Electronic calibration of the ATLAS LAr calorimeter

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Outline

Description of the LAr calorimeters

Signal generation, readout and energy computation at cell level

Description of the calibration procedure :

- The calibration constants
- The chain to reconstruct them
- Their stability

LHC strategy running

Conclusions

The ATLAS LAr calorimeters

- The LAr Calorimeters:
 - EM Barrel : ($|\eta| < 1.475$) [Pb-LAr]
 - EM End-caps : $1.375 < |\eta| < 3.2$ [Pb-LAr]
 - Hadronic End-caps: $1.5 < |\eta| < 3.2$ [Cu-LAr]
 - Forward Calorimeter: $3.1 < |\eta| < 4.9$ [Cu,W-LAr]
- are *sampling* calorimeters:
 - LAr is the “active” medium
 - Signal is the current generated by the ionization electron moving in the electrical field generated by the HV in the LAr “gap”
- ... and we have a lot ($\sim 182k$) of readout channels

The ATLAS Liquid Argon electromagnetic Calorimeter

- 1 barrel
- 2 endcaps (inner & outer wheels)
- Lead absorbers in a liquid argon bath at 88.5K
- Hermetic coverage in ϕ due to its accordion geometry
- Longitudinal segmentation & fine granularity: (for example in the barrel)
 - S0 : presampler
 - S1 : front ($\sim 4 X_0$, $\eta \times \phi$: $0.025/8 \times 0.1$)
 - S2 : middle ($\sim 16 X_0$, $\eta \times \phi$: 0.025×0.025)
 - S3 : back ($2-12 X_0$, $\eta \times \phi$: 0.05×0.025)
- $\sim 173k$ channels in EM calorimeter

The ATLAS Forward and Hadronic Calorimeters

Forward Calorimeter (FCal) :

Per endcap : 1762 cells, 3 wheels (10λ)

- Cu matrix for the first wheel (2.6λ , $28X_0$)
- W matrix for the other two wheels ($2 \times 3.7\lambda$)
- LAr gap FCAL 1/2/3: 250/375/500 μm

Hadronic Endcap Calorimeter (HEC) :

Per endcap : 2816 cells, 2 wheels (10λ)

- Cu absorbers (25mm/50mm thick)
- Each gap consists of 4 sub gaps of 1.85mm

FCal End View

Since the geometry is different from the Electromagnetic Calorimeter, the ionization signals are slightly different...

Requirements on the EM calorimeters

Large acceptance (accordion),

Particle identification (fine granularity & longitudinal segmentation)

Good energy resolution:

- stochastic term : $\sim 10\%/\sqrt{\text{GeV}}$
 - noise term : 180 MeV for EM clusters at low luminosity
 - constant term : 0.7%
- The electronics calibration plays an important role ($\sim 0.25\%$). It is used to obtain calibration constants for physics running (calibration runs in between LHC fills → constants **used online** for energy computation). In addition, it helps to find malfunctioning channels during commissioning.

[less stringent requirements on hadronic calorimeters :

HEC: $\sigma/E = 50\%/\sqrt{E} + 3\%$

FCal : $\sigma/E = 100\%/\sqrt{E} + 10\%$]

From energy deposit to ADC counts

Energy is computed online!

Front End Boards on-detector:

- Dynamical range: 30MeV to 3TeV
- 12bit ADC
- 3 different amplifiers : $\sim 100:10:1$
- Bipolar shaping
- Analog storage during L1-trigger latency
- Digitization at 40 MHz
- Readout up to 75 kHz

Readout drivers off-detector:

- Calculate **Energy**, (and above threshold E_1 : Time and Quality)
- Perform data-integrity checks & higher-level monitoring

Above a certain threshold E_2 , the 5 samples will be transmitted in addition to Energy, Time & Quality

From ADC counts back to energy

ADC to DAC (Ramps)

$$E_{\text{cell}} = \underbrace{F_{\mu A \rightarrow \text{MeV}}}_{\text{Energy}} \cdot \underbrace{F_{DAC \rightarrow \mu A}}_{\text{Sampling fraction}} \cdot \underbrace{\frac{1}{\frac{M_{\text{phys}}}{M_{\text{cali}}}}}_{\text{Calibration board}} \cdot \underbrace{R}_{\text{Optimal Filtering Coefficients}} \left[\sum_{j=1}^{N_{\text{samples}}} \underbrace{a_j}_{\text{Optimal Filtering Coefficients}} \left(\underbrace{s_j}_{\text{Pulse Samples}} - \underbrace{p}_{\text{Pedestals}} \right) \right]$$

The optimal filtering coefficients

The Optimal Filtering (OF)

{ signal maximum amplitude
temporal position

$$A_{max} = \sum_{i=1}^n a_i (S_i - p) \quad \Delta t = \frac{\sum_{i=1}^n b_i (S_i - p)}{A_{max}}$$

Optimal Filtering Coefficients (OFC), $\mathbf{a}_i$ and $\mathbf{b}_i$ are evaluated while minimizing the dispersion in A_{max} and Δt arising from electronics and pile-up noise.

- OF is faster than a fit $\rightarrow$ important for online computation
- OF takes into account the time autocorrelation of noise
- Using 5 samples, the electronic noise is reduced by a factor ~ 1.7 with respect to a readout with only 1 sample

Need to know signal shape and the auto-correlation matrix for every cell

Calibration of the electronic response

A known **exponential** current pulse is injected **at the MB level** and reconstructed through the full readout chain. The actual gain of each readout channel is computed.

Calibration system installed on-detector:

- Charge injected very close to electrode.
- Dynamic range 16 bits.
- non linearity < 0.1%.

The shaper output of the ionization and calibration signal corresponding to the same injected current is different!

The ionization pulse is predicted by factorisation of the readout response or by analytical model

M_{phys}/M_{cali}

Electronic calibration constants

pedestals and noise

FEB are read with no input signal to obtain:

- Pedestal
- Noise
- Noise autocorrelation (OFC computation)

ADC $\rightarrow$ MeV conversion

$$F = \text{ADC2DAC} \times \text{DAC2}\mu\text{A} \times \mu\text{A2MeV}$$

- Scan input current (DAC)
- Fit DAC vs ADC curve with a first (higher) order polynomial, outside of saturation region

response to current pulse

All cells are pulsed with a known current signal:

- A delay between calibration pulses and DAQ is introduced
- The full calibration curve is reconstructed ($\Delta t = 1.04\text{ns}$)

Computation of the calibration constants

Constant stability

Take frequent sets of calibration data:

Pedestal-Gains-Pulses

Automatic processing,
validation vs reference and
production of new
constants ready for Data
Base. Update it if needed.

In smooth running conditions (i.e. stable temperature, cooling..) :

$$\Delta_{\text{pedestal}} < 1 \text{ MeV}$$

$$\Delta_{\text{pulse}} < 0.1\%$$

⇒ No DB update!

LHC running strategy

At each LHC turnaround (~every 8h) :

- Take “pedestal” and “ramps” runs
- Reconstruct them and verify the stability
- If needed, upload the new condition constants into offline/online Data Base, take “Delay” run and compute the “OFC Physics”

If everything is stable, once per week :

- Check the stability of the calibration pulse shape, study the jitter
- Take special “pedestal” runs to study coherent noise

During physics runs:

- Monitor pedestal with random trigger
- Take special stream of data to monitor real ionization pulse
- Measure pileup + electronics autocorrelation matrix with minimum-bias event and/or random trigger

Conclusions

- Calibration measurements (and cosmic muon data) are used successfully to commission LAr detector
- Complex formula to compute the energy of the cell :
 - Used online
 - Different ingredients mainly obtained from calibration runs
 - Monitoring of the constants, stability expected
 - Strategy for LHC running
- Electronics calibration is a key element to achieve a good energy resolution.

Back-up

“Problematic” channels

- 0.02% dead or **very noisy channels** → Masked in reconstruction

- ~0.5% Channels with minor problems :

- increased noise
- **damaged calibration lines**

Patched with their average in ϕ
(negligible impact on physics)

- <6% of HV channels **at reduced voltage**, but sufficient voltage for usable signals in all cases

Effect on Drift Time and
conversion $\mu\text{A} \rightarrow \text{MeV}$ factor

HV EM Correction

ATLAS Preliminary

The ATLAS Electromagnetic Calorimeter (EMC)

$t_{\text{drift}} = \sim 450 \text{ ns}$ in the EM, varies in the EMEC

- Accordion shape in EM barrel (EMB) and end cap EM calorimeters (EMEC)
 - ✓ $> 22X_0$
- 2 wheels (16 modules) in the EMB and 1 wheel (8 modules) per EMEC
- Main advantages
 - ✓ LAr as active material inherently linear
 - ✓ Hermetic coverage (no cracks)
 - ✓ Longitudinal segmentation
 - ✓ High granularity (Cu etching)
 - ✓ Inherently radiation hard
 - ✓ Fast readout possible

LAr EMC: granularity and segmentation

For $|\eta| < 1.8$ a **PreSampler** is located in front of the EMC to correct for energy loss

Longitudinal sampling (barrel)

- S1 (Strips) γ/π^0 separation
- S2 (Middle) main energy deposit
- S3 (Back) high energy showers, had/em separation

Xtalk in the strips

Data, calculation

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LAr readout electronics

$$E_{\text{cell}} = F_{\mu\text{A} \rightarrow \text{MeV}} \cdot F_{\text{DAC} \rightarrow \mu\text{A}} \cdot \frac{1}{\frac{M_{\text{phys}}}{M_{\text{cali}}}} \sum_{i=1}^{M_{\text{ramps}}} R_i \left[\sum_{j=1}^{N_{\text{samples}}} a_j (s_j - p) \right]^i$$

Cell energy (yellow box) Sampling fraction (orange box) Calibration board (grey box) Optimal Filtering Coefficients (red box) Pedestals (green box)

ADC to DAC (Ramps) (purple box) Pulse Samples (yellow box)

The above formula describe the LAr electronic calibration chain (from the signal ADC samples to the raw energy in the cell. Note that this version of the formula uses the general M_{ramps} -order polynomial fit of the ramps. Actually we just use a linear fit (electronic is very linear, and additionally we only want to apply a linear gain in the DSP in order to be able to undo it offline, and apply a more refined calibration). In this case, the formula is simply:

$$E_{\text{cell}} = F_{\mu\text{A} \rightarrow \text{MeV}} \cdot F_{\text{DAC} \rightarrow \mu\text{A}} \cdot \frac{1}{\frac{M_{\text{phys}}}{M_{\text{cali}}}} \cdot R \left[\sum_{j=1}^{N_{\text{samples}}} a_j (s_j - p) \right]$$

List of the ingredients

Pedestals

- ✓ Computed from a **Pedestal run**, it is the average of the triggers at a given sample...

Noise

- ✓ Computed from a **Pedestal run**, it is the RMS of the triggers at a given sample...
 - Used in topological clustering...

Noise Autocorrelation

- ✓ Computed from a **Pedestal run**, it is the correlation of the different samples...
 - Can come from electronics and/or pileup

Ramps

- ✓ Computed from a **Ramp run**, measure the gain slope...
- ✓ *Ramp reconstruction needs the Pedestal to be subtracted, to be read from DB*
- ✓ *Ramp reconstruction needs the Calibration OFC to reconstruct signal peak corresponding to given DAC*
 - *Calibration OFC are computed from Delay pulses and electronic noise Autocorrelation*

uA2MeV

- ✓ Obtained from simulation

DAC2uA

- ✓ Contains the R_{inj} value...

Calibration pulse shape

- ✓ Obtained from a **Delay run**...
- ✓ *Delay reconstruction needs the Pedestal to be subtracted, to be read from DB*

Physics pulse shape

- ✓ May be predicted from the relative calibration pulse by several means...

Optimal Filtering Coefficients

- ✓ Computed from:
 - The "normalized" pulse shape (and derivative) for a given channel
 - The noise autocorrelation matrix for a given channel

Prediction of the physics signal

RTM Method

“Factorization of the readout response”

The readout response of each cell is probed by the calibration pulses, and directly transferred to the physics pulse prediction

- The cell and pulse parameters ($f_{\text{step}}, T_{\text{cali}}, rC, LC$) are completely obtained from the calibration pulses
 - The only additional parameter required is T_{drift} (now from calculation, can be refined when enough data is collected)
- **This method was successfully used in 2004 Test beam and is the default in the commissioning**

FPM Method

"Analytical model of the readout response"

- Uses measured parameters where possible
- A few parameters (T_{shaper}, Z_s) are left free to vary in order to match the measured calibration pulse response thus absorbing residual effects absent in the model

→ **Currently, available only in the barrel**