

# Lepton Flavour Violation in Neutrino Seesaw Scenarios

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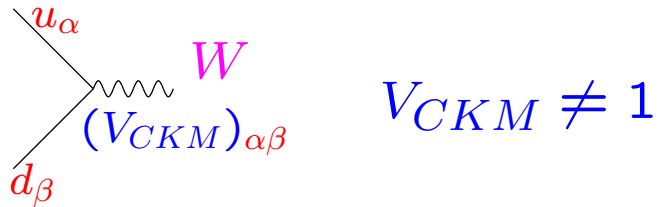
- Flavour Violation in the Standard Model (SM)
- The Seesaw Paradigm for the neutrino mass:  
Triplet versus Singlet realization
- Lepton Flavour Violation (LFV) in the T-Seesaw
- Triplet as Messenger of SUSY breaking: Very predictive picture relating
  - $\nu$  masses
  - LFV
  - Superpartner and Higgs boson Spectrum
  - Electroweak Symmetry Breaking (EWSB)

F.Joaquim, A. Rossi- PRL 97 (2006) 181801  
NPB 765 (2007) 71

# Flavour Violation (FV) in the Standard Model

At Tree-level only FV in charged current

## Quark Sector



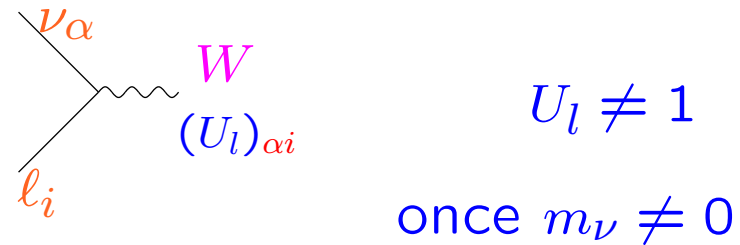
Many exp evidences:

$$|\Delta S|, |\Delta B|, \dots \neq 0$$

e.g.  $K \rightarrow \pi\pi$ ,  $D \rightarrow K\ell\nu$

BUT total baryon number  $B$   
 is conserved

## Lepton sector



ONLY evidence of FV from

Atmospheric, Solar, Accelerator and  
 Reactor neutrinos

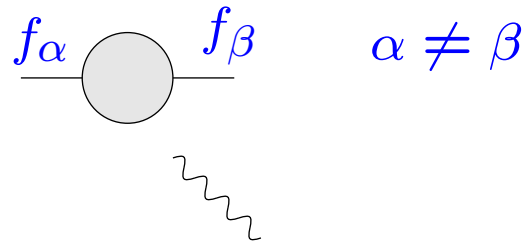
due to Vacuum oscillations and adiabatic  
 resonance in matter

$$\nu_e \rightarrow \nu_\mu \quad , \quad \nu_\mu \rightarrow \nu_\tau$$

$$|\Delta L_e| = |\Delta L_\mu| = |\Delta L_\tau| = 1$$

$L = L_e + L_\mu + L_\tau$  conserved?  
 ...  $\beta\beta 0\nu??$

FV in neutral currents only arises at one-loop



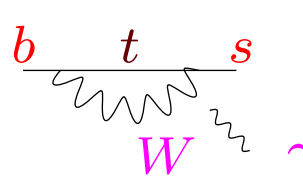
## Quark Sector

many measured processes:

$$|\Delta F| = 1, |\Delta F| = 2$$

$$|\Delta F| = 1 : \text{e.g. } b \rightarrow s\gamma$$

$$i\sqrt{\alpha} m_b \left[ D_L \bar{s} \bar{\sigma}^{\mu\nu} \bar{b}^c + D_R s^c \sigma^{\mu\nu} b \right] F_{\mu\nu}$$



$$D_L \propto \frac{g^2}{16\pi^2} V_{tb}^* V_{ts} \frac{m_t^2}{m_W^4}$$

SM prediction in agreement  
with exp.  $BR \sim 3 \times 10^{-4}$

Strong constraint on New Physics

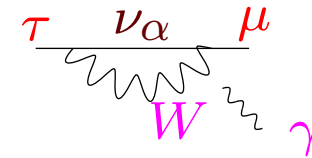
## Lepton sector

no measured processes ... so far

WHY?

e.g.  $\tau \rightarrow \mu\gamma$

$$i\sqrt{\alpha} m_\tau \left[ D_L \bar{\mu} \bar{\sigma}^{\mu\nu} \bar{\tau}^c + D_R \mu^c \sigma^{\mu\nu} \tau \right] F_{\mu\nu}$$



$$D_L \propto \frac{g^2}{16\pi^2} \sum_\alpha U_{\mu\alpha} U_{\tau\alpha}^* \frac{(m_\nu^2)_\alpha}{m_W^4}$$

SM prediction:  $BR(\tau \rightarrow \mu\gamma) \approx 10^{-50}$   
suppressed by tiny  $\nu$  masses  $m_\nu$

Experimental bound

$$BR(\tau \rightarrow \mu\gamma) < 4.8 \times 10^{-8}$$

Potentially sensitive to New Physics

## LFV Processes

BR	Present limits	Future sensitivity
$\mu^- \rightarrow e^- \gamma$	$1.2 \times 10^{-11}$	$10^{-14}$
$\tau^- \rightarrow \mu^- \gamma$	$4.8 \times 10^{-8}$	$10^{-9}$
$\tau^- \rightarrow e^- \gamma$	$1.1 \times 10^{-7}$	$10^{-9}$
$\mu^- \rightarrow e^- e^+ e^-$	$1.0 \times 10^{-12}$	$10^{-14}$
$\tau^- \rightarrow \mu^- \mu^+ \mu^-$	$1.9 \times 10^{-7}$	$10^{-9}$
$\tau^- \rightarrow \mu^- e^+ e^-$	$1.9 \times 10^{-7}$	$10^{-9}$
$\tau^- \rightarrow e^- e^+ e^-$	$2.0 \times 10^{-7}$	$10^{-9}$
$\tau^- \rightarrow e^- \mu^+ \mu^-$	$3.3 \times 10^{-7}$	$10^{-9}$
CR( $\mu \rightarrow e; \text{Ti}$ )	$1.7 \times 10^{-12}$	$10^{-18}$

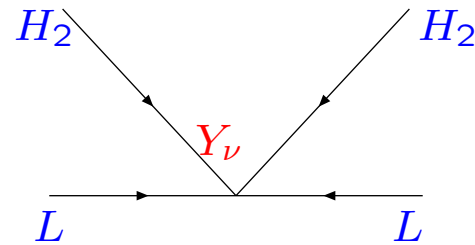
Detecting such LFV signals is a clear NEW Physics evidence

# Lepton Flavour Violation in the (MS)SM comes from

$$m_\nu \neq 0, \quad \theta_{ij}^l \neq 0, \quad (i \neq j)$$

This is understood from  $L = L_e + L_\mu + L_\tau$  violating  $d = 5$  operator

S. Weinberg, 1979



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

$$M_L \gg M_Z$$

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

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

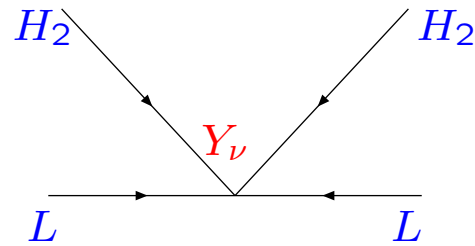
$$m_\nu^D = \text{diag}(m_1, m_2, m_3) \quad U = V(\theta_{12}, \theta_{23}, \theta_{13}, \delta) \times \text{diag}(1, e^{i\phi_1}, e^{i\phi_2})$$

3 masses + 3 angles + 3 phases = 9 independent parameters

Provided by low energy experiments

How to get the neutrino  $d = 5$  operator?

## $\nu$ mass effective operator



Additional high-energy degrees of freedom decouple at  $M_L$

(At tree-level) most-known realizations:

### 1. decoupling fermion singlets ('right-handed') $N$

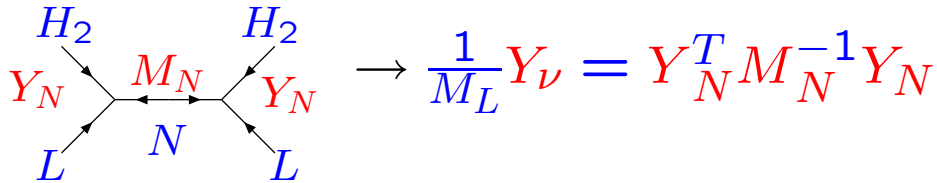
P.Minkowski, 1977; M.Gell-Mann, P.Ramond, R.Slansky, 1979; T.Yanagida, 1979; S.Glashow, 1980;  
R.N.Mohapatra, G.Senjanovic, 1980

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

R.Barbieri, D.Nanopoulos, 1980; M.Magg, C.Wetterich, 1980;  
G.Lazarides, Q,Shafi, C.Wetterich,1981; R.Mohapatra, G.Senjanovic, 1981

## Seesaw with Singlets $N \sim (1, 0)$

$$Y_N^{ij} H_2 L_i N_j + \frac{1}{2} M_N N_i N_j$$

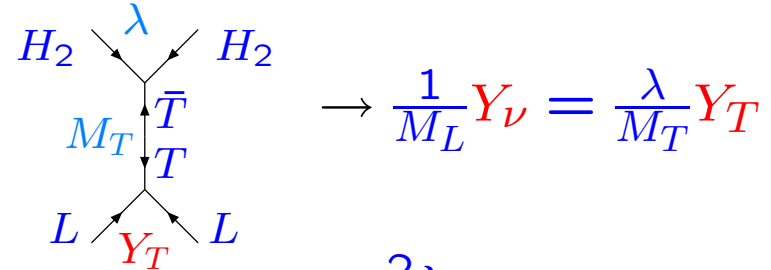


$$m_\nu = v_2^2 Y_N^T M_N^{-1} Y_N$$

- $3N$  needed
- 2 LFV sources  $Y_N, M_N$   
i.e. 12 reals + 6 phases

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

$$Y_T^{ij} L_i T L_j + \lambda H_2 \bar{T} H_2 + M_T T \bar{T}$$



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

- 1 pair  $(T, \bar{T})$  enough
- 1 LFV source  $Y_T$  (symmetric)  
i.e. 6 reals + 3 phases

Low energy data reconstruct  $Y_\nu$ , i.e. 9 parameters

Not enough to fix univocally  $Y_N, M_N$   
e.g. A.Casas, A.Ibarra, 2001

just match with  $Y_T : Y_\nu \leftrightarrow Y_T$   
High-energy Flavour Structure Known

A.R., 2002

## Implications for low-energy LFV processes, such as

$$l_j \rightarrow l_i + \gamma, \quad l_j \rightarrow l_i l_i l_i \text{ etc}$$

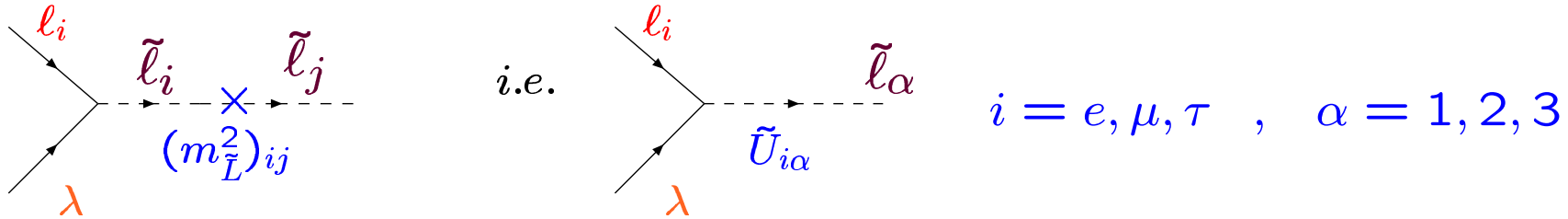
... LFV in  $Y_\nu$  (or  $m_\nu$ ) does not give sizeable effects (besides  $\nu$  oscillations)

but consider that

- The one-loop decoupling of the heavy states (either  $N$  or  $T$ ) could directly induce sizeable LFV under special conditions  
... not addressed here
- **SUPERSYMMETRY** offers new LFV sources:  
sparticle masses  $m_{\tilde{L}}^2$  and scalar couplings  $A_f$  PROVIDED the mass matrices  $m_{\tilde{L}}^2$  of the sleptons are not aligned to the mass matrices of the leptons and the SUSY mass scale  $\tilde{m}$  is not far from the Fermi scale

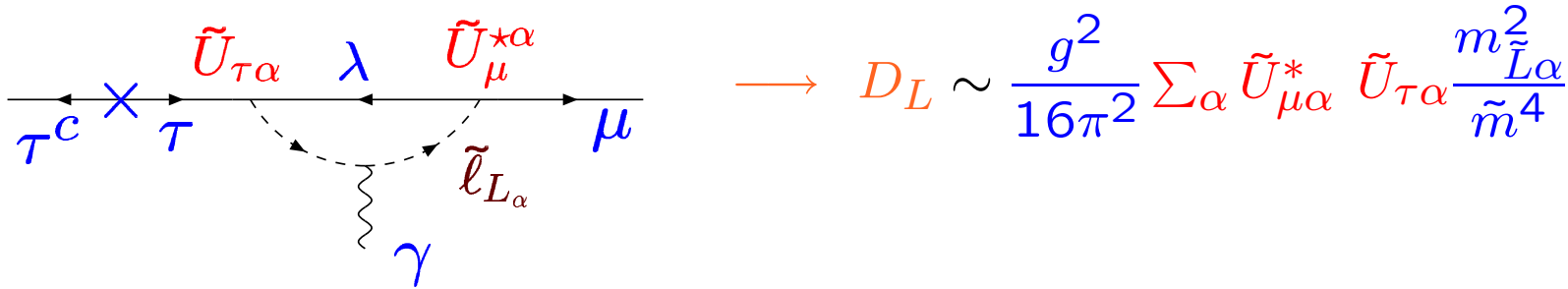
# LFV : Window into New Physics – MSSM case

New LFV vertices: e.g. lepton ( $l$ )-slepton ( $\tilde{l}$ )-gaugino ( $\lambda$ )



LFV resides in  $(m_{\tilde{L}}^2)_{ij} = \tilde{U}_{i\alpha} m_{\tilde{L}\alpha}^2 \tilde{U}_{\alpha j}^\dagger$ ,  $i \neq j$  [ $M_\ell = \text{diag}(m_e, m_\mu, m_\tau)$ ]

Enhancement of  $\tau \rightarrow \mu\gamma$  from SUSY contributions



$$D_L \neq 0 \iff (m_{\tilde{L}}^2)_{\mu\tau} = \tilde{U}_{\mu\alpha}^* m_{\tilde{L}\alpha}^2 \tilde{U}_{\tau\alpha} \neq 0$$

No suppression unless  $\tilde{m} \gg \text{TeV}$

# What about the soft SUSY-breaking (SSB) parameters $m_{\tilde{L}}^2$ ?

- Mass scale not far from the EW scale
- Flavour structure?: theoretically unknown (... more general and open issue) though phenomenologically constrained

Conservative approach inspired by Minimal SUGRA or (High Scale) Gauge Mediation:

- Universality/Flavour-Conservation at high (SUSY - mediation) scale  $M_X$   
 $m_{\tilde{L}}^2 = m_0^2 \mathbb{1}$
- At lower energy **RENORMALIZATION-GROUP (RG) effects** induced by **LFV** Yukawa couplings spoil universality/flavour-conservation

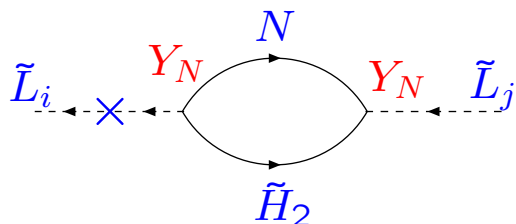
$$(m_{\tilde{L}}^2)_{ij} \neq 0 \quad i \neq j$$

L.Hall, V.Kostelecky, S.Raby,1986

F.Borzumati, A.Masiero,1986; A.R.2002

# LFV in $\tilde{L}^\dagger m_{\tilde{L}}^2 \tilde{L}$

N-Seesaw



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

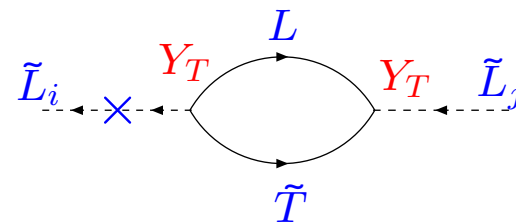
$Y_N^\dagger Y_N$ : not directly linked to  $Y_\nu$  i.e.  $m_\nu$

More (arbitrary) assumptions on  $Y_N$  and  $M_N$  needed to deal with  $m_{\tilde{L}}^2$  flavour structure

J.Hisano et al., 1996;

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

T-Seesaw



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

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

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

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

A.R., 2002

In T-Seesaw  $m_{\tilde{L}}^2$  inherits the low-energy neutrino flavour structure

## T-Seesaw provides a realization of Minimal LFV

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

Relative **LFV** size predicted in a model-independent way

depends only on the neutrino masses  $[m_\nu^D]$  and mixing angles  $[V]$  measured at low-energy ... and not on high-energy parameters (as  $M_T$  or  $\lambda$ )

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

Plugging the neutrino exp data

$$\left| \frac{(m_{\tilde{L}}^2)_{\tau\mu}}{(m_{\tilde{L}}^2)_{\mu e}} \right| \approx 40, \quad \left| \frac{(m_{\tilde{L}}^2)_{\tau e}}{(m_{\tilde{L}}^2)_{\mu e}} \right| \approx 1, \quad [\sin \theta_{13} = 0]$$

$$\left| \frac{(m_{\tilde{L}}^2)_{\tau\mu}}{(m_{\tilde{L}}^2)_{\mu e}} \right| \approx 0.8 \text{ (1.2)}, \quad \left| \frac{(m_{\tilde{L}}^2)_{\tau e}}{(m_{\tilde{L}}^2)_{\mu e}} \right| \approx 3.2 \text{ (3.8)}, \quad [\sin \theta_{13} = 0.2]$$

for the Normal Hierarchy NH, Quasi Degenerate DG (Inverted Hierarchy IH) spectra

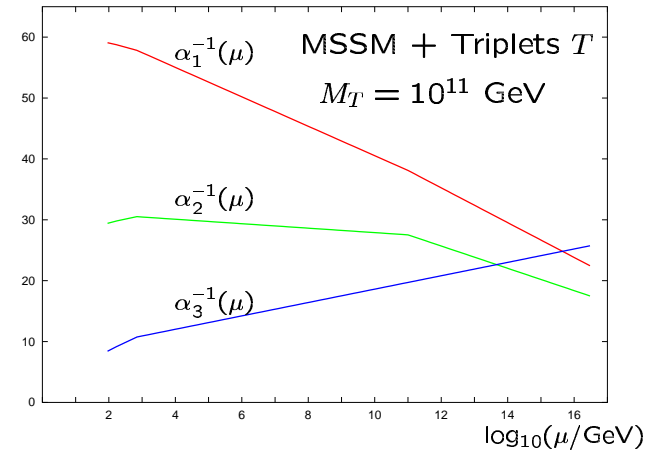
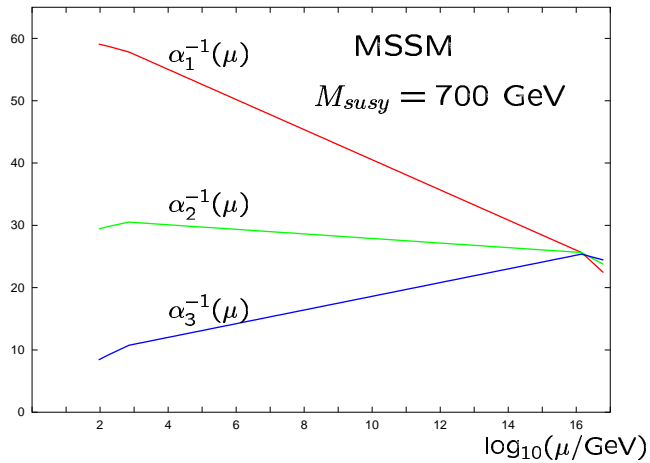
T-Seesaw: Strict predictions for the ratio of LFV Branching Ratios  
given the neutrino parameters ( $\delta = 0$ )

$$\frac{\text{BR}(\tau \rightarrow \mu \gamma)}{\text{BR}(\mu \rightarrow e \gamma)} \approx \left| \frac{(m_{\tilde{L}}^2)_{\tau\mu}}{(m_{\tilde{L}}^2)_{\mu e}} \right|_2 \frac{\text{BR}(\tau \rightarrow \mu \nu_\tau \bar{\nu}_\mu)}{\text{BR}(\mu \rightarrow e \nu_\mu \bar{\nu}_e)} \approx \begin{cases} 300 & [s_{13} = 0] \\ 2(3) & [s_{13} = 0.2] \end{cases}$$

$$\frac{\text{BR}(\tau \rightarrow e \gamma)}{\text{BR}(\mu \rightarrow e \gamma)} \approx \left| \frac{(m_{\tilde{L}}^2)_{\tau e}}{(m_{\tilde{L}}^2)_{\mu e}} \right|_2 \frac{\text{BR}(\tau \rightarrow e \nu_\tau \bar{\nu}_e)}{\text{BR}(\mu \rightarrow e \nu_\mu \bar{\nu}_e)} \approx \begin{cases} 0.2 & [s_{13} = 0] \\ 0.1(0.3) & [s_{13} = 0.2] \end{cases},$$

Notice: Major uncertainty from  $\theta_{13}$

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



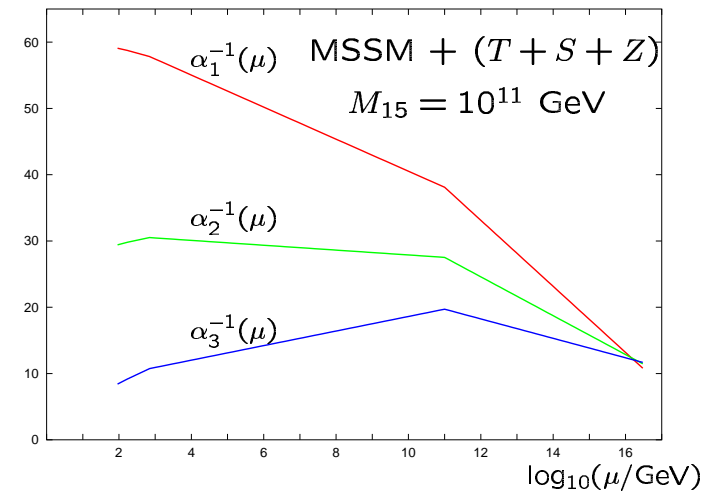
... with Triplets

Recovered by adding extra states to complete a GUT supermultiplet :  $T + \dots$

Minimal extension: SUSY  $SU(5)$  with  $T$  fitting into 15:  $15 = S + T + Z$

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

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



... And which implications for Flavour Violation ?

# Supersymmetric SU(5) + 15 = T + S + Z

Relevant Yukawa term  $Y_{15} \bar{5} 15 \bar{5} = Y_T L T L + Y_S d^c S d^c + Y_Z d^c Z L$   
 $[\bar{5} = d^c + \ell]$

- what happens in MSUGRA with universality at  $M_G$ ?

FV driven by  $Y_{15}$  induced in both the quark and lepton sectors

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

Direct connection between Quark and Lepton FV (from GUT symmetry) given by low-energy neutrino parameters

$$(m_{\tilde{d}}^2)_{ij} \sim (m_{\tilde{L}}^2)_{ij}$$

$$\frac{(m_{\tilde{L}}^2)_{\tau\mu}}{(m_{\tilde{L}}^2)_{\mu e}} \sim \frac{(m_{\tilde{d}}^2)_{bs}}{(m_{\tilde{d}}^2)_{sd}} \sim \frac{[V(m_\nu^D)^2 V^\dagger]_{\tau\mu}}{[V(m_\nu^D)^2 V^\dagger]_{\mu e}}, \quad \frac{(m_{\tilde{L}}^2)_{\tau e}}{(m_{\tilde{L}}^2)_{\mu e}} \sim \frac{(m_{\tilde{d}}^2)_{bd}}{(m_{\tilde{d}}^2)_{sd}} \sim \frac{[V(m_\nu^D)^2 V^\dagger]_{\tau e}}{[V(m_\nu^D)^2 V^\dagger]_{\mu e}}$$

## A Different way to generate $LFV (m_{\bar{L}}^2)_{ij}$

BEFORE: in 2 (unrelated) Steps

1) Flavour universal overall **SSB mass**  $m_0$  generated at some high scale (unrelated to the dynamics of the triplets  $T$ )

2)  $LFV (m_{\bar{L}}^2)_{ij}$  structure generated by RG quantum effects due to the triplet Yukawa  $Y_T$

NOW: Ambitious, more economical and hence predictive program

1 single Step:

Both the overall **SSB mass** and the  $LFV (m_{\bar{L}}^2)_{ij}$  structure are generated at the scale  $M_T$  by exchanging the triplets  $T$  at quantum level

F.Joaquim, A.R., 2006

# Novel SUSY + GUT Triplet Seesaw

F. Joaquim and A.R., 2006

Basic observation:  $15 \supset T$  exchange can generate all soft SUSY masses provided 15 interact with  $X$  breaking SUSY

$$W = \xi X 15 \overline{15} + Y_{15} \bar{5} 15 \bar{5} + \lambda 5_H \overline{15} 5_H + Y_5 10 \bar{5} \bar{5}_H + Y_{10} 10 10 5_H + M_5 \bar{5}_H 5_H$$

$B - L$  is conserved

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

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

$X$  singlet with B-L charge and VEV:  $\langle X \rangle = \langle S_X \rangle + \theta^2 \langle F_X \rangle$

$\langle S_X \rangle \neq 0$  breaks B-L:  $\xi \langle S_X \rangle = M_{15} \longrightarrow W \supset M_{15} 15 \overline{15}$

$\langle F_X \rangle \neq 0$  breaks SUSY and B-L:  $\xi \langle F_X \rangle = B_{15} M_{15} \longrightarrow \mathcal{L}_{SSB} = B_{15} M_{15} 15 \overline{15}$

this is the only Soft SUSY term at  $M_G$

SU(5) BROKEN at  $M_G$ :  $\rightarrow W_{SU(5)} = W_{MSSM} + W_T + W_{S,Z}$

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

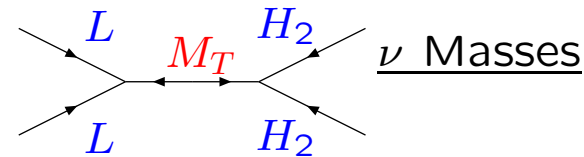
$$W_T = Y_T L T L + \lambda H_2 \bar{T} H_2 + M_T T \bar{T}$$

$$W_{S,Z} = Y_S d^c S d^c + Y_Z d^c Z L + M_Z Z \bar{Z} + M_S S \bar{S} \quad \rightarrow \quad \text{New LFV and Quark FV ints}$$

$$\mathcal{L}_{SSB} = -B_T M_T (T \bar{T} + S \bar{S} + Z \bar{Z}) + \text{h.c.} \quad B_T M_T \equiv B_{15} M_{15}$$

Down to the energy scale  $M_T < M_G$

- Only  $T, \bar{T}$  are Messengers of  ~~$\mathcal{B}$~~  at tree level:



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

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

All SSB mass parameters are generated as FINITE CONTRIBUTIONS at  $M_T$

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

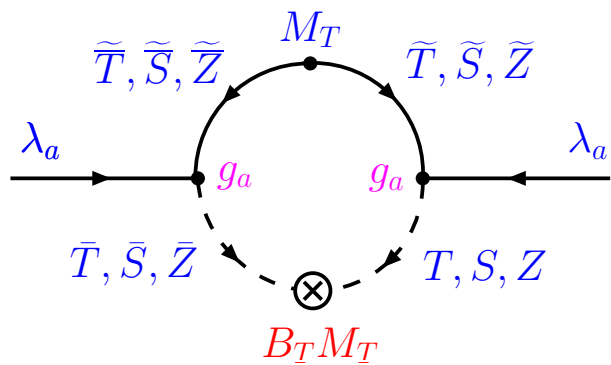
at two loops: all Scalar masses  $m_{\tilde{f}}^2$  and  $m_{H_1}^2, m_{H_2}^2$

$$\text{All SSB mass parameters} \quad \tilde{M} \sim \frac{B_T}{16\pi^2}: \quad \tilde{M} \sim \mathcal{O}(100 \text{ GeV}) \leftrightarrow B_T \sim \mathcal{O}(10 \text{ TeV})$$

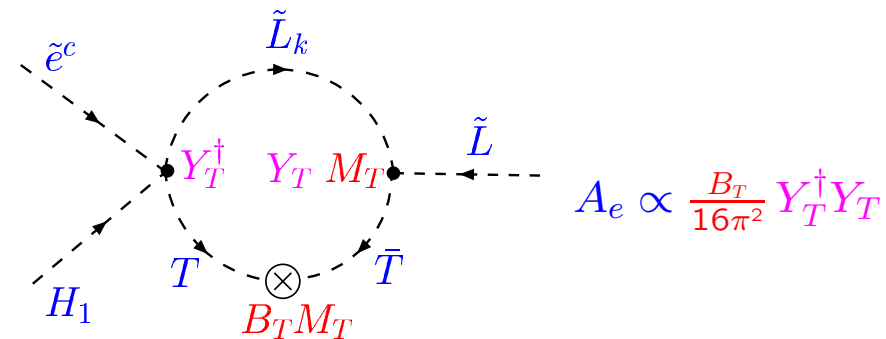
one mass scale fixes all the SSB masses

# SSB terms: Boundary conditions at $M_T$

examples: at one loop



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



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

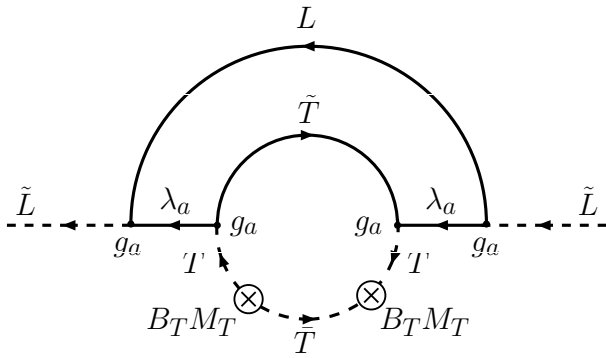
$$A_e = \frac{3B_T}{16\pi^2} Y_e (Y_T^\dagger Y_T + Y_Z^\dagger Y_Z)$$

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

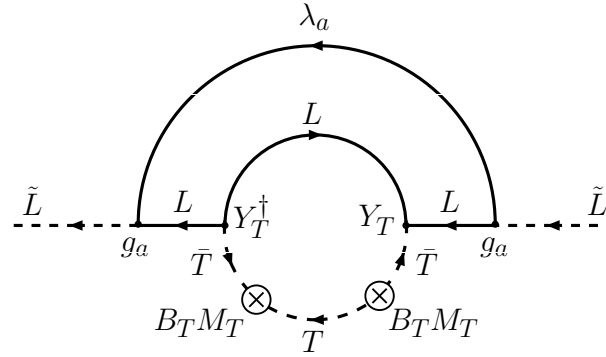
$$M_a = \frac{7B_T}{16\pi^2} g_a^2, \quad B_H = \frac{3B_T}{16\pi^2} |\lambda|^2$$

$Y_T, Y_S, Y_Z$  induce Flavor Violation in  $A_e, A_d$

examples at two - loop for  $m_{\tilde{L}}^2$



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



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

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

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

$$m_{\tilde{Q}}^2 = \frac{|B_T|^2}{(16\pi^2)^2} \left[ \frac{7}{30}g_1^4 + \frac{21}{2}g_2^4 + \frac{56}{3}g_3^4 + \mathcal{O}(Y^4) \right], \quad m_{\tilde{u}^c}^2 = \frac{|B_T|^2}{(16\pi^2)^2} \left[ \frac{56}{15}g_1^4 + \frac{56}{3}g_3^4 + \mathcal{O}(Y^4) \right]$$

$$m_{\tilde{e}^c}^2 = \frac{|B_T|^2}{(16\pi^2)^2} \left[ \frac{42}{5}g_1^4 + \mathcal{O}(Y^4) \right], \quad m_{H_1}^2 = \frac{|B_T|^2}{(16\pi^2)^2} \left[ \frac{21}{10}g_1^4 + \frac{21}{2}g_2^4 + \mathcal{O}(Y^4) \right]$$

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

$Y_T, Y_S, Y_Z$  induce Flavor Violation in  $m_{\tilde{L}}^2, m_{\tilde{d}^c}^2$ : At variance with pure Gauge Mediation Models where SSB  $m_{\tilde{f}}^2$  are Flavor Blind

# VERY PREDICTIVE FRAMEWORK

3 Free parameters:  $B_T, M_T, \lambda$

Bottom-up approach to fix:

$Y_T = U m_\nu^D U^\dagger \frac{M_T}{\lambda v_2^2}$  (as well as  $Y_S, Y_Z$ ) from neutrino parameters

$\mu$  and  $\tan \beta$  from the radiative EWSB conditions

→ Lepton Flavour Violation fixed in the SSB parameters

$Y_T, Y_S, Y_Z$  drive both LFV and QFV

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

Correlation between LFV and QFV can be predicted

$$\frac{(m_{\tilde{d}^c}^2)_{bs}}{(m_{\tilde{d}^c}^2)_{sd}} \sim \frac{(m_{\tilde{L}}^2)_{\tau\mu}}{(m_{\tilde{L}}^2)_{\mu e}} \approx \frac{[V(m_\nu^D)^2 V^\dagger]_{\tau\mu}}{[V(m_\nu^D)^2 V^\dagger]_{\mu e}}, \quad \frac{(m_{\tilde{d}^c}^2)_{bd}}{(m_{\tilde{d}^c}^2)_{sd}} \sim \frac{(m_{\tilde{L}}^2)_{\tau e}}{(m_{\tilde{L}}^2)_{\mu e}} \approx \frac{[U(m_\nu^D)^2 U^\dagger]_{\tau e}}{[U(m_\nu^D)^2 U^\dagger]_{\mu e}}$$

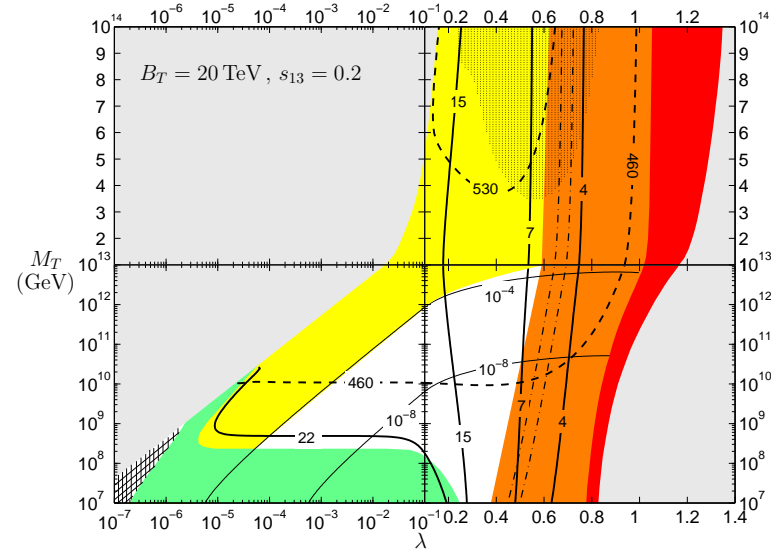
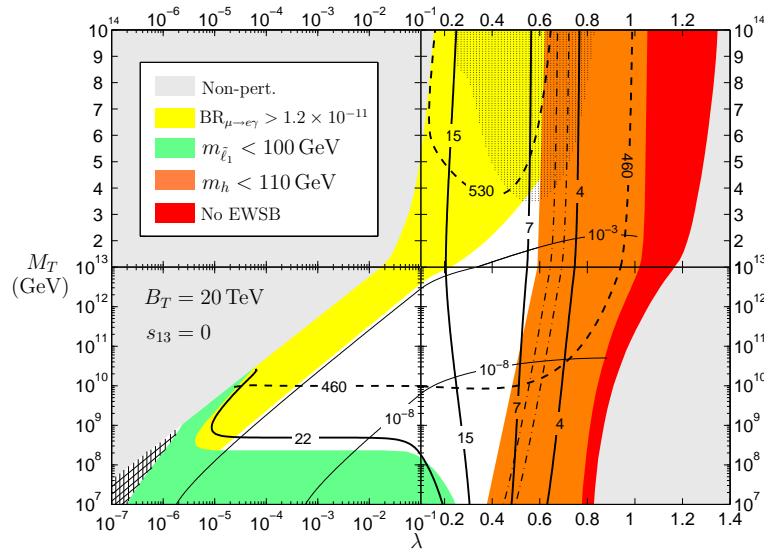
# Phenomenological Viability

in the next

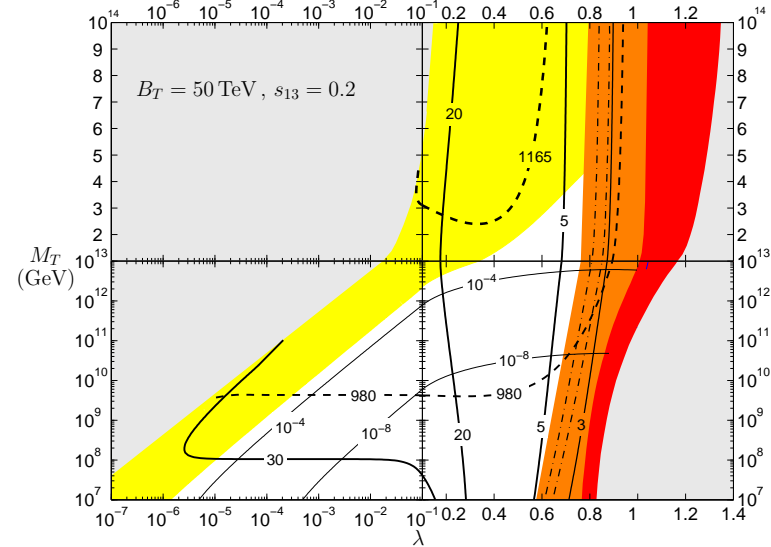
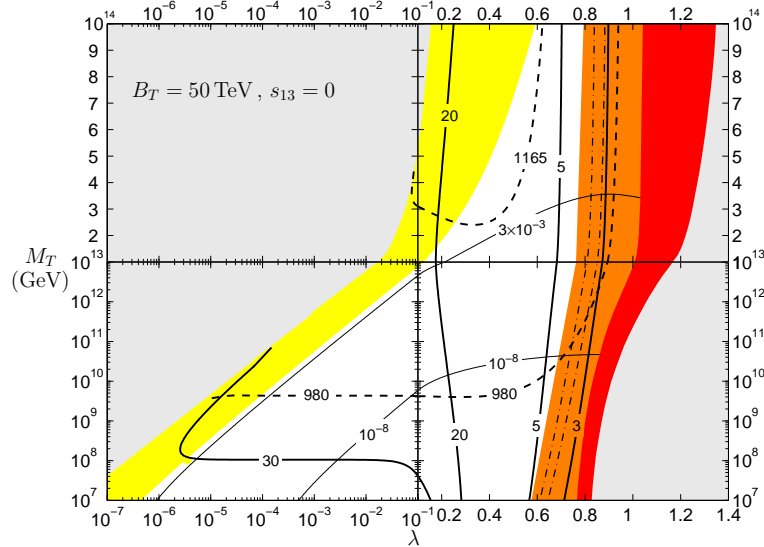
$(B_T, M_T, \lambda)$  - Parameter Space Exploration

$B_T = 20 \text{ TeV}$

F.Joaquim and A.R., PRL + NPB 2006



$B_T = 50 \text{ TeV}$



The model is compatible with experiments for  $M_T \geq 10^7 - 10^8 \text{ GeV}$  and  $B_T \geq 20 \text{ TeV}$

# TESTING THE ALLOWED PARAMETER BY PREDICTIONS ON

MSSM Sparticle and Higgs boson Spectrum

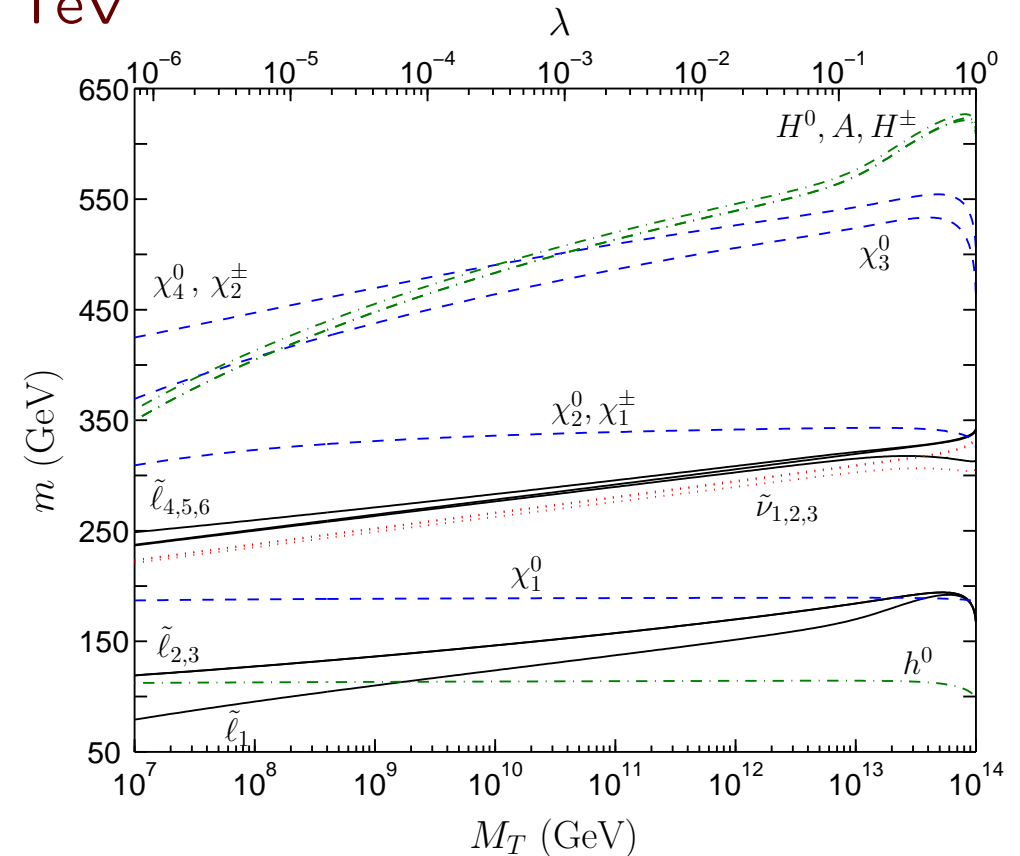
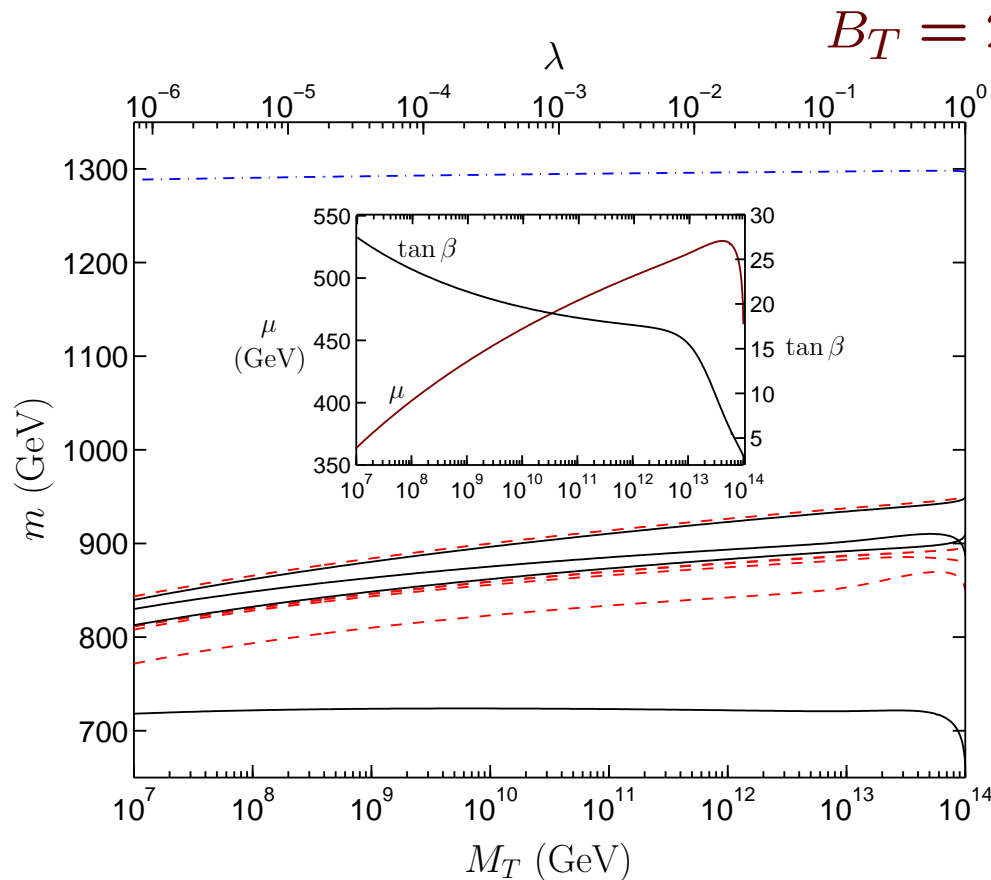
LFV decays

in the next

Spectrum:

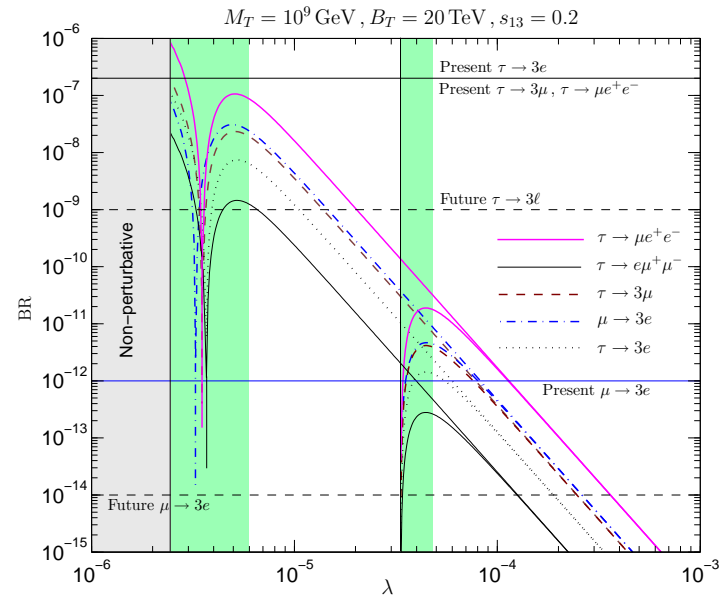
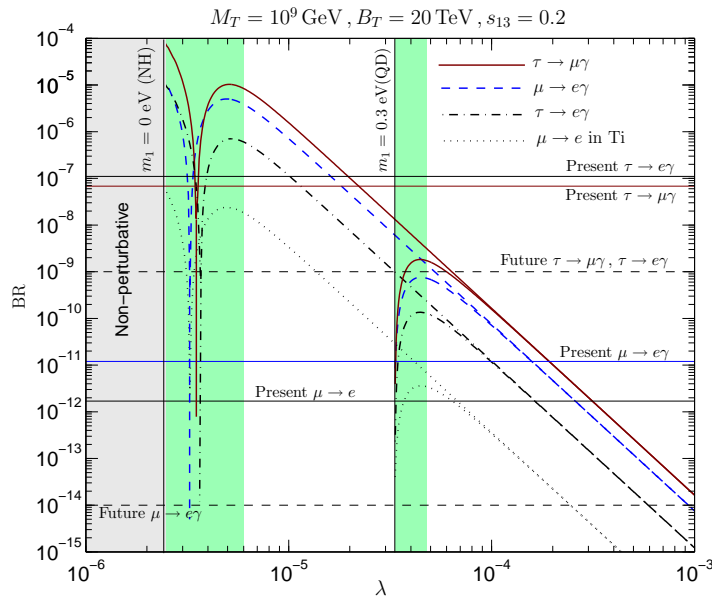
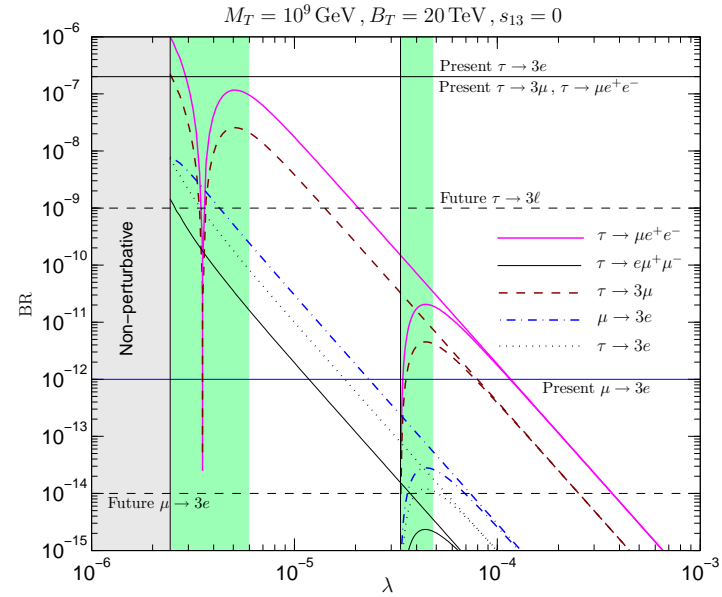
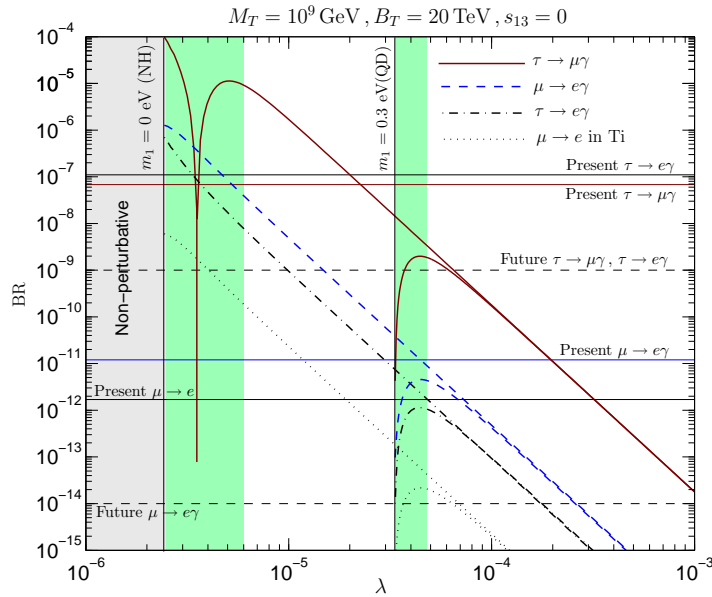
Glauino  $\tilde{g}$ , squark  $\tilde{u}$ , squarks  $\tilde{d}$

Spectrum: Sleptons, neutralinos and Higgs bosons



- The sparticle masses are within the discovery reach of LHC
- Gluino is the heaviest sparticle,  $M_{\tilde{g}} \sim 1.3 \text{ TeV}$
- The slepton  $\tilde{\ell}_1$  is the lightest  $\rightarrow$  gravitino is LSP
- 1 light SM-like Higgs ( $h$ ) + 3 heavy Higgs ( $H, A, H^\pm$ )

# Predictions for LFV Processes ( $B_T = 20 \text{ TeV}$ , $M_T = 10^9 \text{ GeV}$ – NH)



$BR(\tau \rightarrow \mu\gamma)/BR(\mu \rightarrow e\gamma) \sim 300$  for  $s_{13} = 0$  or  $BR(\tau \rightarrow \mu\gamma)/BR(\mu \rightarrow e\gamma) \sim 2$  for  $s_{13} = 0.2$  etc. indep. of  $\lambda$

LFV Correlation pattern taking  $\text{BR}(\mu \rightarrow e\gamma) = 1.2 \times 10^{-11}$

Expectation	$s_{13} = 0$	$s_{13} = 0.2$
$\text{BR}(\tau^- \rightarrow \mu^- \gamma)$	$3 \times 10^{-9}$	$2(3) \times 10^{-11}$
$\text{BR}(\tau^- \rightarrow e^- \gamma)$	$2 \times 10^{-12}$	$1(3) \times 10^{-12}$
$\text{BR}(\mu^- \rightarrow e^- e^+ e^-)$	$6 \times 10^{-14}$	$6 \times 10^{-14}$
$\text{BR}(\tau^- \rightarrow \mu^- \mu^+ \mu^-)$	$7 \times 10^{-12}$	$4(6) \times 10^{-14}$
$\text{BR}(\tau^- \rightarrow \mu^- e^+ e^-)$	$3 \times 10^{-11}$	$2(3) \times 10^{-13}$
$\text{BR}(\tau^- \rightarrow e^- e^+ e^-)$	$2 \times 10^{-14}$	$1(3) \times 10^{-14}$
$\text{BR}(\tau^- \rightarrow e^- \mu^+ \mu^-)$	$3 \times 10^{-15}$	$2(4) \times 10^{-15}$
$CR(\mu \rightarrow e; \text{Ti})$	$6 \times 10^{-14}$	$6 \times 10^{-14}$

Upcoming experimental sensitivity allows to measure

- $s_{13} \ll 0.2$  :  $\text{BR}(\mu \rightarrow e\gamma)$ ,  $\text{BR}(\mu \rightarrow eee)$ ,  $CR(\mu \rightarrow e; \text{Ti})$ ,  $\text{BR}(\tau \rightarrow \mu\gamma)$
- $s_{13} \lesssim 0.2$  :  $\text{BR}(\mu \rightarrow e\gamma)$ ,  $\text{BR}(\mu \rightarrow eee)$ ,  $CR(\mu \rightarrow e; \text{Ti})$

## CONCLUSIONS

LFV already seen with  $\nu_i \rightarrow \nu_j$ , but detection of alternative LFV signals is crucial to confirm NP

The (SUSY) triplet seesaw scenario looks promising:

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

Specific feature: Simple flavour structure ... Hence:

- Potential predictive scenario for LFV: e.g.  $\frac{BR(\tau \rightarrow \mu \gamma)}{BR(\mu \rightarrow e \gamma)}$  fixed by neutrino parameters only
- New predictive SUSY+GUT version with  $T$  playing also the role of SUSY messengers:

the whole sparticle spectrum is fixed by the effective

SUSY scale  $B_T \gtrsim 20$  TeV

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