Lepton flavour violating stau decays versus seesaw parameters

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M. Hirsch, J. W. F. Valle, W. Porod, J. C. Romao and A.V.M., Phys. Rev. D **78**, 013006 (2008)
[arXiv:0804.4072 [hep-ph]]
(Work in progress)

DISCRETE’08, 11-16 December 2008, València

Outline

- Motivation
- Type-I seesaw
- Type-II seesaw $\Rightarrow$ Satoru Kaneko talk
- Production and decays in both type-I and II
- Conclusions

Motivation

- Neutrino data
  - Neutrinos mix $\Rightarrow$ LFV
  - Neutrinos have (very small) masses
- Mechanism of neutrino mass generation?
  - Most popular: Type-I Seesaw Mechanism
- In the framework of mSUGRA
  - Neutrino parameters are related to LFV processes

Type-I SUSY Seesaw

- Particle content

$$\text{MSSM} \quad + \quad 3\,\hat{\nu}_i^c$$

Type-I SUSY Seesaw

- Superpotential

$$W = W_{\mathrm{MSSM}} + Y_\nu^{ji}\hat{L}_i\hat{\nu}_j^c\hat{H}_u + \frac{1}{2}M_R^{ij}\hat{\nu}_i^c\hat{\nu}_j^c$$

Type-I SUSY Seesaw

- Neutrino mass matrix: Basis (ν_L, ν_R)

$$M_\nu = \begin{pmatrix} 0 & v_u/\sqrt{2}\, Y_\nu^T \\ v_u/\sqrt{2}\, Y_\nu & M_R \end{pmatrix}$$

Type-I SUSY Seesaw

- If $m_D \equiv v_u/\sqrt{2}\, Y_\nu \ll M_R$

$$m_\nu \simeq -\frac{v_u^2}{2}\, Y_\nu^T \cdot M_R^{-1} \cdot Y_\nu$$
$$m_N \simeq M_R$$

Type-I SUSY Seesaw

- In the flavour basis:
  - Diagonal Y_e
  - Diagonal M_R
- Neutrino mass eigenvalues:

$$\hat{m}_\nu \equiv \text{diag}\left(m_1, m_2, m_3\right)$$
$$= U^T \cdot m_\nu \cdot U$$
$$\simeq -\frac{v_u^2}{2} U^T \cdot Y_\nu^T \cdot M_R^{-1} \cdot Y_\nu \cdot U$$
$$\hat{m}_N \equiv \text{diag}\left(M_1, M_2, M_3\right) = m_N$$

LFV

- Origin:

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

Basis Y_e diagonal $\Rightarrow M_{\tilde{l}}^2$ NOT diagonal

LFV

- Neglecting *L*-*R* mixing

$$(M^2_{\tilde{l}})_{ij} = \begin{cases} (M^2_{LL})_{ij} = (M^2_{\tilde{L}})_{ij} \\ (M^2_{RR})_{ij} = (M^2_{\tilde{E}})_{ij} \end{cases}$$

LFV

- General MSSM:

$$\left.\begin{array}{l}(M_L^2)_{ij}\\(M_E^2)_{ij}\end{array}\right\}\text{free parameters}$$

LFV

- mSUGRA:
  - At GUT:

$$(M_L^2)_{ij} = (M_E^2)_{ij} = 0$$

  - At low energies:

$$(M_L^2)_{ij} = \frac{-1}{8\pi^2}(3m_0^2 + A_0^2)(Y_\nu^\dagger \cdot L \cdot Y_\nu)$$
$$(M_E^2)_{ij} = 0$$

where $L_{kl} \equiv \log\left(\frac{M_X}{M_k}\right)\delta_{kl}$

LFV and seesaw parameters

- LFV:

$$\mathrm{BR}_{ij} \propto |(M_L^2)_{ij}|^2$$

LFV and seesaw parameters

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- ν physics:

$$(m_1, m_2, m_3) \simeq -\frac{v_u^2}{2} U^T \cdot Y_\nu^T \cdot M_R^{-1} \cdot Y_\nu \cdot U$$

LFV and seesaw parameters

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- Casas & Ibarra parametrization:

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

LFV and seesaw parameters

- LFV:

$$\mathrm{BR}_{ij} \propto |Y_\nu^\dagger \cdot L \cdot Y_\nu|^2$$

- ν physics:

$$(m_1, m_2, m_3) \simeq -\frac{v_u^2}{2} U^T \cdot Y_\nu^T \cdot M_R^{-1} \cdot Y_\nu \cdot U$$

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

LFV and seesaw parameters

- Trick: Ratio of BR's

$$\frac{\mathrm{BR}_{ij}}{\mathrm{BR}_{i'j'}} \simeq \frac{\left| U^*_{i\alpha} U_{j\beta} \sqrt{m_\alpha} \sqrt{m_\beta} R^*_{k\alpha} R_{k\beta} M_k \log\left(\frac{M_X}{M_k}\right)\right|^2}{\left| U^*_{i'\alpha'} U_{j'\beta'} \sqrt{m_{\alpha'}} \sqrt{m_{\beta'}} R^*_{k'\alpha'} R_{k'\beta'} M_{k'} \log\left(\frac{M_X}{M_{k'}}\right)\right|^2}$$

$$\equiv |r^{ij}_{i'j'}|^2$$

LFV and seesaw parameters

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$$\equiv |r^{ij}_{i'j'}|^2$$

- Correlations:

$$\text{LFV observables} \quad \rightleftarrows \quad \nu \text{ parameters}$$

Counting of parameters

- LFV BR's: 3

$$\mathrm{BR}_{12} \qquad \mathrm{BR}_{13} \qquad \mathrm{BR}_{23}$$

Counting of parameters

- Independent ratios of LFV BR's: 2

$$r_{23}^{13} \simeq \frac{\mathrm{BR}_{13}}{\mathrm{BR}_{23}} \qquad r_{23}^{12} \simeq \frac{\mathrm{BR}_{12}}{\mathrm{BR}_{23}}$$

Counting of parameters

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- Seesaw parameters: 18

$$m_i \qquad \theta_{ij} \qquad \delta,\ \alpha_1,\ \alpha_2 \qquad M_i \qquad \theta_i$$

Counting of parameters

- Independent ratios of LFV BR's: 2

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$$m_i \qquad \theta_{ij} \qquad \delta,\ \alpha_1,\ \alpha_2 \qquad M_i \qquad \theta_i$$

⋆ Simplifying assumptions about $\nu_R \Rrightarrow$

Relations between LFV and ν_L parameters

LFV observables

- At colliders

$$\tilde{l}_i \to l_j \chi_1^0 \qquad\qquad \chi_2^0 \to l_i \bar{l}_j \chi_1^0$$

- Low energy constraints

$$l_i \to l_j \gamma \qquad\qquad l_i \to 3 l_j \qquad\qquad l_i \to l_j 2 l_k$$

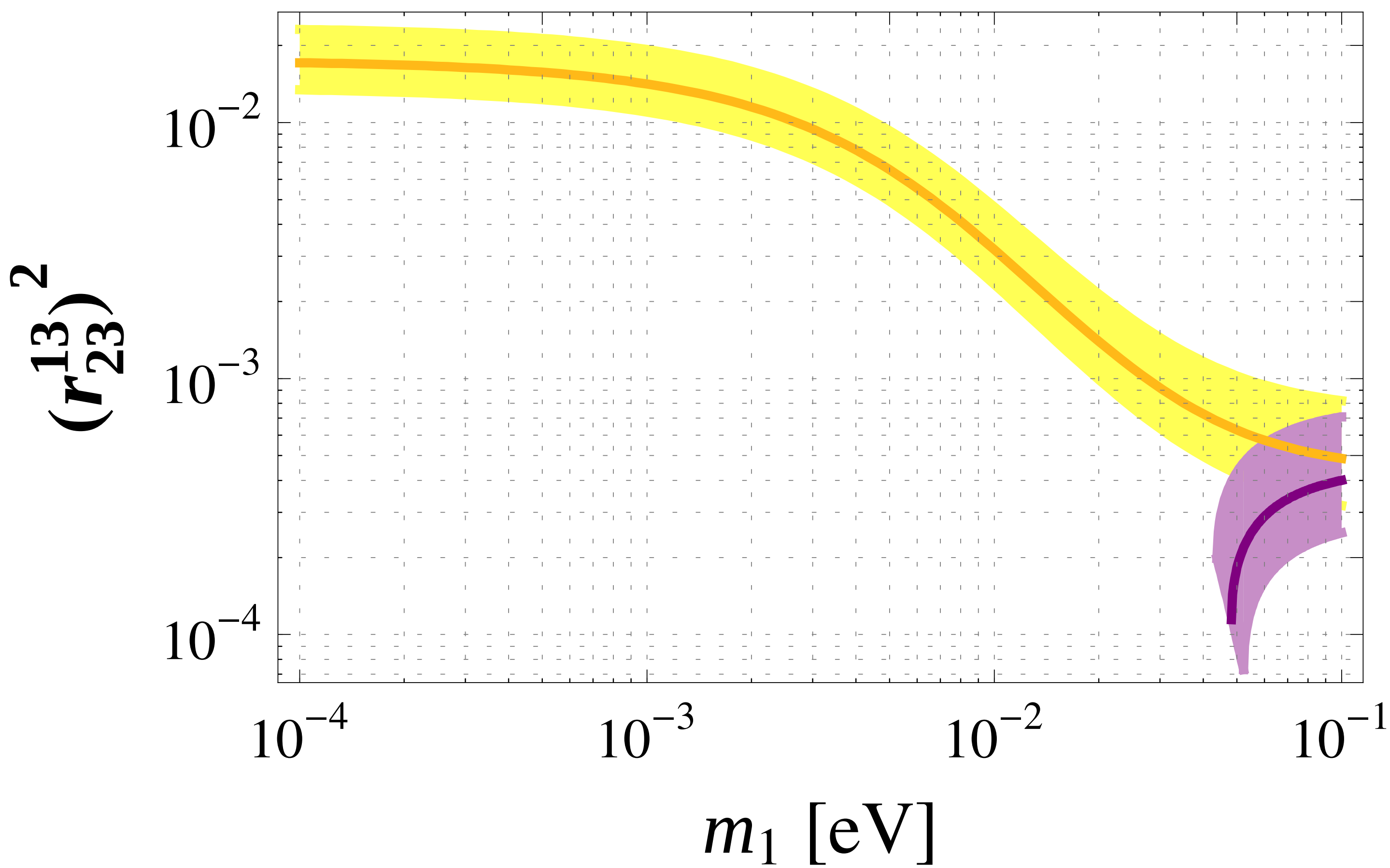
Neutrino Scenario-1

$$\text{TBM}, \quad M_i = M \quad \forall i, \qquad R \in \mathbb{R}$$

$$r_{23}^{13} = \frac{4(m_2 - m_1)^2}{(3m_3 - 2m_2 - m_1)^2}$$

Neutrino Scenario-1

TBM, $\quad M_i = M \quad \forall i, \qquad R \in \mathbb{R}$



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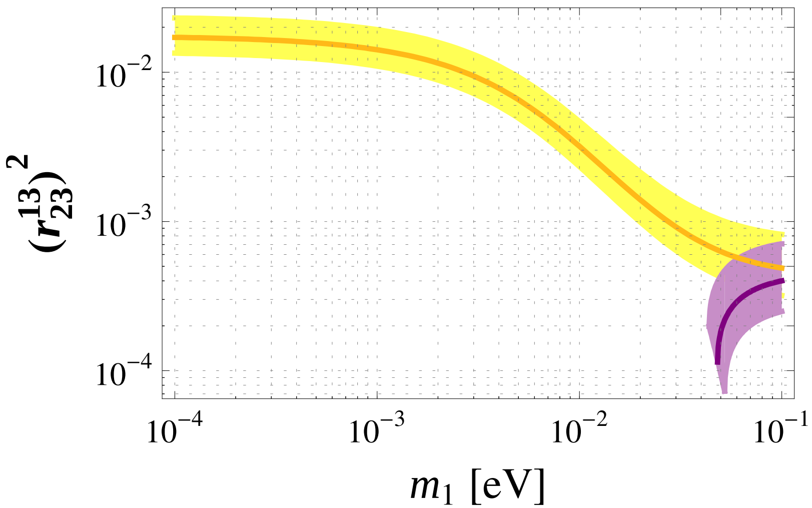
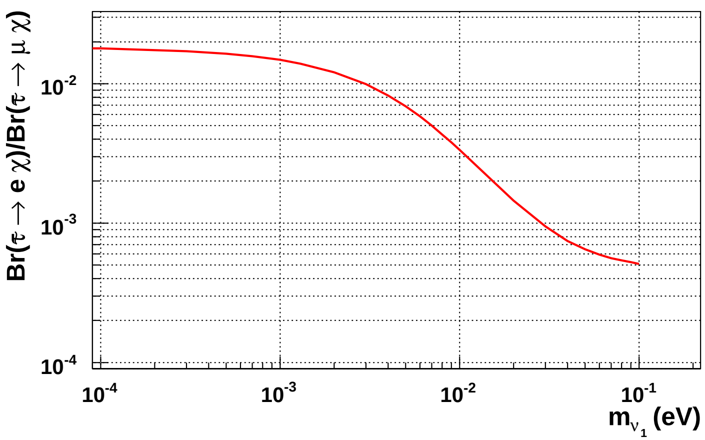


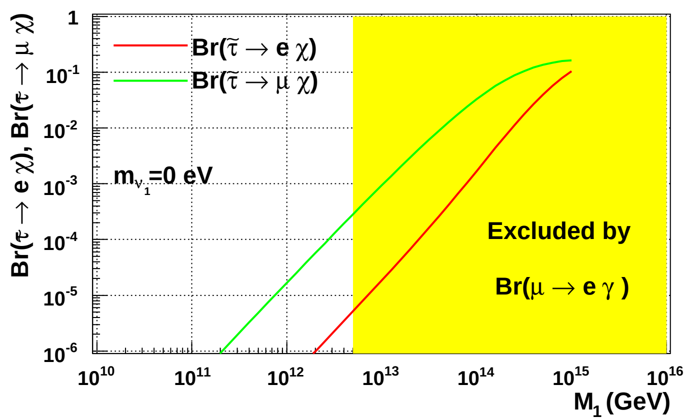


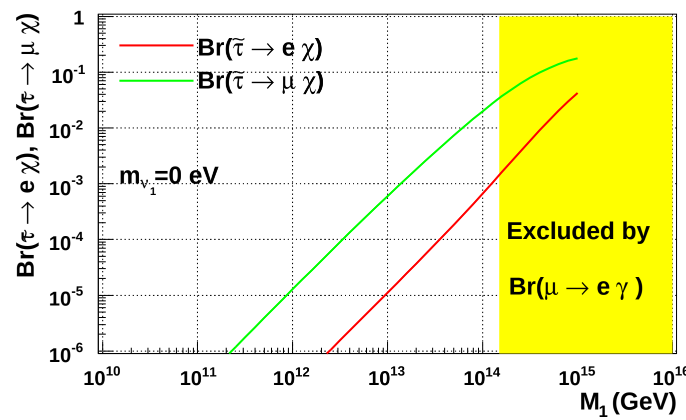
Neutrino Scenario-1

$$\text{TBM}, \quad M_i = M \quad \forall i, \qquad R \in \mathbb{R}$$

SPS1a′

SPS3





Other neutrino scenarios

- Departure from TBM
- Departure from degenerate M_i
- Dependence on $\boldsymbol{R}$

Questions

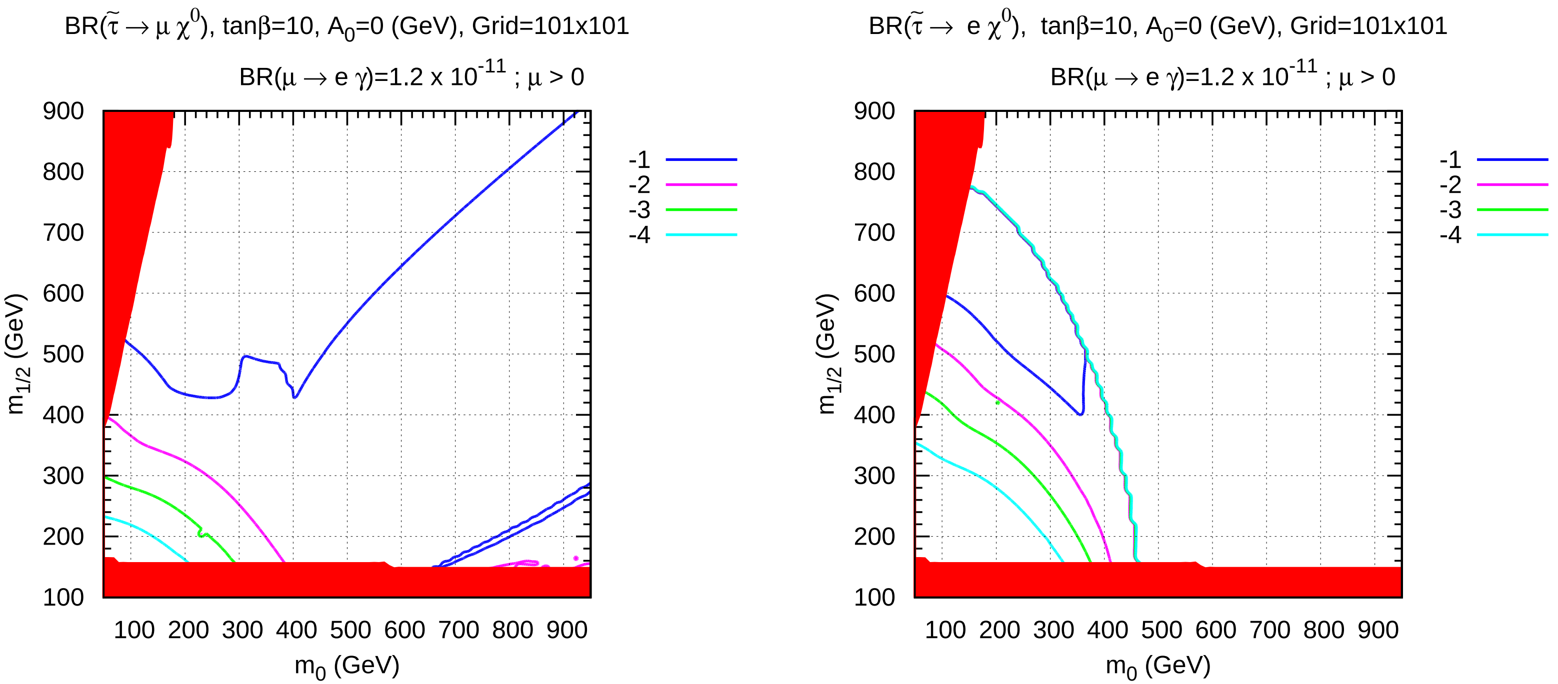
- Only SPS1a′ and SPS3
  - mSUGRA dependence?
- Value of LFV BR's?
- Number of events? Production of χ_2^0?

$$\chi_2^0 \to l_i \tilde{\tau}_2 \to l_i l_j \chi_1^0$$

where $l_i,\ l_j = \{\mu,\ \tau\}$

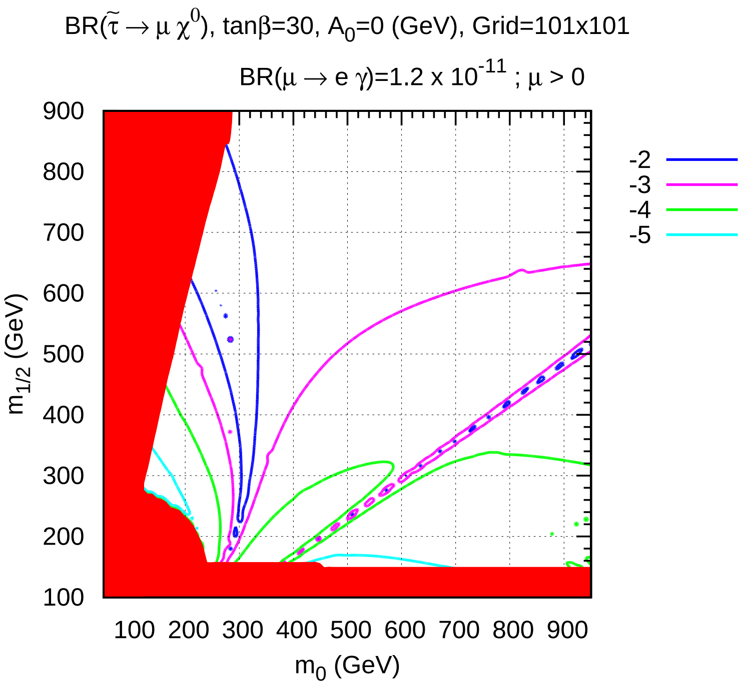
LFV stau decays

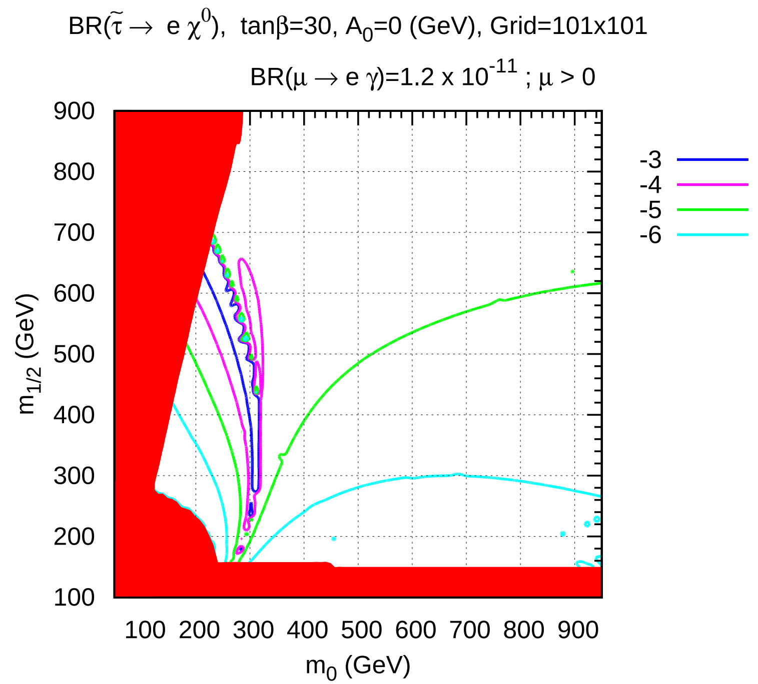
- Type-I: $\tan\beta = 10$, $A_0 = 0$ GeV, $\mu > 0$



LFV stau decays

- Type-I: $\tan\beta = 30$, $A_0 = 0$ GeV, $\mu > 0$





LFV stau decays

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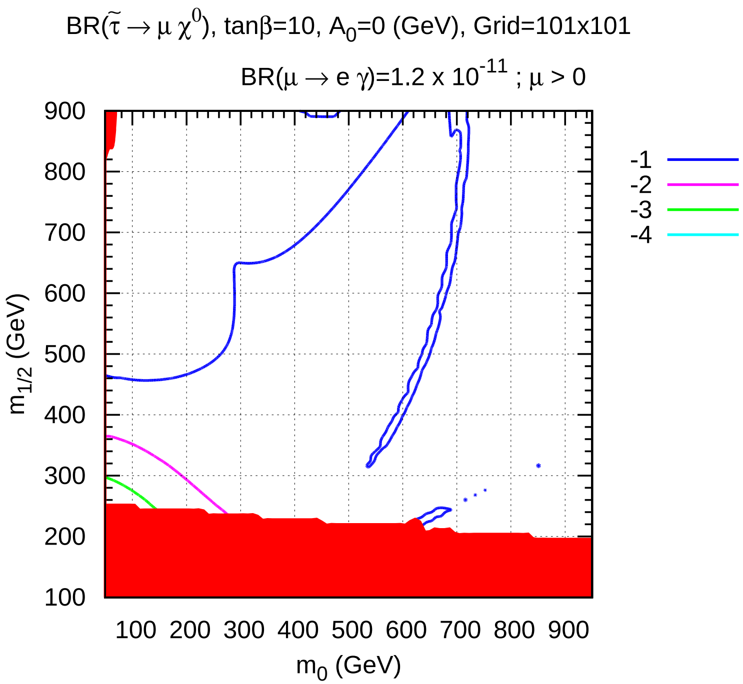
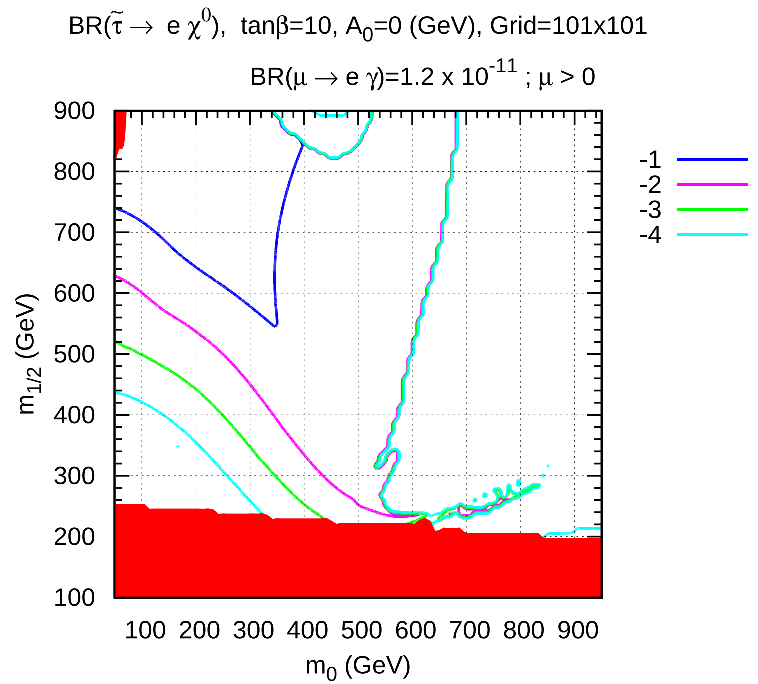
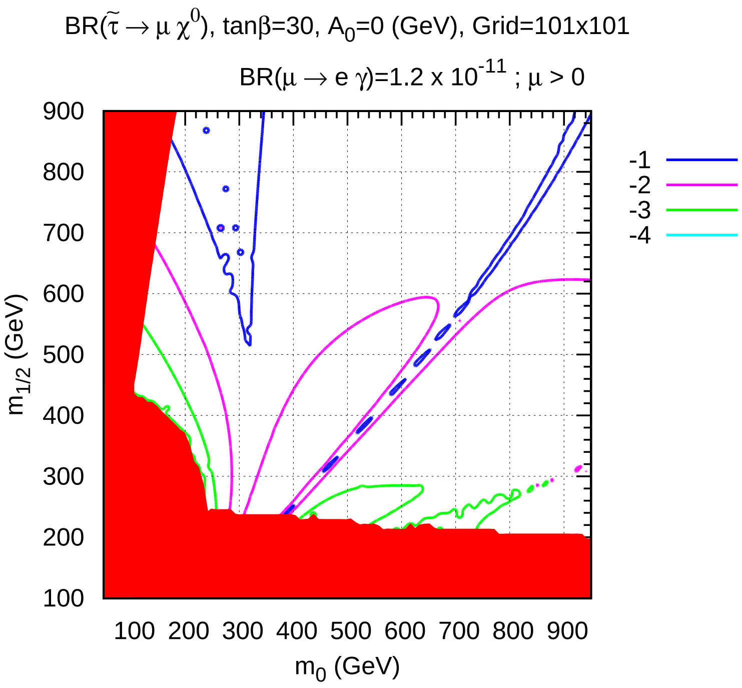
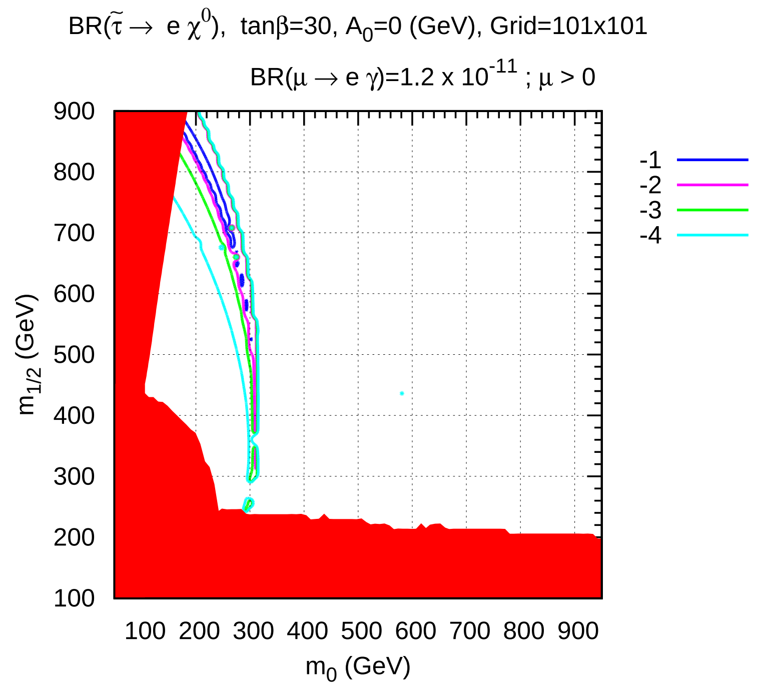




LFV stau decays

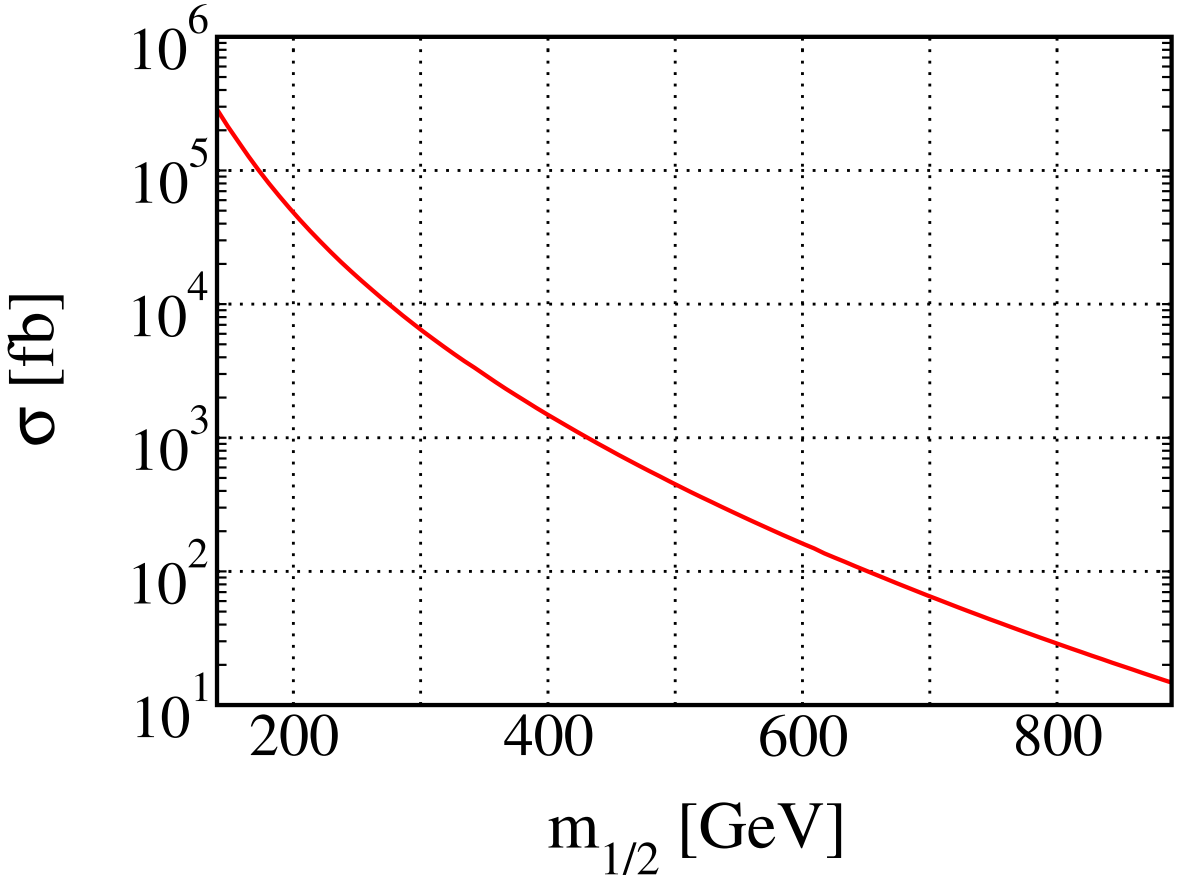
- Type-II: $\tan\beta = 30$, $A_0 = 0$ GeV, $\mu > 0$





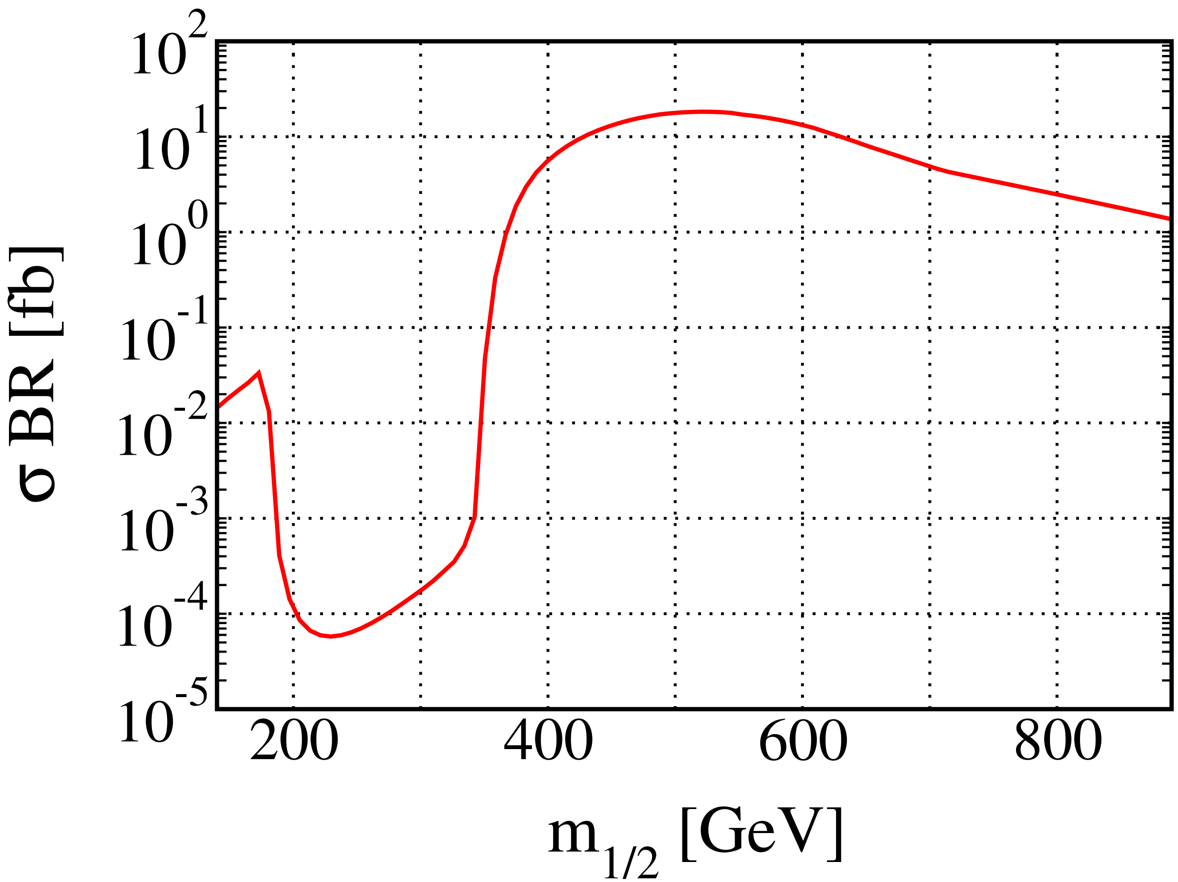
Production

$\sigma(\chi_2^0)$



Production

$\sigma(\chi_2^0) \times \mathrm{BR}(\chi_2^0 \to \mu\tau)$



Conclusions

- Neutrino data
  - Neutrinos are massive
  - Neutrinos mix
- Neutrino mass generation: Type-I SUSY seesaw
- mSUGRA: LFV processes are related to neutrino parameters
- Correlations:
  - Ratios of LFV BR's
  - Squared-ratios of off-diagonal $(M^2_{\tilde{l}})_{ij}$