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Commissioning of the ATLAS Experiment

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The status of the commissioning of the ATLAS experiment as of May 2008 is presented. The sub-detector integration in recent milestone weeks is described. Cosmic commissioning in milestone week M6 included simultaneous data-taking and combined track analysis of the muon detector and inner detector, as well as combined analysis of muon detector and muon trigger. The calorimeters have achieved near-full operation, and are integrated with the calorimeter trigger. The high-level-trigger infrastructure is being installed and algorithms tested in technical runs.

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1. INTRODUCTION

The ATLAS collaboration consists of around 1900 scientific authors, from 165 institutes in 35 countries. The detector is roughly cylinder-shaped with a height of 46 m and 25 m in diameter. It is installed in a cavern 92 m below ground at CERN. A 'ship-in-a-bottle' assembly has been performed, as the cavern is just large enough for the detector. This document focusses on progress of commissioning the detector since the report at HCP2007 [2].

2. ATLAS DETECTOR COMPONENTS

The detector's scale and architecture is determined by the requirements of the physics goals of the LHC programme, most notably excellent energy resolution of the calorimeters is required, as well as very good muon momentum resolution, and inner detector performance for heavy flavour identification. A detailed description of the ATLAS detector is given in [1]. An overview is given below:

- **Inner Detector** with silicon pixel detector (Pixel) closest to the beam-line, silicon strips detector (SCT) and transition radiation tracker (TRT), all located inside a 2 T solenoidal magnetic field. These detectors provide precision tracking of charged particles and secondary vertex finding in the pseudo-rapidity region $|\eta| < 2.5$.
- **Calorimeters**: Liquid argon calorimeter (LAr) for electromagnetic barrel and endcap calorimeters, and hadronic endcaps (HEC) and forward calorimeters (FCAL). The electromagnetic calorimeter provides coverage for $|\eta| < 3.2$, the limit of hermiticity is $|\eta| = 4.9$. Steel and scintillator tiles are used in the barrel region of the hadronic calorimeter (Tile).
- **Muon spectrometer**: consisting of monitored drift tubes (MDT) in the barrel and endcap regions for precision measurements, and cathode strip chambers (CSC) in the forward region, integrated into the air core toroid magnet system. Embedded are the fast-responding muon trigger chambers, which are Resistive Plate Chambers (RPC) in the barrel and thin gap chambers (TGC) in the forward region. The main requirement is precise muon momentum measurements within $|\eta| < 2.7$.
- **Trigger and Data Acquisition** architecture: Three-level data selection architecture. The first level (Level-1) in custom-build parallel-processing pipelined hardware is separated into calorimeter and muon Level-1 trigger. The high level triggers (HLT) consisting of the second level (Level-2) and third level (Event Filter) are implemented in software running on large PC farms with dedicated network infrastructure. The event rate of 40 MHz from the detector is reduced to 200 Hz for event-data recording.
  Readout is performed using custom-built buffers in PCs (Readout System: ROS). Data acquisition (DAQ) software to control, configure and monitor all systems. [1].

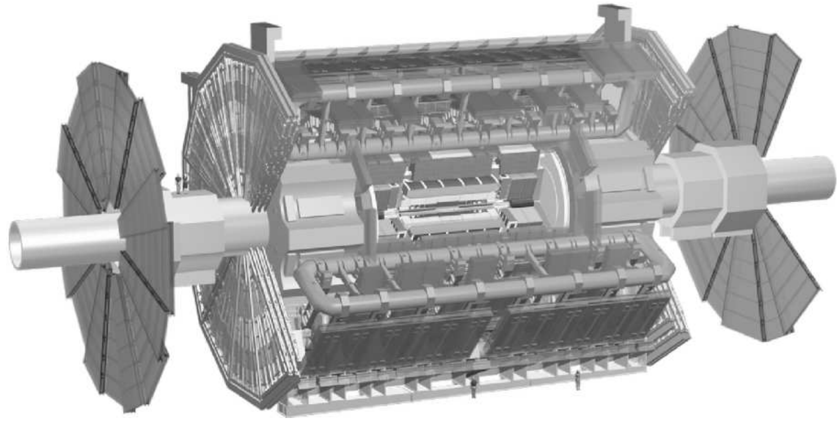

Figure 1: The ATLAS detector. From inside to outside: Inner detector with Pixel, SCT and TRT, then calorimeters (Liquid argon and scintillating tiles), and muon spectrometer outside with toroid magnets.

3. WORKING TOWARDS DATA-TAKING

During the last year, the focus of the commissioning effort has evolved from single detector operation to combined running and integration. Monthly integration weeks are scheduled to integrate detector, trigger and data acquisition into one global setup for each group of sub-detectors (calorimeters, muon detectors and inner detector), which are then combined together for the milestone weeks. All experts are brought together for those weeks, of which the sixth one, M6, took place in April, and M7 in May 2008. In addition, technical runs are performed, feeding simulated and recorded data into the data acquisition system to perform full-rate tests at Level-1 trigger rates of up to 50 KHz. The start-up schedule as of May 2008 expects the ATLAS detector to be closed by mid-July, with first LHC injections by the end of July, and high-energy proton-proton-collisions at 10 TeV by September 2008. A few weeks of stable running is planned, producing a few pb^{-1} of data. The M6 milestone week included all detector parts apart from the Pixel detector, with sizable percentages of each sub-detector included into the data acquisition, especially almost the entire complement of barrel calorimeters, muon barrel system and the Level-1 trigger systems for both.

Cosmic muons are very useful for the detector commissioning. They do however occur with very low rate and also do not originate in the interaction region to really mimic LHC events [2]. Different strategies are followed to make the detection of cosmic muons as useful as possible, modifying the standard data acquisition and reconstruction tools, for example by increasing the recorded time-interval and using calorimeter data to form track-like objects. Other important commissioning tools are the calibration pulser systems built into the detector front-end electronics, and a laser calibration system for the scintillating tile calorimeter.

4. CALORIMETER COMMISSIONING

The Liquid Argon calorimeter endcaps were fully switched on during the April Calo Week after the M6 run. Cosmic muons were used to run in a specially extended 32-sample recording mode and also in 5-sample physics mode. This mode records 32 samples of 25 ns each, unlike the 5-sample-mode in normal LHC operation, which will be the identified bunch-crossing itself plus the two leading and two trailing samples, and in addition with filter coefficients applied in the calorimeters. Timing studies with the trigger systems, both the first stage (Level-1) and the high level triggers (HLT), have been performed, as well as monitoring and data quality tools being tested and improved. The full Liquid Argon calorimeter system was operational and was read out-during the M7 week. Events triggered by the Level-1 calorimeter trigger were studied, and good timing alignment was achieved for the whole detector. Comparison with simulated pulse shapes showed good agreement. The Level-1 calorimeter trigger algorithms foreseen for LHC operations were set-up and adjusted, and trigger objects and results were analysed and verified using samples recorded

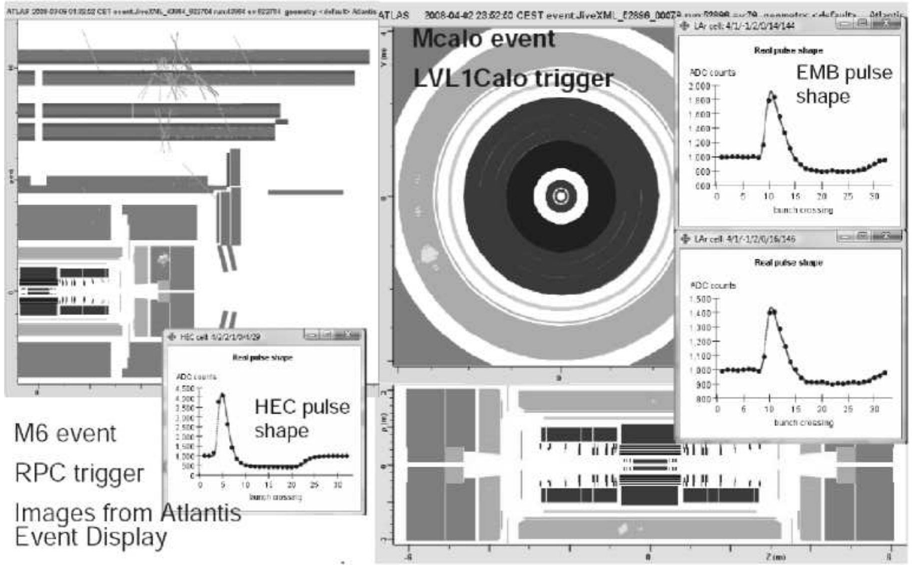

Figure 2: LAr Calorimeter ADC counts and fitted pulse-shapes hadronic endcap (HEC) and electromagnetic barrel (EMB) systems from commissioning in M6 Milestone week and energy deposition in event display (April 2008).

in combined data-taking. Cosmic muon tracks and pulse shapes were studied using event display and monitoring tools.

The hadronic barrel calorimeter, consisting of scintillating tiles, was operational at 95% during M6 with the remaining modules undergoing power supply refurbishment. The detector uses a specially developed algorithm ('TileMuonFitter') for commissioning, which forms track-like objects from the calorimeter cell data, as they would be expected from a cosmic muon passing through. This shows a good energy density peak. No top-bottom bias has been seen in the detector. A laser calibration system is commissioned to send light into the photomultiplier tubes (PMTs) to align the timing, and its operation integrated into the data acquisition. The pulse-shapes from the ADC counts are inspected and compared with the Level-1 trigger pulse-shapes. Fig. 2 shows the pulses as analog-to-digital converter (ADC) counts and fitted pulse-shapes for both the LAr hadronic endcap (HEC) and the electromagnetic barrel LAr calorimeter (EMB), along with an event display of the energy depositions.

5. MUON DETECTOR COMMISSIONING

The barrel and endcap muon spectrometer (MDT) consists of 16 sectors, out of which 12 were ready to operate in the milestone week M6. The upper sectors have already been commissioned with cosmic muons. This effort continues with the remaining four sectors in the lower half. An example of cosmic data analysis is given in Fig. 3, where clusters from the muon trigger chambers (RPC) are compared with tracks in the precision muon spectrometer chambers (MDT), with a very good correlation observed. The residual distribution shows a width of 9 mm. The MDT system shows very good track quality for cosmic muons, with six hits per track, the residuals centred at zero, and a spread in the distribution (RMS) of 160 μm. Timing calibration of the resistive plate chambers (RPC) as part of the Level-1 muon trigger system is performed, where the trigger settings are aligned between the planes using offsets from the time-of-flight distribution. Monitoring and event display tools have been used to achieve synchronised read-out and investigate hits counts, noise levels and track quality.

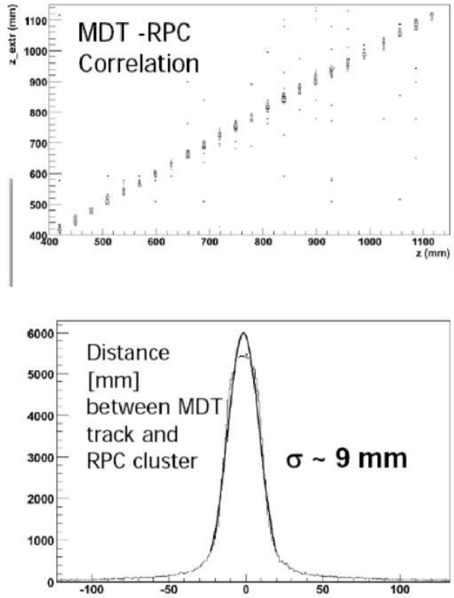

Figure 3: Correlation of muon spectrometer (MDT) and embedded Level-1 muon trigger chambers (RPC) from commissioning with cosmic muons (February 2008). **Top:** Correlation of extrapolated z coordinate from both systems in mm, **bottom:** Distance between clusters in mm.

6. INNER DETECTOR COMMISSIONING

The inner tracking detector commissioning efforts have been seriously disrupted by the break-down of the cooling compressor at the beginning of May after only 5 days of Pixel detector commissioning in-situ. The compressors are being repaired. The SCT has not participated in later milestone weeks as it shares its cooling infrastructure with the Pixel detector. The Pixel detector has not been in combined cosmics running due to the problems with the cooling system, and also as its commissioning was queued behind the SCT commissioning. Combined performance studies of the SCT and TRT have been performed using cosmic data taken during earlier milestone weeks. Alignment and calibration studies and improvements reduce the spread of the residual distribution considerably, e.g. for the TRT from 450 μm to 270 μm. In a further step, the track position as measured by the inner detector (SCT and TRT) and in addition by the precision muon spectrometer (MDT) were combined, this is shown in Fig. 4, along with an event display of a cosmic muon track seen in all three sub-detectors. This uses the top-half muon spectrometer available in this milestone week. For the angle ϕ, the correlation width of $\sigma = 10.3$ mrad is achieved, while for angle Θ the width is $\sigma = 10.7$ mrad. Such an analysis requires all the systems to be operational, timed-in and read-out successfully.

7. TRIGGER AND DATA ACQUISITION

The trigger and data acquisition architecture is described in detail in [1]. The Level-1 calorimeter trigger signals need to be thoroughly tested before access to the detector ends. Level-1 muon trigger commissioning is done sector by sector as they are connected to their respective gas and power supplies. The timing is being addressed to ensure all signals used for the trigger decision are synchronous, throughout the whole system. Data analysis shows that the hits and clusters recorded in the trigger system are well correlated with those reconstructed from the detector read-out. The high-level trigger (HLT) computing farms are being commissioned and tested, at a rate of about ninety rack mounted PCs per week, and they perform second and third stage trigger algorithm (Level-2 and Event Filter) tasks during the commissioning runs. Five server-level PCs, with sufficient buffer diskspace to hold many hours of data, form the last stage of the on-site data acquisition. Then the data is transfered via a dedicated link to the CERN

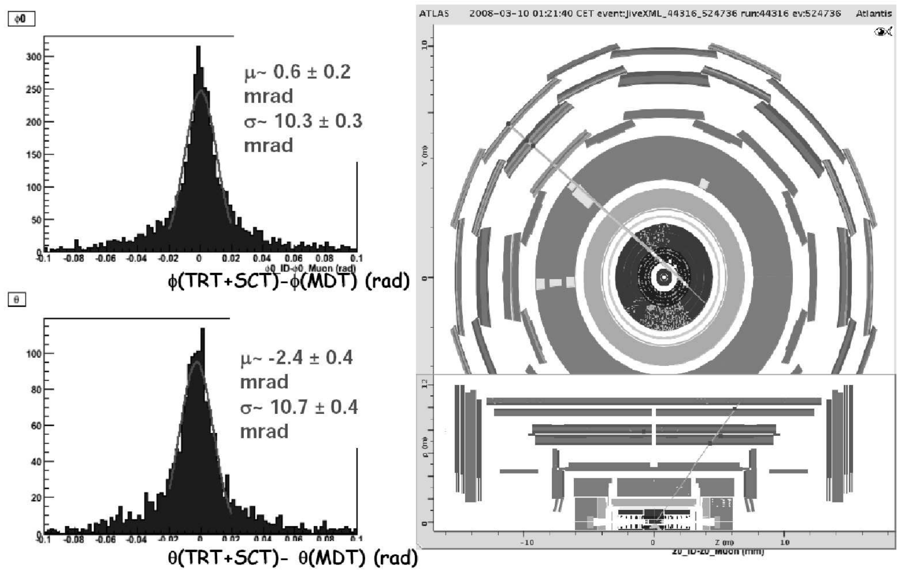

Figure 4: **Left:** Combined analysis of track parameters ϕ and Θ for inner detector (SCT and TRT) and muon spectrometer (MDT), using data from M6 Milestone week (April 2008), **Right:** Event display of a reconstructed cosmic muon track seen in both the inner detector and muon spectrometer.

computing center, where it is reconstructed and made available for analysis. The track trigger implemented into the second trigger stage (Level-2) was studied in cosmic data from the M6 milestone week, regarding its efficiency for events with high-momentum reconstructed tracks and its selectiveness of events to go into different output streams. Dedicated TDAQ technical runs use simulated events, as well as recorded cosmic data from the earlier M4 and M5 weeks, at the expected rate of data at LHC collisions. The high-level trigger infrastructure and algorithms are commissioned to correctly identify cosmic-ray tracks when compared to the reconstructed quantities. These studies use a transparent trigger mode, where events are flagged with high-level trigger results, but not discarded accordingly, as it would happen in standard operation. In the technical runs, stable operation was achieved for hours without intervention, with the system controlling 1500 applications in 350 nodes.

8. THE FUTURE

Looking ahead, the activities during beam commissioning in single-beam operation will include validation of the beam protection systems, first synchronisation with the LHC clock and detailed timing and alignment studies, and feedback to the machine. With collisions, the trigger systems will be fully synchronised with the LHC. Full understanding of the whole detector has to be achieved, using well-known physics processes [4].

9. SUMMARY

ATLAS is in the process of commissioning the detector using cosmic rays and calibration systems. The sizeable fraction of sub-detectors is already integrated with the trigger and data acquisition systems, allowing for stable combined data-taking and combined data analysis. An intense commissioning programme still lies ahead to bring the components so far not integrated into the combined running into operations and achieve stable data taking with the full detector in time for the LHC start-up.

Acknowledgments

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