Sensitivity to the Higgs sector of SUSY-seesaw models via LFV tau decays

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From works
E. Arganda, M.H. and J. Portolés
JHEP06(2008)079 LFV semilep. $\tau$ decays

M.H., J. Portolés and A. Rodríguez-Sánchez
arXiv:0903.5151(hep-ph) $\tau \rightarrow \mu f_0$

E. Arganda et al.
Comparison leptonic/semileptonic LFV $\tau$ decays

SUSY09, Northeastern Univ., Boston, 5-10 June 2009
Motivation

★ Lepton Flavour Violation (LFV) occurs in Nature: $\nu_i - \nu_j$ oscill.

★ LFV is very sensitive to SUSY via loops:
If $\nu$ are Majorana and $m_\nu$ from seesaw mechanism with $\nu_R$ 
$\Rightarrow Y_\nu$ can be large $\geq O(1)$ and induce, via SUSY loops, large LFV rates

★ In SUSY-seesaw the predicted LFV rates are, for some channels and in specific regions of the parameter space, at the present experimental reach

$\Rightarrow$ Interesting connection LFV ↔ neutrino physics in SUSY-seesaw

★ We focus here on LFV in the $\tau - \mu$ sector

★ The most competitive LFV tau decay is $\tau \rightarrow \mu\gamma$

Present bound: $\text{BR}(\tau \rightarrow \mu\gamma) < 1.6 \times 10^{-8}$
but...........it IS NOT sensitive to the Higgs sector

★ Sensitivity to Higgs only possible via Higgs mediated channels

We study and compare here the sensitivity to the Higgs sector in:
$\tau \rightarrow 3\mu$, $\tau \rightarrow \mu KK$, $\tau \rightarrow \mu\eta$, $\tau \rightarrow \mu f_0$ (new)

(selected mesons with strange component: $Hqq$ couplings $\propto m_q$)

Present bounds: $\text{BR}(\tau \rightarrow 3\mu) < 3.2 \times 10^{-8}$, $\text{BR}(\tau \rightarrow \mu KK) < 8 \times 10^{-7}(6.4 \times 10^{-8} \text{tau08})$
$\text{BR}(\tau \rightarrow \mu\eta) < 5.1 \times 10^{-8}$, $\text{BR}(\tau \rightarrow \mu f_0) \times \text{BR}(f_0 \rightarrow \pi^+\pi^-) < 3.4 \times 10^{-8}$
These processes $\tau \rightarrow 3\mu$ and $\tau \rightarrow \mu qq$ have competing contributions:

To reach sensitivity to the Higgs Sector, the H-mediated contrib. must dominate, but this is not always true. A full computation is needed!!
Our Work

- Full one-loop computation of LFV rates
- Require compatibility with $\nu$ data
- Compare with present LFV bounds
- Explore the regions of the SUSY-seesaw parameter space leading to the largest sensitivity to the Higgs sector. Mainly: large $M_{\text{SUSY}}$ and large $\tan \beta$
- Find restrictions on the most relevant parameters. Mainly: $\tan \beta$ and $M_H$
- Provide (in addition to the full one-loop) a set of simple formulas that approximate well the full result and are useful for comparison with present and future data
Framework for LFV

- **Use seesaw (Type I) for \( \nu \) mass generation**

- **Within Constrained MSSM + 3\( \nu_R \) (Majorana) + 3\( \tilde{\nu}_R \)**
  Two scenarios for soft parameters at \( M_X = 2 \times 10^{16} \text{ GeV} \):
  - Universal soft parameters: CMSSM-seesaw
    \( (M_0, M_{1/2}, A_0, \tan \beta, \text{sign}(\mu)) \)
  - Non-universal soft Higgs masses: NUHM-seesaw
    \( (M_0, M_{1/2}, M_{H_1}, M_{H_2}, A_0, \tan \beta, \text{sign}(\mu)) \)

- LFV generated by 1-loop running from \( M_X \) to \( M_Z \)
  Full RGEs including \( \nu \) and \( \tilde{\nu} \) sectors (No Llog approx)

- Mass eigenstates for all SUSY and Higgs particles (No MI 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 eq. : \( m_\nu = -m_D^T m_N^{-1} m_D; \) \( m_D = Y_\nu < H_2 >; \) \( < H_2 > = \nu \sin \beta \)

Solution: \( m_D = i \sqrt{m_N^{\text{diag}}} R \sqrt{m_\nu^{\text{diag}}} U_M^{\dagger} \) [Casas, Ibarra ('01)]

\( R \) is a \( 3 \times 3 \) complex matrix and orthogonal

\[
R = \begin{pmatrix}
c_{2c_3} & -c_1s_3 - s_1s_2c_3 & s_1s_3 - c_1s_2c_3 \\
c_2s_3 & c_1c_3 - s_1s_2s_3 & -s_1c_3 - c_1s_2s_3 \\
s_2 & s_1c_2 & c_1c_2
\end{pmatrix}, \quad c_i = \cos \theta_i, \ s_i = \sin \theta_i, \ \theta_{1,2,3} \text{ complex}
\]

Parameters: \( \theta_{ij}, \delta, \alpha, \beta, m_\nu, m_N, \theta_i \) (18) ; \( m_N, \theta_i \) drive the size of \( Y_\nu \)

Hierarchical \( \nu \)'s : \( m_{\nu_1}^2 << m_{\nu_2}^2 = \Delta m_{\text{sol}}^2 + m_{\nu_1}^2 << m_{\nu_3}^2 = \Delta m_{\text{atm}}^2 + m_{\nu_1}^2 \)

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:**
  \[
  \begin{align*}
  M_0, M_{1/2}, A_0 \text{ (at } M_X \sim 2 \times 10^{16} \text{ GeV)} \\
  \tan \beta = \frac{<H_2>}{<H_1>} \text{ (at EW scale)} \\
  \text{sign}(\mu) \text{ (}\mu\text{ derived from EW breaking)}
  \end{align*}
  \]

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

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

- **Seesaw parameters**
  \[
  \begin{align*}
  m_{\nu_{1,2,3}} \text{ (set by data)} \\
  m_{N_{1,2,3}} \text{ (input)} \\
  U_{MNS} \text{ (set by data)} \\
  R(\theta_1, \theta_2, \theta_3) \text{ (input)}
  \end{align*}
  \]

- **For numerical estimates:**
  \[
  \begin{align*}
  (\Delta m^2)_{12} &= \Delta m^2_{\text{Sol}} = 8 \times 10^{-5} \text{ eV}^2 \\
  (\Delta m^2)_{23} &= \Delta m^2_{\text{atm}} = 2.5 \times 10^{-3} \text{ eV}^2 \\
  \theta_{12} &= 30^\circ; \ \theta_{23} = 45^\circ; \ \delta = \alpha = \beta = 0; \ 0 \leq \theta_{13} \leq 10^\circ \\
  250 \text{ GeV} < M_0, M_{1/2} < 1000 \text{ GeV}, & \ -500 \text{ GeV} < A_0 < 500 \text{ GeV} \\
  5 < \tan \beta < 50, & \ -2 < \delta_{1,2} < 2
  \end{align*}
  \]
Higgs bosons spectra in NUHM versus CMSSM

- In CMSSM ($\delta_{1,2} = 0$) a heavy SUSY spectrum (large $M_0$, $M_{1/2}$) $\Rightarrow$ heavy $H^0$ and $A^0$.
- In NUHM, a proper choice of $\delta_1$ and $\delta_2$, even for very large SUSY masses of $\mathcal{O}(1\,\text{TeV})$, can lead to light $H^0$ and $A^0$, $m_{H^0, A^0} \lesssim 200$ GeV $H^0$ and $A^0$ become lighter with the increase of $\tan\beta$.
- $h^0$ remains always light (for all $\tan\beta$ and $M_{SUSY}$), $m_{h^0} < 150$ GeV.
- $H^0$ and/or $A^0$ relevant Higgses in H-mediated LFV processes: Their couplings to $I = -1/2$ fermions are enhanced at large $\tan\beta$. 
Connection between LFV in the $\tau-\mu$ sector and $\nu$ phys

Within SUSY-Seesaw scenarios, the contributions from SUSY loops, to the off-diagonal entries of slepton matrices are functions of $Y_\nu$. In the Leading Logarithmic Approximation (LLog) the dominant ones are:

$$\delta_{32} = \frac{(\Delta m_{\tilde{L}}^2)_{32}}{M_{\text{SUSY}}^2} = -\frac{1}{8\pi^2} \frac{3 M_0^2 + A_0^2}{M_{\text{SUSY}}^2} (Y_\nu^\dagger L Y_\nu)_{32}$$

$L_{ii} = \log(M_X/m_{N_i})$; $M_{\text{SUSY}}$ is an average SUSY mass

The relation with neutrino physics comes in,

$$v_2^2 (Y_\nu^\dagger L Y_\nu)_{32} = L_{33} m_{N_3} \left[ (\sqrt{m_{\nu_3}} c_1 c_2 c_3) - (\sqrt{m_{\nu_2}} s_1 c_2 c_3)\right]$$

$$+ L_{22} m_{N_2} \left[ (\sqrt{m_{\nu_3}} (-s_1 c_3 - c_1 s_2 s_3) c_2 - \sqrt{m_{\nu_2}} s_1 s_2 s_3 - c_1 c_3) c_1 c_2 s_3\right]$$

$$+ L_{11} m_{N_1} \left[ (\sqrt{m_{\nu_3}} (s_1 c_3) c_2 + \sqrt{m_{\nu_2}} (s_1 c_3) c_1 c_2 s_3\right]$$

The size of $m_{N_i}$ and $\theta_i$ drive the size of $\delta_{32}$
Size of $\delta_{32}$ in Constrained SUSY-Seesaw models

Hierarchical N

Degenerate N

- Large size of $|\delta_{32}|$ for large $\theta_{1,2}$ and/or large $m_N$ if degenerate heavy neutrinos (large $m_{N3}$ if hierarchical. Nearly independent on $m_{N1,2}$)

- Complex $\theta_{1,2}$, with large modulus ($2 < |\theta_{1,2}| < 3$) and argument ($\pi/4 < \arg\theta_{1,2} < 3\pi/4$), and $m_N \sim 10^{14} - 10^{15}$ GeV $\Rightarrow$ $|\delta_{32}| \sim 0.1 - 10$.

- Perturbatativity in Yukawa couplings (as required for ex. in SPheno) $\Rightarrow$ $|Y_\nu|^2/(4\pi) < 1.5$ $\Rightarrow$ $|\delta_{32}| < 0.5$. Estimates for $|\delta_{32}| > 0.5$ must be done with other methods (not using RGEs, for ex. MI approx., see later).
Sensitivity to Higgs in $\tau \to 3\mu$ within SUSY-seesaw??

**CMSSM**

![Graph showing BR(\tau \to 3\mu) vs tan\beta for CMSSM]  

- $m_N = (10^{10}, 10^{11}, 10^{14})$ GeV
- $M_0 = M_{1/2} = 250$ GeV, $A_0 = 0$
- $\theta_1 = 0$, CMSSM
- $\delta_1 = 0$, $\delta_2 = 0$

**NUHM**

![Graph showing BR(\tau \to 3\mu) vs tan\beta for NUHM]  

- $m_N = (10^{10}, 10^{11}, 10^{14})$ GeV
- $M_0 = M_{1/2} = 250$ GeV, $A_0 = 0$
- $\theta_1 = 0$, $\theta_2 = 3e^{i\pi/4}$, $\delta_1 = -2.4$, $\delta_2 = 0$

The three $h^0, H^0, A^0$ participate

$h^0$ contrib. negligible

$\text{BR}|_{H^0, A^0} \sim (\tan \beta)^6$

$H$-contrib. overwhelmed by $\gamma$-contrib. even at large

$\tan \beta \sim 50$ and large $M_0, M_{1/2} \sim O(1 \text{ TeV})$

Even if $m_{A^0, H^0} \lesssim 200$ GeV (as in NUHM)

There is **NOT** sensitivity to Higgs in $\tau \to 3\mu$ in CMSSM nor NUHM
Comparison between $\tau \rightarrow 3\mu$ and $\tau \rightarrow \mu\gamma$

⭐ The proper approximate formulas for the full rates, at large $\tan \beta$, are:

$$\text{BR}(\tau \rightarrow 3\mu)_{\text{approx}} = \frac{\alpha}{3\pi} \left( \log \frac{m_\tau^2}{m_\mu^2} - \frac{11}{4} \right) \text{BR}(\tau \rightarrow \mu\gamma) = 2.3 \times 10^{-3} \text{ BR}(\tau \rightarrow \mu\gamma)$$

$$= 3.4 \times 10^{-5} |\delta_{32}|^2 \left( \frac{100}{M_{\text{SUSY}}(\text{GeV})} \right)^4 \left( \frac{\tan \beta}{60} \right)^2$$

$$\text{BR}(\tau \rightarrow \mu\gamma)_{\text{approx}} = \frac{\alpha^3}{14400\pi^2 \Gamma_\tau \sin^2 \theta_W M_{\text{SUSY}}^3} |\delta_{32}|^2 (\tan \beta)^2$$

$$= 1.5 \times 10^{-2} |\delta_{32}|^2 \left( \frac{100}{M_{\text{SUSY}}(\text{GeV})} \right)^4 \left( \frac{\tan \beta}{60} \right)^2$$

\textbf{NOT:}

$$\text{BR}(\tau \rightarrow 3\mu)_{H_{\text{approx}}} = \frac{G_F^2}{2048\pi^3} \frac{m_\tau^7 m_\mu^2}{\Gamma_\tau} \left( \frac{1}{m_{H^0}^4} + \frac{1}{m_{A^0}^4} + \frac{2}{3m_{H^0}^2 m_{A^0}^2} \right) \left| \frac{g^2 \delta_{32}}{96\pi^2} \right|^2 (\tan \beta)^6$$

Both contain same information on LFV, but $\tau \rightarrow \mu\gamma$ still more competitive than $\tau \rightarrow 3\mu$
Sentitivity to Higgs in LFV semilep. tau decays

\[ \tau \rightarrow \gamma, Z^0 \]
\[ \tau \rightarrow \mu, Z^0 \]
\[ \tau \rightarrow h^0, H^0 \]
\[ \tau \rightarrow \mu, A^0 \]

\[ \tau \rightarrow h^0, H^0 \]
\[ \tau \rightarrow h^0, H^0 \]

\[ P \ (PP = \pi\pi, KK) \]

\[ P \ (P = \pi, \eta, \eta') \]

\[ f_0(980) \ (new) \]
• We use Chiral Perturbation Theory (\(\chi PT\))
  It realizes nicely the large \(N_C\) expansion of \(SU(N_C)\) QCD and is the appropriate scheme to describe strong ints of PG Bosons \(P = \pi, K, \eta\)

  \(\star\) \(\text{BR}(\tau \to \mu P), P = \pi, \eta, \eta',\) from leading \(\mathcal{O}(p^2)\) \(\chi PT\). Results in terms of \(F_\pi\) and \(m_P\) \((F \simeq F_\pi \simeq 92.4\) MeV, \(B_0 F^2 = - < \overline{\psi} \psi >\))

  \(\star\) \(\text{BR}(\tau \to \mu PP), PP = \pi^+\pi^-, K^+K^-, K_0\overline{K}_0\) from \(\chi PT\) plus contributions from resonances (\(R_{\chi T}\)). Results in terms of \(F_\pi, m_P\) and well established form factors \(F_{PP}^{PP}(s), (G.Ecker et al. PLB223(1989)425)\)

\[
F_{\pi\pi}^{\pi\pi}(s) = F(s) \exp \left[ 2 \text{Re} \left( \tilde{H}_{\pi\pi}(s) \right) + \text{Re} \left( \tilde{H}_{KK}(s) \right) \right]
\]

\[
F(s) = \frac{M_\rho^2}{M_\rho^2 - s - iM_\rho \Gamma_\rho(s)} \left[ 1 + \left( \delta \frac{M_\omega^2}{M_\rho^2} - \gamma \frac{s}{M_\rho^2} \right) \frac{s}{M_\omega^2 - s - iM_\omega \Gamma_\omega} \right]
\]

\[
\tilde{H}_{PP}(s) = \frac{s}{F_\pi^2} \left[ \frac{1}{12} \left( 1 - 4 \frac{m_P^2}{s} \right) J_P(s) - \frac{k_P(M_\rho)}{6} + \frac{1}{288\pi^2} \right], \sigma_P(s) = \sqrt{1 - 4 \frac{m_P^2}{s}}
\]

\[
J_P(s) = \frac{1}{16\pi^2} \left[ \sigma_P(s) \ln \frac{\sigma_P(s) - 1}{\sigma_P(s) + 1} + 2 \right], k_P(\mu) = \frac{1}{32\pi^2} \left( \ln \frac{m_P^2}{\mu^2} + 1 \right)
\]
The $\eta(548)$ and $f_0(980)$ mesons

We define $\eta(548)$ via mixing between the octet, $\eta_8$, and singlet, $\eta_0$, components of the $P(0^-)$ nonet of pseudoscalar Goldstone bosons in $\chi PT$

$$\begin{pmatrix} \eta \\ \eta' \end{pmatrix} = \begin{pmatrix} \cos \theta & -\sin \theta \\ \sin \theta & \cos \theta \end{pmatrix} \begin{pmatrix} \eta_8 \\ \eta_0 \end{pmatrix}$$

(1)

$\theta$ ranges from $\sim -12^\circ$ to $\sim -20^\circ$. We take $\theta \sim -18^\circ$ (Ecker et al)

$$\eta = \frac{1}{2B_0F}\{(\sqrt{3}/3 \cos \theta - \sqrt{6}/3 \sin \theta)(\bar{u}i\gamma_5 u + \bar{d}i\gamma_5 d) + (-2\sqrt{3}/3 \cos \theta - \sqrt{6}/3 \sin \theta)\bar{s}i\gamma_5 s\}$$

$s$ most relevant, $g_{Ass} \sim m_s \tan \beta$. Expected large $A^0-\eta$ mixing at large $\tan \beta$

We define $f_0(980)$ via mixing between the octet, $R_8$, and singlet, $R_0$, components of the $R(0^+)$ nonet of resonances in $R\chi T$

$$\begin{pmatrix} f_0(1500) \\ f_0(980) \end{pmatrix} = \begin{pmatrix} \cos \theta_S & -\sin \theta_S \\ \sin \theta_S & \cos \theta_S \end{pmatrix} \begin{pmatrix} R_8 \\ R_0 \end{pmatrix}$$

(2)

$\theta_S$ quite uncertain. We take $\theta_S \sim 7^\circ$ and $\theta_S \sim 30^\circ$ (Cirigliano et al)

$$f_0 = \frac{1}{2\sqrt{2}B_0F}\{(-\sqrt{6}/3 \cos \theta_S - \sqrt{3}/3 \sin \theta_S)(\bar{u}u + \bar{d}d) + (-\sqrt{6}/3 \cos \theta_S + 2\sqrt{3}/3 \sin \theta_S)\bar{s}s\}$$

$s$ most relevant: $g_{H^0 ss} \sim m_s \frac{\cos \alpha}{\cos \beta}$. Expected large $H^0-f_0$ mix. at large $\tan \beta$
The $\tau \rightarrow \mu \eta$ channel

$Z$-dominated at $\tan \beta \lesssim 15$, $A^0$-dominated at $\tan \beta \gtrsim 30$. Not much dependent on $M_{\text{SUSY}}$

- Provided useful approximate formulas, valid at large $\tan \beta \gtrsim 30$

$$\text{BR}(\tau \rightarrow \mu \eta)_{\text{approx}} = \frac{1}{8\pi m_\tau^3} (m_\tau^2 - m_\eta^2)^2 \left| \frac{g}{2m_W} \frac{F}{m_{A^0}^2} B_{L,c}^{(A^0)}(\eta) H_{L,c}^{(A^0)} \right|^2 \frac{1}{\Gamma_\tau}$$

$$= 1.2 \times 10^{-7} |\delta_{32}|^2 \left( \frac{100}{m_{A^0}(\text{GeV})} \right)^4 \left( \frac{\tan \beta}{60} \right)^6 \sim \frac{1}{7} \times \text{BR}_{\text{Sher}(2002)}$$

$$H_{L,c}^{(A^0)} = \frac{i g^3}{16\pi^2} \frac{m_\tau}{12m_W} \delta_{32} \tan^2 \beta, \quad \text{LFV form factor}$$

$$B_{L}^{(A^0)}(\eta) = \frac{1}{4\sqrt{3}} \tan \beta \left[ (3m_\eta^2 - 4m_K^2) \cos \theta - 2\sqrt{2}m_K^2 \sin \theta \right], \quad \text{hadronic form factor}$$

- The $\chi$PT mass relation $B_0 m_s = m_K^2 - \frac{1}{2} m_\pi^2$ (and $F \simeq F_\pi$) is used everywhere
Sensitivity to Higgs in $\tau \rightarrow \mu \eta$ within NUHM

★ Great sensitivity to $A^0$ found in $\tau \rightarrow \mu \eta$ within NUHM
BR($\tau \rightarrow \mu \eta$) at exp. bound for $m_{N_3} = 10^{15}$ GeV, $\tan \beta = 60$, $\theta_2 = 3e^{i\pi/4}$

★ The approximate formula works quite well (within a factor 1.5-2)
Not enough sensitivity to Higgs in $\tau \rightarrow \mu K K$

\[ \gamma \text{-dominated at low } M_{\text{SUSY}}, \ H^0 \text{-dominated at large } M_{\text{SUSY}}: \text{ SUSY non-decoupling} \]

- The Higgs contribution is important at large $\tan \beta \gtrsim 50$
  
  \[ g_{HKK} \sim m_K^2 \tan \beta, \text{ since } g_{Hss} \sim m_s \tan \beta \text{ and } B_0 m_s = m_K^2 - \frac{1}{2} m_{\pi}^2 \]

- However, BR below present exp. bound at $6.4 \times 10^{-8}$ (Prelim,tau08) if $M_{\text{SUSY}} \sim \mathcal{O}(1 \text{ TeV})$

- Provided useful approximate formulas at large $\tan \beta$ which work pretty well

\[ \text{BR}(\tau \rightarrow \mu K^+ K^-)_{H_{\text{approx}}} = 2.8 \times 10^{-8} |\delta_{32}|^2 \left( \frac{100}{m_{H^0}(\text{GeV})} \right)^4 \left( \frac{\tan \beta}{60} \right)^6 \sim \frac{1}{50} \times \text{BR}_{\text{Cheng--Geng(2006)}} \]

\[ \text{BR}(\tau \rightarrow \mu K^+ K^-)_{\gamma_{\text{approx}}} = 3.0 \times 10^{-6} |\delta_{32}|^2 \left( \frac{100}{M_{\text{SUSY}}(\text{GeV})} \right)^4 \left( \frac{\tan \beta}{60} \right)^2 \]
Results for $\tau \to \mu f_0$ (new)

<table>
<thead>
<tr>
<th>$m_N$ (GeV)</th>
<th>$m_{H^0}$ (GeV)</th>
<th>$A_0$ (GeV)</th>
<th>$\tan \beta$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$10^{10}$</td>
<td>$10^{11}$</td>
<td>0</td>
<td>50</td>
</tr>
<tr>
<td>$10^{12}$</td>
<td>$10^{13}$</td>
<td>0</td>
<td>60</td>
</tr>
</tbody>
</table>

$\delta = 2.4$, $\delta_2 = 0$, $\theta = 7^\circ$

- Totally dominated by $H^0$ at all $\tan \beta$ and $M_{SUSY}$, $h^0$ negligible. Not much dependent on $M_{SUSY}$

- Provided approximate formulas, valid at all studied $\tan \beta$. They work pretty well

$$BR(\tau \to \mu f_0(980))_{\text{approx}} = \frac{1}{16\pi m_\tau^3} \left( \frac{m_\tau^2 - m_{f_0}^2}{2m_\tau m_{f_0}} \right)^2 \frac{g}{2m_W} \frac{1}{m_{H^0}^2} J_{H^0}^{(H^0)} H_{L,c}^{(H^0)} \frac{1}{\Gamma_\tau} \left( \frac{100}{m_{H^0}(\text{GeV})} \right)^4 \left( \tan \beta \right)^6 \sim 1/20 BR_{\text{Chen–Geng(2006)}}$$

$$H_{L,c}^{(H^0)} = \frac{g^3}{16\pi^2} \frac{m_\tau}{12m_W} \delta_{32} \tan^2 \beta$$, LFV form factor

$$J_{L}^{(H^0)} = \frac{F}{2\sqrt{3}} \tan \beta \left[ \frac{3}{\sqrt{2}} \sin \theta_S m_\tau^2 + (\cos \theta_S - \sqrt{2} \sin \theta_S) m_{K}^2 \right]$$, hadronic form factor

- Large BR are found for light $m_{H^0} \sim 115 - 250$ GeV within NUHM
We find great sensitivity to $H^0$ in this channel within NUHM

For large $m_{N_3} \sim 5 \times 10^{14} - 10^{15}$ GeV and large $\tan \beta \sim 50 - 60$ the rates are at the present experimental reach

(Note: In the comparison with present exp bound we are assuming $\text{BR}(f_0 \rightarrow \pi^+ \pi) \approx 1$)
Constraining the model parameters from $\tau \rightarrow \mu f_0$

**Excluded Regions**

- **Sensitivity to Higgs sector** $\Rightarrow$ constraining mainly $\tan \beta$ and $m_{H^0}$

- For fixed $|\delta_{32}|$, comparison with present exp. bound $\Rightarrow$ limits on large $\tan \beta$ and light $m_{H^0}$.
  
  For ex., if $|\delta_{32}| = 1 \Rightarrow \tan \beta \gtrsim 50$, $m_{H^0} \lesssim 115$ GeV excluded.
Conclusions

• Semileptonic tau decays complement nicely the searches for LFV in $\tau - \mu$ sector, in addition to $\tau \rightarrow \mu \gamma$ and $\tau \rightarrow 3\mu$.

• They provide a unique access to the Higgs sector of SUSY-Seesaw Models.

• The most competitive semileptonic channels to search for Higgs sector signals are $\tau \rightarrow \mu \eta$ (sensitive to $A^0$) and $\tau \rightarrow \mu f_0$ (sensitive to $H^0$).

• Our set of approx. formulas can be easily used to constrain the model parameters, mainly, $\tan \beta$ and $m_{H^0}$, $m_{A^0}$

• Work on progress in constraining the model parameters from a global study of all Higgs sensitive LFV channels
Additional transparencies
The most competitive LFV tau decay: $\tau \rightarrow \mu \gamma$

From our previous study, JHEP11(2006)090, S.Antusch,E.Arganda,M.H.,A.Teixeira

\[ (-\pi/4 \leq \arg\theta_1 \leq \pi/4, \ 0 \leq \arg\theta_2 \leq \pi/4), \]

(SP1a: $M_0 = 100$ GeV, $M_{1/2} = 250$ GeV, $A_0 = -100$ GeV, $\tan\beta = 10, \mu > 0$)

Present: $\mu \rightarrow e\gamma$ more competitive than $\tau \rightarrow \mu\gamma$, except if very small $\theta_{13}$

MEGA bound, $\text{BR}(\mu \rightarrow e\gamma) < 10^{-11}$, already disfavours $m_{N_3} \gtrsim 10^{14}$ GeV

Conclusion: For a given SPS, $\tau \rightarrow \mu\gamma$ sets upper bounds on $m_{N_3}$ that, if small $\theta_{13}$, are competitive with those from $\mu \rightarrow e\gamma$.

BUT: both are insensitive to Higgs!!. Next: Some LFV semileptonic tau decays do!!
The size of $Y_\nu$ in SUSY-Seesaw with $3 \nu_R$

**Contourplot $|Y_{32}|$**

Perturbativity requirement in all couplings $\Rightarrow |Y_\nu| < 4$ (1)

Equivalently, $\left| \frac{Y_\nu}{4\pi} \right|^2 < 1.5$ (0.1) $\Rightarrow$

restrictions on the size of LFV, typically, $|\delta_{32}| < 1 - 0.5$
Results for $BR(\tau \to \mu f_0)$: CMSSM/NUHM, hierarchical/degenerate

- $BR(\tau \to \mu f_0)_{NUHM} > BR(\tau \to \mu f_0)_{CMSSM}$ due to $m_{H^0|NUHM} < m_{H^0|CMSSM}$

- $BR(\tau \to \mu f_0)$ grows with $m_{N_3}/m_N$

- Independence of $BR(\tau \to \mu f_0)$ with $m_{N_1}$ and $m_{N_2}$ if $m_{N_1} < m_{N_2} < m_{N_3}$

- $BR(\tau \to \mu f_0)_{deg} \geq BR(\tau \to \mu f_0)_{hierch}$ but hierarchical neutrino scenario more appealing for BAU
**Constraints from ’viable’ BAU**

BAU requires complex $R \neq 1 \Rightarrow$ complex $\theta_i \neq 0$. Most relevantly $\theta_2$

$n_B/n_\gamma \in \text{interval} \Rightarrow (\text{Re}(\theta_2), \text{Im}(\theta_2)) \in \text{area ('ring')}$ (WMAP in darkest ring)

### Implications for LFV

- **’viable’ BAU** ↔ $n_b/n_\gamma \in [10^{-10}, 10^{-9}]$ (WMAP $\sim 6.1 \times 10^{-10}$,’06)
  - BAU [disfav]-[fav]-[disfav]-[fav]-[disfav] pattern in $0 < |\theta_2| < 3$
  - The BAU [fav] windows occur at small ($\neq 0$) $|\theta_2| \lesssim 1.5$
- **smaller $|\theta_2|$ ⇒ smaller LFV rates**
- The existence, location and size of the windows depend on $m_{N_1}$
  - $m_{N_1} \sim O(10^{10})$ GeV BAU [fav] windows at $|\theta_2| \sim O(1)$ and $|\theta_2| \sim O(10^{-2})$
  - $m_{N_1} \sim O(10^9)$ GeV only one window at $|\theta_2| \sim O(5 \times 10^{-1})$
Contributions to $\Delta a_{\mu}^{\text{SUSY}}$

$\Delta a_{\mu}^{\text{SUSY}} \in [10^{-8}, 10^{-9}]$: compatible with $a_{\mu}^{\text{EXP}} - a_{\mu}^{\text{SM}} = 3.32 \times 10^{-9} (3.8\sigma)$