Unification of couplings in gauge mediated models

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Abstract

We consider the possibility of unification of the Supersymmetric Standard Model gauge groups with those of the dynamical supersymmetry breaking (DSB) sector in theories with gauge mediated supersymmetry breaking. We find constraints on the DSB gauge group beta function that come from unification of the gauge coupling constants of the two sectors. These constraints are satisfied by a fairly wide class of models. We discuss possible unification scenarios in the context of a simple model.

1 Introduction

Several mechanisms have been suggested to explain supersymmetry breaking which should be present in the Minimal Supersymmetric Standard Model, MSSM (for a recent review, see, e.g., Ref.[1]). One of them assumes that supersymmetry is broken at very high energies in a hidden sector which interacts with the MSSM fields only via gravity (see Ref.[2] for a review). Another possibility is that the dynamical supersymmetry breaking (DSB) occurs at relatively low energies (of order 10^5 to 10^8 GeV), again in a new sector, and is then transmitted to MSSM by chiral superfields that interact with both sectors (see Refs. [3, 4] and references therein). In this paper we consider the latter class of theories where supersymmetry breaking in MSSM has nothing to do with gravity.

One of the most prominent features of the MSSM is the unification of electroweak and strong coupling constants at the scale $M_{GUT} \sim 10^{16}$ GeV. This is a strong indication to Grand Unification. But the price we pay for it in the models with hidden sector is too high. For unification of the groups in the visible sector it is necessary to introduce additional, usually rather cumbersome, set of fields to provide SUSY breaking. The natural way to avoid it is to construct a Super Grand Unified Theory (SGUT), i.e. a theory in which unification of Standard Model and hidden sector groups takes place. The unification of corresponding coupling constants, which is the first step in this direction, is considered in the current paper.

2 Parameters and their ranges

In the DSB scenarios strong interactions in the new sector force F-components of several fields to acquire vacuum expectation values. They are determined by the scale Λ at which the coupling constant of the gauge group of the DSB sector becomes strong. In fact, the DSB models often involve product gauge groups. In that case the dynamics of supersymmetry breaking is usually driven by the strongest coupling, i.e., the F-components are determined by the largest value of the infrared pole Λ. In most low energy supersymmetry breaking models, this effect is fed down to the MSSM by several fields interacting with both sectors. Soft terms in the MSSM are generated by loop effects, so the supersymmetry breaking scale in the MSSM is lower than Λ by factors involving strong and/or electroweak coupling constants. The actual value of the DSB scale Λ depends strongly on the mechanism of transmission of nonzero F's to soft terms in the MSSM, so the estimates of Λ vary in different models [5, 6, 3]. We allow Λ to take values between 10^5 GeV and 10^8 GeV. The lower bound comes from the requirement that superpartners of ordinary particles are not too light, while the upper one is implied by the bounds on gravitino mass and by the analysis of nucleosynthesis [7].

We will assume for definiteness that the underlying GUT for the MSSM is the minimal supersymmetric $SU(5)$ [8]. Let α_G and α be the coupling constants of this $SU(5)$ and the DSB gauge group, respectively. In most of gauge mediation scenarios, the MSSM is extended by adding messenger fields which fall into a vector-like representation of $SU(5)$. We assume that they belong to a single $(5+\bar{5})$ representation, so the gauge couplings of the MSSM group $SU(3)\times SU(2)\times U(1)$ unify at $M_{GUT} = 10^{15.8}$ GeV [1] to a value of $\alpha_G(M_{GUT}) \approx 1/23$ (we use $\alpha_S(M_Z) = 0.118$ and the thresholds $M_{SUSY} = 300$ GeV for SUSY

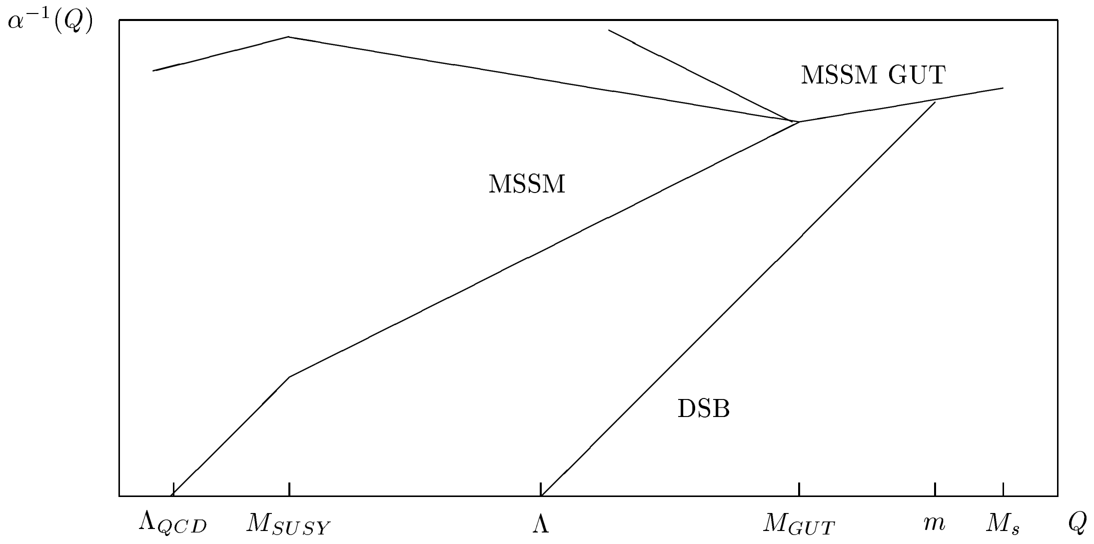

Figure 1: A

particles and $M = 10^5$ GeV for messengers; in fact our results are practically insensitive to the choice of values of M_{SUSY} and M within the range outlined above).

3 Possible scenarios of unification

Several scenarios of unification of gauge couplings of both sectors can be suggested. The first possibility (Fig. 1) is that the DSB gauge coupling is unified with the ordinary GUT coupling somewhere between M_{GUT} and the fundamental scale, $M_s \sim 10^{18}$ GeV, where one believes that string effects become essential. Alternatively, in case of product gauge group in the DSB sector, one may suppose that unification in the MSSM and DSB sectors occurs independently at M_{GUT} and at some scale m, respectively, while the couplings of both GUTs are unified at M_s (Fig. 2). We begin with the former scenario, as it does not require the knowledge of a concrete mechanism of unification in the DSB sector.

4 Unification conditions

The unification condition in the scenario shown in Fig.1 is

$$\alpha_G(m) = \alpha(m), \qquad M_{GUT} < m < M_s.$$

We use the one loop beta function for supersymmetric gauge theories with matter,

$$\beta(\alpha) = -\frac{\alpha^2}{2\pi}C, \qquad C = \left(3T(G) - \sum_i T(R_i)\right),$$

where $T(G)$ and $T(R_i)$ are Dynkin indices (one half of quadratic Casimir operators) for adjoint representation and for the i-th matter superfield representation of the gauge group, respectively. For $SU(N)$ group, one has $T(G) = N$, and each fundamental or anti-fundamental matter multiplet contributes $T(R_i) = 1/2$. For the ordinary supersymmetric $SU(5)$ GUT $C = 2$ with messenger fields taken into account.

Let us suppose first that in the DSB sector, there are no fields with thresholds between Λ and M_s. It is straightforward to see that the restriction 10^5 GeV $< \Lambda < 10^8$ GeV places bounds on the beta function for the gauge coupling with largest infrared pole in the DSB sector

$$4.6 < C < 7.9. \tag{1}$$

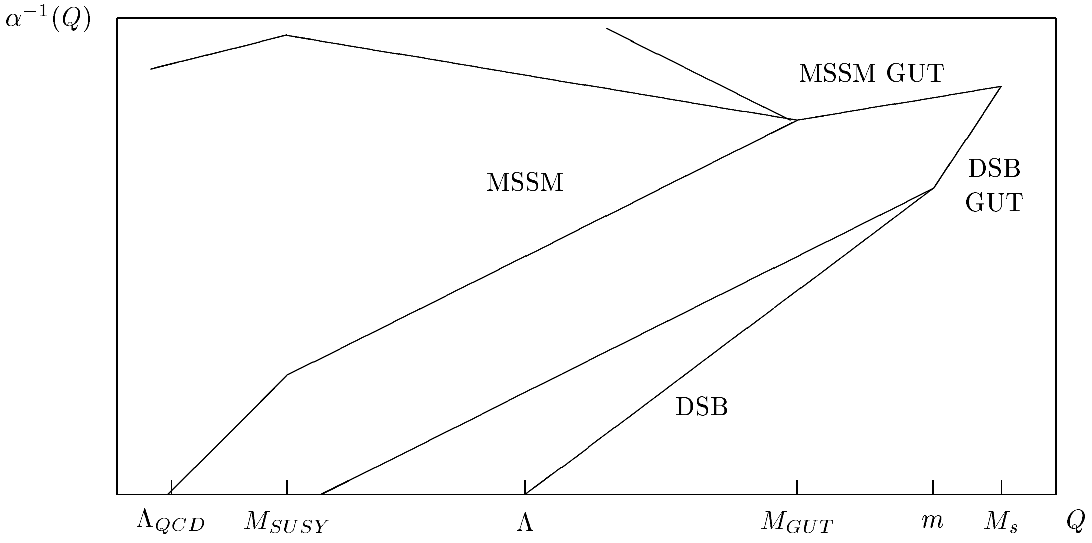

Figure 2: F DB

5 Models

Among relatively simple models exhibiting DSB (see Refs. [4, 9, 3] for reviews), only two have beta functions satisfying Eq. 1). The first one is the well known "3-2" model [10], one of the simplest models explored from the point of view of the DSB scenario [10, 6], which has $C = 7$. Another one is based on the same group $SU(3) \times SU(2)$ but with somewhat more complicated matter content that consists of the following superfields (numbers in parenthesises indicate $SU(3) \times SU(2)$ representations):

$$\begin{array}{c} \text{one field } Q\ (3,2), \\ \text{three fields } \bar{L}_I\ (\bar{3},1),\ I = 1,2,3, \\ \text{one field } L\ (3,1), \\ \text{three fields } \bar{R}_A\ (1,\bar{2}),\ A = 1,2,3. \end{array} \tag{2}$$

This model is a representative of a series of theories based on product groups $SU(N) \times SU(N-M)$ in which DSB occurs through dynamics of the dual group [11, 12, 13] upon adding the superpotential of the form

$$W = \lambda^{IA} \bar{L}_I Q \bar{R}_A + \mathcal{M}^I \bar{L}_I L. \tag{3}$$

In Eq. 3, λ^{IA} is the matrix of Yukawa constants of rank 2 or 3, and $\mathcal{M}$ is a 3×1 mass matrix. In this model $C = 6$ (in both cases it is the $SU(3)$ gauge interactions that drive the dynamics of supersymmetry breaking).

Let us now turn to the case when additional heavy matter superfields with mass of order $M_x \gg \Lambda$ are present in the DSB model. They do not affect the low-energy dynamics responsible for supersymmetry breaking since they can be integrated out from the effective action. However, new threshold appears at M_x, and the first coefficient of the beta function becomes smaller at scales greater than M_x. So, if sufficiently heavy matter superfields are introduced, any model which initially had $C > 4.6$ becomes acceptable. In this way almost all known DSB models can be made consistent with the unification of the MSSM and DSB gauge couplings.

6 Unification in the DSB sector

It is worth noting that the model with matter content Eq. 2 is actually unifiable to an $SU(5)$ gauge theory broken down to $SU(3) \times SU(2) \times U(1)$ by a Higgs 24-plet, in the same manner as in the $SU(5)$ GUT of the Standard Model [8]. Indeed, consider breaking $SU(5) \rightarrow SU(3) \times SU(2)$ in the DSB sector and add following matter multiplets:

$$\begin{aligned} \text{one field } 10 &= (3,2)+(\bar{3},1)+(1,1), \\ \text{one field } 5 &= (3,1)+(1,2), \\ \text{two fields } \bar{5}_i &= (\bar{3},1)_i+(1,\bar{2})_i,\ i=1,2. \end{aligned} \tag{4}$$

Due to the equivalence between the fundamental and conjugate representations of $SU(2)$, it has exactly the matter content Eq. 2 – up to a singlet which does not take part in $SU(3)\times SU(2)$ dynamics (but carries a $U(1)$ charge). The required superpotential Eq. 3 can be written it terms of these $SU(5)$ multiplets,

$$W = \lambda 10_{\alpha\beta}\bar{5}_1^{\alpha}\bar{5}_2^{\beta} + m5_{\alpha}\bar{5}_1^{\alpha}.$$

This superpotential includes couplings required for DSB, Eq. 3, as well as some additional terms which do not spoil the mechanism of supersymmetry breaking. In this way we arrive at a model with the gauge symmetry $SU(5)_{SM}\times SU(5)_{DSB}$.

The matter content of the "3-2" model unifies in $SU(5)$ multiplets 10 and $\bar{5}$. Since no invariant superpotential can be written for $SU(5)$ with single 10 and $\bar{5}$ while tree level superpotential for $SU(3)\times SU(2)$ is required for DSB, the superpotential should be generated by some additional mechanism after breaking of $SU(5)$.

7 Conclusions

To summarize, we have found constraints on the content of the DSB sector under which its gauge couplings are unified with those of the MSSM and its GUT. In the minimal version when no additional heavy matter superfields exist in the DSB sector, these bounds choose two models out of a variety of theories exhibiting DSB. The model with $SU(3)\times SU(2)$ and matter content Eq. 2 is unifiable to $SU(5)$ so that $SU(5)\times SU(5)$ gauge group is favored. Almost every known DSB model can be made consistent with gauge unification by choosing appropriate set of heavy chiral superfields in the DSB sector with threshold $M_x \gg \Lambda$.

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