

Strategy for early SUSY searches at ATLAS

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Abstract. The CERN Large Hadron Collider (LHC) is scheduled to commence operation in 2008 and inclusive searches for supersymmetry (SUSY) will be one of our primary tasks in the first days of LHC operation. It is certain that the final state of “multijets + missing transverse energy” will provide a superior performance in SUSY searches. As yet, well-considered strategies for the understanding of instrumental effects of detectors and the realistic estimations of the Standard Model (SM) backgrounds would not be clear: they are urgent issues for the coming data. We describe the strategy for early SUSY searches at the ATLAS experiment using the first data corresponding to the integrated luminosity up to 1fb^{-1} , which comprises many progresses in the data-driven technique for the SM background estimations.

PACS. 11.30.Pb Supersymmetry

1 Introduction

Supersymmetry (SUSY) imposes a new symmetry between the fermions and bosons[1,2,3,4,5]. The supersymmetric extension of the Standard Model (SM) makes improvements to phenomenological problems in the physics of elementary particles: it provides a natural solution for the gauge hierarchy problem, if sparticles exist at the TeV scale. Moreover, the extrapolation of LEP data within the framework of supersymmetric extension yields a precise unification of gauge couplings at a scale of $\sim 10^{16}$ GeV[6,7]. Due to these properties, the SUSY is one of the most attractive alternatives beyond the SM and has been the subject of many studies in particle physics. However, up to now, no direct evidence for SUSY has been found. It is essential to examine the properties of any new states of matter at energy scales close to the threshold for the new phenomena, or in high energy collisions at the TeV energy scale.

The CERN Large Hadron Collider (LHC), a p - p collider, is scheduled to operate at the center-of-mass energy of 14 TeV in 2008. The ATLAS experiment is one of two general purpose experiments being nearly constructed for the CERN LHC. The ATLAS detector is designed to have a good sensitivity to the full range of high- p_T physics in p - p collisions. Details regarding the detector and its performances are described in Ref.[8]. Currently we focus on preparation for the early data in 2008, aiming for early SUSY discoveries. We describe the strategy for early SUSY searches at the ATLAS experiment using the data of first year corresponding an integrated luminosity of 1fb^{-1} . The results in this paper are obtained using the full de-

tector simulation to understand reconstruction performances, trigger efficiencies and systematic effects of the detector.

2 Inclusive searches

Sparticle production of gluinos (\tilde{g}) and squarks (\tilde{q}) occurs dominantly via strong interactions and its rate may be expected to be considerably large at the LHC. Gluino production leads to a large rate for events with multijets via series of cascade decay and the neutral lightest supersymmetric particle (LSP) in the final state which remains stable and undetectable, if R -parity is conserved. LSP's carry off apparently large missing transverse energy (E_T^{miss}). We note that there are no third generation partons in the initial state, gluino and squark production rates are fixed by SUSY QCD in terms of the gluino and squark masses ($m_{\tilde{g}}$ and $m_{\tilde{q}}$). Thus, inclusive SUSY searches with the early data rely on excesses of events in the channel of “multijets + large E_T^{miss} ” [9] which is a model-independent feature.

In our searches, the events are classified based on the topology, the number of identified isolated leptons, and we try to cover a broad range of experimental signatures. The experimental signatures, corresponding SUSY scenarios and their background processes are summarized in table1. They cover realistic supersymmetric models of minimal supergravity (mSUGRA)[10, 11, 12, 13], anomaly-mediated SUSY breaking (AMSB)[14, 15] and gauge-mediated SUSY breaking (GMSB)[16, 17].

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Table 1. Summary of experimental signatures with E_T^{miss} and corresponding SUSY scenarios and SM background processes.

jet multiplicity	additional signature	covered scenario	background
≥ 4	no lepton	mSUGRA, AMSB, split SUSY, heavy squark	QCD, $t\bar{t}$, W/Z
	single lepton (e, μ)	mSUGRA, AMSB, split SUSY, heavy squark	$t\bar{t}$, W
	dilepton (e, μ)	mSUGRA, AMSB, GMSB	$t\bar{t}$
	ditau	GMSB, large $\tan\beta$	$t\bar{t}$, W
	$\gamma\gamma$	GMSB	—
~ 2	—	light squark	Z

2.1 Event selection

Considering the features of sparticle production and its decay, the signal candidate events are selected by requiring:

- $N_{\text{jet}} \geq 4$,
- $p_T^{J1} > 100 \text{ GeV}/c$ & $p_T^{J4} > 50 \text{ GeV}/c$,
- $S_T > 0.2$,
- $E_T^{\text{miss}} > 100 \text{ GeV}$ & $E_T^{\text{miss}} > 0.2 \times M_{\text{eff}}$,

where N_{jet} , $p_T^{J1(4)}$, S_T and M_{eff} are the number of jets, the transverse momentum of first (fourth) leading jet, the transverse sphericity and the effective mass, respectively. The effective mass is formulated as $M_{\text{eff}} = \sum_{i=0}^4 p_T^i + E_T^{\text{miss}}$, where p_T^i is the transverse momentum of i -th leading jet. In addition, for the singlelepton signature, the events are selected by requiring one isolated lepton with p_T larger than 20 GeV and the transverse mass (M_T) should be large than 100 GeV. The selection cuts described here are based on the definition given in Ref.[8], but will be optimized.

Finally, we look for the SUSY events with large M_{eff} at which the signal exceeds the SM backgrounds. The value of M_{eff} also provides a first estimate of the sparticle masses. Fig.1 shows the M_{eff} distributions for no and singlelepton signatures. For the SUSY signal, we set a bench mark point on the bulk region, where $m_0 = 100 \text{ GeV}$, $m_{1/2} = 300 \text{ GeV}$, $A_0 = 300 \text{ GeV}$, $\tan\beta = 6$ and $\mu > 0$, referred to SU3. If the SUSY exists, we expect there is an excess over the SM background expectation in the distribution for each event topology with an integrated luminosity up to 1fb^{-1} .

2.2 Discovery reach

Fig.2 shows 5σ -discovery reaches in the $m_{\tilde{g}} - m_{\tilde{q}}$ space for each event topology in the mSUGRA model. We see that even for sparticle mass as heavy as $\sim 1 \text{ TeV}$, discoveries are expected for an integrated luminosity of 1fb^{-1} . The discovery reaches also show good stability against the values of $\tan\beta$.

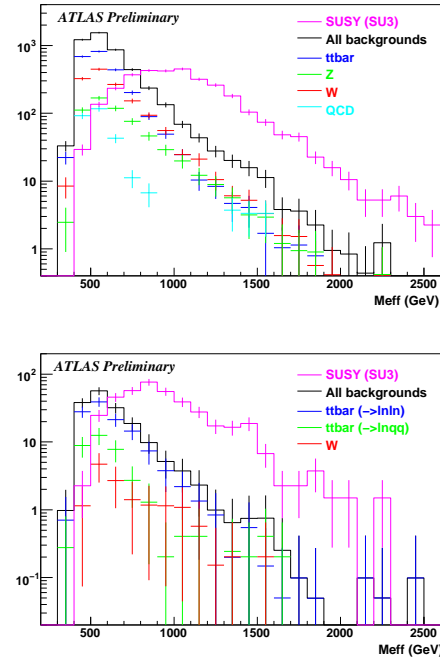


Fig. 1. The M_{eff} distributions for nolepton (upper) and singlelepton (bottom) signatures. The histograms are normalized to the integrated luminosity of 1fb^{-1} .

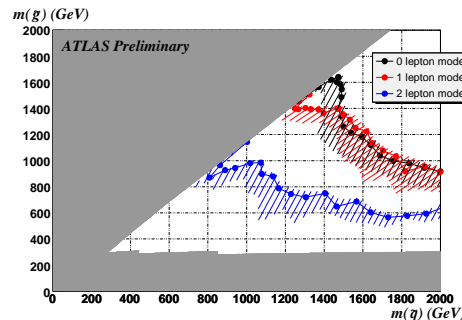


Fig. 2. 5σ -discovery reaches in the $m_{\tilde{g}} - m_{\tilde{q}}$ space for each event topology. Generator-level uncertainties of 100% are shown by the hatched regions. The results are obtained on the assumption of $\tan\beta = 10$, $A_0 = 0$ and $\mu > 0$.

3 In-situ measurements for the E_T^{miss} scale and resolution

As stated above, the E_T^{miss} is the discriminating signature for the SUSY searches, but it is also a complex object: apart from undetected neutral particles, it will comprise contributions from beam halo, cosmic-ray muons and instrumental effects such as noise, hot or dead channels or cracks of the detector. The mismeasurements or inefficiencies for jets and muons also contribute to the E_T^{miss} ; these make up the fake E_T^{miss} . A precise understanding of these contributions and their reduction are crucial, especially in the tails of the distribution.

For the calibration and commissioning of E_T^{miss} , we use the invariant mass distributions of $W \rightarrow l\nu$ and $Z \rightarrow \tau\bar{\tau}$ events where τ 's decay into a lepton and a hadron. For the $Z \rightarrow \tau\bar{\tau}$, as an example, the invariant mass is reconstructed using the collinear approximation; it is sensitive to the E_T^{miss} scale and resolution. Fig.3 shows the $Z \rightarrow \tau\bar{\tau}$ invariant mass peak as a function of the E_T^{miss} scale. A variation of 10% in the E_T^{miss} scale results in a 3% shift of E_T^{miss} scale. The Z mass can be reconstructed with an error of 1%, therefore, with an accumulated data of 100 pb^{-1} we can evaluate the E_T^{miss} scale with an accuracy of $\sim 4\%$. The fake E_T^{miss} originated from the industrial effects of the detector have been also studied. All the results for the commissioning are given in Ref.[18].

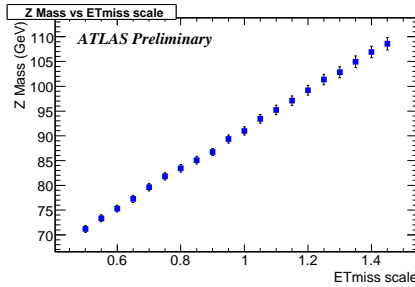


Fig. 3. The $Z \rightarrow \tau\bar{\tau}$ invariant mass as a function of E_T^{miss} scale.

4 Data-driven approaches for background estimations

Even if we get early indications of SUSY, we should justify “beyond SM” signatures with full understandings of generator-level uncertainties and instrumental effects of the detector because they affect the normalization and shapes of predicted backgrounds. However, these uncertainties are hard to estimate in the early stage of the experiment, and they are also expected to be large. Thus, in the early SUSY searches, we take data-driven approaches for the SM background estimation.

4.1 Z/W boson production background

The process of $Z \rightarrow \nu\bar{\nu}$ in association with multijets will give rise to final states with large E_T^{miss} and could be a dominant background for the nolepton signature. For this background contamination, the expectation is derived from the MC distribution of $Z \rightarrow \nu\bar{\nu}$ with the normalization determined by the $Z \rightarrow l\bar{l}$ data, where l is e or μ . We can better measure the $Z \rightarrow l\bar{l}$ yield thanks to small backgrounds in the final state. This normalization factor can be also applied to the $W \rightarrow l\nu$ background due to the same production mechanism at the LHC. Both estimations work sufficiently.

4.2 QCD multijet background

The QCD multijet production could be one of the most dominant SM background sources due to its large cross section. In the QCD events, neutrinos via leptonic decays and the mismeasurements of jets contribute to the tails of E_T^{miss} distribution. For the QCD background contamination, the estimation is derived from the multijet data with a function representing the fluctuations of measured jet energies. The fluctuation of jet energy is evaluated using events of

- $E_T^{\text{miss}} > 60 \text{ GeV}$,
- $\Delta\phi(E_T^{\text{miss}}, \text{jet}) < 0.1$,

where $\Delta\phi(E_T^{\text{miss}}, \text{jet})$ is the ϕ -angle between the missing transverse energy and an isolated jet in radian. We suppose that E_T^{miss} is originated from the fluctuating jet close to the E_T^{miss} direction, and the p_T of initial jet is estimated to be the vectorial sum of p_T^{jet} and E_T^{miss} . Then we can obtain the fluctuating function of jet energies ($R \equiv 1 - \mathbf{p}_T^{\text{jet}} \cdot (\mathbf{p}_T^{\text{jet}} + \mathbf{E}_T^{\text{miss}}) / |\mathbf{p}_T^{\text{jet}} + \mathbf{E}_T^{\text{miss}}|^2$). The jets in QCD multijet events with small E_T^{miss} are smeared according to the jet fluctuating function, which result in fluctuations of E_T^{miss} . Fig.4 shows the jet fluctuating function and the E_T^{miss} distribution with the superimposed QCD background estimation. We can obtain a fair description of the QCD background with this method, especially in the tails of the distribution.

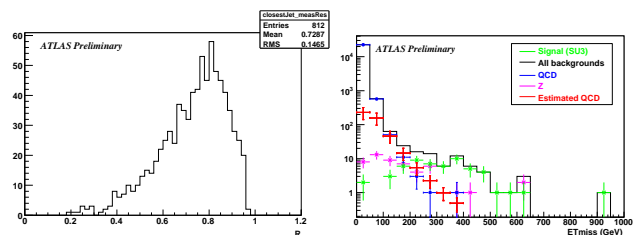


Fig. 4. The jet fluctuating function (left) and the E_T^{miss} distribution (right) for the nolepton signature. The histograms are normalized to an integrated luminosity of 22 pb^{-1} .

4.3 M_T discrimination method

Another advanced method to estimate the SM backgrounds, especially for singlelepton signature, is to use M_T which shows a discriminating power between the SUSY and SM backgrounds but are less dependent on E_T^{miss} . At first, we select events of $M_T < 100$ GeV to enhance the backgrounds (background control sample) and suppose the E_T^{miss} distribution of these events represents that of all the SM backgrounds. Then, the overall normalization of SM backgrounds is determined by comparing the number of events with $M_T < 100$ GeV and that with $M_T \geq 100$ GeV in the low E_T^{miss} region below 200 GeV.

The M_T distribution and the resultant M_{eff} are shown in Fig.5. The estimated number of SM backgrounds with large M_{eff} (> 800 GeV) and the MC prediction are 22.0 ± 0.9 and 24.8 ± 1.6 , respectively. They show a good agreement, however, there could be a contamination of signal events in the background control sample, which results in the overestimation of backgrounds by a factor of ~ 2 . We are making a progress in this method for the reduction of signal contamination and the result will be described in Ref.[18].

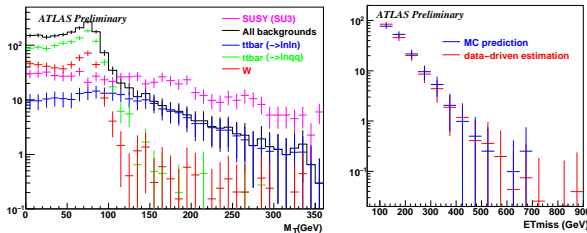


Fig. 5. The M_T distribution of singlelepton candidate events (left) and the M_{eff} distribution of SM backgrounds (right). The histograms are normalized to an integrated luminosity of 1fb^{-1} .

5 Conclusions

We described the strategies for the early SUSY searches at the ATLAS experiment. Using the inclusive signature of multijets plus large E_T^{miss} , we can make an early discovery of SUSY. Our searches are less model-dependent but sensitive to models with squark and gluino masses up to 1 TeV with an integrated luminosity of 1fb^{-1} . However, the precise understanding of the SM backgrounds is crucial for the early discovery. To settle this issue, we have been making many progresses in the *in-situ* calibration of E_T^{miss} and the data-driven technique for the SM background estimations. The opening of a new era of physics beyond the SM is coming with the LHC.

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