SUSY PHYSICS WITH EARLY DATA UNDERSTANDING ATLAS DETECTOR AND BACKGROUNDS*

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With the imminent start of the ATLAS data taking in 2007, the well considered strategy is necessary for the good understanding of the detector performance from in situ calibration and the realistic estimation of the Standard Model background. These are urgent issues for the new physics discovery channels especially for the SUSY searches in the early data taking of LHC run. The talk starts with the brief overview of the ATLAS detector and the calibration commissioning, then the realistic background estimation using real data and the matrix element calculation continues. Finally the newly obtained SUSY discovery potential with newly estimated backgrounds is presented.

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1. Introduction

This talk reports the recent activity and preliminary results from the ATLAS SUSY working group. The main focus is on the understanding of the detector using the commissioning data, and the discovery potential of the SUSY search using the early data taking.

At LHC, the colored sparticle pair-productions dominate the SUSY production in cross section, they generally decay into lighter sparticles subsequently and reach to the lightest supersymmetry particle (LSP) at the end of this cascade decays, assuming the R-parity conservation. During this decay chain, multiple high-$p_{\rm T}$ jets are emitted, together with the stable LSP escaping the detector, and sometimes the isolated leptons are also emitted. Thus the typical SUSY signature is characterized by the Missing $E_{\rm T}$ + multiple Jets (+ leptons) final state. For this reason, distribution of the

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variable $M_{\rm eff}$ = Missing $E_{\rm T} + \sum |p_{\rm T}^{\rm jet}|$ (called as an effective mass) is often used to separate the SUSY events from the SM background. Obviously it is crucial to well understand the performance of the Missing $E_{\rm T}$ and Jet energy measurements, especially by using the data in the early period.

2. Data taking during the commissioning

The detailed description of the ATLAS detector can be found in somewhere else [1]. Here only some of the basic strategies of the calibration methods are described. The first beams and collisions with lower energy ($\sqrt{s} = 0.9$ TeV) will take place in the later half of 2007, and the full physics run with full energy ($\sqrt{s}$ =14 TeV) will follow next year, 2008 [2]. During the commissioning, the 'in situ' calibration using the well-known physics processes will be carried out, and also transporting the information of the well-calibrated EM scale into hadronic scale are performed at this step. The processes, such as Drell–Yan ($Z \to ee, Z \to \mu\mu$) are used for the ECAL calibration and the muon system alignment. The top pair productions (single leptonic decay) will be used for the jet energy scale calibration and the b-tagging adjustments. Table I shows the expected detector performance in the early data taking period and the ultimate goal for the physics run. There

TABLE I

Expected detector performance in ATLAS.

	Day-0	Goal for the physics run
ECAL uniformity	$\sim 1\%$	$< 1\%$
lepton energy scale	$0.5 \sim 2\%$	0.1%
HCAL uniformity	$2 \sim 3\%$	$< 1\%$
Jet energy scale	$< 10\%$	1%
Track alignment	20–200 mm in $r\phi$	Ø(10) mm in $r\phi$

are several calibration methods being planed in ATLAS using the early data. For the jet energy scale calibration, a method called 'template method' will be used. The method has been used in CDF experiment [3, 4]. The idea of this method is to generate the template histogram of the invariant mass of W's ($W \to qq$) from the top pair productions and smear the quark energy with two parameters, α for scale and β for the relative resolution, and determine these two parameters by fitting the template histograms with the ones from the real data. The current study based on the ATLAS full-detector simulation shows that the absolute scale, α can be determined with the precision of $\sim 0.5\%$ over the jet energy range 50–250 GeV. The studies on the effect of the two jets angular resolutions (for the energetic jets, the angle between the $W \to qq$ becomes narrow) are ongoing.

The other method is the calibration using the balance between Z or γ (well calibrated EM objects) and the jets [5]. With this method, the large statistics are expected due to their high cross sections: $\sim$ 2 Hz for γ+jets, $\sim$ 0.1 Hz for Z+jets ($\mathrm{p_T} > 60$ GeV for both cases) are expected. The advantages of this method against the previous one are, the enlarged E_T and η coverages, the ability for the heavy flavor jet calibration at the same time (about 5% fraction of the total statistics). The issues are the contaminations of the multi-jets background, and the difficulties of good precisions in the lower p_T range.

For the validation of the Missing E_T measurements, the resolution and the scale studies are necessary at commissioning stage. Recent study showed the feasibility of the Missing E_T resolution measurement using minimum bias data in the lower scaler p_T sum range. One of the noise suppression schemes called 'topological clustering' shows a good performance in resolution. The study for the larger scaler p_T sum region (> 300 GeV) are in progress using the $W \to \nu l$ process, and the QCD dijets data. For the scale calibration of Missing E_T, several methods are considered. The one idea is to use the $Z \to \tau\tau$ process when one τ decays leptonically and the other decays hadronically. By looking at the reconstructed $m_{\tau\tau}$, assuming the energy scale for the missing ν_τ and the co-linear approximation of the τ and ν_τ, one can obtain the absolute scale of the Missing E_T. This is under development and needs a detailed background study.

3. Background estimation using matrix element and real data

3.1. BG estimation using matrix element generators

For the SUSY search in the early data taking period, the largest obstacle we have to tackle is the Standard Model background estimation. During the study for ATLAS technical design report (TDR) in 1999 [1], most of the works were based on the parton shower (PS) Monte Carlo programs, for example by using PYTHIA [6]. The parton shower is a powerful approximation in the collinear region. However the PS is not proper for the process emitting the hard jets, thus it may underestimate the background especially in the high-p_T tail region, which is the most important for the SUSY search. On the other hand, the recent developments in the matrix element (ME) generators enable the production of the multiple hard jets in the final states. Therefore our current best approach is the combination of the two methods, *i.e.* use the ME for the hard process regime (generator: ALPGEN [7]), and use the PS for the subsequent evolution of the hard jets (generator: HERWIG or PYTHIA), the areas of two are connected by the matching scheme. Fig. 1 illustrates the transition from TDR study to the latest. Recent estimation increases the Standard Model background by a factor of 2–5 times compared to the ones in TDR, which directly impacts the SUSY discovery potential. In no-lepton mode, which requires no muon

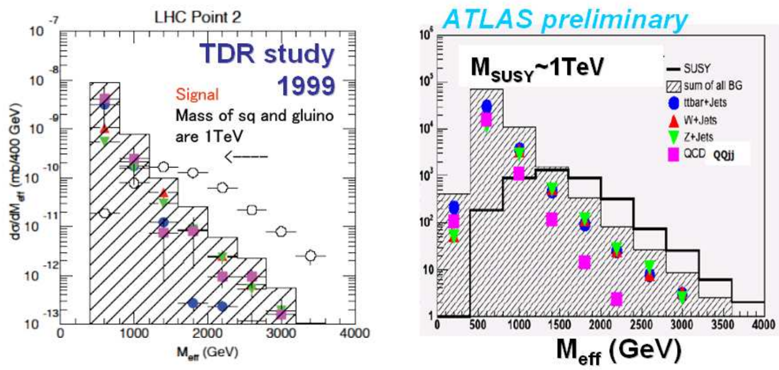

Fig. 1. The effective mass distributions for 0-lepton mode. TDR study (left) and recent results (right). The shaded areas represent the sum of the Standard Model backgrounds.

or isolated electron in the acceptance, the main background contributors for SUSY search are the $t\bar{t}$, W, Z, and QCD multi-jets events. After requiring one isolated lepton, $t\bar{t}$ and W productions become dominant. Thus understanding these backgrounds, especially from the real data, is the highest priority.

3.2. BG estimation from the real data

In order to estimate the background from real data, for example, in Missing E_{T} distributions, one has to find a good variable which is uncorrelated to the Missing E_{T} and isolates the background from the SUSY signal. For $t\bar{t}$, the top mass is reasonably uncorrelated to Missing E_{T} and can be used to isolate the top background as in Fig. 2. In figure, no b-tagging is applied assuming the early data taking period, which results in the large amount of combinatorial background around the top mass peak. The control sample is made by subtracting the events in side band region ($M_{\mathrm{top}} = 200$–260 GeV) from the events in signal region ($M_{\mathrm{top}} = 130$–200 GeV), and it is normalized to the data using low Missing E_{T} region (as in Fig. 3) where contributions from SUSY events are expected to be small. By using the 10 fb^{-1} equivalent full detector simulation data (limiting the top p_{T}: $p_{\mathrm{T}} >$500 GeV), 503 ± 22 events are found with the sample including SUSY events ($M_{\mathrm{SUSY}} \sim 600$ GeV) and 7 ± 35 events are found when assuming no SUSY

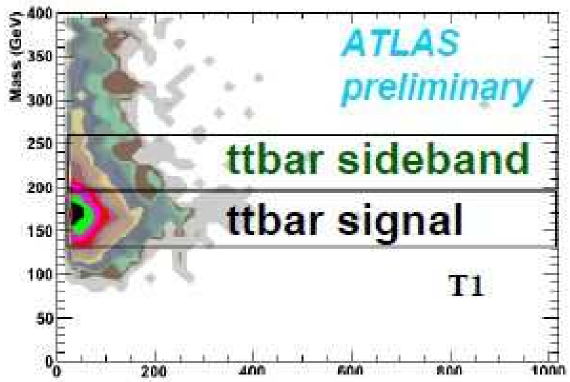

Fig. 2. The top mass *vs.* Missing E_{T} in $t\bar{t}$ sample with semi-leptonic decay.

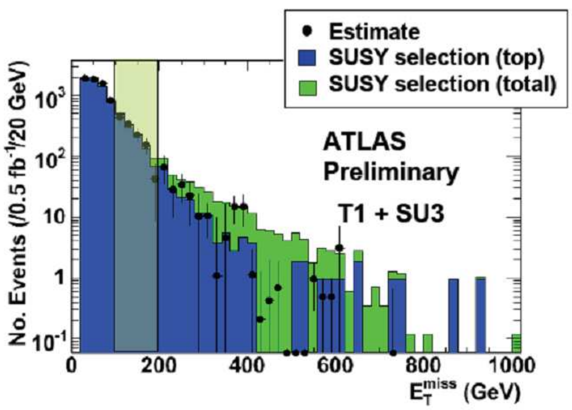

Fig. 3. Missing E_{T} distributions from the top sample (solid lower histogram), SUSY sample (lighter, stacked) and the estimation for top (black points).

event in the high Missing E_{T} region (> 500 GeV). This proves that the method can be used as a powerful tool for the top background estimation (with 13σ significance). Similar approach can be taken for the W ($\rightarrow l\nu$) backgrounds where no mass peak is available in this case. Here, one has to find the other variable uncorrelated to Missing E_{T}. One such candidate could be the scalar p_{T} sum of the four leading jets. The study using this variable shows the feasibility of this technique for W production. The technique is applicable for any other background having no mass peak. This study needs further investigations. The other important background process which needs to be investigated from real data is $Z \rightarrow \nu\nu$. The idea is to use $W \rightarrow \mu\nu$ process, and mimic the $Z \rightarrow \nu\nu$ process by replacing $p_{\mathrm{T}}(\mu\nu)$

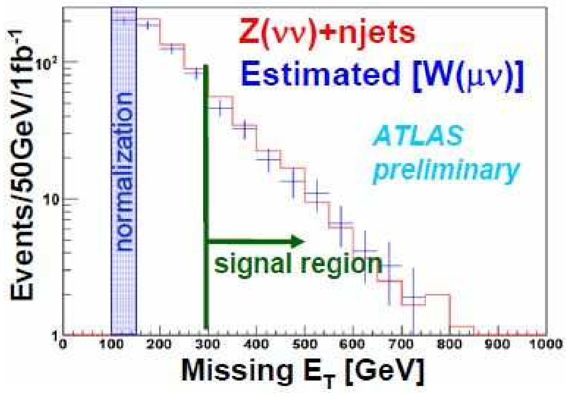

Fig. 4. Missing E_{T} distributions of $Z \to \nu\nu$ process and the estimation from the $W \to \mu\nu$. They are normalized using the region 100–150 GeV.

with the Missing E_{T}. Using the process, $W \to \mu\nu$, is better than Drell–Yan process ($Z \to \mu\mu$) especially in the early data taking due to about 10 times larger cross section available for W production. Fig. 4 shows the feasibility of such estimating method of Missing E_{T} distribution. The number of events in the region, Missing $E_{\mathrm{T}} > 300$ GeV for 1 fb^{-1} luminosity equivalent have a good agreement between $Z \to \nu\nu$ and the estimation from $W \to \mu\nu$. The method is found to be promising and further developments are expected.

4. Discovery potential

In the inclusive SUSY search, one of the powerful discriminators of the SUSY signal from the Standard Model background is the Missing E_{T}. Fig. 5 clearly illustrates this. In the figure, SUSY signals with different SUSY mass scales are shown on top of the Standard Model backgrounds. In this figure, the Standard Model backgrounds are estimated by using ALPGEN. As obviously observed, better signal significance can be achieved by optimizing the cut on the Missing E_{T} depending on the SUSY mass scale rather than simply using the standard SUSY cut, which is 100GeV. Studies are performed for such cut optimization. A particular parameter point $(m_{1/2}, m_0)$ is selected and the best optimized Missing E_{T} cut value is determined which maximize the signal significance ($\equiv S/\sqrt{B}$) at the point. The procedure is iterated through the wide parameter space. The z-axis of Fig. 6 represents the best cut value of the each mSUGRA point. For example, in the large $m_{1/2}$ region the mass of χ_1^0 becomes heavy ($\sim 0.4 m_{1/2}$) thus the optimal Missing E_{T} cut becomes higher, and is less sensitive to m_0. Similar tunes are done for cuts on the leading jet energy, 2nd leading jet energy, and 4th leading jet energy,

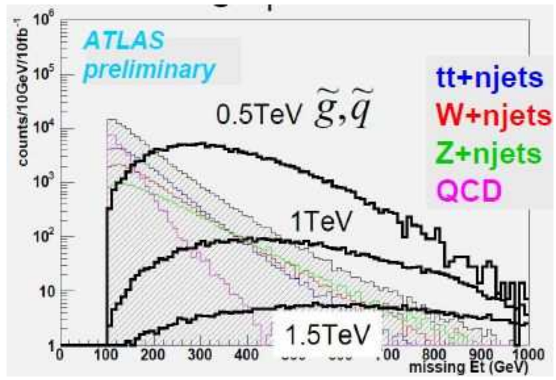

Fig. 5. Missing E_{T} distributions of the SUSY signal for different SUSY scale ($M_{\mathrm{SUSY}} = 0.5, 1.0$, and 1.5 TeV) and Standard Model background after the standard event selection for SUSY study (Missing $E_{\mathrm{T}} > 100$ GeV, $p_{\mathrm{T}}^{1\mathrm{st}} > 100$ GeV, $p_{\mathrm{T}}^{4\mathrm{th}} > 50$ GeV and Transverse sphericity > 0.2).

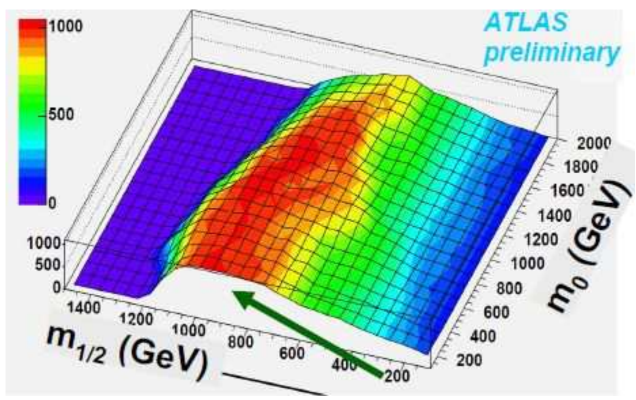

Fig. 6. The 2-dimensional view of the best optimized Missing E_{T} cut value (GeV: z axis) for the mSUGRA parameter space grid ($m_{1/2}, m_0$ plane, other parameters are fixed as $\tan\beta = 10, A = 0, \mu > 0$).

simultaneously together with the Missing E_{T} cut optimization. Fig. 7 shows the 5-σ discovery potential lines after these cut optimizations expected in the early data taking period.

As already explained, the Standard Model background candidates are re-examined by the matrix element based generator (ALPGEN). The 0-lepton mode has larger statistics, while the 1-lepton mode can suppress the systematic error of the background estimation. Therefore it is important to investigate the potential from both approach. The discovery potential expected for the early data taking are $M_{\mathrm{SUSY}} < 1.1$ TeV at 100 pb^{-1}, and $M_{\mathrm{SUSY}} < 1.5$ TeV for 1 fb^{-1}.

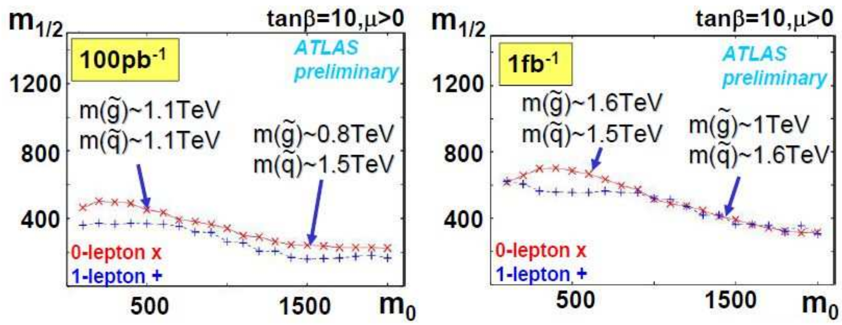

Fig. 7. Newly obtained 5-σ discovery potentials on $m_0, m_{1/2}$ plane expected using the early data for integrated luminosity 100 pb^{-1} (left) and 1 fb^{-1} (right). The x/red and +/blue data lines represent the 0-lepton and 1-lepton tagging mode, respectively.

5. Summary

In this talk, the status of the ATLAS readiness for SUSY search toward the early data taking is presented. ATLAS starts data taking very shortly: the first collisions is expected at 2007, the full physics run will start from year 2008. Thus the successful commissioning of the Missing $E_{\rm T}$ and the jet energy scale calibration is the key for the SUSY discovery in the early period. Various studies are ongoing among the Physics working group, and they look to be promising. Also the realistic re-estimation of the Standard Model backgrounds are crucial. Especially various ideas on the data-driven background estimation are being examined. Finally newly obtained discovery reach for the SUSY discovery is shown with the renewed background estimation and the cut optimization. Preliminary results are obtained: $M_{\rm SUSY} < 1.1$ TeV at $L = 100$ pb^{-1} and $M_{\rm SUSY} < 1.5$ TeV for $L = 1$ fb^{-1}.

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