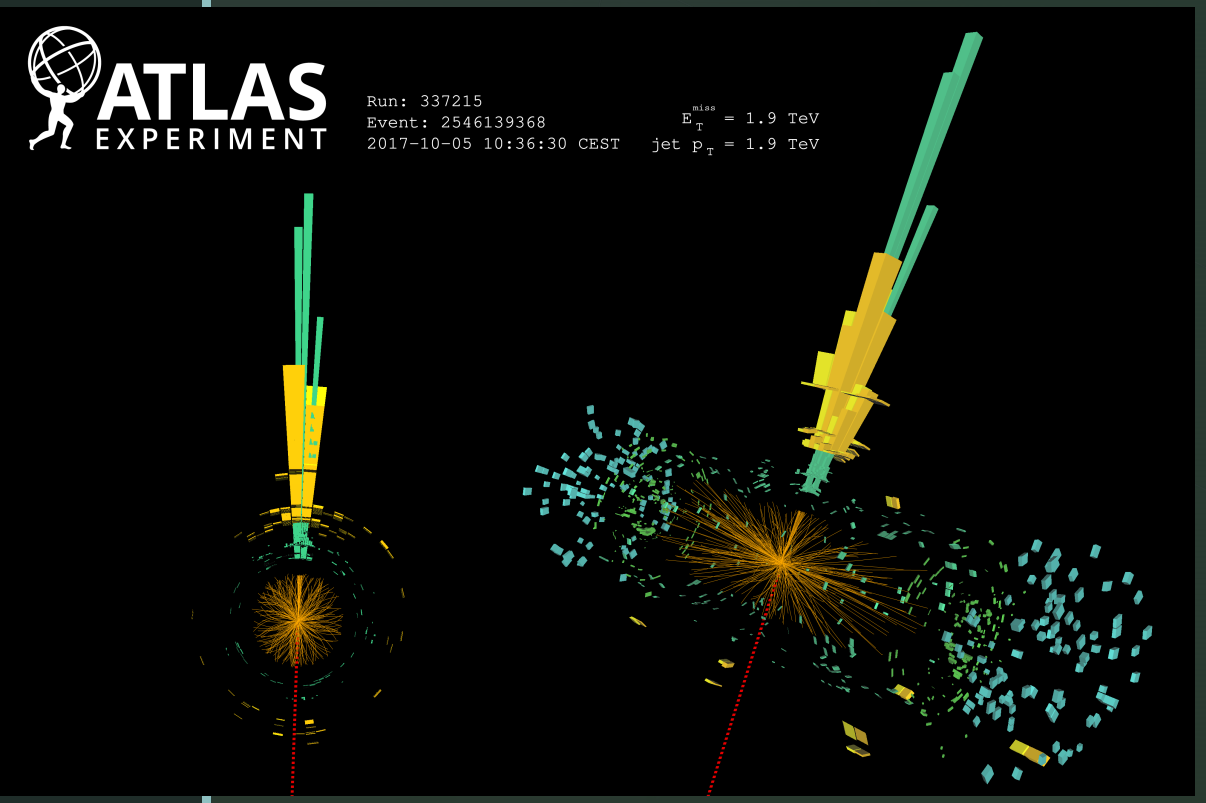
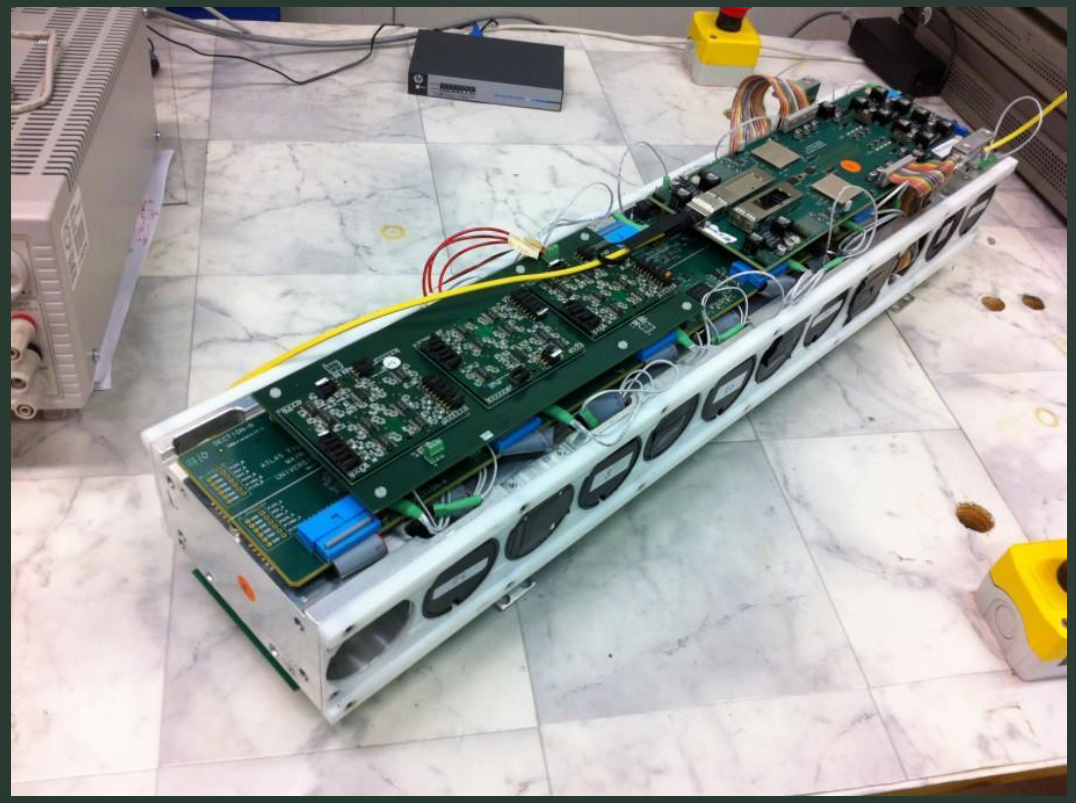
Upgrade of the ATLAS Hadronic Tile Calorimeter for the High Luminosity LHC





On behalf of the ATLAS Tile Calorimeter System

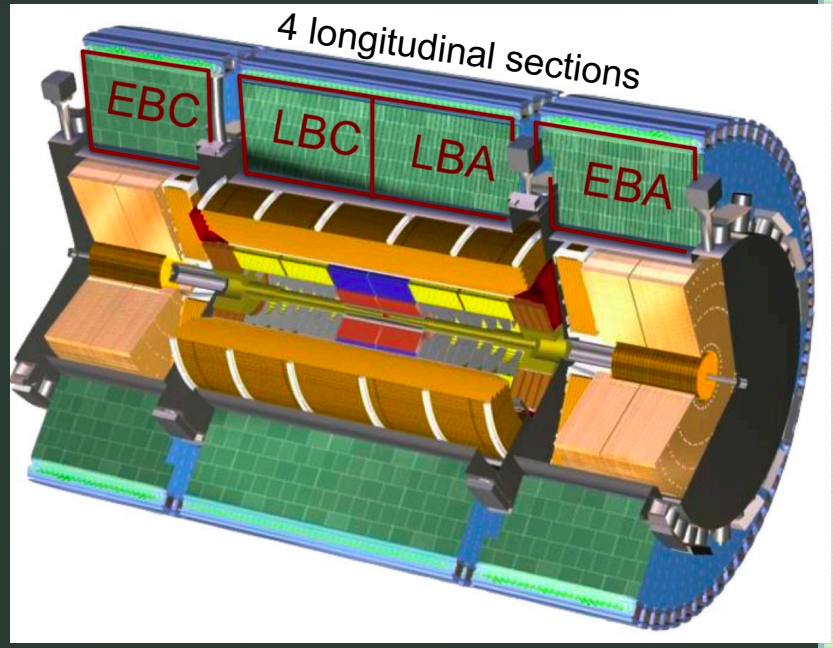
5th International Conference on Particle Physics and Astrophysics – October 7th – Christophe Clément (Stockholm U.)

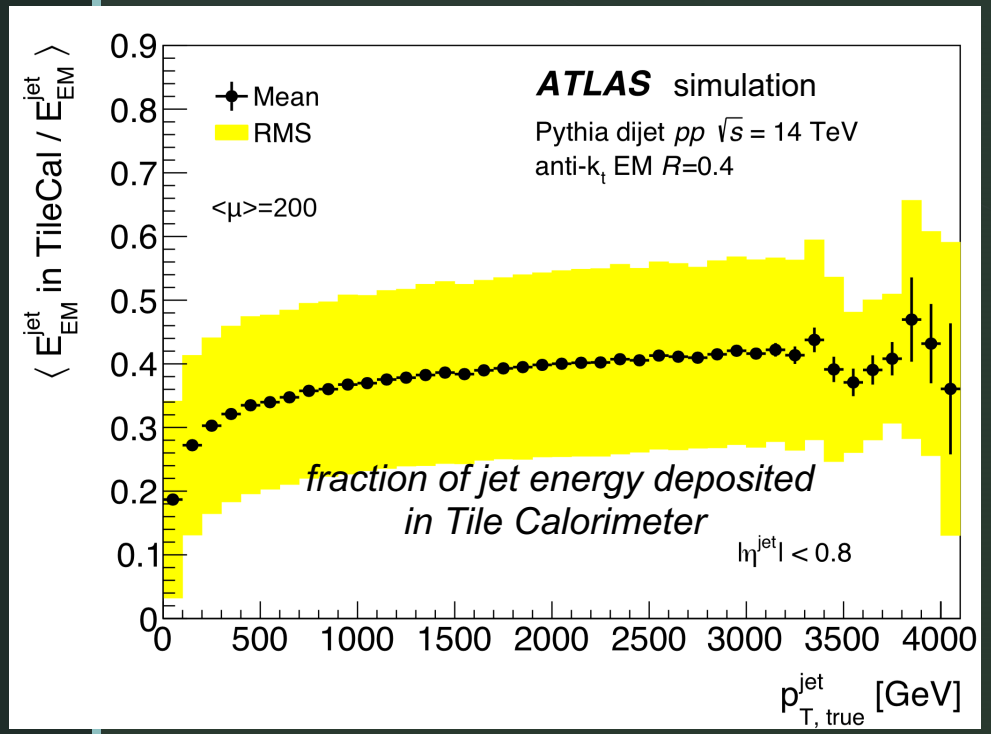
TileCal is the central part ($|\eta|$<1.7) of the ATLAS hadron calorimeter

Crucial for measurements of **high energy hadronic jets** and **Missing Transverse Energy, lepton isolation.**

High energy hadron jets deposit large fraction of their energy in the Tile Calorimeter

Input to the trigger system for jets, missing transverse energy, lepton isolation, topological triggers...



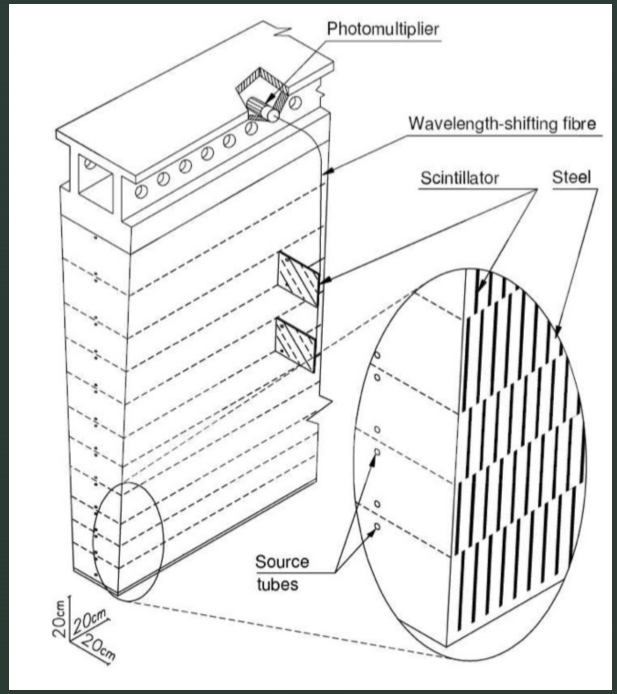


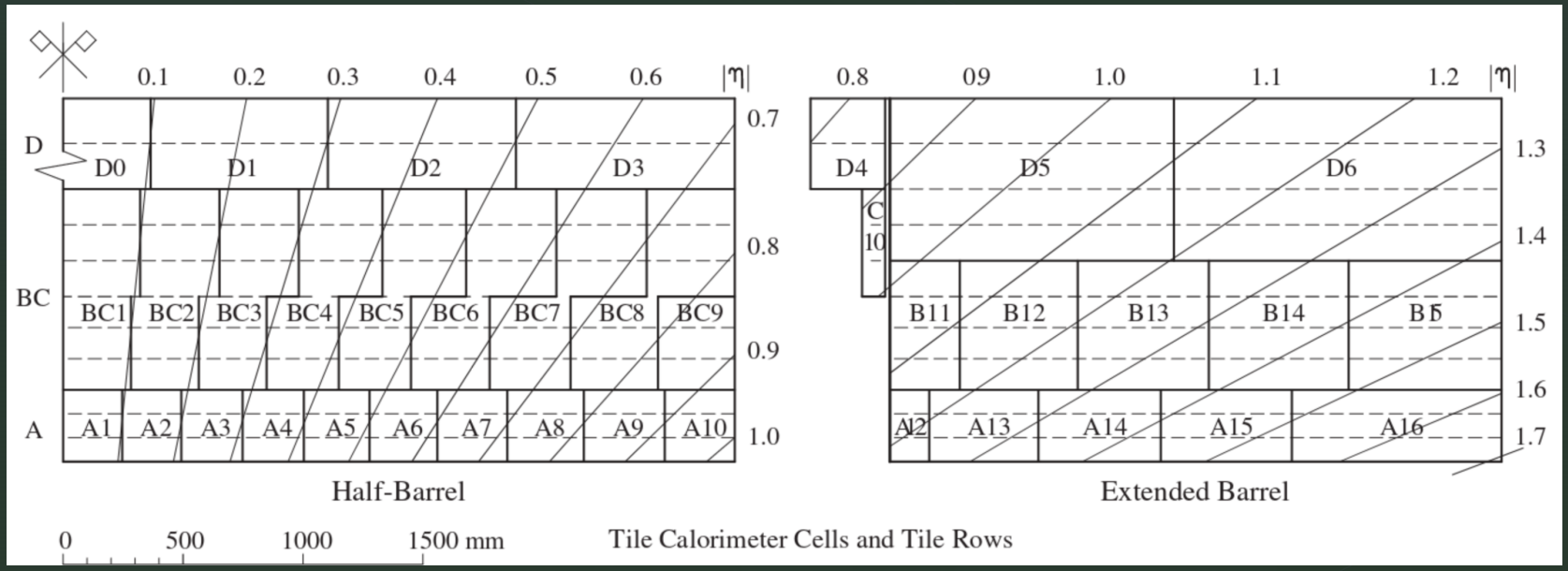
Keep Tile Calorimeter response known to better than 1%

9852 Photomultipliers in 256 wedge modules in 4 longitudinal sections (Extended barrel A, C and Long barrel A,C)

Dynamic range from ~10 MeV to ~2 TeV per calorimeter cell

- TileCal is an iron/scintillator sampling calorimeter
- Read out by WLS fibers and photomultipliers
- Each Calorimeter cell is read out by two photomultipliers (redundancy)
- Dedicated calibration systems allowing to calibrate electronics and optics independently

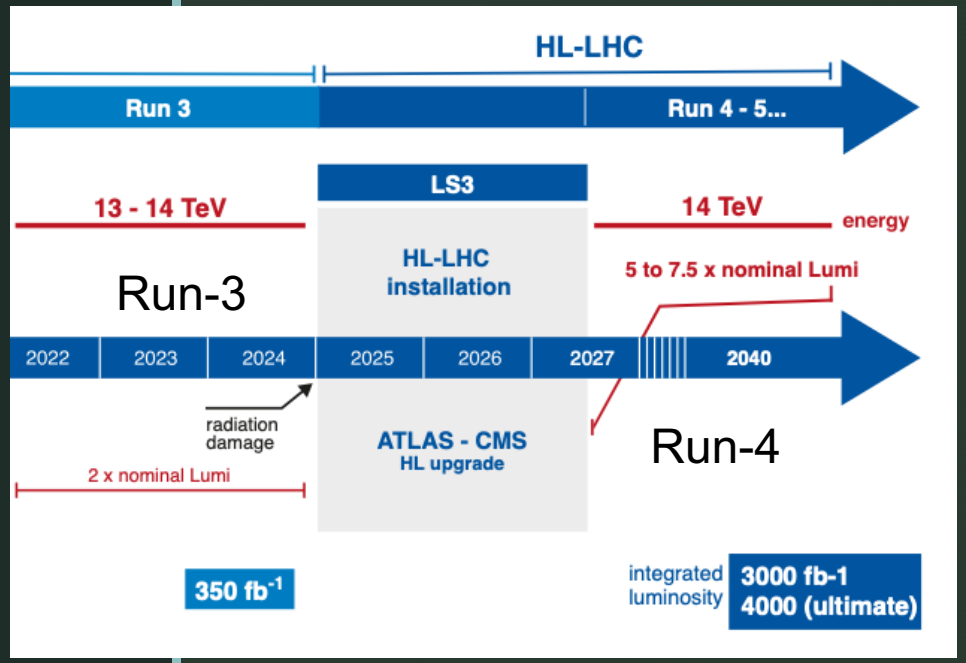




Tile Calorimeter Cells and Tile Rows

High Luminosity LHC Upgrade & Tile Calorimeter

- HL-LHC to increase the instantaneous luminosity by a factor up to 7.5, provide 4000 fb^{-1} dataset
- 200 collisions per bunch crossing
- Radiation environment @ TileCalorimeter
  - Up to ~100 krad, 2 10^{13} neutrons/cm^2, 10^{12} hadrons/cm^2 with safety factors folded in.
  - Most exposed is Low Voltage Power Supplies. Less than half these dosages in Front-End electronics.



TDR published in 2018

Memorandum understand prepared in 2019

High Luminosity LHC Upgrade & Tile Calorimeter

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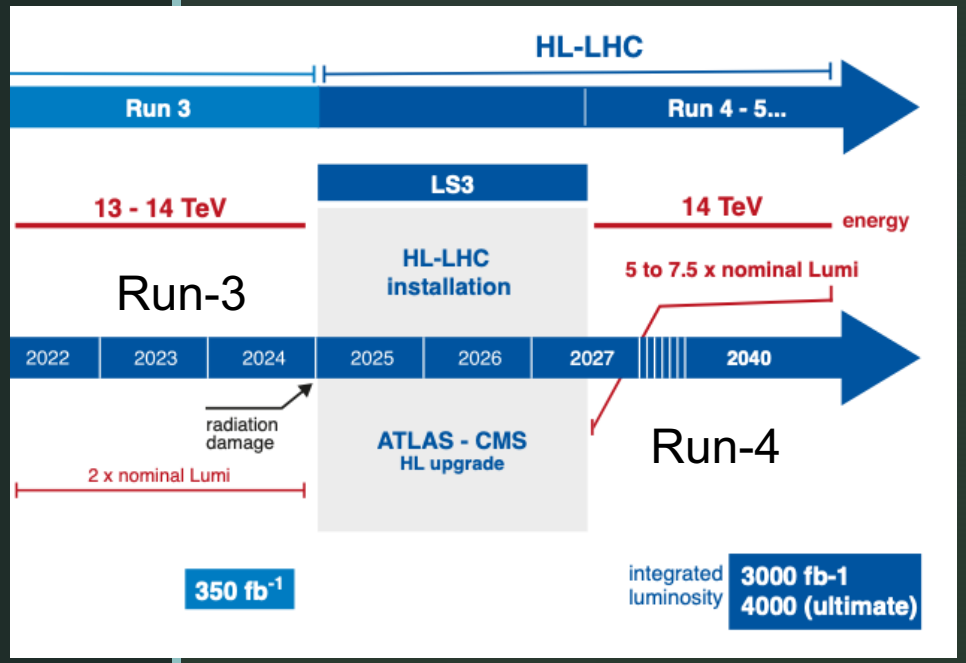


- Upgrade to fully digital trigger, full readout at 40MHz
- No on-detector buffering (radiation)
- Degradation of the most irradiated PMTs at the end of Run-3 => 10% most irradiated PMTs to be replaced
- The rest of the optics is kept from current ATLAS
- New radiation hard front-end electronics
- New radiation hard and modular low and high voltage services

Mechanics

⇒ Guiding principle: facilitate **extraction** and **maintenance**

Long Barrel Module 45 PMTs = 4 mini-drawers (MD)

- 12 PMTs + 12 Front-End-Cards
- 1 Main Board + 1 Daughter Board
- 1 HV Board passive distribution board
- 1 Low Voltage Power Supply

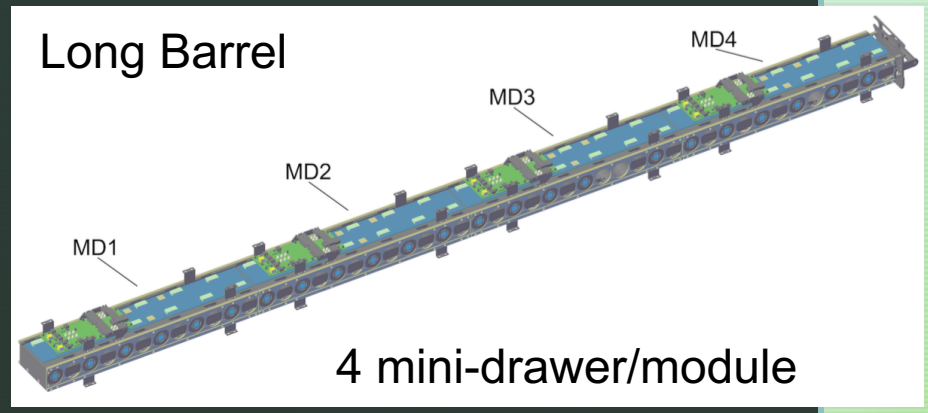
Extended Barrel Module 32 PMTs/module

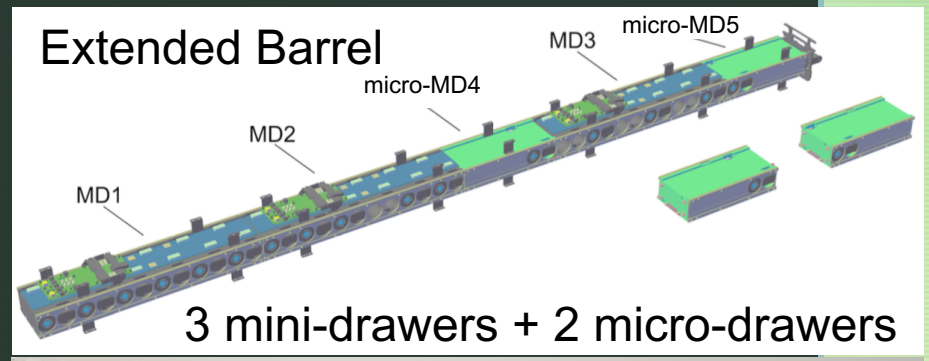
⇒ Can be served by 3 mini-drawers + 2 micro-drawers

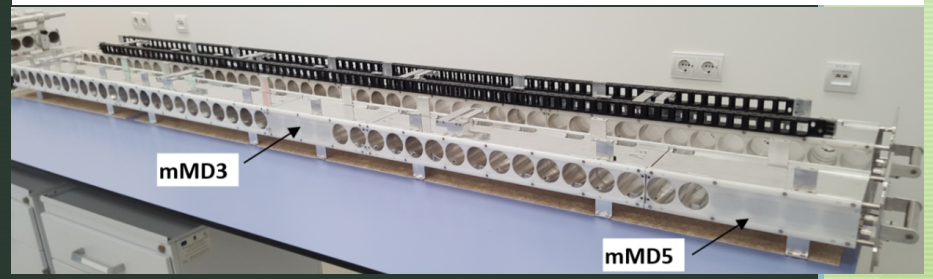
- Mini-drawers mechanics already defined
- A few readout cables need to be longer

Fully validated in testbeam

In production stage ...





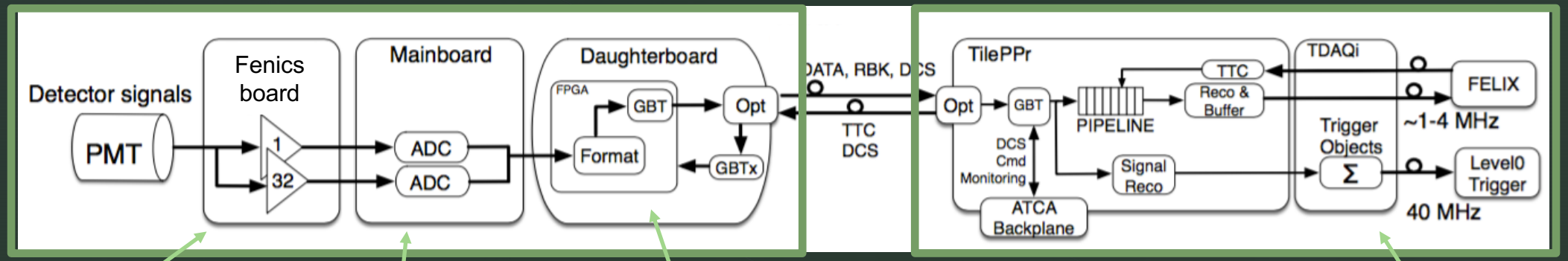


Readout electronics for TileCalorimeter at HL-LHC

- New strategy
  - On-detector electronics to transmit digitized data to the off-electronics at the LHC frequency
  - Buffer pipelines are **moved off-detector** – "PreProcessor FPGAs"
  - Redundancy in data links and power distribution → improvement in the system reliability

On-detector front-end

Underground counting rooms ~100m away



Shaping & amplification
Precision readout and
Integrating readout

Digitization & gain selection

Communication
Control & Timing
Slow monitoring
Reconfigurations of on-detector FPGAs

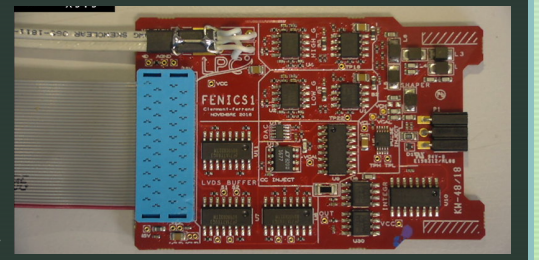
Compute energy, time ... at 40MHz for all cells

TDAQ Interface:
selection of cells of interest
compute trigger objects of interest

Send trigger objects to trigger decision system

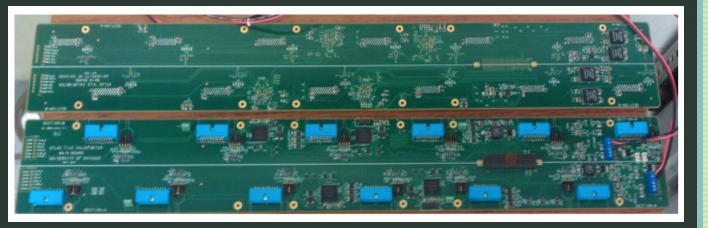
Front-end electronics for TileCal at HL-LHC

- FENICS **- Pulse Shaping, amplification**
  - *Fast Readout:* two gain amplification for physics
  - *PMT Current Integrating Readout* for ^{137}Cs calibration & Luminosity measurements
  - *Integrator Readout has* 6 gains to cover 7-8 orders of magnitudes in luminosity
  - Improved precision and better noise performance than legacy
  - Charge injection system for precise calibration
  - Fully qualified for radiation & In pre-production phase



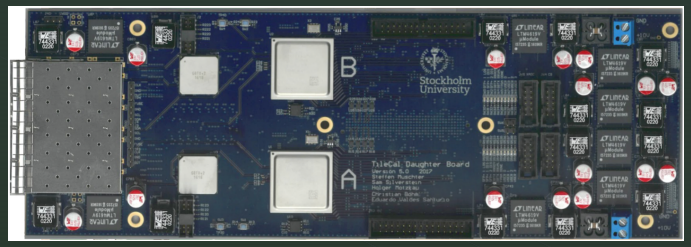
FENICS cards (x10k)

- Main Board **- Digitize signals from 12 PMTs**
  - *Fast readout:* 24 12-bit ADCs @40 Msps
  - *Integrator Readout: 12 16-bit SAR ADCs*
  - Routes the digitized data to the Daughter Board
  - Digital control of the front-end boards (configure for calibration or physics...)
  - Fully qualified for radiation & In pre-production phase



Main Board (x900)

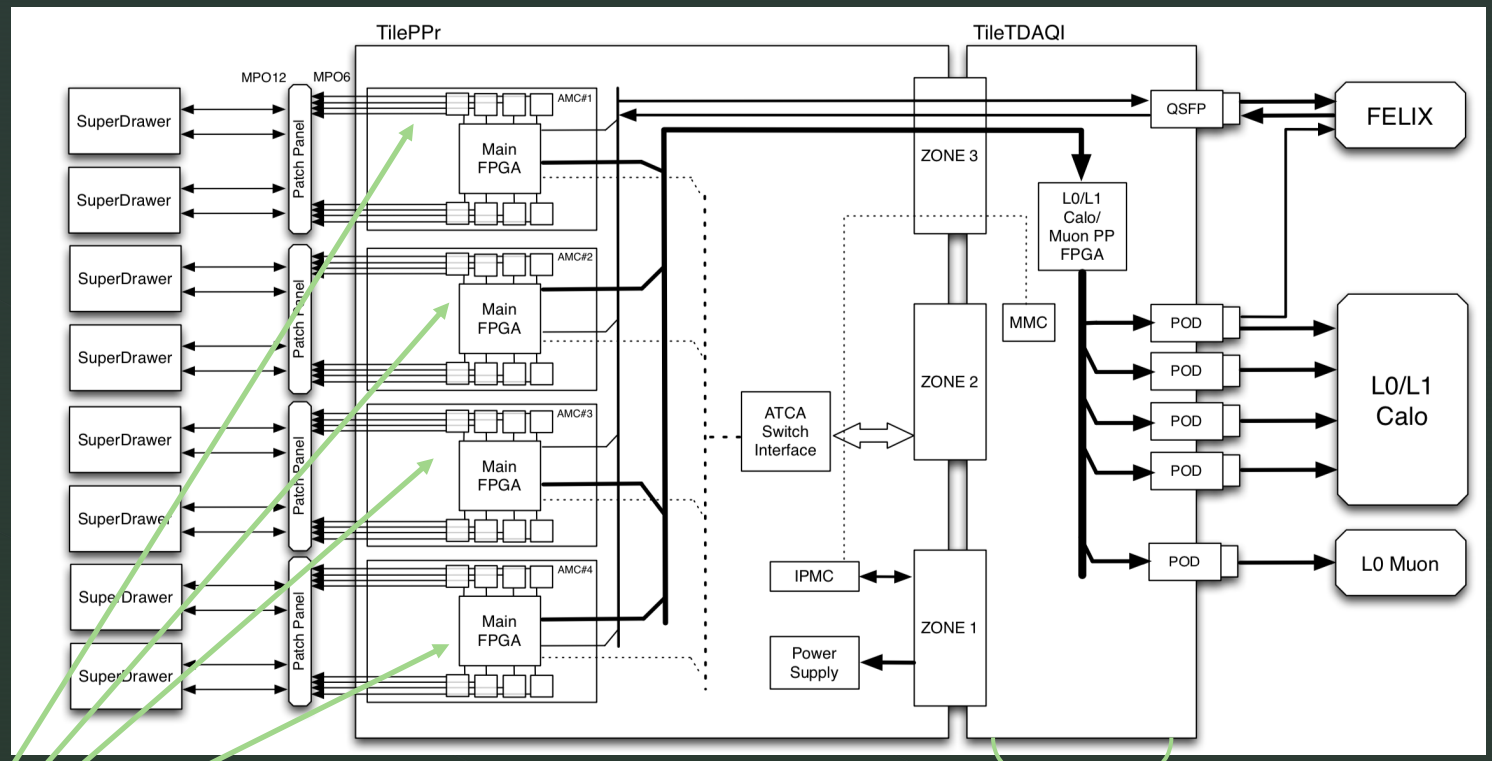
- Daughter Board
  - High Speed communication 4.8/9.6 Gbps
  - Send detector data to off-detector electronics
  - Receive, distribute LHC clocks, configurations and control
  - 2 FPGAs Kintex Ultrascale (KU)
  - Recent redesign due to **single event latch-ups** observed in previous FPGA (KU+)
  - Final prototype in preparation. Preproduction expected to start 2021



Daughter Board (x900)

Back-end electronics

8 TileCal modules (total 256)



ATLAS data readout Clock

Compact Processing Module "CPM" performs Calculations of energy and timing with optimal digital filtering

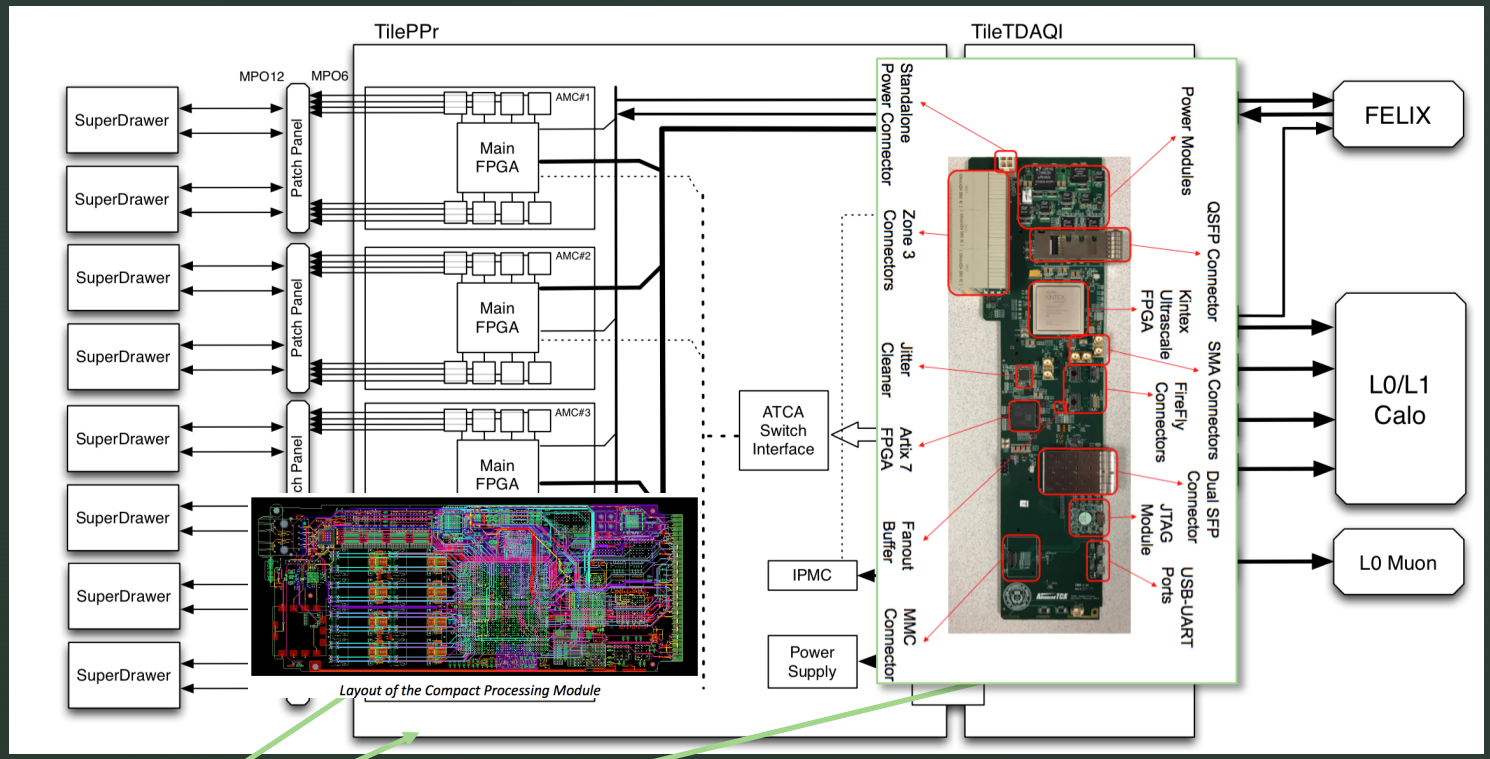
PreProcessor

Process and distribute clock
Separates monitoring from physics data with a System-on-chip.
Ship full readout data to ATLAS readout (FELIX)
Send data to TDAQ interface : "TDAQi"

TDAQi with trigger FPGA compute trigger objects selects cells above threshold

Back-end electronics

8 TileCal modules (total 256)



ATLAS data readout Clock

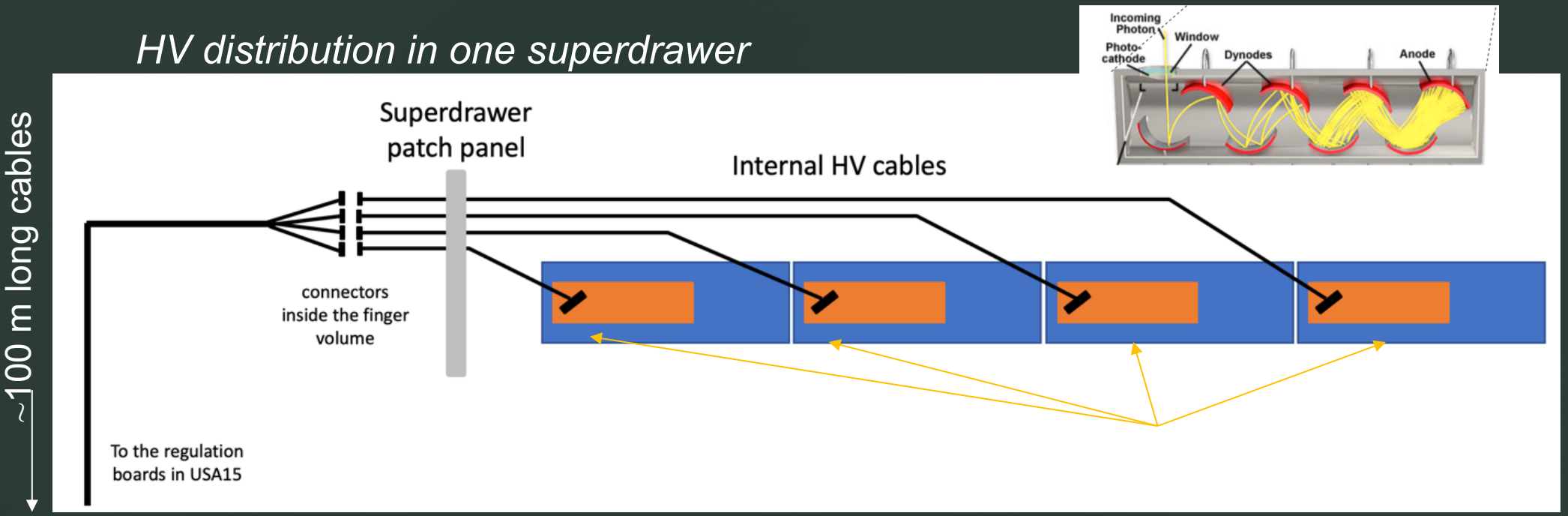
Full-size CPM and carrier board prototyped and extensively tested both in testbeam and in lab with scaled down TDAQi

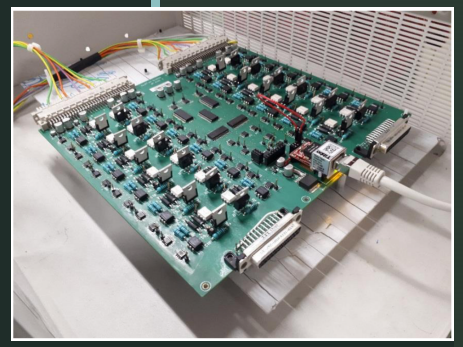
Full size TDAQi in PCB design phase

Also a reduced system "Tile PPr demonstrator" was succesfully employed in testbeam

High Voltage System

HV distribution in one superdrawer





48 channel remote regulation

Based on a **remote regulation** scheme to avoid radiation damage.

Long cables + **remote regulation** boards have been validated in lab and in testbeam.

RMS of HV < 0.5V, <0.2 V/°C, ripple < 20mV
Low temperature dependence
Regulation needed in the range 600-900V

Legacy system has passive HV dividers

Due to the new HL-LHC requirements the high PMT current requires new **Active** dividers to keep the linearity even at high luminosity

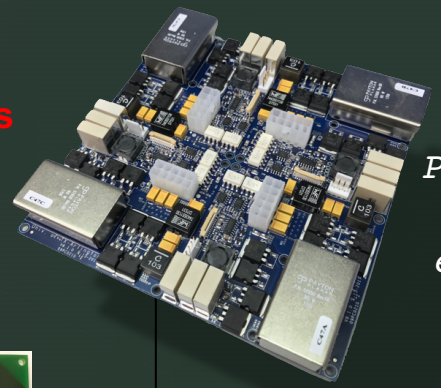
Low Voltage distribution system

Main challenge comes from usage of COTS components & Radiation hardness requirements.

Fully prototyped & tested in vertical slice test with both on and off-detector elements.

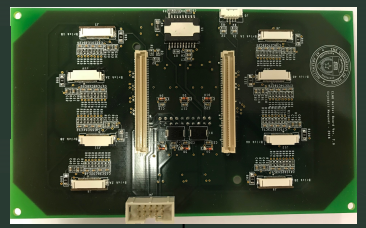
exposed to radiation

LV DC/DC bricks 200V-10 V



Provides 10V to the FE electronics

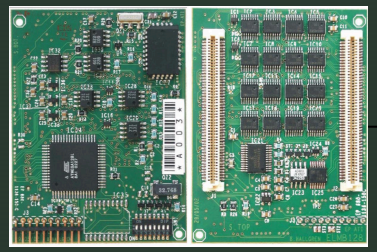
ELMB mother boards



Control (and monitoring)

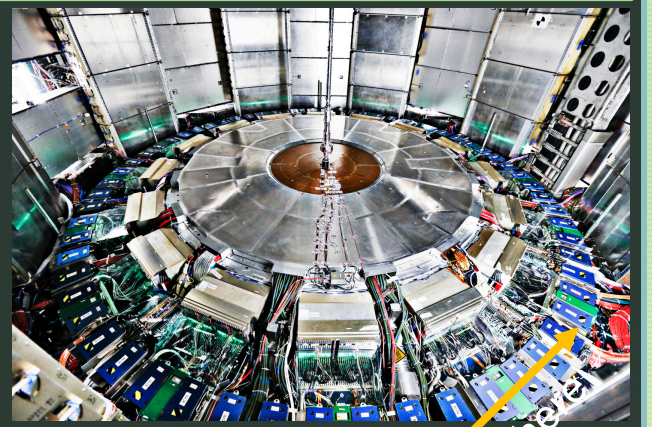
Monitoring only

ELMB2



Assemble LV boxes

Needed for ~April 2024



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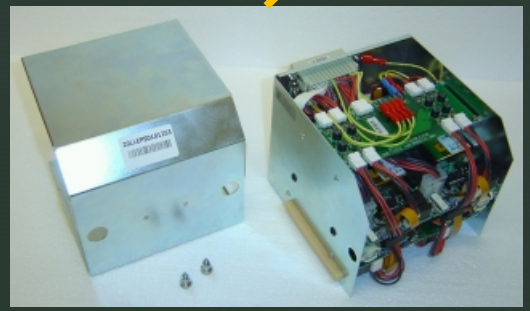


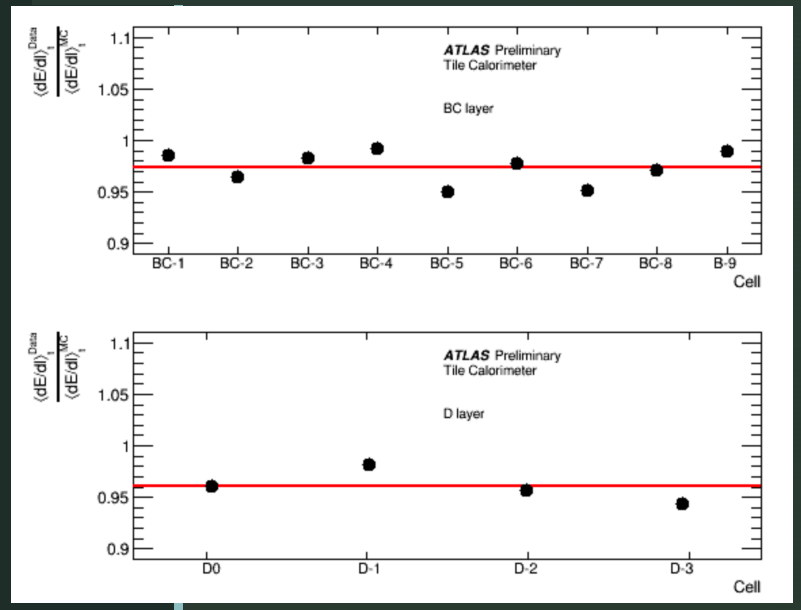
170 x 175 x 150 mm

Auxiliary components in boxes

Testbeam with prototype electronics for HL-LHC

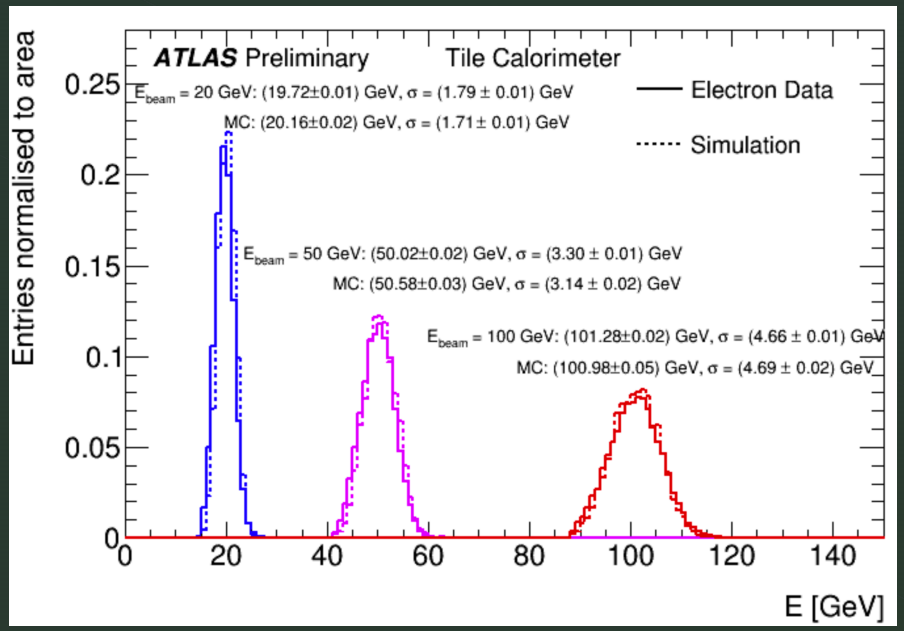
- 5 testbeam campaigns carried out 2016 – 2018 with prototype FE electronics
- Also prototype elements of the low and high voltage systems
- Data taken with
  - Muons, electrons, hadrons

Data to Monte Carlo response with muons

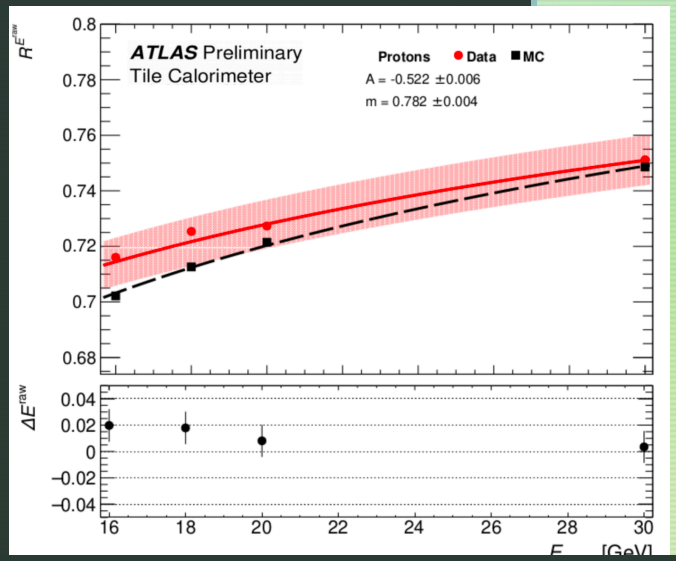


Muons = small signals: verify the good S/N performance of the new electronics

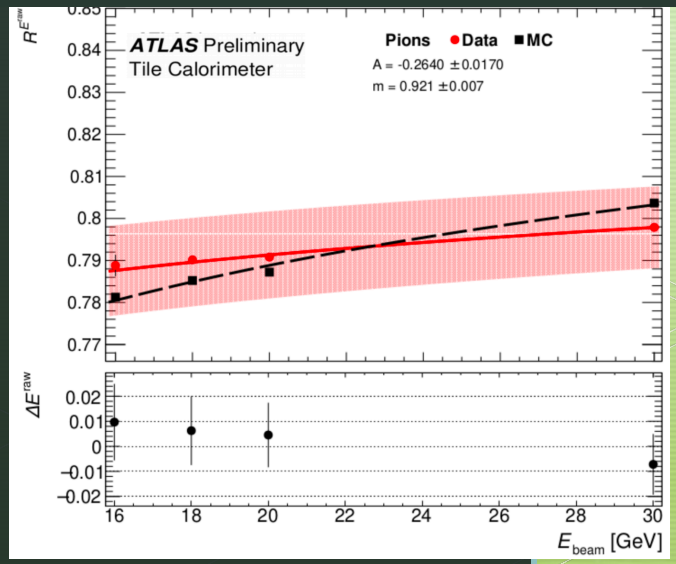
Data to Monte Carlo response with electrons



Determine the EM scale of the calorimeter in pC/GeV and verify linearity



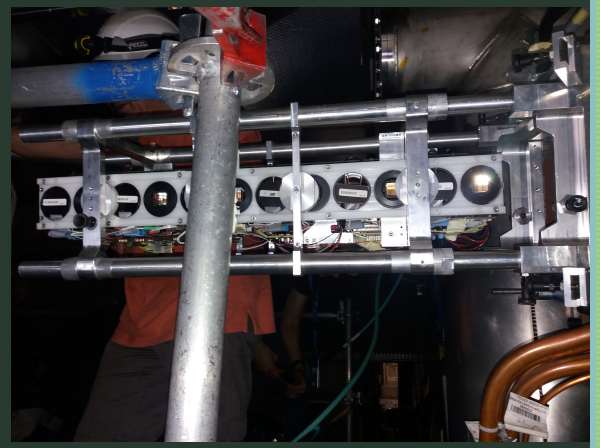
Data to Monte Carlo response with hadrons



Testbeam results can be found here
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ApprovedPlotsTileTestBeamResults

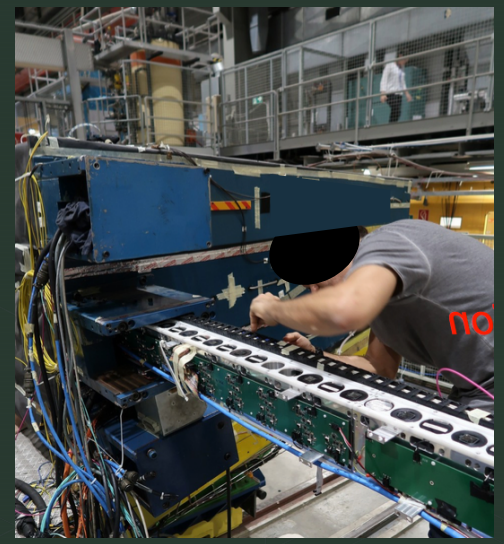
Conclusion

- All elements of the ATLAS TileCal for HL-LHC have been prototyped
- **Extensive radiation campaign almost complete**
- Full scale Demonstrator with HL-LHC FE electronics inserted in ATLAS:
  - Performing well, useful testbed in real environment including services



Demonstrator insertion into ATLAS (2019)

- **Many components of the mechanics and front-end electronics have entered pre-production or production**
- Long shutdown 3 (2025-2027) has a tight planning, requires all components to be validated and ready to be installed by end of 2024
- **Project on schedule for installation in the ATLAS cavern in 2025**



Testbeam 2018