Exclusive Measurements for SUSY Events with the ATLAS Detector at the LHC

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Abstract. We present recent work performed in ATLAS on the SUSY mass measurement techniques by selecting exclusive decay chains as well as on the determination of SUSY model parameters with an integrated luminosity of 1 fb^{-1} at 14 TeV center of mass energy.

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INTRODUCTION

Supersymmetry (SUSY) is one of the most attractive candidates for physics beyond the Standard Model (SM). If SUSY exists in nature and the proposed SUSY particles have masses at the sub-TeV range then SUSY can be discovered by the ATLAS (A Torodial LHC ApparatuS) experiment at the Large Hadron Collider (LHC). A strategy for SUSY discovery by ATLAS has been outlined in this volume [1] based on the inclusive searches. As soon as a signature consistent with SUSY has been established, the next challenge will be to confirm that it is SUSY; by measuring the masses and spins of the new particles and by obtaining the underlying model parameters. Since a complete coverage of all allowed SUSY models is impossible we limit the study to mSUGRA models. The mass measurement techniques developed within this model can be adapted for many SUSY and other similiar models. The study presented here uses Monte Carlo datasets with full detector simulation, all relevant SM backgrounds are taken into account, as are the trigger efficiencies. The full details can be found in [2].

SUSY MASS MEASUREMENTS

In the R-parity conserving mSUGRA models SUSY particles are produced in pairs and SUSY cascade decays typically have large transverse missing energy due to the presence of undetected LSP (Lightest SUSY Particle). No mass peaks can be reconstructed due to the two invisible LSP's in every SUSY event, however kinematic endpoints in the invariant mass distributions of visible decay products can be fitted and then used in deriving relations between SUSY masses. The theoretical positions of the endpoints are calculated from the well known analytical expressions. If sufficiently long decay chains can be isolated and enough endpoints are measured then the masses of the individual particles can be obtained in a model-independent way. For instance from the decay chain:

$$\widetilde{q}_L \to q\widetilde{\chi}_2^0 \to q\widetilde{l}_R^{\pm} l^{\mp} \to q\widetilde{\chi}_1^0 l^{\pm} l^{\mp} \quad (1)$$

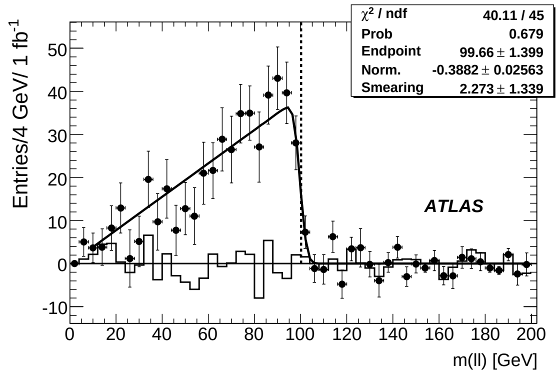

FIGURE 1. The dilepton invariant mass distribution for the SU3 point for 1 fb $^{-1}$.

the masses of $\tilde{q}_L$, $\tilde{l}_R$, $\tilde{\chi}_2^0$ and $\tilde{\chi}_1^0$ can be measured. The advantage of this decay chain is that the presence of charged leptons, missing energy and hadronic jets ensures a large signal to background ratio. Also both the SUSY combinatorial and the SM background can be estimated from the data with high accuracy using the technique known as flavor subtraction. This technique is based on the fact that the signal contains two opposite-sign same-flavor (OSSF) leptons, while the background is due to pair of leptons coming from different decay chains, which can be of the same-flavor (SF) or opposite-flavor (OF) with the same probability. Thus the background cancels in $N(e^+e^-)/\beta + \beta N(\mu^+\mu^-) - N(e^\pm\mu^\mp)$ where N denotes the respective number of events and β is the ratio of the electron and muon reconstruction efficiencies taken as $\beta = 0.86$.

Dilepton Endpoint

The invariant mass distribution of the two leptons (electron and muon) in Eq. (1) has a triangular shape with an endpoint at:

$$m_{\ell\ell}^{\text{edge}} = m_{\tilde{\chi}_2^0}\sqrt{1-\left(\frac{m_{\tilde{l}_R}}{m_{\tilde{\chi}_2^0}}\right)^2}\sqrt{1-\left(\frac{m_{\tilde{\chi}_1^0}}{m_{\tilde{l}_R}}\right)^2} \tag{2}$$

Figure 1 shows the dilepton invariant mass distribution after flavor subtraction for the ATLAS benchmark point SU3 in bulk region ($m_0 = 100$ GeV, $m_{1/2} = 300$ GeV, $A_0 = -300$, $\tan(\beta) = 6$, $\text{sgn}(\mu) = +$). The line histogram is the SM background contribution, while the points are the sum of SM and SUSY contributions. The fitting function (a triangle smeared with a Gaussian) is superimposed and the expected position of the endpoint is indicated by a dashed line. The fitted endpoint is $(99.7 \pm 1.4 \pm 0.3)$ GeV where the first error is due to statistics and the second is the systematic error on the lepton energy scale and the β parameter. Compared to its truth value of 100.2 GeV the endpoint can be measured with a precision of a few percent already with 1 fb^{-1} of integrated luminosity for the considered model.

TABLE 1. Endpoint positions for SU3 benchmark point for 1 fb^{-1}. The truth values are also listed.

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

Leptons+Jets Endpoints

For a determination of the masses of all the SUSY particles involved in the decay chain, further kinematic endpoints from mass distributions involving a jet are measured: $m_{\ell\ell q}^{\mathrm{edge}}$, $m_{\ell\ell q}^{\mathrm{thr}}$, $m_{\ell q(\mathrm{low})}^{edge}$ and $m_{\ell q(\mathrm{high})}^{edge}$. Since it is not possible to identify the quark from the $\widetilde{q}_L$ decay, it is assumed that it hadronises into one of the two highest p_T jets in the event. The label thr indicates lower endpoint of the distribution (a non-zero threshold value) whereas low/high indicate minimum/maximum of the two masses m_{l^+q} and m_{l^-q}.

The fitted endpoints are summarised in Table 1. The first error is statistical, the second and third are the systematic and the jet energy scale uncertainty, respectively. While the measured values are compatible with their truth values, there are large uncertainties due to not having sharp edges (combinatorics from choosing the wrong jet in a true SUSY event) and thus trying to fit the tails (beyond the endpoint) with straight lines.

Ditau Endpoint and Right-handed Squark Mass

Similiarly, from the decay $\widetilde{\chi}_2^0 \to \widetilde{\tau}_1 \tau \to \widetilde{\chi}_1^0 \tau^\pm \tau^\mp$ the endpoint of the invariant mass distribution of ditau, $m_{\tau\tau}^{edge}$, can be measured. Also, from the decay $\widetilde{q}_R \to \widetilde{\chi}_1^0 q$ the mass of the right-handed squark can be measured from the endpoint of the stransverse mass distribution (m_{T2}). Both endpoints contribute to the determination of SUSY parameters as described below.

From Endpoints to SUSY Particle Masses

In order to extract the SUSY particle masses from a combination of endpoints measured above, a numerical χ^2 minimization based on the MINUIT package is used. The masses resulting from the χ^2 fit are shown in Table 2 for the SU3 point. The first error is statistical, the second is the jet energy scale uncertainty. $\mp$ sign indicates an anticorrelation with the jet energy scale variation. The reconstructed masses are highly correlated with $\widetilde{\chi}_1^0$ which is not well determined by the endpoint measurements. Therefore the precision on the absolute mass values is rather moderate. The mass differences are better measured than the absolute masses as expected.

TABLE 2. Reconstructed SUSY particle masses and mass differences for the SU3 benchmark point for 1 fb^{-1}.

Observable	SU3 Reconstructed (GeV)	SU3 Truth (GeV)
$m_{\tilde{\chi}_1^0}$	$88 \pm 60 \mp 2$	118
$m_{\tilde{\chi}_2^0}$	$189 \pm 60 \mp 2$	219
$m_{\tilde{q}_L}$	$614 \pm 91 \pm 11$	634
$m_{\tilde{l}_R}$	$122 \pm 61 \mp 2$	155
$m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0}$	$100.6 \pm 1.9 \mp 0.0$	100.7
$m_{\tilde{q}_L} - m_{\tilde{\chi}_1^0}$	$526 \pm 34 \pm 13$	516.0
$m_{\tilde{l}_R} - m_{\tilde{\chi}_1^0}$	$34.2 \pm 3.8 \mp 0.1$	37.6

FROM ENDPOINTS TO SUSY MODEL PARAMETERS

The ultimate goal is to determine SUSY model parameters. The SUSY parameter-fitting package Fittino is used to perform the calculations of the model parameters from the following endpoint measurements; $m_{\ell\ell}^{\text{edge}}$, $m_{\ell\ell q}^{\text{edge}}$, $m_{\ell\ell q}^{\text{thr}}$, $m_{\ell q(\text{low})}^{edge}$, $m_{\ell q(\text{high})}^{edge}$, $m_{\tau\tau}^{edge}$, $m_{T2}(\tilde{q}_R)$. The fitted mSUGRA parameters for the SU3 point are given in Table 3. The m_0 and the $m_{1/2}$ parameters can already be derived reliably (to better than 10%) with 1 fb^{-1}, however determination of $\tan(\beta)$ and A_0 is more problematic since no information from the Higgs sector is available at low luminosity.

TABLE 3. Fitted mSUGRA parameters for the SU3 point for 1 fb^{-1}. $\text{sgn}(\mu) = +$.

Parameter	SU3 Fitted	SU3 Truth
$\tan(\beta)$	7.4 ± 4.6	6
m_0 (GeV)	98.5 ± 9.3	100
$m_{1/2}$ (GeV)	317.7 ± 6.9	300
A_0 (GeV)	445 ± 408	-300

CONCLUSIONS

Next step after SUSY discovery (if SUSY exists in nature) will be to measure the properties of the new particles. We have focused here on the SUSY mass measurements techniques and the feasibility of SUSY parameters determination. With 1 fb^{-1} the reconstruction of part of SUSY mass spectrum will only be possible for favorable SUSY scenarios and with some assumptions about the decay chains involved. Larger integrated luminosity is needed in order to make more measurements and increase their precisions.

REFERENCES

1. Talks by X. Portell, K. Pajchel and C. Zendler in this volume.
2. G. Aad *et al.*, ATLAS Collaboration, "Expected Performance of the ATLAS Experiment, Detector, Trigger and Physics," *CERN-OPEN-2008-020*, Geneva, 2008, pp. 1617-1642. arXiv:0901.0512.