Supersymmetric Preons II: Dynamic SUSY Breaking

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Abstract

The supersymmetric preon model [1] is based on simplest possible superfields of which the standard model can be constructed. The preon model offers a natural framework for supersymmetry breaking mediated dynamically by gravity. The SUSY breaking interaction Lagrangian contains supersymmetric preon, aka. 'hidden' and visible sector MSSM fields. The low energy limit of the preon model is proposed to be the standard model with broken supersymmetry.

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1 Introduction

A proposal to make supersymmetric preon model a viable platform for standard model (SM) particles was set forth in [1]. In this note arguments are given how realistic broken supersymmetry (SUSY) may be obtained within the model in spite of the present situation with negative experimental results. SUSY breaking occurs when the energy is below the SUSY breaking threshold value M_S. The supersymmetry breaking model is defined on a 'hidden' sector, which in the present scheme is the supersymmetric physical preon sector. Gravity mediates the symmetry breaking by a messenger signal from the preon sector to the minimally supersymmetric standard model (MSSM) in the visible sector, the effect being of gravitational strength. The mass differences between the SM particles and their superpartners are of the order of the gravitino mass $\mathcal{O}(m_{\frac{3}{2}})$. Other possible mechanisms are super-conformal anomaly breaking and gauge boson mediated breaking. The literature of supersymmetry breaking extends over five decades, see e.g. [2, 3, 4, 5, 6]. Recent pedagogical presentations are [7, 8].

The article is organized as follows. In section 2 I give motivation for the preon model. The construction of scalars, quarks and leptons as composite states of supersymmetric preons is presented in subsection 3. Supersymmetry breaking analysis is considered within the preon model in section 4. Conclusions are given in the final section 5.

2 Why Preons?

When one wants to go beyond the standard model one has to consider what is the most important element missing from the SM. Here it is assumed the most important element would be gravity, especially since in section 4 gravity mediated SUSY breaking is adapted. Admittedly, it is also the most difficult problem in particle physics. Therefore it is safer to start with something simple and generally accepted like: global symmetries are forbidden by quantum gravity [9]. In such a scheme the SM particles, quarks and leptons carrying baryon and lepton number, may not be the best particles for supersymmetric model building.

A model for quark and lepton constituents was introduced in [10, 11, 12, 1]. I consider the supersymmetric[1] model scheme with these properties (i) the quantum numbers of basic objects must be those available for vacuum solutions of Einstein equations: mass, spin and charge (no-hair), (ii) supersymmetry is valid for preons; the basic superfields are members of a supermultiplet which includes the graviton, photon, a light spin $\frac{1}{2}$ preon of charge $\frac{1}{3}$, and their superpartners, and (iii) scalar particles, preons, quarks and leptons are classified using the quantum group SLq(2) representations [13, 14]. It is supposed that quantum gravity, when available, will organize the preons in bound state in three generations. Alternatively, there may be a new very strong gauge interaction between the preons. These challenging questions are yet to be studied, and are beyond the scope of this note.

I believe the setup of the preon model brings clarity as compared to the case of traditional approach to supersymmetry. At energies above Λ_{cr} there are only two interactions, gravity and electromagnetism.[2]

3 Supersymmetric Preon Model

In the present scenario, at the energy of the order $\Lambda_{cr} \sim 10^{16\pm1}$ GeV quarks and leptons ionize, or make a phase transition, into their constituents, preons. Below this dividing point, I consider the standard model a well behaving renormalizable theory with a UV momentum cutoff Λ_{cr}. Above this transition energy unbroken supersymmetry enters the scene: it is defined for preons, which are now unbound and massless.

In this simple supersymmetric preon model there is the graviton G and its spin $\frac{3}{2}$ superpartner gravitino $\tilde{G}$

$$G = \begin{pmatrix} \rightarrow \\ \leftarrow \end{pmatrix} \text{ and } \tilde{\mathrm{G}} = \begin{pmatrix} \rightarrow \\ \leftarrow \end{pmatrix} \tag{3.1}$$

In addition I have as the massless basic fields the photon γ and its neutral spin $\frac{1}{2}$ superpartner, the photino, denoted $\tilde{m}^0$. The second superpair is the spin $\frac{1}{2}$, charge $\frac{1}{3}$ preon m^+ and two scalar superpartners $\tilde{s}_i^+$, i = 1, 2. All fields γ, $\tilde{m}^0$, m^+ and $\tilde{s}_i^+$ have two degrees of freedom:

$$\gamma = \begin{pmatrix} \rightarrow \\ \leftarrow \end{pmatrix} \text{ and } \tilde{\mathrm{m}}^0 = \begin{pmatrix} \uparrow \\ \downarrow \end{pmatrix}, \ \mathrm{m}^+ = \begin{pmatrix} \uparrow \\ \downarrow \end{pmatrix} \text{ and } \tilde{\mathrm{s}}^+_{1,2} \tag{3.2}$$

where the horizontal and vertical arrows refer to helicity and spin, respectively, and + and 0 refer to charge in units of $\frac{1}{3}$ electron charge. The $\tilde{m}^0$ is a Majorana fermion. The R-parity for fields in (3.2) is simply $P_R = (-1)^{2(spin)}$. The m^+

[1] Supersymmetry was anticipated in passing in [10].

[2] Because of asymptotic freedom of quantum chromodynamics this may be considered as an approximation to a grand unified theory.

and $\tilde{m}^0$ are assumed to have light mass, of the order of the first generation quark and lepton mass scale.

The preons combine freely without extra assumptions into standard model fermion composite states. They form a three member combinatorial system [11]. For the same charge preons fermionic permutation antisymmetry factor ϵ_{ijk} must be included. These arguments lead heuristically to four bound states made of preons, which form the first generation quarks (q) and leptons (l) (dropping tildes)

$$\begin{aligned} u_k &= \epsilon_{ijk} m_i^+ m_j^+ m^0 \\ \bar{d}_k &= \epsilon_{ijk} m^+ m_i^0 m_j^0 \\ e &= \epsilon_{ijk} m_i^- m_j^- m_k^- \\ \bar{\nu} &= \epsilon_{ijk} \bar{m}_i^0 \bar{m}_j^0 \bar{m}_k^0 \end{aligned} \tag{3.3}$$

More details are given in [1] and references therein.

Bound states of scalar constituents do not make a spectrum like fermions. A neutral, very light two body bound state is expected to exist

$$a_{0i} = \tilde{s}_{0i}^+ \, \tilde{s}_{0i}^-, \quad i = 1, 2 \tag{3.4}$$

Scalar bound states can also be formed from the fermions

$$\begin{aligned} b_0 &= m^+ m^- \\ c_0 &= m^0 m^0 \\ h_\pm &= m^\pm m^0 \end{aligned} \tag{3.5}$$

The states (3.4) and (3.5) (and other similar states including mixtures) are candidates for the Higgs and axion, which are important in spontaneously broken symmetries of the standard model. Finally, the model allows an unbound scalar charge $\frac{1}{3}$ field.

4 Dynamic Supersymmetry Breaking

If supersymmetry would be broken at tree level the advantage of introducing supersymmetry would only be that the breaking parameter M_S would be protected against quantum corrections. It would be better, and more natural, to explain this parameter in a dynamical way. To enter dynamical symmetry breaking (DSB) [15], recall first two points.

Non-renormalization theorems tell that if supersymmetry is unbroken at tree level it cannot be broken at any order in perturbation theory. But it can be broken non-perturbatively. The superpotential looks like $W_{eff} = W_{tree} + W_{non-pert}$.

The second point comes from dimensional transmutation. Renormalization group equations tell how gauge couplings run. Any asymptotically free gauge theory has an intrinsic, dynamical scale Λ which controls the strong coupling dynamics of the theory. Λ is much smaller than the scale M_X at which the coupling is weak. Consider now a supersymmetric gauge theory without tree level symmetry breaking but its strong coupling dynamics provides a contribution to the superpotential $W_{non-pert}$ which contains a non-vanishing term. It can be either D-term or F-term.[3] In the following only the latter case is considered. The F-term will be of the order of the dynamical scale Λ. It is the scale of supersymmetry breaking $M_S \sim \Lambda \ll M_X$. This is the hierarchy between M_S and the UV scale M_X. Numerically $M_X \sim M_{GUT} \sim 10^{15}$ GeV.

Consider F-term based breaking in a model with chiral superfields. The most general renormalizable Lagrangian is of the form [16, 7, 8]

$$\mathcal{L} = \int d^2\theta d^2\bar{\theta}\ \bar{\Phi}_i \Phi^i + \int d^2\theta\ W(\Phi^i) + \int d^2\bar{\theta}\ \overline{W}(\bar{\Phi}_i) \tag{4.1}$$

where

$$W(\Phi^i) = a_i \Phi^i + \frac{1}{2} m_{ij} \Phi^i \Phi^j + \frac{1}{3} g_{ijk} \Phi^i \Phi^j \Phi^k \tag{4.2}$$

The equations of motion for the auxiliary fields are

$$\bar{F}_i(\phi) = \frac{\partial W}{\partial \phi^i} = a_i + m_{ij}\phi^j + g_{ijk}\phi^j\phi^k \tag{4.3}$$

and the potential is

$$V(\phi, \bar{\phi}) = \sum_i |a_i + m_{ij}\phi^j + g_{ijk}\phi^j\phi^k|^2 \tag{4.4}$$

If supersymmetry is broken then necessarily some of the a_i must be different from zero, i.e. linear terms must be present in (4.4).

Let us give a preon sector field a non-zero F-term

$$\langle X \rangle = 0, \quad \langle F_X \rangle \neq 0 \tag{4.5}$$

Such a field X can in the present model be a scalar - as is typical for symmetry breaking - or preon in (3.5). The scalars are on shell when $E < \Lambda_{cr}$, preons instead off-shell if energy is smaller than Λ_{cr}. The gravitational interaction between X and the visible MSSM sector can be described by the Lagrangian

$$\begin{aligned}\mathcal{L}_{int} = & \int d^2\theta d^2\bar{\theta} \left(cM_{\rm Pl}^{-2} X^\dagger X Q_i^\dagger Q^i + b' M_{\rm Pl}^{-2} X^\dagger X H_u H_d + b M_{\rm Pl}^{-1} X^\dagger H_u H_d + h.c. \right) \\ & + \int d^2\theta \Big(s M_{\rm Pl}^{-1} X W_a^\alpha W_\alpha^a + a M_{\rm Pl}^{-1} X Q^i H_u \tilde{Q}_i + h.c. \Big)\end{aligned} \tag{4.6}$$

where the Q_i's stands for up and down Higgs chiral superfields plus all matter superfields. The H_u and H_d are only the up and down Higgs fields. The

[3] Integrals of type $\int d^4x d^2\theta \Phi^n$ which, due to lack of covariant derivatives, cannot be converted into integrals in full superspace $\int d^4x d^2\theta d^2\bar{\theta}...$ are called F-terms. All other terms are D-terms.

parameters a, b, b', c and s are taken independent of i for simplicity. There may be higher order operators in (4.6). Note that (4.6) contains only preons and visible sector fields. It can be noted that, unlike in [1], squarks and sleptons can be obtained by replacing in (3.3) one spin $\frac{1}{2}$ preon by a scalar preon.

Substituting (4.5) into (4.6) gives all possible minimally supersymmetric standard model (for an early review see[17]) soft terms in a relatively simple form: the first term provides non-supersymmetric masses for all sfermions and the second and third terms give mass terms for the scalar Higgs only. The s term gives gaugino masses and the last term generates all A-terms. The terms have one mass scale, call it m_{soft}

$$m_{soft} \sim \frac{\langle F_X \rangle}{M_{\rm Pl}} \tag{4.7}$$

Setting $m_{soft} \sim 1$ TeV the supersymmetry breaking scale is of the order

$$M_S = \sqrt{\langle F_X \rangle} \sim \sqrt{m_{soft} M_{\rm Pl}} \sim 10^{11} \text{GeV} \tag{4.8}$$

One sees that $M_{EW} \ll M_S \ll M_{\rm Pl}$.

In the Lagrangian (4.6) there are three terms giving the Higgs mass. The first contains terms $H_u^\dagger H_u$ and $H_d^\dagger H_d$ contributing to up and down Higgs mass. The second term, the B-term, gives rise to a quadratic term mixing H_u and H_d. The third term can be written as follows

$$\int d^2\theta d^2\bar{\theta} b M_{\rm Pl}^{-1} X^\dagger H_u H_d = b \langle F_X^\dagger \rangle M_{\rm Pl}^{-1} \int d^2\theta H_u H_d \tag{4.9}$$

This is a μ-term contribution. Integrating it in chiral superspace it yields a quadratic contribution in structure like the first term. All these three terms are needed to have the correct electroweak symmetry breaking. The B-term is proportional to $\sin 2\beta$ where $\tan\beta = v_u/v_d$. The μ-term is the only term that can give the higgsino a mass. The μ-term can also be generated from a supersymmetric superpotential coupling in the MSSM Lagrangian: $W = \mu_{SUSY} H_u H_d$, therefore it cannot contribute to the symmetry breaking mechanism. The μ-problem is how to avoid large μ-terms and make them the same order of magnitude with B-terms. In the gravity mediated symmetry breaking model all soft terms like the B- and μ-terms are of the same order of magnitude.

There is, however, a typical problem in gravity mediation: the supersymmetry flavor problem FCNC. The SUSY breaking should be flavor independent but gravity's UV completion is not necessarily like that. In the present preon model the UV behavior is flavor independent - because there is no more flavor, just charge. It is also possible to solve the FCNC problem by anomaly mediation model [3]. A third symmetry breaking method is gauge mediation [6] where the messenger field may be any 'hidden' sector field which is charged under the visible sector gauge group.

5 Conclusions

The present supersymmetric preon model is based on the proposal that the physical domain of unbroken supersymmetry is the preon level instead of quark and lepton level. Supersymmetry breaking occurs in the SM when a signal is carried by a gravitational (or gauge) messenger field which in (4.6) are preon sector scalar bound states or superfieldsfields. A tentative physical mechanism for supersymmetry breaking is that the preon-preon interaction, either gravity or a new interaction, forms scalar bound states which develop vev's and break the symmetry. The preon sector is unstable.

The detailed expressions of the symmetry breaking terms in the Lagrangian has to be determined at the moment phenomenologically. The MSSM has more than one hundred parameters plus the some twenty Standard Model parameters. Accepting three reasonable assumptions (no new source of CP-violation, no FCNC and first and second generation universality) one can reduce the number of additional parameters to nineteen in the phenomenological MSSM (pMSSM) [18]. In any case, further experimental searches of new particles are needed.

It is hoped that the present preon model, constructed using simplest possible superfields consistent with the SM, provides an avenue towards better understanding of the roles of all four interactions. The supersymmetry UV phenomenology is to be calculated and checked, with the hope of extending the model to local supersymmetry [19] with the superfields indicated in (3.2) and (3.1).

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