Some Recent Results from the Generic Supersymmetric Standard Model *

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Abstract

The generic supersymmetric standard model is a model built from a supersymmetrized standard model field spectrum the gauge symmetries only. The popular minimal supersymmetric standard model differs from the generic version in having R-parity imposed by hand. We review an efficient formulation of the model and some of the recently obtained interesting phenomenological features. The latter includes R-parity violating contributions to scalar masses that had been largely overlooked and the related contributions to fermion electric dipole moments and $\mu \rightarrow e \gamma$.

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SOME RECENT RESULTS FROM THE GENERIC SUPERSYMMETRIC STANDARD MODEL

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1 The Generic Supersymmetric Standard Model

A theory built with the minimal superfield spectrum incorporating the Standard Model (SM) particles and interactions dictated by the SM (gauge) symmetries, and the idea that supersymmetry (SUSY) is softly broken is what should be called the the generic supersymmetric standard model. The popular minimal supersymmetric standard model differs from the generic version in having a discrete symmetry, called R parity, imposed by hand to enforce baryon and lepton number conservation. With the strong experimental hints at the existence of lepton number violating neutrino masses, such a theory of SUSY without R-parity deserves more attention than ever before. The generic supersymmetric standard model contains all kind of (so-called) R-parity violating (RPV) parameters. The latter includes the more popular trilinear ($\lambda_{ijk}$, $\lambda^\prime_{ijk}$, and $\lambda^\prime\prime_{ijk}$) and bilinear ($\mu_i$) couplings in the superpotential, as well as soft SUSY breaking parameters of the trilinear, bilinear, and soft mass (mixing) types. In order not to miss any plausible RPV phenomenological features, it is important that all of the RPV parameters be taken into consideration without a priori bias. We do, however, expect some sort of symmetry principle to guard against the dangerous proton decay problem. The emphasis is hence put on the lepton number violating phenomenology.

The renormalizable superpotential for the generic supersymmetric standard model can be written as

$$W = \varepsilon_{ab} \left[ \mu_a \hat{H}^a \hat{L}^b + h^a_\alpha \hat{Q}^a_\alpha \hat{H}^d \hat{U}^e_C + \chi_{ijk} \hat{Q}^a_i \hat{U}^b_j \hat{D}^c_k + \frac{1}{2} \lambda_{\alpha\beta k} \hat{L}^a_\alpha \hat{L}^b_\beta \hat{E}^c_k + \frac{1}{2} \lambda^\prime_{ijk} \hat{U}^a_i \hat{D}^b_j \hat{D}^c_k \right],$$

(1)

where ($a, b$) are $SU(2)$ indices, ($i, j, k$) are the usual family (flavor) indices, and ($\alpha, \beta$) are extended flavor indices going from 0 to 3. At the limit where $\lambda_{ijk}$, $\chi_{ijk}$, $\lambda^\prime_{ijk}$ and $\mu_i$ all vanish, one recovers the expression for the R-parity preserving case, with $\hat{L}_0$ identified as $\hat{H}_d$. Without R-parity imposed, the latter is not a priori distinguishable from the $\hat{L}_i$’s. Note that $\lambda$ is antisymmetric in the first two indices, as required by the $SU(2)$ product rules, as shown explicitly here with $\varepsilon_{12} = -\varepsilon_{21} = 1$. Similarly, $\chi'$ is antisymmetric in the last two indices, from $SU(3)_C$.

The soft SUSY breaking part of the Lagrangian is more interesting, if only for the fact that many of its interesting details have been overlooked in the literature. However, we
will postpone the discussion till after we address the parametrization issue.

2 Parametrization

Doing phenomenological studies without specifying a choice of flavor bases is ambiguous. It is like doing SM quark physics with 18 complex Yukawa couplings, instead of the 10 real physical parameters. As far as the SM itself is concerned, the extra 26 real parameters are simply redundant, and attempts to relate the full 36 parameters to experimental data will be futile. In the generic supersymmetric standard model, the choice of an optimal parametrization mainly concerns the 4 $\hat{L}_0$ flavors. We use here the single-VEV parametrization (SVP), in which flavor bases are chosen such that: 1/ among the $\hat{L}_0$’s, only $\hat{L}_0$, bears a VEV, i.e. $\langle \hat{L}_i \rangle \equiv 0$; 2/ $h^0_{ik}(\equiv \lambda_{0jk}) = \sqrt{2} v_0 \text{diag}\{m_1, m_2, m_3\}$; 3/ $h^d_{jk}(\equiv \lambda'_{0jk}) = \sqrt{2} v_u \text{diag}\{m_4, m_5, m_6\}$; 4/ $h^u_{ik} = \sqrt{2} v_0 V_{\text{CKM}} \text{diag}\{m_u, m_c, m_t\}$, where $v_0 \equiv \sqrt{2} \langle \hat{L}_0 \rangle$ and $v_u \equiv \sqrt{2} \langle \hat{H}_u \rangle$. The big advantage of the SVP is that it gives the complete tree-level mass matrices of all the states (scalars and fermions) the simplest structure.

3 Fermion Sector Phenomenology

The SVP gives quark mass matrices exactly in the SM form. For the masses of the color-singlet fermions, all the RPV effects are parametrized by the $\mu_i$’s only. For example, the five charged fermions (gaugino + Higgsino + 3 charged leptons), we have

$$M_C = \begin{pmatrix} M_2 & \frac{\sqrt{2} v_0}{\sqrt{2}} & 0 & 0 & 0 \\ \frac{\sqrt{2} v_u}{\sqrt{2}} & \mu_0 & \mu_1 & \mu_2 & \mu_3 \\ 0 & 0 & m_1 & 0 & 0 \\ 0 & 0 & 0 & m_2 & 0 \\ 0 & 0 & 0 & 0 & m_3 \end{pmatrix}. \tag{2}$$

Moreover each $\mu_i$ parameter here characterizes directly the RPV effect on the corresponding charged lepton ($\ell_i = e, \mu, \tau$). This, and the corresponding neutrino-neutrino masses and mixings, has been exploited to implement a detailed study of the tree-level RPV phenomenology from the gauge interactions, with interesting results.

Neutrino masses and oscillations is no doubt one of the most important aspects of the model. Here, it is particularly important that the various RPV contributions to neutrino masses, up to 1-loop level, be studied in a framework that takes no assumption on the other parameters. Our formulation provides such a framework. Interested readers are referred to Refs.1,3,4.

4 SUSY Breaking Terms and Related Phenomenology

Obtaining the squark and slepton masses is straightforward, once all the admissible soft SUSY breaking terms are explicitly down\cite{2}. The only RPV contribution to the squark masses is given by a $-(\mu^*_i X^j_{i,jk} \frac{v}{\sqrt{2}})$ term in the $LR$ mixing part. Note that the term contains flavor-changing ($j \neq k$) parts which, unlike the $A$-terms ones, cannot be suppressed through a flavor-blind SUSY breaking spectrum. Hence, it has very interesting implications on quark electric dipole moments (EDM’s) and related processes such as $b \to s \gamma$. For instance, it contributes to neutron EDM at 1-loop order, through
charged scalar masses are given in terms of the blocks

\[
\widetilde{M}_{hh} = \tilde{m}_h^2 + \mu^* \mu_a + M_Z^2 \cos 2\beta \left[ \frac{1}{2} - \sin^2 \theta_W \right] + M_Z^2 \sin^2 \beta \left[ 1 - \sin^2 \theta_W \right],
\]

\[
\widetilde{M}_{LL} = \tilde{m}_l^2 + \frac{1}{2} \tilde{m}_e \tilde{m}_e + M_Z^2 \cos 2\beta \left[ \frac{1}{2} + \sin^2 \theta_W \right] + \left( M_Z^2 \cos^2 \beta \left[ 1 - \sin^2 \theta_W \right] \right)_{0_{3 \times 1}} 0_{3 \times 3} + (\mu^* \mu_a),
\]

\[
\widetilde{M}_{RR} = \tilde{m}_e^2 + \tilde{m}_e \tilde{m}_e + M_e^2 \cos 2\beta \left[ -\sin^2 \theta_W \right],
\]

and

\[
\widetilde{M}_{ii} = (B_a^* + \left( \frac{1}{2} M_Z^2 \sin 2\beta \left[ 1 - \sin^2 \theta_W \right] \right)_{0_{3 \times 1}}),
\]

\[
\widetilde{M}_{ii} = - (\mu^* \lambda_{a\alpha k}) \frac{v_0}{\sqrt{2}},
\]

\[
(\widetilde{M}_{ii})^T = \left( \frac{0}{\mu^* \lambda_{a\alpha k}} \right) \frac{v_0}{\sqrt{2}}.
\]

For the neutral scalars, we have explicitly

\[
\mathcal{M}^2 = \begin{pmatrix}
\mathcal{M}_{SS}^2 & \mathcal{M}_{SP}^2 \\
\mathcal{M}_{PS}^2 & \mathcal{M}_{PP}^2
\end{pmatrix},
\]

where the scalar, pseudo-scalar, and mixing parts are given by

\[
\mathcal{M}_{SS}^2 = \text{Re}(\mathcal{M}_{\phi\phi}^2) + \mathcal{M}_{\phi\phi}^2,
\]

\[
\mathcal{M}_{PP}^2 = \text{Re}(\mathcal{M}_{\phi\phi}^2) - \mathcal{M}_{\phi\phi}^2,
\]

\[
\mathcal{M}_{SP}^2 = -\text{Im}(\mathcal{M}_{\phi\phi}^2),
\]

respectively, with

\[
\mathcal{M}_{SS}^2 = \frac{1}{2} M_Z^2 \begin{pmatrix}
\sin^2 \beta & -\cos \beta \sin \beta & 0_{1 \times 3} \\
-\cos \beta \sin \beta & \cos^2 \beta & 0_{1 \times 3} \\
0_{3 \times 1} & 0_{3 \times 1} & 0_{3 \times 3}
\end{pmatrix},
\]

and

\[
\mathcal{M}_{SP}^2 = \mathcal{M}_{\phi\phi}^2 + \left( \tilde{m}_h^2 + \mu^* \mu_a - \frac{1}{2} M_Z^2 \cos 2\beta \right) \tilde{m}_l^2 + \left( \mu^* \mu_a \right) \left( B_a^* - \frac{1}{2} M_Z^2 \cos 2\beta \right).
\]
Note that \( \tilde{m}^2 \) here is a \( 4 \times 4 \) matrix of soft masses for the \( L_{\alpha} \), and \( B_{\alpha}'s \) are the corresponding bilinear soft terms of the \( \mu_{\alpha}'s \). \( A^e \) is just the \( 3 \times 3 \) R-parity conserving leptonic \( A \)-term. There is no contribution from the admissible RPV \( A \)-terms under the SVP. Also, we have used \( m_{\chi} \equiv \text{diag}\{0, m_1, m_2, m_3\} \).

The RPV contributions to the charged, as well as neutral, scalar masses and mixings give rise to new terms in electron EDM and \( \mu \rightarrow e \gamma \). From our extensive analytical and numerical study, a brief summary of results are shown in Table 1.

### Table 1. Illustrative bounds on combinations of R-parity violating parameters from \( \mu \rightarrow e \gamma \).

| Combination | Bound  |
|-------------|--------|
| \( |\mu_1 \lambda_{121}|/|\mu_0| \), \( |\mu_2 \lambda_{122}|/|\mu_0| \), or \( |\mu_2 \lambda_{132}|/|\mu_0| \) | \( < 1.5 \times 10^{-7} \) |
| \( |\lambda_{121} \lambda_{231}|/|\mu_0|^2 \), \( |\lambda_{122} \lambda_{232}|/|\mu_0|^2 \), \( |\lambda_{132} \lambda_{231}|/|\mu_0|^2 \) | \( < 0.53 \times 10^{-4} \) |
| \( |\lambda_{321} \lambda_{131}|/|\mu_0|^2 \), \( |\lambda_{322} \lambda_{132}|/|\mu_0|^2 \), or \( |\lambda_{323} \lambda_{133}|/|\mu_0|^2 \) | \( < 2.2 \times 10^{-4} \) |
| \( |B_1^* \lambda_{321}|/|\mu_0|^2 \), \( |B_2^* \lambda_{322}|/|\mu_0|^2 \), or \( |B_3^* \lambda_{323}|/|\mu_0|^2 \) | \( < 1.1 \times 10^{-4} \) |
| \( |B_1^* \lambda_{131}|/|\mu_0|^2 \), \( |B_2^* \lambda_{132}|/|\mu_0|^2 \), or \( |B_3^* \lambda_{133}|/|\mu_0|^2 \) | \( < 2.0 \times 10^{-3} \) |
| \( |B_1^* \lambda_{131}|/|\mu_0|^2 \), \( |B_2^* \lambda_{132}|/|\mu_0|^2 \), or \( |B_3^* \lambda_{133}|/|\mu_0|^2 \) | \( < 1.1 \times 10^{-5} \) |

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