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pMSSM SUSY and the ATLAS Z+jets+MET Excess

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A possible explanation of the excesses observed by ATLAS in the Z+jets+MET channel within the p(henomenological)MSSM is discussed. We have found that the cascade of first/second generation squarks to binos to Higgsino LSPs, with judiciously chosen sparticle masses, can provide a viable scenario that is consistent with all other experimental constraints.

The Standard Model (SM) is obviously incomplete and new physics is expected to show up at some point to address the many questions that it leaves unanswered. Supersymmetry (SUSY) provides one of the leading candidate frameworks for physics beyond the SM and new SUSY searches are continuing at the 13 TeV, Run 2 LHC and elsewhere. At the 8 TeV LHC , ATLAS [1] observed a 3σ excess in the Z+(2 or more)jets+MET SUSY search channel corresponding to roughly $\sim 15-20$ additional events above the SM background estimate. On the otherhand, CMS, with a somewhat different analysis which had no H_T cut, observed an event rate consistent with SM expectations [1]. Given the differing kinematic requirements of the two experiments we can ask (at least) three questions: Are there MSSM SUSY models that are consistent with both results? What are the properties of these models? What do such models predict for LHC Run 2 at 13 TeV? In order to make progress addressing these questions we [2] began by employing some of the pMSSM model points from our own earlier detailed study of the associated 19-dimensional parameter space [3] as well as a comparable set of pMSSM model points provided by ATLAS [4]. Using these, we identified specific model points which gave a significant signal rate in the ATLAS analysis while simultaneously satisfying the bounds that were imposed by the null CMS search These successful points were then further employed as templates/seeds to examine the surrounding parameter space. The advantage of using these initial seed points in such a study is that they already satisfy the other existing LHC SUSY searches as well as the constraints from flavor physics, precision measurements and dark matter(DM) search experiments.

Before beginning this search for successful seed models, the expectation was that a SUSY cascade is taking place: some initial light colored sparticle (hence a QCD cross section on order to obtain the necessary event rate) is produced which subsequently decays to the LSP via a 2-step process during which the jets+Z (and possible other particles) are produced. The initial colored state must also be inhibited from decaying directly to the LSP so as to avoid the powerful jets+MET search constraints. We would also anticipate that much of the remainder of the SUSY spectrum is essentially decoupled from this cascade. These considerations tell us that the LSP is most likely not a bino as squarks of any flavor will decay to them directly. They also tell us that that any initial squarks are not likely from the third generation as they will decay to both binos and Higgsinos (as well as winos if the squarks are L-R mixed states). The LSP and intermediate color singlet state cannot be combinations of binos and winos as they do not couple to the Z. Further considerations along these lines rapidly narrow down the set of possible choices to only

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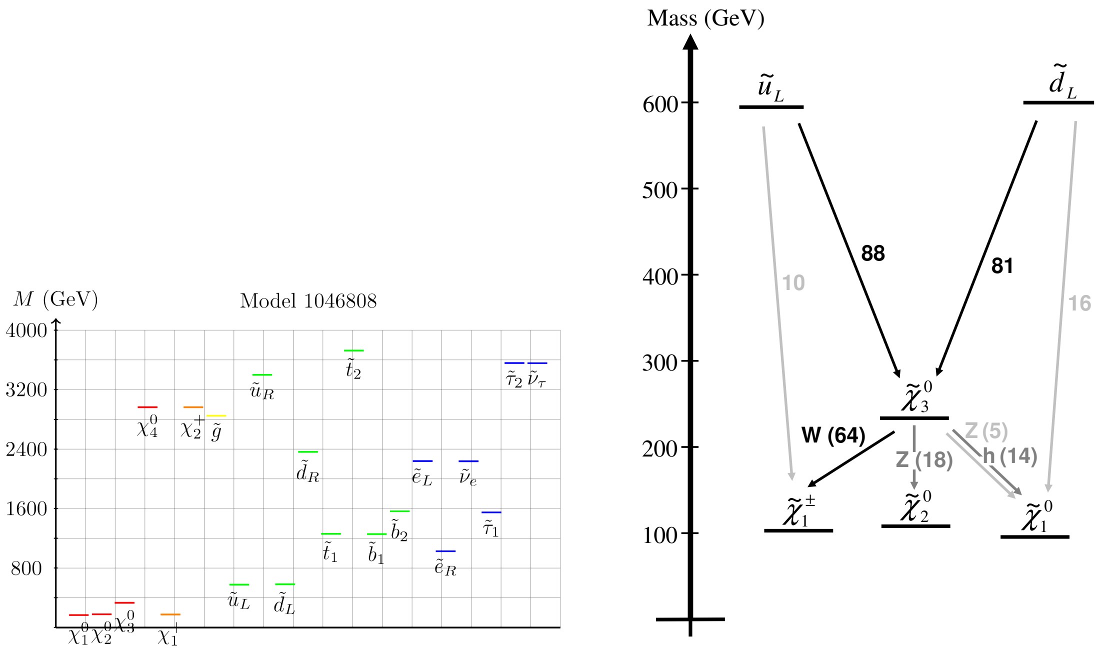

Figure 1 – (Left) Sample seed model spectrum and (Right) the corresponding squark to bino to Higgsino decay pattern.

a few candidates.

Indeed what we find from scanning over the set of pMSSM models as potential seed points lives up to these expectations. Fig. 1 show a typical 'successful' sparticle spectrum for a seed model. Here, a light $1^{st}/2^{nd}$ generation squark decays into an intermediate bino state by emitting a jet and then the bino itself decays to the lighter Higgsinos via Higgs or gauge boson emission. The bino and Higgsino are both slightly mixed thus allowing for these decay modes. The small bino content of the LSP suppresses the direct squark to LSP transition process as needed. Much of the rest of the spectrum, especially the gluino, is seen to be decoupled. However, even though the wino is fairly heavy here, the Higgsinos obtain a small wino content allowing for the squark decay to them via W emission. In addition to the squark doublet being the initiator of the cascade, seed points where only one of $\tilde{u}_R, \tilde{d}_R$ are light and filled this role were also found but they generally yield smaller signal event rates overall since only a single squark state is present. Note that since the bino can decay to the Higgs plus the LSP with a reasonable branching fraction, the observation of this final state is a prediction for all models in this class.

Given these seed points we can then move the squark, bino and Higgsino masses around in an independent manner and explore the impact on the Z+jets+MET rate while still requiring all the other constraints to be satisfied. This is essentially a simplified model analysis as it only relies on a few mass parameters and, in principle, the value of $\tan\beta$. The results of this scan are shown in Fig. 2. Here we see that: (i) $\tilde{Q}_L$ initial states produce larger signal rates than do either $\tilde{u}_R$ or $\tilde{d}_R$, which is not unexpected. (ii) The preferred bino-Higgsino mass splitting lies above ~ 150 GeV; this is a bit surprising as this large mass gap allows for other bino decays into the Higgs final state as noted above. (iii) The preferred LSP mass lies below ~ 150 GeV. Such light Higgsinos can only account for a small fraction of the thermal DM relic density and may eventually have a chance of being observed 'directly' through the monojet/soft track analyses.

Moving forward we can next ask how the various ATLAS and CMS 8 TeV search requirements are shaping the predicted values for the number of expected Z+jets+MET events satisfying the ATLAS cuts and how 'far' the successful models are from the constraint limits. Fig. 3 show these results for the case of the $\tilde{Q}_L$ initiating the cascade. The corresponding constraints for $\tilde{u}_R$

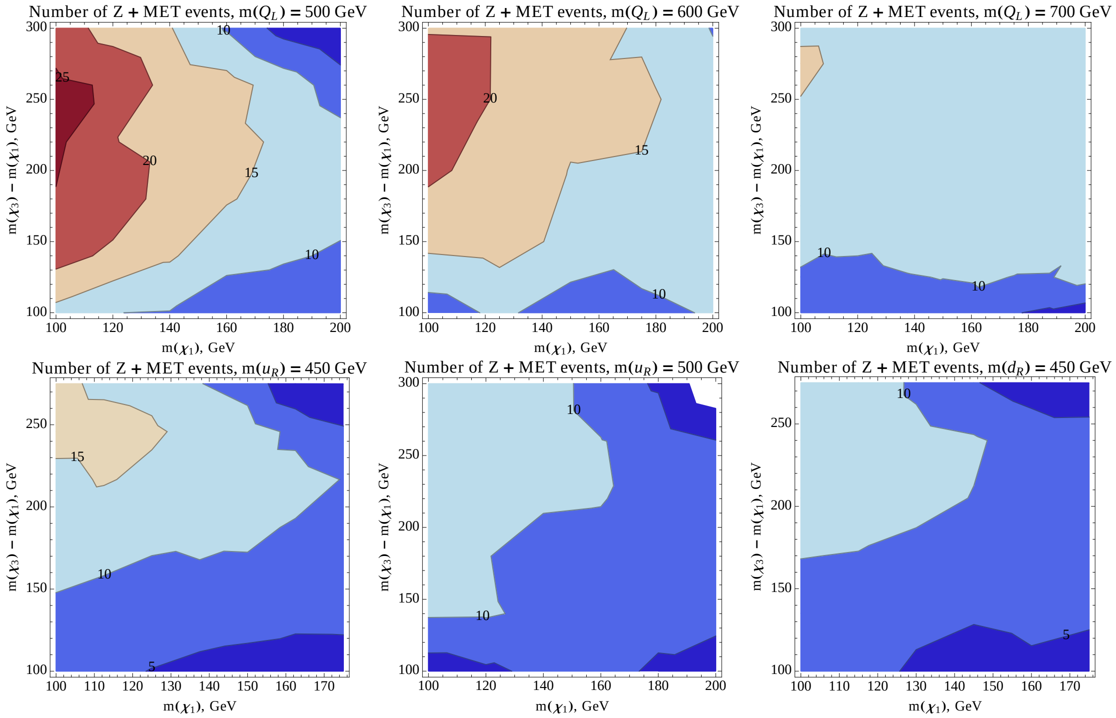

Figure 2 – Signal event rate contours for the ATLAS Z+jets+MET analysis in the bino-Higgsino($\chi_3^0 - \chi_1^0$) mass difference and LSP(χ_1^0) mass plane. The top three panels correspond to the case of $\tilde{Q}_L = 500\,,600\,,700$ GeV from left to right, while the bottom panels are for$\tilde{u}_R = 450\,,500$ GeV and $\tilde{d}_R = 450$ GeV, left to right.

and $\tilde{d}_R$ are found to be qualitatively similar to these but are quantitatively weaker since, overall, these cases generally lead to fewer predicted signal events. From the clustering of model points near the upper boundary, we can observe that the 0l+jets ATLAS search is indeed constraining the maximum size of the Z+jets+MET excess from above. Due to the presence of leptonically decaying W's resulting from the decays of both the initial squarks (at least in the case of $\tilde{Q}_L$) as well as from the intermediate bino, we see that the ATLAS 1l+jets search also plays some role in constraining the parameter space. However, this constraint is seen to be most influential for the Z+jets+MET rates of intermediate values. The last panel shows that the influence of the bound arising from the CMS null result on the dilepton rate is rather weak and that this constraint is relatively easy to satisfy once these other requirements are accounted for. Thus we see that we have demonstrated that the ATLAS 8 TeV excess and the corresponding null result from CMS at 8 TeV can be simultaneously accommodated within the pMSSM with all other search constraints also satisfied. These requirements point to a very particular SUSY scenario.

It is interesting to examine the mass distributions of the squarks, binos and Higgsinos in the subset of models that yield a significant Z+jets+MET signal rate; this is shown in Fig. 4 for each choice of the parent squark. Overall, we see that the initial squark continues to get lighter as we go from $\tilde{Q}_L \to \tilde{u}_R \to \tilde{d}_R$ reflecting a compensation for the decrease in the production cross section at a fixed mass. In all three cases the Bino mass is broadly centered around ~ 350 GeV while the LSP tends to be slightly less massive in the case of the RH-squarks. This results in softer jets in the RH-squark case as well as slightly harder leptons arising from the Z.

The final step in this analysis is to examine the corresponding predictions for 13 TeV. Here the experimental situation is a bit more confusing as ATLAS again observes a (2σ) excess of ~ 10 signal events while CMS, essentially employing the same cuts as ATLAS, still observes agreement with the SM expectation [1]. Clearly, we will need to wait until more data is available to clarify this situation. Fig. 5 shows the predicted number of events passing the ATLAS 13 TeV analysis in the same plane as that employed above for the case of the 8 TeV analysis. Due to the larger $\sqrt{s}$ but much smaller luminosity, fewer numbers of signal events are generally to be

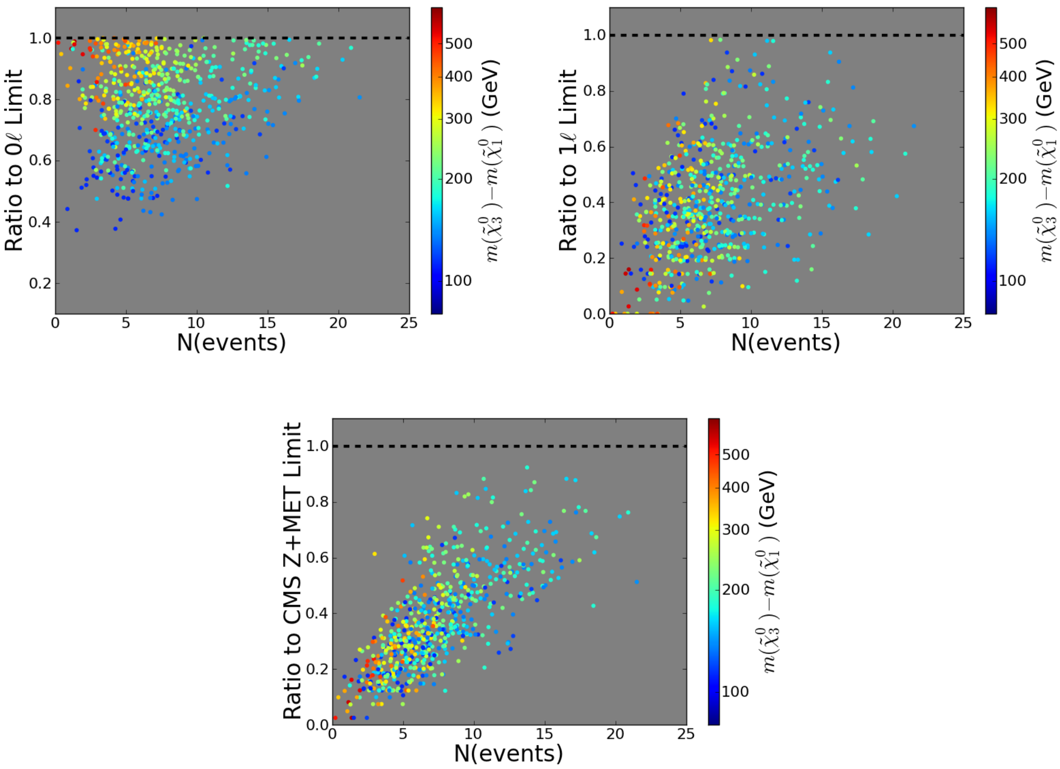

Figure 3 – Ratio of the predicted number of events for the $\tilde{Q}_L$ models in our simplified grid scan to the ATLAS 95% CL. search limit for the 0l+jets and 1l+jets channels as well as that for the CMS dileption search, respectively, as functions of the number of predicted signal events for the ATLAS Z+jets+MET search. The color code corresponds to the value of the $\chi_3^0 - \chi_1^0$ mass splitting.

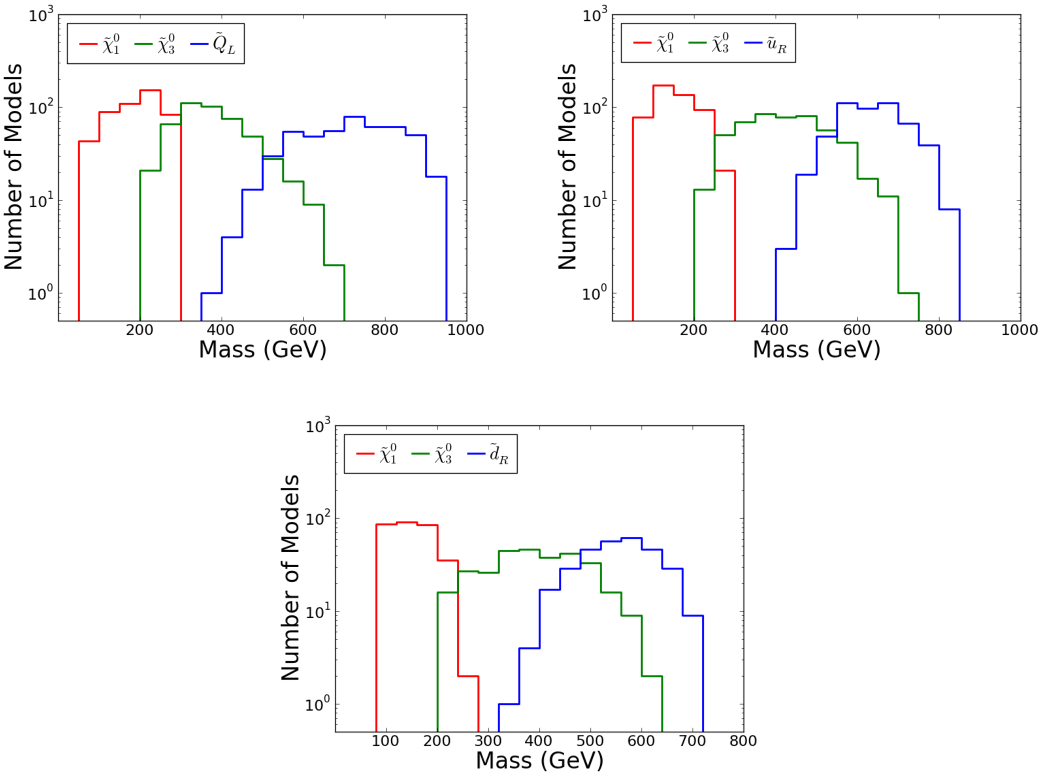

Figure 4 – Mass distributions of the parent squark, χ_3^0 and χ_1^0 states for the models from our grid scan that agree with all null search results and yield at least 5 events in the ATLAS Z+MET channel. The top-left, top-right, and bottom panels correspond to the parent squark cases of $\tilde{Q}_L$, $\tilde{u}_R$, and $\tilde{d}_R$, respectively.

expected to be produced here. However, we do see from this Figure that it is possible to obtain ~ 10 signal events arising from $\tilde{Q}_L$ production and decay with masses of order $\sim 500-600$ GeV or more. Unfortunately the predicted rates arising from either $\tilde{u}_R$ or $\tilde{d}_R$ production cannot make it up to this signal rate threshold. As a final step we must investigate how the other ATLAS SUSY searches at 13 TeV are impacting on the parameter space that allows for a significant Z+jets+MET excess as this energy. This is work that is now in progress [5].

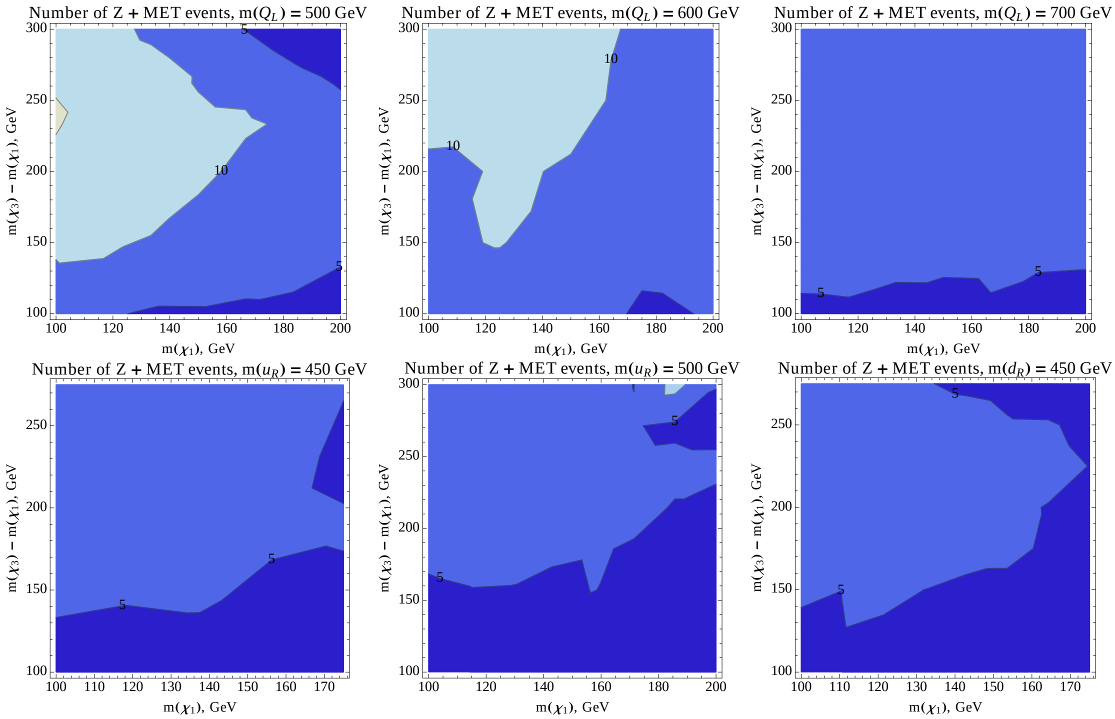

Figure 5 – Same as Fig.2 but now for the ATLAS 13 TeV analysis. For than 10(5) signal events are to be expected in the lightest(darker) region while points in the darkest regions lead to fewer than 5 events.

Acknowledgments

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