Correlations between neutrino physics

& collider physics in the bilinear model

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- Neutrino physics
- Neutralino decays & correlations
- Slepton decays & correlations
- Dark Matter

based on work with M. Díaz, M. Hirsch, D. Restrepo, J.C. Romão , J. Valle

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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 violation in charged lepton sector

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

$BR(\mu^- \to e^- e^+ e^-) \lesssim 10^{-12}$

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

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

$BR(\tau \to l l l') \lesssim O(10^{-6})$ $(l, l' = e, \mu)$

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

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

Neutralino Mass Matrix

basis $\psi^{0T} = (\nu_e, \nu_\mu, \nu_\tau, -i\lambda', -i\lambda^3, \widetilde{H}_d^1, \widetilde{H}_u^2)$ we get:

$$M_N = \begin{bmatrix} 0 & m \\ m^T & \mathcal{M}_{\chi^0} \end{bmatrix}$$

with

$$\mathcal{M}_{\chi^0} = \begin{bmatrix} M_1 & 0 & -\frac{1}{2}g'v_d & \frac{1}{2}g'v_u \\ 0 & M_2 & \frac{1}{2}gv_d & -\frac{1}{2}gv_u \\ -\frac{1}{2}g'v_d & \frac{1}{2}gv_d & 0 & -\mu \\ \frac{1}{2}g'v_u & -\frac{1}{2}gv_u & -\mu & 0 \end{bmatrix}, \quad m = \begin{bmatrix} -\frac{1}{2}g'v_1 & \frac{1}{2}gv_1 & 0 & \epsilon_1 \\ -\frac{1}{2}g'v_2 & \frac{1}{2}gv_2 & 0 & \epsilon_2 \\ -\frac{1}{2}g'v_3 & \frac{1}{2}gv_3 & 0 & \epsilon_3 \end{bmatrix}$$

Approximate diagonalization as in usual seesaw mechanism gives

$$m_{\nu,eff} = \frac{M_1 g^2 + M_2 g'^2}{4\, det(\mathcal{M}_{\chi^0})} \begin{pmatrix} \Lambda_1^2 & \Lambda_1\Lambda_2 & \Lambda_1\Lambda_3 \\ \Lambda_1\Lambda_2 & \Lambda_2^2 & \Lambda_2\Lambda_3 \\ \Lambda_1\Lambda_3 & \Lambda_2\Lambda_3 & \Lambda_3^2 \end{pmatrix}$$

where

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

second ν mass via loops

$$m_\nu^{\text{1lp}} \simeq \frac{1}{16\pi^2}\Big(3h_b^2 \sin(2\theta_{\tilde{b}}) m_b \log\frac{m^2_{\tilde{b}_2}}{m^2_{\tilde{b}_1}} + h_\tau^2 \sin(2\theta_{\tilde{\tau}}) m_\tau \log\frac{m^2_{\tilde{\tau}_2}}{m^2_{\tilde{\tau}_1}}\Big)\frac{(\tilde{\epsilon}_1^2+\tilde{\epsilon}_2^2)}{\mu^2}$$

$$\tilde{\epsilon}_i = V^\nu_{ji}\epsilon_j$$

mixing angles

$$\tan^2\theta_{atm} = \left(\frac{\Lambda_2}{\Lambda_3}\right)^2, U_{e3}^2 = \frac{\Lambda_1^2}{\Lambda_2^2+\Lambda_3^2}, \tan^2\theta_{sol} = \left(\frac{\tilde{\epsilon}_1}{\tilde{\epsilon}_2}\right)^2$$

experimental data require:

$$\frac{|\vec{\Lambda}|}{\sqrt{\det\mathcal{M}_{\tilde{\chi}^0}}} \sim O(10^{-6}), \qquad \frac{|\vec{\epsilon}|}{\mu} \sim O(10^{-4})$$

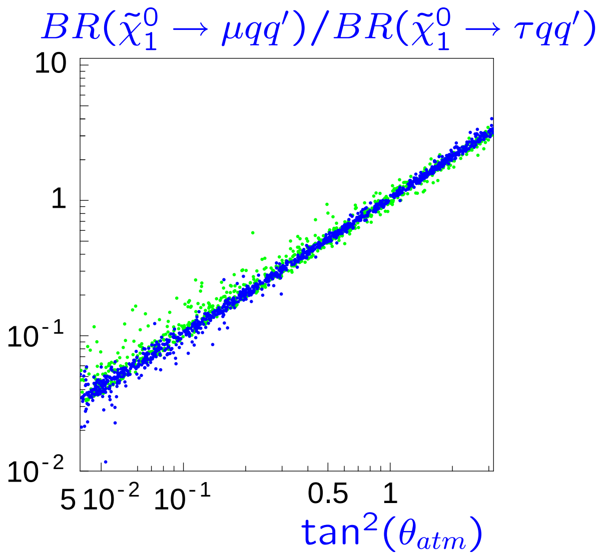
Approximate Couplings

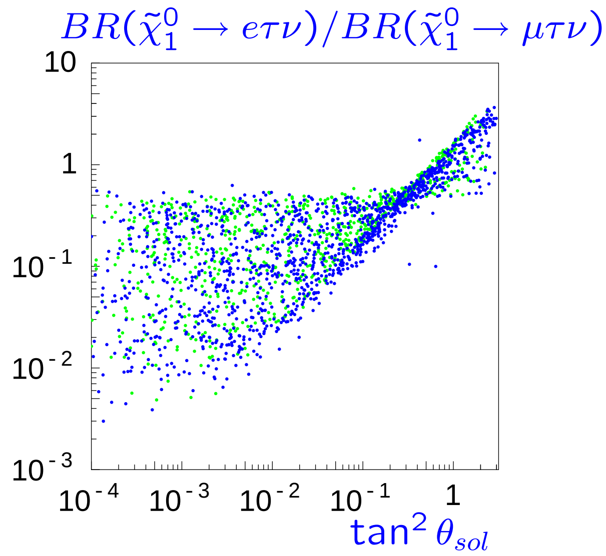
smallness of R-parity coupling $\Rightarrow$ expansion of all R-parity violating couplings:
$c = f(\mu, M_k, A_l, M_{\tilde{j}})\Lambda_i + g(\mu, M_k, A_l, M_{\tilde{j}})\epsilon_i$
e.g. $\tilde{\chi}^0_1$-$W^\pm$-l_i couplings:

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

$$
|O_{Ri}| \ll |O_{Li}|\,, \quad \left|\frac{O_{L2}}{O_{L3}}\right|^2 = \left|\frac{\Lambda_2}{\Lambda_3}\right|^2 \simeq \tan^2\theta_{atm}
$$

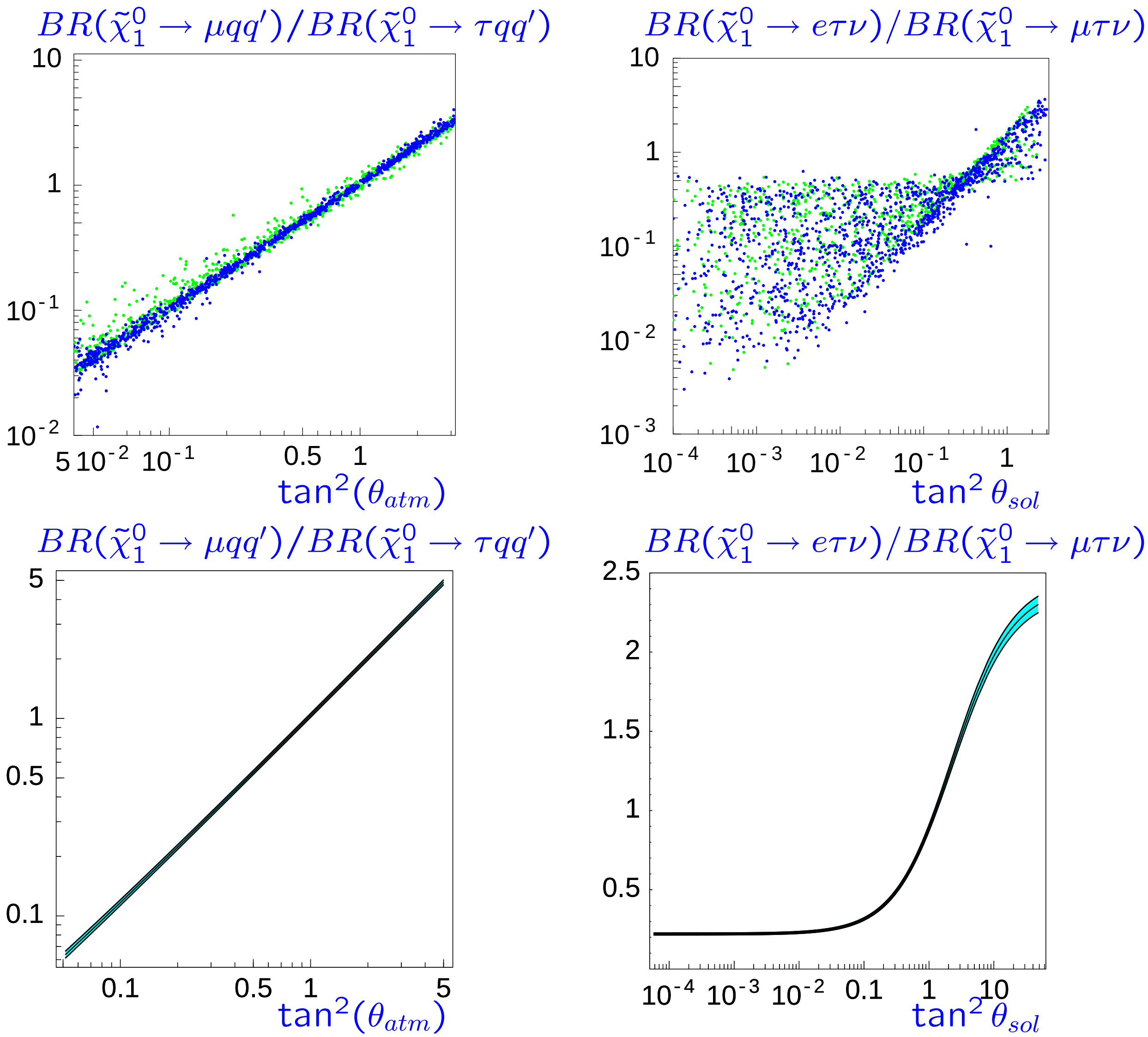
Correlations





Summing over all neutrinos.

Correlations

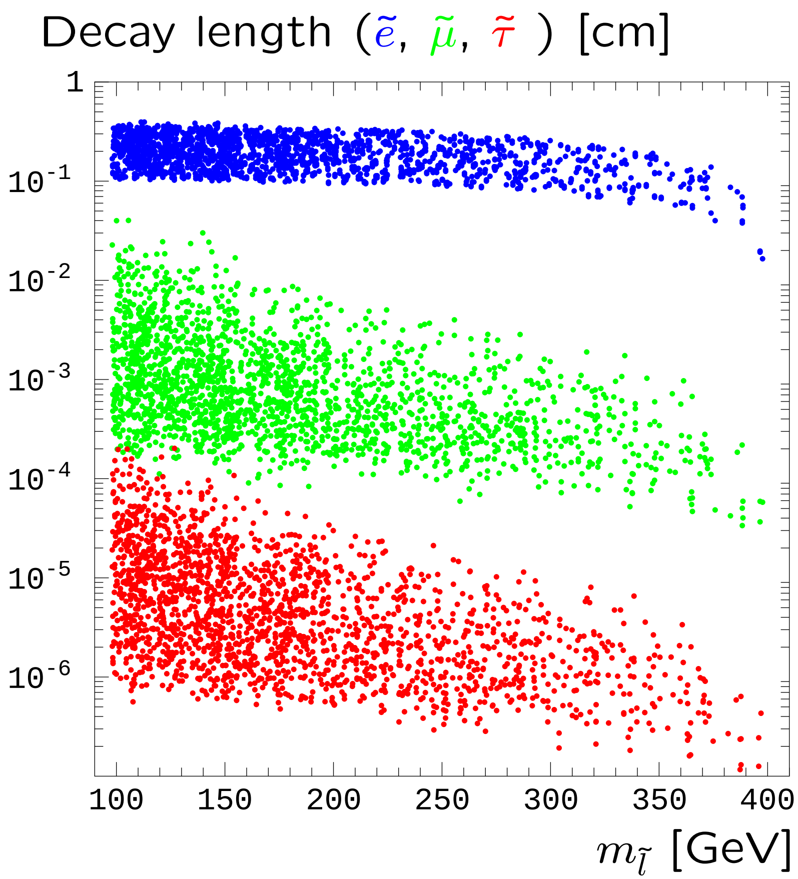


Assumptions:
- spectrum, mixing angles within 10 percent
- statistical error: 10^5 χ_1^0

Parameters:
$M_2 = 120$ GeV, $\mu = 500$ GeV
$\tan\beta = 5$, $m_0 = 500$ GeV
$A = -500$ GeV

Summing over all neutrinos.

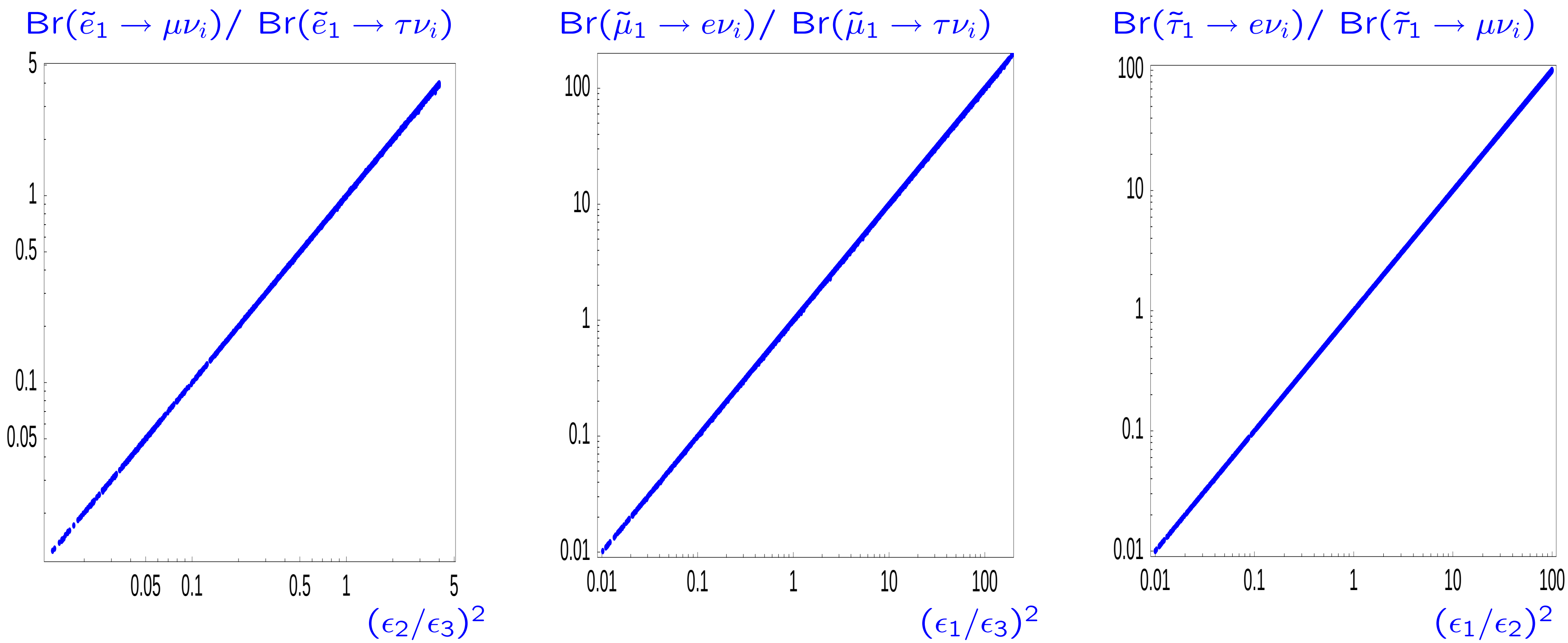
Charged Scalar LSP



$\Rightarrow$ $\tilde{e}$, $\tilde{\mu}$, $\tilde{\tau}$ can be seperated 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)

Neutralino decays

dominant modes R-parity violating modes

$$\Gamma(\tilde{\chi}^0_1 \to W^\pm l_i^\mp) \;\propto\; \frac{\Lambda_i^2}{\det \mathcal{M}_{\tilde{\chi}^0}}$$

$$\Gamma(\tilde{\chi}^0_1 \to \sum_i Z \nu_i)$$

$$\Gamma(\tilde{\chi}^0_1 \to \nu \tau^+ l_i^-) \;\propto\; \frac{\epsilon_i^2}{\mu^2}$$

R-parity conserving mode

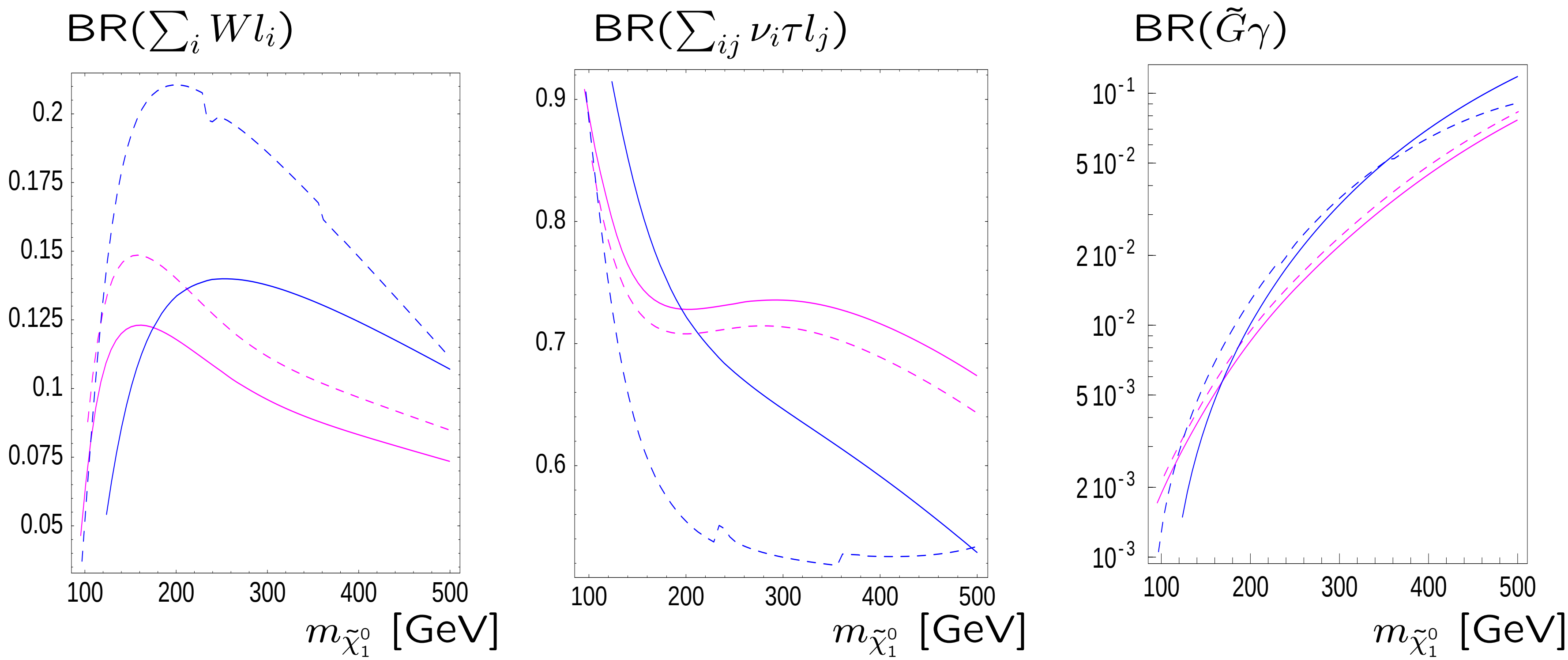
$$\Gamma(\tilde{\chi}^0_1 \to \tilde{G}\gamma) \;\simeq\; 1.2 \times 10^{-6} \kappa_\gamma^2 \left(\frac{m_{\tilde{\chi}^0_1}}{100 \text{ GeV}}\right)^5 \left(\frac{100 \text{ eV}}{m_{3/2}}\right)^2 \text{eV}$$

total width

$$\Gamma \simeq (10^{-4} - 10^{-2})\,\text{eV}$$

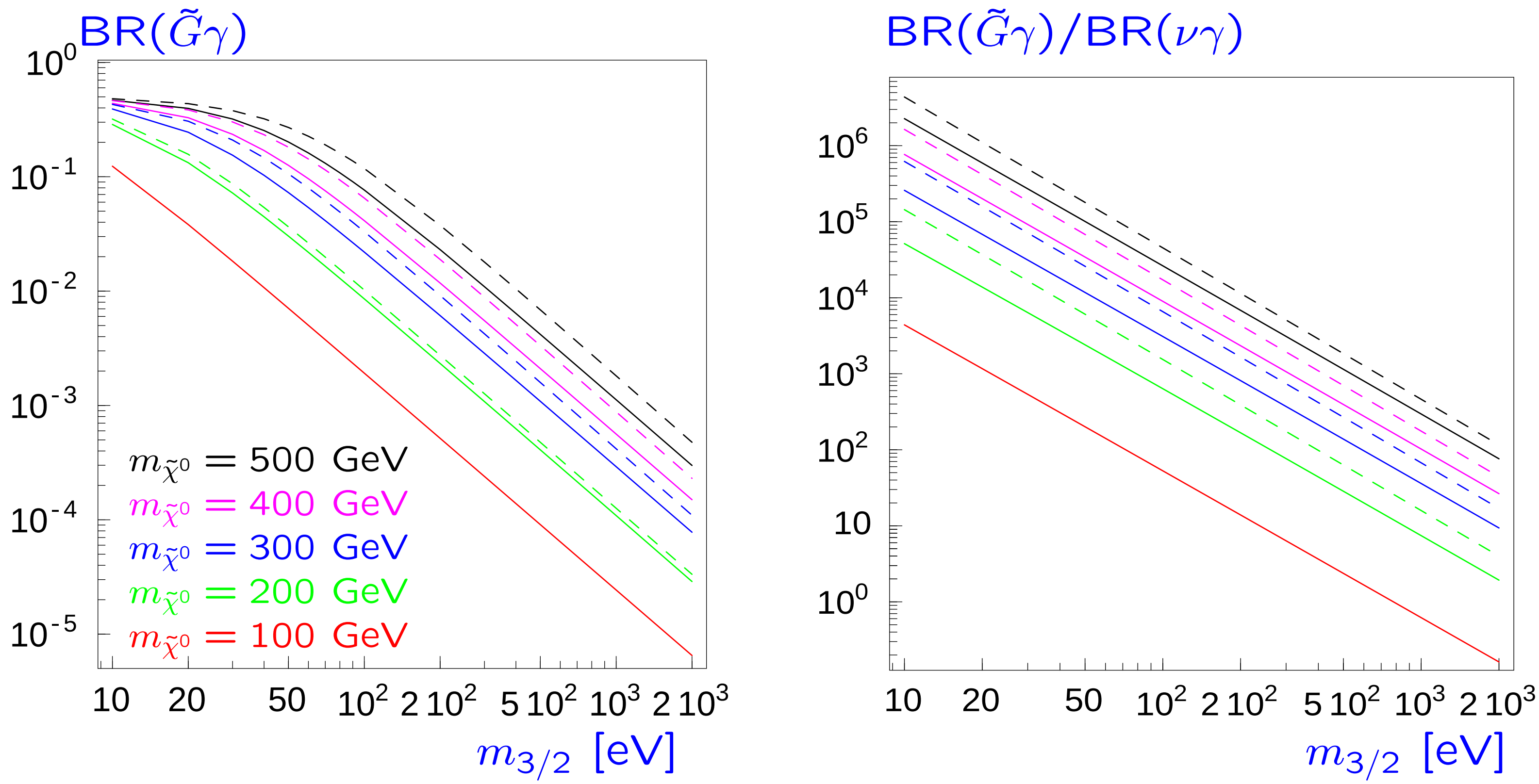
— $\tan\beta = 10,\ \mu > 0$, - - $\tan\beta = 10,\ \mu < 0$

— $\tan\beta = 35,\ \mu > 0$, - - $\tan\beta = 35,\ \mu < 0$



$m_{3/2} = 100$ eV, $n_5 = 1$

GMSB signals



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

Comments

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

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

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

Comments & Summary

- Solution to ν problems imply:
  $BR(\tilde{\chi}_1^0 \to \sum_{i,j,k} \nu_i \nu_j \nu_k) < 10\%$; $BR(\tilde{\chi}_1^0 \to \nu_k \gamma) < 10^{-5}\%$
  $BR(\tilde{\nu}_i \to \sum_{j,k} \nu_j \nu_k) < 1\%$
- It can be shown, that all SUSY particles have correlations between neutrino mixing angles and BRs if they are LSP
- Gravitino Dark Matter (e.g. GMSB) if $m_{3/2} \simeq O(100\ \text{eV})$

Correlations