Cross Section and Rho Parameter versus the Centre-of-Mass Energy for Proton-Proton Collisions

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Abstract: Due to the properties of the superluminal quantum entanglement, theory of proton is classical and statistical. Quantum Physics is a result of neglecting the superluminal entanglement which is a classical phenomenon. Here, within the classical/statistical/non-perturbative Scale-Symmetric Theory (SST), we calculated and showed the origin of the inelastic and elastic cross-section and the rho parameter versus the centre-of-mass energy for the proton-proton collisions. Obtained results are consistent with experimental data.

1. The true and complete theory of the proton is classical and statistical

The two fundamental experimental results that show that the Quantum Physics (QP) and the General Theory of Relativity (GR) are the incomplete theories are as follows:

1.1

According to QP, quantum entanglement should be local (the speed of light in vacuum c should be the maximum speed of exchanged particles) but experiments show that it is superluminal.

1.2

According to GR, gravitational fields must be curved but experiments show that spacetime as a whole is flat.

The application of QP and GR is limited so they frequently deceive scientists.

The transition from the classical physics (CP) to QP via the Poisson bracket is because we neglect the superluminal motions i.e. the components of gravitational fields and the spin-1 entanglons which are responsible for the quantum entanglement [1], [2] (it is because in the fundamental equation in the Matrix Quantum Mechanics there can be the unseen by detector infinitesimal transition which can change spin of a loop by $\pm 1\hbar$ [3]).This means that within QP it is impossible to describe the origin of both gravity and quantum entanglement. Within the classical/statistical/non-perturbative Scale-Symmetric Theory (SST) [1], [2], we derived the Pauli Exclusion Principle and described the hydrogen atom – we showed that the Sommerfeld, Dirac and SST theory of hydrogen atom are equivalent [4].

A system can change its state because of an exchange between its parts or with surroundings one or group of the unobserved entanglons – it leads to the Uncertainty Principle. Such exchanges cannot be controlled.

SST shows that the bare electron creates only one virtual electron-positron pair but due to the unseen exchanges of entanglons, it disappears and appears so there is a distribution of such a pair – the wavefunction $\psi = \psi_o e^{-ipx/\hbar}$ defines a statistical distribution of the virtual pair. Value of e is defined by virtual objects created in the two-component spacetime [5].

The two-component spacetime (the Higgs field plus the Einstein spacetime) [2], [6] forces the transition from the Newtonian to Einsteinian gravity.

Taking this opportunity, notice that in the cosmological model of the subsequent bounces of the Universe in the Cosmos (it is much bigger than the size of the present-day Universe [7]) there must be described three basic phenomena (they are described within SST [1], [7], [8], [9]):

* the inflation that created the initial spacetime,
* a phenomenon that created the spherical boundary of the Cosmos, and
* a phase transition in centre of the spherical Cosmos which transforms contraction into expansion of a small mass of the Cosmos (i.e. the Universe) in relation to the total mass of the spacetime created during the inflation.

Internal structure and properties of proton within the classical/statistical SST are described here [2].

As a recapitulation we can say that in QP, the (simultaneous) superposition of different states of an object should be rejected – due to the superluminal quantum/classical entanglement there is a statistical picture of the successive physical states. On the other hand, the Principle of Equivalence is not valid for the superluminal objects and the speed of light in “vacuum” c is the speed in relation to objects with which the photons (or gluons) are entangled – it causes that application of GR is limited.

2. Inelastic and elastic cross sections versus the centre-of-mass energy

The inelastic proton-proton scattering is described here [10]. For the inelastic cross-section we obtained following formula

$$\sigma_{Inelastic} = F_{Inelastic}\, E^{1/8}\,, \qquad (1)$$

where $F_{Inelastic}$ = 22.384 mb/GeV$^{1/8}$ and $E = s^{1/2}$ [GeV] is the centre-of-mass energy.

For E = 100 GeV is $\sigma_{Inelastic}$ = 39.81 mb whereas for E = 13 TeV is $\sigma_{Inelastic}$ = 73.14 mb (it is the central value obtained with the ATLAS Detector [11]).

According to SST, the asymptotic freedom for the nuclear strong interactions follows from the fact that the absolute rest mass of created virtual pions decreases with increasing energy of nucleons [2]. It means that with increasing energy/temperature, effective radius of nucleons, so characteristic wave length as well, increases. In the gravitating Einstein spacetime, the nucleons colliding in an inelastic way have the four degrees of freedom (the 3 spatial coordinates and time associated with kinetic motion) so temperature is directly proportional to four powers of the characteristic length. On the other hand, the cross section is directly proportional to two powers of the characteristic length. Applying the Stefan-Boltzmann law for total emitted energy of a black body, E, we obtain (we can apply this law to relativistic objects)

$$E \sim T^4 \sim \lambda_{Charact.}{}^{16} \sim \sigma_{Inelastic}{}^{8}. \qquad (2)$$

We calculated the factor $F_{Inelastic}$ from the initial conditions. The muon radius of proton is $R_{proton(muon)}$ = 0.84074 fm [12] so the cross section is $\sigma_{Inelastic} = \pi\, R_{proton(muon)}{}^2$ = 22.206

mb – this value is for the rest energy of proton i.e. for E = 0.93827 GeV. Applying formula (1) we obtain

$$F_{Inelastic} = 22.384\ \text{mb/GeV}^{1/8}. \tag{3}$$

It leads to formula (1).

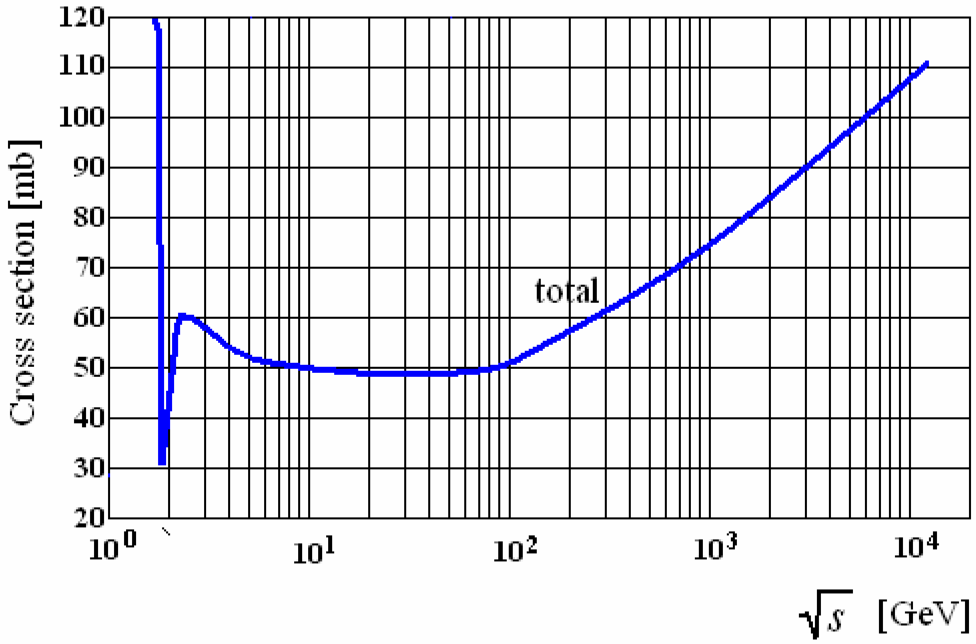

Fig.1
Total cross sections versus the centre-of-mass energy for pp collisions from the Scale-Symmetric Theory.

Contrary to the inelastic scattering, in the elastic collisions, nucleon has two degrees of freedom because it behaves as a disc-like structure perpendicular to direction of motion. It means that we can rewrite formula (2) as follows

$$E \sim T^4 \sim \lambda_{Charact.}{}^8 \sim \sigma_{Elastic}{}^4. \tag{4}$$

The factor of proportionality, $F_{Elastic}$, we can calculate from the boundary conditions for the elastic scattering. The protons interact because they exchange the neutral pions which are produced on the circle with radius $R_{Elastic}$ = 2 A / 3 = 0.46496 fm [2] so the cross section is $\sigma_{Elastic} = \pi\ (2\ \text{A}\ /\ 3)^2$ = 6.7918 mb – this value is for E = 16•0.93827 GeV = 15.012 GeV because each of the 8 characteristic lengths represents one proton-proton pair. From formula (4) and the above initial conditions we obtain

$$\sigma_{Elastic} = F_{Elastic}\ E^{1/4}\ , \tag{5}$$

where

$$F_{Elastic} = 3.4504\ \text{mb/GeV}^{1/4}\ . \tag{6}$$

For E = 100 GeV is $\sigma_{Elastic}$ = 10.91 mb whereas for E = 13 TeV is $\sigma_{Elastic}$ = 36.84 mb.

The total cross section is

$$\sigma_{Total} = \sigma_{Inelastic} + \sigma_{Elastic} \,. \tag{7}$$

For E = 100 GeV is σ_{Total} = 50.72 mb whereas for E = 13 TeV is σ_{Total} = 109.98 mb ≈ 110.0 mb (it is consistent with the TOTEM result: 110.6 ± 3.4 mb [13]).

Notice that we should observe some maxima for the total cross sections associated with creation of the proton-antiproton pairs and hyperon-antihyperon pairs.

The maximum for protons should be for $E = s^{1/2} = 2\,p^+ = 1.88$ GeV. Radius of the nuclear strong field is R_{Strong} = 2.95821 fm [2] so the total cross section should be $\sigma_{Total} = \pi\, R_{Strong}{}^2$ = 275 mb.

The maximum for hyperons Lambda should be for $E = s^{1/2} = 2\,\Lambda = 2.23$ GeV. We can assume that hyperons are produced on the Schwarzschild surface for the strong interactions – radius of it is $R_{Sch} = 2\,A$ = 1.395 fm [2] so total cross section should be $\sigma_{Total} = \pi\, R_{Sch}{}^2$ = 61 mb. This cross section is valid for all hyperons but for the most massive hyperon Omega is $E = s^{1/2} = 2\,\Omega^- = 3.35$ GeV.

3. Rho parameter versus the centre-of-mass energy

Here the symbols of particles denote their mass as well.

SST leads to the atom-like structure of baryons [2]. There is the core with a mass of $H^{+,-}$ = 727.4401 MeV. It consists of the electric-charge/torus $X^{+,-}$ = 318.2955 MeV and the central condensate Y = 424.1245 MeV with a radius of $r_{p,proton}$ = 0.00871094 fm. The large loops m_{LL} = 67.54441 MeV with a radius of $2A/3$, where A = 0.6974425 fm, are produced inside the electric-charge/torus – the neutral pions are built of two such loops. Here π^o denotes the neutral pion whereas p^+ denotes the proton.

The parameter ρ is the ratio of the real to the imaginary part of the forward nuclear elastic scattering amplitude at t = 0.

Consider following three formulae for ρ:

$$\rho_{1,E>11\ TeV} = m_{LL} / (X^+ + X^-) = 0.1061 \,, \tag{8}$$

$$\rho_{2,E>11\ TeV} = \pi^o / (H^+ + H^-) = 0.0928 \,, \tag{9}$$

$$\rho_{min,max} = 2\,\pi^o / [\pm\, (p^+ + p^-)] = \pm\, 0.1439 \,. \tag{10}$$

In the numerators are the real masses of the exchanged particles (the real part) whereas in denominators are masses of the created virtual pairs (the imaginary part).

For a disc-like structure, energy is directly proportional to squared radius. Neutral pion is created on circle with a radius of $2A/3$ – it is because there is created a condensate with such a radius. Since $r_{p,proton}$ corresponds to the $Y = \pi\, \pi^o$, where π = 3.1415927…, so energy E of created disc-like condensate can be calculated from following formula

$$E / (\pi\ \ \pi^o) = [(2\,A / 3) / r_{p,proton}]^2 \,. \tag{11}$$

From (11) we obtain $E = 1.208$ TeV. For this energy, value of the rho parameter should be maximum i.e. $\rho_{max} = 2\ \pi^o\ /\ (p^+ + p^-) = 0.1439$. We can see that the created virtual proton and virtual antiproton simultaneously exchange two neutral pions.

For low energies there appear the virtual pairs which are accompanied by "holes" in the Einstein spacetime so the holes carry negative mass. The pions are exchanged between the holes so for low energies is $\rho_{min} = 2\ \pi^o\ /\ [-(p^+ + p^-)] = -\ 0.1439$. At low energies, instead the neutral pions there are created the electron-positron pairs so applying formula (11) we obtain that ρ_{min} should be for $E = 9.15$ GeV.

We can write formula (11) for the central condensates $Y = 424.12$ MeV when radius of created disc is equal to the radius of the Schwarzschild surface for the nuclear strong interactions – radius of such surface is $2A$ [2]

$$E\ /\ Y = [(2\ A)\ /\ r_{p,proton}]^2\ . \qquad (12)$$

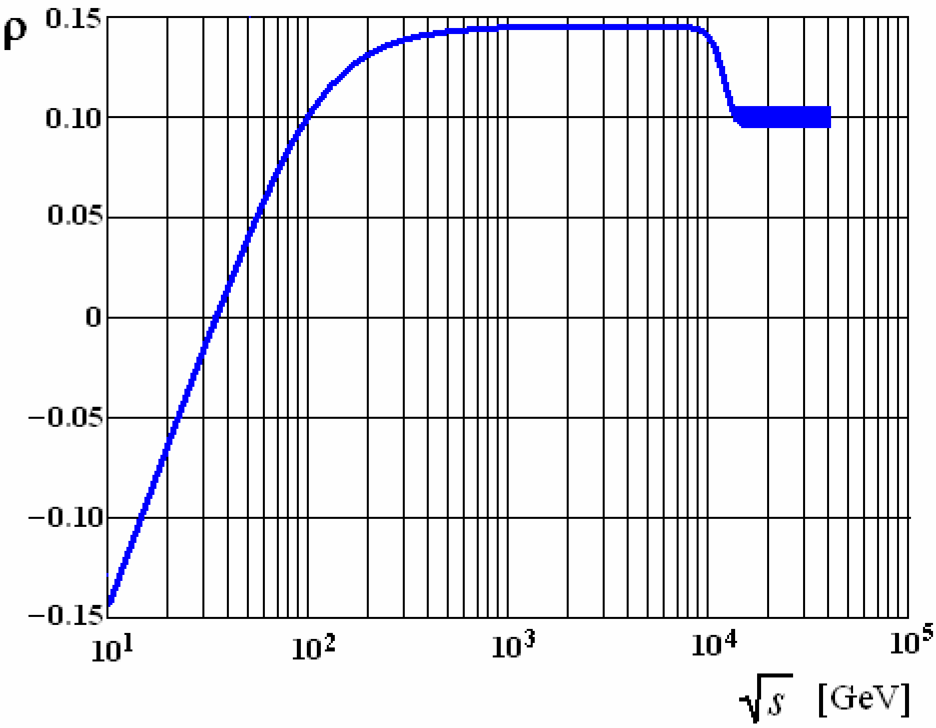

Fig.2
Dependence of the rho parameter on the centre-of-mass energy from the Scale-Symmetric Theory.

From (12) we obtain $E = 10.875$ TeV. For energies higher than $E > 11$ TeV, values of the rho parameter are defined by formulae (8) and (9). For ~11 TeV we should observe some decrease in value of rho from 0.1439 to 0.106 or 0.093. On the Schwarzschild surface for the strong interactions, from the energy E, there are produced the X^+X^- virtual pairs which exchange the real loops m_{LL} or the H^+H^- virtual pairs which exchange the real neutral pions. We can see that for $E > 11$ TeV, the orbits outside the core of baryons [2] are destroyed.

Obtained here values for the rho parameter are consistent with experimental data [14].

4. Summary

Here, within the classical/statistical/non-perturbative Scale-Symmetric Theory, we calculated and showed the origin of the inelastic and elastic cross-section and the rho parameter versus the centre-of-mass energy for the proton-proton collisions. Obtained results are consistent with experimental data.

For inelastic collisions, for $E = s^{1/2} = 13$ TeV, within presented here model, we obtained the central value obtained in the ATLAS experiment which is lower by several units from the TOTEM central value. On the other hand, the total cross section for such energy is consistent with the TOTEM value. It suggests that some more precise experiments should show that the cross sections for inelastic collisions should be a little lower than obtained in the TOTEM experiment – it should be about 6 mb less for 13 TeV.

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