Performance of the ATLAS liquid argon calorimeter

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The liquid argon calorimeter (LAr) [1] of the ATLAS detector [2] measures energy deposited by particles produced in p-p collisions at the CERN Large Hadron Collider (LHC). Figure 1 illustrates the LAr system. It consists of the electromagnetic calorimeter (EM), the hadronic end-cap (HEC) and the forward calorimeter (FCAL). The material utilized for collecting signal is liquid argon. The absorber consists of lead in the EM, copper in the HEC and the first layer of the FCAL and tungsten alloy in the outer two layers of the FCAL. Copper electrodes, electronic boards and various support structures constitute additional material in the calorimeter.

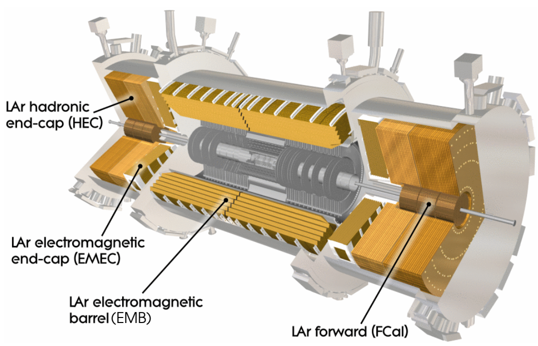

Figure 1: Schematic view of the liquid argon calorimeter system.

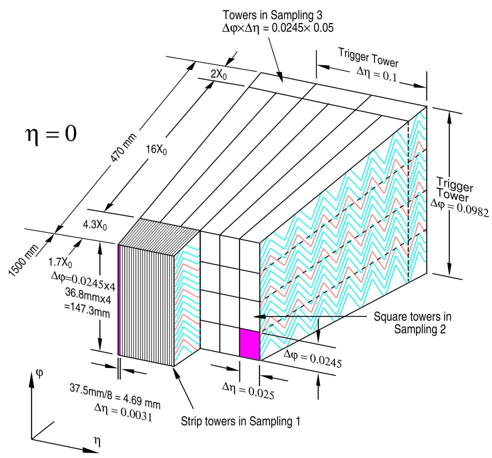

Figure 2: Readout granularity of the EM calorimeter.

The LAr is a sampling calorimeter with fine granularity, especially in the first EM layer, large coverage in $|\eta|$, up to $|\eta| = 4.9$, and full coverage in ϕ. Figure 2 illustrates the granularity of the EM calorimeter [3]. The design energy resolutions for each LAr sub-detector are listed in Table 1.

Ionization electrons are produced by passage of charged particles. They drift to electrodes and produce electrical currents proportional to the energy deposited. The currents have triangular shapes that are amplified, shaped and then sampled $N_{samples}$ (default is 5) times every 25 ns. Each sample is then digitized. The triangular signal has a $\sim$1 ns rise time and several hundreds ns decay time (T_{drift}). The drift time in the barrel region of the calorimeter has a constant value ∼460 ns. Smaller values in the end-caps reflect gap width decreasing with $|\eta|$ [4].

The ionization signal shape can be predicted by modeling of the electronic readout chain. The ionization signal shape is predicted by describing the signal propagation and the response of the electronic readout, that are determined or tuned by the calibration system [4]. A calibration pulse of precisely known amplitude is injected into each cell through the same path as seen through the ionization pulse so probing the electrical and readout properties of each cell. Figure 3 illustrates the agreement of the measured signal shape and the predicted one. The difference is less than 4% [5].

	Resolution
EM Barrel	$\frac{\sigma_E}{E} = \frac{10\%}{\sqrt{E}} \bigoplus 0.7\%$
EM End-Cap	$\frac{\sigma_E}{E} = \frac{10\%}{\sqrt{E}} \bigoplus 0.7\%$
HEC	$\frac{\sigma_E}{E} = \frac{50\%}{\sqrt{E}} \bigoplus 3\%$
FCAL	$\frac{\sigma_E}{E} = \frac{100\%}{\sqrt{E}} \bigoplus 10\%$

Table 1: Design energy resolutions of the LAr calorimeters.

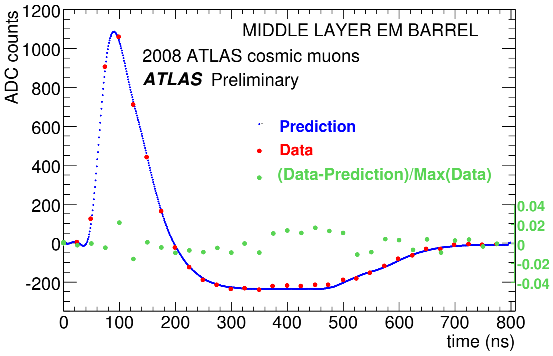

Figure 3: Typical ionization pulse shape in the EM barrel.

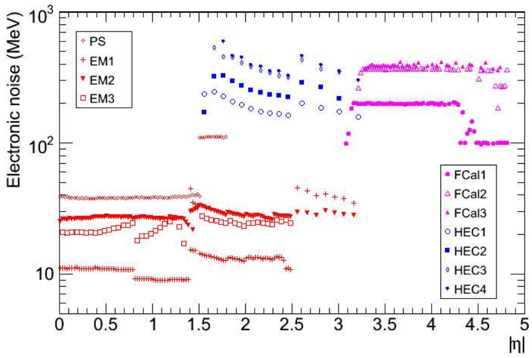

Figure 4: Electronic noise at cell level as a function of $|\eta|$ for each longitudinal layer of the calorimeter.

The individual cell energy is reconstructed from the digitized signal according to the formula:

$$E_{cell} = F_{\mu A \to MeV} \times F_{DAC \to \mu A} \times \left(\frac{M_{phys}}{M_{cali}} \right)^{-1} \times G \times A\,, \tag{1}$$

where A is the amplitude in ADC counts, G represents the gain, $\frac{M_{phys}}{M_{cali}}$ is a correction for the difference of the maxima between the injected and the ionization pulses, $F_{DAC \to \mu A}$ converts current in DAC units to μA and $F_{\mu A \to MeV}$ converts current to energy.

Pedestal, gains and noise are parameters used in the energy reconstruction. Their determination is very important since they affect signal to background ratio and energy resolution.

Pedestal is obtained from runs taken without any beam or calibration pulse injection. Average pedestal is computed for each cell in every run. Gains are obtained from calibration runs. In these runs, a set of fixed current DAC is injected into each cell N times, in which M≤N events are triggered, sampled and digitized. Average response of the M events for each sample is calculated and used to reconstruct the maximum amplitude of the pulse. Gains are obtained by fitting the maximum amplitude as a function of DAC. Stability of the pedestal and gain studied during 6 months in 2009 shows good results. The largest variation of pedestal is 10 MeV from the medium gain in the FCAL. The relative variation of the gain is within 0.3% [5].

Electronic noise (σ_{noise}) as a function of η obtained from randomly triggered events is shown in Figure 4. The noise ranges from 10 to 50 MeV in the EM calorimeter, and from 100 to 500 MeV in the HEC and the FCAL where the size of cells is much larger than that in the EM calorimeter.

The readout clock of each LAr cell must be synchronized to the LHC bunch crossing in order to reconstruct correct energy for every event. Alignment of timing-in for all the LAr cells within 1 ns is required. Measurements of the timing alignment performed in different data taking periods show that the LAr cells are in time as required.

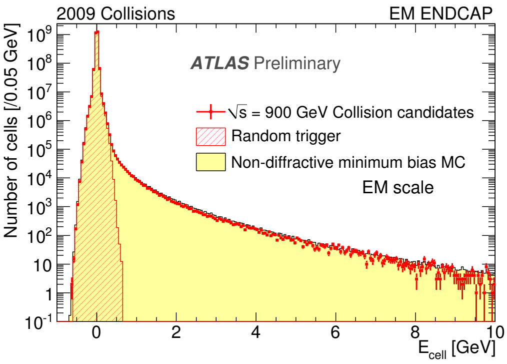

Figure 5: Cell energy distribution for collision events in the EM end-cap calorimeter.

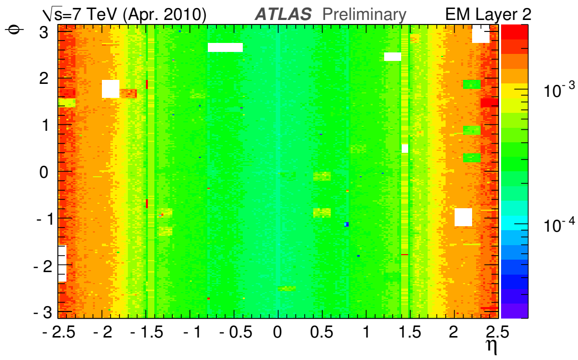

Figure 6: Cell occupancy map in the EM calorimeter with 7 TeV collision data.

Since the delivery of collision data started in 2009, various performance studies have been done. Figure 5 illustrates the cell energy distributions in the EM end-caps. Random trigger events record mainly cell noise. Good agreement between the data and simulated signal due to collision events is observed. Figure 6 illustrates the occupancy map for the second layer of the EM calorimeter. Cell energy larger than 5 σ_{noise} is plotted. White rectangles correspond to the ~1.3% dead readout channels [5].

In addition to the studies of LAr performance discussed above, the temperature uniformity and contamination of the liquid argon were also checked. The measured values are all consistent with design. No extra contribution has been found to global resolution constant term [5].

References

[1] ATLAS liquid argon calorimeter: Technical design report, The ATLAS Collaboration, CERN-LHCC-96-41 (1996) [http://cdsweb.cern.ch/record/331061?ln=pt]

[2] G Aad et al, "The ATLAS Experiment at the CERN Large Hadron Collider, The ATLAS Collaboration" JINST 3 (2008) S08003 [http://cdsweb.cern.ch/record/1125884]

[3] Calorimeter Performance Technical Design Report, The ATLAS Collaboration [http://atlas.web.cern.ch/Atlas/TDR/caloperf/caloperf.html]

[4] G.Aad et al., Drift Time Measurement in the ATLAS Liquid Argon Electromagnetic Calorimeter using Cosmic Muons, The ATLAS Collaboration, Accepted by EPJC [http://arxiv.org/abs/1002.4189]

[5] G.Aad et al., Readiness of the ATLAS Liquid Argon Calorimeter for LHC Collisions, The ATLAS Collaboration, Accepted by EPJC [http://arxiv.org/abs/0912.2642]