Neutrino Masses and Mixing from Bilinear R-Parity Violation

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Abstract

Neutrino masses and mixing are generated in a supersymmetric standard model when R-parity is violated in bilinear mass terms. The mixing matrix among the neutrinos takes a restrictive form if the lepton flavor universality holds in the R-parity violating soft masses. It turns out that only the small angle MSW solution to the solar neutrino problem is consistent with the result of the CHOOZ experiment and the atmospheric neutrino data.

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I. INTRODUCTION

R-parity violation in a supersymmetric standard model provides an intriguing mechanism to generate neutrino masses. The R-parity is a $Z_2$ discrete parity which distinguishes (R-parity odd) superparticles from (R-parity even) ordinary particles. Though one often assumes the R-parity conservation in model building, it can break without conflicting phenomenological problems such as very fast proton decays. If the R-parity violating terms also violate lepton number conservation, the neutrinos acquire masses either at tree level or at loop levels [1]. One of the appealing points of this scenario is that it does not require existence of exotic particles such as heavy right-handed neutrinos apart from the superpartners which are already included in the minimal supersymmetric standard model.

The R-parity violation may also give novel collider signatures. If the R-parity were conserved, superparticles would be produced in pairs, and also the lightest superparticle (LSP) would be stable and escape detection, resulting in a missing energy as a supersymmetry signal. If the R-parity is broken, on the other hand, the lightest superparticle may decay to ordinary particles inside a detector. Detailed study of the final states may reveal properties of the R-violating interaction. Thus in this scenario, useful information on the neutrino masses may also be inferred from collider experiments.

Here we would like to consider the case of bilinear R-parity violation in which R-parity is broken only in bilinear mass terms. This is particularly interesting because it can be embedded into a grand unified theory (GUT) where quarks and leptons belong to one and the same representation of a GUT group. We will argue that, when the lepton flavor universality holds in the soft supersymmetry breaking masses, the neutrino mixing matrix is in a special form which is parameterized only by two angles. Thus the resulting pattern of the neutrino oscillations should be restricted. In fact we find that when we combine the CHOOZ experiment result with the $\nu_\mu$-$\nu_\tau$ oscillation solution to the atmospheric neutrino, the only allowed solar neutrino solution is the small angle MSW [2].

The results presented here are essentially given in Ref. [2] already, but we slightly gener-
alize the previous ones. Namely here we discuss the case where the lepton flavor universality among soft supersymmetry breaking masses is assumed, whereas in the previous paper [2] the lepton-Higgs universality was considered. See Ref. [2] and references therein for more details.

II. BILINEAR R-PARITY VIOLATION

We first explain the model we are considering. The particle contents of the model are those of the minimal supersymmetric standard model (MSSM). We shall assume R-parity breaking bilinear terms in superpotential

\[ W = \mu H_D H_U + \mu_i L_i H_U + Y_i^L L_i H_D E_i^c + Y_i^D Q_i H_D D_i^c + Y_{ij}^U Q_i H_U U_j^c. \]  

(1)

Here \( H_D, H_U \) are two Higgs doublets, \( L_i \) a \( SU(2)_L \) doublet lepton, \( E_i^c \) is a singlet lepton, \( Q_i \) a doublet quark, \( U_i^c, D_i^c \) a singlet quark of up and down type, respectively. Suffices \( i, j \) stand for generations. The soft SUSY breaking terms in the scalar potential are

\[ V_{\text{soft}} = B H_D H_U + B_i \tilde{L}_i H_U + m_{H_D}^2 H_D H_D^\dagger + m_{H_U}^2 H_U H_U^\dagger \]

\[ + m_{H_L}^2 \tilde{L}_i H_D^\dagger + m_{L_{ij}}^2 \tilde{L}_i \tilde{L}_j^\dagger + \cdots. \]  

(2)

where we have written only bilinear terms explicitly. Here we assume the following lepton flavor universality in the soft masses:

\[ B_i \propto \mu_i, \quad m_{L_{ij}}^2 \propto \delta_{ij}, \quad m_{H_L}^2 \propto \mu_i. \]  

(3)

This universality suffers from radiative corrections and we assume that Eq. (3) holds at an energy scale where these soft masses are given as the boundary conditions of the renormalization group equations.

In this model, the R-parity violating terms are parameterized by

\[ s_3 \equiv \sin \theta_3 = \frac{\sqrt{\mu_1^2 + \mu_2^2 + \mu_3^2}}{\sqrt{\mu_1^2 + \mu_2^2 + \mu_3^2 + \mu^2}}. \]
\[
\begin{align*}
    s_2 & \equiv \sin \theta_2 = \frac{\sqrt{\mu_1^2 + \mu_2^2}}{\sqrt{\mu_1^2 + \mu_2^2 + \mu_3^2}}, \\
    s_1 & \equiv \sin \theta_1 = \frac{\mu_1}{\sqrt{\mu_1^2 + \mu_2^2}},
\end{align*}
\]

Here, for simplicity, we have taken \( \mu \) and \( \mu_i \) to be real. \( s_3 \) represents the magnitude of the R-parity violation, while the other two parameters characterize the mixing of the neutrinos.

**III. MNS MIXING MATRIX**

Let us now compute the neutrino masses and their mixing. To do this, it is convenient to use the Lagrangian whose renormalization point is at the electroweak scale. This may be obtained by the use of the renormalization group. Using this technique it is easy to see that one combination of the sneutrino fields \( s_1 s_2 \tilde{\nu}_e + c_1 s_2 \tilde{\nu}_\mu + c_2 \tilde{\nu}_\tau \) dominantly develops a non-vanishing vacuum expectation value (VEV). The VEV induces a mixing between the neutrino and neutralinos, generating a mass for the neutrino at the tree level. The neutrinos also acquire masses at the one-loop level. An analysis of Ref [2] shows that the mixing matrix of the neutrino sector, the MNS matrix [3], becomes

\[
U_{i\alpha} = \begin{pmatrix} U_{\tau 3} & U_{\tau 2} & U_{\tau 1} \\ U_{\mu 3} & U_{\mu 2} & U_{\mu 1} \\ U_{e 3} & U_{e 2} & U_{e 1} \end{pmatrix} = \begin{pmatrix} c_\theta & -s_\theta & 0 \\ c_1 s_\theta & c_1 c_\theta & -s_1 \\ s_1 s_\theta & s_1 c_\theta & c_1 \end{pmatrix},
\]

where \( \theta \) is approximately equal to \( \theta_2 \) with some small correction. Here \( i \) and \( \alpha \) denote the weak current basis and the mass eigen basis, respectively. The MNS matrix obtained here contains only two angles, while a general \( 3 \times 3 \) rotation matrix will have 3 angles. This is essential in the following analysis.

**IV. RESULTS**

We are now at the position to give our results. Here we assume the hierarchical mass structure, namely \( m_3 \gg m_2 \gg m_1 \) so that \( \Delta m_{32}^2 \simeq \Delta m_{31}^2 \gg \Delta m_{21}^2 \), which are naturally
realized in our model.

The atmospheric neutrino can be explained by $\nu_\tau - \nu_\mu$ oscillation. The transition probability is proportional to $4|U_{e3}|^2|U_{\tau 3}|^2 = 4c_\alpha^2 s_\beta^2 c_\beta^2$ and it must be close to unity to accord with the superKamiokande data [4]. On the other hand, the CHOOZ experiment [5] gives a bound on $4|U_{e3}|^2 = 4s_\alpha^2 s_\beta^2$ to be smaller than 0.2. These two constraints imply that the angle $s_1$ must be small. Therefore the solar neutrino [6] must be explained by the small angle MSW solution, since $\nu_\mu - \nu_e$ oscillation involves the small $s_1$ in its transition probability. In fact the large angle solutions require a large $s_1$, in contradiction with the other experimental results. This non-trivial relation comes from the fact that the MNS matrix is characterized by the two angles. If one relaxed the lepton flavor universality among the soft masses, one would get a more general mixing matrix. However, one should carefully choose the soft masses not to conflict with the severe bounds on the lepton flavor violating processes.

Next we would like to discuss the neutrino masses. The atmospheric neutrino requires $\Delta m^2_{\text{atm}} \simeq (2 - 6) \times 10^{-3} \text{eV}^2$ and the small angle MSW to the solar neutrino indicates $\Delta m^2_{\text{SMSW}} \simeq (0.4 - 1) \times 10^{-5} \text{eV}^2$. Since in our scenario the heaviest neutrino mass is obtained at the tree level while the next one is generated at the one loop, the neutrino masses tend to have large hierarchy. The less hierarchical structure suggested by the experiments requires a mild fine tuning of the tree level VEV of the neutrino to suppress the tree-level mass. This can easily be achieved in many ways, one of which is the universality between the leptons and the Higgs in the soft masses and the use of the alignment.

V. CONCLUSIONS

To summarize, we have considered the case of the bilinear R-parity violation with lepton flavor universality among the soft supersymmetry breaking masses. This generates the neutrino masses and mixing. The mixing matrix of the neutrinos has a very special pattern. This leads us to conclude that the large mixing angle solutions to the solar neutrino problem are ruled out when the CHOOZ result and the atmospheric neutrino data are combined
together. Furthermore the relatively less hierarchical structure of the neutrino masses in this case are obtained if the soft SUSY breaking masses are suitably tuned to give small VEV for sneutrinos. It is interesting to mention that neutrino oscillation experiments, e.g. SuperKamiokande, SNO [7], and KamLAND [8], as well as collider experiments in future will provide (critical) tests to our scenario.
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[6] See e.g. Y. Suzuki, talk given at International Symposium on Lepton and Photon Interactions at High Energies (Lepton-Photon’99), Stanford University, (August, 1999).

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[8] KamLAND experiment;

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