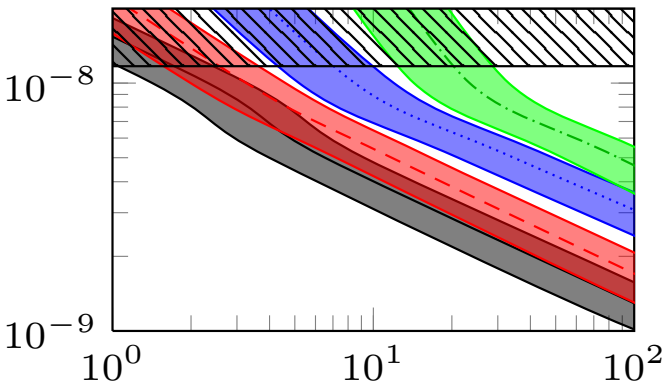
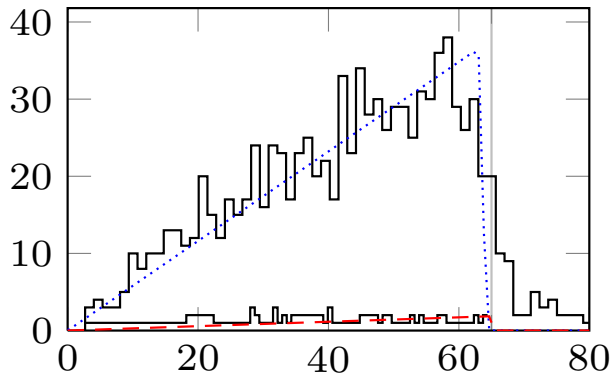
Higgsinos with broken R-parity at the LHC.





Jan Hajer

LEXI – Connecting Particles with the Cosmos
DESY, October 11, 2012

HELMHOLTZ GEMEINSCHAFT

DESY

Higgsinos with broken R-parity at the LHC

> **Higgsino World**
- Mono-jet Signal
- Detectability

> **R-Parity Violation**
- Bilinear R-parity Violation
- Cosmology with Gravitino DM
- Displaced Higgsino Decays
- Discovery Reach

Higgsino World

The Superpotential W and soft SUSY breaking Lagrangian $\mathcal{L}_{\text{soft}}$ of the MSSM

$$
\begin{aligned}
W &= \mu H_u H_d + \lambda^u_{ij} q_i u^c_j H_u + \lambda^d_{ij} d^c_i q_j H_d + \lambda^e_{ij} l_i e^c_j H_d \ , \\
-\mathcal{L}_{\text{soft}} &= m_u^2 H_u^\dagger H_u + m_d^2 H_d^\dagger H_d + (B H_u H_d + \text{h.c.}) \\
&\quad + \widetilde{m}^2_{li} \widetilde{l}^\dagger_i \widetilde{l}_i + \widetilde{m}^2_{ei} \widetilde{e}^{c\dagger}_i \widetilde{e}^c_i + \widetilde{m}^2_{qi} \widetilde{q}^\dagger_i \widetilde{q}_i + \widetilde{m}^2_{ui} \widetilde{u}^{c\dagger}_i \widetilde{u}^c_i + \widetilde{m}^2_{di} \widetilde{d}^{c\dagger}_i \widetilde{d}^c_i \\
&\quad + \frac{1}{2} \left(M_1 \widetilde{B}\widetilde{B} + M_2 \widetilde{W}\widetilde{W} + M_3 \widetilde{g}\widetilde{g} + \text{h.c.} \right) + \text{trilinear } A \text{ terms} \ .
\end{aligned}
$$

- The supersymmetric Higgsino mass parameter μ is, in general, independent of the soft SUSY breaking masses.
- Extra dimensional GUT models may lead to gauge-mediated supersymmetry breaking, generating the soft masses.
- The μ parameter, however, is generated by gravity mediation.
- Hence one can end up with models in which the Higgsinos have masses of order 100 GeV (and a small mass splitting) and the rest of the supersymmetric spectrum is above 1 TeV. [Brümmer and Büchmuller 2011]

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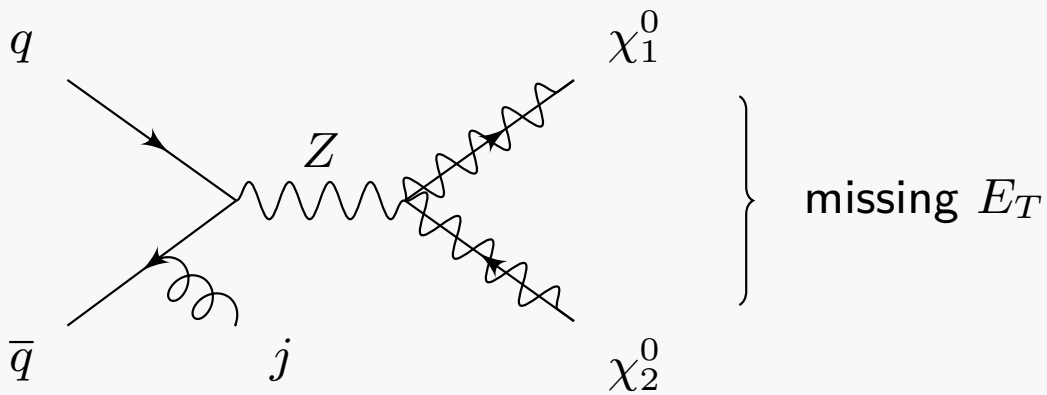
Mono-jet Signal

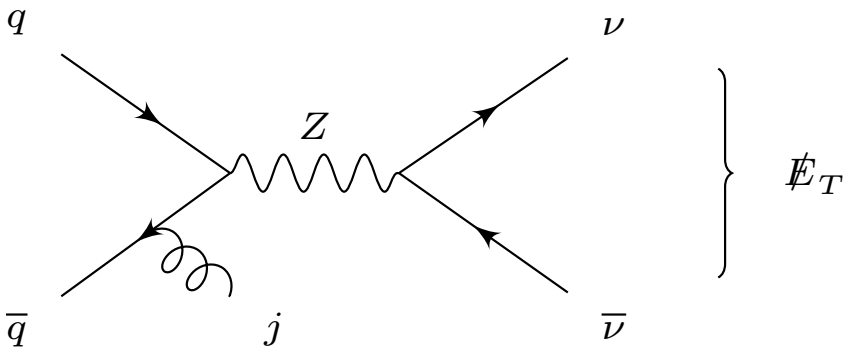
- In such a model the coloured sparticles might be too heavy to be produced at the LHC.
- Hence the usual SUSY decay chains are not accessible.
- Electroweak production of Higgsinos is dominant.

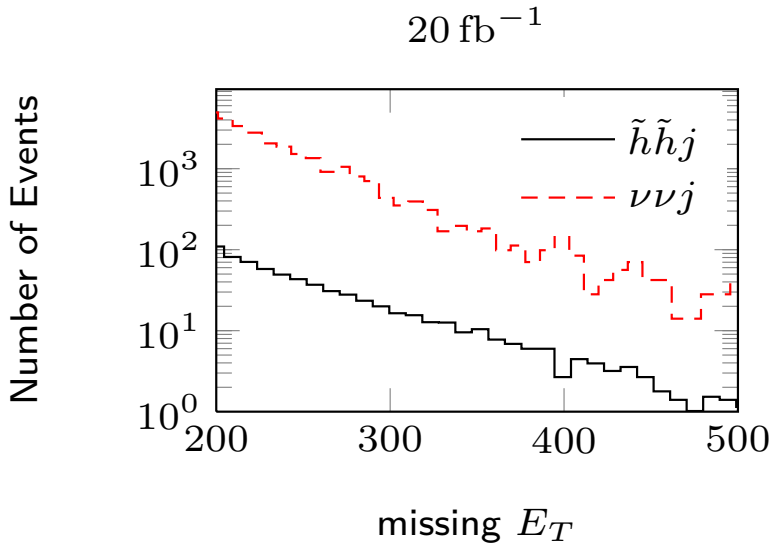
An additional jet leads to an missing E_T signature.



Detectability

The SM background to such an mono-jet event is an invisibly decaying Z boson with a jet.





- There is no possibility to find the signal over this background.
- Hence, SUSY might be right around the corner but invisible.

R-Parity Violation

If R-parity is broken, in general, many new parameters are introduced

$$\Delta W = \mu_i H_u l_i + \frac{1}{2}\lambda_{ijk} l_i e^c_j l_k + \lambda'_{ijk} d^c_i q_j l_k + \lambda''_{ijk} u^c_i d^c_j d^c_k \ ,$$
$$-\Delta\mathcal{L} = B_i H_u \tilde{l}_i + \left(m^2_{id} \tilde{l}^\dagger_i H_d + \text{h.c.}\right) + \text{trilinear terms} \ .$$

- These couplings are strongly constraint by experiment, as they might for example lead to proton decay.
- Hence one has to restrict the couplings.
- One possibility is bilinear R-parity breaking.

Bilinear R-parity Violation

In the case of bilinear R-parity violation, one introduces only the bilinear terms.

$$\Delta W = \mu_i H_u l_i \ , \qquad -\Delta\mathcal{L} = B_i H_u \tilde{l}_i + \left(m_{id}^2 \tilde{l}_i^\dagger H_d + \text{h.c.} \right) \ .$$

A supersymmetric rotation

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

trades the bilinear term in the superpotential for lepton number violating trilinear terms

$$\Delta W = \frac{1}{2} \lambda_{ijk} l_i e_j^c l_k + \lambda'_{ijk} d_i^c q_j l_k \ .$$

which are proportional to the SM Yukawa couplings

$$\lambda_{ijk} = -h_{ij}^e \epsilon_k + h_{kj}^e \epsilon_i \qquad \lambda'_{ijk} = -h_{ij}^d \epsilon_k$$

Bilinear R-parity Violation

A second non-supersymmetric rotation

involving only the scalars

$$H_d' = H_d'' - \epsilon_i' \tilde{l}_i'' \ , \qquad \varepsilon H_u^* = \varepsilon H_u'^* - \epsilon_i'' \tilde{l}_i'' \ , \qquad \tilde{l}_i' = \tilde{l}_i'' + \epsilon_i' H_d'' + \epsilon_i'' \varepsilon H_u'^* \ ,$$

trades all bilinear terms in $\mathcal{L}_{\text{soft}}$ for trilinear terms similar to the first rotation.

After electroweak symmetry breaking

R-parity violating phenomenology depends mostly on one linear combination of the parameters

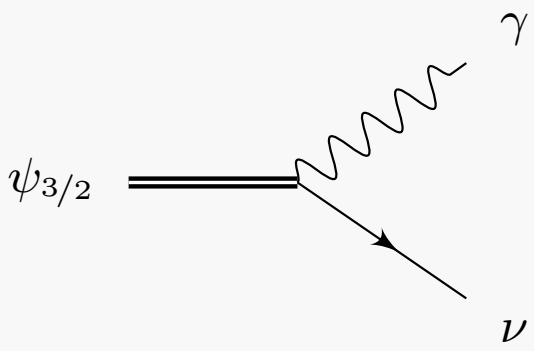
$$\zeta_i = \frac{\epsilon_i' v_d + \epsilon_i'' v_u}{v} \ , \qquad \zeta^2 = \sum_i \zeta_i^2 \ .$$

[Bobrovskyi, Buchmüller, JH, and Schmidt 2010]

Cosmology with Gravitino DM

Gravitino DM

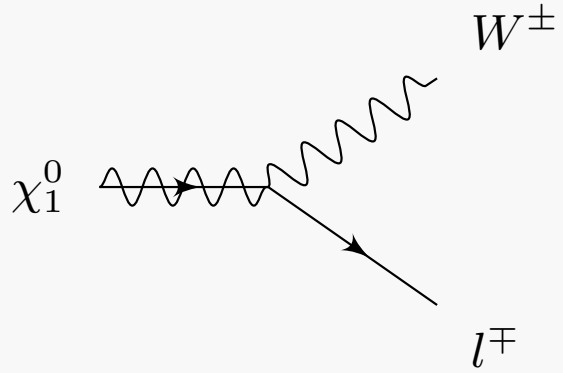
The Gravitino is not stable and decays into neutrinos and photons



As Fermi-LAT has not found a suitable signal, we derive a upper bound of $\zeta \lesssim 10^{-8}$.

Higgsino NLSP

New decay channels for the NSLP open up, it can decay into leptons and W bosons.



For $\zeta \gtrsim 10^{-13}$ all neutralinos decay before BBN.

R-parity violation leads to a consisted Cosmology with decaying Gravitino DM.

$$\tau_{3/2}(\gamma\nu) = 1 \times 10^{27}\,\mathrm{s} \left(\frac{\zeta}{10^{-8}}\right)^{-2} \left(\frac{m_{\chi_3^0}}{1\,\mathrm{TeV}}\right)^{2} \left(\frac{m_{3/2}}{10\,\mathrm{GeV}}\right)^{-3}$$

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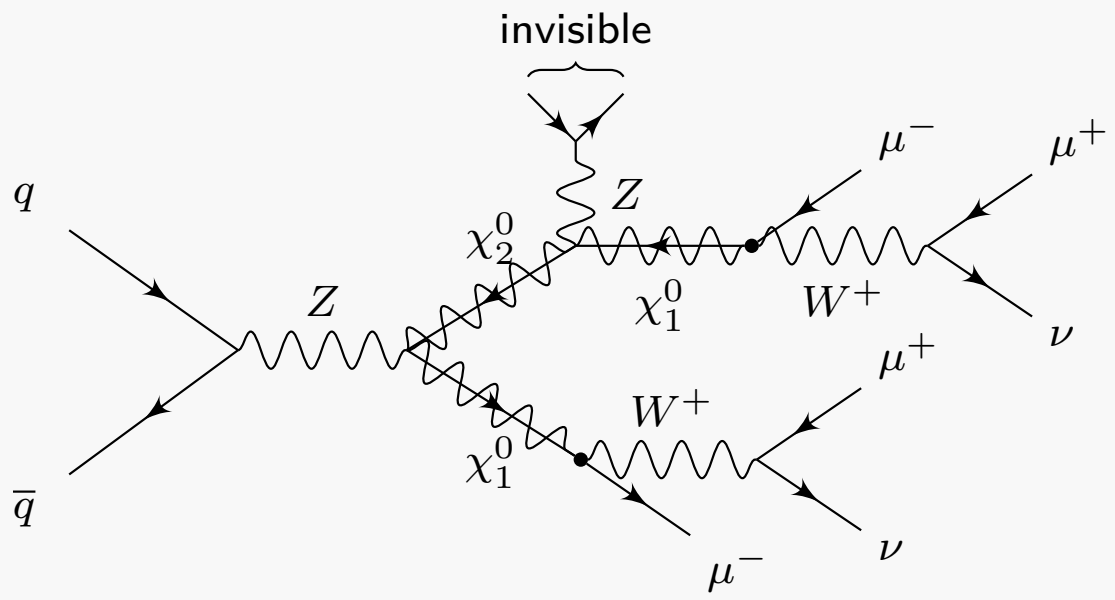
Displaced Higgsino Decays

Higgsino decay length

$$c\tau_{\chi_1^0} \gtrsim 40\,\text{cm} \left(\frac{m_{\chi_1^0}}{100\,\text{GeV}}\right)^{-1} \left(\frac{m_{3/2}}{10\,\text{GeV}}\right)^{3} \left(\frac{\tau_{3/2}(\gamma\nu)}{10^{28}\,\text{s}}\right) f_W(m_{\chi_1^0})^{-1}$$

A typical event at the LHC



- Due to the large decay length we are only considering signals with muons.
- Usually only one neutralino decays inside the detector volume.

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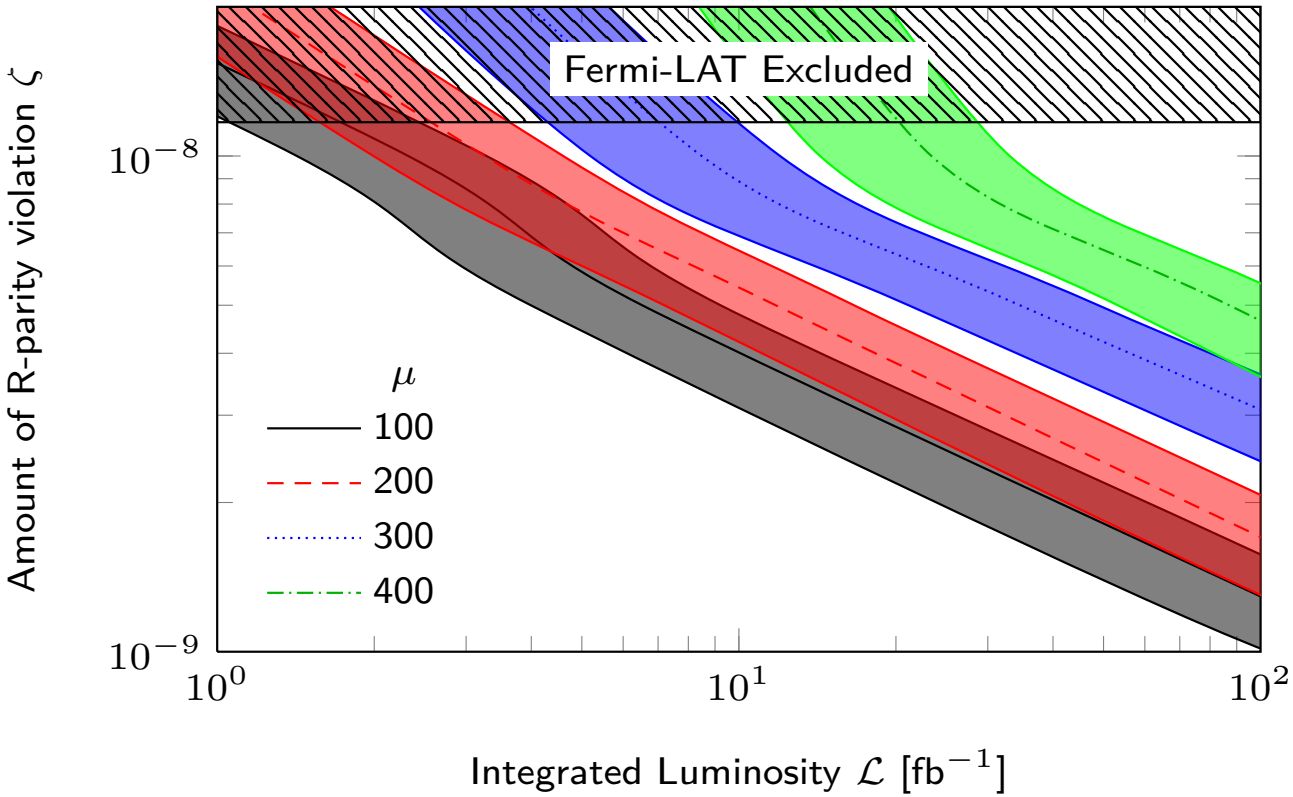
Signal and Background

- Higgsino NLSPs with R-parity violation would lead to two muons with a secondary vertex.
- The most dangerous backgrounds are di-boson and top pair production.
- However, due to the large decay length we are able to separate this background from the signal.
- And we are left with cosmics and detector effects as major background, which we can not simulate.

Discovery Reach

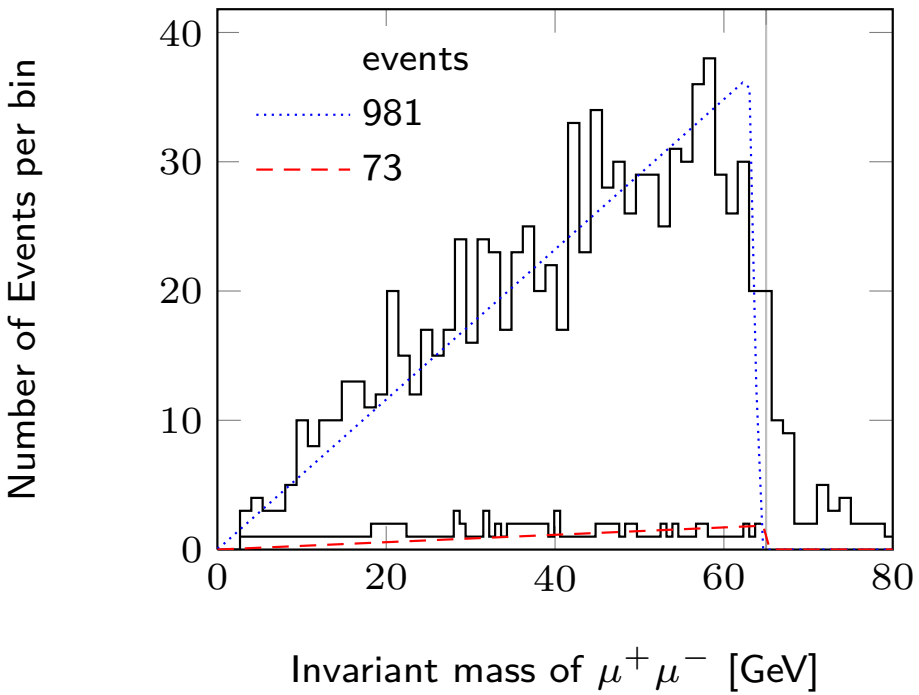
If we live in a Higgsino world with broken R-parity we might be able to see this in the near future

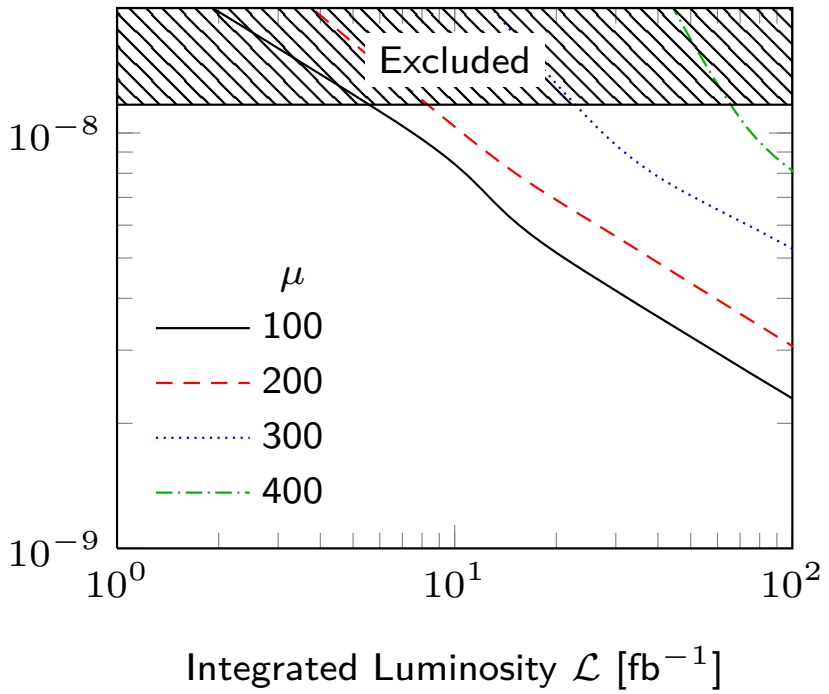


[Bobrovskyi, JH, and Rydbeck 2012]

Discovery Reach

With enough events it is possible to reconstruct the lightest Higgsino mass.





Conclusion

- In hybrid mediation models the Higgsino mass can be considerably smaller than the rest of the SUSY spectrum.
- It is very challenging to find such Higgsinos at the LHC because of the invisible decaying Z.
- If R-parity is broken the Higgsinos would decay and could be observable.
- In this case the Gravitino could be a DM candidate.

Thank You