SUSY Parameter Determination

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The impact of the LHC, SLHC and the ILC on the precision of the determination of supersymmetric parameters is investigated. In particular, in the point SPS1a the measurements performed at the ILC will improve by an order of magnitude the precision obtained by the LHC alone. The SLHC with respect to the LHC has the potential to reduce the errors by a factor two.

1. INTRODUCTION

The supersymmetric extension [1] of the Standard Model is a well motivated extension providing us with a description of physics that can be extended consistently up to the unification scale. If supersymmetry is discovered in the next generation of collider experiments, it will be crucial to determine its fundamental high-scale parameters from weak-scale measurements [2]. The wealth of measurements [3, 4] will require precise theoretical predictions [5–7] as well as complex tools such as Fittino [8, 9] and Sfitter [10] to properly determine the underlying fundamental parameters.

In the following sections, the SPS1a [11] point is explored with the standard set of measurements as detailed in [4], corresponding to an integrated luminosity of 300 fb^{-1} for the LHC. The impact of the SLHC, with a luminosity ten times larger is explored. To obtain the experimental errors for the LHC, the statistical errors were scaled and the systematic error was kept fixed. For the ILC a maximum of 1000 fb^{-1} is used at centre of mass energies up to 1 TeV.

2. SUSY PARAMETER DETERMINATION

The masses measured in SPS1a of the LHC, the ILC and their combination allow to perform a fit of the mSUGRA parameters. In particular, even if the starting point of the fit is far away from the true parameters (e.g. 1TeV for m_0 and $m_{1/2}$), the fit converges to the true values. The sign of μ was fixed to its true value.

Table I: Results for mSUGRA for LHC (masses and edges), ILC and LHC+ILC

	SPS1a	ΔLHC_{masses}	ΔLHC_{edges}	ΔILC	$\Delta LHC+ILC$
m_0	100	3.9	1.2	0.09	0.08
$m_{1/2}$	250	1.7	1.0	0.13	0.11
$\tan\beta$	10	1.1	0.9	0.12	0.12
A_0	-100	33	20	4.8	4.3

The LHC (Table I column ΔLHC_{masses}) can determine the parameters with a precision at the percent level, while the ILC (ΔILC) improves the determination by an order of magnitude. It is interesting to note that the results of the LHC can be improved (Table I ΔLHC_{edges}), significantly by using the measured edges, thresholds and mass differences in the fit instead of the masses. As the masses are determined from the edges in long decay chains, the resulting masses are strongly correlated. In order to restore the initial sensitivity, the full correlation matrix would be necessary.

Of 14 measurements at the LHC in SPS1a, 6 can be improved only marginally by the increase of integrated luminosity at the SLHC, while 8 can be improved by up to a factor 2. The effect on the errors on the mSUGRA parameters is shown in Table II. While the errors from the SLHC alone are reduced by 50% (with the exception of $\tan\beta$), the combined errors SLHC+ILC are essentially the same as LHC+ILC. Only the error on A_0 is reduced by 20%.

Table II: Results for mSUGRA for LHC, SLHC, ILC, LHC+ILC, SLHC+ILC

	SPS1a	ΔLHC	ΔSLHC	ΔLHC+ILC	ΔSLHC+ILC
m_0	100	1.2	0.7	0.08	0.07
$m_{1/2}$	250	1.0	0.6	0.11	0.11
$\tan\beta$	10	0.9	0.7	0.12	0.12
A_0	-100	20	10	4.4	3.8

The precision obtained with the previous fits neglects the theoretical errors. In fact, if reasonable theoretical errors such as 3 GeV [12] on the lightest Higgs boson, 3% on coloured sparticles, 1% on neutralinos and sleptons are taken into account, the error on the m_0 mass increases by an order of magnitude and the other errors are twice as large in the combined LHC+ILC fit. The experimental precision, especially on the ILC measurements will necessitate a vigorous theoretical effort [14] in order to fully exploit the available experimental information.

Between the two extremes of a tightly constrained model such as mSUGRA with only 5 parameters and a full fledged MSSM with more than 120 parameters, it is interesting to study intermediate models [13]. This approach is an alternative to fixing parameters in the MSSM. In particular, the scalar sector (m_0) was separated into three independent parameters: one for the sleptons, one for the squarks and one for the Higgs sector. The result of the study is shown in Table III. The Higgs sector is undetermined as at the LHC only the lightest neutral Higgs boson is observed in SPS1a which is not sensitive to $m^2_{H_{ud}}$. The scalar sector for the squarks is less well determined as the quarks are heavier and their measurement less precise than those of the sleptons. The resulting error is proportional to the product of scalar mass and error.

Table III: Determination of parameters with LHC data in a non-MSUGRA model

	$m_0^{sleptons}$	$m_0^{squarks}$	$m^2_{H_{ud}}$	$m_{1/2}$	$\tan\beta$	A_0
SPS1a	100	100	10000	250	10	-100
ΔLHC	4.6	50	42000	3.5	4.3	181

The determination of supersymmetric parameters is not restricted to the relatively favourable case of SPS1a. At the LHC even difficult regions such as the focus region can be analysed. In particular in the point proposed by [15] the LHC will be able to measure the masses of the three neutral Higgs bosons (in the following the heavier Higgs bosons are taken as two separate measurements in spite of near degeneracy). Additionally the tri-lepton signal gives access to the mass difference between the second lightest neutralino and the lightest neutralino. The mass difference between gluino and χ_2 will also be visible [16]. The results are shown in Table IV under the assumption that the measurements will be limited by the error on knowledge of the absolute energy scale. The errors are shown for experimental errors and when the theoretical and parametric errors are also taken into account. In this point the measurement of $\tan\beta$ is dominated by the heavy Higgs bosons and the scalar mass parameter by the error on the lightest Higgs boson mass. It is interesting to note that even though the sfermions are too heavy to be observed, the fact that m_0 is heavy can be established with the caveat that the theoretical error on the Higgs mass prediction is reduced.

Table IV: Results for EGRET with the LHC

	EGRET	ΔLHC$_{exp}$	ΔLHC$_{all}$
m_0	1400	50	530
$m_{1/2}$	180	2	12
$\tan\beta$	51	181	350
A_0	700	0.3	2

3. CONCLUSIONS

The LHC will allow a first determination of the fundamental parameters of supersymmetry of the order of the percent, the ILC will increase the precision by an order of magnitude. The experimental precision will have to be matched by precise theoretical predictions in order to fully exploit the available information. For the LHC alone, the use of edges instead of masses increases the precision of the determination of the fundamental parameters m_0 and $m_{1/2}$. The SLHC improves on the errors by roughly a factor 2 with respect to the LHC, as many measurements are already dominated at the LHC by the systematic error.

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