R–Parity Breaking in Minimal Supergravity

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Abstract

We consider the Minimal Supergravity Model with universality of scalar and gaugino masses plus an extra bilinear term in the superpotential which breaks R–Parity and lepton number. We explicitly check the consistency of this model with the radiative breaking of the electroweak symmetry. A neutrino mass is radiatively induced, and large Higgs–Lepton mixings are compatible with its experimental bound. We also study briefly the lightest Higgs mass. This one–parameter extension of SUGRA–MSSM is the simplest way of introducing R–parity violation.

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The Minimal Supersymmetric Standard Model (MSSM)\cite{1} contains a large number of soft supersymmetry breaking mass parameters introduced explicitly in order to break supersymmetry without introducing quadratic divergencies. When the MSSM is embedded into a supergravity inspired model (MSSM–SUGRA), the number of unknown parameters can be greatly reduced with the assumption of universality of soft parameters at the unification scale. In addition, in MSSM–SUGRA the breaking of the electroweak symmetry can be achieved radiatively due to the large value of the top quark Yukawa coupling.

The most general extension of the MSSM which violates $R$–parity\cite{2} contains almost 50 new parameters, all of them arbitrary although constrained by, for example, proton stability. The large amount of free parameters makes $R$–parity violating scenarios less attractive. Nevertheless, models of spontaneous $R$–parity breaking do not include trilinear $R$–parity violating couplings, and these models only generate bilinear $R$–parity violating terms\cite{3}.

Motivated by the spontaneous breaking of $R$–parity, we consider here a model where a bilinear $R$–parity violating term of the form $\epsilon_3 \hat{L}_a \hat{H}^b_2$ is introduced explicitly in the superpotential\cite{4}. We demonstrate that this “$\epsilon$–model” can be successfully embedded into supergravity, i.e., it is compatible with universality of soft mass parameters at the unification scale and with the radiative breaking of the electroweak group\cite{5}.

For simplicity we consider that only the third generation of leptons couples to the Higgs. Therefore, our superpotential is

$$W = \epsilon_{ab} \left[ h_t \hat{Q}_3^b \hat{U}_3 \hat{H}^b_2 + h_b \hat{Q}_3^b \hat{D}_3 \hat{H}^a_1 + h_\tau \hat{L}_3^b \hat{R}_3 \hat{H}^a_1 - \mu \hat{H}^a_1 \hat{H}^b_2 + \epsilon_3 \hat{L}_a \hat{H}^b_2 \right] \quad (1)$$

where the last term is the only one not present in the MSSM. This term induces a non–zero vacuum expectation value of the tau sneutrino, which we denote by $\langle \tilde{\nu}_\tau \rangle = v_3 / \sqrt{2}$.

The $\epsilon_3$–term cannot be rotated away by the redefinition of the fields

$$\hat{H}_1' = \frac{\mu \hat{H}_1 - \epsilon_3 \hat{L}_3}{\sqrt{\mu^2 + \epsilon_3^2}}, \quad \hat{L}_3' = \frac{\epsilon_3 \hat{H}_1 + \mu \hat{L}_3}{\sqrt{\mu^2 + \epsilon_3^2}} \quad (2)$$

and in this sense the $\epsilon_3$–term is physical. If the previous rotation is performed, the bilinear $R$–Parity violating term disappear from the superpotential. Nevertheless, a trilinear $R$–Parity violating term is reintroduced in the Yukawa sector and it is proportional to the bottom quark Yukawa coupling. In addition, bilinear terms which induce a non–zero vacuum expectation value of the tau sneutrino reappear in the soft terms, and therefore, the vacuum expectation value of the tau sneutrino is also non–zero in the new basis: $\langle \tilde{\nu}_\tau' \rangle = v_3' \neq 0$. These terms are

$$V_{soft} = (B_2 - B) \frac{\epsilon_3 \mu}{\mu'} \hat{L}_3' H_2 + (m_{H_1}^2 - M_{L_3}^2) \frac{\epsilon_3 \mu}{\mu'^2} \hat{L}_3' H_1' + h.c. + ... \quad (3)$$
Figure 1: Tau neutrino mass as a function of $\xi \equiv (\epsilon_3 v_1 + \mu v_3)^2$, which is related to the v.e.v. of the tau sneutrino in the rotated basis through $\xi = (\mu' v_3')^2$.

where $\mu'^2 = \mu^2 + \epsilon_3^2$, $B$ and $B_2$ are the bilinear soft breaking terms associated to the next-to-last and last terms in eq. (1), and $m_{H_1}$ and $M_{L_3}$ are the soft mass terms associated to $H_1$ and $\tilde{L}_3$.

The presence of the $\epsilon_3$ term and of a non–zero vev of the tau sneutrino induce a mixing between the neutralinos and the tau neutrino. As a consequence, a tau neutrino mass is generated which satisfy $m_{\nu_\tau} \sim (\epsilon_3 v_1 + \mu v_3)^2$. The quantity inside the brackets is proportional to $v_3'$, thus a non–zero vev of the tau sneutrino in the rotated basis is crucial for the generation of a mass for the tau neutrino.

We assume at the unification scale universality of soft scalar masses, gaugino masses, soft bilinear mass parameters, and soft trilinear mass parameters. Using the RGE’s given in [8] we impose the correct electroweak symmetry breaking. In order to do that, we impose that the one–loop tadpole equations are zero, and find the three vacuum expectation values. This tadpole method is equivalent to use the one–loop effective potential [9]. The solutions we find are displayed as scatter plots. In Fig. 1 we have the induced tau neutrino mass $m_{\nu_\tau}$ as a function of the combination $\xi \equiv (\epsilon_3 v_1 + \mu v_3)^2$, which is related to the v.e.v. of the tau sneutrino in the rotated basis through $\xi = (\mu' v_3')^2$.

In Fig. 1 we see that we find plenty of solutions with values of the tau neutrino mass compatible with experimental bounds. The reason is that in models with universality of soft supersymmetry breaking parameters it is natural to find small values of the v.e.v. $v_3' \sim (\epsilon_3 v_1 + \mu v_3)$. This can be understood if we look at the tree level tadpole corresponding
Figure 2: Ratio between the lightest CP-even neutral scalar mass in the $\epsilon$–model and the lightest CP–even Higgs mass in the MSSM, as a function of the tau sneutrino vacuum expectation value $v_3$.

to the tau sneutrino in the rotated basis. The relevant linear term is $V_{\text{linear}} = t'_3 \tilde{\nu}^{R}_\tau + ..., \quad \text{with} \quad \tilde{\nu}^{R}_\tau = \sqrt{2}Re(\nu'_\tau) - v'_3$, and the tree level tadpole equation is

$$t'_3 = (m^2_{\text{H}_1} - M^2_{L_3}) \frac{\epsilon_{3\mu}}{\mu^2} v'_1 + (B_2 - B) \frac{\epsilon_{3\mu}}{\mu^2} v'_2 + \frac{m^2_{\text{H}_1} \epsilon^2_3}{\mu^2} v'_3 + \frac{M^2_{L_3} \mu^2}{\mu^2} v'_3$$

$$+ \frac{1}{8} (g^2 + g'^2) v'_3 (v'^2_1 - v'^2_2 + v'^2_3) = 0 \quad (4)$$

It is clear that the first two terms are generated radiatively, because at the unification scale we have $m_{\text{H}_1} = M_{L_3}$ and $B_2 = B$. The RGE’s of these parameters are such that at the weak scale we have non–zero differences $(m^2_{\text{H}_1} - M^2_{L_3})$ and $(B_2 - B)$ generated at one–loop and proportional to $h^2_b/(16\pi^2)$, where $h_b$ is the bottom quark Yukawa coupling. If for a moment we neglect these radiative corrections, the first two terms in eq. (4) are zero and as a consequence $v'_3 = 0$, implying that the induced tau neutrino mass is zero. In reality this is not the case, and the tau neutrino mass is radiatively generated [7].

In this model, the CP–even Higgs bosons of the MSSM mix with the real part of the tau sneutrino [8]. For this reason, the neutral CP–even scalar sector contains three fields and the mass of the lightest scalar is different compared with the lightest CP–even Higgs of the MSSM. In Fig. 2 we plot the ratio between the mass of the lightest CP–even neutral scalar in the $\epsilon$–model and the lightest CP–even Higgs of the MSSM, as a function of the v.e.v. of the tau sneutrino in the unrotated basis. In the radiative corrections to these masses we have included the most important contribution which is proportional to
$m_t^4$. As it should, the ratio approaches to unity as $v_3$ goes to zero. Most of the time the effect of $v_3$ is to reduce the scalar mass, but there are a few points where the opposite happens.

In summary, we have proved that a bilinear R–Parity violating term can be successfully embedded into supergravity, with universality of soft mass terms at the unification scale, and with radiative breaking of the electroweak symmetry. In addition, the induced neutrino mass is generated radiatively at one–loop, and therefore it is naturally small. This is a one parameter ($\epsilon_3$) extension of MSSM-SUGRA, and therefore the simplest way to study systematically R–Parity violating phenomena.

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