Neutrino Mass Matrix in the Minimal Supergravity Model: Bi-large Mixing with Trilinear R-parity Violation

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We study the correlation between the neutrino oscillation and the production/decay of the lightest supersymmetric particle(LSP) in the context of the minimal supergravity model(mSUGRA) without R-parity. We show how the neutrino masses and mixing which are consistent with the recent neutrino data can be obtained in this model, and describe how to probe the model by observing the LSP decay at collider experiments. It is shown that the generic 1-loop contributions to neutrino masses are too small to account for the solar and atmospheric neutrino oscillations and thus some fine cancellation in tree-level contribution is required to severely constrain the viable parameter space.

In most parameter space of mSUGRA, the neutralino or the stau is LSP. Examining both cases, we find that there is a simple correlation between the neutrino mixing angles and the LSP branching ratios in the small tan$\beta$ region so that the model can be clearly tested in the future colliders. In the large tan$\beta$ region, such a correlation is obscured by the large tau Yukawa contribution which makes it nontrivial to test the model.

PACS numbers: 12.60.-i, 14.60.St

I. INTRODUCTION

The recent progresses in neutrino experiments has led us to convince the existence of neutrino masses and flavor mixing. In this regard, of primary interest are to look for New Physics candidates which are inherited not only with a natural mechanism to generate the observed neutrino mass matrix and but also with some other predictions that can be tested in the near future. One of the best-motivated models endowing such a property would be the Minimal Supersymmetric Standard Model (MSSM) with lepton number violation via R-parity breaking terms, as such models may produce lepton flavour violating signals predicted by the observed neutrino mixing and thus can be tested in future collider experiments. The particle spectrum in MSSM depends on the supersymmetry breaking mechanism. One of the most popular scenarios for supersymmetry breaking is the minimal supergravity scenario (mSUGRA), which assumes a universal gaugino mass $M_{1/2}$, a universal scalar mass $m_0$, a universal trilinear coupling $A_0$ and $B_0$ at $M_{\text{GUT}}$ scale. This framework can successfully evade the appearance of dangerous flavor changing neutral current (FCNC) and is highly predictive because there exist only 5 independent parameters in the model. In this work, we do complete phenomenological analysis on the masses and mixing of neutrinos and lepton number violating signature of LSP decays in the context of mSUGRA with trilinear R-parity violation. The neutrino mass matrix is calculated up to the one-loop order, and it is studied how the predictions concerned with neutrino parameters in mSUGRA can be probed from the collider signals. In almost all parameter space of mSUGRA, the LSP is predicted to be a neutralino or a stau. In both cases, we calculate the production cross section, decay rate, and branching ratios of the LSP to investigate the correlations between neutrino oscillation parameters and collider signatures from the various channels of LSP decay.

II. NEUTRINO MASS MATRIX AND FLAVOR STRUCTURE OF TRILINEAR COUPLINGS IN MSUGRA

Let us begin by writing the superpotential in the basis where the bilinear term $L_iH_2$ is rotated away:

\begin{equation}
W_0 = \mu H_1 H_2 + h^e_i L_i H_1 E^c_i + h^d_i Q_i H_1 D^c_i + h^u_i Q_i H_1 U^c_i \quad (1)
\end{equation}

\begin{equation}
W = \lambda_i L_i L_3 E^c_i + \lambda^*_i L_i Q_3 D^c_3, \quad (2)
\end{equation}

where $W_0$ is R-parity conserving part, whereas $W$ is R-parity violating part, and we assume the dominance of $\lambda^*_i \equiv \lambda^{33}_i$ and $\lambda_i \equiv \lambda^{33}_i$ ($i = 1, 2, 3$) over the other trilinear couplings of lower generations and the universality at the GUT scale is imposed. In this framework, there are 10 free parameters of the model, i.e. five conventional ones plus five R-parity violating ones:

$m_0, A_0, M_{1/2}, \tan b, \text{sign}(\mu) ; \lambda_{1,2,3}^*, \lambda_{1,2}$

*Talk presented by D.W. Jung at 2nd International Conference on Flavor Physics (ICFP 2003) Korea Institute for Advanced Study, Seoul, Korea, Oct. 6-11, 2003
where \( t_\beta = \tan \beta \) is the ratio of two Higgs VEVs. As is well known, non-universality is developed at the weak scale via RGE evolution. The RGE in this basis can be found in Ref. [8]. Non-vanishing soft terms are given by

\[
V = m_{L_i H_1} + B_i t_\beta + \Sigma^{(1)}_{L_i} + \Sigma^{(2)}_{L_i}.
\]  

where \( B_i \) is the dimension-two soft parameter. We note that non-trivial VEVs for sneutrinos can be generated in this case. Including 1-loop contributions \( V_{\text{loop}} \), we obtain the following relation which comes from the minimization condition for the scalar potential,

\[
\xi_i = \frac{m_{L_i H_1}^2 + 2 B_i t_\beta + \Sigma^{(1)}_{L_i}}{m_{\tilde{\nu}}^2 + \Sigma^{(2)}_{L_i}},
\]

where \( \xi_i \equiv (\tilde{\nu}_i)/(|H_1|^2) \), and \( \Sigma^{(1,2)}_{L_i} \) are 1-loop contributions generated from \( V_{\text{loop}} \). The explicit forms of \( \Sigma^{(1,2)}_{L_i} \) are presented in Ref. [8],[9]. Introducing another variables,

\[
\eta_i \equiv \xi_i - \frac{B_i}{B},
\]

we can obtain the relation,

\[
\frac{\xi_i - \eta_i}{\xi_i} = \frac{1}{m_{\tilde{\nu}}^2} - \frac{1}{m_{\tilde{\nu}}^2 + \Sigma^{(2)}_{L_i}}.
\]

whose non-zero values are due to the neutral scalar loops. Then, the tree-level mass is presented in terms of \( \xi_i \):

\[
M_{ij}^{\text{tree}} = - \frac{M_Z}{F_N} \eta_i \eta_j c_\beta^2
\]

where \( F_N = M_1 M_2 / (\epsilon^2_W M_1 + s^2_W M_2) + M_Z^2 c_{2\beta}/\mu \). Including 1-loop corrections, the neutrino mass matrix is written as

\[
M_{ij}^{\nu} = - \frac{M_Z}{F_N} \xi_i \xi_j c_\beta^2 - \frac{M_Z}{F_N} (\xi_i \delta_j + \delta_i \xi_j) c_\beta \xi + \Pi_{ij},
\]

where \( \Pi_{ij} \) denotes the 1-loop contribution of the neutrino self energy, and

\[
\delta_i = \Pi_{\tilde{\nu}_i \tilde{\nu}_0} \left( \frac{-M_2 \sin^2 \theta_W}{M_1 M_2 \tan \theta_W} \right) + \Pi_{\tilde{\nu}_i \tilde{\nu}_3} \left( \frac{M_1 \cos^2 \theta_W}{M_1 M_W} \right)
\]

\[
+ \Pi_{\tilde{\nu}_i \tilde{\nu}_1} \left( \frac{\sin \beta}{\mu} \right) + \Pi_{\tilde{\nu}_i \tilde{\nu}_2} \left( \frac{\cos \beta}{\mu} \right),
\]

\[
M_\tau = c_{\beta}^2 M_1 + s_{\beta}^2 M_2.
\]

Exact expressions of the 1-loop contributions \( \Pi_{ij} \)'s are presented in Ref. [8]. We note that the conventional tau-stau, bottom-sbottom loops and neutral scalar (sneutrino/neutral Higgs boson) loops are essential to achieve

\[
M_{ij}^{\text{loop}} = \frac{3}{8 \pi^2} \frac{\lambda_Y}{m_{\tilde{\nu}}^2} \left( \frac{m_{\tilde{\nu}}^2}{m_{\tilde{\nu}}^2} \right) \ln \frac{m_{\tilde{\nu}}^2}{m_{\tilde{\nu}}^2} + \frac{\lambda_1 \lambda_2}{8 \pi^2} \left( \frac{m_{\tilde{\nu}}^2}{m_{\tilde{\nu}}^2} \right) \ln \frac{m_{\tilde{\nu}}^2}{m_{\tilde{\nu}}^2}.
\]

It is found that the charged scalar (slepton/charged Higgs boson) loops are important only for \( tan \beta > 30 \) as observed in Ref. [10], whereas the neutral scalar loops are important for all \( tan \beta \) in our case. We have observed that the tree level masses are much larger than the 1-loop contributions in mSUGRA, which makes it difficult to accommodate the solar and atmospheric neutrino oscillations. Thus, we need some cancellation in \( \xi_i \) so that the tree mass becomes comparable to the 1-loop contributions. Then, we can obtain a desirable neutrino mass matrix the by combining the tree and 1-loop masses appropriately, but it is possible in some fine-tuned parameter space, as will be shown later. In this case, however, we lose nice predictability of atmospheric and solar neutrino mixing angles measurable in colliders.

### III. Numerical Results: Fitting the Neutrino Data

First of all, we obtain the parameter sets consistent with the solar and atmospheric neutrino data by scanning the input parameters within the ranges,

\[
100 \text{GeV} \leq m_0 \leq 1000 \text{GeV},
\]

\[
100 \text{GeV} \leq M_{1/2} \leq 1000 \text{GeV},
\]

\[
0 \text{GeV} \leq A_0 \leq 700 \text{GeV},
\]

\[
2 \leq \tan \beta \leq 43.
\]

The ranges for \( R \)-parity violating parameters we scan are given

\[
4 \times 10^{-6} \leq |\lambda_1| \leq 6 \times 10^{-4},
\]

\[
4 \times 10^{-6} \leq |\lambda_2| \leq 6 \times 10^{-4},
\]

\[
4 \times 10^{-6} \leq |\lambda_3| \leq 6 \times 10^{-4},
\]

\[
4 \times 10^{-6} \leq |\lambda_4| \leq 6 \times 10^{-4},
\]

\[
4 \times 10^{-6} \leq |\lambda_5| \leq 6 \times 10^{-4}.
\]
set of scattered points lie in that region. We find that give the right value of the mass square ratio. Only small

The points in the region between the two dotted lines vs. \( \tan \beta \) and solar neutrino mixing angles measurable in colliders. So we should make the tree mass terms comparable to contributions in general, whereas the allowed parameter space corresponds
to the case that both signs are positive. We also find that most of the allowed parameter space corresponds
numerical calculations. In mSUGRA scenario, the tree
should take

FIG. 2: Atmospheric neutrino mixing angle vs. \( |\xi_3/\xi_4| \) and \( |\lambda_3'/\lambda_1'| \) for general points

\[
4 \times 10^{-6} \leq |\lambda_2| \leq 6 \times 10^{-4}, \quad (17)
\]
\[
3 \times 10^{-9} \leq |\lambda_1'| \leq 10^{-4}, \quad (18)
\]
\[
4 \times 10^{-6} \leq |\lambda_2'| \leq 10^{-3}, \quad (19)
\]
\[
4 \times 10^{-6} \leq |\lambda_3'| \leq 10^{-3}. \quad (20)
\]

We set the signs of \( M_{1/2} \) and \( A_0 \) arbitrary, but find that most of the allowed parameter space corresponds to the case that both signs are positive. We also find that there are strong correlations between atmospheric neutrino mixing angle and \( \lambda_i \)'s. In order to account for the large atmospheric angle and small Chooz angle, we should take \( \lambda_1 \ll \lambda_2 \approx \lambda_3 \). We have confirmed this by numerical calculations. In mSUGRA scenario, the tree level value of neutrino mass is much larger the 1-loop contributions in general, whereas the allowed parameter sets from the neutrino data are not tree-dominant at all. So we should make the tree mass terms comparable to the 1-loop contributions, and it can be possible in the case that some cancellation in \( xi \) occurs. In doing so, however, we lose beautiful predictability of atmospheric and solar neutrino mixing angles measurable in colliders. FIG.1 shows scattered plot of the ratio \( \Delta m^2_{\text{sol}}/\Delta m^2_{\text{atm}} \) vs. \( \tan \beta \) in the randomly generated parameter space. The points in the region between the two dotted lines give the right value of the mass square ratio. Only small set of scattered points lie in that region. We find that only small number of points among them are consistent with bi-large mixing.

We note that the relative sizes of R-parity violating parameters are correlated with neutrino mixing pattern. But due to the cancellation in \( xi \), it turns out that such a correlation is rather weak. In FIG. 2, we see some correlations between the atmospheric neutrino mixing angle and \( \xi_3/\xi_4 \), \( \lambda_2'/\lambda_1' \) for general parameter sets although they are not very strong because many data points do not lead to tree-dominant neutrino masses. Even though the correlations look so weak, we can obtain some constraints on \( |\lambda_2'/\lambda_3'| \) from the neutrino data \( 0.4 \lesssim |\lambda_2'/\lambda_3'| \lesssim 2.5 \) for small \( \tan \beta \) and \( 0.3 \lesssim |\lambda_2'/\lambda_3'| \lesssim 3.3 \) for large \( \tan \beta \). In FIG. 3, we plot the solar mixing angle vs. \( \lambda_1/\lambda_2 \) for small \( \tan \beta \) and large \( \tan \beta \) cases, respectively. We see that there are strong correlations between the solar mixing angle and \( \lambda_1/\lambda_2 \) ratios. Similar to the above case, we can get some constraints \( 0.3 \lesssim |\lambda_2/\lambda_3| \lesssim 1.6 \) for small \( \tan \beta \) and \( 0.2 \lesssim |\lambda_2/\lambda_3| \lesssim 5 \) for large \( \tan \beta \). Collecting these constraints, the solutions are found for the ranges of

\[
\lambda_{1,2}, \lambda_{2,3}' = (0.1 - 2) \times 10^{-4}, \quad (21)
\]
\[
\lambda_1' < 2.5 \times 10^{-5}. \quad (22)
\]

Let’s summarize the results of this section. In general, in large portion of parameter space, the tree level contribution is much larger than those from 1-loop, so it is hard to get the right mass square ratio which is about
The solutions are possible by suppressing the tree level contributions, which arises through the cancel-
lation in $\xi_i$. In this case, the correlations between $\xi_i$ and mixing angles become worse. In addition to the impor-
tant 1 loop correction by stau and sbottom, the neutral scalar loop can give the important contribution to the
neutrino masses, through the deviation of $\eta_i$ from the direction of $\xi_i$, which determine the tree level neutrino
mass matrix. Instead of those, there are stronger corre-
lations between the atmospheric mixing angle and $\lambda_2/\lambda_3$, the solar mixing angle and $\lambda_1/\lambda_2$. For small $\tan \beta$, it is possible to probe these in collider signal. It will be shown
in the next section.

IV. COLLIDER SIGNALS OF THE MODEL

It is expected that the luminosity of the next linear col-
lider can reach the $1000 fb^{-1}/yr$, and the center of mass
energy over 1 TeV\cite{11,12}. With such a capacity of the
linear collider, it could be possible to probe the supersym-
metric particles pair produced\cite{13} as well as the decay of
LSP inside the detector\cite{14}. We present here the total
cross section and decay rate for various parameter sets,
and discuss the possibility to probe the structure of R-
parity violating parameters constrained by neutrino data.
In the previous sections we got the parameter sets which
are consistent with the known neutrino data. Those
results suffice to determine which is the LSP, neutralino
or light stau. In TABLE I-III, we present the results of
decay rate and branching ratios. The TABLE I shows
the results for the stau LSP case with small $\tan \beta$. TA-
BLE II and III correspond to the Neutralino LSP cases
for small $\tan \beta$. The former is the case that only 3-body
decay is permitted, whereas the latter is the case that
both 2-body and 3-body decays are permitted. Since the
decay lengths are smaller than a few cm for all cases, it is
possible to detect their decay modes in the next linear
collider.

First of all, let’s discuss the stau LSP cases. For small
$\tan \beta$, $\tau_L \sim \tau_R$ due to the small off-diagonal part.
Then the light stau almost decays into leptons via
$\lambda_i L_i L_j E_3^c$ terms in the superpotential. In this case, the following
relation holds,

$$\text{Br}(\nu e) : \text{Br}(\mu \nu) : \text{Br}(\tau \nu) \sim |\lambda_1|^2 : |\lambda_2|^2 : |\lambda_1|^2 + |\lambda_2|^2.$$  

(23)

Thus, by observing the lepton branching ratios, one can
measure the ratio of $\lambda_1$ and $\lambda_2$. If this value is out of the
range constrained by neutrino data, given in the last sec-
tion, we can exclude this model. If $\tan \beta$ become larger,
the above relation does not hold any more because the
Yukawa coupling plays an important role in this case. In
other words, $\tau_1$ cannot be considered as almost $\tau_R$, but
should be the combination of $\tau_L$ and $\tau_R$ and then the
couplings are given by the mixture of $\lambda_i$ and $h_\tau$.

Next, let’s consider the neutralino LSP cases. The 2-
body decay rates are proportional to $|\xi_i|^2$,

$$\Gamma(\nu_i Z) \propto |\xi_i|^2,$$

$$\Gamma(\nu_i W) \propto |\xi_i|^2.$$  

(24)

(25)

For 3-body decay modes, the lepton-quark-quark branch-
ing ratios are proportional to $|\xi_i|^2$ since $W$ boson ex-
change diagrams are dominant. So we can have the fol-
lowing relation,

$$\text{Br}(e jj) : \text{Br}(\mu jj) : \text{Br}(\tau jj) = |\xi_1|^2 : |\xi_2|^2 : |\xi_3|^2.$$  

(26)

Thus, we can obtain the information of $\xi_i$ ratio by mea-
suring the branching ratios, but it is difficult to test
mSUGRA scenario for massive neutrinos via collider sig-
als because the correlation between $\xi_i$’s and neutrino oscilla-
tion parameters is diminished as pointed out in the last section. Similar to the stau LSP case, for small $\tan \beta$, $\nu l \tau \tau$ branching ratios provide $\lambda_i$ information on them;

$$\text{Br}(\nu \ell \pm \tau \mp) : \text{Br}(\nu \mu \pm \tau \mp) : \text{Br}(\nu \tau \pm \tau \mp) \sim |\lambda_1|^2 : |\lambda_2|^2 : |\lambda_1|^2 + |\lambda_2|^2.$$  

(27)

Likewise, if we measure the above branching ratios, the
models can be tested by comparing them with the range
allowed by neutrino data. But since, for large $\tan \beta$, the
terms generated from $h_\tau L_3 H_1 E_3^c$ in the superpotential
become large, and thus the above relation breaks, it is impos-
sible to test this scenario. The examples are presented in the TABLE II and III. In addition, we note that $\eta_i$’s are rather big in all cases, which implies that
some cancellations in $\xi_i$’s occur, as expected before.

V. CONCLUSION

Based on the recent precise experimental results for
neutrino oscillations, we have studied the minimal su-
peregravity model with the lepton number violation via
R-parity violating terms. Since it is impossible to ac-
count for large mixing angle solution of solar neutrino
problem in mSUGRA with only bilinear R-parity viola-
tions, we should include the general trilinear R-parity
violations. So there are additional 5 parameters $\lambda_i$ and
$\lambda_i$ besides the 5 parameters which are from the ordinary
minimal supergravity model. In future collider which can
reach its CM energy over 1 TeV and luminosity up to
$1000 fb^{-1}$ in a year\cite{11,12}, we expect that it is possible
to probe mSUGRA without R-parity via the LSP de-
cay. We have presented how neutrino mass matrix from
mSUGRA with R-parity violation can be constructed at
the 1-loop level. From our analysis, we found that most
parameter space which is consistent with neutrino data
leads to 1-loop contributions as large as comparable with
tree level masses. We have found the strong correlation
between solar neutrino mixing angle and $\lambda_1/\lambda_2$, and also
between atmospheric neutrino mixing angle and $\lambda_2/\lambda_3$.
For searching the LSP decays, we have considered two cases in mSUGRA, neutralino LSP and scalar tau LSP,
and searched each parameter space regions by varying $m_0$ and $M_{1/2}$. For our purpose, we have calculated the production cross section for each cases. For stau LSP case, 2-body decay modes are dominant. Since stau LSP is almost $\tilde{\tau}_R$ for most parameter space, its branching ratios of the decay into top and bottom quark is negligibly small. Since stau LSP decay into $\tau$ takes place via $\lambda_i$, couplings, it is possible to obtain the information on $\lambda_i$’s from branching fractions. We found that $Br(e\nu) : Br(\mu\nu) : Br(\tau\nu) = |\lambda_1|^2 : |\lambda_2|^2 : |\lambda_1|^2 + |\lambda_2|^2$ for not too large $\tan\beta$. For neutralino LSP cases, similar analysis has been done. Unlike the stau LSP cases, neutralino LSP can decay into 3-body final states as well as 2-body decay. From the branching fractions $Br(l_{i,jj})$ for various decay channels of neutralino LSP, we have determined the ratios of $\xi_i$’s, which in turn give the desirable tree level neutrino mass matrix. But, due to rather large loop contributions to neutrino masses the predictability for neutrino parameters is diminished. For small $\tan\beta$, we have obtained the $\lambda_i$’s information which are strongly correlated with solar neutrino mixing angle from the branching fractions $Br(\nu^{\pm}_l \tau \pm)$. But unluckily, since Yukawa couplings become larger for large $\tan\beta$, it is impossible to get information on $\lambda_i$’s. Consequently,

| | setA : Stau LSP | | setB : Neutralino LSP |
|---|---|---|---|
| | $\tan\beta = 5.15$ | $\tan\beta = 4.94$ | |
| | $sgn(\mu) = -1$ | $sgn(\mu) = -1$ | |
| | $\mu = -801.23$ GeV | $\mu = -200.46$ GeV | |
| $A_0$ | 39.47 GeV | 38.93 GeV | |
| $m_0$ | 105.02 GeV | 333.66 GeV | |
| $M_{1/2}$ | 671.02 GeV | 160 GeV | |
| $\lambda_i'$ | $8.03 \times 10^{-6}$ | $-9.326 \times 10^{-9}$ | |
| | $-7.763 \times 10^{-5}$ | $-7.811 \times 10^{-5}$ | |
| | $-6.792 \times 10^{-5}$ | $-7.560 \times 10^{-5}$ | |
| $\lambda_i$ | $8.739 \times 10^{-5}$ | $-5.628 \times 10^{-5}$ | |
| | $-7.44 \times 10^{-5}$ | $-7.345 \times 10^{-5}$ | |
| | 0 | 0 | |
| $\xi_i$ | $-1.03 \times 10^{-6}$ | $-1.234 \times 10^{-6}$ | |
| | $-3.642 \times 10^{-6}$ | $3.247 \times 10^{-7}$ | |
| | $-4.401 \times 10^{-6}$ | $1.88 \times 10^{-6}$ | |
| $\eta_i$ | $9.897 \times 10^{-7}$ | $-1.211 \times 10^{-6}$ | |
| | $-3.045 \times 10^{-6}$ | $2.749 \times 10^{-7}$ | |
| | $-3.728 \times 10^{-6}$ | $1.831 \times 10^{-6}$ | |
| $\nu_{jj}$ | $1.011 \times 10^{-6}$ | $-2.007 \times 10^{-6}$ | |
| | $-1.313 \times 10^{-5}$ | $-1.169 \times 10^{-5}$ | |
| | $-1.192 \times 10^{-5}$ | $-8.742 \times 10^{-6}$ | |
| $BR$ | $l_{i,jj}$ | $\sim 0.066$ % | $\sim 0.066$ % |
| | $\sim 0.066$ % | $\sim 0.066$ % | |
| $\Gamma = 2.921 \times 10^{-7}$ GeV | $\sigma_{e^+e^- \rightarrow \tilde{\tau}_R \tilde{\tau}_L^*} \approx 1.45 \times 10^{-2}$ (Pb), $\sqrt{s} = 1$ TeV | |
| | $m_{\tilde{\tau}_R} = 278.59$ GeV | $(\Delta m^2_1, \Delta m^2_2) = (2.50 \times 10^{-3}, 1.13 \times 10^{-4})$ eV$^2$ | |
| | | $(\sin^2 2\theta_{atm}, \sin^2 2\theta_{sol}, \sin^2 2\theta_{choo}) = (0.98, 0.77, 0.03)$ | |
| | $\sigma_{e^+e^- \rightarrow \tilde{\eta}_i \tilde{\eta}_j} \approx 4.97 \times 10^{-2}$ (Pb), $\sqrt{s} = 1$ TeV | |
| | $m_{\tilde{\eta}_i} = 59.37$ GeV | $\Gamma = 7.137 \times 10^{-15}$ GeV | |
| | $\tilde{\eta}_i$ | 47.01 % | |
| | $\tilde{\eta}_j$ | 2.00 $\times 10^{-3}$% | |
| | $\nu_{\tilde{\eta}_i \tilde{\eta}_j}$ | 8.87 $\times 10^{-2}$% | |
| | $\nu_{\tilde{\eta}_i \tilde{\eta}_j}$ | 9.76 % | |
| | $\nu_{\tilde{\eta}_i \tilde{\eta}_j}$ | 16.60 % | |
| | $\nu_{\tilde{\eta}_i \tilde{\eta}_j}$ | 26.39 % | |

**TABLE I:** A trilinear model realizing the LMA solution for stau-LSP case. Here the couplings $\tilde{\lambda}_i'$ and $\tilde{\lambda}_i$ can be considered as input parameters defined at the weak scale.

**TABLE II:** Neutralino-LSP case, only 3-body decays are possible
in the future collider may exclude scenarios for neutrino oscillation of the sever deviation from these branching fractions. But it becomes hard for large $\tan\beta$. Thus, any observation of the sever deviation from these branching fractions in the future collider may exclude scenarios for neutrino masses in the framework of mSUGRA with appropriate R-parity violation.

| BR | $\nu_{jj}$ | $\nu_{l_{+}\bar{\nu}_{l_{+}}}$ | $m_{\chi_{0}^{0}}=195.00$ GeV | $\sigma_{e^+e^-\rightarrow\chi_{1}^{0}\chi_{1}^{0}} \approx 0.197$ (Pb), | $\sqrt{s} = 1$ TeV |
|----|------------|----------------|----------------|----------------|----------------|
| $\tau$ | 14.77% | 6.36x10^{-2} % | 20.96 % | $\Delta m_{31}^2, \Delta m_{21}^2 = (2.50 \times 10^{-3}, 6.81 \times 10^{-5})$ eV$^2$ |
| $\nu_{l_{+}\bar{\nu}_{l_{+}}}$ | 3.84 x 10^{-1} % | 21.186 % | $\sin^2 2\theta_{atm}, \sin^2 2\theta_{sol}, \sin^2 2\theta_{eboo} = (0.95, 0.96, 0.007)$ |
| $\nu_{l_{+}\bar{\nu}_{l_{+}}}$ | 2.51 x 10^{-1} % | 42.09 % |

TABLE III: Neutralino-LSP case, both 2- and 3-body decays are possible.

Acknowledgments

SKK is supported by BK21 program of the Minstry of Education in Korea, and DWJ is supported by KRF-2002-070-C00022.

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