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Exclusive measurements for SUSY events with the ATLAS detector at the LHC

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We present recent work performed in ATLAS on techniques used to reconstruct the decays of SUSY particles at the LHC. We concentrate on strategies to be applied to the first fb^{-1} of LHC data.

1. INTRODUCTION

The Large Hadron Collider (LHC) has started operation very recently and soon it will deliver pp collisions at a center-of-mass energy of 14 TeV. The ATLAS detector will be used to search for evidence for physics beyond the Standard Model (SM).

Among the many extensions to the SM that predict what this physics might be, supersymmetry (SUSY) with R-parity conservation is a very attractive one. It provides a candidate particle for dark matter, the lightest neutralino, and predicts a light Higgs boson, in agreement with electroweak precision measurements.

The following work is limited to the study of mSUGRA models. A list of predefined points [1] in the parameter space is used. Since there is no LHC data yet, events are generated with Isajet and Herwig, and passed through a realistic simulation of the ATLAS detector. In these models, pair production of SUSY particles is assumed, each decaying in a cascade to the lightest supersymmetric particle (LSP), which can only be detected by a missing transverse energy signature.

2. EDGE MEASUREMENTS

Endpoint measurements are used when one particle is lost in the decay or cannot be measured. In this case, the LSP is only detected by its missing energy signature. To study this, the following decay chain is used:

$$\tilde{q}_L \to \tilde{\chi}^0_2 q (\to \tilde{l}^{\pm} l^{\mp} q) \to \tilde{\chi}^0_1 l^+ l^- q \qquad (1)$$

This decay chain provides a large signal to background ratio due to its final state. In the case of the "Bulk" point (SU3), the decay of the neutralino goes through an extra step involving sleptons, since $\tilde{l}_R$ and $\tilde{e}_1$ are lighter than $\tilde{\chi}^0_2$. For the "Low Mass" point (SU4), the neutralino decays directly to a lepton pair and the LSP since sleptons are heavier. The mSUGRA parameters for SU3 are $m_0 = 100$ GeV, $m_{1/2} = 300$ GeV, $A_0 = -300$ GeV, $\tan\beta = 6$, $\mu > 0$, and for SU4, $m_0 = 200$ GeV, $m_{1/2} = 160$ GeV, $A_0 = -400$ GeV, $\tan\beta = 10$, $\mu > 0$. The NLO cross-section for SU3 is 27.68 pb while for SU4, it is 402.19 pb.

2.1. Dilepton edges

By considering the lepton pair produced in eq. 1, it is possible to obtain insights about the masses involved in the decay. In the SU3 case, we have $m_{ll}^{edge} = m_{\tilde{\chi}^0_2} - m_{\tilde{\chi}^0_1}$ and for SU4, the expression is more complex, as shown in eq. 2. The Events with two or three isolated leptons (electrons or muons) are selected. Opposite sign (OS) lepton pairs are required in the two-lepton events and all possible combinations of opposite sign leptons are considered in the three-lepton events. Lepton pairs with opposite-flavour (OF) are subtracted from the same-flavour (SF) pairs, and cuts are performed on transverse missing energy (E_T^{miss}), transverse momenta of the four leading jets, the ratio between E_T^{miss} and the effective mass and the transverse sphericity.

$$m_{ll}^{edge} = m_{\tilde{\chi}^0_2}\sqrt{1-\left(\frac{m_{\tilde{l}}}{m_{\tilde{\chi}^0_2}}\right)^2}\sqrt{1-\left(\frac{m_{\tilde{\chi}^0_1}}{m_{\tilde{l}}}\right)^2} \quad (2)$$

The invariant mass distribution is fitted with a triangular function smeared with a Gaussian for the SU3 case for 1 fb^{-1} as shown in figure 1. The endpoint value obtained from the fit is (99.7 ± 1.4 ± 0.3) GeV, where the quoted errors are respectively the statistical error, the systematic error on the lepton energy scale and the systematic error on the parameter [1]. The SU4 case requires a 3-body decay theoretical distribution [2] smeared for the experimental resolution. The fit gives an endpoint of (52.7 ± 2.4 ± 0.2) GeV for 0.5 fb^{-1}. The "Coannihilation" point (SU1) shows a double edge in the same invariant mass distribution, due to both left- and right-handed sleptons being lighter than $\tilde{\chi}^0_2$. The edges cannot be fitted with 1 fb^{-1} although an excess is visible, while with 18 fb^{-1}, a fit can be obtained with a lower edge at (55.8 ± 1.2 ± 0.2) GeV and a upper edge at (99.3 ± 1.3 ± 0.3) GeV. All results are consistent with the calculated values of 100.2 GeV (SU3), 53.6 GeV (SU4) and 56.1 and 97.9 GeV (SU1).

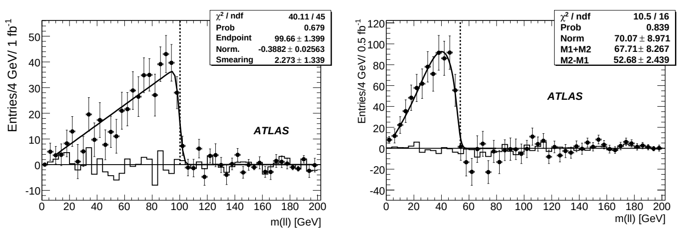

Figure 1: Invariant mass distribution for SU3 (left) and SU4 (right). The points show the sum of the SM and the SUSY contributions, the line histogram is the SM contribution only. The result of the fit is superimposed and the dashed line show the expected position of the endpoint.

2.2. Jet + Lepton edges

As can be seen in eq. 1, all masses can be reconstructed using the jets in the final state to obtain endpoint measurements. Three new quantities can be used: m_{llq} (edge and threshold), $m_{lq(high)}$ and $m_{lq(low)}$, which are the highest and lowest value of m_{lq} in an event using the same jet as m_{llq}. Two straight lines, with a Gaussian smearing for a smooth transition between them, are fitted to a small range of data points in the m_{llq} distribution, for both the edges and the thresholds. The endpoints are explicitely fitted. The results of the fits are shown in Table I.

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

Table I: Endpoint positions from fits for SU3 (1 fb^{-1}) and SU4 (0.5 fb^{-1}), in GeV. Errors are respectively statistical, systematic and jet energy scale uncertainty.

2.3. Tau signatures

In the previous sections, leptons were considered to be only electrons or muons. Tau leptons have to be treated separately. For the decay $\tilde{\chi}^0_2 \to \tilde{\tau}_1 \tau \to \tilde{\chi}^0_1 \tau^+ \tau^-$, the branching ratio is 10 times higher than for other leptons (for SU1 or SU3 scenarios). Also, since the $\tilde{\tau}_1$ is involved in this decay and the neutralino masses can be determined from other measurements, it is possible to determine the $_1$ mass. Since the decay of involves neutrinos in the nal state, it is not possible to get a sharp edge at the maximum kinematic value.

Invariant mass distributions are plotted for SU1 and SU3 models, where the same-sign (SS) distribution is subtracted from the opposite-sign (OS) one. Special care is needed concerning the t results due to polarization e ects on the invariant mass distribution, which can considerably shift the position of the endpoint.

2.4. Right-handed squark pairs

The decay chain presented in eq. 1 holds for left-handed squark decay. In the case of right-handed squarks, the decay goes directly to the LSP and quark: $\tilde{q}_R \to \tilde{\chi}^0_1 q$. In this case, a new variable is introduced, the "transverse mass" m_{T2} [1]. Assuming the mass of the LSP is known from previous measurements, m_{T2} can be used to determine the $\tilde{q}_R$ mass. A linear t is applied to a range of data points around the edge of the m_{T2} distribution to determine the endpoint for SU3 and SU4 models. The results of the t are $591\,^{+13}_{-6}$ (sys) 13 (stat) GeV for SU3 and $407\,^{+10}_{-3}$ (sys) 12 (stat) GeV for SU4 These should be compared with the known values: 637 GeV for SU3 and 405 GeV for SU4.

2.5. Light stop

In the particular case of SU4, all SUSY masses are relatively light and so is the $\tilde{t}_1$, with a mass of 206 GeV. As it is always decaying to the same channel, we can study the following: $\tilde{g} \to \tilde{t}_1 t \to \tilde{\chi}_1 bt$ The upper endpoint of the tb invariant mass depends on all masses involved in the decay. Only the hadronic top decays are included in the distribution. A t is performed on the invariant mass distribution (after W background is subtracted using the sideband method) using a triangular function smeared with a Gaussian. It gives a value for the endpoint of 297 9 GeV (for a 5-parameter t) for 200 pb^{-1}, in agreement with the calculated value of 300 GeV.

3. HIGGS IN SUSY EVENTS

The Higgs boson can be produced in many ways at the LHC. Most commonly, it is looked for in SM interactions (e.g. g g fusion), but it can also occur in the decay of sparticles which were produced by the initial interaction, like here for the neutralino in the SU9 model ("Bulk" point with enhanced Higgs production): $\tilde{\chi}^0_2 \to \tilde{\chi}^0_1 h \to \tilde{\chi}^0_1 bb$. Requiring signi cant missing transverse energy suppresses the QCD background, enabling the observation of Higgs decay to b quarks.

4. MASS AND PARAMETERS MEASUREMENT

The di erent endpoint measurements obtained above for many mSUGRA models can be used to determine the SUSY mass spectra and ts can be performed to constrain the parameters of the given models. In some cases (like the dilepton edges), an analytical formula is known to describe the invariant mass shape and obtain the mass. In the other cases, a χ^2 minimization procedure is used to obtain the sparticle masses from several endpoint values. Parameters of the mSUGRA models were obtained using 500 toy ts for both values of sign(μ). For each t, the observables are smeared using the full correlation matrix. The results can be found in [1]. For the masses, there is agreement between theoretical and experimental values, but the parabolic error for the minimization are still large. As for the mSUGRA parameters, M_0 and $M_{1/2}$ can be determined reliably, while in the case of tan β and A_0, only the order of magnitude can be obtained for the SU3 and SU4 models in a data sample corresponding to 1 fb^{-1}.

Acknowledgments

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