EARLY PHYSICS WITH ATLAS AT LHC

Bellisario Esposito a - On behalf of the ATLAS Collaboration
Istituto Nazionale di Fisica Nucleare, Laboratori Nazionali di Frascati, 00044 Frascati (Italy)

Abstract. The ATLAS experiment is aimed at the exploitation of the full physics potential of LHC. The 2009 - 2010 LHC run will provide the first collision data at an energy above the Tevatron energy. The detector calibration with physics processes and the main physics measurements possible with early data are presented.

1 Introduction

The LHC collider is designed for a proton-proton collision energy of 7+7 TeV and a luminosity of $10^{33}$cm$^{-2}$s$^{-1}$ in order to provide access to the experimentation at an energy scale high enough to make it possible to clarify the mechanism of the spontaneous gauge symmetry breaking and the origin of the particle masses. In addition, new physics expected by models beyond the Standard Model (SM), or unexpected, can take place at such high energy and intensity. The ATLAS experiment aims at covering the full physics potential offered by LHC [1,2]. The ATLAS detector is fully operational [3] and ready to start the campaign of measurements foreseen in its physics program.

The physics perspectives of the first LHC run depend on the performance of the LHC, namely on which is the collision energy and what integrated luminosity is delivered. At the moment of writing these proceedings, data has been collected in the Nov.-Dec. 2009 run ($\sim$ 920k minimum bias events at $\sqrt{s} = 900$ GeV and $\sim$ 34k minimum bias events at $\sqrt{s} = 2.36$ TeV) and the plan is to have a run in 2010-2011 at 3.5+3.5 TeV and reach an integrated luminosity of 1 fb$^{-1}$.

The scenario discussed here corresponds to what was expected at the time of the conference: beam energy between 3.5 and 5 TeV, luminosity $\sim 10^{31}$-10$^{32}$ cm$^{-2}$s$^{-1}$, integrated luminosity $\sim 100$ pb$^{-1}$.

Based on the integrated luminosity expected, a discussion of the physics processes observable is made in Section 2. In Section 3 the use of physics processes for the in-situ calibration is discussed. Section 4 is devoted to report on the main early physics measurements.

2 Physics processes observable with early data

The main known processes (minimum bias, high $p_T$ jet production, b$b$, c$c$, W, Z and top) have large cross section. With 100 pb$^{-1}$ of integrated luminosity large enough statistics can be collected to perform interesting studies of these processes in a new energy regime, to improve the knowledge of the PDF using jets, W and Z events, and to tune the Monte Carlo generator.

a e-mail: bellisaro.esposito@lnf.infn.it
Most of the interesting discovery processes, like Higgs production, have cross section very low and for their discovery a much larger integrated luminosity is required. There are however also new processes like Z' production or gluino or squark production in supersymmetry for which the expected cross section is such that with 100 pb$^{-1}$ there are chances that they are observed, or a significant limit can be established on their mass.

3 Detector performance and in-situ calibration

The ATLAS detector has been designed to provide excellent performance in the measurement of the charged particle tracks in the Inner Detector, the muon tracks in the Muon Detector and in the calorimetric energy measurement of electron, photon and jets [1,2].

<table>
<thead>
<tr>
<th></th>
<th>Initial</th>
<th>Ultimate</th>
<th>Physics samples for calibration</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECAL uniformity</td>
<td>$\sim$2.5%</td>
<td>0.7%</td>
<td>Isolated electrons, Z $\rightarrow$ ee</td>
</tr>
<tr>
<td>e/$\gamma$ Energy-scale</td>
<td>2 - 3%</td>
<td>$\leq$0.1%</td>
<td>J/$\psi$, Z $\rightarrow$ ee, E/p for electrons</td>
</tr>
<tr>
<td>Jet Energy-scale</td>
<td>5 - 6%</td>
<td>1%</td>
<td>$\gamma$/Z+1j, W $\rightarrow$jj in t$\bar{t}$ events</td>
</tr>
<tr>
<td>ID alignment</td>
<td>20 - 200 $\mu$m</td>
<td>5 $\mu$m</td>
<td>Generic tracks, isolated $\mu$, Z $\rightarrow$ $\mu\mu$</td>
</tr>
<tr>
<td>Muon alignment</td>
<td>40 - 1000 $\mu$m</td>
<td>40 $\mu$m</td>
<td>Straight $\mu$, Z $\rightarrow$ $\mu\mu$</td>
</tr>
</tbody>
</table>

Table 1: Initial and ultimate detector performances.

With the calibration and performance studies of the various subdetectors with test beam and cosmic rays, the so-called "day-1" performance, which is already very good, has been obtained. In order to obtain the ultimate design performance it is necessary to perform a calibration of the detector using collision events such as Z $\rightarrow$ $\mu\mu$, Z $\rightarrow$ e e, J/$\psi$, $\gamma$/Z+jet, W $\rightarrow$jj in top events etc. Table 1 summarizes the initial, obtained, and the ultimate, expected, detector performance and the calibration processes to be used.

4 Early physics results

With the expected integrated luminosity many studies can be performed both on standard processes and for the search of new physics. The main expected physics results are discussed in the following subsections.

4.1 Minimum Bias

The goals of the study of the minimum bias events at LHC are to measure the properties of the inelastic pp interaction processes in a new energy regime, and
to determine the characteristics of the background at high luminosity, due to pile-up events. The detector performances required for those studies are an unbiased trigger and tracking efficiency at low $p_T$.

The results expected for the measurement of the charged particle pseudo-rapidity $\eta$ in minimum bias events using the low $p_T$ tracking algorithm are reported in Figure 1. The systematic uncertainty coming from the trigger and selection efficiency correction and from the tracking efficiency correction is about 6-8%. The results of these measurements will allow to disentangle between different expectations based on different extrapolations from low energy data. These expectations have indeed a large uncertainty, as shown in Figure 2.

![Figure 1: Charged particles pseudo-rapidity distributions. MC truth (full line) and the ratio of the analysis result over the MC (at the bottom) are also shown.](image1)

![Figure 2: Central charged particle density for non-single diffractive inelastic events as a function of energy.](image2)

### 4.2 QCD Jet Physics

The LHC energy opens up a much higher $p_T$ region with respect to the Tevatron (Figure 3). The goals of the study of the high $p_T$ jet events are to measure the properties of the very hard pp interaction processes, to look for deviations from QCD predictions due to new physics (quark substructure, resonant production, large extra dimensions) and to determine the characteristics of the background from QCD events for the observation of other processes.

The use of a jet algorithm appropriate for comparison with theoretical calculations (collinear and infrared safe) is required, and the jet energy scale (JES) has to be calibrated accurately for detector effects (non compensation, noise, cracks) and for physics effects (clustering, fragmentation, Initial State Radiation (ISR), Final State Radiation (FSR), Underlying Event (UE)).

In-situ calibration with physics processes (di-jet, $\gamma / Z$ + jet, multi-jet, $W \rightarrow jj$) is used. The calibration with $\gamma$-jet events is illustrated by the plots in Figure 4.
With 100 pb$^{-1}$ a statistical uncertainty on JES of 1-2 % for 100-200 $< p_T <$ 500 GeV is obtained. The systematics from physics is 1-2 % (ISR/FSR, UE).

Figure 3: Inclusive differential jet cross section as a function of $E_T$.

4.3 W and Z Physics

The goals of the study of the W and Z events are to measure their production cross-sections known theoretically with uncertainty at the level of 1 %, to measure $p_T$ distribution to probe QCD initial parton radiation, and to measure rapidity distribution to probe parton density functions (PDF).

The results of an analysis to measure the W and Z cross sections with 50 pb$^{-1}$

<table>
<thead>
<tr>
<th>Signal (N)</th>
<th>Background (B)</th>
<th>$\sigma$ (pb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$W \rightarrow e\nu$</td>
<td>22.67 ± 0.04</td>
<td>6.01 ± 0.92</td>
</tr>
<tr>
<td>$W \rightarrow \mu\nu$</td>
<td>30.04 ± 0.05</td>
<td>2.01 ± 0.12</td>
</tr>
<tr>
<td>$Z \rightarrow ee$</td>
<td>2.71 ± 0.02</td>
<td>0.23 ± 0.04</td>
</tr>
<tr>
<td>$Z \rightarrow \mu\mu$</td>
<td>2.57 ± 0.02</td>
<td>0.10 ± 0.002</td>
</tr>
</tbody>
</table>

Table 2: Signal (N), Background (B) events and cross section measurement with integrated luminosity of 50 pb$^{-1}$.

are reported in Table 2. W and Z events can also be used to perform in-situ detector calibration (absolute energy and momentum scale, resolution, trigger and reconstruction efficiency).
4.4 Top Physics

The goals of the study of top-quark physics are to measure $t\bar{t}$ cross-section and to study top properties and decay. The $t\bar{t}$ events can also provide samples of b-jet and $W \rightarrow j \bar{j}$, very useful for the in-situ detector calibration (b-tagging efficiency, light jet energy scale).

The $t\bar{t}$ signal can be observed in the single lepton channel. The three jet top mass peak and the two jet $W$ mass peak can be observed with a simple cut selection and no b-tagging (Figure 5 and 6). The $t\bar{t}$ cross section measurement with 10-15% accuracy is possible with 100 pb$^{-1}$. The $t\bar{t}$ signal can also be observed in the di-lepton channel with lower statistics but systematic uncertainties smaller than for the single lepton channel.

![Figure 5: Three jet mass distribution. The fit to the top signal (gaussian) and to the background (Cheby- chev polynomial) are indicated.](image1)

![Figure 6: Two jet mass distribution. The fit to the W signal (gaussian) and to the background (Chebychev polynomial) are indicated.](image2)

4.5 Early discoveries of New Physics

The LHC run will not only provide data to study known processes in a new energy regime but will also give the chance of new discoveries even with the initial expected luminosity. In fact with integrated luminosity of 100 pb$^{-1}$ early discoveries are possible.

$Z'$ searches

A $Z'$ signal would show up as a (narrow) mass peak above small and smooth SM background. The discovery for mass up to 1 TeV is possible with 100 pb$^{-1}$ at $\sqrt{s}=10$ TeV (Figure 7). The observation of $Z \rightarrow ll$ signal does not require ultimate detector performance.
Supersymmetry (SUSY) searches

Squarks and gluinos are produced via strong interactions and have large cross-section. Their decay produces spectacular final states with many jets, leptons, missing transverse energy. The results of a simulation study at $\sqrt{s} = 10$ TeV are summarized in Figure 8. A discovery up to squark and gluino masses of 600-700 GeV is possible with 200 pb$^{-1}$. This however requires a very good understanding of the detector effects and of the physics background. The $E_T^{\text{miss}}$ can be checked with known processes, and data-driven methods to estimate the background from the SM processes are to be used.

![Figure 7: Integrated luminosity needed for $Z'$ discovery as a function of center-of-mass energies.](image1)

![Figure 8: SUSY discovery reach in the plan of universal scalar mass $m_0$ and universal gaugino mass $m_{1/2}$.](image2)

5 Conclusions

The study of a variety of SM processes in a new energy regime and the search for some of the new particles foreseen by the models beyond the SM are the physics prospects of the first LHC run. The analysis of the data collected will also provide the verification and the tuning of the ATLAS detector calibration, necessary to improve the performances and reduce the systematics.

With a well understood and calibrated detector, unexpected effects possibly leading to surprising discoveries can be looked upon.

References

