct on mass shell massive states from massless states with momenta along the same line but with three-momenta at opposite directions. Mass squared is given by $M^2 = 4E^2$ in the coordinate frame, where the momenta are opposite and of same magnitude. One could also argue that partonic 2-surfaces carrying quantum numbers of fermions and their superpartners serve as the analogs of point like massless particles and that topologically condensed fermions and gauge bosons plus their superpartners correspond to pairs of wormhole throats. Stringy objects would correspond to pairs of wormhole throats at the same space-time sheet in accordance with the fact that space-time sheet allows a slicing by string worlds sheets with ends at different wormhole throats and defining time like braiding.

The weak form of electric magnetic duality indeed supports this picture. To understand how, one must explain a little bit what the weak form of electric magnetic duality means.

1. Elementary particles correspond to light-like orbits of partonic 2-surfaces identified as 3-D surfaces at which the signature of the induced metric of space-time surface changes from

Euclidian to Minkowskian and 4-D metric is therefore degenerate. The analogy with black hole horizon is obvious but only partial. Weak form of electric-magnetic duality states that the Kähler electric field at the wormhole throat and also at space-like 3-surfaces defining the ends of the space-time surface at the upper and lower light-like boundaries of the causal diamond is proportonial to Kähler magnetic field so that Kähler electric flux is proportional Kähler magnetic flux. This implies classical quantization of Kähler electric charge and fixes the value of the proportionality constant.

2. There are also much more profound implications. The vision about TGD as almost topological QFT suggests that Kähler function defining the Kähler geometry of the "world of classical worlds" (WCW) and identified as Kähler action for its preferred extremal reduces to the 3-D Chern-Simons action evaluated at wormhole throats and possible boundary components. Chern-Simons action would be subject to constraints. Wormhole throats and space-like 3-surfaces would represent extremals of Chern-Simons action restricted by the constraint force stating electric-magnetic duality (and realized in terms of Lagrange multipliers as usual).

   If one assumes that Kähler current and other conserved currents are proportional to current defining Beltrami flow whose flow lines by definition define coordinate curves of a globally defined coordinate, the Coulombic term of Kähler action vanishes and it reduces to Chern-Simons action if the weak form of electric-magnetic duality holds true. One obtains almost topological QFT. The absolutely essential attribute "almost" comes from the fact that Chern-Simons action is subject to constraints. As a consequence, one obtains non-vanishing four-momenta and WCW geometry is non-trivial in M^4 degrees of freedom. Otherwise one would have only topological QFT not terribly interesting physically.

Consider now the question how one could understand stringy objects as bound states of massless particles.

1. The observed elementary particles are not Kähler monopoles and there much exist a mechanism neutralizing the monopole charge. The only possibility seems to be that there is opposite Kähler magnetic charge at second wormhole throat. The assumption is that in the case of color neutral particles this throat is at a distance of order intermediate gauge boson Compton length. This throat would carry weak isospin neutralizing that of the fermion and only electromagnetic charge would be visible at longer length scales. One could speak of electro-weak confinement. Also color confinement could be realized in analogous manner by requiring the cancellation of monopole charge for many-parton states only. What comes out are string like objects defined by Kähler magnetic fluxes and having magnetic monopoles at ends. Also more general objects with three strings branching from the vertex appear in the case of baryons. The natural guess is that the partons at the ends of strings and more general objects are massless for incoming particles but that the 3-momenta are in opposite directions so that stringy mass spectrum and representations of relevant super-conformal algebras are obtained. This description brings in mind the description of hadrons in terms of partons moving in parallel apart from transversal momentum about which only momentum squared is taken as observable.

2. Quite generally, one expects for the preferred extremals of Kähler action the slicing of space-time surface with string world sheets with stringy curves connecting wormhole throats. The ends of the stringy curves can be identified as light-like braid strands. Note that the strings themselves define a space-like braiding and the two braidings are in some sense dual. This has a concrete application in TGD inspired quantum biology, where time-like braiding defines topological quantum computer programs and the space-like braidings induced by it its storage into memory. Stringlike objects defining representations of super-conformal algebras must correspond to states involving at least two wormhole throats. Magnetic flux tubes connecting the ends of magnetically charged throats provide a particular realization of stringy on mass shell states. This would give rise to massless propagation at the parton level. The stringy quantization condition for mass squared would read as $4E^2 = n$ in suitable units for the representations of super-conformal algebra associated with the isometries. For pairs of throats of the same wormhole contact stringy spectrum does not seem plausible since the wormhole

contact is in the direction of CP_2. One can however expect generation of small mass as deviation of vacuum conformal weight from half integer in the case of gauge bosons.

If this picture is correct, one might be able to determine the momentum dependence of the scattering amplitudes by replacing free fermions with pairs of monopoles at the ends of string and topologically condensed fermions gauge bosons with pairs of this kind of objects with wormhole throat replaced by a pair of wormhole throats. This would mean suitable number of doublings of the Grassmannian integrations with additional constraints on the incoming momenta posed by the mass shell conditions for massive states.

Could zero energy ontology make possible full Yangian symmetry?

The partons in the loops are on mass shell particles have a discrete mass spectrum but both signs of energy are possible for opposite wormhole throats. This implies that in the rules for constructing loop amplitudes from tree amplitudes, propagator entanglement is restricted to that corresponding to pairs of partonic on mass shell states with both signs of energy. As emphasized in [B17], it is the Grassmannian integrands and leading order singularities of $\mathcal{N}=4$ SYM, which possess the full Yangian symmetry. The full integral over the loop momenta breaks the Yangian symmetry and brings in IR singularities. Zero energy ontologist finds it natural to ask whether QFT approach shows its inadequacy both via the UV divergences and via the loss of full Yangian symmetry. The restriction of virtual partons to discrete mass shells with positive or negative sign of energy imposes extremely powerful restrictions on loop integrals and resembles the restriction to leading order singularities. Could this restriction guarantee full Yangian symmetry and remove also IR singularities?

Could Yangian symmetry provide a new view about conserved quantum numbers?

The Yangian algebra has some properties which suggest a new kind of description for bound states. The Cartan algebra generators of $n=0$ and $n=1$ levels of Yangian algebra commute. Since the co-product Δ maps $n=0$ generators to $n=1$ generators and these in turn to generators with high value of n, it seems that they commute also with $n \geq 1$ generators. This applies to four-momentum, color isospin and color hyper charge, and also to the Virasoro generator L_0 acting on Kac-Moody algebra of isometries and defining mass squared operator.

Could one identify total four momentum and Cartan algebra quantum numbers as sum of contributions from various levels? If so, the four momentum and mass squared would involve besides the local term assignable to wormhole throats also n-local contributions. The interpretation in terms of n-parton bound states would be extremely attractive. n-local contribution would involve interaction energy. For instance, string like object would correspond to $n=1$ level and give $n=2$-local contribution to the momentum. For baryonic valence quarks one would have 3-local contribution corresponding to $n=2$ level. The Yangian view about quantum numbers could give a rigorous formulation for the idea that massive particles are bound states of massless particles.

2.5 Weak form electric-magnetic duality and its implications

The notion of electric-magnetic duality [B6] was proposed first by Olive and Montonen and is central in $\mathcal{N}=4$ supersymmetric gauge theories. It states that magnetic monopoles and ordinary particles are two different phases of theory and that the description in terms of monopoles can be applied at the limit when the running gauge coupling constant becomes very large and perturbation theory fails to converge. The notion of electric-magnetic self-duality is more natural since for CP_2 geometry Kähler form is self-dual and Kähler magnetic monopoles are also Kähler electric monopoles and Kähler coupling strength is by quantum criticality renormalization group invariant rather than running coupling constant. The notion of electric-magnetic (self-)duality emerged already two decades ago in the attempts to formulate the Kähler geometric of world of classical worlds. Quite recently a considerable step of progress took place in the understanding of this notion [K13] . What seems to be essential is that one adopts a weaker form of the self-duality applying at partonic 2-surfaces. What this means will be discussed in the sequel.

Every new idea must be of course taken with a grain of salt but the good sign is that this concept leads to precise predictions. The point is that elementary particles do not generate monopole fields in macroscopic length scales: at least when one considers visible matter. The first question is whether elementary particles could have vanishing magnetic charges: this turns out to be impossible. The next question is how the screening of the magnetic charges could take place and leads to an identification of the physical particles as string like objects identified as pairs magnetic charged wormhole throats connected by magnetic flux tubes.

1. The first implication is a new view about electro-weak massivation reducing it to weak confinement in TGD framework. The second end of the string contains particle having electroweak isospin neutralizing that of elementary fermion and the size scale of the string is electro-weak scale would be in question. Hence the screening of electro-weak force takes place via weak confinement realized in terms of magnetic confinement.

2. This picture generalizes to the case of color confinement. Also quarks correspond to pairs of magnetic monopoles but the charges need not vanish now. Rather, valence quarks would be connected by flux tubes of length of order hadron size such that magnetic charges sum up to zero. For instance, for baryonic valence quarks these charges could be $(2,-1,-1)$ and could be proportional to color hyper charge.

3. The highly non-trivial prediction making more precise the earlier stringy vision is that elementary particles are string like objects: this could become manifest at LHC energies.

4. The weak form electric-magnetic duality together with Beltrami flow property of Kähler leads to the reduction of Kähler action to Chern-Simons action so that TGD reduces to almost topological QFT and that Kähler function is explicitly calculable. This has enormous impact concerning practical calculability of the theory.

5. One ends up also to a general solution ansatz for field equations from the condition that the theory reduces to almost topological QFT. The solution ansatz is inspired by the idea that all isometry currents are proportional to Kähler current which is integrable in the sense that the flow parameter associated with its flow lines defines a global coordinate. The proposed solution ansatz would describe a hydrodynamical flow with the property that isometry charges are conserved along the flow lines (Beltrami flow). A general ansatz satisfying the integrability conditions is found.

   The strongest form of the solution ansatz states that various classical and quantum currents flow along flow lines of the Beltrami flow defined by Kähler current (Kähler magnetic field associated with Chern-Simons action). Intuitively this picture is attractive. A more general ansatz would allow several Beltrami flows meaning multi-hydrodynamics. The integrability conditions boil down to two scalar functions: the first one satisfies massless d'Alembert equation in the induced metric and the the gradients of the scalar functions are orthogonal. The interpretation in terms of momentum and polarization directions is natural.

2.5.1 Could a weak form of electric-magnetic duality hold true?

Holography means that the initial data at the partonic 2-surfaces should fix the WCW metric. A weak form of this condition allows only the partonic 2-surfaces defined by the wormhole throats at which the signature of the induced metric changes. A stronger condition allows all partonic 2-surfaces in the slicing of space-time sheet to partonic 2-surfaces and string world sheets. Number theoretical vision suggests that hyper-quaternionicity *resp.* co-hyperquaternionicity constraint could be enough to fix the initial values of time derivatives of the imbedding space coordinates in the space-time regions with Minkowskian *resp.* Euclidian signature of the induced metric. This is a condition on modified gamma matrices and hyper-quaternionicity states that they span a hyper-quaternionic sub-space.

Definition of the weak form of electric-magnetic duality

One can also consider alternative conditions possibly equivalent with this condition. The argument goes as follows.

1. The expression of the matrix elements of the metric and Kähler form of WCW in terms of the Kähler fluxes weighted by Hamiltonians of $\delta M^4_\pm$ at the partonic 2-surface X^2 looks very attractive. These expressions however carry no information about the 4-D tangent space of the partonic 2-surfaces so that the theory would reduce to a genuinely 2-dimensional theory, which cannot hold true. One would like to code to the WCW metric also information about the electric part of the induced Kähler form assignable to the complement of the tangent space of $X^2 \subset X^4$.

2. Electric-magnetic duality of the theory looks a highly attractive symmetry. The trivial manner to get electric magnetic duality at the level of the full theory would be via the identification of the flux Hamiltonians as sums of of the magnetic and electric fluxes. The presence of the induced metric is however troublesome since the presence of the induced metric means that the simple transformation properties of flux Hamiltonians under symplectic transformations -in particular color rotations- are lost.

3. A less trivial formulation of electric-magnetic duality would be as an initial condition which eliminates the induced metric from the electric flux. In the Euclidian version of 4-D YM theory this duality allows to solve field equations exactly in terms of instantons. This approach involves also quaternions. These arguments suggest that the duality in some form might work. The full electric magnetic duality is certainly too strong and implies that space-time surface at the partonic 2-surface corresponds to piece of CP_2 type vacuum extremal and can hold only in the deep interior of the region with Euclidian signature. In the region surrounding wormhole throat at both sides the condition must be replaced with a weaker condition.

4. To formulate a weaker form of the condition let us introduce coordinates (x^0, x^3, x^1, x^2) such (x^1, x^2) define coordinates for the partonic 2-surface and (x^0, x^3) define coordinates labeling partonic 2-surfaces in the slicing of the space-time surface by partonic 2-surfaces and string world sheets making sense in the regions of space-time sheet with Minkowskian signature. The assumption about the slicing allows to preserve general coordinate invariance. The weakest condition is that the generalized Kähler electric fluxes are apart from constant proportional to Kähler magnetic fluxes. This requires the condition

$$J^{03}\sqrt{g_4} = KJ_{12} \ . \tag{2.5.1}$$

A more general form of this duality is suggested by the considerations of [K29] reducing the hierarchy of Planck constants to basic quantum TGD and also reducing Kähler function for preferred extremals to Chern-Simons terms [B2] at the boundaries of CD and at light-like wormhole throats. This form is following

$$J^{n\beta}\sqrt{g_4} = K\epsilon \times \epsilon^{n\beta\gamma\delta}J_{\gamma\delta}\sqrt{g_4} \ . \tag{2.5.2}$$

Here the index n refers to a normal coordinate for the space-like 3-surface at either boundary of CD or for light-like wormhole throat. ϵ is a sign factor which is opposite for the two ends of CD. It could be also opposite of opposite at the opposite sides of the wormhole throat. Note that the dependence on induced metric disappears at the right hand side and this condition eliminates the potentials singularity due to the reduction of the rank of the induced metric at wormhole throat.

5. Information about the tangent space of the space-time surface can be coded to the WCW metric with loosing the nice transformation properties of the magnetic flux Hamiltonians if Kähler electric fluxes or sum of magnetic flux and electric flux satisfying this condition are used and K is symplectic invariant. Using the sum

$$J_e + J_m = (1+K)J_{12} \ , \qquad (2.5.3)$$

where J denotes the Kähler magnetic flux, , makes it possible to have a non-trivial WCW metric even for $K=0$, which could correspond to the ends of a cosmic string like solution carrying only Kähler magnetic fields. This condition suggests that it can depend only on Kähler magnetic flux and other symplectic invariants. Whether local symplectic coordinate invariants are possible at all is far from obvious, If the slicing itself is symplectic invariant then K could be a non-constant function of X^2 depending on string world sheet coordinates. The light-like radial coordinate of the light-cone boundary indeed defines a symplectically invariant slicing and this slicing could be shifted along the time axis defined by the tips of CD.

Electric-magnetic duality physically

What could the weak duality condition mean physically? For instance, what constraints are obtained if one assumes that the quantization of electro-weak charges reduces to this condition at classical level?

1. The first thing to notice is that the flux of J over the partonic 2-surface is analogous to magnetic flux

$$Q_m = \frac{e}{\hbar}\oint BdS = n \ .$$

   n is non-vanishing only if the surface is homologically non-trivial and gives the homology charge of the partonic 2-surface.

2. The expressions of classical electromagnetic and Z^0 fields in terms of Kähler form [L1] , [L1] read as

$$\begin{aligned} \gamma &= \frac{eF_{em}}{\hbar} = 3J - sin^2(\theta_W)R_{03} \ , \\ Z^0 &= \frac{g_ZF_Z}{\hbar} = 2R_{03} \ . \end{aligned} \qquad (2.5.4)$$

   Here R_{03} is one of the components of the curvature tensor in vielbein representation and F_{em} and F_Z correspond to the standard field tensors. From this expression one can deduce

$$J = \frac{e}{3\hbar}F_{em} + sin^2(\theta_W)\frac{g_Z}{6\hbar}F_Z \ . \qquad (2.5.5)$$

3. The weak duality condition when integrated over X^2 implies

$$\begin{aligned} \frac{e^2}{3\hbar}Q_{em} + \frac{g_Z^2p}{6}Q_{Z,V} &= K\oint J = Kn \ , \\ Q_{Z,V} &= \frac{I_V^3}{2} - Q_{em} \ , \ \ p = sin^2(\theta_W) \ . \end{aligned} \qquad (2.5.6)$$

   Here the vectorial part of the Z^0 charge rather than as full Z^0 charge $Q_Z = I_L^3 + sin^2(\theta_W)Q_{em}$ appears. The reason is that only the vectorial isospin is same for left and right handed components of fermion which are in general mixed for the massive states.

The coefficients are dimensionless and expressible in terms of the gauge coupling strengths and using $\hbar = r\hbar_0$ one can write

$$\begin{aligned} \alpha_{em}Q_{em} &+ p\frac{\alpha_Z}{2}Q_{Z,V} = \frac{3}{4\pi}\times rnK \ , \\ \alpha_{em} &= \frac{e^2}{4\pi\hbar_0} \ , \ \alpha_Z = \frac{g_Z^2}{4\pi\hbar_0} = \frac{\alpha_{em}}{p(1-p)} \ . \end{aligned} \quad (2.5.7)$$

4. There is a great temptation to assume that the values of Q_{em} and Q_Z correspond to their quantized values and therefore depend on the quantum state assigned to the partonic 2-surface. The linear coupling of the modified Dirac operator to conserved charges implies correlation between the geometry of space-time sheet and quantum numbers assigned to the partonic 2-surface. The assumption of standard quantized values for Q_{em} and Q_Z would be also seen as the identification of the fine structure constants α_{em} and α_Z. This however requires weak isospin invariance.

The value of K from classical quantization of Kähler electric charge

The value of K can be deduced by requiring classical quantization of Kähler electric charge.

1. The condition that the flux of $F^{03} = (\hbar/g_K)J^{03}$ defining the counterpart of Kähler electric field equals to the Kähler charge g_K would give the condition $K = g_K^2/\hbar$, where g_K is Kähler coupling constant which should invariant under coupling constant evolution by quantum criticality. Within experimental uncertainties one has $\alpha_K = g_K^2/4\pi\hbar_0 = \alpha_{em} \simeq 1/137$, where α_{em} is finite structure constant in electron length scale and $\hbar_0$ is the standard value of Planck constant.

2. The quantization of Planck constants makes the condition highly non-trivial. The most general quantization of r is as rationals but there are good arguments favoring the quantization as integers corresponding to the allowance of only singular coverings of CD andn CP_2. The point is that in this case a given value of Planck constant corresponds to a finite number pages of the "Big Book". The quantization of the Planck constant implies a further quantization of K and would suggest that K scales as $1/r$ unless the spectrum of values of Q_{em} and Q_Z allowed by the quantization condition scales as r. This is quite possible and the interpretation would be that each of the r sheets of the covering carries (possibly same) elementary charge. Kind of discrete variant of a full Fermi sphere would be in question. The interpretation in terms of anyonic phases [K50] supports this interpretation.

3. The identification of J as a counterpart of $eB/\hbar$ means that Kähler action and thus also Kähler function is proportional to $1/\alpha_K$ and therefore to $\hbar$. This implies that for large values of $\hbar$ Kähler coupling strength $g_K^2/4\pi$ becomes very small and large fluctuations are suppressed in the functional integral. The basic motivation for introducing the hierarchy of Planck constants was indeed that the scaling $\alpha \to \alpha/r$ allows to achieve the convergence of perturbation theory: Nature itself would solve the problems of the theoretician. This of course does not mean that the physical states would remain as such and the replacement of single particles with anyonic states in order to satisfy the condition for K would realize this concretely.

4. The condition $K = g_K^2/\hbar$ implies that the Kähler magnetic charge is always accompanied by Kähler electric charge. A more general condition would read as

$$K = n\times\frac{g_K^2}{\hbar}, n\in Z \ . \quad (2.5.8)$$

This would apply in the case of cosmic strings and would allow vanishing Kähler charge possible when the partonic 2-surface has opposite fermion and anti-fermion numbers (for both leptons and quarks) so that Kähler electric charge should vanish. For instance, for neutrinos the vanishing of electric charge strongly suggests $n = 0$ besides the condition that abelian Z^0 flux contributing to em charge vanishes.

It took a year to realize that this value of K is natural at the Minkowskian side of the wormhole throat. At the Euclidian side much more natural condition is

$$K = \frac{1}{hbar} . \tag{2.5.9}$$

In fact, the self-duality of CP_2 Kähler form favours this boundary condition at the Euclidian side of the wormhole throat. Also the fact that one cannot distinguish between electric and magnetic charges in Euclidian region since all charges are magnetic can be used to argue in favor of this form. The same constraint arises from the condition that the action for CP_2 type vacuum extremal has the value required by the argument leading to a prediction for gravitational constant in terms of the square of CP_2 radius and α_K the effective replacement $g_K^2 \rightarrow 1$ would spoil the argument.

The boundary condition $J_E = J_B$ for the electric and magnetic parts of Kählwer form at the Euclidian side of the wormhole throat inspires the question whether all Euclidian regions could be self-dual so that the density of Kähler action would be just the instanton density. Self-duality follows if the deformation of the metric induced by the deformation of the canonically imbedded CP_2 is such that in CP_2 coordinates for the Euclidian region the tensor $(g^{\alpha\beta}g^{\mu\nu} - g^{\alpha\nu}g^{\mu\beta})/\sqrt{g}$ remains invariant. This is certainly the case for CP_2 type vacuum extremals since by the light-likeness of M^4 projection the metric remains invariant. Also conformal scalings of the induced metric would satisfy this condition. Conformal scaling is not consistent with the degeneracy of the 4-metric at the wormhole.

Reduction of the quantization of Kähler electric charge to that of electromagnetic charge

The best manner to learn more is to challenge the form of the weak electric-magnetic duality based on the induced Kähler form.

1. Physically it would seem more sensible to pose the duality on electromagnetic charge rather than Kähler charge. This would replace induced Kähler form with electromagnetic field, which is a linear combination of induced Kahler field and classical Z^0 field

$$\begin{aligned} \gamma &= 3J - sin^2\theta_W R_{03} , \\ Z^0 &= 2R_{03} . \end{aligned} \tag{2.5.10}$$

   Here $Z_0 = 2R_{03}$ is the appropriate component of CP_2 curvature form [L1]. For a vanishing Weinberg angle the condition reduces to that for Kähler form.

2. For the Euclidian space-time regions having interpretation as lines of generalized Feynman diagrams Weinberg angle should be non-vanishing. In Minkowskian regions Weinberg angle could however vanish. If so, the condition guaranteeing that electromagnetic charge of the partonic 2-surfaces equals to the above condition stating that the em charge assignable to the fermion content of the partonic 2-surfaces reduces to the classical Kähler electric flux at the Minkowskian side of the wormhole throat. One can argue that Weinberg angle must increase smoothly from a vanishing value at both sides of wormhole throat to its value in the deep interior of the Euclidian region.

3. The vanishing of the Weinberg angle in Minkowskian regions conforms with the physical intuition. Above elementary particle length scales one sees only the classical electric field reducing to the induced Kähler form and classical Z^0 fields and color gauge fields are effectively absent. Only in phases with a large value of Planck constant classical Z^0 field and other classical weak fields and color gauge field could make themselves visible. Cell membrane could be one such system [K54]. This conforms with the general picture about color confinement and weak massivation.

The GRT limit of TGD suggests a further reason for why Weinberg angle should vanish in Minkowskian regions.

1. The value of the Kähler coupling strength mut be very near to the value of the fine structure constant in electron length scale and these constants can be assumed to be equal.

2. GRT limit of TGD with space-time surfaces replaced with abstract 4-geometries would naturally correspond to Einstein-Maxwell theory with cosmological constant which is non-vanishing only in Euclidian regions of space-time so that both Reissner-Nordström metric and CP_2 are allowed as simplest possible solutions of field equations [K71]. The extremely small value of the observed cosmological constant needed in GRT type cosmology could be equal to the large cosmological constant associated with CP_2 metric multiplied with the 3-volume fraction of Euclidian regions.

3. Also at GRT limit quantum theory would reduce to almost topological QFT since Einstein-Maxwell action reduces to 3-D term by field equations implying the vanishing of the Maxwell current and of the curvature scalar in Minkowskian regions and curvature scalar + cosmological constant term in Euclidian regions. The weak form of electric-magnetic duality would guarantee also now the preferred extremal property and prevent the reduction to a mere topological QFT.

4. GRT limit would make sense only for a vanishing Weinberg angle in Minkowskian regions. A non-vanishing Weinberg angle would make sense in the deep interior of the Euclidian regions where the approximation as a small deformation of CP_2 makes sense.

The weak form of electric-magnetic duality has surprisingly strong implications for the basic view about quantum TGD as following considerations show.

2.5.2 Magnetic confinement, the short range of weak forces, and color confinement

The weak form of electric-magnetic duality has surprisingly strong implications if one combines it with some very general empirical facts such as the non-existence of magnetic monopole fields in macroscopic length scales.

How can one avoid macroscopic magnetic monopole fields?

Monopole fields are experimentally absent in length scales above order weak boson length scale and one should have a mechanism neutralizing the monopole charge. How electroweak interactions become short ranged in TGD framework is still a poorly understood problem. What suggests itself is the neutralization of the weak isospin above the intermediate gauge boson Compton length by neutral Higgs bosons. Could the two neutralization mechanisms be combined to single one?

1. In the case of fermions and their super partners the opposite magnetic monopole would be a wormhole throat. If the magnetically charged wormhole contact is electromagnetically neutral but has vectorial weak isospin neutralizing the weak vectorial isospin of the fermion only the electromagnetic charge of the fermion is visible on longer length scales. The distance of this wormhole throat from the fermionic one should be of the order weak boson Compton length. An interpretation as a bound state of fermion and a wormhole throat state with the quantum numbers of a neutral Higgs boson would therefore make sense. The neutralizing throat would have quantum numbers of $X_{-1/2} = \nu_L\overline{\nu}_R$ or $X_{1/2} = \overline{\nu}_L\nu_R$. $\nu_L\overline{\nu}_R$ would not be neutral Higgs boson (which should correspond to a wormhole contact) but a super-partner of left-handed neutrino obtained by adding a right handed neutrino. This mechanism would apply separately to the fermionic and anti-fermionic throats of the gauge bosons and corresponding space-time sheets and leave only electromagnetic interaction as a long ranged interaction.

2. One can of course wonder what is the situation situation for the bosonic wormhole throats feeding gauge fluxes between space-time sheets. It would seem that these wormhole throats

must always appear as pairs such that for the second member of the pair monopole charges and I_V^3 cancel each other at both space-time sheets involved so that one obtains at both space-time sheets magnetic dipoles of size of weak boson Compton length. The proposed magnetic character of fundamental particles should become visible at TeV energies so that LHC might have surprises in store!

Well-definedness of electromagnetic charge implies stringiness

Well-definedness of electromagnetic charged at string world sheets carrying spinor modes is very natural constraint and not trivially satisfied because classical W boson fields are present. As a matter fact, all weak fields should be effectively absent above weak scale. How this is possible classical weak fields identified as induced gauge fields are certainly present.

The condition that em charge is well defined for spinor modes implies that the space-time region in which spinor mode is non-vanishing has 2-D CP_2 projection such that the induced W boson fields are vanishing. The vanishing of classical Z^0 field can be poses as additional condition - at least in scales above weak scale. In the generic case this requires that the spinor mode is restricted to 2-D surface: string world sheet or possibly also partonic 2-surface. This implies that TGD reduces to string model in fermionic sector. Even for preferred extremals with 2-D projecting the modes are expected to allow restriction to 2-surfaces. This localization is possible only for Kähler-Dirac action.

A word of warning is however in order. The GRT limit or rather limit of TGD as Einstein Yang-Mills theory replaces the sheets of many-sheeted space-time with Minkowski space with effective metric obtained by summing to Minkowski metric the deviations of the induced metrics of space-time sheets from Minkowski metric. For gauge potentials a similar identification applies. YM-Einstein equations coupled with matter and with non-vanishing cosmological constant are expected on basis of Poincare invariance. One cannot exclude the possibility that the sums of weak gauge potentials from different space-time sheet tend to vanish above weak scale and that well-definedness of em charge at classical level follows from the effective absence of classical weak gauge fields.

Magnetic confinement and color confinement

Magnetic confinement generalizes also to the case of color interactions. One can consider also the situation in which the magnetic charges of quarks (more generally, of color excited leptons and quarks) do not vanish and they form color and magnetic singles in the hadronic length scale. This would mean that magnetic charges of the state $q_{\pm 1/2} - X_{\mp 1/2}$ representing the physical quark would not vanish and magnetic confinement would accompany also color confinement. This would explain why free quarks are not observed. To how degree then quark confinement corresponds to magnetic confinement is an interesting question.

For quark and antiquark of meson the magnetic charges of quark and antiquark would be opposite and meson would correspond to a Kähler magnetic flux so that a stringy view about meson emerges. For valence quarks of baryon the vanishing of the net magnetic charge takes place provided that the magnetic net charges are $(\pm 2, \mp 1, \mp 1)$. This brings in mind the spectrum of color hyper charges coming as $(\pm 2, \mp 1, \mp 1)/3$ and one can indeed ask whether color hypercharge correlates with the Kähler magnetic charge. The geometric picture would be three strings connected to single vertex. Amusingly, the idea that color hypercharge could be proportional to color hyper charge popped up during the first year of TGD when I had not yet discovered CP_2 and believed on $M^4 \times S^2$.

p-Adic length scale hypothesis and hierarchy of Planck constants defining a hierarchy of dark variants of particles suggest the existence of scaled up copies of QCD type physics and weak physics. For p-adically scaled up variants the mass scales would be scaled by a power of $\sqrt{2}$ in the most general case. The dark variants of the particle would have the same mass as the original one. In particular, Mersenne primes $M_k = 2^k - 1$ and Gaussian Mersennes $M_{G,k} = (1+i)^k - 1$ has been proposed to define zoomed copies of these physics. At the level of magnetic confinement this would mean hierarchy of length scales for the magnetic confinement.

One particular proposal is that the Mersenne prime M_{89} should define a scaled up variant of the ordinary hadron physics with mass scaled up roughly by a factor $2^{(107-89)/2} = 512$. The size scale of color confinement for this physics would be same as the weal length scale. It would look more natural that the weak confinement for the quarks of M_{89} physics takes place in some shorter scale and M_{61} is the first Mersenne prime to be considered. The mass scale of M_{61} weak bosons would be by a factor $2^{(89-61)/2} = 2^{14}$ higher and about 1.6×10^4 TeV. M_{89} quarks would have virtually no weak interactions but would possess color interactions with weak confinement length scale reflecting themselves as new kind of jets at collisions above TeV energies.

In the biologically especially important length scale range 10 nm -2500 nm there are as many as four scaled up electron Compton lengths $L_e(k) = \sqrt{5}L(k)$: they are associated with Gaussian Mersennes $M_{G,k}$, $k = 151, 157, 163, 167$. This would suggest that the existence of scaled up scales of magnetic-, weak- and color confinement. An especially interesting possibly testable prediction is the existence of magnetic monopole pairs with the size scale in this range. There are recent claims about experimental evidence for magnetic monopole pairs [D4] .

Magnetic confinement and stringy picture in TGD sense

The connection between magnetic confinement and weak confinement is rather natural if one recalls that electric-magnetic duality in super-symmetric quantum field theories means that the descriptions in terms of particles and monopoles are in some sense dual descriptions. Fermions would be replaced by string like objects defined by the magnetic flux tubes and bosons as pairs of wormhole contacts would correspond to pairs of the flux tubes. Therefore the sharp distinction between gravitons and physical particles would disappear.

The reason why gravitons are necessarily stringy objects formed by a pair of wormhole contacts is that one cannot construct spin two objects using only single fermion states at wormhole throats. Of course, also super partners of these states with higher spin obtained by adding fermions and anti-fermions at the wormhole throat but these do not give rise to graviton like states [K24] . The upper and lower wormhole throat pairs would be quantum superpositions of fermion anti-fermion pairs with sum over all fermions. The reason is that otherwise one cannot realize graviton emission in terms of joining of the ends of light-like 3-surfaces together. Also now magnetic monopole charges are necessary but now there is no need to assign the entities $X_\pm$ with gravitons.

Graviton string is characterized by some p-adic length scale and one can argue that below this length scale the charges of the fermions become visible. Mersenne hypothesis suggests that some Mersenne prime is in question. One proposal is that gravitonic size scale is given by electronic Mersenne prime M_{127}. It is however difficult to test whether graviton has a structure visible below this length scale.

What happens to the generalized Feynman diagrams is an interesting question. It is not at all clear how closely they relate to ordinary Feynman diagrams. All depends on what one is ready to assume about what happens in the vertices. One could of course hope that zero energy ontology could allow some very simple description allowing perhaps to get rid of the problematic aspects of Feynman diagrams.

1. Consider first the recent view about generalized Feynman diagrams which relies zero energy ontology. A highly attractive assumption is that the particles appearing at wormhole throats are on mass shell particles. For incoming and outgoing elementary bosons and their super partners they would be positive it resp. negative energy states with parallel on mass shell momenta. For virtual bosons they the wormhole throats would have opposite sign of energy and the sum of on mass shell states would give virtual net momenta. This would make possible twistor description of virtual particles allowing only massless particles (in 4-D sense usually and in 8-D sense in TGD framework). The notion of virtual fermion makes sense only if one assumes in the interaction region a topological condensation creating another wormhole throat having no fermionic quantum numbers.

2. The addition of the particles $X^\pm$ replaces generalized Feynman diagrams with the analogs of stringy diagrams with lines replaced by pairs of lines corresponding to fermion and $X_{\pm 1/2}$. The members of these pairs would correspond to 3-D light-like surfaces glued together at the vertices of generalized Feynman diagrams. The analog of 3-vertex would not be splitting of the string to form shorter strings but the replication of the entire string to form two strings with same length or fusion of two strings to single string along all their points rather than

along ends to form a longer string. It is not clear whether the duality symmetry of stringy diagrams can hold true for the TGD variants of stringy diagrams.

3. How should one describe the bound state formed by the fermion and $X^{\pm}$? Should one describe the state as superposition of non-parallel on mass shell states so that the composite state would be automatically massive? The description as superposition of on mass shell states does not conform with the idea that bound state formation requires binding energy. In TGD framework the notion of negentropic entanglement has been suggested to make possible the analogs of bound states consisting of on mass shell states so that the binding energy is zero [K36] . If this kind of states are in question the description of virtual states in terms of on mass shell states is not lost. Of course, one cannot exclude the possibility that there is infinite number of this kind of states serving as analogs for the excitations of string like object.

4. What happens to the states formed by fermions and $X_{\pm 1/2}$ in the internal lines of the Feynman diagram? Twistor philosophy suggests that only the higher on mass shell excitations are possible. If this picture is correct, the situation would not change in an essential manner from the earlier one.

The highly non-trivial prediction of the magnetic confinement is that elementary particles should have stringy character in electro-weak length scales and could behaving to become manifest at LHC energies. This adds one further item to the list of non-trivial predictions of TGD about physics at LHC energies [K37] .

2.6 Quantum TGD very briefly

2.6.1 Two approaches to quantum TGD

There are two basic approaches to the construction of quantum TGD. The first approach relies on the vision of quantum physics as infinite-dimensional Kähler geometry [A7] for the "world of classical worlds" (WCW) identified as the space of 3-surfaces in in certain 8-dimensional space. Essentially a generalization of the Einstein's geometrization of physics program is in question. The second vision is the identification of physics as a generalized number theory involving p-adic number fields and the fusion of real numbers and p-adic numbers to a larger structure, classical number fields, and the notion of infinite prime.

With a better resolution one can distinguish also other visions crucial for quantum TGD. Indeed, the notion of finite measurement resolution realized in terms of hyper-finite factors, TGD as almost topological quantum field theory, twistor approach, zero energy ontology, and weak form of electric-magnetic duality play a decisive role in the actual construction and interpretation of the theory. One can however argue that these visions are not so fundamental for the formulation of the theory than the first two.

Physics as infinite-dimensional geometry

It is good to start with an attempt to give overall view about what the dream about physics as infinite-dimensional geometry is. The basic vision is generalization of the Einstein's program for the geometrization of classical physics so that entire quantum physics would be geometrized. Finite-dimensional geometry is certainly not enough for this purposed but physics as infinite-dimensional geometry of what might be called world of classical worlds (WCW) -or more neutrally WCW of some higher-dimensional imbeddign space- might make sense. The requirement that the Hermitian conjugation of quantum theories has a geometric realization forces Kähler geometry for WCW. WCW defines the fixed arena of quantum physics and physical states are identified as spinor fields in WCW. These spinor fields are classical and no second quantization is needed at this level. The justification comes from the observation that infinite-dimensional Clifford algebra [A2] generated by gamma matrices allows a natural identification as fermionic oscillator algebra.

The basic challenges are following.

1. Identify WCW.

2. Provide WCW with Kähler metric and spinor structure
3. Define what spinors and spinor fields in WCW are.

There is huge variety of finite-dimensional geometries and one might think that in infinite-dimensional case one might be drowned with the multitude of possibilities. The situation is however exactly opposite. The loop spaces associated with groups have a unique Kähler geometry due to the simple condition that Riemann connection exists mathematically [A28] . This condition requires that the metric possesses maximal symmetries. Thus raises the vision that infinite-dimensional Kähler geometric existence is unique once one poses the additional condition that the resulting geometry satisfies some basic constraints forced by physical considerations.

The observation about the uniqueness of loop geometries leads also to a concrete vision about what this geometry could be. Perhaps WCW could be regarded as a union of symmetric spaces [A16] for which every point is equivalent with any other. This would simplify the construction of the geometry immensely and would mean a generalization of cosmological principle to infinite-D context [K29] , [L6] .

This still requires an answer to the question why $M^4 \times CP_2$ is so unique. Something in the structure of this space must distinguish it in a unique manner from any other candidate. The uniqueness of M^4 factor can be understood from the miraculous conformal symmetries of the light-cone boundary but in the case of CP_2 there is no obvious mathematical argument of this kind although physically CP_2 is unique [L12] . The observation that $M^4 \times CP_2$ has dimension 8, the space-time surfaces have dimension 4, and partonic 2-surfaces, which are the fundamental objects by holography have dimension 2, suggests that classical number fields [A10, A3, A12] are involved and one can indeed end up to the choice $M^4 \times CP_2$ from physics as generalized number theory vision by simple arguments [K67] , [L8] . In particular, the choices M^8 -a subspace of complexified octonions (for octonions see [A10]), which I have used to call hyper-octonions- and $M^4 \times CP_2$ can be regarded as physically equivalent: this "number theoretical compactification" is analogous to spontaneous compactification in M-theory. No dynamical compactification takes place so that $M^8 - H$ duality is a more appropriate term.

Physics as generalized number theory

Physics as a generalized number theory (for an overview about number theory see [A9]) program consists of three separate threads: various p-adic physics and their fusion together with real number based physics to a larger structure [K66] , [L11] , the attempt to understand basic physics in terms of classical number fields [K67] , [L8] (in particular, identifying associativity condition as the basic dynamical principle), and infinite primes [K65] , [L4] , whose construction is formally analogous to a repeated second quantization of an arithmetic quantum field theory. In this article a summary of the philosophical ideas behind this dream and a summary of the technical challenges and proposed means to meet them are discussed.

The construction of p-adic physics and real physics poses formidable looking technical challenges: p-adic physics should make sense both at the level of the imbedding space, the "world of classical worlds" (WCW), and space-time and these physics should allow a fusion to a larger coherent whole. This forces to generalize the notion of number by fusing reals and p-adics along rationals and common algebraic numbers. The basic problem that one encounters is definition of the definite integrals and harmonic analysis [A4] in the p-adic context [K41] . It turns out that the representability of WCW as a union of symmetric spaces [A16] provides a universal group theoretic solution not only to the construction of the Kähler geometry of WCW but also to this problem. The p-adic counterpart of a symmetric space is obtained from its discrete invariant by replacing discrete points with p-adic variants of the continuous symmetric space. Fourier analysis [A4] reduces integration to summation. If one wants to define also integrals at space-time level, one must pose additional strong constraints which effectively reduce the partonic 2-surfaces and perhaps even space-time surfaces to finite geometries and allow assign to a given partonic 2-surface a unique power of a unique p-adic prime characterizing the measurement resolution in angle variables. These integrals might make sense in the intersection of real and p-adic worlds defined by algebraic surfaces.

The dimensions of partonic 2-surface, space-time surface, and imbedding space suggest that classical number fields might be highly relevant for quantum TGD. The recent view about the connection is based on hyper-octonionic representation of the imbedding space gamma matrices, and the notions of associative and co-associative space-time regions defined as regions for which the modified gamma matrices span quaternionic or co-quaternionic plane at each point of the region. A further condition is that the tangent space at each point of space-time surface contains a preferred hyper-complex (and thus commutative) plane identifiable as the plane of non-physical polarizations so that gauge invariance has a purely number theoretic interpretation. WCW can be regarded as the space of sub-algebras of the local octonionic Clifford algebra [A2] of the imbedding space defined by space-time surfaces with the property that the local sub-Clifford algebra spanned by Clifford algebra valued functions restricted at them is associative or co-associative in a given region.

The recipe for constructing infinite primes is structurally equivalent with a repeated second quantization of an arithmetic super-symmetric quantum field theory. At the lowest level one has fermionic and bosonic states labeled by finite primes and infinite primes correspond to many particle states of this theory. Also infinite primes analogous to bound states are predicted. This hierarchy of quantizations can be continued indefinitely by taking the many particle states of the previous level as elementary particles at the next level. Construction could make sense also for hyper-quaternionic and hyper-octonionic primes although non-commutativity and non-associativity pose technical challenges. One can also construct infinite number of real units as ratios of infinite integers with a precise number theoretic anatomy. The fascinating finding is that the quantum states labeled by standard model quantum numbers allow a representation as wave fuctions in the discrete space of these units. Space-time point becomes infinitely richly structured in the sense that one can associate to it a wave function in the space of real (or octonionic) units allowing to represent the WCW spinor fields. One can speak about algebraic holography or number theoretic Brahman=Atman identity and one can also say that the points of imbedding space and space-time surface are subject to a number theoretic evolution.

Questions

The experience has shown repeatedly that a correct question and identification of some weakness of existing vision is what can only lead to a genuine progress. In the following I discuss the basic questions, which have stimulated progress in the challenge of constructing WCW geometry.

1. What is WCW?

Concerning the identification of WCW I have made several guesses and the progress has been basically due to the gradual realization of various physical constraints and the fact that standard physics ontology is not enough in TGD framework.

1. The first guess was that WCW corresponds to all possible space-like 3-surfaces in $H = M^4 \times CP_2$, where M^4 denotes Minkowski space and CP_2 denotes complex projective space of two complex dimensions having also representation as coset space $SU(3)/U(2)$ (see the separate article summarizing the basic facts about CP_2 and how it codes for standard model symmetries [L1] , [L9, L1]). What led to the this particular choice H was the observation that the geometry of H codes for standard model quantum numbers and that the generalization of particle from point like particle to 3-surface allows to understand also remaining quantum numbers having no obvious explanation in standard model (family replication phenomenon). What is important to notice is that Poincare symmetries act as exact symmetries of M^4 rather than space-time surface itself: this realizes the basic vision about Poincare invariant theory of gravitation. This lifting of symmetries to the level of imbedding space and the new dynamical degrees of freedom brought by the sub-manifold geometry of space-time surface are absolutely essential for entire quantum TGD and distinguish it from general relativity and string models. There is however a problem: it is not obvious how to get cosmology.

2. The second guess was that WCW consists of space-like 3-surfaces in $H_+ = M^4_+ \times CP2$, where M^4_+ future light-cone having interpretation as Big Bang cosmology at the limit of vanishing mass density with light-cone property time identified as the cosmic time. One obtains cosmology but loses exact Poincare invariance in cosmological scales since translations lead out of future light-cone. This as such has no practical significance but due to the metric 2-dimensionality of light-cone boundary δM^4_+ the conformal symmetries of string model

assignable to finite-dimensional Lie group generalize to conformal symmetries assignable to an infinite-dimensional symplectic group of $S^2 \times CP_2$ and also localized with respect to the coordinates of 3-surface. These symmetries are simply too beautiful to be important only at the moment of Big Bang and must be present also in elementary particle length scales. Note that these symmetries are present only for 4-D Minkowski space so that a partial resolution of the old conundrum about why space-time dimension is just four emerges.

3. The third guess was that the light-like 3-surfaces in H or H_+ are more attractive than space-like 3-surfaces. The reason is that the infinite-D conformal symmetries characterize also light-like 3-surfaces because they are metrically 2-dimensional. This leads to a generalization of Kac-Moody symmetries [A6] of super string models with finite-dimensional Lie group replaced with the group of isometries of H. The natural identification of light-like 3-surfaces is as 3-D surfaces defining the regions at which the signature of the induced metric changes from Minkowskian $(1,-1,-1,-1)$ to Euclidian $(-1-1-1-1)$- I will refer these surfaces as throats or wormhole throats in the sequel. Light-like 3-surfaces are analogous to blackhole horizons and are static because strong gravity makes them light-like. Therefore also the dimension 4 for the space-time surface is unique.

   This identification leads also to a rather unexpected physical interpretation. Single light-like wormhole throat carriers elementary particle quantum numbers. Fermions and their superpartners are obtained by glueing Euclidian regions (deformations of so called CP_2 type vacuum extremals of Kähhler action) to the background with Minkowskian signature. Bosons are identified as wormhole contacts with two throats carrying fermion *resp.* anti-fermionic quantum numbers. These can be identified as deformations of CP_2 vacuum extremals between between two parallel Minkowskian space-time sheets. One can say that bosons and their superpartners emerge. This has dramatic implications for quantum TGD [K15] and QFT limit of TGD [K49] .

   The question is whether one obtains also a generalization of Feynman diagrams. The answer is affirmative. Light-like 3-surfaces or corresponding Euclidian regions of space-time are analogous to the lines of Feynman diagram and vertices are replaced by 2-D surface at which these surfaces glued together. One can speak about Feynman diagrams with lines thickened to light-like 3-surfaces and vertices to 2-surfaces. The generalized Feynman diagrams are singular as 3-manifolds but the vertices are non-singular as 2-manifolds. Same applies to the corresponding space-time surfaces and space-like 3-surfaces. Therefore one can say that WCW consists of generalized Feynman diagrams- something rather different from the original identification as space-like 3-surfaces and one can wonder whether these identification could be equivalent.

4. The fourth guess was a generalization of the WCW combining the nice aspects of the identifications $H = M^4 \times CP_2$ (exact Poincare invariance) and $H = M^4_+ \times CP_2$ (Big Bang cosmology). The idea was to generalize WCW to a union of basic building bricks -causal diamonds (CDs) - which themselves are analogous to Big Bang-Big Crunch cosmologies breaking Poincare invariance, which is however regained by the allowance of union of Poincare transforms of the causal diamonds.

   The starting point is General Coordinate Invariance (GCI). It does not matter, which 3-D slice of the space-time surface one choose to represent physical data as long as slices are related by a diffeomorphism of the space-time surface. This condition implies holography in the sense that 3-D slices define holograms about 4-D reality.

   The question is whether one could generalize GCI in the sense that the descriptions using space-like and light-like 3-surfaces would be equivalent physically. This requires that finite-sized space-like 3-surfaces are somehow equivalent with light-like 3-surfaces. This suggests that the light-like 3-surfaces must have ends. Same must be true for the space-time surfaces and must define preferred space-like 3-surfaces just like wormhole throats do. This makes sense only if the 2-D intersections of these two kinds of 3-surfaces -call them partonic 2-surfaces- and their 4-D tangent spaces carry the information about quantum physics. A strengthening of holography principle would be the outcome. The challenge is to understand, where the intersections defining the partonic 2-surfaces are located.

Zero energy ontology (ZEO) allows to meet this challenge.

(a) Assume that WCW is union of sub-WCWs identified as the space of light-like 3-surfaces assignable to $CD \times CP_2$ with given CD defined as an intersection of future and past directed light-cones of M^4. The tips of CDs have localization in M^4 and one can perform for CD both translations and Lorentz boost for CDs. Space-time surfaces inside CD define the basic building brick of WCW. Also unions of CDs allowed and the CDs belonging to the union can intersect. One can of course consider the possibility of intersections and analogy with the set theoretic realization of topology.

(b) ZEO property means that the light-like boundaries of these objects carry positive and negative energy states, whose quantum numbers are opposite. Everything can be created from vacuum and can be regarded as quantum fluctuations in the standard vocabulary of quantum field theories.

(c) Space-time surfaces inside CDs begin from the lower boundary and end to the upper boundary and in ZEO it is natural to identify space-like 3-surfaces as pairs of space-like 3-surfaces at these boundaries. Light-like 3-surfaces connect these boundaries.

(d) The generalization of GCI states that the descriptions based on space-like 3-surfaces must be equivalent with that based on light-like 3-surfaces. Therefore only the 2-D intersections of light-like and space-like 3-surfaces - partonic 2-surfaces- and their 4-D tangent spaces (4-surface is there!) matter. Effective 2-dimensionality means a strengthened form of holography but does not imply exact 2-dimensionality, which would reduce the theory to a mere string model like theory. Once these data are given, the 4-D space-time surface is fixed and is analogous to a generalization of Bohr orbit to infinite-D context. This is the first guess. The situation is actually more delicate due to the non-determinism of Kähler action motivating the interaction of the hierarchy of CDs within CDs.

In this framework one obtains cosmology: CDs represent a fractal hierarchy of big bang-big crunch cosmologies. One obtains also Poincare invariance. One can also interpret the non-conservation of gravitational energy in cosmology which is an empirical fact but in conflict with exact Poincare invariance as it is realized in positive energy ontology [K71, K60] . The reason is that energy and four-momentum in zero energy ontology correspond to those assignable to the positive energy part of the zero energy state of a particular CD. The density of energy as cosmologist defines it is the statistical average for given CD: this includes the contributions of sub-CDs. This average density is expected to depend on the size scale of CD density is should therefore change as quantum dispersion in the moduli space of CDs takes place and leads to large time scale for any fixed sub-CD.

Even more, one obtains actually quantum cosmology! There is large variety of CDs since they have position in M^4 and Lorentz transformations change their shape. The first question is whether the M^4 positions of both tips of CD can be free so that one could assign to both tips of CD momentum eigenstates with opposite signs of four-momentum. The proposal, which might look somewhat strange, is that this not the case and that the proper time distance between the tips is quantized in octaves of a fundamental time scale $T = R/c$ defined by CP_2 size R. This would explains p-adic length scale hypothesis which is behind most quantitative predictions of TGD. That the time scales assignable to the CD of elementary particles correspond to biologically important time scales [K19] forces to take this hypothesis very seriously.

The interpretation for T could be as a cosmic time quantized in powers of two. Even more general quantization is proposed to take place. The relative position of the second tip with respect to the first defines a point of the proper time constant hyperboloid of the future light cone. The hypothesis is that one must replace this hyperboloid with a lattice like structure. This implies very powerful cosmological predictions finding experimental support from the quantization of redshifts for instance [K60] . For quite recent further empirical support see [E3] .

One should not take this argument without a grain of salt. Can one really realize zero energy ontology in this framework? The geometric picture is that translations correspond to translations of CDs. Translations should be done independently for the upper and lower tip of CD if one wants to speak about zero energy states but this is not possible if the proper time distance is quantized. If the relative M^4_+ coordinate is discrete, this pessimistic conclusion is strengthened further.

The manner to get rid of problem is to assume that translations are represented by quantum operators acting on states at the light-like boundaries. This is just what standard quantum theory assumes. An alternative- purely geometric- way out of difficulty is the Kac-Moody symmetry associated with light-like 3-surfaces meaning that local M^4 translations depending on the point of partonic 2-surface are gauge symmetries. For a given translation leading out of CD this gauge symmetry allows to make a compensating transformation which allows to satisfy the constraint.

This picture is roughly the recent view about WCW. What deserves to be emphasized is that a very concrete connection with basic structures of quantum field theory emerges already at the level of basic objects of the theory and GCI implies a strong form of holography and almost stringy picture.

2.Some Why's

In the following I try to summarize the basic motivations behind quantum TGD in form of various Why's.

1. Why WCW?

   Einstein's program has been extremely successful at the level of classical physics. Fusion of general relativity and quantum theory has however failed. The generalization of Einstein's geometrization program of physics from classical physics to quantum physics gives excellent hopes about the success in this project. Infinite-dimensional geometries are highly unique and this gives hopes about fixing the physics completely from the uniqueness of the infinite-dimensional Kähler geometric existence.

2. Why spinor structure in WCW?

   Gamma matrices defining the Clifford algebra [A2] of WCW are expressible in terms of fermionic oscillator operators. This is obviously something new as compared to the view about gamma matrices as bosonic objects. There is however no deep reason denying this kind of identification. As a consequence, a geometrization of fermionic oscillator operator algebra and fermionic statistics follows as also geometrization of super-conformal symmetries [A15, A6] since gamma matrices define super-generators of the algebra of WCW isometries extended to a super-algebra.

3. Why Kähler geometry?

   Geometrization of the bosonic oscillator operators in terms of WCW vector fields and fermionic oscillator operators in terms of gamma matrices spanning Clifford algebra. Gamma matrices span hyper-finite factor of type II_1 and the extremely beautiful properties of these von Neuman algebras [A25] (one of the three von Neumann algebras that von Neumann suggests as possible mathematical frameworks behind quantum theory) lead to a direct connection with the basic structures of modern physics (quantum groups, non-commutative geometries,.. [A33]).

   A further reason why is the finiteness of the theory.

   (a) In standard QFTs there are two kinds of divergences. Action is a local functional of fields in 4-D sense and one performs path integral over **all** 4-surfaces to construct S-matrix. Mathematically path integration is a poorly defined procedure and one obtains diverging Gaussian determinants and divergences due to the local interaction vertices. Regularization provides the manner to get rid of the infinities but makes the theory very ugly.

   (b) Kähler function defining the Kähler geometry is a expected to be non-local functional of the partonic 2-surface (Kähler action for a preferred extremal having as its ends the positive and negative energy 3-surfaces). Path integral is replaced with a functional integral which is mathematically well-defined procedure and one performs functional integral only over the partonic 2-surfaces rather than all 4-surfaces (holography). The exponent of Kähler function defines a unique vacuum functional. The local divergences of local quantum field theories of local quantum field theories since there are no local interaction vertices. Also the divergences associated with the Gaussian determinant and metric determinant cancel since these two determinants cancel each other in the integration over WCW. As a matter fact, symmetric space property suggest a much more elegant manner to perform the functional integral by reducing it to harmonic analysis in infinite-dimensional symmetric space [K23] .

(c) One can imagine also the possibility of divergences in fermionic degrees of freedom but it has turned out that the generalized Feynman diagrams in ZEO are manifestly finite. Even more: it is quite possible that only finite number of these diagrams give non-vanishing contributions to the scattering amplitude. This is essentially due to the new view about virtual particles, which are identified as bound states of on mass shell states assigned with the throats of wormhole contacts so that the integration over loop momenta of virtual particles is extremely restricted [K23] .

4. Why infinite-dimensional symmetries?

WCW must be a union of symmetric spaces in order that the Riemann connection exists (this generalizes the finding of Freed for loop groups [A28]). Since the points of symmetric spaces are metrically equivalent, the geometrization becomes tractable although the dimension is infinite. A union of symmetric spaces is required because 3-surfaces with a size of galaxy and electron cannot be metrically equivalent. Zero modes distinguish these surfaces and can be regarded as purely classical degrees of freedom whereas the degrees of freedom contributing to the WCW line element are quantum fluctuating degrees of freedom.

One immediate implication of the symmetric space property is constant curvature space property meaning that the Ricci tensor proportional to metric tensor. Infinite-dimensionality means that Ricci scalar either vanishes or is infinite. This implies vanishing of Ricci tensor and vacuum Einstein equations for WCW.

5. Why $M^4 \times CP_2$?

This choice provides an explanation for standard model quantum numbers. The conjecture is that infinite-D geometry of 3-surfaces exists only for this choice. As noticed, the dimension of space-time surfaces and M^4 fixed by the requirement of generalized conformal invariance [A14] making possible to achieve symmetric space property. If $M^4 \times CP_2$ is so special, there must be a good reason for this. Number theoretical vision [K67] , [L8] indeed leads to the identification of this reason. One can assign the hierarchy of dimensions associated with partonic 2-surfaces, space-time surfaces and imbedding space to classical number fields and can assign to imbedding space what might be called hyper-octonionic structure. "Hyper" comes from the fact that the tangent space of H corresponds to the subspaces of complexified octonions with octonionic imaginary units multiplied by a commuting imaginary unit. The space-time regions would be either hyper-quaternionic or co-hyper-quaternionic so that associativity/co-associativity would become the basic dynamical principle at the level of space-time dynamics. Whether this dynamical principle is equivalent with the preferred extremal property of Kähler action remains an open conjecture.

6. Why zero energy ontology and why causal diamonds?

The consistency between Poincare invariance and GRT requires ZEO. In positive energy ontology only one of the infinite number of classical solutions is realized and partially fixed by the values of conserved quantum numbers so that the theory becomes obsolete. Even in quantum theory conservation laws mean that only those solutions of field equations with the quantum numbers of the initial state of the Universe are interesting and one faces the problem of understanding what the the initial state of the universe was. In ZEO these problems disappear. Everything is creatable from vacuum: if the physical state is mathematically realizable it is in principle reachable by a sequence of quantum jumps. There are no physically non-reachable entities in the theory. Zero energy ontology leads also to a fusion of thermodynamics with quantum theory. Zero energy states ae defined as entangled states of positive and negative energy states and entanglement coefficients define what I call M-matrix identified as "complex square root" of density matrix expressible as a product of diagonal real and positive density matrix and unitary S-matrix [K15] .

There are several good reasons why for causal diamonds. ZEO requires CDs, the generalized form of GCI and strong form of holography (light-like and space-like 3-surfaces are physically equivalent representations) require CDs, and also the view about light-like 3-surfaces as generalized Feynman diagrams requires CDs. Also the classical non-determinism of Kähler action can be understood using the hierarchy CDs and the addition of CDs inside CDs to obtain a fractal hierarchy of them provides an elegant manner to undersand radiative corrections and coupling constant evolution in TGD framework.

A strong physical argument in favor of CDs is the finding that the quantized proper time distance between the tips of CD fixed to be an octave of a fundamental time scale defined by CP_2 happens to define fundamental biological time scale for electron, u quark and d quark [K19] : there would be a deep connection between elementary particle physics and living matter leading to testable predictions.

2.6.2 Overall view Kähler action and Kähler Dirac action

In the following the most recent view about Kähler action and the modified Dirac action (Kähler-Dirac action) is explained in more detail.

1. The minimal formulation involves in the bosonic case only 4-D Kähler action with Chern-Simons boundary term localized to partonic orbits at which the signature of the induced metric changes. The coefficient of Chern-Simons term is chosen so that this contribution to bosonic action cancels the Chern-Simons term coming from Kähler action (by weak form of electric-magnetic duality) so that for preferred extremals Kähler action reduces to Chern-Simons terms at the ends of space-time surface at boundaries of causal diamond (CD).

   There are constraint terms expressing weak form of electric-magnetic duality and constraints forcing the total quantal charges for Kähler-Dirac action in Cartan algebra to be identical with total classical charges for Kähler action. This realizes quantum classical correspondence. The constraints do not affect quantum fluctuating degrees of freedom if classical charges parametrize zero modes so that the localization to a quantum superposition of space-time surfaces with same classical charges is possible.

2. By supersymmetry requirement the modified Dirac action corresponding to the bosonic action is obtained by associating to the various pieces in the bosonic action canonical momentum densities and contracting them with imbedding space gamma matrices to obtain modified gamma matrices. This gives rise to Kähler-Dirac equation in the interior of space-time surface. At partonic orbits one only assumes that spinors are generalized eigen modes of Chern-Simons Dirac operator with generalized eigenvalues $p^k\gamma_k$ identified as virtual four-momenta so that C-S-D term gives fermionic propagators. At the ends of space-time surface one obtains boundary conditions stating in absence of measurement interaction terms that fundamental fermions are massless on-mass-shell states.

Lagrange multiplier terms in Kähler action

Weak form of E-M duality can be realized by adding to Kähler action 3-D constraint terms realized in terms of Lagrange multipliers. These contribute to the Chern-Simons Dirac action too by modifying the definition of the modified gamma matrices.

Quantum classical correspondence (QCC) is the principle motivating further additional terms in Kähler action.

1. QCC suggests a correlation between 4-D geometry of space-time sheet and quantum numbers. This could result if the classical charges in Cartan algebra are identical with the quantal ones

assignable to Kähler-Dirac action. This would give very powerful constraint on the allowed space-time sheets in the superposition of space-time sheets defining WCW spinor field. An even strong condition would be that classical correlation functions are equal to quantal ones.

2. The equality of quantal and classical Cartan charges could be realized by adding constraint terms realized using Lagrange multipliers at the space-like ends of space-time surface at the boundaries of CD. This procedure would be very much like the thermodynamical procedure used to fix the average energy or particle number of the the system using Lagrange multipliers identified as temperature or chemical potential. Since quantum TGD can be regarded as square root of thermodynamics in zero energy ontology (ZEO), the procedure looks logically sound.

3. The consistency with Kähler-Dirac equation for which Chern-Simons boundary term at parton orbits (not genuine boundaries) seems necessary suggests that also Kähler action has Chern-Simons term as a boundary term at partonic orbits. Kähler action would thus reduce to contributions from the space-like ends of the space-time surface.

Boundary terms for Kähler-Dirac action

Weak form of E-M duality implies the reduction of Kähler action to Chern-Simons terms for preferred extremals satisfying $j \cdot A = 0$ (contraction of Kähler current and Kähler gauge potential vanishes). One obtains Chern-Simons terms at space-like 3-surfaces at the ends of space-time surface at boundaries of causal diamond and at light-like 3-surfaces defined by parton orbits having vanishing determinant of induced 4-metric. The naive guess that consistency requires Kähler-Dirac-Chern Simons equation at partonic orbits. This need not however be correct and therefore it is best to carefully consider what one wants.

1. What one wants?

It is could to make first clear what one really wants.

1. What one wants is generalized Feynman diagrams demanding massless Dirac propagators at the boundaries of string world sheets interpreted as fermionic lines of generalized Feynman diagrams. This gives hopes that twistor Grassmannian approach emerges at QFT limit. This boils down to the condition

$$\sqrt{g_4}\Gamma^n \Psi = p^k \gamma_k \Psi = 0$$

at the space-like ends of space-time surface. The general idea is that the space-time geometry near the fermion line would *define* the on mass shell massless four-momentum propagating along the line and quantum classical correspondence would be realized.

The basic condition is thus that $\sqrt{g_4}\Gamma^n$ is constant at the space-like boundaries of string world sheets and depends only on the piece of this boundary representing fermion line rather than on its point. Otherwise the propagator does not exist as a global notion. Constancy allows to write $\sqrt{g_4}\Gamma^n \Psi = p^k \gamma_k \Psi$ since only M^4 gamma matrices are constant.

Partonic orbits are not boundaries in the usual sense of the word and this condition is not elegant at them since g_4 vanishes at them. The assignement of Chern-Simons Dirac action to partonic orbits required to be continuous at them solves the problems. One can require that the induced spinors are generalized eigenstates of C-S-D operator with eigenvalues with correspond to virtual four-moment. This guarantees that one obtains massless Dirac propagator from C-S-D action. Note that the localization of induced spinor fields to string world sheets implies that fermionic propagation takes place along their boundaries and one obtains the braid picture.

2. If p^k associated with the partonic orbit is light-like one can assume massless Dirac equation and restriction of the induced spinor field inside the Euclidian regions defining the line of generalized Feynman diagram since the fermion current in the normal direction vanishes. The interpretation would be as on mass-shell massless fermion. If p^k is not light-like, this is not possible and induced spinor field is delocalized outside the Euclidian portions of the

line of generalized Feynman diagram: interactions would be basically due to the dispersion of induced spinor fields to Minkowskian regions. The interpretation would be as a virtual particle. The challenge is to find whether this interpretation makes sense and whether it is possible to articulate this idea mathematically. The alternative assumption is that also virtual particles can localized inside Euclidian regions.

3. One can wonder what the spectrum of p_k could be. If the identification of p^k as virtual momentum is correct, continuous mass spectrum suggests itself. Boundary conditions at the ends of CD might imply quantized mass spectrum and the study of C-S-D equation indeed suggets this if periodic boundary conditions are assumed. For the incoming lines of generalized Feynman diagram one expects light-like momenta so that Γ^n should be light-like. This assumption is consistent with super-conformal invariance since physical states would correspond to bound states of massless fermions, whose four-momenta need not be parallel. Stringy mass spectrum would be outcome of super-conformal invariance and 2-sheetedness forced by boundary conditions for Kähler action would be essential for massivation.

2. Chern-Simons Dirac action from mathematical consistency

A further natural condition is that the possible boundary term is well-defined. At partonic orbits the boundary term of Kähler-Dirac action need not be well-defined since $\sqrt{g_4}\Gamma^n$ becomes singular. This leaves only Chern-Simons Dirac action

$$\overline{\Psi}\Gamma^{\alpha}_{C-S}D_{\alpha}\Psi$$

under consideration at both sides of the partonic orbits and one can consider continuity of C-S-D action as the boundary condition. Here Γ^{α}_{C-S} denotes the C-S-D gamma matrix, which does not depend on the induced metric and is non-vanishing and well-defined. This picture conforms also with the view about TGD as almost topological QFT.

One could restrict Chern-Simons-Dirac action to partonic orbits since they are special in the sense that they are not genuine boundaries. Also Kähler action would naturally contain Chern-Simons term.

One can require that the action of Chern-Simons Dirac operator is equal to multiplication with $ip^k\gamma_k$ so that massless Dirac propagator is the outcome. Since Chern-Simons term involves only CP_2 gamma matrices this would define the analog of Dirac equation at the level of imbedding space. I have proposed this equation already earlier and introduction this it as generalized eigenvalue equation having pseudomomenta p^k as its solutions.

If C-S-D and C-S terms are assigned also with the space-like ends of space-time surface, Kähler action and Kähler function vanish identically if the weak form of em duality holds true. Hence C-S-D and C-S terms can be assigned only with partonic orbits. If space-like ends of space-time surface involve no Chern-Simons term, one obtains the boundary condition

$$\sqrt{g_4}\Gamma^n\Psi = 0 \tag{2.6.1}$$

at them. Ψ would behave like massless mode locally. The condition $\sqrt{g_4}\Gamma^n\Psi = -\gamma^k p_k\Psi = 0$ would state that incoming fermion is massless mode globally. The physical interpretation would be as incoming massless fermions.

Constraint terms at space-like ends of space-time surface

There are constraint terms coming from the condition that weak form of electric-magnetic duality holds true and also from the condition that classical charges for the space-time sheets in the superposition are identical with quantal charges which are net fermionic charges assignable to the strings.

These terms give additional contribution to the algebraic equation $\Gamma^n\Psi = 0$ making in partial differential equation reducing to ordinary differential equation if induced spinor fields are localized at 2-D surfaces. These terms vanish if Ψ is covariantly constant along the boundary of the string world sheet so that fundamental fermions remain massless. By 1-dimensionality covariant constancy can be always achieved.

Associativity (co-associativity) and quantum criticality

Quantum criticality is one of the basic notions of TGD. It was originally introduced to fix the value(s) of Kähler coupling strength as the analog of critical temperature. Quantum criticality implies that second variation of Kähler action vanishes for critical deformations and the existence of conserved current: this current vanishes for Cartan algebra of isometries.

The natural expectation is that the number of critical deformations is infinite and corresponds to conformal symmetries naturally assignable to criticality. The number n of conformal equivalence classes of the deformations can be finite and n would naturally relate to the hierarchy of Planck constants $h_{eff} = n \times h$.

Quantum criticality allows to fix the values of couplings appearing in the measurement interaction by using the condition $K \rightarrow K + f + \overline{f}$. p-Adic coupling constant evolution can be understood also and corresponds to scale hierarchy for the sizes of causal diamonds (CDs).

The conjecture is that quantum critical space-time surfaces are associative (co-associative) in the sense that the tangent vectors span a associative (co-associative) subspace of complexified octonions at each point of the space-time surface is consistent with what is known about preferred extremals. The notion of octonionic tangent space can be expressed by introducing octonionic structure realized in terms of vielbein in manner completely analogous to that for the realization of gamma matrices.

One can also introduce octonionic representations of gamma matrices but this is not absolutely necessarily. The condition that both the modified gamma matrices and spinors are quaternionic at each point of the space-time surface leads to a precise ansatz for the general solution of the modified Dirac equation making sense also in the real context. The octonionic version of the modified Dirac equation is very simple since $SO(7,1)$ as vielbein group is replaced with G_2 acting as automorphisms of octonions so that only the neutral Abelian part of the classical electro-weak gauge fields survives the map.

This condition is analogous to what happens for the spinor modes when they are restricted at string worlds sheets carrying vanishing induced W fields (and also Z^0 fields above weak length scale) to guarantee well-definedness of em charge and it might be that this strange looking condition makes sense. The possibility to define G_2 structure would thus be due to the well-definedness of em charge and in the generic case possible only for string world sheets and possibly also partonic 2-surfaces.

Octonionic gamma matrices provide also a non-associative representation for the 8-D version of Pauli sigma matrices and encourage the identification of 8-D twistors as pairs of octonionic spinors conjectured to be highly relevant also for quantum TGD. Quaternionicity condition implies that octo-twistors reduce to something closely related to ordinary twistors.

The exponent of Kähler function as Dirac determinant for the Kähler Dirac action

Although quantum criticality in principle predicts the possible values of Kähler coupling strength, one might hope that there exists even more fundamental approach involving no coupling constants and predicting even quantum criticality and realizing quantum gravitational holography. Since the definition of WCW geometry relies leads to a direct connection between the modes of Kähler Dirac operator and matrix elements of WCW metric the natural expectation is that Dirac determinant - if it can be defined - could be identified as exponent of Kähler function.

If the modes of the modified Dirac equation (or Kähler-Dirac equation) are localized to 2-D string world sheets as the well-definedness of em charge eigenvalue for the modes of induced spinor field strongly suggests, the definition of Dirac determinant could be rather simple as following argument shows.

The modes of Kähler-Dirac operator (modified Dirac operator) are localized at string world sheets and are holomorphic spinors. K-D operator annihilates these modes so that Dirac determinant must be assigned with the Chern-Simons Dirac term associated with the light-like partonic orbits with vanishing metric determinant g_4. Spinor modes at partonic orbits are assumed to be generalized eigen modes of C-S-D operator with eigenvalues $ip^k\gamma_k$, with p^k interpreted as virtual momentum of the fermion propagating along lined defined by the string world sheet boundary. Therefore C-S-D term acts effectively as massless Dirac action in perturbation theory.

The spectrum of p^k is determined by the boundary conditions for C-S-D operator at the ends of CD and periodic boundary conditions is one natural possibility. As in massless QFTs Dirac determinant could be identified as a square root of the product of mass squared eigenvalues p^2. If the spectrum is unbounded, a regularization must be used. Finite measurement resolution means UV and IR cutoffs and would make Dirac determinant finite. Finite IR resolution would be due to the fact that only space-time surfaces within CD and thus having finite size scale are considered. UV resolution would be due to the lower limit on the size of sub-CDs.

One can however define Dirac determinant directly as the product of the generalized eigenvalues $p^k\gamma_k$ or as product of hyper-quaternions defined by p^k. By symmetry arguments the outcome must be real.

The full Dirac determinant would be product of Dirac determinants associated with various string world sheets. Needless to say that this is an enormous calculational advantage. If Dirac determinant identified in this manner reduces to exponent of Kähler action for preferred extremal this definition of Dirac determinant should give exponent of Kähler function reducing by weak form of electric-magnetic duality to exponent of Chern-Simons terms associated with the space-like ends of the space-time surface. Euclidian and Minkowskian regions would give contributions different by a phase factor $\sqrt{-1}$. The reduction of determinant to exponent of Chern-Simons terms would guarantee its finiteness.

Before trying to calculate Dirac determinant it is good to try to guess what the reduction to Chern Simons action could give as a result. This kind of guesses are of course highly speculative but nothing prevents from trying.

1. Chern Simons action to which Kähler action is expected to reduce for the preferred extremals should be expressible in terms of invariants associated with string world sheets. The only invariant, which comes in mind is Kähler magnetic flux, which is zero mode and by general vision quantized as integer, rational or even algebraic number for surfaces for which parameters in their defining representations correspond to finite algebraic extensions of rationals. For instance, fluxes could belong to rationals with p-adic norm not larger than p^n and allowing realization as flux.

2. Finite measurement resolution suggests that the Kähler magnetic fluxes defined by $J\sqrt{g_2}$, which is constant in preferred coordinates by the internal consistency of quantization of induced spinors, are quantized as integer multiplies or rationals or even algebraic numbers corresponding to the hierarchy of algebraic extensions assignable to the parameters characterizing space-time surfaces (say the coefficients of polynomials defining the space-time sheet). Therefore space-time surface itself would realize the finite measurement resolution in their dynamics as the finiteness for the number of string world sheets and natural cutoffs for the generalized eigenvalue spectrum of C-S-D operator, and the calculation of Dirac determinant using finite number of string world sheets would not be an approximation. Finite measurement resolution would be also a property of state.

3. The value of k could depend on string world sheet so that one would obtain $K(X^3) \propto \sum_i k_i$, where the sum is sum over fluxes associated with string world sheets. Kähler function would be equal to Chern-Simons term in turn equal to the sum of Kähler fluxes over all alowed string world sheets: this looks indeed geometrically attractive.

4. The reduction of Chern-Simons action to a sum of terms proportional to Kähler fluxes takes place if Chern-Simons action is apart from a vanishing integral of divergence proportional to the sum $\sum_i \oint_{C_i} A_\mu dx^\nu$ around the string world sheet. This form would have interpretation in terms of a coupling of charged particles at braid strands to Kähler potential so that particle picture would emerge.

5. Since magnetic flux is conserved, one can argue that Chern-Simons term reduces to an integral of constant magnetic flux J over transverse degrees of freedom multiplied by integral over the boundary of string world sheet given by $\oint_C A_\mu (dx^\mu/ds) ds$ so that one indeed obtains the desired result. The result is non-vanishing only for monopole flux. Elementary particles indeed correspond to throats carrying monopole flux.

6. The arguent about finite measurement resolution can be of course criticized. An alternative argument relies on idea that the sum over logarithms of eigenvalues reduces to integral using as

measure the transversal induced Kähler form J_T and the magnetic flux J over string world sheet. This conforms with the existence of slicing by string world sheets labelled by points of partonic 2-surface.

The formula would be

$$K \propto \oint J(x,y) J_T dx^1 \wedge dx^2 \ . \tag{2.6.2}$$

This would be non-local analog for the local quadratic dependence of Kähler action on Kähler form. This decomposition might have interpretation in terms of intersections of 2-D surfaces in relative homology.

2.6.3 Three Dirac operators and their interpretation

The physical interpretation of Kähler Dirac equation is not at all straightforward. The following arguments inspired by effective 2-dimensionality suggest that the modified gamma matrices and corresponding effective metric could allow dual gravitational description of the physics associated with wormhole throats. This applies in particular to condensed matter physics.

Three Dirac equations

To begin with, Dirac equation appears in three forms in TGD.

1. The Dirac equation in world of classical worlds codes (WCW) for the super Virasoro conditions for the super Kac-Moody and similar representations formed by the states of wormhole contacts forming the counterpart of string like objects (throats correspond to the ends of the string. WCW Dirac operator generalizes the Dirac operator of 8-D imbedding space by bringing in vibrational degrees of freedom. This Dirac equation should give as its solutions zero energy states and corresponding M-matrices generalizing S-matrix and their collection defining the unitary U-matrix whose natural application appears in consciousness theory as a coder of what Penrose calls U-process. The ground states to which super-conformal algebras act correspond to imbedding space spinor modes in accordance with the idea that point like limit gives QFT in imbedding space.

2. The analog of massless Dirac equation at the level of 8-D imbedding space and satisfied by fermionic ground states of super-conformal representations.

3. Kähler Dirac equation is satisfied in the interior of space-time. In this equation the gamma matrices are replaced with modified gamma matrices defined by the contractions of canonical momentum currents $T^\alpha_k = \partial L/\partial_\alpha h^k$ with imbedding space gamma matrices Γ_k. This replacement is required by internal consistency and by super-conformal symmetries. The well-definedness of em charge implies that the modes of induced spinor field are localized at 2-D surfaces so that a connection with string theory type approach emerges.

Kähler-Dirac equation defines Dirac equation at space-time level. Consider first K-D equation in the interior of space-time surface.

1. The condition that electromagnetic charge operator defined in terms of em charge expressed in terms of Clifford algebra is well defined for spinor modes (completely analogous to spin defined in terms of sigma matrices) leads to the proposal that induced spinor fields are necessarily localized at 2-dimensional string worlds sheets [K80]. Only the covariantly constant right handed neutrino and its modes assignable to massless extremals (at least) generating supersymmetry (super-conformal symmetries) would form an exception since electroweak couplings would vanish. Note that the modified gamma matrices possess CP_2 and this must vanish in order to have de-localization.

2. This picture implies stringy realization of super Kac-Moody symmetry elementary particles can be identified as string like objects albeit in different sense than in string models. At light-like 3-surfaces defining the orbits of partonic 2-surfaces spinor fields carrying electroweak quantum numbers would be located at braid strands as also the notion of finite measurement resolution requires. This picture is also consistent with the puzzling observation that the solutions of the Chern-Simons Dirac equation can be localized on light-like curves inside wormhole throat orbits.

3. Could Kähler Dirac equation provide a first principle justification for the light-hearted use of effective mass and the analog of Dirac equation in condensed manner physics? This would conform with the holographic philosophy. Partonic 2-surfaces with tangent space data and their light-like orbits would give hologram like representation of physics and the interior of space-time the 4-D representation of physics. Holography would have in the recent situation interpretation also as quantum classical correspondence between representations of physics in terms of quantized spinor fields at the light-like 3-surfaces on one hand and in terms of classical fields on the other hand.

4. The resulting dispersion relation for the square of the Kähler-Dirac operator assuming that induced like metric, Kähler field, etc. are very slowly varying contains quadratic and linear terms in momentum components plus a term corresponding to magnetic moment coupling. In general massive dispersion relation is obtained as is also clear from the fact that Kähler Dirac gamma matrices are combinations of M^4 and CP_2 gammas so that modified Dirac mixes different M^4 chiralities (basic signal for massivation). If one takes into account the dependence of the induced geometric quantities on space-time point dispersion relations become non-local.

5. Sound as a concept is usually assigned with a rather high level of description. Stringy world sheets could however dramatically raise the status of sound in this respect. The oscillations of string world sheets connecting wormhole throats describe non-local 2-particle interactions. Holography suggests that this interaction just "gravitational" dual for electroweak and color interactions. Could these oscillations inducing the oscillation of the distance between wormhole throats be interpreted at the limit of weak "gravitational" coupling as analogs of sound waves, and could sound velocity correspond to maximal signal velocity assignable to the effective metric?

Various arguments lead to the hypothesis that Kähler-Dirac action contains Chern-Simons-Dirac action localized at partonic orbits as additional term. This term cannot present at the space-like ends of the space-time surfaces. Also Kähler action contains Chern-Simons term and partonic orbits and reduces by field equations to Chern-Simons terms at the space-like ends of space-time surface.

1. The variation of the Kähler-Dirac action gives rise to a boundary term, which is essentially contraction of the normal component of the vector Γ^n defined by Kähler-Dirac gamma matrices. Boundary condition gives $\sqrt{g_4}\Gamma^n\Psi = 0$. Therefore the incoming spinor modes at the boundaries of string world sheets must be massless. A further assumption is that the action of $\sqrt{g_4}\Gamma^n$ equals to that of a massless Dirac operator. By a suitable choice of coordinates this might be achieved. Thus massless Dirac equation in M^4 would emerge for on mass shell states.

2. At parton orbits of wormhole one can assume that the spinors are generalized eigenstates of C-S-D operator reduces to that of massless M^4 Dirac operator. C-S-D Dirac action would give rise to massless Dirac propagator and one would have good hopes that twistor Grassmannian approach works. In TGD based sringy variant of twistor Grassmann approach the integrals over virtual momenta as residue integrals reduce them to 3-D integrals over light-cone subject to momentum conservation constraints at vertices. Virtual fermions are massless but have unphysical polarization. This picture is discussed in detail in [K58].

2.6.4 Does energy metric provide the gravitational dual for condensed matter systems?

The modified gamma matrices define an effective metric via their anti-commutators quadratic in components of energy momentum tensor (canonical momentum densities). This effective metric vanishes for vacuum extremals. Note that the use of the modified gamma matrices guarantees among other things internal consistency and super-conformal symmetries of the theory.

If the above argument is on the right track, this effective metric should have applications in condensed matter theory. The energy metric has a natural interpretation in terms of effective light velocities which depend on direction of propagation. One can diagonalize the energy metric $g_e^{\alpha\beta}$ (contravariant form results from the anti-commutators) and one can denote its eigenvalues by (v_0, v_i) in the case that the signature of the effective metric is $(1, -1, -1, -1)$. The 3-vector v_i/v_0 has interpretation as components of effective light velocity in various directions as becomes clear by thinking the d'Alembert equation for the energy metric. This velocity field could be interpreted as that of hydrodynamic flow. The study of the extremals of Kähler action shows that if this flow is actually Beltrami flow so that the flow parameter associated with the flow lines extends to global coordinate, Kähler action reduces to a 3-D Chern-Simons action and one obtains effective topological QFT. The conserved fermion current $\overline{\Psi}\Gamma_e^\alpha\Psi$ has interpretation as incompressible hydrodynamical flow.

This would give also a nice analogy with AdS/CFT correspondence allowing to describe various kinds of physical systems in terms of higher-dimensional gravitation and black holes are introduced quite routinely to describe condensed matter systems. In TGD framework one would have an analogous situation but with 10-D space-time replaced with the interior of 4-D space-time and the boundary of AdS representing Minkowski space with the light-like 3-surfaces carrying matter. The effective gravitation would correspond to the "energy metric". One can associate with it analogs of curvature tensor, Ricci tensor and Einstein tensor using standard formulas and identify effective energy momentum tensor associated as Einstein tensor with effective Newton's constant appearing as constant of proportionality. Note however that the besides ordinary metric and "energy" metric one would have also the induced classical gauge fields having purely geometric interpretation and action would be Kähler action. This 4-D holography could provide a precise, dramatically simpler, and also a very concrete dual description. This cannot be said about model of graphene based on the introduction of 10-dimensional black holes, branes, and strings chosen in more or less ad hoc manner.

This raises questions. Could this give a general dual gravitational description of dissipative effects in terms of the "energy" metric and induced gauge fields? Does one obtain the analogs of black holes? Do the general theorems of general relativity about the irreversible evolution leading to black holes generalize to describe analogous fate of condensed matter systems caused by dissipation? Can one describe non-equilibrium thermodynamics and self-organization in this manner?

One might argue that the incompressible Beltrami flow defined by the dynamics of the preferred extremals is dissipationless and viscosity must therefore vanish locally. The failure of complete determinism for Kähler action however means generation of entropy since the knowledge about the state decreases gradually. This in turn should have a phenomenological local description in terms of viscosity, which characterizes the transfer of energy to shorter scales and eventually to radiation. The deeper description should be non-local and basically topological and might lead to quantization rules. For instance, one can imagine the quantization of the ratio η/s of the viscosity to entropy density as multiples of a basic unit defined by its lower bound (note that this would be analogous to Quantum Hall effect). For the first M-theory inspired derivation of the lower bound of η/s [D5] . The lower bound for η/s is satisfied in good approximation by what should have been QCD plasma but found to be something different (RHIC and the first evidence for new physics from LHC [K37]).

An encouraring sign comes from the observation that for so called massless extremals representing classically arbitrarily shaped pulses of radiation propagating without dissipation and dispersion along single direction the canonical momentum currents are light-like. The effective contravariant metric vanishes identically so that fermions cannot propate in the interior of massless extremals! This is of course the case also for vacuum extremals. Massless extremals are purely bosonic and represent bosonic radiation. Many-sheeted space-time decomposes into matter containing regions and radiation containing regions. Note that when wormhole contact (particle) is glued to a massless extremal, it is deformed so that CP_2 projection becomes 4-D guaranteeing that the weak form of electric magnetic duality can be satisfied. Therefore massless extremals can be seen as asymptotic regions. Perhaps one could say that dissipation corresponds to a de-coherence process creating space-time sheets consisting of matter and radiation. Those containing matter might be even seen as analogs blackholes as far as energy metric is considered.

Preferred extremals as perfect fluids

2.6.5 Preferred extremals as perfect fluids

Almost perfect fluids seems to be abundant in Nature. For instance, QCD plasma was originally thought to behave like gas and therefore have a rather high viscosity to entropy density ratio $x = \eta/s$. Already RHIC found that it however behaves like almost perfect fluid with x near to the minimum predicted by AdS/CFT. The findings from LHC gave additional conform the discovery [C45]. Also Fermi gas is predicted on basis of experimental observations to have at low temperatures a low viscosity roughly 5-6 times the minimal value [D3] . In the following the argument that the preferred extremals of Kähler action are perfect fluids apart from the symmetry breaking to space-time sheets is developed. The argument requires some basic formulas summarized first.

The detailed definition of the viscous part of the stress energy tensor linear in velocity (oddness in velocity relates directly to second law) can be found in [D2] .

1. The symmetric part of the gradient of velocity gives the viscous part of the stress-energy tensor as a tensor linear in velocity. Velocity gradient decomposes to a term traceless tensor term and a term reducing to scalar.

$$\partial_i v_j + \partial_j v_i = \frac{2}{3}\partial_k v^k g_{ij} + (\partial_i v_j + \partial_j v_i - \frac{2}{3}\partial_k v^k g_{ij}) \ . \tag{2.6.3}$$

The viscous contribution to stress tensor is given in terms of this decomposition as

$$\sigma_{visc;ij} = \zeta \partial_k v^k g_{ij} + \eta(\partial_i v_j + \partial_j v_i - \frac{2}{3}\partial_k v^k g_{ij}) \ . \tag{2.6.4}$$

From $dF^i = T^{ij}S_j$ it is clear that bulk viscosity ζ gives to energy momentum tensor a pressure like contribution having interpretation in terms of friction opposing. Shear viscosity η corresponds to the traceless part of the velocity gradient often called just viscosity. This contribution to the stress tensor is non-diagonal and corresponds to momentum transfer in directions not parallel to momentum and makes the flow rotational. This term is essential for the thermal conduction and thermal conductivity vanishes for ideal fluids.

2. The 3-D total stress tensor can be written as

$$\sigma_{ij} = \rho v_i v_j - p g_{ij} + \sigma_{visc;ij} \ . \tag{2.6.5}$$

The generalization to a 4-D relativistic situation is simple. One just adds terms corresponding to energy density and energy flow to obtain

$$T^{\alpha\beta} = (\rho - p)u^\alpha u^\beta + p g^{\alpha\beta} - \sigma^{\alpha\beta}_{visc} \ . \tag{2.6.6}$$

Here u^α denotes the local four-velocity satisfying $u^\alpha u_\alpha = 1$. The sign factors relate to the concentrations in the definition of Minkowski metric $((1, -1, -1, -1))$.

3. If the flow is such that the flow parameters associated with the flow lines integrate to a global flow parameter one can identify new time coordinate t as this flow parameter. This means a transition to a coordinate system in which fluid is at rest everywhere (comoving coordinates in cosmology) so that energy momentum tensor reduces to a diagonal term plus viscous term.

$$T^{\alpha\beta} = (\rho - p)g^{tt}\delta^{\alpha}_t\delta^{\beta}_t + pg^{\alpha\beta} - \sigma^{\alpha\beta}_{visc} \ . \tag{2.6.7}$$

In this case the vanishing of the viscous term means that one has perfect fluid in strong sense.

The existence of a global flow parameter means that one has

$$v_i = \Psi\partial_i\Phi \ . \tag{2.6.8}$$

Ψ and Φ depend on space-time point. The proportionality to a gradient of scalar Φ implies that Φ can be taken as a global time coordinate. If this condition is not satisfied, the perfect fluid property makes sense only locally.

AdS/CFT correspondence allows to deduce a lower limit for the coefficient of shear viscosity as

$$x = \frac{\eta}{s} \geq \frac{\hbar}{4\pi} \ . \tag{2.6.9}$$

This formula holds true in units in which one has $k_B = 1$ so that temperature has unit of energy.

What makes this interesting from TGD view is that in TGD framework perfect fluid property in appropriately generalized sense indeed characterizes locally the preferred extremals of Kähler action defining space-time surface.

1. Kähler action is Maxwell action with U(1) gauge field replaced with the projection of CP_2 Kähler form so that the four CP_2 coordinates become the dynamical variables at QFT limit. This means enormous reduction in the number of degrees of freedom as compared to the ordinary unifications. The field equations for Kähler action define the dynamics of space-time surfaces and this dynamics reduces to conservation laws for the currents assignable to isometries. This means that the system has a hydrodynamic interpretation. This is a considerable difference to ordinary Maxwell equations. Notice however that the "topological" half of Maxwell's equations (Faraday's induction law and the statement that no non-topological magnetic are possible) is satisfied.

2. Even more, the resulting hydrodynamical system allows an interpretation in terms of a perfect fluid. The general ansatz for the preferred extremals of field equations assumes that various conserved currents are proportional to a vector field characterized by so called Beltrami property. The coefficient of proportionality depends on space-time point and the conserved current in question. Beltrami fields by definition is a vector field such that the time parameters assignable to its flow lines integrate to single global coordinate. This is highly non-trivial and one of the implications is almost topological QFT property due to the fact that Kähler action reduces to a boundary term assignable to wormhole throats which are light-like 3-surfaces at the boundaries of regions of space-time with Euclidian and Minkowskian signatures. The Euclidian regions (or wormhole throats, depends on one's tastes) define what I identify as generalized Feynman diagrams.

   Beltrami property means that if the time coordinate for a space-time sheet is chosen to be this global flow parameter, all conserved currents have only time component. In TGD framework energy momentum tensor is replaced with a collection of conserved currents assignable to various isometries and the analog of energy momentum tensor complex constructed in this manner has no counterparts of non-diagonal components. Hence the preferred extremals allow an interpretation in terms of perfect fluid without any viscosity.

This argument justifies the expectation that TGD Universe is characterized by the presence of low-viscosity fluids. Real fluids of course have a non-vanishing albeit small value of x. What causes the failure of the exact perfect fluid property?

1. Many-sheetedness of the space-time is the underlying reason. Space-time surface decomposes into finite-sized space-time sheets containing topologically condensed smaller space-time sheets containing.... Only within given sheet perfect fluid property holds true and fails at wormhole contacts and because the sheet has a finite size. As a consequence, the global flow parameter exists only in given length and time scale. At imbedding space level and in zero energy ontology the phrasing of the same would be in terms of hierarchy of causal diamonds (CDs).

2. The so called eddy viscosity is caused by eddies (vortices) of the flow. The space-time sheets glued to a larger one are indeed analogous to eddies so that the reduction of viscosity to eddy viscosity could make sense quite generally. Also the phase slippage phenomenon of super-conductivity meaning that the total phase increment of the super-conducting order parameter is reduced by a multiple of 2π in phase slippage so that the average velocity proportional to the increment of the phase along the channel divided by the length of the channel is reduced by a quantized amount.

   The standard arrangement for measuring viscosity involves a lipid layer flowing along plane. The velocity of flow with respect to the surface increases from $v = 0$ at the lower boundary to v_{upper} at the upper boundary of the layer: this situation can be regarded as outcome of the dissipation process and prevails as long as energy is feeded into the system. The reduction of the velocity in direction orthogonal to the layer means that the flow becomes rotational during dissipation leading to this stationary situation.

   This suggests that the elementary building block of dissipation process corresponds to a generation of vortex identifiable as cylindrical space-time sheets parallel to the plane of the flow and orthogonal to the velocity of flow and carrying quantized angular momentum. One expects that vortices have a spectrum labelled by quantum numbers like energy and angular momentum so that dissipation takes in discrete steps by the generation of vortices which transfer the energy and angular momentum to environment and in this manner generate the velocity gradient.

3. The quantization of the parameter x is suggestive in this framework. If entropy density and viscosity are both proportional to the density n of the eddies, the value of x would equal to the ratio of the quanta of entropy and kinematic viscosity η/n for single eddy if all eddies are identical. The quantum would be $\hbar/4\pi$ in the units used and the suggestive interpretation is in terms of the quantization of angular momentum. One of course expects a spectrum of eddies so that this simple prediction should hold true only at temperatures for which the excitation energies of vortices are above the thermal energy. The increase of the temperature would suggest that gradually more and more vortices come into play and that the ratio increases in a stepwise manner bringing in mind quantum Hall effect. In TGD Universe the value of $\hbar$ can be large in some situations so that the quantal character of dissipation could become visible even macroscopically. Whether this a situation with large $\hbar$ is encountered even in the case of QCD plasma is an interesting question.

The following poor man's argument tries to make the idea about quantization a little bit more concrete.

1. The vortices transfer momentum parallel to the plane from the flow. Therefore they must have momentum parallel to the flow given by the total cm momentum of the vortex. Before continuing some notations are needed. Let the densities of vortices and absorbed vortices be n and n_{abs} respectively. Denote by $v_{\parallel}$ *resp.* $v_{\perp}$ the components of cm momenta parallel to the main flow *resp.* perpendicular to the plane boundary plane. Let m be the mass of the vortex. Denote by S are parallel to the boundary plane.

2. The flow of momentum component parallel to the main flow due to the absorbed at S is

$$n_{abs} m v_{\parallel} v_{\perp} S \quad .$$

This momentum flow must be equal to the viscous force

$$F_{visc} = \eta \frac{v_{\parallel}}{d} \times S \quad .$$

From this one obtains

$$\eta = n_{abs} m v_{\perp} d \quad .$$

If the entropy density is due to the vortices, it equals apart from possible numerical factors to

$$s = n$$

so that one has

$$\frac{\eta}{s} = m v_{\perp} d \quad .$$

This quantity should have lower bound $x = \hbar/4\pi$ and perhaps even quantized in multiples of x, Angular momentum quantization suggests strongly itself as origin of the quantization.

3. Local momentum conservation requires that the comoving vortices are created in pairs with opposite momenta and thus propagating with opposite velocities $v_{\perp}$. Only one half of vortices is absorbed so that one has $n_{abs} = n/2$. Vortex has quantized angular momentum associated with its internal rotation. Angular momentum is generated to the flow since the vortices flowing downwards are absorbed at the boundary surface.

   Suppose that the distance of their center of mass lines parallel to plane is $D = \epsilon d$, ϵ a numerical constant not too far from unity. The vortices of the pair moving in opposite direction have same angular momentum $mv \ \ D/2$ relative to their center of mass line between them. Angular momentum conservation requires that the sum these relative angular momenta cancels the sum of the angular momenta associated with the vortices themselves. Quantization for the total angular momentum for the pair of vortices gives

$$\frac{\eta}{s} = \frac{n\hbar}{\epsilon}$$

   Quantization condition would give

$$\epsilon = 4\pi \quad .$$

   One should understand why $D = 4\pi d$ - four times the circumference for the largest circle contained by the boundary layer- should define the minimal distance between the vortices of the pair. This distance is larger than the distance d for maximally sized vortices of radius $d/2$ just touching. This distance obviously increases as the thickness of the boundary layer increases suggesting that also the radius of the vortices scales like d.

4. One cannot of course take this detailed model too literally. What is however remarkable that quantization of angular momentum and dissipation mechanism based on vortices identified as space-time sheets indeed could explain why the lower bound for the ratio η/s is so small.

Is the effective metric one- or two-dimensional?

2.6.6 Is the effective metric effectively one- or two-dimensional?

The following argument suggests that the effective metric defined by the anti-commutators of the modified gamma matrices is effectively one- or two-dimensional. Effective one-dimensionality would conform with the observation that the solutions of the modified Dirac equations can be localized to one-dimensional world lines in accordance with the vision that finite measurement resolution implies discretization reducing partonic many-particle states to quantum superpositions of braids. This localization to 1-D curves occurs always at the 3-D orbits of the partonic 2-surfaces.

The argument is based on the following assumptions.

1. The modified gamma matrices for Kähler action are contractions of the canonical momentum densities T_k^α with the gamma matrices of H.
2. The strongest assumption is that the isometry currents

$$J^{A\alpha} = T_k^\alpha j^{Ak}$$

for the preferred extremals of Kähler action are of form

$$J^{A\alpha} = \Psi^A (\nabla \Phi)^\alpha \qquad (2.6.10)$$

with a common function Φ guaranteeing that the flow lines of the currents integrate to coordinate lines of single global coordinate variables (Beltrami property). Index raising is carried out by using the ordinary induced metric.

3. A weaker assumption is that one has two functions Φ_1 and Φ_2 assignable to the isometry currents of M^4 and CP_2 respectively.:

$$\begin{aligned} J_1^{A\alpha} &= \Psi_1^A (\nabla \Phi_1)^\alpha \ , \\ J_2^{A\alpha} &= \Psi_2^A (\nabla \Phi_2)^\alpha \ . \end{aligned} \qquad (2.6.11)$$

The two functions Φ_1 and Φ_2 could define dual light-like curves spanning string world sheet. In this case one would have effective 2-dimensionality and decomposition to string world sheets [K30] . Isometry invariance does not allow more that two independent scalar functions Φ_i.

Consider now the argument.

1. One can multiply both sides of this equation with j^{Ak} and sum over the index A labeling isometry currents for translations of M^4 and $SU(3)$ currents for CP_2. The tensor quantity $\sum_A j^{Ak} j^{Al}$ is invariant under isometries and must therefore satisfy

$$\sum_A \eta_{AB} j^{Ak} j^{Al} = h^{kl} \ , \qquad (2.6.12)$$

where η_{AB} denotes the flat tangent space metric of H. In M^4 degrees of freedom this statement becomes obvious by using linear Minkowski coordinates. In the case of CP_2 one can first consider the simpler case $S^2 = CP_1 = SU(2)/U(1)$. The coset space property implies in standard complex coordinate transforming linearly under $U(1)$ that only the the isometry currents belonging to the complement of $U(1)$ in the sum contribute at the origin and the identity holds true at the origin and by the symmetric space property everywhere. Identity can be verified also directly in standard spherical coordinates. The argument generalizes to the case of $CP_2 = SU(3)/U(2)$ in an obvious manner.

2. In the most general case one obtains

$$
\begin{aligned}
T_1^{\alpha k} &= \sum_A \Psi_1^A j^{Ak} \times (\nabla\Phi_1)^\alpha \equiv f_1^k (\nabla\Phi_1)^\alpha \ , \\
T_2^{\alpha k} &= \sum_A \Psi_1^A j^{Ak} \times (\nabla\Phi_2)^\alpha \equiv f_2^k (\nabla\Phi_2)^\alpha \ .
\end{aligned} \tag{2.6.13}
$$

3. The effective metric given by the anti-commutator of the modified gamma matrices is in turn is given by

$$
G^{\alpha\beta} = m_{kl} f_1^k f_1^l (\nabla\Phi_1)^\alpha (\nabla\Phi_1)^\beta + s_{kl} f_2^k f_2^l (\nabla\Phi_2)^\alpha (\nabla\Phi_2)^\beta \ . \tag{2.6.14}
$$

   The covariant form of the effective metric is effectively 1-dimensional for $\Phi_1 = \Phi_2$ in the sense that the only non-vanishing component of the covariant metric $G_{\alpha\beta}$ is diagonal component along the coordinate line defined by $\Phi \equiv \Phi_1 = \Phi_2$. Also the contravariant metric is effectively 1-dimensional since the index raising does not affect the rank of the tensor but depends on the other space-time coordinates. This would correspond to an effective reduction to a dynamics of point-like particles for given selection of braid points. For $\Phi_1 \neq \Phi_2$ the metric is effectively 2-dimensional and would correspond to stringy dynamics.

One can also develop an objection to effective 1- or 2-dimensionality. The proposal for what preferred extremals of Kähler action as deformations of the known extremals of Kähler action could be leads to a beautiful ansatz relying on generalization of conformal invariance and minimal surface equations of string model [K8]. The field equations of TGD reduce to those of classical string model generalized to 4-D context.

If the proposed picture is correct, field equations reduce to purely algebraically conditions stating that the Maxwellian energy momentum tensor for the Kähler action has no common index pairs with the second fundamental form. For the deformations of CP_2 type vacuum extremals T is a complex tensor of type (1,1) and second fundamental form H^k a tensor of type (2,0) and (0,2) so that $Tr(TH^k) =$ is true. This requires that second light-like coordinate of M^4 is constant so that the M^4 projection is 3-dimensional. For Minkowskian signature of the induced metric Hamilton-Jacobi structure replaces conformal structure. Here the dependence of CP_2 coordinates on second light-like coordinate of $M^2(m)$ only plays a fundamental role. Note that now T^{vv} is non-vanishing (and light-like). This picture generalizes to the deformations of cosmic strings and even to the case of vacuum extremals.

There is however an important consistency condition involved. The Maxwell energy momentum tensor for Kähler action must have vanishing covariant divergence. This is satisfied if it is linear combination of Einstein tensor and metric. This gives Einstein's equations with cosmological term in the general case. By the algebraic character of field equations also minimal surface equations are satisfied and Einstein's General Relativity would be exact part of TGD.

In the case of modified Dirac equation the result means that modified gamma matrices are contractions of linear combination of Einstein tensor and metric tensor with the induced gamma matrices so that the TGD counterpart of ordinary Dirac equation would be modified by the addition of a term proportional to Einstein tensor. The condition of effective 1- or 2-dimensionality seems to pose too strong conditions on this combination.

2.7 Summary of generalized Feynman diagrammatics

This section gives a summary about the recent view abot generalized Feynman diagrammatics, which can be seen as a hybrid of Feynman diagrammatics and stringy diagrammatics. The analogs of Feynman diagrams are realized at the level of space-time topology and geometry and the lines of these diagrams are Euclidian space-time regions identifiable as wormhole contacts. For fundamental fermions one has the usual 1-D propagator lines.

Physical particles can be seen as bound state of massless fundamental fermions and involve two wormhole contacts forming parts of closed Kähler magnetic flux tubes carrying monople flux. The orbits of wormhole throats are connected by fermionic string world sheets whose boundaries correspond to massless fermion lines defining strands of braids. String world sheets in turn can form 2-braids.

It is a little bit matter of taste whether one refers to these diagrams generalized Feynman diagrams, generalized stringy diagrams, generalized Wilson loops or generalized twistor diagrams. All these labels are partly misleading.

In the sequel the basic action principles - Kähler action and Kähler-Dirac action are discussed first, and then a proposal for the diagrams describing M-matrix elements is discussed.

2.7.1 The basic action principle

In the following the most recent view about Kähler action and the modified Dirac action (Kähler-Dirac action) is explained in more detail.

1. The minimal formulation involves in the bosonic case only 4-D Kähler action with Chern-Simons boundary term localized to partonic orbits at which the signature of the induced metric changes. The coefficient of Chern-Simons term is chosen so that this contribution to bosonic action cancels the Chern-Simons term coming from Kähler action (by weak form of electric-magnetic duality) so that for preferred extremals Kähler action reduces to Chern-Simons terms at the ends of space-time surface at boundaries of causal diamond (CD).

   There are constraint terms expressing weak form of electric-magnetic duality and constraints forcing the total quantal charges for Kähler-Dirac action in Cartan algebra to be identical with total classical charges for Kähler action. This realizes quantum classical correspondence. The constraints do not affect quantum fluctuating degrees of freedom if classical charges parametrize zero modes so that the localization to a quantum superposition of space-time surfaces with same classical charges is possible.

2. By supersymmetry requirement the modified Dirac action corresponding to the bosonic action is obtained by associating to the various pieces in the bosonic action canonical momentum densities and contracting them with imbedding space gamma matrices to obtain modified gamma matrices. This gives rise to Kähler-Dirac equation in the interior of space-time surface. At partonic orbits one only assumes that spinors are generalized eigen modes of Chern-Simons Dirac operator with generalized eigenvalues $p^k\gamma_k$ identified as virtual four-momenta so that C-S-D term gives fermionic propagators. At the ends of space-time surface one obtains boundary conditions stating in absence of measurement interaction terms that fundamental fermions are massless on-mass-shell states.

Lagrange multiplier terms in Kähler action

Weak form of E-M duality can be realized by adding to Kähler action 3-D constraint terms realized in terms of Lagrange multipliers. These contribute to the Chern-Simons Dirac action too by modifying the definition of the modified gamma matrices.

Quantum classical correspondence (QCC) is the principle motivating further additional terms in Kähler action.

1. QCC suggests a correlation between 4-D geometry of space-time sheet and quantum numbers. This could result if the classical charges in Cartan algebra are identical with the quantal ones assignable to Kähler-Dirac action. This would give very powerful constraint on the allowed space-time sheets in the superposition of space-time sheets defining WCW spinor field. An even strong condition would be that classical correlation functions are equal to quantal ones.

2. The equality of quantal and classical Cartan charges could be realized by adding constraint terms realized using Lagrange multipliers at the space-like ends of space-time surface at the boundaries of CD. This procedure would be very much like the thermodynamical procedure used to fix the average energy or particle number of the the system using Lagrange multipliers identified as temperature or chemical potential. Since quantum TGD can be regarded as

square root of thermodynamics in zero energy ontology (ZEO), the procedure looks logically sound.

3. The consistency with Kähler-Dirac equation for which Chern-Simons boundary term at parton orbits (not genuine boundaries) seems necessary suggests that also Kähler action has Chern-Simons term as a boundary term at partonic orbits. Kähler action would thus reduce to contributions from the space-like ends of the space-time surface.

Boundary terms for Kähler-Dirac action

Weak form of E-M duality implies the reduction of Kähler action to Chern-Simons terms for preferred extremals satisfying $j \cdot A = 0$ (contraction of Kähler current and Kähler gauge potential vanishes). One obtains Chern-Simons terms at space-like 3-surfaces at the ends of space-time surface at boundaries of causal diamond and at light-like 3-surfaces defined by parton orbits having vanishing determinant of induced 4-metric. The naive guess that consistency requires Kähler-Dirac-Chern Simons equation at partonic orbits. This need not however be correct and therefore it is best to carefully consider what one wants.

1. What one wants?

It is could to make first clear what one really wants.

1. What one wants is generalized Feynman diagrams demanding massless Dirac propagators at the boundaries of string world sheets interpreted as fermionic lines of generalized Feynman diagrams. This gives hopes that twistor Grassmannian approach emerges at QFT limit. This boils down to the condition

$$\sqrt{g_4}\Gamma^n\Psi = p^k\gamma_k\Psi = 0$$

   at the space-like ends of space-time surface. The general idea is that the space-time geometry near the fermion line would *define* the on mass shell massless four-momentum propagating along the line and quantum classical correspondence would be realized.

   The basic condition is thus that $\sqrt{g_4}\Gamma^n$ is constant at the space-like boundaries of string world sheets and depends only on the piece of this boundary representing fermion line rather than on its point. Otherwise the propagator does not exist as a global notion. Constancy allows to write $\sqrt{g_4}\Gamma^n\Psi = p^k\gamma_k\Psi$ since only M^4 gamma matrices are constant.

   Partonic orbits are not boundaries in the usual sense of the word and this condition is not elegant at them since g_4 vanishes at them. The assignement of Chern-Simons Dirac action to partonic orbits required to be continuous at them solves the problems. One can require that the induced spinors are generalized eigenstates of C-S-D operator with eigenvalues with correspond to virtual four-moment. This guarantees that one obtains massless Dirac propagator from C-S-D action. Note that the localization of induced spinor fields to string world sheets implies that fermionic propagation takes place along their boundaries and one obtains the braid picture.

2. If p^k associated with the partonic orbit is light-like one can assume massless Dirac equation and restriction of the induced spinor field inside the Euclidian regions defining the line of generalized Feynman diagram since the fermion current in the normal direction vanishes. The interpretation would be as on mass-shell massless fermion. If p^k is not light-like, this is not possible and induced spinor field is delocalized outside the Euclidian portions of the line of generalized Feynman diagram: interactions would be basically due to the dispersion of induced spinor fields to Minkowskian regions. The interpretation would be as a virtual particle. The challenge is to find whether this interpretation makes sense and whether it is possible to articulate this idea mathematically. The alternative assumption is that also virtual particles can localized inside Euclidian regions.

3. One can wonder what the spectrum of p_k could be. If the identification of p^k as virtual momentum is correct, continuous mass spectrum suggests itself. Boundary conditions at the ends of CD might imply quantized mass spectrum and the study of C-S-D equation

indeed suggets this if periodic boundary conditions are assumed. For the incoming lines of generalized Feynman diagram one expects light-like momenta so that Γ^n should be light-like. This assumption is consistent with super-conformal invariance since physical states would correspond to bound states of massless fermions, whose four-momenta need not be parallel. Stringy mass spectrum would be outcome of super-conformal invariance and 2-sheetedness forced by boundary conditions for Kähler action would be essential for massivation.

2. Chern-Simons Dirac action from mathematical consistency

A further natural condition is that the possible boundary term is well-defined. At partonic orbits the boundary term of Kähler-Dirac action need not be well-defined since $\sqrt{g_4}\Gamma^n$ becomes singular. This leaves only Chern-Simons Dirac action

$$\overline{\Psi}\Gamma^{\alpha}_{C-S}D_{\alpha}\Psi$$

under consideration at both sides of the partonic orbits and one can consider continuity of C-S-D action as the boundary condition. Here Γ^{α}_{C-S} denotes the C-S-D gamma matrix, which does not depend on the induced metric and is non-vanishing and well-defined. This picture conforms also with the view about TGD as almost topological QFT.

One could restrict Chern-Simons-Dirac action to partonic orbits since they are special in the sense that they are not genuine boundaries. Also Kähler action would naturally contain Chern-Simons term.

One can require that the action of Chern-Simons Dirac operator is equal to multiplication with $ip^k\gamma_k$ so that massless Dirac propagator is the outcome. Since Chern-Simons term involves only CP_2 gamma matrices this would define the analog of Dirac equation at the level of imbedding space. I have proposed this equation already earlier and introduction this it as generalized eigenvalue equation having pseudomomenta p^k as its solutions.

If C-S-D and C-S terms are assigned also with the space-like ends of space-time surface, Kähler action and Kähler function vanish identically if the weak form of em duality holds true. Hence C-S-D and C-S terms can be assigned only with partonic orbits. If space-like ends of space-time surface involve no Chern-Simons term, one obtains the boundary condition

$$\sqrt{g_4}\Gamma^n\Psi = 0 \tag{2.7.1}$$

at them. Ψ would behave like massless mode locally. The condition $\sqrt{g_4}\Gamma^n\Psi = -\gamma^k p_k\Psi = 0$ would state that incoming fermion is massless mode globally. The physical interpretation would be as incoming massless fermions.

Constraint terms at space-like ends of space-time surface

There are constraint terms coming from the condition that weak form of electric-magnetic duality holds true and also from the condition that classical charges for the space-time sheets in the superposition are identical with quantal charges which are net fermionic charges assignable to the strings.

These terms give additional contribution to the algebraic equation $\Gamma^n\Psi = 0$ making in partial differential equation reducing to ordinary differential equation if induced spinor fields are localized at 2-D surfaces. These terms vanish if Ψ is covariantly constant along the boundary of the string world sheet so that fundamental fermions remain massless. By 1-dimensionality covariant constancy can be always achieved.

2.7.2 A proposal for M-matrix

This picture can be taken as a template as one tries to to imagine how the construction of M-matrix could proceed in quantum TGD proper.

1. At the bosonic sector one would have converging functional integral over WCW. This is analogous to the path integral over bosonic fields in QFTs. The presence of Kähler function would make this integral well-defined and would not encounter the difficulties met in the case of path integrals.

2. In fermionic sector Chern-Simons Dirac term in the action and the condition that spinors modes localized at string world sheets are eigenstates of C-S-D operator with generalized eigenvalue $p^k\gamma_k$ defining virtual momentum would give effectively rise to massless Dirac action in M^4 and one would obtain massless fermionic propagators. The generalization of twistor Grassmann approach is suggestive and would mean that the residue integral over fermionic virtual momenta gives only integral over massless momenta and virtual fermions differ from real fermions only in that they have non-physical polarizations so that massless Dirac operator replacing the propagator does not annihilate the spinors at the other end of the line.

3. Fundamental bosons (not elementary particles) correspond to wormhole contacts having fermion and antifermion at opposite throats and bosonic propagators are composite of massless fermion propagators. The directions of virtual momenta are obviously strongly correlated so that the approximation as gauge theory is natural.

4. Physical fermions and bosons correspond to pairs of wormhole contacts with throats carrying Kähler magnetic charge equal to Kähler electric charge (dyon). The absence of Dirac monopoles (as opposed to homological magnetic monopoles due to CP_2 topology) implies that wormhole contacts must appear as pairs (also large numbers of them are possible and 3 valence quarks inside baryons could form Kähler magnetic tripole). Hence elementary particles would correspond to pairs of monopoles and are accompanied by Kähler magnetic flux loop running along the two space-time sheets involved as well as fermionic strings connecting the monopole throats.

   There seems to be no specific need to assign string to the wormhole contact and if is a piece of deformed CP_2 type vacuum extremal this might not be even possible: the Kähler-Dirac gamma matrices would not span 2-D space in this case since the CP_2 projection is 4-D. Hence massless fermion propagators would be assigned only with the boundaries of string world sheets at Minkowskian regions of space-time surface. One could say that physical particles are bound states of massless fundamental fermions and the non-collinearity of their four-momenta can make them massive. Therefore the breaking of conformal invariance would be due to the bound state formation and this would also resolve the infrared divergence problems plaguing Grassmann twistor approach by introducing natural length scale assignable to the size of particles defined by the string like flux tube connecting the wormhole contacts.

   The bound states would form representations of super-conformal algebras so that stringy mass formula would emerge naturally. p-Adic mass calculations indeed assume conformal invariance in $CP2$ length scale assignable to wormhole contacts. Also the long flux tube strings contribute to the particle masses and would explain gauge boson masses.

5. The interaction vertices would correspond to the scattering of fermions at opposite wormhole throats. The natural guess is that the propagator is essentially the inverse of the scaling generator L_0 of conformal algebra. Non-locality suggests that one must product for the inverses of the super-generators G and its hermitian conjugate estimated at the two wormhole throats. There the diagrammatics would be combinations of that for QFT with massless fermions and string model diagrammatics. Topologically the vertices would be analogous to Feynman vertices: two 3-surfaces would fuse at vertices to form third. Stringy trouser diagrams would not have interpretation as decays of particle but as particle travelling two different paths.

6. Wormhole contacts represent fundamental interaction vertex pairs and propagators between them and one has stringy super-conformal invariance. Therefore there are excellent reasons to expect that the perturbation theory is free of divergences. Without stringy contributions for massive conformal excitations of wormhole contacts one would obtain the usual logarithmic UV divergences of massless gauge theories. The fact that physical particles are bound states of massless particles, gives good hopes of avoiding IR divergences of massless theories.

The figures **??**, **??**, `http://www.tgdtheory.fi/appfigures/elparticletgd.jpg` or fig. 6, tgdgraphs in the appendix of this book illustrate the relationship between TGD diagrammatics, QFT diagrammatics and stringy diagrammatics.

Chapter 3

The Recent Vision about Preferred Extremals and Solutions of the Modified Dirac Equation

3.1 Introduction

During years several approaches to what preferred extremals of Kähler action and solutions of the modified Dirac equation could be have been proposed and the challenge is to see whether at least some of these approaches are consistent with each other.

The notion of preferred extremal emerged when I still lived in positive energy ontology. In zero energy ontology (ZEO) situation changes since 3-surfaces are now unions of space-like 3-surfaces at the opposite boundaries of causal diamond (CD). If Kähler action were deterministic, the attribute "preferred" would become obsolete. One of the most important outcomes of non-determinism is quantum criticality realized as a conformal invariance acting as gauge symmetries. The transformations in question are Kac-Moody type symmetries respecting the light-likeness of partonic orbits identified as surfaces at which the signature of the induced metric changes from Minkowskian to Euclidian. The orbits can be grouped to conformal equivalence classes and their number n would define in a natural manner the value of the effective Planck constant $h_{eff} = n \times h$.

One might hope that in finite measurement resolution the attribute "preferred" would not be needed. Bohr orbitology in ZEO would mean that one has Bohr orbits connecting 3-surfaces at boundaries of CD and this would give strong correlations between these 3-surfaces. Not all of them could be connected. Despite these uncertainties, I will talk in the following about preferred extremals. This means no loss since what is known recently is known for extremals.

It is good to list various approaches first.

3.1.1 Construction of preferred extremals

There has been considerable progress in the understanding of both preferred extremals and Kähler-Dirac equation.

1. For preferred extremals the generalization of conformal invariance to 4-D situation is very attractive idea and leads to concrete conditions formally similar to those encountered in string model [K8]. In particular, Einstein's equations with cosmological constant would solve consistency conditions and field equations would reduce to a purely algebraic statements analogous to those appearing in equations for minimal surfaces if one assumes that space-time surface has Hermitian structure or its Minkowskian variant Hamilton-Jacobi structure (Appendix). The older approach based on basic heuristics for massless equations, on effective 3-dimensionality, weak form of electric magnetic duality, and Beltrami flows is also promising. An alternative approach is inspired by number theoretical considerations and identifies space-time surfaces as associative or co-associative sub-manifolds of octonionic imbedding space [K67].

The basic step of progress was the realization that the known extremals of Kähler action - certainly limiting cases of more general extremals - can be deformed to more general extremals having interpretation as preferred extremals.

(a) The generalization boils down to the condition that field equations reduce to the condition that the traces $Tr(TH^k)$ for the product of energy momentum tensor and second fundamental form vanish. In string models energy momentum tensor corresponds to metric and one obtains minimal surface equations. The equations reduce to purely algebraic conditions stating that T and H^k have no common components. Complex structure of string world sheet makes this possible.

Stringy conditions for metric stating $g_{zz} = g_{\overline{z}\overline{z}} = 0$ generalize. The condition that field equations reduce to $Tr(TH^k) = 0$ requires that the terms involving Kähler gauge current in field equations vanish. This is achieved if Einstein's equations hold true (one can consider also more general manners to satisfy the conditions). The conditions guaranteeing the vanishing of the trace in turn boil down to the existence of Hermitian structure in the case of Euclidian signature and to the existence of its analog - Hamilton-Jacobi structure - for Minkowskian signature (Appendix). These conditions state that certain components of the induced metric vanish in complex coordinates or Hamilton-Jacobi coordinates.

In string model the replacement of the imbedding space coordinate variables with quantized ones allows to interpret the conditions on metric as Virasoro conditions. In the recent case a generalization of classical Virasoro conditions to four-dimensional ones would be in question. An interesting question is whether quantization of these conditions could make sense also in TGD framework at least as a useful trick to deduce information about quantum states in WCW degrees of freedom.

The interpretation of the extended algebra as Yangian [A20] [B23] suggested previously [K75] to act as a generalization of conformal algebra in TGD Universe is attractive. There is also the conjecture that preferred extremals could be interpreted as quaternionic of co-quaternionic 4-surface of the octonionic imbedding space with octonionic representation of the gamma matrices defining the notion of tangent space quanternionicity.

3.1.2 Understanding Kähler-Dirac equation

There are several approaches for solving the modified Dirac (or Kähler-Dirac) equation.

(a) The most promising approach is discussed in this chapter. It assumes that the solutions are restricted on 2-D stringy world sheets and/or partonic 2-surfaces. This strange looking view is a rather natural consequence of both strong form of holography and of number theoretic vision, and also follows from the notion of finite measurement resolution having discretization at partonic 2-surfaces as a geometric correlate. Furthermore, the conditions stating that electric charge is well-defined for preferred extremals forces the localization of the modes to 2-D surfaces in the generic case. This also resolves the interpretational problems related to possibility of strong parity breaking effects since induce W fields and possibly also Z^0 field above weak scale, vahish at these surfaces.

(b) One expects that stringy approach based on 4-D generalization of conformal invariance or its 2-D variant at 2-D preferred surfaces should also allow to understand the modified Dirac equation. Conformal invariance indeed allows to write the solutions explicitly using formulas similar to encountered in string models. In accordance with the earlier conjecture, all modes of the modified Dirac operator generate badly broken super-symmetries.

(c) Covariantly constant right-handed neutrino certainly defines solutions de-localized inside entire space-time sheet. This need not be the case if right-handed neutrino is not covarianty constant since the non-vanishing CP_2 part for the induced gamma matrices mixes it with left-handed neutrino. For massless extremals (at least) the CP_2 part however vanishes and right-handed neutrino allows also massless holomorphic modes de-localized at entire space-time surface and the de-localization inside Euclidian region defining the line of generalized Feynman diagram is a good candidate for the right-handed neutrino generating the least broken super-symmetry.This super-symmetry seems however to differ from the ordinary one in that ν_R is expected to behave like a passive spectator in the scattering. Also for the left-handed neutrino solutions localized inside string world sheet the condition that coupling to right-handed neutrino vanishes is guaranteed if gamma matrices are either purely Minkowskian or CP_2 like inside the world sheet.

3.1.3 Measurement interaction term and boundary conditions

Quantum classical correspondence (QCC) requires a coupling between quantum and classical and this coupling should also give rise to a generalization of quantum measurement theory. The big question is how to realize this coupling.

(a) The proposal discussed in previous chapter was that the addition of a measurement interaction term to the modified Dirac action could do the job and solve a handful of problems of quantum TGD and unify various visions about the physics predicted by quantum TGD. This proposal implies QCC at the level of modified Dirac action and Kähler action. The simplest form of this term is completely analogous to algebraic form of Dirac action in M^4 but with integration measure $det(g_4)^{1/2}d^3x$ restricted to the 3-D surface in question.

(b) Another possibility consistent with the considerations of this chapter is that QCC is realized at the level of WCW Dirac operator and modified Dirac operator contains only interior term. I have indeed proposed that WCW spinor fields with given quantum charges in Cartan algebra are superpositions of space-time surfaces with same classical charges. A stronger form of QCC at the level of WCW would be that classical correlation functions for various geometric observables are identical with quantal correlation functions.

The boundary conditions for modified Dirac equation at space-like 3-surfaces are determined by the sum the analog of algebraic massless Dirac operator $p^k\gamma_k$ in M^4 coupled to the formal analog of Higgs field defined by the normal component Γ^n of the Kähler-Dirac gamma matrix. Higgs field is not in question. Rather the equation allows to formulate space-time correlate for stringy mass formula and also to understand how the ground state conformal weight can be negative half-integer as required by the p-adic mass calculations. At lightlike 3-surfaces Γ^n must vanish and the measurement interaction involving $p^k\gamma_k$ vanishes identically.

3.1.4 Progress in the understanding of super-conformal symmetries

The considerations in the sequel lead to a considerable progress in the understanding of super Virasoro representations for super-symplectic and super-Kac-Moody algebra. In particular, the proposal is that super-Kac-Moody currents assignable to string world sheets define duals of gauge potentials and their generalization for gravitons: in the approximation that gauge group is Abelian - motivated by the notion of finite measurement resolution - the exponents for the sum of KM charges would define non-integrable phase factors. One can also identify Yangian as the algebra generated by these charges. The approach allows also to understand the special role of the right handed neutrino in SUSY according to TGD. It must be however emphasized that also a weaker form of Einstein's equations can be considered solving the condition that the energy momentum tensor for Kähler action has vanishing divergence [K84] implying Einstein's equations with cosmological constant in general relativity. The weaker form involves several non-constant parameters analogous to cosmological constant.

The appendix of the book gives a summary about basic concepts of TGD with illustrations. There are concept maps about topics related to the contents of the chapter prepared using CMAP realized as html files. Links to all CMAP files can be found at `http:`

//www.tgdtheory.fi/cmaphtml.html [L20]. Pdf representation of same files serving as a kind of glossary can be found at http://www.tgdtheory.fi/tgdglossary.pdf [L21]. The topics relevant to this chapter are given by the following list.

- TGD as infinite-dimensional geometry [L47]
- WCW spinor fields [L53]
- KD equation [L30]
- Kaehler-Dirac action [L29]

3.2 About deformations of known extremals of Kähler action

I have done a considerable amount of speculative guesswork to identify what I have used to call preferred extremals of Kähler action. The difficulty is that the mathematical problem at hand is extremely non-linear and that I do not know about existing mathematical literature relevant to the situation. One must proceed by trying to guess the general constraints on the preferred extremals which look physically and mathematically plausible. The hope is that this net of constraints could eventually chrystallize to Eureka! Certainly the recent speculative picture involves also wrong guesses. The need to find explicit ansatz for the deformations of known extremals based on some common principles has become pressing. The following considerations represent an attempt to combine the existing information to achieve this.

3.2.1 What might be the common features of the deformations of known extremals

The dream is to discover the deformations of all known extremals by guessing what is common to all of them. One might hope that the following list summarizes at least some common features.

Effective three-dimensionality at the level of action

(a) Holography realized as effective 3-dimensionality also at the level of action requires that it reduces to 3-dimensional effective boundary terms. This is achieved if the contraction $j^\alpha A_\alpha$ vanishes. This is true if j^α vanishes or is light-like, or if it is proportional to instanton current in which case current conservation requires that CP_2 projection of the space-time surface is 3-dimensional. The first two options for j have a realization for known extremals. The status of the third option - proportionality to instanton current - has remained unclear.

(b) As I started to work again with the problem, I realized that instanton current could be replaced with a more general current $j = *B \wedge J$ or concretely: $j^\alpha = \epsilon^{\alpha\beta\gamma\delta} B_\beta J_{\gamma\delta}$, where B is vector field and CP_2 projection is 3-dimensional, which it must be in any case. The contractions of j appearing in field equations vanish automatically with this ansatz.

(c) Almost topological QFT property in turn requires the reduction of effective boundary terms to Chern-Simons terms: this is achieved by boundary conditions expressing weak form of electric magnetic duality. If one generalizes the weak form of electric-magnetic duality to $J = \Phi * J$ one has $B = d\Phi$ and j has a vanishing divergence for 3-D CP_2 projection. This is clearly a more general solution ansatz than the one based on proportionality of j with instanton current and would reduce the field equations in concise notation to $Tr(TH^k) = 0$.

(d) Any of the alternative properties of the Kähler current implies that the field equations reduce to $Tr(TH^k) = 0$, where T and H^k are shorthands for Maxwellian energy momentum tensor and second fundamental form and the product of tensors is obvious generalization of matrix product involving index contraction.

Could Einstein's equations emerge dynamically?

For j^α satisfying one of the three conditions, the field equations have the same form as the equations for minimal surfaces except that the metric g is replaced with Maxwell energy momentum tensor T.

(a) This raises the question about dynamical generation of small cosmological constant Λ: $T = \Lambda g$ would reduce equations to those for minimal surfaces. For $T = \Lambda g$ modified gamma matrices would reduce to induced gamma matrices and the modified Dirac operator would be proportional to ordinary Dirac operator defined by the induced gamma matrices. One can also consider weak form for $T = \Lambda g$ obtained by restricting the consideration to a sub-space of tangent space so that space-time surface is only "partially" minimal surface but this option is not so elegant although necessary for other than CP_2 type vacuum extremals.

(b) What is remarkable is that $T = \Lambda g$ implies that the divergence of T which in the general case equals to $j^\beta J^\alpha_\beta$ vanishes. This is guaranteed by one of the conditions for the Kähler current. Since also Einstein tensor has a vanishing divergence, one can ask whether the condition to $T = \kappa G + \Lambda g$ could the general condition. This would give Einstein's equations with cosmological term besides the generalization of the minimal surface equations. GRT would emerge dynamically from the non-linear Maxwell's theory although in slightly different sense as conjectured [K71]! Note that the expression for G involves also second derivatives of the imbedding space coordinates so that actually a partial differential equation is in question. If field equations reduce to purely algebraic ones, as the basic conjecture states, it is possible to have $Tr(GH^k) = 0$ and $Tr(gH^k) = 0$ separately so that also minimal surface equations would hold true.

What is amusing that the first guess for the action of TGD was curvature scalar. It gave analogs of Einstein's equations as a definition of conserved four-momentum currents. The recent proposal would give the analog of ordinary Einstein equations as a dynamical constraint relating Maxwellian energy momentum tensor to Einstein tensor and metric.

(c) Minimal surface property is physically extremely nice since field equations can be interpreted as a non-linear generalization of massless wave equation: something very natural for non-linear variant of Maxwell action. The theory would be also very "stringy" although the fundamental action would not be space-time volume. This can however hold true only for Euclidian signature. Note that for CP_2 type vacuum extremals Einstein tensor is proportional to metric so that for them the two options are equivalent. For their small deformations situation changes and it might happen that the presence of G is necessary. The GRT limit of TGD discussed in [K71] [L17] indeed suggests that CP_2 type solutions satisfy Einstein's equations with large cosmological constant and that the small observed value of the cosmological constant is due to averaging and small volume fraction of regions of Euclidian signature (lines of generalized Feynman diagrams).

(d) For massless extremals and their deformations $T = \Lambda g$ cannot hold true. The reason is that for massless extremals energy momentum tensor has component T^{vv} which actually quite essential for field equations since one has $H^k_{vv} = 0$. Hence for massless extremals and their deformations $T = \Lambda g$ cannot hold true if the induced metric has Hamilton-Jacobi structure meaning that g^{uu} and g^{vv} vanish. A more general relationship of form $T = \kappa G + \Lambda G$ can however be consistent with non-vanishing T^{vv} but require that deformation has at most 3-D CP_2 projection (CP_2 coordinates do not depend on v).

(e) The non-determinism of vacuum extremals suggest for their non-vacuum deformations a conflict with the conservation laws. In, also massless extremals are characterized by a non-determinism with respect to the light-like coordinate but like-likeness saves the situation. This suggests that the transformation of a properly chosen time coordinate of vacuum extremal to a light-like coordinate in the induced metric combined with Einstein's equations in the induced metric of the deformation could allow to handle the non-determinism.

Are complex structure of CP_2 and Hamilton-Jacobi structure of M^4 respected by the deformations?

The complex structure of CP_2 and Hamilton-Jacobi structure of M^4 could be central for the understanding of the preferred extremal property algebraically.

(a) There are reasons to believe that the Hermitian structure of the induced metric ((1,1) structure in complex coordinates) for the deformations of CP_2 type vacuum extremals could be crucial property of the preferred extremals. Also the presence of light-like direction is also an essential elements and 3-dimensionality of M^4 projection could be essential. Hence a good guess is that allowed deformations of CP_2 type vacuum extremals are such that (2,0) and (0,2) components the induced metric and/or of the energy momentum tensor vanish. This gives rise to the conditions implying Virasoro conditions in string models in quantization:

$$g_{\xi^i\xi^j} = 0 \ , \quad g_{\overline{\xi}^i\overline{\xi}^j} = 0 \ , \ i,j = 1,2 \ . \tag{3.2.1}$$

Holomorphisms of CP_2 preserve the complex structure and Virasoro conditions are expected to generalize to 4-dimensional conditions involving two complex coordinates. This means that the generators have two integer valued indices but otherwise obey an algebra very similar to the Virasoro algebra. Also the super-conformal variant of this algebra is expected to make sense.

These Virasoro conditions apply in the coordinate space for CP_2 type vacuum extremals. One expects similar conditions hold true also in field space, that is for M^4 coordinates.

(b) The integrable decomposition $M^4(m) = M^2(m)+E^2(m)$ of M^4 tangent space to longitudinal and transversal parts (non-physical and physical polarizations) - Hamilton-Jacobi structure- could be a very general property of preferred extremals and very natural since non-linear Maxwellian electrodynamics is in question. This decomposition led rather early to the introduction of the analog of complex structure in terms of what I called Hamilton-Jacobi coordinates $(u, v, w, \overline{w})$ for M^4. (u, v) defines a pair of light-like coordinates for the local longitudinal space $M^2(m)$ and $(w, \overline{w})$ complex coordinates for $E^2(m)$. The metric would not contain any cross terms between $M^2(m)$ and $E^2(m)$: $g_{uw} = g_{vw} = g_{u\overline{w}} = g_{v\overline{w}} = 0$.

A good guess is that the deformations of massless extremals respect this structure. This condition gives rise to the analog of the constraints leading to Virasoro conditions stating the vanishing of the non-allowed components of the induced metric. $g_{uu} = g_{vv} = g_{ww} = g_{\overline{w}\overline{w}} = g_{uw} = g_{vw} = g_{u\overline{w}} = g_{v\overline{w}} = 0$. Again the generators of the algebra would involve two integers and the structure is that of Virasoro algebra and also generalization to super algebra is expected to make sense. The moduli space of Hamilton-Jacobi structures would be part of the moduli space of the preferred extremals and analogous to the space of all possible choices of complex coordinates. The analogs of infinitesimal holomorphic transformations would preserve the modular parameters and give rise to a 4-dimensional Minkowskian analog of Virasoro algebra. The conformal algebra acting on CP_2 coordinates acts in field degrees of freedom for Minkowskian signature.

Field equations as purely algebraic conditions

If the proposed picture is correct, field equations would reduce basically to purely algebraically conditions stating that the Maxwellian energy momentum tensor has no common index pairs with the second fundamental form. For the deformations of CP_2 type vacuum extremals T is a complex tensor of type (1,1) and second fundamental form H^k a tensor of type (2,0) and (0,2) so that $Tr(TH^k) =$ is true. This requires that second light-like coordinate of M^4 is constant so that the M^4 projection is 3-dimensional. For Minkowskian signature of the induced metric Hamilton-Jacobi structure replaces conformal structure. Here the dependence of CP_2 coordinates on second light-like coordinate of $M^2(m)$ only plays a fundamental role. Note that now T^{vv} is non-vanishing (and light-like). This picture generalizes to the deformations of cosmic strings and even to the case of vacuum extremals.

3.2.2 What small deformations of CP_2 type vacuum extremals could be?

I was led to these arguments when I tried find preferred extremals of Kähler action, which would have 4-D CP_2 and M^4 projections - the Maxwell phase analogous to the solutions of Maxwell's equations that I conjectured long time ago. It however turned out that the dimensions of the projections can be $(D_{M^4} \leq 3, D_{CP_2} = 4)$ or $(D_{M^4} = 4, D_{CP_2} \leq 3)$. What happens is essentially breakdown of linear superposition so that locally one can have superposition of modes which have 4-D wave vectors in the same direction. This is actually very much like quantization of radiation field to photons now represented as separate space-time sheets and one can say that Maxwellian superposition corresponds to union of separate photonic space-time sheets in TGD.

Approximate linear superposition of fields is fundamental in standard physics framework and is replaced in TGD with a linear superposition of effects of classical fields on a test particle topologically condensed simultaneously to several space-time sheets. One can say that linear superposition is replaced with a disjoint union of space-time sheets. In the following I shall restrict the consideration to the deformations of CP_2 type vacuum extremals.

Solution ansatz

I proceed by the following arguments to the ansatz.

(a) Effective 3-dimensionality for action (holography) requires that action decomposes to vanishing $j^\alpha A_\alpha$ term + total divergence giving 3-D "boundary" terms. The first term certainly vanishes (giving effective 3-dimensionality) for

$$D_\beta J^{\alpha\beta} = j^\alpha = 0 \ .$$

Empty space Maxwell equations, something extremely natural. Also for the proposed GRT limit these equations are true.

(b) How to obtain empty space Maxwell equations $j^\alpha = 0$? The answer is simple: assume self duality or its slight modification:

$$J = *J$$

holding for CP_2 type vacuum extremals or a more general condition

$$J = k * J \ ,$$

In the simplest situation k is some constant not far from unity. * is Hodge dual involving 4-D permutation symbol. $k = constant$ requires that the determinant of the induced metric is apart from constant equal to that of CP_2 metric. It does not require that the induced metric is proportional to the CP_2 metric, which is not possible since M^4 contribution to metric has Minkowskian signature and cannot be therefore proportional to CP_2 metric.

One can consider also a more general situation in which k is scalar function as a generalization of the weak electric-magnetic duality. In this case the Kähler current is non-vanishing but divergenceless. This also guarantees the reduction to $Tr(TH^k) = 0$.

In this case however the proportionality of the metric determinant to that for CP_2 metric is not needed. This solution ansatz becomes therefore more general.

(c) Field equations reduce with these assumptions to equations differing from minimal surfaces equations only in that metric g is replaced by Maxwellian energy momentum tensor T. Schematically:

$$Tr(TH^k) = 0 \ ,$$

where T is the Maxwellian energy momentum tensor and H^k is the second fundamental form - asymmetric 2-tensor defined by covariant derivative of gradients of imbedding space coordinates.

How to satisfy the condition $Tr(TH^k) = 0$?

It would be nice to have minimal surface equations since they are the non-linear generalization of massless wave equations. It would be also nice to have the vanishing of the terms involving Kähler current in field equations as a consequence of this condition. Indeed, $T = \kappa G + \Lambda g$ implies this. In the case of CP_2 vacuum extremals one cannot distinguish between these options since CP_2 itself is constant curvature space with $G \propto g$. Furthermore, if G and g have similar tensor structure the algebraic field equations for G and g are satisfied separately so that one obtains minimal surface property also now. In the following minimal surface option is considered.

(a) The first opton is achieved if one has

$$T = \Lambda g \ .$$

Maxwell energy momentum tensor would be proportional to the metric! One would have dynamically generated cosmological constant! This begins to look really interesting since it appeared also at the proposed GRT limit of TGD [L17]. Note that here also non-constant value of Λ can be considered and would correspond to a situation in which k is scalar function: in this case the the determinant condition can be dropped and one obtains just the minimal surface equations.

(b) Very schematically and forgetting indices and being sloppy with signs, the expression for T reads as

$$T = JJ - g/4Tr(JJ) \ .$$

Note that the product of tensors is obtained by generalizing matrix product. This should be proportional to metric.

Self duality implies that $Tr(JJ)$ is just the instanton density and does not depend on metric and is constant.

For CP_2 type vacuum extremals one obtains

$$T = -g + g = 0 \ .$$

Cosmological constant would vanish in this case.

(c) Could it happen that for deformations a small value of cosmological constant is generated?

The condition would reduce to

$$JJ = (\Lambda - 1)g \ .$$

Λ must relate to the value of parameter k appearing in the generalized self-duality condition. For the most general ansatz Λ would not be constant anymore.

This would generalize the defining condition for Kähler form

$$JJ = -g \ \ (i^2 = -1 \ \ geometrically)$$

stating that the square of Kähler form is the negative of metric. The only modification would be that index raising is carried out by using the induced metric containing also M^4 contribution rather than CP_2 metric.

(d) Explicitly:

$$J_{\alpha\mu}J^{\mu}_{\ \beta} = (\Lambda - 1)g_{\alpha\beta} \ \ .$$

Cosmological constant would measure the breaking of Kähler structure. By writing $g = s + m$ and defining index raising of tensors using CP_2 metric and their product accordingly, this condition can be also written as

$$Jm = (\Lambda - 1)mJ \ \ .$$

If the parameter k is constant, the determinant of the induced metric must be proportional to the CP_2 metric. If k is scalar function, this condition can be dropped. Cosmological constant would not be constant anymore but the dependence on k would drop out from the field equations and one would hope of obtaining minimal surface equations also now. It however seems that the dimension of M^4 projection cannot be four. For 4-D M^4 projection the contribution of the M^2 part of the M^4 metric gives a non-holomorphic contribution to CP_2 metric and this spoils the field equations.

For $T = \kappa G + \Lambda g$ option the value of the cosmological constant is large - just as it is for the proposed GRT limit of TGD [K71] [L17]. The interpretation in this case is that the average value of cosmological constant is small since the portion of space-time volume containing generalized Feynman diagrams is very small.

More detailed ansatz for the deformations of CP_2 type vacuum extremals

One can develop the ansatz to a more detailed form. The most obvious guess is that the induced metric is apart from constant conformal factor the metric of CP_2. This would guarantee self-duality apart from constant factor and $j^\alpha = 0$. Metric would be in complex CP_2 coordinates tensor of type (1,1) whereas CP_2 Riemann connection would have only purely holomorphic or anti-holomorphic indices. Therefore CP_2 contributions in $Tr(TH^k)$ would vanish identically. M^4 degrees of freedom however bring in difficulty. The M^4 contribution to the induced metric should be proportional to CP_2 metric and this is impossible due to the different signatures. The M^4 contribution to the induced metric breaks its Kähler property but would preserve Hermitian structure.

A more realistic guess based on the attempt to construct deformations of CP_2 type vacuum extremals is following.

(a) Physical intuition suggests that M^4 coordinates can be chosen so that one has integrable decomposition to longitudinal degrees of freedom parametrized by two light-like coordinates u and v and to transversal polarization degrees of freedom parametrized by complex coordinate w and its conjugate. M^4 metric would reduce in these coordinates to a direct sum of longitudinal and transverse parts. I have called these coordinates Hamilton-Jacobi coordinates.

(b) w would be holomorphic function of CP_2 coordinates and therefore satisfy the analog of massless wave equation. This would give hopes about rather general solution ansatz. u and v cannot be holomorphic functions of CP_2 coordinates. Unless wither u or v is constant, the induced metric would receive contributions of type (2,0) and (0,2) coming from u and v which would break Kähler structure and complex structure. These contributions would give no-vanishing contribution to all minimal surface equations. Therefore either u or v is constant: the coordinate line for non-constant coordinate -say u- would be analogous to the M^4 projection of CP_2 type vacuum extremal.

(c) With these assumptions the induced metric would remain $(1,1)$ tensor and one might hope that $Tr(TH^k)$ contractions vanishes for all variables except u because the there are no common index pairs (this if non-vanishing Christoffel symbols for H involve only holomorphic or anti-holomorphic indices in CP_2 coordinates). For u one would obtain massless wave equation expressing the minimal surface property.

(d) If the value of k is constant the determinant of the induced metric must be proportional to the determinant of CP_2 metric. The induced metric would contain only the contribution from the transversal degrees of freedom besides CP_2 contribution. Minkowski contribution has however rank 2 as CP_2 tensor and cannot be proportional to CP_2 metric. It is however enough that its determinant is proportional to the determinant of CP_2 metric with constant proportionality coefficient. This condition gives an additional non-linear condition to the solution. One would have wave equation for u (also w and its conjugate satisfy massless wave equation) and determinant condition as an additional condition.

The determinant condition reduces by the linearity of determinant with respect to its rows to sum of conditions involved 0,1,2 rows replaced by the transversal M^4 contribution to metric given if M^4 metric decomposes to direct sum of longitudinal and transversal parts. Derivatives with respect to derivative with respect to particular CP_2 complex coordinate appear linearly in this expression they can depend on u via the dependence of transversal metric components on u. The challenge is to show that this equation has (or does not have) non-trivial solutions.

(e) If the value of k is scalar function the situation changes and one has only the minimal surface equations and Virasoro conditions.

What makes the ansatz attractive is that special solutions of Maxwell empty space equations are in question, equations reduces to non-linear generalizations of Euclidian massless wave equations, and possibly space-time dependent cosmological constant pops up dynamically. These properties are true also for the GRT limit of TGD [L17].

3.2.3 Hamilton-Jacobi conditions in Minkowskian signature

The maximally optimistic guess is that the basic properties of the deformations of CP_2 type vacuum extremals generalize to the deformations of other known extremals such as massless extremals, vacuum extremals with 2-D CP_2 projection which is Lagrangian manifold, and cosmic strings characterized by Minkowskian signature of the induced metric. These properties would be following.

(a) The recomposition of M^4 tangent space to longitudinal and transversal parts giving Hamilton-Jacobi structure. The longitudinal part has hypercomplex structure but the second light-like coordinate is constant: this plays a crucial role in guaranteeing the vanishing of contractions in $Tr(TH^k)$. It is the algebraic properties of g and T which are crucial. T can however have light-like component T^{vv}. For the deformations of CP_2 type vacuum extremals $(1,1)$ structure is enough and is guaranteed if second light-like coordinate of M^4 is constant whereas w is holomorphic function of CP_2 coordinates.

(b) What could happen in the case of massless extremals? Now one has 2-D CP_2 projection in the initial situation and CP_2 coordinates depend on light-like coordinate u and single real transversal coordinate. The generalization would be obvious: dependence on single light-like coordinate u and holomorphic dependence on w for complex CP_2 coordinates. The constraint is $T = \Lambda g$ cannot hold true since T^{vv} is non-vanishing (and light-like). This property restricted to transversal degrees of freedom could reduce the field equations to minimal surface equations in transversal degrees of freedom. The transversal part of energy momentum tensor would be proportional to metric and hence covariantly constant. Gauge current would remain light-like but would not be given by $j = *d\phi \wedge J$. $T = \kappa G + \Lambda g$ seems to define the attractive option.

It therefore seems that the essential ingredient could be the condition

$$T = \kappa G + \lambda g \ ,$$

which has structure (1,1) in both $M^2(m)$ and $E^2(m)$ degrees of freedom apart from the presence of T^{vv} component with deformations having no dependence on v. If the second fundamental form has (2,0)+(0,2) structure, the minimal surface equations are satisfied provided Kähler current satisfies on of the proposed three conditions and if G and g have similar tensor structure.

One can actually pose the conditions of metric as complete analogs of stringy constraints leading to Virasoro conditions in quantization to give

$$g_{uu} = 0 \ , \quad g_{vv} = 0 \ , \quad g_{ww} = 0 \ , \quad g_{\overline{w}\overline{w}} = 0 \ . \tag{3.2.2}$$

This brings in mind the generalization of Virasoro algebra to four-dimensional algebra for which an identification in terms of non-local Yangian symmetry has been proposed [K75]. The number of conditions is four and the same as the number of independent field equations. One can consider similar conditions also for the energy momentum tensor T but allowing non-vanishing component T^{vv} if deformations has no v-dependence. This would solve the field equations if the gauge current vanishes or is light-like. On this case the number of equations is 8. First order differential equations are in question and they can be also interpreted as conditions fixing the coordinates used since there is infinite number of manners to choose the Hamilton-Jacobi coordinates.

One can can try to apply the physical intuition about general solutions of field equations in the linear case by writing the solution as a superposition of left and right propagating solutions:

$$\xi^k = f^k_+(u,w) + f^k_+(v,w) \ . \tag{3.2.3}$$

This could guarantee that second fundamental form is of form (2,0)+(0,2) in both M^2 and E^2 part of the tangent space and these terms if $Tr(TH^k)$ vanish identically. The remaining terms involve contractions of T^{uw}, $T^{u\overline{w}}$ and T^{vw}, $T^{v\overline{w}}$ with second fundamental form. Also these terms should sum up to zero or vanish separately. Second fundamental form has components coming from f^k_+ and f^k_-

Second fundamental form H^k has as basic building bricks terms $\hat{H}^k$ given by

$$\hat{H}^k_{\alpha\beta} \ = \ \partial_\alpha\partial_\beta h^k + \left({k \atop l\ m}\right) \partial_\alpha h^l \partial_\beta h^m \ . \tag{3.2.4}$$

For the proposed ansatz the first terms give vanishing contribution to H^k_{uv}. The terms containing Christoffel symbols however give a non-vanishing contribution and one can allow only f^k_+ or f^k_- as in the case of massless extremals. This reduces the dimension of CP_2 projection to $D = 3$.

What about the condition for Kähler current? Kähler form has components of type $J_{w\overline{w}}$ whose contravariant counterpart gives rise to space-like current component. J_{uw} and $J_{u\overline{w}}$ give rise to light-like currents components. The condition would state that the $J^{w\overline{w}}$ is covariantly constant. Solutions would be characterized by a constant Kähler magnetic field. Also electric field is represent. The interpretation both radiation and magnetic flux tube makes sense.

3.2.4 Deformations of cosmic strings

In the physical applications it has been assumed that the thickening of cosmic strings to Kähler magnetic flux tubes takes place. One indeed expects that the proposed construction generalizes also to the case of cosmic strings having the decomposition $X^4 = X^2 \times Y^2 \subset M^4 \times CP_2$, where X^2 is minimal surface and Y^2 a complex homologically non-trivial sub-manifold of CP_2. Now the starting point structure is Hamilton-Jacobi structure for $M^2_m \times Y^2$ defining the coordinate space.

(a) The deformation should increase the dimension of either CP_2 or M^4 projection or both. How this thickening could take place? What comes in mind that the string orbits X^2 can be interpreted as a distribution of longitudinal spaces $M^2(x)$ so that for the deformation w coordinate becomes a holomorphic function of the natural Y^2 complex coordinate so that M^4 projection becomes 4-D but CP_2 projection remains 2-D. The new contribution to the X^2 part of the induced metric is vanishing and the contribution to the Y^2 part is of type $(1,1)$ and the the ansatz $T = \kappa G + \Lambda g$ might be needed as a generalization of the minimal surface equations The ratio of κ and G would be determined from the form of the Maxwellian energy momentum tensor and be fixed at the limit of undeformed cosmic strong to $T = (ag(Y^2) - bg(Y^2)$. The value of cosmological constant is now large, and overall consistency suggests that $T = \kappa G + \Lambda g$ is the correct option also for the CP_2 type vacuum extremals.

(b) One could also imagine that remaining CP_2 coordinates could depend on the complex coordinate of Y^2 so that also CP_2 projection would become 4-dimensional. The induced metric would receive holomorphic contributions in Y^2 part. As a matter fact, this option is already implied by the assumption that Y^2 is a complex surface of CP_2.

3.2.5 Deformations of vacuum extremals?

What about the deformations of vacuum extremals representable as maps from M^4 to CP_2?

(a) The basic challenge is the non-determinism of the vacuum extremals. One should perform the deformation so that conservation laws are satisfied. For massless extremals there is also non-determinism but it is associated with the light-like coordinate so that there are no problems with the conservation laws. This would suggest that a properly chosen time coordinate consistent with Hamilton-Jacobi decomposition becomes light-like coordinate in the induced metric. This poses a conditions on the induced metric.

(b) Physical intuition suggests that one cannot require $T = \Lambda g$ since this would mean that the rank of T is maximal whereas the original situation corresponds to the vanishing of T. For small deformations rank two for T looks more natural and one could think that T is proportional to a projection of metric to a 2-D subspace. The vision about the long length scale limit of TGD is that Einstein's equations are satisfied and this would suggest $T = kG$ or $T = \kappa G + \Lambda g$. The rank of T could be smaller than four for this ansatz and this conditions binds together the values of κ and G.

(c) These extremals have CP_2 projection which in the generic case is 2-D Lagrangian sub-manifold Y^2. Again one could assume Hamilton-Jacobi coordinates for X^4. For CP_2 one could assume Darboux coordinates (P_i, Q_i), $i = 1, 2$, in which one has $A = P_i dQ^i$, and that $Y^2 \subset CP_2$ corresponds to $Q_i = constant$. In principle P_i would depend on arbitrary manner on M^4 coordinates. It might be more convenient to use as coordinates (u, v) for M^2 and (P_1, P_2) for Y^2. This covers also the situation when M^4 projection is not 4-D. By its 2-dimensionality Y^2 allows always a complex structure defined by its induced metric: this complex structure is not consistent with the complex structure of CP_2 (Y^2 is not complex sub-manifold).

Using Hamilton-Jacobi coordinates the pre-image of a given point of Y^2 is a 2-dimensional sub-manifold X^2 of X^4 and defines also 2-D sub-manifold of M^4. The following picture suggests itself. The projection of X^2 to M^4 can be seen for a suitable choice of Hamilton-Jacobi coordinates as an analog of Lagrangian sub-manifold in M^4 that is as surface for which v and $Im(w)$ vary and u and $Re(w)$ are constant. X^2 would be obtained by allowing u and $Re(w)$ to vary: as a matter fact, (P_1, P_2) and $(u, Re(w))$ would be related to each other. The induced metric should be consistent with this picture. This would requires $g_{uRe(w)} = 0$.

For the deformations Q_1 and Q_2 would become non-constant and they should depend on the second light-like coordinate v only so that only g_{uu} and g_{uw} and $gu\overline{w}$ $g_{w,w}$ and $g_{\overline{w},\overline{w}}$ receive contributions which vanish. This would give rise to the analogs of Virasoro conditions guaranteeing that T is a tensor of form $(1,1)$ in both M^2 and E^2 indices and that there are no cross components in the induced metric. A more general formulation states that energy momentum tensor satisfies these conditions. The conditions on T might be equivalent with the conditions for g and G separately.

(d) Einstein's equations provide an attractive manner to achieve the vanishing of effective 3-dimensionality of the action. Einstein equations would be second order differential equations and the idea that a deformation of vacuum extremal is in question suggests that the dynamics associated with them is in directions transversal to Y^2 so that only the deformation is dictated partially by Einstein's equations.

(e) Lagrangian manifolds do not involve complex structure in any obvious manner. One could however ask whether the deformations could involve complex structure in a natural manner in CP_2 degrees of freedom so that the vanishing of g_{ww} would be guaranteed by holomorphy of CP_2 complex coordinate as function of w.

One should get the complex structure in some natural manner: in other words, the complex structure should relate to the geometry of CP_2 somehow. The complex coordinate defined by say $z = P_1 + iQ^1$ for the deformation suggests itself. This would suggest that at the limit when one puts $Q_1 = 0$ one obtains $P_1 = P_1(Re(w))$ for the vacuum extremals and the deformation could be seen as an analytic continuation of real function to region of complex plane. This is in spirit with the algebraic approach. The vanishing of Kähler current requires that the Kähler magnetic field is covariantly constant: $D_z J^{z\overline{z}} = 0$ and $D_{\overline{z}} J^{z\overline{z}} = 0$.

(f) One could consider the possibility that the resulting 3-D sub-manifold of CP_2 can be regarded as contact manifold with induced Kähler form non-vanishing in 2-D section with natural complex coordinates. The third coordinate variable- call it s- of the contact manifold and second coordinate of its transversal section would depend on time space-time coordinates for vacuum extremals. The coordinate associated with the transversal section would be continued to a complex coordinate which is holomorphic function of w and u.

(g) The resulting thickened magnetic flux tubes could be seen as another representation of Kähler magnetic flux tubes: at this time as deformations of vacuum flux tubes rather than cosmic strings. For this ansatz it is however difficult to imagine deformations carrying Kähler electric field.

3.2.6 About the interpretation of the generalized conformal algebras

The long-standing challenge has been finding of the direct connection between the super-conformal symmetries assumed in the construction of the geometry of the "world of classical worlds" (WCW) and possible conformal symmetries of field equations. 4-dimensionality and Minkowskian signature have been the basic problems. The recent construction provides new insights to this problem.

(a) In the case of string models the quantization of the Fourier coefficients of coordinate variables of the target space gives rise to Kac-Moody type algebra and Virasoro algebra generators are quadratic in these. Also now Kac-Moody type algebra is expected. If one were to perform a quantization of the coefficients in Laurents series for complex CP_2 coordinates, one would obtain interpretation in terms of $su(3) = u(2) + t$ decomposition, where t corresponds to CP_3: the oscillator operators would correspond to generators in t

and their commutator would give generators in $u(2)$. SU(3)/SU(2) coset representation for Kac-Moody algebra would be in question. Kac-Moody algebra would be associated with the generators in both M^4 and CP_2 degrees of freedom. This kind of Kac-Moody algebra appears in quantum TGD.

(b) The constraints on induced metric imply a very close resemblance with string models and a generalization of Virasoro algebra emerges. An interesting question is how the two algebras acting on coordinate and field degrees of freedom relate to the super-conformal algebras defined by the symplectic group of $\delta M^4_+ \times CP_2$ acting on space-like 3-surfaces at boundaries of CD and to the Kac-Moody algebras acting on light-like 3-surfaces. It has been conjectured that these algebras allow a continuation to the interior of space-time surface made possible by its slicing by 2-surfaces parametrized by 2-surfaces. The proposed construction indeed provides this kind of slicings in both M^4 and CP_2 factor.

(c) In the recent case, the algebras defined by the Fourier coefficients of field variables would be Kac-Moody algebras. Virasoro algebra acting on preferred coordinates would be expressed in terms of the Kac-Moody algebra in the standard Sugawara construction applied in string models. The algebra acting on field space would be analogous to the conformal algebra assignable to the symplectic algebra so that also symplectic algebra is present. Stringy pragmatist could imagine quantization of symplectic algebra by replacing CP_2 coordinates in the expressions of Hamiltonians with oscillator operators. This description would be counterpart for the construction of spinor harmonics in WCW and might provide some useful insights.

(d) For given type of space-time surface either CP_2 or M^4 corresponds to Kac-Moody algebra but not both. From the point of view of quantum TGD it looks as that something were missing. An analogous problem was encountered at GRT limit of TGD [L17]. When Euclidian space-time regions are allowed Einstein-Maxwell action is able to mimic standard model with a surprising accuracy but there is a problem: one obtains either color charges or M^4 charges but not both. Perhaps it is not enough to consider either CP_2 type vacuum extremal or its exterior but both to describe particle: this would give the direct product of the Minkowskian and Euclidian algebras acting on tensor product. This does not however seem to be consistent with the idea that the two descriptions are duality related (the analog of T-duality).

3.3 Under what conditions electric charge is conserved for the modified Dirac equation?

One might think that talking about the conservation of electric charge at 21st century is a waste of time. In TGD framework this is certainly not the case.

(a) In quantum field theories there are two manners to define em charge: as electric flux over 2-D surface sufficiently far from the source region or in the case of spinor field quantum mechanically as combination of fermion number and vectorial isospin. The latter definition is quantum mechanically more appropriate.

(b) There is however a problem. In standard approach to gauge theory Dirac equation in presence of charged classical gauge fields does not conserve electric charge as quantum number: electron is transformed to neutrino and vice versa. Quantization solves the problem since the non-conservation can be interpreted in terms of emission of gauge bosons. In TGD framework this does not work since one does not have path integral quantization anymore. Preferred extremals carry classical gauge fields and the question whether em charge is conserved arises. Heuristic picture suggests that em charge must be conserved.

It seems that one should pose the well-definedness of spinorial em charge as an additional condition. Well-definedness of em charge is not the only problem. How to avoid large parity breaking effects due to classical Z^0 fields? How to avoid the problems due to the fact that color rotations induced vielbein rotation of weak fields? Does this require that classical weak fields vanish in the regions where the modes of induced spinor fields are non-vanishing?

This condition might be one of the conditions defining what it is to be a preferred extremal/solution of Kähler Dirac equation. It is not however trivial whether this kind of additional condition can be posed unless it follows automatically from the recent formulation for Kähler action and Kähler Dirac action. The common answer to these questions is restriction of the modes of induced spinor field to 2-D string world sheets (and possibly also partonic 2-surfaces) such that the induced weak fields vanish. This makes string/parton picture part of TGD. The vanishing of classical weak fields has also number theoretic interpretation: space-time surfaces would have quaternionic (hyper-complex) tangent space and the 2-surfaces carrying spinor fields complex (hyper-complex) tangent space.

3.3.1 Conservation of em charge for Kähler Dirac equation

What does the conservation of em charge imply in the case of the modified Dirac equation? The obvious guess that the em charged part of the modified Dirac operator must annihilate the solutions, turns out to be correct as the following argument demonstrates.

(a) Em charge as coupling matrix can be defined as a linear combination $Q = aI + bI_3$, $I_3 = J_{kl}\Sigma^{kl}$, where I is unit matrix and I_3 vectorial isospin matrix, J_{kl} is the Kähler form of CP_2, Σ^{kl} denotes sigma matrices, and a and b are numerical constants different for quarks and leptons. Q is covariantly constant in $M^4 \times CP_2$ and its covariant derivatives at space-time surface are also well-defined and vanish.

(b) The modes of the modified Dirac equation should be eigen modes of Q. This is the case if the modified Dirac operator D commutes with Q. The covariant constancy of Q can be used to derive the condition

$$\begin{aligned} [D,Q]\,\Psi &= D_1\Psi = 0 \ , \\ D &= \hat{\Gamma}^\mu D_\mu \ , \ D_1 = [D,Q] = \hat{\Gamma}_1^\mu D_\mu \ , \ \hat{\Gamma}_1^\mu = \left[\hat{\Gamma}^\mu, Q\right] \ . \end{aligned} \quad (3.3.1)$$

Covariant constancy of J is absolutely essential: without it the resulting conditions would not be so simple.

It is easy to find that also $[D_1,Q]\Psi = 0$ and its higher iterates $[D_n,Q]\Psi = 0$, $D_n = [D_{n-1},Q]$ must be true. The solutions of the modified Dirac equation would have an additional symmetry.

(c) The commutator $D_1 = [D,Q]$ reduces to a sum of terms involving the commutators of the vectorial isospin $I_3 = J_{kl}\Sigma^{kl}$ with the CP_2 part of the gamma matrices:

$$D_1 = [Q,D] = [I_3,\Gamma_r]\partial_\mu s^r T^{\alpha\mu} D_\alpha \ . \quad (3.3.2)$$

In standard complex coordinates in which $U(2)$ acts linearly the complexified gamma matrices can be chosen to be eigenstates of vectorial isospin. Only the charged flat space complexified gamma matrices Γ^A denoted by Γ^+ and Γ^- possessing charges +1 and -1 contribute to the right hand side. Therefore the additional Dirac equation $D_1\Psi = 0$ states

$$\begin{aligned} D_1\Psi &= [Q,D]\Psi = I_3(A)e_{Ar}\Gamma^A\partial_\mu s^r T^{\alpha\mu} D_\alpha\Psi \\ &= (e_{+r}\Gamma^+ - e_{-r}\Gamma^-)\partial_\mu s^r T^{\alpha\mu} D_\alpha\Psi = 0 \ . \end{aligned} \quad (3.3.3)$$

The next condition is

$$D_2\Psi = [Q,D]\Psi = (e_{+r}\Gamma^+ + e_{-r}\Gamma^-)\partial_\mu s^r T^{\alpha\mu} D_\alpha\Psi = 0 \ . \quad (3.3.4)$$

Only the relative sign of the two terms has changed. The remaining conditions give nothing new.

(d) These equations imply two separate equations for the two charged gamma matrices

$$\begin{aligned} D_+\Psi &= T^{\alpha}_{+}\Gamma^{+}D_{\alpha}\Psi = 0 \ , \\ D_-\Psi &= T^{\alpha}_{-}\Gamma^{-}D_{\alpha}\Psi = 0 \ , \\ T^{\alpha}_{\pm} &= e_{\pm r}\partial_{\mu}s^{r}T^{\alpha\mu} \ . \end{aligned} \quad (3.3.5)$$

These conditions state what one might have expected: the charged part of the modified Dirac operator annihilates separately the solutions. The reason is that the classical W fields are proportional to $e_{r\pm}$.

The above equations can be generalized to define a decomposition of the energy momentum tensor to charged and neutral components in terms of vierbein projections. The equations state that the analogs of the modified Dirac equation defined by charged components of the energy momentum tensor are satisfied separately.

(e) In complex coordinates one expects that the two equations are complex conjugates of each other for Euclidian signature. For the Minkowskian signature an analogous condition should hold true. The dynamics enters the game in an essential manner: whether the equations can be satisfied depends on the coefficients a and b in the expression $T = aG + bg$ implied by Einstein's equations in turn guaranteeing that the solution ansatz generalizing minimal surface solutions holds true [K8].

(f) As a result one obtains three separate Dirac equations corresponding to the the neutral part $D_0\Psi = 0$ and charged parts $D_{\pm}\Psi = 0$ of the modified Dirac equation. By acting on the equations with these Dirac operators one obtains also that the commutators $[D_+, D_-]$, $[D_0, D_{\pm}]$ and also higher commutators obtained from these annihilate the induced spinor field model. Therefore entire -possibly- infinite-dimensional algebra would annihilate the induced spinor fields. In string model the counterpart of Dirac equation when quantized gives rise to Super-Virasoro conditions. This analogy would suggest that modified Dirac equation gives rise to the analog of Super-Virasoro conditions in 4-D case. But what the higher conditions mean? Could they relate to the proposed generalization to Yangian algebra? Obviously these conditions resemble structurally Virasoro conditions $L_n|phys\rangle = 0$ and their supersymmetric generalizations, and might indeed correspond to a generalization of these conditions just as the field equations for preferred extremals could correspond to the Virasoro conditions if one takes seriously the analogy with the quantized string.

What could this additional symmetry mean from the point of view of the solutions of the modified Dirac equation? The field equations for the preferred extremals of Kähler action reduce to purely algebraic conditions in the same manner as the field equations for the minimal surfaces in string model. Could this happen also for the modified Dirac equation and could the condition on charged part of the Dirac operator help to achieve this?

This argument was very general and one can ask for simple manners to realize these conditions. Obviously the vanishing of classical W fields in the region where the spinor mode is non-vanishing defines this kind of condition.

3.3.2 About the solutions of Kähler Dirac equation for known extremals

To gain perpective consider first Dirac equation in in H. Quite generally, one can construct the solutions of the ordinary Dirac equation in H from covariantly constant right-handed neutrino spinor playing the role of fermionic vacuum annihilated by the second half of complexified gamma matrices. Dirac equation reduces to Laplace equation for a scalar function and solution can be constructed from this "vacuum" by multiplying with the spherical harmonics of CP_2 and applying Dirac operator [K34]. Similar construction works quite generally thanks to the existence of covariantly constant right handed neutrino spinor. Spinor harmonics of CP_2 are only replaced with those of space-time surface possessing either hermitian structure of Hamilton-Jacobi structure (corresponding to Euclidian and Minkowskian signatures of the induced metric [K8, K80]). What is remarkable is that these solutions possess well-defined em charge although classical W boson fields are present.

This in sense that H d'Alembertian commutes with em charge matrix defined as a linear combination of unit matrix and the covariantly constant matrix $J^{kl}\Sigma_{kl}$ since the commutators of the covariant derivatives give constant Ricci scalar and $J^{kl}\Sigma_{kl}$ term to the d'Alembertian besides scalar d'Alembertian commuting with em charge. Dirac operator itself does not commute with em charge matrix since gamma matrices not commute with em charge matrix.

Consider now Kähler Dirac operator. The square of Kähler Dirac operator contains commutator of covariant derivatives which contains contraction $[\Gamma^\mu, \Gamma^\nu] F^{weak}_{\mu\nu}$ which is quadratic in sigma matrices of $M^4 \times CP_2$ and does not reduce to a constant term commuting which em charge matrix. Therefore additional condition is required even if one is satisfies with the commutativity of d'Alembertian with em charge. Stronger condition would be commutativity with the Kähler Dirac operator and this will be considered in the following.

To see what happens one must consider space-time regions with Minkowskian and Euclidian signature. What will be assumed is the existence of Hamilton-Jacobi structure [K8] meaning complex structure in Euclidian signature and hyper-complex plus complex structure in Minkowskian signature. The goal is to get insights about what the condition that spinor modes have a well-defined em charge eigenvalue requires. Or more concretely: is the localization at string world sheets guaranteeing well-defined value of em charge predicted by Kähler Dirac operator or must one introduce this condition separately? One can also ask whether this condition reduces to commutativity/co-commutativity in number theoretic vision.

(a) CP_2 type vacuum extremals serve as a convenient test case for the Euclidian signature. In this case the modified Dirac equation reduces to the massless ordinary Dirac equation in CP_2 allowing only covariantly constant right-handed neutrino as solution. Only part of CP_2 so that one give up the constraint that the solution is defined in the entire CP_2. In this case holomorphic solution ansatz obtained by assuming that solutions depend on the coordinates ξ^i, $i = 1, 2$ but not on their conjugates and that the gamma matrices $\Gamma^{\bar{i}}$, $i = 1, 2$, annihilate the solutions, works. The solutions ansatz and its conjugate are of exactly the same form as in case string models where one considers string world sheets instead of CP_2 region.

The solutions are not restricted to 2-D string world sheets and it is not clear whether one can assign to them a well-defined em charge in any sense. Note that for massless Dirac equation in H one obtains all CP_2 harmonics as solutions, and it is possible to talk about em charge of the solution although solution itself is not restricted to 2-D surface of CP_2.

(b) For massless extremals and a very wide class of solutions produced by Hamilton-Jacobi structure - perhaps all solutions representable locally as graphs for map $M^4 \to CP_2$ - canonical momentum densities are light-like and solutions are hyper-holomorphic in the coordinates associated with with string world sheet and annihilated by the conjugate gamma and arbitrary functions in transversal coordinates. This allows localization to string world sheets. The localization is now strictly dynamical and implied by the properties of Kähler Dirac operator.

(c) For string like objects one obtains massless Dirac equation in $X^2 \times Y^2 \subset M^4 \times Y^2$, Y^2 a complex 2-surface in CP_2. Homologically trivial geodesic sphere corresponds to the simplest choice for Y^2. Modified Dirac operator reduces to a sum of massless Dirac operators associated with X^2 and Y^2. The most general solutions would have Y^2 mass. Holomorphic solutions reduces to product of hyper-holomorphic and holomorphic solutions and massless 2-D Dirac equation is satisfied in both factors.

For instance, for S^2 a geodesic sphere and $X^2 = M^2$ one obtains M^2 massivation with mass squared spectrum given by Laplace operator for S^2. Conformal and hyper-conformal symmetries are lost, and one might argue that this is quite not what one wants. One must be however resist the temptation to make too hasty conclusions since the massivation of string like objects is expected to take place. The question is whether it takes place already at the level of fundamental spinor fields or only at the level of elementary particles constructed as many-fermion states of them as twistor Grassmann approach assuming massless M^4 propagators for the fundamental fermions strongly suggests [K58].

(d) For vacuum extremals the Kähler Dirac operator vanishes identically so that it does not make sense to speak about solutions.

What can one conclude from these observations?

(a) The localization of solutions to 2-D string world sheets follows from Kähler Dirac equation only for the Minkowskian regions representable as graphs of map $M^4 \to CP_2$ locally. For string like objects and deformations of CP_2 type vacuum extremals this is not expected to take place.

(b) It is not clear whether one can speak about well-defined em charge for the holomorphic spinors annihilated by the conjugate gamma matrices or their conjugates. As noticed, for imbedding space spinor harmonics this is however possible.

(c) Strong form of conformal symmetry and the condition that em charge is well-defined for the nodes suggests that the localization at 2-D surfaces at which the charged parts of induced electroweak gauge fields vanish must be assumed as an additional condition. Number theoretic vision would suggest that these surfaces correspond to 2-D commutative or co-commutative surfaces. The string world sheets inside space-time surfaces would not emerge from theory but would be defined as basic geometric objects.

    This kind of condition would also allow duals of string worlds sheets as partonic 2-surfaces identified number theoretically as co-commutative surfaces. Commutativity and co-commutativity would become essential elements of the number theoretical vision.

(d) The localization of solutions of the modified Dirac action at string world sheets and partonic 2-surfaces as a constraint would mean induction procedure for Kähler-Dirac matrices from SX^4 to X^2 - that is projection. The resulting em neutral gamma matrices would correspond to tangent vectors of the string world sheet. The vanishing of the projections of charged parts of energy momentum currents would define these surfaces. The conditions would apply both in Minkowskian and Euclidian regions. An alternative interpretation would be number theoretical: these surface would be commutative or co-commutative.

3.3.3 Concrete realization of the conditions guaranteeing well-defined em charge

Well-definedness of the em charge is the fundamental condiiton on spinor modes. Physical intuition suggests that also classical Z^0 field should vanish - at least in scales longer than weak scale. Above the condition guaranteeing vanishing of em charge has been discussed at very general level. It has however turned out that one can understand situation by simply posing the simplest condition that one can imagine: the vanishing of classical W and possibly also Z^0 fields inducing mixing of different charge states.

(a) Induced W fields mean that the modes of Kähler-Dirac equation do not in general have well-defined em charge. The problem disappears if the induced W gauge fields vanish. This does not yet guarantee that couplings to classical gauge fields are physical in long scales. Also classical Z^0 field should vanish so that the couplings would be purely vectorial. Vectoriality might be true in long enough scales only. If W and Z^0 fields vanish in all scales then electroweak forces are due to the exchanges of corresponding gauge bosons described as string like objects in TGD and represent non-trivial space-time geometry and topology at microscopic scale.

(b) The conditions solve also another long-standing interpretational problem. Color rotations induce rotations in electroweak-holonomy group so that the vanishing of all induced weak fields also guarantees that color rotations do not spoil the property of spinor modes to be eigenstates of em charge.

One can study the conditions quite concretely by using the formulas for the components of spinor curvature [L1] (`http://www.tgdtheory.fi/public_html/pdfpool/append.pdf`).

(a) The representation of the covariantly constant curvature tensor is given by

$$\begin{array}{llllll} R_{01} & = & e^0\wedge e^1 - e^2\wedge e^3 \ , & R_{23} & = & e^0\wedge e^1 - e^2\wedge e^3 \ , \\ R_{02} & = & e^0\wedge e^2 - e^3\wedge e^1 \ , & R_{31} & = & -e^0\wedge e^2 + e^3\wedge e^1 \ , \\ R_{03} & = & 4e^0\wedge e^3 + 2e^1\wedge e^2 \ , & R_{12} & = & 2e^0\wedge e^3 + 4e^1\wedge e^2 \ . \end{array} \quad (3.3.6)$$

$R_{01} = R_{23}$ and $R_{03} = -R_{31}$ combine to form purely left handed classical W boson fields and Z^0 field corresponds to $Z^0 = 2R_{03}$.
Kähler form is given by

$$J = 2(e^0\wedge e^3 + e^1\wedge e^2) \ . \quad (3.3.7)$$

(b) The vanishing of classical weak fields is guaranteed by the conditions

$$\begin{array}{c} e^0\wedge e^1 - e^2\wedge e^3 = 0 \ , \\ e^0\wedge e^2 - e^3\wedge e^1 \ , \\ 4e^0\wedge e^3 + 2e^1\wedge e^2 \ . \end{array} \quad (3.3.8)$$

(c) There are many manners to satisfy these conditions. For instance, the condition $e^1 = a\times e^0$ and $e^2 = -a\times e^3$ with arbitrary a which can depend on position guarantees the vanishing of classical W fields. The CP_2 projection of the tangent space of the region carrying the spinor mode must be 2-D.
Also classical Z^0 vanishes if $a^2 = 2$ holds true. This guarantees that the couplings of induced gauge potential are purely vectorial. One can consider other alternaties. For instance, one could require that only classical Z^0 field or induced Kähler form is non-vanishing and deduce similar condition.

(d) The vanishing of the weak part of induced gauge field implies that the CP_2 projection of the region carrying spinor mode is 2-D. Therefore the condition that the modes of induced spinor field are restricted to 2-surfaces carrying no weak fields sheets guarantees well-definedness of em charge and vanishing of classical weak couplings. This condition does not imply string world sheets in the general case since the CP_2 projection of the space-time sheet can be 2-D.

How string world sheets could emerge?

(a) Additional consistency condition to neutrality of string world sheets is that Kähler-Dirac gamma matrices have no components orthogonal to the 2-surface in question. Hence various fermionic would flow along string world sheet.

(b) If the Kähler-Dirac gamma matrices at string world sheet are expressible in terms of two non-vanishing gamma matrices parallel to string world sheet and sheet and thus define an integrable distribution of tangent vectors, this is achieved. What is important that modified gamma matrices can indeed span lower than 4-D space and often do so as already described. Induced gamma matrices defined always 4-D space so that the restriction of the modes to string world sheets is not possible.

(c) String models suggest that string world sheets are minimal surfaces of space-time surface or of imbedding space but it might not be necessary to pose this condition separately.

In the proposed scenario string world sheets emerge rather than being postulated from beginning.

(a) The vanishing conditions for induced weak fields allow also 4-D spinor modes if they are true for entire spatime surface. This is true if the space-time surface has 2-D projection. One can expect that the space-time surface has foliation by string world sheets and the general solution of K-D equation is continuous superposition of the 2-D modes in this case and discrete one in the generic case.

(b) If the CP_2 projection of space-time surface is homologically non-trivial geodesic sphere S^2, the field equations reduce to those in $M^4 \times S^2$ since the second fundamental form for S^2 is vanishing. It is possible to have geodesic sphere for which induced gauge field has only em component?

(c) If the CP_2 projection is complex manifold as it is for string like objects, the vanishing of weak fields might be also achieved.

(d) Does the phase of cosmic strings assumed to dominate primordial cosmology correspond to this phase with no classical weak fields? During radiation dominated phase 4-D string like objects would transform to string world sheets.Kind of dimensional transmutation would occur.

Right-handed neutrino has exceptional role in K-D action.

(a) Electroweak gauge potentials do not couple to ν_R at all. Therefore the vanishing of W fields is un-necessary if the induced gamma matrices do not mix right handed neutrino with left-handed one. This is guaranteed if M^4 and CP_2 parts of Kähler-Dirac operator annihilate separately right-handed neutrino spinor mode. Also ν_R modes can be interpreted as continuous superpositions of 2-D modes and this allows to define overlap integrals for them and induced spinor fields needed to define WCW gamma matrices and super-generators.

(b) For covariantly constant right-handed neutrino mode defining a generator of super-symmetries is certainly a solution of K-D. Whether more general solutions of K-D exist remains to be checked out.

3.3.4 Connection with number theoretic vision?

The interesting potential connection of the Hamilton-Jacobi vision to the number theoretic vision about field equations has been already mentioned.

(a) The vision that associativity/co-associativity defines the dynamics of space-time surfaces boils down to $M^8 - H$ duality stating that space-time surfaces can be regarded as associative/co-associative surfaces either in M^8 or H [**?**]. Associativity reduces to hyper-quaternionicity implying that that the tangent/normal space of space-time surface at each point contains preferred sub-space $M^2(x) \subset M^8$ and these sub-spaces forma an integrable distribution. An analogous condition is involved with the definition of Hamilton-Jacobi structure.

(b) The octonionic representation of the tangent space of M^8 and H effectively replaces $SO(7,1)$ as tangent space group with its octonionic analog obtained by the replacement of sigma matrices with their octonionic counterparts defined by anti-commutators of gamma matrices. By non-associativity the resulting algebra is not ordinary Lie-algebra and exponentiates to a non-associative analog of Lie group. The original wrong belief was that the reduction takes place to the group G_2 of octonionic automorphisms acting as a subgroup of $SO(7)$. One can ask whether the conditions on the charged part of energy momentum tensor could relate to the reduction of $SO(7,1)$

(c) What puts bells ringing is that the modified Dirac equation for the octonionic representation of gamma matrices allows the conservation of electromagnetic charge in the proposed sense. The reason is that the left handed sigma matrices (W charges are left-handed) in the octonionic representation of gamma matrices vanish identically! What remains are vectorial=right-handed em and Z^0 charge which becomes proportional to em charge since its left-handed part vanishes. All spinor modes have a well-defined em charge in the octonionic sense defined by replacing imbedding space spinor locally by its octonionic variant? Maybe this could explain why H spinor modes can have well-defined em charge contrary to the naive expectations.

(d) The non-associativity of the octonionic spinors is however a problem. Even non-commutativity poses problems - also at space-time level if one assumes quaternion-real analyticity for the spinor modes. Could one assume commutativity or co-commutativity for the induced spinor modes? This would mean restriction to associative or co-associative 2-surfaces and (hyper-)holomorphic depends on its (hyper-)complex coordinate. The outcome would be a localization to a hyper-commutative of commutative 2-surface, string world sheet or partonic 2-surface.

(e) These conditions could also be interpreted by saying that for the Kähler Dirac operator the octonionic induced spinors assumed to be commutative/co-commutative are equivalent with ordinary induced spinors. The well-definedness of em charge for ordinary spinors would correspond to commutativity/co-commutativity for octonionic spinors. Even the Dirac equations based on induced and modified gamma matrices could be equivalent since it is essentially holomorphy which matters.

To sum up, these considerations inspire to ask whether the associativity/co-associativity of the space-time surface is equivalent with the reduction of the field equations to stringy field equations stating that certain components of the induced metric in complex/Hamilton-Jacobi coordinates vanish in turn guaranteeing that field equations reduce to algebraic identifies following from the fact that energy momentum tensor and second fundamental form have no common components? Commutativity/co-commutativity would characterize fermionic dynamics and would have physical representation as possibility to have em charge eigenspinors. This should be the case if one requires that the two solution ansätze are equivalent.

3.4 Preferred extremals and solutions of the modified Dirac equation and super-conformal symmetries

The previous considerations concerning super-conformal symmetries and space-time SUSY have been based on general arguments. The new vision about preferred extremals and modified Dirac equation [K80] however leads to a detailed understanding of super-conformal symmetries at the level of field equations and is bound to modify the existing vision about super-conformal symmetries. One important discovery is that Einstein's equations imply the vanishing of terms proportional to Kähler current in field equations for preferred extremals and Equivalence Principle at the classical level could be realized automatically in all scales in contrast to the earlier belief. This obviously must have implications to the general vision about Super-Virasoro representations and one must be ready to modify the existing picture based on the assumption that quantum version of Equivalence Principle is realized in terms coset representations.

The very special role of right handed neutrino is also bound to have profound implications. A further important outcome is the identification of gauge potentials as duals of Kac-Moody currents at the boundaries of string world sheets: quantum gauge potentials are defined only where they are needed that is the curves defining the non-integrable phase factors. This gives also rise to the realization of the conjecture Yangian in terms of the Kac-Moody charges and commutators in accordance with the earlier conjecture.

3.4.1 Super-conformal symmetries

It is good to summarize first the basic ideas about Super-Virasoro representations. TGD allows two kinds of super-conformal symmetries.

(a) The first super-conformal symmetry is associated with $\delta M^4_\pm \times CP_2$ and corresponds to symplectic symmetries of $\delta M^4_\pm \times CP_2$. The reason for extension of conformal symmetries is metric 2-dimensionality of the light-like boundary $\delta M^4_\pm$ defining upper/lower boundary of causal diamond (CD). This super-conformal symmetry is something new and corresponds to replacing finite-dimensional Lie-group G for Kac-Moody symmetry with infinite-dimensional symplectic group. The light-like radial coordinate of $\delta M^4_\pm$ takes the role of the real part of complex coordinate z for ordinary conformal symmetry. Together with complex coordinate of S^2 it defines 3-D restriction of Hamilton-Jacobi variant of 4-D super-conformal symmetries. One can continue the conformal symmetries from light-cone boundary to CD by forming a slicing by parallel copies of $\delta M^4_\pm$. There are two possible slicings corresponding to the choices δM^4_+ and δM^4_- assignable to the upper and lower boundaries of CD. These two choices correspond to two arrows of geometric time for the basis of zero energy states in ZEO.

(b) Super-symplectic degrees of freedom determine the electroweak and color quantum numbers of elementary particles. Bosonic emergence implies that ground states assignable to partonic 2-surfaces correspond to partial waves in $\delta M^4_\pm$ and one obtains color partial waves in particular. These partial waves correspond to the solutions for the Dirac equation in imbedding space and the correlation between color and electroweak quantum numbers is not quite correct. Super-Kac-Moody generators give the compensating color for massless states obtained from tachyonic ground states guaranteeing that standard correlation is obtained. Super-symplectic degrees are therefore directly visible in particle spectrum. One can say that at the point-like limit the WCW spinors reduce to tensor products of imbedding space spinors assignable to the center of mass degrees of freedom for the partonic 2-surfaces defining wormhole throats.

I have proposed a physical interpretation of super-symplectic vibrational degrees of freedom in terms of degrees of freedom assignable to non-perturbative QCD. These degrees of freedom would be responsible for most of the baryon masses but their theoretical understanding is lacking in QCD framework.

(c) The second super-conformal symmetry is assigned light-like 3-surfaces and to the isometries and holonomies of the imbedding space and is analogous to the super-Kac-Moody symmetry of string models. Kac-Moody symmetries could be assigned to the light-like deformations of light-like 3-surfaces. Isometries give tensor factor $E^2 \times SU(3)$ and holonomies factor $SU(2)_L \times U(1)$. Altogether one has 5 tensor factors to super-conformal algebra. That the number is just five is essential for the success p-adic mass calculations [K40, K34].

The construction of solutions of the modified Dirac equation suggests strongly that the fermionic representation of the Super-Kac-Moody algebra can be assigned as conserved charges associated with the space-like braid strands at both the 3-D space-like ends of space-time surfaces and with the light-like (or space-like with a small deformation) associated with the light-like 3-surfaces. The extension to Yangian algebra involving higher multi-linears of super-Kac Moody generators is also highly suggestive. These charges would be non-local and assignable to several wormhole contacts simultaneously. The ends of braids would correspond points of partonic 2-surfaces defining a discretization of the partonic 2-surface having interpretation in terms of finite measurement resolution.

These symmetries would correspond to electroweak and strong gauge fields and to gravitation. The duals of the currents giving rise to Kac-Moody charges would define the counterparts of gauge potentials and the conserved Kac-Moody charges would define the counterparts of non-integrable phase factors in gauge theories. The higher Yangian charges would define generalization of non-integrable phase factors. This would suggest a rather direct connection with the twistorial program for calculating the scattering amplitudes implies also by zero energy ontology.

Quantization recipes have worked in the case of super-string models and one can ask whether the application of quantization to the coefficients of powers of complex coordinates or Hamilton-Jacobi coordinates could lead to the understanding of the 4-D variants of the conformal symmetries and give detailed information about the representations of the Kac-Moody algebra too.

3.4.2 What is the role of the right-handed neutrino?

A highly interesting aspect of Super-Kac-Moody symmetry is the special role of right handed neutrino.

(a) Only right handed neutrino allows besides the modes restricted to 2-D surfaces also the 4D modes de-localized to the entire space-time surface. The first ones are holomorphic functions of single coordinate and the latter ones holomorphic functions of two complex/Hamilton-Jacobi coordinates. Only ν_R has the full $D = 4$ counterpart of the conformal symmetry and the localization to 2-surfaces has interpretation as super-conformal symmetry breaking halving the number of super-conformal generators.

(b) This forces to ask for the meaning of super-partners. Are super-partners obtained by adding ν_R neutrino localized at partonic 2-surface or de-localized to entire space-time surface or its Euclidian or Minkowskian region accompanying particle identified as wormhole throat? Only the Euclidian option allows to assign right handed neutrino to a unique partonic 2-surface. For the Minkowskian regions the assignment is to many particle state defined by the partonic 2-surfaces associated with the 3-surface. Hence for spartners the 4-D right-handed neutrino must be associated with the 4-D Euclidian line of the generalized Feynman diagram.

(c) The orthogonality of the localized and de-localized right handed neutrino modes requires that 2-D modes correspond to higher color partial waves at the level of imbedding space. If color octet is in question, the 2-D right handed neutrino as the candidate for the generator of standard SUSY would combine with the left handed neutrino to form a massive neutrino. If 2-D massive neutrino acts as a generator of super-symmetries, it is is in the same role as badly broken super-symmeries generated by other 2-D modes of the induced spinor field (SUSY with rather large value of $\mathcal{N}$) and one can argue that the counterpart of standard SUSY cannot correspond to this kind of super-symmetries. The right-handed neutrinos de-localized inside the lines of generalized Feynman diagrams, could generate $\mathcal{N} = 2$ variant of the standard SUSY.

How particle and right handed neutrino are bound together?

Ordinary SUSY means that apart from kinematical spin factors sparticles and particles behave identically with respect to standard model interactions. These spin factors would allow to distinguish between particles and sparticles. But is this the case now?

(a) One can argue that 2-D particle and 4-D right-handed neutrino behave like independent entities, and because ν_R has no standard model couplings this entire structure behaves like a particle rather than sparticle with respect to standard model interactions: the kinematical spin dependent factors would be absent.

(b) The question is also about the internal structure of the sparticle. How the four-momentum is divided between the ν_R and and 2-D fermion. If ν_R carries a negligible portion of four-momentum, the four-momentum carried by the particle part of sparticle is same as that carried by particle for given four-momentum so that the distinctions are only kinematical for the ordinary view about sparticle and trivial for the view suggested by the 4-D character of ν_R.

Could sparticle character become manifest in the ordinary scattering of sparticle?

(a) If ν_R behaves as an independent unit not bound to the particle, it would continue in the original direction as particle scatters: sparticle would decay to particle and right-handed neutrino. If ν_R carries a non-negligible energy the scattering could be detected via a missing energy. If not, then the decay could be detected by the interactions revealing the presence of ν_R. ν_R can have only gravitational interactions. What these gravitational interactions are is not however quite clear since the proposed identification of gravitational gauge potentials is as duals of Kac-Moody currents analogous to gauge potentials located at the boundaries of string world sheets. Does this mean that 4-D right-handed neutrino has no quantal gravitational interactions? Does internal consistency require ν_R to have a vanishing gravitational and inertial masses and does this mean that this particle carries only spin?

(b) The cautious conclusion would be following: if de-localized ν_R and parton are uncorrelated particle and sparticle cannot be distinguished experimentally and one might perhaps understand the failure to detect standard SUSY at LHC. Note however that the 2-D fermionic oscillator algebra defines badly broken large $\mathcal{N}$ SUSY containing also massive (longitudinal momentum square is non-vanishing) neutrino modes as generators.

Taking a closer look on sparticles

It is good to take a closer look at the de-localized right handed neutrino modes.

(a) At imbedding space level that is in cm mass degrees of freedom they correspond to covariantly constant CP_2 spinors carrying light-like momentum which for causal diamond could be discretized. For non-vanishing momentum one can speak about helicity having opposite sign for ν_R and $\overline{\nu}_R$. For vanishing four-momentum the situation is delicate since only spin remains and Majorana like behavior is suggestive. Unless one has momentum continuum, this mode might be important and generate additional SUSY resembling standard $\mathcal{N}=1$ SUSY.

(b) At space-time level the solutions of modified Dirac equation are holomorphic or anti-holomorphic.

  i. For non-constant holomorphic modes these characteristics correlate naturally with fermion number and helicity of ν_R . One can assign creation/annihilation operator to these two kinds of modes and the sign of fermion number correlates with the sign of helicity.

  ii. The covariantly constant mode is naturally assignable to the covariantly constant neutrino spinor of imbedding space. To the two helicities one can assign also oscillator operators $\{a_\pm, a_\pm^\dagger\}$. The effective Majorana property is expressed in terms of non-orthogonality of ν_R and and $\overline{\nu}_R$ translated to the the non-vanishing of the anti-commutator $\{a_+^\dagger, a_-\} = \{a_-^\dagger, a_+\} = 1$. The reduction of the rank of the 4×4 matrix defined by anti-commutators to two expresses the fact that the number of degrees of freedom has halved. $a_+^\dagger = a_-$ realizes the conditions and implies that one has only $\mathcal{N}=1$ SUSY multiplet since the state containing both ν_R and $\overline{\nu}_R$ is same as that containing no right handed neutrinos.

  iii. One can wonder whether this SUSY is masked totally by the fact that sparticles with all possible conformal weights n for induced spinor field are possible and the branching ratio to $n=0$ channel is small. If momentum continuum is present, the zero momentum mode might be equivalent to nothing.

What can happen in spin degrees of freedom in super-symmetric interaction vertices if one accepts this interpretation? As already noticed, this depends solely on what one assumes about the correlation of the four-momenta of particle and ν_R.

(a) For SUSY generated by covariantly constant ν_R and $\overline{\nu}_R$ there is no neutrino four-momentum involved so that only spin matters. One cannot speak about the change of direction for ν_R. In the scattering of sparticle the direction of particle changes and introduces different spin quantization axes. ν_R retains its spin and in new system it is superposition of two spin projections. The presence of both helicities requires that the transformation $\nu_R \to \overline{\nu}_R$ happens with an amplitude determined purely kinematically by spin rotation matrices. This is consistent with fermion number conservation modulo 2. $\mathcal{N}=1$ SUSY based on Majorana spinors is highly suggestive.

(b) For SUSY generated by non-constant holomorphic and anti-holomorphic modes carrying fermion number the behavior in the scattering is different. Suppose that the sparticle does not split to particle moving in the new direction and ν_R moving in the original direction so that also ν_R or $\overline{\nu}_R$ carrying some massless fraction of four-momentum changes its direction of motion. One can form the spin projections with respect to the new spin axis but must drop the projection which does not conserve fermion number. Therefore the kinematics at the vertices is different. Hence $\mathcal{N}=2$ SUSY with fermion number conservation is suggestive when the momentum directions of particle and ν_R are completely correlated.

(c) Since right-handed neutrino has no standard model couplings, p-adic thermodynamics for 4-D right-handed neutrino must correspond to a very low p-adic temperature $T=1/n$. This implies that the excitations with non-vanishing conformal weights are effectively absent and one would have $\mathcal{N}=1$ SUSY effectively.

The simplest assumption is that particle and sparticle correspond to the same p-adic mass scale and have degenerate masses: it is difficult to imagine any good reason for why the p-adic mass scales should differ. This should have been observed -say in decay widths of weak bosons - unless the spartners correspond to large $\hbar$ phase and therefore to dark matter. Note that for the badly broken 2-D N=2 SUSY in fermionic sector this kind of almost degeneracy cannot be excluded and I have considered an explanation for the mysterious X and Y mesons in terms of this degeneracy [K37].

Why space-time SUSY is not possible in TGD framework?

LHC suggests that one does not have $\mathcal{N}=1$ SUSY in standard sense. Why one cannot have standard space-time SUSY in TGD framework. Let us begin by listing all arguments popping in mind.

(a) Could covariantly constant ν_R represents a gauge degree of freedom? This is plausible since the corresponding fermion current is non-vanishing.

(b) The original argument for absence of space-time SUSY years ago was indirect: $M^4\times CP_2$ does not allow Majorana spinors so that $\mathcal{N}=1$ SUSY is excluded.

(c) One can however consider $\mathcal{N}=2$ SUSY by including both helicities possible for covariantly constant ν_R. For ν_R the four-momentum vanishes so that one cannot distinguish the modes assigned to the creation operator and its conjugate via complex conjugation of the spinor. Rather, one oscillator operator and its conjugate correspond to the two different helicities of right-handed neutrino with respect to the direction determined by the momentum of the particle. The spinors can be chosen to be real in this basis. This indeed gives rise to an irreducible representation of spin 1/2 SUSY algebra with right-handed neutrino creation operator acting as a ladder operator. This is however $\mathcal{N}=1$ algebra and right-handed neutrino in this particular basis behaves effectively like Majorana spinor. One can argue that the system is mathematically inconsistent. By choosing the spin projection axis differently the spinor basis becomes complex. In the new basis one would have $\mathcal{N}=2$, which however reduces to $\mathcal{N}=1$ in the real basis.

(d) Or could it be that fermion and sfermion do exist but cannot be related by SUSY? In standard SUSY fermions and sfermions forming irreducible representations of super Poincare algebra are combined to components of superfield very much like finite-dimensional representations of Lorentz group are combined to those of Poincare. In TGD framework ν_R generates in space-time interior generalization of 2-D super-conformal symmetry but covarianlty constant ν_R cannot give rise to space-time SUSY.

This would be very natural since right-handed neutrinos do not have any electroweak interactions and are are de-localized into the interior of the space-time surface unlike other particles localized at 2-surfaces. It is difficult to imagine how fermion and ν_R could behave as a single coherent unit reflecting itself in the characteristic spin and momentum dependence of vertices implied by SUSY. Rather, it would seem that fermion and sfermion should behave identically with respect to electroweak interactions.

The third argument looks rather convincing and can be developed to a precise argument.

(a) If sfermion is to represent elementary bosons, the products of fermionic oscillator operators with the oscillator operators assignable to the covariantly constant right handed neutrinos must define might-be bosonic oscillator operators as $b_n = a_n a$ and $b_n^\dagger = a_n^\dagger a^\dagger$ One can calculate the commutator for the product of operators. If fermionic oscillator operators commute, so do the corresponding bosonic operators. The commutator $[b_n, b_n^\dagger]$ is however proportional to occupation number for ν_R in $\mathcal{N} = 1$ SUSY representation and vanishes for the second state of the representation. Therefore $\mathcal{N} = 1$ SUSY is a pure gauge symmetry.

(b) One can however have both irreducible representations of SUSY: for them either fermion or sfermion has a non-vanishing norm. One would have both fermions and sfermions but they would not belong to the same SUSY multiplet, and one cannot expect SUSY symmetries of 3-particle vertices.

(c) For instance, γFF vertex is closely related to $\gamma \tilde{F}\tilde{\overline{F}}$ in standard SUSY. Now one expects this vertex to decompose to a product of $\gamma F\overline{F}$ vertex and amplitude for the creation of $\nu_R \tilde{\nu}_R$ from vacuum so that the characteristic momentum and spin dependent factors distinguishing between the couplings of photon to scalar and and fermion are absent. Both states behave like fermions. The amplitude for the creation of $\nu_R \tilde{\nu}_R$ from vacuum is naturally equal to unity as an occupation number operator by crossing symmetry. The presence of right-handed neutrinos would be invisible if this picture is correct. Whether this invisible label can have some consequences is not quite clear: one could argue that the decay rates of weak bosons to fermion pairs are doubled unless one introduces $1/\sqrt{2}$ factors to couplings.

Where the sfermions might make themselves visible are loops. What loops are? Consider boson line first. Boson line is replaced with a sum of two contributions corresponding to ordinary contribution with fermion and anti-fermion at opposite throats and second contribution with fermion and anti-fermion accompanied by right-handed neutrino ν_R and its antiparticle which now has opposite helicity to ν_R. The loop for ν_R decomposes to four pieces since also the propagation from wormhole throat to the opposite wormhole throat must be taken into account. Each of the four propagators equals to $a^\dagger_{1/2} a^\dagger_{-1/2}$ or its hermitian conjugate. The product of these is slashed between vacuum states and anti-commutations give imaginary unit per propagator giving $i^4 = 1$. The two contributions are therefore identical and the scaling $g \to g/\sqrt{2}$ for coupling constants guarantees that sfermions do not affect the scattering amplitudes at all. The argument is identical for the internal fermion lines.

3.4.3 WCW geometry and super-conformal symmetries

The vision about the geometry of WCW has been roughly the following and the recent steps of progress induce to it only small modifications if any.

(a) Kähler geometry is forced by the condition that hermitian conjugation allows geometrization. Kähler function is given by the Kähler action coming from space-time regions with Euclidian signature of the induced metric identifiable as lines of generalized Feynman diagrams. Minkowskian regions give imaginary contribution identifiable as the analog of Morse function and implying interference effects and stationary phase approximation. The vision about quantum TGD as almost topological QFT inspires the proposal that Kähler action reduces to 3-D terms reducing to Chern-Simons terms by the weak form of electric-magnetic duality. The recent proposal for preferred extremals is consistent with this property realizing also holography implied by general coordinate invariance.

Strong form of general coordinate invariance implying effective 2-dimensionality in turn suggests that Kähler action is expressible in terms of areas of partonic 2-surfaces and string world sheets.

(b) The complexified gamma matrices of WCW come as hermitian conjugate pairs and anti-commute to the Kähler metric of WCW. Also bosonic generators of symplectic transformations of $\delta M^4_\pm \times CP_2$ a assumed to act as isometries of WCW geometry can be complexified and appear as similar pairs. The action of isometry generators coincides with that of symplectic generators at partonic 2-surfaces and string world sheets but elsewhere inside the space-time surface it is expected to be deformed from the symplectic action. The super-conformal transformations of $\delta M^4_\pm \times CP_2$ acting on the light-like radial coordinate of $\delta M^4_\pm$ act as gauge symmetries of the geometry meaning that the corresponding WCW vector fields have zero norm.

(c) WCW geometry has also zero modes which by definition do not contribute to WCW metric expect possibly by the dependence of the elements of WCW metric on zero modes through a conformal factor. In particular, induced CP_2 Kähler form and its analog for sphere $r_M = constant$ of light cone boundary are symplectic invariants, and one can define an infinite number of zero modes as invariants defined by Kähler fluxes over partonic 2-surfaces and string world sheets. This requires however the slicing of CD parallel copies of δM^4_+ or δM^4_-. The physical interpretation of these non-quantum fluctuating degrees of freedom is as classical variables necessary for the interpretation of quantum measurement theory. Classical variable would metaphorically correspond the position of the pointer of the measurement instrument.

(d) The construction receives a strong philosophical inspiration from the geometry of loop spaces. Loop spaces allow a unique Kähler geometry with maximal isometry group identifiable as Kac-Moody group. The reason is that otherwise Riemann connection does not exist. The only problem is that curvature scalar diverges since the Riemann tensor is by constant curvature property proportional to the metric. In 3-D case one would have union of constant curvature spaces labelled by zero modes and the situation is expected to be even more restrictive. The conjecture indeed is that WCW geometry exists only for $H = M^4 \times CP_2$: infinite-D Kähler geometric existence and therefore physics would be unique. One can also hope that Ricci scalar is finite and therefore zero by the constant curvature property so that Einstein's equations are satisfied.

(e) WCW Hamiltonians determined the isometry currents and WCW metric is given in terms of the anti-commutators of the Killing vector fields associated with symplectic isometry currents. The WCW Hamiltonians generating symplectic isometries correspond to the Hamiltonians spanning the symplectic group of $\delta M^4_\pm \times CP_2$. One can say that the space of quantum fluctuating degrees of freedom is this symplectic group of $\delta M^4_\pm \times CP_2$ or its subgroup or coset space: this must have very deep implications for the structure of the quantum TGD.

(f) Zero energy ontology brings in additional delicacies. Basic objects are now unions of partonic 2-surfaces at the ends of CD. Also string world sheets would naturally contribute. One can generalize the expressions for the isometry generators in a straightforward manner by requiring that given isometry restricts to a symplectic transformation at partonic 2-surfaces and string world sheets.

(g) One could criticize the effective metric 2-dimensionality forced by general consistency arguments as something non-physical. The Hamiltonians are expressed using only the data at partonic 2-surfaces: this includes also 4-D tangent space data via the weak form of electric-magnetic duality so that one has only effective 2-dimensionality. Obviously WCW geometry must have large gauge symmetries besides zero modes. The super-conformal symmetries indeed represent gauge symmetries of this kind. Effective 2-dimensionality realizing strong form of holography in turn is induced by the strong form of general coordinate invariance. Light-like 3-surfaces at which the signature of the induced metric changes must be equivalent with the 3-D space-like ends of space-time surfaces at the light-boundaries of space-time surfaces as far as WCW geometry is considered. This requires that the data from their 2-D intersections defining partonic

2-surfaces should dictate the WCW geometry. Note however that Super-Kac-Moody charges giving information about the interiors of 3-surfaces appear in the construction of the physical states.

What is the role of the right handed neutrino in this construction?

(a) In the construction of components of WCW metric as anti-commutators of super-generators only the covariantly constant right-handed neutrino appears in the super-generators analogous to super-Kac-Moody generators. All holomorphic modes of right handed neutrino characterized by two integers could in principle contribute to the WCW gamma matrices identified as fermionic super-symplectic generators anti-commuting to the metric. At the space-like ends of space-time surface the holomorphic generators would restrict to symplectic generators since the radial light-like coordinate r_M identified and complex coordinate of CP_2 allowing identification as restrictions of two complex coordinates or Hamilton-Jacobi coordinates to light-like boundary.

(b) The non-covariantly constant modes could also correspond to purely super-conformal gauge degrees of freedom. Originally the restriction to right-handed neutrino looked somewhat un-satisfactory but the recent view about Super-Kac-Moody symmetries makes its special role rather natural. One could say that WCW geometry possesses the maximal $D = 4$ supersymmetry.

(c) One can of course ask whether the Super-Kac-Moody generators assignable to the isometries of H and expressible as conserved charges associated with the boundaries of string world sheets could contribute to the WCW geometry via the anti-commutators. This option cannot be excluded but in this case the interpretation in terms of Hamiltonians is not obvious.

3.4.4 The relationship between inertial gravitational masses

The relationship between inertial and gravitational masses and Equivalence Principle have been on of the longstanding problems in TGD. Not surprisingly, the realization how GRT space-time relates to the many-sheeted space-time of TGD finally allowed to solve the problem.

ZEO and non-conservation of Poincare charges in Poincare invariant theory of gravitation

In positive energy ontology the Poincare invarance of TGD is in sharpt contrast with the fact that GRT based cosmology predicts non-conservation of Poincare charges (as a matter fact, the definition of Poincare charges is very questionable for general solutions of field equations).

In zero energy ontology (ZEO) all conserved (that is Noether-) charges of the Universe vanish identically and their densities should vanish in scales below the scale defining the scale for observations and assignable to causal diamond (CD). This observation allows to imagine a ways out of what seems to be a conflict of Poincare invariance with cosmological facts.

ZEO would explain the local non-conservation of average energies and other conserved quantum numbers in terms of the contributions of sub-CDs analogous to quantum fluctuations. Classical gravitation should have a thermodynamical description if this interpretation is correct. The average values of the quantum numbers assignable to a space-time sheet would depend on the size of CD and possibly also its location in M^4. If the temporal distance between the tips of CD is interpreted as a quantized variant of cosmic time, the non-conservation of energy-momentum defined in this manner follows. One can say that conservation laws hold only true in given scale defined by the largest CD involved.

Equivalence Principle at quantum level

The interpretation of EP at quantum level has developed slowly and the recent view is that it reduces to quantum classical correspondence meaning that the classical charges of Kähler action can be identified with eigen values of quantal charges associated with Kähler-Dirac action.

(a) At quantum level I have proposed coset representations for the pair of super-symplectic algebras assignable to the light-like boundaries of CD and the Super Kac-Moody algebra assignable to the light-like 3-surfaces defining the orbits of partonic 2-surfaces as realization of EP. For coset representation the differences of super-conformal generators would annihilate the physical states so that one can argue that the corresponding four-momenta are identical. One could even say that one obtains coset representation for the "vibrational" parts of the super-conformal algebras in question. It is now clear that this idea does not work. Note however that coset representations occur naturally for the subalgebras of symplectic algebra and Super Kac-Moody algebra and are naturally induced by finite measurement resolution.

(b) The most recent view (2014) about understanding how EP emerges in TGD is described in [K71] and relies heavily on superconformal invariance and a detailed realisation of ZEO at quantum level. In this approach EP corresponds to quantum classical correspondence (QCC): four-momentum identified as classical conserved Noether charge for space-time sheets associated with Käbler action is identical with quantal four-momentum assignable to the representations of super-symplectic and super Kac-Moody algebras as in string models and having a realisation in ZEO in terms of wave functions in the space of causal diamonds (CDs).

(c) The latest realization is that the eigenvalues of quantal four-momentum can be identified as eigenvalues of the four-momentum operator assignable to the modified Dirac equation. This realisation seems to be consistent with the p-adic mass calculations requiring that the super-conformal algebra acts in the tensor product of 5 tensor factors.

Equivalence Principle at classical level

How Einstein's equations and General Relativity in long length scales emerges from TGD has been a long-standing interpretational problem of TGD.

The first proposal making sense even when one does not assume ZEO is that vacuum extremals are only approximate representations of the physical situation and that small fluctuations around them give rise to an inertial four-momentum identifiable as gravitational four-momentum identifiable in terms of Einstein tensor. EP would hold true in the sense that the average gravitational four-momentum would be determined by the Einstein tensor assignable to the vacuum extremal. This interpretation does not however take into account the many-sheeted character of TGD spacetime and is therefore questionable.

The resolution of the problem came from the realization that GRT is only an effective theory obtained by endowing M^4 with effective metric.

(a) The replacement of superposition of fields with superposition of their effects means replacing superposition of fields with the set-theoretic union of space-time surfaces. Particle experiences sum of the effects caused by the classical fields at the space-time sheets (see fig. `http://www.tgdtheory.fi/appfigures/fieldsuperpose.jpg` or fig. 11 in the appendix of this book).

(b) This is true also for the classical gravitational field defined by the deviation from flat Minkowski metric instandard M^4 coordinates for the space-time sheets. One can define effective metric as sum of M^4 metric and deviations. This effective metric would correspond to that of General Relativity. This resolves long standing issues relating to the interpretation of TGD.

(c) Einstein's equations could hold true for the effective metric. They are motivated by the underlying Poincare invariance which cannot be realized as global conservation laws for the effective metric. The conjecture vanishing of divergence of Khler energy momentum tensor can be seen as the microscopic justification for the claim that Einstein's equations hold true for the effective space-time.

(d) The breaking of Poincare invariance could have interpretation as effective breaking in zero energy ontology (ZEO), in which various conserved charges are length dependent and defined separately for each causal diamond (CD).

One can of course consider the possibility that Einstein's equations generalize for preferred extremals of Kähbler action. This would actually represent at space-time level the notion of QCC rather than realise QCC interpreted as EP. The condition that the energy momentum tensor for Kähler action has vanishing covariant divergence would be satisfied in GRT if Einstein's equations with cosmological term hold true. This is the case also now but one can consider also more general solutions in which one has two cosmological constants which are not genuine constants anymore [K84].

An interesting question is whether inertial-gravitational duality generalizes to the case of color gauge charges so that color gauge fluxes would correspond to "gravitational" color charges and the charges defined by the conserved currents associated with color isometries would define "inertial" color charges. Since the induced color fields are proportional to color Hamiltonians multiplied by Kähler form they vanish identically for vacuum extremals in accordance with "gravitational" color confinement.

3.4.5 Constraints from p-adic mass calculations and ZEO

A further important physical input comes from p-adic thermodynamics forming a core element of p-adic mass calculations.

(a) The first thing that one can get worried about relates to the extension of conformal symmetries. If the conformal symmetries generalize to $D = 4$, how can one take seriously the results of p-adic mass calculations based on 2-D conformal invariance? There is no reason to worry. The reduction of the conformal invariance to 2-D one for the preferred extremals takes care of this problem. This however requires that the fermionic contributions assignable to string world sheets and/or partonic 2-surfaces - Super- Kac-Moody contributions - should dictate the elementary particle masses. For hadrons also symplectic contributions should be present. This is a valuable hint in attempts to identify the mathematical structure in more detail.

(b) ZEO suggests that all particles, even virtual ones correspond to massless wormhole throats carrying fermions. As a consequence, twistor approach would work and the kinematical constraints to vertices would allow the cancellation of divergences. This would suggest that the p-adic thermal expectation value is for the longitudinal M^2 momentum squared (the definition of CD selects $M^1 \subset M^2 \subset M^4$ as also does number theoretic vision). Also propagator would be determined by M^2 momentum. Lorentz invariance would be obtained by integration of the moduli for CD including also Lorentz boosts of CD.

(c) In the original approach one allows states with arbitrary large values of L_0 as physical states. Usually one would require that L_0 annihilates the states. In the calculations however mass squared was assumed to be proportional L_0 apart from vacuum contribution. This is a questionable assumption. ZEO suggests that total mass squared vanishes and that one can decompose mass squared to a sum of longitudinal and transversal parts. If one can do the same decomposition to longitudinal and transverse parts also for the Super Virasoro algebra then one can calculate longitudinal mass squared as a p-adic thermal expectation in the transversal super-Virasoro algebra and only states with $L_0 = 0$ would contribute and one would have conformal invariance in the standard sense.

(d) In the original approach the assumption motivated by Lorentz invariance has been that mass squared is replaced with conformal weight in thermodynamics, and that one first calculates the thermal average of the conformal weight and then equates it with mass squared. This assumption is somewhat ad hoc. ZEO however suggests an alternative interpretation in which one has zero energy states for which longitudinal mass squared of positive energy state derive from p-adic thermodynamics. Thermodynamics - or rather, its square root - would become part of quantum theory in ZEO. M-matrix is indeed product of hermitian square root of density matrix multiplied by unitary S-matrix and defines the entanglement coefficients between positive and negative energy parts of zero energy state.

(e) The crucial constraint is that the number of super-conformal tensor factors is $N = 5$: this suggests that thermodynamics applied in Super-Kac-Moody degrees of freedom assignable to string world sheets is enough, when one is interested in the masses of fermions and gauge bosons. Super-symplectic degrees of freedom can also contribute and determine the dominant contribution to baryon masses. Should also this contribution obey p-adic thermodynamics in the case when it is present? Or does the very fact that this contribution need not be present mean that it is not thermal? The symplectic contribution should correspond to hadronic p-adic length prime rather the one assignable to (say) u quark. Hadronic p-adic mass squared and partonic p-adic mass squared cannot be summed since primes are different. If one accepts the basic rules [K43], longitudinal energy and momentum are additive as indeed assumed in perturbative QCD.

(f) Calculations work if the vacuum expectation value of the mass squared must be assumed to be tachyonic. There are two options depending on whether one whether p-adic thermodynamics gives total mass squared or longitudinal mass squared.

   i. One could argue that the total mass squared has naturally tachyonic ground state expectation since for massless extremals longitudinal momentum is light-like and transversal momentum squared is necessary present and non-vanishing by the localization to topological light ray of finite thickness of order p-adic length scale. Transversal degrees of freedom would be modeled with a particle in a box.

   ii. If longitudinal mass squared is what is calculated, the condition would require that transversal momentum squared is negative so that instead of plane wave like behavior exponential damping would be required. This would conform with the localization in transversal degrees of freedom.

3.4.6 The emergence of Yangian symmetry and gauge potentials as duals of Kac-Moody currents

Yangian symmetry plays a key role in $\mathcal{N} = 4$ super-symmetric gauge theories. What is special in Yangian symmetry is that the algebra contains also multi-local generators. In TGD framework multi-locality would naturally correspond to that with respect to partonic 2-surfaces and string world sheets and the proposal has been that the Super-Kac-Moody algebras assignable to string worlds sheets could generalize to Yangian.

Witten has written a beautiful exposition of Yangian algebras [B23]. Yangian is generated by two kinds of generators J^A and Q^A by a repeated formation of commutators. The number of commutations tells the integer characterizing the multi-locality and provides the Yangian algebra with grading by natural numbers. Witten describes a 2-dimensional QFT like situation in which one has 2-D situation and Kac-Moody currents assignable to real axis define the Kac-Moody charges as integrals in the usual manner. It is also assumed that the gauge potentials defined by the 1-form associated with the Kac-Moody current define a flat connection:

$$\partial_\mu j^A_\nu - \partial_\nu j^A_\nu + [j^A_\mu, j^A_\nu] = 0 \quad . \tag{3.4.1}$$

This condition guarantees that the generators of Yangian are conserved charges. One can however consider alternative manners to obtain the conservation.

(a) The generators of first kind - call them J^A - are just the conserved Kac-Moody charges. The formula is given by

$$J_A = \int_{-\infty}^{\infty} dxj^{A0}(x,t) \ . \tag{3.4.2}$$

(b) The generators of second kind contain bi-local part. They are convolutions of generators of first kind associated with different points of string described as real axis. In the basic formula one has integration over the point of real axis.

$$Q^A = f^A_{BC}\int_{-\infty}^{\infty} dx \int_{x}^{\infty} dyj^{B0}(x,t)j^{C0}(y,t) - 2\int_{-\infty}^{\infty} j^A_x dx \ . \tag{3.4.3}$$

These charges are indeed conserved if the curvature form is vanishing as a little calculation shows.

How to generalize this to the recent context?

(a) The Kac-Moody charges would be associated with the braid strands connecting two partonic 2-surfaces - Strands would be located either at the space-like 3-surfaces at the ends of the space-time surface or at light-like 3-surfaces connecting the ends. Modified Dirac equation would define Super-Kac-Moody charges as standard Noether charges. Super charges would be obtained by replacing the second quantized spinor field or its conjugate in the fermionic bilinear by particular mode of the spinor field. By replacing both spinor field and its conjugate by its mode one would obtain a conserved c-number charge corresponding to an anti-commutator of two fermionic super-charges. The convolution involving double integral is however not number theoretically attractive whereas single 1-D integrals might make sense.

(b) An encouraging observation is that the Hodge dual of the Kac-Moody current defines the analog of gauge potential and exponents of the conserved Kac-Moody charges could be identified as analogs for the non-integrable phase factors for the components of this gauge potential. This identification is precise only in the approximation that generators commute since only in this case the ordered integral $P(exp(i\int Adx))$ reduces to $P(exp(i\int Adx))$.Partonic 2-surfaces connected by braid strand would be analogous to nearby points of space-time in its discretization implying that Abelian approximation works. This conforms with the vision about finite measurement resolution as discretization in terms partonic 2-surfaces and braids.

This would make possible a direct identification of Kac-Moody symmetries in terms of gauge symmetries. For isometries one would obtain color gauge potentials and the analogs of gauge potentials for graviton field (in TGD framework the contraction with M^4 vierbein would transform tensor field to 4 vector fields). For Kac-Moody generators corresponding to holonomies one would obtain electroweak gauge potentials. Note that super-charges would give rise to a collection of spartners of gauge potentials automatically. One would obtain a badly broken SUSY with very large value of $\mathcal{N}$ defined by the number of spinor modes as indeed speculated earlier [K24].

(c) The condition that the gauge field defined by 1-forms associated with the Kac-Moody currents are trivial looks unphysical since it would give rise to the analog of topological QFT with gauge potentials defined by the Kac-Moody charges. For the duals of Kac-Moody currents defining gauge potentials only covariant divergence vanishes implying that curvature form is

$$F_{\alpha\beta} = \epsilon_{\alpha\beta}[j_\mu, j^\mu] \ , \tag{3.4.4}$$

so that the situation does not reduce to topological QFT unless the induced metric is diagonal. This is not the case in general for string world sheets.

(d) It seems however that there is no need to assume that j_μ defines a flat connection. Witten mentions that although the discretization in the definition of J^A does not seem to be possible, it makes sense for Q^A in the case of $G = SU(N)$ for any representation of G. For general G and its general representation there exists no satisfactory definition of Q. For certain representations, such as the fundamental representation of $SU(N)$, the definition of Q^A is especially simple. One just takes the bi-local part of the previous formula:

$$Q^A = f^A_{BC} \sum_{i<j} J_i^B J_j^C \ . \tag{3.4.5}$$

What is remarkable that in this formula the summation need not refer to a discretized point of braid but to braid strands ordered by the label i by requiring that they form a connected polygon. Therefore the definition of J^A could be just as above.

(e) This brings strongly in mind the interpretation in terms of twistor diagrams. Yangian would be identified as the algebra generated by the logarithms of non-integrable phase factors in Abelian approximation assigned with pairs of partonic 2-surfaces defined in terms of Kac-Moody currents assigned with the modified Dirac action. Partonic 2-surfaces connected by braid strand would be analogous to nearby points of space-time in its discretization. This would fit nicely with the vision about finite measurement resolution as discretization in terms partonic 2-surfaces and braids.

The resulting algebra satisfies the basic commutation relations

$$\left[J^A, J^B\right] = f_C^{AB} J^C \ , \ \left[J^A, Q^B\right] = f_C^{AB} Q^C \ . \tag{3.4.6}$$

plus the rather complex Serre relations described in [B23].

3.4.7 Quantum criticality and electroweak symmetries

In the following quantum criticali and electroweak symmetries are discussed for Kähler-Dirac action.

What does one mean with quantum criticality?

Quantum criticality is one of the basic guiding principles of Quantum TGD. What it means mathematically is however far from clear and one can imagine several meanings for it.

(a) What is obvious is that quantum criticality implies quantization of Kähler coupling strength as a mathematical analog of critical temperature so that the theory becomes mathematically unique if only single critical temperature is possible. Physically this means the presence of long range fluctuations characteristic for criticality and perhaps assignable to the effective hierarchy of Planck constants having explanation in terms of effective covering spaces of the imbedding space. This hierarchy follows from the vacuum degeneracy of Kähler action, which in turn implies 4-D spin-glass degeneracy. It is easy to interpret the degeneracy in terms of criticality.

(b) At more technical level one would expect criticality to corresponds to deformations of a given preferred extremal defining a vanishing second variation of Kähler Khler function or Kähler action.

i. For Kähler function this criticality is analogous to thermodynamical criticality. The Hessian matrix defined by the second derivatives of free energy or potential function becomes degenerate at criticality as function of control variables which now would be naturally zero modes not contribution to Kähler metric of WCW but appearing as parameters in it. The bevavior variables correspond to quantum fluctuating degrees of freedom and according to catastrophe theory a big change can in quantum fluctuating degrees of freedom at criticality for zero modes. This would be control of quantum state by varying classical variables. Cusp catastrophe is standard example of this. One can imagined also a situation in which the roles of zero modes and behavior variables change and big jump in the values of zero modes is induced by small variation in behavior variables. This would mean quantum control of classical variables.

ii. Zero modes controlling quantum fluctuating variables in Kähler function would correspond to vanishing of also second derivatives of potential function at extremum in certain directions so that the matrix defined by second derivatives does not have maximum rank. Entire hierarchy of criticalities is expected and a good finite-dimensional model is provided by the catastrophe theory of Thom [A42]. Cusp catastrophe [A1] is the simplest catastrophe one can think of, and here the folds of cusp where discontinuous jump occurs correspond to criticality with respect to one control variable and the tip to criticality with respect to both control variables.

(c) Quantum criticality makes sense also for Kähler action.

i. Now one considers space-time surface connecting which 3-surfaces at the boundaries of CD. The non-determinism of Kähler action allows the possibility of having several space-time sheets connecting the ends of space-time surface but the conditions that classical charges are same for them reduces this number so that it could be finite. Quantum criticality in this sense implies non-determinism analogous to that of critical systems since preferred extremals can co-incide and suffer this kind of bifurcation in the interior of CD. This quantum criticality can be assigned to the hierarchy of Planck constants and the integer n in $h_{eff} = n \times h$ [K22] corresponds to the number of degenerate space-time sheets with same Kähler action and conserved classical charges.

ii. Also now one expects a hierarchy of criticalities and and since criticality and conformal invariance are closely related, a natural conjecture is that the fractal hierarchy of sub-algebras of conformal algebra isomorphic to conformal algebra itself and having conformal weights coming as multiples of n corresponds to the hierarchy of Planck constants. This hierarchy would define a hierarchy of symmetry breakings in the sense that only the sub-algebra would act as gauge symmetries.

iii. The assignment of this hierarchy with super-symplectic algebra having conformal structure with respect to the light-like radial coordinate of light-cone boundary looks very attractive. An interesting question is what is the role of the super-conformal algebra associated with the isometries of light-cone boundary $R_+ \times S^2$ which are conformal transformations of sphere S^2 with a scaling of radial coordinate compensating the scaling induced by the conformal transformation. Does it act as dynamical or gauge symmetries?

(d) I have discussed what criticality could mean for modified Dirac action [K23] .

i. I have conjectured that it leads to the existence of additional conserved currents defined by the variations which do not affect the value of Kähler action. These arguments are far from being mathematically rigorous and the recent view about the solutions of the modified Dirac equation predicting that the spinor modes are restricted to 2-D string world sheets requires a modification of these arguments.

ii. The basic challenge is to understand the mechanism making this kind of currents conserved: the same challenge is met already in the case of isometries since imbedding space coordinates appear as parameters in modified Dirac action. The existence of conserved currents does not actually require the vanishing of the second variation of Kähler action as claimed earlier. It is enough that the first variation of the canonical momentum densities contracted with the imbedding space gamma matrices annihilates the spinor mode. Situation is analogous to massless Dirac equation:it does not imply the vanishing of four-momentum, only the vanishing of mass. Hence conserved currents are obtained also outside the quantum criticality.

iii. It is far from obvious that these conditions can be satisfied. The localization of the spinor modes to string world sheets or partonic 2-surfaces guaranteeing in the generaic case that em charge is well-defined for spinor modes implies holomorphy allowing to formulate current conservation for currents associated with the deformations of the space-time surface for second quantized induced spinor field. The crux is that the deformation respects the holomorphy properties of the modified gamma matrices at string world sheet and thus does not mix Γ^z with $\Gamma^{\overline{z}}$. The deformation of Γ^z has only z-component and also annihilates the holomorphic spinor. This mechanism is possible only for Kähler-Dirac action since the Kähler-Dirac gamma matrices in directions orthogonal to the 2-surface must vanish and this is not possible for other actions. This also means that energy momentum tensor has rank 2 as matrix. Cosmic string solutions are an exception since in this case CP_2 projection of space-time surface is 2-D and conditions guaranteing vanishing of classical W fields can be satisfied.

In the following these arguments are formulated more precisely. The unexpected result is that critical deformations induce conformal scalings of the modified metric and electro-weak gauge transformations of the induced spinor connection at X^2. Therefore holomorphy brings in the Kac-Moody symmetries associated with isometries of H (gravitation and color gauge group) and quantum criticality those associated with the holonomies of H (electro-weak-gauge group) as additional symmetries.

The variation of modes of the induced spinor field in a variation of space-time surface respecting the preferred extremal property

Consider first the variation of the induced spinor field in a variation of space-time surface respecting the preferred extremal property. The deformation must be such that the deformed modified Dirac operator D annihilates the modified mode. By writing explicitly the variation of the modified Dirac action (the action vanishes by modified Dirac equation) one obtains deformations and requiring its vanishing one obtains

$$\delta\Psi = D^{-1}(\delta D)\Psi \ . \tag{3.4.7}$$

D^{-1} is the inverse of the modified Dirac operator defining the analog of Dirac propagator and δD defines vertex completely analogous to $\gamma^k\delta A_k$ in gauge theory context. The functional integral over preferred extremals can be carried out perturbatively by expressing δD in terms of δh^k and one obtains stringy perturbation theory around X^2 associated with the preferred extremal defining maximum of Kähler function in Euclidian region and extremum of Kähler action in Minkowskian region (stationary phase approximation).

What one obtains is stringy perturbation theory for calculating n-points functions for fermions at the ends of braid strands located at partonic 2-surfaces and representing intersections of string world sheets and partonic 2-surfaces at the light-like boundaries of CDs. δD- or more precisely, its partial derivatives with respect to functional integration variables - appear atthe vertices located anywhere in the interior of X^2 with outgoing fermions at braid ends. Bosonic propagators are replaced with correlation functions for δh^k. Fermionic propagator is defined by D^{-1}.

After 35 years or hard work this provides for the first time a reasonably explicit formula for the N-point functions of fermions. This is enough since by bosonic emergence [K49] these N-point functions define the basic building blocks of the scattering amplitudes. Note that bosonic emergence states that bosons corresponds to wormhole contacts with fermion and anti-fermion at the opposite wormhole throats.

What critical modes could mean for the induced spinor fields?

What critical modes could mean for the induced spinor fields at string world sheets and partonic 2-surfaces. The problematic part seems to be the variation of the modified Dirac operator since it involves gradient. One cannot require that covariant derivative remains invariant since this would require that the components of the induced spinor connection remain invariant and this is quite too restrictive condition. Right handed neutrino solutions de-localized into entire X^2 are however an exception since they have no electro-weak gauge couplings and in this case the condition is obvious: modified gamma matrices suffer a local scaling for critical deformations:

$$\delta\Gamma^{\mu} = \Lambda(x)\Gamma^{\mu} . \tag{3.4.8}$$

This guarantees that the modified Dirac operator D is mapped to ΛD and still annihilates the modes of ν_R labelled by conformal weight, which thus remain unchanged.

What is the situation for the 2-D modes located at string world sheets? The condition is obvious. Ψ suffers an electro-weak gauge transformation as does also the induced spinor connection so that D_μ is not affected at all. Criticality condition states that the deformation of the space-time surfaces induces a conformal scaling of Γ^μ at X^2. It might be possible to continue this conformal scaling of the entire space-time sheet but this might be not necessary and this would mean that all critical deformations induced conformal transformations of the effective metric of the space-time surface defined by $\{\Gamma^\mu, \Gamma^\nu\} = 2G^{\mu\nu}$. Thus it seems that effective metric is indeed central concept (recall that if the conjectured quaternionic structure is associated with the effective metric, it might be possible to avoid problem related to the Minkowskian signature in an elegant manner).

In fact, one can consider even more general action of critical deformation: the modes of the induced spinor field would be mixed together in the infinitesimal deformation besides infinitesimal electroweak gauge transformation, which is same for all modes. This would extend electroweak gauge symmetry. Modified Dirac equation holds true also for these deformations. One might wonder whether the conjectured dynamically generated gauge symmetries assignable to finite measurement resolution could be generated in this manner.

The infinitesimal generator of a critical deformation J_M can be expressed as tensor product of matrix A_M acting in the space of zero modes and of a generator of infinitesimal electro-weak gauge transformation $T_M(x)$ acting in the same manner on all modes: $J_M = A_M \otimes T_M(x)$. A_M is a spatially constant matrix and $T_M(x)$ decomposes to a direct sum of left- and right-handed $SU(2) \times U(1)$ Lie-algebra generators. Left-handed Lie-algebra generator can be regarded as a quaternion and right handed as a complex number. One can speak of a direct sum of left-handed local quaternion $q_{M,L}$ and right-handed local complex number $c_{M,R}$. The commutator $[J_M, J_N]$ is given by $[J_M, J_N] = [A_M, A_N] \otimes \{T_M(x), T_N(x)\} + \{A_M, A_N\} \otimes [T_M(x), T_N(x)]$. One has $\{T_M(x), T_N(x)\} = \{q_{M,L}(x), q_{N,L}(x)\} \oplus \{c_{M,R}(x), c_{N,R}(x)\}$ and $[T_M(x), T_N(x)] = [q_{M,L}(x), q_{N,L}(x)]$. The commutators make sense also for more general gauge group but quaternion/complex number property might have some deeper role.

Thus the critical deformations would induce conformal scalings of the effective metric and dynamical electro-weak gauge transformations. Electro-weak gauge symmetry would be a dynamical symmetry restricted to string world sheets and partonic 2-surfaces rather than acting at the entire space-time surface. For 4-D de-localized right-handed neutrino modes the conformal scalings of the effective metric are analogous to the conformal transformations of M^4 for $\mathcal{N} = 4$ SYMs. Also ordinary conformal symmetries of M^4 could be present for string world sheets and could act as symmetries of generalized Feynman graphs since even virtual wormhole throats are massless. An interesting question is whether the conformal invariance associated with the effective metric is the analog of dual conformal invariance in $\mathcal{N} = 4$ theories.

Critical deformations of space-time surface are accompanied by conserved fermionic currents. By using standard Noetherian formulas one can write

$$J_i^\mu = \overline{\Psi}\Gamma^\mu\delta_i\Psi + \delta_i\overline{\Psi}\Gamma^\mu\Psi \ . \quad (3.4.9)$$

Here $\delta\Psi_i$ denotes derivative of the variation with respect to a group parameter labeled by i. Since $\delta\Psi_i$ reduces to an infinitesimal gauge transformation of Ψ induced by deformation, these currents are the analogs of gauge currents. The integrals of these currents along the braid strands at the ends of string world sheets define the analogs of gauge charges. The interpretation as Kac-Moody charges is also very attractive and I have proposed that the 2-D Hodge duals of gauge potentials could be identified as Kac-Moody currents. If so, the 2-D Hodge duals of J would define the quantum analogs of dynamical electro-weak gauge fields and Kac-Moody charge could be also seen as non-integral phase factor associated with the braid strand in Abelian approximation (the interpretation in terms of finite measurement resolution is discussed earlier).

One can also define super currents by replacing $\overline{\Psi}$ or Ψ by a particular mode of the induced spinor field as well as c-number valued currents by performing the replacement for both $\overline{\Psi}$ or Ψ. As expected, one obtains a super-conformal algebra with all modes of induced spinor fields acting as generators of super-symmetries restricted to 2-D surfaces. The number of the charges which do not annihilate physical states as also the effective number of fermionic modes could be finite and this would suggest that the integer $\mathcal{N}$ for the supersymmetry in question is finite. This would conform with the earlier proposal inspired by the notion of finite measurement resolution implying the replacement of the partonic 2-surfaces with collections of braid ends.

Note that Kac-Moody charges might be associated with "long" braid strands connecting different wormhole throats as well as short braid strands connecting opposite throats of wormhole contacts. Both kinds of charges would appear in the theory.

What is the interpretation of the critical deformations?

Critical deformations bring in an additional gauge symmetry. Certainly not all possible gauge transformations are induced by the deformations of preferred extremals and a good guess is that they correspond to holomorphic gauge group elements as in theories with Kac-Moody symmetry. What is the physical character of this dynamical gauge symmetry?

(a) Do the gauge charges vanish? Do they annihilate the physical states? Do only their positive energy parts annihilate the states so that one has a situation characteristic for the representation of Kac-Moody algebras. Or could some of these charges be analogous to the gauge charges associated with the constant gauge transformations in gauge theories and be therefore non-vanishing in the absence of confinement. Now one has electro-weak gauge charges and these should be non-vanishing. Can one assign them to deformations with a vanishing conformal weight and the remaining deformations to those with non-vanishing conformal weight and acting like Kac-Moody generators on the physical states?

(b) The simplest option is that the critical Kac-Moody charges/gauge charges with non-vanishing positive conformal weight annihilate the physical states. Critical degrees of freedom would not disappear but make their presence known via the states labelled by different gauge charges assignable to critical deformations with vanishing conformal weight. Note that constant gauge transformations can be said to break the gauge symmetry also in the ordinary gauge theories unless one has confinement.

(c) The hierarchy of quantum criticalities suggests however entire hierarchy of electro-weak Kac-Moody algebras. Does this mean a hierarchy of electro-weak symmetries breakings in which the number of Kac-Moody generators not annihilating the physical states gradually increases as also modes with a higher value of positive conformal weight fail to annihilate the physical state?

The only manner to have a hierarchy of algebras is by assuming that only the generators satisfying $n\ mod\ N = 0$ define the sub-Kac-Moody algebra annihilating the physical states so that the generators with $n\ mod\ N \neq 0$ would define the analogs of gauge charges. I have suggested for long time ago the relevance of kind of fractal hierarchy of Kac-Moody and Super-Virasoro algebras for TGD but failed to imagine any concrete realization.

A stronger condition would be that the algebra reduces to a finite dimensional algebra in the sense that the actions of generators Q_n and Q_{n+kN} are identical. This would correspond to periodic boundary conditions in the space of conformal weights. The notion of finite measurement resolution suggests that the number of independent fermionic oscillator operators is proportional to the number of braid ends so that an effective reduction to a finite algebra is expected.

Whatever the correct interpretation is, this would obviously refine the usual view about electro-weak symmetry breaking.

These arguments suggests the following overall view. The holomorphy of spinor modes gives rise to Kac-Moody algebra defined by isometries and includes besides Minkowskian generators associated with gravitation also SU(3) generators associated with color symmetries. Vanishing second variations in turn define electro-weak Kac-Moody type algebra.

Note that criticality suggests that one must perform functional integral over WCW by decomposing it to an integral over zero modes for which deformations of X^4 induce only an electro-weak gauge transformation of the induced spinor field and to an integral over moduli corresponding to the remaining degrees of freedom.

3.4.8 The importance of being light-like

The singular geometric objects associated with the space-time surface have become increasingly important in TGD framework. In particular, the recent progress has made clear that these objects might be crucial for the understanding of quantum TGD. The singular objects are associated not only with the induced metric but also with the effective metric defined by the anti-commutators of the modified gamma matrices appearing in the modified Dirac equation and determined by the Kähler action.

The singular objects associated with the induced metric

Consider first the singular objects associated with the induced metric.

(a) At light-like 3-surfaces defined by wormhole throats the signature of the induced metric changes from Euclidian to Minkowskian so that 4-metric is degenerate. These surfaces are carriers of elementary particle quantum numbers and the 4-D induced metric degenerates locally to 3-D one at these surfaces.

(b) Braid strands at light-like 3-surfaces are most naturally light-like curves: this correspond to the boundary condition for open strings. One can assign fermion number to the braid strands. Braid strands allow an identification as curves along which the Euclidian signature of the string world sheet in Euclidian region transforms to Minkowskian one. Number theoretic interpretation would be as a transformation of complex regions to hyper-complex regions meaning that imaginary unit i satisfying $i^2 = -1$ becomes hyper-complex unit e satisfying $e^2 = 1$. The complex coordinates $(z, \overline{z})$ become hyper-complex coordinates $(u = t + ex, v = t - ex)$ giving the standard light-like coordinates when one puts $e = 1$.

The singular objects associated with the effective metric

There are also singular objects assignable to the effective metric. According to the simple arguments already developed, string world sheets and possibly also partonic 2-surfaces are singular objects with respect to the effective metric defined by the anti-commutators of the modified gamma matrices rather than induced gamma matrices. Therefore the effective metric seems to be much more than a mere formal structure.

(a) For instance, quaternionicity of the space-time surface could allow an elegant formulation in terms of the effective metric avoiding the problems due to the Minkowski signature. This is achieved if the effective metric has Euclidian signature $\epsilon \times (1,1,1,1)$, $\epsilon = \pm 1$ or a complex counterpart of the Minkowskian signature $\epsilon(1,1,-1,-1)$.

(b) String word sheets and perhaps also partonic 2-surfaces could be understood as singularities of the effective metric. What happens that the effective metric with Euclidian signature $\epsilon \times (1,1,1,1)$ transforms to the signature $\epsilon(1,1,-1,-1)$ (say) at string world sheet so that one would have the degenerate signature $\epsilon \times (1,1,0,0)$ at the string world sheet.

What is amazing is that this works also number theoretically. It came as a total surprise to me that the notion of hyper-quaternions as a closed algebraic structure indeed exists. The hyper-quaternionic units would be given by $(1, I, iJ, iK)$, where i is a commuting imaginary unit satisfying $i^2 = -1$. Hyper-quaternionic numbers defined as combinations of these units with real coefficients do form a closed algebraic structure which however fails to be a number field just like hyper-complex numbers do. Note that the hyper-quaternions obtained with real coefficients from the basis $(1, iI, iJ, iK)$ fail to form an algebra since the product is not hyper-quaternion in this sense but belongs to the algebra of complexified quaternions. The same problem is encountered in the case of hyper-octonions defined in this manner. This has been a stone in my shoe since I feel strong disrelish towards Wick rotation as a trick for moving between different signatures.

(c) Could also partonic 2-surfaces correspond to this kind of singular 2-surfaces? In principle, 2-D surfaces of 4-D space intersect at discrete points just as string world sheets and partonic 2-surfaces do so that this might make sense. By complex structure the situation is algebraically equivalent to the analog of plane with non-flat metric allowing all possible signatures (ϵ_1, ϵ_2) in various regions. At light-like curve either ϵ_1 or ϵ_2 changes sign and light-like curves for these two kinds of changes can intersect as one can easily verify by drawing what happens. At the intersection point the metric is completely degenerate and simply vanishes.

(d) Replacing real 2-dimensionality with complex 2-dimensionality, one obtains by the universality of algebraic dimension the same result for partonic 2-surfaces and string world sheets. The braid ends at partonic 2-surfaces representing the intersection points of 2-surfaces of this kind would have completely degenerate effective metric so that the modified gamma matrices would vanish implying that energy momentum tensor vanishes as does also the induced Kähler field.

(e) The effective metric suffers a local conformal scaling in the critical deformations identified in the proposed manner. Since ordinary conformal group acts on Minkowski space and leaves the boundary of light-cone invariant, one has two conformal groups. It is not however clear whether the M^4 conformal transformations can act as symmetries in TGD, where the presence of the induced metric in Kähler action breaks M^4 conformal symmetry. As found, also in TGD framework the Kac-Moody currents assigned to the braid strands generate Yangian: this is expected to be true also for the Kac-Moody counterparts of the conformal algebra associated with quantum criticality. On the other hand, in twistor program one encounters also two conformal groups and the space in which the second conformal group acts remains somewhat mysterious object. The Lie algebras for the two conformal groups generate the conformal Yangian and the integrands of the scattering amplitudes are Yangian invariants. Twistor approach should apply in TGD if zero energy ontology is right. Does this mean a deep connection?

What is also intriguing that twistor approach in principle works in strict mathematical sense only at signatures $\epsilon \times (1,1,-1-1)$ and the scattering amplitudes in Minkowski signature are obtained by analytic continuation. Could the effective metric give rise to the desired signature? Note that the notion of massless particle does not make sense in the signature $\epsilon \times (1,1,1,1)$.

These arguments provide genuine a support for the notion of quaternionicity and suggest a connection with the twistor approach.

3.4.9 Realization of large $\mathcal{N}$ SUSY in TGD

The generators large $\mathcal{N}$ SUSY algebras are obtained by taking fermionic currents for second quantized fermions and replacing either fermion field or its conjugate with its particular mode. The resulting super currents are conserved and define super charges. By replacing both fermion and its conjugate with modes one obtains c number valued currents. Therefore $\mathcal{N} = \infty$ SUSY - presumably equivalent with super-conformal invariance - or its finite $\mathcal{N}$ cutoff is realized in TGD framework and the challenge is to understand the realization in more detail.

Super-space viz. Grassmann algebra valued fields

Standard SUSY induces super-space extending space-time by adding anti-commuting coordinates as a formal tool. Many mathematicians are not enthusiastic about this approach because of the purely formal nature of anti-commuting coordinates. Also I regard them as a non-sense geometrically and there is actually no need to introduce them as the following little argument shows.

Grassmann parameters (anti-commuting theta parameters) are generators of Grassmann algebra and the natural object replacing super-space is this Grassmann algebra with coefficients of Grassmann algebra basis appearing as ordinary real or complex coordinates. This is just an ordinary space with additional algebraic structure: the mysterious anti-commuting coordinates are not needed. To me this notion is one of the conceptual monsters created by the over-pragmatic thinking of theoreticians.

This allows allows to replace field space with super field space, which is completely well-defined object mathematically, and leave space-time untouched. Linear field space is simply replaced with its Grassmann algebra. For non-linear field space this replacement does not work. This allows to formulate the notion of linear super-field just in the same manner as it is done usually.

The generators of super-symmetries in super-space formulation reduce to super translations , which anti-commute to translations. The super generators Q_α and $\overline{Q}_{\dot{\beta}}$ of super Poincare algebra are Weyl spinors commuting with momenta and anti-commuting to momenta:

$$\{Q_\alpha, \overline{Q}_{\dot{\beta}}\} = 2\sigma^\mu_{\alpha\ \dot{beta}} P_\mu \ . \tag{3.4.10}$$

One particular representation of super generators acting on super fields is given by

$$\begin{aligned} D_\alpha &= i\frac{\partial}{\partial_{\theta_\alpha}} \ , \\ D_{\dot{\alpha}} &= i\frac{\partial}{\partial_{\overline{\theta}}{}_{\dot{alpha}}} + \theta^\beta\sigma^\mu_{\beta\dot{\alpha}}\partial_\mu \end{aligned} \tag{3.4.11}$$

Here the index raising for 2-spinors is carried out using antisymmetric 2-tensor $\epsilon^{\alpha\beta}$. Super-space interpretation is not necessary since one can interpret this action as an action on Grassmann algebra valued field mixing components with different fermion numbers.

Chiral superfields are defined as fields annihilated by $D_{\dot{\alpha}}$. Chiral fields are of form $\Psi(x^\mu + i\overline{\theta}\sigma^\mu\theta, \theta)$. The dependence on $\overline{\theta}_{\dot{\alpha}}$ comes only from its presence in the translated Minkowski coordinate annihilated by $D_{\dot{\alpha}}$. Super-space enthusiast would say that by a translation of M^4 coordinates chiral fields reduce to fields, which depend on θ only.

The space of fermionic Fock states at partonic 2-surface as TGD counterpart of chiral super field

As already noticed, another manner to realize SUSY in terms of representations the super algebra of conserved super-charges. In TGD framework these super charges are naturally associated with the modified Dirac equation, and anti-commuting coordinates and super-fields do not appear anywhere. One can however ask whether one could identify a mathematical structure replacing the notion of chiral super field.

In [K24] it was proposed that generalized chiral super-fields could effectively replace induced spinor fields and that second quantized fermionic oscillator operators define the analog of SUSY algebra. One would have $\mathcal{N} = \infty$ if all the conformal excitations of the induced spinor field restricted on 2-surface are present. For right-handed neutrino the modes are labeled by two integers and de-localized to the interior of Euclidian or Minkowskian regions of space-time sheet.

The obvious guess is that chiral super-field generalizes to the field having as its components many-fermions states at partonic 2-surfaces with theta parameters and their conjugates in one-one correspondence with fermionic creation operators and their hermitian conjugates.

(a) Fermionic creation operators - in classical theory corresponding anti-commuting Grassmann parameters - replace theta parameters. Theta parameters and their conjugates are not in one-one correspondence with spinor components but with the fermionic creation operators and their hermitian conjugates. One can say that the super-field in question is defined in the "world of classical worlds" (WCW) rather than in space-time. Fermionic Fock state at the partonic 2-surface is the value of the chiral super field at particular point of WCW.

(b) The matrix defined by the $\sigma^\mu \partial_\mu$ is replaced with a matrix defined by the modified Dirac operator D between spinor modes acting in the solution space of the modified Dirac equation. Since modified Dirac operator annihilates the modes of the induced spinor field, super covariant derivatives reduce to ordinary derivatives with respect the theta parameters labeling the modes. Hence the chiral super field is a field that depends on θ_m or conjugates $\overline{\theta}_m$ only. In second quantization the modes of the chiral super-field are many-fermion states assigned to partonic 2-surfaces and string world sheets. Note that this is the only possibility since the notion of super-coordinate does not make sense now.

(c) It would seem that the notion of super-field does not bring anything new. This is not the case. First of all, the spinor fields are restricted to 2-surfaces. Second point is that one cannot assign to the fermions of the many-fermion states separate non-parallel or even parallel four-momenta. The many-fermion state behaves like elementary particle. This has non-trivial implications for propagators and a simple argument [K24] leads to the proposal that propagator for N-fermion partonic state is proportional to $1/p^N$. This would mean that only the states with fermion number equal to 1 or 2 behave like ordinary elementary particles.

How the fermionic anti-commutation relations are determined?

Understanding the fermionic anti-commutation relations is not trivial since all fermion fields except right-handed neutrino are assumed to be localized at 2-surfaces. Since fermionic conserved currents must give rise to well-defined charges as 3-D integrals the spinor modes must be proportional to a square root of delta function in normal directions. Furthermore, the modified Dirac operator must act only in the directions tangential to the 2-surface in order that the modified Dirac equation can be satisfied.

The square root of delta function can be formally defined by starting from the expansion of delta function in discrete basis for a particle in 1-D box. The product of two functions in x-space is convolution of Fourier transforms and the coefficients of Fourier transform of delta function are apart from a constant multiplier equal to 1: $\delta(x) = K \sum_n exp(inx/2\pi L)$.

Therefore the Fourier transform of square root of delta function is obtained by normalizing the Fourier transform of delta function by $1/\sqrt{N}$, where $N \to \infty$ is the number of plane waves. In other words: $\sqrt{\delta(x)} = \sqrt{\frac{K}{N}} \sum_n \sum exp(inx/2\pi L)$.

Canonical quantization defines the standard approach to the second quantization of the Dirac equation.

(a) One restricts the consideration to time=constant slices of space-time surface. Now the 3-surfaces at the ends of CD are natural slices. The intersection of string world sheet with these surfaces is 1-D whereas partonic 2-surfaces have 2-D Euclidian intersection with them.

(b) The canonical momentum density is defined by

$$\begin{aligned} \Pi_\alpha &= \frac{\partial L}{\partial_t \overline{\Psi}_\alpha(x)} = \Gamma^t \Psi \ , \\ \Gamma^t &= \frac{\partial L_K}{\partial(\partial_t h^k)} \ . \end{aligned} \quad (3.4.12)$$

L_K denotes Kähler action density: consistency requires $D_\mu \Gamma^\mu = 0$, and this is guaranteed only by using the modified gamma matrices defined by Kähler action. Note that Γ^t contains also the $\sqrt{g_4}$ factor. Induced gamma matrices would require action defined by four-volume. t is time coordinate varying in direction tangential to 2-surface.

(c) The standard equal time canonical anti-commutation relations state

$$\{\Pi_\alpha, \overline{\Psi}_\beta\} = \delta^3(x,y)\delta_{\alpha\beta} \ . \quad (3.4.13)$$

Can these conditions be applied both at string world sheets and partonic 2-surfaces.

(a) Sttring world sheets do not pose problems. The restriction of the modes to string world sheets means that the square root of delta function in the normal direction of string world sheet takes care of the normal dimensions and the dynamical part of anti-commutation relations is 1-dimensional just as in the case of strings.

(b) Partonic 2-surfaces are problematic. The $\sqrt{g_4}$ factor in Γ^t implies that Γ^t approaches zero at partonic 2-surfaces since they belong to light-like wormhole throats at which the signature of the induced metric changes. Energy momentum tensor appearing in Γ^t involves to index raisins by induced metric so that it can grow without limit as one approaches partonic two-surface. Therefore it is quite possible that the limit is finite and the boundary conditions defined by the weak form of electric magnetic duality might imply that the limit is finite. The open question is whether one can apply canonical quantization at partonic 2-surfaces. One can also ask whether one can define induced spinor fields at wormhole throats only at the ends of string world sheets so that partonic 2-surface would be effectively discretized. This cautious conclusion emerged in the earlier study of the modified Dirac equation [K23].

(c) Suppose that one can assume spinor modes at partonic 2-surfaces. 2-D conformal invariance suggests that the situation reduces to effectively one-dimensional also at the partonic two-surfaces. If so, one should pose the anti-commutation relations at some 1-D curves of the partonic 2-surface only. This is the only sensical option. The point is that the action of the modified Dirac operator is tangential so that also the canonical momentum current must be tangential and one can fix anti-commutations only at some set of curves of the partonic 2-surface.

One can of course worry what happens at the limit of vacuum extremals. The problem is that Γ^t vanishes for space-time surfaces reducing to vacuum extremals at the 2-surfaces carrying fermions so that the anti-commutations are inconsistent. Should one require - as done earlier- that the anti-commutation relations make sense at this limit and cannot therefore have the standard form but involve the scalar magnetic flux formed from the induced Kähler form by permuting it with the 2-D permutations symbol? The restriction to preferred extremals, which are always non-vacuum extremals, might allow to avoid this kind of problems automatically.

In the case of right-handed neutrino the situation is genuinely 3-dimensional and in this case non-vacuum extremal property must hold true in the regions where the modes of ν_R are non-vanishing. The same mechanism would save from problems also at the partonic 2-surfaces. The dynamics of induced spinor fields must avoid classical vacuum. Could this relate to color confinement? Could hadrons be surrounded by an insulating layer of Kähler vacuum?

3.4.10 Comparison of TGD and stringy views about super-conformal symmetries

The best manner to represent TGD based view about conformal symmetries is by comparison with the conformal symmetries of super string models.

Basic differences between the realization of super conformal symmetries in TGD and in super-string models

The realization super conformal symmetries in TGD framework differs from that in string models in several fundamental aspects.

(a) In TGD framework super-symmetry generators acting as configuration space gamma matrices carry either lepton or quark number. Majorana condition required by the hermiticity of super generators which is crucial for super string models would be in conflict with the conservation of baryon and lepton numbers and is avoided. This is made possible by the realization of bosonic generators represented as Hamiltonians of X^2-local symplectic transformations rather than vector fields generating them [K13] . This kind of representation applies also in Kac-Moody sector since the local transversal isometries localized in X^3_l and respecting light-likeness condition can be regarded as X^2 local symplectic transformations, whose Hamiltonians generate also isometries. Localization is not complete: the functions of X^2 coordinates multiplying symplectic and Kac-Moody generators are functions of the symplectic invariant $J = \epsilon^{\mu\nu} J_{\mu\nu}$ so that effective one-dimensionality results but in different sense than in conformal field theories. This realization of super symmetries is what distinguishes between TGD and super string models and leads to a totally different physical interpretation of super-conformal symmetries. The fermionic representations of super-symplectic and super Kac-Moody generators can be identified as Noether charges in standard manner.

(b) A long-standing problem of quantum TGD was that stringy propagator $1/G$ does not make sense if G carries fermion number. The progress in the understanding of second quantization of the modified Dirac operator made it however possible to identify the counterpart of G as a c-number valued operator and interpret it as different representation of G [K15] .

(c) The notion of super-space is not needed at all since Hamiltonians rather than vector fields represent bosonic generators, no super-variant of geometry is needed. The distinction between Ramond and N-S representations important for $N = 1$ super-conformal symmetry and allowing only ground state weight 0 an $1/2$ disappears. Indeed, for $N = 2$ super-conformal symmetry it is already possible to generate spectral flow transforming these Ramond and N-S representations to each other (G_n is not Hermitian anymore).

(d) If Kähler action defines the modified Dirac operator, the number of spinor modes could be finite. One must be here somewhat cautious since bound state in the Coulomb potential associated with electric part of induced electro-weak gauge field might give rise to an infinite number of bound states which eigenvalues converging to a fixed eigenvalue (as in the case of hydrogen atom). Finite number of generalized eigenmodes means that the representations of super-conformal algebras reduces to finite-dimensional ones in TGD framework. Also the notion of number theoretic braid indeed implies this. The physical interpretation would be in terms of finite measurement resolution. If Kähler action is complexified to include imaginary part defined by CP breaking instanton term, the number of stringy mass square eigenvalues assignable to the spinor modes becomes infinite since conformal excitations are possible. This means breakdown of exact holography and effective 2-dimensionality of 3-surfaces. It seems that the inclusion of instanton term is necessary for several reasons. The notion of finite measurement resolution forces conformal cutoff also now. There are arguments suggesting that only the modes with vanishing conformal weight contribute to the Dirac determinant defining vacuum functional identified as exponent of Kähler function in turn identified as Kähler action for its preferred extremal.

(e) What makes spinor field mode a generator of gauge super-symmetry is that is c-number and not an eigenmode of $D_K(X^2)$ and thus represents non-dynamical degrees of freedom. If the number of eigen modes of $D_K(X^2)$ is indeed finite means that most of spinor field modes represent super gauge degrees of freedom.

The super generators G are not Hermitian in TGD!

The already noticed important difference between TGD based and the usual Super Virasoro representations is that the Super Virasoro generator G cannot Hermitian in TGD. The reason is that WCW gamma matrices possess a well defined fermion number. The hermiticity of the WCW gamma matrices Γ and of the Super Virasoro current G could be achieved by posing Majorana conditions on the second quantized H-spinors. Majorana conditions can be however realized only for space-time dimension $D\ mod\ 8 = 2$ so that super string type approach does not work in TGD context. This kind of conditions would also lead to the non-conservation of baryon and lepton numbers.

An analogous situation is encountered in super-symmetric quantum mechanics, where the general situation corresponds to super symmetric operators S, $S^\dagger$, whose anti-commutator is Hamiltonian: $\{S, S^\dagger\} = H$. One can define a simpler system by considering a Hermitian operator $S_0 = S + S^\dagger$ satisfying $S_0^2 = H$: this relation is completely analogous to the ordinary Super Virasoro relation $GG = L$. On basis of this observation it is clear that one should replace ordinary Super Virasoro structure $GG = L$ with $GG^\dagger = L$ in TGD context.

It took a long time to realize the trivial fact that $N = 2$ super-symmetry is the standard physics counterpart for TGD super symmetry. $N = 2$ super-symmetry indeed involves the doubling of super generators and super generators carry $U(1)$ charge having an interpretation as fermion number in recent context. The so called short representations of $N = 2$ super-symmetry algebra can be regarded as representations of $N = 1$ super-symmetry algebra.

WCW gamma matrix Γ_n, $n > 0$ corresponds to an operator creating fermion whereas Γ_n, $n < 0$ annihilates anti-fermion. For the Hermitian conjugate $\Gamma_n^\dagger$ the roles of fermion and anti-fermion are interchanged. Only the anti-commutators of gamma matrices and their Hermitian conjugates are non-vanishing. The dynamical Kac Moody type generators are Hermitian and are constructed as bilinears of the gamma matrices and their Hermitian conjugates and, just like conserved currents of the ordinary quantum theory, contain parts proportional to $a^\dagger a$, $b^\dagger b$, $a^\dagger b^\dagger$ and ab (a and b refer to fermionic and anti-fermionic oscillator operators). The commutators between Kac Moody generators and Kac Moody generators and gamma matrices remain as such.

For a given value of m G_n, $n > 0$ creates fermions whereas G_n, $n < 0$ annihilates anti-fermions. Analogous result holds for $G_n^\dagger$. Virasoro generators remain Hermitian and decompose just like Kac Moody generators do. Thus the usual anti-commutation relations for the super Virasoro generators must be replaced with anti-commutations between G_m and $G_n^\dagger$ and one has

$$\begin{aligned} \{G_m, G_n^\dagger\} &= 2L_{m+n} + \frac{c}{3}(m^2 - \frac{1}{4})\delta_{m,-n} \ , \\ \{G_m, G_n\} &= 0 \ , \\ \{G_m^\dagger, G_n^\dagger\} &= 0 \ . \end{aligned} \tag{3.4.14}$$

The commutators of type $[L_m, L_n]$ are not changed. Same applies to the purely kinematical commutators between L_n and $G_m/G_m^\dagger$.

The Super Virasoro conditions satisfied by the physical states are as before in case of L_n whereas the conditions for G_n are doubled to those of G_n, $n < 0$ and $G_n^\dagger$, $n > 0$.

What could be the counterparts of stringy conformal fields in TGD framework?

The experience with string models would suggest the conformal symmetries associated with the complex coordinates of X^2 as a candidate for conformal super-symmetries. One can imagine two counterparts of the stringy coordinate z in TGD framework.

(a) Super-symplectic and super Kac-Moody symmetries are local with respect to X^2 in the sense that the coefficients of generators depend on the invariant $J = \epsilon^{\alpha\beta}J_{\alpha\beta}\sqrt{g_2}$ rather than being completely free [K13] . Thus the real variable J replaces complex (or hyper-complex) stringy coordinate and effective 1-dimensionality holds true also now but in different sense than for conformal field theories.

(b) The slicing of X^4 by string world sheets Y^2 and partonic 2-surfaces X^2 implied by number theoretical compactification implies string-parton duality and involves the super conformal fermionic gauge symmetries associated with the coordinates u and w in the dual dimensional reductions to stringy and partonic dynamics. These coordinates define the natural analogs of stringy coordinate. The effective reduction of X_l^3 to braid by finite measurement resolution implies the effective reduction of $X^4(X^3)$ to string world sheet. This implies quite strong resemblance with string model. The realization that spinor modes with well- define em charge must be localized at string world sheets makes the connection with strings even more explicit [K80].

One can understand how Equivalence Principle emerges in TGD framework at space-time level when many-sheeted space-time (see fig. `http://www.tgdtheory.fi/appfigures/manysheeted.jpg` or fig. 9 in the appendix of this book) is replaced with effective space-time lumping together the space-time sheets to M^4 endowed with effective metric. The quantum counterpart EP has most feasible interpretation in terms of Quantum Classical Correspondence (QCC): the conserved Kähler four-momentum equals to an eigenvalue of conserved Kähler-Dirac four-momentum acting as operator.

(c) The conformal fields of string model would reside at X^2 or Y^2 depending on which description one uses and complex (hyper-complex) string coordinate would be identified accordingly. Y^2 could be fixed as a union of stringy world sheets having the strands of number theoretic braids as its ends. The proposed definition of braids is unique and characterizes finite measurement resolution at space-time level. X^2 could be fixed uniquely as the intersection of X_l^3 (the light-like 3-surface at which induced metric of space-time surface changes its signature) with $\delta M_\pm^4 \times CP_2$. Clearly, wormhole throats X_l^3 would take the role of branes and would be connected by string world sheets defined by number theoretic braids.

(d) An alternative identification for TGD parts of conformal fields is inspired by $M^8 - H$ duality. Conformal fields would be fields in WCW. The counterpart of z coordinate could be the hyper-octonionic M^8 coordinate m appearing as argument in the Laurent series of WCW Clifford algebra elements. m would characterize the position of the tip of CD and the fractal hierarchy of CDs within CDs would give a hierarchy of Clifford algebras and thus inclusions of hyper-finite factors of type II_1. Reduction to hyper-quaternionic field -that is field in M^4 center of mass degrees of freedom- would be needed to obtained associativity. The arguments m at various level might correspond to arguments of N-point function in quantum field theory.

3.5 Appendix: Hamilton-Jacobi structure

In the following the definition of Hamilton-Jacobi structure is discussed in detail.

3.5.1 Hermitian and hyper-Hermitian structures

The starting point is the observation that besides the complex numbers forming a number field there are hyper-complex numbers. Imaginary unit i is replaced with e satisfying $e^2 = 1$. One obtains an algebra but not a number field since the norm is Minkowskian norm $x^2 - y^2$, which vanishes at light-cone $x = y$ so that light-like hypercomplex numbers $x \pm e$) do not have inverse. One has "almost" number field.

Hyper-complex numbers appear naturally in 2-D Minkowski space since the solutions of a massless field equation can be written as $f = g(u = t - ex) + h(v = t + ex)$ whith $e^2 = 1$ realized by putting $e = 1$. Therefore Wick rotation relates sums of holomorphic and antiholomorphic functions to sums of hyper-holomorphic and anti-hyper-holomorphic functions. Note that u and v are hyper-complex conjugates of each other.

Complex n-dimensional spaces allow Hermitian structure. This means that the metric has in complex coordinates $(z_1, ..., z_n)$ the form in which the matrix elements of metric are non-vanishing only between z_i and complex conjugate of z_j. In 2-D case one obtains just $ds^2 = g_{z\overline{z}}dzd\overline{z}$. Note that in this case metric is conformally flat since line element is proportional to the line element $ds^2 = dzd\overline{z}$ of plane. This form is always possible locally. For complex n-D case one obtains $ds^2 = g_{i\overline{j}}dz^i d\overline{z}^j$. $g_{i\overline{j}} = \overline{g_{j\overline{i}}}$ guaranteeing the reality of ds^2. In 2-D case this condition gives $g_{z\overline{z}} = \overline{g_{z\overline{z}}}$.

How could one generalize this line element to hyper-complex n-dimensional case. In 2-D case Minkowski space M^2 one has $ds^2 = g_{uv}dudv$, $g_{uv} = 1$. The obvious generalization would be the replacement $ds^2 = g_{u_iv_j}du^i dv^j$. Also now the analogs of reality conditions must hold with respect to $u_i \leftrightarrow v_i$.

3.5.2 Hamilton-Jacobi structure

Consider next the path leading to Hamilton-Jacobi structure.

4-D Minkowski space $M^4 = M^2 \times E^2$ is Cartesian product of hyper-complex M^2 with complex plane E^2, and one has $ds^2 = dudv + dzd\overline{z}$ in standard Minkowski coordinates. One can also consider more general integrable decompositions of M^4 for which the tangent space $TM^4 = M^4$ at each point is decomposed to $M^2(x) \times E^2(x)$. The physical analogy would be a position dependent decomposition of the degrees of freedom of massless particle to longitudinal ones ($M^2(x)$: light-like momentum is in this plane) and transversal ones ($E^2(x)$: polarization vector is in this plane). Cylindrical and spherical variants of Minkowski coordinates define two examples of this kind of coordinates (it is perhaps a good exercise to think what kind of decomposition of tangent space is in question in these examples). An interesting mathematical problem highly relevant for TGD is to identify all possible decompositions of this kind for empty Minkowski space.

The integrability of the decomposition means that the planes $M^2(x)$ are tangent planes for 2-D surfaces of M^4 analogous to Euclidian string world sheet. This gives slicing of M^4 to Minkowskian string world sheets parametrized by euclidian string world sheets. The question is whether the sheets are stringy in a strong sense: that is minimal surfaces. This is not the case: for spherical coordinates the Euclidian string world sheets would be spheres which are not minimal surfaces. For cylindrical and spherical coordinates howeverr $M^2(x)$ integrate to plane M^2, which is minimal surface.

Integrability means in the case of $M^2(x)$ the existence of light-like vector field J whose flow lines define a global coordinate. Its existence implies also the existence of its conjugate and together these vector fields give rise to $M^2(x)$ at each point. This means that one has $J = \Psi\nabla\Phi$: Φ indeed defines the global coordinate along flow lines. In the case of M^2 either the coordinate u or v would be the coordinate in question. This kind of flows are called Beltrami flows. Obviously the same holds for the transversal planes E^2.

One can generalize this metric to the case of general 4-D space with Minkowski signature of metric. At least the elements g_{uv} and $g_{z\overline{z}}$ are non-vanishing and can depend on both u, v

and $z, \overline{z}$. They must satisfy the reality conditions $g_{z\overline{z}} = \overline{g_{z\overline{z}}}$ and $g_{uv} = \overline{g_{vu}}$ where complex conjugation in the argument involves also $u \leftrightarrow v$ besides $z \leftrightarrow \overline{z}$.

The question is whether the components g_{uz}, g_{vz}, and their complex conjugates are non-vanishing if they satisfy some conditions. They can. The direct generalization from complex 2-D space would be that one treats u and v as complex conjugates and therefore requires a direct generalization of the hermiticity condition

$$g_{uz} = \overline{g_{v\overline{z}}} \quad , \quad g_{vz} = \overline{g_{u\overline{z}}} \quad .$$

This would give complete symmetry with the complex 2-D (4-D in real sense) spaces. This would allow the algebraic continuation of hermitian structures to Hamilton-Jacobi structures by just replacing i with e for some complex coordinates.

Chapter 4

Elementary Particle Vacuum Functionals

4.1 Introduction

One of the basic ideas of TGD approach has been genus-generation correspondence: boundary components of the 3-surface should be carriers of elementary particle numbers and the observed fermion families should correspond to various boundary topologies. The details of the assumed correspondence have evolved during years.

(a) The first proposal indeed indeed that both fermions and bosons correspond to boundary components so that the genus of the boundary component would classify the particles topologically. At this time I still believed that stringy diagrams would have a direct generalization in TGD framework implying that g would define additive quantum number effectively. Later it became clear that it is Feynman diagrams which must be generalized and the partons at primary vertices must have same genus. Stringy diagrams are still there but have totally different interpretation.

(b) Boundary component was later replaced with the light-like surface at which the signature of the induced metric changes and it was natural to identify bosons as wormhole contacts carrying fermion and anti-fermion quantum numbers at opposite light-like worm-hole throats. Hence bosons would be labeled by pairs (g_1, g_2) of genera. For gravitons one had to assume pairs of wormhole contacts in order to obtain spin 2. Already at this stage it became clear that SU(3) should act as a dynamical symmetry with fermions in triplet representation and bosons in octet and singlet representations. The light bosons would correspond to singlets which would guarantee universality of the couplings to fermion families.

(c) For long time fermions were identified as single throats but twistorial program and the properties of Chern-Simons Dirac operator suggesting strongly that the fundamental entities must be massless, forced to replace physical fermion with a wormhole contact characterized by (g, g) and transforming like triplet with respect to SU(3) as far as vertices are considered. The hypothesis that SU(3) acts as dynamical symmetry for the reaction vertices has very powerful implications and allows only BFF type vertices required also by bosonic emergence and SUSY symmetry.

(d) A further step in the evolution of ideas was the realization that electric-magnetic duality forces to identify all elementary particles as "weak" string like objects consisting of Kähler magnetic flux tubes with opposite magnetic charges at ends. This meant that all elementary particles - not only gravitons- are described by "weak" strings. Note that this stringy character should not be confused with that for wormhole contacts for which throats effectively play the role of string ends. One can say that fundamental objects are massless states at wormhole throats and that all elementary particles as well as string like objects emerge from them.

One might hope that this picture is not too far from the final one as far elementary particles are considered. If one accepts this picture the remaining question is why the number of genera is just three. Could this relate to the fact that $g \leq 2$ Riemann surfaces are always hyper-elliptic (have global Z_2 conformal symmetry) unlike $g > 2$ surfaces? Why the complete bosonic de-localization of the light families should be restricted inside the hyper-elliptic sector? Does the Z_2 conformal symmetry make these states light and make possible de-localization and dynamical $SU(3)$ symmetry? Could it be that for $g > 2$ elementary particle vacuum functionals vanish for hyper-elliptic surfaces? If this the case and if the time evolution for partonic 2-surfaces changing g commutes with Z_2 symmetry then the vacuum functionals localized to $g \leq 2$ surfaces do not disperse to $g > 2$ sectors.

In order to provide answers to either series of questions one must know something about the dependence of the elementary particle state functionals on the geometric properties of the boundary component and in the sequel an attempt to construct what might be called elementary particle vacuum functionals, is made. Irrespective of what identification of interaction vertices is adopted, the arguments involved with the construction involve only the string model type vertices so that the previous discussion seems to apply more or less as such.

The basic assumptions underlying the construction are the following ones:

(a) Elementary particle vacuum functionals depend on the geometric properties of the two-surface X^2 representing elementary particle.

(b) Vacuum functionals possess extended Diff invariance: all 2-surfaces on the orbit of the 2-surface X^2 correspond to the same value of the vacuum functional. This condition is satisfied if vacuum functionals have as their argument, not X^2 as such, but some 2- surface Y^2 belonging to the unique orbit of X^2 (determined by the principle selecting preferred extremal of the Kähler action as a generalized Bohr orbit [K29]) and determined in $Diff^3$ invariant manner.

(c) Zero energy ontology allows to select uniquely the partonic two surface as the intersection of the wormhole throat at which the signature of the induced 4-metric changes with either the upper or lower boundary of $CD \times CP_2$. This is essential since otherwise one one could not specify the vacuum functional uniquely.

(d) Vacuum functionals possess conformal invariance and therefore for a given genus depend on a finite number of variables specifying the conformal equivalence class of Y^2.

(e) Vacuum functionals satisfy the cluster decomposition property: when the surface Y^2 degenerates to a union of two disjoint surfaces (particle decay in string model inspired picture), vacuum functional decomposes into a product of the vacuum functionals associated with disjoint surfaces.

(f) Elementary particle vacuum functionals are stable against the two-particle decay $g \rightarrow g_1 + g_2$ and one particle decay $g \rightarrow g - 1$.

In the following the construction will be described in more detail.

(a) Some basic concepts related to the description of the space of the conformal equivalence classes of Riemann surfaces are introduced and the concept of hyper-ellipticity is introduced. Since theta functions will play a central role in the construction of the vacuum functionals, also their basic properties are discussed.

(b) After these preliminaries the construction of elementary particle vacuum functionals is carried out.

(c) Possible explanations for the experimental absence of the higher fermion families are considered.

The appendix of the book gives a summary about basic concepts of TGD with illustrations. There are concept maps about topics related to the contents of the chapter prepared using CMAP realized as html files. Links to all CMAP files can be found at `http://www.tgdtheory.fi/cmaphtml.html` [L20]. Pdf representation of same files serving as a kind of glossary can be found at `http://www.tgdtheory.fi/tgdglossary.pdf` [L21]. The topics relevant to this chapter are given by the following list.

- TGD view about elementary particles [L49]
- p-Adic mass calculations [L37]
- Elementary particle vacuum functionals [L24]
- Emergence of bosons [L25]

4.2 Identification of elementary particles

The developments in the formulation of quantum TGD which have taken place during the period 2005-2007 [K16, K15] suggest dramatic simplifications of the general picture discussed in the earlier version of this chapter. p-Adic mass calculations [K42, K43, K37] leave a lot of freedom concerning the detailed identification of elementary particles.

4.2.1 The evolution of the topological ideas about elementary particles

One of the basic ideas of TGD approach has been genus-generation correspondence: boundary components of the 3-surface should be carriers of elementary particle numbers and the observed fermion families should correspond to various boundary topologies.

With the advent of zero energy ontology this picture changed somewhat. It is the wormhole throats identified as light-like 3-surfaces at with the induced metric of the space-time surface changes its signature from Minkowskian to Euclidian, which correspond to the light-like orbits of partonic 2-surfaces. One cannot of course exclude the possibility that also boundary components could allow to satisfy boundary conditions without assuming vacuum extremal property of nearby space-time surface. The intersections of the wormhole throats with the light-like boundaries of causal diamonds (CDs) identified as intersections of future and past directed light cones ($CD \times CP_2$ is actually in question but I will speak about CDs) define special partonic 2-surfaces and it is the moduli of these partonic 2-surfaces which appear in the elementary particle vacuum functionals naturally.

The first modification of the original simple picture comes from the identification of physical particles as bound states of pairs of wormhole contacts (see fig. `http://www.tgdtheory.fi/appfigures/wormholecontact.jpg` or fig. 10 in the appendix of this book) and from the assumption that for generalized Feynman diagrams stringy trouser vertices are replaced with vertices at which the ends of light-like wormhole throats meet. In this picture the interpretation of the analog of trouser vertex is in terms of propagation of same particle along two different paths. This interpretation is mathematically natural since vertices correspond to 2-manifolds rather than singular 2-manifolds which are just splitting to two disjoint components. Second complication comes from the weak form of electric-magnetic duality forcing to identify physical particles as weak strings with magnetic monopoles at their ends and one should understand also the possible complications caused by this generalization.

These modifications force to consider several options concerning the identification of light fermions and bosons and one can end up with a unique identification only by making some assumptions. Masslessness of all wormhole throats- also those appearing in internal lines- and dynamical $SU(3)$ symmetry for particle generations are attractive general enough assumptions of this kind. This means that bosons and their super-partners correspond to wormhole contacts with fermion and anti-fermion at the throats of the contact. Free fermions and their superpartners could correspond to CP_2 type vacuum extremals with single wormhole throat. It turns however that dynamical $SU(3)$ symmetry forces to identify massive (and possibly topologically condensed) fermions as (g, g) type wormhole contacts.

Do free fermions correspond to single wormhole throat or (g, g) wormhole?

The original interpretation of genus-generation correspondence was that free fermions correspond to wormhole throats characterized by genus. The idea of $SU(3)$ as a dynamical symmetry suggested that gauge bosons correspond to octet and singlet representations of $SU(3)$. The further idea that all lines of generalized Feynman diagrams are massless poses a strong additional constraint and it is not clear whether this proposal as such survives.

(a) Twistorial program assumes that fundamental objects are massless wormhole throats carrying collinearly moving many-fermion states and also bosonic excitations generated by super-symplectic algebra. In the following consideration only purely bosonic and single fermion throats are considered since they are the basic building blocks of physical particles. The reason is that propagators for high excitations behave like p^{-n}, n the number of fermions associated with the wormhole throat. Therefore single throat allows only spins 0,1/2,1 as elementary particles in the usual sense of the word.

(b) The identification of massive fermions (as opposed to free massless fermions) as wormhole contacts follows if one requires that fundamental building blocks are massless since at least two massless throats are required to have a massive state. Therefore the conformal excitations with CP_2 mass scale should be assignable to wormhole contacts also in the case of fermions. As already noticed this is not the end of the story: weak strings are required by the weak form of electric-magnetic duality.

(c) If free fermions corresponding to single wormhole throat, topological condensation is an essential element of the formation of stringy states. The topological condensation of fermions by topological sum (fermionic CP_2 type vacuum extremal touches another space-time sheet) suggest $(g, 0)$ wormhole contact. Note however that the identification of wormhole throat is as 3-surface at which the signature of the induced metric changes so that this conclusion might be wrong. One can indeed consider also the possibility of (g, g) pairs as an outcome of topological condensation. This is suggested also by the idea that wormhole throats are analogous to string like objects and only this option turns out to be consistent with the BFF vertex based on the requirement of dynamical $SU(3)$ symmetry to be discussed later. The structure of reaction vertices makes it possible to interpret (g, g) pairs as $SU(3)$ triplet. If bosons are obtained as fusion of fermionic and anti-fermionic throats (touching of corresponding CP_2 type vacuum extremals) they correspond naturally to (g_1, g_2) pairs.

(d) p-Adic mass calculations distinguish between fermions and bosons and the identification of fermions and bosons should be consistent with this difference. The maximal p-adic temperature $T = 1$ for fermions could relate to the weakness of the interaction of the fermionic wormhole throat with the wormhole throat resulting in topological condensation. This wormhole throat would however carry momentum and 3-momentum would in general be non-parallel to that of the fermion, most naturally in the opposite direction.

    p-Adic mass calculations suggest strongly that for bosons p-adic temperature $T = 1/n$, $n > 1$, so that thermodynamical contribution to the mass squared is negligible. The low p-adic temperature could be due to the strong interaction between fermionic and anti-fermionic wormhole throat leading to the "freezing" of the conformal degrees of freedom related to the relative motion of wormhole throats.

(e) The weak form of electric-magnetic duality forces second wormhole throat with opposite magnetic charge and the light-like momenta could sum up to massive momentum. In this case string tension corresponds to electroweak length scale. Therefore p-adic thermodynamics must be assigned to wormhole contacts and these appear as basic units connected by Kähler magnetic flux tube pairs at the two space-time sheets involved. Weak stringy degrees of freedom are however expected to give additional contribution to the mass, perhaps by modifying the ground state conformal weight.

Dynamical $SU(3)$ fixes the identification of fermions and bosons and fundamental interaction vertices

For 3 light fermion families $SU(3)$ suggests itself as a dynamical symmetry with fermions in fundamental $N = 3$-dimensional representation and $N \times N = 9$ bosons in the adjoint representation and singlet representation. The known gauge bosons have same couplings to fermionic families so that they must correspond to the singlet representation. The first challenge is to understand whether it is possible to have dynamical $SU(3)$ at the level of fundamental reaction vertices.

This is a highly non-trivial constraint. For instance, the vertices in which n wormhole throats with same (g_1, g_2) glued along the ends of lines are not consistent with this symmetry. The splitting of the fermionic worm-hole contacts before the proper vertices for throats might however allow the realization of dynamical $SU(3)$. The condition of $SU(3)$ symmetry combined with the requirement that virtual lines resulting also in the splitting of wormhole contacts are always massless, leads to the conclusion that massive fermions correspond to (g, g) type wormhole contacts transforming naturally like $SU(3)$ triplet. This picture conformal with the identification of free fermions as throats but not with the naive expectation that their topological condensation gives rise to $(g, 0)$ wormhole contact.

The argument leading to these conclusions runs as follows.

(a) The question is what basic reaction vertices are allowed by dynamical $SU(3)$ symmetry. FFB vertices are in principle all that is needed and they should obey the dynamical symmetry. The meeting of entire wormhole contacts along their ends is certainly not possible. The splitting of fermionic wormhole contacts before the vertices might be however consistent with $SU(3)$ symmetry. This would give two a pair of 3-vertices at which three wormhole lines meet along partonic 2-surfaces (rather than along 3-D wormhole contacts).

(b) Note first that crossing gives all possible reaction vertices of this kind from $F(g_1)\overline{F}(g_2) \rightarrow B(g_1, g_2)$ annihilation vertex, which is relatively easy to visualize. In this reaction $F(g_1)$ and $\overline{F}(g_2)$ wormhole contacts split first. If one requires that all wormhole throats involved are massless, the two wormhole throats resulting in splitting and carrying no fermion number must carry light-like momentum so that they cannot just disappear. The ends of the wormhole throats of the boson must glued together with the end of the fermionic wormhole throat and its companion generated in the splitting of the wormhole. This means that fermionic wormhole first splits and the resulting throats meet at the partonic 2-surface.

This requires that topologically condensed fermions correspond to (g, g) pairs rather than $(g, 0)$ pairs. The reaction mechanism allows the interpretation of (g, g) pairs as a triplet of dynamical $SU(3)$. The fundamental vertices would be just the splitting of wormhole contact and 3-vertices for throats since $SU(3)$ symmetry would exclude more complex reaction vertices such as n-boson vertices corresponding the gluing of n wormhole contact lines along their 3-dimensional ends. The couplings of singlet representation for bosons would have same coupling to all fermion families so that the basic experimental constraint would be satisfied.

(c) Both fermions and bosons cannot correspond to octet and singlet of $SU(3)$. In this case reaction vertices should correspond algebraically to the multiplication of matrix elements e_{ij}: $e_{ij}e_{kl} = \delta_{jk}e_{il}$ allowing for instance $F(g_1, g_2) + \overline{F}(g_2, g_3) \rightarrow B(g_1, g_3)$. Neither the fusion of entire wormhole contacts along their ends nor the splitting of wormhole throats before the fusion of partonic 2-surfaces allows this kind of vertices so that BFF vertex is the only possible one. Also the construction of QFT limit starting from bosonic emergence led to the formulation of perturbation theory in terms of Dirac action allowing only BFF vertex as fundamental vertex [K24] .

(d) Weak electric-magnetic duality brings in an additional complication. $SU(3)$ symmetry poses also now strong constraints and it would seem that the reactions must involve copies of basic BFF vertices for the pairs of ends of weak strings. The string ends with the same Kähler magnetic charge should meet at the vertex and give rise to BFF vertices. For instance, $F\overline{F}B$ annihilation vertex would in this manner give rise to the analog of stringy diagram in which strings join along ends since two string ends disappear in the process.

(e) This picture means that all elementary particles - not only gravitons- are described by "weak" strings involving four wormhole throats. Fundamental objects would be partonic 2-surfaces, which in principle can carry arbitrary high fermion numbers N but only $N = 1, 2$ correspond to particles with fermionic and bosonic propagators and the remaining ones correspond to propagators behaving like p^{-n}, $n > 2$, and having interpretation in terms of broken SUSY with a large value of $\mathcal{N}$ identified as the number of fermionic modes. This compositeness of elementary particles should become manifest below weak length scale. Note that this stringy character should not be confused with that for the wormhole contacts for which conformal invariance implies that throats effectively play the role of string ends. One can say that fundamental objects are massless wormhole throats and that all elementary particles as well as string like objects emerge from them.

4.2.2 Graviton and other stringy states

Fermion and anti-fermion can give rise to only single unit of spin since it is impossible to assign angular momentum with the relative motion of wormhole throats. Hence the identification of graviton as single wormhole contact is not possible. The only conclusion is that graviton must be a superposition of fermion-anti-fermion pairs and boson-anti-boson pairs with coefficients determined by the coupling of the parton to graviton. Graviton-graviton pairs might emerge in higher orders. Fermion and anti-fermion would reside at the same space-time sheet and would have a non-vanishing relative angular momentum. Also bosons could have non-vanishing relative angular momentum and Higgs bosons must indeed possess it.

Gravitons are stable if the throats of wormhole contacts carry non-vanishing gauge fluxes so that the throats of wormhole contacts are connected by flux tubes carrying the gauge flux. The mechanism producing gravitons would the splitting of partonic 2-surfaces via the basic vertex. A connection with string picture emerges with the counterpart of string identified as the flux tube connecting the wormhole throats. Gravitational constant would relate directly to the value of the string tension.

The development of the understanding of gravitational coupling has had many twists and it is perhaps to summarize the basic misunderstandings.

(a) CP_2 length scale R, which is roughly $10^{3.5}$ times larger than Planck length $l_P = \sqrt{\hbar G}$, defines a fundamental length scale in TGD. The challenge is to predict the value of Planck length $\sqrt{\hbar G}$. The outcome was an identification of a formula for $R^2/\hbar G$ predicting that the magnitude of Kähler coupling strength α_K is near to fine structure constant in electron length scale (for ordinary value of Planck constant should be added here).

(b) The emergence of the parton level formulation of TGD finally demonstrated that G actually appears in the fundamental parton level formulation of TGD as a fundamental constant characterizing the M^4 part of CP_2 Kähler gauge potential [K12, K50] . This part is pure gauge in the sense of standard gauge theory but necessary to guarantee that the theory does not reduce to topological QFT. Quantum criticality requires that G remains invariant under p-adic coupling constant evolution and is therefore predictable in principle at least.

(c) The TGD view about coupling constant evolution [K4] predicts the proportionality $G \propto L_p^2$, where L_p is p-adic length scale. Together with input from p-adic mass calculations one ends up to two conclusions. The correct conclusion was that Kähler coupling strength is equal to the fine structure constant in the p-adic length scale associated with Mersenne prime $p = M_{127} = 2^{127} - 1$ assignable to electron [K4] . I have considered also the possibility that α_K would be equal to electro-weak $U(1)$ coupling in this scale.

(d) The additional - wrong- conclusion was that gravitons must always correspond to the p-adic prime M_{127} since G would otherwise vary as function of p-adic length scale. As a matter fact, the question was for years whether it is G or g_K^2 which remains invariant under p-adic coupling constant evolution. I found both options unsatisfactory until I realized that RG invariance is possible for both g_K^2 and G! The point is that the exponent of the Kähler action associated with the piece of CP_2 type vacuum extremal assignable with the elementary particle is exponentially sensitive to the volume of this piece and logarithmic dependence on the volume fraction is enough to compensate the $L_p^2 \propto p$ proportionality of G and thus guarantee the constancy of G.

The explanation for the small value of the gravitational coupling strength serves as a test for the proposed picture. The exchange of ordinary gauge boson involves the exchange of single CP_2 type extremal giving the exponent of Kähler action compensated by state normalization. In the case of graviton exchange two wormhole contacts are exchanged and this gives second power for the exponent of Kähler action which is not compensated. It would be this additional exponent that would give rise to the huge reduction of gravitational coupling strength from the naive estimate $G \sim L_p^2$.

4.2.3 Spectrum of non-stringy states

The 1-throat character of fermions is consistent with the generation-genus correspondence. The 2-throat character of bosons predicts that bosons are characterized by the genera (g_1, g_2) of the wormhole throats. Note that the interpretation of fundamental fermions as wormhole contacts with second throat identified as a Fock vacuum is excluded.

The general bosonic wave-function would be expressible as a matrix M_{g_1,g_2} and ordinary gauge bosons would correspond to a diagonal matrix $M_{g_1,g_2} = \delta_{g_1,g_2}$ as required by the absence of neutral flavor changing currents (say gluons transforming quark genera to each other). 8 new gauge bosons are predicted if one allows all 3×3 matrices with complex entries orthonormalized with respect to trace meaning additional dynamical $SU(3)$ symmetry. Ordinary gauge bosons would be $SU(3)$ singlets in this sense. The existing bounds on flavor changing neutral currents give bounds on the masses of the boson octet. The 2-throat character of bosons should relate to the low value $T = 1/n \ll 1$ for the p-adic temperature of gauge bosons as contrasted to $T = 1$ for fermions.

If one forgets the complications due to the stringy states (including graviton), the spectrum of elementary fermions and bosons is amazingly simple and almost reduces to the spectrum of standard model. In the fermionic sector one would have fermions of standard model. By simple counting leptonic wormhole throat could carry $2^3 = 8$ states corresponding to 2 polarization states, 2 charge states, and sign of lepton number giving 8+8=16 states altogether. Taking into account phase conjugates gives 16+16=32 states.

In the non-stringy boson sector one would have bound states of fermions and phase conjugate fermions. Since only two polarization states are allowed for massless states, one obtains $(2+1) \times (3+1) = 12$ states plus phase conjugates giving 12+12=24 states. The addition of color singlet states for quarks gives 48 gauge bosons with vanishing fermion number and color quantum numbers. Besides 12 electro-weak bosons and their 12 phase conjugates there are 12 exotic bosons and their 12 phase conjugates. For the exotic bosons the couplings to quarks and leptons are determined by the orthogonality of the coupling matrices of ordinary and boson states. For exotic counterparts of W bosons and Higgs the sign of the coupling to quarks is opposite. For photon and Z^0 also the relative magnitudes of the couplings to quarks must change. Altogether this makes 48+16+16=80 states. Gluons would result as color octet states. Family replication would extend each elementary boson state into $SU(3)$ octet and singlet and elementary fermion states into $SU(3)$ triplets.

4.3 Basic facts about Riemann surfaces

In the following some basic aspects about Riemann surfaces will be summarized. The basic topological concepts, in particular the concept of the mapping class group, are introduced, and the Teichmueller parameters are defined as conformal invariants of the Riemann surface, which in fact specify the conformal equivalence class of the Riemann surface completely.

4.3.1 Mapping class group

The first homology group $H_1(X^2)$ of a Riemann surface of genus g contains $2g$ generators [A34, A27, A36] : this is easy to understand geometrically since each handle contributes two homology generators. The so called canonical homology basis can be .

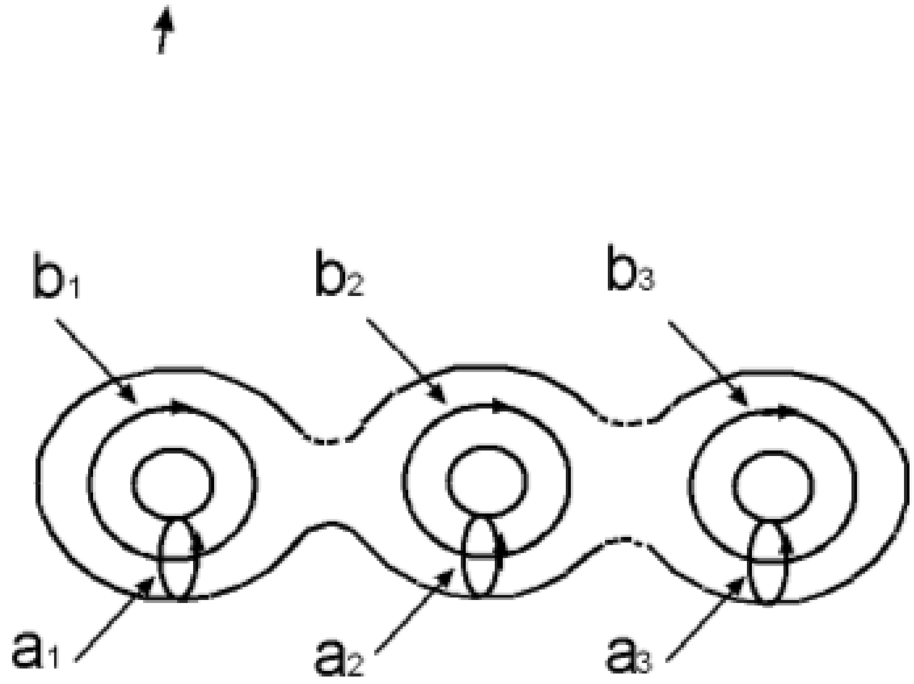

Figure 4.1: Definition of the canonical homology basis

One can define the so called intersection $J(a,b)$ for two elements a and b of the homology group as the number of intersection points for the curves a and b counting the orientation. Since $J(a,b)$ depends on the homology classes of a and b only, it defines an antisymmetric quadratic form in $H_1(X^2)$. In the canonical homology basis the non-vanishing elements of the intersection matrix are:

$$J(a_i,b_j) \quad = \quad -J(b_j,a_i) = \delta_{i,j} \quad . \tag{4.3.1}$$

J clearly defines symplectic structure in the homology group.

The dual to the canonical homology basis consists of the harmonic one-forms $\alpha_i, \beta_i, i = 1,..,g$ on X^2. These 1-forms satisfy the defining conditions

$$\begin{array}{ll} \int_{a_i} \alpha_j = \delta_{i,j} & \int_{b_i} \alpha_j = 0 \ , \\ \int_{a_i} \beta_j = 0 & \int_{b_i} \beta_j = \delta_{i,j} \ . \end{array} \tag{4.3.2}$$

The following identity helps to understand the basic properties of the Teichmueller parameters

$$\int_{X^2} \theta \wedge \eta \quad = \quad \sum_{i=1,..,g} [\int_{a_i} \theta \int_{b_i} \eta - \int_{b_i} \theta \int_{a_i} \eta] \ . \tag{4.3.3}$$

The existence of topologically nontrivial diffeomorphisms, when X^2 has genus $g > 0$, plays an important role in the sequel. Denoting by $Diff$ the group of the diffeomorphisms of X^2 and by $Diff_0$ the normal subgroup of the diffeomorphisms homotopic to identity, one can define the mapping class group M as the coset group

$$M \quad = \quad Diff/Diff_0 \ . \tag{4.3.4}$$

The generators of M are so called Dehn twists along closed curves a of X^2. Dehn twist is defined by excising a small tubular neighborhood of a, twisting one boundary of the resulting tube by 2π and gluing the tube back into the surface: see Fig. 4.3.1.

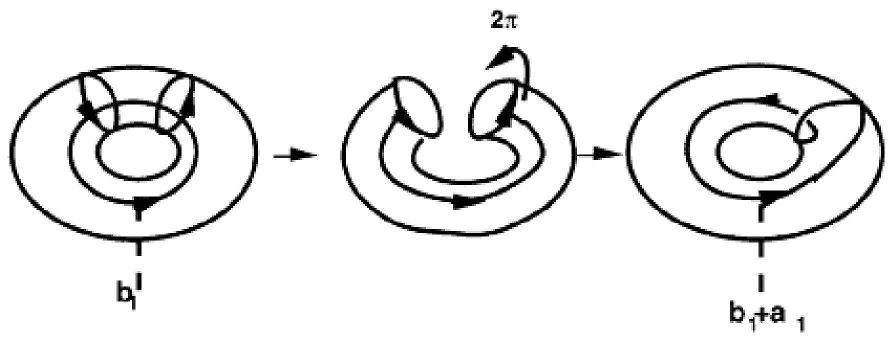

Figure 4.2: Definition of the Dehn twist

It can be shown that a minimal set of generators is defined by the following curves

$$a_1, b_1, a_1^{-1}a_2^{-1}, a_2, b_2, a_2^{-1}a_3^{-11}, ..., a_g, b_g \ . \tag{4.3.5}$$

The action of these transformations in the homology group can be regarded as a symplectic linear transformation preserving the symplectic form defined by the intersection matrix. Therefore the matrix representing the action of $Diff$ on $H_1(X^2)$ is $2g \times 2g$ matrix M with integer entries leaving J invariant: $MJM^T = J$. Mapping class group is often referred also and denoted by $Sp(2g, Z)$. The matrix representing the action of M in the canonical homology basis decomposes into four $g \times g$ blocks A, B, C and D

$$M = \begin{pmatrix} A & B \\ C & D \end{pmatrix} \ , \tag{4.3.6}$$

where A and D operate in the subspaces spanned by the homology generators a_i and b_i respectively and C and D map these spaces to each other. The notation $D = [A, B; C, D]$ will be used in the sequel: in this notation the representation of the symplectic form J is $J = [0, 1; -1, 0]$.

4.3.2 Teichmueller parameters

The induced metric on the two-surface X^2 defines a unique complex structure. Locally the metric can always be written in the form

$$ds^2 = e^{2\phi}dzd\bar{z} . \quad (4.3.7)$$

where z is local complex coordinate. When one covers X^2 by coordinate patches, where the line element has the above described form, the transition functions between coordinate patches are holomorphic and therefore define a complex structure.

The conformal transformations ξ of X^2 are defined as the transformations leaving invariant the angles between the vectors of X^2 tangent space invariant: the angle between the vectors X and Y at point x is same as the angle between the images of the vectors under Jacobian map at the image point $\xi(x)$. These transformations need not be globally defined and in each coordinate patch they correspond to holomorphic (anti-holomorphic) mappings as is clear from the diagonal form of the metric in the local complex coordinates. A distinction should be made between local conformal transformations and globally defined conformal transformations, which will be referred to as conformal symmetries: for instance, for hyper-elliptic surfaces the group of the conformal symmetries contains two-element group Z_2.

Using the complex structure one can decompose one-forms to linear combinations of one-forms of type $(1,0)$ $(f(z,\bar{z})dz)$ and $(0,1)$ $(f(z,\bar{z})d\bar{z})$. $(1,0)$ form ω is holomorphic if the function f is holomorphic: $\omega = f(z)dz$ on each coordinate patch.

There are g independent holomorphic one forms ω_i known also as Abelian differentials Alvarez,Farkas,Mumford and one can fix their normalization by the condition

$$\int_{a_i} \omega_j = \delta_{ij} . \quad (4.3.8)$$

This condition completely specifies ω_i.

Teichmueller parameters Ω_{ij} are defined as the values of the forms ω_i for the homology generators b_j

$$\Omega_{ij} = \int_{b_j} \omega_i . \quad (4.3.9)$$

The basic properties of Teichmueller parameters are the following:

(a) The $g \times g$ matrix Ω is symmetric: this is seen by applying the formula (4.3.3) for $\theta = \omega_i$ and $\eta = \omega_j$.

(b) The imaginary part of Ω is positive: $Im(\Omega) > 0$. This is seen by the application of the same formula for $\theta = \eta$. The space of the matrices satisfying these conditions is known as Siegel upper half plane.

(c) The space of Teichmueller parameters can be regarded as a coset space $Sp(2g,R)/U(g)$ [A36] : the action of $Sp(2g,R)$ is of the same form as the action of $Sp(2g,Z)$ and $U(g) \subset Sp(2g,R)$ is the isotropy group of a given point of Teichmueller space.

(d) Teichmueller parameters are conformal invariants as is clear from the holomorphy of the defining one-forms.

(e) Teichmueller parameters specify completely the conformal structure of Riemann surface [A27]

Although Teichmueller parameters fix the conformal structure of the 2-surface completely, they are not in one-to-one correspondence with the conformal equivalence classes of the two-surfaces:
i) The dimension for the space of the conformal equivalence classes is $D = 3g - 3$, when $g > 1$ and smaller than the dimension of Teichmueller space given by $d = (g \times g + g)/2$ for $g > 3$: all Teichmueller matrices do not correspond to a Riemann surface. In TGD approach this does not produce any problems as will be found later.
ii) The action of the topologically nontrivial diffeomorphisms on Teichmueller parameters is nontrivial and can be deduced from the action of the diffeomorphisms on the homology ($Sp(2g, Z)$ transformation) and from the defining condition $\int_{a_i} \omega_j = \delta_{i,j}$: diffeomorphisms correspond to elements $[A, B; C, D]$ of $Sp(2g, Z)$ and act as generalized Möbius transformations

$$\Omega \rightarrow (A\Omega + B)(C\Omega + D)^{-1} \ . \tag{4.3.10}$$

All Teichmueller parameters related by $Sp(2g, Z)$ transformations correspond to the same Riemann surface.
iii) The definition of the Teichmueller parameters is not unique since the definition of the canonical homology basis involves an arbitrary numbering of the homology basis. The permutation S of the handles is represented by same $g \times g$ orthogonal matrix both in the basis $\{a_i\}$ and $\{b_i\}$ and induces a similarity transformation in the space of the Teichmueller parameters

$$\Omega \rightarrow S\Omega S^{-1} \ . \tag{4.3.11}$$

Clearly, the Teichmueller matrices related by a similarity transformations correspond to the same conformal equivalence class. It is easy to show that handle permutations in fact correspond to $Sp(2g, Z)$ transformations.

4.3.3 Hyper-ellipticity

The motivation for considering hyper-elliptic surfaces comes from the fact, that $g > 2$ elementary particle vacuum functionals turn out to be vanishing for hyper-elliptic surfaces and this in turn will be later used to provide a possible explanation the non-observability of $g > 2$ particles.

Hyper-elliptic surface X can be defined abstractly as two-fold branched cover of the sphere having the group Z_2 as the group of conformal symmetries (see [A21, A27, A36] . Thus there exists a map $\pi : X \rightarrow S^2$ so that the inverse image $\pi^{-1}(z)$ for a given point z of S^2 contains two points except at a finite number (say p) of points z_i (branch points) for which the inverse image contains only one point. Z_2 acts as conformal symmetries permuting the two points in $\pi^{-1}(z)$ and branch points are fixed points of the involution.

The concept can be generalized [A21] : g-hyper-elliptic surface can be defined as a 2-fold covering of genus g surface with a finite number of branch points. One can consider also p-fold coverings instead of 2-fold coverings: a common feature of these Riemann surfaces is the existence of a discrete group of conformal symmetries.

A concrete representation for the hyper-elliptic surfaces [A36] is obtained by studying the surface of C^2 determined by the algebraic equation

$$w^2 - P_n(z) \ = \ 0 \ , \tag{4.3.12}$$

where w and z are complex variables and $P_n(z)$ is a complex polynomial. One can solve w from the above equation

$$w_{\pm} = \pm\sqrt{P_n(z)} \ , \tag{4.3.13}$$

where the square root is determined so that it has a cut along the positive real axis. What happens that w has in general two roots (two-fold covering property), which coincide at the roots z_i of $P_n(z)$ and if n is odd, also at $z = \infty$: these points correspond to branch points of the hyper-elliptic surface and their number r is always even: $r = 2k$. w is discontinuous at the cuts associated with the square root in general joining two roots of $P_n(z)$ or if n is odd, also some root of P_n and the point $z = \infty$. The representation of the hyper-elliptic surface is obtained by identifying the two branches of w along the cuts. From the construction it is clear that the surface obtained in this manner has genus $k - 1$. Also it is clear that Z_2 permutes the different roots $w_{\pm}$ with each other and that $r = 2k$ branch points correspond to fixed points of the involution.

The following facts about the hyper-elliptic surfaces [A27, A36] turn out to be important in the sequel:
i) All $g < 3$ surfaces are hyper-elliptic.
ii) $g \geq 3$ hyper-elliptic surfaces are not in general hyper-elliptic and form a set of codimension 2 in the space of the conformal equivalence classes [A36] .

4.3.4 Theta functions

An extensive and detailed account of the theta functions and their applications can be found in the book of Mumford [A36] . Theta functions appear also in the loop calculations of string [J2] [A34] . In the following the so called Riemann theta function and theta functions with half integer characteristics will be defined as sections (not strictly speaking functions) of the so called Jacobian variety.

For a given Teichmueller matrix Ω, Jacobian variety is defined as the $2g$-dimensional torus obtained by identifying the points z of C^g (vectors with g complex components) under the equivalence

$$z \sim z + \Omega m + n \ , \tag{4.3.14}$$

where m and n are points of Z^g (vectors with g integer valued components) and Ω acts in Z^g by matrix multiplication.

The definition of Riemann theta function reads as

$$\Theta(z|\Omega) = \sum_n exp(i\pi n \cdot \Omega \cdot n + i2\pi n \cdot z) \ . \tag{4.3.15}$$

Here $\cdot$ denotes standard inner product in C^g. Theta functions with half integer characteristics are defined in the following manner. Let a and b denote vectors of C^g with half integer components (component either vanishes or equals to $1/2$). Theta function with characteristics $[a, b]$ is defined through the following formula

$$\Theta[a,b](z|\Omega) = \sum_n exp\left[i\pi(n+a)\cdot\Omega\cdot(n+a) + i2\pi(n+a)\cdot(z+b)\right] \ . \tag{4.3.16}$$

A brief calculation shows that the following identity is satisfied

$$\Theta[a,b](z|\Omega) \quad = \quad exp(i\pi a\cdot\Omega\cdot a + i2\pi a\cdot b)\times\Theta(z+\Omega a+b|\Omega) \tag{4.3.17}$$

Theta functions are not strictly speaking functions in the Jacobian variety but rather sections in an appropriate bundle as can be seen from the identities

$$\begin{aligned} \Theta[a,b](z+m|\Omega) &= exp(i2\pi a\cdot m)\Theta[a,b](z\Omega) \ , \\ \Theta[a,b](z+\Omega m|\Omega) &= exp(\alpha)\Theta[a,b](z|\Omega) \ , \\ exp(\alpha) &= exp(-i2\pi b\cdot m)exp(-i\pi m\cdot\Omega\cdot m - 2\pi m\cdot z) \ . \end{aligned} \tag{4.3.18}$$

The number of theta functions is 2^{2g} and same as the number of nonequivalent spinor structures defined on two-surfaces. This is not an accident [A34] : theta functions with given characteristics turn out to be in a close relation to the functional determinants associated with the Dirac operators defined on the two-surface. It is useful to divide the theta functions to even and odd theta functions according to whether the inner product $4a\cdot b$ is even or odd integer. The numbers of even and odd theta functions are $2^{g-1}(2^g+1)$ and $2^{g-1}(2^g-1)$ respectively.

The values of the theta functions at the origin of the Jacobian variety understood as functions of Teichmueller parameters turn out to be of special interest in the following and the following notation will be used:

$$\Theta[a,b](\Omega) \quad \equiv \quad \Theta[a,b](0|\Omega) \ , \tag{4.3.19}$$

$\Theta[a,b](\Omega)$ will be referred to as theta functions in the sequel. From the defining properties of odd theta functions it can be found that they are odd functions of z and therefore vanish at the origin of the Jacobian variety so that only even theta functions will be of interest in the sequel.

An important result is that also some *even* theta functions vanish for $g>2$ hyper-elliptic surfaces : in fact one can characterize $g>2$ hyper-elliptic surfaces by the vanishing properties of the theta functions [A27, A36] . The vanishing property derives from conformal symmetry (Z_2 in the case of hyper-elliptic surfaces) and the vanishing phenomenon is rather general [A21] : theta functions tend to vanish for Riemann surfaces possessing discrete conformal symmetries. It is not clear (to the author) whether the presence of a conformal symmetry is in fact equivalent with the vanishing of some theta functions. As already noticed, spinor structures and the theta functions with half integer characteristics are in one-to-one correspondence and the vanishing of theta function with given half integer characteristics is equivalent with the vanishing of the Dirac determinant associated with the corresponding spinor structure or equivalently: with the existence of a zero mode for the Dirac operator Alvarez . For odd characteristics zero mode exists always: for even characteristics zero modes exist, when the surface is hyper-elliptic or possesses more general conformal symmetries.

4.4 Elementary particle vacuum functionals

The basic assumption is that elementary particle families correspond to various elementary particle vacuum functionals associated with the 2-dimensional boundary components of the 3-surface. These functionals need not be localized to a single boundary topology. Neither need their dependence on the boundary component be local. An important role in the following considerations is played by the fact that the preferred extremal property associates a unique 3-surface to each boundary component, the "Bohr orbit" of the boundary and this surface provides a considerable (and necessarily needed) flexibility in the definition of the elementary particle vacuum functionals. There are several natural constraints to be satisfied by elementary particle vacuum functionals.

4.4.1 Extended Diff invariance and Lorentz invariance

Extended Diff invariance is completely analogous to the extension of 3-dimensional Diff invariance to four-dimensional Diff invariance in the interior of the 3-surface. Vacuum functional must be invariant not only under diffeomorphisms of the boundary component but also under the diffeomorphisms of the 3- dimensional "orbit" Y^3 of the boundary component. In other words: the value of the vacuum functional must be same for any time slice on the orbit the boundary component. This is guaranteed if vacuum functional is functional of some two-surface Y^2 belonging to the orbit and defined in $Diff^3$ invariant manner.

An additional natural requirement is Poincare invariance. In the original formulation of the theory only Lorentz transformations of the light cone were exact symmetries of the theory. In this framework the definition of Y^2 as the intersection of the orbit with the hyperboloid $\sqrt{m_{kl}m^km^l} = a$ is $Diff^3$ and Lorentz invariant.

1. Interaction vertices as generalization of stringy vertices

For stringy diagrams Poincare invariance of conformal equivalence class and general coordinate invariance are far from being a trivial issues. Vertices are now not completely unique since there is an infinite number of singular 3-manifolds which can be identified as vertices even if one assumes space-likeness. One should be able to select a unique singular 3-manifold to fix the conformal equivalence class.

One might hope that Lorentz invariant invariant and general coordinate invariant definition of Y^2 results by introducing light cone proper time a as a height function specifying uniquely the point at which 3-surface is singular (stringy diagrams help to visualize what is involved), and by restricting the singular 3-surface to be the intersection of $a = constant$ hyperboloid of M^4 containing the singular point with the space-time surface. There would be non-uniqueness of the conformal equivalence class due to the choice of the origin of the light cone but the decomposition of the configuration space of 3-surfaces to a union of WCWs characterized by unions of future and past light cones could resolve this difficulty.

2. Interaction vertices as generalization of ordinary ones

If the interaction vertices are identified as intersections for the ends of space-time sheets representing particles, the conformal equivalence class is naturally identified as the one associated with the intersection of the boundary component or light like causal determinant with the vertex. Poincare invariance of the conformal equivalence class and generalized general coordinate invariance follow trivially in this case.

4.4.2 Conformal invariance

Conformal invariance implies that vacuum functionals depend on the conformal equivalence class of the surface Y^2 only. What makes this idea so attractive is that for a given genus g WCW becomes effectively finite-dimensional. A second nice feature is that instead of trying to find coordinates for the space of the conformal equivalence classes one can construct vacuum functionals as functions of the Teichmueller parameters.

That one can construct this kind of functions as suitable functions of the Teichmueller parameters is not trivial. The essential point is that the boundary components can be regarded as sub-manifolds of $M^4_+ \times CP_2$: as a consequence vacuum functional can be regarded as a composite function:

2-surface $\rightarrow$ Teichmueller matrix Ω determined by the induced metric $\rightarrow \Omega_{vac}(\Omega)$

Therefore the fact that there are Teichmueller parameters which do not correspond to any Riemann surface, doesn't produce any trouble. It should be noticed that the situation differs from that in the Polyakov formulation of string models, where one doesn't assume that the metric of the two-surface is induced metric (although classical equations of motion imply this).

4.4.3 Diff invariance

Since several values of the Teichmueller parameters correspond to the same conformal equivalence class, one must pose additional conditions on the functions of the Teichmueller parameters in order to obtain single valued functions of the conformal equivalence class.

The first requirement of this kind is the invariance under topologically nontrivial Diff transformations inducing $Sp(2g,Z)$ transformation $(A,B;C,D)$ in the homology basis. The action of these transformations on Teichmueller parameters is deduced by requiring that holomorphic one-forms satisfy the defining conditions in the transformed homology basis. It turns out that the action of the topologically nontrivial diffeomorphism on Teichmueller parameters can be regarded as a generalized Möbius transformation:

$$\Omega \rightarrow (A\Omega + B)(C\Omega + D)^{-1} \quad . \tag{4.4.1}$$

Vacuum functional must be invariant under these transformations. It should be noticed that the situation differs from that encountered in the string models. In TGD the integration measure over WCW is Diff invariant: in string models the integration measure is the integration measure of the Teichmueller space and this is not invariant under $Sp(2g,Z)$ but transforms like a density: as a consequence the counterpart of the vacuum functional must be also modular covariant since it is the product of vacuum functional and integration measure, which must be modular invariant.

It is possible to show that the quantities

$$(\Theta[a,b]/\Theta[c,d])^4 \quad . \tag{4.4.2}$$

and their complex conjugates are $Sp(2g,Z)$ invariants [A36] and therefore can be regarded as basic building blocks of the vacuum functionals.

Teichmueller parameters are not uniquely determined since one can always perform a permutation of the g handles of the Riemann surface inducing a redefinition of the canonical homology basis (permutation of g generators). These transformations act as similarities of the Teichmueller matrix:

$$\Omega \rightarrow S\Omega S^{-1} \quad , \tag{4.4.3}$$

where S is the $g \times g$ matrix representing the permutation of the homology generators understood as orthonormal vectors in the g- dimensional vector space. Therefore the Teichmueller parameters related by these similarity transformations correspond to the same conformal equivalence class of the Riemann surfaces and vacuum functionals must be invariant under these similarities.

It is easy to find out that these similarities permute the components of the theta characteristics: $[a,b] \rightarrow [S(a),S(b)]$. Therefore the invariance requirement states that the handles of the Riemann surface behave like bosons: the vacuum functional constructed from the theta functions is invariant under the permutations of the theta characteristics. In fact, this requirement brings in nothing new. Handle permutations can be regarded as $Sp(2g,Z)$ transformations so that the modular invariance alone guarantees invariance under handle permutations.

4.4.4 Cluster decomposition property

Consider next the behavior of the vacuum functional in the limit, when boundary component with genus g splits to two separate boundary components of genera g_1 and g_2 respectively. The splitting into two separate boundary components corresponds to the reduction of the Teichmueller matrix Ω^g to a direct sum of $g_1 \times g_1$ and $g_2 \times g_2$ matrices ($g_1 + g_2 = g$):

$$\Omega^g = \Omega^{g_1} \oplus \Omega^{g_2} \ , \tag{4.4.4}$$

when a suitable definition of the Teichmueller parameters is adopted. The splitting can also take place without a reduction to a direct sum: the Teichmueller parameters obtained via $Sp(2g,Z)$ transformation from $\Omega^g = \Omega^{g_1} \oplus \Omega^{g_2}$ do not possess direct sum property in general.

The physical interpretation is obvious: the non-diagonal elements of the Teichmueller matrix describe the geometric interaction between handles and at this limit the interaction between the handles belonging to the separate surfaces vanishes. On the physical grounds it is natural to require that vacuum functionals satisfy cluster decomposition property at this limit: that is they reduce to the product of appropriate vacuum functionals associated with the composite surfaces.

Theta functions satisfy cluster decomposition property [A34, A36] . Theta characteristics reduce to the direct sums of the theta characteristics associated with g_1 and g_2 ($a = a_1 \oplus a_2$, $b = b_1 \oplus b_2$) and the dependence on the Teichmueller parameters is essentially exponential so that the cluster decomposition property indeed results:

$$\Theta[a,b](\Omega^g) \quad = \quad \Theta[a_1,b_1](\Omega^{g_1})\Theta[a_2,b_2](\Omega^{g_2}) \ . \tag{4.4.5}$$

Cluster decomposition property holds also true for the products of theta functions. This property is also satisfied by suitable homogenous polynomials of thetas. In particular, the following quantity playing central role in the construction of the vacuum functional obeys this property

$$Q_0 \quad = \quad \sum_{[a,b]} \Theta[a,b]^4 \bar{\Theta}[a,b]^4 \ , \tag{4.4.6}$$

where the summation is over all even theta characteristics (recall that odd theta functions vanish at the origin of C^g).

Together with the $Sp(2g,Z)$ invariance the requirement of cluster decomposition property implies that the vacuum functional must be representable in the form

$$\Omega_{vac} \quad = \quad P_{M,N}(\Theta^4,\bar{\Theta}^4)/Q_{MN}(\Theta^4,\bar{\Theta}^4) \tag{4.4.7}$$

where the homogenous polynomials $P_{M,N}$ and $Q_{M,N}$ have same degrees (M and N as polynomials of $\Theta[a,b]^4$ and $\bar{\Theta}[a,b]^4$.

4.4.5 Finiteness requirement

Vacuum functional should be finite. Finiteness requirement is satisfied provided the numerator $Q_{M,N}$ of the vacuum functional is real and positive definite. The simplest quantity of this type is the quantity Q_0 defined previously and its various powers. $Sp(2g,Z)$ invariance and finiteness requirement are satisfied provided vacuum functionals are of the following general form

$$\Omega_{vac} = \frac{P_{N,N}(\Theta^4,\bar{\Theta}^4)}{Q_0^N} , \tag{4.4.8}$$

where $P_{N,N}$ is homogenous polynomial of degree N with respect to $\Theta[a,b]^4$ and $\bar{\Theta}[a,b]^4$. In addition $P_{N,N}$ is invariant under the permutations of the theta characteristics and satisfies cluster decomposition property.

4.4.6 Stability against the decay $g \rightarrow g_1 + g_2$

Elementary particle vacuum functionals must be stable against the genus conserving decays $g \rightarrow g_1 + g_2$. This decay corresponds to the limit at which Teichmueller matrix reduces to a direct sum of the matrices associated with g_1 and g_2 (note however the presence of $Sp(2g,Z)$ degeneracy). In accordance with the topological description of the particle reactions one expects that this decay doesn't occur if the vacuum functional in question vanishes at this limit.

In general the theta functions are non-vanishing at this limit and vanish provided the theta characteristics reduce to a direct sum of the odd theta characteristics. For $g < 2$ surfaces this condition is trivial and gives no constraints on the form of the vacuum functional. For $g = 2$ surfaces the theta function $\Theta(a,b)$, with $a = b = (1/2,1/2)$ satisfies the stability criterion identically (odd theta functions vanish identically), when Teichmueller parameters separate into a direct sum. One can however perform $Sp(2g,Z)$ transformations giving new points of Teichmueller space describing the decay. Since these transformations transform theta characteristics in a nontrivial manner to each other and since all even theta characteristics belong to same $Sp(2g,Z)$ orbit [A34, A36] , the conclusion is that stability condition is satisfied provided $g = 2$ vacuum functional is proportional to the product of fourth powers of all even theta functions multiplied by its complex conjugate.

If $g > 2$ there always exists some theta functions, which vanish at this limit and the minimal vacuum functional satisfying this stability condition is of the same form as in $g = 2$ case, that is proportional to the product of the fourth powers of all even Theta functions multiplied by its complex conjugate:

$$\Omega_{vac} = \prod_{[a,b]} \Theta[a,b]^4 \bar{\Theta}[a,b]^4 / Q_0^N , \tag{4.4.9}$$

where N is the number of even theta functions. The results obtained imply that genus-generation correspondence is one to one for $g > 1$ for the minimal vacuum functionals. Of course, the multiplication of the minimal vacuum functionals with functionals satisfying all criteria except stability criterion gives new elementary particle vacuum functionals: a possible physical identification of these vacuum functionals is most naturally as some kind of excited states.

One of the questions posed in the beginning was related to the experimental absence of $g > 0$, possibly massless, elementary bosons. The proposed stability criterion suggests a nice explanation. The point is that elementary particles are stable against decays $g \rightarrow g_1 + g_2$ but not with respect to the decay $g \rightarrow g +$ *sphere*. As a consequence the direct emission of $g > 0$ gauge bosons is impossible unlike the emission of $g = 0$ bosons: for instance the decay muon $\rightarrow$ electron $+(g = 1)$ photon is forbidden.

4.4.7 Stability against the decay $g \to g-1$

This stability criterion states that the vacuum functional is stable against single particle decay $g \to g-1$ and, if satisfied, implies that vacuum functional vanishes, when the genus of the surface is smaller than g. In stringy framework this criterion is equivalent to a separate conservation of various lepton numbers: for instance, the spontaneous transformation of muon to electron is forbidden. Notice that this condition doesn't imply that that the vacuum functional is localized to a single genus: rather the vacuum functional of genus g vanishes for all surfaces with genus smaller than g. This hierarchical structure should have a close relationship to Cabibbo-Kobayashi-Maskawa mixing of the quarks.

The stability criterion implies that the vacuum functional must vanish at the limit, when one of the handles of the Riemann surface suffers a pinch. To deduce the behavior of the theta functions at this limit, one must find the behavior of Teichmueller parameters, when i:th handle suffers a pinch. Pinch implies that a suitable representative of the homology generator a_i or b_i contracts to a point.

Consider first the case, when a_i contracts to a point. The normalization of the holomorphic one-form ω_i must be preserved so that that ω_i must behaves as $1/z$, where z is the complex coordinate vanishing at pinch. Since the homology generator b_i goes through the pinch it seems obvious that the imaginary part of the Teichmueller parameter $\Omega_{ii} = \int_{b_i} \omega_i$ diverges at this limit (this conclusion is made also in [A36]): $Im(\Omega_{ii}) \to \infty$.

Of course, this criterion doesn't cover all possible manners the pinch can occur: pinch might take place also, when the components of the Teichmueller matrix remain finite. In the case of torus topology one finds that $Sp(2g, Z)$ element $(A, B; C, D)$ takes $Im(\Omega) = \infty$ to the point C/D of real axis. This suggests that pinch occurs always at the boundary of the Teichmueller space: the imaginary part of Ω_{ij} either vanishes or some matrix element of $Im(\Omega)$ diverges.

Consider next the situation, when b_i contracts to a point. From the definition of the Teichmueller parameters it is clear that the matrix elements Ω_{kl}, with $k, l \neq i$ suffer no change. The matrix element Ω_{ki} obviously vanishes at this limit. The conclusion is that i:th row of Teichmueller matrix vanishes at this limit. This result is obtained also by deriving the $Sp(2g, Z)$ transformation permuting a_i and b_i with each other: in case of torus this transformation reads $\Omega \to -1/\Omega$.

Consider now the behavior of the theta functions, when pinch occurs. Consider first the limit, when $Im(\Omega_{ii})$ diverges. Using the general definition of $\Theta[a, b]$ it is easy to find out that all theta functions for which the i:th component a_i of the theta characteristic is non-vanishing (that is $a_i = 1/2$) are proportional to the exponent $exp(-\pi\Omega_{ii}/4)$ and therefore vanish at the limit. The theta functions with $a_i = 0$ reduce to $g-1$ dimensional theta functions with theta characteristic obtained by dropping i:th components of a_i and b_i and replacing Teichmueller matrix with Teichmueller matrix obtained by dropping i:th row and column. The conclusion is that all theta functions of type $\Theta(a, b)$ with $a = (1/2, 1/2, ..., 1/2)$ satisfy the stability criterion in this case.

What happens for the $Sp(2g, Z)$ transformed points on the real axis? The transformation formula for theta function is given by [A34, A36]

$$\Theta[a, b]((A\Omega + B)(C\Omega + D)^{-1}) = exp(i\phi)det(C\Omega + D)^{1/2}\Theta[c, d](\Omega) \ , \tag{4.4.10}$$

where

$$\begin{pmatrix} c \\ d \end{pmatrix} = \begin{pmatrix} A & B \\ C & D \end{pmatrix} \left(\begin{pmatrix} a \\ b \end{pmatrix} - \begin{pmatrix} (CD^T)_d/2 \\ (AB^T)_d/2 \end{pmatrix} \right) \ . \tag{4.4.11}$$

Here ϕ is a phase factor irrelevant for the recent purposes and the index d refers to the diagonal part of the matrix in question.

The first thing to notice is the appearance of the diverging square root factor, which however disappears from the vacuum functionals (P and Q have same degree with respect to thetas). The essential point is that theta characteristics transform to each other: as already noticed all even theta characteristics belong to the same $Sp(2g, Z)$ orbit. Therefore the theta functions vanishing at $Im(\Omega_{ii}) = \infty$ do not vanish at the transformed points. It is however clear that for a given Teichmueller parameterization of pinch some theta functions vanish always.

Similar considerations in the case $\Omega_{ik} = 0$, i fixed, show that all theta functions with $b = (1/2, ..., 1/2)$ vanish identically at the pinch. Also it is clear that for $Sp(2g, Z)$ transformed points one can always find some vanishing theta functions. The overall conclusion is that the elementary particle vacuum functionals obtained by using $g \to g_1 + g_2$ stability criterion satisfy also $g \to g-1$ stability criterion since they are proportional to the product of all even theta functions. Therefore the only nontrivial consequence of $g \to g-1$ criterion is that also $g = 1$ vacuum functionals are of the same general form as $g > 1$ vacuum functionals.

A second manner to deduce the same result is by restricting the consideration to the hyper-elliptic surfaces and using the representation of the theta functions in terms of the roots of the polynomial appearing in the definition of the hyper-elliptic surface [A36] . When the genus of the surface is smaller than three (the interesting case), this representation is all what is needed since all surfaces of genus $g < 3$ are hyper-elliptic.

Since hyper-elliptic surfaces can be regarded as surfaces obtained by gluing two compactified complex planes along the cuts connecting various roots of the defining polynomial it is obvious that the process $g \to g-1$ corresponds to the limit, when two roots of the defining polynomial coincide. This limit corresponds either to disappearance of a cut or the fusion of two cuts to a single cut. Theta functions are expressible as the products of differences of various roots (Thomae's formula [A36])

$$\Theta[a,b]^4 \propto \prod_{i<j\in T} (z_i - z_j) \prod_{k<l\in CT} (z_k - z_l) \ , \tag{4.4.12}$$

where T denotes some subset of $\{1, 2, ..., 2g\}$ containing $g+1$ elements and CT its complement. Hence the product of all even theta functions vanishes, when two roots coincide. Furthermore, stability criterion is satisfied only by the product of the theta functions.

Lowest dimensional vacuum functionals are worth of more detailed consideration.
i) $g = 0$ particle family corresponds to a constant vacuum functional: by continuity this vacuum functional is constant for all topologies.
ii) For $g = 1$ the degree of P and Q as polynomials of the theta functions is 24: the critical number of transversal degrees of freedom in bosonic string model! Probably this result is not an accident.
ii) For $g = 2$ the corresponding degree is 80 since there are 10 even genus 2 theta functions.

There are large numbers of vacuum functionals satisfying the relevant criteria, which do not satisfy the proposed stability criteria. These vacuum functionals correspond either to many particle states or to unstable single particle states.

4.4.8 Continuation of the vacuum functionals to higher genus topologies

From continuity it follows that vacuum functionals cannot be localized to single boundary topology. Besides continuity and the requirements listed above, a natural requirement is that the continuation of the vacuum functional from the sector g to the sector $g + k$ reduces to the product of the original vacuum functional associated with genus g and $g = 0$ vacuum functional at the limit when the surface with genus $g + k$ decays to surfaces with genus g and

k: this requirement should guarantee the conservation of separate lepton numbers although different boundary topologies suffer mixing in the vacuum functional. These requirements are satisfied provided the continuation is constructed using the following rule:

Perform the replacement

$$\Theta[a,b]^4 \rightarrow \sum_{c,d} \Theta[a \oplus c, b \oplus d]^4 \tag{4.4.13}$$

for each fourth power of the theta function. Here c and d are Theta characteristics associated with a surface with genus k. The same replacement is performed for the complex conjugates of the theta function. It is straightforward to check that the continuations of elementary particle vacuum functionals indeed satisfy the cluster decomposition property and are continuous.

To summarize, the construction has provided hoped for answers to some questions stated in the beginning: stability requirements explain the separate conservation of lepton numbers and the experimental absence of $g > 0$ elementary bosons. What has not not been explained is the experimental absence of $g > 2$ fermion families. The vanishing of the $g > 2$ elementary particle vacuum functionals for the hyper-elliptic surfaces however suggest a possible explanation: under some conditions on the surface X^2 the surfaces Y^2 are hyper-elliptic or possess some conformal symmetry so that elementary particle vacuum functionals vanish for them. This conjecture indeed might make sense since the surfaces Y^2 are determined by the asymptotic dynamics and one might hope that the surfaces Y^2 are analogous to the final states of a dissipative system.

4.5 Explanations for the absence of the $g > 2$ elementary particles from spectrum

The decay properties of the intermediate gauge bosons [C103] are consistent with the assumption that the number of the light neutrinos is $N = 3$. Also cosmological considerations pose upper bounds on the number of the light neutrino families and $N = 3$ seems to be favored [C103]. It must be however emphasized that p-adic considerations [K37] encourage the consideration the existence of higher genera with neutrino masses such that they are not produced in the laboratory at present energies. In any case, for TGD approach the finite number of light fermion families is a potential difficulty since genus-generation correspondence suggests that the number of the fermion (and possibly also boson) families is infinite. Therefore one had better to find a good argument showing that the number of the observed neutrino families, or more generally, of the observed elementary particle families, is small also in the world described by TGD.

It will be later found that also TGD inspired cosmology requires that the number of the effectively massless fermion families must be small after Planck time. This suggests that boundary topologies with handle number $g > 2$ are unstable and/or very massive so that they, if present in the spectrum, disappear from it after Planck time, which correspond to the value of the light cone proper time $a \simeq 10^{-11}$ seconds.

In accordance with the spirit of TGD approach it is natural to wonder whether some geometric property differentiating between $g > 2$ and $g < 3$ boundary topologies might explain why only $g < 3$ boundary components are observable. One can indeed find a good candidate for this kind of property: namely hyper-ellipticity, which states that Riemann surface is a two-fold branched covering of sphere possessing two-element group Z_2 as conformal automorphisms. All $g < 3$ Riemann surfaces are hyper-elliptic unlike $g > 2$ Riemann surfaces, which in general do not posses this property. Thus it is natural to consider the possibility that hyper-ellipticity or more general conformal symmetries might explain why only $g < 2$ topologies correspond to the observed elementary particles.

As regards to the present problem the crucial observation is that some even theta functions vanish for the hyper-elliptic surfaces with genus $g > 2$ [A36] . What is essential is that these surfaces have the group Z_2 as conformal symmetries. Indeed, the vanishing phenomenon is more general. Theta functions tend to vanish for $g > 2$ two-surfaces possessing discrete group of conformal symmetries [A21] : for instance, instead of sphere one can consider branched coverings of higher genus surfaces.

From the general expression of the elementary particle vacuum functional it is clear that elementary particle vacuum functionals vanish, when Y^2 is hyper-elliptic surface with genus $g > 2$ and one might hope that this is enough to explain why the number of elementary particle families is three.

4.5.1 Hyper-ellipticity implies the separation of $g \leq 2$ and $g > 2$ sectors to separate worlds

If the vertices are defined as intersections of space-time sheets of elementary particles and if elementary particle vacuum functionals are required to have Z_2 symmetry, the localization of elementary particle vacuum functionals to $g \leq 2$ topologies occurs automatically. Even if one allows as limiting case vertices for which 2-manifolds are pinched to topologies intermediate between $g > 2$ and $g \leq 2$ topologies, Z_2 symmetry present for both topological interpretations implies the vanishing of this kind of vertices. This applies also in the case of stringy vertices so that also particle propagation would respect the effective number of particle families. $g > 2$ and $g \leq 2$ topologies would behave much like their own worlds in this approach. This is enough to explain the experimental findings if one can understand why the $g > 2$ particle families are absent as incoming and outgoing states or are very heavy.

4.5.2 What about $g > 2$ vacuum functionals which do not vanish for hyper-elliptic surfaces?

The vanishing of all $g \geq 2$ vacuum functionals for hyper-elliptic surfaces cannot hold true generally. There must exist vacuum functionals which do satisfy this condition. This suggest that elementary particle vacuum functionals for $g > 2$ states have interpretation as bound states of g handles and that the more general states which do not vanish for hyper-elliptic surfaces correspond to many-particle states composed of bound states $g \leq 2$ handles and cannot thus appear as incoming and outgoing states. Thus $g > 2$ elementary particles would decouple from $g \leq 2$ states.

4.5.3 Should higher elementary particle families be heavy?

TGD predicts an entire hierarchy of scaled up variants of standard model physics for which particles do not appear in the vertices containing the known elementary particles and thus behave like dark matter [K74] . Also $g > 2$ elementary particles would behave like dark matter and in principle there is no absolute need for them to be heavy.

The safest option would be that $g > 2$ elementary particles are heavy and the breaking of Z_2 symmetry for $g \geq 2$ states could guarantee this. p-Adic considerations lead to a general mass formula for elementary particles such that the mass of the particle is proportional to $\frac{1}{\sqrt{p}}$ [K40] . Also the dependence of the mass on particle genus is completely fixed by this formula. What remains however open is what determines the p-adic prime associated with a particle with given quantum numbers. Of course, it could quite well occur that p is much smaller for $g > 2$ genera than for $g \leq 2$ genera.

4.5.4 Could higher genera have interpretation as many-particle states?

The topological explanation of family replication phenomenon of fermions in terms of the genus g defined as the number of handles added to sphere to obtain the quantum number carrying partonic 2-surface distinguishes TGD from GUTs and string models. The orbit of the partonic 2-surface defines 3-D light-like orbit identified as wormhole throat at which the induced metric changes its signature. The original model of elementary particle involved only single boundary component replaced later by a wormhole throat. The generalization to the recent situation in which elementary particles correspond to wormhole flux tubes of length of order weak length scales with pairs of wormhole throats at its ends is straight-forward.

The basic objection against the proposal is that it predicts infinite number of particle families unless the $g \leq 3$ topologies are preferred for some reason. Conformal and modular symmetries are basic symmetries of the theory and global conformal symmetries provide an excellent candidate for the sought for reason why.

(a) For $g \leq 3$ the 2-surfaces are always hyper-elliptic which means that they have have always Z_2 as global conformal symmetries. For $g \geq 2$ these symmetries are absent in the generic case. Moreover, the ¡modular invariant elementary particle vacuum functionals¡/a¿ vanish for hyper-elliptic surfaces for $g \geq 2$. This leaves several options to consider. The basic idea is however that ground states are usually highly symmetric and that elementary particles correspond to ground states.

(b) The simplest guess is that $g \geq 2$ surfaces correspond to very massive states decaying rapidly to states with smaller genus. Due to the the conformal symmetry $g \leq 3$ surfaces would be analogous to ground states and would have small masses.

(c) The possibility to have partonic 2-surfaces of macroscopic and even astrophysical size identifiable as seats of anyonic macroscopic quantum phases [K50] suggests an alternative interpretation consistent with global conformal symmetries. For partonic 2-surfaces of macroscopic size it seems natural to consider handles as particles glued to a much larger partonic 2-surface by topological sum operation (topological condensation).

All orientable manifolds can be obtained by topological sum operation from what can be called prime manifolds. In 2-D orientable case prime manifolds are sphere and torus representing in well-defined sense 0 and 1 so that topological sum corresponds to addition of positive integers arithmetically. This would suggest that only sphere and torus appear as single particle states. Particle interpretation however requires that also $g = 0$ and $g = 2$ surfaces topologically condensed to a larger anyonic 2-surface have similar interpretation, at least if they have small enough size. What kind of argument could justify this kind of interpretation?

(d) An argument based on symmetries suggests itself. The reduction of degrees of freedom is the generic signature of bound state. Bound state property implies also the reduction of approximate single particle symmetries to an exact overall symmetry. Rotational symmetries of hydrogen atom represent a good example of this. For free many particle states each particle transforms according to a representation of rotation group having total angular momentum defined as sum of its spin and angular momentum. For bound states rotational degrees of freedom are strongly correlated and only overall rotations of the state define rotational symmetries.

In this spirit one could interpret sphere as vacuum, torus as single handle state, and torus with handle as a bound state of 2 handles in conformal degrees of freedom meaning that the Z_2 symmetries of vacuum and handles are frozen in topological condensation (topological sum) to single overall Z_2. If this interpretation is correct, $g \geq 2$ 2-surfaces would always have a decomposition to many-particle states consisting of spheres, tori and tori with single handle glued to a larger sphere by topological sum. Each of these topologically condensed composites would possess Z_2 as approximate single particle symmetry.

4.6 Elementary particle vacuum functionals for dark matter

One of the open questions is how dark matter hierarchy reflects itself in the properties of the elementary particles. The basic questions are how the quantum phase $q = ep(2i\pi/n)$ makes itself visible in the solution spectrum of the modified Dirac operator D and how elementary particle vacuum functionals depend on q. Considerable understanding of these questions emerged recently. One can generalize modular invariance to fractional modular invariance for Riemann surfaces possessing Z_n symmetry and perform a similar generalization for theta functions and elementary particle vacuum functionals. In particular, without any further assumptions $n = 2$ dark fermions have only three families. The existence of space-time correlate for fermionic 2-valuedness suggests that fermions indeed correspond to $n = 2$, or more generally to even values of n, so that this result would hold quite generally. Elementary bosons (actually exotic particles) would correspond to $n = 1$, and more generally odd values of n, and could have also higher families.

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4.7.1 Connection between Hurwitz zetas, quantum groups, and hierarchy of Planck constants?

The action of modular group SL(2,Z) on Riemann zeta [A13] is induced by its action on theta function [A19] . The action of the generator $\tau \to -1/\tau$ on theta function is essential in providing the functional equation for Riemann Zeta. Usually the action of the generator $\tau \to \tau + 1$ on Zeta is not considered explicitly. The surprise was that the action of the generator $\tau \to \tau + 1$ on Riemann Zeta does not give back Riemann zeta but a more general function known as Hurwitz zeta $\zeta(s, z)$ for $z = 1/2$. One finds that Hurwitz zetas for certain rational values of argument define in a well defined sense representations of fractional modular group to which quantum group can be assigned naturally. This could allow to code the value of the quantum phase $q = exp(i2\pi/n)$ to the solution spectrum of the modified Dirac operator D.

Hurwitz zetas

Hurwitz zeta is obtained by replacing integers m with $m + z$ in the defining sum formula for Riemann Zeta:

$$\zeta(s, z) = \sum_m (m + z)^{-s} \quad . \tag{4.7.1}$$

Riemann zeta results for $z = n$.

Hurwitz zeta obeys the following functional equation for rational $z = m/n$ of the second argument [A5] :

$$\zeta(1-s,\frac{m}{n}) = \frac{2\Gamma(s)}{2\pi n}^s \sum_{k=1}^{n} cos(\frac{\pi s}{2} - \frac{2\pi km}{n})\zeta(s,\frac{k}{n}) \quad . \tag{4.7.2}$$

The representation of Hurwitz zeta in terms of θ [A5] is given by the equation

$$\int_0^\infty \left[\theta(z,it)-1\right] t^{s/2}\frac{dt}{t} = \pi^{(1-s)/2}\Gamma(\frac{1-s}{2})\left[\zeta(1-s,z)+\zeta(1-s,1-z)\right] \quad . \tag{4.7.3}$$

By the periodicity of theta function this gives for $z=n$ Riemann zeta.

The action of $\tau \rightarrow \tau+1$ transforms $\zeta(s,0)$ to $\zeta(s,1/2)$

The action of the transformations $\tau \rightarrow \tau+1$ on the integral representation of Riemann Zeta [A13] in terms of θ function [A19]

$$\theta(z;\tau)-1 = 2\sum_{n=1}^{\infty}\left[exp(i\pi\tau)\right]^{n^2} cos(2\pi nz) \tag{4.7.4}$$

is given by

$$\pi^{-s/2}\Gamma(\frac{s}{2})\zeta(s) = \int_0^\infty \left[\theta(0;it)-1\right] t^{s/2}\frac{dt}{t} \quad . \tag{4.7.5}$$

Using the first formula one finds that the shift $\tau = it \rightarrow \tau+1$ in the argument θ induces the shift $\theta(0;\tau) \rightarrow \theta(1/2;\tau)$. Hence the result is Hurwitz zeta $\zeta(s,1/2)$. For $\tau \rightarrow \tau+2$ one obtains Riemann Zeta.

Thus $\zeta(s,0)$ and $\zeta(s,1/2)$ behave like a doublet under modular transformations. Under the subgroup of modular group obtained by replacing $\tau \rightarrow \tau+1$ with $\tau \rightarrow \tau+2$ Riemann Zeta forms a singlet. The functional equation for Hurwitz zeta relates $\zeta(1-s,1/2)$ to $\zeta(s,1/2)$ and $\zeta(s,1)=\zeta(s,0)$ so that also now one obtains a doublet, which is not surprising since the functional equations directly reflects the modular transformation properties of theta functions. This doublet might be the proper object to study instead of singlet if one considers full modular invariance.

Hurwitz zetas form n-plets closed under the action of fractional modular group

The inspection of the functional equation for Hurwitz zeta given above demonstrates that $\zeta(s,m/n)$, $m=0,1,...,n$, form in a well-defined sense an n-plet under fractional modular transformations obtained by using generators $\tau \rightarrow -1/\tau$ and $\tau \rightarrow \tau+2/n$. The latter corresponds to the unimodular matrix $(a,b;c,d)=(1,2/n;0,1)$. These matrices obviously form a group. Note that Riemann zeta is always one member of the multiplet containing n Hurwitz zetas.

These observations bring in mind fractionization of quantum numbers, quantum groups corresponding to the quantum phase $q=exp(i2\pi/n)$, and the inclusions for hyper-finite factors of type II_1 partially characterized by these quantum phases. Fractional modular group obtained using generator $\tau \rightarrow \tau+2/n$ and Hurwitz zetas $\zeta(s,k/n)$ could very naturally relate to these and related structures.

4.7.2 Could Hurwitz zetas relate to dark matter?

These observations suggest a speculative application to quantum TGD.

Basic vision about dark matter

(a) In TGD framework inclusions of HFFs of type II_1 are directly related to the hierarchy of Planck constants involving a generalization of the notion of imbedding space obtained by gluing together copies of 8-D $H = M^4 \times CP_2$ with a discrete bundle structure $H \rightarrow H/Z_{n_a} \times Z_{n_b}$ together along the 4-D intersections of the associated base spaces [K22] . A book like structure results and various levels of dark matter correspond to the pages of this book. One can say that elementary particles proper are maximally quantum critical and live in the 4-D intersection of these imbedding spaces whereas their "field bodies" reside at the pages of the Big Book. Note that analogous book like structures results when real and various p-adic variants of the imbedding space are glued together along common algebraic points.

(b) The integers n_a and n_b give Planck constant as $\hbar/\hbar_0 = n_a/n_b$, whose most general value is a rational number. In Platonic spirit one can argue that number theoretically simple integers involving only powers of 2 and Fermat primes are favored physically. Phase transitions between different matters occur at the intersection.

(c) The inclusions $\mathcal{N} \subset \mathcal{M}$ of HFFs relate also to quantum measurement theory with finite measurement resolution with $\mathcal{N}$ defining the measurement resolution so that N-rays replace complex rays in the projection postulate and quantum space $\mathcal{M}/\mathcal{N}$ having fractional dimension effectively replaces $\mathcal{M}$.

(d) Geometrically the fractional modular invariance would naturally relate to the fact that Riemann surface (partonic 2-surface) can be seen as an $n_a \times n_b$-fold covering of its projection to the base space of H: fractional modular transformations corresponding to n_a and n_b would relate points at different sheets of the covering of M^4 and CP_2. This means $Z_{n_a n_b} = Z_{n_a} \times Z_{n_b}$ conformal symmetry. This suggests that the fractionization could be a completely general phenomenon happening also for more general zeta functions.

What about exceptional cases $n = 1$ and $n = 2$?

Also $n = 1$ and $n = 2$ are present in the hierarchy of Hurwitz zetas (singlet and doublet). They do not correspond to allowed Jones inclusion since one has $n > 2$ for them. What could this mean?

(a) It would seem that the fractionization of modular group relates to Jones inclusions ($n > 2$) giving rise to fractional statistics. $n = 2$ corresponding to the full modular group Sl(2,Z) could relate to the very special role of 2-valued logic, to the degeneracy of $n = 2$ polygon in plane, to the very special role played by 2-component spinors playing exceptional role in Riemann geometry with spinor structure, and to the canonical representation of HFFs of type II_1 as fermionic Fock space (spinors in the world of classical worlds). Note also that SU(2) defines the building block of compact non-commutative Lie groups and one can obtain Lie-algebra generators of Lie groups from n copies of SU(2) triplets and posing relations which distinguish the resulting algebra from a direct sum of SU(2) algebras.

(b) Also $n = 2$-fold coverings $M^4 \rightarrow M^4/Z_2$ and $CP_2 \rightarrow CP_2/Z_2$ seem to make sense. One can argue that by quantum classical correspondence the spin half property of imbedding space spinors should have space-time correlate. Could $n = 2$ coverings allow to define the space-time correlates for particles having half odd integer spin or weak isospin? If so, bosons would correspond to $n = 1$ and fermions to $n = 2$. One could of course counter argue that induced spinor fields already represent fermions at space-time level and there is no need for the doubling of the representation.

The trivial group Z_1 and Z_2 are exceptional since Z_1 does not define any quantization axis and Z_2 allows any quantization axis orthogonal to the line connecting two points. For $n \geq 3$ Z_n fixes the direction of quantization axis uniquely. This obviously correlates with $n \geq 3$ for Jones inclusions.

Dark elementary particle functionals

One might wonder what might be the dark counterparts of elementary particle vacuum functionals. Theta functions $\theta_{[a,b]}(z,\Omega)$ with characteristic $[a,b]$ for Riemann surface of genus g as functions of z and Teichmueller parameters Ω are the basic building blocks of modular invariant vacuum functionals defined in the finite-dimensional moduli space whose points characterize the conformal equivalence class of the induced metric of the partonic 2-surface. Obviously, kind of spinorial variants of theta functions are in question with $g+g$ spinor indices for genus g.

The recent case corresponds to $g=1$ Riemann surface (torus) so that a and b are $g=1$-component vectors having values 0 or 1/2 and Hurwitz zeta corresponds to $\theta_{[0,1/2]}$. The four Jacobi theta functions listed in Wikipedia [A19] correspond to these thetas for torus. The values for a and b are 0 and 1 for them but this is a mere convention.

The extensions of modular group to fractional modular groups obtained by replacing integers with integers shifted by multiples of $1/n$ suggest the existence of new kind of q-theta functions with characteristics $[a,b]$ with a and b being g-component vectors having fractional values k/n, $k=0,1...n-1$. There exists also a definition of q-theta functions working for $0 \leq |q| < 1$ but not for roots of unity [A11] . The q-theta functions assigned to roots of unity would be associated with Riemann surfaces with additional Z_n conformal symmetry but not with generic Riemann surfaces and obtained by simply replacing the value range of characteristics $[a,b]$ with the new value range in the defining formula

$$\Theta[a,b](z|\Omega) = \sum_n exp\left[i\pi(n+a)\cdot\Omega\cdot(n+a)+i2\pi(n+a)\cdot(z+b)\right] \quad . \tag{4.7.6}$$

for theta functions. If Z_n conformal symmetry is relevant for the definition of fractional thetas it is probably so because it would make the generalized theta functions sections in a bundle with a finite fiber having Z_n action.

This hierarchy would correspond to the hierarchy of quantum groups for roots of unity and Jones inclusions and one could probably define also corresponding zeta function multiplets. These theta functions would be building blocks of the elementary particle vacuum functionals for dark variants of elementary particles invariant under fractional modular group. They would also define a hierarchy of fractal variants of number theoretic functions: it would be interesting to see what this means from the point of view of Langlands program [A8] discussed also in TGD framework [K31] involving ordinary modular invariance in an essential manner.

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Hierarchy of Planck constants defines a hierarchy of quantum critical systems

Dark matter hierarchy corresponds to a hierarchy of conformal symmetries Z_n of partonic 2-surfaces with genus $g \geq 1$ such that factors of n define subgroups of conformal symmetries of Z_n. By the decomposition $Z_n = \prod_{p|n} Z_p$, where $p|n$ tells that p divides n, this hierarchy corresponds to an hierarchy of increasingly quantum critical systems in modular degrees of freedom. For a given prime p one has a sub-hierarchy Z_p, $Z_{p^2} = Z_p \times Z_p$, etc... such that the moduli at n+1:th level are contained by n:th level. In the similar manner the moduli of Z_n are sub-moduli for each prime factor of n. This mapping of integers to quantum critical systems conforms nicely with the general vision that biological evolution corresponds to the increase of quantum criticality as Planck constant increases.

The group of conformal symmetries could be also non-commutative discrete group having Z_n as a subgroup. This inspires a very short-lived conjecture that only the discrete subgroups of SU(2) allowed by Jones inclusions are possible as conformal symmetries of Riemann surfaces having $g \geq 1$. Besides Z_n one could have tetrahedral and icosahedral groups plus cyclic group Z_{2n} with reflection added but not Z_{2n+1} nor the symmetry group of cube. The conjecture is wrong. Consider the orbit of the subgroup of rotational group on standard sphere of E^3, put a handle at one of the orbits such that it is invariant under rotations around the axis going through the point, and apply the elements of subgroup. You obtain a Riemann surface having the subgroup as its isometries. Hence all discrete subgroups of SU(2) can act even as isometries for some value of g.

The number theoretically simple ruler-and-compass integers having as factors only first powers of Fermat primes and power of 2 would define a physically preferred sub-hierarchy of quantum criticality for which subsequent levels would correspond to powers of 2: a connection with p-adic length scale hypothesis suggests itself.

Spherical topology is exceptional since in this case the space of conformal moduli is trivial and conformal symmetries correspond to the entire $SL(2,C)$. This would suggest that only the fermions of lowest generation corresponding to the spherical topology are maximally quantum critical. This brings in mind Jones inclusions for which the defining subgroup equals to $SU(2)$ and Jones index equals to $\mathcal{M}/\mathcal{N} = 4$. In this case all discrete subgroups of $SU(2)$ label the inclusions. These inclusions would correspond to fiber space $CP_2 \rightarrow CP_2/U(2)$ consisting of geodesic spheres of CP_2. In this case the discrete subgroup might correspond to a selection of a subgroup of $SU(2) \subset SU(3)$ acting non-trivially on the geodesic sphere. Cosmic strings $X^2 \times Y^2 \subset M^4 \times CP_2$ having geodesic spheres of CP_2 as their ends could correspond to this phase dominating the very early cosmology.

Fermions in TGD Universe allow only three families

What is nice that if fermions correspond to $n = 2$ dark matter with Z_2 conformal symmetry as strong quantum classical correspondence suggests, the number of ordinary fermion families is three without any further assumptions. To see this suppose that also the sectors corresponding to $M^4 \rightarrow M^4/Z_2$ and $CP_2 \rightarrow CP_2/Z_2$ coverings are possible. Z_2 conformal symmetry implies that partonic Riemann surfaces are hyper-elliptic. For genera $g > 2$ this means that some theta functions of $\theta_{[a,b]}$ appearing in the product of theta functions defining the vacuum functional vanish. Hence fermionic elementary particle vacuum functionals would vanish for $g > 2$ and only 3 fermion families would be possible for $n = 2$ dark matter.

This results can be strengthened. The existence of space-time correlate for the fermionic 2-valuedness suggests that fermions quite generally to even values of n, so that this result would hold for all fermions. Elementary bosons (actually exotic particles belonging to Kac-Moody type representations) would correspond to odd values of n, and could possess also higher families. There is a nice argument supporting this hypothesis. n-fold discretization provided by covering associated with H corresponds to discretization for angular momentum eigenstates. Minimal discretization for $2j + 1$ states corresponds to $n = 2j + 1$. $j = 1/2$ requires $n = 2$ at least, $j = 1$ requires $n = 3$ at least, and so on. $n = 2j + 1$ allows spins $j \leq n - 1/2$. This spin-quantum phase connection at the level of space-time correlates has counterpart for the representations of quantum SU(2).

These rules would hold only for genuinely elementary particles corresponding to single partonic component and all bosonic particles of this kind are exotics (excitations in only "vibrational" degrees of freedom of partonic 2-surface with modular invariance eliminating quite a number of them.

Chapter 5

Massless States and Particle Massivation

5.1 Introduction

This chapter represents the most recent view about particle massivation in TGD framework. This topic is necessarily quite extended since many several notions and new mathematics is involved. Therefore the calculation of particle masses involves five chapters ([K14, K34, K43, K37] of [K40] . In the following my goal is to provide an up-to-date summary whereas the chapters are unavoidably a story about evolution of ideas.

The identification of the spectrum of light particles reduces to two tasks: the construction of massless states and the identification of the states which remain light in p-adic thermodynamics. The latter task is relatively straightforward. The thorough understanding of the massless spectrum requires however a real understanding of quantum TGD. It would be also highly desirable to understand why p-adic thermodynamics combined with p-adic length scale hypothesis works. A lot of progress has taken place in these respects during last years.

Zero energy ontology providing a detailed geometric view about bosons and fermions, the generalization of S-matrix to what I call M-matrix, the notion of finite measurement resolution characterized in terms of inclusions of von Neumann algebras, the derivation of p-adic coupling constant evolution and p-adic length scale hypothesis from the first principles, the realization that the counterpart of Higgs mechanism involves generalized eigenvalues of the modified Dirac operator: these are represent important steps of progress during last years with a direct relevance for the understanding of particle spectrum and massivation although the predictions of p-adic thermodynamics are not affected.

During 2010 a further progress took place as I wrote articles about TGD to Prespace-time journal [L5, L6, L10, L11, L8, L4, L9, L12]. These steps of progress relate closely to zero energy ontology, bosonic emergence, the realization of the importance of twistors in TGD, and to the discovery of the weak form of electric-magnetic duality. Twistor approach and the understanding of the Chern-Simons Dirac operator served as a midwife in the process giving rise to the birth of the idea that all particles at fundamental level are massless and that both ordinary elementary particles and string like objects emerge from them. Even more, one can interpret virtual particles as being composed of these massless on mass shell particles assignable to wormhole throats so that four-momentum conservation poses extremely powerful constraints on loop integrals and makes them manifestly finite.

The weak form of electric-magnetic duality led to the realization that elementary particles correspond to bound states of two wormhole throats with opposite Kähler magnetic charges with second throat carrying weak isospin compensating that of the fermion state at second wormhole throat. Both fermions and bosons correspond to wormhole contacts: in the case of fermions topological condensation generates the second wormhole throat. This means that altogether four wormhole throats are involved with both fermions, gauge bosons, and gravitons (for gravitons this is unavoidable in any case).

For p-adic thermodynamics the mathematical counterpart of string corresponds to a wormhole contact with size of order CP_2 size with the role of its ends played by wormhole throats at which the signature of the induced 4-metric changes. The key observation is that for massless states the throats of spin 1 particle must have opposite three-momenta so that gauge bosons are necessarily massive, even photon and other particles usually regarded as massless must have small mass which in turn cancels infrared divergences and give hopes about exact Yangian symmetry generalizing that of $\mathcal{N} = 4$ SYM.

Besides this there is weak "stringy" contribution to the mass assignable to the magnetic flux tubes connecting the two wormhole throats at the two space-time sheets. In fact, this contribution can be assigned to the additional conformal weight assignable to the stringy curve. The extension of this conformal algebra to Yangian brings in third integer characterizing the poly-locality of the Yangian generator (n-local generator acts on n partonic 2-surfaces simultaneously. Therefore three integers would characterize the generators of the full symmetry algebra as the very naive expectation on basis of 3-dimensionality of the fundamental objects would suggest. p-Adic mass calculations should be carried out for Yangian generalization of p-adic thermodynamics.

5.1.1 Physical states as representations of super-symplectic and Super Kac-Moody algebras

Physical states belong to the representations of super-symplectic algebra and Super Kac-Moody algebran. The precise identification of the two algebras has been rather tedious task but the recent progress in the construction of WCW geometry and spinor structure led to a considerable progress in this respect [K23, **?**, K86].

(a) In the generic case the generators of both algebras receive information from 1-D ends of 2-D string world sheets at which the modes of induced spinor fields are localized by the condition that the modes are eigenstates of electromagnetic charge. Right-handed neutrino is an exception since it has no electroweak couplings. One must however require that right-handed neutrino does not mix with the left-handed one if the mode is de-localized at entire space-time sheet.

   Either the preferred extremal is such that modified gamma matrices defined in terms of canonical momentum currents of Kähler action consist of only M^4 or CP_2 type flat space gammas so that there is no mixing with the left-handed neutrino. Or the CP_2 and M^4 parts of the Kähler Dirac operator annihilate the right-handed neutrino mode separately. One can of course have also modes which are mixtures of right- and left handed neutrinos but these are necessarily localized at string world sheets.

(b) The definition of super generator involves integration of string curve at the boundary of causal diamond (CD) so that the generators are labelled by *two* conformal weights: that associated with the radial light-like coordinate and that assignable with the string curve. This strongly suggests that the algebra extends to a 4-D Yangian involving multi-local generators (locus means partonic surface now) assignable to various partonic surfaces at the boundaries of CD - as indeed suggested [K75].

(c) As before, the symplectic algebra corresponds to a super-symplectic algebra assignable to symplectic transformations of $\delta M^4_\pm \times CP_2$. One can regard this algebra as a symplectic algebra of $S^2 \times CP_2$ localized with respect to the light-like radial coordinate r_M taking the role of complex variable z in conformal field theories. Super-generators are linear in the modes of right-handed neutrino. Covariantly constant mode and modes decoupling from left-handed neutrino define the most important modes.

(d) Second algebra corresponds to the Super Kac-Moody algebra. The corresponding Lie algebra generates symplectic isometries of $\delta M^4_\pm \times CP_2$. Fermionic generators are linear in the modes of induced spinor field with non-vanishing electroweak quantum numbers: that is left-hand neutrinos, charged leptons, and quarks.

(e) The overall important conclusion is that overall Super Virasoro algebra has five tensor factors corresponding to one tensor factor for super-symplectic algebra, and 4 tensor factors for Super Kac-Moody algebra $SO(2) \times SU(3) \times SU(2)_{rot} \times U(2)_{ew}$ (CP_2 isometries, S^2 isometries, electroweak $SU(2)_{ew} \times U(1)$). This is essential for mass calculations.

What looks like the most plausible option relies on the generalization of a coset construction proposed already for years ago but badly mis-interpreted. The construction itself is strongly supported and perhaps even forced by the vision that WCW is union of homogenous or even symmetric spaces of form G/H [K86], where G is the isometry group of WCW and H its subgroup leaving invariant the chosen point of WCW (say the 3-surface corresponding to a maximum of Kähler function in Euclidian regions and stationary point of the Morse function defined by Kähler action for Minkowskian space-time regions). It seems clear that only the Super Virasoro associated with G can involve four-momentum so that the original idea that there are two identical four-momenta identifiable as gravitational and inertial four-momenta must be given up. This boils dow to the following picture.

(a) Assume a generalization of the coset construction so that the differences of G and H super-conformal generators O_n annihilate the physical states: $(O_n(G) - O_n(H))|phys\rangle = 0$.

(b) In zero energy ontology (ZEO) p-adic thermodynamics must be replaced with its square root so that one consideres genuine quantum states rather than thermodynamical states. Hence the system is quantum coherent. In the simplest situation this implies only that thermodynamical weights are replaced by their square roots possibly multiplied by square roots irrelevant for the mass squared expectation value.

(c) Construct first ground states with negative conformal weight annihilated by G and H generators G_n, L_n, $n < 0$. Apply to these states generators of tensor factors of Super Viraroso algebras to obtain states with vanishing G and H conformal weights. After this construct thermal states as superpositions of states obtained by applying H generators and corresponding G generators G_n,L_n, $n > 0$. Assume that these states are annihilated by G and H generators G_n, L_n,$n > 0$ and by the differences of *all* G and H generators.

(d) Super-symplectic algebra represents a completely new element and in the case of hadrons the non-perturbative contribution to the mass spectrum is easiest to understand in terms of super-symplectic thermal excitations contributing roughly 70 per cent to the p-adic thermal mass of the hadron.

Yangian algebras associated with the super-conformal algebras and motivated by twistorial approach generalize the already generalized super-conformal symmetry and make it multi-local in the sense that generators can act on several partonic 2-surfaces simultaneously. These partonic 2-surfaces generalize the vertices for the external massless particles in twistor Grassmann diagrams [K75]. The implications of this symmetry are yet to be deduced but one thing is clear: Yangians are tailor made for the description of massive bound states formed from several partons identified as partonic 2-surfaces. The preliminary discussion of what is involved can be found in [K75] .

5.1.2 Particle massivation

Particle massivation can be regarded as a generation of thermal conformal weight identified as mass squared and due to a thermal mixing of a state with vanishing conformal weight with those having higher conformal weights. The observed mass squared is not p-adic thermal expectation of mass squared but that of conformal weight so that there are no problems with Lorentz invariance.

One can imagine several microscopic mechanisms of massivation. The following proposal is the winner in the fight for survival between several competing scenarios.

The original observation was that the pieces of CP_2 type vacuum extremals representing elementary particles have random light-like curve as an M^4 projection so that the average motion correspond to that of massive particle. Light-like randomness gives rise to classical Virasoro conditions. This picture generalizes since the basic dynamical objects are light-like but otherwise random 3-surfaces. The identification of elementary particles developed in three steps.

(a) Originally germions were identified as light-like 3-surfaces at which the signature of induced metric of deformed CP_2 type extremals changes from Euclidian to the Minkowskian signature of the background space-time sheet. Gauge bosons and Higgs were identified as wormhole contacts with light-like throats carrying fermion and anti-fermion quantum numbers. Gravitons were identified as pairs of wormhole contacts bound to string like object by the fluxes connecting the wormhole contacts. The randomness of the light-like 3-surfaces and associated super-conformal symmetries justify the use of thermodynamics and the question remains why this thermodynamics can be taken to be p-adic. The proposed identification of bosons means enormous simplification in thermodynamical description since all calculations reduced to the calculations to fermion level. This picture generalizes to include super-symmetry. The fermionic oscillator operators associated with the partonic 2-surfaces act as generators of badly broken SUSY and right-handed neutrino gives to the not so badly broken $\mathcal{N} = 1$ SUSY consistent with empirical facts.

    Of course, "badly" is relative notion. It is quite possible that the mixing of right-handed neutrino with left-handed one becomes important only in CP_2 scale and causes massivation. Hence spartners might well have mass of order CP_2 mass scale. The question about the mass scale of right-handed neutrino remains open.

(b) The next step was to realize that the topological condensation of fermion generates second wormhole throat which carries momentum and symplectic quantum numbers but no fermionic quantum numbers. This is also needed to the massivation by p-adic thermodynamics applied to the analogs of string like objects defined by wormhole throats with throats taking the role of string ends. p-Adic thermodynamics did not however allow a satisfactory understanding of the gauge bosons masses and it became clear that some additional contribution - maybe Higgsy or stringy contribution - dominates for weak gauge bosons. Gauge bosons should also somehow obtain their longitudinal polarizations and here Higgs like particles indeed predicted by the basic picture suggests itself strongly.

(c) A further step was the discovery of the weak form of electric-magnetic duality, which led to the realization that wormhole throats possess Kähler magnetic charge so that a wormole throat with opposite magnetic charge is needed to compensate this charge. This wormhole throat can also compensate the weak isospin of the second wormhole throat so that weak confinement and massivation results. In the case of quarks magnetic confinement might take place in hadronic rather than weak length scale. Second crucial observation was that gauge bosons are necessarily massive since the light-like momenta at two throats must correspond to opposite three-momenta so that no Higgs potential is needed. This leads to a picture in which gauge bosons eat the Higgs scalars and also photon, gluons, and gravitons develop small mass.

(d) A further step was the realization that although the existence of Higgs is established, it need not contribute to neither fermion or gauge boson masses. CP_2 geometry does not even allow covariantly constant holomorphic vector field as a representation for the vacuum expectation value of Higgs. Elementary particles are string like objects and string tension can give additional contribution to the mass squared. This would explain the large masses of weak bosons as compared to the mass of photon predicted also to be non-vanishing in principle. Also a small contribution to fermion masses is expected.

    Higgs vacuum expectation would be replaced with the stringy contribution to the mass squared, which by perturbative argument should apart from normalization factor have the form $\Delta m^2 \propto g^2 T$, where g is the gauge coupling assignable to the weak boson, and T is the analog of hadronic string tension but in weak scale. This predicts correctly the ratio of W and Z boson masses in terms of Weinberg angle.

(e) The conformal weight characterizing fermionic masses in p-adic thermodynamics can be assigned to the very short piece of string connecting the opposite throats of wormhole contact. The conformal weight associated with the long string connecting the throats of two wormhole contacts should give the dominant contribution to the masses of weak gauge bosons. Five tensor factors are needed in super-conformal algebra and super-symplectic and super-Kac Moody contributions assignable to symplectic isometries give five factors.

One can assign conformal weights to both the light-like radial coordinate r_M of $\delta M^4_\pm$ and string. A third integer-valued quantum number comes from the extension of the extended super-conformal algebra to multi-local Yangian algebra. Yangian extension should take place for quark wormhole contacts inside hadrons and give non-perturbative multi-local contributions to hadron masses and might explain most of hadronic mass since quark contribution is very small. That three integers classify states conforms with the very naive first guess inspired by 3-dimensionality of the basic objects.

The details of the picture are however still fuzzy. Are the light-like radial and stringy conformal weights really independent quantum numbers as it seems? These conformal weights however must be additive in the expression for mass squared to get five tensor factors. Could one identify stringy coordinate with the light-like radial coordinate r_M in Minkowskian space-time regions to explain the additivity? The dominating contribution to the vacuum conformal weight must be negative and half-integer valued. What is the origin of this tachyonic contribution?

The fundamental parton level description of TGD is based on almost topological QFT for light-like 3-surfaces.

(a) Dynamics is constrained by the requirement that CP_2 projection is for extremals of Chern-Simons action 2-dimensional and for off-shell states light-likeness is the only constraint. Chern-Simons action and its Dirac counterpart result as boundary terms of Kähler action and its Dirac counterpart for preferred extremals. This requires that $j \cdot A$ contribution to Kähler action vanishes for preferred extremals plus weak form of electric-magnetic duality.

The addition of 3-D measurement interaction term - essentially Dirac action associated with 3-D light-like orbits of partonic 2-surfaces implies that Chern-Simons Dirac operator plus Lagrangian multiplier term realizing the weak form of electric magnetic duality acts like massless M^4 Dirac operator assignable to the four-momentum propagating along the line of generalized Feynman diagram [K23]. This simplifies enormously the definition of the Dirac propagator needed in twistor Grassmannian approach [K58].

(b) That mass squared, rather than energy, is a fundamental quantity at CP_2 length scale is besides Loretnz invariance suggested by a simple dimensional argument (Planck mass squared is proportional to $\hbar$ so that it should correspond to a generator of some Lie-algebra (Virasoro generator L_0!)).

Mass squared is identified as the p-adic thermal expectation value of mass squared operator m^2 appearing as M^4 contribution in the scaling generator $L_0(G)$ in the superposition of states with vanishing total conformal weight but with varying mass squared eigenvalues associated with the difference $L_0(G) - L_0(H)$ annihilating the physical state. This definition does not break Lorentz invariance in zero energy ontology. The states appearing in the superposition of different states with vanishing total conformal weight give different contribution to the p-adic thermodynamical expectation defining mass squared and the ability to physically observe this as massivation might be perhaps interpreted as breaking of conformal invariance.

(c) There is also a modular contribution to the mass squared, which can be estimated using elementary particle vacuum functionals in the conformal modular degrees of freedom of the partonic 2-surface. It dominates for higher genus partonic 2-surfaces. For bosons both Virasoro and modular contributions seem to be negligible and could be due to the smallness of the p-adic temperature.

(d) A long standing problem has been whether coupling to Higgs boson is needed to explain gauge boson masses via a generation of Higgs vacuum expectation having possibly interpretation in terms of a coherent state. Before the detailed model for elementary particles in terms of pairs of wormhole contacts at the ends of flux tubes the picture about the situation was as follows. From the beginning it was clear that is that ground state conformal weight must be negative. Then it became clear that the ground state conformal weight need not be a negative integer. The deviation Δh of the total ground state conformal weight from negative integer gives rise to stringy contribution to the thermal mass squared and dominates in case of gauge bosons for which p-adic temperature is small. In the case of fermions this contribution to the mass squared is small. The possible Higgs vacuum expectation makes sense only at QFT limit perhaps allowing to describe the Yangian aspects, and would be naturally proportional to Δh so that the coupling to Higgs would only apparently cause gauge boson massivation.

(e) A natural identification of the non-integer contribution to the conformal weight is as stringy contribution to the vacuum conformal weight. In twistor approach external fundamental fermions carry light-like momenta and when the three-momenta at opposite wormhole throats are opposite this gives rise to non-vanishing mass. Higgs is necessary to give longitudinal polarizations for weak gauge bosons. Bosonic massivation would be essentially many-sheeted phenomenon.

An important question concerns the justification of p-adic thermodynamics.

(a) The underlying philosophy is that real number based TGD can be algebraically continued to various p-adic number fields. This gives justification for the use of p-adic thermodynamics although the mapping of p-adic thermal expectations to real counterparts is not completely unique. The physical justification for p-adic thermodynamics is effective p-adic topology characterizing the 3-surface: this is the case if real variant of light-like 3-surface has large number of common algebraic points with its p-adic counterpart obeying same algebraic equations but in different number field. In fact, there is a theorem stating that for rational surfaces the number of rational points is finite and rational (more generally algebraic points) would naturally define the notion of number theoretic braid essential for the realization of number theoretic universality.

(b) The most natural option is that the descriptions in terms of both real and p-adic thermodynamics make sense and are consistent. This option indeed makes if the number of generalized eigen modes of modified Dirac operator is finite. This is indeed the case if one accepts periodic boundary conditions for the Chern-Simons Dirac operator. In fact, the solutions are localized at the strands of braids [K23] . This makes sense because the theory has hydrodynamic interpretation [K23] . This reduces $\mathcal{N} = \infty$ to finite SUSY and realizes finite measurement resolution as an inherent property of dynamics.

   The finite number of fermionic oscillator operators implies an effective cutoff in the number conformal weights so that conformal algebras reduce to finite-dimensional algebras. The first guess would be that integer label for oscillator operators becomes a number in finite field for some prime. This means that one can calculate mass squared also by using real thermodynamics but the consistency with p-adic thermodynamics gives extremely strong number theoretical constraints on mass scale. This consistency condition allows also to solve the problem how to map a negative ground state conformal weight to its p-adic counterpart. Negative conformal weight is divided into a negative half odd integer part plus positive part Δh, and negative part corresponds as such to p-adic integer whereas positive part is mapped to p-adic number by canonical identification.

p-Adic thermodynamics is what gives to this approach its predictive power.

(a) p-Adic temperature is quantized by purely number theoretical constraints (Boltzmann weight $exp(-E/kT)$ is replaced with p^{L_0/T_p}, $1/T_p$ integer) and fermions correspond to $T_p = 1$ whereas $T_p = 1/n$, $n > 1$, seems to be the only reasonable choice for gauge bosons.

(b) p-Adic thermodynamics forces to conclude that CP_2 radius is essentially the p-adic length scale $R \sim L$ and thus of order $R \simeq 10^{3.5}\sqrt{\hbar G}$ and therefore roughly $10^{3.5}$ times larger than the naive guess. Hence p-adic thermodynamics describes the mixing of states with vanishing conformal weights with their Super Kac-Moody Virasoro excitations having masses of order $10^{-3.5}$ Planck mass.

5.1.3 What next?

The successes of p-adic mass calculations are basically due to the power of super-conformal symmetries and of number theory. One cannot deny that the description of the gauge boson and hadron massivation involves phenomenological elements. There are however excellent hopes that it might be possible some day to calculate everything from first principles. The non-local Yangian symmetry generalizing the super-conformal algebras suggests itself strongly as a fundamental symmetry of quantum TGD. The generalized of the Yangian symmetry replaces points with partonic 2-surfaces being multi-local with respect to them, and leads to general formulas for multi-local operators representing four-momenta and other conserved charges of composite states.

In TGD framework even elementary particles involve two wormhole contacts having each two wormhole throats identified as the fundamental partonic entities. Therefore Yangian approach would naturally define the first principle approach to the understanding of masses of elementary particles and their bound states (say hadrons). The power of this extended symmetry might be enough to deduce universal mass formulas. One of the future challenges would therefore be the mathematical and physical understanding of Yangian symmetry. This would however require the contributions of professional mathematicians.

The appendix of the book gives a summary about basic concepts of TGD with illustrations. There are concept maps about topics related to the contents of the chapter prepared using CMAP realized as html files. Links to all CMAP files can be found at `http://www.tgdtheory.fi/cmaphtml.html` [L20]. Pdf representation of same files serving as a kind of glossary can be found at `http://www.tgdtheory.fi/tgdglossary.pdf` [L21]. The topics relevant to this chapter are given by the following list.

- TGD view about elementary particles [L49]
- p-Adic mass calculations [L37]

5.2 Identification of elementary particles

5.2.1 Family replication phenomenon topologically

One of the basic ideas of TGD approach has been genus-generation correspondence: boundary components of the 3-surface should be carriers of elementary particle numbers and the observed particle families should correspond to various boundary topologies.

With the advent of zero energy ontology this picture changed somewhat. It is the wormhole throats identified as light-like 3-surfaces at with the induced metric of the space-time surface changes its signature from Minkowskian to Euclidian, which correspond to the light-like orbits of partonic 2-surfaces. One cannot of course exclude the possibility that also boundary components could allow to satisfy boundary conditions without assuming vacuum extremal property of nearby space-time surface. The intersections of the wormhole throats with the light-like boundaries of causal diamonds (CDs) identified as intersections of future and past directed light cones ($CD \times CP_2$ is actually in question but I will speak about CDs) define special partonic 2-surfaces and it is the moduli of these partonic 2-surfaces which appear in the elementary particle vacuum functionals naturally.

The first modification of the original simple picture comes from the identification of physical particles as bound states of pairs of wormhole contacts and from the assumption that for generalized Feynman diagrams stringy trouser vertices are replaced with vertices at which the ends of light-like wormhole throats meet. In this picture the interpretation of the analog of trouser vertex is in terms of propagation of same particle along two different paths. This interpretation is mathematically natural since vertices correspond to 2-manifolds rather than singular 2-manifolds which are just splitting to two disjoint components. Second complication comes from the weak form of electric-magnetic duality forcing to identify physical particles as weak strings with magnetic monopoles at their ends and one should understand also the possible complications caused by this generalization.

These modifications force to consider several options concerning the identification of light fermions and bosons and one can end up with a unique identification only by making some assumptions. Masslessness of all wormhole throats- also those appearing in internal lines- and dynamical $SU(3)$ symmetry for particle generations are attractive general enough assumptions of this kind. This means that bosons and their super-partners correspond to wormhole contacts with fermion and anti-fermion at the throats of the contact. Free fermions and their superpartners could correspond to CP_2 type vacuum extremals with single wormhole throat. It turns however that dynamical $SU(3)$ symmetry forces to identify massive (and possibly topologically condensed) fermions as (g, g) type wormhole contacts.

Do free fermions correspond to single wormhole throat or (g, g) wormhole?

The original interpretation of genus-generation correspondence was that free fermions correspond to wormhole throats characterized by genus. The idea of $SU(3)$ as a dynamical symmetry suggested that gauge bosons correspond to octet and singlet representations of $SU(3)$. The further idea that all lines of generalized Feynman diagrams are massless poses a strong additional constraint and it is not clear whether this proposal as such survives.

(a) Twistorial program assumes that fundamental objects are massless wormhole throats carrying collinearly moving many-fermion states and also bosonic excitations generated by super-symplectic algebra. In the following consideration only purely bosonic and single fermion throats are considered since they are the basic building blocks of physical particles. The reason is that propagators for high excitations behave like p^{-n}, n the number of fermions associated with the wormhole throat. Therefore single throat allows only spins 0,1/2,1 as elementary particles in the usual sense of the word.

(b) The identification of massive fermions (as opposed to free massless fermions) as wormhole contacts follows if one requires that fundamental building blocks are massless since at least two massless throats are required to have a massive state. Therefore the conformal excitations with CP_2 mass scale should be assignable to wormhole contacts also in the case of fermions. As already noticed this is not the end of the story: weak strings are required by the weak form of electric-magnetic duality.

(c) If free fermions corresponding to single wormhole throat, topological condensation is an essential element of the formation of stringy states. The topological condensation of fermions by topological sum (fermionic CP_2 type vacuum extremal touches another space-time sheet) suggest $(g, 0)$ wormhole contact. Note however that the identification of wormhole throat is as 3-surface at which the signature of the induced metric changes so that this conclusion might be wrong. One can indeed consider also the possibility of (g, g) pairs as an outcome of topological conensation. This is suggested also by the idea that wormhole throats are analogous to string like objects and only this option turns out to be consistent with the BFF vertex based on the requirement of dynamical $SU(3)$ symmetry to be discussed later. The structure of reaction vertices makes it possible to interpret (g, g) pairs as $SU(3)$ triplet. If bosons are obtained as fusion of fermionic and anti-fermionic throats (touching of corresponding CP_2 type vacuum extremals) they correspond naturally to (g_1, g_2) pairs.

(d) p-Adic mass calculations distinguish between fermions and bosons and the identification of fermions and bosons should be consistent with this difference. The maximal p-adic temperature $T = 1$ for fermions could relate to the weakness of the interaction of the fermionic wormhole throat with the wormhole throat resulting in topological condensation. This wormhole throat would however carry momentum and 3-momentum would in general be non-parallel to that of the fermion, most naturally in the opposite direction.

p-Adic mass calculations suggest strongly that for bosons p-adic temperature $T = 1/n$, $n > 1$, so that thermodynamical contribution to the mass squared is negligible. The low p-adic temperature could be due to the strong interaction between fermionic and anti-fermionic wormhole throat leading to the "freezing" of the conformal degrees of freedom related to the relative motion of wormhole throats.

(e) The weak form of electric-magnetic duality forces second wormhole throat with opposite magnetic charge and the light-like momenta could sum up to massive momentum. In this case string tension corresponds to electroweak length scale. Therefore p-adic thermodynamics must be assigned to wormhole contacts and these appear as basic units connected by Kähler magnetic flux tube pairs at the two space-time sheets involved. Weak stringy degrees of freedom are however expected to give additional contribution to the mass, perhaps by modifying the ground state conformal weight.

Dynamical $SU(3)$ fixes the identification of fermions and bosons and fundamental interaction vertices

For 3 light fermion families $SU(3)$ suggests itself as a dynamical symmetry with fermions in fundamental $N = 3$-dimensional representation and $N \times N = 9$ bosons in the adjoint representation and singlet representation. The known gauge bosons have same couplings to fermionic families so that they must correspond to the singlet representation. The first challenge is to understand whether it is possible to have dynamical $SU(3)$ at the level of fundamental reaction vertices.

This is a highly non-trivial constraint. For instance, the vertices in which n wormhole throats with same (g_1, g_2) glued along the ends of lines are not consistent with this symmetry. The splitting of the fermionic worm-hole contacts before the proper vertices for throats might however allow the realization of dynamical $SU(3)$. The condition of $SU(3)$ symmetry combined with the requirement that virtual lines resulting also in the splitting of wormhole contacts are always massless, leads to the conclusion that massive fermions correspond to (g, g) type wormhole contacts transforming naturally like $SU(3)$ triplet. This picture conformsl with the identification of free fermions as throats but not with the naive expectation that their topological condensation gives rise to $(g, 0)$ wormhole contact.

The argument leading to these conclusions runs as follows.

(a) The question is what basic reaction vertices are allowed by dynamical $SU(3)$ symmetry. FFB vertices are in principle all that is needed and they should obey the dynamical symmetry. The meeting of entire wormhole contacts along their ends is certainly not possible. The splitting of fermionic wormhole contacts before the vertices might be however consistent with $SU(3)$ symmetry. This would give two a pair of 3-vertices at which three wormhole lines meet along partonic 2-surfaces (rather than along 3-D wormhole contacts).

(b) Note first that crossing gives all possible reaction vertices of this kind from $F(g_1)\overline{F}(g_2) \rightarrow B(g_1, g_2)$ annihilation vertex, which is relatively easy to visualize. In this reaction $F(g_1)$ and $\overline{F}(g_2)$ wormhole contacts split first. If one requires that all wormhole throats involved are massless, the two wormhole throats resulting in splitting and carrying no fermion number must carry light-like momentum so that they cannot just disappear. The ends of the wormhole throats of the boson must glued together with the end of the fermionic wormhole throat and its companion generated in the splitting of the wormhole. This means that fermionic wormhole first splits and the resulting throats meet at the partonic 2-surface.

his requires that topologically condensed fermions correspond to (g, g) pairs rather than $(g, 0)$ pairs. The reaction mechanism allows the interpretation of (g, g) pairs as a triplet of dynamical $SU(3)$. The fundamental vertices would be just the splitting of wormhole contact and 3-vertices for throats since $SU(3)$ symmetry would exclude more complex reaction vertices such as n-boson vertices corresponding the gluing of n wormhole contact lines along their 3-dimensional ends. The couplings of singlet representation for bosons would have same coupling to all fermion families so that the basic experimental constraint would be satisfied.

(c) Both fermions and bosons cannot correspond to octet and singlet of $SU(3)$. In this case reaction vertices should correspond algebraically to the multiplication of matrix elements e_{ij}: $e_{ij}e_{kl} = \delta_{jk}e_{il}$ allowing for instance $F(g_1, g_2) + \overline{F}(g_2, g_3) \rightarrow B(g_1, g_3)$. Neither the fusion of entire wormhole contacts along their ends nor the splitting of wormhole throats before the fusion of partonic 2-surfaces allows this kind of vertices so that BFF vertex is the only possible one. Also the construction of QFT limit starting from bosonic emergence led to the formulation of perturbation theory in terms of Dirac action allowing only BFF vertex as fundamental vertex [K24] .

(d) Weak electric-magnetic duality brings in an additional complication. $SU(3)$ symmetry poses also now strong constraints and it would seem that the reactions must involve copies of basic BFF vertices for the pairs of ends of weak strings. The string ends with the same Kähler magnetic charge should meet at the vertex and give rise to BFF vertices. For instance, $F\overline{F}B$ annihilation vertex would in this manner give rise to the analog of stringy diagram in which strings join along ends since two string ends disappear in the process.

If one accepts this picture the remaining question is why the number of genera is just three. Could this relate to the fact that $g \leq 2$ Riemann surfaces are always hyper-elliptic (have global Z_2 conformal symmetry) unlike $g > 2$ surfaces? Why the complete bosonic de-localization of the light families should be restricted inside the hyper-elliptic sector? Does the Z_2 conformal symmetry make these states light and make possible de-localization and dynamical $SU(3)$ symmetry? Could it be that for $g > 2$ elementary particle vacuum functionals vanish for hyper-elliptic surfaces? If this the case and if the time evolution for partonic 2-surfaces changing g commutes with Z_2 symmetry then the vacuum functionals localized to $g \leq 2$ surfaces do not disperse to $g > 2$ sectors.

The notion of elementary particle vacuum functional

Obviously one must know something about the dependence of the elementary particle state functionals on the geometric properties of the boundary component and in the sequel an attempt to construct what might be called elementary particle vacuum functionals, is made.

The basic assumptions underlying the construction are the following ones:

(a) Elementary particle vacuum functionals depend on the geometric properties of the two-surface X^2 representing elementary particle.

(b) Vacuum functionals possess extended Diff invariance: all 2-surfaces on the orbit of the 2-surface X^2 correspond to the same value of the vacuum functional. This condition is satisfied if vacuum functionals have as their argument, not X^2 as such, but some 2- surface Y^2 belonging to the unique orbit of X^2 (determined by the principle selecting preferred extremal of the Kähler action as a generalized Bohr orbit [K29]) and determined in $Diff^3$ invariant manner.

(c) Zero energy ontology allows to select uniquely the partonic two surface as the intersection of the wormhole throat at which the signature of the induced 4-metric changes with either the upper or lower boundary of $CD \times CP_2$. This is essential since otherwise one one could not specify the vacuum functional uniquely.

(d) Vacuum functionals possess conformal invariance and therefore for a given genus depend on a finite number of variables specifying the conformal equivalence class of Y^2.

(e) Vacuum functionals satisfy the cluster decomposition property: when the surface Y^2 degenerates to a union of two disjoint surfaces (particle decay in string model inspired picture), vacuum functional decomposes into a product of the vacuum functionals associated with disjoint surfaces.

(f) Elementary particle vacuum functionals are stable against the decay $g \rightarrow g_1 + g_2$ and one particle decay $g \rightarrow g - 1$. This process corresponds to genuine particle decay only for stringy diagrams. For generalized Feynman diagrams the interpretation is in terms of propagation along two different paths simultaneously.

In [K14] the construction of elementary particle vacuum functionals is described in more detail. This requires some basic concepts related to the description of the space of the conformal equivalence classes of Riemann surfaces and the concept of hyper-ellipticity. Since theta functions will play a central role in the construction of the vacuum functionals, also their basic properties are needed. Also possible explanations for the experimental absence of the higher fermion families are considered.

5.3 Non-topological contributions to particle masses from p-adic thermodynamics

In TGD framework p-adic thermodynamics provides a microscopic theory of particle massivation in the case of fermions. The idea is very simple. The mass of the particle results from a thermal mixing of the massless states with CP_2 mass excitations of super-conformal algebra. In p-adic thermodynamics the Boltzmann weight $exp(-E/T)$ does not exist in general and must be replaced with p^{L_0/T_p} which exists for Virasoro generator L_0 if the inverse of the p-adic temperature is integer valued $T_p = 1/n$. The expansion in powers of p converges extremely rapidly for physical values of p, which are rather large. Therefore the three lowest terms in expansion give practically exact results. Thermal massivation does not not necessarily lead to light states and this drops a large number of exotic states from the spectrum of light particles. The partition functions of N-S and Ramond type representations are not changed in TGD framework despite the fact that fermionic super generators carry fermion numbers and are not Hermitian. Thus the practical calculations are relatively straightforward albeit tedious.

In free fermion picture the p-adic thermodynamics in the boson sector is for fermion-anti-fermion states associated with the two throats of the bosonic wormhole. The question is whether the thermodynamical mass squared is just the sum of the two independent fermionic contributions for Ramond representations or should one use N-S type representation resulting as a tensor product of Ramond representations.

The overall conclusion about p-adic mass calculations is that fermionic mass spectrum is predicted in an excellent accuracy but that the thermal masses of the intermediate gauge bosons come 20-30 per cent to large for $T_p = 1$ and are completely negligible for $T_p = 1/2$. The bound state character of the boson states could be responsible for $T_p < 1$ and for extremely small thermodynamical contribution to the masses (present also for photon).

This forces to consider seriously the possibility that thermal contribution to the bosonic mass is negligible and that TGD can, contrary to the original expectations, provide dynamical Higgs field as a fundamental field and that even Higgs mechanism could contribute to the particle masses.

Higgs mechanism is probably the only viable description of Higgs mechanism in QFT approach, where particles are point-like but not in TGD, where particles are replaced by string like objects consisting of two wormhole contacts with monopole Kähler magnetic flux flowing between "upper" throats and returning back along "lower" space-time sheets. In this framework the assumption that fermion masses would result from p-adic thermodynamics but boson masses from Higgs couplings looks like an ugly idea. A more plausible vision is that the dominating contribution to gauge boson masses comes from the two flux tubes connecting the two wormhole contacts defining boson. This contribution would be present also for fermions but would be small. The correct W/Z mass ratio is obtained if the string tension is proportional to weak gauge coupling squared. The nice feature of this scenario is that naturalness is not lost: the dimensional gradient coupling of fermion to Higgs is same for all fermions.

The stringy contribution to mass squared could be expressed in terms of the deviation of the ground state conformal weight from negative half integer.

The problem is to understand how the negative value of the ground state conformal weight emerges. This negative conformal weight compensated by the action of Super Virasoro generators is necessary for the success of p-adic mass calculations. The intuitive expectation is that the solution of this problem must relate to the Euclidian signature of the regions representing lines of generalized Feynman diagrams.

5.3.1 Partition functions are not changed

One must write Super Virasoro conditions for L_n and *both* G_n and $G_n^\dagger$ rather than for L_n and G_n as in the case of the ordinary Super Virasoro algebra, and it is a priori not at all clear whether the partition functions for the Super Virasoro representations remain unchanged. This requirement is however crucial for the construction to work at all in the fermionic sector, since even the slightest changes for the degeneracies of the excited states can change light state to a state with mass of order m_0 in the p-adic thermodynamics.

Super conformal algebra

Super Virasoro algebra is generated by the bosonic the generators L_n (n is an integer valued index) and by the fermionic generators G_r, where r can be either integer (Ramond) or half odd integer (NS). G_r creates quark/lepton for $r > 0$ and antiquark/antilepton for $r < 0$. For $r = 0$, G_0 creates lepton and its Hermitian conjugate anti-lepton. The defining commutation and anti-commutation relations are the following:

$$\begin{aligned}
[L_m, L_n] &= (m-n)L_{m+n} + \frac{c}{2}m(m^2-1)\delta_{m,-n} \ , \\
[L_m, G_r] &= (\frac{m}{2} - r)G_{m+r} \ , \\
\left[L_m, G_r^\dagger\right] &= (\frac{m}{2} - r)G_{m+r}^\dagger \ , \\
\{G_r, G_s^\dagger\} &= 2L_{r+s} + \frac{c}{3}(r^2 - \frac{1}{4})\delta_{m,-n} \ , \\
\{G_r, G_s\} &= 0 \ , \\
\{G_r^\dagger, G_s^\dagger\} &= 0 \ .
\end{aligned} \qquad (5.3.1)$$

By the inspection of these relations one finds some results of a great practical importance.

(a) For the Ramond algebra G_0, G_1 and their Hermitian conjugates generate the $r \geq 0, n \geq 0$ part of the algebra via anti-commutations and commutations. Therefore all what is needed is to assume that Super Virasoro conditions are satisfied for these generators in case that G_0 and $G_0^\dagger$ annihilate the ground state. Situation changes if the states are *not* annihilated by G_0 and $G_0^\dagger$ since then one must assume the gauge conditions for both L_1, G_1 and $G_1^\dagger$ besides the mass shell conditions associated with G_0 and $G_0^\dagger$, which however do not affect the number of the Super Virasoro excitations but give mass shell condition and constraints on the state in the cm spin degrees of freedom. This will be assumed in the following. Note that for the ordinary Super Virasoro only the gauge conditions for L_1 and G_1 are needed.

(b) NS algebra is generated by $G_{1/2}$ and $G_{3/2}$ and their Hermitian conjugates (note that $G_{3/2}$ cannot be expressed as the commutator of L_1 and $G_{1/2}$) so that only the gauge conditions associated with these generators are needed. For the ordinary Super Virasoro only the conditions for $G_{1/2}$ and $G_{3/2}$ are needed.

Conditions guaranteeing that partition functions are not changed

The conditions guaranteeing the invariance of the partition functions in the transition to the modified algebra must be such that they reduce the number of the excitations and gauge conditions for a given conformal weight to the same number as in the case of the ordinary Super Virasoro.

(a) The requirement that physical states are invariant under $G \leftrightarrow G^\dagger$ corresponds to the charge conjugation symmetry and is very natural. As a consequence, the gauge conditions for G and $G^\dagger$ are not independent and their number reduces by a factor of one half and is the same as in the case of the ordinary Super Virasoro.

(b) As far as the number of the thermal excitations for a given conformal weight is considered, the only remaining problem are the operators $G_nG_n^\dagger$, which for the ordinary Super Virasoro reduce to $G_nG_n = L_{2n}$ and do not therefore correspond to independent degrees of freedom. In present case this situation is achieved only if one requires

$$(G_nG_n^\dagger - G_n^\dagger G_n)|phys\rangle \quad = \quad 0 \ . \tag{5.3.2}$$

It is not clear whether this condition must be posed separately or whether it actually follows from the representation of the Super Virasoro algebra automatically.

Partition function for Ramond algebra

Under the assumptions just stated, the partition function for the Ramond states not satisfying any gauge conditions

$$Z(t) \quad = \quad 1 + 2t + 4t^2 + 8t^3 + 14t^4 + ... \ , \tag{5.3.3}$$

which is identical to that associated with the ordinary Ramond type Super Virasoro.

For a Super Virasoro representation with $N = 5$ sectors, of main interest in TGD, one has

$$\begin{aligned} Z_N(t) &= Z^{N=5}(t) = \sum D(n)t^n \\ &= 1 + 10t + 60t^2 + 280t^3 + ... \ . \end{aligned} \tag{5.3.4}$$

The degeneracies for the states satisfying gauge conditions are given by

$$d(n) \quad = \quad D(n) - 2D(n-1) \ . \tag{5.3.5}$$

corresponding to the gauge conditions for L_1 and G_1. Applying this formula one obtains for $N = 5$ sectors

$$d(0) = 1 \ , \quad d(1) = 8 \ , \quad d(2) = 40 \ , \quad d(3) = 160 \ . \tag{5.3.6}$$

The lowest order contribution to the p-adic mass squared is determined by the ratio

$$r(n) = \frac{D(n+1)}{D(n)} \ ,$$

where the value of n depends on the effective vacuum weight of the ground state fermion. Light state is obtained only provided the ratio is integer. The remarkable result is that for lowest lying states the ratio is integer and given by

$$r(1) = 8 \ , \quad r(2) = 5 \ , \quad r(3) = 4 \ . \tag{5.3.7}$$

It turns out that $r(2) = 5$ gives the best possible lowest order prediction for the charged lepton masses and in this manner one ends up with the condition $h_{vac} = -3$ for the tachyonic vacuum weight of Super Virasoro.

Partition function for NS algebra

For NS representations the calculation of the degeneracies of the physical states reduces to the calculation of the partition function for a single particle Super Virasoro

$$Z_{NS}(t) \quad = \quad \sum_n z(n/2)t^{n/2} \ . \tag{5.3.8}$$

Here $z(n/2)$ gives the number of Super Virasoro generators having conformal weight $n/2$. For a state with N active sectors (the sectors with a non-vanishing weight for a given ground state) the degeneracies can be read from the N-particle partition function expressible as

$$Z_N(t) \quad = \quad Z^N(t) \ . \tag{5.3.9}$$

Single particle partition function is given by the expression

$$Z(t) \quad = \quad 1 + t^{1/2} + t + 2t^{3/2} + 3t^2 + 4t^{5/2} + 5t^3 + ... \ . \tag{5.3.10}$$

Using this representation it is an easy task to calculate the degeneracies for the operators of conformal weight Δ acting on a state having N active sectors.

One can also derive explicit formulas for the degeneracies and calculation gives

$$\begin{array}{ll} D(0,N) = 1 \ , & D(1/2,N) = N \ , \\ D(1,N) = \frac{N(N+1)}{2} \ , & D(3/2,N) = \frac{N}{6}(N^2+3N+8) \ , \\ D(2,N) = \frac{N}{2}(N^2+2N+3) \ , & D(5/2,N) = 9N(N-1) \ , \\ D(3,N) = 12N(N-1) + 2N(N-1) & . \end{array} \tag{5.3.11}$$

as a function of the conformal weight $\Delta = 0, 1/2, ..., 3$.

The number of states satisfying Super Virasoro gauge conditions created by the operators of a conformal weight Δ, when the number of the active sectors is N, is given by

$$d(\Delta,N) \quad = \quad D(\Delta,N) - D(\Delta-1/2,N) - D(\Delta-3/2,N) \ . \tag{5.3.12}$$

The expression derives from the observation that the physical states satisfying gauge conditions for $G^{1/2}$, $G^{3/2}$ satisfy the conditions for all Super Virasoro generators. For $T_p = 1$ light bosons correspond to the integer values of $d(\Delta+1,N)/d(\Delta,N)$ in case that massless states correspond to thermal excitations of conformal weight Δ: they are obtained for $\Delta = 0$ only (massless ground state). This is what is required since the thermal degeneracy of the light boson ground state would imply a corresponding factor in the energy density of the black body radiation at very high temperatures. For the physically most interesting nontrivial case with $N = 2$ two active sectors the degeneracies are

$$d(0,2) = 1 \ , \quad d(1,2) = 1 \ , \quad d(2,2) = 3 \ , \quad d(3,2) = 4 \ . \tag{5.3.13}$$

N, Δ	0	1/2	1	3/2	2	5/2	3
2	1	1	1	3	3	4	4
3	1	2	3	9	11		
4	1	3	5	19	26		
5	1	4	10	24	150		

Table 3. Degeneracies $d(\Delta, N)$ of the operators satisfying NS type gauge conditions as a function of the number N of the active sectors and of the conformal weight Δ of the operator. Only those degeneracies, which are needed in the mass calculation for bosons assuming that they correspond to N-S representations are listed.

5.3.2 Fundamental length and mass scales

The basic difference between quantum TGD and super-string models is that the size of CP_2 is not of order Planck length but much larger: of order $10^{3.5}$ Planck lengths. This conclusion is forced by several consistency arguments, the mass scale of electron, and by the cosmological data allowing to fix the string tension of the cosmic strings which are basic structures in TGD inspired cosmology.

The relationship between CP_2 radius and fundamental p-adic length scale

One can relate CP_2 'cosmological constant' to the p-adic mass scale: for $k_L = 1$ one has

$$m_0^2 = \frac{m_1^2}{k_L} = m_1^2 = 2\Lambda \ . \tag{5.3.14}$$

$k_L = 1$ results also by requiring that p-adic thermodynamics leaves charged leptons light and leads to optimal lowest order prediction for the charged lepton masses. Λ denotes the 'cosmological constant' of CP_2 (CP_2 satisfies Einstein equations $G^{\alpha\beta} = \Lambda g^{\alpha\beta}$ with cosmological term).

The real counterpart of the p-adic thermal expectation for the mass squared is sensitive to the choice of the unit of p-adic mass squared which is by definition mapped as such to the real unit in canonical identification. Thus an important factor in the p-adic mass calculations is the correct identification of the p-adic mass squared scale, which corresponds to the mass squared unit and hence to the unit of the p-adic numbers. This choice does not affect the spectrum of massless states but can affect the spectrum of light states in case of intermediate gauge bosons.

(a) For the choice

$$M^2 = m_0^2 \leftrightarrow 1 \tag{5.3.15}$$

the spectrum of L_0 is integer valued.

(b) The requirement that all sufficiently small mass squared values for the color partial waves are mapped to real integers, would fix the value of p-adic mass squared unit to

$$M^2 = \frac{m_0^2}{3} \leftrightarrow 1 \ . \tag{5.3.16}$$

For this choice the spectrum of L_0 comes in multiples of 3 and it is possible to have a first order contribution to the mass which cannot be of thermal origin (say $m^2 = p$). This indeed seems to happen for electro-weak gauge bosons.

p-Adic mass calculations allow to relate m_0 to electron mass and to Planck mass by the formula

$$\begin{aligned} \frac{m_0}{m_{Pl}} &= \frac{1}{\sqrt{5+Y_e}} \times 2^{127/2} \times \frac{m_e}{m_{Pl}} \ , \\ m_{Pl} &= \frac{1}{\sqrt{\hbar G}} \ . \end{aligned} \tag{5.3.17}$$

For $Y_e = 0$ this gives $m_0 = .2437 \times 10^{-3} m_{Pl}$.

This means that CP_2 radius R defined by the length $L = 2\pi R$ of CP_2 geodesic is roughly $10^{3.5}$ times the Planck length. More precisely, using the relationship

$$\Lambda = \frac{3}{2R^2} = M^2 = m_0^2 \ ,$$

one obtains for

$$L = 2\pi R = 2\pi\sqrt{\frac{3}{2}}\frac{1}{m_0} \simeq 3.1167 \times 10^4 \sqrt{\hbar G} \ \text{ for } \ Y_e = 0 \ . \tag{5.3.18}$$

The result came as a surprise: the first belief was that CP_2 radius is of order Planck length. It has however turned out that the new identification solved elegantly some long standing problems of TGD.

Y_e	0	.5	.7798
$(m_0/m_{Pl})10^3$	.2437	.2323	.2266
$K_R \times 10^{-7}$	2.5262	2.7788	2.9202
$(L_R/\sqrt{\hbar G}) \times 10^{-4}$	3.1580	3.3122	3.3954
$K \times 10^{-7}$	2.4606	2.4606	2.4606
$(L/\sqrt{\hbar G}) \times 10^{-4}$	3.1167	3.1167	3.1167
K_R/K	1.0267	1.1293	1.1868

Table 1. Table gives the values of the ratio $K_R = R^2/G$ and CP_2 geodesic length $L = 2\pi R$ for $Y_e \in \{0, 0.5, 0.7798\}$. Also the ratio of K_R/K, where $K = 2 \times 3 \times 5 \times 7 \times 11 \times 13 \times 17 \times 19 \times 23 \times 2^{-3} * (15/17)$ is rational number producing R^2/G approximately is given.

The value of top quark mass favors $Y_e = 0$ and $Y_e = .5$ is largest value of Y_e marginally consistent with the limits on the value of top quark mass.

CP_2 radius as the fundamental p-adic length scale

The identification of CP_2 radius as the fundamental p-adic length scale is forced by the Super Virasoro invariance. The pleasant surprise was that the identification of the CP_2 size as the fundamental p-adic length scale rather than Planck length solved many long standing problems of older TGD.

(a) The earliest formulation predicted cosmic strings with a string tension larger than the critical value giving the angle deficit 2π in Einstein's equations and thus excluded by General Relativity. The corrected value of CP_2 radius predicts the value k/G for the cosmic string tension with k in the range $10^{-7} - 10^{-6}$ as required by the TGD inspired model for the galaxy formation solving the galactic dark matter problem.

(b) In the earlier formulation there was no idea as how to derive the p-adic length scale $L \sim 10^{3.5}\sqrt{\hbar G}$ from the basic theory. Now this problem becomes trivial and one has to predict gravitational constant in terms of the p-adic length scale. This follows in principle as a prediction of quantum TGD. In fact, one can deduce G in terms of the p-adic length scale and the action exponential associated with the CP_2 extremal and gets a correct value if α_K approaches fine structure constant at electron length scale (due to the fact that electromagnetic field equals to the Kähler field if Z^0 field vanishes).

Besides this, one obtains a precise prediction for the dependence of the Kähler coupling strength on the p-adic length scale by requiring that the gravitational coupling does not depend on the p-adic length scale. p-Adic prime p in turn has a nice physical interpretation: the critical value of α_K is same for the zero modes with given p. As already found, the construction of graviton state allows to understand the small value of the gravitational constant in terms of a de-coherence caused by multi-p fractality reducing the value of the gravitational constant from L_p^2 to G.

(c) p-Adic length scale is also the length scale at which super-symmetry should be restored in standard super-symmetric theories. In TGD this scale corresponds to the transition to Euclidian field theory for CP_2 type extremals. There are strong reasons to believe that sparticles are however absent and that super-symmetry is present only in the sense that super-generators have complex conformal weights with $Re(h) = \pm 1/2$ rather than $h = 0$. The action of this super-symmetry changes the mass of the state by an amount of order CP_2 mass.

5.4 Color degrees of freedom

The ground states for the Super Virasoro representations correspond to spinor harmonics in $M^4 \times CP_2$ characterized by momentum and color quantum numbers. The correlation between color and electro-weak quantum numbers is wrong for the spinor harmonics and these states would be also hyper-massive. The super-symplectic generators allow to build color triplet states having negative vacuum conformal weights, and their values are such that p-adic massivation is consistent with the predictions of the earlier model differing from the recent one in the quark sector. In the following the construction and the properties of the color partial waves for fermions and bosons are considered. The discussion follows closely to the discussion of [A37] .

5.4.1 SKM algebra and counterpart of Super Virasoro conditions

There have been a considerable progress also in the understanding of super-conformal symmetries [K12, K16].

(a) Super-symplectic algebra corresponds to the isometries of WCW constructed in terms covariantly constant right handed neutrino mode and second quantized induced spinor field Ψ and the corresponding Super-Kac-Moody algebra restricted to symplectic isometries and realized in terms of all spinor modes and Ψ is the most plausible identification of the superconformal algebras when the constraints from p-adic mass calculations are taken into account. These algebras act as dynamical rather than gauge algebras and related to the isometries of WCW.

(b) One expects also gauge symmetries due to the non-determinism of Kähler action. They transform to each other preferred extremals having fixed 3-surfaces as ends at the boundaries of the causal diamond. They preserve the value of Kähler action and those of conserved charges. The assumption is that there are n gauge equivalence classes of these surfaces and that n defines the value of the effective Planck constant $h_{eff} = n \times h$ in the effective GRT type description replacing many-sheeted space-time with single sheeted one. Note that the geometric part of SKM algebra must respect the light-likeness of the partonic 3-surface.

(c) An interesting question is whether the symplectic isometries of $\delta M^4_\pm \times CP_2$ should be extended to include all isometries of $\delta M^4_\pm = S^2 \times R_+$ in one-one correspondence with conformal transformations of S^2.The S^2 local scaling of the light-like radial coordinate r_M of R_+ compensates the conformal scaling of the metric coming from the conformal transformation of S^2. Also light-like 3-surfaces allow the analogs of these isometries.

The requirement that symplectic generators have well defined radial conformal weight with respect to the light-like coordinate r of X^3 restricts M^4 conformal transformations to the group $SO(3) \times E^3$. This involves choice of preferred time coordinate. If the preferred M^4 coordinate is chosen to correspond to a preferred light-like direction in $\delta M^4_\pm$ characterizing the theory, a reduction to $SO(2) \times E^2$ more familiar from string models occurs. SKM algebra contains also $U(2)_{ew}$ Kac-Moody algebra acting as holonomies of CP_2 and having no bosonic counterpart.

p-Adic mass calculations require $N = 5$ sectors of super-conformal algebra. These sectors correspond to the 5 tensor factors for the $SO(3) \times E^3 \times SU(3) \times U(2)_{ew}$ (or $SO(2) \times E^2 \times SU(3) \times U(2)_{ew}$) decomposition of the SKM algebra to gauge symmetries of gravitation, color and electro-weak interactions.

For symplectic isometries (Super-Kac-Moody algebra) fermionic algebra is realized in terms second quantized induced spinor field Ψ and spinor modes with well-defined em charge restricted to 2-D surfaces: string world sheets and possibly also partonic 2-surfaces. The full symplectic algebra is realized in terms of Ψ and covariantly constant right handed neutrino mode. One can consider also the possiblity of extended the symplectic isometries of $\delta M^4_\pm = S^2 \times R_+$ to include all isometries which act as conformal transformations of S^2 and for which conformal scaling of the metric is compensated by S^2 local scaling of the light-like radial coordinate r_M of R_+.

The algebra differs from the standard one in that super generators $G(z)$ carry lepton and quark numbers are not Hermitian as in super-string models (Majorana conditions are not satisfied). The counterparts of Ramond representations correspond to zero modes of a second quantized spinor field with vanishing radial conformal weight.

The Ramond or N-S type Virasoro conditions satisfied by the physical states in string model approach are replaced by the formulas expressing mass squared as a conformal weight. The condition is not equivalent with super Virasoro conditions since four-momentum does not appear in super Virasoro generators. It seems possible to assume that the commutator algebra $[SKM, SC]$ and the commutator of $[SKMV, SSV]$ of corresponding Super Virasoro algebras annihilate physical states. This would give rise to the analog of Super Virasoro conditions which could be seen as a Dirac equation in the world of classical worlds.

CP_2 CM degrees of freedom

Important element in the discussion are center of mass degrees of freedom parameterized by imbedding space coordinates. By the effective 2-dimensionality it is indeed possible to assign to partons momenta and color partial waves and they behave effectively as free particles. In fact, the technical problem of the earlier scenario was that it was not possible to assign symmetry transformations acting only on the light-like 3-surfaces at which the signature of the induced metric transforms from Minkowskian to Euclidian.

The original assumption was that 3-surface has boundary components to which elementary particle quantum numbers were assigned. It however became clear that boundary conditions at boundaries probably fail to be satisfied. Hence the above described light-like 3-surfaces took the role the boundary components. Space-time sheets were replaced with surfaces looking like double-sheeted (at least) structures from M^4 perspective with sheets meeting along 3-D surfaces. Sphere in Euclidian 3-space is the simplest analog for this kind of structure.

One can assign to each eigen state of color quantum numbers a color partial wave in CP_2 degrees of freedom. Thus color quantum numbers are not spin like quantum numbers in TGD framework except effectively in the length scales much longer than CP_2 length scale. The correlation between color partial waves and electro-weak quantum numbers is not physical in general: only the covariantly constant right handed neutrino has vanishing color.

Mass formula, and condition determining the effective string tension

Mass squared eigenvalues are given by

$$M^2 = m^2_{CP_2} + kL_0 \ . \quad (5.4.1)$$

The contribution of CP_2 spinor Laplacian to the mass squared operator is in general not integer valued.

The requirement that mass squared spectrum is integer valued for color partial waves possibly representing light states fixes the possible values of k determining the effective string tension modulo integer. The value $k = 1$ is the only possible choice. The earlier choice $k_L = 1$ and $k_q = 2/3$, $k_B = 1$ gave integer conformal weights for the lowest possible color partial waves. The assumption that the total vacuum weight h_{vac} is conserved in particle vertices implied $k_B = 1$.

5.4.2 General construction of solutions of Dirac operator of H

The construction of the solutions of massless spinor and other d'Alembertians in $M^4_+ \times CP_2$ is based on the following observations.

(a) d'Alembertian corresponds to a massless wave equation $M^4 \times CP_2$ and thus Kaluza-Klein picture applies, that is M^4_+ mass is generated from the momentum in CP_2 degrees of freedom. This implies mass quantization:

$$M^2 = M_n^2 \ ,$$

where M_n^2 are eigenvalues of CP_2 Laplacian. Here of course, ordinary field theory is considered. In TGD the vacuum weight changes mass squared spectrum.

(b) In order to get a respectable spinor structure in CP_2 one must couple CP_2 spinors to an odd integer multiple of the Kähler potential. Leptons and quarks correspond to $n = 3$ and $n = 1$ couplings respectively. The spectrum of the electromagnetic charge comes out correctly for leptons and quarks.

(c) Right handed neutrino is covariantly constant solution of CP_2 Laplacian for $n = 3$ coupling to Kähler potential whereas right handed 'electron' corresponds to the covariantly constant solution for $n = -3$. From the covariant constancy it follows that all solutions of the spinor Laplacian are obtained from these two basic solutions by multiplying with an appropriate solution of the scalar Laplacian coupled to Kähler potential with such a coupling that a correct total Kähler charge results. Left handed solutions of spinor Laplacian are obtained simply by multiplying right handed solutions with CP_2 Dirac operator: in this operation the eigenvalues of the mass squared operator are obviously preserved.

(d) The remaining task is to solve scalar Laplacian coupled to an arbitrary integer multiple of Kähler potential. This can be achieved by noticing that the solutions of the massive CP_2 Laplacian can be regarded as solutions of S^5 scalar Laplacian. S^5 can indeed be regarded as a circle bundle over CP_2 and massive solutions of CP_2 Laplacian correspond to the solutions of S^5 Laplacian with $exp(is\tau)$ dependence on S^1 coordinate such that s corresponds to the coupling to the Kähler potential:

$$s = n/2 \ .$$

Thus one obtains

$$D_5^2 = (D_\mu - iA_\mu\partial_\tau)(D^\mu - iA^\mu\partial_\tau) + \partial_\tau^2 \quad (5.4.2)$$

so that the eigen values of CP_2 scalar Laplacian are

$$m^2(s) = m_5^2 + s^2 \quad (5.4.3)$$

for the assumed dependence on τ.

(e) What remains to do, is to find the spectrum of S^5 Laplacian and this is an easy task. All solutions of S^5 Laplacian can be written as homogenous polynomial functions of C^3 complex coordinates Z^k and their complex conjugates and have a decomposition into the representations of $SU(3)$ acting in natural manner in C^3.

(f) The solutions of the scalar Laplacian belong to the representations $(p, p+s)$ for $s \geq 0$ and to the representations $(p+|s|, p)$ of $SU(3)$ for $s \leq 0$. The eigenvalues $m^2(s)$ and degeneracies d are

$$\begin{aligned} m^2(s) &= \frac{2\Lambda}{3}[p^2 + (|s|+2)p + |s|] \ , \ p > 0 \ , \\ d &= \frac{1}{2}(p+1)(p+|s|+1)(2p+|s|+2) \ . \end{aligned} \quad (5.4.4)$$

Λ denotes the 'cosmological constant' of CP_2 ($R_{ij} = \Lambda s_{ij}$).

5.4.3 Solutions of the leptonic spinor Laplacian

Right handed solutions of the leptonic spinor Laplacian are obtained from the asatz of form

$$\nu_R = \Phi_{s=0}\nu_R^0 \ ,$$

where u_R is covariantly constant right handed neutrino and Φ scalar with vanishing Kähler charge. Right handed 'electron' is obtained from the ansats

$$e_R = \Phi_{s=3}e_R^0 \ ,$$

where e_R^0 is covariantly constant for $n = -3$ coupling to Kähler potential so that scalar function must have Kähler coupling $s = n/2 = 3$ a in order to get a correct Kähler charge. The d'Alembert equation reduces to

$$\begin{aligned} &(D_\mu D^\mu - (1-\epsilon)\Lambda)\Phi = -m^2\Phi \ , \\ &\epsilon(\nu) = 1 \ , \quad \epsilon(e) = -1 \ . \end{aligned} \quad (5.4.5)$$

The two additional terms correspond to the curvature scalar term and $J_{kl}\Sigma^{kl}$ terms in spinor Laplacian. The latter term is proportional to Kähler coupling and of different sign for ν and e, which explains the presence of the sign factor ϵ in the formula.

Right handed neutrinos correspond to (p, p) states with $p \geq 0$ with mass spectrum

$$\begin{aligned} m^2(\nu) &= \frac{m_1^2}{3}\left[p^2 + 2p\right] \ , \ p \geq 0 \ , \\ m_1^2 &\equiv 2\Lambda \ . \end{aligned} \tag{5.4.6}$$

Right handed 'electrons' correspond to $(p, p+3)$ states with mass spectrum

$$m^2(e) = \frac{m_1^2}{3}\left[p^2 + 5p + 6\right] \ , \ p \geq 0 \ . \tag{5.4.7}$$

Left handed solutions are obtained by operating with CP_2 Dirac operator on right handed solutions and have the same mass spectrum and representational content as right handed leptons with one exception: the action of the Dirac operator on the covariantly constant right handed neutrino ($(p = 0, p = 0)$ state) annihilates it.

5.4.4 Quark spectrum

Quarks correspond to the second conserved H-chirality of H-spinors. The construction of the color partial waves for quarks proceeds along similar lines as for leptons. The Kähler coupling corresponds to $n = 1$ (and $s = 1/2$) and right handed U type quark corresponds to a right handed neutrino. U quark type solutions are constructed as solutions of form

$$U_R = u_R \Phi_{s==1} \ ,$$

where u_R possesses the quantum numbers of covariantly constant right handed neutrino with Kähler charge $n = 3$ ($s = 3/2$). Hence Φ_s has $s = -1$. For D_R one has

$$D_R = d_r \Phi_{s=2} \ .$$

d_R has $s = -3/2$ so that one must have $s = 2$. For U_R the representations $(p + 1, p)$ with triality one are obtained and $p = 0$ corresponds to color triplet. For D_R the representations $(p, p + 2)$ are obtained and color triplet is missing from the spectrum ($p = 0$ corresponds to $\bar{6}$).

The CP_2 contributions to masses are given by the formula

$$\begin{aligned} m^2(U, p) &= \frac{m_1^2}{3}\left[p^2 + 3p + 2\right] \ , \ p \geq 0 \ , \\ m^2(D, p) &= \frac{m_1^2}{3}\left[p^2 + 4p + 4\right] \ , \ p \geq 0 \ . \end{aligned} \tag{5.4.8}$$

Left handed quarks are obtained by applying Dirac operator to right handed quark states and mass formulas and color partial wave spectrum are the same as for right handed quarks.

The color contributions to p-adic mass squared are integer valued if $m_0^2/3$ is taken as a fundamental p-adic unit of mass squared. This choice has an obvious relevance for p-adic mass calculations since canonical identification does not commute with a division by integer. More precisely, the images of number xp in canonical identification has a value of order 1 when x is a non-trivial rational whereas for $x = np$ the value is n/p and extremely is small for physically interesting primes. This choice does not however affect the spectrum of massless states but can affect the spectrum of light states in case of electro-weak gauge bosons.

5.4.5 Spectrum of elementary particles

The assumption that $k = 1$ holds true for all particles forces to modify the earlier construction of quark states. This turns out to be possible without affecting the p-adic mass calculations whose outcome depend in an essential manner on the ground state conformal weights h_{gr} of the fermions (which can be negative).

Leptonic spectrum

For $k = 1$ the leptonic mass squared is integer valued in units of m_0^2 only for the states satisfying

$$p \ mod \ 3 \neq 2 \ .$$

Only these representations can give rise to massless states. Neutrinos correspond to (p, p) representations with $p \geq 1$ whereas charged leptons correspond to $(p, p+3)$ representations. The earlier mass calculations demonstrate that leptonic masses can be understood if the ground state conformal weight is $h_{gr} = -1$ for charged leptons and $h_{gr} = -2$ for neutrinos.

The contribution of color partial wave to conformal weight is $h_c = (p^2 + 2p)/3$, $p \geq 1$, for neutrinos and $p = 1$ gives $h_c = 1$ (octet). For charged leptons $h_c = (p^2 + 5p + 6)/3$ gives $h_c = 2$ for $p = 0$ (decouplet). In both cases super-symplectic operator O must have a net conformal weight $h_{sc} = -3$ to produce a correct conformal weight for the ground state. p-adic considerations suggests the use of operators O with super-symplectic conformal weight $z = -1/2 - i\sum n_k y_k$, where $s_k = 1/2 + iy_k$ corresponds to zero of Riemann ζ. If the operators in question are color Hamiltonians in octet representation net super-symplectic conformal weight $h_{sc} = -3$ results. The tensor product of two octets with conjugate super-symplectic conformal weights contains both octet and decouplet so that singlets are obtained. What strengthens the hopes that the construction is not ad hoc is that the same operator appears in the construction of quark states too.

Right handed neutrino remains essentially massless. $p = 0$ right handed neutrino does not however generate $N = 1$ space-time (or rather, imbedding space) super symmetry so that no sparticles are predicted. The breaking of the electro-weak symmetry at the level of the masses comes out basically from the anomalous color electro-weak correlation for the Kaluza-Klein partial waves implying that the weights for the ground states of the fermions depend on the electromagnetic charge of the fermion. Interestingly, TGD predicts lepto-hadron physics based on color excitations of leptons and color bound states of these excitations could correspond topologically condensed on string like objects but not fundamental string like objects.

Spectrum of quarks

Earlier arguments [K43] related to a model of CKM matrix as a rational unitary matrix suggested that the string tension parameter k is different for quarks, leptons, and bosons. The basic mass formula read as

$$M^2 = m_{CP_2}^2 + kL_0 \ .$$

The values of k were $k_q = 2/3$ and $k_L = k_B = 1$. The general theory however predicts that $k = 1$ for all particles.

(a) By earlier mass calculations and construction of CKM matrix the ground state conformal weights of U and D type quarks must be $h_{gr}(U) = -1$ and $h_{gr}(D) = 0$. The formulas for the eigenvalues of CP_2 spinor Laplacian imply that if m_0^2 is used as unit, color conformal weight $h_c \equiv m_{CP_2}^2$ is integer for $p \ mod \ = \pm 1$ for U type quark belonging to $(p+1, p)$ type representation and obeying $h_c(U) = (p^2+3p+2)/3$ and for $p \ mod \ 3 = 1$ for D type quark belonging $(p, p+2)$ type representation and obeying $h_c(D) = (p^2 + 4p + 4)/3$. Only these states can be massless since color Hamiltonians have integer valued conformal weights.

(b) In the recent case $p = 1$ states correspond to $h_c(U) = 2$ and $h_c(D) = 3$. $h_{gr}(U) = -1$ and $h_{gr}(D) = 0$ reproduce the previous results for quark masses required by the construction of CKM matrix. This forces the super-symplectic operator O to compensate the anomalous color to have a net conformal weight $h_{sc} = -3$ just as in the leptonic case. The facts that the values of p are minimal for spinor harmonics and the super-symplectic operator is same for both quarks and leptons suggest that the construction is not had hoc. The real justification would come from the demonstration that $h_{sc} = -3$ defines null state for SSV: this would also explain why h_{sc} would be same for all fermions.

(c) It would seem that the tensor product of the spinor harmonic of quarks (as also leptons) with Hamiltonians gives rise to a large number of exotic colored states which have same thermodynamical mass as ordinary quarks (and leptons). Why these states have smaller values of p-adic prime that ordinary quarks and leptons, remains a challenge for the theory. Note that the decay widths of intermediate gauge bosons pose strong restrictions on the possible color excitations of quarks. On the other hand, the large number of fermionic color exotics can spoil the asymptotic freedom, and it is possible to have and entire p-adic length scale hierarchy of QCDs existing only in a finite length scale range without affecting the decay widths of gauge bosons.

The following table summarizes the color conformal weights and super-symplectic vacuum conformal weights for the elementary particles.

	L	ν_L	U	D	W	γ, G, g
h_{vac}	-3	-3	-3	-3	-2	0
h_c	2	1	2	3	2	0

Table 2. The values of the parameters h_{vac} and h_c assuming that $k = 1$. The value of $h_{vac} \leq -h_c$ is determined from the requirement that p-adic mass calculations give best possible fit to the mass spectrum.

Photon, graviton and gluon

For photon, gluon and graviton the conformal weight of the $p = 0$ ground state is $h_{gr} = h_{vac} = 0$. The crucial condition is that $h = 0$ ground state is non-degenerate: otherwise one would obtain several physically more or less identical photons and this would be seen in the spectrum of black-body radiation. This occurs if one can construct several ground states not expressible in terms of the action of the Super Virasoro generators.

Masslessness or approximate masslessness requires low enough temperature $T_p = 1/n$, $n > 1$ at least and small enough value of the possible contribution coming from the ground state conformal weight.

In NS thermodynamics the only possibility to get exactly massless states in thermal sense is to have $\Delta = 0$ state with one active sector so that NS thermodynamics becomes trivial due to the absence of the thermodynamical excitations satisfying the gauge conditions. For neutral gauge bosons this is indeed achieved. For $T_p = 1/2$, which is required by the mass spectrum of intermediate gauge bosons, the thermal contribution to the mass squared is however extremely small even for W boson.

5.4.6 Some probabilistic considerations

There are uniqueness problems related to the mapping of p-adic probabilities to real ones. These problems find a nice resolution from the requirement that the map respects probability conservation. The implied modification of the original mapping does not change measurably the predictions for the masses of light particles.

How unique the map of p-adic probabilities and mass squared values are mapped to real numbers is?

The mapping of p-adic thermodynamical probabilities and mass squared values to real numbers is not completely unique.

(a) Canonical identification $I : \sum x_n p^n \to \sum x_n p^{-n}$ takes care of this mapping but does not respect the sum of probabilities so that the real images $I(p_n)$ of the probabilities must be normalized. This is a somewhat alarming feature.

(b) The modification of the canonical identification mapping rationals by the formula $I(r/s) = I(r)/I(s)$ has appeared naturally in various applications, in particular because it respects unitarity of unitary matrices with rational elements with $r < p, s < p$. In the case of p-adic thermodynamic the formula $I(g(n)p^n/Z) \to I(g(n)p^n)/I(Z)$ would be very natural although Z need not be rational anymore. For $g(n) < p$ the real counterparts of the p-adic probabilities would sum up to one automatically for this option. One cannot deny that this option is more convincing than the original one. The generalization of this formula to map p-adic mass squared to a real one is obvious.

(c) Options 1) and 2) differ dramatically when the $n = 0$ massless ground state has ground state degeneracy $D > 1$. For option 1) the real mass is predicted to be of order CP_2 mass whereas for option 2) it would be by a factor $1/D$ smaller than the minimum mass predicted by the option a). Thus option 2) would predict a large number of additional exotic states. For those states which are light for option 1), the two options make identical predictions as far as the significant two lowest order terms are considered. Hence this interpretation would not change the predictions of the p-adic mass calculations in this respect. Option 2) is definitely more in accord with the real physics based intuitions and the main role of p-adic thermodynamics would be to guarantee the quantization of the temperature and fix practically uniquely the spectrum of the "Hamiltonian".

Under what conditions the mapping of p-adic ensemble probabilities to real probabilities respects probability conservation?

One can consider also a more general situation. Assume that one has an ensemble consisting of independent elementary events such that the number of events of type i is N_i. The probabilities are given by $p_i = N_i/N$ and $N = \sum N_i$ is the total number of elementary events. Even in the case that N is infinite as a real number it is natural to map the p-adic probabilities to their real counterparts using the rational canonical identification $I(p_i) = I(N_i)/I(N)$. Of course, N_i and N exist as well defined p-adic numbers under very stringent conditions only.

The question is under what conditions this map respects probability conservation. The answer becomes obvious by looking at the pinary expansions of N_i and N. If the integers N_i (possibly infinite as real integers) have pinary expansions having no common pinary digits, the sum of probabilities is conserved in the map. Note that this condition can assign also to a finite ensemble with finite number of a unique value of p.

This means that the selection of a basis for independent events corresponds to a decomposition of the set of integers labelling pinary digits to disjoint sets and brings in mind the selection of orthonormalized basis of quantum states in quantum theory. What is physically highly non-trivial that this "orthogonalization" alone puts strong constraints on probabilities of the allowed elementary events. One can say that the probabilities define distributions of pinary digits analogous to non-negative probability amplitudes in the space of integers labelling pinary digits, and the probabilities of independent events must be orthogonal with respect to the inner product defined by point-wise multiplication in the space of pinary digits.

p-Adic thermodynamics for which Boltzmann weights $g(E)exp(-E/T)$ are replaced by $g(E)p^{E/T}$ such that one has $g(E) < p$ and E/T is integer valued, satisfies this constraint. The quantization of E/T to integer values implies quantization of both T and "energy" spectrum and forces so called super conformal invariance in TGD applications, which is indeed a basic symmetry of the theory.

There are infinitely many ways to choose the elementary events and each choice corresponds to a decomposition of the infinite set of integers n labelling the powers of p to disjoint subsets. These subsets can be also infinite. One can assign to this kind of decomposition a resolution which is the poorer the larger the subsets involved are. p-Adic thermodynamics would represent the situation in which the resolution is maximal since each set contains only single pinary digit. Note the analogy with the basis of completely localized wave functions in a lattice.

5.5 Modular contribution to the mass squared

The success of the p-adic mass calculations gives convincing support for the generation-genus correspondence. The basic physical picture is following.

(a) Fermionic mass squared is dominated by partonic contribution, which is sum of cm and modular contributions: $M^2 = M^2(cm) + M^2(mod)$. Here 'cm' refers to the thermal contribution. Modular contribution can be assumed to depend on the genus of the boundary component only.

(b) If Higgs contribution for diagonal (g,g) bosons (singlets with respect to "topological" $SU(3)$) dominates, the genus dependent contribution can be assumed to be negligible. This should be due to the bound state character of the wormhole contacts reducing thermal motion and thus the p-adic temperature.

(c) Modular contribution to the mass squared can be estimated apart from an overall proportionality constant. The mass scale of the contribution is fixed by the p-adic length scale hypothesis. Elementary particle vacuum functionals are proportional to a product of all even theta functions and their conjugates, the number of even theta functions and their conjugates being $2N(g) = 2^g(2^g + 1)$. Also the thermal partition function must also be proportional to $2N(g)$:th power of some elementary partition function. This implies that thermal/ quantum expectation $M^2(mod)$ must be proportional to $2N(g)$. Since single handle behaves effectively as particle, the contribution must be proportional to genus g also. The success of the resulting mass formula encourages the belief that the argument is essentially correct.

The challenge is to construct theoretical framework reproducing the modular contribution to mass squared. There are two alternative manners to understand the origin modular contribution.

(a) The realization that super-symplectic algebra is relevant for elementary particle physics leads to the idea that two thermodynamics are involved with the calculation of the vacuum conformal weight as a thermal expectation. The first thermodynamics corresponds to Super Kac-Moody algebra and second thermodynamics to super-symplectic algebra. This approach allows a first principle understanding of the origin and general form of the modular contribution without any need to introduce additional structures in modular degrees of freedom. The very fact that super-symplectic algebra does not commute with the modular degrees of freedom explains the dependence of the super-symplectic contribution on moduli.

(b) The earlier approach was based on the idea that he modular contribution could be regarded as a quantum mechanical expectation value of the Virasoro generator L_0 for the elementary particle vacuum functional. Quantum treatment would require generalization the concepts of the moduli space and theta function to the p-adic context and finding an acceptable definition of the Virasoro generator L_0 in modular degrees of freedom. The problem with this interpretation is that it forces to introduce, not only Virasoro generator L_0, but the entire super Virasoro algebra in modular degrees of freedom. One could also consider of interpreting the contribution of modular degrees of freedom to vacuum conformal weight as being analogous to that of CP_2 Laplacian but also this would raise the challenge of constructing corresponding Dirac operator. Obviously this approach has become obsolete.

The thermodynamical treatment taking into account the constraints from that p-adicization is possible might go along following lines.

(a) In the real case the basic quantity is the thermal expectation value $h(M)$ of the conformal weight as a function of moduli. The average value of the deviation $\Delta h(M) = h(M) - h(M_0)$ over moduli space $\mathcal{M}$ must be calculated using elementary particle vacuum functional as a modular invariant partition function. Modular invariance is achieved if this function is proportional to the logarithm of elementary particle vacuum functional: this reproduces the qualitative features basic formula for the modular contribution to the conformal weight. p-Adicization leads to a slight modification of this formula.

(b) The challenge of algebraically continuing this calculation to the p-adic context involves several sub-tasks. The notions of moduli space $\mathcal{M}_p$ and theta function must be defined in the p-adic context. An appropriately defined logarithm of the p-adic elementary particle vacuum functional should determine $\Delta h(M)$. The average of $\Delta h(M)$ requires an integration over $\mathcal{M}_p$. The problems related to the definition of this integral could be circumvented if the integral in the real case could be reduced to an algebraic expression, or if the moduli space is discrete in which case integral could be replaced by a sum.

(c) The number theoretic existence of the p-adic Θ function leads to the quantization of the moduli so that the p-adic moduli space is discretized. Accepting the sharpened form of Riemann hypothesis [K57] , the quantization means that the imaginary *resp.* real parts of the moduli are proportional to integers *resp.* combinations of imaginary parts of zeros of Riemann Zeta. This quantization could occur also for the real moduli for the maxima of Kähler function. This reduces the problematic p-adic integration to a sum and the resulting sum defining $\langle \Delta h \rangle$ converges extremely rapidly for physically interesting primes so that only the few lowest terms are needed.

5.5.1 Conformal symmetries and modular invariance

The full SKM invariance means that the super-conformal fields depend only on the conformal moduli of 2-surface characterizing the conformal equivalence class of the 2-surface. This means that all induced metrics differing by a mere Weyl scaling have same moduli. This symmetry is extremely powerful since the space of moduli is finite-dimensional and means that the entire infinite-dimensional space of deformations of parton 2-surface X^2 degenerates to a finite-dimensional moduli spaces under conformal equivalence. Obviously, the configurations of given parton correspond to a fiber space having moduli space as a base space. Super-symplectic degrees of freedom could break conformal invariance in some appropriate sense.

Conformal and SKM symmetries leave moduli invariant

Conformal transformations and super Kac Moody symmetries must leave the moduli invariant. This means that they induce a mere Weyl scaling of the induced metric of X^2 and thus preserve its non-diagonal character $ds^2 = g_{z\overline{z}}dzd\overline{z}$. This is indeed true if

(a) the Super Kac Moody symmetries are holomorphic isometries of $X^7 = \delta M^4_\pm \times CP_2$ made local with respect to the complex coordinate z of X^2, and

(b) the complex coordinates of X^7 are holomorphic functions of z.

Using complex coordinates for X^7 the infinitesimal generators can be written in the form

$$J^{An} = z^n j^{Ak} D_k + \overline{z}^n j^{A\overline{k}} D_{\overline{k}} \ . \tag{5.5.1}$$

The intuitive picture is that it should be possible to choose X^2 freely. It is however not always possible to choose the coordinate z of X^2 in such a manner that X^7 coordinates are holomorphic functions of z since a consistency of inherent complex structure of X^2 with that induced from X^7 is required. Geometrically this is like meeting of two points in the space of moduli.

Lorentz boosts produce new inequivalent choices of S^2 with their own complex coordinate: this set of complex structures is parameterized by the hyperboloid of future light cone (Lobatchevski space or mass shell), but even this is not enough. The most plausible manner to circumvent the problem is that only the maxima of Kähler function correspond to the holomorphic situation so that super-symplectic algebra representing quantum fluctuations would induce conformal anomaly.

The isometries of δM^4_+ are in one-one correspondence with conformal transformations

For CP_2 factor the isometries reduce to $SU(3)$ group acting also as symplectic transformations. For $\delta M^4_+ = S^2 \times R_+$ one might expect that isometries reduce to Lorentz group containing rotation group of $SO(3)$ as conformal isometries. If r_M corresponds to a macroscopic length scale, then X^2 has a finite sized S^2 projection which spans a rather small solid angle so that group $SO(3)$ reduces in a good approximation to the group $E^2 \times SO(2)$ of translations and rotations of plane.

This expectation is however wrong! The light-likeness of δM^4_+ allows a dramatic generalization of the notion of isometry. The point is that the conformal transformations of S^2 induce a conformal factor $|df/dw|^2$ to the metric of δM^4_+ and the local radial scaling $r_M \rightarrow r_M/|df/dw|$ compensates it. Hence the group of conformal isometries consists of conformal transformations of S^2 with compensating radial scalings. This compensation of two kinds of conformal transformations is the deep geometric phenomenon which translates to the condition $L_{SC} - L_{SKM} = 0$ in the sub-space of physical states. Note that an analogous phenomenon occurs also for the light-like CDs X^3_l with respect to the metrically 2-dimensional induced metric.

The X^2-local radial scalings $r_M \rightarrow r_M(z, \overline{z})$ respect the conditions $g_{zz} = g_{\overline{z}\overline{z}} = 0$ so that a mere Weyl scaling leaving moduli invariant results. By multiplying the conformal isometries of δM^4_+ by z^n (z is used as a complex coordinate for X^2 and w as a complex coordinate for S^2) a conformal localization of conformal isometries would result. Kind of double conformal transformations would be in question. Note however that this requires that X^7 coordinates are holomorphic functions of X^2 coordinate. These transformations deform X^2 unlike the conformal transformations of X^2. For X^3_l similar local scalings of the light like coordinate leave the moduli invariant but lead out of X^7.

Symplectic transformations break the conformal invariance

In general, infinitesimal symplectic transformations induce non-vanishing components $g_{zz}, g_{\overline{z}\overline{z}}$ of the induced metric and can thus change the moduli of X^2. Thus the quantum fluctuations represented by super-symplectic algebra and contributing to the WCW metric are in general moduli changing. It would be interesting to know explicitly the conditions (the number of which is the dimension of moduli space for a given genus), which guarantee that the infinitesimal symplectic transformation is moduli preserving.

5.5.2 The physical origin of the genus dependent contribution to the mass squared

Different p-adic length scales are not enough to explain the charged lepton mass ratios and an additional genus dependent contribution in the fermionic mass formula is required. The general form of this contribution can be guessed by regarding elementary particle vacuum functionals in the modular degrees of freedom as an analog of partition function and the modular contribution to the conformal weight as an analog of thermal energy obtained by averaging over moduli. p-Adic length scale hypothesis determines the overall scale of the contribution.

The exact physical origin of this contribution has remained mysterious but super-symplectic degrees of freedom represent a good candidate for the physical origin of this contribution. This would mean a sigh of relief since there would be no need to assign conformal weights, super-algebra, Dirac operators, Laplacians, etc.. with these degrees of freedom.

Thermodynamics in super-symplectic degrees of freedom as the origin of the modular contribution to the mass squared

The following general picture is the simplest found hitherto.

(a) Elementary particle vacuum functionals are defined in the space of moduli of surfaces X^2 corresponding to the maxima of Kähler function. There some restrictions on X^2. In particular, p-adic length scale poses restrictions on the size of X^2. There is an infinite hierarchy of elementary particle vacuum functionals satisfying the general constraints but only the lowest elementary particle vacuum functionals are assumed to contribute significantly to the vacuum expectation value of conformal weight determining the mass squared value.

(b) The contribution of Super-Kac Moody thermodynamics to the vacuum conformal weight h coming from Virasoro excitations of the $h = 0$ massless state is estimated in the previous calculations and does not depend on moduli. The new element is that for a partonic 2-surface X^2 with given moduli, Virasoro thermodynamics is present also in super-symplectic degrees of freedom.

Super-symplectic thermodynamics means that, besides the ground state with $h_{gr} = -h_{SC}$ with minimal value of super-symplectic conformal weight h_{SC}, also thermal excitations of this state by super-symplectic Virasoro algebra having $h_{gr} = -h_{SC} - n$ are possible. For these ground states the SKM Virasoro generators creating states with net conformal weight $h = h_{SKM} - h_{SC} - n \geq 0$ have larger conformal weight so that the SKM thermal average h depends on n. It depends also on the moduli M of X^2 since the Beltrami differentials representing a tangent space basis for the moduli space $\mathcal{M}$ do not commute with the super-symplectic algebra. Hence the thermally averaged SKM conformal weight h_{SKM} for given values of moduli satisfies

$$h_{SKM} = h(n, M) \ . \tag{5.5.2}$$

(c) The average conformal weight induced by this double thermodynamics can be expressed as a super-symplectic thermal average $\langle\cdot\rangle_{SC}$ of the SKM thermal average $h(n, M)$:

$$h(M) = \langle h(n, M)\rangle_{SC} = \sum p_n(M)h(n) \ , \tag{5.5.3}$$

where the moduli dependent probability $p_n(M)$ of the super-symplectic Virasoro excitation with conformal weight n should be consistent with the p-adic thermodynamics. It is convenient to write $h(M)$ as

$$h(M) = h_0 + \Delta h(M) \ , \tag{5.5.4}$$

where h_0 is the minimum value of $h(M)$ in the space of moduli. The form of the elementary particle vacuum functionals suggest that h_0 corresponds to moduli with $Im(\Omega_{ij}) = 0$ and thus to singular configurations for which handles degenerate to one-dimensional lines attached to a sphere.

(d) There is a further averaging of $\Delta h(M)$ over the moduli space $\mathcal{M}$ by using the modulus squared of elementary particle vacuum functional so that one has

$$h \;=\; h_0 + \langle \Delta h(M) \rangle_{\mathcal{M}} \ . \tag{5.5.5}$$

Modular invariance allows to pose very strong conditions on the functional form of $\Delta h(M)$. The simplest assumption guaranteeing this and thermodynamical interpretation is that $\Delta h(M)$ is proportional to the logarithm of the vacuum functional Ω:

$$\Delta h(M) \;\propto\; -log(\frac{\Omega(M)}{\Omega_{max}}) \ . \tag{5.5.6}$$

Here Ω_{max} corresponds to the maximum of Ω for which $\Delta h(M)$ vanishes.

Justification for the general form of the mass formula

The proposed general ansatz for $\Delta h(M)$ provides a justification for the general form of the mass formula deduced by intuitive arguments.

(a) The factorization of the elementary particle vacuum functional Ω into a product of $2N(g) = 2^g(2^g + 1)$ terms and the logarithmic expression for $\Delta h(M)$ imply that the thermal expectation values is a sum over thermal expectation values over $2N(g)$ terms associated with various even characteristics (a, b), where a and b are g-dimensional vectors with components equal to $1/2$ or 0 and the inner product $4a \cdot b$ is an even integer. If each term gives the same result in the averaging using Ω_{vac} as a partition function, the proportionality to $2N_g$ follows.

(b) For genus $g \geq 2$ the partition function defines an average in $3g-3$ complex-dimensional space of moduli. The analogy of $\langle \Delta h \rangle$ and thermal energy suggests that the contribution is proportional to the complex dimension $3g-3$ of this space. For $g \leq 1$ the contribution the complex dimension of moduli space is g and the contribution would be proportional to g.

$$\begin{aligned} \langle \Delta h \rangle &\propto g \times X(g) \ \text{ for } \ g \leq 1 \ , \\ \langle \Delta h \rangle &\propto (3g-3) \times X(g) \ \text{ for } \ g \geq 2 \ , \\ X(g) &= 2^g(2^g + 1) \ . \end{aligned} \tag{5.5.7}$$

If X^2 is hyper-elliptic for the maxima of Kähler function, this expression makes sense only for $g \leq 2$ since vacuum functionals vanish for hyper-elliptic surfaces.

(c) The earlier argument, inspired by the interpretation of elementary particle vacuum functional as a partition function, was that each factor of the elementary particle vacuum functional gives the same contribution to $\langle \Delta h \rangle$, and that this contribution is proportional to g since each handle behaves like a particle:

$$\langle \Delta h \rangle \;\propto\; g \times X(g) \ . \tag{5.5.8}$$

The prediction following from the previous differs by a factor $(3g-3)/g$ for $g \geq 2$. This would scale up the dominant modular contribution to the masses of the third $g = 2$ fermionic generation by a factor $\sqrt{3/2} \simeq 1.22$. One must of course remember, that these rough arguments allow $g-$ dependent numerical factors of order one so that it is not possible to exclude either argument.

5.5.3 Generalization of Θ functions and quantization of p-adic moduli

The task is to find p-adic counterparts for theta functions and elementary particle vacuum functionals. The constraints come from the p-adic existence of the exponentials appearing as the summands of the theta functions and from the convergence of the sum. The exponentials must be proportional to powers of p just as the Boltzmann weights defining the p-adic partition function. The outcome is a quantization of moduli so that integration can be replaced with a summation and the average of $\Delta h(M)$ over moduli is well defined.

It is instructive to study the problem for torus in parallel with the general case. The ordinary moduli space of torus is parameterized by single complex number τ. The points related by $SL(2,Z)$ are equivalent, which means that the transformation $\tau \rightarrow (A\tau+B)/(C\tau+D)$ produces a point equivalent with τ. These transformations are generated by the shift $\tau \rightarrow \tau+1$ and $\tau \rightarrow -1/\tau$. One can choose the fundamental domain of moduli space to be the intersection of the slice $Re(\tau) \in [-1/2,1/2]$ with the exterior of unit circle $|\tau|=1$. The idea is to start directly from physics and to look whether one might some define p-adic version of elementary particle vacuum functionals in the p-adic counterpart of this set or in some modular invariant subset of this set.

Elementary particle vacuum functionals are expressible in terms of theta functions using the functions $\Theta^4[a,b]\overline{\Theta}^4[a,b]$ as a building block. The general expression for the theta function reads as

$$\Theta[a,b](\Omega) \quad = \quad \sum_n exp(i\pi(n+a)\cdot\Omega\cdot(n+a))exp(2i\pi(n+a)\cdot b) \quad . \tag{5.5.9}$$

The latter exponential phase gives only a factor $\pm i$ or ± 1 since $4a{\cdot}b$ is integer. For $p\ mod\ 4=3$ imaginary unit exists in an algebraic extension of p-adic numbers. In the case of torus (a,b) has the values $(0,0)$, $(1/2,0)$ and $(0,1/2)$ for torus since only even characteristics are allowed.

Concerning the p-adicization of the first exponential appearing in the summands in Eq. 5.5.9, the obvious problem is that π does not exists p-adically unless one allows infinite-dimensional extension.

(a) Consider first the real part of Ω. In this case the proper manner to treat the situation is to introduce and algebraic extension involving roots of unity so that $Re(\Omega)$ rational. This approach is proposed as a general approach to the p-adicization of quantum TGD in terms of harmonic analysis in symmetric spaces allowing to define integration also in p-adic context in a physically acceptable manner by reducing it to Fourier analysis. The simplest situation corresponds to integer values for $Re(\Omega)$ and in this case the phase are equal to $\pm i$ or ± 1 since a is half-integer valued. One can consider a hierarchy of variants of moduli space characterized by the allowed roots of unity. The physical interpretation for this hierarchy would be in terms of a hierarchy of measurement resolutions. Note that the real parts of Ω can be assumed to be rationals of form m/n where n is constructed as a product of finite number of primes and therefore the allowed rationals are linear combinations of inverses $1/p_i$ for a subset $\{p_i\}$ of primes.

(b) For the imaginary part of Ω different approach is required. One wants a rapid convergence of the sum formula and this requires that the exponents reduces in this case to positive powers of p. This is achieved if one has

$$Im(\Omega) \quad = \quad -n\frac{log(p)}{\pi)} \quad , \tag{5.5.10}$$

Unfortunately this condition is not consistent with the condition $Im(\Omega) > 0$. A manner to circumvent the difficulty is to replace Ω with its complex conjugate. Second approach is to define the real discretized variant of theta function first and then map it by canonical identification to its p-adic counterpart: this would map phase to phases and powers of p to their inverses. Note that a similar change of sign must be performed in p-adic thermodynamics for powers of p to map p-adic probabilities to real ones. By rescaling $Im(\Omega) \rightarrow \frac{log(p)}{\pi)} Im(\Omega)$ one has non-negative integer valued spectrum for $Im(\Omega)$ making possible to reduce integration in moduli space to a summation over finite number of rationals associated with the real part of Ω and powers of p associated with the imaginary part of Ω.

(c) Since the exponents appearing in

$$p^{(n+a)\cdot Im(\Omega_{ij,p})\cdot(n+a)} = p^{a\cdot Im(\Omega)\cdot a} \times p^{2a\cdot Im(\Omega\cdot n} \times p^{+n\cdot Im(\Omega_{ij,p})\cdot n}$$

are positive integers valued, $\Theta_{[a,b]}$ exist in R_p and converges. The problematic factor is the first exponent since the components of the vector a can have values 1/2 and 0 and its existence implies a quantization of $Im(\Omega_{ij})$ as

$$Im(\Omega) \quad = \quad -Kn\frac{log(p)}{p} \quad , \quad n \in Z \quad , \quad n \geq 1 \quad , \tag{5.5.11}$$

In p-adic context this condition must be formulated for the exponent of Ω defining the natural coordinate. $K = 4$ guarantees the existence of Θ functions and $K = 1$ the existence of the building blocks $\Theta^4[a,b]\overline{\Theta}^4[a,b]$ of elementary particle vacuum functionals in R_p. The extension to higher genera means only replacement of Ω with the elements of a matrix.

(d) One can criticize this approach for the loss of the full modular covariance in the definition of theta functions. The modular transformations $\Omega \rightarrow \Omega + n$ are consistent with the number theoretic constraints but the transformations $\Omega \rightarrow -1/\Omega$ do not respect them. It seem that one can circumvent the difficulty by restricting the consideration to a fundamental domain satisfying the number theoretic constraints.

This variant of moduli space is discrete and p-adicity is reflected only in the sense that the moduli space makes sense also p-adically. One can consider also a continuum variant of the p-adic moduli space using the same prescription as in the construction of p-adic symmetric spaces [K66] .

(a) One can introduce $exp(i\pi Re(\Omega))$ as the counterpart of $Re(\Omega)$ as a coordinate of the Teichmueller space. This coordinate makes sense only as a local coordinate since it does not differentiate between $Re(\Omega)$ and $Re(\Omega+2n)$. On the other hand, modular invariance states that Ω abd $\Omega + n$ correspond to the same moduli so that nothing is lost. In the similar manner one can introduce $exp^(\pi Im(\Omega)) \in \{p^n, n > 0\}$ as the counterpart of discretized version of $Im(\Omega)$.

(b) The extension to continuum would mean in the case of $Re(\Omega)$ the extension of the phase $exp(i\pi Re(\Omega))$ to a product $exp(i\pi Re(\Omega))exp(ipx) = exp(i\pi Re(\Omega) + exp(ipx)$, where x is p-adic integer which can be also infinite as a real integer. This would mean that each root of unity representing allowed value $Re(\Omega)$ would have a p-adic neighborhood consisting of p-adic integers. This neighborhood would be the p-adic counterpart for the angular integral $\Delta\phi$ for a given root of unity and would not make itself visible in p-adic integration.

(c) For the imaginary part one can also consider the extension of $exp(\pi Im(\Omega))$ to $p^n \times exp(npx)$ where x is a p-adic integer. This would assign to each point p^n a p-adic neighborhood defined by p-adic integers. This neighborhood is same all integers n with same p-adic norm. When n is proportional to p^k one has $exp(npx) - 1 \propto p^k$.

The quantization of moduli characterizes precisely the conformal properties of the partonic 2-surfaces corresponding to different p-adic primes. In the real context -that is in the intersection of real and p-adic worlds- the quantization of moduli of torus would correspond to

$$\tau = K\left[\sum q + i\times n\frac{log(p)}{\pi}\right] \ , \quad (5.5.12)$$

where q is a rational number expressible as linear combination of inverses of a finite fixed set of primes defining the allowed roots of unity. $K = 1$ guarantees the existence of elementary particle vacuum functionals and $K = 4$ the existence of Theta functions. The ratio for the complex vectors defining the sides of the plane parallelogram defining torus via the identification of the parallel sides is quantized. In other words, the angles Φ between the sides and the ratios of the sides given by $|\tau|$ have quantized values.

The quantization rules for the moduli of the higher genera is of exactly same form

$$\Omega_{ij} = K\left[\sum q_{ij} + i\times n_{ij}\times\frac{log(p)}{\pi}\right] \ , \quad (5.5.13)$$

If the quantization rules hold true also for the maxima of Kähler function in the real context or more precisely- in the intersection of real and p-adic variants of the "world of classical worlds" identified as partonic 2-surfaces at the boundaries of causal diamond plus the data about their 4-D tangent space, there are good hopes that the p-adicized expression for Δh is obtained by a simple algebraic continuation of the real formula. Thus p-adic length scale would characterize partonic surface X^2 rather than the light like causal determinant X_l^3 containing X^2. Therefore the idea that various p-adic primes label various X_l^3 connecting fixed partonic surfaces X_i^2 would not be correct.

Quite generally, the quantization of moduli means that the allowed 2-dimensional shapes form a lattice and are thus additive. It also means that the maxima of Kähler function would obey a linear superposition in an extreme abstract sense. The proposed number theoretical quantization is expected to apply for any complex space allowing some preferred complex coordinates. In particular, WCW of 2-surfaces could allow this kind of quantization in the complex coordinates naturally associated with isometries and this could allow to define WCW integration, at least the counterpart of integration in zero mode degrees of freedom, as a summation.

Number theoretic vision leads to the notion of multi-p-p-adicity in the sense that the same partonic 2-surface can correspond to several p-adic primes and that infinite primes code for these primes [K23, K65] . At the level of the moduli space this corresponds to the replacement of p with an integer in the formulas so that one can interpret the formulas both in real sense and p-adic sense for the primes p dividing the integer. Also the exponent of given prime in the integer matters.

5.5.4 The calculation of the modular contribution $\langle\Delta h\rangle$ to the conformal weight

The quantization of the moduli implies that the integral over moduli can be defined as a sum over moduli. The theta function $\Theta[a,b](\Omega)_p(\tau_p)$ is proportional to $p^{a\cdot aIm(\Omega_{ij,p})} = p^{Kn_{ij}m(a)/4}$ for $a\cdot a = m(a)/4$, where $K = 1$ *resp.* $K = 4$ corresponds to the existence existence of elementary particle vacuum functionals *resp.* theta functions in R_p. These powers of p can be extracted from the thetas defining the vacuum functional. The numerator of the vacuum functional gives $(p^n)^{2K\sum_{a,b}m(a)}$. The numerator gives $(p^n)^{2K\sum_{a,b}m(a_0)}$, where a_0 corresponds to the minimum value of $m(a)$. $a_0 = (0,0,..,0)$ is allowed and gives $m(a_0) = 0$ so that the p-adic norm of the denominator equals to one. Hence one has

$$|\Omega_{vac}(\Omega_p)|_p = p^{-2nK\sum_{a,b}m(a)} \quad (5.5.14)$$

The sum converges extremely rapidly for large values of p as function of n so that in practice only few moduli contribute.

The definition of $log(\Omega_{vac})$ poses however problems since in $log(p)$ does not exist as a p-adic number in any p-adic number field. The argument of the logarithm should have a unit p-adic norm. The simplest manner to circumvent the difficulty is to use the fact that the p-adic norm $|\Omega_p|_p$ is also a modular invariant, and assume that the contribution to conformal weight depends on moduli as

$$\Delta h_p(\Omega_p) \quad \propto \quad log(\frac{\Omega_{vac}}{|\Omega_{vac}|_p}) \ . \tag{5.5.15}$$

The sum defining $\langle \Delta h_p \rangle$ converges extremely rapidly and gives a result of order $O(p)$ p-adically as required.

The p-adic expression for $\langle \Delta h_p \rangle$ should result from the corresponding real expression by an algebraic continuation. This encourages the conjecture that the allowed moduli are quantized for the maxima of Kähler function, so that the integral over the moduli space is replaced with a sum also in the real case, and that Δh given by the double thermodynamics as a function of moduli can be defined as in the p-adic case. The positive power of p multiplying the numerator could be interpreted as a degeneracy factor. In fact, the moduli are not primary dynamical variables in the case of the induced metric, and there must be a modular invariant weight factor telling how many 2-surfaces correspond to given values of moduli. The power of p could correspond to this factor.

5.6 The contributions of p-adic thermodynamics to particle masses

In the sequel various contributions to the mass squared are discussed.

5.6.1 General mass squared formula

The thermal independence of Super Virasoro and modular degrees of freedom implies that mass squared for elementary particle is the sum of Super Virasoro, modular and Higgsy contributions:

$$M^2 \quad = \quad M^2(color) + M^2(SV) + M^2(mod) + M^2(Higgsy) \ . \tag{5.6.1}$$

Also small renormalization correction contributions might be possible.

5.6.2 Color contribution to the mass squared

The mass squared contains a non-thermal color contribution to the ground state conformal weight coming from the mass squared of CP_2 spinor harmonic. The color contribution is an integer multiple of $m_0^2/3$, where $m_0^2 = 2\Lambda$ denotes the 'cosmological constant' of CP_2 (CP_2 satisfies Einstein equations $G^{\alpha\beta} = \Lambda g^{\alpha\beta}$).

The color contribution to the p-adic mass squared is integer valued only if $m_0^2/3$ is taken as a fundamental p-adic unit of mass squared. This choice has an obvious relevance for p-adic mass calculations since the simplest form of the canonical identification does not commute with a division by integer. More precisely, the image of number xp in canonical identification has a value of order 1 when x is a non-trivial rational number whereas for $x = np$ the value is n/p and extremely is small for physically interesting primes.

The choice of the p-adic mass squared unit are no effects on zeroth order contribution which must vanish for light states: this requirement eliminates quark and lepton states for which the CP_2 contribution to the mass squared is not integer valued using m_0^2 as a unit. There can be a dramatic effect on the first order contribution. The mass squared $m^2 = p/3$ using $m_0^2/3$ means that the particle is light. The mass squared becomes $m^2 = p/3$ when m_0^2 is used as a unit and the particle has mass of order 10^{-4} Planck masses. In the case of W and Z^0 bosons this problem is actually encountered. For light states using $m_0^2/3$ as a unit only the second order contribution to the mass squared is affected by this choice.

5.6.3 Modular contribution to the mass of elementary particle

The general form of the modular contribution is derivable from p-adic partition function for conformally invariant degrees of freedom associated with the boundary components. The general form of the vacuum functionals as modular invariant functions of Teichmueller parameters was derived in [K14] and the square of the elementary particle vacuum functional can be identified as a partition function. Even theta functions serve as basic building blocks and the functionals are proportional to the product of all even theta functions and their complex conjugates. The number of theta functions for genus $g > 0$ is given by

$$N(g) = 2^{g-1}(2^g+1) \ . \tag{5.6.2}$$

One has $N(1) = 3$ for muon and $N(2) = 10$ for τ.

(a) Single theta function is analogous to a partition function. This implies that the modular contribution to the mass squared must be proportional to $2N(g)$. The factor two follows from the presence of both theta functions and their conjugates in the partition function.

(b) The factorization properties of the vacuum functionals imply that handles behave effectively as particles. For example, at the limit, when the surface splits into two pieces with g_1 and $g - g_1$ handles, the partition function reduces to a product of g_1 and $g - g_1$ partition functions. This implies that the contribution to the mass squared is proportional to the genus of the surface. Altogether one has

$$\begin{aligned} M^2(mod,g) &= 2k(mod)N(g)g\frac{m_0^2}{p} \ , \\ k(mod) &= 1 \ . \end{aligned} \tag{5.6.3}$$

Here $k(mod)$ is some integer valued constant (in order to avoid ultra heavy mass) to be determined. $k(mod) = 1$ turns out to be the correct choice for this parameter.

Summarizing, the real counterpart of the modular contribution to the mass of a particle belonging to $g + 1$:th generation reads as

$$\begin{aligned} M^2(mod) &= 0 \ for \ e,\nu_e,u,d \ , \\ M^2(mod) &= 9\frac{m_0^2}{p(X))} \ for \ X = \mu,\nu_\mu,c,s \ , \\ M^2(mod) &= 60\frac{m_0^2}{p(X)} \ for \ X = \tau,\nu_\tau,t,b \ . \end{aligned} \tag{5.6.4}$$

The requirement that hadronic mass spectrum and CKM matrix are sensible however forces the modular contribution to be the same for quarks, leptons and bosons. The higher order modular contributions to the mass squared are completely negligible if the degeneracy of massless state is $D(0, mod, g) = 1$ in the modular degrees of freedom as is in fact required by $k(mod) = 1$.

5.6.4 Thermal contribution to the mass squared

One can deduce the value of the thermal mass squared in order $O(p^2)$ (an excellent approximation) using the general mass formula given by p-adic thermodynamics. Assuming maximal p-adic temperature $T_p = 1$ one has

$$\begin{aligned} M^2 &= k(sp + Xp^2 + O(p^3)) \ , \\ s_\Delta &= \frac{D(\Delta+1)}{D(\Delta)} \ , \\ X_\Delta &= 2\frac{D(\Delta+2)}{D(\Delta)} - \frac{D^2(\Delta+1)}{D^2(\Delta)} \ , \\ k &= 1 \ . \end{aligned} \quad (5.6.5)$$

Δ is the conformal weight of the operator creating massless state from the ground state.

The ratios $r_n = D(n+1)/D(n)$ allowing to deduce the values of s and X have been deduced from p-adic thermodynamics in [K34] . Light state is obtained only provided $r(\Delta)$ is an integer. The remarkable result is that for lowest lying states this is the case. For instance, for Ramond representations the values of r_n are given by

$$(r_0, r_1, r_2, r_3) = (8, 5, 4, \frac{55}{16}) \ . \quad (5.6.6)$$

The values of s and X are

$$\begin{aligned} (s_0, s_1, s_2) &= (8, 5, 4) \ , \\ (X_0, X_1, X_2) &= (16, 15, 11 + 1/2)) \ . \end{aligned} \quad (5.6.7)$$

The result means that second order contribution is extremely small for quarks and charged leptons having $\Delta < 2$. For neutrinos having $\Delta = 2$ the second order contribution is non-vanishing.

5.6.5 The contribution from the deviation of ground state conformal weight from negative integer

The interpretation inspired by p-adic mass calculations is that the squares λ_i^2 of the eigenvalues of the modified Dirac operator correspond to the conformal weights of ground states. Another natural physical interpretation of λ is as an analog of the Higgs vacuum expectation. The instability of the Higgs=0 phase would corresponds to the fact that $\lambda = 0$ mode is not localized to any region in which ew magnetic field or induced Kähler field is non-vanishing. A good guess is that induced Kähler magnetic field B_K dictates the magnitude of the eigenvalues which is thus of order $h_0 = \sqrt{B_K R}$, R CP_2 radius. The first guess is that eigenvalues in the first approximation come as $(n + 1/2)h_0$. Each region where induced Kähler field is non-vanishing would correspond to different scale mass scale h_0.

(a) The vacuum expectation value of Higgs is only proportional to an eigenvalue λ, not equal to it. Indeed, Higgs and gauge bosons as elementary particles correspond to wormhole contacts carrying fermion and anti-fermion at the two wormhole throats and must be distinguished from the space-time correlate of its vacuum expectation as something proportional to λ. In the fermionic case the vacuum expectation value of Higgs does not seem to be even possible since fermions do not correspond to wormhole contacts between two space-time sheets but possess only single wormhole throat (p-adic mass calculations are consistent with this).

(b) Physical considerations suggest that the vacuum expectation of Higgs field corresponds to a particular eigenvalue λ_i of modified Dirac operator so that the eigenvalues λ_i would define TGD counterparts for the minima of Higgs potential. Since the vacuum expectation of Higgs corresponds to a condensate of wormhole contacts giving rise to a coherent state, the vacuum expectation cannot be present for topologically condensed CP_2 type vacuum extremals representing fermions since only single wormhole throat is involved. This raises a hen-egg question about whether Higgs contributes to the mass or whether Higgs is only a correlate for massivation having description using more profound concepts. From TGD point of view the most elegant option is that Higgs does not give rise to mass but Higgs vacuum expectation value accompanies bosonic states and is naturally proportional to λ_i. With this interpretation λ_i could give a contribution to both fermionic and bosonic masses.

(c) p-Adic mass calculations require negative ground state conformal weight compensated by Super Virasoro generators in order to obtain massless states. The tachyonicity of the ground states would mean a close analogy with both string models and Higgs mechanism. λ_i^2 is very natural candidate for the ground state conformal weights identified but would have wrong sign if the effective metric of X_l^3 defined by the inner products $T_K^{k\alpha}T_K^{l\beta}h_{kl}$ of the Kähler energy momentum tensor $T^{k\alpha} = h^{kl}\partial L_K/\partial h_\alpha^l$ and appearing in the modified Dirac operator D_K has Minkowskian signature.

The situation changes if the effective metric has Euclidian signature. This seems to be the case for the light-like surfaces assignable to the known extremals such as MEs and cosmic strings. In this kind of situation light-like coordinate possesses Euclidian signature and real eigenvalue spectrum is replaced with a purely imaginary one. Since Dirac operator is in question both signs for eigenvalues are possible and one obtains both exponentially increasing and decreasing solutions. This is essential for having solutions extending from the past end of X_l^3 to its future end. Non-unitary time evolution is possible because X_l^3 does not strictly speaking represent the time evolution of 2-D dynamical object but actual dynamical objects (by light-likeness both interpretation as dynamical evolution and dynamical object are present). The Euclidian signature of the effective metric would be a direct analog for the tachyonicity of the Higgs in unstable minimum and the generation of Higgs vacuum expectation would correspond to the compensation of ground state conformal weight by conformal weights of Super Virasoro generators.

(d) In accordance with this λ_i^2 would give constant contribution to the ground state conformal weight. What contributes to the thermal mass squared is the deviation of the ground state conformal weight from half-odd integer since the negative integer part of the total conformal weight can be compensated by applying Virasoro generators to the ground state. The first guess motivated by cyclotron energy analogy is that the lowest conformal weights are of form $h_c = \lambda_i^2 = -1/2 - n + \Delta h_c$ so that lowest ground state conformal weight would be $h_c = -1/2$ in the first approximation. The negative integer part of the net conformal weight can be canceled using Super Virasoro generators but Δh_c would give to mass squared a contribution analogous to Higgs contribution. The mapping of the real ground state conformal weight to a p-adic number by canonical identification involves some delicacies.

(e) p-Adic mass calculations are consistent with the assumption that Higgs type contribution is vanishing (that is small) for fermions and dominates for gauge bosons. This requires that the deviation of λ_i^2 with smallest magnitude from half-odd integer value in the case of fermions is considerably smaller than in the case of gauge bosons in the scale defined by p-adic mass scale $1/L(k)$ in question. Somehow this difference could relate to the fact that bosons correspond to pairs of wormhole throats.

5.6.6 General mass formula for Ramond representations

By taking the modular contribution from the boundaries into account the general p-adic mass formulas for the Ramond type states read for states for which the color contribution to the conformal weight is integer valued as

$$\begin{aligned}
\frac{m^2(\Delta=0)}{m_0^2} &= (8+n(g))p + Yp^2 \ , \\
\frac{m^2(\Delta=1)}{m_0^2} &= (5+n(g)p + Yp^2 \ , \\
\frac{m^2(\Delta=2)}{m_0^2} &= (4+n(g))p + (Y+\frac{23}{2})p^2 \ , \\
n(g) &= 3g\cdot 2^{g-1}(2^g+1) \ .
\end{aligned} \tag{5.6.8}$$

Here Δ denotes the conformal weight of the operators creating massless states from the ground state and g denotes the genus of the boundary component. The values of $n(g)$ for the three lowest generations are $n(0) = 0$, $n(1) = 9$ and $n(2) = 60$. The value of second order thermal contribution is nontrivial for neutrinos only. The value of the rational number Y can, which corresponds to the renormalization correction to the mass, can be determined using experimental inputs.

Using m_0^2 as a unit, the expression for the mass of a Ramond type state reads in terms of the electron mass as

$$\begin{aligned}
M(\Delta,g,p)_R &= K(\Delta,g,p)\sqrt{\frac{M_{127}}{p}}m_e \\
K(0,g,p) &= \sqrt{\frac{n(g)+8+Y_R}{X}} \\
K(1,g,p) &= \sqrt{\frac{n(g)+5+Y_R}{X}} \\
K(2,g,p) &= \sqrt{\frac{n(g)+4+Y_R}{X}} \ , \\
X &= \sqrt{5+Y(e)_R} \ .
\end{aligned} \tag{5.6.9}$$

Y can be assumed to depend on the electromagnetic charge and color representation of the state and is therefore same for all fermion families. Mathematica provides modules for calculating the real counterpart of the second order contribution and for finding realistic values of Y.

5.6.7 General mass formulas for NS representations

Using $m_0^2/3$ as a unit, the expression for the mass of a light NS type state for $T_p = 1$ ad $k_B = 1$ reads in terms of the electron mass as

$$
\begin{aligned}
M(\Delta, g, p, N)_R &= K(\Delta, g, p, N)\sqrt{\frac{M_{127}}{p}}m_e \\
K(0, g, p, 1) &= \sqrt{\frac{n(g)+Y_R}{X}} \ , \\
K(0, g, p, 2) &= \sqrt{\frac{n(g)+1+Y_R}{X}} \ , \\
K(1, g, p, 3) &= \sqrt{\frac{n(g)+3+Y_R}{X}} \ , \\
K(2, g, p, 4) &= \sqrt{\frac{n(g)+5+Y_R}{X}} \ , \\
K(2, g, p, 5) &= \sqrt{\frac{n(g)+10+Y_R}{X}} \ , \\
X &= \sqrt{5+Y(e)_R} \ .
\end{aligned} \tag{5.6.10}
$$

Here N is the number of the 'active' NS sectors (sectors for which the conformal weight of the massless state is non-vanishing). Y denotes the renormalization correction to the boson mass and in general depends on the electro-weak and color quantum numbers of the boson. The thermal contribution to the mass of W boson is too large by roughly a factor $\sqrt{3}$ for $T_p = 1$. Hence $T_p = 1/2$ must hold true for gauge bosons and their masses must have a non-thermal origin perhaps analogous to Higgs mechanism. Alternatively, the non-covariant constancy of charge matrices could induce the boson mass [K34] .

It is interesting to notice that the minimum mass squared for gauge boson corresponds to the p-adic mass unit $M^2 = m_0^2 p/3$ and this just what is needed in the case of W boson. This forces to ask whether $m_0^2/3$ is the correct choice for the mass squared unit so that non-thermally induced W mass would be the minimal $m_W^2 = p$ in the lowest order. This choice would mean the replacement

$$
Y_R \rightarrow \frac{(3Y)_R}{3}
$$

in the preceding formulas and would affect only neutrino mass in the fermionic sector. $m_0^2/3$ option is excluded by charged lepton mass calculation. This point will be discussed later.

5.6.8 Primary condensation levels from p-adic length scale hypothesis

p-Adic length scale hypothesis states that the primary condensation levels correspond to primes near prime powers of two $p \simeq 2^k$, k integer with prime values preferred. Black hole-elementary particle analogy [K45] suggests a generalization of this hypothesis by allowing k to be a power of prime. The general number theoretical vision discussed in [K66] provides a first principle justification for p-adic length scale hypothesis in its most general form. The best fit for the neutrino mass squared differences is obtained for $k = 13^2 = 169$ so that the generalization of the hypothesis might be necessary.

A particle primarily condensed on the level k can suffer secondary condensation on a level with the same value of k: for instance, electron ($k = 127$) suffers secondary condensation on $k = 127$ level. u, d, s quarks ($k = 107$) suffer secondary condensation on nuclear space-time sheet having $k = 113$). All quarks feed their color gauge fluxes at $k = 107$ space-time sheet. There is no deep reason forbidding the condensation of p on p. Primary and secondary condensation levels could also correspond to different but nearly identical values of p with the same value of k.

5.7 Fermion masses

In the earlier model the coefficient of $M^2 = kL_0$ had to be assumed to be different for various particle states. $k = 1$ was assumed for bosons and leptons and $k = 2/3$ for quarks. The fact that $k = 1$ holds true for all particles in the model including also super-symplectic invariance forces to modify the earlier construction of quark states. This turns out to be possible without affecting the earlier p-adic mass calculations whose outcome depend in an essential manner on the ground state conformal weights h_{gr} of the fermions (h_{gr} can be negative). The structure of lepton and quark states in color degrees of freedom was discussed in [K34] .

5.7.1 Charged lepton mass ratios

The overall mass scale for lepton and quark masses is determined by the condensation level given by prime $p \simeq 2^k$, k prime by length scale hypothesis. For charged leptons k must correspond to $k = 127$ for electron, $k = 113$ for muon and $k = 107$ for τ. For muon $p = 2^{113} - 1 - 4 * 378$ is assumed (smallest prime below 2^{113} allowing $\sqrt{2}$ but not $\sqrt{3}$). So called Gaussian primes are to complex integers what primes are for the ordinary integers and the Gaussian counterparts of the Mersenne primes are Gaussian primes of form $(1 \pm i)^k - 1$. Rather interestingly, $k = 113$ corresponds to a Gaussian Mersenne so that all charged leptons correspond to generalized Mersenne primes.

For $k = 1$ the leptonic mass squared is integer valued in units of m_0^2 only for the states satisfying

$$p \ mod \ 3 \neq 2 \ .$$

Only these representations can give rise to massless states. Neutrinos correspond to (p, p) representations with $p \geq 1$ whereas charged leptons correspond to $(p, p + 3)$ representations. The earlier mass calculations demonstrate that leptonic masses can be understood if the ground state conformal weight is $h_{gr} = -1$ for charged leptons and $h_{gr} = -2$ for neutrinos.

The contribution of color partial wave to conformal weight is $h_c = (p^2 + 2p)/3$, $p \geq 1$, for neutrinos and $p = 1$ gives $h_c = 1$ (octet). For charged leptons $h_c = (p^2 + 5p + 6)/3$ gives $h_c = 2$ for $p = 0$ (decouplet). In both cases super-symplectic operator O must have a net conformal weight $h_{sc} = -3$ to produce a correct conformal weight for the ground state. p-adic considerations suggests the use of operators O with super-symplectic conformal weight $z = -1/2 - i\sum n_k y_k$, where $s_k = 1/2 + iy_k$ corresponds to zero of Riemann ζ. If the operators in question are color Hamiltonians in octet representation net super-symplectic conformal weight $h_{sc} = -3$ results. The tensor product of two octets with conjugate super-symplectic conformal weights contains both octet and decouplet so that singlets are obtained. What strengthens the hopes that the construction is not ad hoc is that the same operator appears in the construction of quark states too.

Using CP_2 mass scale m_0^2 [K34] as a p-adic unit, the mass formulas for the charged leptons read as

$$\begin{aligned} M^2(L) &= A(\nu)\frac{m_0^2}{p(L)} \ , \\ A(e) &= 5 + X(p(e)) \ , \\ A(\mu) &= 14 + X(p(\mu)) \ , \\ A(\tau) &= 65 + X(p(\tau)) \ . \end{aligned} \tag{5.7.1}$$

$X(\cdot)$ corresponds to the yet unknown second order corrections to the mass squared.

The following table gives the basic parameters as determined from the mass of electron for some values of Y_e. The mass of top quark favors as maximal value of CP_2 mass which corresponds to $Y_e = 0$.

Y_e	0	.5	.7798
$(m_0/m_{Pl}) \times 10^3$	.2437	.2323	.2266
$K \times 10^{-7}$	2.5262	2.7788	2.9202
$(L_R/\sqrt{G}) \times 10^{-4}$	3.1580	3.3122	3.3954

Table 1. Table gives the values of CP_2 mass m_0 using Planck mass $m_{Pl} = 1/\sqrt{G}$ as unit, the ratio $K = R^2/G$ and CP_2 geodesic length $L = 2\pi R$ for $Y_e \in \{0, 0.5, 0.7798\}$.

The following table lists the lower and upper bounds for the charged lepton mass ratios obtained by taking second order contribution to zero or allowing it to have maximum possible value. The values of lepton masses are $m_e = .510999$ MeV, $m_\mu = 105.76583$ MeV, $m_\tau = 1775$ MeV.

$$\begin{aligned}
\frac{m(\mu)_+}{m(\mu)} &= \sqrt{\frac{15}{5} 2^7 \frac{m_e}{(\mu)}} \simeq 1.0722 \ , \\
\frac{m(\mu)_-}{m(\mu)} &= \sqrt{\frac{14}{6} 2^7 \frac{m_e}{m_(\mu)}} \simeq 0.9456 \ , \\
\frac{m(\tau)_+}{m(\tau)} &= \sqrt{\frac{66}{5} 2^{10} \frac{m_e}{m(\tau)}} \simeq 1.0710 \ , \\
\frac{m(\tau)_-}{m(\tau)} &= \sqrt{\frac{65}{6} 2^{10} \frac{m_e}{m(\tau)}} \simeq .9703 \ .
\end{aligned} \tag{5.7.2}$$

For the maximal value of CP_2 mass the predictions for the mass ratio are systematically too large by a few per cent. From the formulas above it is clear that the second order corrections to mass squared can be such that correct masses result.

τ mass is least sensitive to $X(p(e)) \equiv Y_e$ and the maximum value of $Y_e \equiv Y_{e,max}$ consistent with τ mass corresponds to $Y_{e,max} = .7357$ and $Y_\tau = 1$. This means that the CP_2 mass is at least a fraction .9337 of its maximal value. If Y_L is same for all charged leptons and has the maximal value $Y_{e,max} = .7357$, the predictions for the mass ratios are

$$\begin{aligned}
\frac{m(\mu)_{pr}}{m(\mu)} &= \sqrt{\frac{14 + Y_{e,max}}{5 + Y_{e,max}}} \times 2^7 \frac{m_e}{m(\mu)} \simeq .9922 \ , \\
\frac{m(\tau)_{pr}}{m(\tau)} &= \sqrt{\frac{65 + Y_{e,max}}{5 + Y_e(max}} \times 2^{10} \frac{m_e}{m(\tau)} \simeq .9980 \ .
\end{aligned} \tag{5.7.3}$$

The error is .8 per cent *resp.* .2 per cent for muon *resp.* τ.

The argument leading to estimate for the modular contribution to the mass squared [K34] leaves two options for the coefficient of the modular contribution for $g = 2$ fermions: the value of coefficient is either $X = g$ for $g \leq 1$, $X = 3g - 3$ for $g \geq 2$ or $X = g$ always. For $g = 2$ the predictions are $X = 2$ and $X = 3$ in the two cases. The option $X = 3$ allows slightly larger maximal value of Y_e equal to $Y^{1)}_{e,max} = Y_{e,max} + (5 + Y_{e,max})/66$.

5.7.2 Neutrino masses

The estimation of neutrino masses is difficult at this stage since the prediction of the primary condensation level is not yet possible and neutrino mixing cannot yet be predicted from the basic principles. The cosmological bounds for neutrino masses however help to put upper bounds on the masses. If one takes seriously the LSND data on neutrino mass measurement of [C144, C100] and the explanation of the atmospheric ν-deficit in terms of $\nu_\mu - \nu_\tau$ mixing [C124, C110] one can deduce that the most plausible condensation level of μ and τ neutrinos is $k = 167$ or $k = 13^2 = 169$ allowed by the more general form of the p-adic length scale hypothesis suggested by the blackhole-elementary particle analogy. One can also deduce information about the mixing matrix associated with the neutrinos so that mass predictions become rather precise. In particular, the mass splitting of μ and τ neutrinos is predicted correctly if one assumes that the mixing matrix is a rational unitary matrix.

Super Virasoro contribution

Using $m_0^2/3$ as a p-adic unit, the expression for the Super Virasoro contribution to the mass squared of neutrinos is given by the formula

$$\begin{aligned} M^2(SV) &= (s+(3Yp)_R/3)\frac{m_0^2}{p} \ , \\ s &= 4 \text{ or } 5 \ , \\ Y &= \frac{23}{2}+Y_1 \ , \end{aligned} \tag{5.7.4}$$

where m_0^2 is universal mass scale. One can consider two possible identifications of neutrinos corresponding to $s(\nu) = 4$ with $\Delta = 2$ and $s(\nu) = 5$ with $\Delta = 1$. The requirement that CKM matrix is sensible forces the asymmetric scenario in which quarks and, by symmetry, also leptons correspond to lowest possible excitation so that one must have $s(\nu) = 4$. Y_1 represents second order contribution to the neutrino mass coming from renormalization effects coming from self energy diagrams involving intermediate gauge bosons. Physical intuition suggest that this contribution is very small so that the precise measurement of the neutrino masses should give an excellent test for the theory.

With the above described assumptions and for $s = 4$, one has the following mass formula for neutrinos

$$\begin{aligned} M^2(\nu) &= A(\nu)\frac{m_0^2}{p(\nu))} \ , \\ A(\nu_e) &= 4+\frac{(3Y(p(\nu_e)))_R}{3} \ , \\ A(\nu_\mu) &= 13+\frac{(3Y(p(\nu_\mu)))_R}{3} \ , \\ A(\nu_\tau) &= 64+\frac{(3Y(p(\nu_\tau)))_R}{3} \ , \\ 3Y &\simeq \frac{1}{2} \ . \end{aligned} \tag{5.7.5}$$

The predictions must be consistent with the recent upper bounds [C86]
of order 10 eV, 270 keV and 0.3 MeV for ν_e, ν_μ and ν_τ respectively. The recently reported results of LSND measurement [C100] for $\nu_e -> \nu_\mu$ mixing gives string limits for $\Delta m^2(\nu_e, \nu_\mu)$ and the parameter $sin^2(2\theta)$ characterizing the mixing: the limits are given in the figure 30 of [C100]. The results suggests that the masses of both electron and muon neutrinos are below 5 eV and that mass squared difference $\Delta m^2 = m^2(\nu_\mu) - m^2(\nu_e)$ is between $.25 - 25\ eV^2$. The simplest possibility is that ν_μ and ν_e have common condensation level (in analogy with d and s quarks). There are three candidates for the primary condensation level: namely $k = 163, 167$ and $k = 169$. The p-adic prime associated with the primary condensation level is assumed

to be the nearest prime below 2^k allowing p-adic $\sqrt{2}$ but not $\sqrt{3}$ and satisfying $p\ mod\ 4 = 3$. The following table gives the values of various parameters and unmixed neutrino masses in various cases of interest.

k	p	$(3Y)_R/3$	$m(\nu_e)/eV$	$m(\nu_\mu)/eV$	$m(\nu_\tau)/eV$
163	$2^{163} - 4*144 - 1$	1.36	1.78	3.16	6.98
167	$2^{167} - 4*144 - 1$	.34	.45	.79	1.75
169	$2^{169} - 4*210 - 1$	.17	.22	.40	.87

Could neutrino topologically condense also in other p-adic length scales than $k = 169$?

One must keep mind open for the possibility that there are several p-adic length scales at which neutrinos can condense topologically. Biological length scales are especially interesting in this respect. In fact, all intermediate p-adic length scales $k = 151, 157, 163, 167$ could correspond to metastable neutrino states. The point is that these p-adic lengths scales are number theoretically completely exceptional in the sense that there exist Gaussian Mersenne $2^k \pm i$ (prime in the ring of complex integers) for all these values of k. Since charged leptons, atomic nuclei ($k = 113$) , hadrons and intermediate gauge bosons correspond to ordinary or Gaussian Mersennes, it would not be surprising if the biologically important Gaussian Mersennes would correspond to length scales giving rise to metastable neutrino states. Of course, one can keep mind open for the possibility that $k = 167$ rather than $k = 13^2 = 169$ is the length scale defining the stable neutrino physics.

Neutrino mixing

Consider next the neutrino mixing. A quite general form of the neutrino mixing matrix D given by the table below will be considered.

	ν_e	ν_μ	ν_τ
ν_e	c_1	s_1c_3	s_1s_3
ν_μ	$-s_1c_2$	$c_1c_2c_3 - s_2s_3exp(i\delta)$	$c_1c_2s_3 + s_2c_3exp(i\delta)$
ν_τ	$-s_1s_2$	$c_1s_2c_3 + c_2s_3exp(i\delta)$	$c_1s_2s_3 - c_2c_3exp(i\delta)$

Physical intuition suggests that the angle δ related to CP breaking is small and will be assumed to be vanishing. Topological mixing is active only in modular degrees of freedom and one obtains for the first order terms of mixed masses the expressions

$$\begin{aligned} s(\nu_e) &= 4 + 9|U_{12}|^2 + 60|U_{13}|^2 = 4 + n_1 \ , \\ s(\nu_\mu) &= 4 + 9|U_{22}|^2 + 60|U_{23}|^2 = 4 + n_2 \ , \\ s(\nu_\tau) &= 4 + 9|U_{32}|^2 + 60|U_{33}|^2 = 4 + n_3 \ . \end{aligned} \tag{5.7.6}$$

The requirement that resulting masses are not ultra heavy implies that $s(\nu)$ must be small integers. The condition $n_1 + n_2 + n_3 = 69$ follows from unitarity. The simplest possibility is that the mixing matrix is a rational unitary matrix. The same ansatz was used successfully to deduce information about the mixing matrices of quarks. If neutrinos are condensed on the same condensation level, rationality implies that $\nu_\mu - \nu_\tau$ mass squared difference must come from the first order contribution to the mass squared and is therefore quantized and bounded from below.

The first piece of information is the atmospheric ν_μ/ν_e ratio, which is roughly by a factor 2 smaller than predicted by standard model [C124]. A possible explanation is the CKM mixing of muon neutrino with τ-neutrino, whereas the mixing with electron neutrino is excluded as an explanation. The latest results from Kamiokande [C124] are in accordance with the mixing $m^2(\nu_\tau) - m^2(\nu_\mu) \simeq 1.6 \cdot 10^{-2}\ eV^2$ and mixing angle $sin^2(2\theta) = 1.0$: also the zenith angle dependence of the ratio is in accordance with the mixing interpretation. If mixing matrix is assumed to be rational then only $k = 169$ condensation level is allowed for ν_μ and ν_τ. For this level $\nu_\mu - \nu_\tau$ mass squared difference turns out to be $\Delta m^2 \simeq 10^{-2}\ eV^2$ for $\Delta s \equiv s(\nu_\tau) - s(\nu_\mu) = 1$, which is the only acceptable possibility and predicts $\nu_\mu - \nu_\tau$ mass squared difference correctly within experimental uncertainties! The fact that the predictions for mass squared differences are practically exact, provides a precision test for the rationality assumption.

What is measured in LSND experiment is the probability $P(t, E)$ that ν_μ transforms to ν_e in time t after its production in muon decay as a function of energy E of ν_μ. In the limit that ν_τ and ν_μ masses are identical, the expression of $P(t, E)$ is given by

$$\begin{aligned} P(t,E) &= sin^2(2\theta) sin^2(\frac{\Delta E t}{2}) \ , \\ sin^2(2\theta) &= 4c_1^2 s_1^2 c_2^2 \ , \end{aligned} \tag{5.7.7}$$

where ΔE is energy difference of ν_μ and ν_e neutrinos and t denotes time. LSND experiment gives stringent conditions on the value of $\sin^2(2\theta)$ as the figure 30 of [C100] shows. In particular, it seems that $sin^2(2\theta)$ must be considerably below 10^{-1} and this implies that s_1^2 must be small enough.

The study of the mass formulas shows that the only possibility to satisfy the constraints for the mass squared and $sin^2(2\theta)$ given by LSND experiment is to assume that the mixing of the electron neutrino with the tau neutrino is much larger than its mixing with the muon neutrino. This means that s_3 is quite near to unity. At the limit $s_3 = 1$ one obtains the following (nonrational) solution of the mass squared conditions for $n_3 = n_2 + 1$ (forced by the atmospheric neutrino data)

$$\begin{aligned} s_1^2 &= \frac{69 - 2n_2 - 1}{60} \ , \\ c_2^2 &= \frac{n_2 - 9}{2n_2 - 17} \ , \\ sin^2(2\theta) &= \frac{4(n_2 - 9)}{51} \frac{(34 - n_2)(n_2 - 4)}{30^2} \ , \\ s(\nu_\mu) - s(\nu_e) &= 3n_2 - 68 \ . \end{aligned} \tag{5.7.8}$$

The study of the LSND data shows that there is only one acceptable solution to the conditions obtained by assuming maximal mass squared difference for ν_e and ν_μ

$$\begin{aligned} n_1 &= 2 \ \ n_2 = 33 \ \ n_3 = 34 \ , \\ s_1^2 &= \frac{1}{30} \ \ c_2^2 = \frac{24}{49} \ , \\ sin^2(2\theta) &= \frac{24}{49}\frac{2}{15}\frac{29}{30} \simeq .0631 \ , \\ s(\nu_\mu) - s(\nu_e)) &= 31 \leftrightarrow .32\ eV^2 \ . \end{aligned} \tag{5.7.9}$$

That c_2^2 is near 1/2 is not surprise taking into account the almost mass degeneracy of ν_{mu} and ν_τ. From the figure 30 of [C100] it is clear that this solution belongs to 90 per cent likelihood region of LSND experiment but $sin^2(2\theta)$ is about two times larger than the value allowed by Bugey reactor experiment. The study of various constraints given in [C100] shows that the solution is consistent with bounds from all other experiments. If one assumes that

$k > 169$ for ν_e $\nu_\mu - \nu_e$ mass difference increases, implying slightly poorer consistency with LSND data.

There are reasons to hope that the actual rational solution can be regarded as a small deformation of this solution obtained by assuming that c_3 is non-vanishing. $s_1^2 = \frac{69-2n_2-1}{60-51c_3^2}$ increases in the deformation by $O(c_3^2)$ term but if c_3 is positive the value of $c_2^2 \simeq \frac{24-102c_1^0c_2^0s_2^0c_3}{49} \sim \frac{24-61c_3}{49}$ decreases by $O(c_3)$ term so that it should be possible to reduce the value of $sin^2(2\theta)$. Consistency with Bugey reactor experiment requires $.030 \leq sin^2(2\theta) < .033$. $sin^2(2\theta) = .032$ is achieved for $s_1^2 \simeq .035$,$s_2^2 \simeq .51$ and $c_3^2 \simeq .068$. The construction of U and D matrices for quarks shows that very stringent number theoretic conditions are obtained and as in case of quarks it might be necessary to allow complex CP breaking phase in the mixing matrix. One might even hope that the solution to the conditions is unique.

For the minimal rational mixing one has $s(\nu_e) = 5$, $s(\nu_\mu) = 36$ and $s(\nu_\tau) = 37$ if unmixed ν_e corresponds to $s = 4$. For $s = 5$ first order contributions are shifted by one unit. The masses ($s = 4$ case) and mass squared differences are given by the following table.

k	$m(\nu_e)$	$m(\nu_\mu)$	$m(\nu_\tau)$	$\Delta m^2(\nu_\mu - \nu_e)$	$\Delta m^2(\nu_\tau - \nu_\mu)$
169	.27 eV	.66 eV	.67 eV	.32 eV^2	.01 eV^2

Predictions for neutrino masses and mass squared splittings for $k = 169$ case.

Evidence for the dynamical mass scale of neutrinos

In recent years (I am writing this towards the end of year 2004 and much later than previous lines) a great progress has been made in the understanding of neutrino masses and neutrino mixing. The pleasant news from TGD perspective is that there is a strong evidence that neutrino masses depend on environment [C84]. In TGD framework this translates to the statement that neutrinos can suffer topological condensation in several p-adic length scales. Not only in the p-adic length scales suggested by the number theoretical considerations but also in longer length scales, as will be found.

The experiments giving information about mass squared differences can be divided into three categories [C84].

(a) There along baseline experiments, which include solar neutrino experiments [C119, C126, C138] and [C173] as well as earlier studies of solar neutrinos. These experiments see evidence for the neutrino mixing and involve significant propagation through dense matter. For the solar neutrinos and KamLAND the mass splittings are estimated to be of order $O(8 \times 10^{-5})$ eV^2 or more cautiously 8×10^{-5} eV$^2 < \delta m^2 < 2 \times 10^{-3}$ eV^2. For K2K and atmospheric neutrinos the mass splittings are of order $O(2 \times 10^{-3})eV^2$ or more cautiously $\delta m^2 > 10^{-3}$eV^2. Thus the scale of mass splitting seems to be smaller for neutrinos in matter than in air, which would suggest that neutrinos able to propagate through a dense matter travel at space-time sheets corresponding to a larger p-adic length scale than in air.

(b) There are null short baseline experiments including CHOOZ, Bugey, and Palo Verde reactor experiments, and the higher energy CDHS, JARME, CHORUS, and NOMAD experiments, which involve muonic neutrinos (for references see [C84]. No evidence for neutrino oscillations have been seen in these experiments.

(c) The results of LSND experiment [C100] are consistent with oscillations with a mass splitting greater than $3 \times 10^{-2}eV^2$. LSND has been generally been interpreted as necessitating a mixing with sterile neutrino. If neutrino mass scale is dynamical, situation however changes.

If one assumes that the p-adic length scale for the space-time sheets at which neutrinos can propagate is different for matter and air, the situation changes. According to [C84] a mass 3×10^{-2} eV in air could explain the atmospheric results whereas mass of of order .1 eV and

$.07eV^2 < \delta m^2 < .26eV^2$ would explain the LSND result. These limits are of the same order as the order of magnitude predicted by $k = 169$ topological condensation.

Assuming that the scale of the mass splitting is proportional to the p-adic mass scale squared, one can consider candidates for the topological condensation levels involved.

(a) Suppose that $k = 169 = 13^2$ is indeed the condensation level for LSND neutrinos. $k = 173$ would predict $m_{\nu_e} \sim 7 \times 10^{-2}$ eV and $\delta m^2 \sim .02$ eV^2. This could correspond to the masses of neutrinos propagating through air. For $k = 179$ one has $m_{\nu_e} \sim .8 \times 10^{-2}$ eV and $\delta m^2 \sim 3 \times 10^{-4}$ eV^2 which could be associated with solar neutrinos and KamLAND neutrinos.

(b) The primes $k = 157, 163, 167$ associated with Gaussian Mersennes would give $\delta m^2(157) = 2^6 \delta m^2(163) = 2^{10} \delta m^2(167) = 2^{12} \delta m^2(169)$ and mass scales $m(157) \sim 22.8$ eV, $m(163) \sim 3.6$ eV, $m(167) \sim .54$ eV. These mass scales are unrealistic or propagating neutrinos. The interpretation consistent with TGD inspired model of condensed matter in which neutrinos screen the classical Z^0 force generated by nucleons would be that condensed matter neutrinos are confined inside these space-time sheets whereas the neutrinos able to propagate through condensed matter travel along $k > 167$ space-time sheets.

The results of MiniBooNE group as a support for the energy dependence of p-adic mass scale of neutrino

The basic prediction of TGD is that neutrino mass scale can depend on neutrino energy and the experimental determinations of neutrino mixing parameters support this prediction. The newest results (11 April 2007) about neutrino oscillations come from MiniBooNE group which has published its first findings [C78] concerning neutrino oscillations in the mass range studied in LSND experiments [C76].

1. The motivation for MiniBooNE

Neutrino oscillations are not well-understood. Three experiments LSND, atmospheric neutrinos, and solar neutrinos show oscillations but in widely different mass regions (1 eV^2 , 3×10^{-3} eV^2, and 8×10^{-5} eV^2).

In TGD framework the explanation would be that neutrinos can appear in several p-adically scaled up variants with different mass scales and therefore different scales for the differences Δm^2 for neutrino masses so that one should not try to try to explain the results of these experiments using single neutrino mass scale. In single-sheeted space-time it is very difficult to imagine that neutrino mass scale would depend on neutrino energy since neutrinos interact so extremely weakly with matter. The best known attempt to assign single mass to all neutrinos has been based on the use of so called sterile neutrinos which do not have electro-weak couplings. This approach is an ad hoc trick and rather ugly mathematically and excluded by the results of MiniBooNE experiments.

2. The result of MiniBooNE experiment

The purpose of the MiniBooNE experiment was to check whether LSND result $\Delta m^2 = 1eV^2$ is genuine. The group used muon neutrino beam and looked whether the transformations of muonic neutrinos to electron neutrinos occur in the mass squared region $\Delta m^2 \simeq 1$ eV^2. No such transitions were found but there was evidence for transformations at low neutrino energies.

What looks first as an over-diplomatic formulation of the result was *MiniBooNE researchers showed conclusively that the LSND results could not be due to simple neutrino oscillation, a phenomenon in which one type of neutrino transforms into another type and back again.* rather than direct refutation of LSND results.

3. LSND and MiniBooNE are consistent in TGD Universe

The habitant of the many-sheeted space-time would not regard the previous statement as a mere diplomatic use of language. It is quite possible that neutrinos studied in MiniBooNE have suffered topological condensation at different space-time sheet than those in LSND if they are in different energy range (the preferred rest system fixed by the space-time sheet of the laboratory or Earth). To see whether this is the case let us look more carefully the experimental arrangements.

(a) In LSND experiment 800 MeV proton beam entering in water target and the muon neutrinos resulted in the decay of produced pions. Muonic neutrinos had energies in 60-200 MeV range [C76].

(b) In MiniBooNE experiment [C78] 8 GeV muon beam entered Beryllium target and muon neutrinos resulted in the decay of resulting pions and kaons. The resulting muonic neutrinos had energies the range 300-1500 GeV to be compared with 60-200 MeV.

Let us try to make this more explicit.

(a) Neutrino energy ranges are quite different so that the experiments need not be directly comparable. The mixing obeys the analog of Schrödinger equation for free particle with energy replaced with $\Delta m^2/E$, where E is neutrino energy. The mixing probability as a function of distance L from the source of muon neutrinos is in 2-component model given by

$$P = sin^2(\theta)sin^2(1.27\Delta m^2 L/E) \ .$$

The characteristic length scale for mixing is $L = E/\Delta m^2$. If L is sufficiently small, the mixing is fifty-fifty already before the muon neutrinos enter the system, where the measurement is carried out and no mixing is detected. If L is considerably longer than the size of the measuring system, no mixing is observed either. Therefore the result can be understood if Δm^2 is much larger or much smaller than E/L, where L is the size of the measuring system and E is the typical neutrino energy.

(b) MiniBooNE experiment found evidence for the appearance of electron neutrinos at low neutrino energies (below 500 MeV) which means direct support for the LSND findings and for the dependence of neutron mass scale on its energy relative to the rest system defined by the space-time sheet of laboratory.

(c) Uncertainty Principle inspires the guess $L_p \propto 1/E$ implying $m_p \propto E$. Here E is the energy of the neutrino with respect to the rest system defined by the space-time sheet of the laboratory. Solar neutrinos indeed have the lowest energy (below 20 MeV) and the lowest value of Δm^2. However, atmospheric neutrinos have energies starting from few hundreds of MeV and $\Delta ; m^2$ is by a factor of order 10 higher. This suggests that the the growth of Δm^2 with E^2 is slower than linear. It is perhaps not the energy alone which matters but the space-time sheet at which neutrinos topologically condense. For instance, MiniBooNE neutrinos above 500 MeV would topologically condense at space-time sheets for which the p-adic mass scale is higher than in LSND experiments and one would have $\Delta m^2 >> 1$ eV^2 implying maximal mixing in length scale much shorter than the size of experimental apparatus.

(d) One could also argue that topological condensation occurs in condensed matter and that no topological condensation occurs for high enough neutrino energies so that neutrinos remain massless. One can even consider the possibility that the p-adic length scale L_p is proportional to E/m_0^2, where m_0 is proportional to the mass scale associated with non-relativistic neutrinos. The p-adic mass scale would obey $m_p \propto m_0^2/E$ so that the characteristic mixing length would be by a factor of order 100 longer in MiniBooNE experiment than in LSND.

Comments

Some comments on the proposed scenario are in order: some of the are written much later than the previous text.

(a) Mass predictions are consistent with the bound $\Delta m(\nu_\mu, \nu_e) < 2\ eV^2$ coming from the requirement that neutrino mixing does not spoil the so called r-process producing heavy elements in Super Novae [C157].

(b) TGD neutrinos cannot solve the dark matter problem: the total neutrino mass required by the cold+hot dark matter models would be about 5 eV. In [K17] a model of galaxies based on string like objects of galaxy size and providing a more exotic source of dark matter, is discussed.

(c) One could also consider the explanation of LSND data in terms of the interaction of ν_μ and nucleon via the exchange of $g = 1$ W boson. The fraction of the reactions $\bar{\nu}_\mu + p \rightarrow e^+ + n$ is at low neutrino energies $P \sim \frac{m_W^4(g=0)}{m_W^4(g=1)} sin^2(\theta_c)$, where θ_c denotes Cabibbo angle. Even if the condensation level of $W(g = 1)$ is $k = 89$, the ratio is by a factor of order .05 too small to explain the average $\nu_\mu \rightarrow \nu_e$ transformation probability $P \simeq .003$ extracted from LSND data.

(d) The predicted masses exclude MSW and vacuum oscillation solutions to the solar neutrino problem unless one assumes that several condensation levels and thus mass scales are possible for neutrinos. This is indeed suggested by the previous considerations.

5.7.3 Quark masses

The prediction or quark masses is more difficult due the facts that the deduction of even the p-adic length scale determining the masses of these quarks is a non-trivial task, and the original identification was indeed wrong. Second difficulty is related to the topological mixing of quarks. The new scenario leads to a unique identification of masses with top quark mass as an empirical input and the thermodynamical model of topological mixing as a new theoretical input. Also CKM matrix is predicted highly uniquely.

Basic mass formulas

By the earlier mass calculations and construction of CKM matrix the ground state conformal weights of U and D type quarks must be $h_{gr}(U) = -1$ and $h_{gr}(D) = 0$. The formulas for the eigenvalues of CP_2 spinor Laplacian imply that if m_0^2 is used as a unit, color conformal weight $h_c \equiv m_{CP_2}^2$ is integer for $p\ mod\ = \pm 1$ for U type quark belonging to $(p + 1, p)$ type representation and obeying $h_c(U) = (p^2 + 3p + 2)/3$ and for $p\ mod\ 3 = 1$ for D type quark belonging $(p, p + 2)$ type representation and obeying $h_c(D) = (p^2 + 4p + 4)/3$. Only these states can be massless since color Hamiltonians have integer valued conformal weights.

In the recent case the minimal $p = 1$ states correspond to $h_c(U) = 2$ and $h_c(D) = 3$. $h_{gr}(U) = -1$ and $h_{gr}(D) = 0$ reproduce the previous results for quark masses required by the construction of CKM matrix. This requires super-symplectic operators O with a net conformal weight $h_{sc} = -3$ just as in the leptonic case. The facts that the values of p are minimal for spinor harmonics and the super-symplectic operator is same for both quarks and leptons suggest that the construction is not had hoc. The real justification would come from the demonstration that $h_{sc} = -3$ defines null state for SCV: this would also explain why h_{sc} would be same for all fermions.

Consider now the mass squared values for quarks. For $h(D) = 0$ and $h(U) = -1$ and using $m_0^2/3$ as a unit the expression for the thermal contribution to the mass squared of quark is given by the formula

$$\begin{aligned} M^2 &= (s + X)\frac{m_0^2}{p} \ , \\ s(U) &= 5 \ , \ s(D) = 8 \ , \\ X &\equiv \frac{(3Yp)_R}{3} \ , \end{aligned} \tag{5.7.10}$$

where the second order contribution Y corresponds to renormalization effects coming and depending on the isospin of the quark. When m_0^2 is used as a unit X is replaced by $X = (Y_p)_R$.

With the above described assumptions one has the following mass formula for quarks

$$\begin{array}{lll} M^2(q) = A(q)\frac{m_0^2}{p(q)} \ , & & \\ A(u) = 5 + X_U(p(u) \ , & A(c) = 14 + X_U(p(c)) \ , & A(t) = 65 + X_U(p(t)) \ , \\ A(d) = 8 + X_D(p(d)) \ , & A(s) = 17 + X_D(p(s)) \ , & A(b) = 68 + X_D(p(b)) \ . \end{array} \tag{5.7.11}$$

p-Adic length scale hypothesis allows to identify the p-adic primes labelling quarks whereas topological mixing of U and D quarks allows to deduce topological mixing matrices U and D and CKM matrix V and precise values of the masses apart from effects like color magnetic spin orbit splitting, color Coulomb energy, etc..

Integers n_{q_i} satisfying $\sum_i n(U_i) = \sum_i n(D_i) = 69$ characterize the masses of the quarks and also the topological mixing to high degree. The reason that modular contributions remain integers is that in the p-adic context non-trivial rationals would give CP_2 mass scale for the real counterpart of the mass squared. In the absence of mixing the values of integers are $n_d = n_u = 0$, $n_s = n_c = 9$, $n_b = n_t = 60$.

The fact that CKM matrix V expressible as a product $V = U^\dagger D$ of topological mixing matrices is near to a direct sum of 2×2 unit matrix and 1×1 unit matrix motivates the approximation $n_b \simeq n_t$. The large masses of top quark and of $t\bar{t}$ meson encourage to consider a scenario in which $n_t = n_b = n \leq 60$ holds true.

The model for topological mixing matrices and CKM matrix predicts U and D matrices highly uniquely and allows to understand quark and hadron masses in surprisingly detailed level.

(a) $n_d = n_u = 60$ is not allowed by number theoretical conditions for U and D matrices and by the basic facts about CKM matrix but $n_t = n_b = 59$ allows almost maximal masses for b and t. This is not yet a complete hit. The unitarity of the mixing matrices and the construction of CKM matrix to be discussed in the next section forces the assignments

$$(n_d, n_s, n_b) = (5, 5, 59) \ , \quad (n_u, n_c, n_t) = (5, 6, 58) \ . \tag{5.7.12}$$

fixing completely the quark masses apart possible Higgs contribution [K43] . Note that top quark mass is still rather near to its maximal value.

(b) The constraint that valence quark contribution to pion mass does not exceed pion mass implies the constraint $n(d) \leq 6$ and $n(u) \leq 6$ in accordance with the predictions of the model of topological mixing. $u-d$ mass difference does not affect $\pi^+ - \pi^0$ mass difference and the quark contribution to $m(\pi)$ is predicted to be $\sqrt{(n_d + n_u + 13)/24} \times 136.9$ MeV for the maximal value of CP_2 mass (second order p-adic contribution to electron mass squared vanishes).

The p-adic length scales associated with quarks and quark masses

The identification of p-adic length scales associated with the quarks has turned to be a highly non-trivial problem. The reasons are that for light quarks it is difficult to deduce information about quark masses for hadron masses and that the unknown details of the topological mixing (unknown until the advent of the thermodynamical model [K43]) made possible several p-adic length scales for quarks. It has also become clear that the p-adic length scale can be different form free quark and bound quark and that bound quark p-adic scale can depend on hadron.

Two natural constraints have however emerged from the recent work.

(a) Quark contribution to the hadron mass cannot be larger than color contribution and for quarks having $k_q \neq 107$ quark contribution to mass is added to color contribution to the mass. For quarks with same value of k conformal weight rather than mass is additive whereas for quarks with different value of k masses are additive. An important implication is that for diagonal mesons $M = q\overline{q}$ having $k(q) \neq 107$ the condition $m(M) \geq \sqrt{2}m_q$ must hold true. This gives strong constraints on quark masses.

(b) The realization that scaled up variants of quarks explain elegantly the masses of light hadrons allows to understand large mass splittings of light hadrons without the introduction of strong isospin-isospin interaction.

The new model for quark masses is based on the following identifications of the p-adic length scales.

(a) The nuclear p-adic length scale $L_e(k)$, $k = 113$, corresponds to the p-adic length scale determining the masses of u, d, and s quarks. Note that $k = 113$ corresponds to a so called Gaussian Mersenne. The interpretation is that quark massivation occurs at nuclear space-time sheet at which quarks feed their em fluxes. At $k = 107$ space-time sheet, where quarks feed their color gauge fluxes, the quark masses are vanishing in the first p-adic order. This could be due to the fact that the p-adic temperature is $T_p = 1/2$ at this space-time sheet so that the thermal contribution to the mass squared is negligible. This would reflect the fact that color interactions do not involve any counterpart of Higgs mechanism.

   p-Adic mass calculations turn out to work remarkably well for massive quarks. The reason could be that M_{107} hadron physics means that *all* quarks feed their color gauge fluxes to $k = 107$ space-time sheets so that color contribution to the masses becomes negligible for heavy quarks as compared to Super-Kac Moody and modular contributions corresponding to em gauge flux feeded to $k > 107$ space-time sheets in case of heavy quarks. Note that Z^0 gauge flux is feeded to space-time sheets at which neutrinos reside and screen the flux and their size corresponds to the neutrino mass scale. This picture might throw some light to the question of whether and how it might be possible to demonstrate the existence of M_{89} hadron physics.

   One might argue that $k = 107$ is not allowed as a condensation level in accordance with the idea that color and electro-weak gauge fluxes cannot be feeded at the space-time space time sheet since the classical color and electro-weak fields are functionally independent. The identification of η' meson as a bound state of scaled up $k = 107$ quarks is not however consistent with this idea unless one assumes that $k = 107$ space-time sheets in question are separate.

(b) The requirement that the masses of diagonal pseudo-scalar mesons of type $M = q\overline{q}$ are larger but as near as possible to the quark contribution $\sqrt{2}m_q$ to the valence quark mass, fixes the p-adic primes $p \simeq 2^k$ associated with c, b quarks but not t since toponium does not exist. These values of k are "nominal" since k seems to be dynamical. c quark corresponds to the p-adic length scale $k(c) = 104 = 2^3 \times 13$. b quark corresponds to $k(b) = 103$ for $n(b) = 5$. Direct determination of p-adic scale from top quark mass gives $k(t) = 94 = 2 \times 47$ so that secondary p-adic length scale is in question.

   Top quark mass tends to be slightly too low as compared to the most recent experimental value of $m(t) = 169.1$ GeV with the allowed range being [164.7, 175.5] GeV [C87] . The optimal situation corresponds to $Y_e = 0$ and $Y_t = 1$ and happens to give top mass exactly equal to the most probable experimental value. It must be emphasized that top quark is experimentally in a unique position since toponium does not exist and top quark mass is that of free top.

In the case of light quarks there are good reasons to believe that the p-adic mass scale of quark is different for free quark and bound state quark and that in case of bound quark it can also depend on hadron. This would explain the notions of valence (constituent) quark and current quark mass as masses of bound state quark and free quark and leads also to a TGD counterpart of Gell-Mann-Okubo mass formula [K43] .

1. Constituent quark masses

Constituent quark masses correspond to masses derived assuming that they are bound to hadrons. If the value of k is assumed to depend on hadron one obtains nice mass formula for light hadrons as will be found later. The table below summarizes constituent quark masses as predicted by this model.

2. Current quark masses

Current quark masses would correspond to masses of free quarks which tend to be lower than valence quark masses. Hence k could be larger in the case of light quarks. The table of quark masses in Wikipedia [C21] gives the value ranges for current quark masses depicted in the table below together with TGD predictions for the spectrum of current quark masses.

q	d	u	s
$m(q)_{exp}/MeV$	4-8	1.5-4	80-130
$k(q)$	(122,121,120)	(125,124,123,122)	(114,113,112)
$m(q)/MeV$	(4.5,6.6,9.3)	(1.4,2.0,2.9,4.1)	(74,105,149)
q	c	b	t
$m(q)_{exp}/MeV$	1150-1350	4100-4400	1691
$k(q)$	(106,105)	(105,104)	92
$m(q)/MeV$	(1045,1477)	(3823,5407)	167.8×10^3

Table 3. The experimental value ranges for current quark masses [C21] and TGD predictions for their values assuming $(n_d, n_s, n_b) = (5, 5, 59)$, $(n_u, n_c, n_t) = (5, 6, 58)$, and $Y_e = 0$. For top quark $Y_t = 0$ is assumed. $Y_t = 1$ would give 169.2 GeV.

Some comments are in order.

(a) The long p-adic length associated with light quarks seem to be in conflict with the idea that quarks have sizes smaller than hadron size. The paradox disappears when one realized that $k(q)$ characterizes the electromagnetic "field body" of quark having much larger size than hadron.

(b) u and d current quarks correspond to a mass scale not much higher than that of electron and the ranges for mass estimates suggest that u could correspond to scales $k(u) \in (125, 124, 123, 122) = (5^3, 4 \times 31, 3 \times 41, 2 \times 61)$, whereas d would correspond to $k(d) \in (122, 121, 120) = (2 \times 61, 11^2, 3 \times 5 \times 8)$.

(c) The TGD based model for nuclei based on the notion of nuclear string leads to the conclusion that exotic copies of $k = 113$ quarks having $k = 127$ are present in nuclei and are responsible for the color binding of nuclei [K63, L3] , [L3] .

(d) The predicted values for c and b masses are slightly too low for $(k(c), k(b)) = (106, 105) = (2 \times 53, 3 \times 5 \times 7)$. Second order Higgs contribution could increase the c mass into the range given in [C21] but not that of b.

(e) The mass of top quark has been slightly below the experimental estimate for long time. The experimental value has been coming down slowly and the most recent value obtained by CDF [C89] is $m_t = 165.1 \pm 3.3 \pm 3.1$ GeV and consistent with the TGD prediction for $Y_e = Y_t = 0$.

One can talk about constituent and current quark masses simultaneously only if they correspond to dual descriptions. $M^8 - H$ duality [K34] has been indeed suggested to relate the old fashioned low energy description of hadrons in terms of $SO(4)$ symmetry (Skyrme model) and higher energy description of hadrons based on QCD. In QCD description the mass of say baryon would be dominated by the mass associated with super-symplectic quanta carrying color. In $SO(4)$ description constituent quarks would carry most of the hadron mass.

Can Higgs field develop a vacuum expectation in fermionic sector at all?

An important conclusion following from the calculation of lepton and quark masses is that if Higgs contribution is present, it can be of second order p-adically and even negligible, perhaps even vanishing. There is indeed an argument forcing to consider this possibility seriously. The recent view about elementary particles is following.

(a) Fermions correspond to CP_2 type vacuum extremals topologically condensed at positive/negative energy space-time sheets carrying quantum numbers at light-like wormhole throat. Higgs and gauge bosons correspond to wormhole contacts connecting positive and negative energy space-time sheets and carrying fermion and anti-fermion quantum numbers at the two light-like wormhole throats.

(b) If the values of p-adic temperature are $T_p = 1$ and $T_p = 1/n$, $n > 1$f or fermions and bosons the thermodynamical contribution to the gauge boson mass is negligible.

(c) Different p-adic temperatures and Kähler coupling strengths for fermions and bosons make sense if bosonic and fermionic partonic 3-surfaces meet only along their ends at the vertices of generalized Feynman diagrams but have no other common points [K15] . This forces to consider the possibility that fermions cannot develop Higgs vacuum expectation value although they can couple to Higgs. This is not in contradiction with the modification of sigma model of hadrons based on the assumption that vacuum expectation of σ field gives a small contribution to hadron mass [K37] since this field can be assigned to some bosonic space-time sheet pair associated with hadron.

(d) Perhaps the most elegant interpretation is that ground state conformal is equal to the square of the eigenvalue of the modified Dirac operator. The ground state conformal weight is negative and its deviation from half odd integer value gives contribution to both fermion and boson masses. The Higgs expectation associated with coherent state of Higgs like wormhole contacts is naturally proportional to this parameter since no other parameter with dimensions of mass is present. Higgs vacuum expectation determines gauge boson masses only apparently if this interpretation is correct. The contribution of the ground state conformal weight to fermion mass square is near to zero. This means that λ is very near to negative half odd integer and therefore no significant difference between fermions and gauge bosons is implied.

q	d	u	s	c	b	t
n_q	4	5	6	6	59	58
s_q	12	10	14	11	67	63
$k(q)$	113	113	113	104	103	94
$m(q)/GeV$	.105	.092	.105	2.191	7.647	167.8

Table 2. Constituent quark masses predicted for diagonal mesons assuming $(n_d, n_s, n_b) = (5, 5, 59)$ and $(n_u, n_c, n_t) = (5, 6, 58)$, maximal CP_2 mass scale($Y_e = 0$), and vanishing of second order contributions.

5.8 About the microscopic description of gauge boson massivation

The conjectured QFT limit allows to estimate the quantitative predictions of the theory. This is not however enough. One should identify the microscopic TGD counterparts for various aspects of gauge boson massivation. There is also the question about the consistency of the gauge theory limit with the ZEO inspired view about massivation. The basic challenge are obvious: one should translate notions like Higgs vacuum expectation, massivation of gauge bosons, and finite range of weak interactions to the language of wormhole throats, Kähler magnetic flux tubes, and string world sheets. The proposal is that generalization of super-conformal symmetries to their Yangian counterparts is needed to meet this challenge in mathematically satisfactory manner.

5.8.1 Can p-adic thermodynamics explain the masses of intermediate gauge bosons?

The requirement that the electron-intermediate gauge boson mass ratios are sensible, serves as a stringent test for the hypothesis that intermediate gauge boson masses result from the p-adic thermodynamics. It seems that the only possible option is that the parameter k has same value for both bosons, leptons, and quarks:

$$k_B = k_L = k_q = 1 \ .$$

In this case all gauge bosons have $D(0) = 1$ and there are good changes to obtain boson masses correctly. $k = 1$ together with $T_p = 1$ implies that the thermal masses of very many boson states are extremely heavy so that the spectrum of the boson exotics is reduced drastically. For $T_p = 1/2$ the thermal contribution to the mass squared is completely negligible.

Contrary to the original optimistic beliefs based on calculational error, it turned out impossible to predict W/e and Z/e mass ratios correctly in the original p-adic thermodynamics scenario. Although the errors are of order 20-30 percent, they seemed to exclude the explanation for the massivation of gauge bosons using p-adic thermodynamics.

(a) The thermal mass squared for a boson state with N active sectors (non-vanishing vacuum weight) is determined by the partition function for the tensor product of N NS type Super Virasoro algebras. The degeneracies of the excited states as a function of N and the weight Δ of the operator creating the massless state are given in the table below.

(b) Both W and Z must correspond to $N = 2$ active Super Virasoro sectors for which $D(1) = 1$ and $D(2) = 3$ so that (using the formulas of p-adic thermodynamics the thermal mass squared is $m^2 = k_B(p + 5p^2)$ for $T_p = 1$. The second order contribution to the thermal mass squared is extremely small so that Weinberg angle vanishes in the thermal approximation. $k_B = 1$ gives Z/e mass-ratio which is about 22 per cent too high. For $T_p = 1/2$ thermal masses are completely negligible.

(c) The thermal prediction for W-boson mass is the same as for Z^0 mass and thus even worse since the two masses are related $M_W^2 = M_Z^2 cos^2(\theta_W)$.

The conclusion is that p-adic thermodynamics does not produce a natural description for the massivation of weak bosons. For $p = M_{89}$ the mass scale is somewhat too small even if the second order contribution is maximal. If it is characterized by small integer, the contribution is extremely small. An explanation for the value of Weinberg angle is also missing. Hence some additional contribution to mass must be present. Higgsy contribution is not natural in TGD framework but stringy contribution looks very natural.

5.8.2 The counterpart of Higgs vacuum expectation in TGD

The development of the TGD view about Higgs involves several wrong tracks involving a lot of useless calculation. All this could have been avoided with more precise definition of basic notions. The following view has distilled through several failures and might be taken as starting point.

The basic challenge is to translate the QFT description of gauge boson massivation to microscopic description.

(a) One can say that gauge bosons "eat" the components of Higgs. In unitary gauge one gauge rotates Higgs field to electromagnetically neutral direction defined by the vacuum expectation value of Higgs. The rotation matrix codes for the degrees of freedom assignable to non-neutral part of Higgs and they are transferred to the longitudinal components of Higgs in gauge transformation. This gives rise to the third polarization direction for gauge boson. Photon remains massless because em charge commutes with Higgs.

(b) The generation of vacuum expectation value has two functions: to make weak gauge bosons massive and to define the electromagnetically neutral direction to which Higgs field is rotated in the transition to the unitary gauge. In TGD framework only the latter function remains for Higgs if p-adic thermodynamics takes care of massivation. The notion of induced gauge field together with CP_2 geometry uniquely defines the electromagnetically neutral direction so that vacuum expectation is not needed. Of course, the essential element is gauge invariance of the Higgs gauge boson couplings. In twistor Grassmann approach gauge invariance is replaced with Yangian symmetry, which is excellent candidate also for basic symmetry of TGD.

(c) The massivation of gauge bosons (all particles) involves two contributions. The contribution from p-adic thermodynamics in CP_2 scale (wormhole throat) and the stringy contribution in weak scale more generally, in hadronic scale. The latter contribution cannot be calculated yet. The generalization of p-adic thermodynamics to that for Yangian symmetry instead of mere super-conformal symmetry is probably necessary to achieve this and the construction WCW geometry and spinor structure strongly supports the interpretation in terms of Yangian.

One can look at the situation also at quantitative level.

(a) W/Z mass ratio is extremely sensitive test for any model for massivation. In the recent case this requires that string tension for weak gauge boson depends on boson and is proportional to the appropriate gauge coupling strength depending on Weinberg angle. This is natural if the contribution to mass squared can be regarded as perturbative.

(b) Higgs mechanism is characterized by the parameter m_0^2 defining the originally tachyonic mass of Higgs, the dimensionless coupling constant λ defining quartic self-interaction of Higgs. Higgs vacuum expectation is given by $\mu^2 = m_0^2/\lambda$, Higgs mass squared by $m_0^2 = \mu^2\lambda$, and weak boson mass squared is proportional $g^2\mu^2$. In TGD framework λ takes the role of g^2 in stringy picture and the string tensions of bosons are proportional to g_w^2, g_Z^2, λ respectively.

(c) Whether λ in TGD framework actually corresponds to the quartic self-couplingof Higgs or just to the numerical factor in Higgs string tension, is not clear. The problem of Higgs mechanism is that the mass of observed Higgs is somewhat too low. This requires fine tuning of the parameters of the theory and SUSY, which was hoped to come in rescue, did not solve the problem. TGD approach promises to solve the problem.

5.8.3 Elementary particles in ZEO

Let us first summarize what kind of picture ZEO suggests about elementary particles.

(a) Kähler magnetically charged wormhole throats are the basic building bricks of elementary particles. The lines of generalized Feynman diagrams are identified as the Euclidian regions of space-time surface. The weak form of electric magnetic duality forces magnetic monopoles and gives classical quantization of the Kähler electric charge. Wormhole throat is a carrier of many-fermion state with parallel momenta and the fermionic oscillator algebra gives rise to a badly broken large $\mathcal{N}$ SUSY [K24].

(b) The first guess would be that elementary fermions correspond to wormhole throats with unit fermion number and bosons to wormhole contacts carrying fermion and anti-fermion at opposite throats. The magnetic charges of wormhole throats do not however allow this option. The reason is that the field lines of Kähler magnetic monopole field must close. Both in the case of fermions and bosons one must have a pair of wormhole contacts (see fig. `http://www.tgdtheory.fi/appfigures/wormholecontact.jpg` or fig. 10 in the appendix of this book) connected by flux tubes. The most general option is that net quantum numbers are distributed amongst the four wormhole throats. A simpler option is that quantum numbers are carried by the second wormhole: fermion quantum numbers would be carried by its second throat and bosonic quantum numbers by fermion and anti-fermion at the opposite throats. All elementary particles would therefore be accompanied by parallel flux tubes and string world sheets.

(c) A cautious proposal in its original form was that the throats of the other wormhole contact could carry weak isospin represented in terms of neutrinos and neutralizing the weak isospin of the fermion at second end. This would imply weak neutrality and weak confinement above length scales longer than the length of the flux tube. This condition might be un-necessarily strong.

The realization of the weak neutrality using pair of left handed neutrino and right handed antineutrino or a conjugate of this state is possible if one allows right-handed neutrino to have also unphysical helicity. The weak screening of a fermion at wormhole throat is possible if ν_R is a constant spinor since in this case Dirac equation trivializes and allows both helicities as solutions. The new element from the solution of the modified Dirac equation is that ν_R would be interior mode de-localized either to the other wormhole contact or to the Minkowskian flux tube. The state at the other end of the flux tube is spartner of left-handed neutrino.

It must be emphasized that weak confinement is just a proposal and looks somewhat complex: Nature is perhaps not so complex at the basic level. To understand this better, one can think about how M_{89} mesons having quark and antiquark at the ends of long flux tube returning back along second space-time sheet could decay to ordinary quark and antiquark.

5.8.4 Virtual and real particles and gauge conditions in ZEO

ZEO and twistor Grassmann approach force to build a detailed view about real and virtual particles. ZEO suggests also new approaches to gauge conditions in the attempts to build detailed connection between QFT picture and that provided by TGD. The following is the most conservative one. Of course, also this proposal must be taken with extreme cautiousness.

(a) In ZEO all wormhole throats - also those associated with virtual particles - can be regarded as massless. In twistor Grassmann approach [K58] this means that the fermionic propagators can be by residue integration transformed to their inverses which correspond to online massless states but having an unphysical polarization so that the internal lines do not vanish identically.

(b) This picture inspired by twistorial considerations is consistent with the simplest picture about Kähler-Dirac action. The boundary term for K-D action is $\sqrt{g_4}\overline{\Psi}\Gamma^n_{K-D}\Psi d^3x$ and due to the localization of spinor modes to 2-D surfaces reduces to a term localized at the boundaries of string world sheets. The normal component Γ^n_{K-D} of the modified gamma matrices defined by the canonical momentum currents of Kähler action should define the inverse of massless fermionic propagator. If the action of this operator on the induced spinor mode at stringy curves satisfies

$$\sqrt{g_4}\Gamma^n\Psi = p^k\gamma_k\Psi \ ,$$

this reduction is achieved. One can pose the condition $g_4 = constant$ as a coordinate condition on stringy curves at the boundaries of CD and the condition would correlate the spinor modes at stringy curve with incoming quantum numbers. This is extremely powerful simplification giving hopes about calculable theory. The residue integral for virtual momenta reduces the situation to integral over on mass shell momenta and only non-physical helicities contribute in internal lines. This would generalize twistorial formulas to fermionic context.

One however ends up with an unexpected prediction which has bothered me for a long time. Consider the representation of massless spin 1 gauge bosons as pairs as wormhole throat carrying fermion and antifermion having net quantum numbers of the boson. Neglect the effects of the second wormhole throat. The problem is that for on-mass shell massless fermion and antifermion with physical helicities the boson has spin 0. Helicity 1 state would require that second fermion has unphysical helicity. What does this mean?

(a) Are all on mass shell gauge bosons - including photon - massive? Or is on mass shell massless propagation impossible? Massivation is achieved if the fermion and antifermion have different momentum directions: for instance opposite 3-momen but same sign of energy. Higher order contributions in p-adic thermodynamics could make also photon massive. The 4-D world-lines of fermion and antifermion would not be however parallel, which does not conform with the geometric optics based prejudices.

(b) Or could on mass shell gauge bosons have opposite four-momenta so that the second gauge boson would have negative energy? In this manner one could have massless on mass shell states. ZEO ontology certainly allows the identification massless gauge bosons as on mass shell states with opposite directions of four-momenta. This would however require the weakening of the hypothesis that all incoming (outgoing) fundamental fermions have positive (negative) energies to the assumption that only the incoming (outgoing) particles have positive (negative) energies. In the case of massless gauge boson the gauge condition $p \cdot \epsilon = 0$ would be satisfied by the momenta of both fermion and antifermion. With opposite 3-momenta (massivation) but same energy the condition $p_{tot} \cdot \epsilon = 0$ is satisfied for three polarization since in cm system p_{tot} has only time component.

(c) The problem is present also for internal lines. Since by residue argument only the unphysical fermion helicities contribute in internal lines, both fermion and antifermion must have unphysical helicity. For the same sign of energy the wormhole throat would behave as scalar particle. Therefore it seems that the energies must have different sign or momenta cannot be strictly parallel. This is required also by the possibility of space-like momenta for virtual bosons.

5.8.5 The role of string world sheets and magnetic flux tubes in massivation

What is the role of string world sheets and flux tubes in the massivation? At the fundamental level one studies correlation functions for particles and finite correlation length means massivation.

(a) String world sheets define as essential element in 4-D description. All particles are basically bi-local objects: pairs of string at parallel space-time sheets extremely near to each other and connected by wormhole contacts at ends. String world sheets are expected to represent correlations between wormhole throats.

(b) Correlation length for the propagator of the gauge boson characterizes its mass. Correlation length can be estimated by calculating the correlation function. For bosons this reduces to the calculation of fermionic correlations functions assignable to string world sheets connecting the upper and lower boundaries of CD and having four external fermions at the ends of CD. The perturbation theory reduces to functional integral over space-time sheets and deformation of the space-time sheet inducing the deformation of the induced spinor field expressible as convolution of the propagator associated with the modified Dirac operator with vertex factor defined by the deformation multiplying the spinor field. The external vertices are braid ends at partonic 2-surfaces and internal vertices are in the interior of string world sheet. Recall that the conjecture is that the restriction to the wormhole throat orbits implies the reduction to diagrams involving only propagators connecting braid ends. The challenge is to understand how the coherent state assigned to the Euclidian pion field induces the finite correlation length in the case of gauge bosons other than photon.

(c) The non-vanishing commutator of the gauge boson charge matrix with the vacuum expectation assigned to the Euclidian pion must play a key role. The study of the modified Dirac operator suggests that the braid strands contain the Abelianized variant of non-integrable phase factor defined as $exp(i \int Adx)$. If A is identified as string world sheet Hodge dual of Kac-Moody charge the opposite edges of string world sheet with geometry of square given contributions which compensate each other by conservation of

Kac-Moody charge if A commutes with the operators building the coherent Higgs state. For photon this would be true. For weak gauge bosons this would not be the case and this gives hopes about obtaining destructive interference leading to a finite correlation length.

One can also consider try to build more concrete manners to understand the finite correlation length.

(a) Quantum classical correspondence suggests that string with length of order $L \sim \hbar/E$, $E = \sqrt{p^2 + m^2}$ serves as a correlate for particle defined by a pair of wormhole contacts. For massive particle wave length satisfies $L \leq \hbar/m$. Here (p, m) must be replaced with (p_L, m_L) if one takes the notion of longitudinal mass seriously. For photon standard option gives $L = \lambda$ or $L = \lambda_L$ and photon can be a bi-local object connecting arbitrarily distant objects. For the second option small longitudinal mass of photon gives an upper bound for the range of the interaction. Also gluon would have longitudinal mass: this makes sense in QCD where the decomposition $M^4 = M^2 \times E^2$ is basic element of the theory.

(b) The magnetic flux tube associated with the particle carries magnetic energy. Magnetic energy grows as the length of flux tube increases. If the flux is quantized magnetic field behaves like $1/S$, where S is the area of the cross section of the flux tube, the total magnetic energy behaves like L/S. The dependence of S on L determines how the magnetic energy depends on L. If the magnetic energy increases as function of L the probability of long flux tubes is small and the particle cannot have large size and therefore mediates short range interactions. For $S \propto L^\alpha \sim \lambda^\alpha$, $\alpha > 1$, the magnetic energy behaves like $\lambda^{-\alpha+1}$ and the thickness of the flux tube scales like $\sqrt{\lambda^\alpha}$. In case of photon one might expect this option to be true. Note that for photon string world sheet one can argue that the natural choice of string is as light-like string so that its length vanishes.

What kind of string world sheets are possible? One can imagine two options.

(a) All strings could connect only the wormhole contacts defining a particle as a bi-local object so that particle would be literally the geometric correlate for the interaction between two objects. The notion of free particle would be figment of imagination. This would lead to a rather stringy picture about gauge interactions. The gauge interaction between systems S_1 and S_2 would mean the emission of gauge bosons as flux tubes with charge carrying end at S_1 and neutral end. Absorption of the gauge boson would mean that the neutral end of boson and neutral end of charge particle fuse together line the lines of Feynman diagram at 3-vertex.

(b) Second option allows also string world sheets connecting wormhole contacts of different particles so that there is no flux tube accompanying the string world sheet. In this case particles would be independent entities interacting via string world sheets. In this case one could consider the possibility that photon corresponds to string world sheet (or actually parallel pair of them) not accompanied by a magnetic flux tube and that this makes the photon massless at least in excellent approximation.

The first option represents the ontological minimum.

Super-conformal symmetry involves two conformal weight like integers and these correspond to the conformal weight assignable to the radial light-like coordinate appearing in the role of complex coordiante in super-symplectic Hamiltonians and to the spinorial conformal weight assignable to the solutions of Kähler Dirac equation localized to string world sheets. These conformal weights are independent quantum numbers unless one can use the light-like radial coordinate as string coordinate, which is certainly not possible always. The latter conformal weight should correspond to the stringy contribution to the masses of elementary particles and hadron like states. In fact, it is difficult to distinguish between elementary particles and hadrons at the fundamental level since both involve the stringy aspect.

The Yangian symmetry variant of conformal symmetry is highly suggestive and brings in poly-locality with respect to partonic 2-surfaces. This integer would count the number of partonic 2-surfaces to which the generator acts and need not correspond to spinorial conformal weight as one might think first. In any case, Yangian variant of p-adic termodynamics provides an attractive approach concerning the mathematical realization of this vision.

5.8.6 Weak Regge trajectories

The weak form of electric-magnetic duality suggests strongly the existence of weak Regge trajectories.

(a) The most general mass squared formula with spin-orbit interaction term $M_{L-S}^2 L\cdot S$ reads as

$$M^2 = nM_1^2 + M_0^2 + M_{L-S}^2 L\cdot S \ , \quad n = 0,2,4 \ \text{or} \ n = 1,3,5,..., \ . \tag{5.8.1}$$

M_1^2 corresponds to string tension and M_0^2 corresponds to the thermodynamical mass squared and possible other contributions. For a given trajectory even (odd) values of n have same parity and can correspond to excitations of same ground state. From ancient books written about hadronic string model one vaguely recalls that one can have several trajectories (satellites) and if one has something called exchange degeneracy, the even and odd trajectories define single line in M^2-J plane. As already noticed TGD variant of Higgs mechanism combines together $n=0$ states and $n=1$ states to form massive gauge bosons so that the trajectories are not independent.

(b) For fermions, possible Higgs, and pseudo-scalar Higgs and their super partners also p-adic thermodynamical contributions are present. M_0^2 must be non-vanishing also for gauge bosons and be equal to the mass squared for the $n=L=1$ spin singlet. By applying the formula to $h=\pm 1$ states one obtains

$$M_0^2 = M^2(boson) \ . \tag{5.8.2}$$

The mass squared for transversal polarizations with $(h,n,L) = (\pm 1, n=L=0, S=1)$ should be same as for the longitudinal polarization with $(h=0, n=L=1, S=1, J=0)$ state. This gives

$$M_1^2 + M_0^2 + M_{L-S}^2 L\cdot S = M_0^2 \ . \tag{5.8.3}$$

From $L\cdot S = \left[J(J+1) - L(L+1) - S(S+1)\right]/2 = -2$ for $J=0, L=S=1$ one has

$$M_{L-S}^2 = -\frac{M_1^2}{2} \ . \tag{5.8.4}$$

Only the value of weak string tension M_1^2 remains open.

(c) If one applies this formula to arbitrary $n=L$ one obtains total spins $J=L+1$ and $L-1$ from the tensor product. For $J=L-1$ one obtains

$$M^2 = (2n+1)M_1^2 + M_0^2 \ .$$

For $J=L+1$ only M_0^2 contribution remains so that one would have infinite degeneracy of the lightest states. Therefore stringy mass formula must contain a non-linear term making Regge trajectory curved. The simplest possible generalization which does not affect n=0 and n=1 states is of from

$$M^2 = n(n-1)M_2^2 + (n - \frac{L\cdot S}{2})M_1^2 + M_0^2 \ . \tag{5.8.5}$$

The challenge is to understand the ratio of W and Z^0 masses, which is purely group theoretic and provides a strong support for the massivation by Higgs mechanism.

(a) The above formula and empirical facts require

$$\frac{M_0^2(W)}{M_0^2(Z)} = \frac{M^2(W)}{M^2(Z)} = cos^2(\theta_W) \ . \quad (5.8.6)$$

in excellent approximation. Since this parameter measures the interaction energy of the fermion and anti-fermion decomposing the gauge boson depending on the net quantum numbers of the pair, it would look very natural that one would have

$$M_0^2(W) = g_W^2 M_{SU(2)}^2 \ , \ M_0^2(Z) = g_Z^2 M_{SU(2)}^2 \ . \quad (5.8.7)$$

Here $M_{SU(2)}^2$ would be the fundamental mass squared parameter for $SU(2)$ gauge bosons. p-Adic thermodynamics of course gives additional contribution which is vanishing or very small for gauge bosons.

(b) The required mass ratio would result in an excellent approximation if one assumes that the mass scales associated with $SU(2)$ and $U(1)$ factors suffer a mixing completely analogous to the mixing of $U(1)$ gauge boson and neutral $SU(2)$ gauge boson W_3 leading to γ and Z^0. Also Higgs, which consists of $SU(2)$ triplet and singlet in TGD Universe, would very naturally suffer similar mixing. Hence $M_0(B)$ for gauge boson B would be analogous to the vacuum expectation of corresponding mixed Higgs component. More precisely, one would have

$$\begin{aligned} M_0(W) &= M_{SU(2)} \ , \\ M_0(Z) &= cos(\theta_W)M_{SU(2)} + sin(\theta_W)M_{U(1)} \ , \\ M_0(\gamma) &= -sin(\theta_W)M_{SU(2)} + cos(\theta_W)M_{U(1)} \ . \end{aligned} \quad (5.8.8)$$

The condition that photon mass is very small and corresponds to IR cutoff mass scale gives $M_0(\gamma) = \epsilon cos(\theta_W)M_{SU(2)}$, where ϵ is very small number, and implies

$$\begin{aligned} \frac{M_{U(1)}}{M(W)} &= tan(\theta_W) + \epsilon \ , \\ \frac{M(\gamma)}{M(W)} &= \epsilon \times cos(\theta_W) \ , \\ \frac{M(Z)}{M(W)} &= \frac{1 + \epsilon \times sin(\theta_W)cos(\theta_W)}{cos(\theta_W)} \ . \end{aligned} \quad (5.8.9)$$

There is a small deviation from the prediction of the standard model for W/Z mass ratio but by the smallness of photon mass the deviation is so small that there is no hope of measuring it. One can of course keep mind open for $\epsilon = 0$. The formulas allow also an interpretation in terms of Higgs vacuum expectations as it must. The vacuum expectation would most naturally correspond to interaction energy between the massless fermion and anti-fermion with opposite 3-momenta at the throats of the wormhole contact and the challenge is to show that the proposed formulas characterize this interaction energy. Since CP_2 geometry codes for standard model symmetries and their breaking, it woul not be surprising if this would happen. One cannot exclude the possibility that p-adic thermodynamics contributes to $M_0^2(boson)$. For instance, ϵ might characterize the p-adic thermal mass of photon.

If the mixing applies to the entire Regge trajectories, the above formulas would apply also to weak string tensions, and also photons would belong to Regge trajectories containing high spin excitations.

(c) What one can one say about the value of the weak string tension M_1^2? The naive order of magnitude estimate is $M_1^2 \simeq m_W^2 \simeq 10^4$ GeV^2 is by a factor 1/25 smaller than the direct scaling up of the hadronic string tension about 1 GeV^2 scaled up by a factor 2^{18}. The above argument however allows also the identification as the scaled up variant of hadronic string tension in which case the higher states at weak Regge trajectories would not be easy to discover since the mass scale defined by string tension would be 512 GeV to be compared with the recent beam energy 7 TeV. Weak string tension need of course not be equal to the scaled up hadronic string tension. Weak string tension - unlike its hadronic counterpart- could also depend on the electromagnetic charge and other characteristics of the particle.

5.8.7 Low mass exotic mesonic structures as evidence for dark scaled down variants of weak bosons?

During last years reports about low mass exotic mesonic structures have appeared. It is interesting to combine these bits of data with the recent view about TGD analog of Higgs mechanism and find whether new predictions become possible. The basic idea is to derive understanding of the low mass exotic structures from LHC data by scaling and understanding of LHC data from data about mesonic structures by scaling back.

(a) The article *Search for low-mass exotic mesonic structures: II. attempts to understand the experimental results* by Taticheff and Tomasi-Gustafsson [C174] mentions evidence for exotic mesonic structures. The motivation came from the observation of a narrow range of dimuon masses in $\Sigma^+ \rightarrow pP^0$, $P^0 \rightarrow \mu^-\mu^+$ in the decays of P^0 with mass of $214.3 \pm .5$ MeV: muon mass is 105.7 MeV giving $2m_\mu = 211.4$ MeV. Mesonlike exotic states with masses $M = 62, 80, 100, 181, 198, 215, 227.5,$ and 235 MeV are reported. This fine structure of states with mass difference 20-40 MeV between nearby states is reported for also for some baryons.

(b) The preprint *Observation of the E(38) boson* by Kh.U. Abraamyan et al [C176, C177, C109] reports the observation of what they call E(38) boson decaying to gamma pair observed in d(2.0 GeV/n)+C,d(3.0 GeV/n)+Cu and p(4.6 GeV)+C reactions in experiments carried in JINR Nuclotron.

If these results can be replicated they mean a revolution in nuclear and hadron physics. What strongly suggests itself is a fine structure for ordinary hadron states in much smaller energy scale than characterizing hadronic states. Unfortunately the main stream, in particular the theoreticians interested in beyond standard model physics, regard the physics of strong interactions and weak interactions as closed chapters of physics, and are not interested on results obtained in nuclear collisions.

In TGD framework situation is different. The basic characteristic of TGD Universe is fractality. This predicts new physics in all scales although standard model symmetries are fundamental unlike in GUTs and are reduced to number theory. p-Adic length scale hypothesis characterizes the fractality.

(a) In TGD Universe p-adic length scale hypothesis predicts the possibility of scaled versions of both strong and weak interactions. The basic objection against new light bosons is that the decay widths of weak bosons do not allow them. A possible manner to circumvent the objection is that the new light states correspond to dark matter in the sense that the value of Planck constant is not the standard one but its integer multiple [K22].

The assumption that only particles with the same value of Planck constant can appear in the vertex, would explain why weak bosons do not decay directly to light dark particles. One must however allow the transformation of gauge bosons to their dark counterparts. The 2-particle vertex is characterized by a coupling having dimensions of mass squared in the case of bosons, and p-adic length scale hypothesis suggests that the primary p-adic mass scale characterizes the parameter (the secondary p-adic mass scale is lower by factor $1/\sqrt{p}$ and would give extremely small transformation rate).

(b) Ordinary strong interactions correspond to Mersenne prime M_n, $n = 2^{107} - 1$, in the sense that hadronic space-time sheets correspond to this p-adic prime. Light quarks correspond to space-time sheets identifiable as color magnetic flux tubes, which are much larger than hadron itself. M_{89} hadron physics has hadronic mass scale 512 times higher than ordinary hadron physics and should be observed at LHC. There exist some pieces of evidence for the mesons of this hadron physics but masked by the Higgsteria. The expectation is that Minkowskian M_{89} pion has mass around 140 GeV assigned to CDF bump [C59].

(c) In the leptonic sector there is evidence for lepto-hadron physics for all charged leptons labelled by Mersenne primes M_{127}, $M_{G,113}$ (Gaussian Mersenne), and M_{107} [K70]. One can ask whether the above mentioned resonance P^0 decaying to $\mu^-\mu^+$ pair motivating the work described in [C174] could correspond to pion of muon-hadron physics consisting of a pair of color octet excitations of muon. Its production would presumably take place via production of virtual gluon pair decaying to a pair of color octet muons.

Returning to the observations of [C174]: the reported meson-like exotic states seem to be arranged along Regge trajectories but with string tension lower than that for the ordinary Regge trajectories with string tension $T = .9$ GeV^2. String tension increases slowly with mass of meson like state and has three values $T/GeV^2 \in \{1/390, 1/149.7, 1/32.5\}$ in the piecewise linear fit discussed in the article. The TGD inspired proposal is that IR Regge trajectories assignable to the color magnetic flux tubes accompanying quarks are in question. For instance, in hadrons u and d quarks - understood as constituent quarks - would have $k = 113$ quarks and string tension would be by naive scaling by a factor $2^{107-113} = 1/64$ lower: as a matter of fact, the largest value of the string tension is twice this value. For current quark with mass scale around 5 MeV the string tension would be by a factor of order $2^{107-121} = 2^{-16}$ lower.

Clearly, a lot of new physics is predicted and it begins to look that fractality - one of the key predictions of TGD - might be realized both in the sense of hierarchy of Planck constants (scaled variants with same mass) and p-adic length scale hypothesis (scaled variants with varying masses). Both hierarchies would represent dark matter if one assumes that the values of Planck constant and p-adic length scale are same in given vertex. The testing of predictions is not however expected to be easy since one must understand how ordinary matter transforms to dark matter and vice versa. Consider only the fact, that only recently the exotic meson like states have been observed and modern nuclear physics regarded often as more or less trivial low energy phenomenology was born born about 80 years ago when Chadwick discovered neutron.

5.8.8 Weak Regge trajectories

The weak form of electric-magnetic duality suggests strongly the existence of weak Regge trajectories.

(a) The most general mass squared formula with spin-orbit interaction term $M_{L-S}^2 L\cdot S$ reads as

$$M^2 = nM_1^2 + M_0^2 + M_{L-S}^2 L\cdot S \ , \ n = 0,2,4 \text{ or } n = 1,3,5,..., \ . \quad (5.8.10)$$

M_1^2 corresponds to string tension and M_0^2 corresponds to the thermodynamical mass squared and possible other contributions. For a given trajectory even (odd) values of n have same parity and can correspond to excitations of same ground state. From ancient books written about hadronic string model one vaguely recalls that one can have several trajectories (satellites) and if one has something called exchange degeneracy, the even and odd trajectories define single line in $M^2 - J$ plane. As already noticed TGD variant of Higgs mechanism combines together $n = 0$ states and $n = 1$ states to form massive gauge bosons so that the trajectories are not independent.

(b) For fermions, possible Higgs, and pseudo-scalar Higgs and their super partners also p-adic thermodynamical contributions are present. M_0^2 must be non-vanishing also for gauge bosons and be equal to the mass squared for the $n = L = 1$ spin singlet. By applying the formula to $h = \pm 1$ states one obtains

$$M_0^2 = M^2(boson) \ . \tag{5.8.11}$$

The mass squared for transversal polarizations with $(h, n, L) = (\pm 1, n = L = 0, S = 1)$ should be same as for the longitudinal polarization with $(h = 0, n = L = 1, S = 1, J = 0)$ state. This gives

$$M_1^2 + M_0^2 + M_{L-S}^2 L \cdot S = M_0^2 \ . \tag{5.8.12}$$

From $L \cdot S = [J(J+1) - L(L+1) - S(S+1)]/2 = -2$ for $J = 0, L = S = 1$ one has

$$M_{L-S}^2 = -\frac{M_1^2}{2} \ . \tag{5.8.13}$$

Only the value of weak string tension M_1^2 remains open.

(c) If one applies this formula to arbitrary $n = L$ one obtains total spins $J = L + 1$ and $L - 1$ from the tensor product. For $J = L - 1$ one obtains

$$M^2 = (2n + 1)M_1^2 + M_0^2 \ .$$

For $J = L+1$ only M_0^2 contribution remains so that one would have infinite degeneracy of the lightest states. Therefore stringy mass formula must contain a non-linear term making Regge trajectory curved. The simplest possible generalization which does not affect n=0 and n=1 states is of from

$$M^2 = n(n-1)M_2^2 + (n - \frac{L \cdot S}{2})M_1^2 + M_0^2 \ . \tag{5.8.14}$$

The challenge is to understand the ratio of W and Z^0 masses, which is purely group theoretic and provides a strong support for the massivation by Higgs mechanism.

(a) The above formula and empirical facts require

$$\frac{M_0^2(W)}{M_0^2(Z)} = \frac{M^2(W)}{M^2(Z)} = cos^2(\theta_W) \ . \tag{5.8.15}$$

in excellent approximation. Since this parameter measures the interaction energy of the fermion and anti-fermion decomposing the gauge boson depending on the net quantum numbers of the pair, it would look very natural that one would have

$$M_0^2(W) = g_W^2 M_{SU(2)}^2 \ , \ M_0^2(Z) = g_Z^2 M_{SU(2)}^2 \ . \tag{5.8.16}$$

Here $M_{SU(2)}^2$ would be the fundamental mass squared parameter for $SU(2)$ gauge bosons. p-Adic thermodynamics of course gives additional contribution which is vanishing or very small for gauge bosons.

(b) The required mass ratio would result in an excellent approximation if one assumes that the mass scales associated with $SU(2)$ and $U(1)$ factors suffer a mixing completely analogous to the mixing of $U(1)$ gauge boson and neutral $SU(2)$ gauge boson W_3 leading to γ and Z^0. Also Higgs, which consists of $SU(2)$ triplet and singlet in TGD Universe, would very naturally suffer similar mixing. Hence $M_0(B)$ for gauge boson B would be analogous to the vacuum expectation of corresponding mixed Higgs component. More precisely, one would have

$$\begin{aligned} M_0(W) &= M_{SU(2)} \ , \\ M_0(Z) &= cos(\theta_W)M_{SU(2)} + sin(\theta_W)M_{U(1)} \ , \\ M_0(\gamma) &= -sin(\theta_W)M_{SU(2)} + cos(\theta_W)M_{U(1)} \ . \end{aligned} \tag{5.8.17}$$

The condition that photon mass is very small and corresponds to IR cutoff mass scale gives $M_0(\gamma) = \epsilon cos(\theta_W)M_{SU(2)}$, where ϵ is very small number, and implies

$$\begin{aligned} \frac{M_{U(1)}}{M(W)} &= tan(\theta_W) + \epsilon \ , \\ \frac{M(\gamma)}{M(W)} &= \epsilon \times cos(\theta_W) \ , \\ \frac{M(Z)}{M(W)} &= \frac{1 + \epsilon \times sin(\theta_W)cos(\theta_W)}{cos(\theta_W)} \ . \end{aligned} \tag{5.8.18}$$

There is a small deviation from the prediction of the standard model for W/Z mass ratio but by the smallness of photon mass the deviation is so small that there is no hope of measuring it. One can of course keep mind open for $\epsilon = 0$. The formulas allow also an interpretation in terms of Higgs vacuum expectations as it must. The vacuum expectation would most naturally correspond to interaction energy between the massless fermion and anti-fermion with opposite 3-momenta at the throats of the wormhole contact and the challenge is to show that the proposed formulas characterize this interaction energy. Since CP_2 geometry codes for standard model symmetries and their breaking, it woul not be surprising if this would happen. One cannot exclude the possibility that p-adic thermodynamics contributes to $M_0^2(boson)$. For instance, ϵ might characterize the p-adic thermal mass of photon.

If the mixing applies to the entire Regge trajectories, the above formulas would apply also to weak string tensions, and also photons would belong to Regge trajectories containing high spin excitations.

(c) What one can one say about the value of the weak string tension M_1^2? The naive order of magnitude estimate is $M_1^2 \simeq m_W^2 \simeq 10^4$ GeV^2 is by a factor 1/25 smaller than the direct scaling up of the hadronic string tension about 1 GeV^2 scaled up by a factor 2^{18}. The above argument however allows also the identification as the scaled up variant of hadronic string tension in which case the higher states at weak Regge trajectories would not be easy to discover since the mass scale defined by string tension would be 512 GeV to be compared with the recent beam energy 7 TeV. Weak string tension need of course not be equal to the scaled up hadronic string tension. Weak string tension - unlike its hadronic counterpart- could also depend on the electromagnetic charge and other characteristics of the particle.

5.8.9 Cautious conclusions

The discussion of TGD counterpart of Higgs mechanism gives support for the following general picture.

(a) p-Adic thermodynamics for wormhole contacts contributes to the masses of all particles including photon and gluons: in these cases the contributions are however small. For fermions they dominate. For weak bosons the contribution from string tension of string connecting wormhole contacts as the correct group theoretical prediction for the W/Z mass ratio demonstrates. The mere spin 1 character for gauge bosons implies that they are massive in 4-D sense unless massless fermion and anti-fermion have opposite signs of energy. Higgs provides the longitudinal components of weak bosons by gauge invariance and CP_2 geometry defines unitary gauge so that Higgs vacuum expectation value is not needed. The non-existence of covariantly constant CP_2 vector field does not mean absence of Higgs like particle as believed first but only the impossibility of Higgs vacuum expectation value.

The usual space-time SUSY associated with imbedding space in TGD framework is not needed, and there are strong arguments suggesting that it is not present [**?**] For space-time regarded as 4-surfaces one obtains 2-D super-conformal invariance for fermions localized at 2-surfaces and for right-handed neutrino it extends to 4-D superconformal symmetry generalizing ordinary SUSY to infinite-D symmetry.

(b) The basic predictions to LHC are following. M_{89} hadron physics, whose pion was first proposed to be identifiable as Higgs like particle, will be discovered. The findings from RHIC and LHC concerning collisions of heavy ions and protons and heavy ions already provide support for the existence of string like objects identifiable as mesons of M_{89} physics. Fermi satellite has produced evidence for a particle with mass around 140 GeV and this particle could correspond to the pion of M_{89} physics. This particle should be observed also at LHC and CDF reported already earlier evidence for it. There has been also indications for other mesons of M_{89} physics from LHC discussed in [K37].

(c) Fermion and boson massivation by Higgs mechanism could emerge unavoidably as a theoretical artefact if one requires the existence of QFT limit leading unavoidably to a description in terms of Higgs mechanism. In the real microscopic theory p-adic thermodynamics for wormhole contacts and strings connecting them would describe fermion massivation, and might describe even boson massivation in terms of long parts of flux tubes. Situation remains open in this respect. Therefore the observation of decays of Higgs at expected rate to fermion pairs cannot kill TGD based vision.

The new view about Higgs combined with the stringy vision about twistor Grassmannian [**?**] allows to see several conjectures related to ZEO in new light and also throw away some conjectures such as the idea about restriction of virtual momenta to plane $M^2 \subset M^4$.

(a) The basic conjecture related to the perturbation theory is that wormhole throats are massless on mass shell states in imbedding space sense: this would hold true also for virtual particles and brings in mind what happens in twistor program. The recent progress [K80] in the construction of n-point functions leads to explicit general formulas for them expressing them in terms of a functional integral over four-surfaces. The deformation of the space-time surface fixes the deformation of basis for induced spinor fields and one obtains a perturbation theory in which correlation functions for imbedding space coordinates and fermionic propagator defined by the inverse of the modified Dirac operator appear as building bricks and the electroweak gauge coupling of the modified Dirac operator define the basic vertex. This operator is indeed 2-D for all other fermions than right-handed neutrino.

(b) The functional integral gives some expressions for amplitudes which resemble twistor amplitudes in the sense that the vertices define polygons and external fermions are massless although gauge bosons as their bound states are massive. This suggests a stringy generalization of twistor Grassmannian approach [K58]. The residue integral would replace 4-D integrations of virtual fermion momenta to integrals over massless momenta. The outcome would be non-vanishing for non-physical helicities of virtual fermion. Also the problem due to the fact that fermionic Super Virasoro generator carries fermion number in TGD framework disappears.

(c) There are two conformal weights involved. The conformal weight associated with the light-like radial coordinate of $\delta M^4_{\pm}$ and the spinorial conformal weight associated with the fermionic string connecting wormhole throats and throats of wormhole contact. Are these conformal weights independent or not? For instance, could one use radial light-like coordinate as string coordinate in the generic situation so that the conformal weights would not define independent quantum numbers? This does not look feasible. The Yangian variant of conformal algebra involves two integers. Second integer would naturally be the number of partonic 2-surfaces acted by the generator characterizing the poly-locality of Yangian generators, and it is not clear whether it has anything to do with the spinorial conformal weight. One can of course consider also three integers! This would be in accordance with the idea that the basic objects are 3-dimensional.

If the conjecture that Yangian invariance realized in terms of Grassmannians makes sense, it could allow to deduce the outcome of the functional integral over four-surfaces and one could hope that TGD can be transformed to a calculable theory. Also p-adic mass calculations should be formulated using p-adic thermodynamics assuming Yangian invariance and enlargened conformal algebra.

5.9 About the basic assumptions behind p-adic mass calculations

The motivation for this piece of text was the basic horror experience of theoretician waking him up at early morning hours. Is there something wrong with basic assumptions of some particular piece of theory? At this time it was p-adic thermodynamics. Theoretician tries to figure this out in a drowsy state between wake-up and sleep, fails repeatedly, and blames the mighties of the Universe for his miserable fate as eternal doubter. Eventually merciful sleep arrives and theoretician wakes up in the morning, recalls the problem and feels that nothing is wrong. But theoretician knows that it is better to check everything once again.

So that this is what I am doing in the sequel: listing and challenging the basic assumptions and philosophy behind p-adic mass calculations. As always in this kind of situation, I prefer to think it allover again rather than finding what I have written earlier: reader can check whether the recent me agrees with the earlier me. This list is not the only one that I have made during these years and other, possibly different, lists can be found in the chapters of various books. Although the results of calculations are unique and involve only very general assumptions, the guessing of the detailed physical picture behind them is difficult.

I hope that this piece of text would also help to understand better how p-adic mass calculations as a microscopic theory and the standard description of Higgs mechanism as a phenomenological low energy parameterization relate to each other.

5.9.1 Why p-adic thermodynamics?

p-Adic thermodynamics is a fundamental assumption behind the p-adic mass calculations: p-adic mass squared is identified as a thermal average of mass squared for super-conformal representation with p-adic mass squared given essentially by the conformal weight.

Zero energy ontology (ZEO) has gradually gained a status of second fundamental assumption. In fact, ZEO strongly suggests the replacement of p-adic thermodynamics with its "complex square root" so that one would be actually considering genuine quantum states squaring to thermodynamical states. This idea looks highly satisfactory for anyone used to think that elementary particles cannot be thermodynamical objects. The square root of p-adic thermodynamics raises delicate number theoretical issues [K66] since the p-adic square root of the conformal weight having value p does not exist without a proper algebraic extension of p-adic numbers leading to algebraic integers and generalized notion of primeness.

Q: Why p-adic thermodynamics, which predicts the thermal expectation of p-adic mass squared and requires the mapping of p-adic valued mass squared to real mass squared by some variant of canonical identification?

A: Number theoretical universality requires fusion of real and p-adic number based physics for various primes so that p-adic thermodynamics becomes natural.

(a) The answer inspired by TGD inspired theory of consciousness would be that the interaction of p-adic space-time sheets serving as correlates of cognition with real space-time sheets representing matter makes p-adic topology effective topology in some length scale range also for real space-time sheets (as an effective topology for discretization). One could even speak about cognitive representations of elementary particles using the rational or algebraic intersections of real and p-adic space-time sheets. These cognitive representations are very simple in p-adic topology and it is easy to calculate the masses of the particles using p-adic thermodynamics. Since representation is in question, the result should characterize also real particle.

(b) The pragmatic answer would be that p-adic thermodynamics gives extremely powerful number theoretical constraints leading to the quantization of mass scales and masses with p-adic temperature $T = 1/n$ and p-adic prime appearing as free parameters. Also conformal invariance is strongly favored since the counterpart of Hamiltonian must be integer valued as the super-conformal scaling generator indeed is.

(c) By number theoretical universality one can require that the p-adic mass thermodynamics is equivalent with real thermodynamics for real mass squared. This is the case if partition function has cutoff so that conformal weights only up to some maximum value N are allowed. This has no practical consequences since the real-valued contribution from the conformal weight n is proportional to $p^{-n+1/2}$ and for $n > 2$ is completely negligible since the primes involved are so large ($p = M_{127} = 2^{127} - 1$ for electron for instance).

Q: Is the canonical identification mapping the p-adic mass squared to real mass squared unique? This is not the case. One can imagine a family of identification for which integers $n < p^N$, $N = 1, 2, ...$ are mapped to itself. This however has no practical implications for the calculations since the values of primes involved are so large.

The calculations themselves assume only p-adic thermodynamics and super-conformal invariance. The most important thing that matters is the number of tensor factors in the tensor product of representations of conformal algebra, which must be *five*.

Q: What are the fundamental conformal algebras giving rise to the super conformal symmetries?

A: There are two conformal algebras involved.

(a) The symplectic algebra of $\delta M^4_\pm \times CP_2$ has the formal structure of Kac-Moody algebra with the light-like radial coordinate r of the light-cone boundary $\delta M^4_\pm$ taking the role of complex coordinate z. It has symplectic algebras of CP_2 and sphere S^2 of light-cone boundary as building blocks taking the role of the finite-dimensional Lie group defining Kac-Moody algebra. This algebra has not in string models.

(b) There is also the Kac-Moody algebra assignable to the light-like wormhole throats and assignable to the isometries of the imbedding space having M^4 and CP_2 isometries as factors. There are also electroweak symmetries acting on spinor fields. In fact, the construction of the solutions of the modified Dirac equation [K80] suggests that electroweak and color gauge symmetries become Kac-Moody symmetries in TGD framework. In practice this means that only the generators with positive conformal weight annihilate the physical states. For gauge symmetry also those with negative conformal weight annihilate the physical states.

One can of course ask whether also $SU(2)$ sub-algebra of SL(2,C) acting on spinors should be counted. One could argue that this is not the case since spin does correspond to gauge or Kac-Moody symmetry as electroweak quantum numbers do.

Q: One must have five tensor factors. How should one count the number of tensor factors, in other words what is the basic building brick to which one identifies as a tensor factor of Super-Virasoro algebra?

A: One can imagine two options.

(a) The most general option is that one takes the CP_2 and S^2 symplectic algebras as factors in the symplectic sector. In Kac-Moody sector one has $E^2 \subset M^4$ isometries (longitudinal degrees of freedom of string world sheet carrying induce spinors fields are not physical) and $SU(3)$. Besides this one has electroweak algebra $U(2)$, which almost but quite not decomposes to $SU(2)_L \times U(1)$ (there are correlations between $SU(2)_L$ and

$U(1)$ quantum numbers and the existence of spinor structure of CP_2 makes also these correlations manifest). This would give 5 tensor factors as required.

(b) I have also considered Cartan algebras as separate tensor factors. I must confess, that at this moment I am unable to rediscover what my motivation for this actually has been. This would give a larger number of tensor factors: 1+2 factors in symplectic sector from Cartan algebras of $SO(3) \times SU(3)$ defining subgroup of symplectic group, 2+2 for isometries in Kac-Moody sector from E^2 and $SU(3)$, and 1+1 in the electroweak sector with spin giving a possible further factor. This means 9 (or possibly 10) factors so that thermalization is not possible for all Cartan algebra factors. Symplectic sectors are certainly a natural candidate in this respect so that one would have 5 as required (or 6 if spin is allowed to have Kac-Moody structure) sectors.

The first option looks more convincing to me.

5.9.2 How to understand the conformal weight of the ground state?

Ground state conformal weight which is non-positive can receives various contributions. One contribution is negative and therefore corresponds to a tachyonic mass squared, second contribution corresponds to CP_2 cm degrees of freedom and together with the momentum squared boils down to an eigenvalue of the square of spinor d'Alembertian for $H = M^4 \times CP_2$ (by bosonic emergence). Third one comes from the conformal moduli of the partonic 2-surface at the end of the space-time sheet at light-like boundary of causal diamond and distinguishes between different fermion families.

Q: Tachyonic ground state mass does not look physical and is quite generally seen as a serious - if not lethal - problem also in string models. What is the origin of the tachyonic contribution to the mass squared in TGD framework?

A: The recent picture about elementary particles is as lines of generalized Feynman diagram identified as space-time regions with Euclidian signature of the induced metric. In this regions mass squared is naturally negative and it is natural to think that ground state mass squared receives contributions from both Euclidian and Mionkowskian regions. If so, the necessary tachyonic contribution would be a direct signal for the presence of the Euclidian regions, which have actually turned out to define a generalization of blackhole interior and be assignable to any system as a space-time sheet characterizing the system geometrically [L18]. For instance, my own body as I experience it would correspond to my personal Euclidian space-time seet as a line of generalized Feynman diagram.

Q: Where does the $H = M^4 \times CP_2$ contribution to the scaling generator L_0 assignable to spinor partial waves in H come from?

A: Zero energy ontology (ZEO) allows to assign to each particle a causal diamond CD and according to the recent view emerging from the analysis of the relationship between subjective (experienced) time and geometric time, particle is characterized by a quantum superposition of CDs. Every state function reduction means localization of the upper of lower tip of all CDs in the superposition and de-localization of the other tip. The position of the upper tip has wave function in $H_\pm = M^4_\pm \times CP_2$ and there is a great temptation to identify the wave function as being induced from a partial wave in $H = M^4 \times CP_2$. As a matter fact, number theoretic arguments and arguments related to finite measurement resolution strongly suggest discretization of $H_\pm$. $M^4_\pm$ would be replaced with a union of hyperboloids with a distance from the tip of $M^4_\pm$ which is quantized as a multiple of CP_2 radius. Furthermore at each hyperboloid the allowed points would correspond to the orbit of some discrete subgroup of $SL(2, C)$. CP_2 would be also discretized.

5.9.3 What about Lorentz invariance?

The square root of p-adic thermodynamics implies quantum superposition of states with different values of mass squared and hence four-momenta. In ZEO this does not mean obvious breaking of Lorentz invariance since physical states have vanishing total energy. Note that coherent states of Cooper pairs, which in ordinary ontology would have both ill-defined energy and fermion number, have a natural interpretation in ZEO.

(a) A natural assumption is that the state in the rest system involves only a superposition of states with vanishing three-momentum. For Lorentz boosts the state would be a superposition of states with different three-momenta but same velocity. Classically the assumption about same 3-velocity is natural.

  Q: Could Lorentz invariance break down by the presence of the superposition of different momenta?

  A: This is not the case if only the average four-momentum is observable. The reason is that average four-momentum transforms linearly under Lorentz boosts. I have earlier considered the possibility of replacing momentum squared with conformal weight but this option looks somewhat artificial and even wrong to me now.

(b) The decomposition $M^4 = M^2 \times E^2$ is fundamental in the formulation of quantum TGD, in the number theoretical vision about TGD, in the construction of preferred extremals, and for the vision about generalized Feynman diagrams. It is also fundamental in the decomposition of the degrees of string to longitudinal and transversal ones. An additional item to the list is that also the states appearing in thermodynamical ensemble in p-adic thermodynamics correspond to four-momenta in M^2 fixed by the direction of the Lorentz boost.

  Q: In parton model of hadrons it is assumed that the partons have a distribution with respect to longitudinal momentum, which means that the velocities of partons are same along the direction of motion of hadron. Could one have p-adic thermodynamics for hadrons?

  A: For hadronic p-adic thermodynamics the value of the string tension parameter would be much smaller and the thermal contributions from $n > 0$ states would be completely negligible so that the idea does not look good. In p-adic thermodynamics for elementary particles one would have distribution coming from different values of p-adic mass squared which is integer valued apart from ground state configuration.

5.9.4 What are the fundamental dynamical objects?

The original assumption was that elementary particles correspond to wormhole throats. With the discovery of the weak form of electric-magnetic duality came the realization that wormhole throat is homological magnetic monopole (rather than Dirac monopole) and must therefore have (Kähler) magnetic charge. Magnetic flux lines must be however closed so that the wormhole throat must be associated with closed flux loop.

The most natural assumption is that this loop connects two wormhole throats at the first space-time sheet, that the flux goes through a second wormhole contact to another sheet, returns back along second flux tube, and eventually is transferred to the original throat along the first wormhole contact.

The solutions of the Modified Dirac equation [K80] assign to this flux tube string like curve as a boundary of string world sheet carrying the induced fermion field. This closed string has "short" portions assignable to wormhole contacts and "long" portions corresponding to the flux tubes connecting the two wormhole contacts. One can assign a string tension defined by CP_2 scale with the "short" portions of the string and string tension defined by the primary or perhaps secondary p-adic length scale to the "long" portions of the closed string.

Also the "long" portion of the string can contribute to the mass of the elementary particle as a contribution to the vacuum conformal weight. In the case of weak gauge bosons this would be the case and since the contribution is naturally proportional to gauge couplings strength of W/Z boson one could understand Q/Z mass ratio if the p-adic thermodynamics gives a very small contribution from the "short" piece of string (also photon would receive this small contribution in ZEO): this is the case if one must have $T = 1/2$ for gauge bosons. Note that "long" portion of string can contribute also to fermion masses a small shift. Hence no Higgs vacuum expectation value or coherent state of Higgs would be needed. There are two options for the interpretation of recent results about Higgs and Option II in which Higgs mechanism emerges as an effective description of particle massivation at QFT limit of the theory and both gauge fields and Higgs fields and its vacuum expectation exist only as constructs making sense at QFT limit. Higgs like particles do of course exist. At WCW limit they are replaced by WCW spinor fields as fundamental object.

Q: One can consider several identifications of the fundamental dynamical object of p-adic mass calculations. Either as a wormhole throat (in the case of fermions for which either wormhole throat carries the fermion quantum number this looks natural), as entire wormhole contact, or as the entire flux tube having two wormhole contacts. Which one of these options is correct?

A: The strong analogy with string model implied by the presence of fermionic string world sheet would support that the identification as entire flux tube in which case the large masses for higher conformal excitations could be interpreted in terms of string tension. Note that this is the only possibility in case of gauge bosons.

Q: What about p-adic thermodynamics or its square root in hadronic scale?

A: As noticed the contributions from $n > 0$ conformal excitations would be extremely small in p-adic thermodynamics for "long" portions. It would seem that this contribution is non-thermal and comes from each value of n labelling states in Regge trajectory separately just as in old-fashioned string model. Even weak bosons would have Regge trajectories. The dominant contribution to the hadron mass can be assigned to the magnetic body of the hadron consisting of Kähler magnetic flux tubes. The Kähler-magnetic (or equivalently color-magnetic) flux tubes connecting valence quarks can contribute to the mass squared of hadron. I have also considered the possibility that symplectic conformal symmetries distinguishing between TGD and superstring models could be responsible for a contribution identifiable as color magnetic energy of hadron classically.

5.10 Appendix: The particle spectrum predicted by TGD

The detailed model of elementary particles has evolved slowly during more than 15 years and is still in progress. What SUSY means in TGD framework is second difficult question. In this problem text books provide no help since the SUSY differs in several respects from the standard SUSY. It must be admitted that there are open questions and several competing candidates for interpretations at the level of details and following just summarizes various competing approaches.

5.10.1 The general TGD based view about elementary particles

A rough overall view about the particle spectrum predicted by TGD has remained rather stable since 1995 when I performed first p-adic mass calculations but several important ideas have emerged allowing to make the vision more detailed.

(a) The discovery of bosonic emergence [K49] had far reaching implications for both the formulation and interpretation of TGD. Bosonic emergence means that the basic building bricks of bosons are identifiable as wormhole contacts with throats carrying fermion and anti-fermion quantum numbers.

(b) A big step was the realization wormhole throats carry Kähler magnetic charge [K23]. This forces to assume that observed elementary particles are string like objects carrying opposite magnetic charges at the wormhole ends of magnetic flux tubes. The obvious idea is that weak massivation corresponds to the screening of weak charges by neutrino pairs at the second end of the flux tube.

At least for weak gauge bosons this would fix the length of the flux tube to be given by weak length scale. For fermions and gluons the length of flux tube could also correspond to Compton length: the second end would be invisible since it would contain only neutrino pair. In the case of quarks an attractive idea is that flux tubes carry color magnetic fluxes and connect valence quarks and have hadronic size scale.

There are thus several stringy length scales present. The most fundamental corresponds to wormhole contacts and to CP_2 length scale appearing in p-adic mass calculations and is analogous to the Planck scale characterizing string models. String like objects indeed appear at all levels in TGD Universe: one can say that strings emerge. The assumption that strings are fundamental objects would be a fatal error.

(c) p-Adic massivation does not involve Higgs mechanism [K34]. The idea that Higgs provides longitudinal polarizations for gauge bosons is attractive, and its TGD based variant was that *all* Higgs components become longitudinal polarizations so that also photon has a small mass. The recent formulation of gauge conditions as $p_{M^2} \cdot \epsilon = 0$, where p_{M^2} is a projection of the momentum to to a preferred plane $M^2 \subset M^4$ assignable to a given CD and defining rest system and spin quantization axis, allows three polarizations automatically. Also the construction of gauge bosons as wormhole contacts with fermion and anti-fermion at the ends of throat massless on mass-shell states implies that all gauge bosons must be massive. Therefore Higgs does not seem to serve its original purposes in TGD.

(d) This does not however mean that Higgs like states - or more generally spin 0 particles, could not exist. Here one encounters the problem of formulating what the notions like "scalar" and "pseudo-scalar" defined in M^4 field theory mean when M^4 is replaced with $M^4 \times CP_2$. The reason is that genuine scalars and pseudo-scalars in $M^4 \times CP_2$ would correspond to lepto-quark states and chiral invariance implying separate conservation of quark and lepton numbers denies their existence.

These problems are highly non-trivial, and depending on what one is willing to assume, one can have spin 0 particles which however need not have anything to do with Higgs.

i. For a subset of these spin 0 particles the interpretation as 4 polarizations of gauge bosons in CP_2 direction is highly suggestive: the polarizations can be regarded as doublets $2 \oplus +\overline{2}$ defining representations of $u(2) \subset su(3)$ in its complement and therefore being rather "Higgsy". Another subset consists of triplet and singlet representations for $u(2) \subset u(3)$ allowing interpretation as the analog of strong isospin symmetry in CP_2 scale for the analogs of hadrons defined by wormhole contacts.

ii. $3 \oplus 1$ representation of $u(2) \subset su(3)$ acting on $u(2)$ is highly analogous to (π, η) system and $2 \oplus \overline{2}$ representation assignable naturally to the complement of $u(2)$ is analogous to kaon system. Exactly the same representations are obtained from the model of hadrons as string like objects and the two representations explain the difference between (π, η) like and $(K, \overline{K}$ systems in terms of SU(3) Lie-algebra. Also the vector bosons associated with pseudo-scalar mesons identified as string like objects have counterparts at the level of wormhole contacts. A surprisingly precise analogy between hadronic spectrum and the spectrum of elementary particle states emerges and could help to understand the details of elementary particle spectrum in TGD Universe.

In both cases charge matrices are expressible in terms of Killing vector fields of color isometries and gamma matrices or sigma matrices acting however on electroweak spin degrees of freedom so that a close connection between color and strong isospin is suggestive. This connection is empirically suggested also by the conserved vector current hypothesis and and partially conserved vector current hypothesis allowing to express strong interaction observables in terms of weak currents. In TGD framework color and electro-weak quantum numbers are therefore not totally unrelated as they are in standard model and it would be interesting to see whether this could allow to distinguish between TGD and standard model.

The detailed model for elementary particles involves still many un-certainties and in the following some suggestions allowing more detailed view are considered.

5.10.2 Construction of single fermion states

The general prediction of TGD is that particles correspond to partonic 2-surfaces, which can carry arbitrary high fermion number. The question is why only wormhole throats seem to carry fermion number 1 or 0 and why higher fermion numbers can be only assigned to the possibly existing super-partners.

(a) p-Adic calculations assume that fermions correspond at imbedding space level to color partial waves assignable to the CP_2 cm degrees of freedom of partonic 2-surface. The challenge is to give a precise mathematical content to the statement that partonic 2-surface moves in color partial wave. Color partial wave for the generic partonic 2-surface in general varies along the surface. One must either identify a special point of the surface as cm or assume that color partial wave is constant at the partonic 2-surface.

(b) The first option looks artificial. Constancy condition is however very attractive since it would correlate the geometry of partonic 2-surface with the geometry of color partial wave and therefore code color quantum numbers to the geometry of space-time surface. This quantum classical correlation cannot hold true generally but could be true for the maxima of Kähler function.

(c) Similar condition can be posed in M^4 degrees of freedom and would state that the plane wave representing momentum eigenstate is constant at the partonic 2-surface.

For momentum eigenstates one obtains only one condition stating

$$p_{M^4} \cdot m = constant = C$$

at the partonic 2-surface located at the light-like boundary of CD. Here p_{M^4} denotes the M^2 projection of the four-momentum. CD projection is at most 2-dimensional and at the surface of ellipsoid of form

$$x^2 + y^2 + k^2(z - z_0)^2 = R^2 \ ,$$

where the parameters are expressible in terms of the momentum components p_0, p_3 parameter C. In this case, the assumption that fermions have collinear M^2 momentum projection allows to add several fermions to the state provided the conditions in CP_2 degrees of freedom allow this. In particular, covariantly constant right-handed neutrino must be collinear with the other fermions possibly present in the state.

For color partial waves the condition says that color partial wave is complex constant at partonic 2-surface $\Psi = C$.

(a) The condition implies that the CP_2 projection of the color partial wave is 2-dimensional so that one obtains a family of 2-surfaces Y^2 labelled by complex parameter C. Color transformations act in this space of 2-surfaces. In general Y^2 is not holomorphic since only the lowest representations (1,0) and (0,1) of $SU(3)$ correspond to holomorphic color partial waves. What is highly satisfying is that the condition allows CP_2 projection with maximal possible dimension.

(b) If one requires covariant constancy of fermionic spinors, only vanishing induced spinor curvature is possible and CP_2 projection is 1-dimensional, which does not conform with the assumption that elementary particles correspond to Kähler magnetic monopoles.

(c) There is an objection against this picture. The topology of CP_2 projection must be consistent with the genus of the partonic 2-surface [K14]. The conditions that plane waves and color partial waves are constant at the partonic 2-surface means that one can regard partonic 2-surfaces as sub-manifolds in 4-dimensional sub-manifold of $A \times B \subset \delta CD \times CP_2$. The topologies of $AandB$ pose no conditions on the genus of partonic 2-surface locally. Therefore the objection does not bite.

One can consider also partonic 2-surfaces containing several fermions. In the case of covariantly constant right-handed neutrino this gives no additional conditions in CP_2 degrees of freedom if the right handed neutrino has M^2 momentum projection collinear with the already existing fermion. Therefore $\Psi = C$ constraint is consistent with SUSY in TGD sense. For other fermions N-fermion state gives $2N$ conditions in CP_2 degrees of freedom. Already for $N = 2$ the solutions consist of discrete points of CP_2. Physical intuition suggests that the states with higher fermion number are not realized as maxima of Kähler function and are effectively absent unlike the observed states and their spartners.

5.10.3 About the construction of mesons and elementary bosons in TGD Universe

It looks somewhat strange to talk about the construction of mesons and elementary bosons in the same sentence. The construction recipes are however structurally identical so that it is perhaps sensible to proceed from mesons to elementary bosons. Therefore I will first consider the construction of meson like states relevant for the TGD based model of hadrons, in particular for the model of the pion of M_{89} hadron physics possibly explaining the 125 GeV state for which LHC finds evidence. The more standard interpretation is as elementary spin 0 boson, which need not however have anything to do with Higgs. Amusingly, the two alternatives obey very similar mathematics.

Construction of meson like states in TGD framework

The challenge is how translate attributes like scalar and pseudo-scalar making sense at M^4 level to statements making sense at the level of $M^4 \times CP_2$.

In QCD the view about construction of pseudo-scalar mesons is roughly that one has string like object having quark and antiquark at its ends, call them A and B. The parallel translation of the antiquark spinor from A to B is needed in order to construct gauge invariant object of type $\overline{\Psi} O \Psi$, where O characterizes the meson. The parallel translation implies stringy non-locality. In lattice QCD this string correspond to the edge of lattice cell. For a general meson O is "charge matrix" obtained as a combination of gamma matrices (γ_5 matrix for pseudo-scalar), polarization vectors, and isospin matrices.

This procedure must be generalized to TGD context. In fact a similar procedure applies also in the construction of gauge bosons possible Higgs like states since also in this case one must have general coordinate invariance and gauge invariance. Consider as an example pseudo-scalars.

(a) Pseudo-scalars in M^4 are replaced with axial vectors in $M^4 \times CP_2$ with components in CP_2 direction. One can say that these pseudo-scalars have CP_2 polarization representing the charge of the pseudo-scalar meson. One replaces γ_5 with $\gamma_5 \times O_a$ where $O_a = O_a^k \gamma_k$ is the analog of $\epsilon^k \gamma_k$ for gauge boson. Now however the gamma matrices are CP_2 gamma matrices and O_a^k is some vector field in CP_2. The index a labels the isospin components of the meson.

(b) What can one assume about O_a at the partonic 2-surfaces? In the case of pseudo-scalars pion and η (or vector mesons ρ and ω with nearly the same masses) one should have four such fields forming isospin triplet and singlet with large mass splitting. In the case of kaon would should have also 4 such fields but with almost degenerate masses. Why such a large difference between kaon and (π, η) system? A plausible explanation is in terms of mixing of neutral pseudo-scalar mesons with vanishing weak isospin mesons raising the mass of η but one might dream of alternative explanations too.

   i. Obviously O_a:s should form strong isospin triplets and singlets in case of (π, η) system. In the case of kaon system they should form strong isospin doublets. The group in question should be identifiable as strong isospin group. One can formally identify the subgroup $U(2) \subset SU(3)$ as a counterpart of strong isospin group. The group $SO(3) \subset SU(3)$ defines second candidate of this kind. These subgroups correspond to two different geodesic spheres of S^2. The first gives rise to vacuum extremals of Kähler action and second one to non-vacuum extremals carrying magnetic charge at the partonic 2-surface. Cosmic strings as vacuum extremals and cosmic strings as magnetically charged objects are basic examples of what one obtains. The fact that partonic 2-surfaces carry Kähler magnetic charge strongly suggests that $U(2)$ option is the only sensible one but one must avoid too strong conclusions.

ii. Could one identify O_a as Killing vector fields for $u(2) \subset su(3)$ or for its complement and in this manner obtain two kinds of meson states directly from the basic Lie algebra structure of color algebra? For $u(2)$ one would obtain 3+1 vector fields forming a representation of $u(2)$ decomposing to a direct sum of representations 3 and 1 of $U(2)$ having interpretation in terms of π and η the symmetry breaking is expected to be small between these representations. For the complement of $u(2)$ one would obtain doublet and its conjugate corresponding to kaon like states. Mesons states are constructed from the four states $U_i\overline{D}_j$, $\overline{U}_iD_j$, $U_i\overline{U}_j$, $D_i\overline{D}_j$. For $i = j$ one would have $u(2)$ and for $i \neq j$ its complement.

iii. One would obtain a connection between color group and strong isospin group at the level of meson states and one could say that mesons states are not color invariants in the strict sense of the world since color would act on electroweak spin degrees of freedom non-trivially. This could relate naturally to the possibility to characterize hadrons at the low energy limit of theory in terms of electroweak quantum numbers. Strong force at low energies could be described as color force but acting only on the electroweak spin degrees of freedom. This is certainly something new not predicted by the standard model.

(c) Covariant constancy of O_a at the entire partonic 2-surface is perhaps too strong a constraint. One can however assume this condition only at the the braid ends.

i. The holonomy algebra of the partonic 2-surface is Abelian and reduces to a direct sum of left and right handed parts. For both left- and right-handed parts it reduces to a direct sum of two algebras. Covariant constancy requires that the induced spinor curvature defining classical electroweak gauge field commutes with O_a. The physical interpretation is that electroweak symmetries commute with strong symmetries defined by O_a. There would be at least two conditions depending only on the CP_2 projection of the partonic 2-surface.

ii. The conditions have the form

$$F^{AB}j^a_B = 0 \ ,$$

where a is color index for the sub-algebra in question and A, B are electroweak indices. The conditions are quadratic in the gradients of CP_2 coordinates. One can interpret F^{AB} as components of gauge field in CP_2 with Abelian holonomy and j^a as electroweak current. The condition would say that the electroweak Lorentz force acting on j^a vanishes at the partonic 2-surface projected to CP_2. This interpretation looks natural classically. The conditions are trivially satisfied at points, where one has $j^a_B = 0$, that is at the fixed points of the one-parameter subgroups of isometries in question. O_a would however vanish identically in this case.

iii. The condition $F^{AB}j^a_B = 0$ at all points of the partonic 2-surface looks un-necessary strong and might fail to have solution. The reason is that quantum classical correspondence strongly suggests that the color partial waves of fermions and plane waves associated with 4-momentum are constant along the partonic surface. The additional condition $F^{AB}j^a_B = 0$ allows only a discrete set of solutions.
A weaker form of these conditions would hold true for the braid ends only and could be used to identify them. This conforms with the notion of finite measurement resolution and looks rather natural from the point of view of quantum classical correspondence. Both forms of the conditions allows SUSY in the sense that one can add to the fermionic state at partonic 2-surface a covariantly constant right-handed neutrino spinor with opposite fermionic helicity.

iv. These conditions would be satisfied only for the operators O_a characterizing the meson state and this would give rise to symmetry breaking relating to the mass splittings. Physical intuition suggests that the constraint on the partonic 2-surface should select or at least pose constraints on the maximum of Kähler function. This would give the desired quantum classical correlation between the quantum numbers of meson and space-time surface.

(d) The parallel translation between the ends connecting the partonic 2-surfaces at which quark and antiquark reside at braid ends is along braid strand defining the state of string like object at the boundary of CD. These stringy world sheets are fundamental structures in quantum TGD and a possible interpretation is as singularity of the effective covering of the imbedding space associated with the hierarchy of Planck constants and due to the vacuum degeneracy of Kähler action implying that canonical momentum densities correspond to several values for the gradients of imbedding space coordinates. The parallel translation is therefore unique once the partonic 2-surface is fixed. This is of outmost importance for the well-definedness of quantum states. Obviously this state of affairs gives an additional "must" for braids.

The construction recipe generalizes trivially to scalars. There is however a delicate issue associated with the construction of spin 1 partners of the pseudo-scalar mesons. One must assign to a spin 1 meson polarization vector using $\epsilon^k\gamma_k$ as an additional factor in the "charge matrix" slashed between fermion and anti-fermion. If the charge matrix is taken to be $Q_a = \epsilon^k\gamma_k j^a_k\Gamma^k$, it has matrix elements only between quark and lepton spinors. The solution of the problem is simple. The triplet of charge matrices defined as $Q_a = \epsilon^k\gamma_k D_k j^a_l\Sigma^{kl}$ transforms in the same manner as the original triplet under $U(2)$ rotations and can be used in the construction of spin 1 vector mesons.

Generalization to the construction of gauge bosons and spin 0 bosons

The above developed argument generalizes with trivial modifications to the construction of the gauge bosons and possible Higgs like states as well as their super-partners.

(a) Now one must form bi-linears from fermion and anti-fermion at the opposite throats of the wormhole contact rather than at the ends of magnetic flux tube. This requires braid strands along the wormhole contact and parallel translation of the spinors along them. Hadronic strings are replaced with the TGD counterparts of fundamental strings.

(b) For electro-weak gauge bosons O corresponds to the product $\epsilon_k\gamma^k Q_i$, where Q_i is the charge matrix associated with gauge bosons contracted between both leptonic and quark like states. For gluons the charge matrix is of form $Q_A = \epsilon_k\gamma^k H_A$, where H_A is the Hamiltonian of the corresponding color isometry.

(c) One can also consider the possibility of charge matrices of form $Q_A = \epsilon^k\gamma_k D_k j^A_l\Sigma^{kl}$, where j^A is the Killing vector field of color isometry. These states would compose to representations of $u(2) \subset u(3)$ to form the analogs of (ρ, ω) and $(K^*, \overline{K}^*)$ system in CP_2 scale. This is definitely something new.

(d) In the case of spin zero states polarization vector is replaced with polarization in CP_2 degrees of freedom represented by one of the operators O_a already discussed. One would obtain the analogs of (π, η) and $(K, \overline{K})$ systems at the level of wormhole contacts. Higgs mechanism for these does not explain fermionic masses since p-adic thermodynamics gives the dominant contributions to them. It is also difficult to imagine how gauge bosons could eat these states and what the generation of vacuum expectation value could mean mathematically. Higgs mechanism is essentially 4-D concept and now the situation is 8-dimensional.

(e) At least part of spin zero states corresponds to polarizations in CP_2 directions for the electroweak gauge bosons. This would mean that one replaces $\epsilon_k\gamma^k$ with $j^k_a\Gamma_k$, where j_a is Killing vector field of color isometry in the complement of $u(2) \subset su(3)$. This would give four additional polarization states. One would have 4+2=6 polarization just as one for a gauge field in 8-D Minkowski space. What about the polarization directions defined by $u(2)$ itself? For the Kähler part of electroweak gauge field this part would give just the (ρ, ω) like states already mentioned. Internal consistency might force to drop these states from consideration.

The nice aspect of p-adic mass calculations is that they are so general: only super-conformal invariance and p-adic thermodynamics and p-adic length scale hypothesis are assumed. The drawback is that this leaves a lot of room for the detailed modelling of elementary particles.

(a) Lightest mesons are lowest states at Regge trajectories and also p-adic mass calculations assign Regge trajectories in CP_2 scale to both fermions and bosons.

(b) It would be natural to assign the string tension with the wormhole contact in the case of bosons and identifiable in terms of the Kähler action assignable to the wormhole contact modellable as piece of CP_2 type vacuum extremal and having interpretation in terms of the action of Kähler magnetic fields.

(c) Free fermion has only single wormhole throat. The action of the piece of CP_2 type vacuum extremal could give rise to the string tension also now. One would have something analogous to a string with only one end, and one can worry whether this is enough. The magnetic flux of the fermion however enters to the Minkowskian region and ends up eventually to a wormhole throat with opposite magnetic charge. This contribution to the string tension is however expected to be small being proportional to $1/S$, where S is the thickness of the magnetic flux tube connecting the throats. Only if the magnetic flux tube remains narrow, does one obtain the needed string tension from the Minkowskian contribution. This is the case if the flux tube is very short. It seem that the dominant contribution to the string tension must come from the wormhole throat.

(d) The explanation of family replication phenomenon [K14] based on the genus of wormhole throat works for fermions if the the genus is same for the two throats associated with the fermion. In case of bosons the possibility of different genera leads to a prediction of dynamical SU(3) group assignable to genus degree of freedom and gauge bosons should appear also in octets besides singlets corresponding to ordinary elementary particles. For the option assuming identical genera also for bosons only the singlets are possible.

(e) Regge trajectories in CP_2 scale indeed absolutely essential in p-adic thermodynamics in which massless states generate thermal mass in p-adic sense. This makes sense in zero energy ontology without breaking of Poincare invariance if CD corresponds to the rest system of the massive particle. An alternative way to achieve Lorentz invariance is to assume that observed mass squared equals to the thermal expectation value of thermal weight rather than being thermal expectation for mass squared.

It must be emphasized that spin 0 states and exotic spin 1 states together with their superpartners might be excluded by some general arguments. Induced gauge fields have only two polarization states, and one might argue that that same reduction takes place at the quantum level for the number of polarization states which would mean the elimination of $F_L\overline{F}_R$ type states having interpretation as CP_2 type polarizations for gauge bosons. One could also argue that only gauge bosons with charge matrices corresponding to induced spinor connection and gluons are realized. The situation remains open in this respect.

5.10.4 What SUSY could mean in TGD framework?

What SUSY means in TGD framework is second long-standing problem. In TGD framework SUSY is inherited from super-conformal symmetry at the level of WCW [K13, K16]. The SUSY differs from $\mathcal{N}=1$ SUSY of the MSSM and from the SUSY predicted by its generalization and by string models. One obtains the analog of the $\mathcal{N}=4$ SUSY in bosonic sector but there are profound differences in the physical interpretation.

(a) One could understand SUSY in very general sense as an algebra of fermionic oscillator operators acting on vacuum states at partonic 2-surfaces. Oscillator operators are assignable to braids ends and generate fermionic many particle states. SUSY in this sense is badly broken and the algebra corresponds to rather large $\mathcal{N}$. The restriction to covariantly constant right-handed neutrinos (in CP_2 degrees of freedom) gives rise to the counterpart of ordinary SUSY, which is more physically interesting at this moment.

(b) Right handed neutrino and antineutrino are not Majorana fermions. This is necessary for separate conservation of lepton and baryon numbers. For fermions one obtains the analog $\mathcal{N} = 2$ SUSY.

(c) Bosonic emergence [K49] means the construction of bosons as bound states of fermions and anti-fermions at opposite throats of wormhole contact. This reduces TGD SUSY to that for fermions. This difference is fundamental and means deviation from the SUSY of $\mathcal{N} = 4$ SUSY, where SUSY acts on gauge boson states. Bosonic representations are obtained as tensor products of representation assigned to the opposite throats of wormhole contacts. Further tensor products with representations associated with the wormhole ends of magnetic flux tubes are needed to construct physical particles. This represents a crucial difference with respect to standard approach, where one introduces at the fundamental level both fermions and bosons or gauge bosons as in $\mathcal{N} = 4$ SUSY. Fermionic $\mathcal{N} = 2$ representations are analogous to "short" $\mathcal{N} = 4$ representations for which one half of super-generators annihilates the states.

(d) The introduction of both fermions and gauge bosons as fundamental particles leads in quantum gravity theories and string models to $d = 10$ condition for the target space, spontaneous compactification, and eventually to the landscape catastrophe.

For a supersymmetric gauge theory (SYM) in d-dimensional Minkowski space the condition that the number of transversal polarization for gauge bosons given by $d-2$ equals to the number of fermionic states made of Majorana fermions gives $d - 2 = 2^k$, since the the number of fermionic spinor components is always power of 2.

This allows only $d = 3, 4, 6, 10, 16, ...$ Also the dimensions $d + 1$ are actually possible since the number of spinor components for d and $d + 1$ is same for d even. This is the standard argument leading to super-string models and M-theory. It it lost - or better to say, one gets rid of it - if the basic fields include only fermion fields and bosonic states are constructed as the tensor products of fermionic states. This is indeed the case in TGD, where spontaneous compactification plays no role and bosons are emergent.

(e) Spontaneous compactification leads in string model picture from $\mathcal{N} = 1$ SUSY in say $d = 10$ to $\mathcal{N} > 1$ SUSY in $d = 4$ since the fermionic multiplet reduces to a direct sum of fermionic multiplets in $d = 4$. In TGD imbedding space is not dynamical but fixed by internal consistency requirements, and also by the condition that the theory is consistent with the standard model symmetries. The identification of space-time as 4-surface makes the induced spinor field dynamical and the notion of many-sheeted space-time allows to circumvent the objections related to the fact that only 4 field like degrees of freedom are present.

The missing energy predicted standard SUSY is absent at LHC. The easy explanation would be that the mass scale of SUSY is unexpectedly high, of order 1 TeV. This would however destroy the original motivations for SUSY.

In TGD framework the natural first guess was hat the missing energy corresponds to covariantly constant right-handed neutrinos carrying four-momentum. The objection is that covariantly constant right-handed neutrinos cannot appear in asymptotic states because one cannot assign a super-multiplet to right-handed neutrinos consistently. Covariantly constant right-handed neutrinos can however generate SUSY.

This alone would explain the missing missing momentum at LHC predicted by standard SUSY. The assumption that fermions correspond to color partial waves in H implies that color excitations of the right handed neutrino that would appear in asymptotic states are necessarily colored. It could happen that these excitations are color neutralized by super-conformal generators. If this is not the case, these neutrinos would be like quarks and color confinement would explain why they cannot be observed as asymptotic states in macroscopic scales. So called lepto-hadrons could correspond to bound states of colored sleptons and have same p-adic mass scale as leptons have [K70]. Even in the case of quarks the situation could be the same.

Second possibility considered earlier is that SUSY itself is generated by color partial waves of right-handed neutrino, octet most naturally. This option is not however consistent with the above model for one-fermion states and their super-partners.

The breakthrough in the understanding of the preferred extremals of Kähler action and solutions of the modified Dirac equation led to a radical reconsideration of the existing picture. The most natural conclusion is that the TGD counterpart of standard SUSY is most naturally absent. The arguments in favor of this conclusion discussed in the last section are rather strong. The breakthrough in understanding of TGD counterpart for Higgs like particle - Euclidian M_{89} pion - led to a model for the generation of weak gauge bosons masses free of the problem of the standard Higgs mechanism caused by the fact that tachyonic mass term is not stable under radiative corrections. In TGD framework this kind of term is absent. Therefore also the basic motivation for standard SUSY as stabilizer of radiative corrections disappears. Standard space-toime SUSY would be replaced with 4-D generalization of 2-D super-conformal invariance but restricted to the modes of right-handed neutrino. For other fermion states the modes would be restricted to 2-D string world sheets and partonic 2-surfaces and super-conformal symmetry would reduce to 2-D one. The 2-D super-conformal symmetry is mathematically analogous to badly broken SUSY with very large value of $\mathcal{N}$ and massive neutrino would represent the least broken aspect of this symmetry. The masses of sparticles are expected to be higher than particles for this SUSY.

Part II

NEW PHYSICS PREDICTED BY TGD

Chapter 6

p-Adic Particle Massivation: Hadron Masses

6.1 Introduction

In this chapter the results of the calculation of elementary particle masses will be used to construct a model predicting hadron masses. The new elements are a revised identification for the p-adic length scales of quarks and the realization that number theoretical constraints on topological mixing can be realized by assuming that topological mixing leads to a thermodynamical equilibrium. This gives an upper bound of 1200 for the number of different U and D matrices and the input from top quark mass and $\pi^+ - \pi^0$ mass difference implies that physical U and D matrices can be constructed as small perturbations of matrices expressible as a direct sum of essentially unique 2×2 and 1×1 matrices.

The assumption about the presence of scaled up variants of light quarks in light hadrons leads to a surprisingly successful model for pseudo scalar meson masses in terms of only quark masses. This conforms with the idea that at least light pseudo scalar mesons are Goldstone bosons in the sense that color Coulombic and magnetic contributions to the mass cancel each other. Also the mass differences between baryons containing different numbers of strange quarks can be understood if s quark appears as three scaled up versions. The earlier model for the purely hadronic contributions to hadron masses simplifies dramatically and only the color Coulombic and magnetic contributions to color conformal weight are needed.

6.1.1 Construction of U and D matrices

The basic constraint on the topological mixing that the modular contributions to the conformal weight defining the mass squared remain integer valued in the proper units: if this condition does not hold true, the order of magnitude for the real counterpart of the p-adic mass squared corresponds to 10^{-4} Planck masses.

Number theory gives strong constraints on CKM matrix. p-Adicization requires that U and D matrix elements are algebraic numbers. A strong constraint would be that the mixing probabilities are rational numbers implying that matrices defined by the moduli of U and D involve only square roots of rationals. The phases of matrix elements should belong to a finite extension of complex rationals.

Little can be said about the details of the dynamics of topological mixing. Nothing however prevents for constructing a thermodynamical model for the mixing. A thermodynamical model for U and D matrices maximizing the entropy defined by the mixing probabilities subject to the constraints fixing the values of n_{q_i} and the sums of row/column probabilities to one gives a thermodynamical ensemble with two quantized temperatures and two quantized chemical potentials. The resulting polynomial equations allow at most 1200 different solutions so that the number of U and D matrices is relatively small. The fact that matrix elements are algebraic numbers guarantees that the matrices are continuable to p-adic number fields as required.

The detailed study of quark mass spectrum leads to a tentative identification $(n_d, n_s, n_b) = (5, 5, 59)$ and $(n_u, n_c, n_t) = (5, 6, 58)$ of the modular contributions of conformal weights of quarks: note that in absence of mixing the contributions would be $(0, 9, 60)$ for both U and D type quarks. That b and t quark masses are nearly maximal and thus mix very little with lighter quarks is forced by the masses of t quark and $t\bar{t}$ meson. The values of n_{q_i} for light quarks follow by considering $\pi^+ - \pi^0$ mass difference.

One might consider the possibility that n_{q_i} for slightly dynamical and can vary in light mesons in order to guarantee that $u\overline{u}$, $d\bar{d}$ and $s\overline{s}$ give identical modular contributions to the conformal weight in states which are linear combinations of quark pairs. It turns out that unitarity does not allow the choices $(n_1 = 4, n_2 < 9)$, and that the choice $(n_d, n_s) = (5, 5)$, $(n_u, n_c) = (5, 6)$ is the unique choice producing a realistic CKM matrix. The requirement that quark contribution to pseudo scalar meson mass is smaller than meson mass is possible to satisfy and gives a constraint on CP_2 mass scale consistent with the prediction of leptonic masses when second order p-adic contribution to lepton mass is allowed to be non-vanishing.

The small mixing with b and t quarks is natural since the modular conformal weight of unmixed state having spectrum $\{0, 9, 60\}$ is analogous to energy so that Boltzmann weight for $n(g = 3)$ thermal excitation is small for $g = 1, 2$ ground states.

The maximally entropic solutions can be found numerically by using the fact that only the probabilities p_{11} and p_{21} can be varied freely. The solutions are unique in the accuracy used, which suggests that the system allows only single thermodynamical phase.

The matrices U and D associated with the probability matrices can be deduced straightforwardly in the standard gauge. The U and D matrices derived from the probabilities determined by the entropy maximization turn out to be unitary for most values of n_1 and n_2. This is a highly non-trivial result and means that mass and probability constraints together with entropy maximization define a sub-manifold of $SU(3)$ regarded as a sub-manifold in 9-D complex space. The choice $(n_u, n_c) = (4, n)$, $n < 9$, does not allow unitary U whereas $(n_u, n_c) = (5, 6)$ does. This choice is still consistent with top quark mass and together with $n_d = n_s = 5$ it leads to a rather reasonable CKM matrix with a value of CP breaking invariant within experimental limits. The elements V_{i3} and V_{3i}, $i = 1, 2$ are however roughly twice larger than their experimental values deduced assuming standard model. V_{31} is too large by a factor 1.6. The possibility of scaled up variants of light quarks could lead to too small experimental estimates for these matrix elements. The whole parameter space has not been scanned so that better candidates for CKM matrices might well exist.

6.1.2 Observations crucial for the model of hadron masses

The evolution of the model for hadron masses involves several key observations made during the more decade that I have been working with p-adic mass calculations.

The p-adic mass scales of quarks are dynamical

The existence of scaled up variants of quarks is suggested by various anomalies such as Aleph anomaly [C178] and the strange bumpy structure of the distribution of the mass of the top quark candidate. This leads to the idea that the the integer $k(q)$ characterizing the p-adic mass scale of quark is different for free quarks and bound quarks and that $k(q)$ can depend on hadron. Hence one can understand not only the notions of current quark mass and constituent quark mass but reproduce also the p-adic counterpart of Gell-Mann-Okubo mass formula. Indeed, the assumption about scaled up variants of u, d, s, and even c quarks in light hadrons leads to an excellent fit of meson masses with quark contribution explaining almost all of meson mass.

Quarks give dominating contribution to the masses of pseudo-scalar mesons

The interpretation is that color Coulombic and color magnetic interaction conformal weights (rather than interaction energies) cancel each other in a approximation for pseudo-scalar mesons in accordance with the idea that pseudo scalar mesons are massless as far as color interactions are considered. In the case of baryons the assumption that s quark appears in three different scaled up versions (which are Λ, $\{\Sigma, \Xi\}$, and Ω) allows to understand the mass differences between baryons with different s quark content. The dominating contribution to baryon mass has however remained hitherto unidentified.

What it means that Higgs like contribution to fermion masses is negligible?

The failure of the simplest form of p-adic thermodynamics for intermediate gauge bosons led to the unsatisfactory conclusion that p-adic thermodynamics is not enough and the coupling to Higgs bosons contributes to the gauge boson masses. This option had its own problems.

(a) There are good, purely topological - reasons to believe that Higgs expectation for the fermionic space-time sheets is vanishing although fermions couple to Higgs. p-Adic thermodynamics would explain fermion masses completely: this indeed turns out to be the case within experimental uncertainties. The absence of Higgs contribution to fermion masses would however mean asymmetry between fermions and bosons unless also boson masses have some other origin.

(b) The recent view about elementary particles is as pairs of wormhole contacts connected by magnetic flux tubes carrying monopole flux. The modes of Kähler-Dirac equation are localized at 2-D surfaces: string world sheets and possibly also partonic 2-surfaces and flux tubes are accompanied by oneor more string world sheets. Therefore there is a strong temptation to assign an additional contribution to mass squared. The flux tube would give the dominating contribution to gauge boson masses and only a small contribution to fermion masses. One can even consider the possibility of Regge trajectories for gauge bosons.

The fact that the prediction of the model for the top quark mass is consistent with the most recent limits on it [C88], fixes the CP_2 mass scale with a high accuracy to the maximal one obtained if second order contribution to electron's p-adic mass squared vanishes. This is very valuable constraint on the model.

Mass squared is additive for quarks with same p-adic prime

An essential element of the new understanding is that mass squared (conformal weight) is additive for quarks with the same p-adic length scale whereas mass is additive for quarks with different values of p. For instance, the masses of heavy $q\overline{q}$ mesons are equal to $\sqrt{2}\times m(q)$ rather than $2m(q)$. Since $k = 107$ for hadronic space-time sheet, for quarks with $k(q) \neq 107$, additivity holds true for the quark and color contributions for mass rather than mass squared.

This hypothesis yields surprisingly good fit for meson masses but for some mesons the predicted mass is slightly too high. The reduction of CP_2 mass scale to cure the situation is not possible since top quark mass would become too low. In case of diagonal mesons for which quarks correspond to same p-adic prime, quark contribution to mass squared can be reduced by ordinary color interactions and in case of non-diagonal mesons one can require that quark contribution is not larger than meson mass.

A remark about terminology

Before continuing a remark about terminology is in order.

(a) In the generalized coset construction the symplectic algebra of $\delta M^4_\pm \times CP_2$ and Super-Kac Moody algebras at light-like partonic surfaces X^3 are lifted to hyper-complex algebras inside the causal diamond of $M^4 \times CP_2$ carrying the zero energy states. SKM is identified as a sub-algebra of SC and the differences of SC and SKM Super-Virasoro generators annihilate the physical states. All purely geometric contributions and their super-counterparts can be regarded as SC contributions. The fermionic contributions in electro-weak and spin degrees of freedom responsible also for color partial waves are trivially one and same. One could say that there is no other contribution than SC which can be however divided into a contribution from imbedded SKM subalgebra and a genuine SC contribution.

(b) In the coset construction a tachyonic ground state of negative SC conformal weight from which SKM generators create massless states must have a negative conformal weight also in SKM sense. Therefore the earlier idea that genuine SC generators create the ground states with a negative conformal weight assignable to elementary particles does not work anymore: the negative conformal weight must be due to SKM generators with conformal weight which is most naturally of form $h = -1/2 + iy$.

(c) Super-symplectic contribution with a positive conformal weight can be regarded also as a product of genuine SC contribution with a vanishing conformal weight and a contribution having also interpretation as SKM contribution. What motivates the term "super-symplectic bosons" used in the sequel is that in a non-perturbative situation this contribution is most naturally calculated by regarding it as a super-symplectic contribution. This contribution is highly constrained since it comes solely from generators which are color octets and singlets have spin one or spin zero. Genuine SC contribution with a zero conformal weight comes from the products of super-Hamiltonians in higher representations of $SU(3) \times SO(3)$ containing both positive and negative conformal weights compensating each other. This contribution must have vanishing color quantum numbers and spin since otherwise Dirac operators of H in SKM and SC degrees of freedom could not act on it in the same manner. Note that gluons do not correspond to SKM generators but to pairs of quark and antiquark at throats of a wormhole contact.

Super-symplectic bosons at hadronic space-time sheet can explain the constant contribution to baryonic masses

Quarks explain only a small fraction of the baryon mass and that there is an additional contribution which in a good approximation does not depend on baryon. This contribution should correspond to the non-perturbative aspects of QCD.

A possible identification of this contribution is in terms of super-symplectic gluons predicted by TGD. Baryonic space-time sheet with $k = 107$ would contain a many-particle state of super-symplectic gluons with net conformal weight of 16 units. This leads to a model of baryons masses in which masses are predicted with an accuracy better than 1 per cent. super-symplectic gluons also provide a possible solution to the spin puzzle of proton.

Hadronic string model provides a phenomenological description of non-perturbative aspects of QCD and a connection with the hadronic string model indeed emerges. Hadronic string tension is predicted correctly from the additivity of mass squared for $J = 2$ bound states of super-symplectic quanta. If the topological mixing for super-symplectic bosons is equal to that for U type quarks then a 3-particle state formed by 2 super-symplectic quanta from the first generation and 1 quantum from the second generation would define baryonic ground state with 16 units of conformal weight.

In the case of mesons pion could contain super-symplectic boson of first generation preventing the large negative contribution of the color magnetic spin-spin interaction to make pion a tachyon. For heavier bosons super-symplectic boson is not absolutely necessary but a very precise prediction for hadron masses results by assuming that the spin of hadron correlates with its super-symplectic particle content.

Color magnetic spin-spin splitting formulated in terms of conformal weight

What remains to be understood are the contributions of color Coulombic and magnetic interactions to the mass squared. There are several delicate points to be taken into account.

(a) The QCD based formula for the color magnetic interaction energy fails completely since the dependence of color magnetic spin-spin splittings on quark mass scale is nearer to logarithmic dependence on p-adic length scale than being of form $1/m(q_i)m(q_j) \propto L(k_i)L(k_j)$. This finding supports the decade old idea that the proper notion is not color interaction energy but color conformal weight. A model based on this assumption is constructed assuming that all pseudo-scalars are Goldstone boson like states. The predictions for the masses of mesons are not so good than for baryons, and one might criticize the application of the format of perturbative QCD in an essentially non-perturbative situation.

(b) The comparison of the super-symplectic conformal weights associated with spin 0 and spin 1 states and spin 1/2 and spin 3/2 states shows that the different masses of these states could be understood in terms of the super-symplectic particle contents of the state correlating with the total quark spin. The resulting model allows excellent predictions also for the meson masses and implies that only pion and kaon can be regarded as Goldstone boson like states. The model based on spin-spin splittings is consistent with the model.

To sum up, the model provides an excellent understanding of baryon and meson masses. This success is highly non-trivial since the fit involves only the integers characterizing the p-adic length scales of quarks and the integers characterizing color magnetic spin-spin splitting plus p-adic thermodynamics and topological mixing for super-symplectic gluons. The next challenge would be to predict the correlation of hadron spin with super-symplectic particle content in the case of long-lived hadrons.

6.1.3 A possible model for hadron

These findings suggest that the following model for hadrons deserves a testing. Hadron can be characterized in terms of $k \geq 113$ partonic 2-surfaces $X^2(q_i)$ connected by join along boundaries bonds (JABs, flux tubes) to $k = 107$ 2-surface $X^2(H)$ corresponding to hadron. These flux tubes which for $k = 113$ have size much larger than hadron can be regarded as "field bodies" of quarks which themselves have sub-hadronic size. Color flux tubes between quarks are replaced with pairs of flux tubes from $X^2(q_1)) \rightarrow X^2(H) \rightarrow X^2(q_2)$ mediating color Coulombic and magnetic interactions between quarks. In contrast to the standard model, mesons are characterized by two flux tubes rather than only one flux tube. Certainly this model gives nice predictions for hadron masses and even the large color Coulomb contribution to baryon masses can be deduced from $\rho - \pi$ mass splitting in a good approximation.

The appendix of the book gives a summary about basic concepts of TGD with illustrations. There are concept maps about topics related to the contents of the chapter prepared using CMAP realized as html files. Links to all CMAP files can be found at `http://www.tgdtheory.fi/cmaphtml.html` [L20]. Pdf representation of same files serving as a kind of glossary can be found at `http://www.tgdtheory.fi/tgdglossary.pdf` [L21]. The topics relevant to this chapter are given by the following list.

- p-Adic physics [L38]
- p-Adice length scale hypothesis [L39]
- TGD view about elementary particles [L49]
- p-Adic mass calculations [L37]
- Higgs in TGD [L28]
- Leptohadron hypothesis [L32]
- M89 hadron physics [L33]

6.2 Quark masses

The prediction or quark masses is more difficult due the facts that the deduction of even the p-adic length scale determining the masses of these quarks is a non-trivial task, and the original identification was indeed wrong. Second difficulty is related to the topological mixing of quarks. The new scenario leads to a unique identification of masses with top quark mass as an empirical input and the thermodynamical model of topological mixing as a new theoretical input. Also CKM matrix is predicted highly uniquely.

6.2.1 Basic mass formulas

By the earlier mass calculations and construction of CKM matrix the ground state conformal weights of U and D type quarks must be $h_{gr}(U) = -1$ and $h_{gr}(D) = 0$. The formulas for the eigenvalues of CP_2 spinor Laplacian imply that if m_0^2 is used as a unit, color conformal weight $h_c \equiv m_{CP_2}^2$ is integer for $p\ mod\ = \pm 1$ for U type quark belonging to $(p+1, p)$ type representation and obeying $h_c(U) = (p^2 + 3p + 2)/3$ and for $p\ mod\ 3 = 1$ for D type quark belonging $(p, p+2)$ type representation and obeying $h_c(D) = (p^2 + 4p + 4)/3$. Only these states can be massless since color Hamiltonians have integer valued conformal weights.

In the recent case the minimal $p = 1$ states correspond to $h_c(U) = 2$ and $h_c(D) = 3$. $h_{gr}(U) = -1$ and $h_{gr}(D) = 0$ reproduce the previous results for quark masses required by the construction of CKM matrix. This requires super-symplectic operators O with a net conformal weight $h_{sc} = -3$ to compensate the anomalous color just as in the leptonic case. The facts that the values of p are minimal for spinor harmonics and the super-symplectic operator is same for both quarks and leptons suggest that the construction is not had hoc.

Consider now the mass squared values for quarks. For $h(D) = 0$ and $h(U) = -1$ and using $m_0^2/3$ as a unit the expression for the thermal contribution to the mass squared of quark is given by the formula

$$\begin{aligned} M^2 &= (s+X)\frac{m_0^2}{p} \ , \\ s(U) &= 5 \ , \ s(D) = 8 \ , \\ X &\equiv \frac{(3Yp)_R}{3} \ , \end{aligned} \tag{6.2.1}$$

where the second order contribution Y corresponds to renormalization effects coming and depending on the isospin of the quark.

With the above described assumptions one has the following mass formula for quarks

$$\begin{aligned} &M^2(q) = A(q)\tfrac{m_0^2}{p(q)} \ , \\ &A(u) = 5 + X_U(p(u) \ , \quad A(c) = 14 + X_U(p(c)) \ , \quad A(t) = 65 + X_U(p(t)) \ , \\ &A(d) = 8 + X_D(p(d)) \ , \quad A(s) = 17 + X_D(p(s)) \ , \quad A(b) = 68 + X_D(p(b)) \ . \end{aligned} \tag{6.2.2}$$

p-Adic length scale hypothesis allows to identify the p-adic primes labeling quarks whereas topological mixing of U and D quarks allows to deduce topological mixing matrices U and D and CKM matrix V and precise values of the masses apart from effects like color magnetic spin orbit splitting, color Coulomb energy, etc..

Integers n_{q_i} satisfying $\sum_i n(U_i) = \sum_i n(D_i) = 69$ characterize the masses of the quarks and also the topological mixing to high degree. The reason that modular contributions remain integers is that in the p-adic context non-trivial rationals would give CP_2 mass scale for the real counterpart of the mass squared. In the absence of mixing the values of integers are $n_d = n_u = 0$, $n_s = n_c = 9$, $n_b = n_t = 60$.

The fact that CKM matrix V expressible as a product $V = U^\dagger D$ of topological mixing matrices is near to a direct sum of 2×2 unit matrix and 1×1 unit matrix motivates the approximation $n_b \simeq n_t$.

The model for topological mixing matrices and CKM matrix predicts U and D matrices highly uniquely and allows to understand quark and hadron masses in surprisingly detailed level.

The large masses of top quark and of $t\bar{t}$ meson encourage to consider a scenario in which $n_t = n_b = n \leq 60$ holds true.

(a) $n_d = n_u = 60$ is not allowed by number theoretical conditions for U and D matrices and by the basic facts about CKM matrix but $n_t = n_b = 59$ allows almost maximal masses for b and t. This is not yet a complete hit. The unitarity of the mixing matrices and the construction of CKM matrix to be discussed in the next section forces the assignments

$$(n_d, n_s, n_b) = (5, 5, 59) \ , \quad (n_u, n_c, n_t) = (5, 6, 58) \ . \tag{6.2.3}$$

fixing completely the quark masses apart from a possible few per cent renormalization effects of hadronic mass scale in topological condensation which seem to be present and will be discussed later [1]. Note that top quark mass is still rather near to its maximal value.

(b) The constraint that quark contribution to pion mass does not exceed pion mass implies the constraint $n(d) \leq 6$ and $n(u) \leq 6$ in accordance with the predictions of the model of topological mixing. It is important to notices that $u - d$ mass difference does not affect $\pi^+ - \pi^0$ mass difference and the quark contribution to $m(\pi)$ is predicted to be $\sqrt{(n_d + n_u + 13)/24} \times 136.9$ MeV for the maximal value of CP_2 mass (second order p-adic contribution to electron mass squared vanishes).

6.2.2 The p-adic length scales associated with quarks and quark masses

The identification of p-adic length scales associated with the quarks has turned to be a highly non-trivial problem. The reasons are that for light quarks it is difficult to deduce information about quark masses for hadron masses and that the unknown details of the topological mixing (unknown until the advent of the thermodynamical model) made possible several p-adic length scales for quarks. It has also become clear that the p-adic length scale can be different form free quark and bound quark and that bound quark p-adic scale can depend on hadron.

Two natural constraints have however emerged from the recent work.

(a) Quark contribution to the hadron mass cannot be larger than color contribution and for quarks having $k_q \neq 107$ quark contribution to mass is added to color contribution to the mass. For quarks with same value of k conformal weight rather than mass is additive whereas for quarks with different value of k masses are additive. An important implication is that for diagonal mesons $M = q\bar{q}$ having $k(q) \neq 107$ the condition $m(M) \geq \sqrt{2} m_q$ must hold true. This gives strong constraints on quark masses.

(b) The realization that scaled up variants of quarks explain elegantly the masses of light hadrons allows to understand large mass splittings of light hadrons without the introduction of strong isospin-isospin interaction.

The new model for quark masses is based on the following identifications of the p-adic length scales.

[1] As this was written I had not realized that there is also a Higgs contribution which tends to increase top quark mass

(a) The nuclear p-adic length scale $L_e(k)$, $k = 113$, corresponds to the p-adic length scale determining the masses of u, d, and s quarks. Note that $k = 113$ corresponds to a so called Gaussian Mersenne. The interpretation is that quark massivation occurs at nuclear space-time sheet at which quarks feed their em fluxes. At $k = 107$ space-time sheet, where quarks feed their color gauge fluxes, the quark masses are vanishing in the first p-adic order. This could be due to the fact that the p-adic temperature is $T_p = 1/2$ at this space-time sheet so that the thermal contribution to the mass squared is negligible. This would reflect the fact that color interactions do not involve any counterpart of Higgs mechanism.

p-Adic mass calculations turn out to work remarkably well for massive quarks. The reason could be that M_{107} hadron physics means that *all* quarks feed their color gauge fluxes to $k = 107$ space-time sheets so that color contribution to the masses becomes negligible for heavy quarks as compared to Super-Kac Moody and modular contributions corresponding to em gauge flux feeded to $k > 107$ space-time sheets in case of heavy quarks. Note that Z^0 gauge flux is feeded to space-time sheets at which neutrinos reside and screen the flux and their size corresponds to the neutrino mass scale. This picture might throw some light to the question of whether and how it might be possible to demonstrate the existence of M_{89} hadron physics.

One might argue that $k = 107$ is not allowed as a condensation level in accordance with the idea that color and electro-weak gauge fluxes cannot be feeded at the space-time space time sheet since the classical color and electro-weak fields are functionally independent. The identification of η' meson as a bound state of scaled up $k = 107$ quarks is not however consistent with this idea unless one assumes that $k = 107$ space-time sheets in question are separate.

(b) The requirement that the masses of diagonal pseudo-scalar mesons of type $M = q\bar{q}$ are larger but as near as possible to the quark contribution $\sqrt{2}m_q$ to the valence quark mass, fixes the p-adic primes $p \simeq 2^k$ associated with c, b quarks but not t since toponium does not exist. These values of k are "nominal" since k seems to be dynamical. c quark corresponds to the p-adic length scale $k(c) = 104 = 2^3 \times 13$. b quark corresponds to $k(b) = 103$ for $n(b) = 5$. Direct determination of p-adic scale from top quark mass gives $k(t) = 94 = 2 \times 47$ so that secondary p-adic length scale is in question.

(c) Top quark is experimentally in a unique position since toponium does not exist and top quark mass is that of free top. The prediction for top quark mass (see Table 1 below) is 167.8 GeV for $Y_t = Y_e = 0$ (second order contributions to mass vanish) and 169.1 GeV for $Y_t = 1$ and $Y_e = 0$ (maximal possible mass for top). The experimental estimate for m_t remained for a long time somewhat higher than the prediction but the estimates have gradually reduced. The previous experimental average value was $m(t) = 169.1$ GeV with the allowed range being [164.7, 175.5] GeV [C21, C88] . The fine tuning $Y_e = 0, Y_t = 1$ giving 169.1 GeV is somewhat un-natural. The most recent value obtained by CDF and discussed in detail by Tommaso Dorigo [C89] is $m_t = 165.1 \pm 3.3 \pm 3.1$ GeV. This is value is consistent with the lower bound predicted by TGD for $Y_e = Y_t = 0$ and increase of Y_t increases the value of the predicted mass. Clearly, TGD passes the stringent test posed by top quark.

(d) There are good reasons to believe that the p-adic mass scale of quark is different for free quark and bound state quark and that in case of bound quark it can also depend on hadron. This would explain the notions of valence (constituent) quark and current quark mass as masses of bound state quark and free quark and leads also to a TGD counterpart of Gell-Mann-Okubo mass formula.

1. Constituent quark masses

Constituent quark masses correspond to masses derived assuming that they are bound to hadrons. If the value of k is assumed to depend on hadron one obtains nice mass formula for light hadrons as will be found later. The following table summarizes constituent quark masses labelled by k_q deduced from the masses of diagonal mesons.

q	d	u	s	c	b	t
n_q	4	5	6	6	59	58
s_q	12	10	14	11	67	63
$k(q)$	113	113	113	104	103	94
$m(q)/GeV$	.105	.0923	.105	2.191	7.647	167.8

Table 1. Constituent quark masses predicted for diagonal mesons assuming $(n_d, n_s, n_b) = (5, 5, 59)$ and $(n_u, n_c, n_t) = (5, 6, 58)$, maximal CP_2 mass scale($Y_e = 0$), and vanishing of second order contributions.

2. Current quark masses

Current quark masses would correspond to masses of free quarks which tend to be lower than valence quark masses. Hence k could be larger in the case of light quarks. The table of quark masses in Wikipedia [C21] gives the value ranges for current quark masses depicted in the table below together with TGD predictions for the spectrum of current quark masses.

q	d	u	s
$m(q)_{exp}/MeV$	4-8	1.5-4	80-130
$k(q)$	(122,121,120)	(125,124,123,122)	(114,113,112)
$m(q)/MeV$	(4.5,6.6,9.3)	(1.4,2.0,2.9,4.1)	(74,105,149)
q	c	b	t
$m(q)_{exp}/MeV$	1150-1350	4100-4400	1691
$k(q)$	(106,105)	(105,104)	92
$m(q)/MeV$	(1045,1477)	(3823,5407)	167.8

Table 2. The experimental value ranges for current quark masses [C21] and TGD predictions for their values assuming $(n_d, n_s, n_b) = (5, 5, 59)$, $(n_u, n_c, n_t) = (5, 6, 58)$, $Y_e = 0$, and vanishing of second order contributions.

Some comments are in order.

(a) The long p-adic length associated with light quarks seem to be in conflict with the idea that quarks have sizes smaller than hadron size. The paradox disappears when one realized that $k(q)$ characterizes the electromagnetic "field body" of quark having much larger size than hadron.

(b) u and d current quarks correspond to a mass scale not much higher than that of electron and the ranges for mass estimates suggest that u could correspond to scales $k(u) \in (125, 124, 123, 122) = (5^3, 4 \times 31, 3 \times 41, 2 \times 61)$, whereas d would correspond to $k(d) \in (122, 121, 120) = (2 \times 61, 11^2, 3 \times 5 \times 8)$.

(c) The TGD based model for nuclei based on the notion of nuclear string leads to the conclusion that exotic copies of $k = 113$ quarks having $k = 127$ are present in nuclei and are responsible for the color binding of nuclei [K63, L3] , [L3] .

(d) The predicted values for c and b masses are slightly too low for $(k(c), k(b)) = (106, 105) = (2 \times 53, 3 \times 5 \times 7)$. Second order Higgs contribution could increase the c mass into the range given in [C21] but not that of b.

One can talk about constituent and current quark masses simultaneously only if they correspond to dual descriptions. $M^8 - H$ duality [K34] has been indeed suggested to relate the old fashioned low energy description of hadrons in terms of $SO(4)$ symmetry (Skyrme model) and higher energy description of hadrons based on QCD. In QCD description the mass of say baryon would be dominated by the mass associated with super-symplectic quanta carrying color. In $SO(4)$ description constituent quarks would carry most of the hadron mass.

6.2.3 Are scaled up variants of quarks also there?

The following arguments suggest that p-adically scaled up variants of quarks might appear not only at very high energies but even in low energy hadron physics.

Aleph anomaly and scaled up copy of b quark

The prediction for the b quark mass is consistent with the explanation of the Aleph anomaly [C178] inspired by the finding that neutrinos seem to condense at several p-adic length scales [C84]. If b quark condenses at $k(b) = 97$ level, the predicted mass is $m(b, 97) = 52.3$ GeV for $n_b = 59$ for the maximal CP_2 mass consistent with η' mass. If the the mass of the particle candidate is defined experimentally as one half of the mass of resonance, b quark mass is actually by a factor $\sqrt{2}$ higher and scaled up b corresponds to $k(b) = 96 = 2^5 \times 3$. The prediction is consistent with the estimate 55 GeV for the mass of the Aleph particle and gives additional support for the model of topological mixing. Also the decay characteristics of Aleph particle are consistent with the interpretation as a scaled up b quark.

Scaled variants of top quark

Tony Smith has emphasized the fact that the distribution for the mass of the top quark candidate has a clear structure suggesting the existence of several states, which he interprets as excited states of top quark [C167]. According to the figures 6.2.3 and 6.2.3 representing published FermiLab data, this structure is indeed clearly visible.

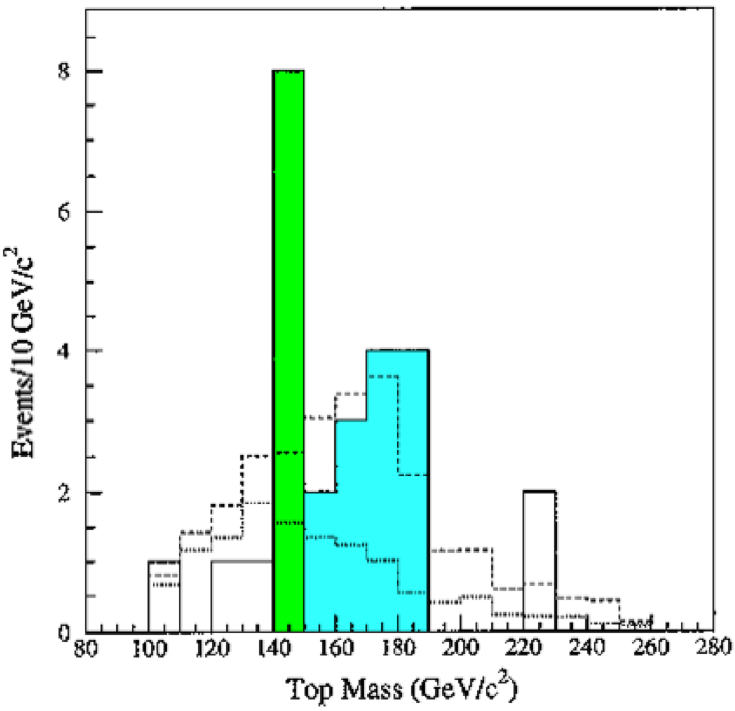

Figure 6.1: Fermilab semileptonic histogram for the distribution of the mass of top quark candidate (FERMILAB-PUB-94/097-E).

There is evidence for a sharp peak in the mass distribution of the top quark in 140-150 GeV range (Fig. 6.2.3). There is also a peak slightly below 120 GeV, which could correspond to a p-adically scaled down variant t quark with $k = 95$ having mass 119.6 GeV for $(Y_e = 0, Y_t = 1)$

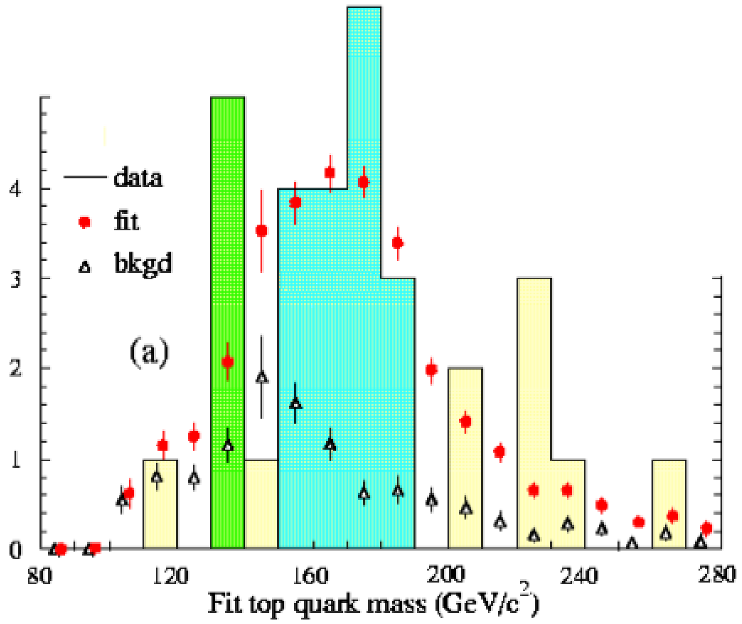

Figure 6.2: Fermilab D0 semileptonic histogram for the distribution of the mass of top quark candidate (hep-ex/9703008, April 26, 1994

There is also a small peak also around 265 GeV which could relate to $m(t(93)) = 240.4$ GeV. There top could appear at least for the p-adic scales $k = 93, 94, 95$ as also u and d quarks seem to appear as current quarks.

Scaled up variants of d, s, u, c in top quark mass scale

The fact that all neutrinos seem to appear as scaled up versions in several scales, encourages to look whether also u, d, s, and c could appear as scaled up variants transforming to the more stable variants by a stepwise increase of the size scale involving the emission of electro-weak gauge bosons. In the following the scenario in which t and b quarks mix minimally is considered.

q	$m(92)/GeV$	$m(91)/GeV$	$m(90)/GeV$
u	134	189	267
d	152	216	304
c	140	198	280
s	152	216	304

Table 3. The masses of $k = 92, 91$ and $k = 90$ scaled up variants of u,d,c,s quarks assuming same integers n_{q_i} as for ordinary quarks in the scenario $(n_d, n_s, n_b) = (5, 5, 59)$ and $(n_u, n_c, n_t) = (5, 6, 58)$ and maximal CP_2 mass consistent with the η' mass.

(a) For $k = 92$, the masses would be $m(q, 92)$ =134,140,152,152 GeV in the order q= u,c,d,s so that all these quarks might appear in the critical region where the top quark mass has been wandering.

(b) For $k = 91$ copies would have masses $m(q, 91)$ =189, 198, 256, 256 GeV in the order q= u,c,d,s. The masses of u and c are somewhat above the value of latest estimate 170

GeV for top quark mass [C88] .

Note that it is possible to distinguish between scaled up quarks of M_{107} hadron physics and the quarks of M_{89} hadron physics since the unique signature of M_{89} hadron physics would be the increase of the scale of color Coulombic and magnetic energies by a factor of 512. As will be found, this allows to estimate the masses of corresponding mesons and baryons by a direct scaling. For instance, M_{89} pion and nucleon would have masses 71.7 GeV and 481 GeV.

It must be added that the detailed identifications are sensitive to the exact value of the CP_2 mass scale. The possibility of at most 2.5 per cent downward scaling of masses occurs is allowed by the recent value range for top quark mass.

Fractally scaled up copies of light quarks and low mass hadrons?

One can of course ask, whether the fractally scaled up quarks could appear also in low lying hadrons. The arguments to be developed in detail later suggest that u, d, and s quark masses could be dynamical in the sense that several fractally scaled up copies can appear in low mass hadrons and explain the mass differences between hadrons.

In this picture the mass splittings of low lying hadrons with different flavors would result from fractally scaled up excitations of s and also u and d quarks in case of mesons. This notion would also throw light into the paradoxical presence of two kinds of quark masses: constituent quark masses and current quark masses having much smaller values than constituent quarks masses. That color spin-spin splittings are of same order of magnitude for all mesons supports the view that color gauge fluxes are feeded to $k = 107$ space-time sheet.

The alert reader has probably already asked whether also proton mass could be understood in terms of scaled up copies of u and d quarks. This does not seem to be the case, and an argument predicting with 23 per cent error proton mass scale from $\rho - \pi$ and $\Delta - N$ color magnetic splittings emerges.

To sum up, it seems quite possible that the scaled up quarks predicted by TGD have been observed for decade ago in FermiLab about that the prevailing dogmas has led to their neglect as statistical fluctuations. Even more, scaled up variants of s quarks might have been in front of our eyes for half century! Phenomenon is an existing phenomenon only if it is an understood phenomenon.

The mystery of two Ω_b baryons

Tommaso Dorigo has three interesting postings [C90] about the discovery of Ω_b baryon containing two strange quarks and one bottom quark. Ω_b has been discovered -even twice. This is not a problem. The problem is that the masses of these Ω_bs differ quite too much. D0 collaboration discovered Ω_b with a significance of 5.4 sigma and a mass of 6165 ± 16.4 MeV [C68] . Later CDF collaboration announced the discovery of the same particle with a significance of 5.5 sigma and a mass of 6054.4 ± 6.9 MeV. Both D0 and CDF agree that the particle is there at better than 5 sigma significance and also that the other collaboration is wrong. They cant both be right Or could they? In some other Universe that that of standard model and all its standard generalizations, maybe in some less theoretically respected Universe, say TGD Universe?

The mass difference between the two Ω_b candidates is 111 MeV, which represents the mass scale of strange quark. TDG inspired model for quark masses relies on p-adic thermodynamics and predicts that quarks can appear in several p-adic mass scales forming a hierarchy of half octaves - in other words mass scales comes as powers of square root of two. This property is absolutely essential for the TGD based model for masses of even low lying baryons and mesons where strange quarks indeed appear with several different p-adic mass scales. It also explains the large difference of the mass scales assigned to current quarks and constituent quarks. Light variants of quarks appear also in nuclear string model where nucleons are connected by color bonds containing light quark and antiquark at their ends.

Ω_b contains two strange quarks and the mass difference between the two candidates is of order of mass of strange quark. Could it be that both Ω_b s are real and the discrepancy provides additional support for p-adic length scale hypothesis? The prediction of p-adic mass calculations for the mass of s quark is 105 MeV (see Table 1) so that the mass difference can be understood if the second s-quark in Ω_b has mass which is twice the "standard" value. Therefore the strange finding about Ω_b could give additional support for quantum TGD. Before buying a bottle of champaigne, one should however understand why D0 and CDF collaborations only one Ω_b instead of both of them.

6.3 Topological mixing of quarks

The requirement that hadronic mass spectrum is physical requires mixing of U and D type boundary topologies. In this section quark masses and the mixing of the boundary topologies are considered on the general level and CKM matrix is derived using the existing empirical information plus the constraints on the quark masses to be derived from the hadronic mass spectrum in the later sections.

6.3.1 Mixing of the boundary topologies

In TGD the different mixings of the boundary topologies for U and D type quarks provide the fundamental mechanism for CKM mixing and also CP breaking. In the determination of CKM matrix one can use following conditions.

(a) Mass squared expectation values in order $O(p)$ for the topologically mixed states must be integers and the study of the hadron mass spectrum leads to very stringent conditions on the values of these integers. Physical values for these integers imply essentially correct value for Cabibbo angle provided U and D matrices differ only slightly from the mixing matrices mixing only the two lowest generations.

(b) The matrices U and D describing the mixing of U and D type boundary topologies are unitary in the p-adic sense. The requirement that the moduli squared of the matrix elements are rational numbers, is very attractive since it suggests equivalence of p-adic and real probability concepts and therefore could solve some conceptual problems related to the transition from the p-adic to real regime. It must be however immediately added that rationality assumption for the probabilities defined by S-matrix turns out to be non-physical. It turns out that the mixing scenario reproducing a physical CKM matrix is consistent with the rationality of the moduli squared of the matrix elements of U and D matrices but not with the rationality of the matrix elements themselves. The phase angles appearing in U and D matrix can be rational and in this case they correspond to Pythagorean triangles. In principle the rationality of the CKM matrix is possible.

(c) The requirements that Cabibbo angle has correct value and that the elements $V(t,d)$ and $V(u,b)$ of the CKM matrix have small values not larger than 10^{-2} fixes the integers n_i characterizing quark masses to a very high degree and in a good approximation one can estimate the angle parameters analytically. remains open at this stage. The requirement of a realistic CKM matrix leads to a scenario for the values of n_i, which seems to be essentially unique.

The mass squared constraints give for the D matrix the following conditions

$$
\begin{aligned}
9|D_{12}|^2 + 60|D_{13}|^2 &= n_1(D) \equiv n_d \ , \\
9|D_{22}|^2 + 60|D_{23}|^2 &= n_2(D) \equiv n_s \ , \\
9|D_{32}|^2 + 60|D_{33}|^2 &= n_3(D) \equiv n_b = 69 - n_2(D) - n_1(D) \ .
\end{aligned}
\tag{6.3.1}
$$

The third condition is not independent since the sum of the conditions is identically true by unitarity.

For U matrix one has similar conditions:

$$\begin{aligned} 9|U_{12}|^2+60|U_{13}|^2 &= n_1(U)\equiv n_u \ , \\ 9|U_{22}|^2+60|U_{23}|^2 &= n_2(U)\equiv n_c \ , \\ 9|U_{32}|^2+60|U_{33}|^2 &= n_3(U)\equiv n_t = 69-n_2(U)-n_1(U) \ . \end{aligned} \tag{6.3.2}$$

The integers n_d, n_s and n_u, n_c characterize the masses of the physical quarks and the task is to derive the values of these integers by studying the spectrum of the hadronic masses. The second task is to find unitary mixing matrices satisfying these conditions.

The general form of U and D matrices can be deduced from the standard parameterization of the CKM matrix given by

$$V=\left[\begin{array}{ccc} c_1 & s_1c_3 & s_1s_3 \\ -s_1c_2 & c_1c_2c_3-s_2s_3exp(i\delta_{CP}) & c_1c_2s_3+s_2c_3exp(i\delta_{CP}) \\ -s_1s_2 & c_1s_2c_3+c_2s_3exp(i\delta_{CP}) & c_1s_2s_3-c_2c_3exp(i\delta_{CP}) \end{array}\right] \tag{6.3.3}$$

This form of the CKM matrix is always possible to achieve by multiplying each U and D type quark fields with a suitable phase factor: this induces a multiplication U and D from left by a diagonal phase factor matrix inducing the multiplication of the columns of U and D by phase factors:

$$\begin{aligned} & U\rightarrow U\times d(\phi_1,\phi_2,\phi_3) \ , \\ & D\rightarrow D\times d(\chi_1,\chi_2,\chi_3) \ , \\ & d(\phi_1,\phi_2,\phi_3)\equiv diag(exp(i\phi_1),exp(i\phi_2),exp(i\phi_3)) \ . \end{aligned}$$

The multiplication of the columns by the phase factors affects CKM matrix defined as

$$V \ = \ U^{\dagger}D\rightarrow d(-\phi_1,-\phi_2,-\phi_3)Vd(\chi_1,\chi_2),\chi_3) \ . \tag{6.3.4}$$

By a suitable choice of the phases, the first row and column of V can be made real. The multiplication of the rows of U and D from the left by the same phase factors does not affect the elements of V. One can always choose D to be of the same general form as the CKM matrix but must allow U to have nontrivial phase overall factors on the second and third row so that the most general U matrix is parameterized by six parameters.

Mass squared conditions give two independent conditions on the values of the moduli of the matrix elements of U and D. This eliminates two coordinates so that the most general D matrix can be chosen to depend on 2 parameters, which can be taken to be $r_{11}\equiv|D_{11}|$ and $r_{21}\equiv|D_{21}|$. U matrix contains also the overall phase angles associated with the second and third row and hence depends on four parameters altogether.

6.3.2 The constraints on U and D matrices from quark masses

The new view about quark masses allows a surprisingly simple model for U and D matrices predicting in the lowest order approximation that the probabilities defined by these matrices are identical and that the integers characterizing the masses of U and D type quarks are identical.

The constraints on $|U|$ and $|D|$ matrices from quark masses

The understanding of quark masses pose strong constraints on U and D matrices. The constraints are identical in the approximation that V-matrix is identity matrix and read in the case of D-matrix as

$$\begin{aligned} n_d &= 13 = P_{12}^D \times 9 + P_{13}^D \times 60 \ , \\ n_s &= 31 = P_{22}^D \times 9 + P_{23}^D \times 60 \ . \end{aligned} \tag{6.3.5}$$

The conditions for b quark give nothing new. The extreme cases when only $g = 1$ or $g = 2$ contributes to n_q gives the bounds

$$\begin{aligned} \frac{15}{36} &\leq P_{13}^D \leq \frac{15}{60}, \\ \frac{22}{60} &\leq P_{23}^D \leq \frac{31}{60} \ . \end{aligned} \tag{6.3.6}$$

Unitarity conditions

The condition $D = VU$ and the fact that V is in not too far from unit matrix being in a good approximation a direct sum of 2×2 matrix and 1×1 identity matrix, imply together that U an D cannot differ much from each other. At least the probabilities defined by the moduli squared of matrix elements are near to each other.

(a) Instead of trying numerically to solve U and D matrices by a direct numerical search, it is more appropriate to try to deduce estimates for the probabilities $P_{ij}^U = |U_{ij}|^2$ and $P_{ij}^D = |D_{ij}|^2$ determined by the moduli squared of the matrix elements and satisfying the unitarity conditions $\sum_j P_{ij}^X = 1$ and $\sum_i P_{ij}^X = 1$.

(b) The formula $D = UV$ using the fact that V_{i3} is small for $i = 1, 2$ implies $|D_{i3}| \simeq |U_{i3}|$. By probability conservation also the condition $|D_{33}| \simeq |U_{33}|$ must hold true so that the third columns of U and D are same in a reasonable approximation.

1. Parametrization of $|U|$ and $|D|$ matrices

The following parameterization is natural for the matrices P_{ij}^X.

$$\begin{aligned} P_{12}^D &= \tfrac{k_D}{9} \ , & P_{13}^D &= \tfrac{n_d - k_D}{9} \ , \\ P_{22}^D &= \tfrac{l_D}{9} \ , & P_{23}^D &= \tfrac{n_s - l_D}{60} \ , \\ P_{32}^D &= \tfrac{9 - k_D - l_D}{9} \ , & P_{33}^D &= \tfrac{60 - n_s - n_d - k_D - l_D}{60} \ . \end{aligned} \tag{6.3.7}$$

A similar parameterization holds true for P_{ij}^U but with $n_d = n_u$ and $n_s = n_c$ but possibly different values of k_U and l_U. Since $l_D \ll n_s$ is expected to hold true, P_{23}^D is in a good approximation equal to $P_{23}^D = n_s/60 = 31/60$. Same applies to P_{23}^U.

$k_X = 2$ (k_X need not be an integer) gives a good first estimate for mixing probabilities of u and d quark. Thus only the parameter l_X remains free if $k_D = 2$ is accepted.

The approximation $P_{i3}^U = P_{i3}^D$ motivated by the near unit matrix property of V, gives the parameterization

$$P_{12}^D = P_{12}^U = \frac{k}{9} \ , \ P_{13}^D = P_{13}^U \frac{n_d - k}{60} \ . \tag{6.3.8}$$

2. Constraints from CKM matrix in $|U| = |D|$ approximation

The condition $D_{12} = (UV)_{12}$ when feeded to the condition

$$P_{12}^U = P_{12}^D \tag{6.3.9}$$

using the approximation $k_D = k_U = k$ $l_D = l_U = l$ gives

$$|U_{i2}|^2 - |U_{i1}V_{12} + U_{i2}V_{22} + U_{i3}V_{32}|^2 = 0 \ . \tag{6.3.10}$$

$i = 1, 2, 3$ In the approximation that the small V_{32} term does not contribute, this gives

$$|U_{i1}V_{12} + U_{i2}V_{22})|^2 = |U_{i2}|^2 \ . \tag{6.3.11}$$

By dividing with $|U_{i1}|^2|V_{22}|^2$ and using the approximation $|V_{22}|^2 = 1$ this gives

$$\begin{aligned} v_i^2 &+ 2u_i v_i \times cos(\Psi_i) = 0 \ , \\ \Psi_i &= arg(V_{i2}) - arg(V_{32}) + arg(U_{i1}) - arg(U_{i2}) \ . \\ u_i &= |\frac{U_{i2}}{U_{i1}}| \ , \ v_i = |\frac{V_{i2}}{V_{22}}| \ . \end{aligned} \tag{6.3.12}$$

This gives

$$\begin{aligned} cos(\Psi_i) &= -\frac{v_i}{2u_i} = -\frac{v_i}{2}\sqrt{\frac{9x_i}{k_i}} \ , \\ x_i &= P_{ii}^D = 1 - \frac{k_i}{9} - \frac{n(i) - k(i)}{60} \ , \\ k(1) &= k \ , \ k(2) = l \ , \ n(1) = n_d, \ n(2) \equiv n_s \ . \end{aligned} \tag{6.3.13}$$

The condition $|cos(\Psi)| \leq 1$ is trivially satisfied. For $n_d = 13$ and $k = 2$ the condition gives $x = .59$ and $cos(\Psi_1) = .185$. $k = 1.45$ gives $x = .65$ and $cos(\Psi) = .226$, which is rather near to V_{12}.

6.3.3 Constraints from CKM matrix

Besides the constraints from hadron masses, there are constraints from CKM matrix $V = U^{\dagger}D$ on U and D matrices.

(a) The fact that CKM matrix is near unit matrix implies that U and D matrix are near to each other and the assumption $n(U_i) = n(D_i)$ predicting quark masses correctly is consistent with this.

(b) Cabibbo angle allows to derive the estimate for the difference $|U_{11}| - |D_{11}|$. Together with other conditions this difference fixes the scenario essentially uniquely.

(c) The requirement that CP breaking invariant J has a correct order of magnitude gives a very strong constraint on D matrix. The smallness of J implies that V is nearly orthogonal matrix and same assumption can be made about U and D matrices.

(d) The requirement that the moduli the first row (column) of CKM matrix are predicted correctly makes it possible to deduce for given D (U) U (D) matrix essentially uniquely. Unitarity requirement poses very strong additional constraints. It must be emphasized that the constraints from the moduli of the CKM alone are sufficient to determine U and D matrices and hence also quark masses and hadron masses to very high degree.

1. Bounds on CKM matrix elements

The most recent experimental information [C41] concerning CKM matrix elements is summarized in table below

$\|V_{13}\| \equiv \|V_{ub}\| = (0.087 \pm 0.075)V_{cb}\, :\, 0.42 \cdot 10^{-3} < \|V_{ub}\| < 6.98 \cdot 10^{-3}$
$\|V_{23}\| \equiv \|V_{cb}\| = (41.2 \pm 4.5) \cdot 10^{-3}$
$\|V_{31}\| \equiv \|V_{td}\| = (9.6 \pm 0.9) \cdot 10^{-3}$
$\|V_{32}\| \equiv \|V_{ts}\| = (40.2 \pm 4.4) \cdot 10^{-3}$
$s_{Cab} = 0.226 \pm 0.002$

Table 4. The experimental constraints on the absolute values of the CKM matrix elements.

$$\begin{aligned} s_1 &= .226 \pm .002 \ , \\ s_1 s_2 &= V_{31} = (9.6 \pm .9) \cdot 10^{-3} \ , \\ s_1 s_3 &= V_{13} = (.087 \pm .075) \cdot V_{23} \ , \\ V_{23} &= (40.2 \pm 4.4) \cdot 10^{-3} \ . \end{aligned} \tag{6.3.14}$$

The remaining parameter is $sin(\delta)$ or equivalently the CP breaking parameter J:

$$J = Im(V_{11}V_{22}\overline{V}_{12}\overline{V}_{21}) = c_1c_2c_3s_2s_3s_1^2 sin(\delta) \ , \tag{6.3.15}$$

where the upper bound is for $sin(\delta) = 1$ and the previous average values of the parameters s_i, c_i (note that the poor knowledge of s_3 affects on the upper bound for J considerably). Unitary triangle [C132] gives for the CP breaking parameter the limits

$$1.0 \times 10^{-4} \leq J \leq 1.7 \times 10^{-4} \ . \tag{6.3.16}$$

2. CP breaking in $M - \overline{M}$ systems as a source of information about CP breaking phase

Information about the value of $sin(\delta)$ as well as on the range of possible top quark masses comes from CP breaking in $K-\bar{K}$ and $B-\bar{B}$ systems.

The observables in $K_L \rightarrow 2\pi$ system [C156]

$$\begin{aligned}
\eta_{+-} &= \frac{A(K_L \rightarrow \pi^+\pi^-)}{A(K_S \rightarrow \pi^+\pi^-)} = \epsilon + \frac{\epsilon'}{1+\omega/\sqrt{2}} \ , \\
\eta_{00} &= \frac{A(K_L \rightarrow \pi^0\pi^0)}{A(K_S \rightarrow \pi^0\pi^0)} = \epsilon - 2\frac{\epsilon'}{1-\sqrt{2}\omega} \ , \\
\omega &\sim \frac{1}{20} \ , \\
\epsilon &= (2.27 \pm .02)\cdot 10^{-3}\cdot exp(i43.7^o) \ , \\
|\frac{\epsilon'}{\epsilon}| &= (3.3 \pm 1.1)\cdot 10^{-3} \ . \qquad (6.3.17)
\end{aligned}$$

The phases of ϵ and ϵ' are in good approximation identical. CP breaking in $K-\bar{K}$ mass matrix comes from the CP breaking imaginary part of $\bar{s}d \rightarrow s\bar{d}$ amplitude M_{12} (via the decay to intermediate W^+W^- pair) whereas $K^0\bar{K}^0$ mass difference Δm_K comes from the real part of this amplitude: the calculation of the real part cannot be done reliably for kaon since perturbative QCD does not work in the energy region in question. On can however relate the real part to the known mass difference between K_L and K_S: $2Re(M_{12}) = \Delta m_K$.

Using the results of [C156]) one can express ϵ and ϵ'/ϵ in the following numerical form

$$\begin{aligned}
|\epsilon| &= \frac{1}{\sqrt{2}}\frac{Im(M_{12}^{sd})}{\Delta m_K} - .05\cdot|\frac{\epsilon'}{\epsilon}| = 2J(22.2B_K\cdot X(m_t) - .28B_K') \ , \\
|\frac{\epsilon'}{\epsilon}| &= C\cdot J\cdot B_K' \ , \\
X(m_t) &= \frac{H(m_t)}{H(m_t = 60\ GeV)} \ , \\
H(m_t) &= -\eta_1 F(x_c) + \eta_2 F(x_t)K + \eta_3 G(x_c,x_t) \ , \\
x_q &= \frac{m(q)^2}{m_W^2} \ , \\
K &= s_2^2 + s_2 s_3 cos(\delta) \ . \qquad (6.3.13)
\end{aligned}$$

Here the values of QCD parameters η_i depend on top mass slightly. B_K' and B_K are strong interaction matrix elements and vary between 1/3 and 1. The functions F and G [C156] are given by

$$\begin{aligned}
F(x) &= x\left[\frac{1}{4} + \frac{9}{4}\frac{1}{1-x} - \frac{3}{2}\frac{1}{(1-x)^2}\right] + \frac{3}{2}(\frac{x}{x-1})^3 log(x) \ , \\
G(x,y) &= xy\left[\frac{1}{x-y}\left[\frac{1}{4} + \frac{3}{2}\frac{1}{1-x} - \frac{3}{4}\frac{1}{(1-x)^2}\right]log(x) + (y\rightarrow x) - \frac{3}{4}\frac{1}{(1-x)(1-y)}\right] \ . \qquad (6.3.12)
\end{aligned}$$

One can solve parameter B_K' by requiring that the value of ϵ'/ϵ corresponds to the experimental mean value:

$$B_K' = \frac{1}{C\times J}\frac{\epsilon'}{\epsilon} \ . \qquad (6.3.13)$$

The most recent measurements by KTeV collaboration in Fermi Lab [C1] give for the ratio $|\epsilon'/\epsilon|$ the value $|\epsilon'/\epsilon| = (28\pm1)\times10^{-4}$. The proposed standard model explanation for the large value of B'_K is that s-quark has running mass about $m_s(m_c) \simeq .1$ GeV at m_c [C181]. The explanation is marginally consistent with the TGD prediction $m(s) = 127$ MeV for the mass of s quark. Also the effects caused by the predicted higher gluon generations having masses around 33 GeV can increase the value of ϵ'/ϵ by a factor 3 in the lowest approximation since the corrections involve sum over three different one-gluon loop diagrams with gluon mass small respect to intermediate boson mass scale [K37] .

A second source of information comes from $B-\bar{B}$ mass difference. At the energies in question perturbative QCD is expected to be applicable for the calculation of the mass difference and mass difference is predicted correctly if the mass of the top quark is essentially the mass of the observed top candidate [C35].

3. U and D matrices could be nearly orthogonal matrices

The smallness of the CP breaking phase angle δ_{CP} means that V is very near to an orthogonal matrix. This raises the hope that in a suitable gauge also U and D are nearly orthogonal matrices and would be thus almost determined by single angle parameter θ_X, $X = U, D$. Cabibbo angle $s_c = sin(\theta_c) = .226$ which is not too far from $sin^2(\theta_W) \simeq .23$ and appears in V matrix rotating the rows of U to those of D. In very vague sense this angle would characterize between the difference of angle parameters characterizing U and D matrices. If U is orthogonal matrix then the decomposition

$$V = V_1V_2 = \begin{bmatrix} c_1 & s_1 & 0 \\ -s_1c_2 & c_1c_2 & s_2exp(i\delta_{CP}) \\ -s_1s_2 & c_1s_2 & -c_2exp(i\delta_{CP}) \end{bmatrix} \times \begin{bmatrix} 1 & 0 & 0 \\ 0 & c_3 & s_3 \\ 0 & -s_3 & c_3 \end{bmatrix} \quad (6.3.14)$$

suggests that CP breaking can be visualized as a process in which first s and b quarks are slightly mixed to s' and b' by V_2 ($s_3 \simeq 1.4\times10^{-2}$) after which V_1 induces a slightly CP-breaking mixing of d and s' with b' ($s_2 \simeq .04$).

4. How the large mixing between u and c results

The prediction that u quark spends roughly 1/3 of time in $g = 0$ state looks bizarre and it is desirable to understand this from basic principles. The basic observations are following.

(a) V matrix is in good approximation direct sum of 2×2 matrix inducing relatively large rotation with $sin(\theta_c) \simeq .23$ and unit matrix. In particular, V_{i3} are very small for $i = 1, 2$. Using the formula $D = UV$ one finds that $|U_{i3}| = |D_{i3}|$ in a good approximation for $i = 1, 2$ and by unitarity also for $I = 3$. Thus the third columns of U and D are identical in a good approximation.

(b) Assume that also U_{i3} and D_{i3} are small for $i = 1, 2$. A stronger assumption is that even the contribution of D_{13} and U_{13} are so small that they do not affect u and d masses. This implies

$$\begin{aligned} n_d &= 9|D_{12}|^2 + 60|D_{13}|^2 \simeq 9|D_{12}|^2 \ , \\ n_u &\simeq 9|U_{12}|^2 \ . \end{aligned} \quad (6.3.14)$$

Unitarity implies in this approximation

$$\begin{aligned} &|U_{11}|^2 \leq 1 - \frac{n_u}{9} = \frac{1}{3} \ , \\ &|D_{11}|^2 \leq 1 - \frac{n_d}{9} = \frac{5}{9} \ . \end{aligned} \quad (6.3.14)$$

(c) It might be that there are also solutions for which mixing of u resp. d quark is mostly with t resp. b quarks but numerical experimentation does not favor this idea since CP breaking becomes extremely small. Since mixing presumably involves topology change, it seems obvious that topological mixing involving a creation or annihilation of two handles is improbable.

6.4 Construction of U, D, and CKM matrices

In this section it will be found that various mathematical and experimental constraints on U and D matrices determine them essentially uniquely.

6.4.1 The constraints from CKM matrix and number theoretical conditions

The requirement that U, D and V allow an algebraic continuation to finite-dimensional extensions of various p-adic number fields provides a very strong additional constraints. The mathematical problem is to understand how many unitary V matrices acting on U as $U \rightarrow D = UV$ respect the number theoretic constraints plus the constraints $n_u = n_d + 2$ and $n_c = n_d - 2$.

It is instructive to what happens in much simpler 2-dimensional case. In this case the conditions boil down to the conditions on $n(i)$ imply $|U| = |D|$ and this condition is equivalent with (say) the condition $|U_{11}| = D_{11}$. U and D can be parameterized as

$$U = \begin{pmatrix} cos(\theta)exp(i(\psi) & sin(\theta)exp(i\phi) \\ -sin(\theta)exp(-i\phi) & cos(\theta)exp(-i\psi) \end{pmatrix} .$$

If $cos(\theta)^2$ and $sin(\theta)^2$ are rational numbers, $exp(i\theta)$ is associated with a Gaussian integer. A more general requirement is that $exp(i\theta)$ belongs to a finite-dimensional extension of rational numbers and thus corresponds to a products of a phase associated with Gaussian integer and a phase in a finite-dimensional algebraic extension of rational numbers.

Eliminating the trivial multiplicative phases gives a set of matrices U identifiable as a double coset space $X^2 = SU(2)/U(1)_R \times U(1)_L$. The value of $cos(\theta) = |U_{11}|$ serving as a coordinate for X^2 is respected by the right multiplication with V. Eliminating trivial $U(1)_R$ phase multiplication, the space of V:s reduces to $S^2 = SU(2)/U(1)_R$. The condition that $cos(\theta)$ is not changed leaves one parameter set of allowed matrices V.

The translation of these results to 3-dimensional case is rather straightforward. In the 3-dimensional case the probabilities P_{i2}, P_{i3}, $i = 1, 2$ characterize a general matrix $|U|$, and V can affect these probabilities subject to constraints on $n(I)$. When trivial phases affecting the probabilities are eliminated, the matrices U correspond naturally to points of the 4-dimensional double coset space $X^4 = SU(3)/(U(1)\times U(1))_R \times U(1)\times U(1))_L$ having dimension $D = 4$.

The two constraints on the probabilities mean that allowed solutions for given values of $n(I)$ define a 2-dimensional surface X^2 in X^4. The allowed unitary transformations V must be such that they move U along this surface. Certainly they exist since X^2 can be regarded as a local section in $SU(3) \rightarrow X^2$ bundle obtained as a restriction of $SU(3) \rightarrow X^4$ bundle. The action of V on rows of U is ordinary unitary transformation plus a 2-dimensional unitary transformation preserving the Hermitian degenerate lengths $L_i = 9|U_{i2}|^2 + 60|U_{i3}|^2 = n_i$ defining the sub-bundle $SU(3) \rightarrow X^2$. Note for $L_1 = 0$ ($L_2 = 0$) the situation becomes 2-dimensional and solutions correspond to points in S^2. Thus these points seem to represent a conical singularity of X^2.

The 2-dimensionality of the solution space means that two moduli (probabilities) of any row or column of U or D matrix characterize the matrix apart from the non-uniqueness due to the gauge choice allowing $U(1)_L \times U(1)_R$ transformation of U. Of course, discrete sign degeneracy might be present.

A highly non-trivial problem is whether the set X^2 contains rational points and what is the number of these points. For instance, Fermat's theorem says that no rational solutions to the equation $x^n + y^n - z^n = 0$ exist for $n > 2$. The fact that the degenerate situation allows infinite number of rational solutions suggest that they exist also in the general case. Note also that the additional conditions are second order polynomial equations with rational coefficients so that $SU(3,Q)$ should contain non-trivial solutions to the equations.

It is possible to write $|U|$ in a form containing minimal number of square roots:

$$\begin{array}{lll} |U_{11}| = \sqrt{n_u}\frac{p_1}{N_1} \ , & |U_{12}| = \sqrt{\frac{n_u}{9}}\frac{r_1}{N_1} \ , & |U_{13}| = \sqrt{\frac{n_u}{60}}\frac{s_1}{N_1} \ , \\ |U_{21}| = \sqrt{n_c}\frac{p_2}{N_2} \ , & |U_{22}| = \sqrt{\frac{n_c}{9}}\frac{r_2}{N_2} \ , & |U_{23}| = \sqrt{\frac{n_c}{60}}\frac{s_2}{N_2} \ , \\ |U_{31}| = \sqrt{n_t}\frac{p_3}{N_3} \ , & |U_{32}| = \sqrt{\frac{n_t}{9}}\frac{r_3}{N_3} \ , & |U_{23}| = \sqrt{\frac{n_t}{60}}\frac{s_3}{N_3} \ . \end{array} \quad (6.4.1)$$

Completely analogous expression holds true for D. r_i, s_i and N_i are integers, and the defining equations reduce in both cases to equations generalizing those satisfied by Pythagorean triangles

$$\begin{array}{rcl} r_1^2 + s_1^2 & = & N_1^2 \ , \\ r_2^2 + s_2^2 & = & N_2^2 \ , \\ r_3^2 + s_3^2 & = & N_3^2 \ . \end{array} \quad (6.4.0)$$

The square roots of n_i are also eliminated from the unitarity conditions which become equations with rational coefficients for the phases appearing in U and D. Hence there are good hopes that even rational solutions to the conditions might exist.

6.4.2 How strong number theoretic conditions one can pose on U and D matrices?

It is not quite clear how strong the number theoretic conditions on U and D matrices are. An attractive working hypothesis is that mixing probabilities are rational. This leaves a lot of freedom concerning the mixing matrices themselves since square roots of rationals, Pythagorean phases, and finite roots of unity can appear in the mixing matrices.

(a) The most stringent requirement would be that U and D matrices are rational unitary matrices. p-Adicization without algebraic extension allows only matrices for which various phases and trigonometric functions are products of Pythagorean phases. This option will be found to be too restrictive. The minimal extension allows square roots requiring a finite-dimensional extension of p-adic numbers: geometrically this means a generalization Pythagorean triangles to triangles for which short sides are integer valued and long side is square root of integer. Pythagorean phases and their generalizations span infinite discrete subgroups of SU(3).

(b) Both the phases and also cosines and sines appearing in the mixing matrices could be restricted to algebraic roots of unit that is of form $exp(i2\pi/N)$ requiring finite algebraic extension of rationals and p-adic numbers. Roots of unity could define finite discrete subgroup of SU(3) implying rather stringent conditions on the model. Root of unity option is highly suggestive in light of the most recent developments (more than decade after development of the model) related to the p-adicization in terms of harmonic analysis in symmetric spaces relying on the counterparts of plane waves defined in terms of roots of unity and leading to a p-adic version of real symmetric space [K66] . Finite roots of unity define as a special case discrete subgroups of SU(3) implying rather stringent conditions on the model. For instance, in case of SU(2) these finite groups are well-known.

6.4.3 Could rational unitarity make sense?

In this section the considerations are restricted mostly to rational unitarity which at the time of writing of this chapter looked more attractive than the allowance of algebraic roots of unity. The number theoretic conditions following from the rational unitarity on the moduli of the U and D matrices are not completely independent of the parameterization used. The reason is that the products of the parameters in some algebraic extension of the rationals can combine to give a rational number. The safest parameterization to use is the one based on the moduli of the U and D matrix.

Parameterization of moduli in the case of rational unitarity

If one assumes rationality for the mixing matrix then all moduli can be written in the form

$$|D_{ij}| = \frac{n_{ij}}{N} . \tag{6.4.1}$$

If only moduli squared are required to be rational, the condition is replaced with a milder one:

$$|D_{ij}| = \frac{n_{ij}}{\sqrt{N}} . \tag{6.4.2}$$

Here $\sqrt{N}$ belongs to square root allowing algebraic extension of the p-adic numbers but is not an integer itself. An even milder condition is

$$|D_{ij}| = \sqrt{\frac{n_{ij}}{N}} . \tag{6.4.3}$$

The following arguments show that only this option or more general option allowing roots of unity with rational mixing probabilities is allowed. These options is also natural in light or preceding general considerations.

Unitary and mass conditions modulo 8 for rational unitarity

For $p_{ij} = (\sqrt{\frac{n_{ij}}{N}})^k$, $k = 1$ or 2, the requirement that the rows are unit vectors implies

$$\begin{aligned} \sum_j n_{i,j}^k &= N^k , \\ k &= 1 \text{ or } 2 . \end{aligned} \tag{6.4.3}$$

The problem of finding vectors with integer valued components and with a given integer valued length squared m ($k = 2$ case) is a well known and well understood problem of the number theory [A30] . The basic idea is to write the conditions modulo 8 and use the fact that the square of odd (even) integer is 1 (0 or 4) modulo 8. The result is that one must have

$$m \in \{1, 2, 3, 5, 6\} , \tag{6.4.4}$$

for the conditions to possess nontrivial solutions. For $m = N$ case this is the only condition needed. In $m = N^2$ case the condition implies that N must be odd.

Using this result one can write the mass squared conditions modulo 8 for $k = 2$ as

$$\begin{aligned} 3n_{i,2}^2 + 4n_{i,3}^2 &= n_i X \ , \\ X &= 1 \text{ for } m = N^2 \ , \\ X &\in \{1,2,3,5,6\} \text{ for } m = N \ . \end{aligned} \quad (6.4.3)$$

Here modulo 8 arithmetics is understood. In $m = N^2$ case one must have $n_i \in \{0, 3, 4\}$ modulo 8. These conditions are not satisfied in general. For $m = N$ conditions allow considerably more general set of solutions. By summing the equations and using probability conservation one however obtains $7N = 5N$ implying $2N = 0$ so that the non-allowed value $N = 4$ or 0 results.

For $k = 1$ no obvious conditions result on the values of n_i and only this option is allowed by mass conditions for the physical masses.

Rational unitarity cannot hold true for U and D matrices separately

The mixing scenario is not consistent with the assumption that the matrix elements of U and D matrix are complex rational numbers. If this were the case then matrix elements had to be proportional to a common denominator $1/N$ such that N is odd integer (otherwise the conditions stating that the unit vector property of the rows is not satisfied). The conditions

$$\begin{aligned} \sum_j r_{ij} &= 1 \ , \\ 9r_{12} + 60r_{13} &= n_d \ , \\ 9r_{22} + 60r_{23} &= n_s \ , \\ 9r_{32} + 60r_{33} &= n_b \ , \\ r_{ij} &= \frac{n_{ij}}{N_i} \ , \end{aligned} \quad (6.4.-1)$$

can be written modulo 8 as

$$\begin{aligned} \sum_j n_{ij}^k &= N^k \ , \\ n_{12}^k + 4n_{13}^k &= n_d N^k \ , \\ n_{22}^k + 4n_{23}^k &= n_s N^k \ , \\ n_{32}^k + 4n_{33}^k &= n_b N^k \ , \\ r_{ij} &= (\frac{n_{ij}}{N})^{k/2} \ , \quad k = 1 \text{ or } 2 \ . \end{aligned} \quad (6.4.-5)$$

(a) Consider first the case $k = 2$. For odd n $n^2 = 1$ holds true and for even n $n^2 = 4$ or 0 holds true. It is easy to see that the conditions can be satisfied only of all integers are proportional to 4 but this cannot be possible since it would be possible since n_{ij} an N cannot contain common factors. Thus at least an extension allowing square roots is needed. Quite generally from $N^2 = 1$ mod 8 the above equations give

$$n_{q_i}\ mod\ 8 \in \{0,3,4,7\} \ .$$

This condition fails to be satisfied by in the general case.

(b) For the option $k=1$ for which only the probabilities are rational the sum of all three equations gives $5N = 5N$ so that equations are consistent.

The result favors the possibility that roots of unity are the basic building bricks of the mixing matrices. This does not exclude the possibility that mixing probabilities are rational numbers.

Rational unitarity for phase factors

The phase factors associated with the rows of the mixing matrix are rational provided the corresponding angles correspond to Pythagorean triangles. It must be however emphasized that roots of unit are highly suggestive in the recent vision about p-adicization. Combining this property with the orthogonality conditions for the rows of the U matrix, one obtains highly nontrivial conditions relating the integers characterizing the sides of the Pythagorean triangle to the integers n_{ij}. The requirement that the imaginary parts of the inner product vanish, gives the conditions

$$\frac{s_{i,2}}{s_{i3}} = \frac{n_{13}n_{i3}}{n_{12}n_{22}} \ , \ i=2,3 \ . \tag{6.4.-4}$$

Combining this conditions with the general representation for the sines of the Pythagorean triangle

$$sin(\phi) = \frac{2rs}{r^2+s^2} \text{ or } \frac{r^2-s^2}{r^2+s^2} \ , \tag{6.4.-3}$$

one obtains conditions relating the integers appearing characterizing the triangle to the integers on the right hand side.

An interesting possibility is that the lengths of the hypothenusae of the triangles associated with $s(i,2)$ $((r(i),s(i)))$ and s_{i3} $((r_1(i),s_1(i)))$ are the same and sines correspond to the products $2rs$:

$$\begin{aligned} r^2(i)+s^2(i) &= r_1^2(i)+s_1^2(i) \ , \\ s_{i,2} &= 2r(i)s(i)/(r^2(i)+s^2(i)) \ , \\ s_{i,3} &= 2r_1(i)s_1(i)/(r_1^2(i)+s_1^2(i)) \ . \end{aligned} \tag{6.4.-4}$$

In this case the conditions give

$$\frac{r(i)s(i)}{r_1(i)s_1(i)} = \frac{n_{13}n_{i3}}{n_{12}n_{22}} \ . \tag{6.4.-3}$$

The conditions are satisfied if one has

$$\begin{aligned} r(i)s(i) &= n_{13}n_{i3} \ , \\ r_1(i)s_1(i) &= n_{12}n_{22} \ . \end{aligned} \tag{6.4.-3}$$

This implies that $r(i)$ and $s(i)$ are products of the factors contained in the product $n_{13}n_{i3}$. Analogous conclusion applies to $r_1(i)$ and $s_1(i)$.

Additional number theoretic conditions are obtained from the requirement that the real parts of the inner products between first row and second and third rows vanish:

$$n_{11}n_{i1} + c_{i,2}n_{12}n_{i2} + c_{i,3}n_{13}n_{i3} = 0 \ , \ i = 2,3 \ . \quad (6.4.\text{-}2)$$

6.4.4 The parameterization suggested by the mass squared conditions

To understand the consequences of the mass squared conditions, it is useful to use a parameterization, which is more natural for the treatment of the mass squared conditions than the standard parameterization:

$$U = \begin{bmatrix} r_{11} & r_{12} & r_{13} \\ r_{21}x_2 & r_{22}x_2exp(i\phi_{22}) & r_{23}x_2exp(i\phi_{23}) \\ r_{31}x_3 & r_{32}x_3exp(i\phi_{32}) & r_{33}x_3exp(i\phi_{33}) \end{bmatrix}$$
$$x_2 = exp(i\phi_2) \ , \quad x_3 = exp(i\phi_3) \ . \quad (6.4.\text{-}1)$$

In case of D matrix, the phase factors x_2 and x_3 can be chosen to be trivial. As far as the treatment of the mass conditions and unitarity conditions for the rows is considered, one can restrict the consideration to the case, when the overall phase factors are trivial. The remaining parameters are not independent and one on can deduce the formulas relating the moduli r_{ij} as well as the phase angles ϕ_{ij} to the parameters r_{11} and r_{12}. In general, the resulting parameters are not real and unitarity is broken.

Mass squared conditions and the requirement that the rows are unit vectors:

$$\begin{aligned} 9r_{i2}^2 + 60r_{i3}^2 &= n_i \ , \ i = 1,2 \ , \\ \sum_k r_{ik}^2 &= 1 \ , \end{aligned} \quad (6.4.\text{-}1)$$

allows one to express r_{i2} and r_{i3} in terms of r_{i1}

$$\begin{aligned} r_{i2} &= \sqrt{[-\frac{n_i}{51} + \frac{20}{17}(1 - r_{i1}^2)]} \ , \\ r_{i3} &= \sqrt{[\frac{n_i}{51} - \frac{3}{17}(1 - r_{i1}^2)]} \ . \end{aligned} \quad (6.4.\text{-}1)$$

The requirement that the rows are orthogonal to each other, relates the phase angles ϕ_{ij} in terms to r_{11} and r_{21}. Using the notations $sin(\phi_{ij}) = s_{ij}$ and $cos(\phi_{ij}) = c_{ij}$, one has

$$\begin{array}{ll} c_{i2} = \frac{a_i}{b_i} \ , & c_{i3} = -\frac{(A_{1i} + c_{i2}A_{2i})}{A_{3i}} \ , \\ s_{i2} = \epsilon(i)\sqrt{1 - c_{i2}^2} \ , & s_{i3} = -\frac{A_{2i}}{A_{3i}}s_{i2} \ , \\ A_{1i} = r_{11}r_{i1} \ , & A_{2i} = r_{12}r_{i2} \\ A_{3i} = r_{13}r_{i3} \ , & \epsilon(i) = \pm 1 \ . \\ a_i = A_{3i}^2 - A_{1i}^2 - A_{2i}^2 \ , & b_i = 2A_{1i}A_{2i} \ , \end{array} \quad (6.4.0)$$

The sign factors $\epsilon(i)$ are not completely free and must be chosen so that the second and third row are orthogonal.

The mass conditions imply the following bounds for the parameters r_{i1}

$$\begin{aligned} m_i &\leq r_{i1} \leq M_i \ , \\ m_i &= \sqrt{1-\frac{n_i}{9}} \text{ for } n_i \leq 9 \ , \\ m_i &= 0 \text{ for } n_i \geq 9 \ , \\ M_i &= \sqrt{1-\frac{n_i}{60}} \ . \end{aligned} \tag{6.4.-2}$$

The boundaries for the regions of the solution manifold in (r_{11}, r_{21}) plane can be understood as follows. For given values of r_{11} and r_{21} there are in general two solutions corresponding to the sign factor $\epsilon(i)$ appearing in the equations defining the solutions of the mass squared conditions. This means just that complex conjugation gives a new solution from a given one. These two branches become degenerate, when the phase factors become ± 1 so that (s_{i2}, s_{i3}) vanishes for $i = 2$ or $i = 3$. Thus the curves at which one has $(s_{i2} = 0, s_{i3} = 0)$ define the boundaries of the projection of the solution manifold to (r_{11}, r_{21}) plane. At the boundaries the orthogonality conditions reduce to the form

$$\begin{aligned} & r_{11}r_{i1} + \epsilon(i,2)r_{12}r_{i2} + \epsilon_{i3}r_{13}r_{i3} = 0 \ , \ i = 2 \text{ or } 3 \ , \\ & \epsilon_{22} = \epsilon_{32} \ , \\ & \epsilon_{23} = -\epsilon_{33} \end{aligned} \tag{6.4.-1}$$

where ϵ_{ij} corresponds to the value of the cosine of the phase angle in question. Consistency requires that either second or third row becomes real on the boundary of the unitarity region and that the matrices reduce to orthogonal matrices at the dip of the region allowed by unitarity.

6.4.5 Thermodynamical model for the topological mixing

What would be needed is a physical model for the topological mixing allowing to deduce U and D matrices from first principles. The physical mechanism behind the mixing is change of the topology of X^2 in the dynamical evolution defined by the light like 2-surface X_l^3 defining parton orbit. This suggests that the topology changes $g \rightarrow g \pm 1$ dominate the dynamics so that matrix elements U_{13} and D_{13} should be indeed small so that the weird looking result $P_{11}^U \simeq 1/3$ follows from the requirement $n_u = 6$. This model however suggests that the matrix elements U_{23} and D_{23} could be large unlike in the original model for U and D matrices.

Solution of thermodynamical model

A possible approach to the construction of mixing matrices is based on the idea that the interactions causing the mixing lead to a thermal equilibrium so that the entropies for the ensemble defined by the probabilities p_{ij}^U and p_{ij}^D matrix is maximized (the subscripts U and D are dropped in the sequel).

(a) The elements in the three rows of the mixing matrix represent probabilities for three states of the system with energies $(E_{i1}, E_{i2}, E_{i3}) = (0, 9, 60)$ and average energy is fixed to $\langle E \rangle = 69$.

(b) There are usual constraints from probability conservation for each row plus two independent constraints from columns. The latter constraints can be regarded as a constraint on a second quantity equal to 1 for each column and brings in variable analogous to chemical potential besides temperature.

The constraint from mass squared for the third row follows from these constraints. The independent constraints can be chosen to be the following ones

$$\begin{array}{ll} \sum_j p_{ij} - 1 = 0 \ , \ \ i = 1,2,3 & \sum_i p_{ij} - 1 = 0, \ \ j = 1,2 \ , \\ 9p_{i2} + 60p_{i3} - n_{q_i} = 0 \ , \ \ i = 1,2 \ . & \end{array} \tag{6.4.0}$$

The obvious notations $(q_1, q_2) = (d, s)$ and $(q_1, 2_2) = (u, c)$ are introduced. The conditions on mass squared are completely analogous to the conditions fixing the energy of the ensemble and thus its temperature, and thermodynamical intuition suggests that the probabilities p_{ij} decrease exponentially as function of E_j in the absence of additional constraints coming from the probability conservation for the columns and meaning presence of chemical potential.

The variational principle maximizing entropy in presence of these constraints can be expressed as

$$\begin{aligned} L &= S + S_c \\ S &= \sum_{i,j} p_{ij} \times log(p_{ij}) \\ S_c &= \sum_i \lambda_i (\sum_j p_{ij} - 1) + \sum_{j=1,2} \mu_j (\sum_i p_{ij} - 1) + \sum_{i=1,2} \sigma_i (9p_{i2} + 60p_{i3} - n_{q_i}) \ . \end{aligned} \tag{6.4.-2}$$

The variational equation is

$$\partial_{p_{ij}} L = 0 \ , \tag{6.4.-1}$$

and gives the probabilities as

$$\begin{array}{lll} p_{11} = \frac{1}{Z_1} \ , & p_{12} = \frac{x x_1^3}{Z_1} & p_{13} = \frac{y x_1^{20}}{Z_1} \ , \\ p_{21} = \frac{1}{Z_2} \ , & p_{22} = \frac{x x_2^3}{Z_2} & p_{13} = \frac{y x_2^{20}}{Z_2} \ , \\ p_{31} = \frac{1}{Z_3} \ , & p_{32} = \frac{x}{Z_3} & p_{33} = \frac{y}{Z_3} \ , \end{array} \tag{6.4.-1}$$

Here the parameters x, y, x_1, x_2 are defined as

$$\begin{array}{ll} x = exp(-\mu_2) \ , & y = exp(-\mu_3) \ , \\ x_1 = exp(-3\sigma_1) \ , & x_2 = exp(-3\sigma_2) \ . \end{array} \tag{6.4.-1}$$

whereas the row partition functions Z_i are defined as

$$Z_1 = 1 + xx_1^3 + yx_1^{20} \ , \quad Z_2 = 1 + xx_2^3 + yx_2^{20} \ , \quad Z_3 = 1 + x + y \ . \tag{6.4.0}$$

Note that the parameters λ_i have been eliminated. There are four parameters $\mu_2, \mu_3, \sigma_2, \sigma_3$ and 2 conditions from columns and 2 mass conditions so that the number of solutions is discrete and only finite number of U and D matrices are possible in the thermodynamical approximation.

Mass squared conditions

The mass squared conditions read as

$$9xx_1^3 + 60yx_1^{20} = n(q_1)Z_1 \ , \quad 9xx_2^3 + 60yx_2^{20} = n(q_2)Z_2 \ . \tag{6.4.1}$$

These equations allow to solve y as a simple linear function of x

$$y = \frac{n(q_1) - xx_1^3(9 - n(q_1))}{(60 - n(q_1))x_1^{20}} \equiv kx + l \ , \quad y = \frac{n(q_2) - xx_2^3(9 - n(q_2))}{(60 - n(q_2)x_2^{20}} \ . \tag{6.4.2}$$

The identification of the two expressions for y allows to solve x_1 in terms of x_2 using equation of form $x_1^{20} - bx_1^3 + c = 0$:

$$\begin{aligned} & \left[60 - n(q_2)x_2^{20}\right]\left[n(q_1) - xx_1^3(9 - n(q_1))\right] \\ = \ & \left[60 - n(q_1))x_1^{20}\right]\left[n(q_2) - xx_2^3(9 - n(q_2)\right] \ . \end{aligned} \tag{6.4.2}$$

In the most general case the equation allows 20 roots $x_1 = x_2(x_1)$.

Probability conservation

Probability conditions give additional information. By solving $1/Z_3$ from the first column gives

$$Z_1Z_2Z_3 - Z_1Z_2 - Z_2Z_3 - Z_1Z_3 = 0 \ , \tag{6.4.3}$$
$$\tag{6.4.4}$$

This equation is a polynomial equation for in x_1 and x_2 with degree 20 and together with Eq. 6.4.2 having same degree determines and (x_1, x_2) the possible values of x_1 and x_2 as function of x. The number of real positive roots is at most $20^2 = 400$.

Probability conservation for the second column gives

$$x\left[(1 - x_1^3)Z_2 + (1 - x_2^3)Z_1\right] + (1 - x)Z_1Z_2 = 0 \ . \tag{6.4.5}$$

The row partition functions Z_i are linear functions of x and y and mass squared conditions give $y = kx + l$ (see Eq. 6.4.2) so that a third order polynomial equation for x results and gives the roots as functions of control parameters x_1 and x_2. Either 1 or 3 real roots are obtained for x. The values of x_1 and x_2 are determined by the probability constraint Eq. 6.4.4 for the first column and Eq. 6.4.2 relating x_1 and x_2.

The analogy with spontaneous magnetization

Physically the situation is analogous to a spontaneous symmetry breaking with y representing the external magnetizing field and x linear magnetization or vice versa. x_1 and x_2 are control parameters characterizing the interaction between spins. For single real root for x no spontaneous magnetization occurs but for 3 real roots there are two directions of spontaneous magnetization plus unstable state. In the recent case the roots must be positive. Since the maximal number of roots for (x_1, x_2) is 400, the maximal number of real roots is 1200. The trivial solution to the conditions is $p_{11} = 1, p_{22} = 1$, $p_{33} = 1$ with $x = y = 0$ represents corresponds to the absence of external magnetizing field and of magnetization.

Catastrophe theoretic description of the system

In the catastrophe theoretic approach one can see that situation as a cusp catastrophe with x as a behavior variable and x_1, x_2 in the role of control variables. In the standard parameterization of the cusp catastrophe [A42] the conditions correspond to the equation

$$x^3 - a - bx = 0 \ , \tag{6.4.5}$$

In the recent case a more general polynomial $P_3(x)$ easily transformable to the standard form is in question. The coefficients of the polynomial $P_3(x) = Dx^3 + Cx^2 + Bx + A$ are

$$\begin{aligned} A &= Q(x_1)Q(x_2) \ , \\ B &= P(x_1)Q(x_2) + P(x_2)Q(x_1) + R(x_2) + R(x_1) \ , \\ C &= P(x_1)R(x_2) + P(x_2)R(x_1) - R(x_1)Q(x_2) - R(x_2)Q(x_1) \ , \\ D &= R(x_1)R(x_2) \ , \\ P(u) &= 1 - u^3 \ , \ \ Q(u) = 1 + lu^{20} \ , \ \ R(u) = u^3 + ku^{20} \ . \end{aligned} \tag{6.4.2}$$

The trivial scaling transformation $A \to A/D = \hat{A}$, $B \to B/D = \hat{B}$, $C \to C/D = \hat{C}$ and the shift $x \to x + \hat{C}/3$ casts the equation in the standard form and gives

$$\begin{aligned} a &= -\hat{A} + \frac{\hat{C}^3}{9} \ , \\ b &= -\hat{B} + \frac{\hat{C}^2}{3} \ . \end{aligned} \tag{6.4.1}$$

The curve

$$a = \pm 2(\frac{b}{3})^{3/2} \ , b \geq 0 \tag{6.4.2}$$

represents the bifurcation set for the solutions. For $b \geq 0$, $|a| \leq (\frac{b}{3})^{3/2}$ three roots are obtained for x. $a = b = 0$ corresponds to the dip of the cusp. Three solutions result under the conditions

$$
\begin{aligned}
\frac{\hat{C}^2}{3} &\geq 3\hat{B} \ , \\
(-\hat{B}+\frac{\hat{C}^2}{3})^3 &\leq \frac{(-\hat{A}+\frac{\hat{C}^3}{9})^2}{4} \ , \\
\hat{A} &= \frac{Q(x_1)Q(x_2)}{R(x_1)R(x_2)} \ , \\
\hat{B} &= \frac{P(x_1)Q(x_2)+P(x_2)Q(x_1)+R(x_2)+R(x_1)}{R(x_1)R(x_2)} \ , \\
\hat{C} &= \frac{P(x_1)R(x_2)+P(x_2)R(x_1)-R(x_1)Q(x_2)-R(x_2)Q(x_1)}{R(x_1)R(x_2)} \ , \\
P(u) &= 1-u^3 \ , \ Q(u)=1+lu^{20} \ , \ R(u)=u^3+ku^{20} \ . \qquad (6.4.-2)
\end{aligned}
$$

The boundaries of the regions are defined by polynomial equations for x_1 and x_2. . The two mass squared conditions and the probability conservation for the first row select a discrete set of parameter combinations.

One might ask whether U and D matrices could correspond to different solutions of these equations for same values of n_{q_i}. This cannot be the case since this would predict too large $u-d$ mass difference. Orthogonalization conditions for the rows should determine the phases more or less uniquely and could force CP breaking. The requirement that probabilities are rational valued implies that x_1, x_2, x and y are rational and poses very strong additional conditions to the solutions. The roots should correspond to very special solutions possessing symmetries so that the solutions of polynomial equations give probabilities as rational numbers. Note however that the solutions of polynomial equations with integer coefficients are in question and the solutions are algebraic numbers: this is enough as far as the p-adicization of the theory is considered.

Maximization of entropy solving constraint equations explicitly

The mass squared conditions allow to express the probabilities p_{ij} in terms of p_{11} and p_{21} (for instance) and this allows a rather concise representation for the solution to the maximization the entropy of topological mixing. The key formulas are following.

$$
\begin{aligned}
p_{31} &= 1-p_{11}-p_{12} \ , \\
p_{i2} &= -\frac{n_i}{51}+\frac{20}{17}(1-p_{i1}) \ , \ i=1,2 \ , \\
p_{i3} &= \frac{n_i}{51}-\frac{3}{17}(1-p_{i1}) \ , \ i=1,2 \ . \qquad (6.4.-3)
\end{aligned}
$$

Expressing entropy directly in terms of p_{11} and p_{21}, the conditions for the maximization of entropy imply the equations

$$
log(p_{ij})X^{ij}=0 \ , \ log(p_{ij})Y^{ij}=0 \ , \qquad (6.4.-2)
$$

where a summation over repeated indices is carried out. The matrices $X^{ij}=\partial_{p_{11}}p_{ij}$ and $Y^{ij}=\partial_{p_{21}}p_{ij}$ are given by

$$X = \begin{pmatrix} 1 & -\frac{20}{17} & \frac{3}{17} \\ 0 & 0 & 0 \\ -1 & \frac{20}{17} & -\frac{3}{17} \end{pmatrix}$$

$$Y = \begin{pmatrix} 0 & 0 & 0 \\ 1 & -\frac{20}{17} & \frac{3}{17} \\ -1 & \frac{20}{17} & -\frac{3}{17} \end{pmatrix}$$

(6.4.-3)

The equations can be transformed into the form

$$\prod_{ij} p_{ij}^{X_{ij}} = 1 \ , \quad \prod_{ij} p_{ij}^{Y_{ij}} = 1 \ . \tag{6.4.-2}$$

When written explicitly, these equations read as

$$\frac{p_{11}}{1-p_{11}-p_{21}} \times (\frac{-n_1+60(1-p_{11})}{-n_3+60(p_{11}+p_{21})})^{-20/17} \times (\frac{n_1-9(1-p_{11})}{n_3-9(p_{11}+p_{21})})^{3/17} = 1 \ ,$$

$$\frac{p_{21}}{1-p_{11}-p_{21}} \times (\frac{-n_2+60(1-p_{21})}{-n_3+60(p_{11}+p_{21})})^{-20/17} \times (\frac{n_2-9(1-p_{21})}{n_3-9(p_{11}+p_{21})})^{3/17} = 1 \ .$$

(6.4.-2)

The equations can be cast into polynomial equations in p_{11} and p_{21} by taking 17:th power of both equations. This gives polynomial equations of degree $d = 17 + 20 + 3 = 40$. The total number of solutions to the equations is at most $40 \times 40 = 1600$. The previous estimate gave upper bound $3 \times 20 \times 20 = 1200$ for the number of solution. It might be that some symmetry is involved and reduces the upper bound by a factor 3/4.

The solutions can be sought using gradient dynamics in which system in (p_{11}, p_{21}) plane drifts in the force field defined by the gradient ∇S of the entropy $S = -\sum_{ij} p_{ij} log(p_i j)$ and ends up to the maximum of S, $S = -\sum_{ij} p_{ij} log(p_i j)$.

$$\frac{dp_{11}}{dt} = \partial_{p_{11}} S = -X^{ij} log(p_{ij}) \ ,$$
$$\frac{dp_{21}}{dt} = \partial_{p_{21}} S = -Y^{ij} log(p_{ij}) \ ,$$

(6.4.-2)

The conditions that the probabilities are positive give the constraints

$$\begin{aligned} 1 - \frac{n_1}{9} &\leq p_{11} \leq 1 - \frac{n_1}{60} \ , \\ 1 - \frac{n_2}{9} &\leq p_{21} \leq 1 - \frac{n_2}{60} \ , \\ 0 &\leq p_{21} \leq 1 - p_{11} \ , \\ \frac{69 - n_1 - n_2}{60} - p_{11} &\leq p_{21} \leq \frac{69 - n_1 - n_2}{9} - p_{11} \end{aligned}$$

(6.4.-5)

on the region containing the solutions.

6.4.6 U and D matrices from the knowledge of top quark mass alone?

As already found, a possible resolution to the problems created by top quark is based on the additivity of mass squared so that top quark mass would be about 230 GeV, which indeed corresponds to a peak in mass distribution of top candidate, whereas $t\bar{t}$ meson mass would be 163 GeV. This requires that top quark mass changes very little in topological mixing. It is easy to see that the mass constraints imply that for $n_t = n_b = 60$ the smallness of V_{i3} and $V(3i)$ matrix elements implies that both U and D must be direct sums of 2×2 matrix and 1×1 unit matrix and that V matrix would have also similar decomposition. Therefore $n_b = n_t = 59$ seems to be the only number theoretically acceptable option. The comparison with the predictions with pion mass led to a unique identification $(n_d, n_b, n_b) = (5, 5, 59)$,$(n_u, n_c, n_t) = (4, 6, 59)$.

U and D matrices as perturbations of matrices mixing only the first two genera

This picture suggests that U and D matrices could be seen as small perturbations of very simple U and D matrices satisfying $|U| = |D|$ corresponding to $n = 60$ and having $(n_d, n_b, n_b) = (4, 5, 60)$, $(n_u, n_c, n_t) = (4, 5, 60)$ predicting V matrix characterized by Cabibbo angle alone. For instance, CP breaking parameter would characterize this perturbation. The perturbed matrices should obey thermodynamical constraints and it could be possible to linearize the thermodynamical conditions and in this manner to predict realistic mixing matrices from first principles. The existence of small perturbations yielding acceptable matrices implies also that these matrices be near a point at which two different matrices resulting as a solution to the thermodynamical conditions coincide.

D matrix can be deduced from U matrix since $9|D_{12}|^2 \simeq n_d$ fixes the value of the relative phase of the two terms in the expression of D_{12}.

$$
\begin{aligned}
|D_{12}|^2 &= |U_{11}V_{12} + U_{12}V_{22}|^2 \\
&= |U_{11}|^2|V_{12}|^2 + |U_{12}|^2|V_{22}|^2 \\
&+ 2|U_{11}||V_{12}||U_{12}||V_{22}|cos(\Psi) = \frac{n_d}{9} \ , \\
\Psi &= arg(U_{11}) + arg(V_{12}) - arg(U_{12}) - arg(V_{22}) \ .
\end{aligned}
\tag{6.4.-8}
$$

Using the values of the moduli of U_{ij} and the approximation $|V_{22}| = 1$ this gives for $cos(\Psi)$

$$
\begin{aligned}
\cos(\Psi) &= \frac{A}{B} \ , \\
A &= \frac{n_d - n_u}{9} - \frac{9 - n_u}{9}|V_{12}|^2 \ , \\
B &= \frac{2}{9|V_{12}|}\sqrt{n_u(9 - n_u)} \ .
\end{aligned}
\tag{6.4.-9}
$$

The experimentation with different values of n_d and n_u shows that $n_u = 6, n_d = 4$ gives $cos(\Psi) = -1.123$. Of course, $n_u = 6, n_d = 4$ option is not even allowed by $n_t = 60$. For $n_d = 4, n_u = 5$ one has $cos(\Psi) = -0.5958$. $n_d = 5, n_u = 6$ corresponding to the perturbed solution gives $cos(\Psi) = -0.6014$.

Hence the initial situation could be $(n_u = 5, n_s = 4, n_b = 60)$, $(n_d = 4, n_s = 5, n_t = 60)$ and the physical U and D matrices result from U and D matrices by a small perturbation as one unit of t (b) mass squared is transferred to u (s) quark and produces symmetry breaking as $(n_d = 5, n_s = 5, n_b = 59)$, $(n_u = 6, n_c = 4, n_t = 59)$.

The unperturbed matrices $|U|$ and $|D|$ would be identical with $|U|$ given by

$$|U_{11}| = |U_{22}| = \frac{2}{3} \ , \quad |U_{12}| = |U_{21}| = \frac{\sqrt{5}}{3} \ , \tag{6.4.-8}$$

The thermodynamical model allows solutions reducing to a direct sum of 2×2 and 1×1 matrices, and since $|U|$ matrix is fixed completely by the mass constraints, it is trivially consistent with the thermodynamical model.

Direct search of U and D matrices

The general formulas for p^U and p^D in terms of the probabilities p_{11} and p_{21} allow straightforward search for the probability matrices having maximum entropy just by scanning the (p_{11}, p_{21}) plane constrained by the conditions that all probabilities are positive and smaller than 1. In the physically interesting case the solution is sought near a solution for which the non-vanishing probabilities are $p_{11} = p_{22} = (9 - n_1)/9$, $p_{12} = p_{21} = n_1/9$, $p_{33} = 1$, $n_1 = 4$ or 5. The inequalities allow to consider only the values $p_{11} \geq (9 - n_1)/9$.

1. Probability matrices p^U and p^D

The direct search leads to maximally entropic p^D matrix with $(n_d, n_s) = (5, 5)$:

$$p^D = \begin{pmatrix} 0.4982 & 0.4923 & 0.0095 \\ 0.4981 & 0.4924 & 0.0095 \\ 0.0037 & 0.0153 & 0.9810 \end{pmatrix} \ , \ p_0^D = \begin{pmatrix} 0.5556 & 0.4444 & 0 \\ 0.4444 & 0.5556 & 0 \\ 0 & 0 & 1 \end{pmatrix} \ . \tag{6.4.-8}$$

p_0^D represents the unperturbed matrix p_0^D with $n(d = 4), n_s = 5$ and is included for the purpose of comparison. The entropy $S(p^D) = 1.5603$ is larger than the entropy $S(p_0^D) = 1.3739$. A possible interpretation is in terms of the spontaneous symmetry breaking induced by entropy maximization in presence of constraints.

A maximally entropic p^U matrix with $(n_u, n_c) = (5, 6)$ is given by

$$p^U = \begin{pmatrix} 0.5137 & 0.4741 & 0.0122 \\ 0.4775 & 0.4970 & 0.0254 \\ 0.0088 & 0.0289 & 0.9623 \end{pmatrix} \tag{6.4.-8}$$

The value of entropy is $S(p^U) = 1.7246$. There could be also other maxima of entropy but in the range covering almost completely the allowed range of the parameters and in the accuracy used only single maximum appears.

The probabilities p_{ii}^D *resp.* p_{ii}^U satisfy the constraint $p(i,i) \geq .492$ *resp.* $p_{ii} \geq .497$ so that the earlier proposal for the solution of proton spin crisis must be given up and the solution discussed in [K26] remains the proposal in TGD framework.

2. Near orthogonality of U and D matrices

An interesting question whether U and D matrices can be transformed to approximately orthogonal matrices by a suitable $(U(1) \times U(1))_L \times (U(1) \times U(1))_R$ transformation and whether CP breaking phase appearing in CKM matrix could reflect the small breaking of orthogonality. If this expectation is correct, it should be possible to construct from $|U|$ ($|D|$) an approximately orthogonal matrix by multiplying the matrix elements $|U_{ij}|$, $i, j \in \{2, 3\}$ by appropriate sign factors. A convenient manner to achieve this is to multiply $|U|$ ($|D|$) in an element wise manner $((A \circ B)_{ij} = A_{ij} B_{ij})$ by a sign factor matrix S.

(a) In the case of $|U|$ the matrix $U = S \circ |U|$, $S(2,2) = S(2,3) = S(3,2) = -1$, $S_{ij} = 1$ otherwise, is approximately orthogonal as the fact that the matrix U^TU given by

$$U^TU = \left(\begin{array}{lll} 1.0000 & 0.0006 & -0.0075 \\ 0.0006 & 1.0000 & -0.0038 \\ -0.0075 & -0.0038 & 1.0000 \end{array} \right)$$

is near unit matrix, demonstrates.

(b) For D matrix there are two nearly orthogonal variants. For $D = S \circ |D|$, $S(2,2) = S(2,3) = S(3,2) = -1$, $S_{ij} = 1$ otherwise, one has

$$D^TD = \left(\begin{array}{lll} 1.0000 & -0.0075 & 0.0604 \\ -0.0075 & 1.0000 & 0.0143 \\ 0.0604 & 0.0143 & 1.0000 \end{array} \right) .$$

The choice $D = S \circ D$, $S(2,2) = S(2,3) = S(3,3) = -1$, $S_{ij} = 1$ otherwise, is slightly better

$$D^TD = \left(\begin{array}{lll} 1.0000 & -0.0075 & 0.0604 \\ -0.0075 & 1.0000 & 0.0143 \\ 0.0601 & 0.0143 & 1.0000 \end{array} \right) .$$

3. The matrices U and D in the standard gauge

Entropy maximization indeed yields probability matrices associated with unitary matrices. 8 phase factors are possible for the matrix elements but only 4 are relevant as far as the unitarity conditions are considered. The vanishing of the inner products between row vectors, gives 6 conditions altogether so that the system seems to be over-determined. The values of the parameters s_1, s_2, s_3 and phase angle δ in the "standard gauge" can be solved in terms of r_{11} and r_{21}.

The requirement that the norms of the parameters c_i are not larger than unity poses non-trivial constraints on the probability matrices. This should should be the case since the number of unitarity conditions is 9 whereas probability conservation for columns and rows gives only 5 conditions so that not every probability matrix can define unitary matrix. It would seem that that the constraints are satisfied only if the the 2 mass squared conditions and 2 conditions from the entropy maximization are equivalent with 4 unitarity conditions so that the number of conditions becomes 5+4=9. Therefore entropy maximization and mass squared conditions would force the points of complex 9-dimensional space defined by 3×3 matrices to a 9-dimensional surface representing group $U(3)$ so that these conditions would have a group theoretic meaning.

The formulas

$$\begin{aligned} r_{i2} &= \sqrt{[-\frac{n_i}{51} + \frac{20}{17}(1 - r_{i1}^2)]} \ , \\ r_{i3} &= \sqrt{[\frac{n_i}{51} - \frac{3}{17}(1 - r_{i1}^2)]} \ . \end{aligned} \tag{6.4.-8}$$

and

$$U = \left[\begin{array}{ccc} c_1 & s_1c_3 & s_1s_3 \\ -s_1c_2 & c_1c_2c_3 - s_2s_3exp(i\delta) & c_1c_2s_3 + s_2c_3exp(i\delta) \\ -s_1s_2 & c_1s_2c_3 + c_2s_3exp(i\delta) & c_1s_2s_3 - c_2c_3exp(i\delta) \end{array} \right] \tag{6.4.-7}$$

give

$$
\begin{array}{ll}
c_1 = r_{11} \ , & c_2 = \frac{r_{21}}{\sqrt{1-r_{11}^2}} \ , \\
s_3 = \frac{r_{13}}{\sqrt{1-r_{11}^2}} \ , & cos(\delta) = \frac{c_1^2c_2^2c_3^2+s_2^2s_3^2-r_{22}^2}{2c_1c_2c_3s_2s_3} \ .
\end{array}
\qquad (6.4.-6)
$$

Preliminary calculations show that for $n_1 = n_2 = 5$ case the matrix of moduli allows a continuation to a unitary matrix but that for $n_1 = 4, n_2 = 6$ the value of $cos(\delta)$ is larger than one. This would suggest that unitarity indeed gives additional constraints on the integers n_i. The unitary (in the numerical accuracy used) $(n_d, n_s) = (5,5)$ D matrix is given by

$$
D = \begin{pmatrix} 0.7059 & 0.7016 & 0.0975 \\ -0.7057 & 0.7017 - 0.0106i & 0.0599 + 0.0766i \\ -0.0608 & 0.0005 + 0.1235i & 0.4366 - 0.8890i \end{pmatrix} \ .
$$

The unitarity of this matrix supports the view that for certain integers n_i the mass squared conditions and entropy maximization reduce to group theoretic conditions. The numerical experimentation shows that the necessary condition for the unitarity is $n_1 > 4$ for $n_2 < 9$ whereas for $n_2 \geq 9$ the unitarity is achieved also for $n_1 = 4$.

Direct search for CKM matrices

The standard gauge in which the first row and first column of unitary matrix are real provides a convenient representation for the topological mixing matrices: it is convenient to refer to these representations as U_0 and D_0. The possibility to multiply the rows of U_0 and D_0 by phase factors ($(U(1) \times U(1))_R$ transformations) provides 2 independent phases affecting the values of $|V|$. The phases $exp(i\phi_j)$, $j = 2,3$ multiplying the second and third row of D_0 can be estimated from the matrix elements of $|V|$, say from the elements $|V_{11}| = cos(\theta_c) \equiv v_{11}$, $sin\theta_c = .226 \pm .002$ and $|V_{31}| = (9.6 \pm .9) \cdot 10^{-3} \equiv v_{31}$. Hence the model would predict two parameters of the CKM matrix, say s_3 and δ_{CP}, in its standard representation.

The fact that the existing empirical bounds on the matrix elements of V are based on the standard model physics raises the question about how seriously they should be taken. The possible existence of fractally scaled up versions of light quarks could effectively reduce the matrix elements for the electro-weak decays $b \rightarrow c + W$, $b \rightarrow u + W$ *resp.* $t \rightarrow s + W$, $t \rightarrow d + W$ since the decays involving scaled up versions of light quarks can be counted as decays $W \rightarrow bc$ *resp.* $W \rightarrow tb$. This would favor too small experimental estimates for the matrix elements V_{i3} and V_{3i}, $i = 1,2$. In particular, the matrix element $V_{31} = V_{td}$ could be larger than the accepted value.

Various constraints do not leave much freedom to choose the parameters n_{q_i}. The preliminary numerical experimentation shows that the choice $(n_d, n_s) = (5,5)$ and $(n_u, n_c) = (5,6)$ yields realistic U and D matrices. In particular, the conditions $|U(1,1)| > .7$ and $|D(1,1)| > .7$ hold true and mean that the original proposal for the solution of spin puzzle of proton must be given up. In [K26] an alternative proposal based on more recent findings is discussed. Only for this choice reasonably realistic CKM matrices have been found.

(a) The requirement that the parameters $|V_{11}|$ (or equivalently, Cabibbo angle and $|V_{31}|$ are produced correctly, yields CKM matrices for which CP breaking parameter J is roughly one half of its accepted value. The matrix elements $V_{23} \equiv V_{cb}$, $V_{32} \equiv V_{tc}$, and $V_{13} \equiv V_{ub}$ are roughly twice their accepted value. This suggests that the condition on V_{31} should be loosened.

(b) The following tables summarize the results of the search requiring that

i. the value of the Cabibbo angle s_{Cab} is within the experimental limits $s_{Cab} = .223 \pm .002$,

ii. $V_{31} = (9.6 \pm .9) \cdot 10^{-3}$, is allowed to have value at most twice its upper bound,

iii. V_{13} whose upper bound is determined by probability conservation, is within the experimental limits $.42 \cdot 10^{-3} < |V_{ub}| < 6.98 \cdot 10^{-3}$ whereas $V_{23} \simeq 4 \times 10^{-3}$ should come out as a prediction,

iv. the CP breaking parameter satisfies the condition $|(J - J_0)/J_0| < .6$, where $J_0 = 10^{-4}$ represents the lower bound for J (the experimental bounds for J are $J \times 10^4 \in (1 - 1.7)$).

The pairs of the phase angles (ϕ_1, ϕ_2) defining the phases $(exp(i\phi_1), exp(i\phi_2))$ are listed below

$$\begin{array}{lccccc} class\ 1: & \phi_1 & 0.1005 & 0.1005 & 4.8129 & 4.8129 \\ & \phi_2 & 0.0754 & 1.4828 & 4.7878 & 6.1952 \\ class\ 2: & \phi_1 & 0.1005 & 0.1005 & 4.8129 & 4.8129 \\ & \phi_2 & 2.3122 & 5.5292 & 0.7414 & 3.9584 \end{array} \quad (6.4.-6)$$

The phase angle pairs correspond to two different classes of U, D, and V matrices. The U, D and V matrices inside each class are identical at least up to 11 digits(!). Very probably the phase angle pairs are related by some kind of symmetry.

The values of the fitted parameters for the two classes are given by

$$\begin{array}{lcccc} & |V_{11}| & |V_{31}| & |V_{13}| & J/10^{-4} \\ class\ 1 & 0.9740 & 0.0157 & 0.0069 & .93953 \\ class\ 2 & 0.9740 & 0.0164 & 0.0067 & 1.0267 \end{array}$$

V_{31} is predicted to be about 1.6 times larger than the experimental upper bound and for both classes V_{23} and V_{32} are roughly too times too large. Otherwise the fit is consistent with the experimental limits for class 2. For class 1 the CP breaking parameter is 7 per cent below the experimental lower bound. In fact, the value of J is fixed already by the constraints on V_{31} and V_{11} and reduces by a factor of one half if V_{31} is required to be within its experimental limits.

U, D and $|V|$ matrices for class 1 are given by

$$U = \begin{bmatrix} 0.7167 & 0.6885 & 0.1105 \\ -0.6910 & 0.7047 - 0.0210i & 0.0909 + 0.1310i \\ -0.0938 & 0.0696 + 0.1550i & 0.1747 - 0.9653i \end{bmatrix}$$
$$D = \begin{bmatrix} 0.7059 & 0.7016 & 0.0975 \\ -0.6347 - 0.3085i & 0.6358 + 0.2972i & 0.0203 + 0.0951i \\ -0.0587 - 0.0159i & -0.0317 + 0.1194i & 0.6534 - 0.7444i \end{bmatrix}$$
$$|V| = \begin{bmatrix} 0.9740 & 0.2265 & 0.0069 \\ 0.2261 & 0.9703 & 0.0862 \\ 0.0157 & 0.0850 & 0.9963 \end{bmatrix} \quad (6.4.-8)$$

U, D and $|V|$ matrices for class 2 are given by

$$U = \begin{bmatrix} 0.7167 & 0.6885 & 0.1105 \\ -0.6910 & 0.7047 - 0.0210i & 0.0909 + 0.1310i \\ -0.0938 & 0.0696 + 0.1550i & 0.1747 - 0.9653i \end{bmatrix}$$

$$D = \begin{bmatrix} 0.7059 & 0.7016 & 0.0975 \\ -0.6347 - 0.3085i & 0.6358 + 0.2972i & 0.0203 + 0.0951i \\ -0.0589 - 0.0151i & -0.0302 + 0.1198i & 0.6440 - 0.7525i \end{bmatrix}$$

$$|V| = \begin{bmatrix} 0.9740 & 0.2265 & 0.0067 \\ 0.2260 & 0.9704 & 0.0851 \\ 0.0164 & 0.0838 & 0.9963 \end{bmatrix} \tag{6.4.-10}$$

What raises worries is that the values of $|V_{23}| = |V_{cb}|$ and $|V_{32}| = |V_{ts}|$ are roughly twice their experimental estimates. This, as well as the discrepancy related to V_{31}, might be understood in terms of the electro-weak decays of b and t to scaled up quarks causing a reduction of the branching ratios $b \rightarrow c + W$, $t \rightarrow s + W$ and $t \rightarrow t + d$. The attempts to find more successful integer combinations n_i has failed hitherto. The model for pseudo-scalar meson masses, the predicted relatively small masses of light quarks, and the explanation for $t\bar{t}$ meson mass supports this mixing scenario.

6.5 Hadron masses

Besides the quark contributions already discussed, hadron mass squared can contain several other contributions and the task is to find a model allowing to identify and estimate these contributions. There are several guidelines for the numerical experimentation.

(a) Conformal weight, that is mass squared, is assumed to be additive for quarks corresponding to the same p-adic prime. For instance, in case of $q\bar{q}$ mesons the mass would be $\sqrt{2}m(q)$ and the contribution of $k = 113$ u, d, s quarks to nucleon mass would be $\sqrt{3} \times 100$ MeV and thus surprisingly small. For cd meson quark masses would be additive.

(b) Old fashioned quark model explains reasonably well hadron masses in terms of constituent quark masses. Effective 2-dimensionality of partons suggests an interpretation for the constituent quark as a composite structure formed by the current quark identified as a partonic 2-surface X^2 characterized by $k(q)$ and by join along boundaries bond, kind of a gluonic "rubber band" characterized by $k = 107$ and connecting X^2 to the $k = 107$ hadronic 2-surface $X^2(H)$ representing hadron. $X^2(q_i)$ could be perhaps regarded as a hole in $k = k(q)$ 3-surface. The 2-dimensional visualization for a 3-dimensional topological condensation would become much more than a mere visualization. This view about hadrons brings in mind unavoidably the surreal 2-dimensional structures formed by organs like retina. Of course, effective 2-dimensionality allows to characterize the entire Universe as an extremely complex fractal 2-surface.

The large mass of the constituent quark would be due to the color Coulombic and spin-spin interaction conformal weights of join along boundaries bond. Quark mass and the mass due to the color interaction conformal weight would be additive unless $k = 107$ for the quark (it seems that for η' this is indeed the case!). Classical color gauge fluxes would flow between $k = 107$ and $k \neq 107$ space-time sheets along the bonds. Color dynamics would take place at $k = 107$ space-time sheet in the sense that color gauge flux between quarks q_1 and q_2 flows first from $X^2((k(q_1)$ to the hadronic 2-surface $X^2(k = 107)$ and then back to $X^2(k(q_2))$. The induced Kähler field is always accompanied by a classical color gauge field and the classical color gauge flux would represent non-perturbative aspects of color interactions at space-time level.

(c) A crucial observation is that the mass of η meson is rather precisely 4 times the pion mass whereas the mass of its spin excited companion ω is very nearly the same as the mass of ρ meson. This suggests that u, d quarks correspond to $k = 109$ inside η but to $k = 113$ inside ω. This inspires the idea that the p-adic mass scale of quarks is dynamical and sensitive to small perturbations as the fact that for CP_2 type extremals the operators corresponding to different p-adic primes reduce to one and same operator forces to suspect. If k characterizes the length scale associated with the elementary particle horizon as $\sqrt{k}$ multiple of CP_2 length scale, quark mass would be characterized by the size of elementary particle horizon sensitive to the dynamics in hadronic mass scale.

    The physical states would result as small perturbations of this degenerate ground state and the value of $k(q)$ would be sensitive to the perturbation. A rather nice fit for meson and baryon masses results by assuming that the p-adic length scale of the quark is dynamical.

(d) In the case of pseudo-scalar mesons the scaled up versions of light quarks identifiable as constituent quarks, turn out to explain almost all of the pseudo scalar meson mass, and this inspires a new formulation for the old vision about pseudo-scalar mesons as Goldstone bosons. At least light pseudo-scalar mesons are Goldstone bosons in the sense that the color Coulombic and spin-spin interaction energies cancel in a good approximation so that quarks at $k \neq 107$ space-time sheets are responsible for most of the meson mass. The assumption that only $k(s)$ is dynamical for light baryons is enough to understand the mass differences between baryons having different numbers of strange quarks.

(e) Color magnetic spin-spin interaction energies are indeed surprisingly constant among baryons. Also for mesons spin-spin interaction energies vary much less than the scaling of quark masses would predict on basis of QCD formula. This motivates the replacement of the interaction energy with interaction conformal weight in the case of color interactions. The interaction conformal weight is assignable to $k = 107$ space-time sheet, and the fact that spin-spin splittings of also heavy hadrons can be measured in few hundred MeVs, supports this identification. The mild dependence of color Coulombic conformal weight and spin-spin interaction conformal weight on hadron would be due to their dependence on the primes $k(q_i)$ and $k = 107$ characterizing space-time sheets connected by the the color bonds $q_i \rightarrow 107$ and $107 \rightarrow q_j$.

(f) The values for the parameters s^c_{ij} and S_{ij} characterizing color Coulombic and color magnetic interaction conformal weights can be deduced from the mass squared differences for hadrons and assuming definite values for the parameters $k(q_i)$ characterizing quark masses. It seems that no other sources to meson mass (or at least pion mass) are needed.

(g) In the case of nucleons the understanding of nucleon mass requires a large additional contribution about 780 MeV since quarks contribute only about 160 MeV to the mass of nucleon. This contribution can be assumed to be same for all baryons as the possibility to understand baryon mass differences in terms of quark masses demonstrates. The most plausible identification of this contribution is in terms of 2- or 3-particle state formed by super-symplectic gluons assignable to $k = 107$ hadronic space-time sheet and having conformal weight $s = 16$ corresponding to mass 934.2 MeV (rather near to nucleon mass and η' mass). This leads to a vision about non-perturbative aspects of color interactions and allows to understand baryon masses with accuracy better than one per cent. Also a connection with hadronic string model emerges and hadronic string tension is predicted correctly.

6.5.1 The definition of the model for hadron masses

The defining assumptions of the model of hadron masses are following. CP_2 mass defines the overall elementary particle mass scale. Electron mass determines this mass only in certain limits.

Model for hadronic quarks

The numerical construction of U and D matrices using the thermodynamical model for the topological mixing justifies the assumptions $n_d = n_s = 5, n_b = 59$ and $n_u = 5, n_c = 6, n_t = 58$.

Quarks can appear both as free quarks and bound state quarks and the value of $k(q)$ is in general different for free and bound state quarks and can depend on hadron in case of bound state quarks. This allows to understand satisfactorily the masses of low lying hadrons.

Quark mass contribution to the mass of the hadron

Quark mass squared is p-adically additive for quarks with same value of p-adic prime. In the case of meson one has

$$m_M^2(p_1 = p_2) = m_{q_1}^2 + m_{q_2}^2 \ . \tag{6.5.1}$$

m_q denotes constituent quark mass which is larger than current quark mass due to the smaller value of k.

Masses are additive for different values of p.

$$m_M(p_1 \neq p_2) = m_{q_1} + m_{q_2} \ . \tag{6.5.2}$$

The generalization of these formulas to the cse of baryons is trivial.

Super-symplectic gluons and non-perturbative aspects of hadron physics

At least in the case of light pseudo-scalar mesons the contribution of quark masses to the mass squared of meson dominates whereas spin 1 mesons contain a large contribution identified as color interaction conformal weight (color magnetic spin-spin interaction conformal weight and color Coulombic conformal weight). This conformal weight cannot however correspond to the ordinary color interactions alone and is negative for pseudo-scalars and compensated by some unknown contribution in the case of pion in order to avoid tachyonic mass. Quite generally this realizes the idea about light pseudo-scalar mesons as Goldstone bosons. Analogous mass formulas hold for baryons but in this case the additional contribution which dominates.

The unknown contribution can be assigned to the $k = 107$ hadronic space-time sheet and must correspond to the non-perturbative aspects of QCD and the failure of the quantum field theory approach at low energies. In TGD the failure of QFT picture corresponds to the presence of WCW degrees of freedom ("world of classical worlds") in which super-symplectic algebra acts. The failure of the approximation assuming single fixed background space-time is in question.

The purely bosonic generators carry color and spin quantum numbers: spin has however the character of orbital angular momentum. The only electro-weak quantum numbers of super-generators are those of right-handed neutrino. If the super-generators degrees carry the quark spin at high energies, a solution of proton spin puzzle emerges [K37] .

The presence of these degrees of freedom means that there are two contributions to color interaction energies corresponding to the ordinary gluon exchanges and exchanges of super-symplectic gluons. For $g = 0$ these gluons are massless and in absence of topological mixing could form a contribution analogous to sea or Bose-Einstein condensate. For $g = 1$ their mass can be calculated. It turns out the model assuming same topological mixing as in case of U quarks leads to excellent understanding of baryon masses assuming that hadron spin correlates with the super-symplectic particle content of the hadronic space-time sheet.

Top quark mass as a fundamental constraint

CP_2 mass is an important parameter of the model. The vanishing second order contribution to electron mass gives an upper bound for CP_2 mass. The bound $Y_e \leq .7357$ can be derived from the requirement that it is possible to reproduce τ mass in p-adic thermodynamics. Maximal second order contribution corresponds to a minimal CP_2 mass reduced by a factor $\sqrt{5/6} = .9129$ from its maximal value. There is a natural mechanism making second order contribution negligible. Leptonic masses tend to be predicted to be few per cent too high [K34] if the second order contribution from p-adic thermodynamics to the electron mass vanishes, which suggests that second order contribution might be there.

For $Y_e = 0$ and $Y_t = 1$ the most recent experimental best estimate 169.1 GeV [C88] for top quark mass is reproduced exactly. Even $Y_t = 0$ allows a prediction in the allowed range. For too large Y_e top quark mass is predicted to be too small unless one allows first order Higgs contribution to the top quark mass. This means that CP_2 mass can be scaled down from its maximal value at most 2.5 per cent. This translates to the condition $Y_e < .26$. It is possible to understand quark masses satisfactorily by assuming that Higgs contribution is second order p-adically and even negligible. In fact, there are good arguments suggesting that Higgs does not develop vacuum expectation at fermionic space-time sheets [K34] . If this is the case, top quark mass gives a very strong constraint to the model.

The super-symplectic color interactions associated with $k = 107$ space-time sheet give rise to the dominant reduction of the color conformal weight having interpretation in terms of color magnetic and electric conformal weights. Canonical correspondence implies that this contribution is always non-negative. Therefore the simple additive formula can lead to a situation in which the contribution of quarks to the meson mass can be slightly larger than meson mass and it is not obvious whether it is possible to reduce this contribution by any means since the reduction of CP_2 mass scale makes top quark mass too small.

For diagonal mesons for which quarks have the same value of p-adic prime, ordinary color interaction between quarks can contribute negative conformal weight reducing the contribution to the mass squared. In the case of non-diagonal mesons it is not clear whether this kind of color interaction exists. This kind of gluons would correspond to pairs of light-like partonic 3-surfaces for which throats correspond to different values of p-adic prime p. These are in principle possible but could couple weakly to matter. It seems that the parameters of the model, essentially CP_2 mass scale strongly constrained by the top quark mass, allow the quark contributions of non-diagonal mesons to be below the mass of the meson.

The fact that standard QCD model for color binding energies works rather well for heavy mesons suggests that the notion of negative color binding energy might make sense and could explain the discrepancy. The mixing of real and p-adic physics descriptions is however aesthetically very un-appealing but might be the only way out of the problem. The p-adic counterpart of this description in case of heavy diagonal mesons would be based on the introduction of a negative color Coulombic contribution to the the conformal weight of quark pair.

Smallness of isospin splittings

The smallness of isospin splittings inside $I_s = 1/2$ doublets poses an further constraint. $d_{113} - u_{113}$ mass difference is about $\Delta m_{d-u} = 13$ MeV and larger than typical isospin splitting. The repulsive Coulomb interaction between quarks typically tends to reduce the mass differences due to Δm_{d-u} and the the sign of Δm_{d-u} explains the "wrong" sign of n-p mass difference equal to $\Delta m_{n-p} = 1.3$ MeV. Non-diagonal hadrons containing scaled up u and d quarks would have anomalously large isospin splittings. On the other hand, for a diagonal meson containing b quark and scaled up u and d quark isospin splitting is proportional to $(m_d^2 - m_u^2)/m_b$ and small. B meson corresponds to this kind of situation.

6.5.2 The anatomy of hadronic space-time sheet

Although the presence of the hadronic space-time sheet having $k = 107$ has been obvious from the beginning, the questions about its anatomy emerged only quite recently after the vision about the spectrum of Kähler coupling strength had emerged [K4, K37] .

In the case of pseudo-scalar mesons quarks give the dominating contribution to the meson mass. This is not true for spin 1/2 baryons and the dominating contribution must have some other origin. TGD allows to identify this contribution in terms of states created by purely bosonic generators of super-symplectic algebra and having as a space-time correlate CP_2 type vacuum extremals topologically condensed at $k = 107$ hadronic space-time sheet (or having this space-time sheet as field body). Proton and neutron masses are predicted with .5 per cent accuracy and $\Delta - N$ mass splitting with .6 per cent accuracy. A further outcome is a possible solution to the spin puzzle of proton proposed already earlier [K37] .

Quark contribution cannot dominate light baryon mass

The first guess would be that the masses give dominating contribution to the mass of baryon. Since mass squared is additive, this would require rather large quark masses for proton and neutron. $k(d) = k(u) = k(s) = 108$ would give $(m(d), m(u), m(s)) = (571.3, 520.4, 616.6)$ MeV and $(m(n), m(p)) = (961.1, 931.7)$ MeV to be compared with the actual masses $(m(n), m(p) = (939.6, 938.3)$ MeV. The difference looks too large to be explainable in terms of Coulombic self-interaction energy. $\lambda - n$ mass splitting would be 27.6 MeV for $k(s) = 108$ which is much smaller than the real mass splitting 176.0 MeV. For $k(s) = 110$ one would have 120.0 MeV.

Does $k = 107$ hadronic space-time sheet give the large contribution to baryon mass?

In the sigma model for baryons the dominating contribution to the mass of baryon results as a vacuum expectation value of scalar field and light pseudo-scalar mesons are analogous to Goldstone bosons whose masses are basically due to the masses of light quarks.

This would suggest that $k = 107$ gluonic/hadronic space-time sheet gives a large contribution to the mass squared of baryon. p-Adic thermodynamics allows to expect that the contribution to the mass squared is in a good approximation of form

$$\Delta m^2 = nm^2(107) \ ,$$

where $m^2(107)$ is the minimum possible p-adic mass mass squared and n a positive integer. One has $m(107) = 2^{10}m(127) = 2^{10}m_e/\sqrt(5) = 233.55$ MeV for $Y_e = 0$ favored by the top quark mass.

(a) $n = 11$ predicts $(m(n), m(p)) = (944.5, 939.3)$ MeV for $k = 113$ quarks: the actual masses are $(m(n), m(p) = (939.6, 938.3)$ MeV. Coulomb repulsion between u quarks could reduce the p-n difference to a realistic value.

(b) $\lambda - n$ mass splitting would be 184.7 MeV for $k(s) = 111$ to be compared with the real difference which is 176.0 MeV. Note however that color magnetic spin-spin splitting requires that the ground state mass squared is larger than $11m_0^2(107)$.

What is responsible for the large ground state mass of the baryon?

The observations made above do not leave much room for alternative models. The basic problem is the identification of the large contribution to the mass squared coming from the hadronic space-time sheet with $k = 107$. This contribution could have the energy of classical color field as a space-time correlate.

(a) The assignment of the energy to the vacuum expectation value of sigma boson does not look very promising since the very existence sigma boson is questionable and it does not relate naturally to classical color gauge fields. More generally, since no gauge symmetry breaking is involved, the counterpart of Higgs mechanism as a development of a coherent state of scalar bosons does not look a plausible idea.

(b) One can however consider the possibility of a Bose-Einstein condensate or of a more general many-particle state of massive bosons possibly carrying color quantum numbers. A many-boson state of exotic bosons at $k = 107$ space-time sheet having net mass squared

$$m^2 = nm_0^2(107) \ , \quad n = \sum_i n_i$$

could explain the baryonic ground state mass. Note that the possible values of n_i are predicted by p-adic thermodynamics with $T_p = 1$.

Glueballs cannot be in question

Glueballs [C7, C19] define the first candidate for the exotic boson in question. There are however several objections against this idea.

(a) QCD predicts that lightest glue-balls consisting of two gluons have $J^{PC} = 0^{++}$ and 2^{++} and have mass 1650 MeV [C19] . If one takes QCD seriously, one must exclude this option. One can also argue that light glue balls should have been observed long ago and wonder why their Bose-Einstein condensate is not associated with mesons.

(b) There are also theoretical objections in TGD framework.

i) Can one really apply p-adic thermodynamics to the bound states of gluons? Even if this is possible, can one assume the p-adic temperature $T_p = 1$ for them if $T_p < 1$ holds true for gauge bosons consisting of fermion-anti-fermion pairs [K4, K37] .

ii) Baryons are fermions and one can argue that they must correspond to single space-time sheet rather than a pair of positive and negative energy space-time sheets required by the glueball Bose-Einstein condensate realized as wormhole contacts connecting these space-time sheets. This argument should be taken with a big grain of salt.

Do exotic colored bosons give rise to the ground state mass of baryon?

The objections listed above lead to an identification of bosons responsible for the ground state mass, which looks much more promising.

1. Super-symplectic gluons

TGD predicts exotic bosons and their super-conformal partners. The bosons created by the purely bosonic part of super-symplectic algebra [K13, K12] , whose generators belong to the representations of the color group and 3-D rotation group but have vanishing electro-weak quantum numbers. Their spin is analogous to orbital angular momentum whereas the spin of ordinary gauge bosons reduces to fermionic spin. The super-partners of the super-symplectic bosons have quantum numbers of a right handed neutrino and have no electro-weak couplings. Recall that super-symplectic algebra is crucial for the construction of WCW Kähler geometry.

Exotic bosons are single-sheeted structures meaning that they correspond to a single wormhole throat associated with a CP_2 type vacuum extremal. The assignment of these bosons to hadronic space-time having $k = 107$ is an attractive idea. The only contribution to the mass would come from the genus and $g = 0$ state would be massless in absence of topological mixing. In this case $g = 0$ bosons could condense on the ground state and define the analog of gluonic contribution to the parton sea. If they mix situation changes.

In the following calculations it is assumed that the contributions to mass from different p-adic primes sum up linearly whereas for contributions with same value of p-adic prime mass squared is additive. This rule is required if one wants to understand the mass differences of mesons and baryons in terms of mass differences due to quark flavor and the dependence of the p-adic length scale of quark on hadron. If one assumes that all contributions to masses sum up quadratically, unreasonably large quark mass differences are required. The objection from QCD based approach is that quarks contribute less than 2 per cent to the mass of the hadron. In TGD sea quarks would correspond to large value of p-adic prime and only their contribution would be so small whereas the contribution of the valence quarks would be of the order of largest quark mass present.

$g = 1$ unmixed super-symplectic boson would have mass squared $9m_0^2(k)$ (mass would be 700.7 MeV). For a ground state containing two $g = 1$ exotic bosons, one would have ground state mass squared $M_0^2 = 18m_0^2$ corresponding to $(m(n), m(p)) = (1160.8, 1155.6)$ MeV. Negative color Coulombic conformal weight and color magnetic spin-spin splitting can reduce the mass of the system. Electromagnetic Coulomb interaction energy can reduce the p-n mass splitting to a realistic value.

(a) Color magnetic spin-spin splitting for baryons gives a test for this hypothesis. The splitting of the conformal weight is by group theoretic arguments of the same general form as that of color magnetic energy and given by $(m^2(N), m^2(\Delta)) = (18m_0^2 - X, 18m_0^2 + X)$ in absence of topological mixing. $n = 11$ for nucleon mass implies $X = 7$ and $m(\Delta) = 5m_0(107) = 1338$ MeV to be compared with the actual mass $m(\Delta) = 1232$ MeV. The prediction is too large by about 8.6 per cent.

(b) If one allows negative color Coulombic conformal weight $\Delta s = -2$ the mass squared reduces by 2 units. The alternative is topological mixing one can have $m^2 = 8m_0^2$ instead of $9m_0^2$. This gives $m(\Delta) = 1240$ MeV so that the error is only .6 per cent. The mass of topologically mixed exotic boson would be 660.6 MeV and equals to m_{104}.

One must consider also the possibility that super-symplectic gluons suffer topological mixing identical with that suffered by say U type quarks in which the conformal weights would be (5,6,58) for the three lowest generations.

(a) For this option the ground state of baryon could consist of 2 gluons of lowest generation and one gluon of second generation $(5 + 5 + 6 = 16)$.

(b) If the mixing is same as for D type quarks with weights (5,5,59), one can have only $s = 15$ state. It turns out that this option allows to predict hadron masses with amazing precision if one assumes correlation between hadron spin and its super-symplectic particle content.

(c) For this option one can even consider the possibility that super-symplectic gluons are are able to represent also color Coulombic conformal weight so that model would simply considerably.

The conclusion is that a many-particle state of super-symplectic bosons could be responsible for the ground state mass of baryon. Also the baryonic spin puzzle caused by the fact that quarks give only a small contribution to the spin of baryons, could find a natural solution since these bosons could give to the spin of baryon an angular momentum like contribution having nothing to do with the angular momentum of quarks.

2. A connection with hadronic string model

Hadronic string model provides a phenomenological description of the non-perturbative aspects of hadron physics, and TGD was born also as a generalization of the hadronic string model. Hence one can ask whether something resembling hadronic string model might emerge from the super-symplectic sector. TGD allows string like objects but the fundamental string tension is gigantic, roughly a factor 10^{-8} of that defined by Planck constant. The hypothesis motivated by the p-adic length scale hypothesis is that vacuum extremals deformed to non-vacuum extremals give to a hierarchy of string like structures with string tension $T \propto 1/L_p^2$, L_p the p-adic length scale. The challenge has been the identification of quantum counterpart of this picture.

The fundamental mass formula of the string model relates mass squared and angular momentum of the stringy state. It has the form

$$M^2 = kJ \ , \ k \simeq .9 \ GeV^2 \ . \tag{6.5.3}$$

A more general formula is $M^2 = kn$.

This kind of formula results from the additivity of the conformal weight (and thus mass squared) if one constructs a many particle state from $g = 1$ super-symplectic bosons with a thermal mass squared $M^2 = M_0^2 n$, $M_0^2 = n_0 m_{107}^2$. The angular momentum of the building blocks has some spectrum fixed by Virasoro conditions. If the basic building block has angular momentum J_0 and mass squared M_0^2, one obtains $M^2 = M_0^2 J$, $k = M_0^2$, $J = nJ_0$. The values of n are even in old fashioned string model for a Regge trajectory with a fixed parity. $J_0 = 2$ implies the same result so that basic unit might be called "strong graviton".

One can consider several candidates for the values of n_0. In the absence of topological mixing one has $n_0 = 9$ for super-symplectic gluons. The bound state of two super-symplectic $g = 1$ bosons with mass squared $M_0^2 = 16m_{107}^2$ (two units of color binding conformal weight) could be responsible for the ground state mass of baryons. If topological mixing occurs and is same as for U type quarks then also a bound state of 2 gluons of first generation and 1 gluon of second generation gives $M_0^2 = 16m_{107}^2$.

The table below summarizes the prediction for the string tension in various cases. The identification of the basic excitations as many-particle states from from bound states of super-symplectic gluons with $M_0^2 = 16m_{107}^2$ predicts the nominal value of the .9 GeV with 3 per cent accuracy.

n_0	5	9	16	18
M_0^2/GeV^2	.273	.490	0.872	0.982

Table 6. The prediction for the hadronic string tension for some values of the mass squared of super-symplectic particle used to construct hadronic excitations.

Pomeron [C158] represented an anomaly of the hadronic string model as a hadron like particle which was not accompanied by a Regge trajectory. A natural interpretation would be as a space-time sheet containing valence quarks as a structure connected by color flux tubes to single structure. There is recent quite direct experimental evidence for the existence of Pomeron [C111, C94, C95] in proton photon collisions: Pomeron seems to leave the hadronic space-time sheet for a moment and collide with photon after which it topologically condenses back to the hadronic space-time sheet. For a more detailed discussion see [K37] .

This picture allows also to consider a possible mechanism explaining spin puzzle of proton and I have already earlier considered an explanation in terms of super-symplectic spin [K37] assuming that state is superposition of ordinary $(J = 0, J_q = 1/2)$ state and $(J = 2, J_q = 3/2)$ state in which super-symplectic bound state has spin 2.

3. Some implications

If one accepts this picture, it becomes possible to derive general mass formulas also for the baryons of scaled up copies of QCD possibly associated with various Mersenne primes and Gaussian Mersennes. In particular, the mass formulas for leptobaryons, in particular "electro-baryons", can be deduced [K70] . Good estimates for the masses of the mesons and baryons of M_{89} hadron physics are also obtained by simple scaling of the ordinary hadron masses by factor 512. Scaled up isospin splittings would be one signature of M_{89} hadron physics: for instance, n-p splitting of 1.3 MeV would scale up to 665.6 MeV.

What about mesons?

The original short-lived belief was that only baryons are accompanied by a pair of super-symplectic bosons condensed at hadronic $k = 107$ space-time sheet. By noticing that color magnetic spin-spin splitting requires an additional contribution to the conformal weight of meson cancelled by spin-spin splitting conformal weight in the case of pseudo-scalar mesons to first order in p, one ends up with the conclusion that also mesons could possess the hadronic space-time sheet.

It is however unclear whether one must included besides the quantized contribution of super-symplectic gluons also color Coulombic contribution having interpretation as perturbative contribution. These contributions are of same form and one could argue that only super-symplectic contribution should be allowed. This would mean very strong quantization rules.

It however turns out that the contribution of super-symplectic massive boson is necessarily only in the case of $\pi - \rho$ system and produces mere nuisance in the case of heavier mesons. The special role of $\pi - \rho$ system could be understood in terms of color confinement which would make pion $k = 107$ tachyon without the presence of additional mass squared.

Assuming topological mixing of super-symplectic bosons to be same as for U type quarks, the super-symplectic contribution must correspond to a conformal weight of 5 units in the case of pion and thus to *single* super-symplectic boson with $m^2 = 5m_{107}^2$ instead of $9m_{107}^2$ as for $g = 1$ super-symplectic bosons. A possible interpretation is in terms of $g = 0$ boson which has suffered a topological mixing. That 5 units of conformal weight result also in the topological mixing of u and d quarks supports this option and forces to ask whether also super-symplectic topological mixing is same inside baryons and mesons. If it is same for U type quarks and super-symplectic bosons one has $(s_1, s_2, s_3) = (5, 6, 58)$ for the super-symplectic gluons. As noticed, $S_{SC} = 16$ for baryons is obtained if one has a bound state of 2 bosons of first generation and one boson of second generation giving $s_{SC} = 5 + 5 + 6 = 16$. One can wonder how tightly the super-symplectic gluons are associated with baryonic valence quarks.

6.5.3 Pseudoscalar meson masses

The requirement that all contributions to the meson masses have p-adic origin allows to fix the model uniquely and also constraints on the value of the parameter Y_e emerge. In the following only pseudo-scalar mesons will be considered.

Light pseudo-scalar mesons as analogs of Goldstone bosons

Fractally scaled up versions of light quarks allow a rather simple model for hadron masses. In the old fashioned $SU(3)$ based quark model η meson is regarded as a combination $u\overline{u} + d\overline{d} - 2s\overline{s}$. The basic observation is that η mass is rather precisely 4 times the mass of π whereas the mass of ω is very near to ρ mass. This suggests that η results by a fractal scaling of quark masses obtained by the replacement $k(q) = 113 \rightarrow 109$ for the quarks appearing in η. This inspires the idea that mesonic quarks are scaled up variants of light quarks and at least light pseudo-scalar mesons are almost Goldstone bosons in the sense that quark contribution to the mass is as large as possible but smaller than meson mass. This idea must of course be taken as an interesting ansatz and in the end of the chapter it will be found that this idea might work only in the case of pion and kaon systems.

Quark contributions to meson masses

The following table summarizes the predictions for quark contributions to the masses of mesons assuming $k(q)$ depending on meson and assuming $Y_e = 0$ guaranteeing maximum value of top quark mass.

Meson	*scaled quarks*	$m_q(M)/MeV$	m_{exp}/MeV
π^0	d_{113}, u_{113}	140.0	135.0
π^+	d_{113}, u_{113}	140.0	139.6
K^0	d_{114}, s_{109}	495.5	497.7
K^+	u_{114}, s_{109}	486.3	493.7
η	$u_{109}, d_{109}, s_{109}$	522.2	548.9
η'	$u_{107}, d_{107}, s_{107}, c_{107}$	1144.2	957.6
$\eta' = B_{SC} + \sum_i q_i\overline{q}_i$	q_{118}	959.2	957.6
η_c	c_{104}	3098	2980
D^0	c_{105}, u_{113}	1642	1865
D^+	c_{105}, d_{113}	1654	1870
Υ	b_{103}	10814	9460
B	$b_{104}, d_{104}, u_{104}$	5909	5270

Table 7. Summary of the model for contribution of quarks to the masses of mesons containing scaled up u,d, and s quarks. The model assumes the maximal value of CP_2 mass allowed by η' mass and the condition $Y_e = 0$ favored by top quark mass.

(a) The quark contribution to pion mass is predicted to be 140 MeV, which is by few percent above the pion mass. Ordinary color interactions between pionic quarks can however reduce the conformal weight of pion by one unit. The reduction of CP_2 mass scaled cannot be considered since it would reduce top quark mass to 163.3 GeV which is slightly below the favored range of values [C88] .

(b) The success of the fit requires that spin-spin splitting cancels the mass of super-symplectic boson in a good approximation for pseudo-scalar mesons. This would be in accordance with the Goldstone boson interpretation of pseudo-scalar mesons in the sense that color contribution to the mass from $k = 107$ space-time sheet vanishes in the lowest p-adic order.

(c) In the case of η *resp.* η' meson it has been assumed that the states have form $(u\overline{u} + \overline{d} - 2s\overline{s})/\sqrt{6}$ *resp.* $(u\overline{u} + \overline{d} + s\overline{s})/\sqrt{3}$.

(d) B mesons have anomalously large coupling to $\eta' K$ and $\eta' X$ [C99], which indicates an anomalously large coupling of η' to gluons [C37] . The interpretation has been in terms of a considerable mixing η' with gluon-gluon bound state.

η' mass is only 2.5 per cent higher than the mass $4m_{107}$ of super-symplectic boson B_{SC} associated with the hadronic space-time sheet of hadron. Large mixing scenario is however not consistent with the existence of Φ with nearly the same mass. This encourages to consider the possibility that η' corresponds to a super-symplectic boson B_{SC} plus quark pair with $k(d) = k(u) = k(s) = k(c) = 118$ with maximal mixing. In this case the contribution of quarks to the mass would be 25.1 MeV and one would have $m(\eta') = 959.2$ MeV which coincides with the actual mass with 1 per mille accuracy. Note that this model predicts identical couplings to various quark pairs as does also the model assuming that $\eta' - \Phi$ system is singlet with respect to flavor $SU(3)$ (having no fundamental status in TGD).

It is clear from the above table that the quark contributions to the masses of π, η' and B are slightly above the meson masses. In the case of B the discrepancy is largest and about 12 per cent. If one assumes that all contributions to the mass have p-adic origin, they are necessarily non-negative.

(a) In the case of diagonal mesons the ordinary color interactions can reduce the contribution of quark masses to the mass of the meson. In the case of η' baruyonic super-symplectic gluon B_{SC} could resolve the problem.

(b) In the case of non-diagonal mesons the only possible solution of the problem is that $Y_e > 0$ holds true so that mass scale is reduced by a factor $1 - P = \sqrt{5/(5 + Y_e)}$ giving

$Y_e \simeq .056$. The prediction for top quark mass is reduced by 1.1 per cent to 167.2 GeV which belongs to the allowed range [C88] .

(c) In the case of B meson one is forced to assume $k_b = k_d = k_u = 104$ although it would be possible to achieve smaller quark contribution by an alternative choice. This choice explains the observed very small isospin splitting and diagonality allows the ordinary color interaction to reduce the quark contribution to the B meson mass.

(d) At the end of the chapter an alternative scenario in which quark masses give in good approximation only the masses of pion and kaon will be considered.

An example about how the mesonic mass formula works

The mass of the B_c meson (bound state of b and c quark) has been measured with a precision by CDF (see the blog posting by Tommaso Dorigo [C87]) and is found to be $M(B_c) = 6276.5 \pm 4.8$ MeV. Dorigo notices that there is a strange "crackpottian" co-incidence involved. Take the masses of the fundamental mesons made of $c\bar{c}$ (Ψ) and $b\bar{b}$ (Υ), add them, and divide by two. The value of mass turns out to be 6278.6 MeV, less than one part per mille away from the B_c mass!

The general p-adic mass formulas and the dependence of k_q on hadron explain the co-incidence. The mass of B_c is given as $m(B_c) = m(c, k_c(B_c)) + m(b, k_b(B_c))$, whereas the masses of Ψ and Υ are given by $m(\Psi) = \sqrt{2}m(c, k_\Psi)$ and $m(\Upsilon) = \sqrt{2}m(b, k_\Upsilon)$. Assuming $k_c(B_c) = k_c(\Psi)$ and $k_b(B_c) = k_b(\Upsilon)$ would give $m(B_c) = [m(\Psi) + m(\Upsilon)]/\sqrt{2}$ which is by a factor $\sqrt{2}$ higher than the prediction of the "crackpot" formula. $k_c(B_c) = k_c(\Psi) + 1$ and $k_b(B_c) = k_b(\Upsilon) + 1$ however gives the correct result.

As such the formula makes sense but the one part per mille accuracy must be an accident in TGD framework.

(a) The predictions for Ψ and Υ masses are too small by 2 *resp.* 5 per cent in the model assuming no effective scaling down of CP_2 mass.

(b) The formula makes sense if the quarks are effectively free inside hadrons and the only effect of the binding is the change of the mass scale of the quark. This makes sense if the contribution of the color interactions, in particular color magnetic spin-spin splitting, to the heavy meson masses are small enough. Ψ and η_c correspond to spin 1 and spin 0 states and their masses by 3.7 per cent ($m(\eta_c) = 2980$ MeV and $m(\Psi) = 3096.9$) so that color magnetic spin-spin splitting is measured using per cent as natural unit.

6.5.4 Baryonic mass differences as a source of information

The first step in the development of the model for the baryon masses was the observations that $B - n$ mass differences can be understood if baryons are assumed to contain scaled versions of strange and heavy quarks. The deduction of precise values of $k(q)$ is however not quite straightforward since the color magnetic contribution to the mass affects the situation. Thus a working hypothesis worth of studying is that ground state contribution is same for all baryons and that for spin 1/2 baryons quark contribution to the mass added to this contribution is near as possible to the real mass but smaller than it.

The purpose of the following explicit is to to convince the reader that baryon mass difference can be indeed understood in terms of quark mass differences. This of course requires that quark space-time sheet is not the hadronic $k = 107$ space-time sheet. Otherwise quadratic mass formula applies.

(a) $\Lambda - n$ mass difference is 176 MeV and $(k(s) = 111, k(d) = 114)$ for λ would predict the mass difference $m(\lambda) - m(n) = m_q(\lambda) - m_q(n)$, where one has $m_q(\lambda) = m(s_{111}) + \sqrt{2}m(d_{114}) - m(n)$, $m_q(n) = \sqrt{m(u_{113})^2 + 2m(d_{113})^2)}$. The prediction equals to 141 MeV. It is possible to achieve smaller discrepancy but more precise considerations support this identification. Note that the spin-spin interaction energy is same if u and

d quark form the paired quark system which is in $J = 0$ or $J = 1$ state so that the mass difference indeed can be regarded as quark mass difference.

(b) $\Sigma - n$ mass difference is 257 MeV. If sigma contains s_{111}, u_{114} and d_{114}, the mass difference is predicted to be $m_q(\Sigma) - m_q(n)$, $m_q(\Sigma) = m(s_{111}) + \sqrt{2}m(d_{114})$ and comes out as 228 MeV.

(c) If Ξ contains two s_{110} quarks and u_{113} (d_{113}), he mass difference comes out as 351 MeV to be compared with the experimental value 381 MeV.

(d) Even single hadron, such as Ω, could contain several scaled up variants of s quark. $s_{108} + 2s_{111}$ decomposition would give mass difference 718 MeV to be compared with the real mass difference 734 MeV.

(e) For Λ_c the mass is 2282 MeV. For $k(c) = 105$ instead of $k(c) = 104$ the predicted $\Lambda_c - n$ mass difference is 1341 MeV whereas the experimental difference is 1344 MeV.

(f) For Λ_b the mass is 5425 MeV. For $k(b) = 104$ instead of $k(b) = 103$ the predicted $\Lambda_b - n$ mass difference is 4403 MeV. The experimental difference is 4485 MeV.

Baryon	*s content*	$\Delta m/MeV$	$\Delta m_{exp}/MeV$
Λ	s_{111}	141	176
Σ	s_{110}	228	257
Ξ	$s_{110} + s_{111}$	351	381
Ω	$s_{108} + 2s_{110}$	718	734
Λ_c	$c_{105}, d_{112}, u_{112}$	1341	1344
Λ_b	$b_{105}, u_{106}, d_{106}$	4403	4485

Table 8. Summary of the model for the quark contribution to the masses of baryons containing strange quarks deduced from mass differences and neglecting second order contributions to the mass. Δm denotes the predicted $B - n$ mass difference $m(B) - m(n)$. The subscript 'exp' refer to experimental value of the quantity in question.

6.5.5 Color magnetic spin-spin splitting

Color magnetic hyperfine splitting makes it possible to understand the $\rho - \pi$, $K^{\star} - K$, $\Delta - N$, etc. mass differences [B12] . That the order of magnitude for the splittings remains same over the entire spectrum of hadrons serves as a support for the idea that color fluxes are feeded to $k = 107$ space-time sheet. This would suggest that color coupling strength does not run for the physical states and runs only for the intermediate states appearing in parton description of the hadron reactions. A possible manner to see the situation in terms of intermediate states feeding color gauge flux to space-time sheets with $k > 107$ so that the additive color Coulombic interaction conformal weights $s(q_i, q_j)$ would depend only on the integers $k(q_i), k(q_j)$. It will be found that the dependence is roughly of form $1/(k(q_i)+k(q_j))$, which brings in mind a logarithmic dependence of α_s on p-adic length scales involved.

There are two approaches to the problem of estimating spin-spin splitting: the first one is based on spin-spin interaction energy and the second one on spin-spin interaction conformal weight. The latter one turns out to be the only working one.

The model based on spin-spin interaction energy fails

Classical model would apply real number based physics to estimate the splittings and calculate color magnetic interaction energies. Standard QCD approach predicts that the color magnetic interaction energy is of form

$$\Delta E = S \sum_{pairs} \frac{\bar{s}_i \cdot \bar{s}_j}{m_i m_j r_{ij}^3} \ . \qquad (6.5.4)$$

The mass differences for hadrons allow to deduce information about the nature of color magnetic interaction and make some conclusions about the applicability this model.

(a) For mesons the spin-spin splitting various from 630 MeV for $\rho - \pi$ system to 120 MeV $\Psi - \eta_c$ excludes the classical model predicting that the splitting should be proportional to $1/m(q_1)m(q_2)$ (variation by a factor $2^{113-106} = 128$ instead of 5 would be predicted if the size of the hadron remains same). Also the predicted ratio of $K^* - K$ splitting to $\rho - \pi$ splitting would be 1/4 rather than .63. The ratio of $\eta - \omega$ splitting to $\rho - \pi$ splitting would be 1/16 rather than .34. The ratio of $\Phi - \eta\prime$ splitting to $\rho - \pi$ splitting would be $1/32 \simeq .03$ instead of .11.

The inspection of the spin-spin interaction energies would suggest that the interaction energy scales $E(i,j)$ obey roughly the formula

$$E(i,j) \sim \frac{5}{2} \times \frac{1}{(\Delta k(q_1) + \Delta k(q_2))} =$$

$$5 \times \frac{1}{log_2\{[L(113)/L(k(q_1)] \times [L(113)/L(k(q_2)]\}}$$

$$\Delta k(q) = 113 - k(q)$$

rather than being proportional to $2^{-k(q_1)-k(q_1)}$. The hypothesis that p-adic length scale $L(k)$ of order CP_2 length scale range corresponds to the size of elementary particle horizon associated with wormhole contacts feeding gauge fluxes of the CP_2 type extremal representing particle to the larger space-time sheet with $p \simeq 2^k$ might allow to understand this dependence.

(b) $\Delta - N$, $\Sigma^* - \Sigma$, and $\Xi^* - \Xi$ mass differences are 291 MeV, 194 MeV, 220 MeV. If strange quark inside Σ corresponds to $k = 110$, the ratio of $\Sigma^* - \Sigma$ splitting to $\Delta - N$ splitting is predicted to be by a factor 1.17 larger than experimental ratio. $\Xi^* - \Xi$ splitting assuming $k(s) = 109$ the ratio would be .19 and quite too small. Assuming that s, u, d quarks have more or less same mass, the model would predict reasonably well the ratios of the splittings. Either the idea about scaled up variants of s is wrong or the notion of interaction energy must be replaced with interaction conformal weight in order to calculate the effects of color interactions to hadron masses.

The modelling of color magnetic spin-spin interaction in terms of conformal weight

The model based on the notion of interaction conformal weight generalizes the formula for color magnetic interaction energy to the p-adic context so that color magnetic interaction contributes directly to the conformal weight rather than rest mass. The effect is so large that it must be p-adically first order (the maximal contribution in second order to hadron mass would be however only 224 MeV) and the generalization of the mass splitting formula is rather obvious:

$$\Delta s = \sum_{pairs} S_{ij} \bar{s}_i \cdot \bar{s}_j \quad . \tag{6.5.5}$$

The coefficients S_{ij} depend must be such that integer valued Δs results and CP_2 masses are avoided: this makes the model highly predictive. Coefficients can depend both on quark pair and on hadron since the size of hadron need not be constant. In any case, very limited range of possibilities remains for the coefficients.

This might be understood if the color flux tube carrying color magnetic flux and connecting quark to $k = 107$ hadronic space-time sheet is also characterized by a value of $k \geq 113$. This fixes practically completely the model in the case of mesons. If the interaction strengths $s_c(i,j)$ characterizing color Coulombic interaction conformal weight between two quarks depends only on the flux tube pair connecting the quarks via $k = 107$ space-time sheet via the integers $k(q_i)$, the model contains only very few parameters.

The modelling of color magnetic- spin-spin splitting in terms of super-symplectic boson content

The recent variant for the model of the color magnetic spin-spin splitting replacing energy with conformal weight is considerably simpler than the earlier one. Still one can argue that a model using perturbative QCD as a format is not the optimal one in a genuinely non-perturbative situation.

The explicit comparison of the super-symplectic conformal weights associated with spin 0 and spin 1 states on one hand and spin 1/2 and spin 3/2 states on the other hand is carried out at the end of the chapter. The comparison demonstrates that the difference between these states could be understood in terms of super-symplectic particle contents of the states by introducing only single additional negative conformal weight s_c describing color Coulomb binding . s_c is constant for baryons($s_c = -4$) and in the case of mesons non-vanishing only for pions ($s_c = -5$) and kaons ($s_c = -12$). This leads to an excellent prediction for the masses also in the meson sector since pseudo-scalar mesons heavier than kaon are not Golstone boson like states in this model.

The correlation of the spin of quark-system with the particle content of the super-symplectic sector increases dramatically the predictive power of the model since the allowed conformal weights of super-symplectic bosons are (5,6,58). One can even consider the possibility that also exotic hadrons with different super-symplectic particle content exist: this means a natural generalization of the notion of Regge trajectories. This description will be summarized at the end of the chapter.

6.5.6 Color magnetic spin-spin interaction and super-symplectic contribution to the mass of hadron

Since $k = 107$ contribution to hadron mass is always non-negative, spin-spin interaction conformal weight and also color Coulombic conformal weight must be subtracted from some additional contribution both in the case of pseudo-scalars and spin 1/2 baryons.

Baryonic case

In the case of baryons the additional contribution could be identified as a 2-particle state of super-symplectic bosons with mass squared $9m_{107}^2$ in case of baryons. The net mass is $s_{CS} = 18m_{107}^2$. The study of $N - \Delta$ system shows that color Coulomb interaction energy for single super-symplectic structural unit corresponds to $\Delta s_{SC} = -2$ in the case of nucleon system so that one has $s_{SC} = 18 \rightarrow 16$. If topological mixing for super-symplectic bosons is same as for U type quarks with conformal weights (5,6,58), the already discussed three-particle state of would give $s_{SC} = 5 + 5 + 6 = 16$.

The basic requirement is that the the sum of spin-spin interaction conformal weight and s_{CS} reduces to the conformal weight corresponding to the difference of nucleon mass and quark contribution to 774.6 MeV and corresponds to $s = 11$.

One might hope that the situation could be the same for all baryons but it is safer to introduce an additional color Coulombic conformal weight $s_c(B)$ which vanishes for $N - \Delta$ system and hope that it is small as suggested by the fact that quark contributions explain quite satisfactorily the mass differences of baryons. This conformal weight could be assigned to the interaction of quarks via super-symplectic gluons and would represent a correction to the simplest model. Strictly speaking, the term "*color Coulombic*" should be taken as a mere convenient letter sequence.

Pseudo scalars

In the case of pseudo-scalars the situation is not so simple. What is clear that quark masses determine the meson mass in good accuracy.

In this case s_{CS} can be determined uniquely from the requirement that in case of pion it is cancelled the conformal weight characterizing $\rho - \pi$ color magnetic spin-spin splitting:

$$s_{SC} = |\Delta s(\pi, spin - spin)| \ . \tag{6.5.6}$$

This gives $s_{SC} = 21/4 \simeq 5$.

The conformal weights assignable to gluons and super-symplectic gluon must compensate the negative color magnetic spin-spin splitting making pion a tachyon. The following options represent the extremes

(a) A positive color Coulombic conformal weight assignable to ordinary gluons compensates the negative conformal weight .

(b) Conformal weight of the lightest topologically mixed super-symplectic gluon takes care of the compensation.

The interpretation as a bound state of unmixed super-symplectic $g = 1$ with $n = 9$ and massless $g = 0$ gluon would require binding conformal weight by 4 units i which looks somewhat strange. The masslessness of $g = 0$ gluon does not support the formation of this kind of bound state. An alternative option is in terms of topological mixing in which case $g = 0$ boson should receive 5 units of conformal weight which is near to the .

Explicit calculations demonstrate that for mesons heavier than pion the role of s_c is to compensate s_{SC}. This suggests that the boson of lowest generation is present only inside $\pi - \rho$ system and prevents the large and negative color magnetic spin-spin interaction conformal weight to make pion a tachyon. The special role of pion could be understood in terms of a phase transition to color confining phase. Note however that the mass of η' could be understood by assuming baryonic super-symplectic boson of conformal weight $s_{SC} = 16$ and fully mixed $k = 118$ quarks.

Formulas for $s_c(H)$ for mesons

There are two options to consider. For option I one has $s_{SC} = 5$ for all mesons. For option II s_{CS} vanishes for all mesons except π and ρ. For option I one obtains the formula

$$s_c(M) = -s_{SC} - \Delta s(M_0, spin - spin) = -5 + |\Delta s(M_0, spin - spin)| \ . \tag{6.5.6}$$

For option II one has

$$s_c(M) = -5 + |\Delta s(M_0, spin - spin)| \ , \ M = \pi, \rho \ , \tag{6.5.6}$$

$$s_c(M) = |\Delta s(M_0, spin - spin)| \ , \ M \neq \pi, \rho \ . \tag{6.5.7}$$

M_0 refers to the pseudo-scalar.

Formulas for $s_c(H)$ for baryons

In the case of spin 1/2 baryons the requirement that the sum of color Coulombic and color magnetic conformal weights is same as for nucleons fixes the values of $s_c(B)$:

$$\begin{aligned} s_c(B) &= s_0 - s_{SC} - \Delta s(B_{1/2}, spin - spin) = -5 + |\Delta s(B_{1/2}, spin - spin)| \ , \\ s_{SC} &= 16 \ , \\ s_0 &= S(m(n) - m_q(n), 107) \ , \\ m_q(n) &= \sqrt{2m_d^2 + m_u^2} \ , \\ S(x, 107) &\equiv [(\frac{x}{m_{107}})^2] \ . \end{aligned} \quad (6.5.4)$$

$s_0 = 11$ corresponds to the contribution difference of (say) neutron mass and quark contribution to the nucleon mass. s_{CS} corresponds to the conformal weight due to super-symplectic bosons. In the defining formula for $S(x, 107)$ $[x]$ denotes the integer closest to x.

The conformal weights associated with spin-spin splitting

The general formula for the spin-spin splitting allowing to determine the parameters S_{ij} from the masses of a pair $H^\star - H$ of hadrons (say $\rho - \pi$ or $\Delta - N$). The parameters can be deduced from the observation that the mass difference $m(M^*) - m(M)$ for mesons corresponds to the difference of spin-splitting contributions to the mass:

$$\Delta s(M^*) - \Delta s(M) = S(m(M^*) - m(M), 107) \ . \quad (6.5.5)$$

For baryons one has

$$\begin{aligned} \Delta s(B^*) - \Delta s(B) &= X_1 - X_0 \ , \\ X_1 &= S(m(B^*) - m_q(B), 107) = \ , \\ X_0 &= S(m(B) - m_q(B), 107) \ . \end{aligned} \quad (6.5.4)$$

Here $m_q(B) = m_q(B^*)$ denotes the quark contribution to the nucleon mass. The possibility to understand the mass differences of spin 1/2 baryons in terms of differences for$m_q(B)$ inspires the hypothesis that X_0 is constant also for baryons (it vanishes for mesons). If so X_0 can be determined from neutron mass as

$$\begin{aligned} X_0 &= S(m(n) - m_q(n), 107) \ , \\ m_q(n) &= \sqrt{2m_d^2 + m_u^2)} \ . \end{aligned} \quad (6.5.4)$$

Here $m_q(n)$ is the contribution of quarks to neutron mass.

These formulas are *not* identical with those used in the earlier calculations and the difference is due to the fact that $k = 107$ contributions and quark contributions are calculated separately unless quarks correspond $k = 107$. The formula allows to calculate second order contribution to the mass splitting.

p-Adicization brings in additional constraints. The requirement that the predicted mass of spin 1 boson and spin 3/2 fermion is not larger than than the experimental mass can pose strong constraints the scaling factor $\sqrt{5/(5+Y_e)}$ in the case of non-diagonal hadrons unless one is willing to modify the model for spin-spin splittings. It was already found that in case of $\rho-\pi$ system this implies that top quark mass is at the lower limit of the allowed mass interval. One cannot take these constraints so seriously as the constraints that quark mass contribution is lower than meson mass in the case the quarks do not correspond to $k=107$.

General mass formula

The general formula for the mass of hadron can be written as a sum of perturbative and non-perturbative contributions as

$$m(H) = m_P + m_{NP} \quad . \tag{6.5.5}$$

Preceding considerations lead to a simple formula for the non-perturbative contribution m_{NP} to the masses of spin 0 and spin 1 doublet of mesons:

$$\begin{aligned} m_{NP}(M) &= \sqrt{s_{NP}(M)} \times m_{107} \ , \\ s_{NP}(M_0) &= 0 \ , \\ s_{NP}(M_1) &= S(m(M^*) - m(M), 107) \ . \end{aligned} \tag{6.5.4}$$

For spin 1/2 and 3/2 doublet of baryons one has

$$\begin{aligned} m_{NP}(B) &= \sqrt{s_{NP}(B)} \times m_{107} \ , \\ s_{NP}(B_{1/2}) &= S(m_n - \sqrt{2m_d^2 + m_u^2}, 107) \ , \\ s_{NP}(B_{3/2}) &= S(m(B^*) - m_q(B), 107) \ . \end{aligned} \tag{6.5.3}$$

Perturbative contribution m_P contains in the lowest order approximation only the contribution of quark masses. In the case of diagonal mesons also a contribution from the ordinary color-Coulombic force and color magnetic spin-spin splitting can be present. For heavy mesons this contribution seems necessary since pure quark contribution is exceeds by few per cent the mass of meson.

Spin-spin interaction conformal weights for baryons

Consider now the determination of S_{ij} in the case of baryons. The general splitting pattern for baryons resulting from color Coulombic, and spin-spin interactions is given by the following table. The following equations summarize spin-spin splittings for baryons in a form of a table.

$baryon$	J	J_{12}	Δs^{spin}
N	$\frac{1}{2}$	0	$-\frac{3}{4}S_{d,d}$
Δ	$\frac{3}{2}$	1	$\frac{3}{4}S_{d,d}$
Λ	$\frac{1}{2}$	0	$-\frac{3}{4}S_{d,d}$
Σ	$\frac{1}{2}$	0	$-\frac{3}{4}S_{d,d}$
Σ^*	$\frac{1}{2}$	0	$\frac{1}{4}S_{d,d}$ $+\frac{1}{2}S_{d,s}$
Ξ	$\frac{1}{2}$	0	$-\frac{3}{4}S_{s,s}$
Ξ^*	$\frac{1}{2}$	0	$\frac{1}{4}S_{s,s}$ $+\frac{1}{2}S_{d,s}$
Ω	$\frac{3}{2}$	1	$\frac{3}{4}S_{s,s}$

(6.5.3)

Spin-spin splittings are deduced from the formulas

$$\begin{aligned} \Delta s^{spin} &= S_{q_1,q_)}(\frac{J_{12}(J_{12}+1)}{2}-\frac{3}{4}) \ , \\ &+ \frac{1}{4}(S_{q_1,q_3}+S_{q_2,q_3})(J(J+1)-J_{12}(J_{12}+1)-\frac{3}{4}) \ , \end{aligned} \tag{6.5.2}$$

where J_{12} is the angular momentum eigenvalue of the 'first two quarks', whose value is fixed by the requirement that magnetic moments are of correct sign.

The masses determine the values of the parameters uniquely if one assumes that color binding energy is constant as indeed suggested by the very notion of M_{107} hadron physics. The requirement is that the mass difference squared for $\Delta - N$, $\Sigma^* - \Sigma$, and $\Xi^* - \Xi$ come out correctly.

Consider now the values of S_{ij} for the models assuming $k = 113$ light quarks and dynamical $k(s)$.

(a) For $N - \Delta$ system the equation is

$$S_{d_{113},d_{113}} = \frac{1}{3}S(m(\Delta) - m_q(N), 107) - S(m(N) - m_q(N), 107) \ .$$

Here $m_q(N)$ refers to the quark contribution to the baryon mass.

(b) For $\Sigma^* - \Sigma$ system the basic equation can be written as

$$S_{d_{114},s_{110}} = 2[S(m(\Sigma^*) - m_q(\Sigma), 107) - S(m(\Sigma) - m_q(\Sigma), 107) - S(d_{114}, d_{114})] \ .$$

One must make some assumption in order to find a unique solution. The simplest assumption is that $S_{d_{114},d_{114}} = S_{d_{114},s_{110}}$. This implies

$$S_{d_{114},d_{114}} = \frac{1}{3}[S(m(\Sigma^*) - m_q(\Sigma), 107) - S(m(\Sigma) - m_q(\Sigma), 107)] \ .$$

(c) In the case of $\Xi^* - \Xi$ system the equation is

$$S_{s110,s110} = -\frac{1}{2}S_{d113,s110} + [S(m(\Xi^*) - m_q(\Xi), 107) - S(m(\Xi) - m_q(\Xi), 107)] \ .$$

If one assumes $S_{s110,s110} = S_{d113,s110}$ one obtains

$$S_{s110,s110} = \frac{1}{3}[S(m(\Xi^*) - m_q(\Xi), 107) - S(m(\Xi) - m_q(\Xi), 107)] \ .$$

The resulting values of the parameters characterizing baryonic spin-spin splittings are in the table below. The parameters rela

$S_{d113,d113}$	$S_{d114,d114}$	$S_{d114,s110}$	$S_{s110,s110}$	$S_{d113,s110}$
7	6	6	$\frac{8}{3}$	$\frac{8}{3}$

(6.5.3)

The mass squared unit used is m_0^2 and $k = 107$ defines the p-adic length scale used. The elements of $S_{i,j}$ between different p-adic primes are assumed to be vanishing. The matrix elements are quite near to each other which raises the hope that the model indeed makes sense.

Color Coulombic binding conformal weights are given by the expression $s_c = -5 + |\Delta s(B_{1/2}, spin-spin)|$. The weights are given in the following table

baryon	N	Σ	Ξ
s_c	$\frac{1}{4}$	$-\frac{1}{2}$	-3

(6.5.3)

Some remarks are in order.

(a) A good sign is that the values of s_c are small as compared to the value of $s_{CS} = 18$ in all baryons so that only a small correction is in question.

(b) The magnitude of s_c increases with the mass of baryon which does not conform with the expectations raised by ordinary QCD evolution. Could this mean that asymptotic freedom means that the color interaction between quarks occurs increasingly via super-symplectic gluons? For $N - \Delta$ system the actual value of s_c should vanish.

(c) One might worry about the fact the color binding conformal weights are not integral valued. The total conformal weights determining the mass squared are however integers.

Spin-spin interaction conformal weights for mesons

The values of mesonic interaction strengths $S_{i,j}$ can in principle deduced from the observed mass splittings. The following equations summarize the spin-spin splitting pattern for mesons in a form of table.

$meson$	Δs^{spin}
π	$-\frac{3}{4}S_{d,d}$
ρ	$\frac{1}{4}S_{d,d}$
η	$-\frac{3}{4}S_{d,d}$
ω	$\frac{1}{4}S_{d,d}$
$K^{\pm}, K^0(CP=1)$	$-\frac{3}{4}S_{d,s}$
$K^0(CP=-1)$	$-\frac{3}{4}S_{d,s}$
$K^{*,\pm}, K^{*,0}(CP=1)$	$\frac{1}{4}S_{d,s}$
$K^{*,0}(CP=-1)$	$\frac{1}{4}S_{d,s}$
η'	$-\frac{3}{4}S_{s,s}$
Φ	$\frac{1}{4}S_{s,s}$
η_c	$-\frac{3}{4}S_{c,c}$
Ψ	$\frac{1}{4}S_{c,c}$
$D^{\pm}, D^0(CP=1)$	$-\frac{3}{4}S_{d,c}$
$D^0(CP=-1)$	$-\frac{3}{4}S_{d,c}$
$D^{*,\pm}, D^{*0}(CP=1)$	$\frac{1}{4}S_{d,c}$
$D^{*0}(CP=-1)$	$\frac{1}{4}S_{d,c}$

(6.5.3)

Consider the spin-spin interaction for mesons.

(a) For $\rho - \pi$ system one has

$$S_{d_{113},d_{113}} = s(m(\rho) - m_q(\pi)) \ .$$

Using $s(\rho) = 14$ and $s(\pi) = 0$ gives $S(d_{113}, d_{113}) = 13$.

(b) $\omega - \eta$ system one obtains

$$S_{q_{109},q_{109}} = S(m(\omega) - m_q(\eta), 107)$$

(c) $K^\star - K$-splitting gives $S_{d_{114},s_{109}} = S(m(K^*) - m_q(K), 107)$.

(d) $\Phi - \eta'$ splitting gives $S_{q_{107},q_{107}} = S(m(\Phi) - m_q(\eta'), 107)$.

(e) $D^* - D$ mass splitting gives $S_{d_{113},c_{105}} = S(m(D^*) - m_q(D), 107)$.

(f) $\Psi - \eta_c$ mass difference gives $S_{c_{104},c_{104}} = s(m(\Psi) - m_q(\eta_c), 107)$.

The results for the spin-spin interaction strengths S_{ij} are summarized in the table below. q_{109} refers to u, d, and s quarks.

$S_{d_{113},d_{113}}$	$S_{q_{109},q_{109}}$	$S_{q_{107},q_{107}}$	$S_{d_{114},s_{109}}$	$S_{d_{113},c_{105}}$	$S_{c_{104},c_{104}}$
7	1	0	3	2	0

(6.5.3)

Note that interaction strengths tend to be weaker for mesons than for baryons. For scaled up quarks the value of interaction strength tends to decrease and is smaller for non-diagonal than diagonal interactions. Since the values of $k(q_i)$ maximize the quark contribution to hadron masses, the interaction strength produce a satisfactory mass fit for hadrons with errors of not larger than about five cent.

The color Coulombic binding conformal weights for meson states are given in the following table:

$meson$	π	K	η	η'	D	ψ
$s_c(I)$	$+1/4$	$-4-1/4$	-6	$-3-1/4$	$-4-1/2$	-5
$s_c(II)$	$1/4$	$3/4$	1	$1+3/4$	$1/2$	0

(6.5.3)

For option I $g = 1$ boson is present in all mesons. The magnitude of s_c increases with the mass of the meson and more or less compensates $s_{CS} = 5$. This forces to consider the possibility that only pion contains the super-symplectic boson compensating the large and negative spin-spin interaction conformal weight making the state tachyon otherwise. The alternative possibility is that positive color Coulomb energy due to sea gluons does this. For option II s_c is relatively small and positive for this option.

6.5.7 Summary about the predictions for hadron masses

The following tables summarize the predictions for baryon masses following from the proposed model with optimal choices of the integers $k(q)$ characterizing the mass scales of quarks and requiring that the predicted isospin splittings are of same order than the observed splittings. This condition is non-trivial: for instance, in case of B meson the smallness of splitting forces the condition $k(b) = k(d) = k(u) = 104$ so that mass squared is additive and the large contribution of b quark minimizes the isospin splitting.

Meson masses assuming that all pseudo-scalars are Goldstone bosons

$Meson$	$quarks$	$m_{pr}(M)/MeV$	m_{exp}/MeV
π^0	d_{113}, u_{113}	140.0	135.0
π^+	d_{113}, u_{113}	140.0	139.6
ρ^0	d_{113}, u_{113}	756	772
ρ^+	d_{113}, u_{113}	756	770
K^0	d_{114}, s_{109}	496	498
K^+	u_{114}, s_{109}	486	494
K^{0*}	d_{114}, s_{109}	896	900
K^{+*}	u_{114}, s_{109}	892	891
η	$u_{109}, d_{109}, s_{109}$	522	549
ω^0	$u_{109}, d_{109}, s_{109}$	817	783
η'	$u_{107}, d_{107}, s_{107}, c_{107}$	1144	958
Φ	$u_{107}, d_{107}, s_{107}, c_{107}$	1144	1019
η_c	c_{104}	3098	2980
D^0	c_{105}, u_{113}	1642	1865
D^+	c_{105}, d_{113}	1655	1870
D^{*0}	c_{105}, u_{114}	1971	2007
D^{*+}	c_{105}, d_{114}	1985	2010
F	$c_{105}, s(106)$	1954	2021
Υ	b_{103}	10814	9460
B	$b_{104}, d_{104}, u_{104}$	5909	5270

Table 9. The prediction of meson masses. The model assumes the maximal value of CP_2 mass allowed by η' mass and the condition $Y_e = 0$ favored by top quark mass.

In the case of meson masses the predictions for masses are not so good as for baryons. Errors are at worst about 5 per cent. For non-diagonal mesons the predicted masses are smaller than actual masses and in the case of kaons excellent. Also the prediction of pion mass is good but about 5 per cent too large. In the case of diagonal mesons ordinary color interactions could reduce the predicted masses in case that they are larger than actual ones.

Meson masses assuming that only pion and kaon are Goldstone bosons

The Golstone boson interpretation does not seem completely satisfactory. In order to make progress one can check whether the masses associated with super-symplectic bosons could serve as basic units for pseudo-scalar and vector boson masses. A more general fit would be based on the use of fictive boson B_{107} with mass m_{107} as a basic unit in $k = 107$ contribution to the mass. The table below gives very accurate formulas for the meson masses in terms of the scale m_{107} and quark contribution to the masses.

$Meson$	$quarks$	$m_{pr}(M)/MeV$	m_{exp}/MeV
π^0	d_{113}, u_{113}	140.0	135.0
π^+	d_{113}, u_{113}	140.0	139.6
ρ^0	$7B_{107} + d_{113}, u_{113}$	758	772
ρ^+	$7B_{107} + d_{113}, u_{113}$	758	770
K^0	d_{114}, s_{109}	496	498
K^+	u_{114}, s_{109}	486	494
K^{0*}	$3B_{107} + d_{114}, s_{109}$	901	900
K^{+*}	$3B_{107} + u_{114}, s_{109}$	891	891
η	$B_{SC,1} + u_{118}, d_{118}, s_{118}$	548	549
ω^0	$2B_{SC,1} + u_{118}, d_{118}, s_{118}$	803	783
η'	$2B_{SC,1} + B_{SC,2} + q_{118}$	959	958
Φ	$2B_{SC,1} + B_{SC,2} + q_{118}$	959	1019
η_c	$2B_{SC,1} + c_{105}$	2929	2980
Ψ	$3B_{SC,1} + c_{105}$	3098	3100
D^0	$2B_{SC,1} + c_{106}, u_{118}$	1853	1865
D^+	$2B_{SC,1} + c_{106}, d_{118}$	1850	1870
D^{*0}	$3B_{SC,1} + c_{106}, u_{118}$	2019	2007
D^{*+}	$3B_{SC,1} + c_{106}, d_{118}$	2016	2010
F	$3B_{SC,2} + c_{105}, s(113)$	2010	2021
Υ	$B_{SC,3} + b_{104}$	9441	9460
$B^{\pm}$	$3B_{SC,2} + b_{105}, d_{105}, u_{105}$	5169	5270

Table 10. Table demonstrates that scalar and vector meson masses can be effectively regarded as expressible in terms of quark contribution and contribution coming from many particle states of super-symplectic bosons $B_{SC,k}$, $k = 1, 2, 3$, with conformal weights (5,6,58) associated also with U type quarks. B_{107} denotes effective super-symplectic boson with conformal weight 1 and mass $m_{107} = 233.6$ MeV. $Y_e = 0$ favored by top quark mass is assumed.

The table demonstrates following.

(a) For mesons heavier than kaons, the masses can be expressed effective sums of masses for quarks and many-particle state formed by super-symplectic bosons allowed by the topological mixing of U type quarks. For lighter mesons it is not possible to express the masses in terms of the conformal weights of quarks and super-symplectic gluons. This suggests that one must introduce positive color Coulombic conformal weight as the analog of positive Coulomb energy. The simplest assumption is that this conformal weight compensates for the color-magnetic spin-spin splitting in the case pf pseudo-scalars and to the Goldstone boson option. This option indeed looks more reasonable.

(b) For $\pi - \rho$ *resp.* $K - K^*$ systems the masses can be expressed using effective $7B_{107}$ state state *resp.* $3B_{107}$ state. Second order contribution to the conformal weight from the super-symplectic color interaction can explain the too small mass of ρ and too large mass of π if it interferes with the corresponding quark mass contribution.

(c) For pseudo-scalars heavier than kaon the mass of the super-symplectic meson is not completely compensated by spin-spin splitting for the pseudo-scalar state so that Goldstone boson interpretation does not make sense anymore. In the case of heavy mesons the predicted masses of pseudo-scalars are slightly below the actual mass.

(d) The predicted masses are not larger than actual masses (ω_0 is the troublemaker) if one assumes 2.5 per cent reduction of CP_2 mass scale for which top quark mass is at the lower bound of the allowed mass range.

(e) Color magnetic spin-spin splitting parameters can be deduced from the differences of super-symplectic conformal weights for pseudo-scalar and spin one boson. There is however no absolute need for this perturbative construct.

(f) One can consider the possibility that the super-symplectic boson content is actual and correlates with the spin of quark-antiquark system for mesons heavier than kaons. The point would be that the representability in terms of super-symplectic bosons would make the model for the color magnetic spin-spin splittings highly predictive. This interpretation makes sense in the case of $\pi-\rho$ and $K-K^*$ systems only if one introduces negative color Coulombic conformal weight s_c. For heavier mesons only this contribution would be second order in p which is more or less consistent with the view about color coupling evolution. $\pi-\rho$ would correspond to B_1 ($s=5$) and $2B_2$ ($s=12$) ground states with color Coulombic conformal weight $s_c=-12$. $K-K^*$ would correspond to $2B_2$ ($s=12$) and $3B_1$ with $s_c=-12$. The presence of ground state bosons saves π and K from becoming tachyons.

Whatever the correct physical interpretation of the mass formulas represented by the table above is, it is clear that m_{107} defines a fundamental mass scale also for meson systems.

Baryon masses

One can ask whether the representability of spin-spin splitting in terms of super-symplectic conformal boson content is possible also in the case of baryons so that perturbative formulas altogether would not be necessary. The physical interpretation would be that the total spin of baryonic quarks correlates with the content of super-symplectic bosons. The existence of this kind of representation would be one step towards understanding of also spin-spin splitting from first principles.

This is indeed the case if one accepts negative color Coulombic conformal weight $s_c=-4$. What is disturbing is that the sign of the corresponding parameter is positive for mesons and compensates color magnetic spin-spin splitting for pseudo-scalars (for Goldstone option). Spin 1/2 ground states would correspond to $3B_1$ with conformal weight $s=15$, one B_1 for each valence quark. Spin 3/2 states would correspond to $5B_1$ with $s=25$ in the case of Δ, to $2B_1+B_2$ in the case of Σ^* with $s=23$, and to B_1+3B_2 with $s=24$ in case of Ξ^*.

$Baryon$	$quarks$	$m_{pr}(B)/MeV$	m_{exp}/MeV
p	$3B_1 + u_{113}, d_{113}$	942.3	938.3
n	$3B_1 + u_{113}, d_{113}$	949.8	939.6
Δ^{++}	$5B_1 + u_{113}$	1230	1231
Δ^{+}	$5B_1 + u_{113}, d_{113}$	1238	1235
Δ^{0}	$5B_1 + u_{113}, d_{113}$	1245	1237
Δ^{-}	$5B_1 + d_{113}$	1253	≤ 1238
Λ	$3B_1 + u_{114}, d_{114}, s_{111}$	1090	1116
Σ^{+}	$3B_1 + u_{114}, s_{110}$	1165	1189
Σ^{0}	$3B_1 + u_{114}, d_{113}, s_{110}$	1171	1192
Σ^{-}	$3B_1 + d_{114}, s_{110}$	1178	1197
Σ^{*+}	$2B_1 + 2B_2 + u_{114}, s_{110}$	1381	1385
Ξ^{0}	$2B_1 + 2B_2 + u_{113}, s_{110}, s_{111}$	1301	1315
Ξ^{-}	$3B_1 + d_{113}, s_{110}$	1288	1321
Ξ^{*0}	$B_1 + 3B_2 + u_{113}, s_{110}$	1531	1532
Ξ^{*-}	$B_1 + 3B_2 + d_{113}, s_{110}$	1505	1535
Ω^{-}	$3B_1 + s_{108}, s_{111}$	1667	1672
Λ_c	$3B_1 + d_{110}, u_{110}, c_{106}$	2261	2282
Λ_b	$3B_1 + d_{108}, u_{108}, b_{105}$	5390	5425

Table11. The predictions for baryon masses assuming $Y_e = 0$. One can represent color magnetic spin-spin splittings by assuming different super-symplectic boson content for spin 1/2 and spin 3/2 states. The number of super-symplectic bosons need not be however different for them.

From the table for the predicted baryon masses one finds that the predicted masses are slightly below the experimental masses for all baryons except for some baryons in $N-\Delta$ multiplet and for Ω. The reduction of the CP_2 mass scale by a factor of order per cent consistent with what is known about top quark mass cures this problem (also ordinary color interactions could take of the problem).

In principle the quark contribution to the hadron mass is measurable. Suppose that color binding conformal weight can be assigned to the color interaction in super-symplectic degrees of freedom alone. Above the "ionization" energy, which corresponds to the contribution of quarks to the mass of hadron, valence quark space-time sheet can separate from the hadronic space-time sheet in the collisions of hadrons. This threshold might be visible in the collision cross sections for say nucleon-nucleon collisions. For nucleons this energy corresponds to 170 MeV.

6.5.8 Some critical comments

The number theoretical model for quark masses and topological mixing matrices and CKM matrix as well as the simple model for hadron masses give strong support for the belief that the general vision is correct. One must bear in mind that the scenario need not be final so that the basic objections deserve an explicit articulation.

Is the canonical identification the only manner to map mass squared values to their real counterparts

In p-adic thermodynamics p-adic particle mass squared is mapped to its real counterpart by the canonical identification. If the $O(p)$ contribution corresponds to non-trivial rational number, the real mass is of order CP_2 mass. This allows to eliminate a large number of exotics. In particular, it implies that the modular contribution to the mass squared must be of form np rather than $(r/s)p$. This assumption is absolutely crucial in the model of topological mixing matrices and CKM matrix.

One can however question the use of the standard form of the canonical identification to map p-adic mass squared to its real counterpart. The requirement that p-adic and real S-matrix elements (in particular coupling constants) are related in a realistic manner, forces a modification of the canonical identification. Instead of a direct identification of real and p-adic rationals, the p-adic rationals in R_p are mapped to real rationals (or vice versa) using a variant of the canonical identification $I_{R\to R_p}$ in which the expansion of rational number $q = r/s = \sum r_n p^n / \sum s_n p^n$ is replaced with the rational number $q_1 = r_1/s_1 = \sum r_n p^{-n} / \sum s_n p^{-n}$ interpreted as a p-adic number:

$$q = \frac{r}{s} = \frac{\sum_n r_n p^n}{\sum_m s_n p^n} \to q_1 = \frac{\sum_n r_n p^{-n}}{\sum_m s_n p^{-n}} = \frac{I(r)}{I(s)} \quad . \tag{6.5.4}$$

The nice feature of this variant of the canonical identification is that it respects quantitative behavior of amplitudes, respects symmetries, and maps unitary matrices to unitary matrices if the matrix elements correspond to rationals (or generalized rationals in algebraic extension of rationals) if the p-adic integers involved are smaller than p. At the limit of infinitely large p this is always satisfied.

Quite generally, the thermodynamical contribution to the particle mass squared is in the lowest p-adic order of form rp/s, where r is the number of excitations with conformal weight 1 and s the number of massless excitations with vanishing conformal weight. The real counterpart of mass squared for the ordinary canonical identification is of order CP_2 mass by $r/s = R + r_1 p + ...$ with $R < p$ near to p. Hence the states for which massless state is degenerate become ultra heavy if r is not divisible by s. For the new variant of canonical identification these states would be light.

Even worse, the new form does not require the modular contribution to the p-adic mass squared to be of form np. Some other justification for this assumption would be needed. The first guess is that the conditions on mass squared plus probability conservation might not be consistent with unitarity unless the modular contribution to the mass squared remains integer valued in the mixing (note that all integer values are not possible). Direct numerical experimentation however shows that that this is not the case.

The predicted integer valued contributions to the mass squared are minimal in the case of u and d quarks and very nearly maximal in the case t and b quarks. This suggests a possible way out of the difficulty. Perhaps the rational valued p-adic mass squared of u and d quarks are minimal and those of b and t quarks maximal or nearly maximal. This might also allow to improve the prediction for the CKM matrix.

The objection against the use of the new variant of canonical identification is that the predictions of p-adic thermodynamics for mass squared are not rational numbers but infinite power series. p-Adic thermodynamics itself however defines a unique representation of probabilities as ratios of generalized Boltzmann weights and partition function and thus the variant of canonical identification might indeed generalize. If this representation generalizes to the sum of modular and Virasoro contributions, then the new form of canonical identification becomes very attractive. Also an elegant model for the masses of intermediate gauge bosons results if $O(p)$ contribution to mass squared is allowed to be a rational number.

Uncertainties related to the CP_2 length scale

The uncertainties related to the CP_2 length scale mean that one cannot take the detailed model for hadron masses too literally unless one takes the recent value of top quark mass at face value and requiring $(Y_e = 0, Y_t = 1)$ in rather high accuracy. This constraint allows at most 2.5 per cent reduction of the fundamental mass scale and baryonic masses suggest a 1 per cent reduction. The accurate knowledge of top quark mass is therefore of fundamental importance from the point of view of TGD.

Chapter 7

Higgs or Something Else?

7.1 Introduction

The question whether TGD predicts Higgs or not has been one of the longstanding issues of TGD. For 10 years ago I would not have hesitated to tell that TGD does not predict Higgs and had good looking arguments for my claim. During years my views have been alternating between Higgs and no-Higgs option. In the light of after wisdom the basic mistake has been the conscious attempt to localize precisely the location of the problem and suggest a minimal modification of standard theory picture to solve it.

Now the situation is settled experimentally: Higgs is there. It is however somewhat too light so that Higgs mechanism is not stable against radiative corrections. SUSY cannot take care of this problem since LHC demonstrated that SUSY mass scale is too high. One has the problem known as loss of "naturalness". Hence Higgs is not yet a fully written page in the history of physics. Furthermore, the experiments demonstrate the existence of Higgs, not the reality of Higgs mechanism. Higgs mechanism in fermionic sector is indeed an ugly duckling: the dimensionless couplings of fermions to Higgs vary in huge range: 12 orders of magnitude between neutrinos and top quark.

This is what motivates to write a separate chapter about Higgs in TGD framework. Originally the idea was to represent various approaches to Higgs in TGD framework. I decided however to save reader from the sad story and try to tell about the recent situation. I am however unable to continue before I list my worst sins during last years.

(a) I have considered the identification of Higgs candidate as pion (or perhaps sigma) of M_{89} hadron physics predicted by p-adic length scale hypothesis. There are good reasons to expect that this pion exists: the strange behavior of what was expected to be quark gluon plasma both in heavy ion collisions and in collisions of protons with heavy ions supports the existence of string like hadronic objects in TeV scale. M_{89} pion cannot be however identified with Higgs.

(b) On basis of zero energy ontology (ZEO) I have proposed that there are no Higgs like states and even their superpartners should be absent. All massless multiplets would generate small mass and "eat" the generalized Higgs like states with smaller helicities than the defining helicity. Even photon and graviton would have small mass. This idea does not however have obvious realization based on gauge invariance: the gauge boson for which charge matrix commutes with Higgs direction must remain massless unless p-adic thermodynamics provides a small mass for it.

(c) I have considered a hybrid of p-adic thermodynamics and Higgs mechanism in which Higgs develops a coherent state and gives masses to gauge bosons whereas fermions would get the dominating contribution to their mass from p-adic thermodynamics. Now this proposal looks ugly.

To confess all, I have even discussed a proposal for a microscopic description of the tachyonic term in Higgs potential based on the coupling of pseudo-scalar Higgs to instanton term.

7.1.1 Can one do without standard model Higgs?

There are several arguments against standard model Higgs, which by definition provides masses for both weak gauge bosons and fermions.

(a) Essentially one assumption, the separate conservation of quark and lepton numbers realized in terms of 8-D chiral invariance, excludes Higgs like states in scalar particles in *8-D sense* as also standard $\mathcal{N} = 1$ SUSY: here Higgs likeness means that the couplings to fermions are proportional to fermion masses.

If Higgs like states exist, they must be Minkowski scalars and vectors in CP_2 tangent space or CP_2 spinors. Higgs doublets indeed have this interpretation. One motivation for assuming absence of Higgs is that CP_2 geometry does not allow any covariantly constant vector so that no acceptable classical correlate for Higgs vacuum expectation exists. I have however proposed that CP_2 part for the trace of the second fundamental form serve as this correlate: it cannot be however covariantly constant.

The minimal conclusion is that Higgs particle can quite well exist but that its vacuum expectation value as coviantly constant CP_2 vector cannot.

(b) Zero energy ontology led much later to an argument against Higgs: all Higgs like particles could be "eaten" by gauge bosons and even other particles with spin.

   i. The view about bosons as wormhole throats carrying fermionic quantum numbers are the opposite light-like wormhole throats of the contact makes it very difficult to assume that scalar particles would not exist. On the other hand, twistorial considerations force to assume that the wormhole throats as basic building bricks of particles are massless and that even virtual particles correspond to composites of on mass shell massless states with both signs of energy allowed. Massless fermions with unphysical helicity can indeed appear as virtual particles.

   ii. This argument seems to force the conclusion that spin 1 particles are necessary massive. Higgs like wormhole throats can be however massless since the helicities of massless fermion and anti-fermion are opposite so that the light-like momenta are parallel.

   This inspired the crazy proposal that all Higgs like particles might be eaten by gauge bosons (also photon would be massive). Even the super-partners of Higgs bosons would experience the same fate.

   iii. The assumption that photon "eats" neutral Higgs is *not* consistent with the picture provided by gauge invariance: in unitary gauge weak bosons are massive and photon remains massless since em charge matrix commutes with the direction of Higgs field defined by its vacuum expectation value. In fact, in TGD framework CP_2 geometry fixes unique direction of Higgs field and thus unitary gauge so that vacuum expectation value is not needed for this purpose. p-Adic thermodynamics could take care of massivation of at least fermions. The massivation of gauge bosons requires something more [K34].

   One should not however make too hasty conclusions: photon could get very small mass from p-adic thermodynamics as also weak bosons: weak bosons get additional mass by eating three components of Higgs like particle. In the case of photon one should however understand where the third polarization comes from.

(c) There are very general arguments requiring new physics at TeV scale. Also standard model Higgs has its difficulties with radiative corrections and standard SUSY has been the candidate for this new physics. The data from LHC however suggest that standard SUSY is not the choice of Nature. TGD proposal has been new hadron physics obtained as scaled up variant of standard hadron physics. The pion of this hadron physics could yield decay signatures suggesting interpretation as Higgs like state. I have considered this option seriously but it is excluded by experimental facts.

7.1.2 Why Higgs like particle is needed?

There are also several arguments in favor of Higgs like particle. These arguments do not however require Higgs vacuum expectation value.

(a) The W/Z mass ratio having group theoretic origin (Higgs should transform as $2+\overline{2}$ under $U(2)$) and predicted correctly by Higgs mechanism is a strong argument in favor that gauge boson massivation can be understood in terms of Higgs mechanism. Higgs would provide the third polarization states of gauge bosons becoming manifest in unitary gauge: this however requires only gauge invariance and *some* condition defining the unitary gauge. In standard model Higgs vacuum expectation defines the unitary gauge. In TGD framework CP_2 geometry takes care of this so that Higgs vacuum expectation is not needed unless massivation requires it.

(b) In TGD framework the masses of fermions are predicted with amazing accuracy by p-adic thermodynamics. It however fails to provide elegant explanation for W/Z mass ratio [K34]: it seems that the contribution of p-adic thermodynamics to gauge boson masses corresponds to same p-adic temperature as for photon and is therefore very small due to the lower p-adic temperature quantized as $T = 1/n$ (for fermions one has $T = 1$). Therefore one can consider the possibility that Higgs like state gives weak bosons their masses. This kind of hybrid model looks ugly.

(c) A more elegant option is based on the realization that elementary particles correspond to pairs of wormhole contacts connected by strings assignable to 2-D string world sheet at which fermionic modes are localized by the requirement that the modes are eigenstates of em charge. This suggests that there is an additional stringy contribution to the masses of the particles and that for weak bosons this contribution dominates over the contribution from p-adic thermodynamics. The contribution could be present also for fermions but would be small for leptons. In hadrons the contribution would dominate over quark contributions and is usually identified as gluonic contribution.

    The stringy contribution to gauge boson mass squared could be expressed in terms of formula involving string tension just as the contribution from p-adic thermodynamics in degrees of freedom assignable to wormhole contacts. The proper mathematical framework for expressing this contribution could be Yangian symmetry expanding super-conformal symmetries and involving two conformal weights instead of one [K34].

The conclusion is that Higgs seems to be needed but that the vacuum expectation of Higgs is not encouraged by the propoerties of CP_2 geometry. Only the neutral Higgs particles having representation completely analogous to that for gauge bosons and fermions would appear in the spectrum in unitary gauge. The fermion content of Higgs is determined from the condition that it forms $SU(2)_L$ doublet and $SU(2)_R$ singlet.

7.1.3 The recent situation

The existence of Higgs like particle is now established. Often this is taken as proof for particle massivation based on Higgs mechanism. There are however two very disturbing findings. The mass of Higgs like particle is somewhat too small so that radiative corrections to the mass of the Higgs instabilize the situation and fine tuning is required to reproduce experimental mass. The original hope was $\mathcal{N} = 1$ supersymmetry would help by cancelling the radiative corrections at high energies but on basis of observations made at LHC the mass scale of SUSY particles seems to be too high to achieve this. Predictivity is lost.

There is also the difficulty than one can only reproduce the fermion masses rather than being able to really predict them and the mass scales of fermion masses are widely different (consider only top/neutrino mass ratio of order 10^{12}!). It seems that one cannot avoid the introduction of the notion of mass scale depending on particle as a new degree of freedom.

Here TGD could finally add the missing piece of the puzzle. If one wants QFT description then the only possibility is the description based on Higgs mechanism but this is only an effective description - the best that one can have if one assumes point like particles. If one gives up this dogma, p-adic thermodynamics making sense in zero energy ontology provides the natural description and brings in the hierarchy of p-adic length scales via p-adic length scale hypothesis.

(a) Higgs mechanism is replaced by p-adic thermodynamics. The couplings of Higgs to fermions are by dimensional arguments very naturally gradient couplings with coupling constant, which has dimensions of inverse mass. This dimensional coupling is same for all fermions so that naturalness is achieved.

(b) Massivation of gauge bosons combines Higgs components and weak gauge bosons to massive particles in unitary gauge but leaves photon massless apart from small higher order corrections form p-adic thermodynamics.

(c) W/Z mass squared ratio - the source of troubles in p-adic thermodynamics based approach - is expressible in terms of corresponding gauge coupling strengths g_i^2, $i = W, Z$, if the string tension of the flux tube connecting the two wormhole contacts assignable to gauge boson is proportional to g_i^2.

(d) p-Adic thermodynamics relying on super-conformal invariance can describe only the contributions of wormhole contacts to the particle masses [K34]. The contributions from "long strings" connecting different wormhole contacts cannot be calculated. To achieve this one must generalize conformal invariance to Yangian invariance and define p-adic thermodynamics for the representations of Yangian.

The recent construction of WCW geometry [K86] indeed leads to a picture allowing interpretation in terms of Yangian extension of super-conformal invariance. The matrix elements of WCW metrix are labelled by two conformal weights assignable to the light-like radial coordinate of light-cone boundary and to the coordinate along string defining the boundary of string world sheet at which fermions are located from the condition that spinor modes have a well-defined value of em charge.

It has recently become clear that the boundary conditions for the Kähler-Dirac equation lead to the appearence of analog of classical Higgs field but this seems to prove space-time counterpart for the stringy mass formula and could also allow to understand why the ground state conformal weight of super-conformal representations is negative half integer plus something p-adically small (tachyonicity).

This chapter is an attempt to summarize the recent view of related to the status of Higgs in TGD. It is certainly not a summary of final results in a concise form and can still contain contradictory arguments containing delicate errors. Also the recent situation is critical and the experimental results from LHC will be decisive for future developments.

The appendix of the book gives a summary about basic concepts of TGD with illustrations. There are concept maps about topics related to the contents of the chapter prepared using CMAP realized as html files. Links to all CMAP files can be found at `http://www.tgdtheory.fi/cmaphtml.html` [L20]. Pdf representation of same files serving as a kind of glossary can be found at `http://www.tgdtheory.fi/tgdglossary.pdf` [L21]. The topics relevant to this chapter are given by the following list.

- TGD view about elementary particles [L49]
- p-Adic mass calculations [L37]
- Higgs in TGD [L28]

7.2 Background

In the following some general background related to particle massivation and Higgs is summarized.

7.2.1 GUT paradigm

The leading thread in the story of particle physics is GUT paradigm, which emerged for four decades ago. It however has its problems besides the fact that not a single thread of evidence has accumulated to support it.

(a) The basic idea of GUTs is to put all fermions and bosons to multiplets of some big gauge group extending the standard model gauge group. This idea is applied also in the generalization of gauge theories to supersymmetric gauge theories and in superstring models. Scalar fields developing vacuum expectations define a key element of this approach and give hopes of obtaining a realistic mass spectrum. This rather simple minded approach would make unification an easy job. There are however difficulties.

(b) One of the basic implications is that baryon and lepton numbers are not conserved separately. Proton decays would make this non-conservation manifest. These decays have not been however observed, and one of the challenges of the GUT based models is fine-tuning of couplings so that proton is long-lived enough. This raises the question whether one could somehow understand the separate conservation of B and L from basic principles.

(c) Putting all fermions in the same multiplet would suggest that the mass ratios for fermions should be simple algebraic numbers not too far from unity. Fermion families have however widely differing mass scales and the ratio of top quark mass scale to neutrino mass scale is gigantic. This suggests that fermion generations and even different charge states of fermions of single generation are characterized by inherent mass scales and do not belong to a multiplet of a big gauge group. Standard model gauge group would be the fundamental gauge group and the challenge would be to deduce it from some fundamental principles. In TGD framework number theoretical vision indeed leads to an explanation for standard model gauge group [K67].

It is also an empirical fact that fermion generations are identical copies of each other apart from widely different masses. This suggests some non-group theoretic explanation for family replication phenomenon. In TGD framework 2-D wormhole throats characterized topological by their genus in orientable category are the fundamental particle like objects. This provides a possible explanation for the family replication phenomenon. One must of course explain why genera higher than $g = 2$ are heavy or absent from the spectrum, and one can indeed develop an argument for this based on the fact that $g \leq 2$ 2-surfaces allow always Z_2 as conformal symmetries unlike $g > 2$ 2-surfaces [K14].

(d) Particle massivation is in GUT framework is described by coupling the fermions and gauge bosons to a scalar field. The vacuum expectation values of the scalar fields define the mass scales. In the case of standard model one has only single scalar/Higgs field and by choosing the couplings to Higgs field to be proportional to fermion mass one can reproduce particle masses. Only a reproduction is in question and theory is certainly not microscopic. Vacuum expectation value (VEV) paradigm is central also for the inflationary cosmology - in fact for the entire theoretical particle physics developed during last decades. The no-existence of Higgs would force to return to the roots to the situation four decades ago. Therefore the new spinless particle could be a turning point in the history of physics, and it is easy to understand why the attitudes against or on behalf of Higgs interpretation are so passionate and why facts tend to be forgotten.

7.2.2 How to achieve separate conservation of B and L?

A possible manner to understand the separate conservation of both B and L would be via the identification of spinors as different chiralities of higher-dimensional spinors.

(a) This would however require the identification of color quantum numbers as angular momentum like quantum numbers assignable to partial waves in internal space. This is indeed the identification performed in TGD framework and $H = M^4 \times CP_2$ is the unique choice of imbedding space coding for the standard model quantum numbers. In

TGD approach quarks and leptons correspond to different imbedding space chiralities, and this excludes Higgs as a genuine imbedding space scalar since it would couple to quark-lepton pairs. To get the couplings correctly Higgs should correspond to imbedding space vector having components only the direction of CP_2 but it is rather difficult to imagine how gauge bosons could "eat" components of Higgs in this case. As a matter fact, Higgs components should be characterized by same charge matrices as weak bosons and would be a TGD counterpart for a mixture of scalar and pseudo-scalar.

(b) Chiral invariance is indeed essential for the renormalizability of 4-D gauge theories.The absence of 8-D scalars would allow also a generalization of chiral invariance from 4-D to 8-D context implying separate conservation of B and L. This is the case even in string model framework if separate conservation of B and L is assumed. It is worth of mentioning that the separate conservation of B and L is not consistent with the standard $\mathcal{N}=1$ SUSY realized in terms of Majorana spinors. This is not a catastrophe since LHC has already excluded quite a considerable portion of parameter space for $\mathcal{N}=1$ SUSY. $\mathcal{N}=2$ SUSY however is and is generated in TGD framework by right-handed neutrino and its antiparticle.

There are however quite intricate delicacies involved discussed in detail in [K80]. For instance, the modes of covariantly constant right-handed neutrino spinor of CP_2 generates 4-D generalization of super-conformal symmetry as modes de-localized into entire space-time surfaces whereas other modes are localized to 2-D surfaces and generate badly broken SUSY with very large value of $\mathcal{N}$. An open question is whether the ν_R covariantly constant also in M^4 degrees of freedom could generate $\mathcal{N}=1$ SUSY analogous to the standard SUSY. In any case, TGD seems to be inconsistent with both scalar VEV paradigm and standard $\mathcal{N}=1$ SUSY.

The recent work with WCW geometry and spinors structure (definition of gamma matrices) suggests strongly that super-conformal symmetries generalizes to their Yangian variants meaning that one has two conformal weights and multi-locality. Second integer corresponds to the the integer assignable to strings connecting wormhole contacts.

(c) p-Adic physics and p-adic length scale hypothesis allow to understand the widely different mass scales of fermions and various gauge bosons since p-adic prime and the primary p-adic length scale defined by it become the characterizers of elementary particle. Also the secondary p-adic length and time scales are important: for electron secondary p-adic time scale is .1 seconds and quite intriguingly the fundamental time scale of biology. p-Adic thermodynamics provides the microscopic theory of particle massivation leading to highly successful predictions not only for particle mass scale ratios but also for the particle masses. p-Adic primes near powers of two - in particular Mersenne primes - pop up naturally and define positive integer characterizing given particle. Number theory becomes the tool of understanding the mystery number 10^{38} defined by the ratio of Planck mass and proton mass (this number is essentially the ratio of CP_2 mass to electron mass) [K34].

In TGD framework Higgs like states could provide gauge bosons with longitudinal polarizations. They are not needed for massivation except in the case of gauge bosons. Higgs like states are certainly possible in TGD framework, and if one does not accept them one must invent a good explanation for their absence.

7.2.3 Particle massivation from p-adic thermodynamics

p-Adic thermodynamics defines a core element of p-adic mass calculations [K14, K34, K43]. p-Adic thermodynamics is thermodynamics for the conformal scaling generator L_0 in the tensor product representation of super-conformal algebra and the masses are fixed one the p-adic prime characterizing the particle is fixed. p-Adic length scale hypothesis $p \simeq 2^k$, k integer, implies an exponential sensitivity of the particle mass scale on k so that a fitting of particle masses is not possible.

(a) The first thing that one can get worried about relates to the extension of conformal symmetries. If the conformal symmetries for light-like surfaces and $\delta M^4_\pm \times CP_2$ generalize to $D = 4$, how can one take seriously the results of p-adic mass calculations based on 2-D conformal invariance? There is actually no reason to worry. The reduction of the conformal invariance to 2-D one for the solutions of modified Dirac equation takes care of this problem [K80] This however requires that the fermionic contributions assignable to string world sheets and/or partonic 2-surfaces - Super- Kac-Moody contributions - dictate the elementary particle masses. For hadrons also super-symplectic contributions would be present and would give the dominating contribution to baryon masses.

The modes of right handed neutrino are de-localized to a 4-D region of space-time surface and characterized by two integers. The absence of all standard model interactions suggests that no thermalization takes place for them. These modes are de-localized either to a region of Euclidian signature identifiable as 4-D line of generalized Feynman graph or to a region of Minkowskian signature. Since modified gamma matrices vanish identically for CP_2 type vacuum extremals, one can ask whether the 4-D neutrino modes are associated only with Minkowskian regions. In this case the counterpart of $\mathcal{N} = 1$ SUSY would assign spartner to a many-particle state rather than to elementary particle. This could explain for why LHC has not seen the analog of standard SUSY.

(b) ZEO suggests that the wormhole throats carrying many-fermion states with parallel momenta are massless: this applies even to virtual wormhole throats [K73]. As a consequence, the twistor approach would work and the on mass shell kinematical constraints to the vertices would allow the cancellation of UV divergences. The 2-D Kac-Moody generators assignable to the boundaries of string world sheets would generate Yangian algebra [K75]. IR divergences would cancel because incoming and outgoing particles would be massive on mass shell particles as states involving several wormhole throats. The p-adic thermal expectation value is for the longitudinal M^2 momentum squared rather than for the four-momentum squared (the definition of CD selects $M^1 \subset M^2 \subset M^4$ as also does number theoretic vision). Also propagator would be determined by M^2 momentum. Lorentz invariance would be achieved by averaging over the moduli for CD including also Lorentz boosts of CD.

(c) In the original approach states with arbitrary large values of L_0^{tot} were allowed as physical states. Usually one would require that the generator L_0^{tot} of conformal scaling annihilates the states. In the calculations however mass squared was assumed to be proportional L_0^{tot} apart from vacuum contribution. This is a questionable assumption. ZEO suggests that total mass squared vanishes and that one can decompose mass squared to a sum of longitudinal and transversal parts. If one can do the same decomposition for the longitudinal and transverse parts also for the Super Virasoro algebra, one can calculate longitudinal mass squared as a p-adic thermal expectation of L_0^{tr} in the transversal Super-Virasoro algebra and only states with $L_0^{tot} = 0$ would contribute and one would have conformal invariance in the standard sense. The decomposition is indeed possible since longitudinal parts correspond to pure gauge degrees of freedom.

Thermodynamics - or rather, its square root - would become part of quantum theory in ZEO. M-matrix is indeed product of hermitian square root of density matrix multiplied by unitary S-matrix and defines the entanglement coefficients between positive and negative energy parts of zero energy state. Different M-matrices orthogonal to each other with respect to trace become rows of the unitary U-matrix.

(d) The crucial constraint is that the number of super-conformal tensor factors is $N = 5$: this suggests that thermodynamics applied in Super-Kac-Moody degrees of freedom assignable to string world sheets is enough if one is interested in the masses of fermions and gauge bosons. Super-symplectic degrees of freedom can also contribute and determine the dominant contribution to baryon masses. Should also this contribution obey p-adic thermodynamics in the case when it is present? Or does the very fact that this contribution need not be present mean that it is not thermal? The symplectic contribution should correspond to hadronic p-adic length scale rather the much longer (!) p-adic length scale assignable to say u quark (this paradoxical looking result can be understood in terms of uncertainty principle and the assignment of quarks to the color magnetic body of hadron). Hadronic p-adic mass squared and partonic p-adic mass squared cannot be summed since primes are different. If one accepts the basic rules [K43], longitudinal energy and momentum are additive as indeed assumed in perturbative QCD.

(e) Calculations work if the vacuum expectation value of the mass squared is assumed to be tachyonic. One could argue that the total mass squared has naturally tachyonic ground state expectation since for massless extremals (MEs, topological light rays [K8]) longitudinal momentum is light-like and transversal momentum squared is necessary present and non-vanishing by the localization to topological light ray of finite thickness of order p-adic length scale. Transversal degrees of freedom would be modeled with a particle in a box.

This is the general picture. One crucially important implication is that gauge conditions $p \cdot \epsilon = 0$ in Lorentz gauge must be satisfied.

(a) Suppose that gauge bosons can be approximated as composites of fermion and antifermion characterized by polarization and total momentum. For massless gauge boson the four-momenta could be taken to be parallel such that second fermion has negative energy. The gauge conditions are separately satisfied by fermion and antifermion and one obtains two polarization states. For massive gauge bosons one can go to rest system and finds that three polarization states are possible since 3-momentum vanishes.

(b) Number theoretical considerations and also parton model have motivated the proposal that only longitudinal M^2 momentum could appear in the propagators (recall that total mass squared vanishes and cannot appear in the propagator if virtual particles are massless). Therefore only M^2 momentum would appear in the gauge conditions: $p_L \cdot \epsilon = 0$ holds true and implies that also longitudinal polarization is allowed. Massivation is also unavoidable.

The first approximation for gauge boson state is as a wormhole contact containing fermion and anti-fermion at 3-D light-like wormhole throats. One must have spin 1 but since fermion and anti-fermion are massless they must have non-parallel 3-momenta in order to have parallel spins. For instance, they could have parallel and massive longitudinal momenta but non-parallel transverse momenta. The longitudinal mass squared would be in general non-vanishing and hence mass squared as the average over moduli of CD involving also integration over Lorentz boosts of CD.

Higgs could be *identified* in terms of spinless fermion antifermion pairs and gauge invariance would allow to eliminate all but neutral components of Higgs.

7.2.4 The conservation of em charge in TGD framework

An important aspect of the standard model Higgs mechanism is that it respects em charge leaving photons massless. In standard model the conservation of em charge defined as isospin like quantum number is non-trivial since the presence of classical gauge fields induces transitions between different charge states of fermions. In second quantization this problem is circumvented by replacing classical gauge fields with quantized ones. The so called unitary gauge defined by a gauge transformation depending on Higgs fields allows to express the action in terms of physical (in general massive) fields and makes charge conservation explicit.

The first thing to notice is that unitary gauge is coded CP_2 geometry: the em neutral direction for electroweak algebra identified as holonomy algebra of CP_2 is uniquely fixed unlike in standard model. This has logically trivial but physically far reaching implication: Higgs vacuum expectation is not needed to define the electromagnetically neutral direction in electweak gauge algebra.

This does not yet guarantee the conservation and well-definedness of em charge as a quantum number characterizing modes of the induced spinor field. How the conservation of em charge is obtained in TGD?

(a) Doesn't one have the same problem but as a much worse variant since classical long range electro-weak gauge fields are unavoidable in TGD and there is no path integral but preferred extremals? Could it make sense to speak about unitary gauge also in TGD framework? Could one turn around this idea to derive classical Higgs from the possibly existing gauge transformation to unitary gauge? The answer is negative. There is actually no need for the unitary gauge.

As a matter fact, the conservation for em charge in spinorial sense leads to the earlier conjecture that the solutions of the modified Dirac equations are localized at 2-D surfaces whose ends define braid strands at space-like 3-surfaces at the ends of causal diamonds and at the light-like 3-surfaces connecting them and defining lines for generalized Feynman diagrams. This picture was earlier derived from the notion of finite measurement resolution implying discretization at the level of partonic 2-surfaces and also from number theoretical vision suggesting that basic objects correspond to 2-D commutative and co-commutative identifiable as sub-manifolds of 4-D associative and co-associated surfaces.

(b) The point is that the Kähler form of CP_2 is covariantly constant and one can identify covariantly constant em charge as a matrix of form $Q = aI + bJ_{kl}\Sigma^{kl}$: the coefficients a and B are different for quarks and leptons (different chiralities of H-spinors). This matrix is covariantly constant also with respect to the induced spinor structure and commutes with Dirac operator (be it the TGD counterpart of the ordinary massless Dirac operator or modified Dirac operator). Therefore one should be able to choose the modes of induced spinor field to have a well-defined em charge at each point of space-time surface. The covariantly constant Kähler form of CP_2 is an important element in making possible the conservation of em charge and derives from the supersymmetry generated by covariantly constant right-handed neutrino.

It also allows to define identified electromagnetic charge as a preferred direction in gauge algebra. This is just what is needed to define unitary gauge uniquely and in standard model Higgs vacuum expectation is needed to achieve this. This is however not enough as it became clear.

(c) Rather unexpectedly, the challenge of understanding the charge conservation in the spinorial sense led to a breakthrough in understanding of the modes of the modified Dirac equation. The condition for conservation leads to three separate analogs of Dirac equations and the two additional ones are satisfied if em charged projections of the generalized energy momentum currents defining components of modified gamma matrices vanish. If these components define Beltrami fields expressible as products $j = \Psi\nabla\Phi$ the conditions can be satisfied for $\Psi = 0$. Since Ψ is complex or hyper-complex, the conditions are satisfied for 2-dimensional surfaces of space-time surfaces identifiable as string world sheets and partonic 2-surfaces. This picture was earlier derived from various arguments. Em charge conservation does not there give rise to a counterpart of unitary gauge but leads to a bridge between modified Dirac equation and general view about quantum TGD based on generalization of super-conformal invariance.

To sum up, higgsteria and all cold showers accompanying it has had quite powerful positive impact in TGD framework. Consider only the improved understanding of em charge, solutions of Kähler Dirac eqution and preferred extremals of Kähler action, of Higgs itself, and p-adic thermodynamics, its limitations and possible generalization!

7.3 About the microscopic description of gauge boson massivation

The conjectured QFT limit allows to estimate the quantitative predictions of the theory. This is not however enough. One should identify the microscopic TGD counterparts for various aspects of gauge boson massivation. There is also the question about the consistency of the gauge theory limit with the ZEO inspired view about massivation. The basic challenge are obvious: one should translate notions like Higgs vacuum expectation, massivation of gauge bosons, and finite range of weak interactions to the language of wormhole throats, Kähler magnetic flux tubes, and string world sheets. The proposal is that generalization of super-conformal symmetries to their Yangian counterparts is needed to meet this challenges in mathematically satisfactory manner.

7.3.1 The counterpart of Higgs vacuum expectation in TGD

The development of the TGD view about Higgs involves several wrong tracks involving a lot of useless calculation. All this could have been avoided with more precise definition of basic notions. The following view has distilled through several failures and might be taken as starting point.

The basic challenge is to translate the QFT description of gauge boson massivation to microscopic description.

(a) One can say that gauge bosons "eat" the components of Higgs. In unitary gauge one gauge rotates Higgs field to electromagnetically neutral direction defined by the vacuum expectation value of Higgs. The rotation matrix codes for the degrees of freedom assignable to non-neutral part of Higgs and they are transferred to the longitudinal components of Higgs in gauge transformation. This gives rise to the third polarization direction for gauge boson. Photon remains massless because em charge commutes with Higgs.

(b) The generation of vacuum expectation value has two functions: to make weak gauge bosons massive and to define the electromagnetically neutral direction to which Higgs field is rotated in the transition to the unitary gauge. In TGD framework only the latter function remains for Higgs if p-adic thermodynamics takes care of massivation. The notion of induced gauge field together with CP_2 geometry uniquely defines the electromagnetically neutral direction so that vacuum expectation is not needed. Of course, the essential element is gauge invariance of the Higgs gauge boson couplings. In twistor Grassmann approach gauge invariance is replaced with Yangian symmetry, which is excellent candidate also for basic symmetry of TGD.

(c) The massivation of gauge bosons (all particles) involves two contributions. The contribution from p-adic thermodynamics in CP_2 scale (wormhole throat) and the stringy contribution in weak scale more generally, in hadronic scale. The latter contribution cannot be calculated yet. The generalization of p-adic thermodynamics to that for Yangian symmetry instead of mere super-conformal symmetry is probably necessary to achieve this and the construction WCW geometry and spinor structure strongly supports the interpretation in terms of Yangian.

One can look at the situation also at quantitative level.

(a) W/Z mass ratio is extremely sensitive test for any model for massivation. In the recent case this requires that string tension for weak gauge boson depends on boson and is proportional to the appropriate gauge coupling strength depending on Weinberg angle. This is natural if the contribution to mass squared can be regarded as perturbative.

(b) Higgs mechanism is characterized by the parameter m_0^2 defining the originally tachyonic mass of Higgs, the dimensionless coupling constant λ defining quartic self-interaction of Higgs. Higgs vacuum expectation is given by $\mu^2 = m_0^2/\lambda$, Higgs mass squared by $m_0^2 = \mu^2\lambda$, and weak boson mass squared is proportional $g^2\mu^2$. In TGD framework λ takes the role of g^2 in stringy picture and the string tensions of bosons are proportional to g_w^2, g_Z^2, λ respectively.

(c) Whether λ in TGD framework actually corresponds to the quartic self-couplingof Higgs or just to the numerical factor in Higgs string tension, is not clear. The problem of Higgs mechanism is that the mass of observed Higgs is somewhat too low. This requires fine tuning of the parameters of the theory and SUSY, which was hoped to come in rescue, did not solve the problem. TGD approach promises to solve the problem.

7.3.2 Elementary particles in ZEO

Let us first summarize what kind of picture ZEO suggests about elementary particles.

(a) Kähler magnetically charged wormhole throats are the basic building bricks of elementary particles. The lines of generalized Feynman diagrams are identified as the Euclidian regions of space-time surface. The weak form of electric magnetic duality forces magnetic monopoles and gives classical quantization of the Kähler electric charge. Wormhole throat is a carrier of many-fermion state with parallel momenta and the fermionic oscillator algebra gives rise to a badly broken large $\mathcal{N}$ SUSY [K24].

(b) The first guess would be that elementary fermions correspond to wormhole throats with unit fermion number and bosons to wormhole contacts carrying fermion and anti-fermion at opposite throats. The magnetic charges of wormhole throats do not however allow this option. The reason is that the field lines of Kähler magnetic monopole field must close. Both in the case of fermions and bosons one must have a pair of wormhole contacts (see fig. `http://www.tgdtheory.fi/appfigures/wormholecontact.jpg` or fig. 10 in the appendix of this book) connected by flux tubes. The most general option is that net quantum numbers are distributed amongst the four wormhole throats. A simpler option is that quantum numbers are carried by the second wormhole: fermion quantum numbers would be carried by its second throat and bosonic quantum numbers by fermion and anti-fermion at the opposite throats. All elementary particles would therefore be accompanied by parallel flux tubes and string world sheets.

(c) A cautious proposal in its original form was that the throats of the other wormhole contact could carry weak isospin represented in terms of neutrinos and neutralizing the weak isospin of the fermion at second end. This would imply weak neutrality and weak confinement above length scales longer than the length of the flux tube. This condition might be un-necessarily strong.

The realization of the weak neutrality using pair of left handed neutrino and right handed antineutrino or a conjugate of this state is possible if one allows right-handed neutrino to have also unphysical helicity. The weak screening of a fermion at wormhole throat is possible if ν_R is a constant spinor since in this case Dirac equation trivializes and allows both helicities as solutions. The new element from the solution of the modified Dirac equation is that ν_R would be interior mode de-localized either to the other wormhole contact or to the Minkowskian flux tube. The state at the other end of the flux tube is spartner of left-handed neutrino.

It must be emphasized that weak confinement is just a proposal and looks somewhat complex: Nature is perhaps not so complex at the basic level. To understand this better, one can think about how M_{89} mesons having quark and antiquark at the ends of long flux tube returning back along second space-time sheet could decay to ordinary quark and antiquark.

7.3.3 Virtual and real particles and gauge conditions in ZEO

ZEO and twistor Grassmann approach force to build a detailed view about real and virtual particles. ZEO suggests also new approaches to gauge conditions in the attempts to build detailed connection between QFT picture and that provided by TGD. The following is the most conservative one. Of course, also this proposal must be taken with extreme cautiousness.

(a) In ZEO all wormhole throats - also those associated with virtual particles - can be regarded as massless. In twistor Grassmann approach [K58] this means that the fermionic propagators can be by residue integration transformed to their inverses which correspond to online massless states but having an unphysical polarization so that the internal lines do not vanish identically.

(b) This picture inspired by twistorial considerations is consistent with the simplest picture about Kähler-Dirac action. The boundary term for K-D action is $\sqrt{g_4}\overline{\Psi}\Gamma^n_{K-D}\Psi d^3x$ and due to the localization of spinor modes to 2-D surfaces reduces to a term localized at the boundaries of string world sheets. The normal component Γ^n_{K-D} of the modified gamma matrices defined by the canonical momentum currents of Kähler action should define the inverse of massless fermionic propagator. If the action of this operator on the induced spinor mode at stringy curves satisfies

$$\sqrt{g_4}\Gamma^n\Psi = p^k\gamma_k\Psi \ ,$$

this reduction is achieved. One can pose the condition $g_4 = constant$ as a coordinate condition on stringy curves at the boundaries of CD and the condition would correlate the spinor modes at stringy curve with incoming quantum numbers. This is extremely powerful simplification giving hopes about calculable theory. The residue integral for virtual momenta reduces the situation to integral over on mass shell momenta and only non-physical helicities contribute in internal lines. This would generalize twistorial formulas to fermionic context.

One however ends up with an unexpected prediction which has bothered me for a long time. Consider the representation of massless spin 1 gauge bosons as pairs as wormhole throat carrying fermion and antifermion having net quantum numbers of the boson. Neglect the effects of the second wormhole throat. The problem is that for on-mass shell massless fermion and antifermion with physical helicities the boson has spin 0. Helicity 1 state would require that second fermion has unphysical helicity. What does this mean?

(a) Are all on mass shell gauge bosons - including photon - massive? Or is on mass shell massless propagation impossible? Massivation is achieved if the fermion and antifermion have different momentum directions: for instance opposite 3-momen but same sign of energy. Higher order contributions in p-adic thermodynamics could make also photon massive. The 4-D world-lines of fermion and antifermion would not be however parallel, which does not conform with the geometric optics based prejudices.

(b) Or could on mass shell gauge bosons have opposite four-momenta so that the second gauge boson would have negative energy? In this manner one could have massless on mass shell states. ZEO ontology certainly allows the identification massless gauge bosons as on mass shell states with opposite directions of four-momenta. This would however require the weakening of the hypothesis that all incoming (outgoing) fundamental fermions have positive (negative) energies to the assumption that only the incoming (outgoing) particles have positive (negative) energies. In the case of massless gauge boson the gauge condition $p \cdot \epsilon = 0$ would be satisfied by the momenta of both fermion and antifermion. With opposite 3-momenta (massivation) but same energy the condition $p_{tot} \cdot \epsilon = 0$ is satisfied for three polarization since in cm system p_{tot} has only time component.

(c) The problem is present also for internal lines. Since by residue argument only the unphysical fermion helicities contribute in internal lines, both fermion and antifermion must have unphysical helicity. For the same sign of energy the wormhole throat would behave as scalar particle. Therefore it seems that the energies must have different sign or momenta cannot be strictly parallel. This is required also by the possibility of space-like momenta for virtual bosons.

7.3.4 The role of string world sheets and magnetic flux tubes in massivation

What is the role of string world sheets and flux tubes in the massivation? At the fundamental level one studies correlation functions for particles and finite correlation length means massivation.

(a) String world sheets define as essential element in 4-D description. All particles are basically bi-local objects: pairs of string at parallel space-time sheets extremely near to each other and connected by wormhole contacts at ends. String world sheets are expected to represent correlations between wormhole throats.

(b) Correlation length for the propagator of the gauge boson characterizes its mass. Correlation length can be estimated by calculating the correlation function. For bosons this reduces to the calculation of fermionic correlations functions assignable to string world sheets connecting the upper and lower boundaries of CD and having four external fermions at the ends of CD. The perturbation theory reduces to functional integral over space-time sheets and deformation of the space-time sheet inducing the deformation of the induced spinor field expressible as convolution of the propagator associated with the modified Dirac operator with vertex factor defined by the deformation multiplying the spinor field. The external vertices are braid ends at partonic 2-surfaces and internal vertices are in the interior of string world sheet. Recall that the conjecture is that the restriction to the wormhole throat orbits implies the reduction to diagrams involving only propagators connecting braid ends. The challenge is to understand how the coherent state assigned to the Euclidian pion field induces the finite correlation length in the case of gauge bosons other than photon.

(c) The non-vanishing commutator of the gauge boson charge matrix with the vacuum expectation assigned to the Euclidian pion must play a key role. The study of the modified Dirac operator suggests that the braid strands contain the Abelianized variant of non-integrable phase factor defined as $exp(i\int Adx)$. If A is identified as string world sheet Hodge dual of Kac-Moody charge the opposite edges of string world sheet with geometry of square given contributions which compensate each other by conservation of Kac-Moody charge if A commutes with the operators building the coherent Higgs state. For photon this would be true. For weak gauge bosons this would not be the case and this gives hopes about obtaining destructive interference leading to a finite correlation length.

One can also consider try to build more concrete manners to understand the finite correlation length.

(a) Quantum classical correspondence suggests that string with length of order $L \sim \hbar/E$, $E=\sqrt{p^2+m^2}$ serves as a correlate for particle defined by a pair of wormhole contacts. For massive particle wave length satisfies $L \leq \hbar/m$. Here (p,m) must be replaced with (p_L,m_L) if one takes the notion of longitudinal mass seriously. For photon standard option gives $L=\lambda$ or $L=\lambda_L$ and photon can be a bi-local object connecting arbitrarily distant objects. For the second option small longitudinal mass of photon gives an upper bound for the range of the interaction. Also gluon would have longitudinal mass: this makes sense in QCD where the decomposition $M^4=M^2\times E^2$ is basic element of the theory.

(b) The magnetic flux tube associated with the particle carries magnetic energy. Magnetic energy grows as the length of flux tube increases. If the flux is quantized magnetic field behaves like $1/S$, where S is the area of the cross section of the flux tube, the total magnetic energy behaves like L/S. The dependence of S on L determines how the magnetic energy depends on L. If the magnetic energy increases as function of L the probability of long flux tubes is small and the particle cannot have large size and therefore mediates short range interactions. For $S\propto L^\alpha \sim \lambda^\alpha$, $\alpha>1$, the magnetic energy behaves like $\lambda^{-\alpha+1}$ and the thickness of the flux tube scales like $\sqrt{\lambda^\alpha}$. In case of photon one might expect this option to be true. Note that for photon string world sheet one can argue that the natural choice of string is as light-like string so that its length vanishes.

What kind of string world sheets are possible? One can imagine two options.

(a) All strings could connect only the wormhole contacts defining a particle as a bi-local object so that particle would be literally the geometric correlate for the interaction between two objects. The notion of free particle would be figment of imagination. This would lead to a rather stringy picture about gauge interactions. The gauge interaction between systems S_1 and S_2 would mean the emission of gauge bosons as flux tubes with charge carrying end at S_1 and neutral end. Absorption of the gauge boson would mean that the neutral end of boson and neutral end of charge particle fuse together line the lines of Feynman diagram at 3-vertex.

(b) Second option allows also string world sheets connecting wormhole contacts of different particles so that there is no flux tube accompanying the string world sheet. In this case particles would be independent entities interacting via string world sheets. In this case one could consider the possibility that photon corresponds to string world sheet (or actually parallel pair of them) not accompanied by a magnetic flux tube and that this makes the photon massless at least in excellent approximation.

The first option represents the ontological minimum.

Super-conformal symmetry involves two conformal weight like integers and these correspond to the conformal weight assignable to the radial light-like coordinate appearing in the role of complex coordiante in super-symplectic Hamiltonians and to the spinorial conformal weight assignable to the solutions of Kähler Dirac equation localized to string world sheets. These conformal weights are independent quantum numbers unless one can use the light-like radial coordinate as string coordinate, which is certainly not possible always. The latter conformal weight should correspond to the stringy contribution to the masses of elementary particles and hadron like states. In fact, it is difficult to distinguish between elementary particles and hadrons at the fundamental level since both involve the stringy aspect.

The Yangian symmetry variant of conformal symmetry is highly suggestive and brings in poly-locality with respect to partonic 2-surfaces. This integer would count the number of partonic 2-surfaces to which the generator acts and need not correspond to spinorial conformal weight as one might think first. In any case, Yangian variant of p-adic termodynamics provides an attractive approach concerning the mathematical realization of this vision.

7.3.5 Weak Regge trajectories

The weak form of electric-magnetic duality suggests strongly the existence of weak Regge trajectories.

(a) The most general mass squared formula with spin-orbit interaction term $M^2_{L-S}L\cdot S$ reads as

$$M^2 = nM_1^2 + M_0^2 + M^2_{L-S}L\cdot S \ , \quad n = 0,2,4 \ \text{or} \ n = 1,3,5,..., \ . \tag{7.3.1}$$

M_1^2 corresponds to string tension and M_0^2 corresponds to the thermodynamical mass squared and possible other contributions. For a given trajectory even (odd) values of n have same parity and can correspond to excitations of same ground state. From ancient books written about hadronic string model one vaguely recalls that one can have several trajectories (satellites) and if one has something called exchange degeneracy, the even and odd trajectories define single line in M^2-J plane. As already noticed TGD variant of Higgs mechanism combines together $n=0$ states and $n=1$ states to form massive gauge bosons so that the trajectories are not independent.

(b) For fermions, possible Higgs, and pseudo-scalar Higgs and their super partners also p-adic thermodynamical contributions are present. M_0^2 must be non-vanishing also for gauge bosons and be equal to the mass squared for the $n=L=1$ spin singlet. By applying the formula to $h=\pm 1$ states one obtains

$$M_0^2 = M^2(boson) \ . \tag{7.3.2}$$

The mass squared for transversal polarizations with $(h,n,L) = (\pm 1, n=L=0, S=1)$ should be same as for the longitudinal polarization with $(h=0, n=L=1, S=1, J=0)$ state. This gives

$$M_1^2 + M_0^2 + M_{L-S}^2 L \cdot S = M_0^2 \ . \qquad (7.3.3)$$

From $L \cdot S = [J(J+1) - L(L+1) - S(S+1)]/2 = -2$ for $J = 0, L = S = 1$ one has

$$M_{L-S}^2 = -\frac{M_1^2}{2} \ . \qquad (7.3.4)$$

Only the value of weak string tension M_1^2 remains open.

(c) If one applies this formula to arbitrary $n = L$ one obtains total spins $J = L+1$ and $L-1$ from the tensor product. For $J = L-1$ one obtains

$$M^2 = (2n+1)M_1^2 + M_0^2 \ .$$

For $J = L+1$ only M_0^2 contribution remains so that one would have infinite degeneracy of the lightest states. Therefore stringy mass formula must contain a non-linear term making Regge trajectory curved. The simplest possible generalization which does not affect n=0 and n=1 states is of from

$$M^2 = n(n-1)M_2^2 + (n - \frac{L \cdot S}{2})M_1^2 + M_0^2 \ . \qquad (7.3.5)$$

The challenge is to understand the ratio of W and Z^0 masses, which is purely group theoretic and provides a strong support for the massivation by Higgs mechanism.

(a) The above formula and empirical facts require

$$\frac{M_0^2(W)}{M_0^2(Z)} = \frac{M^2(W)}{M^2(Z)} = cos^2(\theta_W) \ . \qquad (7.3.6)$$

in excellent approximation. Since this parameter measures the interaction energy of the fermion and anti-fermion decomposing the gauge boson depending on the net quantum numbers of the pair, it would look very natural that one would have

$$M_0^2(W) = g_W^2 M_{SU(2)}^2 \ , \ M_0^2(Z) = g_Z^2 M_{SU(2)}^2 \ . \qquad (7.3.7)$$

Here $M_{SU(2)}^2$ would be the fundamental mass squared parameter for $SU(2)$ gauge bosons. p-Adic thermodynamics of course gives additional contribution which is vanishing or very small for gauge bosons.

(b) The required mass ratio would result in an excellent approximation if one assumes that the mass scales associated with $SU(2)$ and $U(1)$ factors suffer a mixing completely analogous to the mixing of $U(1)$ gauge boson and neutral $SU(2)$ gauge boson W_3 leading to γ and Z^0. Also Higgs, which consists of $SU(2)$ triplet and singlet in TGD Universe, would very naturally suffer similar mixing. Hence $M_0(B)$ for gauge boson B would be analogous to the vacuum expectation of corresponding mixed Higgs component. More precisely, one would have

$$\begin{aligned} M_0(W) &= M_{SU(2)} \ , \\ M_0(Z) &= cos(\theta_W)M_{SU(2)} + sin(\theta_W)M_{U(1)} \ , \\ M_0(\gamma) &= -sin(\theta_W)M_{SU(2)} + cos(\theta_W)M_{U(1)} \ . \end{aligned} \qquad (7.3.6)$$

The condition that photon mass is very small and corresponds to IR cutoff mass scale gives $M_0(\gamma) = \epsilon cos(\theta_W)M_{SU(2)}$, where ϵ is very small number, and implies

$$
\begin{aligned}
\frac{M_{U(1)}}{M(W)} &= tan(\theta_W) + \epsilon \ , \\
\frac{M(\gamma)}{M(W)} &= \epsilon \times cos(\theta_W) \ , \\
\frac{M(Z)}{M(W)} &= \frac{1 + \epsilon \times sin(\theta_W)cos(\theta_W)}{cos(\theta_W)} \ .
\end{aligned} \quad (7.3.5)
$$

There is a small deviation from the prediction of the standard model for W/Z mass ratio but by the smallness of photon mass the deviation is so small that there is no hope of measuring it. One can of course keep mind open for $\epsilon = 0$. The formulas allow also an interpretation in terms of Higgs vacuum expectations as it must. The vacuum expectation would most naturally correspond to interaction energy between the massless fermion and anti-fermion with opposite 3-momenta at the throats of the wormhole contact and the challenge is to show that the proposed formulas characterize this interaction energy. Since CP_2 geometry codes for standard model symmetries and their breaking, it woul not be surprising if this would happen. One cannot exclude the possibility that p-adic thermodynamics contributes to $M_0^2(boson)$. For instance, ϵ might characterize the p-adic thermal mass of photon.

If the mixing applies to the entire Regge trajectories, the above formulas would apply also to weak string tensions, and also photons would belong to Regge trajectories containing high spin excitations.

(c) What one can one say about the value of the weak string tension M_1^2? The naive order of magnitude estimate is $M_1^2 \simeq m_W^2 \simeq 10^4$ GeV^2 is by a factor 1/25 smaller than the direct scaling up of the hadronic string tension about 1 GeV^2 scaled up by a factor 2^{18}. The above argument however allows also the identification as the scaled up variant of hadronic string tension in which case the higher states at weak Regge trajectories would not be easy to discover since the mass scale defined by string tension would be 512 GeV to be compared with the recent beam energy 7 TeV. Weak string tension need of course not be equal to the scaled up hadronic string tension. Weak string tension - unlike its hadronic counterpart- could also depend on the electromagnetic charge and other characteristics of the particle.

7.3.6 Low mass exotic mesonic structures as evidence for dark scaled down variants of weak bosons?

During last years reports about low mass exotic mesonic structures have appeared. It is interesting to combine these bits of data with the recent view about TGD analog of Higgs mechanism and find whether new predictions become possible. The basic idea is to derive understanding of the low mass exotic structures from LHC data by scaling and understanding of LHC data from data about mesonic structures by scaling back.

(a) The article *Search for low-mass exotic mesonic structures: II. attempts to understand the experimental results* by Taticheff and Tomasi-Gustafsson [C174] mentions evidence for exotic mesonic structures. The motivation came from the observation of a narrow range of dimuon masses in $\Sigma^+ \rightarrow pP^0$, $P^0 \rightarrow \mu^-\mu^+$ in the decays of P^0 with mass of $214.3 \pm .5$ MeV: muon mass is 105.7 MeV giving $2m_\mu = 211.4$ MeV. Mesonlike exotic states with masses $M = 62, 80, 100, 181, 198, 215, 227.5,$ and 235 MeV are reported. This fine structure of states with mass difference 20-40 MeV between nearby states is reported for also for some baryons.

(b) The preprint *Observation of the E(38) boson* by Kh.U. Abraamyan et al [C176, C177, C109] reports the observation of what they call E(38) boson decaying to gamma pair observed in d(2.0 GeV/n)+C,d(3.0 GeV/n)+Cu and p(4.6 GeV)+C reactions in experiments carried in JINR Nuclotron.

If these results can be replicated they mean a revolution in nuclear and hadron physics. What strongly suggests itself is a fine structure for ordinary hadron states in much smaller energy scale than characterizing hadronic states. Unfortunately the main stream, in particular the theoreticians interested in beyond standard model physics, regard the physics of strong interactions and weak interactions as closed chapters of physics, and are not interested on results obtained in nuclear collisions.

In TGD framework situation is different. The basic characteristic of TGD Universe is fractality. This predicts new physics in all scales although standard model symmetries are fundamental unlike in GUTs and are reduced to number theory. p-Adic length scale hypothesis characterizes the fractality.

(a) In TGD Universe p-adic length scale hypothesis predicts the possibility of scaled versions of both strong and weak interactions. The basic objection against new light bosons is that the decay widths of weak bosons do not allow them. A possible manner to circumvent the objection is that the new light states correspond to dark matter in the sense that the value of Planck constant is not the standard one but its integer multiple [K22].

    The assumption that only particles with the same value of Planck constant can appear in the vertex, would explain why weak bosons do not decay directly to light dark particles. One must however allow the transformation of gauge bosons to their dark counterparts. The 2-particle vertex is characterized by a coupling having dimensions of mass squared in the case of bosons, and p-adic length scale hypothesis suggests that the primary p-adic mass scale characterizes the parameter (the secondary p-adic mass scale is lower by factor $1/\sqrt{p}$ and would give extremely small transformation rate).

(b) Ordinary strong interactions correspond to Mersenne prime M_n, $n = 2^{107} - 1$, in the sense that hadronic space-time sheets correspond to this p-adic prime. Light quarks correspond to space-time sheets identifiable as color magnetic flux tubes, which are much larger than hadron itself. M_{89} hadron physics has hadronic mass scale 512 times higher than ordinary hadron physics and should be observed at LHC. There exist some pieces of evidence for the mesons of this hadron physics but masked by the Higgsteria. The expectation is that Minkowskian M_{89} pion has mass around 140 GeV assigned to CDF bump [C59].

(c) In the leptonic sector there is evidence for lepto-hadron physics for all charged leptons labelled by Mersenne primes M_{127}, $M_{G,113}$ (Gaussian Mersenne), and M_{107} [K70]. One can ask whether the above mentioned resonance P^0 decaying to $\mu^-\mu^+$ pair motivating the work described in [C174] could correspond to pion of muon-hadron physics consisting of a pair of color octet excitations of muon. Its production would presumably take place via production of virtual gluon pair decaying to a pair of color octet muons.

Returning to the observations of [C174]: the reported meson-like exotic states seem to be arranged along Regge trajectories but with string tension lower than that for the ordinary Regge trajectories with string tension $T = .9$ GeV^2. String tension increases slowly with mass of meson like state and has three values $T/GeV^2 \in \{1/390, 1/149.7, 1/32.5\}$ in the piecewise linear fit discussed in the article. The TGD inspired proposal is that IR Regge trajectories assignable to the color magnetic flux tubes accompanying quarks are in question. For instance, in hadrons u and d quarks - understood as constituent quarks - would have $k = 113$ quarks and string tension would be by naive scaling by a factor $2^{107-113} = 1/64$ lower: as a matter of fact, the largest value of the string tension is twice this value. For current quark with mass scale around 5 MeV the string tension would be by a factor of order $2^{107-121} = 2^{-16}$ lower.

Clearly, a lot of new physics is predicted and it begins to look that fractality - one of the key predictions of TGD - might be realized both in the sense of hierarchy of Planck constants (scaled variants with same mass) and p-adic length scale hypothesis (scaled variants with varying masses). Both hierarchies would represent dark matter if one assumes that the values of Planck constant and p-adic length scale are same in given vertex. The testing of predictions is not however expected to be easy since one must understand how ordinary matter transforms to dark matter and vice versa. Consider only the fact, that only recently the exotic meson like states have been observed and modern nuclear physics regarded often as more or less trivial low energy phenomenology was born born about 80 years ago when Chadwick discovered neutron.

7.3.7 Cautious conclusions

The discussion of TGD counterpart of Higgs mechanism gives support for the following general picture.

(a) p-Adic thermodynamics for wormhole contacts contributes to the masses of all particles including photon and gluons: in these cases the contributions are however small. For fermions they dominate. For weak bosons the contribution from string tension of string connecting wormhole contacts as the correct group theoretical prediction for the W/Z mass ratio demonstrates. The mere spin 1 character for gauge bosons implies that they are massive in 4-D sense unless massless fermion and anti-fermion have opposite signs of energy. Higgs provides the longitudinal components of weak bosons by gauge invariance and CP_2 geometry defines unitary gauge so that Higgs vacuum expectation value is not needed. The non-existence of covariantly constant CP_2 vector field does not mean absence of Higgs like particle as believed first but only the impossibility of Higgs vacuum expectation value.

The usual space-time SUSY associated with imbedding space in TGD framework is not needed, and there are strong arguments suggesting that it is not present [**?**] For space-time regarded as 4-surfaces one obtains 2-D super-conformal invariance for fermions localized at 2-surfaces and for right-handed neutrino it extends to 4-D superconformal symmetry generalizing ordinary SUSY to infinite-D symmetry.

(b) The basic predictions to LHC are following. M_{89} hadron physics, whose pion was first proposed to be identifiable as Higgs like particle, will be discovered. The findings from RHIC and LHC concerning collisions of heavy ions and protons and heavy ions already provide support for the existence of string like objects identifiable as mesons of M_{89} physics. Fermi satellite has produced evidence for a particle with mass around 140 GeV and this particle could correspond to the pion of M_{89} physics. This particle should be observed also at LHC and CDF reported already earlier evidence for it. There has been also indications for other mesons of M_{89} physics from LHC discussed in [K37].

(c) Fermion and boson massivation by Higgs mechanism could emerge unavoidably as a theoretical artefact if one requires the existence of QFT limit leading unavoidably to a description in terms of Higgs mechanism. In the real microscopic theory p-adic thermodynamics for wormhole contacts and strings connecting them would describe fermion massivation, and might describe even boson massivation in terms of long parts of flux tubes. Situation remains open in this respect. Therefore the observation of decays of Higgs at expected rate to fermion pairs cannot kill TGD based vision.

The new view about Higgs combined with the stringy vision about twistor Grassmannian [**?**] allows to see several conjectures related to ZEO in new light and also throw away some conjectures such as the idea about restriction of virtual momenta to plane $M^2 \subset M^4$.

(a) The basic conjecture related to the perturbation theory is that wormhole throats are massless on mass shell states in imbedding space sense: this would hold true also for virtual particles and brings in mind what happens in twistor program. The recent progress [K80] in the construction of n-point functions leads to explicit general formulas for them expressing them in terms of a functional integral over four-surfaces. The deformation of the space-time surface fixes the deformation of basis for induced spinor fields and one obtains a perturbation theory in which correlation functions for imbedding space coordinates and fermionic propagator defined by the inverse of the modified Dirac operator appear as building bricks and the electroweak gauge coupling of the modified Dirac operator define the basic vertex. This operator is indeed 2-D for all other fermions than right-handed neutrino.

(b) The functional integral gives some expressions for amplitudes which resemble twistor amplitudes in the sense that the vertices define polygons and external fermions are massless although gauge bosons as their bound states are massive. This suggests a stringy generalization of twistor Grassmannian approach [K58]. The residue integral would replace 4-D integrations of virtual fermion momenta to integrals over massless momenta. The outcome would be non-vanishing for non-physical helicities of virtual fermion. Also the problem due to the fact that fermionic Super Virasoro generator carries fermion number in TGD framework disappears.

(c) There are two conformal weights involved. The conformal weight associated with the light-like radial coordinate of $\delta M^4_\pm$ and the spinorial conformal weight associated with the fermionic string connecting wormhole throats and throats of wormhole contact. Are these conformal weights independent or not? For instance, could one use radial light-like coordinate as string coordinate in the generic situation so that the conformal weights would not define independent quantum numbers? This does not look feasible. The Yangian variant of conformal algebra involves two integers. Second integer would naturally be the number of partonic 2-surfaces acted by the generator characterizing the poly-locality of Yangian generators, and it is not clear whether it has anything to do with the spinorial conformal weight. One can of course consider also three integers! This would be in accordance with the idea that the basic objects are 3-dimensional.

If the conjecture that Yangian invariance realized in terms of Grassmannians makes sense, it could allow to deduce the outcome of the functional integral over four-surfaces and one could hope that TGD can be transformed to a calculable theory. Also p-adic mass calculations should be formulated using p-adic thermodynamics assuming Yangian invariance and enlargened conformal algebra.

7.4 Two options for Higgs like states in TGD framework

HCP2012 conference (Hadron Collider Physics Symposium) at Kyoto will provide new data about Higgs candidate at next Wednesday. Resonaances has summarized the basic problem related to the interpretation as standard model Higgs: two high yield of gamma pairs and too low yield of $\tau\overline{\tau}$ and and $b\overline{b}$ pairs. It is of course possible that higher statistics changes the situation.

7.4.1 Two options concerning the interpretation of Higgs like particle in TGD framework

Theoretically the situation quite intricate. The basic starting point is that the original p-adic mass calculations provided excellent predictions for fermion masses. For the gauge bosons the situation was different: a natural prediction for the W/Z mass ratio in terms of Weinberg angle is the fundamental prediction of Higgs mechanism and this prediction did not follow automatically from the p-adic mass calculation in the original form. Classical Higgs field does not seem to have any natural counterpart in the geometry of space-time surface (the trace of the second fundamental form does not work since it vanishes for preferred extremals which are also minimal surfaces). This raised the question whether there is any Higgs boson in TGD Universe and for some time I took seriously the interpretation of the Higgs like state observed by LHC as a pion of M_{89}. To sum up, the evolution of ideas about TGD counterpart of Higgs mechanism has been full of twists and turns. This summary is warmly recommended for a seriously interested reader.

p-Adic mass calculations and the results from LHC leave two options under consideration.

(a) Option I: Only fermions get the dominating contribution to their masses from p-adic thermodynamics and in the case of gauge bosons the dominating contribution is due to the standard Higgs mechanism. p-Adic thermodynamics would contribute also to the boson masses, in particular photon mass but the contribution would be extremely small and correspond to p-adic temperature $T = 1/n$, $n > 2$. For this option only gauge bosons would have standard model couplings to Higgs whereas fermionic couplings could be small. Of course, standard model couplings proportional to fermion mass are also possible. One can criticize this option because fermions and bosons are in an asymmetric position. The beautiful feature is that one could get rid of the hierarchy problem due to the couplings of Higgs to heavy fermions.

This option is excluded by the recent data about Higgs candidate demonstrating that it behaves in the predicted manner.

(b) Option II: p-Adic mass calculations explain also the masses of gauge bosons and Higgs like particle. If Higgs like state develops a coherent state describable in terms of vacuum expectation value as M^4 QFT limit, this expectation value is determined by the mass spectrum determine by the p-adic mass calculations. The mass spectrum of particles determines Higgs expectation and the couplings of Higgs rather than vice versa! For this option Weinberg angle would be *defined* by the ratio of W and Z boson mass as $cos^2(\theta_W) = m_W^2/m_Z^2$ and these masses should be given by p-adic mass calculations. The fact that Higgs vacuum expectation has no space-time counterpart as covariantly constant CP_2 vector field supports the absence of Higgs mechanism but allows Higgs like field providing longitudinal polarizations of weak bosons.

The recent view about particles as Kähler magnetic loops carrying monopole flux is forced by the assumption that the corresponding partonic 2-surfaces are Kähler magnetic monopoles (implied by the weak form of electric-magnetic duality). The loop proceeds from wormhole throat to another one, then traverses along wormhole contact to another space-time sheet and returns back and eventually is transferred to the first sheet via wormhole contact. The mass squared assignable to this flux loop could give the contribution usually assigned to Higgs vacuum expectation. If this picture is correct, then the reduction of the W/Z mass ratio to Weinberg angle might be much easier to understand. As a matter fact, I have proposed that the flux loop gives rise to a stringy spectrum of states with string tension determined by p-adic length scale associated with M_{89}.

This option is attractive because fermions and bosons are in an exactly same position. Hierarchy problem is possible problem of this approach: note however that the considerations in the sequel imply that standard model action is predicted to be an effective action giving only tree diagrams so that there are no radiative corrections at M^4 QFT limit.

The original interpretation of Higgs like state was oas M_{89} pion. The recent observations from Fermi telescope suggest the existence of a boson with mass 135 GeV. It would be a good candidate for M_{89} pion. One can test the hypothesis by scaling the mass of ordinary neutral pion, which corresponds to M_{107}. The scaling gives mass 69.11 GeV. p-Adic length scale however allows also octaves of the minimum mass (they appear for lepto-pions) and scaling by two gives mass equal to 138.22 GeV not too far from 135 GeV.

There is also second encouraging numerical co-incidence. It is probably not an accident that Higgs vacuum expectation value corresponds to the minimum mass for $p = M_{89}$ if the p-adic counterpart of Higgs expectation squared is of order $O(p)$ in other words one has $\mu^2/m_{CP_2}^2 = p = M_{89}$.

My sincere hope is that the results of HCP2012 would allow to distinguish between these two options.

7.4.2 Microscopic description of gauge bosons and Higgs like and meson like states

Under the pressures from LHC it has become gradually clear that the understanding of whether TGD has M^4 QFT limit or not, and how this limit can be defined, is essential for the understanding also the role of Higgs. This is basically an exercise in conceptual hygiene: one must make clear what is QFT and what is TGD. In the following a first attempt to understand this limit is made. I find it somewhat surprising that I am making this attempt only now but the understanding of the proper role of the classical gauge potentials has been quite a challenge.

(a) By bosonic emergence also gauge bosons correspond at microscopic level to fermion and anti-fermion at opposite throats of wormhole contacts. Meson like states in turn correspond to fermion and anti-fermion at the ends of a flux tube connecting throats of two different wormhole contacts so that both Higgs, gauge bosons, and meson-like states are obtained using similar construction recipe.

(b) The popular statement "gauge bosons eat almost all Higgs components" makes sense at the M^4 QFT limit and also in TGD proper: by gauge invariance just the transition to the unitary gauge fixed uniquely by CP_2 geometry effectively eliminates all but one of the components of the Higgs like state and gauge bosons get the third polarization. Massivation could take place by p-adic thermodynamics extended so that it describes also gauge boson massivation by taking into account the stringy contributions to the mass. This favors option II.

(c) If one believes that M^4 QFT is a good approximation to TGD at low energy limit then the standard description of Higgs mechanism seems to be the only possibility: this just on purely mathematical grounds. The interpretation would however be that the masses of the particles determine Higgs vacuum expectation value and Higgs couplings rather than vice versa. This would of course be nothing unheard in the history of physics: the emergence of a microscopic theory - in the recent case p-adic thermodynamics - would force to change the direction of the causal arrow in "Higgs makes particles massive" to that in "Higgs expectation is determined by particle masses". In particular, fermionic couplings would be gradient couplings and dimensional coupling constant would be same for all fermions: a good news for a friend of "naturalness".

(d) The existence of M^4 QFT limit is an intricate issue. In TGD Universe baryon and lepton number correspond to different chiralities of $H = M^4 \times CP_2$ spinors, and this means that Higgs like state cannot be H scalar (it would be lepto-quark in this case). Rather, Higgs like state must be a vector in CP_2 tangent space degrees of freedom. The decomposition of Higgs like state to fermion antifermion pairs suggests the $2+\overline{2}$ decomposition of CP_2 tangent vector representing Higgs under $SU(2)_L$. Complex structure of CP_2 would be essential and stanard CP_2 complex coordinates would be analogous to Higgs in group theoretical sense.

Higgs like $M4$ scalar carries fermion and anti-fermion at opposite throat of the wormhole contact. In QFT context is easy to imagine that a coherent state having Higgs expectation as M^4 QFT correlate is formed. What coherent statesfor wormholeo contacts means is not at all clear. Most importantly, one cannot however have a covariantly constant vector field transforming like CP_2 coordinates so that Higgs vacuum expectation does not make sense at the fundamental level. The coherent state could be a formal description for the underlying stringy contribution to gauge boson masses.

7.4.3 Trying to understand the QFT limit of TGD

The counterparts of gauge potentials and Higgs field are not needed in the microscopic description if p-adic thermodynamics gives the masses so that the gauge potentials and Higgs field should emerge only at M^4 QFT limit. It is not even necessary to speak about Higgs and YM parts of the action at the microscopic level. The functional integral defined by the vacuum function expressed as exponent of Kähler action for preferred extremals to which couplings of microscopic expressions of particles in terms of fermions coupled to the effective fields describing them at QFT limit should define the effective action at QFT limit.

The basic recipe is simple.

(a) Start from the vacuum functional which is exponent of Kähler action for preferred extremals with Euclidian regions giving real exponent and Minkowskian regions imaginary exponent.

(b) Add to this action terms which are bilinear in the microscopic expression for the particle state and the corresponding effective field appearing in the effective action.

(c) Perform the functional integration over WCW ("world of classical worlds") and take vacuum expectation value in fermionic degrees of freedom.

(d) This gives an effective field theory in $M^4 \times CP_2$. To get M^4 QFT integrate over CP_2 degrees of freedom in the action. This dimensional reduction is similar to that occurring in Kaluza-Klein theories.

The functional integration of WCW induces also integration of induced spinor fields which apart from right-handed neutrino are restricted to the string world sheets. In principle induced spinor fields could be non-vanishing also at partonic 2-surfaces but simple physical considerations suggest that they are restricted to the intersection points of partonic 2-surfaces and string world sheets defining the ends of braid strands. Therefore the effective spinor fields Ψ_{eff} would appear only at braid ends in the integration over WCW and one has good hopes of performing the functional integral.

(a) One can assign to the induced spinor fields Ψ imbedding space spinor fields Ψ_{eff} appearing in the effective action. The dimensions of Ψ and Ψ_{eff} are $1/L^{3/2}$. A dimensionally correct guess is the term $\int d^2x\sqrt{g_2}\overline{\Psi}_{eff}(P)D^{-1}\Psi + h.c$, where Γ^α denotes the induced gamma matrices, P denotes the end point of a braid strand at the wormhole throat, and D denotes the "ordinary" massless Dirac operator $\Gamma^\alpha D_\alpha$ for the induced gamma matrices. Propagator contributes dimension L and is well-defined since Ψ is not annihilated by D but by the modified Dirac operator in which modified gamma matrices defined by the modified Dirac action appear. Note that internal consistency does not allow the replacement of Kähler action with four-volume. Integral over the second wormhole throat contributes dimension L^2. Therefore the outcome is a dimensionless finite quantity, which reduces to the value of integrand at the intersection of partonic 2-surface and string world sheet - that is at ends of braid strand since induced spinors are localized at string world sheets unless right-handed neutrinos are in question. The fact that induced spinor fields are proportional to a delta function restricting them to string world sheets does not lead to problems since the modified Dirac action itself vanishes by modified Dirac equation.

(b) Both Higgs and gauge bosons correspond to bi-local objects consisting of fermion and anti-fermion at opposite throats of wormhole contact and restricted to braid ends. The are connected by the analog of non-integrable phase factor defined by classical gauge potentials. These bilinear fermionic objects should correspond to Higgs and gauge potentials at QFT limit. The two integrations over the partonic 2-surfaces contribute L^2 both, whereas the dimension of the quantity defining the gauge boson or Higgs like state is $1/L^3$ from the dimensions of spinor fields and from the dimension of generalized polarization vector compensated by that of gamma matrices. Hence the dimensions of the bi-local quantities are L for both gauge bosons and Higgs like particles. They must be coupled to their effective QFT counterparts so that a dimensionless term in action results. Note that delta functions associated with the induced spinor fields reduce them to the end points of braid strand connecting wormhole throats and finite result is obtained.

(c) How to identify these dimensional bilinear terms defining the QFT limit? The basic problem is that the microscopic representation of the particle is bi-local and the effective field at QFT limit should be local. The only possibility is to consider an average of the effective field over the stringy curve connecting the points at two throats. The resulting quantities must have dimensions $1/L$ in accordance with naive scaling dimensions of gauge bosons and Higgs to compensate the dimension L of the microscopic representation of bosons. For gauge bosons having zero dimension as 1-forms the average $\int A_\mu dx^\mu/l$ along a unique stringy curve of length l connecting wormhole throats defines a quantity with dimension $1/L$. For Higgs components having dimension $1/L$ the quantities $\int H_A\sqrt{g_1}dx/l$, where g_1 corresponds to the induced metric at the stringy curve, has also dimension $1/L$. The presence of the induced metric depending on CP_2

metric guarantees that the effective action contains dimensional parameters so that the breaking of scale invariance results.

To sum up, for option II the parameters for the counterpart of Higgs action emerging at QFT limit must be determined by the p-adic mass calculations in TGD framework and the flux tube structure of particles would in the case of gauge bosons should give the standard contribution to gauge boson masses. For option I fermionic masses would emerge as mass parameters of the effective action. The presence of Euclidian regions of space-time having interpretation as lines of generalized Feynman diagrams is absolutely crucial in making possible Higgs like states. One must however emphasize that at this stage both option I and II must be considered.

7.4.4 To deeper waters

7.4.5 To deeper waters

Higgs issue seems to divide theoreticians to two classes: the simple-minded pragmatists and real thinkers.

For pragmatists the existence of Higgs and Higgs mechanism is something absolute: Higgs exists of not and one can make a bet about it. Most bloggers and most phenomenologists applying numerical models belong to this group. In particular, bloggers have had heated discussions and have made bets pro and and co, mostly pro.

Thinkers see the situation in a wider perspective. The real issue is the status of quantum field theory as a description of fundamental forces. Is QFT something fundamental or is it only a low energy limit of a more fundamental microscopic theory? Could it even happen that QFT limit fails in some respects and could the description of particle massivation represent such an aspect?

Already string models taught (or at least should have taught) to see quantum field theory as an effective description of a microscopic theory working at low energy limit. Since string theorists have not been able cook up any convincing answer to the layman's innocent question "How would you describe atom using these tiny strings which are so awe inspiring?", QFT limits have become what string models actually are at the phenomenological level. AdS-CFT correspondence actually equates string theory with a conformal quantum field theory in Minkowski space so that hopes about genuine microscopic theory are lost. This is disappointing but not surprising since strings are still too simple: they are either open or closed, there is no interesting internal topology.

In TGD framework string world sheets are replaced with 4-D space-time surfaces. One ends up with a very concrete vision about matter based on the notion of many-sheeted space-time and the implications are highly non-trivial in all scales. For instance, blackhole interior is replaced with a space-time region with Euclidian signature of the induced metric characterizing any physical system be it elementary particle, condensed matter system, or astrophysical object. Therefore the key question becomes the following. Does TGD have QFT in M^4 as low energy limit or rather - as a limit holding true in a given scale in the infinite length scale hierarchies predicted by theory (p-adic length scale hierarchy and hierarchy of effective Planck constants and hierarchy of causal diamonds)?

Deeper question: Does QFT limit of the fundamental theory exist?

Could the QFT limit defined as QFT in M^4 fail to exist? After this question one cannot avoid questions about the character of Higgs and Higgs mechanism.

(a) It is quite possible that in QFT framework Higgs mechanism is the only description of particle massivation. But this is just a mimicry, not a predictive description. QFT limit can only reproduce the spectrum of elementary particles masses or rather - mass ratios. The ratio of Planck mass (also an ad hoc concept) to proton mass remains a complete mystery.

This failure has been convincingly demonstrated by a huge amount of work in particle phenomenology. First came the GUT theorists. They applied every imaginable gauge group with elementary particles put in all imaginable group representations to reproduce the known part of the particle spectrum. They have reproduced standard model gauge symmetries at low energy limit. They have also done the necessary fine-tuning to make proton long-lived enough, to give large enough masses for the exotics, and to make beta functions sensical.

The same procedures have been repeated in SUSY framework and finally super string phenomenology has produced QFT limits with Higgs mechanism, and are now doing intense fine tuning to save poor SUSY from the aggressive attacks by LHC. During these 40 years of busy modelling practically nothing has been achieved but the work goes on since theoreticians have their methods and they must produce highly technical papers to preserve the illusion of hard science.

(b) Higgs mechanism is also plagued by profound problems. The hierarchy problem means that the Higgs mechanism with mass of about 125 GeV is just at the border of stability. The problem is that the sign of mass squared term in Higgs potential can change by radiative corrections so that the vacuum with a vanishing Higgs expectation value becomes stable. SUSY was hoped to solve the hierarchy problem but LHC has made SUSY in standard sense implausible. Even if it exists cannot help in this issue. Another problem is that the coefficients of the fourth power in the Higgs potential can become negative so that vacuum becomes unstable: the bottom of a valley becomes top of a hill. The value of Higgs mass is such that also this seems to happen! (see the posting of Resonaances).

Quite generally, fine tuning problems are the characteristic issues of the QFT limit. Proton must be long-lived enough, baryon and lepton number violating decay rates cannot be too high, the predicted exotic particles implied by the extension of the standard model gauge group must be massive enough, and so on... This requires a lot of fine tuning. Theory has transformed from a healer to a patient: the efforts of theoreticians reduce to attempts to resuscitate the patient. All this becomes understandable as one realizes that QFT is just a mimicry, not the fundamental theory.

One could also see these two problems of the Higgs mechanism as the last attempt of the frustrated Nature to signal to the busy mainstream career builders something very profound about reality by using paradox as its last means. From TGD vantage point the intended message of Nature looks quite obvious.

Shut up and calculate

The problem in the recent theoretical physics is that thinking has not been allowed for more than half century. Thinking is seen as "philosophy" - something very very bad. The fathers of quantum theory were philosophers: they realized the deep problems of quantum measurement theory and considered possible conclusions for the world view. For instance, Bohr - whose view became orthodoxy - concluded that objective reality cannot exist at all and that quantum theory is just a collection of calculational recipes with Ψ having no real existence. Einstein had totally different view. He believed that quantum theory is somehow fundamentally wrong.

Neither of them was yet mature to see that the problem involves the conscious observer in a very intimate manner: in particular, how the subjective time and the geometric time of physicist - certainly not one and the same thing - relate to each other. Both were also unable to see that objective reality could be replaced by objective realities identified as "solutions of field equations" and that quantum jumps would take between them and give rise to conscious experience. This would resolve both the problem of time and the basic problem of quantum measurement theory.

Later theoreticians followed the advice which has been put to the mouth of Feynman, and decided to just shut up and calculate. This long silence has lasted more than half a century now. I belong to those few who refused to follow the advice with the consequence that the decision makers of Helsinki University gave me officially a label of a madman and besides intensive blackmailing did their best to prevent any support for my work (see previous posting motivated by a warning of young readers about the dangers of reading my blog - sent by presumably finnish physics authority calling himself Anonymous).

LHC has now demonstrated how catastrophic consequences can be when the profession of the theoretician reduces to mindless calculation. We have got lost generations of theoreticians who continue to fill hep-th and hep-ph with preprints with a minimal connection to physical reality and mostly trying to solve the problems created by the theory itself rather than those provided by physics. This is however what they are able to do: collective silence has lasted too long. Even string model gurus have lost their beliefs on The Only Possible Theory of Everything. Some of them have suffered a regression to surprisingly childish models of gravitation (entropic gravity). Some have begun to see everything as black-holes without realizing that blackholes as a mathematical failure of general relativity should have been the starting point rather than the end. Some are making bets and having learned debates about paradoxes related to blackholes (firewall paradox is the latest newcomer (see the blog posting).

Or could thinking be a rewarding activity after all?

There are also some theoreticians who have followed their own star and have not been able to resist the temptation to think and imagine. I have used to call my own star TGD. As described in previous posting, p-adic thermodynamics can be seen as a- or even *the* - microscopic mechanism of massivation in TGD framework. There are two options to consider. According to Option I p-adic thermodynamics alone explains only fermion masses and the microscopic counterpart of Higgs mechanism would give the dominant contribution to gauge boson masses. For Option II p-adic thermodynamics would produce both gauge boson and Higgs masses and Higgs mechanism could appear at QFT limit as a mere phenomenological description of the massivation.

Option II is the most conservative option and apparently conforms with the standard model view. It also treats all particles in the same position. Note that in standard model Higgs itself like eye which cannot see itself since its tachyonic bare mass is put in by hand. Option II is also aesthetically more satisfactory if one believes that QFT limit of TGD indeed exists. For Option I one should invent new QFT mechanism describing fermion massivation in QFT framework or give up the idea about QFT limit altogether. In fact, experimental findings have selected Option II.

The existence of M^4 QFT limit is not obvious in TGD framework. This is due to a dramatic simplification in the microscopic description of particles. The only fundamental fields are spinors of $H = M^4 \times CP_2$ having just spin and electroweak quantum numbers and conserved carrying quark or lepton number depending on H-chirality. Color emerges and corresponds to color partial waves in H. Also bosons emerge meaning that gauge bosons, Higgs, and graviton have pairs of fermion and anti-fermion at the opposite throats of wormhole contacts as building bricks. Gauge fields, Higgs field, gravitational field and also Higgs mechanism can emerge in this approach only as a phenomenological description at M^4 QFT limit assuming that it exists. Fermionic families emerge from topology and also bosons are expected the analog of family replication phenomenon induced from the fermionic one.

Higgs like bosons might also develop coherent states characterized by the vacuum expectation value of Higgs but already this possibility must be taken critically since coherent states is a QFT based notion and it is not quite clear whether it generalizes to microscopic level. Covariantly constant complex CP_2 vector field should characterize vacuum expectation value. Tht this kind of vector fields do not exist is not an encouraging sign. The microscopic description in terms of string tension seems to be the only natural description of gauge boson massivation.

What is important that Higgs does not make fermions massive. For Option II this is true also for bosons. Rather, the couplings and vacuum expectation of Higgs are such that Higgs can pretend of achieving this feat. Higgs mechanism reproduces: p-adic thermodynamics predicts.

Standard model action is only an effective action providing tree diagrams so that the loop corrections leading to the hierarchy problem are not present unless the counterpart of fatal radiative corrections appear in the effective action which must depend on p-adic length scale (in TGD the discrete p-adic length scale evolution replaces the continuous renormalization group evolution of quantum field theories). Zero energy ontology however dramatically modifies the view about Feynman diagrammatics, and can save the situation since standard SUSY generalizes to super-conformal invariance.

There are of course lot of critical questions to be answered. I have written an entire book motivated by the challenge of understanding why p-adic thermodynamics should be needed in real number based physics. p-Adic physics for single prime is definitely not enough: one must fuse p-adic physics for various primes p and real physics to single coherent whole and this requires a lot of not yet existing mathematics such as generalization of number concept. The connections of p-adic physics to the description of cognition and intention in quantum consciousness theory are also obvious and p-adic space-time sheet would correspond to the "mind stuff" of Descartes. These few examples show how profound and totally unexpected new visions a more philosophical and imaginative attitude to physics generates.

Another book is devoted to the physical implications of p-adic physics and of the hierarchy of effective Planck constants, a notion implied by the very special properties of the basic variational principle dictating the space-time dynamics in TGD framework.

Chapter 8

SUSY in TGD Universe

8.1 Introduction

TGD based vision about supersymmetry has developed rather slowly.

(a) From the beginning it was clear that super-conformal symmetry is realized in TGD but differs in many respects from the more standard realizations such as $\mathcal{N} = \infty$ SUSY realized in MSSM [B8] involving Majorana spinors in an essential manner. The covariantly constant right-handed neutrino generates the super-symmetry at the level of CP_2 geometry and the construction of super-partners would be more or less equivalent with the addition of right-handed covariantly constant right-handed neutrino and antineutrinos. It was however not clear whether space-time supersymmetry is realized at all since one could argue that that these states are just gauge degrees of freedom.

(b) A more general general SUSY algebra is generated by the modes of the modified Dirac operator at partonic 2-surface. The value of $\mathcal{N}$ can be very large-even infinite- for this algebra and the SUSY is badly broken: this picture leads to a construction of QFT limit of TGD [K24], which seems to be crucial also for the understanding of TGD itself. Right-handed neutrinos represent the sub-SUSY with minimal breaking induced by the mixing of right- and left handed neutrinos caused by the properties of the modified gamma matrices for which mixing between M^4 and CP_2 gamma matrices takes place induced breaking of M^4 chirality serving as a signature for massivation.

(c) R-parity conservation leading to strong predictions in the case of MSSM is broken and since super-particles can decay to neutrino and particles the life-times of super-partners are finite and there is no lightest sparticle. The decay to neutrinos would however produce missing energy and the problem of missing missing energy, which is the basic difficulty of the standard SUSY, might be encountered also in TGD framework. One proposal avoiding this difficulty relies on the assumption that the right-handed neutrino generating supersymmetry is colored and color confinement forces spartners to combine to non-colored state transforming to ordinary hadrons.

(d) Quite recent developments in the understanding of the modified Dirac equation [K80] (I am writing this 2012) have led to a considerable understanding of the special role of right-handed neutrino. Whereas all other fermions are localized to 2-D string world sheets and partonic 2-surfaces by the condition that electromagnetic charge defined in spinorial sense is conserved, right-handed neutrino is de-localized at entire space-time surface and there is unbroken 4-dimensional counterpart of 2-D super-conformal symmetry associated with it. One has also 2-D badly broken SUSY generated by all fermion modes of the modified Dirac equation and labelled by conformal weight. This SUSY could be also interpreted super-conformal symmetry. One has also the unbroken $\mathcal{N} = 2$ space-time SUSY generated by right-handed neutrino and antineutrino. The rapid experimental progress at LHC during 2011-2012 has more or less eliminated standard

SUSY and this gives a powerful constraint in the attempts to understand what TGD SUSY could be.

What remains to be understood is the role of the covariantly constant right-handed neutrino spinor carrying no momentum: it behaves like Majorana spinor and its helicity is not constrained by Dirac equation. It is not clear whether the states defined by 2-D parton and by parton plus 4-D de-localized right-handed neutrino can be distinguished experimentally if right-handed neutrino does not carry four-momentum. This would be a trivial explanation for the failure to find evidence for SUSY at LHC. In fact, this argument can be developed to a more precise one: both fermions and sfermions exists and form representations of SUSY with second state having zero norm. Therefore fermion and sfermion candidates exist but belong to different representations of SUSY, and right-handed neutrinos remain invisible in the dynamics and the characteristic spin and momentum dependent vertex factors distinguishing between particle and sparticle are absent. The loss of space-time SUSY is not a catastrophe since it is not needed to stabilize Higgs in TGD framework since the variant of Higgs mechanism based on Higgs like pseudo-scalar is based conformally covariant Higgs potential containing no tachyonic Higgs mass term and is free of the problems related to radiative instability of the tachyonic Higgs mass term.

Personally I have a temptation to take the argument for the absence of space-time SUSY - space-time understood here as M^4 or $M^4 \times CP_2$ - seriously. This would conform with the failure of LHC to find space-time SUSY. At first one might see the absence of space-time SUSY as disappointing. Space-time SUSY however extends to the 4D analog of super-conformal invariance (not the usual super-conformal invariance but an infinite-dimensional symmetry) when space-time is understand as space-time surface.

If this argument - described later in more detail in the section "What is the role of the right-handed neutrino?" - one can conclude that most of the chapter is more or less obsolete! It is however better to be very cautious: some-one has said that our theories are much more intelligent than their builders, and from my personal experience I can fully agree with this statement! Therefore I dare not take the recent view as the final one: only the experimental input allows to fill in the details correctly. It is however clear that TGD based SUSY differs dramatically from the SUSY as it is usually understood and that LHC could allow to decide which of these views is nearer to truth.

In the following I will describe the evolution of ideas related to SUSY in TGD framework. There is no attempt to build a coherent final view and arguments in different sections represent how the views have developed.

The appendix of the book gives a summary about basic concepts of TGD with illustrations. There are concept maps about topics related to the contents of the chapter prepared using CMAP realized as html files. Links to all CMAP files can be found at `http://www.tgdtheory.fi/cmaphtml.html` [L20]. Pdf representation of same files serving as a kind of glossary can be found at `http://www.tgdtheory.fi/tgdglossary.pdf` [L21]. The topics relevant to this chapter are given by the following list.

- SUSY and TGD [L43]

8.1.1 What do experiments say about the situation?

Do also Higgsinos disappear from the spectrum?

In the following still some comments about TGD based view about symmetry breaking, Higgs, electroweak symmetry breaking, and SUSY. There are several unclear issues at the level of details. This is thanks to my unforgivable laziness in writing down the details. The results from LHC are however so fascinating that they force me to win my laziness. In the following I try to clarify my thoughts.

1. Is the earlier conjectured pseudo-scalar Higgs there at all?

Spin 1 gauge bosons and Higgs differ only by different spin direction of fermions at opposite wormhole throats. For spin 1 gauge bosons the 3-momenta at two wormhole throats cannot be parallel if if one wants non-vanishing spin component in the direction of moment. 3-momenta are most naturally opposite for the massless states at throats. This forces massivation for all gauge bosons and even graviton and this in turn requires Higgs even in the case of gluons.

The question is whether the parity properties of the couplings of gauge boson and corresponding Higgs transforming like 3+1 under SU(2) (this is due to the special character of imbedding space spinors) be exactly the same? Higgs would couple like a mixture of scalar and pseudo-scalar to fermions just as weak gauge bosons couple and the mixture would be just the same. If there are no axial variants of vector gauge bosons there should exist no pseudo-scalar Higgs. The non-existence of axial variants of vector gauge bosons is suggested by quantum classical correspondence: only gauge bosons having classical space-time correlates as induced gauge potentials should be allowed, nothing else. Note that color variant of Higgs would exist and would be eaten by gluons to get mass.

2. Could Higgs mechanism lead to the disappearance of also Higgsinos?

The similarity of the construction of gauge bosons and Higgsinos as pairs of wormhole throats containing fermion and anti-fermion encourages to think that Higgs mechanism is invariant under supersymmetries. If so, also Higgsinos would be eaten and one would have massive super-symmetric gauge theory with fermions with photon and other massless particle possessing a tiny mass. This looks very simple. The testable implication would be that only weak gauginos should contribute to muon g-2 anomaly.

3. Electroweak symmetry breaking

The recent view about electroweak symmetry breaking is less than year old. The basic realization was that wormhole throats carrying elementary particle quantum numbers possess Kähler magnetic charge (in homological sense- CP_2 has non-trivial second homology). This magnetic charge must be compensated and this is achieved if the particle wormhole throat is connected to a second wormhole throat by a magnetic flux tube. The second wormhole would carry a weak charge of neutrino pair compensating the weak isospin of the particle so that weak interactions would be screened above the weak length scale. For colored states the compensation could also occur in longer length scale and corresponds to color confinement.

This does not actually require the length scale of flux tubes associated with all elementary particles to be the weak length scale as I have thought. Rather, the flux tube length for a particle at rest could correspond to the Compton length of the particle. For instance, for electron the maximal flux tube length would be about 10^{-13} meters. For particles not at rest the length would get shorter by length contraction. For very light but massive particles such as photon and graviton the maximum length of flux tube would be very long. The interaction of very low energy photons and gravitons would be essentially classical and induced by the classical oscillations of induced gauge fields induced by a long flux tube connecting the interacting systems. For high energy quanta this interaction would be essentially quantal and realized as absorption of quanta with flux tube length -essentially wave length of quantum- much shorter than the distance between the interacting systems. Gravitational waves would interact essentially classically even when absorbed since absorption would mean that the flux tube would connects two parts of the measurement apparatus. For large $\hbar$ gravitons the length of flux tube could correspond to the distance between interaction systems.

A fascinating possibility is that electronic Cooper pairs of superconductors with large value of $\hbar$, could correspond to long flux tubes with electron's quantum numbers at both ends. Maybe this takes place in high T_c super conductors.

4. Some details of the SUSY predictions

TGD SUSY differs from the standard SUSY in many respects.

(a) All fermionic oscillator operators assignable to the wormhole throats generate supersymmetries. These oscillator operators differ from ordinary ones in that they do not have momentum label and momentum can be only assigned to the entire state. Therefore the interpretation of all states assignable to wormhole throats as large SUSY multiplet is possible. This SUSY is badly broken and there is hierarchy of breakings defined by the interactions inducing the breaking in turn define by the quantum numbers of SUSY generators. For quark generators the breaking is largest and the smallest breaking is associated with the oscillator operators assignable to right-handed neutrinos since they have only gravitational interactions.

(b) The symmetry generators are not Majorana spinors and this does not lead to any difficulties as has been found. Only if one would try stringy quantization trying to define stringy diagrams in terms of stringy propagators defined by stringy form of super-conformal algebra, one would end up with difficulties. Majorana property is also excluded by the separate conservation of baryon and lepton number.

For single wormhole throat one can see the situation in terms of N=2 SUSY with right handed neutrino and its antiparticle appearing as SUSY generators carrying conserved fermion number. One can classify the superpartners by their right-handed neutrino number which is +/-1. For instance, for single wormhole throat one obtains fermion and its partner containing ν_R pair, and fermion number 0 and fermion number 2 sfermions. In the case of gauge bosons and Higgs similar degeneracy is obtained for both wormhole throats.

(c) Since induced gamma matrices and modified gamma matrices are mixtures of M^4 and CP_2 gamma matrices right handed neutrino is mixed with the left handed neutrino meaning breaking of R-parity. The simplest decays of sparticles are of form $P \rightarrow P + \nu$ and can be said to be gravitationally induced since the mixing of gamma matrices is indeed a characteristic phenomenon of induced spinor structure. Also more complex decays with neutrino replaced with charge lepton are possible. The basic signature is lonely lepton not possible in decays of weak bosons.

(d) The basic outcome of SUSY QFT limit of TGD [K24] is that wormhole throat can carry only spin 0,1/2,1 corresponding to fermion and fermion pair if one wants to obtain standard propagator: otherwise one obtains $1/p^n$, $n > 2$ and this is not an ordinary particle pole. The reason is that one cannot assign to fermionic oscillator operators independent momenta but only common momentum so they propagate effectively collinearly.

One can criticize this argument as being inconsistent with the twistorial approach combined with zero energy ontology implying that wormhole throats are massless even for on mass shell states. In this approach one in principle avoids completely the use of propagators which would of course diverge for on shell wormhole throats. Also for twistor diagrams the counterparts of virtual particles are massless and off shell. The so called region momentum replaces momentum in Grassmannian twistor approach and has a direct counterpart as eigenvalue of the modified Dirac operator so that the analog of propagator exists in TGD framework. Since QFT limit must be a reasonable approximation to the full theory, one might hope that the QFT based argument makes sense when one replaces momentum with region momentum (or pseudo momentum as I have called it in TGD framework).

(e) Should one allow both $\nu_R$and its antiparticle as SUSY generators? This would mean more states as in standard SUSY for which only $\overline{\nu}_R$ would be allowed for fermion. This would assign to a given wormhole throat with fermion number 1 spin 1 and spin 0 super partner and companion of fermion containing $\nu_R - \overline{\nu}_R$ pair. For this state however propagator would behave like $1/p^3$ should that again strong SUSY breaking would occur for this extended SUSY. Only one half of SUSY would be broken weakly by the mixing of M^4 and CP_2 gamma matrices appearing in modified gamma matrices: the mixing would not involve weak or color interactions but could be said to be gravitational but not in the sense of abstract for geometry but induced geometry.

The breaking of symmetries by this mechanism would be a beautiful demonstration that it is sub-manifold geometry rather than abstract manifold geometry that matters. Again string theorists managed to miss the point by effectively eliminating induced geometry from the original string model by inducing the metric of space-time sheet as an independent variable. The motivation was that it became easy to calculate! The price paid was symmetry breaking mechanisms involving hundreds of three parameters.

(f) Single wormhole contact could carry spin J=2 and give rise to graviton like state. If one constructs from this gravitino by adding right-handed neutrinos, and if SUSY QFT limit makes sense, one obtains particle with propagator decreasing faster at either throat so that gravitino in standard sense would not exist. This would represent strong SUSY breaking in gravitational sector. These results are of utmost importance since the basic argument in favor dimension D=10 or D=11 for the target space of superstring models is that higher dimensions would give fundamental massless particles with higher spin.

Note that the replacement of wormhole throats by flux tubes having neutrino pair at the second end of the flux tube complicates the situation since one can add right handed neutrino also to the neutrino end. The SUSY QFT criterion would however suggest that these states are not particle like.

Super-symplectic bosons

Super-symplectic bosons

TGD predicts also exotic bosons which are analogous to fermion in the sense that they correspond to single wormhole throat associated with CP_2 type vacuum extremal whereas ordinary gauge bosons corresponds to a pair of wormhole contacts assignable to wormhole contact connecting positive and negative energy space-time sheets. These bosons have super-conformal partners with quantum numbers of right handed neutrino and thus having no electro-weak couplings. The bosons are created by the purely bosonic part of super-symplectic algebra [K13, K12] , whose generators belong to the representations of the color group and 3-D rotation group but have vanishing electro-weak quantum numbers. Their spin is analogous to orbital angular momentum whereas the spin of ordinary gauge bosons reduces to fermionic spin. Recall that super-symplectic algebra is crucial for the construction of WCW Kähler geometry. If one assumes that super-symplectic gluons suffer topological mixing identical with that suffered by say U type quarks, the conformal weights would be (5,6,58) for the three lowest generations. The application of super-symplectic bosons in TGD based model of hadron masses is discussed in [K43] and here only a brief summary is given.

As explained in [K43] , the assignment of these bosons to hadronic space-time sheet is an attractive idea.

(a) Quarks explain only a small fraction of the baryon mass and that there is an additional contribution which in a good approximation does not depend on baryon. This contribution should correspond to the non-perturbative aspects of QCD. A possible identification of this contribution is in terms of super-symplectic gluons. Baryonic space-time sheet with $k = 107$ would contain a many-particle state of super-symplectic gluons with net conformal weight of 16 units. This leads to a model of baryons masses in which masses are predicted with an accuracy better than 1 per cent.

(b) Hadronic string model provides a phenomenological description of non-perturbative aspects of QCD and a connection with the hadronic string model indeed emerges. Hadronic string tension is predicted correctly from the additivity of mass squared for $J = 2$ bound states of super-symplectic quanta. If the topological mixing for super-symplectic bosons is equal to that for U type quarks then a 3-particle state formed by 2 super-symplectic quanta from the first generation and 1 quantum from the second generation would define baryonic ground state with 16 units of conformal weight. A very precise prediction for hadron masses results by assuming that the spin of hadron correlates with its super-symplectic particle content.

(c) Also the baryonic spin puzzle caused by the fact that quarks give only a small contribution to the spin of baryons, could find a natural solution since these bosons could give to the spin of baryon an angular momentum like contribution having nothing to do with the angular momentum of quarks.

(d) Super-symplectic bosons suggest a solution to several other anomalies related to hadron physics. The events observed for a couple of years ago in RHIC [C97] suggest a creation of a black-hole like state in the collision of heavy nuclei and inspire the notion of color glass condensate of gluons, whose natural identification in TGD framework would be in terms of a fusion of hadronic space-time sheets containing super-symplectic matter materialized also from the collision energy. In the collision, valence quarks connected together by color bonds to form separate units would evaporate from their hadronic space-time sheets in the collision, and would define TGD counterpart of Pomeron, which experienced a reincarnation for few years ago [C111]. The strange features of the events related to the collisions of high energy cosmic rays with hadrons of atmosphere (the particles in question are hadron like but the penetration length is anomalously long and the rate for the production of hadrons increases as one approaches surface of Earth) could be also understood in terms of the same general mechanism.

8.1.2 Experimental situation

The experimental situation in the case of SUSY is still open but it there are excellent hopes that the results from LHC will determine the fate of the MSSM SUSY and also constraint more general scenarios. Unfortunately, the research concentrates to the signatures of MSSM and its variants quite different from those of TGD SUSY so that it might happen that TGD SUSY will be discovered accidentally if its there: say by the decays of spartner to partner and neutrino. Already from the recent results it is clear that the allowed parameter space for MSSM SUSY is very small and that superpartners of quarks and also weak gauge bosons must be very heavy if MSSM SUSY is realized. This leads to difficulties with the only known evidence for SUSY coming from the g-2 anomaly of muon. TGD based SUSY allows light masses and also SUSY explanation of g-2 anomaly if sneutrino masses are light.

The representation involves a lot of references to blog postings and this might irritate so called serious scientists. I however feel that since blogs provide my only contact to the particle physics it is only fair to make clear that this communication tool is absolutely essential for a scientist working as out-of-law in academic community. Blogs could indeed bring democracy to science and mean end of the era of secrecy and censorship by the referee system.

Experimental indication for space-time super-symmetry

There is experimental indication for super-symmetry dating back to 1995 [C155] . The event involves $e^+e^-\gamma\gamma$ plus missing transverse energy $\not{E}_T$. The electron-positron pair has transversal energies $E_T = (36, 59)$ GeV and invariant mass $M_{ee} = 165$ GeV. The two photons have transversal energies (30,38) GeV. The missing transverse energy is $\not{E}_T = 53$ GeV. The cross sections for these events in standard model are too small to be observed. Statistical fluctuation could be in question but one could also consider the event as an indication for super-symmetry.

In [C117] an explanation of the event in terms of minimal super-symmetric standard model (MSSM) was proposed.

(a) The collision of proton and antiproton would induce an annihilation of quark and antiquark to selectron pair $\tilde{e}^-\tilde{e}^+$ via virtual photon or Z^0 boson with the mass of $\tilde{e}$ in the range (80,130) GeV (the upper bound comes from the total energy of the particles involved.

(b) $\tilde{e}^\pm$ would in turn decay to $e^\pm$ and neutralino χ_2^0 and χ_2^0 in turn to the lightest super-symmetric particle χ_1^0 and photon. The neutralinos are in principle mixtures of the super partners associated with γ, Z^0, and neutral higgs h (there are two of them in minimal super-symmetric generalization of standard model). The highest probability for the chain is obtained if χ_2^0 is zino and χ_1^0 is higgsino.

(c) The kinematics of the event allows to deduce the bounds

$$\begin{aligned} 80 &< m(\tilde{e})/GeV < 130 \ , \\ 38 &\leq m(\chi_2^0)/GeV \leq min\left[1.12m(\tilde{e})/GeV - 37, 95 + 0.17m(\chi_1^0)/GeV\right] \ , \\ m(\chi_1^0)/GeV &\leq m(\chi_2^0)/GeV \leq min\left[1.4m(\tilde{e})/GeV - 105, 1.6m(\chi_2^0)/GeV - 60\right] \ . \end{aligned} \quad (8.1.\text{-}2)$$

Note that the bounds give no lower bound for $m(\chi_1^0)$ so that it could correspond to neutrino.

(d) Sfermion production rate depends only on masses of the sfermions, so that slepton production cross section decouples from the analysis of particular scenarios. The cross section is at the level of $\sigma = 10$ fb and consistent with data (one event!). The parameters of MSSM are super-symmetric soft-breaking parameters, super-potential parameters, and the parameter $tan(\beta)$. This allows to derive more stringent limits on the masses and parameters of MSSM.

Consider now the explanation of the event in TGD framework.

(a) For the simplest TGD inspired option both Higgs and higgsino would disappear from the spectrum in the massivation and χ_2^0 would decay to photon and neutrino so that the missing energy would consist of neutrinos.

(b) By the properties of super-partners the production rate for $\tilde{e}^-\tilde{e}^+$ is predicted to be same as in MSSM for $\tilde{e} = e_R\overline{\nu}_R$. Same order of magnitude is predicted also for more exotic super-partners such as $e_L\overline{\nu}_R$ with spin 1.

(c) In TGD framework it is safest to use just the kinematical bounds on the masses and p-adic length scale hypothesis. If super-symmetry breaking means same mass formula from p-adic thermodynamics but in a different p-adic mass scale, $m(\tilde{e})$ is related by a power of $\sqrt{2}$ to $m(e)$. Using $m(\tilde{e}) = 2^{(127-k(\tilde{e}))/2}m(e)$ one finds that the mass range $[80, 130]$ GeV allows two possible masses for selectron corresponding to $p \simeq 2^k$, $k = 91$ with $m(\tilde{e}) = 131.1$ GeV and $k = 92$ with $m(\tilde{e}) = 92.7$ GeV. The bounds on $m(Z)$ leave only the option $m(\tilde{Z}) = m(Z) = 91.2$ GeV and $m(\tilde{e}) = 131.1$ GeV.

(d) In the earlier variant of the TGD inspired model the existence of Higgs was considered as a realistic option. The indirect determinations of Higgs masses from experimental data seemed to converge to two different values. The first one seemed to correspond to $m(h) =$ 129 GeV and $k(h) = 94$ and second one to $m(h) = 91$ GeV with $k(h) = 95$ [K34] . The fact that already the TGD counterpart for the Gell-Mann-Okubo mass formula in TGD framework requires quarks to exist at several p-adic mass scales [K43], suggests that Higgs can exist in both of these mass scales depending on the experimental situation. The mass of Higgsino would correspond to some half octave of $m(h)$. Note that the model allows to conclude that Higgs indeed exists also in TGD Universe although it does not seem to play the same role in particle massivation as in the standard model. The bounds allow only $k(\tilde{h}) = k(h) + 3 = 97$ and $m(\tilde{h}) = 45.6$ GeV for $m(h) = 129$ GeV . The same same mass is obtained for $m(h) = 91$ GeV. Therefore the kinematic limits plus super-symmetry breaking at the level of p-adic mass scale fix completely the masses of the super-particles involved in absence of mixing effects for sneutralinos.

To sum up, the masses of sparticles involved for the option allowing Higgs are predicted to be

$$m(\tilde{e}) = 131 \ \ GeV \ \ , \quad m(\tilde{Z}^0) = 91.2 \ \ GeV \ \ , \quad m(\tilde{h}) = 45.6 \ \ GeV \ \ . \quad (8.1.\text{-}1)$$

If Higgs and Higgsino are both eaten in the massivation, the third condition drops off. The argument to be represented below suggests that also sleptons could correspond to Mersennes and Gaussian Mersennes: this option predictions $k(\tilde{e}) = 89$ so that the mass would be 250 GeV: this excludes the proposed interpretation of the strange event.

Goodbye large extra dimensions and MSSM

New results giving strong constraints on large extra dimensions and on the parameters of minimally supersymmetric standard model (MSSM) have come from LHC and one might say that both larger extra dimensions and MSSM are experimentally excluded.

1. The problems of MSSM

According to the article The fine-tuning price of the early LHC by A. Strumia [C26] the results from LHC reduce the parameter space of MSSM dramatically. Recall that the king idea of MSSM is that the presence of super partners tends to cancel the loop corrections from ordinary particles giving to Higgs mass much larger correction that the mass itself. Note that the essential assumption is that R-parity is an exact symmetry so that the lightest superpartner is stable. The signature of SUSY is indeed missing energy resulting in the decay chain beginning with the decay of gluino to chargino and quark pair followed by the decay of chargino to W boson and neutralino representing missing energy.

The article Search for supersymmetry using final states with onelepton, jets, and missing transverse momentum with the ATLAS detector in $s^{1/2} = 7$ TeV pp collisions [C23] by ATLAS collaboration at LHC poses strong limits on the parameters of MSSM implying that the mass of gluino is above 700 GeV in the case that gluino mass is same as that of squark. In Europhysics 1011 meeting the lower bounds for squark and gluino masses were raised to about 1 TeV. The experimental lower bounds on masses of superpartners are so high and the upper bound on Higgs mass so low that the superpartners cannot give rise to large enough compensating corrections to stabilize Higgs. This requires fine-tuning even in MSSM known as little hierarchy problem.

In typical models this also means that the bounds on slepton masses are too high to be able to explain the muonic g-2 anomaly, which was one of the original experimental motivations for MSSM. Therefore the simplest candidates for supersymmetric unifications are lost. This strengthens the suspicion that something is badly wrong with the standard view about SUSY forcing among other things to assume instability of proton due to non-conservation of baryon and lepton numbers separately.

2. The difficulties of large extra dimensions

The results from LHC do not leave much about the dream of solving hierarchy problem using SUSY. One must try something else. One example of this something else are large extra dimensions implying massive graviton, which could provide a new mechanism for massivation based on the idea that massive particle in Minkowski space are massless particles in higher dimensional space (also essential element of TGD). This could perhaps the little hierarchy problem if the mass of Kaluza-Klein graviton is in TeV range.

The article LHC bounds on large extra dimensions by A. Strumia and collaborators [C13] poses very strong constraints on large extra dimensions and mass and effective coupling constant parameter of massive graviton. Kaluza-Klein graviton would appear in exchange diagrams and loop diagrams for 2-jet production and could become visible in higher energy proton-proton collisions at LHC. KK graviton would be also produced as invisible KK-graviton energy in proton-proton collisions. The general conclusion from data gathered hitherto shrinks dramatically the allowed parameter space for the KK-graviton. Does this mean that we are left with the anthrophic option?

3. Also M-theorists admit that there are reasons for the skepticism

Michael Dine admits in the article Supersymmetry From the Top Down [C24] that there are strong reasons for skepticism. Dine emphasizes that the hierarchy problem related to the instability of Higgs mass due to the radiative corrections is the main experimental motivation for SUSY but that little hierarchy problem remains the greatest challenge of the approach. As noticed, in TGD this problem is absent. The same basic vision based on zero energy ontology and twistors predicts among other things

- the cancellation of UV and IR infinities in generalized Feynman (or more like twistor-) diagrammatics,
- predicts that in the electroweak scale the stringy character of particles identifiable as magnetically charged wormhole flux tubes should begin to make itself manifest,
- particles regarded usually as massless eat all Higgs like particles accompanying them (here "predict" is perhaps too strong a statement),
- also pseudo-scalar counterparts of Higgs-like particles which avoid the fate of their scalar variants (there already exist indications for pseudo-scalar gluons).

Combined with the powerful predictions of p-adic thermodynamics for particle masses these qualitative successes make TGD a respectable candidate for the follower of string theory.

Could TGD approach save super-symmetry?

In TGD framework the situation is not at all so desolate. Due to the differences between the induced spinor structure and ordinary spinors, Higgs corresponds to SU(2) triplet and singlet in TGD framework rather than complex doublet. The recent view about particles as bound states of massless wormhole throats forced by twistorial considerations and emergence of physical particles as bound states of wormhole contacts carrying fermion number and vibrational degrees of freedom strongly suggests- I do not quite dare to say "implies"- that also photon and gluons become massive and eat their Higgs partners to get longitudinal polarization they need. No Higgs- no fine tuning of Higgs mass- no hierarchy problems.

Note that super-symmetry is not given up in TGD but differs in many essential respects from that of MSSM. In particular, super-symmetry breaking and breaking of R-parity are automatically present from the beginning and relate very closely to the massivation.

(a) If the gamma matrices were induced gamma matrices, the mixing would be large by the light-likeness of wormhole throats carrying the quantum numbers. Induced gamma matrices are however excluded by internal consistency requiring modified gamma matrices obtained as contractions of canonical momentum densities with imbedding space gamma matrices. Induced gamma matrices would require the replacement of Kähler action with 4-volume and this is unphysical option.

(b) In the interior Kähler action defines the canonical momentum densities and near wormhole throats the mixing is large: one should note that the condition that the modified gamma matrices multiplied by square root of metric determinant must be finite. One should show that the weak form of electric-magnetic duality guarantees this: it could even imply the vanishing of the limiting values of these quantities with the interpretation that the space-time surfaces becomes the analog of Abelian instanton with Minkowski signature having vanishing energy momentum tensor near the wormhole throats. If this is the case, Euclidian and Minkowskian regions of space-time surface could provide dual descriptions of physics in terms of generalized Feynman diagrams and fields.

(c) At wormhole throats Abelian Chern-Simons-Kähler action with the constraint term guaranteeing the weak form of electric-magnetic duality defines the modified gamma matrices. Without the constraint term Chern-Simons gammas would involve only CP_2 gamma matrices and no mixing of M^4 chiralities would occur. The constraint term transforming TGD from topological QFT to almost topological QFT by bringing in M^4 part to the modified gamma matrices however induces a mixing proportional to Lagrange multiplier. It is difficult to say anything precise about the strength of the constraint force density but one expect that the mixing is large since it is also large in the nearby interior.

If the mixing of the modified gamma matrices is indeed large, the transformation of the right-handed neutrino to its left handed companion should take place rapidly. If this is the case, the decay signatures of spartners are dramatically changed as will be found and the bounds on the masses of squarks and gluinos derived for MSSM do not apply in TGD framework.

1. Proposal for the mass spectrum of sfermions

In TGD framework p-adic length scale hypothesis (stating that preferred p-adic primes come as $p \simeq 2^k$, k integer) allows to predict the masses of sleptons and squarks modulo scaling by a powers $\sqrt{2}$ determined by the p-adic length scale by using information coming from CKM mixing induced by topological mixing of particle families in TGD framework. Also natural guesses for the mass scales of ew gauginos and gluinos are obtained.

(a) If one assumes that the mass scale of SUSY corresponds to Mersenne prime M_{89} assigned with intermediate gauge bosons one obtains unique predictions for the various masses apart from uncertainties due to the mixing of quarks and neutrinos [K34] .

(b) In first order the p-adic mass formulas for fermions read as

$$\begin{aligned} m_F &= \sqrt{\frac{n_F}{5}} \times 2^{(127-k_F)/2} \times m_e \ , \\ n_L &= (5,14,65) \ , \ n_\nu = (4,24,64) \ , \ n_U = (5,6,58) \ , \ n_D = (4,6,59) \ . \end{aligned} \quad (8.1.-2)$$

Here k_F is the integer characterizing p-adic mass scale of fermion via $p \simeq 2^{k_F}$. The values of k_F are not listed here since they are not needed now. Note that electroweak symmetry breaking distinguish U and D type fermions is very small when one uses p-adic length scale as unit.

By taking $k_F = 89$ for super-partners as a reference mass scale, one obtains in good approximation (the first calculation contained erratic scaling factor)

$$\begin{aligned} \frac{m_{\tilde{L}}}{GeV} &= 2^{(89-k_F)/2}(262,439,945) \ , \\ \frac{m_{\tilde{\nu}}}{GeV} &= 2^{(89-k_F)/2}(235,423,938) \ , \\ \frac{m_{\tilde{U}}}{GeV} &= 2^{(89-k_F)/2}(262,287,893) \ , \\ \frac{m_{\tilde{D}}}{GeV} &= 2^{(89-k_F)/2}(235,287,900) \ . \end{aligned} \quad (8.1.-5)$$

Charged leptons correspond to subsequent Mersennes or Gaussian Mersennes. The first guess is that this holds true also for charged sleptons. This would give $k_F(\tilde{e}) = 89$, $k_F(\tilde{\mu}) = 79$, and $k_F(\tilde{\tau}) = 61$. For quarks one has $k_F(q) \geq 113$ ($k = 113$ corresponds to Gaussian Mersenne). If one generalizes this to $k_F(\tilde{q}) \leq 79$, all sfermion masses expect those of selectron and sneutrinos are above 13 TeV. This option might well be consistent with the recent experimental data require that squark masses are above 1 TeV. The possible problem is selectron mass 262 GeV.

(c) The simplest possibility is that ew gauginos are characterized by $k = 89$ and have same masses as W and Z in good approximation. Therefore $\tilde{W}$ could be the lightest supersymmetric particle and could be observed directly if the neutrino mixing is not too fast and allowing the decay $\tilde{W} + \nu$. Also gluinos could be characterized by M_{89} and have mass of order intermediate gauge boson mass. For this option to be discussed below the decay scenario of MSSM changes considerably.

(d) It should be noticed that the single strange event reported 1995 [C155] discussed in [**?**]ives for the mass of selectron the estimate 131 GeV, which corresponds to M_{91} instead of M_{89} and is thus one half of the selectron mass for Mersenne option. This event allowed also to estimate the masses of Zino and corresponding Higgsino. The results are summarized by the following table:

$$m(\tilde{e}) = 131 \ \ GeV \ , \ \ m(\tilde{Z}^0) = 91.2 \ \ GeV \ , \ \ m(\tilde{h}) = 45.6 \ \ GeV \ . \quad (8.1.-4)$$

If one takes these results at face value one must conclude either that M_{89} hypothesis is too strong or M_{SUSY} corresponds to M_{91} or that M_{89} is correct identification but also sfermions can appear in several p-adic mass scales.

The decay cascades searched for in LHC are initiated by the decay $q \rightarrow \tilde{q}+\tilde{g}$ and $g \rightarrow \tilde{q}+\tilde{q}_c$. Consider first R-parity conserving decays. Gluino could decay in R-parity conserving manner via $\tilde{g} \rightarrow \tilde{q}+q$. Squark in turn could decay via $\tilde{q} \rightarrow q_1+\tilde{W}$ or via $\tilde{q} \rightarrow q+\tilde{Z}^0$. For the proposed first guess about masses the decay $\tilde{W} \rightarrow \nu_e+\tilde{e}$ or $\tilde{Z}^0 \rightarrow \nu_e+\tilde{\nu}_e$ would not be possible on mass shell.

If the mixing of right-handed and left-handed neutrinos is fast enough, R-parity is not conserved and the decays $\tilde{g} \rightarrow g+\nu$ and $\tilde{q} \rightarrow q+\nu$ could take place by the mixing $\nu_R \rightarrow \nu_L$ following by electroweak interaction between ν_L quark or antiquark appearing as composite of gluon. The decay signature in this case would be pair of jets (quark and antiquark or gluon gluon jet both containing a lonely neutrino not accompanied by a charged lepton required by electroweak decays. Also the decays of electroweak gauginos and sleptons could produce similar lonely neutrinos.

The lower bound to quark masses from LHC is about 600 GeV and 800 GeV for gluon masses assuming light neutralino is slightly above the proposed masses of lightest squarks [C9] . In Europhysics 2011 lower bounds were raised to 1 TeV for both gluino and squark masses. These bounds are consistent with the above speculative picture. These masses are allowed for R-parity conserving option if the decay rate producing chargino is reduced by the large mass of chargino the bounds become weaker. If the decay via R-parity breaking is fast enough no bounds on masses of squarks and gluinos are obtained in TGD framework but jets with neutrino unbalanced by a charged lepton should be observed.

2. How to relate MSSM picture to TGD picture?

In order to utilize MSSM calculation in TGD framework one must relate MSSM picture to TGD picture. The basic constraint is that Higgs is absent. This could apply also to Higgsino. This certainly simplifies the formulas. A further condition is that superpartners obey the same mass formulas as partners for same pa-dic length scale.

It has been proposed that the loops involving superpartners could explain the anomaly [C171] . In one-loop order one would have the processes $\mu \rightarrow \tilde{\mu}+\tilde{Z}^0$ and $\mu \rightarrow \tilde{\nu}_\mu+\tilde{W}^0$. The situation is complicated by the possible mixing of the gauginos and Higgsinos and in MSSM this mixing is described by the mixing matrices called X and Y. The general conclusion is however clear: if muonic sneutrino is light, it is possible to have sizeable contribution to the g-2 anomaly.

(a) Magnetic moment operator mixes different M^4 chiralities. For simplest one-loop diagrams this corresponds in TGD framework to coupling in the modified Dirac equation mixing different chiralities describable as an effective mass term. The couplings between right and left handed sfermions also contributes to the magnetic moment and these couplings reduce to those of sfermions being basically induced by the fermionic chirality mixing which reduces to the fact that modified gamma matrices are superpositions of M^4 and CP_2 gamma matrices.

(b) The basic outcome in the standard SUSY approach is that the mixing is proportional to the factor m_μ^2/m_{SUSY}^2. One expects that in the recent situation $m_{SUSY}=m_W$ is a reasonable first guess so that the mixing is large and could explain the anomaly. Second guess is as M_{89} p-adic mass scale.

(c) MSSM calculations for anomalous g-2 involve the mixing of both $\tilde{f}_L$ and $\tilde{f}_R$ and of gauginos and Higgsinos. In MSSM the mixing matrices involve the parameter $tan(\beta)$ where the angle β characterizes the ratio of mass scales of U and D type fermions fixed by the ratio of Higgs expectations for the two complex Higgs doublets [C171] . $tan(\beta)$ also characterizes in MSSM the ratio of vacuum expectation values of two Higgses assignable to U and D type quarks and cannot be fixed from this criterion since in TGD framework one has one scalar Higgs and pseudo-scalar Higgs decomposing to triplet and singlet under SU(2) and the mass ratio is fixed by p-adic mass calculations.

The question is what happens if Higgs and Higgsino are absent and what one can conclude about the value of β in TGD framework where p-adic mass calculations give the dominant contribution to fermion masses and the mass formulas for particles and sparticles should be identical for a fixed p-adic prime.

2.1 Mixing of charged gauginos and Higgsinos

Consider first the mixing between charged gauginos and Higgsinos. The angle β characterizes also the mixing of $\tilde{W}$ and charged Higgsino parametrized by the mass matrix

$$X = \begin{pmatrix} M_2 & M_W\sqrt{2}sin(\beta) \\ M_W\sqrt{2}cos(\beta) & \mu \end{pmatrix} . \quad (8.1.-3)$$

The $tan(\beta)$ gives the ratio of mass scales of U and D type quarks in MSSM. In MSSM $tan(\beta)$ reduces to the ratio of Higgs vacuum expectations and it would be better to get rid of the entire parameter in TGD framework. The maximally symmetric situation corresponds to the same mass scale for U and D type quarks and this suggests that one has $sin(\beta) = cos(\beta) = 1/\sqrt{2}$ implying $tan(\beta) = 1$. In MSSM $tan(\beta) > 2$ is required and this is due to the large value of the m_{SUSY}.

Whether this parameterization makes sense in TGD framework depends on whether one allows Higgsino.

(a) If also Higgsino is absent the formula does not make sense. A natural condition is that the value of $tan(\beta)$ does not appear at all in the limiting formulas for the anomalous g-2. Note that in p-adic mass calculations do not contain this kind of a priori continuous parameter. There the simplest TGD based option is that the Higgsino is just absent and the mass matrix reduces 1×1 matrix M_2 giving wino mass. The idea that particle and sparticles have identical masses for the same p-adic mass scale would give $M_2 = M_W$. One must however remember that in TGD framework mass operator acts like a preferred combination of gamma matrices in CP_2 degrees of freedom mixing M^3 chiralities.

(b) If one allows Higgsinos, the simplest guess is that apart from p-adic mass scale same has $M_2 = -\mu = m$: this guarantees identical masses for the mixed states in accordance with the ideas that different masses for particles and sparticles result from the different p-adic length scale. For $cos(\beta) = 1/\sqrt{2}$ this would give mass matrix with eigen values $(M, -M)$, $M = \sqrt{m^2 + m_W^2}$ so that mass squared values of of the mixed states would be identical and above m_W mass for $p = M_{89}$. Symmetry breaking by an increase of the p-adic length scale could however reduce the mass of other state by a power of $\sqrt{2}$.

If also winos and zinos eat the higgsinos, one can argue that the determinant of X must vanish so that the eigenstate with vanishing eigen value would correspond to an unphysical state meaning the elimination of second state from the spectrum. This would require $M_2\mu - M_W^2 sin(2\beta) = 0$. $sin(\beta) = 1/\sqrt{2}$ and $M_2 = \mu = M_W$ is the simplest solution to the condition. This looks tricky.

2.2 Mixing of neutral gauginos and Higgsinos

In MSSM 4×4 matrix is needed to describe the mixing of neutral gauginos and two kinds of neutral Higgsinos. In TGD framework second Higgs (if it exists at all) is pseudo-scalar and does not contribute and the 2×2 matrices describe the mixing also now.

$$X = \begin{pmatrix} \begin{pmatrix} M_1 & 0 \\ 0 & M_2 \end{pmatrix} & M_Z \begin{pmatrix} s_W cos(\beta) & s_W sin(\beta) \\ c_W cos(\beta) & c_W sin(\beta) \end{pmatrix} \\ M_Z \begin{pmatrix} s_W cos(\beta) & s_W sin(\beta) \\ c_W cos(\beta) & c_W sin(\beta) \end{pmatrix} & -\mu \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \end{pmatrix} . \quad (8.1.-2)$$

For $sin(\beta) = cos(\beta) = 0$ the non-diagonal part of the mass matrix is degenerate.

Again there are two options depending on whether Higgsinos are present and if they are absent the dependence on the angle β vanishes. Indeed, if Higgsinos are absent the matrix reduces to a diagonal 2×2 mass matrix for U(1) gaugino $\tilde{B}$ and neutral SU(2) gaugino $\tilde{W}^3$. If one takes seriously MSSM, there would be no mixing. On the other hand, TGD suggests that neutral gauginos mix in the same manner as neutral gauge bosons so that Weinberg angle would characterize the mixing with photino and zino appearing as mass eigen states. Again for same value of p-adic prime the values of mass squared for gauge bosons and gauginos should be identical.

One can also consider the option with Higgsino.

(a) Since Higgs and Higgsino have representation content 3+1 with respect to electroweak SU(2) in TGD framework, one can speak about $\tilde{h}_B$, $B = W, Z, \gamma$. An attractive assumption is that Weinberg angle characterizes also the mixing giving rise to $\tilde{Z}$ and $\tilde{\gamma}$ on one hand and $\tilde{h}_\gamma$ and $\tilde{h}_Z$ on the other hand if these belong to the spectrum. This would reduce the mixing matrix to two 2×2 matrices: the first one for $\tilde{\gamma}$ and $\tilde{h}_\gamma$ and the second one for $\tilde{Z}$ and $\tilde{h}_Z$.

(b) A further attractive assumption is that the mass matrices describing mixing of gauginos and corresponding Higgsinos are in some sense universal with respect to electroweak interactions. The form of the mixing matrix would be essentially same for all cases. This would suggest that M_W is replaced in the above formula with the mass of Z^0 and photon in these matrices (recall that it is assumed that photon gets small mass by eating the neutral Higgs). Note that for photino and corresponding Higgsino the mixing would be small. The guess is $M_2 = -\mu = m_Z$. For photino one can guess that M_2 corresponds to M_{89} mass scale.

These assumptions of course define only the first maximally symmetric guess and the simplest modification that one can imagine is due to the different p-adic mass scales. If the above discussed values for zino and neutralino masses deduced from the 1995 event [C155] are taken at face value, the eigenvalues would be $\pm\sqrt{M_Z^2 + m^2}$ with $m = M_2 = -\mu$ for $\tilde{Z} - \tilde{h}_Z$-mixing and the other state would have p-adic length scale $k = 91$ rather than $k = 89$. M and μ would have opposite signs as required by the correct sign for the $g - 2$ anomaly for muon assuming that smuons correspond to $p = M_{89}$ as will be found.

2.3 The relationship between masses of charged sleptons and sneutrinos

In MSSM approach one has also the formula relating the masses of sneutrinos and charged sleptons [C171]:

$$m_{\tilde{\nu}}^2 = m_{\tilde{L}}^2 + \frac{1}{2} M_Z^2 cos(2\beta) \quad . \tag{8.1.-1}$$

For $\beta = \pm\pi/4$ one would have $tan(\beta) = 1$ and

$$m_{\tilde{\nu}}^2 = m_{\tilde{L}}^2 \quad .$$

In p-adic mass calculations this kind of formula is highly questionable and could make sense only if the particles involved correspond to same value of p-adic prime and therefore would not make sense after symmetry breaking.

3. The anomalous magnetic moment of muon as a constraint on SUSY

The anomalous magnetic moment $a_\mu \equiv (g-2)/2$ of muon has been used as a further constraint on SUSY. The measured value of a_μ is $a_\mu^{exp} = 11659208.0(6.3) \times 10^{10}$. The theoretical prediction decomposes to a sum of reliably calculable contributions and hadronic contribution for which the low energy photon appearing as vertex correction decays to virtual hadrons. This contribution is not easy to calculate since non-perturbative regime of QCD is involved. The deviation between prediction and experimental value is $\Delta a_\mu(exp - SM) = 23.9(9.9) \times 10^{-10}$ giving $\Delta a_\mu(exp - SM/)a_\mu = 2 \times 10^{-6}$. The hadronic contribution is estimated to be 692.3×10^{-10} so that the anomaly is 3 per cent from the hadronic contribution [C171]. One can ask whether the uncertainties due to the non-perturbative effects could explain the anomaly.

The following calculation is a poor man's version of MSSM calculation [C171]. Also now SUSY requires that the electroweak couplings between particles dictate those between sparticles. Supersymmetry for massivation suggests that in TGD framework higgsinos do not belong to the spectrum. Light sfermions appear as single copy with vanishing fermion number so that various mixing matrices of MSSM reduce to unit matrices. This leads to a rough recipe: take only the one loop contributions to g-2 and assume trivial mixing matrices and drop off summations. At least a good order of magnitude estimate should result in this manner.

3.1 A rough MSSM inspired estimate g-2 anomaly

Consider now a rough estimate for the g-2 anomaly by using the formulas 56-58 of [C171]. One obtains for the charged loop the expression

$$\Delta a_\mu^\pm = -\frac{21 g_2^2}{32\pi^2} \times (\frac{m_\mu}{m_W})^2 \times sign(\mu M_2) \ . \tag{8.1.0}$$

This however involves a formula relating sneutrino and charged slepton masses. There is no reason to expect this formula to hold true in TGD framework.

For neutral contribution the expression is more difficult to deduce. As physical intuition suggests, the expression inversely proportional to $1/m_W^2$ since m_W corresponds now m_{SUSY} although this is not obvious on the basis of the general formulas suggesting the proportionality toi $1/m_{\tilde{\nu}_\mu}^2$. The p-adic mass scale corresponding to M_{89} is the natural guess for M_{SUSY} and would give $M_{SUSY} = 104.9$ GeV. The fact that the correction has positive sign requires that μ and M_2 have opposite signs unlike in MSSM. The sign factor is opposite to that in MSSM because sfermion mass scales are assumed to be much higher than weak gaugino mass scale.

The ratio of the correction to the lowest QED estimate $a_{\mu,0} = \alpha/2\pi$ can be written as

$$\frac{\Delta a_\mu^+}{a_{\mu,0}} = \frac{21}{4sin^2(\theta_W)} \times (\frac{m_\mu}{m_{SUSY}})^2 \simeq 2.73 \times 10^{-5} \ . \tag{8.1.1}$$

which is roughly 10 times larger than the observed correction. The contribution Δa_μ^0 could reduce this contribution. At this moment I am however not yet able to transform the formula for it to TGD context. Also the scaling up of the m_{SUSY} by a factor of order $2^{3/2}$ could reduce the correction.

The parameter values $(tan(\beta) = 1, M_{SUSY} = 100$ GeV) corresponds to the boundary of the region allowed by the LHC data and $g-2$ anomaly is marginally consistent with these parameter values (see figure 16 of [C171]). The reason is that in the recent case the mass of lightest Higgs particle does not pose any restrictions (the brown region in the figure). Due to the different mixing pattern of gauginos and higgsinos in neutral sector TGD prediction need not be identidal with MSSM prediction.

The contribution from Higgs loop is not present if Higgs is eaten by photon [C139] . This contribution by a factor of order $(m_\mu/h_H)^2$ smaller than the estimate for the SUSY contribution so that the dropping of Higgs contribution does not affect considerably the situation.

$$\Delta a_\mu^H = \frac{2}{2.24^2}(\frac{m_\mu}{m_H})^4) \times (log((\frac{m_H}{m_\tau})^2) - \frac{3}{2}) \ . \tag{8.1.2}$$

The proposed estimate is certainly poor man's estimate since it is not clear how near the proposed twistorial approach relying on zero energy ontology is to QFT approach. It is however encouraging that the simplest possible scenario might work and that this is essentially due to the p-adic length scale hypothesis.

3.2 An improved estimate for g-2 anomaly

An attractive scenario for sfermion masses marginally consistent with the recent data from LHC generalizes the observation that charged lepton masses correspond to subsequent Mersenne primes of Gaussian Mersennes. The only sfermions lighter than about 13 TeV are selectron with mass 262 GeV ($k = 89$) and sneutrinos, which can have much smaller masses. $\tilde{W}\tilde{\nu}_\mu$ virtual state would be mostly responsible for the muonic g-2 anomaly since the largest term in the correction is proportional to $m(\mu)m(\tilde{W})/m^2(\tilde{\nu}_\mu)$ and the anomaly might allow to determine $m(\tilde{\nu}_\mu)$. This option should be explain the g-2 anomaly.

The following estimate demonstrates that there are hopes about this. Using the formulas of [C171] one can write the one loop contributions to the anomalous contribution $a(\mu)$ as

$$\begin{aligned} a_\mu^{\chi^0} &= \frac{m(\mu)}{16\pi^2}\sum_{i,m} X_{im} \ , \\ X_{im} &= -\frac{m(\mu)}{12m^2(\tilde{\mu}_m)}\left[|n_{im}^L|^2 + |n_{im}^R|^2\right] F_1^N(x_{im}) + \frac{m(\chi_i^0)}{3m^2(\tilde{\mu}_m)} Re\left[n_{im}^L n_{im}^R\right] F_2^N(x_{im}) \ , \end{aligned} \tag{8.1.1}$$

and

$$\begin{aligned} a_\mu^{\chi^\pm} &= \frac{m(\mu)}{16\pi^2}\sum_{k} X_{k} \ , \\ X_{k} &= -\frac{m(\mu)}{12m^2(\tilde{\nu}_\mu)}\left[|c_k^L|^2 + |c_k^R|^2\right] F_1^C(x_k) + \frac{2m(\chi_k^\pm)}{3m^2(\tilde{\nu}_\mu)} Re\left[c_k^L c_k^R\right] F_2^C(x_k) \ . \end{aligned} \tag{8.1.0}$$

Here $i = 1,...,4$ denotes neutralino indices which should reduce to two if also Higgsinos disappear from the spectrum. $k = 1,2$ denotes the neutral and charginos indices reducing to single index now. $m = 1,2$ denotes smuon index. Note that TGD suggests strongly that the masses of $\tilde{\mu}_R$ and $\tilde{\mu}_L$ are degenerate. The matrices n_{im}^L, n_{im}^L and c_k^L and c_k^R relate to the mixing of mass eigenstates and are given explicitly in MSSM [C171].

The kinematic variables are defined as the mass ratios $x_{im} = m^2(\chi_i^0)/m^2(\tilde{\mu}_m)$ and $x_k = m^2(\chi_k^\pm)/m^2(\tilde{\nu}_\mu)$ and the loop functions are given by

$$\begin{aligned} F_1^N(x) &= \frac{2}{(1-x)^4}\left[1 - 6x + 3x^2 + 2x^3 - 6x^2 log(x)\right] \ , \\ F_2^N(x) &= \frac{3}{(1-x)^3}\left[1 - x^2 + 2x log(x)\right] \ , \\ F_1^C(x) &= \frac{2}{(1-x)^4}\left[2 + 3x - 6x^2 + x^3 + 6x log(x)\right] \ , \\ F_2^C(x) &= \frac{3}{(1-x)^3}\left[-3 + 4x - x^2 - 2 log(x)\right] \ . \end{aligned} \tag{8.1.-3}$$

If one does not assume any relationship betwen sneutrino and charged slepton masses then for $m(\tilde{\nu}_\mu)/m(\tilde{\mu}) << 1$, $m(\mu)/m(\chi^\pm) << 1$, and $m(\chi_k^0)/m(\tilde{\mu}) << 1$ the functions F_1^N and $F_2^N(x)$ are in good approximation constant and the corresponding contributions are negligible. One has $F_1^C(x) \simeq 1/x$ and $F_2^C(x) \simeq 3/x$. It rurns out that the terms proportional to $F_1^C(x)$ and $F_2^C(x_k)$ are of the same order of magnitude. If Higgsinos do not belong to the spectrum one has $U_{k2} = 0$ giving $V_{k1}U_{k2} = 0$ leaving only the F_1^C contribution.

Consider now the mixing matrices for sfermions.

(a) One has

$$\begin{aligned} c_k^L &= -g_2 V_{k1} \ , \ c_k^R = y_\mu U_{k2} \ , \\ y_\mu &= \frac{m(\mu)}{m(W)} \frac{g_2}{\sqrt{2}cos(\beta)} \ , g_2 = \frac{e}{sin(\theta_W)} \ . \end{aligned} \quad (8.1.\text{-}3)$$

Here the index k refers to the mixed states of L and R type sfermions. Since they are formed from fermion and right-handed neutrino, one expects that at higher energies the mixing is negligible. Mixing is however present and induced by the mixing of right and left handed fermion so that the mixing matrices are non-trivial at low energies and give relate closely to the massivation of sfermions and fermions.

(b) One obtains

$$\begin{aligned} c_k^L c_k^R &= -g_2^2 \frac{m(\mu)}{m(W)} \frac{1}{\sqrt{2}cos(\beta)} V_{k1}U_{k2} = -\frac{m(\mu)}{m(W)} \times \frac{4\pi\alpha}{sin^2(\theta_W)} \times \frac{1}{\sqrt{2}cos(\beta)} V_{k1}U_{k2} \ , \\ |c_k^L|^2 + |c_k^R|^2 &= g_2^2 \left[|V_{k1}|^2 + \frac{m^2(\mu)}{m^2(W)} \frac{1}{2cos^2(\beta)} |U_{k2}|^2 \right] \ . \end{aligned} \quad (8.1.\text{-}3)$$

Using these results one obtains explicit expressions for the two terms in a_μ.

(a) The expressions for the term resulting from mixing of right and left handed sfermions is given by

$$\begin{aligned} a_\mu^{mix,k} &= \frac{m(\mu)}{8\pi^2 m(\chi_k^\pm)} \sum_k Re[c_k^L c_k^R] \\ &= \frac{1}{8\pi^2} \frac{4\pi\alpha}{sin^2(\theta_W)\sqrt{2}cos(\beta)} \frac{m^2(\mu)}{m(W)m(\chi_k^\pm)} Re[V_{k1}U_{k2}] \ . \end{aligned} \quad (8.1.\text{-}3)$$

(b) Second term is diagonal and non-vanishing also when Higgsino is absent from the spectrum.

$$a_\mu^{diag,k} = \frac{1}{8\pi^2} \frac{m^2(\mu)}{m^2(\chi^\pm)} \left[|c_k^L|^2 + |c_k^R|^2 \right] \ . \quad (8.1.\text{-}2)$$

Note that $|c_k^R << c_k^L$ holds true unless $cos(\beta)$ is very small.

(c) The ratio of the contributions is

$$|\frac{a_\mu^{diag,k}}{a_\mu^{mix,k}}| = \frac{m(W)}{m(\chi^\pm)_k} \sqrt{2}cos(\beta) \times |\frac{V_{k1}}{U_{k_2}}| \ . \quad (8.1.\text{-}1)$$

For $c_k^R = 0$ (no Higgsino) one has

$$a_\mu \simeq a_\mu^{diag,k} = \frac{1}{8\pi^2} \frac{m^2(\mu)}{m^2(\chi^\pm)} \sqrt{2}cos(\beta) \frac{4\pi\alpha}{sin^2(\theta_W)} |V_{k1}|^2 \ . \quad (8.1.0)$$

The dependence on the mass of muonic sneutrino disappears so that one cannot conclude anything about its value in this approximation. a_μ is determined by the mass scale of $\tilde{W}$, which should be of the same order of magnitude as W boson mass. The sign of the diagonal term is positive so that this contribution gives to g-2 a contribution which is of correct sign. This encourages to consider the option for which Higgsinos disappear from the spectrum.

The experimental value of the anomaly is equal to $\Delta a_\mu \simeq 23.9 \times 10^{-10}$. The order of magnitude estimate obtained by assuming $(cos(\beta) = 1/\sqrt{2}, V_{k1} = 1, U_{k2} = 0)$ one obtains $a_\mu = 82.7 \times 10^{-10} \times (m(W)/m(\chi^\pm)^2$, which for $m(W)/m(\chi^\pm) = 1$ is roughly 3.46 times larger than the anomaly. The p-adic scaling $k(\tilde{W}) = 89 \rightarrow k(\tilde{W}) - 2 = 87$ would give a value of a_μ near to the observed one. The mass of $\tilde{W}$ would be 160.8 GeV. Clearly the TGD inspired view about SUSY leads to a remarkably simple picture explaining the g-2 anomaly.

4. Basic differences between MSSM and TGD

The basic differences between TGD and MSSM [B24] and related approaches deserve to be noticed (see also the article about the experimental side [C142]). If Higgses and Higgsinos are absent from the spectrum, SUSY in TGD sense does not introduce flavor non-conserving currents (FNCC problem plaguing MSSM type approaches). In MSSM approach the mass spectrum of superpartners can be only guessed using various constraints and in a typical scenario masses of sfermions are assumed to be same in GUT unification scales so that at long length scales the mass spectrum for sfermions is inverted from that for fermions with stop and stau being the lightest superpartners. In TGD framework p-adic thermodynamics and the topological explanation of family replication phenomenon changes the situation completely and the spectrum of sfermions is very naturally qualitatively similar to that of fermions (genus generation correspondence is the SUSY invariant answer to the famous question of Rabi "Who ordered them?" !). This is essential for the explanation of g-2 anomaly for instance. Note that the experimental searches concentrating on finding the production of stop or stau pairs are bound to fail in TGD Universe.

Another key difference is that in TGD the huge number of parameters of MSSM is replaced with a single parameter- the universal coupling characterizing the decay

sparticle $\rightarrow$ particle+right handed neutrino,

which by its universality is very "gravitational". The gravitational character suggests that it is small so that SUSY would not be badly broken meaning for instance that sparticles are rather long-lived and R-parity is a rather good symmetry.

One can try to fix the coupling by requiring that the decay rate of sfermion is proportional to gravitational constant G or equivalently, to the square of CP_2radius

$$R \simeq 10^{7+1/2} (\frac{G}{\hbar_0})^{1/2} \ .$$

Sfermion-fermion-neutrino vertex coupling to each other same fermion M^4 chiralities involves the gradient of the sfermion field. Yukawa coupling - call it L - would have dimension of length. For massive fermions in M^4 it would reduce to dimensionless coupling g different M^4 chiralities. In equal mass case g would be proportional to $L(m_1 + m_2)/\hbar$, where m_i are the masses of fermions.

(a) For the simplest option L is expressible in terms of CP_2 geometry alone and corresponds to

$$L = kR \ .$$

k is a numerical constant of order unity. $\hbar_0$denotes the standard value of Planck constant, whose multiple the effective value of Planck constant is in TGD Universe in dark matter sectors. The decay rate of sfermion would be proportional to

$$k^2R^2(\frac{M}{hbar})^3 \simeq k^2 \times 10^7 \times \frac{G}{\hbar_0} \times (\frac{M}{\hbar})^3 \ ,$$

where M is the mass scale characterizing the phase space volume for the decays of sfermion and is given by the mass of sfermion multiplied by a dimensionless factor depending on mass ratios. The decay rate is extremely low so that R-parity conservation would be an excellent approximate symmetry. In cosmology this could mean that zinos and photinos would decay by an exchange of sfermions rather than directly and could give rise to dark matter like phase as in MSSM.

(b) Second option carries also information about Kähler action one would have apart from a numerical constant of order unity $k = \alpha_K$. The Kähler coupling strength

$$\alpha_K = \frac{g_K^2}{4\pi \times \hbar_0} \simeq 1/137$$

is the fundamental dimensionless coupling of TGD analogous to critical temperature.

(c) For the option which "knows" nothing about CP_2 geometry the length scale would be proportional to the Schwartchild radius

$$L = kGM \ .$$

In this case the decay rate would be proportional to $k^2G^2M^2(M/\hbar)^3$ and extremely low.

(d) The purely kinematic option which one cannot call "gravitational" "knows" only about sfermion mass and f Planck constant, and one would have

$$L = k \times \frac{\hbar}{M} \ .$$

The decay rate would be proportional to the naive order of magnitude guess $k^2(M/\hbar)$ and fast unlike in all "gravitational cases". R-parity would be badly broken. Again$k \propto \alpha_K$ option can be considered.

Note that also in mSUGRA gravitatational sector in short length scales determines MSSM parameters via flavor blind interactions and also breaking of SUSY via breaking of local SUSY in short scales.

8.1.3 Do X and Y mesons provide evidence for color excited quarks or squarks?

Now and then come the days when head is completely empty of ideas. One just walks around and gets more and more frustrated. One can of course make authoritative appearances in blog groups and express strong opinions but sooner or later one is forced to look for web if one could find some problem. At this time I had good luck. By some kind of divine guidance I found myself immediately in Quantum Diaries and found a blog posting with title *Who ordered that?! An X-traordinary particle?* [L14].

Not too many unified theorists take meson spectroscopy seriously. Although they are now accepting low energy phenomenology (*the* physics for the rest of us) as something to be taken seriously, meson physics is for them a totally uninteresting branch of botany. They could not care less. As a crackpot I am however not well-informed about what good theoretician should do and shouldn't do and got interested. Could this give me a problem that my poor crackpot brain is crying for?

The posting told me that in the spectroscopy of $c\overline{c}$ type mesons is understood except for some troublesome mesons christened imaginatively with letters X and Y plus brackets containing their mass in MeVs. X(3872) is the firstly discovered troublemaker and what is known about it can be found in the blog posting and also in Particle Data Tables [C20]. The problem is that these mesons should not be there. Their decay widths seem to be narrow taking into account their mass and their decay characteristics are strange: in particular the kinematically allow decays to $D\overline{D}$ dominating the decays of $\Psi(3770)$ with branching ratio 93 per cent has not been observed whereas the decay to $D\overline{D}\pi^0$ occurs with a branching fraction $> 3.2 \times 10^{-3}$. Why the pion is needed? $X(3872)$ should decay to photon and charmonium state in a predictable way but it does not.

Could these be the good questions?

TGD predicts a lot of exotic physics and I of course started to exclude various alternatives. First one must however try to invent a good question. Maybe the following questions might satisfy the criterion of goodness.

(a) Why these exotic states appear only for mesons made of heavy quark and antiquark? Why not for light mesons? Why not for mesons containing one heavy quark and light quark? Could it be that also $b\overline{b}$ mesons could have exotic partners not yet detected? Could it be that also exotic $b\overline{c}$ type mesons could be there? Why the presence of light quark would eliminate the exotic partner from the spectrum?

(b) Do the decays obey some selection rules? There is indeed this kind of rule: the numbers of c and $\overline{c}$ quarks in the final state are equal to one.

   i. If c and $\overline{c}$ exist in the initial state and the decay involves only strong interactions, the rule holds true.

   ii. If c and $\overline{c}$ are not present in the initial state the only option that one can imagine is the exhange of two W bosons transforming d type quarks to c type quarks must be present. If this were the case the initial state should correspond to $d\overline{d}$ like state rather than $c\overline{c}$ and this looks very strange from the standard physics point of view. Also the rate for this kind of decays would be very small and it seems that this option cannot make sense.

Both leptons and quarks have color excitations in TGD Universe

TGD predicts that both leptons and quarks have color excitations [K70]. For leptons they correspond to color octets and there is a lot of experimental evidence for them. Why we do not have any evidence for color excited quarks? Or do we actually have?! Could these strange X:s and Y:s provide this evidence?

Ordinary quarks correspond to triality one color triplet partial waves in CP_2. The higher color partial waves would also correspond to triality one states but in higher color partial waves in CP_2. The representations of the color group are labelled by two integers (p,q) and the dimension of the representation is given by

$$d = \frac{(p+1)(q+1)(p+q+2)}{2} \quad .$$

A given $t = \pm 1$ representation is accompanied by its conjugate with the same dimension and opposite triality $t = \mp 1$. $t = 1$ representations satisfy $p - q = 1$ modulo 3 and come as (1,0), (0,2), (3,0), (2,1), with dimensions 3, 6, 10, 15,... The simplest candidate for the color excitations would correspond to the representation $\overline{6}$. It does not correspond directly the a solution of the Dirac equation in CP_2 since physical states involve also color Kac-Moody generators [K34].

Some remarks are in order:

(a) The tensor product of gluon octet with $t = 1$ with color triplet representation contains $8 \times 3 = 24$ states and decomposes into $t = 1$ representations as $3 \oplus \overline{6} \oplus 15$. The coupling of gluons by Lie algebra action can couple given representation only with itself. The coupling between triplet and $\overline{6}$ and 15 is therefore not by Lie algebra action. The coupling constant between quarks and color excited quarks is *assumed* to be proportional to color coupling.

(b) The existence of this kind of coupling would explain the selection rules elegantly. If this kind of coupling is not allowed then only the annihilation of exotic quark to gluon decaying to quark pair can transform exotic mesons to ordinary ones and I have not been able to explain selection rules using this option.

The basic constraint applying to all variants based on exotic states of quarks comes from the fact that the decay widths of intermediate gauge bosons do not allow new light particles. This objection is encountered already in the model of lepto-hadrons [K70]. The solution is that the light exotic states are possible only if they are dark in TGD sense having therefore non-standard value of Planck constant and behaving as dark matter. The value of Planck constant is only effective and has purely geometric interpretation in TGD framework. This implies that a phase transition transforming quarks and gluons to their dark counterparts is the key element of the model. After this a phase transition a gluon exchange would transform the quark pair to an exotic quark pair.

Also squarks could explain exotic charmonium states

Supersymmetry provides an alternative mechanism. Right-handed neutrino generates supersymmetries in TGD Universe and quarks are accompanied by squarks consisting in a well-defined sense of of quark and right-handed neutrino. Super-symmetry would allow completely standard couplings to gluons by adding to the spectrum squarks and gluinos.Exactly the same selection rules result if these new states are mesonlike states from from squark and anti-squark and the exchange of gluino after the $\hbar$ changing phase transition transforms exotic meson to ordinary one and vice versa.

In the sequel it will be shown that the existence of color excited quarks or of their superpartners could indeed allow to understand the origin of X and Y mesons and also the absence of analogous states accompanying mesons containing light quarks or antiquarks.

This picture would lead to a completely new view about detection of squarks and gluinos.

(a) In the standard scenario the basic processes are production of squark and gluino pair. The creation of squark-antisquark pair is followed by the decay of squark (anti-squark) to quark (antiquark) and neutralino or chargino. If R-parity is conserved, the decay chain eventually gives rise to at least two hadron jets and lightest neutralinos identifiable as missing energy. Gluinos in turn decay to quark and anti-squark (squark and antiquark) and squark (anti-squark) in turn to quark (anti-quark) and neutralino or chargino. At least four hadron jets and missing energy is produced. In TGD framework neutralinos would decay eventually to zinos or photinos and right-handed neutrino transforming to ordinary neutrino (R-parity is not conserved). This process might be however slow.

(b) In the recent case quite different scenario relying on color confinement and "shadronization" suggests itself. By definition smesons consist of squarks and antisquark. Sbaryons could consist of two squarks containing right-handed neutrino and its antineutrino ($\mathcal{N} = 2$ SUSY) and one quark and thus have same quantum numbers as baryon. Note that the squarks are dark in TGD sense.

    Also now dark squark or gluino pair would be produced at the first step and would require $\hbar$ changing phase transition of gluon. These would shadronize to form a dark shadron. One can indeed argue that the required emisson of winos and zinos and photinos is too slow a process as compared to shadronization. Shadrons (mostly smesons) would in turn decay to hadrons by the exchange of gluinos between squarks. No neutralinos (missing energy) would be produced. This would explain the failure to detect squarks and gluinos at LHC.

    This mechanism does not however apply to sleptons so that it seems that the p-adic mass scale of sleptons must be much higher for sleptons than that for squarks as I have indeed proposed.

Could exotic charmonium states consist of color excited c and $\overline{c}$ or of their spartners?

Could one provide answers to the questions presented in the beginning assuming that exotic charmonium states consists of dark color excited c and $\overline{c}$: or more generally, a mixture of ordinary charmonium and exotic charmonium state? The mixing is expected since $\hbar$ changing phase transition followed by a gluon exchange can transform these meson states to each other. Also annihilation to gluon and back to quark pair can induce this mixing. The mixing is however small for heavy quarks for which $\alpha_s \simeq .1$ holds true. Exactly the same arguments apply to the meson like bound states of squarks and in the following only the first option will be discussed.

(a) In the case of charged leptons colored excitations have have same p-adic mass scale: for τ however several p-adic mass scales appear as the model if the two year old CDF anomaly is taken seriously [K70]. Assume that p-adic mass scales - but not necessarily masses- are the same also now. This assumption might be non-sensical since also light mesons would have exotic counterparts and somehow they should disappear from the spectrum. To simplify the estimates one could even assume even that the masses are same.

(b) In the presence of small mixing the decay amplitude would come solely from the small contribution of the ordinary $c\overline{c}$ state present in the state dominated by color excited pair. The two manners to see the situation should give essentially the same answer.

(c) The decays would take place via strong interactions.

The challenge is to understand why the dominating decays to $D\overline{D}$ with branching fraction of 93 per cent are not allowed whereas $D\overline{D}\pi^0$ takes place. Why the pion is needed? The second challenge is to understand why X does not decay to charmonium and photon.

(a) For ordinary charmonium the decay to $D\overline{D}$ could take place by the emission of gluon from either c or $\overline{c}$ which then decays to light quark pair whose members combine with c and $\overline{c}$ to form D and $\overline{D}$. Now this mechanism does not work. At least *two* gluons must be emitted to transform colored excited $c\overline{c}$ to ordinary $c\overline{c}$. If these gluons decay to light quark pairs one indeed obtains an additional pion in hadronization. The emission of two gluons instead of only one is expected to reduce the rate roughly by $\alpha_s^2 \simeq 10^{-2}$ factor.

(b) Also ordinary decays are predicted to occur but with a slower rate. The first step would be an exchange of gluon transforming color excited charmed quark pair to an ordinary charmed quark pair. After the transformation to off mass shell $c\overline{c}$ pair, the only difference to the decays of charmonium states would be due to the fact that charmonium would be replaced with $c\overline{c}$ pair. The exchange of the gluon preceding this step could reduce the decay rate with respect to charmonium decay rates by a factor of order $\alpha_s^2 \simeq 10^{-2}$. Therefore also the ordinary decay modes should be there but with a considerably reduced rate.

(c) Why the direct decays to photon and charmonium state do not occur in the manner predicted by the model of charmonium? For ordinary charmonium the decay proceeds by an emission of photon by either quark or antiquark. Same mechanism applies for exotic charmonium states but leads to final state which consists of *exotic* charmonium and photon. In the case of $X(3872)$ there exists no lighter exotic charmonium state so that the decay is forbidden in this order of perturbation theory. Heavier exotic charmonium states can however decay to photon plus exotic charmonium state in this order of perturbation theory if discrete symmetries favor this.

Essentially identical arguments go through if c and $\overline{c}$ are replaced with their dark spartners and exchange of gluon by the emission of gluino. The transformation of gluon to its dark variants is an essential element in the process.

Why the color excitations/spartners of light quarks would be effectively absent?

Can one understand the effective absence of mesons consisting of color excited light quarks or squarks if the excitations have same mass scale and even mass as the light quarks? The following arguments are for color excited quarks but they apply also to squarks.

(a) Suppose that the mixing induced by $\hbar$ changing phase transition followed by a gluon exchange and annihilation is described by mass squared matrix containing besides diagonal components $M_1^2 = M_2^2$ also non-diagonal component $M_{12}^2 = \overline{M_{21}^2}$. The eigenstates of the mass squared matrix correspond to the physical states which are mixtures of states consisting of ordinary quark pair and pair of color excited quarks. The non-diagonal elements of the mass squared matrix corresponds to gluon exchange and since color interactions get very strong at low energy scales, one expects that these elements get very large. In the degenerate case $M_1^2 = M_2^2$ the mass squared eigen values are given by

$$M_{\pm}^2 = M_0^2 \pm |M_{12}|^2 \ . \tag{8.1.1}$$

(b) Suppose that $M_0^2 = 0$ holds true in accordance with approximate pseudo Goldstone nature of pion and more generally all light pseudo-scalar mesons. In fact assume that this is the case before color magnetic spin-spin splitting has taken place so that in this approximation pion and ρ would have same mass $m_\pi^2 = m_\rho^2 = M_0^2$. In TGD based model for color magnetic spin-spin splitting M_0^2 energy is replaced with mass squared [K43] and M_0^2 is obtained in terms of physical masses of π and ρ from the basic formulas

$$\begin{aligned} m_\pi^2 &= M_0^2 - \frac{1}{4}\Delta \ , \ m_\rho^2 = M_0^2 + \frac{3}{4}\Delta \ , \\ M_0^2 &= \frac{m_\rho^2 + 3m_\pi^2}{2} \ , \ \Delta = m_\rho^2 - m_\pi^2 \ . \end{aligned} \tag{8.1.0}$$

The exotic π and ρ would have masses

$$\begin{aligned} m_{\pi_{ex}}^2 &= -M_0^2 - \frac{1}{4}\Delta = m_\pi^2 - 2M_0^2 \ , \\ m_{\rho_{ex}}^2 &= -M_0^2 + \frac{3}{4}\Delta = m_{rho}^2 - 2M_0^2\Delta \ . \end{aligned} \tag{8.1.0}$$

For $m_\pi = 140 MeV$ and $m_\rho = 770$ MeV the calculation gives $m_{\pi_{ex}} = i \times 685$ MeV so a tachyon would be in question. For ρ one would have $m_{\pi_{ex}} = 323$ MeV so that the mass would not be tachyonic.

One can try to improve the situation by allowing $M_1^2 \neq M_2^2$ giving additional flexibility and hopes about tachyonicity of the exotic ρ.

(a) In this case one obtains the equations

$$\begin{aligned} m_\pi^2 &= M_+^2 - \frac{1}{4}\Delta \ , \ m_\rho^2 = M_+^2 + \frac{3}{4}\Delta \\ m_{\pi_{ex}}^2 &= M_-^2 - \frac{1}{4}\Delta \ , \ m_{\rho_{ex}}^2 = M_-^2 + \frac{3}{4}\Delta \ ., \\ M_+^2 &= \frac{M_1^2 + M_2^2}{2} + \sqrt{(\frac{M_1^2 + M_2^2}{2})^2 + M_{12}^4} = \frac{m_\rho^2 + 3m_\pi^2}{2} \ , \\ M_-^2 &= \frac{M_1^2 + M_2^2}{2} - \sqrt{(\frac{M_1^2 + M_2^2}{2})^2 + M_{12}^4} = M_+^2 - 2\sqrt{(\frac{M_1^2 + M_2^2}{2})^2 + M_{12}^4} \end{aligned} \tag{8.1.2}$$

(b) The condition that ρ_{ex} is tachyonic gives

$$m^2_{\rho_{ex}} = M_-^2 + \frac{3}{4}\Delta < 0 \ , \tag{8.1.-2}$$

giving

$$\begin{aligned} m_\rho^2 &< 2\sqrt{(\frac{(M_1^2+M_2^2}{2})^2 + M_{12}^4} \ , \\ M_+^2 &= \frac{M_1^2+M_2^2}{2} + \sqrt{(\frac{(M_1^2+M_2^2}{2})^2 + M_{12}^4} = \frac{m_\rho^2 + 3m_\pi^2}{2} \ , \end{aligned} \tag{8.1.-2}$$

(c) In the parameterization $(m_1^2, m_2^2, M_{12}^2) = (x, y, z)m_\rho^2$ one obtains the conditions

$$\begin{aligned} D \equiv \sqrt{(x+y)^2 + z^2} &> 1/2 \ , \\ \frac{x+y}{2} + D = \frac{1}{2} + \frac{3}{2}\frac{m_\pi^2}{m_\rho^2} & \ . \end{aligned} \tag{8.1.-2}$$

(d) These equations imply the conditions

$$\begin{aligned} x + y &< 3\frac{m_\pi^2}{m_\rho^2} \simeq .099 \ , \\ .490 &< z < .599 \ . \end{aligned} \tag{8.1.-2}$$

The first condition implies $\sqrt{m_1^2 + m^2} < 242.7$ MeV. Second condition gives $339 < M_{12}/MeV < 595.9$ so that rather stringent bounds on the parameters are obtained. The simplest solution to the conditions corresponds to $x = y = 0$ and $z = .599$. This solution would mean vanishing masses in the absence of mixing and spin-spin splitting and could be defended by the Golstone boson property of pions mass degenerate with ρ mesons.

This little calculation encourages to consider the possibility that all exotic counterparts of light mesons are tachyonic and that this due the very large mixing induced by gluon exchange (gluino exchange squark option) at low energies. It would be nice if also mesons containing only single heavy quark were tachyonic and this could be the case if the p-adic length scale defining the strength of color interactions corresponds to that of the light quark so that the mass matrix has large enough non-diagonal component. Here one must be however very cautious since experimental situation is far from clear.

The model suggests that ordinary charmonium states and their exotic partners are in 1-1 correspondence. If so then many new exotic states are waiting to be discovered.

The option based on heavy color excitations/spartners of light quarks

An alternative option is that color excitations/spartners of light quarks have large mass: this mass should not be however larger than the mass of c quarks if we want to explain X:s and Y:s as pairs of color excitations of light quarks. Suppose that the p-adic mass scale is same as that for c quarks or near it (not that the scales come as powers of $\sqrt{2}$). This raises the question whether exotic $c\overline{c}$ mesons really consist of exotic c and $\overline{c}$: why not color excitations of u, d, s and their antiquarks? As a matter fact, we cannot be sure about the quark content of X and Y mesons. Could these states be $d\overline{d}$ and $u\overline{u}$ states for their color excitations? It however seems that the presence of two W exchanges makes the decay rate quite too low so that this option seems to be out of question.

One can however consider the option in which the squarks associated with light quarks are heavy. This option is indeed realized in standard SUSY were the mass scales of particles families are inverted so that stop and sbottom are the lightest squarks and super-partners of u and d the heaviest ones. This would would predict that the smesons associated with $\bar{t}$ and $b\bar{b}$ are lighter than X and Y (s)mesons. This option does not look at all natural in TGD but of course deserves experimential checking.

How to test the dark squark option?

The identification of X and Y as dark smesons looks like a viable option and explains the failure to find SUSY at LHC if shadronization is a fast process as compared to the selectro-weak decays. The option certainly deserves an experimental testing. One could learn a lot about SUSY in TGD sense (or maybe in some other sense!) by just carefully scanning the existing data at lower energies. For instance, one could try to answer the following questions by analyzing the already existing experimental data.

(a) Are X and Y type mesons indeed in 1-1 correspondence with charmonium states? One could develop numerical models allowing to predict the precise masses of scharmonium states and their decay rates to various final states and test the predictions experimentally.

(b) Do $b\bar{b}$ mesons have smesonic counterparts with the same mass scale? What about B_c type smesons containing two heavy squarks?

(c) Do the mesons containing one heavy quark and one light quark have smesonic counterparts? My light-hearted guess that this is not the case is based on the assumption that the general mass scale of the mass squared matrix is defined by the p-adic mass scale of the heavy quark and the non-diagonal elements are proportional to the color coupling strength at p-adic length scale associated with the light quark and therefore very large: as a consequence the second mass eigenstate would be tachyonic.

(d) What implications the strong mixing of light mesons and smesons would have for CP breaking? CP breaking amplitudes would be superpositions of diagrams representing CP breaking for mesons *resp.* smesons. Could the presence of smesonic contributions perhaps shed light on the poorly understood aspects of CP breaking?

Objection against covariantly constant neutrinos as SUSY generators

TGD SUSY in its simplest form assumes that covariantly constant right-handed neutrino generates SUSY. The second purely TGD based element is that squarks would correspond to the same p-adic mass scale as partners.

This looks nice but there are objections.

(a) The first objection relates to the tachyonicity needed to get rid of double degeneracy of light mesons consisting of u, d, and s quarks. Mesons and smesons consisting of squark pair mix and for large α_s the mixing is large and can indeed make second eigenvalue of the mass squared matrix negative. If so, these states disappears from spectrum. At least to me this looks however somewhat unaesthetic.

Luckily, the transformation of second pion-like state to tachyon and disappearance from spectrum is not the only possibility. After a painful search I found experimental work [C174] claiming the existence of states analogous to ordinary pion with masses 60, 80, 100, 140,.... MeV. Also nucleons have this kind of satellite states. Could it be that one of these states is spion predicted by TGD SUSY for ordinary hadrons? But what about other states? They are not spartners: what are they?

(b) The second objection relates to the missing energy. SUSY signatures involving missing energy have not been observed at LHC. This excludes standard SUSY candidates and could do the same in the case of TGD. In TGD framework the missing energy would be eventually right handed neutrinos resulting from the decays of sfermions to fermion and sneutrino in turn decaying to neutrino and right handed neutrino. The naive argument is that shadronization would be much faster process than the decay of squarks to quarks and spartners of electro-weak gauge bosons and missing energy so that these events would not be observed. Shadrons would in turn decay to hadrons by gluino exchanges. The problem with this argument is that the weak decays of squarks producing right handed neutrinos as missing energy are still there!

This objection forces to consider the possibility that covariantly constant right handed neutrino which generates SUSY is replaced with a color octet. Color excitations of leptons of lepto-hadron hypothesis would be sleptons which are color octets so that SUSY for leptons would have been seen already at seventies in the case of electron. The whole picture would be nicely unified. Sleptons and squark states would contain color octet right handed neutrino the same wormhole throats as their em charge resides. In the case of squarks the tensor product $3 \otimes 8 = 3 + \overline{6} + 15$ would give several colored exotics. Triplet squark would be like ordinary quark with respect to color.

Covariantly constant right-handed neutrino as such would represent pure gauge symmetry, a super-generator annihilating the physical states. Something very similar can occur in the reduction of ordinary SUSY algebra to sub-algebra familiar in string model context. By color confinement missing energy realized as a color octet right handed neutrino could not be produced and one could overcome the basic objections against SUSY by LHC.

What about the claimed anomalous trilepton events at LHC interpreted in terms of SUSY, which however breaks either the conservation of lepton or baryon number. I have proposed TGD based interpretation [K37] is in terms of the decays of W to $\tilde{W}$ and $\tilde{Z}$, which in turn decay and produce the three lepton signature. Suppose that $\tilde{W}$ and $\tilde{Z}$ are color octets and that sleptons replace the color octet excitations of leptons responsible for lepto-hadron physics [K70]. One possible decay chain would involve the decays $\tilde{W}^+ \rightarrow \tilde{L}^+ + \overline{\nu}_L$ and $\tilde{Z} \rightarrow L^+ + \tilde{L}^-$. Color octet sleptons pair combine to form lepto-pion which decays to lepton pair. This decay cascade would produce missing energy as neutrino and this seems to be the case for other options too.e could overcome the basic objections against SUSY by LHC.

This view about TGD SUSY clearly represents a hybrid of the two alternative views about X and Y bosons as composites of either color excitations of quarks or of squarks and is just one possibility. The situation is not completely settled and one must keep mind open.

Does one really obtain pseudo-scalar smesons?

The critical question is whether one obtains pseudo-scalar states as meson-like bound states of squarks. This depends on what one means with squarks. Also the notion of pseudo-scalar is not the same for $M^4 \times CP_2$ and M^4. In TGD framework M^4 (pseudo–)scalars constructed from fermions and anti-fermions are replaced by CP_2 (pseudo–)vectors since the chiral symmetry for $M^4 \times CP_2$ implying separate conservation of lepton and baryon numbers implies that genuine fermionic H-scalars and pseudo-scalars would have quantum numbers of leptoquark.

(a) The first question is what one means with ordinary pseudo-scalar mesons in TGD framework. These mesons should be characterized by a bi-local quantity which behaves like a preferred CP_2 pseudo-vector and therefore like M^4 pseudo-scalar. One should identify a unique direction of CP_2 polarization mathematically analogous to Higgs vacuum expectation value and construct a bilinear in quark wave functions associated with the partonic 2-surfaces assigned to the quarks. The problem is however that CP_2 is not a flat space. Also non-locality is a problem. Somehow one should be able to construct general coordinate invariant quantities with well-defined transformation properties under discrete symmetries.

(b) The effective 2-dimensionality implying the notions of partonic 2-surfaces and string world sheets suggests a solution to the non-locality problem. Also the experience with

QCD suggests that bilinear expression contains a non-integrable phase factor U connecting quark and anti-quark ad defined by the classical color gauge potentials which are just projections of SU(4) Killing vector fields to the space-time surface. The curve would be analogous to a string connecting the partonic 2-surfaces and fixed uniquely by the strong form of holography in turn reducing to the strong form of general coordinate invariance. TGD indeed predicts the existence of string world sheets and thus strings at the 3-D ends of space-time sheets defined by causal diamond.

(c) What about the preferred CP_2 vector?

i. The first candidate is the quantity $X = I_3 j_3^{Ak}\Gamma_k + Y j_Y^{Ak}\Gamma_k$ where I_3 and Y denote color isospin and hyper-charge of the quark and j_i^{Ak} corresponding Killing vectors. The preferred vector would be due to the choice of quantization axes. This option is natural for in the case of quark bilinears but fails for a bilinear constructed from covariantly constant right handed neutrino.

ii. Second candidate would the CP_2 part for the trace of the second fundamental form contracted with CP_2 gamma matrices -denote it by $X = H^k\Gamma_k$ -at the either end of the string connecting fermion and anti-fermion at partonic 2-surfaces. This option would be natural for the right-handed neutrino. Bi-local super-generators would vanish when the partonic 2-surface is minimal surface. This would be analogous to the representations of SUSY for which $2^{-k}\mathcal{N}$ generators annihilate the physical states and act as pure gauge symmetries.

(d) This would suggest that the basic invariants in the construction is the quantity $\overline{\Psi}_1 UXO\Psi_2$. Sub-script $i = 1, 2$ refers to the partonic 2-surface, X can occur at both ends and γ_5 guarantees pseudo-scalar property. O is $1 \pm \gamma_5$ for right- *resp.* left-handed quarks. The recipe would apply also to the bilinears formed right-handed neutrinos: now only the projector $(1+\gamma_5)$ to right-handed neutrino appears so that only single state is obtained.

Most of the options that one can imagine give something else that pseudo-scalar smeson.

(a) Assuming that $\mathcal{N} = 2$ symmetry is not too badly broken, one can add to the partonic 2-surface carrying quark either right-handed neutrino or anti-neutrino or both so that one obtains a 4-plet containing two quark states, spin zero squark and and spin 1 squark. From these states one can construct meson like states.

i. The first implication is degeneracy of quark like states because of the presence of neutrino pair. TGD however predicts large breaking of SUSY. According to the arguments of [K24] the state containing right handed neutrino pair has propagator behaving like $1/p^3$ and does not correspond to ordinary particle. It is not at all clear whether this kind squarks can give rise to meson like states. Also the R-parity of these squarks would be $+1$ and the model requires negative R-parity.

ii. For spin one squarks one obtains pseudo-vector state with spin 1: the smeson state would transform like the cross product of the vectors characterizing spin 1 squarks. These states could be also present in the spectrum although they do not correspond to pseudo-scalars.

This suggests that $\mathcal{N} = 2$ SUSY is badly broken and one must restrict the consideration to $\mathcal{N} = 1$ option.

(b) For $\mathcal{N} = 1$ option both squarks are scalars (quark plus anti-neutrino option).

i. Forgetting the non-locality and regarding partonic 2-surfaces as basic objects as a whole, one has bound state of scalar squarks and the possible meson-like state is most naturally a scalar rather than pseudo-scalar.

ii. Non-locality brought in by strings however changes the situation. One could construct a pseudo-scalar by starting from pseudo-scalar meson constructed by using the non-local recipe. To add neutrino and anti-neutrino at the partonic 2-surfaces one could use the bilinears $\overline{\nu}_{R,1}H^k\Gamma_k\nu_{R,2}$ and $\overline{\nu}_{R,2}H^k\Gamma_k\nu_{R,1}$ to obtain the needed right-handed CP_2 current, which is neither scalar nor pseudo-scalar. The stringy picture (braids as representation of many fermion states) forced by the strong from of general coordinate invariance (or strong form of holography or effective two-dimensonality) would be absolutely essential for this picture to work.

To sum up, it is not completely clear whether the squark option really gives pseudo-scalar smesons. One cannot exclude additional pseudo-vector states and scalars unless $\mathcal{N} = 2$ SUSY is badly broken. The option based on color excitations in turn predicts only pseudo-scalar smesons but also for this option a non-local state construction is needed.

What are the implications for M_{89} hadron physics?

Lubos Motl told about the latest information concerning Higgs search. It is not clear how much these data reflect actual situation [C5]. Certainly the mass values must correspond to observed bumps. The statistical significances are *expected* statistical significances, not based on real data. Hence a special caution is required. At 4.5/fb of data one has following bumps together with their expected statistical significance:

- 119 GeV: 3 sigma
- 144 Gev: 6 sigma(!)
- 240 GeV: 4.5 sigma
- 500 GeV: 4 sigma

It is interesting to try to interpret these numbers in TGD framework. The first thing to observe is that weak boson decay widths do not pose any constraints on the model and one could assume that M_{89} squarks are not dark.

1. The interpretation of 144 GeV bump

Consider first the 144 GeV state 6 sigma expected significance, which is usually regarded as a criterion for discovery. Of course this is only expected statistical significance, which cannot be taken seriously.

(a) 144 GeV is exactly the predicted mass of the pion of M_{89} hadron physics which was first observed by CDF and then decided to be a statistical fluctuation. I found myself rather alone while defending the interpretation as M_{89} pion in viXra log and trying to warn that one should not throw baby with the bath water.

(b) From an earlier posting of Lubos one learns that 244 GeV state must be CP odd -just like neutral pion- and should correspond to A_0 Higgs of SUSY. Probably this conclusion as well as the claimed CP even property of 119 GeV state follow both from the assumption that these states correspond to SUSY Higgses so that one must not take them seriously.

(c) The next step before TGD will be accepted is to discover that this state cannot be Higgs of any kind.

2. Possible identification of the remaining bumps

Could the other bumps correspond to the pseudo-scalar mesons of M_{89} hadron physics? For only a week ago I would have answered 'Definitely not'! Could the claimed bumps explained by assuming that also M_{89} quarks have either color excitations or super partners with the same mass scale and the same mechanism is at work for M_{89} mesons as for ordinary mesons. The same question can be made for the option based on color excitations of quarks in $\overline{6}$ or 15.

Consider now the possible identification of the remaining Higgs candidates concentrating for definiteness to the squark option.

(a) In the earlier framework there was no identification for meson like states below 144 GeV. The discovery of this week was however that squarks could have the same p-adic mass scale as quarks and that one has besides mesons also smesons consisting of squark pair as a consequence. Every meson would be accompanied by a smeson. Gluino exchange however mixes mesons and smesons so that mass eigenstates are mixtures of these states. At low energies however the very large non-diagonal element of mass squared matrix can make second mass eigenstate tachyonic. This must happen for mesons consisting of light quarks. This of course for the M_{107} hadron physics familiar to us.

(b) Does same happen in M_{89} hadron physics? Or is the non-diagonal element of mass squared matric so small that both states remain in the spectrum? Could 119 GeV state and 144 GeV state correspond to the mass eigenstates of supersymmetric M_{89} hadron physics? If this is the case one could understand also this state.

(c) What about 240 GeV state? The proposal has been that selectron corresponds to M_{89} . This would give it the mass 262.14 GeV by direct scaling; $m(selectron) = 2^{(127-89)/2}m(electron)$. This is somewhat larger than 240 GeV.

Could this state correspond to spartner of the ρ_{89} consisting of M_{89} squarks. There is already earlier evidence for bumps at 325 GeV interpreted in terms ofρ_{89} and ω_{89}. The mass squared difference should be same for pionic mass eigenstates and ρ_{89} like mass eigenstates. This would predict that the mass of the second ρ like eigenstate is 259 GeV, which is not too far from 240 GeV.

Tommaso Dorigo's newest posting The Plot Of The Week - The 327 GeV ZZ Anomaly [C27] tells about further support about ZZ anomaly at 327 GeV, which in TGD framework could be interpreted in terms of decays of the neutral member of ρ_{89} isospin triplet or ω_{89}, which is isospin singlet. A small splitting in mass found earlier is expected unless this decay corresponds to ω_{89}. Also WZ anomaly is predicted.

(d) What about the interpretation of 500 GeV state? The η' meson of M_{107} hadron physics has mass 957.66 MeV. The scaling by 512 gives 490.3 GeV- not too far from 500 GeV!

The alternative option replaces squarks with their color excitations. The arguments are identical in this case. Many other pseudo-scalar mesons states are predicted if either of these options is correct. In the case of squark option one could say that also SUSY in TGD sense has been discovered and has been discovered in ordinary hadron physics for 8 years ago! SUSY would not reveal itself via the usual signatures since shadronization would be faster process than the decay of squarks via emission of selectro-weak bosons.

All these looks too good to be true. I do not know how the *expected* significances are estimated and how precisely the mass values correspond to experimental data. In any case, if these states turn out to be pseudo-scalars, one can say that this is a triump for TGD. Combining this with the neutrino super-luminality which can be explained easily in terms of sub-manifold gravitation, the prospects for TGD to become the next TOE are brighter than ever.

8.1.4 Strange trilepton events at CMS

Lubos Motl reports that CMS sees SUSY-like trilepton excesses. Also Matt Strassler tells about indications that something curious has been detected at the Large Hadron Collider [C172]. Probably a statistical fluctuation is in questions as so many times earlier. The dream to discover SUSY ieasily leads to mis-interpretations. Trilepton events however provide an excellent opportunity to learn about SUSY in TGD framework.

The recent view about TGD SUSY briefly

Before continuing it is good to say something about what SUSY in TGD Universe might mean and also about expected masses of squarks and sleptons as well as intermediate gauge bosons in TGD Universe. The picture is of course preliminary and developing all the time in strong interaction with experimental input from LHC so that there is no guarantee that I agree with this view for the rest of my life.

(a) Super-partner of the particle is obtained by adding a the partonic 2-surface a parallelly moving right-handed neutrino or antineutrino so that one has $\mathcal{N} = 1$ SUSY. It must be emphasized that one has higher SUSYs but they are badly broken. Allowing both right-handed neutrino and antineutrino one obtains $\mathcal{N} = 2$ SUSY and interpreting all fermionic oscillator operators as generators of SUSY one obtains badly broken SUSY with rather large $\mathcal{N}$, which is however finite by finite measurement resolution inducing a cutoff on the number of fermionic oscillator operators.

(b) R-parity is broken in TGD SUSY since sparticle can decay to particle and neutrino. Therefore all neutral sparticles manifesting themselves as missing energy in TGD framework eventually decay and produce neutrinos as the eventual missing energy. The decay rates to particles and neutrinos can however be so slow that photino and sneutrinos leave the reactor volume before decaying.

(c) The basic assumption is that particle and sparticle obey the same mass formula apart from p-adic mass scale that can be different. For instance, the masses of sleptons are half-octaves of lepton masses. This breaking of SUSY is extremely elegant and is absolutely essential part of ordinary particle massivation too explaining the enormous mass scale differences between neutrinos and top quark in a natural manner.

(d) I have proposed that the super-partners of M_{107} quarks (ordinary quarks) and gluon could have the same mass scale but be dark in TGD sense, in other words have Planck constant which is integer multiple of the ordinary Planck constant. This is required by the fact that intermediate gauge boson decay widths do not allow light exotic particles. This hypothesis could allow to understand the exotic X and Y mesons and also the absence of smesons containing light squarks could be understood. Since shadronization is expected to proceed much faster than selectro-weak decays of squarks, the squarks of M_{89} hadron physics need not be dark and M_{89} shadrons might be there. The fruitless search for squarks would be based on wrong signatures if this the case and already now we would have direct evidence for the squarks of M_{89} hadron physics.

(e) Only the decays of electro-weak gauginos and sleptons would produce the standard signatures.

   i. Charged sleptons must have large p-adic scales in TGD Universe. Ordinary leptons correspond to Mersenne prime M_{127}, Gaussian Mersenne $M_{G,113}$, and Mersenne prime M_{107}. If also sleptons obey this rule, they would correspond to the Mersenne primes M_{89} and Gaussian Mersennes $M_{G,n}$, $n = 79, 73$. Assuming that particle and sparticle obey the same mass formula apart from different p-adic mass scale, the masses of selectron, smuon, and stau would be about 267 GeV, 13.9 TeV, and 164.6 TeV. Only selectron is expected to be visible at LHC.

   ii. About the mass scales of sneutrinos it is difficult to say anything definite. A natural guess is that sneutrinos are relatively light so that they would be produced in the decays of sleptons and electro-weak gauginos. Same applies to photino. These particles are good candidates to missing energy unless their decay to particle plus neutrino is fast enough.

   iii. There seems to be no strong constraints to the mass scales of $\tilde{W}$ and $\tilde{Z}$. The mass scale could be even M_{89} characterizing W and Z. p-Adic length scale hypothesis predicts that the p-adic mass scale is half octave of intermediate boson mass scale and if the Weinberg angle is same the masses are half octaves of W/Z masses.

(f) The most general option inspired by twistorial considerations (absence of IR divergences) and zero energy ontology is that both Higgs like states and Higgsinos and their higher spin generalizations are eaten so that the outcome is spectrum of massive states. This might have something do with the phenomenon in which some supersymmetry generators annihilate physical states. In any case the fermions at wormhole throats are always massless- even the virtual particles identified in terms of wormhole contacts consist of massless wormhole throats which can have also negative energy.

It is important to notice that trilepton events as signals for SUSY have nothing to do with squarks and gluinos for which I have proposed a non-standard interpretation in the previous postings (see this, this ,this) and in the article [L14].

How to interpret the trilepton events in TGD framework?

Trilepton events [C134] represent the simplest SUSY signal and would be created in the decays $W \rightarrow \tilde{W} + \tilde{Z}$. The decays $Z \rightarrow \tilde{W^+} + \tilde{W^-}$ would give rise to dilepton events. Electro-weak gauginos would in turn decay and yield multi-lepton events. Neither W/Z boson nor the gauginos need to be on mass shell.

In the following I will discuss these decays taking seriously the above listed conjectures about SUSY a la TGD.

(a) Obviously the situation reduces to the study of the decays of $\tilde{W}$ and $\tilde{Z}$.

  i. For $\tilde{W}$ the decay channels are $\tilde{W} \rightarrow W + \tilde{\gamma}$ and $\tilde{W} \rightarrow L + \tilde{\overline{\nu}}_L$. W would decay to charged lepton-neutrino pair. One charged lepton would result in both cases.

  ii. For $\tilde{Z}$ the decay channels are $\tilde{Z} \rightarrow \nu + \tilde{\overline{\nu}}_L$, $\tilde{Z} \rightarrow \tilde{W}^+ + W^-$, and $\tilde{Z} \rightarrow \tilde{L} + \overline{L}$ and charge conjugates of these. For the second decay mode the decays of W^+ and $\tilde{W}^-$ produce lepton antilepton pair. For the third decay mode selectron is the most plausible slepton candidate and is expected to have rather large masses in TGD Universe (about 267 GeV and thus off mass-shell). $\tilde{L} \rightarrow L + \tilde{\gamma}$ is the most natural decay for slepton.

(b) The decay cascade beginning with $Z \rightarrow \tilde{W^+} + \tilde{W^-}$ would produce 2 charged leptons (more generally even number of charged leptons) plus missing energy. Charged leptons would have opposite charges. No sleptons would be needed as intermediate states and all lepton families would be democratically represented as final states.

(c) The decay cascade beginning with $W \rightarrow \tilde{W} + \tilde{Z}$ would produce 2 or 3 charged leptons plus missing energy.

  i. For $\tilde{Z} \rightarrow \tilde{W}^+ + W^-$ option 3 charged leptons would result and there would be a complete family democracy. For this option the rate is expected to be largest.

  ii. For the option having slepton as intermediate state, the large masses for smuon and stau would favor selectron for 3 lepton events. 3-lepton events would have charge signatures $-+$ or ++- following from charge conservation alone. The suggested large mass for selectron would however reduce also the rate of 3 lepton events considerably. Note that the reported events have total transversal energy larger than 200 GeV.

(d) In MSSM also $sZ \rightarrow \tilde{\chi}_1^0 + Z$ followed by $Z \rightarrow L^+ + L^-$ is possible so that trilepton state results. Here $\tilde{\chi}_1^0$ denotes the lightest neutral sboson and is a mixture of $\tilde{h}, \tilde{Z}$, and $\tilde{\gamma}$. If $\tilde{h}$ is not in the spectrum, then $\tilde{\gamma}$ is an excellent candidate for the lightest neutral gaugino. If the Weinberg angle is SUSY invariant the decay producing three charged leptons in this manner is not possible.

(e) Photinos would decay to photons and neutrinos producing photons and missing energy. It is not clear whether this decay is fast enough to take place in the reactor volume.

To sum up, the trilepton events are possible and would be produced in the decays $\tilde{Z} \rightarrow \tilde{W} + W$ and $\tilde{W} \rightarrow e + \tilde{\gamma}$. The trilepton events involving selectron as intermediate state do not look highly plausible in TGD framework if one takes seriously the guess for the slepton mass scales.

More about strange trilepton events

I already told about indications for strange charged tri-lepton events at CMS. The inspiration came from a posting CMS sees SUSY-like tri-lepton excesses of Lubos.

Only a few days later both Tommaso and Lubos discussed a quite recent paper telling about charged tri-lepton events observed at CMS.

(a) From Tommaso's posting one learns that three charged leptons with total mass near to Z mass have been observed. Charge conservation of course requires fourth charged lepton if the particles originate in the decay of Z as assumed and Tommaso argues that this lepton has so low energy that it is not detected. This kind of lepton could results in an energy asymmetric decay of photon. The assumption that Z is the decaying particle might be however un-necessarily strong: it could be quite well W with almost the same mass. In this case charge conservation allows genuine charged tri-lepton event. The above discussion suggests the decay $W \rightarrow \tilde{W} + \tilde{Z}$ to be the source of charged tri-lepton events.

(b) The authors of the paper propose that the reaction could be initiated by a decay of squark or gluino and necessarily involving R-parity breaking. There are two possibile options for R-parity breaking allowed by proton stability depending on whether it conserves lepton or baryon number. For lepton number violating option intermediate particle is neutralino (lightest sparticle which is stable in R-parity breaking scenarios) and for baryon number violating scenatior bino or higgsino. The R-parity violating decay of lightest spartner (neutral) would yield slepton-lepton pair and the R-parity violating decay of slepton a lepton pair plus neutrino. This would produce instead single observed lepton charged tri-lepton state. The authors do not give enough details to make possible for a non-professional to deduce what the detailed model for the process really is.

It is interesting to consider the situation in TGD framework in light of the crucial additional data (the three charged leptons have mass rather near to that of Z and therefore to that of$W$).

(a) The decay of $W \rightarrow \tilde{W} + \tilde{Z}$ with the decays $\tilde{W}$ and $\tilde{Z}$ proceeding in either of the two manners discussed above would predict that the *total mass of all particles produced* is near to W mass (and therefore Z mass) and also why one obtains genuine charged tri-lepton states. The problem is that missing energy in the form of neutrinos and neutral sparticles is present and it is not at all clear why this energy should be small.

(b) An option not discussed discussed above is the decay $W \rightarrow \tilde{\nu} + L$ followed by the decay $\tilde{\nu} \rightarrow L + \tilde{W}$ followed by $\tilde{W} \rightarrow L + \tilde{\nu}$ would not break R-parity and would produce $\tilde{\nu}$. Total energy would correspond to W mass but it is not clear why the missing energy assigned with $\tilde{\nu}$ should be small.

(c) R-parity violation predicted by TGD however allows also to consider the direct decay $\tilde{\nu} \rightarrow L^+ + L^-$ so that there would be no missing energy. One could say that the decay is the reversal of a process in which $L^+ + L^-$ annihilates to a $\tilde{\nu}$ identifiable as a pair of neutrino and right-handed neutrino at microscopic level. All standard model quantum numbers would be conserved.

In TGD framework R-parity violation is a prediction of the theory and it would not violate either baryon or lepton number conservation. There is no need to assume undetected charged lepton since charge conservation allows charged tri-lepton final state as such without any missing energy. Obviously the TGD based model is by several orders of magnitude simpler than the model based on standard SUSY.

8.1.5 CMS observes large diphoton excess

LHC has started to produce data indicating that the new physics required by very general arguments indeed is there. Lubos (`http://motls.blogspot.com/2011/11/cms-very-large-excess-of-dipl` `html`) told today about a preprint by CMS collaboration [C63] showing a very large excess of di-photons in proto-proton collisions. This excess is so large that only a rough systematic error can threat its status.

What has been observed?

The following two data bits give strong hints about what might be involved.

(a) From the figure in the posting of Lubos (`http://motls.blogspot.com/2011/11/cms-very-large-excess-of-diphotons.html`) one learns that the distribution for the difference $\Delta\phi$ for the difference of the azimutal angles with respect to the beam direction covers rather evenly the span $\Delta\phi < 2.80$ and the production rate is considerably higher than predicted by QCD calculations except near π where the production rate is smaller than the prediction. From momentum conservation one would expect $\Delta\phi \sim \pi$ in a good approximation in the cm frame of photons. Unless the resonance does not move with a very high velocity, the photons $\Delta\phi \simeq \pi$ should hold true quite generally. This gives hints about the production mechanism.

(b) Figure 3 of the CMS preprint [C63] gives the differential cross section with respect to diphoton invariant mass $m_{\gamma\gamma}$ as a function of $m_{\gamma\gamma}$. The distribution has a sharp knee between 45-55 GeV. One might be able to see double peak at invariant masses about 50 GeV and 75 GeV and even third peak around 175 GeV. The differential cross section is however anomalous already around 20 GeV which serves as transverse momentum cutoff for photons

The naive question by a non-professional is whether there could be resonance decaying to two photons with mass in this range. $\Delta\phi \sim \pi$ would be however required if the resonance does not move very fast in the cm frame of colliding protons. The cut on transversal momenta is 20 GeV making 40 GeV transversal energy and I am not absolutely sure whether this could cause the shoulder. The experimenters however speak about shoulder and certainly they would not do this if it were due to the cufoff. Therefore I will assume that the shoulder is genuine.

(c) If the shoulder located roughly between 45 GeV and 75 GeV is real, it would seem that the two-photon state must be accompanied by a state with opposite momentum and roughly the same energy and thus moving in opposite direction. This suggests two states with mass(es) in the range [90,150] GeV.

What could it be?

The speculation of Lubos is that the decay of Higgs like state with mass around 119 GeV might explain the finding but admits that standard model Higgs should not produce any visible effect. Even worse, the so called little Higgs alternative would predict a reduction of diphoton production rate. There are also exotic explanations involving large dimensions and exotic gravitons but to my opininion these alternatives belong to the realm of bad science fiction and can be safely forgotten.

In my naive mind frame the strong knee around 55 GeV is something which I find very difficult to not interpret as a bump suggesting the presence of a meson like state. On the other hand, the distribution for $\Delta\phi$; does not fit with this simplistic picture.

What about the TGD inspired interpretation? The first interpretation that comes into mind relies on the TGD based view about SUSY, which differs considerably from the standard view.

(a) As explained in [K37], TGD could allow the realization of SUSY in which quarks and squarks have same p-adic mass scale- perhaps even masses- before the mixing of hadrons and shadrons allowed by R-parity conservation. The mechanism explaining the experimental absence of squarks would be shadronization proceeding faster than the decay of squarks to quark and electroweak gaugino.

  i. In this framework the mysterious X and Y mesons accompanying charmonium states would be their super partners in a good approximation since the mixing would be small. The mixing of mesons and smesons would be however very large near confinement mass scale and make the other mixed state (identified as eigen state of mass squared matrix) tachyonic and eliminate it from the spectrum. The companion of pion would be tachyonic and excluded from spectrum: this would hold true for all smesons containing light quarks and perhaps also those containing only single light squark if the mass scale of the mass squared matrix is determined by the heavier quark and α_s by the lighter quark so that mixing is very large.

  ii. A crucial assumption is that the squarks are dark in the sense of having a non-standard value of Planck constant: otherwise the decay widths of electro-weak gauge bosons would be too large. The phase transition changing the value of $\hbar$

and having a purely geometric (topological) meaning in TGD framework would accompany also the mixing process being analogous to mass insertions in the lines of Feynman graph.

(b) In TGD framework the proposed view about squarks as particles having common p-adic mass scale with quark is suggested to hold true in both the ordinary M_{107}- and M_{89} hadron physics. There is however no need to assume that M_{89} squarks are dark. The pion of M_{89} hadron physics could identified as the earlier 144 GeV Higgs candidate, forgotten but mentioned again by Lubos (`http://motls.blogspot.com/2011/10/cms-atlas-delivered-5-inverse.html`), would have 119 GeV bump as a lighter companion. The two states would be mixtures of pion and spion. The mass values for the bumps assigned to ρ_{89} and ω_{89} and to their spartner candidates allow to estimate the mass of the partner of π_{89}. The mass would be near to 119 GeV for which there are slight indications [K37].

How the shoulder around 45-55 GeV could be created from the decays of the partner of π_{89}- a (probably strong) mixture of pion and spion (no breaking of R-symmetry). Could the two mixtures of M_{89} pion and its spartner with masses (say) 119 GeV and 144 GeV (one should not take these number too literally) be responsible for the effect as the indications about two peaked structure suggest? Could the spionic parts of the states produce the events diphoton events.

(a) The simplest Feynman diagram for the decay of the pion-like state would describe the turn around of squark backwards in time via the emission of two photons. This would produce onlty $\Delta\phi \sim \pi$ events and photons with energies around 60 GeV and 72 GeV for the proposed masses 119 GeV and 144 GeV.

Comment: 144 GeV is the estimate for the mass of $\pi_{89}^{\pm}$, one obtains 138 GeV for π_{89}^{0}: I have earlier neglected electromagnetic mass splitting of pions and approximated pion masses with charged pion mass 140 MeV. This scales the second mass to 69 GeV.

(b) For a more complex Feynman diagram exchanged squark turning around in time would emit quark and antiquark transforming in this manner to gluino and back to squark. Another possibility is emission of two gluons. This would give photon pair and something which could be just two hadron jets if the emitted quarks and gluons transform to ordinary quarks.

(c) The objection is that this model need not explain the strong concentration of diphoton invariant mass to the range 45-75 GeV since in principle 4-particle final states are in question and phase space distribution does not predict anything like this. p-Adic length scale hypothesis however suggests that the resulting quark pairs actually form a p-adically scaled down variant of the pion like state and have therefore mass, which is half of its mass. This would give rise to a resonance like behavior and impy a strong concentration of the events to the invariant masses which are one half of the mass of the mother particle.

The p-adically scaled up quarks appear even in the TGD based model of light hadrons and produce mass formula replacing Gell-Mann-Nishijina mass formula (see this). As a matter fact, the naive prediction for the mass of M_{89} pion is just 512 times the mass of the ordinary neutral pion and gives 69.1 GeV!

(d) One must also worry about overall parity conservation required if only strong and electromagnetic interactions are involved with the decay process. Pion is pseudo-scalar and the decay of pion to two pions with scaled down mass requires parity breaking in the effective action involving the pion fields only unless the vertex contains derivatives but one cannot build a Lorentz invariant involving 4-D permutation symbol from three pion fields. Should one assume that the process breaks parity conservation and involves therefore weak interactions? Or should one assume that second scaled down pion is replaced with two pions with mass equal 1/4 the mass of the decaying pion to give parity invariant effective interaction Lagrangian as assumed in the model of CDF anomaly. This would predict also diphoton pairs with invariant masses scaled down to

22.5-40 GeV. The differential cross section is anomalous down to the 20 GeV cutoff. One should be able to resolve this issue before one can take the model seriously.

A connection with Aleph anomaly?

There is an old anomaly known as Aleph anomaly [C149] producing 4-jets states with *jet-jet* invariant mass of 55 GeV. According to the reference, the anomaly did not survive improved statistics. Delphi and L3 also observed 4-jet anomaly with dijet invariant mass about 68 GeV: this not too far from the mass for p-adically scaled down mass of π_{89} equal to 69.1 GeV! Remarkably, according to the above reference L3 observation survived the improvement of the statistics!

(a) For more than decade ago I proposed an explanation of Aleph anomaly in terms of a meson-like state formed by p-adically scaled up variants of b quark and its antiquark [K43]. The mass of the resonance was predicted correctly using p-adic length scale hypothesis predicting that the mass of scaled up b quark is half octave of the mass of b quark.

(b) The model could be generalized by replacing b quark with its super-partner if one assumes that SUSY breaking means only different p-adic mass scale. There is however an aesthetic problem (I take aesthetic arguments very seriously). The model for X and Y mesons assumed that the p-adic mass scale is same: now one should give up this assumption for b quark. The reader has probably already asked whether Aleph anomaly and the recent CMS anomaly could correspond to the same meson like state. 4-jets could be produced when $\tilde{b}$ and $\tilde{b}^*$ decay to bb^* pair by emission of gluinos which then exchange quark to produce quark pair or gluon pair. In the decays of X and Y mesons the resulting quark pair would form pion or some other meson. Now two quark or gluon jets by exchanged gluinos would be produced giving altogether four jets.

(c) CMS anomaly suggests a different interpretation. Perhaps the 4-jets with di-jet energies around 55 GeV and 68 GeV are produced by the decays of the mixtures of M_{89} pion and spion with masses around 110 GeV and 144 GeV producing as intermediate state the 2-adically scaled down pions with half of their original masses.

 The same mechanism is assumed also in themodel of CDF anomaly discovered for three years ago but already forgotten [K70]. Political memory is short! The mechanism would be a modification of that producing the diphoton excess. Squark and anti-squark would transform to quark-antiquark pair giving rise to intermediate scaled down pionlike state decaying to two jets with invariant mass concentrated around the mass of pion-like state. The exchanged gluino emits quark and antiquark or two gluons. Quark antiquark state could also form a scaled down M_{89} pion before the decay to two jets. The outcome would be four jets with concentration to preferred invariant masses.

8.1.6 No SUSY dark matter and too small electron dipole moment for standard SUSY

8.1.7 No SUSY dark matter and too small electron dipole moment for standard SUSY

LUX group has reported that one leading dark matter candidate has disappeared (`http://luxdarkmatter.org/papers/LUX_First_Results_2013.pdf`). [C77] Lubos (`http://motls.blogspot.fi/2013/10/dark-matter-wars-are-over-lux-safely.html`) tells more about this. The candidate is light fermion - so called neutralino predicted by SUSY models as a candidate for dark matter. What makes it a candidate is that it stable against decays if R-parity is conserved: this implies that neutralino can disappear only via pair annihilation. This is also a further blow against $\mathcal{N} = 1$ SUSY paradigm in its standard form implying among other things the non-conservation of baryon and lepton number or both.

The result of course does not mean that there would be no dark matter. It only says that the main stream of particle physics community has been at completely wrong track concerning the nature of dark matter. As I have patiently explained year after year in this blog, dark matter is not some exotic particle this or that. Dark matter is something much deeper and its understanding requires a generalization of quantum theory to include hierarchy of Planck constants. This requires also a profound generalization of the notion of space-time time.

In particular, all standard particles can be in dark phase characterized by the value of Planck constant, and the main applications are TGD inspired quantum biology and consciousness theory since dark matter with large value of Planck constant can form macroscopic quantum phases. Also dark energy in TGD sense is something very different from the standard dark energy. Dark energy in TGD Universe corresponds to Kähler magnetic energy assignable to magnetic flux tubes carrying monopole flux. These magnetic fields need no currents to generate them, which explains why cosmos can full of magnetic fields. Superconductors at the verge of breakdown of superconductivity and even ordinary ferromagnets might carry these Kähler monopole fluxes although monopoles themselves do not exist.

The result of LUX was expected from TGD point of view and does not exclude particles dark in TGD sense. Even dark particles at the mass scale of tau lepton and even at mass scale of 7-8 GeV can be considered and the CDF anomaly reported few years ago could have explanation in terms of dark variant of tau-pion identifiable as pion like bound state of colored tau leptons: also for other leptons analogous states have been reported [K70]. The experimental signatures of this kind of particles are however very different from the dark particles that LUX was searching for and could explain some reports about evidence for dark matter in ordinary sense.

The lesson to learn is that one can find only what one is searching for in recent day particle physics. Particle phenomenologists should return to the roots. Challenging the cherished beliefs - even the beliefs about what QCD color is - is painful but is the only way to make progress.

A further blow against standard SUSY came few weeks after dark matter results. ACME collaboration has deduced a new upper boundon the electric dipole moment of electron, which is by order of magnitude smaller than the previous one (`http://arxiv.org/abs/1310.7534`) [C44]. Jester (`http://resonaances.blogspot.fi/2013/11/electric-dipole-moments-and-new-physics.html`) and Lubos (`http://motls.blogspot.fi/2013/11/electron-electric-dipole-moment.html`) have more detailed commentaries.

The measurement of the dipole moment relies on a simple idea: electric dipole moment gives rise to additional precession if one has parallel magnetic and electric fields. The additional electric field is now that associated with the molecule containing electrons plus strong molecular electric field in the direction of spin quantization axes. One puts the molecules containing the electrons into magnetic field and measurex the precession of spins by detecting the photons produced in the process. The deviation of the precession frequency from its value in magnetic field only should allow to deduce the upper bound for the dipole moment.

Semiclassically the non-vanishing dipole moment means asymmetric charge distribution with respect to the spin quantization axis. The electric dipole coupling term for Dirac spinors comes to effective action from radiative corrections and has the same form as magnetic dipole coupling involving sigma matrices except that one has an additional γ_5 matrix bringing in CP breaking. The standard model prediction is of order $d_e \simeq 10^{-40} e \times m_e$: this is by a factor 10^{-5} smaller than Planck length!

The new upper bound is $d_e \simeq .87 \times 10^{-32} e \times m_e$ and still much larger than standard model prediction. Standard SUSY predicts typically non-vanishing dipole moment for electron. The estimate for the electron dipole moment coming from SUSYs and is by dimensional considerations of form $d_e = c\hbar; e \times m_e/16\pi^2 M^2$, where c is of order unity and M is the mass scale for the new physics. The Feynman diagram in question involves the decay of electron to virtual neutrino and virtual chargino and the coupling of the latter to photon before absoption.

This upper bound provides a strong restriction on "garden variety" SUSY models (involving no fine tuning to make dipole moment smaller) and the scale at which SUSY could show itself becomes of order 10 TeV at least so that hopes for detecting SUSY at LHC should be rather meager. One can of course do fine tuning. "Naturality" idea does not favor fine tunings but is not in fashion nowadays: the existing theoretical models do not simply allow such luxury. The huge differences between elementary particle mass scales and quite "too long" proton lifetime represent basic example about "non-naturality" in the GUT framework. For an outsider like me this strongly suggests that although Higgs exist, Higgs mechanism provides only a parameterization of particle masses - maybe the only possible theoretical description in quantum field theory framework treating particles as point like - and must be eventually replaced with a genuine theory. For instance, Lubos does not see this fine tuning is not seen as reason for worrying too much. Personally I however feel worried since my old-fashioned view is that theoretical physicists must be able to make predictions rather than only run away the nasty data by repeated updating of the models so that they become more and more complicated.

8.2 Understanding of the role of right-handed neutrino in supersymmetry

From the beginning it was clear that right-handed neutrino should generate super-conformal symmetry of some kind and the natural question was whether it generates also space-time SUSY. $\mathcal{N}=1$ SUSY was excluded by separate conservation of B and L but $\mathcal{N}=2$ variant of this symmetry could be considered. The new element in the picture was the physical realization of the supersymmetry by adding right-handed neutrino to the state: Does this produce in the case of covariantly constant right-handed neutrino space-time SUSY or something else?: this was the question. Only the breakthrough in understanding of the preferred extremals of Kähler action and solutions of the modified Dirac equations allowed to provide reasonably convincing negative answer to the question about existence of space-time SUSY.

8.2.1 Basic vision

What SUSY means in TGD framework is second long-standing problem. In TGD framework SUSY is inherited from super-conformal symmetry at the level of WCW [K13, K16]. The SUSY differs from $\mathcal{N}=1$ SUSY of the MSSM and from the SUSY predicted by its generalization and by string models. One obtains the analog of the $\mathcal{N}=4$ SUSY in bosonic sector but there are profound differences in the physical interpretation.

(a) One could understand SUSY in very general sense as an algebra of fermionic oscillator operators acting on vacuum states at partonic 2-surfaces. Oscillator operators are assignable to braids ends and generate fermionic many particle states. SUSY in this sense is badly broken and the algebra corresponds to rather large $\mathcal{N}$. The restriction to covariantly constant right-handed neutrinos (in CP_2 degrees of freedom) gives rise to the counterpart of ordinary SUSY, which is more physically interesting at this moment.

(b) Right handed neutrino and antineutrino are not Majorana fermions. This is necessary for separate conservation of lepton and baryon numbers. For fermions one obtains the analog $\mathcal{N}=2$ SUSY.

(c) Bosonic emergence [K49] means the construction of bosons as bound states of fermions and anti-fermions at opposite throats of wormhole contact. This reduces TGD SUSY to that for fermions. This difference is fundamental and means deviation from the SUSY of $\mathcal{N}=4$ SUSY, where SUSY acts on gauge boson states. Bosonic representations are obtained as tensor products of representation assigned to the opposite throats of wormhole contacts. Further tensor products with representations associated with the wormhole ends of magnetic flux tubes are needed to construct physical particles. This represents a crucial difference with respect to standard approach, where one introduces at the fundamental level both fermions and bosons or gauge bosons as in $\mathcal{N}=4$ SUSY. Fermionic $\mathcal{N}=2$ representations are analogous to "short" $\mathcal{N}=4$ representations for which one half of super-generators annihilates the states.

(d) The introduction of both fermions and gauge bosons as fundamental particles leads in quantum gravity theories and string models to $d = 10$ condition for the target space, spontaneous compactification, and eventually to the landscape catastrophe.

For a supersymmetric gauge theory (SYM) in d-dimensional Minkowski space the condition that the number of transversal polarization for gauge bosons given by $d-2$ equals to the number of fermionic states made of Majorana fermions gives $d - 2 = 2^k$, since the the number of fermionic spinor components is always power of 2.

This allows only $d = 3, 4, 6, 10, 16, ...$ Also the dimensions $d + 1$ are actually possible since the number of spinor components for d and $d + 1$ is same for d even. This is the standard argument leading to super-string models and M-theory. It it lost - or better to say, one gets rid of it - if the basic fields include only fermion fields and bosonic states are constructed as the tensor products of fermionic states. This is indeed the case in TGD, where spontaneous compactification plays no role and bosons are emergent.

(e) Spontaneous compactification leads in string model picture from $\mathcal{N} = 1$ SUSY in say $d = 10$ to $\mathcal{N} > 1$ SUSY in $d = 4$ since the fermionic multiplet reduces to a direct sum of fermionic multiplets in $d = 4$. In TGD imbedding space is not dynamical but fixed by internal consistency requirements, and also by the condition that the theory is consistent with the standard model symmetries. The identification of space-time as 4-surface makes the induced spinor field dynamical and the notion of many-sheeted space-time allows to circumvent the objections related to the fact that only 4 field like degrees of freedom are present.

8.2.2 What is the role of the right-handed neutrino?

The general ansatz for the preferred extremals of Kähler action and application of the conservation of em charge to the modified Dirac equation have led to a rather detailed view about classical and TGD and allowed to build a bridge between general vision about super-conformal symmetries in TGD Universe and field equations. This vision is discussed in detail in [L19] and [K80] and also in the second chapter of this book. This input represents the newest layer of TGD and I cannot guarantee a full consistency with other pieces of text about SUSY appearing in this chapter.

(a) I have conjected that Equivalence Principle is realized as Einstein's equations in all scales follows directly. The general ansatz for preferred extremals implying that space-time surface has either hermitian or Hamilton-Jacobi structure (which of them depends on the signature of the induced metric) also implies that the covariant divergence of energy momentum tensor for Kähler action vanishes. This would guaranteed by Einstein's equation with cosmological term but one can imagine also more general solutions [K84].

Many-sheeted space-time means that single space-time sheet need not be a good approximation for astrophysical systems. The GRT limit of TGD can be interpreted as obtained by lumping many-sheeted space-time time to Minkowski space with effective metric defined as sum M^4 metric and sum of deviations from M^4 metric for various space-time sheets involved [K71]. This effective metric should correspond to that of General Relativity and Einstein's equations would reflect the underlying Poincare invariance. Gravitational and cosmological constants follow as predictions and EP is satisfied.

(b) The general structure of Super Virasoro representations can be understood: super-symplectic algebra is responsible for the non-perturbative aspects of QCD and determines also the ground states of elementary particles determining their quantum numbers.

(c) Super-Kac-Moody algebras associated with isometries and holonomies dictate standard model quantum numbers and lead to a massivation by p-adic thermodynamics: the crucial condition that the number of tensor factors in Super-Virasoro represention is 5 is satisfied.

(d) One can understand how the Super-Kac-Moody currents assignable to stringy world sheets emerging naturally from the conservation of em charge defined as their string world sheet Hodge duals gauge potentials for standard model gauge group and also their analogs for gravitons. Also the conjecture Yangian algebra generated by Super-Kac-Moody charges emerges naturally.

(e) One also finds that right handed neutrino is in a very special role because of its lacking couplings in electroweak sector and its role as a generator of the least broken SUSY. All other modes of induced spinor field are restricted to 2-D string world sheets and partonic 2-surfaces. Right-handed neutrino allows also the mode de-localized to entire space-time surface or perhaps only to the Euclidian regions defined by the 4-D line of the generalized Feynman diagrams.

In fact, in the following the possibility that the resulting sparticles cannot be distinguished from particles since the presence of right handed neutrino is not seen in the interactions and does not manifest itself in different spin structures for the couplings of particle and sparticle. This could explain the failure to detect spartners at LHC. Intermediate gauge boson decay widths however require that sparticles are dark in the sense of having non-standard value of Planck constant. Another variant of the argument assumes that 4-D right handed neutrinos are associated with space-time regions of Minkowskian signature and SUSY is defined for many-particle states rather than single particle states. It should be emphasized that TGD predicts that all fermions act as generators of badly broken supersymmetries at partonic 2-surfaces but these supersymmetries could correspond to much higher mass scale as that associated with the de-localized right-handed neutrino. The following piece of text summarizes the argument.

Right-handed neutrino has a very special role in TGD view about Super-Kac-Moody symmetry and its generalization to 4-D context.

(a) Only right handed neutrino allows besides the modes restricted to 2-D surfaces also the 4D modes de-localized to the entire space-time surface. The first ones are holomorphic functions of single coordinate and the latter ones holomorphic functions of two complex/Hamilton-Jacobi coordinates. Only ν_R has the full $D = 4$ counterpart of the conformal symmetry and the localization to 2-surfaces has interpretation as super-conformal symmetry breaking halving the number of super-conformal generators.

(b) This forces to ask for the meaning of super-partners. Are super-partners obtained by adding ν_R neutrino localized at partonic 2-surface or de-localized to entire space-time surface or its Euclidian or Minkowskian region accompanying particle identified as wormhole throat? Only the Euclidian option allows to assign right handed neutrino to a unique partonic 2-surface. For the Minkowskian regions the assignment is to many particle state defined by the partonic 2-surfaces associated with the 3-surface. Hence for spartners the 4-D right-handed neutrino must be associated with the 4-D Euclidian line of the generalized Feynman diagram.

(c) The orthogonality of the localized and de-localized right handed neutrino modes requires that 2-D modes correspond to higher color partial waves at the level of imbedding space. If color octet is in question, the 2-D right handed neutrino as the candidate for the generator of standard SUSY would combine with the left handed neutrino to form a massive neutrino. If 2-D massive neutrino acts as a generator of super-symmetries, it is is in the same role as badly broken super-symmetries generated by other 2-D modes of the induced spinor field (SUSY with rather large value of $\mathcal{N}$) and one can argue that the counterpart of standard SUSY cannot correspond to this kind of super-symmetries. The right-handed neutrinos de-localized inside the lines of generalized Feynman diagrams, could generate $\mathcal{N} = 2$ variant of the standard SUSY.

How particle and right handed neutrino are bound together?

Ordinary SUSY means that apart from kinematical spin factors sparticles and particles behave identically with respect to standard model interactions. These spin factors would allow to distinguish between particles and sparticles. But is this the case now?

(a) One can argue that 2-D particle and 4-D right-handed neutrino behave like independent entities, and because ν_R has no standard model couplings this entire structure behaves like a particle rather than sparticle with respect to standard model interactions: the kinematical spin dependent factors would be absent.

(b) The question is also about the internal structure of the sparticle. How the four-momentum is divided between the ν_R and and 2-D fermion. If ν_R carries a negligible portion of four-momentum, the four-momentum carried by the particle part of sparticle is same as that carried by particle for given four-momentum so that the distinctions are only kinematical for the ordinary view about sparticle and trivial for the view suggested by the 4-D character of ν_R.

Could sparticle character become manifest in the ordinary scattering of sparticle?

(a) If ν_R behaves as an independent unit not bound to the particle, it would continue in the original direction as particle scatters: sparticle would decay to particle and right-handed neutrino. If ν_R carries a non-negligible energy the scattering could be detected via a missing energy. If not, then the decay could be detected by the interactions revealing the presence of ν_R. ν_R can have only gravitational interactions. What these gravitational interactions are is not however quite clear since the proposed identification of gravitational gauge potentials is as duals of Kac-Moody currents analogous to gauge potentials located at the boundaries of string world sheets. Does this mean that 4-D right-handed neutrino has no quantal gravitational interactions? Does internal consistency require ν_R to have a vanishing gravitational and inertial masses and does this mean that this particle carries only spin?

(b) The cautious conclusion would be following: if de-localized ν_R and parton are uncorrelated particle and sparticle cannot be distinguished experimentally and one might perhaps understand the failure to detect standard SUSY at LHC. Note however that the 2-D fermionic oscillator algebra defines badly broken large $\mathcal{N}$ SUSY containing also massive (longitudinal momentum square is non-vanishing) neutrino modes as generators.

Taking a closer look on sparticles

It is good to take a closer look at the de-localized right handed neutrino modes.

(a) At imbedding space level that is in cm mass degrees of freedom they correspond to covariantly constant CP_2 spinors carrying light-like momentum which for causal diamond could be discretized. For non-vanishing momentum one can speak about helicity having opposite sign for ν_R and $\overline{\nu}_R$. For vanishing four-momentum the situation is delicate since only spin remains and Majorana like behavior is suggestive. Unless one has momentum continuum, this mode might be important and generate additional SUSY resembling standard $\mathcal{N} = 1$ SUSY.

(b) At space-time level the solutions of modified Dirac equation are holomorphic or anti-holomorphic.

   i. For non-constant holomorphic modes these characteristics correlate naturally with fermion number and helicity of ν_R . One can assign creation/annihilation operator to these two kinds of modes and the sign of fermion number correlates with the sign of helicity.

   ii. The covariantly constant mode is naturally assignable to the covariantly constant neutrino spinor of imbedding space. To the two helicities one can assign also oscillator operators $\{a_{\pm}, a^{\dagger}_{\pm}\}$. The effective Majorana property is expressed in terms of non-orthogonality of ν_R and and $\overline{\nu}_R$ translated to the the non-vanishing of the anti-commutator $\{a^{\dagger}_{+}, a_{-}\} = \{a^{\dagger}_{-}, a_{+}\} = 1$. The reduction of the rank of the 4×4 matrix defined by anti-commutators to two expresses the fact that the number of degrees of freedom has halved. $a^{\dagger}_{+} = a_{-}$ realizes the conditions and implies that one has only $\mathcal{N}=1$ SUSY multiplet since the state containing both ν_R and $\overline{\nu}_R$ is same as that containing no right handed neutrinos.

iii. One can wonder whether this SUSY is masked totally by the fact that sparticles with all possible conformal weights n for induced spinor field are possible and the branching ratio to $n=0$ channel is small. If momentum continuum is present, the zero momentum mode might be equivalent to nothing.

What can happen in spin degrees of freedom in super-symmetric interaction vertices if one accepts this interpretation? As already noticed, this depends solely on what one assumes about the correlation of the four-momenta of particle and ν_R. One can only imagine alternatives.

(a) For SUSY generated by covariantly constant ν_R and $\overline{\nu}_R$ there is no neutrino four-momentum involved so that only spin matters. One cannot speak about the change of direction for ν_R. In the scattering of sparticle the direction of particle changes and introduces different spin quantization axes. ν_R retains its spin and in new system it is superposition of two spin projections. The presence of both helicities requires that the transformation $\nu_R \rightarrow \overline{\nu}_R$ happens with an amplitude determined purely kinematically by spin rotation matrices. This is consistent with fermion number conservation modulo 2. $\mathcal{N}=1$ SUSY based on Majorana spinors is highly suggestive.

(b) For SUSY generated by non-constant holomorphic and anti-holomorphic modes carrying fermion number the behavior in the scattering is different. Suppose that the sparticle does not split to particle moving in the new direction and ν_R moving in the original direction so that also ν_R or $\overline{\nu}_R$ carrying some massless fraction of four-momentum changes its direction of motion. One can form the spin projections with respect to the new spin axis but must drop the projection which does not conserve fermion number. Therefore the kinematics at the vertices is different. Hence $\mathcal{N}=2$ SUSY with fermion number conservation is suggestive when the momentum directions of particle and ν_R are completely correlated.

(c) Since right-handed neutrino has no standard model couplings, p-adic thermodynamics for 4-D right-handed neutrino must correspond to a very low p-adic temperature $T=1/n$. This implies that the excitations with non-vanishing conformal weights are effectively absent and one would have $\mathcal{N}=1$ SUSY effectively.

The simplest assumption is that particle and sparticle correspond to the same p-adic mass scale and have degenerate masses: it is difficult to imagine any good reason for why the p-adic mass scales should differ. This should have been observed -say in decay widths of weak bosons - unless the spartners correspond to large $\hbar$ phase and therefore to dark matter. Note that for the badly broken 2-D N=2 SUSY in fermionic sector this kind of almost degeneracy cannot be excluded and I have considered an explanation for the mysterious X and Y mesons in terms of this degeneracy [K37].

Why space-time SUSY is not possible in TGD framework?

LHC suggests that one does not have $\mathcal{N}=1$ SUSY in standard sense. Why one cannot have standard space-time SUSY in TGD framework. Let us begin by listing all arguments popping in mind.

(a) Could covariantly constant ν_R represents a gauge degree of freedom? This is plausible since the corresponding fermion current is non-vanishing.

(b) The original argument for absence of space-time SUSY years ago was indirect: $M^4 \times CP_2$ does not allow Majorana spinors so that $\mathcal{N}=1$ SUSY is excluded.

(c) One can however consider $\mathcal{N}=2$ SUSY by including both helicities possible for covariantly constant ν_R. For ν_R the four-momentum vanishes so that one cannot distinguish the modes assigned to the creation operator and its conjugate via complex conjugation of the spinor. Rather, one oscillator operator and its conjugate correspond to the two different helicities of right-handed neutrino with respect to the direction determined by the momentum of the particle. The spinors can be chosen to be real in this basis. This indeed gives rise to an irreducible representation of spin 1/2 SUSY algebra with right-handed neutrino creation operator acting as a ladder operator. This is however $\mathcal{N}=1$ algebra and right-handed neutrino in this particular basis behaves effectively like Majorana spinor. One can argue that the system is mathematically inconsistent. By choosing the spin projection axis differently the spinor basis becomes complex. In the new basis one would have $\mathcal{N}=2$, which however reduces to $\mathcal{N}=1$ in the real basis.

(d) Or could it be that fermion and sfermion do exist but cannot be related by SUSY? In standard SUSY fermions and sfermions forming irreducible representations of super Poincare algebra are combined to components of superfield very much like finite-dimensional representations of Lorentz group are combined to those of Poincare. In TGD framework ν_R generates in space-time interior generalization of 2-D super-conformal symmetry but covarianlty constant ν_R cannot give rise to space-time SUSY.

This would be very natural since right-handed neutrinos do not have any electroweak interactions and are are de-localized into the interior of the space-time surface unlike other particles localized at 2-surfaces. It is difficult to imagine how fermion and ν_R could behave as a single coherent unit reflecting itself in the characteristic spin and momentum dependence of vertices implied by SUSY. Rather, it would seem that fermion and sfermion should behave identically with respect to electroweak interactions.

The third argument looks rather convincing and can be developed to a precise argument.

(a) If sfermion is to represent elementary bosons, the products of fermionic oscillator operators with the oscillator operators assignable to the covariantly constant right handed neutrinos must define might-be bosonic oscillator operators as $b_n = a_n a$ and $b_n^\dagger = a_n^\dagger a^\dagger$ One can calculate the commutator for the product of operators. If fermionic oscillator operators commute, so do the corresponding bosonic operators. The commutator $[b_n, b_n^\dagger]$ is however proportional to occupation number for ν_R in $\mathcal{N}=1$ SUSY representation and vanishes for the second state of the representation. Therefore $\mathcal{N}=1$ SUSY is a pure gauge symmetry.

(b) One can however have both irreducible representations of SUSY: for them either fermion or sfermion has a non-vanishing norm. One would have both fermions and sfermions but they would not belong to the same SUSY multiplet, and one cannot expect SUSY symmetries of 3-particle vertices.

(c) For instance, $\gamma F F$ vertex is closely related to $\gamma\tilde{F}\tilde{\overline{F}}$ in standard SUSY. Now one expects this vertex to decompose to a product of $\gamma F\overline{F}$ vertex and amplitude for the creation of $\nu_R\tilde{\nu}_R$ from vacuum so that the characteristic momentum and spin dependent factors distinguishing between the couplings of photon to scalar and and fermion are absent. Both states behave like fermions. The amplitude for the creation of $\nu_R\tilde{\nu}_R$ from vacuum is naturally equal to unity as an occupation number operator by crossing symmetry. The presence of right-handed neutrinos would be invisible if this picture is correct. Whether this invisible label can have some consequences is not quite clear: one could argue that the decay rates of weak bosons to fermion pairs are doubled unless one introduces $1/\sqrt{2}$ factors to couplings.

Where the sfermions might make themselves visible are loops. What loops are? Consider boson line first. Boson line is replaced with a sum of two contributions corresponding to ordinary contribution with fermion and anti-fermion at opposite throats and second contribution with fermion and anti-fermion accompanied by right-handed neutrino ν_R and its antiparticle which now has opposite helicity to ν_R. The loop for ν_R decomposes to four pieces since also the propagation from wormhole throat to the opposite wormhole throat must be taken into account. Each of the four propagators equals to $a_{1/2}^\dagger a_{-1/2}^\dagger$ or its hermitian conjugate. The product of these is slashed between vacuum states and anti-commutations give imaginary unit per propagator giving $i^4=1$. The two contributions are therefore identical and the scaling $g \to g/\sqrt{2}$ for coupling constants guarantees that sfermions do not affect the scattering amplitudes at all. The argument is identical for the internal fermion lines.

8.2.3 The impact from LHC and evolution of TGD itself

The missing energy predicted standard SUSY is absent at LHC. The easy explanation would be that the mass scale of SUSY is unexpectedly high, of order 1 TeV. This would however destroy the original motivations for SUSY. The arguments developed in the following manner.

(a) In TGD framework the natural first guess was hat the missing energy corresponds to covariantly constant right-handed neutrinos carrying four-momentum. The objection is that covariantly constant right-handed neutrinos cannot appear in asymptotic states because one cannot assign a super-multiplet to right-handed neutrinos consistently. Covariantly constant right-handed neutrinos could however generate SUSY in some sense.

(b) This alone would not explain the missing missing momentum at LHC predicted by standard SUSY. The assumption that fermions correspond to color partial waves in H implies that color excitations of the right handed neutrino that would appear in asymptotic states are necessarily colored. It could happen that these excitations are color neutralized by super-conformal generators. If this is not the case, these neutrinos would be like quarks and color confinement would explain why they cannot be observed as asymptotic states in macroscopic scales.

Second possibility considered earlier is that SUSY itself is generated by color partial waves of right-handed neutrino, octet most naturally. This option is not however consistent with the above model for one-fermion states and their super-partners.

(c) The breakthrough in the understanding of the preferred extremals of Kähler action and solutions of the modified Dirac equation led to a radical reconsideration of the existing picture. The most natural conclusion is that the TGD counterpart of standard SUSY is most naturally absent. The arguments in favor of this conclusion discussed in the last section are rather strong. The breakthrough in understanding of TGD counterpart for Higgs like particle - Euclidian M_{89} pion - led to a model for the generation of weak gauge bosons masses free of the problem of the standard Higgs mechanism caused by the fact that tachyonic mass term is not stable under radiative corrections. In TGD framework this kind of term is absent. Therefore also the basic motivation for standard SUSY as stabilizer of radiative corrections disappears.

Standard space-time SUSY would be replaced with 4-D generalization of 2-D super-conformal invariance but restricted to the modes of right-handed neutrino. For other fermion states the modes would be restricted to 2-D string world sheets and partonic 2-surfaces and super-conformal symmetry would reduce to 2-D one. The 2-D super-conformal symmetry is mathematically analogous to badly broken SUSY with very large value of $\mathcal{N}$ and massive neutrino would represent the least broken aspect of this symmetry. The masses of sparticles are expected to be higher than particles for this SUSY and there is no reason to require that they should correspond to the TeV scale required by the radiative stability of the standard model Higgs.

8.2.4 Conclusions

The conclusion that the standard SUSY is absent looks very attractive in light of various arguments discussed in this chapter and also conforms with the LHC data. During the attempts to understand SUSY several ideas emerged and the original discussions are retained as such in this chapter. It is interesting to see that their fate is if standard SUSY has no TGD counterpart.

(a) One of the craziest ideas was that spartners indeed exists and even with the same p-adic mass scale but might be realized as dark matter. Same mass is indeed natural prediction since right-handed neutrino carries no momentum and has no electroweak interactions with fermions. Therefore even the mesons of ordinary hadron physics would be accompanied by smesons - pairs of squark and anti-squark. In fact, this is what the most recent form of the theory predicts: unfortunately there is no manner to experimentally distinguish between fermion and pseudo-sfermion if ν_R is zero momentum state lacking even gravitational interactions.

(b) There are indications that charmonium as exotic states christened as X and Y mesons and the question was that they could correspond to mesons built either from colored excitations of charged quark and antiquark or from squark and anti-squark. The recent view leaves only the option based on colored excitations alive. The states in question would be analogous to pairs of color excitations of leptons introduced to explain various anomalies in leptonic sector [K70]. The question was whether lepto-hadrons could correspond to bound states of colored sleptons and have same p-adic mass scale as leptons have [K70]. The original form of lepto-hadron hypothesis remains intact.

(c) Evidence that pion and also other hadrons have what could be called infrared Regge trajectories has been reported, and one could ask whether these trajectories could include spion identified as a bound state of squarks. Also this identification is excluded and the proposed identification in terms of stringy states assignable to long color magnetic flux tubes accompanying hadron remains under consideration. IR Regge trajectories would serve as a signature for the non-perturbative aspects of hadron physics.

8.3 Could $\mathcal{N} = 2$ or $\mathcal{N} = 4$ SYM be a part of TGD after all?

Whether right-handed neutrinos generate a supersymmetry in TGD has been a long standing open question. $\mathcal{N} = 1$ SUSY is certainly excluded by fermion number conservation but already $\mathcal{N} = 2$ defining a "complexification" of $\mathcal{N} = 1$ SUSY is possible and could generate right-handed neutrino and its antiparticle. These states should however possess a non-vanishing light-like momentum since the fully covariantly constant right-handed neutrino generates zero norm states. So called massless extremals (MEs) allow massless solutions of the modified Dirac equation for right-handed neutrino in the interior of space-time surface, and this seems to be case quite generally in Minkowskian signature for preferred extremals. This suggests that particle represented as magnetic flux tube structure with two wormhole contacts sliced between two MEs could serve as a starting point in attempts to understand the role of right handed neutrinos and how $\mathcal{N} = 2$ or $\mathcal{N} = 4$ SYM emerges at the level of space-time geometry. The following arguments inspired by the article of Nima Arkani-Hamed et al [B16] about twistorial scattering amplitudes suggest a more detailed physical interpretation of the possible SUSY associated with the right-handed neutrinos.

The fact that right handed neutrinos have only gravitational interaction suggests a radical re-interpretation of SUSY: no SUSY breaking is needed since it is very difficult to distinguish between mass degenerate spartners of ordinary particles. In order to distinguish between different spartners one must be able to compare the gravitomagnetic energies of spartners in slowly varying external gravimagnetic field: this effect is extremely small.

8.3.1 Scattering amplitudes and the positive Grassmannian

The work of Nima Arkani-Hamed and others represents something which makes me very optimistic and I would be happy if I could understand the horrible technicalities of their work. The article Scattering Amplitudes and the Positive Grassmannian by Arkani-Hamed, Bourjaily, Cachazo, Goncharov, Postnikov, and Trnka [B16] summarizes the recent situation in a form, which should be accessible to ordinary physicist. Lubos has already discussed the article. The following considerations do not relate much to the main message of the article (positive Grassmannians) but more to the question how this approach could be applied in TGD framework.

All scattering amplitudes have on shell amplitudes for massless particles as building bricks

The key idea is that all planar amplitudes can be constructed from on shell amplitudes: all virtual particles are actually real. In zero energy ontology I ended up with the representation of TGD analogs of Feynman diagrams using only mass shell massless states with both positive and negative energies. The enormous number of kinematic constraints eliminates UV and IR divergences and also the description of massive particles as bound states of massless ones becomes possible.

In TGD framework quantum classical correspondence requires a space-time correlate for the on mass shell property and it indeed exists. The mathematically ill-defined path integral over all 4-surfaces is replaced with a superposition of preferred extremals of Kähler action analogous to Bohr orbits, and one has only a functional integral over the 3-D ends at the light-like boundaries of causal diamond (Euclidian/Minkowskian space-time regions give real/imaginary Chern-Simons exponent to the vacuum functional). This would be obviously the deeper principle behind on mass shell representation of scattering amplitudes that Nima and others are certainly trying to identify. This principle in turn reduces to general coordinate invariance at the level of the world of classical worlds.

Quantum classical correspondence and quantum ergodicity would imply even stronger condition: the quantal correlation functions should be identical with classical correlation functions for any preferred extremal in the superposition: all preferred extremals in the superposition would be statistically equivalent [K80]. 4-D spin glass degeneracy of Kähler action however suggests that this is is probably too strong a condition applying only to building bricks of the superposition.

Minimal surface property is the geometric counterpart for masslessness and the preferred extremals are also minimal surfaces: this property reduces to the generalization of complex structure at space-time surfaces, which I call Hamilton-Jacobi structure for the Minkowskian signature of the induced metric. Einstein Maxwell equations with cosmological term are also satisfied.

Massless extremals and twistor approach

The decomposition $M^4 = M^2 \times E^2$ is fundamental in the formulation of quantum TGD, in the number theoretical vision about TGD, in the construction of preferred extremals, and for the vision about generalized Feynman diagrams. It is also fundamental in the decomposition of the degrees of string to longitudinal and transversal ones. An additional item to the list is that also the states appearing in thermodynamical ensemble in p-adic thermodynamics correspond to four-momenta in M^2 fixed by the direction of the Lorentz boost. In twistor approach to TGD the possibility to decompose also internal lines to massless states at parallel space-time sheets is crucial.

Can one find a concrete identification for $M^2 \times E^2$ decomposition at the level of preferred extremals? Could these preferred extremals be interpreted as the internal lines of generalized Feynman diagrams carrying massless momenta? Could one identify the mass of particle predicted by p-adic thermodynamics with the sum of massless classical momenta assignable to two preferred extremals of this kind connected by wormhole contacts defining the elementary particle?

Candidates for this kind of preferred extremals indeed exist. Local $M^2 \times E^2$ decomposition and light-like longitudinal massless momentum assignable to M^2 characterizes "massless extremals" (MEs, "topological light rays"). The simplest MEs correspond to single space-time sheet carrying a conserved light-like M^2 momentum. For several MEs connected by wormhole contacts the longitudinal massless momenta are not conserved anymore but their sum defines a time-like conserved four-momentum: one has a bound states of massless MEs. The stable wormhole contacts binding MEs together possess Kähler magnetic charge and serve as building bricks of elementary particles. Particles are necessary closed magnetic flux tubes having two wormhole contacts at their ends and connecting the two MEs.

The sum of the classical massless momenta assignable to the pair of MEs is conserved even when they exchange momentum. Quantum classical correspondence requires that the conserved classical rest energy of the particle equals to the prediction of p-adic mass calculations. The massless momenta assignable to MEs would naturally correspond to the massless momenta propagating along the internal lines of generalized Feynman diagrams assumed in zero energy ontology. Masslessness of virtual particles makes also possible twistor approach. This supports the view that MEs are fundamental for the twistor approach in TGD framework.

Scattering amplitudes as representations for braids whose threads can fuse at 3-vertices

Just a little comment about the content of the article. The main message of the article is that non-equivalent contributions to a given scattering amplitude in $\mathcal{N} = 4$ SYM represent elements of the group of permutations of external lines - or to be more precise - decorated permutations which replace permutation group S_n with $n!$ elements with its decorated version containing $2^n n!$ elements. Besides 3-vertex the basic dynamical process is permutation having the exchange of neighboring lines as a generating permutation completely analogous to fundamental braiding. BFCW bridge has interpretation as a representations for the basic braiding operation.

This supports the TGD inspired proposal (TGD as almost topological QFT) that generalized Feynman diagrams are in some sense also knot or braid diagrams allowing besides braiding operation also two 3-vertices [K30]. The first 3-vertex generalizes the standard stringy 3-vertex but with totally different interpretation having nothing to do with particle decay: rather particle travels along two paths simultaneously after $1 \rightarrow 2$ decay. Second 3-vertex generalizes the 3-vertex of ordinary Feynman diagram (three 4-D lines of generalized Feynman diagram identified as Euclidian space-time regions meet at this vertex). The main idea is that in TGD framework knotting and braiding emerges at two levels.

(a) At the level of space-time surface string world sheets at which the induced spinor fields (except right-handed neutrino [K80]) are localized due to the conservation of electric charge can form 2-knots and can intersect at discrete points in the generic case. The boundaries of strings world sheets at light-like wormhole throat orbits and at space-like 3-surfaces defining the ends of the space-time at light-like boundaries of causal diamonds can form ordinary 1-knots, and get linked and braided. Elementary particles themselves correspond to closed loops at the ends of space-time surface and can also get knotted (possible effects are discussed in [K30]).

(b) One can assign to the lines of generalized Feynman diagrams lines in M^2 characterizing given causal diamond. Therefore the 2-D representation of Feynman diagrams has concrete physical interpretation in TGD. These lines can intersect and what suggests itself is a description of non-planar diagrams (having this kind of intersections) in terms of an algebraic knot theory. A natural guess is that it is this knot theoretic operation which allows to describe also non-planar diagrams by reducing them to planar ones as one does when one constructs knot invariant by reducing the knot to a trivial one. Scattering amplitudes would be basically knot invariants.

"Almost topological" has also a meaning usually not assigned with it. Thurston's geometrization conjecture stating that geometric invariants of canonical representation of manifold as Riemann geometry, defined topological invariants, could generalize somehow. For instance, the geometric invariants of preferred extremals could be seen as topological or more refined invariants (symplectic, conformal in the sense of 4-D generalization of conformal structure). If quantum ergodicity holds true, the statistical geometric invariants defined by the classical correlation functions of various induced classical gauge fields for preferred extremals could be regarded as this kind of invariants for sub-manifolds. What would distinguish TGD from standard topological QFT would be that the invariants in question would involve length scale and thus have a physical content in the usual sense of the word!

8.3.2 Could $\mathcal{N}$ =2 or $\mathcal{N} = 4$ SUSY have something to do with TGD?

$\mathcal{N} = 4$ SYM has been the theoretical laboratory of Nima and others. $\mathcal{N} = 4$ SYM is definitely a completely exceptional theory, and one cannot avoid the question whether it could in some sense be part of fundamental physics. In TGD framework right handed neutrinos have remained a mystery: whether one should assign space-time SUSY to them or not. Could they give rise to something resembling $\mathcal{N} = 2$ or $\mathcal{N} = 4$ SUSY with fermion number conservation?

Earlier results

My latest view is that *fully* covariantly constant right-handed neutrinos decouple from the dynamics completely. I will repeat first the earlier arguments which consider only fully covariantly constant right-handed neutrinos.

(a) $\mathcal{N} = 1$ SUSY is certainly excluded since it would require Majorana property not possible in TGD framework since it would require superposition of left and right handed neutrinos and lead to a breaking of lepton number conservation. Could one imagine SUSY in which both MEs between which particle wormhole contacts reside have $\mathcal{N} = 2$ SUSY which combine to form an $\mathcal{N} = 4$ SUSY?

(b) Right-handed neutrinos which are covariantly constant right-handed neutrinos in both M^4 degrees of freedom cannot define a non-trivial theory as shown already earlier. They have no electroweak nor gravitational couplings and carry no momentum, only spin.

The fully covariantly constant right-handed neutrinos with two possible helicities at given ME would define representation of SUSY at the limit of vanishing light-like momentum. At this limit the creation and annihilation operators creating the states would have vanishing anti-commutator so that the oscillator operators would generate Grassmann algebra. Since creation and annihilation operators are hermitian conjugates, the states would have zero norm and the states generated by oscillator operators would be pure gauge and decouple from physics. This is the core of the earlier argument demonstrating that $\mathcal{N} = 1$ SUSY is not possible in TGD framework: LHC has given convincing experimental support for this belief.

Could massless right-handed neutrinos covariantly constant in CP_2 degrees of freedom define $\mathcal{N} = 2$ or $\mathcal{N} = 4$ SUSY?

Consider next right-handed neutrinos, which are covariantly constant in CP_2 degrees of freedom but have a light-like four-momentum. In this case fermion number is conserved but this is consistent with $\mathcal{N} = 2$ SUSY at both MEs with fermion number conservation. $\mathcal{N} = 2$ SUSYs could emerge from $\mathcal{N} = 4$ SUSY when one half of SUSY generators annihilate the states, which is a basic phenomenon in supersymmetric theories.

(a) At space-time level right-handed neutrinos couple to the space-time geometry - gravitation - although weak and color interactions are absent. One can say that this coupling forces them to move with light-like momentum parallel to that of ME. At the level of space-time surface right-handed neutrinos have a spectrum of excitations of four-dimensional analogs of conformal spinors at string world sheet (Hamilton-Jacobi structure).

For MEs one indeed obtains massless solutions depending on longitudinal M^2 coordinates only since the induced metric in M^2 differs from the light-like metric only by a contribution which is light-like and contracts to zero with light-like momentum in the same direction. These solutions are analogs of (say) left movers of string theory. The dependence on E^2 degrees of freedom is holomorphic. That left movers are only possible would suggest that one has only single helicity and conservation of fermion number at given space-time sheet rather than 2 helicities and non-conserved fermion number: two real Majorana spinors combine to single complex Weyl spinor.

(b) At imbedding space level one obtains a tensor product of ordinary representations of $\mathcal{N} = 2$ SUSY consisting of Weyl spinors with opposite helicities assigned with the ME. The state content is same as for a reduced $\mathcal{N} = 4$ SUSY with four $\mathcal{N} = 1$ Majorana spinors replaced by two complex $\mathcal{N} = 2$ spinors with fermion number conservation. This gives 4 states at both space-time sheets constructed from ν_R and its antiparticle.

Altogether the two MEs give 8 states, which is one half of the 16 states of $\mathcal{N} = 4$ SUSY so that a degeneration of this symmetry forced by non-Majorana property is in question.

Is the dynamics of $\mathcal{N} = 2$ or $\mathcal{N} = 4$ SYM possible in right-handed neutrino sector?

Could $\mathcal{N} = 2$ or $\mathcal{N} = 4$ SYM be a part of quantum TGD? Could TGD be seen a fusion of a degenerate $\mathcal{N} = 4$ SYM describing the right-handed neutrino sector and string theory like theory describing the contribution of string world sheets carrying other leptonic and quark spinors? Or could one imagine even something simpler?

What is interesting that the net momenta assigned to the right handed neutrinos associated with a pair of MEs would correspond to the momenta assignable to the particles and obtained by p-adic mass calculations. It would seem that right-handed neutrinos provide a representation of the momenta of the elementary particles represented by wormhole contact structures. Does this mimicry generalize to a full duality so that all quantum numbers and even microscopic dynamics of defined by generalized Feynman diagrams (Euclidian space-time regions) would be represented by right-handed neutrinos and MEs? Could a generalization of $\mathcal{N} = 4$ SYM with non-trivial gauge group with proper choices of the ground states helicities allow to represent the entire microscopic dynamics?

Irrespective of the answer to this question one can compare the TGD based view about supersymmetric dynamics with what I have understood about $\mathcal{N} = 4$ SYM.

(a) In the scattering of MEs induced by the dynamics of Kähler action the right-handed neutrinos play a passive role. Modified Dirac equation forces them to adopt the same direction of four-momentum as the MEs so that the scattering reduces to the geometric scattering for MEs as one indeed expects on basic of quantum classical correspondence. In ν_R sector the basic scattering vertex involves four MEs and could be a re-sharing of the right-handed neutrino content of the incoming two MEs between outgoing two MEs respecting fermion number conservation. Therefore $\mathcal{N} = 4$ SYM with fermion number conservation would represent the scattering of MEs at quantum level.

(b) $\mathcal{N} = 4$ SUSY would suggest that also in the degenerate case one obtains the full scattering amplitude as a sum of permutations of external particles followed by projections to the directions of light-like momenta and that BCFW bridge represents the analog of fundamental braiding operation. The decoration of permutations means that each external line is effectively doubled. Could the scattering of MEs can be interpreted in terms of these decorated permutations? Could the doubling of permutations by decoration relate to the occurrence of pairs of MEs?

 One can also revert these questions. Could one construct massive states in $\mathcal{N} = 4$ SYM using pairs of momenta associated with particle with integer label k and its decorated copy with label $k + n$? Massive external particles obtained in this manner as bound states of massless ones could solve the IR divergence problem of $\mathcal{N} = 4$ SYM.

(c) The description of amplitudes in terms of leading singularities means picking up of the singular contribution by putting the fermionic propagators on mass shell. In the recent case it would give the inverse of massless Dirac propagator acting on the spinor at the end of the internal line annihilating it if it is a solution of Dirac equation.

 The only way out is a kind of cohomology theory in which solutions of Dirac equation represent exact forms. Dirac operator defines the exterior derivative d and virtual lines correspond to non-physical helicities with $d\Psi \neq 0$. Virtual fermions would be on mass-shell fermions with non-physical polarization satisfying $d^2\Psi = 0$. External particles would be those with physical polarization satisfying $d\Psi = 0$, and one can say that the Feynman diagrams containing physical helicities split into products of Feynman diagrams containing only non-physical helicities in internal lines.

(d) The fermionic states at wormhole contacts should define the ground states of SUSY representation with helicity +1/2 and -1/2 rather than spin 1 or -1 as in standard realization of $\mathcal{N} = 4$ SYM used in the article. This would modify the theory but the twistorial and Grassmannian description would remain more or less as such since it depends on light-likeness and momentum conservation only.

3-vertices for sparticles are replaced with 4-vertices for MEs

In $\mathcal{N}=4$ SYM the basic vertex is on mass-shell 3-vertex which requires that for real light-like momenta all 3 states are parallel. One must allow complex momenta in order to satisfy energy conservation and light-likeness conditions. This is strange from the point of view of physics although number theoretically oriented person might argue that the extensions of rationals involving also imaginary unit are rather natural.

The complex momenta can be expressed in terms of two light-like momenta in 3-vertex with one real momentum. For instance, the three light-like momenta can be taken to be p, k, and $p-ka$ with $k=ap_R$. Here p (incoming momentum) and p_R are real light-like momenta satisfying $p\cdot p_R=0$ but with opposite sign of energy, and a is complex number. What is remarkable that also the negative sign of energy is necessary also now.

Should one allow complex light-like momenta in TGD framework? One can imagine two options.

(a) Option I: no complex momenta. In zero energy ontology the situation is different due to the presence of a pair of MEs meaning replaced of 3-vertices with 4-vertices or 6-vertices, the allowance of negative energies in internal lines, and the fact that scattering is of sparticles is induced by that of MEs. In the simplest vertex a massive external particle with non-parallel MEs carrying non-parallel light-like momenta can decay to a pair of MEs with light-like momenta. This can be interpreted as 4-ME-vertex rather than 3-vertex (say) BFF so that complex momenta are not needed. For an incoming boson identified as wormhole contact the vertex can be seen as BFF vertex.

To obtain space-like momentum exchanges one must allow negative sign of energy and one has strong conditions coming from momentum conservation and light-likeness which allow non-trivial solutions (real momenta in the vertex are not parallel) since basically the vertices are 4-vertices. This reduces dramatically the number of graphs. Note that one can also consider vertices in which three pairs of MEs join along their ends so that 6 MEs (analog of 3-boson vertex) would be involved.

(b) Option II: complex momenta are allowed. Proceeding just formally, the $\sqrt{g_4}$ factor in Kähler action density is imaginary in Minkowskian and real in Euclidian regions. It is now clear that the formal approach is correct: Euclidian regions give rise to Kähler function and Minkowskian regions to the analog of Morse function. TGD as almost topological QFT inspires the conjecture about the reduction of Kähler action to boundary terms proportional to Chern-Simons term. This is guaranteed if the condition $j^\mu_K A_\mu=0$ holds true: for the known extremals this is the case since Kähler current j_K is light-like or vanishing for them. This would seem that Minkowskian and Euclidian regions provide dual descriptions of physics. If so, it would not be surprising if the real and complex parts of the four-momentum were parallel and in constant proportion to each other.

This argument suggests that also the conserved quantities implied by the Noether theorem have the same structure so that charges would receive an imaginary contribution from Minkowskian regions and a real contribution from Euclidian regions (or vice versa). Four-momentum would be complex number of form $P=P_M+iP_E$. Generalized light-likeness condition would give $P_M^2=P_E^2$ and $P_M\cdot P_E=0$. complexified momentum would have 6 free components. A stronger condition would be $P_M^2=0=P_E^2$ so that one would have two light-like momenta "orthogonal" to each other. For both relative signs energy P_M and P_E would be actually parallel: parameterization would be in terms of light-like momentum and scaling factor. This would suggest that complex momenta do not bring in anything new and Option II reduces effectively to Option I. If one wants a complete analogy with the usual twistor approach then $P_M^2=P_E^2\neq 0$ must be allowed.

Is SUSY breaking possible or needed?

It is difficult to imagine the breaking of the proposed kind of SUSY in TGD framework, and the first guess is that all these 4 super-partners of particle have identical masses. p-Adic thermodynamics does not distinguish between these states and the only possibility is that the p-adic primes differ for the spartners. But is the breaking of SUSY really necessary? Can one really distinguish between the 8 different states of a given elementary particle using the recent day experimental methods?

(a) In electroweak and color interactions the spartners behave in an identical manner classically. The coupling of right-handed neutrinos to space-time geometry however forces the right-handed neutrinos to adopt the same direction of four-momentum as MEs has. Could some gravitational effect allow to distinguish between spartners? This would be trivially the case if the p-adic mass scales of spartners would be different. Why this should be the case remains however an open question.

(b) In the case of unbroken SUSY only spin distinguishes between spartners. Spin determines statistics and the first naive guess would be that bosonic spartners obey totally different atomic physics allowing condensation of selectrons to the ground state. Very probably this is not true: the right-handed neutrinos are de-localized to 4-D MEs and other fermions correspond to wormhole contact structures and 2-D string world sheets.

   The coupling of the spin to the space-time geometry seems to provide the only possible manner to distinguish between spartners. Could one imagine a gravimagnetic effect with energy splitting proportional to the product of gravimagnetic moment and external gravimagnetic field B? If gravimagnetic moment is proportional to spin projection in the direction of B, a non-trivial effect would be possible. Needless to say this kind of effect is extremely small so that the unbroken SUSY might remain undetected.

(c) If the spin of sparticle be seen in the classical angular momentum of ME as quantum classical correspondence would suggest then the value of the angular momentum might allow to distinguish between spartners. Also now the effect is extremely small.

What can one say about scattering amplitudes?

One expect that scattering amplitudes factorize with the only correlation between right-handed neutrino scattering and ordinary particle scattering coming from the condition that the four-momentum of the right-handed neutrino is parallel to that of massless extremal of more general preferred extremal having interpretation as a geometric counterpart of radiation quantum. This momentum is in turn equal to the massless four-momentum associated with the space-time sheet in question such that the sum of classical four-momenta associated with the space-time sheets equals to that for all wormhole throats involved. The right-handed neutrino amplitude itself would be simply constant. This certainly satisfies the SUSY constraint and it is actually difficult to find other candidates for the amplitude. The dynamics of right-handed neutrinos would be therefore that of spectator following the leader.

8.3.3 Right-handed neutrino as inert neutrino?

There is a very interesting posting by Jester in Resonaances with title How many neutrinos in the sky? [C8]. Jester tells about the recent 9 years WMAP data [C106] and compares it with earlier 7 years data. In the earlier data the effective number of neutrino types was $N_{eff} = 4.34 \pm 0.87$ and in the recent data it is $N_{eff} = 3.26 \pm 0.35$. WMAP alone would give $N_{eff} = 3.89 \pm 0.67$ also in the recent data but also other data are used to pose constraints on N_{eff}.

To be precise, N_{eff} could include instead of fourth neutrino species also some other weakly interacting particle. The only criterion for contributing to N_{eff} is that the particle is in thermal equilibrium with other massless particles and thus contributes to the density of matter considerably during the radiation dominated epoch.

Jester also refers to the constraints on N_{eff} from nucleosynthesis, which show that $N_{eff} \sim 4$ us slightly favored although the entire range $[3, 5]$ is consistent with data.

It seems that the effective number of neutrinos could be 4 instead of 3 although latest WMAP data combined with some other measurements favor 3. Later a corrected version of the eprint appeared [C106] telling that the original estimate of N_{eff} contained a mistake and the correct estimate is $N_{eff} = 3.84 \pm 0.40$.

An interesting question is what $N_{eff} = 4$ could mean in TGD framework?

(a) One poses to the modes of the modified Dirac equation the following condition: electric charge is conserved in the sense that the time evolution by modified Dirac equation does not mix a mode with a well-defined em charge with those with different em charge. The implication is that all modes except pure right handed neutrino are restricted at string world sheets. The first guess is that string world sheets are minimal surfaces of space-time surface (rather than those of imbedding space). One can also consider minimal surfaces of imbedding space but with effective metric defined by the anti-commutators of the modified gamma matrices. This would give a direct physical meaning for this somewhat mysterious effective metric.

For the neutrino modes localized at string world sheets mixing of left and right handed modes takes place and they become massive. If only 3 lowest genera for partonic 2-surfaces are light, one has 3 neutrinos of this kind. The same applies to all other fermion species. The argument for why this could be the case relies on simple observation [K14]: the genera g=0,1,2 have the property that they allow for all values of conformal moduli Z_2 as a conformal symmetry (hyper-ellipticity). For $g > 2$ this is not the case. The guess is that this additional conformal symmetry is the reason for lightness of the three lowest genera.

(b) Only purely right-handed neutrino is completely de-localized in 4-volume so that one cannot assign to it genus of the partonic 2-surfaces as a topological quantum number and it effectively gives rise to a fourth neutrino very much analogous to what is called sterile neutrino. De-localized right-handed neutrinos couple only to gravitation and in case of massless extremals this forces them to have four-momentum parallel to that of ME: only massless modes are possible. Very probably this holds true for all preferred extremals to which one can assign massless longitudinal momentum direction which can vary with spatial position.

(c) The coupling of ν_R is to gravitation alone and all electroweak and color couplings are absent. According to standard wisdom de-localized right-handed neutrinos cannot be in thermal equilibrium with other particles. This according to standard wisdom. But what about TGD?

One should be very careful here: de-localized right-handed neutrinos is proposed to give rise to SUSY (not $\mathcal{N} = 1$ requiring Majorana fermions) and their dynamics is that of passive spectator who follows the leader. The simplest guess is that the dynamics of right handed neutrinos at the level of amplitudes is completely trivial and thus trivially supersymmetric. There are however correlations between four-momenta.

i. The four-momentum of ν_R is parallel to the light-like momentum direction assignable to the massless extremal (or more general preferred extremal). This direct coupling to the geometry is a special feature of the modified Dirac operator and thus of sub-manifold gravity.

ii. On the other hand, the sum of massless four-momenta of two parallel pieces of preferred extremals is the - in general massive - four-momentum of the elementary particle defined by the wormhole contact structure connecting the space-time sheets (which are glued along their boundaries together since this is seems to be the only manner to get rid of boundary conditions requiring vacuum extremal property near the boundary). Could this direct coupling of the four-momentum direction of right-handed neutrino to geometry and four-momentum directions of other fermions be enough for the right handed neutrinos to be counted as a fourth neutrino species in thermal equilibrium? This might be the case!

One cannot of course exclude the coupling of 2-D neutrino at string world sheets to 4-D purely right handed neutrinos analogous to the coupling inducing a mixing of sterile neutrino with ordinary neutrinos. Also this could help to achieve the thermal equilibrium with 2-D neutrino species.

Experimental evidence for sterile neutrino?

Many physicists are somewhat disappointed to the results from LHC: the expected discovery of Higgs has been seen as the main achievement of LHC hitherto. Much more was expected. To my opinion there is no reason for disappointment. The exclusion of the standard SUSY at expected energy scale is very far reaching negative result. Also the fact that Higgs mass is too small to be stable without fine tuning is of great theoretical importance. The negative results concerning heavy dark matter candidates are precious guidelines for theoreticians. The non-QCD like behavior in heavy ion collisions and proton-ion collisions is bypassed my mentioning something about AdS/CFT correspondence and non-perturbative QCD effects. I tend to see these effects as direct evidence for M_{89} hadron physics [K37].

In any case, something interesting has emerged quite recently. Resonaances tells that the recent analysis [C104] of X-ray spectrum of galactic clusters claims the presence of monochromatic 3.5 keV photon line. The proposed interpretation is as a decay product of sterile 7 keV neutrino transforming first to a left-handed neutrino and then decaying to photon and neutrino via a loop involving W boson and electron. This is of course only one of the many interpretations. Even the existence of line is highly questionable.

One of the poorly understood aspects of TGD is right-handed neutrino, which is obviously the TGD counterpart of the inert neutrino.

(a) The old idea is that covariantly constant right handed neutrino could generate $\mathcal{N} = 2$ super-symmetry in TGD Universe. In fact, all modes of induced spinor field would generate superconformal symmetries but electroweak interactions would break these symmetries for the modes carrying non-vanishing electroweak quantum numbers: they vanish for ν_R. This picture is now well-established at the level of WCW geometry [K86]: super-conformal generators are labelled angular momentum and color representations plus two conformal weights: the conformal weight assignable to the light-like radial coordinate of light-cone boundary and the conformal weight assignable to string coordinate. It seems that these conformal weights are independent. The third integer labelling the states would label genuinely Yangian generators: it would tell the poly-locality of the generator with locus defined by partonic 2-surface: generators acting on single partonic 2-surface, 2 partonic 2-surfaces, ...

(b) It would seem that even the SUSY generated by ν_R must be badly broken unless one is able to invent dramatically different interpretation of SUSY. The scale of SUSY breaking and thus the value of the mass of right-handed neutrino remains open also in TGD. In lack of better one could of course argue that the mass scale must be CP_2 mass scale because right-handed neutrino mixes considerably with the left-handed neutrino (and thus becomes massive) only in this scale. But why this argument does not apply also to left handed neutrino which must also mix with the right-handed one!

(c) One can of course criticize the proposed notion of SUSY: wonder whether fermion + extremely weakly interacting ν_R at same wormhole throat (or interior of 3-surface) can behave as single coherent entity as far spin is considered [K78]?

(d) The condition that the modes of induced spinor field have a well-defined electromagnetic charge eigenvalue [K80] requires that they are localized at 2-D string world sheets or partonic 2-surfaces: without this condition classical W boson fields would mix the em charged and neutral modes with each other. Right-handed neutrino is an exception since it has no electroweak couplings. Unless right-handed neutrino is covariantly constant, the modified gamma matrices can however mix the right-handed neutrino with the left handed one and this can induce transformation to charged mode. This does not happen if each modified gamma matrix can be written as a linear combination of either M^4 or CP_2 gamma matrices and modified Dirac equation is satisfied separately by M^4 and CP_2 parts of the modified Dirac equation.

(e) Is the localization of the modes other than covariantly constant neutrino to string world sheets a consequence of dynamics or should one assume this as a separate condition? If one wants similar localization in space-time regions of Euclidian signature - for which

CP_2 type vacuum extremal is a good representative - one must assume it as a separate condition. In number theoretic formulation string world sheets/partonic 2-surfaces would be commutative/co-commutative sub-manifolds of space-time surfaces which in turn would be associative or co-associative sub-manifolds of imbedding space possessing (hyper-)octonionic tangent space structure. For this option also right-handed neutrino would be localized to string world sheets. Right-handed neutrino would be covariantly constant only in 2-D sense.

One can consider the possibility that ν_R is de-localized to the entire 4-D space-time sheet. This would certainly modify the interpretation of SUSY since the number of degrees of freedom would be reduced for ν_R.

(f) Non-covariantly constant right-handed neutrinos could mix with left-handed neutrinos but not with charged leptons if the localization to string world sheets is assumed for modes carrying non-vanishing electroweak quantum numbers. This would make possible the decay of right-handed to neutrino plus photon, and one cannot exclude the possibility that ν_R has mass 7 keV.

Could this imply that particles and their spartners differ by this mass only? Could it be possible that practically unbroken SUSY could be there and we would not have observed it? Could one imagine that sfermions have annihilated leaving only states consisting of fundamental fermions? But shouldn't the total rate for the annihilation of photons to hadrons be two times the observed one? This option does not sound plausible.

What if one assumes that given sparticle is charactrized by the same p-adic prime as corresponding particle but is dark in the sense that it corresponds to non-standard value of Planck constant. In this case sfermions would not appear in the same vertex with fermions and one could escape the most obvious contradictions with experimental facts. This leads to the notion of shadron: shadrons would be [K78] obtained by replacing quarks with dark squarks with nearly identical masses. I have asked whether so called X and Y bosons having no natural place in standard model of hadron could be this kind of creatures.

The interpretation of 3.5 keV photons as decay products of right-handed neutrinos is of course totally ad hoc. Another TGD inspired interpretation would be as photons resulting from the decays of excited nuclei to their ground state.

(a) Nuclear string model [L3] predicts that nuclei are string like objects formed from nucleons connected by color magnetic flux tubes having quark and antiquark at their ends. These flux tubes are long and define the "magnetic body" of nucleus. Quark and antiquark have opposite em charges for ordinary nuclei. When they have different charges one obtains exotic state: this predicts entire spectrum of exotic nuclei for which statistic is different from what proton and neutron numbers deduced from em charge and atomic weight would suggest. Exotic nuclei and large values of Planck constant could make also possible cold fusion [K20].

(b) What the mass difference between these states is, is not of course obvious. There is however an experimental finding [C113] (see *Analysis of Gamma Radiation from a Radon Source: Indications of a Solar Influence*) that nuclear decay rates oscillate with a period of year and the rates correlate with the distance from Sun. A possible explanation is that the gamma rays from Sun in few keV range excite the exotic nuclear states with different decay rate so that the average decay rate oscillates [L3]. Note that nuclear excitation energies in keV range would also make possible interaction of nuclei with atoms and molecules.

(c) This allows to consider the possibility that the decays of exotic nuclei in galactic clusters generates 3.5 keV photons. The obvious question is why the spectrum would be concentrated at 3.5 keV in this case (second question is whether the energy is really concentrated at 3.5 keV: a lot of theory is involved with the analysis of the experiments). Do the energies of excited states depend on the color bond only so that they would be essentially same for all nuclei? Or does single excitation dominate in the spectrum? Or is this due to the fact that the thermal radiation leaking from the core of stars excites predominantly single state? Could $E = 3.5$ keV correspond to the maximum intensity for thermal radiation in stellar core? If so, the temperature of the exciting radiation would be about $T \simeq E/3 \simeq 1.2 \times 10^7$ K. This in the temperature around which formation of Helium by nuclear fusion has begun: the temperature at solar core is around 1.57×10^7 K.

Chapter 9

New Physics Predicted by TGD: Part I

9.1 Introduction

TGD predicts a lot of new physics and it is quite possible that this new physics becomes visible at LHC. Although calculational formalism is still lacking, p-adic length scale hypothesis allows to make precise quantitative predictions for particle masses by using simple scaling arguments. Actually there is already now evidence for effects providing further support for TGD based view about QCD and first rumors about super-symmetric particles have appeared.

Before detailed discussion it is good to summarize what elements of quantum TGD are responsible for new physics.

(a) The new view about particles relies on their identification as partonic 2-surfaces (plus 4-D tangent space data to be precise). This effective metric 2-dimensionality implies generalization of the notion of Feynman diagram and holography in strong sense. One implication is the notion of field identity or field body making sense also for elementary particles and the Lamb shift anomaly of muonic hydrogen could be explained in terms of field bodies of quarks.

(b) The topological explanation for family replication phenomenon implies genus generation correspondence and predicts in principle infinite number of fermion families. One can however develop a rather general argument based on the notion of conformal symmetry known as hyper-ellipticity stating that only the genera $g = 0, 1, 2$ are light [**?**] What "light" means is however an open question. If light means something below CP_2 mass there is no hope of observing new fermion families at LHC. If it means weak mass scale situation changes.

For bosons the implications of family replication phenomenon can be understood from the fact that they can be regarded as pairs of fermion and anti-fermion assignable to the opposite wormhole throats of wormhole throat. This means that bosons formally belong to octet and singlet representations of dynamical SU(3) for which 3 fermion families define 3-D representation. Singlet would correspond to ordinary gauge bosons. Also interacting fermions suffer topological condensation and correspond to wormhole contact. One can either assume that the resulting wormhole throat has the topology of sphere or that the genus is same for both throats.

(c) The view about space-time supersymmetry differs from the standard view in many respects. First of all, the super symmetries are not associated with Majorana spinors. Super generators correspond to the fermionic oscillator operators assignable to leptonic and quark-like induced spinors and there is in principle infinite number of them so that formally one would have $\mathcal{N} = \infty$ SUSY. I have discussed the required modification of the formalism of SUSY theories in [**?**]nd it turns out that effectively one obtains just $\mathcal{N} = 1$

SUSY required by experimental constraints. The reason is that the fermion states with higher fermion number define only short range interactions analogous to van der Waals forces. Right handed neutrino generates this super-symmetry broken by the mixing of the M^4 chiralities implied by the mixing of M^4 and CP_2 gamma matrices for induced gamma matrices. The simplest assumption is that particles and their superpartners obey the same mass formula but that the p-adic length scale can be different for them.

(d) The new view about particle massivation based on p-adic thermodynamics raises the question about the role of Higgs field. The vacuum expectation value (VEV) of Higgs is not feasible in TGD since CP_2 does not allow covariantly constant holomorphic vector fields. The original too strong conclusion from this was that TGD does not allow Higgs. Higgs VEV is not needed for the selection of preferred electromagnetic direction in electro-weak gauge algebra (unitary gauge) since CP_2 geometry does that. p-Adic thermodynamics explains fermion masses bout the masses of weak bosons cannot be understood on basis of p-adic thermodynamics alone giving extremely small second order contribution only and failing to explain W/Z mass ratio. Weak boson mass can be associated to the string tension of the strings connecting the throats of two wormhole contacts associated with elementary particle (two of them are needed since the monopole magnetic flux must have closed field lines).

At M^4 QFT limit Higgs VEV is the only possible description of massivation. Dimensional gradient coupling to Higgs field developing VEV explains fermion masses at this limit. The dimensional coupling is same for all fermions so that one avoids the loss of "naturalness" due to the huge variation of Higgs-fermion couplings in the usual description.

The stringy contribution to elementary particle mass cannot be calculated from the first principles. A generalization of p-adic thermodynamics based on the generalization of super-conformal algebra is highly suggestive. There would be two conformal weights corresponding the the conformal weight assignable to the radial light-like coordinate of light-cone boundary and to the stringy coordinate and third integer characterizing the poly-locality of the generator of Yangian associated with this algebra (n-local generator acts on n partonic 2-surfaces simultaneously).

(e) One of the basic distinctions between TGD and standard model is the new view about color.

   i. The first implication is separate conservation of quark and lepton quantum numbers implying the stability of proton against the decay via the channels predicted by GUTs. This does not mean that proton would be absolutely stable. p-Adic and dark length scale hierarchies indeed predict the existence of scale variants of quarks and leptons and proton could decay to hadons of some zoomed up copy of hadrons physics. These decays should be slow and presumably they would involve phase transition changing the value of Planck constant characterizing proton. It might be that the simultaneous increase of Planck constant for all quarks occurs with very low rate.

   ii. Also color excitations of leptons and quarks are in principle possible. Detailed calculations would be required to see whether their mass scale is given by CP_2 mass scale. The so called lepto-hadron physics proposed to explain certain anomalies associated with both electron, muon, and τ lepton could be understood in terms of color octet excitations of leptons [?]

(f) Fractal hierarchies of weak and hadronic physics labelled by p-adic primes and by the levels of dark matter hierarchy are highly suggestive. Ordinary hadron physics corresponds to $M_{107} = 2^{107} - 1$ One especially interesting candidate would be scaled up hadronic physics which would correspond to $M_{89} = 2^{89} - 1$ defining the p-adic prime of weak bosons. The corresponding string tension is about 512 GeV and it might be possible to see the first signatures of this physics at LHC. Nuclear string model in turn predicts that nuclei correspond to nuclear strings of nucleons connected by colored flux tubes having light quarks at their ends. The interpretation might be in terms of M_{127} hadron physics. In biologically most interesting length scale range 10 nm-2.5 μm contains four electron Compton lengths $L_e(k) = \sqrt{5}L)k)$ associated with Gaussian Mersennes and the conjecture is that these and other Gaussian Mersennes are associated with zoomed up variants of hadron physics relevant for living matter. Cosmic rays might also reveal copies of hadron physics corresponding to M_{61} and M_{31}

The well-definedness of em charge for the modes of induced spinor fields localizes them at 2-D surfaces with vanishing W fields and also Z^0 field above weak scale. This allows to avoid undesirable parity breaking effects.

(g) Weak form of electric magnetic duality implies that the fermions and anti-fermions associated with both leptons and bosons are Kähler magnetic monopoles accompanied by monopoles of opposite magnetic charge and with opposite weak isospin. For quarks Kähler magnetic charge need not cancel and cancellation might occur only in hadronic length scale. The magnetic flux tubes behave like string like objects and if the string tension is determined by weak length scale, these string aspects should become visible at LHC. If the string tension is 512 GeV the situation becomes less promising.

In this chapter the predicted new elementary particle physics and possible indications for it are discussed. Second chapter is devoted to new hadron physics and scaled up variants of hardon physics in both quark and lepton sector.

The appendix of the book gives a summary about basic concepts of TGD with illustrations. There are concept maps about topics related to the contents of the chapter prepared using CMAP realized as html files. Links to all CMAP files can be found at `http://www.tgdtheory.fi/cmaphtml.html` [L20]. Pdf representation of same files serving as a kind of glossary can be found at `http://www.tgdtheory.fi/tgdglossary.pdf` [L21]. The topics relevant to this chapter are given by the following list.

- TGD view about elementary particles [L49]
- p-Adic length scale hypothesis [L39]
- p-Adic mass calculations [L37]
- Geometrization of fields [L27]
- Magnetic body [L34]
- Emergent ideas and notions [L26]
- Elementary particle vacuum functionals [L24]
- Emergence of bosons [L25]
- Leptohadron hypothesis [L32]
- M89 hadron physics [L33]
- SUSY and TGD [L43]

9.2 Family replication phenomenon

9.2.1 Higher gauge boson families

TGD predicts that also gauge bosons, with gravitons included, should be characterized by family replication phenomenon but not quite in the expected manner. The first expectation was that these gauge bosons would have at least 3 light generations just like quarks and leptons.

Only within last two years it has become clear that there is a deep difference between fermions and gauge bosons. Elementary fermions and particles super-conformally related to elementary fermions correspond to single throat of a wormhole contact assignable to a topologically condensed CP_2 type vacuum extremal whereas gauge bosons would correspond to a wormhole throat pair assignable to wormhole contact connecting two space-time sheets. Wormhole throats correspond to light-like partonic 3-surfaces at which the signature of the induced metric changes.

In the case of 3 generations gauge bosons can be arranged to octet and singlet representations of a dynamical SU(3) and octet bosons for which wormhole throats have different genus could be massive and effectively absent from the spectrum.

Exotic gauge boson octet would induce particle reactions in which conserved handle number would be exchanged between incoming particles such that total handle number of boson would be difference of the handle numbers of positive and negative energy throat. These gauge bosons would induce flavor changing but genus conserving neutral current. There is no evidence for this kind of currents at low energies which suggests that octet mesons are heavy. Typical reaction would be $\mu + e \rightarrow e + \mu$ scattering by exchange of $\Delta g = 1$ exotic photon.

New view about interaction vertices and bosons

There are two options for the identification of particle vertices as topological vertices.

1. *Option a)*

The original assumption was that one can assign also to bosons a partonic 2-surface X^2 with more or less well defined genus g. The hypothesis is consistent with the view that particle reactions are described by smooth 4-surfaces with vertices being singular 3-surfaces intermediate between two three-topologies. The basic objection against this option is that it can induce too high rates for flavor changing currents. In particular $g > 0$ gluons could induce these currents. Second counter argument is that stable $n > 4$-particle vertices are not possible.

2. *Option b)*

According to the new vision (option 2)), particle decays correspond to branchings of the partonic 2-surfaces in the same sense as the vertices of the ordinary Feynman diagrams do correspond to branchings of lines. The basic mathematical justification for this vision is the enormous simplification caused by the fact that vertices correspond to non-singular 2-manifolds. This option allows also $n > 3$-vertices as stable vertices.

A consistency with the experimental facts is achieved if the observed gauge bosons have each value of $g(X^2)$ with the same probability. Hence the general boson state would correspond to a phase $exp(in2\pi g/3)$, $n = 0, 1, 2$, in the discrete space of 3 lowest topologies $g = 0, 1, 2$. The observed bosons would correspond to $n = 0$ state and exotic higher states to $n = 1, 2$.

The nice feature of this option is that no flavor changing neutral electro-weak or color currents are predicted. This conforms with the fact that CKM mixing can be understood as electro-weak phenomenon described most naturally by causal determinants X_l^3 (appearing as lines of generalized Feynman diagram) connecting fermionic 2-surfaces of different genus.

Consider now objections against this scenario.

(a) Since the modular contribution does not depend on the gradient of the elementary particle vacuum functional but only on its logarithm, all three boson states should have mass squared which is the average of the mass squared values $M^2(g)$ associated with three generations. The fact that modular contribution to the mass squared is due to the super-symplectic thermodynamics allows to circumvent this objection. If the super-symplectic p-adic temperature is small, say $T_p = 1/2$, then the modular contribution to the mass squared is completely negligible also for $g > 0$ and photon, graviton, and gluons could remain massless. The wiggling of the elementary particle vacuum functionals at the boundaries of the moduli spaces $\mathcal{M}_g$ corresponding to 2-surfaces intermediate between different 2-topologies (say pinched torus and self-touching sphere) caused by the change of overall phase might relate to the higher p-adic temperature T_p for exotic bosons.

(b) If photon states had a 3-fold degeneracy, the energy density of black body radiation would be three times higher than it is. This problem is avoided if the the super-symplectic temperature for $n = 1, 2$ states is higher than for $n = 0$ states, and same as for fermions, say $T_p = 1$. In this case two mass degenerate bosons would be predicted with mass squared being the average over the three genera. In this kind of situation the factor $1/3$ could make the real mass squared very large, or order CP_2 mass squared, unless the sum of the modular contributions to the mass squared values $M^2_{mod}(g) \propto n(g)$ is divisible by 3. This would make also photon, graviton, and gluons massive. Fortunately, $n(g)$ is divisible by 3 as is clear form $n(0) = 0$, $n(1) = 9$, $n(2) = 60$.

Masses of genus-octet bosons

For option 1) ordinary bosons are accompanied by $g > 0$ massive partners. For option 2) both ordinary gauge bosons and their exotic partners have suffered maximal topological mixing in the case that they are singlets with respect to the dynamical SU(3). There are good reasons to expect that Higgs mechanism for ordinary gauge bosons generalizes as such and that $1/T_p > 1$ means that the contribution of p-adic thermodynamics to the mass is negligible. The scale of Higgs boson expectation would be given by p-adic length scale and mass degeneracy of octet is expected. A good guess is obtained by scaling the masses of electro-weak bosons by the factor $2^{(k-89)/2}$. Also the masses of genus-octet of gluons and photon should be non-vanishing and induced by a vacuum expectation of Higgs particle which is electro-weak singlet but genus-octet.

Indications for genus-generation correspondence for gauge bosons

Tommaso Dorigo is a highly inspiring blogger since he writes from the point of view of experimental physicist without the burden of theoretical dogmas. I share with him also the symptoms of splitting of personality to fluctuation-enthusiast and die-hard skeptic. This makes life interesting but not easy. This time Tommaso told about the evidence for new neutral gauge boson states in $p\overline{p}$ collisions. The title of the posting was "A New Z' Boson at 240 GeV? No, Wait, at 720!?" [C29] .

1. The findings

The title tells that the tentative interpretation of these states are as excited states of Z^0 boson and that the masses of the states are around 240 GeV and 720 GeV. The evidence for the new states comes from electron-positron pairs in relatively narrow energy interval produced by the decays of the might-be-there gauge boson. This kind of decay is an especially clean signature since strong interaction effects are not present and it appears at sharp energy.

240 GeV bump was reported by CDF last year [C53] CDF last year in $p\overline{p}$ collisions at $\sqrt{s} = 1.96$ TeV. The probability that it is a fluctuation is .6 per cent. What is encouraging that also D0 found the same bump. If the particle in question is analogous to Z^0, it should decay also to muons. CDF checked this and found a negative result. This made Tommaso rather skeptic.

Also indications for 720 GeV resonance (720 GeV is just a nominal value, the mass could be somewhere between 700-800 GeV) was reported by D0 collaboration: the report is titled as "Search for high-mass narrow resonances in the di-electron channel at D0" [C69] . There are just 2 events above 700 GeV but background is small: just three events above 600 GeV. It is easy to guess what skeptic would say.

Before continuing I want to make clear that I refuse to be blind believer or die-hard skeptic and that I am unable to say anything serious about the experimental side. I am just interested to see whether these events might be interpreted in TGD framework. TGD indeed predicts -or should I say strongly suggests- a lot of new physics above intermediate boson length scale.

2. Are exotic Z^0 bosons p-adically scaled up variants of ordinary Z^0 boson?

p-Adic length scale hypothesis allows the p-adic length scale characterized by prime $p \simeq 2^k$ vary since k can have several integer values. The TGD counterpart of Gell-Mann-Okubo mass formula involves varying value of k for quark masses. Several anomalies reported by Tommaso during years could be resolved if k can have several values. Last anomaly was the discovery that Ω_b baryon containing two strange quarks and bottom quark seems to appear with two masses differing by about 100 MeV. TGD explains the mass difference correctly by assuming that strange quark can have besides ordinary mass scale mass differing by factor of 2. The prediction is 105 MeV.

One can look whether p-adic length scale hypothesis could explains the masses of exotic Z^0 candidates as multiples of half octaves of Z^0 mass which is 91 GeV. k=3 would give 257 GeV, not too far from 240 GeV. k=6 would give 728 GeV consistent with the nominal value of the mass. Also other masses are predicted and this could serve as a test for the theory. This option does not however explain why muon pairs are not produced in the case of 240 GeV resonance.

3. Support for topological explanation of family replication phenomenon?

The improved explanation is based on TGD based view about family replication phenomenon [K14] .

(a) In TGD the explanation of family replication is in terms of genus of 2-dimensional partonic surface representing fermion. Fermions correspond to SU(3) triplet of a dynamical symmetry assignable to the three lowest genera (sphere, torus, sphere with two handles). Bosons as wormhole contacts have two wormhole throats carrying fermion numbers and correspond to SU(3) singlet and octet. Sooner or later the members of the octet - presumably heavier than singlet- should be observed (maybe this has been done now;-)).

(b) The exchange of these particles predicts also charged flavor changing currents respecting conservation of corresponding "isospin" and "hypercharge." For instance, lepton quark scattering $e+s \rightarrow \mu+d$ would be possible. The most dramatic signature of these states is production of muon-positron pairs (for instance) via decays.

(c) Since the Z^0 or photon like boson in question has vanishing "isospin" and "hypercharge", it must be orthogonal to the ordinary Z^0 which couples identically to all families. There are two states of this kind and they correspond to superpositions of fermion pairs of different generations in TGD framework. The two bosons - very optimistically identified as 240 GeV and 720 GeV Z^0, must be orthogonal to the ordinary Z^0. This requires that the phase factors in superposition of pairs adjust themselves properly. Also mixing effects breaking color symmetry are possible and expected to occur since the SU(3) in question is not an exact symmetry. Hence the exotic Z^0 bosons *could* couple preferentially to some fermion generation. This kind of mixing might be used to explain the absence of muon pair signal in the case of 240 GeV resonance.

(d) The prediction for the masses is same as for the first option if the octet and singlet bosons have identical masses for same p-adic mass scale so that mass splitting between different representations would take place via the choice of the mass scale alone.

4. Could scaled up copy of hadron physics involved?

One can also ask whether these particles could come from the decays of hadrons of a scaled up copy of hadron physics strongly suggested by p-Adic length scale hypothesis.

(a) Various hadron physics would correspond to Mersenne primes: standard hadron physics to M_{107} and new hadron physics to Mersenne prime $M_{89} = 2^{89} - 1$. The first guess for the mass scale of "light" M^{89} hadrons would be $2^{(107-89)/2} = 512$ times that for ordinary hadrons. The electron pairs might result in a decay of scaled up variant of pseudo-scalar mesons π , η, or of η' or spin one ρ and ω mesons with nearly the same mass. Only scaled up ρ and ω mesons remains under consideration if one assumes spin 1.

(b) The scaling of pion mass about 140 MeV gives 72 GeV. This is three times smaller than 240 GeV but this is extremely rough estimate. Actually it is the p-adic mass scale of quarks involved which matters rather than that of hadronic space-time sheet characterized by M_{89}. The naive scaling of the mass of η meson with mass 548 MeV would give about 281 GeV. η' would give 490 GeV. ρ meson with mass would give 396 GeV. The estimates are just order of magnitude estimates since the mass splitting between pseudo-scalar and corresponding vector meson is sensitive to quark mass scale.

(c) This option does not provide any explanation for the lack of muon pairs in decays of 240 GeV resonance.

To conclude, family replication phenomenon for gauge bosons is consistent with the claimed masses and also absence of muon pairs might be understood and it remains to be seen whether only statistical fluctuations are in question.

9.2.2 A slight indication for the exotic octet of gauge bosons from forward-backward asymmetry in top pair production

CDF has reported two anomalies related to the production of top quark pairs. The production rate for the pairs is too high and the forward backward asymmetry is also anomalously high. Both these anomalies could be understood as support for the octet of gauge bosons associated predicted by TGD based explanation of family replication phenomenon [K14] . The exchange of both gauge bosons would induce both charged and neutral flavour changing electroweak and color currents.

Two high production rate for top quark pairs

Both Jester and Lubos tell about top quark related anomaly in proton-antiproton collisions at Tevatron reported by CDF collaboration. The anomaly has been actually reported already last summer but has gone un-noticed. For more detailed data see this [C16] .

What has been found is that the production rate for jet pairs with jet mass around 170 GeV, which happens to correspond to top quark mass, the production cross section is about 3 times higher higher than QCD simulations predict. 3.44 sigma deviation is in question meaning that its probability is same as for the normalized random variable x/σ to be larger than 3.44 for Gaussian distribution $exp(-(x/\sigma)^2/2)/(2\pi\sigma^2)^{1/2}$. Recall that 5 sigma is regarded as so improbable fluctuation that one speaks about discovery. If top pairs are produced by some new particle, this deviation should be seen also when second top decays leptonically meaning a large missing energy of neutrino. There is however a slight deficit rather than excess of these events.

One can consider three interpretations.

(a) The effect is a statistical fluke. But why just at the top quark mass?

(b) The hadronic signal is real but there is a downwards fluctuation reducing the number of leptonic events slightly from the expected one. In the leptonic sector the measurement resolution is poorer so that this interpretation looks reasonable. In this case the decay of some exotic boson to top quark pair could explain the signal. Below this option will be considered in more detail in TGD framework and the nice thing is that it can be connected to the anomalously high forward backward asymmetry in top quark pair production reported by CDF for few weeks ago [C55] .

(c) Both effects are real and the signal is due to R-parity violating 3-particle decays of gluinos with mass near to top quark mass. This is the explanation proposed in the paper of Perez and collabators.

Too high forward backward asymmetry in the production rate for top quark pairs

There is also a second anomaly involved with top pair production. Jester reports new data [C125] about the strange top-pair forward-backward asymmetry in top pair production in p-pbar collisions already mentioned [C55]. In Europhysics 2011 conference D0 collaboration reported the same result. CMS collaboration found however no evidence for the asymmetry in p-p collisions at LHC [C62]. For top pairs with invariant mass above 450 GeV the asymmetry is claimed by CDF to be stunningly large 48+/-11 per cent. 3 times more often top quarks produced in qqbar annihilation prefer to move in the direction of quark. Note that this experiment would have reduced the situation from the level of ppbar collisions to the level of quark-antiquark collisions and the negative result suggests that valence quarks might play an essential role in the anomaly.

The TGD based explanation for the finding would relation on the flavor octet of gluons and the new view about Feynman diagrams.

(a) The identification of family replication phenomenon in terms of genus of the wormhole throats (see this) predicts that family replication corresponds to a dynamical SU(3) symmetry (having nothing to do with color SU(3)or Gell-Mann's SU(3)) with gauge bosons belonging to the octet and singlet representations. Ordinary gauge bosons would correspond besides the familar singlet representation also to exotic octet representation for which the exchanges induce neutral flavor changing currents in the case of gluons and neutral weak bosons and charge changing ones in the case of charged gauge bosons. The exchanges of the octet representation for gluons could explain both the anomalously high production rate of top quark pairs and the anomalously large forward backward asymmetry! Also electroweak octet could of course contribute.

(b) This argument requires a more detailed explanation for what happens in the exchange of gauge boson changing the genus. Particles correspond to wormhole contacts. For topologically condensed fermions the genus of the second throat is that of sphere created when the fermionic CP_2 vacuum extremal touches background space sheet. For bosons both wormhole throats are dynamical and the topologies of both throats matter. The exchange diagram corresponds to a situation in which $g = g_i$ fermionic wormhole throat from past turns back in time spending some time as second throat of virtual boson wormhole contact and $g = g_f$ from future turns back in time and defines the second throat of virtual boson wormhole contact. The turning corresponds to gauge boson exchange represented by a wormhole contact with $g = g_i$ and $g = g_f$ wormhole throats. Ordinary gauge bosons are quantum superpositions of (g, g) pairs transforming as SU(3) singlets and SU(3) charged octet bosons are of pairs (g_1, g_2) with $g_1 \neq g_2$. In the absence of topological mixing of fermions inducing CKM mixing the exchange is possible only between fermions of same generation. The mixing is however large and changes the situation.

(c) One could say that top quark from the geometric future transforms at exchange line to space-like t-quark (genus $g = 2$) and returns to future. The quark from the geometric past does the same and returns back to the past as antiquark of antiproton. In the exchange line this quark combines with t-quark to form a virtual color octet gluon.

This mechanism could also give additional contributions to the mechanism generating CP breaking since new box diagrams involving two exchanges of flavor octet weak boson contribute to the mixings of quark pairs in mesons. The exchanges giving rise to an intermediate state of two top quarks are expected to give the largest contribution to the mixing of the neutral quark pairs making up the meson. This involves exchange of a member W boson flavor octet boson analogous to the usual exchange of the flavor singlet boson. This might relate to the reported anomalous like sign muon asymmetry in BBbar decay [C70] suggesting that the CP breaking in this system is roughly 50 times larger than predicted by CKM matrix. The new diagrams would only amplify the CP breaking associated with CKM matrix rather than bringing in any new source of CP breaking. This mechanism increases also the CP breaking in KKbar system known to be also anomalously high.

9.2.3 The physics of $M-\overline{M}$ systems forces the identification of vertices as branchings of partonic 2-surfaces

For option 2) gluons are superpositions of $g=0,1,2$ states with identical probabilities and vertices correspond to branchings of partonic 2-surfaces. Exotic gluons do not induce mixing of quark families and genus changing transitions correspond to light like 3-surfaces connecting partonic 2-surfaces with different genera. CKM mixing is induced by this topological mixing. The basic testable predictions relate to the physics of $M\overline{M}$ systems and are due to the contribution of exotic gluons and large direct CP breaking effects in $K-\overline{K}$ favor this option.

For option 1) vertices correspond to fusions rather than branchings of the partonic 2-surfaces. The prediction that quarks can exchange handle number by exchanging $g>0$ gluons (to be denoted by G_g in the sequel) could be in conflict with the experimental facts.

1. CP breaking in $K-\bar{K}$ as a basic test

CP breaking physics in kaon-antikaon and other neutral pseudo-scalar meson systems is very sensitive to the new physics. What makes the situation especially interesting, is the recently reported high precision value for the parameter ϵ'/ϵ describing direct CP breaking in kaon-antikaon system [C93] . The value is almost by an order of magnitude larger than the standard model expectation. $K-\bar{K}$ mass difference predicted by perturbative standard model is 30 per cent smaller than the the experimental value and one cannot exclude the possibility that new physics instead of/besides non-perturbative QCD might be involved.

In standard model the low energy effective action is determined by box and penguin diagrams. $\Delta S=2$ piece of the effective weak Lagrangian, which describes processes like $s\bar{d}\rightarrow d\bar{s}$, determines the value of the $K-\bar{K}$ mass difference Δm_K and since this piece determines $K\rightarrow\bar{K}$ amplitude it also contributes to the parameter ϵ characterizing indirect CP breaking. $\Delta S=2$ part of the weak effective action corresponds to box diagrams involving two W boson exchanges.

2. Δm_K kills option a

For option 1) box diagrams involving Z and $g>0$ exchanges are allowed provided exchanges correspond to exchange of both Z and $g>0$ gluon. The most obvious objection is that the exchanges of $g>0$ gluons make strong $\Delta S>0$ decays of mesons possible: $K_S\rightarrow\pi\pi$ is a good example of this kind of decay. The enhancement of the decay rate would be of order $(\alpha_s(g=1)/\alpha_{em})^2(m_W/m_G(g=1)^2\sim 10^3$. Also other $\Delta S=1$ decay rates would be enhanced by this factor. The real killer prediction is a gigantic value of Δm_K for kaon-antikaon system resulting from the possibility of $\overline{s}d\rightarrow\overline{d}s$ decay by single $g=1$ gluon exchange. This prediction alone excludes option 1).

3. Option 2) could explain direct CP breaking

For option 2) box diagrams are not affected in the lowest order by exotic gluons. The standard model contributions to Δm_K and indirect CP breaking are correct for the observed value of the top quark mass which results if top corresponds to a secondary padic length scale $L(2,k)$ associated with $k=47$ (Appendix). Higher order gluonic contribution could increase the value of Δm_K predicted to be about 30 per cent too small by the standard model.

In standard model penguin diagrams contribute to $\Delta S=1$ piece of the weak Lagrangian, which determines the direct CP breaking characterized by the parameter ϵ'/ϵ. Penguin diagrams, which describe processes like $s\bar{d}\rightarrow d\bar{d}$, are characterized by effective vertices dsB, where B denotes photon, gluon or Z boson. dsB vertices give the dominant contribution to direct CP breaking in standard model. The new penguin diagrams are obtained from ordinary penguin diagrams by replacing ordinary gluons with exotic gluons.

For option 2) the contributions predicted by the standard model are multiplied by a factor 3 in the approximation that exotic gluon mass is negligible in the mass scale of intermediate gauge boson. These diagrams affect the value of the parameter ϵ'/ϵ characterizing direct CP

breaking in $K - \bar{K}$ system found experimentally to be almost order of magnitude larger than standard model expectation [C93] .

9.3 Dark matter in TGD Universe

TGD based explanation of dark matter means one of the strongest departures of TGD from the more standard approaches. In standard approaches dark matter corresponds to some very weakly interaction exotic particles contributing to the mass density of the Universe a fraction considerably larger than the contributions of "visible" matter. In TGD Universe dark matter corresponds to phases with non-standard value of Planck constant and also ordinary particles could be in dark phase.

9.3.1 Dark matter and energy in TGD Universe

In TGD framework the identification of dark matter comes from arguments which could start from the strange finding that ELF em fields in frequency range of EEG have quantal effects on vertebrate brain [K19]. This is impossible in standard physics since the energies of photons many orders of magnitude below the thermal energy.

The proposal is that Planck constant is dynamical having a discrete integer valued spectrum so that for a given frequency the energy of photon can be above thermal energy for sufficiently large value of Planck constant. Large values of Planck constant make possible macroscopic quantum coherence so that the hypothesis would explain how living matter manages to be quantum system in macroscopic scales. Particles characterized by different values of Planck constant cannot appear in same interaction vertices so that in this sense particles with different values of Planck constant are dark relative to each other. This however allows interactions by particle exchange involving phase transition changing the value of Planck constant and also the interaction via classical fields.

The observation of Nottale [E4] that planetary orbits could be understood as Bohr orbits with a gigantic value of gravitational Planck constant leads also to the same idea [K59, K48]. The expression $\hbar_{gr} = GMm/v_0$, where v_0 has dimensions of velocity, forces to identify the Planck constant as a characterizer of the space-time sheets mediating the gravitational interaction between Sun and planet. Quite generally, there is a strong temptation to assign dark matter with the field bodies (or magnetic bodies) of physical systems and this assumption is made in the model of living matter based on the notion of the magnetic body.

One must be cautious with the identification of galactic dark matter in terms of phases with large value of Planck constant. One explanation for the galactic dark matter would be in terms of string like objects containing galaxies like pearls in the necklace [K17]. The Newtonian gravitational potential of the long galactic string would give rise to constant velocity spectrum. It could of course be that dark matter in TGD sense resides as particles at the long strings which could also carry antimatter. At least part of dark matter could be in this form. One must also bear in mind that $\hbar_{grav}$ has gigantic values and could have different origin as large $\hbar$ assignable to living matter: this is discussed in [K59].

What can one the concldue about dark energy in this framework?

(a) Dark energy might allow interpretation as dark matter at the space-time sheets mediating gravitational interaction and macroscopically quantum coherent in cosmological scales. The enormous Compton wave lengths would imply that the density of dark energy would be constant as required by the interpretation in terms of cosmological constant.

(b) This is however not the only possible interpretation. The magnetic tension of the magnetic flux tubes gives rise to the negative "pressure" inducing the accelerated expansion of the Universe serving as the basic motivation for the dark energy [K60].

(c) The Robertson-Walker cosmologies with critical or over-critical mass density imbeddable to the imbedding space are characterized by their necessarily finite duration and possess a negative pressure. The interpretation as a constraint force due to the imbeddability to $M^2 \times CP_2$ might explain dark energy [K60].

(d) The GRT limit of TGD based on Einstein-Maxwell system with cosmological constant assigned with Eudlidian regions of space-time allowing to get CP_2 as a special solution of field equation suggests that cosmological constant equals to the cosmological constant of CP_2 multiplied by the fraction of 3-volume with Euclidian signature of metric [K71] and representing generalized Feynman graphs [K27].

Whether these explanations represent different manners to say one and the same thing is not clear.

One could add the hierarchy of Planck constants as a separate postulate to TGD but it has turned out that the vacuum degeneracy characterizing TGD could imply this hierarchy as an effective hierarchy so that at the fundamental level one would have just the standard value of Planck constant [K22]. For both options the geometric realization for the hierarchy of Planck constants comes in terms of local covering spaces of imbedding space inducing covering space structure for the space-time surfaces.

(a) If the hierarchy is postulated rather than derived, the coverings in questions would be those of the causal diamond $CD \times CP_2$ such that the number of sheets of the covering equals to the value of Planck constant. The coverings of both CD and CP_2 are possible so that Planck constant is product of integers.

(b) The hierarchy of local coverings would follow from the fact that time derivatives of imbedding space coordinates are in general many-valued functions of canonical momentum densities by the vacuum degeneracy of Kähler action. In this case the covering would be covering of H assignable to a regions of space-time sheet. Note that, for the vacuum extremals for which induced Kähler gauge field is pure gauge and CP_2 projection any 2-D Lagrangian of CP_2, an infinite number of branches of the covering co-incide. The situation can be characterized in terms of a generalization of catastrophe theory [A42] to infinite-D context.

(c) Constant torque as a dynamical mechanism necessitating the covering is discussed in [K32].,

An open question is whether dark matter phases can/must correspond to same p-adic length scale and therefore same mass. Dark matter would correspond to particles with non-standard values of Planck constant and also ordinary particles with standard values of masses could appear in dark phase and is assumed in TGD inspired quantum biology. Even quarks with Compton lengths scaled up to cell length scale appear in the model of DNA as topological quantum computer [K21]. The model of lepto-pions [K70] in terms of colored excitations of leptons would suggests that colored excitations of leptons have same mass as leptons or possibibly p-adically scaled octave of it in the case of colored ta lepton. The colored excitation of lepton with ordinary value of Planck constant must have mass larger than one half of intermediate gauge boson mass scale. Same applies to possible colored excitations of quarks.

This picture modifies profoundly the ideas about how to detect dark matter.

(a) For instance, it might be possible to photograph dark matter and it might be that Peter Gariaev and his group have actually achieved this. What they observe are strange flux tube like structures associated with DNA sample [I3]: a TGD based model for the findings is developed in [K1]. If dark matter is what TGD claims it to be, the experimental methods used to detect dark matter might be on wrong track.

(b) One should try to find a situation in which the particles must be created in dark phase and in this respect colored excitations of leptons are a good candidate since the decay widths of intermediate gauge boson do not allow new light fermions so that if these excitations exist they must have non-standard value of Planck constant.

(c) The recent results of DAMA and Cogent suggesting the existence of dark matter particles with mass around 7 GeV are in conflict with the findings of CDMS and Xenon100 experiments. It is encouraging that this conflict could be explained by using the fact that the detection criteria in these experiments are different and by assuming that the dark matter particles involved are tau-pions formed as bound states of colored excitations of tau-leptons.

9.3.2 Shy positrons

The latest weird looking effect in atomic physics is the observation that positrium atoms consisting of positron and electron scatter particles almost as if they were lonely electrons [C150, C118] . The effect has been christened cloaking effect for positron.

The following arguments represent the first attempts to understand the cloaking of positron in terms of these notions.

(a) Let us start with the erratic argument since it comes first in mind. If positron and electron correspond to different space-time sheets and if the scattered particles are at the space-time sheet of electron then they do not see positron's Coulombic field at all. The objection is obvious. If positron interacts with the electron with its full electromagnetic charge to form a bound state, the corresponding electric flux at electron's space-time sheet is expected to combine with the electric flux of electron so that positronium would look like neutral particle after all. Does the electric flux of positron return back to the space-time sheet of positronium at some distance larger than the radius of atom? Why should it do this? No obvious answer.

(b) Assume that positron dark but still interacts classically with electron via Coulomb potential. In TGD Universe darkness means that positron has large $\hbar$ and Compton size much larger than positronic wormhole throat (actually wormhole contact but this is a minor complication) would have more or less constant wave function in the volume of this larger space-time sheet characterized by zoomed up Compton length of electron. The scattering particle would see point-like electron plus background charge diffused in a much larger volume. If the value of $\hbar$ is large enough, the effect of this constant charge density to the scattering is small and only electron would be seen.

(c) As a matter fact, I have proposed this kind of mechanism to explain how the Coulomb wall, which is the basic argument against cold fusion could be overcome by the incoming deuteron nucleus [L3] , [L3] . Some fraction of deuteron nuclei in the palladium target would be dark and have large size just as positron in the above example. It is also possible that only the protons of these nuclei are dark. I have also proposed that dark protons explain the effective chemical formula $H_{1.5}O$ of water in scattering by neutrons and electrons in atto-second time scale [L3] , [L3] . The connection with cloaked positrons is highly suggestive.

(d) Also one of TGD inspired proposals for the absence of antimatter is that antiparticles reside at different space-time sheets as dark matter and are apparently absent [K60]. Cloaking positrons (shy as also their discoverer Dirac!) might provide an experimental supports for these ideas.

The recent view about the detailed structure of elementary particles forces to consider the above proposal in more detail.

(a) According to this view all particles are weak string like objects having wormhole contacts at its ends and magnetically charged wormhole throats (four altogether) at the ends of the string like objects with length given by the weak length cale connected by a magnetic flux tube at both space-time sheets. Topological condensation means that these structures in turn are glued to larger space-time sheets and this generates one or more wormhole contacts for which also particle interpretation is highly suggestive and could serve as space-time correlate for interactions described in terms of particle exchanges. As far electrodynamics is considered, the second ends of weak strings containing neutrino pairs are effectively non-existing. In the case of fermions also only the second wormhole throat carrying the fermion number is effectively present so that for practical purposes weak string is only responsible for the massivation of the fermions. In the case of photons both wormhole throats carry fermion number.

(b) An interesting question is whether the formation of bound states of two charged particles at the same space-time sheet could involve magnetic flux tubes connecting magnetically charged wormhole throats associated with the two particles. If so, Kähler magnetic monopoles would be part of even atomic and molecular physics. I have proposed already earlier that gravitational interaction in astrophysical scales involves magnetic flux tubes. These flux tubes would have o interpretation as analogs of say photons responsible for bound state energy. In principle it is indeed possible that the energies of the two wormhole throats are of opposite sign for topological sum contact so that the net energy of the wormhole contact pair responsible for the interaction could be negative.

(c) Also the interaction of positron and electron would be based on topological condensation at the same space-time sheet and the formation of wormhole contacts mediating the interaction. Also now bound states could be glued together by magnetically charged wormhole contacts. In the case of dark positron, the details of the interaction are rather intricate since dark positron would correspond to a multi-sheeted structure analogous to Riemann surface with different sheets identified in terms of the roots of the equation relating generalized velocities defined by the time derivatives of the imbedding space coordinates to corresponding canonical momentum densities.

9.3.3 Dark matter puzzle

Sean Carroll has explained in Cosmic Variance (`http://blogs.discovermagazine.com/cosmicvariance/`) the latest rather puzzling situation in dark matter searches. Some experiments support the existence of dark matter particles with mass of about 7 GeV, some experiments exclude them. The following arguments show that TGD based explanation might allow to understand the discrepancy.

How to detect dark matter and what's the problem?

Consider first the general idea behind the attempts to detect dark matter particles and how one ends up with the puzzling situation.

(a) Galactic nucleus serves as a source of dark matter particles and these one should be able to detect. There is an intense cosmic ray flux of ordinary particles from galactic center which must be eliminated so that only dark matter particles interacting very weakly with matter remain in the flux. The elimination is achieved by going sufficiently deep underground so that ordinary cosmic rays are shielded but extremely weakly interacting dark matter particles remain in the flux. After this one can in the ideal situation record only the events in which dark matter particles scatter from nuclei provided one eliminates events such as neutrino scattering.

(b) DAMA experiment does not detect dark matter events as such but annual variations in the rate of events which can include besides dark matter events and other kind of events. DAMA finds an annual variation interpreted as dark matter signal since other sources of events are not expected to have this kind of variation [C74]. Also CoGENT has reported the annual variation with 2.8 sigma confidence level [C130]. The mass of the dark matter particle should be around 7 GeV rather than hundreds of GeVs as required by many models. An unidentified noise with annual variation having nothing to do with dark matter could of course be present and this is the weakness of this approach.

(c) For a few weeks ago we learned that XENON100 experiment detects no dark matter [C83] (`http://blogs.discovermagazine.com/cosmicvariance/2011/04/14/no-dark-matter-seen-`

Also CDMS has reported a negative result [C60]. According to Sean Carroll, the detection strategy used by XENON100 is different from that of DAMA: individual dark matter scatterings on nuclei are detected. This is a very significant difference which might explain the discrepancy since the theory laden prejudices about what dark matter particle scattering can look like, could eliminate the particles causing the annual variations. For instance, these prejudices are quite different for the habitants of the main stream Universe and TGD Universe.

TGD based explanation of the DAMA events and related anomalies

I have commented earlier the possible interpretation of DAMA events in terms of tau-pions (`http://matpitka.blogspot.com/2010/10/tau-pions-again-but-now-in-galactic.html`). The spirit is highly speculative.

(a) Tau-pions would be identifiable as the particles claimed by Fermi Gamma Ray telescope with mass around 7 GeV and decaying into tau pairs so that one could cope with several independent observations instead of only single one.

(b) Recall that the CDF anomaly gave for two and half years ago support for tau-pions whereas earlier anomalies dating back to seventies give support for electro-pions and mu-pions. The existence of these particles is purely TGD based phenomenon and due to the different view about the origin of color quantum numbers. In TGD colored states would be partial waves in CP_2 and spin like quantum numbers in standard theories so that leptons would not have colored excitations.

(c) Tau-pions are of course highly unstable and would not come from the galactic center. Instead, they would be created in cosmic ray events at the surface of Earth and if they can penetrate the shielding eliminating ordinary cosmic rays they could produce events responsible for the annual variation caused by that for the cosmic ray flux from galactic center.

Can one regard tau-pion as dark matter in some sense? Or must one do so? The answer is affirmative to both questions on both theoretical and experimental grounds.

(a) The existence of colored variants of leptons is excluded in standard physics by intermediate gauge boson decay widths. They could however appear as states with non-standard value of Planck constant and therefore not appearing in same vertices with ordinary gauge bosons so that they would not contribute to the decay widths of weak bosons. In this minimal sense they would be dark and this is what is required in order to understand what we know about dark matter.

    Of course, all particles can in principle appear in states with non-standard value of Planck constant so that tau-pion would be one special instance of dark matter. For instance, in living matter the role of dark variants of electrons and possibly also other stable particles would be decisive. To put it bluntly: in mainstream approach dark matter is identified as some exotic particle with ad hoc properties whereas in TGD framework dark matter is outcome of a generalization of quantum theory itself.

(b) DAMA experiment requires that the tau-pions behave like dark matter: otherwise they would never reach the strongly shielded detector. The interaction with the nuclei of detector would be preceded by a transformation to a particle-tau-pion or something else- with ordinary value of Planck constant.

TGD based explanation for the dark matter puzzle

The criteria used in experiments to eliminate events which definitely are not dark matter events - according to the prevailing wisdom of course - dictates to high degree what interactions of tau pions with solid matter detector are used as a signature of dark matter event. It could well be that the criteria used in XENON100 do not allow the scatterings of tau-pions with nuclei. This is indeed the case. The clue comes from the comments of Jester in Resonaances. From a comment of Jester one learns that CoGENT - and also DAMA utilizing the same detections strategy - "does not cut on ionization fraction". Therefore, if dark matter mimics electron recoils (as Jester says) or if dark matter produced in the collisions of cosmic rays with the nuclei of the atmosphere decays to charged particles one can understand the discrepancy.

The TGD based model [K70] explaining the more than two years old CDF anomaly [C54, C114] indeed explains also the discrepancy between XENON100 and CDMS on one hand and DAMA and CoGENT on the other hand. The TGD based model for the CDF anomaly can be found in [K70].

(a) To explain the observations of CDF [C54, C114] one had to assume that tau-pions and therefore also color excited tau-leptons inside them appear as several p-adically scaled up variants so that one would have several octaves of the ground state of tau-pion with masses in good approximation equal to 3.6 GeV (two times the tau-lepton mass), 7.2 GeV, 14.4 GeV. The 14.4 GeV tau-pion was assumed to decay in a cascade like manner via lepto-strong interactions to lighter tau-pions- both charged and neutral- which eventually decayed to ordinary charged leptons and neutrinos.

(b) Also other decay modes -say the decay of neutral tau-pions to gamma pair and to a pair of ordinary leptons- are possible but the corresponding rates are much slower than the decay rates for cascade like decay via multi-tau-pion states proceeding via lepto-strong interactions.

(c) Just this cascade would take place also now after the collision of the incoming cosmic ray with the nucleus of atmosphere. The mechanism producing the neutral tau-pions - perhaps a coherent state of them- would degenerate in the collision of charged cosmic ray with nucleus generating strong non-orthogonal electric and magnetic fields and the production amplitude would be essentially the Fourier transform of the "instanton density" $E \cdot B$. The decays of 14 GeV neutral tau-pions would produce 7 GeV charged tau-pions, which would scatter from the protons of nuclei and generate the events excluded by XENON100 but not by DAMA and Cogent.

(d) In principle the model predicts to a high degree quantitatively the rate of the events. The scattering rates are proportional to an unknown parameter characterizing the transformation probability of tau-pion to a particle with ordinary value of Planck constant and this allows to perform some parameter tuning. This parameter would correspond to a mass insertion in the tau-pion line changing the value of Planck constant and have dimensions of mass squared.

The overall conclusion is that the discrepany between DAMA and XENON100 might be interpreted as favoring TGD view about dark matter and it is fascinating to see how the situation develops. This confusion is not the only confusion in recent day particle physics. All believed-to-be almost-certainties are challenged.

Has Fermi observed dark matter?

Resonaances (`http://resonaances.blogspot.com/2012/04/dark-matter-signal-in-fermi.html`) reports about a possible dark matter signal at Fermi satellite [C180]. Also Lubos (`http://motls.blogspot.com/2012/04/fermi-fifty-dark-matter-photons-at-130.html`) has a posting about the finding and mentions that the statistical significance is 3.3 sigma.

The proposed dark matter interpretation for the signal would be pair of monochromatic photons with second one detected at Earth. The interpretation would be that dark matter particles with mass m nearly at rest in galactic center annihilate to a pair of photons so that one obtains a pair of photons with energy equal to the cm energy which is in a good approximation the sum $E = 2 \times m$ for the masses of the particles. The mass value would be around m=130 GeV if the final state involves only 2 photons.

In TGD framework I would consider as a first guess a pion like state decaying to two photons with standard coupling given by the coupling to the "instanton density" $E \cdot B$ of electromagnetic field. The mass of this particle would be 260 GeV, in reasonable approximation 2 times the mass m=125 GeV of the Higgs candidate.

(a) Similar coupling was assumed to [K70]. The anomaly would have been produced by tau-pions, which are pionlike states formed by pairs of colored excitations of tau and its antiparticle (or possibly their super-partners). What was remarkable that the mass had three values coming as powers of two: $M = 2^k \times 2m(\tau;)$, $k = 0, 1, 2$. The interpretation in terms of p-adic length scale hypothesis would be obvious: also the octaves of the basic state are there. The constraint from intermediate gauge boson decay widths requires that these states are dark in TGD sense and therefore correspond to a non-standard value of Planck constant coming as an integer multiple of the standard value.

(b) Also the explanation of the findings of Pamela discussed in this chapter require octaves of tau-pion produced in Earth's atmosphere.

(c) Even ordinary pion should have 2-adic octaves. But doesn't this kill the hypothesis? We "know" that pion does not have any octaves! Maybe not, there is recent evidence for satellites of ordinary pion with energy scale of 40 MeV interpreted in terms of IR Regge trajectories assignable to the color magnetic flux tubes assignable to pion. There has been several wrong alarms about Higgs: at 115 GeV and 155 GeV at least. Could it be that there there is something real behind these wrong alarms: the scale for IR Regge trajectories would be about 20 GeV now!

So: could the dark matter candidates with mass around 260 GeV correspond to the first octave of M_{89} pion with mass around 125 GeV, the particle that colleagues want to call Higgs boson although its decay signatures suggest something different?

(a) In this case it does not seem necessary to assume that the Planck constant has non-standard value although this is possible.

(b) This particle should be produced in M_{89} strong interactions in the galactic center. This would require the presence of matter consisting of M_{89} nucleons emitting these pions in strong interactions. Galactic center (`http://en.wikipedia.org/wiki/Galactic_center`) is very exotic place and believed to contain even super-massive black hole. Could this environment accommodate also a scaled up copy of hadron physics? Presumably this would require very high temperatures with thermal energy of order .5 TeV correspond to the mass of M_{89} proton to make possible the presence of M_{89} matter. Or could M_{89} pion be produced in ultrastrong non-orthogonal electric and magnetic fields in the galactic center by the coupling to the instanton density. The needed field strengths would be extremely high. I have indeed proposed long time ago an explanation of very high energy cosmic rays in terms of the decay products of scaled up hadron physics (see "Cosmic Rays and Mersenne primes" in this chapter).

One can of course imagine that the photon pair is produced in the annilation of M_{89} pions with opposite charges via standard electromagnetic coupling. Also the annihilation of M_{89} spions consisting of squark pair can be considered in TGD framework where squarks could have same mass scale as quarks. In this case mass would be near 125 GeV identified as mass of neutral M_{89} pion. By scaling up the mass difference 139.570-134.976 MeV of the ordinary charged and neutral pion by the ratio of the pion M_{89} and M_{107} pion masses equal to $(125/140) \times 10^3$ one obtains that the charged M_{89} pion should have mass equal to 129.6 MeV to be compared with the 130 GeV mass suggested by experimental evidence.

The story did not end here as so often when observations cannot be replicated. The Estonian researchers Elmo Tempel, Andi Hektora and Martti Raidala have found a confirmation for the 130 GeV Fermi excess in gamma radiation from galactic center discovered by Cristoph Weniger [E1]. An important conclusion of these researchers is that best fit is obtained if the dark matter candidates decay by two-body annihilation to photons and have mass 145 GeV. The reason for why the gamma peak is at 130 GeV rather than 145 GeV would be due to the emission light particle pairs by the photons. There are also indications for a peak at 111 GeV: this could be assigned to γZ finals state of two-body decay.

In TGD framework the annihilating particles with mass about 145 GeV mass could be charged pion-like states of M_{89} hadron physics. They could be dark in the sense of having large value of Planck constant but it is not clear whether this is necessarily so. The TGD based on view about galactic dark matter locates in cosmic string like objects containing galaxies as pearls in necklace and no halo is needed to explain galactic rotation spectrum [K17]. An ultrahigh temperature would be needed to excite M_{89} hadron physics and if there is giant blackhole in galactic nucleus, there are hopes about this. M_{89} hadron physics could also produce ultrahigh energy cosmic rays as described in this chapter.

It is amusing that also CDF found for a couple of years ago evidence for a bump at the same 145 GeV energy (this has been forgotten long time ago by bloggers in 125 GeV Higgs hysteria). Estonians propose that also a particle with 290 GeV (mass would twice that of 145 GeV state) is needed. This brings further support for the idea about mass octaves of ground state of pionlike states needed to explain various anomalies (see this chapter and [K70]).

If one takes seriously the evidence for 125 GeV state and its identification as Eucdlian pion together with the evidence for galactic pionlike state with mass of 145 GeV identified as M_{89}, one has a nice support for the overall TGD based view about situation described in this chapter. The small splitting between pionlike states has possible counterpart in the ordinary hadron physics: there is evidence for satellites of pion, mesons, and baryons in 20-40 MeV scale for mass splittings and in TGD framework they would correspond to IR Regge trajectories with the scale of 10-20 GeV mass splittings (see this chapter).

We are living exciting times!

9.3.4 AMS results about dark matter

The results of AMS-02 experiment are published. There is an article [C46] at , live blog at `http://www.quantumdiaries.org/2013/04/03/april-2013-ams-liveblog/` from CERN, and article of Economist at `http://www.economist.com/news/science-and-technology/21575729-hunt-missing-85-matter-universe-closing-its?utm_source=twitterfeed&utm_medium=twitte`. There is also press release from CERN at `http://press.web.cern.ch/press-releases/2013/04/ams-experiment-measures-antimatter-excess-space`. Also Lubos has written a summary from the point of view of SUSY fan who wants to see the findings as support for the discovery of SUSY neutralino, see `http://motls.blogspot.fi/2013/04/ams-02-dark-matter-announcements.html`. More balanced and somewhat skeptic representations paying attention to the hype-like features of the announcement come from Jester at `http://resonaances.blogspot.fi/2013/04/first-results-of-ams-02.html` and Matt Strassler at `http://profmattstrassler.com/2013/04/03/ams-presents-some-first-res`

The abstract of the article is here.

A precision measurement by the Alpha Magnetic Spectrometer on the International Space Station of the positron fraction in primary cosmic rays in the energy range from 0.5 to 350 GeV based on 6.8×10^6 *positron and electron events is presented. The very accurate data show that the positron fraction is steadily increasing from 10 to 250 GeV, but, from 20 to 250 GeV, the slope decreases by an order of magnitude. The positron fraction spectrum shows no fine structure, and the positron to electron ratio shows no observable anisotropy. Together, these features show the existence of new physical phenomena.*

New physics has been observed. The findings confirm the earlier findings of Fermi and Pamela also showing positron excess. The experimenters do not give data above 350 GeV but say that the flux of electrons does not change. The press release states that the data are consistent with dark matter particles annihilating to positron pairs. For instance, the flux of the particles is same everywhere, which does not favor supernovae in galactic plane as source of electron positron pairs. According to the press release, AMS should be able to tell within forthcoming months whether dark matter or something else is in question - this sounds rather hypeish statement.

About the neutralino interpretation

Lubos trusts on his mirror neurons and deduces from the body language of Samuel Ting that the flux drops abruptly above 350 GeV as neutralino interpretation predicts.

(a) The neutralino interpretation (see `http://en.wikipedia.org/wiki/Neutralino`) assumes that the positron pairs result in the decays $\chi\chi \rightarrow e^+e^-$ and predicts a sharp cutoff above mass scale of neutralino due to the reduction of the cosmic temperature below critical value determined by the mass of the neutralino.

(b) According the press release and according to the figure 5 of the article [C46] the positron fraction settles to small but constant fraction before 350 GeV. The dream of Lubos is that abrupt cutoff takes place above 350 GeV: about this region we did not learn anything yet because the measurement uncertainties are too high. From Lubos's dream I would intuit that neutralino mass should be of the order 350 GeV. The electron/positron flux is fitted as a sum of diffuse background proportional to $C_e^{\pm}E^{-\gamma_e^{\pm}}$ and a contribution resulting from decays and parametrized as $C_sE^{-\gamma_s}exp(-E/E_s)$ - same for electron and positron. The cutoff E_s of order $E_s = 700$ GeV: error bars are rather large. The factor $exp(-E/E_s)$ does not vary too much in the range 1-350 GeV so that the exponential is probably motivated by the possible interpretation as neutralino for which sharp cutoff is expected. The mass of neutralino should be of order E_s. The positron fraction represented in figure 5 of the article [C46] seems to approach constant near 350 GeV. The weight of the common source is only 1 per cent of the diffuse electron flux.

(c) Lubos Motl notices that in neutralino scenario also a new interaction mediated by a particle with mass of order 1 GeV is needed to explain the decrease of the positron fraction above 1 GeV. It would seem that Lubos is trying to force right leg to the shoe of the left leg. Maybe one could understand the low end of the spectrum solely in terms of particle or particles with mass of order 10 GeV and the upper end of the spectrum in terms of particles of M_{89} hadron physics.

(d) Jester lists several counter arguments against the interpretation of the observations in terms of dark matter. The needed annihilation cross section must be two orders of magnitude higher than required for the dark matter to be a cosmic thermal relic, this holds true also for the neutralino scenario. Second problem is that the annihilation of neutralinos to quark pairs predicts also antiproton excess, which has not been observed. One must tailor the couplings so that they favor leptons. It has been also argued that pulsars could explain the positron excess: the recent finding is that the flux is same from all directions.

What could TGD interpretation be?

What can one say about the results in TGD framework? The first idea that comes to mind is that electron-positron pairs result from single particle annihilations but it seems that this option is not realistic. Fermion-anti-fermion annihilations are more natural and brings in strong analogy with neutralinos, which would give rise to dark matter as a remnant remaining after annihilation in cold dark matter scenario. An analogous scenario is obtained in TGD Universe by replacing neutralinos with baryons of some dark and scaled up variant of ordinary hadron physics of lepto-hadron physics.

(a) The positron fraction increases from 10 to 250 GeV with its slope decreasing between 20 GeV and 250 GeV by an order of magnitude. The observations suggest to my innocent mind a scale of order 10 GeV. The TGD inspired model for already forgotten CDF anomaly [K70] suggests the existence of τ pions with masses coming as three first octaves of the basic mass which is two times the mass of τ lepton. For years ago I proposed interpretation of the Fermi and Pamela anomalies now confirmed by AMS in terms τ pions. The predicted mass of the three octaves of τ pion would be 3.6 GeV, 7.2 GeV, and 14.4 GeV. Could the octaves of τ pion could explain the increase of the production rate up to 20 GeV and its gradual drop after that?

There is a severe objection against this idea. The energy distribution of τ pions dictates the width of the energy interval in which their decays contribute to the electron spectrum and what suggests itself is that decays of τ pions yield almost monochromatic peaks rather than the observed continuum extending to high energies. Any resonance should yield similar distribution and this suggests that the electron positron pairs must be produced in the two particle annihilations of some particles.

The annihilations of colored τ leptons and their antiparticles could however contribute to the spectrum of electron-positron pairs. Also the leptonic analogs of baryons could annihilate with their antiparticles to lepton pairs. For these two options the dark particles would be fermions as also neutralino is.

(b) Could colored τ leptons and - hadrons and their muonic and electronic counterparts be really dark matter? These particles might be dark matter in TGD sense - that is particle with a non-standard value of effective Planck constant $\hbar_{eff}$ coming as integer multiple of $\hbar$. The existence of colored excitations of leptons and pion like states with mass in good approximation twice the mass of lepton leads to difficulties with the decay widths of W and Z unless the colored leptons have non-standard value of effective Planck constant and therefore lack direct couplings to W and Z. A more general hypothesis would be that the hadrons of all scaled up variant of QCD like world (lepto-hadron physics and scaled variants of hadron physics) predicted by TGD correspond to non-standard value of effective Planck constant and dark matter in TGD sense. This would mean that these new scaled up hadron physics would couple only very weakly to the standard physics.

(c) At the high energy end of the spectrum M_{89} hadron physics would be naturally involved and also now the hadrons could be dark in TGD sense. E_s might be interpreted as temperature, which is in the energy range assigned to M_{89} hadron physics and correspond to a mass of some M_{89} hadron. The annihilations nucleons and anti-nucleons of M_{89} hadron physics could contribute to the spectrum of leptons at higher energies. The direct scaling of M_{89} proton mass gives mass of order 500 GeV and this value is consistent with the limits 480 GeV and 1760 GeV for E_s.

(d) There would be also a relation to the observations of Fermi suggesting annihilation of some bosonic states to gamma pairs with gamma energy around 135 GeV could be interpreted in terms of annihilations of a M_{89} pion with mass of 270 GeV (maybe octave of lepto-pion with mass 135 Gev in turn octave of pion with mass 67.5 GeV).

How to resolve the objections against dark matter as thermal relic?

The basic objection against dark matter scenarios is that dark matter particles as thermal relics annihilate also to quark pairs so that proton excess should be also observed. TGD based vision could also circumvent this objection.

(a) Cosmic evolution would be a sequence of phase transitions between hadron physics characterized by Mersenne primes. The lowest Mersenne primes are $M_2 = 3$, $M_3 = 7$, $M_5 = 31$, $M_7 = 127$, M_{13}, M_{17}, M_{19}, M_{31}, M_{61}, M_{89}, and M_{107} assignable to the ordinary hadron physics are involved but it might be possible to have also M_{127}. There are also Gaussian Mersenne primes $M_{G,n} = (1+i)^n - 1$. Those labelled by $n = 151, 157, 163, 167$ and spanning p-adic length scales in biologically relevant length scales 10 nm,..., 2.5 μm.

(b) The key point is that at given period characterised by M_n the hadrons characterized by larger Mersenne primes would be absent. In particular, before the period of the ordinary hadrons only M_{89} hadrons were present and decayed to ordinary hadrons. Therefore no antiproton excess is expected - at least by the mechanism producing it in the standard dark matter scenarios where all dark and ordinary particles are present simultaneously.

(c) Since M_{89} hadrons are strongly interacting one can hope that the cross section is indeed high enough to produce positron excess.

(d) Second objection relates to the cross section, which must be two orders of magnitude larger than required by the cold dark matter scenarios. I am unable to say anything definite about this. The fact that both M¡sub¿89¡/sub¿ hadrons and colored leptons are strongly interacting would increase corresponding annilation cross section and lepto-hadrons could later decay to ordinary leptons.

Connection with strange cosmic ray events and strange observations at RHIC and LHC

The model allows also to understand the strange cosmic ray events (Centauros) suggesting a formation of a blob ("hot spot" of exotic matter in atmosphere and decaying to ordinary hadrons. In the center of mass system of atmospheric particle and incoming cosmic ray cm energies are indeed of order M_{89} mass scale. As suggested [K37] already earlier, these hot spots would be hot in p-adic sense and correspond to p-adic temperature assignable to M_{89}. Also the strange events observed already at RHIC in heavy ion collisions and later at LHC in proton-heavy ion collisions), and in conflict with the perturbative QCD predicting the formation of quark gluon plasma could be understood as a formation of M_{89} hot spots. The basic finding was that there were strong correlations: two particles tended to move either parallel or antiparallel, as if they had resulted in a decay of string like objects. The AdS/CFT inspired explanation was in terms of higher dimensional blackholes. TGD explanation is more prosaic: string like objects (color magnetic flux tubes) dominating the low energy limit of M_{89} hadron physics were created.

The question whether M_{89} hadrons, or their cosmic relics are dark in TGD sense remains open. In the case of colored variants of the ordinary leptons the decay widths of weak bosons force this. In the case of colored variants of the ordinary leptons the decay widths of weak bosons force this. It however seems that a coherent story about the physics in TGD Universe is developing as more data emerges. This story is bound to remain to qualitative description: quantitative approach would require a lot of collective theoretical work.

Also CDMS claims dark matter

Also CDMS (Cryogenic Dark Matter Search) reports new indications for dark matter particles: see the Nature blog article Another dark matter sign from a Minnesota mine at `http://blogs.nature.com/news/2013/04/another-dark-matter-sign-from-a-minnesota-mine.htm`. Experimenters have observed 3 events with expected background of .7 events and claim that the mass of the dark matter particle is 8.6 GeV. This mass is much lighter than what has been expected: something like 350 GeV was suggested as explanation of the AMS observations. The low mass is however consistent with the identification as first octave of tau-pion with mass about 7.2 GeV for which already forgotten CDF anomaly provided support for years ago (as explained above p-adic length scale hypothesis allows octaves of the basic mass for lepto-pion which is in good approximation 2 times the mass of the charged lepton, that is 3.6 GeV). The particle must be dark in TGD sense, in other words it must have non-standard value of effective Planck constant. Otherwise it would contribute to the decay widths of W and Z.

9.4 Scaled variants of quarks and leptons

9.4.1 Fractally scaled up versions of quarks

The strange anomalies of neutrino oscillations [C84] suggesting that neutrino mass scale depends on environment can be understood if neutrinos can suffer topological condensation in several p-adic length scales [K34] . The obvious question whether this could occur also in the case of quarks led to a very fruitful developments leading to the understanding of hadronic mass spectrum in terms of scaled up variants of quarks. Also the mass distribution of top quark candidate exhibits structure which could be interpreted in terms of heavy variants of light quarks. The ALEPH anomaly [C178], which I first erratically explained in terms of a light top quark has a nice explanation in terms of b quark condensed at $k = 97$ level and having mass $\sim$ 55 GeV. These points are discussed in detail in [K43] .

The emergence of ALEPH results [C178] meant a an important twist in the development of ideas related to the identification of top quark. In the LEP 1.5 run with $E_{cm} = 130-140\ GeV$, ALEPH found 14 e^+e^- annihilation events, which pass their 4-jet criteria whereas 7.1 events are expected from standard model physics. Pairs of dijets with vanishing mass difference are in question and dijets could result from the decay of a new particle with mass about 55 GeV.

The data do not allow to conclude whether the new particle candidate is a fermion or boson. Top quark pairs produced in e^+e^- annihilation could produce 4-jets via gluon emission but this mechanism does not lead to an enhancement of 4-jet fraction. No $b\bar{b}b\bar{b}$ jets have been observed and only one event containing b has been identified so that the interpretation in terms of top quark is not possible unless there exists some new decay channel, which dominates in decays and leads to hadronic jets not initiated by b quarks. For option 2), which seems to be the only sensible option, this kind of decay channels are absent.

Super symmetrized standard model suggests the interpretation in terms of super partners of quarks or/and gauge bosons [C128] . It seems now safe to conclude that TGD does not predict sparticles. If the exotic particles are gluons their presence does not affect Z^0 and W decay widths. If the condensation level of gluons is $k = 97$ and mixing is absent the gluon masses are given by $m_g(0) = 0$, $m_g(1) = 19.2\ GeV$ and $m_g(2) = 49.5\ GeV$ for option 1) and assuming $k = 97$ and hadronic mass renormalization. It is however very difficult to understand how a pair of $g = 2$ gluons could be created in e^+e^- annihilation. Moreover, for option 2), which seems to be the only sensible option, the gluon masses are $m_g(0) = 0$, $m_g(1) = m_g(2) = 30.6\ GeV$ for $k = 97$. In this case also other values of k are possible since strong decays of quarks are not possible.

The strong variations in the order of magnitude of mass squared differences between neutrino families [C84] can be understood if they can suffer a topological condensation in several p-adic length scales. One can ask whether also t and b quark could do the same. In absence of mixing effects the masses of $k = 97$ t and b quarks would be given by $m_t \simeq 48.7$ GeV and $m_b \simeq 52.3$ GeV taking into account the hadronic mass renormalization. Topological mixing reduces the masses somewhat. The fact that b quarks are not observed in the final state leaves only $b(97)$ as a realistic option. Since Z^0 boson mass is $\sim$ 94 GeV, $b(97)$ does not appreciably affect Z^0 boson decay width. The observed anomalies concentrate at cm energy about 105 GeV. This energy is 15 percent smaller than the total mass of top pair. The discrepancy could be understood as resulting from the binding energy of the $b(97)\bar{b}(97)$ bound states. Binding energy should be a fraction of order $\alpha_s \simeq .1$ of the total energy and about ten per cent so that consistency is achieved.

9.4.2 Could neutrinos appear in several p-adic mass scales?

There are some indications that neutrinos can appear in several mass scales from neutrino oscillations [C18]. These oscillations can be classified to vacuum oscillations and to solar neutrino oscillations believed to be due to the so called MSW effect in the dense matter of Sun. There are also indications that the mixing is different for neutrinos and antineutrinos [C85, C17].

In TGD framework p-adic length scale hypothesis might explain these findings. The basic vision is that the p-adic length scale of neutrino can vary so that the mass squared scale comes as octaves. Mixing matrices would be universal. The large discrepancy between LSND and MiniBoone results [C85] contra solar neutrino results could be understood if electron and muon neutrinos have same p-adic mass scale for solar neutrinos but for LSND and MiniBoone the mass scale of either neutrino type is scaled up. The existence of a sterile neutrino [C140] suggested as an explanation of the findings would be replaced by p-adically scaled up variant of ordinary neutrino having standard weak interactions. This scaling up can be different for neutrinos and antineutrinos as suggested by the fact that the anomaly is present only for antineutrinos.

The different values of Δm^2 for neutrinos and antineutrinos in MINOS experiment [C17] can be understood if the p-adic mass scale for neutrinos increases by one unit. The breaking of CP and CPT would be spontaneous and realized as a choice of different p-adic mass scales and could be understood in zero energy ontology. Similar mechanism would break supersymmetry and explain large differences between the mass scales of elementary fermions, which for same p-adic prime would have mass scales differing not too much.

Experimental results

There several different type of experimental approaches to study the oscillations. One can study the deficit of electron type solar electron neutrinos (Kamiokande, Super-Kamiokande); one can measure the deficit of muon to electron flux ratio measuring the rate for the transformation of ν_μ to ν_τ (super-Kamiokande); one can study directly the deficit of ν_e ($\overline{\nu}_e$) neutrinos due to transformation to ν_μ $\nu_{\overline{\mu}}$ coming from nuclear reactor with energies in the same range as for solar neutrinos (KamLAND); and one can also study neutrinos from particle accelerators in much higher energy range such as solar neutrino oscillations (K2K,LSND,Miniboone,Minos).

1. Solar neutrino experiments and atmospheric neutrino experiments

The rate of neutrino oscillations is sensitive to the mass squared differences Δm_{12}^2, Δm_{12}^2, Δm_{13}^2 and corresponding mixing angles θ_{12}, θ_{13}, θ_{23} between ν_e, ν_μ, and ν_τ (ordered in obvious manner). Solar neutrino experiments allow to determine $sin^2(2\theta_{12})$ and Δm_{12}^2. The experiments involving atmospheric neutrino oscillations allow to determine $sin^2(2\theta_{23})$ and Δm_{23}^2.

The estimates of the mixing parameters obtained from solar neutrino experiments and atmospheric neutrino experiments are $sin^2(2\theta_{13}) = 0.08$, $sin^2(2\theta_{23}) = 0.95$, and $sin^2(2\theta_{12}) = 0.86$. The mixing between ν_e and ν_τ is very small. The mixing between ν_e and ν_μ, and ν_μ and ν_τ tends is rather near to maximal. The estimates for the mass squared differences are $\Delta m_{12}^2 = 8\times 10^{-5}$ eV^2, $\Delta m_{23}^2 \simeq \Delta m_{13}^2 = 2.4\times 10^{-3}$ eV^2. The mass squared differences have obviously very different scale but this need not means that the same is true for mass squared values.

2. The results of LSND and MiniBoone

LSND experiment measuring the transformation of $\overline{\nu}_\mu$ to $\overline{\nu}_e$ gave a totally different estimate for Δm_{12}^2 than solar neutrino experiments MiniBoone [C140]. If one assumes same value of $sin^2(\theta_{12})^2 \simeq .86$ one obtains $\Delta m_{23}^2 \sim .1$ eV^2 to be compared with $\Delta m_{12}^2 = 8\times 10^{-5}$ eV^2. This result is known as LSND anomaly and led to the hypothesis that there exists a sterile neutrino having no weak interactions and mixing with the ordinary electron neutrino and inducing a rapid mixing caused by the large value of Δm^2. The purpose of MiniBoone experiment [C85] was to test LSND anomaly.

(a) It was found that the two-neutrino fit for the oscillations for $\nu_\mu \to \nu_e$ is not consistent with LSND results. There is an unexplained 3σ electron excess for $E < 475$ MeV. For $E > 475$ MeV the two-neutrino fit is not consistent with LSND fit. The estimate for Δm^2 is in the range $.1 - 1$ eV^2 and differs dramatically from the solar neutrino data.

(b) For antineutrinos there is a small 1.3σ electron excess for $E < 475$ MeV. For $E > 475$ MeV the excess is 3 per cent consistent with null. Two-neutrino oscillation fits are consistent with LSND. The best fit gives $(\Delta m_{12}^2, sin^2(2\theta_{12}) = (0.064\ eV^2, 0.96)$. The value of Δm_{12}^2 is by a factor 800 larger than that estimated from solar neutrino experiments.

All other experiments (see the table of the summary of [C140] about sterile neutrino hypothesis) are consistent with the absence of $\nu_\mu \to n_e$ and $\overline{\nu}_\mu \to \overline{\nu}_e$ mixing and only LSND and MiniBoone report an indication for a signal. If one however takes these findings seriously they suggest that neutrinos and antineutrinos behave differently in the experimental situations considered. Two-neutrino scenarios for the mixing (no sterile neutrinos) are consistent with data for either neutrinos or antineutrinos but not both [C140].

3. The results of MINOS group

The MINOS group at Fermi National Accelerator Laboratory has reported evidence that the mass squared differences between neutrinos are not same for neutrinos and antineutrinos [C17]. In this case one measures the disappearance of ν_μ and $\overline{\nu}_\mu$ neutrinos from high energy beam beam in the range .5-1 GeV and the dominating contribution comes from the transformation to τ neutrinos. Δm_{23}^2 is reported to be about 40 percent larger for antineutrinos than for neutrinos. There is 5 percent probability that the mass squared differences are same. The best fits for the basic parameters are $(\Delta m_{23}^2 = 2.35\times 10^{-3}, sin^2(2\theta_{23} = 1)$ for neutrinos with error margin for Δm^2 being about 5 per cent and $(\Delta m_{23}^2 = 3.36\times 10^{-3}, sin^2(2\theta_{23}) = .86)$ for antineutrinos with errors margin around 10 per cent. The ratio of mass squared differences is $r \equiv \Delta m^2(\overline{\nu})/\Delta m^2(\nu) = 1.42$. If one assumes $sin^2(2\theta_{23}) = 1$ in both cases the ratio comes as $r = 1.3$.

Explanation of findings in terms of p-adic length scale hypothesis

p-Adic length scale hypothesis predicts that fermions can correspond to several values of p-adic prime meaning that the mass squared comes as octaves (powers of two). The simplest model for the neutrino mixing assumes universal topological mixing matrices and therefore for CKM matrices so that the results should be understood in terms of different p-adic mass scales. Even CP breaking and CPT breaking at fundamental level is un-necessary although it would occur spontaneously in the experimental situation selecting different p-adic mass scales for neutrinos and antineutrinos. The expression for the mixing probability a function of neutrino energy in two-neutrino model for the mixing is of form

$$P(E) = sin^2(2\theta)sin^2(X) \ \ , \ \ X = k\times \Delta m^2 \times \frac{L}{E} \ \ .$$

Here k is a numerical constant, L is the length travelled, and E is neutrino energy.

1. LSND and MiniBoone results

LSND and MiniBoone results are inconsistent with solar neutrino data since the value of Δm_{12}^2 is by a factor 800 larger than that estimated from solar neutrino experiments. This could be understood if in solar neutrino experiments ν_μ and ν_w correspond to the same p-adic mass scale $k = k_0$ and have very nearly identical masses so that Δm^2 scale is much smaller than the mass squared scale. If either p-adic scale is changed from k_0 to $k_0 + k$, the mass squared difference increases dramatically. The counterpart of the sterile neutrino would be a p-adically scaled up version of the ordinary neutrino having standard electroweak interactions. The p-adic mass scale would correspond to the mass scale defined by Δm^2 in LSND and MiniBoone experiments and therefore a mass scale in the range .3-1 eV. The electron Compton scale assignable to eV mass scale could correspond to $k = 167$, which corresponds to cell length scale of 2.5 μm. $k = 167$ defines one of the Gaussian Mersennes $M_{G,k} = (1+i)^k - 1$. $L_e(k) = \sqrt{5}L(k)$, $k = 151, 157, 163, 167$, varies in the range 10 nm (cell membrane thickness) and 2.5 μm defining the size of cell nucleus. These scales could be fundamental for the understanding of living matter [K19] .

2. MINOS results

One must assume also now that the p-adic mass scales for ν_τ and $\overline{\nu}_\tau$ are near to each other in the "normal" experimental situation. Assuming that the mass squared scales of ν_μ or $\overline{\nu}_\mu$ come as 2^{-k} powers of $m_{\nu_\mu}^2 = m_{\nu_\tau}^2 + \Delta m^2$, one obtains

$$m_{\nu_\tau}^2(k_0) - m_{\overline{\nu}_\mu}^2(k_0+k) = (1-2^{-k})m^2_{nu_\tau} - 2^{-k}\Delta m_0^2 \ \ .$$

For $k=1$ this gives

$$r = \frac{\Delta m^2(k=2)}{\Delta m^2(k=1)} = \frac{\frac{3}{2}-\frac{2r}{3}}{1-r} \ , \ r = \frac{\Delta m_0^2}{m_{\nu_\tau}^2} \ . \quad (9.4.1)$$

One has $r \geq 3/2$ for $r > 0$ if one has $m_{\nu_\tau} > m_{\nu_\mu}$ for the same p-adic length scale. The experimental ratio $r \simeq 1.3$ could be understood for $r \simeq -.31$. The experimental uncertainties certainly allow the value $r = 1.5$ for $k(\overline{\nu}_\mu) = 1$ and $k(\nu_\mu) = 2$.

This result implies that the mass scale of ν_μ and ν_τ differ by a factor 1/2 in the "normal" situation so that mass squared scale of ν_τ would be of order 5×10^{-3} eV^2. The mass scales for $\overline{\nu}_\tau$ and ν_τ would about .07 eV and .05 eV. In the LSND and MiniBoone experiments the p-adic mass scale of other neutrino would be around .1-1 eV so that different p-adic mass scale large by a factor $2^{k/2}$, $2 \leq 2 \leq 7$ would be in question. The different resuts from various experiments could be perhaps understood in terms of the sensitivity of the p-adic mass scale to the experimental situation. Neutrino energy could serve as a control parameter.

CPT breaking [B3] requires the breaking of Lorentz invariance. Zero energy ontology could therefore allow a spontaneous breaking of CP and CPT. This might relate to matter antimatter asymmetry at the level of given CD.

There is some evidence that the mixing matrices for neutrinos and antineutrinos are different in the experimental situations considered [C17, C85]. This would require CPT breaking in the standard QFT framework. In TGD p-adic length scale hypothesis allowing neutrinos to reside in several p-adic mass scales. Hence one could have apparent CPT breaking if the measurement arrangements for neutrinos and antineutrinos select different p-adic length scales for them [K37] .

Is CP and T breaking possible in zero energy ontology?

The CKM matrices for quarks and possibly also leptons break CP and T. Could one understand the breaking of CP and T at fundamental level in TGD framework?

(a) In standard QFT framework Chern-Simons term breaks CP and T. Kähler action indeed reduces to Chern-Simons terms for the proposed ansatz for preferred extremals assuming that weak form of electric-magnetic duality holds true.

    In TGD framework one must however distinguish between space-time coordinates and imbedding space coordinates. CP breaking occurs at the imbedding space level but instanton term and Chern-Simons term are odd under P and T only at the space-time level and thus distinguish between different orientations of space-time surface. Only if one identifies P and T at space-time level with these transformations at imbedding space level, one has hope of interpreting CP and T breaking as spontaneous breaking of these symmetries for Kähler action and basically due to the weak form of electric-magnetic duality and vanishing of $j \cdot A$ term for the preferred extremals. This identification is possible for space-time regions allowing representation as graphs of maps $M^4 \rightarrow CP_2$.

    Chern-Simons Dirac action is assigned with the light-like parton orbits as the only non-singular action principle and the condition that the action of C-S-D operator equals to that of massless Dirac operator is posed as additional condition allowing to obtain perturbation theory and connection with twistor Grassmannian approach. It is natural to add also to the Kähler action Chern-Simons term restricted to tge partonic orbits so that the action reduces to the Chern-Simons contributions from the ends the space-time surfaces by weak form of electric magnetic duality. Chern-Simons Dirac terms could be responsible for the breaking of CP and T symmetries as they appear in CKM matrix.

(b) The GRT-QFT limit of TGD obtained by lumping together various space-time sheets to a region of Minkowski space with effective metric defined by the sum of Minkowski metric and deviations of the induced metrics of sheets from Minkowski metric. Gauge potentials for the effective space-time would idenfied as sums of gauge potentials for space-time sheets. At this limit the identification of P and T at space-time level and imbedding space level would be natural. Could the resulting effective theory in Minkowski space or GRT space-time break CP and T slightly? If so, CKM matrices for quarks and fermions would emerge as a result of representing different topologies for wormhole throats with different topologies as single point like particle with additional genus quantum number.

(c) Could the breaking of CP and T relate to the generation of the arrow of time? The arrow of time relates to the fact that state function reduction can occur at either boundary of CD [K6]. Zero energy states do not change at the boundary at which reduction occurs repeatedly but the change at the other boundary and also the wave function for the position of the second boundary of CD changes in each quantum jump so that the average temporal distance between the tips of CD increases. This gives to the arrow of psychological time, and in TGD inspired theory of consciousness "self" as a counterpart of observed can be identified as sequence of quantum jumps for which the state function reduction occurs at a fixed boundary of CD. The sequence of reductions at fixed boundary breaks T-invariance and has interpretation as irreversibility. The standard view is that the irreversibility has nothing to do with breaking of T-invariance but it might be that in elementary particle scales irreversibility might manifest as small breaking of T-invariance.

Is CPT breaking needed/possible?

Different values of Δm_{ij}^2 for neutrinos and antineutrinos would require in standard QFT framework not only the violation of CP but also CP [B3] which is the cherished symmetry of quantum field theories. CPT symmetry states that when one reverses time's arrow, reverses the signs of momenta and replaces particles with their antiparticles, the resulting Universe obeys the same laws as the original one. CPT invariance follows from Lorentz invariance, Lorentz invariance of vacuum state, and from the assumption that energy is bounded from below. On the other hand, CPT violation requires the breaking of Lorentz invariance.

In TGD framework this kind of violation does not seem to be necessary at fundamental level since p-adic scale hypothesis allowing neutrinos and also other fermions to have several mass scales coming as half-octaves of a basic mass scale for given quantum numbers. In fact, even in TGD inspired low energy hadron physics quarks appear in several mass scales. One could explain the different choice of the p-adic mass scales as being due to the experimental arrangement which selects different p-adic length scales for neutrinos and antineutrinos so that one could speak about spontaneous breaking of CP and possibly CPT. The CP breaking at the fundamental level which is however expected to be small in the case considered. The basic prediction of TGD and relates to the CP breaking of Chern-Simons action inducing CP breaking in the modified Dirac action defining the fermionic propagator [L7]. For preferred extremals Kähler action would indeed reduce to Chern-Simons terms.

In TGD one has breaking of translational invariance and the symmetry group reduces to Lorentz group leaving the tip of CD invariant. Positive and negative energy parts of zero energy states correspond to different Lorentz groups and zero energy states are superpositions of state pairs with differen values of mass squared. Is the breaking of Lorentz invariance in this sense enough for breaking of CPT is not clear.

One can indeed consider the possibility of a spontaneous breaking of CPT symmetry in TGD framework since for a given CD (causal diamond defined as the intersection of future and past directed light-cones whose size scales are assumed to come as octaves) the Lorentz invariance is broken due to the preferred time direction (rest system) defined by the time-like line connecting the tips of CD. Since the world of classical worlds is union of CDs with all boosts included the Lorentz invariance is not violated at the level of WCW. Spontaneous symmetry breaking would be analogous to that for the solutions of field equations possessing the symmetry themselves. The mechanism of breaking would be same as that for supersymmetry. For same p-adic length scale particles and their super-partners would have same masses and only the selection of the p-adic mass scale would induces the mass splitting.

9.5 Scaled variants of hadron physics and of weak bosons

9.5.1 Leptohadron physics

TGD suggest strongly ('predicts' is perhaps too strong expression) the existence of color excited leptons. The mass calculations based on p-adic thermodynamics and p-adic conformal invariance lead to a rather detailed picture about color excited leptons.

(a) The simplest color excited neutrinos and charged leptons belong to the color octets ν_8 and L_{10} and $L_{\overline{10}}$ decouplet representations respectively and lepto-hadrons are formed as the color singlet bound states of these and possible other representations. Electro-weak symmetry suggests strongly that the minimal representation content is octet and decouplets for both neutrinos and charged leptons.

(b) The basic mass scale for lepto-hadron physics is completely fixed by p-adic length scale hypothesis. The first guess is that color excited leptons have the levels $k = 127, 113, 107, ...$ ($p \simeq 2^k$, k prime or power of prime) associated with charged leptons as primary condensation levels. p-Adic length scale hypothesis allows however also the level $k = 11^2 = 121$ in case of electronic lepto-hadrons. Thus both $k = 127$ and $k = 121$ must be considered as a candidate for the level associated with the observed lepto-hadrons. If also lepto-hadrons correspond non-perturbatively to exotic Super Virasoro representations, lepto-pion mass relates to pion mass by the scaling factor $L(107)/L(k) = k^{(107-k)/2}$. For $k = 121$ one has $m_{\pi_L} \simeq 1.057$ MeV which compares favorably with the mass $m_{\pi_L} \simeq 1.062$ MeV of the lowest observed state: thus $k = 121$ is the best candidate contrary to the earlier beliefs. The mass spectrum of lepto-hadrons is expected to have same general characteristics as hadronic mass spectrum and a satisfactory description should be based on string tension concept. Regge slope is predicted to be of order $\alpha' \simeq 1.02/MeV^2$ for $k = 121$. The masses of ground state lepto-hadrons are calculable once primary condensation levels for colored leptons and the CKM matrix describing the mixing of color excited lepton families is known.

The strongest counter arguments against color excited leptons are the following ones.

(a) The decay widths of Z^0 and W boson allow only $N = 3$ light particles with neutrino quantum numbers. The introduction of new light elementary particles seems to make the decay widths of Z^0 and W intolerably large.

(b) Lepto-hadrons should have been seen in e^+e^- scattering at energies above few MeV. In particular, lepto-hadronic counterparts of hadron jets should have been observed.

A possible resolution of these problems is provided by the loss of asymptotic freedom in lepto-hadron physics. Lepto-hadron physics would effectively exist in a rather limited energy range about one MeV.

The development of the ideas about dark matter hierarchy [K26, K63, K20, K18] led however to a much more elegant solution of the problem.

(a) TGD predicts an infinite hierarchy of various kinds of dark matters which in particular means a hierarchy of color and electro-weak physics with weak mass scales labelled by appropriate p-adic primes different from M_{89}: the simplest option is that also ordinary photons and gluons are labelled by M_{89}.

(b) There are number theoretical selection rules telling which particles can interact with each other. The assignment of a collection of primes to elementary particle as characterizer of p-adic primes characterizing the particles coupling directly to it, is inspired by the notion of infinite primes [K65] , and discussed in [K26] . Only particles characterized by integers having common prime factors can interact by the exchange of elementary bosons: the p-adic length scale of boson corresponds to a common primes.

(c) Also the physics characterized by different values of $\hbar$ are dark with respect to each other as far quantum coherent gauge interactions are considered. Laser beams might well correspond to photons characterized by p-adic prime different from M_{89} and de-coherence for the beam would mean decay to ordinary photons. De-coherence interaction involves scaling down of the Compton length characterizing the size of the space-time of particle implying that particles do not anymore overlap so that macroscopic quantum coherence is lost.

(d) Those dark physics which are dark relative to each other can interact only via graviton exchange. If lepto-hadrons correspond to a physics for which weak bosons correspond to a p-adic prime different from M_{89}, intermediate gauge bosons cannot have direct decays to colored excitations of leptons irrespective of whether the QCD in question is asymptotically free or not. Neither are there direct interactions between the QED:s and QCD:s in question if M_{89} characterizes also ordinary photons and gluons. These ideas are discussed and applied in detail in [K26, K63, K20] .

Skeptic reader might stop the reading after these counter arguments unless there were definite experimental evidence supporting the lepto-hadron hypothesis.

(a) The production of anomalous e^+e^- pairs in heavy ion collisions (energies just above the Coulomb barrier) suggests the existence of pseudo-scalar particles decaying to e^+e^- pairs. A natural identification is as lepto-pions that is bound states of color octet excitations of e^+ and e^-.

(b) The second puzzle, Karmen anomaly, is quite recent [C141] . It has been found that in charge pion decay the distribution for the number of neutrinos accompanying muon in decay $\pi \rightarrow \mu + \nu_\mu$ as a function of time seems to have a small shoulder at $t_0 \sim ms$. A possible explanation is the decay of charged pion to muon plus some new weakly interacting particle with mass of order 30 MeV [C175] : the production and decay of this particle would proceed via mixing with muon neutrino. TGD suggests the identification of this state as color singlet leptobaryon of, say type $L_B = f_{abc}L_8^a L_8^b \bar{L}_8^c$, having electro-weak quantum numbers of neutrino.

(c) The third puzzle is the anomalously high decay rate of orto-positronium. [C101] . e^+e^- annihilation to virtual photon followed by the decay to real photon plus virtual lepto-pion followed by the decay of the virtual lepto-pion to real photon pair, $\pi_L\gamma\gamma$ coupling being determined by axial anomaly, provides a possible explanation of the puzzle.

(d) There exists also evidence for anomalously large production of low energy e^+e^- pairs [C120, C96, C115, C38] in hadronic collisions, which might be basically due to the production of lepto-hadrons via the decay of virtual photons to colored leptons.

In this chapter a revised form of lepto-hadron hypothesis is described.

(a) Sigma model realization of PCAC hypothesis allows to determine the decay widths of lepto-pion and lepto-sigma to photon pairs and e^+e^- pairs. Ortopositronium anomaly determines the value of $f(\pi_L)$ and therefore the value of lepto-pion-lepto-nucleon coupling and the decay rate of lepto-pion to two photons. Various decay widths are in accordance with the experimental data and corrections to electro-weak decay rates of neutron and muon are small.

(b) One can consider several alternative interpretations for the resonances.

Option 1: For the minimal color representation content, three lepto-pions are predicted corresponding to $8, 10, \overline{10}$ representations of the color group. If the lightest lepto-nucleons e_{ex} have masses only slightly larger than electron mass, the anomalous e^+e^- could be actually $e^+_{ex} + e^-_{ex}$ pairs produced in the decays of lepto-pions. One could identify 1.062, 1.63 and 1.77 MeV states as the three lepto-pions corresponding to $8, 10, \overline{10}$ representations and also understand why the latter two resonances have nearly degenerate masses. Since d and s quarks have same primary condensation level and same weak quantum numbers as colored e and μ, one might argue that also colored e and μ correspond to $k = 121$. From the mass ratio of the colored e and μ, as predicted by

TGD, the mass of the muonic lepto-pion should be about 1.8 MeV in the absence of topological mixing. This suggests that 1.83 MeV state corresponds to the lightest $g = 1$ lepto-pion.

Option 2: If one believes sigma model (in ordinary hadron physics the existence of sigma meson is not established and its width is certainly very large if it exists), then lepto-pions are accompanied by sigma scalars. If lepto-sigmas decay dominantly to e^+e^- pairs (this might be forced by kinematics) then one could adopt the previous sceneario and could identify 1.062 state as lepto-pion and 1.63, 1.77 and 1.83 MeV states as lepto-sigmas rather than lepto-pions. The fact that muonic lepto-pion should have mass about 1.8 MeV in the absence of topological mixing, suggests that the masses of lepto-sigma and lepto-pion should be rather close to each other.

Option 3: One could also interpret the resonances as string model 'satellite states' having interpretation as radial excitations of the ground state lepto-pion and lepto-sigma. This identification is not however so plausible as the genuinely TGD based identification and will not be discussed in the sequel.

(c) PCAC hypothesis and sigma model leads to a general model for lepto-hadron production in the electromagnetic fields of the colliding nuclei and production rates for lepto-pion and other lepto-hadrons are closely related to the Fourier transform of the instanton density $\bar{E}\cdot\bar{B}$ of the electromagnetic field created by nuclei. The first source of anomalous e^+e^- pairs is the production of $\sigma_L\pi_L$ pairs from vacuum followed by $\sigma_L \rightarrow e^+e^-$ decay. If $e^+_{ex}e^-_{ex}$ pairs rather than genuine e^+e^- pairs are in question, the production is production of lepto-pions from vacuum followed by lepto-pion decay to lepto-nucleon pair.

Option 1: For the production of lepto-nucleon pairs the cross section is only slightly below the experimental upper bound for the production of the anomalous e^+e^- pairs and the decay rate of lepto-pion to lepto-nucleon pair is of correct order of magnitude.

Option 2: The rough order of magnitude estimate for the production cross section of anomalous e^+e^- pairs via $\sigma_l\pi_l$ pair creation followed by $\sigma_L \rightarrow e^+e^-$ decay, is by a factor of order $1/\sum N_c^2$ (N_c is the total number of states for a given colour representation and sum over the representations contributing to the ortopositronium anomaly appears) smaller than the reported cross section in case of 1.8 MeV resonance. The discrepancy could be due to the neglect of the large radiative corrections (the coupling $g(\pi_L\pi_L\sigma_L) = g(\sigma_L\sigma_L\sigma_L)$ is very large) and also due to the uncertainties in the value of the measured cross section.

Given the unclear status of sigma in hadron physics, one has a temptation to conclude that anomalous e^+e^- pairs actually correspond to lepto-nucleon pairs.

(d) The vision about dark matter suggests that direct couplings between leptons and lepto-hadrons are absent in which case no new effects in the direct interactions of ordinary leptons are predicted. If colored leptons couple directly to ordinary leptons, several new physics effects such as resonances in photon-photon scattering at cm energy equal to lepto-pion masses and the production of $e_{ex}\bar{e}_{ex}$ (e_{ex} is leptobaryon with quantum numbers of electron) and $e_{ex}\bar{e}$ pairs in heavy ion collisions, are possible. Lepto-pion exchange would give dominating contribution to $\nu-e$ and $\bar{\nu}-e$ scattering at low energies. Lepto-hadron jets should be observed in e^+e^- annihilation at energies above few MeV:s unless the loss of asymptotic freedom restricts lepto-hadronic physics to a very narrow energy range and perhaps to entirely non-perturbative regime of lepto-hadronic QCD.

During 18 years after the first published version of the model also evidence for colored μ has emerged. Towards the end of 2008 CDF anomaly gave a strong support for the colored excitation of τ. The lifetime of the light long lived state identified as a charged τ-pion comes out correctly and the identification of the reported 3 new particles as p-adically scaled up variants of neutral τ-pion predicts their masses correctly. The observed muon jets can be understood in terms of the special reaction kinematics for the decays of neutral τ-pion to 3 τ-pions with mass scale smaller by a factor 1/2 and therefore almost at rest. A spectrum of new particles is predicted. The discussion of CDF anomaly led to a modification and generalization of the original model for lepto-pion production and the predicted production cross section is consistent with the experimental estimate.

9.5.2 First evidence for M_{89} hadron physics?

The first evidence -or should we say indication- for the existence of M_{89} hadron physics has emerged from CDF which for two and half years ago provided evidence also for the colored excitations of tau lepton and for lepto-hadron physics.

Has CDF discovered a new boson with mass around 145 GeV?

The story began when The eprint of CDF collaboration [C10] reported evidence for a new resonance like state, presumably a boson decaying to a dijet (jj) with mass around 145 GeV. The dijet is produced in association with W boson. The interpretation as Higgs is definitely excluded.

Bloggers reacted intensively to the possibility of a new particle. Tommaso Dorigo gave a nice detailed analysis about the intricacies of the analysis of the data leading to the identification of the bump. Also Lubos and Resonaances commented the new particle. Probably the existence of the bump had been known for months in physics circles. The flow of eprints to arXiv explaining the new particle begun immediately.

One should not forget that 3 sigma observation was in question and that 5 sigma is required for discovery. It is quite possible that the particle is just a statistical fluke due to an erratic estimation of the background as Tommaso Dorigo emphasizes. Despite this anyone who has a theory able to predict something is extremely keen to see whether the possibly existing new particle has a natural explanation. This also provides the opportunity for dilettantes like me to develop the theoretical framework in more detail. We also know from general consistency conditions that New Physics must emerge in TeV scale: what we do not know what this New Physics is. Therefore all indications for it must be taken seriously.

CDF bump did not disappear and the most recent analysis assigns 4.1 sigma significance to it. The mass of the bump was reported to be at 147 ± 5 GeV. Also some evidence that the entire Wjj system results in a decay of a resonance with mass slightly below 300 GeV has emerged. D0 was however not able to confirm the existence of the bump and the latest reincarnation of the bump is as 2.8 sigma evidence for Higgs candidate in the range 140-150 GeV range and one can of ask whether this is actually evidence for the familiar 145 GeV boson which cannot be Higgs. The story involves many twists and turns and teaches how cautiously theoretician should take also the claims of experimentalists. In the following I pretend that the 145 GeV bump is real but this should not confuse the reader to believe that this is really the case.

Why an exotic weak boson a la TGD cannot be in question?

For the inhabitant of the TGD Universe the most obvious identification of the new particle would be as an exotic weak boson. The TGD based explanation of family replication phenomenon predicts that gauge bosons come in singlets and octets of a dynamical SU(3) symmetry associated with three fermion generations (fermion families correspond to topologies of partonic wormhole throats characterized by the number of handles attached to sphere). Exotic Z or W boson could be in question.

If the symmetry breaking between octet and singlet is due to different value of p-adic prime alone then the mass would come as an power of half-octave of the mass of Z or W. For W boson one would obtain 160 GeV only marginally consistent with 145 GeV. Z would give 180 GeV mass which is certainly too high. The Weinberg angle could be however different for the singlet and octet so that the naive p-adic scaling need not hold true exactly.

Note that the strange forward backward asymmetry in the production of top quark pairs [C55, C125] might be understood in terms of exotic gluon octet whose existence means neutral flavor changing currents as discussed in this chapter.

The *extremely* important data bit is that the decays to two jets favor quark pairs over lepton pairs. A model assuming exotic Z -called $Z^{'}$- produced together with W and decaying preferentially to quark pairs has been proposed as an explanation [C14]. Neither ordinary nor the exotic weak gauge bosons of TGD Universe have this kind of preference to decay to quark pairs so that my first guess was wrong.

Is a scaled up copy of hadron physics in question?

The natural explanation for the preference of quark pairs over lepton pairs would be that strong interactions are somehow involved. This suggests a state analogous to a charged pion decaying to W boson two gluons annihilating to the quark pair (box diagram). This kind of proposal is indeed made in Technicolor at the Tevatron [C25]: the problem is also now why the decays to quarks are favored. Techicolor has as its rough analog second fundamental prediction of TGD that p-adically scaled up variants of hadron physics should exist and one of them is waiting to be discovered in TeV region. This prediction emerged already for about 15 years ago as I carried out p-adic mass calculations and discovered that Mersenne primes define fundamental mass scales.

Also colored excitations of leptons and therefore lepto-hadron physics are predicted [K70]. What is amusing that CDF discovered towards the end of 2008 what became known as CDF anomaly giving support for tau-pions. The evidence for electro-pions and mu-pions had emerged already earlier (for references see [K70]). All these facts have been buried underground because they simply do not fit to the standard model wisdom. TGD based view about dark matter is indeed needed to circumvent the fact that the lifetimes of weak bosons do not allow new light particles. There is also a long series of blog postings in my blog summarizing development of the TGD based model for CDF anomaly.

As should have become already clear, TGD indeed predicts p-adically scaled up copy of hadron physics in TeV region and the lightest hadron of this physics is a pion like state produced abundantly in the hadronic reactions. Ordinary hadron physics corresponds to Mersenne prime $M_{107} = 2^{107} - 1$ whereas the scaled up copy would correspond to M_{89}. The mass scale would be 512 times the mass scale 1 GeV of ordinary hadron physics so that the mass of M_{89} proton should be about 512 GeV. The mass of the M_{89} pion would be by a naive scaling 71.7 GeV and about two times smaller than the observed mass in the range 120-160 GeV and with the most probable value around 145 GeV as Lubos reports in his blog. $2 \times 71.7 GeV = 143.4$ GeV would be the guess of the believer in the p-adic scaling hypothesis and the assumption that pion mass is solely due to quarks. It is important to notice that this scaling works precisely only if CKM mixing matrix is same for the scaled up quarks and if charged pion consisting of u-d quark pair is in question. The well-known current algebra hypothesis that pion is massless in the first approximation would mean that pion mass is solely due to the quark masses whereas proton mass is dominated by other contributions if one assumes that also valence quarks are current quarks with rather small masses. The alternative which also works is that valence quarks are constituent quarks with much higher mass scale.

According to p-adic mass calculations the mass of pion is just the sum of mass squared for the quarks composing. If one assumes that u and d quarks of M_{89} hadron physics correspond to $k = 93$ (top corresponds to $k = 94$, the mass of these quarks is predicted to be 102 GeV whereas the pion mass is predicted to be 144.3 GeV (the argument will be discussed in detail later). My guess based on deep ignorance about the experimental side is that this signature should be easily testable: one should try to detect mono-chromatic gamma pairs with gamma ray energy around 72.2 GeV.

The simplest identification of the 145 GeV resonance

The picture about CDF resonance has become (see the postings Theorists vs. the CDF bump and More details about the CDF bump by Jester [C34]. One of the results is that leptophobic Z' can explain only 60 per cent of the production rate. There is also evidence that Wjj corresponds to a resonance with mass slightly below 300 GeV as naturally predicted by technicolor models [C92].

The simplest TGD based model indeed relies on the assumption that the entire Wjj corresponds to a resonance with mass slightly below 300 GeV for which there is some evidence as noticed. If one assume that only *neutral pions* are produced in strong non-orthogonal electric and magnetic fields of colliding proton and antiproton, the mother particle must be actually second octave of 147 GeV pion and have mass somewhat below 600 GeV producing in its possibly allowed strong decays pions which are almost at rest for kinematic reasons. Therefore the production mechanism could be exactly the same as proposed for two and one half year old CDF anomaly and for the explanation of DAMA events and DAMA-Xenon100 discrepancy,

(a) This suggests that the mass of the mother resonance is in a good accuracy two times the mass of 145 GeV bump for which best estimate is 147 ± 5 GeV. This brings in mind the explanation for the two and half year old CDF anomaly in which tau-pions with masses coming as octaves of basic tau-pion played a key role (masses were in good approximation $2^k \times m(\pi_\tau)$, $m(\pi_\tau) \simeq 2m_\tau$, $k = 1, 2$. The same mechanism would explain the discrepancy between the DAMA and Xenon100 experiments.

(b) If this mechanism is at work now, the mass of the lowest M_{89} pion should be around 73 GeV as the naivest scaling estimate gives. One can however consider first the option for which lightest M_{89} has mass around 147 GeV so that the 300 GeV resonance could correspond to its first p-adic octave. This pion would decay to W and neutral M_{89} pion with mass around 147 GeV in turn decaying to two jets. At quark level the simplest diagram would involve the emission of W and exchange of gluon of M_{89} hadron physics. Also the decay to Z and charged pion is possible but in this case the decay of the final state could not take place via annihilation to gluon so that jet pair need not be produced.

(c) One could also imagine the mother particle to be ρ meson of M_{89} hadron physics with mass in a good approximation equal to pion mass. At the level of mathematics this option is very similar to the technicolor model of CDF bump based also on the decay of ρ meson discussed in [C92]. In this model the decays of π to heavy quarks have been assumed to dominate. In TGD framework the situation is different. If π consists of scaled up u and d quarks, the decays mediated by boson exchanges would produce light quarks. In the annihilation to quark pair by a box diagram involving two gluons and two quarks at edges the information about the quark content of pion is lost. The decays involving emission of Z boson the resulting pion would be charged and its decays by annihilation to gluon would be forbidden so that Wjj final states would dominate over Zjj final states as observed.

(d) The strong decay of scaled up pion to charged and neutral pion are forbidden by parity conservation. The decay can however proceed by via the exchange of intermediate gauge boson as a virtual particle. The first quark would emit virtual W/Z boson and second quark the gluon of the hadron physics. Gluon would decay to a quark pair and second quark would absorb the virtual W boson so that a two-pion final state would be produced. The process would involve same vertices as the decay of ρ meson to W boson and pion. The proposed model of the two and one half year old CDF anomaly and the explanation of DAMA and Xenon100 experiments assumes cascade like decay of pion at given level of hierarchy to two pions at lower level of hierarchy and the mechanism of decay should be this.

Consider next the masses of the M_{89} mesons. Naive scaling of the mass of ordinary pion gives mass about 71 GeV for M_{89} pion. One can however argue that color magnetic spin-spin splitting need not obey scaling formula and that it becomes small because if is proportional to eB/m where B denotes typical value of color magnetic field and m quark mass scale which is now large. The mass of pion at the limit of vanishing color magnetic splitting given by m_0 could however obey the naive scaling.

(a) For (ρ, π) system the QCD estimate for the color magnetic spin-spin splitting would be

$$(m(\rho), m(\pi)) = (m_0 + 3\Delta/4, m_0 - \Delta/4) \ .$$

p-Adic mass calculations are for mass squared rather than mass and the calculations for the mass splittings of mesons [K43] force to replace this formula with

$$(m^2(\rho), m^2(\pi)) = (m_0^2 + 3\Delta^2/4, m_0^2 - \Delta^2/4) \ . \quad (9.5.1)$$

The masses of ρ and ω are very near to each other: $(m(\rho), m(\omega) = (.770, .782)$ GeV and obey the same mass formula in good approximation. The same is expected to hold true also for M_{89}.

(b) One obtains for the parameters Δ and m_0 the formulas

$$\Delta = [m^n(\rho) - m^n(\pi)]^{1/n} \ , \ m_0 = [(m^2(\rho) + 3m(\pi)^2)/4]^{1/n} \ . \quad (9.5.2)$$

Here $n = 1$ corresponds to ordinary QCD and $n = 2$ to p-adic mass calculations.

(c) Assuming that m_0 experiences an exact scaling by a factor 512, one can deduce the value of the parameter Δ from the mass 147 GeV of M_{89} pion and therefore predict the mass of ρ_{89}. The results are following

$$m_0 = 152.3 \ GeV \ , \ \Delta = 21.3 \ GeV \ , \ m(\rho_{89}) = 168.28 \ GeV \quad (9.5.3)$$

for QCD model for spin-spin splitting and

$$m_0 = 206.7 \ GeV \ , \ \Delta = 290.5 \ GeV \ , \ m(\rho_{89}) = 325.6 \ GeV \ . \quad (9.5.4)$$

for TGD model for spin-spin splitting.

(d) Rather remarkably, there are indications from D0 [C32] for charged and from CDF [C32, C33] for neutral resonances with masses around 325 GeV such that the neutral one is split by .2 GeV: the splitting could correspond to $\rho - \omega$ mass splitting. Hence one obtains support for both M_{89} hadron physics and p-adic formulas for color magnetic spin-spin splitting. Note that the result excludes also the interpretation of the nearly 300 GeV resonance as ρ_{89} in TGD framework.

(e) This scenario allows to make estimates also for the masses other resonances and naive scaling argument is expected to improve as the mass increases. For (K_{89}, K^*_{89}) system this would predict mass $m(K_{89}) > 256$ GeV and $m(K^*_{89}) < 456.7$ GeV.

The nasty question is why the octaves of pion are not realized as a resonances in ordinary hadron physics. If they were there, their decays to ordinary pion pairs by this mechanism would very slow.

(a) Could it be that also ordinary pion has these octaves but are not produced by ordinary strong interactions in nucleon collisions since the nucleons do not contain the p-adically scaled up quarks fusing to form the higher octave of the pion. Also the fusion rate for two pions to higher octave of pion would be rather small by parity breaking requiring weak interactions.

(b) The production mechanism for the octaves of ordinary pions, for M_{89} pions in the collisions of ordinary nucleons, and for lepto-hadrons would be universal, namely the collision of charged particles with cm kinetic energy above the octave of pion. The presence of strong non-orthogonal electric and magnetic fields varying considerably in the time scale defined by the Compton time of the pion is necessary since the interaction Lagrangian density is essentially the product of the abelian instanton density and pion field. In fact, in [C92] it is mentioned that 300 GeV particle candidate is indeed created at rest in Tevatron lab -in other words in the cm system of colliding proton and antiproton beams.

(c) The question is whether the production of the octaves of scaled up pions could have been missed in proton-proton and proton antiproton collisions due to the very peculiar kinematics: pions would be created almost at rest in cm system [K70]. Whether or not this is the case should be easy to test. For a theorists this kind of scenario does not look impossible but at the era of LHC it would require a diplomatic genius and authority of Witten to persuade experimentalists to check whether low energy collisions of protons produce octaves of pions!

There is also the question about the general production mechanisms for M_{89} hadrons.

(a) Besides the production of scalar mesons in strong non-orthogonal magnetic and electric fields also the production via annihilation of quark pairs to photon and weak bosons in turn decaying to the quarks of M_{89} hadron physics serves as a possible production mechanism. These production mechanisms do not give much hopes about the production of nucleons of M_{89} physics.

(b) If ordinary gluons couple to M_{89} quarks, also the production via fusion to gluons is possible. If the transition from M_{107} hadron physics corresponds to a phase transition transforming M_{107} hadronic space-time sheets/gluons to M_{89} space-time sheets/gluons, M_{107} gluons do not couple directly to M_{89} gluons. In this case however color spin glass phase for M_{107} gluons could decay to M_{89} gluons in turn producing also M_{89} nucleons. Recall that naive scalings for M_{89} nucleon the mass 481 GeV. The actual mass is expected to be higher but below the scaled up Δ resonance mass predicted to be below 631 GeV.

How could one understand CDF-D0 discrepancy concerning 145 GeV resonance?

The situation concerning 145 GeV bump has become rather paradoxical. CDF claims that 145 GeV resonance is there at 4.3 sigma level. The new results from D0 however fail to support CDF bump [C73] (see Lubos, Jester, and Tommaso).

This shows only that either CDF or D0 is wrong, not that CDF is wrong as some of us suddenly want to believe. My own tentative interpretation -not a belief- relies on bigger picture provided by TGD and is that both 145 GeV, 300 GeV, and 325 GeV resonances are there and have interpretations in terms of π and its p-adic octave, ρ, and ω of M_{89} hadron physics. I could of course be wrong. LHC will be the ultimate jury.

In any case, neither CDF and D0 are cheating and one should explain the discrepancy rationally. Resonaances mentions different estimates for QCD background as a possible explanation. What one could say about this in TGD framework allowing some brain storming?

(a) There is long history of this kind of forgotten discoveries having same interpretation in TGD framework. Always pionlike states-possibly coherent state of them- would have been produced in strong non-orthogonal magnetic and electric fields of the colliding charges and most pion-like states predicted to be almost at rest in cm frame.

Electro-pions were observed already at seventies in the collisions of heavy nuclei at energies near Coulomb wall, resonances having interpretation as mu-pions about three years ago, tau-pions detected by CDF for two and half years ago with refutation coming from D0, now DAMA and Cogent observed dark matter candidate having explanation in terms of tau-pion in TGD framework but Xenon100 found nothing (in this case on can understand the discrepancy in TGD framework). The octaves of M_{89} pions would represent the last episode of this strange history. In the previous posting universality of the production mechanism forced to made the proposal that also the collisions of ordinary nuclei could generate octaves of ordinary pions. They have not been observed and as I proposed this might due to the peculiarity of the production mechanism.

What could be a common denominator for this strange sequence of almost discoveries? Light colored excitations of leptons can be of course be argued to be non-existent because intermediate boson decay widths do not allow them but it is difficult to believe that his would have been the sole reason for not taking lepto-pions seriously.

(b) Could the generation of a pionic coherent state as a critical phenomenon very sensitive to the detailed values of the dynamical parameters, say the precise cm energies of the colliding beams? For lepto-pions a phase transition generating dark colored variants of leptons (dark in the sense having non-standard value of Planck constant) would indeed take place so that criticality might make sense. Could also M_{89} quarks be dark or colored excitations of ordinary quarks which are dark? Could the $M_{107} \rightarrow M_{89}$ phase transition take place only near criticality? This alone does not seem to be enough however.

(c) The peculiarity of the production mechanism is that the pion like states are produced mostly at rest in cm frame of the colliding charges. Suppose that the cm frame for the colliding charged particles is not quite the lab frame in D0. Since most dark pions are produced nearly at rest in the cm frame, they could in this kind of situation leave the detector before decaying to ordinary particles: they would behave just like dark matter is expected to behave and would not be detected. The only signature would be missing energy. This would also predict that dark octaves of ordinary pions would not be detected in experiments using target which is at rest in lab frame.

(d) This mechanism is actually quite general. Dark matter particles decaying to ordinary matter and having long lifetime remain undetected if they move with high enough velocity with respect to laboratory. Long lifetime would be partially due to the large value of $\hbar$ and relativistic with respect to laboratory velocities also time dilation would increases the lifetime. Dark matter particles could be detected only as a missing energy not identifiable in terms of neutrinos. A special attention should be directed to state candidates which are nearly at rest in laboratory.

An example from ordinary hadron physics is the production of pions and their octaves in the strong electric and magnetic field of nuclei colliding with a target at rest in lab. The lifetime of neutral pion is about 10^{-8} seconds and scaled up for large $\hbar$ and by time dilation when the colliding nucleons have relativistic energies. Therefore the dark pion might leave the measurement volume before decay to two gammas when the the target is at rest in laboratory. It is not even clear whether the gammas need to have standard value of Planck constant.

For the second octave of M_{89} pion the lifetime would be scaled down by the ratio of masses giving a factor 2^{11} and lifetime of order $.5 \times 10^{-11}$ seconds. Large $\hbar$ would scale up the lifetime. For non-relativistic relativistic velocities the distance travelled before the decay to gamma pair would $L = (\hbar/\hbar_0) \times (v/c) \times 1.1$ mm.

If also the gamma pair is dark, the detection would require even larger volume. TGD suggests strongly that also photons have a small mass which they obtain by eating the remaining component of Higgs a la TGD (transforming like 1+3 under vectorial weak SU(2)). If photon mass defines the upper bound for the rate for the transformation to ordinary photons, dark photons would remain undetected.

Higgs or a pion of M_{89} hadron physics?

D0 refuted the 145 GeV bump and after this it was more or less forgotten in blogs, which demonstrates how regrettably short the memory span of blog physicists is. CDF reported it in Europhysics 2011 and it seems that the groups are considering seriously possible explanations for the discrepancy. To my opinion the clarification of his issue is of extreme importance.

The situation changed at the third day of conference (Saturday) when ATLAS reported about average 2.5 sigma evidence for what might be Higgs in the mass range 140-150 GeV. The candidate revealed itself via decays to WW in turn decaying to lepton pairs. Also D0 and CDF told suddenly that they have observed similar evidence although the press release had informed that Higgs had been located to the mass range 120-137 GeV. There is of course no reason to exclude the possibility that the decays of 145 GeV resonance are in question and in this case the interpretation as standard model Higgs would be definitely excluded. If the pion of M_{89} physics is in question it would decay to WW pair instead of quark pair producing two jets. Since weak decay is in question one an expect that the decay rate is small.

If this line of reasoning is correct, standard model Higgs is absent. TGD indeed predicts that the components of TGD Higgs become longitudinal components of gauge bosons since also photon and graviton gain a small mass. This however leaves the two Higgses predicted by MSSM under consideration. The stringent lower bounds for the masses of squarks and gluinos of standard SUSY were tightened in the conference and are now about 1 TeV and this means that the the basic argument justifying MSSM (stability of Higgs mass against radiative corrections) is lost.

The absence of Higgs forces a thorough re-consideration of the fundamental ideas about particle massivation. p-Adic thermodynamics combined with zero energy ontology and the identification of massive particles as bound states of massless fermions is the vision provided by TGD.

Short digression to TGD SUSY

Although the question about TGD variant of SUSY is slightly off-topic, its importance justifies a short discussion. Although SUSY is not needed to stabilize Higgs mass, the anomaly of muonic g-2 suggests TGD SUSY and the question is whether TGD SUSY could explain it.

(a) Leptons are characterized by Mersennes or Gaussian Mersennes: $(M_{127}, M_{G,113}, M_{107})$ for (e, μ, τ). If also sleptons correspond to Mersennes of Gaussian Mersennes, then (selectron, smuon, stau) should correspond to $(M_{89}, M_{G,79}, M_{61})$ is one assumes that selectron corresponds to M_{89}. Selectron mass would be 250 GeV and smuon mass 13.9 TeV. g-2 anomaly for muon [K37] suggests that the mass of selectron should not be much above .1 TeV and M_{89} fits the bill. Valence quarks correspond to the Gaussian Mersenne $k \leq 113$, which suggests that squarks have $k \geq 79$ so that squark masses should be above 13 TeV. If sneutrinos correspond to Gaussian Mersenne $k = 167$ then sneutrinos could have mass below electron mass scale. Selectron would remain the only experiment signature of TGD SUSY at this moment.

(b) One decay channel for selectron would be to electron+ sZ or neutrino+ sW. sZ/sW would eventually decay to possibly virtual Z+ neutrino/W+neutrino: that is weak gauge boson plus missing energy. Neutralino and chargino need not decay in the detection volume. The lower bound for neutralino mass is 46 GeV from intermediate gauge boson decay widths. Hence this option is not excluded by experimental facts.

(c) If the sfermions decay rapidly enough to fermion plus neutrino, the signature of TGD SUSY would be excess of events of type lepton+ missing energy or jet+ missing energy. For instance, lepton+missing jet could be mis-identified as decay products of possibly exotic counterpart of weak gauge boson. The decays of 250 GeV selectron would give rise to decays which might be erratically interpreted as decays of W' to electron plus missing energy. The study of CDF at $\sqrt{s}$= 1.96 TeV in p-pbar collisions excludes heavy W′ with mass below 1.12 TeV [C58]. The decay rate to electron plus neutrino must therefore be slow.

    There are indications for a tiny excess of muon + missing energy events in the decays of what has been tentatively identified as a heavy W boson W^{prime} (see Figure 1 of [C50]). The excess is regarded as insignificant by experimenters. W^{prime} candidate is assumed to have mass 1.0 TeV or 1.4 TeV. If smuon is in question, one must give up the Mersenne hypothesis.

The mass of u and d quarks of M_{89} physics

While updating the chapter about the p-adic model for hadronic masses [K43] I found besides some silly numerical errors also a gem that I had forgotten. For pion the contributions to mass squared from color-magnetic spin-spin interaction and color Coulombic interaction and super-symplectic gluons cancel and the mass is in excellent approximation given by the $m^2(\pi) = 2m^2(u)$ with $m(u) = m(d) = 0.1$ GeV in good approximation. That only quarks contribute is the TGD counterpart for the almost Goldstone boson character of pion meaning that its mass is only due to the massivation of quarks. The value of the p-adic prime is $p \simeq 2^k$, with $k(u) = k(d) = 113$ and the mass of charged pion is predicted with error of .2 per cent.

If the reduction of pion mass to mere quark mass holds true for all scaled variants of ordinary hadron physics, one can deduce the value of u and d quark masses from the mass of the pion of M_{89} hadron physics and vice versa. The mass estimate is 145 GeV if one identifies the bump claimed by CDF [C59] as M_{89} pion. Recall that D0 did not detect the CDF bump [C73] (I have discussed possible reasons for the discrepancy in terms of the hypothesis that dark quarks are in question). From this one can deduce that the p-adic prime $p \simeq 2^k$ for the u and d quarks of M_{89} physics is $k = 93$ using $m(u, 93) = 2^{(113-93)/2} m(u, 113)$, $m(u, 113) \simeq .1$ GeV. For top quark one has $k = 94$ so that a very natural transition takes place to a new hadron physics. The predicted mass of $\pi(89)$ is 144.8 GeV and consistent with the value claimed by CDF. What makes the prediction non-trivial is that possible quark masses comes as as half-octaves meaning exponential sensitivity with respect to the p-adic length scale.

The common mass of $u(89)$ and $d(89)$ quarks is 102 GeV in a good approximation and quark jets with mass peaked around 100 GeV should serve as a signature for them. The direct decays of the $\pi(89)$ to M_{89} quarks are of course non-allowed kinematically.

A connection with the top pair backward-forward asymmetry in the production of top quark pars?

One cannot exclude the possibility that the predicted exotic octet of gluons proposed as an explanation of the anomalous backward-forward asymmetry in top pair production correspond sto the gluons of the scaled up variant of hadron physics. M_{107} hadron physics would correspond to ordinary gluons only and M_{89} only to the exotic octet of gluons only so that a strict scaled up copy would not be in question. Could it be that given Mersenne prime tolerates only single hadron physics or lepto-hadron physics?

In any case, this would give a connection with the TGD based explanation of the backward-forward asymmetry in the production of top pairs also discussed in this chapter. In the collision incoming quark of proton and antiquark of antiproton would topologically condense at M_{89} hadronic space-time sheet and scatter by the exchange of exotic octet of gluons: the exchange between quark and antiquark would not destroy the information about directions of incoming and outgoing beams as s-channel annihilation would do and one would obtain the large asymmetry. The TGD based generalized Feynman diagram would involve an exchange of a gluon represented by a wormhole contact. The first wormhole throat would have genus two as also top quark and second throat genus zero. One can imagine that the top quark comes from future and then travels along space-like direction together with antiquark wormhole throat of genus zero a and then turns back to the future. Incoming quark and antiquark perform similar turn around [K37].

This asymmetry observed found a further confirmation in Europhysics 2011 conference [C67]. The obvious question is whether this asymmetry could be reduced to that in collisions of quarks and antiquarks. Tommaso Dorigo tells that CMS has found that this is not the case, which suggests that the phenomenon might be assignable to valence quarks only.

9.5.3 Other indications for M_{89} hadron physics

Also other indications for M_{89} hadron physics have emerged during this year and although the fate of these signals is probably the usual one, they deserve to be discussed briefly.

Bumps also at CDF and D0?

It seems that experimentalists have gone totally crazy. Maybe new physics is indeed emerging from LHC and they want to publish every data bit in the hope of getting paid visit to Stockholm. *CDF* and ATLAS have told about bumps and now Lubos [C32] tells about a new 3 sigma bump reported by D0 collaboration at mass 325 GeV producing muon in its decay producing W boson plus jets [C72]. The proposed identification of bump is in terms of decay of t′ quark producing W boson.

Lubos mentions also second mysterious bump at 324.8 GeV or 325.0 GeV reported by *CDF* collaboration [C57] and discussed by Tommaso Dorigo [C33] towards the end of the last year. The decays of these particles produce 4 muons through the decays of two Z bosons to two muons. What is peculiar is that two mass values differing by .2 GeV are reported. The proposed explanation is in terms of Higgs decaying to two Z bosons. TGD based view about new physics suggests strongly that the three of four particles forming a multiplet is in question.

One can consider several explanations in TGD framework without forgetting that these bumps very probably disappear. Consider first the D0 anomaly alone.

(a) TGD predicts also higher generations but there is a nice argument based on conformal invariance and saying that higher particle families are heavy. What "heavy" means is not clear. It could of mean heavier that intermediate gauge boson mass scale. This explanation does not look convincing to me.

(b) Another interpretation would be in terms of scaled up variant of top quark. The mass of top is around 170 GeV and p-adic length scale hypothesis would predict that the mass should equal to a multiple of half octave of top quark mass. Single octave would give mass of 340 GeV. The deviation from predicted mass would be 5 per cent.

(c) The third interpretation is in terms of ρ and ω mesons of M_{89}. By assuming that the masses of M_{89} π and ρ in absence of color magnetic spin-spin splitting scale naively in the transition from M_{107} to M_{89} physics and by determining the parameter characterizing color magnetic spin-spin splitting from the condition that M_{89} pion has 157 GeV mass, one predicts that M_{89} ρ and ω have same mass 325.6 GeV in good approximation The .2 GeV mass difference would have interpretation as $\rho-\omega$ mass difference. In TGD framework this explanation is unique.

Indications for M_{89} charmonium from ATLAS

Lubos commented last ATLAS release about dijet production. There is something which one might interpret as the presence of resonances above 3.3 TeV [see Fig. 2) of the article] [C47]. Of course, just a slight indication is in question, so that it is perhaps too early to pay attention to the ATLAS release. I am however advocating a new hadron physics and it is perhaps forgivable that I am alert for even tiniest signals of new physics.

In a very optimistic mood I could believe that a new hadron physics is being discovered (145 GeV boson could be identified as charged pion and 325 GeV bumps could allow interpretation as kaons). With this almost killer dose of optimism the natural question is whether this extremely slight indication about new physics might have interpretation as a scaled up J/Ψ and various other charmonium states above it giving rise to what is not single very wide bump to a family of several resonances in the range 3-4 TeV by scaling the 3-4 GeV range for charmonium resonances. For instance, J/Ψ decay width is very small, about .1 MeV, which is about $.3\times 10^{-4}$ of the mass of J/Ψ. In the recent case direct scaling would give decay of about 300 MeV for the counterpart of J/Ψ if the decay is also now slow for kinematic reasons. For other charmonium resonances the widths are measurement in per cents meaning in the recent case width of order of magnitude 30 GeV: this estimate looks more reasonable as the first estimate.

One can also now perform naive scalings. J/Ψ has mass of about 3 GeV. If the scaling of ordinary pion mass from .14 GeV indeed gives something like 145 GeV then one can be very naive and apply the same scaling factor of about 1030 to get the scaled up J/Ψ; with mass of order 3.1 TeV. The better way to understand the situation is to assume that color-magnetic spin spin splitting is small also for M_{89} charmonium states and apply naive scaling to the mass of J/Ψ; to get a lower bound for the mass of its M_{89} counterpart. This would give mass of 1.55 TeV which is by a factor 1/2 too small. p-Adic mass calculations lead to the conclusion that c quark is characterized by $p \simeq 2^k$, $k = 104$. Naive scaling would give $k = 104 - 18 = 86$ and 1.55 TeV mass for J/Ψ. Nothing however excludes $k = 84$ and the lower bound 3.1 TGD for the mass of J/Ψ. Since color magnetic spin-spin splitting is smaller for M_{89} pion, same is expected to be true also for charmonium states so that the mass might well be around 3.3 TeV.

Blackholes at LHC: or just bottonium of M_{89} hadron physics?

The latest Tommaso Dorigo's posting has a rather provocative title: The Plot Of The Week - A Black Hole Candidate. Some theories inspired by string theories predict micro black holes at LHC. Micro blackholes have been proposed as explanation for certain exotic cosmic ray events such as Centauros, which however seem to have standard physics explanation.

Without being a specialist one could expect that evaporating black hole would be in many respects analogous to quark gluon plasma phase decaying to elementary particles producing jets. Or any particle like system, which has forgot all information about colliding particles which created it- say the information about the scattering plane of partons leading to the jets as a final state and reflecting itself as the coplanarity of the jets. If the information about the initial state is lost, one would expect more or less spherical jet distribution. The variable used as in the study is sum of transverse energies for jets emerging from same point and having at least 50 GeV transverse energy. QCD predicts that this kind of events should be rather scarce and if they are present, one can seriously consider the possibility of new physics.

The LHC document containing the sensational proposal is titled Search for Black Holes in pp collisions at $\sqrt{s} = 7$ TeV [C43] and has the following abstract:

An update on a search for microscopic black hole production in pp collisions at a center-of-mass energy of 7 TeV by the CMS experiment at the LHC is presented using a 2011 data sample corresponding to an integrated luminosity of 190 pb1. This corresponds to a six-fold increase in statistics compared to the original search based on 2010 data. Events with large total transverse energy have been analyzed for the presence of multiple energetic jets, leptons, and photons, typical of a signal from an evaporating black hole. A good agreement with the expected standard model backgrounds, dominated by QCD multijet production, has been observed for various multiplicities of the final state. Stringent model-independent limits on new physics production in high-multiplicity energetic final states have been set, along with model-specific lim- its on semi-classical black hole masses in the 4-5 TeV range for a variety of model parameters. This update extends substantially the sensitivity of the 2010 analysis.

The abstract would suggest that nothing special has been found but in sharp contrast with this the article mentions black hole candidate decaying to 10 jets with total transverse energy S_T. The event is illustrated in the figure 3 of the article. The large number of jets emanating from single point would suggest a single object decaying producing the jets.

Personally I cannot take black holes as an explanation of the event seriously. What can I offer instead? p-Adic mass calculations rely on p-adic thermodynamics and this inspires obvious questions. What p-adic cooling and heating processes could mean? Can one speak about p-adic hot spots? What p-adic overheating and over-cooling could mean? Could the octaves of pions and possibly other mesons explaining several anomalous findings including CDF bump correspond to unstable over-heated hadrons for which the p-adic prime near power of two is smaller than normally and p-adic mass scale is correspondingly scaled up by a power of two?

The best manner to learn is by excluding various alternative explanations for the 10 jet event.

(a) M_{89} variants of QCD jets are excluded both because their production requires higher energies and because their number would be small. The first QCD three-jets were observed around 1979 [C168]. $q - \overline{q} - g$ three-jet was in question and it was detected in e^+e^- collision with cm energy about 7 GeV. The naive scaling by factor 512 would suggest that something like 5.6 TeV cm energy is needed to observed M_{89} parton jets. The recent energy is 7 TeV so that there are hopes of observing M_{89} three- jets in decays of heavy M_{89}. For instance, the decays of charmonium and bottonium of M_{89} physics to three gluons or two-gluons and photon would create three-jets.

(b) Ordinary quark gluon plasma is excluded since in a sufficiently large volume of quark gluon plasma so called jet quenching [C11] occurs so that jets have small transverse energies. This would be due to the dissipation of energy in the dense quark gluon plasma. Also ordinary QCD jets are predicted to be rare at these transverse energies: this is of course the very idea of how black hole evaporation might be observed. Creation of quark gluon plasma of M_{89} hadron physics cannot be in question since ordinary quark gluon plasma was created in p-anti-p collision with cm energy of few TeV so that something like 512 TeV of cm energy might be needed!

(c) Could the decay correspond to a decay of a blob of M_{89} hadronic phase to M_{107} hadrons? How this process could take place? I proposed for about 15 years ago [K37] that the transition from M_{89} hadron physics to M_{107} hadron physics might take place as a p-adic cooling via a cascade like process via highly unstable intermediate hadron physics. The p-adic temperature is quantized and given by $T_p = n/log(p) \simeq n/klog(2)$ for $p \simeq 2^k$ and p-adic cooling process would proceed in a step-wise manner as $k \to k+2 \to k+4+...$ Also $k \to k+1 \to k+2+..$ with mass scale reduced in powers of $\sqrt{2}$ can be considered. If only octaves are allowed, the p-adic prime characterizing the hadronic space-time sheets and quark mass scale could decrease in nine steps from M_{89} mass scale proportional to $2^{-89/2}$ octave by octave down to the hadronic mass scale proportional $2^{-107/2}$ as $k = 89 \to 91 \to 93... \to 107$. At each step the mass in the propagator of the particle would be changed. In particular on mass shell particles would become off mass shell particles which could decay.

At quark level the cooling process would naturally stop when the value of k corresponds to that characterizing the quark. For instance b quark one has $k(b) = 103$ so that 7 steps would be involved. This would mean the decay of M_{89} hadrons to highly unstable intermediate states corresponding to $k = 91, 93, ..., 107$. At every step states almost at rest could be produced and the final decay would produce large number of jets and the outcome would resemble the spectrum blackhole evaporation. Note that for u, d, s quarks one has $k = 113$ characterizing also nuclei and muon which would mean that valence quark space-time sheets of lightest hadrons would be cooler than hadronic space-time sheet, which could be heated by sea partons. Note also that quantum superposition of phases with several p-adic temperatures can be considered in zero energy ontology.

This is of course just a proposal and might not be the real mechanism. If M_{89} hadrons are dark in TGD sense as the TGD based explanation of CDF-D0 discrepancy suggests, also the transformation changing the value of Planck constant is involved.

(d) This picture does not make sense in the TGD inspired model explaining DAMA observations and DAMA-Xenon100 anomaly, CDF bump discussed in this chapter and two and half year old CDF anomaly [K70]. The model involves creation of second octave of M_{89} pions decaying in stepwise manner. A natural interpretation of p-adic octaves of pions is in terms of a creation of over-heated unstable hadronic space-time sheet having $k = 85$ instead of $k = 89$ and p-adically cooling down to relatively thermally stable M_{89} sheet and containing light mesons and electroweak bosons. If so then the production of CDF bump would correspond to a creation of hadronic space-time sheet with p-adic temperature corresponding to $k = 85$ cooling by the decay to $k = 87$ pions in turn decaying to $k = 89$. After this the decay to M_{107} hadrons and other particles would take place.

Consider now whether the 10 jet event could be understood as a creation of a p-adic hot spot perhaps assignable to some heavy meson of M_{89} physics. The table below is from [K34, K42] and gives the p-adic primes assigned with constituent quarks identified as valence quarks. For current quarks the p-adic primes can be much large so that in the case of u and d quark the masses can be in 10 MeV range (which together with detailed model for light hadrons supports the view that quarks can appear at several p-adic temperatures).

(a) According to p-adic mass calculations [K42] ordinary charmed quark corresponds to $k = 104 = 107 - 3$ and that of bottom quark to $k = 103 = 107 - 4$, which is prime and correspond to the second octave of M_{107} mass scale assignable to the highest state of pion cascade. By naive scaling M_{89} charmonium states (Ψ would correspond to $k = 89 - 3 = 86$ with mass of about 1.55 TeV by direct scaling. $k = 89 - 4 = 85$ would give mass about 3.1 GeV and there is slight evidence for a resonance around 3.3 TeV perhaps identifiable as charmonium. Υ (bottonium) consisting of $b\bar{b}$ pair correspond to $k = 89 - 4 = 85$ just like the second octave of M_{89} pion. The mass of M_{89} Υ meson would be about 4.8 TeV for $k = 85$. $k = 83$ one obtains 9.6 TeV, which exceeds the total cm energy 7 TeV.

(b) Intriguingly, $k = 85$ for the bottom quark and for first octave of charmonium would correspond to the second octave of M_{89} pion. Could it be that the hadronic space-time sheet of Υ is heated to the p-adic temperature of the bottom quark and then cools down in a stepwise manner? If so, the decay of Υ could proceed by the decay to higher octaves of light M_{89} mesons in a process involving two steps and could produce a large number jets.

(c) For the decay of ordinary Υ meson 81.7 per cent of the decays take place via ggg state. In the recent case they would create three M_{89} parton jets producing relativistic M_{89} hadrons. 2.2 per cent of decays take place via γgg state producing virtual photon plus M_{89} hadrons. The total energies of the three jets would be about 1.6 TeV each and much higher than the energies of QCD jets so that this kind of jets would serve as a clearcut signature of M_{89} hadron physics and its bottom quark. Note that there already exists slight evidence for charmonium state. Recall that the total transverse energy of the 10 jet event was about 1 TeV.

Also direct decays to M_{89} hadrons take place. η' +anything- presumably favored by the large contribution of $b\bar{b}$ state in η'- corresponds to 2.9 per cent branching ratio for ordinary hadrons. If second octaves of η' and other hadrons appear in the hadron state, the decay product could be nearly at rest and large number of M_{89} would result in the p-adic cooling process (the naive scaling of η' mass gives .5 TeV and second octave would correspond to 2 TeV.

(d) If two octave p-adic over-heating is dynamically favored, one must also consider the first octave of of scaled variant of J/Ψ state with mass around 3.1 GeV scaled up to 3.1 TeV for the first octave. The dominating hadronic final state in the decay of J/Ψ is $\rho^{\pm}\pi^{\mp}$ with branching ratio of 1.7 per cent. The branching fractions of $\omega\pi^+\pi^+\pi^-\pi^-$, $\omega\pi^+\pi^-\pi^0$, and $\omega\pi^+\pi^+pi^-$ are 8.5×10^{-3} 4.0×10^{-3}, and 8.6×10^{-3} respectively. The second octaves for the masses of ρ and π would be 1.3 TeV and .6 TeV giving net mass of 1.9 TeV so that these mesons would be relativistic if charmonium state with mass around 3.3 TeV is in question. If the two mesons decay by cooling, one would obtain two jets decaying two jets. Since the original mesons are relativistic one would probably obtain two wide jets decomposing to sub-jets. This would not give the desired fireball like outcome.

The decays $\omega\pi^+\pi^+\pi^-\pi^-$ (see Particle Data Tables would produce five mesons, which are second octaves of M_{89} mesons. The rest masses of M_{89} mesons would in this case give total rest mass of 3.5 TeV. In this kind of decay -if kinematically possible- the hadrons would be nearly at rest. They would decay further to lower octaves almost at rest. These states in turn would decay to ordinary quark pairs and electroweak bosons producing a large number of jets and black hole like signatures might be obtained. If the process proceeds more slowly from M_{89} level, the visible jets would correspond to M_{89} hadrons decaying to ordinary hadrons. Their transverse energies would be very high.

q	d	u	s	c	b	t
n_q	4	5	6	6	59	58
s_q	12	10	14	11	67	63
$k(q)$	113	113	113	104	103	94
$m(q)/GeV$	.105	.092	.105	2.191	7.647	167.8

Constituent quark masses predicted

for diagonal mesons assuming $(n_d, n_s, n_b) = (5, 5, 59)$ and $(n_u, n_c, n_t) = (5, 6, 58)$, maximal CP_2 mass scale($Y_e = 0$), and vanishing of second order contributions.

To sum up, the most natural interpretation for the 10-jet event in TGD framework would be as p-adic hot spots produced in collision.

Has CMS detected λ baryon of M_{89} hadron physics?

In his recent posting Lubos tells about a near 3-sigma excess of 390 GeV 3-jet RPV-gluino-like signal reported by CMS collaboration in article Search for Three-Jet Resonances in p-p collisions at $\sqrt{s} = 7$ TeV [C49]. This represents one of the long waited results from LHC and there are good reason to consider it at least half-seriously.

Gluinos are produced in pairs and in the model based on standard super-symmetry decay to three quarks. The observed 3-jets in question would correspond to a decay to uds quark triplet. The decay would be R-parity breaking. The production rate would however too high for standard SUSY so that something else is involved if the 3 sigma excess is real.

1. Signatures for standard gluinos correspond to signatures for M_{89} baryons in TGD framework

In TGD Universe gluinos would decay to ordinary gluons and right-handed neutrino mixing with the left handed one so that gluino in TGD sense is excluded as an explanation of the 3-jets. In TGD framework the gluino candidate would be naturally replaced with $k = 89$ variant of strange baryon λ decaying to *uds* quark triplet. Also the 3-jets resulting from the decays of proton and neutron and Δ resonances are predicted. The mass of ordinary λ is $m(\lambda, 107) = 1.115$ GeV. The naive scaling by a factor 512 would give mass $m(\lambda, 107) = 571$ GeV, which is considerably higher than 390 GeV. Naive scaling would predict the scaled up copies of the ordinary light hadrons so that the model is testable.

It is quite possible that the bump is a statistical fluctuation. One can however reconsider the situation to see whether a less naive scaling could allow the interpretation of 3-jets as decay products of M_{89} λ-baryon.

2. Massivation of hadrons in TGD framework

Let us first look the model for the masses of nucleons in p-adic thermodynamics [K43].

(a) The basic model for baryon masses assumes that mass squared -rather than energy as in QCD and mass in naive quark model- is additive at space-time sheet corresponding to given p-adic prime whereas masses are additive if they correspond to different p-adic primes. Mass contains besides quark contributions also "gluonic contribution" which dominates in the case of baryons. The additivity of mass squared follows naturally from string mass formula and distinguishes dramatically between TGD and QCD. The value of the p-adic prime $p \simeq 2^k$ characterizing quark depends on hadron: this explains the mass differences between baryons and mesons. In QCD approach the contribution of quark masses to nucleon masses is found to be less than 2 per cent from experimental constraints. In TGD framework this applies only to sea quarks for which masses are much lighter whereas the light valence quarks have masses of order 100 MeV.

    For a mass formula for quark contributions additive with respect to quark mass squared quark masses in proton would be around 100 MeV. The masses of u, d, and s quarks are in good approximation 100 MeV if p-adic prime is $k = 113$, which characterizes the nuclear space-time sheet and also the space-time sheet of muon. The contribution to proton mass is therefore about $\sqrt{3} \times 100$ MeV.

    Remark: The masses of u and d sea quarks must be of order 10 MeV to achieve consistency with QCD. In this case p-adic primes characterizing the quarks are considerably larger. Quarks with mass scale of order MeV are important in nuclear string model which is TGD based view about nuclear physics [L3].

(b) If color magnetic spin-spin splitting is neglected, p-adic mass calculations lead to the following additive formula for mass squared.

$$M(baryon) = M(quarks) + M(gluonic) \ , \ M^2(gluonic) = nm^2(107) \ . \qquad (9.5.5)$$

The value of integer n can almost predicted from a model for the TGD counterpart of the gluonic contribution [K43] to be $n = 18$. $m^2(107)$ corresponds to p-adic mass squared associated with the Mersenne prime $M_{107} = 2^{107} - 1$ characterizing hadronic space-time sheet responsible for the gluonic contribution to the mass squared. One has $m(107) = 233.55$ MeV from electron mass $m_e \simeq \sqrt{5} \times m(127) \simeq 0.5$ MeV and from $m(107) = 2^{(127-107)/2} \times m(127)$.

(c) For proton one has

$$M(quarks) = (\sum_{quarks} m^2(quark))^{1/2} \simeq 3^{1/2} \times \ 100 \ MeV$$

for $k(u) = k(d) = 113$ [K43].

3. Super-symplectic gluons as TGD counterpart for non-perturbative aspects of QCD

A key difference as compared to QCD is that the TGD counterpart for the gluonic contribution would contain also that due to "super-symplectic gluons" besides the possible contribution assignable to ordinary gluons.

(a) Super-symplectic gluons do not correspond to pairs of quark and and antiquark at the opposite throats of wormhole contact as ordinary gluons do but to single wormhole throat carrying purely bosonic excitation corresponding to color Hamiltonian for CP_2. They therefore correspond directly to wave functions in WCW ("world of classical worlds") and could therefore be seen as a genuinely non-perturbative objects allowing no description in terms of a quantum field theory in fixed background space-time.

(b) The description of the massivation of super-symplectic gluons using p-adic thermodynamics allows to estimate the integer n characterizing the gluonic contribution. Also super-symplectic gluons are characterized by genus g of the partonic 2-surface and in the absence of topological mixing $g = 0$ super-symplectic gluons are massless and do not contribute to the ground state mass squared in p-adic thermodynamics. It turns out that a more elegant model is obtained if the super-symplectic gluons suffer a topological mixing assumed to be same as for U type quarks. Their contributions to the mass squared would be $(5, 6, 58) \times m^2(107)$ with these assumptions.

(c) The quark contribution $(M(nucleon) - M(gluonic))/M(nucleon)$ is roughly 82 per cent of proton mass. In QCD approach experimental constraints imply that the sum of quark masses is less that 2 per cent about proton mass. Therefore one has consistency with QCD approach if one assumes that the light quarks correspond to sea quarks.

4. What happens in $M_{107} \rightarrow M_{89}$ transition?

What happens in the transition $M_{107} \rightarrow M_{89}$ depends on how the quark and gluon contributions depend on the Mersenne prime.

(a) One can also scale the "gluonic" contribution to baryon mass which should be same for proton and λ. Assuming that the color magnetic spin-spin splitting and color Coulombic conformal weight expressed in terms of conformal weight are same as for the ordinary baryons, the gluonic contribution to the mass of $p(89)$ corresponds to conformal weight $n = 11$ reduced from its maximal value $n = 3 \times 5 = 15$ corresponding to three topologically mixed super-symplectic gluons with conformal weight 5 [K43]. The reduction is due to the negative colour Coulombic conformal weight. This is equal to

$M_g = \sqrt{11} \times 512 \times m(107)$, $m(107) = 233.6$ MeV, giving $M_g = 396.7$ GeV which happens to be very near to the mass about 390 GeV of CMS bump. The facts that quarks appear already in light hadrons in several p-adic length scales and quark and gluonic contributions to mass are additive, raises the question whether the state in question corresponds to p-adically hot ($1/T_p \propto log(p) \simeq klog(2)$ gluonic/hadronic space-time sheet with $k = 89$ containing ordinary quarks giving a small contribution to the mass squared. Kind of overheating of hadronic space-time sheet would be in question.

(b) The option for which quarks have masses of thermally stable M_{89} hadrons with quark masses deduced from the questionable 145 GeV CDF bump identified as the pion of M_{89} physics does not work.

i. If both contributions scale up by factor 512, one obtains $m(p, 89) = 482$ GeV and $m(\lambda) = 571$ GeV. The values are too large.

ii. A more detailed estimate gives the same result. One can deduce the scaling of the quark contribution to the baryon mass by generalizing the condition that the mass of pion is in a good approximation just $m(\pi) = \sqrt{2}m(u, 107)$ (Goldstone property). One obtains that u and d quarks of M_{89} hadron physics correspond to $k = 93$ whereas top quark corresponds to $k = 94$: the transition between hadron physics would be therefore natural. One obtains $m(u, 89) = m(d, 89) = 102$ GeV in good approximation: note that this predicts quark jets with mass around 100 GeV as a signature of M_{89} hadron physics.
The contribution of quarks to proton mass would be $M_q = \sqrt{3}\times 2^{(113-93)/2} m(u, 107) \simeq$ 173 GeV. By adding the quark contribution to gluonic contribution $M_g = 396.7$ GeV, one obtains $m(p, 89) = 469.7$ GeV which is rather near to the naively scaled mass 482 GeV and too large. For $\lambda(89)$ the mass is even larger: if $\lambda(89)-p(89)$ mass difference obeys the naive scaling one has $m(\lambda, 89) - m(p, 89) = 512 \times m(\lambda, 107) - m(p, 107)$. One obtains $m(\lambda, 89) = m(p, 89) + m(s, 89) - m(u, 89) = 469.7 + 89.6$ GeV $= 559.3$ GeV rather near to the naive scaling estimate 571 GeV. This option fails.

Maybe I would be happier if the 390 GeV bump would turn out to be a fluctuation (as it probably does) and were replaced with a bump around 570 GeV plus other bumps corresponding to nucleons and Δ resonances and heavier strange baryons. The essential point is however that the mass scale of the gluino candidate is consistent with the interpretation as λ baryon of M_{89} hadron physics. Quite generally, the signatures of R-parity breaking standard SUSY have interpretation as signatures for M_{89} hadron physics in TGD framework.

3-jet and 9-jet events as a further evidence for M_{89} hadron physics?

The following arguments represent a fresh approach to 390 GeV bump which I developed without noticing that I had discussed already earlier the above un-successful explanation.

Lubos Motl told about slight 3-jet and 9-jet excesses seen by CMS collaboration in LHC data. There is an article about 3-jet excess titled Search for Three-Jet Resonances in pp Collisions at $s^{1/2} = 7$ TeV by CMS collaboration [C65]. The figure in Lubos's blog [C31] shows what has been found. In 3-jet case the effects exceeds 3-sigma level between 350 GeV and 410 GeV and the center is around 380-390 GeV.

Experimenters see 3-jets as 1.9 sigma evidence for SUSY. It is probably needless to tell that 1.9 sigma evidences come and go and should not be taken seriously. Gluino pair would be produced and each gluino with mass around 385 GeV would decay to three quarks producing three jets. In tri-jet case altogether 3+3=6 jets would be produced in the decays of gluinos. The problem is that there is no missing energy predicted by MSSM scenario without R-parity breaking. Therefore the straightforward proposal of CMS collaboration is that R-parity is broken by a coupling of gluino to 3 quark state so that gluino would effectively have quark number three and gluino can decay to 3 light quarks- say uds.

The basic objection against this idea is that the distribution of 3-jet masses is very wide extending from 75 GeV (slightly below 100 GeV for selected events) to about 700 GeV as one learns from figure 1 of the CMS preprint [C65]. Resonance interpretation does not look convincing to me and to my humble opinion this is a noble but desperate attempt to save the standard view about SUSY. After proposing the explanation which follows I realized to my surprise that I had already earlier tried to explain the 390 GeV bump in terms of M_{89} baryon but found that this explanation fails [L15] since the mass is too low to allow this interpretation.

There is also an article about nona-jets titled Has SUSY Gone Undetected in 9-jet Events? A Ten-Fold Enhancement in the LHC Signal Efficiency [C122] but I will not discuss this except by noticing that nona-jet events would serve as a unique signature of M_{89} baryon decays in TGD framework if the proposed model for tri-jets is correct.

Before continuing I want to make clear my motivations for spending time with thinking about this kind events which are probably statistical fluctuations. If I were an opportunist I would concentrate all my efforts to make a maximum noise about the successes of TGD. I am however an explorer rather than career builder and physics is to me a passion- something much more inspiring than personal fame. My urge is to learn what TGD SUSY is and what it predicts and this kind of activity is the best manner to do it.

1. Could one interpret the 3-jet events in terms of TGD SUSY without R-parity breaking?

I already mentioned the very wide range of 3-jet distribution as a basic objection against gluino pair interpretation. But just for curiousity one can also consider a possible interpretation in the framework provided by TGD SUSY.

As I have explained in the article [L14], one could understand the apparent absence of squarks and gluinos in TGD framework in terms of shadronization which would be faster process than the selectro-weak decays of squarks so that the standard signatures of SUSY (jest plus missing energy) would not be produced. The mass scales and even masses of quark and squark could be identical part from a splitting caused by mixing. The decay widths of weak bosons do not however allow light exotic fermions coupling to them and this in the case of ordinary hadron physics this requires that squarks are dark having therefore non-standard value of Planck constant coming as an integer multiple of the ordinary Planck constant [K22]. For M_{89} hadron physics this constraint is not necessary.

One can indeed imagine an explanation for 3-jets in terms of decays of gluino pair in TGD framework without R-parity breaking.

(a) Both gluinos would decay as $\tilde{g} \rightarrow \tilde{q} + \overline{q}$ (or charge conjugate of this) and squark in turn decays as $\tilde{q} \rightarrow q + \tilde{g}$. This would give quark pair and two virtual gluinos. Virtual gluinos would transform to a quark pair by an exchange of virtual squark: $\tilde{g} \rightarrow q + \overline{q}$. This would give 3 quark jets and 3 anti-quark jets.

(b) Why this option possible also in MSSM is not considered by CMS collaboration? Do the bounds on squark masses make the rate quite too low? The very strong lower bounds on squark masses in MSSM type SUSY were indeed known towards the end of August when the article was published. In TGD framework these bounds are not present since squarks could appear with masses of ordinary quarks if they are dark in TGD sense. Gluinos would be however dark and the amplitude for the phase transition transforming gluon to its dark variant decaying to a gluino pair could make the rate too low.

(c) If one takes the estimate for the M_{89} gluino mass seriously and scales to a very naive mass estimate for M_{107} gluino by a factor 1/512, one obtains $m(\tilde{g}_{107}) = 752$ MeV.

As already noticed, I do not take this explanation too seriously: the tri-jet distribution is quite too wide.

2. Could tri-jets be interpreted in terms of decays of M_{89} quarks to three ordinary quarks?

3+3 jets are observed and they correspond to 3 quarks and antiquarks. If one takes 3-jet excess seriously it seems that one has to assume a fermion decaying to 3 quarks or two quarks and antiquark. All these quarks could be light (u, d, s type quarks).

Could M_{89} quarks decaying to three M_{107} (ordinary) quarks ($q_{89} \to q_{107}q_{107}\overline{q}_{107}$) be in question? If this were the case the 9-jets might allow interpretation as decays of M_{89} proton or neutron with mass which from naive scaling would be $512 \times .94$ GeV $\simeq 481$ GeV resulting when each quark the nucleon decays to three ordinary quarks. Nona-jets would serve as a unique signature for the production of M_{89} baryons!

M_{89} quarks must decay somehow to ordinary quarks.

(a) The simplest guess is that the transformation $q_{89} \to q_{107}q_{107}\overline{q}_{107}$ begins with the decay $q_{89} \to q_{107} + g_{89}$. Here g_{89} can be virtual.

(b) This would be followed by $g_{89} \to q_{107}\overline{q}_{107}$. The final state would consist of two quarks and one antiquark giving rise to tri-jet. The decay of M_{89} gluon could produce all quark families democratically apart from phase space factors larger for light quarks. This would produce 3+3 jets with a slight dominance of light quark 3-jets.

There are two options to consider. The first option corresponds to a production of a pair of on mass shell M_{89} quarks with mass around 385 GeV (resonance option) and second option to a production of a pair of virtual M_{89} quarks suggested by the wide distribution of tri-jets.

(a) Could the resonance interpretation make sense? Can the average 3-jet mass about 385 GeV correspond to the mass of M_{89} quark? The formulas $m(\pi_{89}) = 2^{1/2}m(u_{89})$ (mass squared is additive) together with $m(\pi_{89}) = 144$ GeV would give $m(u_{89}) \simeq 101.8$ GeV. Unfortunately the mass proposed for the gluino is almost 4 times higher. The naive scaling by factor 512 for charmed quark mass $m(c_{107}) = 1.29$ GeV would give 660.5 GeV, which is quite too high. It seems very difficult to find any reasonable interpretation in terms of decays of on mass shell M_{89} quarks with mass around 385 GeV.

(b) One can however consider completely different interpretation. From figure 1 [C65] of the CMS preprint one learns that the distribution of 3-jet masses is very wide beginning around 75 GeV (certainly consistent with 72 GeV, which is one half of the predicted mass 144 GeV of M_{89} pion) for all triplets and slightly below 100 GeV for selected triplets.

    Could one interpret the situation without selection by assuming that a pair of M_{89} quarks forming a virtual M_{89} pion is produced just as the naive expectation that the old-fashioned proton-pion picture could make sense at "low" energies (using of course M_{89} QCD Λ as a natural mass scale) also for M_{89} physics. The total mass of M_{89} quark pair would be above 144 GeV and its decay to virtual M_{89} quark pair would give quark pair with quark masses above 72 GeV. Could the selected events with total 3-jet mass above 100 GeV correspond to the production of a virtual M_{89} quark pair?

To sum up, if one takes the indications for 3-jets seriously, the interpretation in terms of M_{89} hadron physics is the most plausible TGD option. I am unable to say anything about the 9-jet article but 9-jets would serve as a unique and very dramatic signature of M_{89} baryons: the naive prediction for the mass of M_{89} nucleon is 481 GeV.

3 sigma evidence for kaons of M_{89} hadron physics?

The news about Moriond conference (for details see for the posting of Phil Gibbs) did not bring anything really new concerning the situation with Higgs. The two-photon discrepancy is still there although the production rate is now about 1.6 times higher than predicted. The error bars are however getting narrower so that there are excellent reasons to hope/fear that unexpected kind of new physics is trying to tell about itself. Also the masses deduced from gamma pair and Z pair decay widths are slightly different.

The TGD-based explanation would be in terms of M_{89} hadron physics, a fractal copy of ordinary hadron physics with 512 times higher overall mass scale. If the pion of this new physics has mass not too far from 125 GeV its decays to gamma and Z pairs would affect the observed decay rates of Higgs to gamma and Z pairs if one assumes just standard model. Fermi anomaly suggests mass of about 135 GeV for the pion of M_{89} hadron physics. The observations of RHIC and those from proton-heavy nucleus collisions - correlated pairs of charged particles moving in same or opposite directions- could be understood in terms of decays of M_{89} mesons behaving like hadronic strings in low energies in the relevant energy scale.

Lubos tells in his recent posting about 3 sigma excess for new charged and neutral particles with mass around 420 GeV [C52]. They would be produced as pairs of charged and neutral particle. M_{89} physics based explanation would be in terms of kaons of M_{89} hadron physics. The naive scaling by the ratio $r = m(\pi^+_{107})/m(K^+_{107})$ of masses of ordinary pion and kaon predicts that the M_{89} pion should have mass $m(\pi^+_{89}) = r \times 420$ GeV. This would give $m(\pi^+_{89}) = 119$ GeV not too far from 125 GeV to affect the apparent decay rates of Higgs to gamma and Z pairs since its width as strongly interacting particle decaying to ordinary quarks and gluons is expected to be large. This mass however deviates from the 135 GeV mass suggested by Fermi data by 18 per cent.

9.5.4 LHC might have produced new matter: are M_{89} hadrons in question?

Large Hadron Collider May Have Produced New Matter is the title of popular article explaining briefly the surprising findings of LHC made for the first time September 2010. A fascinating possibility is that these events could be seen as a direct signature of brand new hadron physics. I distinguish this new hadron physics using the attribute M_{89} to distinguish it from ordinary hadron physics assigned to Mersenne prime $M_{107} = 2^{107} - 1$.

Some background

Quark gluon plasma is expected to be generated in high energy heavy ion collisions if QCD is *the* theory of strong interactions. This would mean that quarks and gluons are de-confined and form a gas of free partons. Something different was however observed already at RHIC: the surprise was the presence of highly correlated pairs of charged particles. The members of pairs tended to move in parallel: either in same or opposite directions.

This forced to give up the description in terms of quark gluon plasma and to introduce what was called color glass condensate. The proposal was that so called color glass condensate, which is liquid with strong correlations between the velocities of nearby particles rather than gas like state in which these correlations are absent, is created: one can imagine that a kind of thin wall of gluons is generated as the highly Lorentz contracted nuclei collide. The liquid like character would explain why pairs tend to move in parallel manner. Why they can move also in antiparallel manner is not obvious to me although I have considered the TGD based view about color glass condensate inspired by the fact that the field equations for preferred extremals are hydrodynamical and it might be possible to model this phase of collision using scaled version of critical cosmology which is unique apart from scaling of the parameter characterizing the duration of this critical period. Later LHC found a similar behavior in heavy ion collisions. The theoretical understanding of the phenomenon is however far from complete.

The real surprise was the observation of similar events in proton proton collisions at LHC: for the first time already at 2010. Lubos Motl wrote a nice posting about this observation. Also I wrote a short comment about the finding. Now the findings have been published: preprint can be found in arXiv [C66]. Below is the abstract of the preprint.

Results on two-particle angular correlations for charged particles emitted in pPb collisions at a nucleon-nucleon center-of-mass energy of 5.02 TeV are presented. The analysis uses two million collisions collected with the CMS detector at the LHC. The correlations are studied over a broad range of pseudorapidity η, and full azimuth ϕ, as a function of charged particle multiplicity and particle transverse momentum, p_T. In high-multiplicity events, a long-range ($2 < |(\Delta\eta| < 4$), near-side $\Delta\phi$ approximately 0) structure emerges in the two-particle $\Delta\eta$–$\Delta\phi$ correlation functions. This is the first observation of such correlations in proton-nucleus *collisions, resembling the ridge-like correlations seen in high-multiplicity pp collisions at $s^{1/2}$ = 7 TeV and in A on A collisions over a broad range of center-of-mass energies. The correlation strength exhibits a pronounced maximum in the range of p_T = 1-1.5 GeV and an approximately linear increase with charged particle multiplicity for high-multiplicity events. These observations are qualitatively similar to those in pp collisions when selecting the same observed particle multiplicity, while the overall strength of the correlations is significantly larger in pPb collisions.*

Could M_{89} hadrons give rise to the events?

Second highly attractive explanation discussed by Lubos is in terms of production of string like objects. In this case the momenta of the decay products tend to be parallel to the strings since the constituents giving rise to ultimate decay products are confined inside 1-dimensional string like object. In this case it is easy to understand the presence of both parallel and antiparallel pairs. If the string is very heavy, a large number of particles would move in collinear manner in opposite directions. Color quark condensate would explain this in terms of hydrodynamical flow.

In TGD framework these string like objects would correspond to color magnetic flux tubes. These flux tubes carrying quark and antiquark at their ends should however make them manifest only in low energy hadron physics serving as a model for hadrons, not at ultrahigh collision energies for protons. Could this mean that these flux tubes correspond to hadrons of M_{89} hadron physics? M_{89} hadron physics would be low energy hadron physics since the scaled counterpart of QCD Λ around 200 MeV is about 100 GeV and the scaled counterpart of proton mass is around .5 TeV (scaling is by factor is 512 as ratio of square roots of $M_{89} = 2^{89} - 1$, and M_{107}). What would happen in the collision would be the formation of p-adically hot spot at p-adic temperature $T = 1$ for M_{89}.

For instance, the resulting M_{89} pion would have mass around 67.5 GeV if a naive scaling of ordinary pion mass holds true. p-Adic length scale hypothesis allows power of $2^{1/2}$ as a multiplicative factor and one would obtain something like 135 GeV for factor 2: Fermi telescope has provided evidence for this kind particle although it might be that systematic error is involved (see the nice posting of Resonaances). The signal has been also observed by Fermi telescope for the Earth limb data where there should be none if dark matter in galactic center is the source of the events. I have proposed that M_{89} hadrons - in particular M_{89} pions - are also produced in the collisions of ultrahigh energy cosmic rays with the nuclei of the atmosphere: maybe this could explain also the Earth limb data. Recall that my first erratic interpretation for 125 GeV Higgs like state was as M_{89} pion and only later emerged the interpretation of Fermi events in terms of M_{89} pion.

What about the explanation in terms of M_{89} color spin glass? It does not make sense. First of all, both color spin glass and quark gluon plasma would be higher energy phenomena in QCD like theory. Now low energy M_{89} hadron physics would be in question. Secondly, for the color spin glass of ordinary hadron physics the temperature would be about 1 GeV, the mass of proton in good approximation. For M_{89} color spin glass the temperature would be by a factor 512 higher, that is .5 TeV: this cannot make sense since the model based on temperature 1 GeV works satisfactorily.

How this picture relates to earlier ideas?

I have made three earlier proposals relating to the unexpected correlations just discussed. The earlier picture is consistent with the recent one.

(a) I have already earlier proposed a realization of the color glass condensate in terms of color magnetic flux tubes confining partons to move along string like objects. This indeed explains why charged particle pairs tend to move in parallel or antiparallel manner. Amusingly, I did not realize that ordinary hadronic strings (low energy phenomenon) cannot be in question, and therefore failed to make the obvious conclusion that M_{89}

hadrons could be in question. Direct signals of M_{89} hadron physics have been in front of our eyes since the findings of RHIC around 2005 but our prejudices - in particular, the stubborn belief that QCD is a final theory of strong interactions - have prevented us to see them! Instead of this we try desperately to see superstrings and standard SUSY!

(b) One basic question is how the hadrons and quarks of M_{89} hadron physics decay to ordinary hadrons. I proposed the basic idea for about fifteen years ago - soon after the discovery of p-adic physics. The idea was that the hadrons of M_{89} physics are p-adic hot spots created in the collisions of hadrons. Also quarks get heated so that corresponding p-adic prime increases and the mass of the quark increases by some power of $\sqrt{2}$ meaning a reduction in size by the same power. The cooling of these hot spots is a sequence of phase transitions increasing the p-adic prime of the appropriate (hadronic or partonic) space-time sheet so that the eventual outcome consists of ordinary hadrons. p-Adic length scale hypothesis suggests that only primes near powers of 2 (or their subset) appear in the sequence of phase transitions. For instance, M_{89} hadronic space-time sheet would end up to an ordinary hadronic space-time sheets consisting of at most 18 steps from $M_{107}/M_{89} \simeq 2^{18}$. If only powers of 2 are allowed as scalings (the analog of period doubling) there are 9 steps at most.

Each step scales the size of the space-time sheet in question so that the process is highly analogous to cosmic expansion leading from very short and thin M_{89} flux tube to M_{107} flux tube with scaled up dimensions. Since a critical phenomenon is in question and TGD Universe is fractal, a rough macroscopic description would be in terms of scaled variant of critical cosmology, which is unique apart from its finite duration and describes accelerated cosmic expansion. The almost uniqueness of the critical cosmology follows from the imbeddability to $M^4 \times CP_2$. Cosmic expansion would take place only during these periods. Both the cosmic expansion expansion associated with the cooling of hadronic and partonic space-time sheets would take via jerks followed by stationary periods with no expansion. The size of the scale of the hadronic or partonic space-time sheet would increase by a power of $\sqrt{2}$ during a single jerk.

By the fractality of the TGD Universe this model of cosmic expansion based on p-adic phase transitions should apply in all scales. In particular, it should apply to stars and planetary systems. The fact that various astrophysical objects do not seem to participate in cosmic expansion supports the view that the expansion takes place in jerks identifiable as phase transitions increasing the p-adic prime of particular space-time sheet so that in the average sense a continuous smooth expansion is obtained. For instance, I have proposed a variant of expanding Earth model [K48] explaining the strange observation that the continents would nicely cover the entire surface of Earth if the radius of Earth were one half of its recent radius. The assumed relatively rapid phase transition doubling the radius of Earth explains several strange findings in the thermal, geological, and biological history of Earth.

This approach also explains also how the magnetic energy of primordial cosmic strings identifiable as dark energy has gradually transformed to dark or ordinary matter [L13]. In this model the vacuum energy density of inflation field is replaced with that of Kähler magnetic field assignable to the flux tubes originating from primordial cosmic strings with a 2-D M^4 projection. The model explains also the magnetic fields filling the Universe in all scales: in standard Big Bang cosmology their origin remains a mystery.

(c) What about the energetics of the process? If the jerk induces an overall scaling, the Kähler magnetic energy of the magnetic flux tubes decreases since - by the conservation of magnetic flux giving $B \propto 1/S$ - the energy is proportional to L/S scaling like $1/\sqrt{p}$ (L and S denote the length and the transversal area of the flux tube). Therefore magnetic energy is liberated in the process and by p-adic length scale hypothesis the total rest energy liberated is $\Delta E = E_i(1-2^{(k_i-k_f)/2})$, where i and f refer to initial and final values of the p-adic prime $p \simeq 2^k$. Similar consideration applies to partons. The natural assumption is that the Kähler magnetic (equivalently color magnetic) energy is liberated as partons. These partons would eventually transform to ordinary partons and materialize to ordinary hadrons. The scaling of the flux tube would preserve its size would force the observed correlations.

To conclude, the brave conjecture would be that a production of M_{89} hadrons could explain the observations. There would be no quark gluon plasma nor color spin glass (a highly questionable notion in high energy QCD). Instead of this new hadron physics would emerge by the confinement of quarks (or their scaled up variants) in shorter length scale as collision energies become high enough, and already RHIC would have observed M_{89} hadron physics!

9.5.5 New results from PHENIX concerning quark gluon plasma

New results have been published on properties of what is conventionally called quark gluon plasma (QGP) . As a matter fact, this phase does not resemble plasma at all. The decay patterns bring in mind decays of string like objects parallel to the collision axes rather than isotropic blackbody radiation. The initial state looks like a perfect fluid rather than plasma and thus more like a particle like object.

The results of QGP - or color glass condensate (CGC) as it is also called - come from three sources and are very similar. The basic characteristic of the collisions is the cm energy $\sqrt{s}$ of nucleon pair. The data sources are Au-Au collisions at RHIC, Brookhaven with $\sqrt{s} = 130$ GeV, p-p collisions and p-nucleus collisions at LHC with $\sqrt{s} = 200$ GeV [C91] and d-Au collisions at RHIC with $\sqrt{s} = 200$ GeV studied by PHENIX collaboration [C82].

According to the popular article telling about the findings of PHENIX collaboration (`http://www.sciencedaily.com/releases/2013/12/131206163022.htm#.UqYYWdqz7Fg.email`) the collisions are believed to involve a creation of what is called hot spot. In Au-Au collisions this hot spot has size of order Au nucleus. In d-Au collisions it is reported to be much, much smaller. What does this mean? The size of deuteron nucleus or of nucleon? Or something even much smaller? Hardly so if one believes in QCD picture. If this is however the case, the only reasonable candidate for its size would be the longitudinal size scale of colliding nucleon-nucleon system of order $L = \hbar/\sqrt{s}$ if an object with this size is created in the collision. I did my best to find some estimate for the very small size of the hot spot from articles some related to the study but failed [C81, C82, C91]: paranoid would see this as a conspiracy to keep this as a state secret.

How to understand the findings?

I have already earlier considered the basic characteristics of the collisions. What is called QGP does not behave at all like plasma phase for which one would expect particle distributions mimicking blackbody radiation of quarks and gluons. Strong correlations are found between charged particles created in the collision and the best manner to describe them is in terms of a creation of longitudinal string-like objects parallel to the collision axes.

In TGD framework this observation leads to the proposal that the string like objects could be assigned with M_{89} hadron physics introduced much earlier to explain strange cosmic ray events like Centauro. The p-adic mass scale assignable to M_{89} hadron physics is obtained from that of electron (given by p-adic thermodynamics in good approximation by $m_{127} = m_e/\sqrt{5}$) as $m_{89} = 2^{(127-89)/2} \times m_e/\sqrt{5}$. This gives $m_{89} = 111.8$ GeV. This is conveniently below the cm mass of nucleon pair in all the experiments.

In standard approach based on QCD the description is completely different. The basic parameters are now thermodynamical. One assumes that thermalized plasma phase is created and is parametrized by the energy density assignable to gluon fields for which QCD gives the estimate $\epsilon \geq 1$ GeV/fm^3 and by temperature which is about $T = 170$ GeV and more or less corresponds to QCD Λ. One can think of the collision regions as highly flattened pancake (Lorentz contraction) containing very density gluon phase called color glass condensate, which would be something different from QGP and definitely would not conform with the expectations from perturbative QCD since QGP would be precisely a manifestation of perturbative QGP [C91].

Also a proposal has been made that this phase could be described by AdS/CFT correspondence non-perturbatively - again in conflict with the basic idea that perturbative QCD should work. It has however turned out that this approach does not work even qualitatively as Bee lucidly explains this in her blog article *Whatever happened to AdS/CFT and the Quark Gluon Plasma?* (http://backreaction.blogspot.fi/2013/09/whatever-happened-to-adscft-and-quark.html).

Strangely enough, this failure of QGP and AdS/CFT picture has not created any fuss although one might think that the findings challenging the basic pillars of standard model should be seen as sensational and make happy all those who have publicly told that nothing would be more well-come than the failure of standard model. Maybe particle theorists have enough to do with worrying about the failure of standard SUSY and super string inspired particle phenomenology that they do not want to waste their time to the dirty problems of low energy phenomenology.

A further finding mentioned in the popular article is stronger charm-anticharm suppression in head-on collisions than in peripheral collisions [C105]. What is clear that if M_{89} hadrons are created, they consist of lightest quarks present in the lightest hadrons of M_{89} hadron physics - that is u and d (and possibly also s) of M_{89} hadrons, which are scaled variants of ordinary u and d quarks and decay to u and d (and possibly s) quarks of M_{107} hadron physics. If the probability of creating a hot M_{89} spot is higher in central than peripheral collisions the charm suppression is stronger. Could a hot M_{89} spot associated with a nucleon-nucleon pair heat some region around it to M_{89} hadronic phase so that charm suppression would take place inside larger volume than in periphery?

There is also the question whether the underlying mechanism relies on specks of hot QGP or some inherent property of nuclei themselves. At the first sight, the latter option could not be farther from the TGD inspired vision. However, in nuclear string model [L3] inspired by TGD nuclei consists of nucleons connected by color bonds having quark and antiquark at their ends. These bonds are characterized by rather large p-adic prime characterizing current quark mass scale of order 5-20 GeV for u and d quarks (the first rough estimate for the p-adic scales involved is $p \simeq 2^k$, $k = 121$ for 5 MeV and $k = 119$ for 20 MeV). These color bonds Lorentz contract in the longitudinal direction so that nearly longitudinal color bonds would shorten to M_{89} scale whereas transversal color bonds would get only thinner. Could they be able to transform to color bonds characterized by M_{89} and in this manner give rise to M_{89} mesons decaying to ordinary hadrons?

Flowers to the grave of particle phenomenology

The recent situation in theoretical particle physics and science in general does not raise optimism. Super string gurus are receiving gigantic prizes from a theory that was a failure. SUSY has failed in several fronts and cannot be anymore regarded as a manner to stabilize the mass of Higgs. Although the existence of Higgs is established, the status of Higgs mechanism is challenged by its un-naturalness: the assumption that massivation is due to some other mechanism and Higgs has gradient coupling provides a natural explanation for Higgs couplings. This coupling is dimensional and could be critized for this reason. Also Higgs couplings contain dimensional parameter (tachyonic Higgs mass squared).

The high priests (http://www.math.columbia.edu/~woit/wordpress/?p=6457) are however talking about "challenges" instead of failures. Even evidence for the failure of even basic QCD is accumulating as explained above. Peter Higgs, a Nobel winner of this year, commented the situation ironically (http://www.theguardian.com/science/2013/dec/06/peter-higgs-boson-acade by saying that he would have not got a job in the recent day particle physics community since he is too slow.

The situation is not much better in the other fields of science. Randy Scheckman, also this year's Nobel prize winner in physiology and medicine (http://www.theguardian.com/science/2013/dec/09/nobel-winner-boycott-science-journals) has declared boycott of top science journals Nature, Cell and Science. Scheckman said that the pressure to publish in "luxury" journals encourages researchers to cut corners and pursue trendy fields of science instead of doing more important work. The problem is exacerbated, he said, by editors who were not active scientists but professionals who favoured studies that were likely to make a splash.

Theoretical and experimental particle physics is a marvellous creation of humankind. Perhaps we should bring flowers to the grave of the particle physics phenomenology and have a five minutes' respectful silence. It had to leave us far too early.

9.5.6 Anomalous like sign dimuons at LHC?

We are not protected against particle physics rumors even during Christmas. This time the rumor was launched from the comment section of Peter Woit's blog (`http://www.math.columbia.edu/~woit/wordpress/?p=5428`) and soon propagated to the blogs of Lubos (`http://motls.blogspot.fi/2012/12/christmas-rumor-105gev-dimuon-excess-at.html#more`) and Phil Gibbs (`http://blog.vixra.org/2012/12/25/christmas-rumour/`).

The rumor says that ATLAS has observed 5 sigma excess of like sign di-muon events. This would suggests a resonance with charge $Q = \pm 2$ and muon number two. In the 3-triplet SUSY model there is a Higgs with charge 2 but the lower limit for its mass is already now around 300-400 GeV. Rumors are usually just rumors and at this time the most plausible interpretation is as a nasty joke intended to spoil the Christmas of phenomenologists. Lubos however represents a graph from a publication of ATLAS (`http://arxiv.org/abs/1210.5070`) [C51] based on 2011 data giving a slight support for the rumor. The experiences during last years give strong reasons to believe that statistical fluctuation is in question. Despite this the temptation to find some explanation is irresistible.

TGD view about color allows charge 2 leptomesons

TGD color differs from that of other unified theories in the sense that colored states correspond to color partial waves in CP_2. Most of these states are extremely massive but I have proposed that light color octet leptons are possible [K70], and there is indeed some evidence for pion like states with mass very near to $m = 2m_L$ for all charged lepton generations decaying to lepton-antilepton pairs and gamma pairs also p-adically scaled up variant having masses coming as octaves of the lowest state have been reported for the tau-pion.

Since leptons move in triality zero color partial waves, color does not distinguish between lepton and anti-lepton so that also leptons with the same charge can in principle form a pion-like color singlet with charge $Q = \pm 2$. This is of course not possible for quarks. In the recent case the p-adic prime should be such that the mass for the color octet muon is 105/2 GeV which is about $2^9 m(\mu)$, where $m(\mu) = 105.6$ MeV is the mass of muon. Therefore the color octet muons would correspond to $p \simeq 2^k$, $k = k(\mu) - 2 \times 9 = 113 - 18 = 95$, which not prime but is allowed by the p-adic length scale hypothesis.

But why just $k = 95$? Is it an accident that the scaling factor is same as between the mass scales of the ordinary hadron physics characterized by M_{107} and M_{89} hadron physics? If one applies the same argument to tau leptons characterized by M_{107}, one finds that like sign tau pairs should result from pairs of M_{89} τ leptons having mass $m = 512 \times 1.776 GeV = 909$ GeV. The mass of resonance would be twice this. For electron one has $m = 512 \times .51$ MeV= 261.6 MeV with resonance mass equal to 523.2 MeV. Skeptic would argue that this kind of states should have been observed for long time ago if they really exist.

Production of parallel gluon pairs from the decay of strings of M_{89} hadron physics as source of the leptomesons?

The production mechanism would be via two-gluon intermediate states. Both gluons would decay to unbound colored lepton-antilepton pair such that the two colored leptons and two antileptons would fuse to form two like sign lepton pairs. This process favors gluons moving in parallel. The required presence of also other like sign lepton pair in the state might allow to kill the hypothesis easily.

The presence of parallel gluons could relate to the TGD inspired explanation [K37] for the correlated charged particle pairs observed in proton proton collisions (QCD predicts quark gluon plasma and the absence of correlations) in terms of M_{89} hadron physics. The decay of M_{89} string like objects is expected to produce not only correlated charged pairs but also correlated gluon pairs with members moving in parallel or antiparallel manner. Parallel gluons could produce like sign di-muons and di-electrons and even pairs of like sign μ and e. In the case of ordinary hadron physics this mechanism would not be at work so that one could understand why resonances with electron number two and mass 523 MeV have not been observed earlier.

Even leptons belonging to different generations could in principle form this kind of states and Phil Gibbs has represented a graph which he interprets as providing indications for a state with mass around 105 GeV decaying to like sign μ e pairs. In this case one would however expect that mass is roughly 105/2 GeV since electron is considerably lighter than muon in given p-adic length scale.

The decay of bound states of two colored leptons with same (or opposite) charge would require a trilinear coupling gLL_8 analogous to magnetic moment coupling. Color octet leptons L_8 would transform to ordinary leptons by gluon emission.

To sum up, if the rumor is true, then M_{89} hadron physics would have begun to demonstrate its explanatory power. The new hadron physics would explain the correlated charged particle pairs not possible to understand in high energy QCD. The additional gamma pair background resulting from the decays of M_{89} pions could explain the two-gamma anomaly of Higgs decays, and also the failure to get same mass for the Higgs from ZZ and gamma-gamma decays. One should not forget that M_{89} pion explains the Fermi bump around 135 GeV. And it would also explain the anomalous like sign lepton pairs if one accepts TGD view about color.

9.6 QCD and TGD

During last week I have been listening some very inspiring Harward lectures relating to QCD, jets, gauge-gravity correspondence, and quark gluon plasma. Matthew Schwartz gave a talk titled *The Emergence of Jets at the Large Hadron Collider* [C165]. Dam Thanh Son gave a talk titled *Viscosity, Quark Gluon Plasma, and String Theory* [C169]. Factorization theorems of jet QCD discussed in very clear manner by Ian Stewart [C170] in this talk titled *Mastering Jets: New Windows into Strong Interaction and Beyond*.

These lecture inspired several blog postings and also the idea about systematical comparison of QCD and TGD. This kind of comparisons are always very useful - at least to myself - since they make it easier to see why the cherished beliefs- now the belief that QCD is *the* theory of strong interactions - might be wrong.

There are several crucial differences between QCD and TGD.

(a) The notion of color is different in these two theories. One prediction is the possibility of lepto-hadron physics [K70] involving colored excitations of leptons.

(b) In QCD AdS/CFT duality is hoped to allow the description of strong interactions in long scales where perturbative QCD fails. The TGD version of gauge-gravity duality is realized at space-time level and is much stronger: string-parton duality is manifest at the level of generalized Feynman diagrams.

(c) TGD form of gauge-gravity duality suggests a stronger duality: p-adic-real duality. This duality allows to sum the perturbation theories in strong coupling regime by summing the p-adic perturbation series and mapping it to real one by canonical correspondence between p-adics and reals. This duality suggests that factorization "theorems" have a rigorous basis basis due to the fact that quantum superposition of amplitudes would be possible inside regions characterized by given p-adic prime. p-Adic length scale hypothesis suggests that p-adically scaled up variants of quarks are important for the understanding of the masses of low lying hadrons. Also scaled up versions of hadron physics are important and both Tevatron and LHC have found several indications for M_{89} hadron physics.

(d) Magnetic flux tubes are the key entities in TGD Universe. In hadron physics color magnetic flux tubes carrying Kähler magnetic monopole fluxes would be responsible for the non-perturbative aspects of QCD [K27]. Reconnection process for the flux tubes (or for the corresponding strings) would be responsible for the formation of jets and their hadronization. Jets could be seen as structures connected by magnetic flux tubes to form a connected structure and therefore as hadron like objects. Ideal QCD plasma would be single hadron like objects. In QCD framework quark-gluon plasma would be more naturally gas of partons.

(e) Super-symmetry in TGD framework differs from the standard SUSY and the difficult-to-understand X and Y bosons believed to consist of charmed quark pair force to consider the possibility that they are actually smesons rather than mesons [K37]. This leads to a vision in which squarks have the same p-adic length scale as quarks but that the strong mixing between smesons and mesons makes second mass squared eigenstate tachyonic and thus unphysical. This together with the fact that shadronization is a fast process as compared to electroweak decays of squarks weak bosons and missing energy would explain the failure to observer SUSY at LHC.

(f) p-Adic length scale hypothesis leads to the prediction that hadron physics should possess scaled variants. A good guess is that these scaled variants correspond to ordinary Mersenne primes $M_n = 2^n - 1$ or Gaussian (complex) Mersenne primes. $M_{89} = 2^{89} - 1$ hadron physics would be one such scaled variant of hadron physics. The mass scale of hadrons would be roughly 512 higher than for ordinary hadrons, which correspond to M_{107}. In zero energy ontology Higgs is not necessarily needed to give mass for gauge bosons and if Higgs like states are there, all of them are eaten by states which become massive. Therefore Higgs would be only trouble makers in TGD Universe.

    The neutral mesons of M_{89} hadron physics would however give rise to Higgs like signals since their decay amplitudes are very similar to those of Higgs even at quantitative level if one accepts the generalization of partially conserved axial current hypothesis [K37] [L16].

    The recent reports by ATLAS and CMS about Higgs search support the existence of Higgs like signal around about 125 GeV. In TGD framework the interpretation would be as pion like state. There is however also evidence for Higgs like signals at higher masses and standard Higgs is not able to explain this signals. Furthermore, Higgs with about 125 GeV mass is just at the border of vacuum stability, and new particles would be needed to stabilize the vacuum. The solution provided by TGD is that entire scaled up variant of hadron physics replaces Higgs. Within a year it should become clear whether the observed signal is Higgs or pionlike state of M_{89} hadron physics or something else.

9.6.1 How the TGD based notion of color differs from QCD color

TGD view about color is different from that of QCD. In QCD color is spin like quantum number. In TGD Universe it is like angular momentum and one can speak about color partial waves in CP_2. Quarks and leptons must have non-trivial coupling to CP_2 Kähler gauge potential in order to obtain a respectable spinor structure. This coupling is odd multiplet of Kähler gauge potential and for $n = 1$ for quarks and $n = 3$ for leptons one obtains a geometrization of electro-weak quantum numbers in terms of induced spinor structure and geometrization of classical and color gauge potentials. This has several far reaching implications.

(a) Lepton and baryon numbers are separetely conserved. This is not possible in GUTs. Despite the intense search no decays of proton predicted by GUTs have been observed: a strong support for TGD approach.

(b) Infinite number of color partial waves can assigned to leptons and quarks and they obey the triality rule: $t = 0$ or leptons and $t = +1/-1$ for quarks/antiquarks. The color partial waves however depend on charge and CP_2 handedness and therefore on M^4

chirality. The correlation is not correct. Also the masses are gigantic of order CP_2 mass as eigenvalues of CP_2 Laplace operator. Only right handed covariantly constant lepton would have correct color quantum numbers.

The problem can be cured if one accepts super-conformal invariance. Conformal generators carrying color contribute to the color quantum numbers of the particle state. p-Adic mass calculations show that if ground states have simple negative conformal weight making it tachyon, it is possible to have massless states with correct correlation between electroweak quantum numbers and color¿ [K34].

(c) Both leptons and quarks have color excited states. In leptonic sector color octet leptons are possible and there is evidence already from seventies that states having interpretation as lepto-pion are created in heavy ion collisions [K70]. During last years evidence for muo-pions and tau-pions has emerged and quite recently CDF provided additional evidence for tau-pions.

Light colored excitations of leptons and quarks are in conflict what is known about the decay width of intermediate gauge bosons and the way out is to assume that these states are dark matter in the sense that they have effective value of Planck constant coming as integer multiple of the ordinary Planck constant [K22]. Only particles with the same value of Planck constant can appear in the same vertex of generalized Feynman diagram so that these particles are dark in the weakest possible sense of the world. The Planck constant can however change when particle tunnels between different sectors of the generalized imbedding spaces consisting of coverings of the imbedding space $M^4 \times CP_2$.

The attribute "effective" applies in the simplest interpretation for the dark matter hierarchy based on many-valuedness of the normal derivatives of the imbedding space coordinates as functions of the canonical momentum densities of Kähler action. Many-valuedness is implied by the gigantic vacuum degeneracy of Kähler action: any 4-surfce with CP_2 projection which is Lagrangian manifold of CP_2 is vacuum extremal and preferred extremals are deformations of these. The branches co-incide at 3-D space-like ends of the space-time surface at boundaries of CD and at 3-D light-like orbits of wormhole throats at which the signature of the induced metric changes. The value of the effective Planck constant corresponds to the number of sheets of this covering of imbedding space and there are arguments suggesting that this integer is product of two integers assignable to the multiplicities of the branches of space-like 3-surfaces and light-like orbits. At partonic 2-surfaces the degeneracy is maximal since all $n = n_1 \times n_2$ sheets co-incide. This structure brings very strongly in mind the stack of branes infinitesimally near to each other appearing in AdS/CFT duality. TGD analogs of 3-branes of the stacks would be distinct in the interior of the space-time surface.

(d) TGD predicts the presence of long ranged classical color gauge potentials identified as projections of CP_2 Killing forms to the space-time surface. Classical color gauge fields are proportional to induced Kähler form and Hamiltonians of color isometries: $G_A = H_A J$. Alle components of the classical gluon field have the same direction. Also long ranged classical electroweak gauge fields are predicted and one of the implications is an explanation for the large parity breaking in living matter (chiral selection of molecules).

Long ranged classical color fields mean a very profound distinction between QCD color and TGD color and in TGD inspired hadron physics color magnetic flux tubes carrying classical color gauge fields are responsible for the strong interactions in long length scales. These color magnetic fields carrying Kähler magnetic monopole fluxes are absolutely essential in TGD based view about quark distribution functions and hadronic fragmentation functions of quarks and represent the long range hadron physics about which QCD cannot say much using analytic formulas: numerical lattice calculations provide the only manner to tackle the problem.

(e) Twistorial approach to $\mathcal{N} = 4$ super-symmetric gauge theory could be seen as a diametrical opposite of jet QCD. It has been very successful but it is perturbative approach and I find it difficult to see how it could produce something having the explanatory power of color magnetic flux tubes.

9.6.2 Basic differences between QCD and TGD

The basic difference between QCD and TGD follow from different views about color, zero energy ontology, and from the notion of generalized Feynman diagram.

Generalized Feynman diagrams and string-parton duality as gauge-gravity duality

Generalized Feynman diagrams reduce to generalized braid diagrams [K27]. Braid strands have unique identification as so called Legendrean braids identifiable as boundaries of string world sheets which are minimal surfaces for which area form is proportional to Kähler flux. One can speak about sub-manifold braids.

There are no $n > 2$-vertices at the fundamental braid strand level. Together with the fact that in zero energy ontology (ZEO) all virtual states consist of on mass shell massless states assignable to braid strands, this means that UV and IR infinities are absent. All physical states are massive bound states of massless on mass shell states. Even photon, gluon, and graviton have small masses. No Higgs is needed since for the generalized Feynman diagrams the condition eliminating unphysical polarizations eliminates only the polarization parallel to the projection of the total momentum of the particle to the preferred plane M^2 defining the counterpart of the plane in which one usually projects Feynman diagrams.

The crossings for the lines of non-planar Feynman diagrams represent generalization of the crossings of the braid diagrams and integrable M^2 QFT is suggested to describe the braiding algebraically. This would mean that non-planar diagrams are obtained from planar ones by braiding operations and generalized Feynman diagrams might be constructed like knot invariants by gradually trivializing the braid diagram. This would allow to reduce the construction of also non-planar Feynman amplitudes to twistorial rules.

One can interpret gluons emission by quark as an emission of meson like state by hadron. This duality is exact and does not requires $N_c \to \infty$ limit allowing to neglect non-planar diagrams as AdS/CFT correspondence requires. The interpretation is in terms of duality: one might call this duality parton-hadron duality, gauge-gravity duality, or particle-string duality.

Q^2 dependent quark distribution functions and fragmentation functions in zero energy ontology

Factorization of the strong interaction physics in short and long time scales is one of the basic assumptions of jet QCD and originally motivated by parton model which preceded QCD [C136, C137]. The physical motivation for the factorization in higher energy collision is easy to deduce at the level of parton model. By Lorentz contraction of colliding hadrons look very thin and by time dilation the collision time is very long in cm system. Therefore the second projectile moves in very short time through the hadron and sees the hadron in frozen configuration so that the state of the hadron can be thought of as being fixed during collision and partons interact independently. This looks very clear intuitively but it is not at all clear whether QCD predicts this picture.

1. Probabilistic description of quarks in ZEO

Probabilistic description requires further assumptions. Scattering matrix element is in good approximation sum over matrix elements describing scattering of partons of hadron from -say- the partons of another hadron or from electron. Scattering amplitudes in the sum reduce to contractions of current matrix elements with gluon or gauge boson propagator. Scattering probability is the square of this quantity and contains besides diagonal terms for currents also cross terms. Probabilistic description demands that the sum of cross terms can be neglected. Why the phases of the terms in this sum should vary randomly? Does QCD really imply this kind of factorization?

Could the probabilistic interpretation require and even have a deeper justification?

(a) p-Adic real correspondence to be discussed in more detail below suggest how to proceed. Quarks with different p-adic mass scales can correspond to different p-adic number fields with real amplitudes or probabilities obtained from their p-adic counterparts by canonical identificaton. Interference makes sense only for amplitudes in the same number field. Does this imply that cross terms involving different p-adic primes cannot appear in the scattering amplitudes?

(b) Should one assume only a density matrix description for the many quark states formed from particles with different values of p-adic prime p? If so the probabilistic description would be un-avoidable. This does not look an attractive idea as such. Zero energy ontology however replaces density matrix with M-matrix defined as the hermitian square root of the density matrix multiplied by a universal unitary S-matrix. The modulus squared of M-matrix element gives scattering probability.

One can one imagine that M-matrix at least approximately decomposes to a tensor product of M-matrices in different length scales: these matrices could correspond to different number fields before the map to real numbers and probabilities could be formed as "numbers" in the tensor product of p-adic number fields before the mapping to real numbers by canonical identification.

In finite measurement resolution one sums over probabilities in short length scales so that the square of M-matrix in short scale gives density matrix. Could this lead to a probabilistic description at quark level? Distribution functions and fragmentation functions could indeed correspond to these probabilities since they emerge in QCD picture from matrix elements between initial and final states of quark in scattering process. Now these states correspond to the positive and negative energy parts of zero energy state.

2. Q^2 dependence of distribution and fragmentation functions in ZEO

The probabilistic description of the jet QCD differs from that of parton model in that the parton distributions and fragmentation functions depend on the value of Q^2, where Q is defined as the possibly virtual momentum of the initial state of the parton level system. Q could correspond to the momentum of virtual photon annihilation to quark pair in the annihilation of e^+e^- pair to hadrons, to the virtual photon decaying to $\mu^+\mu^-$ pairs and emitted by quark after quark-quark scattering in Drell-Yan process, or to the momentum of gluon or quark giving rise to a jet, ... What is highly non-trivial is that distribution and fragmentation functions are universal in the sense that they do not depend on the scattering process. Furthermore, the dependence on Q^2 can be determined from renormalization group equations [C136, C137].

What does Q^2s dependence mean in TGD framework?

(a) In partonic model this dependence looks strange. If one thinks the scattering at quantum level, this dependence is very natural since it corresponds to the dependence of the matrix elements of current operators on the momentum difference between quark spinors in the matrix element. In QCD framework Q^2 dependence is not mysterious. It is the emergence of probabilistic description which is questionable in QFT framework.

(b) One could perhaps say that Q^2 represents resolution and that hadron looks different in different resolutions. One could also say that there is no hadron "an sich": what hadron looks like depends on the process used to study it.

(c) In zero energy ontology the very notion of state changes. Zero energy state corresponds to physical event or quantum superposition of them with M-matrix defining the time like entanglement coefficient and equal to a hermitian square root of density matrix and S-matrix. In this framework different values of Q correspond to different momentum differences for spinor pairs appearing in the matrix element of the currents and Q^2 dependence of the probabilistic description is very natural. The universality of distribution and fragmentation functions follows in zero energy ontology if one assumes the factorization of the dynamics in different length scales. This should follow from the universality of the S-matrix in given number field (in given p-adic length scale).

9.6.3 p-Adic physics and strong interactions

p-Adic physics provides new insights to hadron physics not provided by QCD.

p-Adic real correspondence as a new symmetry

The exactness of the gauge-gravity duality suggests the presence of an additional symmetry. Perhaps the non-converging perturbative expansion at long scales could make sense after all in some sense. p-Adic-real duality suggests how.

(a) The perturbative expansion is interpreted in terms of p-adic numbers and the effective coupling constant g^2MN_c is interpreted as p-adic number which for some preferred primes is proportional to the p-adic prime p and therefore p-adically small. Hence the expansion converges rapidly p-adically. The p-adic amplitudes would be obtained by interpreting momenta as p-adic valued momenta. If the momenta are rationals not divisible by any non-trivial power of p the canonical identification maps the momenta to themselves. If momenta are small rationals this certainly makes sense but does so also more generally.

(b) The converging p-adic valued perturbation series is mapped to real numbers using the generalization of the canonical identification appearing in quantum arithmetics [K76]. The basic rule is simple: replace powers of p with their inverses everywhere. The coefficients of powers of p are however allowed to be rationals for which neither numerator or denominator is divisible by p. This modification affects the predictions of p-adic mass calculations only in a negligible manner.

(c) p-Adic-real duality has an interpretation in terms of cognition having p-adic physics as a correlate: it maps the physical system in long length scale to short length scales or vice versa and the image of the system assigning to physical object thought about it or vice versa provides a faithful representation. Same interpretation could explain also the successful p-adic mass calculations. It must be emphasized that real partonic 2-surfaces would obey effective p-adic topology and this would be due to the large number of common points shared by real and p-adic partonic 2-surfaces. Common points would be rational points in the simplest picture: in quantum arithmetics they would be replaced by quantum rationals.

p-Adic-real correspondence generalizes the canonical identification used to map the p-adic valued mass squared predicted by p-adic thermodynamics as the analog of thermal energy to a real number. An important implication is that *p-adic mass squared value is additive* [K43].

(a) For instance, for mesons consisting of pairs of quark and its antiquark the values of p-adic mass squared for quark and antiquark are additive and this sum is mapped to a real number: this kind of additivity was observed already at early days of hadron physics but there was no sensible interpretation for it. In TGD framework additivity of the scaling generator of Virasoro algebra is in question completely analogous to the additivity of energy.

(b) For mesons consisting of quarks labelled by different value of p-adic prime p, one cannot sum mass squared values since they belong to different number fields. One must map both of them first to real numbers and after this sum real mass values (rather than mass squared values).

This picture generalizes. Only p-adic valued amplitudes belonging to same p-adic number field and therefore corresponding to the same p-adic length scales can be summed. There is no interference between amplitudes corresponding to different p-adic scales.

(a) This could allow to understand at deeper level the somewhat mysterious and ad hoc assumption of jet QCD that the strong interactions in long scales and short scales factorize at the level of probabilities. Typically the reaction rate is expressible using products of probabilities. The probability for pulling out quarks from colliding protons (non-perturbative QCD), the probability describing parton level particle reaction (perturbative QCD), and the probability that the scattering quarks fragment to the final state hadrons (non-perturbative QCD). Ordinary QCD would suggest the analog of this formula but with probability amplitudes replacing probabilities and in order to obtain a probabilistic description one must assume that various interference terms sum up to zero (de-coherence). p-Adic-real duality would predict the relative docoherence of different scales as an exact result. p-adic length scale hypothesis would also allow to define the notion of scale precisely. From the stance provided by TGD it seems quite possible that the standard belief that jet QCD follows from QCD is simply wrong. The repeated emphasis of this belief is of course part of the liturgy: it would be suicidical for a specialist of jet QCD to publicly conjecture that jet QCD is more than QCD.

(b) The number theoretical de-coherence would be very general and could explain the somewhat mysterious de-coherence phenomenon. Decoherence could have as a number theoretical correlate the decomposition of space-time surfaces to regions characterized by different values of p-adic primes. In given region the amplitudes would be constructed as p-adic valued amplitudes and then mapped to real amplitudes by canonical identification. A space-time region characterized by given p would be the number theoretical counterpart of the coherence region. The regions with different value of p would behave classically with respect to each other and region with given p could understand what happens in regions with different values of p using classical probability. This would also the resolve paradoxes like whether the Moon is there when no-one is looking. It could also mean that the anti-commutative statistics for fermions holds true only for fermionic oscilator operators associated with a space-time region with given value of p-adic prime p. Somewhat ironically, p-adic physics would bring quantum reality much nearer to the classical reality.

Logarithmic corrections to cross sections and jets

Even in the perturbative regime exclusive cross sections for parton-parton scattering contain large logarithmic corrections of form $log(Q^2/\mu^2)$ [C136], where Q is cm energy and μ is mass scale which could be assigned to quark or - perhaps more naturally - to jet. These corrections spoil the convergence of the perturbative expansion at $Q^2 \to \infty$ limit. One can also say that the cross sections are singular at the limit of vanishing quark mass: this is the basic problem of the twistor approach.

For "infra-red safe" cross sections the logarithmic singularities can be eliminated by summing over all initial and final states not distinguishable from each other in the energy and angle resolutions available. It is indeed impossible to distinguish between quark and quark and almost collinear soft gluon and one must therefore sum over all final states containing soft gluons. A simple example about IR safe cross section is the cross section for e^+e^- annihilation to hadrons in finite measurement resolution, from which logarithms $log(Q/\mu)$ disappear.

In hadronic reactions jets are studied instead of hadrons. IR safety is one criterion for what it is to be a jet. Jet can be imagined to result as a cascade. Parton annihilates to a pair of partons, resulting partons annihilate into softer partons, and so on... The outcome is a cascade of increasingly softer partons. The experimental definition of jet ris constrained by a finite measurement resolution for energy and angle, and jet is parameterized by the cm energy Q, by the energy resolution ϵ, and by the jet opening angle δ: apart from a fraction ϵ all cm energy Q of the jet is contained within a cone with opening angle δ. According to the estimate [C136] the mass scale of the jet resulting at the k:th step of the cascade is roughly $\delta^k Q$.

What could be the counterpart for this description of jets in TGD framework?

(a) Jet should be a structure with a vanishing total Kähler magnetic charge bound by flux tubes to a connected hadron like structure. By hadron-parton duality gluon emission from quark has interpretation as a meson emission from hadron: jets could be also interpreted as collections of hadrons at different space-time sheets. Reconnection process could play a key role in the decay of jet to hadrons. p-Adic length scale hypothesis suggests the interpretation of jets as hadron like objects which are off mass shell in the sense that the p-adic prime $p \simeq 2^k$ characterizing the jet space-time sheets is smaller than M_{107} characterizing the final state hadrons. One could say that jets represent p-adically hot hadron-like objects which cool and decay to hadrons. If so, the transition from M_{107} hadron physics to M_{89} hadron physics could be rather smooth. The only new thing would be the abnormally long lifetime of M_{89} hadrons formed as intermediate states in the process.

(b) p-Adic length scale hypothesis suggests that the p-adic length scale assignable to the parton (hadron like object) at the $k+1$:th step is by power of $\sqrt{2}$ longer than that associated with k:th step: $p \rightarrow p_{next} \simeq 2 \times p$ is the simplest possibility. The naive formula $Q(k+1) \sim \delta \times Q(k)$ would probably require a generalization to $Q(k+1) \sim 2^{-r/2} \times Q(k)$, r integer with $\delta = 2^{-nr/2} \times 2\pi$, n an integer. $r = 1$ would be the simplest option. The cascade at the level of jet space-time sheets would stop when the p-adic length scale corresponds to M_{107}, which corresponds to .5 GeV mass scale. At the level of quarks one can imagine a similar cascade stopping at p-adic length scales corresponding to the mass scale about 5 MeV for u and d quarks.

(c) Zero energy ontology brings in natural IR cutoffs since also gluons have small mass. Final and initial state quarks could emit only a finite number of gluons as brehmstrahlung and soft gluons could not produce IR divergences.

(d) The notion of finite measurement resolution in QCD involves the cone opening angle δ and energy resolution characterized by ϵ. In TGD framework the notion of finite measurement resolution is fundamental and among other things implies the description in terms of braids. Could TGD simplify the QCD description for finite measurement resolution? Discretization in the space of momentum directions is what comes in mind first and is strongly suggested also by the number theoretical vision. One would not perform integral over the cone but sum over all events producing quark and a finite number of collinear gluons with an upper bound form them deducible from cm energy and gluon mass. For massive gluons the number of amplitudes to be summed should be finite and the jet cascade would have only finite number of steps.

Could number theoretical constraints allow additional insights? Are the logarithmic singularities present in the p-adic approach at all? Are they consistent with the number theoretical constraints?

(a) The p-adic amplitudes might well involve only rational functions and thus be free of logarithmic singularities resulting from the loop integrals which are dramatically simplified in zero energy ontology by on mass shell conditions for massless partonic 2-surfaces at internal lines.

(b) For the sheer curiousity one can consider the brehmstrahlung from a quark characterized by p-adic prime p. Do the logarithms $log((Q^2/\mu^2)$, where μ^2 is naturally p-adic mass scale, make sense p-adically? This is the case of one has $Q^2/\mu^2 = (1 + O(p))$. The logarithm would be of form $O(p)$ and p-adically very small. Also its real counterpart obtained by canonical identification would be very small for $O(p) = np$, $n << p$. For $Q^2/mu^2 = m(1 + O(p))$, m integer, one must introduce an extension of p-adic numbers guaranteeing that $log(m)$ exists for $1 < m < p$. Only single logarithm $log(a)$ and its powers are needed since for primitive roots a of unity one as $m = a^n \mod p$ for some n. Since the powers of $log(a)$ are algebraically independent, the extension is infinite-dimensional and therefore can be questioned.

(c) For the original form of the canonical identification one would have $O(p) = np$. In the real sense the value of Q^2 would be gigantic for $p = M_{107}$ (say). p-Adically Q^2 would be extremely near to μ^2. The modified form of canonical identification replaces pinary expansion $x = \sum x_n p^n$, $0 \leq x_n < p$, of the p-adic integer with the quantum rational $q = \sum q_n p^n$, where q_n are quantum rationals, which are algebraic numbers involving only the quantum phase $e^{i2\pi/p}$ and are not divisible by any power of p [K76].

This would allow physically sensible values for $Q^2/mu^2 = 1 + qp + ..$ in the real sense for arbitrarily large values of p-adic prime. In the canonical identification they would be mapped to $Q^2/mu^2 = 1 + q/p + ..$ appearing in the scattering amplitude. For q/p near unity logarithmic corrections could be sizeable. If qp is of order unity as one might expect, the corrections are of order q/p and completely negligible. Even at the limit $Q^2 \to \infty$ understood in the real sense the logarithmic corrections would be always negligible if Q^2 is p-adic quantum rational. Similar extremely rapid convergence characterizes p-adic thermodynamics [K34] and makes the calculations practically exact. Smallness of logarithmic corrections quite generally could thus distinguish between QCD and TGD.

(d) In p-adic thermodynamics the p-adic mass squared defined as a thermal average of conformal weight is a ratio of two quantities infinite as real numbers. Even when finite cutoff of conformal weight is introduced one obtains a ratio of two gigantic real numbers. The limit taking cutoff for conformal weight to infinity does not exist in real sense. Does same true for scattering amplitudes? Quantum arithmetics would guarantee that canonical identification respects discretized symmetries natural for a finite measurement resolution.

p-Adic length scale hypothesis and hadrons

Also p-adic length scale hypothesis distinguishes between QCD and TGD. The basic predictions are scaled variants of quarks and the TGD variant of Gell-Mann Okubo mass formula indeed assumes that in light hadrons quarks can appear in several p-adic mass scales. One can also imagine the possibility that quarks can have short lived excitations with non-standar p-adic mass scale. The model for tau-pion needed to explain the 3-year old CDF anomaly for which additional support emerged recently, assumes that color octet version of tau lepton appears as three different mass scales coming as octaves of the basic mass scale [K70]. Similar model has been applied to explain also some other other anomalies.

M_{89} hadron physics corresponds to a p-adic mass scale in TeV range [K37]: the proton of M_{89} hadron physics would have mass near 500 GeV if naive scaling holds true. The findings from Tevatron and LHC have provided support for the existence of M_{89} mesons and the bumps usually seen as evidence for Higgs would correspond to the mesons of M_{89} hadron physics. It is a matter of time to settle whether M_{89} hadron physics is there or not.

9.6.4 Magnetic flux tubes and and strong interactions

Color magnetic flux tubes carrying Kähler magnetic monopole flux define the key element of quantum TGD and allow precise formulation for the non-perturbative aspects of strong interaction physics.

Magnetic flux tube in TGD

The following examples should make clear that magnetic flux tubes are the central theme of entire TGD present in all scales.

(a) Color magnetic flux tubes are the key element of hadron physics according to TGD and will be discussed in more detail below.

(b) In TGD Universe atomic nucleus is modelled as nuclear string with nucleons connected by color magnetic flux tubes which have length of order Compton length of u and d quark [K63, L3]. One of the basic predictions is that the color flux tubes can be also charged. This predicts a spectrum of exotic nuclei. The energy scale of these states could be small and measured using keV as a natural unit. These exotic states with non-standard value of Planck constant giving to the flux tubes the size of the atom and the scaling up electroweak scale to atomic scale could explain cold fusion for which empirical support is accumulating.

(c) Magnetic flux tubes are also an essential element in the model of high T_c super conductivity. The transition to super-conductivity in macroscopic scale would be a percolation type process in which shorter flux tubes would combine at critical point to form long flux tubes so that the supra currents could flow over macroscopic distances [K11]. The basic prediction is that there are two critical temperatures. Below the first one the super-conductivity is possible for "short" flux tubes and at lower critical temperature the "short" flux tubes fuse to form long flux tubes. Two critical temperatures have been indeed observed.

(d) Magnetic flux tubes carrying dark matter are the corner stone of TGD inspired quantum biology, where the notion of magnetic body is in a central role. For instance, the vision about DNA as topological quantum computer is based on the braiding of flux tubes connecting DNA nucleotides and the lipids of nuclear or cellular membrane [K21].

(e) In the very early TGD inspired cosmology [K60] string like objects with 2-D M^4 projection are the basic objects. Cosmic evolution means gradual thickening of their M^4 projection and flux conservation means that the flux weakens. If the lengths of the flux tubes increase correspondingly, magnetic energy is conserved. Local phase transitions increasing Planck constant locally can occur and led to a thickening of the flux tube and liberation of magnetic energy as radiation which later gives rise to radiation and matter. This mechanism replaces the decay of the energy of inflation field to radiation as a mechanism giving rise to stars and galaxies [K59]. The magnetic tension is responsible for the negative pressures explaining accelerated expansion and magnetic energy has identification as the dark energy.

Reconnection of color magnetic flux tubes and non-perturbative aspects of strong interactions

The reconnection of color magnetic flux tubes is the key mechanism of hadronization and a slow process as compared to quark gluon emission.

(a) Reconnection vertices have interpretation in terms of stringy vertices $AB + CD \rightarrow AD + BC$ for which interiors of strings serving as representatives of flux tubes touch. The first guess is that reconnection is responsible for the low energy dynamics of hadronic collisions.

(b) Reconnection process takes place for both the hadronic color magnetic flux tubes and those of quarks and gluons. For ordinary hadron physics hadrons are characterized by Mersenne prime M_{107}. For M_{89} hadron physics reconnection process takes place in much shorter scales for hadronic flux tubes.

(c) Each quarks is characterized by a p-adic length scale: this scale characterizes the length scale of the magnetic bodies of the quark. Therefore reconnection at the level of the magnetic bodies of quarks take places in several time and length scales. For top quark the size scale of magnetic body is very small as is also the reconnection time scale. In the case of u and d quarks with mass in MeV range the size scale of the magnetic body would be of the order of electron Compton length. This scale assigned with quark is longer than the size scale of hadrons characterized by M_{89}. Classically this does not make sense but in quantum theory Uncertainty Principle predicts it from the smallness of the light quark masses as compared to the hadron mass. The large size of the color magnetic body of quark could explain the strange finding about the charge radius of proton [K37].

(d) Reconnection process in the beginning of proton-proton collision would give rise to the formation of jets identified as big hadron like entities connected to single structure by color magnetic flux tubes. The decay of jets to hadrons would be also reconnection process but in opposite time direction and would generate the hadrons in the final state (negative energy part of the zero energy state). The short scale process would be the process in which partons scatter from each other and produce partons. These processes would have a dual description in terms of hadronic reactions.

(e) Factorization theorems are the corner stone of jet QCD. They are not theorems in the mathematical sense of the word and one can quite well ask whether they really follow from QCD or whether they represent correct physical intuitions transcending the too rigid framework provided by QCD as a gauge theory. Reconnection process would obviously represent the slow non-perturbative aspects of QCD and occur both for the flux tubes associated with quarks and those assignable to hadrons. Several scales would be present in case of quarks corresponding to p-adic length scales assigned to quarks which even in light hadrons would depend on hadron [K43]. The hadronic p-adic length scale would correspond to Mersenne prime M_{107}. One of the basic predictions of TGD is the existence of M_{89} hadron physics and there are several indications that LHC has already observed mesons of this hadron physics. p-Adic-real duality would provide a further mathematical justification for the factorization theorems as a consequence of the fact that interference between amplitudes belong to different p-adic number fields is not possible.

Reconnection process is not present in QCD although it reduces to string re-connection in the approximation that partonic 2-surfaces are replaced by braids. An interesting signature of 4-D stringyness is the knotting of the color flux tubes possible only because the strings reside in 4-D space-time. This braiding ad knotting could give rise to effects not predicted by QCD or at least its description using AdS/CFT strings. The knotting and linking of color flux tubes could give rise to exotic topological effects in nuclear physics if nuclei are nuclear strings.

Quark gluon plasma

A detailed qualitative view about quark-gluon plasma in TGD Universe can be found from [K27].

(a) The formation of quark gluon plasma would involve a reconnection process for the magnetic bodies of colliding protons or nuclei in short time scale due to the Lorentz contraction of nuclei in the direction of the collision axis. Quark-gluon plasma would correspond to a situation in which the magnetic fluxes are distributed in such a manner that the system cannot be decomposed to hadrons anymore but acts like a single coherent unit. Therefore quark-gluon plasma in TGD sense does not correspond to the thermal quark-gluon plasma in the naive QCD sense in which there are no long range correlations. Ideal quark gluon plasma is like single very large hadron rather than a gas of partons bound to single unit by the conservation of magnetic fluxes connecting the quarks and antiquarks.

(b) Long range correlations and quantum coherence suggest that the viscosity to entropy ratio is low as indeed observed [K37]. The earlier arguments suggest that the preferred extremals of Kähler action have interpretation as perfect fluid flows [K23]. This means at given space-time sheet allows global time coordinate assignable to flow lines of the flow and defined by conserved isometry current defining Beltrami flow. As a matter fact, all conserved currents are predicted to define Beltrami flows. Classically perfect fluid flow implies that viscosity, which is basically due to a mixing causing the loss of Beltrami property, vanishes. Viscosity would be only due to the finite size of space-time sheets and the radiative corrections describable in terms of fractal hierarchy CDs within CDs. In quantum field theory radiative corrections indeed give rise to the absorbtive parts of the scattering amplitudes. In the case of quark gluon plasma viscosity is very large although the viscosity to entropy ratio is near to its minimum $\eta/s = \hbar/4\pi$ predicted by AdS/CFT correspondence. In TGD framework the lower bound is smaller [K27].

(c) There are good motivations for challenging the belief that QCD predicts strongly interacting quark gluon plasma having very large viscosity begin more like glass than a gas of partons. The reason for the skepticism is that classical color magnetic fields carrying magnetic monopole charges are absent. Also the notion of many-sheeted space-time (see fig. `http://www.tgdtheory.fi/appfigures/manysheeted.jpg` or fig. 9 in the appendix of this book) is essential element of the description. The recent evidence for the failure of AdS/CFT correspondence in the description of jet fragmentation in plasma support the pessimistic views.

9.6.5 Exotic pion like states: "infra-red" Regge trajectories or Shnoll effect?

TGD based view about non-perturbative aspects of hadron physics (see this) relies on the notion of color magnetic flux tubes. These flux tubes are string like objects and it would not be surprising if the outcome would be satellite states of hadrons with string tension below the pion mass scale. One would have kind of infrared Regge trajectories satisfying in a reasonable approximation a mass formula analogous to string mass formula. What is amazing that this phenomenon could allow new interpretation for the claims for a signal interpreted as Higgs at several masses (115 GeV by ATLAS, at 125 GeV by ATLAS and CMS, and at 145 GeV by CDF). They would not be actually statistical fluctuations but observations of states at IR Regge trajectory of pion of M_{89} hadron physics!

Consider first the mass formula for the hadrons at IR Regge trajectories.

(a) There are two options depending on whether the mass squared or mass for hadron and for the flux tubes are assumed to be additive. p-Adic physics would suggest that if the p-adic primes characterizing the flux tubes associated with hadron and hadron proper are different then mass is additive. If the p-adic prime is same, the mass squared is additive.

(b) The simplest guess is that the IR stringy spectrum is universal in the sense that m_0 does not depend on hadron at all. This is the case if the flux tubes in question correspond to hadronic space-time sheets characterized by p-adic prime M_{107} in the case of ordinary hadron physics. This would give for the IR contribution to mass the expression

$$m^2 = \sqrt{m_0^2 + nm_1^2} \ .$$

(c) The net mass of hadron results from the contribution of the "core" hadron and the stringy contribution. If mass squared is additive, one obtains $m(H_n) = \sqrt{m^2(H_0) + m_0^2 + nm_1^2}$, where H_0 denotes hadron ground state and H_n its excitation assignable to magnetic flux tube. For heavy hadrons this would give the approximate spectrum

$$m(H_n) \simeq m(H_0) + \frac{m_0^2 + nm_1^2}{2m(H_0)} \ .$$

The mass unit for the excitations decreases with the mass of the hadron.

(d) If mass is additive as one indeed expects since the p-adic primes characterizing heavy quarks are smaller than hadronic p-adic prime, one obtains

$$m(H_n) = m(H_0) + \sqrt{m_0^2 + nm_1^2} \ .$$

For $m_0^2 \gg m_1^2$ one has

$$m(H_n) = m(H_0) + m_0 + n\frac{m_1^2}{2m_0} \ .$$

If the flux tubes correspond to p-adic prime. This would give linear spectrum which is same for all hadrons.

There is evidence for this kind of states.

The experimental claim of Tatischeff and Tomasi-Gustafsson is that pion is accompanied by pion like states with mass 60, 80, 100, 140, 181, 198, 215, 227.5, and 235 MeV means that besides spion also other pion like states should be there. Similar satellites have been observed for nucleons with ground state mass 934 MeV: the masses of the satellites are 1004, 1044, 1094 MeV. Also the signal cross sections for Higgs to gamma pairs at LHC [C48, C64] suggest the existence of several pion and spion like states, and this was the reason why I decided to to again the search for data about this kind of states (I remembered vaguely that Tommaso Dorigo had talked about them but I failed to find the posting). What is their interpretation? One can imagine two explanations which could be also equivalent.

(a) The states could be "infrared" Regge trajectories assignable to magnetic flux tubes of order Compton length of u and d quark (very long and with small string tension) could be the explanation. Hadron mass spectrum would have microstructure. This is something very natural in many-sheeted space-time with the predicted p-adic fractal hierarchy of physics. This conforms with the proposal that all baryons have the satellite states and that they correspond to stringy excitations of magnetic flux tubes assignable to quarks. Similar fine structure for nuclei is predicted for nuclei in nuclear string model [L3]. In fact, the first excited state for ^4He has energy equal to 20 MeV not far from the average energy difference 17.5 MeV for the excited states of pion with energies 198, 215, and 227.5 MeV so that this state might correspond to an excitation of a color magnetic flux tube connecting two nucleons.

(b) The p-adic model for Shnoll effect [K5] relies on universal modification of the notion of probability distribution based on the replacement of ordinary arithmetics with quantum arithmetics. Both the rational valued parameters characterizing the distribution and the integer or rational valued valued arguments of the distribution are replaced with quantum ratinals. Quantum arithmetics is characterized by quantum phase $q = exp(i2\pi/p)$ defined by the p-adic prime p. The primes in the decomposition of integer are replaced with quantum primes except p which remains as such. In canonical identification powers of p are mapped to their inverses. Quite generally, distributions with single peak are replaced with many peaked ones with sub-peak structure having number theoretic origin. A good example is Poisson distribution for which one has $P(n) = \lambda^n/n!$. The quantum Poisson distribution is obtained by replacing λ and $n!$ with their quantum counterparts. Quantum Poisson distribution could apply in the case of resonance bump for which the number of count in a given mass squared interval is integer valued variable.

    There are objections against Shnoll effect based explanation.

    i. If the p-adic prime assignable to quark or hadron characterizes quantum arithmetics it is not distinguishable from ordinary arithmetics since the integers involved are certainly much smaller than say $M_{107} = 2^{107} - 1$. In the case of nuclear physics Shnoll effect involves small primes so that this argument is not water tight. For instance, if $p = 107$ defines the quantum arithmetics, the effects would be visible in good enough resolution and one might even expect variations in the bump structure in the time scale of year.

    ii. The effect is present also for nucleons but the idea about a state with large width splitting into narrower bumps does not fit nicely with the stability of proton.

    For Higgs like signals IR-Regge trajectories/Shnoll effect would be visible as a splitting of wide bumps for spion and pion of M_{89} physics to sub-bumps. This oscillatory bumpy structure is certainly there but is regarded as a statistical artefact. It would be really fascinating to see this quantum deformation of the basic arithmetics at work even in elementary particle physics.

Second piece of evidence comes from two articles by Eef van Beveren and George Rupp. The first article is titled *First indications of the existence of a 38 MeV light scalar boson* [C176]. Second article has title *Material evidence of a 38 MeV boson* [C177]. The basic observations are following. The rate for the annihilation $e^+ + e^- \rightarrow u\overline{u}$ assignable to the reaction $e^+ + e^- \rightarrow \pi^+\pi^-$ has a small periodic oscillation with a period of 78 ± 2 MeV and amplitude of about 5 per cent. The rate for the annihilation $e^+ + e^- \rightarrow b\overline{b}$, assignable to the reaction $e^+ + e^- \rightarrow \Upsilon\pi^+\pi^-$ has similar oscillatory behavior with a period of 73 ± 3 MeV and amplitude about 12.5 per cent. The rate for the annihilation $p\overline{p} \rightarrow c\overline{c}$ assignable to the reaction $e^+ + e^- \rightarrow J/\Psi\pi^+\pi^-$ has similar oscillatory behavior with period of 79 ± 5 MeV and amplitude .75 per cent.

In these examples universal Regge slope is consistent with the experimental findings and supports additive mass formula and the assignment of IR Regge trajectories to hadronic flux tubes with fixed p-adic length scale. There is also consistency with the experiments of Tatitscheff and Tomasi-Gustafsson.

What does one obtain if one scales up the IR Regge trajectories to the M_{89} which replaces Higgs in TGD framework?

(a) In the case of M_{89} pion the mass differences 20 MeV and 40 MeV appearing in the IR Regge trajectories of pion would scale up to 10 GeV and 20 GeV respectively. This would suggest the spectrum of pion like states with masses 115, 125, 145, 165 GeV. What makes this interesting that ATLAS reported during last year evidence for a signal at 115 GeV taken as evidence for Higgs and CDF reported before this signal taken as evidence for Higgs around 145 GeV! 125 GeV is the mass of the the most recent Higgs candidate. Could it be that all these reported signals have been genuine signals - not for Higgs- but for M_{89} pion and corresponding spion consisting of squark pair and its IR satellites?

(b) I the case of M_{89} hadron physics the naive scaling of the parameters m_0 and m_1 by factor 512 would scale 38 MeV to 19.5 GeV.

9.7 Cosmic rays and Mersenne Primes

Sabine Hossenfelder has written two excellent blog postings about cosmic rays. The first one is about the GKZ cutoff for cosmic ray energies and second one about possible indications for new physics above 100 TeV. This inspired me to read what I have said about cosmic rays and Mersenne primes- this was around 1996 - immediately after performing for the first time p-adic mass calculations. It was unpleasant to find that some pieces of the text contained a stupid mistake related to the notion of cosmic ray energy. I had forgotten to take into account the fact that the cosmic ray energies are in the rest system of Earth- what a shame! The recent version should be free of worst kind of blunders. Before continuing it should be noticed I am now living year 2012 and this section was written for the first time for around 1996 - and as it became clear - contained some blunders due to the confusion with what one means with cosmic ray energy. The recent version should be free of worst kind of blunders.

TGD suggests the existence of a scaled up copy of hadron physics associated with each Mersenne prime $M_n = 2^n - 1$, n prime: M_{107} corresponds to ordinary hadron physics. Also lepto-hadrons are predicted. Also Gaussian Mersennes $(1+i)^k - 1$, could correspond to hadron physics. Four of them ($k = 151, 157, 163, 167$) are in the biologically interesting length scale range between cell membrane thickness and the size of cell nucleus. Also leptonic counterparts of hadron physics assignable to certain Mersennes are predicted and there is evidence for them [K70].

The scaled up variants of hadron physics corresponding to $k < 107$ are of special interest. $k = 89$ defines the interesting Mersenne prime at LHC, and the near future will probably tell whether the 125 GeV signal corresponds to Higgs or a pion of M_{89} physics. Also cosmic ray spectrum could provide support for M_{89} hadrons and quite recent cosmic ray observations [C166] are claimed to provide support for new physics around 100 TeV. M_{89} proton would correspond to .5 TeV mass considerably below 100 TeV but this mass scale could correspond to a mass scale of a scaled up copy of a heavy quark of M_{107} hadron physics: a naive scaling of top quark mass by factor 512 would give mass about 87 TeV. Also the lighter hadrons of M_{89} hadron physics should contribute to cosmic ray spectrum and there are indeed indications for this.

The mechanisms giving rise to ultra high energy cosmic rays are poorly understood. The standard explanation would be acceleration in huge magnetic fields. TGD suggests a new mechanism based on the decay cascade of cosmic strings. The basis idea is that cosmic string decays *cosmic string* $\rightarrow M_2$ *hadrons* $\rightarrow M_3$ *hadrons* ....$\rightarrow M_{61} \rightarrow M_{89} \rightarrow M_{107}$ *hadrons* could be a new source of cosmic rays. Also variants of this scenario with decay cascade beginning from larger Mersenne prime can be considered. One expects that the decay cascade leads rapidly to extremely energetic ordinary hadrons, which can collide with ordinary hadrons in atmosphere and create hadrons of scaled variants of ordinary hadron physics. These cosmic ray events could serve as a signature for the existence of these scale up variants of hadron physics.

(a) Centauro events and the peculiar events associated with $E > 10^5$ GeV radiation from Cygnus X-3. E refers to energy in Earth's rest frame and for a collision with proton the cm energy would be $E_{cm} = \sqrt{2EM} > 10$ TeV in good approximation whereas M_{89} variant of proton would have mass of .5 TeV. These events be understood as being due to the collisions of energetic M_{89} hadrons with ordinary hadrons (nucleons) in the atmosphere.

(b) The decay $\pi_n \rightarrow \gamma\gamma$ produces a peak in the spectrum of the cosmic gamma rays at energy $\frac{m(\pi_n)}{2}$. These produce peaks in cosmic gamma ray spectrum at energies which depend on the energy of π_n in the rest system of Earth. If the pion is at rest in the cm system of incoming proton and atmospheric proton one can estimate the energy of the peak if the total energy of the shower can be estimated reliably.

(c) The slope in the hadronic cosmic ray spectrum changes at $E = 3 \cdot 10^6$ GeV. This corresponds to the energy $E_{cm} = 2.5$ TeV in the cm system of cosmic ray hadron and atmospheric proton. This is not very far from M_{89} proton mass .5 TeV. The creation of M_{89} hadrons in atmospheric collisions could explain the change of the slope.

(d) The ultra-higher energy cosmic ray radiation having energies of order 10^9 GeV in Earth's rest system apparently consisting of protons and nuclei not lighter than Fe might be actually dominated by gamma rays: at these energies γ and p induced showers have same muon content. $E = 10^9$ GeV corresponds to $E_{cm} = \sqrt{2Em_p} = 4 \times 10^4$ GeV. M_{89} nucleon would correspond to mass scale 512 GeV.

(e) So called GKZ cutoff should take place for cosmic gamma ray spectrum due to the collisions with the cosmic microwave background. This should occur around $E = 6 \times 10^{10}$ GeV, which corresponds to $E_{cm} = 3.5 \times 10^5$ GeV. Cosmic ray events above this cutoff are however claimed. There should be some mechanism allowing for ultra high energy cosmic rays to propagate over much longer distances as allowed by the limits. Cosmic rays should be able to propagate without collisions. Many-sheeted space-time suggests manners for how gamma rays could avoid collisions with microwave background. For instance, gamma rays could be dark in TGD sense and therefore have large value of Planck constant. One can even imagine exotic variants of hadrons, which differ from ordinary hadrons in that they do not have quarks and therefore no interactions with the microwave background.

(f) The highest energies of cosmic rays are around $E = 10^{11}$ GeV, which corresponds to $E_{cm} = 4 \times 10^5$ GeV. M_{61} nucleon and pion correspond to the mass scale of 6×10^6 GeV and 8.4×10^5 GeV. These events might correspond to the creation of M_{61} hadrons in atmosphere.

The identification of the hadronic space-time sheet as super-symplectic mini black-hole [K43] suggests the science fictive possibility that part of ultra-high energy cosmic rays could be also protons which have lost their valence quarks. These particles would have essentially same mass as proton and would behave like mini black-holes consisting of dark matter. They could even give a large contribution to the dark matter. Since electro-weak interactions are absent, the scattering from microwave background is absent, and they could propagate over much longer distances than ordinary particles. An interesting question is whether the ultrahigh energy cosmic rays having energies larger than the GZK cut-off of 5×10^{10} GeV in the rest system of Earth are super-symplectic mini black-holes associated with M_{107} hadron physics or some other copy of hadron physics.

9.7.1 Mersenne primes and mass scales

p-Adic mass calculations lead to quite detailed predictions for elementary particle masses. In particular, there are reasons to believe that the most important fundamental elementary particle mass scales correspond to Mersenne primes $M_n = 2^n - 1$, $n = 2, 3, 7, 13, 17, 19, ...$

$$\begin{aligned} m_n^2 &= \frac{m_0^2}{M_n} \ , \\ m_0 &\simeq 1.41 \cdot \frac{10^{-4}}{\sqrt{G}} \ , \end{aligned} \tag{9.7.0}$$

where $\sqrt{G}$ is Planck length. The lower bound for n can be of course larger than $n = 2$. The known elementary particle mass scales were identified as mass scales associated identified with Mersenne primes $M_{127} \simeq 10^{38}$ (leptons), M_{107} (hadrons) and M_{89} (intermediate gauge bosons). Of course, also other p-adic length scales are possible and it is quite possible that not all Mersenne primes are realized. On the other hand, also Gaussian Mersennes could be important (muon and atomic nuclei corresponds to Gaussian Mersenne $(1 + i)^k - 1$ with $k = 113$).

Theory predicts also some higher mass scales corresponding to the Mersenne primes M_n for $n = 89, 61, 31, 19, 17, 13, 7, 3$ and suggests the existence of a scaled up copy of hadron physics with each of these mass scales. In particular, masses should be related by simple scalings to the masses of the ordinary hadrons.

An attractive first working hypothesis hypothesis is that the color interactions of the particles of level M_n can be described using the ordinary QCD scaled up to the level M_n so that that masses and the confinement mass scale Λ is scaled up by the factor $\sqrt{M_n/M_{107}}$.

$$\Lambda_n = \sqrt{\frac{M_n}{M_{107}}}\Lambda \ . \tag{9.7.1}$$

In particular, the naive scaling prediction for the masses of the exotic pions associated with M_n is given by

$$m(\pi_n) = \sqrt{\frac{M_n}{M_{107}}}m_\pi \ . \tag{9.7.2}$$

Here $m_\pi \simeq 135\ MeV$ is the mass of the ordinary pion. This estimte is of course extremely naive and the recent LHC data suggests that the 125 GeV Higgs candidate could be M_{89} pion. The mass would be two times higher than the naive estimate gives. p-Adic scalings by small powers of $\sqrt{2}$ must be considered in these estimates.

The interactions between the different level hadrons are mediated by the emission of electroweak gauge bosons and by gluons with cm energies larger than the energy defined by the confinement scale of level with smaller p. The decay of the exotic hadrons at level M_{n_k} to exotic hadrons at level $M_{n_{k+1}}$ must take place by a transition sequence leading from the effective M_{n_k}-adic space-time topology to effective $M_{n_{k+1}}$-adic topology. All intermediate p-adic topologies might be involved.

9.7.2 Cosmic strings and cosmic rays

Cosmic strings are fundamental objects in quantum TGD and dominated during early cosmology.

Cosmic strings

Cosmic strings (not quite the same thing in TGD as in GUTs) are basic objects in TGD inspired cosmology [K17, K60] .

(a) In TGD inspired galaxy model galaxies are regarded as mass concentrations around cosmic strings and the energy of the string corresponds to the dark energy whereas the particles condensed at cosmic strings and magnetic flux tubes resulting from them during cosmic expansion correspond to dark matter [K17, K60] . The galactic nuclei, often regarded as candidates for black holes, are the most probable seats for decaying highly entangled cosmic strings.

(b) Galaxies are known to organize to form larger linear structures. This can be understood if the highly entangled galactic strings organize around long strings like pearls in necklace. Long strings could correspond to galactic jets and their gravitational field could explain the constant velocity spectrum of distant stars in the galactic halo.

(c) In [K17, K60, K59] it is suggested that decaying cosmic strings might provide a common explanation for the energy production of quasars, galactic jets and gamma ray bursters and that the visible matter in galaxies could be regarded as decay products of cosmic strings. The magnetic and Z^0 magnetic flux tubes resulting during the cosmic expansion from cosmic strings allow to assign at least part of gamma ray bursts to neutron stars. Hot spots (with temperature even as high as $T \sim \frac{10^{-3,5}}{\sqrt{G}}$) in the cosmic string emitting ultra high energy cosmic rays might be created under the violent conditions prevailing in the galactic nucleus.

The decay of the cosmic strings provides a possible mechanism for the production of the exotic hadrons and in particular, exotic pions. In [C123] the idea that cosmic strings might produce gamma rays by decaying first into 'X' particles with mass of order 10^{15} GeV and then to gamma rays, was proposed. As authors notice this model has some potential difficulties resulting from the direct production of gamma rays in the source region and the presence of intensive electromagnetic fields near the source. These difficulties are overcome if cosmic strings decay first into exotic hadrons of type M_{n_0}, $n_0 \geq 3$ of energy of order $2^{-n_0+2}10^{25}$ GeV , which in turn decay to exotic hadrons corresponding to M_k, $k > n_0$ via ordinary color interaction, and so on so that a sequence of M_k:s starting some value of n_0 in $n = 2, 3, 7, 13, 17, 19, 31, 61, 89, 107$ is obtained. The value of n remains open at this stage and depends on the temperature of the hot spot and much smaller temperatures than the $T \sim m_0$ are possible: favored temperatures are the temperatures $T_n \sim m_n$ at which M_n hadrons become unstable against thermal decay.

Decays of cosmic strings as producer of high energy cosmic gamma rays

In [C147] the gamma ray signatures from ordinary cosmic strings were considered and a dynamical QCD based model for the decay of cosmic string was developed. In this model the final state particles were assumed to be ordinary hadrons and final state interactions were neglected. In the recent case the string decays first to M_{n_0} hadrons and the time scale of for color interaction between M_{n_0} hadrons is extremely short (given by the length scale defined by the inverse of π_{n_0} mass) as compared to the time time scale in case of ordinary hadrons. Therefore the interactions between the final state particles must be taken into account and there are good reasons to expect that thermal equilibrium sets on and much simpler thermodynamic description of the process becomes possible.

A possible description for the decaying part of the highly tangled cosmic string is as a 'fireball' containing various M_{n_0} $(n \geq 3)$ partons in thermal equilibrium at Hagedorn temperature T_{n_0} of order $T_{n_0} \sim m_{n_0} = 2^{-2+n_0} \frac{10^{-4}}{k\sqrt{G}}$, $k \simeq 1.288$. The experimental discoveries made in RHIC suggest [C145] that high energy nuclear collisions create instead of quark gluon plasma a liquid like phase involving gluonic BE condensate christened as color glass condensate. Also black hole like behavior is suggested by the experiments.

RHIC findings inspire a TGD based model for this phase as a macroscopic quantum phase condensed on a highly tangled color magnetic string at Hagedorn temperature. The model relies also on the notion of dynamical but quantized $\hbar$ [K18] and its recent form to the realization that super-symplectic many-particle states at hadronic space-time sheets give dominating contribution to the baryonic mass and explain hadronic masses with an excellent accuracy.

This phase has no direct gauge interactions with ordinary matter and is identified in TGD framework as a particular instance of dark matter. Quite generally, quantum coherent dark matter would reside at magnetic flux tubes idealizable as string like objects with string tension determined by the p-adic length scale and thus outside the "ordinary" space-time. This suggests that color glass condensate forms when hadronic space-time sheets fuse to single long string like object containing large number of super-symplectic bosons.

Color glass condensate has black-hole like properties by its electro-weak darkness and there are excellent reasons to believe that also ordinary black holes could by their large density correspond to states in which super-symplectic matter would form single connected string like structure (if Planck constant is larger for super-symplectic hadrons, this fusion is even more probable).

This inspires the following mechanism for the decay of exotic boson.

(a) The tangled cosmic string begins to cool down and when the temperature becomes smaller than $m(\pi_{n_0})$ mass it has decayed to M_{n_1} matter which in turn continues to decay to M_{n_2} matter. The decay to M_{n_1} matter could occur via a sequence $n_0 \rightarrow n_0 - 1 \rightarrow ...n_1$ of phase transitions corresponding to the intermediate p-adic length scales $p \simeq 2^k$, $n_1 \geq k > n_0$. Of course, all intermediate p-adic length scales are in principle possible so that the process would be practically continuous and analogous to p-adic length scale evolution with $p \simeq 2^k$ representing more stable intermediate states.

(b) The first possibility is that virtual hadrons decay to virtual hadrons in the transition $k \rightarrow k-1$. The alternative option is that the density of final state hadrons is so high that they fuse to form a single highly entangled hadronic string at Hagedorn temperature T_{k-1} so that the process would resemble an evaporation of a hadronic black hole staying in quark plasma phase without freezing to hadrons in the intermediate states. This entangled string would contain partons as "color glass condensate".

(c) The process continues until all particles have decayed to ordinary hadrons. Part of the M_n low energy thermal pions decay to gamma ray pairs and produce a characteristic peak in cosmic gamma ray spectrum at energies $E_n = \frac{m(\pi_n)}{2}$ (possibly red-shifted by the expansion of the Universe). The decay of the cosmic string generates also ultra high energy hadronic cosmic rays, say protons. Since the creation of ordinary hadron with ultra high energy is certainly a rare process there are good hopes of avoiding the problems related to the direct production of protons by cosmic strings (these protons produce two high flux of low energy gamma rays, when interacting with cosmic microwave background [C123]).

Topologically condensed cosmic strings as analogs super-symplectic black-holes?

Super-symplectic matter has very stringy character. For instance, it obeys stringy mass formula due the additivity and quantization of mass squared as multiples of p-adic mass scale squared [K43] . The ensuing additivity of mass squared defines a universal formula for binding energy having no independence on interaction mechanism. Highly entangled strings carrying super-symplectic dark matter are indeed excellent candidates for TGD variants of black-holes. The space-time sheet containing the highly entangled cosmic string is separated from environment by a wormhole contact with a radius of black-hole horizon. Schwartschild radius has also interpretation as Compton length with Planck constant equal to gravitational Planck constant $\hbar/\hbar_0 = 2GM^2$. In this framework the proposed decay of cosmic strings would represent nothing but the TGD counterpart of Hawking radiation. Presumably the value of p-adic prime in primordial stage was as small as possible, even $p = 2$ can be considered.

Exotic cosmic ray events and exotic hadrons

One signature of the exotic hadrons is related to the interaction of the ultra high energy gamma rays with the atmosphere. What can happen is that gamma rays in the presence of an atmospheric nucleus decay to virtual exotic quark pair associated with M_{n_k}, which in turn produces a cascade of exotic hadrons associated with M_{n_k} through the ordinary scaled up color interaction. These hadrons in turn decay $M_{n_{k+1}}$ type hadrons via mechanisms to be discussed later. At the last step ordinary hadrons are produced. The collision creates in the atmospheric nucleus the analog of quark gluon plasma which forms a second kind of fireball decaying to ordinary hadrons. RHIC experiments have already discovered these fireballs and identified them as color glass condensates [C145]. It must be emphasized that it is far from clear whether QCD really predicts this phase.

These showers differ from ordinary gamma ray showers in several respects.

(a) Exotic hadrons can have small momenta and the decay products can have isotropic angular distribution so that the shower created by gamma rays looks like that created by a massive particle.

(b) The muon content is expected to be similar to that of a typical hadronic shower generated by proton and larger than the muon content of ordinary gamma ray shower [C179] .

(c) Due to the kinematics of the reactions of type $\gamma + p \rightarrow H_{M_n} + ... + p$ the only possibility at the available gamma ray energies is that M_{89} hadrons are produced at gamma ray energies above 10 TeV. The masses of these hadrons are predicted to be above 70 GeV and this suggests that these hadrons might be identified incorrectly as heavy nuclei (heavier than ^{56}Fe). These signatures will be discussed in more detail in the sequel in relation to Centauro type events, Cygnus X-3 events and other exotic cosmic ray events. For a good review for these events and models form them see the review article [C4] .

Some cosmic ray events [C131, C80] have total laboratory energy as high as 3000 TeV which suggests that the shower contains hadron like particles, which are more penetrating than ordinary hadrons.

(a) One might argue that exotic hadrons corresponding M_k, $k > 107$with interact only electro-weakly (color is confined in the length scale associated with M_n) with the atmosphere one might argue that they are more penetrating than the ordinary hadrons.

(b) The observed highly penetrating fireballs could also correspond super-symplectic dark matter part of incoming, possibly exotic, hadron fused with that for a hadron of atmosphere. Both hadrons would have lost their valence quarks in the collision just as in the case of Pomeron events. Large fraction of the collision energy would be transformed to super-symplectic quanta in the process and give rise to a large color spin glass condensate. These condensates would have no direct electro-weak interactions with ordinary matter which would explain their long penetration lengths in the atmosphere. Sooner or later the color glass condensate would decay to hadrons by the analog of blackhole evaporation. This process is different from QCD type hadronization process occurring in hadronic collisions and this might allow to understand the anomalously low production of neutral pions.

Exotic mesons can also decay to lepton pairs and neutral exotic pions produce gamma pairs. These gamma pairs in principle provide a signature for the presence of exotic pions in the cosmic ray shower. If M_{89} proton is sufficiently long-lived enough they might be detectable.The properties of Centauro type events however suggest that M_{89} protons are short lived.

9.7.3 Centauro type events, Cygnus X-3 and M_{89} hadrons

The results reported by Brazil-Japan Emulsion Chamber Collaboration [C131, C107] on multiple production of hadrons induced by cosmic rays with energies $E_{lab} > 10^5$ GeV provide evidence for new Physics. The distributions for the transverse momentum p_T and longitudinal momentum fraction x for pions were found to differ from the distributions extrapolated from lower energies. The widening of the transversal momentum distributions has also been observed at accelerator energies (ISR above $\sqrt{s} = 63\ GeV$ and CERN SPS-p$\bar{p}$ Collider at $\sqrt{s} = 540\ GeV$). Furthermore, exotic events called Geminion, Centauro, Chiron with emission of $n_B \leq 100$ hundred baryons but practically no pions were detected. There are also peculiar events associated with the radiation coming from Cygnus X-3. A recent summary about peculiar events is given in the review article [C4] .

Mirim, Acu and Quacu

The exotic cosmic ray events are described in the review article of [C131] . In [C131] the multiple production of pions is classified into 3 jet types called Mirim, Acu and Quacu. Although the transverse momentum distributions for pions observed at low energies are universal, Acu and Quacu jets are characterized by wider transverse momentum distributions with larger value of average transverse momentum p_T than in low energy pionization: this widening is in accordance with accelerator results. The distributions for the longitudinal momentum fraction x scale but differ from the low energy situation for Acu and Quacu jets.

In [C131, C153] a description of these events in terms of 'fireballs' decaying into ordinary hadrons were considered. The p_T distribution associated with Mirim is just the ordinary low energy transverse momentum distribution whereas the distributions associated with Acu and Quacu are wider. The masses of the fireballs were assumed to be discrete and were found to be $M_0 \sim 2-3\ GeV$ (Mirim), $M_1 \sim 15-30\ GeV$ (Acu) , $M_2 \sim 100-300\ GeV$ (Quacu). It should be noticed that the upper bounds for the masses associated with Acu and Quacu fireballs are roughly by a factor of two smaller than the naive mass estimates 69 GeV and 481 GeV associated with M_{89} pion and M_{89} proton. The temperatures were found to be in range $0.4-10\ GeV$ for Acu and Quacu fireball and to be substantially larger than the ordinary Hagedorn temperature $T_H \simeq 0.16\ GeV$.

Chirons, Centauros, anti-Centauros, and Geminions

For the second class of events consisting of Chirons, Centauros and Geminions observed at laboratory energies $100-1000\ TeV$ pion production is strongly suppressed (gamma pairs resulting from the decay of neutral pions are almost absent) [C131] . The primary event takes place few hundred meters above the detector and decay products are known to be hadrons and mostly baryons: about 15 (100) for Mini-Centauros (Centauros). This excludes the possibility that exotic hadrons decay in emulsion chamber and implies also that the decay mechanism of the primary particle is such that very few mesons are produced.

The fireball hypothesis has been applied also to Centauro type events assuming that fireballs corresponds to a different phase than in the case of Mirim, Acu and Quacu [C131] . The fireball masses associated with Mini-Centauro and Centauro are according to the estimate of [C131] $M_{mini} = 35$ GeV and $M_{Centauro} = 230$ GeV. These masses are almost exactly one half of the masses of the M_{89} pion (70 GeV) and proton (470 GeV) respectively!

$$\begin{aligned} M_{Mini} &\simeq \frac{m(\pi_{89})}{2} \ , \\ M_{Centauro} &\simeq \frac{m(p_{89})}{2} \ . \end{aligned} \qquad (9.7.2)$$

This suggests that the decay of cosmic gamma ray to M_{89} quark pair which in turn hadronizes to (possibly virtual) M_{89} hadrons induced by the interaction with the nucleon of atmosphere is the origin of Mini-Centauro/Centauro events.

The basic difference between the decaying fireballs in Acu/Quacu events and Centauro type events is that Acu/Quacu decays produce neutral pions unlike Centauros.

The appearance of the factor of 1/2 in the mass estimates needs an explanation. One explanation is systematic error in the evaluation of hadronic energy: for instance, the gamma inelasticity k_γ telling which fraction of hadronic energy is transformed to electromagnetic energy might be actually smaller than believed by a factor of order two. An alternative explanation is related to the decay mechanism of M_{89} particle: if the decay takes place via a decay to two off mass shell M_{89} hadrons decaying in turn to hadrons then the average rest energy of the fireball is indeed one half of the mass of the decaying on mass shell particle. The reason for the necessity of off mass shell intermediate states is perhaps the stability of the on mass shell exotic hadrons against the direct decay to ordinary hadrons.

Anti-Centauros are much like Centauros except that neutral pions are over-abundant [C4] . The speculative model [C39] relies on the notion of chiral condensates consisting of neutral pions in the case of Centauros and charged pions in the case of anti-Centauros. If one wants to explain Anti-Centauros in terms of M_{89} physics should be able to explain the over abundance of neutral pions in terms of decay products of ordinary hadrons at later stages of the decay cascade.

The case of Cygnus X-3

There are peculiar events associated with the cosmic rays coming from Cygnus X-3 at gamma ray energies above 10^5 GeV [C40] . The primary particle must be massless particle and is most probably ordinary gamma ray. The structure of the shower however suggests that the decaying particle is very massive! Furthermore, the muon content of the shower is larger than that associated with gamma ray shower. A possible explanation is that the gamma rays coming from Cygnus X-3 with energy above the threshold 10^4 GeV produce M_{89} hadrons, which in turn create the cosmic ray shower through the decay to M_{89} hadrons and the decay of these to the ordinary M_{107} hadrons: this indeed means that the gamma rays behave like a massive particles in the atmosphere.

9.7.4 TGD based explanation of the exotic events

The TGD based model for exotic events involve p-adic length scale hierarchy, many-sheeted space-time, and TGD inspired view about dark matter. A decisive empirical input comes from RHIC events suggesting that quark gluon plasma is actually a liquid like "macroscopic" quantum phase identifiable as a particular instance of dark matter.

General considerations

The mass estimates for the fireballs and the absence of neutral pions suggest that Mini-Centauro/Centauro type events correspond to the decay of M_{89} hadrons (pion/proton) to ordinary hadrons. The general model for the exotic events would be following.

(a) Cosmic gamma ray decays first into M_{89} quark pair via electromagnetic interaction with the nucleon of the atmosphere. Pairs of Centauros/anti-Centauros and quark-gluon-plasma blobs explaing Mirim/Qcu/Quacu events would be naturally created in these collisions.

(b) The quark pair in turn hadronizes to M_{89} hadrons decaying to virtual $k > 89$ hadrons which in turn end up via a sequential decay process to ordinary hadrons. This process is kinematically possible if the condition $E_{tot} > 2M^2/m_p$, is satisfied (M is the mass of the exotic hadron). For example, the energy of the gamma ray must be larger than 500 TeV for exotic proton pair production. For the exotic pion the corresponding lower bound is about 10 TeV. The energies of the exotic events are indeed above 100 TeV in accordance with these bounds. The average total energy is about $E_{tot} = 1740$ TeV for Centauros and $E_{tot} \simeq 903$ TeV for Mini-Centauros [C131]. The mechanism implies that two M_{89} fireballs are produced. 'Binocular' events (Geminions) consisting of two widely separated fireballs have indeed been observed [C131] .

(c) If anti-Centauros result via the same mechanism there must be a mechanism explaining why the production of neural pions varies from event to event. One proposal is that the difference is due to a formation of pion condensates consisting of neural *resp.* charged pions in the two situations [C39] . This hypothesis would unify Centauro events with anti-Centauro events in which the production of neutral pions is abnormally high [C4] .

(d) Mirim/Acu/Quacu events could correspond to the decay of a high temperature quark-gluon plasma blob, or rather color glass condensate, to hadrons (recall that the estimated plasma temperatures are much lower than for Centauros). The collision of M_{89} hadron possibly generated in the interaction of the cosmic gamma ray with ordinary nucleon could induce both the decay of M_{89} hadron to virtual hadrons and generate quark-gluon plasma blob in the atmospheric target nucleus. Hagedorn temperature $T(k)$, $89 < k \leq 107$ is a good guess for the temperature of this plasma blob. RHIC findings [C145] suggest that the blob corresponds to highly tangled hadronic string containing super-symplectic dark matter and decaying by de-coherence to ordinary hadrons [K18] .

Connection with TGD based model for RHIC events

The counterparts of Centauros and other exotic events have not been observed in accelerator experiments. More than a decade after writing the first version of the model for Centauros came however data from RHIC experiment [C145], which seems to provide a connection between laboratory and cosmic ray data. In RHIC collisions of very energetic Gold nuclei are studied. The collisions were expected to create a quark gluon plasma freezing to ordinary hadrons. The surprise was that the resulting state behaves like an ideal liquid and has also black hole like properties [C145].

Recall that the TGD based model [K59, K18] for RHIC findings is following.

(a) The state in question corresponds to a highly entangled hadronic string at Hagedorn temperature defining the analog of black hole and decaying by evaporation. The gravitational constant defined by Planck length is effectively replaced by a hadronic gravitational constant defined by the hadronic length scale. p-Adic length scale hypothesis predicts entire hierarchy of Hagedorn temperatures.

(b) Bose-Einstein condensate of gluons referred to as color glass condensate has been proposed as an explanation for the liquid like behavior of the quark-gluon phase. TGD based explanation for the liquid like state is that that the state in question corresponds to a large Bose-Einstein condensate like state of super-symplectic particles resulting as hadronic space-time sheets fuse. Super-symplectic bosons have vanishing electro-weak quantum numbers since super-symplectic generators are either purely bosonic or possess quantum numbers of right handed neutrino. Dark matter is in question.

(c) LHC has already produce evidence for quark gluon plasma possessing anomalous properties but created in collisions of protons rather than those of heavy nuclei. The TGD based explanation is in formation of long highly entangled color flux tube producing hadrons as it decays [K37] . It might be that the creation of these objects in the decays of M_{89} hadrons are responsible for some aspects of the exotic cosmic ray events.

A more precise model for exotic events

A more detailed formulation necessitates a rough model for the transformation of M_{89} hadrons to M_{107} hadrons.

(a) On mass shell exotic hadrons can be assumed to be stable against direct decay to ordinary hadrons so that their decay must take place via a sequential decay to off mass shell exotic hadrons characterized by $107 > k > 89$, which eventually decay to ordinary hadrons. The simplest decay mode is the decay to two virtual exotic hadrons with average mass, which is one half of the mass of the decaying exotic hadron in accordance with observations.

(b) M_{89} hadron decays to virtual hadrons with $p \simeq 2^k > M_{89}$ dominate over electro-weak decays since the characteristic time scale is defined by $\Lambda(QCD, M_{89}) = 512\Lambda(QCD, 107)$. This means that most of the energy in the process goes to virtual $k > 89$ virtual mesons. Neutral $k > 89$ virtual pions, if created, can decay to gamma pairs so that the problem of understanding the absence of neutral pions remains.

(c) M_{89} hadronic space-time sheet suffers a topological phase transition to M_{107} hadronic space-time sheet via several steps $k = 89 \rightarrow k_1 > 89.. \rightarrow k_n = 107$. In the process the size of hadronic surface suffers a $2^9 = 512$-fold expansion meaning the increase of volume by a factor for $2^{27} \sim 10^9/8$ so that a small scale Big Bang is really in question! The expansion brings in mind liquid-vapor phase transition but the freezing to hadrons (due to the properties of color coupling constant evolution) makes the transition more like a liquid-solid phase transition.

As noticed, all p-adic length scales in the range involved could be present but $p \simeq 2^k$ would define more stable intermediate states. A possible experimental signature for the sequence of the phase transitions labeled by $89 \leq k \leq 107$ is a bumpy structure of the detected hadronic cascades with a maximum of 17 maxima. This kind of structure with a constant distance between maxima and 11 maxima has been indeed observed for some cascades (see Fig. 8 of [C4]).

A good guess for the critical temperature of the Big Bang like phase transition to occur is $T_{cr}(89) = km_{89}$, where k is some numerical factor. TGD inspired model for the early cosmology provides a universal hydrodynamics model for this period as a mini Big Bang, or rather "a soft whisper amplified to a relatively big bang", containing the duration of the period as the only parameter [K60] .

(d) If the decay process is fast enough, the density of virtual hadrons in the final state becomes so high that they form single highly tangled cosmic string in Hagedorn temperature $T(k)$. An entire sequence of $T(k) = km_k$, $107 > k > 89$ of phase transition temperatures could be involved without intermediate freezing to hadrons. Since the transformation of $k = 89$ hadrons to $k = 107$ hadrons would be essentially a decay process, the distribution of decay products is isotropic in the center of mass frame of $k = 89$ hadron (Centauros/anti-Centauros). The same conclusion holds true for the decay of quark gluon plasma (Mirim/Qcu/Quacu).

How to understand the anomalous production of pions?

One can imagine two different explanations for the varying number of pions in the events.

1. M_{89} hadrons produce M_{89} pions

This model would explain the special features of Centauros. To Anti-Centauros the model does not apply. One could hope that the decay cascade of Centauro leads at later stages to color glass phases for ordinary hadrons producing surplus of neutral pions.

2. Restoration of electro-weak symmetry?

The anomalous production of pions might relate to the restoration of electro-weak symmetry in case of M_{89} hadrons. For M_{89} hadrons the restoration of the electro-weak symmetry would be natural since in TGD framework classical induced gauge fields are massless for known non-vacuum extremals below the p-adic length scale $L(89)$ defining the fundamental electro-weak length scale. The finite size of the space-time sheet carrying these fields brings in the length scale determining the boson mass when the space-time sheet in question looks point like in the length scale resolution used. The model of elementary particles as weak strings (Kähler magnetic flux tubes) suggests that electroweak symmetry restoration takes place inside weak magnetic flux tubes and that one might have Bose-Einstein condensate with negative and positive net charges in turn implying the abundance of charged pions. One might argue argue that for particles topologically condensed to space-time sheets with $k > 89$ M_{61} defines the weak scale so that weak interactions effectively disappear.

In zero energy ontology zero energy states are characterized by time-like entanglement coefficients defining M-matrices in turn identifiable as the rows of the unitary U-matrix coding for physics in TGD Universe. The superposition of zero energy states for which positive energy parts have varying values of conserved charges (say electromagnetic charge) do not break conservation laws. Note that also in super-conductors coherent states of Cooper pairs make sense in zero energy ontology without breaking the conservation of fermion number. Therefore one can consider generation of coherent states of pions with non-standard direction of isospin in the collisions of cosmic rays with the nuclei of atmosphere. The TGD inspired model for lepto-hadrons [K70] assumes that the coherent states of lepto-pions consisting of pionlike bound states of colored excitations of leptons are created in the strong non-orthogonal magnetic and electric fields of the colliding heavy nuclei or other charged particles. Similar situation might be encountered in the collision of high energy cosmic rays with the nuclei of the atmosphere.

Both Centauros and anti-Centauros could be understood if the transformation of M_{89} hadrons to ordinary hadrons generates "mis-aligned" pionic BE condensates. $U(2)_{ew}$ symmetry is restored for M_{89} hadrons and there is no preferred isospin direction for the order parameter of M_{89} pionic BE condensate. This BE condensate is however excluded by energetic considerations. The sequence of phase transitions leading to M_{107} hadrons involving intermediate p-adic length scales could however generate this kind of BE condensate.

If an overcooling occurs in the sense that electro-weak symmetry is not lost, the first intermediate pion condensate can correspond to π_+,π_- or π_0. Charged π condensates would be created in pairs with opposite charges. In this kind of situation the number of gamma rays produced in the decay to ordinary hadrons would vary from event to event.

The presence of pionic BE condensates favors the decay to M_{107} hadrons via hadronic intermediate states rather than via the cooling of partonic phase condensed on single tangled string whose length grows. This and the idea that $U(2)_{ew}$ symmetry could be exact for the dark matter phase, encourages to consider also the possibility that M_{89} hadron decays to a state consisting of dark M_{107} hadrons forming a BE condensate like state behaving like single coherent unit and interacting with the ordinary matter only via emission of dark gauge boson BE condensates de-cohering to ordinary gauge bosons.

Dark pionic BE condensates with various charges could be present. These dark π condensates would decay coherently to pairs of dark ew boson "laser beams", which can interact with the ordinary matter only after they have de-cohered to ordinary ew gauge bosons and remain undetected if the de-coherence time for dark bosons is long enough, probably not so. Dark hadron option could thus explain also the abnormally long penetration lengths.

3. Is long range charge entanglement involved?

The variation for the number of pions could involve electromagnetic charge entanglement between particles produced in the event and ordinary matter. This would guarantee strict charge conservation when the quantization axis for weak isospin for the resulting hadrons differs from that for the ordinary matter. The decay of the pion to gamma pair becomes possible only after the entanglement is reduced and if de-coherence time is long enough it is possible to understand the variation.

9.7.5 Cosmic ray spectrum and exotic hadrons

The hierarchy of M_n hadron physics provides also a mechanism producing ultra high energy cosmic gamma rays and hadrons.

Do gamma rays dominate the spectrum at ultrahigh energies?

A possible piece of evidence for M_{89} hadrons is related to the analysis [C121] of the cosmic ray composition near $E = 10^9$ GeV (note that the energy is in the rest frame of Earth). The analysis was based on the assumption that the spectrum consists of nuclei. The assumptions and conclusions of the analysis can be criticized:

(a) There is argument [C135] , which states that the interaction of protons having energy above 10^9 GeV with the cosmic microwave background implies pion pair creation and a rapid loss of proton energy so that the contribution of protons should be strongly suppressed in the cosmic ray spectrum above $E = 7 \cdot 10^{10}$ GeV. If protons dominate, cosmic ray spectrum should effectively terminate at energy of order $7 \cdot 10^{10}$ GeV: some events above $E = 10^{11}$ GeV have been however detected [C154] .

(b) It is not obvious whether one can distinguish between protons and gamma rays at these energies since the muon content of the photon and proton showers are near to each other at these energies [C123] . Therefore the particles identified as protons might well be gamma rays.

(c) The spectrum can be fitted assuming that cosmic ray spectrum has two components. Light component ('protons') can be identified as protons and He nuclei. The heavy component ('Fe') corresponds to Fe and heavier nuclei. The nuclei between He and Fe seem to be peculiarly absent. Furthermore, there are also indications that spectrum contains only light nuclei in the range $3 \cdot 10^7 - 10^{11}$ GeV [C143] .

An alternative interpretation suggested also in [C123] is that cosmic ray flux is dominated by gamma rays at these energies. 'Protons' could correspond to gamma rays interacting ordinarily with matter. 'Fe nuclei' correspond to the fraction of gamma rays decaying first into M_{89} exotic quark pair producing corresponding exotic hadrons, which then decay to ordinary hadrons and produce showers resembling ordinary heavy nucleus shower. Super-symplectic vision allows to consider the possibility that 'protons' correspond to super-symplectic part of proton having essentially the same mass.

Hadronic component of the cosmic ray spectrum

The properties of the hadronic cosmic ray spectrum above $4 \cdot 10^5$ GeV are not well understood. This energy correspond for a collision with atmospheric proton to cm energy of about $E_{cm} = 10^3$ GeV which suggests that the production of M_{89} hadrons in atmosphere is involved.

(a) It has turned out difficult to invent acceleration mechanisms producing hadronic cosmic rays having energies above 10^5 GeV [C121] .

(b) The spectrum contains a 'knee' (power $E^{-2.7}$ changes to about E^{-3} at the knee), which is at the energy $E = 3 \cdot 10^6$ GeV corresponding to $E_{cm} = 2.5 \times 10^3$ GeV [C121] . This could relate to production of M_{89} hadrons: the mass of M_{89} proton is 512 GeV by naive scaling. It is difficult to understand how the knee is generated although several explanations have been proposed (these are reviewed shortly in [C121]).

A possible solution of the problems is that part of the hadronic cosmic rays are generated in the decay of string like objects rather than by some acceleration mechanism. Assume that M_{n_k} hadron is created in the decay cascade. Since $M_{n_{k+m}}$, $m = 1, 2, ..$ hadrons can have rest masses above M_{n_k} threshold mass, one can consider the possibility that M_{n_k} hadron decays sequentially to ordinary M_{107} hadron with arbitrary large rest mass (even larger than M_{n_k} pion mass) and that this ordinary hadron in turn produces some very energetic low mass hadrons, say proton and antiproton, identifiable as cosmic rays. The most efficient producers of hadrons are M_{n_k} pions since these are produced most abundantly in the decay of $M_{n_{k+1}}$ hadrons. M_{n_k} pion at rest cannot however decay to ordinary hadrons with energy above M_{n_k} pion mass. Therefore the slope of the cosmic ray energy flux should become steeper above M_{n_k}, in particular M_{61}, threshold.

The incoming hadrons would outcome of the decay sequence and therefore ordinary hadrons. They would collide with the hadrons of atmosphere and collisions would create M_{89} hadrons if sufficiently energetic.

The problem of relic quarks and hierarchy of QCD:s

Baryon and lepton numbers are conserved separately in TGD and one of the basic problems of the gauge theories with conserved baryon number is the problem of relic quarks. Hadronization starts in temperature of the order of quark mass and since hadronization is basically many quark process it continues until the expansion rate of the Universe becomes larger than the rate of the hadronization. As a consequence the number density of relic quarks is much larger than the upper bound $n_{relic} < \rho_B/m_q = 10^{-9} n_\gamma m_p/m_q$ obtained from the requirement that the contribution of relic quarks to mass density is smaller than the baryonic mass density. There is also an experimental upper bound $n_{relic} < 10^{-28} n_\gamma$.

The assumption about the existence of QCD:s with a hierarchy of increasing scales $\Lambda_{QCD}(M_n)$ implies that the length scale $L(n) \sim 1/\sqrt{\Lambda_{QCD}(M_n)}$ below which quarks are free, decreases with increasing cosmic temperature and therefore the problem of the relic quarks disappears.

9.7.6 Ultrahigh energy cosmic rays as super-symplectic quanta?

Near the end of year 2007 Pierre Auger Collaboration made a very important announcement relating to ultrahigh energy cosmic rays. I glue below a popular summary of the findings [E2] .

Scientists of the Pierre Auger Collaboration announced today (8 Nov. 2007) that active galactic nuclei are the most likely candidate for the source of the highest-energy cosmic rays that hit Earth. Using the Pierre Auger Observatory in Argentina, the largest cosmic-ray observatory in the world, a team of scientists from 17 countries found that the sources of the highest-energy particles are not distributed uniformly across the sky. Instead, the Auger results link the origins of these mysterious particles to the locations of nearby galaxies that have active nuclei in their centers. The results appear in the Nov. 9 issue of the journal Science.

Active Galactic Nuclei (AGN) are thought to be powered by supermassive black holes that are devouring large amounts of matter. They have long been considered sites where high-energy particle production might take place. They swallow gas, dust and other matter from their host galaxies and spew out particles and energy. While most galaxies have black holes at their center, only a fraction of all galaxies have an AGN. The exact mechanism of how AGNs can accelerate particles to energies 100 million times higher than the most powerful particle accelerator on Earth is still a mystery.

What has been found?

About million cosmic ray events have been recorded and 80 of them correspond to particles with energy above the so called GKZ bound, which is $.54 \times 10^{11}$ GeV. Electromagnetically interacting particles with these energies from distant galaxies should not be able to reach Earth. This would be due to the scattering from the photons of the microwave background. About 20 particles of this kind however comes from the direction of distant active galactic nuclei and the probability that this is an accident is about 1 per cent. Particles having only strong interactions would be in question. The problem is that this kind of particles are not predicted by the standard model (gluons are confined).

What could TGD say about the finding?

TGD provides a possible explanation for the new kind of particles.

(a) The original TGD based model for the galactic nucleus is as a highly tangled cosmic string (in TGD sense of course [K17] . Much later it became clear that also TGD based model for black-hole is as this kind of string like object near Hagedorn temperature [K17] . Ultrahigh energy particles could result as decay products of a decaying split cosmic string as an extremely energetic galactic jet. Kind of cosmic fire cracker would be in question. Originally I proposed this decay as an explanation for the gamma ray bursts. It seems that gamma ray bursts however come from thickened cosmic strings having weaker magnetic field and much lower energy density [K59] .

(b) TGD predicts particles having only strong interactions [K34] . I have christened these particles super-symplectic quanta. These particles correspond to the vibrational degrees of freedom of partonic 2-surface and are not visible at the quantum field theory limit for which partonic 2-surfaces become points.

What super-symplectic quanta are?

Super-symplectic quanta are created by the elements of super-symplectic algebra, which creates quantum states besides the super Kac-Moody algebra present also in super string model. Both algebras relate closely to the conformal invariance of light-like 3-surfaces.

(a) The elements of super-symplectic algebra are in one-one correspondence with the Hamiltonians generating symplectic transformations of $\delta M^4_+ \times CP_2$. Note that the 3-D light-cone boundary is metrically 2-dimensional and possesses degenerate symplectic and Kähler structures so that one can indeed speak about symplectic (canonical) transformations.

(b) This algebra is the analog of Kac-Moody algebra with finite-dimensional Lie group replaced with the infinite-dimensional group of symplectic transformations [K13] . This should give an idea about how gigantic a symmetry is in question. This is as it should be since these symmetries act as the largest possible symmetry group for the Kähler geometry of the world of classical worlds (WCW) consisting of light-like 3-surfaces in 8-D imbedding space for given values of zero modes (labeling the spaces in the union of infinite-dimensional symmetric spaces). This implies that for the given values of zero modes all points of WCW are metrically equivalent: a generalization of the perfect cosmological principle making theory calculable and guaranteeing that WCW metric exists mathematically. Super-symplectic generators correspond to gamma matrices of WCW and have the quantum numbers of right handed neutrino (no electro-weak interactions). Note that a geometrization of fermionic statistics is achieved.

(c) The Hamiltonians and super-Hamiltonians have only color and angular momentum quantum numbers and no electro-weak quantum numbers so that electro-weak interactions are absent. Super-symplectic quanta however interact strongly.

Also hadrons contain super-symplectic quanta

One can say that TGD based model for hadron is at space-time level kind of combination of QCD and old fashioned string model forgotten when QCD came in fashion and then transformed to the highly unsuccessful but equally fashionable theory of everything.

(a) At quantum level the energy corresponding to string tension explaining about 70 per cent of proton mass corresponds to super-symplectic quanta [K43] . Super-symplectic quanta allow to understand hadron masses with a precision better than 1 per cent.

(b) Super-symplectic degrees of freedom allow also to solve spin puzzle of the proton: the average quark spin would be zero since same net angular momentum of hadron can be obtained by coupling quarks of opposite spin with angular momentum eigen states with different projection to the direction of quantization axis.

(c) If one considers proton without valence quarks and gluons, one obtains a boson with mass very nearly equal to that of proton (for proton super-symplectic binding energy compensates quark masses with high precision). These kind of pseudo protons might be created in high energy collisions when the space-time sheets carrying valence quarks and super-symplectic space-time sheet separate from each other. Super-symplectic quanta might be produced in accelerators in this manner and there is actually experimental support for this from Hera.

(d) The exotic particles could correspond to some p-adic copy of hadron physics predicted by TGD and have very large mass smaller however than the energy. Mersenne primes $M_n = 2^n - 1$ define excellent candidates for these copies. Ordinary hadrons correspond to M_{107}. The protons of M_{61} hadron physics would have the mass of proton scaled up by a factor $2^{(107-61)/2} = 2^{23} \simeq 8 \times 10^6$. GKZ limit $E = .54 \times 10^{11}$ GeV corresponds to cm energy $E_{cm} = 3.3 \times 10^5$ GeV and is below 8×10^6 GeV. Super-symplectic M_{89} protons having no valence quarks can propagate without interactions with cosmic microwave background. Note that CP_2 mass corresponds roughly to about 10^{14} proton masses.

(e) Ideal blackholes would be very long highly tangled string like objects, scaled up hadrons, containing only super-symplectic quanta. Hence it would not be surprising if they would emit super-symplectic quanta. The transformation of supernovas to neutron stars and possibly blackholes would involve the fusion of hadronic strings to longer strings and eventual annihilation and evaporation of the ordinary matter so that only super-symplectic matter would remain eventually. A wide variety of intermediate states with different values of string tension would be possible and the ultimate blackhole would correspond to highly tangled cosmic string. Dark matter would be in question in the sense that Planck constant could be very large.

Chapter 10

New Physics Predicted by TGD: Part II

10.1 Introduction

In this chapter the focus is on the hadron physics . The applications are to various anomalies discovered during years.

10.1.1 Application of the many-sheeted space-time concept in hadron physics

The many-sheeted space-time concept involving also the notion of field body can be applied to hadron physics to explain findings which are difficult to understand in the framework of standard model

(a) The spin puzzle of proton [C108, C112] is at the time of writing a two decades old mystery with no satisfactory explanation in QCD framework. The notion of hadronic space-time sheet which could be imagined as string like rotating object suggests a possible approach to the spin puzzle. The entanglement between valence quark spins and the angular momentum states of the rotating hadronic space-time sheet could allow natural explanation for why the average valence quark spin vanishes.

(b) The notion of Pomeron was invented during the Bootstrap era preceding QCD to solve difficulties of Regge approach. There are experimental findings suggesting the reincarnation of this concept [C111, C94, C95]. The possibility that the newly born concept of Pomeron of Regge theory might be identified as the sea of perturbative QCD in TGD framework is considered. Geometrically Pomeron would correspond to hadronic space-time sheet without valence quarks.

(c) The discovery that the charge radius of proton deduced from the muonic version of hydrogen atom is about 4 per cent smaller than from the radius deduced from hydrogen atom [C129, C148] is in complete conflict with the cherished belief that atomic physics belongs to the museum of science. The title of the article *Quantum electrodynamics-a chink in the armour?* of the article published in Nature [C116] expresses well the possible implications, which might actually go well extend beyond QED. TGD based model for the findings relies on the notion of color magnetic body carrying both electromagnetic and color fields and extends well beyond the size scale of the particle. This gives rather detailed constraints on the model of the magnetic body.

(d) The soft photon production rate in hadronic reactions is by an average factor of about four higher than expected [**?**] In the article soft photons assignable to the decays of Z^0 to quark-antiquark pairs. This anomaly has not reached the attention of particle physics which seems to be the fate of anomalies quite generally nowadays: large extra dimensions and black-holes at LHC are much more sexy topics of study than the anomalies about which both existing and speculative theories must remain silent. TGD based model is based on the notion of electric flux tube.

10.1.2 Quark gluon plasma

QCD predicts that at sufficiently high collision energies de-confinement phase transitions for quarks should take place leading to quark gluon plasma. In heavy ion collisions at RHIC [C97] something like this was found to happen. The properties of the quark gluon plasma were however not what was expected. There are long range correlations and the plasma seems to behave like perfect fluid with minimal viscosity/entropy ratio. The lifetime of the plasma phase is longer than expected and its density much higher than QCD would suggest. The experiments at LHC for proton proton collisions suggest also the presence of quark gluon plasma with similar properties.

TGD suggests an interpretation in terms of long color magnetic flux tubes containing the plasma so that additional support for the notion of field would would emerge. The confinement to color magnetic flux tubes would force higher density. The preferred extremals of Kähler action have interpretation as defining a flow of perfect incompressible fluid and the perfect fluid property is broken only by the many-sheeted structure of space-time with smaller space-time sheets assignable to sub-CDs representing radiative corrections. The phase in question corresponds to a non-standard value of Planck constant: this could also explain why the lifetime of the phase is longer than expected.

10.1.3 Breaking of discrete symmetries

Zero energy ontology provides a fresh approach to discrete symmetries and provides also a general mechanism for their breaking. A general vision about breaking of discrete symmetries relies on quantum measurement theory: the quantum jump selecting the quantization axes induces localization to a single CD and therefore induces breaking of discrete symmetries due to the choice of quantization axes. The time scale of CD is excellent candidate for defining mass and time scales characterizing the symmetry breaking. Entropic gravity idea has a variant in TGD framework resulting from the fact that in ZEO quantum theory is a square root of thermodynamics in a well-defined sense. This suggests that thermodynamical stability forces the generation of the arrow of time and forces it to be different for matter and antimatter inducing in this manner matter antimatter asymmetry and breaking of discrete symmetries like CP. Also CPT can be broken spontaneously and there are experimental indications that this takes place for top quark with mass difference which is surprisingly large- few per cent of top mass.

The anomalously large direct CP breaking in $K_L \rightarrow \pi\pi$ decays is included as old application of TGD. The breaking is explained in terms of loop corrections due to the predicted 2 exotic gluons having masses around 33.6 GeV. It will be also found that the TGD version of the chiral field theory believed to provide a phenomenological low energy description of QCD differs from its standard model version in that quark masses are replaced in TGD framework with shifts of quark masses induced by the vacuum expectation values of the scalar meson fields. This conforms with the TGD view about Higgs mechanism as causing only small mass shifts. It must be however emphasized that there is an argument suggesting that the vacuum expectation value of Higgs in fermionic case does not even make sense.

10.1.4 Are exotic Super Virasoro representations relevant for hadron physics?

The last section of the chapter can be taken as miscellaneous material, which I have not been able to throw away yet. In p-adic context exotic representations of Super Virasoro with $M^2 \propto p^k$, $k = 1, 2, ..m$ are possible. For $k = 1$ the states of these representations have same mass scale as elementary particles although in real context the masses would be gigantic. This inspires the question whether non-perturbative aspects of hadron physics could be assigned to the presence of these representations.

The prospects for this are promising. Pion mass is almost exactly equal to the mass of lowest state of the exotic representation for $k = 107$ and Regge slope for rotational excitations of hadrons is predicted with three per cent accuracy assuming that they correspond to the states of $k = 101$ exotic Super Virasoro representations. This leads to the idea that hadronization and fragmentation correspond to phase transitions between ordinary and exotic Super Virasoro representations and that there is entire fractal hierarchy of hadrons inside hadrons and QCD:s inside QCD:s corresponding to p-adic length scales $L(k)$, $k = 107, 103, 101, 97, ...$. Some intriguing numerical co-incidences suggest that the exotic representations of Super-Virasoro should be assigned with hadron and whereas ordinary Virasoro representations could be assigned with the quark-gluon plasma or possibly sea partons.

The appendix of the book gives a summary about basic concepts of TGD with illustrations. There are concept maps about topics related to the contents of the chapter prepared using CMAP realized as html files. Links to all CMAP files can be found at `http://www.tgdtheory.fi/cmaphtml.html` [L20]. Pdf representation of same files serving as a kind of glossary can be found at `http://www.tgdtheory.fi/tgdglossary.pdf` [L21]. The topics relevant to this chapter are given by the following list.

- TGD view about elementary particles [L49]
- p-Adic length scale hypothesis [L39]
- p-Adic mass calculations [L37]
- Geometrization of fields [L27]
- Magnetic body [L34]
- Emergent ideas and notions [L26]
- Elementary particle vacuum functionals [L24]
- Emergence of bosons [L25]
- Leptohadron hypothesis [L32]
- M89 hadron physics [L33]
- SUSY and TGD [L43]

10.2 New space-time concept applied to hadrons

10.2.1 A new twist in the spin puzzle of proton

The so called proton spin crisis or spin puzzle of proton was an outcome of the experimental finding that the quarks contribute only 13-17 per cent of proton spin [C108, C112] whereas the simplest valence quark model predicts that quarks contribute about 75 per cent to the spin of proton with the remaining 25 per cent being due to the orbital motion of quarks. Besides the orbital motion of valence quarks also gluons could contribute to the spin of proton. Also polarized sea quarks can be considered as a source of proton spin.

Quite recently, the spin crisis got a new twist [C127] . One of the few absolute predictions of perturbative QCD (pQCD) is that at the limit, when the momentum fraction of quark approaches unity, quark spin should be parallel to the proton spin. This is due to the helicity conservation predicted by pQCD in the lowest order. The findings are consistent with this expectation in the case of protonic u quarks but not in the case of protonic d quark. The discovery is of a special interest from the point of view of TGD since it might have an explanation involving the notions of many-sheeted space-time, of color-magnetic flux tubes, the predicted super-symplectic "vacuum" spin, and also the concept of quantum parallel dissipation.

The experimental findings

In the experiment performed in Jefferson Lab [C127] neutron spin asymmetries A_1^n and polarized structure functions $g_{1,2}^n$ were deduced for three kinematic configurations in the deep inelastic region from e-^{3}He scattering using 5.7 GeV longitudinally polarized electron beam and a polarized ^3He target. A_1^n and $g_{1,2}^n$ were deduced for $x = .33, .47$, and .60 and $Q^2 = 2.7, 3.5$ and 4.8 (GeV/c)^2. A_1^n and g_1^n at $x = .33$ are consistent with the world data. At $x = .47$ A_1^n crosses zero and is significantly positive at $x = 0.60$. This finding agrees with the next-to-leading order QCD analysis of previous world data without the helicity conservation constraint. The trend of the data agrees with the predictions of the constituent quark model but disagrees with the leading order pQCD assuming hadron helicity conservation.

By isospin symmetry one can translate the result to the case of proton by the replacement $u \leftrightarrow d$. By using world proton data, the polarized quark distribution functions were deduced for proton using isospin symmetry between neuron and proton. It was found that $\Delta u/u$ agrees with the predictions of various models while $\Delta d/d$ disagrees with the leading-order pQCD.

Let us denote by $q(x) = q^{\uparrow} + q^{\downarrow}(x)$ the spin independent quark distribution function. The difference $\Delta q(x) = q^{\uparrow} - q^{\downarrow}(x)$ measures the contribution of quark q to the spin of hadron. The measurement allowed to deduce estimates for the ratios $(\Delta q(x) + \Delta \overline{q}(x))/(q(x) + \overline{q}(x))$.

The conclusion of [C127] is that for proton one has

$$\frac{\Delta u(x) + \Delta \overline{u}(x)}{u(x) + \overline{u}(x)} \simeq .737 \pm .007 \quad , \quad \text{for} \quad x = .6 \quad .$$

This is consistent with the pQCD prediction. For d quark the experiment gives

$$\frac{\Delta d(x) + \Delta \overline{d}(x)}{d(x) + \overline{d}(x)} \simeq -.324 \pm .083 \quad \text{for} \quad x = .6 \quad .$$

The interpretation is that d quark with momentum fraction $x > .6$ in proton spends a considerable fraction of time in a state in which its spin is opposite to the spin of proton so that the helicity conservation predicted by first order pQCD fails. This prediction is of special importance as one of the few absolute predictions of pQCD.

The finding is consistent with the relativistic $SU(6)$ symmetry broken by spin-spin interaction and the QCD based model interpolated from data but giving up helicity conservation [C127] . $SU(6)$ is however not a fundamental symmetry so that its success is probably accidental.

It has been also proposed that the spin crisis might be illusory [C146] and due to the fact that the vector sum of quark spins is not a Lorentz invariant quantity so that the sum of quark spins in infinite-momentum frame where quark distribution functions are defined is not same as, and could thus be smaller than, the spin sum in the rest frame. The correction due to the transverse momentum of the quark brings in a non-negative numerical correction factor which is in the range $(0, 1)$. The negative sign of $\Delta d/d$ is not consistent with this proposal.

TGD based model for the findings

The TGD based explanation for the finding involves the following elements.

(a) TGD predicts the possibility of vacuum spin due to the super-symplectic symmetry. Valence quarks can be modelled as a star like formation of magnetic flux tubes emanating from a vertex with the conservation of color magnetic flux forcing the valence quarks to form a single coherent structure. A good guess is that the super-symplectic spin corresponds classically to the rotation of the the star like structure.

(b) By parity conservation only even values of super-symplectic spin J are allowed and the simplest assumption is that the valence quark state is a superposition of ordinary $J = 0$ states predicted by pQCD and $J = 2$ state in which all quarks have spin which is in a direction opposite to the direction of the proton spin. The state of $J = 1/2$ baryon is thus replaced by a new one:

$$\begin{aligned} |B, \frac{1}{2}, \uparrow\rangle &= a|B, 1/2, \frac{1}{2}\rangle|J = J_z = 0\rangle + b|B, \frac{3}{2}, -\frac{3}{2}\rangle|J = J_z = 2\rangle \ , \\ |B, 1/2, \frac{1}{2}\rangle &= \sum_{q_1,q_2,q_3} c_{q_1,q_2,q_3} q_1^{\uparrow} q_2^{\uparrow} q_3^{\downarrow} \ , \\ |B, \frac{3}{2}, -\frac{3}{2}\rangle &= d_{q_1,q_2,q_3} q_1^{\downarrow} q_2^{\downarrow} q_3^{\downarrow} \ . \end{aligned} \quad (10.2.-1)$$

$|B, 1/2, \frac{1}{2}\rangle$ is in a good approximation the baryon state as predicted by pQCD. The coefficients c_{q_1,q_2,q_3} and d_{q_1,q_2,q_3} depend on momentum fractions of quarks and the states are normalized so that $|a|^2 + |b|^2 = 1$ is satisfied: the notation $p = |a|^2$ will be used in the sequel. The quark parts of $J = 0$ and $J = 2$ have quantum numbers of proton and Δ resonance. $J = 2$ part need not however have the quark distribution functions of Δ.

(c) The introduction of $J = 0$ and $J = 2$ ground states with a simultaneous use of quark distribution functions makes sense if one allows quantum parallel dissipation. Although the system is coherent in the super-symplectic degrees of freedom which correspond to the hadron size scale, there is a de-coherence in quark degrees of freedom which correspond to a shorter p-adic length scale and smaller space-time sheets.

(d) Consider now the detailed structure of the $J = 2$ state in the case of proton. If the d quark is at the rotation axis, the rotating part of the triangular flux tube structure resembles a string containing u-quarks at its ends and forming a di-quark like structure. Di-quark structure is taken to mean correlations between u-quarks in the sense that they have nearly the same value of x so that $x < 1/2$ holds true for them whereas the d-quark behaving more like a free quark can have $x > 1/2$.

A stronger assumption is that di-quark behaves like a single colored hadron with a small value of x and only the d-quark behaves as a free quark able to have large values of x. Certainly this would be achieved if u quarks reside at their own string like space-time sheet having $J = 2$.

From these assumptions it follows that if u quark has $x > 1/2$, the state effectively reduces to a state predicted by pQCD and $u(x) \rightarrow 1$ for $x \rightarrow 1$ is predicted. For the d quark the situation is different and introducing distribution functions $q^{J)}(x)$ for $J = 0, 2$ separately, one can write the spin asymmetry at the limit $x \rightarrow 1$ as

$$\begin{aligned} A_d &\equiv \frac{\Delta d(x) + \Delta \overline{d}(x)}{d(x) + \overline{d}(x)} = \frac{p(\Delta d_0 + \Delta \overline{d}_0) + (1-p)(\Delta d_2 + \Delta \overline{d}_2)}{p(d_0 + \overline{d}_0) + (1-p)(d_2 + \overline{d}_2)} \ , \\ p &= |a|^2 \ . \end{aligned} \quad (10.2.-1)$$

Helicity conservation gives $\Delta d_0/d_0 \rightarrow 1$ at the limit $x \rightarrow 1$ and one has trivially $\Delta d_2/d_2 = -1$. Taking the ratio

$$y = \frac{d_2}{d_0}$$

as a parameter, one can write

$$A_d \rightarrow \frac{p - (1-p)y}{p + (1-p)y} \quad (10.2.0)$$

at the limit $x \rightarrow 1$. This allows to deduce the value of the parameter y once the value of p is known:

$$y = \frac{p}{1-p} \times \frac{1-A_d}{1+A_d} \ . \tag{10.2.1}$$

From the requirement that quarks contribute a fraction $\Sigma = \sum_q \Delta q \in (13,17)$ per cent to proton spin, one can deduce the value of p using

$$\frac{p \times \frac{1}{2} - (1-p) \times \frac{3}{2}}{\frac{1}{2}} = \Sigma \tag{10.2.2}$$

giving $p = (3+\Sigma)/4 \simeq .75$.

Eq. 10.2.1 allows estimate the value of y. In the range $\Sigma \in (.13,.30)$ defined by the lower and upper bounds for the contribution of quarks to the proton spin, $A_d = -.32$ gives $y \in (6.98, 9.15)$. $d_2(x)$ would be more strongly concentrated at high values of x than $d_0(x)$. This conforms with the assumption that u quarks tend to carry a small fraction of proton momentum in $J = 2$ state for which uu can be regarded as a string like di-quark state.

A further input to the model comes from the ratio of neutron and proton F_2 structure functions expressible in terms of quark distribution functions of proton as

$$R^{np} \equiv \frac{F_2^n}{F_2 p} = \frac{u(x)+4d(x)}{4u(x)+d(x)} \ . \tag{10.2.3}$$

According to [C127] $R^{np}(x)$ is a straight line starting with $R^{np}(x \to 0) \simeq 1$ and dropping below $1/2$ as $x \to 1$. The behavior for small x can be understood in terms of sea quark dominance. The pQCD prediction for R^{np} is $R^{np} \to 3/7$ for $x \to 1$, which corresponds to $d/u \to z = 1/5$. TGD prediction for R^{np} for $x \to 1$

$$\begin{aligned} R^{np} &\equiv \frac{F_2^n}{F_2^p} = \frac{pu_0 + 4(pd_0 + (1-p)d_2)}{4pu_0 + pd_0 + (1-p)d_2} \\ &= \frac{p + 4z(p + (1-p)y}{4p + z(p + (1-p)y)} \ . \end{aligned} \tag{10.2.3}$$

In the range $\Sigma \in (.13,.30)$ which corresponds to $y \in (6.98, 9.15)$ for $A_d = -.32$ $R^{np} = 1/2$ gives $z \simeq .1$, which is 20 per cent of pQCD prediction. 80 percent of d-quarks with large x predicted to be in $J = 0$ state by pQCD would be in $J = 2$ state.

10.2.2 Topological evaporation and the concept of Pomeron

Topological evaporation provides an explanation for the mysterious concept of Pomeron originally introduced to describe hadronic diffractive scattering as the exchange of Pomeron Regge trajectory [C158]. No hadrons belonging to Pomeron trajectory were however found and via the advent of QCD Pomeron was almost forgotten. Pomeron has recently experienced reincarnation [C111, C94, C95]. In Hera [C111] $e-p$ collisions, where proton scatters essentially elastically whereas jets in the direction of incoming virtual photon emitted by electron are observed. These events can be understood by assuming that proton emits color singlet particle carrying small fraction of proton's momentum. This particle in turn collides with virtual photon (antiproton) whereas proton scatters essentially elastically.

The identification of the color singlet particle as Pomeron looks natural since Pomeron emission describes nicely diffractive scattering of hadrons. Analogous hard diffractive scattering events in pX diffractive scattering with $X = \bar{p}$ [C94] or $X = p$ [C95] have also been observed. What happens is that proton scatters essentially elastically and emitted Pomeron collides with X and suffers hard scattering so that large rapidity gap jets in the direction of X are observed. These results suggest that Pomeron is real and consists of ordinary partons.

TGD framework leads to two alternative identifications of Pomeron relying on same geometric picture in which Pomeron corresponds to a space-time sheet separating from hadronic space-time sheet and colliding with photon.

Earlier model

The earlier model is based on the assumption that baryonic quarks carry the entire four-momentum of baryon. p-Adic mass calculations have shown that this assumption is wrong. The modification of the model requires however to change only wordings so that I will represent the earlier model first.

The TGD based identification of Pomeron is very economical: Pomeron corresponds to sea partons, when valence quarks are in vapor phase. In TGD inspired phenomenology events involving Pomeron correspond to pX collisions, where incoming X collides with proton, when valence quarks have suffered coherent simultaneous (by color confinement) evaporation into vapor phase. System X sees only the sea left behind in evaporation and scatters from it whereas valence quarks continue without noticing X and condense later to form quasi-elastically scattered proton. If X suffers hard scattering from the sea the peculiar hard diffractive scattering events are observed. The fraction of these events is equal to the fraction f of time spent by valence quarks in vapor phase.

Dimensional argument can be used to derive a rough order of magnitude estimate for f as $f \sim 1/\alpha = 1/137 \sim 10^{-2}$ for f: f is of same order of magnitude as the fraction (about 5 per cent) of peculiar events from all deep inelastic scattering events in Hera. The time spent in condensate is by dimensional arguments of the order of the p-adic length scale $L(M_{107})$, not far from proton Compton length. Time dilation effects at high collision energies guarantee that valence quarks indeed stay in vapor phase during the collision. The identification of Pomeron as sea explains also why Pomeron Regge trajectory does not correspond to actual on mass shell particles.

The existing detailed knowledge about the properties of sea structure functions provides a stringent test for the TGD scenario. According to [C94] Pomeron structure function seems to consist of soft ($(1-x)^5$), hard ($(1-x)$) and super-hard component (delta function like component at $x = 1$). The peculiar super hard component finds explanation in TGD based picture. The structure function $q_P(x,z)$ of parton in Pomeron contains the longitudinal momentum fraction z of the Pomeron as a parameter and $q_P(x,z)$ is obtained by scaling from the sea structure function $q(x)$ for proton $q_P(x,z) = q(zx)$. The value of structure function at $x = 1$ is non-vanishing: $q_P(x = 1, z) = q(z)$ and this explains the necessity to introduce super hard delta function component in the fit of [C94].

Updated model

The recent developments in the understanding of hadron mass spectrum involve the realization that hadronic $k = 107$ space-time sheet is a carrier of super-symplectic bosons (and possibly their super-counterparts with quantum numbers of right handed neutrino) [K43] . The model leads to amazingly simple and accurate mass formulas for hadrons. Most of the baryonic momentum is carried by super-symplectic quanta: valence quarks correspond in proton to a relatively small fraction of total mass: about 170 MeV. The counterparts of string excitations correspond to super-symplectic many-particle states and the additivity of conformal weight proportional to mass squared implies stringy mass formula and generalization of Regge trajectory picture. Hadronic string tension is predicted correctly. Model also provides a solution to the proton spin puzzle.

In this framework valence quarks would naturally correspond to a color singlet state formed by space-time sheets connected by color flux tubes having no Regge trajectories and carrying a relatively small fraction of baryonic momentum. In the collisions discussed valence quarks would leave the hadronic space-time sheet and suffer a collision with photon. The lightness of Pomeron and and electro-weak neutrality of Pomeron support the view that photon stripes valence quarks from Pomeron, which continues its flight more or less unperturbed. Instead of an actual topological evaporation the bonds connecting valence quarks to the hadronic space-time sheet could be stretched during the collision with photon.

The large value of $\alpha_K = 1/4$ for super-symplectic matter suggests that the criterion for a phase transition increasing the value of Planck constant [K22] and leading to a phase, where $\alpha_K \propto 1/hbar$ is reduced, could occur. For α_K to remain invariant, $\hbar_0 \to 26\hbar_0$ would be required. In this case, the size of hadronic space-time sheet, "color field body of the hadron", would be $26 \times L(107) = 46$ fm, roughly the size of the heaviest nuclei. Hence a natural expectation is that the dark side of nuclei plays a role in the formation of atomic nuclei. Note that the sizes of electromagnetic field bodies of current quarks u and d with masses of order few MeV is not much smaller than the Compton length of electron. This would mean that super-symplectic bosons would represent dark matter in a well-defined sense and Pomeron exchange would represent temporary separation of ordinary and dark matter.

Note however that the fact that super-symplectic bosons have no electro-weak interactions, implies their dark matter character even for the ordinary value of Planck constant: this could be taken as an objection against dark matter hierarchy. My own interpretation is that super-symplectic matter is dark matter in the strongest sense of the world whereas ordinary matter in the large $\hbar$ phase is only apparently dark matter because standard interactions do not reveal themselves in the expected manner.

Astrophysical counterpart of Pomeron events

Pomeron events have direct analogy in astrophysical length scales. In the collision of two galaxies dark and visible matter parts of the colliding galaxies have been found to separate by Chandra X-ray Observatory [C151] .

Imagine a collision between two galaxies. The ordinary matter in them collides and gets interlocked due to the mutual gravitational attraction. Dark matter, however, just keeps its momentum and keeps going on leaving behind the colliding galaxies. This kind of event has been detected by the Chandra X-Ray Observatory by using an ingenious manner to detect dark matter. Collisions of ordinary matter produces a lot of X-rays and the dark matter outside the galaxies acts as a gravitational lens.

10.2.3 The incredibly shrinking proton

The discovery that the charge radius of proton deduced from the muonic version of hydrogen atom is about 4 per cent smaller than from the radius deduced from hydrogen atom [C129, C148] is in complete conflict with the cherished belief that atomic physics belongs to the museum of science. The title of the article *Quantum electrodynamics-a chink in the armour?* of the article published in Nature [C116] expresses well the possible implications, which might actually go well extend beyond QED.

The finding is a problem of QED or to the standard view about what proton is. Lamb shift [C12] is the effect distinguishing between the states hydrogen atom having otherwise the same energy but different angular momentum. The effect is due to the quantum fluctuations of the electromagnetic field. The energy shift factorizes to a product of two expressions. The first one describes the effect of these zero point fluctuations on the position of electron or muon and the second one characterizes the average of nuclear charge density as "seen" by electron or muon. The latter one should be same as in the case of ordinary hydrogen atom but it is not. Does this mean that the presence of muon reduces the charge radius of proton as determined from muon wave function? This of course looks implausible since the radius of proton is so small. Note that the compression of the muon's wave function has the same effect.

Before continuing it is good to recall that QED and quantum field theories in general have difficulties with the description of bound states: something which has not received too much attention. For instance, van der Waals force at molecular scales is a problem. A possible TGD based explanation and a possible solution of difficulties proposed for two decades ago is that for bound states the two charged particles (say nucleus and electron or two atoms) correspond to two 3-D surfaces glued by flux tubes rather than being idealized to points of Minkowski space. This would make the non-relativistic description based on Schrödinger amplitude natural and replace the description based on Bethe-Salpeter equation having horrible mathematical properties.

Basic facts and notions

In this section the basic TGD inspired ideas and notions - in particular the notion of field body- are introduced and the general mechanism possibly explaining the reduction of the effective charge radius relying on the leakage of muon wave function to the flux tubes associated with u quarks is introduced. After this the value of leakage probability is estimated from the standard formula for the Lamb shift in the experimental situation considered.

1. Basic notions of TGD which might be relevant for the problem

Can one say anything interesting about the possible mechanism behind the anomaly if one accepts TGD framework? How the presence of muon could reduce the charge radius of proton? Let us first list the basic facts and notions.

(a) One can say that the size of muonic hydrogen characterized by Bohr radius is by factor $m_e/m_\mu = 1/211.4 = 4.7\times 10^{-4}$ smaller than for hydrogen atom and equals to 250 fm. Hydrogen atom Bohr radius is .53 Angstroms.

(b) Proton contains 2 quarks with charge 2e/3 and one d quark which charge -e/3. These quarks are light. The last determination of u and d quark masses [C102] gives masses, which are $m_u = 2$ MeV and $m_d = 5$ MeV (I leave out the error bars). The standard view is that the contribution of quarks to proton mass is of same order of magnitude. This would mean that quarks are not too relativistic meaning that one can assign to them a size of order Compton wave length of order $4\times r_e \simeq 600$ fm in the case of u quark (roughly twice the Bohr radius of muonic hydrogen) and $10\times r_e \simeq 24$ fm in the case of d quark. These wavelengths are much longer than the proton charge radius and for u quark more than twice longer than the Bohr radius of the muonic hydrogen. That parts of proton would be hundreds of times larger than proton itself sounds a rather weird idea. One could of course argue that the scales in question do not correspond to anything geometric. In TGD framework this is not the way out since quantum classical correspondence requires this geometric correlate.

(c) There is also the notion of classical radius of electron and quark. It is given by $r = \alpha\hbar/m$ and is in the case of electron this radius is 2.8 fm whereas proton charge radius is .877 fm and smaller. The dependence on Planck constant is only apparent as it should be since classical radius is in question. For u quark the classical radius is .52 fm and smaller than proton charge radius. The constraint that the classical radii of quarks are smaller than proton charge radius gives a lower bound of quark masses: p-adic scaling of u quark mass by $2^{-1/2}$ would give classical radius .73 fm which still satisfies the bound. TGD framework the proper generalization would be $r = \alpha_K\hbar/m$, where α_K is Kähler coupling strength defining the fundamental coupling constant of the theory and quantized from quantum criticality. Its value is very near or equal to fine structure constant in electron length scale.

(d) The intuitive picture is that light-like 3-surfaces assignable to quarks describe random motion of partonic 2-surfaces with light-velocity. This is analogous to zitterbewegung assigned classically to the ordinary Dirac equation. The notion of braid emerges from the localization of the modes of the induced spinor field to 2-D surfaces - string world sheets and possibly also partonic 2-surfaces carrying vanishing W fields and Z^0 field at least above weak scale. It is implied by well-definedness of em charge for the modes of Kähler-Dirac action. The orbits of partonic 2-surface effectively reduces to braids carrying fermionic quantum numbers. These braids in turn define higher level braids which would move inside a structure characterizing the particle geometrically. Internal consistency suggests that the classical radius $r = \alpha_K \hbar/m$ characterizes the size scale of the zitterbewegung orbits of quarks.

I cannot resist the temptation to emphasize the fact that Bohr orbitology is now reasonably well understood. The solutions of field equations with higher than 3-D CP_2 projection describing radiation fields allow only generalizations of plane waves but not their superpositions in accordance with the fact it is these modes that are observed. For massless extremals with 2-D CP_2 projection superposition is possible only for parallel light-like wave vectors. Furthermore, the restriction of the solutions of the Chern-Simons Dirac equation at light-like 3-surfaces to braid strands gives the analogs of Bohr orbits. Wave functions of -say electron in atom- are wave functions for the position of wormhole throat and thus for braid strands so that Bohr's theory becomes part of quantum theory.

(e) In TGD framework quantum classical correspondence requires -or at least strongly suggests- that also the p-adic length scales assignable to u and d quarks have geometrical correlates. That quarks would have sizes much larger than proton itself how sounds rather paradoxical and could be used as an objection against p-adic length scale hypothesis. Topological field quantization however leads to the notion of field body as a structure consisting of flux tubes and and the identification of this geometric correlate would be in terms of Kähler (or color-, or electro-) magnetic body of proton consisting of color flux tubes beginning from space-time sheets of valence quarks and having length scale of order Compton wavelength much longer than the size of proton itself. Magnetic loops and electric flux tubes would be in question. Also secondary p-adic length scale characterizes field body. For instance, in the case of electron the causal diamond assigned to electron would correspond to the time scale of .1 seconds defining an important bio-rhythm.

2. Could the notion of field body explain the anomaly?

The large Compton radii of quarks and the notion of field body encourage the attempt to imagine a mechanism affecting the charge radius of proton as determined from electron's or muon's wave function.

(a) Muon's wave function is compressed to a volume which is about 8 million times smaller than the corresponding volume in the case of electron. The Compton radius of u quark more that twice larger than the Bohr radius of muonic hydrogen so that muon should interact directly with the field body of u quark. The field body of d quark would have size 24 fm which is about ten times smaller than the Bohr radius so that one can say that the volume in which muons sees the field body of d quark is only one thousandth of the total volume. The main effect would be therefore due to the two u quarks having total charge of 4e/3.

One can say that muon begins to "see" the field bodies of u quarks and interacts directly with u quarks rather than with proton via its electromagnetic field body. With d quarks it would still interact via protons field body to which d quark should feed its electromagnetic flux. This could be quite enough to explain why the charge radius of proton determined from the expectation value defined by its wave function wave function is smaller than for electron. One must of course notice that this brings in also direct magnetic interactions with u quarks.

(b) What could be the basic mechanism for the reduction of charge radius? Could it be that the electron is caught with some probability into the flux tubes of u quarks and that Schrödinger amplitude for this kind state vanishes near the origin? If so, this portion of state would not contribute to the charge radius and the since the portion ordinary state would smaller, this would imply an effective reduction of the charge radius determined from experimental data using the standard theory since the reduction of the norm of the standard part of the state would be erratically interpreted as a reduction of the charge radius.

(c) This effect would be of course present also in the case of electron but in this case the u quarks correspond to a volume which million times smaller than the volume defined by Bohr radius so that electron does not in practice "see" the quark sub-structure of proton. The probability P for getting caught would be in a good approximation proportional to the value of $|\Psi(r_u)|^2$ and in the first approximation one would have

$$\frac{P_e}{P_\mu} \sim (a_\mu/a_e)^3 = (m_e/m_\mu)^3 \sim 10^{-7} \quad .$$

from the proportionality $\Psi_i \propto 1/a_i^{3/2}$, i=e,$\mu$.

3. A general formula for Lamb shift in terms of proton charge radius

The charge radius of proton is determined from the Lamb shift between 2S- and 2P states of muonic hydrogen. Without this effect resulting from vacuum polarization of photon Dirac equation for hydrogen would predict identical energies for these states. The calculation reduces to the calculation of vacuum polarization of photon inducing to the Coulomb potential and an additional vacuum polarization term. Besides this effect one must also take into account the finite size of the proton which can be coded in terms of the form factor deducible from scattering data. It is just this correction which makes it possible to determine the charge radius of proton from the Lamb shift.

(a) In the article [C36] the basic theoretical results related to the Lamb shift in terms of the vacuum polarization of photon are discussed. Proton's charge density is in this representation is expressed in terms of proton form factor in principle deducible from the scattering data. Two special cases can be distinguished corresponding to the point like proton for which Lamb shift is non-vanishing only for S wave states and non-point like proton for which energy shift is present also for other states. The theoretical expression for the Lamb shift involves very refined calculations. Between 2P and 2S states the expression for the Lamb shift is of form

$$\Delta E(2P_{3/2}^{F=2}2S_{1/2}^{F=1} = a - br_p^2 + cr_p^3 = 209.968(5)5.2248 \times r_p^2 + 0.0347 \times r_p^3 \ \ meV \quad (10.2.4)$$

where the charge radius $r_p = .8750$ is expressed in femtometers and energy in meVs.

(b) The general expression of Lamb shift is given in terms of the form factor by

$$E(2P - 2S) = \int \frac{d^3q}{2\pi)^3} \times (-4\pi\alpha)\frac{F(q^2)}{q^2}\frac{\Pi(q^2)}{q^2} \times \int (|\Psi_{2P}(r)|^2 - |\Psi_{2S}(r)|^2) exp(iq\cdot r)dV \quad . \quad (10.2.4)$$

Here Π is is a scalar representing vacuum polarization due to decay of photon to virtual pairs.

The model to be discussed predicts that the effect is due to a leakage from "standard" state to what I call flux tube state. This means a multiplication of $|\Psi_{2P}|^2$ with the normalization factor $1/N$ of the standard state orthogonalized with respect to flux tube state. It is essential that $1/N$ is larger than unity so that the effect is a genuine quantum effect not understandable in terms of classical probability.

The modification of the formula is due to the normalization of the 2P and 2S states. These are in general different. The normalization factor $1/N$ is same for all terms in the expression of Lamb shift for a given state but in general different for 2S and 2P states. Since the lowest order term dominates by a factor of ~ 40 over the second one, one one can conclude that the modification should affect the lowest order term by about 4 per cent. Since the second term is negative and the modification of the first term is interpreted as a modification of the second term when r_p is estimated from the standard formula, the first term must increase by about 4 per cent. This is achieved if this state is orthogonalized with respect to the flux tube state. For states Ψ_0 and Ψ_{tube} with unit norm this means the modification

$$\begin{aligned} \Psi_0 &\rightarrow \frac{1}{1-|C|^2} \times (\Psi_i - C\Psi_{tube}) \ , \\ C &= \langle \Psi_{tube}|\Psi_0\rangle \ . \end{aligned} \tag{10.2.4}$$

In the lowest order approximation one obtains

$$a - br_p^2 + cr_p^3 \quad \rightarrow \quad (1+|C|^2)a - br_p^2 + cr_p^3 \ . \tag{10.2.5}$$

Using instead of this expression the standard formula gives a wrong estimate r_p from the condition

$$a - b\hat{r}_p^2 + c\hat{r}_p^3 \rightarrow (1+|C|^2)a - br_p^2 + cr_p^3 \ . \tag{10.2.6}$$

This gives the equivalent conditions

$$\begin{aligned} \hat{r}_p^2 &= r_p^2 - \frac{|C|^2 a}{b} \ , \\ P_{tube} &\equiv |C|^2 \simeq 2\frac{b}{a} \times r_p^2 \times \frac{(r_p - \hat{r_p}}{r_p}) \ . \end{aligned} \tag{10.2.6}$$

The resulting estimate for the leakage probability is $P_{tube} \simeq .0015$. The model should be able to reproduce this probability.

A model for the coupling between standard states and flux tube states

Just for fun one can look whether the idea about confinement of muon to quark flux tube carrying electric flux could make sense.

(a) Assume that the quark is accompanied by a flux tube carrying electric flux $\int EdS = -\int \nabla\Phi \cdot dS = q$, where $q = 2e/3 = ke$ is the u quark charge. The potential created by the u quark at the proton end of the flux tube with transversal area $S = \pi R^2$ idealized as effectively 1-D structure is

$$\Phi = -\frac{ke}{\pi R^2}|x| + \Phi_0 \ . \tag{10.2.7}$$

The normalization factor comes from the condition that the total electric flux is q. The value of the additive constant V_0 is fixed by the condition that the potential coincides with Coulomb potential at $r = r_u$, where r_u is u quark Compton length. This gives

$$e\Phi_0 = \frac{e^2}{r_u} + Kr_u \ , \ K = \frac{ke^2}{\pi R^2} \ . \tag{10.2.8}$$

(b) Parameter R should be of order of magnitude of charge radius $\alpha_K r_u$ of u quark is free parameter in some limits. $\alpha_K = \alpha$ is expected to hold true in excellent approximation. Therefore a convenient parameterization is

$$R = z\alpha r_u \ . \tag{10.2.9}$$

This gives

$$K = \frac{4k}{\alpha r_u^2} \ , \ e\Phi_0 = 4(\pi\alpha + \frac{k}{\alpha})\frac{1}{r_u} \ . \tag{10.2.10}$$

(c) The requirement that electron with four times larger charge radius that u quark can topologically condensed inside the flux tube without a change in the average radius of the flux tube (and thus in a reduction in p-adic length scale increasing its mass by a factor 4!) suggests that $z \geq 4$ holds true at least far away from proton. Near proton the condition that the radius of the flux tube is smaller than electron's charge radius is satisfied for $z = 1$.

1. Reduction of Schrödinger equation at flux tube to Airy equation

The 1-D Schrödinger equation at flux tube has as its solutions Airy functions and the related functions known as "Bairy" functions.

(a) What one has is a one-dimensional Schrödinger equation of general form

$$-\frac{\hbar^2}{2m_\mu}\frac{d^2\Psi}{dx^2} + (Kx - e\Phi_0)\Psi = E\Psi \ , \ K = \frac{ke^2}{\pi R^2} \ . \tag{10.2.11}$$

By performing a linear coordinate change

$$u = (\frac{2m_\mu K}{\hbar^2})^{1/3}(x - x_E) \ , \ x_E = \frac{-|E| + e\Phi_0}{K} \ , \tag{10.2.12}$$

one obtains

$$\frac{d^2\Psi}{du^2} - u\Psi = 0 \ . \tag{10.2.13}$$

This differential equation is known as Airy equation (or Stokes equation) and defines special functions $Ai(x)$ known as Airy functions and related functions $Bi(x)$ referred to as "Bairy" functions [B1] . Airy functions characterize the intensity near an optical directional caustic such as that of rainbow.

(b) The explicit expressions for $A_i(u)$ and $Bi(u)$ are is given by

$$\begin{aligned} Ai(u) &= \frac{1}{\pi}\int_0^\infty cos(\frac{1}{3}t^3 + ut)dt \ , \\ Bi(u) &= \frac{1}{\pi}\int_0^\infty \left[exp(-\frac{1}{3}t^3) + sin(\frac{1}{3}t^3 + ut)dt\right] \ . \end{aligned} \tag{10.2.13}$$

$Ai(u)$ oscillates rapidly for negative values of u having interpretation in terms of real wave vector and goes exponentially to zero for $u > 0$. $Bi(u)$ oscillates also for negative values of x but increases exponentially for positive values of u. The oscillatory behavior and its character become obvious by noticing that stationary phase approximation is possible for $x < 0$.

The approximate expressions of $Ai(u)$ and $Bi(u)$ for $u > 0$ are given by

$$\begin{aligned} Ai(u) &\sim \frac{1}{2\pi^{1/2}} exp(-\frac{2}{3}u^{3/2})u^{-1/4} \ , \\ Bi(u) &\sim \frac{1}{\pi^{1/2}} exp(\frac{2}{3}u^{3/2})u^{-1/4} \ . \end{aligned} \quad (10.2.13)$$

For $u < 0$ one has

$$\begin{aligned} Ai(u) &\sim \frac{1}{\pi^{1/2}} sin(\frac{2}{3}(-u)^{3/2})(-u)^{-1/4} \ , \\ Bi(u) &\sim \frac{1}{\pi^{1/2}} cos(\frac{2}{3}(-u)^{3/2})(-u)^{-1/4} \ . \end{aligned} \quad (10.2.13)$$

(c) $u = 0$ corresponds to the turning point of the classical motion where the kinetic energy changes sign. $x = 0$ and $x = r_u$ correspond to the points

$$\begin{aligned} u_{min} \equiv u(0) &= -(\frac{2m_\mu K}{\hbar^2})^{1/3} x_E \ , \\ u_{max} \equiv u(r_u) &= (\frac{2m_\mu K}{\hbar^2})^{1/3} (r_u - x_E) \ , \\ x_E &= \frac{-|E| + e\Phi_0}{K} \ . \end{aligned} \quad (10.2.12)$$

(d) The general solution is

$$\Psi = aAi(u) + bBi(u) \ . \quad (10.2.13)$$

The natural boundary condition is the vanishing of Ψ at the lower end of the flux tube giving

$$\frac{b}{a} = -\frac{Ai(u(0)}{Bi(u(0))} \ . \quad (10.2.14)$$

A non-vanishing value of b implies that the solution increases exponentially for positive values of the argument and the solution can be regarded as being concentrated in an excellent approximation near the upper end of the flux tube.

Second boundary condition is perhaps most naturally the condition that the energy is same for the flux tube amplitude as for the standard solution. Alternative boundary conditions would require the vanishing of the solution at both ends of the flux tube and in this case one obtains very large number of solutions as WKB approximation demonstrates. The normalization of the state so that it has a unit norm fixes the magnitude of the coefficients a and b since one can choose them to be real.

2. Estimate for the probability that muon is caught to the flux tube

The simplest estimate for the muon to be caught to the flux tube state characterized by the same energy as standard state is the overlap integral of the ordinary hydrogen wave function of muon and of the effectively one-dimensional flux tube. What one means with overlap integral is however not quite obvious.

(a) The basic condition is that the modified "standard" state is orthogonal to the flux tube state. One can write the expression of a general state as

$$\begin{aligned}\Psi_{nlm} &\rightarrow N\times(\Psi_{nlm}-C(E,nlm)\Phi_{nlm}) \ ,\\ \Phi_{nlm} &= Y_{lm}\Psi_E \ ,\\ C(E,nlm) &= \langle\Psi_E|\Psi_{nlm}\rangle \ .\end{aligned} \tag{10.2.13}$$

Here Φ_{nlm} depends a flux tube state in which spherical harmonics is wave function in the space of orientations of the flux tube and Ψ_E is flux tube state with same energy as standard state. Here an inner product between standard states and flux tube states is introduced.

(b) Assuming same energy for flux tube state and standard state, the expression for the total total probability for ending up to single flux tube would be determined from the orthogonality condition as

$$P_{nlm} = \frac{|C(E,nlm)|^2}{1-|C(E,lmn)|^2} \ . \tag{10.2.14}$$

Here E refers to the common energy of flux tube state and standard state. The fact that flux tube states vanish at the lower end of the flux tube implies that they do not contribute to the expression for average charge density. The reduced contribution of the standard part implies that the attempt to interpret the experimental results in "standard model" gives a reduced value of the charge radius. The size of the contribution is given by P_{nlm} whose value should be about 4 per cent.

One can consider two alternative forms for the inner product between standard states and flux tube states. Intuitively it is clear that an overlap between the two wave functions must be in question.

(a) The simplest possibility is that one takes only overlap at the upper end of the flux tube which defines 2-D surface. Second possibility is that that the overlap is over entire flux tube projection at the space-time sheet of atom.

$$\begin{aligned}\langle\Psi_E|\Psi_{nlm}\rangle &= \int_{end}\overline{\Psi}_r\Psi_{nlm}dS \ \ \text{(Option I)} \ ,\\ \langle\Psi_E|\Psi_{nlm}\rangle &= \int_{tube}\overline{\Psi}_r\Psi_{nlm}dV \ \ \text{(Option II)} \ .\end{aligned} \tag{10.2.14}$$

(b) For option I the inner product is non-vanishing only if Ψ_E is non-vanishing at the end of the flux tube. This would mean that electron ends up to the flux tube through its end. The inner product is dimensionless without introduction of a dimensional coupling parameter if the inner product for flux tube states is defined by 1-dimensional integral: one might criticize this assumption as illogical. Unitarity might be a problem since the local behaviour of the flux tube wave function at the end of the flux tube could imply that the contribution of the flux tube state in the quantum state dominates and this does not look plausible. One can of course consider the introduction to the inner product a coefficient representing coupling constant but this would mean loss of predictivity. Schrödinger equation at the end of the flux tubes guarantees the conservation of the probability current only if the energy of flux tube state is same as that of standard state or if the flux tube Schrödinger amplitude vanishes at the end of the flux tube.

(c) For option II there are no problems with unitary since the overlap probability is always smaller than unity. Option II however involves overlap between standard states and flux tube states even when the wave function at the upper end of the flux tube vanishes. One can however consider the possibility that the possible flux tube states are orthogonalized with respect to standard states with leakage to flux tubes. The interpretation for the overlap integral would be that electron ends up to the flux tube via the formation of wormhole contact.

3. Option I fails

The considerations will be first restricted to the simpler option I. The generalization of the results of calculation to option II is rather straighforward. It turns out that option II gives correct order of magnitude for the reduction of charge radius for reasonable parameter values.

(a) In a good approximation one can express the overlap integrals over the flux tube end (option I) as

$$\begin{aligned} C(E,nlm) &= \int_{tube} \overline{\Psi}_E \Psi_{nlm} dS \simeq \pi R^2 \times Y_{lm} \times C(E,nl) \ , \\ C(E,nl) &= \overline{\Psi}_E(r_u) R_{nl}(r_u) \ . \end{aligned} \tag{10.2.14}$$

An explicit expression for the coefficients can be deduced by using expression for Ψ_E as a superposition of Airy and Bairy functions. This gives

$$\begin{aligned} C(E,nl) &= \overline{\Psi}_E(r_u) R_{nl}(r_u) \ , \\ \Psi_E(x) &= a_E Ai(u_E) + bBi(u_E) \ , \ \frac{a_E}{b_E} = -\frac{Bi(u_E(0))}{Ai(u_E(0)} \ , \\ u_E(x) &= (\frac{2m_\mu K}{\hbar^2})^{1/3}(x - x_E) \ , \ x_E = \frac{|E| - e\Phi_0}{K} \ , \\ K &= \frac{ke^2}{\pi R^2} \ , \ R = z\alpha_K r_u \ , \ k = \frac{2}{3} \ . \end{aligned} \tag{10.2.11}$$

The normalization of the coefficients is fixed from the condition that a and b chosen in such a manner that Ψ has unit norm. For these boundary conditions Bi is expected to dominate completely in the sum and the solution can be regarded as exponentially decreasing function concentrated around the upper end of the flux tube.

In order to get a quantitative view about the situation one can express the parameters u_{min} and u_{max} in terms of the basic dimensionless parameters of the problem.

(a) One obtains

$$\begin{aligned} u_{min} \equiv u(0) &= -2(\frac{k}{z\alpha})^{1/3}\left[1 + \pi\frac{z}{k}\alpha^2(1 - \frac{1}{2}\alpha r)\right] \times r^{1/3} \ , \\ u_{max} \equiv u(r_u) &= u(0) + 2\frac{k}{z\alpha} \times r^{1/3} \ , \\ r &= \frac{m_\mu}{m_u} \ , \ R = z\alpha r_u \ . \end{aligned} \tag{10.2.10}$$

Using the numerical values of the parameters one obtains for $z = 1$ and $\alpha = 1/137$ the values $u_{min} = -33.807$ and $u_{max} = 651.69$. The value of u_{max} is so large that the normalization is in practice fixed by the exponential behavior of Bi for the suggested boundary conditions.

(b) The normalization constant is in good approximation defined by the integral of the approximate form of Bi^2 over positive values of u and one has

$$N^2 \simeq \frac{dx}{du} \times \int_{u_{min}}^{u_{max}} Bi(u)^2 du \ , \ \frac{dx}{du} = \frac{1}{2}(\frac{z^2\alpha}{k})^{1/3} \times r^{1/3} r_u \ , \tag{10.2.10}$$

By taking $t = exp(\frac{4}{3}u^{3/2})$ as integration variable one obtains

$$\begin{aligned}\int_{u_{min}}^{u_{max}} Bi(u)^2 du &\simeq \pi^{-1}\int_{u_{min}}^{u_{max}} exp(\frac{4}{3}u^{3/2})u^{-1/2}du \\ &= (\frac{4}{3})^{2/3}\pi^{-1}\int_{t_{min}}^{t_{max}} \frac{dt}{log(t)^{2/3}} \simeq \frac{1}{\pi}\frac{exp(\frac{4}{3}u_{max}^{3/2})}{u_{max}} \ . \end{aligned} \quad (10.2.10)$$

This gives for the normalization factor the expression

$$N \simeq \frac{1}{2}(\frac{z^2\alpha}{k})^{2/3}r^{1/3}r_u^{1/2}exp(\frac{2}{3}u_{max}^{3/2}) \ . \quad (10.2.11)$$

(c) One obtains for the value of Ψ_E at the end of the flux tube the estimate

$$\Psi_E(r_u) = \frac{Bi(u_{max})}{N} \simeq 2\pi^{-1/2}\times(\frac{k}{z^2\alpha})^{2/3}r^{1/3}r_u^{-1/2} \ , \ r=\frac{r_u}{r_\mu} \ . \quad (10.2.12)$$

(d) The inner product defined as overlap integral gives for the ground state

$$\begin{aligned}C_{E,00} &= \Psi_E(r_u)\times\Psi_{1,0,0}(r_u)\times\pi R^2 \\ &= 2\pi^{-1/2}(\frac{k}{z^2\alpha})^{2/3}r^{1/3}r_u^{-1/2}\times(\frac{1}{\pi a(\mu)^3})^{1/2}\times exp(-\alpha r)\times\pi z^2\alpha^2 r_u^2 \\ &= 2\pi^{1/2}k^{2/3}z^{2/3}r^{11/6}\alpha^{17/6}exp(-\alpha r) \ . \end{aligned} \quad (10.2.11)$$

The relative reduction of charge radius equals to $P = C_{E,00}^2$. For $z = 1$ one obtains $P = C_{E,00}^2 = 5.5\times 10^{-6}$, which is by three orders of magnitude smaller than the value needed for $P_{tube} = C_{E,20}^2 = .0015$. The obvious explanation for the smallness is the α^2 factor coming from the area of flux tube in the inner product.

4. Option II could work

The failure of the simplest model is essentially due to the inner product. For option II the inner product for the flux tube states involves the integral over the area of flux tube so that the normalization factor for the state is obtained from the previous one by the replacement $N\rightarrow N/\sqrt{\pi R^2}$. In the integral over the flux tube the exponent function is is in the first approximation equal to constant since the wave function for ground state is at the end of the flux tube only by a factor .678 smaller than at the origin and the wave function is strongly concentrated near the end of the flux tube. The inner product defined by the overlap integral over the flux tube implies $N\rightarrow NS^{1/2}$, $S=\pi R^2 = z^2\alpha^2 r_u^2$. In good approximation the inner product for option II means the replacement

$$\begin{aligned}C_{E,n0} &\rightarrow A\times B\times C_{E,n0} \ , \\ A &= \frac{\frac{dx}{du}}{\sqrt{\pi R^2}} = \frac{1}{2\sqrt{\pi}}z^{-1/3}k^{-1/3}\alpha^{-2/3}r^{1/3} \ , \\ B &= \frac{\int Bi(u)du}{\sqrt{Bi(u_{max})}} = u_{max}^{-1/4} = 2^{-1/4}z^{1/2}k^{-1/4}\alpha^{1/4}r^{-1/12} \ . \end{aligned} \quad (10.2.10)$$

Using the expression

$$R_{20}(r_u) = \frac{1}{2\sqrt{2}}\times(\frac{1}{a_\mu})^{3/2}\times(2-r\alpha)\times exp(-r\alpha) \ , \ r=\frac{r_u}{r_\mu} \quad (10.2.11)$$

one obtains for $C_{E,20}$ the expression

$$C_{E,20} = 2^{-3/4}z^{5/6}k^{1/12}\alpha^{29/12}r^{25/12} \times (2 - r\alpha) \times exp(-r\alpha) \ . \quad (10.2.12)$$

By the earlier general argument one should have $P_{tube} = |C_{E,20}|^2 \simeq .0015$. $P_{tube} = .0015$ is obtained for $z = 1$ and $N = 2$ corresponding to single flux tube per u quark. If the flux tubes are in opposite directions, the leakage into 2P state vanishes. Note that this leakage does not affect the value of the coefficient a in the general formula for the Lamb shift. The radius of the flux tube is by a factor 1/4 smaller than the classical radius of electron and one could argue that this makes it impossible for electron to topologically condense at the flux tube. For $z = 4$ one would have $P_{tube} = .015$ which is 10 times too large a value. Note that the nucleus possess a wave function for the orientation of the flux tube. If this corresponds to S-wave state then only the leakage beween S-wave states and standard states is possible.

Are exotic flux tube bound states possible?

There seems to be no deep reason forbidding the possibility of genuine flux tube states decoupling from the standard states completely. To get some idea about the energy eigenvalues one can apply WKB approximation. This approach should work now: in fact, the study on WKB approximation near turning point by using linearization of the the potential leads always to Airy equation so that the linear potential represents an ideal situation for WKB approximation. As noticed these states do not seem to be directly relevant for the recent situation. The fact that these states have larger binding energies than the ordinary states of hydrogen atom might make possible to liberate energy by inducing transitions to these states.

(a) Assume that a bound state with a negative energy E is formed inside the flux tube. This means that the condition $p^2 = 2m(E - V) \geq 0$, $V = -e\Phi$, holds true in the region $x \leq x_{max} < r_u$ and $p^2 = 2m(E - V) < 0$ in the region $r_u > x \geq x_{max}$. The expression for x_{max} is

$$x_{max} = \frac{\pi R^2}{k}(-\frac{|E|}{e^2} + \frac{1}{r_u} + \frac{kr_u}{\pi R^2})\hbar \ . \quad (10.2.13)$$

$x_{max} < r_u$ holds true if one has

$$|E| < \frac{e^2}{r_u} = E_{max} \ . \quad (10.2.14)$$

The ratio of this energy to the ground state energy of muonic hydrogen is from $E(1) = e^2/2a(\mu)$ and $a = \hbar/\alpha m$ given by

$$\frac{E_{max}}{E(n = 1)} = \frac{2m_u}{\alpha m_\mu} \simeq 5.185 \ . \quad (10.2.15)$$

This encourages to think that the ground state energy could be reduced by the formation of this kind of bound state if it is possible to find a value of n in the allowed range. The physical state would of course contain only a small fraction of this state. In the case of electron the increase of the binding energy is even more dramatic since one has

$$\frac{E_{max}}{E(n = 1)} = \frac{2m_u}{\alpha m_e} = \frac{8}{\alpha} \simeq 1096 \ . \quad (10.2.16)$$

Obviously the formation of this kind of states could provide a new source of energy. There have been claims about anomalous energy production in hydrogen [D6] . I have discussed these claims from TGD viewpoint in [K69]

(b) One can apply WKB quantization in the region where the momentum is real to get the condition

$$I = \int_0^{x_{max}} \sqrt{2m(E+e\Phi)}\frac{dx}{\hbar} = n+\frac{1}{2} \ . \quad (10.2.17)$$

By performing the integral one obtains the quantization condition

$$\begin{aligned} I &= k^{-1}(8\pi\alpha)^{1/2}\times\frac{R^2}{r_u^{3/2}r_\mu}\times A^{3/2} = n+\frac{1}{2} \ , \\ A &= 1+kx^2-\frac{|E|r_u}{e^2} \ , \\ x &= \frac{r_u}{R} \ , \ k=\frac{2}{3\pi} \ , \ r_i=\frac{\hbar}{m_i} \ . \end{aligned} \quad (10.2.16)$$

(c) Parameter R should be of order of magnitude of charge radius $\alpha_K r_u$ of u quark is free parameter in some limits. $\alpha_K=\alpha$ is expected to hold true in excellent approximation. Therefore a convenient parameterization is

$$R = z\alpha r_u \ . \quad (10.2.17)$$

This gives for the binding energy the general expression in terms of the ground state binging energy $E(1,\mu)$ of muonic hydrogen as

$$\begin{aligned} |E| &= C\times E(1,\mu) \ , \\ C &= D\times(1+Kz^{-2}\alpha^{-2}-(\frac{y}{z^2})^{2/3}\times(n+1/2)^{2/3}) \ , \\ D &= 2y\times(\frac{K^2}{8\pi\alpha})^{1/3} \ , \\ y &= \frac{m_u}{m_\mu} \ , \ K=\frac{2}{3\pi} \ . \end{aligned} \quad (10.2.15)$$

(d) There is a finite number of bound states. The above mentioned consistency conditions coming from $0<x_{max}<r_\mu$ give $0<C<C_{max}=5.185$ restricting the allowed value of n to some interval. One obtains the estimates

$$\begin{aligned} n_{min} &\simeq \frac{z^2}{y}(1+Kz^{-2}\alpha^{-2}-\frac{C_{max}}{D})^{3/2}-\frac{1}{2} \ , \\ n_{max} &= \frac{z^2}{y}(1+Kz^{-2}\alpha^{-2})^{3/2}-\frac{1}{2} \ . \end{aligned} \quad (10.2.15)$$

Very large value of n is required by the consistency condition. The calculation gives $n_{min}\in\{1.22\times10^7, 4.59\times10^6, 1.48\times10^5\}$ and $n_{max}\in\{1.33\times10^7, 6.66\times10^6, 3.34\times10^6\}$ for $z\in\{1,2,4\}$. This would be a very large number of allowed bound states -about 3.2×10^6 for $z=1$.

The WKB state behaves as a plane wave below x_{max} and sum of exponentially decaying and increasing amplitudes above x_{max}:

$$\begin{aligned} &\frac{1}{\sqrt{k(x)}}\left[Aexp(i\int_0^x k(y)dy)+Bexp(-i\int_0^x k(y)dy)\right] \ , \\ &\frac{1}{\sqrt{\kappa(x)}}\left[Cexp(-\int_{x_{max}}^x \kappa(y)dy+Dexp(\int_{x_{max}}^x \kappa(y)dy\right] \ , \\ &k(x)=\sqrt{2m(-|E|+e\Phi} \ , \ \kappa(x)\sqrt{2m(|E|-e\Phi} \ . \end{aligned} \quad (10.2.12)$$

At the classical turning point these two amplitudes must be identical.

The next task is to decide about natural boundary conditions. Two types of boundary conditions must be considered. The basic condition is that genuine flux tube states are in question. This requires that the inner product between flux tube states and standard states defined by the integral over flux tube ends vanishes. This is guaranteed if the Schrödinger amplitude for the flux tube state vanishes at the ends of the flux tube so that flux tube behaves like an infinite potential well. The condition $\Psi(0) = 0$ at the lower end of the flux tube would give $A = -B$. Combined with the continuity condition at the turning point these conditions imply that Ψ can be assumed to be real. The $\Psi(r_u) = 0$ gives a condition leading to the quantization of energy.

The wave function over the directions of flux tube with a given value of n is given by the spherical harmonics assigned to the state (n, l, m).

10.2.4 Explanation for the soft photon excess in hadron production

There is quite a recent article entitled Study of the Dependence of Direct Soft Photon Production on the Jet Characteristics in Hadronic Z^0 Decays discussing one particular manifestation of an anomaly of hadron physics known for two decades: the soft photon production rate in hadronic reactions is by an average factor of about four higher than expected. In the article soft photons assignable to the decays of Z^0 to quark-antiquark pairs. This anomaly has not reached the attention of particle physics which seems to be the fate of anomalies quite generally nowadays: large extra dimensions and blackholes at LHC are much more sexy topics of study than the anomalies about which both existing and speculative theories must remain silent.

Soft photon anomaly

The general observations are summarized by the abstract of the paper.

An analysis of the direct soft photon production rate as a function of the par ent jet characteristics is presented, based on hadronic events collected by the DELPHI experiment at LEP1. The dependences of the photon rates on the jet kinematic characteristics (momentum, mass, etc.) and on the jet charged, neutral and total hadron multiplicities are reported. Up to a scale factor of about four, which characterizes the overall value of the soft photon excess, a similarity of the observed soft photon behaviour to that of the inner hadronic bremsstrahlung predictions is found for the momentum, mass, and jet charged multiplicity dependences. However for the dependence of the soft photon rate on the jet neutral and total hadron multiplicities a prominent difference is found for the observed soft photon signal as compared to the expected bremsstrahlung from final state hadrons. The observed linear increase of the soft photon production rate with the jet total hadron multiplicity and its strong dependence on the jet neutral multiplicity suggest that the rate is proportional to the number of quark pairs produced in the fragmentation process, with the neutral pairs being more effectively radiating than the charged ones.

I try to abstract the essentials of the article.

(a) One considers soft photon production in kinematic range .2 GeV$< E <$ 1 GeV, $p_T < .08$ GeV, where p_T is photon transverse momentum with respect to the parent jet direction. The soft photon excess is associated with hadron production only and does not appear in leptonic sector. As one subtracts the photon yield due to the decays of hadrons (mainly neutral pions), one finds that what remains is on the average 4 times larger than the photon yield by inner hadronic brehmstrahlung, which means bremsstrahlung by charged final state hadrons. This suggests that the description in terms of charged hadron bremstrahlung is not correct and one must go to quark level.

(b) Up to the scale factor with average value four, the dependence of soft photon production on jet momentum, mass, and jet charged multiplicity is consistent with the inner hadronic bremsstrahlung predictions.

(c) The dependence of the soft photon rate on jet neural and total hadron multiplicities differs from the expected bremsstrahlung from final state hadrons. The linear increase of the rate with the jet total hadron multiplicity and strong dependence on the jet neutral multiplicity does not conform with internal hadron bremsstrahlung prediction which suggests that the anomalous soft photon production is proportional to the number of neutral quark pairs giving rise to neutral mesons. For some reason neutral pairs would thus radiate more effectively than the charged ones. Therefore the hypothesis that sea quarks alone are responsible for anomalous brehmstrahlung cannot hold true as such.

The article discusses the data and also the models that has been proposed. Incoherent production of photons by quarks predict satisfactorily the linear dependence of total intensity of brehmstrahling on total number of jet particle if the number of quarks in jet is assumed to be proportional to the number jet particles (see Fig. 7 of [C75]). The model cannot however explain the deviations from the model based on charged hadron inner brehmstrahling: the problems are produced by the sensitive dependence on the number of neutral hadrons (see Fig. 6 of [C75]).

The models assuming that jet acts as a coherent structure fail also and it is proposed that somehow neutral quark pairs must act as electric dipoles generating dipole radiation at low energies. The dipole moments assignable to neutral quark pairs $U\overline{U}$ and $D\overline{D}$. $U\overline{D}$, $D\overline{U}$ with given respect to center of mass are proportional to the difference of the quark charges $4/3, 2/3, 1/3, -1/3$ so that one might argue that the dipole radiation from neutral pairs is by a factor 16 *resp.* 4 stronger than from charged pair and authors argue that this might be part of the explanation. This would suggest that the excess radiation comes from dipole radiation from quarks inside neutral hadrons. The dipole radiation intensity is expected to be weaker than monopole radiation by a factor $1/\lambda^2$ roughly so that this line of thought does not look promising.

TGD based explanation of the anomaly

Could one find an explanation for the anomaly in TGD framework? The following model finds its inspiration from TGD inspired models for two other anomalies.

(a) The first model explains the reported deviation of the charge radius of muonic hydrogen from the predicted radius. Key role is played by the electric flux tubes associated with quarks and having size scale of order quark Compton radius and therefore extending up to the Bohr radius of muonic hydrogen in the case of u quark.

(b) Second model explains the observed anomalous behavior of the quark-gluon plasma. What is observed is almost perfect fluid behavior instead of gas like behavior reflecting itself as small viscosity to entropy ratio. The findings suggest coherence in rather long length scales and also existence of string like objects. Color magnetic (or color electric or both) flux tubes containing quarks and antiquarks are proposed as a space-time correlate for the quark gluon plasma.

Electric flux tubes as basic objects provide a promising candidate for the counterparts of dipoles now. In the case of neutral hadrons color flux tubes and em flux tubes can be one and the same thing. In the case of charged hadrons this cannot be the case and em flux tubes connect oppositely charged hadrons. This could explain the difference between neutral and charged hadrons. If the production amplitude is coherent sum over amplitudes for quarks and antiquarks inside hadron and if also sea quarks contribute, only neutral hadrons would contribute to the brehmstrahlung at long wave length limit and the excess would correspond to the contribution of sea quarks inside neutral hadrons.

A more precise argument goes as follows.

(a) The first guess would be that the production amplitude of photons is sum over incoherent contributions of valence and sea quarks. This cannot be the case since both charged and neutral hadrons would contribute equally.

(b) Quantum classical correspondence requires some space-time correlate for the classical electric fields. In TGD electric flux is carried by flux tubes and this suggests that flux tubes serve as this correlate. These flux tubes must begin from quark and end to an anti-quark of opposite charge. One must distinguish between the flux tubes assignable to electric field and gluon field. The flux tubes connecting charged hadrons cannot correspond to color flux tubes. For electromagnetically neutral hadrons color flux tubes and em flux tubes can be one and the same thing: this conforms with the fact that classical color fields are proportional to the induced Kähler form as is also the U(1) part of the classical em field. This will be assumed so that only the flux tubes associated with neutral quark pairs (hadrons) can contribute to the coherent dipole radiation. In particular, the sea quarks at these flux tubes can contribute. The flux tubes connecting different hadrons of the final state would not carry color gauge flux making possible materialization of sea quarks from vacuum. If the sea quarks at flux electric flux tubes are responsible for the anomaly, the excess is present only for the neutral hadrons.

(c) Low energy phenomenon is in question. This means that the description of quark pairs as coherently scattering pairs of charges (dipole approximation is not necessary) should make sense only when the photon wavelength is longer than the size scale of the dipole: the relevant length scale could be expressed in terms of the distance d between the quark and antiquark of the pair. The criterion can be written as $\lambda \geq xd/2$, where x is a numerical constant of order unity whose value, which should be fixed by the precise criterion of coherence length which should be few wave lengths. For higher energies description as incoherently radiating quarks should be a good approximation. The quark and antiquark with opposite charges can belong to the same to-be-hadron or different charged to-be-hadrons. In the first case there distance remains more or less the same during fragmentation process. In the latter case it increases. In the first case the treatment of the flux tube as a coherently radiating unit makes sense for wavelengths $\lambda \geq xd/2$.

(d) The assumption that the brehmstrahlung amplitude is a coherent sum over the amplitudes for the quarks and antiquarks inside to-be-hadron gives a heuristic estimate for the radiation power. Consider first the situation in which the ends of the flux tube contain quark and antiquark. Denoting by A value of the photon emission amplitude for free quark, this would give amplitude squared $|A|^2|(1 - exp(exp(ik \cdot d))|^2$, whose maximum value is by a factor 4 larger than that for a single particle. The maxima would correspond to $\lambda = 2dcos(\theta)/(2n+1)$, where θ is the angle between the wave vector of photon and d. $n = 0$ would correspond to $\lambda = 2dcos(\theta)$. For given value of λ one would obtain a diffraction pattern with maxima at $cos(\theta) = (n + 1/2)\lambda/d$. This cannot however give large enough radiation power: the angle average of the factor $|1 - exp(i\phi)|^2$ is 2 instead of 4 and corresponds to the incoherent sum of production rates.

(e) More complex model would assume that the flux tubes contain quarks and antiquarks also in their interior so that one would have coherent sum of a larger number of amplitudes which would give diffraction conditions for λ analogous to those above. In this case the maximum of the diffractive factor would be N^2, where $N = 2n$ is total number of quarks and antiquarks for mesons. For neutral baryons flux tube would contain odd number of quarks. The angle average would be in this case be equal to N. If all quarks and antiquarks inside the flux tube appear as valence quarks of the final state hadron, one obtains just the result predicted by the independent quark model. Therefore the only possible interpretation for additional contribution is in terms of sea quarks.

Consider now a more detailed quantitative estimate. Assume that the emission inside flux tubes is incoherent. Assume that the sea quarks with charges $\pm 2/3$ and $\pm 1/3$ appear with same probabilities and this is true also for valence quarks for energetic enough jets. Therefore the average quark charge squared is $\langle Q_q^2 \rangle = 5/18$.

(a) The model based on incoherent brehmstrahlung on quarks mentioned in [C75] assumes that the number of partons in jet is proportional to the hadrons in the jet:

$$R \propto (N_{sea,neu} + N_{val,neu} + N_{sea,ch} + N_{val,ch}) \propto N_{tot} \quad . \tag{10.2.13}$$

According to [C75] the model explains the excess as a a linear function of jet total hadron multiplicity N_{tot} (see Fig. 7 of [C75]). This behavior is obtained if the production rate satisfies

$$R \propto (N_{sea,neu} + N_{val,neu} + N_{sea,ch} + N_{val,ch})\langle Q_q^2\rangle \quad .$$

One however considers inclusive distribution meaning integration over the various combinations (N_{neu}, N_{ch}) and also other jet variables weighted by differential cross section so that similar result is obtained under much weaker conditions.

(b) Indeed, if sea quarks and valence quarks have same p-adic mass scale, one has

$$R \propto (N_{sea,neu} + N_{val,neu} + N_{val,ch})\langle Q_q^2\rangle \tag{10.2.14}$$

p-Adic length cale hypothesis however allows the sea quarks to be considerably lighter than valence quarks so that their contribution to the brehmstrahlung can be larger. This would mean the proportionality

$$R \propto (xN_{sea,neu} + N_{val,neu} + N_{val,ch})\langle Q_q^2\rangle \quad ,$$
$$x = (\frac{m_{val}}{m_{sea}})^2 \quad . \tag{10.2.14}$$

p-Adic length scale hypothesis predicts that x is power of two: $x = 2^k$, $k \in \{0, 1, 2, ..\}$. The above constraint gives rise to the consistency condition

$$\langle R\rangle \propto \langle xN_{sea,neu} + N_{val,neu} + N_{val,ch}\rangle \propto N_{tot} \quad . \tag{10.2.15}$$

(c) The data [C75] support the the appearance of $N_{sea,neu}$ in the rate.

i. The dependence on xN_{sea} could explain the exceptionally large deviation (by factor of 8, see Fig. 5 of [C75]) from hadronic inner bremsstrahlung for smallest charged multiplicity meaning large number sea quarks assignable to neutral hadrons. For large values of charged multiplicity the contribution of $xN_{sea,neu}+N_{val,neu}$ becomes small and the one should obtain approximate factor 4.

ii. The linear fit of the distribution in the form $R = a_1N_{ch} + a_2N_{neu}$ gives $a_2/a_1 \simeq 6$ so that the dependence on neutral multiplicity is six time stronger than on charged multiplicity (see table 6 of [C75]). This suggests that $xN_{sea,neu}$ dominates in the formula. The first possibility is that the parameter $r = N_{sea,neu}/N_{val,neu}$ is considerably larger than unity. Second possibility is that one has $x > 1$.

iii. The ratio of signal to bremsstrahlung prediction increases rapidly as a function of neutral jet multiplicity n_{neu} and increases from 2.5 to about 16 in the range $[0, 6]$ for the neutral multiplicity (see Fig. 6 of [C75]). This conforms with the dependence on $N_{sea,neu}$. Also the dependence of the signal to brehmstrahlung ratio on the core charged multiplicity is non-trivial being largest for vanishing core charge and decreasing with core n_{ch}. Also this confirms with the proposal.

To sum up, the model depends crucially on the notion of induced gauge field and proportionality of the classical color fields and U(1) part of em field to the induced Kähler form and therefore the anomaly gives support for the basic prediction of TGD distinguishing it from QCD. It is possible that two times lighter p-adic mass scale for sea quarks than for valence quarks is needed in order to explain the findings.

10.3 Simulating Big Bang in laboratory

Ultra-high energy collisions of heavy nuclei at Relativistic Heavy Ion Collider (RHIC) can create so high temperatures that there are hopes of simulating Big Bang in laboratory. The experiment with PHOBOS detector [C98] probed the nature of the strong nuclear force by smashing two Gold atoms together at ultrahigh energies. The analysis of the experimental data has been carried out by Prof. Manly and his collaborators at RHIC in Brookhaven, NY [C97]. The surprise was that the hydrodynamical flow for non-head-on collisions did not possess the expected longitudinal boost invariance.

This finding stimulates in TGD framework the idea that something much deeper might be involved.

(a) The quantum criticality of the TGD inspired very early cosmology predicts the flatness of 3-space as do also inflationary cosmologies. The TGD inspired cosmology is 'silent whisper amplified to big bang' since the matter gradually topologically condenses from decaying cosmic string to the space-time sheet representing the cosmology. This suggests that one could model also the evolution of the quark-gluon plasma in an analogous manner. Now the matter condensing to the quark-gluon plasma space-time sheet would flow from other space-time sheets. The evolution of the quark-gluon plasma would very literally look like the very early critical cosmology.

(b) What is so remarkable is that critical cosmology is not a small perturbation of the empty cosmology represented by the future light cone. By perturbing this cosmology so that the spherical symmetry is broken, it might possible to understand qualitatively the findings of [C97]. Maybe even the breaking of the spherical symmetry in the collision might be understood as a strong gravitational effect on distances transforming the spherical shape of the plasma ball to a non–spherical shape without affecting the spherical shape of its M^4_+ projection.

(c) The model seems to work at qualitative level and predicts strong gravitational effects in elementary particle length scales so that TGD based gravitational physics would differ dramatically from that predicted by the competing theories. Standard cosmology cannot produce these effects without a large breaking of the cherished Lorentz and rotational symmetries forming the basis of elementary particle physics. Thus the the PHOBOS experiment gives direct support for the view that Poincare symmetry is symmetry of the imbedding space rather than that of the space-time.

(d) This picture was completed a couple of years later by the progress made in hadronic mass calculations [K43] . It has already earlier been clear that quarks are responsible only for a small part of the mass of baryons (170 GeV in case of nucleons). The assumption that hadronic $k = 107$ space-time sheet carries a many-particle state of super-symplectic particles with vanishing electro-weak quantum numbers (meaning darkness in the strongest sense of the word.)

(e) TGD allows a model of hadrons predicting their masses with accuracy better than one per cent. In this framework color glass condensate can be identified as a state formed when the hadronic space-time sheets of colliding hadrons fuse to single long stringy object and collision energy is transformed to super-symplectic hadrons.

What I have written above reflects the situation around 2005 when RHIC was in blogs. After 5 years later (2010) LHC gave its first results suggesting similar phenomena in proton-proton collisions. These results provide support for the idea that the formation of long entangled hadronic strings by a fusion of hadronic strings forming a structure analogous to black hole or initial string dominated phase of the cosmology are responsible for the RHIC findings. In the LHC case the mechanism leading to this kind of strings must be different since initial state contains only two protons. I would not anymore distinguish between hadrons and super-symplectic hadrons since in the recent picture super-symplectic excitations are responsible for most of the mass of the hadron. The view about dark matter as macroscopic quantum phase with large Planck constant has also evolved a lot from what it was at that time and I have polished reference to some short lived ideas for the benefit of the reader and me. I did not speak about zero energy ontology at that time and the understanding of the general mathematical structure of TGD has improved dramatically during these years.

10.3.1 Experimental arrangement and findings

Heuristic description of the findings

In the experiments using PHOBOS detector ultrahigh energy Au+Au collisions at center of mass energy for which nucleon-nucleon center of mass energy is $\sqrt{s_{NN}} = 130$ GeV, were studied [C98].

(a) In the analyzed collisions the Au nuclei did not collide quite head-on. In classical picture the collision region, where quark gluon plasma is created, can be modelled as the intersection of two colliding balls, and its intersection with plane orthogonal to the colliding beams going through the center of mass of the system is defined by two pieces of circles, whose intersection points are sharp tips. Thus rotational symmetry is broken for the initial state in this picture.

(b) The particles in quark-gluon plasma can be compared to a persons in a crowded room trying to get out. The particles collide many times with the particles of the quark gluon plasma before reaching the surface of the plasma. The distance $d(z, \phi)$ from the point $(z, 0)$ at the beam axis to the point $(0, \phi)$ at the plasma surface depends on ϕ. Obviously, the distance is longest to the tips $\phi = \pm\pi/2$ and shortest to the points $\phi = 0, \phi = \phi$ of the surface at the sides of the collision region. The time $\tau(z, \phi)$ spent by a particle to the travel to the plasma surface should be a monotonically increasing function $f(d)$ of d:

$$\tau(z, \phi) = f(d(z, \phi)) \ .$$

For instance, for diffusion one would have $\tau \propto d^2$ and $\tau \propto d$ for a pure drift.

(c) What was observed that for $z = 0$ the difference

$$\Delta\tau = \tau(z = 0, \pi/2) - \tau(z = 0, 0)$$

was indeed non-vanishing but that for larger values of z the difference tended to zero. Since the variation of z correspond that for the rapidity variable y for a given particle energy, this means that particle distributions depend on rapidity which means a breaking of the longitudinal boost invariance assumed in hydrodynamical models of the plasma. It was also found that the difference vanishes for large values of y: this finding is also important for what follows.

A more detailed description

Consider now the situation in a more quantitative manner.

(a) Let z-axis be in the direction of the beam and ϕ the angle coordinate in the plane E^2 orthogonal to the beam. The kinematical variables are the rapidity of the detected particle defined as $y = log[E+p_z)/(E-p_z)]/2$ (E and p_z denote energy and longitudinal momentum), Feynman scaling variable $x_F \simeq 2E/\sqrt{s}$, and transversal momentum p_T.

(b) By quantum-classical correspondence, one can translate the components of momentum to space-time coordinates since classically one has $x^\mu = p^\mu a/m$. Here a is proper time for a future light cone, whose tip defines the point where the quark gluon plasma begins to be generated, and $v^\mu = p^\mu/m$ is the four-velocity of the particle. Momentum space is thus mapped to an $a = constant$ hyperboloid of the future light cone for each value of a.

In this correspondence the rapidity variable y is mapped to $y = log[(t + z)/(t - z)]$, $|z| \leq t$ and non–vanishing values for y correspond to particles which emerge, not from the collision point defining the origin of the plane E^2, but from a point above or below E^2. $|z| \leq t$ tells the coordinate along the beam direction for the vertex, where the particle was created. The limit $y \rightarrow 0$ corresponds to the limit $a \rightarrow \infty$ and the limit $y \rightarrow \pm\infty$ to $a \rightarrow 0$ (light cone boundary).

(c) Quark-parton models predict at low energies an exponential cutoff in transverse momentum p_T; Feynman scaling $dN/dx_F = f(x_F)$ independent of s; and longitudinal boost invariance, that is rapidity plateau meaning that the distributions of particles do not depend on y. In the space-time picture this means that the space-time is effectively two-dimensional and that particle distributions are Lorentz invariant: string like space-time sheets provide a possible geometric description of this situation.

(d) In the case of an ideal quark-gluon plasma, the system completely forgets that it was created in a collision and particle distributions do not contain any information about the beam direction. In a head-on collision there is a full rotational symmetry and even Lorentz invariance so that transverse momentum cutoff disappears. Rapidity plateau is predicted in all directions.

(e) The collisions studied were not quite head-on collisions and were characterized by an impact parameter vector with length b and direction angle ψ_2 in the plane E^2. The particle distribution at the boundary of the plane E^2 was studied as a function of the angle coordinate $\phi - \psi_2$ and rapidity y which corresponds for given energy distance to a definite point of beam axis.

The hydrodynamical view about the situation looks like follows.

(a) The particle distributions $N(p^\mu)$ as function of momentum components are mapped to space-time distributions $N(x^\mu, a)$ of particles. This leads to the idea that one could model the situation using Robertson-Walker type cosmology. Co-moving Lorentz invariant particle currents depending on the cosmic time only would correspond in this picture to Lorentz invariant momentum distributions.

(b) Hydrodynamical models assign to the particle distribution $d^2N/dyd\phi$ a hydrodynamical flow characterized by four-velocity $v^\mu(y, \phi)$ for each value of the rapidity variable y. Longitudinal boost invariance predicting rapidity plateau states that the hydrodynamical flow does not depend on y at all. Because of the breaking of the rotational symmetry in the plane orthogonal to the beam, the hydrodynamical flow v depends on the angle coordinate $\phi - \psi_2$. It is possible to Fourier analyze this dependence and the second Fourier coefficient v_2 of $cos(2(\phi - \psi_2)$ in the expansion

$$\frac{dN}{d\phi} \simeq 1 + \sum_n v_n cos(n(\phi - \psi_2)) \tag{10.3.1}$$

was analyzed in [C97].

(c) It was found that the Fourier component v_2 depends on rapidity y, which means a breaking of the longitudinal boost invariance. v_2 also vanishes for large values of y. If this is true for all Fourier coefficients v_n, the situation becomes effectively Lorentz invariant for large values of y since one has $v(y, \phi) \rightarrow 1$.

Large values of y correspond to small values of a and to the initial moment of big bang in cosmological analogy. Hence the finding could be interpreted as a cosmological Lorentz invariance inside the light cone cosmology emerging from the collision point. Small values of y in turn correspond to large values of a so that the breaking of the spherical symmetry of the cosmology should be manifest only at $a \rightarrow \infty$ limit. These observations suggest a radical re-consideration of what happens in the collision: the breaking of the spherical symmetry would not be a property of the initial state but of the final state.

10.3.2 TGD based model for the quark-gluon plasma

Consider now the general assumptions the TGD based model for the quark gluon plasma region in the approximation that spherical symmetry is not broken.

(a) Quantum-classical correspondence supports the mapping of the momentum space of a particle to a hyperboloid of future light cone. Thus the symmetries of the particle distributions with respect to momentum variables correspond directly to space-time symmetries.

(b) The M^4_+ projection of a Robertson-Walker cosmology imbedded to $H = M^4_+ \times CP_2$ is future light cone. Hence it is natural to model the hydrodynamical flow as a mini-cosmology. Even more, one can assume that the collision quite literally creates a space-time sheet which locally obeys Robertson-Walker type cosmology. This assumption is sensible in many-sheeted space-time (see fig. `http://www.tgdtheory.fi/appfigures/manysheeted.jpg` or fig. 9 in the appendix of this book) and conforms with the fractality of TGD inspired cosmology (cosmologies inside cosmologies).

(c) If the space-time sheet containing the quark-gluon plasma is gradually filled with matter, one can quite well consider the possibility that the breaking of the spherical symmetry develops gradually, as suggested by the finding $v_2 \rightarrow 1$ for large values of $|y|$ (small values of a). To achieve Lorentz invariance at the limit $a \rightarrow 0$, one must assume that the expanding region corresponds to $r = constant$ "coordinate ball" in Robertson-Walker cosmology, and that the breaking of the spherical symmetry for the induced metric leads for large values of a to a situation described as a "not head-on collision".

(d) Critical cosmology is by definition unstable, and one can model the Au+Au collision as a perturbation of the critical cosmology breaking the spherical symmetry. The shape of $r = constant$ sphere defined by the induced metric is changed by strong gravitational interactions such that it corresponds to the shape for the intersection of the colliding nuclei. One can view the collision as a spontaneous symmetry breaking process in which a critical quark-gluon plasma cosmology develops a quantum fluctuation leading to a situation described in terms of impact parameter. This kind of modelling is not natural for a hyperbolic cosmology, which is a small perturbation of the empty M^4_+ cosmology.

The imbedding of the critical cosmology

Any Robertson-Walker cosmology can be imbedded as a space-time sheet, whose M^4_+ projection is future light cone. The line element is

$$ds^2 = f(a)da^2 - a^2(K(r)dr^2 + r^2 d\Omega^2) \ . \tag{10.3.2}$$

Here a is the scaling factor of the cosmology and for the imbedding as surface corresponds to the future light cone proper time.

This light cone has its tip at the point, where the formation of quark gluon plasma starts. (θ, ϕ) are the spherical coordinates and appear in $d\Omega^2$ defining the line element of the unit sphere. a and r are related to the spherical Minkowski coordinates (m^0, r_M, θ, ϕ) by $(a = \sqrt{(m^0)^2 - r_M^2}, r = r_M/a)$. If hyperbolic cosmology is in question, the function $K(r)$ is given by $K(r) = 1/(1+r^2)$. For the critical cosmology 3-space is flat and one has $K(r) = 1$.

(a) The critical cosmologies imbeddable to $H = M^4_+ \times CP_2$ are unique apart from a single parameter defining the duration of this cosmology. Eventually the critical cosmology must transform to a hyperbolic cosmology. Critical cosmology breaks Lorentz symmetry at space-time level since Lorentz group is replaced by the group of rotations and translations acting as symmetries of the flat Euclidian space.

(b) Critical cosmology replaces Big Bang with a silent whisper amplified to a big but not infinitely big bang. The silent whisper aspect makes the cosmology ideal for the space-time sheet associated with the quark gluon plasma: the interpretation is that the quark gluon plasma is gradually transferred to the plasma space-time sheet from the other space-time sheets. In the real cosmology the condensing matter corresponds to the decay products of cosmic string in 'vapor phase'. The density of the quark gluon plasma cannot increase without limit and after some critical period the transition to a hyperbolic cosmology occurs. This transition could, but need not, correspond to the hadronization.

(c) The imbedding of the critical cosmology to $M_+^4 \times S^2$ is given by

$$\begin{aligned} sin(\Theta) &= \frac{a}{a_m} \ , \\ \Phi &= g(r) \ . \end{aligned} \quad (10.3.2)$$

Here Θ and Φ denote the spherical coordinates of the geodesic sphere S^2 of CP_2. One has

$$\begin{aligned} f(a) &= 1 - \frac{R^2k^2}{(1-(a/a_m)^2)} \ , \\ (\partial_r\Phi)^2 &= \frac{a_m^2}{R^2} \times \frac{r^2}{1+r^2} \ . \end{aligned} \quad (10.3.2)$$

Here R denotes the radius of S^2. From the expression for the gradient of Φ it is clear that gravitational effects are very strong. The imbedding becomes singular for $a = a_m$. The transition to a hyperbolic cosmology must occur before this.
This model for the quark-gluon plasma would predict Lorentz symmetry and $v = 1$ (and $v_n = 0$) corresponding to head-on collision so that it is not yet a realistic model.

TGD based model for the quark-gluon plasma without breaking of spherical symmetry

There is a highly unique deformation of the critical cosmology transforming metric spheres to highly non–spherical structures purely gravitationally. The deformation can be characterized by the following formula

$$sin^2(\Theta) = (\frac{a}{a_m})^2 \times (1 + \Delta(a,\theta,\phi)^2) \ . \quad (10.3.3)$$

(a) This induces deformation of the g_{rr} component of the induced metric given by

$$g_{rr} = -a^2\left[1 + \Delta^2(a,\theta,\phi)\frac{r^2}{1+r^2}\right] \ . \quad (10.3.4)$$

Remarkably, g_{rr} does not depend at all on CP_2 size and the parameter a_m determining the duration of the critical cosmology. The disappearance of the dimensional parameters can be understood to reflect the criticality. Thus a strong gravitational effect independent of the gravitational constant (proportional to R^2) results. This implies that the expanding plasma space-time sheet having sphere as M_+^4 projection differs radically from sphere in the induced metric for large values of a. Thus one can understand why the parameter v_2 is non-vanishing for small values of the rapidity y.

(b) The line element contains also the components g_{ij}, $i,j \in \{a,\theta,\phi\}$. These components are proportional to the factor

$$\frac{1}{1-(a/a_m)^2(1+\Delta^2)} \ , \quad (10.3.5)$$

which diverges for

$$a_m(\theta,\phi) = \frac{a_m}{\sqrt{1+\Delta^2}} \ . \quad (10.3.6)$$

Presumably quark-gluon plasma phase begins to hadronize first at the points of the plasma surface for which $\Delta(\theta,\phi)$ is maximum, that is at the tips of the intersection region of the colliding nuclei. A phase transition producing string like objects is one possible space-time description of the process.

10.3.3 Further experimental findings and theoretical ideas

The interaction between experiment and theory is pure magic. Although experimenter and theorist are often working without any direct interaction (as in case of TGD), I have the strong feeling that this disjointness is only apparent and there is higher organizing intellect behind this coherence. Again and again it has turned out that just few experimental findings allow to organize separate and loosely related physical ideas to a consistent scheme. The physics done in RHIC has played completely unique role in this respect.

Super-symplectic matter as the TGD counterpart of CGC?

The model discussed above explained the strange breaking of longitudinal Lorentz invariance in terms of a hadronic mini bang cosmology. The next twist in the story was the shocking finding, compared to Columbus's discovery of America, was that, rather than behaving as a dilute gas, the plasma behaved like a liquid with strong correlations between partons, and having density 30-50 times higher than predicted by QCD calculations [C164] . When I learned about these findings towards the end of 2004, I proposed how TGD might explain them in terms of what I called conformal confinement [K34] . This idea - although not wrong for any obvious reason - did not however have any obvious implications. After the progress made in p-adic mass calculations of hadrons leading to highly successful model for both hadron and meson masses [K43] , the idea was replaced with the hypothesis that the condensate in question is Bose-Einstein condensate like state of super-symplectic particles formed when the hadronic space-time sheets of colliding nucleons fuse together to form a long string like object.

A further refinement of the idea comes from the hypothesis that quark gluon plasma is formed by the topological condensation of quarks to hadronic strings identified as color flux tubes. This would explain the high density of the plasma. The highly entangled hadronic string would be analogous to the initial state of TGD inspired cosmology with the only difference that string tension is extremely small in the hadronic context. This structure would possess also characteristics of blackhole.

Fireballs behaving like black hole like objects

The latest discovery in RHIC is that fireball, which lasts a mere 10^{-23} seconds, can be detected because it absorbs jets of particles produced by the collision [C159]. The association with the notion black hole is unavoidable and there indeed exists a rather esoteric M-theory inspired model "The RHIC fireball as a dual black hole" by Hortiu Nastase [C152] for the strange findings.

The Physics Today article [C145] "What Have We Learned From the Relativistic Heavy Ion Collider?" gives a nice account about experimental findings. Extremely high collision energies are in question: Gold nuclei contain energy of about 100 GeV per nucleon: 100 times proton mass. The expectation was that a large volume of thermalized Quark-Gluon Plasma (QCP) is formed in which partons lose rapidly their transverse momentum. The great surprise was the suppression of high transverse momentum collisions suggesting that in this phase strong collective interactions are present. This has inspired the proposal that quark gluon plasma is preceded by liquid like phase which has been christened as Color Glass Condensate (CGC) thought to contain Bose-Einstein condensate of gluons.

The theoretical ideas relating CGC to gravitational interactions

Color glass condensate relates naturally to several gravitation related theoretical ideas discovered during the last year.

1. Classical gravitation and color confinement

Just some time ago it became clear that strong classical gravitation might play a key role in the understanding of color confinement [K67] . Whether the situation looks confinement or asymptotic freedom would be in the eyes of beholder: this is one example of dualities filling TGD Universe. If one looks the situation at the hadronic space-time sheet or one has asymptotic freedom, particles move essentially like free massless particles. But - and this is absolutely essential- in the induced metric of hadronic space-time sheet. This metric represents classical gravitational field becoming extremely strong near hadronic boundary. From the point of view of outsider, the motion of quarks slows down to rest when they approach hadronic boundary: confinement. The distance to hadron surface is infinite or at least very large since the induced metric becomes singular at the light-like boundary! Also hadronic time ceases to run near the boundary and finite hadronic time corresponds to infinite time of observer. When you look from outside you find that this light-like 3-surface is just static surface like a black hole horizon which is also a light-like 3-surface. This gives confinement.

2. Dark matter in TGD

The evidence for hadronic black hole like structures is especially fascinating. In TGD Universe dark matter can be (not always) ordinary matter at larger space-time sheets in particular magnetic flux tubes. The mere fact that the particles are at larger space-time sheets might make them more or less invisible.

Matter can be however dark in much stronger sense, should I use the word "black"! The findings suggesting that planetary orbits obey Bohr rules with a gigantic Planck constant [K59] , [E4] would suggest quantum coherence of dark matter even in astrophysical length scales and this raises the fascinating possibility that Planck constant is dynamical so that fine structure constant. Dark matter would correspond to phases with non-standard value of Planck constant. This quantization saves from black hole collapse just as the quantization of hydrogen atom saves from the infrared catastrophe.

The basic criterion for the transition to this phase would be that it occurs when some coupling strength - say fine structure constant multiplied by appropriate charges or gravitational constant multiplied by masses- becomes so large that the perturbation series for scattering amplitudes fails to converge. The phase transition increases Planck constant so that convergence is achieved. The attempts to build a detailed view about what might happen led to a generalization of the imbedding space concept by replacing M^4 (or rather the causal diamond) and CP_2 with their singular coverings. During 2010 it turned out that this generalization could be regarded as a conventional manner to describe a situation in which space-time surface becomes analogous to a multi-sheeted Riemann surface. If so, then Planck constant would be replaced by its integer multiple only in effective sense.

The obvious questions are following. Could black hole like objects/magnetic flux tubes/cosmic strings consist of quantum coherent dark matter? Does this dark matter consist dominantly from hadronic space-time sheets which have fused together and contain super-symplectic bosons and their super-partners (with quantum numbers of right handed neutrino) having therefore no electro-weak interactions. Electro-weak charges would be at different space-time sheets.

(a) Gravitational interaction cannot force the transition to dark phase in a purely hadronic system at RHIC energies since the product GM_1M_2 characterizing the interaction strength of two masses must be larger than unity ($\hbar = c = 1$) for the phase transition increasing Planck constant to occur. Hence the collision energy should be above Planck mass for the phase transition to occur if gravitational interactions are responsible for the transition.

(b) The criterion for the transition to dark phase is however much more general and states that the system does its best to stay perturbative by increasing its Planck constant in discrete steps and applies thus also in the case of color interactions and governs the phase transition to the TGD counterpart of non-perturbative QCD. Criterion would be roughly $\alpha_s Q_s^2 > 1$ for two color charges of opposite sign. Hadronic string picture would suggests that the criterion is equivalent to the generalization of the gravitational criterion to its strong gravity analog $nL_p^2M^2 > 1$, where L_p is the p-adic length scale characterizing color magnetic energy density (hadronic string tension) and M is the mass of the color magnetic flux tube and n is a numerical constant. Presumably L_p, $p = M_{107} = 2^{107} - 1$, is the p-adic length scale since Mersenne prime M_{107} labels the space-time sheet at which partons feed their color gauge fluxes. The temperature during this phase could correspond to Hagedorn temperature (for the history and various interpretations of Hagedorn temperature see the CERN Courier article [B14]) for strings and is determined by string tension and would naturally correspond also to the temperature during the critical phase determined by its duration as well as corresponding black-hole temperature. This temperature is expected to be somewhat higher than hadronization temperature found to be about $\simeq 176$ MeV. The density of inertial mass would be maximal during this phase as also the density of gravitational mass during the critical phase.

Lepto-hadron physics [K70] , one of the predictions of TGD, is one instance of a similar situation. In this case electromagnetic interaction strength defined in an analogous manner becomes larger than unity in heavy ion collisions just above the Coulomb wall and leads to the appearance of mysterious states having a natural interpretation in terms of lepto-pion condensate. Lepto-pions are pairs of color octet excitations of electron and positron.

3. Description of collisions using analogy with black holes

The following view about RHIC events represents my immediate reaction to the latest RHIC news in terms of black-hole physics instead of notions related to big bang. Since black hole collapse is roughly the time reversal of big bang, the description is complementary to the earliest one.

In TGD context one can ask whether the fireballs possibly detected at RHIC are produced when a portion of quark-gluon plasma in the collision region formed by to Gold nuclei separates from hadronic space-time sheets which in turn fuse to form a larger space-time sheet separated from the remaining collision region by a light-like 3-D surface (I have used to speak about light-like causal determinants) mathematically completely analogous to a black hole horizon. This larger space-time sheet would contain color glass condensate of super-symplectic gluons formed from the collision energy. A formation of an analog of black hole would indeed be in question.

The valence quarks forming structures connected by color bonds would in the first step of the collision separate from their hadronic space-time sheets which fuse together to form color glass condensate. Similar process has been observed experimentally in the collisions demonstrating the experimental reality of Pomeron, a color singlet state having no Regge trajectory [C111] and identifiable as a structure formed by valence quarks connected by color bonds. In the collision it temporarily separates from the hadronic space-time sheet. Later the Pomeron and the new mesonic and baryonic Pomerons created in the collision suffer a topological condensation to the color glass condensate: this process would be analogous to a process in which black hole sucks matter from environment.

Of course, the relationship between mass and radius would be completely different with gravitational constant presumably replacement by the the square of appropriate p-adic length scale presumably of order pion Compton length: this is very natural if TGD counterparts of black-holes are formed by color magnetic flux tubes. This gravitational constant expressible in terms of hadronic string tension of .9 GeV^2 predicted correctly by super-symplectic picture would characterize the strong gravitational interaction assignable to super-symplectic $J = 2$ gravitons. I have long time ago in the context of p-adic mass calculations formulated quantitatively the notion of elementary particle black hole analogy making the notion of elementary particle horizon and generalization of Hawking-Bekenstein law [K45] .

The size L of the "hadronic black hole" would be relatively large using protonic Compton radius as a unit of length. For instnce, for $\hbar = 26\hbar_0$ the size would be $26 \times L_e(107) = 46$ fm and correspond to a size of a heavy nucleus. This large size would fit nicely with the idea about nuclear sized color glass condensate. The density of partons (possibly gluons) would be very high and large fraction of them would have been materialized from the brehmstrahlung produced by the de-accelerating nuclei. Partons would be gravitationally confined inside this region. The interactions of partons would lead to a generation of a liquid like dense phase and a rapid thermalization would occur. The collisions of partons producing high transverse momentum partons occurring inside this region would yield no detectable high p_T jets since the matter coming out from this region would be somewhat like a thermal radiation from an evaporating black hole identified as a highly entangled hadronic string in Hagedorn temperature. This space-time sheet would expand and cool down to QQP and crystallize into hadrons.

4. Quantitative comparison with experimental data

Consider now a quantitative comparison of the model with experimental data. The estimated freeze-out temperature of quark gluon plasma is $T_f \simeq 175.76$ MeV [C145, C152], not far from the total contribution of quarks to the mass of nucleon, which is 170 MeV [K43] . Hagedorn temperature identified as black-hole temperature should be higher than this temperature. The experimental estimate for the hadronic Hagedorn temperature from the transversal momentum distribution of baryons is $\simeq 160$ MeV. On the other hand, according to the estimates of hep-ph/0006020 the values of Hagedorn temperatures for mesons and baryons are $T_H(M) = 195$ MeV and $T_H(B) = 141$ MeV respectively.

D-dimensional bosonic string model for hadrons gives for the mesonic Hagedorn temperature the expression [B14]

$$T_H = \frac{\sqrt{6}}{2\pi(D-2)\alpha'} , \qquad (10.3.7)$$

For a string in $D = 4$-dimensional space-time and for the value $\alpha' \sim 1$ GeV^{-2} of Regge slope, this would give $T_H = 195$ MeV, which is slightly larger than the freezing out temperature as it indeed should be, and in an excellent agreement with the experimental value of [B11] . It deserves to be noticed that in the model for fireball as a dual 10-D black-hole the rough estimate for the temperature of color glass condensate becomes too low by a factor 1/8 [C152]. In light of this I would not yet rush to conclude that the fireball is actually a 10-dimensional black hole.

Note that the baryonic Hagedorn temperature is smaller than mesonic one by a factor of about $\sqrt{2}$. According to [B11] this could be qualitatively understood from the fact that the number of degrees of freedom is larger so that the effective value of D in the mesonic formula is larger. $D_{eff} = 6$ would give $T_H = 138$ MeV to be compared with $T_H(B) = 141$ MeV. On the other hand, TGD based model for hadronic masses [K43] assumes that quarks feed their color fluxes to $k = 107$ space-time sheets. For mesons there are two color flux tubes and for baryons three. Using the same logic as in [B11] , one would have $D_{eff}(B)/D_{eff}(M) = 3/2$. This predicts $T_H(B) = 159$ MeV to be compared with 160 MeV deduced from the distribution of transversal momenta in p-p collisions.

10.3.4 Are ordinary black-holes replaced with super-symplectic black-holes in TGD Universe?

Some variants of super string model predict the production of small black-holes at LHC. I have never taken this idea seriously but in a well-defined sense TGD predicts black-holes associated with super-symplectic gravitons with strong gravitational constant defined by the hadronic string tension. The proposal is that super-symplectic black-holes have been already seen in Hera, RHIC, and the strange cosmic ray events.

Baryonic super-symplectic black-holes of the ordinary M_{107} hadron physics would have mass 934.2 MeV, very near to proton mass. The mass of their M_{89} counterparts would be 512 times higher, about 478 GeV if quark massses scale also by this factor. This need not be the case: if one has $k = 113 \rightarrow 103$ instead of 105 one has 434 GeV mass. "Ionization energy" for Pomeron, the structure formed by valence quarks connected by color bonds separating from the space-time sheet of super-symplectic black-hole in the production process, corresponds to the total quark mass and is about 170 MeV for ordinary proton and 87 GeV for M_{89} proton. This kind of picture about black-hole formation expected to occur in LHC differs from the stringy picture since a fusion of the hadronic mini black-holes to a larger black-hole is in question.

An interesting question is whether the ultrahigh energy cosmic rays having energies larger than the GZK cut-off of 5×10^{10} GeV are baryons, which have lost their valence quarks in a collision with hadron and therefore have no interactions with the microwave background so that they are able to propagate through long distances.

In neutron stars the hadronic space-time sheets could form a gigantic super-symplectic black-hole and ordinary black-holes would be naturally replaced with super-symplectic black-holes in TGD framework (only a small part of black-hole interior metric is representable as an induced metric). This obviously means a profound difference between TGD and string models.

(a) Hawking-Bekenstein black-hole entropy would be replaced with its p-adic counterpart given by

$$S_p = (\frac{M}{m(CP_2)})^2 \times log(p) \ , \tag{10.3.8}$$

where $m(CP_2)$ is CP_2 mass, which is roughly 10^{-4} times Planck mass. M is the contribution of p-adic thermodynamics to the mass. This contribution is extremely small for gauge bosons but for fermions and super-symplectic particles it gives the entire mass.

(b) If p-adic length scale hypothesis $p \simeq 2^k$ holds true, one obtains

$$S_p = klog(2) \times (\frac{M}{m(CP_2)})^2, \tag{10.3.9}$$

$m(CP_2) = \hbar/R$, R the "radius" of CP_2, corresponds to the standard value of $\hbar_0$ for all values of $\hbar$.

(c) Hawking-Bekenstein area law gives in the case of Schwartschild black-hole

$$S = \frac{A}{4G} \times \hbar = \pi G M^2 \times \hbar \ . \tag{10.3.10}$$

For the p-adic variant of the law Planck mass is replaced with CP_2 mass and $klog(2) \simeq log(p)$ appears as an additional factor. Area law is obtained in the case of elementary particles if k is prime and wormhole throats have M^4 radius given by p-adic length scale $L_k = \sqrt{k}R$ which is exponentially smaller than L_p. For macroscopic super-symplectic black-holes modified area law results if the radius of the large wormhole throat equals to Schwartschild radius. Schwartschild radius is indeed natural: in [K71] I have shown that a simple deformation of the Schwartschild exterior metric to a metric representing rotating star transforms Schwartschild horizon to a light-like 3-surface at which the signature of the induced metric is transformed from Minkowskian to Euclidian.

(d) The formula for the gravitational Planck constant appearing in the Bohr quantization of planetary orbits and characterizing the gravitational field body mediating gravitational interaction between masses M and m [K59] reads as

$$\hbar_{gr} = \frac{GMm}{v_0}\hbar_0 \ .$$

$v_0 = 2^{-11}$ is the preferred value of v_0. One could argue that the value of gravitational Planck constant is such that the Compton length $\hbar_{gr}/M$ of the black-hole equals to its Schwartshild radius. This would give

$$\hbar_{gr} = \frac{GM^2}{v_0}\hbar_0 \ , \ \ v_0 = 1/2 \ . \quad (10.3.11)$$

The requirement that $\hbar_{gr}$ is a ratio of ruler-and-compass integers expressible as a product of distinct Fermat primes (only four of them are known) and power of 2 would quantize the mass spectrum of black hole [K59] . Even without this constraint M^2 is integer valued using p-adic mass squared unit and if p-adic length scale hypothesis holds true this unit is in an excellent approximation power of two.

(e) The gravitational collapse of a star would correspond to a process in which the initial value of v_0 , say $v_0 = 2^{-11}$, increases in a stepwise manner to some value $v_0 \leq 1/2$. For a supernova with solar mass with radius of 9 km the final value of v_0 would be $v_0 = 1/6$. The star could have an onion like structure with largest values of v_0 at the core as suggested by the model of planetary system. Powers of two would be favored values of v_0. If the formula holds true also for Sun one obtains $1/v_0 = 3 \times 17 \times 2^{13}$ with 10 per cent error.

(f) Black-hole evaporation could be seen as means for the super-symplectic black-hole to get rid of its electro-weak charges and fermion numbers (except right handed neutrino number) as the antiparticles of the emitted particles annihilate with the particles inside super-symplectic black-hole. This kind of minimally interacting state is a natural final state of star. Ideal super-symplectic black-hole would have only angular momentum and right handed neutrino number.

(g) In TGD light-like partonic 3-surfaces are the fundamental objects and space-time interior defines only the classical correlates of quantum physics. The space-time sheet containing the highly entangled cosmic string might be separated from environment by a wormhole contact with size of black-hole horizon.

This looks the most plausible option but one can of course ask whether the large partonic 3-surface defining the horizon of the black-hole actually contains all super-symplectic particles so that super-symplectic black-hole would be single gigantic super-symplectic parton. The interior of super-symplectic black-hole would be a space-like region of space-time, perhaps resulting as a large deformation of CP_2 type vacuum extremal. Black-hole sized wormhole contact would define a gauge boson like variant of the black-hole connecting two space-time sheets and getting its mass through Higgs mechanism. A good guess is that these states are extremely light.

10.3.5 Very cautious conclusions

The model for quark-gluon plasma in terms of valence quark space-time sheets separated from hadronic space-time sheets forming a color glass condensate relies on quantum criticality and implies gravitation like effects due to the presence of super-symplectic strong gravitons. At space-time level the change of the distances due to strong gravitation affects the metric so that the breaking of spherical symmetry is caused by gravitational interaction. TGD encourages to think that this mechanism is quite generally at work in the collisions of nuclei. One must take seriously the possibility that strong gravitation is present also in longer length scales (say biological), in particular in processes in which new space-time sheets are generated. Critical cosmology might provide a universal model for the emergence of a new space-time sheet.

The model supports TGD based early cosmology and quantum criticality. In standard physics framework the cosmology in question is not sensible since it would predict a large breaking of the Lorentz invariance, and would mean the breakdown of the entire conceptual framework underlying elementary particle physics. In TGD framework Lorentz invariance is not lost at the level of imbedding space, and the experiments provide support for the view about space-time as a surface and for the notion of many-sheeted space-time.

The attempts to understand later strange events reported by RHIC have led to a dramatic increase of understanding of TGD and allow to fuse together separate threads of TGD.

(a) The description of RHIC events in terms of the formation of hadronic black hole and its evaporation seems to be also possible and essentially identical with description as a mini bang.

(b) It took some time to realize that scaled down TGD inspired cosmology as a model for quark gluon plasma predicts a new phase identifiable as color glass condensate and still a couple of years to realize the proper interpretation of it in terms of super-symplectic bosons having no counterpart in QCD framework.

(c) There is also a connection with the dramatic findings suggesting that Planck constant for dark matter has a gigantic value.

(d) Black holes and their scaled counterparts would not be merciless information destroyers in TGD Universe. The entanglement of particles having particle like integrity would make black hole like states ideal candidates for quantum computer like systems. One could even imagine that the galactic black hole is a highly tangled cosmic string in Hagedorn temperature performing quantum computations the complexity of which is totally out of reach of human intellect! Indeed, TGD inspired consciousness predicts that evolution leads to the increase of information and intelligence, and the evolution of stars should not form exception to this. Also the interpretation of black hole as consisting of dark matter follows from this picture.

Summarizing, it seems that thanks to some crucial experimental inputs the new physics predicted by TGD is becoming testable in laboratory.

10.3.6 Five years later

The emergence of the first interesting findings from LHC by CMS collaboration [C61, C6] provide new insights to the TGD picture about the phase transition from QCD plasma to hadronic phase and inspired also the updating of the model of RHIC events (mainly elimination of some remnants from the time when the ideas about hierarchy of Planck constants had just born).

Anomalous behavior of quark gluon plasma is observed also in proton proton collisions

In some proton-proton collisions more than hundred particles are produced suggesting a single object from which they are produced. Since the density of matter approaches to that observed in heavy ion collisions for five years ago at RHIC, a formation of quark gluon plasma and its subsequent decay is what one would expect. The observations are not however quite what QCD plasma picture would allow to expect. Of course, already the RHIC results disagreed with what QCD expectations. What is so striking is the evolution of long range correlations between particles in events containing more than 90 particles as the transverse momentum of the particles increases in the range 1-3 GeV (see the excellent description of the correlations by Lubos Motl in his blog [C30]).

One studies correlation function for two particles as a function of two variables. The first variable is the difference $\Delta\phi$ for the emission angles and second is essentially the difference for the velocities described relativistically by the difference $\Delta\eta$ for hyperbolic angles. As the transverse momentum p_T increases the correlation function develops structure. Around origin of $\Delta\eta$ axis a widening plateau develops near $\Delta\phi = 0$. Also a wide ridge with almost constant value as function of $\Delta\eta$ develops near $\Delta\phi = \pi$. The interpretation is that particles tend to move collinearly and or in opposite directions. In the latter case their velocity differences are large since they move in opposite directions so that a long ridge develops in $\Delta\eta$ direction in the graph.

Ideal QCD plasma would predict no correlations between particles and therefore no structures like this. The radiation of particles would be like blackbody radiation with no correlations between photons. The description in terms of string like object proposed also by Lubos on basis of analysis of the graph showing the distributions as an explanation of correlations looks attractive. The decay of a string like structure producing particles at its both ends moving nearly parallel to the string to opposite directions could be in question.

Since the densities of particles approach those at RHIC, I would bet that the explanation (whatever it is!) of the hydrodynamical behavior observed at RHIC for some years ago should apply also now. The introduction of string like objects in this model was natural since in TGD framework even ordinary nuclei are string like objects with nucleons connected by color flux tubes [L3] , [L3] : this predicts a lot of new nuclear physics for which there is evidence. The basic idea was that in the high density hadronic color flux tubes associated with the colliding nucleon connect to form long highly entangled hadronic strings containing quark gluon plasma. The decay of these structures would explain the strange correlations. It must be however emphasized that in the recent case the initial state consists of two protons rather than heavy nuclei so that the long hadronic string could form from the QCD like quark gluon plasma at criticality when long range fluctuations emerge.

The main assumptions of the model for the RHIC events and those observed now deserve to be summarized. Consider first the "macroscopic description".

(a) A critical system associated with confinement-deconfinement transition of the quark-gluon plasma formed in the collision and inhibiting long range correlations would be in question.

(b) The proposed hydrodynamic space-time description was in terms of a scaled variant of what I call critical cosmology defining a universal space-time correlate for criticality: the specific property of this cosmology is that the mass contained by comoving volume approaches to zero at the the initial moment so that Big Bang begins as a silent whisper and is not so scaring;-). Criticality means flat 3-space instead of Lobatchevski space and means breaking of Lorentz invariance to SO(4). Breaking of Lorentz invariance was indeed observed for particle distributions but now I am not so sure whether it has much to do with this.

(c) The system behaves like almost perfect fluid in the sense that the viscosity entropy ratio is near to its lower bound whose values is predicted by string theory considerations to be $\eta/s = \hbar/4\pi$.

The microscopic level the description would be like follows.

(a) A highly entangled long hadronic string like object (color-magnetic flux tube) would be formed at high density of nucleons via the fusion of ordinary hadronic color-magnetic flux tubes to much longer one and containing quark gluon plasma. In QCD world plasma would not be at flux tube.

(b) This geometrically (and perhaps also quantally!) entangled string like object would straighten and split to hadrons in the subsequent "cosmological evolution" and yield large numbers of almost collinear particles. The initial situation should be apart from scaling similar as in cosmology where a highly entangled soup of cosmic strings (magnetic flux tubes) precedes the space-time as we understand it. Maybe ordinary cosmology could provide analogy as galaxies arranged to form linear structures?

(c) This structure would have also black hole like aspects but in totally different sense as the 10-D hadronic black-hole proposed by Nastase to describe the findings. Note that M-theorists identify black holes as highly entangled strings: in TGD 1-D strings are replaced by 3-D string like objects.

This picture leaves does not yet make the perfect fluid behavior obvious. The following argument relates it to the properties of the preferred extremals of Kähler action.

Preferred extremals as perfect fluids

10.3.7 Preferred extremals as perfect fluids

Almost perfect fluids seems to be abundant in Nature. For instance, QCD plasma was originally thought to behave like gas and therefore have a rather high viscosity to entropy density ratio $x = \eta/s$. Already RHIC found that it however behaves like almost perfect fluid with x near to the minimum predicted by AdS/CFT. The findings from LHC gave additional conform the discovery [C45]. Also Fermi gas is predicted on basis of experimental observations to have at low temperatures a low viscosity roughly 5-6 times the minimal value [D3] . In the following the argument that the preferred extremals of Kähler action are perfect fluids apart from the symmetry breaking to space-time sheets is developed. The argument requires some basic formulas summarized first.

The detailed definition of the viscous part of the stress energy tensor linear in velocity (oddness in velocity relates directly to second law) can be found in [D2] .

(a) The symmetric part of the gradient of velocity gives the viscous part of the stress-energy tensor as a tensor linear in velocity. Velocity gradient decomposes to a term traceless tensor term and a term reducing to scalar.

$$\partial_i v_j + \partial_j v_i = \frac{2}{3}\partial_k v^k g_{ij} + (\partial_i v_j + \partial_j v_i - \frac{2}{3}\partial_k v^k g_{ij}) \ . \tag{10.3.12}$$

The viscous contribution to stress tensor is given in terms of this decomposition as

$$\sigma_{visc;ij} = \zeta \partial_k v^k g_{ij} + \eta(\partial_i v_j + \partial_j v_i - \frac{2}{3}\partial_k v^k g_{ij}) \ . \tag{10.3.13}$$

From $dF^i = T^{ij}S_j$ it is clear that bulk viscosity ζ gives to energy momentum tensor a pressure like contribution having interpretation in terms of friction opposing. Shear viscosity η corresponds to the traceless part of the velocity gradient often called just viscosity. This contribution to the stress tensor is non-diagonal and corresponds to momentum transfer in directions not parallel to momentum and makes the flow rotational. This term is essential for the thermal conduction and thermal conductivity vanishes for ideal fluids.

(b) The 3-D total stress tensor can be written as

$$\sigma_{ij} = \rho v_i v_j - p g_{ij} + \sigma_{visc;ij} \ . \tag{10.3.14}$$

The generalization to a 4-D relativistic situation is simple. One just adds terms corresponding to energy density and energy flow to obtain

$$T^{\alpha\beta} = (\rho - p) u^\alpha u^\beta + p g^{\alpha\beta} - \sigma^{\alpha\beta}_{visc} \ . \tag{10.3.15}$$

Here u^α denotes the local four-velocity satisfying $u^\alpha u_\alpha = 1$. The sign factors relate to the concentrations in the definition of Minkowski metric $((1,-1,-1,-1))$.

(c) If the flow is such that the flow parameters associated with the flow lines integrate to a global flow parameter one can identify new time coordinate t as this flow parameter. This means a transition to a coordinate system in which fluid is at rest everywhere (comoving coordinates in cosmology) so that energy momentum tensor reduces to a diagonal term plus viscous term.

$$T^{\alpha\beta} = (\rho - p) g^{tt} \delta^\alpha_t \delta^\beta_t + p g^{\alpha\beta} - \sigma^{\alpha\beta}_{visc} \ . \tag{10.3.16}$$

In this case the vanishing of the viscous term means that one has perfect fluid in strong sense.

The existence of a global flow parameter means that one has

$$v_i = \Psi \partial_i \Phi . \tag{10.3.17}$$

Ψ and Φ depend on space-time point. The proportionality to a gradient of scalar Φ implies that Φ can be taken as a global time coordinate. If this condition is not satisfied, the perfect fluid property makes sense only locally.

AdS/CFT correspondence allows to deduce a lower limit for the coefficient of shear viscosity as

$$x = \frac{\eta}{s} \geq \frac{\hbar}{4\pi} . \tag{10.3.18}$$

This formula holds true in units in which one has $k_B = 1$ so that temperature has unit of energy.

What makes this interesting from TGD view is that in TGD framework perfect fluid property in appropriately generalized sense indeed characterizes locally the preferred extremals of Kähler action defining space-time surface.

(a) Kähler action is Maxwell action with U(1) gauge field replaced with the projection of CP_2 Kähler form so that the four CP_2 coordinates become the dynamical variables at QFT limit. This means enormous reduction in the number of degrees of freedom as compared to the ordinary unifications. The field equations for Kähler action define the dynamics of space-time surfaces and this dynamics reduces to conservation laws for the currents assignable to isometries. This means that the system has a hydrodynamic interpretation. This is a considerable difference to ordinary Maxwell equations. Notice however that the "topological" half of Maxwell's equations (Faraday's induction law and the statement that no non-topological magnetic are possible) is satisfied.

(b) Even more, the resulting hydrodynamical system allows an interpretation in terms of a perfect fluid. The general ansatz for the preferred extremals of field equations assumes that various conserved currents are proportional to a vector field characterized by so called Beltrami property. The coefficient of proportionality depends on space-time point and the conserved current in question. Beltrami fields by definition is a vector field such that the time parameters assignable to its flow lines integrate to single global coordinate. This is highly non-trivial and one of the implications is almost topological QFT property due to the fact that Kähler action reduces to a boundary term assignable to wormhole throats which are light-like 3-surfaces at the boundaries of regions of space-time with Euclidian and Minkowskian signatures. The Euclidian regions (or wormhole throats, depends on one's tastes) define what I identify as generalized Feynman diagrams.

Beltrami property means that if the time coordinate for a space-time sheet is chosen to be this global flow parameter, all conserved currents have only time component. In TGD framework energy momentum tensor is replaced with a collection of conserved currents assignable to various isometries and the analog of energy momentum tensor complex constructed in this manner has no counterparts of non-diagonal components. Hence the preferred extremals allow an interpretation in terms of perfect fluid without any viscosity.

This argument justifies the expectation that TGD Universe is characterized by the presence of low-viscosity fluids. Real fluids of course have a non-vanishing albeit small value of x. What causes the failure of the exact perfect fluid property?

(a) Many-sheetedness of the space-time is the underlying reason. Space-time surface decomposes into finite-sized space-time sheets containing topologically condensed smaller space-time sheets containing.... Only within given sheet perfect fluid property holds true and fails at wormhole contacts and because the sheet has a finite size. As a consequence, the global flow parameter exists only in given length and time scale. At imbedding space level and in zero energy ontology the phrasing of the same would be in terms of hierarchy of causal diamonds (CDs).

(b) The so called eddy viscosity is caused by eddies (vortices) of the flow. The space-time sheets glued to a larger one are indeed analogous to eddies so that the reduction of viscosity to eddy viscosity could make sense quite generally. Also the phase slippage phenomenon of super-conductivity meaning that the total phase increment of the superconducting order parameter is reduced by a multiple of 2π in phase slippage so that the average velocity proportional to the increment of the phase along the channel divided by the length of the channel is reduced by a quantized amount.

The standard arrangement for measuring viscosity involves a lipid layer flowing along plane. The velocity of flow with respect to the surface increases from $v = 0$ at the lower boundary to v_{upper} at the upper boundary of the layer: this situation can be regarded as outcome of the dissipation process and prevails as long as energy is feeded into the system. The reduction of the velocity in direction orthogonal to the layer means that the flow becomes rotational during dissipation leading to this stationary situation.

This suggests that the elementary building block of dissipation process corresponds to a generation of vortex identifiable as cylindrical space-time sheets parallel to the plane of the flow and orthogonal to the velocity of flow and carrying quantized angular momentum. One expects that vortices have a spectrum labelled by quantum numbers like energy and angular momentum so that dissipation takes in discrete steps by the generation of vortices which transfer the energy and angular momentum to environment and in this manner generate the velocity gradient.

(c) The quantization of the parameter x is suggestive in this framework. If entropy density and viscosity are both proportional to the density n of the eddies, the value of x would equal to the ratio of the quanta of entropy and kinematic viscosity η/n for single eddy if all eddies are identical. The quantum would be $\hbar/4\pi$ in the units used and the suggestive interpretation is in terms of the quantization of angular momentum. One of course expects a spectrum of eddies so that this simple prediction should hold true only at temperatures for which the excitation energies of vortices are above the thermal energy. The increase of the temperature would suggest that gradually more and more vortices come into play and that the ratio increases in a stepwise manner bringing in mind quantum Hall effect. In TGD Universe the value of $\hbar$ can be large in some situations so that the quantal character of dissipation could become visible even macroscopically. Whether this a situation with large $\hbar$ is encountered even in the case of QCD plasma is an interesting question.

The following poor man's argument tries to make the idea about quantization a little bit more concrete.

(a) The vortices transfer momentum parallel to the plane from the flow. Therefore they must have momentum parallel to the flow given by the total cm momentum of the vortex. Before continuing some notations are needed. Let the densities of vortices and absorbed vortices be n and n_{abs} respectively. Denote by $v_{\parallel}$ *resp.* $v_{\perp}$ the components of cm momenta parallel to the main flow *resp.* perpendicular to the plane boundary plane. Let m be the mass of the vortex. Denote by S are parallel to the boundary plane.

(b) The flow of momentum component parallel to the main flow due to the absorbed at S is

$$n_{abs} m v_{\parallel} v_{\perp} S \quad .$$

This momentum flow must be equal to the viscous force

$$F_{visc} = \eta \frac{v_{\parallel}}{d} \times S \quad .$$

From this one obtains

$$\eta = n_{abs} m v_{\perp} d \quad .$$

If the entropy density is due to the vortices, it equals apart from possible numerical factors to

$$s = n$$

so that one has

$$\frac{\eta}{s} = m v_{\perp} d \quad .$$

This quantity should have lower bound $x = \hbar/4\pi$ and perhaps even quantized in multiples of x, Angular momentum quantization suggests strongly itself as origin of the quantization.

(c) Local momentum conservation requires that the comoving vortices are created in pairs with opposite momenta and thus propagating with opposite velocities $v_{\perp}$. Only one half of vortices is absorbed so that one has $n_{abs} = n/2$. Vortex has quantized angular momentum associated with its internal rotation. Angular momentum is generated to the flow since the vortices flowing downwards are absorbed at the boundary surface.

Suppose that the distance of their center of mass lines parallel to plane is $D = \epsilon d$, ϵ a numerical constant not too far from unity. The vortices of the pair moving in opposite direction have same angular momentum $mv \ D/2$ relative to their center of mass line between them. Angular momentum conservation requires that the sum these relative angular momenta cancels the sum of the angular momenta associated with the vortices themselves. Quantization for the total angular momentum for the pair of vortices gives

$$\frac{\eta}{s} = \frac{n\hbar}{\epsilon}$$

Quantization condition would give

$$\epsilon = 4\pi \quad .$$

One should understand why $D = 4\pi d$ - four times the circumference for the largest circle contained by the boundary layer- should define the minimal distance between the vortices of the pair. This distance is larger than the distance d for maximally sized vortices of radius $d/2$ just touching. This distance obviously increases as the thickness of the boundary layer increases suggesting that also the radius of the vortices scales like d.

(d) One cannot of course take this detailed model too literally. What is however remarkable that quantization of angular momentum and dissipation mechanism based on vortices identified as space-time sheets indeed could explain why the lower bound for the ratio η/s is so small.

10.3.8 Evidence for TGD view about QCD plasma

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10.4 Duality between low energy and high energy descriptions of hadron physics

I found the talk of Matthew Schwartz titled *The Emergence of Jets at the Large Hadron Collider* [C165] belonging to the Monday Colloqium Series at Harward. The talk told about the history of the notion of jet and how it is applied at LHC. The notion of jet is something between perturbative and non-perturbative QCD and therefore not a precisely defined concept as one approaches small mass limit for jets.

The talk inspired some questions relating to QCD and hadron physics in general. I am of course not competent to say anything interesting about jet algorithms. Hadronization process is however not well understood in the framework of QCD and uses phenomenological fragmentation functions. The description of jet formation in turn uses phenomenological quark distribution functions. TGD leads to a rather detailed fresh ideas about what quarks, gluons, and hadrons are and stringy and QFT like descriptions emerge as excellent candidates for low and high energy descriptions of hadrons. Low energies are the weakness of QCD and one can well ask whether QCD fails as a physical theory at infrared. Could TGD do better in this respect?

Only a minor fraction of the rest energy of proton is in the form of quarks and gluons. In TGD framework these degrees of freedom would naturally correspond to color magnetic flux tubes carrying color magnetic energy and in proton-proton collisions the color magnetic energy of p-p system in cm system is gigantic. The natural question is therefore about what happens to the "color magnetic bodies" of the colliding protons and of quarks in proton-proton collision.

In the sequel I will develop a simple argument leading to a very concrete duality between two descriptions of hadron reactions manifest at the level of generalized Feynman graphs. The first description is in terms of meson exchanges and applies naturally in long scales. Second one is terms of perturbative QCD applying in short scales. The basic ingredients of the argument are the weak form of electric-magnetic duality [K23] and bosonic emergence [K49] leading to a rather concrete view about physical particles, generalized Feynman diagrams reducing to generalized braid diagrams in the framework of zero energy ontology (ZEO), and reconnection of Kähler magnetic flux tubes having interpretation in terms of string diagrams providing the mechanism of hadronization. Basically the prediction follows from the dual interpretations of generalized Feynman diagrams either as stringy diagrams (low energies) or as Feynman diagrams (high energies).

It must be emphasized that this duality is something completely new and a simple prediction of the notion of generalized Feynman diagram. The result is exact: no limits (such as large N limit) are needed.

10.4.1 Weak form of electric magnetic duality and bosonic emergence

The weak form of electric magnetic duality allows the identification of quark wormhole throats as Kähler magnetic monopoles with non-vanishing magnetic charges Q_m. The closely related bosonic emergence [K49] effectively eliminates the fundamental BFF vertices from the theory.

(a) Elementary fermion corresponds to single wormhole throat with Kähler magnetic charge. In topological condensation a wormhole throat is formed and the working hypothesis is that the second throat is Kähler magnetically neutral. The throats created in topological condensation (formation of topological sum) are always homologically trivial since purely local process is in question.

(b) In absence of topological condensation physical leptons correspond to string like objects with opposite Kähler magnetic charges at the ends. Topologically condensed lepton carries also neutralizing weak isospin carried by neutrino pair at the throats of the neutralizing wormhole contact. Wormhole contact itself carries no Kähler magnetic flux. The neutralization scale for Q_m and weak isospin could be either weak length scale for both fermions and bosons. The alternative option is Compton length quite generally - this even for fermions since it is enough that the weak isospin of weak bosons is neutralized in the weak scale. The alert reader have of course asked whether the weak isospin of fermion must be neutralized at all if this is the case. Whether this really happens is not relevant for the following arguments.

(c) Whether a given quark is accompanied by a wormhole contact neutralizing its weak isospin is not quite clear: this need not be the case since the Compton length of weak bosons defines the range of weak interactions. Therefore one can consider the possibility that physical quarks have non-vanishing Q_m and that only hadrons have $Q_m = 0$. Now the Kähler magnetic flux tubes would connect valence quarks. In the case of proton one would have three of them. About 31 year old proposal is that color hyper charge is proportional to Kähler magnetic charge. If so then color confinement would require Kähler magnetic confinement.

(d) By bosonic emergence bosons correspond to wormhole contacts or pairs of them. Now wormhole throats have opposite values of Q_m but the contact itself carries vanishing Kähler magnetic flux. Fermion and anti-fermion are accompanied by neutralizing Kähler magnetic charge at the ends of their flux tubes and neutrino pair at its throats neutralizes the weak charge of the boson.

10.4.2 The dual interpretations of generalized Feynman diagrams in terms of hadronic and partonic reaction vertices

Generalized Feynman diagrams are defined in the framework of zero energy ontology (ZEO). Bosonic emergence eliminates fundamental BFF vertices and reduces generalized Feynman diagrams to generalized braid diagrams. This is essential for the dual interpretation of the qqg vertex as a meson emission vertex for hadron. The key idea is following.

(a) Topologically condensed hadron - say proton- corresponds to a double sheeted structure: let us label the sheets by letters A and B. Suppose that the sheet A contains wormhole throats of quarks carrying magnetic charges. These wormhole throats are connected by magnetically neutral wormhole contact to sheet B for which wormhole throats carry vanishing magnetic charges.

(b) What happens when hadronic quark emits a gluon is easiest to understand by considering first the annihilation of topologically non-condensed charged lepton and antilepton to photon - that is $L + \overline{L} \rightarrow \gamma$ vertex. Lepton and antilepton are accompanied by flux tubes at different space-time sheets A and B and each has single wormhole throat: one can speak of a pair of topologically condensed deformations of CP_2 type vacuum extremals as a correlate for single wormhole throat. At both ends of the flux tubes deformations o fCP_2 type vacuum extremals fuse via topological sum to form a pair of photon wormhole contacts carrying no Kähler magnetic flux. The condition that the resulting structure has the size of weak gauge boson suggests that weak scale defines also the size of leptons and quarks as magnetic flux tubes. Quarks can however carry net Kähler magnetic charge (the ends of flux tube do not have opposite values of Kähler magnetic charge.

(c) With some mental gymnastics the annihilation vertex $L + \overline{L} \to \gamma$ can be deformed to describe photon emission vertex $L \to L + \gamma$: The negative energy antilepton arrives from future and positive energy lepton from the past and they fuse to a virtual photon in the manner discussed.

(d) qqg vertex requires further mental gymnastics but locally nothing is changed since the protonic quark emitting the gluon is connected by a color magnetic flux tube to another protonic quark in the case of incoming proton (and possibly to neutrino carrying wormhole contact with size given by the weak length scale). What happens is therefore essentially the same as above. The protonic quark has become part of gluon at space-time sheet A but has still flux tube connection to proton. Besides this there appears wormhole throat at space-time sheet B carrying quark quantum numbers: this quark would in the usual picture correspond to the quark after gluon emission and antiquark at the same space-time sheet associated with the gluon. Therefore one has proton with one quark moving away inside gluon at sheet A and a meson like entity at sheet B. The dual interpretation as the emission of meson by proton makes sense. This vertex does not correspond to the stringy vertex $AB + CD \to AD + BC$ in which strings touch at some point of the interior and recombine but is something totally new and made possible by many-sheeted space-time. For gauge boson magnetically charge throats are at different space-time sheets, for meson they at the same space-time sheet and connected by Kähler magnetic flux tube.

(e) Obviously the interpretation as an emission of meson like entity makes sense for any hadron like entity for which quark or antiquark emits gluon. This is what the duality of hadronic and parton descriptions would mean. Note that bosonic emergence is absolutely essential element of this duality. In QCD it is not possible to understand this duality at the level of Feynman diagrams.

10.4.3 Reconnection of color magnetic flux tubes

The reconnection of color magnetic flux tubes is the key mechanism of hadronization and a slow process as compared to quark gluon emission.

(a) Reconnection vertices have interpretation in terms of stringy vertices $AB + CD \to AD + BC$ for which interiors of strings serving as representatives of flux tubes touch. The first guess is that reconnection is responsible for the low energy dynamics of hadronic collisions.

(b) Reconnection process takes place for both the hadronic color magnetic flux tubes and those of quarks and gluons. For ordinary hadron physics hadrons are characterized by Mersenne prime M_{107}. For M_{89} hadron physics reconnection process takes place in much shorter scales for hadronic flux tubes.

(c) Each quarks is characterized by p-adic length scales: in fact this scale characterizes the length scale of the the magnetic bodies of the quark. Therefore Reconnection at the level of the magnetic bodies of quarks take places in several time and length scales. For top quark the size scale of magnetic body is very small as is also the reconnection time scale. In the case of u and d quarks with mass in MeV range the size scale of the magnetic body would be of the order of electron Compton length. This scale assigned with quark is longer than the size scale of hadrons characterized by M_{89}. Classically this does not make sense but in quantum theory Uncertainty Principle predicts it from the smallness of the light quark masses as compared to the hadron mass. The large size of the color magnetic body of quark could explain the strange finding about the charge radius of proton [K37].

(d) For instance, the formation of quark gluon plasma would involve reconnection process for the magnetic bodies of colliding protons or nuclei in short time scale due to the Lorentz contraction of nuclei in the direction of the collision axis. Quark-gluon plasma would correspond to a situation in which the magnetic fluxes are distributed in such a manner that the system cannot be decomposed to hadrons anymore but acts like a single coherent unit. Therefore quark-gluon plasma in TGD sense does not correspond to the thermal quark-gluon plasma in the naive QCD sense in which there are no long range correlations.

Long range correlations and quantum coherence suggest that the viscosity to entropy ratio is low as indeed observed [K37]. The earlier arguments suggest that the preferred extremals of Kähler action have interpretation as perfect fluid flows [K23]. This means at given space-time sheet allows global time coordinate assignable to flow lines of the flow and defined by conserved isometry current defining Beltrami flow. As a matter fact, all conserved currents are predicted to define Beltrami flows. Classically perfect fluid flow implies that viscosity, which is basically due to a mixing causing the loss of Beltrami property, vanishes. Viscosity would be only due to the finite size of space-time sheets and the radiative corrections describable in terms of fractal hierarchy CDs within CDs. In quantum field theory radiative corrections indeed give rise to the absorbtive parts of the scattering amplitudes.

10.4.4 Hadron-parton duality and TGD as a "square root" of the statistical QCD description

The main result is that generalized Feynman diagrams have dual interpretations as QCD like diagrams describing partonic reactions and stringy diagrams describing hadronic reactions so that these matrix elements can be taken between either hadronic states or partonic states. This duality is something completely new and distinguishes between QCD and TGD.

I have proposed already earlier this kind of duality but based on group theoretical arguments inspired by what I call $M^8 - M^4 \times CP_2$ duality [K23] and two hypothesis of the old fashioned hadron physics stating that vector currents are conserved and axial currents are partially conserved. This duality suggests that the group $SO(4) = SU(2)_L \times SU(2)_R$ assignable to weak isospin degrees of freedom takes the role of color group at long length scales and can be identified as isometries of $E^4 \subset M^8$ just like $SU(3)$ corresponds to the isometries of CP_2.

Initial and final states correspond to positive and negative energy parts of zero energy states in ZEO. These can be regarded either partonic or hadronic many particle states. The inner products between *positive* energy parts of partonic and hadronic state basis define the "square roots" of the parton distribution functions for hadrons. The inner products of between *negative* energy parts of hadronic and partonic state basis define the "square roots" of the fragmentations functions to hadrons for partons. M-matrix defining the time-like entanglement coefficients is representable as product of hermitian square root of density matrix and S-matrix is not time reversal invariant and this partially justifies the use of statistical description of partons in QCD framework using distribution functions and fragmentation functions. Decoherence in the sum over quark intermediate states for the hadronic scattering amplitudes is essential for obtaining the standard description.

10.5 Quark gluon plasma in TGD framework

This section was inspired by an an excellent talk by Dam Thanh Son in Harward Monday seminar series [C169]. The title of the talk was *Viscosity, Quark Gluon Plasma, and String Theory*. What the talk represents is a connection between three notions which one would not expect to have much to do with each other.

In the following I shall briefly summarize the basic points of Son's talk which I warmly recommend for anyone wanting to sharpen his or her mental images about quark gluon plasma.

(a) Besides this I discuss a TGD variant of AdS/CFT correspondence based on string-parton duality allowing a concrete identification of the process leading to the formation of strongly interacting quark gluon plasma.

(b) "Strongly interacting" means that partonic 2-surfaces are connected by Kähler magnetic flux tubes making the many-hadron system single large hadron in the optimal case rather than a gas of uncorrelated partons. This allows a concrete generalization of the formula of kinetic gas theory for the viscosity.

(c) One ends up also to a concrete interpretation for the formula for the η/s ratio in terms of TGD variant of Einsteinian gravitation and the analogs of black-hole horizons identified as partonic 2-surfaces. This gravitation is not fictive gravitation in 10-D space but real sub-manifold gravitation in 4-D space-time.

(d) It is essential that TGD does not assume gravitational constant as a fundamental constant but as a prediction of theory depending on the p-adic length scale and the typical value of Kähler action for the lines of generalized Feynman graphs. Feeding in the notion of gravitational Planck constant, one finds beautiful interpretation for the lower limit viscosity which is smaller than the one predicted by AdS-CFT correspondence.

10.5.1 Some points in Son's talk

Son discusses first the notion of shear viscosity at undergraduate level - as he expresses it. First the standard Wikipedia definition for shear viscosity is discussed in terms of the friction forces created in a system consisting two parallel plates containing liquid between them as one moves a plate with respect to another parallel plate.

Son explains how Maxwell explains the viscosity of gases in terms of kinetic gas theory and entered with a strange result: the estimate $\eta = \rho v l_{free}$ leads to the conclusion that the viscosity has no pressure dependence: Maxwell himself verified the result experimentally. Imagining that the interaction of gas molecules can be reduced to zero leads to a paradox: the viscosity of the ideal gas is infinite. The solution of the paradox is simple: the theory applies only if l_{free} is considerably smaller than the size scale of the system, say the distance between the two plates, one of which is moving.

Son discusses the viscosity for some condensed matter systems and finds that the value of viscosity increases very rapidly as a function of temperature: does this mean a rapid increase of l_{free} with temperature? Son also notices that the viscosity seems to be bounded from below. Son discusses also η/s ratio for the condensed matter systems and finds that it is typically by a factor 10-100 larger than the minimal values $\hbar/4\pi$ suggested by AdS/CFT correspondence [B22].

Son describes gauge-gravity duality briefly. AdS/CFT approach does not allow simple arguments analogous to those used in the kinetic theory of gases.

(a) One central formula is Kubo's formula giving viscosity as the low frequency limit for the Fourier component of the component of energy momentum tensor commutation $[T^{yx}(x,t), T^{yx}(0,0)]$ as

$$\eta = \frac{1}{2\hbar\omega} \int \langle [T^{yx}(x,t), T^{yx}(0,0)]\, d^4x \rangle_{\omega\to 0}$$

for$\mathcal{N} = 4$ SUSY defined in M^4. Now this theory is $\mathcal{N} = 4$ SUSY so that there is no hope about simple interpretation. Note that the formula is consistent with the dimensions of viscosity which is M/L^3. I confess that I do not understand the origin of the formula at the level details. Green-Kubo relations [B5] are certainly the starting point having very general justification as an outcome of fluctuation theorem [B4] allowing understood relatively easily in Gaussian model for thermodynamics. Since energy momentum tensor serves as a source of gravitons and is the basic observable in hydrodynamics, it is clear that this formula is consistent with gauge theory-gravity correspondence. $\omega \to 0$ limit means that the low energy sector of the gauge theory is in question so that the perturbative approach fails.

(b) In TGD framework the analog of this formula need not be useful. If it apply it should apply to partonic 2-surfaces and $AdS_5 \times S_5$ should be replaced with space-time surface.

The energy momentum tensor should be the energy momentum tensor of partonic 2-surface fixed to a high degree by conformal invariance. One should sum over all partonic 2-surfaces. The partonic 2-surfaces would correspond to both ends of a braid strands at the opposite light-like boundaries of CD. The integral at the level of the partonic 2-surface is now only 2-dimensional and the dimension of η would be $1\hbar/L$ in this case. In the kinetic gas theory formula this follows from the fact that mass density has now dimension m/L rather than m/L^3. The summation over the partonic 2-surfaces could correspond in many particle system integration. I tend to see this kind of approach as too formal.

AdS/CFT duality [B22] reduces the calculation of the viscosity to that for the graviton absorption cross section for $AdS_5 \times S_5$ black hole when the N-stack of branes is replaced with a brane black hole in $AdS_5 \times S^5$. Viscosity is is reduced essentially to the area of the black-hole multiplied by Planck constant. Since the dimension of 4-D viscosity is $\hbar/L^3$, the area must be measured using Planck length squared G as a unit. Is viscosity the number density multiplied by this dimensionless quantity? I must admit that I do not really understand this result.

10.5.2 What is known about quark-gluon plasma?

Son sums up some facts about quark-gluon plasma and they are included in the following summary about what little I know.

(a) The first surprise was produced by RHIC observing that the viscosity to entropy density ratio for quark gluon plasma is near $\hbar/4\pi$ -its lower limit as predicted by AdS/CFT duality. The low value of η/s ratio does not mean that the viscosity would be low. As a matter fact it is gigantic - of order 10^{14} centipoise and therefore 14 orders of magnitude higher than for water! Glass is the the only condensed matter system possessing a higher viscosity in the list of Son. The challenge is to understand why the ratio is so small in terms of QCD or perhaps a theory transcending the limitations of QCD at low energies. From Kubo's formula it is clear that the low energy limit of QCD is indeed needed to understand the viscosity.

(b) In the nuclear collisions allowing to deduce information about viscosity the nuclei do not collide quite head on. The time of collision is short due to the Lorentz contraction. The projection of the collision region in the plane orthogonal to the collision axes is almond shaped so that rotational symmetry is lost and implies that viscous forces enters the game. If the system reaches thermal equilibrium, the notion of pressure make senses. The force caused by the pressure gradient is stronger in transversal than longitudinal direction of almond since the almond in transversal direction is shorter than in longitudinal direction. That jets in this direction are more energetic supports the view that pressure is a well-defined concept. On the other hand, the viscous force in the longitudinal direction is large and tends to compensate this effect. This effect gives hopes of measuring the viscosity.

(c) η/s ratio seems to be near $\hbar/4\pi$ for the quark-gluon plasma formed in both heavy ion collisions and in proton-proton collisions although the energy scales are quite different. This is not expected on basis of the strong temperature dependence of viscosity in condensed matter systems.

(d) On basis of RHIC results [C22, C152] for heavy ion collisions and the LHC results for proton-proton collisions, which unexpectedly demonstrated similar plasma behavior for proton-proton collisions one can conclude that quark gluon plasma is a strongly interacting system. The temperature assignable to the quark-gluon plasma possibly formed in proton-proton collisions is of course must higher than at RHIC. Recently also the results from lead-lead collisions at LHC have emerged: the temperature of the plasma should be about 500 MeV as compared to the temperature 250 MeV at RHIC. In this case AdS/CFT duality gives hopes for describing the non-perturbative aspects of the system. This is just a hope: AdS/CFT correspondence requires many assumptions which might not hold true for the quark-gluon plasma and there are preliminary indications [C160], which do not support AdS/CFT duality [C2, C3]. The experiments favor a model in which the situation is described based old-fashioned Lund model [C15] treating gluons as strings. This description is a a simplified version of the description provided by TGD.

10.5.3 Gauge-gravity duality in TGD framework

AdS/CFT duality is one variant of a more general gauge-gravity duality. Gauge-gravity in turn involves several variants depending on whether one assumes that Einstein's curvature scalar provides a good approximation to the description of gravitational sector. This requires that higher spin excitations of string like objects are very heavy and can be neglected. It might be that since low energy limit is in question as is clear from Kubo's formula, the use of Einstein's action makes sense very generally.

String-gauge theory duality in TGD framework

If I were enemy of string theory and follower of the usual habits of my species, I would be very skeptic from the beginning. There are however no rational reasons to be hostile since string worlds sheets at 4-D space time sheets appear also in TGD and there very strong reasons to expect duality between QFT like descriptions and stringy description. I indeed discussed in previous section how this duality can be understood directly at the level of generalized Feynman diagrams as a kind of combinatorial identity. There is no need to introduce strings in $AdS_5 \times S^5$ as in the usual AdS/CFT approach and $N_c \rightarrow \infty$ implying the vanishing of the contribution of non-planar Feynman diagrams is not needed.

The reduction to Einsteinian gravity need not take place

String-gauge theory duality need not reduce QCD to Einsteinian gravity allowing modelling in terms of curvature scalar.

(a) In TGD framework the physics for small deformations of vacuum extremals - whose number is gigantic (any Lagrangian sub-manifold of CP_2 defines a vacuum sector of the theory) - would be governed by Einstein's equations. The value of gravitational constant is however dynamical and a little dimensional analysis argument suggests that the gravitational constant satisfies [K45]

$$G_{eff}(p) = L^2(k)exp(-2S_K) \ ,$$

where L_p is p-adic length scales associated with p-adic prime $p \simeq 2^k$ and S_K is the Kähler action for a deformation of CP_2 type vacuum extremal in general smaller than for full CP_2.

(b) Ordinary gravitational constant would correspond to $p = M_{127} = 2^{127} - 1$ assignable to electron: M_{127} is the largest Mersenne prime which does not define a completely super-astrophysical p-adic length scale. The value of S_K would be almost maximal and induce an enormous reduction of the value of G.

(c) For hadron physics S_K should not be large and in reasonable approximation this would give $G_{eff} \simeq \hbar L^2(k = 107)$. The deformations of CP_2 type vacuum extremals, whose M^4 projections are random light-like curves. are assignable to elementary particles such as gluons. In the case of hadrons these projections are expected to be short and so that the exponent is expected to be near unity. One might hope that these contributions dominate in the calculation of viscosity so that Einstein's picture indeed works.

(d) In the case of hadron physics there are no strong reason to expect a general reduction to Einsteinian gravity. Higher spin states at the hadronic Regge trajectories are important and hadron physics does not reduce to gravitational theory involving the exchanges of only spin two strong gravitons.

This requires additional assumption which the lecture of Son tried to clarify. The assumption is that the coordinate of AdS_5 orthogonal to its boundary M^4 representing 4-D Minkowski space represents scaling of the physical system and that the interactions in the bulk are ultra-local with respect to this coordinate. Only systems with same scale size interact. This assumption looks very strange to me but has analog in quantum TGD. Personally I would take this argument with a big grain of salt.

Reduction to hydrodynamics

The AdS$_5$/CFT duality in the strong form reduces the dynamics at the boundary of AdS_5 to Einstein's gravity in the interior of AdS and the N-stack of 3-branes corresponds to brane black-hole in $AdS_5 \times S_5$. There are also good reasons to expect that Einstein's gravity in turn reduces to hydrodynamics.

The field equations of TGD are conservation laws for isometry currents and Kähler currents plus their super counterparts. Also in hydrodynamics the basic equations reduce to conservation laws. The structural equations of hydrodynamics correspond to the identification of gauge fields and metrics as induced structures.

The reduction to 4-D hydrodynamics in much stronger sense is suggestive since a large class of preferred extremals of Kähler action have interpretation as hydrodynamic flows for which flow lines define coordinate curves of a global coordinate [K23]. Beltrami flows are in question. For instance, a magnetic field for which Lorentz force vanishes is a good example of 3-D Beltrami flow. There are good arguments in favor of the existence of a unique preferred coordinate system defined in terms of light-like local direction and its dual direction plus two orthogonal local polarization directions.

Could AdS/CFT duality have some interpretation in TGD framework?

In TGD framework the duality between strings and particles replacing AdS/CFT duality means the replacement of $AdS \times S_5$ with space-time surface represented as surface in $M^4 \times CP_2$. Furthermore M^4 is replaced with partonic 2-surfaces the super-conformal invariance of $\mathcal{N} = 4$ SUSY in M^4 is replaces with 2-D super-conformal invariance. Therefore the attempts to build analogies with AdS/CFT duality type description might be waste of time. The temptation for the search of analogies is however too high.

In the case of AdS/CFT duality for Minkowski space that coordinate of AdS_5 orthogonal to its M^4 boundary is interpreted as a scale parameter for the system and also has interpretation as a scalar field in M^4. Could this scaling degree have some sensible interpretation in TGD framework. What about the N-stack of 3-branes representing a copy of M^4 identified as the boundary of AdS_5?

(a) In TGD framework the only physically sensible interpretation would be in terms of the hierarchy of Planck constants [K22]. The quantum size of the particle scales like $\hbar$ and is therefore integer valued. This suggests that the continuous AdS_5 coordinate orthogonal to M^4 could be replaced with the integer labeling the effective values of Planck constant and hence the local coverings of $M^4 \times CP_2$ providing a convenient description for the fact that -due to the enormous vacuum degeneracy of Kähler action- the time derivatives of the imbedding space coordinates are multi-valued functions of the canonical momentum densities. Different coverings that they effectively correspond to different sectors of the effective imbedding space which can be seen as a finite covering of $M^4 \times CP_2$. Only the particles with the same value of Planck constant can appear in the same vertex of generalized Feynman diagrams and this is nothing but the strange assumption made to guarantee the locality of AdS dynamics.

(b) Same collapse of the sheets of the covering actually applies in the directions transversal to space-like and light-like 3-surfaces so that both of them represent branchings and the total number of branches in the interior os $n_1 n_2$.

(c) One must assume that the sheets of the covering collapse at the partonic 2-surfaces and perhaps also at the string world sheets. This strange orbifold property brings strongly in mind the stack of N-branes which collapse to single 3 brane however remembering its N-stack property: for instance, a dynamical gauge group $SU(N)\times U(1)$ describing finite measurement resolution emerges. The loss of the infinitely thin stack property in the interior guarantees that N-stack property is not forgotten. I have indeed proposed that similar emergence of gauge groups allowing to represent finite measurement resolution in terms of gauge symmetry emerges also in TGD framework.

(d) The effective dimensionless coupling in the perturbative expansion is $g^2N/\hbar$ and for large N limit the series does not converge. If N corresponds to the number of colors for dynamically generated gauge group labeling colors, the substitution $\hbar = N\hbar_0$ however implies that the expansion parameter does not change at all so that the limit would be different from the usual $N \rightarrow \infty$ limit used to derive AdS/CFT duality.

An integrable QFT in M^2 identified as hyper-complex plane in number theoretic vision is necessary for interpreting generalized Feynman diagrams as generalized braids. One can of course ask whether one would have super-conformal QFT in M^2 and wheter AdS_3 could be replaced with its discrete version with normal coordinate identified as the integer characterizing the value of Planck constant. To me this approach seems highly artificial although it might make sense formally.

One can of course ask whether $M^4 \times CP_2$ could have some deep connection with $AdS_5 \times S_5$. This might be the case: CP_2 is obtained from S^5 by identifying all points of its geodesic circles and M^4 is obtained from AdS_5 by identifying all points of radial geodesics in the the scaling direction.

Do black-holes in $AdS_5 \times S_5$ have TGD counterpart?

The black-holes in $AdS_5 \times S_5$ have very natural counterparts as regions of the space-time surfaces with Euclidian signature of the induced metric. These regions represent generalized Feynman diagrams. By holography one could restrict the consideration also to the partonic 2-surfaces at the ends of CDs and if string world sheets and partonic 2-surfaces are dual to string world sheets coming as Minkowskian and Euclidian variants.

Black-holes in TGD framework would have Euclidian metric and their presence is absolutely essential for reducing the functional integral to a genuine integral. Otherwise one would have the analog of path integral with the exponential of Kähler action defining a mere phase factor.

The entropy area law for the black-holes generalizes to p-adic thermodynamics and the p-adic mass squared value for the particle predicted by p-adic thermodynamics is essentially the p-adic entropy: both are mapped to the real sector by canonical identification. Also the black hole entropy is proportional to mass squared.

The gigantic value of the gravitational Planck constants brings in additional interpretational issues to be discussed later.

10.5.4 TGD view about strongly interacting quark gluon plasma

The magnetic flux tubes/strings connecting quarks make the QCD plasma strongly interacting in TGD framework.

(a) In the hadronic phase the network formed by these flux tubes decomposes to sub-networks assignable to the colliding protons. In the final state the sub-networks are associated with the outgoing hadrons. In the collision a network is formed in which the flux tubes can connect larger number of quarks and one obtains much longer cycles in the network as in the initial and final states. This can be regarded as a defining property of strongly interaction quark gluon plasma. In quantum world one obtains a quantum superposition over networks with different connectedness structures. The quark-gluon plasma is not ideal in quantum sense.

(b) The presence of plasma blob predicts the reduction of jet production cross section. Typically a pair of jets is produced. If this occurs in deep interior of the plasma, the jets cannot escape the plasma. If this occurs near the surface of the plasma, the other jet escapes. This predicts reduction of the jet production cross section.

(c) The decomposition to connected flux tube networks could explain why the experimentally detected ratio for jet production cross section nucleonic total scattering cross section is larger than the predicted one: the flux tube network would consist of disconnected network with a considerably property and for these the jet production cross section would not be so dramatically reduced by the fact that the other member of the never gets out from the plasma blob.

In TGD context the basic process leading to the formation of the quark-gluon plasma is reconnection for the flux tubes describable in terms of string diagrams $AB-CD \rightarrow AD+BC$. In the case of ordinary quark gluon plasma the density is so high that nucleons overlap geometrically and lead to the formation of the plasma. In TGD framework the magnetic bodies of quarks having size scale characterized by quark Compton length would overlap. The Compton lengths for light quarks with masses estimated to be of order 10 MeV are much larger than the size scale of nucleon and even that of nucleus. What does this mean? Does the reconnection process take place in several scales so that the notion of quark gluon plasma would be fractal? Note that in the recent proton-proton collisions the energy per nucleon is about 200 GeV. Does quark gluon plasma at LHC involve the fusion of the flux tubes of the color magnetic bodies of nucleons? Do these form connected structures.

In the kinetic gas theory viscous force in the system of parallel plates is caused by the diffusion of particles moving with velocity u which depends on the coordinate orthogonal to the parallel plates. One can imagine a fictive plane through which the particles diffuse in both directions and the forces is due to that fact that the diffusing particles have different velocities differing by $\Delta u_x = \partial_y u_x l_{free}$ on the average. In the case of magnetic flux tubes the presence of magnetic flux tube connection the two quarks at the opposite sides of the fictive plane leads to a stretching of the flux tube and this costs energy. This favors the diffusion of either quark to the other side of the fictive plane and this induces the transformed of momentum parallel to the plates. Similar argument could apply also in the case of the ordinary liquids if one allows also electric flux tubes.

Jets and flux tubes structures

Magnetic flux tube provide also a more concrete vision about the notion of jet.

(a) Jets are collinear particle like objects producing collinear hadrons. The precise definition of jets is however problematic in QCD framework. TGD suggests a more precise definition of jets as connected sub-networks formed by partons and by definition having vanishing total Kähler magnetic charge. Jet would be kind of super-hadron which decays to ordinary nearly collinear hadrons as the flux tube structure decomposes by reconnection process to smaller connected flux tube structures during hadronization.

(b) Factorization theorems of QCD discussed in very clear manner by Ian Stewart [C170] state that the dynamics at widely different scales separate for each other so that quantum mechanical interference effects can be neglected and probabilistic description applies in long length scales and quantal effects reduce to non-perturbative ones. The initial and final stages of the collision process proceed slowly as compared to those describable in terms of perturbative QCD. Hence one can apply partonic distribution functions and fragmentation functions. These functions should have a description in terms of reconnection process.

(c) The presence of different scales means in TGD framework to p-adic length scale hierarchy assignable to flux tubes gives a much more precise articulation for the notion of scale. No quantum interference effects can take place between different p-adic scales if the real amplitudes are obtained from p-adic valued amplitudes by the generalization of canonical identification discussed in [K76]. For instance, in p-adic mass calculations the values p-adic mass squared are summed for for given p-adic prime before the mapping to real mass squared by canonical identification. For different values of p-adic primes the additive quantities are the real masses.

Possible generalizations of Maxwell's formula formula for the viscosity

Could one understand the viscosity if one assumes that the reconnection of the magnetic flux tubes replaces the collisions of particles in the kinetic theory of gases? One can imagine several alternatives.

(a) The free path of the particle appears in the kinetic gas theory estimate $\eta = nmvl_{free}$ for the viscosity. If this decomposition makes sense now, l_{free} should correspond to the size scale of the magnetic body of light quark and if its size corresponds to the Compton length of the quark one would have $l_{free} \sim \hbar/m$. If one assumes $s \sim n$ one has $\eta = nv\hbar$. For $v = c = 1$ this would give $\eta/s \sim \hbar/4\pi$ apart from numerical constant.

If $\hbar$ indeed appears in l_{free} and the magnetic flux tube size scales as $\hbar$, the minimum value for the viscosity would scale as $\hbar$. It is difficult to say whether one should regard this as good or bad prediction from the point of view of the hierarchy of Planck constants. Over-optimistically one might ask whether large $\hbar$ could explain the non-minimal values of η/s in terms of large $\hbar$. Note however that the minimal value of η/s can be smaller than $\hbar/4\pi$ in some systems.

(b) One could consider the replacement of the Compton length $r_C = \hbar/m_q$ with the classical charge radius of quark defined as $r_{cl} = g^2/m_q$. In this case the size scale of the magnetic body would not depend on $\hbar$. For color coupling strength $\alpha_s = .1$ one would have $r_{cl}/r_C = 1.26$ so that experimental data do not allow to distinguish between these options. At low energies r_{cl} would grow and therefore also the viscosity since the lengths of flux tubes would get longer.

(c) One can also purely gravitational view about single partonic 2-surface. Taking the notion of gravitational Planck constant seriously [K59], one can consider the replacement of v with the velocity parameter v_0 (dimensionless in the units used) appearing in the gravitational Planck constant $\hbar_{gr} = G_{eff}M^2/v_0$ and the identification $l_{free} = 2r_S = 4G_{eff}M$: the diameter of the black hole identified as partonic 2-surface. Note that Schwartchild radius would be equal to Planck length. Entropy would be given $4\pi(2G_{eff}M)^2/\hbar G_{eff}$ multiplied by the number $N = \hbar/\hbar_0$ of the sheets of the covering. This would give the lower bound $\hbar_0 v_0/4\pi$ which is smaller than that provided by AdS/CFT approach. This option looks the most attractive one.

For all three options one would expect that η/s ratio is same for the quark-gluon plasma formed in heavy ion collisions and in proton-proton collisions. The critical reader probably wonders what one means with the entropy in the strongly interacting system. Magnetic flux tubes could be seen as space-time correlates for entanglement. Can one regard the entropy as a single particle observable? Can one assign to each partonic 2-surfaces an entanglement entropy or does the entropy characterizes pairs of parton surfaces being analogous to potential energy rather than kinetic energy?

The formula for viscosity based on black-hole analogy

The following argument is a longer version of very concise argument of previous section suggesting that the notion of gravitational Planck constant allows to generalize the formula of the kinetic gas theory to give viscosity in the more general case. Partonic 2-surface is regarded as an analog the horizon of a black-hole. The interior of the black-hole corresponds to a region with an Euclidian signature of the induced metric. The space-time metric in question could be either the induced metric or the effective metric defined by the modified gamma matrices defined by Kähler action [K23]. Induced metric seems to be the correct option since it is non-trivial for vacuum extremals of Kähler action but also the effective metric probably has physical meaning. Only the data at horizon having by definition degenerate four-metric appear in the formula for η/s.

(a) The notion of gravitational Planck constant for space-time sheets carrying self gravitational interaction is given by $\hbar_{gr} = kGM^2/v_0$, where $v_0 < c = 1$ has dimensions of velocity. The interpretation is in terms of Planck constant assignable with flux tubes mediating self gravitation and carrying dark energy identified as magnetic energy. The enormous value of Planck constant means cosmological quantum coherence explaining why this energy density is very slow varying and can be therefore described in terms of cosmological constant in good approximation. Negative "pressure" corresponds to magnetic tension.

(b) Suppose that v_0 is identified as the velocity appearing as typical velocity in the kinetic theory estimate $\eta = Mnvl_{free}$. Suppose that l_{free} corresponds to Schwartschild radius for the effective gravitational constant $l_{free} = 2r_s = 4G_{eff}M$. Another possible identification is as the scaled up Planck length $l_{free} = l_P = \sqrt{\hbar G} = GM/\sqrt{v_0}$. Suppose that the formula for black hole entropy holds true and gives for the entropy of single particle the expression $S = 4\pi(2G_{eff}M)^2/\hbar G_{eff}$. This gives $\eta/s = \hbar v_0/4\pi$ for the first option (note that v_0 dependence disappears. One obtains $\eta/s = \hbar/16\pi\sqrt{v_0}$ for the second option so that v_0 dependence remains.

(c) The objection is that black hole entropy goes to zero as $\hbar$ increases. One can indeed argue that the $S = 4\pi(2G_{eff}M)^2/\hbar G_{eff}$ gives only the contribution of single sheet in the $N = hbar/\hbar_0$ fold covering of $M^4 \times CP_2$ so that one must multiply this entropy with N. This would give

$$\frac{\eta}{S} = \frac{\hbar_0}{4\pi} \times \frac{v_0}{c} \ .$$

The minimum viscosity can be smaller than $\hbar_0/4\pi$ and the essential parameter is the velocity parameter $v_0 = v_0 < c = 1$. This is true also in AdS-CFT correspondence.

This argument suggests that the Einsteinian dark gravity with gravitational gauge coupling having as parameters p-adic length scale and the typical Kähler action of deformed CP_2 type vacuum extremal could allow to understand viscosity in terms of string-QFT duality in the idealization that the situation reduces to a black-hole physics with partonic 2-surfaces taking the role of black holes. This proposal might make even in the case of condensed matter if one one gives up the assumption that the basic objects are more analogous to stars than black-holes.

10.5.5 AdS/CFT is not favored by LHC

As already noticed that the first experimental results from LHC [C160] do not favor AdS/CFT duality but are qualitatively consistent with TGD view about gauge-gravity duality. Because of the importance of the results I add a version of my blog posting [C3] about these results.

Sabine Hossenfelder told in BackReaction blog about the first results from lead-lead ion collisions at LHC, which have caused a cold shower for AdS/CFT enthusiasts. Or summarizing it in the words of Sabine Hossenfelder:

As the saying goes, a picture speaks a thousand words, but since links and image sources have a tendency to deteriorate over time, let me spell it out for you: The AdS/CFT scaling does not agree with the data at all.

The results

The basic message is that AdS/CFT fails to explain the heavy ion collision data about jets at LHC. The model should be able to predict how partons lose their momentum in quark gluon plasma assumed to be formed by the colliding heavy nuclei. The situation is of course not simple. Plasma corresponds to low energy QCD and strong coupling and is characterized by temperature. Therefore it could allow description in terms of AdS/CFT duality allowing to treat strong coupling phase. Quarks themselves have a high transversal momentum and perturbative QCD applies to them. One has to understand how plasma affects the behavior of partons. This boils to simple question: What is the energy loss of the jet in plasma before it hadronizes.

The prediction of AdS/CFT approach is a scaling law for the energy loss $E \propto L^3T$, where L is the length that parton travels through the plasma and the temperature T is about 500 MeV is the temperatures of the plasma (at RHIC it was about 350 MeV). The figure in the posting of Sabine Hossenfelder [C2] compares the prediction for the ratio R_{AA} of the predicted nuclear cross section for jets in lead-lead collisions to those in proton-proton collisions to experimental data normalized in such a manner that if the nucleus behaved like a collection of independent nucleons the ratio would be equal to one.

That the prediction for R_{AA} is too small is not so bad a problem: the real problem is that the curve has quite different shape than the curve representing the experimental data. In the real situation R_{AA} as a function of the average transversal momentum p_T of the jets approaches faster to the "nucleus as a collection of independent nucleons" situation than predicted by AdS/CFT approach. Both perturbative QCD and AdS/CFT based model fail badly: their predictions do not actually differ much.

An imaginative theoretician can of course invent a lot of excuses. It might be that the number $N_c = 3$ of quark colors is not large enough so that strong coupling expansion and AdS/CFT fails. Supersymmetry and conformal invariance actually fail. Maybe the plasma temperature is too high (higher that at RHIC where the observed low viscocity of gluon plasma motivated AdS/CFT approach). The presence of both weak coupling regime (high energy partons) and strong coupling regime (the plasma) might have not been treated correctly. One could also defend AdS/CFT by saying that maybe one should take into account higher stringy corrections for strings moving in 10 dimensional $AdS_5 \times S^5$. Why not branes? Why not black holes? And so on....

Could the space-time be 4-dimensional after all?

What is remarkable that a model called "Yet another Jet Energy-loss Model" (YaJEM) based on the simple old Lund model [C15] treating gluons as strings in 4-D space-time works best! Also the parameters derived for RHIC do not need large re-adjustment at LHC.

4-D space-time has been out of fashion for decades and now every-one well-informed theoretician talks about emergent space-time. Don't ask what this means. Despite my attempts to understand I (and very probably any-one) do not have a slightest idea. What I know is that string world sheets are 2-dimensional and the only hope to get 4-D space-time is by this magic phenomenon of emergence. In other worlds, 3-brane is what is wanted and it should emerge "non-perturbatively" (do not ask what *this* means!).

Since there are no stringy authorities nearby, I however dare to raise a heretic question. Could it be that string like objects in 4-D space-time are indeed the natural description? Could strings, branes, blackholes, etc. in 10-D space-time be completely un-necessary stuff needed to keep several generations of misled theoreticians busy? Why not to to start by trying to build abstraction from something which works? Why not start from Lund model or hadronic string model and generalize it?

This is what TGD indeed was when it emerged some day in October year 1977: a generalization of the hadronic string model by replacing string world sheets with space-time sheets. Another motivation for TGD was as a solution to the energy problem of GRT. In this framework the notion of (color) magnetic flux tubes emerges naturally and magnetic flux tubes are one of the basic structures of the theory now applied in all length scales. The improved mathematical understanding of the theory has led to notions like effective 2-dimensionality and stringy worlds sheets and partonic 2-surfaces at 4-D space-time surface of $M^4 \times CP_2$ as basic structures of the theory.

What TGD can say about the situation?

In TGD framework a naive interpretation for LHC results would be that the colliding nuclei do not form a complete plasma and this non-ideality becomes stronger as p_T increases. As if for higher p_T the parton would traverse several blobs rather than only single big one and situation would be between an ideal plasma and to that in which nucleus form collections of independent nucleons. Could quantum superposition of states with each of them representing a collection of some number of plasma blobs consisting of several nucleons be in question. Single plasma blob would correspond to the ideal situation. This picture would conform with the vision about color magnetic flux tubes as a source of long range correlations implying that what is called quark-gluon plasma is in the ideal case like single very large hadron and thus a diametrical opposite for parton gas.

In TGD framework where hadrons themselves correspond to space-time sheets, this interpretation is suggestive. The increase of the temperature of the plasma corresponds to the reduction of α_s suggesting that with at T=500 GeV at LHC the plasma is more "blobby" than at T=350 GeV at RHIC. This would conform with the fact that at lower temperature at RHIC the AdS/CFT model works better. Note however that at RHIC the model parameters for AdS/CFT are very different from those at LHC [C2]: not a good sign at all.

I have also discussed the TGD based explanation of RHIC results for heavy ion collisions and the unexpected behavior of quark-gluon plasma in proton-proton (rather than heavy ion) collisions at LHC [K38].

10.6 Breaking of discrete symmetries

Zero energy ontology provides a fresh approach to the rather poorly understood breaking patterns of discrete symmetries. In the following TGD based vision about breaking of discrete symmetries is discussed and some examples are considered. The old quantitative model for anomalously large CP breaking in kaon-antikaon system is in need of updating and is left to a separate section.

10.6.1 Experimental inputs

There are several findings which do not fit with the picture about the breaking of discrete symmetries provided by standard model.

(a) The large parity breaking in living matter manifesting itself as chiral selection remains a mystery in standard model framework. In TGD framework the possibility of classical weak fields in macroscopic scales combined with the hierarchy of Planck constants suggests a solution of this parity breaking and also a connection with the breaking of matter antimatter asymmetry is suggestive.

(b) KTeV collaboration in Fermilab [C93] has measured the parameter $|\epsilon'/\epsilon|$ characterizing the size of the direct CP violation in the decays of kaons to two pions. The value of the parameter was found to be $|\epsilon'/\epsilon| = (2.8 \pm .1)10^{-3}$ and is almost by an order of magnitude larger than the naive standard model expectations based on the hypothesis that direct CP breaking is induced by CKM matrix. In [C181] it was shown that the value of the parameter could be understood without introducing any new physics if the value of running strange quark mass at m_c is about $m_s(m_c) = .1$ GeV and $m_d << m_s$ holds true.

(c) During year 2010 also large CP breaking in$B - \overline{B}$ system was reported by D0 collaboration [C70].The claimed symmetry breaking is about 50 times larger than the breaking predicted by the standard model, and manifests itself as an asymmetry in the production of $\mu^+\mu^+$and $\mu^-\mu^-$pairs in the decays producing $B^0\overline{B}^0$ pairs. The asymmetry is due to the oscillations between almost mass degenerate states B^0 and $\overline{B}^0$. It is the mass difference which is much larger than predicted one.

There has been also claims for the breaking of CPT symmetry which is regarded as cherished in Lorentz invariant quantum field theories,

(a) There are indications that the mixing is different for muonic neutrinos and antineutrinos [C85, C17, C79] meaning that the masses of neutrino and antineutrino are different. In TGD framework a possible explanation is obtained by assuming different p-adic length scales for neutrinos and antineutrinos in turn dictated by the interactions with environment which could be different for neutrinos and antineutrinos by the nature of measurement apparatus used to detect them. Hence a spontaneous breaking induced by environment could be in question [K37].

    Remark: The improved analysis of MINOS collaboration using larger statistics than half year ago has led to the evaporation of the evidence for different masses for muonic neutrinos and antineutrinos [?] The values for Δm^2 and mixing angle parameter $sin^2(2\theta)$ for muonic antineutrino are consistent with the values of these parameters for the muonic neutrino.

(b) 2 sigma evidence for a gigantic CPT breaking in top-antitop system have been claimed. *Measurement of the mass difference between t and $\bar{t}$ quarks* [C56] is the title of the e-print by a group working in Fermilab. The finding of the group is that $t-\bar{t}$ mass difference is

$$\Delta M = M_t - M_{\bar{t}} = -3.3 \pm 1.7 \text{ GeV} .$$

    The best fit is obtained with

$$\Delta M = -4 \ GeV .$$

    For top quark mass M_t= 170 GeV this means $\Delta M/M \simeq 2.3$ per cent and is the scale for electromagnetic mass splittings. The result deviates from CPT-symmetric expectation $\Delta M = 0$ at 2σ level. Also D0 collaboration has reportded similar results two years earlier (PRL 103, 132001 (2009)) but at time the errors bars were so large that the finding was consistent with CPT symmetry. The last twist in the story is the eprint of D0 collaboration reporting that the value of the mass difference is consistent with zero [C71]. The huge value of the CPT breaking suggest for a conservative mind that the issue is settled. At this time I will adopt the conservative approach.

(c) The findings encourage to consider the possibility of CPT breaking seriously [B15, B3] . In TGD framework a very strong form of apparent CPT breaking results if fermion and anti-fermion correspond to different values of p-adic prime so that mass scales differ by a multiple of half octave. The different choices of the p-adic mass scale would be induced by the interaction with environment. This option might explain the observations suggesting that neutrino and antineutrino masses and mixing matrices are different without introducing sterile neutrino: sterile neutrino would correspond to neutrino but in different p-adic length scale. In the recent case this option is excluded by the smallness of the mass difference. In zero energy ontology, which assigns to elementary particles size scale which which is macroscopic, one can however consider a more delicate breaking of CPT induced by the interactions with environment.

If one takes conservative attitude only the anomalously large CP breaking in B-Bbar system remains to be explained.

10.6.2 Discrete symmetries in zero energy ontology

Discrete symmetries C,P,T, CP, and even CPT are not too well-understood in standard model and zero energy ontology combined with the various experimental inputs (many of them still uncertain) leads to a vision about the breaking of discrete symmetries in TGD Universe.

Years after writing this section, the development of detailed view about basic action principle behind TGD led to the realization that CP and T breaking emerges at fundamental level in

TGD. The basic variational principle involves Kähler action and Kähler-Dirac action. In order to obtain non-trivial fermionic propagators at the boundaries of string world sheets carrying fermions one must add to the Kähler action Chern-Simons term located at partonic orbits defined as 3-surfaces at which the signature of the induced metric changes from Minkowskian to Euclidian. By supersymmetry one must add to Kähler-Dirac action Chern-Simons Dirac term. These terms breaks CP and T explicitly and in principle could explain the CP breaking occurring for CKM matrix and also matter antimatter asymmetry.

CP breaking and ground state degeneracy

CP breaking and ground state degeneracy

The Minkowskian contribution of Kähler action is imaginary due to the negativity of the metric determinant and gives a phase factor to vacuum functional reducing to Chern-Simons terms at wormhole throats. Ground state degeneracy due to the possibility of having both signs for Minkowskian contribution to the exponent of vacuum functional provides a general view about the description of CP breaking in TGD framework.

(a) In TGD framework path integral is replaced by inner product involving integral over WCV. The vacuum functional and its conjugate are associated with the states in the inner product so that the phases of vacuum functionals cancel if only one sign for the phase is allowed. Minkowskian contribution would have no physical significance. This of course cannot be the case. The ground state is actually degenerate corresponding to the phase factor and its complex conjugate since $\sqrt{g}$ can have two signs in Minkowskian regions. Therefore the inner products between states associated with the two ground states define 2×2 matrix and non-diagonal elements contain interference terms due to the presence of the phase factor. At the limit of full CP_2 type vacuum extremal the two ground states would reduce to each other and the determinant of the matrix would vanish.

(b) A small mixing of the two ground states would give rise to CP breaking and the first principle description of CP breaking in systems like $K-\overline{K}$ and of CKM matrix should reduce to this mixing. K^0 mesons would be CP even and odd states in the first approximation and correspond to the sum and difference of the ground states. Small mixing would be present having exponential sensitivity to the actions of CP_2 type extremals representing wormhole throats. This might allow to understand qualitatively why the mixing is about 50 times larger than expected for B^0 mesons.

(c) There is a strong temptation to assign the two ground states with two possible arrows of geometric time. At the level of M-matrix the two arrows would correspond to state preparation at either upper or lower boundary of CD. Do long- and shortlived neutral K mesons correspond to almost fifty-fifty orthogonal superpositions for the two arrow of geometric time or almost completely to a fixed arrow of time induced by environment? Is the dominant part of the arrow same for both or is it opposite for long and short-lived neutral measons? Different lifetimes would suggest that the arrow must be the same and apart from small leakage that induced by environment. CP breaking would be induced by the fact that CP is performed only K^0 but not for the environment in the construction of states. One can probably imagine also alternative interpretations.

What CPT and CPT breaking do mean?

To begin, recall that CPT breaking would mean that the invariance condition

$$P(\Psi_i, \Psi_f) = P(\theta\Psi_f, \theta\Psi_i) \tag{10.6.1}$$

for probabilities fails to be satisfied. Here θ is a shorthand for CPT. The permutation of initial and final states is what distinguishes T and thus CPT from ordinary symmetries and means that T must be realized anti-linearly. In standard QFT P and T have geometric meaning whereas C does not. In TGD framework also C is geometric and this means that one must reconsider CPT and its tests based on phenomenological models.

CPT symmetry is one of the basic tenets of quantum field theory. In particular, the breaking of CPT requires the breaking of Lorentz invariance in standard QFT framework. In TGD framework the situation is actually different as I realized only now! The reason is that also charge conjugation is induced by a geometric transformation just like P and T. C indeed involves complex conjugation of CP_2 coordinates, and one can quite well consider a situation in with T and P are unbroken and only C is broken so that CPT is broken. What actually happens depends on the detailed action of the symmetries on the modified Dirac action.

Some factd about zero energy ontology

Before one one can proceed, one must consider in more detail the notion of CD. CD is a product of CD proper defined as intersection of future and past directed light-cones of M^4 and of CP_2. The scales of CDs are assumed to come in powers of two of CP_2 scale to explain p-adic length scale hypothesis (one can consider also prime and even integer multiples). What is of utmost significance is that these scales are macroscopic. Poincare transformations affect CDs and give rise to a moduli space for CDs. In the case of CP_2 this is not the case unless one introduces additional physically well motivated structure.

Quite generally, this additional structure corresponds to the choice choice of quantization axes for various isometry currents realized at the level of the geometry of world of classical worlds which decomposes to a union of the geometries assigned with difference CDs labelled by moduli specifying the choice of quantization axes. In the case of M^4 the line joining the tips of CD defines a unique rest system with origin at the middle point of the line and selects quantization axes of energy. The direction of spin quantization axes is fixed if one introduces preferred plane M^2 physically analogous to the preferred plane of unphysical polarizations. This plane is fixed also by number theoretical vision and correspond to hyper-octonionic plane of complexified octonions highly relevant for the number theoretic formulation of TGD.

One must also introduce CP_2 coordinates transforming linearly with respect to U(2) subgroup. The choice of preferred point of CP_2 at either boundary of CD allows to fix complex coordinates of CP_2 only apart from U(2) rotation. Hyper-charge quantization axes is fixed but color isospin direction remains free. In fact, there is a preferred color isospin generator leaving the points of the geodesic sphere invariant whereas hypercharge generator induces phase multiplication. By choosing two preferred points of CP_2 assigned to the opposite boundaries of CD one can identify the geodesic line connecting the points as a flow line of color isospin rotations so that the quantization axes are fixed.

The choices of preferred plane M^2 and preferred geodesic sphere S^2 make sense also at the level of the preferred extremals of Kähler action and this leads to a concrete realization of the conjectured slicing of the space-time surface by string world sheets having braid strands at their ends at light-like wormhole throats carrying particle quantum numbers.

The vision about how quantum TGD gives rise to symplectic theory of knots, braids, braid cobordisms, and of two-knots [K30] (see also the blog posting) led to the realization that preferred extremals should involve preferred geodesic sphere of CP_2, whose inverse image under imbedding map assigns to the space-time surface unique complex of stringy two surfaces. These stringy two-surfaces define braid cobordisms and 2-knots and provide also the reduction of quantum TGD to string theory like structure in finite measurement resolution meaning the replacement of the orbits of partonic 2-surfaces with braids.

Charge conjugation is geometric in TGD framework

Charge conjugation in TGD Universe involves complex conjugation of CP_2 coordinates. Complex conjugation commutes with color rotations only if they belong to a subgroup $U(2) \subset SU(3)$ leaving a preferred point of CP_2 invariant remaining invariant also under

C just like the origin of M^4 remains invariant under P and T. The situation differs from that for P and T decisively since the scale of CP_2 is about 10^4 Planck lengths. More general color rotations acting non-linearly and affecting non-trivially on the preferred point do not commute with C.

A simple example is provided by sphere. In this case C would act in complex coordinates as $\phi \rightarrow -\phi$, where ϕ is the phase angle of the complex coordinate with origin at the preferred point of the sphere. The action obviously depends on the choice of the preferred point.

The situation is therefore same as for P and T which also fail to commute with Poincare group and commute only with Lorentz transformations leaving the selected space-time point fixed. In TGD framework this point would correspond naturally to the center of the line connecting the tips of the causal diamond proper.

The action of C on physical states involves a linear transformation of spinors transformation besides the geometric action. The details of this action were discussed already in my thesis for almost three decades ago and the reader can consult the appendix of some of the books about TGD or the little article titled The Geometry of CP_2 and its Relationship to Standard Model as the appendix of an article series summarizing Quantum TGD published in Prespace-time Journal. What is essential is that the action of C does does not commute with color rotations acting on the moduli of CD unless they belong to the U(2) subgroup leaving the geodesic sphere invariant. One can define C for the two boundaries of CD by requiring that the corresponding geodesic spheres remain invariant under C.

The action of CPT in zero energy ontology

The action of CPT is following.

(a) First one applies P and T. If one assumes that the preferred point of M^4 corresponds to the middle point of the line connecting the tips of CD proper, these transformations permute upper and lower boundaries of CD proper. This is indeed a very natural requirement and means that positive and negative energy parts of the quantum state serving as counterparts of initial and finals states in positive energy ontology are permuted just as they are permuted in CPT. That T is realized anti-linearly conforms with the fact that T does leave invariant the boundary of CD proper.

(b) Next one applies C involving complex conjugation which in general affects the moduli of CD. If C is chosen differently at the opposite boundaries it leaves the corresponding moduli invariant but since CPT involves the permutation of positive and negative energy states the moduli of CD are changed since the preferred point of upper boundary becomes the preferred point of the lower boundary and vice versa.

Only in the case that the preferred points assigned to the upper and lower boundaries are same, this does not happen but in this case the quantization axes are not completely fixed which could make sense only if color isospin of all particles or at least of the positive (and negative) energy part of the zero energy state vanishes. Unless the CD has a wave function in the space of moduli which is constant, a spontaneous and a purely geometric breaking of C symmetry is induced. The breaking would be highly analogous to the breaking of rotational symmetry in spontaneous magnetization taking place in many particle systems.

(c) The size scale of the CD proper is macroscopic even for elementary particles and corresponds to the secondary p-adic length scale associated with the particle. For electron with $p = M_{127} = 2^{127} - 1$ this time scale is $T(2,127) = .1$ seconds, defining the fundamental biological rhythm. For u and d quarks it is of order millisecond and for t quark characterized by $p \simeq 2^{93}$ it is given by

$$T(2,93)2^{-127+93} \times T(2,127) \simeq 5.8 \times 10^{-12} \ \text{seconds} \ .$$

The corresponding length scale is 1.74 mm and is macroscopic. There are very many particles in CD of this size scale which suggests the possibility of spontaneous C breaking inducing by a localization in the moduli space of CDs implying the breaking of the CPT invariance condition. The many-particle system would be present since the CDs assignable to individual quarks intersect which suggests that they correspond to common CD. The non-invariance of the many-particle system under CPT could also result from that under PT operation in macroscopic situation.

Building a quantitative picture about CPT breaking requires answering many questions. The mass difference should depend on the moduli of CDs characterizing color quantization axes and characterize by preferred points of CP_2 assigned with future and past boundaries of CD. A natural measure for the symmetry breaking is defined by the geodesic distance -call it s- between the preferred points so that one expects that the mass of a fermion assigned with a particular CD involves a small contribution depending on s. This distance is however not changed in C.

The additional contribution to the mass should contain a term which is odd under C (most naturally), CP, or CPT. Could the oddness come from the spontaneous symmetry breaking giving rise to an interaction term with environment affecting the mass of particle and antiparticle in different manner? This oddness would be analogous to the oddness of the interaction energy of magnetic dipole with an external magnetic field.

Questions

This picture inspires several questions.

(a) Can one consider C breaking without the presence of P and T breakings? If the CP breaking assigned with kaon-antikaon system and other neutral meson systems is CP breaking in TGD sense, does it involve the breaking of T at all? The answers to these questions are not obvious since the tests of discrete symmetries rely on the standard view about charge conjugation lacking totally the geometric aspect of C in TGD Universe.

(b) Could it be that the different topological mixings of U and D quarks inducing in turn CKM mixing are induced by C breaking basically so that the mass differences would correlate directly with CKM mixing parameters?

(c) Is the geometric view about about breaking of C relevant for the understanding of matter antimatter asymmetry? I have considered several models fro the generation of matter antimatter asymmetry, one of them assuming that antimatter is eaten by long cosmic strings with breaking induced by the Kähler electric fields inducing small difference in the densities of fermions and anti-fermions outside cosmic strings. Could matter antimatter asymmetry be mathematically analogous to chiral selection in living matter so that P would be only replaced with C? Whether the geometric view about C is relevant for the understanding of the matter antimatter asymmetry must be however left open question. Different masses for fermions anti-fermions could however help to understand why this kind of separation takes place.

(d) C acts in CP_2 and in color degrees of freedom. Does this mean that for non-colored states C is not broken and that CP breaking is present only for quarks but not for leptons? The answers to these questions are not obvious since in TGD framework $M^4 \times CP_2$ spinor harmonics correspond to color partial waves which have wrong correlation with electro-weak quantum numbers. Only covariantly constant right-handed neutrino spinor generating supersymmetry can move in color single partial wave. The physical color assignments are the result of a state construction involving super-conformal algebra with algebra elements carrying color.

10.6.3 An attempt to build a concrete model for the breaking of discrete symmetries

In the following a concrete proposal for the mechanism for the breaking of discrete symmetries is considered in the case of hadrons.

How zero energy ontology could help?

The experimental findings about breaking of CP and other discrete symmetries suggest that new physics is involved and zero energy ontology (ZEO) suggests what might be involved. In ZEO the notion of causal diamond (CD) is central. Causal diamonds form a fractal hierarchy with CDs within CDs. The most general assumption is that size scales of CDs come as integer multiples of CP_2 size scale. p-Adic length scale hypothesis would suggest that the integers correspond to powers of two but the recent construction of U-matrix allows and M-matrices leaves only integer multiples as the only mathematically elegant option [K15]. Discrete Lorentz boosts of CDs are allowed and the condition that the geometry of CDs represents symmetry breaking representing the choice of quantization axes implies rather rich moduli space for CDs.

One can say that the world of classical worlds decomposes into a union of WCWs associated with various CDs and that the choice quantization axes in quantum measurement implies a localization to a WCW with definite quantization axes. The geometry of CD breaks both Lorentz invariance and color symmetry although the entire WCW geometry is Poincare and color invariant.

In order to obtain non-trivial fermionic propagators one must add to Kähler-Dirac action Chern-Simons Dirac term at partonic orbits at which the signature of the induced metric changes. By super-symmetry one must add Chern-Simons term to Kähler action cancelling that the partonic Chern-simons terms so that only Chern-Simons terms localized at the space-like ends of the space-time surfaces survive. What is important that Chern-Simons and Chern-Simons-Dirac terms explicitly break CP and T symmetries and one can understand CP breaking at elementary particle level and has also hopes about understanding of matter antimatter asymmetry.

Even CPT could be broken since the breaking of Lorentz invariance necessary for CPT breaking takes place. If this mechanism is at work the secondary p-adic time scale characterizing the CD characterizing particle should characterize the energy and time scales of CP breaking. This is quite strong a prediction since in the existing models one must take CP breaking parameters as given and coded by the CKM matrix.

(a) In the case of $K-\overline{K}$ system the scale of the mass splitting comes out correctly: the scale for the mass difference between short and long lived kaons is about 10^{-6} eV and corresponds to the Mersenne prime M_{107} characterizing hadrons.

(b) For $B-\overline{B}$ the secondary p-adic length scale deduced from the mass difference of order 10^{-2} eV would however correspond to M_{89}, which suggests that M_{89} hadron physics is somehow involved. Could M_{89} hadrons appear in the loops giving rise to the symmetry breaking? This kind of difference between kaons and B mesons looks strange.

Zero energy ontology implies that quantum theory can be regarded as a square root of thermodynamics in a well-define sense. M-matrices forming the rows of the unitary U-matrix acting between zero energy states define the counterpart of ordinary S-matrix and are expressible as products of Hermitian square root of density matrices and unitary S-matrix. An attractive hypothesis is that Hermitian square roots of density matrices commute with S-matrix and therefore form a symmetry algebra of S-matrix. One can even consider the possibility that the M-matrices define Kac-Moody type algebra with integer powers of S-matrix defining the analog for the powers of phase for Kac-Moody algebras. This hierarchy of U-matrices would make sense for the hierarchy CDs for which scales are integer multiples of a fundamental scale. One could say that zero energy states would represent their own symmetry algebra.

ZEO leads to a variant of entropic gravity [B28] in which one does not assume that space-time emerges and that gravitons are absent [K71], [L17] Gravitons arriving along flux tubes from the source are simply thermalized when the distance of the source is much longer than the wavelength of the gravitons and this explains the basic formulas for the temperature and entropy. The arguments however apply also to electromagnetic interaction [B19] but imply that the temperature is negative either for particle or antiparticle. This suggests that thermal instability of antimatter for the standard arrow of geometric time and that antimatter resides at space-time regions with opposite arrow of geometric time. The arrow of geometric time in turn would be realized at the level of quantum states as a property of zero energy states. One can localize either the future or past part of zero energy state so that it has well define particle number and various other quantum numbers and represents naturally the incoming state of particle reaction.

The natural expectation is that the breaking of CP and T at the fundamental level relate to the thermodynamical instability of the antimatter explaining also why it is so difficult to manufacture dark matter in laboratory. Also the recently observed strange behavior of positronium atom [C150, C118] could relate to this asymmetry.

This framework suggests also a more concrete view abot the breaking of discrete symmetries.

(a) Gravitons are still there but in thermal equilibrium at flux tubes along which their travel and also photons are in similar thermal equilibrium so all interactions are entropic in TGD sense as the vision about quantum theory as a square root of thermodynamics suggests.

(b) Entropic gravity and electromagnetism would provide a phenomenological view about what happens and would also suggests a general view about how discrete symmetries break down. Charged matter and antimatter could obey different arrow of geometric time by the requirement of thermal stability (temperatures are proportional to the normal component of electric field have opposite sign for charged particle and antiparticle).

(c) The arrow of geometric time is a property of zero energy states rather than dynamics and realized as a property of M-matrix for which states are localized with respect to various quantum numbers (in particular particle- and fermion numbers) at the second end of the causal diamond defining the counterpart of initial state).

CPT, T and CPT breaking in zero energy ontology

CPT breaking [B3] requires the breaking of Lorentz invariance. Zero energy ontology could therefore allow a spontaneous breaking of CP and CPT. This might relate to matter antimatter asymmetry at the level of given CD.

There is some evidence that the mixing matrices for neutrinos and antineutrinos are different in the experimental situations considered [C17, C85]. This would require CPT breaking in the standard QFT framework. In TGD p-adic length scale hypothesis allowing neutrinos to reside in several p-adic mass scales. Hence one could have apparent CPT breaking if the measurement arrangements for neutrinos and antineutrinos select different p-adic length scales for them [K37] .

Could one understand the breaking of CP and T at fundamental level in TGD framework?

(a) In standard QFT framework Chern-Simons term breaks CP and T. Kähler action indeed reduces to Chern-Simons terms for the proposed ansatz for preferred extremals assuming that weak form of electric-magnetic duality holds true. This does not however need mean CP breaking. One must however add to the Kähler-Dirac action Chern-Simons Dirac term at the parton orbits in order to obtain non-trivial fermion propagator by requiring that spinor modes are generalized eigenstates of C-S-D operator with eigenvalues $p^k\gamma_k$ given by virtual momenta. One obtains thus perturbation theory and a connection with twistor Grassmannian approach. By supersymmetry one must add Chern-Simons term to Kähler action too so that it reduces to Chern-Simons terms at the space-like ends of space-time surface by weak form of electric magnetic duality. Chern-Simons Dirac terms could be responsible for the breaking of CP and T symmetries as they appear in CKM matrix.

In TGD framework one must however distinguish between space-time coordinates and imbedding space coordinates. CP breaking occurs at the imbedding space level but instanton term and Chern-Simons term are odd under P and T only at the space-time level and thus distinguish between different orientations of space-time surface. Only if one identifies P and T at space-time level with these transformations at imbedding space level, one has hope of interpreting CP and T breaking as spontaneous breaking of these symmetries for Kähler action and basically due to the weak form of electric-magnetic duality and vanishing of $j \cdot A$ term for the preferred extremals. This identification is possible for space-time regions allowing representation as graphs of maps $M^4 \rightarrow CP_2$.

(b) The GRT-QFT limit of TGD obtained by lumping together various space-time sheets to a region of Minkowski space with effective metric defined by the sum of Minkowski metric and deviations of the induced metrics of sheets from Minkowski metric. Gauge potentials for the effective space-time would identified as sums of gauge potentials for space-time sheets. At this limit the identification of P and T at space-time level and imbedding space level would be natural. Could the resulting effective theory in Minkowski space or GRT space-time break CP and T slightly? If so, CKM matrices for quarks and fermions would emerge as a result of representing different topologies for wormhole throats with different topologies as single point like particle with additional genus quantum number.

(c) Could the breaking of CP and T relate to the generation of the arrow of time? The arrow of time relates to the fact that state function reduction can occur at either boundary of CD [K6]. Zero energy states do not change at the boundary at which reduction occurs repeatedly but the change at the other boundary and also the wave function for the position of the second boundary of CD changes in each quantum jump so that the average temporal distance between the tips of CD increases. This gives to the arrow of psychological time, and in TGD inspired theory of consciousness "self" as a counterpart of observed can be identified as sequence of quantum jumps for which the state function reduction occurs at a fixed boundary of CD. The sequence of reductions at fixed boundary breaks T-invariance and has interpretation as irreversibility. The standard view is that the irreversibility has nothing to do with breaking of T-invariance but it might be that in elementary particle scales irreversibility might manifest as small breaking of T-invariance.

Anomalously high asymmetry production of top pairs in proton-antiproton collisions and CP breaking in B-Bbar system

The above theoretical arguments do not help in attempts to build a concrete model for CP breaking in say B-Bbar system. Something more concrete is needed. Here the two anomalies discovered in the production of top pairs in ppbar collisions at Tevatron come in rescue. At first they do not seem to have anything to do with the CP breaking in BBbar system.

(a) Both Jester and Lubos tell about top quark related anomaly in proton-antiproton collisions at Tevatron reported by CDF collaboration. The anomaly has been actually reported already last summer but has gone un-noticed. For more detailed data see this [C16] .

What has been found is that the production rate for jet pairs with jet mass around 170 GeV, which happens to correspond to top quark mass, the production cross section is about 3 times higher higher than QCD simulations predict. 3.44 sigma deviation is in question meaning that its probability is same as for the normalized random variable x/σ to be larger than 3.44 for Gaussian distribution $exp(-(x/\sigma)^2/2)/(2\pi\sigma^2)^{1/2}$. Recall that 5 sigma is regarded as so improbable fluctuation that one speaks about discovery. If top pairs are produced by some new particle, this deviation should be seen also when second top decays leptonically meaning a large missing energy of neutrino. There is however a slight deficit rather than excess of these events.

(b) There is also a second anomaly involved with top pair production. Jester reports new data [C125] about the strange top-pair forward-backward asymmetry in top pair production in p-pbar collisions already mentioned [C55]. In Europhysics 2011 conference D0 collaboration reported the same result. CMS collaboration found however no evidence for the asymmetry in p-p collisions at LHC [C62]. For top pairs with invariant mass above 450 GeV the asymmetry is claimed by CDF to be stunningly large 48+/-11 per cent. 3 times more often top quarks produced in qqbar annihilation prefer to move in the direction of quark. Note that this experiment would have reduced the situation from the level of ppbar collisions to the level of quark-antiquark collisions and the negative result suggests that valence quarks might play an essential role in the anomaly.

The TGD based explanation for the finding would relation on the flavor octet of gluons and the new view about Feynman diagrams.

(a) The identification of family replication phenomenon in terms of genus of the wormhole throats (see this) predicts that family replication corresponds to a dynamical SU(3) symmetry (having nothing to do with color SU(3)or Gell-Mann's SU(3)) with gauge bosons belonging to the octet and singlet representations. Ordinary gauge bosons would correspond besides the familiar singlet representation also to exotic octet representation for which the exchanges induce neutral flavor changing currents in the case of gluons and neutral weak bosons and charge changing ones in the case of charged gauge bosons. The exchanges of the octet representation for gluons could explain both the anomalously high production rate of top quark pairs and the anomalously large forward backward asymmetry! Also electroweak octet could of course contribute.

(b) One could say that top quark from the geometric future transforms at exchange line to space-like t-quark (genus $g = 2$) and returns to future. The quark from the geometric past does the same and returns back to the past as antiquark of antiproton. In the exchange line this quark combines with t-quark to form a virtual color octet gluon.

This mechanism could also give additional contributions to the mechanism generating CP breaking since new box diagrams involving two exchanges of flavor octet weak boson contribute to the mixings of quark pairs in mesons. The exchanges giving rise to an intermediate state of two top quarks are expected to give the largest contribution to the mixing of the neutral quark pairs making up the meson. This involves exchange of a member W boson flavor octet boson analogous to the usual exchange of the flavor singlet boson. This might relate to the reported anomalous like sign muon asymmetry in BBbar decay [**?**]uggesting that the CP breaking in this system is roughly 50 times larger than predicted by CKM matrix. The new diagrams would only amplify the CP breaking associated with CKM matrix rather than bringing in any new source of CP breaking. This mechanism increases also the CP breaking in KKbar system known to be also anomalously high.

10.7 TGD based explanation for the anomalously large direct CP violation in $K \rightarrow 2\pi$ decay

KTeV collaboration in Fermilab [C93] has measured the parameter $|\epsilon'/\epsilon|$ characterizing the size of the direct CP violation in the decays of kaons to two pions. The value of the parameter was found to be $|\epsilon'/\epsilon| = (2.8 \pm .1)10^{-3}$ and is almost by an order of magnitude larger than the naive standard model expectations based on the hypothesis that direct CP breaking is induced by CKM matrix. In [C181] it was shown that the value of the parameter could be understood without introducing any new physics if the value of running strange quark mass at m_c is about $m_s(m_c) = .1$ GeV and $m_d << m_s$ holds true.

10.7.1 How to solve the problems in TGD framework

Problems

Also in TGD framework the situation looks confusing.

(a) The TGD based prediction for the value of the CP breaking parameter for CKM matrices satisfying the constraints coming from p-adicity is within the experimental constraints $1.0 \times 10^{-4} \leq J \leq 1.7 \times 10^{-4}$ coming from the standard model so that J produces no problems (see [K43] or Appendix for the CKM matrix as predicted by TGD).

(b) The dominating contributions of the chiral field theory to $Re(\epsilon'/\epsilon)$ are proportional to $1/(m_s + m_d)^2$. The predictions of p-adic thermodynamics for s and d quark masses for $k(d) = k(s) = 113$ are $m_d(113) = m_s(113) = 90$ MeV and if this mass can be interpreted as $m_s(m_c) \simeq 0.1$ GeV, the prediction is too small by a factor 1/4. Even worse, if m_s corresponds to the scaled up mass $m_s(109) \simeq 360$ MeV of the s quark inside kaon, the situation changes completely and ϵ'/ϵ is too small by a factor $\sim 1/4.5^2 \simeq .05$.

(c) TGD predicts that family replication phenomenon has also a bosonic counterpart. In the original scenario gauge bosons had single light-like wormhole throat as space-time correlate just like fermions and two exotic gluons were predicted corresponding to $g = 1$ and $g = 2$. The assumption that fermions at partonic space-time sheets are free fermions however forces to identify gauge bosons as wormhole contacts such that the two light-like wormhole throats carry quantum numbers of fermion and anti-fermion. Gauge bosons can be arranged into SU(3) singlet corresponding to ordinary gauge bosons and octet, where SU(3) states correspond to pairs (g_1, g_2) of handle numbers $0 \leq g_i \leq 2$.

    The experimental non-existence of flavor changing currents suggest strongly that the masses of octet gauge bosons are high. This requires that they correspond to $L(89)$ or even shorter p-adic length scale. Hence these gauge bosons are not interesting from the point of view of CP breaking.

(d) The recent breakthrough in p-adic mass calculations for hadrons [K43] led also the understanding of non-perturbative aspects of hadron physics in terms of super-symplectic bosons which correspond to single light-like wormhole throat so that they couplings to quarks in the sense of generalized Feynman diagrams do not imply flavor changing neutral currents.

The basic prediction is that topologically mixed super-symplectic bosons are responsible for the most of the mass of proton and that it is possible to deduce the super-symplectic content of hadrons from their masses if their topological mixing is assumed to be same as for U type quarks. The masses of these bosons correspond to p-adic length scale $L(107)$ and are small in length scale $L(89)$ relevant for CP breaking. These observations suggest that higher gluon genera of the earlier model should be replaced with super-symplectic gluons.

In the standard diagrammatic expression for the CP breaking parameter gluon propagators are replaced by a sum of ordinary massless and two exotic gluon massive gluon propagators. The fact that the matrix elements relevant for the estimation of the CP breaking parameter are estimated at momentum transfer of order $\mu = m_W$, implies that gluon masses do not significantly change the contribution of the super-symplectic gluons to the amplitude apart from the change in value of color coupling strength. Hence the penguin amplitudes are simply multiplied by some factor X determined by the number of super-symplectic gluons light in length scale $L(89)$ and by the coupling constants of these gluons and the ratio ϵ'/ϵ is multiplied by a factor X. Unfortunately, it is not possible to calculate this factor at this stage.

The model based on exotic gluons and current quarks

It is essential that exotic gluons correspond to single light-like wormhole throat and thus have family replication phenomenon analogous to that of fermions. Two models can be considered.

(a) The original model based on the assumption that ordinary gauge bosons correspond to single wormhole throat. There are good reasons to believe that this interpretation is wrong.

(b) The new model based on super-symplectic exotic gluons whose number is not known but is multiple of 3. The couplings to quarks are not known. Also color single super-symplectic bosons could be also present.

1. The difficulty of the original model

The problem of this model is that assuming exotic gluons in sense 1) ϵ'/ϵ would be still by a factor .15 too small for $m_s(109)$ relevant for kaons.

The basic observation is that the gluon contribution is proportional to $1/(m_s+md)^2$ and for $m_s(113)$ instead of $m_s(119)$ ϵ'/ϵ would be a fraction $(16+1)/2=8.5$ large and by a factor 1.275 larger than the experimental value since $m_d=m_s$ rather than $m_d << m_s$ holds true.

This observation stimulated the idea that a transition $s_{109} \rightarrow s_{113}$ occurs before electro-weak process and would have an interpretation as a transformation of a constituent quark to current quark. This requires that the amplitudes for the transition $s(109) \rightarrow s(113)$ and its reversal are near to unity.

The question is why $s(109) \rightarrow s(113)$ constituent-current transformation should occur in electro-weak interactions and why it occurs with amplitude $A \sim 1$. Of course it could also be that also d quark is transformed to a very low mass variant with mass about 4 MeV predicted by chiral field theory. This would correspond to $k=125$. As a result the amplitude would be multiplied by a factor 4 and $A=1/2$ would become possible.

For some reason the join along boundaries bonds feeding em gauge flux of s quark to $k=109$ space-time sheet would be transferred to nuclear space-time sheets with $k=113$ before the electro-weak scattering process responsible for the CP breaking. Note that the value of strange quark mass about 176 MeV deduced from τ lepton decay rate corresponds to $m_s(111)$ in a good approximation. Also this indicates that various scaled up variants of quark masses can appear in the electro-weak dynamics as intermediate states.

The assumption for the proportionality $\epsilon'/\epsilon \propto 1/(m_s+m_d)^2$ derivable from chiral field theory can be criticized. Finding a justification for this assumption seems to be a non-trivial challenge since it is not at all clear that chiral field theory based on $SU(3)$ flavor symmetry makes sense in TGD context.

2. Super-symplectic variant of the original model

For super-symplectic gluons one can predict only that the relevant gluon exchange amplitude increases by a factor

$$X = \sum_{i,j} \alpha_s(B_{i,j})) \quad ,$$

where $\alpha_s(B_{i,j})$ is the color coupling strength to j:th generation of the super-symplectic gluon B_i. In principle also color neutral super-symplectic bosons having spin might contribute.

For $\alpha_s(B_{i,j}) = \alpha_s(B_i)$ one would have

$$X = 3\sum_i \alpha_s(B_i) \quad .$$

If the number of light super-symplectic gluons large enough, it is possible to have a large enough value of X to compensate for the factor .14 so that the assumption about the transformation $s(109) \rightarrow s(113)$ from constituent quark to current quark would become un-necessary. $X \sim 8$ would be needed.

Recall that super-symplectic algebra is analogous to Kac-Moody algebra in the sense that finite-dimensional Lie-group is replaced with symplectic group. Super-symplectic gluons correspond to states created by super-algebra generators, which are in one-one correspondence Hamiltonians of $\delta M^4_+ \times CP_2$ subject to some additional conditions making subset of states zero norm states. Therefore more than single octet of super-symplectic bosons and also higher dimensional representations might be possible.

All depends on which of these super-symplectic states correspond to light particles. This in turn depends on the details of super-symplectic representations (they correspond to the states of negative conformal weight annihilated by Virasoro generators L_n, $n<0$ [K16]). Here the help of a mathematician specialized to the representations of super-conformal algebras would be needed.

At this moment it is not possible to know whether the transformation to current quark is needed or even possible and this motivates the following discussion of the basic notions and chiral field theory approach in more detail in order to clarify what is involved.

10.7.2 Basic notations and concepts

Until 1963 CP symmetry was believed to be an exact symmetry of Nature. In this year it was however observed by Christensen, Cronin, Fitch and Turlay that CP symmetry is violated in hadronic decays of neutral kaons. In order to interpret the experimental evidence one must consider the strong Hamiltonian eigen states K^0 and its CP conjugate $\bar{K}^0$ as a mixture of physical short lived K_S decaying predominantly to two pions and long-lived K_L decaying mostly semi-leptonically and into 3 pion states. Two- and three pion final states have odd and even CP parity. In absence of CP breaking one would identify K_S and K_L as the CP even and CP odd states

$$\begin{aligned} K_1 &= (K^0 + \bar{K}^0)/\sqrt{2} \ , \\ K_2 &= (K^0 - \bar{K}^0)/\sqrt{2} \ . \end{aligned} \qquad (10.7.0)$$

What was observed in 1963 was that K_L decays also to two-pion final states.

There are two mechanisms of CP violation. The indirect mechanism involves a slight mixing of K^1 and K^2 characterized by a complex mixing parameter $\bar{\epsilon}$

$$\begin{aligned} K_S &= \frac{K_1 + \bar{\epsilon} K_2}{1 + |\bar{\epsilon}|^2} \ , \\ K_L &= \frac{K_2 + \bar{\epsilon} K_1}{1 + |\bar{\epsilon}|^2} \ . \end{aligned} \qquad (10.7.0)$$

Direct mechanism involves the direct decay of K_2 to two pion state and is induced by the weak interaction Lagrangian L_W directly. Both mechanisms can be parameterized in terms of the small ratios

$$\begin{aligned} \eta_{00} &= \frac{\langle \pi^0\pi^0 | L_W | K_L \rangle}{\langle \pi^0\pi^0 | L_W | K_S \rangle} \ , \\ \eta_{+-} &= \frac{\langle \pi^+\pi^- | L_W | K_L \rangle}{\langle \pi^+\pi^- | L_W | K_S \rangle} \ . \end{aligned} \qquad (10.7.\text{-}1)$$

Here L_W represents the $\Delta S = 1$ part of the weak Lagrangian. The equations for η parameters can be also written as

$$\begin{aligned} \eta_{00} &= \epsilon - \frac{2\epsilon'}{1 - \omega\sqrt{2}} \simeq \epsilon - 2\epsilon' \ , \\ \eta_{+-} &= \epsilon - \frac{2\epsilon'}{1 + \omega/\sqrt{2}} \simeq \epsilon + \epsilon' \ . \end{aligned} \qquad (10.7.\text{-}1)$$

Parameter $\bar{\epsilon}$ is simply related to ϵ. The parameter ω measures the ratio

$$|\omega| = \frac{|\langle(\pi\pi)_{I=2}|L_W|K_S\rangle|}{|\langle(\pi\pi)_{I=0}|L_W|K_S\rangle|} \simeq 1/22.2 \quad . \tag{10.7.0}$$

$I=0$ and $I=2$ denote the isospin states of final state pions.

The CP violating parameters are expressible in terms of $K_{S,L}$ decay amplitudes as

$$\begin{aligned} \epsilon &= \frac{\langle(\pi\pi)_{I=0}|L_W|K_L\rangle}{\langle(\pi\pi)_{I=0}|L_W|K_S\rangle} \quad , \\ \epsilon' &= \frac{\epsilon}{\sqrt{2}}\left[\frac{\langle(\pi\pi)_{I=2}|L_W|K_L\rangle}{\langle(\pi\pi)_{I=0}|L_W|K_L\rangle} - \frac{\langle(\pi\pi)_{I=2}|L_W|K_S\rangle}{\langle(\pi\pi)_{I=0}|L_W|K_S\rangle}\right] \quad . \end{aligned} \tag{10.7.0}$$

By Watson's theorem one can write the generic amplitudes for K^0 and $\bar{K}^0$ decay as

$$\begin{aligned} \langle(\pi\pi)_I|L_W|K^0\rangle &= -iA_I exp(i\delta_I) \quad , \\ \langle(\pi\pi)_I|L_W|\bar{K}^0\rangle &= -iA_I^* exp(i\delta_I) \quad , \end{aligned} \tag{10.7.0}$$

where the phases δ_I arise from the pion finals state interactions. In good approximation ($|\bar{\epsilon} ImA_0| \ll |ReA_0|$, $|\bar{\epsilon}|^2 \ll 1$) one can write

$$\begin{aligned} \epsilon' &= exp(i(\pi/2+\delta_2-\delta_1)) \times \frac{\omega}{\sqrt{2}} \times (\frac{ImA_2}{ReA_2} - \frac{ImA_0}{ReA_0}) \quad , \\ \omega &= \frac{ReA_2}{ReA_0} \quad . \end{aligned} \tag{10.7.0}$$

With the approximations used one obtains a relationship

$$\epsilon' = \bar{\epsilon} + i\frac{ImA_0}{ReA_0} \quad . \tag{10.7.1}$$

One can find a more detailed representation of the subject in various review articles [C156, C162, C163] . The standard model of CP breaking is based on the presence of complex phases in CKM matrix.

The value of the parameter ϵ describing indirect CP violation is well established and given by

$$|\epsilon| = (2.266 \pm .017) \times 10^{-3} \quad .$$

The phases of ϵ and ϵ' are in good approximation identical so that their signs are same. The value of $Re(\epsilon'/\epsilon)$ was finally established by KTeV collaboration at Fermi Lab to be

$$Re(\frac{\epsilon'}{\epsilon}) = (2.8 \pm .01) \times 10^{-3} \quad .$$

The measurement is consistent with the result of the CERN experiment NA31, which has also found a non-vanishing value for this parameter.

There are several theories of CP violation. The so called milliweak theory predicts vanishing value of ϵ'. The model based on the presence of CP breaking phases in three-generation

CKM matrix predicts non-vanishing value for the parameter. Also Higgs particles can effect the value of the parameter in standard model. Standard model predicts this parameter to be nonzero but the expectation has been that the value is roughly ten times smaller than the measured value.

A possible explanation of the effect which does not introduce new physics is based on the hypothesis that the mass of s quark is smaller than the mass of d quark: the running mass $m_s(2\ GeV) \simeq .1$ GeV is needed to explain the anomaly if CP breaking parameter J is taken to be in the range $(1-1.7)\times 10^{-4}$ claimed in [C132] to follow from unitarity. There is however experimental evidence from τ decays for $m_s(m(\tau)) = (172 \pm 31)\ MeV$. This suggests that some new short length scale physics is involved.

Standard model prediction for $Re(\epsilon'/\epsilon)$ [C181] can be summarized in a handy formula

$$
\begin{aligned}
Re(\frac{\epsilon'}{\epsilon}) &= J \times \left[-1.35 + R_s \left(A_6 B_6^{1/2} + A_8 B_8^{3/2}\right)\right] \ , \\
A_6 &= 1.1|r_Z^8| \ , \\
A_8 &= 1.0 - .67|r_Z^8| \ .
\end{aligned} \tag{10.7.0}
$$

The subscript Z refers to renormalization mass m_Z. The parameter R_s is given by

$$
R_s \simeq \left[\frac{150\ MeV}{m_s(m_c) + m_d(m_c)}\right]^2 \ . \tag{10.7.1}
$$

The dominating contributions to $Re(\frac{\epsilon'}{\epsilon})$ come from second (A_6) and third terms (A_8). These terms correspond to gluonic and electro-weak penguin diagram contributions to the CP breaking decays and of opposite sign. Clearly, the sum of the two terms is roughly one third of the gluonic term alone.

10.7.3 Separation of short and long distance physics using operator product expansion

The calculation of CP breaking parameters involves physics in very wide energy scale. The strategy is to derive low energy effective action by functionally integrating over the short distance effects coming from energies larger than m_c. This leads to Wilson expansion for the low energy electro-weak effective Lagrangian

$$
L_{low,W} = -\sum_i C_i(\mu, m_c, m_b, m_t, m_W, ...)Q_i(\mu) \ . \tag{10.7.2}
$$

The coefficients C_i of the operators Q_i in the low energy effective action for light quarks (u, d, s) are functionals of various parameters characterizing short distance physics. The coefficients $C_i(\mu)$ in Wilson expansion of electro-weak effective action can be written as

$$
C_i(\mu) = \frac{G_F}{\sqrt{2}} V_{ud} V_{us}^* \left[x_i(\mu) + \tau y_i(\mu)\right] \ . \tag{10.7.3}
$$

Here x_i and y_i are Wilson coefficients. V_{ij} denotes CKM matrix and τ is defined as $\tau = V_{td}V_{ts}^*/V_{ud}V_{us}^*$. $V_{td}V_{ts}^*$ is identical with CP breaking invariant J in standard parameterization. Coefficients $y_i(\mu)$ summarize short distance CP breaking physics and in order to determine CP breaking one needs to consider only the coefficients y_i.

Long distance physics is the difficult part of the calculation since it involves calculation of matrix elements of the quark operators Q_i between initial kaon state and final two-pion state. There are several approaches to the problem. Chiral field theory [C133] is phenomenological approach and relies on the idea that low energy effective action for quarks can be expressed in a good approximation using meson fields. Lattice QCD is believed to provide a more fundamental direct method for the calculation of the correlation functions of Q_i.

Short distance physics

In present initial states are kaons and μ denotes the momentum exchange for a typical diagram associated with the scattering of $d\bar{s}$ quark to final state consisting of of light quarks. μ is taken to be of order m_W and by using renormalization group equations one can deduce the values of the coefficients $C_i(\mu)$ at energy scales, typically of order 1 GeV.

The basic standard diagrams contributing to the $\Delta S = 1$ and $\Delta S = 2$ processes are given by the figure below.

The quark operators Q_i appearing in the expansion can be classified. In present case the list of relevant operators correspond to various terms possible in four-fermion Fermi interaction and are given by the following list.

$$
\begin{aligned}
Q_1 &= (\bar{s}_\alpha u_\beta)_{V-A}(\bar{u}_\beta d_\alpha)_{V-A} \ , && (10.7.3)\\
Q_2 &= (\bar{s}u)_{V-A}(\bar{u}d)_{V-A} \ , && (10.7.3)\\
Q_{3,5} &= (\bar{s}d)_{V-A}\sum_q (\bar{q}q)_{V\mp A} \ , \\
Q_{4,6} &= (\bar{s}_\alpha d_\beta)_{V-A}\sum_q (\bar{q}_\beta q_\alpha)_{V\mp A} \ , \\
Q_{7,9} &= \frac{3}{2}(\bar{s}d)_{V-A}\sum_q \hat{e}_q(\bar{q}q)_{V\pm A} \ , \\
Q_{8,10} &= \frac{3}{2}(\bar{s}_\alpha d_\beta)_{V-A}\sum_q \hat{e}_q(\bar{q}_\beta q_\alpha)_{V\pm A} \ . && (10.7.1)
\end{aligned}
$$

α, β denote color indices and $\hat{e}_q$ denote quark charges. $V \pm A$ refers to the Dirac structure $\gamma_\mu(1\pm\gamma_5)$. Q_2 is induced by mere W exchange whereas gluonic loop corrections to Q_2 induce Q_1. QCD through penguin loop induces the penguin operators Q_{3-6}. Electro-weak loops, in which penguin gluon is replaced with electro-weak gauge boson, induce $Q_{7,9}$ and part of Q_3. The operators $Q_{8,10}$ are induced by the QCD renormalization of the electro-weak loop operators $Q_{7,9}$.

As far as the calculation of ϵ'/ϵ is considered, the dominating contributions come from the penguin diagrams, which are proportional to the vertices $s\bar{d}V$, where V is either gluon or electro-weak gauge boson and to the propagator denominator of V with momentum squared equal to momentum exchange between initial state quarks, which equals to $(p_i - p_j)^2 = \mu^2$. For option 2) the standard gluon contribution is replaced with a sum over contributions of ordinary and exotic gluons. For option 1) situation is more complicated since $g > 0$ gluons can change the genus of the fermion.

The operators Q_6 and Q_8 give the dominating contributions to ϵ'/ϵ and these contributions are competing. Q_6 and Q_8 differ only by the fact that in Q_8 penguin gluon is replaced with penguin electro-weak boson γ or Z^0. For neutral kaon initial state electro-weak penguin diagram is proportional to the product $e_q e_{\bar{q}} = -e_q^2$ of the virtual quark whereas in case of gluons the factor $Tr(T^aT^a) > 0$ appears. Therefore the contributions associated with Q_6 and Q_8 are of opposite sign and mutually competing.

Detailed calculations lead to the formula already described:

$$
\begin{aligned}
Re(\frac{\epsilon'}{\epsilon}) &= J \times \left[-1.35 + R_s \left(A_6 B_6^{1/2} + A_8 B_8^{3/2}\right)\right] \ , \\
A_6 &= 1.1|r_Z^8| \ , \\
A_8 &= 1.0 - .67|r_Z^8| \ .
\end{aligned}
\tag{10.7.0}
$$

for $Re(\epsilon'/\epsilon)$. The coefficients B_6 and B_8 code the long distance physics and their values do not differ too much from $B_6 = B_8 = 1$. Clearly, the sum of Q_6 and Q_8 contributions is roughly one third of the Q_6 contribution alone. From the general structure of Feynman diagrams it ss clear that for option 2) the effect caused by the introduction of exotic gluons is in a good approximation a simple scaling of the Q_6 contribution by a factor 3 in the approximation that gluon masses are negligible as compared to W mass, and that this new contribution can enhance direct CP breaking dramatically.

Chiral field theory approach

The basic problem is to calculate electro-weak matrix elements of the quark effective action between hadronic states. These matrix elements reduce to vacuum expectation values of various quark bi-linears appearing in four-fermion Fermi interaction Lagrangian. This problem is very difficult since non-perturbative QCD is involved in an essential manner. An attempt to circumvent this problem [C133] is based on the hypothesis that low energy effective action for quarks is essentially equivalent with the low energy effective action, where pseudo-scalar meson fields as dynamical fields and scalar, vector and axial vector meson fields occur as external fields not subject to variations. Quark masses are identified as vacuum expectation values of the external scalar meson field. The approximate symmetry of the chiral field theory is flavor $SU(3)_L \times SU(3)_R$ which is exact symmetry at the limit of massless quarks. This symmetry can be realized if mesons are represented by an element U of $SU(3)$ regarded as a dynamical field: the two $SU(3)$:s act on U from left and right respectively. For small perturbations around ground state mesons correspond to various Lie-algebra generators of $SU(3)$. Chiral field develops vacuum expectation value. If vacuum expectation is not proportional to unit matrix it corresponds to the presence of coherent states associated with the neutral components of the pseudo scalar meson field.

The basic formulation of the chiral field theory approach is described in [C133] whereas its application to the calculation of ϵ'/ϵ is described in [C162] . The strong part of the chiral action [C133] is given by the formula

$$
\begin{aligned}
L_S &= \frac{f^2}{4}\left[Tr\{D_\mu U^\dagger D^\mu U\} + 2B_0 Tr\{(s-ip)U\} + 2B_0^* Tr\{(s+ip)U^\dagger\}\right] \\
&+ \frac{1}{12} H_0 D_\mu \theta D^\mu \theta \ .
\end{aligned}
\tag{10.7.0}
$$

D_μ denotes the covariant derivative defined by the couplings to the left and right handed gauge bosons L_μ and R_μ defined as superpositions $R_\mu = v_\mu + a_\mu$ and $L_\mu = v_\mu - a_\mu$ of the vector and axial vector mesons fields v and a. Action contains three coupling constant parameters: f, B_0 and H_0, which is present because the presence of color instantons can lead to a non-vanishing value of the θ parameter in QCD. In lowest order f is pion decay constant f_π and B_0 sets the scale in the formula $M_M^2 = B_0(\sum_i m(q_i))$ inspired by broken $SU(3)$ symmetry and resulting as a prediction of the model. The components for the non-vanishing vacuum expectation value for the external scalar field are identified as quark masses. The generation of vacuum expectation value of s implies that quark condensates are developed:

$$\begin{aligned}
\langle \bar{q}_i q_j \rangle &= B_0 f^2 \delta_{i,j} \ , \\
B_0 f^2 &= \frac{f_\pi^2 m_\pi^2}{(m_u + m_d)} = \frac{f_K^2 m_K^2}{(m_s + m_d)} \ .
\end{aligned} \quad (10.7.0)$$

Note that the strong part of the chiral Lagrangian is invariant under the overall scaling of quark masses.

The weak part of the chiral action corresponds to the sigma model counterpart of the most general electro-weak four-fermion action. The recipe for constructing this action is described in more detail in [C162] and can be summarized as rules associating with various fermionic bi-linears appearing in the generalized Fermi action corresponding terms of the weak part of the chiral action. In particular, the following rules hold true:

$$\begin{aligned}
\bar{q}_L^j \gamma^\mu q_L^i &\rightarrow -i f_\pi^2 (U^\dagger D_\mu U)_{ij} \ , \\
\bar{q}_R^j \gamma^\mu q_R^i &\rightarrow -i f_\pi^2 (U D_\mu U^\dagger)_{ij} \ , \\
\bar{q}_L^j \gamma^\mu q_R^i &\rightarrow -2B_0 \left[\frac{f^2}{4} U + \text{higher order terms} \right]_{ij} \ , \\
\bar{q}_R^j \gamma^\mu q_L^i &\rightarrow -2B_0 \left[\frac{f^2}{4} U^\dagger + \text{higher order terms} \right]_{ij} \ .
\end{aligned} \quad (10.7.-2)$$

The chiral counterparts of the left and right handed currents are proportional to BM and depend on the ratios of quark masses only. The terms giving dominating contribution to the $\Delta S = 1$ part of the weak effective action involve the chiral counterparts of terms $\bar{q}_L^j q_R^i$ breaking chiral invariance. The chiral counterparts of these terms are proportional to B and, in accordance with expectations, fail to be invariant under the overall scaling of quark masses. The higher order contributions to these terms are important for the calculations of direct CP breaking effects but are not written explicitly here because they are not needed in the estimate for how the predictions of the standard model are modified in TGD framework. The terms breaking chiral symmetry give rise to ϵ'/ϵ a contribution, which is proportional to $1/(m_s + m_d)^2$.

The $\Delta S = 2$ part of effective quark action is involved with $K^0 \rightarrow \bar{K}^0$ transitions and the corresponding quark operator is given by

$$Q_{S2} = (\bar{s}_L \gamma^\mu d_L)(\bar{s}_L \gamma^\mu d_L) \ . \quad (10.7.-1)$$

The chiral counterpart of this operator is obviously invariant under overall scaling of quark masses.

Does chiral theory approach make sense in TGD framework?

The TGD based model for the large direct CP breaking based on exotic gluons and on the transformation of s_{109} to s_{113} has been already discussed. The open question is whether the $1/(m_s + m_d)^2$ proportionality of the CP breaking amplitude can be justified in TGD context where it is not at all clear that chiral theory approach makes sense.

In standard model framework chiral field theory provides a phenomenological description of the low energy hadron physics and makes possible the calculation of various hadronic matrix elements needed to derive the predictions for CP breaking effect.

Chiral field theory limit however involves some questionable assumptions about the relationship between QCD and low energy hadron physics.

(a) $SU(3)$ symmetry is assumed and allows description of light mesons in terms of $SU(3)$ valued chiral field U possessing $SU(3)_R \times SU(3)_R$ symmetry broken only by quark mass matrix. In TGD framework $SU(3)$ symmetry is purely phenomenological symmetry since the fundamental gauge group is the gauge group of the standard model.

(b) The generation of quark masses is described as effective spontaneous symmetry breaking caused by the vacuum expectation value of $SU(3)$ Lie-algebra valued external scalar field s. Quark masses are identified as the components of the diagonal vacuum expectation value of this field. Physically the scalar field corresponds to scalar meson field so that quark masses would result from the coupling of the quarks to coherent states of scalar mesons. This cannot be a correct physical description in TGD framework, where p-adic thermodynamics gives rise to quark masses. Of course, the presence of the scalar field can give rise to a small shift in the values of the quark masses. Also Higgs field could be in question.

(c) The coupling of the field s to chiral field U implies in the standard model context that the mass squared values of mesons are proportional to the sums of masses of the mesonic quarks: for instance, $M_\pi^2 = B_0(m_u + m_d)$ and $M_K^2 = B_0(m_s + m_d)$, where B_0 is one of the basic coupling constants of the chiral field theory. This formula is not consistent with the p-adic mass calculations, where quark mass squared is additive for quarks with the same value of k_q and quark mass for different values of k_q. Indeed, the formulas $M_\pi^2 = m_u^2 + m_d^2$ and $M_K^2 = (m_s + m_d)^2$ are true. The chiral field formula predicts $m_s/m_d \simeq 24$ requiring $m_u = m_d \simeq 13$ MeV ($k = 121$) for $m_s(113) = 320$ MeV whereas TGD predicts $m_s(109)/m_d(107) = 4$. For $m_s \simeq 100$ MeV the prediction is $m_d \simeq 4.2$ MeV. This looks suspiciously small.

To sum up, although the basic assumptions of chiral field theory limit look too specific in TGD framework, its predictions for low energy hadron physics are well-tested and TGD could be consistent with them. If this the case, the assumption about $s_{109} \to s_{107}$ transition allows a correct prediction of direct CP breaking amplitude using chiral field theory limit.

10.7.4 Very Special Relativity as justification for the special role of M^2

The preferred role of M^2 in the construction of generalized Feynman diagrams could be used as a criticism. Poincare invariance is lost. The first answer to the criticism is that one integrates of the choices of M^2 so that Poincare invariance is lost. One can however defend this assumption also from different view point. Actually Glashow and Cohen did this in their Very Special Relativity proposal [B13]! While scanning old files, I found an old text about Very Special Relativity of Glashow and Cohen, and realized that it relates very closely to the special role of M^2 in the construction of generalized Feynman diagrams. There is article Very Special Relativity and TGD [L2] at my homepage but for some reason the text has disappeared from the book that contained it. I add the article more or less as such here.

WCW ("world of classical worlds", WCW) decomposes into a union of sub-WCWs associated with future and past light-cones and these in turn decompose to sub-sub-WCWs characterized by selection of quantization axes of spin and color quantum numbers. At this level Poincare and even Lorentz group are reduced. The possibility that this kind of breaking might be directly relevant for physics is discussed below.

One might think that Poincare symmetry is something thoroughly understood but the Very Special Relativity [B13] proposed by nobelist Sheldon Glashow and Andrew Cohen suggests that this might belief might be wrong. Glashow and Cohen propose that instead of Poincare group, call it P, some subgroup of P might be physically more relevant than the whole P. To not lose four-momentum one must assume that this group is obtained as a semi-direct product of some subgroup of Lorentz group with translations. The smallest subgroup, call it L_2, is a 2-dimensional Abelian group generated by $K_x + J_y$ and $K_y - J_x$. Here K refers to Lorentz boosts and J to rotations. This group leaves invariant light-like momentum in z direction. By adding J_z acting in L_2 like rotations in plane, one obtains L_3, the maximal subgroup leaving invariant light-like momentum in z direction. By adding also K_z one obtains the scalings of light-like momentum or equivalently, the isotropy group L_4 of a light-like ray.

The reasons why Glashow and Cohen regard these groups so interesting are following.

(a) All kinematical tests of Lorentz invariance are consistent with the reduction of Lorentz invariance to these symmetries.

(b) The representations of group L_3 are one-dimensional in both *massive* and massless case (the latter is familiar from massless representations of Poincare group where particle states are characterized by helicity). The mass is invariant only under the smaller group. This might allow to have left-handed massive neutrinos as well as massive fermions with spin dependent mass.

(c) The requirement of CP invariance extends all these reduced symmetry groups to the full Poincare group. The observed very small breaking of CP symmetry might correlate with a small breaking of Lorentz symmetry. Matter antimatter asymmetry might relate to the reduced Lorentz invariance.

The idea is highly interesting from TGD point of view. The groups L_3 and L_4 indeed play a very prominent role in TGD.

(a) The full Lorentz invariance is obtained in TGD only at the level of the entire WCW which is union over sub-WCWs associated with future and past light-cones (space-time sheets inside future or past light-cone) [K29, K13]. These sub-WCWs decompose further into a union of sub-sub-WCWs for which a choice of quantization axes of spin reflects itself at the level of generalized geometry of the imbedding space (quantum classical correspondence requires that the choice of quantization axes has imbedding space and space-time correlates) [K74, K22]. The construction of the geometry for these sub-worlds of classical worlds reduces to light-cone boundary so that the little group L_3 leaving a given point of light-cone boundary invariant is in a special role in TGD framework.

(b) The selection of a preferred light-like momentum direction at light-cone boundary corresponds to the selection of quantization axis for angular momentum playing a key role in TGD view about hierarchy of Planck constants associated with a hierarchy of Jones inclusions implying a breaking of Lorentz invariance induced by the selection of quantization axis [K74, K22]. The number theoretic vision about quantum TGD implies a selection of two preferred axes corresponding to time-like and space-like direction corresponding to real and preferred imaginary unit for hyper-octonions [K67, K65]. In both cases L_4 emerges naturally.

(c) The TGD based identification of Kac-Moody symmetries as local isometries of the imbedding space acting on 3-D light-like orbits of partonic 2-surfaces involves a selection of a preferred light-like direction and thus the selection of L_4.

(d) Also the so called massless extremals representing a precisely targeted propagation of patterns of classical gauge fields with light velocity along typically cylindrical tubes without a change in the shape involve L¡sub¿4¡/sub¿. A very general solution ansatz to classical field equations involves a local decomposition of M^4 to longitudinal and transversal spaces and selection of a light-like direction [K8].

(e) The parton model of hadrons assumes a preferred longitudinal direction of momentum and mass squared decomposes naturally to longitudinal and transversal mass squared. Also p-adic mass calculations rely heavily on this picture and thermodynamics mass squared might be regarded as a longitudinal mass squared [K40]. In TGD framework right handed covariantly constant neutrino generates a super-symmetry in CP_2 degrees of freedom and it might be better to regard left-handed neutrino mass as a longitudinal mass.

This list justifies my own hunch that Glashow and Cohen might have discovered something very important.

10.8 Wild speculations about non-perturbative aspects of hadron physics and exotic Super Virasoro representations

If the canonical correspondence mapping the p-adic mass squared values to real numbers is taken completely seriously, then TGD predicts infinite hierarchy of exotic light representations of Super Virasoro. These exotic states are created by sub-algebras of Super Kac-Moody and SKM algebras whose generators have conformal weights divisible by p^n, $n = 1, 2, ...$ Ordinary representations would correspond to $n = 0$.

10.8.1 Exotic Super-Virasoro representations

For the exotic representations the p-adic mass squared of the particle is proportional to Virasoro p^n. When the value of the p-adic mass squared is power of p: $M^2 \propto p^n$, $n = 1, 2, ..,$ the real counterpart of the mass squared in canonical identification is extremely small since it is proportional to $1/p^n$ in this case. It is of course not at all clear whether these representations have have any real counterpart and if even this the case the could be thermally unstable in an environment with higher p-adic temperature.

Also ordinary low temperature ($T_p = 1/n$) Super Virasoro representations allow extremely light states but in this case there is no subalgebra generating these states. If these representations exist they could correspond to low energy-long length scale fractal copies of elementary particles. Due to the state degeneracy providing an enormous information storage capacity associated with these states these representations, if realized in nature, might have biological relevance [K36, K47] .

There is however an objection against this idea: these representations are possible also in elementary particle length scales and for $M^2 \propto L_0 = npm_0^2$ the representations have same mass scale as ordinary elementary particles. These representations couple to ordinary elementary particles via classical gauge fields and could therefore be present also in elementary particle physics. For reasons which become clear below, exotic Super Virasoro representations might provide a model for low energy hadron physics.

(a) The formula

$$M_R^2 = \frac{nm_0^2}{p}$$

is generalization of the mass formula of hadronic string models and reduces to it when the angular momentum

$$J = \alpha' M^2$$

of the hadronic state satisfies $J = n$. From this Regge slope α' and string tension T are given by

$$T = \frac{1}{2\pi\alpha'} \ , \quad \frac{1}{\alpha'} = \frac{m_0^2}{p} \ .$$

The observed value of the Regge slope is $\alpha' = .9/GeV^2$.

(b) The value of the predicted string tension is easily found. The prediction of TGD based mass calculations for the value of the p-adic pion mass squared is

$$m_\pi^2 = pm_0^2 + O(p^2) \simeq pm_0^2 \ , \quad p = M_{107} \ .$$

$m_\pi \geq m_0/\sqrt{M_{107}}$ and $m_\pi = 134$ MeV gives upper bound for m_0 which is consistent with the prediction for the mass of electron. For $k = 107$ the value of α' would be roughly 64 times too large as simple calculation shows. For $k = 101$ one has

$$\alpha' = \frac{.87}{GeV^2} \ ,$$

which deviates from the value $\alpha' = .9/GeV^2$ determined from ρ Regge trajectory only by three per cent.

(c) This would suggest that excited states of ordinary hadrons contain $k = 101$ space-time sheets with p-adic length scale of .3 fm condensed on $k = 107$ hadronic space-time sheet with 8 times larger p-adic length scale and that the angular momentum of these excitations is not assignable to the ordinary quarks but to the states of $k = 101$ exotic Super Virasoro representation. The slight deviation from $.9/GeV^2$ could be explained if the contribution of quarks and gluons to the mass squared decreases as a function of J so that the effective value of α' increases and effective string tension increases. This might be due to the transformation of parton mass squared to the mass squared associated with $k = 101$ exotic Super Virasoro states. Note that $n = 1$ excitation of $k = 101$ Super Virasoro has mass $m_1 = 1.07$ GeV, which is larger than proton mass: therefore the spin of these excitations cannot resolve the spin crisis of proton.

(d) For $k = 103$ the predicted value of string tension is by a factor 1/4 smaller. An interesting question is whether $k = 107$ and $k = 103$ excitations might be observable in low energy hadron physics.

10.8.2 Could hadrons correspond to exotic Super-Virasoro representations and quark-gluon plasma to the ordinary ones?

The second thought provoking observation is that pion mass squared corresponds in excellent approximation to that for $n = 1$ state of exotic Super Virasoro representation for $k = 107$. This suggests that in case of pion quark masses are compensated apart from $O(p^2)$ contributions completely by various interaction energy and the energy associated with exotic Super Virasoro representation contributes to the mass squared. This would be p-adic articulation for the statement that pion is massless Goldstone boson. Since pion represents essentially non-perturbative aspects of QCD, this raises the possibility that exotic Super Virasoro representations could provide the long sought first principle theory of low energy hadronic physics.

(a) In this theory hadrons would correspond to exotic Super Virasoro representations whereas quark-gluon plasma would correspond to ordinary p-adic Super Virasoro representations. In color confined phase p-adic α_c would have increased to the critical value $\alpha_c = p + O(p^2)$ implying dramatic drop of the real counterpart of α_c to $\alpha_c^R \simeq 1/p$ so that color interactions would disappear effectively and only electro-weak interactions and the geometric interactions between the space-time sheets would remain. What is important is that these phases can exist inside hadron for several values of p. This suggests a fractal hierarchy of hadrons inside hadrons and QCD:s inside QCD:s with the values of $\Lambda(k) \propto 1/L^2(k)$, $k = 107, 103, 101, ...$ In particular, rotational excitations would mean generation of $k = 101$ hadrons inside $k = 107$ hadrons.

(b) Hadronization and fragmentation are semi-phenomenological aspects of QCD and would correspond at fundamental level to the phase transitions between the exotic Super Virasoro representations and ordinary Super Virasoro representations. Also the concepts of sea and Pomeron could be reduced the states of exotic Super Virasoro representations associated with $k = 107, 103, 101, 97, ...$

In light of the successes of the hadron model based on super-symplectic many-particle states assigned to hadrons [K43] the exotic Super Virasoro representations do not look attractive from the point of view of ordinary hadron physics. Also the thermal instability is a good objection against them.

10.9 Appendix

10.9.1 Effective Feynman rules and the effect of top quark mass on the effective action

The effective low energy field theory relevant for $K-\bar{K}$ systems is in the standard model context summarized elegantly using the Feynman rules of effective field theory deriving from box and penguin diagrams. The rules in t'Hooft-Feynman gauge are summarized in excellent review article of Buras and Fleischer [C42]. For box diagrams the rules are following:

$$\begin{aligned} Box(\Delta S=2) &= \lambda_i^2 \frac{G_F^2}{16\pi^2} M_W^2 S_0(x_i)(\bar{s}d)_{V-A}(\bar{s}d)_{V-A} \ , \\ Box(T_3=-1/2) &= \lambda_i \frac{G_F}{\sqrt{2}} \frac{\alpha}{sin^2(\theta_W)} B_0(x_i)(\bar{s}d)_{V-A}(\bar{\mu}\mu)_{V-A} \ , \\ Box(T_3=1/2) &= \lambda_i \frac{G_F}{\sqrt{2}} \frac{\alpha}{sin^2(\theta_W)} \left[-4B_0(x_i)\right](\bar{s}d)_{V-A}(\bar{\nu}\nu)_{V-A} \ , \\ \lambda_i &= V_{is}^* V_{id} \ . \end{aligned} \tag{10.9.-2}$$

The box vertices listed here describe the decays $K_0 \rightarrow \bar{K}_0$ and contribute to $K_0 \rightarrow \bar{\mu}\mu$ and $K_0 \rightarrow \bar{\nu}\nu$ decays. $(\bar{q}_1 q_2)_{V-A}$ is shorthand notation for the left handed weak current involving gamma matrices and the products of fermionic bi-linears actually involve contraction of the gamma matrix indices.

Penguin diagrams can be characterized by the effective vertices $\bar{s}dB$, where B is photon, Z boson or gluon, which is treated as usual in effective field theory

$$\begin{aligned} \bar{s}Zd &= i\lambda_i \frac{G_F}{\sqrt{2}} \frac{g_Z}{2\pi^2} M_Z^2 g_Z C_0(x_i)\bar{s}\gamma^\mu(1-\gamma_5)d \ , \\ \bar{s}\gamma d &= -i\lambda_i \frac{G_F}{\sqrt{2}} \frac{e}{8\pi^2} D_0(x_i)\bar{s}(q^2\gamma^\mu - q^\mu q^\nu \gamma_\nu)(1-\gamma_5)d \ , \\ \bar{s}G^a d &= -i\lambda_i \frac{G_F}{\sqrt{2}} \frac{g_s}{8\pi^2} E_0(x_i)\bar{s}(q^2\gamma^\mu - q^\mu q^\nu \gamma_\nu)(1-\gamma_5)T^a d \ . \end{aligned} \tag{10.9.-3}$$

The vertices above correspond to the exchange of Z, photon and gluon between the quarks. Boson propagator and second vertex is constructed using the standard Feynman rules. The counterparts of the sdB vertices are easily constructed for $g>0$ gluons. The orthogonality of single hadron states requires that flavor is conserved for $g>0$ exchanges.

The functions $B_0, C_0, ...$ characterize the low energy effective action at mass scale $\mu = m_W$. The subscript '0' refers to the values of these functions without QCD corrections, which are taken into account using renormalization group equations to deduced the functions at mass scale of order 1 GeV. The functions are listed below:

$$
\begin{aligned}
B_0(x_t) &= \frac{1}{4}\left[\frac{x_t}{y_t}+\frac{x_t log(x_t)}{y_t^2}\right] \ , \\
C_0(x_t) &= \frac{x_t}{8}\left[-\frac{x_t-6}{y_t}+\frac{3x_t+2}{y_t^2}log(x_t)\right] \ , \\
D_0(x_t) &= -\frac{4}{9}log(x_t)-\frac{25x_t^2-19x_t^3}{36y_t^3}+\frac{x_t^2(-6-2x_t+5x_t^2)}{18y_t^3}log(x_t) \ , \\
E_0(x_t) &= -\frac{2}{3}log(x_t)+\frac{x_t^2(15-16x_t-4x_t^2)}{6y_t^4}log(x_t)+\frac{x_t(18-11x_t-x_t^2)}{12y_t^3} \ , \\
S_0(x_t) &= \frac{4x_t-11x_t^2+x_t^3}{4y_t^2}-\frac{3x_t^2log(x_t)}{2y_t^3} \ , \\
S_0(x_c,x_t) &= x_c\left[log(\frac{x_t}{x_c})-\frac{3x_t}{4y_t}-\frac{3x_t^2log(x_t)}{4y_t^2}\right] \ , \\
& \quad x_c=(\frac{m_c}{m_W})^2 \quad x_t=(\frac{m_t}{m_W})^2 \ , \quad y_t=1-x_t \ .
\end{aligned} \tag{10.9.-8}
$$

Although x_t, being the interesting parameter, appears as the only argument of these functions, also the contributions coming from light quarks propagating in the loops are included. For comparison purposes it is useful to give the explicit relations between electro-weak coupling parameters and G_F.

$$
\begin{aligned}
\frac{G_F}{\sqrt{2}} &= \frac{g_W^2}{8m_W^2} \ , \\
g_W &= \frac{e}{sin(\theta_W)} \ , \\
g_Z &= \frac{e}{sin(\theta_W)cost(\theta_W)} \ .
\end{aligned} \tag{10.9.-9}
$$

The following table summarizes the effect of the change of the top quark mass on the functions $B_0, C_0, ...$ What is given are the ratios $r(f) = f(55)/f(175)$ of the functions $B_0, C_0, ..$ evaluated for top quark masses 55 GeV and 175 GeV respectively.

f	$B_0(x_t)$	$C_0(x_t)$	$D_0(x_t)$	$E_0(x_t)$	$S_0(x_t)$	$S_0(x_c, x_t)$
r	.51	.09	$-.70$	3.44	.15	.81

(10.9.-8)

These results leave allow only the identification of the experimental candidate as a realistic candidate for top quark.

(a) The function B_0 is reduced only by a factor of 1/2 and there are no new physics contributions to B_0 in the lowest order. The function C_0 characterizing Z penguin diagrams is reduced by an order of magnitude. The coefficient $C_0(x_t) - 4B_0(x_t)$ characterizes the dominating contribution to $K \rightarrow \mu^+\mu^-$ decay in standard model and the decay amplitude is reduced by a factor .27 so that this decay would provide a stringent test selecting between 55 GeV top quark and 175 GeV top quark. Unfortunately, the predicted $K \rightarrow \mu^+\mu^-$ rate is still by several orders of magnitude below the experimental upper bound.

(b) The function $S_0(x_t)$ characterizing $B-\bar{B}$ and $K-\bar{K}$ mass differences is reduced almost by an order of magnitude. Note that in case of Δm_K the ratio $r(tt/ct)$ of the WW box diagram amplitudes with two top quarks and c and t in internal fermion lines is $r(tt/ct) \sim 738$ for $m_t = 175$ GeV and $r(tt/ct) \sim 138$ for $m_t = 55$ GeV (the moduli of the factors coming from CKM matrix are taken into account). Thus $m_t = 175$ GeV is the only sensible choice.

10.9.2 U and D matrices from the knowledge of top quark mass alone?

As already found, a possible resolution to the problems created by top quark is based on the additivity of mass squared so that top quark mass would be about 230 GeV, which indeed corresponds to a peak in mass distribution of top candidate, whereas $t\bar{t}$ meson mass would be 163 GeV. This requires that top quark mass changes very little in topological mixing. It is easy to see that the mass constraints imply that for $n_t = n_b = 60$ the smallness of V_{i3} and $V(3i)$ matrix elements implies that both U and D must be direct sums of 2×2 matrix and 1×1 unit matrix and that V matrix would have also similar decomposition. Therefore $n_b = n_t = 59$ seems to be the only number theoretically acceptable option. The comparison with the predictions with pion mass led to a unique identification $(n_d, n_b, n_b) = (5, 5, 59)$,$(n_u, n_c, n_t) = (4, 6, 59)$.

U and D matrices as perturbations of matrices mixing only the first two genera

This picture suggests that U and D matrices could be seen as small perturbations of very simple U and D matrices satisfying $|U| = |D|$ corresponding to $n = 60$ and having$(n_d, n_b, n_b) = (4, 5, 60)$, $(n_u, n_c, n_t) = (4, 5, 60)$ predicting V matrix characterized by Cabibbo angle alone. For instance, CP breaking parameter would characterize this perturbation. The perturbed matrices should obey thermodynamical constraints and it could be possible to linearize the thermodynamical conditions and in this manner to predict realistic mixing matrices from first principles. The existence of small perturbations yielding acceptable matrices implies also that these matrices be near a point at which two different matrices resulting as a solution to the thermodynamical conditions coincide.

D matrix can be deduced from U matrix since $9|D_{12}|^2 \simeq n_d$ fixes the value of the relative phase of the two terms in the expression of D_{12}.

$$\begin{aligned} |D_{12}|^2 &= |U_{11}V_{12} + U_{12}V_{22}|^2 \\ &= |U_{11}|^2|V_{12}|^2 + |U_{12}|^2|V_{22}|^2 \\ &+ 2|U_{11}||V_{12}||U_{12}||V_{22}|cos(\Psi) = \frac{n_d}{9} \ , \\ \Psi &= arg(U_{11}) + arg(V_{12}) - arg(U_{12}) - arg(V_{22}) \ . \end{aligned} \quad (10.9.-11)$$

Using the values of the moduli of U_{ij} and the approximation $|V_{22}| = 1$ this gives for $cos(\Psi)$

$$\begin{aligned} \cos(\Psi) &= \frac{A}{B} \ , \\ A &= \frac{n_d - n_u}{9} - \frac{9 - n_u}{9}|V_{12}|^2 \ , \\ B &= \frac{2}{9|V_{12}|}\sqrt{n_u(9 - n_u)} \ . \end{aligned} \quad (10.9.-12)$$

The experimentation with different values of n_d and n_u shows that $n_u = 6, n_d = 4$ gives $cos(\Psi) = -1.123$. Of course, $n_u = 6, n_d = 4$ option is not even allowed by $n_t = 60$. For $n_d = 4, n_u = 5$ one has $cos(\Psi) = -0.5958$. $n_d = 5, n_u = 6$ corresponding to the perturbed solution gives $cos(\Psi) = -0.6014$.

Hence the initial situation could be $(n_u = 5, n_s = 4, n_b = 60)$, $(n_d = 4, n_s = 5, n_t = 60)$ and the physical U and D matrices result from U and D matrices by a small perturbation as one unit of t (b) mass squared is transferred to u (s) quark and produces symmetry breaking as $(n_d = 5, n_s = t, n_b = 59)$, $(n_u = 6, n_c = 4, n_t = 59)$.

The unperturbed matrices $|U|$ and$|D|$ would be identical with $|U|$ given by

$$|U_{11}| = |U_{22}| = \frac{2}{3} \ , \quad |U_{12}| = |U_{21}| = \frac{\sqrt{5}}{3} \ , \tag{10.9.-11}$$

The thermodynamical model allows solutions reducing to a direct sum of 2×2 and 1×1 matrices, and since $|U|$ matrix is fixed completely by the mass constraints, it is trivially consistent with the thermodynamical model.

Direct search of U and D matrices

The general formulas for p^U and p^D in terms of the probabilities p_{11} and p_{21} allow straightforward search for the probability matrices having maximum entropy just by scanning the (p_{11}, p_{21}) plane constrained by the conditions that all probabilities are positive and smaller than 1. In the physically interesting case the solution is sought near a solution for which the non-vanishing probabilities are $p_{11} = p_{22} = (9 - n_1)/9$, $p_{12} = p_{21} = n_1/9$, $p_{33} = 1$, $n_1 = 4$ or 5. The inequalities allow to consider only the values $p_{11} \geq (9 - n_1)/9$.

1. Probability matrices p^U and p^D

The direct search leads to maximally entropic p^D matrix with $(n_d, n_s) = (5, 5)$:

$$p^D = \begin{pmatrix} 0.4982 & 0.4923 & 0.0095 \\ 0.4981 & 0.4924 & 0.0095 \\ 0.0037 & 0.0153 & 0.9810 \end{pmatrix} \ , \quad p_0^D = \begin{pmatrix} 0.5556 & 0.4444 & 0 \\ 0.4444 & 0.5556 & 0 \\ 0 & 0 & 1 \end{pmatrix} \ . \tag{10.9.-11}$$

p_0^D represents the unperturbed matrix p_0^D with $n(d = 4), n_s = 5$ and is included for the purpose of comparison. The entropy $S(p^D) = 1.5603$ is larger than the entropy $S(p_0^D) = 1.3739$. A possible interpretation is in terms of the spontaneous symmetry breaking induced by entropy maximization in presence of constraints.

A maximally entropic p^U matrix with $(n_u, n_c) = (5, 6)$ is given by

$$p^U = \begin{pmatrix} 0.5137 & 0.4741 & 0.0122 \\ 0.4775 & 0.4970 & 0.0254 \\ 0.0088 & 0.0289 & 0.9623 \end{pmatrix} \tag{10.9.-11}$$

The value of entropy is $S(p^U) = 1.7246$. There could be also other maxima of entropy but in the range covering almost completely the allowed range of the parameters and in the accuracy used only single maximum appears.

The probabilities p_{ii}^D *resp.* p_{ii}^U satisfy the constraint $p(i,i) \geq .492$ *resp.* $p_{ii} \geq .497$ so that the earlier proposal for the solution of proton spin crisis must be given up and the solution discussed in [K26] remains the proposal in TGD framework.

2. Near orthogonality of U and D matrices

An interesting question whether U and D matrices can be transformed to approximately orthogonal matrices by a suitable $(U(1) \times U(1))_L \times (U(1) \times U(1))_R$ transformation and whether CP breaking phase appearing in CKM matrix could reflect the small breaking of orthogonality. If this expectation is correct, it should be possible to construct from $|U|$ ($|D|$) an approximately orthogonal matrix by multiplying the matrix elements $|U_{ij}|$, $i, j \in \{2, 3\}$ by appropriate sign factors. A convenient manner to achieve this is to multiply $|U|$ ($|D|$) in an element wise manner ($(A \circ B)_{ij} = A_{ij} B_{ij}$) by a sign factor matrix S.

(a) In the case of $|U|$ the matrix $U = S \circ |U|$, $S(2,2) = S(2,3) = S(3,2) = -1$, $S_{ij} = 1$ otherwise, is approximately orthogonal as the fact that the matrix $U^T U$ given by

$$U^T U = \begin{pmatrix} 1.0000 & 0.0006 & -0.0075 \\ 0.0006 & 1.0000 & -0.0038 \\ -0.0075 & -0.0038 & 1.0000 \end{pmatrix}$$

is near unit matrix, demonstrates.

(b) For D matrix there are two nearly orthogonal variants. For $D = S \circ |D|$, $S(2,2) = S(2,3) = S(3,2) = -1$, $S_{ij} = 1$ otherwise, one has

$$D^T D = \begin{pmatrix} 1.0000 & -0.0075 & 0.0604 \\ -0.0075 & 1.0000 & 0.0143 \\ 0.0604 & 0.0143 & 1.0000 \end{pmatrix} .$$

The choice $D = S \circ D$, $S(2,2) = S(2,3) = S(3,3) = -1$, $S_{ij} = 1$ otherwise, is slightly better

$$D^T D = \begin{pmatrix} 1.0000 & -0.0075 & 0.0604 \\ -0.0075 & 1.0000 & 0.0143 \\ 0.0601 & 0.0143 & 1.0000 \end{pmatrix} .$$

3. The matrices U and D in the standard gauge

Entropy maximization indeed yields probability matrices associated with unitary matrices. 8 phase factors are possible for the matrix elements but only 4 are relevant as far as the unitarity conditions are considered. The vanishing of the inner products between row vectors, gives 6 conditions altogether so that the system seems to be over-determined. The values of the parameters s_1, s_2, s_3 and phase angle δ in the "standard gauge" can be solved in terms of r_{11} and r_{21}.

The requirement that the norms of the parameters c_i are not larger than unity poses non-trivial constraints on the probability matrices. This should should be the case since the number of unitarity conditions is 9 whereas probability conservation for columns and rows gives only 5 conditions so that not every probability matrix can define unitary matrix. It would seem that that the constraints are satisfied only if the the 2 mass squared conditions and 2 conditions from the entropy maximization are equivalent with 4 unitarity conditions so that the number of conditions becomes 5+4=9. Therefore entropy maximization and mass squared conditions would force the points of complex 9-dimensional space defined by 3×3 matrices to a 9-dimensional surface representing group $U(3)$ so that these conditions would have a group theoretic meaning.

The formulas

$$\begin{aligned} r_{i2} &= \sqrt{[-\frac{n_i}{51} + \frac{20}{17}(1 - r_{i1}^2)]} \ , \\ r_{i3} &= \sqrt{[\frac{n_i}{51} - \frac{3}{17}(1 - r_{i1}^2)]} \ . \end{aligned} \qquad (10.9.-11)$$

and

$$U = \begin{bmatrix} c_1 & s_1 c_3 & s_1 s_3 \\ -s_1 c_2 & c_1 c_2 c_3 - s_2 s_3 exp(i\delta) & c_1 c_2 s_3 + s_2 c_3 exp(i\delta) \\ -s_1 s_2 & c_1 s_2 c_3 + c_2 s_3 exp(i\delta) & c_1 s_2 s_3 - c_2 c_3 exp(i\delta) \end{bmatrix} \qquad (10.9.-10)$$

give

$$c_1 = r_{11} \ , \qquad c_2 = \frac{r_{21}}{\sqrt{1-r_{11}^2}} \ , \\ s_3 = \frac{r_{13}}{\sqrt{1-r_{11}^2}} \ , \quad cos(\delta) = \frac{c_1^2c_2^2c_3^2+s_2^2s_3^2-r_{22}^2}{2c_1c_2c_3s_2s_3} \ . \qquad (10.9.-9)$$

Preliminary calculations show that for $n_1 = n_2 = 5$ case the matrix of moduli allows a continuation to a unitary matrix but that for $n_1 = 4, n_2 = 6$ the value of $cos(\delta)$ is larger than one. This would suggest that unitarity indeed gives additional constraints on the integers n_i. The unitary (in the numerical accuracy used) $(n_d, n_s) = (5, 5)$ D matrix is given by

$$D = \begin{pmatrix} 0.7059 & 0.7016 & 0.0975 \\ -0.7057 & 0.7017 - 0.0106i & 0.0599 + 0.0766i \\ -0.0608 & 0.0005 + 0.1235i & 0.4366 - 0.8890i \end{pmatrix} \ .$$

The unitarity of this matrix supports the view that for certain integers n_i the mass squared conditions and entropy maximization reduce to group theoretic conditions. The numerical experimentation shows that the necessary condition for the unitarity is $n_1 > 4$ for $n_2 < 9$ whereas for $n_2 \geq 9$ the unitarity is achieved also for $n_1 = 4$.

Direct search for CKM matrices

The standard gauge in which the first row and first column of unitary matrix are real provides a convenient representation for the topological mixing matrices: it is convenient to refer to these representations as U_0 and D_0. The possibility to multiply the rows of U_0 and D_0 by phase factors ($(U(1) \times U(1))_R$ transformations) provides 2 independent phases affecting the values of $|V|$. The phases $exp(i\phi_j)$, $j = 2, 3$ multiplying the second and third row of D_0 can be estimated from the matrix elements of $|V|$, say from the elements $|V_{11}| = cos(\theta_c) \equiv v_{11}$, $sin\theta_c = .226 \pm .002$ and $|V_{31}| = (9.6 \pm .9) \cdot 10^{-3} \equiv v_{31}$. Hence the model would predict two parameters of the CKM matrix, say s_3 and δ_{CP}, in its standard representation.

The fact that the existing empirical bounds on the matrix elements of V are based on the standard model physics raises the question about how seriously they should be taken. The possible existence of fractally scaled up versions of light quarks could effectively reduce the matrix elements for the electro-weak decays $b \rightarrow c + W$, $b \rightarrow u + W$ *resp.* $t \rightarrow s + W$, $t \rightarrow d + W$ since the decays involving scaled up versions of light quarks can be counted as decays $W \rightarrow bc$ *resp.* $W \rightarrow tb$. This would favor too small experimental estimates for the matrix elements V_{i3} and V_{3i}, $i = 1, 2$. In particular, the matrix element $V_{31} = V_{td}$ could be larger than the accepted value.

Various constraints do not leave much freedom to choose the parameters n_{q_i}. The preliminary numerical experimentation shows that the choice $(n_d, n_s) = (5, 5)$ and $(n_u, n_c) = (5, 6)$ yields realistic U and D matrices. In particular, the conditions $|U(1, 1)| > .7$ and $|D(1, 1)| > .7$ hold true and mean that the original proposal for the solution of spin puzzle of proton must be given up. In [K26] an alternative proposal based on more recent findings is discussed. Only for this choice reasonably realistic CKM matrices have been found. For $n_t = 58$ the mass of $t\bar{t}$ meson mass is reduced by one percent from 2×163 GeV for $n(5) = 59$ so that $n_t = 58$ is still acceptable if the additivity of conformal weight rather than mass is accepted for diagonal mesons.

(a) The requirement that the parameters $|V_{11}|$ (or equivalently, Cabibbo angle) and $|V_{31}|$ are produced correctly, yields CKM matrices for which CP breaking parameter J is roughly one half of its accepted value. The matrix elements $V_{23} \equiv V_{cb}$, $V_{32} \equiv V_{tc}$, and $V_{13} \equiv V_{ub}$ are roughly twice their accepted value. This suggests that the condition on V_{31} should be loosened.

(b) The following tables summarize the results of the search requiring that
i) the value of the Cabibbo angle s_{Cab} is within the experimental limits $s_{Cab} = .223 \pm .002$

,
ii) $V_{31} = (9.6 \pm .9) \cdot 10^{-3}$, is allowed to have value at most twice its upper bound,
iii) V_{13} whose upper bound is determined by probability conservation, is within the experimental limits $.42 \cdot 10^{-3} < |V_{ub}| < 6.98 \cdot 10^{-3}$ whereas $V_{23} \simeq 4 \times 10^{-3}$ should come out as a prediction,
iv) the CP breaking parameter satisfies the condition $|(J - J_0)/J_0| < .6$, where $J_0 = 10^{-4}$ represents the lower bound for J (the experimental bounds for J are $J \times 10^4 \in (1-1.7)$).

The pairs of the phase angles (ϕ_1, ϕ_2) defining the phases $(exp(i\phi_1), exp(i\phi_2))$ are listed below

$$\begin{array}{llcccc} class \;\; 1: & \phi_1 & 0.1005 & 0.1005 & 4.8129 & 4.8129 \\ & \phi_2 & 0.0754 & 1.4828 & 4.7878 & 6.1952 \\ class \;\; 2: & \phi_1 & 0.1005 & 0.1005 & 4.8129 & 4.8129 \\ & \phi_2 & 2.3122 & 5.5292 & 0.7414 & 3.9584 \end{array} \tag{10.9.-9}$$

The phase angle pairs correspond to two different classes of U, D, and V matrices. The U, D and V matrices inside each class are identical at least up to 11 digits(!). Very probably the phase angle pairs are related by some kind of symmetry.

The values of the fitted parameters for the two classes are given by

	$\vert V_{11}\vert$	$\vert V_{31}\vert$	$\vert V_{13}\vert$	$J/10^{-4}$
class 1	0.9740	0.0157	0.0069	.93953
class 2	0.9740	0.0164	0.0067	1.0267

V_{31} is predicted to be about 1.6 times larger than the experimental upper bound and for both classes V_{23} and V_{32} are roughly too times too large. Otherwise the fit is consistent with the experimental limits for class 2. For class 1 the CP breaking parameter is 7 per cent below the experimental lower bound. In fact, the value of J is fixed already by the constraints on V_{31} and V_{11} and reduces by a factor of one half if V_{31} is required to be within its experimental limits.

U, D and $|V|$ matrices for class 1 are given by

$$U = \left[\begin{array}{ccc} 0.7167 & 0.6885 & 0.1105 \\ -0.6910 & 0.7047 - 0.0210i & 0.0909 + 0.1310i \\ -0.0938 & 0.0696 + 0.1550i & 0.1747 - 0.9653i \end{array}\right]$$

$$D = \left[\begin{array}{ccc} 0.7059 & 0.7016 & 0.0975 \\ -0.6347 - 0.3085i & 0.6358 + 0.2972i & 0.0203 + 0.0951i \\ -0.0587 - 0.0159i & -0.0317 + 0.1194i & 0.6534 - 0.7444i \end{array}\right]$$

$$|V| = \left[\begin{array}{ccc} 0.9740 & 0.2265 & 0.0069 \\ 0.2261 & 0.9703 & 0.0862 \\ 0.0157 & 0.0850 & 0.9963 \end{array}\right] \tag{10.9.-11}$$

U, D and $|V|$ matrices for class 2 are given by

$$U = \begin{bmatrix} 0.7167 & 0.6885 & 0.1105 \\ -0.6910 & 0.7047 - 0.0210i & 0.0909 + 0.1310i \\ -0.0938 & 0.0696 + 0.1550i & 0.1747 - 0.9653i \end{bmatrix}$$

$$D = \begin{bmatrix} 0.7059 & 0.7016 & 0.0975 \\ -0.6347 - 0.3085i & 0.6358 + 0.2972i & 0.0203 + 0.0951i \\ -0.0589 - 0.0151i & -0.0302 + 0.1198i & 0.6440 - 0.7525i \end{bmatrix}$$

$$|V| = \begin{bmatrix} 0.9740 & 0.2265 & 0.0067 \\ 0.2260 & 0.9704 & 0.0851 \\ 0.0164 & 0.0838 & 0.9963 \end{bmatrix} \quad (10.9.-13)$$

What raises worries is that the values of $|V_{23}| = |V_{cb}|$ and $|V_{32}| = |V_{ts}|$ are roughly twice their experimental estimates. This, as well as the discrepancy related to V_{31}, might be understood in terms of the electro-weak decays of b and t to scaled up quarks causing a reduction of the branching ratios $b \rightarrow c + W$, $t \rightarrow s + W$ and $t \rightarrow t + d$. The attempts to find more successful integer combinations n_i has failed hitherto. The model for pseudo-scalar meson masses, the predicted relatively small masses of light quarks, and the explanation for $t\bar{t}$ meson mass supports this mixing scenario.

10.10 Figures and Illustrations

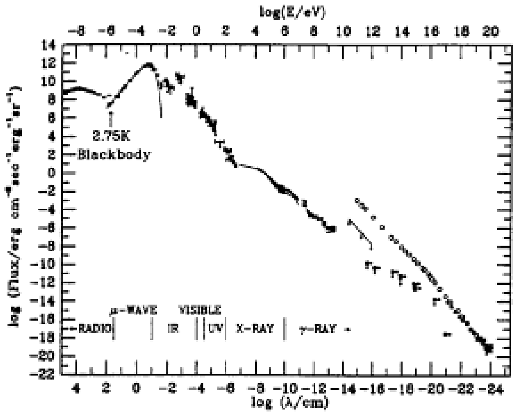

Figure 10.1: There are some indications that cosmic gamma ray flux contains a peak in the energy interval $10^{10} - 10^{11}$ eV. Figure is taken from [C161] .

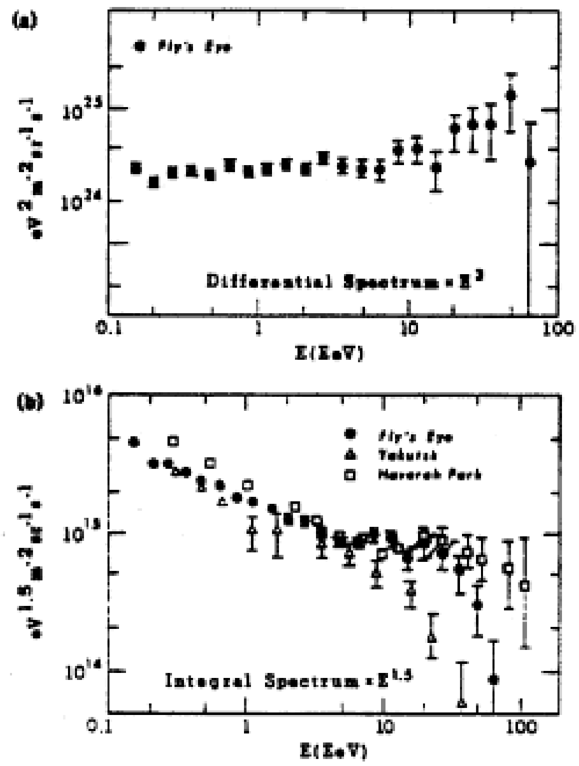

FIG. 2. (a) Differential spectrum $J(E)$ plotted as $E^3J(E)$. A power-law best fit of the form $J(E)=aE^{-\gamma}$ yields $a=109.6\pm2.2$ EeV^{-1} km^{-2} sr^{-1} yr^{-1} and $\gamma=2.94\pm0.02$ for events at $E<10$ EeV. Between 10 and 50 EeV we obtain $a=34\pm17$ EeV^{-1} km^{-2} sr^{-1} yr^{-1} and $\gamma=2.42\pm0.27$. The lack of events above 50 EeV indicates that the flattened slope does not continue. (b) Integral spectrum $I(>E)$ plotted as $E^{1.5}I(>E)$. Data from both Haverah Park and Yakutsk (Refs. 10, 12, and 13) experiments are also shown.

Figure 10.2:

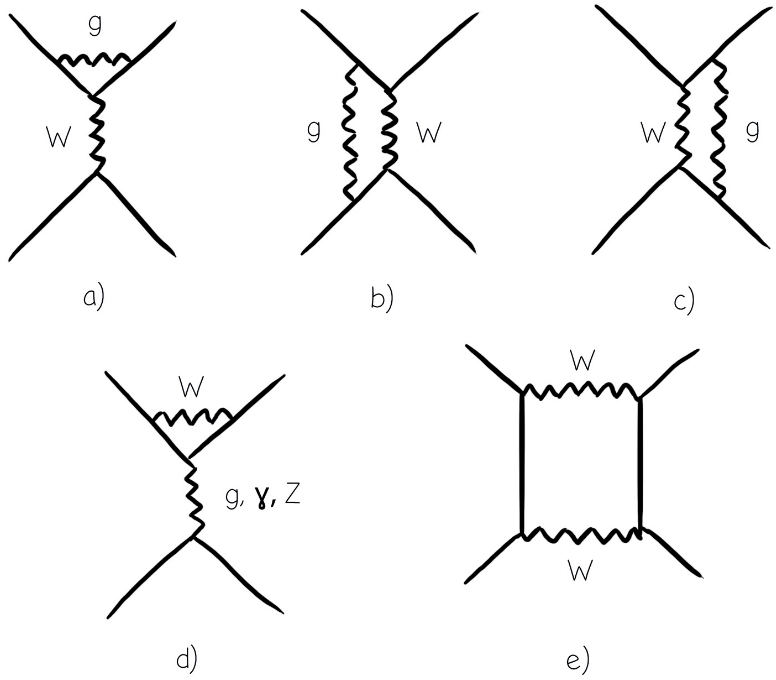

Figure 10.3: Standard model contributions to the matching of the quark operators in the effective flavor-changing Lagrangian

Chapter 1

Appendix

Originally this appendix was meant to be a purely technical summary of basic facts but in its recent form it tries to briefly summarize those basic visions about TGD which I dare to regarded stabilized. I have added illustrations making it easier to build mental images about what is involved and represented briefly the key arguments. This chapter is hoped to help the reader to get fast grasp about the concepts of TGD.

The basic properties of imbedding space and related spaces are discussed and the relationship of CP_2 to standard model is summarized. The notions of induction of metric and spinor connection, and of spinor structure are discussed. Many-sheeted space-time and related notions such as topological field quantization and the relationship many-sheeted space-time to that of GRT space-time are discussed as well as the recent view about induced spinor fields and the emergence of fermionic strings. Various topics related to p-adic numbers are summarized with a brief definition of p-adic manifold and the idea about generalization of the number concept by gluing real and p-adic number fields to a larger book like structure. Hierarchy of Planck constants can be now understood in terms of the non-determinism of Kähler action and the recent vision about connections to other key ideas is summarized.

A-1 Imbedding space $M^4 \times CP_2$ and related notions

Space-times are regarded as 4-surfaces in $H = M^4 \times CP_2$ the Cartesian product of empty Minkowski space - the space-time of special relativity - and compact 4-D space CP_2 with size scale of order 10^4 Planck lengths. One can say that imbedding space is obtained by replacing each point m of empty Minkowski space with 4-D tiny CP_2. The space-time of general relativity is replaced by a 4-D surface in H which has very complex topology. The notion of many-sheeted space-time gives an idea about what is involved.

Fig. 1. Imbedding space $H = M^4 \times CP_2$ as Cartesian product of Minkowski space M^4 and complex projective space CP_2. `http://www.tgdtheory.fi/appfigures/Hoo.jpg`

Denote by M^4_+ and M^4_- the future and past directed lightcones of M^4. Denote their intersection, which is not unique, by CD. In zero energy ontology (ZEO) causal diamond (CD) is defined as cartesian product $CD \times CP_2$. Often I use CD to refer just to $CD \times CP_2$ since CP_2 factor is relevant from the point of view of ZEO.

Fig. 2. Future and past light-cones M^4_+ and M^4_-. Causal diamonds (CD) are defined as their intersections. `http://www.tgdtheory.fi/appfigures/futurepast.jpg`

Fig. 3. Causal diamond (CD) is highly analogous to Penrose diagram but simpler. `http://www.tgdtheory.fi/appfigures/penrose.jpg`

A rather recent discovery was that CP_2 is the only compact 4-manifold with Euclidian signature of metric allowing twistor space with Kähler structure. M^4 is in turn is the only 4-D space with Minkowskian signature of metric allowing twistor space with Kähler structure so that $H = M^4 \times CP_2$ is twistorially unique.

One can loosely say that quantum states in a given sector of "world of classical worlds" (WCW) are superpositions of space-time surfaces inside CDs and that positive and negative energy parts of zero energy states are localized and past and future boundaries of CDs. CDs form a hierarchy. One can have CDs within CDs and CDs can also overlap. The size of CD is characterized by the proper time distance between its two tips. One can perform both translations and also Lorentz boosts of CD leaving either boundary invariant. Therefore one can assign to CDs a moduli space and speak about wave function in this moduli space.

In number theoretic approach it is natural to restrict the allowed Lorentz boosts to some discrete subgroup of Lorentz group and also the distances between the tips of CDs to multiples of CP_2 radius defined by the length of its geodesic. Therefore the moduli space of CDs discretizes. The quantization of cosmic recession velocities for which there are indications, could relate to this quantization.

A-2 Basic facts about CP_2

CP_2 as a four-manifold is very special. The following arguments demonstrates that it codes for the symmetries of standard models via its isometries and holonomies.

A-2.1 CP_2 as a manifold

CP_2, the complex projective space of two complex dimensions, is obtained by identifying the points of complex 3-space C^3 under the projective equivalence

$$(z^1, z^2, z^3) \equiv \lambda(z^1, z^2, z^3) \ . \tag{A-2.1}$$

Here λ is any non-zero complex number. Note that CP_2 can be also regarded as the coset space $SU(3)/U(2)$. The pair z^i/z^j for fixed j and $z^i \neq 0$ defines a complex coordinate chart for CP_2. As j runs from 1 to 3 one obtains an atlas of three coordinate charts covering CP_2, the charts being holomorphically related to each other (e.g. CP_2 is a complex manifold). The points $z^3 \neq 0$ form a subset of CP_2 homoeomorphic to R^4 and the points with $z^3 = 0$ a set homeomorphic to S^2. Therefore CP_2 is obtained by "adding the 2-sphere at infinity to R^4".

Besides the standard complex coordinates $\xi^i = z^i/z^3$, $i = 1, 2$ the coordinates of Eguchi and Freund [A39] will be used and their relation to the complex coordinates is given by

$$\begin{aligned} \xi^1 &= z + it \ , \\ \xi^2 &= x + iy \ . \end{aligned} \tag{A-2.1}$$

These are related to the "spherical coordinates" via the equations

$$\begin{aligned} \xi^1 &= rexp(i\frac{(\Psi + \Phi)}{2})cos(\frac{\Theta}{2}) \ , \\ \xi^2 &= rexp(i\frac{(\Psi - \Phi)}{2})sin(\frac{\Theta}{2}) \ . \end{aligned} \tag{A-2.1}$$

The ranges of the variables r, Θ, Φ, Ψ are $[0, \infty], [0, \pi], [0, 4\pi], [0, 2\pi]$ respectively.

Considered as a real four-manifold CP_2 is compact and simply connected, with Euler number Euler number 3, Pontryagin number 3 and second $b=1$.

Fig. 4. CP_2 as manifold. `http://www.tgdtheory.fi/appfigures/cp2.jpg`

A-2.2 Metric and Kähler structure of CP_2

In order to obtain a natural metric for CP_2, observe that CP_2 can be thought of as a set of the orbits of the isometries $z^i \rightarrow exp(i\alpha)z^i$ on the sphere S^5: $\sum z^i\bar{z}^i = R^2$. The metric of CP_2 is obtained by projecting the metric of S^5 orthogonally to the orbits of the isometries. Therefore the distance between the points of CP_2 is that between the representative orbits on S^5.

The line element has the following form in the complex coordinates

$$ds^2 = g_{a\bar{b}}d\xi^a d\bar{\xi}^b \ , \quad \text{(A-2.2)}$$

where the Hermitian, in fact Kähler metric $g_{a\bar{b}}$ is defined by

$$g_{a\bar{b}} = R^2\partial_a\partial_{\bar{b}}K \ , \quad \text{(A-2.3)}$$

where the function K, Kähler function, is defined as

$$\begin{aligned} K &= log(F) \ , \\ F &= 1+r^2 \ . \end{aligned} \quad \text{(A-2.3)}$$

The Kähler function for S^2 has the same form. It gives the S^2 metric $dzd\bar{z}/(1+r^2)^2$ related to its standard form in spherical coordinates by the coordinate transformation $(r,\phi) = (tan(\theta/2),\phi)$.

The representation of the CP_2 metric is deducible from S^5 metric is obtained by putting the angle coordinate of a geodesic sphere constant in it and is given

$$\frac{ds^2}{R^2} = \frac{(dr^2+r^2\sigma_3^2)}{F^2} + \frac{r^2(\sigma_1^2+\sigma_2^2)}{F} \ , \quad \text{(A-2.4)}$$

where the quantities σ_i are defined as

$$\begin{aligned} r^2\sigma_1 &= Im(\xi^1 d\xi^2 - \xi^2 d\xi^1) \ , \\ r^2\sigma_2 &= -Re(\xi^1 d\xi^2 - \xi^2 d\xi^1) \ , \\ r^2\sigma_3 &= -Im(\xi^1 d\bar{\xi}^1 + \xi^2 d\bar{\xi}^2) \ . \end{aligned} \quad \text{(A-2.3)}$$

R denotes the radius of the geodesic circle of CP_2. The vierbein forms, which satisfy the defining relation

$$s_{kl} = R^2\sum_A e_k^A e_l^A \ , \quad \text{(A-2.4)}$$

are given by

$$\begin{array}{lllllll} e^0 & = & \frac{dr}{F} & , & e^1 & = & \frac{r\sigma_1}{\sqrt{F}} & , \\ e^2 & = & \frac{r\sigma_2}{\sqrt{F}} & , & e^3 & = & \frac{r\sigma_3}{F} & . \end{array} \quad \text{(A-2.5)}$$

The explicit representations of vierbein vectors are given by

$$\begin{array}{lllllll} e^0 & = & \frac{dr}{F} & , & e^1 & = & \frac{r(sin\Theta cos\Psi d\Phi+sin\Psi d\Theta)}{2\sqrt{F}} & , \\ e^2 & = & \frac{r(sin\Theta sin\Psi d\Phi-cos\Psi d\Theta)}{2\sqrt{F}} & , & e^3 & = & \frac{r(d\Psi+cos\Theta d\Phi)}{2F} & . \end{array}$$

(A-2.5)

The explicit representation of the line element is given by the expression

$$ds^2/R^2 = \frac{dr^2}{F^2} + \frac{r^2}{4F^2}(d\Psi + cos\Theta d\Phi)^2 + \frac{r^2}{4F}(d\Theta^2 + sin^2\Theta d\Phi^2) \ .$$

(A-2.5)

The vierbein connection satisfying the defining relation

$$de^A = -V^A_B \wedge e^B \ , \quad \text{(A-2.6)}$$

is given by

$$\begin{array}{lllllll} V_{01} & = & -\frac{e^1}{r} & , & V_{23} & = & \frac{e^1}{r} & , \\ V_{02} & = & -\frac{e^2}{r} & , & V_{31} & = & \frac{e^2}{r} & , \\ V_{03} & = & (r-\frac{1}{r})e^3 & , & V_{12} & = & (2r+\frac{1}{r})e^3 & . \end{array} \quad \text{(A-2.7)}$$

The representation of the covariantly constant curvature tensor is given by

$$\begin{array}{lllllll} R_{01} & = & e^0\wedge e^1 - e^2\wedge e^3 & , & R_{23} & = & e^0\wedge e^1 - e^2\wedge e^3 & , \\ R_{02} & = & e^0\wedge e^2 - e^3\wedge e^1 & , & R_{31} & = & -e^0\wedge e^2 + e^3\wedge e^1 & , \\ R_{03} & = & 4e^0\wedge e^3 + 2e^1\wedge e^2 & , & R_{12} & = & 2e^0\wedge e^3 + 4e^1\wedge e^2 & . \end{array} \quad \text{(A-2.8)}$$

Metric defines a real, covariantly constant, and therefore closed 2-form J

$$J = -ig_{a\bar{b}}d\xi^a d\bar{\xi}^b \ , \quad \text{(A-2.9)}$$

the so called Kähler form. Kähler form J defines in CP_2 a symplectic structure because it satisfies the condition

$$J^k_{\ r}J^{rl} = -s^{kl} \ . \quad \text{(A-2.10)}$$

The form J is integer valued and by its covariant constancy satisfies free Maxwell equations. Hence it can be regarded as a curvature form of a $U(1)$ gauge potential B carrying a magnetic charge of unit $1/2g$ (g denotes the gauge coupling). Locally one has therefore

$$J = dB \ , \tag{A-2.11}$$

where B is the so called Kähler potential, which is not defined globally since J describes homological magnetic monopole.

It should be noticed that the magnetic flux of J through a 2-surface in CP_2 is proportional to its homology equivalence class, which is integer valued. The explicit representations of J and B are given by

$$\begin{aligned} B &= 2re^3 \ , \\ J &= 2(e^0 \wedge e^3 + e^1 \wedge e^2) = \frac{r}{F^2} dr \wedge (d\Psi + cos\Theta d\Phi) + \frac{r^2}{2F} sin\Theta d\Theta d\Phi \ . \end{aligned} \tag{A-2.10}$$

The vierbein curvature form and Kähler form are covariantly constant and have in the complex coordinates only components of type (1,1).

Useful coordinates for CP_2 are the so called canonical coordinates in which Kähler potential and Kähler form have very simple expressions

$$\begin{aligned} B &= \sum_{k=1,2} P_k dQ_k \ , \\ J &= \sum_{k=1,2} dP_k \wedge dQ_k \ . \end{aligned} \tag{A-2.10}$$

The relationship of the canonical coordinates to the "spherical" coordinates is given by the equations

$$\begin{aligned} P_1 &= -\frac{1}{1+r^2} \ , \\ P_2 &= \frac{r^2 cos\Theta}{2(1+r^2)} \ , \\ Q_1 &= \Psi \ , \\ Q_2 &= \Phi \ . \end{aligned} \tag{A-2.8}$$

A-2.3 Spinors in CP_2

CP_2 doesn't allow spinor structure in the conventional sense [A37] . However, the coupling of the spinors to a half odd multiple of the Kähler potential leads to a respectable spinor structure. Because the delicacies associated with the spinor structure of CP_2 play a fundamental role in TGD, the arguments of Hawking are repeated here.

To see how the space can fail to have an ordinary spinor structure consider the parallel transport of the vierbein in a simply connected space M. The parallel propagation around a closed curve with a base point x leads to a rotated vierbein at x: $e^A = R^A_B e^B$ and one can associate to each closed path an element of $SO(4)$.

Consider now a one-parameter family of closed curves $\gamma(v) : v \in (0,1)$ with the same base point x and $\gamma(0)$ and $\gamma(1)$ trivial paths. Clearly these paths define a sphere S^2 in M and the element $R^A_B(v)$ defines a closed path in $SO(4)$. When the sphere S^2 is contractible to a point e.g., homologically trivial, the path in $SO(4)$ is also contractible to a point and therefore represents a trivial element of the homotopy group $\Pi_1(SO(4)) = Z_2$.

For a homologically nontrivial 2-surface S^2 the associated path in $SO(4)$ can be homotopically nontrivial and therefore corresponds to a nonclosed path in the covering group Spin(4) (leading from the matrix 1 to -1 in the matrix representation). Assume this is the case.

Assume now that the space allows spinor structure. Then one can parallel propagate also spinors and by the above construction associate a closed path of Spin(4) to the surface S^2. Now, however this path corresponds to a lift of the corresponding $SO(4)$ path and cannot be closed. Thus one ends up with a contradiction.

From the preceding argument it is clear that one could compensate the non-allowed -1- factor associated with the parallel transport of the spinor around the sphere S^2 by coupling it to a gauge potential in such a way that in the parallel transport the gauge potential introduces a compensating -1-factor. For a $U(1)$ gauge potential this factor is given by the exponential $exp(i2\Phi)$, where Φ is the magnetic flux through the surface. This factor has the value -1 provided the $U(1)$ potential carries half odd multiple of Dirac charge $1/2g$. In case of CP_2 the required gauge potential is half odd multiple of the Kähler potential B defined previously. In the case of $M^4 \times CP_2$ one can in addition couple the spinor components with different chiralities independently to an odd multiple of $B/2$.

A-2.4 Geodesic sub-manifolds of CP_2

Geodesic sub-manifolds are defined as sub-manifolds having common geodesic lines with the imbedding space. As a consequence the second fundamental form of the geodesic manifold vanishes, which means that the tangent vectors h^k_α (understood as vectors of H) are covariantly constant quantities with respect to the covariant derivative taking into account that the tangent vectors are vectors both with respect to H and X^4.

In [A32] a general characterization of the geodesic sub-manifolds for an arbitrary symmetric space G/H is given. Geodesic sub-manifolds are in 1-1-correspondence with the so called Lie triple systems of the Lie-algebra g of the group G. The Lie triple system t is defined as a subspace of g characterized by the closedness property with respect to double commutation

$$[X,[Y,Z]] \in t \ \text{ for } \ X,Y,Z \in t \ . \tag{A-2.9}$$

$SU(3)$ allows, besides geodesic lines, two nonequivalent (not isometry related) geodesic spheres. This is understood by observing that $SU(3)$ allows two nonequivalent $SU(2)$ algebras corresponding to subgroups $SO(3)$ (orthogonal 3×3 matrices) and the usual isospin group $SU(2)$. By taking any subset of two generators from these algebras, one obtains a Lie triple system and by exponentiating this system, one obtains a 2-dimensional geodesic sub-manifold of CP_2.

Standard representatives for the geodesic spheres of CP_2 are given by the equations

$$S^2_I \ : \ \xi^1 = \bar{\xi}^2 \ \text{ or equivalently } \ (\Theta = \pi/2, \Psi = 0) \ ,$$

$$S^2_{II} \ : \ \xi^1 = \xi^2 \ \text{ or equivalently } \ (\Theta = \pi/2, \Phi = 0) \ .$$

The non-equivalence of these sub-manifolds is clear from the fact that isometries act as holomorphic transformations in CP_2. The vanishing of the second fundamental form is also easy to verify. The first geodesic manifold is homologically trivial: in fact, the induced Kähler form vanishes identically for S^2_I. S^2_{II} is homologically nontrivial and the flux of the Kähler form gives its homology equivalence class.

A-3 CP_2 geometry and standard model symmetries

A-3.1 Identification of the electro-weak couplings

The delicacies of the spinor structure of CP_2 make it a unique candidate for space S. First, the coupling of the spinors to the $U(1)$ gauge potential defined by the Kähler structure provides the missing $U(1)$ factor in the gauge group. Secondly, it is possible to couple different H-chiralities independently to a half odd multiple of the Kähler potential. Thus the hopes of obtaining a correct spectrum for the electromagnetic charge are considerable. In the following it will be demonstrated that the couplings of the induced spinor connection are indeed those of the GWS model [B20] and in particular that the right handed neutrinos decouple completely from the electro-weak interactions.

To begin with, recall that the space H allows to define three different chiralities for spinors. Spinors with fixed H-chirality $e = \pm 1$, CP_2-chirality l, r and M^4-chirality L, R are defined by the condition

$$\begin{aligned} \Gamma\Psi &= e\Psi \ , \\ e &= \pm 1 \ , \end{aligned} \tag{A-3.0}$$

where Γ denotes the matrix $\Gamma_9 = \gamma_5 \times \gamma_5$, $1 \times \gamma_5$ and $\gamma_5 \times 1$ respectively. Clearly, for a fixed H-chirality CP_2- and M^4-chiralities are correlated.

The spinors with H-chirality $e = \pm 1$ can be identified as quark and lepton like spinors respectively. The separate conservation of baryon and lepton numbers can be understood as a consequence of generalized chiral invariance if this identification is accepted. For the spinors with a definite H-chirality one can identify the vielbein group of CP_2 as the electro-weak group: $SO(4) = SU(2)_L \times SU(2)_R$.

The covariant derivatives are defined by the spinorial connection

$$A = V + \frac{B}{2}(n_+ 1_+ + n_- 1_-) \ . \tag{A-3.1}$$

Here V and B denote the projections of the vielbein and Kähler gauge potentials respectively and $1_{+(-)}$ projects to the spinor H-chirality $+(-)$. The integers $n_\pm$ are odd from the requirement of a respectable spinor structure.

The explicit representation of the vielbein connection V and of B are given by the equations

$$\begin{aligned} V_{01} &= -\frac{e^1}{r} \ , & V_{23} &= \frac{e^1}{r} \ , \\ V_{02} &= -\frac{e^2}{r} \ , & V_{31} &= \frac{e^2}{r} \ , \\ V_{03} &= (r - \frac{1}{r})e^3 \ , & V_{12} &= (2r + \frac{1}{r})e^3 \ , \end{aligned} \tag{A-3.2}$$

and

$$B = 2re^3 \ , \tag{A-3.3}$$

respectively. The explicit representation of the vielbein is not needed here.

Let us first show that the charged part of the spinor connection couples purely left handedly. Identifying Σ^0_3 and Σ^1_2 as the diagonal (neutral) Lie-algebra generators of $SO(4)$, one finds that the charged part of the spinor connection is given by

$$A_{ch} = 2V_{23}I_L^1 + 2V_{13}I_L^2 \ , \tag{A-3.4}$$

where one have defined

$$\begin{aligned} I_L^1 &= \frac{(\Sigma_{01} - \Sigma_{23})}{2} \ , \\ I_L^2 &= \frac{(\Sigma_{02} - \Sigma_{13})}{2} \ . \end{aligned} \tag{A-3.4}$$

A_{ch} is clearly left handed so that one can perform the identification

$$W^{\pm} = \frac{2(e^1 \pm ie^2)}{r} \ , \tag{A-3.5}$$

where $W^{\pm}$ denotes the charged intermediate vector boson.

Consider next the identification of the neutral gauge bosons γ and Z^0 as appropriate linear combinations of the two functionally independent quantities

$$\begin{aligned} X &= re^3 \ , \\ Y &= \frac{e^3}{r} \ , \end{aligned} \tag{A-3.5}$$

appearing in the neutral part of the spinor connection. We show first that the mere requirement that photon couples vectorially implies the basic coupling structure of the GWS model leaving only the value of Weinberg angle undetermined.

To begin with let us define

$$\begin{aligned} \bar{\gamma} &= aX + bY \ , \\ \bar{Z}^0 &= cX + dY \ , \end{aligned} \tag{A-3.5}$$

where the normalization condition

$$ad - bc = 1 \ ,$$

is satisfied. The physical fields γ and Z^0 are related to $\bar{\gamma}$ and $\bar{Z}^0$ by simple normalization factors.

Expressing the neutral part of the spinor connection in term of these fields one obtains

$$\begin{aligned} A_{nc} &= [(c+d)2\Sigma_{03} + (2d-c)2\Sigma_{12} + d(n_+1_+ + n_-1_-)]\bar{\gamma} \\ &+ [(a-b)2\Sigma_{03} + (a-2b)2\Sigma_{12} - b(n_+1_+ + n_-1_-)]\bar{Z}^0 \ . \end{aligned} \tag{A-3.4}$$

Identifying Σ_{12} and $\Sigma_{03} = 1\times\gamma_5\Sigma_{12}$ as vectorial and axial Lie-algebra generators, respectively, the requirement that γ couples vectorially leads to the condition

$$c = -d \ . \tag{A-3.5}$$

Using this result plus previous equations, one obtains for the neutral part of the connection the expression

$$A_{nc} = \gamma Q_{em} + Z^0(I_L^3 - sin^2\theta_W Q_{em}) \ . \tag{A-3.6}$$

Here the electromagnetic charge Q_{em} and the weak isospin are defined by

$$\begin{aligned} Q_{em} &= \Sigma^{12} + \frac{(n_+1_+ + n_-1_-)}{6} \ , \\ I_L^3 &= \frac{(\Sigma^{12} - \Sigma^{03})}{2} \ . \end{aligned} \tag{A-3.6}$$

The fields γ and Z^0 are defined via the relations

$$\begin{aligned} \gamma &= 6d\bar{\gamma} = \frac{6}{(a+b)}(aX + bY) \ , \\ Z^0 &= 4(a+b)\bar{Z}^0 = 4(X - Y) \ . \end{aligned} \tag{A-3.6}$$

The value of the Weinberg angle is given by

$$sin^2\theta_W = \frac{3b}{2(a+b)} \ , \tag{A-3.7}$$

and is not fixed completely. Observe that right handed neutrinos decouple completely from the electro-weak interactions.

The determination of the value of Weinberg angle is a dynamical problem. The angle is completely fixed once the YM action is fixed by requiring that action contains no cross term of type γZ^0. Pure symmetry non-broken electro-weak YM action leads to a definite value for the Weinberg angle. One can however add a symmetry breaking term proportional to Kähler action and this changes the value of the Weinberg angle.

To evaluate the value of the Weinberg angle one can express the neutral part F_{nc} of the induced gauge field as

$$F_{nc} = 2R_{03}\Sigma^{03} + 2R_{12}\Sigma^{12} + J(n_+1_+ + n_-1_-) \ , \tag{A-3.8}$$

where one has

$$\begin{aligned} R_{03} &= 2(2e^0 \wedge e^3 + e^1 \wedge e^2) \ , \\ R_{12} &= 2(e^0 \wedge e^3 + 2e^1 \wedge e^2) \ , \\ J &= 2(e^0 \wedge e^3 + e^1 \wedge e^2) \ , \end{aligned} \tag{A-3.7}$$

in terms of the fields γ and Z^0 (photon and Z- boson)

$$F_{nc} = \gamma Q_{em} + Z^0(I_L^3 - sin^2\theta_W Q_{em}) \ . \tag{A-3.8}$$

Evaluating the expressions above one obtains for γ and Z^0 the expressions

$$\begin{aligned} \gamma &= 3J - sin^2\theta_W R_{03} \ , \\ Z^0 &= 2R_{03} \ . \end{aligned} \tag{A-3.8}$$

For the Kähler field one obtains

$$J = \frac{1}{3}(\gamma + sin^2\theta_W Z^0) \ . \tag{A-3.9}$$

Expressing the neutral part of the symmetry broken YM action

$$\begin{aligned} L_{ew} &= L_{sym} + fJ^{\alpha\beta}J_{\alpha\beta} \ , \\ L_{sym} &= \frac{1}{4g^2}Tr(F^{\alpha\beta}F_{\alpha\beta}) \ , \end{aligned} \tag{A-3.9}$$

where the trace is taken in spinor representation, in terms of γ and Z^0 one obtains for the coefficient X of the γZ^0 cross term (this coefficient must vanish) the expression

$$\begin{aligned} X &= -\frac{K}{2g^2} + \frac{fp}{18} \ , \\ K &= Tr\left[Q_{em}(I_L^3 - sin^2\theta_W Q_{em})\right] \ , \end{aligned} \tag{A-3.9}$$

In the general case the value of the coefficient K is given by

$$K = \sum_i \left[-\frac{(18+2n_i^2)sin^2\theta_W}{9}\right] \ , \tag{A-3.10}$$

where the sum is over the spinor chiralities, which appear as elementary fermions and n_i is the integer describing the coupling of the spinor field to the Kähler potential. The cross term vanishes provided the value of the Weinberg angle is given by

$$sin^2\theta_W = \frac{9\sum_i 1}{(fg^2 + 2\sum_i(18+n_i^2))} \ . \tag{A-3.11}$$

In the scenario where both leptons and quarks are elementary fermions the value of the Weinberg angle is given by

$$sin^2\theta_W = \frac{9}{(\frac{fg^2}{2} + 28)} \ . \tag{A-3.12}$$

The bare value of the Weinberg angle is 9/28 in this scenario, which is quite close to the typical value 9/24 of GUTs [B30] .

A-3.2 Discrete symmetries

The treatment of discrete symmetries C, P, and T is based on the following requirements:

(a) Symmetries must be realized as purely geometric transformations.

(b) Transformation properties of the field variables should be essentially the same as in the conventional quantum field theories [B9] .

The action of the reflection P on spinors of is given by

$$\Psi \quad \rightarrow \quad P\Psi = \gamma^0 \otimes \gamma^0 \Psi \quad . \tag{A-3.13}$$

in the representation of the gamma matrices for which γ^0 is diagonal. It should be noticed that W and Z^0 bosons break parity symmetry as they should since their charge matrices do not commute with the matrix of P.

The guess that a complex conjugation in CP_2 is associated with T transformation of the physicist turns out to be correct. One can verify by a direct calculation that pure Dirac action is invariant under T realized according to

$$\begin{aligned} m^k &\rightarrow T(M^k) \ , \\ \xi^k &\rightarrow \bar{\xi}^k \ , \\ \Psi &\rightarrow \gamma^1\gamma^3 \otimes 1\Psi \ . \end{aligned} \tag{A-3.12}$$

The operation bearing closest resemblance to the ordinary charge conjugation corresponds geometrically to complex conjugation in CP_2:

$$\begin{aligned} \xi^k &\rightarrow \bar{\xi}^k \ , \\ \Psi &\rightarrow \Psi^\dagger\gamma^2\gamma^0 \otimes 1 \ . \end{aligned} \tag{A-3.12}$$

As one might have expected symmetries CP and T are exact symmetries of the pure Dirac action.

A-4 The relationship of TGD to QFT and string models

TGD could be seen as a generalization of quantum field theory (string models) obtained by replacing pointlike particles (strings) as fundamental objects with 3-surfaces.

Fig. 5. TGD replaces point-like particles with 3-surfaces. `http://www.tgdtheory.fi/appfigures/particletgd.jpg`

The fact that light-like 3-surfaces are effectively metrically 2-dimensional and thus possess generalization of 2-dimensional conformal symmetries with light-like radial coordinate defining the analog of second complex coordinate suggests that this generalization could work and extend the super-conformal symmetries to their 4-D analogs.

The boundary $\delta M^4_+ = S^2 \times R_+$- of 4-D light-cone M^4_+ is also metrically 2-dimensional and allows extended conformal invariance. Also the group of isometries of light-cone boundary and of light-like 3-surfaces is infinite-dimensional since the conformal scalings of S^2 can be compensated by S^2-local scaling of the light-like radial coordinate of R_+. These simple facts mean that 4-dimensional Minkowski space and 4-dimensional space-time surfaces are in completely unique position as far as symmetries are considered.

String like objects obtained as deformations of cosmic strings $X^2 \times Y^2$, where X^2 is minimal surface in M^4 and Y^2 a holomorphic surface of CP_2 are fundamental extremals of Kähler action having string world sheet as M^4 projections. Cosmic strings dominate the primordial cosmology of TGD Universe and inflationary period corresponds to the transition to radiation dominated cosmology for which space-time sheets with 4-D M^4 projection dominate.

Also genuine string like objects emerge from TGD. The conditions that the em charge of modes of induces spinor fields is well-defined requires in the generic case the localization of the modes at 2-D surfaces -string world sheets and possibly also partonic 2-surfaces. This in Minkowskian space-time regions.

Fig. 6. Well-definedness of em charge forces the localization of induced spinor modes to 2-D surfaces in generic situtation in Minkowskian regions of space-time surface. `http://www.tgdtheory.fi/appfigures/fermistring.jpg`

TGD based view about elementary particles has two aspects.

(a) The space-time correlates of elementary particles are identified as pairs of wormhole contacts with Euclidian signature of metric and having 4-D CP_2 projection. Their throats behave effectively as Kähler magnetic monopoles so that wormhole throats must be connected by Kähler magnetic flux tubes with monopole flux so that closed flux tubes are obtained.

(b) Fermion number is carried by the modes of the induced spinor field. In Minkowskian space-time regions the modes are localized at string world sheets connecting the wormhole contacts.

Fig. 7. TGD view about elementary particles. a) Particle corresponds 4-D generalization of world line or b) with its light-like 3-D boundary (holography). c) Particle world lines have Euclidian signature of the induced metric. d) They can be identified as wormhole contacts. e) The throats of wormhole contacs carry effective Kähler magnetic charges so that wormhole contacts must appear as pairs in order to obtain closed flux tubes. f) Wormhole contacts are accompnied by fermionic strings connecting the throats at same sheet: the strings do not extend inside the wormhole contacts. `http://www.tgdtheory.fi/appfigures/elparticletgd.jpg`

Particle interactions involve both stringy and QFT aspects.

(a) The boundaries of string world sheets correspond to fundamental fermions. This gives rise to massless propagator lines in generalized Feynman diagrammatics. One can speak of "long" string connecting wormhole contacts and having hadronic string as physical counterpart. Long strings should be distinguished from wormhole contacts which due to their super-conformal invariance behave like "short" strings with length scale given by CP_2 size, which is 10^4 times longer than Planck scale characterizing strings in string models.

(b) Wormhole contact defines basic stringy interaction vertex for fermion-fermion scattering. The propagator is essentially the inverse of the superconformal scaling generator L_0. Wormhole contacts containing fermion and antifermion at its opposite throats beheave like virtual bosons so that one has BFF type vertices typically.

(c) In topological sense one has 3-vertices serving as generalizations of 3-vertices of Feynman diagrams. In these vertices 4-D "lines" of generalized Feynman diagrams meet along their 3-D ends. One obtains also the analogs of stringy diagrams but stringy vertices do not have the usual interpretation in terms of particle decays but in terms of propagation of particle along two different routes.

Fig. 8. a) TGD analogs of Feynman and string diagrammatics at the level of space-time topology. b) The 4-D analogs of both string diagrams and QFT diagrams appear but the interpretation of the analogs stringy diagrams is different. `http://www.tgdtheory.fi/appfigures/tgdgraphs.jpg`

A-5 Induction procedure and many-sheeted space-time

Since the classical gauge fields are closely related in TGD framework, it is not possible to have space-time sheets carrying only single kind of gauge field. For instance, em fields are accompanied by Z^0 fields for extremals of Kähler action.

Classical em fields are always accompanied by Z^0 field and some components of color gauge field. For extremals having homologically non-trivial sphere as a CP_2 projection em and Z^0 fields are the only non-vanishing electroweak gauge fields. For homologically trivial sphere only W fields are non-vanishing. Color rotations does not affect the situation.

For vacuum extremals all electro-weak gauge fields are in general non-vanishing although the net gauge field has U(1) holonomy by 2-dimensionality of the CP_2 projection. Color gauge field has $U(1)$ holonomy for all space-time surfaces and quantum classical correspondence suggest a weak form of color confinement meaning that physical states correspond to color neutral members of color multiplets.

Induction procedure for gauge fields

Induction procedure for gauge potentials and spinor structure is a standard procedure of bundle theory. If one has imbedding of some manifold to the base space of a bundle, the bundle structure can be induced so that it has as base space the imbedded manifold. In the recent case the imbedding of space-time surface to imbedding space defines the induction procedure. The induce gauge potentials and gauge fields are projections of the spinor connection of the imbedding space to the space-time surface. Induction procedure makes sense also for the spinor fields of imbedding space and one obtains geometrization of both electroweak gauge potentials and of spinors.

Fig. 9. Induction of spinor connection and metric as projection to the space-time surface. `http://www.tgdtheory.fi/appfigures/induct.jpg`

Induced gauge fields for space-times for which CP$_2$ projection is a geodesic sphere

If one requires that space-time surface is an extremal of Kähler action and has a 2-dimensional CP$_2$ projection, only vacuum extremals and space-time surfaces for which CP$_2$ projection is a geodesic sphere, are allowed. Homologically non-trivial geodesic sphere correspond to vanishing W fields and homologically non-trivial sphere to non-vanishing W fields but vanishing γ and Z^0. This can be verified by explicit examples.

$r = \infty$ surface gives rise to a homologically non-trivial geodesic sphere for which e_0 and e_3 vanish imply the vanishing of W field. For space-time sheets for which CP$_2$ projection is $r = \infty$ homologically non-trivial geodesic sphere of CP_2 one has

$$\gamma = (\frac{3}{4} - \frac{sin^2(\theta_W)}{2})Z^0 \simeq \frac{5Z^0}{8} \ .$$

The induced W fields vanish in this case and they vanish also for all geodesic sphere obtained by $SU(3)$ rotation.

$Im(\xi^1) = Im(\xi^2) = 0$ corresponds to homologically trivial geodesic sphere. A more general representative is obtained by using for the phase angles of standard complex CP_2 coordinates constant values. In this case e^1 and e^3 vanish so that the induced em, Z^0, and Kähler fields vanish but induced W fields are non-vanishing. This holds also for surfaces obtained by color rotation. Hence one can say that for non-vacuum extremals with 2-D CP$_2$ projection color rotations and weak symmetries commute.

A-5.1 Many-sheeted space-time

TGD space-time is many-sheeted: in other words, there are in general several space-sheets which have projection to the same M^4 region. Second manner to say this is that CP_2 coordinates are many-valued functions of M^4 coordinates. The original physical interpretation of many-sheeted space-time time was not correct: it was assumed that single sheet corresponds to GRT space-time and this obviously leads to difficulties since the induced gauge fields are expressible in terms of only four imbedding space coordinates.

Fig. 10. Illustration of many-sheeted space-time of TGD. http://www.tgdtheory.fi/appfigures/manysheeted.jpg

Superposition of effects instead of superposition of fields

The first objection against TGD is that superposition is not possible for induced gauge fields and induced metric. The resolution of the problem is that it is effects which need to superpose, not the fields.

Test particle topologically condenses simultaneously to all space-time sheets having a projection to same region of M^4 (that is touches them). The superposition of effects of fields at various space-time sheets replaces the superposition of fields.This is crucial for the understanding also how GRT space-time relates to TGD space-time, which is also in the appendix of this book).

Wormhole contacts

Wormhole contacts are key element of many-sheeted space-time. One does not expect them to be stable unless there is non-trivial Kähler magnetic flux flowing through then so that the throats look like Kähler magnetic monopoles.

Fig. 11. Wormhole contact. http://www.tgdtheory.fi/appfigures/wormholecontact.jpg

Since the flow lines of Kähler magnetic field must be closed this requires the presence of another wormhole contact so that one obtains closed monopole flux tube decomposing to two Minkowskian pieces at the two space-time sheets involved and two wormhole contacts with Euclidian signature of the induced metric. These objects are identified as space-time correlates of elementary particles and are clearly analogous to string like objects.

The relationship between the many-sheeted space-time of TGD and of GRT space-time

The space-time of general relativity is single-sheeted and there is no need to regard it as surface in H although the assumption about representability as vacuum extremal gives very powerful constraints in cosmology and astrophysics and might make sense in simple situations.

The space-time of GRT can be regarded as a long length scale approximation obtained by lumping together the sheets of the many-sheeted space-time to a region of M^4 and providing it with an effective metric obtained as sum of M^4 metric and deviations of the induced metrics of various space-time sheets from M^4 metric. Also induced gauge potentials sum up in the similar manner so that also the gauge fields of gauge theories would not be fundamental fields.

Fig. 12. The superposition of fields is replaced with the superposition of their effects in many-sheeted space-time. http://www.tgdtheory.fi/appfigures/fieldsuperpose.jpg

Space-time surfaces of TGD are considerably simpler objects that the space-times of general relativity and relate to GRT space-time like elementary particles to systems of condensed matter physics. Same can be said about fields since all fields are expressible in terms of imbedding space coordinates and their gradients, and general coordinate invariance means that the number of bosonic field degrees is reduced locally to 4. TGD space-time can be said to be a microscopic description whereas GRT space-time a macroscopic description. In TGD complexity of space-time topology replaces the complexity due to large number of fields in quantum field theory.

Topological field quantization and the notion of magnetic body

Topological field quantization also TGD from Maxwell's theory. TGD predicts topological light rays ("massless extremals (MEs)) as space-time sheets carrying waves or arbitrary shape propagating with maximal signal velocity in single direction only and analogous to laser beams and carrying light-like gauge currents in the generi case. There are also magnetic flux quanta and electric flux quanta. The deformations of cosmic strings with 2-D string orbit as M^4 projection gives rise to magnetic flux tubes carrying monopole flux made possible by CP_2 topology allowing homological Kähler magnetic monopoles.

Fig. 13. Topological quantization for magnetic fields replaces magnetic fields with bundles of them defining flux tubes as topological field quanta. `http://www.tgdtheory.fi/appfigures/field.jpg`

The imbeddability condition for say magnetic field means that the region containing constant magnetic field splits into flux quanta, say tubes and sheets carrying constant magnetic field. Unless one assumes a separate boundary term in Kähler action, boundaries in the usual sense are forbidden except as ends of space-time surfaces at the boundaries of causal diamonds. One obtains typically pairs of sheets glued together along their boundaries giving rise to flux tubes with closed cross section possibly carrying monopole flux.

These kind of flux tubes might make possible magnetic fields in cosmic scales already during primordial period of cosmology since no currents are needed to generate these magnetic fields: cosmic string would be indeed this kind of objects and would dominated during the primordial period. Even superconductors and maybe even ferromagnets could involve this kind of monopole flux tubes.

A-5.2 Imbedding space spinors and induced spinors

One can geometrize also fermionic degrees of freedom by inducing the spinor structure of $M^4 \times CP_2$.

CP_2 does not allow spinor structure in the ordinary sense but one can couple the opposite H-chiralities of H-spinors to an $n = 1$ ($n = 3$) integer multiple of Kähler gauge potential to obtain a respectable modified spinor structure. The em charges of resulting spinors are fractional (integer valued) and the interpretation as quarks (leptons) makes sense since the couplings to the induced spinor connection having interpretation in terms electro-weak gauge potential are identical to those assumed in standard model.

The notion of quark color differs from that of standard model.

(a) Spinors do not couple to color gauge potential although the identification of color gauge potential as projection of $SU(3)$ Killing vector fields is possible. This coupling must emerge only at the effective gauge theory limit of TGD.

(b) Spinor harmonics of imbedding space correspond to triality $t = 1$ ($t = 0$) partial waves. The detailed correspondence between color and electroweak quantum numbers is however not correct as such and the interpretation of spinor harmonics of imbedding space is as representations for ground states of super-conformal representations. The wormhole pairs associated with physical quarks and leptons must carry also neutrino pair to neutralize weak quantum numbers above the length scale of flux tube (weak scale or Compton length). The total color quantum numbers or these states must be those of standard model. For instance, the color quantum numbers of fundamental left-hand neutrino and lepton can compensate each other for the physical lepton. For fundamental quark-lepton pair they could sum up to those of physical quark.

The well-definedness of em charge is crucial condition.

(a) Although the imbedding space spinor connection carries W gauge potentials one can say that the imbedding space spinor modes have well-defined em charge. One expects that this is true for induced spinor fields inside wormhole contacts with 4-D CP_2 projection and Euclidian signature of the induced metric.

(b) The situation is not the same for the modes of induced spinor fields inside Minkowskian region and one must require that the CP_2 projection of the regions carrying induced spinor field is such that the induced W fields and above weak scale also the induced Z^0 fields vanish in order to avoid large parity breaking effects. This condition forces the CP_2 projection to be 2-dimensional. For a generic Minkowskian space-time region this is achieved only if the spinor modes are localized at 2-D surfaces of space-time surface - string world sheets and possibly also partonic 2-surfaces.

(c) Also the Kähler-Dirac gamma matrices appearing in the modified Dirac equation must vanish in the directions normal to the 2-D surface in order that Kähler-Dirac equation can be satisfied. This does not seem plausible for space-time regions with 4-D CP_2 projection.

(d) One can thus say that strings emerge from TGD in Minkowskian space-time regions. In particular, elementary particles are accompanied by a pair of fermionic strings at the opposite space-time sheets and connecting wormhole contacts. Quite generally, fundamental fermions would propagate at the boundaries of string world sheets as massless particles and wormhole contacts would define the stringy vertices of generalized Feynman diagrams. One obtains geometrized diagrammatics, which brings looks like a combination of stringy and Feynman diagrammatics.

(e) This is what happens in the the generic situation. Cosmic strings could serve as examples about surfaces with 2-D CP_2 projection and carrying only em fields and allowing delocalization of spinor modes to the entire space-time surfaces.

A-5.3 Space-time surfaces with vanishing em, Z^0, or Kähler fields

In the following the induced gauge fields are studied for general space-time surface without assuming the extremal property. In fact, extremal property reduces the study to the study of vacuum extremals and surfaces having geodesic sphere as a CP_2 projection and in this sense the following arguments are somewhat obsolete in their generality.

Space-times with vanishing em, Z^0, or Kähler fields

The following considerations apply to a more general situation in which the homologically trivial geodesic sphere and extremal property are not assumed. It must be emphasized that this case is possible in TGD framework only for a vanishing Kähler field.

Using spherical coordinates (r, Θ, Ψ, Φ) for CP_2, the expression of Kähler form reads as

$$\begin{aligned} J &= \frac{r}{F^2} dr \wedge (d\Psi + cos(\Theta) d\Phi) + \frac{r^2}{2F} sin(\Theta) d\Theta \wedge d\Phi \ , \\ F &= 1 + r^2 \ . \end{aligned} \tag{A-5.0}$$

The general expression of electromagnetic field reads as

$$\begin{aligned} F_{em} &= (3+2p)\frac{r}{F^2} dr \wedge (d\Psi + cos(\Theta) d\Phi) + (3+p)\frac{r^2}{2F} sin(\Theta) d\Theta \wedge d\Phi \ , \\ p &= sin^2(\Theta_W) \ , \end{aligned} \tag{A-5.0}$$

where Θ_W denotes Weinberg angle.

(a) The vanishing of the electromagnetic fields is guaranteed, when the conditions

$$\begin{aligned} \Psi &= k\Phi \ , \\ (3+2p)\frac{1}{r^2F}(d(r^2)/d\Theta)(k+cos(\Theta)) &+ (3+p)sin(\Theta) = 0 \ , \end{aligned} \quad \text{(A-5.0)}$$

hold true. The conditions imply that CP_2 projection of the electromagnetically neutral space-time is 2-dimensional. Solving the differential equation one obtains

$$\begin{aligned} r &= \sqrt{\frac{X}{1-X}} \ , \\ X &= D\left[|\frac{(k+u}{C}|\right]^{\epsilon} \ , \\ u &\equiv cos(\Theta) \ , \ C = k + cos(\Theta_0) \ , \ D = \frac{r_0^2}{1+r_0^2} \ , \ \epsilon = \frac{3+p}{3+2p} \ , \end{aligned} \quad \text{(A-5.-1)}$$

where C and D are integration constants. $0 \leq X \leq 1$ is required by the reality of r. $r = 0$ would correspond to $X = 0$ giving $u = -k$ achieved only for $|k| \leq 1$ and $r = \infty$ to $X = 1$ giving $|u + k| = [(1 + r_0^2)/r_0^2)]^{(3+2p)/(3+p)}$ achieved only for

$$sign(u+k) \times [\frac{1+r_0^2}{r_0^2}]^{\frac{3+2p}{3+p}} \leq k+1 \ ,$$

where $sign(x)$ denotes the sign of x.
The expressions for Kähler form and Z^0 field are given by

$$\begin{aligned} J &= -\frac{p}{3+2p}Xdu\wedge d\Phi \ , \\ Z^0 &= -\frac{6}{p}J \ . \end{aligned} \quad \text{(A-5.-1)}$$

The components of the electromagnetic field generated by varying vacuum parameters are proportional to the components of the Kähler field: in particular, the magnetic field is parallel to the Kähler magnetic field. The generation of a long range Z^0 vacuum field is a purely TGD based feature not encountered in the standard gauge theories.

(b) The vanishing of Z^0 fields is achieved by the replacement of the parameter ϵ with $\epsilon = 1/2$ as becomes clear by considering the condition stating that Z^0 field vanishes identically. Also the relationship $F_{em} = 3J = -\frac{3}{4}\frac{r^2}{F}du \wedge d\Phi$ is useful.

(c) The vanishing Kähler field corresponds to $\epsilon = 1, p = 0$ in the formula for em neutral space-times. In this case classical em and Z^0 fields are proportional to each other:

$$\begin{aligned} Z^0 &= 2e^0\wedge e^3 = \frac{r}{F^2}(k+u)\frac{\partial r}{\partial u}du\wedge d\Phi = (k+u)du\wedge d\Phi \ , \\ r &= \sqrt{\frac{X}{1-X}} \ , \ X = D|k+u| \ , \\ \gamma &= -\frac{p}{2}Z^0 \ . \end{aligned} \quad \text{(A-5.-2)}$$

For a vanishing value of Weinberg angle ($p = 0$) em field vanishes and only Z^0 field remains as a long range gauge field. Vacuum extremals for which long range Z^0 field vanishes but em field is non-vanishing are not possible.

The effective form of CP_2 metric for surfaces with 2-dimensional CP_2 projection

The effective form of the CP_2 metric for a space-time having vanishing em,Z^0, or Kähler field is of practical value in the case of vacuum extremals and is given by

$$
\begin{aligned}
ds^2_{eff} &= (s_{rr}(\frac{dr}{d\Theta})^2 + s_{\Theta\Theta})d\Theta^2 + (s_{\Phi\Phi} + 2ks_{\Phi\Psi})d\Phi^2 = \frac{R^2}{4}[s^{eff}_{\Theta\Theta}d\Theta^2 + s^{eff}_{\Phi\Phi}d\Phi^2] \ , \\
s^{eff}_{\Theta\Theta} &= X \times \left[\frac{\epsilon^2(1-u^2)}{(k+u)^2} \times \frac{1}{1-X} + 1 - X\right] \ , \\
s^{eff}_{\Phi\Phi} &= X \times \left[(1-X)(k+u)^2 + 1 - u^2\right] \ , \qquad \text{(A-5.-3)}
\end{aligned}
$$

and is useful in the construction of vacuum imbedding of, say Schwartchild metric.

Topological quantum numbers

Space-times for which either em, Z^0, or Kähler field vanishes decompose into regions characterized by six vacuum parameters: two of these quantum numbers (ω_1 and ω_2) are frequency type parameters, two (k_1 and k_2) are wave vector like quantum numbers, two of the quantum numbers (n_1 and n_2) are integers. The parameters ω_i and n_i will be referred as electric and magnetic quantum numbers. The existence of these quantum numbers is not a feature of these solutions alone but represents a much more general phenomenon differentiating in a clear cut manner between TGD and Maxwell's electrodynamics.

The simplest manner to avoid surface Kähler charges and discontinuities or infinities in the derivatives of CP_2 coordinates on the common boundary of two neighboring regions with different vacuum quantum numbers is topological field quantization, 3-space decomposes into disjoint topological field quanta, 3-surfaces having outer boundaries with possibly macroscopic size.

Under rather general conditions the coordinates Ψ and Φ can be written in the form

$$
\begin{aligned}
\Psi &= \omega_2 m^0 + k_2 m^3 + n_2\phi + \text{Fourier expansion} \ , \\
\Phi &= \omega_1 m^0 + k_1 m^3 + n_1\phi + \text{Fourier expansion} \ . \qquad \text{(A-5.-3)}
\end{aligned}
$$

m^0,m^3 and ϕ denote the coordinate variables of the cylindrical M^4 coordinates) so that one has $k = \omega_2/\omega_1 = n_2/n_1 = k_2/k_1$. The regions of the space-time surface with given values of the vacuum parameters ω_i,k_i and n_i and m and C are bounded by the surfaces at which space-time surface becomes ill-defined, say by $r > 0$ or $r < \infty$ surfaces.

The space-time surface decomposes into regions characterized by different values of the vacuum parameters r_0 and Θ_0. At $r = \infty$ surfaces n_2,ω_2 and m can change since all values of Ψ correspond to the same point of CP_2: at $r = 0$ surfaces also n_1 and ω_1 can change since all values of Φ correspond to same point of CP_2, too. If $r = 0$ or $r = \infty$ is not in the allowed range space-time surface develops a boundary.

This implies what might be called topological quantization since in general it is not possible to find a smooth global imbedding for, say a constant magnetic field. Although global imbedding exists it decomposes into regions with different values of the vacuum parameters and the coordinate u in general possesses discontinuous derivative at $r = 0$ and $r = \infty$ surfaces. A possible manner to avoid edges of space-time is to allow field quantization so that 3-space (and field) decomposes into disjoint quanta, which can be regarded as structurally stable units a 3-space (and of the gauge field). This doesn't exclude partial join along boundaries for neighboring field quanta provided some additional conditions guaranteeing the absence of edges are satisfied.

For instance, the vanishing of the electromagnetic fields implies that the condition

$$\Omega \equiv \frac{\omega_2}{n_2} - \frac{\omega_1}{n_1} = 0 \ , \qquad \text{(A-5.-2)}$$

is satisfied. In particular, the ratio ω_2/ω_1 is rational number for the electromagnetically neutral regions of space-time surface. The change of the parameter n_1 and n_2 (ω_1 and ω_2) in general generates magnetic field and therefore these integers will be referred to as magnetic (electric) quantum numbers.

A-6 p-Adic numbers and TGD

A-6.1 p-Adic number fields

p-Adic numbers (p is prime: 2,3,5,...) can be regarded as a completion of the rational numbers using a norm, which is different from the ordinary norm of real numbers [A22] . p-Adic numbers are representable as power expansion of the prime number p of form

$$x = \sum_{k \geq k_0} x(k)p^k, \ x(k) = 0, ..., p-1 \ . \qquad \text{(A-6.1)}$$

The norm of a p-adic number is given by

$$|x| = p^{-k_0(x)} \ . \qquad \text{(A-6.2)}$$

Here $k_0(x)$ is the lowest power in the expansion of the p-adic number. The norm differs drastically from the norm of the ordinary real numbers since it depends on the lowest pinary digit of the p-adic number only. Arbitrarily high powers in the expansion are possible since the norm of the p-adic number is finite also for numbers, which are infinite with respect to the ordinary norm. A convenient representation for p-adic numbers is in the form

$$x = p^{k_0}\varepsilon(x) \ , \qquad \text{(A-6.3)}$$

where $\varepsilon(x) = k + ...$ with $0 < k < p$, is p-adic number with unit norm and analogous to the phase factor $exp(i\phi)$ of a complex number.

The distance function $d(x,y) = |x-y|_p$ defined by the p-adic norm possesses a very general property called ultra-metricity:

$$d(x,z) \leq max\{d(x,y), d(y,z)\} \ . \qquad \text{(A-6.4)}$$

The properties of the distance function make it possible to decompose R_p into a union of disjoint sets using the criterion that x and y belong to same class if the distance between x and y satisfies the condition

$$d(x,y) \leq D \ . \qquad \text{(A-6.5)}$$

This division of the metric space into classes has following properties:

(a) Distances between the members of two different classes X and Y do not depend on the choice of points x and y inside classes. One can therefore speak about distance function between classes.

(b) Distances of points x and y inside single class are smaller than distances between different classes.

(c) Classes form a hierarchical tree.

Notice that the concept of the ultra-metricity emerged in physics from the models for spin glasses and is believed to have also applications in biology [B25] . The emergence of p-adic topology as the topology of the effective space-time would make ultra-metricity property basic feature of physics.

A-6.2 Canonical correspondence between p-adic and real numbers

The basic challenge encountered by p-adic physicist is how to map the predictions of the p-adic physics to real numbers. p-Adic probabilities provide a basic example in this respect. Identification via common rationals and canonical identification and its variants have turned out to play a key role in this respect.

Basic form of canonical identification

There exists a natural continuous map $I : R_p \rightarrow R_+$ from p-adic numbers to non-negative real numbers given by the "pinary" expansion of the real number for $x \in R$ and $y \in R_p$ this correspondence reads

$$\begin{aligned} y &= \sum_{k>N} y_k p^k \rightarrow x = \sum_{k<N} y_k p^{-k} \quad , \\ y_k &\in \{0, 1, .., p-1\} \quad . \end{aligned} \tag{A-6.5}$$

This map is continuous as one easily finds out. There is however a little difficulty associated with the definition of the inverse map since the pinary expansion like also decimal expansion is not unique ($1 = 0.999...$) for the real numbers x, which allow pinary expansion with finite number of pinary digits

$$\begin{aligned} x &= \sum_{k=N_0}^{N} x_k p^{-k} \quad , \\ x &= \sum_{k=N_0}^{N-1} x_k p^{-k} + (x_N - 1)p^{-N} + (p-1)p^{-N-1} \sum_{k=0,..} p^{-k} \quad . \end{aligned} \tag{A-6.4}$$

The p-adic images associated with these expansions are different

$$\begin{aligned} y_1 &= \sum_{k=N_0}^{N} x_k p^k \quad , \\ y_2 &= \sum_{k=N_0}^{N-1} x_k p^k + (x_N - 1)p^N + (p-1)p^{N+1} \sum_{k=0,..} p^k \\ &= y_1 + (x_N - 1)p^N - p^{N+1} \quad , \end{aligned} \tag{A-6.3}$$

so that the inverse map is either two-valued for p-adic numbers having expansion with finite pinary digits or single valued and discontinuous and non-surjective if one makes pinary expansion unique by choosing the one with finite pinary digits. The finite pinary digit expansion is a natural choice since in the numerical work one always must use a pinary cutoff on the real axis.

The topology induced by canonical identification

The topology induced by the canonical identification in the set of positive real numbers differs from the ordinary topology. The difference is easily understood by interpreting the p-adic norm as a norm in the set of the real numbers. The norm is constant in each interval $[p^k, p^{k+1})$ (see Fig. **??**) and is equal to the usual real norm at the points $x = p^k$: the usual linear norm is replaced with a piecewise constant norm. This means that p-adic topology is coarser than the usual real topology and the higher the value of p is, the coarser the resulting topology is above a given length scale. This hierarchical ordering of the p-adic topologies will be a central feature as far as the proposed applications of the p-adic numbers are considered.

Ordinary continuity implies p-adic continuity since the norm induced from the p-adic topology is rougher than the ordinary norm. p-Adic continuity implies ordinary continuity from right as is clear already from the properties of the p-adic norm (the graph of the norm is indeed continuous from right). This feature is one clear signature of the p-adic topology.

Fig. 14. The real norm induced by canonical identification from 2-adic norm. `http://www.tgdtheory.fi/appfigures/norm.png`

The linear structure of the p-adic numbers induces a corresponding structure in the set of the non-negative real numbers and p-adic linearity in general differs from the ordinary concept of linearity. For example, p-adic sum is equal to real sum only provided the summands have no common pinary digits. Furthermore, the condition $x +_p y < max\{x, y\}$ holds in general for the p-adic sum of the real numbers. p-Adic multiplication is equivalent with the ordinary multiplication only provided that either of the members of the product is power of p. Moreover one has $x \times_p y < x \times y$ in general. The p-Adic negative -1_p associated with p-adic unit 1 is given by $(-1)_p = \sum_k (p-1)p^k$ and defines p-adic negative for each real number x. An interesting possibility is that p-adic linearity might replace the ordinary linearity in some strongly nonlinear systems so these systems would look simple in the p-adic topology.

These results suggest that canonical identification is involved with some deeper mathematical structure. The following inequalities hold true:

$$
\begin{aligned}
(x+y)_R &\leq x_R + y_R \ , \\
|x|_p |y|_R \leq (xy)_R &\leq x_R y_R \ ,
\end{aligned}
\tag{A-6.3}
$$

where $|x|_p$ denotes p-adic norm. These inequalities can be generalized to the case of $(R_p)^n$ (a linear vector space over the p-adic numbers).

$$
\begin{aligned}
(x+y)_R &\leq x_R + y_R \ , \\
|\lambda|_p |y|_R \leq (\lambda y)_R &\leq \lambda_R y_R \ ,
\end{aligned}
\tag{A-6.3}
$$

where the norm of the vector $x \in T_p^n$ is defined in some manner. The case of Euclidian space suggests the definition

$$
(x_R)^2 = (\sum_n x_n^2)_R \ . \tag{A-6.4}
$$

These inequalities resemble those satisfied by the vector norm. The only difference is the failure of linearity in the sense that the norm of a scaled vector is not obtained by scaling the norm of the original vector. Ordinary situation prevails only if the scaling corresponds to a power of p.

These observations suggests that the concept of a normed space or Banach space might have a generalization and physically the generalization might apply to the description of some non-linear systems. The nonlinearity would be concentrated in the nonlinear behavior of the norm under scaling.

Modified form of the canonical identification

The original form of the canonical identification is continuous but does not respect symmetries even approximately. This led to a search of variants which would do better in this respect. The modification of the canonical identification applying to rationals only and given by

$$I_Q(q = p^k \times \frac{r}{s}) = p^k \times \frac{I(r)}{I(s)} \tag{A-6.5}$$

is uniquely defined for rationals, maps rationals to rationals, has also a symmetry under exchange of target and domain. This map reduces to a direct identification of rationals for $0 \leq r < p$ and $0 \leq s < p$. It has turned out that it is this map which most naturally appears in the applications. The map is obviously continuous locally since p-adically small modifications of r and s mean small modifications of the real counterparts.

Canonical identification is in a key role in the successful predictions of the elementary particle masses. The predictions for the light elementary particle masses are within extreme accuracy same for I and I_Q but I_Q is theoretically preferred since the real probabilities obtained from p-adic ones by I_Q sum up to one in p-adic thermodynamics.

Generalization of number concept and notion of imbedding space

TGD forces an extension of number concept: roughly a fusion of reals and various p-adic number fields along common rationals is in question. This induces a similar fusion of real and p-adic imbedding spaces. Since finite p-adic numbers correspond always to non-negative reals n-dimensional space R^n must be covered by 2^n copies of the p-adic variant R_p^n of R^n each of which projects to a copy of R_+^n (four quadrants in the case of plane). The common points of p-adic and real imbedding spaces are rational points and most p-adic points are at real infinity.

Real numbers and various algebraic extensions of p-adic number fields are thus glued together along common rationals and also numbers in algebraic extension of rationals whose number belong to the algebraic extension of p-adic numbers. This gives rise to a book like structure with rationals and various algebraic extensions of rationals taking the role of the back of the book. Note that Neper number is exceptional in the sense that it is algebraic number in p-adic number field Q_p satisfying $e^p \ mod \ p = 1$.

Fig. 15. Various number fields combine to form a book like structure. `http://www.tgdtheory.fi/appfigures/book.jpg`

For a given p-adic space-time sheet most points are literally infinite as real points and the projection to the real imbedding space consists of a discrete set of rational points: the interpretation in terms of the unavoidable discreteness of the physical representations of cognition is natural. Purely local p-adic physics implies real p-adic fractality and thus long range correlations for the real space-time surfaces having enough common points with this projection.

p-Adic fractality means that M^4 projections for the rational points of space-time surface X^4 are related by a direct identification whereas CP_2 coordinates of X^4 at these points are related by I, I_Q or some of its variants implying long range correlates for CP_2 coordinates. Since only a discrete set of points are related in this manner, both real and p-adic field equations can be satisfied and there are no problems with symmetries. p-Adic effective topology is expected to be a good approximation only within some length scale range which means infrared and UV cutoffs. Also multi-p-fractality is possible.

A-6.3 The notion of p-adic manifold

The notion of p-adic manifold is needed in order to fuse real physics and various p-adic physics to a larger structure which suggests that real and p-adic number fields should be glued together along common rationals bringing in mind adeles. The notion is problematic because p-adic topology is totally disconnected implying that p-adic balls are either disjoint or nested so that ordinary definition of manifold using p-adic chart maps fails. A cure is suggested to be based on chart maps from p-adics to reals rather than to p-adics (see the appendix of the book)

The chart maps are interpreted as cognitive maps, "thought bubbles" with reverse map interpreted as a transformation of intention to action and would be realized in terms of canonical identification or some of its variants.

Fig. 16. The basic idea between p-adic manifold. `http://www.tgdtheory.fi/appfigures/padmanifold.jpg`

There are some problems.

(a) Canonical identification does not respect symmetries since it does not commute with second pinary cutoff so that only a discrete set of rational points is mapped to their real counterparts by chart map arithmetic operations which requires pinary cutoff below which chart map takes rationals to rationals so that commutativity with arithmetics and symmetries is achieved in finite resolution: above the cutoff canonical identification is used

(b) Canonical identification is continuous but does not map smooth p-adic surfaces to smooth real surfaces requiring second pinary cutoff so that only a discrete set of rational points is mapped to their real counterparts by chart map requiring completion of the image to smooth preferred extremal of Kähler action so that chart map is not unique in accordance with finite measurement resolution

(c) Canonical identification vreaks general coordinate invariance of chart map: (cognition-induced symmetry breaking) minimized if p-adic manifold structure is induced from that for p-adic imbedding space with chart maps to real imbedding space and assuming preferred coordinates made possible by isometries of imbedding space: one however obtains several inequivalent p-adic manifold structures depending on the choice of coordinates: these cognitive representations are not equivalent.

A-7 Hierarchy of Planck constants and dark matter hierarchy

Hierarchy of Planck constants was motivated by the "impossible" quantal effects of ELF em fields on vertebrate cyclotron energies $E = hf = \hbar \times eB/m$ are above thermal energy is possible only if $\hbar$ has value much larger than its standard value. Also Nottale's finding that planetary orbits migh be understood as Bohr orbits for a gigantic gravitational Planck constant.

Hierachy of Planck constant would mean that the values of Planck constant come as integer multiples of ordinary Planck constant: $h_{eff} = n \times h$. The particles at magnetic flux tubes characterized by h_{eff} would correspond to dark matter which would be invisible in the sense that only particle with same value of h_{eff} appear in the same vertex of Feynman diagram.

Hierarchy of Planck constants would be due to the non-determism of the Kähler action predicting huge vacuum degeneracy allowing all space-time surfaces which are sub-manfolds of any $M^4 \times Y^2$, where Y^2 is Lagrangian sub-manifold of CP_2. For agiven Y^2 one obtains new manifolds Y^2 by applying symplectic transformations of CP_2.

Non-determinism would mean that the 3-surface at the ends of causal diamond (CD) can be connected by several space-time surfaces carrying same conserved Kähler charges and having same values of Kähler action. Conformal symmetries defined by Kac-Moody algebra associated with the imbedding space isometries could act as gauge transformations and respect the light-likeness property of partonic orbits at which the signature of the induced metric changes from Minkowskian to Euclidian (Minkowskianb space-time region transforms to wormhole contact say). The number of conformal equivalence classes of these surfaces could be finite number n and define discrete physical degree of freedom and one would have $h_{eff} = n \times h$. This degeneracy would mean "second quantization" for the sheets of n-furcation: not only one but several sheets can be realized.

This relates also to quantum criticality postulated to be the basic characteristics of the dynamics of quantum TGD. Quantum criticalities would correspond to an infinite fractal hierarchy of broken conformal symmetries defined by sub-algebras of conformal algebra with conformal weights coming as integer multiples of n. This leads also to connections with quantum criticality and hierarchy of broken conformal symmetries, p-adicity, and negentropic entanglement which by consistency with standard quantum measurement theory would be described in terms of density matrix proportional $n \times n$ identity matrix and being due to unitary entanglement coefficients (typical for quantum computing systems).

Formally the situation could be described by regarding space-time surfaces as surfaces in singular n-fold singular coverings of imbedding space. A stronger assumption would be that they are expressible as as products of n_1 -fold covering of M^4 and n_2-fold covering of CP_2 meaning analogy with multi-sheeted Riemann surfaces and that M^4 coordinates are n_1-valued functions and CP_2 coordinates n_2 -valued functions of space-time coordinates for $n = n_1 \times n_2$. These singular coverings of imbedding space form a book like structure with singularities of the coverings localizable at the boundaries of causal diamonds defining the back of the the book like structure.

Fig. 17. Hierarchy of Planck constants. `http://www.tgdtheory.fi/appfigures/planckhierarchy.jpg`

A-8 Some notions relevant to TGD inspired consciousness and quantum biology

Below some notions relevant to TGD inspired theory of consciousness and quantum biology.

A-8.1 The notion of magnetic body

Topological field quantization inspires the notion of field body about which magnetic body is especially important example and plays key role in TGD inspired quantum biology and consciousness theory. This is a crucial departure fromt the Maxwellian view. Magnetic body brings in third level to the description of living system as a system interacting strongly with environment. Magnetic body would serve as an intentional agent using biological body as a motor instrument and sensory receptor. EEG would communicated the information from biological body to magnetic body and Libet's findings from time delays of consciousness support this view.

The following pictures illustrate the notion of magnetic body and its dynamics relevant for quantum biology in TGD Universe.

Fig. 18. Magnetic body associated with dipole field. `http://www.tgdtheory.fi/appfigures/fluxquant.jpg`

Fig. 19. Illustration of the reconnection by magnetic flux loops. http://www.tgdtheory.fi/appfigures/reconnect1.jpg

Fig. 20. Illustration of the reconnection by flux tubes connecting pairs of molecules. http://www.tgdtheory.fi/appfigures/reconect2.jpg

Fig. 21. Flux tube dynamics. a) Reconnection making possible magnetic body to "recognize" the presence of another magnetic body, b) braiding, knotting and linking of flux tubes making possible topological quantum computation, c) contraction of flux tube in phase transition reducing the value of h_{eff} allowing two molecules to find each other in dense molecular soup. http://www.tgdtheory.fi/appfigures/fluxtubedynamics.jpg

A-8.2 Number theoretic entropy and negentropic entanglement

TGD inspired theory of consciousness relies heavily p-Adic norm allows an to define the notion of Shannon entropy for rational probabilities (and even those in algebraic extension of rationals) by replacing the argument of logarithm of probability with its p-adic norm. The resulting entropy can be negative and the interpretation is that number theoretic entanglement entropy defined by this formula for the p-adic prime minimizing its value serves as a measure for conscious information. This negentropy characterizes two-particle system and has nothing to do with the formal negative negentropy assignable to thermodynamic entropy characterizing single particle. Negentropy Maximization Principle (NMP) implies that number theoretic negentropy increases during evolution by quantum jumps. The condition that NMP is consistent with the standard quantum measurement theory requires that negentropic entanglement has a density matrix proportional to unit matrix so that in 2-particle case the entanglement matrix is unitary.

Fig. 22. Schrödinger cat is neither dead or alive. For negentropic entanglement this state would be stable. http://www.tgdtheory.fi/appfigures/cat.jpg

A-8.3 Life as something residing in the intersection of reality and p-adicities

In TGD inspired theory of consciousness p-adic space-time sheets correspond to space-time correlates for thoughts and intentions. The intersections of real and p-adic preferred extremals consist of points whose coordinates are rational or belong to some extension of rational numbers in preferred imbedding space coordinates. They would correspond to the intersection of reality and various p-adicities representing the "mind stuff" of Descartes. There is temptation to assign life to the intersection of realities and p-adicities. The discretization of the chart map assigning to real space-time surface its p-adic counterpart would reflect finite cognitive resolution.

At the level of "world of classical worlds" (WCW) the intersection of reality and various p-adicities would correspond to space-time surfaces (or possibly partonic 2-surfaces) representable in terms of rational functions with polynomial coefficients with are rational or belong to algebraic extension of rationals.

The quantum jump replacing real space-time sheet with p-adic one (vice versa) would correspond to a buildup of cognitive representation (realization of intentional action).

Fig. 23. The quantum jump replacing real space-time surface with corresponding p-adic manifold can be interpreted as formation of though, cognitive representation. Its reversal would correspond to a transformation of intention to action. http://www.tgdtheory.fi/appfigures/padictoreal.jpg

A-8.4 Sharing of mental images

The 3-surfaces serving as correlates for sub-selves can topologically condense to disjoint large space-time sheets representing selves. These 3-surfaces can also have flux tube connections and this makes possible entanglement of sub-selves, which unentangled in the resolution defined by the size of sub-selves. The interpretation for this negentropic entanglement would be in terms of sharing of mental images. This would mean that contents of consciousness are not completely private as assumed in neuroscience.

Fig. 24. Sharing of mental images by entanglement of subselves made possible by flux tube connections between topologically condensed space-time sheets associated with mental images. `http://www.tgdtheory.fi/appfigures/sharing.jpg`

A-8.5 Time mirror mechanism

Zero energy ontology (ZEO) is crucial part of both TGD and TGD inspired consciousness and leads to the understanding of the relationship between geometric time and experience time and how the arrow of psychological time emerges. One of the basic predictions is the possibiity of negative energy signals propagating backwards in geometric time and having the property that entropy basically associated with subjective time grows in reversed direction of geometric time. Negative energy signals inspire time mirror mechanism (see fig. `http://www.tgdtheory.fi/appfigures/timemirror.jpg` or fig. 24 in the appendix of this book) providing mechanisms of both memory recall, realization of intentational action initiating action already in geometric past, and remote metabolism. What happens that negative energy signal travels to past and is reflected as positive energy signal and returns to the sender. This process works also in the reverse time direction.

Fig. 25. Zero energy ontology allows time mirror mechanism as a mechanism of memory recall. Essentially "seeing" in time direction is in question. `http://www.tgdtheory.fi/appfigures/timemirror.jpg`

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P-ADIC LENGTH SCALE HYPOTHESIS

Topological Geometrodynamics (TGD) is a modification of general relativity inspired by the problems related to the definition of inertial and gravitational energies in general relativity. TGD is also a generalization of super string models. Physical space-times are seen as four-dimensional surfaces in certain 8-dimensional space H. The choice of H is fixed by symmetries of standard model and leads to a geometrization of known classical fields and elementary particle numbers. In fermionic sector strings indeed emerge.

Many-sheeted space-time replaces Einsteinian space-time, which follows as a long length scale approximation in which sheets of the many-sheeted space-time are lumped together. The extension of number concept based on the fusion of real numbers and p-adic number fields implies a further generalisation of the space-time concept allowing to identify space-time correlates of cognition and intentionality.

Zero energy ontology forces an extension of quantum measurement theory to a theory of consciousness and a hierarchy of phases identified as dark matter is predicted with far reaching implications for the understanding of consciousness and living systems. This all implies an elegant theoretical projection of our reality honoring the work by renowned scientists (such as Wheeler, Feynman, Penrose, Einstein, Josephson to name a few) and creating a solid foundation for modeling our Universe in terms of geometry.

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Matti Pitkänen started to work with the basic idea of TGD at 1977, published his thesis work about TGD at 1982, and has since then worked to transform the basic vision to a consistent predictive mathematical framework, to solve various interpretational issues, and understand the relationship of TGD with existing theories.

TGD Web Pages: http://www.tgdtheory.com
TGD Diary and Blog: http://matpitka.blogspot.com