First experience with the ATLAS Muon Spectrometer

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Abstract

The ATLAS experiment at the Large Hadron Collider (LHC) at CERN is currently being assembled to be ready to take first data in fall 2007. Its muon spectrometer is designed to achieve a momentum resolution of better than 10% at $p_\mu = 1$ TeV. The spectrometer consists of of one barrel and two endcap superconducting air-core toroid magnets instrumented with three layers of precision drift chambers as tracking detectors and a dedicated trigger system. We report on our experience with the commissioning and installation of the precision and trigger chambers. First results of the cosmic ray test of the barrel muon spectrometer with magnetic field are presented, including results of the calibration of the drift chambers and the spectrometer alignment.

1 Introduction

The ATLAS muon spectrometer (see fig. 1) consist of three superconducting air-core toroid magnets and is instrumented with 1194 precision drift chambers—Monitored Drift Tube (MDT) chambers or, in the extreme forward region, Cathode Strip Chambers (CSCs)—and 2264 trigger chambers—Resistive Plate Chambers (RPCs) in the barrel and Thin Gap Chambers (TGCs) in the endcaps [1]. The chambers are arranged in three layers and cover an active area of more than 5500 m^2; individual chamber sizes vary from 1 m^2 to 11 m^2. The magnets provide an average field integral of 3 Tm in the barrel and 5 Tm in the endcap region, with a typical path length of 5 m. The muon spectrometer has been designed to be capable of stand-alone operation with a momentum resolution of 2–3% for transverse muon momenta of $\mathrm{p_T} < 200$ GeV and better than 10% at $\mathrm{p_T} = 1$ TeV. It covers the pseudo-rapidity region of $|\eta| < 2.7$ (trigger chamber coverage extends to $|\eta| < 2.4$). To achieve the desired momentum resolution, each precision chamber must reconstruct its track point with an accuracy of better than 50 μm, including uncertainties from chamber misalignment across 5–10 m. A system of more than 12000 optical sensors constantly monitors the positions of all precision chambers and their deformations in-

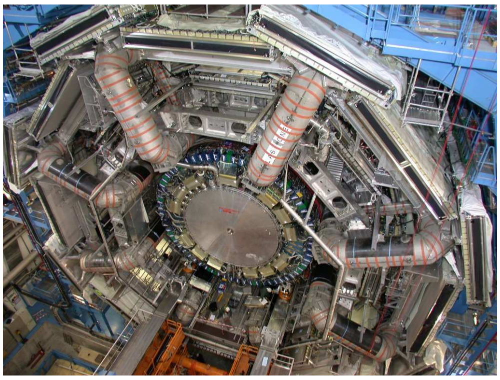

Fig. 1. Photo of the ATLAS detector in Feb. 2007. Visible are the 8 coils of the barrel toroid, the installed muon chambers and the endcap calorimeter.

side the detector. The data is used for alignment corrections in the offline software.

2 Certification, Integration and Installation of Muon Chambers

Upon their arrival at CERN, all precision and trigger chambers are subjected to a test programme—gas leak, high voltage, and noise test—to discover any damage which might have occurred during transport and to guarantee their required performance in the experiment. These tests supplement any quality assurance and commissioning that already took place at their respective production sites after assembly. Chambers are finalized if needed at CERN and additional sensors (alignment and B-field) are mounted and tested, as well as photogrammetric targets for optical surveys after installation. To simplify their installation on the rail system in the detector, the barrel MDT chambers of the middle and outer layers are combined with their RPC trigger chambers to form single units, so called muon stations. For the same reason, the endcap precision and trigger chambers, which are arranged in vertical wheel-like structures with a diameter of up to 22 m in the detector, are preassembled to sectors. As a final certification step before installation, the muon stations and sectors undergo a complete system test with cosmic rays measuring the response and homogeneity of the precision and trigger chambers and the functioning of the on-chamber Level 1 trigger electronics. In February 2007, all barrel muon station have been certified and 92% of them have been installed in the experiment. The first of six TGC wheels has been assembled and then released from the wall support structure. Distortions of only a few millimeters have been measured, which will have no negative effect on the detector integrity; the geometrical accuracy of the chamber positions is still satisfactory. The first of six MDT wheels has been assembled as well. Again, the accuracy of the chamber positions—measured with the internal alignment system—meets the required precision. Preliminary tests of the muon chambers (gas leak, HV and noise test) after installation showed no major problems. The failure rates of the on-chamber electronic components is less than 1%. Table 2 lists the number of dead channels, which are below the limits for both, precision and trigger chambers.

Type	Channel	Dead Channel	Perc. / %
B MDT	184944	123	0.07
B RPC	373344	1726	0.46
E MDT BW1A+C	147072	61	0.04
E TGC BW1C	30000	5	0.06

Table 1
Number of dead channels in the barrel (B) and endcap (E) muon chambers. The limit for the precision chambers (MDT) is 0.1%, for the trigger chambers (RPC and TGC) 1%.

3 Preliminary Results from the First Cosmic-Ray Data Taking with Magnetic Field

A complete system test of the ATLAS barrel muon spectrometer, including precision and trigger chambers, the alignment system, the central trigger processor and the data acquisition took place during November 2006 when the barrel toroid magnet was operated at its nominal full field for the first time. 13 muon stations of the lower barrel region participated in the test and took data with cosmic-rays, see. fig. 1 [1].

The barrel alignment system was used to measure the deformation of the toroid shape during the magnet operation and movements of the precision chambers. The deformations of the toroid of a few millimeter at full field (cp. fig 1) are in agreement with the calculations. Relative movements of the MDT chambers up to 500 μm

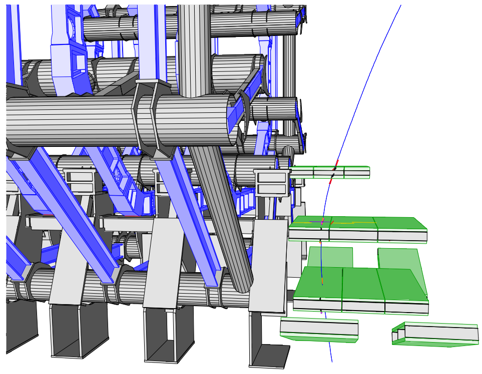

Fig. 2. Cut-away view of the ATLAS detector, showing only the 13 muon stations participating in the Nov. 2006 cosmic data taking with magnetic field and parts of the barrel toroid. The solid line marks the track of a reconstructed muon with 1.6 GeV momentum.

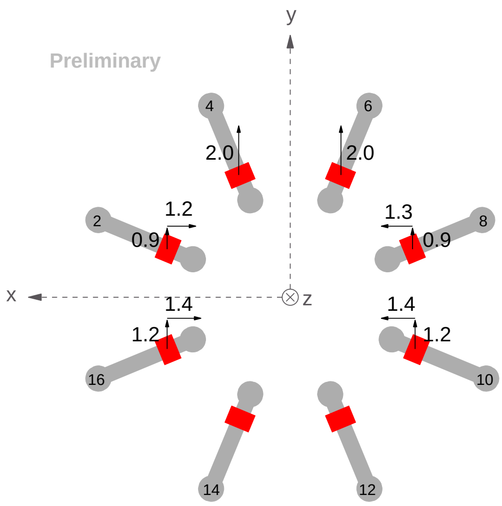

Fig. 3. Deformation of the barrel toroid magnet at full field. All units are in mm. View along the beam axis.

were recorded. Both results underline the importance of the alignment corrections to reach required precision in the muon momentum measurement for which a knowledge of the precision chamber positions with an accuracy of 30 μm is needed.

[1] In this section only preliminary results of the alignment system, the magnetic field measurements and the MDT precision chambers are discussed. The performance of the RPC trigger chambers during the test is described in [2], the Level 1 trigger in [3].

Measurements of the magnetic field with an NMR probe at the middle MDT layer agree better than 0.25% with a linear extrapolation of calculations for half the field strength. Perturbations of the toroid field at the outer MDT layer caused by the access structures surrounding the detector can reach up to 50 mT. The scale of the perturbations is well simulated, but the models still need further refinement.

Fig. 1 shows the angular distribution of positive and negative muons which is consistent with the geometry of the two access shafts leading down to the ATLAS cavern and the (angles of 10° for the near shaft and -20° for the far one) and the position of the muon chambers. The rate of muons entering from the far shaft is reduced compared to the ones from the near shaft, as they have to pass approx. 30 m of rock and concrete before entering the detector. The muons are clearly separated by the magnetic field according to their charge. The momentum distribution of the cosmic muons shows a fall-off consistent with expectations and the ratio of the number of positive to negative muons

$$N_{\mu^+}/N_{\mu^-} = 1.48 \pm 0.27 \text{ (prelim.)}$$

is in agreement with the PDG value of 1.1–1.4 [4].

To reach the required point resolution of 50 μm of an MDT chamber, the space-drift time relation (rt-relation) for the drift tubes has to be known with an accuracy of 20 μm. The rt-relation is determined with an iterative algorithm, the so-called au-

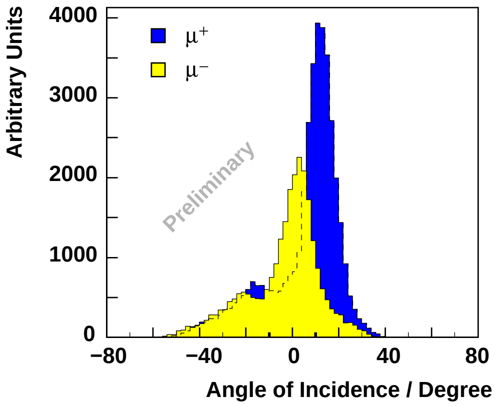

Fig. 4. Angular distribution of cosmic muons measured during cosmic data taking in Nov. 2006.

tocalibration [5], from muon tracks. The autocalibration zones, for which a common rt-relation can be obtained, have to be of the size of a single MDT chamber to provide the necessary number of tracks and angular spread to allow a stable application of the algorithm. As the toroid field is inhomogeneous over these areas, the rt-relation has to be corrected for the effect of the magnetic field to reach the necessary precision: in test beam experiments [6,7] a shift of the maximum drift time of 70 ns/($\mathbf{B}_2$/T^2) has been measured, leading to a deviation of up to 500 μm from the rt-relation without magnetic field. A model [6,7] of the change of the drift time $t(r)$ as a function of the magnetic field $\mathbf{B}$ has been developed and yields an accuracy of better than 20 μm. Fig 1 shows a comparison of the modeled change of the rt-relation as a function of the drift radius. The measurement is in excellent agreement with the expectation.

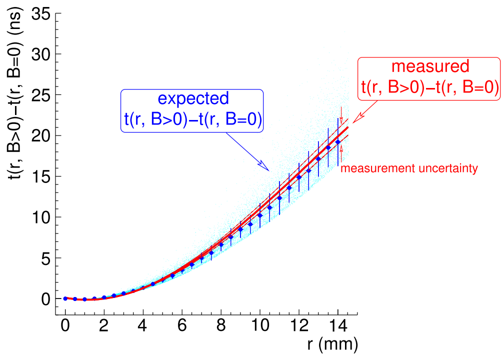

Fig. 5. Comparison between the expected (points) and measured (lines) shift of the drift time as function of the drift radius in the MDT chamber tube due to the magnetic field. The light dots show the expected shift for the different magnetic field along the drift tubes, the dark points their average, and the error bars the RMS spread.

4 Summary

The installation of the ATLAS barrel muon spectrometer is almost complete, all muon station have been assembled and successfully certified. Commissioning of the barrel spectrometer with cosmic rays will start in March 2007 and proceed with a speed of 2 (of 16) sectors per month. The endcap spectrometer is well advanced, all muon chambers have been tested and 75% of the sectors are preassembled. Two of ten endcap wheels have already been installed in the detector. Preliminary test of the barrel and endcap muon chambers after installation showed no major problems. A system test of the barrel muon spectrometer with the toroid magnet at full field and cosmic ray data taking with a subset of muon chambers has been successful. The data will provide important input for studies on the calibration of the muon spectrometer.

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References

[1] ATLAS Muon Collaboration, ATLAS Muon Spectrometer Technical Design Report, CERN/LHCC/97-22, CERN (1997).

[2] G. Chiodini, paper presented at the conference.

[3] D. Berge et al., paper presented at the conference.

[4] W.-M. Yao et al., J. Phys. **G**33,1 (2006).

[5] See e.g. J. v. Loeben, diploma thesis, Max-Planck-Institut für Physik München (2006).

[6] O. Kortner et al., NIM **A**572,1 p.50–52 (2007).

[7] C. Valderanis, PhD thesis, Max-Planck-Institut für Physik München (2007), in preparation.