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Slepton mass-splittings as a signal of LFV at the LHC

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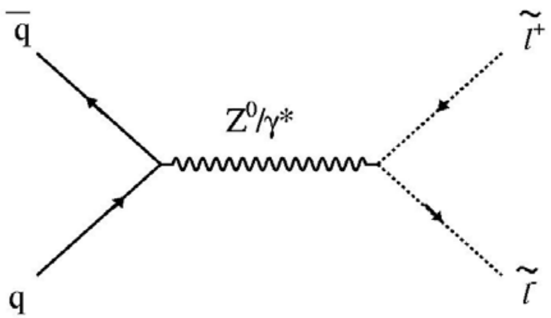
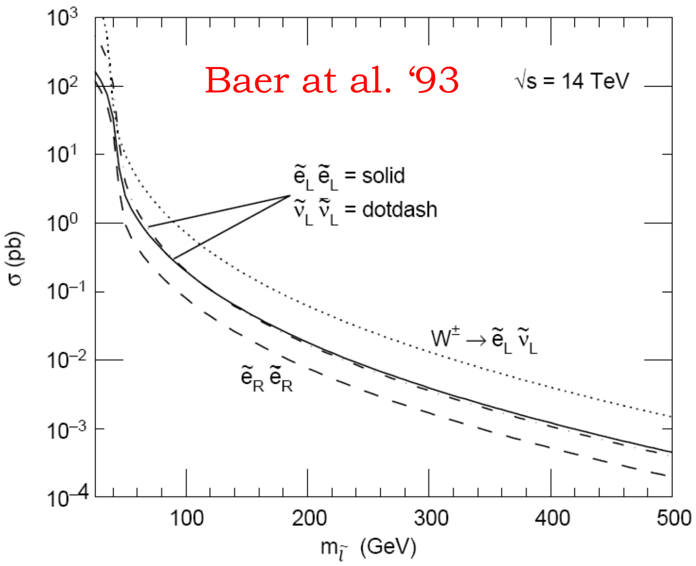
based on

A. J. Buras, L.C., P. Paradisi, arXiv:0912.1309 [hep-ph], to appear on JHEP.

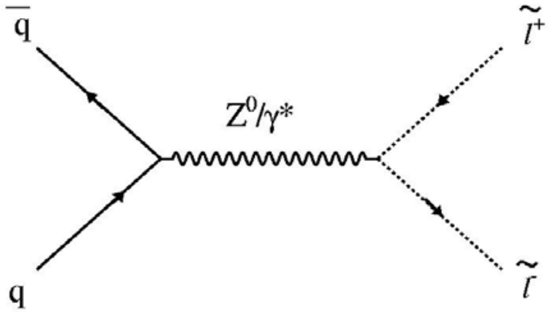
- Direct production (Drell-Yan):

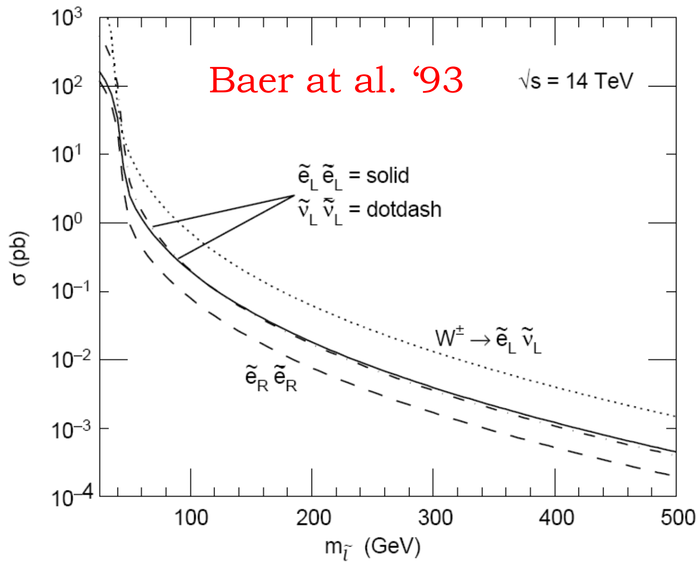




Slepton production and mass measurement at the LHC

- Direct production (Drell-Yan):





- Indirect production (cascade decays):

$$\tilde{q}_L \to q_L\, \tilde{\chi}^0_2 \to q_L\, \tilde{\ell}^{\pm} \ell^{\mp}$$

Wino-like $\tilde{\chi}^0_2$:

$$\mathrm{BR}(\tilde{q}_L \to q_L\, \tilde{\chi}^0_2) \simeq 1/3$$

Kinematic end-point:

$$\tilde{\chi}^0_2 \to \tilde{\ell}^{\pm} \ell^{\mp} \to \tilde{\chi}^0_1 \ell^{\pm} \ell^{\mp} \quad \xRightarrow{m_{\tilde{\chi}^0_2} > m_{\tilde{\ell}}} \quad m^2_{ll} = \frac{(m^2_{\tilde{\chi}^0_2} - m^2_{\tilde{\ell}})(m^2_{\tilde{\ell}} - m^2_{\tilde{\chi}^0_1})}{m^2_{\tilde{\ell}}}$$

Paige '96; Hinchliffe et al. '96

Slepton production and mass measurement at the LHC

Can the measurement of the kinematic edges of the *e-e* and *μ-μ* invariant mass distributions resolve a mass difference between selectron and smuon?

$$\frac{\Delta m_{\tilde{\ell}}}{m_{\tilde{\ell}}} \quad \Rightarrow \quad \frac{\Delta m_{ll}}{m_{ll}} = \frac{\Delta m_{\tilde{\ell}}}{m_{\tilde{\ell}}} \left(\frac{m^2_{\tilde{\chi}^0_1} m^2_{\tilde{\chi}^0_2} - m^4_{\tilde{\ell}}}{(m^2_{\tilde{\chi}^0_2} - m^2_{\tilde{\ell}})(m^2_{\tilde{\ell}} - m^2_{\tilde{\chi}^0_1})} \right)$$

Can the measurement of the kinematic edges of the *e*-*e* and *μ*-*μ* invariant mass distributions resolve a mass difference between selectron and smuon?

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It can be measured at the LHC with precision below the percent level!

Allanach et al. '08

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It can be measured at the LHC with precision below the percent level!

Allanach et al. '08

- Is a measurable selectron-smuon splitting possible within the CMSSM?
- If not, it could point towards a LFV effect
- Alternatively, it can be due to non-degeneracy already at the SUSY breaking scale in models with alignment

Feng et al. '07, '09

Lepton flavour conserving case

In the CMSSM in absence of flavour mixing:

$$m^2_{\tilde{\ell}_{1,2}} = \frac{(m^2_{\tilde{\ell}_L} + m^2_{\tilde{\ell}_R})}{2} \mp \frac{\sqrt{(m^2_{\tilde{\ell}_L} - m^2_{\tilde{\ell}_R})^2 + 4(\Delta^{\tilde{\ell}\tilde{\ell}}_{RL})^2}}{2}$$

$$m^2_{\tilde{\ell}_L} \approx m_0^2(1 - |c| y_\ell^2) + 0.5 M^2_{1/2} \qquad m^2_{\tilde{\ell}_R} \approx m_0^2(1 - 2|c| y_\ell^2) + 0.15 M^2_{1/2}$$

$$|c| \approx (3 + a_0^2) \ln(M_X/M_Z)/(4\pi)^2$$

$$\Delta^{\tilde{\ell}\tilde{\ell}}_{RL} = m_\ell (A_\ell - \mu \tan\beta)$$

We get for smuons and selectrons:

$$\frac{\Delta m_{\tilde{\ell}}}{m_{\tilde{\ell}}} \simeq \frac{m_{\tilde{e}_R} - m_{\tilde{\mu}_R}}{m_{\tilde{\ell}}} + \frac{(\Delta^{\tilde{\mu}\tilde{\mu}}_{RL})^2}{m^2_{\tilde{\ell}}(m^2_{\tilde{\mu}_L} - m^2_{\tilde{\mu}_R})}$$ ~ 0.1 %, even for large tanβ

⇨ not measurable at the LHC

If $\Delta m_{\tilde{\ell}}/m_{\tilde{\ell}}$ induced by LFV → correlation with low-energy LFV, $\ell_i \to \ell_j \gamma$

- Strong constrains from $\mathrm{BR}(\mu \to e\gamma)$ for LFV sources in the 1-2 sector

  ($\Delta m_{\tilde{\ell}}/m_{\tilde{\ell}} \sim 1\%$ only in cancellation regime) Hisano et al. '02, '08

- What about LFV in the 2-3 (or 1-3) sector? $(\delta_{\rm XY})_{ij} \equiv (\tilde{m}^2_{\rm XY})_{ij}/\sqrt{(\tilde{m}^2_{\rm XY})_{ii}(\tilde{m}^2_{\rm XY})_{jj}}$

$(\delta_{\rm LL})_{32}$ ⟹ $\tilde{e}_L - \tilde{\mu}_L$ splitting

$(\delta_{\rm RR})_{32}$ ⟹ $\tilde{e}_R - \tilde{\mu}_R$ splitting

$$\left|\frac{\Delta m_{\tilde{\ell}}}{m_{\tilde{\ell}}}\right| \simeq \frac{|\delta_{32}|}{2}$$

(Clearly splitting is induced also between stau and smuon, but stau masses are also affected by possibly large RG effects, LR mixing …)

Lepton flavour violating case

If $\Delta m_{\tilde{\ell}}/m_{\tilde{\ell}}$ induced by LFV → correlation with low-energy LFV, $\ell_i \to \ell_j \gamma$

- Strong constrains from $\mathrm{BR}(\mu \to e\gamma)$ for LFV sources in the 1-2 sector

  ($\Delta m_{\tilde{\ell}}/m_{\tilde{\ell}} \sim 1\%$ only in cancellation regime) Hisano et al. '02, '08

- What about LFV in the 2-3 (or 1-3) sector? $(\delta_{\rm XY})_{ij} \equiv (\tilde{m}^2_{\rm XY})_{ij}/\sqrt{(\tilde{m}^2_{\rm XY})_{ii}(\tilde{m}^2_{\rm XY})_{jj}}$

$$(\delta_{\rm LL})_{32} \Longrightarrow \tilde{e}_L - \tilde{\mu}_L \text{ splitting}$$

$$(\delta_{\rm RR})_{32} \Longrightarrow \tilde{e}_R - \tilde{\mu}_R \text{ splitting}$$

$$\left|\frac{\Delta m_{\tilde{\ell}}}{m_{\tilde{\ell}}}\right| \simeq \frac{|\delta_{32}|}{2}$$

⟹ Possible hints of (2-3) LFV from flavour conserving processes such:

$$\tilde{\chi}^0_2 \to \tilde{\chi}^0_1 \mu^+\mu^- / \ \tilde{\chi}^0_1 e^+ e^-$$

If δ_{32} is the origin of a selectron-smuon mass splitting, LFV processes are clearly unavoidable.

- Low-energy LFV:

$$\frac{\mathrm{BR}(\tau \to \mu\gamma)}{\mathrm{BR}(\tau \to \mu\nu_\tau\bar{\nu_\mu})} = \frac{48\pi^3\alpha}{G_F^2}(|A_L^{32}|^2 + |A_R^{32}|^2)$$

$$A_L^{32} \simeq \frac{\alpha_2}{60\pi}\frac{\tan\beta}{\tilde{m}^2}(\delta_{\mathrm{LL}})_{32}\,, \qquad A_R^{32} \simeq -\frac{\alpha_1}{4\pi}\frac{\tan\beta}{\tilde{m}^2}\frac{(\delta_{\mathrm{RR}})_{32}}{60}\,.$$

- High-energy LFV:

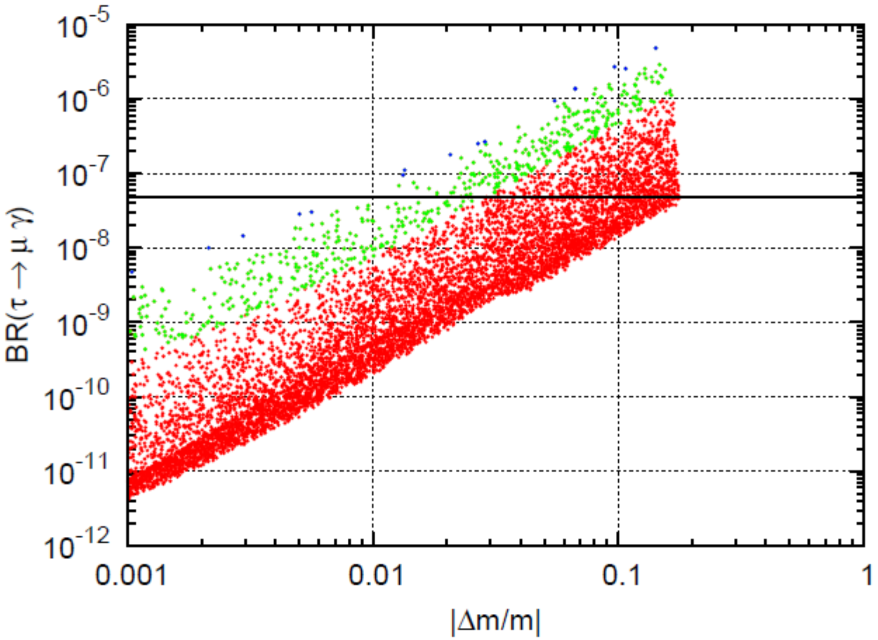
$$\boxed{\tilde{\chi}_2^0 \to \tilde{\chi}_1^0\tau^\pm\mu^\mp}$$

Arkani-Hamed et al. ’96, ’97
Hinchliffe and Paige ’00
Carvalho et al.’02, Carquin et al. ’08
...

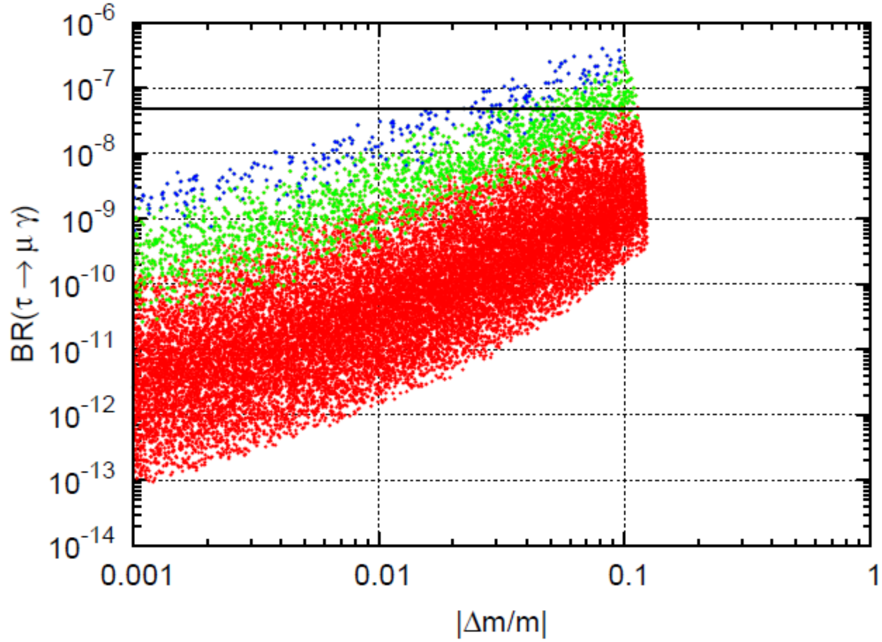
$$\mathrm{BR}(\tilde{\chi}_2^0 \to \ell_i\ell_j\tilde{\chi}_1^0) = \Big[\mathrm{BR}(\tilde{\chi}_2^0 \to \ell_i\tilde{\ell}_\alpha)\mathrm{BR}(\tilde{\ell}_\alpha \to \ell_j\tilde{\chi}_1^0) + \mathrm{BR}(\tilde{\chi}_2^0 \to \ell_j\tilde{\ell}_\alpha)\mathrm{BR}(\tilde{\ell}_\alpha \to \ell_i\tilde{\chi}_1^0)\Big] \quad (8)$$

Results

$10^{-3} < (\delta_{LL})_{32} < 0.3$



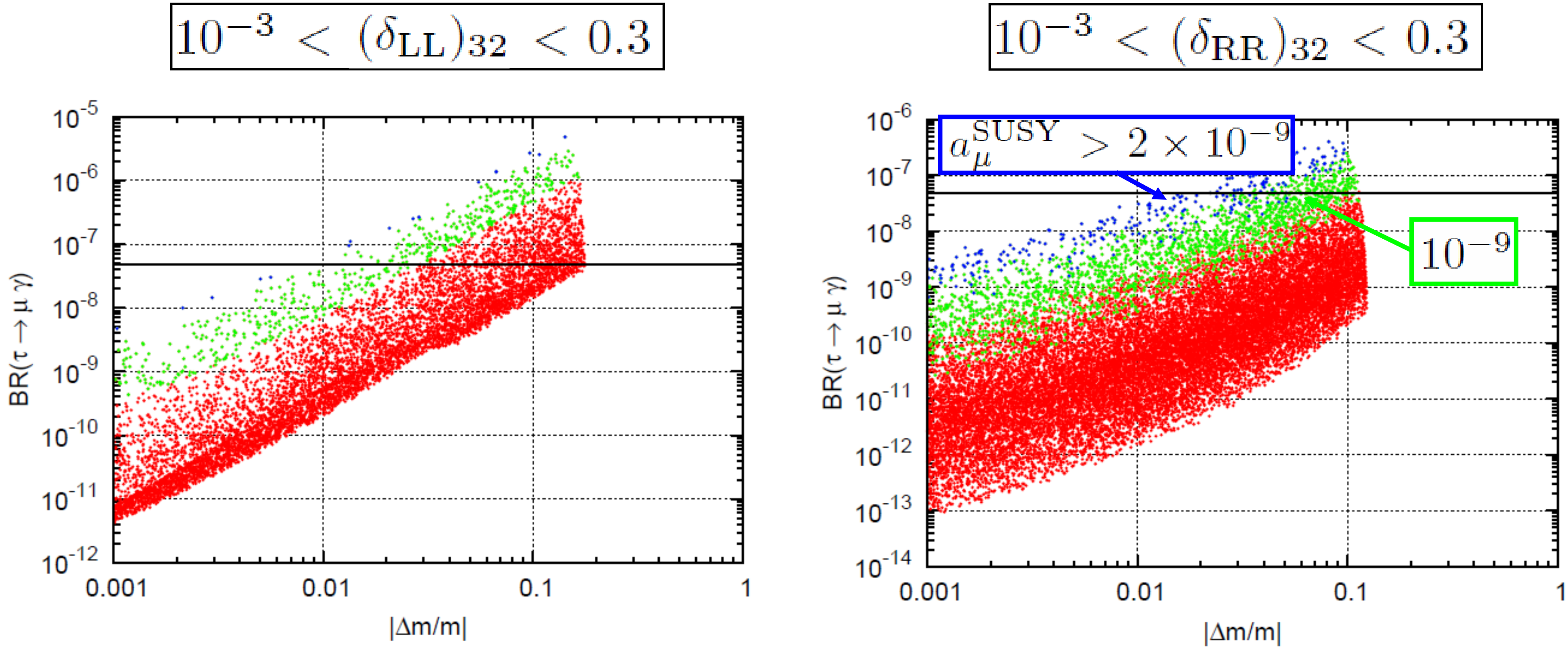
$10^{-3} < (\delta_{RR})_{32} < 0.3$



$\tan\beta = 10, \ A_0 = 0 \quad m_0, M_{1/2} \leq 1 \ \text{TeV}$

$m_{\tilde{e}} \ , m_{\tilde{\mu}} \ < m_{\tilde{\chi}_2^0}$

Results



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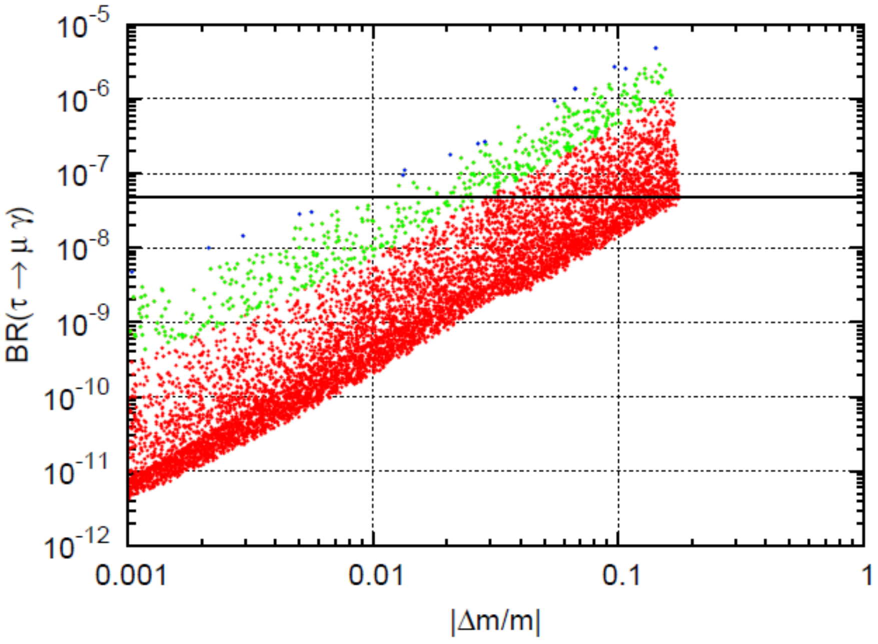

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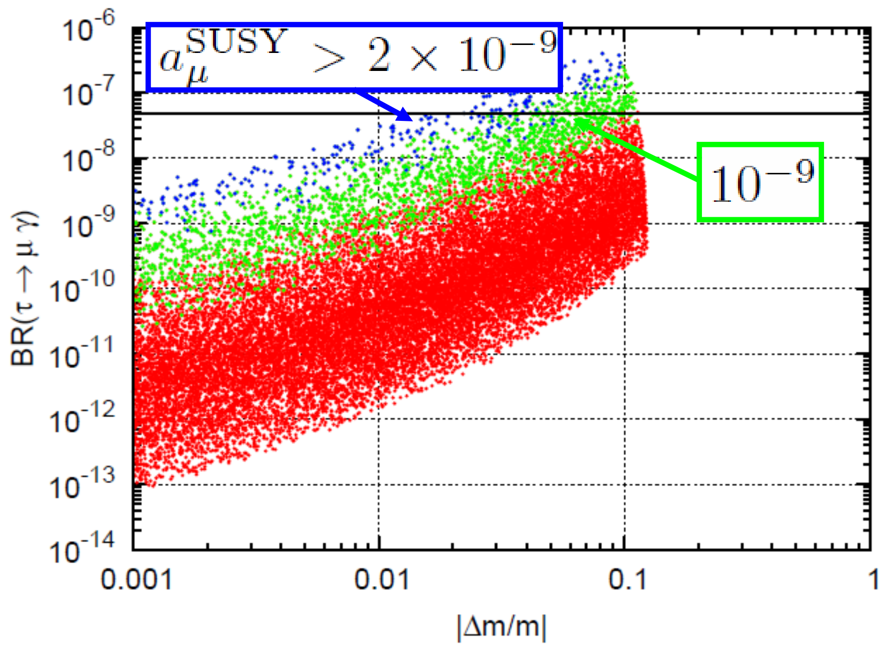


$$\tan\beta = 10, \; A_0 = 0 \quad m_0, M_{1/2} \leq 1 \text{ TeV}$$

$$m_{\tilde{e}} \; , m_{\tilde{\mu}} \; < m_{\tilde{\chi}_2^0}$$

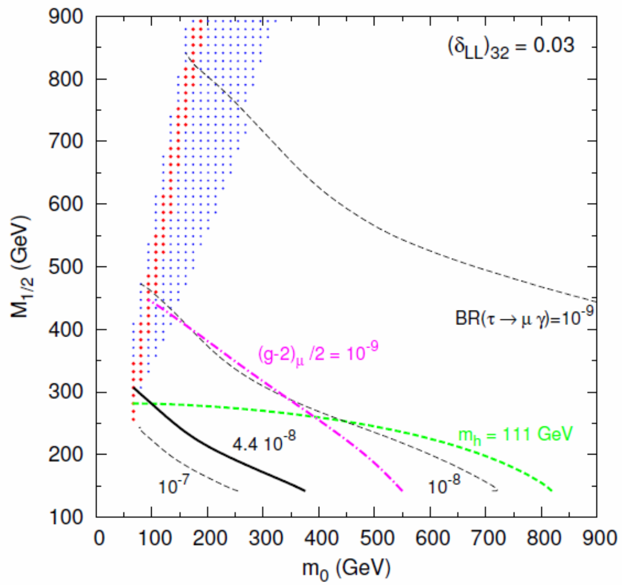
Enhancement factor in the edge splitting:

- always enhanced (*at least* ~3) in the LL case
- enhancement or suppression (>1/3) in the RR case

Results

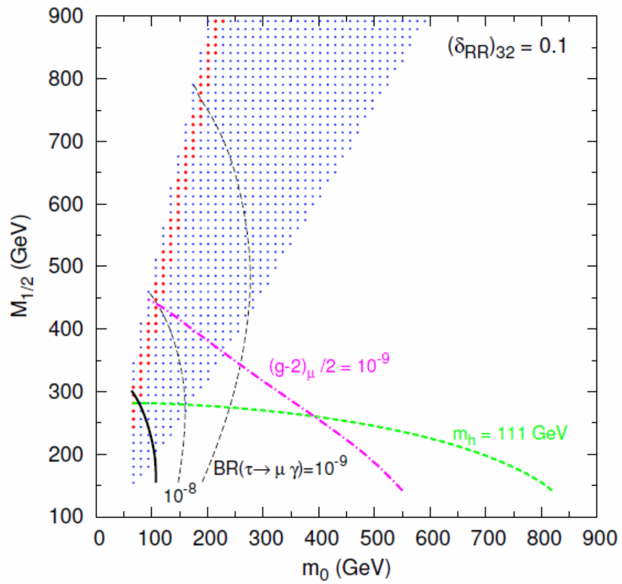
$$\boxed{(\delta_{\rm LL})_{32} \;=\; 0.03}$$

$(\Delta m_{\tilde\ell}/m_{\tilde\ell})_L$ around 1-1.5 %



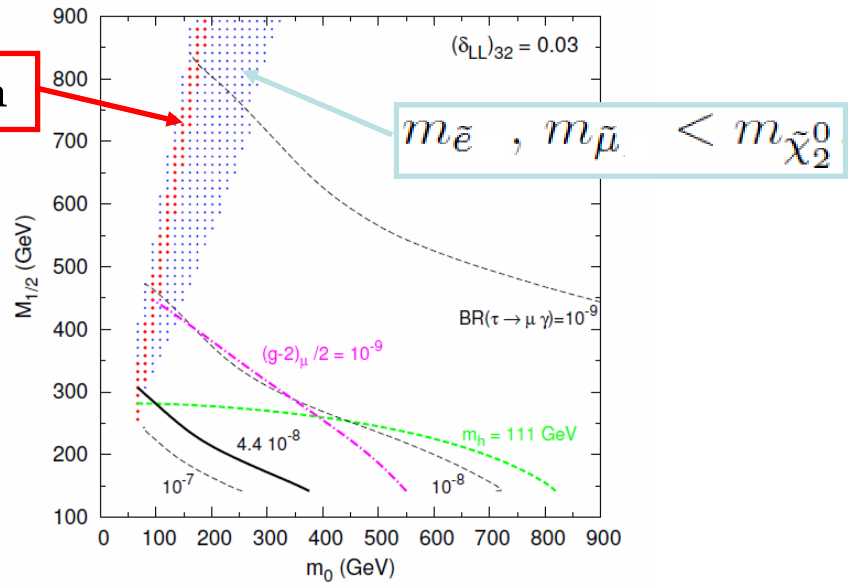
$$\boxed{(\delta_{\rm RR})_{32} = 0.1}$$

$2\% \lesssim (\Delta m_{\tilde\ell}/m_{\tilde\ell})_R \lesssim 4\%$



Results

Coannihilation



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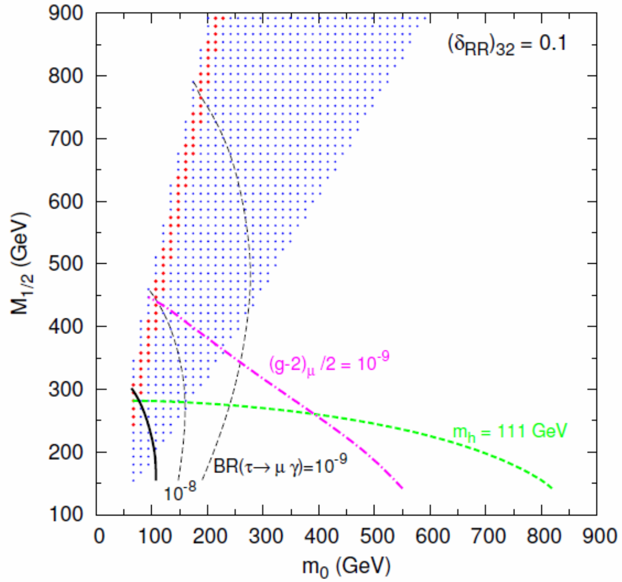
$(\Delta m_{\tilde{\ell}}/m_{\tilde{\ell}})_L$ around 1-1.5 %



$(\delta_{RR})_{32} = 0.1$

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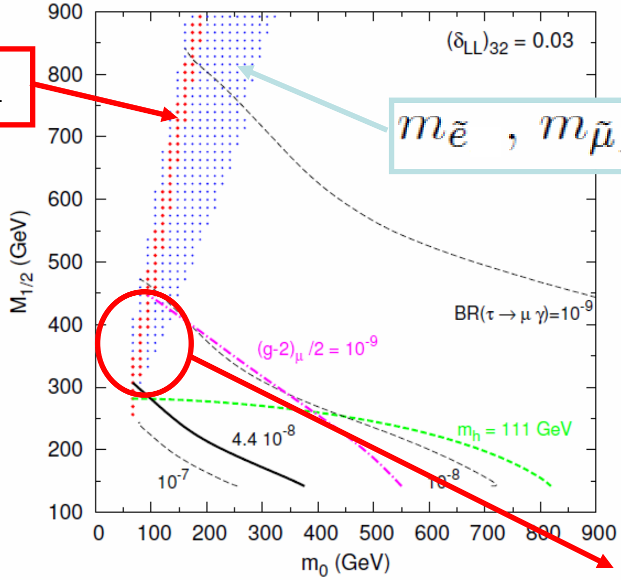
Results

Coannihilation

$m_{\tilde{e}}\ ,\ m_{\tilde{\mu}}\ < m_{\tilde{\chi}^0_2}$

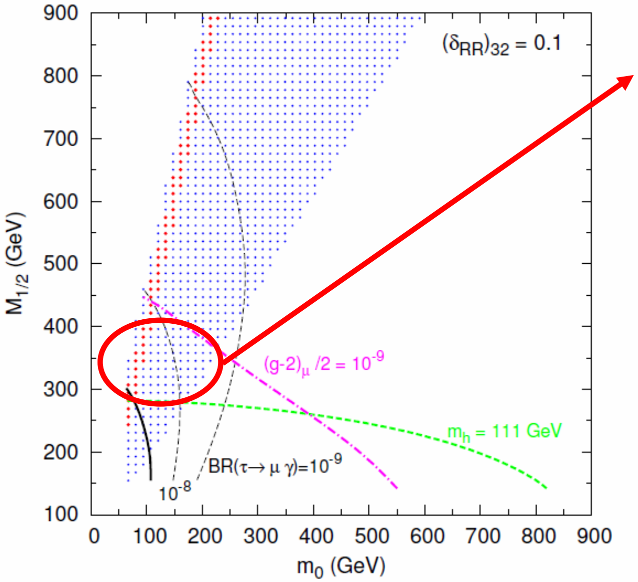


$(\delta_{\rm LL})_{32}\ =\ 0.03$

$(\Delta m_{\tilde{\ell}}/m_{\tilde{\ell}})_L$ around 1-1.5 %

At the same time:

- selectrons ans smuons produced in cascade decays
- $\mathrm{BR}(\tau\ \to\ \mu\gamma)\ >\ 10^{-8}$ (Super-KEK-B)
- $(g\text{-}2)_\mu$ tension below 2σ
- WMAP bound from coann.



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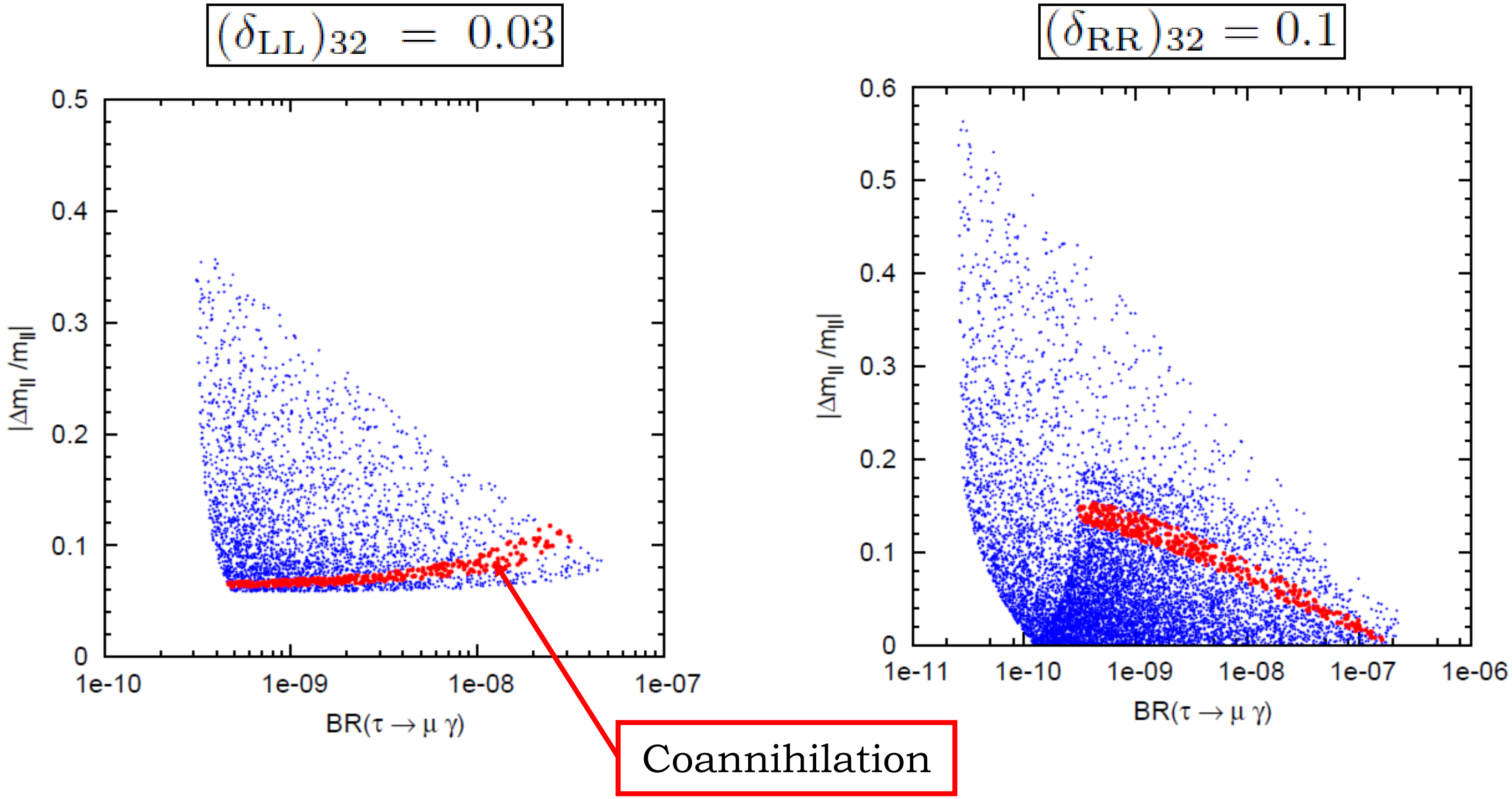
Splitting of the di-muon and di-electron distributions edges:



Results

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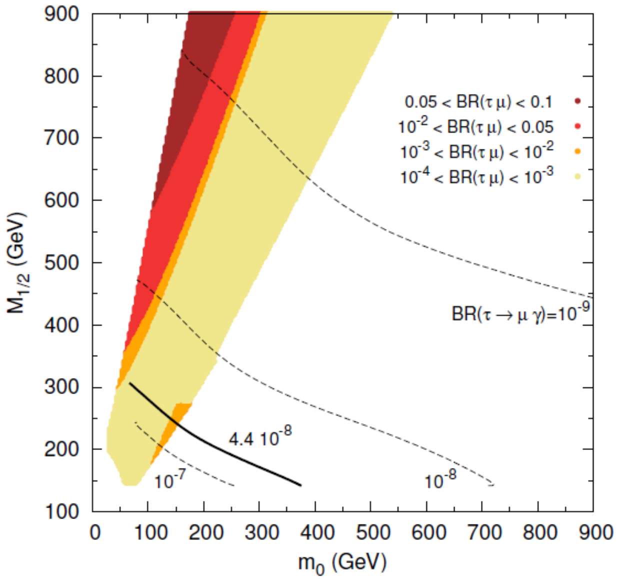
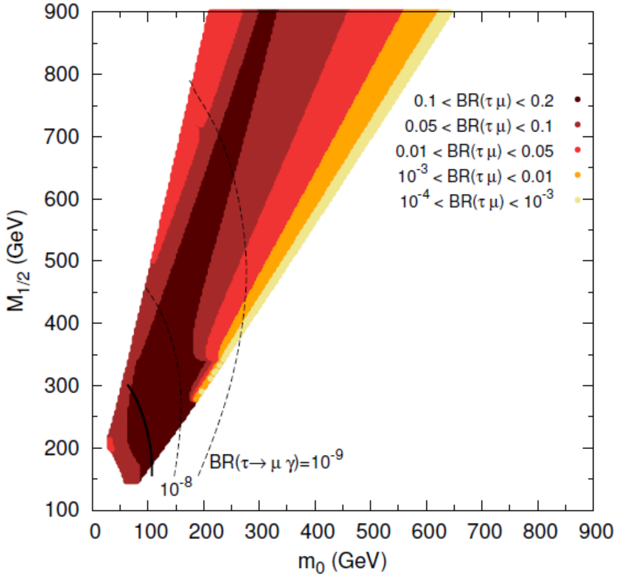
$(\Delta m_{\tilde{\ell}}/m_{\tilde{\ell}})_L$ around 1-1.5 %



$$\mathrm{BR}(\tilde{\chi}^0_2 \to \tilde{\chi}^0_1 \tau^\pm \mu^\mp)$$

$$(\delta_{RR})_{32} = 0.1$$

$$2\% \lesssim (\Delta m_{\tilde{\ell}}/m_{\tilde{\ell}})_R \lesssim 4\%$$



Results

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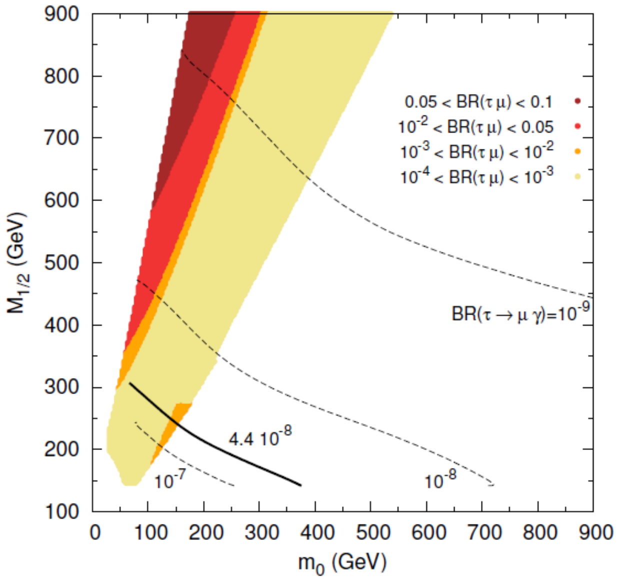

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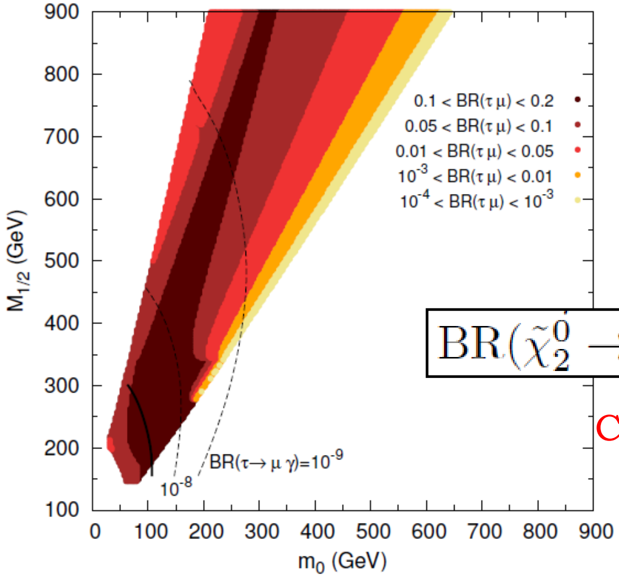


Good prospects at the LHC if:

$$\boxed{\mathrm{BR}(\tilde{\chi}^0_2 \to \tilde{\chi}^0_1 \tau\mu)/\mathrm{BR}(\tilde{\chi}^0_2 \to \tilde{\chi}^0_1 \tau\tau) \gtrsim 0.1}$$

Carvalho et al.'02, Carquin et al. '08

Conclusions

• We considered a mSUGRA SUSY breaking scenario, in which selectrons and smuons are predicted to be highly degenerate (in absence of LFV)

• Any evidence of a sizeable splitting between selectron and smuon masses points towards either a different SUSY breaking mechanism or different realizations of mSUGRA: we considered the case of LFV-induced splitting

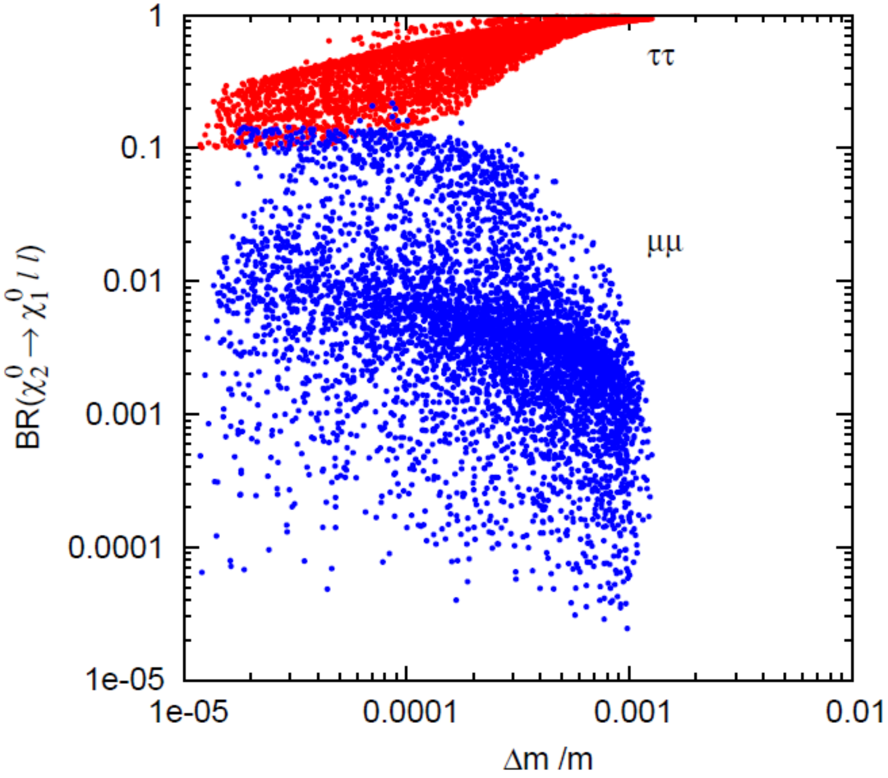
• Mixing between *second* and *third* generation sleptons can induce sizeable (and measurable at the LHC) mass-splittings between first and second generation sleptons

• Processes such as $\tau \to \mu\gamma$ and $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 \tau^\pm \mu^\mp$ can be detectable and help to shed light on the origin of the mass-splitting

⇨ nice example of the inteplay between *high-energy* and *high-intensity* (low-energy) frontier experiments

Additional transparencies

Lepton flavour conserving case



$$m_0, M_{1/2} \leq 1 \text{ TeV}$$

$$-3 \leq a_0 \leq +3$$

$$\tan\beta \leq 50$$

Signals and backgrounds estimates

$$\sigma_{ee} \equiv \sigma(\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 e^+ e^-) = \sigma_{\tilde{\chi}_2^0} \times \mathrm{BR}(\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 e^+ e^-)$$
$$\sigma_{\mu\mu} \equiv \sigma(\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 \mu^+ \mu^-) = \sigma_{\tilde{\chi}_2^0} \times \mathrm{BR}(\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 \mu^+ \mu^-)$$
$$\sigma_{\tau\mu} \equiv \sigma(\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 \tau^\pm \mu^\mp) = \sigma_{\tilde{\chi}_2^0} \times \mathrm{BR}(\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 \tau^\pm \mu^\mp)$$

	σ_{SUSY}	σ_{ee}	$\sigma_{\mu\mu}$	$\sigma_{\tau\mu}$	$\lvert\Delta m_{\tilde{l}}/m_{\tilde{l}}\rvert$	$\lvert\Delta m_{ll}/m_{ll}\rvert$	a_μ^{SUSY}	$\mathrm{BR}(\tau \to \mu\gamma)$
Point A	5.2 pb	63 fb	43 fb	24 fb	1.1 %	10 %	1.2×10^{-9}	1.7×10^{-8}
Point B	1.8 pb	32 fb	18 fb	15 fb	1.3 %	7.6 %	8.0×10^{-10}	7.3×10^{-9}
Point C	9.7 pb	62 fb	49 fb	110 fb	2.7 %	4.9 %	1.5×10^{-9}	2.4×10^{-8}
Point D	18.2 pb	169 fb	91 fb	536 fb	3.0 %	6.2 %	1.6×10^{-9}	1.3×10^{-8}

Signals and backgrounds estimates

$$
\begin{aligned}
B_{\ell^+\ell^-}^{\tilde\chi^+\tilde\chi^-} = \; & \sigma_{\tilde\chi^+\tilde\chi^-} \times \epsilon_\ell^2 \times \epsilon_{\rm cut} \times L \times \\
& \times \Big[{\rm BR}(\tilde\chi_1^\pm \to \tilde\nu \ell^\pm) + \\
& + {\rm BR}(\tilde\chi_1^\pm \to \tilde\ell^\pm \nu)\, {\rm BR}(\tilde\ell^\pm \to \ell^\pm \tilde\chi^0) + \\
& + {\rm BR}(\tilde\chi_1^\pm \to W^\pm \tilde\chi^0)\, {\rm BR}(W^\pm \to \ell^\pm \nu) \Big]^2 ,
\end{aligned}
$$

	$S_{\mu^+\mu^-}$	$B_{\mu^+\mu^-}^{(\tilde\chi^+\tilde\chi^-)}$	$B_{\mu^+\mu^-}^{(\tau\tau)}$	$B_{\mu^+\mu^-}^{(\tau\mu)}$	$S_{e^+e^-}$	$B_{e^+e^-}^{(\tilde\chi^+\tilde\chi^-)}$	$B_{e^+e^-}^{(\tau\tau)}$	$S_{\tau\mu}$	$B_{\tau\mu}^{(\tilde\chi^+\tilde\chi^-)}$	$B_{\tau\mu}^{(\tau\tau)}$	$\frac{{\rm BR}(\tau\mu)}{{\rm BR}(\tau\tau)}$
Point A	850	0.65 $S_{\mu^+\mu^-}$	0.12 $S_{\mu^+\mu^-}$	0.09 $S_{\mu^+\mu^-}$	1275	0.44 $S_{e^+e^-}$	0.09 $S_{e^+e^-}$	490	1.15 $S_{\tau\mu}$	1.3 $S_{\tau\mu}$	0.12
Point B	364	0.64 $S_{\mu^+\mu^-}$	0.07 $S_{\mu^+\mu^-}$	0.14 $S_{\mu^+\mu^-}$	648	0.35 $S_{e^+e^-}$	0.04 $S_{e^+e^-}$	307	0.82 $S_{\tau\mu}$	0.53 $S_{\tau\mu}$	0.32
Point C	992	0.48 $S_{\mu^+\mu^-}$	0.19 $S_{\mu^+\mu^-}$	0.38 $S_{\mu^+\mu^-}$	1255	0.38 $S_{e^+e^-}$	0.15 $S_{e^+e^-}$	1126	0.21 $S_{\tau\mu}$	0.5 $S_{\tau\mu}$	0.34
Point D	1842	0.16 $S_{\mu^+\mu^-}$	0.45 $S_{\mu^+\mu^-}$	1.02 $S_{\mu^+\mu^-}$	3822	0.09 $S_{e^+e^-}$	0.24 $S_{e^+e^-}$	10974	0.03 $S_{\tau\mu}$	0.44 $S_{\tau\mu}$	0.38

TABLE III: Expected number of signal and background events for the relevant flavour conserving and violating channels. The estimate has been done taking for the integrated luminosity $L = 100$ fb^{-1}.