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SUSY Without Prejudice at the 7 and 8 TeV LHC: Gravitino LSPs

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We have examined the capability of the LHC, running at both 7 and 8 TeV, to explore the 19(20)-dimensional parameter space of the pMSSM with neutralino(gravitino) LSPs and soft masses up to 4 TeV employing the ATLAS SUSY analysis suite. Here we present some preliminary results for the gravitino model set, following the ATLAS analyses whose data were publically available as of mid-September 2012. We find that the impact of the reduced MET, resulting from models with gravitino LSPs on sparticle searches is more than off-set by the detectability of the many possible long-lived NLSPs.

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Although searches at the LHC are continuing unabated and a SM-like Higgs boson has been recently discovered[1], there is still no hint of SUSY or any other new physics beyond the Standard Model on the horizon. Several conventional SUSY breaking scenarios, such as the mSUGRA/cMSSM framework in its most naive form, are now highly disfavored by the data. It is clear that more model-independent approaches to SUSY which still allow for correlations among the many different experimental results are required. We [2] have recently begun a detailed study of SUSY within the 19-parameter p(henomenological)MSSM and have examined the effects of numerous ATLAS-based SUSY searches at both 7 and 8 TeV on our model set with neutralino LSPs. This very general parametrization allows for a wide range of phenomenological SUSY signatures while simultaneously correlating, *e.g.*, collider and dark matter searches. Here we will briefly present some of the preliminary results obtained for the corresponding 20-parameter case with gravitino LSPs. For more details of these analyses and as well as of our overall model generation framework and procedures, see[2].

As discussed in previous work[2] we reproduce the suite of ATLAS-based SUSY searches as closely as possible using a modified version of PGS[3], employing ATLAS SM backgrounds and validating against ATLAS benchmark models. The obvious place to begin such a study is with the 'vanilla', generalized MET searches at both 7 and 8 TeV since these are powerful analyses that usually cover a large fraction of the model parameter space. It is important when doing this to include analyses at both center of mass energies, since some models which are excluded by the 7 TeV data remain allowed at 8 TeV. We previously observed the same effect in our neutralino model set, likely as a result of the harder cuts bypassing models with compressed spectra. We note that we expect the coverage provided by these MET-based analyses to be somewhat diminished overall for the gravitino model set as the many long-lived NLSPs occuring at the bottom of decay chains lead to a reduction in the overall amount of MET. However, this is partially compensated by the fact that most of our gravitinos are effectively massless leading to large MET in models where the NLSP does decay to the gravitino within the inner detector. A further potential compensation is provided by the much higher frequency of light binos in the gravitino set which can lead in some cases to final states with large MET and additional leptons. Interestingly, searches for long-lived sparticles lead to a substantial overall increase in model coverage, more than compensating for the reduced MET.

Tables 1 and 2 show the results of the 7 and 8 TeV 'vanilla' MET searches, respectively. Here we see several things: (*i*) In comparison to the corresponding results for the neutralino models[2] the model coverage from jets plus MET is somewhat degraded due to reduced MET as we expected at both center of mass energies. (*ii*) While the 2-6 jets analysis remains the most powerful here, the roles played by the multijet and single lepton analyses at both energies and the SSDL analysis at 8 TeV are significantly enhanced with respect to the results obtained for neutralino LSPs. Searches with leptons are found to be more effective because of lepton production in decays to non-neutralino NLSPs, and also because bino NLSPs are common [2]. (*iii*) Many of the models are found to be excluded by multiple analyses. (*iv*) Including the additional requirement on the model set of a Higgs boson with a mass of $m_h = 126 \pm 3$ GeV (here referred to as the "Higgs Subset") does not significantly alter the amount of model coverage although some degradation is observed (as was the case for the neutralino set). The magnitude of this degradation is found to be somewhat less for the gravitino set. (*v*) We find that ~ 1.3k gravitino LSP models are excluded by the 7 TeV analyses

Search	Reference	Full Model Set	Higgs Subset
2-6 jets	ATLAS-CONF-2012-033	17.76%	16.67%
multijets	ATLAS-CONF-2012-037	2.27%	2.09%
1-lepton	ATLAS-CONF-2012-041	5.31%	4.63%
Total		19.44%	17.95%

Table 1: Fraction of our pMSSM models with gravitino LSPs excluded (in per cent) by the general "vanilla" MET ATLAS searches at the 7 TeV LHC with 4.7 fb^{-1} of integrated luminosity for both the full model set as well as for the "Higgs Sub set" satisfying the Higgs mass constraint, $m_h = 126 \pm 3$ GeV.

Search	Reference	Full Model Set	Higgs Subset
2-6 jets	ATLAS-CONF-2012-109	21.83%	20.82%
multijets	ATLAS-CONF-2012-103	4.13%	4.02%
1-lepton	ATLAS-CONF-2012-104	5.38%	5.05%
SS dileptons	ATLAS-CONF-2012-105	11.50%	11.14%
Total		28.69%	27.19%

Table 2: Same as Table 1 but for the 8 TeV, 5.8 fb^{-1} ATLAS searches.

that were *not* excluded by the 8 TeV analyses.

In Table 3 we see the results for both the heavy flavor(HF) and multilepton(ML) ATLAS analyses that probe for light third generation squarks and light gauginos, respectively, as might be expected to occur in pMSSM models with low values of fine-tuning[2]. These searches produce results which are somewhat different than those found for neutralino LSPs. Both types of searches, but particularly in the case of the ML searches (as would be expected from the above discussion), are found to be much more effective for the gravitino models. The somewhat lighter stops and sbottoms in the gravitino model set also partially enhance the HF search capabilities.

In Table 4 we see the corresponding results for the non-MET searches. The search for heavy stable charged particles(HSCP) is found to be significantly more effective in the case of gravitino LSPs due to the high frequency of long-lived NLSPs in this set. These gains, plus those for the leptonic searches as discussed above, are then responsible for the overall increase in pMSSM model coverage that we find for the gravitino pMSSM ($\sim 46\%$) in comparison with the neutralino pMSSM ($\sim 34\%$)[2]. Note that the effect of the Higgs mass cut on the *total* model space coverage is found to be minimal for both model sets.

How does the gravitino pMSSM parameter space respond to these null searches? Fig. 1 presents histograms of the distribution for the gluino, the lightest 1st/2nd generation squark, the lightest stop and the lightest sbottom in our gravitino model set. The effect of sequentially applying LHC searches on these distributions is shown as a series of colored histograms in the following order from top to bottom: The original model set as generated (black), 7 and 8 TeV 'vanilla' searches (red), heavy flavor (green), multileptons (blue), HSCP and disappearing tracks (magenta), $B_s \to \mu^+\mu^-$ and $H/A \to \tau^+\tau^-$ (cyan), and $m_h = 126 \pm 3$ GeV (brown).

For both the gluinos and the lightest 1st/2nd generation squarks, the vanilla and stable sparticle searches are seen to be most effective in excluding models. Overall, these distributions are

Search	Reference	Full Model Set	Higgs Subset
Gluino → Stop/Sbottom	1207.4686	4.06%	4.38%
Very Light Stop	ATLAS-CONF-2012-059	0.03%	0.01%
Medium Stop	ATLAS-CONF-2012-071	4.92%	4.34%
Heavy Stop (0l)	1208.1447	3.29%	3.87%
Heavy Stop (1l)	1208.2590	2.26%	2.51%
GMSB Direct Stop	1204.6736	0.05%	0.06%
Direct Sbottom	ATLAS-CONF-2012-106	2.80%	2.83%
3 leptons	ATLAS-CONF-2012-108	5.91%	5.48%
1-2 leptons	1208.4688	8.15%	7.19%
Direct slepton/gaugino (2l)	1208.2884	1.18%	1.02%
Direct gaugino (3l)	1208.3144	5.54%	4.82%
HF Total		11.14%	11.30%
ML Total		12.10%	10.97%

Table 3: Same as Table 1 but for the HF and ML searches.

Search	Reference	Full Model Set	Higgs Subset
HSCP	1205.0272	16.93%	15.36%
Dis. Tracks	ATLAS-CONF-2012-111	1.12%	1.16%
$B_s \to \mu^+\mu^-$	ATLAS-CONF-2012-061	3.11%	6.11%
$A/H \to \tau^+\tau^-$	1202.4083	0.07%	0.03%
All Searches		45.57%	45.62%

Table 4: Same as Table 1 but now for the non-MET searches. The corresponding combined results obtained from all searches is also shown.

qualitatively similar to those for the neutralino model set. Once again, we note the presence of viable models with light 1st/2nd generation squarks below 600 GeV, gluinos below 700 GeV, and 3rd generation squarks below 400 GeV, although in each case the low-mass region is more depleted than in the neutralino model set. (We expect some models in the low-mass regions because of the significant number of models with a stable neutralino NLSP, producing a scenario identical to the neutralino model set except for differences in cosmological constraints.) We also observe that the 3rd generation searches remain effective at higher stop and sbottom masses in the gravitino set, likely as a result of sensitivity to models in which the 3rd generation squarks decay promptly to gravitinos, producing clean signatures with lots of MET.

In Fig. 2 we display the distribution of masses for the NLSP as a function of the gravitino mass for various possible NLSP identities, both as initially generated and after applying all of the LHC constraints discussed above except for the Higgs mass cut which essentially only reduces the overall statistics. The boundary lines and corresponding bands at the model generation level arise due to both the nucleosynthesis constraints and those on long-lived sparticles which roughly scale as $\sim M^5/m_{3/2}^2$ with $M(m_{3/2})$ being the NLSP(gravitino) mass. The location of the bands them-

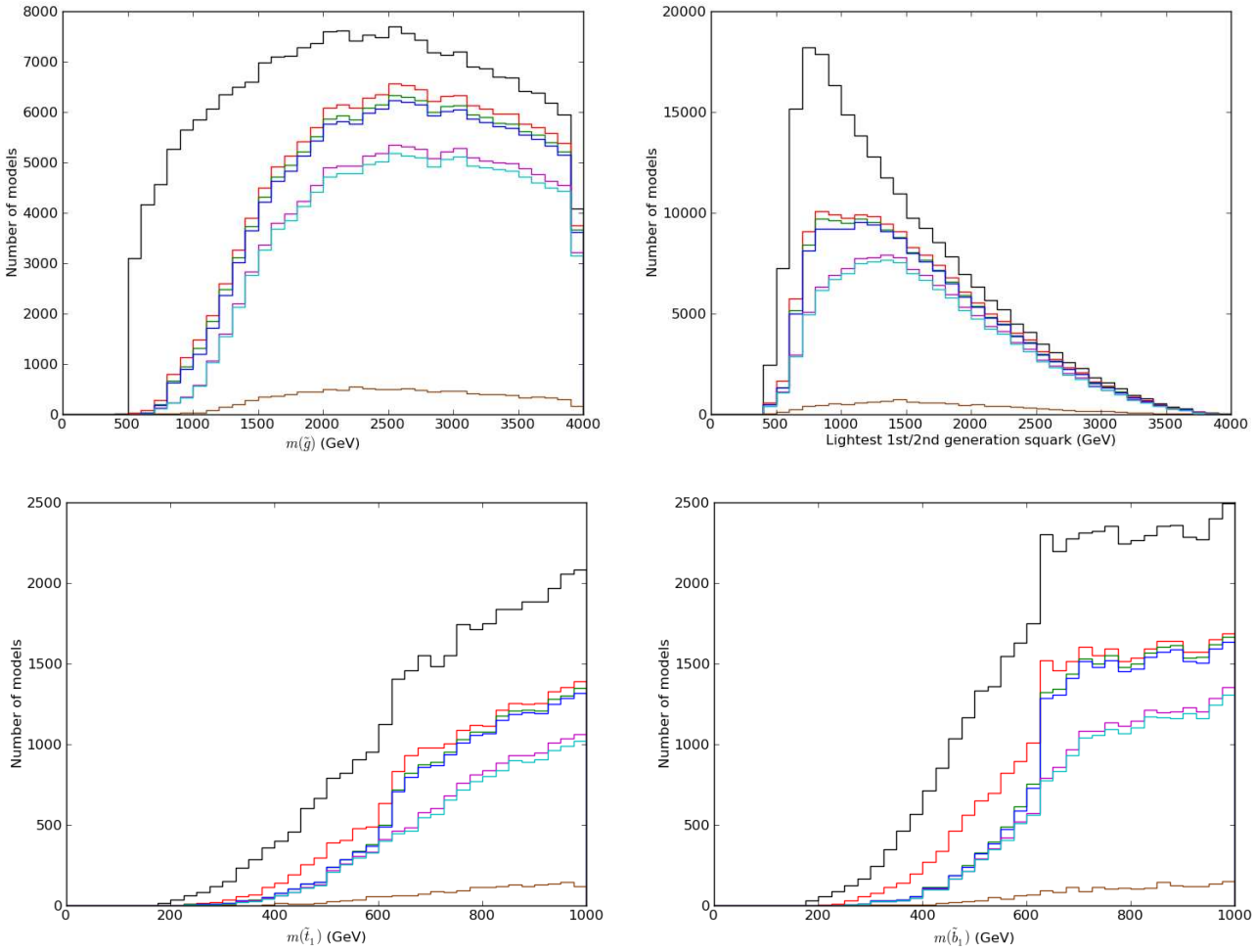

Figure 1: Mass distributions for the gluino (top left), lightest first/second generation squark (top right), lightest stop (bottom left) and lightest sbottom (bottom right) as they respond to the null LHC SUSY searches. The various histograms are described in detail in the text.

selves are correlated with the amount of electromagnetic and/or hadronic energy deposition the various NLSP candidates can release via their decay to gravitinos during nucleosynthesis. Clearly neutral, color-singlet NLSPs are least constrained by these considerations while, *e.g.*, colored sparticles are strongly depleted. After the various LHC search constraints are applied, we see in the RH panel that some of the original bands, particularly those for NLSPs which are charginos, sleptons or squarks in the central part of the plot are now essentially absent. In particular, chargino NLSPs are strongly depleted when the gravitino is heavy enough that the NLSP is stable. Stable slepton NLSPs, meanwhile, remain viable at low masses due to small production cross-sections, but are uniformly depleted up to high masses ($\tilde{8}$00 GeV) through production in cascade decays and subsequent exclusion by stable particle searches. The distribution of models with sneutrino and neutralino NLSPs is relatively unaltered, since the exclusion of these models depends on producing charged or colored sparticles

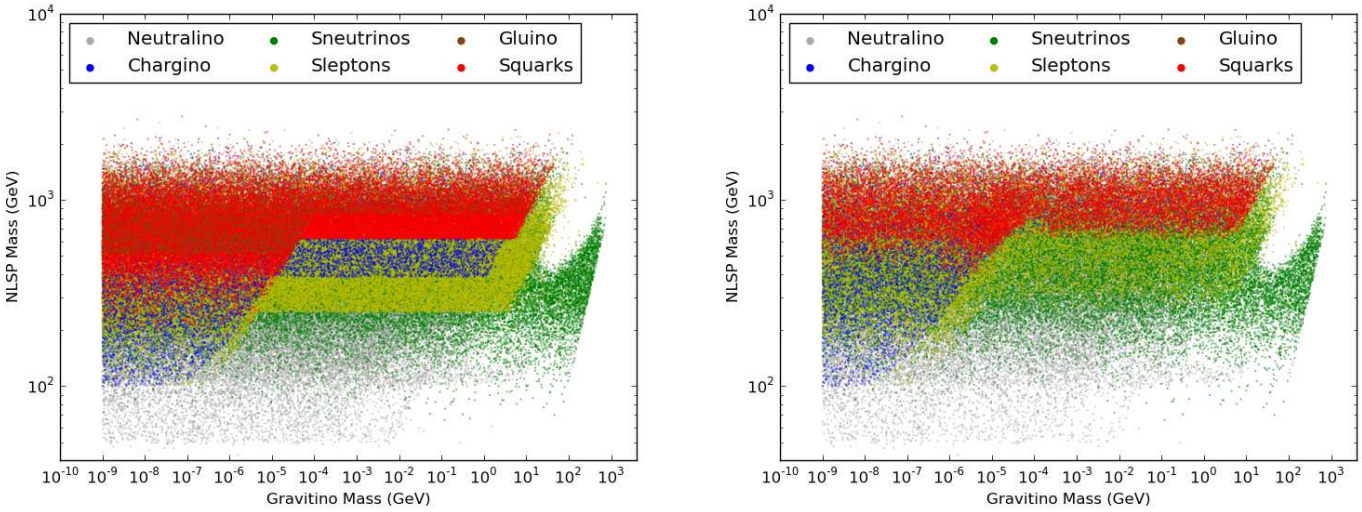

Figure 2: Viable models in the NLSP - gravitino mass plane, color-coded according to NLSP type as labeled. The two plots show the gravitino pMSSM model set before (left) and after (right) the LHC constraints (with the exception of the Higgs mass cut) have been applied. The horizontal and slanting lines in the plot on the left show the effects of model-independent limits on stable particles which have been superseded by a model-dependent implementation of LHC HSCP searches. The structure on the far right of each graph is produced by the cosmological constraints described in [2].

In this report we have provided a brief overview of the impact of the ATLAS SUSY searches on the pMSSM with gravitino LSPs and contrasted these with the earlier results obtained for the neutralino LSP case. Overall we find that due to the increased effectiveness of the HF, ML and, most particularly, the long-lived sparticle searches, the LHC coverage of the pMSSM model space with gravitino LSPs is substantially larger than that for the corresponding neutralino models. For either NLSP choice we have found that the restriction to the subset of models with $m_h = 126 \pm 3$ GeV has almost no impact on the fraction of models covered by the complete set of LHC searches. Clearly additional searches, particularly ones which are sensitive to long-lived sparticles, will likely be able to further increase the coverage for the gravitino model set as we will see in future work [2].

References

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