Quasi-stable neutralinos at the LHC.

The gravitino – neutralino connection



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Outline

> Framework and model

- Gravitino problem
- Bilinear R-parity breaking

> Detection possibilities

Gravitino LSP decays
Neutralino NLSP decays

> Conclusion

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R-parity violation (RPV)

- > RPV allows the NLSP to decay non gravitationally.
- > Lower bound of 10^{-12} on RPV couplings solves the gravitino problem.
- > Upper bound of 10^{-7} ensures non wash-out of baryon asymmetry.
- > This range lies much lower than in usual RPV benchmark points.



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- > Adding a lepton number violating term to the superpotential

$$\Delta W = \mu_i H_u l_i$$

and accordant terms to the soft Susy breaking Lagrangian

$$-\Delta \mathcal{L} = B_i H_u \tilde{l}_i + m_{id}^2 \tilde{l}_i^{\dagger} H_d + \text{h.c.}$$

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$$l_i \longrightarrow \times \longrightarrow \widetilde{h} \qquad l_i \xrightarrow{\langle \widetilde{\nu}_i \rangle \ |} \widetilde{h}$$

> Notably, the sneutrino acquires a VEV.



- > It is convenient to trade the mass mixing and its effects for Yukawa couplings.
- > This is done by supersymmetric field redefinitions:

$$H_d = H'_d - \epsilon_i l'_i , \qquad l_i = l'_i + \epsilon_i H'_d , \qquad \epsilon_i = \frac{\mu_i}{\mu}$$



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> Afterwards non-supersymmetric field redefinitions in the scalar sector eliminate the remaining bilinear couplings (as well as the sneutrino VEV):*

$$H'_{d} = H''_{d} - \epsilon'_{i} \tilde{l}''_{i} \qquad \epsilon'_{i} \text{ and } \epsilon''_{i} \text{ are } f(\epsilon_{i}, B_{i}, m^{2}_{id})$$
$$\varepsilon H^{*}_{u} = \varepsilon H'^{*}_{u} - \epsilon''_{i} \tilde{l}'_{i} \qquad \tilde{l}'_{i} = \tilde{l}''_{i} + \epsilon'_{i} H''_{d} + \epsilon''_{i} \varepsilon H'^{*}_{u}$$

^{*}S. Bobrovskyi, W. Buchmüller, J. Hajer, J. Schmidt: JHEP 1010, 061 (2010) – arXiv:1007.5007 [hep-ph]



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$$\begin{split} H'_{d} &= H''_{d} - \epsilon'_{i} \tilde{l}''_{i} & \epsilon'_{i} \text{ and } \epsilon''_{i} \text{ are } f(\epsilon_{i}, B_{i}, m_{id}^{2}) \\ \varepsilon H^{*}_{u} &= \varepsilon H'^{*}_{u} - \epsilon''_{i} \tilde{l}''_{i} & \tilde{l}'_{i} = \tilde{l}''_{i} + \epsilon'_{i} H''_{d} + \epsilon''_{i} \varepsilon H'^{*}_{u} \\ \\ \Rightarrow \text{ The combination } |\zeta_{i}| &= \left| \frac{\epsilon'_{i} v_{d} + \epsilon''_{i} v_{u}}{v} \right| \text{ is a measure for RPV.} \end{split}$$

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Gravitino LSP lifetime

> The Gravitino decay



leads to a Lifetime longer than the age of the universe:

$$\tau_{3/2}(\gamma\nu) = 1 \times 10^{27} \,\mathrm{s} \left(\frac{\zeta}{10^{-7}}\right)^{-2} \left(\frac{m_{\chi_1^0}}{100 \,\mathrm{GeV}}\right)^2 \left(\frac{m_{3/2}}{10 \,\mathrm{GeV}}\right)^{-3}$$



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-> Hence gravitino is still a viable dark matter candidate.



Constraining ζ with gravitino LSP decays

- > Detection of Gravitino decays is possible with gamma rays.
- > Absence of signal at Fermi LAT leads to upper bound of $\zeta = 3 \times 10^{-8}$.*



*G. Vertongen, C. Weniger: JCAP 1105, 027 (2011) - arXiv:1101.2610 [hep-ph]





Neutralino NLSP decay length

- > Neutralino is the NLSP in a large range of the mSUGRA parameter space.
- > After production at the LHC it will predominantly decay via RPV couplings into SM particles.





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> Hence, the neutralino has a macroscopic decay length:

$$\begin{split} c\tau_{\chi_1^0} \gtrsim 2.7\,\mathrm{m} \left(\frac{m_{\chi_1^0}}{100\,\mathrm{GeV}}\right)^{-1} \left(\frac{\zeta}{3\times 10^{-8}}\right)^{-2} \\ \times \left(2f_W(m_{\chi_1^0}) + f_Z(m_{\chi_1^0})\right)^{-1}\,. \end{split}$$

-> This is detectable at the LHC.



Typical decay cascade at the LHC

Squarks and gluinos produced at the LHC will decay into the lightest neutralino.





Typical decay cascade at the LHC

Squarks and gluinos produced at the LHC will decay into the lightest neutralino, which in turn decay into SM particles.



We have concentrated our search on muons with a secondary vertex coming from the ${\cal Z}$ decay.



Simulation

- > We performed a simulation with MadGraph for the $7\,\mathrm{TeV}$ LHC.
- > With Pythia we generated events with mSUGRA boundary conditions.

 $m_{1/2} = m_0 = 270, \ 350, \ 500, \ 650, \ 800 \,\text{GeV}$ $\tan \beta = 10 \ , \quad a_0 = 0$ and $\zeta = 3 \times 10^{-8} \ \dots \ 10^{-10}.$

> Afterwards we analyzed the decays with DELPHES in a CMS like geometry.



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- > Afterwards we analyzed the decays with DELPHES in a CMS like geometry.
- > Due to the large secondary vertex we could suppress the SM background very efficiently.

Of $10^6 \ {\rm generated}$ background events $0 \ {\rm remained}$ after cuts.

> The detector response to cosmic muons remains as major hard-to-predict background.



Detector

Layout of one quarter of the generic detector used for particle identification.





Contour plot for the density of neutralino decays

$$m_{1/2} = m_0 = 270 \,\text{GeV}, \quad \zeta = 3 \times 10^{-8} \quad \text{and} \quad \mathcal{L} = 10 \,\text{fb}^{-1}$$





Location of all neutralino decays





5σ discovery reach in ζ

$$\chi_1^0 \to Z\nu \to \mu^+\mu^-\nu$$



The bands represent different assumptions about the background.



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- > Neutralino and gravitino decays are governed by the same coupling.
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Gravitino – neutralino connection

- Neutralino and gravitino decays are governed by the same coupling.
- -> Hence, model independent predictions are possible.
- > Measurement of mass and lifetime of both particles allows microscopic determination of the Planck mass:*

$$\begin{split} M_{\rm P} &= 3.6 \times 10^{18} \,{\rm GeV} \left(\frac{m_{3/2}}{m_{\chi_1^0}}\right)^{3/2} \left(\frac{\tau_{3/2}(\gamma\nu)}{10^{28}\,{\rm s}}\right)^{1/2} \left(\frac{\tau_{\chi_1^0}}{10^{-7}\,{\rm s}}\right)^{-1/2} \\ & \times \left(2f_W(m_{\chi_1^0}) + f_Z(m_{\chi_1^0})\right)^{-1/2} \end{split}$$

*W. Buchmüller, L. Covi, K. Hamaguchi, A. Ibarra, T. Yanagida: JHEP 0703, 037 (2007) – [hep-ph/0702184 [HEP-PH]]

- > I presented a model derived from consistent Cosmology.
- > Dark matter decays are detectable via gamma ray lines.
- > Quasi-stable neutralino decays are detectable at the LHC.
- > Microscopic determination of the Planck mass is possible.



Thank You!

References

- S. Bobrovskyi, W. Buchmüller, J. Hajer, J. Schmidt Broken R-Parity in the Sky and at the LHC JHEP 1010, 061 (2010) – arXiv:1007.5007 [hep-ph]
- S. Bobrovskyi, W. Buchmüller, J. Hajer, J. Schmidt Quasi-stable neutralinos at the LHC arXiv:1107.0926 [hep-ph]

