ATLAS Tile Calorimeter Data Quality assessment with commissioning data

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Abstract. TileCal is the barrel hadronic calorimeter of the ATLAS experiment presently in an advanced state of installation and commissioning at the LHC accelerator.
The complexity of the experiment, the number of electronics channels and the high rate of acquired events requires a detailed commissioning of the detector, during the installation phase of the experiment and in the early life of ATLAS, to verify the correct behaviour of the hardware and software systems. This is done through the acquisition, monitoring, reconstruction and validation of calibration signals as well as processing data obtained with cosmic muons.
To assess the detector status and verify its performance a set of tools have been developed spanning from the hardware detector verification tests and the online monitoring to the offline reconstruction, tools allowing for a fast and partly automated analysis of the result have been also developed and the system is completed with web interfaces to allow for remote monitoring and data quality assessment.

1. Introduction

ATLAS [1] is one the four experiments under final installation at CERN along the Large Hadron Collider (LHC), the new accelerator that will provide proton-proton collisions with an energy of 14 TeV in the center-of-mass system of reference.

The Tile Calorimeter (TileCal)[2] is the central section of the hadronic calorimeter and it is presently undergoing an intense phase of commissioning. To assess the status of the detector the data collected during the commissioning runs are verified and checked with the help of monitoring tools. These tools and the strategy to assess TileCal data quality is the main topic of this paper. This system will be described with examples from the current activities in the experimental hall.
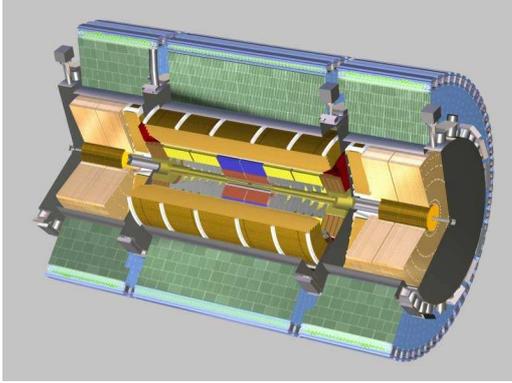
Figure 1. Layout of the ATLAS Tile Calorimeter (in green) surrounding the liquid argon electromagnetic calorimeter. ATLAS muon chambers and the toroidal magnetic systems, surrounding TileCal are not shown.
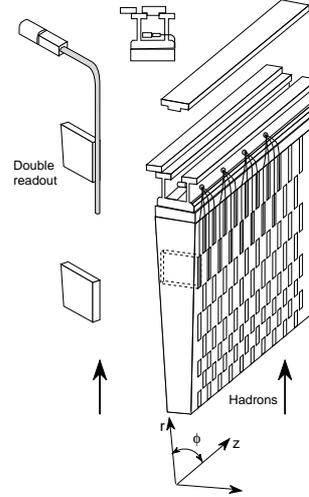
Figure 2. Schematic view of a TileCal module.

2. The Tile Calorimeter and its commissioning

The Tile Calorimeter (TileCal) is the central section of the ATLAS hadronic calorimeteric system designed to measure the energy deposits of hadrons and jets. It is a sampling calorimeter that uses plastic scintillating tiles as the active material and iron as absorber. The calorimeter consists of a cylinder with an inner radius of 2280 mm and an outer radius of 4230 mm. It is mechanically subdivided into a 5640 mm central long barrel and two 2910 mm extended barrels (see Figure 1). Each cylinder is composed of 64 wedges in phi (modules). The scintillating tiles of each module are read by two wave length shifting fibres collected on the external surface of the calorimeter. The photomultipliers (PMTs) and the front-end electronics are organized in *drawers*, each module hosts one drawer inside a girder on the external surface of the calorimeter (see Figure 2).

Fibres are bundled obtaining the readout geometry: the cells are organized in three radial layers with a granularity of $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$ in the first two layers and $\Delta\eta \times \Delta\phi = 0.1 \times 0.2$ in the most external layer. Each cell is read by two PMTs and the entire TileCal is read with about ten thousand PMTs.

Insertion and monitoring of the drawers started at the beginning of 2006. At present all drawers have been inserted and quality assessment will continue up to beginning of 2008, when combined commissioning with other ATLAS detectors will start.

The goal of this phase of the commissioning is to identify all the components in the front-end electronics that fail or that tend to degrade with time. Drawers that do not pass quality controls are eventually extracted and repaired. At the beginning of LHC data taking, precise measurements of E_T^{miss} requires less than 5% of dead cells.

3. Data Quality strategies and tools

Validation and quality assurance of the drawers is obtained performing on the modules a set of tests that mimic the operational model of the future data taking during collisions: data are acquired and stored wtih the ATLAS Trigger and Data AcQuisition (TDAQ) system [3] and are reconstructed with the ATLAS offline reconstruction software (athena).

Different types of runs can be acquired with TileCal detector during the commissioning phase:
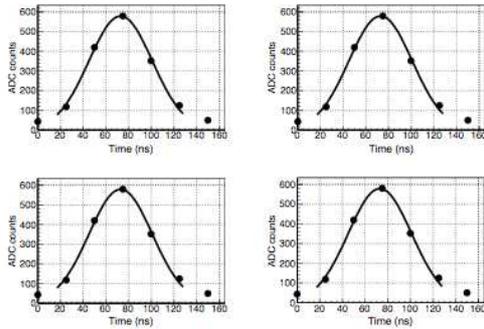
Figure 3. The pulse shape for different PMT as acquired through DVS tests. These results are available for detailed debug and investigation in case of errors.
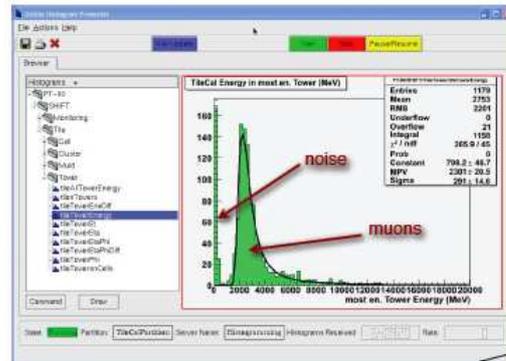
Figure 4. The online histogram presenter. On the left panel the list of all available histograms is shown. The muon energy deposit peak is well visible in the application main window (right).

- **Noise runs**: a random trigger is generated for this type of runs, since no signal is expected it is possible to monitor the level of the electronic noise.
- **Charge injection runs**: a charge is injected in the electronic readout through the calibration Charge Injection System (CIS). The charge is varied in amplitude and phase. From these runs the front-end electronics response can be verified and the pC/GeV constants are extracted.
- **Laser runs**: light is injected directly in the PMTs and the electronic chain together with the PMT are monitored to verify the presence of dead channels, the linearity of the read-out chain and to verify the detector timing. At the time being the laser system is being installed in the experimental hall and a LED system has been used to verify the presence of dead channels.
- **Slow integrator runs**: these are similar to CIS runs but the readout is performed through a parallel readout. This system will be used for the modules equalization at the nominal gain with a radioactive Cesium source and by the minimum bias monitor system.
- **Trigger studies**: the response of TileCal trigger analog output is verified. The signals will be used to form the first level of trigger.
- **Cosmic trigger runs**: a special trigger setup detects passing cosmic muons. These runs have a typical sub-Hertz rate and last for more than one day. They are used to verify the stability of the system and for detailed offline analysis performance studies.

A data quality system has been developed for some of these run types in this paper we will describe the ones in a more advanced state (CIS, noise, laser/LED, cosmic runs). In general the data quality tests can be grouped in two macro areas.

The tools that give a feedback to the user on the status of the system in a very short time (minutes) are considered *online dq tools* (detector verification tests and online monitoring tools), while the tools that require the reconstruction and analysis of the data through offline software and give a feedback to the users in a longer time-scale (few hours) are considered *offline dq tools* (bulk reconstruction and monitoring, automatic histogram checking).

3.1. Online Data Quality
The first step in the assessment of the detector status is performed before the data are acquired. The user runs a series of tests to verify the correct communication with the front-end modules,

to measure the level of the electronic noise, to verify the response to an injected charge and to verify the coarse timing (see Figure 3).

The tests are embedded in ATLAS Detector Verification System (DVS)[4]. DVS uses TDAQ configuration database to control the execution of the diagnostic tests. The tests are arranged in hierarchical order. Therefore the simple tests, e.g. the verification of the communication with the superdrawers, are performed first and eventually, in case all the previous tests are successful, the more sophisticated tests are performed. DVS provides the information about the test results to the user, in case of errors an additional output is displayed.

After all tests have been executed with success and errors have been identified and corrected the detector is ready for data taking and the data acquisition can be started. The raw data for the different run types are acquired with the TDAQ software and they are sent to mass storage for the offline analysis. During this process it is possible to verify the quality of the data being acquired through various online monitoring processes. ATLAS TDAQ system allows to spy the data-flow, at different levels in the acquisition chain, without interfering or slowing down the data acquisition process.

Different frameworks[5] exist to develop monitoring application and TileCal community strategy is to perform online monitoring at the very first stage of the data acquisition (directly in the back-end readout devices, the RODs), just before TileCal data-fragments enter the event building network (with dedicated applications reading event fragments from the readout system computers, the ROS's) and after the full event has been built (using dedicated monitoring PCs connected to the storage nodes). This hierarchical structure of the online monitoring guarantees enough redundancy (each monitoring level can run independently of the status of the others) with different granularities (for the ROD monitoring it is the single drawer, for the ROS-level monitoring it is a set of 32 drawers, it is the full event for the last monitoring level) and it also allows for an efficient balancing of the computational overhead induced by monitoring tasks.

TileCal detector is monitored with four different technologies:

- **DSP Monitoring**. Dedicated monitoring code is running on the digital signal processors (DSPs) responsible of the drawer read-out, monitored quantities include estimation of the noise level and communication error counting. This processes, one for each one of the 128 TileCal DSPs, are currently at the end of their development life cycle.

- **ROD Monitoring**. Four read-out DSP chips, one ROD, are responsible of the read-out of eight drawers. Thus 8 RODs, hosted in the same crate, can read-out one entire section (64 modules in phi) of the calorimeter. Each crate is equipped with a supervising single-board computer also responsible to monitor the global status of the crate (error counters, number of events flowing).

- **GNAM Monitoring**. Dedicated TileCal plug-ins have been developed for the GNAM monitoring framework[6] and simple reconstructed quantities are monitored. These include PMT level quantities: noise, timing, pulse shapes, energy. The code is sufficiently light-weighted to allow the monitoring of the entire calorimeter at a rate of about 100 events/sec.

- **Athena based monitoring**. The offline reconstruction framework athena can also be used for online monitoring[7]. The flexibility of the system and the access to all the tools typical of the offline world (e.g. databases, calibration constants) allow to develop a monitoring application to reconstruct, with offline-quality, quantities to debug in detail the detector. In particular this tool is used during the long cosmic runs: muon tracks are reconstructed and quantities like timing, direction and the energy deposits in the pseudo-projective towers are monitored.

The TileCal monitoring system produces a large number of detailed histograms, about a hundred thousand, of which only some tens are needed to verify the status of the detector. The others are needed only in case of error to identify the failing component. To help the users to
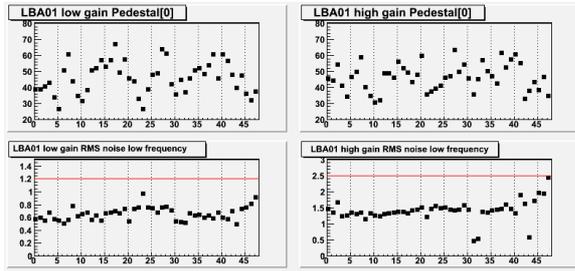
Figure 5. Summary histograms produced by the offline reconstruction. The histograms refer to the noise level, as a function of PMT number, for the module LBA01. The pedestal level (top plots) and the rms of the pedestal distribution(bottom plots) are shown independently for the two gains of the read-out electronics.

Figure 6. Example of the web interface with data quality results. On the left panel the tree-structure summarizes all the tests executed on a single module, selecting one of the data quality tests, on the right panel additional information are displayed. In particular it is available a link to an image of the histogram that produced the result.

navigate through the histograms and to display them in real-time a graphical display, the Online Histogram Presenter (OHP), has been developed and included in the TDAQ[8]. An example of histograms produced by the online monitoring system, displayed in OHP graphical user interface is shown in Figure 4. The histogram shows the energy deposit distribution of muons in TileCal.

3.2. Offline Data Quality

Online data quality is completed by a set of tools developed in the context of the offline frameworks. Differently from online monitoring the offline data quality is performed on full statistics and with complete reconstruction of the events. This allows to verify the presence of rare errors and to study in detail the evolution of the detecor as a function of time, comparing the result obtained in different periods.

The reconstruction job is automatically started as soon as a new run is available: when a TDAQ run is started some information are stored in the commissioning database (the *Comminfo* sql database). This information include the run number, the run type and the list of modules that have been tested. The metadata contained in the Comminfo database are used to configure the reconstruction and analysis job that runs at the CERN batch system. The offline data validation is performed through the following steps:

(i) **Reconstruction and monitoring**: depending on the run type some important quantities are monitored producing detailed and summary histograms. These include data sanity checks (CRC errors, dead channels, corruption of data stream), measurement of the noise level (see Figure 5) and, for the CIS runs, the measured signal amplitude over injected charge ratio. For each module a detailed ntuple is also produced. The output files (containing ntuples and histograms) are stored at CERN. In case of need the user can retrieve the files and perform a detailed analysis. An athena package, TileMonitoring, has been developed to produce the detailed and summary histograms. Since the package has been developed with the atlas offline framework it is possible, if needed, to use it also online in conjunction with the high level trigger software framework. This algorithm can thus be added to the athena-based monitoring previously described.

(ii) **Automatic data quality checks**: to cope with the large number of histograms (several summary histograms for each module) an automatic system to verify the validity of the
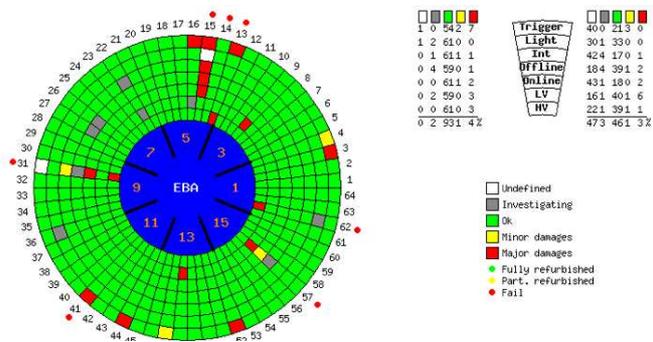
Figure 7. Online status display: the information on the overall status of all modules is displayed. Each module is subdivided into seven sectors, each one representing a specific aspect or subsystem, from the most inner sector: high and low voltage systems status, status as acquired with DVS and online monitoring, offline analysis, results from the slow integrator tests, results from laser system and analog trigger readout results. For each sector a status flag and a detailed comment can be inserted.

histogram content has been developed. This system takes as input the histograms produced during reconstruction and, depending on the run configuration, executes algorithms (e.g. checking the mean and rms values) that produce a data quality flag (DQ result): *good*, *bad* and *to be investigated*. The system has been developed with the help of the Data Quality Monitoring Framework (DQMF). DQMF has been initially developed to be used to check the results produced by online monitoring tasts. Thus the package has been customized to be run offline: a set of python programs have been developed to configure, run and retrieve the results of the DQMF application.

(iii) **Histograms and DQ result presentation**: a database has been prepared to easily access the plots and the data quality results and to allow navigation through the results. For each run an entry is inserted, and, associated to that entry, the list of all tested modules with the results from DQMF and the images of the plots. Access through this information is obtained through web interfaces (the *Web Interfaces for Shifters - WIS*). The DQ results are organized in a tree structure: several DQ groups have been created each one defined to contain the information relative to a functional aspect of the module (data integrity, noise level, response to injected charge, timing). A DQ result is calculated for each group based on the status of the leaves. This configuration allows to easily navigate through the DQ results and spot, in few steps, the failing component. Additional information, algorithm dependent, is stored together with the DQ result and a direct link to the histogram image that produced the result is also available. An example of the DQ result tree for one module is presented with is shown in Figure 6. Other functionalities of the web interfaces allow to query the database for all the results relative to a specific module, to insert user comments and to display them as a function of time, thus allowing to show the evolution of a module during the commissioning activities.

The quality assessment of TileCal front-end electronics is performed through many steps, both online and offline, with different time scales and, even more important, by different users. Thus a system to collect and share the information becomes essential. The overall status of the detector is presented through web pages. A graphic representation of the four TileCal cylinders is divided into 64 sectors (the modules) and in seven concentric rings (see Figure 7). Thus, for each module, up to seven sectors are available, each one representing one particular subsystem or one specific aspect of the modules (high and low voltage systems, slow integrator subsystem, analog trigger readout, digital readout, optical system). To each sector a quality flag and, if needed, a detailed comment can be associated. The results obtained with the online and offline tools that have been described are summarized and shared among the collaboration with this

tool. The interface allows to crete snapshots of the calorimeter status, recording the comments and status flag for each module at predefined time intervals. With this view it is possible to show the evolution, as a function of time, of the commissioning activities.

4. Conclusions

The ATLAS central hadronic calorimeter TileCal is in an intense installation and commissioning phase since two years and this phase will end in 2008 when all subdetectors of the the ATLAS experiment will start to be commissioned together with the first collisions provided by the LHC.

In the past years many tools have been developed by the TileCal community to assess the quality of the hardware components installed in the experimental hall. During the daily activities the detector status is verified in detail, first with specific hardware tests and, during data taking, with online monitor tools. Once the events have been acquired they are reconstructed and analyzed with the ATLAS offline software. Automatic DQ checks are performed on monitoring results and the obtained information is gathered to web interfaces.

The system has proved to ease the integration of the various commissioning activities and it is used by the different teams working in the experimental hall or in the control room. The use of the web interfaces to present and to navigate the data quality results allows for remote monitoring of the detector: users perform part of the commissioning activities from their home institutes.

Some aspects of the TileCal data quality system are still under development and new tests and controls are expected to be developed in the forthcoming months. To minimize code-duplication and limit maintenance effort particular attention has been put in developing tools that use as much as possible ATLAS frameworks. In many occasions this also resulted in positive feedback from TileCal experience to the developers to improve the general tools.

TileCal community is gaining experience in using data quality tools that will evolve in the final version of the system that will be used during the entire life of the ATLAS experiment.

5. Acknowledgments

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