Gauge and Yukawa mediated SUSY breaking in Triplet Seesaw Scenario

Anna Rossi
Padova University

Flavour in the era of the LHC, 3rd meeting - 16 May 2006

F. R. Joaquim and A. Rossi, hep-ph/0604083

- Triplet (type II) versus Singlet (type I) Seesaw Mechanisms

- Specific features of Lepton Flavour Violation (LFV) in the T-Seesaw case

- Novel SUSY + GUT version of the T-Seesaw : T are messengers of SUSY breaking

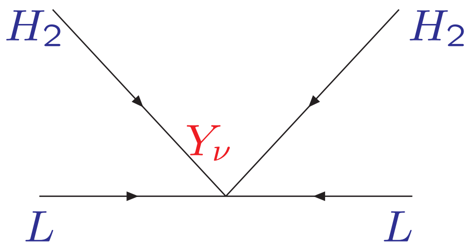
  Very predictive picture relating ν masses, LFV, superpartner spctrum and Electroweak symmetry breaking (EWSB)

Experimental Evidence of Neutrino mass

$$m_\nu \neq 0, \qquad \theta^l_{ij} \neq 0, \qquad (i \neq j) \qquad \longrightarrow \text{LFV}$$

In the (MS)SM this is understood from $L = L_e + L_\mu + L_\tau$ violating $d = 5$ operator

S. Weinberg, 1979



$$\frac{1}{M_L} Y_\nu^{ij} (L_i H_2)(L_j H_2)$$

$$M_L \gg M_Z$$

$\langle H_2 \rangle = v_2 \qquad m_\nu^{ij} = \frac{v_2^2}{M_L} Y_\nu^{ij}$ Mass scale suppression

$$m_\nu \sim 0.1 \text{ eV} \quad \longrightarrow Y_\nu^{-1} M_L \sim 10^{15} \text{ GeV}$$

$$m_\nu = U^* m_\nu^D U^\dagger$$

$m_\nu^D = \text{diag}(m_1, m_2, m_3) \qquad U = U(\theta_{12}, \theta_{23}, \theta_{13}, \delta, \phi_{1,2})$

3 masses + 3 angles + 3 phases
= 9 independent parameters
provided by low energy experiments

(At tree-level) most-known realizations of the Seesaw:

1. decoupling singlets ('right-handed') N

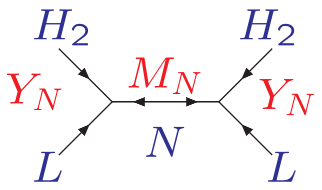
   P.Minkowski, 1977; M.Gell-Mann, P.Ramond, R.Slansky, 1979; T.Yanagida, 1979; S.Glashow, 1980; R.N.Mohapatra, G.Senjanovic, 1980

2. decoupling $SU(2)_W$ triplets T

   M.Magg, C.Wetterich, 1980; R.Mohapatra, G.Senjanovic, 1981

Singlets $N \sim (1,0)$

$Y_N H_2 L N + \frac{1}{2} M_N N N$



$\frac{1}{M_L} Y_\nu = Y_N^T M_N^{-1} Y_N$

$m_\nu = v_2^2 \; Y_N^T M_N^{-1} Y_N$

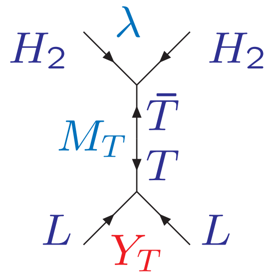
- $3N$ needed

- 2 LFV sources Y_N, M_N

i.e. 12 reals + 6 phases

Triplets $T, \bar{T} \sim (3, \pm 1)$

$Y_T L T L + \lambda H_2 \bar{T} H_2 + M_T T \bar{T}$



$\frac{1}{M_L} Y_\nu = \frac{\lambda}{M_T} Y_T$

$m_\nu = \frac{v_2^2 \lambda}{M_T} Y_T$

- 1 pair $(T, \bar{T})$ enough

- 1 LFV source $Y_T = Y_T^T$

i.e. 6 reals + 3 phases

Low energy data reconstruct Y_ν, *i.e.* 9 paramaters

not enough to determine univocally Y_N, M_N

e.g. S.Davidson, A.Ibarra, 2001

just match with Y_T

$Y_\nu \leftrightarrow Y_T$

High-energy Flavour Structure known

LFV in Y_ν does not give sizeable effects (besides ν oscillations)

$$\left(\frac{m_\nu}{M_Z}\right)^2 \quad \text{suppression}$$

e.g. in $l_i \to l_j \gamma, \quad l_i \to l_j l_j l_j$

Supersymmetry offers new LFV sources:
sparticle masses $m^2_{\tilde{f}}$, scalar couplings A_f

What about $m^2_{\tilde{f}}$?

- mass scale not far from the EW scale

- unknown flavour structure (... more general issue)

Conservative/Pragmatic attitude inspired by Minimal SUGRA or (High Scale) Gauge Mediation:

Universality at high ($\not{S}\not{U}\not{S}$Y - mediation) scale M_X

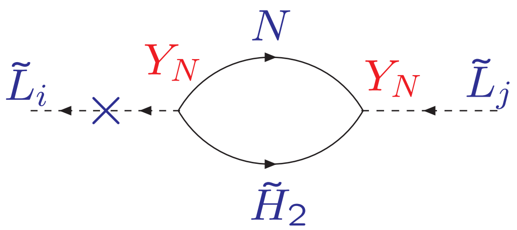
$$m^2_{\tilde{f}} = m^2_0 1\!\mathrm{l}$$

At low energy RG EFFECTS induced by LFV Yukawa couplings spoil universality

$$(m^2_{\tilde{f}})_{ij} \neq 0 \qquad\qquad i \neq j$$

Lepton Flavour Violation in $\tilde{L}^\dagger m^2_{\tilde{L}} \tilde{L}$

N-Seesaw



$$(m^2_{\tilde{L}})_{ij} \sim \frac{m_0^2}{16\pi^2} (Y_N^\dagger Y_N)_{ij} \ln \frac{M_X}{M_N}$$

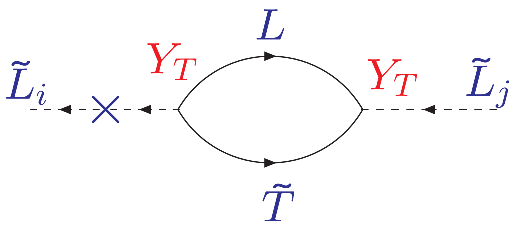
$Y_N^\dagger Y_N$: not directly linked to Y_ν

More assumptions to deal with $m^2_{\tilde{L}}$ flavour structure

J.Hisano et al.,1996;

J.A.Casas, A.Ibarra, 2001;

T-Seesaw



$$(m^2_{\tilde{L}})_{ij} \sim \frac{m_0^2}{16\pi^2} (Y_T^\dagger Y_T)_{ij} \ln \frac{M_X}{M_T}$$

direct link $Y_T \leftrightarrow Y_\nu(m_\nu)$

$$(m^2_{\tilde{L}})_{ij} \sim \frac{m_0^2}{16\pi^2} \left(\frac{M_T}{\lambda v_2^2}\right) (m_\nu^\dagger m_\nu)_{ij} \ln \frac{M_X}{M_T}$$

A.R., 2002

In T-Seesaw $m^2_{\tilde{L}}$ inherits

the low-energy neutrino flavour structure

$$(m^2_{\tilde{L}})_{ij} \sim \frac{m_0^2}{16\pi^2} \left(\frac{M_T}{\lambda v_2^2}\right) \left[U (m_\nu^D)^2 U^\dagger\right]_{ij} \ln \frac{M_X}{M_T}$$

STRICT PREDICTIONS

$$\frac{(m^2_{\tilde{L}})_{\tau\mu}}{(m^2_{\tilde{L}})_{\mu e}} \approx \frac{\left[U (m_\nu^D)^2 U^\dagger\right]_{\tau\mu}}{\left[U (m_\nu^D)^2 U^\dagger\right]_{\mu e}}, \qquad \frac{(m^2_{\tilde{L}})_{\tau e}}{(m^2_{\tilde{L}})_{\mu e}} \approx \frac{\left[U (m_\nu^D)^2 U^\dagger\right]_{\tau e}}{\left[U (m_\nu^D)^2 U^\dagger\right]_{\mu e}}$$

T-Seesaw: relative LFV size predicted in a model-independent way

depends only on the neutrino masses and mixing angles measured at low-energy

From ν Exps:

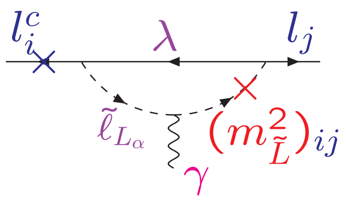
$$\Delta m^2_{12} \simeq 8 \times 10^{-5}\ \text{eV}^2, \quad \Delta m^2_{23} \simeq 2.2 \times 10^{-3}\ \text{eV}^2$$

$$\sin^2_{12} \simeq 0.3, \quad \sin^2_{23} \simeq 0.5, \quad \sin^2_{13} \lesssim 10^{-2}$$

Assume *e.g.* hierarchical spectrum $m_1 \ll m_2 \ll m_3$

$$\frac{(m^2_{\tilde{L}})_{\tau\mu}}{(m^2_{\tilde{L}})_{\mu e}} \approx \left(\frac{m_3}{m_2}\right)^2 \frac{\sin 2\theta_{23}}{\sin 2\theta_{12} \cos\theta_{23}} \sim 40, \quad \frac{(m^2_{\tilde{L}})_{\tau e}}{(m^2_{\tilde{L}})_{\mu e}} \approx \tan\theta_{23} \sim 1$$

SUSY Enhanced contributions to radiative LFV decays



$\propto (m^2_{\tilde{L}})_{ij}$

A.R., 2002

$$\frac{BR(\tau \to \mu\gamma)}{BR(\mu \to e\gamma)} \approx \left(\frac{(m^2_{\tilde{L}})_{\tau\mu}}{(m^2_{\tilde{L}})_{\mu e}}\right)^2 \frac{BR(\tau \to \mu\nu_\tau\bar{\nu}_\mu)}{BR(\mu \to e\nu_\mu\bar{\nu}_e)} \sim 300$$

$$\frac{BR(\tau \to e\gamma)}{BR(\mu \to e\gamma)} \approx \left(\frac{(m^2_{\tilde{L}})_{\tau e}}{(m^2_{\tilde{L}})_{\mu e}}\right)^2 \frac{BR(\tau \to e\nu_\tau\bar{\nu}_e)}{BR(\mu \to e\nu_\mu\bar{\nu}_e)} \sim 10^{-1}$$

T-Seesaw Motivates Grand Unified Theory (GUT)

$SU(2)_W$ Triplet States below M_G alter (simple) Gauge Coupling Unification

Recovered by adding extra states to complete a GUT supermultiplet

$$T + \ldots$$

Minimal extension: SUSY SU(5)

Triplets T fit into 15: 15 = S + T + Z

$SU(3)_C \times SU(2)_W \times U(1)_Y$ decomposition

$$S \sim (6, 1, -\frac{2}{3}), \quad T \sim (1, 3, 1), \quad Z \sim (3, 2, \frac{1}{6})$$

relevant SU(5) Yukawa term $Y_{15}\ \bar{5}\ 15\ \bar{5} = Y_T LTL + \ldots$

$[\bar{5} = d^c + \ell]$

- what do we expect in the MSUGRA with universality at M_G?

Flavour violation from the Yukawa Y_{15} induced in both the quark and lepton sectors

A.R, 2002

Novel SUSY + GUT Triplet Seesaw

F. Joaquim and A.R, hep-ph/0604083

Can do more: $15 \supset T$ exchange also generates soft ~~SUSY~~ masses

$\longrightarrow$ 15 interact with X breaking SUSY

Then impose B-L Conservation

$$W_{SU(5)} = \xi X 15\ \overline{15} + Y_{15}\ \bar{5}\ 15\ \bar{5} + \lambda 5_H\ \overline{15}\ 5_H$$
$$+ Y_5\ 10\ \bar{5}\ \bar{5}_H + Y_{10}\ 10\ 10\ 5_H + M_5 \bar{5}_H\ 5_H$$

$10 = (u^c, d^c, Q); 5_H = (t, H_2)$

$\bar{5}_H = (\bar{t}, H_1)$

X singlet with B-L charge and VEV

$$\langle X \rangle = \langle S_X \rangle + \theta^2 \langle F_X \rangle$$

$$\xi \langle S_X \rangle = M_{15} \qquad \xi \langle F_X \rangle = B_{15} M_{15}$$

$\langle S_X \rangle \neq 0$ breaks B-L

$$\longrightarrow W_{SU(5)} \supset M_{15}\ 15\ \overline{15}$$

$\langle F_X \rangle \neq 0$ breaks SUSY and B-L

$$\longrightarrow \mathcal{L}_{SSB} = B_{15} M_{15}\ 15\ \overline{15}$$

$15, \overline{15}$: Messengers to the observable sector of

- ~~B-L~~ via Yukawa interactions at tree level
- ~~SUSY~~ via Gauge and Yukawa interactions

SU(5) BROKEN at M_G

$$W_{SU(5)} = W_{MSSM} + W_T + W_{S,Z}$$

$$W_{MSSM} = Y_d \; d^c H_1 Q + Y_e e^c H_1 L + Y_u u^c Q H_2 + \mu H_1 H_2$$

$$W_T = Y_T \, LTL + \lambda H_2 \bar{T} H_2 + M_T T \bar{T}$$

$\longrightarrow$ ν masses

$$W_{S,Z} = Y_S \; d^c S d^c + Y_Z \, d^c Z L + M_Z Z \bar{Z} + M_S S \bar{S}$$

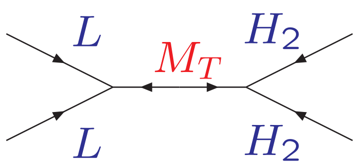
$\longrightarrow$ New LFV and Quark FV ints

$$\mathcal{L}_{SSB} = -B_T M_T (T\bar{T} + Z\bar{Z} + Z\bar{Z}) + \text{h.c.}$$

$B_T = B_{15}, \; M_T = M_{15}$

- Only $T, \bar{T}$ are Messengers of $\not L$ at tree level

  <u>ν Masses</u>



  Colored $S, \bar{S}, Z, \bar{Z}$ are not Messengers of $\not B$

- All $T, \bar{T}$ and $S, \bar{S}, Z, \bar{Z}$ are Messengers of ~~SUSY~~ at quantum level

  <u>All Soft-SUSY breaking mass parameters are generated as</u>

FINITE CONTRIBUTIONS at M_T

at one loop: Gaugino masses, Trilinear couplings A_f, bilinear Higgs parameter B_H

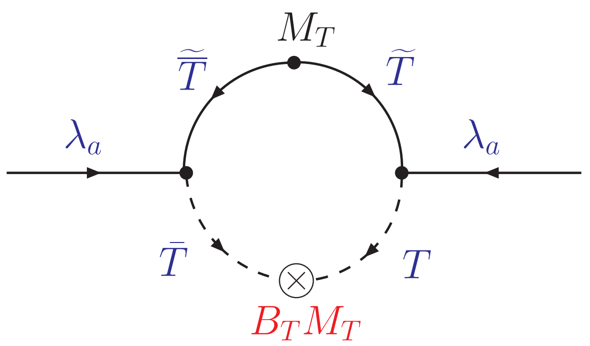
at two loops: all Scalar masses $m^2_{\tilde{f}}$ and $m^2_{H_1}, m^2_{H_2}$

All SSB mass parameters $\quad \tilde{M} \sim \dfrac{B_T}{16\pi^2}$

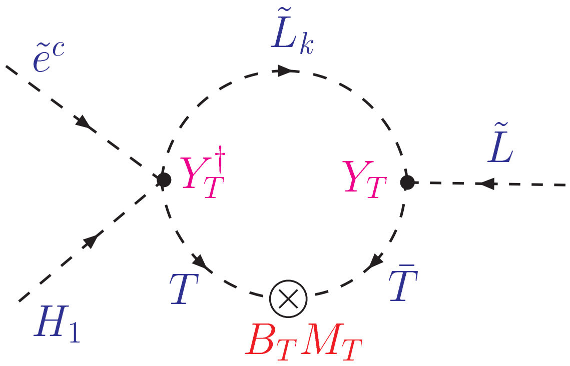
$\tilde{M} \sim \mathcal{O}(100 \text{ GeV}) \longrightarrow B_T \sim \mathcal{O}(10 \text{ TeV})$

one mass scale fixes all the SSB masses

examples: at one loop

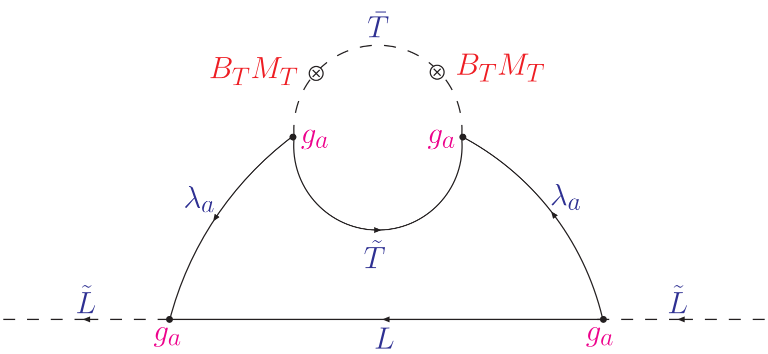


$$M_a \propto \frac{B_T}{16\pi^2}\, g_a^2$$

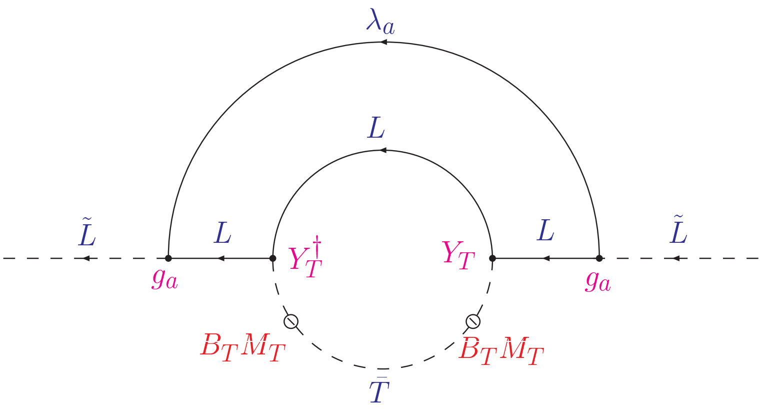


$$A_e \propto \frac{B_T}{16\pi^2}\, Y_T^\dagger Y_T$$

at two - loop



$$m^2_{\tilde{L}} \propto \left(\frac{B_T}{16\pi^2}\right)^2 g_a^4$$



$$\propto \left(\frac{B_T}{16\pi^2}\right)^2 g_a^2\, Y_T^\dagger Y_T$$

SSB terms: Boundary conditions at M_T

$$A_e = \frac{3B_T}{16\pi^2} Y_e (Y_T^\dagger Y_T + Y_Z^\dagger Y_Z)$$

$$A_u = \frac{3B_T}{16\pi^2} Y_u |\lambda|^2 , \quad A_d = \frac{2B_T}{16\pi^2} (Y_Z Y_Z^\dagger + 2 Y_S Y_S^\dagger) Y_d$$

$$M_a = \frac{7B_T}{16\pi^2} g_a^2 , \quad B_H = \frac{7B_T}{16\pi^2} |\lambda|^2$$

$$m_{\tilde{L}}^2 = \frac{|B_T|^2}{(16\pi^2)^2} \left[\frac{21}{10} g_1^4 + \frac{21}{2} g_2^4 - (\frac{27}{5} g_1^2 + 21 g_2^2) Y_T^\dagger Y_T - (\frac{21}{15} g_1^2 + 9 g_2^2 + 16 g_3^2) Y_Z^\dagger Y_Z + \mathcal{O}(Y^4) \right]$$

$$m_{\tilde{e}^c}^2 = \frac{|B_T|^2}{(16\pi^2)^2} \left[\frac{42}{5} g_1^4 + \mathcal{O}(Y^4) \right]$$

$$m_{\tilde{d}^c}^2 = \frac{|B_T|^2}{(16\pi^2)^2} \left[\frac{14}{15} g_1^4 + \frac{56}{3} g_3^4 - (\frac{16}{5} g_1^2 + 48 g_3^2) Y_S^\dagger Y_S - (\frac{14}{15} g_1^2 + 6 g_2^2 + \frac{32}{3} g_3^2) Y_Z Y_Z^\dagger + \mathcal{O}(Y^4) \right]$$

$$m_{\tilde{Q}}^2 = \frac{|B_T|^2}{(16\pi^2)^2} \left[\frac{7}{30} g_1^4 + \frac{21}{2} g_2^4 + \frac{56}{3} g_3^4 + \mathcal{O}(Y^4) \right]$$

$$m_{\tilde{u}^c}^2 = \frac{|B_T|^2}{(16\pi^2)^2} \left[\frac{56}{15} g_1^4 + \frac{56}{3} g_3^4 + \mathcal{O}(Y^4) \right]$$

$$m_{H_1}^2 = \frac{|B_T|^2}{(16\pi^2)^2} \left[\frac{21}{10} g_1^4 + \mathcal{O}(Y^4) \right]$$

$$m_{H_2}^2 = \frac{|B_T|^2}{(16\pi^2)^2} \left[\frac{21}{10} g_1^4 + \frac{21}{2} g_2^4 - (\frac{27}{5} g_1^2 + 21 g_2^2) \lambda^2 + 9 \lambda^2 \mathrm{Tr}(Y_u^2 Y_u^\dagger) + \mathcal{O}(Y^4) \right]$$

Y_T, Y_S, Y_Z induce Flavor Violation in $A_e, A_d, m_{\tilde{L}}^2, m_{\tilde{d}^c}^2$

At variance with pure Gauge Mediation Models where SSB $m_{\tilde{f}}^2$ are Flavor blind

VERY PREDICTIVE FRAMEWORK

3 Free parameters: B_T, M_T, λ

Bottom-up approach to fix:

$$Y_T = U m_\nu^D U^\dagger \frac{M_T}{\lambda v_2^2}$$

μ and $\tan\beta$ from the EWSB conditions

Possible Flavour Violation Pictures

A. $Y_S \sim Y_Z \ll Y_T$ [due to GUT-breaking effects]:

only Y_T drives LFV : $(m^2_{\tilde{L}})_{ij} \propto Y_T^\dagger Y_T$

B. $Y_S = Y_Z = Y_T$:
all Y_T, Y_S, Y_Z drive both LFV and QFV

$$(m^2_{\tilde{L}})_{ij} \propto Y_T^\dagger Y_T + Y_Z^\dagger Y_Z, \qquad (m^2_{\tilde{d}^c})_{ij} \propto Y_S Y_S^\dagger + Y_Z Y_Z^\dagger$$

Correlation between LFV and QFV can be predicted

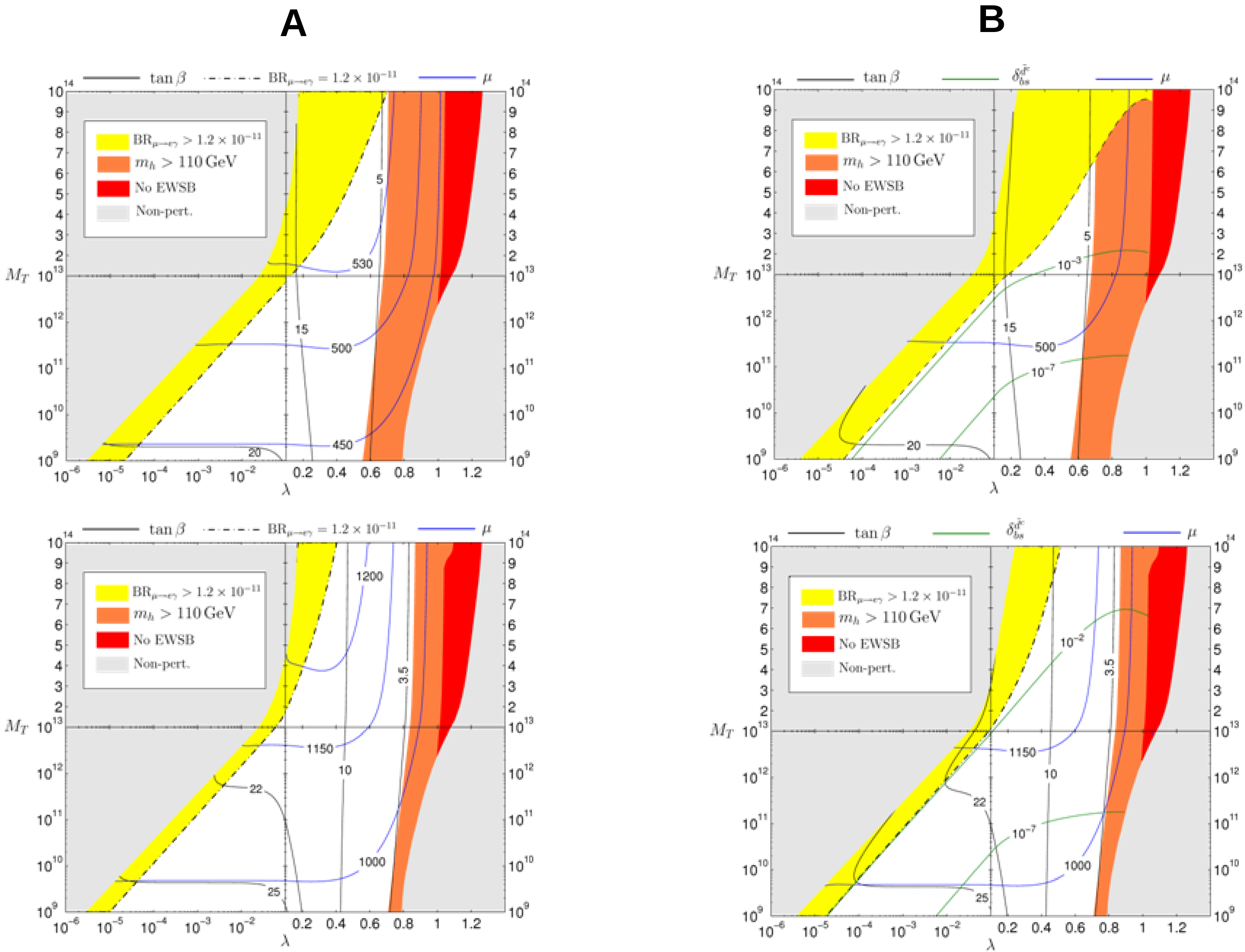
$$\frac{(m^2_{\tilde{d}^c})_{bs}}{(m^2_{\tilde{d}^c})_{sd}} \sim \frac{(m^2_{\tilde{L}})_{\tau\mu}}{(m^2_{\tilde{L}})_{\mu e}} \approx \frac{\left[U(m_\nu^D)^2 U^\dagger\right]_{\tau\mu}}{\left[U(m_\nu^D)^2 U^\dagger\right]_{\mu e}} \sim 40$$

$$\frac{(m^2_{\tilde{d}^c})_{bd}}{(m^2_{\tilde{d}^c})_{sd}} \sim \frac{(m^2_{\tilde{L}})_{\tau e}}{(m^2_{\tilde{L}})_{\mu e}} \approx \frac{\left[U(m_\nu^D)^2 U^\dagger\right]_{\tau e}}{\left[U(m_\nu^D)^2 U^\dagger\right]_{\mu e}} \sim 0.1$$

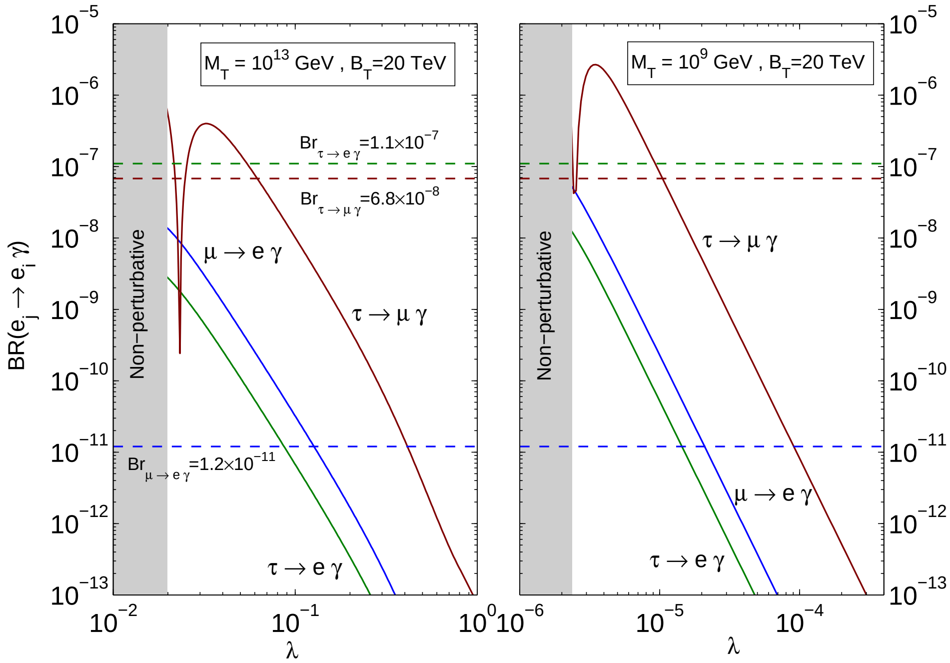
Phenomenological Viability

in the next

Parameter Space Exploration

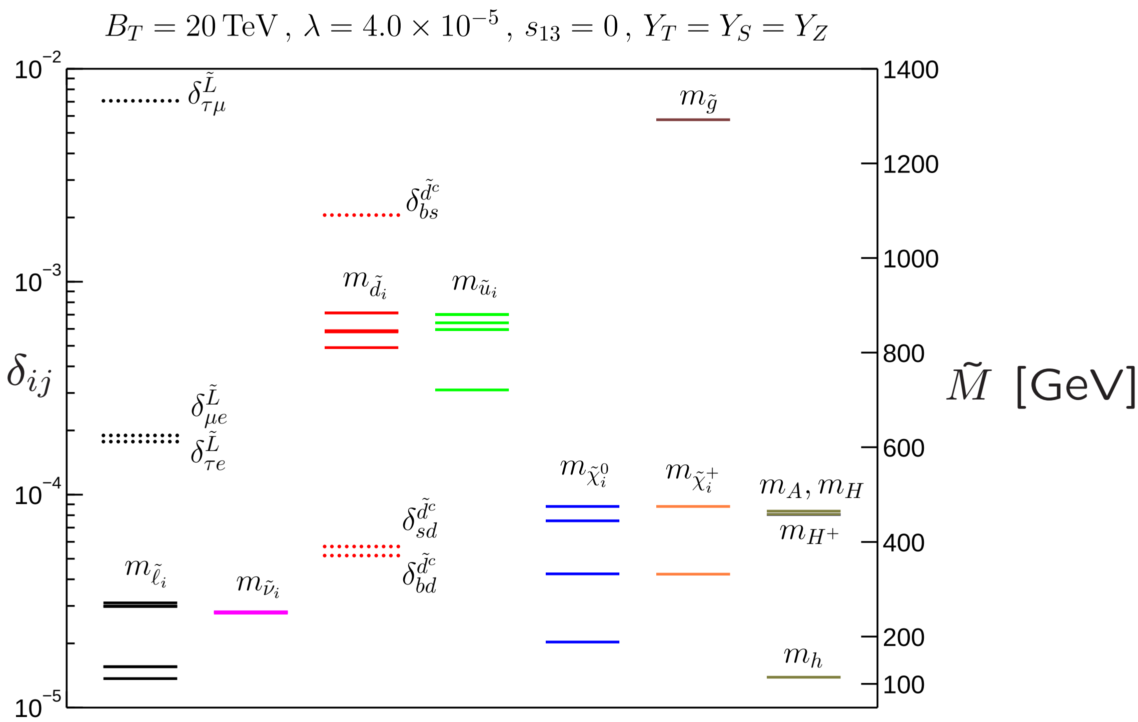

A
B
tan β
BR_{μ→eγ} = 1.2 × 10^{-11}
μ
δ_{bs}^{d̃^c}
BR_{μ→eγ} > 1.2 × 10^{-11}
m_h > 110 GeV
No EWSB
Non-pert.
M_T
λ

Predictions for the LFV Branching Ratios



$$\frac{BR(\tau\to\mu\gamma)}{BR(\mu\to e\gamma)} \sim 300, \qquad \frac{BR(\tau\to e\gamma)}{BR(\mu\to e\gamma)} \sim 0.1$$

The Sparticle Spectrum ($B_T = 20$ TeV, $M_T = 10^9$ GeV)



CONCLUSIONS

- Neutrino masses can arise as well from exchange of heavy triplets $T, \bar{T}$

  Specific feature: Simple flavour structure ...
  Hence:

- Potential predictive scenario for LFV: *e.g.* $\frac{BR(\tau \to \mu\gamma)}{BR(\mu \to e\gamma)}$ fixed by neutrino parameters only

  interesting scenario also for resonant leptogenesis and for EDM's

  [G. D'Ambrosio, T. Hambye, A. Hector, M. Raidal and A. R., 2004]
  [E. J. Chun, A. Masiero, A. R. and S. Vempati, 2005]

- New predictive SUSY+GUT version with T playing also the role of ~~SUSY~~ messengers:

  the whole sparticle spectrum is determined by the effective ~~SUSY~~ scale $B_T \gtrsim 20$ TeV

  strong correlation among neutrino parameters, LFV/QFV, the sparticle spectrum and electroweak symmetry breaking

  More phenomenological analysis regarding the hadronic sector can be interesting ...

  F. Joaquim and A. R.;
  J. Foster, F. Joaquim and A. R, works in progress