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 ray muons. To assess the detector status and verify its performance a set of tools has been developed spanning from the hardware detector verification tests and the online monitoring to the offline reconstruction. Tools allowing for a fast and semi-automated analysis of the result have been developed and the system includes web interfaces to allow for remote monitoring and data quality assessment.

1. Introduction

ATLAS \cite{1, 2} 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 a centre-of-mass energy of 14 TeV.

The TileCal \cite{3} 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 are the main topics of this paper. This system will be described with examples from the current activities in the experimental hall.

2. The Tile Calorimeter and its commissioning

The Tile Calorimeter (TileCal) is the central section of the ATLAS hadronic calorimetric system designed to measure the energy deposits of hadrons and jets. It is a sampling calorimeter that
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.

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 $\Delta \eta \times \Delta \phi = 0.2 \times 0.1$ 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. As of spring 2008 all drawers have been inserted and the quality assessment is well underway, in conjunction with the combined commissioning of other ATLAS subdetectors.

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 $E_{\text{miss}}$ requires less than 5% of the cells to be dead.

3. Data Quality strategies and tools

Validation and quality assurance of the drawers is obtained by 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 with the ATLAS Trigger and Data AcQuisition (TDAQ) system [4] and are reconstructed with the ATLAS offline reconstruction software (Athena).

Different types of runs can be acquired with TileCal detector during the commissioning phase:

- **Noise runs**: a random trigger is generated for this type of run; 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
Figure 3. The pulse shape for different PMT’s as acquired through DVS tests. These results are available for detailed debugging 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 clearly visible in the application main window (right).

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 ADC counts/pC constants are extracted.

- **Laser runs**: light is injected into the PMT’s, and the electronics chain together with the PMT’s 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 monitoring system.

- **Trigger studies**: the response of TileCal trigger analog output is verified. The signals will be used to form the first level trigger decision.

- **Cosmic trigger runs**: a special trigger setup detects the top-bottom coincidence of cosmic ray muons passing through the TileCal. 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: online and offline.

The tools that give a feedback to the user on the status of the system in a very short time (a few 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 (a 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 electronics noise, to verify the response to an injected charge and to verify the coarse timing of pulses in individual channels (see Figure 3).

The tests are embedded in ATLAS Detector Verification System (DVS) [5]. DVS uses the 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 [6] exist to develop monitoring application and the 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 Read Out Drivers - ROD’s), just before TileCal data-fragments enter the event building network (with dedicated applications reading event fragments from the readout system computers, the Read Out System - 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 sufficient 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; for the last monitoring level it is the full event) 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 run on the digital signal processors (DSP’s) responsible for the drawer readout, the monitored quantities include estimation of the noise level and communication error counting. These processes, one for each one of the 128 TileCal DSP’s, are currently at the end of their development life cycle.

- **ROD Monitoring.** Four read-out DSP chips, comprising one ROD, are responsible for the readout 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 for monitoring the global status of the crate (error counters, number of events transferred).

- **GNAM Monitoring.** Dedicated TileCal plug-ins have been developed for the GNAM monitoring framework [7] and simple reconstructed quantities are monitored. These include PMT level quantities: noise, timing, pulse shapes, energy. The code is sufficiently lightweight to allow for 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 [8]. The flexibility of the system and the access to all the tools typical of the offline world (e.g. databases, calibration constants) allow one 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 an error when one needs to identify the failing component. To help the
users to 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 [9]. 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
framework. In contrast to online monitoring, the offline data quality tests are performed on
the full-statistics data sets with complete reconstruction of the events. This allows one to verify
the presence of rare errors and to study in detail the evolution of the detector as a function of
time, comparing the results 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 is stored in the commissioning database (the Comminfo
sql database). This information includes 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 safety
checks (CRC errors, dead channels, corruption of data stream), measurement of the noise
level (see Figure 5) and, for the CIS runs, the measured ratio of signal amplitude over
injected charge ratio. For each module a detailed ntuple is also produced. The output files
(continuing ntuples and histograms) are stored at CERN. If necessary, 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 within the ATLAS offline framework, it is possible, if needed, to use it online in
conjunction with the High Level Trigger software framework. This algorithm can thus be
added to the Athena-based monitoring described previously.
Figure 7. Online status display: the information on the overall status of all modules is displayed. Each module is divided into seven segments, each one representing a specific aspect or subsystem. These are from the innermost segment: high and low voltage systems status, status as acquired with DVS and online monitoring, offline analysis, results from the slow integrator tests, results from the laser system and analog trigger readout results. For each segment a status flag and a detailed comment can be inserted.

(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 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 tasks. 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 to 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 one 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 shown in Figure 6. Other functionalities of the web interfaces allow one 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 one to show the evolution of a module during the commissioning activities.

The quality assessment of the TileCal front-end electronics is performed through many steps, both online and offline, with different time scales and, even more importantly, 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 a 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 amongst the collaboration with this tool. The
interface allows one to create 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 has undergone an intense installation and
commissioning phase for several years, and this is reaching a conclusion in 2008 with the
combined commissioning of all ATLAS subdetectors and the first LHC beams.

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 information obtained is displayed via 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.

The TileCal community is gaining invaluable experience in using data quality tools which
will evolve into the final system to be used throughout the lifetime of the ATLAS experiment.

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