SUSY parameter determination

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1 Introduction

Since March 2010, the Large Hadron Collider (LHC) started deliverying proton-proton collisions at the center-of-mass energy of 7 TeV and the experiments are accumulating data at a rapid pace. Evidence of physics beyond the Standard Model (SM) may be discovered in a few years. Once evidence of new physics is discovered at the LHC, we must understand the model of the new physics and determine its fundamental parameters. Supersymmetry (SUSY) is one of the most attractive models which may solve several remaining problems of SM such as the hierarchy problem or the missing dark matter candidate.

We investigate the prospects of determining SUSY parameters taking the minimal supergravity (mSUGRA) as the model at the SPS1a benchmark point [1]. This is well-motivated from current experimental contraints as we shall explain in the next section. We show results expected with 1 and 10 fb^{-1} of integrated luminosity at the LHC. Also, we point out that there is an ambiguity on the particle assignments in the cascade decay such as $\tilde{q} \to q\tilde{\chi}_2^0 \to ql^{\pm}\tilde{l}^{\mp} \to ql^{\pm}l^{\mp}\tilde{\chi}_1^0$ and show how it affects the interpretatoin of data and the parameter determination.

2 SUSY parameter fit with Fittino

The program Fittino [2] has been used for the study presented here. The program consists of a collection of fitting algorithms and statistical tools with an interface to external theory programs using the Les Houches Accord format [3]. This allows to include any model into the framework. For the calculation of observables, SPheno [4] and Mastercode [5] were used to calculate SUSY and low energy observables, respectively.

Parameter	Best fit value	SPS1a value
M_0	$76.2^{+79.2}_{-29.1}$ (GeV)	100
$M_{1/2}$	331.5 ± 86.6 (GeV)	250
A_0	383.8 ± 647	-100
$\tan\beta$	13.2 ± 7.2	10

Table 1: Best fit value of mSUGRA parameters from low energy measurements. Values of the SPS1a benchmark point are also shown for comparison.

All measurements performed at various high energy experiments (LEP, SLC, Tevatron and B-factories) have been successfully explained by SM and there is no evidence of SUSY so far. However, some observables are sensitive to the effects of SUSY via higher order corrections such as the anomalous magnetic moment of the muon, $(g-2)_\mu$, and the cold dark matter relic density, Ω_{CDM}, from cosmological measurements. We refer to these existing observables as *low energy observables*. It is possible to set constraints on the allowed region in the SUSY parameter space using these observables. A fit to the mSUGRA model with sgn(μ) = +1 was performed with measurements at LEP, SLC and Tevatron as well as $(g-2)_\mu$ and Ω_{CDM}, in order to derive the allowed region in the mSUGRA parameter space and the best fit point with uncertainties. The complete list of observables used in the fit can be found elsewhere [6].

The best fit values for M_0, $M_{1/2}$, A_0 and $\tan\beta$ are shown in table 1. It was found that $(g-2)_\mu$ and Ω_{CDM} were the most effective to constrain the parameter space. The values for the SPS1a benchmark point is shown too for comparison. It is seen that the best fit values are consistent with the benchmark point.

3 Prospects with LHC data and decay chain ambiguity

As seen in the previous section, the SPS1a benchmark point lies very close to the current best fit values within the mSUGRA model. Therefore, the SPS1a benchmark point has been used for the investigation of the SUSY parameter determination at the LHC. In general, observables with exclusive final states are considered for the SUSY parameter determination as they can be related to SUSY particle masses easily than more inclusive measurements. One example is the decay chain $\tilde{q} \to q\tilde{\chi}^0_2 \to ql^\pm\tilde{l}^\mp_R \to ql^\pm l^\mp\tilde{\chi}^0_1$ following the squark or gluino production. From such a decay chain, it is possible to reconstruct the invariant mass distribution of the two leptons. It is known that the kinematic end-point of the distribution is related to masses of SUSY particles involved in the decay, so that they can be included in the fit with an explicit formula. In addition to the above decay chain, similar decay chains, $\tilde{q} \to q\tilde{\chi}^0_2 \to q\tau^\pm\tilde{\tau}^\mp_R \to q\tau^\pm\tau^\mp\tilde{\chi}^0_1$ and $\tilde{q} \to q\tilde{\chi}^0_4 \to ql^\pm\tilde{l}^\mp_L \to ql^\pm l^\mp\tilde{\chi}^0_1$ are considered in the fit in order to increase the sensitivity. The full list of possible measurements at the LHC and expected uncertainties are taken from previous studies [1, 6] which are based on detailed studies by the ATLAS and CMS collaborations.

When one uses these observables, it is usually assumed that the SUSY particles involved in a certain decay chain are known. However, in a typical decay chain, e.g. $\tilde{q} \to q\tilde{\chi}^0_2 \to ql^\pm\tilde{l}^\mp \to ql^\pm l^\mp\tilde{\chi}^0_1$, all SUSY particles in the decay chain are not directly detected. As the squark undergoes a cascade decay towards the lightest SUSY particle (LSP), one only detects SM particles and a possible missing transverse energy ($E_{\mathrm{T}}^{\mathrm{miss}}$) in the detector, and relates the kinematic endpoints to the corresponding SUSY particle masses. However, there is no guarantee that the assumptions on the particles in the decay chain is correct. This may lead to a misinterpretation of the measurement and a wrong determination of SUSY parameters. Under the assumption that the signature $ql^\pm l^\mp + E_{\mathrm{T}}^{\mathrm{miss}}$ was produced within the mSUGRA framework, it is reasonable to consider that several neutralinos and sleptons (either right- or left-handed) were involved in the decay chain. This leads to considering the decay chain $\tilde{q} \to q\tilde{\chi}^0_i \to ql^\pm\tilde{l}^\mp_{L,R} \to ql^\pm l^\mp\tilde{\chi}^0_j$ with all possible combinations of neutralinos and sleptons.

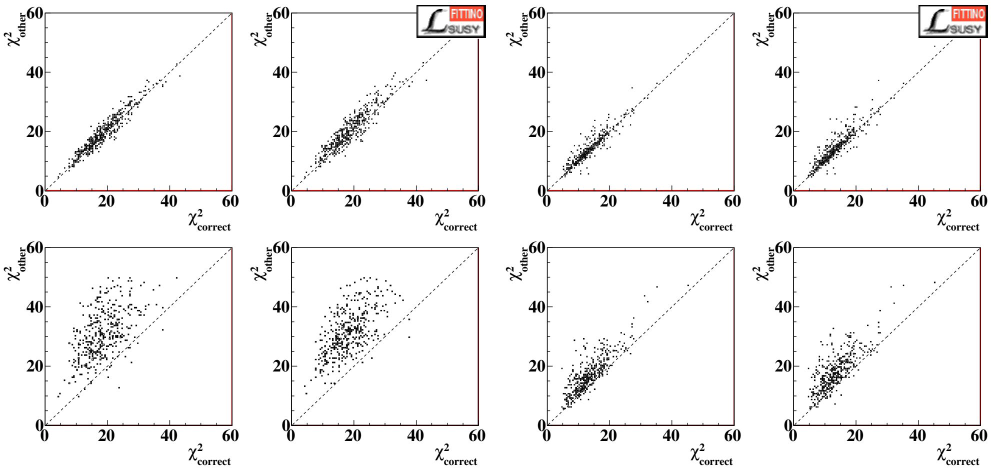
Among the observables considered here, the following three decay chains may be interpreted with different particle assignments.

(a) $\tilde{q} \to q\tilde{\chi}^0_2 \to ql^\pm\tilde{l}^\mp_R \to ql^\pm l^\mp\tilde{\chi}^0_1$

(b) $\tilde{q} \to q\tilde{\chi}^0_2 \to q\tau^\pm\tilde{\tau}^\mp_R \to q\tau^\pm\tau^\mp\tilde{\chi}^0_1$

(c) $\tilde{q} \to q\tilde{\chi}^0_4 \to ql^\pm\tilde{l}^\mp_L \to ql^\pm l^\mp\tilde{\chi}^0_1$

Fits were performed taking these ambiguities into account. Toy fits were repeated by smearing the observables around the best fit point. Toy fits are usually used in order to evaluate uncertainties on fit parameters. Here, one may use the same technique to obtain the probability



(a) (b)

Figure 1: χ^2 correlation of the fit assuming (a) 10 fb^{-1} and (b) 1 fb^{-1} of luminoisty

that a wrong interpretation may have a smaller χ^2 than the correct interpretation, by comparing the χ^2 given by different interpretations. If such a probability is high, one can claim that the decay chain ambiguity must be considered seriously when interpreting the measurements. Figure 1 (a) shows the correlation of χ^2 between the correct model and the wrong interpretation ordered by the probability of having the lowest χ^2 among all interpretations considered assuming 10 fb^{-1} of luminosity at the LHC. Particle assignments considered in these cases and their probabilities of having the smallest χ^2 are given in table 2. In order to evaluate the results for 1 fb^{-1} of luminosity at the LHC, statistical uncertainties of the measurements were scaled according to the ratio of the luminosities while keeping the same values for systematic uncertainties. Results for 1 fb^{-1} of luminosity are shown in figure 1 (b) and table 3.

As tables 2 and 3 show, the probability of the wrong interpretation having smaller χ^2 reaches up to $\simeq 50\%$ and is bigger with larger statistical uncertainties on the measurements. In spite of performing a fit with a wrong interpretation, little differences in fitted parameters were observed in the case of 10 fb^{-1}. In case of 1 fb^{-1}, the fit results are rather unstable which indicates that better precision or more observables than considered here are necessary to have a reliable fit.

Table 2: Interpretation of the decay chain and the probability of it having the smallest χ^2 among other interpretations in the toy fit assuming 10 fb^{-1} of luminosity.

Interpretation of the decay chain	Probability (%)
Correct interpretation	69
(c) $\tilde{\chi}^0_3 \to l^\pm \tilde{l}^\mp_L \to l^\pm l^\mp \tilde{\chi}^0_2$	16
(c) $\tilde{\chi}^0_2 \to l^\pm \tilde{l}^\mp_R \to l^\pm l^\mp \tilde{\chi}^0_1$	12
(a) $\tilde{\chi}^0_3 \to l^\pm \tilde{l}^\mp_L \to l^\pm l^\mp \tilde{\chi}^0_1$, (b) $\tilde{\chi}^0_4 \to \tau^\pm \tilde{\tau}^\mp_R \to \tau^\pm l^\mp \tilde{\chi}^0_1$	3
(a) $\tilde{\chi}^0_3 \to l^\pm \tilde{l}^\mp_R \to l^\pm l^\mp \tilde{\chi}^0_1$, (b) $\tilde{\chi}^0_3 \to \tau^\pm \tilde{\tau}^\mp_R \to \tau^\pm l^\mp \tilde{\chi}^0_1$	< 0.1

Table 3: Interpretation of the decay chain and the probability of it having the smallest χ^2 among other interpretations in the toy fit assuming 1 fb^{-1} of luminosity.

Interpretation of the decay chain	Probability (%)
Correct interpretation	48
(a) $\tilde{\chi}_3^0 \to l^\pm \tilde{l}_R^\mp \to l^\pm l^\mp \tilde{\chi}_1^0$, (b) $\tilde{\chi}_3^0 \to \tau^\pm \tilde{\tau}_R^\mp \to \tau^\pm \tau^\mp \tilde{\chi}_1^0$	21
(a) $\tilde{\chi}_3^0 \to l^\pm \tilde{l}_L^\mp \to l^\pm l^\mp \tilde{\chi}_1^0$, (b) $\tilde{\chi}_4^0 \to \tau^\pm \tilde{\tau}_R^\mp \to \tau^\pm \tau^\mp \tilde{\chi}_1^0$	19
(a) $\tilde{\chi}_4^0 \to l^\pm \tilde{l}_R^\mp \to l^\pm l^\mp \tilde{\chi}_1^0$, (b) $\tilde{\chi}_3^0 \to \tau^\pm \tilde{\tau}_R^\mp \to \tau^\pm \tau^\mp \tilde{\chi}_1^0$	3.6
(a) $\tilde{\chi}_3^0 \to l^\pm \tilde{l}_L^\mp \to l^\pm l^\mp \tilde{\chi}_1^0$, (b) $\tilde{\chi}_4^0 \to \tau^\pm \tilde{\tau}_L^\mp \to \tau^\pm \tau^\mp \tilde{\chi}_1^0$	2.5

4 Conclusion

With the start of the LHC operation, evidence of SUSY may be discovered in the near future. The interpretation of experimental measurements and SUSY parameter determination are crucial for understanding the new physics model. Within the studied mSUGRA model, model parameters can be determined to a good precision with $\simeq 10$ fb^{-1} of luminosity at the LHC while the ambiguity in the particle assignment in the decay chain is not negligible while the differences in fitted parameters are modest.

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