Using the phenomenological MSSM to elucidate complementarity of sensitivity to supersymmetry from future colliders, astrophysical and cosmological data, and precision measurements.

Sam Bein (University of Hamburg), Jennet Dickinson (Fermilab),
Kenichi Hatakeyama (Baylor University), Jim Hirschauer (Fermilab),
Andrew Whitbeck (Texas Technical University)

Abstract: We propose to use the 19-parameter phenomenological minimal supersymmetric standard model (pMSSM) to quantify individual sensitivity to supersymmetry (SUSY) from a variety of current and future experiments including high energy lepton and hadron colliders; direct and indirect searches for dark matter; astrophysical and cosmological surveys; and precise measurements of standard model processes, properties, and regimes including muon g-2, heavy flavor physics, and electroweak physics.

Motivation: It is well known that the standard model (SM), while finally a complete theory since the discovery of the Higgs boson, cannot be the ultimate theory of fundamental particles and interactions. Most obviously, the SM does not incorporate gravity and explains neither the identity of the astronomically observed dark matter (DM) nor the observed multiplicities and hierarchies of interactions, flavor, and fermion generations. Of the many models proposed to address the shortcomings of the SM, supersymmetry (SUSY) garners significant interest because it simultaneously explains the finite mass of the recently discovered Higgs particle, provides a DM candidate, and allows more precise unification of the forces.

The minimal supersymmetric standard model (MSSM) has 120 parameters describing particle masses and interactions. In order to facilitate interpretation of experimental results within the MSSM framework, these 120 free parameters have traditionally been reduced to five, by assuming relationships between MSSM parameters based on a choice of the SUSY breaking mechanism at high energy scale, in the form of the constrained MSSM (cMSSM) [1] or two parameters, by assuming pair production of a single SUSY particle (sparticle) with fixed decay chain, in the form of simplified model spectra (SMS) [2]. While the cMSSM and SMS provide frameworks for efficient interpretation of results in order to both exclude regions of MSSM parameter space and understand the impact of experiment constraints on those exclusions, they do so at the expense of sampling only a very small part of the phase space of the MSSM and potentially focusing on signatures that may not be realized in nature.

Recently, ATLAS, CMS, and theorists have attempted to ameliorate the limitations of interpretations based on the cMSSM and SMS by use of the phenomenological MSSM (pMSSM) [3], which reduces the 120-parameter MSSM space to 19 free parameters, specified at the electroweak (EW) scale, based on assumptions related to current experimental constraints (including those from flavor, CP violation, and EW symmetry breaking) rather than details of the SUSY breaking mechanism. In practice, the 19-parameter space is sampled by selecting random values for all 19 parameters from flat distributions within ranges chosen to be consistent with experimental constraints and provide collider-accessible SUSY particle masses. For each generated pMSSM point, properties of theoretical and experimental interest are calculated (including Higgs mass, dark matter relic abundance, muon g-2, heavy flavor branching fractions, Z boson width, etc.) to illustrate general trends in the effects of collider constraints on these measurements.

Proposed Studies: We propose to build on the mature, published methods of the CMS and ATLAS collaborations to develop a flexible framework for interpretation of SUSY sensitivity studies for future colliders in the framework of the pMSSM. The framework should allow generation and selection of pMSSM model points for electron, muon, and hadron colliders at a variety of center-of-mass energies to match collider scenarios envisioned for Snowmass 2021. Detector simulation for the majority of pMSSM models will be performed with publicly available configurations for the Delphes software package, but special attention will likely be required for pMSSM models giving rise to signatures that are challenging to model well with a parameterized simulation. Finally, the pMSSM framework should allow full compatibility with the sample generation software and processes developed by the Snowmass 2021 Monte Carlo Task Force.

The pMSSM-based interpretations will include latest published results from LHC Run 2, existing projections including those performed for future lepton and hadron colliders for the European Strategy update, and new projections performed by a variety of topical groups within the Snowmass 2021 organization including planned muon collider studies. Summaries should also include comparisons to SMS-based exclusions in order to identify regions of SMS space where the fraction of pMSSM models excluded are higher or lower than expected based on the SMS exclusion. Regions with higher than expected exclusion fraction will be studied for the presence of potential signatures with unappreciated power for constraining SUSY; regions with lower than expected exclusion fraction will be studied to identify potential classes of models with similar experimental challenges. We will also collaborate with other Snowmass frontiers to include projections for improved understanding of precision observables (such as those related to flavor, CP violation, Higgs and EW symmetry breaking, dark matter, and muon g-2) in the proposed pMSSM-interpretation summaries.

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