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Monitoring and Data Quality assessments for the ATLAS Liquid Argon Calorimeter at the LHC

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Abstract:

The ATLAS detector at the Large Hadron Collider is expected to collect an unprecedented wealth of data at a completely new energy scale. In particular its Liquid Argon (LAr) electromagnetic and hadronic calorimeters will play an essential role in measuring final states with electrons and photons and in contributing to the measurement of jets and missing transverse energy.

The ATLAS LAr calorimeter is a system of three sampling calorimeters (electromagnetic barrel and endcaps, hadronic endcaps and forward calorimeters) with LAr as sensitive medium. It is composed of 182,468 readout channels and covers a pseudo-rapidity region up to 4.9. Efficient monitoring will be crucial from the earliest data taking onward and at multiple levels of the electronic readout and triggering systems. Detection of serious data integrity issues along the read-out chain during data taking will be essential so that quick actions can be taken. Moreover, by providing essential information about the performance of each sub-detector, the quality of the data collected (hot or dead channels, alignment and calibration problems, timing problems...) and their impact on physics measurable, the monitoring will be critical in guaranteeing that data is ready for physics analysis in due time. Software tools and criteria for monitoring the LAr data during the cosmic muon runs, which have been taking place since October 2006, are discussed. The further extension to the strategy for monitoring collisions data expected at the end of year 2009 is also described.

1. Introduction: ATLAS Data Flow

During the LHC operations, the acquisition rate in ATLAS will be of the order of 200 Hz, each event representing on average 1.6 Mbytes of data. During normal detector running conditions (10 hours of data taking per day), 23 TBytes per day of raw data are expected to be recorded in ATLAS.

The raw data are stored on buffer disks at Tier0. After reconstruction, the data are transferred to tape. The size of the buffer disks is of the order of 610 TBytes, allowing only a few days of data storage before the migration to tape becomes necessary. After migration to tape, the readout rate is very slow, basically the same at the data acquisition rate, of the order of 200 Hz. Therefore, it is very important to be able process the bulk of the data within a limit of 5 days, to not accumulate any delay with respect to the data acquisition. To achieve this, a very efficient monitoring and data quality feedback loop are required.

2. ATLAS Data Processing and Data Quality Model

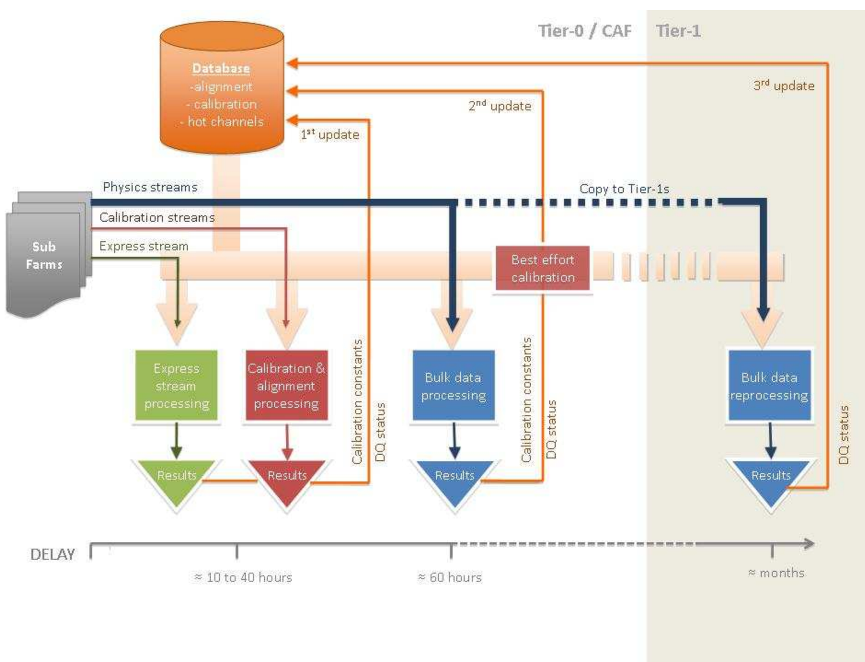


Figure 1: ATLAS data processing model and data quality loop

The dataflow in ATLAS is organized in streams:

- **Physics streams**: the bulk of the data to be used for physics analysis. These data have to be processed with the "best effort calibration" in the time scale of a few days. Refined calibration and correction can be done during further reprocessing.
- **Calibration streams:** specific data used to perform detector calibration and detector alignment. Those data have to be processed within 24h, in order to provide the best possible picture of the detector and allow for database conditions update before the first bulk processing. These data are processed on dedicated farms at Tier0.

- **Express stream:** a fraction of the bulk data (~10%). These data are used to get a first data quality assessment on a very short time scale (of the order of a few hours). The processing of this stream starts during the data acquisition, and should be finished shortly after the end of a run.

Using the output of the express stream and the calibration stream processing, the conditions databases can be updated. The express stream will be processed a second time with the new database conditions in order to cross-check the reconstruction, and new data quality checks will be performed. If the result is acceptable, the processing of the bulk can start.

The following sections will focus more specifically on the liquid argon calorimeter. Section 3 will briefly describe the basic detector components and the energy reconstruction. In Section 4, several illustrations of the monitoring and data quality tools necessary to validate the data will be presented.

3. The Liquid Argon Calorimeter

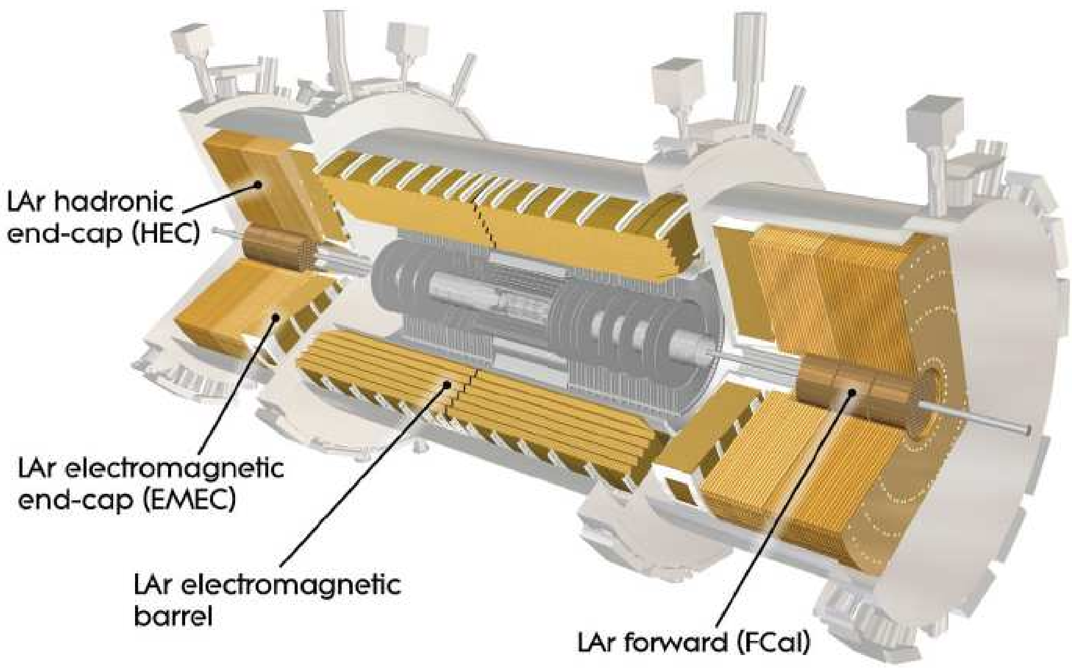


Figure 2: The ATLAS liquid Argon Calorimeter system

The ATLAS liquid argon calorimeters (Figure 2) consist of three sampling detectors using liquid argon as the active medium. The liquid argon has been chosen for its linear behavior, its stability of response over time and its intrinsic radiation-hardness. The purity and the temperature of the liquid argon are important parameters to monitor, since they influence the charge collection and the drift time. The absorber consists of lead in the electromagnetic regions, copper in the hadronic endcaps, while the forward calorimeter is made of copper and tungsten. An accordion geometry has been chosen for the absorbers and the electrodes of the electromagnetic barrel and endcap to provide a full coverage in ϕ without any cracks and a fast extraction of the electrodes signal.

The liquid argon calorimeter has a very high granularity: 1524 front-end boards (FEB) are necessary to read the 182 468 channels of the detector. The front-end boards (Figure 3) receive the raw calorimeter signals and perform the analogue processing, digitization and transmission of the signals. The shaped signals are sampled at the LHC bunch-crossing frequency of 40MHz by switched-capacitor array (SCA). The SCA stores the analogue signals during the L1 trigger latency in pipelines of 144 cells. For events accepted by the L1 trigger, typically five samples per channel and only one of the three gain scales are read out from the SCA. A gain-selector chip (GSEL) is used to select the optimal readout gain individually for each calorimeter channel, and the signal is finally sent to the readout drivers (ROD) through an optical link (OTX).

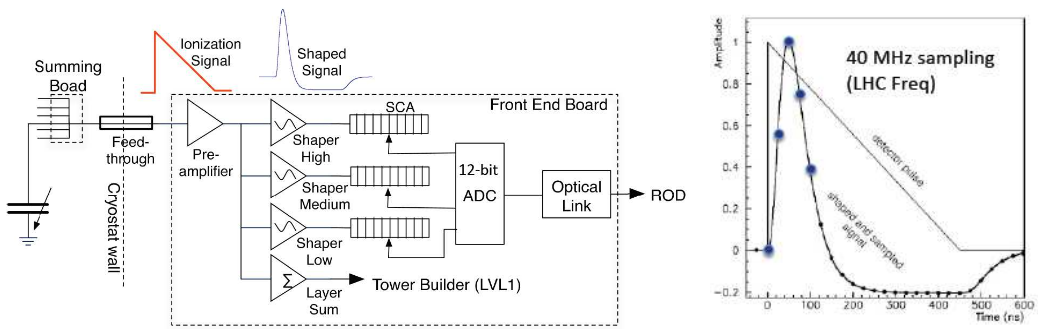


Figure 3: Front-end board (left) and digitization of the signal (right)

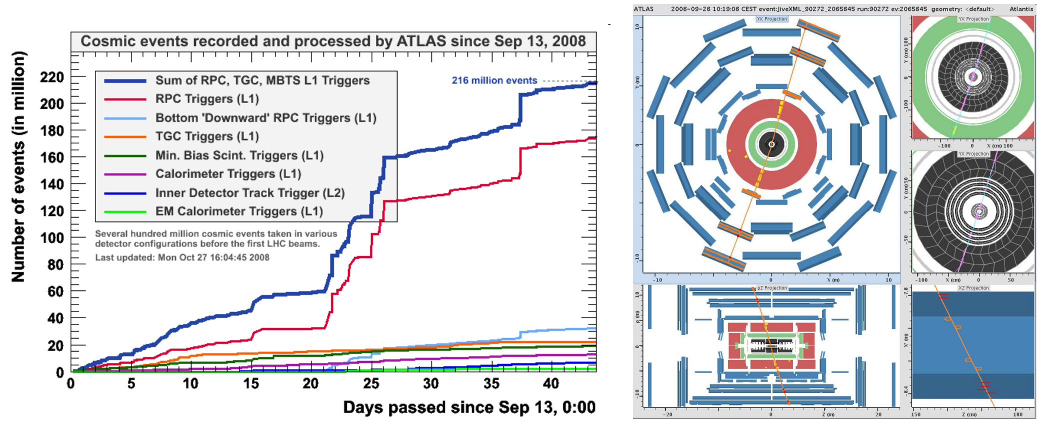
The RODs are responsible for processing the data from the front-end electronics. Each ROD board receives data from 8 FEBs; the 128 channels of each FEB are processed by one Digital Signal Processor (DSP) chip. The most important task of the DSP is to apply an optimal-filtering method [1] to the digitized signal using calibration constants to compute online the deposited energy (in GeV), the signal timing (in ns) and a quality factor for each cell. The digits are also transmitted for the most energetic cells (or for all cells in transparent mode), and can be used to cross-check the DSP computation. Each step of this electronic chain will precisely be monitored for all of the calorimeter cells during data acquisition and reconstruction.

More details about the detector geometry, electronic boards and signal reconstruction can be found in [2].

4. Liquid Argon Calorimeter Monitoring and Data Quality

The liquid argon monitoring is organized in five different categories:

- **Detector Control System:** monitoring of the operational parameters like liquid argon purity, liquid argon and front-end board temperatures, high voltage values, low voltage power supplies and cooling [3]
- **Data Integrity:** monitoring of the electronic front-end boards and signal transmission.
- **Signal Peak position:** monitoring of the detector timing.
- **Misbehaving channels:** monitoring of hot or miscalibrated channels that might affect the physics objects reconstruction.
- **Physics objects:** monitoring of global object, like electrons, photons, jets, missing transverse energy.



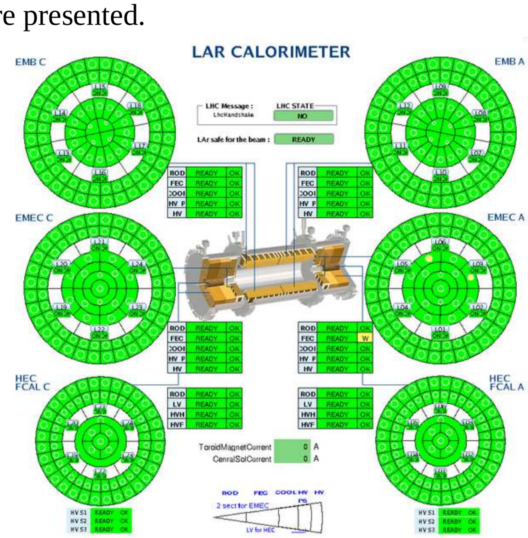
<u>Figure 4</u>: Cosmic data recorded in ATLAS since Sept. 2008 (left). Event display of a cosmic event seen in the ATLAS detector (right).

Since September 2008, a large campaign of cosmic data taking including all ATLAS sub-detectors has been undertaken. In addition to the gain of experience regarding the daily detector operations, the large amount of cosmic data collected (Figure 4) allowed us to validate the full reconstruction chain, to build the data quality criteria and to develop automatic monitoring tools, both online and offline.

In the control room, the attention is drawn to the most basic detector information extracted from the Detector Control System and from the front-end boards (digits and error words), the goal being to spot very quickly serious problems that compromise the data integrity and might require to stop the run. Data quality checks aiming at identifying problems that can be corrected at a later stage of the data processing (like noisy calorimeter regions or wrong calibration constants for isolated cells) require more statistics and more complicated treatments, and are performed offline, on the Express stream data.

In the following, a few examples of the monitoring tools and how their use to commission the liquid argon calorimeter are presented.

Figure 5 shows the Detector Control System display available in the control room for shifters, as a summary page giving the status of all the detector components and services. During the last cosmic campaign in June 2009, the liquid argon detector was fully operational.



<u>Figure 5</u>: ATLAS DCS Status

At the start of a physics run, the full detector must be in a "READY" state (Green), without any warning or error. For physics analysis, the basic requirement is to keep a constant detector coverage and stable calorimeter behavior during a run. A basic data quality check is therefore to assess a warning flag when the detector states changes during a run.

For calorimeter cells above a certain energy threshold (typically above a few GeV), in addition to the energy and time, the signal digits are also transferred from the DSP. The individual digits (in ADC counts) are used to recompute the cell energy offline by applying the exact same optimal filtering method as the DSP. By comparing the result of the offline energy reconstruction with the energy computed online in the DSP, we can test the calibration constants loading and the DSP code. Figure 6 illustrates the perfect reliability of the DSP over more than 40 000 events. The few events found in the 1 MeV tails of the distribution lie within the expected accuracy. The same type of plot is produced for the computed time and quality factor of the cell.

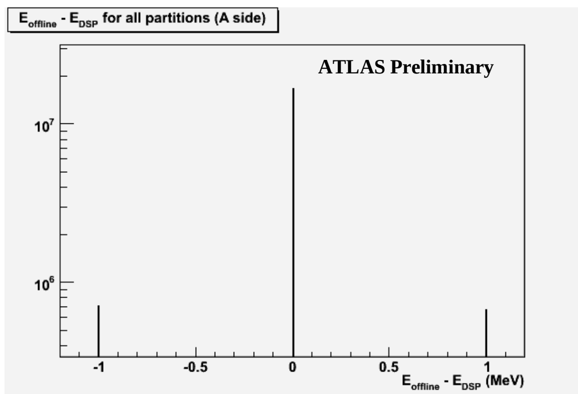


Figure 6: Difference between the cell energy computed online in the DSP and the energy computed offline from the individual digits.

For the very energetic cells with the digits available, it is also possible to build an average pulse shape (Figure 7). The position of the sample with maximum energy is a very simple and robust observable to compare the timing between the different liquid argon detector parts. This monitoring plot is also very important for ATLAS. As the liquid argon calorimeter is the sub-detector with the largest readout time window (for a signal digitized in 32 samples, it corresponds to 800 ns), it is used to align the timing between different ATLAS trigger sources.

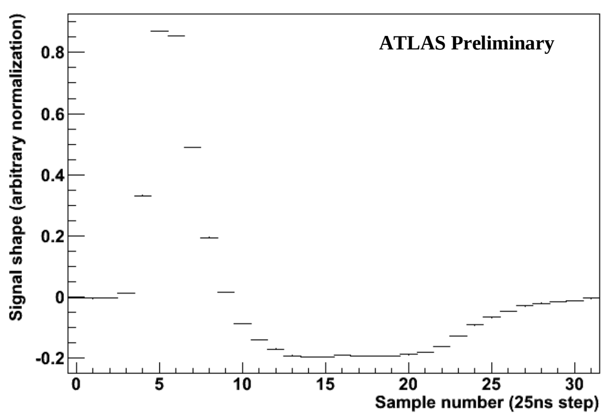


Figure 7: Average pulse shape of high energy cells in liquid argon calorimeter

For each calorimeter cell, the electronic noise (Figure 8) is measured in random triggered events, and stored in a database. The electronic noise is used during physics runs as a reference to spot channels with deviant behaviors. Two types of problems can be identified:

- **Isolated noisy cells:** these cells can be identified by counting the number of events where the cell energy is above 3 times the expected database noise. With a perfectly Gaussian noise, 0.27% of events should pass the cut in each cell. A significantly higher fraction of events, will identify a noisy cell (Figure 9).
- **Global detector noise:** for each event, assuming a Gaussian noise, the number of cells with energy above 3 times the expected database noise should be 0.27%. Given the very low muon rate in cosmic data, the physics signal does not bias the expected event rate and 0.27% of cells above threshold are expected. Therefore,

events found with a large fraction of cells above the noise threshold in cosmic data are very probably triggered by coherent noise (Figure 10).

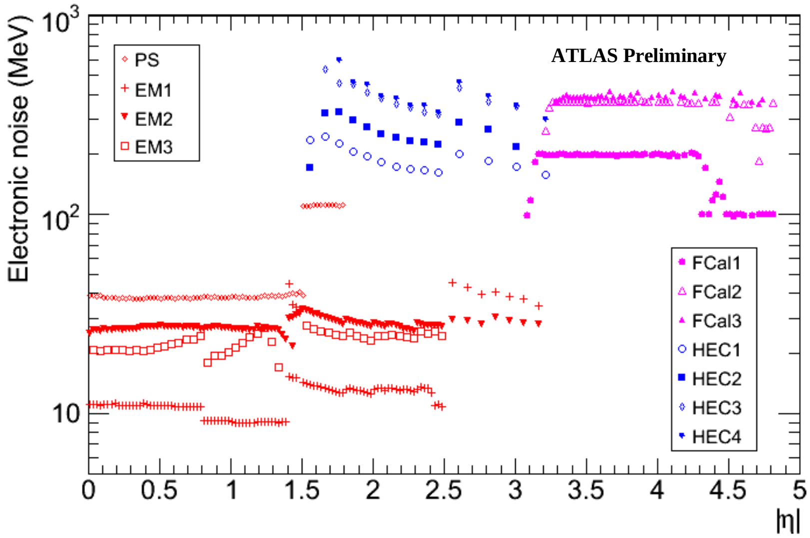


Figure 8: Expected electronic noise of individual cells in the various sampling layers of the liquid argon calorimeters as a function of η

Figure 9 shows for all the calorimeter cells the number of events where the energy is found above 3 times the expected database noise, for two different time periods. The blue curve shows a distribution observed in October 2008 cosmic data. Very large tails (more than 10 times the expected value 0.27%) are clearly visible. After investigations, it was established that the tails are populated with channels with unstable and noisy shapers, creating large noise pulses. A major refurbishment of the calorimeter front-end boards was done during winter 2009 in order to replace the faulty shapers. In the new cosmic data from April 2009 (red curve): the tails vanished.

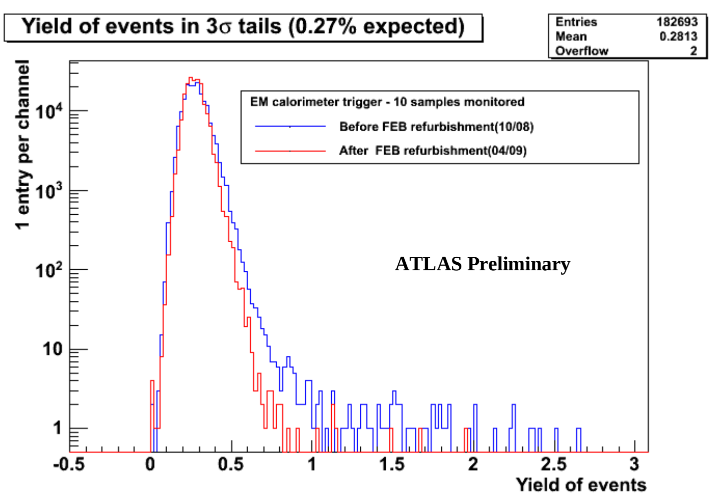


Figure 9: Percentage of events where a cell is found above 3 times its expected electronic noise. In blue, data from October 2008, where noisy shapers were affecting the data. In red, data taken in April 2009, after the front-end boards were repaired. The tails disappeared.

Figure 10 shows the number of cells with energy higher than 3 times the expected electronic noise. In December 2007 (Figure 10, top plot), a few tenths of events out of 3000 are located in non-Gaussian tails. In these events, a large number of cells exhibit a high energy fluctuation at the same time. The problem was found to be due to a 1 to

2 volts difference between the cryostat ground and the high voltage module ground (Figure 11). This grounding difference was degrading the performances of the filter box which is supposed to filter the coherent noise induced in the high voltage cables. This problem was fixed in January 2008 by adding a capacitive link between the high voltage filter box and the cryostat. After the intervention, the detector went back to a perfect Gaussian behavior (Figure 10, bottom plot).

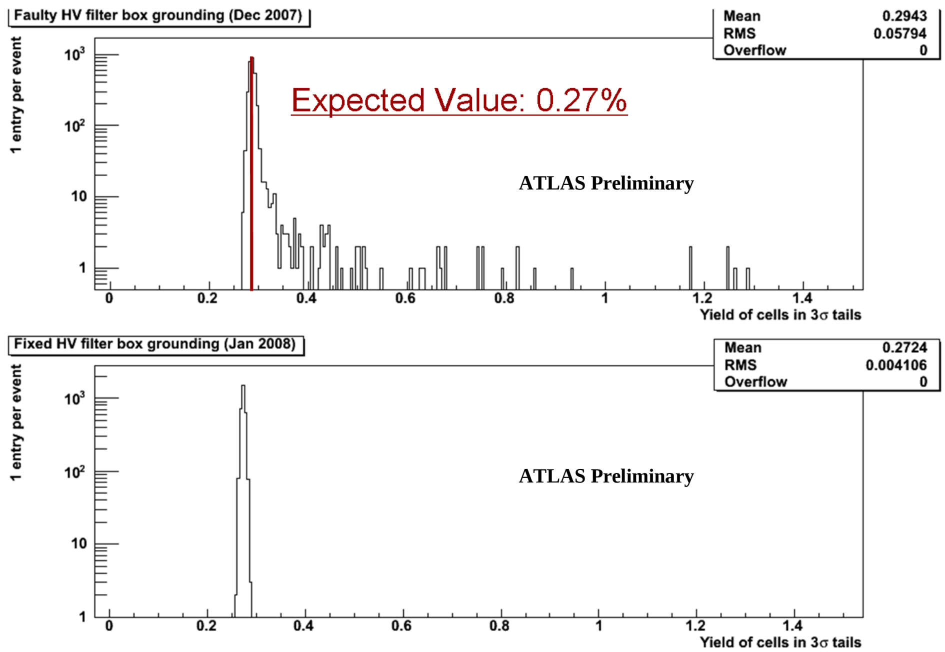


Figure 10: Percentage of cells above 3 times their expected electronic noise. On the top plot, large tails are due to coherent noise not properly filtered in high voltage cables. On the bottom plot, the source of the noise has been fixed, and a perfectly Gaussian behavior is observed, with an average of 0.27% of cells above the threshold per event.

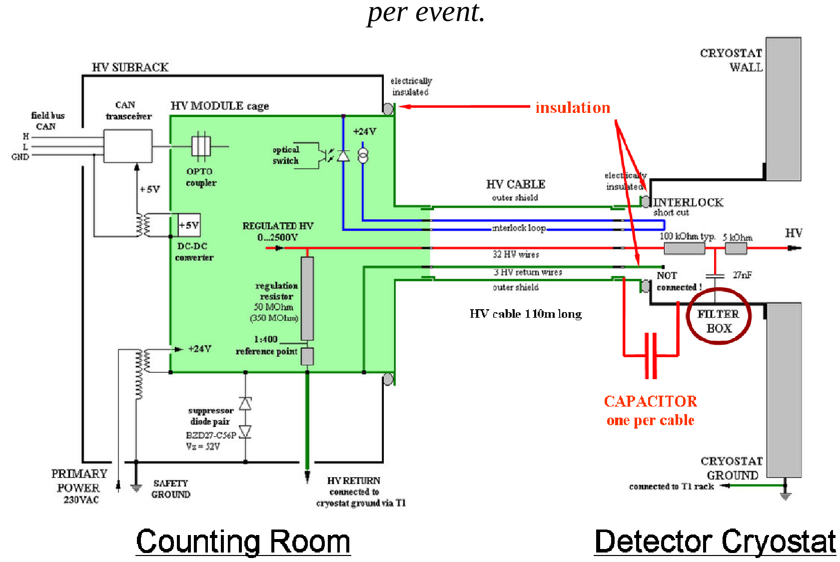


Figure 11: Schema of the grounding between the high voltage modules and the detector cryostat. The red arrows shows the faulty connections.

5. Conclusions

The liquid Argon Monitoring and Data Quality have been developed and tested with cosmic data since 2006 and extensively used to commission the detector. The liquid argon monitoring also provides meaningful information about timing to the others ATLAS sub-detectors. Today, the liquid argon detector is fully operational and in very good operating conditions, with 98.8% of its readout channels active and calibrated. The ATLAS liquid argon group is ready to take data and looking forward to see the first collisions!

References

1. W.E. Cleland and E.G. Stern, Signal processing considerations for liquid ionization calorimeters in a high rate environment, Nucl. Instrum. Meth. A 338 (1994) 467.

2. The ATLAS Collaboration G. Aad et al., The ATLAS Experiment at the CERN Large Hadron Collider, JINST 3 (2008) S08003. Calorimetry, Chapter 5.

3. A .Poy et al., The Detector Control System of the ATLAS experiment, JINST 3 (2008) P05006