Operation and Performance of the ATLAS Tile Calorimeter and its readiness for Run 3

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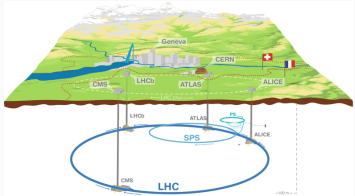
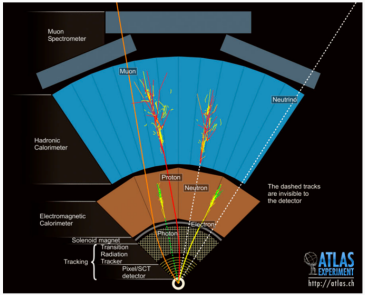
ATLAS Hadronic Tile Calorimeter

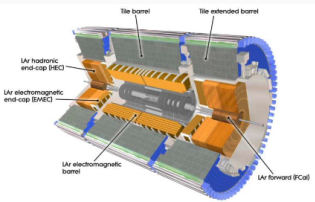
- The Hadronic Tile calorimeter (TileCal) is the outermost calorimeter in the ATLAS detector on the Large Hadron Collider (LHC) at CERN
  - Hadronic sampling calorimeter, covering $|\eta| < 1.7$
  - Important in jet, τ, $E_{\mathrm{T}}^{\mathrm{miss}}$ and μ identification and triggering
  - Scintillating tile with steel absorber
  - $\Delta\eta x \Delta\phi = 0.1x0.1$ in two innermost layers
    - $\Delta\eta x \Delta\phi = 0.2x0.1$ in outermost layer
  - Designed with a stand-alone energy resolution for jets of $\frac{\sigma}{E} = \frac{50\%}{\sqrt{E(GeV)}} \oplus 3\%$
  - Technical Design Report : 10.17181/CERN.JRBJ.7O28



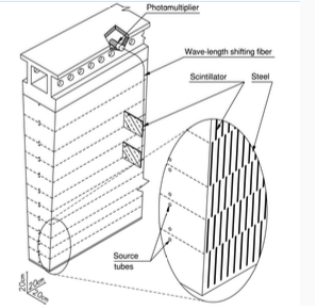


ATLAS Tile Calorimeter Signal Collection and Processing

- Ionizing particles cause plastic tiles to scintillate
- Light is absorbed in wave length shifting (WLS) fibers, re-emitted, then transmitted to photomultiplier tubes (PMTs)
- PMT signal is shaped, amplified (two gains, ratio of 64:1), and digitized at 40 MHz frequency with 10-bit ADCs
- If event is accepted by trigger system, data is sent off-detector for further processing and analysis
- Amplitude (A) and time (t_0) are reconstructed with Optimal Filtering algorithm
- Majority of cells are readout with 2 PMTs (one on each side)
- $\sim 10,000$ readout channels, $\sim 5,000$ cells in total



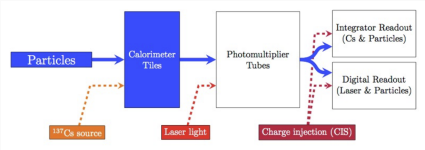
ATLAS Tile Calorimeter Barrel



Tile Calorimeter Wedge Module

ATLAS Tile Calorimeter Calibration Systems

- Cesium (Special runs)
  - Cs_{137} source is hydraulically moved throughout detector, calibrates entire readout chain ($\sim$ 0.3% precision)
- Laser (daily)
  - Measures response of PMTs w.r.t. last Cs scan ($\sim$ 0.5% precision)
  - Taken during LHC collision empty bunches and individual calibration runs
- Charge Injection (daily)
  - Measures response of digitizers and readout electronics via a range of controlled charges ($\sim$ 0.7% precision)

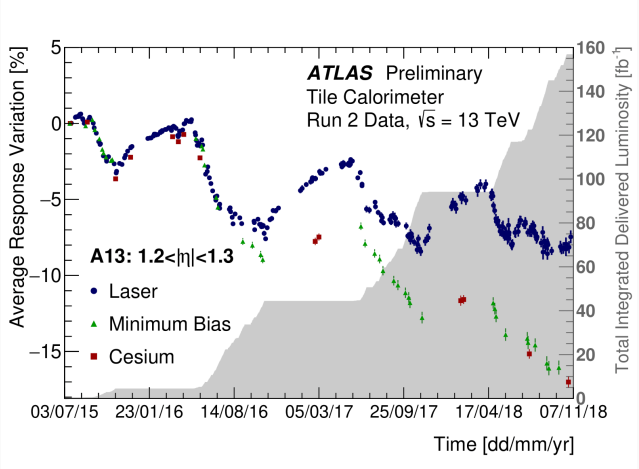


- Minimum Bias
  - Integrates signal over $\sim 10 - 20$ ms during physics data taking
  - Provides corrections in absence of Cs calibration
- Energy reconstructed at the EM scale

$$E = \frac{A[ADC\ Counts]}{C_{Cs} \cdot C_{Las} \cdot C_{CIS}[ADCcounts/pC] \cdot C_{TB}[pC/GeV]}$$

C_{TB} determined at dedicated test beams

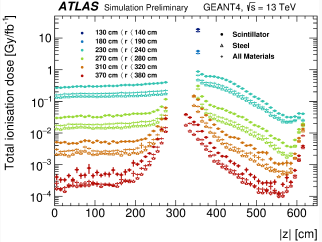
Combined Calibration of the ATLAS Tile Calorimeter



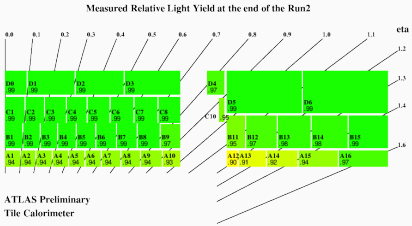
- Laser system probes PMT response
  - Down-drift during collisions
  - Recovery seen during beam-off periods
- Cs and Minimum Bias both measure the drift in PMTs, optical fibers, and scintillators
- Difference between Laser and Cs (or Laser and Minimum Bias) is due to degradation of tiles and WLS fibers

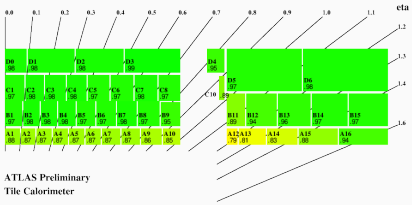
Effects of Ionizing Radiation on the ATLAS Tile Calorimeter

- A12 is the most irradiated cell
  - $\sim$ 10% degradation of optics seen at end of Run 2
  - Expect close to 20% at the end of Run 3 ($350\ fb^{-1}$)



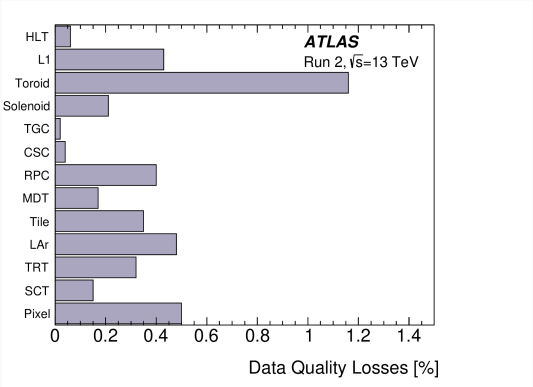
Radiation dose of TileCal, normalized to 1 fb^{-1}
ATL-PHYS-PUB- 2016-017 (2016)





Data Quality of the ATLAS Tile Calorimeter

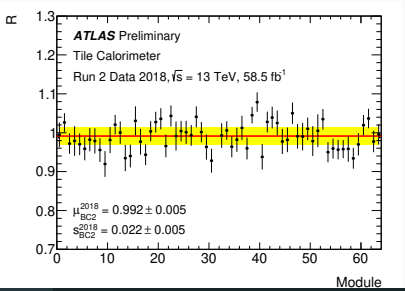
- In Run 2, TileCal reported 99.65% data quality efficiency
- More information on all ATLAS data quality in Run 2 here: JINST 15 (2020) P04003



EM Energy Scale Performance with Isolated μ

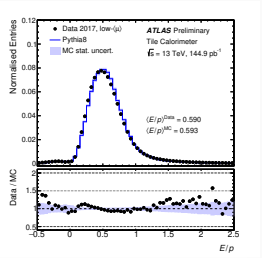
- $20 - 80$ GeV μ from W decays are used to check the EM scale and uniformity of TileCal
  - Ionization dominates
  - Energy deposited in cell (ΔE) scales with path length within the cell (Δx)
- Cell response defined as truncated mean of $\frac{\Delta E}{\Delta x}$ (remove highest 1% of events)
- Final figure of merit is $R = \frac{\langle \frac{\Delta E}{\Delta x} \rangle_{Data}}{\langle \frac{\Delta E}{\Delta x} \rangle_{MC}}$

- Results
  - Consistent cell uniformity across azimuth (2.4%) between different cell types
  - All layers are consistent with $R = 1$ within 2%
  - Comparison of 2015+2016, 2017 and 2018 data shows stability in time within a few %



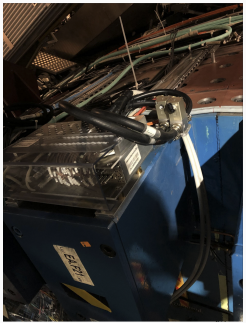
Jet Energy Scale Performance

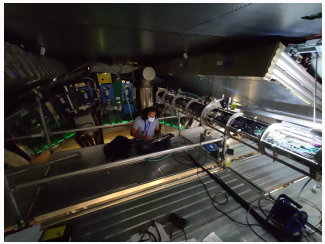
- Clusters in the calorimeter with associated tracks are used
  - Tracks in the Inner Detector measure momentum
  - Cluster energy is measured in TileCal
- Ratio of calorimeter energy and track momentum (E/p)
  - TileCal is a non-compensating, so $E/p < 1$
- Performed in three pileup bins
  - $< \mu \approx 0 >$, $< \mu \approx 2 >$, $< \mu \approx 10 - 20 >$
- Results
  - Good Data/MC agreement in all bins
  - In highest pileup bin, $\sim 3\%$ differences due to pileup mismodelling

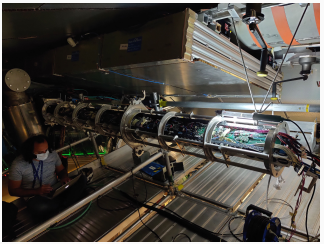


TileCal After LHC Long Shutdown 2

- Several projects were completed during Long Shutdown 2
  - General maintenance $\sim$ 170 modules with tracked issues were fixed
  - Installed isolating cooling valves for all 256 modules
  - Installed a demonstrator module with the ATLAS TileCal Phase-II Upgrade electronics
  - Overhaul of data quality monitoring software for physics and calibration

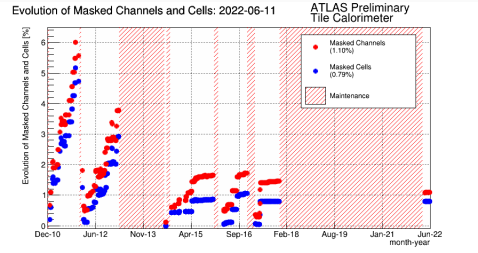


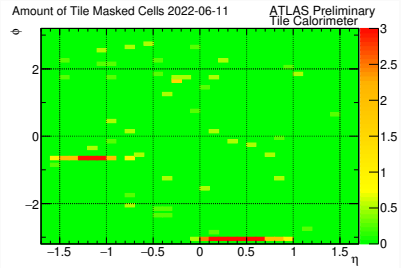




Run 3 Readiness

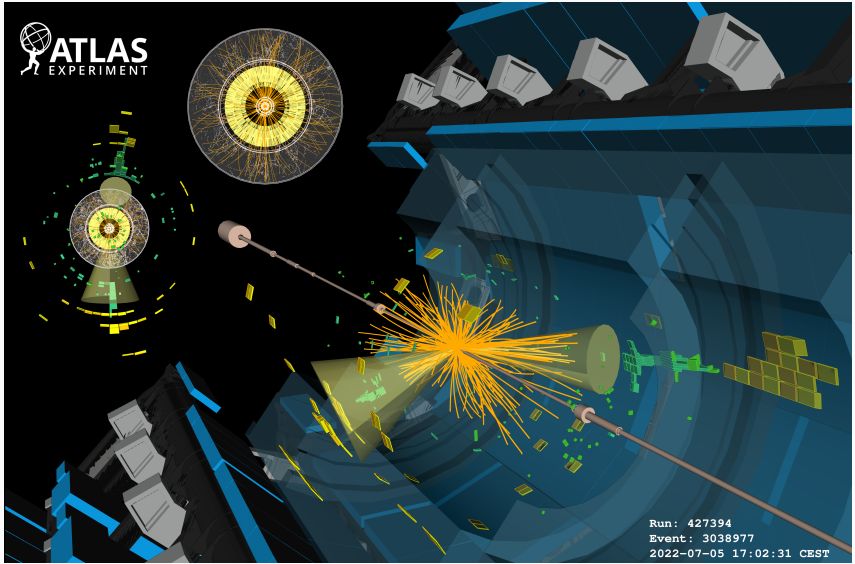
- Two modules failed during the closing of the detector
  - In 2018, had two modules off due to an unrelated issue, overall impact on data is manageable
- One module in emergency mode
  - Not possible to tune high voltage for individual PMTs
  - Okay for physics data taking
- Starting Run 3 with 0.79% of cells masked (1.1% of channels)





- TileCal performed well throughout Run 2
  - Combination of calibration systems guarantees very good response stability
  - Muons and hadrons were used to verify EM and jet energy scale performance
  - Detailed operation and performance paper for Run 2 coming soon
- Many maintenance items taken care of over the long shutdown
- TileCal is ready for Run 3

Thank You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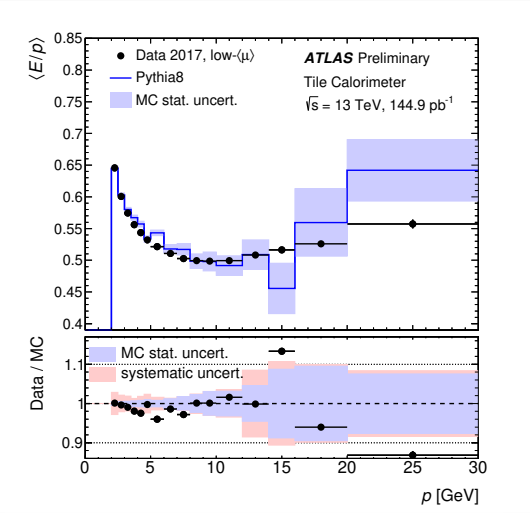
ATLAS Tile Calorimeter

The ATLAS Tile Calorimeter (TileCal) is the central section of the hadronic calorimeter of the ATLAS experiment. It provides essential information for reconstructing hadrons, jets, hadronic decays of tau leptons and missing transverse energy. This sampling calorimeter uses steel plates as an absorber and scintillating tiles as the active medium. The light produced by the tiles is transmitted by wavelength shifting fibers to photomultiplier tubes (PMTs). PMT signals are then digitized at 40 MHz and stored on the detector, and are only transferred off detector once the first level trigger acceptance has been confirmed (at a rate of 100 kHz at maximum). The readout is segmented into about 5000 cells (longitudinally and transversally), each being read out by two PMTs in parallel. A set of calibration systems is used to calibrate and monitor the stability and performance of each element of the readout chain during the data taking. The TileCal calibration system includes Cesium radioactive sources, laser, charge injection elements and an integrator-based readout system. Combined information from all systems allows monitoring and equalizing the calorimeter response at each stage of the signal production, from scintillation light to digitization.

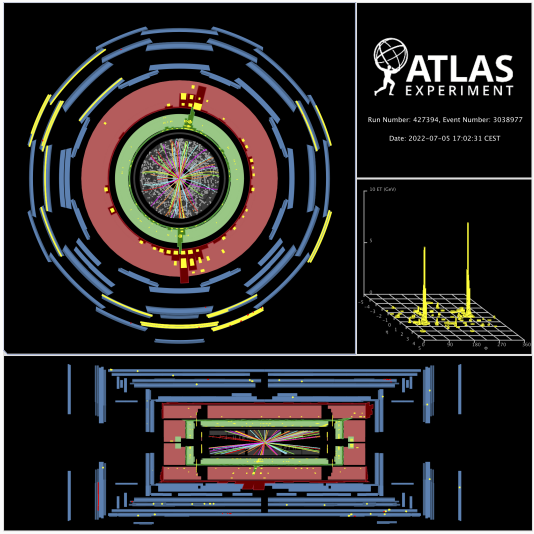
A large sample of proton-proton collisions was used to study the detector's performance, including pile-up's influence on the detector noise levels and time resolution. Cosmic ray muons, collision high momentum muons and isolated hadrons were used as probes to study the response of the calorimeter.

This presentation will show the TileCal operation, its performance during Run 2, and its readiness for LHC Run 3 after an extended LHC shutdown.

Jet Energy Scale Performance



Run 3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