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Status of the ATLAS detector and first measurements at the LHC

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Summary. — The status of the ATLAS detector is presented together with the first results on proton-proton collisions at the Large Hadron Collider (LHC). Measurements of kinematical variables and multiplicities of charged particle produced in 900 GeV collisions are presented together with some relevant commissioning studies. Preliminary results on 7 TeV collisions are also presented including two W-decay candidates.

PACS 13.85.-t – Hadron-induced high- and super-high-energy interactions (energy > 10 GeV).
PACS 13.85.Hd – Inelastic scattering: many-particle final states.
PACS 13.38.Be – Decays of W bosons.

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 coordinate which measures the track deflection in the magnetic field and then the

(1) Pseudorapidity is defined as $\eta = -\ln\tan(\theta/2)$.

particle momentum. In case of the Pixel and SCT the second measured coordinate (along the beam direction) is measured with an accuracy of, respectively, 115 and 580 μm. A track from a particle traversing the barrel detector would typically have 11 silicon hits (3 pixel clusters and 8 strip clusters), and more than 30 straw hits.

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.

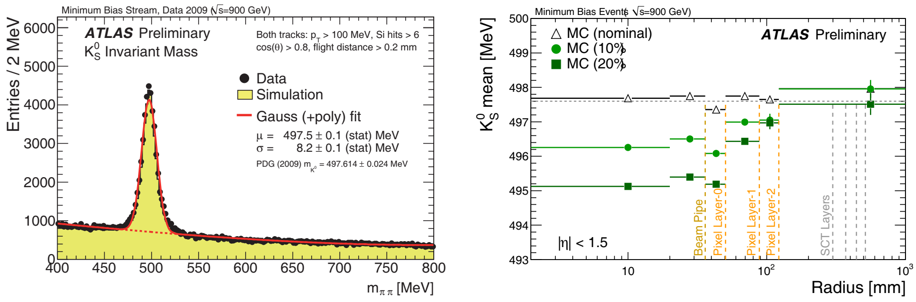
2. – Data taking and trigger at 900 GeV

In the 2009 900 GeV run, ATLAS recorded approximately 538000 collisions with stable beam and all detectors operational. This corresponds to an integrated luminosity of $\approx 9\,\mu\text{b}^{-1}$ with a systematic uncertainty of about 30%. The maximum peak luminosity as measured in ATLAS was $L \approx 7 \times 10^{26}\,\text{cm}^{-2}\,\text{s}^{-1}$. The lifetime of ATLAS during the 2009 run was close to 100%.

The ATLAS detector has a complex three-level trigger system, which has not been used in this run as the collision rate was still below the number of events which could be recorded by the Data Acquisition System. The 2009 collision trigger relied on the signals from the Beam Pickup Timing devices (BPTX) and the Minimum Bias Trigger Scintillators (MBTS). 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 are 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 was to detect the bunches passing through the beam pipe and therefore to define "possible collisions", the role of the MBTS was to detect particles emerging from the actual collisions occurring in the center of ATLAS. The BPTX, being fully unbiassed, has been prescaled and used to measure the trigger efficiency.

3. – Inner detector operation

ATLAS has produced a large amount of results on detector and combined performance on the 2009 data at 900 GeV center-of-mass energy. While these results cover all the ATLAS sub-detectors, this section will only show few of them which are meant to prove the excellent operation and level of understanding of the inner detector. This is an important prerequisite for the first measurement ATLAS has performed and which will be described in sect. **4**. More details of the overall ATLAS commissioning can be found in the report of M. Donegà [3] at this conference.



(a) (b)

Fig. 1. – (a) Reconstructed invariant-mass spectra of $K_s \to \pi^+\pi^-$ and (b) fitted K_s mass as a function of the decay radius for various MC simulated material descriptions.

The reconstruction of well-known particle decays such as $K_s \to \pi^+\pi^-$, is a powerful tool to understand and validate the performance of the detector, in particular the correctness of the momentum scale. Figure 1 shows that 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 [4]. The width of the distribution is in very good agreement between data and Monte Carlo. This proves the good understanding of the detector at this early stage of data taking. In particular the amount and distribution of the material in the inner detector is well described by the simulation (the increase of material would change the energy loss correction and therefore the mean value of the K_s mass).

4. – Charged-particle multiplicities at $\sqrt{s} = 900\,\text{GeV}$

The study of charged-particle multiplicities at a centre-of-mass energy of 900 GeV is described in the first physics paper [5] published by ATLAS. The measurement of charged-particle multiplicities in proton-proton reactions constrains phenomenological models of soft Quantum Chromodynamics (QCD) and therefore is an important ingredient for future studies of high-transverse-momentum phenomena at the LHC.

The charged-particle multiplicities were measured at 900 GeV within the kinematic range of $|\eta| < 2.5$, $p_{\rm T} > 500\,\text{MeV}$ and the requirement of at least one charged particle within this range and a reconstructed primary vertex in the event. The data were presented as fully corrected inclusive-inelastic distributions at the particle level:

$$\frac{1}{N_{\rm ev}}\frac{{\rm d}N_{\rm ch}}{{\rm d}\eta}, \qquad \frac{1}{N_{\rm ev}}\frac{1}{2\pi p_{\rm T}}\frac{{\rm d}^2 N_{\rm ch}}{{\rm d}\eta {\rm d}p_{\rm T}}, \qquad \frac{1}{N_{\rm ev}}\frac{{\rm d}N_{\rm ev}}{{\rm d}n_{\rm ch}} \qquad \text{and} \qquad \langle p_{\rm T}\rangle \; vs. \; n_{\rm ch},$$

where $N_{\rm ev}$ is the number of events with at least one charged particle inside the selected kinematic range, $N_{\rm ch}$ is the total number of charged particles, $n_{\rm ch}$ is the number of charged particles in an event and $\langle p_{\rm T}\rangle$ is the average $p_{\rm T}$ for a given number of charged particles. A primary charged particle was defined as a particle with a mean lifetime of $\tau < 0.3 \times 10^{-10}$ s which is either directly produced in the pp collision or stems from a subsequent decay of a particle with a shorter lifetime.

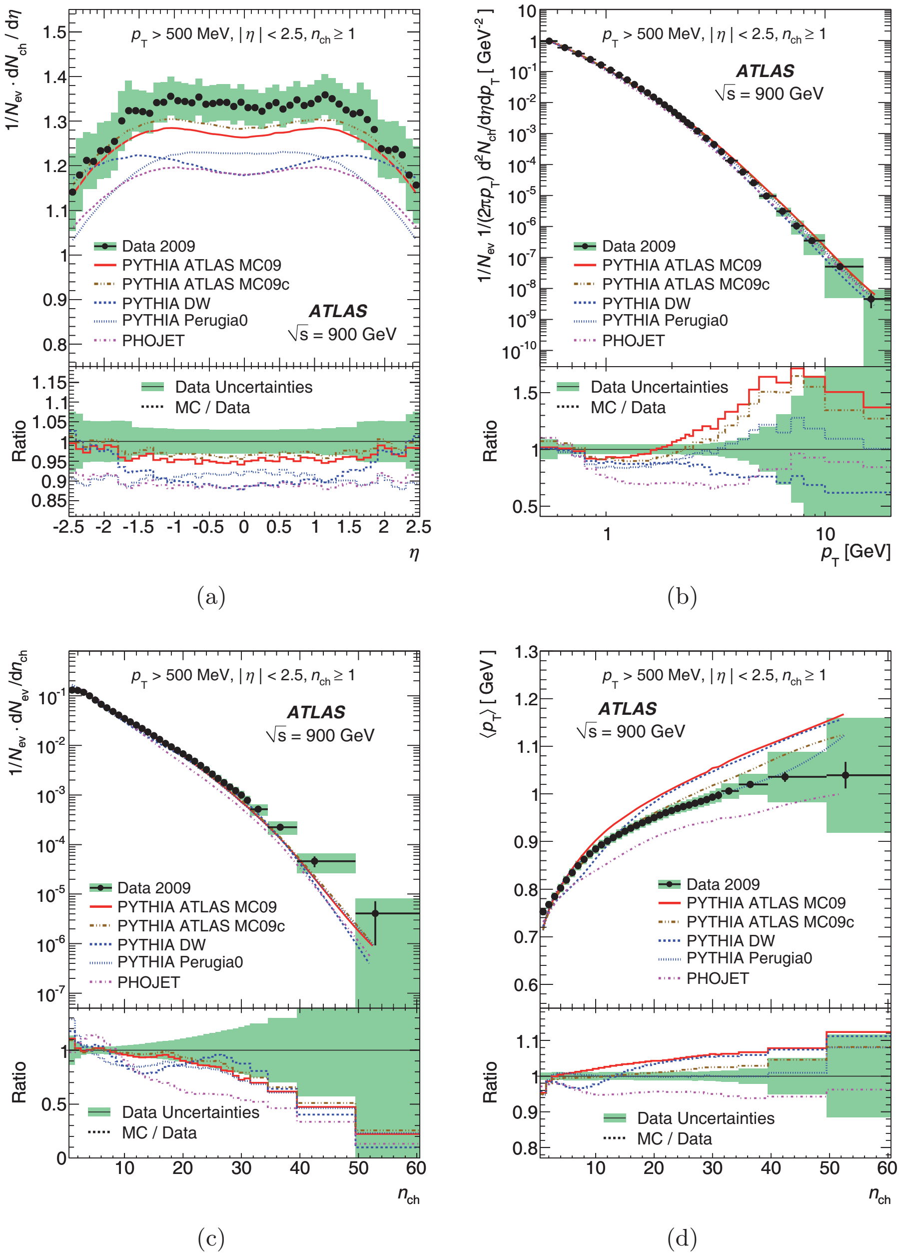
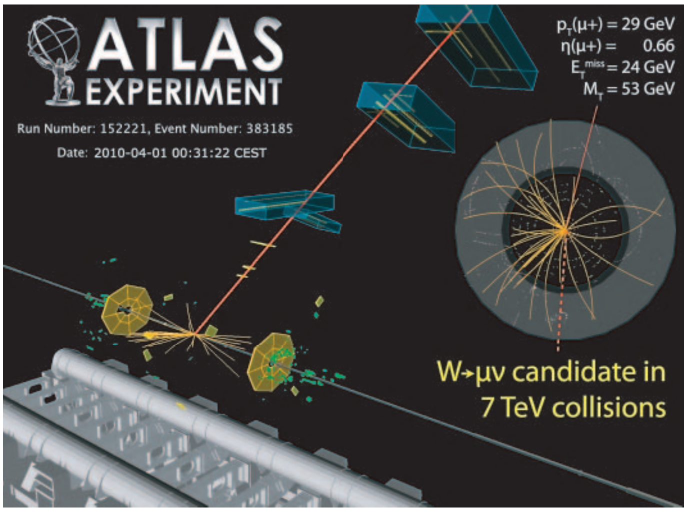
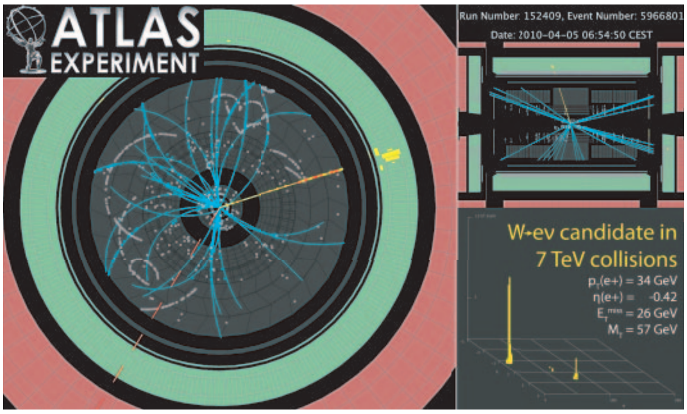


Fig. 2. – Inclusive-inelastic distributions of primary charged particles in the kinematic range $p_T > 500\,\text{MeV}$ and $|\eta| < 2.5$ in data at a centre-of-mass energy of $\sqrt{s} = 900\,\text{GeV}$.

The trigger used for this analysis was a combination of the Beam Pickup Timing devices (BPTX) and the Minimum Bias Trigger Scintillators (MBTS) as described in sect. **2**. The MBTS trigger was configured to require one hit above threshold from either side of the detector (the so-called single-arm trigger). The efficiency of this trigger was



(a)



(b)

Fig. 3. – (a) Candidate for W $\rightarrow \mu\nu$ decay, collected on 1 April 2010. Event properties: $p_T(\mu^+) = 29\,\text{GeV}$, $\eta(\mu^+) = 0.66$, $E_T^{\text{miss}} = 24\,\text{GeV}$, $M_T = 53\,\text{GeV}$ and (b) candidate for W $\rightarrow$ e ν decay, collected on 5 April 2010. Event properties: $p_T(\text{e}^+) = 34\,\text{GeV}$, $\eta(\text{e}^+) = -0.42$, $E_T^{\text{miss}} = 26\,\text{GeV}$, $M_T = 57\,\text{GeV}$.

derived from data and was obtained by comparison with an independent prescaled L1 BPTX trigger which was filtered to obtain inelastic interactions by loose inner detector requirements at the second level trigger. The efficiency to reconstruct the primary vertex was also derived from data and was measured with respect to the L1 MBTS trigger. It was found to only depend on the number of reconstructed tracks per event and, in case of only one reconstructed track also on η of the track. The background contributions from cosmic-rays and beam-induced background were measured to be of the order of 10^{-4} and 10^{-6}, respectively. The contribution from secondary tracks which have been reconstructed as primary tracks was estimated to be $(2.20 \pm 0.05(\text{stat.}) \pm 0.11(\text{syst.}))\%$.

The tracking efficiency was derived from detailed Monte Carlo studies. All distributions were corrected for trigger, primary vertex reconstruction and tracking efficiency.

The final corrected distributions for primary charged particles are shown in fig. 2, where they are compared to predictions of models tuned to a wide range of measurements. The charged-particle pseudorapidity density is shown in fig. 2(a). It is approximately flat in the range $|\eta| < 1.5$. The charged-particle multiplicity per event and unit of pseudorapidity at $\eta = 0$ is measured to be $1.333 \pm 0.003(\text{stat.}) \pm 0.040(\text{syst.})$, which is 5–15% higher than the Monte Carlo model predictions. The particle density is found to drop at higher values of $|\eta|$. The N_{ch} distribution in bins of p_{T} is shown in fig. 2(b) and is constructed by weighting each entry by $1/p_{\text{T}}$. The multiplicity distribution as a function of n_{ch} is shown in fig. 2(c) and finally fig. 2(d) shows the average p_{T} as a function of n_{ch}. The latter is found to increase with increasing n_{ch} and a change of slope is observed around $n_{\text{ch}} = 10$. This behavior was already observed by the CDF experiment in pp collisions at 1.96 TeV [6].

5. – First data taking at 7 TeV

On March 30 the first 7 TeV collisions have been recorded in ATLAS. Beam lifetimes of several hours already allowed, in the first afternoon of data taking, to collect an integrated luminosity equivalent to the complete 2009 run and, in the few days preceding this conference, of $\approx 200\,\mu\text{b}^{-1}$.

In these data ATLAS has been able to observe two W-candidate decays, while one event was expected on a background of 0.2. A W-candidate decaying in $\mu\nu$ is shown in fig. 3(a). A W-candidate decaying in $\text{e}\nu$ is shown in fig. 3(b). The observation of these candidates marks the beginning of the high-p_T physics of ATLAS.

6. – Conclusion

First start-up and physics results with the ATLAS detector at a centre-of-mass energy of 900 GeV of the 2009 LHC data taking are presented. The results of the first physics paper of ATLAS about inclusive-inelastic distributions of primary charged-particle multiplicities in 900 GeV proton proton collisions have been presented together with some commissioning results showing the good performance of ATLAS. The charged-particle multiplicity per event and unit of pseudorapidity at $\eta = 0$ is measured to be $1.333 \pm 0.003(\text{stat.}) \pm 0.040(\text{syst.})$, which is 5–15% higher than the Monte Carlo model predictions. The start-up of the 7 TeV run has been very successful and two W-candidate events have been found in the first $\approx 200\,\mu\text{b}^{-1}$ of integrated luminosity.

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