Neutrino Mass Matrix in the Minimal Supergravity Model : Bi-large mixing with trilinear R-parity violation

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Contents

Introduction

- **Neutrinos : Massive & get Mixed**

  $\Rightarrow$ Beyond the Standard Model feature

  The problems;

  How to make neutrinos massive with,

  — Very light masses,

  — Right mixing angles.

- **Supersymmetric model with R-parity violation**

  $\Rightarrow$ Good solution for Neutrino masses.

  — Theoretically allowed

  — Contain Lepton # violation $\longrightarrow$ Neutrino mass

  — The Lightest Supersymmetric particle(LSP) decay

  : detectable at Collider Experiments

  — Interplay of Neutrino Physics and Collider Physics

- **What we have done,**

  In the minimal Supergravity scenario with R-parity violation,

  — Construct the Neutrino mass matrix

  — Determine the Lightest Supersymmetric Particle

  — Production and decay rate of LSP

  — Investigate the various branching ratios

  $\Longrightarrow$ Phenomenological Study on the relation between Neutrino Physic and Collider signals

  $\Longrightarrow$ Constraints with each other

  $\Longrightarrow$ Allow or Exclude the scenarios

Status of Neutrino Physics

- **Neutrino Oscillation**

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix},$$

with

$$\mathbf{U}\mathbf{U}^\dagger = \mathbf{1}$$

If no CP violation, U is real and usual parametrization is

$$\begin{aligned} \mathbf{U} &= \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13} \\ 0 & 1 & 0 \\ -s_{13} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \\ &= \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13} & c_{12}c_{23} - s_{12}s_{23}s_{13} & s_{23}c_{13} \\ s_{12}s_{23} - c_{12}c_{23}s_{13} & -c_{12}s_{23} - s_{12}c_{23}s_{13} & c_{23}c_{13} \end{pmatrix}. \end{aligned}$$

with $c_{ij} = \cos\theta_{ij}, s_{ij} = \sin\theta_{ij}$

5 Parameters

- **the solar neutrino mixing angle**
$\theta_{SOL} \equiv \theta_{12}$ **(large, but non-maximal),**
and solar mass splitting $\Delta m^2_{21} \equiv \Delta m^2_{SOL}$.

- **the atmospheric neutrino mixing angle**
$\theta_{ATM} \equiv \theta_{23}$ **(nearly maximal),**
and atmospheric splitting $\Delta m^2_{32} \equiv \Delta m^2_{ATM} (\gg m^2_{SOL})$.

- **the reactor angle** θ_{13}**(small).**

Experimental Values

- **So-called Large Mixing Angle(LMA)-MSW solution at** 3σ **level,**

LMA-MSW

$$\begin{aligned} 0.26 \leq & \tan^2\theta_{SOL} & \leq 0.85 \\ 2.6\times 10^{-5}\mathrm{eV}^2 \leq & \Delta m^2_{SOL} & \leq 3.3\times 10^{-4}\mathrm{eV}^2. \end{aligned}$$

Global fit

$$\tan^2\theta_{SOL} = 0.46, \quad \Delta m^2_{SOL} = 6.6\times 10^{-5}\mathrm{eV}^2$$

- **The official SK analysis with 3σ range,**

$$
\begin{aligned}
0.3 \leq & \sin^2\theta_{ATM} & \leq 0.7 \\
1.2\times 10^{-3}\text{eV}^2 \leq & \Delta m^2_{ATM} & \leq 4.8\times 10^{-3}\text{eV}^2
\end{aligned}
$$

The global fit

$$
\sin^2\theta_{ATM} = 0.5, \quad \Delta m^2_{ATM} = 2.5\times 10^{-3}\text{eV}^2
$$

- **From reactor experiments,**

For $\Delta m^2_{32} \gtrsim 1\times 10^{-3}\text{eV}^2$,

$$
\Longrightarrow \sin^2 2\theta_{13} \lesssim 0.2.
$$

- **Solar Neutrino + KamLAND**

$$
\begin{aligned}
0.29 \leq & \tan^2\theta_{SOL} & \leq 0.86 \\
5.1\times 10^{-5}\text{eV}^2 & \Delta m^2_{SOL} & \leq 9.7\times 10^{-5}\text{eV}^2, \\
1.2\times 10^{-5} \leq \text{eV}^2 & \Delta m^2_{SOL} & \leq 1.9\times 10^{-5}\text{eV}^2.
\end{aligned}
$$

The Minimal Supergravity Model without R-Parity

- **Superpotential allowed by gauge invariance**

$$W_0 = \mu H_1 H_2 + h_i^e L_i H_1 E_i^c + h_i^d Q_i H_1 D_i^c + h_i^u Q_i H_2 U_i^c,$$

$$W_1 = \mu_i L_i H_2 + \frac{1}{2}\lambda_{ijk} L_i L_j E_k^c + \lambda'_{ijk} L_i Q_j D_k^c + \frac{1}{2}\lambda''_{ijk} U_i^c D_j^c D_k^c$$

— First 3 terms : Lepton number violation

— Last term : Baryon number violation

W_1 **leads to proton decay**

$$\propto \frac{\lambda'_{ijk}\lambda''_{11k}}{m^2_{\tilde{d}^c_k}} \qquad \textbf{j=1 or 2.}$$

$$\tau_p \gtrsim 10^{32} yrs \Rightarrow \lambda'_{ijk}\lambda''_{11k} \lesssim 10^{-27}\left(\frac{\tilde{m}}{100\text{GeV}}\right)^2.$$

- **R-parity**

$$R_p = (-1)^{3B+L+2s},$$

s: spin of the particle

– **Standard model particle and Higgs bosons :** $R_p = +1$

– **Supersymmetric particles :** $R_p = -1$**.**

– $R_p(W_1) = -1$**.**

If R_p **is imposed** $\longrightarrow W_1$ **forbidden**

– **Lightest Supersymmetric Particle(LSP) stable**

– **Candidate for Dark Matter**

If not,

– **LSP unstable** $\rightarrow$ **decay**

– **Sneutrinos get VEV's**

– **Particle-sparticle Mixing**

- **mSUGRA scenario**

  At Grand Unified Scale (GUT-scale)

  $M_X \backsimeq 2 \times 10^{16}\mathrm{GeV}$**,**

  Universal Gaugino masses

$$M_3(M_X^2) \ = \ M_2(M_X^2) \ = \ M_1(M_X^2) \ = \ M_{1/2}.$$

  Universal scalar masses

$$m_{ij}^2 \ = \ m_0^2 \ \delta_{ij}.$$

  Universal A **parameter**

$$A_\tau(M_X^2) \ = \ A_b(M_X^2) \ = \ A_t(M_X^2) \ = \ \cdots \ = \ A_0.$$

  Five parameters at GUT scale,
  except for R_p **violating parameters.**

$$(\ m_0,\ M_{1/2},\ A_0,\ \tan\beta\ (= v_2/v_1),\ \mathrm{sgn}(\mu)\ ).$$

  ⇒RG running from GUT scale to Electro weak scale.

We have assumed

$*\ \lambda_i \equiv \lambda_{i33}$ **and** $\lambda_i' \equiv \lambda_{i33}'$ **dominate over ohters**

$\Leftarrow$ **quark and lepton Yukawa hierarchy**

$*\ \lambda_{ijk}'' \equiv 0$

$\Leftarrow$ **To prevent fast proton decay**

Neutrino Masses

- **Tree Mass**

  Sneutrinos get VEV's

$$u_i = \langle \widetilde{\nu}_i \rangle = -\frac{B_i \mu_i \langle H_2^0 \rangle + \left(m^2_{L_i H_1} + \mu \mu_i \right) \langle H_1^0 \rangle^* + \Sigma^{(1)}_{L_i} \langle H_1^0 \rangle^*}{m^2_{L_i} + \frac{1}{2} M_Z^2 cos 2\beta + \Sigma^{(2)}_{L_i}}$$

The 7×7 neutrino-neutralino mass matrix
In the basis $\left(\nu_i, \widetilde{B}, \widetilde{W}^3, \widetilde{H}_1, \widetilde{H}_2 \right)$,

$$M_{\mathbf{N}} = \begin{pmatrix} 0 & M_{\nu \widetilde{\chi}^0} \\ M^{\dagger}_{\nu \widetilde{\chi}^0} & M_{\widetilde{\chi}^0 \widetilde{\chi}^0} \end{pmatrix},$$

where,

$$M_{\nu \widetilde{\chi}^0} = \begin{pmatrix} \frac{1}{\sqrt{2}} g' u_1 & -\frac{1}{\sqrt{2}} g u_1 & 0 & \mu_1 \\ \frac{1}{\sqrt{2}} g' u_2 & -\frac{1}{\sqrt{2}} g u_2 & 0 & \mu_2 \\ \frac{1}{\sqrt{2}} g' u_3 & -\frac{1}{\sqrt{2}} g u_3 & 0 & \mu_3 \end{pmatrix}$$

$$M_{\widetilde{\chi}^0 \widetilde{\chi}^0} = \begin{pmatrix} M_1 & 0 & \frac{1}{\sqrt{2}} g' v_1 & -\frac{1}{\sqrt{2}} g' v_2 \\ & M_2 & -\frac{1}{\sqrt{2}} g v_1 & \frac{1}{\sqrt{2}} g v_2 \\ & & 0 & \mu \\ & & & 0 \end{pmatrix}$$

•Neutrino mass matrix-Tree level

$$\begin{aligned} M_{ij}^{\nu} &= -\frac{M_Z^2}{F_N}\xi_i\xi_j\cos^2\beta, \\ F_N &= \left(M_1M_2/M_{\widetilde{\gamma}} + M_Z^2\sin 2\beta/\mu\right), \\ M_{\widetilde{\gamma}} &= M_1\cos^2\theta_W + M_2\sin^2\theta_W. \end{aligned}$$

where $\xi_i \equiv u_i/v_1 - \epsilon_i$,

which gives only one non-zero eigenvalue $\propto \sum_i \xi_i^2$**.**

• 1-Loop corrected Masses

$$M_{ij}^{\nu} = -\frac{M_Z^2}{F_N}\xi_i\xi_j\cos^2\beta - \frac{M_Z^2}{F_N}\left(\xi_i\delta_j + \delta_i\xi_j\right)\cos\beta + \Pi_{ij},$$

where,

$$\begin{aligned} \delta_i &= \Pi_{\nu_i\widetilde{B}^0}\left(\frac{-M_2\sin^2\theta_W}{M_{\widetilde{\gamma}}M_W\tan\theta_W}\right) + \Pi_{\nu_i\widetilde{W}_3}\left(\frac{M_1\cos^2\theta_W}{M_{\widetilde{\gamma}}M_W}\right) \\ &\quad + \Pi_{\nu_i\widetilde{H}_1^0}\left(\frac{\sin\beta}{\mu}\right) + \Pi_{\nu_i\widetilde{H}_2^0}\left(\frac{-\cos\beta}{\mu}\right). \end{aligned}$$

1-Loop diagrams are classified

$*$ **Gauge-Gauge Type**

$*$ **Gauge-Yukawa Type**

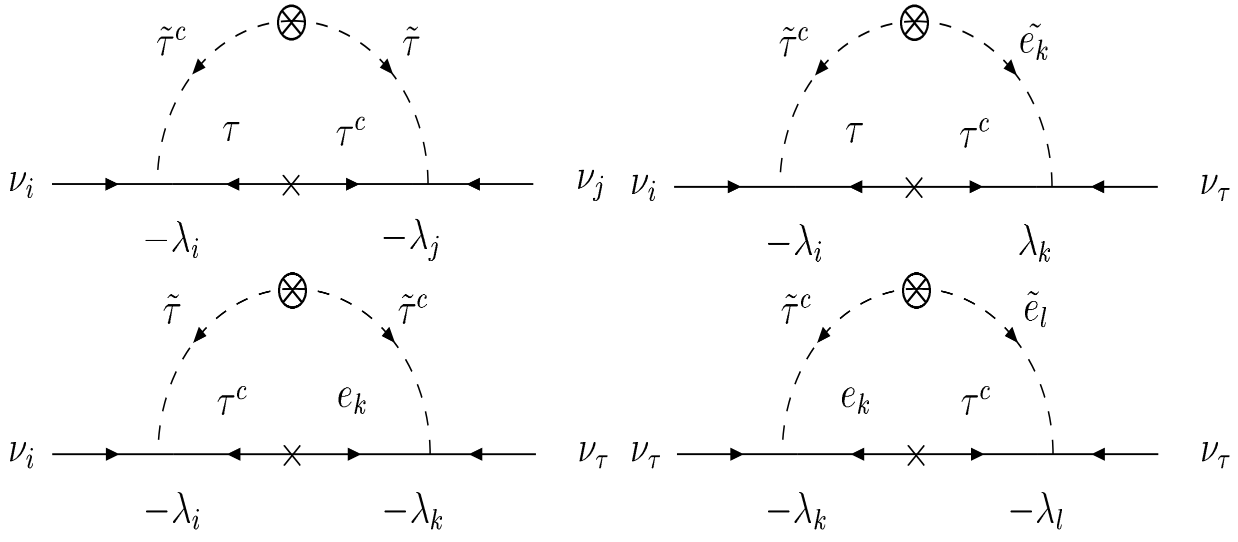
$*$ **Yukawa-Yukawa Type**

$*$ **Gauge-λ Type**

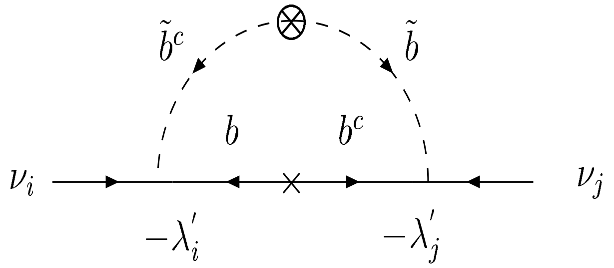
$*$ **Yukawa-λ Type**

$*$ $\lambda - \lambda$ **Type** $\Rightarrow$ **Important**

$*$ $\lambda^{'} - \lambda^{'}$ **Type** $\Rightarrow$ **Important**



Loop diagram $\lambda - \lambda$ type



Loop diagram $\lambda' - \lambda'$ tpye

Numerical Results

In the basis where the bilinear term $L_i H_2$ is rotated away,

$$W_1 = \frac{1}{2}\lambda_i L_i L_3 E_3^c + \lambda_i^{'} L_i Q_3 D_3^c$$

Free parameters,

$$m_0,\ A_0,\ M_{1/2},\ t_\beta,\ \mathbf{sign}(\mu)\ \ ;\ \ \lambda'_{1,2,3},\ \lambda_{1,2}$$

$$\begin{aligned} 100\mathrm{GeV} \leq & \quad m_0 & \leq 1000\mathrm{GeV}, \\ 100\mathrm{GeV} \leq & \quad m_{1/2} & \leq 1000\mathrm{GeV}, \\ 0\mathrm{GeV} \leq & \quad A_0 & \leq 700\mathrm{GeV}, \\ 2 \leq & \quad \tan\beta & \leq 43. \end{aligned}$$

$$\begin{aligned} 4\times 10^{-6} \leq & \quad |\lambda_1| & \leq 6\times 10^{-4}, \\ 4\times 10^{-6} \leq & \quad |\lambda_2| & \leq 6\times 10^{-4}, \\ 3\times 10^{-9} \leq & \quad \left|\lambda_1^{'}\right| & \leq 10^{-4}, \\ 4\times 10^{-6} \leq & \quad \left|\lambda_2^{'}\right| & \leq 10^{-3}, \\ 4\times 10^{-6} \leq & \quad \left|\lambda_3^{'}\right| & \leq 10^{-3}. \end{aligned}$$

• Tree level contribution is much larger than that of loop, generally. $\rightarrow$ hard to get the right mass ratio.

• Suppress the tree-level contribution through the cancelation in ξ_i.

• Strong correlations;
Between the atmospheric ν mixing angle and $\lambda_2^{'}/\lambda_3^{'}$,
Between the solar ν mixing angle and λ_1/λ_2,

• Constraints from Neutrino data

$$|\lambda_2'/\lambda_3'| = (0.4 - 2.5), (0.3 - 3.3).$$

$$|\lambda_1/\lambda_2| = (0.3 - 1.6),\ \ (0.2 - 5)$$

where, $\tan\beta = 3 - 15, \tan\beta = 30 - 40$**, each.**

Total,

$$\begin{aligned} \left|\lambda_{1,2}, \lambda_{2,3}'\right| &= (0.1 - 2) \times 10^{-4}, \\ |\lambda_1'| &< 2.5 \times 10^{-5}. \end{aligned}$$

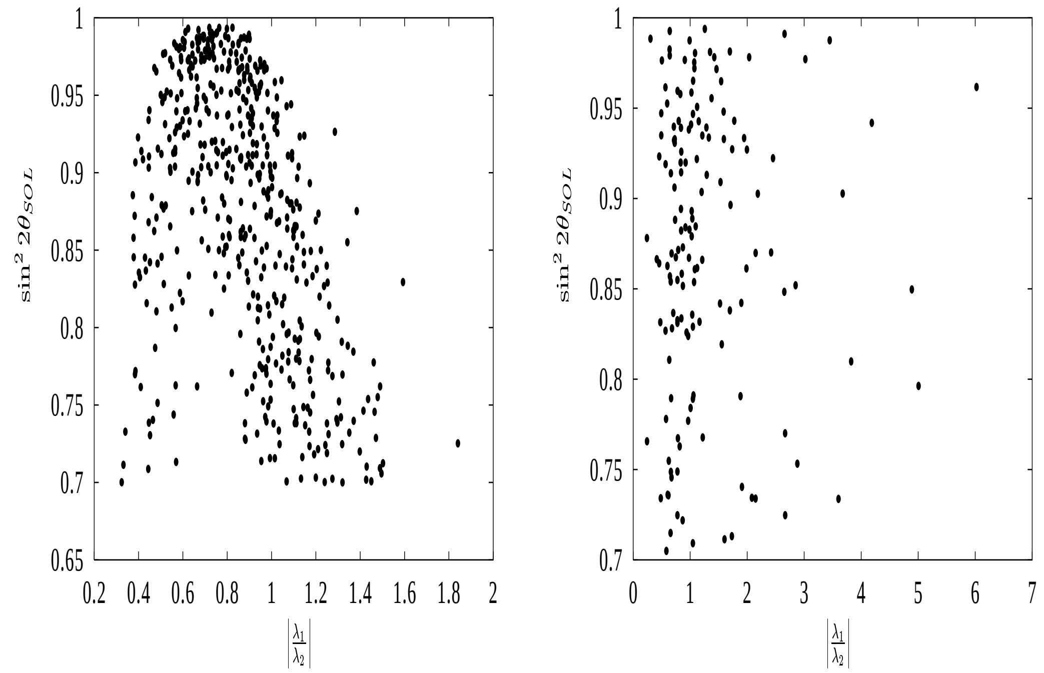


Figure 1: The solar mixing angle and λ_1/λ_2 ratio for solution points, Left : small $\tan\beta, \sim 3-15$ Right : for large $\tan\beta, \sim 30-40$

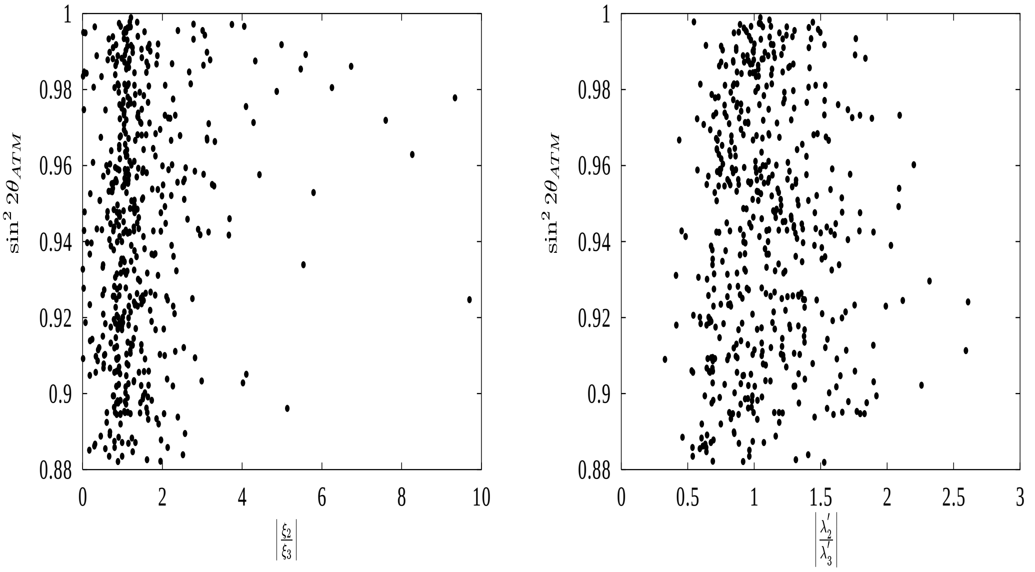


Figure 2: For solution points, small $\tan\beta, \sim 3 - 15$

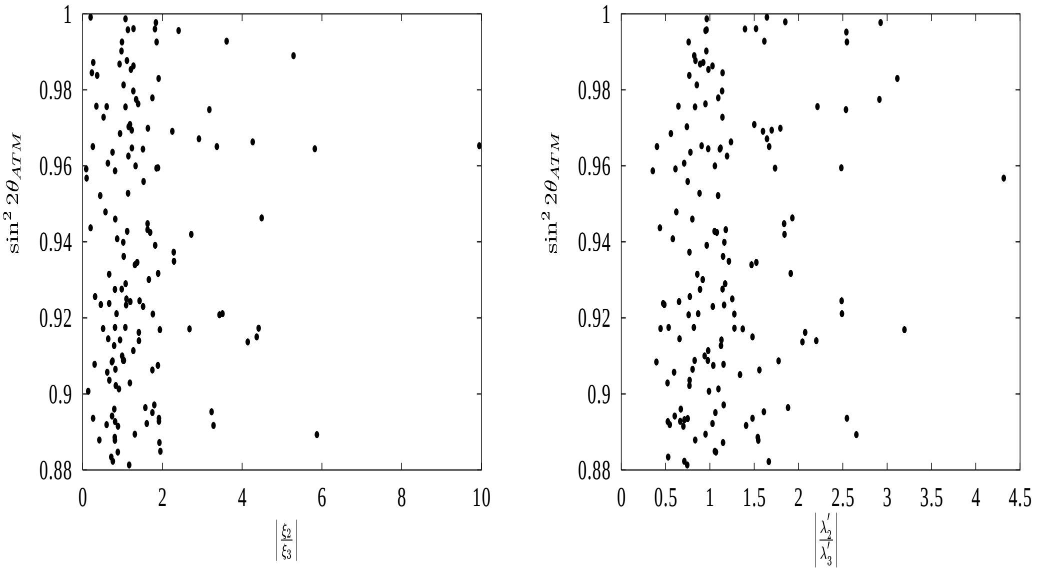


Figure 3: For solution points, large $\tan\beta, \sim 30 - 40$

- **Determination of LSP**

Neutralino mass

$$m_{\chi_1^0} = M_1 + \frac{M_Z^2 \sin^2\theta_W}{M_1^2 - \mu^2}(M_1 - \mu \sin 2\beta),$$

Since $\frac{M_1}{g_1^2} \simeq \frac{M_2}{g_3^2} \simeq \frac{M_3}{g_3^2} \simeq \frac{M_{1/2}}{g_{GUT}^2}$**,**

$$\therefore M_1 \simeq \frac{1}{2} M_{1/2}.$$

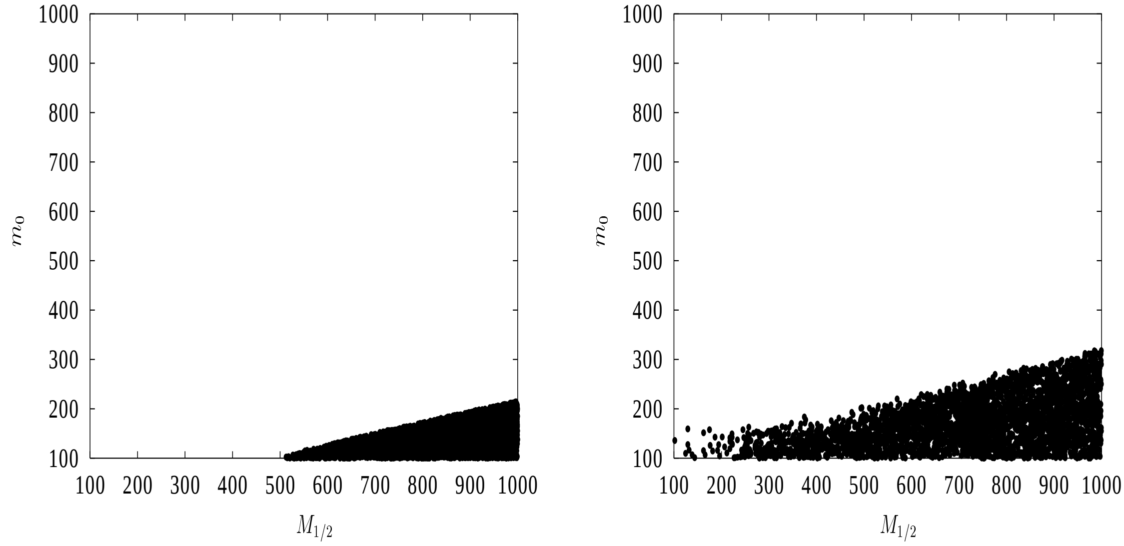
Stau Mass

The mass matrix

$$-\mathcal{L}_{mass} = \begin{pmatrix} \tilde{\tau}_L^* & \tilde{\tau}_R^* \end{pmatrix} \begin{pmatrix} m_{\tilde{\tau}_L}^2 & m_{\tilde{\tau}_{LR}}^2 \\ m_{\tilde{\tau}_{LR}}^2 & \tilde{\tau}_R \end{pmatrix} \begin{pmatrix} \tilde{\tau}_L \\ \tilde{\tau}_R \end{pmatrix}$$

where,

$$\begin{aligned} m_{\tilde{\tau}_L}^2 &= m_0^2 + \zeta_{\tilde{l}_L} M_{1/2}^2 + m_\tau^2 + M_Z^2 \cos 2\beta (T_{3L} - Q \sin^2\theta_W) \\ m_{\tilde{\tau}_R}^2 &= m_0^2 + \zeta_{\tilde{l}_R} M_{1/2}^2 + m_\tau^2 + M_Z^2 \cos 2\beta Q \sin^2\theta_W \\ m_{\tilde{\tau}_{LR}}^2 &= -m_\tau (A_\tau^* - \mu \tan\beta) \end{aligned}$$



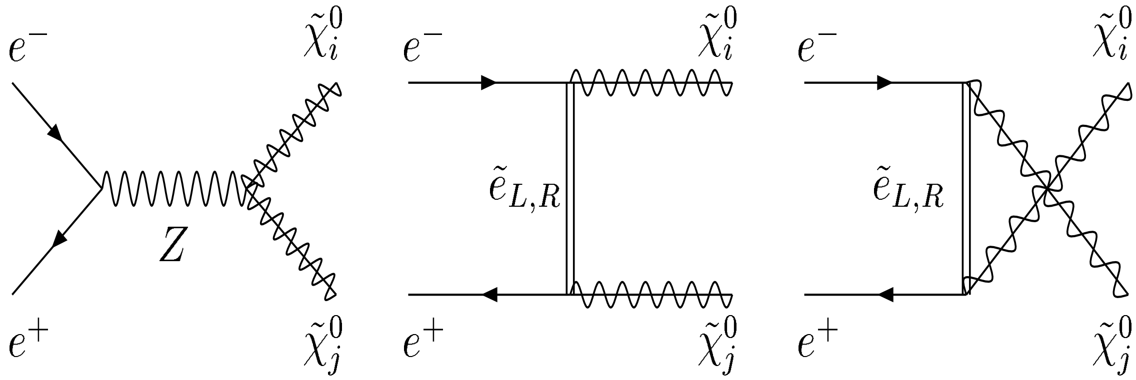
Stau lsp region ,balnk is neutralino lsp region for (a) $\tan\beta = 3$, (b) $\tan\beta = 30$, each

- **LSP pair production**

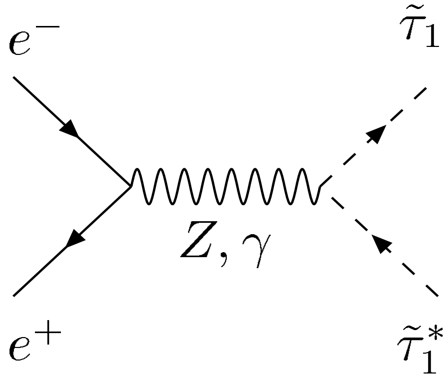
  – **In the next e^+e^- linear collider,**
  LSP can be pair-produced.

  – **Expected Luminosity** $\sim \mathcal{L} \sim 1000\text{fb}^{-1}$ **/yrs**

  – **CM energy** $\sim$ **over 1 TeV**



Diagrams for Neutralino pair production



Diagrams for Stau pair production

- **Decay of LSP**

  Stau decay

  Two modes: leptons and quarks

For not too large $\tan\beta$, decays to leptons almost from

$$\lambda_i L_i L_3 E_3^c$$

Then,

$$Br(e\nu) : Br(\mu\nu) : Br(\tau\nu) = |\lambda_1|^2 : |\lambda_2|^2 : |\lambda_1|^2 + |\lambda_2|^2$$

Decay to top and bottom quark from

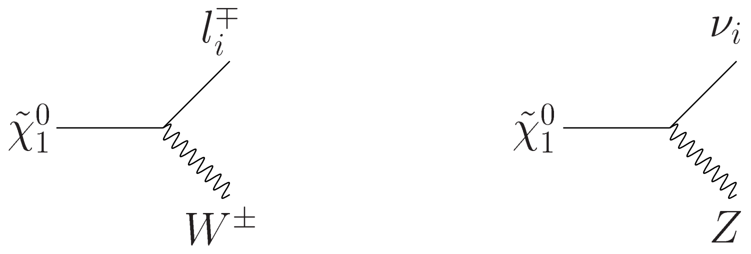
$$\lambda_i^{'} L_i Q_3 D_3^c$$

—**Suppresses in most cases**

—$\tilde{\tau}_1 \sim \tilde{\tau}_R$ **in most cases.**

Neutralino Decay

- **2-body decay**



and Decay rate,

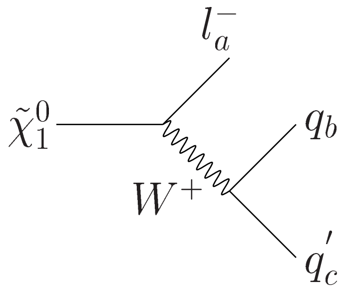
$$\Gamma(\nu_i Z) \propto |\xi_i|^2,$$
$$\Gamma(l_i W) \propto |\xi_i|^2$$

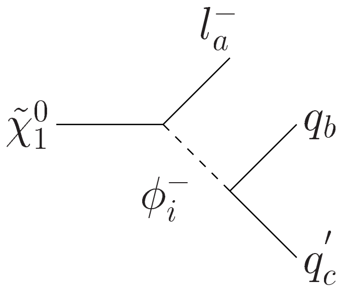
- **3 body decay**

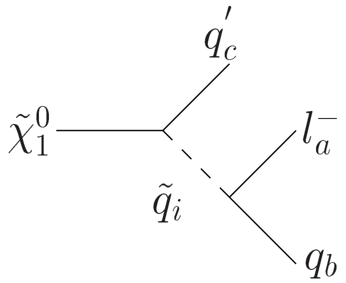
various decay modes

$$\nu\nu\nu\,, \quad \nu l_i^{\pm} l_j^{\mp}\,, \quad \nu q\bar{q}'\,, \quad l_i^{\pm} q q'\,.$$

$\underline{l_a^- q_b\ q_c^{'}}$





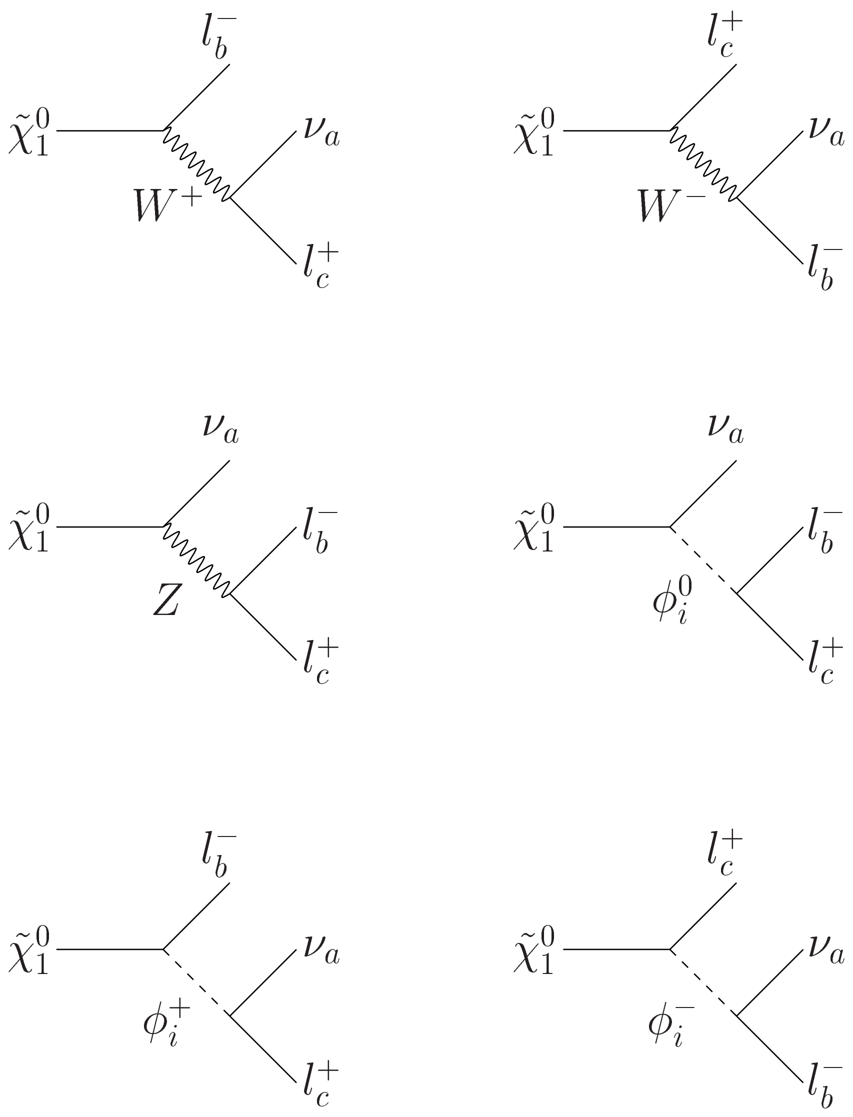


— W **exchange are dominant**

$$Br(ejj) : Br(\mu jj) : Br(\tau jj) = |\xi_1|^2 : |\xi_2|^2 : |\xi_3|^2$$

— **little information on Neutrino oscillation**

$\underline{\nu_a\ \ l_b^-\ \ l_c^+}$



For sufficiently small $\tan\beta$**,**
$\nu\ l_i^{\pm}\ \tau^{\mp}$ **Branching ratios** $\Longrightarrow$ λ_i **information.**

$$Br(\nu e^{\pm}\tau^{\mp}) : Br(\nu\mu^{\pm}\tau^{\mp}) : Br(\nu\tau^{\pm}\tau^{\mp})$$
$$\simeq |\lambda_1|^2 : |\lambda_2|^2 : |\lambda_1|^2 + |\lambda_2|^2$$

Bur for large $\tan\beta$**,**

$$h_\tau L_3 H_1 E_3^c$$

become important

$\Longrightarrow$ **Interference with** λ_i **contribution**

- **Results**
  - **Stau LSP decay rate and branching ratios**
  - **Neutralino LSP decay rate and branching ratios for 2 and 3-body decay**

	setA : Stau LSP		
	$\tan\beta = 5.15$	$\text{sgn}(\mu) = -1$	$\mu = -801.23$ GeV
	$A_0 = 39.47$GeV	$m_0 = 105.02$ GeV	$M_{1/2} = 671.02$ GeV
λ'_i	8.403×10^{-6}	-7.663×10^{-5}	-6.792×10^{-5}
λ_i	8.739×10^{-5}	-7.444×10^{-5}	0
ξ_i^0	-1.003×10^{-6}	-3.642×10^{-6}	-4.401×10^{-6}
ξ_i	-9.897×10^{-7}	-3.045×10^{-6}	-3.728×10^{-6}
η_i	1.011×10^{-6}	-1.313×10^{-5}	-1.192×10^{-5}
BR	e	μ	τ
$l_i\nu$	28.93 %	20.99 %	50.02 %
$\bar{t}\ b$		~ 0.066 %	
	$m_{\tilde{\tau}_1}$=278.59 GeV	$\Gamma =$	2.921×10^{-7} GeV
	$\sigma_{e^+e^-\to\tilde{\tau}_1\tilde{\tau}_1^*}$	$\simeq 1.450 \times 10^{-2}$ (Pb),	$\sqrt{s} = 1$ TeV

$(\Delta m_{31}^2,\ \Delta m_{21}^2) = (2.50 \times 10^{-3},\ 1.13 \times 10^{-4})$ eV^2

$(\sin^2 2\theta_{atm},\ \sin^2 2\theta_{sol},\ \sin^2 2\theta_{chooz}) = (0.98,\ 0.77,\ 0.03)$

The decay length $L \simeq 6.74 \times 10^{-8} cm$

Table 1: A trilinear model realizing the LMA solution. Here the couplings $\tilde{\lambda}'_i$ and $\tilde{\lambda}_i$ can be considered as input parameters defined at the weak scale.

		setB : Stau LSP	
	$\tan\beta = 37.95$	$\mathrm{sgn}(\mu) = -1$	$\mu = -460.12$ GeV
	$A_0 = 678.96$GeV	$m_0 = 233.36$ GeV	$M_{1/2} = 462.11$ GeV
λ'_i	1.528×10^{-6}	-1.481×10^{-5}	-5.835×10^{-6}
λ_i	3.646×10^{-6}	5.407×10^{-6}	0
ξ_i^0	-7.809×10^{-6}	-2.854×10^{-5}	-2.277×10^{-6}
ξ_i	-7.760×10^{-6}	-2.811×10^{-5}	-2.300×10^{-6}
η_i	8.171×10^{-6}	-3.379×10^{-5}	-1.729×10^{-5}
BR	e	μ	τ
$l_i\nu$	11.46 %	25.45 %	47.15 %
$\bar{t}\ b$		$\sim$ 15.95 %	
	$m_{\tilde{\tau}_1}$=188.71 GeV	$\Gamma =$	7.985×10^{-10} GeV
	$\sigma_{e^+e^- \to \tilde{\tau}_1\tilde{\tau}_1^*}$	$\simeq 1.964 \times 10^{-2}$ (Pb),	$\sqrt{s} = 1$ TeV

$(\Delta m^2_{31},\ \Delta m^2_{21}) = (2.48 \times 10^{-3},\ 4.61 \times 10^{-5})$ eV^2

$(\sin^2 2\theta_{atm},\ \sin^2 2\theta_{sol},\ \sin^2 2\theta_{chooz}) = (0.99,\ 0.74,\ 0.005)$

The decay length $L \simeq 2.47 \times 10^{-5} cm$

Table 2: Same as previous table

	setC : Neutralino LSP		
	$\tan\beta = 4.94$	$\mathrm{sgn}(\mu) = -1$	$\mu = -200.46$ GeV
	$A_0 = 38.93$GeV	$m_0 = 333.66$ GeV	$M_{1/2} = 160$ GeV
λ'_i	-9.326×10^{-9}	-7.811×10^{-5}	-7.560×10^{-5}
λ_i	-5.628×10^{-5}	-7.345×10^{-5}	0
ξ_i^0	-1.234×10^{-6}	3.247×10^{-7}	1.880×10^{-6}
ξ_i	-1.211×10^{-6}	2.749×10^{-7}	1.831×10^{-6}
η_i	-2.007×10^{-6}	-1.169×10^{-5}	-8.742×10^{-6}
BR	e	μ	τ
νjj		47.01 %	
$l_i^\pm jj$	3.88 $\times 10^{-2}$ %	2.00 $\times 10^{-3}$%	8.87 $\times 10^{-2}$%
$\nu l_i^\pm l_3^\mp$	9.76 %	16.60 %	26.39 %
	$m_{\tilde{\chi}_1^0}$=59.37 GeV		$\Gamma = 7.137 \times 10^{-15}$ GeV
	$\sigma_{e^+e^-\to\tilde{\chi}_1^0\tilde{\chi}_1^0} \simeq 4.897 \times 10^{-2}$ (Pb),		$\sqrt{s} = 1$ TeV

$(\Delta m^2_{31},\ \Delta m^2_{21}) = (2.51 \times 10^{-3},\ 9.64 \times 10^{-5})$ eV^2

$(\sin^2 2\theta_{atm},\ \sin^2 2\theta_{sol},\ \sin^2 2\theta_{chooz}) = (0.98,\ 0.99,\ 0.008)$

The decay length $L \simeq 2.76cm$

Table 3: Same as previous table.

	setD : Neutralino LSP		
	$\tan\beta = 33.47$	$\mathrm{sgn}(\mu) = -1$	$\mu = -172.87$ GeV
	$A_0 = 269.49$GeV	$m_0 = 632.75$ GeV	$M_{1/2} = 198.60$ GeV
λ_i'	-1.146×10^{-5}	-1.036×10^{-4}	-9.809×10^{-5}
λ_i	1.092×10^{-4}	-5.077×10^{-5}	0
ξ_i^0	-8.354×10^{-6}	-1.536×10^{-5}	-1.149×10^{-5}
ξ_i	-8.372×10^{-6}	-1.518×10^{-5}	-1.143×10^{-5}
η_i	5.520×10^{-5}	-2.148×10^{-4}	-1.761×10^{-4}
BR	e	μ	τ
νjj		65.08%	
$l_i^{\pm} jj$	0.16 %	0.52%	0.31%
$\nu l_i^{\pm} l_3^{\mp}$	11.95×10^{-2} %	3.72 %	17.76 %
	$m_{\tilde{\chi}_1^0}$= 77.01 GeV	$\Gamma =$	1.002×10^{-14} GeV
	$\sigma_{e^+e^- \to \tilde{\chi}_1^0 \tilde{\chi}_1^0}$	$\simeq 2.22\times10^{-2}$ (Pb),	$\sqrt{s} = 1$ TeV

$(\Delta m_{31}^2,\ \Delta m_{21}^2) = (2.50 \times 10^{-3},\ 3.06 \times 10^{-5})$ eV^2

$(\sin^2 2\theta_{atm},\ \sin^2 2\theta_{sol},\ \sin^2 2\theta_{chooz}) = (0.96,\ 0.87,\ 0.07)$

The decay length $L \simeq 1.97cm$

Table 4: Same as previous table.

	setE : Neutralino LSP		
	$\tan\beta = 4.05$	$\mathrm{sgn}(\mu) = -1$	$\mu = -535.92$ GeV
	$A_0 = 14.28$GeV	$m_0 = 113.88$ GeV	$M_{1/2} = 444.57$ GeV
λ'_i	-9.069×10^{-9}	-1.396×10^{-4}	-1.842×10^{-4}
λ_i	-7.966×10^{-5}	-7.995×10^{-5}	0
ξ_i^0	1.274×0^{-6}	2.896×10^{-6}	2.138×10^{-6}
ξ_i	1.212×10^{-6}	2.976×10^{-6}	2.409×10^{-6}
η_i	4.038×10^{-7}	-1.305×10^{-5}	-1.768×10^{-5}
BR	e	μ	τ
νjj		14.77%	
$l_i^{\pm} jj$	$6.36{\times}10^{-2}$ %	$3.84\ {\times}10^{-1}$%	$2.51\ {\times}10^{-1}$%
$\nu l_i^{\pm} l_3^{\mp}$	20.96 %	21.186 %	42.09 %
	$m_{\tilde{\chi}_1^0}$=195.00 GeV	$\Gamma =$	4.744×10^{-11} GeV
	$\sigma_{e^+e^- \to \tilde{\chi}_1^0 \tilde{\chi}_1^0}$	$\simeq 0.197$ (Pb),	$\sqrt{s} = 1$ TeV

$(\Delta m_{31}^2,\ \Delta m_{21}^2) = (2.50 \times 10^{-3},\ 6.81 \times 10^{-5})\ \mathrm{eV}^2$

$(\sin^2 2\theta_{atm},\ \sin^2 2\theta_{sol},\ \sin^2 2\theta_{chooz}) = (0.95,\ 0.96,\ 0.007)$

The decay length $L \simeq 4.15 \times 10^{-4} cm$

Table 5: Same as previous table.

	setF : Neutralino LSP		
	$\tan\beta = 35.87$	$\mathrm{sgn}(\mu) = -1$	$\mu = -265.70$ GeV
	$A_0 = 436.62$GeV	$m_0 = 949.53$ GeV	$M_{1/2} = 359.97$ GeV
λ'_i	-2.418×10^{-9}	-8.341×10^{-5}	-1.376×10^{-4}
λ_i	-8.548×10^{-5}	-8.177×10^{-5}	0
ξ_i^0	-2.256×10^{-7}	-3.095×10^{-5}	-4.637×10^{-5}
ξ_i	-2.055×10^{-7}	-3.070×10^{-5}	-4.608×10^{-5}
η_i	-6.607×10^{-5}	-2.259×10^{-4}	-2.818×10^{-4}
BR	e	μ	τ
νjj		31.53 %	
$l_i^{\pm} jj$	4.79×10^{-4} %	10.69 %	24.95 %
$\nu l_i^{\pm} l_3^{\mp}$	4.64 %	6.48 %	6.64 %
	$m_{\tilde{\chi}_1^0}$=152.78 GeV	$\Gamma =$	8.807×10^{-13} GeV
	$\sigma_{e^+e^-\to\tilde{\chi}_1^0\tilde{\chi}_1^0}$	$\simeq 1.323\times10^{-2}$ (Pb),	$\sqrt{s} = 1$ TeV

$(\Delta m_{31}^2,\ \Delta m_{21}^2) = (2.50 \times 10^{-3},\ 6.21 \times 10^{-5})\ \mathrm{eV}^2$

$(\sin^2 2\theta_{atm},\ \sin^2 2\theta_{sol},\ \sin^2 2\theta_{chooz}) = (0.93,\ 0.94,\ 0.115)$

The decay length $L \simeq 2.24 \times 10^{-2} cm$

Table 6: Same as previous table.

Conclusion

- **Neutrino mass can be described in R-parity violation scheme.**
- **Solution points**

  — **some cancellation in** ξ_i

  — ξ_i **cannot determine the neutrino property**
- **Strong correlations between**

$$\lambda_1/\lambda_2 \;\; \& \;\; \text{Solar neutrino mixing angle}$$
$$\lambda_2^{'}/\lambda_3^{'} \;\; \& \;\; \text{Atmospheric neutrino mixing angle}$$

  $\Longrightarrow$ **can give some constraints**
- **Stau Decay**

  $\Longrightarrow$ λ_i **information from branching fraction**
- **Neutralino Decay**

  — $Br(l_i jj) \longrightarrow |\xi_i|$

  — $Br(\nu\ l_i^{\pm}\ \tau^{\mp}) \longrightarrow \lambda_i$

  but for large $\tan\beta$ $\longrightarrow$ **Impossible**
- **We can give some parameter region which exclude the Model for small** $\tan\beta$**.**