Lepton flavour violating slepton decays to test type-I and II seesaw at the LHC

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Outline

- Motivation
- How to test type-I seesaw?
- Production and estimated event rates 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:

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

LFV

- Origin:
  Basis Y_e diagonal $\Rightarrow M^2_{\tilde{l}}$ NOT diagonal
  - Small mixing angle approximation:

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

LFV

- Neglecting *L*-*R* mixing

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

LFV

- General MSSM:

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

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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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:

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

- 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

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

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

LFV and seesaw parameters

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

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

- Correlations:

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

Counting of parameters

- LFV BR's: 3

BR_{12} BR_{13} 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

$$3 : m_i \quad 3 : \theta_{ij} \quad 3 : \delta,\ \alpha_1,\ \alpha_2 \quad 3 : M_i \quad 6 : \theta_i$$

Counting of parameters

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⋆ Simplifying assumptions about $\nu_R \Rightarrow$

Relations between LFV and ν_L parameters

LFV observables

- At colliders

$$\tilde{\ell}_i \longrightarrow \ell_j \chi_1^0 \qquad\qquad \chi_2^0 \longrightarrow \ell_i \bar{\ell}_j \chi_1^0$$

- Low energy constraints

$$\ell_i \longrightarrow \ell_j \gamma \qquad \ell_i \longrightarrow 3\ell_j \qquad \ell_i \longrightarrow \ell_j 2\ell_k$$

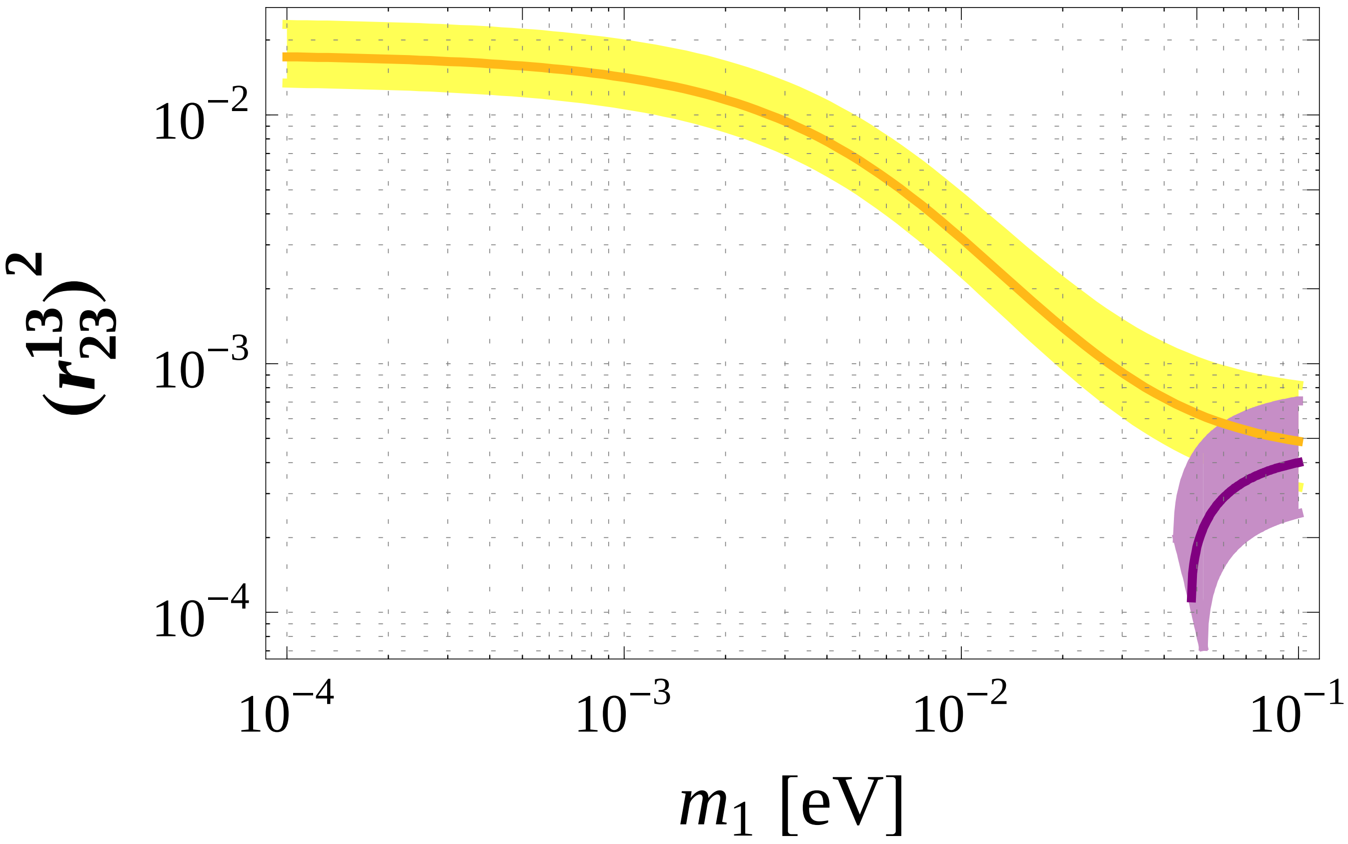
Neutrino Scenario-1

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

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

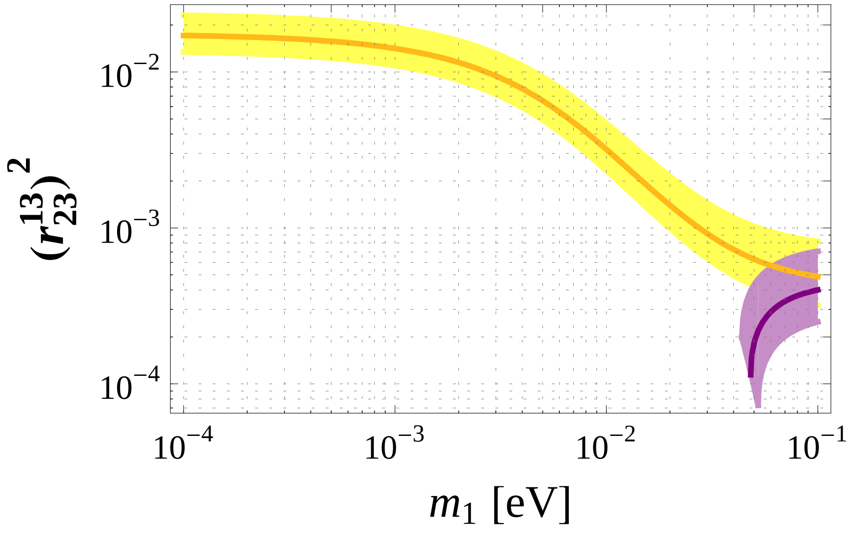
Neutrino Scenario-1

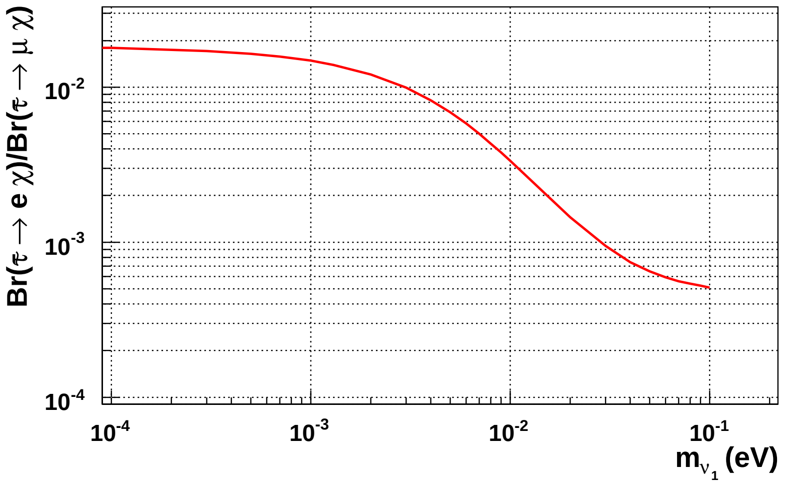
- TBM, $M_i = M \quad \forall i, \qquad R \in \mathbb{R}$



Neutrino Scenario-1

- TBM, $M_i = M \quad \forall i, \qquad R \in \mathbb{R}$
- Numerical calculation: SPHENO

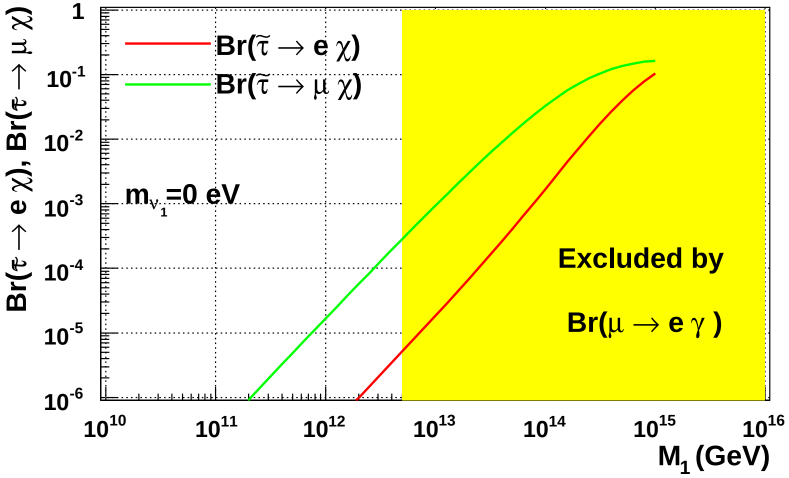




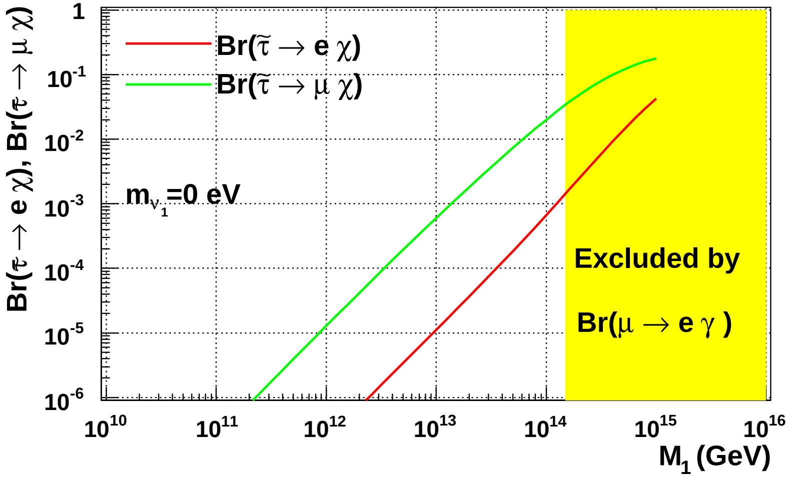
Neutrino Scenario-1

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

SPS1a′



SPS3



Other neutrino scenarios

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

Questions

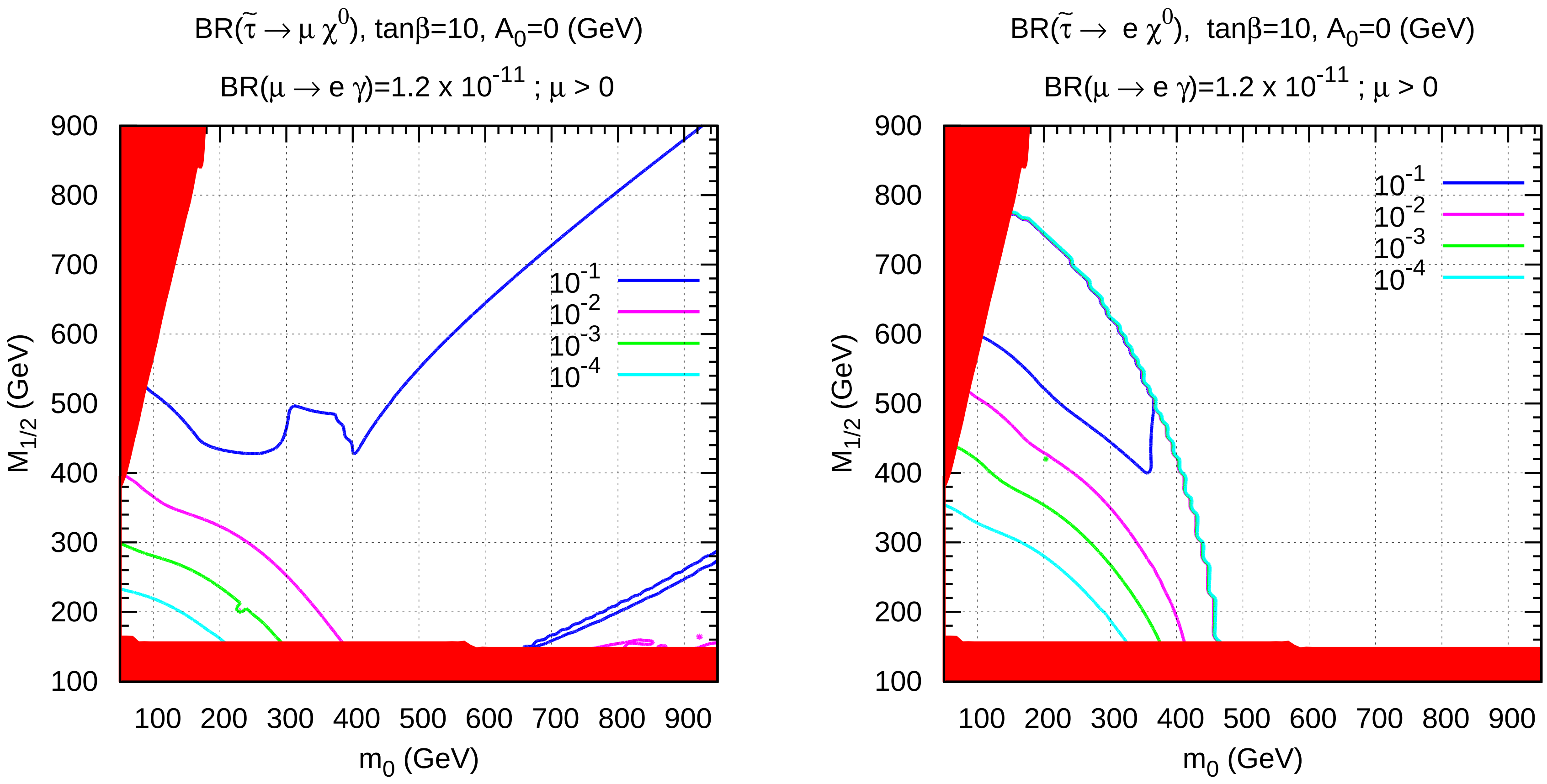
- Only SPS1a′ and SPS3
  - NO mSUGRA dependence of r_{23}^{13}
- Absolute value of LFV BR's?
- Absolute events rates?
  - mSUGRA dependence!

Numerical procedure

- How large can BR($\tilde{\tau}_2 \longrightarrow e/\mu + \chi^0_1$) be?
  - Program package: SPHENO
  - Experimental constraints:
    Upper bounds on BR($\ell_i \longrightarrow \ell_j \gamma$)
- Estimate event rate for $\chi^0_2 \longrightarrow \chi^0_1 \mu\tau$?
  - Program package: PROSPINO

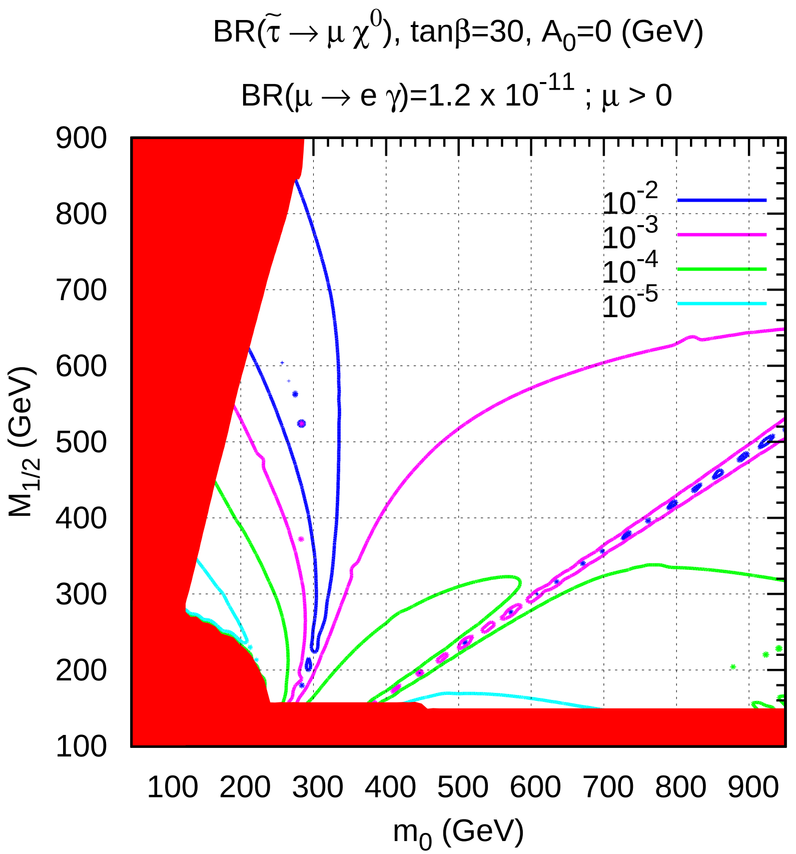
LFV stau decays

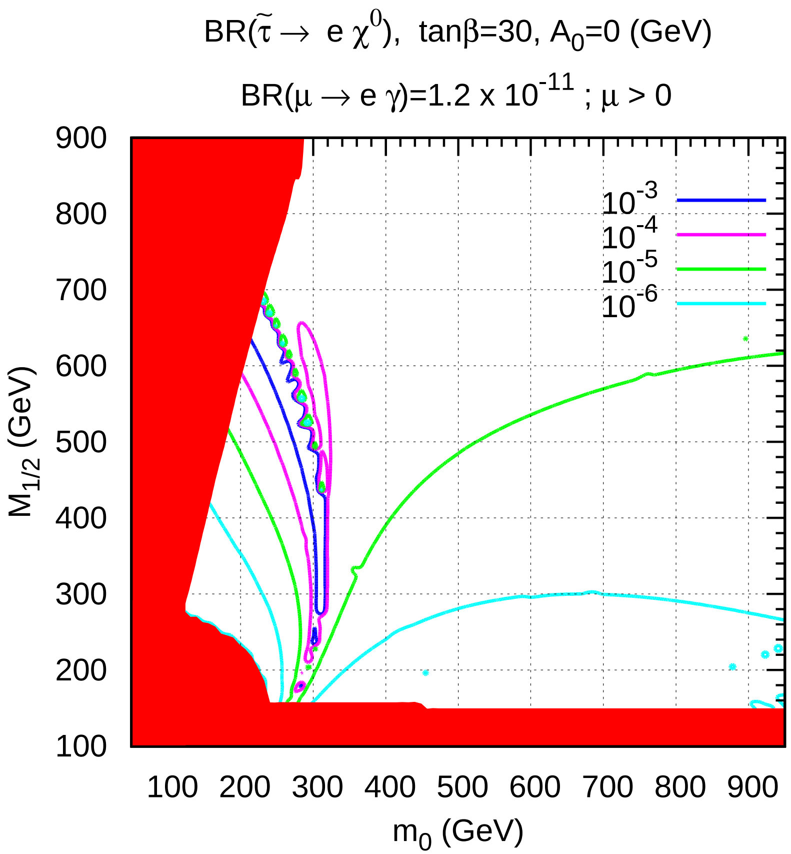
- Type-I: $\tan\beta = 10$, $A_0 = 0$ GeV, $\mu > 0$



LFV stau decays

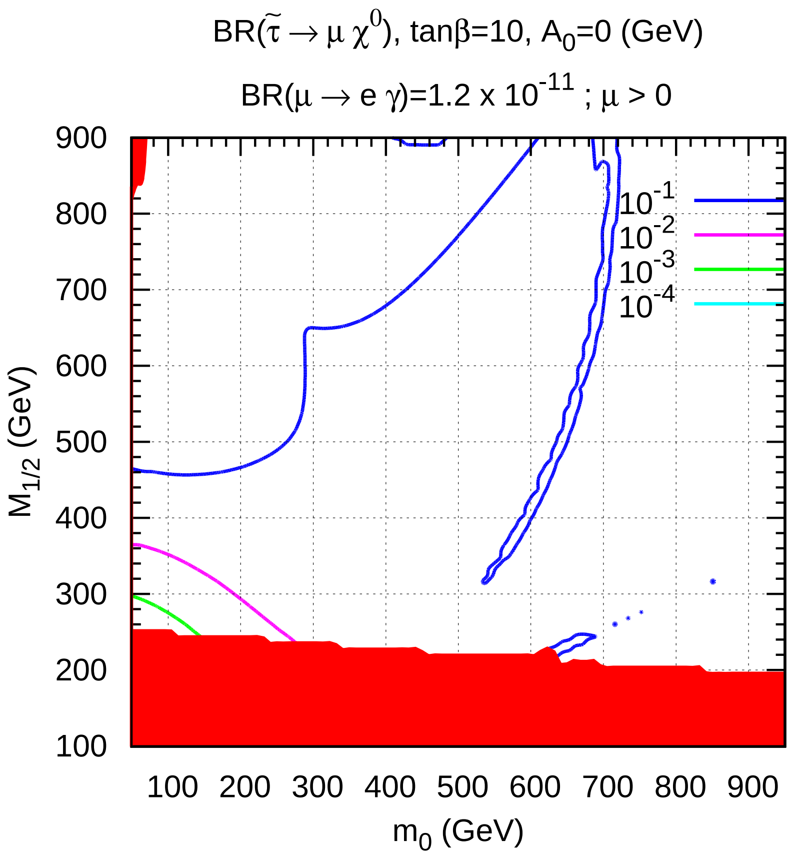
- Type-I: $\tan\beta = 30$, $A_0 = 0$ GeV, $\mu > 0$

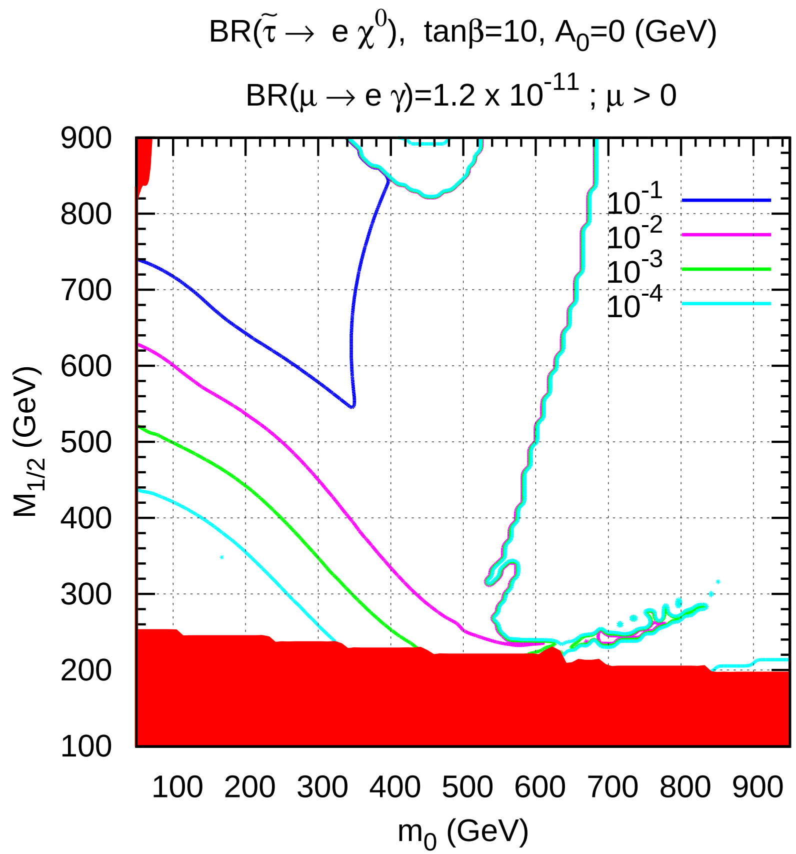




LFV stau decays

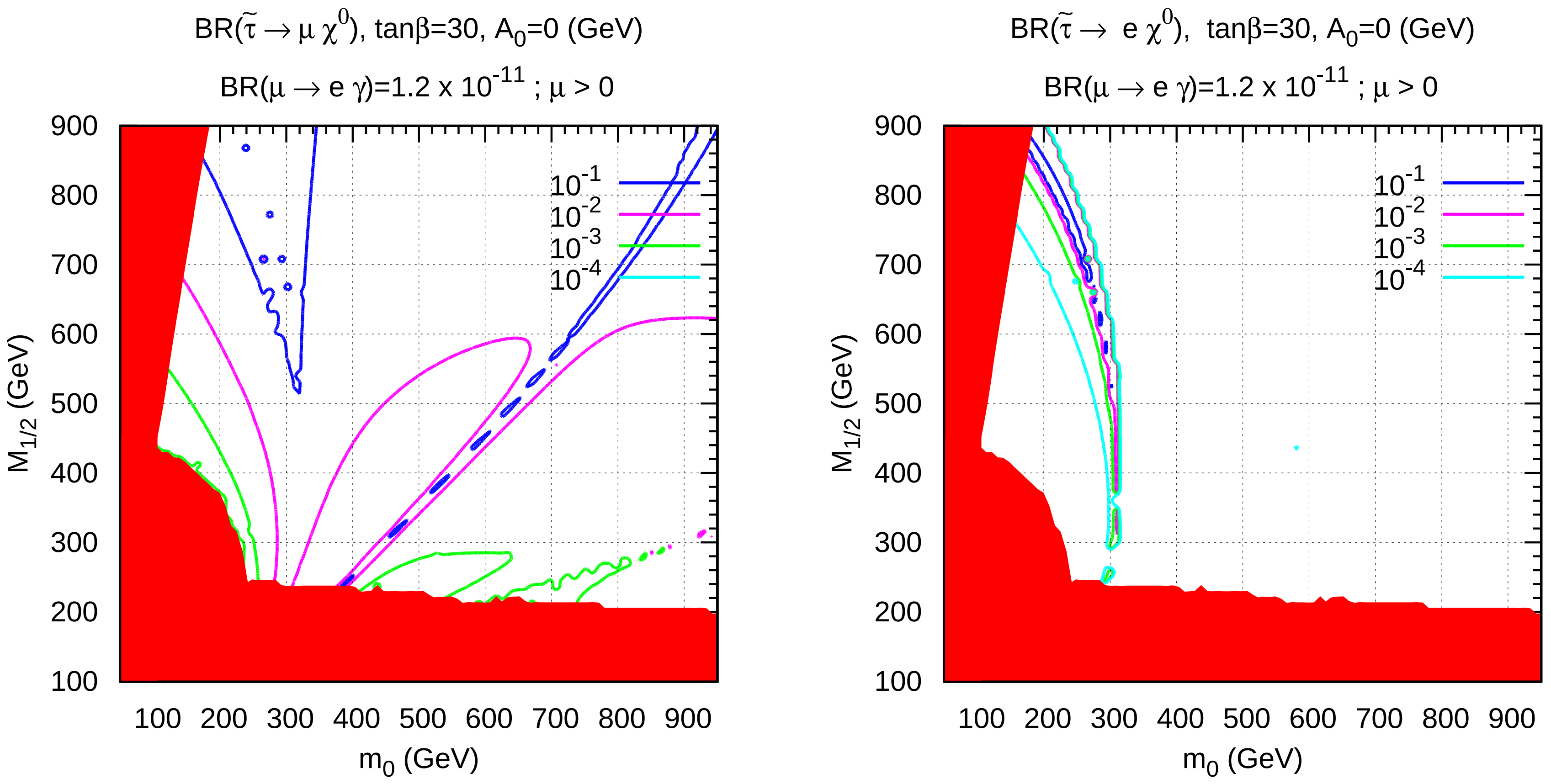
- Type-II: $\tan\beta = 10$, $A_0 = 0$ GeV, $\mu > 0$





LFV stau decays

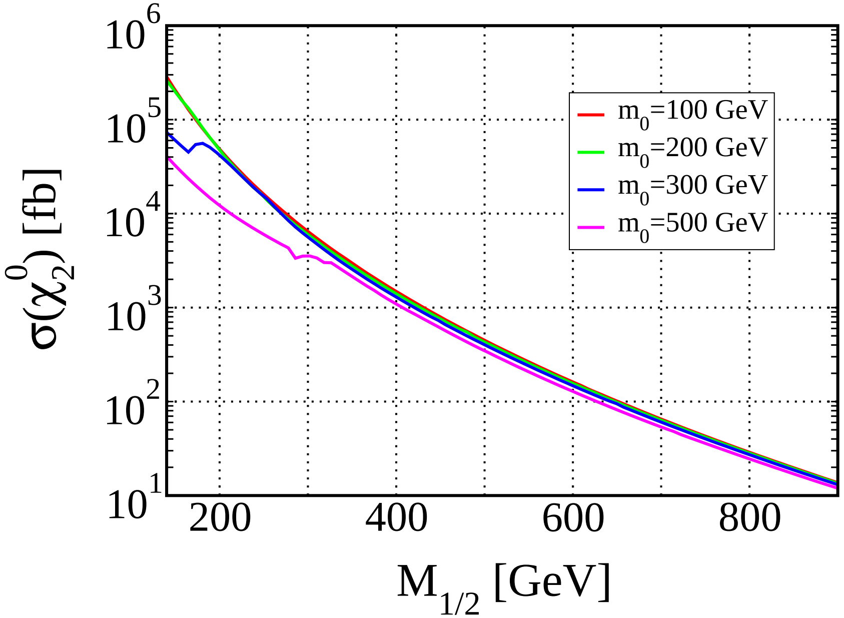
- Type-II: $\tan\beta = 30$, $A_0 = 0$ GeV, $\mu > 0$



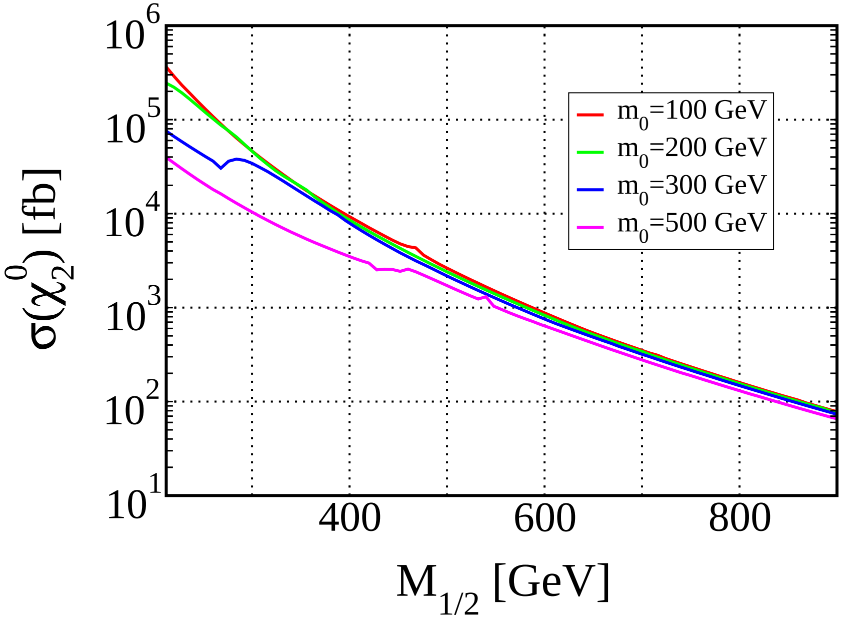
Production

- $\sigma(\chi_2^0)$

Type-I



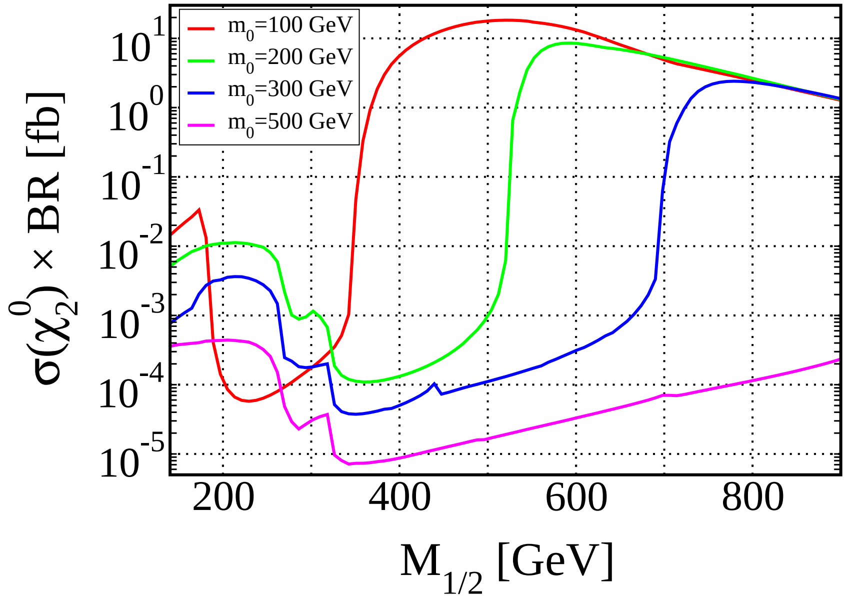
Type-II



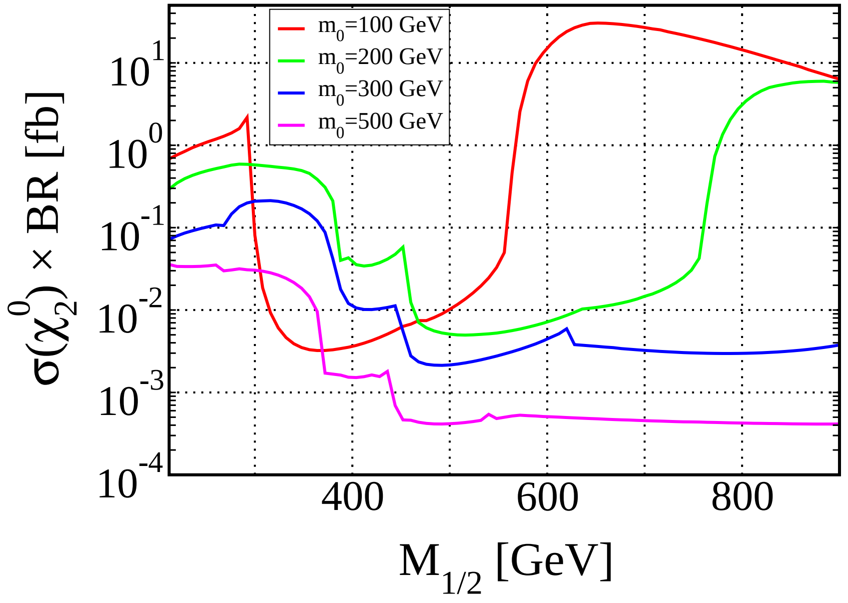
Estimated event rate

- $\sigma(\chi_2^0) \times \mathrm{BR}(\chi_2^0 \to \chi_1^0 \mu \tau)$

Type-I



Type-II



Conclusions

- Neutrino data
  - Neutrinos are massive
  - Neutrinos mix
- Neutrino mass generation:
  Type-I SUSY seesaw
- mSUGRA: LFV processes are related to neutrino parameters
- mSUGRA regions where event rate might be large enough
- More detailed study is needed