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The LHC Confronts the pMSSM

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Abstract

We explore the impact of current (7+8 TeV) and future (14 TeV) LHC searches on the range of viable sparticle spectra within the 19/20 - dimensional phenomenological MSSM (pMSSM). Considering both neutralino and gravitino LSPs, we compare our results with simplified model exclusion limits and describe important cases where the pMSSM results differ significantly from the simplified model descriptions. We also consider models that are poorly constrained by LHC data because of unusual decay topologies and/or displaced decays, and discuss ways to improve the LHC sensitivity in these scenarios. Finally, motivated by naturalness, we examine the sensitivity of current searches to models with light stops and to a specialized set of models with fine-tuning better than 1%. We show that the 14 TeV LHC will be a very powerful probe of natural pMSSM models.

Keywords:
Supersymmetry, MSSM, LHC

1. Introduction

Although the first run of the LHC was highly successful and culminated in the discovery of a SM-like Higgs boson, it failed to uncover definitive evidence for new physics. While this failure could indicate that the new particles have masses beyond the reach of the LHC, it is also possible that light new particles have simply been hidden by large backgrounds from standard model processes. As a result, a broad experimental and theoretical program has focused on understanding and improving the LHC's sensitivity to a broad range of new physics scenarios. These efforts range from specific studies of UV-complete theories (such as minimal supergravity) to generic studies employing simplified models (in which only one or two particles are considered) or even effective operators. Each technique has important advantages and limitations. Specific theories are highly predictive, but exploring the entire range of possible theories (even qualitatively) is clearly impossible. Simplified models do a poor job of describing cases in which several particles are important for the process of interest, and for considering correlations with *e.g.* dark matter observables. Effective operators are valid only in cases where the intermediate physics is heavy enough to be integrated out, which can be problematic given the large mass scales accessible at the LHC. In this paper, we study the LHC signatures of the minimal supersymmetric standard model (MSSM) using the framework of the pMSSM, which shares some of the advantages of both specific and generic approaches. The results presented here were obtained as part of the Snowmass planning process. Additional details about our methods can be found in [1] and the references contained therein.

The MSSM is perhaps the best-motivated theory for physics beyond the Standard Model, due to its ability to solve the hierarchy problem, unify the SM gauge couplings, and potentially provide a stable dark matter candidate. Unfortunately, the general MSSM contains over 100 free parameters. Although we expect that many of these parameters are fixed by details of the UV-complete theory, such as the mechanism of SUSY breaking and possibly the breakdown of a unified gauge group, it is by no means guaranteed that we can anticipate the specific theory realized in nature. In particular, it is possible that

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$m_{\tilde{L}(e)_{1/2,3}}$
$m_{\tilde{Q}(u,d)_{1/2}}$
$m_{\tilde{Q}(u,d)_{3}}$
$\lvert M_1 \rvert$
$\lvert M_2 \rvert$
$\lvert \mu \rvert$
M_3
$\lvert A_{t,b,\tau} \rvert$
M_A
$\tan\beta$

Table 1: The 19 parameters of the pMSSM with a neutralino LSP. Models with a gravitino LSP are described by the same 19 parameters plus the gravitino mass $m(\tilde{G})$.

a theory with non-minimal particle content could reduce to the MSSM in the low energy limit, suggesting that we should treat the MSSM as an effective theory for which the UV completion is as yet unknown. Fortunately, this approach is aided by very strong experimental constraints on many of the parameters of the general MSSM Lagrangian, motivating an approach in which we apply experimentally-motivated assumptions to simplify the general MSSM. Specifically, we derive the pMSSM from the general R-parity conserving MSSM by assuming (*i*) CP conservation, (*ii*) Minimal Flavor Violation at the electroweak scale so that flavor physics is essentially controlled by the CKM mixing matrix, (*iii*) degenerate 1$^{\text{st}}$ and 2$^{\text{nd}}$ generation sfermion soft mass parameters (*e.g.*, right-handed up and charm squarks are degenerate apart from small corrections due to non-zero quark masses), and (*iv*) negligible Yukawa couplings and A terms for the first two generations. After these assumptions, the pMSSM is characterized by the 19 parameters listed in Table 1, with an additional parameter, the gravitino mass, becoming important in the case where the gravitino is the lightest supersymmetric particle (LSP). Although a complete scan of this smaller space is still clearly impossible, a numerical scan is still useful to search for and understand model characteristics which may impede discovery at the LHC. In particular, it is clear that many observables will only depend on a small subset of the parameters, in which case our scan will more fully explore the possible range of phenomenology for that observable.

2. Methods

In this paper, we study the LHC phenomenology of several sets of pMSSM models that are consistent with the set of pre-LHC experimental data and theoretically viable. In particular, we study ~223k models with a neutralino LSP and ~229k models with a gravitino LSP, all of which predict a LSP abundance that is *less than or equal to* the total dark matter abundance. The specific constraints applied to select these models are detailed in [2]. We also study a special set of ~10.2k models with a neutralino LSP that have low fine tuning ($\Delta < 100$) according to the Barbieri-Giudice measure and additionally predict an LSP abundance *equal to* the total dark matter abundance, the generation of which was described in [1]. Although many of the models in the general neutralino and gravitino model sets do not predict the observed Higgs mass, we have found that the LHC searches are approximately independent of the Higgs mass requirement within the allowed range of masses. In order to obtain a reasonably comprehensive picture of the LHC SUSY results, we simulate the ATLAS and CMS searches listed in Tables 2 and 3 and determine whether each model is excluded or allowed by the combined search results. We also simulate the potential impact of null results from ATLAS Jets+MET and stop searches at 14 TeV with both 300 and 3000 fb^{-1}. Due to the large amount of CPU resources required, we simulate 14 TeV events only for the subsets of models predicting the correct Higgs mass. For all of these simulations, we generate events with PYTHIA 6.4.26 [3] and scale the event rates to NLO using K-factors calculated by Prospino 2.1 [4]. We then employ PGS 4 [5] for our fast detector simulation. Both PYTHIA and PGS have been modified to correctly deal with gravitinos, multibody decays, hadronization of stable colored sparticles, and ATLAS b-tagging. Finally, we apply the cuts for the simulated analyses using our customized analysis code, which follows the cuts and selection criteria employed in the searches as closely as possible. Models are considered excluded if the event rate in any signal region is above the 95% CL_s limit set by ATLAS or CMS. We validate our results by running our simulation on benchmark models for each signal region in the various analyses and comparing our results with the published selection efficiencies.

3. Results

3.1. Neutralino LSP

We first examine models with a neutralino LSP, including both the general neutralino and Low-FT model sets described above. Since the LHC is a hadron collider, we expect large production rates for colored sparticles, particularly $1^{st}/2^{nd}$ generation squarks and gluinos, and correspondingly strong limits on their