ATLAS Tile Calorimeter time calibration, monitoring and performance

(additional material)

Michaela Mlynarikova (NIU)
on behalf of the ATLAS Tile Calorimeter System

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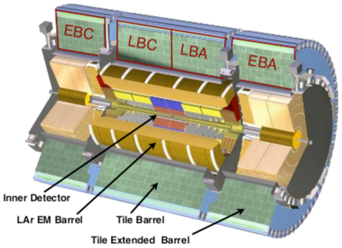
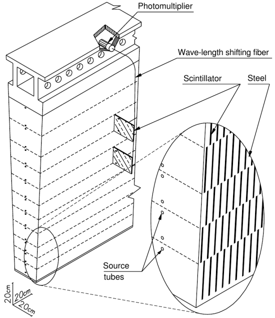
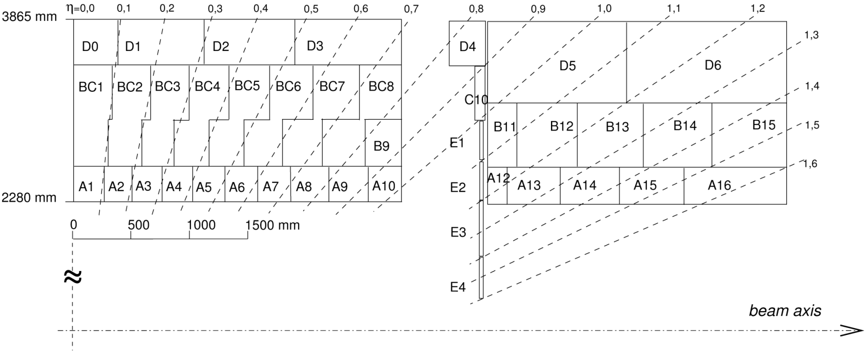
ATLAS Tile Calorimeter

- Measures energies of hadrons, jets, τ-leptons and contributes to the E_T^{miss} reconstruction
- 4 partitions: EBC, LBC, LBA, EBA
  - LBC and LBA form Long barrel (LB) $\rightarrow$ coverage: $|\eta| < 1.0$
  - EBC and EBA form Extended barrel (EB) $\rightarrow$ coverage: $0.8 < |\eta| < 1.7$
- Each partition has 64 modules $\rightarrow$ to achieve full azimuthal coverage around the beam axis
  - One module hosts up to 48 photomultiplier tubes (PMTs), as shown on the bottom plot
- Sampling calorimeter built from plastic scintillator tiles and steel absorber plates
- A particle traversing the detector generates light in the scintillators, which is collected on both sides of the tile and further transported to the PMTs by wavelength shifting fibres
- Around 10.000 readout channels





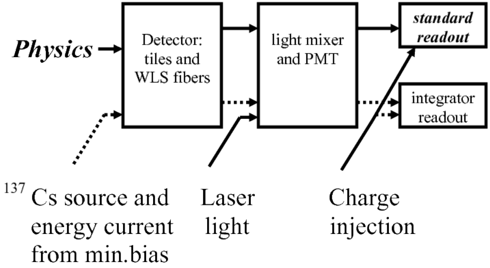
Readout cells geometry



- The readout cell geometry is given by a group of wavelength shifting fibres from individual tiles coupled to PMTs
- Usually, a cell is read out by two PMTs, with each corresponding to a single channel
  - The cell energy is then reconstructed as the sum of energies measured by two channels
- The radial segmentation divides the module into three layers – A, BC (B in the EB), D
  - Layers comprise of cells with different dimensions
  - Dimensions of A and BC cells are $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$
  - Dimensions of D cells are $\Delta\eta \times \Delta\phi = 0.2 \times 0.1$

Calibration

- Tile Calorimeter uses 3 dedicated calibration systems, each of them covering different stage of signal processing:
  - Cesium
  - Laser
  - Charge injection



- More details about TileCal calibrations and performance in dedicated talk by Siarhei Harkusha on Wednesday afternoon

Signal reconstruction

- The analog signal from each PMT is shaped and split into two branches (high- and low-gain, gain ratio 64:1) to ensure both good signal-to-noise ratio for small signals (e.g. from muons) and large dynamic range up to $\sim$ 800 GeV in each channel
- Each pulse is then sampled every 25 ns and the signal amplitude (A) and time (t_0) are reconstructed, several methods available:

- Fit method: fitted by a function

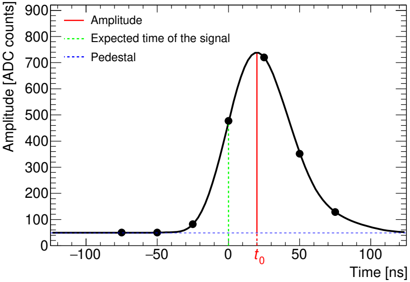
$$f(t) = A * g(t - t_0) + \text{Ped},$$

where $g(t)$ is known normalized pulse shape

- Optimal Filtering method: weighted sum of measured samples, designed to minimize the noise

$$A = \sum a_i S_i,$$

$$t_0 = \frac{1}{A} \sum b_i S_i$$

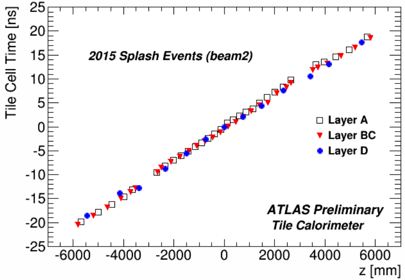


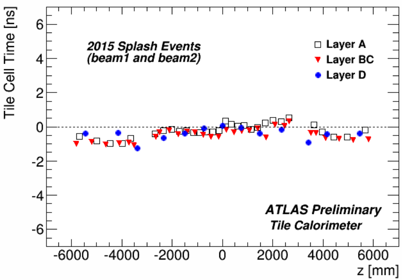
Time calibration motivation and overview

- The time calibration is important for the energy reconstruction as well as for the time measurement
- The time measurement is exploited in
  - Event & object selection – non-collision background can be removed also based on the time information (e.g. jet cleaning)
  - Specific physics analyses – searches for heavy R-hadrons decaying in calorimeters, the corresponding signal would be delayed from that of standard jets
- Calibration procedure
  - The time calibration aims to set the channel time calibration constant in such a way, that a particle traveling from the interaction point at the speed of light gives a signal with measured time $t_0 = 0$
  - During Run-2, the initial time constant settings was performed using high-energy muons (parallel to the beam axis), which originate from single beam events hitting closed collimator upstream of ATLAS detector (so called splash events, not available each year)
  - After the first collisions, time calibration constants are fine-tuned exploiting jet events

Time calibration with splash events

- The single beam events are used by detectors for calibrations and are usually organized in the beginning of LHC data-taking period
- Many high energy muons enter the calorimeter parallel to the beam axis, producing very large signal in all calorimeter cells
  - Data averaged over cells with same azimuth (ϕ)
  - Slope matches the time particles need to cross the calorimeter in z-direction (left)
- Due to large signals, time is precisely measured and, after correcting for time-of-flight (right), the time constants are derived for each channel



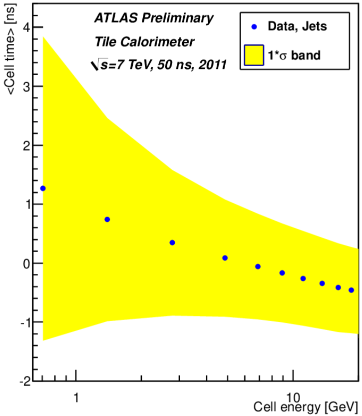


Time calibration with jets

- In collision data, we exploit only cells that are part of reconstructed jets (to avoid possible bias from non-collision background etc)

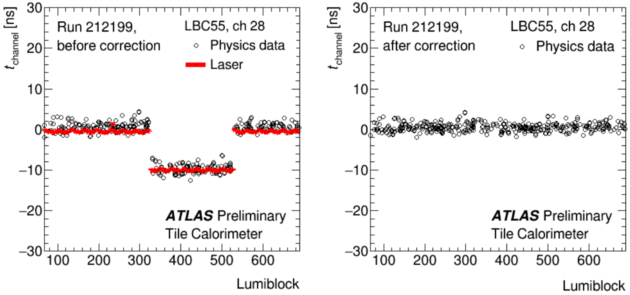
- The cell time slightly depends on cell energy, due to slow neutrons/hadronic component of the shower

- Therefore, a certain energy-bin is used to calibrate the time in each channel ($2 < E_{\text{channel}} < 4$ GeV), chosen as a trade-off between statistics and Gaussian shape of the time spectrum



Time stability monitoring motivation and overview

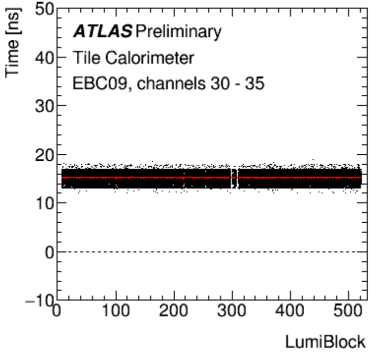
- Especially in Run-1, TileCal suffered from frequent sudden changes of the time settings (mostly associated to module mis-configuration after the power restart), as demonstrated in the left plot
- Hence, two monitoring methods were developed
  - Using laser events shot during empty LHC bunch-crossings
  - Using jet events from collision data, similarly to the calibration

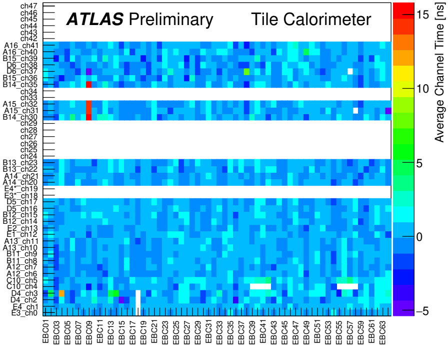


- Results from the monitoring are available shortly after the data are taken, so time constants can be corrected before the data are processed for the physics analyses (right plot)

Time stability monitoring

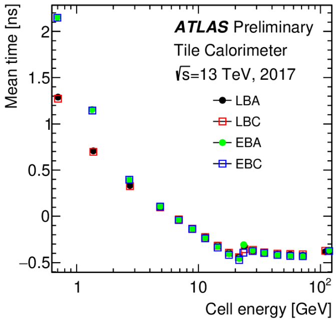
- The tool exploiting jet events evaluates the mean channel time from events where the corresponding cell is associated to a jet
- Monitoring plots using laser events (left) and jets (right) are perfectly compatible

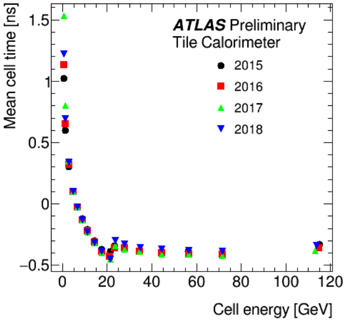




Time performance in Run-2

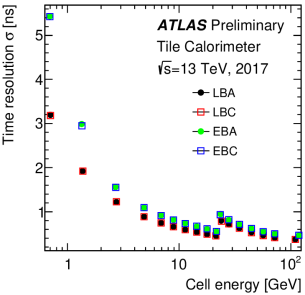
- *pp* collision data at $\sqrt{s} = 13$ TeV are used for performance studies
- All Tile Calorimeter cells belonging to reconstructed jets with $p_{\mathrm{T}} > 20$ GeV are considered, after applying the usual event and jet cleaning procedures
- The region close to 22 GeV corresponds to the high-/low-gain channel readout transition
- Plots show the mean cell time in jet events as a function of the energy deposited in cells (per partition, 2017 - left plot, all partitions combined - right plot)
  - The mean cell time slowly decreases with deposited energy due to neutrons/slow hadronic component of the hadronic showers

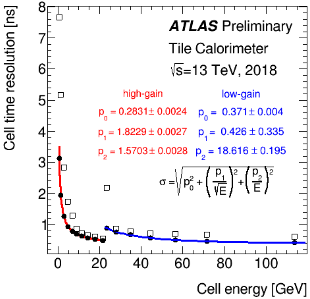




Cell time resolution in jet events

- Results per partition shown in the left plot, slightly worse resolution obtained in EBA and EBC due to larger cells
- Results from four partitions combined are shown in the right plot
  - The closed circles correspond to Gaussian σ the open squares indicate the RMS of the underlying time distributions
  - The resolution is fitted with the displayed formula for high- and low-gain separately, as indicated with red and blue curves
  - Resolution is better than 1 ns for $E_{\text{cell}} > 4$ GeV; constant term $\sim$ 280 ps and $\sim$ 370 ps for high- and low-gain, respectively



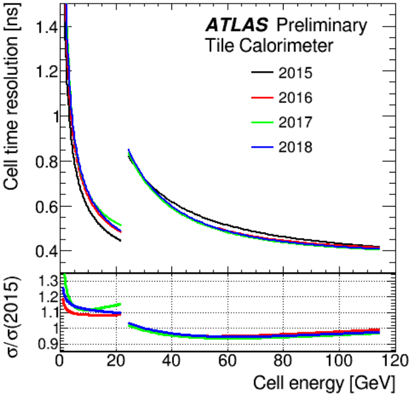


Cell time resolution comparison

- Fits of the cell time resolution in jet events (*pp* data at $\sqrt{s} = 13$ TeV) as a function of the cell energy are shown for each year
- The resolution is fitted with the formula

$$\sigma = \sqrt{p_0^2 + \left(\frac{p_1}{\sqrt{E}}\right)^2 + \left(\frac{p_2}{E}\right)^2},$$

  separately for the high- and low-gain
- In the high-gain, the differences among the years arise from different pile-up conditions
- The improved low-gain calibration procedure was implemented in 2016 and it brings better time resolution even with higher pile-up
- The bottom panel shows the fitted time resolution relative to that obtained in 2015



Conclusions

- Tile Calorimeter channel time calibration is performed each year at the beginning of data taking using beam splash events and jet collision data
- The time calibration is monitored during the data taking using the laser calibration system and jet collision data, hence the time constants can be corrected before the data are processed for physics analyses
- In jet events, the mean cell time slightly decreases with energy deposited in cells
- The time resolution improves with energy and the constant term approaches ~ 280 ps and ~ 370 ps for high- and low-gain, respectively
- Time calibration showed stable performance under varying conditions during the LHC Run-2