Event Filter Monitoring with the ATLAS Tile Calorimeter

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Abstract. The ATLAS Tile Calorimeter detector is presently involved in an intense phase of subsystems integration and commissioning with muons of cosmic origin. Various monitoring programs have been developed at different levels of the data flow to tune the set-up of the detector running conditions and to provide a fast and reliable assessment of the data quality already during data taking. This paper focuses on the monitoring system integrated in the highest level of the ATLAS trigger system, the Event Filter, and its deployment during the Tile Calorimeter commissioning with cosmic ray muons. The key feature of Event Filter monitoring is the capability of performing detector and data quality control on complete physics events at the trigger level, hence before events are stored on disk. In ATLAS' online data flow, this is the only monitoring system capable of giving a comprehensive event quality feedback.

1. Introduction

The ATLAS detector [1] is one of the major experiments currently being commissioned at the CERN Large Hadron Collider (LHC) that will provide proton-proton collisions at an unprecedented center-of-mass energy of 14 TeV. The complete ATLAS detector comprises roughly 140 million electronics channels registering collisions at the LHC's bunch crossing frequency of 40 MHz. A three stage trigger system will reduce the number of processed events from 10^5 events/sec at the first level to 200 events/sec finally written to tape storage. In order to ensure that only good quality data is saved, various monitoring systems are deployed at different levels of the online data-flow to detect potential problems as soon as possible already at the trigger level.

The Event Filter (EF) is the highest trigger level and has access to complete event information and conditions databases. The EF Monitoring installed at this level is the only online monitoring system capable of performing detector and data quality control on complete and calibrated physics events. Both individual subdetector as well as global reconstruction quantities can be monitored at this level, using the same code base as used in the offline reconstruction.

The ATLAS Tile Calorimeter detector (TileCal) [2] contributes with about 10^4 readout channels and is presently in an intense phase of commissioning with cosmic rays and integration with other subdetector systems. This paper starts out with a brief overview of TileCal, followed by a description of the EF Monitoring infrastructure. Different aspects of data recorded with TileCal and monitored at EF level are discussed and examples from recent data taking periods with cosmic muons are presented before a summary is given.

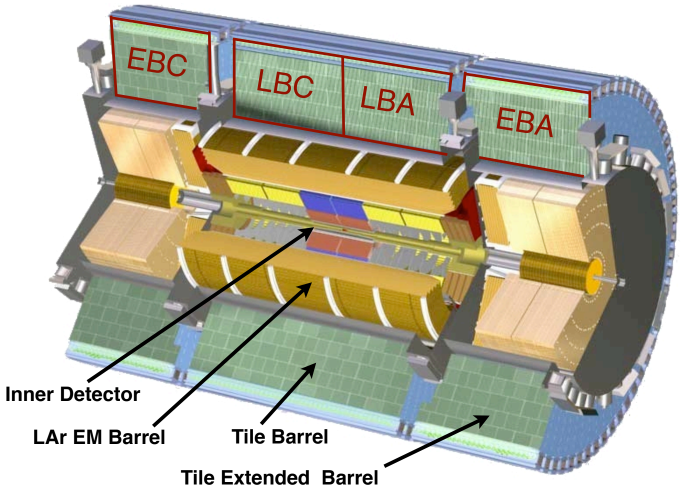


Figure 1. Layout of the ATLAS Tile Calorimeter, surrounding the LAr calorimeters and the inner detector system. The muon and magnetic systems completing the ATLAS detector outside of TileCal's volume are not shown.

2. The ATLAS Tile Calorimeter

The ATLAS Tile Calorimeter is the part of the ATLAS detector which is dedicated to measuring energy depositions of hadrons and jets. It is based on a sampling technique where plastic scintillating plates (tiles) are embedded in iron absorber plates and read out by wavelength shifting fibers. Together with the electromagnetic calorimeter and the hadronic end caps, both based on liquid argon technology, it comprises the calorimeter system of ATLAS. The Tile Calorimeter consists of a cylindrical structure with an inner radius of 2280 mm and an outer radius of 4230 mm, surrounding the liquid argon calorimeters, see Fig. 1. It is subdivided into a 5640 mm central long barrel (LB) and two 2910 mm extended barrels (EB). The whole calorimeter is subdivided into four readout partitions labeled as EBA, LBA, LBC and EBC. Each partition is assembled out of 64 wedge-shaped modules staggered in ϕ. These modules are in turn subdivided into readout cells, bundling the light collected in a number of scintillating tiles. Every module is subdivided into three radial layers of cells with a granularity of $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$ in the first two layers and 0.2×0.1 in the last. η and ϕ are defined in the ATLAS right-handed coordinate system where the z-axis is aligned with the beam direction, the x-axis points towards the center of the LHC ring and the y-axis points upwards. $\phi = \arctan\frac{y}{x}$ is the azimuthal angle and $\eta = -\ln\tan\frac{\theta}{2}$ is the pseudo-rapidity derived from the polar angle θ with respect to the z-axis, cf. Fig. 3.

Each cell is read out by two photo-multipliers (PMTs), converting the light collected from two sides of each cell into electric currents. The roughly 10,000 PMTs used to read out the complete Tile Calorimeter translate into the same number of readout channels that need to be monitored during data taking. Eight (five) trigger towers are defined in the long (extended) barrel by adding up the signal recorded in three radially staggered cells, quasi-pointing to the interaction point.

3. Event Filter Monitoring

A monitoring system is needed in the data acquisition system to verify the good quality of data sent to the permanent storage. In the ATLAS data acquisition and data flow, the Event Filter is the third level of the trigger system, receiving completely assembled physics events from the Sub-Farm Input (SFI). Data is transmitted by the Event Filter Data Flow (EFD) to Processing Tasks (PT), where trigger algorithms run.

The EF is therefore the natural place to perform the monitoring of high level physics quantity and cross-checks among different detectors. The key feature of the EF monitoring is its capability of providing data quality checks even before data is stored to disk.

The EF monitoring system is based on a monitoring framework [3] provided by the ATLAS TDAQ system. Fundamental services provided by the monitoring framework [4] are listed in the following:

Event Monitoring (Emon) provides event sampling. User programs can request event fragments from a specific sampling source.

Online Histogram Service (OHS) handles histogram objects and in particular ROOT histograms. It is used to share informations among histogram providers and subscribers. The functionalities for providers are: create, update and delete, while subscribers can subscribe to a particular histogram in OHS and be notified about a change in its state.

TrigMonTHistSvc is a service of the High Level Trigger (HLT) infrastructure that collects histograms from the ATHENA histogram service and publish them in the OHS.

Gatherer is a processes used to collect from OHS histograms from different nodes, merge them and publish the resulting histograms to OHS.

Online Histogram Presenter (OHP) OHP [5] is a histogram presenter based on QT and ROOT. It can browse histograms published in OHS and display them in automatically updating tabs with user-defined graphical options.

The EF segment, controlled remotely by the DAQ system, is running on a dedicate node so that PT processes don't share resources with other DAQ subsystems. Several PTs are started sampling events from different SFI nodes in order to accumulate statistics in the merged histograms produced by the Gatherer.

Most of the Data Acquisition and Trigger system of ATLAS, outlined in Fig.2, is actually in place. During commissioning tests, event data are passed to the PT not by the EFD, but via the Emon service from the SFI nodes. The PTs are synchronized with the DAQ transition states via the EF Process Steering Control (EF PSC) which is part of the HLT interface.

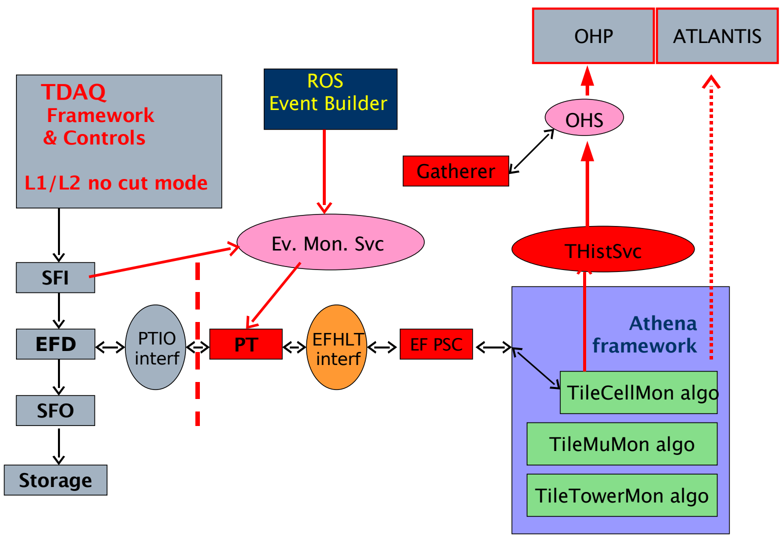


Figure 2. Schematic description of an EF monitoring segment.

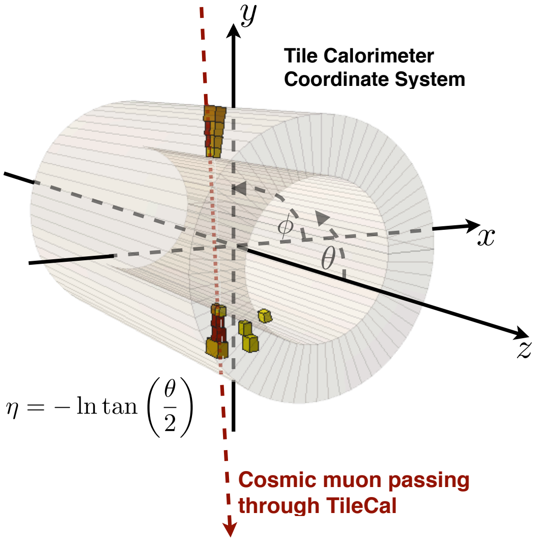


Figure 3. Schematic view of a cosmic muon traversing TileCal, including the coordinate system used. Readout cells are depicted by colored boxes where the shade is proportional to the deposited energy. Darker shades correspond to higher energies. All cells with energy less then 400 MeV have been suppressed in this event display, resulting in a clear visualization of the muon's path.

The algorithms running in PT are the same ATHENA algorithms as used in the offline reconstruction: ATHENA algorithms create reconstructed objects like event informations, clusters of hits in the trackers, various kind of tracks, calorimeter cells and clusters and store them in Store Gate (SG) containers. These containers are then accessed by the various monitoring algorithms and the output histograms are updated. A special algorithm transforms the information stored in SG into the XML format used by ATLAS event display (ATLANTIS) and provides such data on the network to any ATLANTIS client connected to it.

4. EF Monitoring with TileCal

In order to test and calibrate the various subdetector components and their integration into a combined readout system, larger and larger parts of the ATLAS detector are read out aiming at recording the passage of muons with cosmic origin ("cosmic muons") through the detector. The Tile Calorimeter has been an integral part of these cosmic runs due to its advanced stage of construction in the ATLAS cavern and its good signal over noise ratio with respect to cosmic muons. All data presented in this paper has been recorded with the EBA, LBA & LBC partitions of TileCal. Twelve consecutive modules at the top and twelve at the bottom of each partition have been used to trigger the readout of all integrated ATLAS subsystems. A trigger signal is generated if any of the trigger towers in the top twelve modules and any of the bottom trigger towers show in coincidence a significant signal over noise, indicating the passage of a cosmic muon through the detector. A schematic view of such an event is shown in Fig. 3. Another muon event is shown in Fig. 4 using the ATLANTIS event display.

The Event Filter Monitoring has been successfully deployed in TileCal during cosmic runs. Aspects of the muon signal ranging from the readout channel level to quantities related to completely reconstructed muon tracks have been monitored. The set of monitoring histograms provided to the TileCal shifter in the OHP during data taking has been designed with the idea to give a quick overview over the operation of the whole detector. Regions with unusual activity can be identified and the information is then passed on to reconstruction experts to investigate the problem further. The final goal is to build a set of monitoring histograms allowing to navigate, in a tree-like way, deeper and deeper into the finer readout details, for example from module to readout channel level.

For cosmic runs, the energy deposited in trigger towers and the position and direction of reconstructed muon tracks are especially helpful to ensure that really muons are recorded since

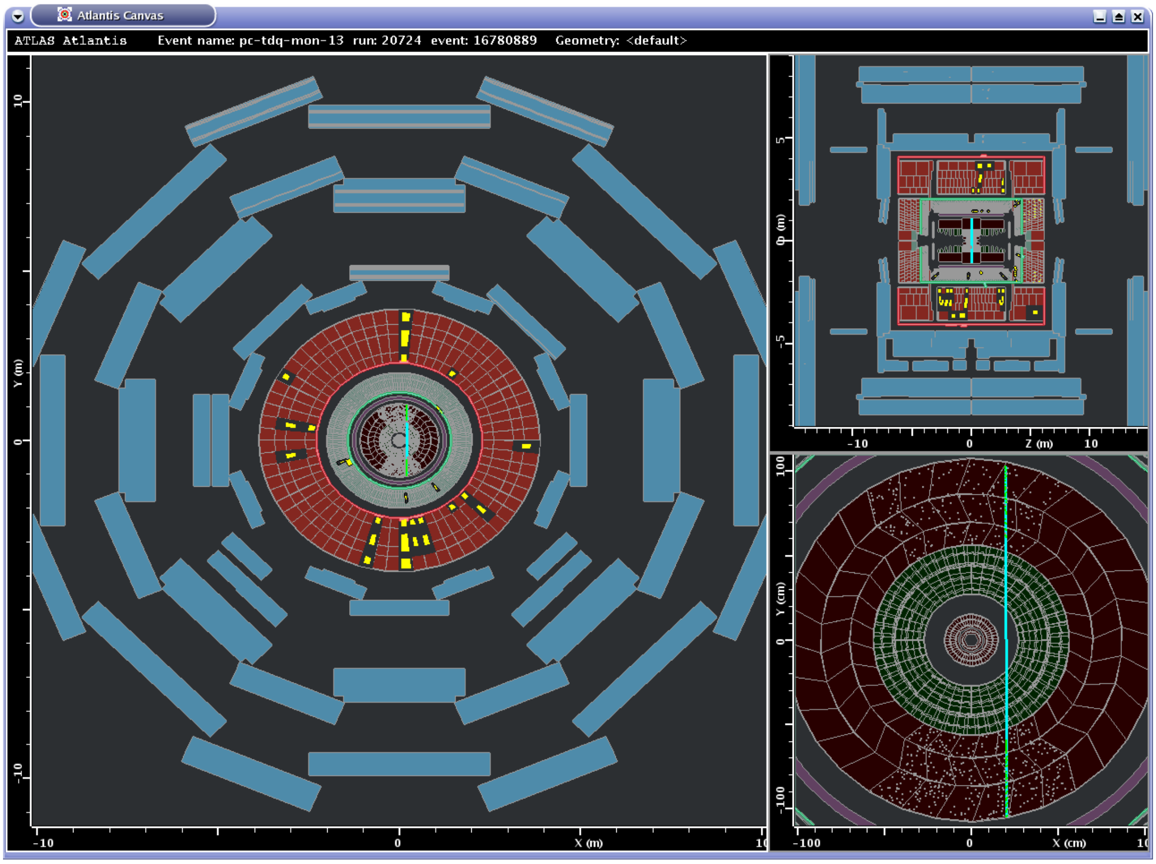


Figure 4. A cosmic muon event visualized in the ATLANTIS event display. TileCal is represented by the red ring with yellow boxes representing energy depositions in cells. The lower right window shows a zoom up of the inner detector with hits in the transition radiation tracker (TRT) indicated as white dots. A TRT track has been reconstructed which lines up with the energy depositions in TileCal.

those are clearly identifiable in these distributions. Cell level quantities and the event display are useful for spotting noisy cells and trigger towers, which can be masked in the readout. In the following a selection of monitored quantities at different levels in the event building process are presented, starting with the cell level and ending with higher level quantities such as reconstructed muon tracks.

4.1. Cell level quantities

The energy deposited in each TileCal cell is estimated by two independent readout channels. Since these twin channels measure the amount of energy and time of deposition in the same cell, the resulting measurement are expected to be compatible. A useful quantity to monitor is thus the difference of the energies and deposition times between the two readout channels of the same cell. Figure 5 shows the time difference between twin readout channels in each radial TileCal cell layer. Since a cosmic muon deposits energy only in the few calorimeter cells along its path, most cells contain no signal. For cells with no significant signal over noise the energy reconstruction algorithm sets the reconstruction time to 0 ns, resulting in the large population of the central bin in all distributions.

Another view of the energy and time imbalance between the two readout channels connected

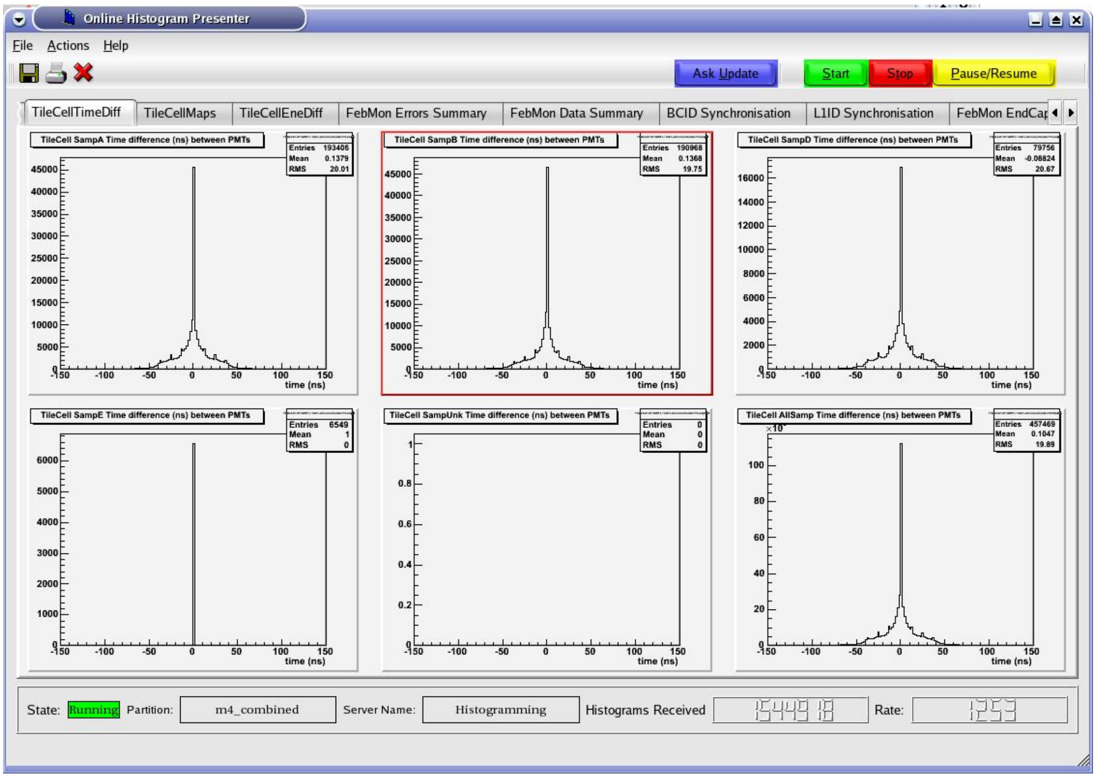


Figure 5. Screen shot of an OHP window during a cosmic run in August 2007. The difference in reconstruction time between two channels reading out the same calorimeter cell is plotted for each radial TileCal cell layer.

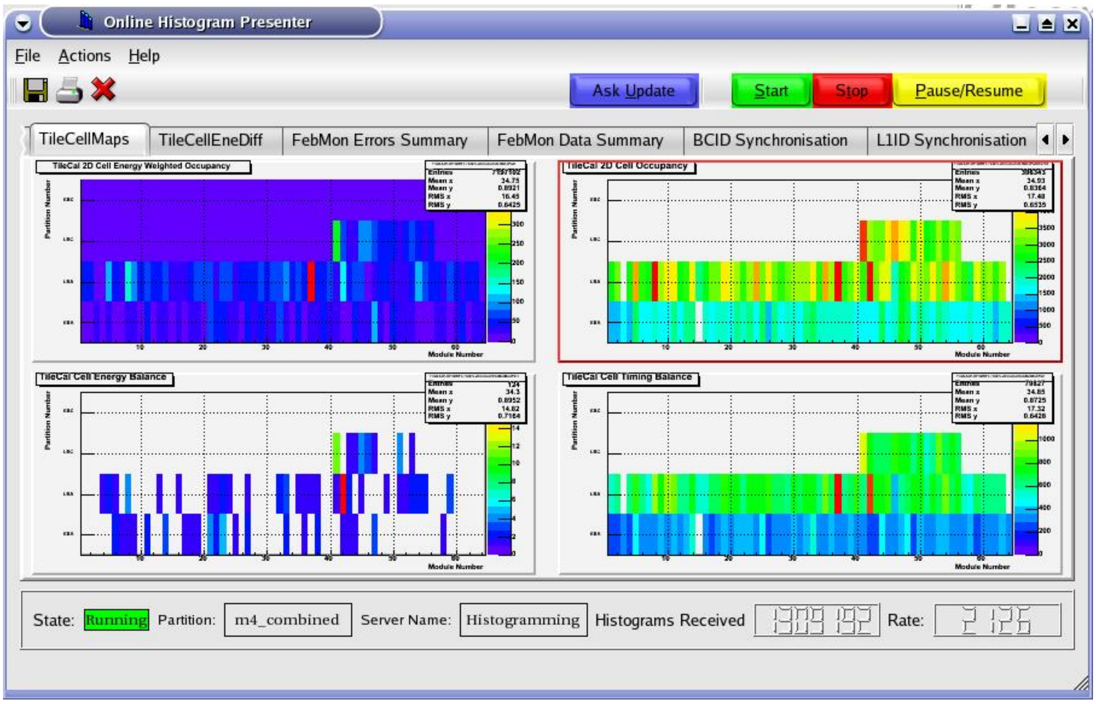


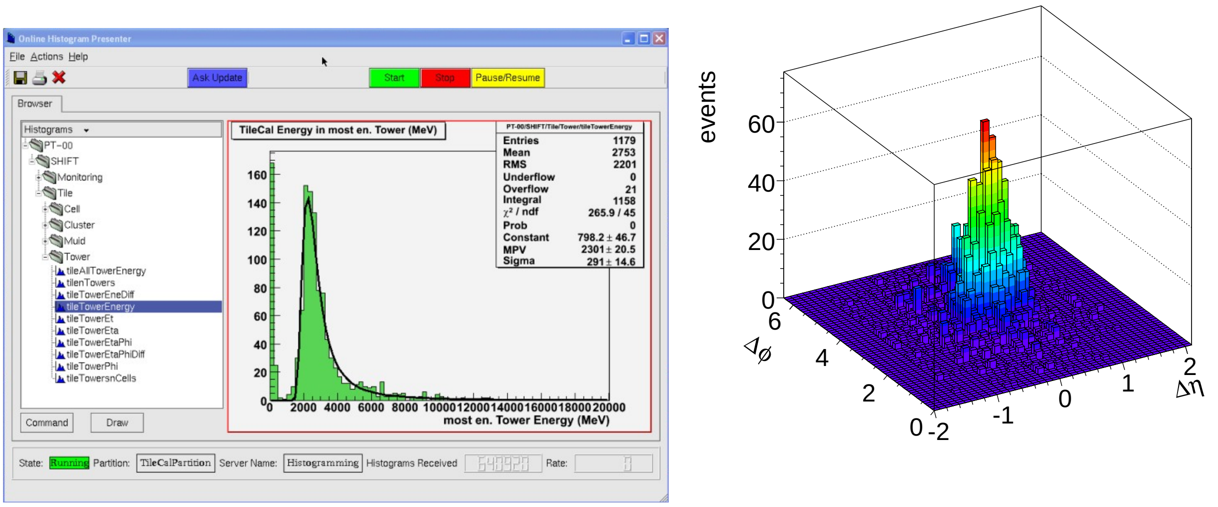
Figure 6. Screen shot of an OHP window showing an overview of TileCal cell level related quantities.

to each cell is presented in the bottom two histograms of Fig. 6. In all four histograms displayed, each TileCal module is represented by one bin. During a run, the content of a bin in the lower left histogram is increased by one unit every time a cell in the corresponding module shows a reconstructed energy imbalance between the two connected readout channels larger than 300 %. The lower right histogram monitors the time imbalance in a similar manner, increasing bin entries if the time imbalance is larger than 25 ns.

The upper left histogram in Fig. 6 is designed to spot cells producing fake signals due to a high noise level. It shows the energy weighted occupancy summed over all cells within a module. Modules with noisy cells show a much higher count in their corresponding bin than the properly functioning modules. The displayed histogram thus indicates a problem with module 37 in the LBA partition due to its high occupancy represented by the red color.

4.2. Tower level quantities

Monitoring the energy deposited in TileCal towers enables a first quick assessment of the purity of the recorded cosmic muon sample. Since a typical cosmic muon passes through the detector as a minimum ionizing particle, the energy it deposits is proportional to the effective path length through the plastic scintillators. The expected energy deposited in a TileCal tower is of the order of 2–3 GeV. The top left plot of Figure 7 shows the distribution of the energy in the most



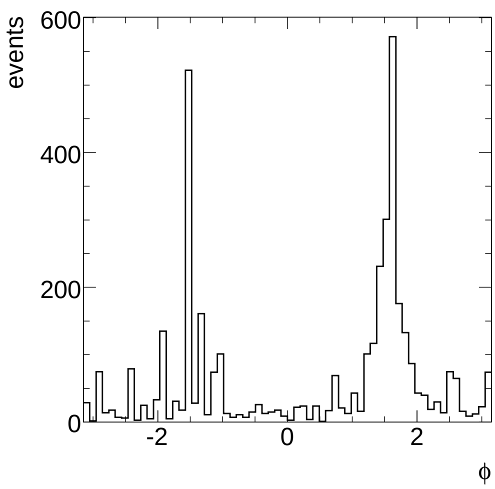
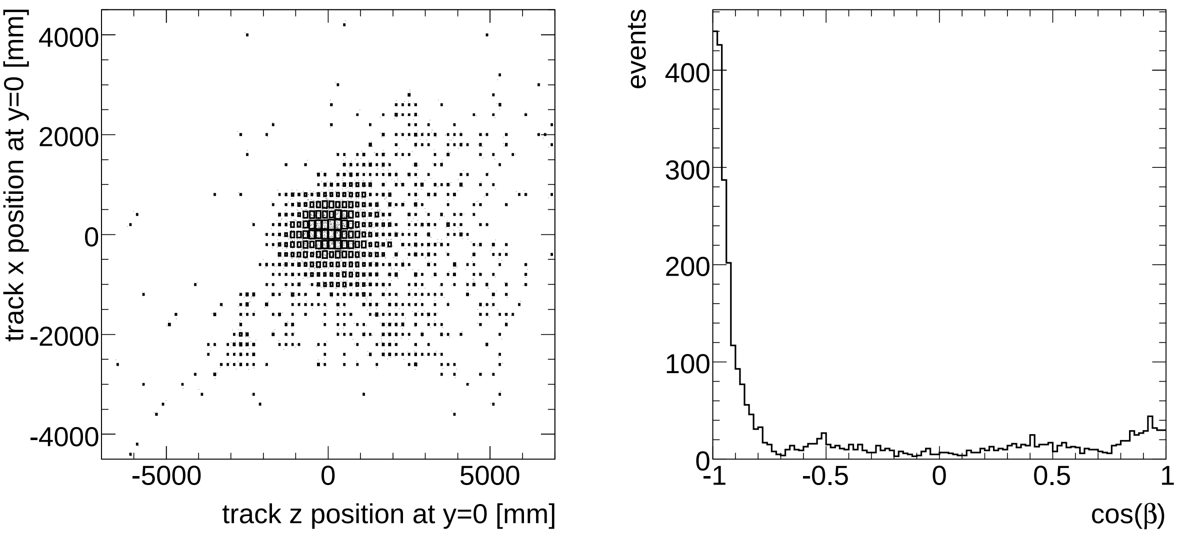


Figure 7. Selection of histograms monitoring TileCal tower quantities. The distribution of the energy of the most energetic tower in each event is shown in the top left plot using the OHP. Also shown is the ϕ coordinate of the most energetic tower (bottom left) and its correlation with the most energetic one of the opposite hemisphere in the $\Delta\eta - \Delta\phi$-space (top right).



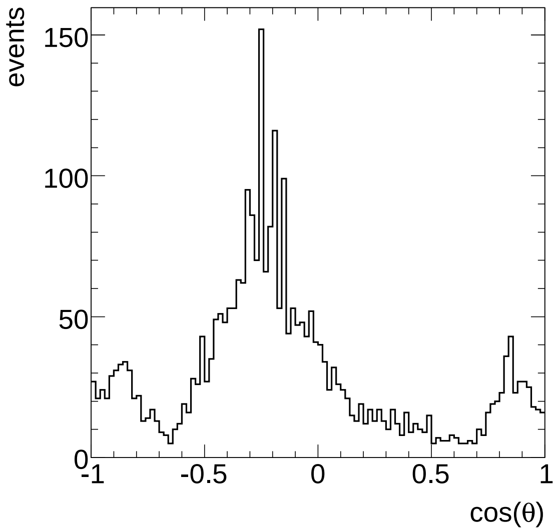


Figure 8. A selection of histograms monitoring quantities related to muon tracks reconstructed with TileCal cells: The intersection point of the reconstructed track with the horizontal x-z-plane (top left), the cosine of the angle of the track with respect to the y-axis (top right) and the cosine of the track's angle with respect to the z-axis (bottom left).

energetic tower for each event. A muon signal is clearly visible in the fitted peak over the noise accumulating in the lowest histogram bins.

Since no magnetic field is applied in cosmic runs, a muon passes the detector on a straight line. Hence energy depositions are expected both in a top and a bottom tower roughly opposite of one another. This correlation is measured by calculating the distance in η-ϕ-space between the most energetic towers in two opposite hemispheres. The histogram shows the expected behavior with a clear peak at $\Delta\eta = 0$ and $\Delta\phi = \pi$. The bottom left histogram in Figure 7 monitors the ϕ-coordinate of the most energetic tower. The preference for the vertical up and down directions at $\phi = -\frac{\pi}{2}$ and $\phi = +\frac{\pi}{2}$ is evident.

4.3. Reconstructed muon track quantities

The Event Filter Monitoring has the capability of monitoring reconstructed physics objects, typically constructed by applying pattern recognition algorithms to a subset of readout channels. A Tile Calorimeter specific application is the reconstruction of the tracks of cosmic muons passing through the detector. The track is reconstructed based on the signal recorded in individual readout channels, improving the resolution in ϕ by taking the energy sharing between the two readout channels of a given cell into account. For each event, a straight line is fitted through the highest energy cells, minimizing the energy density weighted squared distance between each calorimeter cell and the track. Cell timing information determines the particle's direction along its track.

Figure 8 shows a selection of attributes related to the reconstructed muon tracks which are monitored in order to confirm the expected muon passage through TileCal. The top-left histogram shows the distribution of intersection points of reconstructed muon tracks with the x-z-plane at $y = 0$. An accumulation of tracks passing close to the center of the detector is observed with an extended tail towards higher z-coordinates. The latter is due to the non-symmetrical setup with only the EBA but not the EBC partition included in the readout.

The remaining histograms of Fig. 8 show the direction of the fitted muon track with respect to the z-axis ($\cos\theta$, bottom left) and the y-axis ($\cos\beta$, bottom right). The $\cos(\beta)$ distribution shows a strong peak at $\cos(\beta) = -1$, indicating that indeed most muon tracks are reconstructed as pointing vertically downwards. A smaller peak is also evident at $\cos(\beta) = +1$, wrongly suggesting the detection of vertically upwards flying muons. However, the timing of individual TileCal channels to the same global time frame is still insufficient, resulting in a fraction of mismeasured muon directions along their paths.

5. Summary & Outlook

The monitoring of cosmic muon events during commissioning runs at the Event Filter level has been successfully implemented for the ATLAS Tile Calorimeter. The selection of histograms accessible though the Online Histogram Presenter during data taking enables the shifter to assess the quality of the recored data. Malfunctioning detector parts can be identified and pointed out to experts for a more detailed analysis. The emphasis of upcoming commissioning runs will lie on implementing a full set of calibration constants with the aim of calibrating the complete TileCal to best current knowledge. This will improve the quality of the reconstruction and enable monitoring algorithms to spot problems currently obscured by effects due to miscalibrations.

A monitoring specific tasks to be handled in the future is the extraction of reference histograms and the implementation of monitoring algorithms which raise an alarm automatically if a monitored observable deviates significantly from its reference. Further the possibility to navigate from overview histograms to lower detector levels will be implemented with the aim of enabling experts to detect problems at the level of individual channels.

6. Acknowledgments

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