The Higgs Boson/Quantum Gravity/Cosmological Constant Connections

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Abstract

We suggest discovery targets for the Higgs boson and a Tev mass scale for quantum gravity, in terms of the cosmological constant, and ultimately, the electron.

Introduction

The Higgs boson really needs no introduction, as it is the focus of world-wide attention by the particle physics community, at FermiLab, and CERN, where the Large Hadron Collider (LHC) was built primarily for its Higgs discovery potential. If found when the LHC begins science runs later this year, it will constitute the last missing link in the highly successful standard model (SM) of particle physics.

Since its completion one-third of a century ago, the Glashow-Weinberg-Salam (GSW) theory of electroweak (EW) interactions has rendered precise predictions for the masses of the W and Z vector bosons [1]. In contrast, the GSW theory can only assert that the Higgs mass is given by its vacuum expectation value (vev), (~ 246Gev), scaled by an unknown coupling constant, which is not computable from within the SM [2].

Outside the SM, versions such as the minimally supersymmetric standard model (MSSM) have produced many predictions over the last decade [3]. Indeed, some predictions of the Higgs mass lie outside the window over which current experimental searches focus on, such as conformal symmetry [4] with $M_H \sim 10^{-33}$ ev, to extra-dimensional gauge fields [5], with $M_H \sim 60$ Gev, and to 5-D versions of the SM [6] with $M_H > 600$ Gev.

The W and Z vector bosons were subsequently observed in the early 1980's [7]. What has gone unobserved, despite prior intense efforts at CERN and Fermilab is the Higgs boson, the essential element to complete the GSW electroweak triad. As of 1996, continuing attempts to refine the value of the W boson and top quark masses has resulted in a shrinking of the theoretical search window for the Higgs [8], in concert with the experimental one released last year, from the CDF/D0 collaboration at Fermilab [9].

Experimental Discovery Window

In March of 2007, it appeared that a dramatic narrowing of the search window for the Higgs boson had arrived, when an indirect exclusion window was published [10], ranging from 114 - 144 Gev, at the 95% confidence level (CL).

Two years later, in March 2009 the upper bound from the direct search window extended the range, from the LEP2 lower bound of 114.4, up to and excluding the band from 160 - 170 Gev at 95% CL [11]. Recent analysis has reduced this exclusion band to 162 - 166 Gev [12].

Just this month, Erler [13] has produced a powerful global analysis, culled from electro-weak precision and Higgs search data which delineates a 90% CL search window for the Higgs boson, extending from 115 to 148 Gev, nearly identical to that of Blazey [10], as are seven predictions ranging from 117 – 146 Gev from extra-dimensional theories [3]. The probablility distribution in [13] is highly skewed toward the lower end, due to prior LEP2 and Tevatron searches. We will see below, that naturally occurring scales point strongly to this region as well, favoring a light Higgs.

Theory

I. Higgs boson

In a recent paper [14], Beck has presented a statistical argument that there is a connection between the properties of the electron and the cosmological constant, which can be expressed more transparently through the relation,

$$(1) \quad \left(\frac{l_p}{\alpha\,\lambda_e}\right)^6 = l_p^{\,2}\Lambda\,,$$

where l_p is the Planck length, λe is the electron wavelength, α is the fine structure constant, and Λ is the cosmological constant, corresponding to a value for the vacuum energy density which is in excellent agreement with the WMAP value, namely 3.9 Gev/m^3, vs. 4.1 Gev/m^3 from (1) [14].

The physical content of (1) is striking, in that the horizon entropy associated to the cosmological constant is just the inverse of the right-hand side, while the QED parameters α and the electron mass appear on the left. Moreover, the square of the Planck length can be viewed as the geometric mean of the zitterbewegung and Schwarzschild radii of the electron, suggestive of the black hole model of the Dirac electron [15]. Taking the square root of (1), we can write it in terms of the the cosmological constant mass as:

$$(2) \quad \left(\frac{m_e}{\alpha\,\underline{m_p}}\right)^3 = 8\pi\left(\frac{m_{cc}}{\underline{m_p}}\right)^2$$, where $\underline{m_p} = 2.43x10^{18}$ Gev is the reduced Planck mass;

Thus (2) predicts,

$$(3) \quad m_{cc} = 0.00237 \text{ ev}.$$

So one could suggest that m_{cc} (me, α), and indeed there are several models in which the cosmological constant is postulated to have a quantum electrodynamical (QED) origin [16-18].

Although it is not obvious whether the electron is the source of the CC or vice versa, it is clear that (2) constitutes an intriguing constraint between elementary particle and cosmological parameters where apriori, none is apparent in either standard model.

Indeed for years now, it has been part of the folklore [19] that the proton bears a remarkable relation to these parameters as well,

$$(4)\quad \log_{10}\left(\frac{mcc}{Mp}\right) = -11.6 \approx \frac{-1}{\sqrt{\alpha}} = -11.7$$

As a result, one could argue that $mcc\,(Mp,\, me,\, \alpha)$, and is more naturally expressed in terms of dimensionless parameters, e.g., $mcc\,(\mu, \alpha)$, where $\mu = \frac{Mp}{me} = 1836$ is the proton-electron mass ratio.

As Ozer points out [20], there is a remarkable scale equivalence between the Higgs, Inflaton, and, cosmological constant masses,

$$(5)\quad \frac{mcc}{M_H} \approx \frac{M_H}{M_I} \sim 10^{-14}$$

Since the vacuum energies associated to the epochs of Hubble acceleration and inflation can be modeled by Higgs fields [21-22], we conjecture that this proportion may correspond to an equality,

$$(6)\quad M_H^2 = mcc\, M_I$$

Indeed, dimensional analysis suggests a model-independent measure of the inflaton mass. It has long been known that the electron charge, mass, and Newton's gravitational constant define an electro-gravitational mass, via the electronic and gravitational fine structure constants α and β, and the Planck mass,

$$(7)\quad M_{EG}^2 = \alpha\, mp^2 = \frac{\alpha}{\beta}\, me^2$$

If we now construct a reduced electro-gravitational mass, which is the geometric mean of the reduced Planck mass and some intermediate mass scale, such that,

$$(8)\quad \underline{M}_{EG}^2 = mx\, \underline{mp} = \alpha\, \underline{mp}^2$$, or in terms of the electron mass,

$$(9)\quad mx = \alpha\, \underline{mp} = \frac{\alpha}{\sqrt{8\pi\beta}}\, me = 1.78 \times 10^{16}\ Gev$$

This is in remarkable agreement with the MSSM GUT-scale of $\sim 2\, x10^{16} Gev$ [23], and they are ostensibly identical. Taking the inflaton mass as the geometric mean of this GUT-scale mass, and the mass corresponding to the reheating temperature given in [21], we compute an inflaton mass of,

$$(10)\quad M_I = (M_{GUT} M_{reheat})^{1/2} = (1.8\, x10^{16} Gev \times 2.0\, x10^{15}\, Gev)^{1/2} = 6.0 \text{ x } 10^{15} \text{ Gev.}$$

Inserting this value into (6) gives a Higgs mass of,

$$(11)\quad M_H = 120 \text{ Gev.}$$

In Erler [13], this value for the Higgs mass is in close proximity to a narrow maximum in the Higgs mass probability, peaked around 117 Gev; A mere 3% lower reheating temperature in (10) reproduces this value exactly, as does a recent computation of the two-photon Higgs decay process [24].

These calculations strongly suggest that a Higgs boson with a mass near 120 Gev will be discovered in Tevatron or LHC data, and that the cosmological constant, inflaton, electron and GUT-scale masses are all mutually constrained. The implications for cosmological and particle physics are enormous if this interlinkage evolves from our vacuum state near the time of inflation, up to the recent dark energy epoch, as a sort of `DNA' coding of our universe, encompassing some 61 decades connecting the Planck and deSitter scales. It also explains why the value of the cosmological constant is non-vanishing: all mass scales may ultimately derive from it.

II. Tev-scale Quantum Gravity vs. Supersymmetry (SUSY)

Twelve years ago, an alternative resolution of the hierarchy problem was announced [25], in which large extra dimensions (LXD) effectively lowered the scale of quantum gravity from the Planck scale of 10^{19} Gev, down to the Tev scale, accessible to particle accelerators such as the Tevatron or the LHC, which might observe them directly. Thus a reduced quantum gravity scale now vied with SUSY to resolve the hierarchy problem.

In a very recent paper [26], Gasperini has convincingly argued that the vacuum energy, first measured twelve years ago by astronomers, owes its existence to SUSY breaking, which should manifest at the Tev scale.

A direct calculation of the upper bound gives,

$$(12)\quad M_{SUSY} \leq \sqrt{m_{cc} m_p} = 2.4 \text{ Tev}$$

He goes on to argue that failure to observe SUSY effects such as sparticles below this scale, would likely constitute experimental evidence *against* the existence of supersymmetry.

This would leave the theory of LXD as the primary candidate for solving the Hierarchy problem. Fortunately, a new test of LXD has just emerged [27], which produces a unique particle decay signature at a threshold of 6 Tev. Thus we enquire as to whether the relations in (2) could predict an energy scale consistent with this threshold.

If there are six LXD, they constitute a 6-volume, $V_{(6)}$ from which one can compute the reduced scale of quantum gravitational effects as,

$$(13)\quad M_{QG}^{4} = \left(\frac{m_p^{2}}{V_{(6)}} \right)^{\frac{1}{2}}$$

From differential geometry [28], the volume of a 6-dimensional hypersphere is given by,

$$(14)\quad V_{(6)} = \frac{\pi^{3}}{6} R^{6}$$

Equations (1) and (2) can be squared and combined to give,

$$(15)\quad \left(\frac{l_p}{\alpha \lambda_e} \right)^{6} = 8\pi \left(\frac{m_{cc}}{m_p} \right)^{4}$$

Where, m_p= 1.22 x10^{19} Gev, is now identified as the Planck mass.

In (15), we recognize the left-hand denominator as the classical Lorentz radius of the electron,

$$(16)\quad R_L = \alpha \lambda_e = 2.82 \times 10^{-15}\ \mathrm{m}$$

If we now identify the Lorentz radius as the radius of the 6-d hypersphere, we can express it in terms of the cosmological constant mass as,

$$(17)\quad R_L^{6} = \frac{1}{8\pi} \left(\frac{m_p}{m_{cc}} \right)^{4} l_p^{6}$$

Thus from (14) we obtain the 6-volume,

$$(18)\quad V_{(6)} = (\pi^{2} / 48) \left(\frac{m_p}{m_{cc}} \right)^{4} l_p^{6}$$; Inserting this into (13) gives, after some algebra,

(19) $$M_{QG}^2 = \sqrt[4]{\frac{48}{\pi^2}}\, m_{cc}\, m_p \,;$$

Thus we arrive at a reduced quantum gravity scale given by,

(20) M_{QG} = 6.5 Tev,

which is in excellent agreement with the threshold value cited in [27].

Conclusion

It appears that through its unique linkage to the cosmological constant, the electron apportions scales centered around a Tev, which probably correspond to black holes and the Higgs boson. Coincidentally, it is also the scale below which SUSY effects, such as sparticles, are expected to manifest, if at all.

It would be extraordinary if nature, in defiance of Occam's razor, accomodated *two* such physical phenomena capable of resolving the hierarchy problem. Hence one expects to see one *or* the other, but not both. Given the paucity of experimental evidence for SUSY in three decades of searching, as well as recent evidence against it, in which the measured B_s meson switching rate was much smaller than the SUSY prediction [29], this author feels that the odds favor observing a signature of quantum gravity effects, such as enhanced lepton production beyond SM predictions, and/or black holes possibly later this year, once the LHC begins operating at the 7.0 Tev center-of-mass energy level.

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