ATLAS Tile Calorimeter
Time Calibration, Monitoring and Performance

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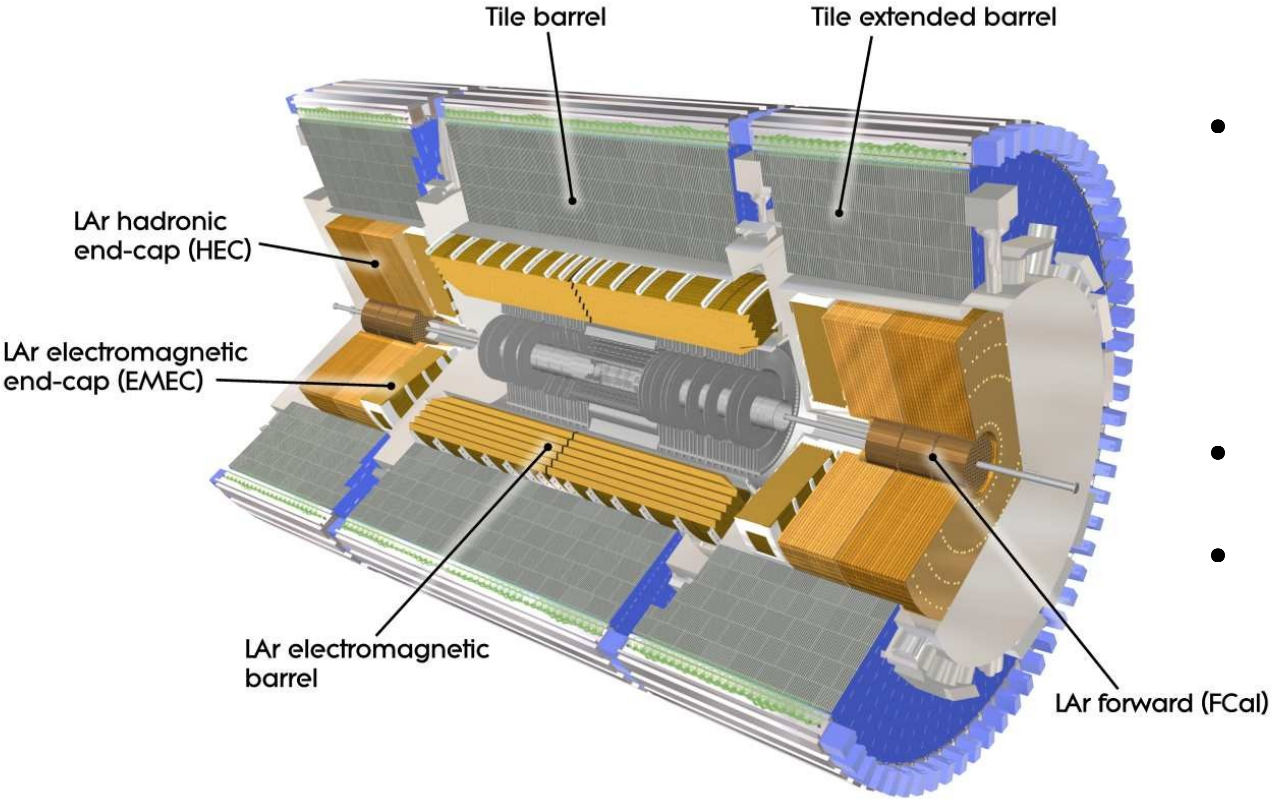
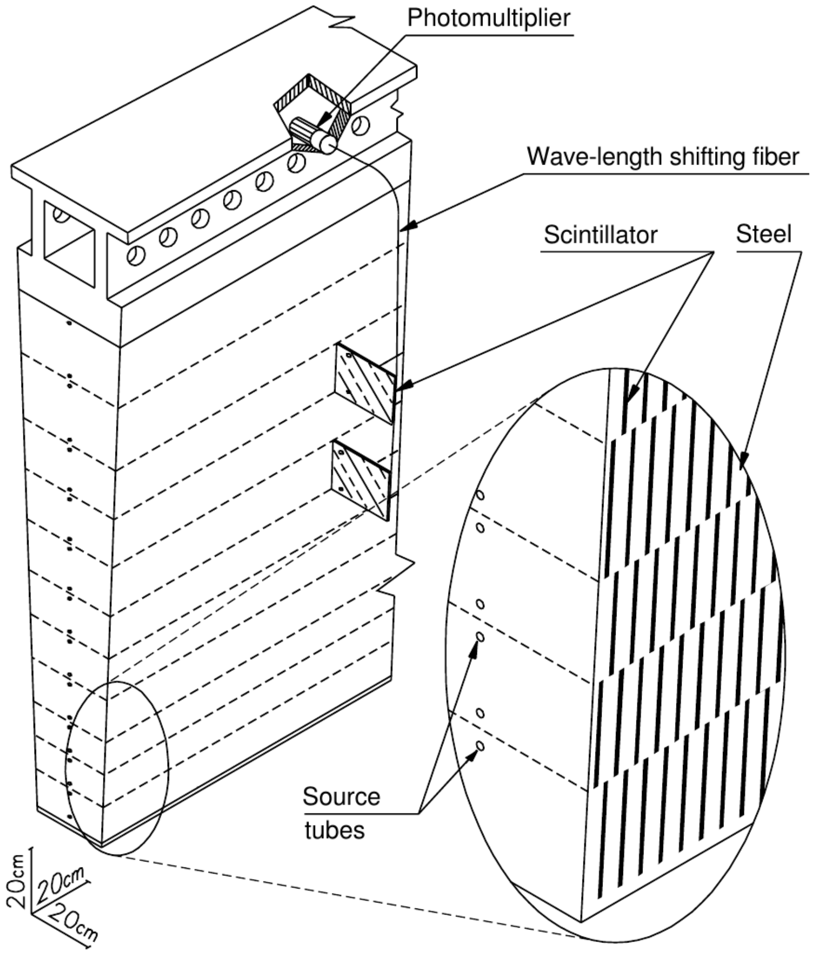
Tile Calorimeter (1)



- Steel/plastic scintillator sampling hadronic calorimeter of the ATLAS experiment
- Measures jets, single hadrons, hadronically-decaying τ-leptons and contributes to missing E_T measurement
- Assists in muon identification
- Covers the central region $|\eta| < 1.7$, mechanically split into 3 cylinders (LB + 2xEB)

Tile Calorimeter (2)

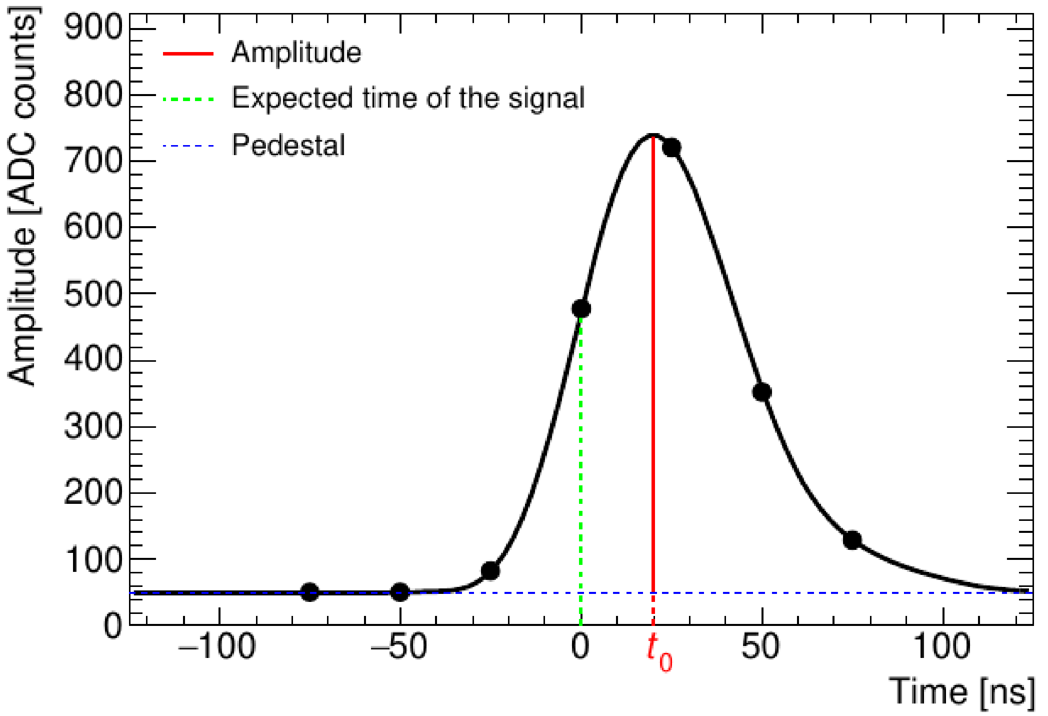
- Pseudo-projective cells organized into 3 radial layers
- Cell size: $\Delta\eta \times \Delta\varphi = 0.1 \times 0.1$ (0.2×0.1 in last radial layer)
- Light from scintillators collected by wavelength-shifting fibers and routed to PMTs
- Every cell read-out from both sides, i.e. using two PMTs (channels)



Tile Calorimeter (3)

- Signal reconstruction:
  - PMT pulse shaped, split into 2 gains and digitised every 25 ns
  - 7 digitized samples input to Optimal Filtering (OF) algorithm, reconstruction of amplitude (A), pulse phase ($\tau = t - t_0$) and quality factor

$$A = \sum_{i=1}^{n=7} a_i S_i, \qquad A\tau = \sum_{i=1}^{n=7} b_i S_i,$$

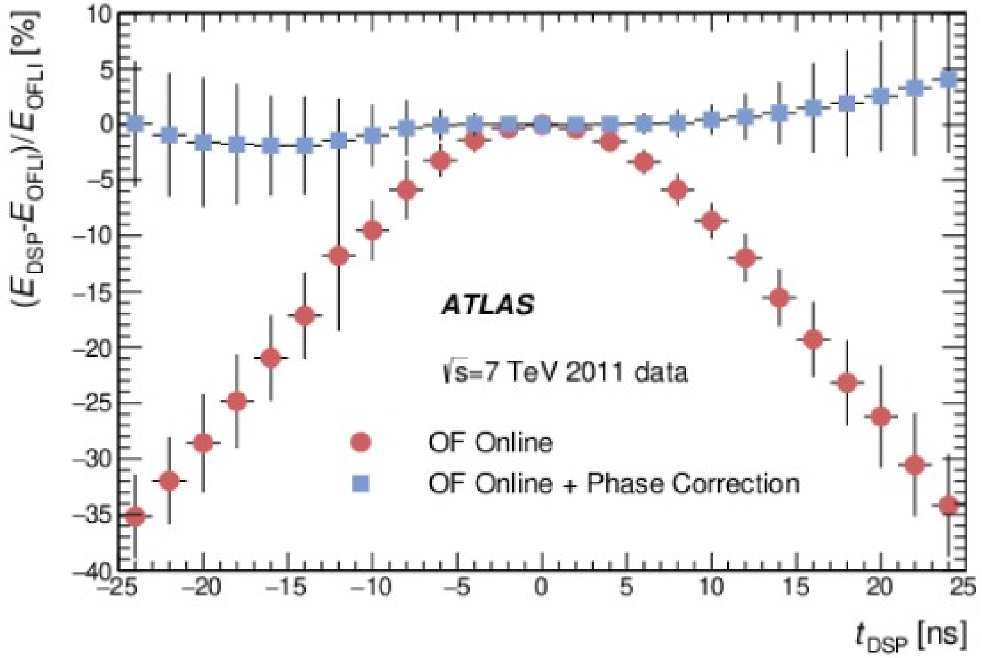


- Time calibration assures that signals from particles originating in the ATLAS interaction point and moving with speed of light comes at $\tau = 0$.

Motivation for Time Calibration

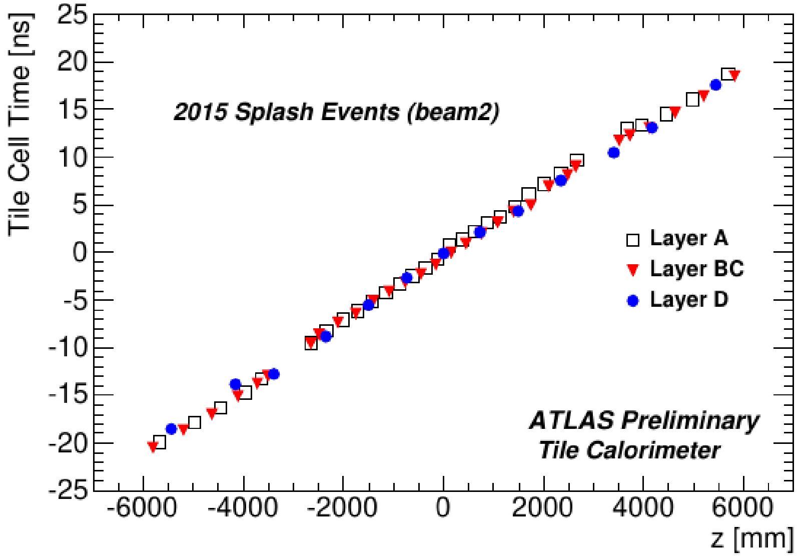
- Precision of the signal reco with non-iterative OF depends on the knowledge of t_0

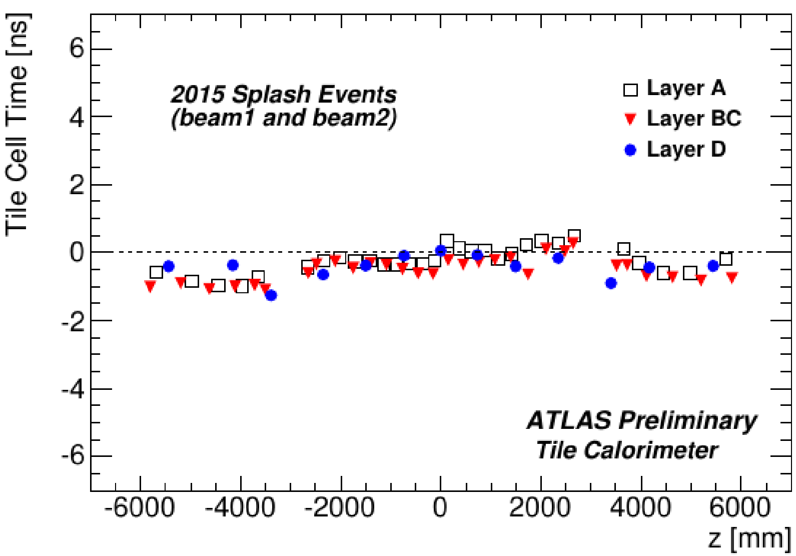
- Time-of-flight measurement important for
  - event filtering (e.g. removal of non-collision background, out-of-time pile-up)
  - physics analyses looking for e.g. slow heavy (meta)stable particles (Refs. [8,9])



Time Calibration (1)

- Pre-calibration:
  - **laser** - basically comparing timing between now and previous data-taking period
  - **splash events** - beam hits closed collimator, producing many high-energy particles
    - only high-energy muons reach the calorimeter, flying parallel to beam axis
    - after accouting for time-of-flight, one can determine the time calibration in each channel
    - caveats: trigger, comparison A-C side, impact of the toroidal end-cap magnets

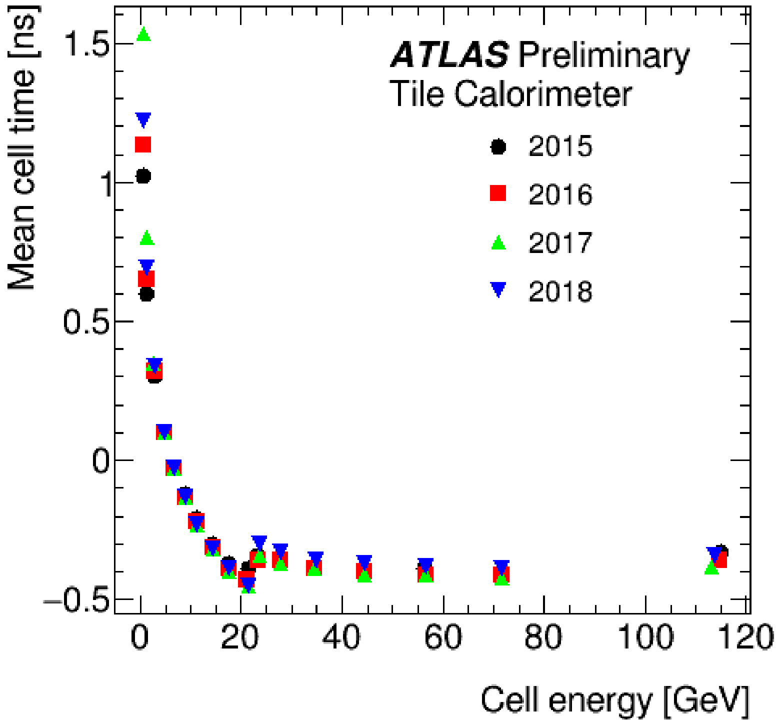




Refs. [1,4]

Time Calibration (2)

- Final calibration is performed with initial collision data
  - using jets since we need high statistics
  - using only cells that are part of reco'ed jets to avoid bias from pile-up and non-collision background
  - as the mean time slightly depends on the energy, choosing $2 < E_{ch} < 4$ GeV (high-gain) and $15 < E_{ch} < 50$ GeV (low-gain)
    - trade-off between statistics and Gaussian shape (negatively influenced by pile-up at low energies)
  - caveats: channel-level information not available in standard DAOD format, using special monitoring tool operating on HIST level



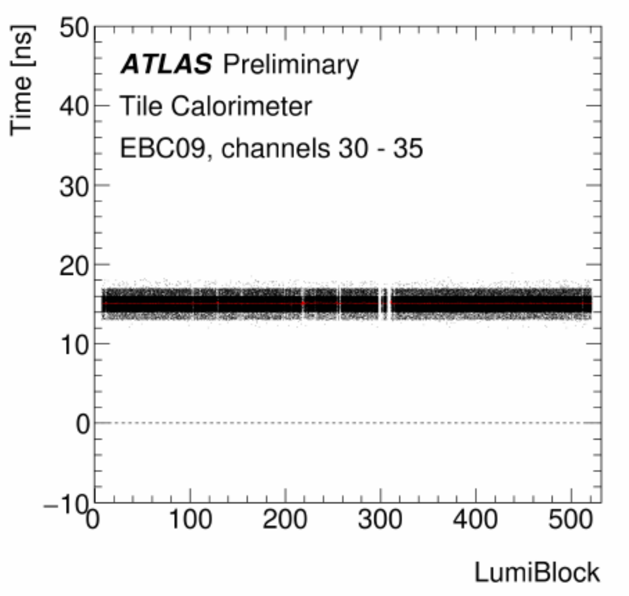
Refs. [1,4]

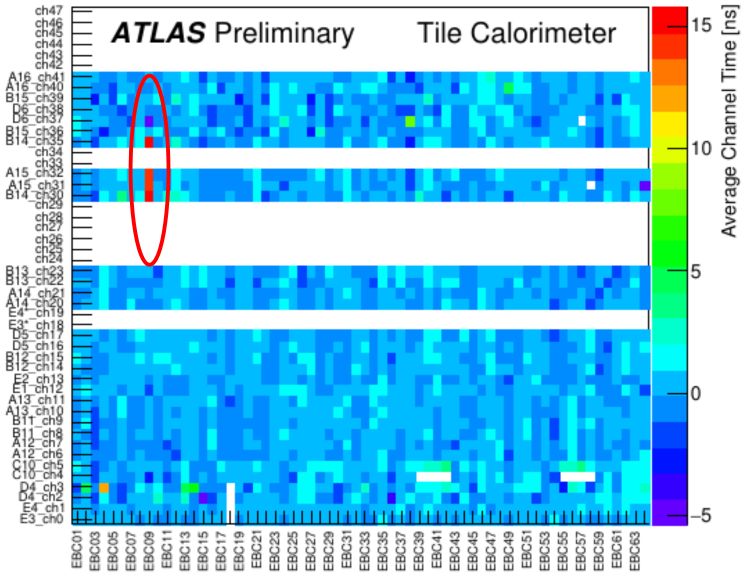
Time Monitoring (1)

- Performed with two independent tools:
  - **physics events** – similar event selection as for the calibration, histogram show the average reco'ed time in each channel in the given run
  - **laser-in-gap** – laser triggers sent to all TileCal PMTs during the „empty bunches". Special monitoring tool allows to monitor the reco'ed time in each channel as a function of the lumiblock

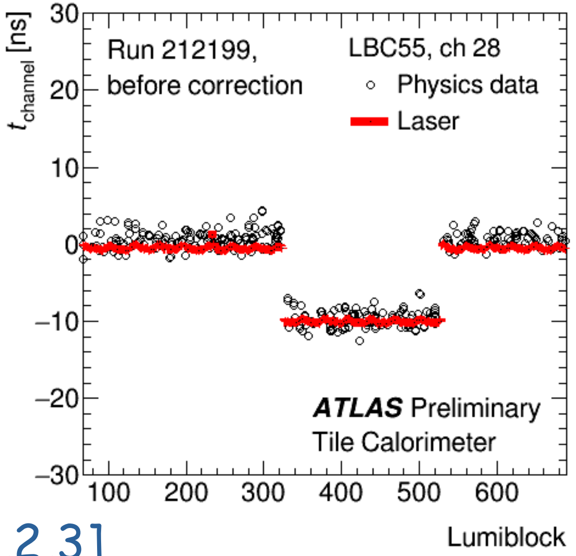
Note the nice match between the tools !!

Refs. [1,4,6]





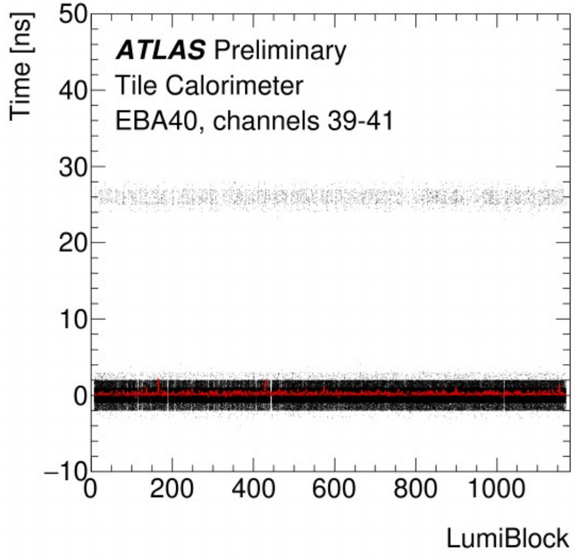
Time Monitoring (2)

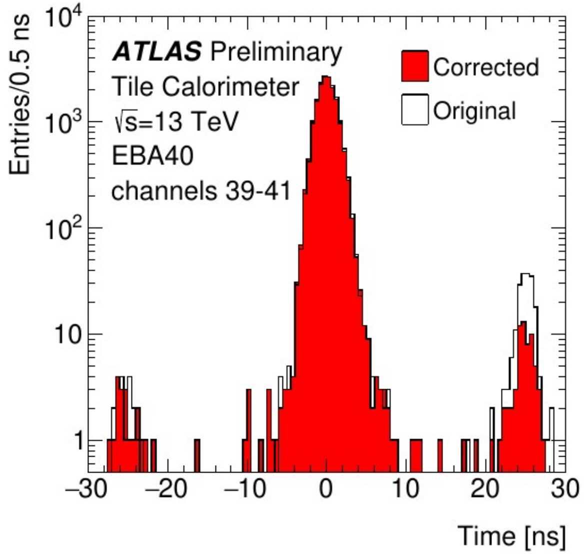


- Features discovered with laser-in-gap tool:
  - **timing jumps**
    - sudden changes of reco'ed time in a group of 6 adjacent channels
    - occurs both in the whole run as well as in part of it
    - corrected either during the calibration loop or for reprocessing
  - **bunch-crossing offset**
    - intermittent offsets by ±25 ns or ±50 ns, correlated across three channels governed by single TileDMU
    - dedicated sw tool mitigates such events in physics

Refs. [1,2,3]

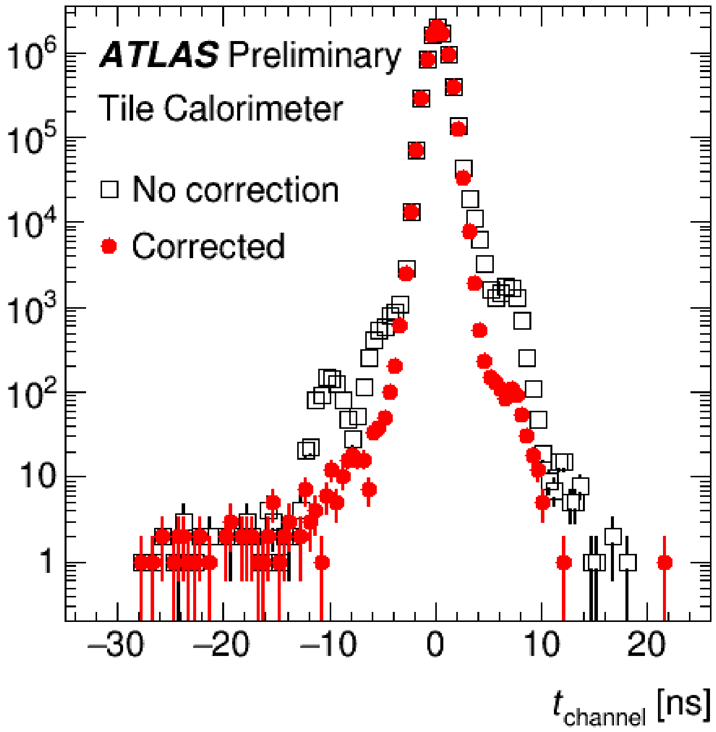
Refs. [1,4,5,6]





Performance (1)

- Corrections for large number of timing jumps during Run-1 improved the **overall RMS** of the reco'ed channel time by 10%
- Since Run-2 the timing jumps are much less frequent, we focused on improvements in monitoring
  - discovery of the bunch-crossing offset problem in few groups of channels (see previous slide)
  - improved sw tool now able to spot timing jumps above 1 ns (originally only above 3 ns)

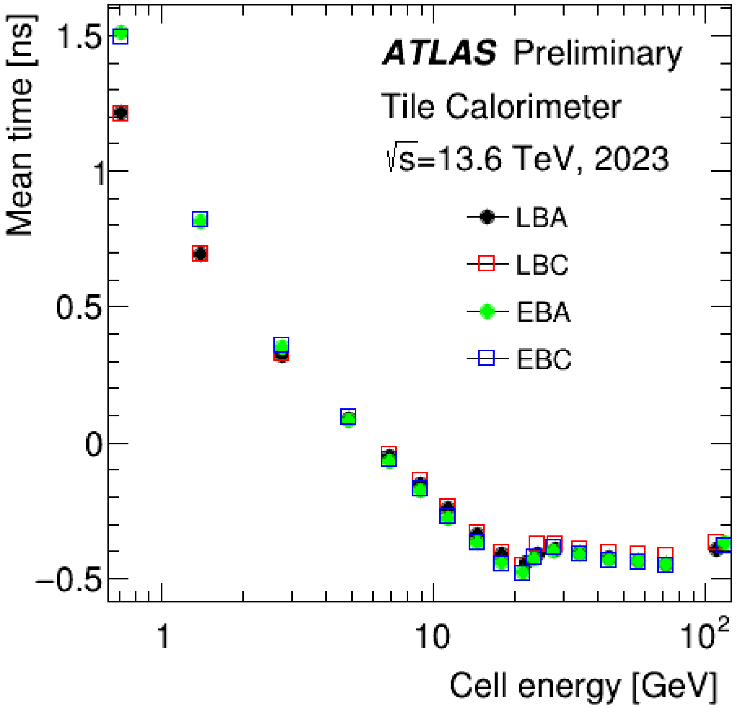


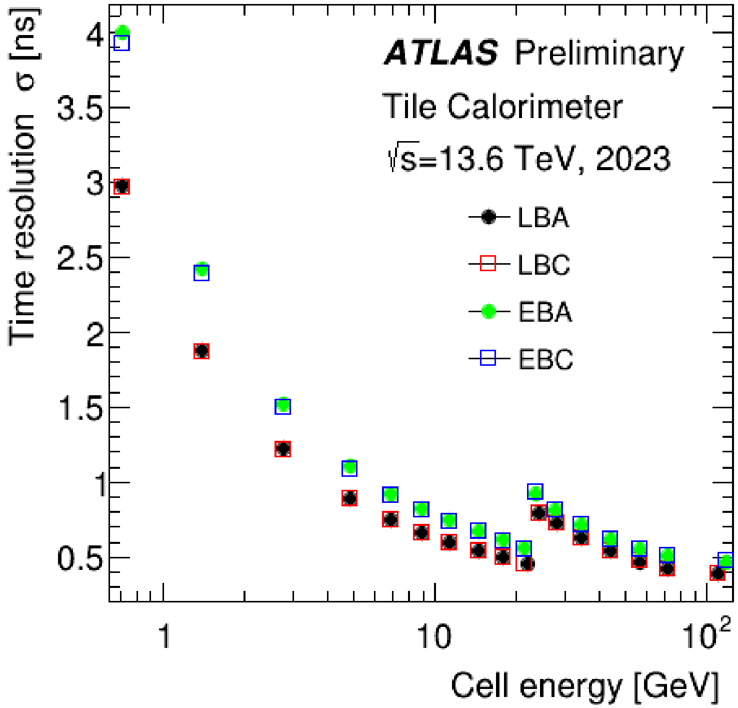
Refs. [1,2,3]

Performance (2)

- Time performance essentially stable
  - mean time essentially the same across individual parts of the calorimter
  - time resolution slightly better in central Long Barrel (LB) than in Extended Barrel (EB) due to larger cells in EB wrt LB

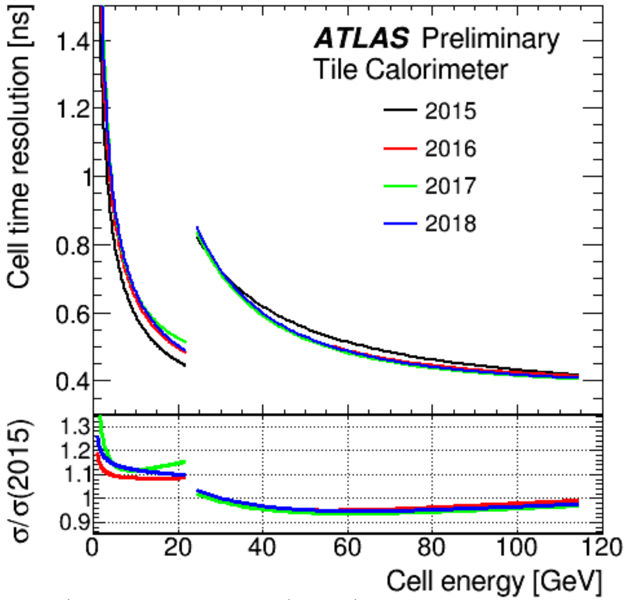
Ref. [1]



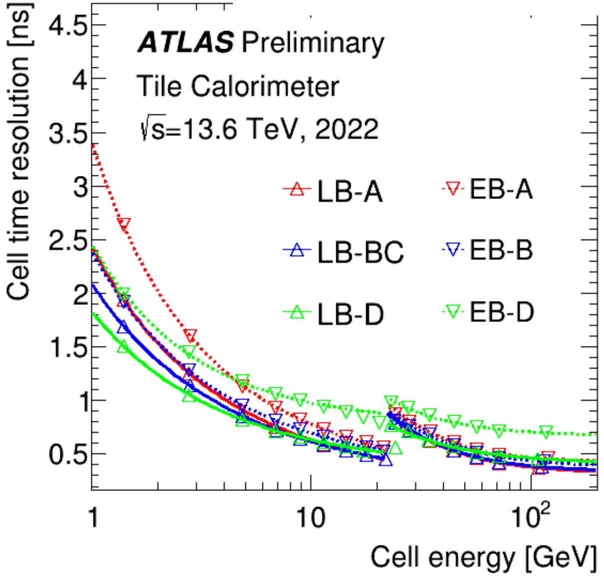


Performance (3)

- Time resolution in low-gain improved after dedicated calibration since 2016
  - otherwise stable across the years, small differences at small energies due to different pile-up
- Time resolution recently measured separately in individual radial layers. Differences understood due to:
  - geometry – physically larger cells in EB show worse time resolution than in LB, especially in outermost layer D
  - pile-up worsens the time resolution at small energies, namely in the innermost layer A



Refs. [1,4,6]



Refs. [1,7]

Conclusions

- Time calibration important for the energy reconstruction as well as for the time-of-flight measurement, already used in several analyses (Refs [8,9])
- Time calibration extensively monitored by two independent tools, showing a very good match
- The improvements in the sw tools allows to catch small changes in calibration as well as spotting and correcting for special cases

References (1)

1) Tile public plots, https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TileCaloPublicResultsTiming
2) Tilecal timing jump detection and correction in Run 1 data, ATL-TILECAL-INT-2014-006
3) Operation and performance of the ATLAS Tile Calorimeter in Run 1, Eur. Phys. J. C 78, 987 (2018)
4) Time calibration and monitoring in the Tile Calorimeter, ATL-TILECAL-INT-2020-003
5) Laser calibration of the ATLAS Tile Calorimeter during LHC Run 2, JINST 18 P06023 (2023)
6) Operation and performance of the ATLAS tile calorimeter in LHC Run 2, submitted to EPJC, arXiv:2401.16034
7) Time Calibration and Response of the ATLAS Tile Calorimeter, MSc thesis of M. Divisek, 2024

References (2)

8) Search for heavy, long-lived, charged particles with large ionisation energy loss in pp collisions at $\sqrt{s}$ = 13 TeV using the ATLAS experiment and the full Run 2 dataset, JHEP 06 (2023) 158

9) Search for massive, long-lived charged particles with large specific ionisation and low-β in 140 fb−1 of pp collisions at $\sqrt{s}$=13 TeV using the ATLAS experiment, ATLAS-CONF-2023-044

Thank you

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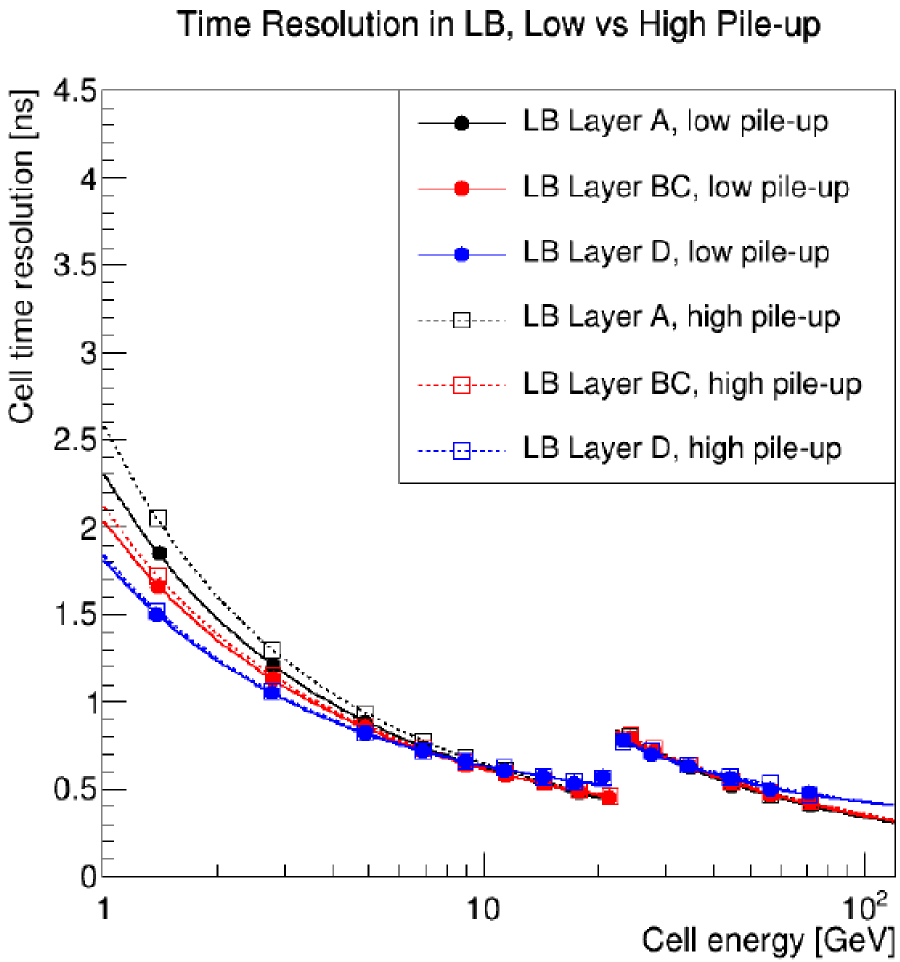
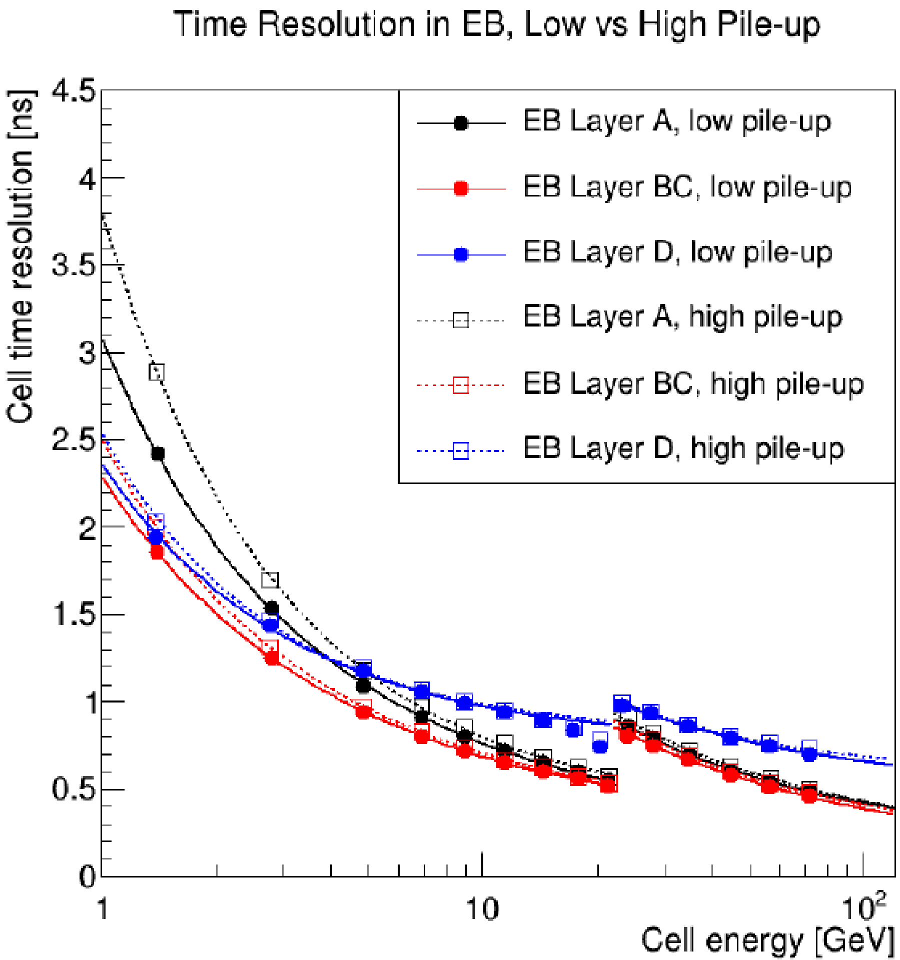
BACKUP

Time resolution vs pile-up





Ref. [7]