Neutrino Masses and $\mu \rightarrow e \gamma$ in the Generic Supersymmetric Standard Model*

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Abstract

We summarized our report on neutrino masses and $\mu \rightarrow e \gamma$ in the generic supersymmetric standard model, emphasizing on the much overlooked scalar masses contributions from R-parity violation.

* Talk presented at SUSY’01 conference (Jun 11 - 17), Dubna, Russia — submission for the proceedings.
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1 On Lepton Number Violation

The overall lepton number together with its constituents of the three lepton flavor numbers ($L = L_e + L_\mu + L_\tau$) are accidental global symmetries of the Standard Model (SM). Experimental data does give some support to the idea that they are pretty good symmetries. A list of illustrative bounds are given by $Br(\mu \rightarrow e \gamma) < 1.2 \times 10^{-11}$, $Br(\tau \rightarrow e \gamma) < 2.7 \times 10^{-6}$, $Br(\tau \rightarrow \mu \gamma) < 1.1 \times 10^{-6}$, $Br(\mu \rightarrow 3e) < 1.2 \times 10^{-12}$, and $Br(\tau \rightarrow \ell_1 \ell_2 \ell_3) \lesssim 2 \times 10^{-6}$. These show the stringent constraints on the possible magnitude of lepton flavor violation (LFV). However, the strong hints of neutrino masses and mixings from the various experiments say otherwise. The SM itself does not allow neutrino mass. And apart from the highly unlikely scenario of pure Dirac masses for the neutrinos, an extension of the SM giving rise to neutrino masses and mixings has to violate the lepton numbers. The present talk focuses on the minimal supersymmetric framework to describe such violations.

2 The Generic Supersymmetric Standard Model

A theory built with the minimal superfield spectrum incorporating the SM particles, the admissible renormalizable interactions dictated by the SM (gauge) symmetries together with the idea that SUSY is softly broken is what should be called the generic supersymmetric standard model (GSSM). The popular minimal supersymmetric standard model (MSSM) differs from the generic version in having a discrete symmetry, called R parity, imposed by hand to enforce baryon and lepton number conservation. The GSSM contains all kinds of (so-called) R-parity violating (RPV) parameters, including the

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superpotential, as well as soft SUSY breaking parameters. In order not to miss any plausible RPV phenomenological features, it is important that all of the RPV parameters be taken into consideration without \textit{a priori} bias. We expect the lepton numbers to be violated, but are otherwise ignorant about which admissible Lagrangian terms are mainly responsible to the resulted phenomenology. We do, however, expect some sort of symmetry principle to guard against the very dangerous proton decay problem.

The renormalizable superpotential for the GSSM can be written as

\[
W = \varepsilon_{ab} \left[ \mu \hat{H}_0^a \hat{L}_b^c + h^u_{ik} \hat{Q}_a^i \hat{H}_b^{u \dagger} \hat{U}_C^k + \lambda_{\alpha jk} \hat{L}_a^\alpha \hat{L}_b^\beta \hat{E}_C^k + \frac{1}{2} \lambda^u_{\alpha \beta k} \hat{L}_a^\alpha \hat{L}_b^\beta \hat{E}_C^k \right] + \frac{1}{2} \lambda^d_{ijk} \hat{U}_C^i \hat{D}_C^j \hat{D}_C^k .
\] (1)

We use here the single-VEV parametrization\cite{1} (SVP), in which flavor bases are chosen such that: 1/ among the $\hat{L}_a$’s, only $\hat{L}_0$, bears a VEV, \textit{i.e.} $\langle \hat{L}_i \rangle \equiv 0$; 2/ $h^u_{ik} (\equiv \lambda_{0jk}) = \sqrt{2} v_0 \text{diag}\{m_1, m_2, m_3\}$; 3/ $h^d_{ik} (\equiv \lambda_{0jk}) = \sqrt{2} v_0 \text{diag}\{m_u, m_c, m_t\}$; 4/ $h^e_{ik} (\equiv \lambda_{0jk}) = \sqrt{2} V_{\text{CKM}} \text{diag}\{m_u, m_c, m_t\}$, where $v_0 \equiv \sqrt{2} \langle H_u \rangle$ and $v_e \equiv \sqrt{2} \langle H_u \rangle$. 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. Readers are referred to my other talk at Dubna\cite{2} and references therein for details of the model formulation.

3 Neutrino Masses in GSSM

Neutrino masses and oscillations is no doubt a central aspect of any RPV model. In our opinion, it is particularly important to study the various RPV contributions in a framework that takes no assumption on the other parameters. Our formulation provides such a framework. Earlier works alone the line include Refs.\cite{3,4,5}. We would like to emphasize that the best strategy to study neutrino masses in GSSM would be to admit our ignorance and listed all sources of neutrino masses from different combinations of lepton number violating parameters.\cite{6}

4 $\mu \rightarrow e \gamma$ in GSSM

We gave explicitly the complete tree-level scalar masses of the model in a recent paper\cite{7}. Many of such RPV scalar mass contributions and their phenomenological implications have been overlooked. We are starting to explore into the domain.\cite{8,9,10}
Table 1. Illustrative bounds on combinations of RPV parameters from $\mu \rightarrow e \gamma$.

| Combination | Bound |
|-------------|-------|
| $|\mu_3^\ast \lambda_{321}|$, $|\mu_1^\ast \lambda_{121}|$, $|\mu_3 \lambda_{312}|$, or $|\mu_2 \lambda_{212}|$ | $< 1.5 \times 10^{-7}$ |
| $|\mu_2^\ast \mu_2|^2$, $|\mu_3^\ast \mu_3|^2$, $|\mu_3 \mu_3|^2$, or $|\mu_2 \mu_2|^2$ | $< 0.53 \times 10^{-4}$ |
| $|\lambda_{321} \lambda_{33}^\ast|$, $|\lambda_{222} \lambda_{132}^\ast|$, or $|\lambda_{321} \lambda_{133}^\ast|$, or $|\lambda_{221} \lambda_{232}^\ast|$ | $< 2.2 \times 10^{-4}$ |
| $|\lambda_{122} \lambda_{131}|$, $|\lambda_{122} \lambda_{231}|$, or $|\lambda_{122} \lambda_{231}|$, or $|\lambda_{232} \lambda_{231}|$ | $< 1.1 \times 10^{-4}$ |
| $|B_1^\ast \lambda_{321}|$, $|B_1^\ast \lambda_{121}|$, $|B_2 \lambda_{321}|$, or $|B_2 \lambda_{321}|$ | $< 2.0 \times 10^{-3}$ |
| $|B_1^\ast \mu_2|^2$, $|B_1^\ast \mu_3|^2$, $|B_2 \mu_2|^2$, or $|B_2 \mu_3|^2$ | $< 1.1 \times 10^{-5}$ |

A brief summary of resulted constraints from our extensive analytical and numerical study on $\mu \rightarrow e \gamma$ are shown in Table 1. In terms of LFV, the parameter combinations involved obviously have $\Delta L_e = 1$ and $\Delta L_\mu = -1$. The combinations $\mu_k^\ast \lambda_{k21}$, $\mu_k^\ast \lambda_{k12}$, and $\mu_k^\ast \mu_i$ are directly reflecting the corresponding slepton mass mixing contributions. The bounds on a $\mu_k$ and $\lambda_{ki}$ combination are stringent even in comparison to the sub-eV neutrino mass bounds. Exploring the correlation of the two would be particularly interesting.

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