SUSY Parameter Measurements with Fittino

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This article presents the results of a realistic global fit of the Lagrangian parameters of the Minimal Supersymmetric Standard Model with no assumptions on the SUSY breaking mechanism using the fit program Fittino. The fit is performed using the precision of future mass measurements of superpartners at the LHC and mass and polarized topological cross-section measurements at the ILC. Higher order radiative corrections are accounted for wherever possible to date. Results are obtained for a modified SPS1a MSSM benchmark scenario (general MSSM without assumptions on the breaking mechanism) and for a specific mSUGRA scenario. Exploiting a simulated annealing algorithm, a stable result is obtained without any *a priori* assumptions on the fit parameters. Most of the Lagrangian parameters can be extracted at the percent level or better if theoretical uncertainties are neglected. Neither LHC nor ILC measurements alone will be sufficient to obtain a stable result.

1. Introduction

Provided low-energy Supersymmetry (SUSY) [1] is realized in Nature, the next generation of colliders, the Large Hadron Collider (LHC) [2] and the International Linear Collider (ILC) [3] are likely to produce most particles of the SUSY spectrum and will allow for precise measurements of their properties. If SUSY is established experimentally, it is the main task to explore the unknown mechanism of SUSY breaking. Specific SUSY breaking models (e. g. minimal supergravity (mSUGRA) [4]) can be tested against the observables in a straight-forward manner due to the small number of parameters. However, an exploration of the parameters of the general Minimal Supersymmetric Standard Model (MSSM) parameter space is significantly more ambitious, especially without the use of any *a priori* assumptions on the parameter values. Using the best-studied MSSM scenario available to date, SPS1a [5–7], the prospects for SUSY parameter measurements using the fit program Fittino [8] are outlined in the following.

2. SUSY Parameter measurement in the MSSM with Fittino

Fittino has been created to determine the parameters of the MSSM Lagrangian without any *a priori* assumptions, using available loop-level precision predictions (e. g. [9]) and observables from present and future colliders, cosmology and rare decay measurements in a χ^2 fit. Since finding the χ^2-minimum in a many-dimensional (≈ 20) parameter space is difficult, a 3-step technique is used: First, the parameters are estimated using tree-level relations. Second, simulated annealing is used to find the global minimum. Third, a global fit is used to find the precise minimum and determine the parameter uncertainties and correlations.

In order to test the parameter measurement using simulated measurements from future colliders, the SPS1a' scenario [6] is chosen. Unification is assumed in the first two generations, and the top quark mass m_t is fitted as an additional parameter to account for parametric uncertainties. In total, 19 free parameters are fitted. The observables and their simulated uncertainties used in the fit are given in [7, 10]. By fitting to edges in LHC spectra instead of masses derived from the spectra [7], correlations among observables are taken into account where known to date.

Using simulated measurements from LHC only, most relative uncertainties on the parameters are in the order of 100 %. Therefore, the data from the ILC is needed to understand the low-energy MSSM Lagrangian. The fit including the simulated ILC measurements is stable, very well under control (see Fig. 1) and shows no biases [10].
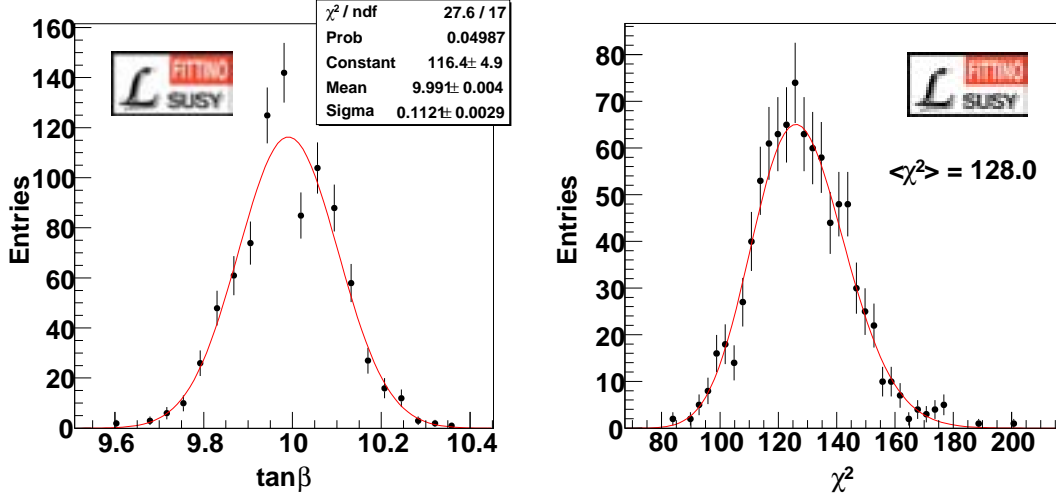
Figure 1: *The plot on the left shows the toy fit value distributions for ~1000 independent fits with observables smeared within their uncertainties for the parameter $\tan\beta$. The right plot shows the χ^2 distribution for ~1000 independent fits with observables smeared within their uncertainties. The mean χ^2 from a χ^2 function fitted to the observed distribution of 128.0 agrees with the expectation of 129.0 ± 0.7 [10].*

Parameter	Fit value & "True" Value	Uncertainty (exp.)	Uncertainty (exp.+theor.)	Parameter	Fit value & "True" Value	Uncertainty (exp.)	Uncertainty (exp.+theor.)
$\tan\beta$	10.00	0.11	0.15	$M_{\tilde{q}_R}$	503. GeV	12. GeV	16. GeV
μ	400.4 GeV	1.2 GeV	1.3 GeV	$M_{\tilde{b}_R}$	497. GeV	8. GeV	16. GeV
X_τ	$-4449.$ GeV	20. GeV	29. GeV	$M_{\tilde{t}_R}$	380.9 GeV	2.5 GeV	3.7 GeV
$M_{\tilde{e}_R}$	115.60 GeV	0.13 GeV	0.43 GeV	$M_{\tilde{q}_L}$	523. GeV	3.2 GeV	4.3 GeV
$M_{\tilde{\tau}_R}$	109.89 GeV	0.32 GeV	0.56 GeV	$M_{\tilde{t}_L}$	467.7 GeV	3.1 GeV	5.1 GeV
$M_{\tilde{e}_L}$	181.30 GeV	0.06 GeV	0.09 GeV	M_1	103.27 GeV	0.06 GeV	0.14 GeV
$M_{\tilde{\tau}_L}$	179.54 GeV	0.12 GeV	0.17 GeV	M_2	193.45 GeV	0.08 GeV	0.13 GeV
X_t	-565.7 GeV	6.3 GeV	15.8 GeV	M_3	569. GeV	7. GeV	7.4 GeV
X_b	$-4935.$ GeV	1207. GeV	1713. GeV	$m_{A_{run}}$	312.0 GeV	4.3 GeV	6.5 GeV
				m_t	178.00 GeV	0.05 GeV	0.12 GeV

Table I: *The Fittino fit result for the SPS1a' inspired scenario. The left column shows the values predicted by SPheno version 2.2.2 for this scenario, which for all parameters are identical to the central values of the fit with unsmeared input observables, the third column displays the parameter uncertainties for the fit with experimental uncertainties only. The last column shows the parameter uncertainties for the fit with experimental and theoretical uncertainties [10].*

The numerical values of the fit uncertainties are given in Tab. I. Both with and without the inclusion of present theoretical uncertainties, the precision for most of the parameters lies in the per-cent or sub-percent range. Theoretical uncertainties, however, can increase the uncertainties by up to a factor of 2.5 (in the case of X_t) and hence need to be reduced to make use of the full experimental information of the high-precision ILC measurements.

3. SUSY Parameter Measurement in mSUGRA

High-scale MSSM scenarios such as mSUGRA with only 4 real parameters can also be tested using the limited set of measurements from the LHC alone. A result of such a fit is shown in Tab. II [10]. However, also in such a case the precision obtained with the combined LHC and ILC data is more precise by more than an order of magnitude, and hence the sensitivity on deviations from a pure high-scale scenario is strongly enhanced by the ILC, underlining its ability to be a telescope to GUT scale physics.

	SPS1a' value	Fitted value	$\Delta_{\text{LHC+ILC}}$	$\Delta_{\text{LHC only}}$
$\tan\beta$	10.000	10.000	0.036	1.3
M_0 (GeV)	70.000	70.000	0.070	1.4
$M_{1/2}$ (GeV)	250.000	250.000	0.065	1.0
A_0 (GeV)	-300.0	-300.0	2.5	16.6

Table II: *Fit results for fits within mSUGRA scenario. The meanings of the columns are (starting from the left): SPS1a' values, the fitted mSUGRA parameters, parameter uncertainties for a fit to LHC+ILC observables and parameter uncertainties for a fit to "LHC only" observables. In both cases theoretical uncertainties are not included [10].*

4. Conclusions

Using Fittino, the Lagrangian parameters of the MSSM, assuming real parameters but without assumptions on the SUSY breaking mechanism, can be correctly reconstructed without usage of *a priori* information. This has been achieved using simulated precision measurements at the LHC and ILC as input to a global fit exploiting the techniques implemented in the program Fittino. Most of the Lagrangian parameters can be determined to a precision around the percent level. For some parameters an accuracy of better than 1 per mil is achievable if theoretical uncertainties are neglected. Assuming present theoretical uncertainties for the predictions, the precision of the Lagrangian parameter measurement is significantly deteriorated. While the experimental information from the LHC alone without the additional information from the ILC is not sufficient to determine the full low-energy MSSM Lagrangian parameters, it is enough to determine the parameters of a high-scale mSUGRA scenario. However, the precision of the parameter determination (and hence the sensitivity on deviations from perfect unification) increases by more than an order of magnitude if ILC data are added. These results highlight the need of the ILC for a precise understanding of Supersymmetry and its value to explore physics from the Terascale to the GUT scale..

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