# R–parity violating sneutrino decays

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* Based on the article: *R–parity Violating Sneutrino Decays*,

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# Outline of the Talk

- Motivation

  Neutrino oscillation experiments tell us neutrinos are massive. R–parity breaking models provide a possible explanation to the origin of neutrino masses.

- Model

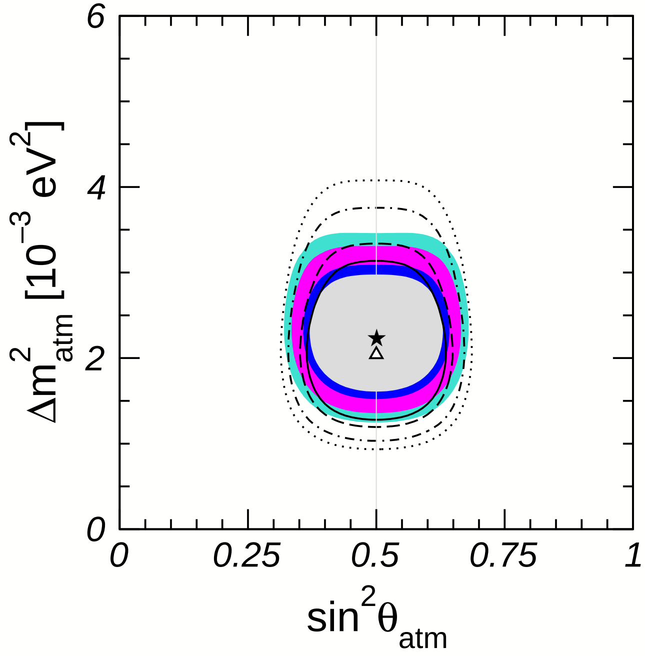
  - R–parity violation via lepton number non–conserving interactions.
  - Sneutrino is the LSP: Once R–parity is violated any sparticle can be the LSP. Moreover from the phenomenological point of view there is no reason to prefer the neutralino over the sneutrino.

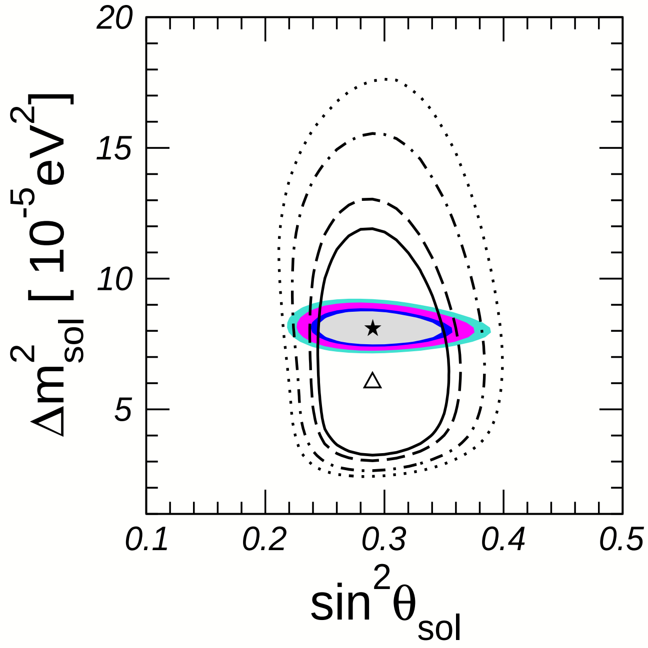
- Results.
- Conclusions.

# Neutrino masses

- SuperKamiokande – SNO – KamLAND:

Neutrino oscillations ⇒ massive neutrinos !!.



# The Model

In the basis where the lepton mass matrix is already diagonal

$$W_{\not{L}} = \varepsilon_{ab}\left[\frac{1}{2}\lambda_{ijk}\widehat{L}_i^a\widehat{L}_j^b\widehat{E}_k + \lambda'_{ijk}\widehat{L}_i^a\widehat{Q}_j^b\widehat{D}_k + \epsilon_i\widehat{L}_i^a\widehat{H}_u^b\right]$$

The soft BRpV SUSY breaking potential

$$V_{\text{soft}}^{\text{BRpV}} = -\varepsilon_{ab}B_i\epsilon_i\widetilde{L}_i^a H_u^b$$

induce sneutrino vevs, $\langle\nu_i\rangle = v_i$.

Huge number of parameters:

$\Rightarrow$ 9 $\lambda_{ijk}$, 27 $\lambda'_{ijk}$, 3 $\epsilon_i$ and 3 $B_i\epsilon_i$.

Are these 42 parameters physical ?

# The Bilinears

In the superpotential:

$$W_{\text{bilinear}} = -\varepsilon_{ab}\left(\mu \widehat{H}_d^a \widehat{H}_u^b - \epsilon_i \widehat{L}_i^a \widehat{H}_u^b\right)$$

$\widehat{L}'_\beta = R_{\beta\alpha}\widehat{L}_\alpha$ with $\widehat{L}_\alpha = (\widehat{H}_d, \widehat{L}_1, \widehat{L}_2, \widehat{L}_3)$

$\Rightarrow \epsilon_i$ rotated away.

- Only in the case $B = B_i$ and $m^2_{H_d} = m^2_{L_i} \Rightarrow$ all BRpV rotated away. However this condition is Not stable under RGE running $\Rightarrow$ There are 39 physical parameters

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Remark

$\widehat{L}'_\beta \Rightarrow$ trilinear: that follow the hierarchy of $d$-quarks and $\ell$ masses

$$\lambda'_{i33} \sim (\epsilon_i/\mu)h_b$$

# BRpV and $\nu$–masses I

BRpV $\Rightarrow$ Neutralino–neutrino mixing

Neutralino–neutrino mass matrix ($7 \times 7$)

$$\mathbf{M}_N = \begin{pmatrix} \mathbf{M}_{\chi^0} & \mathbf{m}^T \\ \mathbf{m} & \mathbf{0} \end{pmatrix}$$

$\mathbf{M}_{\chi^0}$ is the neutralino mass matrix and $\mathbf{m}$ is given by

$$\mathbf{m} = \begin{pmatrix} -\frac{1}{2}g'v_1 & \frac{1}{2}gv_1 & 0 & \epsilon_1 \\ -\frac{1}{2}g'v_2 & \frac{1}{2}gv_2 & 0 & \epsilon_2 \\ -\frac{1}{2}g'v_3 & \frac{1}{2}gv_3 & 0 & \epsilon_3 \end{pmatrix}$$

# BRpV and $\nu$–masses II

Because of smallness of measured neutrino masses the mixing is small and hence $\mathbf{M_N}$ can be diagonalized perturbatively

$\widehat{\mathbf{M}}_N = \text{diag}(\mathbf{M}_{\chi^0}, \mathbf{m}_{\text{eff}})$

$$\mathbf{m}_{\text{eff}} = \frac{(M_1 g^2 + M_2 {g'}^2)}{4\ \det(\mathbf{M}_{\chi^0})} \begin{pmatrix} \Lambda_e^2 & \Lambda_e\Lambda_\mu & \Lambda_e\Lambda_\tau \\ \Lambda_e\Lambda_\mu & \Lambda_\mu^2 & \Lambda_\mu\Lambda_\tau \\ \Lambda_e\Lambda_\tau & \Lambda_\mu\Lambda_\tau & \Lambda_\tau^2 \end{pmatrix}$$

$\Lambda_i = \mu v_i + v_d \epsilon_i$.

$$\tan\theta_{13} = -\frac{\Lambda_e}{\sqrt{\Lambda_\mu^2 + \Lambda_\tau^2}} \qquad \tan\theta_{23} = -\frac{\Lambda_\mu}{\Lambda_\tau}$$

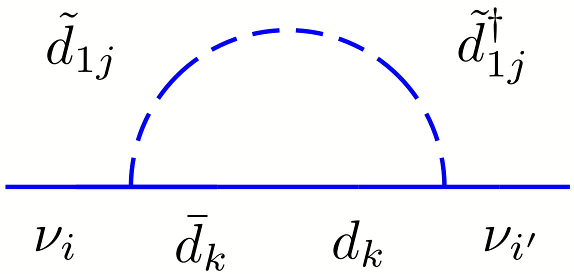
So at tree level one neutrino acquire mass.

# TRpV $\nu$–masses

Trilinears $\lambda$ and $\lambda'$ contribute to $\nu$ mass matrix

$$m^{1-\text{loop}} = m^{\lambda'} + m^{\lambda}$$

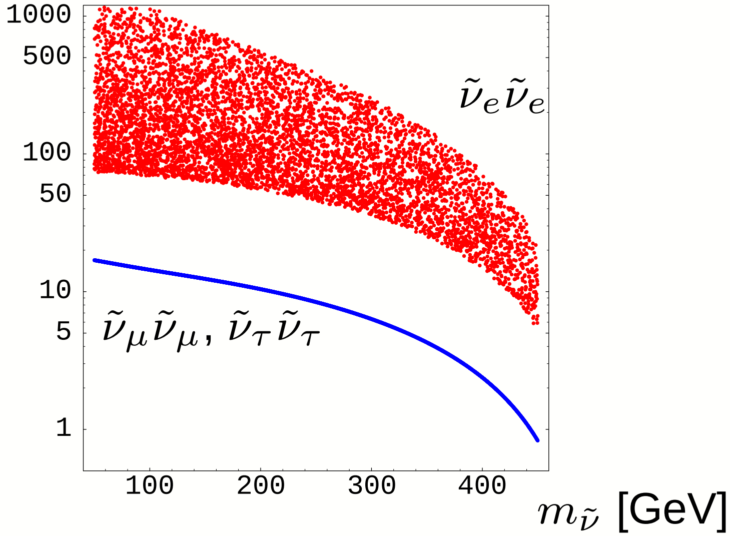
$$m^{\lambda'} =$$



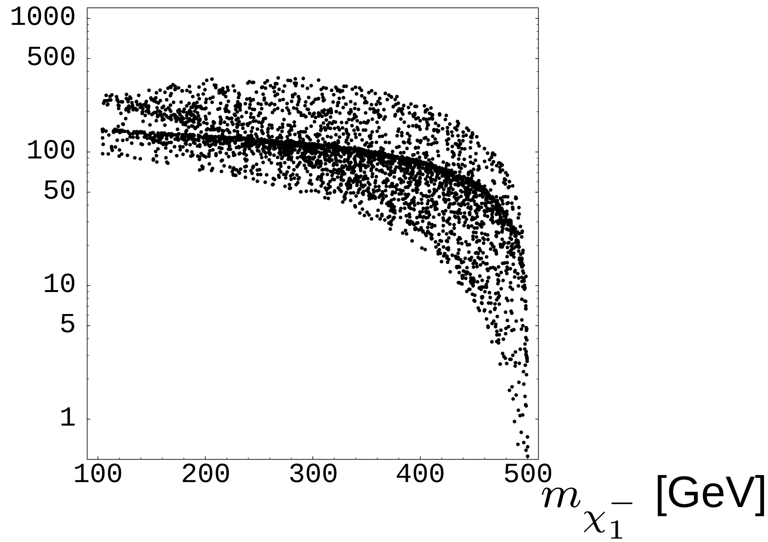

$$m^{\lambda(\lambda')}_{ii'} \sim \lambda^{(\prime)}_{ijk}\lambda^{(\prime)}_{i'kj}\left[m_k \sin 2\theta_j \ln\left(\frac{m^2_{2j}}{m^2_{1j}}\right)\right]$$

# $\widetilde{\nu}$ and $\chi^+$ production

$\sigma(e^+e^- \to \tilde{\nu}_i\tilde{\nu}_i)$ [fb]




$\sigma(e^+e^- \to \chi_1^+\chi_1^-)$ [fb]




✓ $e^+e^-$ collider with unpolarized beams and $\sqrt{s} = 1$ TeV $\Rightarrow$ $\mathcal{L} = 1$ ab$^{-1}$ at least $10^4$ sneutrino and chargino pairs are produced.

✓ $m^2_{L_i} \simeq m^2_L$ $\Rightarrow$ Degenerate sneutrinos. So, how can the $\widetilde{\nu}_\ell$ flavour be identified ?

✓ Chargino decays $\Rightarrow$ flavour identification: $\chi_1^+ \to \ell^+_\alpha \tilde{\nu}_{\ell_\alpha} \to \ell^+_\alpha \ell^+_\beta \ell^-_\gamma$

# Scenarios

We have considered three extreme scenarios constructed with the following assumptions:

- **Scenario I**

  Neutrino mass matrix dominated by BRpV parameters:

  - Atmospheric scale: Tree level.
  - Solar scale: induced by loops.

- **Scenario II**

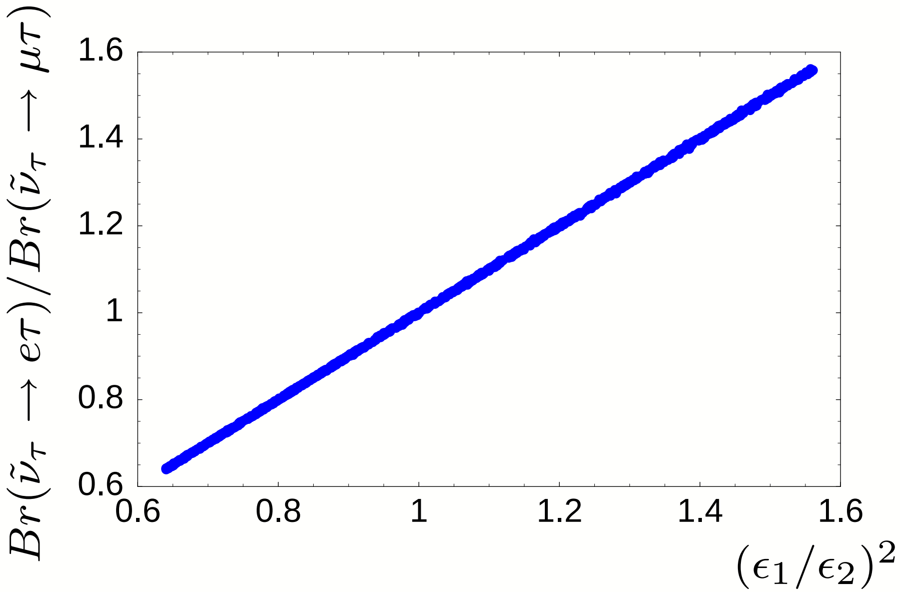
  $\lambda'_{ijk} = 0$ (which implies few hadronic jets).

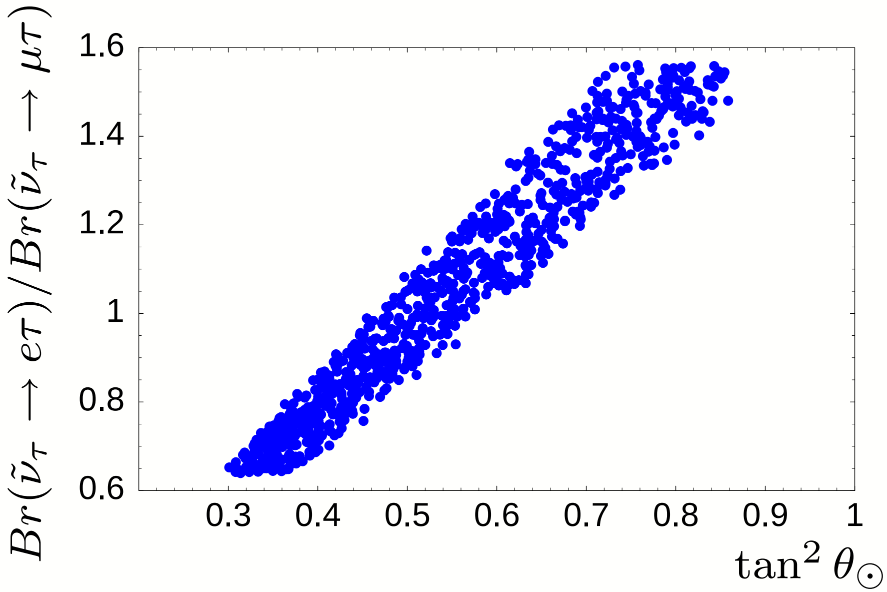
  - Atmospheric scale: tree level BRpV.
  - Solar scale: scalar loops $\lambda_{ijk}$ (These trilinears do not follow the hierarchy of the trilinears induced by the basis rotation).

- **Scenario III**

  Neutrino mass matrix dominated by TRpV parameters and $\langle\tilde{\nu}_i\rangle = v_i \approx 0$

# Scenario I

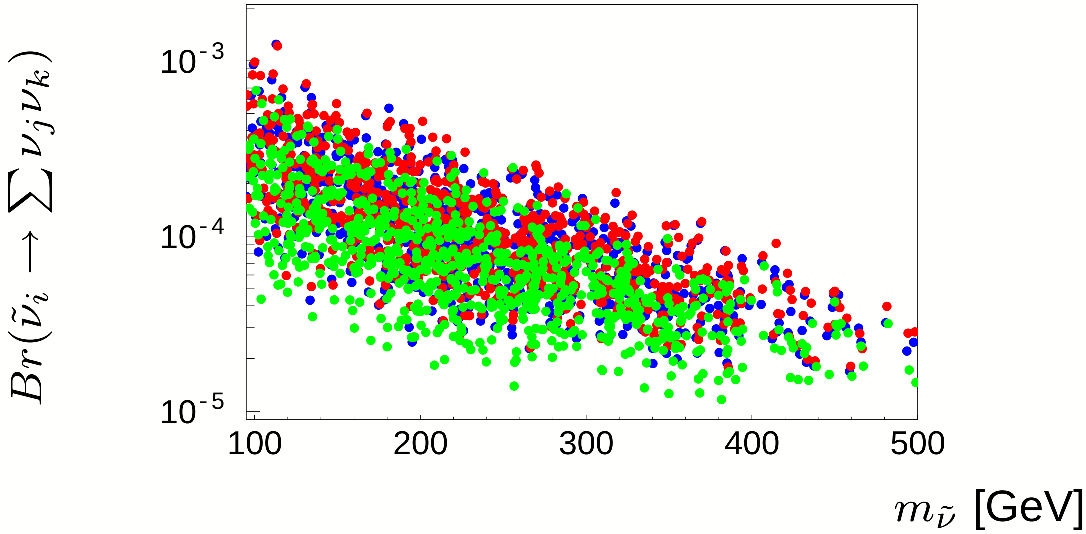


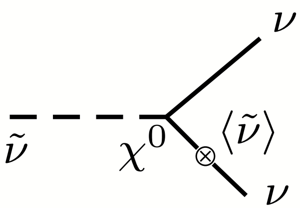




$$\Gamma(\tilde{\nu}_i \to \ell_j \ell_k) \sim \lambda^2_{ijk} \quad \text{and} \quad \Gamma(\tilde{\nu}_i \to d_j \bar{d}_k) \sim \lambda'^2_{ijk}$$

- ✔ $\lambda_{ijk}$ and $\lambda'_{ijk}$ propotional to $h_\ell$ and $h_d$ respectively $\Rightarrow$ sneutrino observables related to these Yukawas
- ✔ Ratios of branching ratios independent of all parameters *e.g.* $Br(\tilde{\nu}_{e,\mu} \to \tau\tau)/Br(\tilde{\nu}_{e,\mu} \to bb) \simeq h^2_\tau/(3h_b(1+\Delta_{\text{QCD}}))$
- ✔ Measurement of ratios of Branching ratios allow the measurement of BRpV parameters *e.g.* $Br(\tilde{\nu}_\tau \to e\tau)/Br(\tilde{\nu}_\tau \to \mu\tau) = \epsilon^2_1/\epsilon^2_2$

# Scenario I–Invisible decay

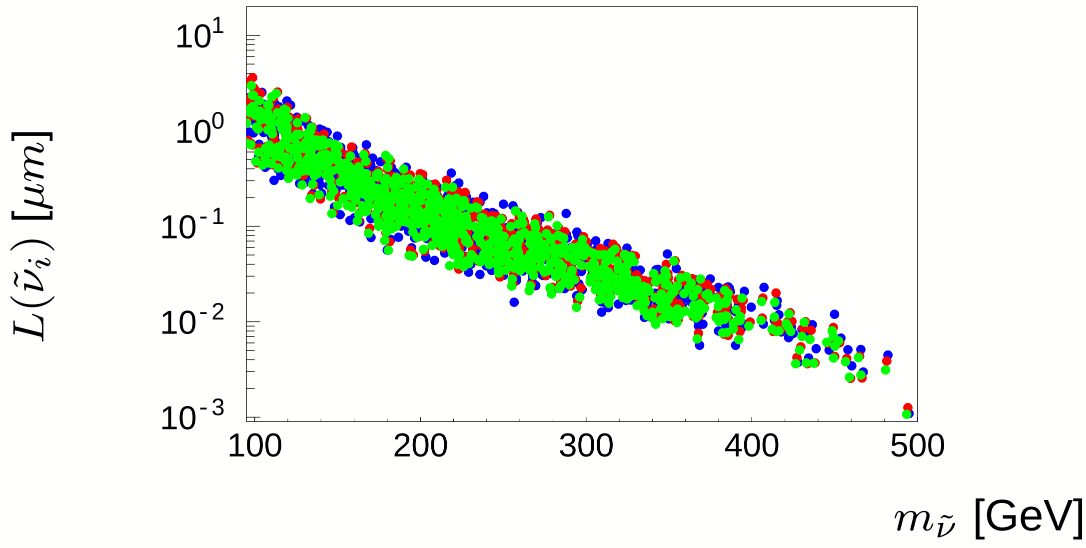



$\Rightarrow \quad \tilde{\nu} \to \nu\nu \quad \Rightarrow$ Invisible decays evidence $\langle\tilde{\nu}\rangle$

- $Br(\tilde{\nu}_i \to \sum \nu_j \nu_k) \geqslant 10^{-5} \Rightarrow$ some invisible sneutrino decays are expected

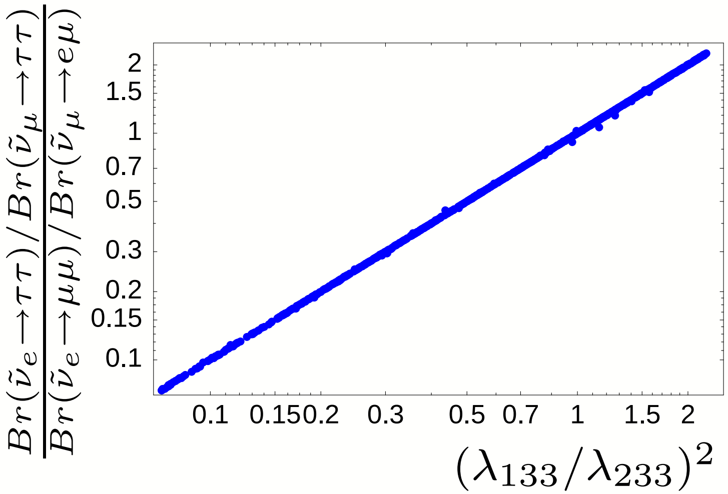
# Scenario I–Decay length

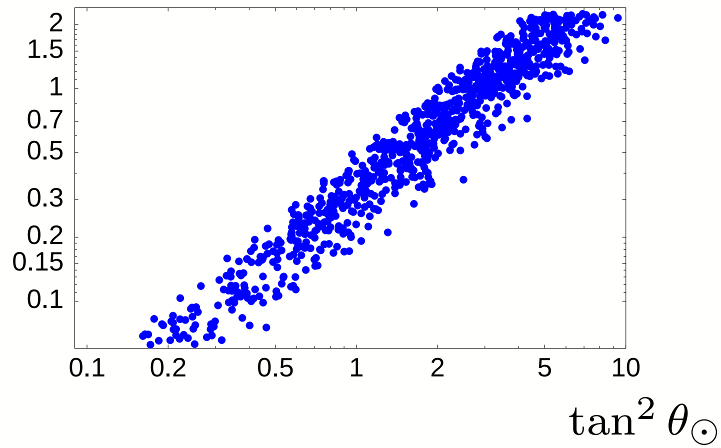



- For $\sqrt{s} = 1$ TeV and due to the smallness of $\Delta m^2 \;\Rightarrow$ $L = \frac{\hbar c}{\Gamma}\sqrt{\frac{s}{4m^2} - 1} < 10\mu$m. Future colliders sensitivities $\sim$ 10 $\mu$m $\Rightarrow$ absolute values of R-parity violating parameters can not be measured.

- Turning the argument: $L > 10\mu$m would rule out R-parity violation as the dominant source of $m_\nu$

# Scenario II



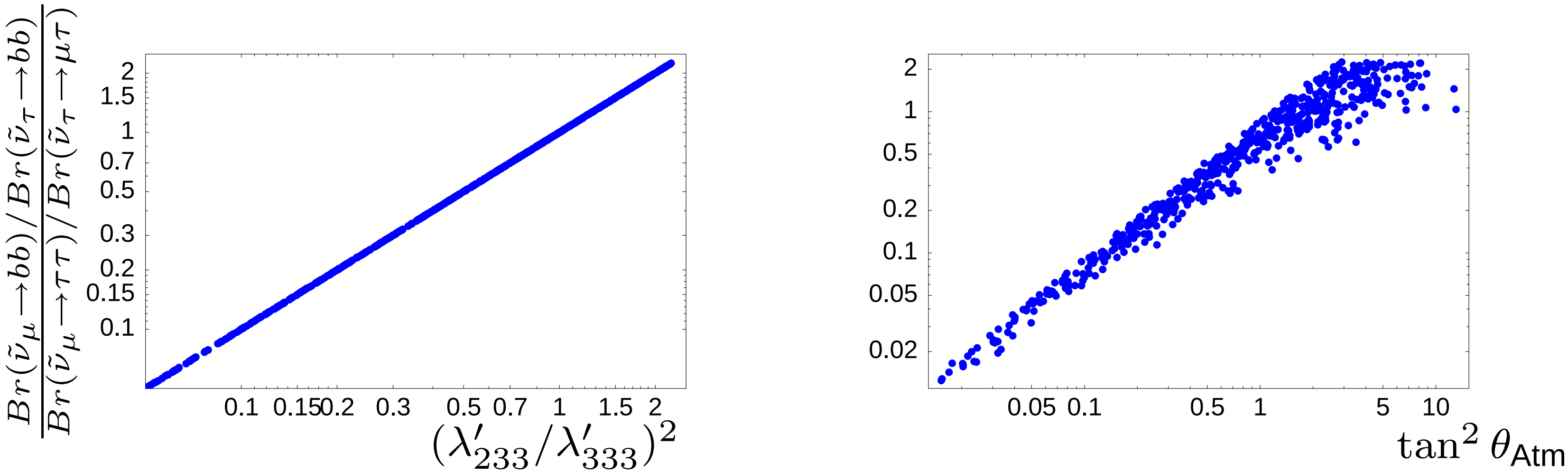

- Final states mainly leptonic.
- In this case measurement of R–parity breaking parameters involve measurements of ratios of ratios of branching ratios *e.g.*

$$Br(\tilde{\nu}_e \to \tau\tau) \simeq c_{\tilde{\nu}_e}\lambda^2_{133}\ , \quad Br(\tilde{\nu}_\mu \to \tau\tau) \simeq c_{\tilde{\nu}_\mu}\lambda^2_{233}$$
$$Br(\tilde{\nu}_e \to \mu\mu) \simeq c_{\tilde{\nu}_e}\lambda^2_{122}\ , \quad Br(\tilde{\nu}_\mu \to e\mu) \simeq c_{\tilde{\nu}_\mu}\lambda^2_{122}$$

$$\Rightarrow \quad \frac{Br(\tilde{\nu}_e\to\tau\tau)/Br(\tilde{\nu}_\mu\to\tau\tau)}{Br(\tilde{\nu}_e\to\mu\mu)/Br(\tilde{\nu}_\mu\to e\mu)} = \left(\frac{\lambda_{133}}{\lambda_{233}}\right)^2$$

- Decay lengths as well as $\tilde{\nu}$ invisible decays are smaller than in scenario I.

# Scenario III




- As in scenario II measurement of R–parity breaking parameters imply the measurement of ratios of ratios of branching ratios *e.g.*

$$\frac{Br(\tilde{\nu}_e \to \tau\tau)/Br(\tilde{\nu}_\mu \to \tau\tau)}{Br(\tilde{\nu}_e \to \mu\mu)/Br(\tilde{\nu}_\mu \to e\mu)} = \left(\frac{\lambda_{133}}{\lambda_{233}}\right)^2 \text{ and } \frac{Br(\tilde{\nu}_\mu \to bb)/Br(\tilde{\nu}_\tau \to bb)}{Br(\tilde{\nu}_\mu \to \tau\tau)/Br(\tilde{\nu}_\tau \to \mu\tau)} = \left(\frac{\lambda'_{233}}{\lambda'_{333}}\right)^2$$

- Assuming that $\lambda_{i33}$ and $\lambda'_{233}$ and $\lambda'_{333}$ are somewhat larger than the other $\lambda_{ijk}$ and $\lambda'_{ijk}$ it is possible to make a consistency check with the solar and atmospheric angle.

- Decay lengths are smaller than in scenario II.

# Conclusions

- We have considered the general R–parity violating model and we have found that if sneutrino is the LSP:
  - There are different scenarios where, despite the large number of R–parity breaking parameters, sneutrino decay patterns can be used to obtain information about the relative importance of these parameters.
  - Sneutrino decay patterns are correlated with $\tan^2\theta_\odot$ or $\tan^2\theta_{\text{Atm}}$. These correlations can be used to cross check each scenario.
  - Sneutrino vevs, induced by BRpV terms, can be probed by measuring the branching ratio of sneutrinos to invisible final states but we expect these branchings to be small.
  - Sneutrino decay lengths are small ($< 10\ \mu$m). This information can be used to rule out R–parity violation as the source of $m_\nu$.