# First physics prospects with the ATLAS detector at LHC

*Judith Katzy on behalf of the ATLAS Collaboration*
DESY, Hamburg, Germany

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**Abstract**

The status of the ATLAS detector at the time of the first circulating LHC beam is presented. We report on the physics prospects for the early data with center of mass energies of 10 TeV and 14 TeV and integrated luminosities of 10 $pb^{-1}$ up to 1 $fb^{-1}$.

## 1 Introduction

ATLAS (A Toroidal LHC ApparatuS) is one of the two general purpose detectors built to probe proton-proton collisions at 14 TeV. Here we present the status and physics start-up plans as of October 2008. The paper is organized as follows: The ATLAS detector concept and status is explained. Detector studies with data taken before proton-proton collisions are described and the plans for early physics are outlined.

### 1.1 The ATLAS detector

The ATLAS detector presents the typical large acceptance concentric collider detector structure. The inner tracking detectors (ID) surround the beam pipe. They consist of cylindrical layers (in the barrel part) and disks (in the forward parts) of silicon pixel with $0.8 \cdot 10^8$ channels and silicon strips with $6 \cdot 10^6$ channels, followed by a Transition Radiation Tracker (TRT) used for tracking and particle identification (e/$\pi$ separation) with a momentum resolution of $\sigma(p_T)/p_T = 5 \cdot 10^{-4}\ p_T + 0.01$. The ID covers the acceptance region of $|\eta| < 2.5$ and is immersed in a 2 Tesla magnetic field.

An electromagnetic lead-liquid argon sampling calorimeter system with accordion shape (LAr) is housed in a barrel and two endcap cryostats. The endcap cryostats also contain a hadronic sampling calorimeter with copper absorbers as well as the forward calorimeters with electromagnetic and hadronic sections made out of copper and tungsten absorbers respectively. The liquid argon calorimeter is complemented by barrel and extended barrel tile calorimeters (TileCal) using scintillating tiles with iron absorbers. The electromagnetic calorimeter has 180000 channels including longitudinal segmentation. Its energy resolution in the barrel and endcap regions is $\sigma(E)/E = 10\%/\sqrt(E) \bigoplus 0.7\%$ . The hadronic energy resolution is $\sigma(E)/E \simeq 50\%/\sqrt(E) \bigoplus 3\%$ in the Iron-Tiles and $\sigma(E)/E \simeq 100\%/\sqrt(E) \bigoplus 10\%$ in the copper/tungsten part. The LAr is fully installed and has been operated steadily since May 2008 with only 0.02% dead channels. The calorimetry is surrounded by the large air-core toroid muon system which includes precision tracking chambers with a standalone momentum resolution of $\Delta p_T/p_T < 10\%$ up to 1 TeV and additional trigger chambers.

For luminosity measurements, LUCID, a Cherenkov detector, is situated at 17 m from the interaction point close to the beam pipe. Two additional calorimeters will be placed at 140 and 240 m respectively. A detailed description of the full detector can be found at [1].

### 1.2 Pre-Collision data

Test beam measurements have been performed from May-November 2004 at the CERN H8 beam line with a vertical slice of the full detector corresponding to about 1% of the full size. The detector was put into magnetic fields between 0-1.4T strength. The response of the detector to particles was measured for $e^{+/-}, \pi^{+/-}, \mu, p, \gamma$ in energy ranges between 1-350 GeV. In total $9 \cdot 10^7$ events were collected. Both this and previous testbeam data was used in tuning the GEANT4 simulation of the ATLAS detector.

Since spring of 2008 cosmic data have been collected with the components installed in ATLAS. The rate of cosmic events crossing the inner detector is  15 Hz. A wealth of information can be extracted from these events for alignment, detector timing, pulse shape analysis and energy calibration. For example, the uniformity of the response of the LAr electromagnetic calorimeter has been cross-checked at the 3% level [2].

## 2 Collisions: A physics roadmap

One of the main goals with first collisions will be to calibrate the detectors in-situ using well known physics samples. The measurement of known Standard Model signals will serve also to validate and tune MC generators. At the same time, one should be prepared for surprises of very striking new physics signatures. A few examples of analysis are described in this section. A recent and exhaustive review of the physics potential of ATLAS can be found in reference [3].

At the time of the talk initial collisions at 10TeV were planned with an integrated luminosity of up to few $\text{pb}^{-1}$. After the LHC accident on September 19, 2008 the schedule has been revised and a clear decision on the start-up beam energy has not been taken at the time of writing. However, 10 TeV collisions are still likely expected first and are therefore considered here together with the physics capabilities of low luminosity 14 TeV samples.

### 2.1 Minimum-Bias and underlying event

About 2/3 of the total pp cross-section can be measured with to the so-called minimum bias trigger configuration which basically selects the non-single-diffractive events. There are large uncertainties in the extrapolation of the charged particle multiplicity produced in Minimum-Bias events from Tevatron to LHC energies, as shown in Figure 1. It is important to measure this cross-section, as Minimum-Bias events are the source of pile-up at higher luminosity. Up to about 20 events per bunch crossing are expected at design luminosity. They will need to be well understood to do precision physics. These measurements are best done with early data at low instantaneous luminosity. The expected $p_T$ spectrum of the particles is soft with the cross-section peaking at 250 MeV. To increase the precision of the measurement, the reconstruction of tracks for these events can be extended down to 150 MeV.

## 2.2 W/Z Boson Production

The Z and W Boson cross-sections can be measured for leptonic decays with an initial robust analysis. The analysis is based on leptons with $p_T > 20$ GeV ($p_T > 25$ GeV for W) at $|\eta| < 2.5$. Lepton trigger and reconstruction efficiencies are extracted using the tag-and-probe method [3]. The overall efficiency for the signal is expected to be close to 70% (80%) for the Z (W) analysis, resulting in about 25,000 expected signal events and 100 expected background events for an integrated luminosity of 50 pb$^{-1}$ for $Z \rightarrow \mu\mu$, see Figure 2. The expected errors of the cross-section are 0.8% (statistical) and 3% (systematic). An additional uncertainty will come from the uncertainty of the luminosity, which is estimated to be 10% at that stage. For $W \rightarrow \mu\nu$ 300,000 selected events are expected with 20,000 background, resulting in expected errors on the cross-section of 0.2% (statistical) and 3% (systematic). The precision of the measurement of W and Z will be quickly dominated by systematic effects and a final precision of 1-2% will be already reachable with 1fb$^{-1}$.

Due to the relatively high rate and the clean final state, the samples of Z and W boson with leptonic decays will be used to determine detector efficiencies like lepton trigger and reconstruction efficiencies, optimize the tau reconstruction and calibrate the energy scale of the calorimeters with progressively increasing precision. These studies can already start with 10 TeV collisions as the production cross-section is reduced by only 30%.

## 2.3 Inclusive Jet measurements

When measuring inclusive QCD jet cross-sections, one quickly enters into new territory. With an integrated luminosity of 20 pb$^{-1}$ at 14 TeV, 10 jets of 2 TeV are expected, an energy beyond the reach of the Tevatron. The achievable precision of the measurement will depend on the level of understanding of the Jet Energy Scale at that time. Initially, a jet scale precision of 5-10% with a resultion of 60-75%/$\sqrt(E) \pm$ 7% is expected at central rapidity. It should be noted that the reconstruction of the jet energy scale and resolution depends strongly on the underlying event and the simulation of the hadronic shower and can therefore not be measured with test beams. Study of the high-$p_T$ tails of the inclusive jet cross-section is sensitive to New Physics e.g. quark compositeness or contact interactions.

## 2.4 Top

At the LHC, the dominant $t\bar{t}$ pair production process is gluon-gluon fusion with a cross-section about 100 times larger than at the Tevatron, whereas backgrounds are expected to rise only by about a factor 10. The cross-section for the gold-plated semi-leptonic decay $t\bar{t} \rightarrow bW\bar{b}W \rightarrow blvbjj$ with l= e,$\mu$, is of the order of 250 pb at 14 TeV. A robust analysis has been developed to establish a clear signal with the first data [3]. It relies solely on the measurement of four jets (3 jets with $p_T > 40$ GeV and 1 with $p_T > 20$ GeV), one isolated electron or muon with $p_T > 20$ GeV (including trigger) and Missing $E_T > 20$ GeV. It does not make use of the full b-tagging capability, since precise alignment of the inner detector may not be available in the early days. With an integrated luminosity of 100 pb$^{-1}$, about 500 reconstructed hadronic top decays are expected over background composed mainly of internal combinatorics within $t\bar{t}$ events and W+jets events. Thanks to the over-constrained kinematics of the $t\bar{t}$ system, it will be possible to measure b-tagging performance and Missing $E_T$ and to calibrate the light jet energy scale. The $t\bar{t}$ cross-section will also be measured in the di-lepton channel. With 100 pb$^{-1}$ the cross-section can be measured with an uncertainty of 5-10%, dominated by systematics and excluding the uncertainty on luminosity.

## 3 Early discovery

New heavy states forming a narrow resonance decaying into opposite sign dileptons are predicted in many extensions of the Standard Model: grand unified theories, technicolor, little Higgs models, and models including extra dimensions [3]. The signature of these events is a mass peak in the invariant mass distribution of opposite sign dileptons on top of the Drell-Yan spectrum. The sensitivity to this clear signature rises with decreasing mass of the resonance, a resonance peak around 1 TeV (which is unreachable by the Tevatron experiments) could be discovered with as little as 100 pb$^{-1}$.

Super Symmetry (SUSY) is the second candidate for early discovery at the LHC. Relatively large cross-sections are predicted for squark pair-, squarkgluino- and gluino pair production. These processes would have spectacular signatures with events with many jets, high $p_T$ leptons and missing $E_T$. The best experimental signature would be events with 4 jets plus one lepton. R-parity conserving SUSY can be found with 1 fb$^{-1}$ if the gluino and squark masses are O(1TeV). However, it would still require a good understanding of the background. Conversely, if gluinos and squarks are much heavier they might still be found at the LHC eventually, but it will be difficult to study them in detail.

### 3.1 Higgs

In the Standard Model, the electroweak symmetry is spontaneously broken via the Higgs mechanism. The Higgs boson is the only piece of the Standard Model that has not been observed experimentally and its possible discovery is one of the main goals of the LHC.

The Higgs boson couples preferentially to heavy particles and this determines its production mechanisms and decay modes. At LHC, gluon fusion, $gg \rightarrow H$, dominates, followed by vector boson fusion, $qq \rightarrow qqH$, with two forward quark jets and lack of color exchange between those quarks. Other mechanisms are associated production with weak gauge bosons, $qq \rightarrow WH/ZH$, or heavy quarks, $qq, gg \rightarrow ttH$. They are relevant for low mass Higgs searches, i.e. at $m_H < 130$ GeV. For this range, the $b\bar{b}$ decay mode dominates but is difficult to exploit because of the large background from jets. Below 140 GeV the $H \rightarrow \gamma\gamma$ decay mode is one of the interesting channels that can be exploited both in inclusive analysis or optimized for specific associated production mechanisms. Sensitivity to low mass Higgs comes also from $H \rightarrow \tau\tau$ in the vector boson fusion mode.

The most favorable decay modes are WW and ZZ when kinematically allowed. The most powerful channel with the cleanest signature is $H \rightarrow ZZ^* \rightarrow 4l$ with good discovery potential in the range $130 < m_H < 600$ GeV, except in the mass region around $2m_W$. A Standard Model Higgs boson with mass above 130 GeV might be discovered with 5 fb$^{-1}$. Eventually, the full mass range will be explored at the LHC. More data may be needed if the mass is close to the direct LEP bound of 114.4 GeV. If the Higgs is discovered its mass can be determined to a precision of 0.1%.

### 3.2 Summary

The LHC operation is about to start. During the last five years, all the elements of the ATLAS detector have been progressively installed in the cavern, the last ones in July 2008. Overall the detector is ready and functioning well with full solid angle coverage and only a very small fraction of dead channels. Many dedicated combined commissioning runs recording cosmic ray events have taken place in the last two years, helping in pre-calibrating the detector and having the full chain ready for data taking. With first collisions the most urgent task will be to understand the detector in detail and perform first measurements of Standard Model physics: minimum-bias events, QCD jets, W/Z and top pair production. These measurements will test the Standard Model in a much extended kinematic region and provide important first constraints on the MC generators. One should be open to the possibility of finding new physics if Nature has chosen a scenario which would provide spectacular signatures at LHC energies. We will progressively study the TeV scale in more detail with increased statistics looking for hints of the Higgs and of many possible phenomena beyond the Standard Model.

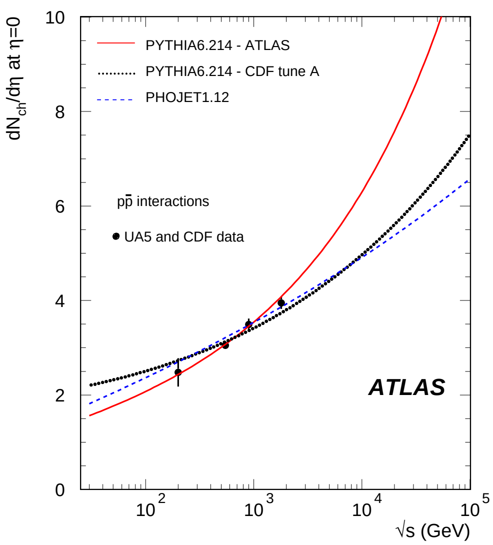


Fig. 1: Charged particle multiplicity in minimum bias events. Predictions for LHC.

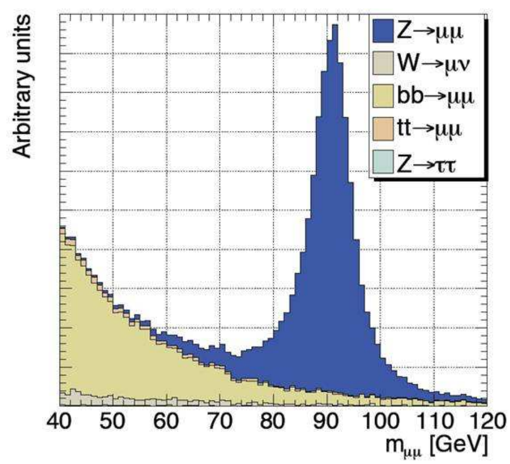


Fig. 2: Di-muon invariant mass distribution in the $Z \longrightarrow \mu\mu$ channel for signal and background for 50 pb$^{-1}$

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## References


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