LFV at Colliders

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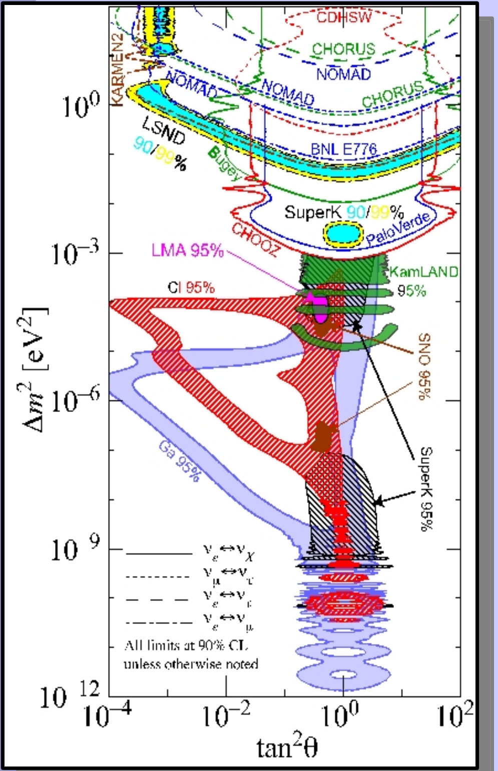
Introduction

- SUSY Seesaw
  - LFV at LHC
    - Neutralino Decays
    - Drell-Yan Slepton-Pair Production
    - Tau decays
  - LFV at ILC
    - Slepton-Pair Production
    - $e\gamma$-Collider Option
  - Correlation/Complementarity to rare processes
- Variations/Alternatives
- Conclusions

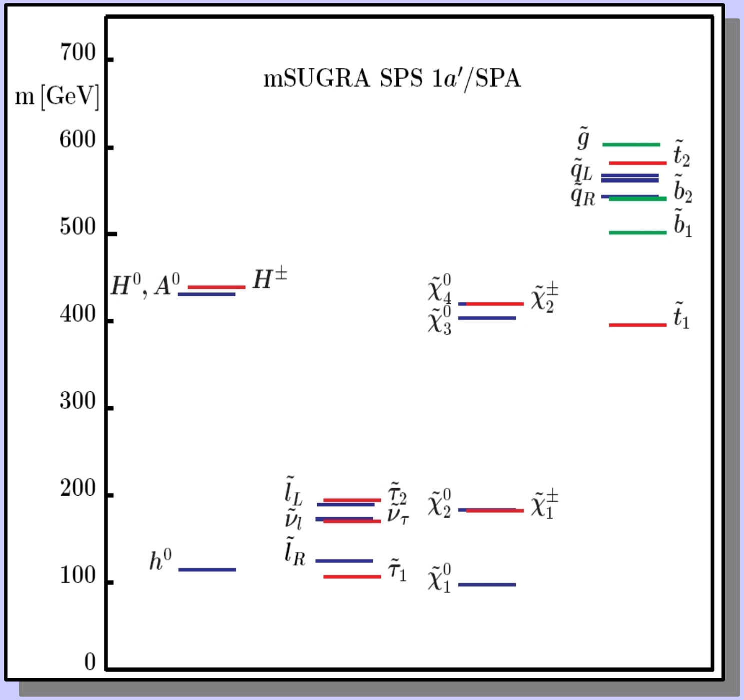
SUSY Seesaw

mSUGRA constrained MSSM with R-parity conservation



Neutrino oscillations
⇒ neutrinos have masses and lepton flavor is violated

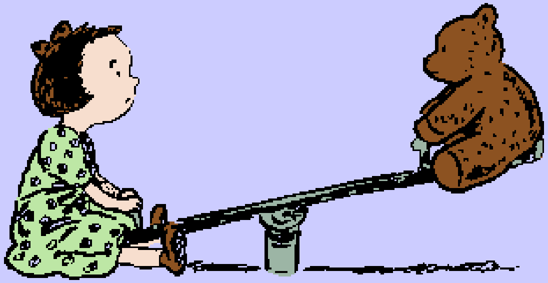
Absolute neutrino mass $\boxed{m_{\nu_1} < 0.5\,\mathrm{eV}}$ **(Cosmology, 0νββ)**
⇒ much lighter than other fermions



Add heavy right-handed neutrinos, Seesaw Type I:

$$W = W_{\mathrm{MSSM}} - \frac{1}{2}\hat{\nu}_R^{cT} M_R \hat{\nu}_R^c + \hat{\nu}_R^{cT} Y_\nu \hat{L}\cdot\hat{H}_u$$

$$m_\nu \approx 0.1\,\mathrm{eV}\left(\frac{m_D}{100\,\mathrm{GeV}}\right)^2\left(\frac{M_R}{10^{14}\,\mathrm{GeV}}\right)^{-1}$$



Susy Seesaw Teddy

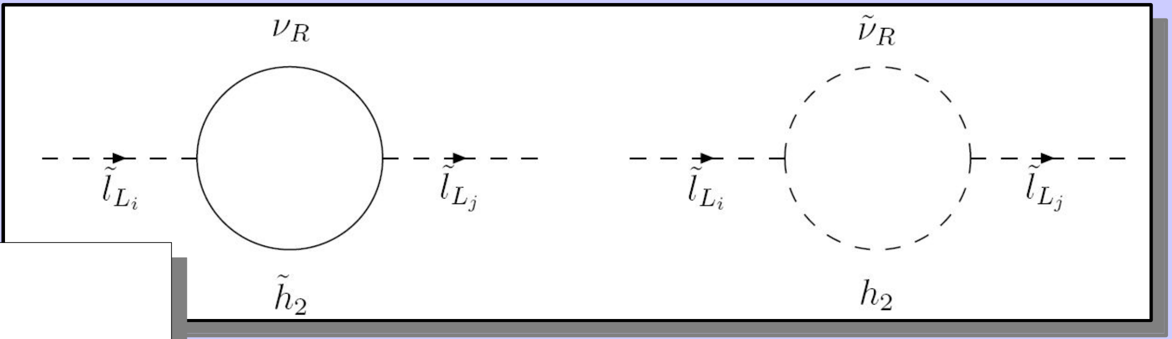
Rare LFV Decays

- Current bounds and future sensitivities

	Current bounds		and future sensitivities
Br($\mu\to e\gamma$)	$< 1.2\cdot 10^{-11}$	(MEGA)	10^{-13} (MEG)
Br($\tau\to\mu\gamma$)	$< 3.1\cdot 10^{-7}$	(Belle)	10^{-8} (Super-B Factory, LHC?)
Br($\tau\to e\gamma$)	$< 3.7\cdot 10^{-7}$	(BaBar)	10^{-8} (Super-B Factory)
R($\mu\, N\to e\, N$)	$< 7\cdot 10^{-13}$	(Sindrum)	10^{-18} (PRIME) (μ–e conversion in nuclei)

  - $\mu\to 3e$, $\tau\to 3\mu$ (LHC), $Z\to\mu\tau$ (LHC)

- SUSY Seesaw
  - Neutrino flavor mixing radiatively induces slepton flavor mixing from M_{GUT} to the right-handed neutrino mass scales



$$\left(\delta m^2_{\tilde{L}}\right)_{ij} = \frac{-1}{8\pi^2}\left(3m_0 + A_0\right)\left(Y_\nu^+ L Y_\nu\right)_{ij}$$

$$\left(\delta m^2_{\tilde{R}}\right)_{ij} = 0 \qquad L = \log\left(\frac{M_{GUT}}{M_{\nu_{Ri}}}\right)\delta_{ij}$$

$$\left(\delta m^2_{\tilde{L}\tilde{R}}\right)_{ij} = \frac{-3A_0}{8\pi^2} Y_e \left(Y_\nu^+ L Y_\nu\right)_{ij}$$

Rare LFV Decays

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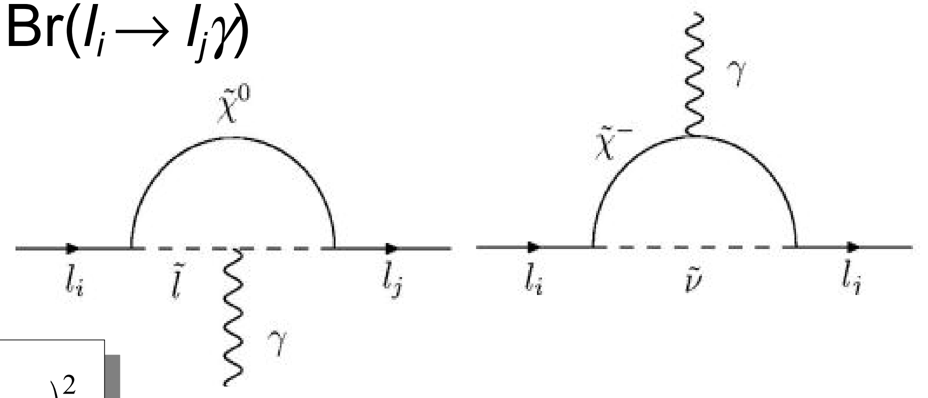
Br($l_i\to l_j\gamma$)



$$Br(\mu\to e\gamma)\approx\frac{\alpha^3\tan^2\beta}{\tilde m^8}\frac{m_\mu^5}{\Gamma_\mu}\left|\left(\delta m^2_{\tilde L}\right)_{12}\right|^2\propto\left(Y_\nu^+ L\, Y_\nu\right)^2_{12}$$

LFV at LHC

LFV Neutralino and Slepton Decays

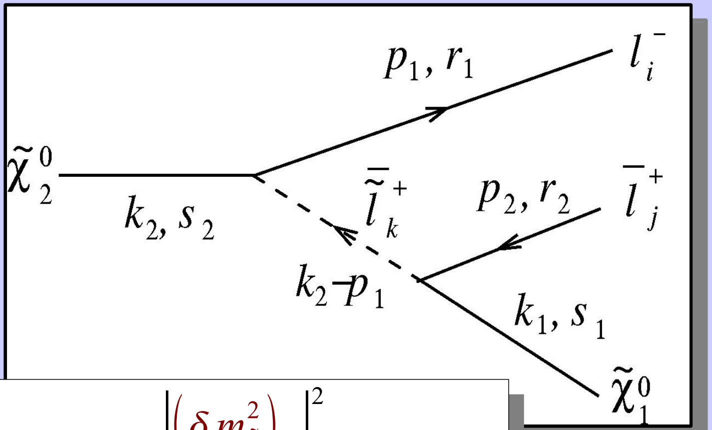
- Squark and gluino production

$$pp \to \tilde{q}\,\tilde{q}\,,\tilde{g}\,\tilde{q}\,,\tilde{g}\,\tilde{g}$$

- ... followed by cascade decays via second lightest neutralino

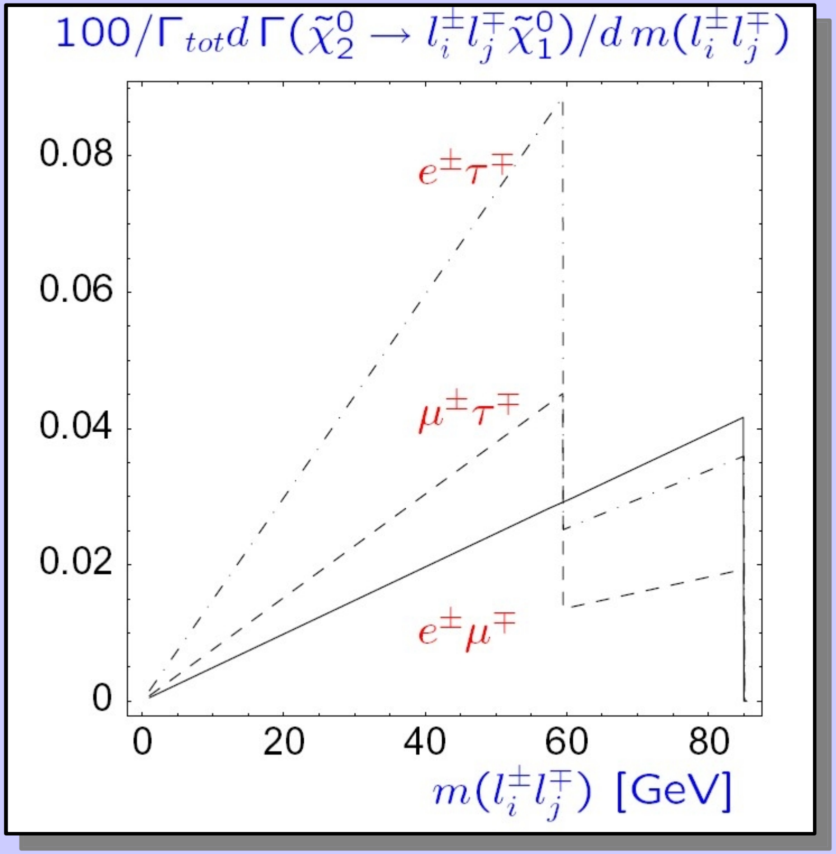
$$\tilde{q}(\tilde{g}) \to \tilde{\chi}_2^0 q(g)$$

- ... followed by LFV decay via sleptons (Agashe/Graesser, Hisano et al., Bartl et al., Hinchliffe/Paige, Carvalho et al., Andreev et al.)



$$Br(\tilde{\chi}_2^0 \to \mu^- e^+ \tilde{\chi}_1^0) \propto \frac{\left|\left(\delta m_{\tilde{L}}^2\right)_{12}\right|^2}{m_{\tilde{l}}^2 \Gamma_{\tilde{l}}^2} Br(LFC)$$

- Edge structure of di-lepton invariant mass distribution



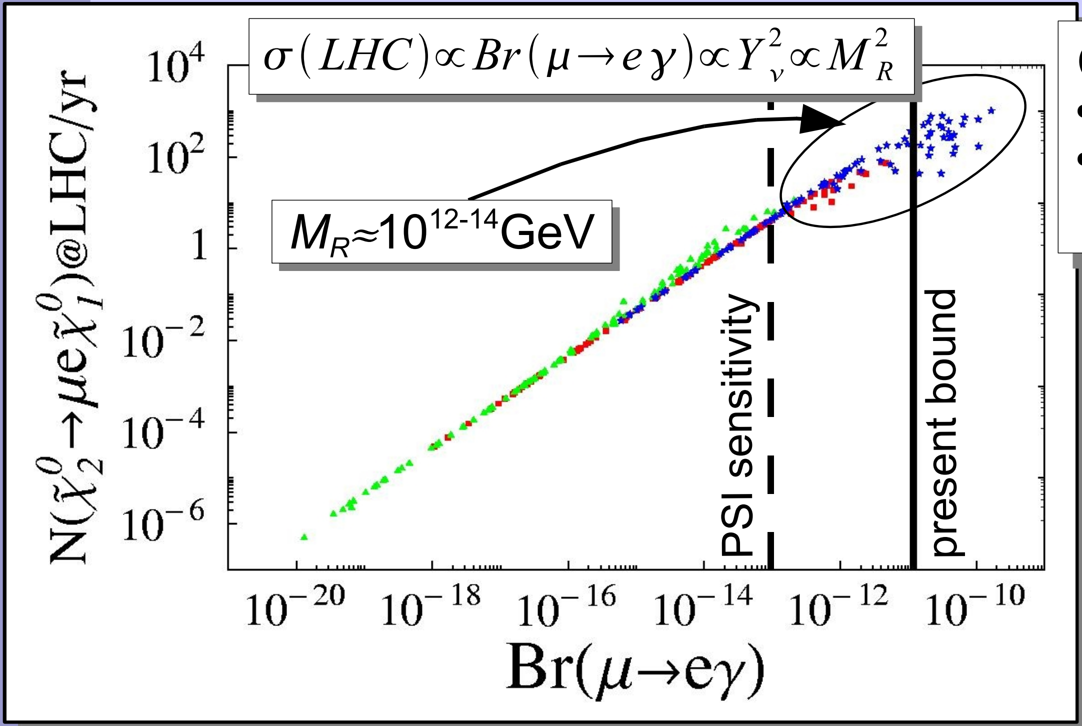
Bartl et al, hep-ph/0510074

- Reach:

$$Br(\tilde{\chi}_2^0 \to \mu\, e\, \tilde{\chi}_1^0) = 2-4\%\,,\ L = 30\,\mathrm{fb}^{-1}$$

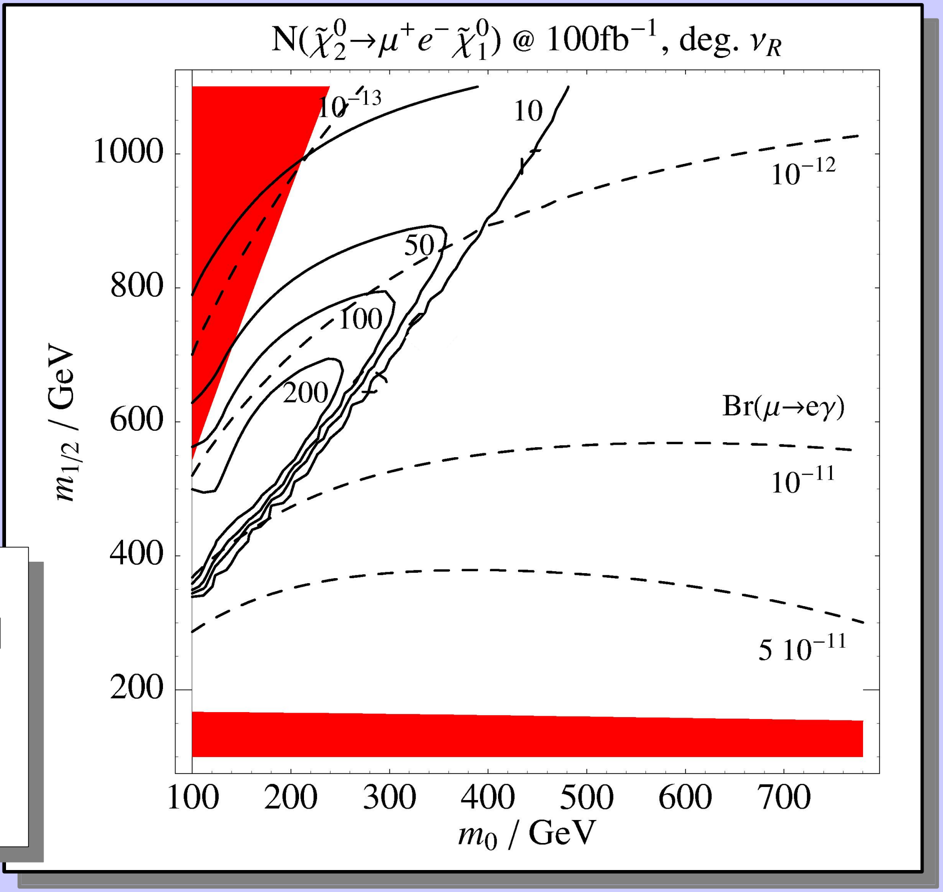
LFV at LHC

LFV Neutralino and Slepton Decays



Correlation with Br($\mu\to e\gamma$)

- Fixed mSUGRA scenario: SPS1a
- Variation of neutrino parameters, **deg L/R**, **hier L/R** and **hier L/deg R** neutrinos

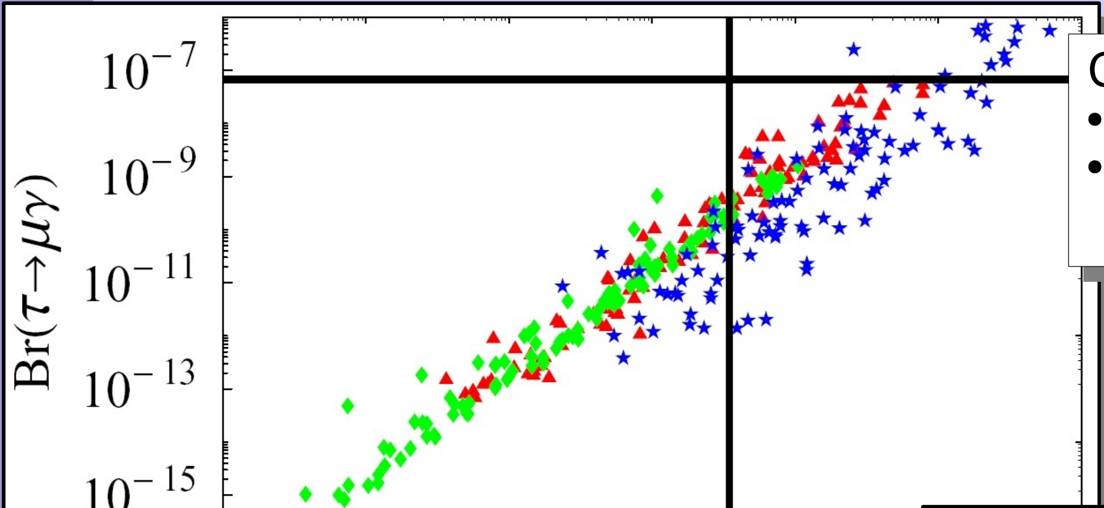


Comparing sensitivity reach

- Fixed neutrino parameters: hierarchical light, degenerate heavy: $M_R = 10^{14}$ GeV
- Variation of $m_{1/2}$, m_0 ($A_0 = 0$, $\tan\beta = 10$, signμ = +)

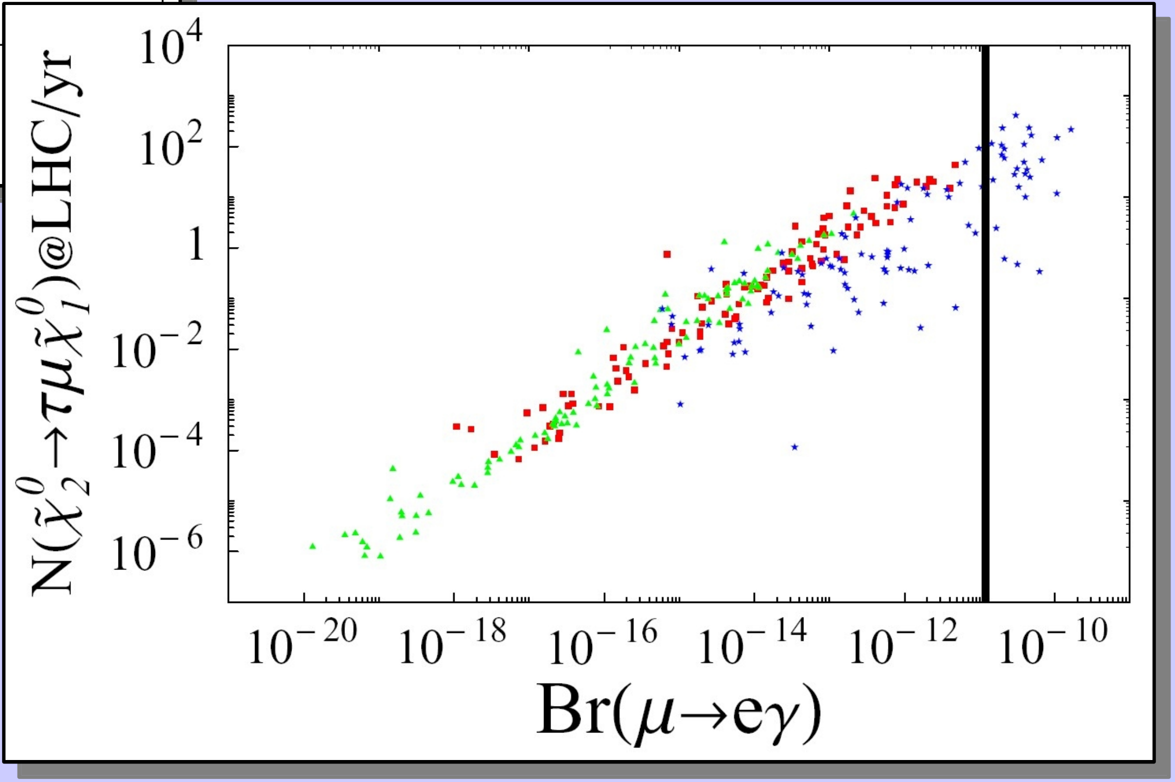
LFV at LHC

LFV Neutralino and Slepton Decays



Comparison of different flavor combinations

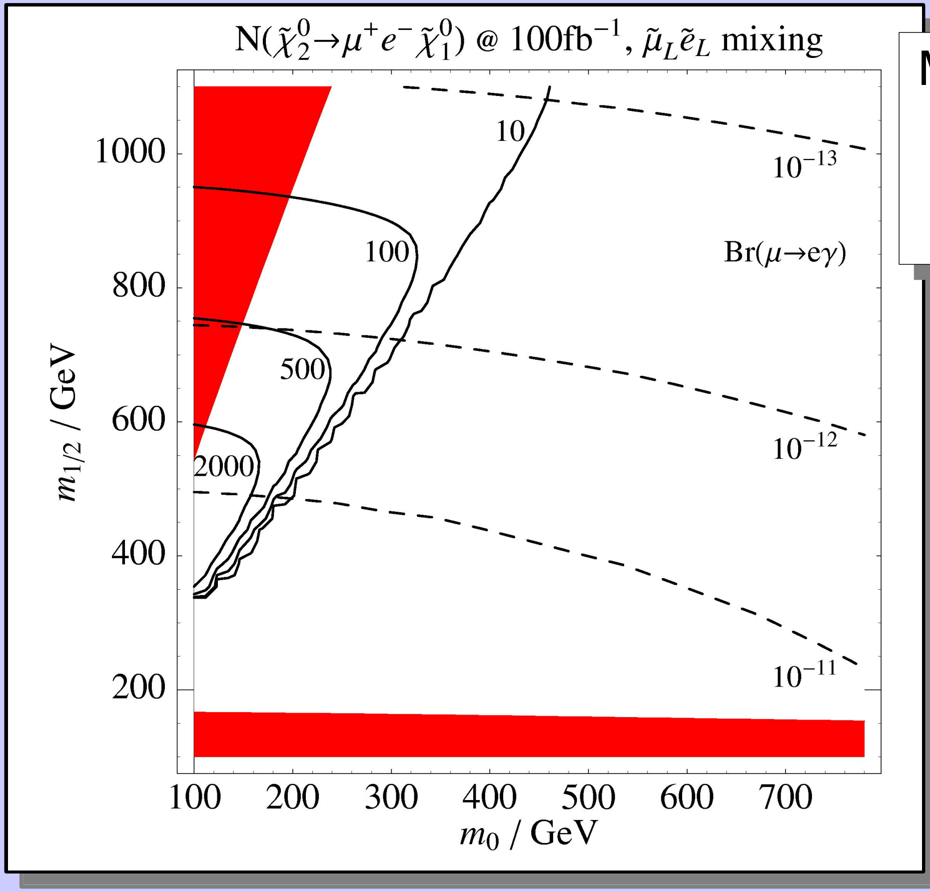
- Fixed mSUGRA scenario: SPS1a
- Variation of neutrino parameters, **deg L/R**, **hier L/R** and **hier L/deg R** neutrinos



Within SUSY Seesaw, $Br(\mu\to e\gamma)$ can be a more stringent bound on $Br(\tilde{\chi}_2^0\to\tau\mu\tilde{\chi}_1^0)$ than $Br(\tau\to\mu\gamma)$

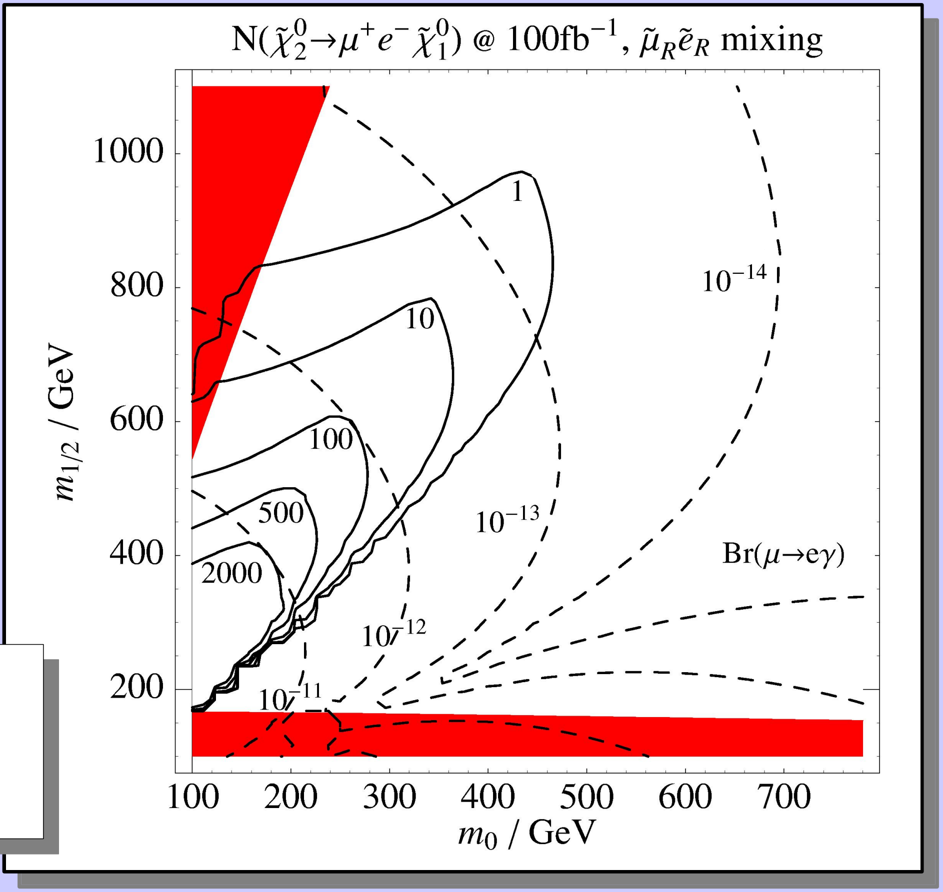
LFV at LHC

General Slepton Mixing (2 Flavor)



Maximal left-handed slepton mixing (2 flavor)

$$\begin{pmatrix}\tilde l_1\\ \tilde l_2\end{pmatrix}=\begin{pmatrix}c_{\theta_L} & s_{\theta_L}\\ -s_{\theta_L} & c_{\theta_L}\end{pmatrix}\cdot\begin{pmatrix}\tilde e_L\\ \tilde\mu_L\end{pmatrix},\ \theta_L=\frac{\pi}{4},\ \Delta\tilde m=1\,\text{GeV}$$



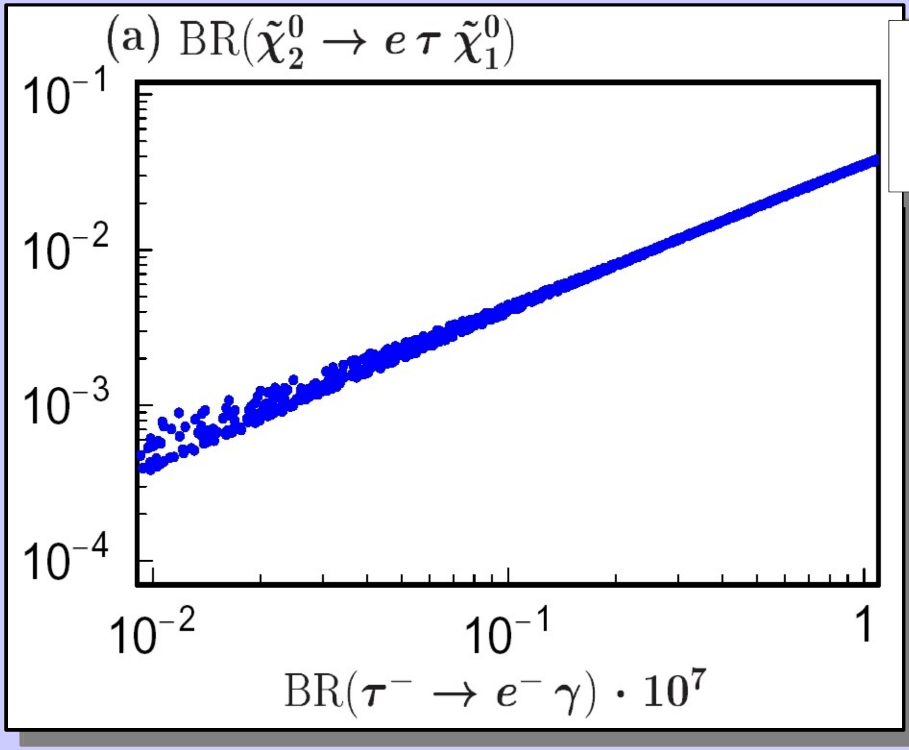
Maximal right-handed slepton mixing

$$\theta_R=\frac{\pi}{4},\ \Delta\tilde m=1\,\text{GeV}$$

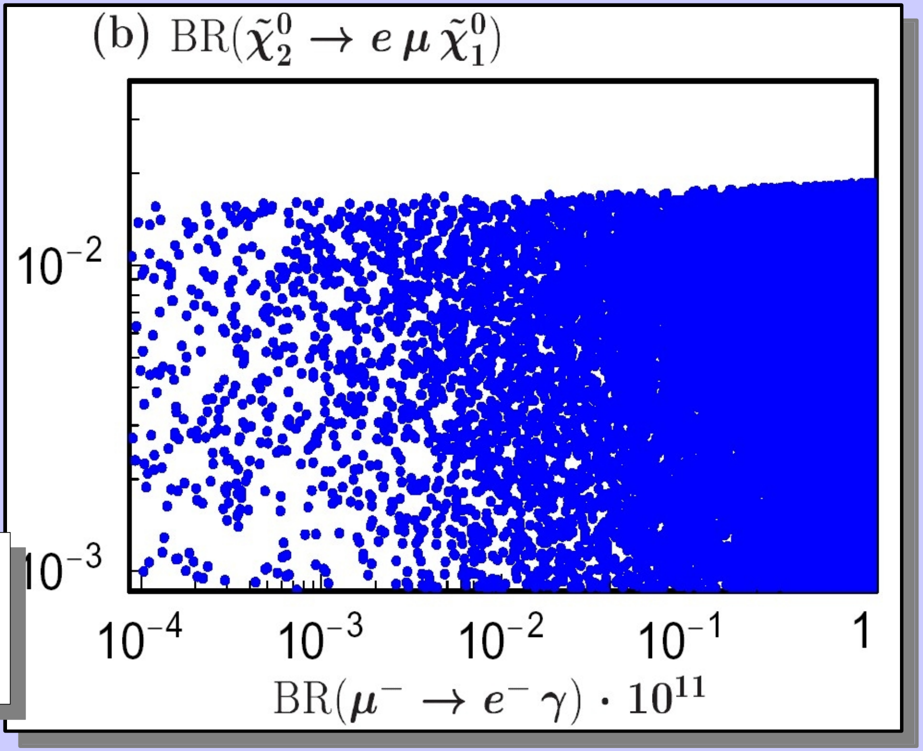
LFV at LHC

General Slepton Mixing (3 Flavor)

- Random variation of right-handed slepton mass matrix, with all experimental limits fulfilled (Bartl et al, hep-ph/0510074)
- Breakdown of mass-insertion approximation



Contribution from $(\delta m^2_{\tilde{R}})^2_{13}$ dominant, $(\delta m^2_{\tilde{R}})_{12}(\delta m^2_{\tilde{R}})_{23}$ strongly constrained



Loss of correlation, $(\delta m^2_{\tilde{R}})_{13}(\delta m^2_{\tilde{R}})_{23}$ can be dominant over $(\delta m^2_{\tilde{R}})^2_{12}$

LFV at LHC

Drell-Yan Slepton-Pair Production

$$pp \rightarrow \tilde{l}_i \tilde{l}_i \rightarrow l_\alpha l_\beta + 2\,\tilde{\chi}_1^0$$

- Signal: di-leptons of different flavour and large missing pT
- Background: ttbar,WW, SUSY
- Generally difficult but could be worthwhile
- Reach for maximal LFV (S. Bityukov/N. Krasnikov, hep-ph/9712358):
  - Slepton mass up to 250GeV
  - LSP mass ≤ 0.5 slepton mass
- Complementary to N2 decays

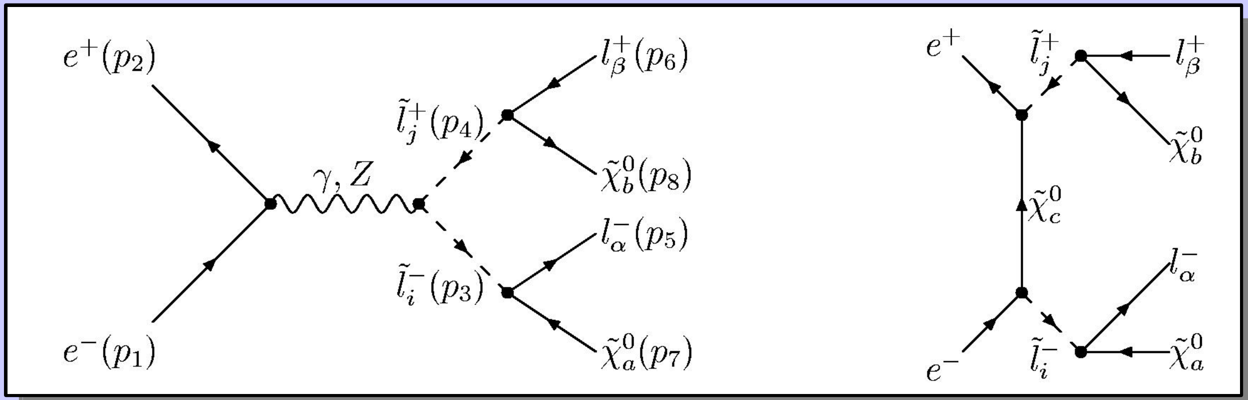
LFV at LHC

Tau decays

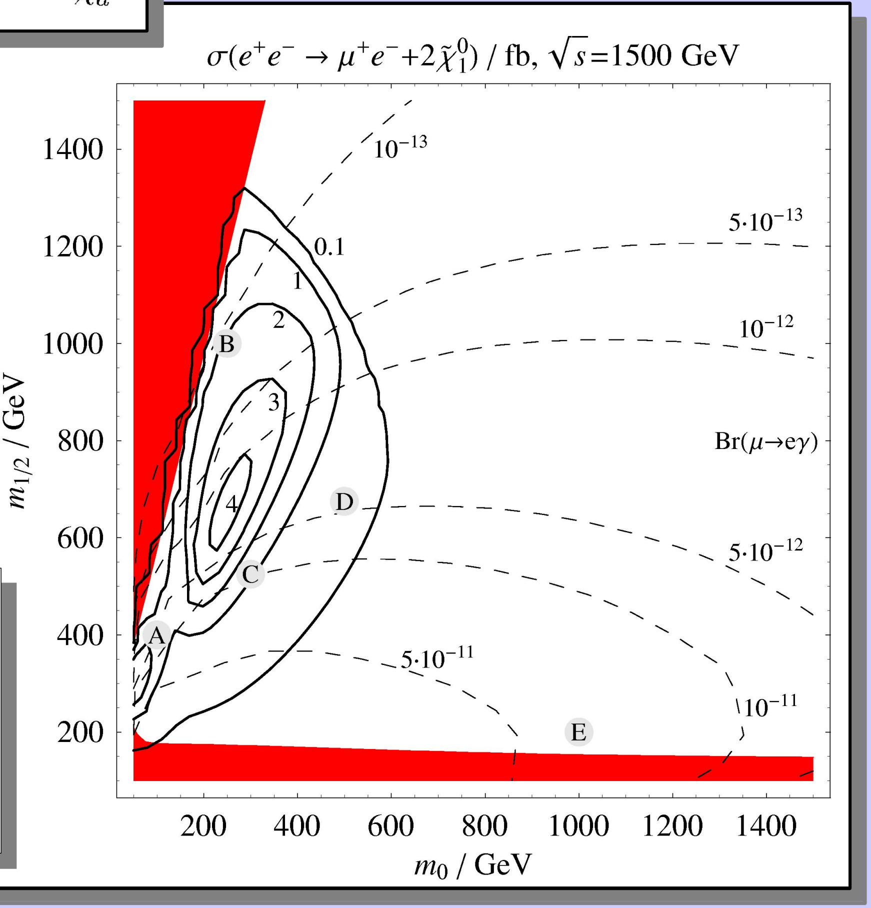
- $\tau \rightarrow \mu\gamma$ (L. Serin and R. Stroynowski (ATL-PHYS-97-114):
  - For 30fb^{-1} data: $Br(\tau \rightarrow \mu\gamma) < 0.6\ 10^{-6}$
- $\tau \rightarrow \mu\mu\mu$ (CMS, Talks by S. Banerjee, M. Giffels):
  - $Br(\tau \rightarrow \mu\mu\mu) < 10^{-10}$

LFV at ILC

Slepton Pair-Production



- 1fb signal $\Rightarrow$ 5σ effect, SPS1a, L=500fb^{-1}
- See Talk by U. Martyn



Comparing sensitivity reach

- Fixed neutrino parameters: hierarchical light, degenerate heavy: M_R = 10^{14} GeV
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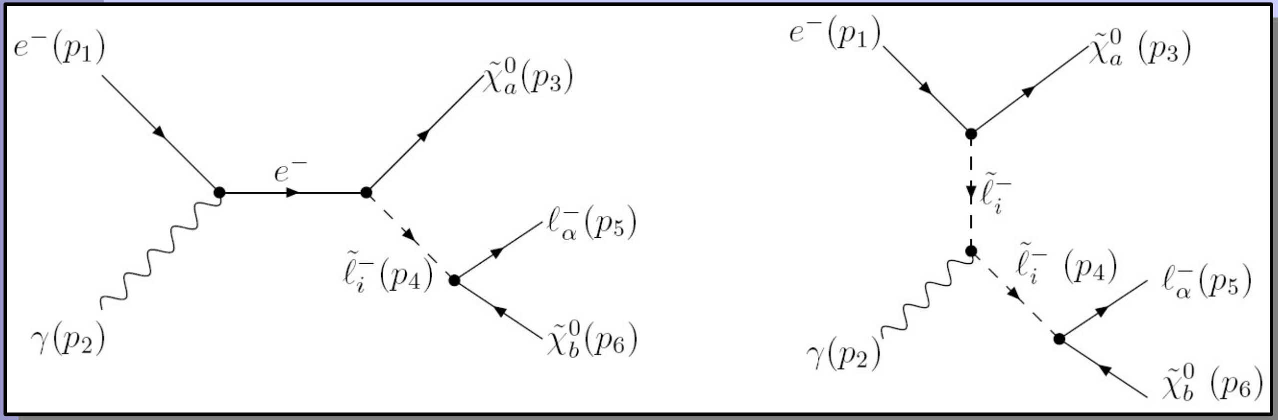
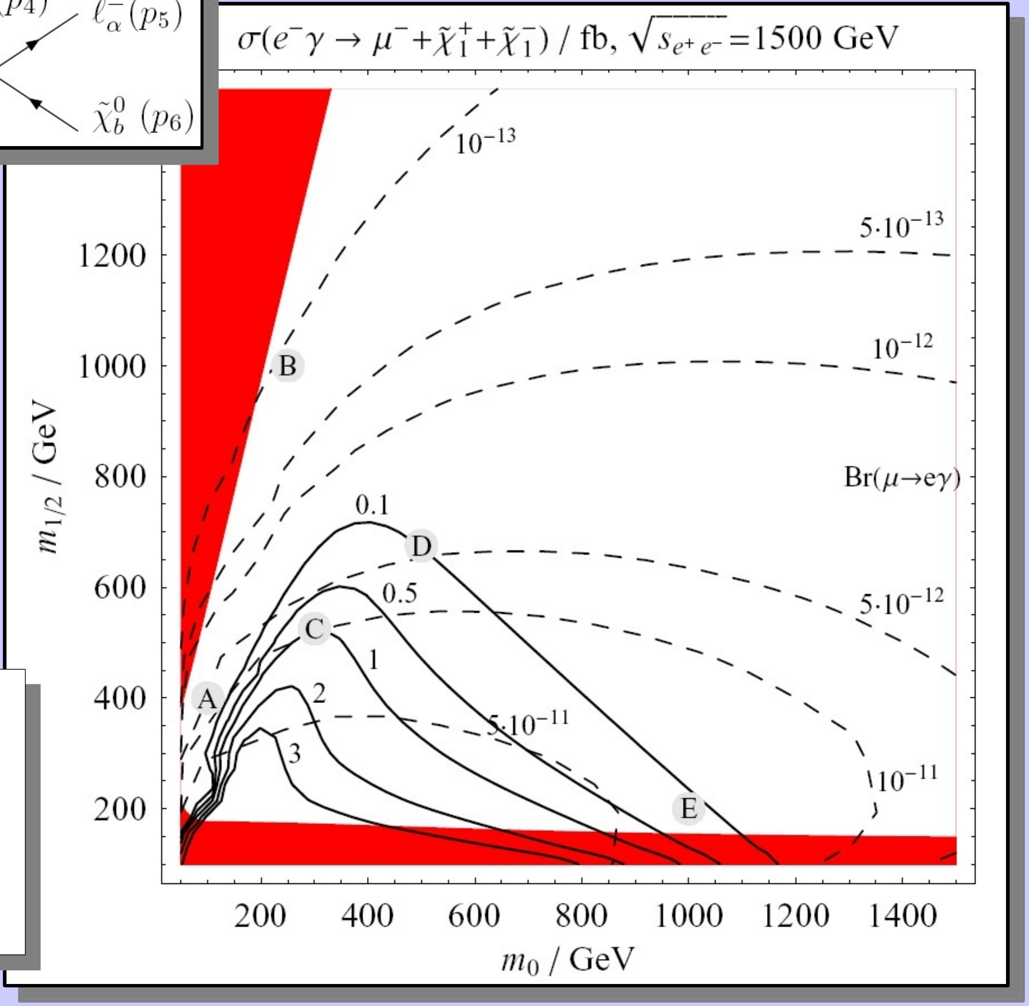
LFV at ILC

Electron-Photon-Collider Option





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Variations/Alternatives

- SO(10) SUSY GUT (e.g. L. Calibbi et al, hep-ph/0605139)
  - more predictive by fixing Y_ν
- Seesaw II (e.g. F. R. Joaquim and A. Rossi, hep-ph/0604083, Talk by A. Rossi)
  - neutrino mass generated by triplet Higgs term
- Long-lived stau NLSP (K. Hamaguchi/A. Ibarra, hep-ph/0412229, WG1)
  - Stau can decay to μ, e in detector
- R-parity violating SUSY (e.g. M. Hirsch et al., hep-ph/0004115, WG1)
  - can serve as neutrino mass generation mechanism
  - true alternative to Seesaw

Conclusion

- SUSY Seesaw as "benchmark" model for LFV
  - Rare decays, e.g. $Br(\mu \to e\gamma)$, and other low energy processes
  - Decays of second lightest neutralino at LHC
  - Slepton pair production at ILC
  - Correlations among these processes and neutrino parameters
- Sensitivity comparison
  - Complementary sensitivity of low and high energy processes
  - Radiative processes have higher mass reach
  - Colliders provide more information (sparticle masses etc.)
- Determination of model parameters
  - e.g. $Br(\mu \to e\gamma) = 10^{-11}$, N(LHC) = 200 $\Rightarrow M_R \approx 10^{12\text{-}14}$ GeV