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Supersymmetry Without (Too Much) Prejudice

Thomas G.Rizzo

SLAC National Accelerator Laboratory, 2575 Sand Hill Rd., Menlo Park, CA, 94025, USA

Abstract. We have recently completed a detailed scan of the 19-dimensional parameter space of the phenomenological MSSM, *i.e.*, the CP-conserving MSSM assuming Minimal Flavor Violation(MFV) with the first two sfermion generations degenerate. We found a large set of parameter space points that satisfied all of the existing experimental and theoretical constraints. This analysis allows us to examine the general features of the MSSM without reference to any particular SUSY breaking scenario or any other assumptions about physics at higher scales. This study opens up new possibilities for SUSY phenomenology both at colliders and in astrophysical observations.

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Beyond the domains of the specific SUSY breaking scenarios (*e.g.*, mSUGRA, AMSB, GMSB, *etc*), how well do we really know the properties of the MSSM? Are there parameter space regions which lead to sparticle properties which produce new or different experimental signatures not previously encountered? Are atypical dark matter signals possible? To begin to address these and related questions we[1, 2] performed a pair of scans of a limited 19-dimensional subspace of the full 100+ parameter (R-parity conserving!) MSSM obtained by assuming a thermal relic neutralino LSP, CP conservation(*i.e.*, only real soft breaking parameters), weak scale MFV and by taking the first 2 sfermion generations degenerate (flavor by flavor) with negligible Yukawa couplings. Note that we have made no assumptions about any high-scale physics in this analysis.

To perform our scans, we need to choose suitable ranges for the soft-breaking SUSY parameters (evaluated at the TeV scale) and determine how the values of these parameters are picked within these assumed ranges. We purposefully chose ranges that would lead to SUSY which is relatively easy to access kinematically at the LHC. For the analysis presented here, we actually made two independent parameter scans. In the first case, we randomly generated 10^7 sets of parameters (*i.e.*, models), assuming flat priors, *i.e.*, we assumed that the parameter values are chosen *uniformly* throughout their allowed ranges. For this flat prior scan we employed the following ranges for our 19 parameters:

$$\begin{aligned} 100\,\mathrm{GeV} \leq m_{\tilde{f}} &\leq 1\,\mathrm{TeV}\,, \\ 50\,\mathrm{GeV} \leq |M_{1,2}, \mu| &\leq 1\,\mathrm{TeV}\,, \\ 100\,\mathrm{GeV} \leq M_3 &\leq 1\,\mathrm{TeV}\,, \\ |A_{b,t,\tau}| &\leq 1\,\mathrm{TeV}\,, \\ 1 \leq \tan\beta &\leq 50\,, \\ 43.5\,\mathrm{GeV} \leq m_A &\leq 1\,\mathrm{TeV}\,. \end{aligned} \tag{1}$$

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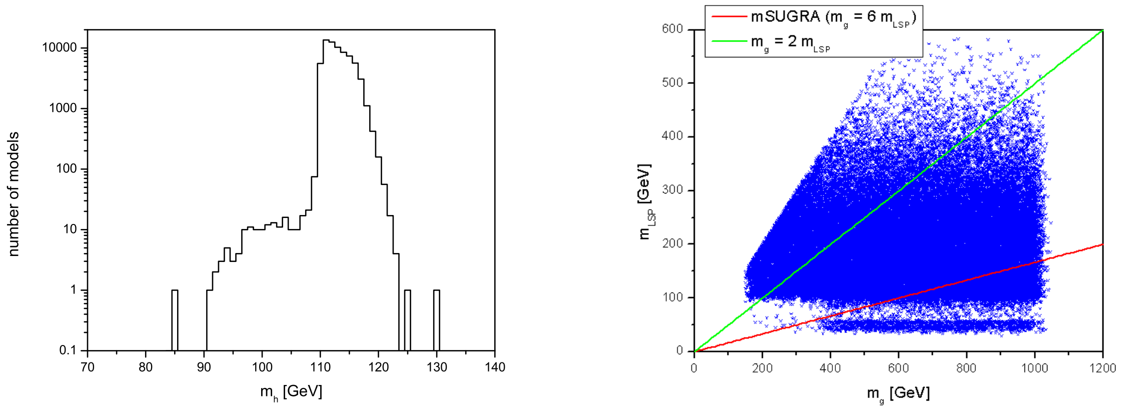

FIGURE 1. For flat priors: (left)Light Higgs mass distribution and (right)the correlation of the gluino and the LSP masses. The red line is the mSUGRA prediction.

For our second scan, we randomly generated 2×10^6 model points assuming log priors for the mass parameters with slightly modified allowed ranges. The goal of this second scan is to make contrasts and comparisons to the flat prior study in order to determine the dependence of the final model properties on the scan assumptions. For the case of our two priors we find that they yield qualitatively and semi-quantitatively very similar results.

To obtain a valid model we required a very large number of constraints to be satisfied including those from flavor physics, precision measurements, the muon g-2, dark matter direct detection as well as those from Higgs and SUSY searches at both LEP and the Tevatron[1] requiring detector simulation studies. The WMAP dark matter density constraint was also employed but only as an upper bound to allow for other dark matter to exist besides the LSP. Theoretical constraints, such as Higgs potential stability and the absence of color breaking minima were also imposed. For the flat(log) prior analysis this yielded $\sim 68.5(2.8)$k successful models whose properties we briefly discuss below[1]. Once we have these model sets we can examine their properties to see how they differ from the standard scenarios and discover if they lead to new experimental signatures not previously considered[2]. Note that our goal is not to find the **best-fit** models here but to find successful ones that produce new signatures.

In Fig.1 we see the predicted distribution of possible Higgs masses for the surviving models. Note that rather light masses are allowed relative to the $\sim$ 114 GeV SM LEP search bound due to both reduced $Zb\bar{b}$ couplings as well as the existence of the $h \to 2\chi_1^0$ decay channel in some cases. This figure also shows a comparison of the gluino and LSP masses. In mSUGRA this mass ratio is ~ 6 but here all values are possible; the chunk removed from the lower left part of the figure is due to direct Tevatron searches. Note that rather light gluinos(with masses below 200 GeV) are possible when the gluino-LSP mass splitting is small since in this case the resulting jets are too soft to pass the Tevatron search cuts. These sparticles will be difficult to find at the LHC for similar reasons.

Fig.2 shows the predicted mass distributions for neutralinos and charginos; the LSP mass peak is near $\sim$ 150 GeV. Note that many models predict charginos and possibly

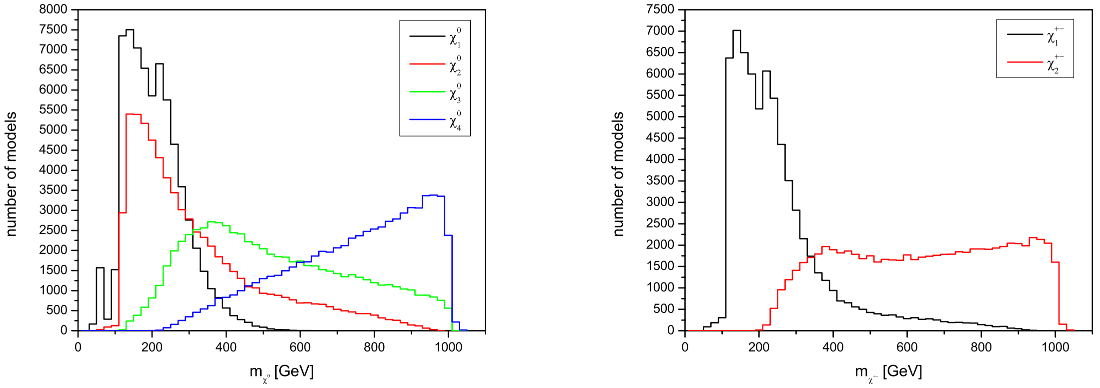

FIGURE 2. Mass distributions for (left) neutralinos and (right)charginos assuming flat priors.

second neutralinos with masses not far above that of the LSP. This is due to the rather frequent occurance of either wino- or higgsino-dominated LSPs in our final model sample(s). Fig.3 shows the predicted mass splitting between the nLSP and the LSP as a function of the LSP mass. The range is quite extraordinary from over 500 GeV to below 1 MeV. The chunk removed from the plot on the lower left side is due to Tevatron stable particle searches as applied to charginos, *i.e.*, for mass splittings below ~ 100 MeV these charginos are detector stable. This figure indicates that SUSY particle spectra with small mass splittings should be a rather likely possibility at the LHC. This would imply that stable particle searches will be important as will searches for sparticles decaying after traveling some finite distance inside the detector. Also shown in Fig.3 is the identity of the nLSP itself. While much of the time the nLSP is either the lightest chargino or the second neutralino, the 11 other possibilities can also occur with a reasonable frequency especially in the case of bino-like LSPs. Many of these scenarios are unusual and have not been well studied (if at all) at the LHC and may yield difficult or unusual signatures.

Fig.4 shows the LSP decomposition as a function of the nLSP-LSP mass splitting. Much of the time the LSP is relatively close to being a weak eigenstate. Here we see that the region of very small mass splittings is dominated by wino-like LSPs ($\sim 23.3\%$ of the time) while for large mass splittings the LSP is more likely to be bino-like ($\sim 17.1\%$ of the time). In the intermediate mass region the LSP is found to be mostly Higgsino-like ($\sim 45.6\%$ of the time). Fig.4 also shows the distribution of predicted masses for the first and second generation squarks. As in the case of gluinos, light squarks remain a distinct possibility despite the Tevatron direct searches. Most commonly, this is again due to the potential small mass splitting that can occur between the squark and the LSP which leads to rather soft jets in the final state. Light squarks with such small mass splittings will also be difficult to see at the LHC.

As discussed above and in [1, 2] the predictions of the MSSM can be vastly different from what one finds in any of the well-studied SUSY breaking scenarios. This can lead to unusual signatures at the LHC which may even be missed by conventional searches.

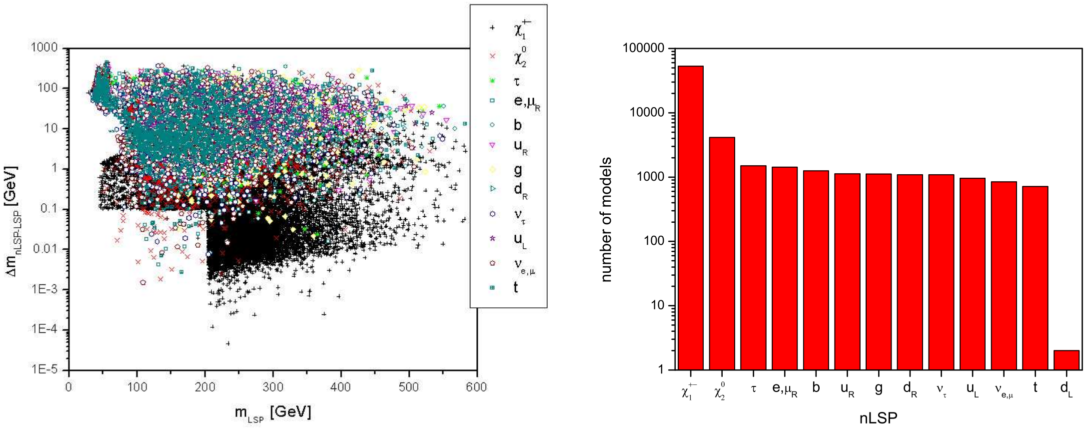

FIGURE 3. (Left)The nLSP-LSP mass splitting as a function of the LSP mass and (right)the identity of the nLSP both for flat priors.

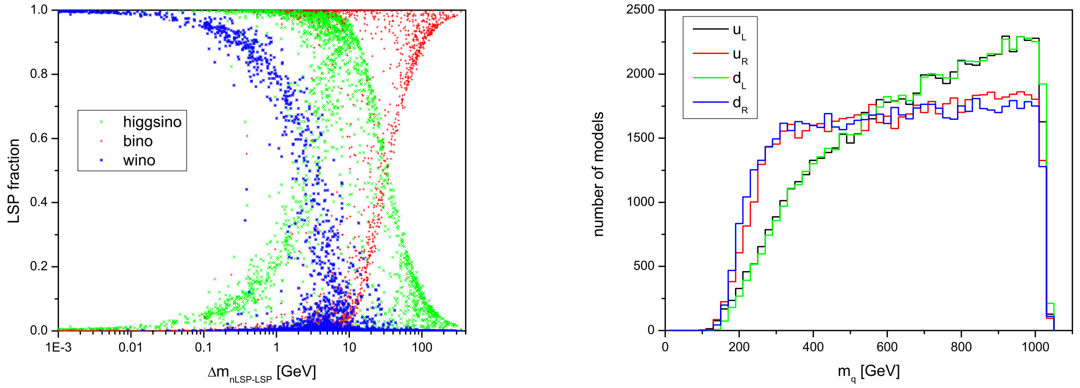

FIGURE 4. (Left)The LSP composition for log prior models as a function of the nLSP-LSP mass splitting and (right) the predicted mass distribution for squarks for the flat prior case.

ACKNOWLEDGMENTS

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REFERENCES

1. For details of this analysis, original references and further results, see C. F. Berger, J. S. Gainer, J. L. Hewett and T. G. Rizzo, JHEP **0902**, 023 (2009) [arXiv:0812.0980 [hep-ph]] and R. C. Cotta, J. S. Gainer, J. L. Hewett and T. G. Rizzo, arXiv:0903.4409 [hep-ph].
2. For discussions of the implications of these results to LHC and dark matter searches, see the presentations by J. Conley and J. Gainer, respectively.