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STATUS OF ATLAS DETECTOR COMMISSIONING

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ATLAS is one of the four detector systems currently under construction at the Large Hadron Collider at CERN. It is scheduled to commence physics data taking for proton-proton collisions in the early summer of 2008. This paper reviews the status of the detector, the installation of individual subdetector components and their commissioning.

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1. *Introduction*

The ATLAS detector [1] is one of four large detector systems currently built at the European Laboratory for Particle Physics (CERN) in Geneva, Switzerland for data taking at the Large Hadron Collider (LHC), which is also under construction. Both ATLAS and LHC are scheduled to commence operation with beam and physics data taking in the early summer of 2008. LHC will provide proton-proton collisions at the center-of-mass energy of 14 TeV, with a luminosity of $10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$, expected to be reached after the initial years of operations.

ATLAS – **A** **T**oroidal **L**HC **A**pparatu**S** – has the total length of 46 meters, the diameter of 25 meters and the total weight of 7000 tons. It is the largest of the LHC detectors; it is aimed at a broad physics program reaching from Higgs and SUSY searches over QCD and B-physics studies to searches for exotic states.

The main components of ATLAS are the Inner Detector [2], the Calorimeter System [3], the Muon Spectrometer [4] and the Magnet System [5]. The Inner Detector comprises three different technologies: The Pixel Detector is located closest to the interaction point; with its $1.4 \cdot 10^8$ channels and a resolution of $10 \times 110\mu$m, its primary task is the vertex determination. Moving outwards from the interaction point it is followed by the Silicon Tracker, comprising $6 \cdot 10^6$ channels with strips arranged in 4 cylindrical layers in the barrel region and $2 \cdot 9$ disks in the endcap region, and the Transition Radiation Tracker (TRT). The TRT is built of 4mm diam. straw tubes interleaved with stacks of PE/PP foil. The straw tubes, operated with a Xe - CO_2 - O_2 gas mixture, detect both charged particles and transition radiation photons produced in the PE/PP material. The TRT significantly enhances the pion-electron separation capability of ATLAS while at the same time providing track reconstruction and momentum determination for tracks in the Inner Detector region.

Hadron calorimetry is based on a sandwich structure of scintillating tiles and iron absorbers in the barrel region (Tile Calorimeter). Hadron calorimetry in the endcap as well as eletromagnetic calorimetry in both endcap and barrel is provided by different Liquid Argon Calorimeters, the former using copper and tungsten, the latter specially shaped lead absorbers.

In the Muon Spectrometer, Monitored Drift Tube (MDT) chambers are used for precision track reconstruction except in the innermost region of the endcap where they are replaced by Cathode Strip Chambers. The MDT chambers are interconnected by a set of optical alignment lines which monitor both chamber movements and deformation. The Muon Spectrometer provides a momentum resolution $\Delta p_t/p_t$ of better than 10% up to 1 TeV energy. Resistive Plate (RPC) and Thin Gap (TGC) Chambers are used for triggering in the barrel and endcap, respectively. They provide a fast identification of muon tracks with momentum above a programmable threshold and the region of the detector they traversed (region of interest).The trigger chambers in addition are used to determine the track coordinate in direction parallel to the drift tube wire.

ATLAS contains four superconducting magnets: the central solenoid provides a field of 2 Tesla in the Inner Detector while the two endcap and the barrel toroid system provide the bending field for the muon spectrometer. The air-core toroids, each consisting of 8 coils and delivering a peak field strength of 4 Tesla, distinguishes ATLAS both from the other LHC detectors and most collider experiments built in the past. In particular, it allows the ATLAS Muon Spectrometer to be operated standalone, without depending on track reconstruction in the Inner Detector, while maintaining excellent momentum resolution.

2. Installation

During installation, all detector elements had to be lowered from the surface through two shafts of 12 and 18 meter diameter to the experimental cavern located 90 meters below the ground. Due to the large overall size of ATLAS, most of the detector had to be assembled in situ underground, the largest individual piece weighing 280 tons.

Installation started in 2003 with the end of the cavern excavation work. The first major components installed were the barrel toroid and Tile Calorimeter in 2004/5, followed by the calorimeters and the barrel muon stations in 2006. Major components installed in 2007 were most of the Inner Detector, a large part of the muon endcap and the endcap toroid magnets. Installation will be finished with the remaining endcap muon chambers beginning of next year, with the beam pipe being planned to be closed in March 2008.

3. *Commissioning status: magnet system*

Installation of all four ATLAS magnets has been completed, with the last of the endcap toroids having been lowered into the cavern in July 2007 (Fig. 1). The central solenoid has been fully commissioned with full current of 7.6 kA in August 2006. At the same time (before the Inner Detector was installed) a detailed field map with 0.5 mT accuracy was obtained using a specially designed apparatus comprising 48 hall probes mounted on two rotating arms which were movable along the detector (beam) axis. The produced field map satisfies the requirement $\Delta(\int B(l)dl)/\int B(l)dl < 0.05\%$, which in the physics analysis is driven by the determination of the W mass.

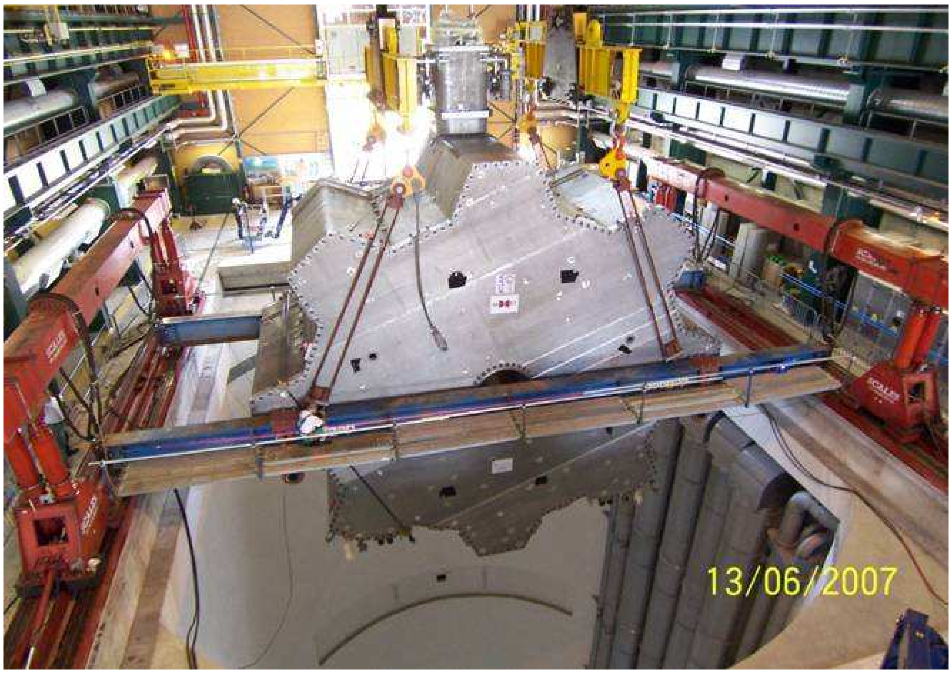

Fig. 1. One of the endcap toroid magnets being lowered into the ATLAS experimental cavern.

For the toroid magnets, commissioning of the barrel toroid is most advanced: It has been cooled down in July 2006 and was tested with nominal current of 20.5 kA in November 2007. Both slow and fast dump procedures, the latter being needed in case of any anomaly, have been successfully tested. The field mapping used for the solenoid was not possible for the toroid since the regions around the toroid are occupied by various other detector elements, e.g. muon chambers. A different approach is thus used in which the magnetic field is measured by 1789 3D hall probes. These are located both on the muon chambers and on the access structure surrounding the detector. In a second step, the mechanical shape of the 8 toroid coils is allowed to vary according to a numerical fit procedure such that the field calculated using the Biot-Savart's law and taking into account the contributions from any neighbouring magnetic material is in best agreement with the measured field values. After the geometry of the coils was determined, the field map used for track reconstruction is calculated and stored for offline data analysis. Work in understanding the toroid field and in particular the contribution from iron containing materials in the experimental hall is still in progress.

For the endcap toroid magnets, a first run with current ON is planned for November 2007. Field studies following the same procedure as for the barrel will follow and culminate in a first combined run of all three toroids.

4. Commissioning status: calorimeters

Installation of both the hadronic and electromagnetic calorimeters has been finished including all service connections. Cosmic muon data have been successfully taken for all calorimeter technologies (hadronic barrel, hadronic endcap, electromagnetic). For many months, the barrel calorimeters provide a trigger when running several ATLAS sub-detectors in combined mode with cosmic muons. Main current activities focus on the full integration of the systems with the ATLAS overall data acquisition (DAQ), detector control (DCS) and safety (DSS) systems as well as on the calibration of the calorimeter modules. This is of particular importance for the Liquid Argon Calorimeters, where one aims to extract the relative timing to the level of better than 1 ns, the relative position of cells to better than 1 mm and the uniformity of the response to better than 0.5% for all 160000 cells.

5. Commissioning status: Inner Detector

The Inner Detector differs from the other ATLAS subdetectors in so far as it could be assembled in large parts already on the surface due to its comparatively small size (Fig. 2). Both the Transition Radiation Tracker and the Silicon Tracker were extensively tested with cosmic muons before they were installed in the experimental cavern in September 2006 (barrel) and June 2007 (endcap). Data have been taken after installation both in cosmic muon and in noise runs. The results so far are very similar to the detector behaviour observed at the surface. In particular, the barrel SCT has been fully signed off with less than 0.3% of dead channels, well within the design requirements.

Inner Detector installation has been completed with putting the Pixel Detector in place at the end of June 2007, after it had been preassembled with the beam pipe and extensively tested at the surface under clean room conditions. Successive integration of the Pixel detector into the ATLAS DAQ and various control systems will happen over the next months.

Fig. 2. The pre-assembled TRT-SCT package for the barrel part of the Inner Detector.

6. Commissioning status: Muon Spectrometer

Installation of the barrel Muon Spectrometer has been completed except for a few stations left out to facilitate access to the inner parts of the detector during commissioning. A total of approximately 650 individual muon stations has been installed one-by-one on rails running parallel to the detector axis. Chambers have been positioned and the optical alignment system has largely been brought to its operational state. For the MDTs, service connections are mostly completed, while for the trigger chambers (RPC) service connection is still under way. An important milestone for the Muon Barrel was a data taking run for cosmic muons with the barrel toroid magnet on in November 2006. Even though only one sector of the spectrometer was read out at this time, the run provided the first opportunity to record and reconstruct curved track and validate the full chain of momentum reconstruction.

The main part of installing the endcap Muon Spectrometer took place after the barrel had been finished. The ATLAS Muon Endcap consists of the so called wheels which are located at three different distances from the interaction point. The Big Wheels, containing both trigger (TGC) and precision MDT chambers have been completed (Fig. 3). The Small Wheels are currently assembled on the surface (Fig. 4) and will be put in place at the beginning of 2008. The muon chambers located on the cavern wall, and thus farthest from the interaction point, are under installation.

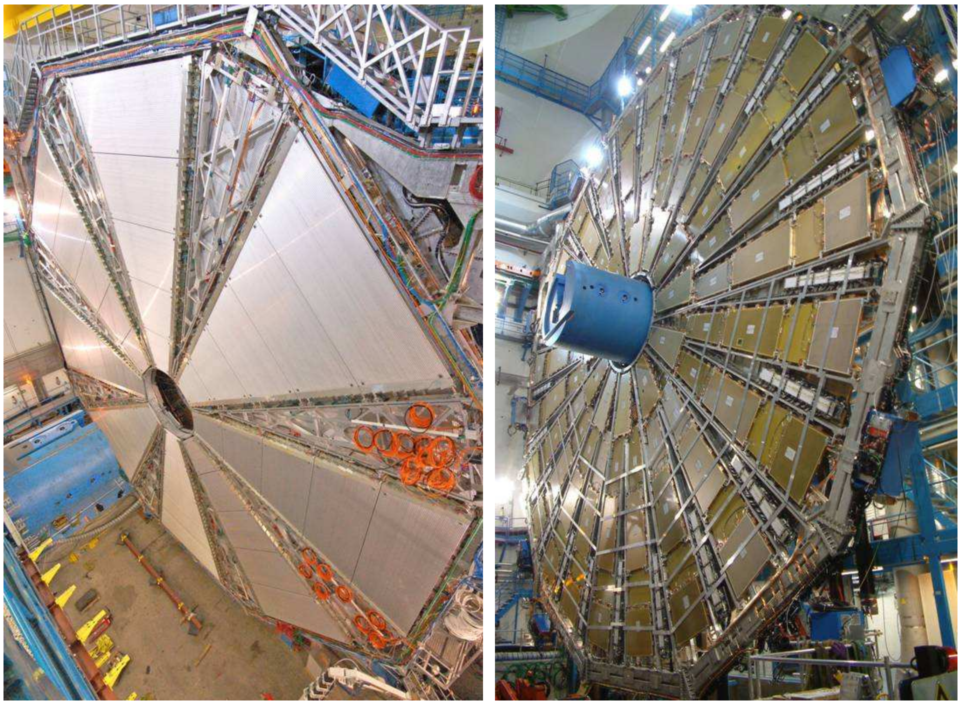

Fig. 3. Completed Muon Big Wheels. Left: Precision MDT chambers. Right: trigger (TGC) chambers.

Fig. 4. One of the two Muon Small Wheels being assembled on the surface.

7. Conclusions and outlook

With the installation of most ATLAS subsystems completed and the remaining installation work in its final stages, preparation for data taking moves closer and closer to the commissioning. In this, ATLAS follows a multi-step approach. In phase 1, individual systems or parts of systems are brought into operation in the standalone mode. In particular, this phase contains all testing of connections and cabling after services have been put into place. Phase 2 is dedicated to system integration, merging sub-detectors with the central services like data acquisition and trigger. Combined data taking plays a more and more important role. Finally, phase 3 are the last few months before physics data taking. It is the transition phase from the commissioning to the standard ATLAS operation.

Phase 1 commissioning is very well advanced for all subsystems, with the current emphasis on phase 2. Of particular importance are the formal milestone runs and weeks with a well-defined program of combined data taking. In total, six such periods are scheduled, the last one for February 2008. In addition to bringing the detector hardware to its operational readiness, the milestone runs also play an important role in setting up, testing and first evaluation of the offline software infrastructure and reconstruction chain. ATLAS should thus be well prepared for first physics data expected for the middle of 2008, bringing a construction and design effort of many years to an end.

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STAVLJANJE DETEKTORA ATLAS U POGON

ATLAS je jedan od četiri detektorska sustava koji se grade uz velik hadronski sudarač (LHC) u CERN-u. Prema planu, sakupljanje podataka mjerenja sudara proton-proton treba započeti rano u ljeto 2008. U ovom se radu daje pregled napretka gradnje detektora, instalacije pojedinih dijelova te njihovog puštanja u pogon i ispitivanje.