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SUSY global fits with future colliders using GAMBIT

Thematic Areas:

■ (EF08) BSM: Model specific explorations

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Abstract:

In this LoI we propose to study the impact of future electron-positron colliders, such as CEPC, CLiC, ILC and FCC-ee, on global fits of the simplest supersymmetric models, such as the CMSSM, NUHM1, NUHM2 and pMSSM-7. We plan to use the publicly available GAMBIT code and publicly available data published by the GAMBIT Community. As a preliminary step, we will update existing GAMBIT results using likelihoods for the latest searches for supersymmetry and Higgs at the LHC, direct and indirect searches for dark matter, electroweak precision and flavour observables. We will then include additional likelihoods for potential results from future colliders assuming specific benchmark points. From the impact of the additional likelihoods, we will judge the discovery prospects and reaches of future colliders. The purpose of this LoI is to provide a further motivation for the construction of future electron-positron colliders.

1 Introduction

A near future lepton collider is a crucial next step in the luminosity frontier. Compelling proposals for such a facility include the Circular Electron-Position Collider (CEPC) [1], the Compact Linear Collider (CLIC) [2], the FCC-ee [3], and the International Linear Collider (ILC) [4]. These machines can shed complementary light on the status of low energy supersymmetric (SUSY) extensions of the Standard Model (SM). Restricted by collision energy, the direct searches for supersymmetric particles (sparticles) at electron-positron colliders are not as robust as hadron colliders. However, they provide a powerful tool to perform high precision measurements of the Higgs and electroweak (EW) sector, which can significantly affect the global fit of SUSY models.

Global fits provide the most comprehensive information on a new physics model. They allow us to infer the maximal amount of information on a given model from the widest range of experimental data. Global fits assess and compare the validity of the models, identify the range of the model parameters with the highest likelihood or posterior probability and study the predictions and consequences for future searches and experiments. The same exploration is also an important part of the Technical Design Report (TDR) for future electron-positron colliders.

The GAMBIT Collaboration [5] have performed the most comprehensive global fits on five supersymmetric models: the Constrained Minimal Supersymmetric Standard Model (CMSSM), its Non-Universal Higgs Mass generalisations NUHM1 and NUHM2 [6], as well as the seven-dimensional phenomenological MSSM (pMSSM7) with all parameters defined at the weak scale [7], and a four-dimensional electroweakino sector of MSSM (EWMSSM) [8]. The likelihood functions of the first four global fits include a number of direct and indirect dark matter searches, a large collection of electroweak precision and flavour observables, direct searches for supersymmetry at the Large Electron-Positron collider (LEP) and Runs I and II of the Large Hadron Collider (LHC), and constraints from Higgs observables. All GAMBIT input files and generated likelihood samples for these models are publicly available online through Zenodo [9, 10].

In this study, we plan to post-process the public GAMBIT samples with likelihoods of expected precision limits from future electron-positron colliders. By comparing the preferred regions and best fits before and after applying such likelihoods, we can estimate the prospective reaches of future colliders.

2 Models

We consider four constrained versions of the general R-parity-conserving MSSM:

- CMSSM. Inspired by scenarios where SUSY breaking is transmitted through supergravity interactions, the soft mass parameters at the Grand Unified Theory (GUT) scale are fixed to a universal scalar mass m_0, a universal gaugino mass $m_{1/2}$ and a universal trilinear couping A_0. The remaining free parameters in the Higgs sector are the sign of μ and the ratio of the vacuum expectation values of the two Higgs doublets $\tan\beta = v_u/v_d$, which is defined at the scale m_Z.

- NUHM1. The GUT-scale constraint on the soft scalar Higgs masses is relaxed, introducing the additional free parameter m_H . The soft Higgs masses m_{H_u} and m_{H_d} are not set equal to m_0, but instead obey the relation $m_{H_u} = m_{H_d} = m_H$ at the GUT scale.

- NUHM2. The constraint on the soft Higgs masses is further relaxed so that m_{H_u} and m_{H_d} become independent, real, dimension-one parameters at the GUT scale.

- pMSSM-7. All the input parameters are defined at an energy near the electroweak scale. Inspired by GUT scale gaugino mass universality, we set $3/5\cos^2\theta_W M_1 = \sin^2\theta_W M_2 = \alpha/\alpha_s M_3$. We assume that all entries in A_u, A_d and A_e are zero except for $(A_u)_{33} = A_{u_3}$ and $(A_d)_{33} = A_{d_3}$. We take all of the off-diagonal entries in m_Q^2, m_u^2, m_d^2, m_L^2 and m_e^2 to be zero, so as to suppress flavour-changing neutral currents. By setting all remaining mass matrix entries to a universal squared sfermion mass $m_{\tilde{f}}^2$, we reduce the final list of free parameters to M_2, A_{u_3}, A_{d_3}, $m_{\tilde{f}}^2$, $m_{H_u}^2$, $m_{H_d}^2$ and $\tan\beta$ (plus the input scale Q and the sign of μ).

The scanned parameter ranges can be found in Ref. [6, 7]. All dimensionful parameters are allowed to vary up to 10 TeV, safely covering scenarios that are motivated by the hierarchy problem and the most phenomenologically interesting regions within reach of colliders.

3 Updated experimental constraints

Before studying the future electron-positron colliders, we need to post-process the public GAMBIT samples with the latest version of GAMBIT, as those samples were generated using a likelihood from experimental results three years ago.

For instance, the most powerful constraints on spin-independent DM-nucleon scattering back then were from the LUX experiment with a 3.35×10^4 kg day exposure [11]. At a DM mass of $50\,\mathrm{GeV}$, WIMP-nucleon spin-independent cross sections above 1.1×10^{-46} cm^2 are excluded at the 90% confidence level. Now the limit has been pushed down to 5.3×10^{-47} cm^2 by the XENON1T experiment using 278.8 days of data [12].

The integrated luminosity of data recorded by the ATLAS and CMS experiments in $\sqrt{s} = 13\,\mathrm{TeV}$ LHC has increased from 36 fb^{-1} to about 139 fb^{-1}. Thus the experimental uncertainties on SM-like Higgs couplings are significantly smaller, and the bounds on masses of sparticles are much stronger than the ones used in the previous GAMBIT likelihood. Furthermore, plenty of new searches at the LHC have been added to GAMBIT since then.

4 Projected constraints from the future electron-positron colliders

As Higgs factories, the future electron-positron colliders can achieve a precision for Higgs properties, including couplings, cross section and branching ratios, of about 10^{-3}, and for the EW observables of 10^{-6}, and provide excellent sensitivity to indirect new physics.

Using these projected precisions and assuming the results are SM-like or centering on the present supersymmetric best-fit point, we can build likelihooods for the future electron-positron colliders. Comparing the preferred regions and best fits with and without the likelihoods, we can estimate the prospective reaches and discovery prospects of future colliders.

The direct bounds on masses of sparticles obtained from lepton colliders are usually smaller than half of the highest centre-of-mass collision energy. However, unlike hadron colliders, these limits from lepton colliders are almost independent of decay modes of the sparticles and the mass of lightest sparticle. As a result, some compressed regions of SUSY that escape the LHC searches can be excluded at the future electron-positron colliders. Investigating whether such regions exist in the results of our global fit is also a goal of this project.

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