

Search for SUSY at ATLAS

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The search for physics beyond the Standard Model is one of the main goals of the general purpose ATLAS detector at Large Hadron Collider at CERN. This report summarizes the prospects of the ATLAS detector to find experimental evidence for R-parity conserving Supersymmetry in channels with large missing transverse energy, multiple high energy jets and eventually leptons for both 14 TeV and 10 TeV centre-of-mass energies. The 5σ discovery reach was addressed with systematic uncertainties included. Supersymmetric particles mass measurements and determination of minimal Supergravity model parameters are also discussed.

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1. Introduction

Supersymmetry (SUSY) [1] is one of the most attractive extensions of the Standard Model. Supersymmetry predicts that every Standard Model particle has its supersymmetric partner whose spin differs by $1/2$. Since supersymmetric particles have not been discovered yet, it is supposed that they are heavy and that supersymmetry is broken. One mechanism of supersymmetry breaking is the minimal Supergravity model (mSUGRA). Within mSUGRA model all masses, mixings and decays of SUSY and Higgs particles are determined in terms of four characteristic parameters and a sign: the scalar mass m_0 , the gaugino mass $m_{1/2}$, the trilinear coupling A_0 , the ratio of the Higgs vacuum expectation values $\tan\beta$ and the sign of the supersymmetric Higgs mass parameter μ . In mSUGRA model R-parity is conserved. As a consequence SUSY particles are always produced in pairs and at the end of the decay chain of every SUSY particle is the lightest supersymmetric particle (LSP), which is stable, massive, neutral, weakly interacting and thus undetectable.

Search for the Supersymmetric particles is one of the most important aims of the ATLAS experiment at Large Hadron Collider (LHC) at CERN, which started data taking at the end of 2009. ATLAS made a lot of effort in the previous few years in order to prepare for the analysis of the first LHC data. This report presents the results from the Computing System Commissioning (CSC) exercise [2], normalised to the LHC integrated luminosity of 1 fb^{-1} at the center of mass energy of 14 TeV. Post-CSC ATLAS studies [3, 4] for 10 TeV center-of-mass energies and integrated luminosity of 200 pb^{-1} are also discussed. We focus on the mSUGRA model here.

2. Inclusive searches

It is expected that squarks and gluinos will be dominantly produced in the initial proton-proton interactions at LHC and that their cascade decays will give high transverse momenta jets, leptons and LSP particles in the final states. Due to the presence of the undetectable LSP particle, the lightest neutralino $\tilde{\chi}_1^0$, there will be a large missing transverse energy E_T^{miss} in the event. ATLAS have analyzed [2, 3] various channels with 2, 3 or 4 jets and 0, 1 or 2 leptons. The study presented here was performed on the selected set of benchmark points in the mSUGRA five dimensional parameter space. Event selection was performed by applying cuts on the number and transverse momenta of hadronic jets, missing transverse energy, lepton transverse momenta and sphericity of event. For the one-lepton channel additional cut is applied on transverse mass $M_T = \sqrt{2(p_T^{\text{lep}} E_T^{\text{miss}} (1 - \cos(\Delta\Phi(\text{lep}, E_T^{\text{miss}}))))}$ formed from the missing transverse energy and the identified lepton. The effective mass M_{eff} is used to check whether there is an excess of SUSY over Standard Model events. The effective mass is defined as the sum of the missing transverse energy, transverse momenta of the most energetic jets and transverse momenta of all leptons in the event, $M_{\text{eff}} = E_T^{\text{miss}} + \sum_{i=1}^{N_{\text{jets}}} p_T^{\text{jet},i} + \sum_{i=1}^{N_{\text{lep}}} p_T^{\text{lep},i}$ (N_{jets} is the number of jets (2-4) and N_{lep} is the number of leptons (0-2)). The effective mass also gives an indication of the SUSY mass scale. The 0-lepton mode is the most generic one, but it is sensitive to the background from mismeasured QCD multijet events. Asking one lepton in addition reduces QCD background and the 1-lepton mode is often considered to be the golden mode for early SUSY searches. Figure 1 shows the effective mass M_{eff} distributions for the mSUGRA benchmark point SU4 ($m_0 = 200 \text{ GeV}$, $m_{1/2} = 160 \text{ GeV}$, $A_0 = -400$, $\tan\beta = 10$, $\text{sign}(\mu) = +$) and the Standard Model background for an integrated

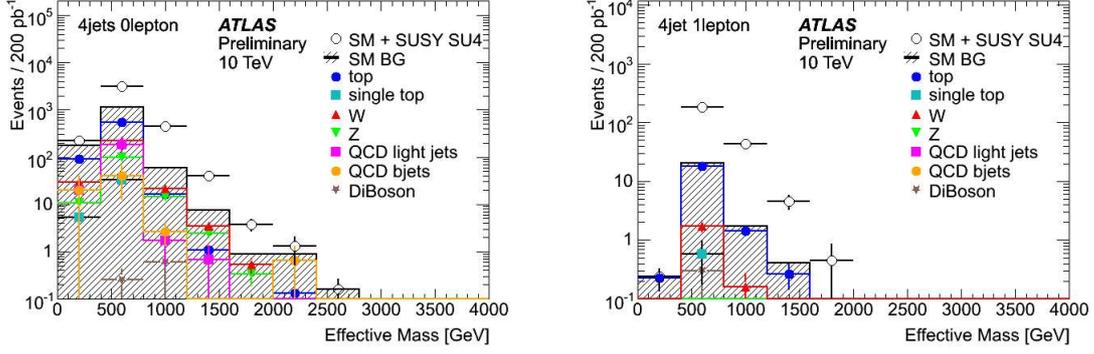


Figure 1: M_{eff} distribution in the 0-lepton channel (left) and 1-lepton channel (right) of the SUSY inclusive searches for an integrated luminosity of 200 pb^{-1} at 10 TeV. The open circles shows the signal (ATLAS mSUGRA benchmark point SU4) and Standard Model background summed together, while the shaded area shows the total Standard Model background. The legend gives the components of the Standard Model background.

luminosity of 200 pb^{-1} at 10 TeV in the channel with 0-leptons and 4-jets and in the channel with 1-lepton and 4-jets (ATLAS study [3]). Clear excess of SUSY over Standard Model background events is visible in both distributions. The squark and gluino masses for the SU4 point are the following: $m(\tilde{g}) = 413.37 \text{ GeV}$, $m(\tilde{d}_L) = 419.84 \text{ GeV}$, $m(\tilde{u}_L) = 412.25 \text{ GeV}$, $m(\tilde{b}_1) = 358.49 \text{ GeV}$, $m(\tilde{t}_1) = 206.04 \text{ GeV}$, $m(\tilde{d}_R) = 406.22 \text{ GeV}$, $m(\tilde{d}_R) = 404.92 \text{ GeV}$, $m(\tilde{b}_2) = 399.18 \text{ GeV}$, $m(\tilde{t}_2) = 445.00 \text{ GeV}$.

The same-charge dilepton channel with jets and missing transverse energy, described in details in ATLAS study [4], is also a powerful channel for early SUSY discovery and is almost background free. Data-driven method was used in order to estimate Standard Model background in this channel. After event preselection cuts (two leptons with $p_T^{l1} > 20 \text{ GeV}$, $p_T^{l2} > 10 \text{ GeV}$ and invariant mass $m_{ll} > 5 \text{ GeV}$, at least two jets with $p_T > 40 \text{ GeV}$ and $E_T^{miss} > 50 \text{ GeV}$) remaining signal and background processes are classified into four different categories by using four variables: E_T^{miss} , transverse momentum of the second leading lepton p_T^{l2} , transverse momentum of the second leading jet p_T^{j2} and transverse mass M_T . Regions are selected as follows: signal region SR ($E_T^{miss} > 80 \text{ GeV}$, $p_T^{j2} > 80 \text{ GeV}$), sideband region SB ($50 < E_T^{miss} < 80 \text{ GeV}$, $40 < p_T^{j2} < 80 \text{ GeV}$), A region ($p_T^{l2} > 20 \text{ GeV}$, $M_T > 80 \text{ GeV}$) and B region ($10 < p_T^{l2} < 20 \text{ GeV}$, $50 < M_T < 80 \text{ GeV}$). The purpose of this selection was to estimate the number of background events in the region dominated by the signal events A_{SR} , by using extrapolation method: $\frac{A_{SB}}{B_{SB}} \simeq \frac{A_{SR}}{B_{SR}}$. It was concluded that for the benchmark point SU4 clear signature can be observed with an integrated luminosity of 200 pb^{-1} at 10 TeV.

A scan of parameter space was performed [2–4] in order to explore a 5σ discovery reach of different SUSY models. Figure 2 shows the 5σ discovery reach as a function of m_0 and $m_{1/2}$ for $\tan\beta = 10$ mSUGRA scan for the channels with 0, 1 and 2 leptons. Results obtained for the integrated luminosity $L=1 \text{ fb}^{-1}$ and 14 TeV are displayed on the left, while the results for the integrated luminosity $L=200 \text{ pb}^{-1}$ at 10 TeV are on the right. For the 14 TeV analysis [2] with 1 fb^{-1} of data a systematic error of 50% for QCD background and 20% for W , Z and t background is estimated by using data-driven method. The best reach with squark and gluino masses up to 1.5 TeV is obtained in 0-lepton channel. In the 1-lepton channel, which is more robust against QCD

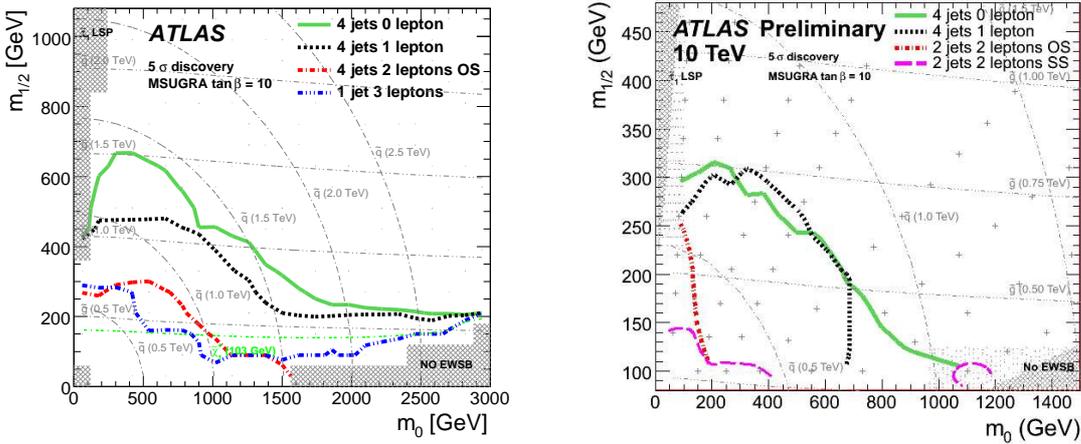


Figure 2: 5σ discovery reach as a function of m_0 and $m_{1/2}$ for $\tan\beta = 10$ mSUGRA scan for the channels with 0, 1 and 2 leptons. Left: integrated luminosity $L=1 \text{ fb}^{-1}$ and 14 TeV center-of-mass energy. Right: integrated luminosity $L=200 \text{ pb}^{-1}$ at 10 TeV.

background, masses close to 1 TeV are attainable. For the 10 TeV studies [3, 4] and integrated luminosity of $L=200 \text{ pb}^{-1}$, a systematic uncertainty of 50% is assumed. In this case the 0-lepton and 1-lepton channels have similar discovery reach with SUSY masses up to 600-700 GeV.

3. Mass and parameter measurements

After SUSY signatures have been established, it is crucial to measure masses and spins of the new particles and to obtain underlying model parameters. Due to the presence of the undetectable lightest supersymmetric particles $\tilde{\chi}_1^0$ in the final state of every SUSY decay, direct mass reconstruction is not possible. The distributions of the invariant masses formed from the detectable final state particles have kinematic endpoints that can be fitted and used for extraction of SUSY masses. The theoretical positions of the endpoints can be calculated from the conservations of energy and momentum. From the left squark cascade decay [2] $\tilde{q}_L \rightarrow \tilde{\chi}_2^0 q \rightarrow \tilde{l}_R^\pm l^\mp q \rightarrow l^+ l^- q \tilde{\chi}_1^0$ (where $\tilde{q}_L = \tilde{u}_L, \tilde{d}_L, \tilde{s}_L, \tilde{c}_L, \tilde{l} = \tilde{e}, \tilde{\mu}, \tilde{\tau}$) a few invariant masses can be reconstructed: dilepton invariant mass m_{ll} , lepton-lepton-jet invariant mass m_{llj} and two lepton-jet invariant masses $m_{lj(\text{high})}$ and $m_{lj(\text{low})}$. The label low/high indicates minimum/maximum of the two masses m_{l-j} and m_{l+j} . Combinatorial SUSY and Standard Model background can be suppressed effectively by using flavour subtraction. For the SU3 mSUGRA benchmark point ($m_0 = 100 \text{ GeV}$, $m_{1/2} = 300 \text{ GeV}$, $A_0 = -300$, $\tan\beta = 6$, $\text{sign}\mu = +$) the fitted endpoints of the reconstructed invariant mass distributions together with their theoretical values are shown in Table 1, for the integrated luminosity $L=1 \text{ fb}^{-1}$ at 14 TeV. The first error is statistical, the second and third are the lepton energy scale uncertainty and the jet energy scale uncertainty, respectively. Labels *min* and *max* of the endpoints denote kinematic minimum and maximum of the mass distributions. All measured endpoints are compatible with their true values. Kinematic endpoints of mass distributions formed with jets have larger uncertainties due to the fact that among all jet permutations, the wrong jet might be selected. The mSUGRA model parameters can be obtained from the set of measured endpoints [2]. For the SU3 point m_0 and

Endpoints	SU3 Measured (GeV)	SU3 Truth (GeV)
m_{ll}^{max}	$99.7 \pm 1.4 \pm 0.3$	100.2
m_{llj}^{max}	$517 \pm 30 \pm 10 \pm 13$	501
m_{llj}^{min}	$265 \pm 17 \pm 15 \pm 7$	249
$m_{lj(low)}^{max}$	$333 \pm 6 \pm 6 \pm 8$	325
$m_{lj(high)}^{max}$	$445 \pm 11 \pm 11 \pm 11$	418

Table 1: Measured endpoint values for the mSUGRA benchmark point SU3 with an integrated luminosity $L=1 \text{ fb}^{-1}$ at 14 TeV. The truth values are also listed.

$m_{1/2}$ parameters can be derived with a precision better than 10% already with 1 fb^{-1} of data. The determination of the parameters $\tan\beta$ and A_0 is more complicated since no information from the Higgs sector is available at low luminosity.

4. Conclusions

If SUSY masses are within sub-TeV range the ATLAS experiment will be sensitive to early SUSY searches described by R-parity conserving models at 10 TeV center-of-mass energy already with integrated luminosity of 200 pb^{-1} . Understanding the detector performance and controlling the Standard Model background are important goals of early SUSY analysis. Once a signal is established, the kinematic endpoints reconstructed in the specific SUSY decay chains will be used to extract corresponding SUSY masses.

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