Lepton Flavour & Number Violation @ LHC

Werner Porod

IFIC-CSIC

- R-parity conservation
  - Sources flavour violation in supersymmetric models
  - Lepton flavour violating decays of supersymmetric particles; Implications for LHC observables
- R-parity violation
  - ν physics
  - predictions for LSP decays

Experimental Information

Large mixing angles in neutrino sector

$$|\tan\theta_{atm}|^2 \simeq 1$$
$$|\tan\theta_{sol}|^2 \simeq 0.4$$
$$|U_{e3}|^2 \lesssim 0.05$$

Small flavour and CP violation violation in charged lepton sector

$BR(\mu \to e\gamma) \lesssim 1.2 \cdot 10^{-11}$ $\quad BR(\mu^- \to e^- e^+ e^-) \lesssim 10^{-12}$

$BR(\tau \to e\gamma) \lesssim 1.1 \cdot 10^{-7}$ $\quad BR(\tau \to \mu\gamma) \lesssim 6.8 \cdot 10^{-8}$

$BR(\tau \to l l l') \lesssim O(10^{-7})$ $(l, l' = e, \mu)$

$$|d_e| \lesssim 10^{-27}\ e\,cm,\ |d_\mu| \lesssim 1.5 \cdot 10^{-18}\ e\,cm,\ |d_\tau| \lesssim 1.5 \cdot 10^{-16}\ e\,cm$$

possible SUSY contributions to magnetic moments of leptons

$$|\Delta a_e| \leq 10^{-12},\ \ 0 \leq \Delta a_\mu \leq 43 \cdot 10^{-10},\ \ |\Delta a_\tau| \leq 0.058$$

Sources of Flavour Violation

Sleptons:

$$M^2_{\tilde{l}} = \begin{pmatrix} M^2_{L,ij} + \frac{v_d^2 Y^{E*}_{ki} Y^E_{kj}}{2} + D_L \delta_{ij} & \frac{v_d A_{ij} - \mu v_u (Y^E_{ij})^*}{\sqrt{2}} \\ \frac{v_d A^*_{ij} - \mu v_u Y^E_{ij}}{\sqrt{2}} & M^2_{E,ij} + \frac{v_d^2 Y^E_{ik} Y^{E*}_{jk}}{2} + D_R \delta_{ij} \end{pmatrix}$$

Sneutrinos:

$$M^2_{\tilde{\nu}} = M^2_{L,ij} + D_\nu \delta_{ij}$$

where

$$D_L = \frac{\left(g'^2 - g^2\right)(v_d^2 - v_u^2)}{8}, \qquad D_R = \frac{g'^2 (v_d^2 - v_u^2)}{4}$$

$$D_\nu = \frac{\left(g^2 + g'^2\right)(v_d^2 - v_u^2)}{8}$$

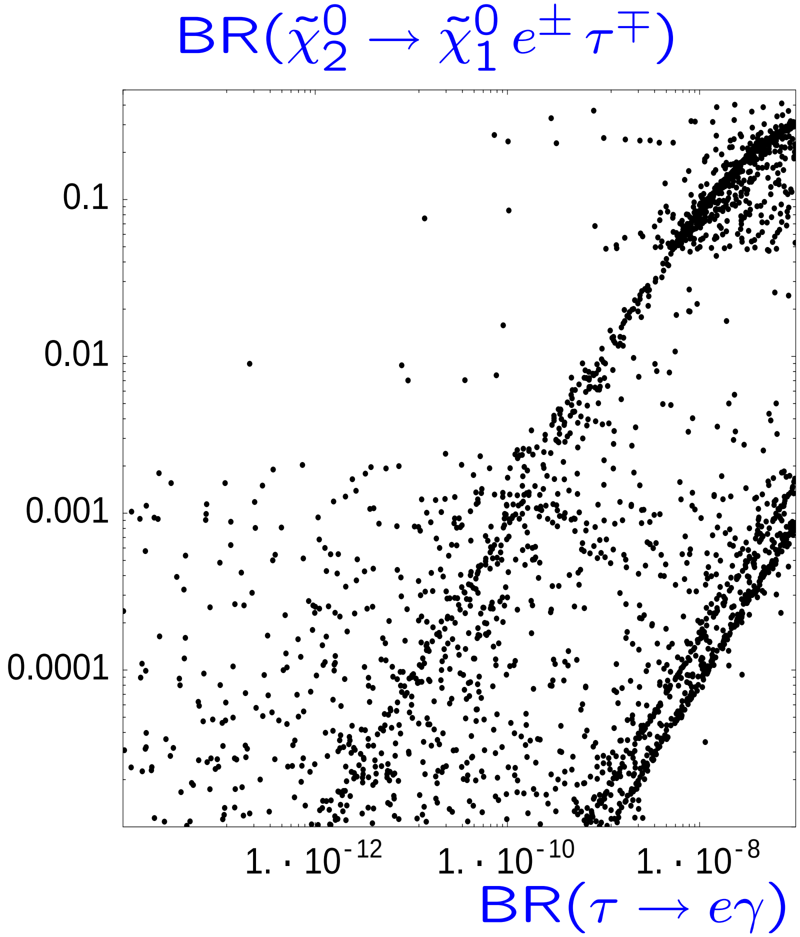
Without loss of generality: $Y^E_{ij} = Y^E_i \delta_{ij}$, Y^E_i real

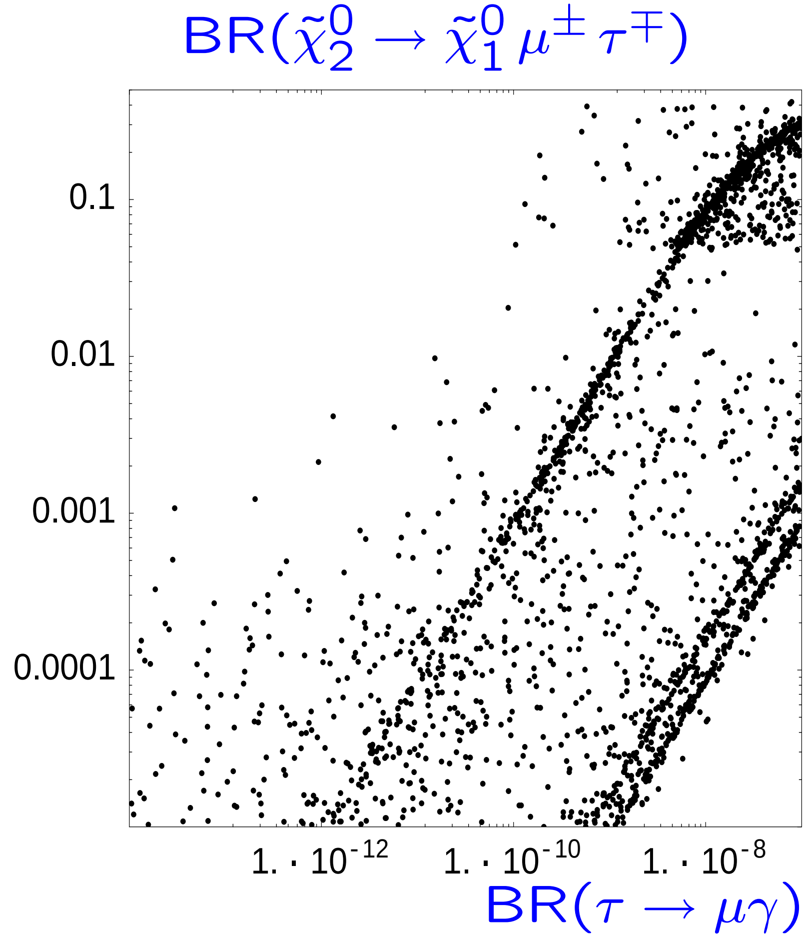
Lepton flavour violating SUSY decays

Lepton flavour violating couplings:

- $\tilde{l}_i - l_j - \tilde{\chi}^0_k \Rightarrow \tilde{l}_i \to l_j \, \tilde{\chi}^0_k, \; \tilde{\chi}^0_k \to l_j \, \tilde{l}_i$
- $\tilde{\nu}_i - l_j - \tilde{\chi}^+_k$
- $\tilde{l}_i - \tilde{\nu}^\dagger_j - W, \; \tilde{l}_i - \tilde{\nu}^\dagger_j - H^+$
- $\tilde{l}_i - \tilde{l}^\dagger_j - Z, \; \tilde{l}_i - \tilde{l}^\dagger_j - (h^0, \; H^0, \; A^0)$
- $\tilde{\nu}_i - \nu_j - \tilde{\chi}^0_k, \; \tilde{l}_i - \nu_j - \tilde{\chi}^+_k$

$$\tilde{\chi}^0_2 \to \tilde{l}_i l_j \to l_k l_j \tilde{\chi}^0_1$$





Variations around SPS1a

Implications for LHC

studies by:

- F. Paige, I. Hinchliffe, PRD 63 (2001) 115006
- J. Hisanao, R. Kitano, M. Nojiri, PRD 65 (2002) 116002
- D.F. Carvalho et al., PLB 618 (2005) 162
- A. Bartl et al., hep-ph/0510074
- talk by R. Rückl

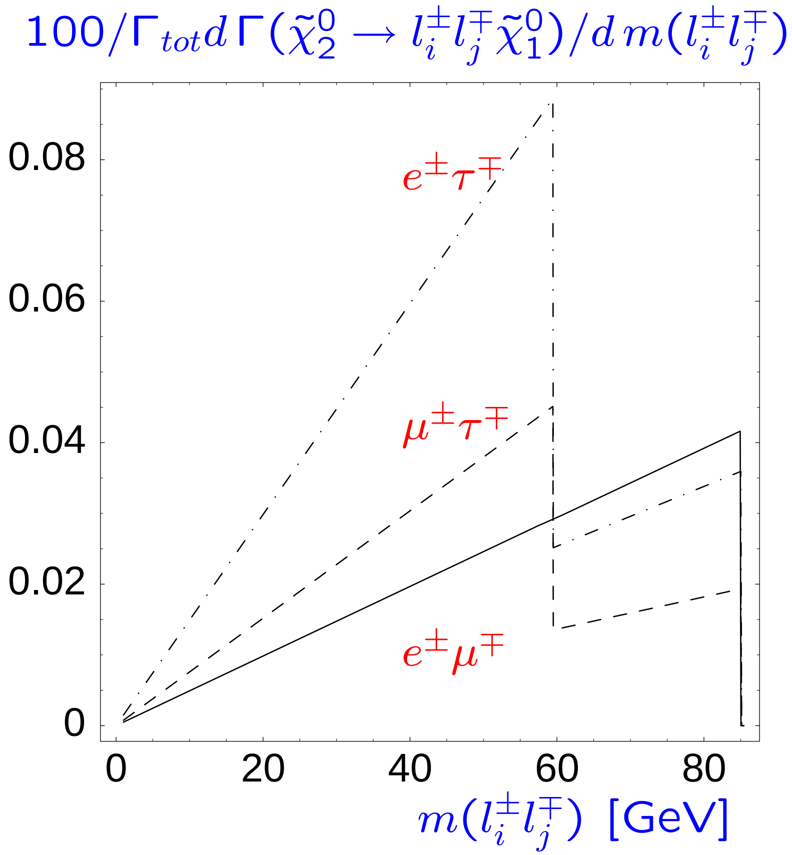
Edge variables positions changes only sightly: $\pm$(1-2) %

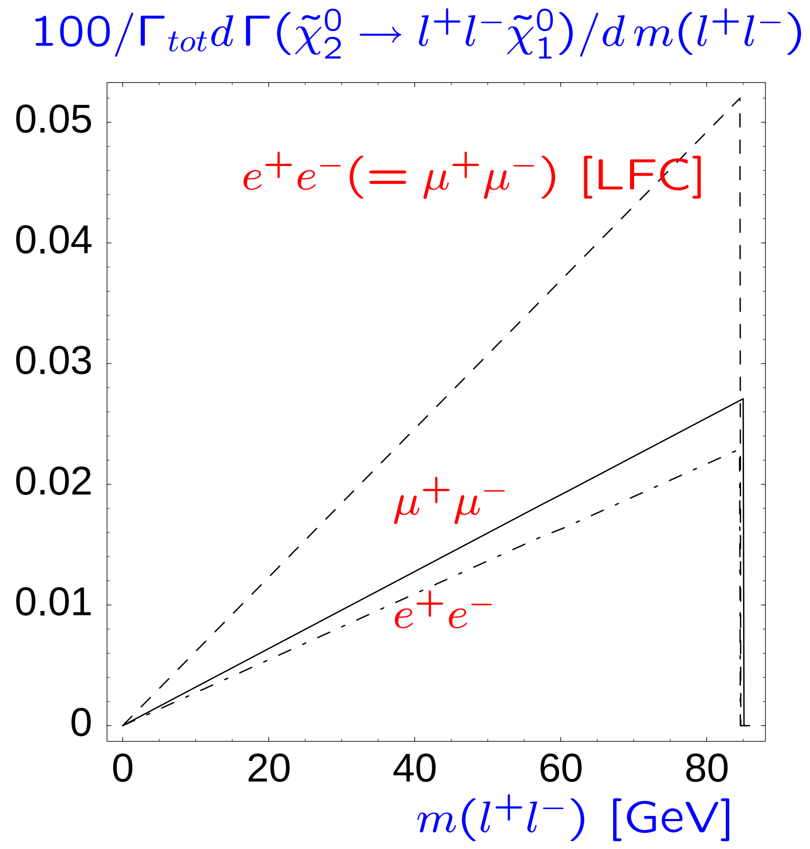
However, new combinations: $m_{ll}^{max} \to m_{e\mu}^{max}\ m_{e\tau}^{max}\ m_{\mu\tau}^{max}$

similarly for m_{llq}^{max} and m_{llq}^{min}

Note: BR($\tilde{\chi}_2^0 \to \tilde{\chi}_1^0\, e^\pm\, \tau^\mp$), BR($\tilde{\chi}_2^0 \to \tilde{\chi}_1^0\, \mu^\pm\, \tau^\mp$) $\simeq$ BR($\tilde{\chi}_2^0 \to \tilde{\chi}_1^0\, e^\pm\, e^\mp$) or even larger

$\Rightarrow$ pairing of different lepton flavours necessary


$100/\Gamma_{tot} d\,\Gamma(\tilde{\chi}^0_2 \to l_i^\pm l_j^\mp \tilde{\chi}^0_1)/d\,m(l_i^\pm l_j^\mp)$
0.08
0.06
0.04
0.02
0
0
20
40
60
80
$m(l_i^\pm l_j^\mp)$ [GeV]
$e^\pm\tau^\mp$
$\mu^\pm\tau^\mp$
$e^\pm\mu^\mp$


$100/\Gamma_{tot} d\,\Gamma(\tilde{\chi}^0_2 \to l^+ l^- \tilde{\chi}^0_1)/d\,m(l^+ l^-)$
0.05
0.04
0.03
0.02
0.01
0
0
20
40
60
80
$m(l^+ l^-)$ [GeV]
$e^+e^-(=\mu^+\mu^-)$ [LFC]
$\mu^+\mu^-$
e^+e^-

Bilinearly broken R-parity

Is defined as MSSM + $\epsilon_i \hat{L}_i \hat{H}_u$ + $B_i \epsilon_i \tilde{L}_i H_u$

$B_i \epsilon_i$ induces sneutrinos vevs v_i

$(\lambda'_{ijk} \simeq (\epsilon_i/\mu) h^D_{jk}, \ \lambda_{ijk} \simeq (\epsilon_{[i}/\mu) h^E_{j]k} + v'_i \ )$

Induced mixings: (leptons, charginos), (neutrinos, neutralinos), (Higgs bosons, sleptons)

Solves neutrino problems:

Atmospheric at tree level, solar at loop level

Negligible flavour violating decays of leptons:

BR($\mu \to e\gamma$) $< 10^{-17}$, BR($\tau \to e\gamma, \mu\gamma$) $< 10^{-16}$.

Leads to predictions for collider physics

Parameters controlling ν-Physics

If $m_{\nu,Loop} \ll m_{\nu,Tree}$

Δm^2_{atm}	$M_2/det(\mathcal{M}_{\chi^0})\ |\vec{\Lambda}|^2$
$\tan^2\theta_{atm}$	$|\Lambda_3/\Lambda_3|^2$
CHOOZ	$|\Lambda_1|/\sqrt{\Lambda_2^2+\Lambda_3^2}$
$\tan^2\theta_{sol}$	$|\epsilon_1/\epsilon_2|^2$
m^2_{sol}/m^2_{atm}	$|\vec{\epsilon}|^2/|\vec{\Lambda}|$

where

$$\Lambda_i = \mu v_i + v_d \epsilon_i$$

Approximate Couplings

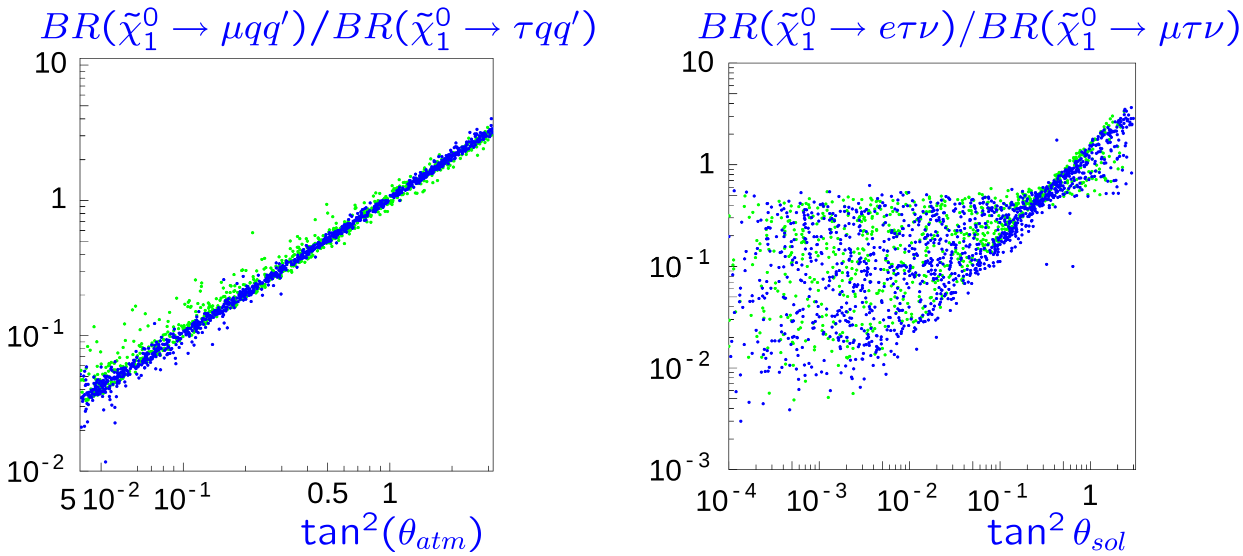
smallness of R-parity coupling $\Rightarrow$ expansion of all R-parity violating couplings:

$c = f(\mu, M_k, A_l, M_{\tilde{j}})\Lambda_i + g(\mu, M_k, A_l, M_{\tilde{j}})\epsilon_i$

e.g. $\tilde{\chi}^0_1$-$W^\pm$-l_i couplings:

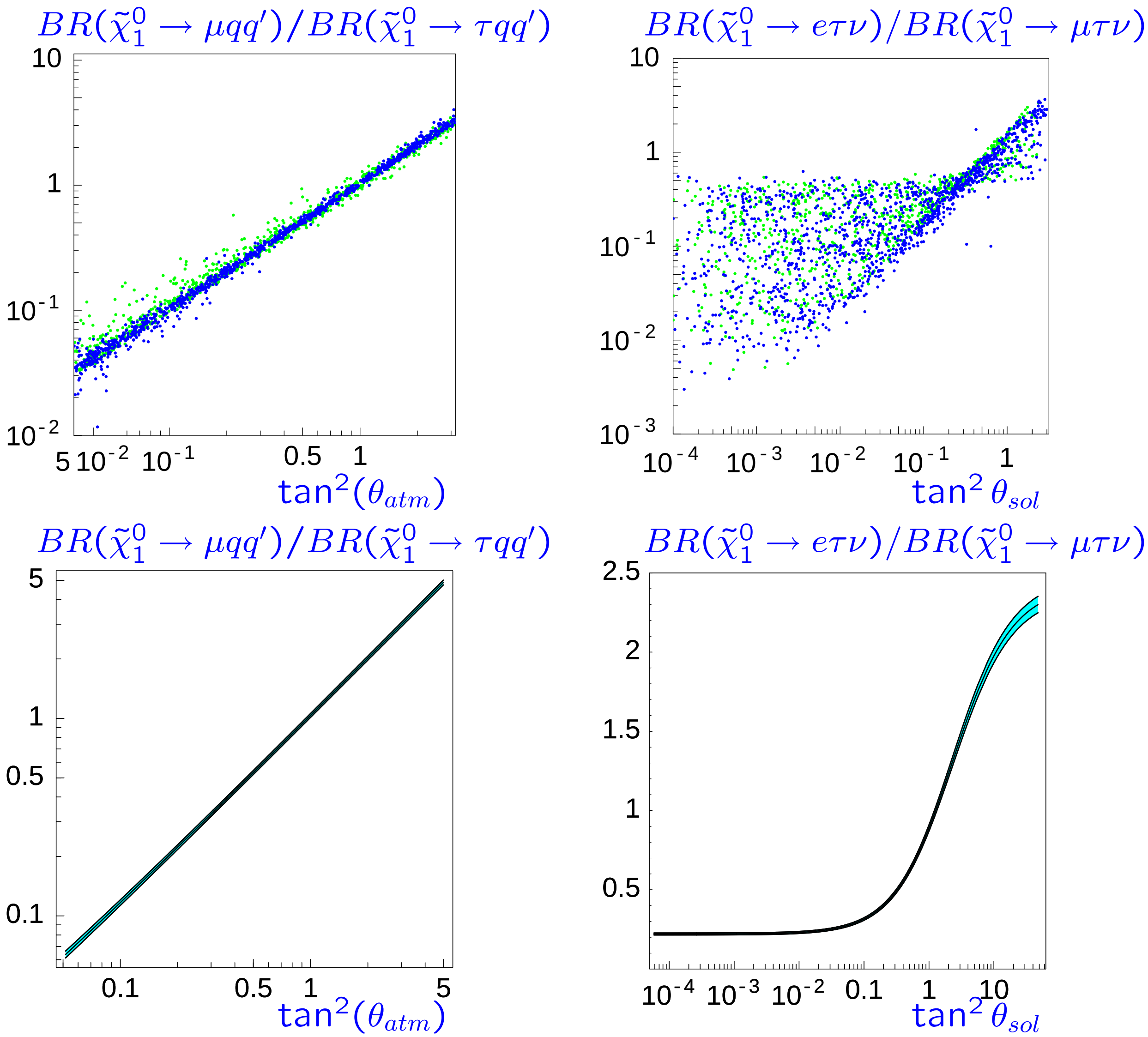
$$
\begin{aligned}
O_{Ri} &= \frac{g h^E_{ii} v_d}{2\mathrm{Det}_+}\left[\frac{g v_d N_{12} + M_2 N_{14}}{\mu}\epsilon_i\right. \\
&+ \left. g\,\frac{\left(2\mu^2 + g^2 v_d v_u\right) N_{12} + (\mu + M_2)\, g v_u N_{14}}{2\mu\mathrm{Det}_+}\Lambda_i\right] \\
O_{Li} &= \frac{g\Lambda_i}{\sqrt{2}}\left[-\frac{g' M_2 \mu}{2\mathrm{Det}_0}N_{11} + g\left(\frac{1}{\mathrm{Det}_+} + \frac{M_1\mu}{2\mathrm{Det}_0}\right)N_{12}\right. \\
&\quad -\frac{v_u}{2}\left(\frac{g^2 M_1 + g'^2 M_2}{2\mathrm{Det}_0} + \frac{g^2}{\mu\mathrm{Det}_+}\right)N_{13} \\
&\quad \left. + \frac{v_d(g^2 M_1 + g'^2 M_2)}{4\mathrm{Det}_0}N_{14}\right] \\
|O_{Ri}| &\ll |O_{Li}|\,, \quad \left|\frac{O_{L2}}{O_{L3}}\right|^2 = \left|\frac{\Lambda_2}{\Lambda_3}\right|^2 \simeq \tan^2\theta_{atm}
\end{aligned}
$$

Correlations



Summing over all neutrinos.

Correlations



Assumptions:

- spectrum, mixing angles within 10 percent
- statistical error: 10^5 χ^0_1

Parameters:

$M_2 = 120$ GeV, $\mu = 500$ GeV

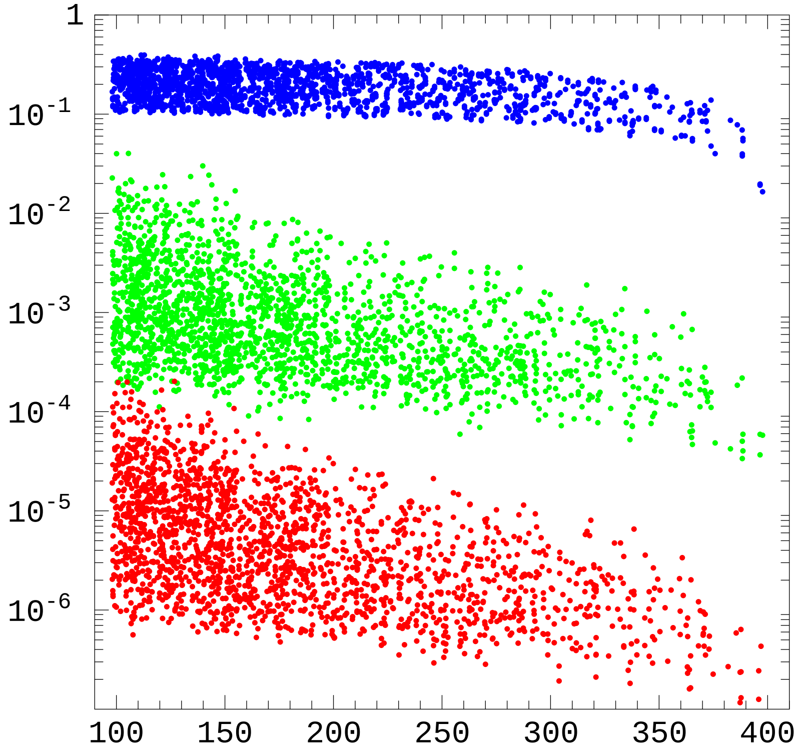
$\tan\beta = 5$, $m_0 = 500$ GeV

$A = -500$ GeV

Summing over all neutrinos.

Charged Scalar LSP

Decay length ($\tilde{e}$, $\tilde{\mu}$, $\tilde{\tau}$) [cm]

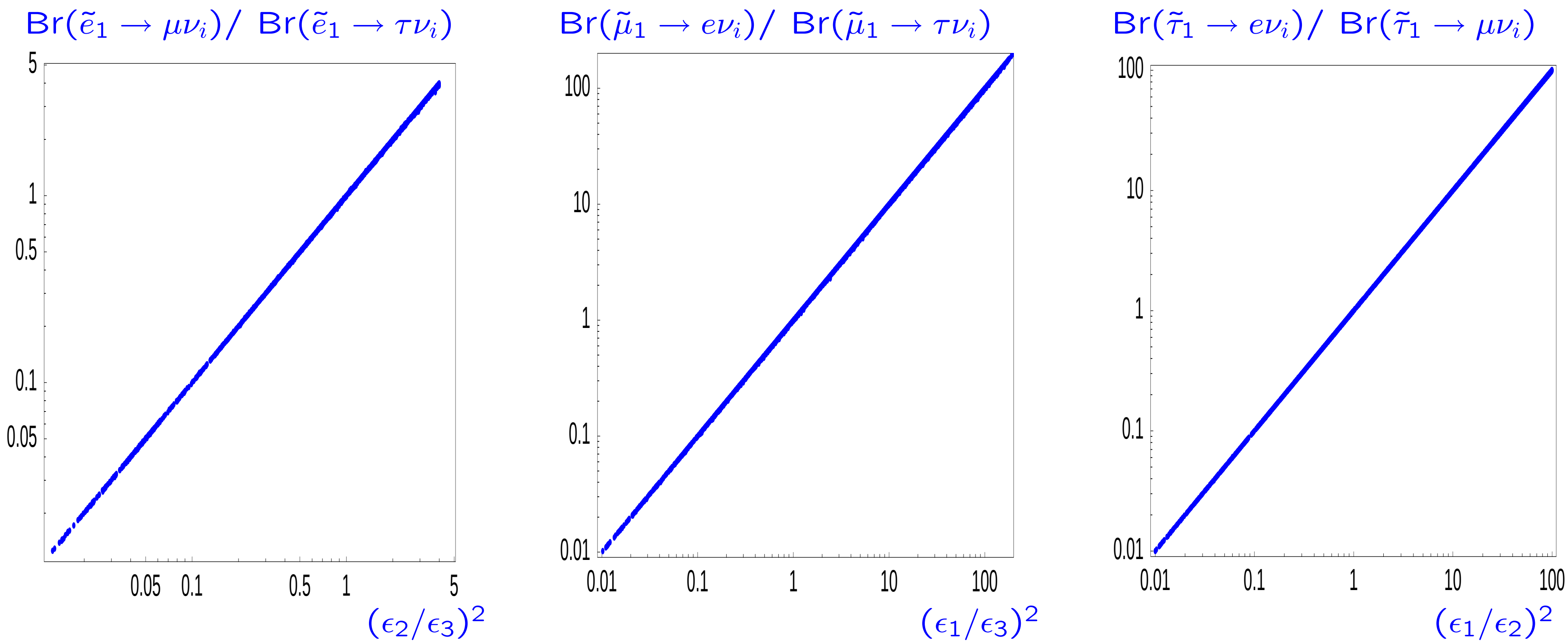


$m_{\tilde{l}}$ [GeV]

$\Rightarrow$ $\tilde{e}$, $\tilde{\mu}$, $\tilde{\tau}$ can be separated in this model.

Moreover

$$\frac{\Gamma(\tilde{\tau})}{\Gamma(\tilde{\mu})} \simeq \left(\frac{Y_\tau}{Y_\mu}\right)^2 \frac{m_{\tilde{\tau}}}{m_{\tilde{\mu}}}$$



Cross check possible: $(\epsilon_1/\epsilon_3)^2/(\epsilon_1/\epsilon_2)^2 \equiv (\epsilon_2/\epsilon_3)^2$

$\Rightarrow$ Measure 2 ratios, 3rd is fixed.

Gravitino Dark Matter

GMSB: light gravitino LSP, $\tilde{\chi}_1^0$ of $\tilde{l}_R$ NLSP

Standard thermal history of the universe:

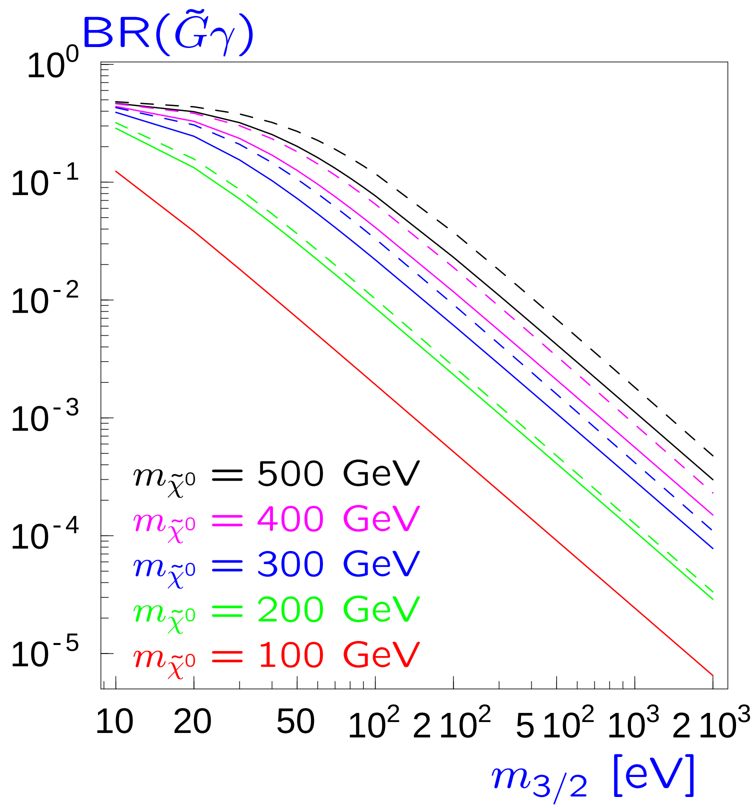
$$\Omega_{3/2}h^2 \simeq 0.11 \left(\frac{m_{3/2}}{100\,\mathrm{eV}}\right)\left(\frac{100}{g_*}\right) \qquad (g_* \simeq 90 - 140)$$

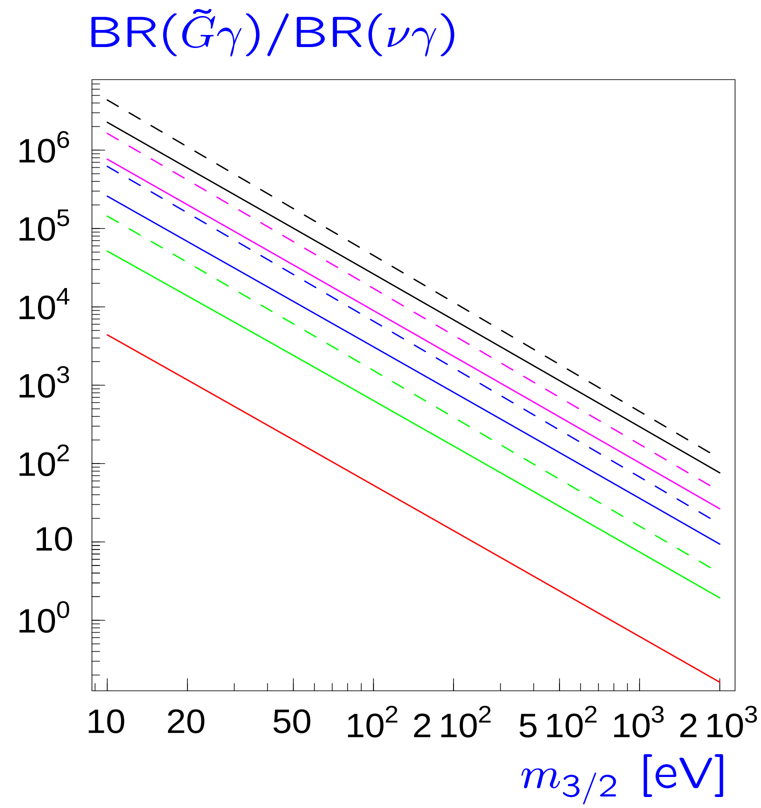
Current data: $\Omega_M h^2 \simeq 0.134 \pm 0.006$, $\Omega_B h^2 \simeq 0.023 \pm 0.001$

$\Rightarrow m_{3/2} \simeq 100$ eV if DM candidate, warm dark matter
constraints from Lyman-α forest: $m_{WDM} \gtrsim 550$ eV
(M. Viel et al., arXiv:astro-ph/0501562)

$\Rightarrow$ assume additional entropy production, e.g. non-standard decays of messenger particles
(E. Baltz, H. Murayama, astro-ph/0108172; M. Fujii and T. Yanagida hep-ph/0208191)

GMSB signals





$n_5 = 1$, $\tan\beta = 10$

Comments

- $$\frac{m_{\tilde{\tau}_1}}{m_{\tilde{\chi}_1^0}} \propto \frac{1}{\sqrt{n_5}}$$

  $\Rightarrow$ for $n_5 \geq 3$ hardly points with $\tilde{\chi}_1^0$ NLSP

- $\tilde{l}_R$ NLSPs: BR$(l\nu) >$ BR$(l\tilde{G})$

- $n_5 = 2$: BR$(\tilde{G}\gamma)$ reduced by a factor 2-3

- $\tilde{G}$ decays via R-parity violating couplings, however:

  $\Gamma(\tilde{G}) \simeq 3.5 \cdot 10^{-16} \frac{m_\nu[\text{eV}]}{0.05\text{eV}} \frac{m_{3/2}^3}{M_{Pl}^2} \;\; \Rightarrow \tau(\tilde{G}) \sim O(10^{31})$Hubbletimes