The ATLAS Tile Calorimeter: Commissioning and Preparation for Collisions

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Abstract. The ATLAS tile calorimeter has been assembled and commissioned in the underground cavern. Large data sets of cosmic rays and other calibration data have been acquired to test the stability of operation and validate the data acquisition system, detector control system and data quality monitoring.

Introduction
The ATLAS [1] TileCal[2] non-compensating sampling calorimeter, shown in fig.1, is constructed of steel plates (absorber) and scintillating plastic tiles (active material). It is designed as one barrel and two extended barrel parts. All the three sections have a cylindrical structure divided in φ by 64 wedge modules. The tile calorimeter covers the pseudorapidity |η| < 1.7.

Within modules, the light from the scintillating tiles, oriented perpendicular to the beam axis, is collected by PMTs via wavelength shifting fibers from both sides, as shown in fig.2. The module is divided into a number of cells corresponding to the projective geometry. Front-end electronics are located inside modules’ girders and are organized in extractable drawers[3]. The total number of PMTs in entire calorimeter is about 10000. Each PMT signal is shaped and amplified with 2 gains, digitized by sampling ADCs, and the data are read out via optical fibres. Analog sums of projective trigger towers are available to the level-1 trigger.

Figure 1. ATLAS calorimetry layout. Tile calorimeter is shown as outer cylinder.

Figure 2. Tile cell geometry and readout.
1. Installation and services
By the end of year 2005 the barrel part of tile calorimeter was installed and positioned at the final place at Z=0 as presented in fig.3. During the year 2006, both extended barrels were assembled, see fig.4, and the services were connected, in parallel with standalone front-end electronics commissioning, as described in [4]. In 2007 and 2008 all low-voltage power supplies for the front-end electronics were fully installed, together with the refurbishment of the front-end electronics, to strengthen the power and signal distribution inside the drawers to avoid complete module readout failures.

The multitude of optical fibres for triggering and front-end configuration required a new set of tools and procedures to verify the connectivity and integrity of these services. Optical Time-Domain Reflectometers (OTDR) have been used to analyse the loss of signal in optical fibre by injecting short laser pulses into it and counting the back-scattering and reflection of photons as a function of time. This allows to locate any break or bad splice with the precision of a few centimeters. The precise fibre length is used to calculate correct trigger delays. A total of 12 fibres out of 512 of the barrel part had to be re-spliced (2%). These tests were performed for trigger, readout and laser calibration fibres.

2. Front-end electronics commissioning
Because of the lack of access to the front-end electronics after the closure of the detector for beam, it is very important to fully commission it beforehand. The following steps have been taken:

- in-situ certification with mobile readout unit MobiDICK[5]
- online commissioning with back-end electronics and short tests with MobiDAQ[6]
- offline commissioning with data written by ATLAS DAQ system

The certification with the MobiDICK system consists of detailed tests of all front-end electronic components of a single drawer and is used both before and after the installation to verify any additional failure caused during commissioning and to certify the repairs.

Tests with MobiDAQ station mimics all functions of the final read-out. It allows data taking with a set of 8 drawers at once. Besides electronic checks, it was used to develop commissioning software tools.

Finally, the ReadOut Driver (ROD) back-end system, which is capable of reading all tile calorimeter channels at once, was used to take various calibration runs, to be analyzed offline, and to develop the software to be used during ATLAS data taking.
To verify the performance of the electronics various kinds of data have been collected:

- pedestals - to measure the noise levels
- charge injection - to calibrate digitization electronics
- laser - to verify the photomultipliers performance
- cosmics - scintillating tiles, photomultipliers and readout combined

A rich set of automation tools was developed and successfully used to analyse the results of these tests, to present them, and to provide summary status of the commissioning, in a form of databases, plots and web interfaces. The summary status display, electronics performance history tables, and web interface for shifters proved to be invaluable for the commissioning process.

3. DAQ, DCS and monitoring systems

The data acquisition system (DAQ) for the tile calorimeter, based on standard ATLAS DAQ software, is routinely used to collect calibration data for the commissioning purposes and to record physics events, triggered by cosmic muons. The stability of the data acquisition system can be underlined by the 106 hours of continuous running over the Easter weekend, collecting cosmic rays data with the full tile calorimeter.

The detector control system (DCS) is fully operational and is used to control the low-voltage and high-voltage power supplies, logging all the essential control and environmental parameters to the database for later analysis. The detector safety system has been verified to turn-off detector electronics in case of major hazards like fire or cooling failure.

Data quality monitoring is proven to be crucial to acquire valid physics data. Tile calorimeter is being monitored at all levels, from channel-based quantities like pedestals to the physics objects, and results in form of histograms are checked in an automated way, as presented in fig.5.

![Figure 5](image-url)
Figure 6. The effect of channel timing equalization with the laser system. Top plot shows the reconstructed time of the laser calibration pulse vs. channel number. The bottom plot shows the same distribution after the adjustment.

4. Calibration Systems
Tile calorimeter has a number of calibration systems at multiple levels of the readout chain, described in details in[7].

The charge injection system (CIS), designed to calibrate the response of readout electronics and to monitor the variations of the response it time, has performed very well to confirm the stability of the digitizer’s ADC. During a 3 months period the calibration constants variation was less than 0.1%

The laser calibration system, which is designed to calibrate the responses of individual PMTs, and to monitor the short and long term PMT gain stability, has been installed and used for commissioning and timing studies. It also allows to establish the timing equalization of the signals from different channels, as shown in fig.6.

The cesium radioactive source calibration system [8, 9] that is conceived to determine the quality of optical response of the detector, is now fully installed and is used to perform the calorimeter cell response equalization. The source movement control software and data readout are performing well. First data from all the tile calorimeter modules have been collected, and the high voltage adjustment is in progress. The aim is to calibrate all 10000 channels with the precision better than 2% at electromagnetic scale.

As the tile calorimeter is providing the analog sums of the projective trigger towers to the level-1 trigger, a special set of joint calibration runs was taken to setup the energy scale and establish the correct timing of individual channels of the trigger system. Thanks to the charge injection system, it is also possible to simulate the physics kind of signal, like jets, to verify the performance of the level one calorimeter trigger system. The laser pulsed runs are used for the timing adjustments.

5. Integration
Starting from the end of the year 2006 a number of integration weeks was organized in order to move from stand-alone detector commissioning to the combined one. During these periods the various sub-detector groups were able to collect cosmic data with different trigger sources, perform calibrations, timing and trigger setup. These weeks were essential to train shifters, multiply experts, enhance monitoring tools and documentation, and to arrive well prepared for the first beams.
Figure 7. Event display of a large cosmic ray air shower, generating 120 GeV of $E_T$. On the right there are digitized samples from the ADC with the nominal pulse shape superimposed. The top vs. bottom signal time difference is about 16ns, that corresponds to the time of flight of a muon through the calorimeter.

6. Cosmic data taking
Before the circulation of the first beams in the LHC, the performance of the installed detector can be studied with the physics data from cosmic rays. During the 2005-2008 years we acquired a large number of data sets of such events, and used them for detector commissioning, monitoring tools development, systems integration and preparation for the physics data from the beam.

Apart from the calibration purposes[10], these events were also useful to develop a strategy, tools and methods to identify fake missing $E_T$ from front-end electronics failures, large cosmic ray showers and hard bremsstrahlung events. The distribution of missing energy in these kind of events extends from the several hundred GeV, like in fig. 7, up to a few TeV for very rare cases.

Methods to reject this background using calorimeter timing have been explored on simulated and real cosmic ray data. Further rejection is possible using the cuts on an electromagnetic fraction of energy deposited in calorimeters, to improve the quality of the data sample.

7. Conclusions
ATLAS tile calorimeter is fully installed and powered with all the necessary services. All front-end and back-end electronics have been thoroughly commissioned to arrive to the first collisions with minimal number of bad channels (<1%). DCS and DAQ systems are running in full swing. A number of software and hardware tools have been developed during commissioning and used to ensure good performance after the installation. A rich set of monitoring tools is ready to verify the performance and quality of the detector during data taking. All calibrations systems are installed and working to provide well-calibrated detector for the first beams. Tile calorimeter is fully integrated with other ATLAS subsystems, including L1 trigger. Large data sets of cosmics data have been acquired and being studied. Several methods to reject cosmic ray background events have been explored with the real data. An impressive number of experts and shifters are prepared for ATLAS running.
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