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Commissioning with cosmic rays of the Muon Spectrometer of the ATLAS experiment at the Large Hadron Collider

P. Fleischmann[1], **R. Nicolaidou**[1]
on behalf of the ATLAS Muon Group
[1] DAPNIA/SPP, CEA Saclay, 91191 Gif sur Yvette, France
E-mail: philipp.fleischmann@cern.ch, Rosy.Nicolaidou@cern.ch

Abstract. The ATLAS experiment designed to exploit the full discovery potential of the Large Hadron Collider (LHC) at CERN, is currently being assembled and tested. Its Muon Spectrometer designed to measure muons in the final state from proton-proton interactions at the LHC with good momentum resolution (from 3% - 11% for muons of momentum of 1TeV), is being commissioned at the ATLAS cavern. It consists of four types of detectors, each using a different technology. Throughout this paper, a brief description of the commissioning procedure, the software tools developed and the first results obtained is given.

1. Introduction

The ATLAS Muon Spectrometer [1] is made of a large toroidal magnet (with an average magnetic field of 0.5 Tesla) and consists of four types of detectors, each using a different technology. Muon Drift Tube chambers (MDT) are used as precision chambers both in the barrel (BR) and end-cap region (ER). In addition the inner most layer of the ER is equipped with Cathode Strip Chambers (CSC). As trigger chambers Resistive Plate Chambers (RPC) are used in the BR and Thin Gap Chambers (TGC) in the ER. The chambers are arranged in three layers. Each layer has a 16-fold (12-fold for TGC) segmentation following the azimuthal symmetry of the magnet structure (Figure 1).

By now the installation of the chambers in the BR has been almost completed (more than 98%). The installation in the ER is well advanced, having the first wheels of TGC and MDT chambers completed.

2. The Commissioning

The commissioning of the ATLAS Muon Spectrometer takes place in several steps. Every single chamber is tested individually before and after its installation. Each completed sector is tested afterwards using the final services together with the detector control system (DCS), the optical alignment system, the central trigger processor, the data acquisition (DAQ), the on-line monitoring system and on-line event display. A calibration stream is sent to external institutes, which provide quasi on-line updated corrections to the off-line reconstruction. Various analysis packages have been developed for the off-line analysis of the data using the final framework of future physics analyses. At all stages feedback is sent to a central data quality service (DQ), which holds the most detailed information for each data run. A simplified sketch of the data flow is shown in Figure 2.

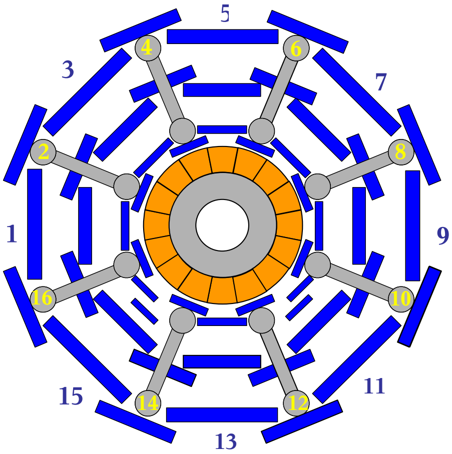

Figure 1. Sketch of the barrel Muon Spectrometer, showing the sector numbering scheme.

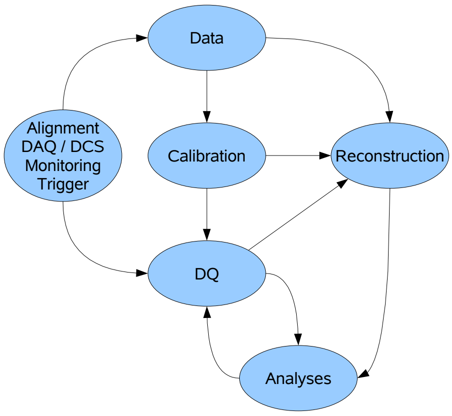

Figure 2. Simplified sketch of the data flow from the data acquisition to the off-line analysis.

Beside the hardware testing, the emphasis of the commissioning is mainly on the operation of the broad and complex system. One challenge of the distributed computing system is the security scheme implemented at the LHC experiments, which protects the internal system from hacker attacks or external network problems. Shift operators are being trained to get experience in the combined running of the individual components of the ATLAS Muon Spectrometer and the control software (Figure 3 and 4). The collected feedback is also essential for the further development of the software.

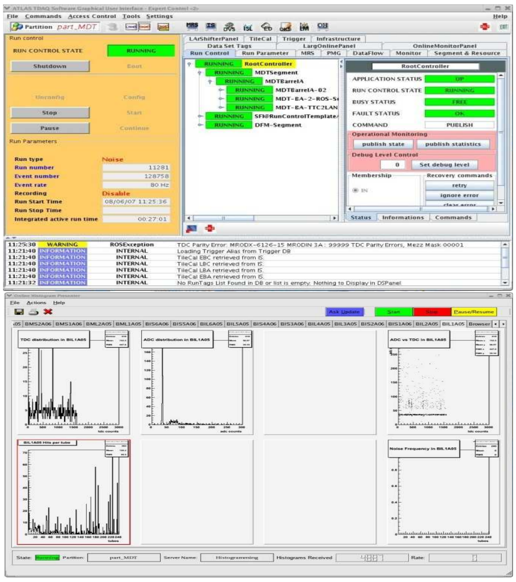

Figure 3. Screenshot of the control room panels showing examples of the DAQ and on-line monitoring tools.

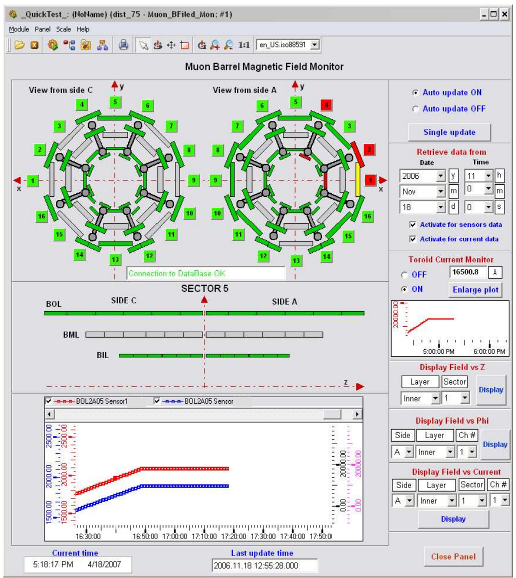

Figure 4. Screenshot of the control room panels showing examples of the DCS tools.

In addition to the stand-alone Muon Spectrometer commissioning, the ATLAS collaboration is performing combined runs integrating parts of several sub-detectors in the read-out every two to three months, in order to test the full functionality of the ATLAS detector. In these runs the muon trigger chambers provide information to all sub-systems involved.

3. Examples of obtained results

In November 2006 a full system test has been performed including the first RPC and MDT chambers in the bottom sector of the BR. At the same time the barrel toroid magnet underwent a stability test and was powered up to its nominal current. The magnetic field has been calculated using the measurements of the sensors equipped with Hall probes, which are distributed over the full volume of the ATLAS detector. The sensors' measurements of the upper part of the coil have been compared with calculations and have been used to reconstruct the position and shape of the conductors; a good agreement of the deformation of the coil between these measurements and the ones done on the same toroid coil three years ago at 300 K has been found (Figure 5).

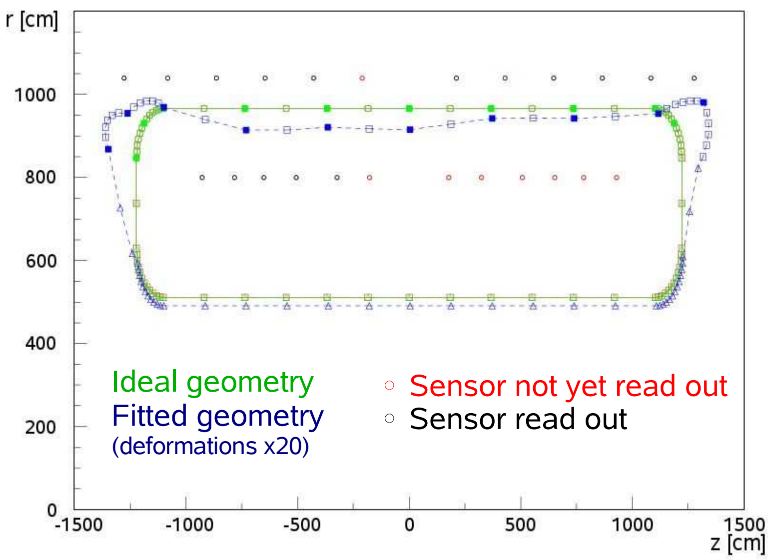

Figure 5. Reconstructed shape of a barrel toroid coil.

During this period, we had for the first time the opportunity to measure curved tracks of cosmic ray muons inside the detector. Over one million of cosmic events were recorded by the read-out system of the sector 13 with acquisition rates of 13-50 Hz. These events were reconstructed using the full ATLAS software chain. Figure 6 shows a cosmic ray muon reconstructed in the bottom sector of the barrel region of the ATLAS Muon Spectrometer, with its track curved by the toroid magnetic field. The Muonboy package [1] was used for the reconstruction of muon tracks inside the muon spectrometer. Figure 6 shows the momentum distribution of the muon reconstructed tracks (μ^+ and μ^-). The ratio of the fluxes of μ^+ and μ^- was also measured for the first time and found to be in good agreement with the expectation (from Particle Data Group this ratio varies from 1.1 to 1.4 for a momentum range from 1-100 GeV [2])

In March 2007 two sectors at the top of the BR have been tested using a first version of the detector control system including the power supply. Since then the database driven MDT chamber initialisation is running.

In June 2007 about 27.000 drift tubes have been successfully read out. Also the first three MDT sectors in the ER as well as a first TGC sector was included in the system tests. The full

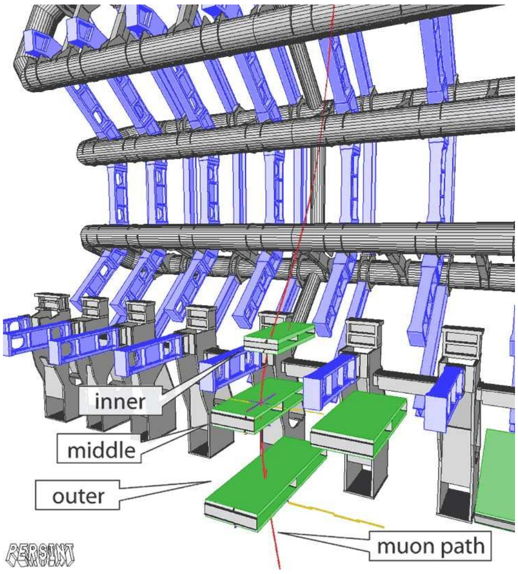

Figure 6. Event display showing a reconstructed muon track in the magnetic field of the barrel toroid.

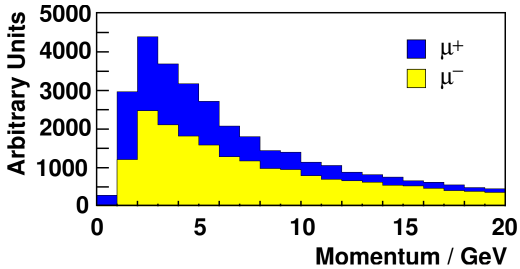

Figure 7. Off-line analysis result showing the momentum distribution of μ^+ and μ^- particles.

chain from the detector hardware over the data acquisition to the control room software is used in daily tests. The calibration stream has been tested, but is not yet included in the regular operations.

Currently the ATLAS Muon Spectrometer participates in another large scale test including also parts of the calorimeter and the inner detector. All muon chambers of four sectors in the BR and several TGC and MDT chambers in the ER are operated by a large team of physicists. One of the main topics is the testing and further development of the data quality tools. Automated histogram verification is used in both on-line and off-line monitoring.

4. Future Perspectives

The commissioning of the ATLAS Muon Spectrometer with cosmic ray muons will continue until the start of the LHC running. The use of the calibration stream on a regular basis is foreseen to be implemented before the end of this year, together with most of the database replications that will allow the proper exchange of data between CERN and the calibration sites. The cosmic ray data recorded during the commissioning will provide very useful information in order to calculate and check alignment and calibration issues of the muon chambers as well as to test the full chain of ATLAS data taking from the acquisition of the data to their full reconstruction.

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[2] Particle data group, *http://pdg.lbl.gov/2006/reviews/cosmicayrpp.pdg*, page 7

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