Performance of the ATLAS Tile Calorimeter

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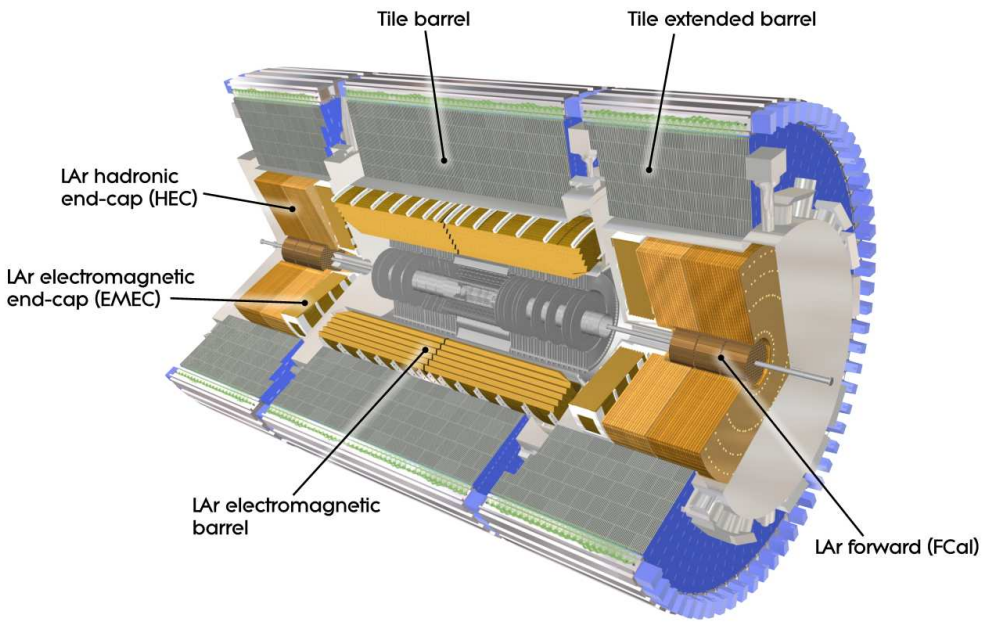
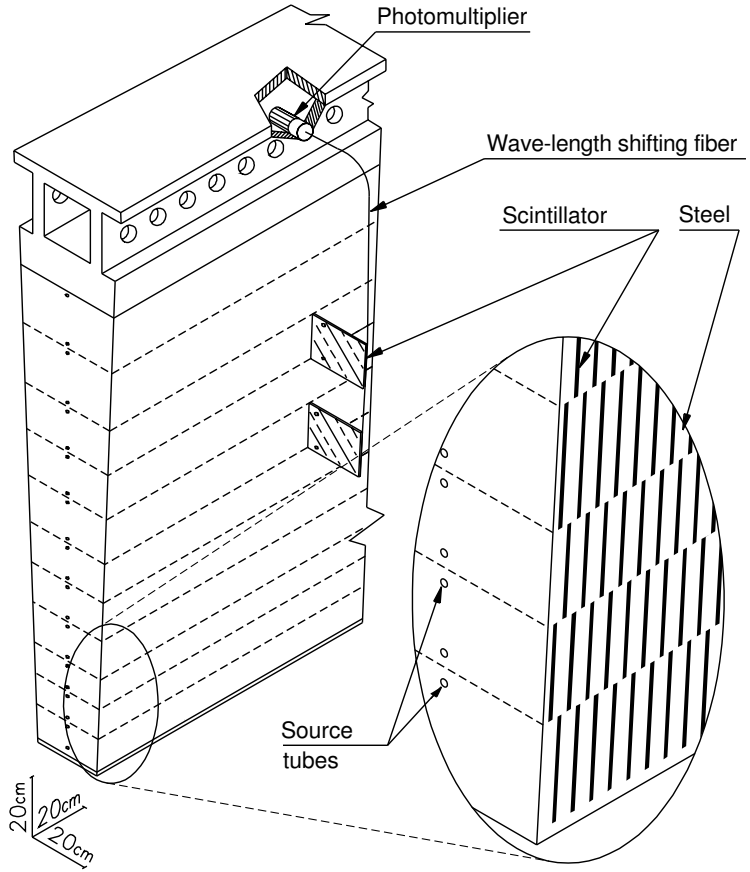
Tile Calorimeter

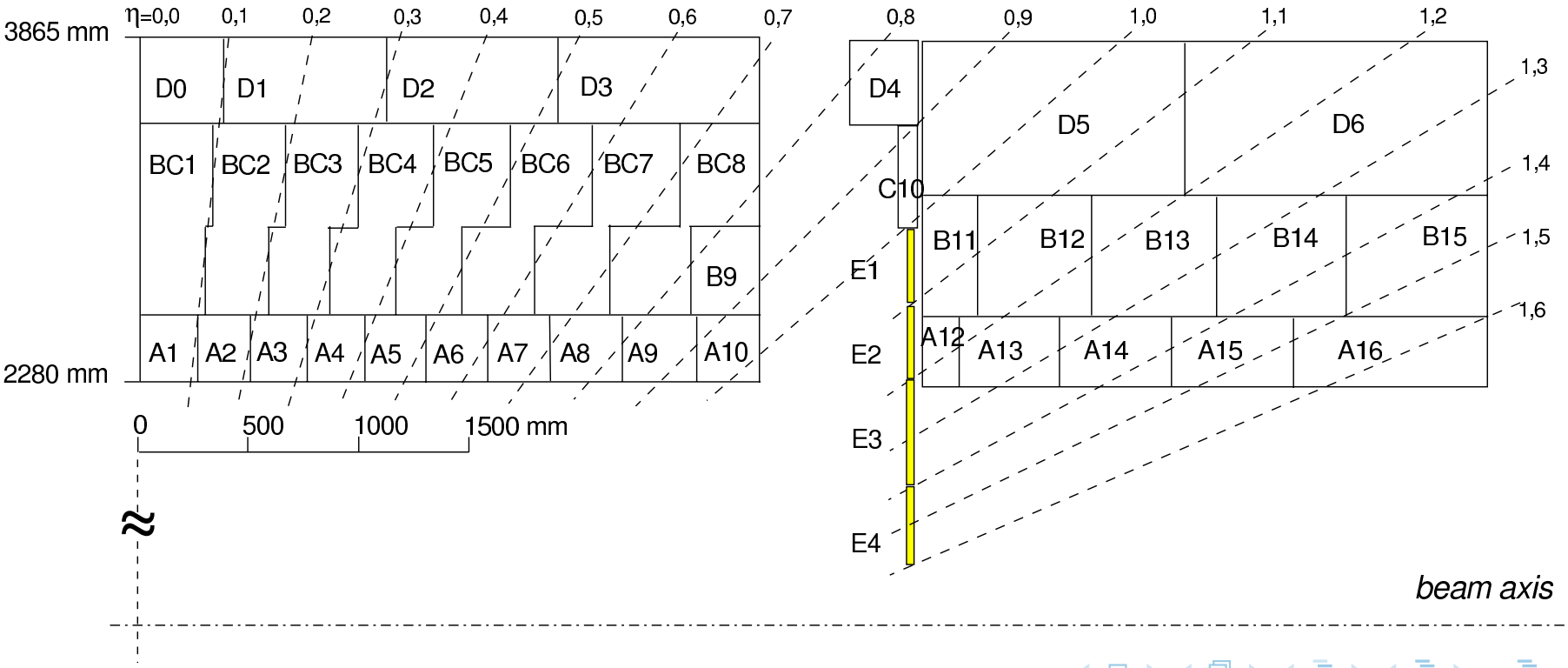
- Central hadronic calorimeter of the ATLAS experiment
- Measures energy and direction of particles and jets
- Long barrel, two extended barrels
- Sampling calorimeter
  - Steel absorber
  - Plastic scintillator tiles





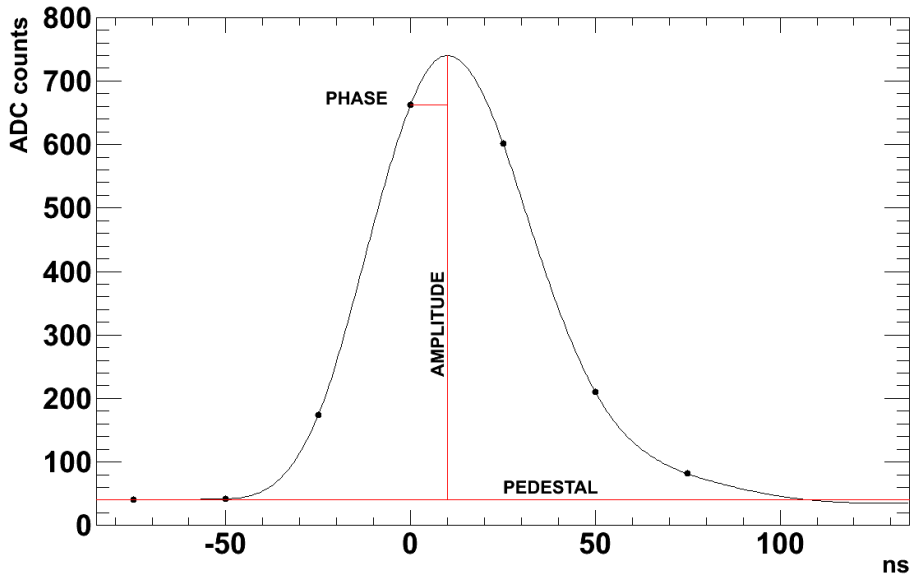
Tile Calorimeter

- Scintillator signal → wavelength-shifting fibers → photomultiplier tubes (PMTs)
- Calorimeter divided into modules and cells
- Calorimeter cell—usually 2 PMTs (channels) on both sides of the module
- 5 182 cells, 9 852 channels in total



Signal reconstruction

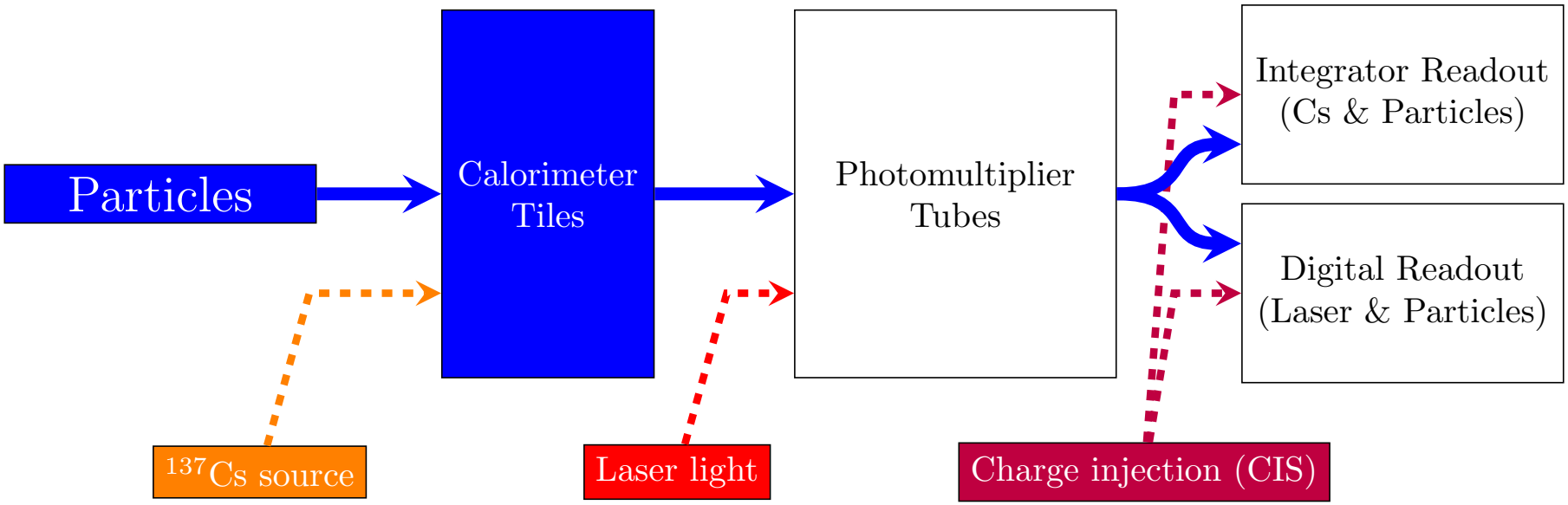
- PMT signal
  - Shaped → constant width
  - Amplified—two gains, 64:1 ratio → wide energy range
- Pulse sampled every 25 ns by analog-to-digital converter (ADC)



- Amplitude, time, and pedestal reconstructed from 7 samples (optimal filtering algorithm)
  - Amplitude proportional to measured energy
  - Amplitude reconstruction dependent on correct time phase

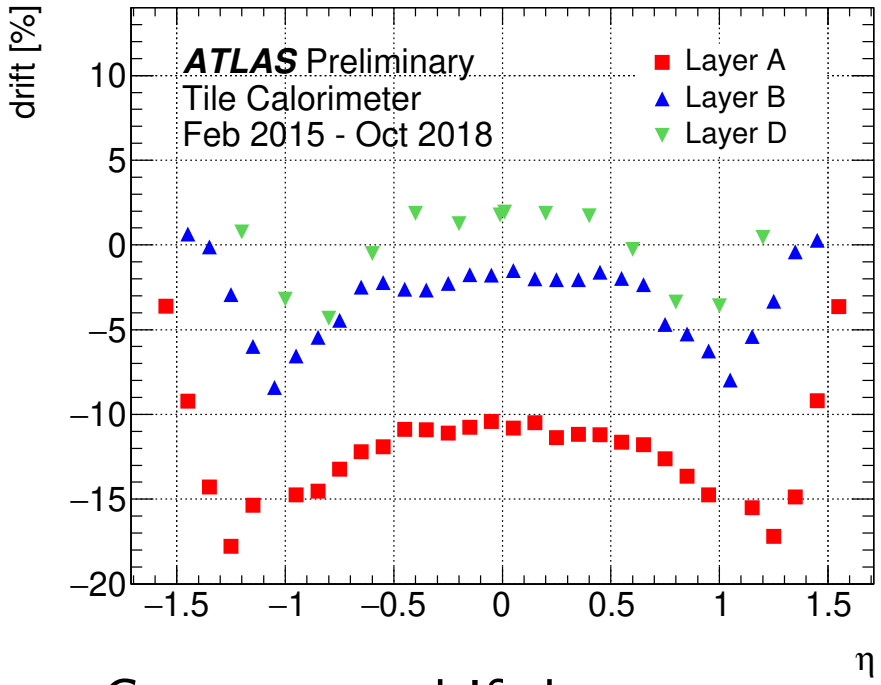
Calibration

- Multiple calibration systems to monitor different steps of the signal reconstruction chain:
  - Cesium
  - Laser
  - Charge injection



Calibration—cesium

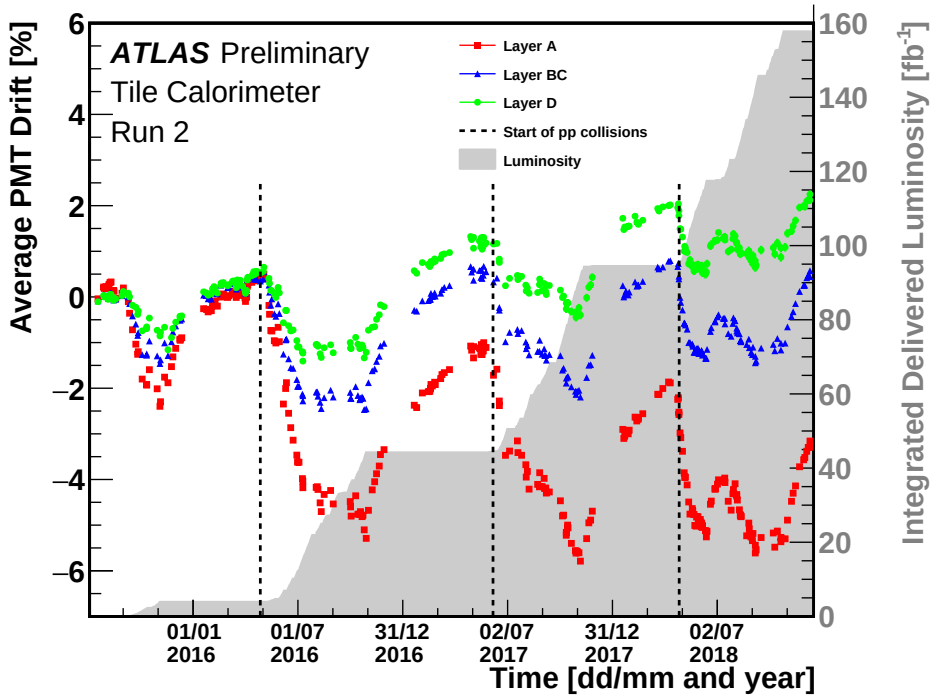
- ^{137}Cs passing through all tiles
- Monitoring all optics components and PMTs
- Dedicated read-out system (PMT signal integrated over 10–20 ms)
- Deviation from expected response to cesium due to:
  - Scintillator degradation (irradiation)
  - PMT gain variation



- Cs response drift between beginning and end of Run-2
- Most significant for innermost radial layer (layer A)

Calibration—laser

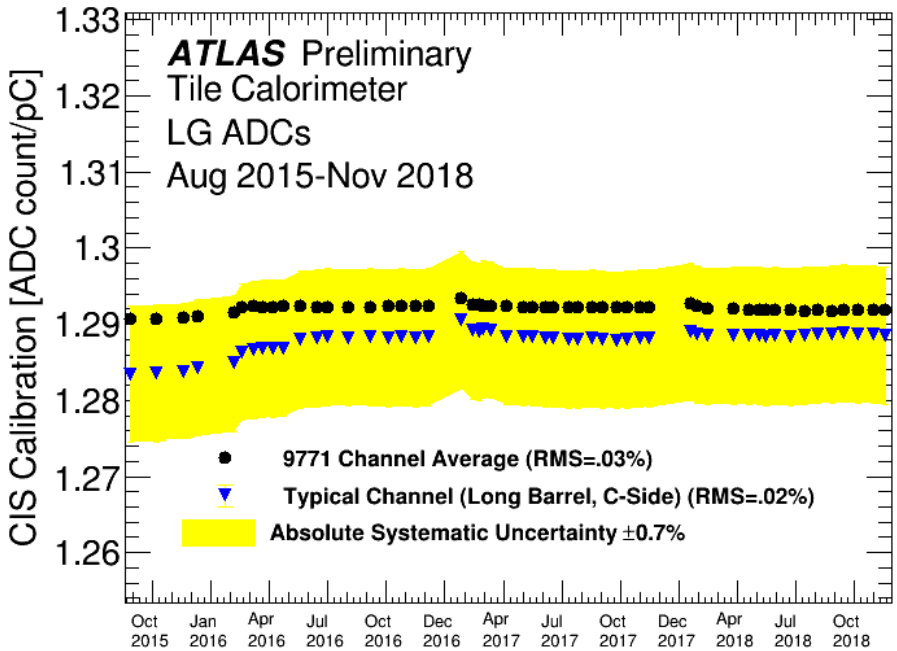
- Light pulses sent to PMTs
- Monitoring gain stability of PMTs
- Photocatode degradation
  - Down-drift of response
  - Most significant for innermost layer



- Laser response drift between beginning and end of Run-2
- Photocatode recovery during off periods

Calibration—charge injection

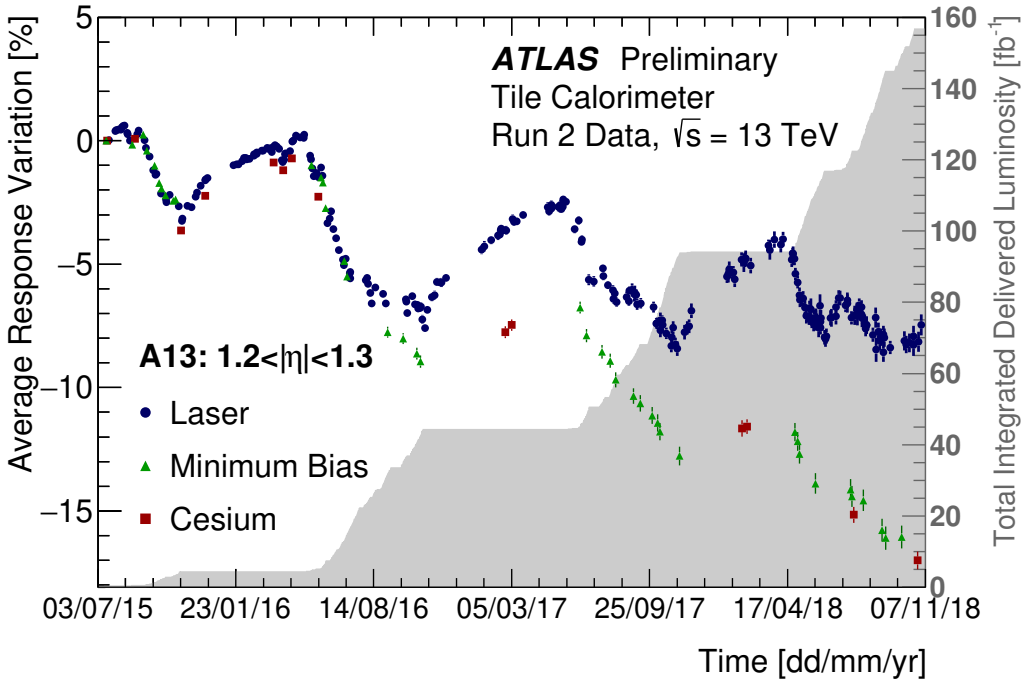
- Defined charge injected into readout system
- Monitoring electronics, ADC response
- Covers whole dynamic range of ADCs in both gains



- Average pulse amplitude to charge ratio in Run-2 (low gain)
- Great stability

Calibration—combined calibration & ageing

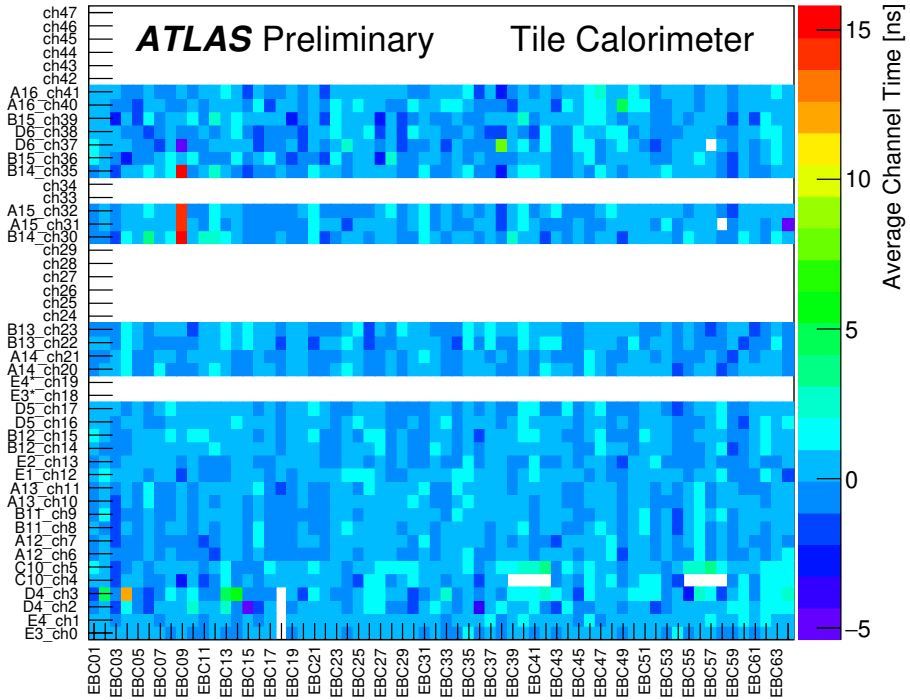
- Minimum bias (MB)
  - Inelastic *pp* collisions
  - Same dedicated read-out system as Cs calibration
- PMTs down-drift and recovery
  - Visible using laser, MB, and Cs
- Degradation of scintillator tiles and WLS fibers
  - Laser vs MB/Cs difference
  - 3–10% in innermost radial layer after Run-2
  - $\sim$ 1% in other layers after Run-2



- Variation of response to Laser, MB, and Cs in Run-2 for cell A13 (most irradiated standard cell)
- A13: $\sim$ 10% degradation of tiles and WLS fibers at the end of Run-2

Time calibration

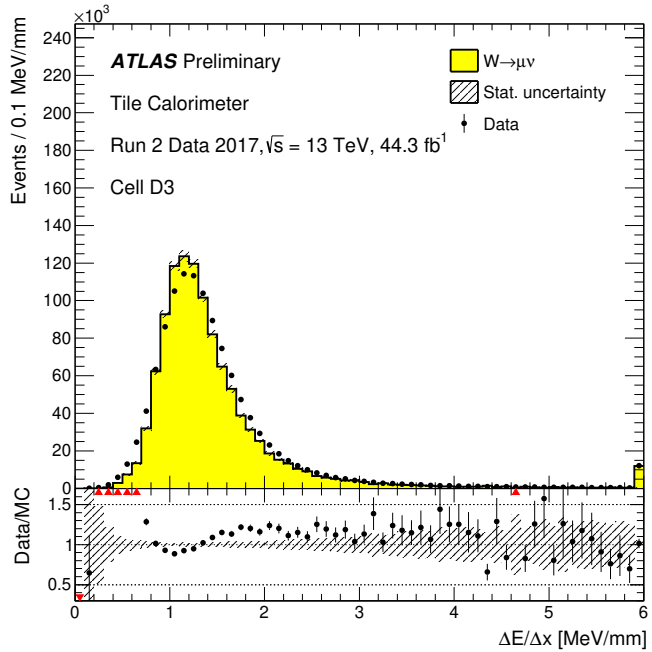
- Goal: particles traveling from interaction point at speed of light produce signal with measured time=0 in all channels
- Important for energy reconstruction, ToF measurement
- Per-channel basis, final calibration using collision data
- Monitored using
  - Laser (during empty LHC bunch crossings)
  - Physics collision data (jets)

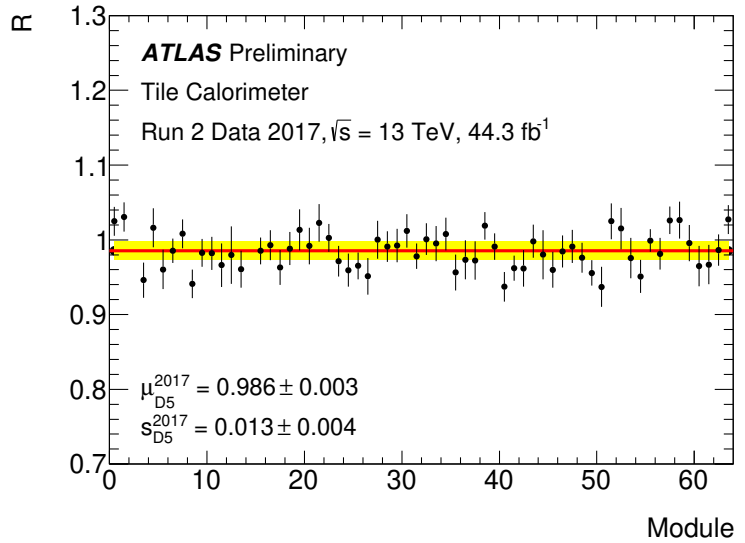


- Average channel time monitored using jets in collision data

Performance—response to single muons

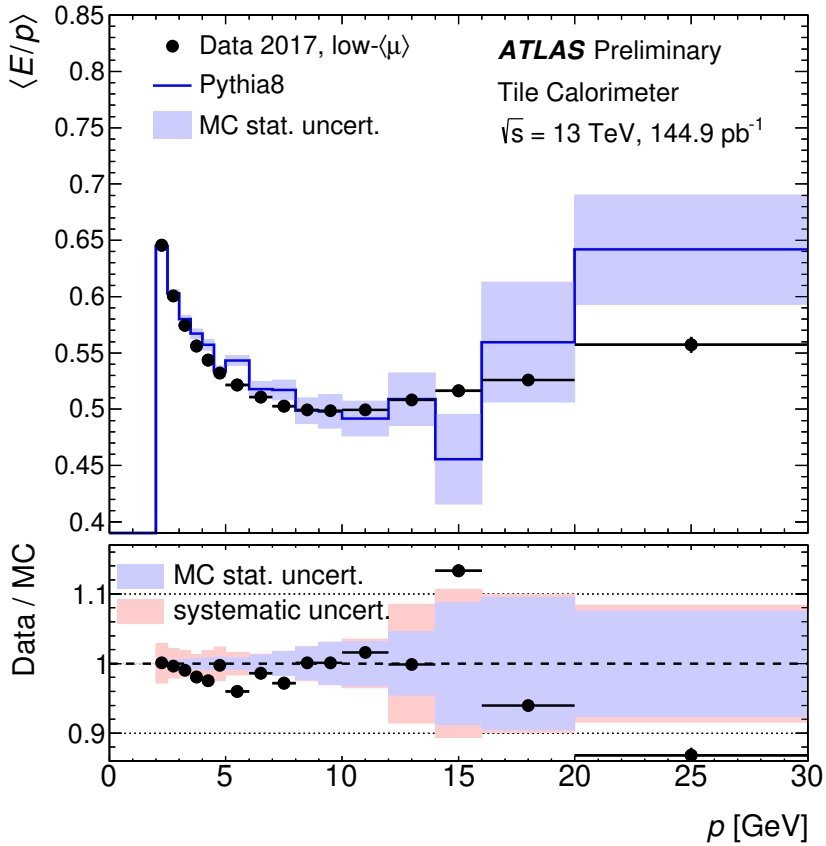
- To validate EM scale, check uniformity
- Using muons from $W \to \mu\nu$
- Truncated mean $\langle \Delta E/\Delta x \rangle_{1\%}$
  - Deposited energy over path length
  - Remove top 1% events
- Ratio data vs simulation
  $R \equiv \frac{\langle \Delta E/\Delta x \rangle_{1\%}^{\text{data}}}{\langle \Delta E/\Delta x \rangle_{1\%}^{\text{MC}}}$
- Ratio very close to 1
- Good uniformity of response across calorimeter modules



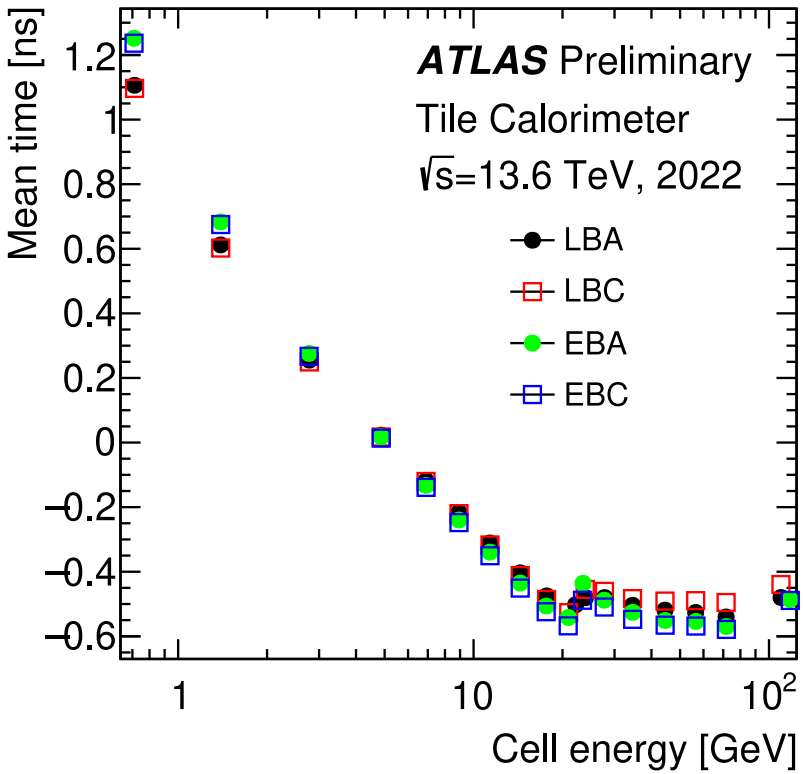


Performance—response to single hadrons

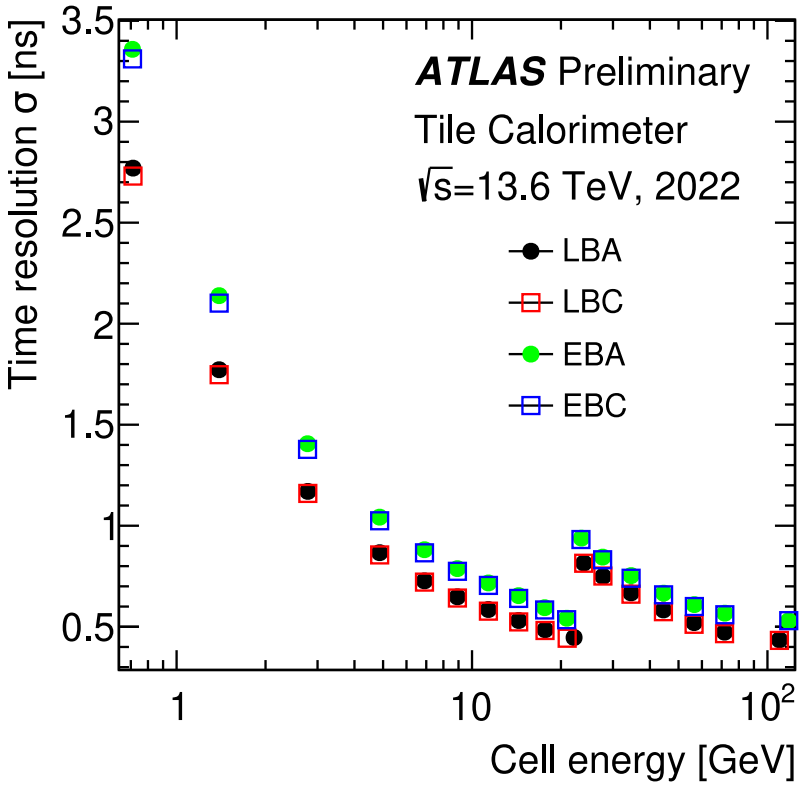
- Using isolated charged hadrons
- $\langle E/p \rangle$
  - E = energy measured by Tile Calorimeter
  - p = momentum measured by ATLAS Inner Detector
- Non-linear response to hadrons (non-compensating calorimeter)



Time performance



- Mean cell time in collision data, Run-3
- Slight dependence on deposited energy (neutrons and slow hadronic component of shower)



- Time resolution in collision data, Run-3
- Slightly worse resolution in extended barrel (larger cells than in long barrel)

Conclusion

- Calibration systems of ATLAS Tile Calorimeter presented
  - Monitoring components of signal reconstruction chain (response, ageing, . . .)
  - Each system has precision better than 1%
- EM response validated using isolated muons
  - Cell uniformity within few percent
- Hadronic response studied using isolated charged hadrons
  - Non-linear response typical for non-compensating calorimeters
- Time performance studied using jets in collision data
  - Time resolution in Run-3 presented
  - Better than 1 ns for cell energy > 4 GeV