Required experimental accuracy to select between supersymmetrical models

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Abstract. We will present a method to decide *a priori* whether various supersymmetrical scenarios can be distinguished based on sparticle mass data alone. For each model, a scan over all free SUSY breaking parameters reveals the extent of that model's physically allowed region of sparticle-mass-space. Based on the geometrical configuration of these regions in mass-space, it is possible to obtain an estimate of the required accuracy of future sparticle mass measurements to distinguish between the models. We will illustrate this algorithm with an example. This talk is based on work done in collaboration with B C Allanach (LAPTH, Annecy) and F Quevedo (DAMTP, Cambridge).

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1. Background

Rather than analyzing single mSUGRA points in detail [1] or reconstructing SUSY breaking parameters from low-scale observables [2], we propose a procedure aiming to look at various models of SUSY breaking simultaneously, scanning over wide ranges of their input parameters to try to find the minimal set of measurements that is required to separate the models. We wish to investigate whether it is possible to decide *a priori* that two high-scale models can be distinguished on experimental grounds, and want to determine the necessary measurement accuracy to do so.

At the root of our procedure stands the observation that any sparticle spectrum study basically deals with two kinds of quantities. On the one hand we have a set of input parameters at the high scale, determined by some fundamental theory; on the other we have a set of observables at the electroweak scale. Both sets of quantities can be looked at as vectors in their respective parameter spaces. The first space, $\mathcal{I}$, is one of free model parameters at the high scale. Each model m under consideration will have its own input space $\mathcal{I}_m$. The number of its dimensions is determined by the number of free parameters in the model. To make our analysis technically feasible, this should be a small number, typically smaller than 6–8. Each point in $\mathcal{I}_m$ then corresponds to one fixed choice of high-scale input parameter values for model m.

The second space, $\mathcal{M}$, is the space of physical measurements at the electroweak scale. There is only one unique $\mathcal{M}$, since all models describe the same electroweak

scale physics. Its dimensionality equals the number of low-scale observables under consideration. Typical values are as large as 20–30 (taking in all sparticle masses). Each point in $\mathcal{M}$ denotes one set of fixed values for the observables.

Each model also specifies a set of renormalization group equations (often this may be the standard MSSM RGEs), through which each point in $\mathcal{I}_m$ can potentially be mapped onto a point in $\mathcal{M}$ (see figure 1). Consequently, a scan over all N parameters in $\mathcal{I}_m$ will build up an N-dimensional hypersurface in $\mathcal{M}$, which we will call the *footprint* of the high-scale model under consideration. One restriction is imposed at this step: only physical points which do not violate experimental bounds are considered part of the footprint.

Different models will have different footprints, some of which may be disjoint, while others may overlap. However, as long as the footprints' hypersurfaces are of much lower dimensionality than $\mathcal{M}$, as is generally the case, it will be quite unlikely that there will be any overlap between the prints. As soon as it is established that the two prints are disjoint, it is possible to conclude that the two models can in principle be distinguished experimentally, as long as a certain measurement accuracy can be achieved. To determine the required level of accuracy, a minimization algorithm can be used to find $\vec{v}$, the vector spanning the closest approach of the two footprints. The required relative accuracy for the various measurements (which lie along the axes of $\mathcal{M}$) can now be determined by examining the respective components of $\vec{v}$.

2. Example study

As a test case for our procedure we looked at the three Type I string motivated models we have used previously in [3]. The input spaces here are four-dimensional subsets of the standard mSUGRA parameter space, and they all use the same set of parameters (namely two goldstino angles θ and ϕ, $\tan\beta$ and the gravitino mass $m_{3/2}$). The models differ in the running of the RGEs that were used to obtain the footprints. One model assumes the standard gauge coupling unification at $m_{\mathrm{GUT}} = 10^{16}\,\mathrm{GeV}$, the second uses a fundamental scale of $10^{11}\,\mathrm{GeV}$ with mirage
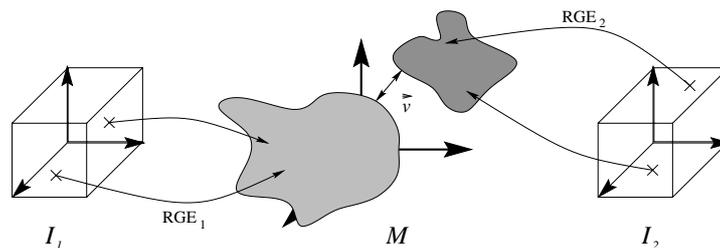
Figure 1. $\mathcal{I}_1$ and $\mathcal{I}_2$ are input parameter spaces for two different SUSY breaking models. Each point within $\mathcal{I}_m$ corresponds to one set of high-scale parameters for model m, serving as input to this model's RGEs. They uniquely map each input point onto a point in $\mathcal{M}$, the space of measurements. Scanning over $\mathcal{I}_m$ point by point builds up the footprint of model m in $\mathcal{M}$. The closest approach of the two footprints is indicated by $\vec{v}$.
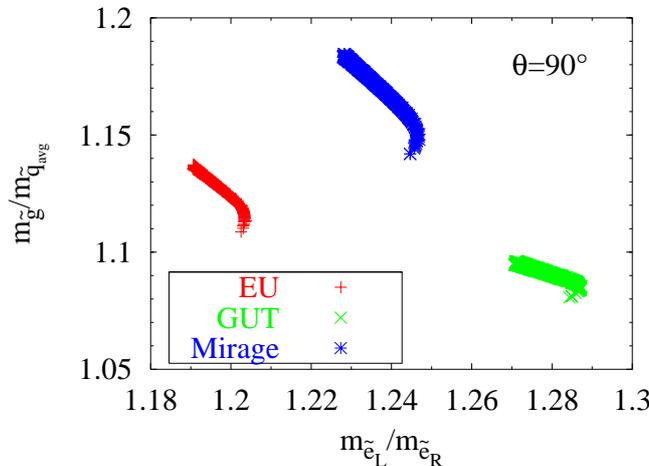
Figure 2. Footprints generated by scanning 1000 random points in the dilaton domination limit for each of the three considered models. (Updated figure from [3].)

unification, the third achieves early unification at $10^{11}\,\text{GeV}$ through the addition of extra slepton multiplets (see [3] for details). To obtain the sparticle spectra, we used a slightly modified version of SOFTSUSY 1.7.1 [4].

The determination of $\vec{v}$ turned out to be problematic for standard minimization algorithms such as MINUIT [5] because of the very irregular nature of the footprints' boundaries which originates in the exclusion of unphysical points. A more promising approach which we are currently working on is the use of genetic algorithms [6], which are more robust against the occurrence of excluded points. The choice of observables to be plotted against the axes in $\mathcal{M}$ turned out to be somewhat critical. We found it to be useful to plot mass ratios rather than the masses directly, to eliminate the dependence of the plots on the overall size of the SUSY mass splittings.

In [3], we have shown that the separation of the three models is possible in the dilaton dominated case (see figure 2), where one of the input parameters is held at a fixed value: $\theta = 90°$. To distinguish the models, a combined theoretical and experimental accuracy [7] of about 2–3% is required for the determination of both $m_{\tilde{g}}/m_{\tilde{q}_{\text{avg}}}$ and $m_{\tilde{e}_{\text{L}}}/m_{\tilde{e}_{\text{R}}}$, which could be achievable in a combined linear collider/LHC analysis.

With our new automatized approach, we were able to extend this result to show separation for $60° \leq \theta \leq 90°$, and are currently working on extending it towards the full dimensionality scan over all four free input parameters.

Possible future directions for this work could include a study of other high-scale models, which do not necessarily have to be string models. Large improvements can probably be made in the design of the minimization algorithm and the choice of investigated observables.

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