Neutrino masses and lepton flavour violation in supersymmetric type-I seesaw

A. Villanova del Moral

LUPM, Laboratoire Univers et Particules de Montpellier

In collaboration with: M. Hirsch, W. Porod, J. C. Romão and J. W. Valle

Phys. Rev. D **78** 013006 (2008)

INTRODUCTION

Motivation

- Neutrino data:
  - ⇒ Neutrinos mix ⇒ Lepton Flavor Violation exists
  - ⇒ Neutrinos have very small masses
- What is the mechanism of neutrino mass generation? SUSY type-I seesaw?
  - ⇒ Smallness of neutrino masses due to a suppression by a very large mass scale
- Framework of mSUGRA: LFV emerges only from neutrino Yukawas
  - ⇒ **Neutrino parameters are related to LFV processes**

SUSY type-I seesaw

- Particle content:

$$\text{MSSM} + 3\ \widehat{N}^c_i$$

- Leptonic superpotential:

$$W = Y_e^{ji}\widehat{L}_i\widehat{H}_d\widehat{E}^c_j + Y_\nu^{ji}\widehat{L}_i\widehat{H}_u\widehat{N}^c_j + M_i\widehat{N}^c_i\widehat{N}^c_i.$$

- Effective neutrino mass matrix:

$$m_\nu = -\frac{v_U^2}{2} Y_\nu{}^T \cdot \frac{1}{M_R} \cdot Y_\nu \qquad \Rightarrow \text{Diagonalized by:} \quad \hat{m}_\nu = U^T \cdot m_\nu \cdot U$$

- The Yukawa can be expressed in terms of neutrino parameters:

$$Y_\nu = \sqrt{2}\frac{i}{v_U}\sqrt{\hat{M}_R}R\sqrt{\hat{m}_\nu}U^\dagger.$$

- **Neutrino parameters:**

$$\hat{m}_\nu \equiv \mathrm{diag}(m_1, m_2, m_3)\,, \quad U_{ij}\,, \quad \hat{m}_R \equiv \mathrm{diag}(M_1, M_2, M_3)\,, \quad R_{ij} = \delta_{ij}$$

Lepton Flavor Violation in mSUGRA

- Lepton Flavour Violating processes originate from non-zero off-diagonal elements in the slepton mass matrix

$$\mathrm{BR}_{ij} \propto |(M^2_{\tilde{l}})_{ij}|^2$$

- In mSUGRA, off-diagonal elements in the left-slepton mass matrix are

$$(M^2_{\tilde{l}})_{ij} = (\Delta M^2_{\tilde{L}})_{ij} = -\frac{1}{8\pi^2}(3m_0^2 + A_0^2)(Y_\nu^\dagger L Y_\nu)_{ij}$$

⇒ LFV processes are related to neutrino parameters

$$\mathrm{BR}_{ij} \propto \left|(Y_\nu{}^\dagger L Y_\nu)_{ij}\right|^2 \propto \left|U_{i\alpha}U^*_{j\beta}\sqrt{m_\alpha}\sqrt{m_\beta}R^*_{k\alpha}R_{k\beta}M_k \log\left(\frac{M_X}{M_k}\right)\right|^2$$

- We use **ratios of LFV branching ratios** to minimize the dependence on SUSY parameters:

$$\frac{Br(\tilde{\tau}_2 \to e + \chi^0_1)}{Br(\tilde{\tau}_2 \to \mu + \chi^0_1)} \simeq \left(\frac{(\Delta M^2_{\tilde{L}})_{13}}{(\Delta M^2_{\tilde{L}})_{23}}\right)^2 \equiv (r^{13}_{23})^2$$

Degenerate M_i

- **Tribimaximal (TBM) mixing**

$$U = U_{\mathrm{TBM}} = \begin{pmatrix} \sqrt{\frac{2}{3}} & \frac{1}{\sqrt{3}} & 0 \\ -\frac{1}{\sqrt{6}} & \frac{1}{\sqrt{3}} & \frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{6}} & -\frac{1}{\sqrt{3}} & \frac{1}{\sqrt{2}} \end{pmatrix}$$

⇒ Ratios of off-diagonal elements

$$r^{12}_{13} = 1$$

$$r^{12}_{23} = r^{13}_{23} = \frac{2(m_2 - m_1)}{|3m_3 - 2m_2 - m_1|}$$

- **Strict Normal Hierarchy (SNH)** $[m_1 = 0]$

$$r^{12}_{23} = r^{13}_{23} = \frac{2\sqrt{\alpha}}{3\sqrt{1+\alpha} - 2\sqrt{\alpha}} \qquad \Rightarrow \text{B.F.P.: } (r^{13}_{23})^2 = 1.7 \times 10^{-2}$$

where $\alpha \equiv \Delta m^2_{\mathrm{S}}/|\Delta m^2_{\mathrm{A}}|$

- **Strict Inverse Hierarchy (SIH)** $[m_3 = 0]$

$$r^{12}_{23} = r^{13}_{23} = \frac{2(1 - \sqrt{1-\alpha})}{2 + \sqrt{1-\alpha}} \qquad \Rightarrow \text{B.F.P.: } (r^{13}_{23})^2 = 1.1 \times 10^{-4}$$

- **Quasidegenerate neutrinos (QD)** $[m_i \ll \sqrt{\Delta m^2_{\mathrm{A}}}]$

$$r^{12}_{23} = r^{13}_{23} = \frac{2\alpha}{3\sigma_{\mathrm{A}} + \alpha} \qquad \Rightarrow \text{B.F.P.: } \begin{cases} (r^{13}_{23})^2 = 4.4 \times 10^{-4} & \text{for QDNH} \\ (r^{13}_{23})^2 = 4.6 \times 10^{-4} & \text{for QDIH} \end{cases}$$

$$\text{where } \sigma_{\mathrm{A}} \equiv \Delta m^2_{\mathrm{A}}/|\Delta m^2_{\mathrm{A}}| = \begin{cases} +1 & \text{for QDNH} \\ -1 & \text{for QDIH} \end{cases}$$

- **Non-tribimaximal mixing but** $s_{13} = 0$

$$r^{12}_{13} = \frac{c_{23}}{s_{23}}$$

$$r^{12}_{23} = \frac{c_{23}}{s_{23}} r^{13}_{23} = \frac{1}{s_{23}} s_{12}c_{12}\frac{m_2 - m_1}{|m_3 - c^2_{12}m_2 - s^2_{12}m_1|}$$

Dominant M_1

- **Non-tribimaximal mixing but** $s_{13} = 0$

$$r^{12}_{13} = \frac{c_{23}}{s_{23}} \qquad r^{12}_{23} = \frac{c_{12}}{s_{12}s_{23}} \qquad r^{13}_{23} = \frac{c_{12}}{s_{12}c_{23}} \qquad \Rightarrow \text{TBM: } (r^{13}_{23})^2 = 4$$

Dominant M_2

- **Non-tribimaximal mixing but** $s_{13} = 0$

$$r^{12}_{13} = \frac{c_{23}}{s_{23}} \qquad r^{12}_{23} = \frac{s_{12}}{c_{12}s_{23}} \qquad r^{13}_{23} = \frac{s_{12}}{c_{12}c_{23}} \qquad \Rightarrow \text{TBM: } (r^{13}_{23})^2 = 1$$

Dominant M_3

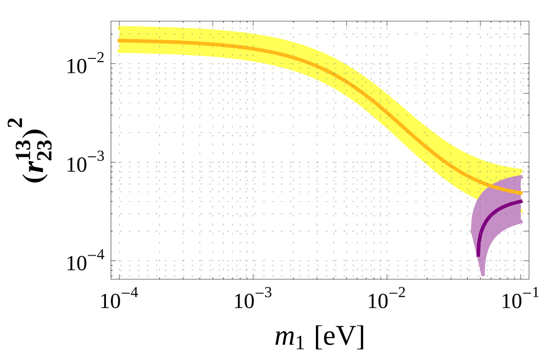
- **Non-tribimaximal mixing but** $s_{13} = 0$

$$r^{12}_{23} = 0 \qquad r^{13}_{23} = 0 \qquad \Rightarrow \text{Note: } (r^{13}_{23})^2 = 0$$

ANALYSIS

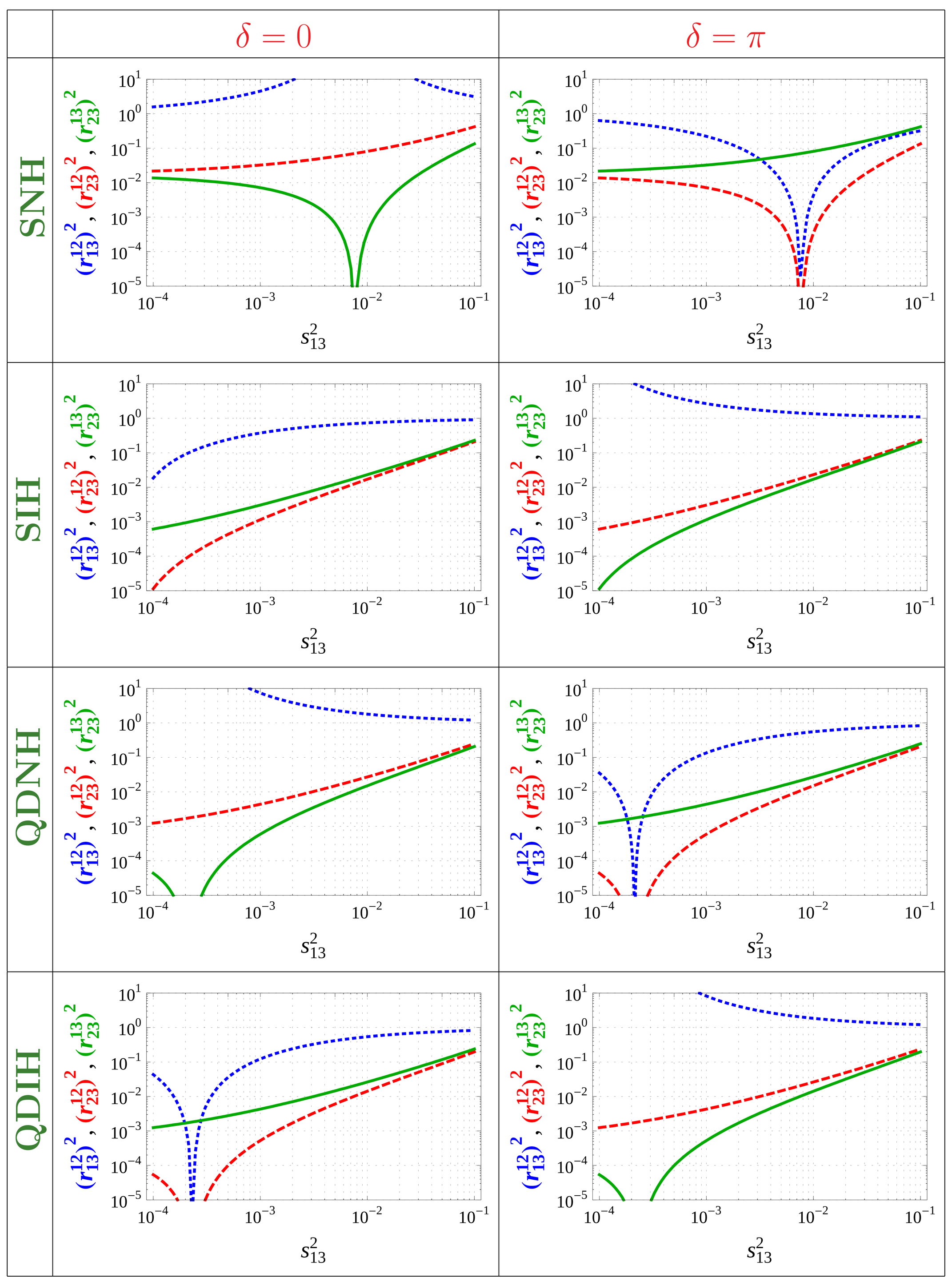
Degenerate M_i

- **Tribimaximal mixing**



- ⇒ Normal hierarchy (NH) and Inverse Hierarchy (IH)
- ⇒ Δm^2_{S} and Δm^2_{A} set to
  - b.f.p. values → lines
  - 3σ ranges → bands

- **Tribimaximal mixing but** $s_{13} \neq 0$



- If $\tan\theta_{23} = 1$
  - ⇒ For **SNH** and **SIH**:

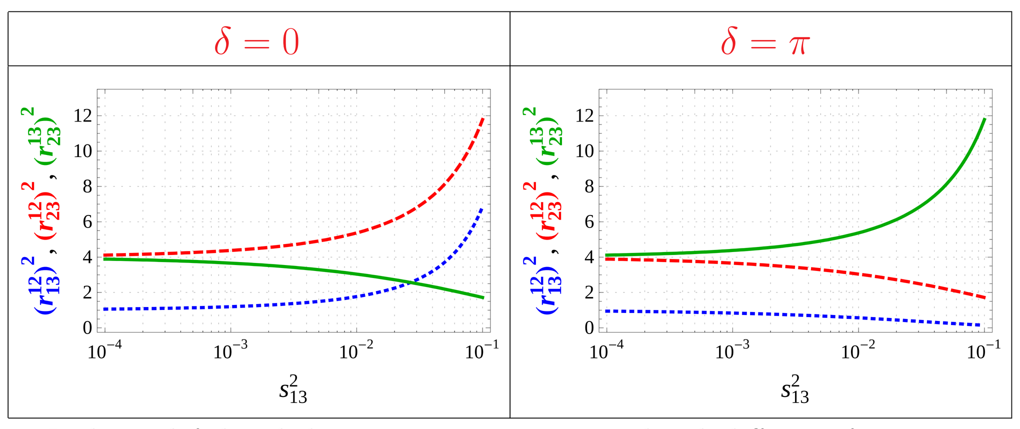
$$(r^{12}_{23})^2 \leftrightarrow (r^{13}_{23})^2 \qquad \text{if} \qquad \delta = 0 \leftrightarrow \delta = \pi$$

  - ⇒ For **QDNH** and **QDIH**:

$$(r^{12}_{23})^2 \leftrightarrow (r^{13}_{23})^2 \qquad \text{if} \qquad \{\delta = 0 \leftrightarrow \delta = \pi \quad \text{and} \quad \text{QDNH} \leftrightarrow \text{QDIH}\}$$

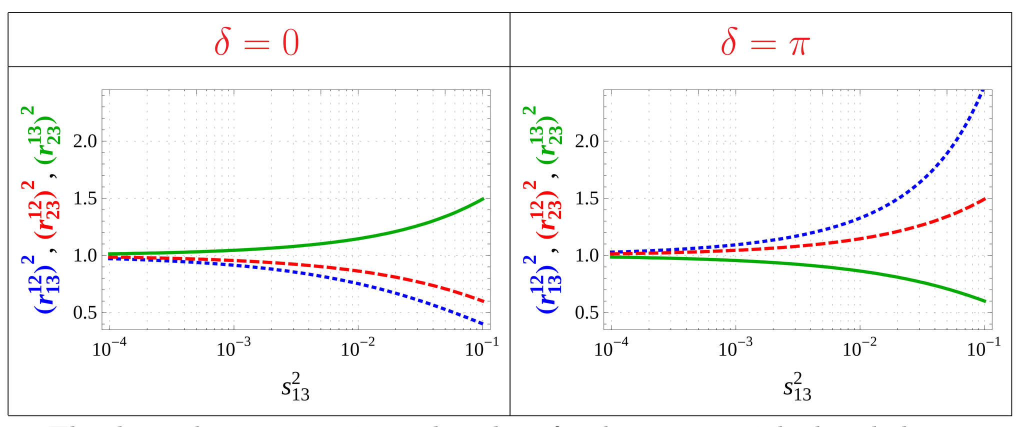
- Either $(r^{12}_{23})^2$ or $(r^{13}_{23})^2$ is different from 0, for all s_{13} values

Dominant M_1



- Lightest left-handed neutrino mass is considered different from zero $(m_1 \neq 0)$
- The dependence on s_{13} is not so strong than for degenerate right-handed neutrinos
- None of the $(r^{ij}_{kl})^2$ vanish in the allowed range of s_{13}

Dominant M_2



- The dependence on s_{13} is weaker than for degenerate right-handed neutrinos
- None of the $(r^{ij}_{kl})^2$ vanish in the allowed range of s_{13}
- The numerical values differ from the ones for the case of M_1 dominance

Dominant M_3

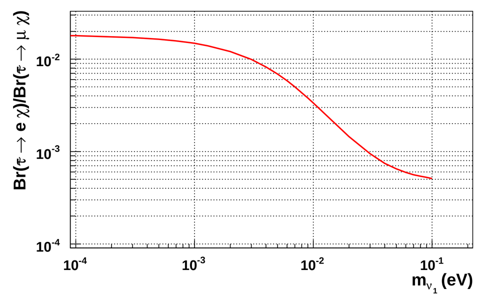
$$\left(\Delta M^2_{\tilde{L}}\right)_{12} = \frac{s_{23}}{c_{23}} \left(\Delta M^2_{\tilde{L}}\right)_{13} \propto s_{13}e^{-i\delta}c_{13}s_{23} \qquad \left(\Delta M^2_{\tilde{L}}\right)_{23} \propto c_{13}{}^2 s_{23}c_{23}$$

- For $s_{13} = s^{\max}_{13}$ ⇒ $(r^{13}_{23})^2 = 1.1 \times 10^{-1}$

RESULTS

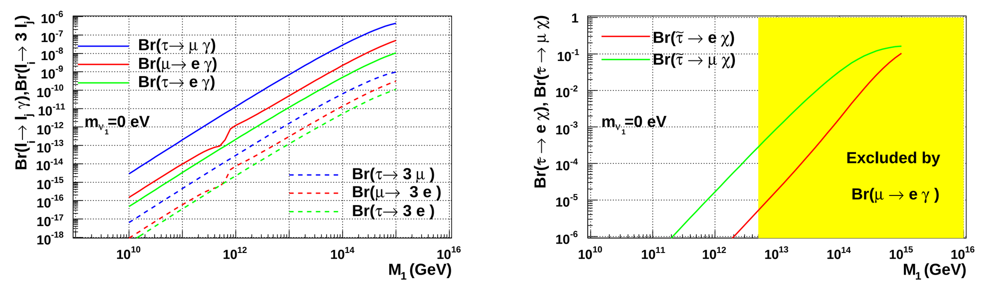
Degenerate M_i

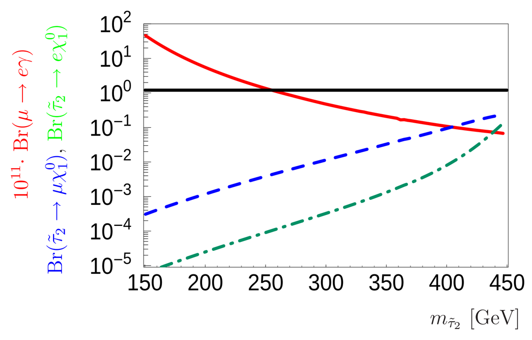
- **SPS1a', tribimaximal mixing and Normal Hierarchy**



- ⇒ TBM mixing
- ⇒ Δm^2_{S} and Δm^2_{A} set to b.f.p. values
- ⇒ $M_R = 5 \times 10^{12}$ GeV

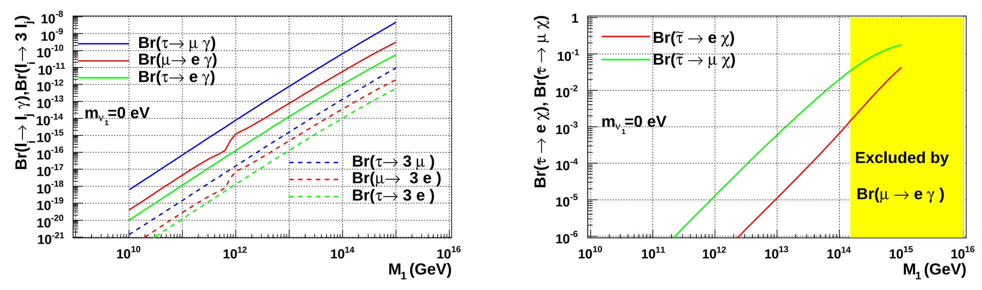
- **SPS1a', tribimaximal mixing and SNH** $(m_1 = 0)$





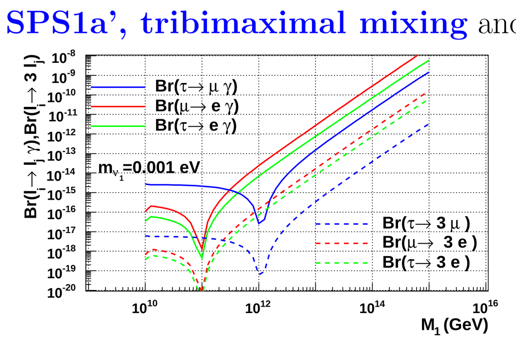
- ⇒ **SPS1a varied along its slope**
- ⇒ For $m_{\tilde{\tau}_2} > 250$ GeV, BR$(\mu \to e\gamma)$ drops below its experimental limit
- ⇒ $\tilde{\tau}_2$ LFV decay BR's increase for increasing $m_{\tilde{\tau}_2}$

- **SPS3, tribimaximal mixing and SNH** $(m_1 = 0)$



Dominant M_1

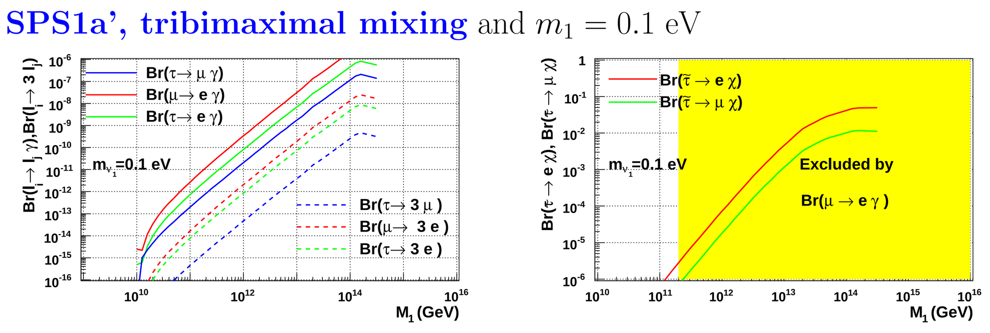
- **SPS1a', tribimaximal mixing** and $m_1 = 0.001$ eV



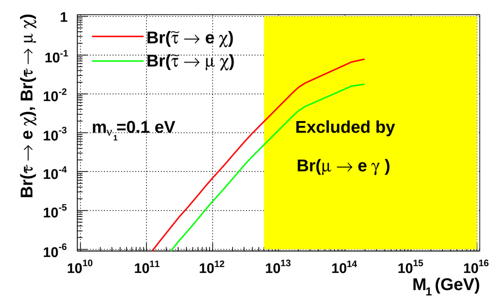
- ⇒ curves are not monotonous functions of M_1, as they scale like

$$m_1 M_1 \log M_1$$

- **SPS1a', tribimaximal mixing** and $m_1 = 0.1$ eV

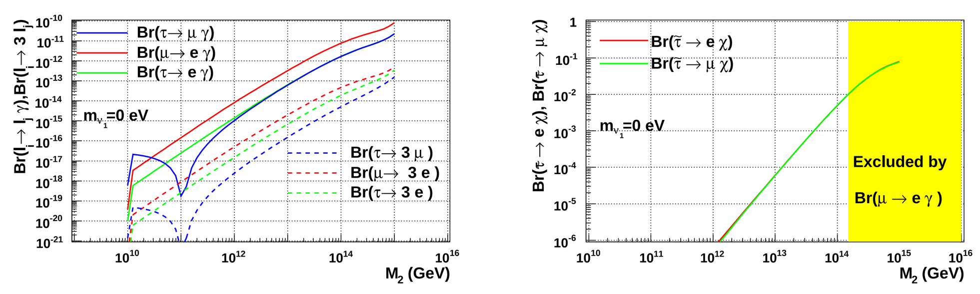


- **SPS3 and tribimaximal mixing**

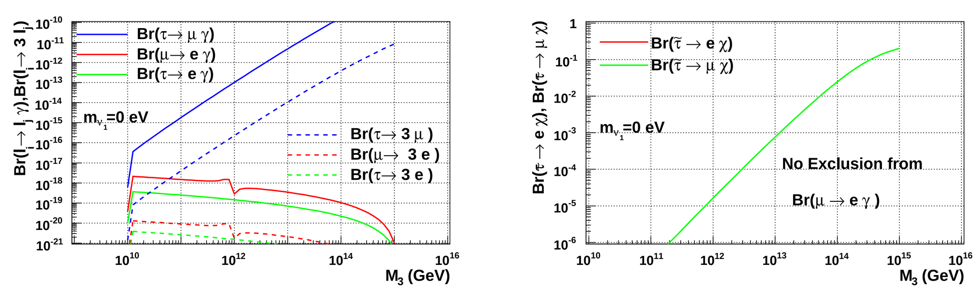


- ⇒ $\mathbf{Br}(\tilde{\tau}_2 \to e\chi^0_1) > \mathbf{Br}(\tilde{\tau}_2 \to \mu\chi^0_1)$ for M_1 dominance, in contrast with the case of degenerate right-handed neutrinos.

Dominant M_2 (SPS3 and TBM)



Dominant M_3 (SPS3 and TBM)



SUMMARY

- Neutrino oscillation data have demonstrated that neutrinos are massive and mix
- One possible mechanism for neutrino mass generation ⇒ SUSY type-I seesaw
- mSUGRA: LFV processes are related to neutrino parameters
- Consistency tests for correlations between:
  - Ratios of LFV BR's
  - Neutrino parameter relations from off-diagonal $\left|(Y_\nu{}^\dagger L Y_\nu)_{ij}\right|^2$