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Constraints on sparticle spectrum in different supersymmetry breaking models

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Abstract. We derive sum rules for the sparticle masses in different models of supersymmetry breaking. This includes the gravity-mediated models (SUGRA models) as well as models in which supersymmetry breaking terms are induced by super-Weyl anomaly (AMSB models). These sum rules can help in distinguishing between these models. In particular, we obtain an upper bound on the mass of the lightest neutralino as a function of the gluino mass in SUGRA and AMSB models.

Keywords. Supersymmetry breaking; neutralino; sum rules.

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1. Introduction

Since no supersymmetric partners of the standard model (SM) particles have been seen, supersymmetry (SUSY), if it exists, must be a broken symmetry. Mechanisms for SUSY breaking may be classified according to the magnitude of the gravitino mass $m_{3/2}$: $m_{3/2} \sim 1$ TeV (gravity-mediated; SUGRA), $m_{3/2} \gg 1$ TeV (anomaly-mediated; AMSB) and $m_{3/2} \ll 1$ TeV (gauge-mediated). In SUGRA models there are operators $\sim 1/M_{\rm P}$ connecting the hidden sector to the observable sector which communicate the SUSY breaking. In minimal supergravity models one can choose a Kahler potential such that squarks or sleptons have universal soft masses, and universal soft trilinear parameters of order $m_{3/2}$. One can also choose gauge kinetic functions so that one has universal gaugino masses $M_{1/2}$ of order $m_{3/2}$ at high energies.

On the other hand, if the soft SUSY breaking terms are determined by the breaking of scale invariance [1], then they can be written in terms of β-functions and anomalous dimensions in the form of relations which hold at all energies. An immediate consequence of such models, known as anomaly-mediated supersymmetry breaking (AMSB) models, is that supersymmetry breaking terms are completely insensitive to the physics in the ultraviolet. However, it turns out that pure scalar mass-squared anomaly contributions for sleptons are negative [1]. There are a number of proposals for solving this problem of tachyonic slepton masses [2]. The simplest of these is to add a common mass parameter m_0 to all the squared scalar masses, assuming that such an addition does not reintroduce the supersymmetric flavor problem [3].

In this talk we shall discuss the sparticle sum rules in gravity-mediated models and anomaly-mediated models. In particular, we shall discuss an upper limit on the mass of the lightest neutralino as a function of the gluino mass in these models.

2. Sum rules

In the case of minimal supersymmetric standard model (MSSM) with gravity-mediated supersymmetry breaking, there are seven physical sfermion masses for the first two generations which can be written in terms of four parameters (for a given $\tan\beta = v_2/v_1, v_1$ and v_2 being the vacuum expectation values of the two Higgs doublets of MSSM). This results in three sum rules for the sparticle masses of the first two generations [4], which can be used to test the various assumptions of MSSM with gravity-mediated supersymmetry breaking. These can be written as

$$M^2_{\tilde{d}_{\rm L}} - M^2_{\tilde{u}_{\rm L}} = -\cos 2\beta M^2_W,\ M^2_{\tilde{e}_{\rm L}} - M^2_{\tilde{\nu}} = -\cos 2\beta M^2_W, \tag{1}$$

$$2(M^2_{\tilde{u}_{\rm R}} - M^2_{\tilde{d}_{\rm R}}) + (M^2_{\tilde{d}_{\rm R}} - M^2_{\tilde{d}_{\rm L}}) + (M^2_{\tilde{e}_{\rm L}} - M^2_{\tilde{e}_{\rm R}}) = \frac{10}{3}\sin^2\theta_W M^2_Z \cos 2\beta. \tag{2}$$

The sum rules (1), which relate the masses of squarks and sleptons living in the same $SU(2)_{\rm L}$ doublet, depend only on the D-term contribution to the squark and slepton masses. They are, thus, independent of the supersymmetry breaking model and test only the gauge structure of the effective low energy supersymmetric model. On the other hand, the sum rule (2) depends on the assumption of a universal soft breaking mass parameter m_0, and is, therefore, a test of universality of the soft scalar masses in anomaly-mediated supersymmetry breaking (AMSB) models as well.

There are four remaining relations between the masses of the first two generations of squarks and sleptons. In anomaly-mediated models, two of these can be used to obtain expressions for the input parameters m_0 and $m_{3/2}$ in terms of squark and slepton masses. The remaining two equations can then be converted to two additional sum rules. These sum rules, which are unique to the minimal AMSB models, can be written as

$$\begin{aligned}&(M^2_{\tilde{e}_{\rm L}} - M^2_{\tilde{e}_{\rm R}}) + \frac{3}{4}\left(3 - \frac{3}{11}\cot^4\theta_W\right)(M^2_{\tilde{u}_{\rm R}} - M^2_{\tilde{d}_{\rm R}})\\ &= \left[-\frac{1}{2} + \left(\frac{17}{4} - \frac{9}{44}\cot^4\theta_W\right)\sin^2\theta_W\right] M^2_Z \cos 2\beta,\end{aligned} \tag{3}$$

$$\begin{aligned}&(M^2_{\tilde{e}_{\rm L}} - M^2_{\tilde{e}_{\rm R}}) + \left(\frac{9}{4} - \frac{g_2^4}{2g_3^4}\right)(M^2_{\tilde{u}_{\rm R}} - M^2_{\tilde{d}_{\rm R}}) - \frac{3}{16}\frac{g_2^4}{g_3^4}(M^2_{\tilde{d}_{\rm R}} - M^2_{\tilde{e}_{\rm R}})\\ &= \left[-\frac{1}{2} + \left(\frac{17}{4} - \frac{5}{8}\frac{g_2^4}{g_3^4}\right)\sin^2\theta_W\right] M^2_Z \cos 2\beta.\end{aligned} \tag{4}$$

In AMSB models, where extra contributions to the soft squared masses can be generated in alternative ways, one can also obtain sum rules which can be used

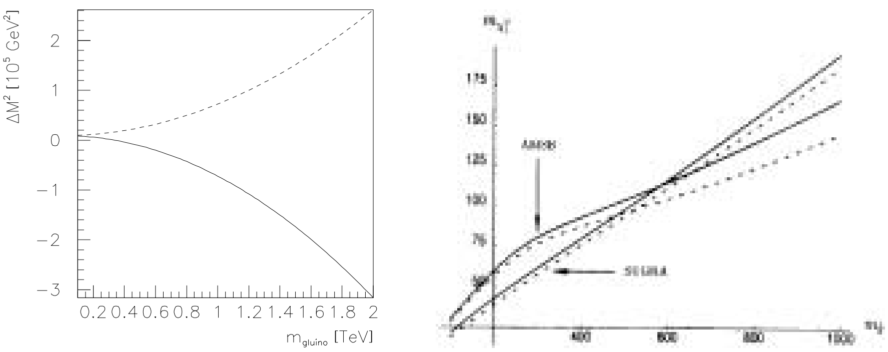

Figure 1. Left: The average mass difference $\Delta m^2 \equiv 2\sum M^2_{\chi_i^\pm} - \sum M^2_{\chi_i^0}$ in the AMSB models (solid line), and in the MSSM (dashed line) as a function of the gluino mass $m_{\tilde{g}}$. Right: The upper bound on the lightest neutralino mass as a function of gluino mass in SUGRA and in AMSB models. The tree level results are represented by dashed lines and the NLO results by the solid lines.

to distinguish these models from the minimal AMSB model as well as from the SUGRA models [2].

The gaugino sector is same in all the models discussed in this paper. However, in AMSB models there is a close proximity of the lightest neutralino and chargino masses, which is a direct consequence of the soft supersymmetry breaking gaugino mass hierarchy in these models. Thus the winos are the lightest neutralinos and charginos, and one would expect that the lightest chargino is only slightly heavier than the lightest neutralino. It is not feasible to obtain mass sum rules for the neutralino states, since the physical neutralino mass matrix is a 4×4 matrix. However, from the trace of neutralino and chargino mass matrices one obtains a sum rule [2] which relates the average mass squared difference:

$$2\sum M^2_{\chi_i^\pm} - \sum M^2_{\chi_i^0} = \frac{1}{9}\left[\frac{g_2^4}{g_3^4} - \left(\frac{33}{5}\right)^2 \frac{g_1^4}{g_3^4}\right] m_{\tilde{g}}^2 + 4M_W^2 - 2M_Z^2. \qquad (5)$$

We have plotted in the left panel of figure 1 the sum rule (5) both in the AMSB models and the MSSM. The average mass difference in the AMSB models is first positive, but then quickly turns negative (solid line), while in the MSSM it is always positive (dashed line). Thus, this sum rule could be one of the signatures of the AMSB type models. Since neutralino is supposed to be the lightest supersymmetric particle in models with R-parity conservation, it is of crucial importance to have a knowledge of its mass. From the structure of the neutralino mass matrix, we have derived an analytical upper bound on the mass of the lightest neutralino in supersymmetric models [5,6]. This is plotted in the right panel of figure 1, and includes the next-to-leading order radiative corrections. We note that for most of the values of the gluino mass, the upper bound is different for SUGRA and AMSB models.

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