ATLAS Status

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The status of the ATLAS detector is presented together with the first measurements on 7 TeV proton-proton collisions at the Large Hadron Collider (LHC). Emphasis is given to the commissioning results and to their comparison to simulation.

1. Introduction

The ATLAS detector [1] at the LHC [2] has been designed to study a wide range of physics topics at the TeV energy scale. It uses a combination of superconducting solenoidal and toroidal magnetic fields and covers a large fraction of the solid angle around the collision point with layers of tracking detectors, calorimeters and muon chambers.

The ATLAS inner detector has full coverage in ϕ and covers the pseudorapidity ¹ range $|\eta| < 2.5$. It consists of an inner part made of silicon detectors (Pixel and silicon microstrip detector (SCT)) and an outer part made of straw tubes (transition radiation tracker (TRT)). These detectors cover a sensitive radial distance from the interaction point of 50.5-150 mm, 299-560 mm and 563-1066 mm, respectively, and are immersed in a 2 T axial magnetic field. The inner-detector barrel (end-cap) parts consist of 3 (2×3) pixel layers, 4 (2×9) double-layers of single-sided silicon microstrips with a 40 mrad stereo angle, while up to 36 (45) measurements at large radius are provided by the TRT straws. These detectors have position resolutions of typically 10, 17 and 130 μm for the R- ϕ co-ordinate which measures the track deflection in the magnetic field and then the particle momentum.

High granularity Liquid Argon (LAr) electromagnetic sampling calorimeters, with excellent performance in terms of energy and position resolution, cover the pseudorapidity range of up

to $|\eta| = 4.9$. The hadronic calorimetry in the range $|\eta| < 1.7$ is provided by a scintillator-tile calorimeter, which is separated into a large barrel and two smaller extended barrel cylinders, one on either side of the central barrel.

The calorimeter is surrounded by the muon spectrometer. The air-core toroid system, with a long barrel and two inserted end-cap magnets, generates a 8 Tm bending power in a large volume within a light open structure designed to minimize the multiple-scattering effects. Excellent muon momentum resolution (10% at p_T of 1 TeV) is achieved with three layers of high precision tracking chambers. The muon instrumentation includes, as a key component, trigger chambers with timing resolution of the order of 1.5-4 ns. The muon spectrometer defines the overall dimensions (25 m high and 46 m long) of the ATLAS detector.

2. Data Taking and Trigger

ATLAS has so far (end of May 2010) collected $\approx 15 \text{ nb}^{-1}$ of data at 7 TeV under LHC stable beam conditions (which are mandatory to safely switch on and operate the ATLAS tracker). The maximum instantaneous luminosity has been of $\approx 2 \times 10^{29} \text{ cm}^{-2}\text{s}^{-1}$ and the overall experiment lifetime has been close to 95%.

The ATLAS detector has a complex three-level trigger system, which has not been used (but only exercised) as the collision rate is still below the number of events which could be recorded by the Data Acquisition System. A much simpler trigger (Minimum Bias Collision Trigger) which relies on the signals from the Beam Pickup Timing

¹Pseudorapidity is defined as $\eta = -\ln \tan(\theta/2)$, where θ is the particle zenith angle referenced to the direction of the crossing beams

devices (BPTX) and the Minimum Bias Trigger Scintillators (MBTS) has been used. The BPTX are composed of beam pick-ups attached to the beam pipe at $z = \pm 175$ m from the center of the ATLAS detector. The MBTS is made of 16 scintillator tiles mounted at each end of the detector in front of the liquid-argon end-cap calorimeter cryostat at $z = \pm 3.56$ m and covers the pseudorapidity range $2.1 < |\eta| < 3.8$. The role of the BPTX is to detect the bunches passing through the beam pipe and therefore to define "possible collisions", the role of the MBTS is to detect particles emerging from the actual collisions occurring in the center of ATLAS. The BPTX, being fully unbiased, has been prescaled and used to measure the trigger efficiency.

Figure 1. L1 efficiency for the trigger selecting electromagnetic clusters above 3 counts (≈ 3 GeV) as a function of the raw (uncalibrated) offline cluster transverse energy E_T .

First level trigger based on electromagnetic objects above a 3 GeV threshold, on jets with energy exceeding 5 GeV and on muons reaching the muon spectrometer (therefore with momentum above 2.5 GeV) have been commissioned together with a full menu of high level triggers prepared for the measurements to be performed when the luminosity will exceed $10^{30} \text{ cm}^{-2}\text{s}^{-1}$. It is inter-

esting to observe that the trigger thresholds are quite well defined, are in good agreement with simulation and can be adjusted to low values (one example is shown in Fig. 1).

3. Detector Performance Highlights

This section will show few significant commissioning results which are meant to prove the excellent operation and level of understanding of the ATLAS experiment. This is an important prerequisite for the first measurement ATLAS has performed and are the foundations for those expected in the near future. More details on the most recent ATLAS measurements can be found in the report of F. Dittus [3] at this conference.

3.1. Tracking

The first physics paper [4] published by ATLAS is about charged track multiplicities and it has therefore required a complete understanding of the Inner Detector (ID) data. This is obtained through the detailed comparison of key variables (e.g. hit density distribution) between data and simulation.

The first step to be able to use the information of the ID is the alignment of all detector modules. This procedure starts with the survey positions (which are precise to a fraction of a millimeter) and is then refined using tracks (first cosmics, then collision tracks). Figure 2 shows the alignment of the SCT End Cap modules and indicates that we are already very close to the Monte Carlo (MC) expectations. This means that ATLAS can reconstruct tracks efficiently and precisely.

The reconstruction of well known particle decays such as $K_s \rightarrow \pi^+\pi^-$, has shown to be a powerful tool to understand and validate the performance of the ID, in particular the correctness of the momentum scale.

Figure 3 shows the reconstructed invariant mass spectra of the K_s . The mean value of the reconstructed particle mass for the K_s , agree very well with the world average [5]. The width of the distribution is in very good agreement between data and MC. In particular the amount and distribution of the material in the inner detector is well described by the simulation (the increase of

Figure 2. SCT local x residual distributions integrated over all hits-on-tracks in end-cap modules. Local x is the coordinate which measures the bending of the tracks in the magnetic field.

material would change the energy loss correction and therefore the mean value of the K_s mass).

The role of the ID for high- p_T physics is strongly dependent on its capability to select particles with lifetimes around a picosecond, in particular b-hadrons decaying inside jets. The b-tagging have been studied at 7 TeV using 57700 jets with $|\eta| < 1.8$ and $p_T > 20$ GeV found in ≈ 0.4 nb $^{-1}$ of data. Secondary vertices have been reconstructed in these jets and their rate and properties are compared with MC simulation. The agreement is good as shown in Fig. 4, more details can be found in [6].

3.2. Jets

Jets are key observable for most of the Standard Model(SM) measurements and for the high- p_T physics beyond the SM.

ATLAS measures the energy and the other properties of jets produced in proton-proton collisions using primarily the LAr electromagnetic calorimeter, the Tile hadronic calorimeter and the LAr hadronic end-cap calorimeter. Clusters of energy are used as inputs to jet reconstruction. Jets in ATLAS are reconstructed using the anti- k_t jet algorithm [7] with a distance parameter $R =$

Figure 3. Reconstructed invariant mass spectra of $K_s \rightarrow \pi^+ \pi^-$.

0.6. Topological energy clusters represent dynamically formed three-dimensional objects seeded by a calorimeter cell with $|E_{cell}| > 4\sigma_{cell}$ above the noise. Neighbor cells with $|E_{cell}| > 2\sigma_{cell}$ are then added to the cluster, increasing the size of the cluster until no nearest-neighbor cell has an energy above $2\sigma_{cell}$ of the noise. In a final step, all nearest-neighbor cells surrounding the clustered cells are added to the cluster, as this was shown to improve energy resolution in single pion test beam studies. These clusters can then be split or merged depending on local maxima or minima within the clusters. These calorimeter-based measurements can also be combined with and correlated to charged particle properties measured with the ID, leading to improvements in the jet energy resolution.

The most important aim of the initial jet studies is the determination of the jet energy scale, which, once optimized, is the basis of all precision measurements involving jets. The comparison of data to predictions from a MC simulation based on phenomenological models of non-diffractive processes and including a full simulation of the detector response is the mandatory step to understand the jet energy scale and to pin down the measurement indetermination. Considering only jets with $p_T > 20$ GeV and $|\eta| < 2.8$ the agreement between the p_T distributions in data

Figure 4. The three-dimensional decay length significance, signed with respect to the calorimeter jet axis, for all secondary vertices reconstructed in data events (markers). The expectation from simulated events (histogram) for non-diffractive minimum bias events, normalized to the number of jets in the data, is superimposed.

and in MC simulation is very good over 6 orders of magnitude as shown in Fig. 5.

The worsening of the agreement at high- p_T can be explained assuming some limitations in the hard-scattering process description provided by the PYTHIA MC generator. More details can be found in [8].

The comparison of momentum measured in the ID and energy measured in the calorimeter is an additional powerful tool to assess the systematic uncertainties related to the jet energy scale. This comparison is also sensitive to the amount and distribution of material in the tracker and can then help to define precisely this specific source of error. Figure 6 shows the energy deposited in the calorimeter versus the momentum measured by the ID in the barrel region $|\eta| < 0.6$ for isolated hadrons of momentum between 1.2 and 1.8 GeV [9]. The remarkable agreement between data and simulation (including the peak at zero which results from particles interacting in the ID)

Figure 5. Topological cluster jets Transverse momentum distributions using the Monte Carlo-based p_T and jet calibration.

proves that the jet energy scale systematics is already well under control and that the description of material of the ID is good.

3.3. Missing Transverse Energy

The missing transverse energy (E_T^{miss}) in one event is a critical observable for some SM channels (e.g. W decays) and plays a major role in supersymmetric searches.

It is not an easy observable to calibrate as it is based on absence of a signal, which may happen for very many reasons. E_T^{miss} can, nevertheless, be calibrated using events, like a sample of minimum bias collisions, where no significant missing energy unbalance is expected. This has been done in ATLAS using 46 10^6 collision candidates, corresponding to 0.3 nb^{-1} of data at 7 TeV collected using the Minimum Bias Collision Trigger (see Sect.2 for details). Selecting only those events which have a primary vertex with at least 5 tracks exceeding a 150 MeV p_T -cut reduces the statistics to 14.4 10^6 events. The E_T^{miss} of those events is compared [10] with a MC simulation in Fig. 7. The agreement between data and simula-

Figure 6. E/p distribution for isolated tracks with $|\eta| < 0.6$ and momentum between 1.2 and 1.8 GeV. The track is isolated if no other track is reconstructed within a cone of 0.4 both in η and ϕ .

tion is excellent over more than 6 orders of magnitude and, what is also very important for the use of E_T^{miss} in high- p_T physics, the tails of the distribution dies out at ≈ 40 GeV in good agreement with expectations.

4. Conclusion

The first results on the ATLAS performance prove not only that the experiment is working very well, but also that the level of understanding of the detector and of the analysis chain is very good already in this early phase of operation. This is the result of many years of detailed work in the preparation of the apparatus and of all the control and analysis tools for ATLAS. This unprecedented level of preparation has allowed to go through the physics of many decades in just few months of operation. Starting from the "1 GeV" physics of the 50's (with K_s and Λ observation) and reaching the "100 GeV" physics of the 80's (with the observation of the W and Z bosons [3]) in a very short time is a result that augurs well for the future measurements and, hopefully, discoveries for which ATLAS has been built.

Figure 7. Distribution of E_T^{miss} as measured in a data sample of 14.4 million selected minimum bias events (dots) at 7 TeV center-of-mass energy, recorded in April 2010. In the calculation only topological cluster cell are used, with energies calibrated at the electromagnetic scale. The expectation from Monte Carlo simulation is superimposed (histogram) and normalized to the number of events in data.

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