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A Model of Preons with Short Distance Scalar Interaction

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Abstract

A preon model is proposed based on spin $\frac{1}{2}$ fermion and spin 0 boson constituents. They interact via a massive scalar field which is tentatively considered a phenomenological model of quantum gravity. Implications to generations, heavy boson states and dark matter are briefly discussed.

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1 Introduction and Summary

A model for the first generation quark and lepton subconstituents was suggested in [1]. Each quark and lepton was supposed to consist of three mini black hole preons bound together by a confining subcolor interaction. Considering internal symmetry and spin, it turns out that this type of construction leads to too broad a spectrum of states. Recent LHC data indicate support of the SM without any new particles so far. Additionally, QCD-like interactions may not be realistic to explain the spectrum of quarks and leptons.

A more satisfactory scheme would seem be to assume quarks and leptons consisting of two preons. We still assume that the preons are black holes of Planck scale. What kind of an object is a black hole at the Planck scale? How do we take into account necessary quantum effects?

't Hooft calculated the density of states and entropy at the horizon and found it to diverge [2]. This can be understood in terms of quantum uncertainty between position and momentum near a sharp boundary which divides spacetime into observable and unobservable region. Sharp boundary implies infinite momentum and energy though we know the energy is finite. Therefore quantum fluctuations of the black hole geometry smooth away the horizon and central singularity which are produced classically when the ratio of the Compton wavelength of the black hole to its Schwarzschild radius approaches zero [3].

It has also been proposed that black holes at small scales are "fuzzballs" of stringy objects [4], or condensate of gravitons [5]. We think it rather well justified that Planck scale black holes are non-singular objects rather than something expected as the final state of large scale massive star collapse.

We start with a lefthanded spin $\frac{1}{2}$ isospin doublet fermions p of charge $+\frac{1}{2}$ and m with charge -$\frac{1}{2}$ [6]. To provide color and lepton number the fermion is "dressed" with a scalar preon h = (l, r, g, b) with charges -$\frac{1}{2}$, $+\frac{1}{6}$, $+\frac{1}{6}$, $+\frac{1}{6}$, resp. The first generation quarks and leptons are the following bound states

$$u_r = (p, r) \tag{1}$$
$$d_r = (m, r) \tag{2}$$

$$e^- = (m, l) \tag{3}$$
$$\nu_e = (p, l) \tag{4}$$

We assume that a kind of 'confinement' is operating between the preons producing only these spin $\frac{1}{2}$ bound states. The second and third generation quarks and leptons are dynamical excitations of these lowest states.

The dynamics between the preons in our scheme is assumed to be the Planck scale limit of gravity. There are theoretical indications that this could be due to a scalar field with a quartic self-coupling as has been studied in [7] on the basis of lattice spinor gravity [8]. The problem of metric ambiguity is studied there in detail. It is concluded that in the long distance limit the metric is universal and is described by a massless graviton. In the short distance limit, around the Planck length geometry looses its universal meaning and other degrees of freedom come to play, namely massive scalars and symmetric second rank tensors. We build a model based on the massive scalar Abelian Higgs model. Attention is given to Nielsen-Olesen vortex solution [9] smoothly joinig the preons of the bound states.

In this short note we wish to propose a modified setup of the model [1]. Sections 2 (The Abelian Higgs Model) and 3 (The Nielsen-Olesen Vortex) consist of brief summary of earlier theoretical work. The model and its implications are discussed in Sections 4 (The Model of Quarks and Leptons), and 5 (The Preon Model Bosons). In Section 6 (Setting the Mass Scales) we discuss the electro-weak to Planck hierarchy problem and introduce extra dimensions in the model. Conclusions are given in Section 7. Sections 2, 3, and 6 contain basic reference material.

2 The Abelian Higgs Model

Traditionally black holes carry only the quantum numbers of mass, charge, and angular momentum but baryon and lepton numbers are not good quantum numbers. Now it is known that the no-hair theorems have their limitations. Here we consider the case Abelian Higgs model which has been shown to support long hair of a U(1) vortex. This has been first studied in [10] for cosmic strings and black holes.

The Abelian Higgs lagrangian is

$$\mathcal{L}[\Phi, A_\mu] = D_\mu \Phi^\dagger D^\mu \Phi - \frac{1}{4} F_{\mu\nu} F^{\mu\nu} - \frac{\lambda}{4}(\Phi^\dagger \Phi - \eta^2)^2 \tag{5}$$

where Φ is a complex scalar field, $D_\mu = \nabla_\mu - ieA_\mu$ is the usual gauge covariant derivative, and $F_{\mu\nu}$ the field strength associated with A_μ. Planck units are indicated: $G = \hbar = c = 1$ and (+,-,-,-) signature. The vacuum manifold is $|\Phi| = \eta$, and therefore is a circle in the complex plane. The vortex takes the form

$$\Phi = \eta X_0(r) e^{i\phi}, \quad ; \quad A_\mu = A_0(r) \nabla_\mu \phi, \tag{6}$$

in cylindrical polar coordinates. The string tension is simply $\mu \sim 2\pi\eta^2$

3 The Nielsen-Olesen Vortex

Cosmic string splitting has been studied in [11] and the Nielsen-Olesen vortex was considered in [12]. These authors use metrics with conical deficits and assume the conical deficit can be smoothed out and replaced by a cosmic string. It was shown that a real vortex can be woven into these metrics, smoothly rounding off the conical deficit. The authors of [13] show that provided the mass of the black holes involved is sufficiently large, the Nielsen-Olesen solution can be used to approximate the field configuration, and the gravitational effect of the string will be shown to smooth out the conical singularity. Therefore the Nielsen-Olesen vortices need not be stable to non-perturbative topology changing processes, and that strings might indeed split.

It was pointed out in [12] and [14] that there is no obstruction to terminating the string on a black hole. The Abelian gauge potential has to be defined in at least two patches on 2-spheres surrounding the black hole. Depending on the actual spatial topology, it is quite possible for a string to leave a neighborhood and thus effectively terminate as far as a local observer is concerned.

Such a situation occurs in the C-metrics considered in [15] and a modification of the static metrics considered in [16]. A C-metric is an axially symmetric solution to the Einstein equations which represents two black holes uniformly accelerating apart. The force for this acceleration is provided either by a conical excess, a strut, between the holes, or alternatively by a conical deficit, a string, extending from each hole to infinity (or of course a combination of the two). The metric of [16] represents two black holes held in equilibrium by a strut. An important fact about these metrics is that the horizons of the two black holes can be identified, forming a wormhole in space [15], [17]. The presence of this wormhole then provides a hole through which the string can exit, thus it is not necessary to consider charged black holes and topologically unstable strings, these uncharged metrics can directly swallow a Nielsen-Olesen vortex. The basic idea then is to paint a vortex directly onto the metric, using the core to smooth out the conical deficit of the exact metric.

For small string tension μ, and string width much less than the black hole radius, the Nielsen-Olesen solution solves the Abelian Higgs equations. Terms of order μ are neglected since these correspond to the back reaction of the geometry on the Abelian Higgs equations, and can be accounted for via an iterative procedure.

We recall that in the early 1970's the Nielsen-Olesen strings were meant to be a realisation of the Nambu action. The open strings would have to satisfy certain boundary conditions, namely that the ends travel at the speed of light.

4 The Model of Quarks and Leptons

The quark and lepton generations are assumed to be dynamical excitations of the ground states (1) - (4). Factors contributing to these excitations may include: winding number and momentum excitations, scalar field excitations, (resonating) quasi normal modes, multi-vortex states. The resulting spectrum should include an effective trajectory of zero slope, instead or in addition of the usual Regge slope of one.

In terms of potential models, the interpreon interaction should be gently sloping at short distances and steeply rising thereafter to produce the heavier quark masses. It is possible that the top quark mass comes around through a different mechanism. The QCD quark-antiquark potential is not steep enough, and likewise for the harmonic one. The ϕ^4 form is in the right direction. This part of the model needs deatailed elaboration.

5 The Preon Model Bosons

The Higgs is basically elementary in our model, eq. (5). The weak bosons may be considered as either elementary as in the Standard Model, or bound states (in fact, they are mixtures) as follows:

$$
\begin{aligned}
W^+ &= \overline{m}p && (7)\\
W^- &= \overline{p}m && (8)\\
W^3 &= \frac{1}{\sqrt{2}}(\overline{p}p - \overline{m}m) && (9)
\end{aligned}
$$

$$
X^0 = \frac{1}{\sqrt{2}}(\overline{p}p + \overline{m}m) \qquad (10)
$$

X^0 is not in the Standard Model. Its mass must be large, around 1 TeV. Other models also predict new states in this mass region. It would a subject of its own to study all these - after the mass region around 125 GeV has been cleared experimentally.

In addition, preon-antipreon bound states $\overline{p}p$, $\overline{h}h$ with spins 0 and 1 (and $\frac{3}{2}$ etc.) must exist, in three families. These states should be compared with the supersymmetric (s)particles. Their analysis is beyond the scope of this short note.

The preon-antipreon states are candidates for Dark Matter. Recall that also at astrophysical scales the cosmic string splitting takes place rather naturally in the present, model producing the Dark Matter.

For the very early moments of the Big Bang this model predicts three times more Dark Matter production than ordinary matter.

6 Setting the Mass Scales

Considering the numerical values of Planck scale, $\sim 10^{19} GeV$, and the quark and lepton bound states, $\sim 1 GeV$, it it is not likely that the scale hierarchy can be hidden this way. A mechanism is needed to bring down the composite interaction scale toward the bound state scale. An obvious candidate scale is the weak interaction scale $m_{EW} \sim 100 GeV$. This can be achieved by introducing large extra dimensions (LED) [18], [19]. Then the 4+n dimensional Planck Scale is m_{EW}, and it is the only scale. In a black hole model, an immediate problem occurs though: the decay of the proton. A second problem is localization of the Standard Model fields.

Let us assume that the space-time is $R^4 \times M_n$, $n \geq 2$ and M_n is an n dimensional compact manifold of volume R^n, and

$$R \sim 10^{30/n-17} (\frac{1Tev}{m_{EW}})^{1+2/n} cm \tag{11}$$

The value n=2 looks exciting since the LHC experiments are performed at an energy sensitive to $R \sim 1mm$, and gravity has not been probed below this distance. The Planck scale M_{Pl} is not any more a fundamental scale. Its large value is due to the large size of the new dimensions.

Gravitons can propagate freely in the 4+n dimensions, the bulk. At energies below m_{EW} the Standard Model fields must be localized to a wall or three brane of thickness $1/m_{EW}$ in the extra dimensions. In this picture the LHC could be measuring strong gravitational phenomena.

The proton can be made stable by gauging the global baryon (B) and lepton (L) number symmetries of the Standard Model. Gauging the B-L symmetry means that the B-L charge of an atom is its neutron number. The hydrogen atom does not feel this force, and it is isotope dependent for other elements.

The masses of the left-handed neutrinos are believed to be between 10^{-2} and 10^{-3} eV. The right-handed neutrino does not have a charge with respect to the SM gauge bosons. Therefore the right-handed neutrino can escape to the bulk, unlike the left-handed neutrino, which is localized to the wall.

It turn out that the neutrino mass gets a supprssion factor $V_n^{-1/2}$ [20]

$$m_\nu \sim v/\sqrt{V_n M_f^n} \sim v M_f / M_{Pl} \tag{12}$$

7 Conclusions

The preon model introduced here is admittedly a rather diverse collection of ideas. It is built, however, on a few rather established theoretical objects joined smoothly together: Abelian Higgs model, small scale black holes (something very dense but non-singular stuff), and vortices combined in a new way. Less firm ideas include extra dimensions, detailed short distance behavior of gravity and the details of the fuzzball proposal.

It has been shown earlier that the Nielsen-Olesen solution can be used to construct regular metrics which represent vortices which end on black holes in static equilibrium (or accelerating off to infinity). Our preon model for quarks and leptons is, at this stage, based on this construction. The Plank scale 10^{19} GeV can be brought down to the weak scale to solve the mass hierarchy problem. Alternatively, the preons could be 'stringy' objects with relatively light mass. States of 'closed strings' - containing two or more vortices - are expected to show up.

The first generation quarks and leptons are fermion-scalar preon 'open string' bound states, of presumably zero mass. For the second and third generation the dynamics of the very dense matter is an open question. There is no general, unique way to calculate the excitations, various mechanisms are known in the literature.

The model predicts new preon-antipreon bound states. They are candidates for Dark Matter and they may have been formed in Big Bang and later due to cosmic string splitting.

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