Status of the Atlas Liquid Argon Calorimeter and its performance after three years of LHC operation

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The ATLAS experiment is designed to study the proton-proton collisions produced at the Large Hadron Collider (LHC) at CERN. Liquid argon sampling calorimeters are used for all electromagnetic calorimetry covering the pseudo-rapidity region up to 3.2, as well as for hadronic calorimetry in the range 1.4-4.9. The electromagnetic calorimeters use lead as passive material and are characterized by an accordion geometry that allows a fast and uniform azimuthal response without any gap. Copper and tungsten were chosen as passive material for the hadronic calorimetry; whereas a classic plate geometry was adopted at large polar angles, an innovative one based on cylindrical electrodes with thin argon gaps was designed for the coverage at low angles, where the particles flow is higher. All detectors are housed in three cryostats kept at 87 K. After installation in 2004-2006, the calorimeters were extensively commissioned over the three years period prior to first collisions in 2009, using cosmic rays and single LHC beams. Since then, around 27 fb$^{-1}$ of data have been collected at a center of mass energy of 7-8 TeV. During all these stages, the calorimeter has been operating almost optimally, with performances very close to the specification ones.
1. Introduction

The ATLAS detector [1] has been fully operational for three years of LHC operation, collecting over \(5 \text{ fb}^{-1}\) of proton-proton collision data at a centre-of-mass energy of 7 TeV and over 21 \(\text{fb}^{-1}\) at a centre-of-mass energy of 8 TeV. During this time, the Liquid Argon (LAr) calorimeters [2] have been operating almost optimally. LAr calorimeters contribute to a negligible fraction of the ATLAS on-line inefficiency and have developed very robust data quality procedures (Section 4).

2. The LAr calorimeter system

The LAr calorimeters (Fig. 1) are sampling calorimeters with liquid argon as the active medium. They cover the pseudorapidity range \(|\eta| < 4.9\) and provide energy measurements. The system is divided into four different sub-systems, contained in three separate cryostats; the barrel cryostat houses the Barrel electromagnetic calorimeter (EMB) while the two end-cap cryostats contain the electromagnetic end-cap (EMEC), the hadronic end-cap (HEC) and the forward calorimeters (FCAL).

The electromagnetic calorimetry is provided by the EMB (\(|\eta| < 1.475\)) and the EMEC (\(1.375 < |\eta| < 3.2\)). They were constructed following an accordion geometry with lead as the absorber material and are divided into three longitudinal layers (two for \(|\eta| > 2.5\) and a presampler (for \(|\eta| < 1.8\)). The hadronic calorimetry provided by the HEC complements the tile calorimeter, covers the pseudo-rapidity region \(1.5 < |\eta| < 3.2\) and it is comprised of four longitudinal layers with a parallel plate geometry that uses copper as the absorber. Finally, the FCAL covers the region \(3.1 < |\eta| < 4.9\) and is divided into three modules with a geometry consisting of rods positioned concentrically inside tubes parallel to the beam axis supported by a metal matrix and equipped with a very narrow liquid argon gap (needed to withstand the particle fluxes in that region). The absorber is made out of copper for the module closest to the interaction point and tungsten for the rest.

Figure 1: The ATLAS Liquid Argon calorimeter [2].
2.1 Liquid Argon monitoring

To work with liquid argon based calorimeters, it is paramount to have a very good monitoring of the various properties that can have an effect on both the ionisation and the charge collection, namely, the temperature and the purity.

Variations of the liquid argon temperature have an effect on the energy response, which decreases 2% for each degree Kelvin increase. To monitor any change, there are 508 PT100 probes immersed into the liquid argon. The distribution of the average temperature measured over ten days for temperature probes within the EMB cryostat is shown in Fig. 2 (left) which shows an inhomogeneity well below the specification requirements (<100 mK).

Electronegative impurities can lead to a reduction of the signal; there are 30 purity monitors, read out every 10-15 minutes to control the purity. The stability of the system is shown on Fig. 2 (right), which demostrates that the impurity is always very stable and well below the required values.

![Temperature Distribution](image)

**Figure 2:** (left) Distribution of the average temperature measured over ten days for temperature probes within the EM Barrel cryostat [3]. (right) Impurity levels in O\textsubscript{2} equivalents for EMBA. Each point represents the average value measured over a single day [3].

3. Signal readout and working principle

Ionisation from charged particles crossing the liquid argon gap in the calorimeters drifts through a high electric field generated by the high-voltage (HV) system between the absorber plates and readout electrodes (Fig. 3 (left)). This produces a triangle shaped ionisation pulse shown in Fig. 3 (right). This signal is then processed by front-end boards where it is transmitted through two paths, an analog one which is used for the Level 1 calorimeter trigger system and a digital one which is used for physics reconstruction. In the digital path the signal is shaped with a bipolar filter [1], split into three overlapping linear gain scales, in order to meet the large dynamic range required for the expected physics signals, digitised, and finally transfered to the Back-End electronics housed outside the experimental cavern. The amplitude and timing of the signal are obtained with the formulae
\[ A = \sum_{i=1}^{N} a_i (s_i - p) \quad \text{and} \quad \tau = \sum_{i=1}^{N} \frac{1}{A} b_i (s_i - p), \]  

(3.1)

where \( N \) is the number of samples (usually five for data taking), \( s_i \) are the digitised samples in ADC counts, \( p \) are the pedestals and \( a_i \) and \( b_i \) are calculated according to an optimal filtering algorithm that optimises the resultant energy and timing resolution \([4]\).

Calibration boards, housed in the front-end crates, take care of the calibration of the electronics by injecting a well known exponential pulse in the system that can be read back using the regular readout chain. There are three types of calibration runs; Pedestal runs, taken without injecting any signal into the system, Ramp runs, where the timing of the pulses injected is held fixed and the amplitude is mapped, and Delay runs, where the amplitude is kept fixed and the pulses are injected with various delays with respect to the sampling clock. Using the data from this calibration sets it is possible to compute the optimal filtering coefficients and the rest of the constants needed to reconstruct the energy.

![Diagram of the barrel structure and pulse shapes](image)

**Figure 3:** (left) Accordion structure of the barrel. The top figure is a view of a small sector of the barrel calorimeter in a plane transverse to the LHC beams. Honeycomb spacers, in the liquid argon gap, position the electrodes between the lead absorber plates \([5]\). (right) Pulse shape before and after shapers \([1]\).

4. Data quality monitoring

Data quality for the LAr calorimeters has been in constant improvement since the early periods of data taking; more than 99\% of the data taken during the 2012 proton-proton campaign are suitable for analysis (to be compared with approximately 90\% in 2010 and approximately 97\% in 2011), with the main sources of data loss being HV trips (0.46\%) and noise bursts (0.2\%).

If a HV line trips, some data are lost since the HV values are varying too quickly to be accounted for properly. To reduce the impact of these trips on data taking several steps have been
taken, such as reducing the HV on problematic lines and installing innovative modules in problematic regions. These modules can switch to current-controlled mode in the case of a trip, avoiding the voltage drop and therefore the data loss. Fig. 4 (left) shows the evolution of the data loss associated to HV trips during 2012.

Noise bursts occur when many cells in a region of the calorimeter give large signals with distorted shapes for a very brief period of time (mostly below 5 µs). The source of the noise is not fully understood, it manifests itself only in the presence of collisions and is known to scale with instantaneous luminosity. A useful variable for the description of noise burst events is $Y_{3\sigma}$, which represents the yield of channels with a signal greater than three times the electronic noise measured in LHC empty bunches, in between the proton bunch trains; it is expected to peak around 0.13% in absence of coherent noise. Hard noise effects (high $Y_{3\sigma}$) can efficiently be flagged using pulse quality based flags (quality factor), but softer noise bursts are not; the latter are usually peripheral to a hard noise burst. To improve the rejection of these softer events, a time window veto procedure is established, which vetoes events in a window of 250 ms around hard noise bursts. The efficiency of this method, shown in Fig. 4 (right), is very high, inducing only marginal data loss.

![Figure 4: (left) Evolution of the HV associated data loss during 2012 [6]. (right) Distribution of the percentage of noisy channels in the EMEC, measured with LHC empty bunches [6].](image)

References


