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Exclusive SUSY measurements and determination of SUSY parameters from LHC data

Peter Wienemann for the ATLAS Collaboration

Physikalisches Institut, Universität Bonn, Nussallee 12, 53115 Bonn, Germany

Abstract. A selection of exclusive SUSY measurements is presented which can be performed provided SUSY will be discovered at the LHC. Such measurements allow to determine the properties of supersymmetry and thus help to pin down the underlying theoretical model. It is described on an mSUGRA example point how sparticle masses can be reconstructed from endpoints in mass spectra using early LHC data. Finally it is shown how well mSUGRA model parameters can be derived from these measurements.

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INTRODUCTION

It is widely expected that the Large Hadron Collider (LHC) which starts operation in autumn 2008 will uncover physics beyond the present standard model of particle physics. Supersymmetry (SUSY) is one of the most promising candidate for new physics. Among its virtues are the potential to overcome the hierarchy problem, to provide a dark matter candidate and make a unification of gauge coupling constants at a high energy scale possible. If the SUSY mass scale is in the sub-TeV range, already first LHC data will be sufficient to claim the discovery of new physics. The subsequent challenge will be to determine the properties of the observed new physics. Among the questions seeking an answer are: Is it really SUSY? If yes, SUSY of which type? How is SUSY broken? Finally everything should be destilled to a set of Lagrangian parameters. To accomplish this, as many observables as possible need to be studied. They include masses, couplings and spins. In this report we will concentrate on techniques to extract masses of SUSY particles using first LHC data, based on an integrated luminosity of 1 fb^{-1} in a favourable mSUGRA bulk region scenario.

SUSY MASS MEASUREMENTS

In the following we assume conserved R-parity. As a consequence sparticles can only be produced pairwise and the lightest SUSY particle (LSP) is stable. To evade cosmological problems, the LSP must be a neutral, weakly interacting particle which escapes detection in high-energy physics detectors. Due to two escaping LSPs in every SUSY event, no mass peaks can be reconstructed and masses must be measured by other means.

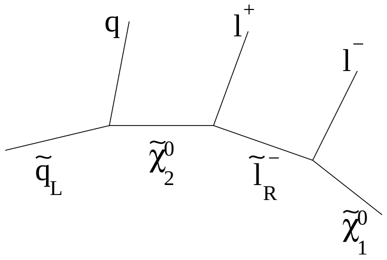

FIGURE 1. Prime example of a decay chain allowing a model independent reconstruction of the involved SUSY masses.

The main source of mass information is provided by $\tilde{\chi}^0_2$ decays such as $\tilde{\chi}^0_2 \to \tilde{\ell}^\pm\ell^\mp \to \tilde{\chi}^0_1\ell^+\ell^-$, $\tilde{\chi}^0_2 \to \tilde{\chi}^0_1 Z^{(*)}$ and $\tilde{\chi}^0_2 \to \tilde{\chi}^0_1 h \to \tilde{\chi}^0_1 b\bar{b}$ [1]. Provided that a decay chain with at least three two-body decays can be identified, the masses of the involved SUSY masses can be reconstructed in a model-independent way. As an example for such a case we assume that the decay chain shown in Fig. 1 is open and illustrate some important mass extraction techniques on this example. This collection of possible measurements is based on studies described in detail in [2].

Di-lepton mass

First we consider the invariant mass spectrum of the two leptons $m_{\ell\ell}$ from the decay chain in Fig. 1. Due to the scalar nature of the slepton, $m_{\ell\ell}$ exhibits a triangular shape with a sharp drop-off at a maximal value $m_{\ell\ell}^{\max}$. The position of this endpoint depends on the masses of

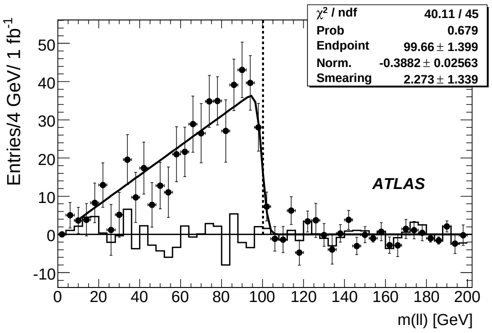

FIGURE 2. Flavour subtracted di-lepton mass spectrum for the ATLAS bulk region point SU3. The dashed line shows the expected endpoint position.

the sparticles involved in the decay:

$$m_{\ell\ell}^{\max} = m_{\tilde{\chi}_2^0}\sqrt{1-\left(\frac{m_{\tilde{\ell}_R}}{m_{\tilde{\chi}_2^0}}\right)^2}\sqrt{1-\left(\frac{m_{\tilde{\chi}_1^0}}{m_{\tilde{\ell}_R}}\right)^2}. \qquad (1)$$

To suppress combinatorial SUSY and standard model (SM) background, the endpoint is measured from the flavour subtracted di-lepton mass distribution $N(\mathrm{e}^+\mathrm{e}^-)/\beta + \beta N(\mu^+\mu^-) - N(\mathrm{e}^\pm\mu^\mp)$. Here N means the respective number of events and β is the ratio of the electron and muon reconstruction efficiencies ($\beta \approx 0.86$). Fig. 2 shows this mass distribution for the ATLAS bulk region point SU3 ($\tan\beta = 6$, $M_0 = 100$ GeV, $M_{1/2} = 300$ GeV, $A_0 = -300$ GeV, $\mathrm{sign}(\mu) = +1$). For an integrated luminosity of 1 fb^{-1}, the position of the endpoint can be reconstructed to be $(99.7 \pm 1.4 \pm 0.3)$ GeV where the first uncertainty is statistical and the second one due to systematic uncertainties from the lepton energy scale and β. This needs to be compared to the nominal endpoint position for the studied benchmark point which is located at 100.2 GeV, indicated by the dashed line in Fig. 2. Apart from this simple triangular shape for a single two-body decay also more complicated situations are possible such as several superimposed triangles if more than one two-body decay is open or even more general, SUSY-model dependent shapes if only three-body decays are possible.

Visible di-tau mass

A similar analysis can also be performed if one replaces the electrons and muons by taus. But due to the escaping neutrinos from the tau decay, the visible di-tau mass distribution is not triangular anymore (see Fig. 3). This complicates measuring the endpoint of the spectrum. A rather robust strategy to evade this problem is to fit a suitable function to the trailing edge of the visible di-tau mass spectrum and use the inflection point as a endpoint sensitive observable. The relation between endpoint and inflection point can be established by a simple (rather model-independent) calibration procedure. Fig. 3 shows the charge subtracted visible di-tau mass distribution $N(\tau^+\tau^-) - N(\tau^\pm\tau^\pm)$ which is used to suppress background from fake taus and combinatorical background. The reconstructed endpoint position for the SU3 benchmark point is $(102 \pm 17^{\mathrm{stat}} \pm 5.5^{\mathrm{syst}} \pm 7^{\mathrm{pol}})$ GeV to be compared with the nominal value of 98 GeV. The last uncertainty is introduced by the SUSY-model dependent polarisation of the two taus.

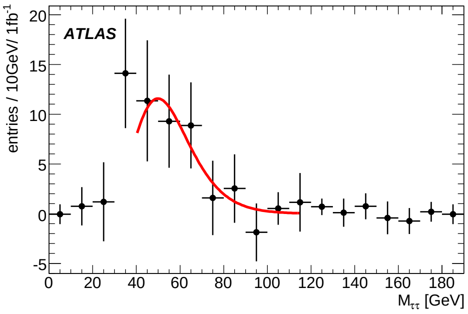

FIGURE 3. Charge subtracted visible di-tau mass spectrum for the ATLAS bulk region point SU3.

Leptons + jet mass endpoints

By including the jet produced in association with the $\tilde{\chi}_2^0$ in the $\tilde{q}_L$ decay (see Fig. 1), several other endpoints of measurable mass combinations are possible: $m_{\ell q(\mathrm{low})}^{\max}$, $m_{\ell q(\mathrm{high})}^{\max}$, $m_{\ell\ell q}^{\min}$ and $m_{\ell\ell q}^{\max}$. The label min/max denotes a lower/upper endpoint of the spectrum. The index low/high indicates that the minimum/maximum of the two masses $m_{\ell^+ q}$ and $m_{\ell^- q}$ is used. The reconstructed values for these quantities are summarised in Tab. 1 for an integrated luminosity of 1 fb^{-1} in case of the bulk re-

TABLE 1. Reconstructed endpoint positions for leptons+jet masses for an integrated luminosity of 1 fb^{-1} in the SU3 bulk point scenario. Given uncertainties are statistical, systematic and jet energy scale related, respectively.

Endpoint	SU3 truth (GeV)	Measured (GeV)
$m_{\ell q(\mathrm{low})}^{\max}$	325	$333 \pm 6 \pm 6 \pm 8$
$m_{\ell q(\mathrm{high})}^{\max}$	418	$445 \pm 11 \pm 11 \pm 11$
$m_{\ell\ell q}^{\min}$	249	$265 \pm 17 \pm 15 \pm 7$
$m_{\ell\ell q}^{\max}$	501	$517 \pm 30 \pm 10 \pm 13$

gion point SU3. There are several reasons for the larger uncertainties on the positions of these endpoints compared to the $m_{\ell\ell}^{\max}$ measurement. First, the endpoints are not as pronounced as in the $m_{\ell\ell}$ case. Second, some distributions suffer from remaining background close to the endpoint spoiling the measurement and third, due to the involved jet, these measurements are subject to the jet energy scale uncertainty which is an order of magnitude larger than the lepton energy scale uncertainty.

$\tilde{q}_R$ mass reconstruction

Information about the $\tilde{q}_R$ mass can be gathered by exploiting the decay $\tilde{q}_R \rightarrow \tilde{\chi}_1^0 q$. The endpoint of the stransverse mass [3] distribution as function of the $\tilde{\chi}_1^0$ mass hypothesis establishes a relationship between the $\tilde{q}_R$ and the $\tilde{\chi}_1^0$ masses. In the SU3 scenario, the stransverse mass endpoint is reconstructed to be 590 ± 9(stat) $^{+13}_{-6}$ GeV for the nominal $\tilde{\chi}_1^0$ mass assuming 1 fb^{-1} integrated luminosity which needs to be compared with the nominal value of 637 GeV.

Mass determination from edge positions

The positions of the various endpoints are a function of the masses of the sparticles involved in the respective decays. Since the inversion of the endpoint formulae is only possible for a few specific cases, the masses are extracted numerically by a χ^2 fit. The reconstructed masses using the di-lepton and the leptons+jet endpoints in the SU3 scenario for an integrated luminosity of 1 fb^{-1} is summarised in Tab. 2. The reconstructed masses are highly correlated with $m_{\tilde{\chi}_1^0}$ which is only poorly contrained by the endpoint measurements. Therefore the precision on the absolute mass values is rather moderate. Significantly higher accuracy is obtained for the mass differences between the various masses and the $\tilde{\chi}_1^0$ mass.

TABLE 2. Reconstructed sparticle masses for an integrated luminosity of 1 fb^{-1} in the SU3 bulk point scenario.Given uncertainties are statistical and jet energy scale related. ∓ indicates an anti-correlation with the jet energy scale variation.

Mass	SU3 truth (GeV)	Reconstructed (GeV)
$m_{\tilde{\chi}_1^0}$	118	$88 \pm 60 \mp 2$
$m_{\tilde{\chi}_2^0}$	219	$189 \pm 60 \mp 2$
$m_{\tilde{\ell}_R}$	155	$122 \pm 61 \mp 2$
$m_{\tilde{q}_L}$	634	$614 \pm 91 \pm 11$
$m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0}$	100.7	$100.6 \pm 1.9 \mp 0$
$m_{\tilde{\ell}_R} - m_{\tilde{\chi}_1^0}$	37.6	$34.2 \pm 3.8 \mp 0.1$
$m_{\tilde{q}_L} - m_{\tilde{\chi}_1^0}$	516.0	$526 \pm 34 \pm 13$

MSUGRA PARAMETER FITS

Apart from the model-independent mass reconstruction one also would like to test the consistency of the data with various models and to determine their parameters. To accomplish this, several programs are available exploiting different parameter estimation techniques (see e. g. [4], [5]). Tab. 3 contains a summary of the precision with which the mSUGRA parameters can be determined using the endpoint measurements mentioned in the previous sections. Even with 1 fb^{-1} the scalar and the gaugino mass parameter can already be determined to better than 10 %. For $\tan\beta$ and the trilinear coupling parameter only an $\mathcal{O}(100\ \%)$ measurement is feasible. But as soon as Higgs sector information will become available with higher luminosity the uncertainty on latter parameters will drop sizably.

TABLE 3. Fitted mSUGRA parameters for an integrated luminosity of 1 fb^{-1} in the SU3 bulk point scenario.

Parameter	SU3 truth	Fitted
$\tan\beta$	6	7.4 ± 4.6
A_0 (GeV)	−300	445 ± 408
M_0 (GeV)	100 GeV	98.5 ± 9.3
$M_{1/2}$ (GeV)	300 GeV	317.7 ± 6.9

CONCLUSIONS

Provided sparticles masses are in the sub-TeV regime, already first LHC data will allow to perform a rough SUSY spectroscopy. First checks of high-scale unification models are also feasible. Higher precision and more difficult measurements follow as the integrated luminosity increases.

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