The ATLAS Liquid Argon Calorimeter

Construction, Integration, Commissioning and Performance from Selected Particle Beam Test Results

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Abstract–**Construction of the ATLAS liquid argon calorimeter is now complete and integration with the ATLAS detector in the cavern at LHC Point 1 is currently in progress. Here we briefly review the design of the calorimeter and discuss the status of the integration, testbeam studies and plans for commissioning.**

I. INTRODUCTION

THE ATLAS detector is one of two general purpose detectors being constructed to record the products of the collisions of 7 TeV proton beams that will be produced by the Large Hadron Collider (LHC) beginning in 2007. It consists of three main sub-systems; the Inner Tracking System, the Calorimeter, and the Muon Spectrometer. Each of these sub-systems is in turn composed of a number of sub-detectors. The calorimeter system is composed of a barrel calorimeter (Fig. 1) and two endcap calorimeters (Figs. 1and 2). The former comprises an accordion-geometry liquid argon (LAr) electromagnetic calorimeter, surrounded by a hadronic calorimeter made of steel and scintillating tile (TileCal). In the endcap region of the detector all of the calorimetry uses LAr as the active material. There are three sub-detectors; an accordion geometry electromagnetic calorimeter, a hadronic calorimeter with a more conventional parallel-plate structure using copper as the absorber, and an integrated forward calorimeter with a novel paraxial electrode structure as described later. The LAr Calorimeter is described in detail in [1].

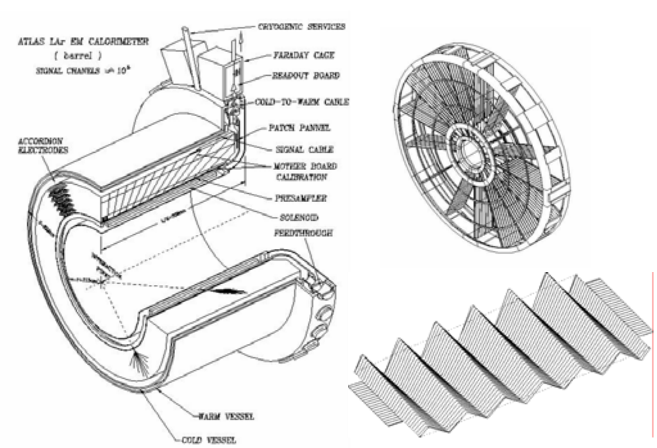

Fig. 1. View of the Electromagnetic Barrel and Endcap Calorimeters The left schematic shows a view of a half-barrel assembly of the EMB. The right-hand side shows a skeletal view of an EMEC wheel, and a view of a folded absorber plate for the inner wheel, showing the variable amplitude folds.

The current plan for the LHC is to run for about three years at a "low" luminosity of about 10^{33} $cm^{-2}s^{-1}$ before moving to the design luminosity of 10^{34} $cm^{-2}s^{-1}$. Particularly the high-luminosity running makes the radiation environment at ATLAS is particularly challenging. The choice of LAr as the active material in the calorimetry was largely driven by issues of radiation hardness, and speed and uniformity of response. The use of LAr also permits the use of common readout electronics for most of the calorimetry, which has benefits in terms of development, maintenance and repair.

Construction of all calorimeter sub-detectors was completed in 2004, and the integration of these detectors into the cryostats was completed earlier this year. Integration of the LAr calorimeter with the rest of the ATLAS detector was started about a year ago with the move of the barrel cryostat to the ATLAS cavern. Since then, integration of the endcap calorimeters into the two endcap cryostats has also been completed; one cryostat is currently on the surface at LHC Point 1, waiting to be lowered into the cavern. The other will be moved to Point 1 by late 2005 / early 2006. In what follows we briefly describe the various components of the ATLAS LAr calorimeter and outline the calorimeter testbeams that have taken place over the last several years. We then discuss the status of the detector integration with ATLAS, and the plans for commissioning.

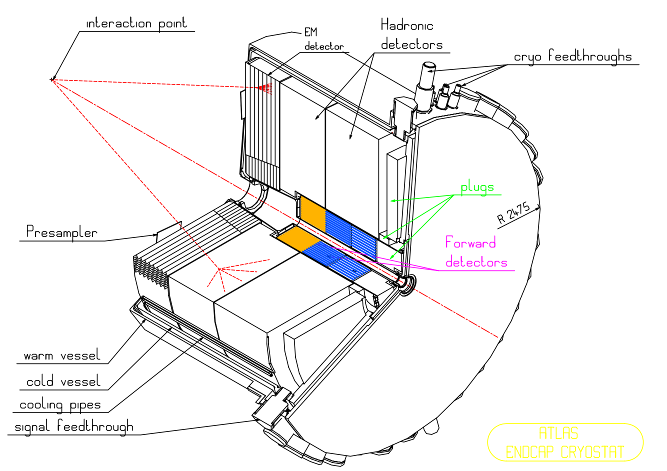

Fig. 2. View of the ATLAS endcap cryostat with its one EMEC wheel, two HEC wheels, and integrated FCal, with one electromagnetic and two hadronic modules.

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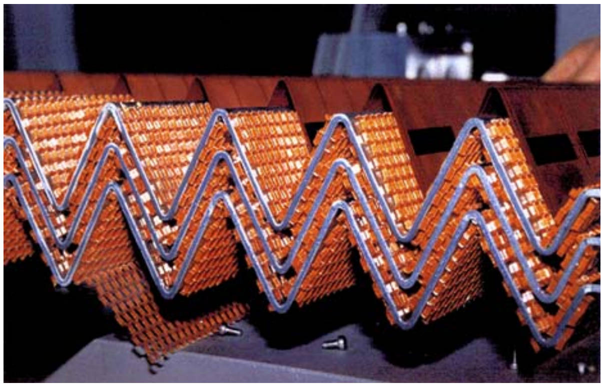


Fig. 3. The accordion structure of EMB calorimeter. Honeycomb spacers position the electrodes between the lead absorber plates.

II. Calorimeter Design and Construction

A. The Electromagnetic Barrel Calorimeter (EMB)

The ATLAS electromagnetic barrel calorimeter is the fruit of a long R&D effort that began with the RD3 Collaboration [2] in the early 1990s. It is a lead-LAr sampling calorimeter with an accordion geometry motivated by the desire to eliminate projective azimuthal cracks that contribute to the constant term of the electromagnetic energy resolution. Early on, the design of the ATLAS EM calorimeter was driven by the need for a constant term of 0.7% or less, in order to provide the best possible resolution for high-energy electromagnetic objects, in particular for the photons from $H^0 \rightarrow \gamma\gamma$ which at the time was felt to be the "golden" channel for the discovery of a low-mass Higgs. The accordion geometry, eliminating projective cracks, and the use of LAr as the active medium, both provide for the response uniformity needed to attain this very small constant term. A cross-sectional view of the barrel cryostat is shown in Fig.1, which illustrates the accordion shape of the azimuthal modules, as well as the projective nature of the readout towers. The accordion electrode structure is illustrated in Fig. 3.

B. The Electromagnetic Endcap Calorimeter (EMEC)

The Electromagnetic Endcap Calorimeter is also a lead liquid argon sampling calorimeter with an accordion geometry. Constraints associated with the implementation of this geometry in the wheel-like structure used in the endcap lead to a design consisting of an inner and outer wheel, each constructed of azimuthal sections, as illustrated in Fig. 1. The orientation of the accordion shaped absorbers and electrodes is illustrated in Fig. 2, in which EMEC wheel is visible at the front of the endcap cryostat, closest to the interaction point. The accordion fold amplitude varies with the radius from the wheel center (see Fig. 1) leading to a varying gap size. High-voltage requirements are therefore different in different radial regions, and special care is needed in the characterization of the electrical properties of individual cells since these also vary with radius. An excellent understanding of the electrical properties of each cell is crucial for the calibration of the detector response.

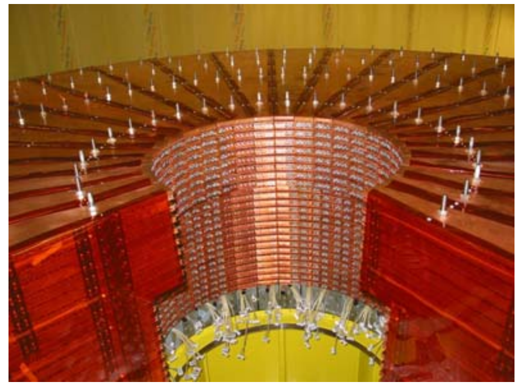


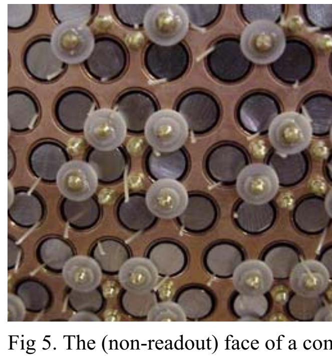
Fig. 4. A partially assembled HEC1 wheel, showing the azimuthal modules.

C. The Hadronic Endcap Calorimeter (HEC)

The Hadronic Endcap Calorimeter is a more conventional parallel-plate copper-LAr sampling calorimeter. Electrodes made of carbon-loaded kapton are positioned in the 8.5 mm gap between the copper plates forming a multi-gap electrode structure that provides redundancy in the case of high-voltage (HV) faults. Each endcap cryostat contains two HEC wheels, each constructed from 32 azimuthal modules. A partially constructed HEC1 wheel is shown in Fig. 4.

D. The Forward Calorimeter (FCal)

The particle flux expected in the very forward region of ATLAS requires that LAr calorimetry in this region use extremely narrow LAr gaps, to avoid problems due to positive ion buildup. For the ATLAS FCal, which is integrated into the endcap calorimetry, this narrow gap size is achieved using a novel electrode structure; copper tubes, which form the cathode of the LAr cell are set into an absorber matrix, copper in the case of the EM module and tungsten in the case of the two hadronic modules. Into each of these tubes is inserted an anode rod, made of the same material as the absorber matrix. Each rod, which has a diameter slightly less than the inner diameter of the tube, is positioned concentrically using a helically-wound radiation-hard plastic fibre (PEEK), which maintains a very narrow, annular LAr gap. This gap size is 250μm for the electromagnetic modules, and 375μm (500μm) for the first (second) hadronic modules. This is illustrated in Fig. 5 for one of the hadronic modules. The numbers of electrodes are, respectively, about 12K, 10K, and 8K.



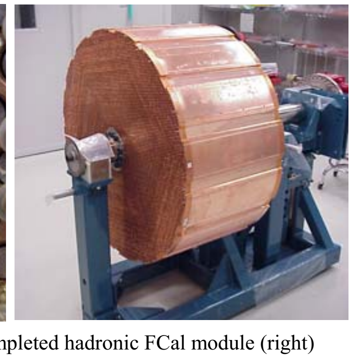


Fig 5. The (non-readout) face of a completed hadronic FCal module (right)

E. Liquid Argon Readout Electronics

With the exception of the HEC, which uses cold GaAs preamplifiers, the LAr calorimeter readout uses common electronics. The physics pulse from the LAr gap is subjected to bipolar shaping for faster readout, with a shaping time optimized for running at $10^{34}cm^{-2}s^{-1}$. The shaped signal is sampled every 25 ns, in time with the LHC clock and the samples are stored in an analog pipeline for readout after the Level-1 trigger processing. Accepted events are digitized and read out. The peak value of the shaped signal is reconstructed from the samples using the optimal filtering method [3]. Electronic calibration is performed with the help of calibration pulser boards located in the Front End Crates that hold the readout electronics. These allow a known current pulse to be injected near or onto the electrodes; in the case of the FCal the pulses are send directly to the base-plane of the FEC. The location of the pulse injection and the techniques used for the electronic calibration differ for the different sub-detectors, as do the requirements on the precision of the calibrations, which are most stringent for the EM calorimeter.

III. Calorimeter Testbeams

Over the past several years there have been a series of testbeam programmes targeted at calibration of the LAr calorimeters and studies of other issues related to their performance. In 2002 there was a combined testbeam of the HEC and EMEC detectors, primarily to study the combined response to pions. The analysis of that data has been published [4]. In the summer of 2003 there was a testbeam for calibration of the FCal response to pions and electrons, and for studies of its performance for particles impacting at very high η. In 2004 there were two testbeams programmes dedicated to studies of the combined performance of ATLAS calorimeters in the barrel and endcap. In the case of the barrel, this was part of a test of a full slice though the ATLAS detector including the inner detector and the muon spectrometer. For the endcap, the main goal was study of the transition region between the HEC/EMEC and the FCal, which occurs at around η~3.2. In this region there is a large amount of un-instrumented material between the interaction point and the calorimeter, primarily due to the projective cone of the support tube that houses the FCal. The effect of this "crack" region on the combined response of the endcap calorimeter is illustrated in Fig. 6, where the dip in response in the region of the crack (as indicated on the figure) is visible.

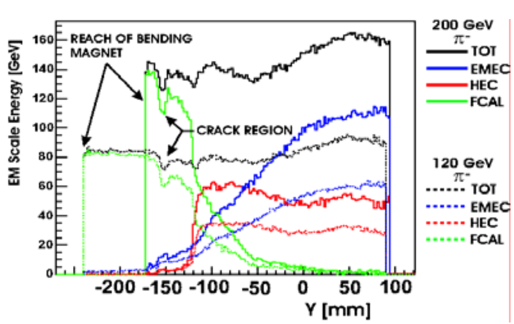


Fig. 6. Combined response of the endcap calorimeter testbeam modules to 120 GeV and 200 GeV pions scanned over the crack at η~3.2.

IV. LAr Calorimeter Integration

Integration of the calorimeters into their respective cryostats began with the EMB installation into the barrel cryostat 2004. Fig. 7 shows a view of the calorimeter after insertion into the cryostat. A pre-sampler is also visible just inside the EMB. The solenoid for the inner tracker was then inserted inside the calorimeter/pre-sampler. The completed cryostat is also shown; visible around the circumference are the pedestals that sit atop the cryogenic feed-throughs which hold the Front End Crates which house the radiation-hard LAr readout electronics. Fig. 7 also shows the barrel cryostat being moved into the ATLAS Cavern in Oct. 2004. It was lowered onto the bottom half of the TileCal, the construction of which was then completed around it. A similar procedure will be used for the Endcap Cryostats, which are also surrounded by the TileCal (the extended-barrel).

As was illustrated in Fig. 2, each endcap calorimeter contains one wheel of electromagnetic calorimetry, two wheels of hadronic calorimetry and an integrated forward calorimeter

Fig. 7. Top: View of the ATLAS EMB calorimeter installed in the Barrel Cryostat. The pre-sampler is visible inside the calorimeter. The right-hand photo shows the completed cryostat. The pedestals for the Front End Crates are visible around the periphery. Below: View of the ATLAS Barrel Cryostat being lowered into the ATLAS Cavern at LHC Point 1. The cryostat is lowered onto the partially assembled Tile Calorimeter, the construction of which is then completed around it (lower right).

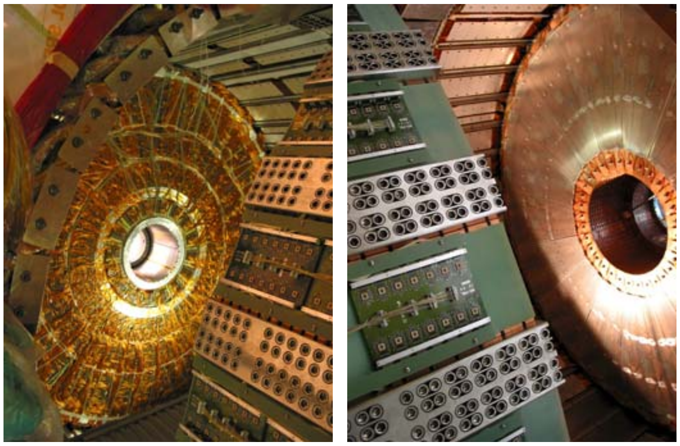


Fig. 8. Insertion of the HEC1 and HEC2 wheels into the endcap cryostat. In the left-hand photo the fully inserted EMEC module is visible at the front of the cryostat, while the insertion of the HEC1 wheel is in progress. The right-hand photo shows the fully inserted HEC1wheel and the insertion of The HEC2 wheel in progress.

which is assembled inside a support tube that forms part of the mechanical structure of the cryostat. Installation of the EMEC, HEC, and FCal detectors into the cryostats was completed in 2005. Installation of the EMEC and HEC calorimeters into the cryostat is illustrated in Fig. 8. The EMEC wheels are the first be installed; a fully inserted wheel is visible in the left hand photo of Fig. 8, which also shows the insertion of the first of two HEC wheels. The insertion of the second wheel is shown in the right-hand photo. Fig. 9 shows a view of the rear face of the HEC2 after the three wheels of calorimetry have been installed in the cryostat and cabled to the feed-throughs. The FCal is designed to fit into the remaining bore; the insertion is performed after the cryostat cold cover has been installed. This is shown in Fig. 10, which shows the cryostat ready for installation of the cold cover and illustrates the insertion of the FCal.

V. Calorimeter Cold-testing and Commissioning

Calorimeter modules are extensively cold-tested as part of the construction process, to ensure HV integrity. Full HV tests are also performed on the completed calorimeters once they have been installed into their respective cryostats, first at warm temperatures, then after filling with LAr. Full cold-testing of the completed calorimeters is initially performed in the surface building where the detector integration takes place. Those tests have been completed and showed no major problems. They will be repeated in the ATLAS cavern once all the detectors are underground and the cryogenics system is available.

Commissioning of the calorimeters has been divided into three phases. Phases I and II are technical, having to do with the installation and testing of the readout electronics, and integration of the calorimeter data acquisition software with the ATLAS Trigger/DAQ (TDAQ) system. Phase III of the commissioning of the LAr Calorimeter is the stage involving initial operation of the detectors. This will entail cold-testing of the detectors and the performance of noise studies and calibration runs to characterize the properties of individual electronic channels. The main part of the Phase-III commissioning will involve data-taking, first with cosmic rays, then with beam-halo / beam-gas events once LHC commissioning with single beams begins in 2007. Initial commissioning with colliding beams is also expected later in 2007. For both the Barrel and Endcap Calorimeters, triggering for the cosmic running will be provided by the TileCal using purpose-built trigger / coincidence boards. For the single-beam running, a minimum-bias trigger will be available, based on scintillators mounted on the front-faces of the endcap calorimeters. For the EMB, the installation of the Front-End Boards is currently in progress, and the detector is scheduled to be cold and ready for cosmic-ray data-taking in February of 2006. Initial work on the installation of the cryogenic lines for the barrel cryostat was performed with the barrel calorimeter sitting at the end of the cavern, beneath the access

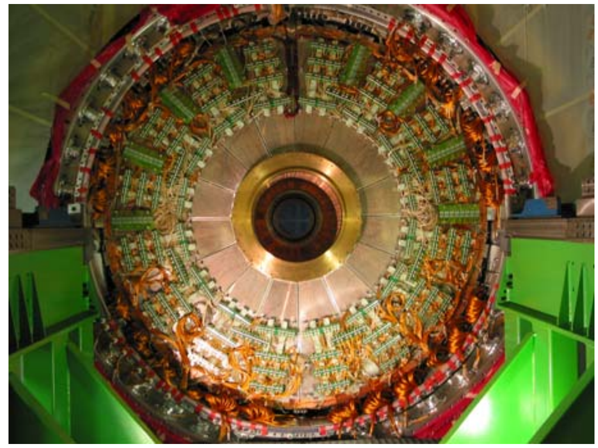


Fig. 9. Rear view of the fully HEC2 wheel in the endcap cryostat. The remaining bore is occupied by the forward calorimeter. Installation occurs only after the cryostat cold cover has been installed (see Fig. 9)

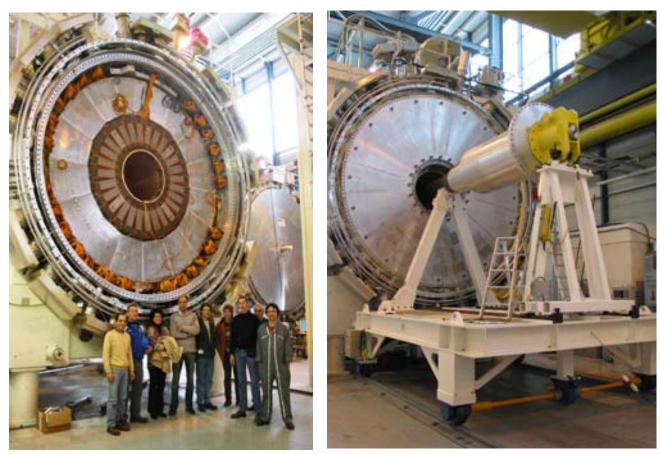


Fig. 10. .Installation of the Forward Calorimeter. The first photo shows a rear view of the cryostat, prior to installation of the cold cover. In this view, the rear face of the HEC is covered for protection, and around the bore, summing boards, which distribute the FCal HV and do summing of readout channels, are visible.

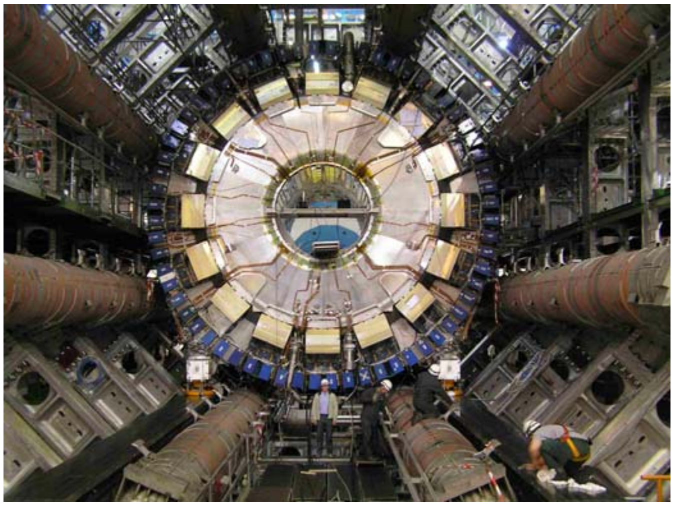


Fig. 11. End view of the barrel calorimeter prior to the move to z=0.

shaft, where the TileCal assembly was completed. At the end of Oct. 2005, the barrel calorimeter was moved to the interaction point, inside the barrel toroid magnets for the muon spectrometer. A view of the calorimeter just prior to the move to z=0 is shown in Fig. 11. The barrel toroid magnets are visible in the photo, as are the 16 Front-End Crates on one end of the barrel cryostat. Completion of the cryo-line installation will take place with the calorimeter in position at the interaction point.

The endcap calorimeters will be moved to the ATLAS cavern in late 2006 / early 2007. Fig. 12 shows the transportation of the first of the two endcap cryostats from the assembly building on the CERN main site, to LHC Point 1. As was the case for the Barrel transport in 2004, the move was achieved without subjecting the devices to significant g-forces. The first endcap cryostat will be lowered into the ATLAS cavern in by the end of 2006. The second will be moved in January 2007. The endcap cryostats are expected to be cold and ready for cosmic-ray running in the Fall of 2006.

Fig.12. Transportation of one of the ATLAS Endcap Cryostats from the integration hall on the CERN main site, to LHC Point 1.

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