ATLAS Status and First Results
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The ATLAS experiment at the Large Hadron Collider at CERN has been recording a rapidly growing data sample during the few months since proton–proton collisions at the LHC started in November 2009. This article summarizes the status of the experiment and highlights some of the first results achieved.

1. Introduction

After many years of construction and commissioning with cosmic rays, the ATLAS experiment \cite{1} at CERN recorded the first proton–proton collision events at the Large Hadron Collider (LHC) in November 2009. Since then commissioning of both ATLAS and LHC have been progressing quickly, and the amount of collision data collected has been growing rapidly. During the first data taking period in December 2009 at $\sqrt{s} = 900$ GeV an integrated luminosity of 12 $\mu$b$^{-1}$ was recorded during stable beam\textsuperscript{1} operation at a peak luminosity of $7 \cdot 10^{26} \text{ cm}^{-2} \text{ s}^{-1}$. In July, at the time of this conference, over 40 nb$^{-1}$ had been collected at $\sqrt{s} = 7$ TeV, reaching a luminosity of $1 \cdot 10^{26} \text{ cm}^{-2} \text{ s}^{-1}$. At the time of this writing in September 2010 the data sample exceeds 7 pb$^{-1}$ and the accelerator is getting close to its target luminosity of $10^{32}$ cm$^{-2}$ s$^{-1}$ for the first year of operation.

The ATLAS detector covers almost the whole solid angle around the collision point and consists of an inner tracking system surrounded by electromagnetic and hadronic calorimeters and by the muon spectrometer. All of these subsystems are working very well, with 97\% or more of the signal channels operational. The data taking efficiency is better than 90\%.

In the following each of the subdetectors will be introduced briefly and their status will be illustrated using selected results based on early data samples of up to 8 nb$^{-1}$ at $\sqrt{s} = 7$ TeV. Within the scope of this note only a small fraction of the results obtained since the start of ATLAS data taking can be discussed. Further details and many more results can be found on the ATLAS Public Results page linked from \cite{2}.

2. Trigger

The ATLAS detector has a three-level trigger system consisting of Level 1 (L1), Level 2 (L2) and the Event Filter (EF). L2 and EF are referred to as High Level Trigger (HLT). At the initial low luminosity a non-prescaled L1 trigger based on hits in scintillator counters (MBTS) mounted at $\pm 3.5$ m from the interaction point was used. At a luminosity above a few times $10^{27} \text{ cm}^{-2} \text{ s}^{-1}$ this trigger was prescaled, and above $\sim 10^{29}$ cm$^{-2}$ s$^{-1}$ active event selection by the HLT was enabled (Figure 1, left). By running in parallel trigger chains not involved in the event selection, their efficiencies and turn-on curves could be measured (Figure 1, right).

3. Inner detector

The inner tracking system (Inner Detector) consists of a silicon pixel detector whose innermost layer is at a radial distance of 50.5 mm from the nominal interaction point, a silicon strip detector (SCT) and a Transition Radiation Tracker (TRT). The latter provides both tracking and particle identification by transition radiation. The Inner Detector is operating in an axial mag-
The magnetic field of 2 T. It provides full coverage in \( \phi \).
The two silicon detectors (TRT) cover the pseudorapidity range \(|\eta| < 2.5\) (2.0).

Very good alignment and knowledge of the detector geometry and material inside the Inner Detector are crucial for reaching the desired tracking performance. The examples shown in Figure 2 demonstrate excellent progress: the Inner Detector alignment is already close to ideal and detector geometry and material distribution are modeled well by the Monte-Carlo simulation. Tracking and reconstruction are well understood, and particle identification via transition radiation is working well.

Combining reconstructed tracks into vertices allows the determination of the primary vertex (or vertices in case of multiple interactions). From their distribution (Figure 3, left) the luminous region (beam spot) can be determined [3]. Given the good knowledge of the uncertainties on the track and primary vertex parameters, the luminous size can be extracted from a log-likelihood fit to the vertex distribution and, as a cross-check, compared to the luminous size expected from measurements of emittances and \( \beta^* \) of the accelerator (Figure 3, right). Good agreement is found.

Reconstructing well-established resonances is a way to verify the performance of the Inner Detector and serves as a building block for future physics analyses, in particular in the area of B physics. Examples are shown in Figure 4 [2,4].

Using the Inner Detector and a single-arm MBTS trigger the first published ATLAS physics result reports on the measurement of charged-particle multiplicities in proton–proton interactions at \( \sqrt{s} = 900\) GeV [5]. Results are presented as inclusive-inelastic distributions, with minimal model-dependence by requiring one charged particle within the acceptance of the measurement. Recent updates [6,7] extend these results to \( \sqrt{s} = 7\) TeV and to a diffractive limited phase space (requiring at least 6 charged particles) and were used to generate an improved new Monte Carlo tune of Pythia6. An example is shown in Figure 5.

4. Calorimeter

The calorimeter system covers the pseudorapidity range \(|\eta| < 4.9\) using a variety of detector technologies. Liquid argon (LAr) sampling calorimeters are used for the electromagnetic barrel and end-caps as well as for the hadronic end-cap calorimeters, using either lead or copper as absorber material. The electromagnetic calorimeter is surrounded by a hadronic sampling calorimeter using steel as the absorber and scintillator as the active material.

Decays of \( \pi^0 \rightarrow \gamma\gamma \) reconstructed from clusters in the electromagnetic (EM) calorimeter can be used to test the performance and calibration of the EM calorimeter (Figure 6). From the ratio of the fitted diphoton mass between data and Monte-Carlo the uniformity of the EM calorimeter response is determined to be better than \( \pm 2\% \).
Figure 2. Top left: Comparison of unbiased residuals in the pixel barrel detector for tracks with $p_T > 2$ GeV with the residuals expected from Monte-Carlo simulation for perfect alignment. Top right: SCT hits on reconstructed tracks as a function of $\eta$. This distribution is very sensitive to the correct modeling of detector geometry and material. Bottom left: Radial distribution of reconstructed vertices from photon conversion as a measure of material. The three pixel and the first two SCT layers are clearly visible. The small discrepancy at $R \approx 220$ mm reveals an imperfect simulation of the material in the pixel support structure. Vertices from Dalitz decays at $(R \approx 0)$ allow to precisely constrain the material in the beam pipe. Bottom right: Probability for a TRT high-threshold hit as a function of Lorentz factor $\gamma = E/m$ for pure electrons obtained from photon conversions ($\gamma > 1000$), and for inclusive tracks ($\gamma < 1000$).

Figure 3. Left: Distribution of primary vertices in the x–z plane. Right: Evolution of resolution-corrected luminous size (points with error bars) and emittances during a LHC fill. The red circles are the values predicted from emittances and $\beta^*$ and have an estimated uncertainty of about 10%.
Figure 4. Left: Invariant mass distribution of two track vertices in the range 400 to 800 MeV. No mass constraint is applied during the vertex fit. Right: Distribution of the mass difference $\Delta M = M(K\pi\pi) - M(K\pi\pi)$ for $D^+\pi^-$ candidates and for wrong-charge combinations.

Figure 5. Charged particle multiplicity vs $\eta$ for a diffractive limited phase space at $\sqrt{s} = 7$ TeV, and comparison with different Monte-Carlo tunes.

Figure 6. Diphoton invariant mass distribution.

Figure 7. $p_T^{\text{jet}}$ distribution for jets with $p_T^{\text{jet}} > 30$ GeV and $|y| < 2.8$. Only statistical errors are shown. Distributions are normalized using the total number of jets.
Many jet and multi-jet events have been observed [8], including events with six jets in the final state. Figure 7 shows the observed $p_T^{\text{jet}}$ distribution of jets reconstructed using the anti-$k_T$ algorithm compared to Monte-Carlo predictions. At this early stage, the systematic uncertainty on the jet energy scale is about $\pm 7\%$.

Good understanding of missing energy will be crucial for new physics discoveries. Figure 8 shows the missing energy distribution $E_{\text{miss}}$ in minimum bias events, where the average missing energy is expected to be very small. Excellent agreement between data and Monte-Carlo is found over six orders of magnitude [9].

5. Muon system

The muon system consists of three (one barrel, two end-caps) large superconducting air-core toroid magnets instrumented with both trigger and high-precision tracking chambers. It covers the pseudorapidity range $|\eta| < 2.7$ and is designed to achieve a momentum resolution $\sigma(p_T)/p_T \sim 10\%$ at $p_T = 1 \text{ TeV}$. Good progress has been made towards achieving this resolution (Figure 9).

As for the Inner Detector, reconstructing the decay of known resonances such as $J/\psi \rightarrow \mu^+\mu^-$ is an important benchmark for the performance of the muon system and a step towards measurements of various B-physics channels. Figure 10 shows the invariant mass distribution of reconstructed $J/\psi \rightarrow \mu^+\mu^-$ candidates using both the muon system and the Inner Detector [10].

6. Rediscovery of the Standard Model

With all ATLAS subdetectors working very well, the “rediscovery of the Standard Model” as a prerequisite for future discoveries is well under way. An example is the observation of $W \rightarrow \ell\nu$ and $Z \rightarrow \ell\ell$ at $\sqrt{s} = 7 \text{ TeV}$ [11]. Figure 11 shows the $E_{\text{miss}}$ distribution of selected $W \rightarrow \ell\nu$ candidates in the electron and muon channel. After final cuts, 17 (40) candidate events are selected in the electron (muon) channel with an expected background of less than 3 events and in good agreement with expectations. A similar analysis of $Z \rightarrow \ell\ell$ finds a total of 3 candidates, also in good agreement with expectations.

7. Conclusions

After 15 years of preparation, the ATLAS detector performs beautifully, with high data taking efficiency and a detector response that is remark-
Figure 11. $E_T^{\text{miss}}$ of selected $W \to \ell \nu$ candidates in the electron (left) and muon (right) channel.

Figure 10. Invariant mass distribution of reconstructed $J/\psi \to \mu^+ \mu^-$ candidates after vertexing. Same sign combinations (open circles) are superimposed.

...ably well understood at this early stage. First physics measurements have been made and the emphasis is shifting from performance measurements and re-observations to increasingly precise physics measurements. With the very rapidly growing luminosity delivered by LHC, the first searches for new physics beyond the existing limits from earlier experiments are becoming feasible.

REFERENCES
7. ATLAS-CONF-2010-031, available from [2].
8. ATLAS-CONF-2010-043, available from [2].