Correlations between ν physics and LC physics (A no-lose theorem)

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Experimental information

Neutrino Physics:

two large mixing angle:

atmospheric and solar neutrinos

SuperK and KamLAND

one small mixing angle: CHOOZ

Rare Lepton decays:

BR($\mu \to e\gamma$) $< O(10^{-11})$, BR($\mu \to eee$) $< O(10^{-12})$
BR($\tau \to l\gamma$) $< O(10^{-6})$, BR($\tau \to lll$) $< O(10^{-6})$
BR($\tau \to lll'$) $< O(10^{-6})$ $(l, l' = e, \mu)$

Bilinearly broken R-parity

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

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

Solves neutrino problems: Atmospheric at tree level, solar at loop level (J.Romão, Phys. Rev. *D60*, 071703 (2000); M.Hirsch et al., Phys. Rev. *D62*, 113008 (2000); M. A. Diaz et al., hep-ph/0302021.

Negligible flavour violating decays of leptons: BR$(\mu \to e\gamma) < 10^{-17}$, BR$(\tau \to e\gamma, \mu\gamma) < 10^{-18}$. D.F. Carvalho et al., Phys. Rev. D *65* (2002) 093013)

Neutrino physics requires small R-parity violating parameters in this class of models $\Rightarrow$ production and decays of SUSY particle is as in the MSSM except that the LSP is decaying.

The small R-parity violating parameters allow for a systematic expansion of all interesting quantities in terms of these parameters.

Quantities controlling ν physics

- $m_{\nu_3} \propto M_2 |\vec{\Lambda}|^2 / \mathrm{Det}(\tilde{\chi}^0)$ with $\Lambda_i = \epsilon_i v_d + \mu v_i$ (v_i ... sneutrino vevs), tree level mass
- $(\tan\theta_{\mathrm{atm}})^2 \simeq (\Lambda_2/\Lambda_3)^2$
- $U_{e3}^2 \simeq \Lambda_1^2/(\Lambda_2^2 + \Lambda_3^2)$
- $m_{\nu_2} \propto |\vec{\epsilon}|^2/(16\pi^2\mu^2)$, loop mass
- $(\tan\theta_{\mathrm{sol}})^2 \simeq (\tilde{\epsilon}_1/\tilde{\epsilon}_2)^2$ where $\tilde{\epsilon}_i = V_{ij}^{\nu,\mathrm{tree}}\epsilon_j$, if $(\epsilon_2\Lambda_2)/(\epsilon_3\Lambda_3) < 0 \Rightarrow \tilde{\epsilon}_1/\tilde{\epsilon}_2 \simeq \epsilon_1/\epsilon_2$

All R-parity violating coupling are of the form

$$\sum_j c_j g_j \left(\frac{\epsilon_i}{\mu}, \frac{\Lambda_i}{\sqrt{\mathrm{Det}(\tilde{\chi}^0)}}, \frac{\Lambda_i}{\mathrm{Det}(\tilde{\chi}^+)} \right)$$

where c_j are products of MSSM mixing matrices, gauge couplings and Yukawa couplings. Note, that also gauginos and gauge bosons have R-parity violating couplings.

Leads to predictions for collider physics:

- Neutralino decays (W.Porod et al., Phys. Rev. D *63* (2001) 115004),
- Stop decays (D.Restrepo et al., Phys. Rev. *D64* (2001) 055011
- Charged slepton decays (M.Hirsch et al., Phys. Rev. *D66* (2002) 095006

In this talk we discuss the remaining possibilities for LSPs to show: Independent of the nature of the LSP there is always at least one correlation between ratios of LSP branching ratios and and one of the neutrino mixing angles

In the numerical results below:

- Random sample over SUSY parameter space; only assumption is that the shown particle is the LSP and that its mass is below 400 GeV.
- R-parity parameters are fixed such, that Δ^2_{atm} and Δ^2_{sol} are consistent with experiment
- Correlations become significantly better once information on $\tilde{\chi}^0_j$, $\tilde{\chi}^+_k$, $\tilde{\tau}_i$, $\tilde{b}_i$ and H^+ is provided

Sneutrinos

Decay modes

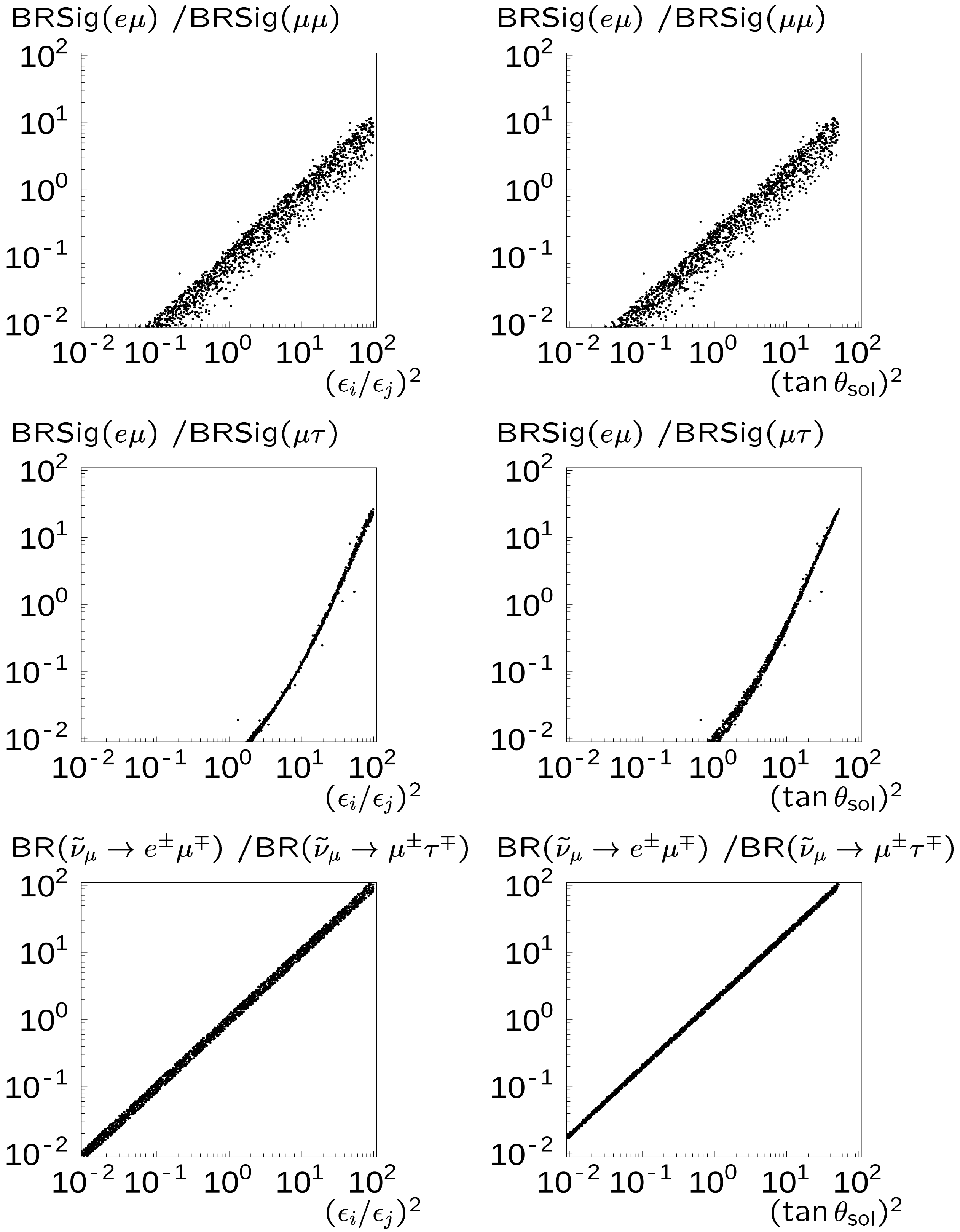
$$\begin{aligned} \tilde{\nu}_i &\to q\bar{q} \\ \tilde{\nu}_i &\to l_j^+ l_k^- \\ \tilde{\nu}_i &\to \nu_j \nu_k \end{aligned}$$

General features

- $\tilde{\nu}_i \to b\bar{b}$ dominating mode
  $\Rightarrow \Gamma(\nu_1) : \Gamma(\nu_2) : \Gamma(\nu_3) \simeq \epsilon_1^2 : \epsilon_2^2 : \epsilon_3^2$
- BR($\tilde{\nu}_i \to l_j^+ l_k^-$) order few per–cent, except $i = j = k$ which is strongly suppressed
- BR($\nu_i \to \nu_j \nu_k$) order per–mile or below

Define:
BRSig($l_i l_j$):= $\sum_{rs} \sigma(e^+e^- \to \tilde{\nu}_r \tilde{\nu}_s \to b\bar{b} l_i^{\pm} l_j^{\mp})$

Examples: BRSig($e\mu$) = O(10^{-2})–O(1) fb
BRSig($\mu\mu$) = O(0.1) fb
BRSig($\mu\tau$) = O(0.1)–O(10) fb


BRSig($e\mu$) /BRSig($\mu\mu$)
$(\epsilon_i/\epsilon_j)^2$
BRSig($e\mu$) /BRSig($\mu\mu$)
$(\tan\theta_{\rm sol})^2$
BRSig($e\mu$) /BRSig($\mu\tau$)
$(\epsilon_i/\epsilon_j)^2$
BRSig($e\mu$) /BRSig($\mu\tau$)
$(\tan\theta_{\rm sol})^2$
BR($\tilde{\nu}_\mu \to e^\pm\mu^\mp$) /BR($\tilde{\nu}_\mu \to \mu^\pm\tau^\mp$)
$(\epsilon_i/\epsilon_j)^2$
BR($\tilde{\nu}_\mu \to e^\pm\mu^\mp$) /BR($\tilde{\nu}_\mu \to \mu^\pm\tau^\mp$)
$(\tan\theta_{\rm sol})^2$
10^{-2} 10^{-1} 10^{0} 10^{1} 10^{2}

Charginos

Two body decays

$$\begin{aligned}\tilde{\chi}_1^+ &\to W^+\nu_i \\ \tilde{\chi}_1^+ &\to Z^0 l_i^+, h^0 l_i^+\end{aligned}$$

Consideration of 2-body decay modes is not sufficient, because couplings to virtual particles can be 1-2 orders of magnitudes larger than coupling mediating 2-body decays

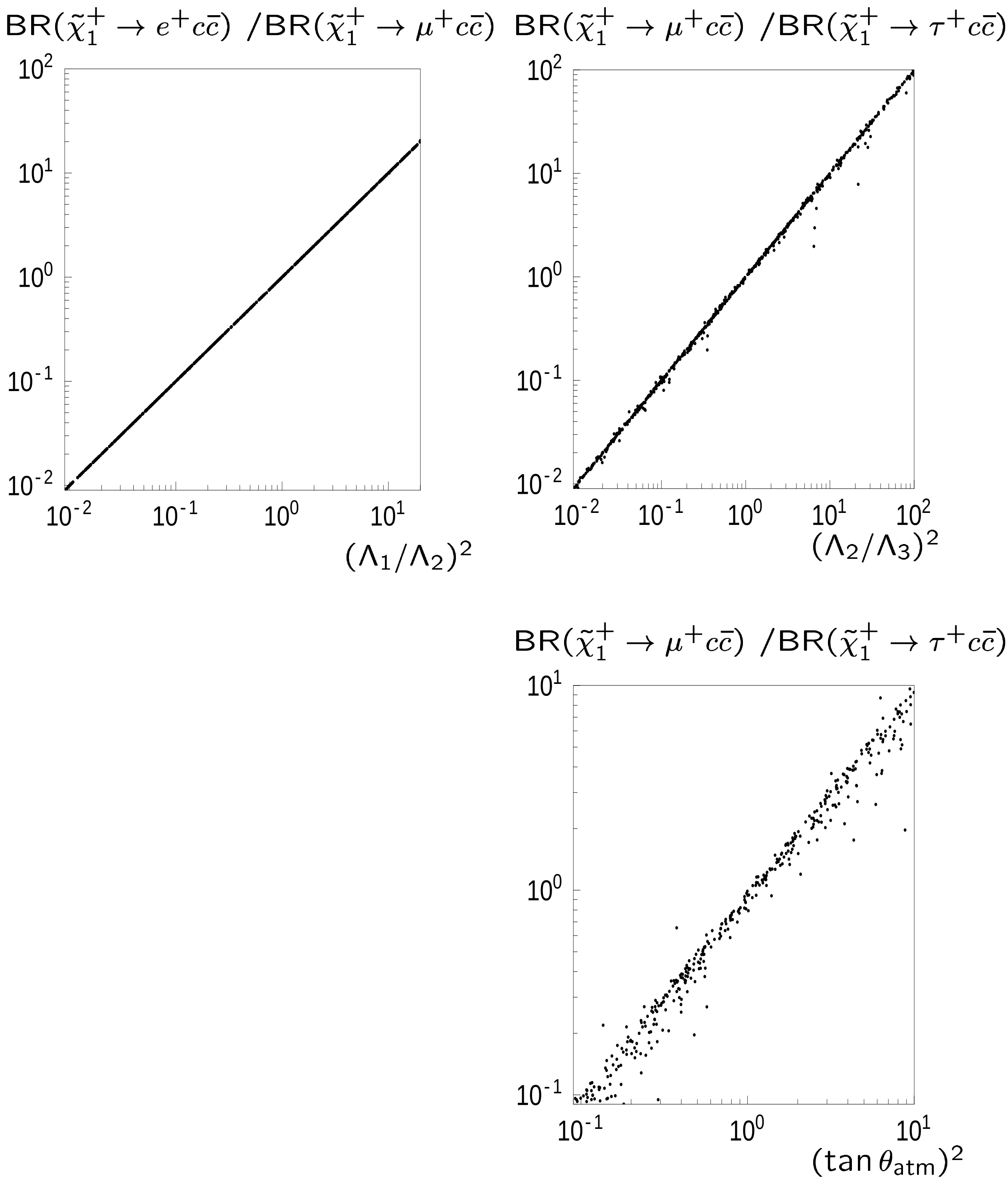
$\Rightarrow$ calculate always 3-body decay modes:

$$\begin{aligned}\tilde{\chi}_1^+ &\to \nu_i \bar{q} q' \\ \tilde{\chi}_1^+ &\to l_i^+ q\bar{q} \\ \tilde{\chi}_1^+ &\to l_i^+ l_j^+ l_k^- \\ \tilde{\chi}_1^+ &\to l_i^+ \nu_r \nu_s\end{aligned}$$

General feature:

$\chi_1^+ \to \nu_i \bar{q} q'$ dominates (BR up to 65%)

remaining branching ratios are in the per-mile to few per–cent range



Various ratios of chargino branching ratios

Squarks

Decay modes

R-parity violating

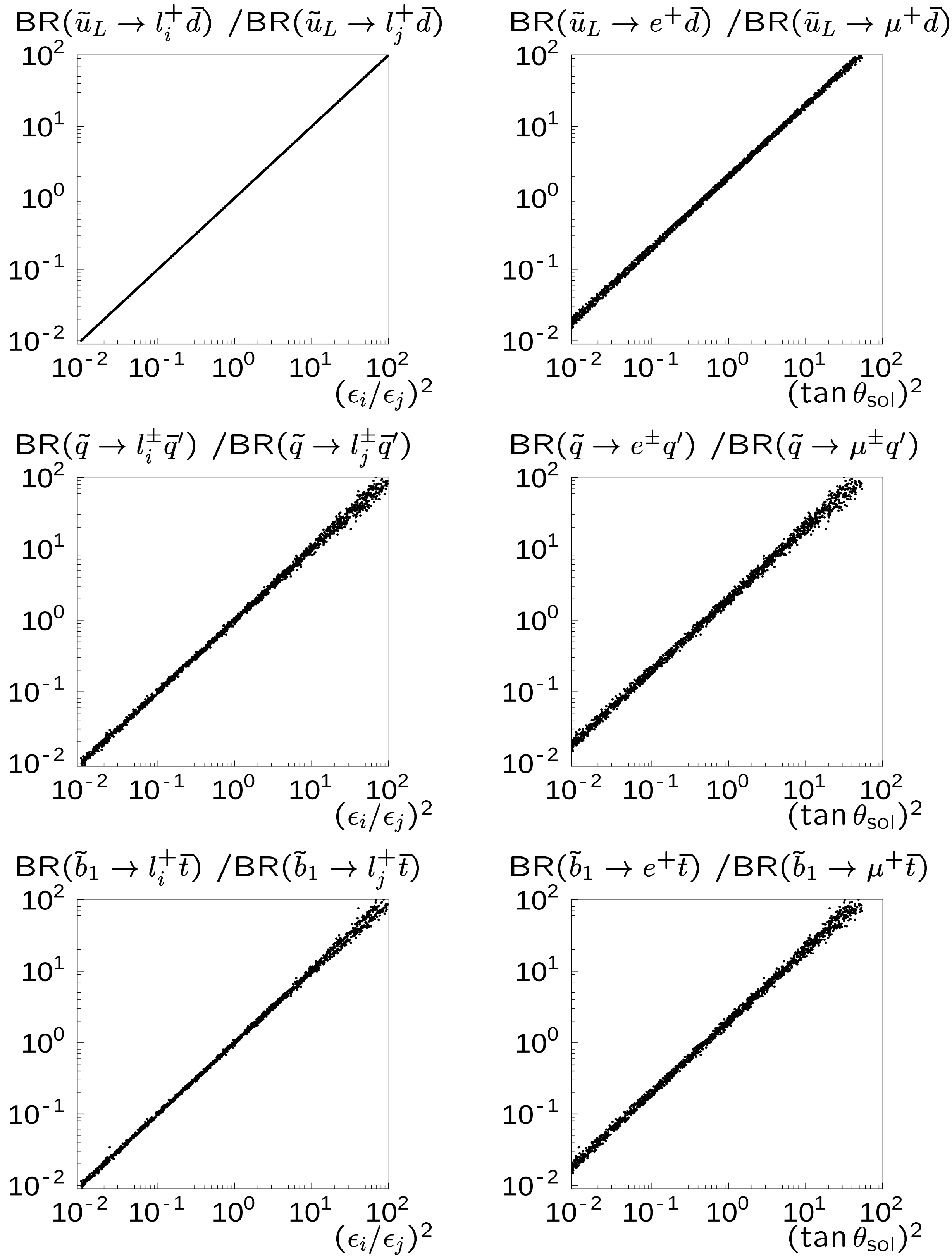
$$\tilde{q} \rightarrow q\,\nu$$
$$\tilde{q} \rightarrow q'\,l$$

R-parity conserving*

$$\tilde{q} \rightarrow \tilde{q}'\,q\,\overline{q}'$$

Later dominates if $m_{\tilde{q}} > m_{\tilde{q}'} + 5GeV$, important for $\tilde{d}_L$, because $m_{\tilde{d}_L} > m_{\tilde{u}_L} + 5GeV$ for $m_{\tilde{Q}} < 500$ GeV and $\tan\beta \geq 3$.

*A. Djouadi and Y. Mambrini, Phys. Rev. *D* 63 (2001)



Various ratios of squark branching ratios

Gluino

Decay modes

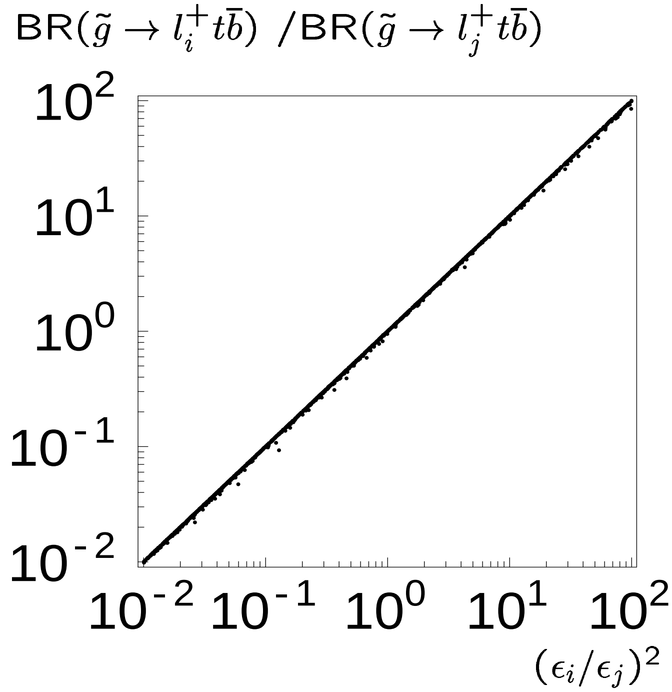
$$\tilde{g} \rightarrow \nu_i q\bar{q}$$
$$\tilde{g} \rightarrow l_j^{\pm} q'\bar{q}$$
$$\tilde{g} \rightarrow \nu_i g$$

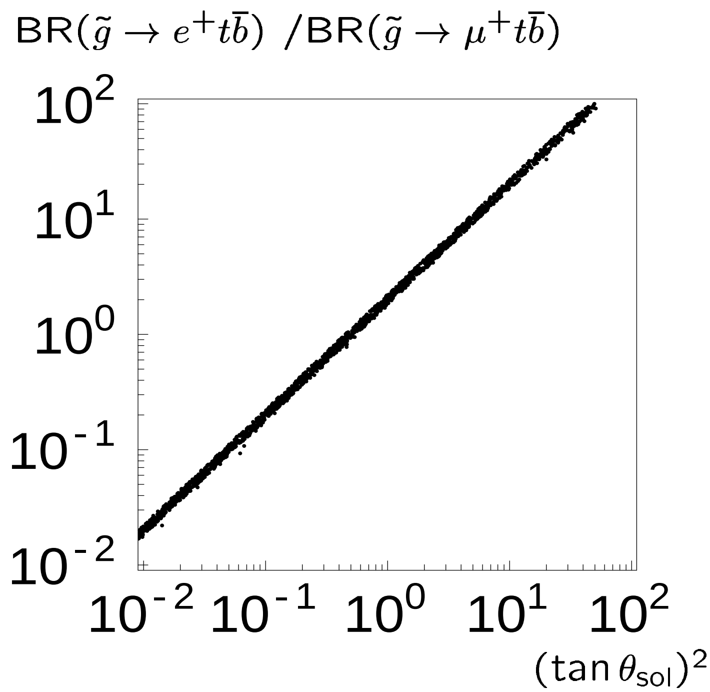
General features

$\tilde{g} \rightarrow \nu_i b\bar{b}$ dominates

BR($\tilde{g} \rightarrow l_j^- t\bar{b}$) is order per–cent

BR($\tilde{g} \rightarrow \nu_i c\bar{c}$) and BR($\tilde{g} \rightarrow \nu_i g$) is below per-mile





Various ratios of gluino branching ratios

Summary

- Independent of the nature of the LSPs: Always a correlation between ratios of the LSP branching ratios and neutrino mixing angles

- LSPs sensitive to atmospheric angle: $\tilde{\chi}^0_1$ and $\tilde{\chi}^+_1$

- LSPs sensitive to solar angle: $\tilde{l}$, $\tilde{\nu}$, $\tilde{q}$ and $\tilde{g}$

- GMSB with gravitino as LSP: R-parity violating decay modes of NLSP dominate over decay mode into gravitino