The ATLAS Tile Calorimeter Performance and its upgrade toward High-Luminosity LHC

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On behalf of the ATLAS Tile Calorimeter system

PANIC virtual workshop – 5-10 september 2021

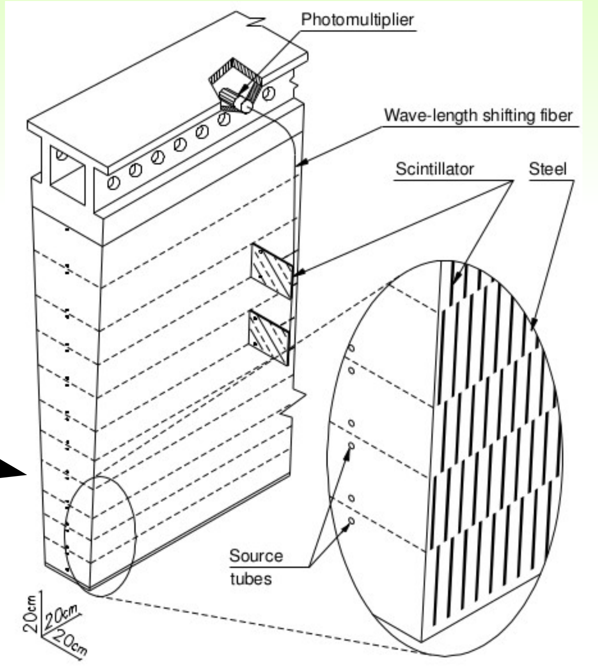
ATLAS EXPERIMENT

LPC Particules pLasmas Univers applicationS Laboratoire de Physique de Clermont

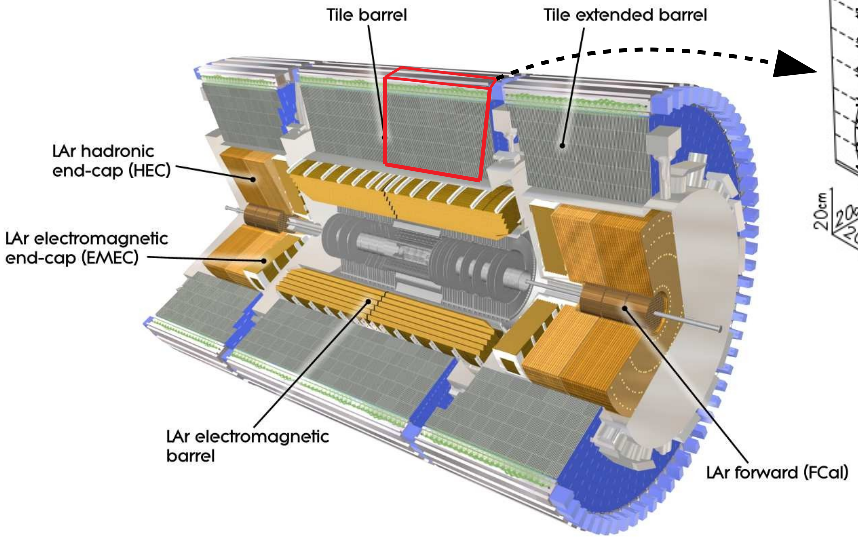
UNIVERSITÉ Clermont Auvergne

The Tile Calorimeter system

- Central hadronic calorimeter of ATLAS
  - **Long barrel** ($0 < |\eta| < 1.0$)
  - **extended barrels** ($0.8 < |\eta| < 1.7$)
- Scintillating tiles (active) and steel absorber
  - **Photon production** in active tiles with charged particles
  - Light guided toward **PMTs** through **optical fibers**

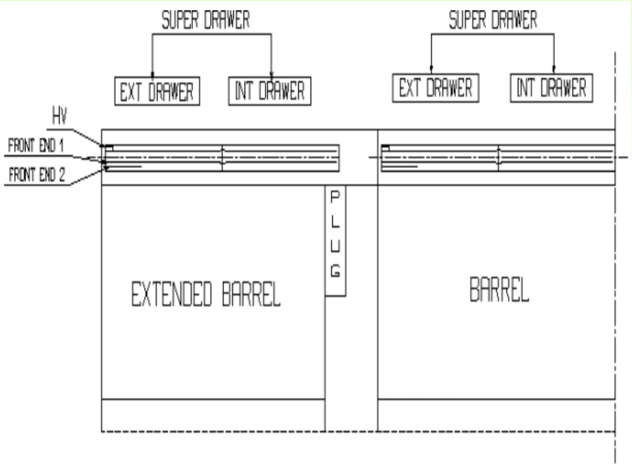


5182 cells (2 PMTs per cell)



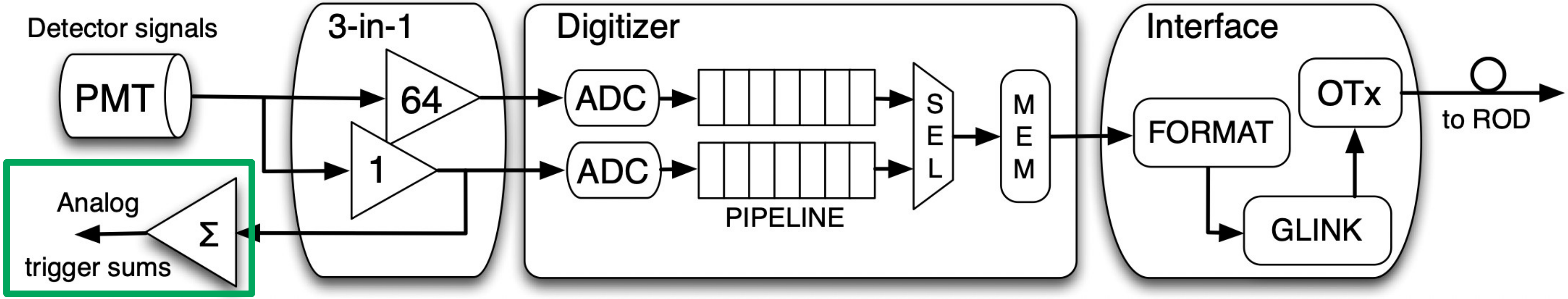
Architecture

- Super drawer mechanics
  - Split in 2 **interconnected** drawers
  - 256 super drawers in total
  - Drawers contains the front-end electronics



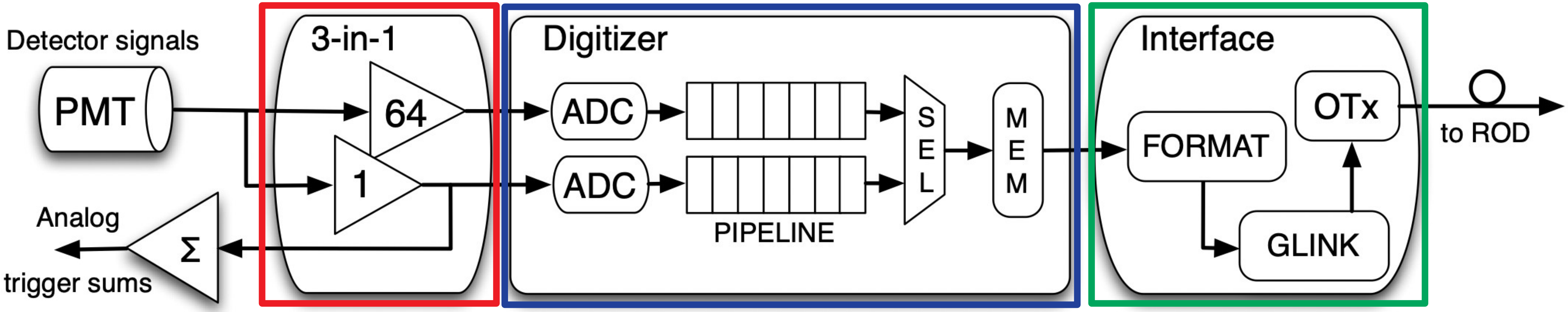
- Electronics

  Analogical trigger



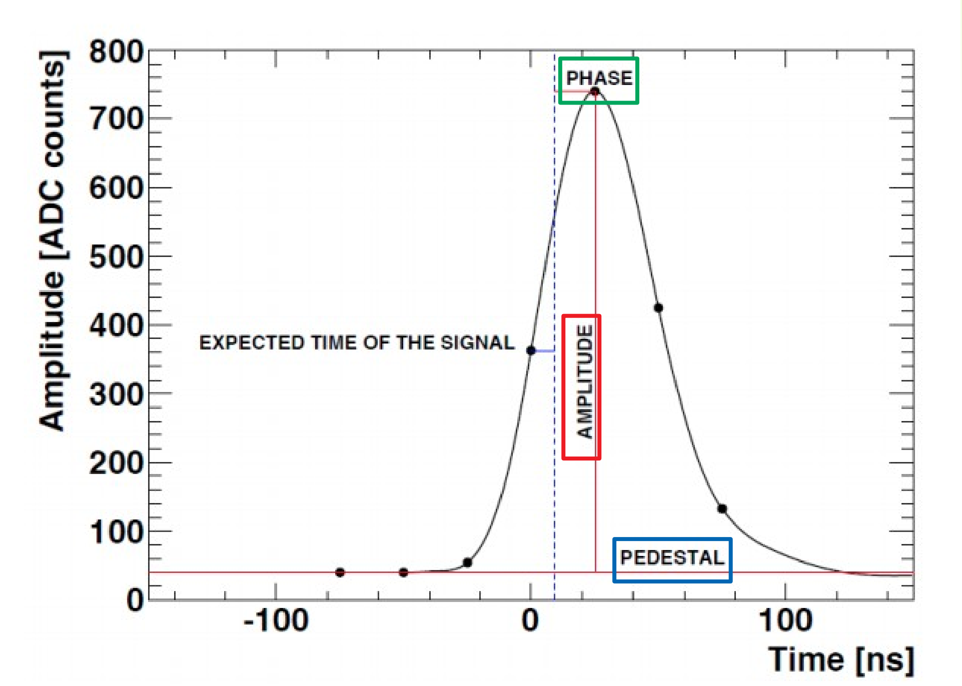
Signal reconstruction

- On-detector processing workflow
  - **Shaping**
  - **Amplification** : 2 gains with 1/64 ratio
  - **Digitization** : 7 samples each 25 ns with 10 bits ADC
  - **Transmission** of data on reception of trigger signal (max rate of 100kHz)

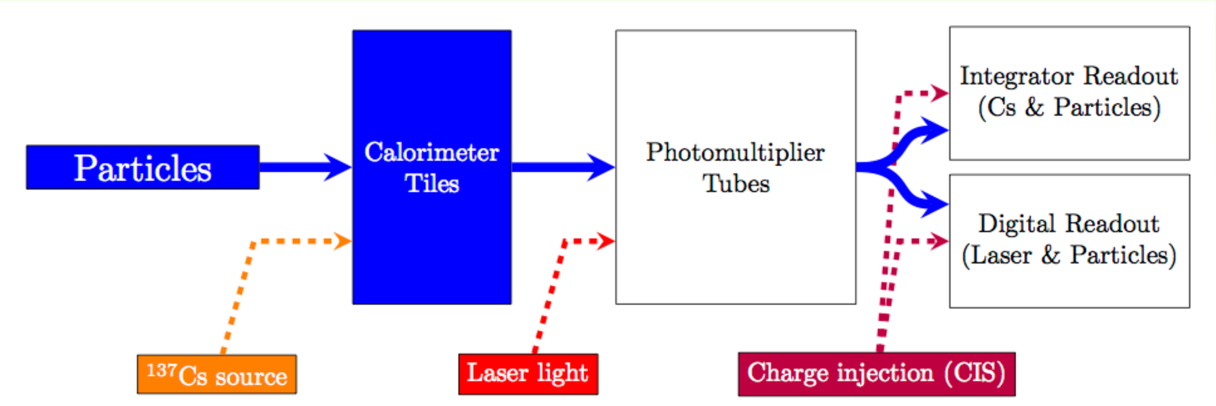


Signal reconstruction

- Optimal Filtering
  - amplitude, pedestal, phase
  - Assume a known pulse shape
  - Energy is reconstructed based on the pulse characteristics



Calibration systems



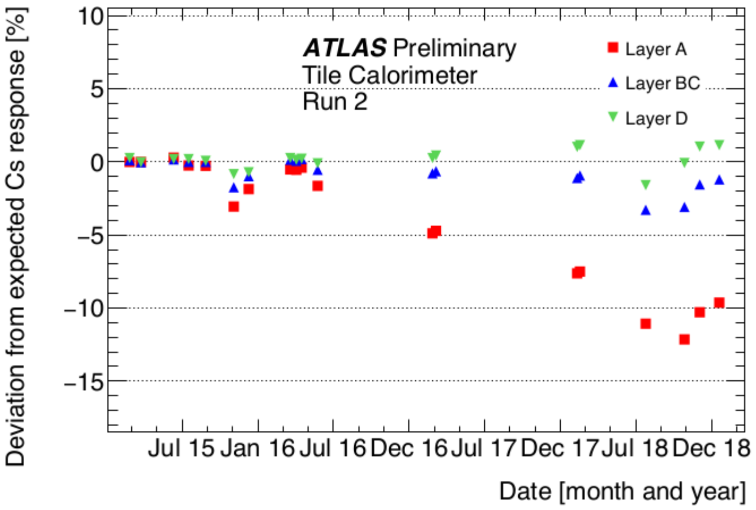
← Schematic of the calibration systems

- Calibration system components
  - **Cesium system** : f_{Cs} (optics and gains) 0.3% precision
  - **Laser system** : f_{las} (variations from electronics and PMTs) 0.5% precision
  - **Charge Injection System** (CIS) : $f_{ADC \to pC}$ (ADC response) 0.7% precision
  - **Minimum Bias system** (MB) : full optical chain monitoring (with integrator read-out)
- Energy scale obtained with test beam : $f_{pC \to GeV}$

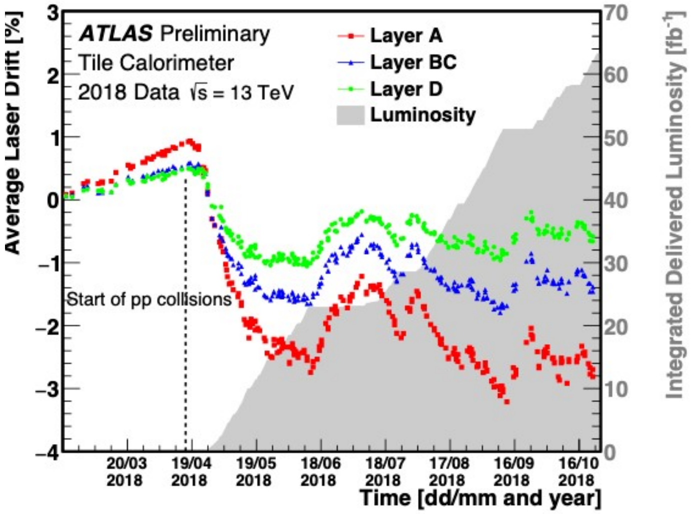
$$E[GeV] = A[ADC] \times f_{ADC \to pC} \times f_{pC \to GeV} \times f_{Cs} \times f_{las}$$

Calibration systems

- Run 2 results
  - Results obtained during run 2 (2015-2018)
  - Calibration runs taken regularly



Cesium calibration
Few times per year



Laser calibration
Every week

Variations of PMTs

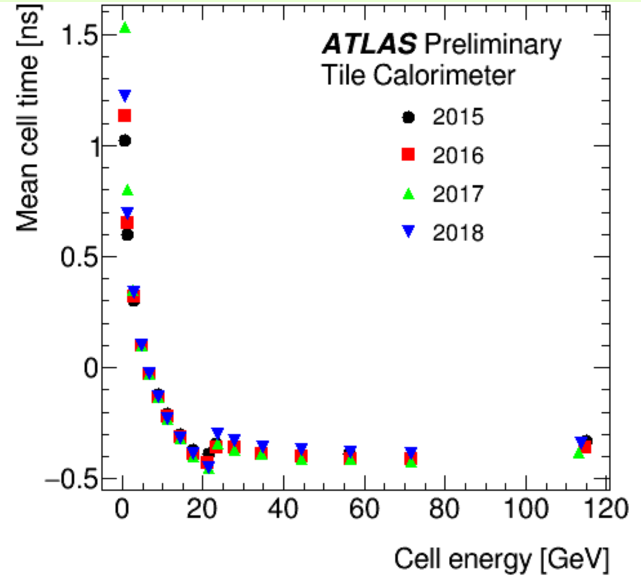
Down drift due to radiations

Up drift due to recovery between data taking

More exposed layers are **more impacted**

Time calibration and noise

- Time calibration
  - **Synchronize** pulse with sampling clock
    signal peak must be centered in time window
  - In jet events, signal phase < 1 ns for E_{cell} > 4 GeV
  - More details on timing in **poster 127** by S. Polacek
    (second session, room K)



- Noise
  - Comes from **electronics** and **pile-up**
  - Electronics contribution measured in pedestal runs (noise level ~20 MeV)
  - Largest noise in high exposure regions

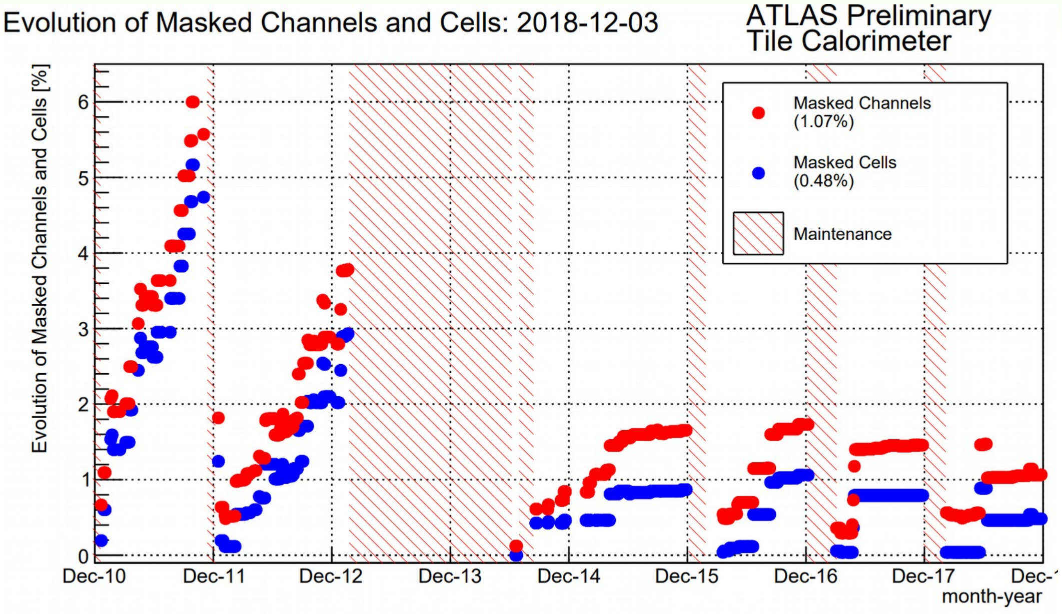
Run 2 performances

- Masked channel monitoring

Problematic channels that can impact physics results are masked

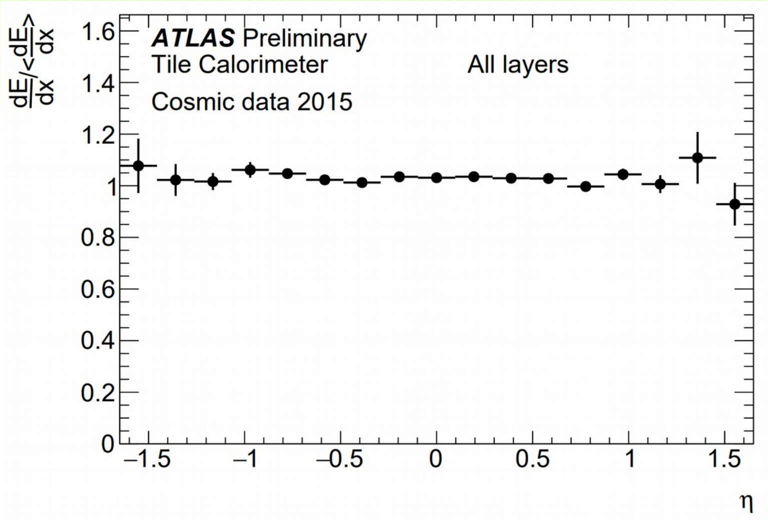
2 channels per cells (redundancy)

During run 2, only very few masked cells

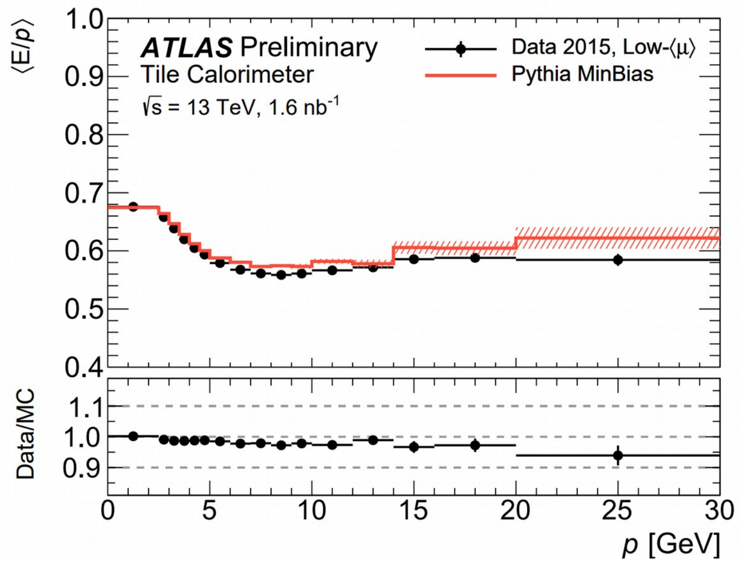


Run 2 performances

- Single particle response



Cosmic muon response →
EM scale and cell intercalibration
Uniformity in η better than 5%
Uniformity in φ better that 1%



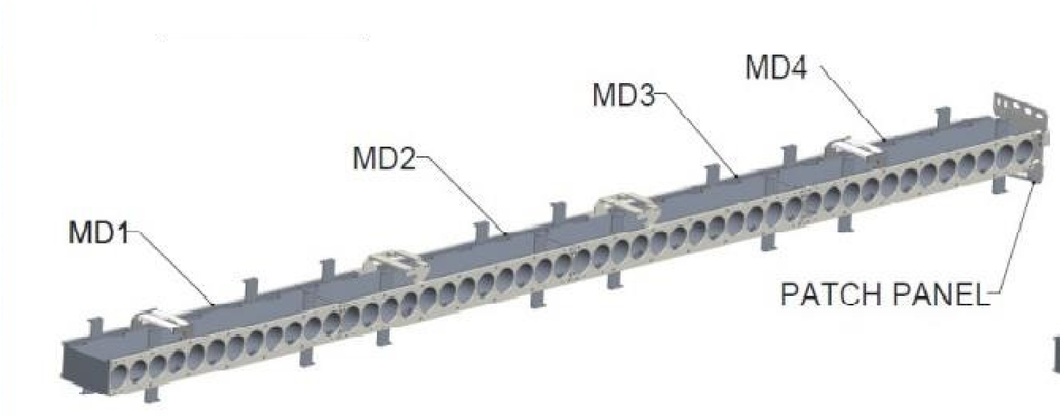
← Single hadron response
Measured energy / track momentum
Data and MC agree within 5%

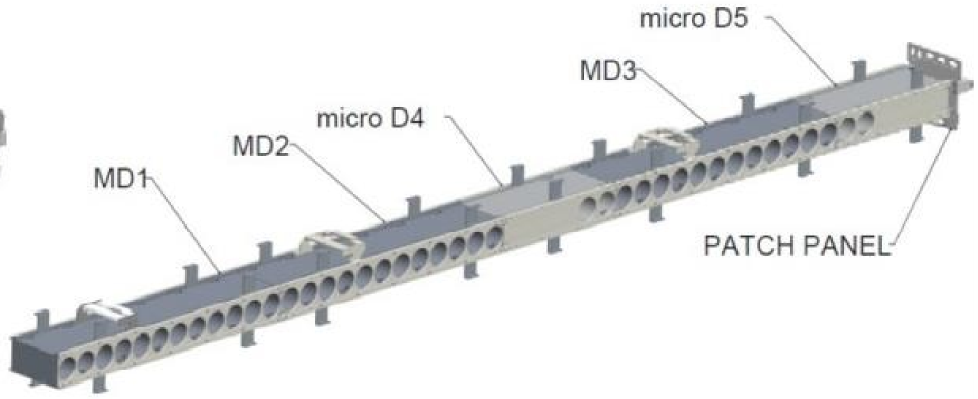
High-Luminosity upgrade & Tile Calorimeter

- HL-LHC
  - Installation during LS3 (2025-2027)
  - **Increase of peak luminosity**, with up to 4000 fb^{-1} integrated luminosity in the end
  - **High pile-up contribution** (50 → 200 collisions by bunch crossing)
- Changes for Tile Calorimeter
  - New electronics, and mechanical structure
  - Improved LV and HV system
  - **New digital trigger** with up to 40 MHz rate
  - **Increased bandwidth** : 40 Tbps for the entire detector

HL-LHC : mechanics

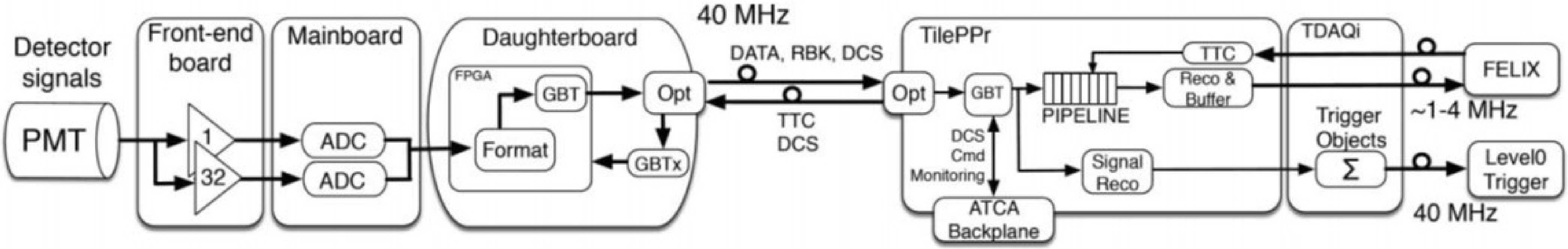
- New super-drawer architecture
  - Modules split in electrically independent mini drawers (MD)
    => More segmentation (256 → 1024) for more reliability
  - Up to 12 PMTs per MD
  - Architecture fully validated, production has already started
  - Additional micro-drawer added for extended barrel modules





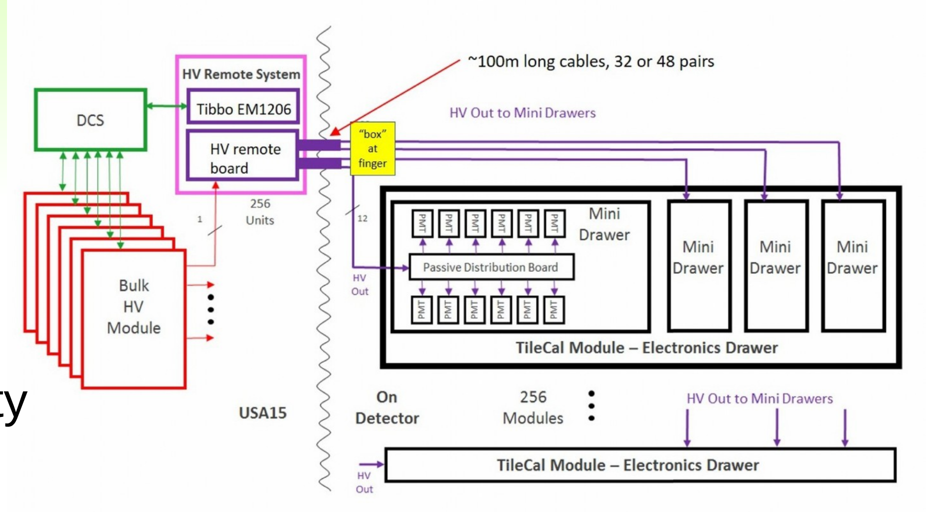
HL-LHC : Front-end and back-end electronics

- On-detector electronics
  - **FENICS front-end board** : shaping, amplification (2 gains with 1/40 ratio) integrator (luminosity)
  - **Mainboard** : digitization (12 bits ADCs signal, 16 bit ADCs for integrator)
  - **Daughterboard** : formatting and transmission of data to back-end (40 MHz rate)
- Off-detector electronics
  - Detector data storage (pipeline) until trigger signal is received
  - **New digital trigger** (allow more advanced trigger algorithms)
  - Monitoring

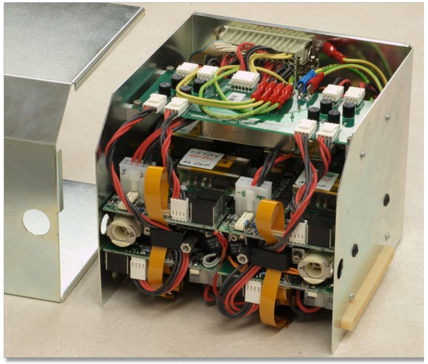


HV and LV systems

- HV distribution
  - Regulation and distribution of HV will be off-detector (easy access)
  - On-detector passive distribution board
  - Active dividers for each PMT => better performances at high luminosity



- Low Voltage Power Supply (LVPS)
  - LVPS bricks located on-detector (1 per module)
  - System based on current LVPS bricks
  - Improved reliability, noise level and radiation hardness

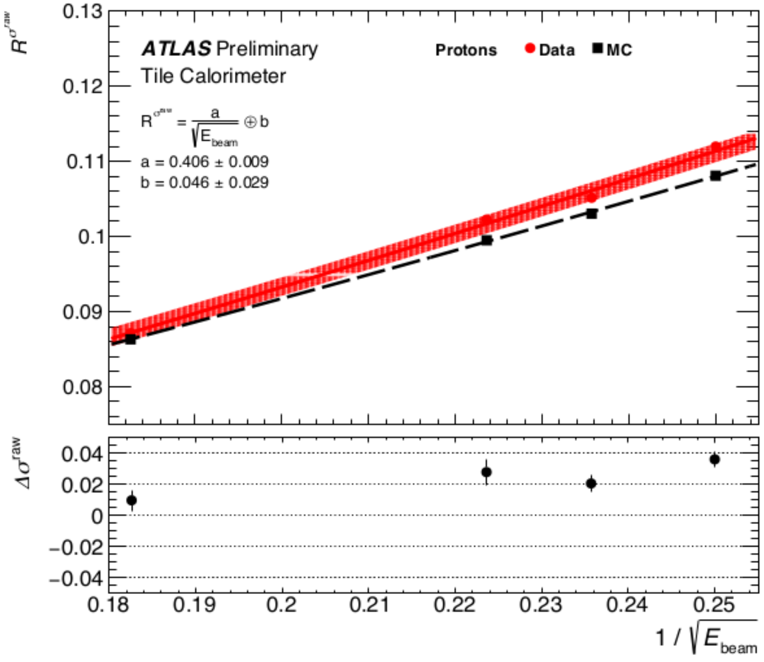


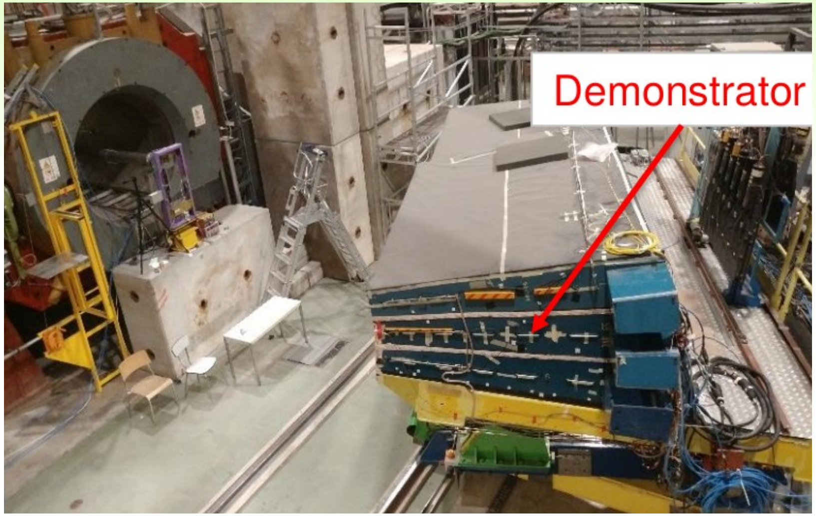
Demonstrator

- Demonstrator module
  - Project to operate backward-compatible upgraded electronics
  - Inserted in ATLAS in July 2019
  - Upgraded version of the electronics (upgraded 3-in-1 with 1/32 gain ratio, mainboard, daughterboard)
  - Adder cards for retro-compatibility with current trigger system
  - Demonstrator will be kept in ATLAS during run 3
- Demonstrator PreProcessor
  - Modified system to ensure retro-compatibility with current TDAQ and TTC
  - Demonstrator can be controlled and monitored like any other module

Demonstrator performance and stability

- Results from test beam
  - 7 test beam campaigns between 2015 and 2018
  - Beam of different particles and energies





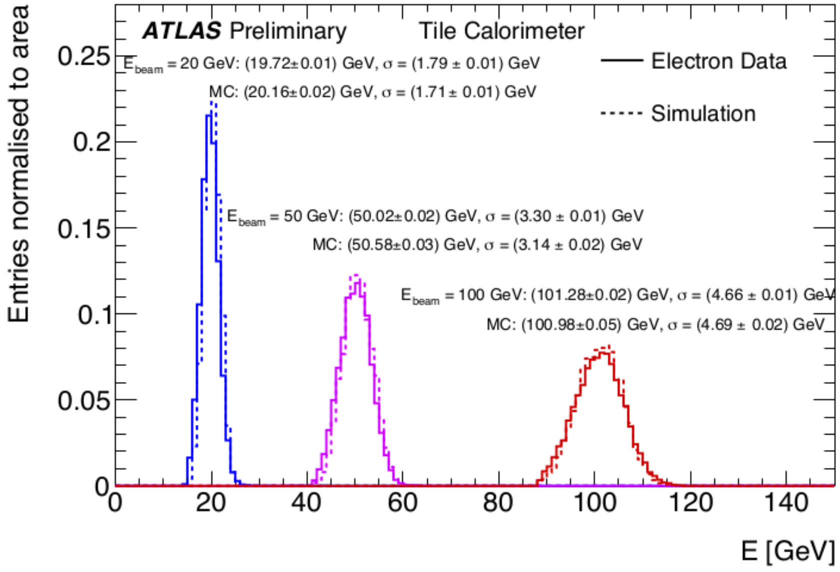
Response to single hadrons

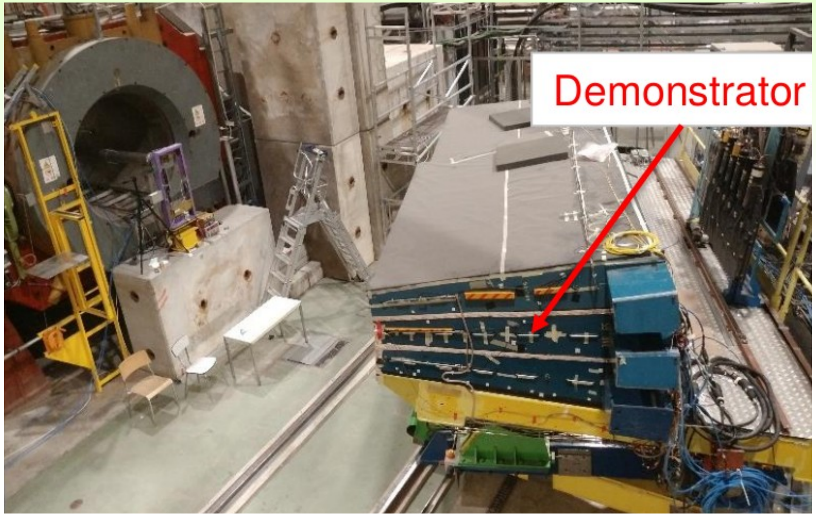
Measurement of energy response ratio

Good resolution and agreement with MC

Demonstrator performance and stability

- Results from test beam
  - 7 test beam campaigns between 2015 and 2018
  - Beam of different particles and energies





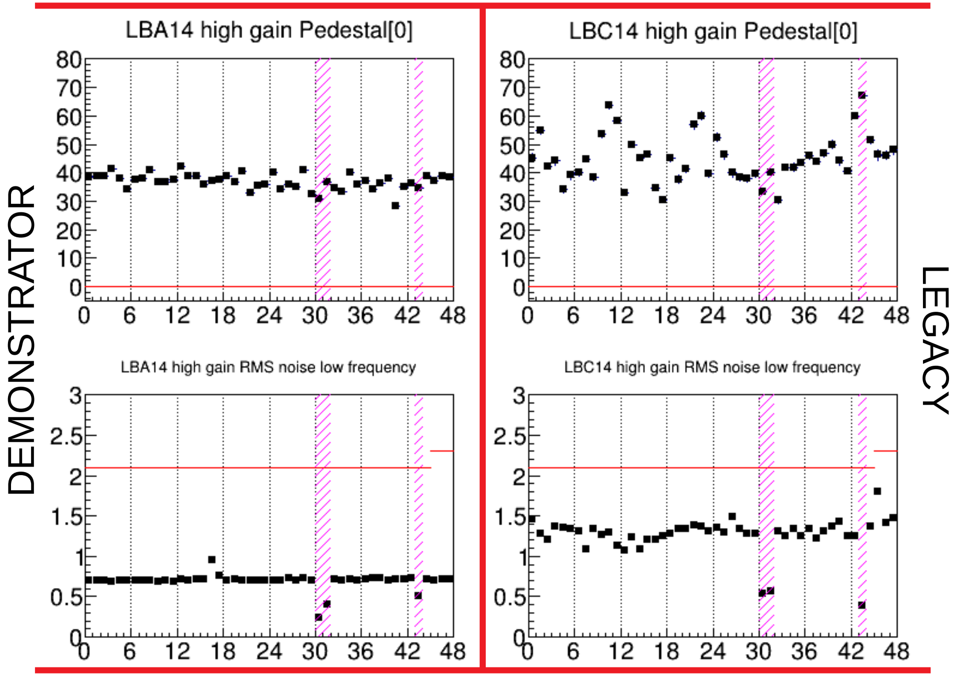
Response to electrons

Energy calibration

Good data/MC agreement

Demonstrator performance and stability

- Results from inside ATLAS detector
  - Data taken after insertion of demonstrator <u>in the detector</u>
  - Comparison with legacy module



Data taken from a laser run

Measurement of **average pedestal** for each channel

Demonstrator shows **good stability** and **low noise level**

Conclusion

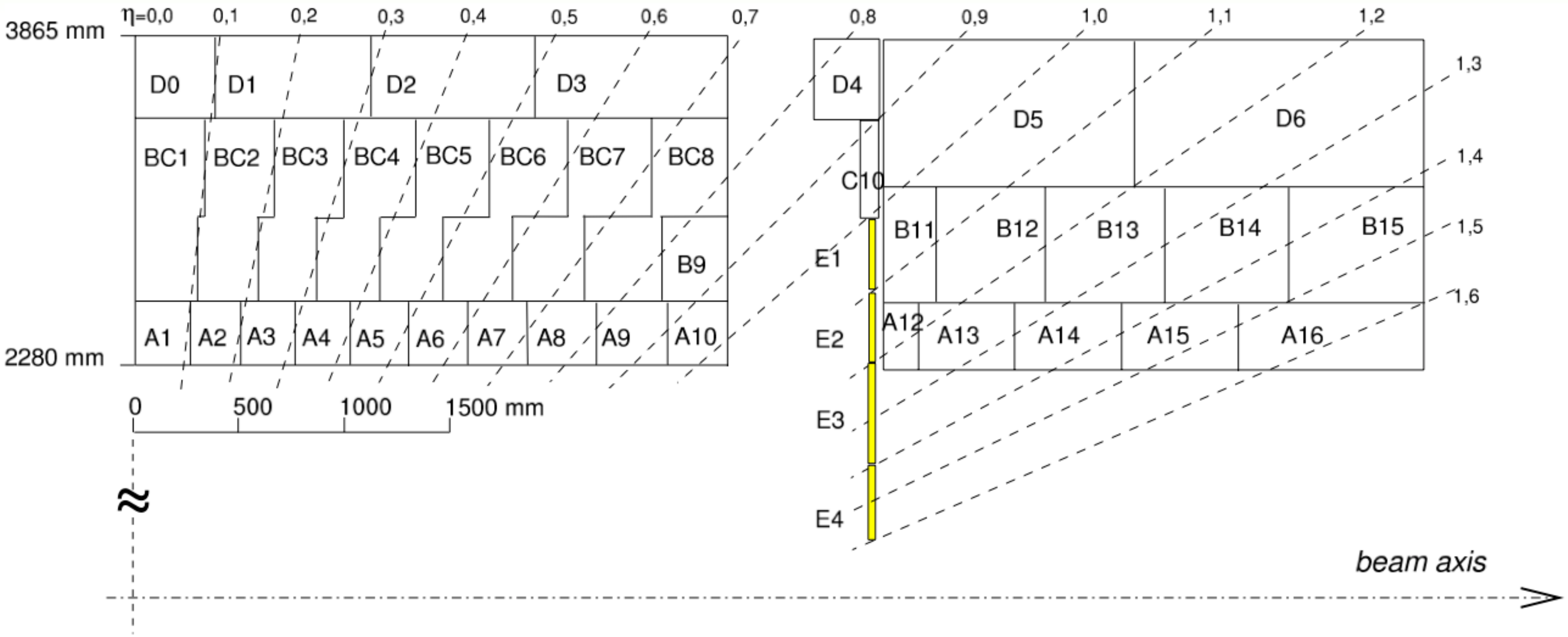
- ATLAS Tile calorimeter showed **good performances** during run 1 and run 2
  - 0.48% masked cells (end of run 2) and cell energy scale maintained within 1%
  - Precise and continuous monitoring thanks to calibration systems
  - Extensive maintenance campaign during LS2 to be ready for run 3
- The **High-Luminosity** phase of LHC will bring **new challenges** (High luminosity, pile-up, radiations …)
- **Upgrade** of the Tile Calorimeter system is required and well on track
  - **New mechanical structure and electronics** (more reliable)
  - **New trigger system** (higher rate with better algorithms)
- The Tile demonstrator is **fully operational**
  - Results from test beam and test inside the detector show overall good performances and stability

Thank you !!

Backup

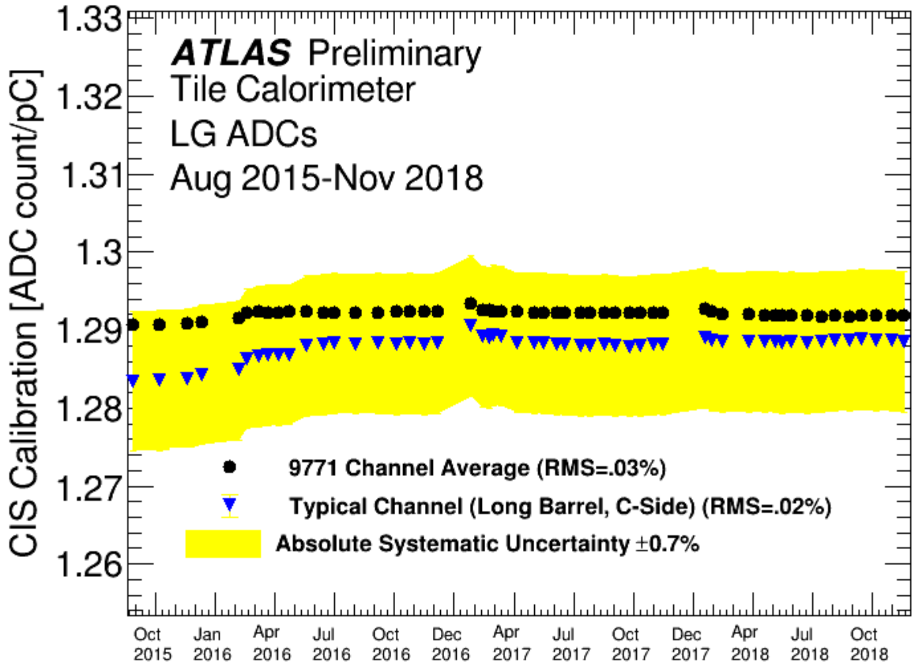
The Tile Calorimeter system

- Cell mapping of Tile Calorimeter



Calibration systems

- Run 2 results
  - Results obtained during run 2 (2015-2018)
  - Calibration runs taken regularly



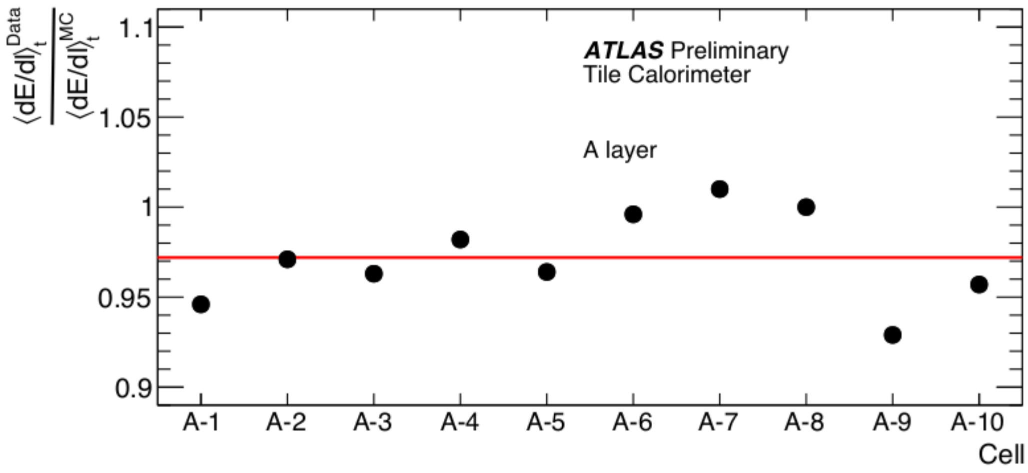
CIS calibration

Dedicated runs taken weekly
Also used to calibrate L1 calo trigger

Monitoring of CIS calibration constant in time
0.03% stability over time

Demonstrator performance and stability

- Results from test beam
  - 7 test beam campaigns between 2015 and 2018
  - Beam of different particles and energies

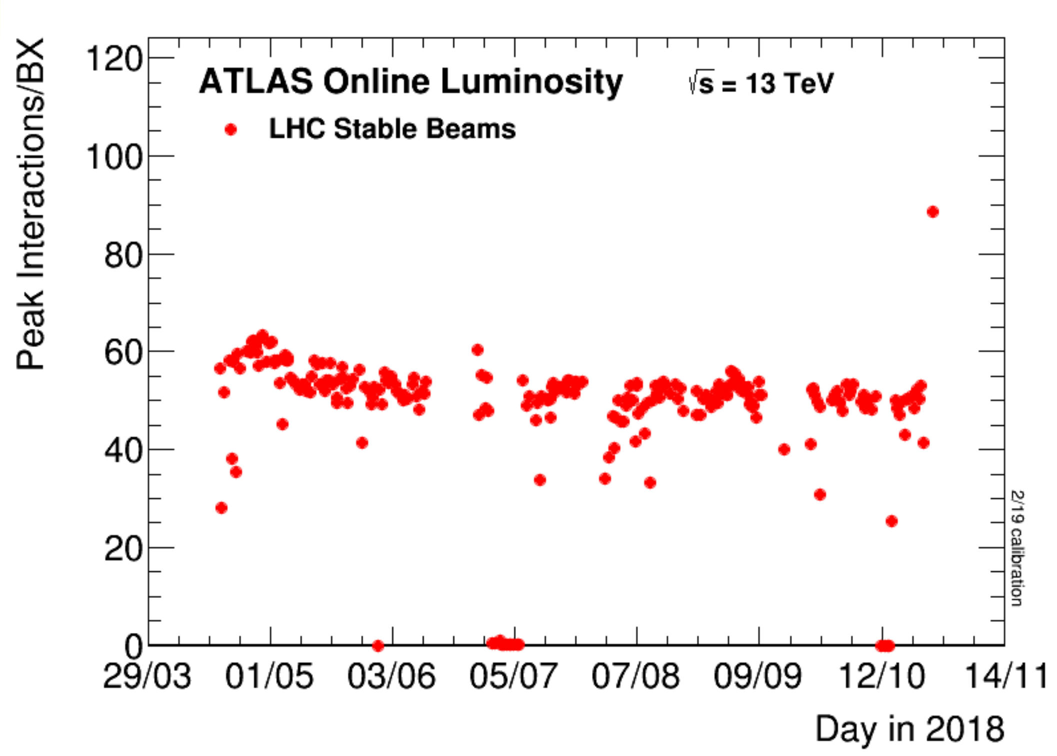


Response to muons

Check EM scale and linearity

Pile-up

- Interactions per bunch crossing in 2018

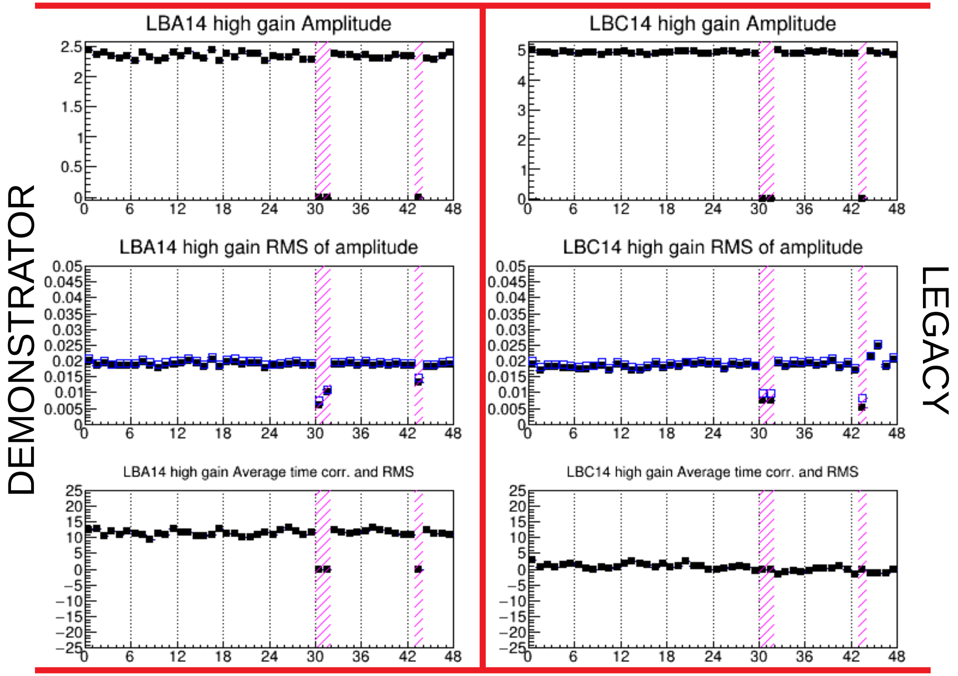


Between 50 and 60 interactions / bunch crossing in average

For HL-LHC, we expect at least 4x more

Demonstrator performance and stability

- Results from inside ATLAS detector
  - Data taken after insertion of demonstrator in the detector (module LBA14)
  - Comparison with legacy module (LBC14)



Data taken from a CIS run

Measurement of average amplitude and phase

Demonstrator show good stability and noise on par with legacy module

Factor 2 for mean amplitude comes from different gain

Difference in phase comes from calibration