Large evolution of the bilinear Higgs coupling parameter in SUSY models and reduction of phase sensitivity

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Abstract

The phase parameters in low-energy supersymmetry (SUSY) models are highly constrained by the electric dipole moments (EDM) of the fermions. Further imposing radiative electroweak symmetry breaking (REWSB) condition results in a large degree of fine tuning of the phase parameters at the unification scale. In supergravity models, one finds highly fine tuned values for the phases of the bilinear Higgs coupling parameter B at the unification scale (GUT) scale which in turn also constrain the phase of universal trilinear coupling A_0. We analysed how a GUT inspired definite non-universal gaugino mass(NUGM) model can reduce such fine-tuning keeping superparticle masses within the naturalness domain.

1 Introduction

Minimal Supersymmetric Standard Model (MSSM) has large number of the unknown parameters including phases. Definite SUSY breaking mechanism at the high scale can be proposed to eliminate the large number of unknown parameters. The gravity mediated SUSY breaking (SUGRA) is the most popular choice in this respect. The minimal version of the model (mSUGRA) can be characterized by the parameters $\tan\beta$, $m_{1/2}$, m_0, A_0, sign(μ) and two independent phase parameters [1, 2]. We can parameterize these phases as ϕ_{A_0} for A_0 (at $M_G \sim 2\times 10^{16}$Gev) and θ_B for the B parameter at the electroweak (EW) scale [2]. These phase parameters are highly restricted by the experimental limits on the EDMs of the electron and the neutron [3]. This results into the so called SUSY-CP problem and we are restricted to the following scenarios.

1. The phase θ_B needs to be very small—$O(10^{-2})$ or $O(10^{-3})$—if the superpartners are within TeV range [2] Such small θ_B typically translates into *highly fine-tuned* value for θ_{B_0} (i,e phase of B parameter at M_G) which may also constrain the phase ϕ_{A_0} of A_0.
2. The phases are large and less fine-tuned but the sparticles have to be really super-massive.
3. There are also special parameter points where a large amount of internal cancellations between the diagrams contributing to the EDMs of electron and neutron could make phases large and less fined tuned even with smaller sparticle masses [4]

The issue of fine-tuning in phases at the GUT scale arises out of the combined requirement of satisfying the EDM constraints and the radiative electroweak symmetry breaking condition. Here we always impose REWSB condition to evaluate μ^2 and B at the EW scale.

The objective of the work is to explore the role of NUGM models in reducing the fine-tuning of the phase θ_{B_0}. Now to quantify the fine-tuning, we define a *naturalness like* measure,

$$\Phi = [\Delta\theta_{B_0}/\Delta\theta_B]_{\theta_B\to 0}. \qquad (1)$$

Clearly, a large value for Φ would mean a lesser degree of fine-tuning of θ_{B_0}. Here we evaluate the phase-derivative at $\theta_B \sim 0$ in order to satisfy the EDM constraints.

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2 Non-universal gaugino masses in supergravity

In supergravity models gaugino masses originate from the gauge kinetic energy function $f_{\alpha\beta}$ which is a function of the chiral superfields in the theory. The indices α, β run over the generators of the gauge group (for example, $\alpha = 1, 2, \ldots 24$ for SU(5)). Since gauginos are Majorana particles, $f_{\alpha\beta}$, transforms under the symmetric product of the adjoint representations of the gauge group. Thus for $SU(5)$ one has,

$$f_{\alpha\beta} \supset (24 \otimes 24)_{sym} = 1 \oplus 24 \oplus 75 \oplus 200 \,. \tag{2}$$

Clearly the singlet one represents mSUGRA with universal gaugino masses. Similarly,there could be non-universal gaugino masses originating from the different non-singlet representations which in isolation will not introduce any new phases.

In general $M_i(M_G) = m_{\frac{1}{2}} \sum_r C_r n_i^r$ where C_r and n_i^r's corresponds to the relative weights and Clebsch-Gordan coefficients of different representations. For the case of $SU(5)$, the coefficients n_i^r are displayed in the following Table.

r	Label	M_3^G	M_2^G	M_1^G
1	mSUGRA	1	1	1
24	NUGM:24	2	−3	−1
75	NUGM:75	1	3	−5
200	NUGM:200	1	2	10

Clearly, in NUGM:24 the electro-weak gauginos appears with negative value at the GUT scale, a signature which is different from mSUGRA. We will show that this particular feature is mainly responsible for reducing fine-tuning in phases of the soft breaking parameters.

3 Evolution of B and reduction of fine tuning

We now identify the differences between mSUGRA and NUGM:24 in regard to the evolution of the B-parameter *in the absence of CP violating SUSY phases.* The B parameter evolution equation reads as

$$\frac{dB}{dt} = (3\tilde{\alpha}_2\tilde{m}_2 + \frac{3}{5}\tilde{\alpha}_1\tilde{m}_1) + (3Y_tA_t + 3Y_bA_b + Y_\tau A_\tau) \,, \tag{3}$$

where $Y_i = y_i^2/(4\pi)^2$, with y_i being the Yukawa couplings. For small $\tan\beta$, the contributions from the bottom quark Yukawa coupling (y_b) and the tau lepton Yukawa coupling (y_τ) can be neglected, and the above RGE may be approximately integrated to obtain [1]

$$B - B_0 \simeq \frac{D_0(t) - 1}{2} A_0 - C(t)\, m_{\frac{1}{2}} \,, \tag{4}$$

where definition of each quantities may be found in Ref [1].

There are two different contributions in dB/dt, the gaugino contribution and the trilinear contribution. It turns out that the gaugino contribution is positive for mSUGRA, but negative only for NUGM:24. Regarding evolution of the trilinear couplings, with moderate A_0, the dominant contribution comes from A_t, A_b which typically turns out to be negative at the electroweak scale for both mSUGRA and NUGM:24. Thus in mSUGRA, the gaugino and the trilinear parts would tend to cancel each other giving $B_0 \simeq B$. But for NUGM:24 since the signs of $\tilde{m}_1$,$\tilde{m}_2$ are reversed, the different contributions would now enhance each other leading to a large value of $\Delta B(= B_0 - B)$ in NUGM:24.

Introducing SUSY CP phases the solutions for real and imaginary parts of B are given by [1]

$$\begin{aligned} |B| \sin\theta_B &= |B_0| \sin\theta_{B_0} - \frac{1}{2}(1 - D_0)|A_0| \sin\phi_{A_0} \\ |B| \cos\theta_B &= |B_0| \cos\theta_{B_0} - \frac{1}{2}(1 - D_0)|A_0| \cos\phi_{A_0} - Cm_{\frac{1}{2}} \end{aligned} \tag{5}$$

Using the expressions (1)and (5) one can immediately write

$$\Phi \sim |B| / |B_0| \frac{1}{\cos\theta_{B_0}} \tag{6}$$

For a small $\tan\beta$, $\sin 2\beta$ is large, therefore $|B|$ is appreciably large(via REWSB condition). Since in mSUGRA $|B_0| \simeq |B|$, for moderate $|A_0|$ ($|A_0| \sin\phi_{A_0} \ll |B| \sin\theta_B$) one usually gets $\theta_{B_0} \simeq \theta_B$ [5] , thereby causing Φ to be too small (Fig:1). However in NUGM:24 larger evolution of $|B|$ could make $|B_0| \sim 0$,that essentialy leads to large Φ (Fig:1). Clearly, Φ can be larger in NUGM:24 by a factor of 10-20 compared to the mSUGRA scenario. However the enhancement of Φ is not so much pronounced for large $\tan\beta$.

In our numerical computation we restricted ourselves for really small θ_B ($\lesssim 0.01$) to satisfy the EDM constraints. We keep ϕ_{A_0} fixed to $\pi/2$ for our entire work as it maximize the EDM values.

4 Conclusion

In minimal supergravity, θ_B, the phase of the B parameter is highly constrained ($\sim$ 0.01) to satisfy experimental upper bounds of the EDM of the fermions. This, however leads to a severe fine-tuning for θ_{B_0}, the value of the B parameter at the unification scale. This is a generic problem of low energy SUSY that arises from REWSB condition and EDM limits. Here we have demonstrated that models admitting a large RG evolution of the bilinear Higgs coupling parameter could be interesting in the context of a reduction in the fine-tuning of phases. In particular, we considered GUT motivated non-universal gaugino mass scenario that could reduce the above mentioned fine-tuning significantly. The result shows a reduction of fine tuning by a factor of 10-20. Although our analysis is based on 24 representation of $SU(5)$, the same conclusion can also be made for the 54 representation of the $SO(10)$ model. To conclude, we should say that our result shows a considerable degree of reduction of phase fine tuning even for smaller sparticle masses.

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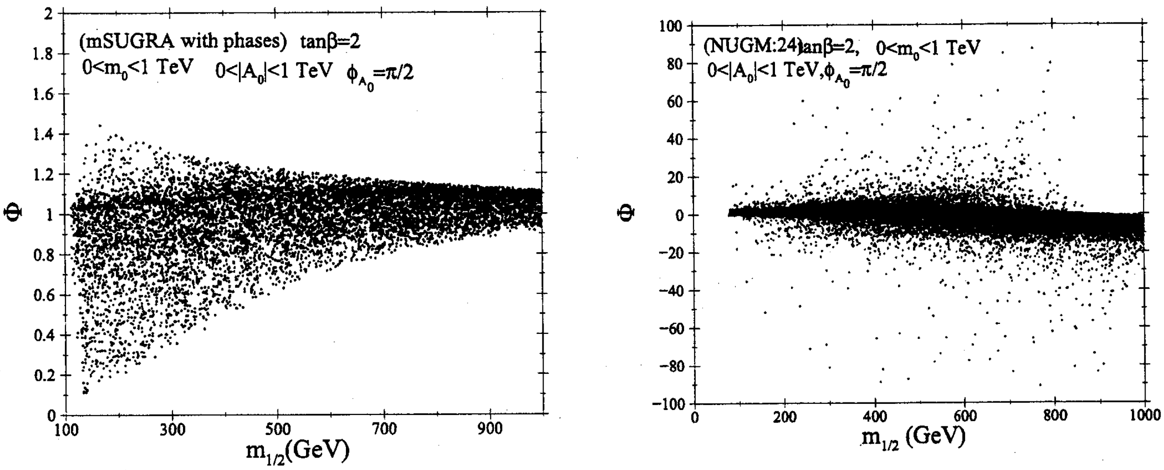

Figure 1: Φ *vs* $m_{\frac{1}{2}}$ *for mSUGRA and NUGM:24 for* $\tan\beta = 2$*, when* m_0 *and* $|A_0|$ *are scanned up to 1 TeV for* $\phi_{A_0} = \pi/2$.