# Higgs Mediated Lepton Flavour Violation (LFV)

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# SM Framework

- Neutrino Oscillation $\Longrightarrow$ LFV in the neutrino sector $\Longrightarrow$ LFV also in the Charged Lepton Sector
- LFV transitions (like $\mu \to e\gamma$) appear through the one loop exchange of $W$ and $\nu$
- $Br(\mu \to e\gamma) \sim \frac{m_\nu^4}{M_W^4} \leq 10^{-50}$ has a strong GIM Suppression
- The same (leptonic) GIM mechanism suppress LFV transitions in the Higgs Sector, at one loop i.e. $h^0 \to l_i l_j$ (with $i \neq j$)

$$\Downarrow$$

**We do not expect any LFV signals from a SM framework**

# SUSY Framework

- SUSY provides new direct sources of LFV as off-diagonal soft terms in the slepton mass matrices (i.e., the mass insertions (MI) $\delta_{ij}$ with $i \neq j$)
- LFV would originate from any misalignment between fermion and sfermion mass eigenstates
- The SUPER-GIM suppression is much less severe than the SM-GIM one $\Rrightarrow$ LFV processes at a (potential) visible level
- LFV processes arise at one loop level through the exchange of neutralinos (charginos) and charged sleptons (sneutrinos)

# Higgs Mediated LFV

- General Multi Higgs Doublet Models allow LFV couplings among Higgs bosons and fermions $Hl_il_j$ with $i \neq j$
- The MSSM has a type-II 2HDM structure at tree level but it is broken by loop effects
- LFV $Hl_il_j$ and $Hl_i\nu_j$ Yukawa Interactions induced radiatively by non-holomorphic terms:

$$
\begin{aligned}
-\mathcal{L} \;&\simeq\; (2G_F^2)^{\frac{1}{4}}\frac{m_{l_i}}{c_\beta^2}\left(\Delta_L^{ij}\bar{l}_R^i l_L^j + \Delta_R^{ij}\bar{l}_L^i l_R^j\right)\left(c_{\beta-\alpha}h^0 - s_{\beta-\alpha}H^0 - iA^0\right) \\
&+\; (8G_F^2)^{\frac{1}{4}}\frac{m_{l_i}}{c_\beta^2}\left(\Delta_L^{ij}\bar{l}_R^i \nu_L^j + \Delta_R^{ij}\nu_L^i \bar{l}_R^j\right)H^\pm + h.c.
\end{aligned}
$$

$$\Delta_{3j} \sim \frac{\alpha_2}{4\pi}\,\delta_{3j}\,f_{loop}$$

# Higgs Mediated LFV Phenomenology

We will study Higgs Mediated LFV effects in the following processes:

- **Rare Decays**: $\tau \rightarrow l_j l_k l_k$, $\tau \rightarrow l_j \eta$, $\tau \rightarrow l_j \gamma$ with $i, j = e, \mu$

  [P. Paradisi hep-ph/0508054]

- **High Precision Electroweak Test**: $\pi \rightarrow l\nu\,(\pi l2)$ and $K \rightarrow l\nu\,(Kl2)$ with $l = e, \mu$

  [A. Masiero, P. Paradisi and R. Petronzio, to appear]

# Phenomenology: $\tau \to l_j X$ $(X = \gamma, \eta, \mu\mu)$ decays

- Tree level Higgs exchange, i.e. $\tau \to l_j \mu\mu$ and $\tau \to l_j \eta$

$$\frac{Br(\tau \to l_j \mu\mu)}{Br(\tau \to l_j \bar{\nu}_j \nu_\tau)} \simeq \frac{m_\tau^2 m_\mu^2}{32 m_A^4} \left[3 + 5\delta_{j\mu}\right] \Delta_{\tau j}^2 \tan^6\beta$$

[K.S.Babu and C.Kolda hep-ph/0206310]

$$\frac{Br(\tau \to l_j \eta)}{Br(\tau \to l_j \bar{\nu}_j \nu_\tau)} \simeq 18\pi^2 \left(\frac{f_\eta^8 m_\eta^2}{m_A^2 m_\tau}\right)^2 \left(1 - \frac{m_\eta^2}{m_\tau^2}\right)^2 \Delta_{3j}^2 \tan^6\beta$$

[M.Sher hep-ph/0207136]

- One loop Higgs exchange, i.e. $\tau \to l_j \gamma$

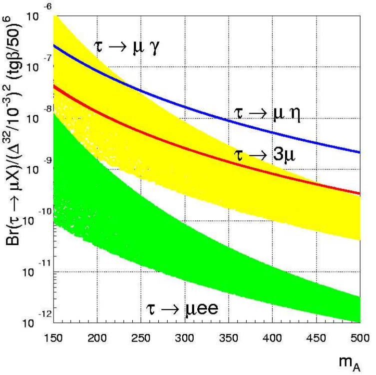
$$\frac{Br(\tau \to l_j \gamma)}{Br(\tau \to l_j \bar{\nu}_j \nu_\tau)} \simeq \frac{3\alpha_{el}}{2\pi} \left(\frac{m_\tau^2}{m_A^2}\right)^2 \left(\frac{\delta m}{m_A} \log\frac{m_\tau^2}{m_A^2} + \frac{1}{6}\right)^2 \Delta_{\tau j}^2 \tan^6\beta$$

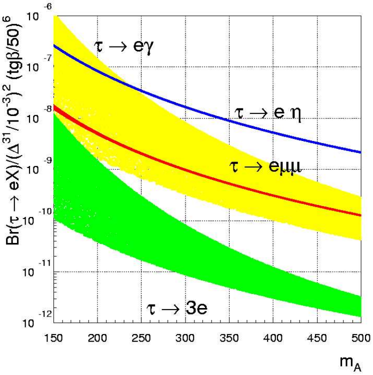
$(\Delta_{3j} \sim \frac{\alpha_2}{4\pi} \delta_{3j} f_{loop})$

[P.Paradisi hep-ph/0508054]

# Phenomenology: $\tau \to l_j X$ $(X = \gamma, \eta, \mu\mu)$ decays

$$\text{If } \delta m/m_A \sim 10\% \text{ (possible for } m_A \sim M_W) \Longrightarrow \frac{Br(\tau\to l_j\gamma)}{Br(\tau\to l_j\eta)} \sim 1$$





# $\mu - e$ universality in $K \to l\nu$ and Higgs Mediated LFV

- $\mu - e$ universality: $R_{K,\pi} = \Gamma(K(\pi) \to e\nu_e)/\Gamma(K(\pi) \to \mu\nu_\mu)$
  - K physics

$$R_K^{exp.} = (2.416 \pm 0.043_{stat.} \pm 0.024_{syst.}) \cdot 10^{-5} \quad \text{NA48/2}$$

[L. Fiorini talk, hep '05]

$$R_K^{exp.} = (2.44 \pm 0.11) \cdot 10^{-5} \quad PDG$$
$$R_K^{SM} = (2.472 \pm 0.001) \cdot 10^{-5} \quad SM$$

  - $\pi$ physics

$$R_\pi^{exp.} = (1.230 \pm 0.004) \cdot 10^{-4} \quad \text{PDG}$$

$$R_\pi^{SM} = (1.2354 \pm 0.0002) \cdot 10^{-4} \quad \text{SM}$$

# $\mu - e$ universality in $K \to l\nu$ and Higgs Mediated LFV

- Denoting by $\Delta r_{NP}^{e-\mu}$ the deviation from $\mu - e$ universality in $R_{K,\pi}$ due to new physics, i.e.:

$$R_{K,\pi} = R_{K,\pi}^{SM}\left(1 + \Delta r_{K,\pi\, NP}^{e-\mu}\right),$$

  - we get at the $2\sigma$ level:

$$-0.063 \leq \Delta r_{K\, NP}^{e-\mu} \leq 0.017 \quad \text{NA48/2}$$

$$-0.0107 \leq \Delta r_{\pi\, NP}^{e-\mu} \leq 0.0022 \quad \text{PDG}$$

# Susy contributions to $\Delta r_{NP}^{e-\mu}$

- $K(\pi) \to l\nu$ are helicity suppressed in the SM $\Rightarrow$ they are very sensitive to non-SM effects.
- Charged Higgs (of any 2HDM) gives, at tree level, the same lepton mass dependence as the SM contribution to $K(\pi) \to l\nu$
- $R_K$ and $R_\pi$ feel Charged Higgs effects from one loop level

$$\Delta r_{SUSY}^{e-\mu} \sim \frac{\alpha_2}{4\pi} \left( \frac{m_\mu^2 - m_e^2}{m_H^2} \right) \tan^2 \beta \leq 10^{-6}$$

- Charginos/neutralinos sleptons ($\tilde{l}_{e,\mu}$) contributions to $\Delta r_{SUSY}^{e-\mu}$

$$\Delta r_{SUSY}^{e-\mu} \sim \frac{\alpha_2}{4\pi} \left( \frac{\tilde{m}_\mu^2 - \tilde{m}_e^2}{\tilde{m}_\mu^2 + \tilde{m}_e^2} \right) \frac{m_W^2}{M_{SUSY}^2} \leq 10^{-4}$$

# LFV Susy contributions to $\Delta r_{NP}^{e-\mu}$

- In presence of LFV channels we take the $R_{\pi,K}^{LFV}$ quantity

$$R_{\pi,K}^{LFV} = \frac{\sum_i \Gamma(\pi(K) \to e\nu_i)}{\sum_i \Gamma(\pi(K) \to \mu\nu_i)} \,, \qquad i = e, \mu, \tau$$

- The relevant LFV Yukawa coupling is

$$eH^{\pm}\nu_{\tau} \to \frac{g_2}{\sqrt{2}} \frac{m_{\tau}}{M_W} \Delta_R^{31} \tan^2\beta \,, \quad \Delta_R^{31} \sim \frac{\alpha_2}{4\pi} \, \delta_{RR}^{31} \, f_{loop}$$

- The $\mu - e$ non-universal contribution in $R_K$ is:

$$\Delta r_{K\,SUSY}^{e-\mu} \simeq \left( \frac{m_K^4}{M_{H^{\pm}}^4} \right) \left( \frac{m_{\tau}^2}{m_e^2} \right) |\Delta_R^{31}|^2 \tan^6\beta$$

# LFV Susy contributions to $\Delta r_{NP}^{e-\mu}$

- $\Delta r_{K\,SUSY}^{e-\mu}$ can reach the percent level

$$\Delta r_{K\,SUSY}^{e-\mu} \simeq 0.013 \left(\frac{\tan\beta}{40}\right)^6 \left(\frac{500\,GeV}{M_{H^\pm}}\right)^4 \left(\frac{\Delta_R^{31}}{5\cdot 10^{-4}}\right)^2$$

- $\Delta r_{\pi\,SUSY}^{e-\mu}$ remain below its experimental resolution

$$\Delta r_{\pi\,SUSY}^{e-\mu} \simeq \left(\frac{m_d}{m_u + m_d}\right)^2 \left(\frac{m_\pi^4}{m_k^4}\right) \Delta r_{K\,SUSY}^{e-\mu} \leq 10^{-4}$$

- For the same values, the corresponding LFV tau decays, like $\tau \rightarrow eX$ (with $X = \gamma, \eta, \mu\mu$), are

$$Br(\tau \rightarrow e\eta) \leq 10^{-10}$$

$$Br(\tau \rightarrow e\mu\mu) \leq 10^{-11}\ , \quad Br(\tau \rightarrow e\gamma) \leq 10^{-11}$$

# LFV Susy contributions to $\Delta r_{NP}^{e-\mu}$

- SUSY LFV effects to LFC channels in $R_K$

$$eH^{\pm}\nu_e \rightarrow \frac{g_2}{\sqrt{2}}\frac{m_e}{M_W}\tan\beta\left(1+\frac{m_\tau}{m_e}\Delta_{RL}^{11}\tan\beta\right)$$

$$\Delta_{RL}^{11} \sim \frac{\alpha_1}{4\pi}\delta_{RR}^{13}\delta_{LL}^{31} f_{loop} \sim 10^{-4}$$

- Deviations from $\mu - e$ universality in $Kl2$

$$R_K^{LFV} \simeq R_K^{SM}\left[1 \; - \; 2\left(\frac{m_K^2}{M_{H^\pm}^2}\right)\left(\frac{m_\tau}{m_e}\right)\Delta_{RL}^{11}\tan^3\beta + \left(\frac{m_K^4}{M_{H^\pm}^4}\right)\left(\frac{m_\tau^2}{m_e^2}\right)|\Delta_R^{31}|^2\tan^6\beta\right].$$

$$R_K^{LFV} \simeq R_K^{SM}(1-0.032)$$

# Conclusion

- Higgs mediated LFV can play a relevant role in $\tau$ decays
- One loop Higgs exchange effects ($\tau \to \mu\gamma$) can dominate over a tree level Higgs exchange ($\tau \to l_j\mu\mu$ and $\tau \to l_j\eta$)
- Rather surprisingly, a precise measurement of the flavor conserving $K_{l2}$ decays may shed light on the size of LFV in new physics.
- If a discrepancy between the SM prediction and the experimental measures will be found, LFV SUSY effects could explain such a discrepancy