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A String Model for Preons and the Standard Model Particles

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Abstract

A preon model for standard model particles is proposed based on spin $\frac{1}{2}$ fermion and spin 0 boson constituents. The preons are quantum mechanical strings. Implications to the number of generations, heavy boson states, and dark matter are briefly considered.

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1 Introduction

A model for the first generation quark and lepton subconstituents was suggested in [1]. Each quark and lepton was supposed to consist of three preons bound together by a confining subcolor interaction. A more economic scheme is to assume quarks and leptons consisting of two preons. We propose that the preons are ordinary 1-dimensional quantum mechanical strings of some mass scale m in 1+3 dimensions. The preons couple to a massive scalar field. The Standard Model quarks and leptons are built of a preon pair bound by the scalar field.

The LHC data indicate support of the SM without any new particles for the present. This model agrees with the SM results so far but takes it one step beyond it in an attempt to reduce the number constituents and couplings of popular Beyond Standard Model theories.

2 A String Model of Preons, Quarks and Leptons

We present here a scheme for the logical structure of the model. The basic building block of the model is a string of length l such that $l_P << l < l_w$ where $1/l_w$ is of the order of the electro-weak symmetry breaking scale of about 100 GeV. For a string of length nl_P, using Dirichlet boundary conditions with Planck length l_P as the cutoff, the number of states is $\frac{1}{2}(n^2 - n)$.

The setup of the model is as follows. We assume a left-handed spin $\frac{1}{2}$ isospin doublet fermion p of charge $+\frac{1}{2}$ and m with charge -$\frac{1}{2}$ [2]. 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

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

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

The bound states are formed by a scalar field interaction like the hydrogen atom with the scalar playing the role of the photon.

For the confining scalar we consider the case of Abelian Higgs model, which has been shown to support a U(1) vortex. This has been first studied in [3] 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 the complex scalar field, $D_\mu = \nabla_\mu - ieA_\mu$ is the covariant derivative, and $F_{\mu\nu}$ the field strength associated with A_μ. The string tension is $\sim 2\pi\eta^2$. [2]

The second and third generation quarks and leptons are string excitations, with masses m_i, of the lowest states: (m_0, m_1) and (m_1, m_1).

Alternatively, the model could be constructed with the preons carrying the charge and color quantum numbers and the scalar interaction between them providing the families. Three generations imply a shallow short range Yukawa interaction. The preons are confined by the longer range Abelian vortex. Dynamical details would be needed to determine the exact number of generations.

The mass m of the scalar (h_A) is expected to be about 1 TeV (or more). The W, Z, Higgs, and the top quark masses are of the order of m while the light particles need an argument.

The quarks and leptons get a second stage mass from the SM Higgs coupling. This may help to understand the increasing mass differences between the generations.

The particle content and parameter economy compared to the SM is discussed in the Appendix, where also two other types of SM extensions are mentioned.

In an early, dense phase of the universe the shorter wave length Abelian Higgs interacted first between the strings and later the SM Higgs broke the electro-weak symmetry.

There is a more remote possibility for the origin of the scalar field. On the basis of lattice spinor gravity model [4] there are calculations indicating that a massive scalar interaction could be a term in the short distance limit of gravity.

3 The Preon Model Bosons

The weak bosons may be considered as either elementary as in the Standard Model, or bound states (in fact, they are mixtures) as follows:

$$W^+ = \overline{m}p \tag{6}$$
$$W^- = \overline{p}m \tag{7}$$
$$W^3 = \frac{1}{\sqrt{2}}(\overline{p}p - \overline{m}m) \tag{8}$$

$$X^0 = \frac{1}{\sqrt{2}}(\overline{p}p + \overline{m}m) \tag{9}$$

X^0 is not in the Standard Model. Its mass must be large, around 1 TeV.

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. The preon-antipreon states are candidates for dark

[2] Instead of the scalar interaction a color-like confinement has been used [2].

matter. There may be mixing due to electromagnetic interaction between dark and ordinary matter.

For the early moments of the Big Bang this model predicts three times more dark matter production than ordinary matter. Relic density is by construction right order of magnitude. Generally, a particle's thermal relic density is [5]

$$\Omega_x \propto \frac{1}{\langle \sigma v \rangle} \sim \frac{m_x^2}{g_x^4} \ , \tag{10}$$

where $\langle \sigma v \rangle$ is its thermally-averaged annihilation cross section, m_x and g_x are the characteristic mass scale and coupling in this cross section, and the last step follows from dimensional analysis. The observed value $\Omega_X \approx 0.24$ is obtained within an order of magnitude for $m_x \sim 100 GeV$ and $g_x \sim 0.6$.

4 Summary

The preon model discussed here is built on the following assumptions:

- basic quantum constituents, preons, are strings having mass scale close to the weak scale,
- the strings interact by a scalar interaction,
- two preon bound states make the standard model particles.

The properties of the model include

- a singlet scalar boson h_A, and an X^0, both with mass about 1 TeV,
- new preon-antipreon bound states in the 100 GeV to 1 TeV range,
- no other elementary Higgs scalars,
- substantial reduction in number of fundamental particles and model parameters as discussed in the Appendix.

The preon-antipreon bound states are candidates for dark matter. They also contribute at the LHC with background-like behavior.

Appendix: Particle Content and Parameter Comparison

The Standard Model and the present model spin $\frac{1}{2}$ and spin 0 particle content comparison is shown in the table. For the present model only the total number of particles (rightmost column) is indicated. The 12 gauge bosons are the same in both models.

	Type	Color	Gener	Antip	Total SM	Tot.this
Quarks	2	3	3	pair	36	12
Leptons	2	-	3	pair	12	4
Scalar	1	-	1	own	1	2
Total					49	18

Table

There are 19 parameters in the SM: 6 quark masses, 3 lepton masses, 3 gauge couplings, 4 CKM parameters, QCD vacuum angle, Higgs mass and vev. The present model would add to these the second Higgs mass and vev but would reduce the 9 fermion masses down to, say 2, making a total of 14 parameters.

Other Beyond Standard Model (BSM) schemes include Grand Unified Theories (GUT) and Supersymmetry. A promising GUT theory is based on the group SO(10) [6]. There all the first generation SM fermions sit in a 16 dimensional representation of the group and gauge bosons in a 45 dimensional of which 33 bosons are new. The Higgs sector is rather complicated, representations like 10+45+126 may be needed. The number of parameters is of the order 100. Supersymmetric models include the Minimal Supersymmetric Standard Model (MSSM) [7]. The MSSM contains 120 new parameters.

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