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Measurement of SUSY parameters in 2-lepton events with the ATLAS detector

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The prospects for the most relevant measurements of SUSY parameters, with the ATLAS detector at LHC, are presented, using events characterised by the presence of two leptons. Particular attention will be devoted to the determination of the masses of SUSY particles in the mSUGRA scenario with early data.

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1. Generalities on supersymmetry

One of the main purposes of LHC is the search for physics beyond the Standard Model (SM). In this framework, Supersymmetry (SUSY) is one of the most popular and credited candidate to extend the SM [1]. It introduces a new symmetry that, for each SM boson, predicts a fermionic super-partner and vice-versa. Following this symmetry, one can classify all SUSY particles foreseen by the theory as either: scalar partners of the SM fermions (called sleptons and squarks) or fermionic gauginos (called Winos, Binos, Zinos and gluinos). The Higgs sector is composed by two doublets of fermions (in order to avoid triangular anomalies) that give origin to five physical scalar bosons, and four fermionic partners called Higgsinos (two neutral and two charged). While the gluino is a mass eigenstate, Higgsinos and other gauginos mix giving four charged mass eigenstates called Charginos and four neutral mass eigenstates called Neutralinos. In the R-parity (quantum number that has value +1 or -1 respectively for SM and SUSY particles) conserving models, the lightest neutralino is the LSP (Lightest Supersymmetric Particle) that provides a suitable candidate for Dark Matter because it's stable, neutral and weakly interacting. Nevertheless SUSY has not been discovered yet, and this means that this symmetry must be broken. Hence, one needs to add in the lagrangian some terms breaking Supersymmetry in order to remove mass degeneracies between particles and their super-partners.

The final number of free parameters needed for MSSM (Minimal Supersymmetric Standard Model) is then 105, including mass terms, couplings, mixing angles and CP-violation phases. Because of this large number of free parameters, more constrained frameworks are often used at LHC in order to develop analysis strategies. In this paper the focus will be on strategies for mSUGRA scenario.

The mSUGRA model is characterised by gravity mediated SUSY-breaking[2], and foresees only five independent parameters to define SUSY sector: the common gaugino mass $m_{1/2}$, the common scalar mass m_0, the common trilinear gauge coupling A_0 at some high unification scale, the ratio of the vacuum expectation values of the two Higgs doublets tanβ and the sign of the Higgsino mixing parameter μ. The top mass can be taken as a sixth independent parameter because it strongly affects the value of physical quantities. All the analyses in this section are performed in this framework with the addition of the R-parity conservation. In order to perform detailed studies of SUSY discovery potential, specific sets of values of the mSUGRA space parameters have been chosen [3] taking into account the constraints arising from experimental data (direct searches on Higgs and SUSY at LEP, precision tests at B-factory), theoretical reasons (request of electroweak symmetry breaking mechanism) and cosmological data (compatibility of abundance of cold Dark Matter in the Universe with relic density of lightest neutralinos)[4].

2. Measurements from supersymmetric events

SUSY can be discovered by the ATLAS [5] experiment at the LHC during the initial running period, if some coloured sparticles have masses of the order of hundreds of GeV and production cross-sections of the order of a few pb [3].

Once a signature consistent with Supersymmetry has been established, the experimental emphasis will move on to measure the sparticle mass spectrum and derive the parameters of the model. In the case of R-parity-conserving models, the decay chain of sparticles cannot be completely recon-

structed, as sparticles eventually decay into LSPs that cannot be detected. For this reason, edges, rather than mass peaks, are measured in the invariant mass distribution of sparticle decay products. During initial data-taking, the uncertainty on such measurements will be limited by statistics, making measurements possible only for models with moderate ($\leq$ 1 TeV) values of the SUSY mass scale where enough events can be isolated.
A typical SUSY event selection, in the mSUGRA scenario with R-parity conservation, is characterised by the request of high missing energy due to LSPs and high p_T hadronic jets due to coloured sparticles decay. The additional signature considered here is the presence of two isolated leptons (electrons or muons) with opposite charge in the final state.
Hence, the following decay chain is particularly suited to measure the mass of the SUSY particles involved using this signature:

$$\tilde{q}_L \to \tilde{\chi}_2^0 q \to \tilde{\ell}^{\pm}\ell^{\mp} q \to \chi_1^0 \ell^+\ell^- q \tag{2.1}$$

where $\ell = e, \mu$. The interest here is on the reconstruction of the endpoints in the $\ell^+\ell^-$, $\ell^+\ell^- q$ and $\ell^{\pm} q$ invariant mass distributions and of thresholds in the $\ell^+\ell^- q$ and $\ell^{\pm} q$ invariant mass distributions. These distribution are function of the masses of $\tilde{\chi}_1^0$, $\tilde{\chi}_2^0$, $\tilde{\ell}$ and the $\tilde{q}_L$. The goal is to use these relations in order to determine the values of the masses of the sparticles in the decay chain.
Although the discussion here is on the reconstruction of edges and thresholds within the mSUGRA framework, the same methodology can be applied to the large variety of SUSY models where the $\tilde{q}_L$ decay channel in Eq. 2.1 is open.

3. Event selection and results

Events with two or three isolated leptons (electrons or muons) with $p_T > 10$ GeV and $|\eta| < 2.5$ are selected. If two leptons are selected, they are required to have opposite signs. If three leptons are present, the two opposite-sign combinations are considered and treated independently in the rest of the analysis.
In order to select SUSY events and reject the Standard Model background, one must require the presence of energetic jets and missing energy. Selection criteria were performed on the transverse missing energy, the transverse momenta of the four hardest jets, the ratio between the transverse missing energy and the effective mass (e.g the scalar sum of the transverse missing energy and the four hardest jets of the event), and the transverse sphericity (S_T).
The dominant SM background, after the selection criteria, is from $t\bar{t}$ events, with a small contribution from W+jets and Z+jets events. The QCD contribution is negligible.
The selection criteria on these variables are optimised in order to maximise the value of
$S = (N_{OSSF} - N_{OSDF})/\sqrt{N_{OSSF} + N_{OSDF}}$, where N_{OSSF} and N_{OSDF} are the number of same-flavour and different- flavour lepton pairs respectively. The corresponding selection criteria were:
$E^T_{MISS} > 120(100)$ GeV, $p_T^{j1} > 180(100)$ GeV and $p_T^{j2} > 100(50)$ GeV, for SU3 (SU4) benchmark points. The S variable can be computed from data, then no Monte Carlo information is used.
An advantage of the decay chain in Eq.2.1 is the possibility of estimating both the SUSY combinatorial background and the SM from the data with high accuracy. The technique, known as *flavour subtraction*, is based on the fact that the signal contains two opposite-sign same-flavour (OSSF)

leptons, while the background is from of leptons coming from different decay chains, which can be of the same flavour or of different flavour with the same probability. The background thus cancels in the subtraction:

$$N(e^+e^-)/\beta + \beta N(\mu^+\mu^-) - N(e^\pm\mu^\mp) \tag{3.1}$$

where β is an efficiency correction factor equal to the ratio of the electron and muon reconstruction efficiencies. The value of β is assumed to be known with an uncertainty of 10%.

The $\ell^+\ell^-$ invariant mass distribution after the flavour subtraction is shown in Fig.1 for the benchmark points SU3 (left) and SU4 (right) (see [3] for the coordinates in the mSUGRA parameter space) and for luminosities of 1 fb^{-1} and 0.5 fb^{-1} respectively. The power of the flavour subtraction technique is visible in the region beyond the endpoint, where the dominant combinatorial background has been cancelled by the subtraction.

A fit of the two distributions has been performed using a triangular function for the SU3 point and using the theoretical function of a three body decay [6] for the SU4 point (in the SU4 point, $m(\tilde{\ell}) > m(\tilde{\chi}_2^0)$, then the decay is $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 \ell^+\ell^-$). Both fit functions have been smeared by the gaussian effect of the experimental resolution.

The values of the endpoints from the fit are $(99.7 \pm 1.4 \pm 0.3)$ GeV (true value 100.2 GeV) for the SU3 point and $(52.7 \pm 2.4 \pm 0.2)$ GeV (true value 53.6 GeV) for SU4 point. The first error is statistical while the second is the systematic error on the lepton energy scale and on the β parameter. Both measurements are compatible with the truth values.

For a determination of the masses of all the particles in the decay chain 2.1, further mass distribu-

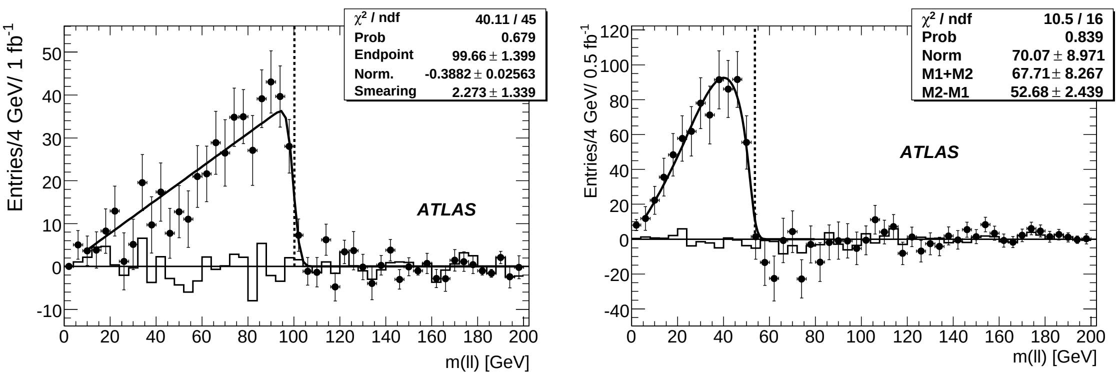

Figure 1: Left: Distribution of $\ell^+\ell^-$ invariant mass after flavour subtraction for the SU3 benchmark point with an integrated luminosity of 1 fb^{-1}. Right: the same distribution is shown for the SU4 benchmark point and an integrated luminosity of 0.5 fb^{-1}. The line histogram is the Standard Model contribution, while the points are the sum of Standard Model and SUSY contributions. The fitting function is superimposed and the expected position of the endpoint is indicated by a dashed line.

tions involving a jet are used: $m_{\ell\ell q}$, $m_{\ell\ell q}^{thr}$, $m_{\ell q(low)}$ and $m_{\ell q(high)}$. Since the quark from the $\tilde{q}_L$ decay cannot be identified, the assumption that it generates one of the two highest p_T jets in the event is made based on the fact that the $\tilde{q}_L$ is much heavier than the $\tilde{\chi}_2^0$.

For the $m_{\ell\ell q}$ distribution, a maximum value of the distribution is expected so the jet giving the lowest $m_{\ell\ell q}$ value is used, while in the $m_{\ell\ell q}^{thr}$ distribution a minimum is expected, so the jet giving the highest $m_{\ell\ell q}$ value is used in this distribution.

Endpoint	SU3 truth [GeV]	SU3 measured [GeV]	SU4 truth [GeV]	SU4 measured [GeV]
$m_{\ell\ell q}^{edge}$	501	517±30±10±13	340	343±12±3±9
$m_{\ell\ell q}^{thr}$	249	265±17±15±7	168	161±36±20±4
$m_{\ell q(low)}^{max}$	325	333±6±6±8	240	201±9±3±5
$m_{\ell q(high)}^{max}$	418	445±11± 11±11	340	320±8±3± 8

Table 1: Endpoint positions for SU3 and SU4, in GeV. The first error is statistical, the second and third are the systematic and the jet energy scale uncertainty, respectively. The theoretical values are also given for ease of comparison to the left of the fitted values. The integrated luminosity assumed is 1 fb^{-1} for SU3 and 0.5 fb^{-1} for SU4.

The distributions $m_{\ell q(low)}$ and $m_{\ell q(high)}$ are formed from the lower and higher $m_{\ell q}$ value of each event using the same jet as for $m_{\ell\ell q}$. Both distributions have well-defined endpoints [7].
The fit values for the endpoints and the thresholds in the $\ell\ell q$ and ℓq invariant mass distributions are listed in Table 1.

4. Conclusions

A brief overview of the strategies developed in ATLAS to measure the mass of the SUSY particles using events with two leptons, missing energy and jets has been shown. The measurement of endpoints and thresholds in the $\ell^+\ell^-$, $\ell^+\ell^- q$ and $\ell^\pm q$ invariant mass distributions, allows to extract information on the mass of the SUSY particles involved in the decay chain in Eq.2.1.
With an integrated luminosity of 1 fb^{-1}, endpoints and thresholds are measured with an uncertainty of 2-5% in the mSUGRA framework. Using these measurements, the uncertainties on $\tilde{q}_L$ and $\tilde{\chi}^0_{1,2}$ masses are respectively 15% and 50% for the SU3 benchmark point.
More statistics is needed to reduce the uncertainty on the masses and then to constraint the mSUGRA space parameter and eventually discriminate among different SUSY models.

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