Lepton Flavour Violation in CMSSM-seesaw models

Ernesto Arganda
Dpt. Física Teórica/IFT, Universidad Autónoma de Madrid

From works

E.A. and María J. Herrero PRD73,055003(2006)

S.Antusch, E.A., María J. Herrero and A.Teixeira JHEP 0611(2006)090

E.A., María J. Herrero and A.Teixeira JHEP 0710(2007)104

E.A., María J. Herrero and J.Portolés IFT-UAM/CSIC-07-27

XLIII Rencontres de Moriond, La Thuile, 5 March 2008

Motivation

- ⋆ Lepton Flavour Violation (LFV) occurs in Nature, $\nu_i - \nu_j$ oscill.
- ⋆ In SM: no LFV if $m_\nu = 0$; very suppresed if $m_\nu \neq 0$
- ⋆ Many exp. bounds (present/future sensitivities):

MEGA, SINDRUM, BABAR, Belle / MEG,...PRISM/PRIME

$\text{BR}(\mu \to e\gamma)$	$<$	$1.2 \times 10^{-11}/10^{-13}$	$\text{BR}(\tau \to \mu\eta)$	$<$	5.1×10^{-8}
$\text{BR}(\tau \to \mu\gamma)$	$<$	$4.5 \times 10^{-8}/10^{-8}$	$\text{BR}(\tau \to \mu\eta')$	$<$	5.3×10^{-8}
$\text{BR}(\tau \to e\gamma)$	$<$	$1.2 \times 10^{-7}/10^{-8}$	$\text{BR}(\tau \to \mu\pi)$	$<$	5.8×10^{-8}
$\text{BR}(\mu \to 3e)$	$<$	$1.0 \times 10^{-12}/10^{-13}$	$\text{BR}(\tau \to \mu\rho)$	$<$	2×10^{-7}
$\text{BR}(\tau \to 3\mu)$	$<$	$1.9 \times 10^{-7}/10^{-8}$	$\text{BR}(\tau \to \mu\pi^+\pi^-)$	$<$	4.8×10^{-7}
$\text{BR}(\tau \to 3e)$	$<$	$2.0 \times 10^{-7}/10^{-8}$	$\text{BR}(\tau \to \mu\pi^0\pi^0)$	$<$	???
$\text{CR}(\mu - e, \text{Au})$	$<$	7×10^{-13}	$\text{BR}(\tau \to \mu K^+K^-)$	$<$	8.0×10^{-7}
$\text{CR}(\mu - e, \text{Ti})$	$<$	$4.3 \times 10^{-12}/\mathbf{10^{-18}}$	$\text{BR}(\tau \to \mu K^0\bar{K}^0)$	$<$	???

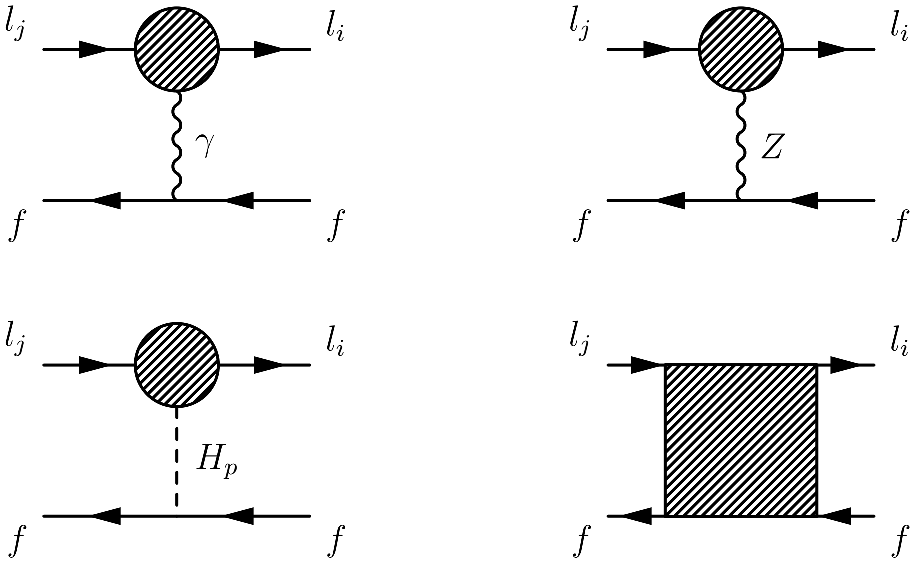
- ⋆ Measurement of LFV $\Rightarrow$ Window for new physics
- ⋆ Very sensitive to SUSY: if Majorana ν, Y_ν can be $\mathcal{O}(1)$
  Large Y_ν induce, via SUSY loops, large LFV rates
- ⋆ If no LFV found $\Rightarrow$

  Restrictions on SUSY and/or seesaw parameters

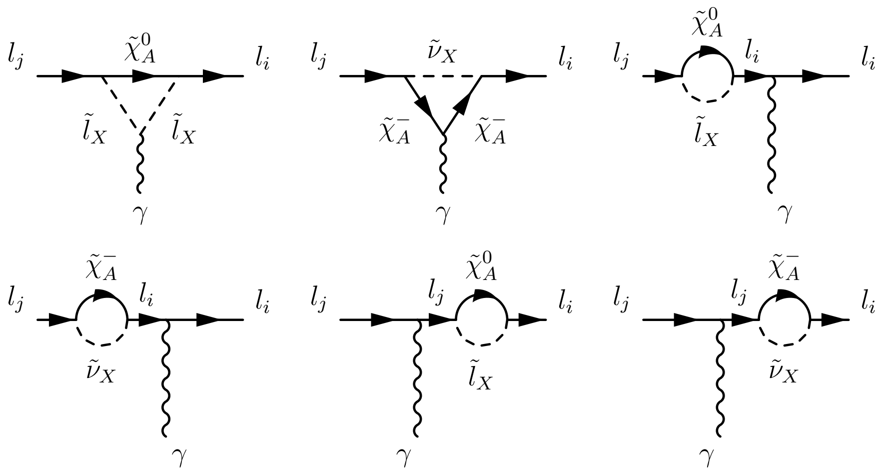
Our Work

- **Prediction of LFV rates within SUSY-seesaw:**
  - ⋆ all $l_j \to l_i\gamma$
  - ⋆ all $l_j \to 3l_i$
  - ⋆ some semileptonic tau decays:
    $\tau \to \mu PP,\ PP = \pi^+\pi^-, \pi^0\pi^0, K^+K^-, K^0\bar{K}^0$
    $\tau \to \mu P,\ P = \rho, \pi, \eta, \eta'$
  - ⋆ $\mu - e$ conversion in nuclei: Ti, Au,...
- **Full one-loop computation of LFV BRs**
- **Require compatibility with ν data**
- **Compare with present/future LFV bounds/sensitivities**
- **Explore sensitivity to SUSY and seesaw parameters**
- **Study impact of θ_{13} on LFV, specially $\mu - e$**
- **Study of correlated/un-correlated processes: competing future sensitivities?**

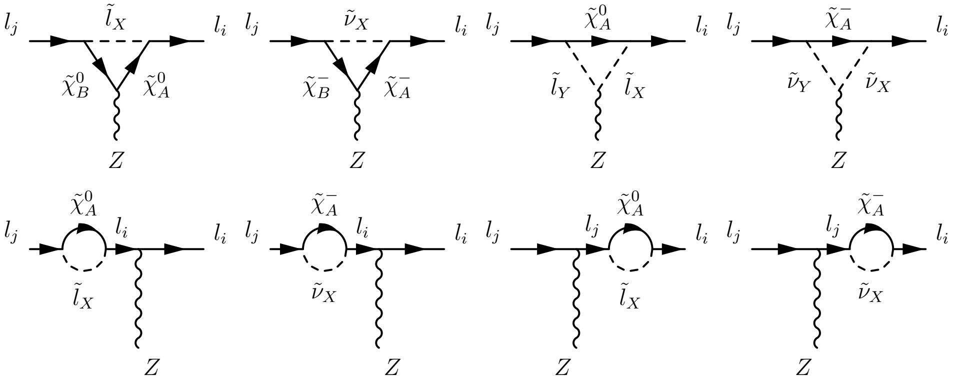
1-loop diagrams in $l_j \to 3l_i$, $\tau \to \mu\, P(P)$, $\mu - e$ conversion



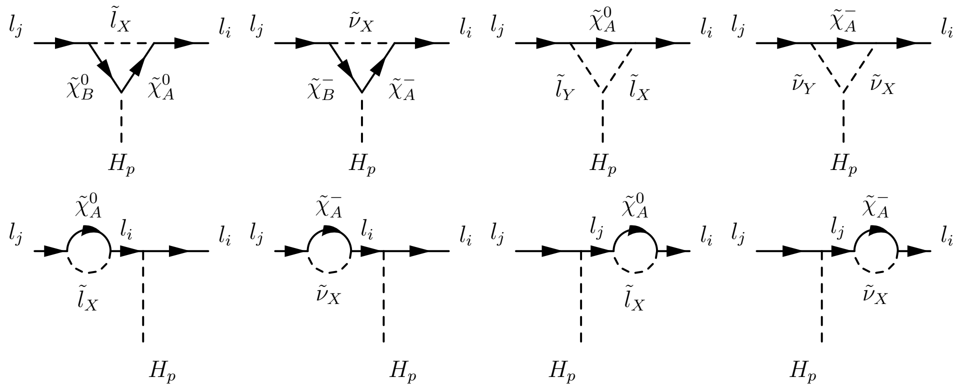
Generic



Photon-mediated



Z boson-mediated



H boson-mediated

Framework

- **Use seesaw (Type I) for ν mass generation**
- **Work within CMSSM + $3\nu_R$ (Majorana) + $3\tilde{\nu}_R$**
  Two scenarios for soft parameters at $M_X = 2 \times 10^{16}$ GeV:
  - ⋆ Universal soft Higgs masses: CMSSM-seesaw
    $(M_0, M_{1/2}, A_0, \tan\beta, \mathrm{sign}(\mu))$
  - ⋆ Non-universal soft Higgs masses: NUHM-seesaw
    $(M_0, M_{1/2}, M_{H_1}, M_{H_2}, A_0, \tan\beta, \mathrm{sign}(\mu))$
- LFV generated by 1-loop running from M_X to M_Z
  Full RGEs including ν and $\tilde{\nu}$ sectors (No Llog approx)
- Mass eigenstates for all SUSY and Higgs particles (No MIA approx)
- **Numerical estimates:**
  - ⋆ SPheno 2.2.2 (W.Porod) for int. of RGEs and SUSY spectrum
  - ⋆ Additional subroutines for all LFV processes (by us)
    Also subroutines for checks of BAU, EDM and $(g-2)_\mu$

Seesaw parameters versus neutrino data

SeeSaw equation: $m_\nu = -m_D^T {m_N}^{-1} m_D$

Solution: $$\boxed{m_D = i\sqrt{m_N^{diag}}\, R \sqrt{m_\nu^{diag}}\, U^\dagger_{MNS}}$$ [Casas, Ibarra ('01)]

R is a 3×3 complex matrix and orthogonal

$$R = \begin{pmatrix} c_2c_3 & -c_1s_3 - s_1s_2c_3 & s_1s_3 - c_1s_2c_3 \\ c_2s_3 & c_1c_3 - s_1s_2s_3 & -s_1c_3 - c_1s_2s_3 \\ s_2 & s_1c_2 & c_1c_2 \end{pmatrix}$$, $c_i = \cos\theta_i$, $s_i = \sin\theta_i$, $\theta_{1,2,3}$ complex

Parameters: θ_{ij},δ,α,β,m_{ν_i},m_{N_i},θ_i **(18)** ; m_{N_i}, θ_i drive the size of Y_ν

Hierarchical ν's : $m^2_{\nu_1} << m^2_{\nu_2} = \Delta m^2_{\text{sol}} + m^2_{\nu_1} << m^2_{\nu_3} = \Delta m^2_{\text{atm}} + m^2_{\nu_1}$

2 Scenarios

- Degenerate N's

$m_{N_1} = m_{N_2} = m_{N_3} = m_N$

- Hierarchical N's

$m_{N_1} << m_{N_2} << m_{N_3}$

Our choice of input parameters

Constrained MSSM $+3\nu_R + 3\tilde{\nu}_R +$ seesaw

- CMSSM:

$$\left\{\begin{array}{l} M_0, M_{1/2}, A_0 \text{ (at } M_X \sim 2\times 10^{16}\text{ GeV)} \\ \tan\beta = <H_2> / <H_1> \text{ (at EW scale)} \\ \text{sign}(\mu) \text{ (}\mu\text{ derived from EW breaking)} \end{array}\right\} \text{Choose SPS points}$$

- NUHM: $(M_0, M_{1/2}, M_{H_1}, M_{H_2}, A_0, \tan\beta, \text{sign}(\mu))$

Choose $M_0 = M_{1/2},\ M^2_{H_1} = M_0^2(1+\delta_1),\ M^2_{H_2} = M_0^2(1+\delta_2)$

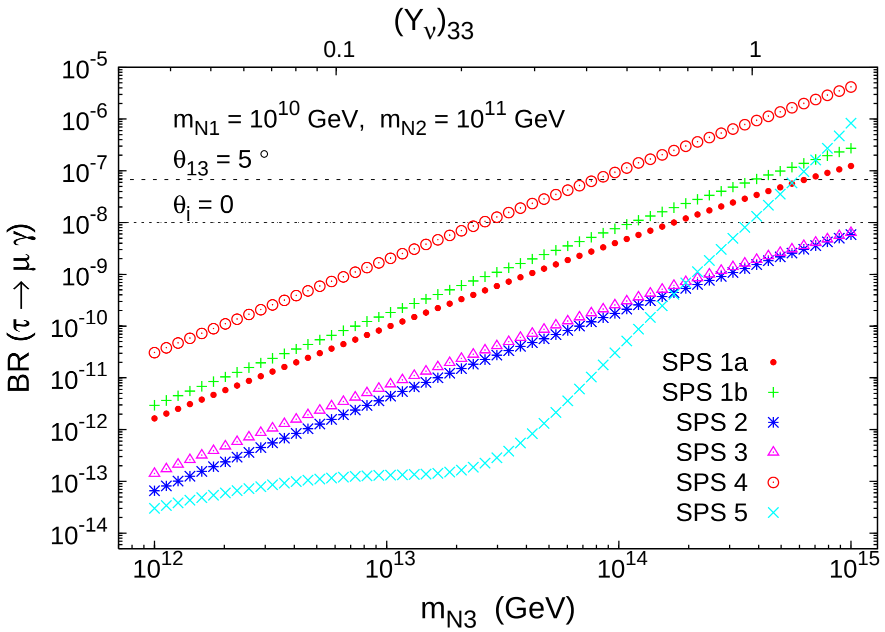
- Seesaw parameters $\left\{\begin{array}{l} m_{\nu_{1,2,3}} \text{ (set by data)} \\ m_{N_{1,2,3}} \text{ (input)} \\ U_{MNS} \text{ (set by data)} \\ R(\theta_1,\ \theta_2,\ \theta_3) \text{ (input)} \end{array}\right.$

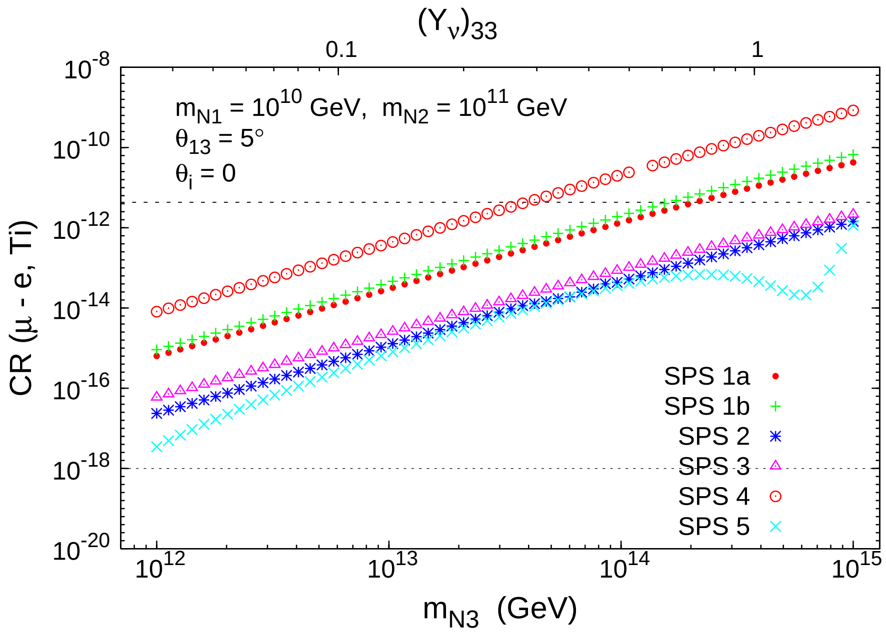
- For numerical estimates:

$$(\Delta m^2)_{12} = \Delta m^2_{\text{sol}} = 8\times 10^{-5}\ \text{eV}^2$$
$$(\Delta m^2)_{23} = \Delta m^2_{\text{atm}} = 2.5\times 10^{-3}\text{eV}^2$$
$$\theta_{12} = 30^o;\ \theta_{23} = 45^o;\ \delta = \alpha = \beta = 0;\ \ 0 \le \theta_{13} \le 10^o$$
$$250\text{ GeV} < M_0, M_{1/2} < 1000\text{ GeV},\ -500\text{ GeV} < A_0 < 500\text{ GeV}$$
$$5 < \tan\beta < 50,\ -2 < \delta_{1,2} < 2$$

Results for CMSSM-seesaw

The most relevant paramenter: Hierarchical: m_{N_3} / Degenerate: m_N





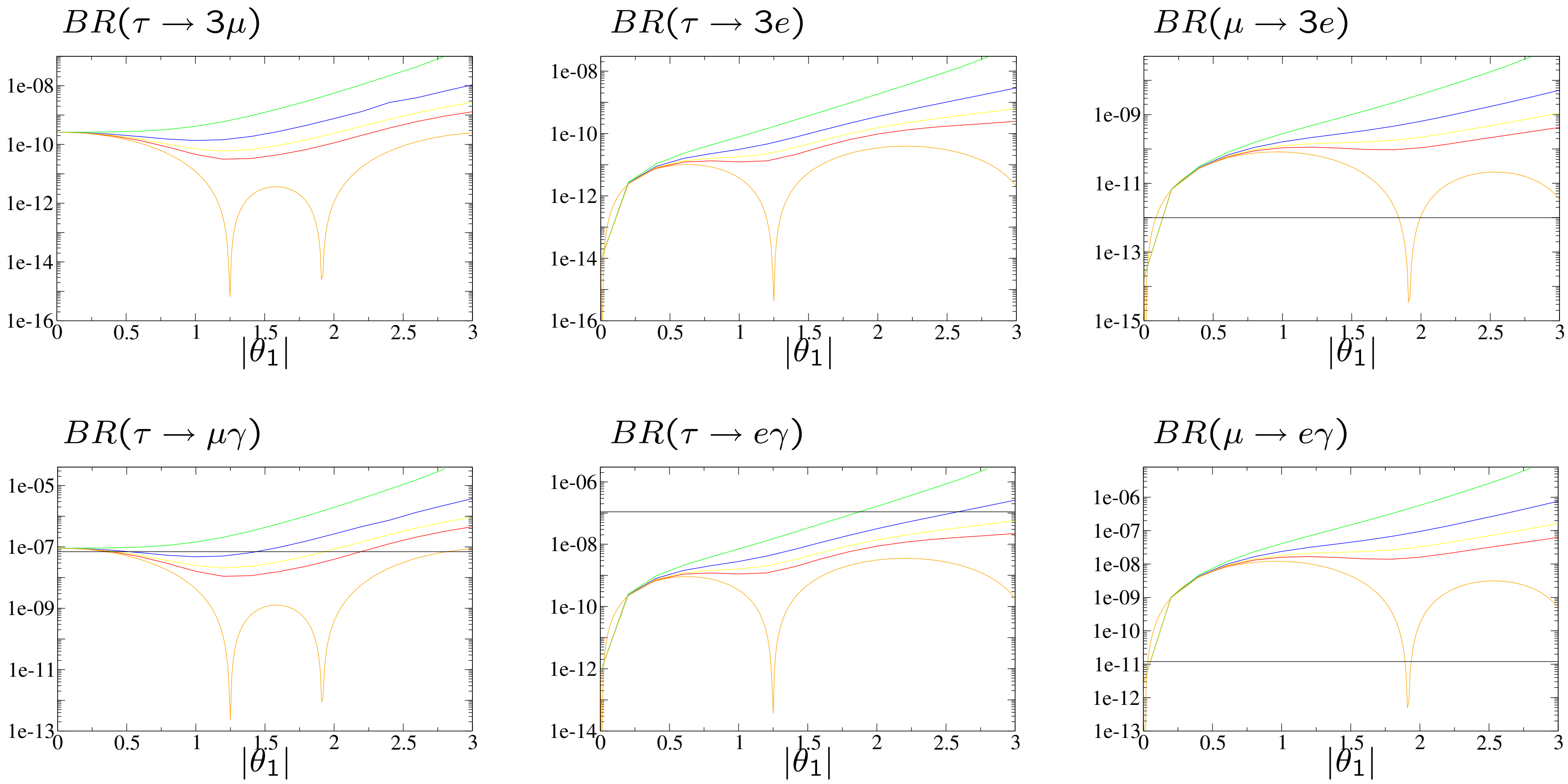
- ⋆ Most observables reach experimental limit at $m_{N_3} \in \left[10^{13}, 10^{15}\right]$ GeV, corresponding to $(Y_\nu)_{33,32} \sim 0.1 - 1$
- ⋆ BR$\sim |m_{N_3} \log m_{N_3}|^2$ except for SPS5: Llog fails in $\sim 10^4$!!
- ⋆ Present: the most restrictive one is $\mu \to e\gamma$ (if $\theta_{13} \neq 0$)
  Bounds for SPS1a $m_{N_3} < 10^{13} - 10^{14}$ GeV
  Next are $\mu - e$, $\mu \to 3e$; $\tau \to \mu\gamma$ competitive if $\theta_{13} \simeq 0$ and N's hier.
- ⋆ Future: $\mu - e$ conversion the best: sensitive to $m_{N_3} > 10^{12}$ GeV

Large Yukawa couplings: role of θ_i

Hierarchical m_{N_i} and complex θ_i

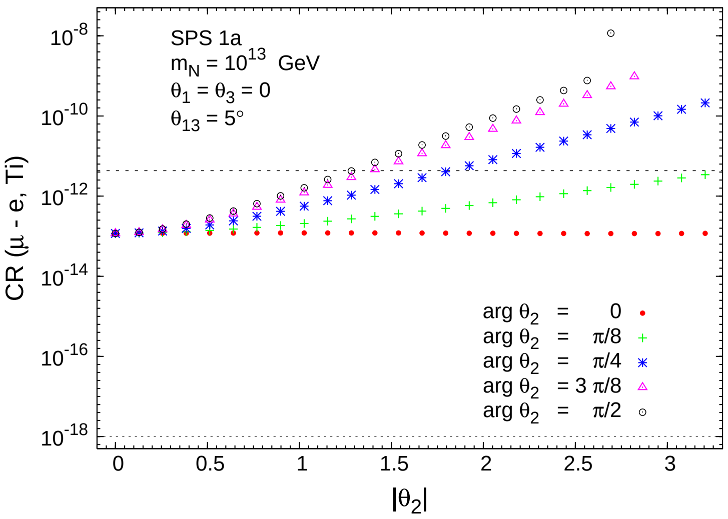
$(m_{N_1}, m_{N_2}, m_{N_3}) = (10^8, 2\times 10^8, 10^{14})$ GeV, $\arg(\theta_1) = 0, \pi/10, \pi/8, \pi/6, \pi/4\ (\theta_2 = \theta_3 = 0)$

SPS 4

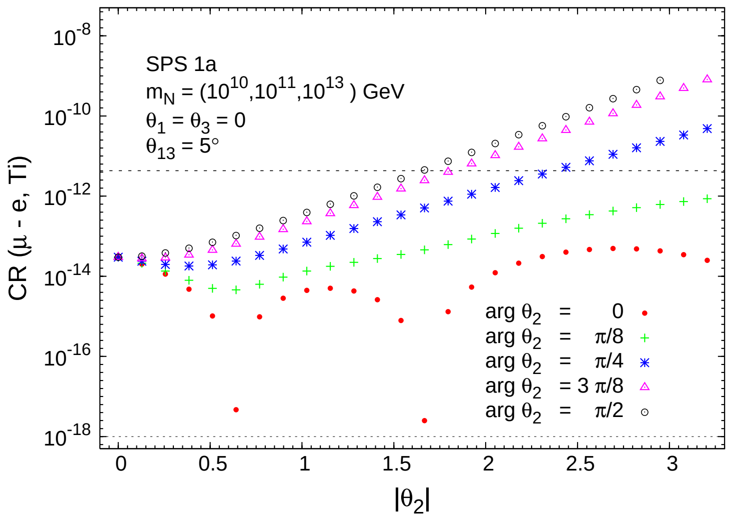


- ⋆ BRs for $0 < |\theta_i| < \pi$, $0 < \arg\theta_i < \pi/2$ can increase up to $10^2 - 10^4$ respect to $\theta_i = 0$
- ⋆ **BRs above present experimental bounds**: mainly $\mu \to e\gamma$, $\mu \to 3e$ and $\tau \to \mu\gamma$
- ⋆ Similar results for θ_2. BRs nearly constant with θ_3 in the case of hier. N's

Role of θ_i (cont.)

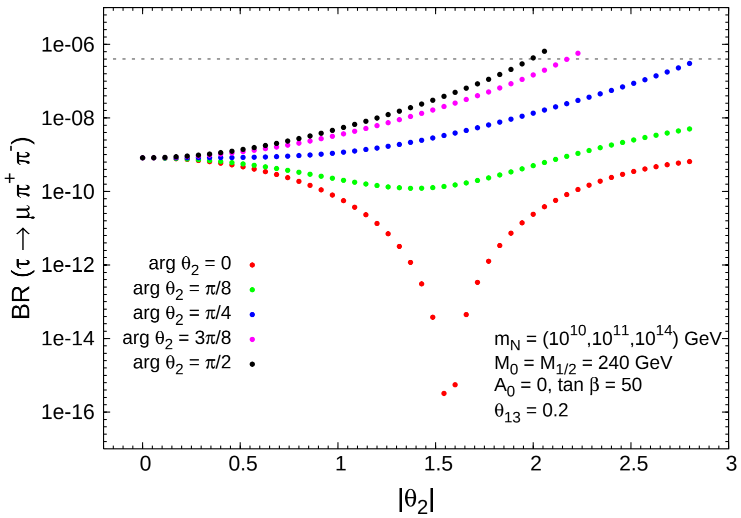


N's Deg. Eq. dep. all θ_i



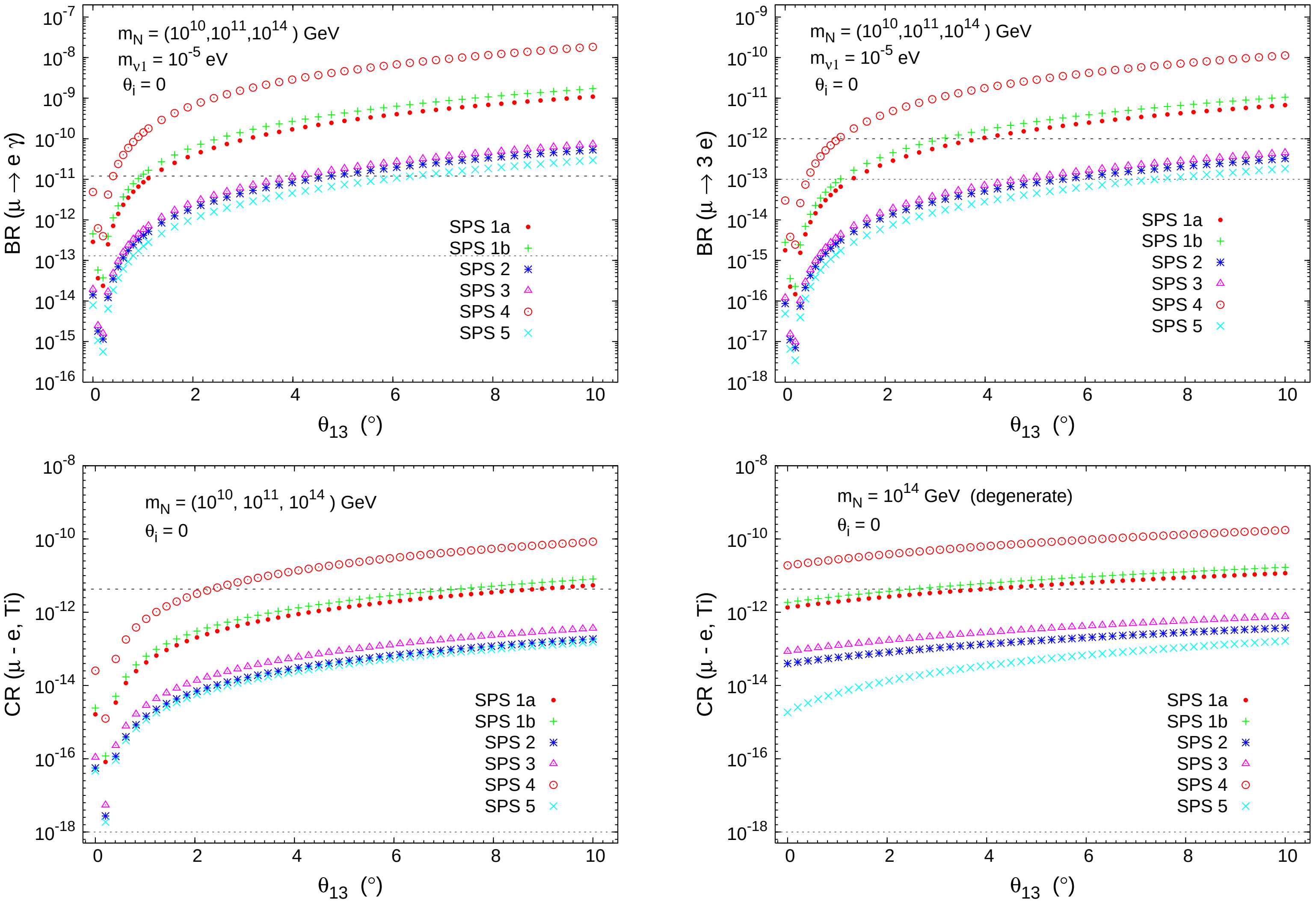
N's Hier. relevant: $\theta_{1,2}$

★ CR($\mu - e$) reach exp. bound even for $m_N = 10^{13}$ GeV if complex $\theta_i \neq 0$



★ BR($\tau \to \mu\pi^+\pi^-$) reach exp. bound at high $m_{N_3} \sim 10^{14}$ GeV and large complex $\theta_{1,2}$

High sensitivity to θ_{13}: the case $\theta_i = 0$

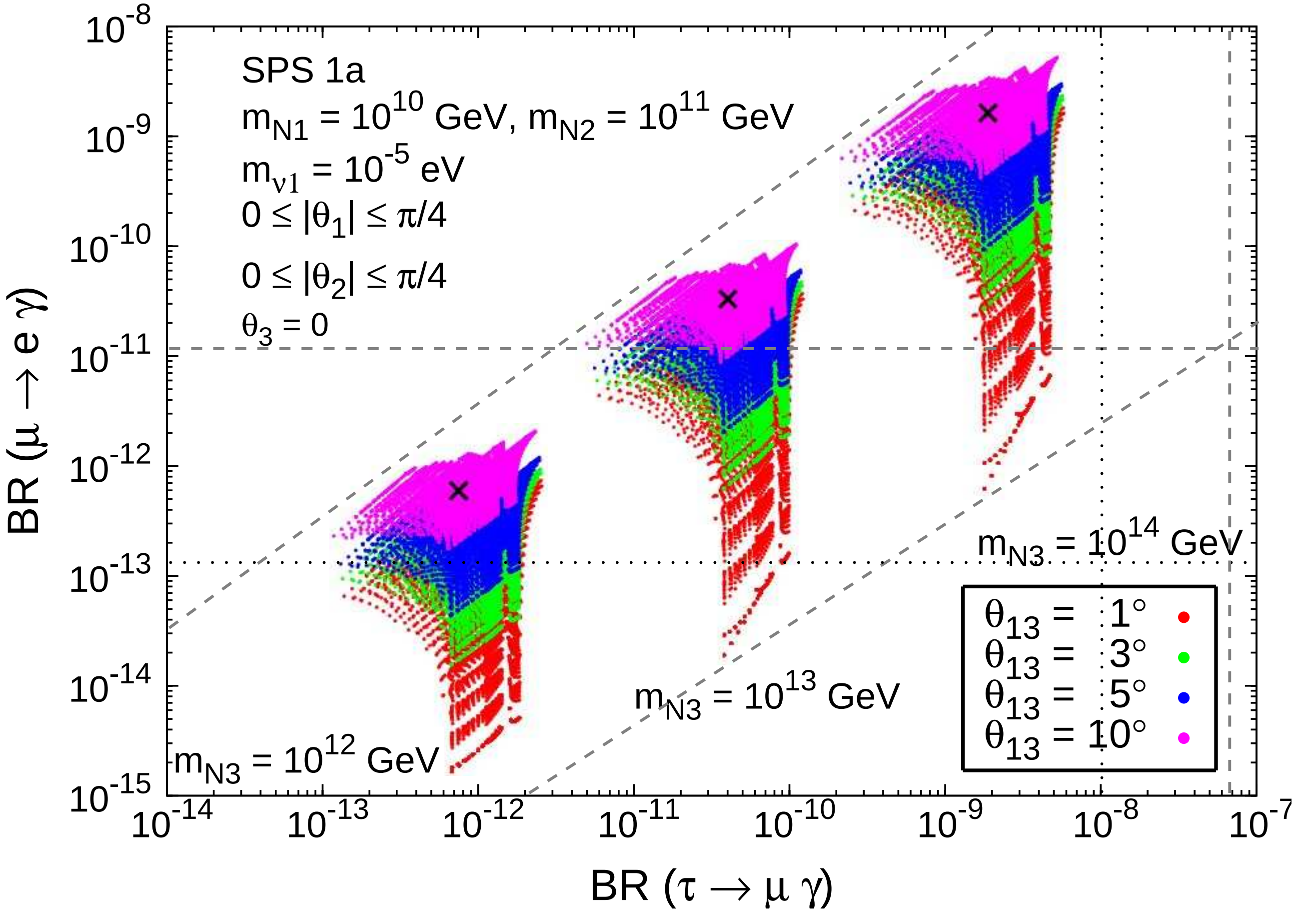


- ⋆ $\mu \to e\gamma$, $\mu \to 3e$, $\mu - e$ extremely sensitive to θ_{13} if Hier.N's: BRs $\times 10^5$ in $0^\circ < \theta_{13} < 10^\circ$
- ⋆ $\tau \to e\gamma$, $\tau \to 3e$ also, but not within exp.reach ($\tau \to \mu\gamma$, $\tau \to 3\mu$ are not!!)
- ⋆ Sensitivity of $\mu \to e\gamma$ clearly **within exp. reach**: $\mathrm{BR}_{\text{all SPS}} > \mathrm{BR}_{\text{exp}}^{\text{present}}$ for $\theta_{13} \gtrsim 5^o$!!

Impact of θ_{13} on LFV processes

(All plotted points lead to 'viable BAU', respect EDM bounds, OK with $(g-2)_\mu$)

$(-\pi/4 \lesssim \arg\theta_1 \lesssim \pi/4,\ 0 \lesssim \arg\theta_2 \lesssim \pi/4)$



Correlations in LFV BRs help: similar dependence on m_{N_3} and $\tan\beta$

MEGA bound already disfavours $\theta_{13} \gtrsim 10^o(2^o)$ for $m_{N_3} \gtrsim 10^{13}(10^{14})$ GeV

A measurement of BRs and θ_{13} will provide some insight into m_{N_3} !!

Results for NUHM-seesaw

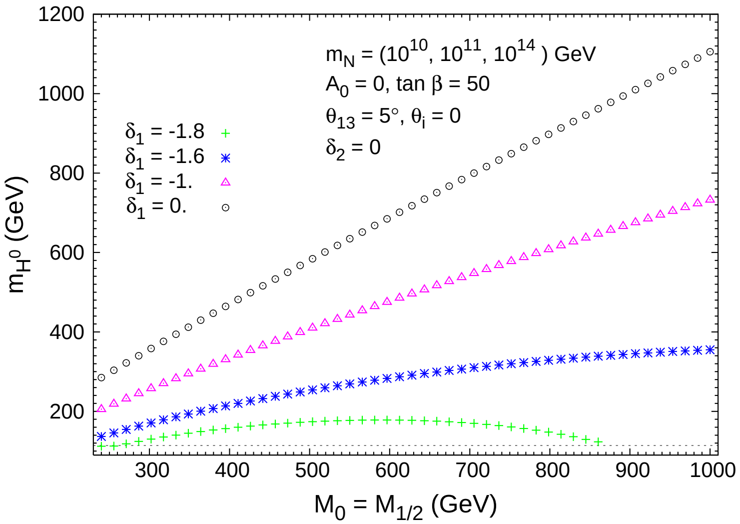
- Looking for solutions with light Higgs sector as functions of non-universal soft parameters: $M^2_{H_{1,2}} = M^2_0(1+\delta_{1,2})$, $-2 < \delta_{1,2} < 2$

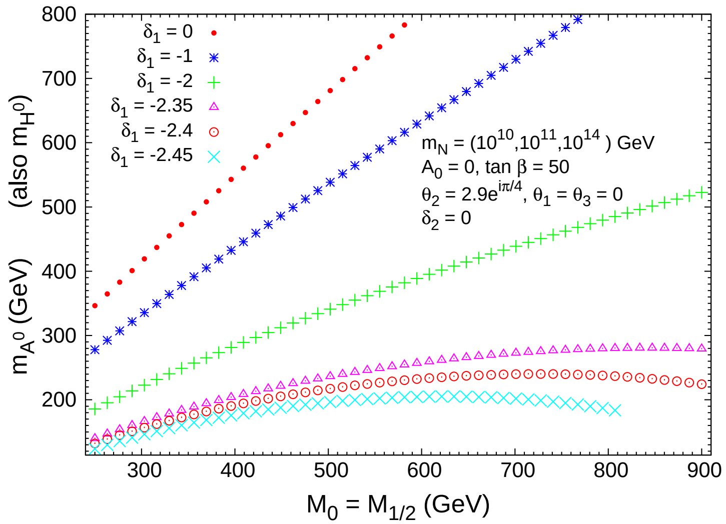
- Study of correlation loss between related LFV observables due to Higgs-mediated contributions that can dominate the photon-mediated ones
  Relevant for:
  - ⋆ $\mu - e$ conversion in nuclei versus $\mu \to e\gamma$
  - ⋆ $\tau \to \mu PP$ versus $\tau \to \mu\gamma$
  - ⋆ $\tau \to \mu P$ versus $\tau \to \mu\gamma$

  due to large Higgs couplings to strange quarks (not relevant for $l_j \to 3l_i$)

- Explore ratios of observables looking for enhacements respect to the universal case

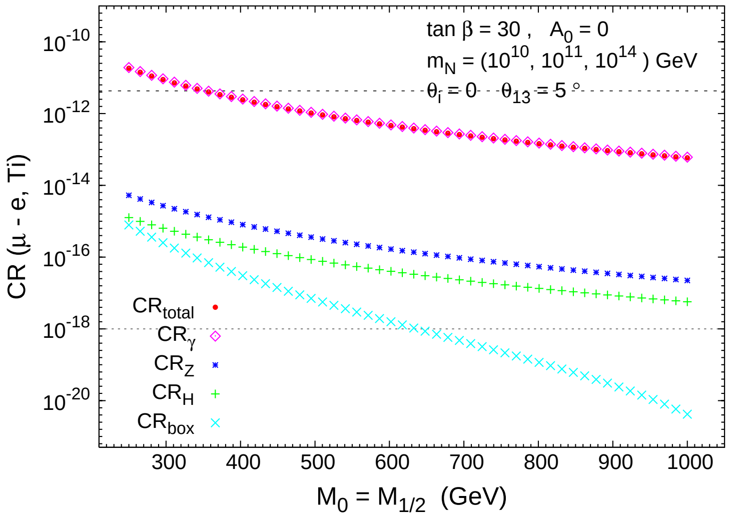
Light Higgs sector in NUHM-seesaw



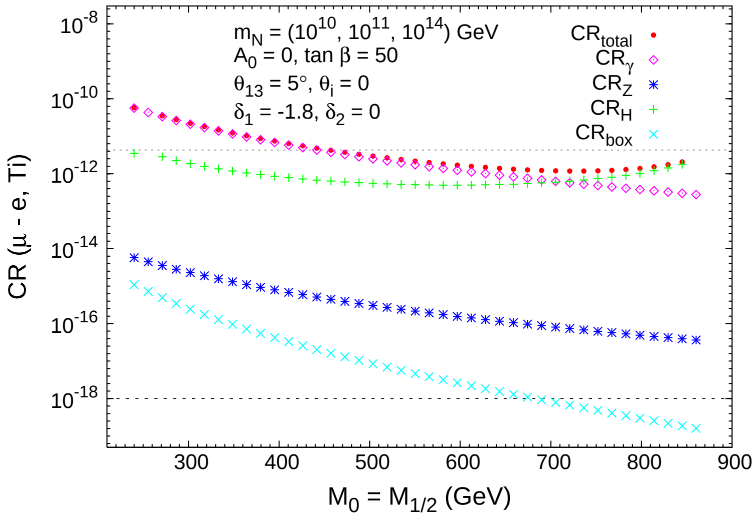


- ⋆ We find solutions with **light Higgs particles** even for large $M_0 = M_{1/2} = M_{\text{SUSY}}$
- ⋆ Choice of δ_1 and δ_2 not arbitrary: **correct EWSB**
- ⋆ Ex.: for $M_{\text{SUSY}} = 850$ GeV, $\tan\beta = 50$, $A_0 = 0$, $\delta_1 = -1.8$, $\delta_2 = 0$, we find:
  light Higgs: $m_{H^0} = 127$ GeV, $m_{h^0} = 123$ GeV, $m_{A^0} = 127$ GeV, $m_{H^+} = 155$ GeV
  heavy SUSY: $m_{\tilde{l}_1} = 734$ GeV, $m_{\tilde{\nu}_1} = 971$ GeV, $m_{\tilde{\chi}_1^-} = 687$ GeV, $m_{\tilde{\chi}_1^0} = 362$ GeV

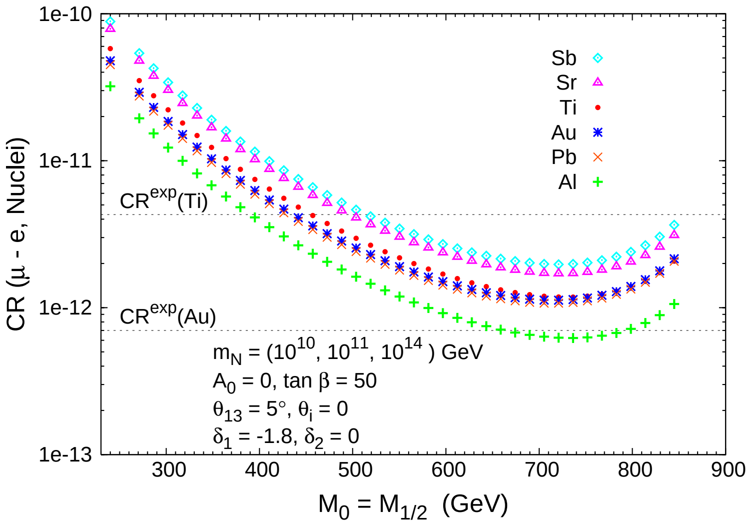
$\mu - e$ conversion in nuclei: universality versus non-universality



universality: γ dominance



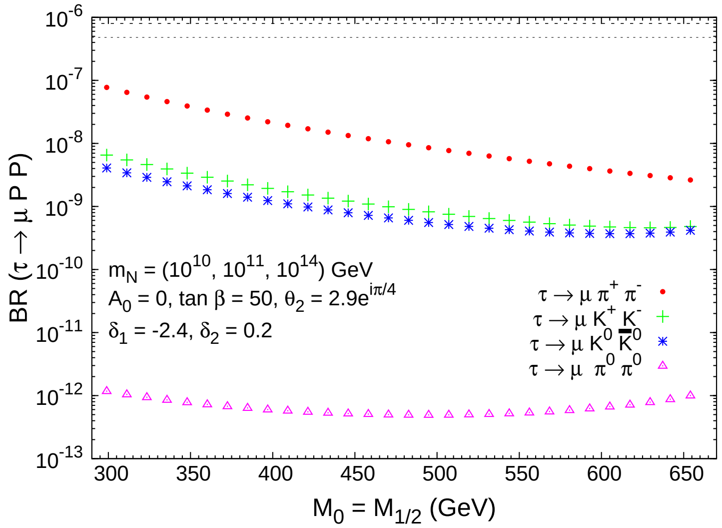
non-universality: H^0 dominance

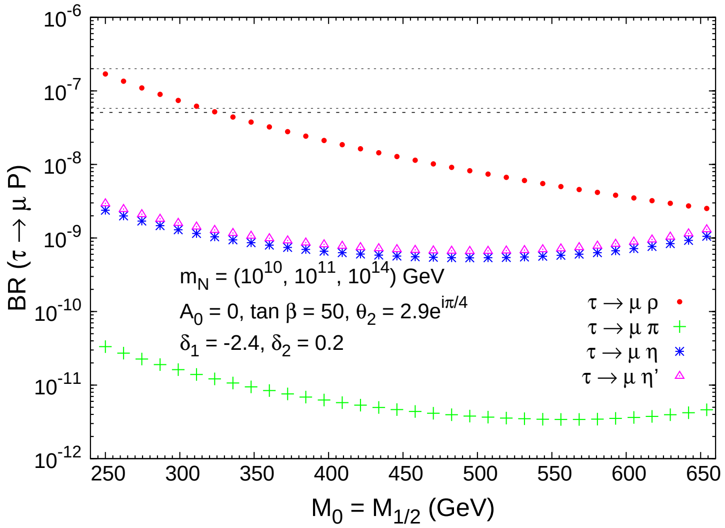


★ H^0 dominance $\Rightarrow$ heavy SUSY spectra do not decouple in $\mu - e$ conversion

CR($\mu - e$, Au) above present experimental bound even for heavy SUSY

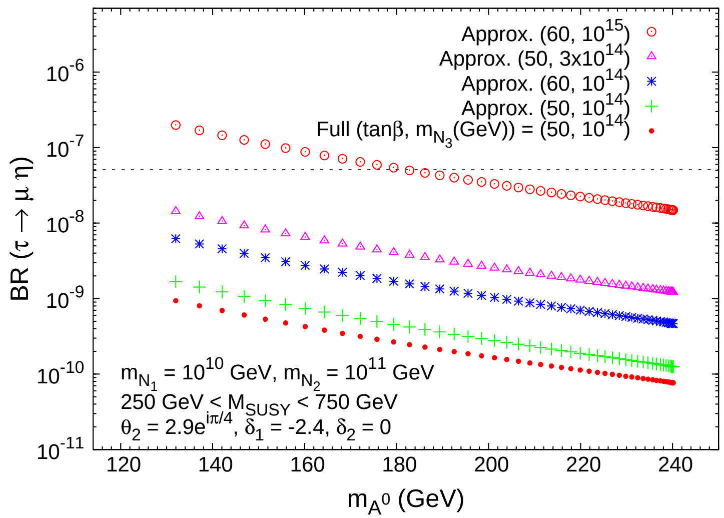
LFV semileptonic tau decay rates





★ Heavy SUSY do not decouple in $\tau \to \mu P(P)$ for scenarios with Higgs-dominance

$\tau \to \mu\rho$ most competitive channel for large θ_i



★ Ratio of $\tau \to \mu P$ to $\tau \to \mu PP$ can be a factor 10 larger than in CMSSM

If SUSY exists:
LFV observables constitute an interesting lab that, together with low-energy neutrino data, can provide some insight into the heavy neutrino sector and seesaw parameters. Also into Higgs sector if NUHM like scenarios