

LFV and slepton mass splittings at the LHC

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in collaboration with

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Introduction: Beyond the SM overview and Motivation

Beyond the SM: supersymmetry + seesaw type-I

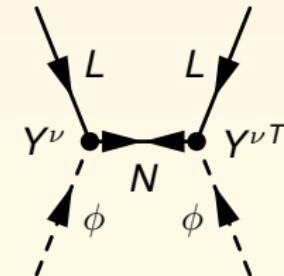
- ➊ Eases the Higgs fine-tuning problem and offers a solution to the hierarchy problem;
- ➋ + One possible explanation for small neutrino masses.

$$\mathcal{L}_{\text{dim}5}^{\nu} = \frac{1}{2} \left(\frac{f}{\Lambda} \right)_{ij} (\phi i\sigma_2 L_i) \cdot (\phi i\sigma_2 L_j) \Rightarrow M_{ij}^{\nu} = -v_u^2 \left(\frac{f}{\Lambda} \right)_{ij}$$

$$\left(\frac{f}{\Lambda} \right) = Y^{\nu} M_R^{-1} Y^{\nu T}, \quad Y^{\nu T} = \frac{1}{v_u} \sqrt{M_R} R \sqrt{\hat{M}^{\nu}} U_{PMNS}^{\dagger}$$

$$(3 \times 2)_R + (3+3)_{PMNS} + 3_{m_{\nu}} + 3_{\mathcal{M}} = 18$$

Unknown: 14 continuous + 1 LH hierarchy type



Motivation: (s)lepton sector

- ➊ Lepton flavour information;
- ➋ Involved in clean signals at colliders – multi-lepton final states;
- ➌ Will carry some hint on the true mechanism for generating neutrino masses.

Slepton masses in the CMSSM (1/3)

Slepton masses after EWSB

$$(m_{\tilde{l}, LL}^2)_{ij} = (m_{\tilde{L}}^2)_{ij} + \delta_{ij} \left[m_{l_j}^2 + M_Z^2 (-1/2 + s_w^2) \cos 2\beta \right]$$

$$(m_{\tilde{l}, RR}^2)_{ij} = (m_{\tilde{l}_R}^2)_{ij} + \delta_{ij} \left[m_{l_j}^2 + M_Z^2 s_w^2 \cos 2\beta \right]$$

$$(m_{\tilde{l}, LR}^2)_{ij} = (m_{\tilde{l}, LR}^2)_{ji}^* = v_d (A')_{ji} - \delta_{ij} \mu m_{l_j} \tan \beta$$

Universal LFC trilinear couplings $\Rightarrow v_d (A')_{ji} = \delta_{ij} m_{l_i} A_0$.

Universal $SU(2)_L \otimes U(1)$ gaugino masses ($m_{1/2}$) and $\alpha_2 > \alpha_1 = 5\alpha'/3$
 $\Rightarrow m_{wino} > m_{bino}$

+ Universal slepton masses (m_0) $\Rightarrow m_{\tilde{L}} > m_{\tilde{l}_R}$

$$m_{\tilde{L}}^2 \simeq m_0^2 + 0.5 m_{1/2}^2 + 0.0375 m_{1/2}^2 + \delta m_{\tilde{L}}^2$$

$$m_{\tilde{l}_R}^2 \simeq m_0^2 + 0.15 m_{1/2}^2 + \delta m_{\tilde{l}_R}^2$$

where $\delta m_{\tilde{L}, \tilde{l}_R}^2$ stands for flavour dependent RGE contributions:

$$(\delta m_{\tilde{L}}^2)_{ij} \simeq \frac{1}{2} (\delta m_{\tilde{l}_R}^2)_{ij} \simeq -\frac{1}{8\pi^2} \delta_{ij} |Y'_i|^2 \left(m_{H_d}^2 + (m_{\tilde{L}}^2)_{ii} + (m_{\tilde{l}_R}^2)_{ii} + |A_0|^2 \right) \ln \frac{M_{GUT}}{M_{SUSY}}$$

Slepton masses in the CMSSM (2/3)

Low energy slepton masses non-universality caused by one unique source, Y' , which is communicated through:

- ① F-type 4-scalar interactions after EWSB $\propto m_{l_i}^2 \Leftarrow \text{negligible};$
- ② Left-Right (LR) mixing $\propto m_{l_i} (A_0 - \mu \tan \beta);$
- ③ Flavoured RGE induced contribution $\propto Y_{l_i} m_0^2.$

Effects 2. and 3. mainly relevant for the stau sector as $m_\tau \gg m_\mu \gg m_e.$

Slepton mass splittings (SMS) $\frac{\Delta m}{m}(x, y) \equiv 2|x - y|/(x + y)$

$$\begin{aligned}\frac{\Delta m}{m}(\tilde{\mu}_L, \tilde{\tau}_2) &\approx \frac{1}{16\pi^2} |Y_\tau|^2 \left[3 \left(\frac{m_0}{m_L} \right)^2 + \left(\frac{A_0}{m_L} \right)^2 \right] + \frac{1}{2} \left(\frac{m_\tau^2}{m_L^2 - m_{l_R}^2} \right) \left(\frac{A_0 - \mu \tan \beta}{m_L} \right)^2 \\ &\approx (0.07\% - 2.32\%) 10^{-2} c_\beta^{-2} + (0.07 - 0.7) 10^{-2} t_\beta^2\end{aligned}$$

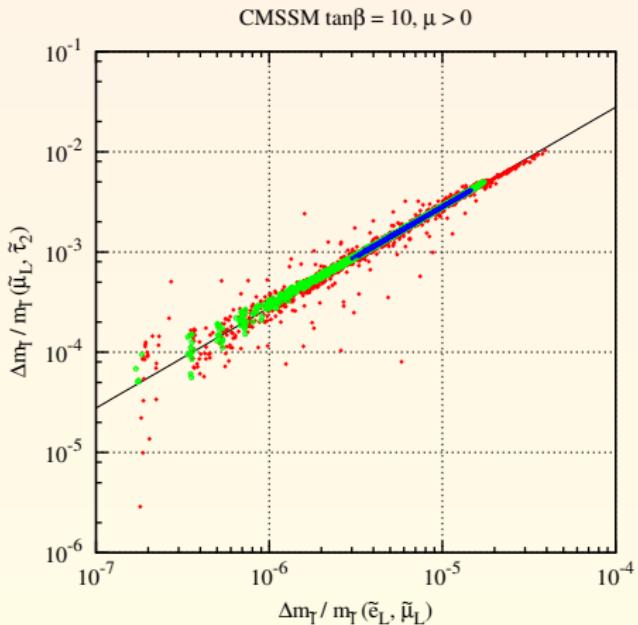
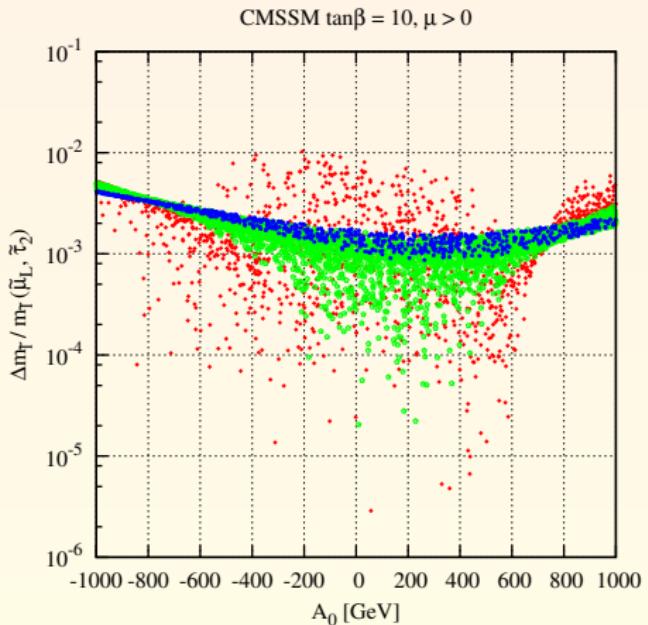
$$\frac{\Delta m}{m}(\tilde{e}_L, \tilde{\mu}_L) \approx \left(\frac{m_\mu}{m_\tau} \right)^2 \frac{\Delta m}{m}(\tilde{\mu}_L, \tilde{\tau}_2) \approx 3.6 \times 10^{-3} \frac{\Delta m}{m}(\tilde{\mu}_L, \tilde{\tau}_2)$$

assumptions^a: typical $m_{1/2} \approx 400 \text{ GeV}$, $m_0 \approx 100 \text{ GeV}$,

$|\mu| \approx \sqrt{m_0^2 + 0.5m_{1/2}^2}$ and maximum $|A_0| \approx 1 \text{ TeV}.$

^aStandard window: $m_{\tilde{\chi}_2^0} - m_{l_L} \geq 10 \text{ GeV}$ and $\tilde{\chi}_1^0$ is the LSP.

Slepton masses in the CMSSM (3/3)



< 600	$m_{\tilde{\chi}_2^0} [\text{GeV}]$
:	.
$[600, 900]$	•
	> 900

(SPHENO 3.0)

$\tan\beta$	$\frac{\Delta m}{m}(\tilde{\mu}_L, \tilde{\tau}_2)$	$\frac{\Delta m}{m}(\tilde{e}_L, \tilde{\mu}_L)$
10	(0.01 – 1) %	$(10^{-4} – 10^{-3})$ %
40	(0.1 – 10) %	$(10^{-3} – 10^{-2})$ %

Mass measurement strategies at the LHC (1/3)

Two standard methods

- ① Reconstruct entire decay chains by measuring all final state momenta;
- ② Construct invariant kinematical quantities which are “easy” to measure. Their distribution edges provide information on mass relations between decay chain’s intermediate states.

R-parity conserving model \Rightarrow each SUSY event has two stable WIMPs \Rightarrow large amount of missing energy.

\Rightarrow **Conclusion:** 1st method cannot be used.

[B. C. Allanach and C. G. Lester and M. A. Parker and B. R. Webber, **Measuring sparticle masses in non-universal string inspired models at the LHC**, hep-ph/0007009v2]

[Henri Bachacou and Ian Hinchliffe and Frank E. Paige, **Measurements of Masses in SUGRA Models at LHC**, hep-ph/9907518v1]

SUSY @ LHC occurs primarily by gluon-gluon and quark-gluon fusion and quark-quark scattering $pp \rightarrow \tilde{q} \tilde{g}, \rightarrow \tilde{q} \tilde{q}^\dagger$ and $\rightarrow \tilde{q} \tilde{q}$.

Strong and electroweak sectors mass hierarchy:

$$m_{\tilde{g}} > m_{wino} > m_{bino}, \quad m_{\tilde{q}} > m_{\tilde{l}}$$

Mass measurement strategies at the LHC (2/3)

Therefore, two main squark decay modes:

- ① $\tilde{q}_L \rightarrow \tilde{\chi}_2^0 q \Leftarrow BR(\tilde{q}_L \rightarrow \tilde{\chi}_2^0 q) \approx 0.31;$
- ② $\tilde{q}_R \rightarrow \tilde{\chi}_1^0 q;$

followed by $\tilde{\chi}_2^0$ decay to final state leptons or $b\bar{b}$ hadronization:

- ① $\tilde{\chi}_2^0 \rightarrow \bar{\nu} \tilde{\nu}_L \rightarrow \bar{\nu} \nu \tilde{\chi}_1^0 \Leftarrow$ unobservable but $\sum_\nu BR_\nu \approx 50\%$ in our scenario;
- ② $\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 h \rightarrow \tilde{\chi}_1^0 X(b\bar{b}\dots) \Leftarrow BR \approx 1-3\%;$
- ③ $\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 Z \rightarrow \tilde{\chi}_1^0 l\bar{l} \Leftarrow BR \lesssim 0.2\%.$
- ④ $\tilde{\chi}_2^0 \rightarrow \tilde{l}_{L,R} \bar{l} \rightarrow \tilde{\chi}_1^0 l\bar{l};$

From the chain $\tilde{q}_L \rightarrow \tilde{\chi}_2^0 \rightarrow \tilde{l}_{L,R} \rightarrow \tilde{\chi}_1^0$ we can construct 3 observable di-particle invariant masses whose end-points have a common structure:

$$m_{ll}^{(max)} = M(m_{\tilde{\chi}_2^0}, m_{\tilde{l}_{L,R}}, m_{\tilde{\chi}_1^0}), \quad m_{l(near)q}^{(max)} = M(m_{\tilde{q}_L}, m_{\tilde{\chi}_2^0}, m_{\tilde{l}_{L,R}}), \quad m'_{l(far)q}^{(max)} = M'(m_{\tilde{q}_L}, m_{\tilde{\chi}_2^0}, m_{\tilde{l}_{L,R}}, m_{\tilde{\chi}_1^0})$$

and one tri-particle invariant mass

$$m_{llq}^{(max)} = M(m_{\tilde{q}_L}, m_{\tilde{\chi}_2^0}, m_{\tilde{\chi}_1^0})$$

neglecting the jet mass.

$$M(x, y, z) = \frac{1}{y} \sqrt{(x^2 - y^2)(y^2 - z^2)}, \quad M'(x, y, w, z) = \frac{1}{w} \sqrt{(x^2 - y^2)(w^2 - z^2)}$$

Mass measurement strategies at the LHC (3/3)

Standard window representative points

Point	m_0 [GeV]	$m_{1/2}$ [GeV]	A_0 [GeV]	$\tan \beta$	$sign(\mu)$	$\Omega_{CDM} h^2$
A	80	380	0	10	1	0.109
B	200	944	900	10	1	0.115
C	78.9	386	-1000	3	1	0.103

(SPHENO 3.0 + MICROMEGRAs v2.2)

Approximate mass spectrum

Point	$m_{\tilde{\chi}_2^0}$ [GeV]	$m_{\tilde{\chi}_1^0}$ [GeV]	$m_{l_{X(L)}}$ [GeV]	$m_{l_{X(R)}}$ [GeV]	$m_{\tilde{q}}$ [GeV]
A	285	152	~ 272	~ 163	740 – 800
B	744	396	~ 638	~ 399	1700 – 1820
C	296	155	~ 273	~ 165	700 – 820

(SPHENO 3.0)

\tilde{q}_L production cross section

Point	NLO Cross section [pb]			
	$\tilde{q}_L \tilde{g}$	$\tilde{q}_L \tilde{q}$	$\tilde{q}_L \tilde{q}^\dagger + \tilde{q} \tilde{q}_L^\dagger$	total
A	1.56	0.92	0.90	3.39
B	3.88×10^{-3}	7.79×10^{-3}	2.84×10^{-3}	1.45×10^{-2}
C	1.41	0.85	0.82	3.08

(PROSPINO2.1)

RGE induced LFV & mass splittings in type I SUSY seesaw

Low energy LH charged slepton masses and trilinear couplings

$$m_{\tilde{L}_{ij}}^2 \simeq \delta_{ij} m_0^2 + \frac{1}{8\pi^2} (3m_0^2 + A_0^2) Y_{jk}^\nu t_k Y_{ki}^{\nu\dagger}, \quad t_k \equiv \ln \left(\frac{(M_R)_k}{M_{GUT}} \right)$$

$$A_{ij}^I \simeq \delta_{ij} A_0 Y_{ii}^I + \frac{3}{16\pi^2} A_0 Y_{ii}^I Y_{ik}^\nu t_k Y_{kj}^{\nu\dagger}$$

Small angle approximation

- ① Dominant $(m_{\tilde{L},LL}^2)_{ii}$, driven by $SU(2)_L$ gaugino:

$$m_{\tilde{L},LL}^2 \simeq m_0^2 + 0.5 m_{1/2}^2 + 0.0375 m_{1/2}^2$$

- ② Mixing $LL \gg RL, LR$

$$\tilde{R^I} \simeq \begin{pmatrix} 1 & \delta_{12} & \delta_{13} \\ -\delta_{12} & 1 & \delta_{23} \\ -\delta_{13} & -\delta_{23} & 1 \end{pmatrix}, \quad \delta_{ij} = \frac{\Delta m_{\tilde{L}(ij)}^2}{m_{\tilde{L}(ii)}^2 - m_{\tilde{L}(jj)}^2}$$

Assumptions on unknown seesaw parameters

Recall Casas-Ibarra parametrization:

$$Y^{\nu T} = \frac{1}{v_u} \sqrt{M_R} R \sqrt{\hat{M}^\nu} U_{PMNS}^\dagger$$

Assumptions:

- ① $(M_R)_3 \gg (M_R)_{1,2}$ (hierarchical RH neutrinos);
- ② $R = 1$;
- ③ TBM mixing angles except for the Chooz (θ_{13});
- ④ normal ordered light neutrinos.

The RH neutrinos induced flavour violation is thus proportional to

$$\delta'_{ji} \equiv v_u^2 [Y^\nu t Y^{\nu\dagger}]_{ij} \Rightarrow \begin{cases} (M_R)_3^{-1} t_3^{-1} \delta'_{21} \simeq m_3 \frac{c_{13}s_{13}}{\sqrt{2}} e^{i\delta} \\ (M_R)_3^{-1} t_3^{-1} \delta'_{31} \simeq m_3 \frac{c_{13}s_{13}}{\sqrt{2}} e^{i\delta} \\ (M_R)_3^{-1} t_3^{-1} \delta'_{32} \simeq m_3 \frac{c_{13}^2}{2} \end{cases}$$

Experimental signals

At colliders:

- ➊ Flavoured slepton mass splittings
– expected slepton mass splittings sensitivity @ LHC:
 $\sim \mathcal{O}(0.1)\%$;
- ➋ Sizable LFV decay width $\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 l_i l_j$ ($i \neq j$);
- ➌ Multiple edges in LFC di-lepton invariant mass distribution
 $\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 l \bar{l}$.

At low energy experiments:

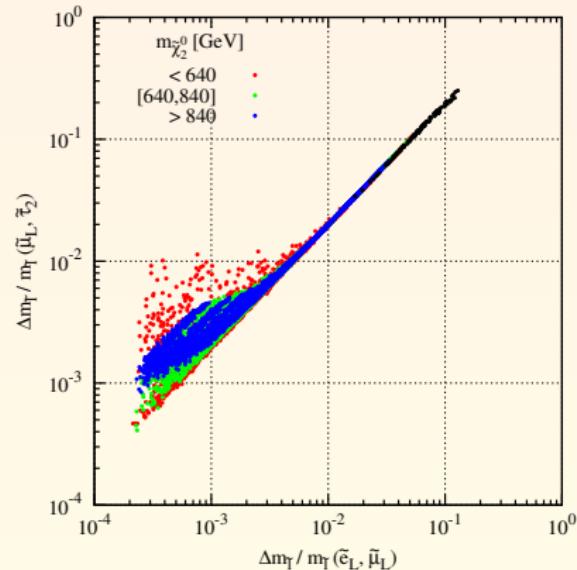
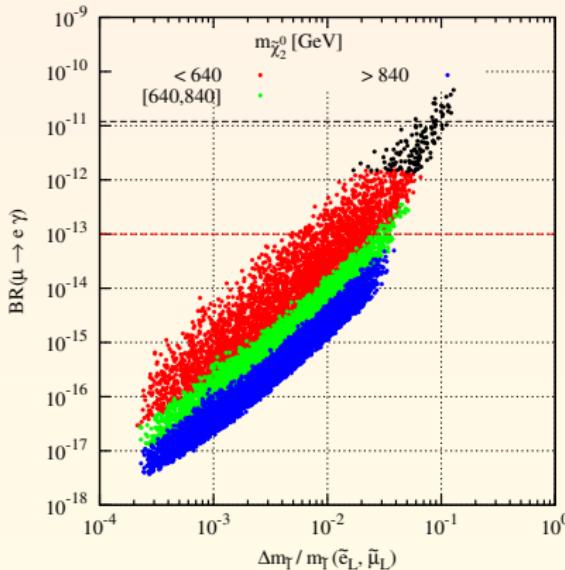
$$BR(l_i \rightarrow l_j \gamma) \approx \left(\frac{1}{c_\beta^2 s_\beta^4} \right) \left(\frac{3m_0^2 + A_0^2}{m_{\tilde{L}}^4} \right)^2 |\delta'_{ji}|^2 \times \begin{cases} 6.36 \times 10^{-10}, & \text{for } i = \tau \\ 3.58 \times 10^{-9}, & \text{for } i = \mu \end{cases}$$

[PDG 2008]

Mode	BR (at 90% CL)	Mode	BR (at 90% CL)
$\mu \rightarrow e \gamma$	$< 1.2 \times 10^{-11}$	$\mu \rightarrow e \bar{e} e$	$< 1.0 \times 10^{-12}$
$\tau \rightarrow e \gamma$	$< 1.1 \times 10^{-7}$	$\tau \rightarrow e \bar{e} e$	$< 3.6 \times 10^{-8}$
$\tau \rightarrow \mu \gamma$	$< 4.5 \times 10^{-8}$	$\tau \rightarrow \mu \bar{\mu} \mu$	$< 3.2 \times 10^{-8}$

Future sensitiveness $BR(\mu \rightarrow e \gamma) \gtrsim 10^{-13}$ [MEG experiment].

Slepton mass splittings as a $|l_i \rightarrow l_j \gamma|$ indicator



Low $\theta_{13} \Rightarrow \tau\text{-}\mu$ mixing is $\sim 1/s_{13}^2$ enhanced, dominating the slepton flavour mixing¹:

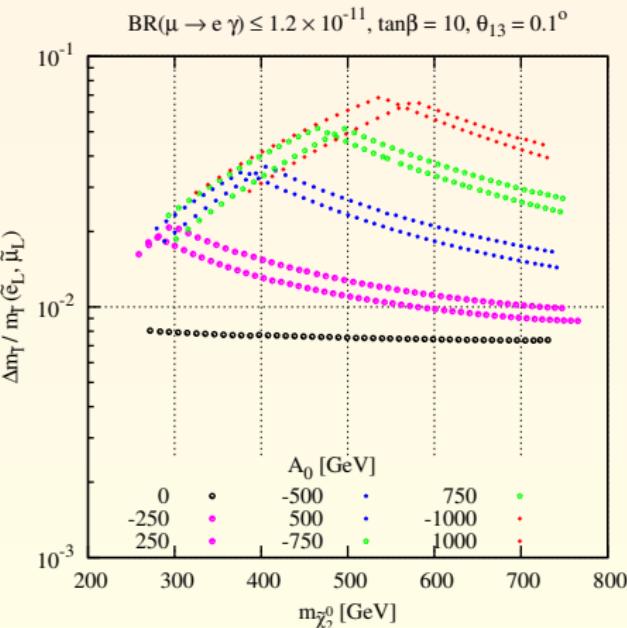
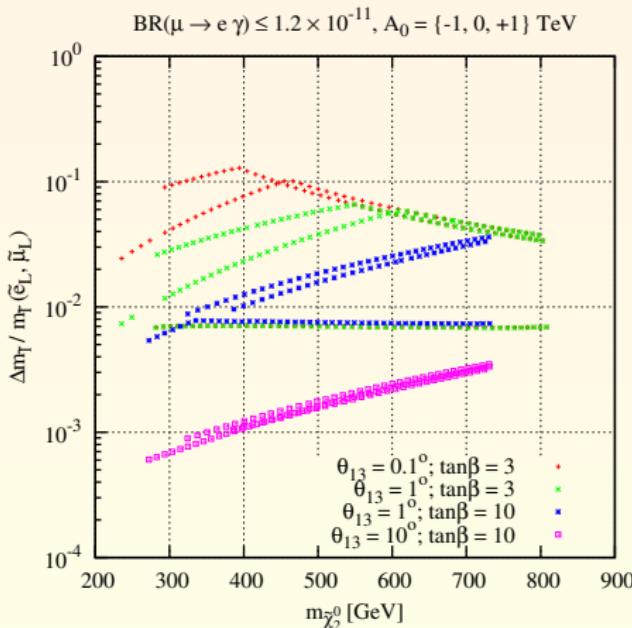
$$\frac{\Delta m}{m}(\tilde{\mu}_L, \tilde{\tau}_2) \simeq 2 \frac{\Delta m}{m}(\tilde{e}_L, \tilde{\mu}_L) \approx \left| \frac{(m_{\tilde{L}}^2)_{23}}{(m_{\tilde{L}}^2)_{33}} \right|$$

¹Not true in any of these situations: (i) non-hierarchical RH neutrinos, (ii) hierarchical RH neutrinos with a non-trivial R -matrix, (iii) light neutrinos with an inverted mass spectrum.

$m_{\tilde{\chi}_2^0} + \text{slepton mass splittings as a } \tan\beta \text{ vs } |A_0| \text{ probe}$

$$\frac{\Delta m}{m}(\tilde{\mu}_L, \tilde{\tau}_2) \approx \frac{1}{8\pi^2 m_L^2} \left(3m_0^2 + A_0^2\right) \left| Y_{2k}^\nu t_k Y_{k3}^{\nu\dagger} \right|, \quad m_L^2 = m_0^2 + 0.5375 m_{1/2}^2$$

(Ωh^2 fitted around 0.1109 allowing a maximum of 2σ deviation)



① $\lim_{m_0 \rightarrow \infty} \frac{\Delta m}{m}(\tilde{\mu}_L, \tilde{\tau}_2) \simeq \frac{3}{4\pi^2} \frac{|Y_{2k}^\nu t_k Y_{k3}^{\nu\dagger}|}{2+a^2}, \text{ where } m_{1/2} = a m_0;$

$m_{\tilde{\chi}_2^0} +$ slepton mass splittings as a $\tan \beta$ vs $|A_0|$ probe

Remarks

Perturbative bounds on Y^ν :

- ➊ Robust upper bound (independent of LFV decay rates) on slepton mass splittings for a fixed $|A_0|$;
- ➋ $|A_0| \sim 0$ GeV $\Rightarrow \text{Max}\left[\frac{\Delta m}{m}(\tilde{e}_L, \tilde{\mu}_L)\right] \lesssim 0.8\%$.

Current upper bounds on LFV decay rates imply

$$\text{Max}\left[\frac{\Delta m}{m}(\tilde{e}_L, \tilde{\mu}_L)\right] \approx 15\%$$

$$\Rightarrow \tan \beta \lesssim 3 \text{ and } |A_0| \approx 1 \text{ TeV while } m_{\tilde{\chi}_2^0} \approx 350 - 450 \text{ GeV}$$

for $\theta_{13} \lesssim 0.3^\circ$.

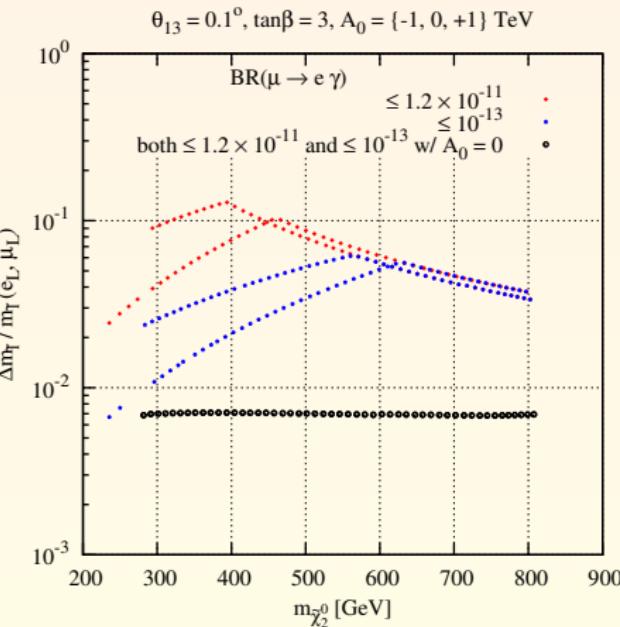
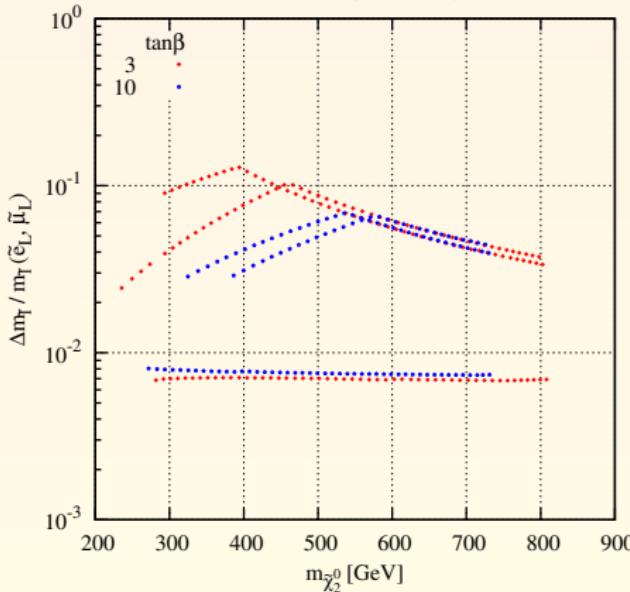
Deviations from TBM ($\theta_{13} \gtrsim 1^\circ$) imply

for **current** LFV upper bounds: $\text{Max}\left[\frac{\Delta m}{m}(\tilde{e}_L, \tilde{\mu}_L)\right] \lesssim 7\%$.

$m_{\tilde{\chi}_2^0} + \text{slepton mass splittings as a } \tan\beta \text{ vs } |A_0| \text{ probe}$

(Ωh^2 fitted around 0.1109 allowing a maximum of 2σ deviation)

$\text{BR}(\mu \rightarrow e \gamma) \leq 1.2 \times 10^{-11}, \theta_{13} = 0.1^\circ, A_0 = \{-1, 0, +1\} \text{ TeV}$



- ② $BR(l_i \rightarrow l_j \gamma)$ constrained mass splitting

$$\frac{\Delta m}{m}(\tilde{\mu}_L, \tilde{\tau}_2) = 1.66 \times 10^{-2} \times \left[\frac{m_L^2}{\text{GeV}^2} \right] c_\beta \left\{ \begin{array}{l} \sqrt{BR(\tau \rightarrow \mu \gamma)} \\ 0.3 \times t_{13}^{-1} \sqrt{BR(\mu \rightarrow e \gamma)} \end{array} \right.$$

$m_{\tilde{\chi}_2^0} +$ slepton mass splittings as a $\tan \beta$ vs $|A_0|$ probe

Remarks

Future upper bound on $BR(\mu \rightarrow e \gamma)$ for $\theta_{13} \sim 0.1^\circ$ imply

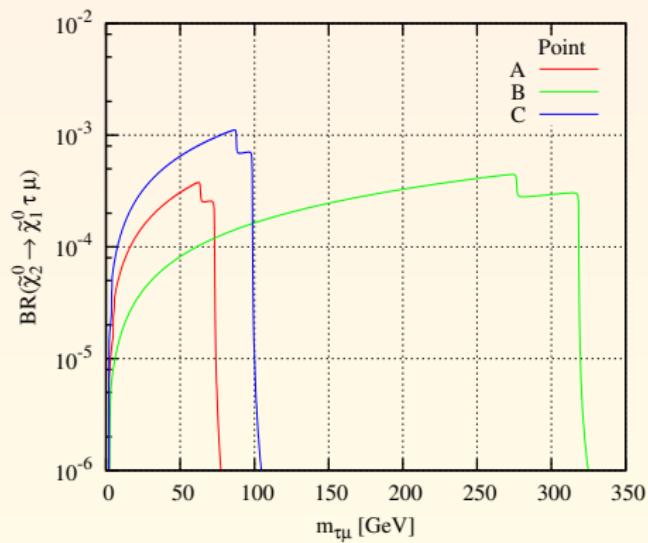
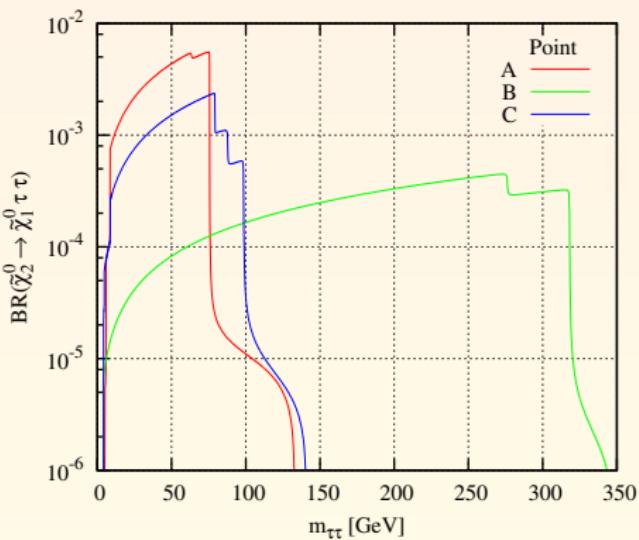
$$\text{Max} \left[\frac{\Delta m}{m} (\tilde{e}_L, \tilde{\mu}_L) \right] \approx 6\%$$

$\Rightarrow \tan \beta \lesssim 3$ and $|A_0| \approx 1$ TeV while $m_{\tilde{\chi}_2^0} \approx 550 - 650$ GeV

Deviations from TBM ($\theta_{13} \gtrsim 1^\circ$) imply

for **future** $BR(\mu \rightarrow e \gamma)$ upper bound: $\text{Max} \left[\frac{\Delta m}{m} (\tilde{e}_L, \tilde{\mu}_L) \right] \lesssim 2\%$
 $(m_{\tilde{\chi}_2^0} \approx 850 - 950$ GeV).

Di-lepton invariant mass distributions



Point	$\frac{\Delta m}{m}(\tilde{\mu}_L, \tilde{\tau}_2)$	$\frac{\Delta m}{m}(\tilde{e}_L, \tilde{\mu}_L)$	$(M_R)_3$ [GeV]
A	1.33%	0.73%	8.2×10^{14}
B	6.40%	-	1.9×10^{15}
C	2.14%	-	2.0×10^{13}

$$BR(\mu \rightarrow e \gamma) \lesssim 10^{-13}, \theta_{13} = 0.1^\circ \Rightarrow BR(\tau \rightarrow \mu \gamma) \lesssim 3 \times 10^{-9}$$

$$BR(\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 \bar{\mu} e) \approx 10^{-4} BR(\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 \bar{\tau} \mu), \quad (\theta_{13} = 0.1^\circ)$$

Di-lepton invariant mass distributions

Remarks

Number of events expected for $\int \mathcal{L} dt = 100 \text{ fb}^{-1}$

- ➊ Point A: $\sim 24822 (\tau\bar{\tau})$ and $\sim 1554 (\tau\bar{\mu})$;
- ➋ Point B: $\sim 34 (\tau\bar{\tau})$ and $\sim 34 (\tau\bar{\mu})$;
- ➌ Point C: $\sim 10461 (\tau\bar{\tau})$ and $\sim 5480 (\tau\bar{\mu})$.

$\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 \bar{\mu} e \Rightarrow$ rather unlikely to be observable.

m_{\parallel} and LFC signals of LFV in the slepton sector:

- ➊ Sufficient: 3 edges in LFC processes (point C);
- ➋ Necessary: 2 edges in LFC processes when $\tilde{\chi}_2^0$ decay via \tilde{l}_R is highly suppressed;
- ➌ 2 edges in LFC processes with a heavy mass spectrum (point B) and proper dark matter relic density ($\Rightarrow m_{\tilde{\tau}_1} - m_{\tilde{\chi}_1^0} \lesssim 0.1 \text{ GeV}$ – features a long lived $\tilde{\tau}_1$).

Flavour quasi-degenerated sleptons ($\tilde{\tau}_2, \tilde{\mu}_L$) give rise to:

- ➊ 3 edges in LFC processes;
- ➋ Similar number of $\tau\mu$ and $\tau\tau$ events at the LHC.

Conclusion

A non-negligible $\tilde{e}_L - \tilde{\mu}_L$ mass splitting or a non-conventional $\frac{\Delta m}{m}(\tilde{e}_L, \tilde{\mu}_L)$ vs $\frac{\Delta m}{m}(\tilde{\mu}_L, \tilde{\tau}_2)$ correlation requires a proper explanation:

- ① Is slepton non-universality generated @ GUT (by SUSY-breaking)?
- ② or is it generated by the same mechanism responsible for neutrino masses? For example, a seesaw type-I

We have seen that the second answer implies

- ① Correlation between low energy LFV observables and slepton mass splittings;
- ② Possible hints on $\tan \beta$ and $|A_0|$ for a given mass splitting;
- ③ 2- and even 3-edge structures in di-lepton invariant mass distributions from $\tilde{\chi}_2^0$ decay.