The ATLAS detector: status of the construction and installation a year before the first p-p collisions at the LHC Collider

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Abstract — The ATLAS experiment (A Toroidal LHC ApparatuS) is one of the five detector experiments (ALICE, ATLAS, CMS, TOTEM, and LHCb) currently being constructed at the Large Hadron Collider, at CERN in Geneva. It is a general purpose detector, designed to study p-p collision at a center of mass energy of \( \sqrt{s} = 14 \text{ TeV} \) and a luminosity of \( 10^{34} \text{ cm}^{-2} \text{s}^{-1} \). When completed, ATLAS will be 46 metres long and 25 metres in diameter, and will weight about 7,000 tonnes. The project involves roughly 2,000 scientists and engineers of 165 institutions in 35 countries. The construction and installation in the underground cavern is scheduled to be completed in August 2007 to be ready for the initial p-p collisions at a center of mass energy of \( \sqrt{s} = 900 \text{ GeV} \) by the end of 2007. The detector design has been optimized to cover the largest possible range of LHC physics: searches for Higgs bosons and alternative schemes for the spontaneous symmetry-breaking mechanism; searches for supersymmetric particles, new gauge bosons, leptoquarks, and quark and lepton compositeness indicating extensions of the Standard Model and new physics beyond it; high-precision measurements of Standard Model processes such as the W-Boson mass and the top-quark mass and its decay properties.

The article describes the present status of the construction and the installation in the experimental area of the different detector parts.

1 Introduction

The ATLAS detector, shown in the Fig. 1, includes an inner tracking detector inside a 2 T solenoid providing an axial field, electromagnetic and hadronic calorimeters outside the solenoid and in the forward regions, barrel and end-cap muon chambers inside three superconducting air-core toroidal magnets [1]. Precision measurements of photons, electrons, muons and hadrons are performed over a large pseudorapidity range [2]. The complete energy measurement, important for the correct determination of the transverse missing energy, extends over \( |\eta| < 4.9 \). The inner tracking detector consists, going from the outer to the most inner part, of straw drift tubes interleaved with transition radiators for robust pattern recognition and electron identification, and several layers of semiconductor strip and pixel detectors providing high-precision space points. The electromagnetic calorimeter is a lead-Liquid Argon sampling calorimeter with an integrated preshower detector and a presampler layer immediately behind the cryostat wall for energy recovery. The end-cap hadronic calorimeters also use Liquid Argon technology, with copper absorber plates. The end-cap cryostats house the e.m., hadronic and forward calorimeters (tungsten-Liquid Argon sampling). The barrel hadronic calorimeter is an iron-scintillating tile sampling calorimeter with longitudinal tile geometry. A barrel and two end-cap muon spectrometers are used to trigger and measure the muon momentum up to \( |\eta| < 2.7 \), eight superconducting coils are used in the barrel region complemented with superconducting end-cap toroids in the forward regions. The toroids are instrumented with Monitored Drift Tubes (Cathode Strip Chambers at large rapidity where there are high radiation levels). The muon trigger and second coordinate measurement for muon tracks are provided by Resistive Plate Chambers in the barrel and Thin Gap Chambers in the end-caps. The ATLAS trigger scheme is a three-level trigger and data-acquisition system. The first-level trigger signatures are: high-\( p_T \) muons, electrons, photons, jets and large missing transverse energy. For low-luminosity operation of LHC, a low-\( p_T \) muon signature will be used in addition. At levels two and three, more
complex signatures will be used to select the events to be retained for analysis [3].

The distributed series production of detector components is completed. The technical efforts are now fully concentrated on the remaining surface integration work, the massive underground installation activity and the rapidly growing detector commissioning. The status of work on the different detectors will be analyzed in the following sections.

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2 Magnet system

The ATLAS superconducting magnet system comprises the central solenoid, the barrel toroid (BT), two end-cap toroids (ECT), and their common services [4].

2.1 Central Solenoid

The solenoid has been successfully commissioned at full current and its safety systems tested in-situ during August 2006, followed by a field mapping measurement. The goal was to measure the field integral seen by the particles with a precision of $5 \times 10^{-4}$ (equivalent to the knowledge of the field everywhere to $\leq 10$ Gauss). The measurements confirmed the required mapping precision and the coil position obtained from survey and monitor system.

2.2 Barrel Toroid

The BT cool-down in-situ was completed in August 2006 and it has been followed by initial electrical tests at very low current. Full excitation tests have been made in November after a final cleaning campaign of the cavern from magnetic material. The eight coils, powered in series by one power supply, where brought for a 24 hours test to the working currents of 20.5 kA that corresponds to the maximum field value of 4 T at the surface of the superconductor and shortly up to 21 kA to prove a safety margin then a fast dump was experienced after a provoked quench. The quench system protection worked very well producing an uniform distribution of the stored energy (1.08 GJ) between the eight coils of the magnets. All coils reached a temperature of about 60 K. It was confirmed that the position monitor system works according to specification and that the detectors are safe in case of a fast dump. During the BT commissioning, one million of cosmic ray muons were collected using the RPC trigger chambers in sector 13 that were at that time implemented with all services. An event display of a cosmic muon track, recorded during the test with the Barrel Toroid at the nominal current, is shown in Fig. 2.

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Figure 1: A drawing of the ATLAS experiment.
2.3 End-Cap Toroids

The assembly of the cold masses for both ECTs has been progressed well, but after insertion of the first one into the vacuum vessel, technical problems arose for accurately aligning it with respect to the outside force transfer points. A corrective mechanical design change is now being implemented. However this causes a major delay in their installation of about 6 months and puts them on the critical path for the overall installation schedule. The first ECT, side A, is scheduled to be ready for the pit only at the end of March 2007. The second ECT will follow about 2 months later.

3 Inner Detector

The Inner Detector (ID) combines three concentric sub-system layers, from inside out: the Pixel detectors, the Silicon Tracker (SCT) and the Transition Radiation Straw Tracker (TRT). Each of them consists of a barrel and two end-caps (EC Side-A and EC Side-C). The detectors are located inside the 2 T magnetic field generated by the Central Solenoid magnet [5].

The distributed module production is finished, the remaining integration work is proceeding in the clean room facility SR1 at the Point 1 surface area and during the past month the barrel SCT and TRT components have been successfully installed underground inside the barrel calorimeter (as shown in Fig. 3).

3.1 Pixel Detectors

In the past months, the detector assembly experienced a technical problem with leaks due to corrosion in some of the barrel cooling tubes that has been overcome by implementing a successful repair and replacement strategy. A further issue had to be faced with broken low-mass cables for the barrel services. With very strict quality checks, and a new production of part of these delicate cables, the integration of the barrel cylinders has been resumed after an interruption of about three months. The integration of the three barrel cylinder layers have been recently completed. Both end-caps, each containing three fully integrated disks, have been delivered to CERN and passed all acceptance tests. All the barrel recovery actions proceed so far encouragingly well along a very tight schedule which foresees readiness for installation in spring 2007. A photo of the pixel detector integrated with barrel, beam pipe and endcaps is shown in Fig. 4.
3.2 Silicon Tracker

After the insertion of the barrel SCT into the TRT, a successful cosmic ray test took place in SR1 with both detectors and in September 2006 both of them have been installed underground into the barrel LAr cryostat. The end-cap integration is also well advanced, and both sides are now inserted into the corresponding TRT end-caps. The production of the off-detector read-out electronics and of the power supplies is essentially completed. Final integration and tests for the two end-caps followed by their installation in-situ is planned for the spring 2007.

3.3 Transition Radiation Tracker (TRT)

The barrel TRT has been integrated, tested and installed with the barrel SCT, as mentioned above. The integration work for the two end-caps has progressed well, and they have been integrated with the corresponding end-cap SCT during the last months.

3.4 Infrastructure and Common ID Items

The underground services installation has been completed as far as needed for the detector installation and proceeds for the rest. A sizeable fraction of the evaporative cooling, the liquid cooling and the gas distribution plants have been commissioned. The installation of electronics and the planning for overall commissioning are well underway.

4 Calorimeters system

The calorimetry consisting of a barrel electromagnetic and hadronic calorimeter, end-cap calorimeters and forward calorimeters. All of them are constructed and already lowered in the cavern [6].

4.1 Liquid Argon Calorimeter

All three LAr calorimeter cryostats are installed and the main activities concentrate on completing electronics installation and system commissioning in the experimental area. Major points of attention remain the low and high-voltage power supplies which impact the commissioning progress. The LAr barrel calorimeter, in its final position, is cold since May 2006, and is now gradually being brought into operation. Cosmic ray signals in the combined LAr and Tile calorimeters have been recorded very recently in the first modules. For the LAr end-cap calorimeters, the mechanical installation of both end-caps is completed, and the work proceeds now with
completing the services connections and the on-detector electronics installation. Completion of the services and electronics installations, followed by cool down and system commissioning is foreseen in the coming months. Both the low- and high-voltage power supply situations continue to call for special attention. In both cases intense iterations with the two different suppliers are ongoing and have improved the performance, albeit not yet fully satisfactorily, and with slow delivery rates. In order to keep open a back-up option, alternative suppliers are being investigated for the future. All other electronics components are on schedule and commissioning is progressing well.

4.2 Tile Calorimeter

All three Tile Calorimeter cylinders are installed and the in-situ commissioning is proceeding well. A major activity, just started, is to record combined cosmic ray data together with the LAr EM calorimeter. The commissioning of the on-detector electronics has been slowed down because of failures in the low-voltage power supplies and occasional HV trips. The implementation of corrective actions for both issues shows good improvements. However, the low-voltage power supply system requires implementation of a redesign which is very time-critical for the LHC start-up, and commissioning therefore has to proceed with a temporary modification to the control electronics in question. Combined cosmic ray tests of a few barrel modules with the corresponding modules of the LAr EM calorimeter were recently recorded. An event display of a cosmic ray triggered by the tile calorimeter is shown in Fig. ??.

5 Muon chambers

The Muon Spectrometer is instrumented with precision chambers for the momentum measurement (Monitored Drift Tube chambers, MDTs, and for a small high-radiation forward area Cathode Strip Chambers, CSCs) and with fast chambers for triggering (Resistive Plate Chambers, RPCs, in the barrel, and Thin Gap Chambers, TGCs, in the end-caps) [7]. The series construction of all the chamber sub-systems has been completed and so also the assembly in the BB5 area of RPC and MDT detectors for the middle and outer muon stations together with the level-1 electronics and services. The barrel station installation in the cavern is well advanced (see Fig. 6) and the chamber commissioning ongoing [8]. The end-cap sector pre-assembly and their installation in the cavern are in progress.

5.1 Barrel chambers

Over the past months the installation of the barrel stations (MDT plus RPC only in the middle and outer layers) have progressed constantly, within the access constraints given by the overall installation activities in the cavern.
About 95% of the stations are installed, although a part of them needs still final positioning. Along with the chambers the services and the alignment system are put into place. The system commissioning has started, and first cosmic ray tracks have been recorded, for example, jointly in muon stations of sector 13 and Tile Calorimeter modules.

5.2 Forward chambers

The main activity concentrates on the assembly and integration of fully tested sectors for the end-cap wheels, including their alignment system and their installation. The so-called Big Wheels in the middle station consist of a total of 2 MDT wheels and 6 TGC wheels, preassembled in 32 MDT sectors and 72 TGC sectors. The first TGC Big-Wheel has been completed in the underground cavern as it is shown in the Fig. 7. The completion of the Big Wheels is on the critical path, and their installation will be affected by the ECT delays reported in section 2.3. As corrective action it has been decided to duplicate the installation tools for enabling parallel work on both sides of the cavern. The integration of the Small Wheel chambers for the inner end-cap station is planned to start at the end of 2006 and is expected to meet the schedule. The special stations in the barrel to end-cap transition region are on schedule as well. The duplication of Big Wheel installation tools, to enable parallel work, is planned to meet the installation schedule.

6 Trigger and DAQ system

The Level-1 Trigger, the High Level Trigger (HLT), the Data Acquisition (DAQ) and the Detector Control System (DCS) have all been field-proven in the combined test beam running and large-scale system tests over the past years. Components of the final system are now being installed at Point 1, both in the underground control room as well as in the surface HLT/DAQ computer room, and they are gradually being used in the commissioning of the ATLAS detector as it gets installed. The level-1 trigger system (with the sub-systems calorimeter, muon and central trigger processor (CTP)) is fully in production and installation for both hardware and software. The muon trigger sub-system proceeds on a very tight schedule for the off-chamber components (Read Out Drivers). The calorimeter trigger installation is following the availability of the corresponding detector signals in the underground counting room. Major parts of the CTP sub-system have been already installed and all components are available. The HLT, DAQ and DCS activities proceed according to plans. Major emphasis is put on all aspects of the HLT and
Figure 6: ATLAS side A (with the calorimeter end-cap partially inserted). The barrel calorimeter is visible in the center surrounded by the BT muon spectrometer. The organization of the muon stations in three layers (inner, middle and outer) along the radius and in 16 sectors around the eight coils, is also visible.

Figure 7: The first TGC Big Wheel assembled in the cavern.
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DAQ software developments. The HLT and DAQ pre-series system hardware at Point-1 was used successfully in a 10% data flow test already last year. The system installations are now growing according to the needs for detector commissioning work. An important element for the initial commissioning is the local DAQ capability available to the detector system communities. The operational infrastructure at Point-1 is fully active (central file server and a number of local service machines operational with standard DAQ software, system administration, and networking). Furthermore, large parts of the final Read Out Systems have been installed and commissioned, for example for the barrel LAr and Tile Calorimeters.

7 ATLAS Forward Detectors

In order to have an efficient and reliable luminosity measurements, three types of forward detectors are being developed in ATLAS [8]. The Absolute Luminosity for ATLAS (ALFA) detector is dedicated to measure the differential elastic cross-section \( \frac{d\sigma}{dt} \) in the region of Coulomb Nuclear interference at \( t = 6 \cdot 10^{-4} GeV^2 \) (3.5 \( \mu \) rad). The fit of the corresponding distribution yields the absolute luminosity, the total cross-section, the ratio of real and imaginary parts of amplitude \( \rho \) and the slope parameter \( b \). The precision of the absolute luminosity measurement is of the order of 2%, which is limited mainly by the corresponding systematic uncertainties. The ALFA detector consists of a scintillator tracker having 10 \( U + 10 \) \( V \) planes of 64 fibers (0.5mm\(^2\)), read out by 24 multi-anode photomultiplier tubes. The tracker has a 3 mm gap for the beam and is mounted in Roman Pots, which will be installed between the Dump Resistor Boxes 237 m on each side of the interaction point at Point 1. Installation of the Roman Pots is scheduled for either May 2007 or for the 2007-2008 shutdown period. The scintillator tracker is scheduled to be installed not before the 2008-2009 shutdown period. A Technical Design Report for the ALFA detector is being prepared and submitted to the LHCC. The Luminosity measurement using a Cherenkov Integrated Detector (LUCID) is dedicated to measure the inelastic cross-section. The detector will be positioned 17 m on either side of the interaction point at Point 1. The two LUCID detectors consist of 168 gas filled (isobutane) aluminum tubes surrounding the beam pipe. The Cherenkov light in the tubes is read out by 1176 optical fibers, which are connected to multi-anode photomultipliers. The LUCID schedule foresees the installation of the initial detector, consisting of between 8-10 tubes on each side, prior to the first LHC run in 2007. The Zero Degree Calorimeter (ZDC) will measure the forward neutral particle production, and it will be used for the centrality measurement in heavy ion collisions and for the measurement of luminosity in p-p collisions. The detector is built in several blocks, each made of scintillator plates and tungsten converters. The ZDC sits 140 m either side of the Interaction Point in slots in the TAN absorber, which protects the LHC magnet behind it from radiation coming from the collision region. The goal is to install the ZDC in summer 2007 (fallback in the 2008 shutdown). A layout drawing of the forward detectors, with their position along the beam pipe, is shown in Fig. 8.

Figure 8: The forward detectors and their location along the LHC beam.
8 ATLAS Detector Installation Schedule

The present installation schedule foresees the detector ready for physics at the start of the first LHC collisions in November 2007. It must be noted that in all cases the installation of the services and cables, with their cable trays, patch panels and movable chains, is one of the most manpower-intense activities in the underground cavern in the coming months. This massive activity will remain on the critical path until the spring of 2007. Moreover a critical issue for the ATLAS detector is the timely production and delivery of power supplies for both calorimeters and muon chambers. The installation of the initial detector is scheduled to be completed by August 2007, whereas the installation of the end-wall muon chambers may continue until October 2007.

At the time we write this article an additional problem arose connected to the Inner Detector heaters in the evaporative cooling system. Corrosion was discovered on some heaters localized at the Thermo-Couple inserts. One heater failed (burned) catastrophically in the pit during commissioning. Repair is needed before insertion of the end-caps and the Pixel detector. Intense activity is going on to replace and qualify new heaters, as well as to develop a backup solution. The impact on the installation schedule is at moment under evaluation.

9 Conclusions

The Atlas experiment has concluded successfully the construction phase and is currently under massive installation and commissioning work of the different detectors [9]. The Barrel part, except the Pixel detector, is mostly installed and the commissioning with cosmic rays is proceeding well. The main goal is to debug the detector, computing and software and gain, as efficiently as possible, an excellent understanding of the detector performance to ensure the quality of the data when the collisions start. The first physics is at this stage very much driven by the planning for the very early phase of the LHC operation [10].

References