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Multiphoton Signatures of Multisector Gauge Mediation

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Abstract. We report on a study of models of gauge mediation with multiple hidden sectors. In such models, the neutralino sector is augmented with an additional pseudo-goldstino for each sector. This leads to modified decay chains with extra photons in the final state. In the case where the lightest ordinary SUSY particle is a Bino, this gives rise to multiphoton plus missing energy signatures at the LHC. We present the number of signal events expected in the case of slepton pair production in both RUN 1 and in the current 2015 data sample, as well as a preliminary, Montecarlo based, estimate of the background. Our conclusion is that a targeted multiphoton plus MET search would be quite sensitive to this type of models already with the present data.

INTRODUCTION

Supersymmetry [1] (SUSY) is a very appealing idea that potentially explains the hierarchy problem, provides dark matter candidates and facilitates grand-unification. Sadly, there has been no sign of SUSY at the LHC after RUN-1. This has led to the exclusion of large regions of parameter space for the prototypical minimal scenarios. For the class of SUSY models of direct relevance for this work – those based on the mechanism of gauge mediation (GM) – the strongest limits to-date are found in [2] and [3].

For those of us who are not ready to give up on SUSY yet, these negative results indicate the need to broaden the search to non-minimal scenarios and non-standard signatures in RUN-2, in order to cover the largest possible region of the SUSY terrain and ensure that we do not miss any of its possible incarnations. Here we discuss the particular example of multiphoton ($n_\gamma \geq 3$) + MET signatures that can expose models of Gauge Mediation with multiple Hidden Sectors while weakening current constraints.

In the context of supergravity, models with multiple hidden sectors have been studied in [4]. The first theoretical investigation of multiple hidden sectors in the context of GM was done in [5]. The collider phenomenology of GM with goldstini was discussed in [6], for the case where the Lightest Observable-Sector Particle (LOSP) was a gaugino-like neutralino or a stau, and in [7] for the case of higgsino LOSP. In all these investigations the attention was focused mainly on the case of two SUSY breaking sectors. (Further work on electro-weak production can be found in [8].)

New phenomena arise in the case of more than two sectors and they were discussed in [9]. This last aspect will be the focus of this note.

GAUGE MEDIATED SUSY BREAKING

In models of GM [10], SUSY is broken spontaneously by a hidden sector and mediated to the MSSM (or possibly a larger observable sector) by gauge interactions. This has the main advantage of suppressing unacceptable flavor changing interaction.

GM is characterized by a low SUSY breaking scale $\sqrt{f}$ and the gravitino (of mass $m_{3/2} = f/\sqrt{3}M_{\rm P}$) is necessarily the LSP. Since the gravitino is almost massless we can use the equivalence theorem [11] and treat it as a spin $1/2$ goldstino $\tilde{G}$. Since the decay to the goldstino is suppressed by $1/f$, typically 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

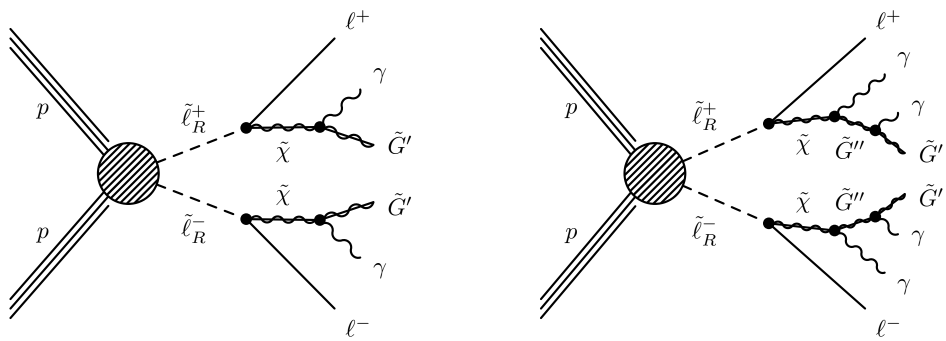

FIGURE 1. The processes relevant at the LHC in the (left) two- and (right) three-sector models. Picture taken from [9].

mediation is thus given by the last (prompt) decay where the NLSP decays into a goldstino and a SM particle. In this talk for brevity we focus only on the typical scenario

$$\tilde{\chi}_1^0 \text{ (mostly Bino) } \to \gamma\, \tilde{G} \tag{1}$$

In the case where many hidden sectors contribute to SUSY breaking [9], the massless goldstino is only one particular linear combination of the goldstini η_i from each sector $\tilde{G} \approx (f_1\tilde{\eta}_1 + \ldots f_n\eta_n)/f, \quad (f^2 \equiv f_1^2 + \ldots f_n^2)$. The remaining mass eigenvectors $\tilde{G}', \tilde{G}''$ ... are the pseudo-goldstini (pGLD). They acquire masses ($\lesssim$ 100 GeV) at tree and loop level [5].

Just like the goldstino, these pGLD have negligible direct production cross section, so they can only be produced in the decay chain involving the LOSP. In our scenario the LOSP is the Bino and decays preferably to the heaviest pGLD. The pGLD successively decays to lighter pGLD: $\tilde{G}'' \to \gamma\, \tilde{G}'$. A numerical analysis of the decay rates shows that the only relevant (prompt) decay mode is $\tilde{G}'' \to \gamma\, \tilde{G}'$ ($\tilde{G}'' \to V\ V\ \tilde{G}'$ and $\tilde{G}'' \to f\ \bar{f}\ \tilde{G}'$ are never competitive, $\tilde{G}'' \to Z\, \tilde{G}'$ is phase-space suppressed, if allowed at all.) Moreover, one can have at most one such additional prompt decay. Thus, the simplified model with three sectors, with $\tilde{G}'$ collider stable, captures all the collider phenomenology of these models. Setting $m_{\tilde{G}'} = 0$ or $m_{\tilde{G}''} = m_{\tilde{G}'} = 0$ reduces this simplified model to the two-sector model or to the ordinary case.

More specifically, the decay $\tilde{G}'' \to \gamma\, \tilde{G}'$ is mediated by the dimension five operator

$$\propto\ \tilde{G}''\sigma^{\mu}\bar{\sigma}^{\nu}\tilde{G}'F_{\mu\nu} \tag{2}$$

This operator arises from the last term in the SUSY operator

$$-\int d^2\theta \frac{M_{B(i)}}{2f_i} X_i WW \supset -\frac{M_{B(i)}}{2}\left(\tilde{B}\tilde{B} - \frac{\sqrt{2}}{f_i}\tilde{\eta}_i\tilde{B}D_Y - \frac{i}{\sqrt{2}f_i}\tilde{B}\sigma^{\mu}\bar{\sigma}^{\nu}\tilde{\eta}_i B_{\mu\nu}\right) \tag{3}$$

after rotating all fields to their mass eigenbasis. Note that a term such as (2) vanishes if $\tilde{G}' = \tilde{G}''$. In particular it vanishes in the standard scenario with only one sector.

SLEPTON PAIR PRODUCTION

In [9] we studied the production mode via right-handed sleptons. We considered both the case where the neutralino LOSP decays to a collider stable pGLD as in Fig. 1(left) as well as the case when the pGLD undergoes a further decay an is Fig. 1(right). The former process has the same topology as the ordinary GM one but with what effectively behaves as a “massive goldstino”. The latter entails a new topology giving rise to up to four high p_T prompt photons. For the three sector case we considered the four benchmark points indicated in Table 1

For these models, the most relevant search at the time was the ATLAS diphoton + MET search [12]:

$$4.8\ \text{fb}^{-1},\ 7\ \text{TeV}: \quad p_T^{\gamma_{1,2}} > 50\ \text{GeV}, \quad \text{MET} > 100,\ 125,\ 200\ \text{GeV} \tag{4}$$

TABLE 1. Benchmarks for the three sector case.

M_{ℓ_R}	M_χ	$M_{G''}$	$M_{G'}$
200	150	100	50
200	150	100	0
200	150	50	0
200	100	50	0

This search is now superseded by [3]

$$20.3\ \text{fb}^{-1},\ 8\ \text{TeV}: \quad p_T^{\gamma_{1,2}} > 75\ \text{GeV}, \quad \text{MET} > 150,\ 200,\ 250\ \text{GeV} \tag{5}$$

However, 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 still not excluded by these searches. We also accounted for the searches [13] and [14] which also include leptons in their final states, and are thus relevant to the chosen production mode. These searches turned out to be less sensitive than [12].

On the other hand, searches with $\geq 3\ \gamma\ +$ MET in the final state would be very sensitive to these models. As an illustration, in Table 2 we give the number of signal events expected with 20 fb^{-1} of data at 8 TeV for our simplified model with right-slepton production, requiring loose cuts on the photons.

$$p_T^{\gamma_{1,2,3,(4)}} > 20\ \text{GeV}, \quad |\eta| < 2.5, \quad \Delta R > 0.4 \tag{6}$$

TABLE 2. Number of expected events with 20 fb^{-1} of data at 8 TeV for the four benchmark models in Table 1 after the cuts (6).

final state	MET	150-100-50	150-100-0	150-50-0	100-50-0
3γ	>50 GeV	45	56	46	36
	> 100 GeV	11	19	14	9.0

final state	MET	150-100-50	150-100-0	150-50-0	100-50-0
4γ	> 50 GeV	18	27	19	12
	> 100 GeV	3.4	8.3	5.6	3.0

In Table 3 we also report the number of expected events (abridged from [9]) with $n_\gamma \geq 4$ and MET > 50 GeV, still with the requirements (6), to be expected after 3 fb^{-1} at 13 TeV as we stand roughly at the end of the 2015 run. We see that even with fairly low luminosity one still would get a handful of events.

TABLE 3. Number of expected events with 3 fb^{-1} of data at 13 TeV for the four benchmark models in Table 1 after the cuts (6) imposing $n_\gamma \geq 4$ and MET > 50 GeV.

150-100-50	150-100-0	150-50-0	100-50-0
6.1	8.4	6.2	4.1

The main open issues at this point is a reliable estimate of the background as well as the extension of the analysis to other production modes. We report now preliminary results on both of these point.

For an estimate of the background, we have generated Montecarlo samples using MadGraph5 [15], Pythia6 [16], FastJet [17] and Delphes3 [18] with the ATLAS standard detector specification modified only by setting the jet radius parameter to 0.4. This is not enough for a quantitatively reliable estimate as it does not take into account pile-up and other detector effects. However it should give an idea of the severity of the problem.

The main sources of background are diphoton and triphoton plus jets, where one of the jets is faking a photon, as well as SM processes with irreducible missing energy, such as invisible Z decay or leptonic W decay, in addition to photons and jets.

We have simulated the purely QED+QCD background (photons and jets only) in two ways. First we generated the $q\,\bar{q} \to \gamma\,\gamma$ and $q\,\bar{q} \to \gamma\,\gamma\,\gamma$ processes at partonic level and subsequently showered with Pythia (the $q\,\bar{q} \to \gamma\,\gamma\,\gamma\,\gamma$ process has a negligible cross section). As a second attempt, we generated the above processes, together with up to two jets at partonic level and performed MLM matching [19]. In this second case, in order to provide a hard scale for the matching, we required the p_T of the leading photon to be at least 70 GeV. The second sample gave the larger contribution to the background, with 3 events at 8 TeV with 20 fb^{-1} in the case of MET > 50 GeV and $n_\gamma \geq 3$ photons with the same p_T and $|\eta|$ requirements as in (6) and a negligible contribution in the remaining cases of Table 2.

The largest contribution from a process containing a vector boson came from a leptonically decaying W together with 2 photons and up to one matched jet. Here there was no need to impose additional requirements on the p_T of the leading photon since the W provided the hard scale for the matching algorithm. We obtained 0.7 events at 8 TeV with 20 fb^{-1} in the case MET > 50 GeV and $n_\gamma \geq 3$ photons and, again, a negligible result in the other cases.

A similar study has been performed at 13 TeV with 3 fb^{-1} and similar conclusions have been reached. in particular the background should be negligible for the case presented in Table 3.

Although a more reliable estimate of backgrounds of this type should come from a data driven analysis perhaps supplemented by a full detector simulation for the vector boson case, we take these results as an indication that the background can in fact be brought under control and that the proposed searches are sensitive to the signal even for such low values of p_T and MET.

The scope of the signal generation using slepton pair production is rather limited given the low cross section and a full analysis will require considering strong and electroweak production modes as well. In order to accomplish this, we have made a minor modification at the UFO level [20] of the pre-existing code for gauge mediated SUSY [21] by adding the second goldstino with the interaction (2) together with non-zero masses and widths for all the particles involved. We have validated the code on some benchmark processes and we now plan to start the generation of signal samples for both strong and electroweak production as well as different LOSP candidates. We hope to report on the results in the near future.

CONCLUSIONS

In this contribution we reported on a study [9] of models of gauge mediation with multiple hidden sectors. We discussed the non-standard signatures that are to be expected in the case of a Bino LOSP, namely multiphoton final states accompanied by some amount of MET. Due to the different kinematic the leading photon spectrum is softer than in the usual case and the MET signature is reduced. We showed the number of signal events expected in the case of slepton pair production as well as a preliminary, Montecarlo based, estimate of the background. Our conclusion is that a targeted multiphoton plus MET search would be quite sensitive to this type of models already with the 8 TeV results and also in the new 13 TeV run.

We conclude this short note by stressing the two main qualitative points that have driven this investigation and should have a broader significance in the context of gauge mediated SUSY breaking:

First, do not necessarily assume that the “Goldstino/Gravitino” is nearly massless. The LOSP could be decaying to a heavy “impostor”–the pseudo-goldstino. This is what happens generically in models with more than one hidden sector and looking at such non-minimal models is more motivated now that the most commonly expected SUSY signals have failed to turn up in LHC searches.

Secondly, do not necessarily assume that the “impostor” is collider stable. There is still room for one prompt decay into a photon and a lighter (pseudo)-goldstino. This occurs in fairly generic regions of the parameter space of multi-sector models. Further decays or other decays modes such as $\tilde{G}'' \to \tilde{G}'\,\gamma\,\gamma$ or $\tilde{G}'' \to \tilde{G}'\,l^+\,l^-$ have however too small a partial width to be of interest for collider phenomenology.

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