Collider signals of gravitino dark matter

in bilinearly broken R-parity

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Gauge Mediated SUSY Breaking (GMSB)

Basis idea: transfer of SUSY breaking from hidden sector via messenger fields using gauge interactions

Messenger scale: $M_i(M_M) \sim g(x)\alpha_i\Lambda_G$, $M_j^2(M_M) \sim f(x)\sum C_i\alpha_i^2\Lambda_G^2$
$x = \Lambda_G/M_M$, $f(x), g(x) = (n_5 + 3n_{10})O(1)$

Generic prediction: light gravitino being the LSP

NLSP: $\tilde\chi_1^0$ *or* $\tilde l_R$ *(*$l = e, \mu, \tau$*)*

add bilinear R-parity violating terms:

$$W = W_{MSSM} + \epsilon_i \widehat{L}_i \widehat{H}_u, \qquad V_{\text{soft}} = V_{\text{soft}}^{MSSM} + B_i\epsilon_i\tilde L_i H_u.$$

$\Rightarrow$ *sneutrino vevs* v_i
in the following: take v_i *as free parameters instead* B_i

Gravitino Dark Matter

Standard thermal history of the universe:

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

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*)*

R-parity violation and neutrino masses/mixings

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

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

with

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

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

$$
\begin{aligned}
m_\nu^{\text{1lp}} &\simeq \frac{1}{16\pi^2}\Big(3h_b^2\sin(2\theta_{\tilde{b}})m_b\log\frac{m^2_{\tilde{b}_2}}{m^2_{\tilde{b}_1}} \\
&\qquad +h_\tau^2\sin(2\theta_{\tilde{\tau}})m_\tau\log\frac{m^2_{\tilde{\tau}_2}}{m^2_{\tilde{\tau}_1}}\Big)\frac{(\tilde{\epsilon}_1^2+\tilde{\epsilon}_2^2)}{\mu^2} \\
\tilde{\epsilon}_i &= V^\nu_{ji}\epsilon_j
\end{aligned}
$$

mixing angles

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

experimental data require:

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

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

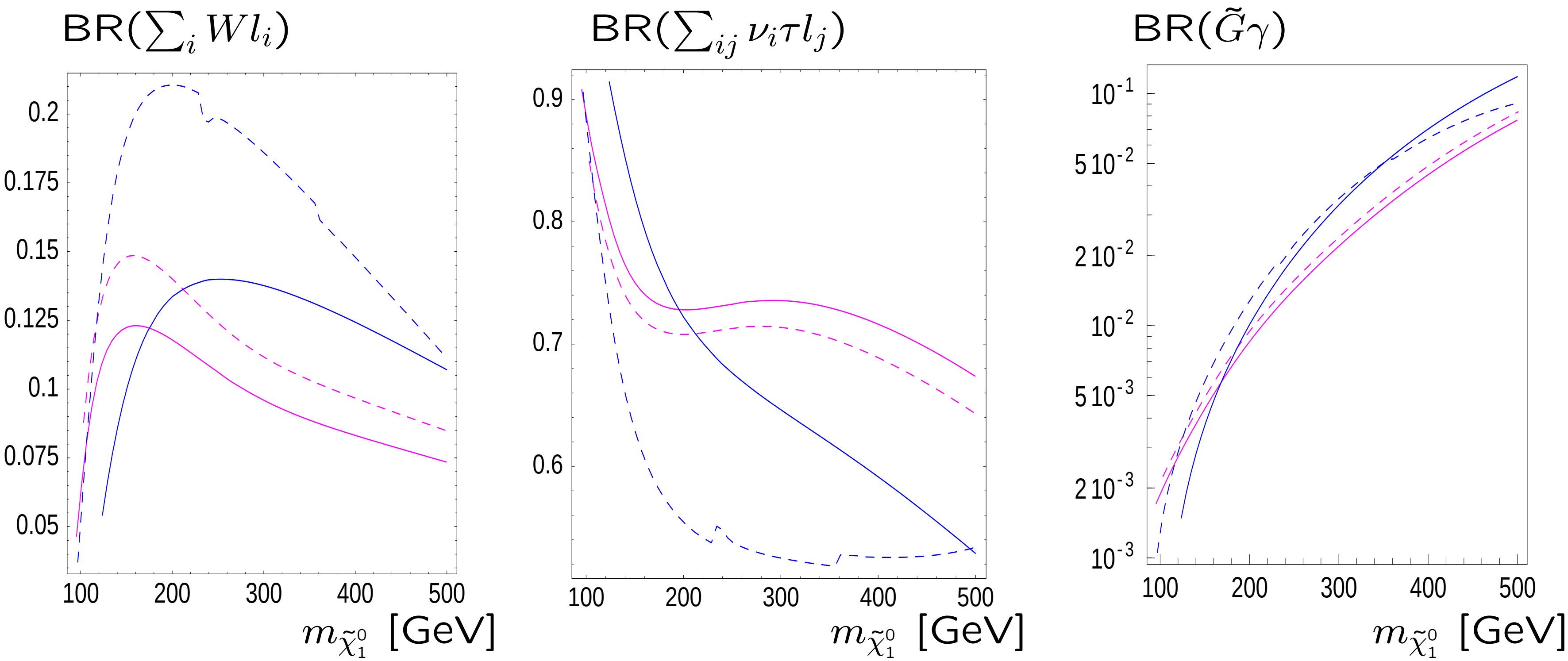
$$\Gamma(\tilde{\chi}^0_1 \to \tilde{G}\gamma) \;\simeq\; 1.2\times 10^{-6}\kappa_\gamma^2 \left(\frac{m_{\tilde{\chi}^0_1}}{100\text{ GeV}}\right)^5 \left(\frac{100\text{ eV}}{m_{3/2}}\right)^2 \text{eV}$$

total width

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

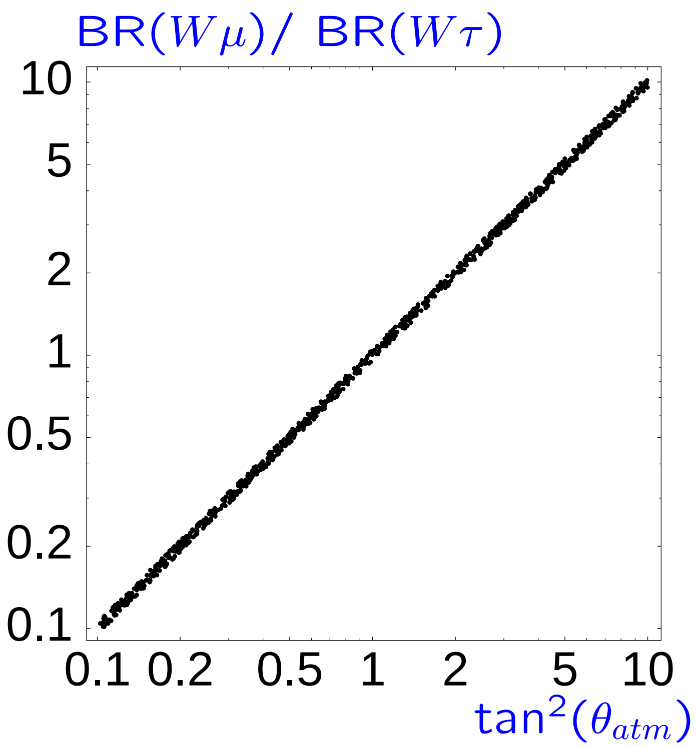
— $\tan\beta = 10,\ \mu > 0$, - - $\tan\beta = 10,\ \mu < 0$

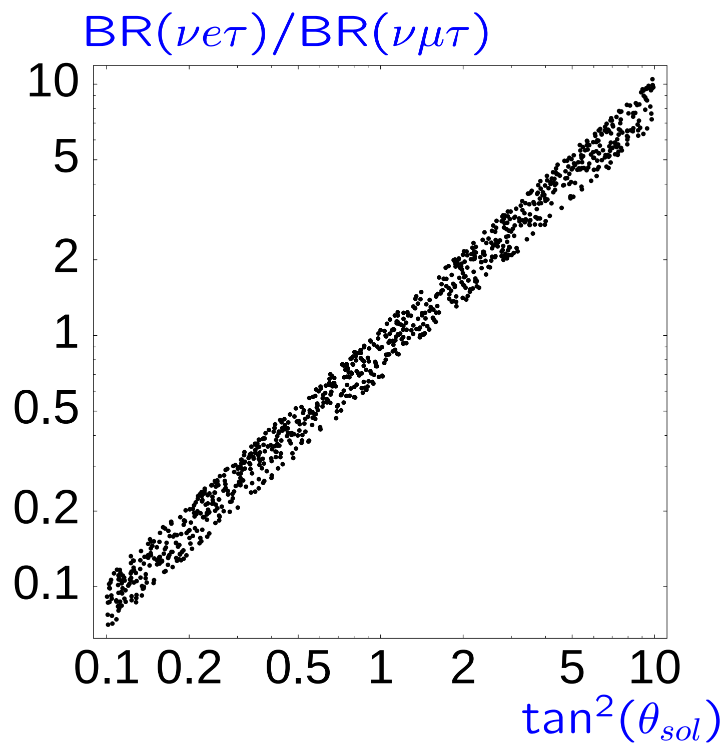
— $\tan\beta = 35,\ \mu > 0$, - - $\tan\beta = 35,\ \mu < 0$



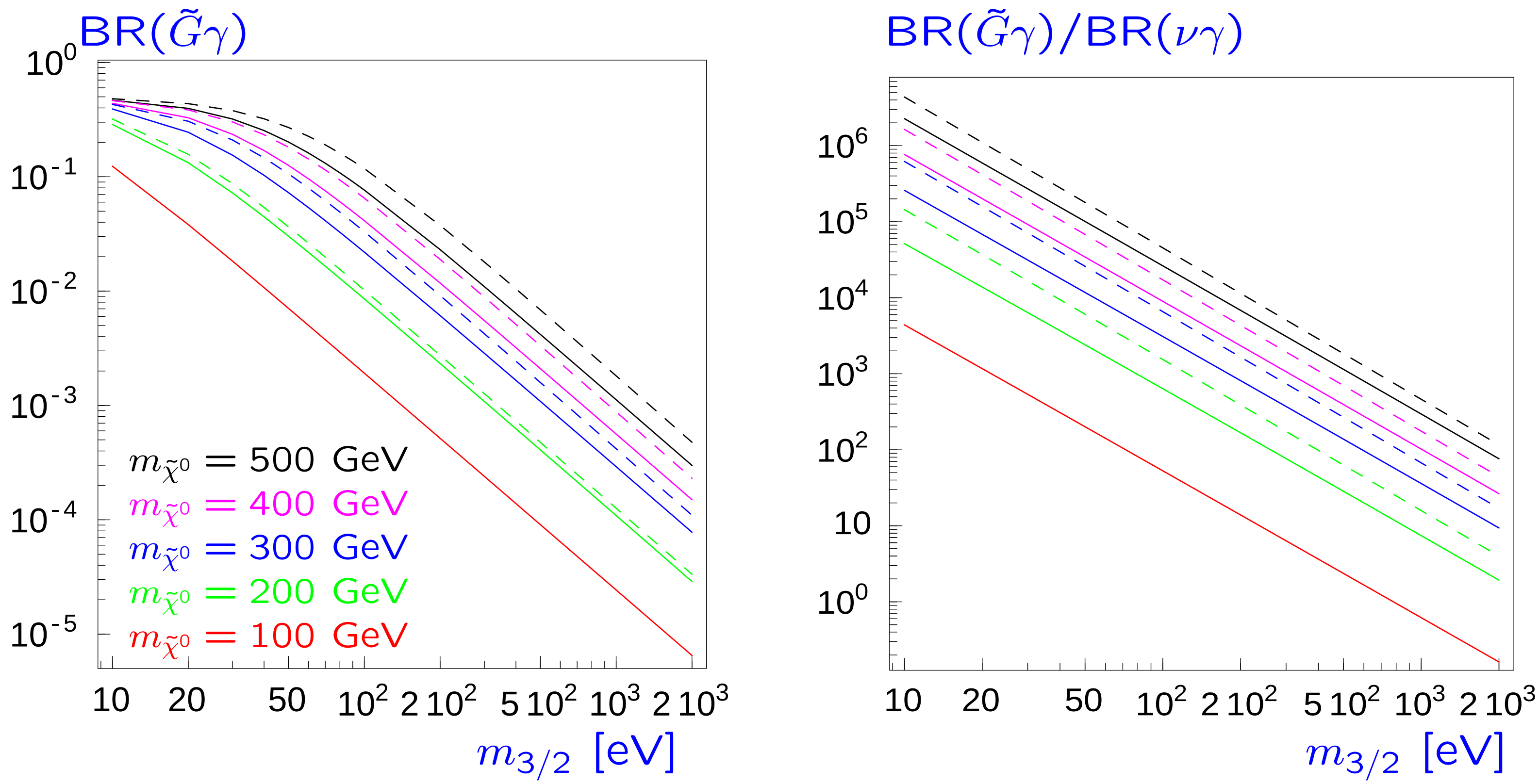
$m_{3/2} = 100$ eV, $n_5 = 1$

Correlations





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* $\tilde{\chi}^0_1$

- $\tilde{l}_R$ *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:*

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

Conclusions

- *GMSB + RP-violation:* $\tilde{G}$ *is natural DM candidate*
- *BR(*$\tilde{\chi}_1^0 \to \tilde{G}\,\gamma$*) sufficiently large in the cosmologically interesting region to get* $m_{3/2}$
- *correlations between neutralino decay modes and neutrino mixing angles*