Slepton Flavour Violation

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Flavour in the Era of the LHC, CERN, Nov 2005

- minimal scenario: MSSM + 3 families of right-handed neutrino singlet fields ν_R
  - superpotential $W \supset W_\nu = \frac{1}{2}\nu_R^{cT} M \nu_R^c + \nu_R^{cT} Y_\nu L \cdot H_2$
  - EWSB $\rightarrow$ Dirac mass $m_D = Y_\nu \langle H_2 \rangle \ll$ Majorana mass scale M_R
  - neutrino mass matrix $\frac{1}{2} \begin{pmatrix} \overline{\nu_L} & \overline{\nu_R^c} \end{pmatrix} \begin{pmatrix} 0 & m_D^T \\ m_D & M \end{pmatrix} \begin{pmatrix} \nu_L^c \\ \nu_R \end{pmatrix}$

light neutrinos: $M_\nu = -m_D^T M^{-1} m_D \sim \frac{\langle H_2 \rangle^2}{M_R}$

heavy neutrinos: $M \sim M_R$

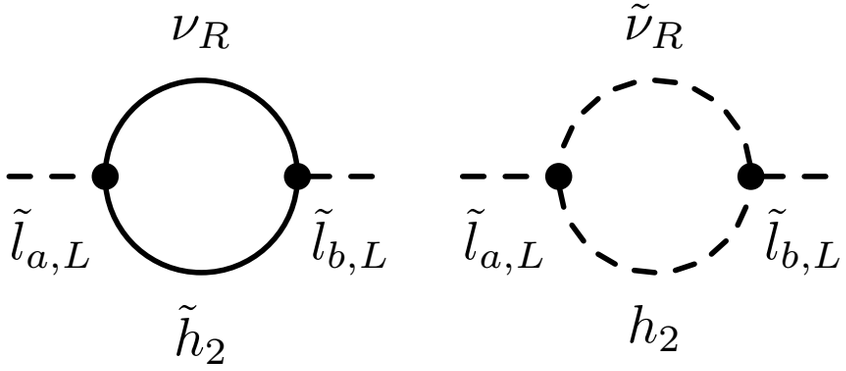
- diagonalization in flavour space

$$\begin{aligned} U^T M_\nu U &= \mathrm{diag}\,(m_1, m_2, m_3) \\ U &= \mathrm{diag}(e^{i\phi_1}, e^{i\phi_2}, 1) V\,(\theta_{12}, \theta_{13}, \theta_{23}, \delta) \end{aligned}$$

masses and mixing angles from experiment

in MSUGRA: $$m^2_{\tilde{l}} = \begin{pmatrix} m^2_{\tilde{l}_L} & m^{2\dagger}_{\tilde{l}_{LR}} \\ m^2_{\tilde{l}_{LR}} & m^2_{\tilde{l}_R} \end{pmatrix} = \tilde{m}^2_{MSSM} + \begin{pmatrix} \delta m^2_L & \delta m^{2\dagger}_{LR} \\ \delta m^2_{LR} & \delta m^2_R \end{pmatrix}$$

flavor non-diagonal terms generated by renormalization from M_{GUT} to M_R



$$\begin{aligned} \delta m^2_L &\simeq -\frac{1}{8\pi^2}(3m_0^2 + A_0^2) Y_\nu^\dagger L Y_\nu \\ \delta m^2_R &\simeq 0 \text{ (model specific)} \\ \delta m^2_{LR} &\simeq -\frac{3A_0}{16\pi^2} Y_l Y_\nu^\dagger L Y_\nu v \cos\beta \end{aligned}$$

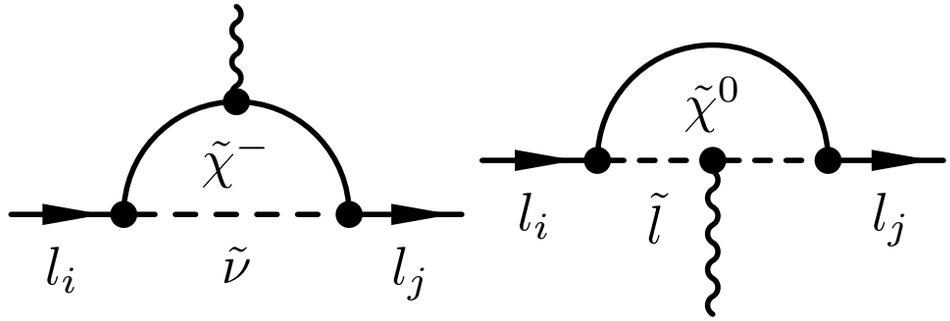
with $L = D\left(\ln(\frac{M_{GUT}}{M_i})\right)$ and

neutrino Yukawa coupling matrix ($R = R^T$ undetermined complex matrix)

$$\boxed{Y_\nu = \frac{1}{v \sin\beta} D\left(\sqrt{M_i}\right) \; R \; D\left(\sqrt{m_j}\right) U^\dagger}$$

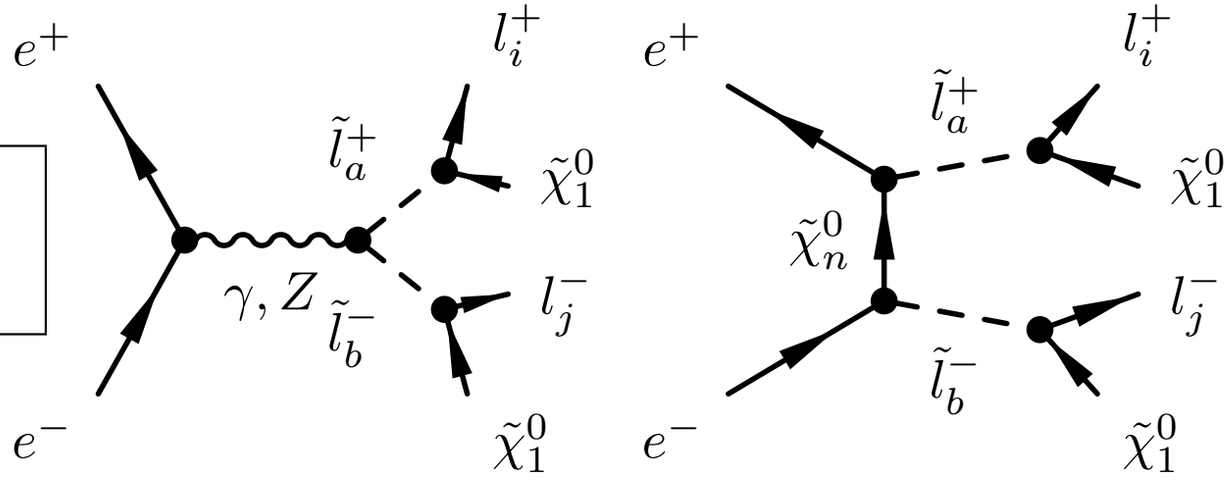
for degenerate M_i and real R: $$Y_\nu^\dagger L Y_\nu = \frac{M_R}{v^2 \sin^2\beta} V \cdot D(m_i) \cdot V^\dagger \ln \frac{M_{GUT}}{M_R}$$

$$\mu \to e\gamma, \tau \to e\gamma, \tau \to \mu\gamma$$



$$\Gamma\left(l_i \to l_j\gamma\right) \propto \alpha^3 m_{l_i}^5 \frac{|\left(\delta m_L\right)_{ij}^2|^2}{\tilde{m}^8} \tan^2\beta \propto M_R^2 \text{ for fixed neutrino masses}$$

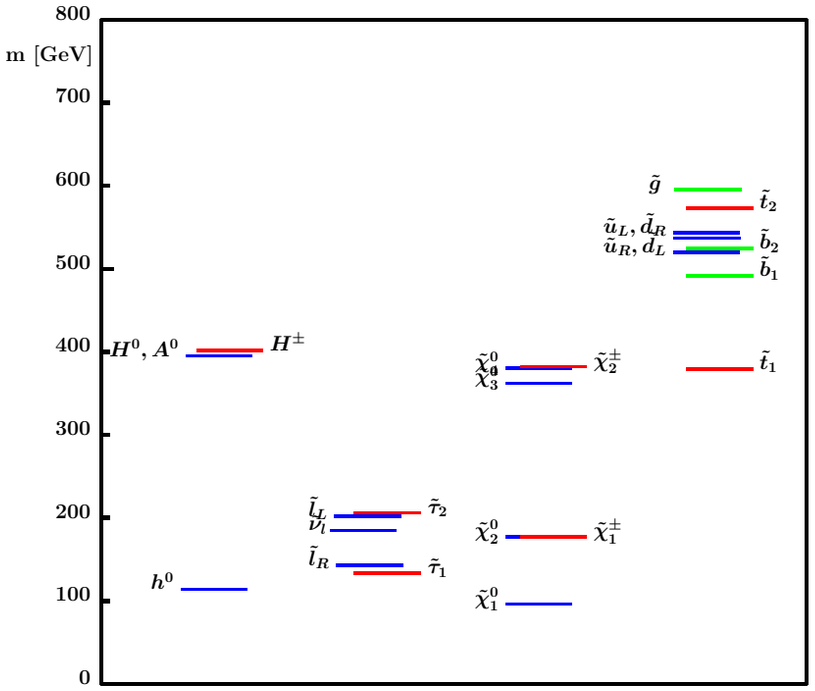
$$e^+e^- \to l_i^+ l_j^- + 2\tilde{\chi}_1^0$$



$$\sigma(l_i^+ l_j^-) \propto \frac{|(\delta m_L)_{ij}^2|^2}{\tilde{m}^2\Gamma_{\tilde{l}}^2} \sigma(e^+e^- \to \tilde{l}_a^+ \tilde{l}_b^-) Br(\tilde{l}_a^+ \to l_i^+ \tilde{\chi}_1^0) Br(\tilde{l}_b^- \to l_j^- \tilde{\chi}_1^0)$$

Scenario	$m_{1/2}$/GeV	m_0/GeV	$\tan\beta$	A_0/GeV	signμ
B’	250	60	10	0	+
C’	400	85	10	0	+
G’	375	115	20	0	+
I’	350	175	35	0	+
SPS1a	250	100	10	-100	+

- MSUGRA benchmark models
  B’,..I’ *(Battaglia et al., hep-ph/0306219)*
  SPS1a *(http://spa.desy.de/spa)*
- universal scalar masses keep LFV small



$$\Delta m^2_{12} = 6.9^{+0.36}_{-0.36} \cdot 10^{-5}\ \mathrm{eV}^2$$

$$\Delta m^2_{13} = 2.6^{+1.2}_{-1.2} \cdot 10^{-3}\ \mathrm{eV}^2$$

$$\tan^2\theta_{12} = 0.43^{+0.47}_{-0.22}$$

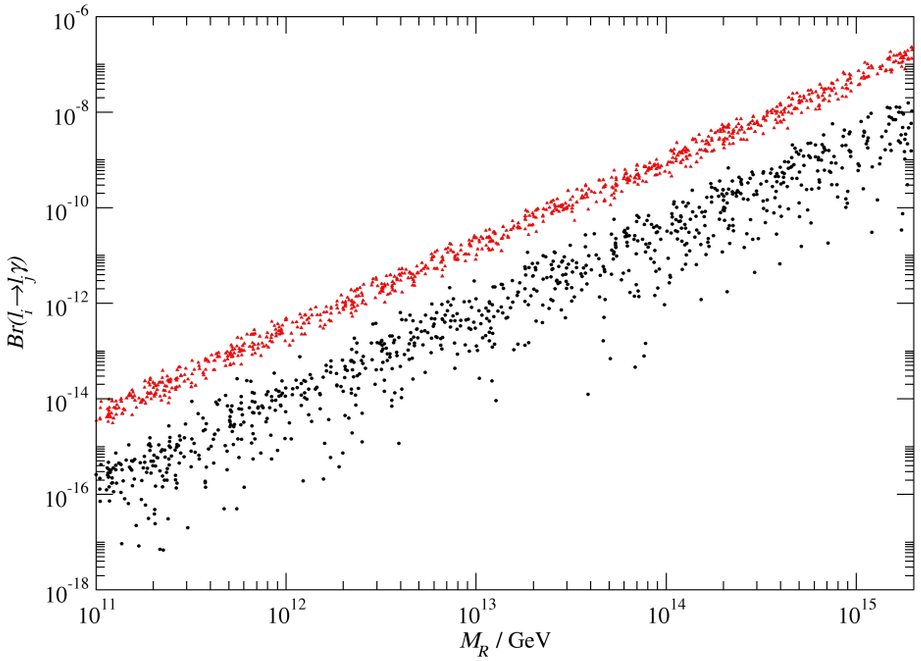
$$\tan^2\theta_{23} = 1.10^{+1.39}_{-0.60}$$

$$\tan^2\theta_{13} = 0.006^{+0.001}_{-0.006}$$

- central values from *M. Maltoni et al., PRD68(2003)113010*
- 90% C.L. errors as anticipated for running/proposed experiments
- Dirac phase unconstrained
- absolute mass scale $m_1 \leq 0.03$ eV
- degenerate Majorana masses, real R-matrix
  $18 \to 8$ parameters $(m_i, \theta_i, \delta, M_R)$

$Br(\mu \to e\gamma)$ and $Br(\tau \to \mu\gamma)$

SUSY scenario SPS1a, uncertainties from neutrino data



related LFV decays:

$$\frac{Br(\tau \to 3\mu)}{Br(\tau \to \mu\gamma)} \simeq 2 \cdot 10^{-3}$$

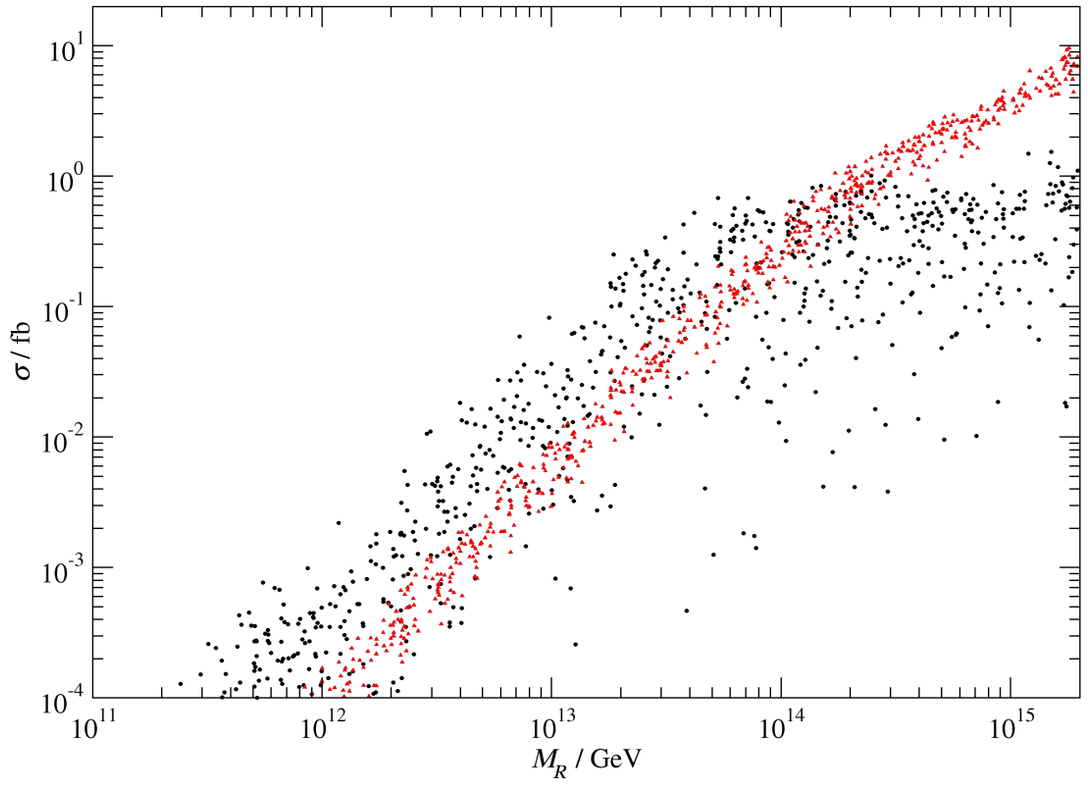
$$\frac{Br(\mu \to 3e)}{Br(\mu \to e\gamma)} \simeq 7 \cdot 10^{-3}$$

$Br(\tau \to \mu\gamma) < 6.8 \cdot 10^{-8}$ (90 % C.L., *BABAR 2005*)

$Br(\mu \to e\gamma) < 1.2 \cdot 10^{-11}$ (90 % C.L., *PDG 2004*)

$$\sigma(e^+e^- \to \mu^+e^-(\tau^+\mu^-) + 2\tilde{\chi}_1^0)$$

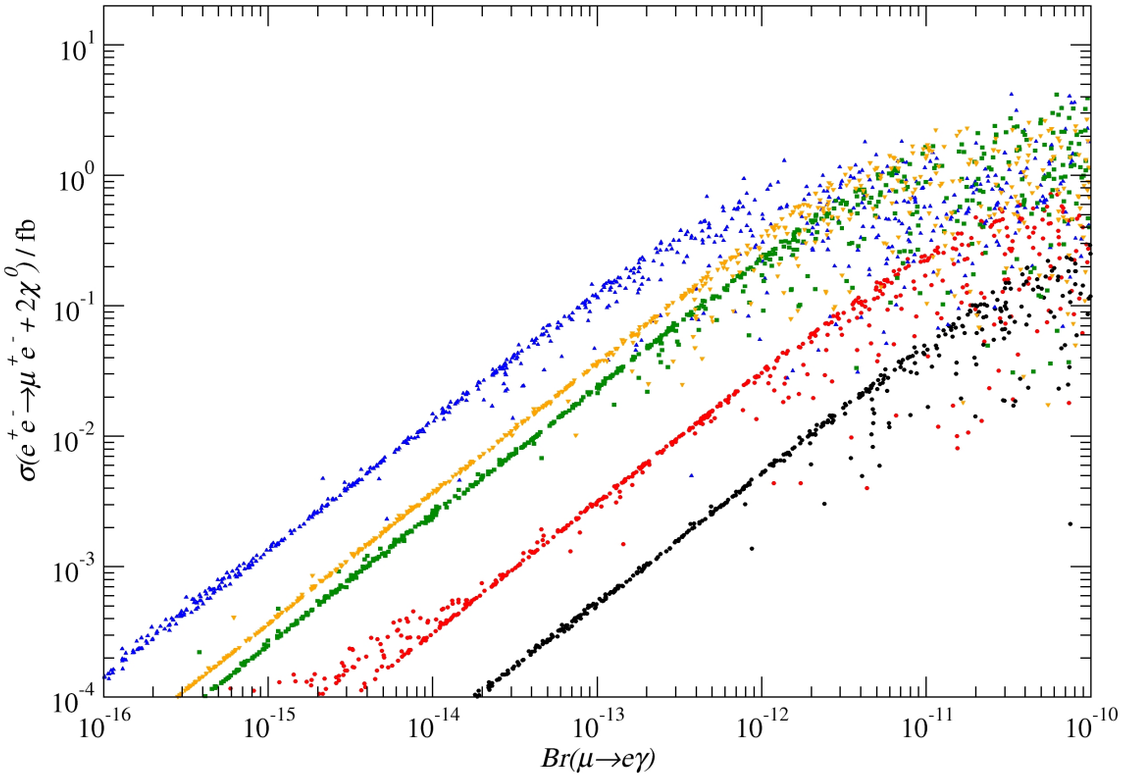
SUSY scenario SPS1a, $\sqrt{s} = 500$ GeV, unpolarized



direct production only, neutralino and chargino cascades not included

SUSY points C', G', B', SPS1a, I'

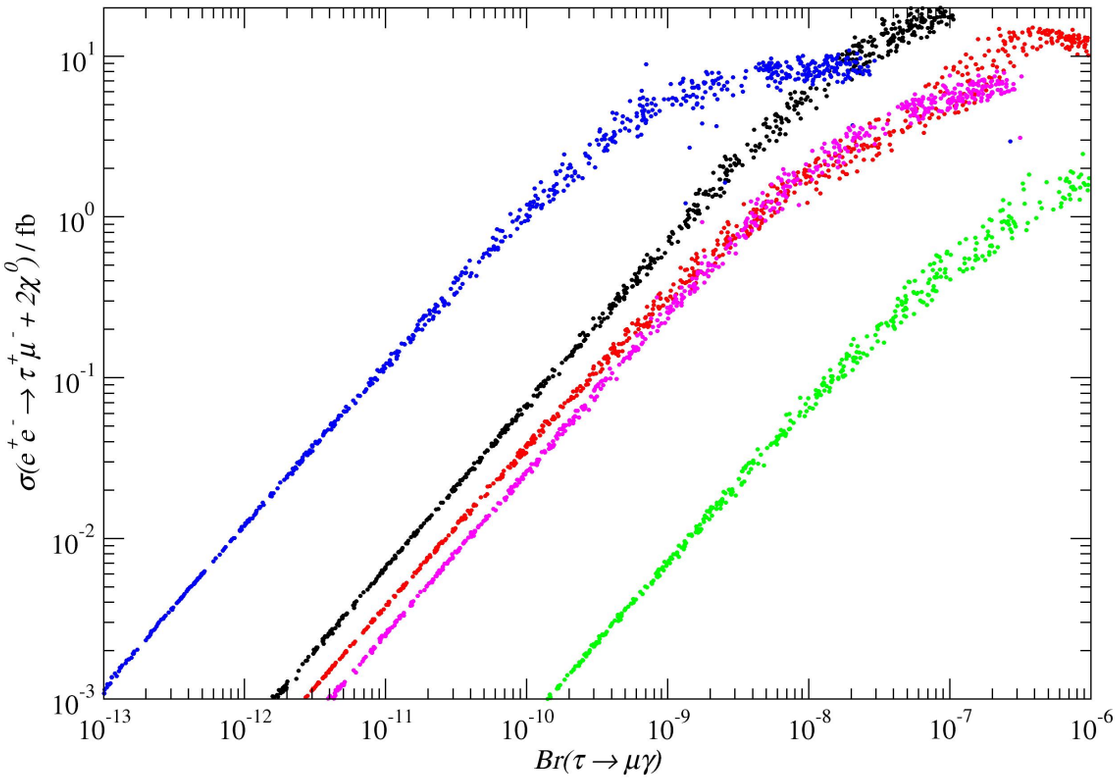
$\sqrt{s} = 800$ GeV



$Br(\mu \to e\gamma) > 10^{-12}$ implies $\sigma(e^+e^- \to \mu e + 2\tilde{\chi}_1^0) > 0.01$ to 1 fb

SUSY points C', B', SPS1, G', I'

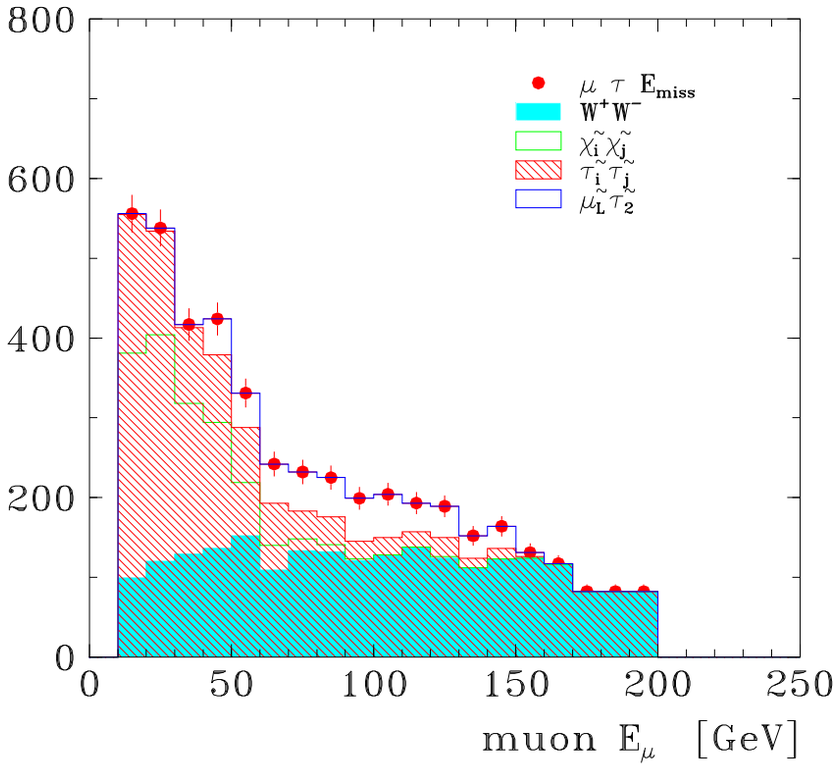
$\sqrt{s} = 800$ GeV



$Br(\tau \to \mu\gamma) < 6.8 \cdot 10^{-8}$ implies $\sigma(e^+e^- \to \tau\mu + 2\tilde{\chi}_1^0) < 0.3$ to 20 fb

$\tau\mu$ final states

SUSY scenario SPS1a, $\sqrt{s} = 500$ GeV, unpolarized, 500 fb^{-1}



- 4 fb signal cross section (flat lepton energy spectrum)
- SM+MSSM background (soft E_μ spectrum)
- standard selection criteria (τ identification via hadronic decays, 25% efficiency)
- $\sigma(\tilde{\tau}_2\tilde{\mu}_L) = 2$ fb $\rightarrow 5\sigma$ effect

H.-U. Martyn (2004)

defining benchmark models:

MSSM, NMSSM, SUSY breaking, GUT relations,
RPV, seesaw mechanism (type I, II), ...

constraining parameters:

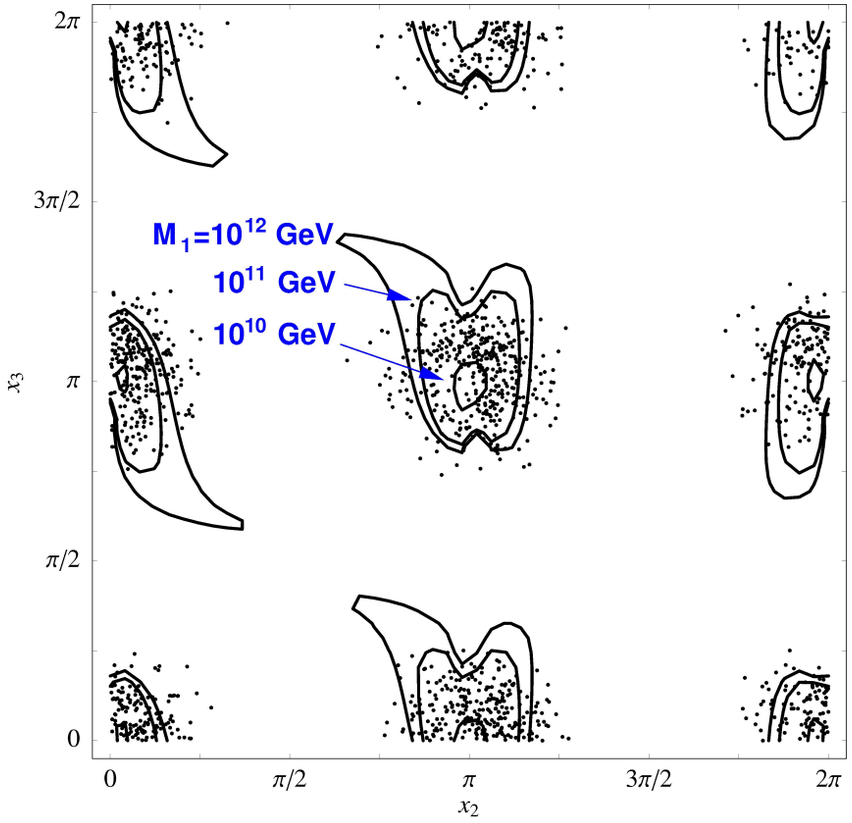
rare processes, g-2, EDM, leptogenesis, ...
DPRR (2005) to appear

investigating search channels:

lepton-photon, dilepton, trilepton,.....

generation of lepton asymmetry in out-of-equilibrium decays of N_1
later on transformation to baryon asymmetry through sphaleron processes

$$\eta_B = \frac{n_B - n_{\bar{B}}}{n_\gamma} = (6.3 \pm 0.3) \cdot 10^{-10}$$



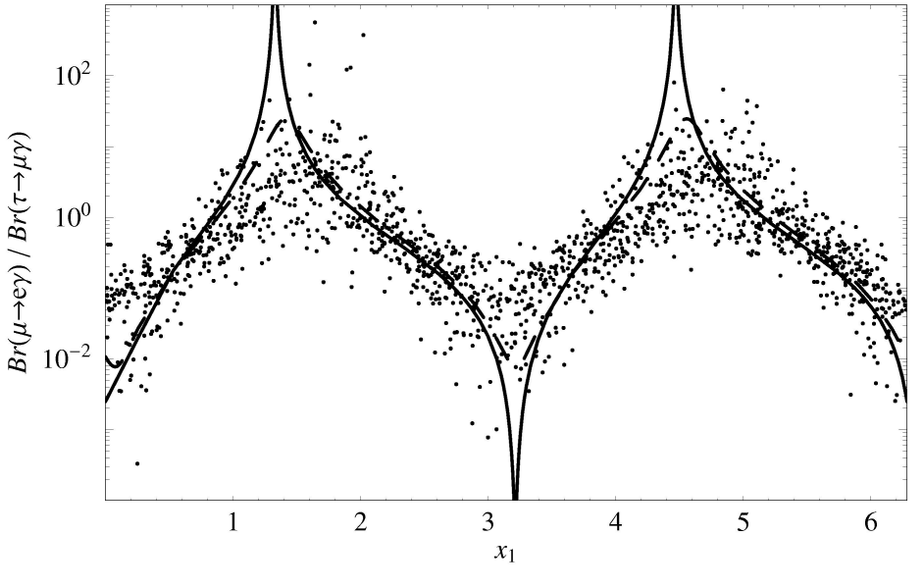
$$Y_\nu = \frac{1}{v \sin\beta} D\left(\sqrt{M_i}\right) \; R \; D\left(\sqrt{m_j}\right) U^\dagger$$

$$M_1 << M_2 << M_3, \; M_1 \leq 10^{11}$$

$$R(\cos(x_j + iy_j), \sin(x_j + iy_j), j = 1, 2, 3)$$

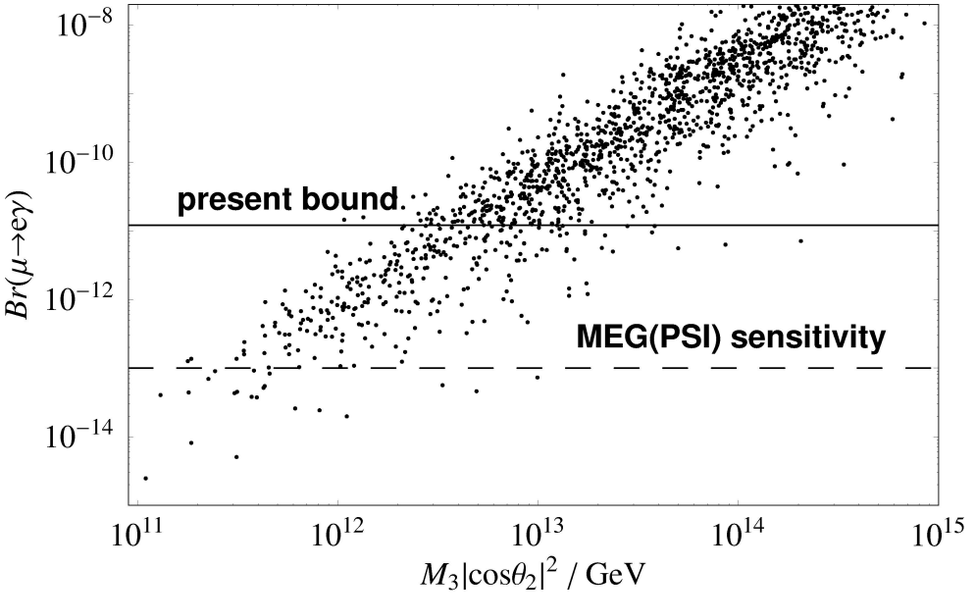
- $0 \leq x_1 \leq 2\pi$
- $10^{-3} < y_i < \mathcal{O}(1)$
- contours with $y_i = 0.1$

$$\Rightarrow x_2, x_3 \simeq n\pi$$



$\Rightarrow x_1$

- successfull leptogenesis
- $x_{2,3} \simeq n\pi$
- $0 \leq x_1 \leq 2\pi$
- $10^{-3} < y_i < \mathcal{O}(1)$
- $y_i = 0.01$ (solid), 0.1 (dashed)



$\Rightarrow M_3 \lesssim 10^{13}$ GeV

very different scenarios

- selected SUSY points or scans in paramter space
- LFV only in L or R sector, 2 or 3 flavour mixing
- maximal LFV allowed by present experimental bounds
- seesaw machanismus and neutrino data

LFV radiative decays: $W \to \tau\nu,\ \tau \to \mu\gamma$

Serin, Stroynowski, ATLAS Internal Note (1997)

- signal: $M(\mu\gamma) = m_\tau$
- background: QED radiation in production and decay
- reach (30 fb^{-1}): $Br(\tau \to \mu\gamma) \simeq 6 \cdot 10^{-7}$

direct DY production of sleptons: $\tilde{l}_i\tilde{l}_i \to l_j l_k 2\tilde{\chi}_1^0$

Bityukov,Krasniov, hep-ph/9712358
Agashe, Graesser, hep-ph/ 9904422

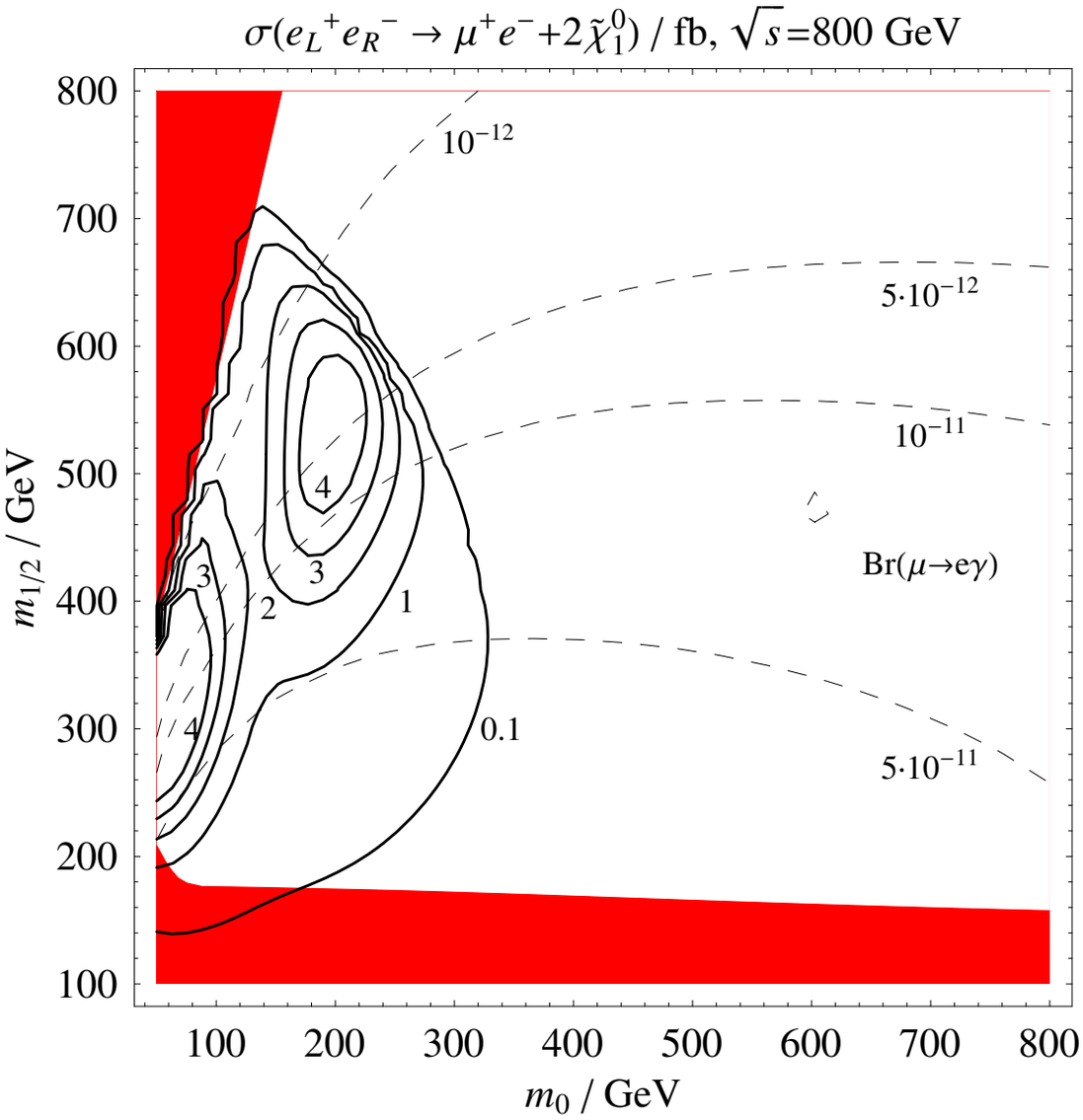
- signal: dileptons of different flavour and large missing p_T
- background: $t\bar{t}, W^+W^-, \chi^+\chi^-$
- generally very difficult

LFV neutralino and slepton decays: $\tilde{g}, \tilde{q} \to \tilde{\chi}_2^0 \to \tilde{l}_i l_j \to \tilde{\chi}_1^0 l_k l_j$

Agashe, Graesser, hep-ph/ 9904422
Hinchliffe, Paige, hep-ph/0010086
Hisano et al., PRD D65(2002)116002
Carvalho et al., hep-ph/0206148
Bartl et al., hep-ph/0510074

- signal: dilepton mass distribution
- background: $t\bar{t}$, SUSY channels
- reach (30 fb^{-1}): $Br(\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 l_k l_j) \simeq$ 2 to 4 %
- complementary to or more sensitive than radiative decays

$A_0 = 0$, $\tan\beta = 5$, sign$\mu = +$



ratios od branching ratios

$$\frac{Br\left(l_i \to l_j \gamma\right)}{Br\left(l_{i'} \to l_{j'} \gamma\right)} \sim \frac{m_{l_i}^5 \Gamma_{i'}}{m_{l_i'}^5 \Gamma_i} \frac{\left|\left(Y_\nu^\dagger L Y_\nu\right)_{ij}\right|^2}{\left|\left(Y_\nu^\dagger L Y_\nu\right)_{i'j'}\right|^2}$$

Example:

- hierarchical light neutrinos, central best-fit values for neutrino parameters
- vanishing Dirac/Majorana phases, $R = \mathbf{1}$
- SUSY scenario C

Majorana masses		
Ratios	$M_i = M_R$	$M_1 : M_2 : M_3 = 1 : 10 : 100$
$\tau \to \mu\gamma / \mu \to e\gamma$	4	12
$\tau \to \mu\gamma / \tau \to e\gamma$	2500	160
$\mu \to e\gamma / \tau \to e\gamma$	640	13

correlation of signals in $\tau\mu$ and $e\mu$-channels

SUSY scenario SPS1, $\sqrt{s} = 800$ GeV