

# MSSM Dark Matter Without Prejudice

James S. Gainer<sup>1</sup>

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

**Abstract.** Recently we examined a large number of points in a 19-dimensional parameter subspace of the CP-conserving MSSM with Minimal Flavor Violation. We determined whether each of these points satisfied existing theoretical, experimental, and observational constraints. Here we discuss the properties of the parameter space points allowed by existing data that are relevant for dark matter searches.

**Keywords:** pMSSM, general MSSM phenomenology, dark matter

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## INTRODUCTION

The MSSM has a large parameter space; this raises the question of how well we know its properties aside from specific SUSY breaking scenarios such as mSUGRA, AMSB, GMSB, etc. In an attempt to address this question, we performed scans of a 19-dimensional subspace of the full 100+ parameter (R-parity conserving) MSSM (sometimes referred to as the “phenomenological MSSM”) and applied a comprehensive set of theoretical, experimental, and observational constraints, thereby obtaining a large set of “models” (parameter space points) which are consistent with existing data[1]. The particulars of and results from this scan are discussed in other presentations at this conference[2, 3]. Here we will be concerned with the implications of this scan for dark matter, addressing the properties of LSPs in the set of allowed MSSM models generated, and in particular their signatures in direct detection and indirect detection experiments.

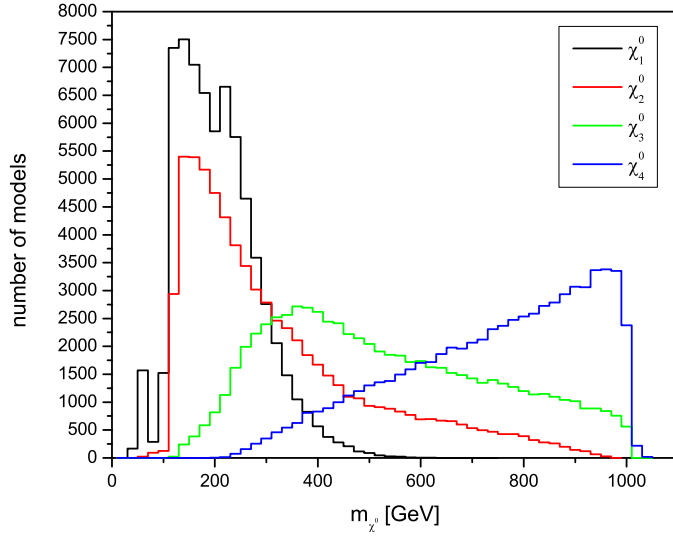
## PROPERTIES OF THE LSP

A histogram of the masses of the four neutralino species in the model set is shown in Figure 1. In all models in this set, the lightest neutralino is the LSP.

It is also notable that most LSPs are relatively pure eigenstates, with models where the LSP is Higgsino or mostly Higgsino being by far the most common. A precise description of the content of LSPs in the model set is presented in Table 1. The prevalence of nearly pure eigenstates is not surprising; one would expect the LSP be a pure eigenstate

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<sup>1</sup> Present addresses: Department of Physics and Astronomy, Northwestern University, Evanston, IL 60208  
High Energy Physics Division, Argonne National Laboratory, Argonne, IL 60439



**FIGURE 1.** The distribution of neutralino masses for models in the model set.

**TABLE 1.** The fractions of models in the model set for which the LSP is of each of the given types. These types are defined in terms of the modulus squared of elements of neutralino mixing matrix in the SLHA convention.

LSP Type	Definition	Fraction of Models
Bino	$ Z_{11} ^2 > 0.95$	0.14
Mostly Bino	$0.8 <  Z_{11} ^2 \leq 0.95$	0.03
Wino	$ Z_{12} ^2 > 0.95$	0.14
Mostly Wino	$0.8 <  Z_{12} ^2 \leq 0.95$	0.09
Higgsino	$ Z_{13} ^2 +  Z_{14} ^2 > 0.95$	0.32
Mostly Higgsino	$0.8 <  Z_{13} ^2 +  Z_{14} ^2 \leq 0.95$	0.12
All other models		0.15

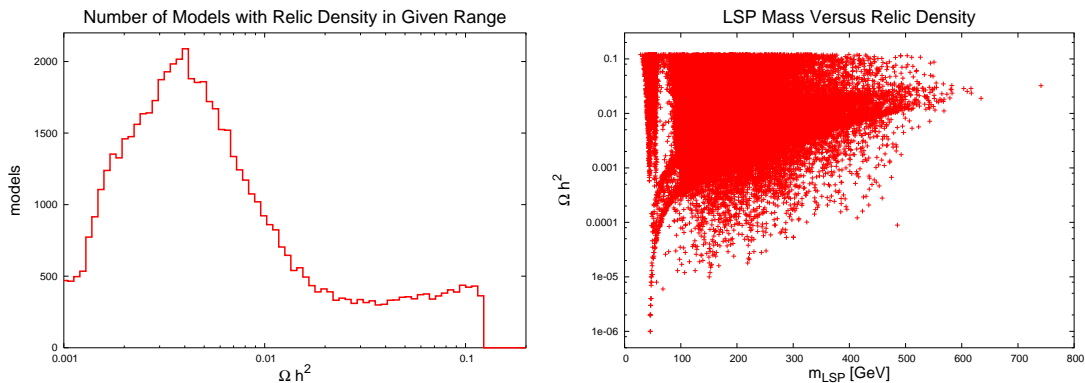
fairly often in a random scan of Lagrangian parameters such as that performed. As the differences between  $M_1, M_2$ , and  $\mu$  will often be large compared to  $M_Z$ , the eigenstates of the resulting mixing matrix will be essentially pure gaugino and Higgsino states.

## RELIC DENSITY

In applying constraints to models, we did not demand that the LSP, in any given model, account for all of the dark matter; we required only that the (thermal) LSP relic density not be too large to be consistent with WMAP. The distribution of  $\Omega h^2|_{\text{LSP}}$  values in our model set is shown in the left panel of Figure 2. It is interesting to note that this

distribution is peaked at small values of  $\Omega h^2|_{\text{LSP}}$  and that the range of possible values of  $\Omega h^2|_{\text{LSP}}$  is found to be much larger than those obtained by analyses of specific SUSY breaking scenarios.

The distribution of predictions for  $\Omega h^2|_{\text{LSP}}$  as a function of the LSP mass for models in the model set is shown in the right panel of Figure 2. We see from this figure that  $\Omega h^2|_{\text{LSP}}$  generally increases with the LSP mass. However, a large range of values for the relic density are possible at any given LSP mass. The empty region in Figure 2 where  $\Omega h^2|_{\text{LSP}} \approx 0.001 - 0.1$  and  $m_{\text{LSP}} \approx 50 - 100$  is due to the paucity of models with Higgsino or Wino LSPs in this mass range (as such models would generally have a chargino light enough for discovery at LEP) together with the fact that in general, LSPs which are mostly Higgsino or Wino give lower values of  $\Omega h^2|_{\text{LSP}}$ .



**FIGURE 2.** The left panel shows the distribution of  $\Omega h^2|_{\text{LSP}}$  for models in the model set. The right panel shows the values of  $\Omega h^2|_{\text{LSP}}$  versus LSP mass for models in the model set.

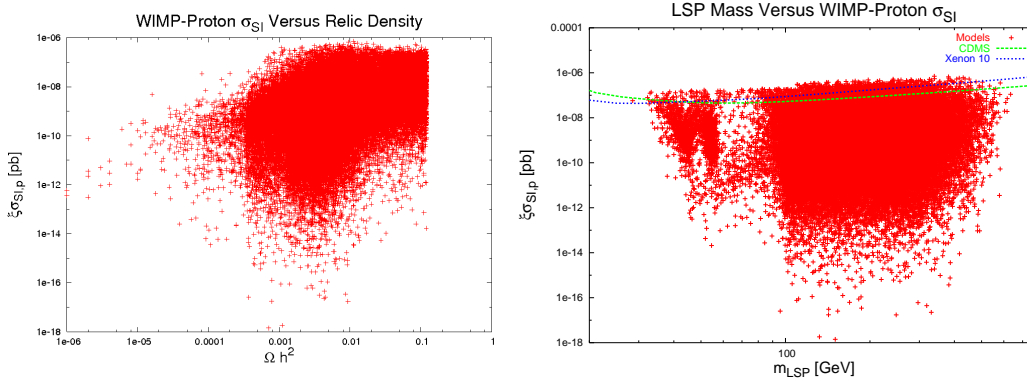
## DIRECT DETECTION OF DARK MATTER

To implement constraints on MSSM parameter space resulting from direct WIMP detection experiments and to study the direct detection signature of allowed models, we calculated the spin-dependent and spin-independent WIMP-nucleon cross sections using micrOMEGAs 2.21. The quantity actually measured in experiments is the WIMP-nucleon cross section scaled to the fraction of the dark matter density represented by the LSP, hence the cross section data presented in the figure below are scaled by  $\xi = \Omega h^2|_{\text{LSP}} / \Omega h^2|_{\text{WMAP}}$ . These experiments generally provide a more significant bound on the spin-independent WIMP-nucleon cross sections, and hence we will focus on these.

In the left panel of Figure 3, the distribution for the scaled WIMP-proton spin-independent cross section versus relic density for our model sample is presented. Perhaps not surprisingly, larger values of the cross section are generally found at larger values of  $\Omega h^2|_{\text{LSP}}$ . However, we note that even for relic densities close to the WMAP value, where there is little contribution to the diversity in scaled cross section from variation in the relic density,  $\xi \sigma_{p,SI}$  is seen to vary by almost eight orders of magnitude.

In the right panel of Figure 3, we see the scaled WIMP-proton spin-dependent and spin-independent cross sections as a function of the LSP mass, together with the con-

straints from XENON10 and CDMS. To take into account significant theoretical uncertainties in the calculation of the WIMP-proton cross section, we allowed for a factor of 4 uncertainty in the calculation of the WIMP-nucleon cross section. Here as well, the range in the value of the scaled WIMP-nucleon cross section is notable.



**FIGURE 3.** The left panel shows the distribution of scaled WIMP-proton spin-independent cross section versus the LSP contribution to relic density for models in the model set, while the right hand panel shows the values of scaled WIMP-proton spin-dependent cross versus LSP mass for models in the model set. In the right panel, the CDMS and Xenon10 bounds, which provide the strongest limits for the range in LSP mass relevant for these models, are shown.

## Indirect Detection of Dark Matter

The PAMELA collaboration has recently claimed an excess in the ratio of cosmic ray positrons to electrons observed at energies above 10 GeV. An attempt to quantify the extent to which these results, together with various other observations including those of the Fermi-LAT, may be understood in terms of LSP annihilation in SUSY models in the model set described here is ongoing; some early results have been presented[4].

## ACKNOWLEDGMENTS

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## REFERENCES

1. For details of the model scan, 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]].
2. The procedure by which this model set was generated is also described in more detail in the presentation by T. G. Rizzo: arXiv:0907.1668 [hep-ph].
3. For discussions of the implications of these results to LHC searches, see the presentation by J. Conley.
4. A more in depth discussion of the implications of our pMSSM scan for dark matter searches, with original references and further results is found in R. C. Cotta, J. S. Gainer, J. L. Hewett and T. G. Rizzo, arXiv:0903.4409 [hep-ph], which will be appearing in the NJP focus issue, 'Dark Matter and Particle Physics'.