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Theoretical Uncertainties in Sparticle Mass Predictions

B.C. Allanach*
TH Division, CERN, Geneva 23, CH 1211 Switzerland
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We contrast the sparticle spectra obtained from three modern publicly available codes along model lines in minimal supersymmetric standard model (MSSM) parameter space. From this we gain an idea of the uncertainties involved with sparticle spectra calculations. The differences in predicted sparticle masses are typically at the several percent-level. In the focus-point scenario, there are differences of 30% in the weak gaugino masses. These uncertainties need to be reduced in order to obtain accurate information about fundamental models of supersymmetry breaking.

MSSM phenomenology is so complicated that studies of the ability of future colliders to search for and measure supersymmetric parameters has focused on isolated 'bench-mark' model points [1, 2, 3]. This approach, while being a start, is not ideal because one is not sure how many of the features used in the analyses will apply to other points of parameter space. In an attempt to cover more of the available parameter space, the *Direct Investigations of SUSY Subgroup* of *SNOWMASS 2001* has proposed eight bench-mark model lines for study.

The lines have been defined to have the spectrum output from the `ISASUGRA` program (part of the `ISAJET7.51` package [4]) for $m_t = 175$ GeV. `ISASUGRA` solves the MSSM normalization group equations subject to boundary conditions at low energy (measured Standard Model couplings and constraints from consistent electroweak symmetry breaking) and a higher energy scale (the theoretical boundary condition on the soft mass parameters). Knowledge of the uncertainties will be important when data is confronted with theory, i.e. when information upon a high-energy SUSY breaking sector is sought from low-energy data. Here, we intend to investigate the theoretical uncertainties in sparticle mass determination. To this end, we contrast the sparticle masses predicted by three modern publicly available supported codes: `ISASUGRA`, `SOFTSUSY` [5] and `SUSPECT` [6].

Each of the three packages calculates sparticle masses in a similar way, but with different approximations [7]. In each of the model line scenarios, we calculate the fractional difference for some sparticle s

$$f_s^{\text{CODE}} = \frac{m_s^{\text{ISASUGRA}} - m_s^{\text{CODE}}}{m_s^{\text{ISASUGRA}}}, \qquad (1)$$

where CODE refers to `SOFTSUSY1.2`, or `SUSPECT2.0`. f_s^{CODE} then gives the fractional difference of the mass of sparticle s between the predictions of CODE and `ISASUGRA`. A positive value of f_s^{CODE} then implies that s is heavier in `ISASUGRA` than in CODE.

We focus upon model lines in scenarios which are currently supported by all three packages, i.e. supergravity mediated supersymmetry breaking (mSUGRA). At a high unification scale $M_{GUT} \equiv 1.9 \times 10^{16}$, the soft-breaking scalar masses are set to be all equal to m_0, the universal scalar trilinear coupling to A_0 and each gaugino mass $M_{1,2,3}$ is set. $\tan\beta$ is set at M_Z. The three choices of model lines are displayed in Table I. Model line A displays gaugino mass dominance, ameliorating the SUSY flavor problem. Model line B has non-universal gaugino masses and model line F corresponds to focus-point supersymmetry [8], close to the electroweak symmetry breaking boundary.

We pick various sparticle masses that show a large difference in their prediction between the three calculations. For model line A, Fig. 1a shows $f^{\text{SOFTSUSY}}_{\tau_1, b_1, q_1, h^0, \chi_1^0, \chi_1^+, g}$ (the lightest stau, sbottom, squark, neutral Higgs, neutralino,

TABLE I: Model lines in mSUGRA investigated here. $m_t = 175$ GeV, $M_{GUT} = 1.9 \times 10^{16}$ GeV and $\alpha_s(M_Z)^{\overline{MS}} = 0.119$ are used.

Model line	$\tan\beta$	A_0	M_1	M_2	M_3	m_0	sgnμ
A	10	-0.4$M_{1/2}$	$M_{1/2}$	$M_{1/2}$	$M_{1/2}$	$0.4M_{1/2}$	+
B	10	0	$1.6M_2$	M_2	M_2	$M_2/2$	+
F	10	0	$M_{1/2}$	$M_{1/2}$	$M_{1/2}$	$2M_{1/2} + 800$ GeV	+

*benjamin.allanach@cern.ch; `http://allanach.home.cern.ch/allanach/`

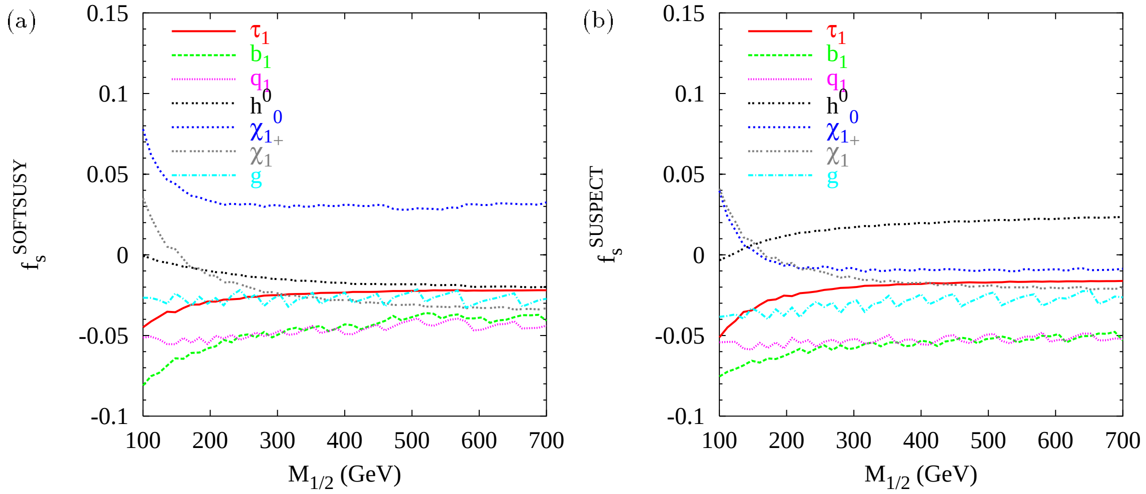

FIG. 1: Fractional differences between the spectra predicted for mSUGRA model line A

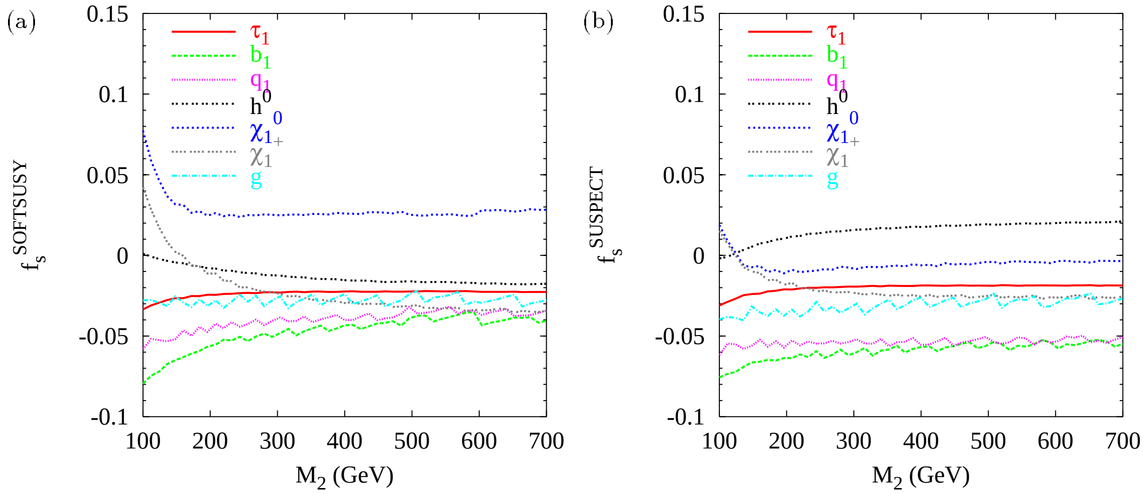

FIG. 2: Fractional differences between the spectra predicted for model line B

chargino and gluino mass difference fractions respectively). Fig. 1b shows the equivalent results for the output of SUSPECT. Model line B differences are shown in Fig. 2. Jagged curves in the figures are a result of numerical error in the ISASUGRA calulcation, and are at the 1% level for squarks, gluinos and the lightest neutralino. The stau, lightest Higgs and lightest chargino do not display any appreciable numerical error. We have checked that SOFTSUSY and SUSPECT do not have any numerical error that is detectable by eye for any of the sparticles.

Figs. 1,2 share some common features. In general, the largest discrepancies occur for low $M_{1/2}$, where the super-particle spectrum is lightest. The gluino and squark masses are consistently around 5% lower in ISASUGRA than the other two codes, which agree with each other to better than 1%. We note here that this uncertainty is not small, a 5% error on the gluino mass at $M_{1/2} = 700$ GeV in model A corresponds to an error on the predicted gluino mass of 75 GeV, for example. The lightest neutralino mass predicted by SUSPECT is in agreement with ISASUGRA to 2%, whereas SOFTSUSY predicts this neutralino to be lighter by another 2% or so. The Higgs masses also agree to above 2% between each code and ISASUGRA, but SOFTSUSY and SUSPECT have opposite sign differences. This is probably due to the fact that SOFTSUSY uses a FeynhiggsFast calculation of the neutral Higgs masses with important two-loop effects added [9], which predicts masses that tend to be higher than the one-loop calculation (as used in ISASUGRA or SUSPECT). The stau mass also looks fairly consistent between SUSPECT and SOFTSUSY (2% lighter than ISASUGRA), but this could conceivably be due to their one-loop running of scalar masses. The lightest neutralino mass shows large deviations between all codes up to 5%, and this is not currently understood.

The focus-point scenario (model line F) is displayed in Fig. 3. The overall view of spectral differences is similar to that in model lines A and B except for the masses of the lightest chargino and neutralino. They display large 10-30% differences. The large spikes come from numerical errors in the ISASUGRA calculation. In focus

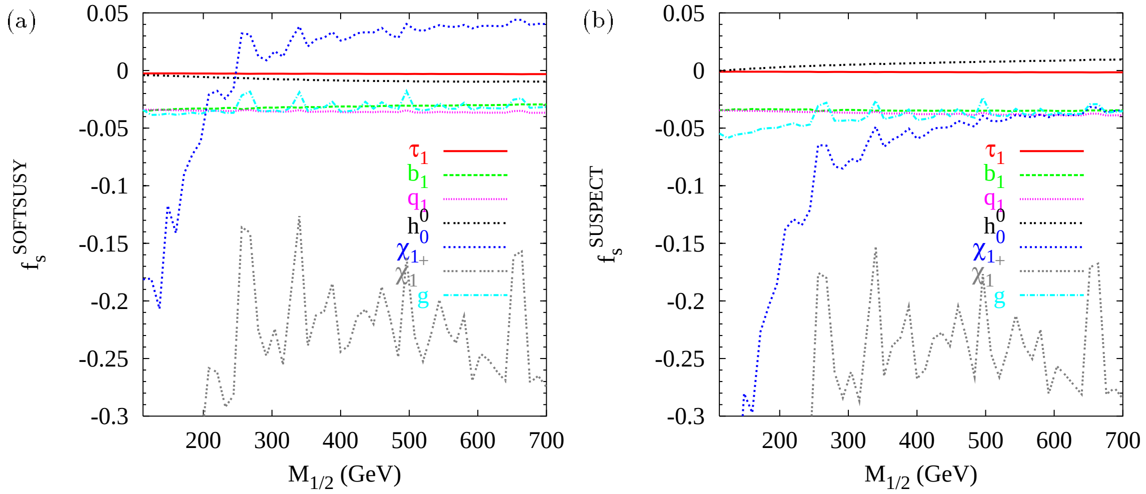

FIG. 3: Fractional differences between the spectra predicted for model line F

point supersymmetry, the bilinear Higgs mass parameter μ is close to zero and is very sensitive to threshold corrections to m_t [10]. For small $\mu < M_Z$, the lightest chargino and neutralino masses become sensitive to its value. The predicted value of $\mu(M_Z)$ differs by 50%-100% between all of the three code's output. Only a few of the threshold corrections to m_t are included in the `ISASUGRA` calculation, whereas `SOFTSUSY`, for example, includes all one-loop corrections with sparticles in the loop. `SUSPECT` also adds many of the sparticle loop corrections to m_t.

In order to discriminate high energy models of supersymmetry breaking, it will be necessary to have better than 1% accuracy in both the experimental *and* theoretical determination of superparticle masses [11]. An alternative bottom-up approach [12] is to evolve soft supersymmetry breaking parameters from the weak scale to a high scale once they are 'measured'. The parameters of the high-scale theory are then inferred, and theoretical errors involved in the calculation will need to be minimised. We note that possible future linear colliders could determine some sparticle masses at the per-mille level [13]. An increase in accuracy of the theoretical predictions of sparticle masses by about a factor 10 will be necessary.

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