Relating neutrino masses, LFV and SUSY breaking

F. R. Joaquim
(Univ. di Padova and INFN Padua)

Work done in collaboration with Anna Rossi (hep-ph/0604083 and hep-ph/0606xxx)

PLAN:

Predictions for LFV processes in the triplet seesaw mechanism

Sensitivity to low-energy neutrino parameters

General analysis of the parameter space

Conclusions

A kind of introduction...

- SUSY breaking is communicated to the observable sector via Gauge and Yukawa interactions

$$W = \frac{1}{\sqrt{2}}(\mathbf{Y}_T LTL + \mathbf{Y}_S d^c S d^c) + \mathbf{Y}_Z d^c Z L + \mathbf{Y}_d d^c Q H_1 + \mathbf{Y}_e e^c L H_1 + \mathbf{Y}_u u^c Q H_2$$
$$+ \frac{1}{\sqrt{2}} \lambda H_2 \bar{T} H_2 + M_T T\bar{T} + M_Z Z\bar{Z} + M_S S\bar{S} + \mu H_1 H_2$$

- Soft SUSY breaking terms generated at one and two-loop level (finite contributions at the messenger decoupling scale)

$$-\mathcal{L}_{\rm soft} \supset (H_1 \tilde{e}^c \mathbf{A}_e \tilde{L} + H_1 \tilde{d}^c \mathbf{A}_d \tilde{Q} - H_2\, \tilde{u}^c \mathbf{A}_u \tilde{Q} + \frac{1}{2} M_a \lambda_a \lambda_a + B_H \mu H_1 H_2 + \text{h.c.}) +$$
$$\tilde{L}^\dagger \mathbf{m}^2_{\tilde{L}} \tilde{L} + \tilde{e}^c \mathbf{m}^2_{\tilde{e}^c} \tilde{e}^{c*} + \tilde{d}^c \mathbf{m}^2_{\tilde{d}^c} \tilde{d}^{c*} + + \tilde{u}^c \mathbf{m}^2_{\tilde{u}^c} \tilde{u}^{c*} + \tilde{Q}^\dagger\, \mathbf{m}^2_{\tilde{Q}} \tilde{Q} + m^2_{H_1} H_1^\dagger H_1 + m^2_{H_2} H_2^\dagger H_2$$

M_T, B_T, λ: $\quad m^2_{H_2}\big|_{M_T}\ ,\ m^2_{H_1}\big|_{M_T}\ ,\ B_H\big|_{M_T}$ and $\mathbf{m}^2_X\big|_{M_T}\ ,\ \mathbf{A}_X\big|_{M_T}\ ,\ M_a\big|_{M_T}$

RGE running

$\mu_{\rm EWSB}$: $\quad |\mu|^2 = \dfrac{1}{\cos(2\beta)}(m^2_{H_2}\sin^2\beta - m^2_{H_1}\cos^2\beta) - \dfrac{1}{2}m^2_Z\ ,\ B_H^{\rm EW}\mu = \dfrac{1}{2}\sin(2\beta)(m^2_{H_1} + m^2_{H_2} + 2|\mu|^2)$

$\tan\beta$ scanning and matching between $B_H^{\rm EW}$ and B_H required $\longrightarrow$ $\tan\beta$, sgn(μ) and $|\mu|$ fixed

Typically the dominant contributions to the off-diagonal slepton masses are: $(\mathbf{m}^2_{\tilde{L}})_{ij} \propto \frac{B_T^2}{(16\,\pi^2)^2}(\mathbf{Y}_T^\dagger \mathbf{Y}_T)_{ij}$

Direct relation with the effective neutrino mass matrix: $(\mathbf{m}^2_{\tilde{L}})_{ij} \propto (\mathbf{Y}_T^\dagger \mathbf{Y}_T)_{ij} \sim \left(\frac{M_T}{\lambda\, v_2^2}\right)^2 (\mathbf{m}_\nu^\dagger \mathbf{m}_\nu)_{ij} \;,\; i \neq j$

In terms of the PMNS mixing matrix and neutrino masses: $\mathbf{U} \equiv \mathbf{U}^\delta\, \mathrm{diag}(e^{i\phi_1}, e^{i\phi_2}, 1) \;,\; (\mathbf{m}_\nu^\dagger \mathbf{m}_\nu)_{ij} = \mathbf{U}^\delta_{ik}\, m_k^2\, \mathbf{U}^{\delta\dagger}_{kj}$

Normal ordering:

$(m_1 < m_2 < m_3)$

$$m_2^2 = m_1^2 + \Delta m^2_\odot$$

$$m_3^2 = m_1^2 + \Delta m^2_\odot + \Delta m^2_{\rm atm}$$

$$(\mathbf{m}_\nu^\dagger \mathbf{m}_\nu)_{ij} = m_1^2\,\delta_{ij} + \Delta m^2_\odot \mathbf{U}_{i2}\mathbf{U}^*_{j2} + (\Delta m^2_{\rm atm} + \Delta m^2_\odot)\mathbf{U}_{i3}\mathbf{U}^*_{j3}$$

Inverted ordering:

$(m_3 < m_1 < m_2)$

$$m_2^2 = m_3^2 + \Delta m^2_{\rm atm}$$

$$m_1^2 = m_3^2 - \Delta m^2_\odot + \Delta m^2_{\rm atm}$$

$$(\mathbf{m}_\nu^\dagger \mathbf{m}_\nu)_{ij} = m_3^2\,\delta_{ij} + \Delta m^2_{\rm atm} \mathbf{U}_{i2}\mathbf{U}^*_{j2} + (\Delta m^2_{\rm atm} - \Delta m^2_\odot)\mathbf{U}_{i1}\mathbf{U}^*_{j1}$$

For $i \neq j$, $(\mathbf{m}_\nu^\dagger \mathbf{m}_\nu)_{ij}$ does not depend on the lightest neutrino mass.

$$\rho \equiv \frac{\Delta m^2_\odot}{\Delta m^2_{\rm atm}}$$

Normal ordering: $m_1 < m_2 < m_3$

$$\left\{\begin{array}{l} (\mathbf{m}^2_{\tilde{L}})_{\mu e} \propto c_{13}\,[\,\rho\, c_{23}\sin(2\theta_{12}) + 2\, s_{13}\, s_{23}\,] \\ (\mathbf{m}^2_{\tilde{L}})_{\tau\mu} \propto c^2_{13}\,\sin(2\theta_{23}) \\ (\mathbf{m}^2_{\tilde{L}})_{\tau e} \propto c_{13}\,[\,2\,(1+\rho\, c^2_{12}) s_{13}\, c_{23} - \rho\, s_{23}\sin(2\theta_{12})\,] \end{array}\right. \Rightarrow \left\{\begin{array}{l} \left.\dfrac{(\mathbf{m}^2_{\tilde{L}})_{\tau\mu}}{(\mathbf{m}^2_{\tilde{L}})_{\mu e}}\right|_{s_{13}\ll\rho/2} \simeq \dfrac{\Delta m^2_{\rm atm}}{\Delta m^2_\odot}\,\dfrac{\sin(2\theta_{23})}{c_{23}\sin(2\theta_{12})} \simeq 40 \\ \left.\dfrac{(\mathbf{m}^2_{\tilde{L}})_{\tau e}}{(\mathbf{m}^2_{\tilde{L}})_{\mu e}}\right|_{s_{13}\ll\rho/2} \simeq -\tan\theta_{23} \simeq -1 \end{array}\right.$$

Inverted ordering: $m_3 < m_1 < m_2$

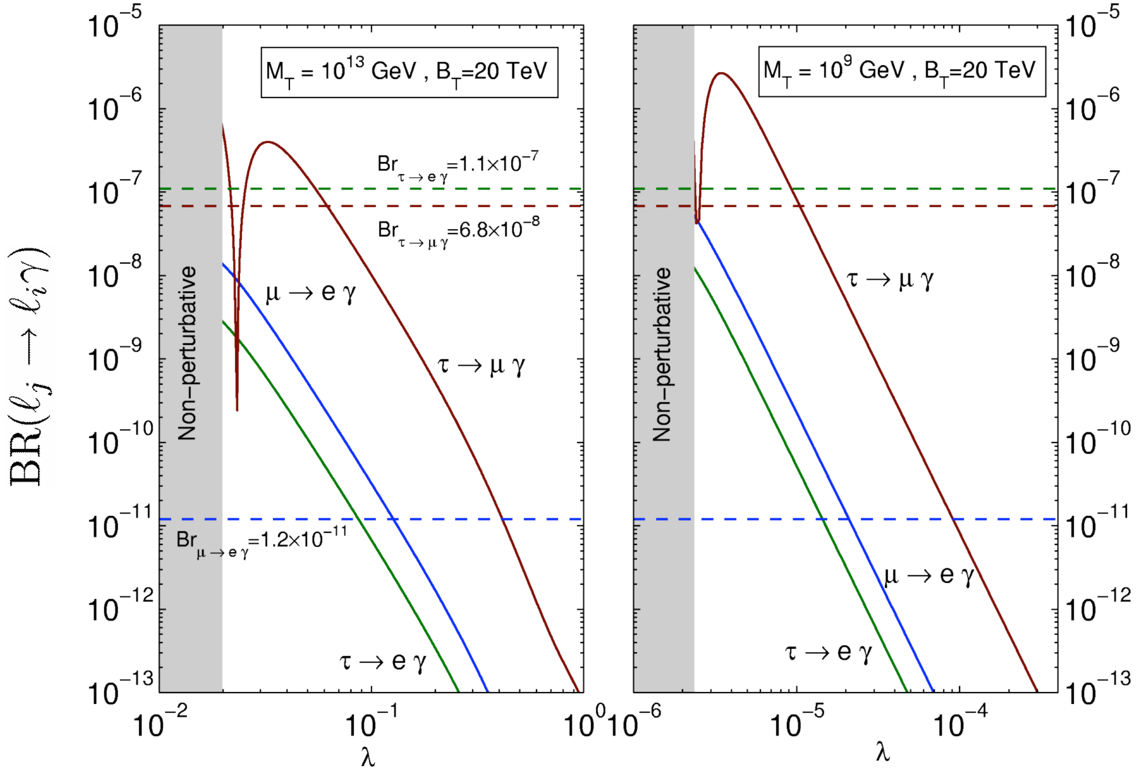
$$\left\{\begin{array}{l} (\mathbf{m}^2_{\tilde{L}})_{\mu e} \propto c_{13}\,[\,\rho\, c_{23}\sin(2\theta_{12}) - 2\,(1-\rho\, c^2_{12})\; s_{13}\, s_{23}\,] \\ (\mathbf{m}^2_{\tilde{L}})_{\tau\mu} \propto -c^2_{13}\,\sin(2\theta_{23}) \\ (\mathbf{m}^2_{\tilde{L}})_{\tau e} \propto -c_{13}\,[\,\rho\, s_{23}\sin(2\theta_{12}) + 2\, s_{13}\, c_{23}\,] \end{array}\right. \Rightarrow \left\{\begin{array}{l} \left.\dfrac{(\mathbf{m}^2_{\tilde{L}})_{\tau\mu}}{(\mathbf{m}^2_{\tilde{L}})_{\mu e}}\right|_{s_{13}\ll\rho/2} \simeq -\dfrac{\Delta m^2_{\rm atm}}{\Delta m^2_\odot}\,\dfrac{\sin(2\theta_{23})}{c_{23}\sin(2\theta_{12})} \simeq -40 \\ \left.\dfrac{(\mathbf{m}^2_{\tilde{L}})_{\tau e}}{(\mathbf{m}^2_{\tilde{L}})_{\mu e}}\right|_{s_{13}\ll\rho/2} \simeq -\tan\theta_{23} \simeq -1 \end{array}\right.$$

Predictions for $\ell_j \to \ell_i \gamma$

$$\frac{\mathrm{BR}(\tau \to \mu\gamma)}{\mathrm{BR}(\mu \to e\gamma)} \simeq \left|\frac{(\mathbf{m}^2_{\tilde{L}})_{\tau\mu}}{(\mathbf{m}^2_{\tilde{L}})_{\mu e}}\right|^2 \frac{\mathrm{BR}(\tau \to \mu\nu_\tau\bar{\nu}_\mu)}{\mathrm{BR}(\mu \to e\nu_\mu\bar{\nu}_e)}$$

$$\frac{\mathrm{BR}(\tau \to e\gamma)}{\mathrm{BR}(\mu \to e\gamma)} \simeq \left|\frac{(\mathbf{m}^2_{\tilde{L}})_{\tau e}}{(\mathbf{m}^2_{\tilde{L}})_{\mu e}}\right|^2 \frac{\mathrm{BR}(\tau \to e\nu_\tau\bar{\nu}_e)}{\mathrm{BR}(\mu \to e\nu_\mu\bar{\nu}_e)}$$

$\theta_{13} = 0$



$\theta_{13} = 0$

$$\frac{\mathrm{BR}(\tau \to \mu\gamma)}{\mathrm{BR}(\mu \to e\gamma)} \sim 300$$

$\mathrm{BR}(\mu \to e\gamma) < 1.1 \times 10^{-11}$ [MEGA'99]

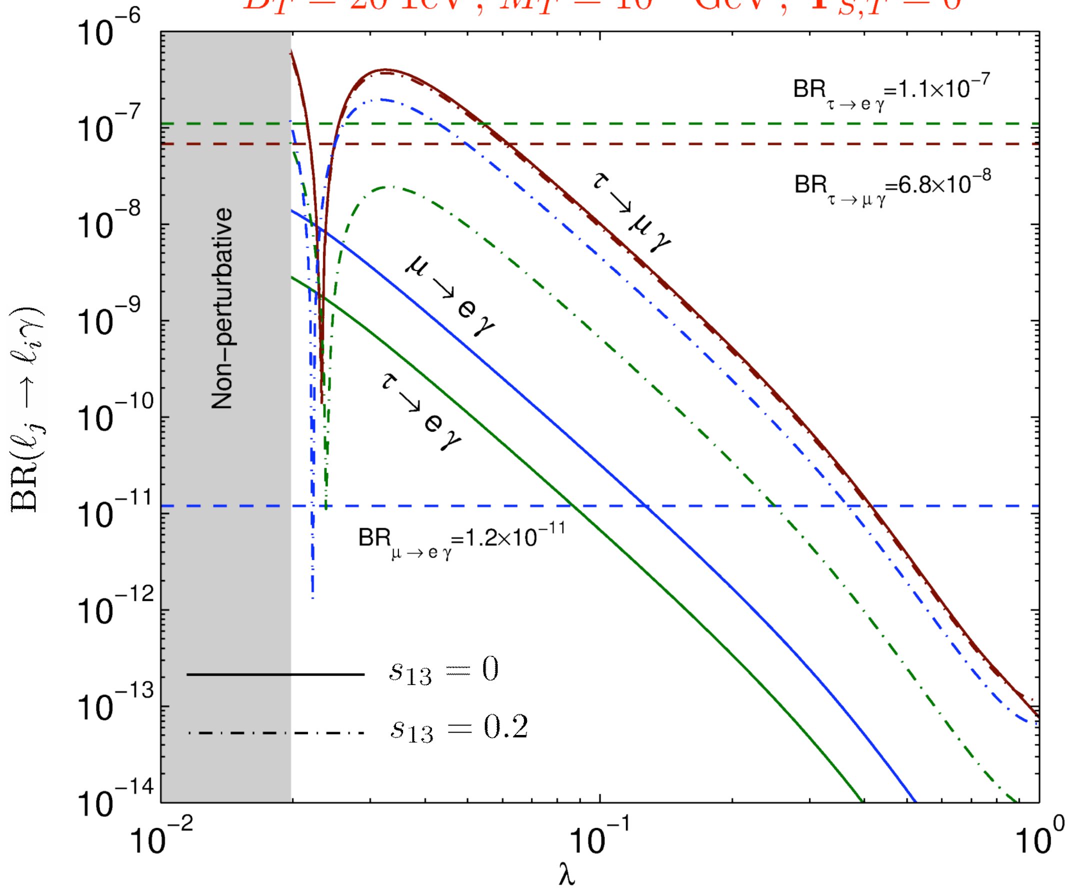
$\mathrm{BR}(\tau \to \mu\,\gamma) < 6.8 \times 10^{-8}$ [BaBar'05]

$\mathrm{BR}(\tau \to e\,\gamma) < 1.1 \times 10^{-7}$ [BaBar'05]

$$\frac{\mathrm{BR}(\tau \to e\gamma)}{\mathrm{BR}(\mu \to e\gamma)} \sim 0.2$$

Sensitivity to 1-3 neutrino mixing

$B_T = 20\,\text{TeV}\,,\ M_T = 10^{13}\,\text{GeV}\,,\ \mathbf{Y}_{S,T} = 0$



$$\frac{\mathrm{BR}(\tau\to e\gamma)}{\mathrm{BR}(\mu\to e\gamma)} \simeq \left|\frac{(\mathbf{m}^2_{\tilde{L}})_{\tau e}}{(\mathbf{m}^2_{\tilde{L}})_{\mu e}}\right|^2 \frac{\mathrm{BR}(\tau\to e\nu_\tau\bar{\nu}_e)}{\mathrm{BR}(\mu\to e\nu_\mu\bar{\nu}_e)}$$

$$\frac{\mathrm{BR}(\tau\to \mu\gamma)}{\mathrm{BR}(\mu\to e\gamma)} \simeq \left|\frac{(\mathbf{m}^2_{\tilde{L}})_{\tau \mu}}{(\mathbf{m}^2_{\tilde{L}})_{\mu e}}\right|^2 \frac{\mathrm{BR}(\tau\to \mu\nu_\tau\bar{\nu}_\mu)}{\mathrm{BR}(\mu\to e\nu_\mu\bar{\nu}_e)}$$

For $s_{13} = 0.2$:

$$\left|\frac{(\mathbf{m}^2_{\tilde{L}})_{\tau\mu}}{(\mathbf{m}^2_{\tilde{L}})_{\mu e}}\right|^2_{\theta_{13}=0.2} \simeq 9.0\ ,\quad \left|\frac{(\mathbf{m}^2_{\tilde{L}})_{\tau e}}{(\mathbf{m}^2_{\tilde{L}})_{\mu e}}\right|^2_{\theta_{13}=0.2} \simeq 0.7$$

$$\left.\frac{\mathrm{BR}(\tau\to\mu\gamma)}{\mathrm{BR}(\mu\to e\gamma)}\right|_{s_{13}=0.2} \simeq 2.0$$

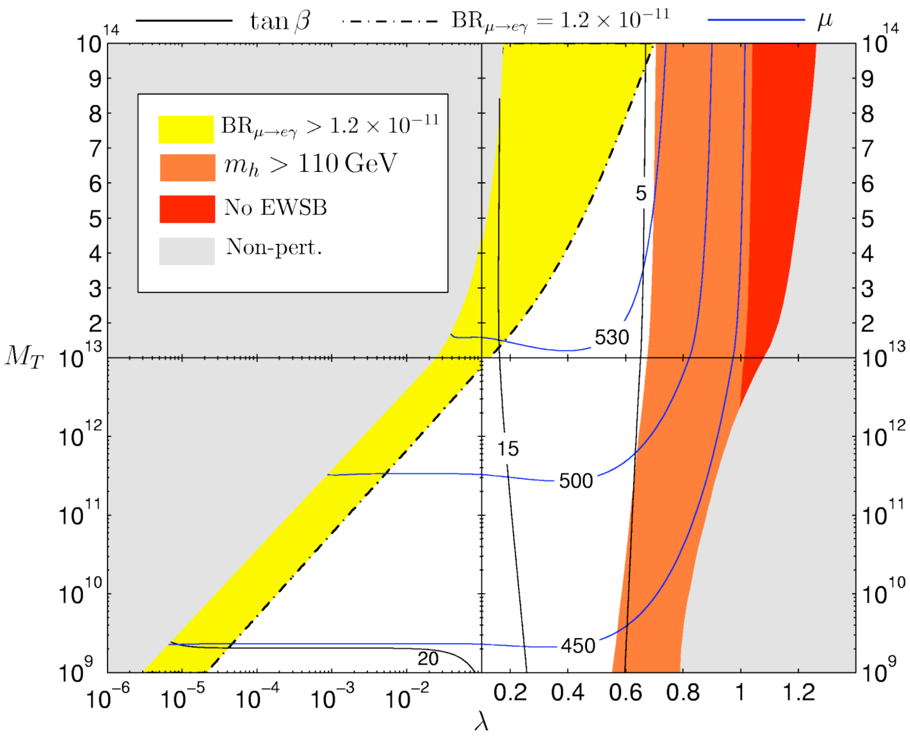
$$\left.\frac{\mathrm{BR}(\tau\to e\gamma)}{\mathrm{BR}(\mu\to e\gamma)}\right|_{s_{13}=0.2} \simeq 0.1$$

$$(\mathbf{m}^2_{\tilde{L}})_{\mu e} \propto c_{13}\left[\,\rho\, c_{23}\sin(2\theta_{12}) + 2\, s_{13}\, s_{23}\,\right]$$

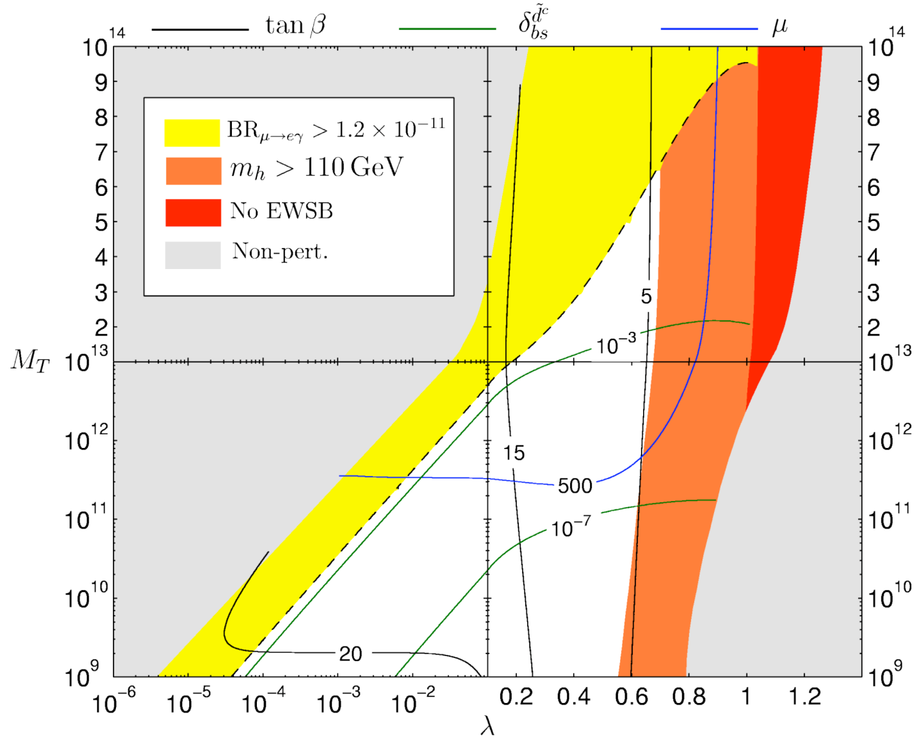
$$(\mathbf{m}^2_{\tilde{L}})_{\tau\mu} \propto c^2_{13}\, \sin(2\theta_{23})$$

$$(\mathbf{m}^2_{\tilde{L}})_{\tau e} \propto c_{13}\left[\,2\,(1+\rho\, c^2_{12}) s_{13}\, c_{23} - \rho\, s_{23}\sin(2\theta_{12})\,\right]$$

$B_T = 20\,\mathrm{TeV}\,,\ \mathbf{Y}_S = \mathbf{Y}_Z = 0$



$B_T = 20\,\mathrm{TeV}\,,\ \mathbf{Y}_S = \mathbf{Y}_Z = \mathbf{Y}_T$



Conclusions:

- Very predictive framework: strict relation between LFV, REWSB and low-energy neutrino physics.
- More information from low-energy neutrino physics needed: neutrino masses, 1-3 mixing angle, (leptonic CP-violation)
- Information about the SUSY spectrum, Higgs mass, etc...