Testing Supersymmetry with Lepton Flavor Violating τ and μ decays

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VIII Jornadas en Física de Altas Energías

XXX Bienal de la RSEF, Septiembre 2005

Motivation

⋆ Strong evidence of lepton flavor changing neutrino oscillations in neutrino data

- Neutrinos have non-zero masses
- Lepton number violating processes can occur (Leptogenesis...)
- Lepton flavor violating processes can occur ($\mu \to e\gamma$...)

⋆ Lepton Flavor Violating processes:
Window to look for new phyics

- There are not LFV processes within SM $(m_\nu = 0)$

⋆ We assume Majorana ν_R reponsible for $m_\nu \neq 0$

⋆ Seesaw mechanism for neutrino mass generation

⋆ Large LFV rates in SUSY-seesaw models due to flavor mixing in soft slepton masses

- many studies on $\mu \to e\gamma$, τ rare decays, $Z \to \tau\bar{\mu}$...

⋆ We study LFV decays of τ and μ within the CMSSM-seesaw:

$\tau^- \to \mu^-\mu^-\mu^+$, $\tau^- \to e^-e^-e^+$, $\mu^- \to e^-e^-e^+$

- Full one-loop computation
- Parallel study of $l_j \to l_i\gamma$, $i \neq j$, to insure compatibility with data

LFV in the MSSM-seesaw

- We assume universal soft-SUSY-breaking masses at large energies $M_X >> m_M$,

  $m_M =$ Majorana ν_R mass; $M_X = 2 \times 10^{16}\,\mathrm{GeV}$

$$(m_{\tilde{L}})^2_{ij} = M_0^2 \delta_{ij},\ (m_{\tilde{E}})^2_{ij} = M_0^2 \delta_{ij},\ (m_{\tilde{M}})^2_{ij} = M_0^2 \delta_{ij},$$
$$M_1 = M_2 = M_{1/2},\ M_{H_1} = M_{H_2} = M_0$$

- The RGE-running down to m_M generates flavor non-diagonal soft masses due to Y_ν,

$$(\Delta m^2_{\tilde{L}})_{ij} = -\frac{1}{8\pi^2}(3M_0^2 + A_0^2)(Y_\nu^* L Y_\nu^T)_{ij}$$
$$(\Delta A_l)_{ij} = -\frac{3}{16\pi^2} A_0 Y_{l_i} (Y_\nu^* L Y_\nu^T)_{ij}$$
$$(\Delta m^2_{\tilde{E}})_{ij} = 0\ ;\ L_{kl} \equiv \log\left(\frac{M_X}{m_{M_k}}\right)\delta_{kl}$$

- We assume three ν_R and use the parametrization of A. Casas and A. Ibarra (Nucl.Phys.B 618(2001)171)

Flavor diagonal basis for l and ν_R; Flavor non-diagonal Y_ν,

$$Y_{l_i} = \frac{m_{l_i}}{v_1},\ (Y_\nu)_{ij} = \frac{(m_D)_{ij}}{v_2},\ v_{(1,2)} = v(\cos\beta, \sin\beta)$$
$$m_D^T = i m_N^{diag\,1/2} R m_\nu^{diag\,1/2} U^+_{MNS}\ ;\ \ R^T R = 1$$

R complex matrix; m_N^{diag}, m_ν^{diag} physical masses

Seesaw and physical parameters setup

⋆ We consider two scenarios, compatible with data:

- quasi-degenerate light and degen. heavy neutrinos:

$$m_{\nu_1} = 0.2\, eV\,, m_{\nu_2} = m_{\nu_1} + \frac{\Delta m^2_{sol}}{2m_{\nu_1}}\,, m_{\nu_3} = m_{\nu_1} + \frac{\Delta m^2_{atm}}{2m_{\nu_1}},$$
$$m_{N_1} = m_{N_2} = m_{N_3} = m_N$$

- hierarchical light and hierarchical heavy neutrinos:

$$m_{\nu_1} \simeq 0\, eV\,, m_{\nu_2} = \sqrt{\Delta m^2_{sol}}\,, m_{\nu_3} = \sqrt{\Delta m^2_{atm}},$$
$$m_{N_1} \leq m_{N_2} < m_{N_3}$$

⋆ We take input values for Δm^2 and U_{MNS} :

$$\sqrt{\Delta m^2_{sol}} = 0.008\, eV,\ \sqrt{\Delta m^2_{atm}} = 0.05\, eV; \delta = \alpha = \beta = 0$$
$$\theta_{12} = \theta_{sol} = 30^o,\ \theta_{23} = \theta_{atm} = 45^o,\ \theta_{13} = 0^o,$$

⋆ We compute the LFV τ and μ decay rates for various choices of $m_{N_{1,2,3}}$ and R

$$R = \begin{pmatrix} c_2c_3 & -c_1s_3 - s_1s_2c_3 & s_1s_3 - c_1s_2c_3 \\ c_2s_3 & c_1c_3 - s_1s_2s_3 & -s_1c_3 - c_1s_2s_3 \\ s_2 & s_1c_2 & c_1c_2 \end{pmatrix}$$

$c_i = \cos\theta_i;\ s_i = \sin\theta_i,\ \theta_{1,2,3} =$complex angles

Parameters in R constrained by perturbativity of Y_ν

Favourable values for Baryogenesis $m_{N_{1,2,3}} > 10^8\,\mathrm{GeV}$

MSSM parameters setup

⋆ We work in the physical basis:

Involved SUSY particles in the one-loop diagrams: $\chi^-, \chi^0, \tilde{l}, \tilde{\nu}$

- Charge slepton sector:

  Once leptons and neutrinos are rotated to the physical basis, the slepton mass matrices are NOT diagonal: lepton-slepton misalignment

$$M_{\tilde{l}}^2 = \begin{pmatrix} M_{LL}^{ee\,2} & M_{LR}^{ee\,2} & M_{LL}^{e\mu\,2} & M_{LR}^{e\mu\,2} & M_{LL}^{e\tau\,2} & M_{LR}^{e\tau\,2} \\ M_{RL}^{ee\,2} & M_{RR}^{ee\,2} & M_{RL}^{e\mu\,2} & M_{RR}^{e\mu\,2} & M_{RL}^{e\tau\,2} & M_{RR}^{e\tau\,2} \\ M_{LL}^{\mu e\,2} & M_{LR}^{\mu e\,2} & M_{LL}^{\mu\mu\,2} & M_{LR}^{\mu\mu\,2} & M_{LL}^{\mu\tau\,2} & M_{LR}^{\mu\tau\,2} \\ M_{LR}^{\mu e\,2} & M_{RR}^{\mu e\,2} & M_{RL}^{\mu\mu\,2} & M_{RR}^{\mu\mu\,2} & M_{RL}^{\mu\tau\,2} & M_{RR}^{\mu\tau\,2} \\ M_{LL}^{\tau e\,2} & M_{LR}^{\tau e\,2} & M_{LL}^{\tau\mu\,2} & M_{LR}^{\tau\mu\,2} & M_{LL}^{\tau\tau\,2} & M_{LR}^{\tau\tau\,2} \\ M_{RL}^{\tau e\,2} & M_{RR}^{\tau e\,2} & M_{RL}^{\tau\mu\,2} & M_{RR}^{\tau\mu\,2} & M_{RL}^{\tau\tau\,2} & M_{RR}^{\tau\tau\,2} \end{pmatrix}$$

referred to $(\tilde{e}_L, \tilde{e}_R, \tilde{\mu}_L, \tilde{\mu}_R, \tilde{\tau}_L, \tilde{\tau}_R)$

$$M_{LL}^{ij\,2} = m_{\tilde{L},ij}^2 + \frac{1}{2}v_1^2\left(Y_l^\dagger Y_l\right)_{ij} + m_Z^2\cos 2\beta\left(-\frac{1}{2}+\sin^2\theta_W\right)\delta_{ij}$$

$$M_{RR}^{ij\,2} = m_{\tilde{E},ij}^2 + \frac{1}{2}v_1^2\left(Y_l^\dagger Y_l\right)_{ij} - m_Z^2\cos 2\beta\sin^2\theta_W\delta_{ij}$$

$$M_{LR}^{ij\,2} = \frac{1}{\sqrt{2}}\left(v_1\left(A_l^{ij}\right)^* - \mu Y_l^{ij}\right)$$

$$M_{RL}^{ij\,2} = \left(M_{LR}^{ij\,2}\right)^*, \qquad i,j = e,\mu,\tau$$

- Sneutrino sector: ($\tilde{\nu}_R$ decouple)

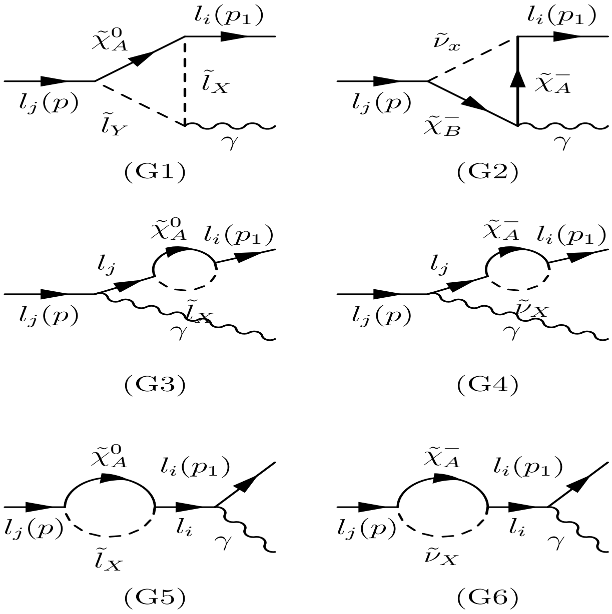
$$M_{\tilde{\nu}}^2 = \begin{pmatrix} m_{\tilde{L},e}^2 + \frac{1}{2}m_Z^2\cos 2\beta & m_{\tilde{L},e\mu}^2 & m_{\tilde{L},e\tau}^2 \\ m_{\tilde{L},\mu e}^2 & m_{\tilde{L},\mu}^2 + \frac{1}{2}m_Z^2\cos 2\beta & m_{\tilde{L},\mu\tau}^2 \\ m_{\tilde{L},\tau e}^2 & m_{\tilde{L},\tau\mu}^2 & m_{\tilde{L},\tau}^2 + \frac{1}{2}m_Z^2\cos 2\beta \end{pmatrix}$$

referred to $(\tilde{\nu}_{eL}, \tilde{\nu}_{\mu L}, \tilde{\nu}_{\tau L})$

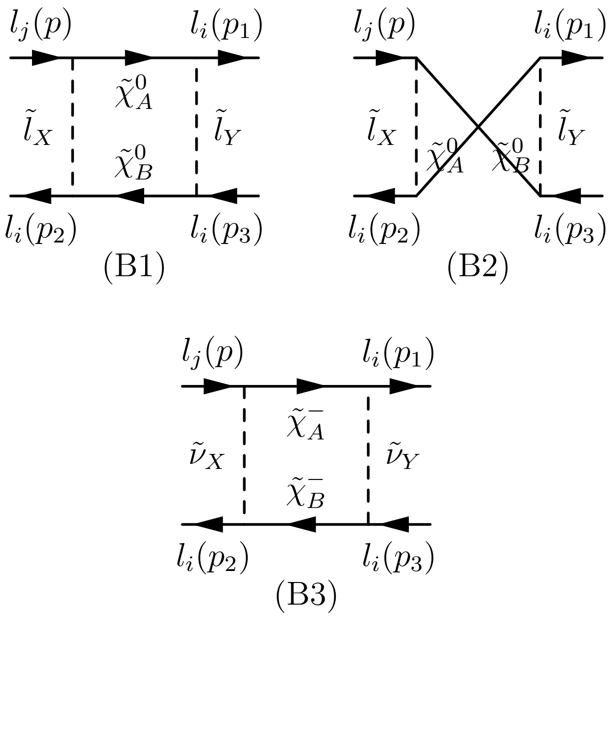
⋆ Soft parameters from RGE-running down to EW scale (SPheno programme)

⋆ μ from EW breaking condition

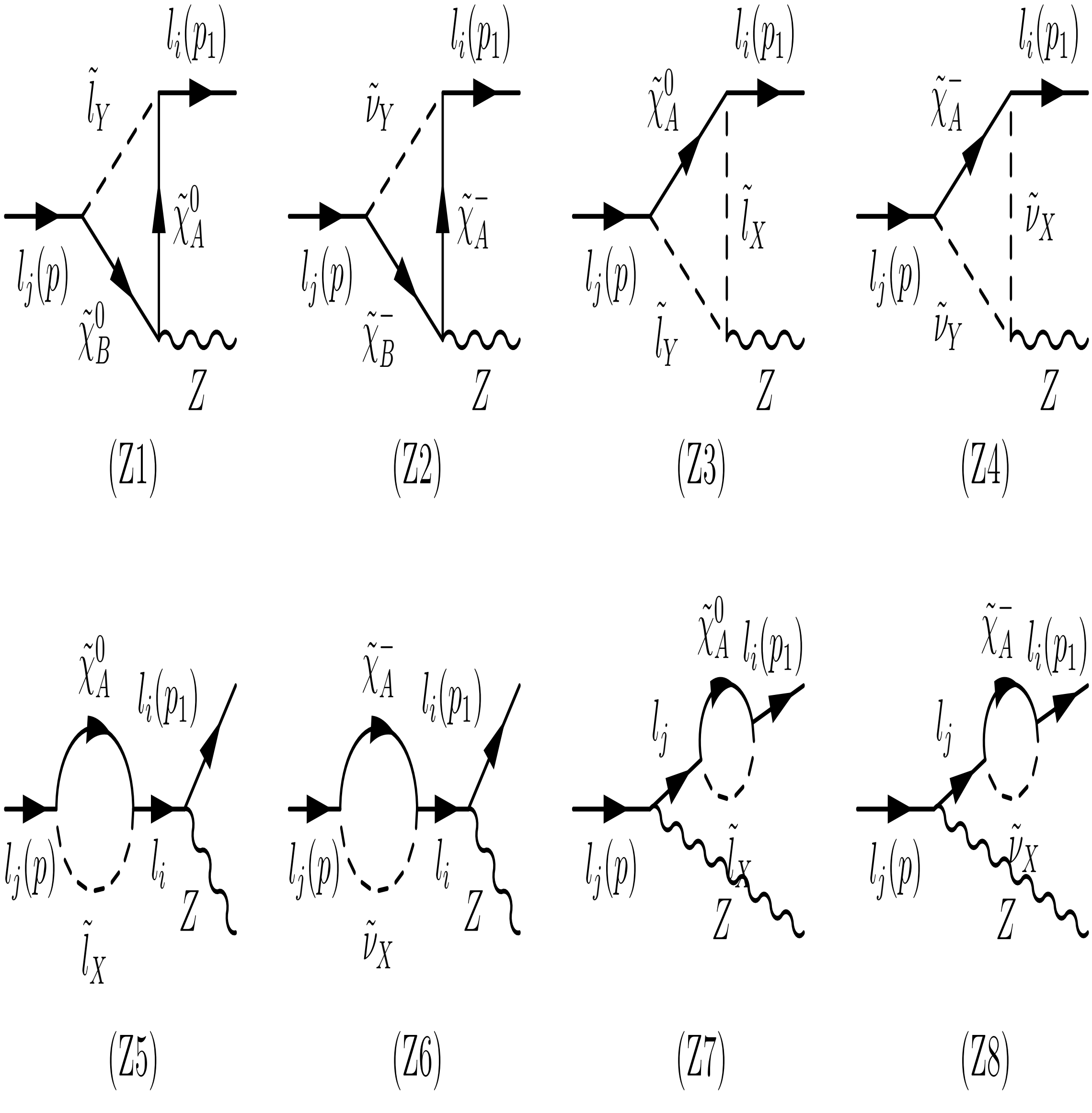
γ-penguin diagrams



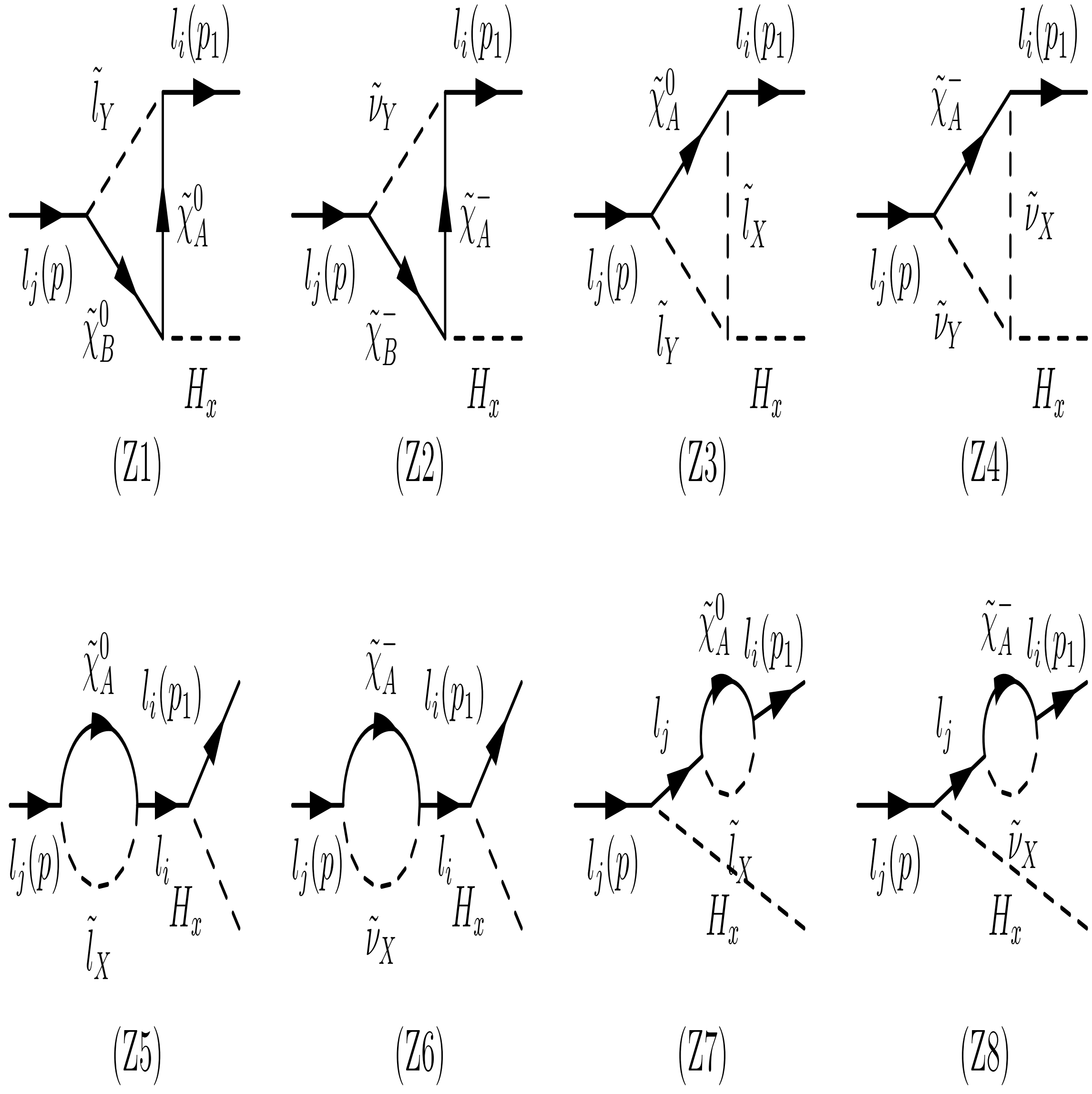
Box-type diagrams



Z-penguin diagrams

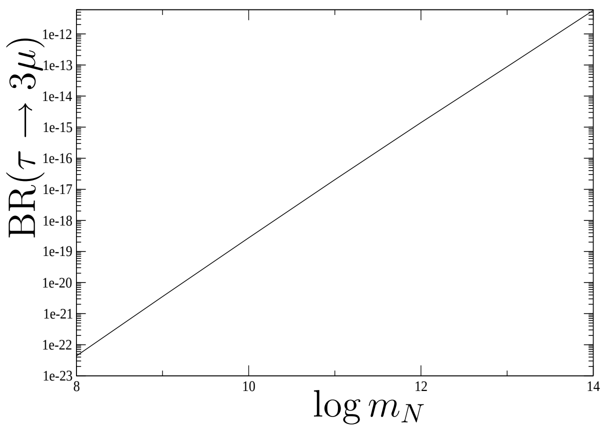


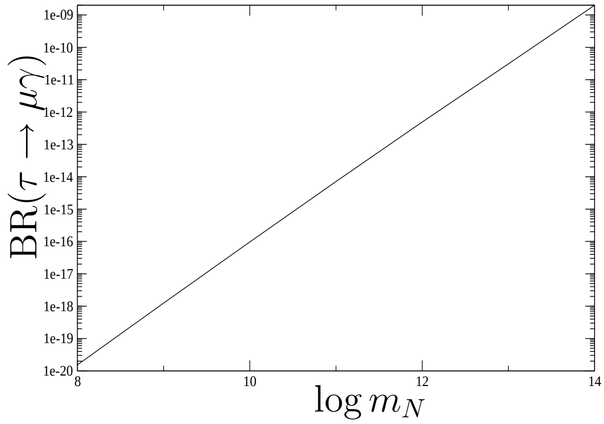
H-penguin diagrams

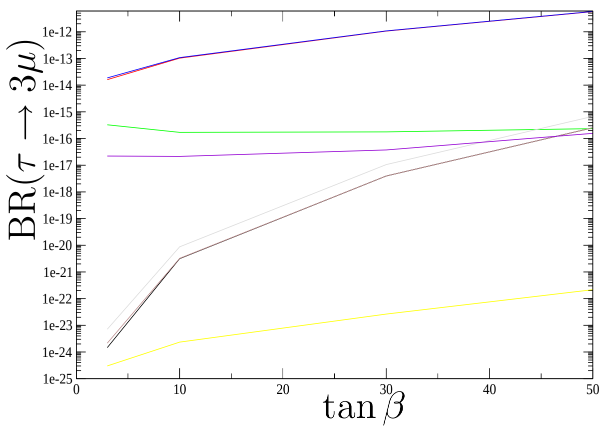


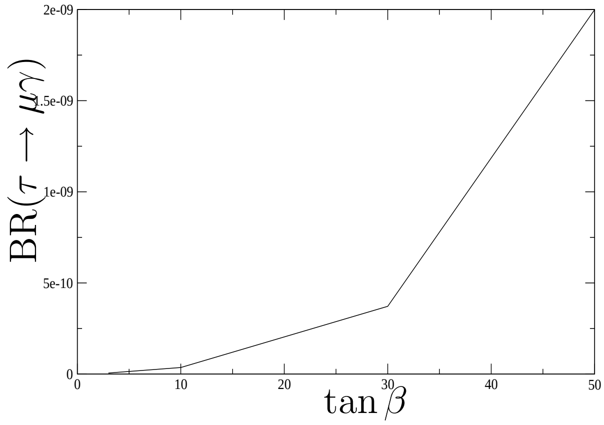
Branching ratios dependence with m_N and $\tan\beta$ degenerate m_{N_i} and real R

Explored values: $10^8 \leq m_N(\mathrm{GeV}) \leq 10^{14}$
$(M_0, M_{1/2}, A_0) = (400, 300, 0)$ GeV









- ⋆ All rates grow with $m_N(\mathrm{GeV})$ as expected
- ⋆ Total rates grow as $(\tan\beta)^2$
- ⋆ $BR(\tau^- \to \mu^-\mu^-\mu^+) < 10^{-11}$, $\tan\beta < 50$
- ⋆ $BR(\tau \to \mu\gamma)$ below exp. limits: 7×10^{-8} for $m_N < 10^{14}$ GeV
- ⋆ Smaller rates for $\tau \to 3e$, $\mu \to 3e$, $\tau \to e\gamma$, $\mu \to e\gamma$

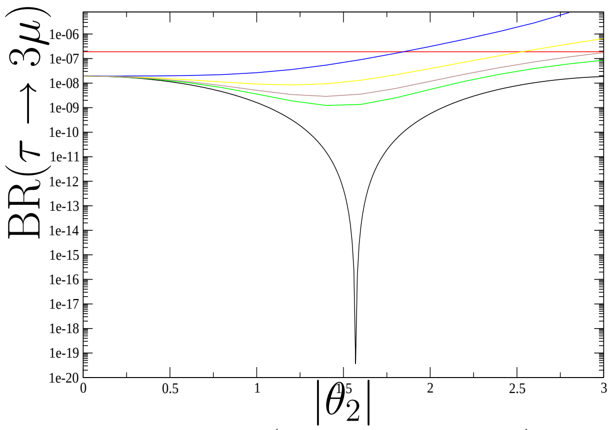
Branching ratios dependence with R

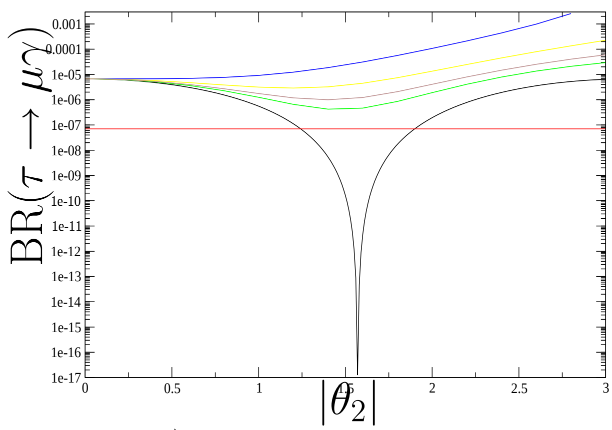
hierarchical neutrinos

$$(m_{N_1}, m_{N_2}, m_{N_3}) = (10^8, 2\times 10^8, 10^{14})\,\mathrm{GeV}$$

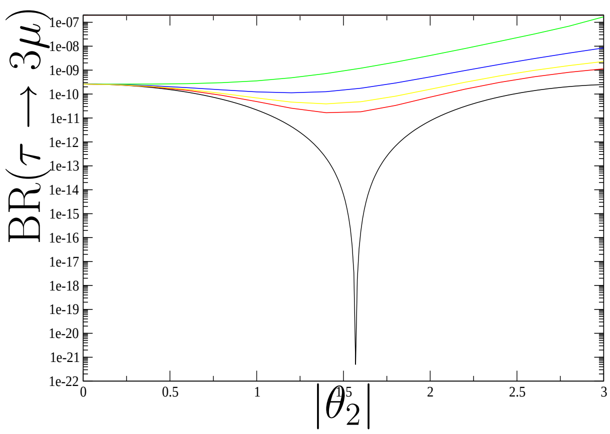
⋆ **Complex θ_2** $(\arg(\theta_2) = 0, \pi/4, \pi/6, \pi/8, \pi/10, \theta_1 = \theta_3 = 0)$

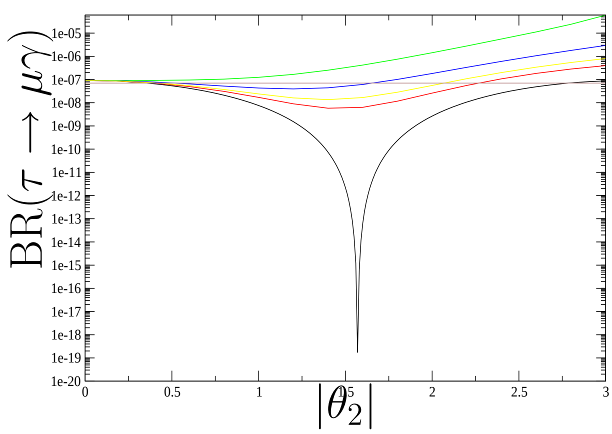
$\tan\beta = 50,\ (M_0, M_{1/2}, A_0) = (200, 100, 0)\,\mathrm{GeV}$





$\tan\beta = 50,\ (M_0, M_{1/2}, A_0) = (400, 300, 0)\,\mathrm{GeV}$





Hierarchical: Much larger rates than for degenerate case.
Light SUSY spectra severely constrained

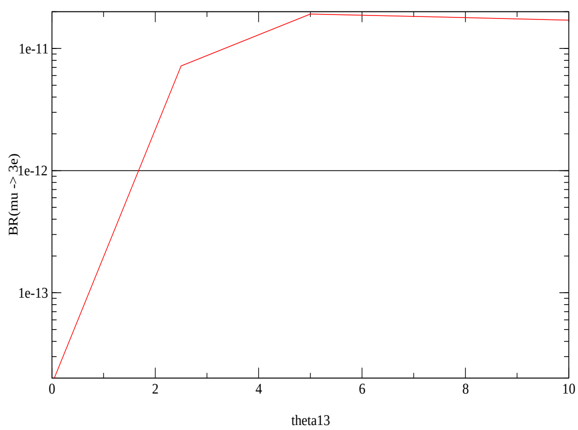
Branching ratios dependence with θ_{13}

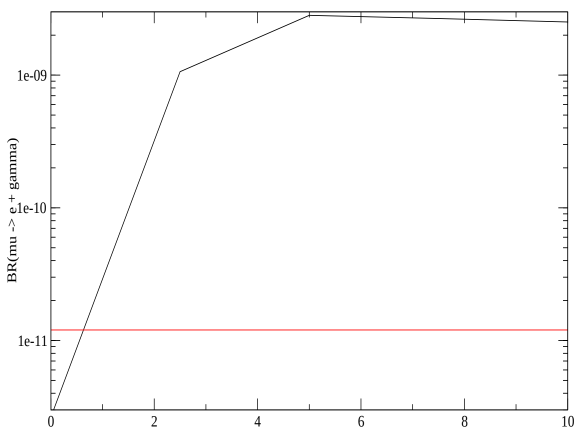
hierarchical neutrinos

$$(m_{N_1}, m_{N_2}, m_{N_3}) = (10^8, 2 \times 10^8, 10^{14})\,\mathrm{GeV}$$

$$\theta_1 = \theta_2 = \theta_3 = 0$$

$$\tan\beta = 50,\ (M_0, M_{1/2}, A_0) = (400, 300, 0)\,\mathrm{GeV}$$





$\theta_{13} > 2^o$ are unallowed by LFV data

Conclusions:

- ⋆ LFV τ and μ decays with ratios $BR(\tau^- \to \mu^-\mu^-\mu^+) \sim 10^{-5}$ are found in the MSSM-seesaw for hierarchical neutrinos with the largest heavy mass at $10^{14}\mathrm{GeV}$ and large $\tan\beta = 50$

- ⋆ SUSY parameters significantly restricted

- ⋆ Deserves further studies