Lepton flavor violating Higgs boson decays from massive seesaw neutrinos

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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 Higgs bosons within the MSSM-seesaw:

$H \to \tau\bar{\mu},\ \tau\bar{e},\ \mu\bar{e}$, $H = h^0, H^0, A^0$

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

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; $M_X = 2 \times 10^{16}\, GeV$

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

- 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,

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

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 Higgs 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

$$R = e^{iA},\ A = \begin{pmatrix} 0 & a & b \\ -a & 0 & c \\ -b & -c & 0 \end{pmatrix}$$

$a,\ b,\ c$ real parameters

Parameters in R constrained by perturbativity of Y_ν

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

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

$$M_{\tilde{l}}^2 = \begin{pmatrix} M_{LL}^{ee\,2} & M_{LR}^{ee\,2} & M_{LL}^{e\mu\,2} & 0 & M_{LL}^{e\tau\,2} & 0 \\ M_{RL}^{ee\,2} & M_{RR}^{ee\,2} & 0 & 0 & 0 & 0 \\ M_{LL}^{\mu e\,2} & 0 & M_{LL}^{\mu\mu\,2} & M_{LR}^{\mu\mu\,2} & M_{LL}^{\mu\tau\,2} & 0 \\ 0 & 0 & M_{RL}^{\mu\mu\,2} & M_{RR}^{\mu\mu\,2} & 0 & 0 \\ M_{LL}^{\tau e\,2} & 0 & M_{LL}^{\tau\mu\,2} & 0 & M_{LL}^{\tau\tau\,2} & M_{LR}^{\tau\tau\,2} \\ 0 & 0 & 0 & 0 & M_{RL}^{\tau\tau\,2} & M_{RR}^{\tau\tau\,2} \end{pmatrix}$$

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

$$M_{LL}^{ll\,2} = m_{\tilde{L},l}^2 + m_l^2 + m_Z^2 \cos 2\beta(-\frac{1}{2} + \sin\theta_w^2)$$
$$M_{RR}^{ll\,2} = m_{\tilde{E},l}^2 + m_l^2 - m_Z^2 \cos 2\beta \sin\theta_w^2$$
$$M_{LR}^{ll\,2} = M_{RL}^{ll\,2} = m_l(A_l - \mu\tan\beta), \;\; l = e, \mu, \tau$$
$$M_{LL}^{e\mu\,2} = (\Delta m_{\tilde{L}}^2)_{12}\,;\; M_{LL}^{\mu e\,2} = (\Delta m_{\tilde{L}}^2)_{21}$$
$$M_{LL}^{e\tau\,2} = (\Delta m_{\tilde{L}}^2)_{13}\,;\; M_{LL}^{\tau e\,2} = (\Delta m_{\tilde{L}}^2)_{31}$$
$$M_{LL}^{\mu\tau\,2} = (\Delta m_{\tilde{L}}^2)_{23}\,;\; M_{LL}^{\tau\mu\,2} = (\Delta m_{\tilde{L}}^2)_{32}$$

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

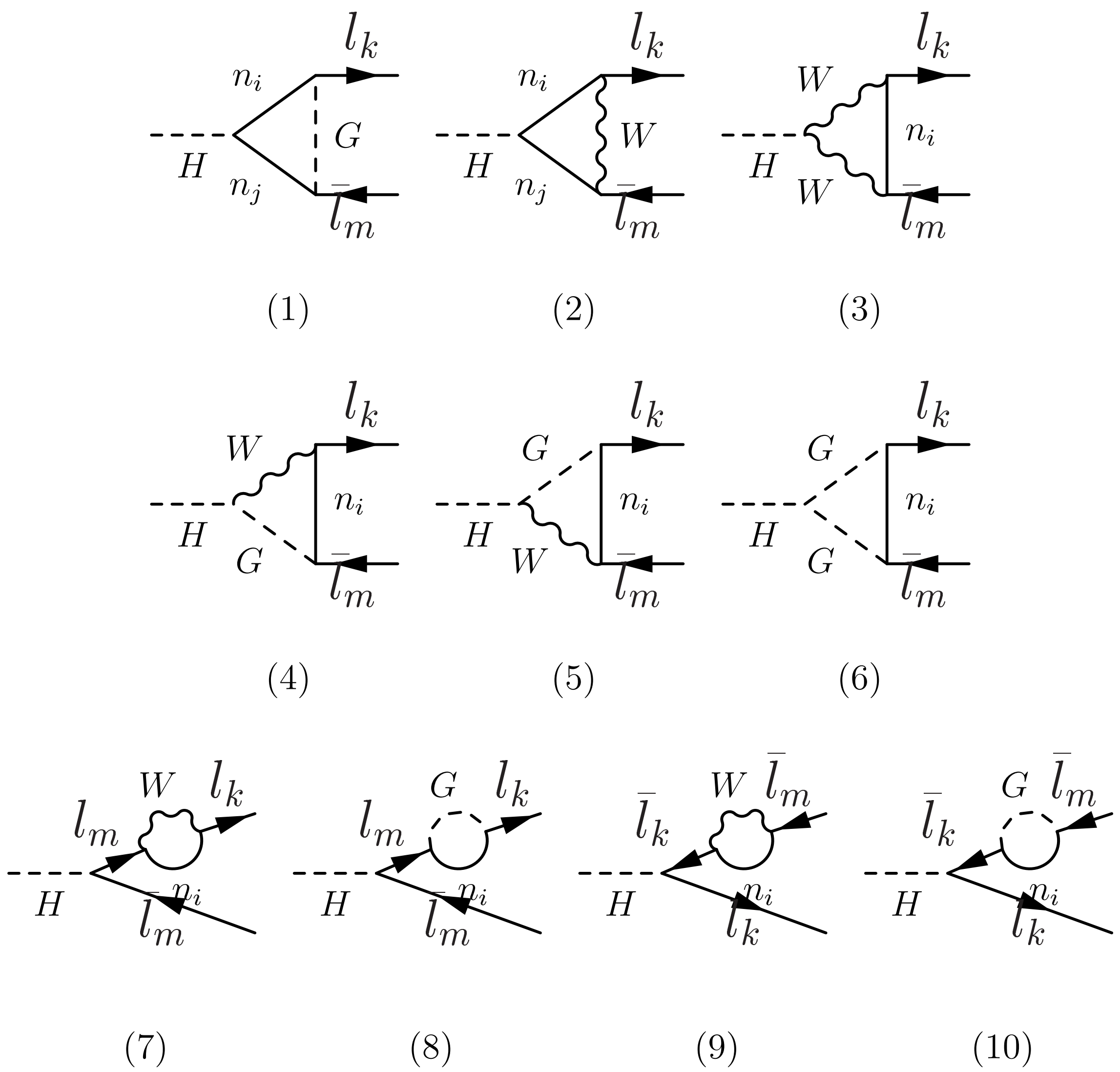
$$M_{\tilde{\nu}}^2 = \begin{pmatrix} m_{\tilde{L},e}^2 + \frac{1}{2}m_Z^2\cos 2\beta & (\Delta m_{\tilde{L}}^2)_{12} & (\Delta m_{\tilde{L}}^2)_{13} \\ (\Delta m_{\tilde{L}}^2)_{21} & m_{\tilde{L},\mu}^2 + \frac{1}{2}m_Z^2\cos 2\beta & (\Delta m_{\tilde{L}}^2)_{23} \\ (\Delta m_{\tilde{L}}^2)_{31} & (\Delta m_{\tilde{L}}^2)_{32} & m_{\tilde{L},\tau}^2 + \frac{1}{2}m_Z^2\cos 2\beta \end{pmatrix}$$

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

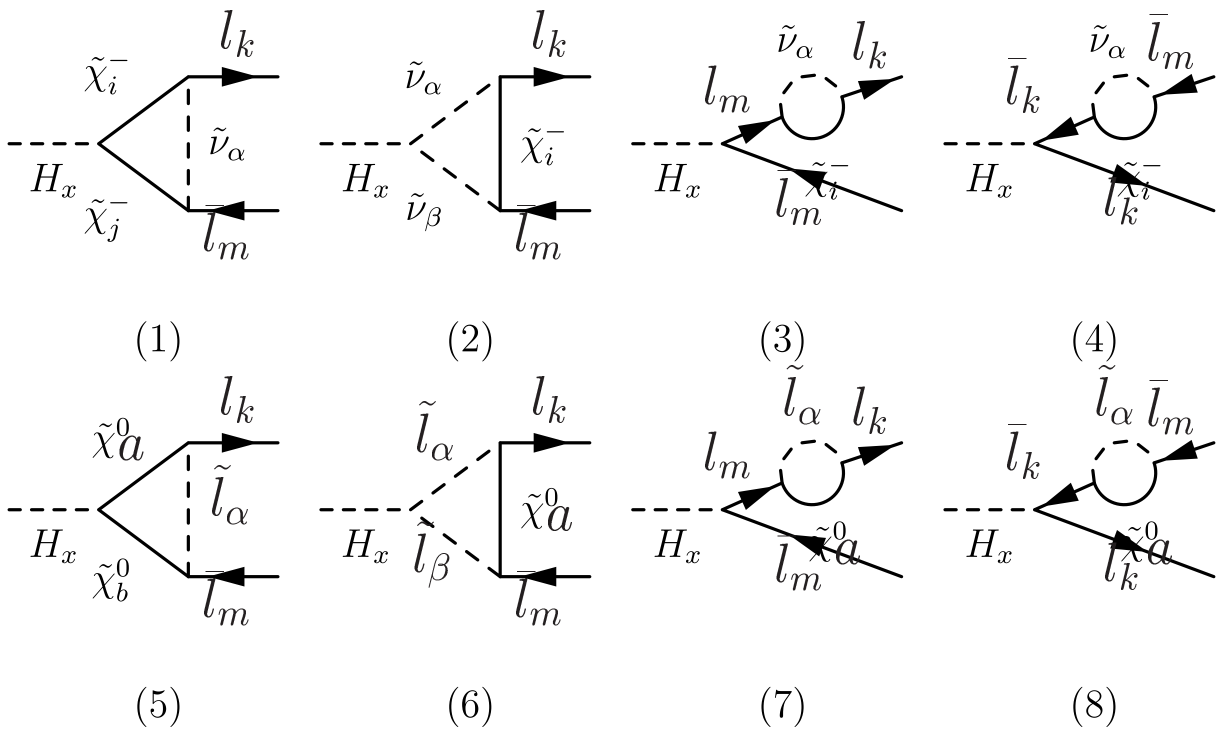
⋆ Soft parameters from RGE-running down to EW scale (mSUSPECT programme)

⋆ μ from EW breaking condition

One-loop diagrams in the SM-seesaw



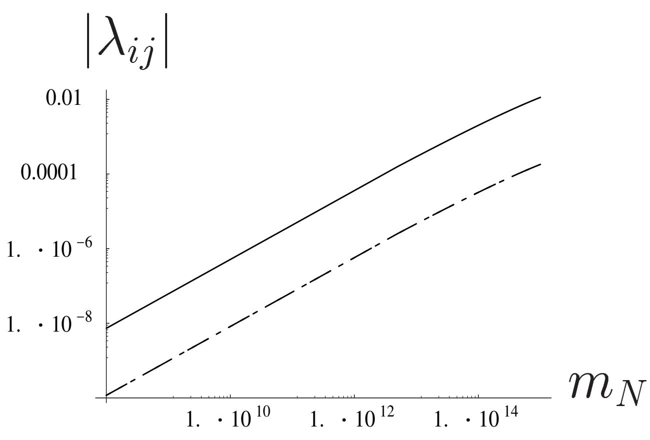
One-loop diagrams in the MSSM-seesaw



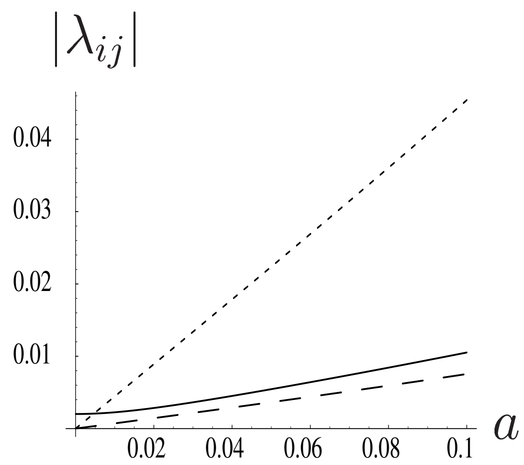
λ_{ij} dependence with the seesaw parameters

Lepton-slepton misalignment parametrized by $\lambda_{ij} \equiv \frac{(\Delta m^2_{\tilde{L}})_{ij}}{M_0^2}$

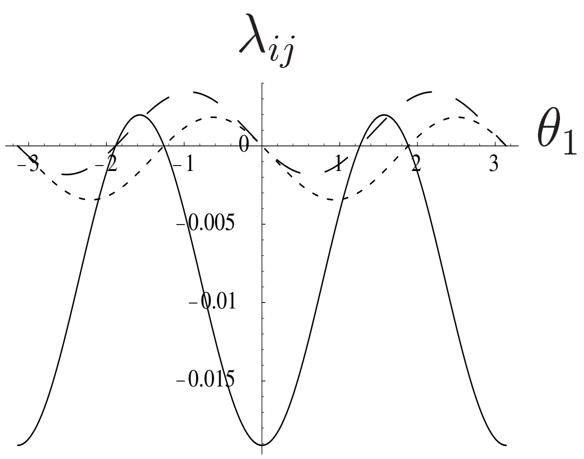
Solid lines :λ_{23} ; Long-dashed lines : λ_{13} ; Short-dashed lines : λ_{12}



deg. m_{N_i}; real R



deg. $m_{N_i} = 10^{14}\, GeV$; $R = e^{iA}$



hierarchical $(m_{N_1}, m_{N_2}, m_{N_3}) = (10^8, 2 \times 10^8, 10^{14})\, GeV$, real R with $\theta_2 = \theta_3 = 0$

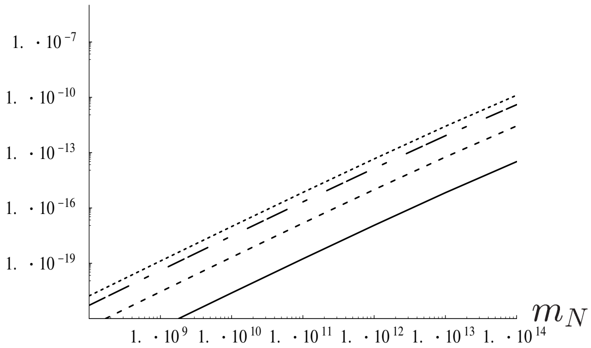
- ⋆ Size increases with m_N and $arg(R)$
- ⋆ Typical size is $|\lambda_{ij}| \leq \mathcal{O}(0.01)$ for real R
- ⋆ $|\lambda_{ij}|$ can be as large as $\mathcal{O}(1)$ for complex R

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

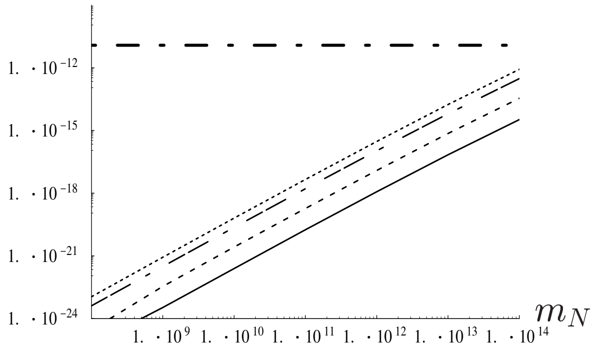
Explored values: $10^8 \le m_N(GeV) \le 10^{14}$

$\tan\beta = 3$ (solid), 10 (dashed), 30 (dashed-dotted), 50 (dotted)
$(M_0, M_{1/2}, A_0) = (400, 300, 0)GeV$

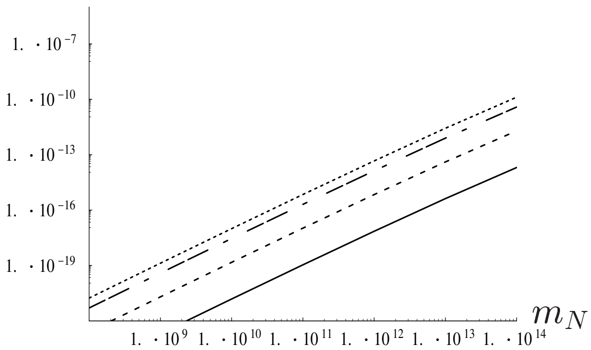
$BR(H_0 \to \tau\bar{\mu})$



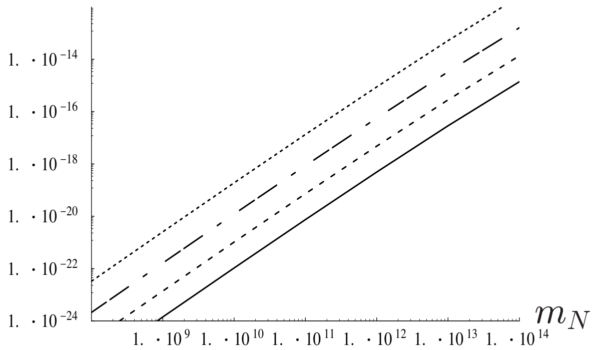
$BR(\mu \to e\gamma)$



$BR(A_0 \to \tau\bar{\mu})$



$BR(h_0 \to \tau\bar{\mu})$



- ⋆ All rates grow with $m_N(GeV)$ as $(m_N \log(m_N))^2$
- ⋆ LFVHD rates grow as $(\tan\beta)^4$; lepton rates as $(\tan\beta)^2$
- ⋆ $BR(H^0, A^0 \to \tau\bar{\mu}) < 10^{-10}$, $BR(h^0 \to \tau\bar{\mu}) < 10^{-12}$, $\tan\beta < 50$ compared with $BR(H_{SM} \to \tau\bar{\mu}) < 10^{-44}$!!
- ⋆ $BR(\mu \to e\gamma)$, $BR(\tau \to \mu\gamma)$, $BR(\tau \to e\gamma)$ below exp. limits: 1.2×10^{-11}, 3.1×10^{-7}, 2.7×10^{-6} for $m_N < 10^{14} GeV$
- ⋆ $BR(\tau\bar{\mu})/BR(\tau\bar{e}) = 4 \times 10^3$, $BR(\tau\bar{\mu})/BR(\mu\bar{e}) = 1.2 \times 10^6$, $\tan\beta = 50$

Branching ratios dependence with R

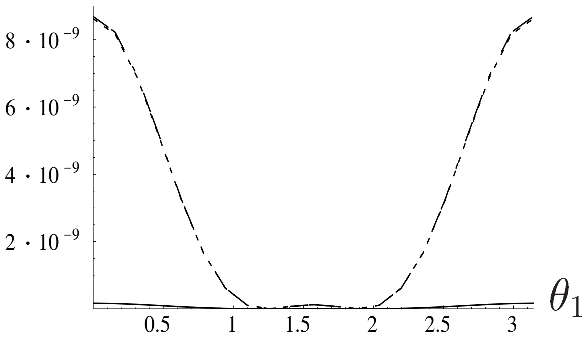
hierarchical neutrinos

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

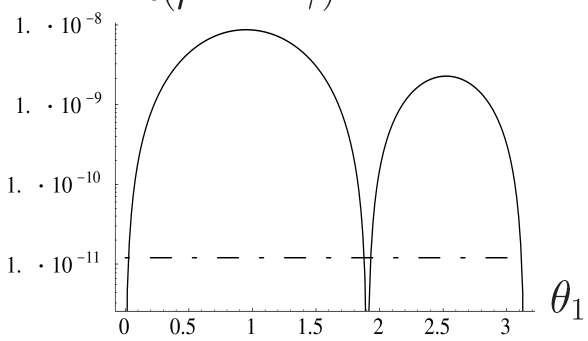
$$\tan\beta = 50,\ (M_0, M_{1/2}, A_0) = (400, 300, 0)\, GeV$$

⋆ Real θ_1 $(\theta_2 = \theta_3 = 0)$

$BR(H_x \to \tau\bar{\mu})$

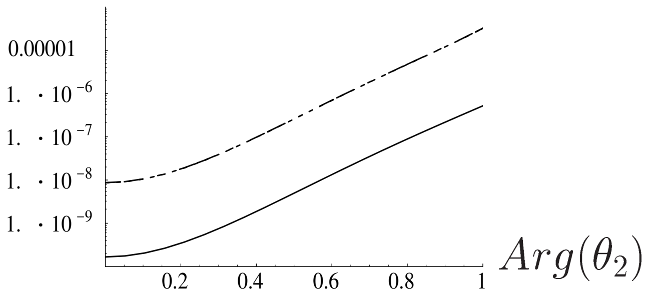


$BR(\mu \to e\gamma)$

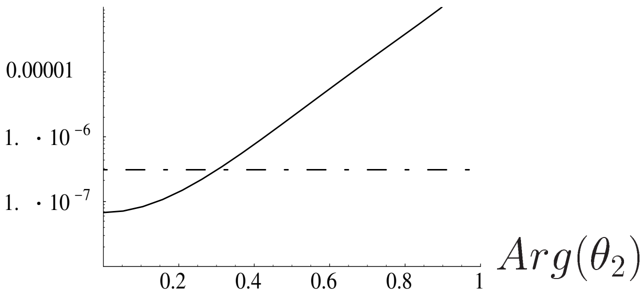


⋆ Complex θ_2 $(|\theta_2| = \pi, \theta_2 = \theta_3 = 0)$

$BR(H_x \to \tau\bar{\mu})$



$BR(\tau \to \mu\gamma)$



Hierarchical: Larger $BR(H \to \tau\bar{\mu}))$ rates. Compatibility with $BR(l_j \to l_i\gamma)$ data constraints the maximum allowed LFVHD rates

Branching ratios dependence with M_0 and $M_{1/2}$

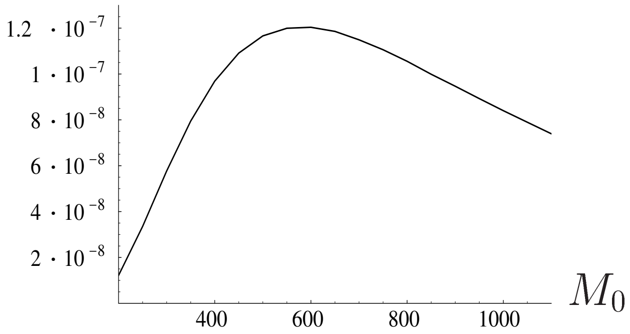
hierarchical neutrinos

$(m_{N_1}, m_{N_2}, m_{N_3}) = (10^8, 2\times 10^8, 10^{14})\, GeV,\ \tan\beta = 50$

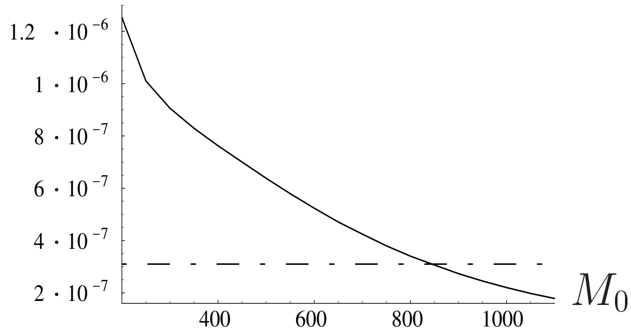
$M_{1/2} = 300 GeV (M_0 = 400 GeV), \theta_2 = \pi e^{0.4i} (\pi e^{0.8i})$ first (second) two plots

$M_0 = M_{1/2} (GeV), \theta_2 = \pi e^{0.8i}$ last two plots

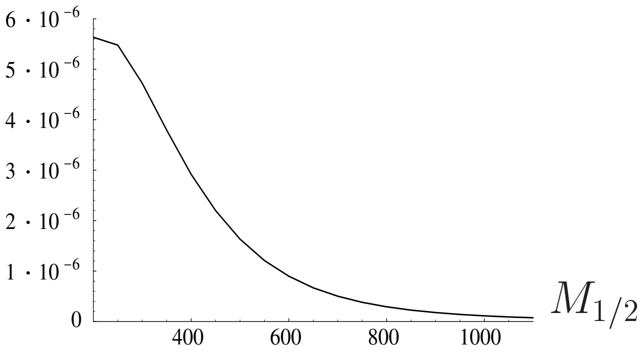
$BR(H_0 \to \tau\bar{\mu})$



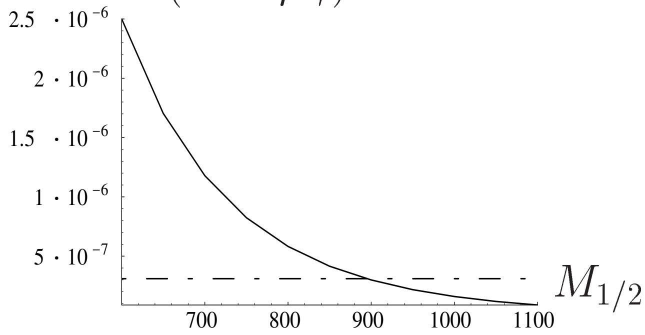
$BR(\tau \to \mu\gamma)$



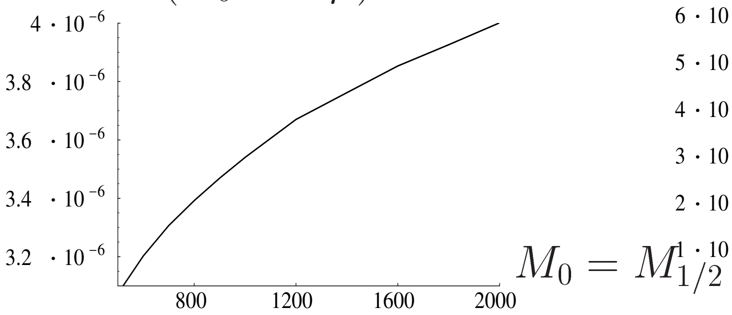
$BR(H_0 \to \tau\bar{\mu})$



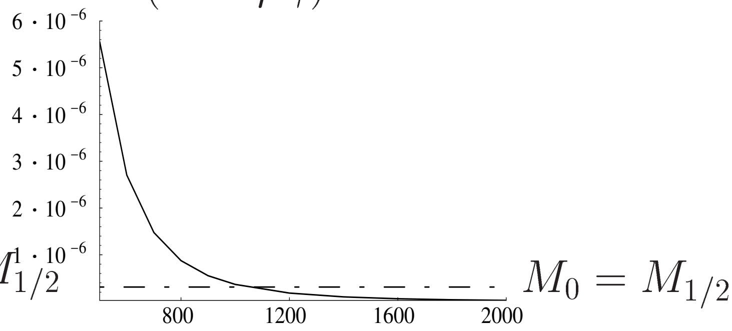
$BR(\tau \to \mu\gamma)$



$BR(H_0 \to \tau\bar{\mu})$



$BR(\tau \to \mu\gamma)$



Milder dependence of $BR(H_0 \to \tau\bar{\mu})$ with M_0 and $M_{1/2}$

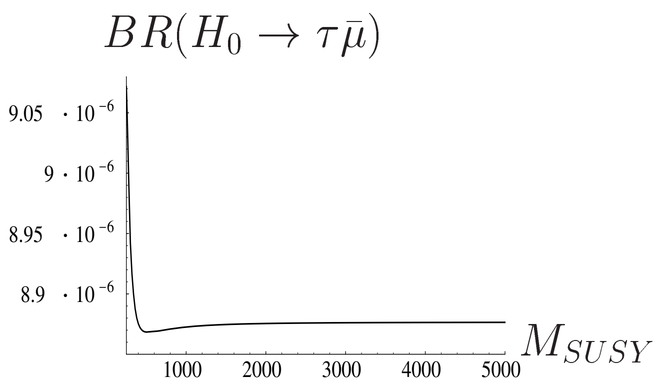
LFVHD ratios up to 4×10^{-6} for large $M_0 = M_{1/2}$

Non-decoupling of the SUSY particles in LFVHD

Study behaviour at large SUSY masses,

choose one common scale $M_{SUSY}(GeV)$

$$M_{SUSY} \equiv m_{\tilde{L},l} = m_{\tilde{E},l} = M_0 = \mu,\ M_2 = 2/3\mu,\ M_1 = \frac{5}{3}\tan^2\theta_W M_2$$



$(\lambda_{23} = -0.4,\ \lambda_{12} = \lambda_{13} = 0,\ \tan\beta = 50,\ m_{H_0} = 340\,GeV)$

- ⋆ The Higgs ratios tend to a non-vanishing constant at large M_{SUSY}

  Non-decoupling of $\chi^+, \chi^0, \tilde{l}, \tilde{\nu}$

- ⋆ In contrast to $BR(\mu \to e\gamma) \sim (M_W/M_{SUSY})^4$

Conclusions:

- ⋆ LFV Higgs boson decays with ratios $BR(H_0 \to \tau\bar{\mu}) \sim 10^{-5}$ are found in the MSSM-seesaw for hierarchical neutrinos with the largest heavy mass at $10^{14} GeV$ and large $\tan\beta = 50$

- ⋆ Large rates, but still below the expected experimental reach at LHC of about 10^{-4}

- ⋆ Larger values would require $\tan\beta > 50$ and consequently a resummation of the large $\tan\beta$ contributions