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Abstract

SFITTER is a new tool to determine supersymmetric model parameters from collider measurements. It allows to perform a grid search for the minimal χ^2 and/or a fit of a given model. Currently, the model parameters in the general MSSM or in a gravity mediated SUSY breaking model can be tested using a given set of mass, branching ratio and cross section measurements.

SFITTER: A Tool to Determine Supersymmetric Parameters

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Abstract
SFITTER is a new tool to determine supersymmetric model parameters from collider measurements. It allows to perform a grid search for the minimal χ^2 and/or a fit of a given model. Currently, the model parameters in the general MSSM or in a gravity mediated SUSY breaking model can be tested using a given set of mass, branching ratio and cross section measurements.

1. Introduction

The most important task for the LHC as well as for any future Linear Collider is to study in detail the mechanism which leads to electroweak symmetry breaking. While the Standard Model describes all available high energy physics experiments, it still has to be regarded as an effective theory, valid at the weak scale. New physics are expected to appear at the TeV energy scale. The minimal supersymmetric extension of the Standard Model (MSSM) can provide a description of physics up to the unification scale.

If supersymmetry or any other high-scale extension of the Standard Model is discovered, it will be crucial to determine its fundamental high-scale parameters from weak-scale measurements [1, 2]. The LHC and a future Linear Collider will provide a wealth of measurements [3], which due to their complexity require a proper treatment to unravel the corresponding high-scale physics. Even in the general weak-scale MSSM without any unification or SUSY breaking assumptions the measurements of masses and couplings are not likely to be independend measurements; moreover, linking supersymmetric particle masses to weak-scale SUSY parameters involves non-trivial mixing to mass eigenstates in essentially every sector of the theory. On top of that, for example in gravity mediated SUSY breaking scenarios (mSUGRA/cMSSM) a given weak-scale SUSY parameter will always be sensitive to several high-scale parameters which contribute through renormalization group running. Therefore, a fit of the model parameters using all experimental information available will lead to the best sensitivity and make the most efficient use of the information available.

If the starting point of the fit is not known and many parameters are involved, the allowed parameter space might not be sampled completely in the fit approach. To avoid boundaries imposed by non-physical parameter points, which can confine the fit to a ‘wrong’ parameter region, combining the fit with an initial evaluation of a multi-dimensional grid is the optimal approach. In the general MSSM the weak-scale parameters can vastly outnumber the collider measurements, so that a complete parameter fit is not possible and one has to limit oneselve to a subset of parameters. In SFITTER both grid and fit are realised and can be combined, including a general correlation matrix and the option to exclude parameters of the model from the fit/grid by fixing them to a value.

2. SFITTER — Program Structure

Currently, SFITTER uses the predictions for the supersymmetric masses provided by SUSPECT [4], but the conventions of the SUSY Les Houches accord [5] could be helpful, if provided as a common block/C-structure, to ease interfacing other programs. The branching ratios and e^+e$^-$ production cross sections are provided by MSMlib [6], which has been used extensively at LEP and cross checked with Ref. [7]. The next-to-leading order hadron collider cross sections are computed using PROSPINO [8, 9, 10]. The fitting program uses the MINUIT package [11]. The determination of χ^2 includes a general correlation matrix between measurements. For unphysical points in supersymmetric parameter space, χ^2 is set to 10^{30}.

2.1 Initialization and Steering

The program SFITTER is driven by two files: the first one sets up the measurements and the corresponding errors. For each measurement one specifies if it is to be used in the grid (G) or in the MINUIT fit (M) or in both.

```
//set all errors to 0.5% of their central value
DATA_ERR = 0.005
//randomize the measurements around their nominal value
RANDOMIZE = 1
//Higgs mass and error to be used in the Fit only
m_h      = 112.6 +/- 0.1 [-/M]
//Neutralino1 mass to be used in Grid and Fit
m_chi0_1 = 180.2 +/- 5.1 [G/M]
//Correlation between two chargino mass measurements
CORR(m_chi+_1,m_chi+_2) = 0.03
```

The second file initializes everything related to the weak-scale or high-scale MSSM model parameters. First the model (mSUGRA, pMSSM etc) is specified, then the starting values of all MSSM parameters, boundaries, stepsize and the number of points in the grid are specified. Moreover, the user defines if a certain MSSM model parameter is included in the grid and in the fit:

```
MODEL=MSUGRA    // use MSUGRA
// use the GRID (or not)
GRID=1
// M0 used in grid and fit, grid of 10+1 steps between 0 and 1000.
M0=500. [M/G] STEP=200. LOW=0. HIGH=1000. GRID=10
// A0 used only in fit
A0=0. [M/-] STEP=200. LOW=-1000. HIGH=1000.
```

2.2 mSUGRA/cMSSM Parameter Determination

Assuming that SUSY breaking is mediated by gravitational interactions (mSUGRA/cMSSM) we fit four universal high-scale parameters to a toy set of collider measurements: the universal scalar and gaugino masses, m_0, $m_{1/2}$, the trilinear coupling A_0 and the ratio of the Higgs vacuum expectation values, $\tan\beta$. The sign of the Higgsino mass parameter μ is a discrete parameter and therefore fixed. The assumed data set is the set of all supersymmetric particle masses for the SUSY parameter point SPS1a [12, 13], as computed by SUSPECT. The errors on the toy mass measurements are uniformly set to 0.5%. The starting points for the mSUGRA parameters are fixed to the mean of the lower and upper limit in the fit, *i.e.* they are not necessarily even close to the true SPS1a values. The result of the fit is shown in Tab. 1. With SFITTER the true parameter values were reconstructed well within the quoted errors, in spite of starting values relatively far away from the true ones. The measurement of m_0 and $m_{1/2}$ is very precise, while the sensitivity of the masses on $\tan\beta$ and A_0 is significantly weaker.

The correlations between the different high-scale SUSY parameters are also given in Tab. 1. One can understand the correlation matrix step by step [14]: first, the universal gaugino mass $m_{1/2}$ can be extracted very precisely from the physical gaugino masses. The determination of the universal scalar mass m_0 is dominated by the weak-scale scalar particle spectrum, but in particular the squark masses are also strongly dependent on the universal gaugino mass, because of mixing effects in the renormalization group running. Hence, a strong correlation between the m_0 and $m_{1/2}$ occurs. The universal trilinear coupling A_0 can be measured through the third generation weak-scale mass parameters $A_{b,t,\tau}$. However, the $A_{b,t,\tau}$ which appear for example in the off-diagonal elements of the scalar mass matrices, also depend on m_0 and $m_{1/2}$, so that A_0 is strongly correlated with m_0 and $m_{1/2}$.

In the SPS1a scenario, the pseudoscalar Higgs is heavy and the Higgs masses do not show a strong dependence on $\tan\beta$. Because of the large mass difference between gauginos and Higgsinos they

	True	FitStart	FitResult
m_0	100	500	100.01±0.58
$m_{1/2}$	250	500	249.99±0.31
$\tan\beta$	10	50	10.03±0.37
A_0	-100	0	-100.1±5.26

	m_0	$m_{1/2}$	$\tan\beta$	A_0
m_0	1	-0.47	0.41	0.26
$m_{1/2}$		1	-0.07	-0.30
$\tan\beta$			1	0.35
A_0				1

Table 1: Left: summary of mSUGRA fit in SPS1a: true values, starting values, fit values. As in SPS1a we fix $\mu > 0$. All mass values are given in GeV. Right: the (symmetric) correlation matrix of all SUSY parameters in the mSUGRA fit.

essentially decouple, and the neutralino/chargino sector will not yield a good determination of $\tan\beta$. The stop mixing is governed by A_t, and not by $\mu/\tan\beta$, while the sbottom mixing is small altogether. Only the stau mixing is large and driven by $\mu\tan\beta$ in the off-diagonal element of the stau mass matrix. The stau mass parameters are dominated by m_0, in particular the smaller right handed stau mass. Therefore, one expects $\tan\beta$ to be strongly correlated with m_0 and less with $m_{1/2}$. The result from SFITTER as shown in Tab. 1 is in agreement with this prediction. Thus, the results obtained with SFITTER can be understood from the particular features of the SPS1a spectrum.

2.3 MSSM Parameter Determination

In total 24 parameters describe the unconstrained weak-scale MSSM. They are listed in Tab. 2: $\tan\beta$ just like in mSUGRA, plus three soft SUSY breaking gaugino masses M_i, the Higgsino mass parameter μ, the pseudoscalar Higgs mass m_A, the soft SUSY breaking masses for the right sfermions, $M_{\tilde{f}_R}$, the corresponding masses for the left doublet sfermions, $M_{\tilde{f}_L}$ and finally the trilinear couplings of the third generation sfermions $A_{t,b,\tau}$.

In any MSSM spectrum, in first approximation, the parameters M_1, M_2, μ and $\tan\beta$ determine the neutralino and chargino masses and couplings. We exploit this feature to illustrate the option to use a grid before the start the complete MINUIT fit. For testing purposes, the error on all mass measurements is again set 0.5%. The starting values of the parameters are set to their nominal values, this study is thus less general than the one of mSUGRA. Then we minimize χ^2 on a grid. For this grid minimization the six chargino and neutralino masses are used as measurements to determine the four SUSY parameters M_1, M_2, μ and $\tan\beta$ only. The step size of the grid is 10 for $\tan\beta$ and 100 GeV for the three mass parameters. After the minimization, these four parameters obtained from the minimum χ^2 on the grid are fixed and all remaining parameters are fitted. Only in a final run all SUSY parameters are released and fitted, to give the final results quoted in Tab. 2.

In Tab. 2 the intermediate (after the grid evaluation) results, the final results and the nominal values are shown. The final fit values indeed converges to the correct central values within its error. The central values of the fit are in good agreement with generated values, except for the trilinear coupling A_b. As already mentioned in the discussion of the mSUGRA fit, the mixing between the two sbottom mass states is very small, so the assumed precision of the 0.5% is insufficient to determine the parameter from the mass measurements alone. As A_t enters in the calculation of the lightest Higgs, additional sensitivity for this parameter comes from the mass measurement of the lightest Higgs boson. The use of branching ratios and cross section measurements should significantly increase the precision in future studies, especially for A_τ and A_b.

3. Conclusions

SFITTER is a new program to determine suspersymmetric parameters from experimental measurements. The parameters can be extracted either using a fit, a multi-dimensional grid minimisation, or a combination of the two. Correlations between measurements can be specified and are taken into account in the calculation of the χ^2. SUSPECT, MSMlib and PROSPINO are used to calculate the predictions for

	AfterGrid	AfterFit	SPS1a		AfterGrid	AfterFit	SPS1a
$\tan\beta$	10	10.62±2.5	10	$M_{\tilde u_R}$	528.03	528.06±2.8	532.1
M_1	100	102.05±0.61	102.2	$M_{\tilde d_R}$	525.12	525.14±2.8	529.3
M_2	200	191.65±1.4	191.8	$M_{\tilde c_R}$	528.03	528.06±2.8	532.1
M_3	579.37	579.33±4.8	589.4	$M_{\tilde s_R}$	525.12	525.15±2.8	529.3
μ	300	344.04±1.2	344.3	$M_{\tilde t_R}$	417.36	415.44±5.7	420.2
m_A	399.38	399.14±1.2	399.1	$M_{\tilde b_R}$	524.59	523.99±2.9	525.6
$M_{\tilde e_R}$	138.24	138.23±0.76	138.2	$M_{\tilde q1_L}$	549.58	549.61±2.1	553.7
$M_{\tilde\mu_R}$	138.24	138.23±0.76	138.2	$M_{\tilde q2_L}$	549.58	549.61±2.1	553.7
$M_{\tilde\tau_R}$	135.58	135.51±2.1	135.5	$M_{\tilde q3_L}$	493.59	494.38±2.7	501.3
$M_{\tilde e_L}$	198.74	198.75±0.68	198.7	$A_{\tilde\tau}$	-724.25	-286.78±549	-253.5
$M_{\tilde\mu_L}$	198.74	198.75±0.68	198.7	$A_{\tilde t}$	-502.19	-495.19±15	-504.9
$M_{\tilde\tau_L}$	197.79	197.81±0.89	197.8	$A_{\tilde b}$	975.12	999.78±49	-799.4

Table 2: Result for the general MSSM parameter determination in SPS1a. Shown are the nominal parameter values, the result after the grid and the final result. The deviation in the squark sector of 1% is an artefact of differences between MSSM and mSUGRA part of the renomalization group code [4]. All masses are given in GeV.

the masses, branching ratios and production cross sections. A more realistic set of the measurements for example assuming the SPS1a mass spectrum for the LHC and and a future Linear Collider will be studied as a next step. The impact of correlations between measurements on the estimated errors of MSSM parameters will be studied in detail. In the future public version of the program we will include different generators for the calculation of masses and branching ratios.

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