

Multiphoton Signatures of Multisector Gauge Mediation

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First of all, sorry for the title change!



Motivation

- ▶ No sign of SUSY after RUN-1 – Minimal scenarios are already tightly constrained.
- ▶ Need to broaden the search to non-minimal scenarios and non-standard signatures.
- ▶ E.g. Multiphoton ($n_\gamma \geq 3$) + MET signatures can expose models of Gauge Mediation with multiple Hidden Sectors.
- ▶ Multiphotons (with or without MET) are also of interest for a large variety of models (exotic Higgs decays, new vector bosons, CP odd scalars) but not much has been done so far.

Plan

- ▶ General remarks on SUSY breaking and GMSB
- ▶ Show how the standard phenomenology of GMSB is modified if SUSY is broken in more than one hidden sector.
- ▶ Main Points
 - Softer final state spectrum
 - Existing LHC searches are poorly sensitive
 - Additional photons in the final states
 - These models can be probed with new, dedicated, searches

Some Theory References

- ▶ The idea of multiple hidden sectors was discussed originally in the context of Gravity Mediation in: C. Cheung, Y. Nomura and J. Thaler, “*Goldstini*,” JHEP **1003** (2010) 073 [arXiv:1002.1967 [hep-ph]].
- ▶ Earlier work in the “brane-world” context: K. Benakli and C. Moura, “*Brane-Worlds Pseudo-Goldstinos*,” Nucl. Phys. B **791** (2008) 125 [arXiv:0706.3127 [hep-th]].
- ▶ The extension to the case of Gauge Mediation was done in R. Argurio, Z. Komargodski and A. Mariotti, “*Pseudo-Goldstini in Field Theory*,” Phys. Rev. Lett. **107** (2011) 061601 [arXiv:1102.2386 [hep-th]].

- ▶ The phenomenological implications of this last scenario were examined in a series of works:
 - R. Argurio, K. De Causmaecker, G. Ferretti, A. Mariotti, K. Mawatari and Y. Takaesu, “*Collider signatures of goldstini in gauge mediation,*” JHEP **1206** (2012) 096 [arXiv:1112.5058 [hep-ph]].
 - T. Liu, L. Wang and J. M. Yang, “*Higgs decay to goldstini and its observability at the LHC,*” Phys. Lett. B **726** (2013) 228 [arXiv:1301.5479 [hep-ph]].
 - G. Ferretti, A. Mariotti, K. Mawatari and C. Petersson, “*Multiphoton signatures of goldstini at the LHC,*” JHEP **1404** (2014) 126 [arXiv:1312.1698 [hep-ph]].
 - T. Liu, L. Wang and J. M. Yang, “*Pseudo-goldstino and electroweakinos via VBF processes at LHC,*” JHEP **1502** (2015) 177 [arXiv:1411.6105 [hep-ph]].
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In models of **Gauge Mediation**, SUSY is broken spontaneously by a hidden sector and “mediated” to the MSSM by **gauge interactions**.

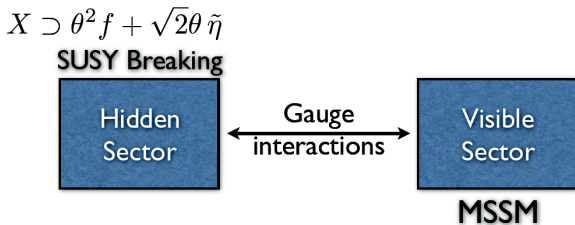
Gauge mediation is characterized by a **low SUSY breaking scale** \sqrt{f} and **the gravitino** (of mass $m_{3/2} = f/\sqrt{3}M_{\text{P}}$) **is necessarily the LSP**. Since it is almost massless we can use the equivalence theorem and **treat it as a spin 1/2 goldstino** \tilde{G} .

Since the decay to the goldstino is suppressed by $1/M_{\text{P}}$ **only the NLSP** (which does not have any other choice in R-parity preserving theories) **decays into it**.

The distinguishing signature of models of gauge mediation is thus given by the last (prompt) decay where the NLSP decays into goldstino and a SM particle. **In this talk for brevity we focus only on the most typical scenarios**

$$\tilde{\chi}_1^0 \text{ (mostly Bino)} \rightarrow \gamma \tilde{G}$$

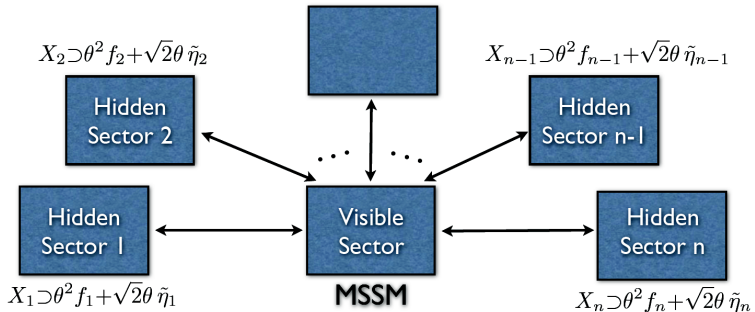
Standard Case: One hidden sector



$\tilde{\eta}$ is the goldstino arising by spontaneous SUSY breaking in the hidden sector.

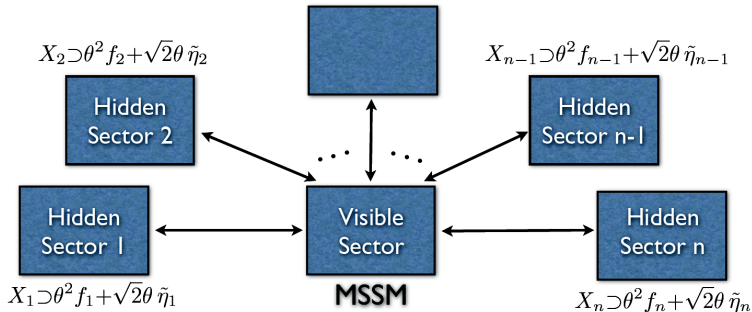
Strictly speaking, $\tilde{\eta}$ mixes with the other four R-odd neutral fermions in the MSSM and \tilde{G} is the lightest mass eigenstate. However, to a good degree $\tilde{G} \approx \tilde{\eta}$.

Extended Case: Multiple hidden sector



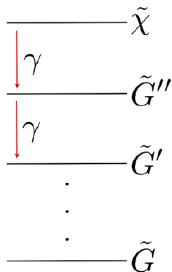
Now we have a $(4 + n) \times (4 + n)$ mass matrix. Once again, to good approximation, it is block-diagonal.

Extended Case: Multiple hidden sector

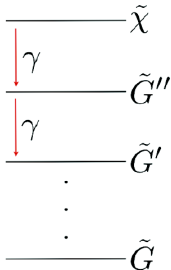


$\tilde{G} \approx (f_1 \tilde{\eta}_1 + \dots f_n \tilde{\eta}_n) / f$, ($f^2 \equiv f_1^2 + \dots f_n^2$) is the massless goldstino.
 The remaining eigenvectors \tilde{G}' , $\tilde{G}'' \dots$ are the pseudo-goldstini (pGLD).
 They acquire masses (0-100 GeV) at tree and loop level.

Just like the goldstino, these pGLD have negligible direct production cross section, so they can only be produced in the decay chain involving the **NNN..LSP** (now called the **LOSP**: “**Lightest Observable Sector Particle**”).

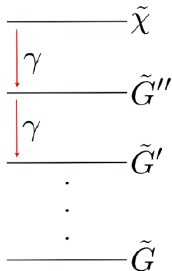


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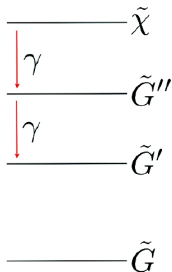


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← The pGLD successively decay to lighter pGLD: $\tilde{G}'' \rightarrow \gamma \tilde{G}'$.

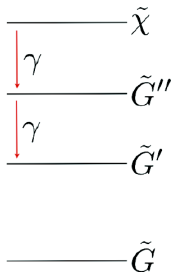
A numerical analysis of the decay rates shows that **the only case where the decay is prompt is for $\tilde{G}'' \rightarrow \gamma \tilde{G}'$** ($\tilde{G}'' \rightarrow V V \tilde{G}'$ and $\tilde{G}'' \rightarrow f \bar{f} \tilde{G}'$ are never competitive, $\tilde{G}'' \rightarrow Z \tilde{G}'$ is phase-space suppressed, if allowed at all.)

Moreover, **one can have at most one such additional decay.**



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Moreover, one can have at most one such additional decay.



← The simplified model with three sectors, with \tilde{G}' collider stable thus captures all the phenomenology of these models.

Setting $m_{\tilde{G}'} = 0$ or $m_{\tilde{G}''} = m_{\tilde{G}'} = 0$ reduces to the two-sector model or to the ordinary case.

The decay $\tilde{G}'' \rightarrow \gamma \tilde{G}'$ is mediated by the dimension five operator

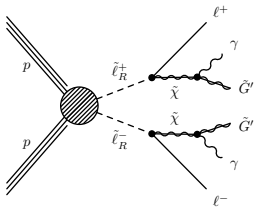
$$\propto \tilde{G}'' \sigma^\mu \bar{\sigma}^\nu \tilde{G}' F_{\mu\nu}$$

This operator arises from the the SUSY operator

$$-\int d^2\theta \frac{M_{B(i)}}{2f_i} X_i WW \supset -\frac{M_{B(i)}}{2} \left(\tilde{B}\tilde{B} - \frac{\sqrt{2}}{f_i} \tilde{\eta}_i \tilde{B} D_Y - \frac{i}{\sqrt{2}f_i} \tilde{B} \sigma^\mu \bar{\sigma}^\nu \tilde{\eta}_i B_{\mu\nu} \right)$$

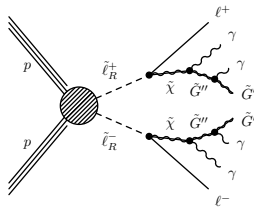
after rotating all fields to their mass eigenbasis.

In 1312.1698 we studied the production mode via right sleptons.



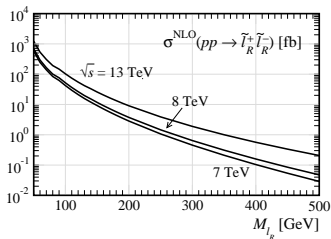
Two sector model

$$\begin{aligned}
 m_{\tilde{\ell}_R} &= 200 \text{ GeV} \\
 m_{\tilde{G}'} &= 0, 75, 150 \text{ GeV} \\
 m_{\tilde{\chi}_1^0} &= xm_{\tilde{\ell}_R} + (1-x)m_{\tilde{G}'} \\
 (x &= 0, 0.5, 0.9)
 \end{aligned}$$

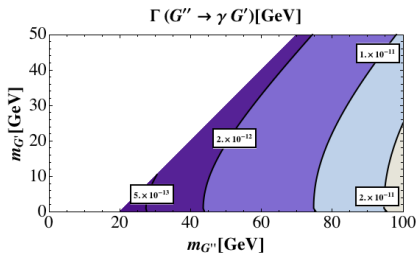


Three sector model

$M_{\tilde{\ell}_R}$	$M_{\tilde{\chi}}$	$M_{\tilde{G}''}$	$M_{\tilde{G}'}$
200	150	100	50
200	150	100	0
200	150	50	0
200	100	50	0



Right-handed slepton pair-production cross section at the LHC, for a single flavor, as a function of the slepton mass.



The partial decay width $\Gamma(\tilde{G}'' \rightarrow \gamma \tilde{G}')$ as a function of the \tilde{G}'' and \tilde{G}' masses.

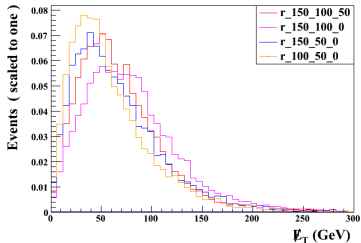
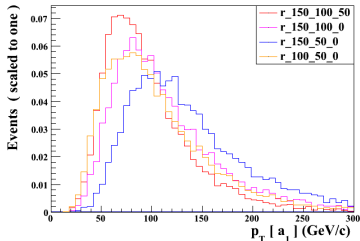
For these models, the most relevant search at the time was ATLAS diphoton + MET [arXiv:1209.0753 [hep-ex]].

4.8 fb⁻¹, 7 TeV : $p_T^{\gamma_{1,2}} > 50$ GeV, MET > 100, 125, 200 GeV

This search is now superseded by ATLAS [arXiv:1507.05493 [hep-ex]]

20.3 fb⁻¹, 8 TeV : $p_T^{\gamma_{1,2}} > 75$ GeV, MET > 150, 200, 250 GeV

Due to the small amount of MET and the softness of the photons, these searches are poorly sensitive to these models. In particular, the four benchmarks for the three sector model are not excluded by these searches.



On the other hand, searches with $\geq 3 \gamma + \text{MET}$ in the final state would be very sensitive to these models.

Number of signal events with 20 fb^{-1} of data at 8 TeV for our simplified model with right-slepton production, requiring looser cuts on the photons

$$p_T^{\gamma_{1,2,3,(4)}} > 20 \text{ GeV}, \quad |\eta| < 2.5, \quad \Delta R > 0.4$$

final state	MET	150-100-50	150-100-0	150-50-0	100-50-0
3γ	$> 50 \text{ GeV}$	45	56	46	36
	$> 100 \text{ GeV}$	11	19	14	9.0
final state	MET	150-100-50	150-100-0	150-50-0	100-50-0
4γ	$> 50 \text{ GeV}$	18	27	19	12
	$> 100 \text{ GeV}$	3.4	8.3	5.6	3.0

Take Home Points for those interested in Gauge Mediation

- ▶ Do not necessarily assume that the "Goldstino/Gravitino" is nearly massless. The LOSP could be decaying to a heavy "impostor"—the pseudo-goldstino.
- ▶ Do not necessarily assume that the "impostor" is collider stable. There still room for one prompt decay into a photon and a lighter (pseudo)-goldstino.
- ▶ These models are less constrained by current searches.
- ▶ We focused on right-slepton pair production for definiteness, but other production modes have been considered.
- ▶ A full survey of the most relevant production modes and of the associated backgrounds still needs to be carried out.
- ▶ Already with the cases analyzed we can say that **a search for $\geq 3 \gamma + \text{MET}$ would be very sensitive, already with the existing LHC data set!**