Implications of the Higgs Boson Discovery

Richard St. Denis [a]

School of Physics and Astronomy, Glasgow University, G128QQ, Glasgow, UK

Abstract. In this paper the significance of the discovery of a new boson with the ATLAS detector at the LHC proton-proton at a mass of

$$m_H = 124.3^{+0.6}_{-0.5}(\text{stat.})^{+0.5}_{-0.3}(\text{syst.})\,\text{GeV}$$

is explored. A number of computations that should be rather simple are suggested and imply that this mass may well be a fine-tuned value that is required for galaxy formation. It is argued that it points to the scale where new physics must exist and implies a range of possible new physics symmetries over a variety of scales. This leads to fundamental questions regarding quantities such as action, entropy as well as fundamental concepts of causality and an uncertainty principle regarding causality is suggested. A checklist of computable and verifiable computations is provided.

1 Introduction

The discovery of the Higgs is significant for a number of reasons, not the least of which is the completion of the observation of the last of the fundamental particles in the Standard Model (SM). In this paper the significance of this value is considered and leads to a number of suggestions for how to cope with fine tuning as well as how to choose the fine tuning needed based on cosmological bounds. The problem is illustrated by considering an experiment where collisions occur at a centre-of-mass energy just above, below or equal to the planck mass. Consideration is then given to how one would realize it and what the broad characteristics of the phenomnology would be. The role of black holes is then investigated and it is proposed that there are different classes of black holes but that all black holes contain collision scales that are compressed to that which is of order the Planck Mass, thereby providing an abundant number of accelerators in which to observe the proposed experiment. A new class of black hole is considered to be the instatiation of the Fermi sea of anti matter which contains energy and hence is dark matter. The paper is organized as follows. The signficance of the Higgs mass is considered in Section 2 and the fine tuning problem is outlined. The proposed experiment is described in Section 3 where its phenomenology is also described and a connection to black holes is suggested and the melding relativisitic quantum field theory with a theory of general relativity and quantum mechanics is considered. In Section consideration is given to how one might observe the phenomnology of Planck Mass scale interactions. In light of cosmological arguments fine tuning is addressed in Section 5. Consideration of the physics within the black hole is given in Section 6 and this leads to a discussion of causality and a possible uncertainty principle that sets the scale in which causlity may be violated.

[a]E-mail: `richard.stdenis@glasgow.ac.uk`

2 Significance of the Higgs Mass

There is a deeper significance to the discovery of the Higgs Boson: the value of the Higgs Boson mass itself. The importance of this lies in the fact that the SM is valid to scales of order the Planck mass but as one approaches such scales, the vacuum becomes metastable [?]; however, for the SM to be a valid description of phenomena at this scale it is necessary to fine tune the Higgs mass to a level of one part in 10^{52} [?]. This feature of the SM is referred to as the naturalness problem [?] and has motivated the formation of theories beyond the SM to try to eliminate this fine tuning. One of the most popular theories to reduces this problem is Supersymmetry [?]. The theory is usually cast in terms of the Minimal Supersymmetric Model (MSSM) [?] in order to allow for computations to be performed with a limited set of parameters as inspired by assumptions of a Grand Unification Theory that includes gravity and breaks down to SUSY at the electroweak scale, of order 1 TeV. SUSY is however a broken symmetry and as such there remains a fine tuning of the Higgs fields in that theory, but to a much smaller degree than in the SM, being of order 10^{-2} to $10^{-}3$ [?]. Furthermore, the boson that was discovered can be the CP-even scalar in SUSY since it is SM-like in all properties except for 20% differences in cross section. Currently these differences can be easily accomodated within the present experimental statistics [?]. However it is true that the loop corrections in SUSY that correspond to the tree level limit that the lightest Higgs must have a mass less than that of the Z become quite unstable when accomodating a Higgs mass of order 125 GeV.

3 Proposed Experiment

In either the case of the SM or the MSSM it is interesting to consider an experiment that explores the SM processes that one typically measures at a collider such as cross sections and differential measurements of jets, boson production, Higgs production, heavy quark production, but to consider these at scales approaching the Planck Mass. Specifically it is interesting to consider what is expected from an e^+e^- collider with $\sqrt{s} = 10^{16}$ GeV? Furthermore one could sweep a range of energies from $\sqrt{s}_{SM} \equiv 10^{15}$ to $\sqrt{s}_{GRQ} \equiv 10^{17}$ GeV. The energy scan includes values that should be described by the SM to values where the Planck Mass is exceed and the theory must include a relativistic quantum field theory that incorporates General Relativity (GR). This is indicated here by the subscript GRQ. Candidate models currently include string theory [?].

While considering this experiment, one has to examine how the vacuum predicted by the SM is changing with the scale. For values below $\sqrt{s}_{SM}$ and around $\sqrt{s}_{SM}$ the vacuum has a minimum and states computed as excitations above this minimum in the normal Relativistic Quantum Field Theory (RQFT) will lead to the effects that are normally understood within the context of computations in perturbation theory although accuracy may demand rather higher order computations in order to match observation. As one approaches the point where the vacuum has no minimum, then there is no broken symmetry and all the bosons will be massless, like photons. The unbroken SM would then be a basis for these phenomonelogical computations. Once there is no minimum for the vacuum for values of $\sqrt{s} = \sqrt{s}_{GRQ}$ the framework of RQFT would no longer be valid and a complete theory based on the computation of QM with GR would be required. As one does this energy sweep, it would also be true that the tunneling probability from the region where the vacuum has a minimum to one outside that minimum would increase and the state may well be one in which the universe tunnels and the states are free with no minimum.

4 Cosmic accelerator

It is entirely possible to consider the computations suggested for the collider experiment proposed in Section /refsec:collider and to confront the possibility of tunneling and how that might manifest itself. If the energy input to a collision were to be dissipated by tunneling, then that would appear as black hole formation. While it is impractical to perform the experiment it is possible that collisions of these energies could be observed in particle astrophysics. There have been many examples where one could find phenomena that seem to be odd and rare. Gravitational lensing was considered an interesting thought experiment, unlikely to be found because it required a very specific arrangement of galaxies and observers; however, this has been observed and indeed has been used in measurements of MACHOS. It is commonplace. Also, supernovae were thought to be hard to find until systematic scanning of the sky using large data collection methods and CCD cameras has led to the ability to find supernovae on demand and indeed to measure the accelerating expansion of the universe. Therefore in order to observe the collisions that are of sufficient energy that lead to tunneling one needs to look for this.

Black holes appear to come in two mass ranges. One is that set by the death of stars having masses between eight and fifty solar masses leading to black holes in this mass range. The other is much larger, of order billions of solar masses and these are found at the centre of galaxies. There is a black hole observed in the globular cluster Omega Centauri that has a mass of 40,000 solar masses and could be of particular interest because of its unique intermediate mass value. There are also various generations of stars in Omega Centauri. It is thought that supermassive black holes that are at the centres come from the merging of smaller black holes and that these intermediate sizes are important to show the process of merging in place. However given the new information on the mass of the Higgs, and considering the possibility of tunneling when collisions at the scale of the Planck mass occur, it may be that the larger black holes are in fact due to these tunneling phenomena rather than the fusion of black holes. If one were to have fusion of black holes the spectrum of masses should be continuous rather than discrete. If collisions have occurred that cause a tunneling, then it may be that the process results in some characteristically larger size for black hole formation and indeed that as the tunneling takes place, it may be possible to observe the tunneling process building up.

This would require that there are simply cases of acceleration in the universe that can reach centre-of-mass energies large enough for tunneling to occur. Alteratively the supermassive black holes may have been formed when the universe was young enough to have a high probability for collisions at high energy to occur. This would have had to have happened just at the end of the inflationary period and implies another form of fine tuning. It would have been necessary that tunneling probability not be too large such that every collision would lead to black holes so that the universe would not get started; however, it would have to be large enough to allow for sufficient black holes to be formed such that they produce the correct numbers of galaxies. In addition the total mass of the universe should be large enough that these black holes do not condense and prevent formation of the universe at all.

5 Fine Tuning Embraced

This implies a set of parameters for the formation of the universe: the probability of tunneling per high energy interaction, P_{tunnel}, the spectrum of particle center of mass collisions as a function of the size and density of the universe $S\left(t, \rho\right)$ and the size of the tunneling $D\left(\sqrt{s}\right)$. The tuning of these parameters is related to the Higgs potential and hence to the fine tuning of the Higgs mass. As was stated in Section 2, the amount of fine tuning that is required for the Higgs may well indicate if the particle needs to be SM or MSSM.

If one considers the experiment in Section 3 then the theory to describe the full scan of masses is that which accomodates Quantum Mechanics and General Relativity, a theory of GRQ. The energy scan is the same as a scan in size, and just as in atomic physics there must be a correspondence priciple where the size or energy regime in which both theories are valid give a consisent answer. In this case the incomplete theory is not Newtonian mechanics but RQFT based on Special Relativity and the more complete theory is not quantum mechances but GRQ. One would imagine that the dynamics of the black hole formation would be described by RQFT and set the parameters for the rate at which the tunneling occurs and the dynamics that limit the tunneling such a to have some turn-off mechanism. In addition it is possible that a structure of a RQFT GUT would be set by the GRQ, with symmetries such as SO(10) or SU(5) predicted by the theory. From the point of view of RQFT, it would appear as an ad-hoc fact that some symmetry and indeed the breaking of the symmetry is described by some set of parameters that have to be set by hand. In the breaking of the symmetry and any further symmetries a set of Higgs bosons would be generated and of course a set of new particles. Therefore it remains well worth pursuit of the search for these high mass particles throughout the scales up to the Planck mass to try to get a clue on the form of the manifestation of the theory from which they follow.

In addition to this it is possible to formulate various ensembles of broken symmetries and hence fine tunings that allow a range of fine tunings to be generated. Thus one is not limited to only a fine tuning of the Higgs mass to the large degree required by the Standard Model nor to the small degree of the MSSM, but could choose tunings in a spectrum of values. It is therefore proposed that a computation of the fine tunings for various scenarios of symmetries being broken be examined to see what possiblities exist and how that then can be compared to the probabilities for the formation of black holes for galaxies.

In consider the formation of the black holes, it is also interesting to understand if these galaxies and their black holes can eventually serve as portals to the next Big Bang or if indeed each of the provides a transport of matter and energy to the formation of another Big Bang in smaller universes. The expansion of the universe implies that these galaxies will not have an opportunity to coalesce and be the source of the next Big Bang. This would have happened if the universe were contracting and would provide a means by which matter and energy could be transformed in the Big Crunch.

6 Faster than Light Neutrinos and Physics Near the Planck Mass

While the faster than light (FTL) neutrino observation turned out to be the result of an instrumental error, it was useful to think about what would one do to accomodate such an observation. A fundamental assumption of RQFT is causality and if one considers FTL neutrinos one should ask if there is a consistent field theory where causality is formally abandoned. It is possible to formulate such a theory [?] but the result is considered uninteresting since the particles of that theory cannot interact with slower than light particles. This however is considered in the context of RQFT rather than GRQ. Therefore it could be possible that interactions could arise from gravity. Since causality is a statement regarding time, it is therefore necessary to abandon the need to consider time in FTL theory. Given that time slows down as one approaches a black hole and stops at a black hole, it is possible to consider that the dynamics within a black hole allow for time to be undefined and indeed correspond to scales smaller than that suggested by the Planck Mass. It is possible that the black holes from tunneling are then different from those created by stellar collapse or that the scale of the black hole is not characterized by the event horizon but necessarily by the Planck Scale. This implies then that the physics at the Planck scale is much more common than one would otherwise suspect and that indeed collisions at that scale can be created in the stellar collapse. This in turn implies that the formation of super massive black holes comes from stellar collapse seeds that then provide the opportunity for a tunnelling black hole.

One does not have to abandon causality entirely but it may be that causality can be formulated in an uncertainty principle that requires abandoment for small distances only and that a new constant analagous to Planck's constant can characterize the abandoment of causality.

It has been suggested that as one looks at scales near the Planck Mass [**?**] that space-time becomes foamy. It is natural to consider that at those scales causality can be abandoned. If one were to try to formulate a path integral where the path is foamy, then it is expected there would be issues with causality. Therefore it is sensible to revisit the principle of least action and its definition once again, just as was first done by LaGrange, later by Feynman who accomodated the Heisenburg uncertainty principle. The issue with causality becomes an issue of getting lost as one tries to integrate over the path.

7 Causality, Vacuum, Dark Matter and Dark Energy

Having established that action needs to be redefined has a number of implications. First, since the definition of action is the difference in kinetic and potential energies, it is reasonable that once one considers action in a GRQ theory, there could be terms that correspond in GR to the energy contained in the quantum foam which in turn could be the definition of the vacuum energy above which excitations are computed in RQFT. The definition of the vacuum in special relativity has been a difficulty. It is possible that dark matter and dark energy are manifestations of the energy contained in this foam and are not related in any way to the MSSM. The interaction of particles of dark matter would indeed be entirely through gravitation and not require a RQFT formulation at all. By providing an energy density the infinities usually sidestepped in RQFT would become finite since the size and density of the foam is set by the Planck Scale - one need only fill up the universe with this background of foam. The nature of the foam would be that of a third class of black holes that in fact are the source of the negative energy sea of RQFT.

8 Summary

In this paper it has been proposed to consider the investigations of particle astrophysics in light of the understanding of the implications of the Higgs mass. An investigation of the phenomenology associated with collisions just below and above the centre of mass energy at the Planck Mass scale is suggeted. It is also suggested to compute the possible fine tunings required for various scenarios of symmetry breaking. With these numbers in hand, then it is worth considering how these phenomena would be observed in cosmic accelerators and that the likelihood of such observations may be quite large. The physics associated with this scan may also require a new interpretation of causality and the vacuum to be studies may be one that describes the dark energy and dark matter of the universe as well as being the vacuum upon which excitations of particles from RQFT is currently computed. Indeed the vacuum is considered to be a third class of black holes that can provide a source of the Fermi sea of anti matter through Hawking radiation and that matter arises from the evaporation of these black holes.

Acknowledgments

The author would like to thank the organisers of the conference for their hospitality and the intellectually stimulating atomosphere.