Upgrade of ATLAS Hadronic Tile Calorimeter for the High Luminosity LHC

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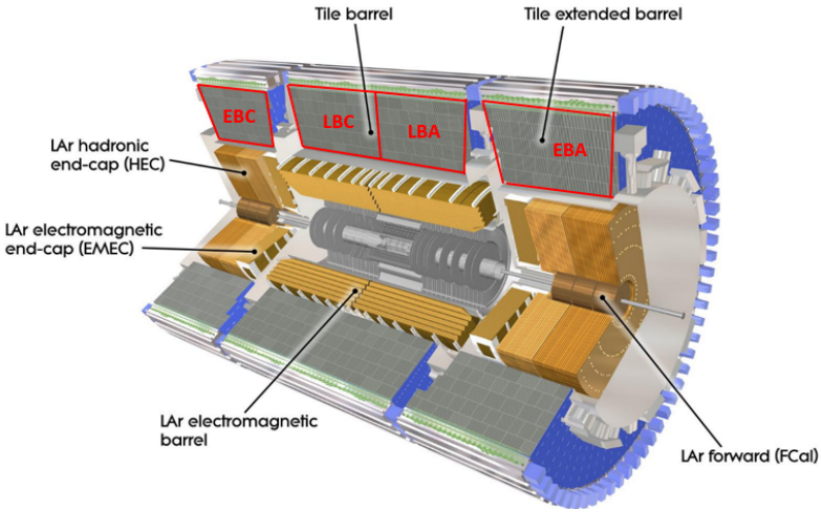
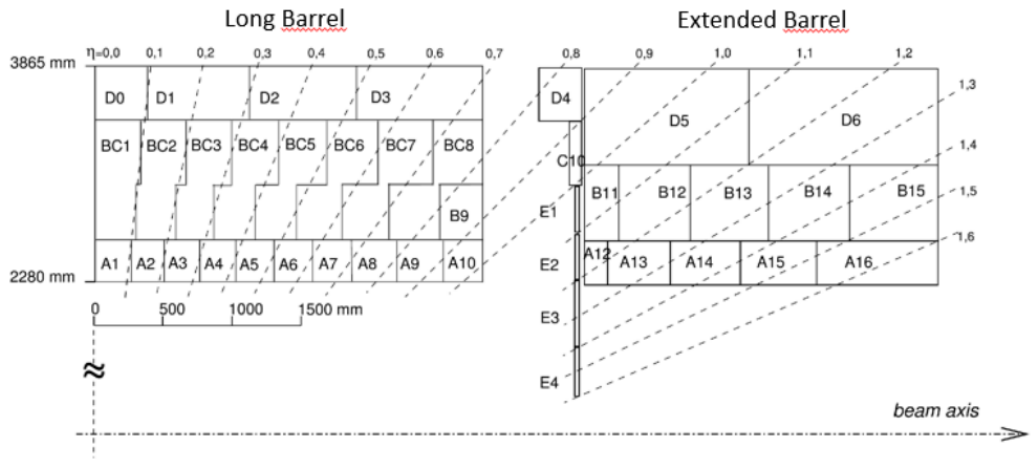
Introduction

The ATLAS Tile Calorimeter:

- Central hadronic calorimeter of the ATLAS experiment.
- Reconstruction of hadrons, jets, tau-particles and missing transverse momentum.
- Composed of three cylinders subdivided azimuthally into 64 wedge modules each.
- Two readout sections of the central cylinder form the Long Barrel sides (LBA, LBC) and two Extended Barrel sections (EBA, EBC).

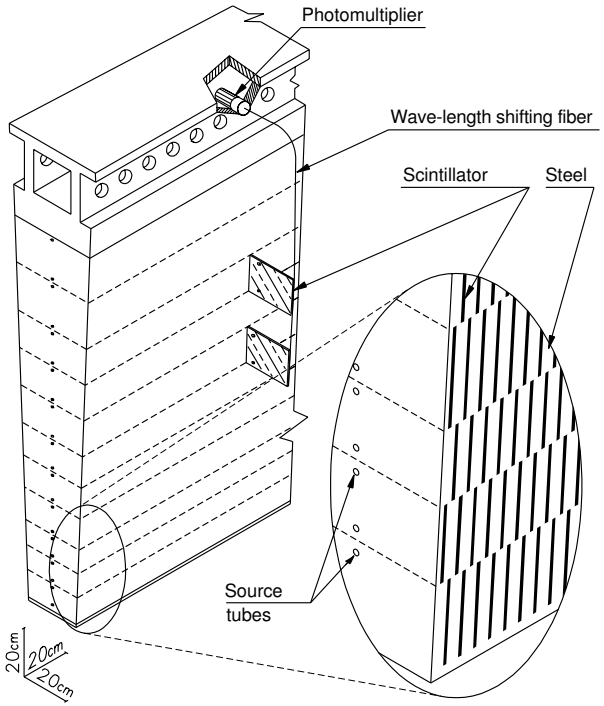


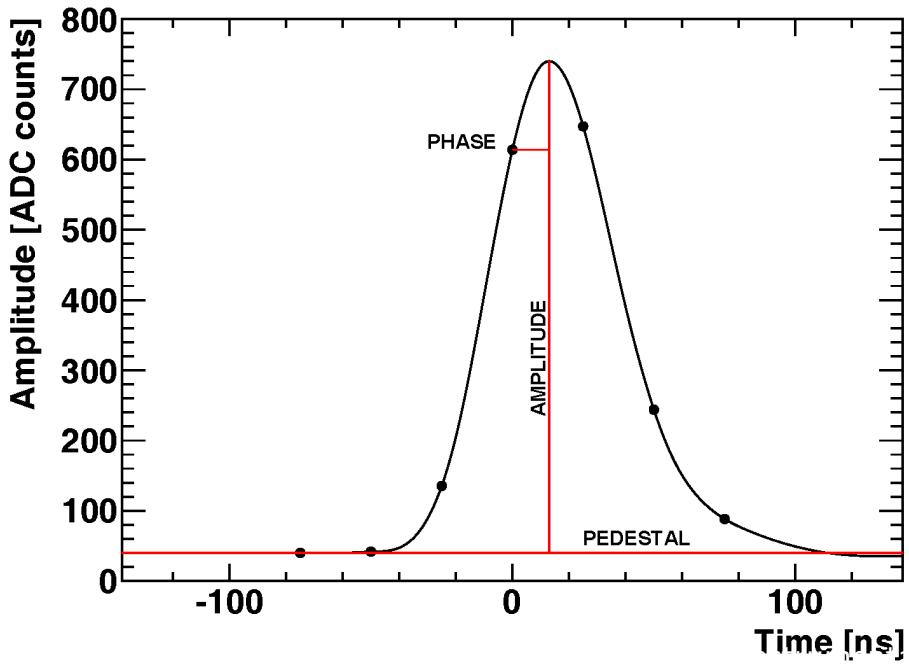


Introduction

The ATLAS Tile Calorimeter:

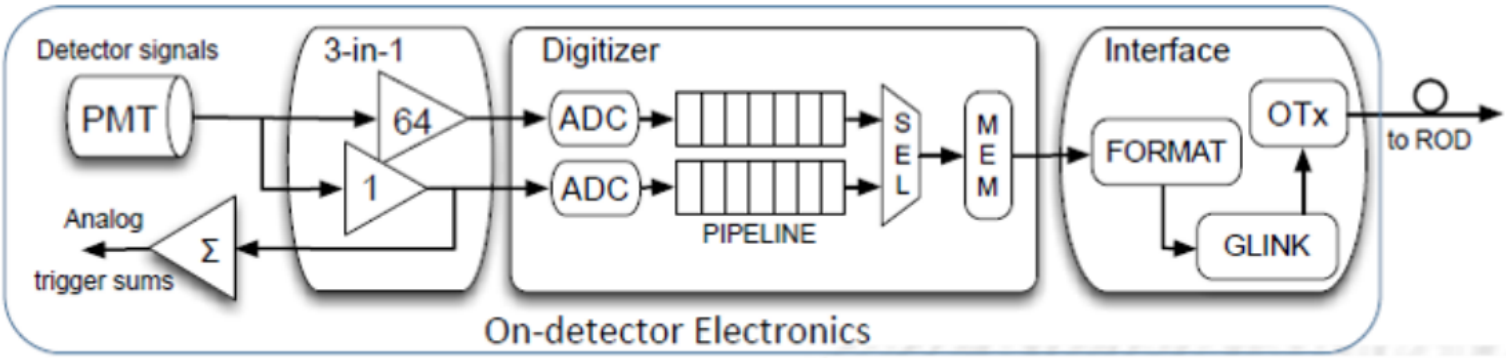
- Sampling calorimeter using steel plates as passive absorber and plastic scintillator tiles as active material.
- The light produced by scintillating tiles is collected by wavelenght shifting (WLS) fibers and fed to readout Photo-Multipliers (PMT).
- The PMT output signal is conditioned and digitized for parameter estimation such as the amplitude (energy).





Current TileCal readout system

- Signals selected by the Level-1 trigger system are transmitted to the off-detector ReadOut Drivers (RODs) at a maximum average rate of 100 kHz.
- Digital Signal Processors (DSPs) carry out energy and time reconstructions, synchronization of detector and trigger data, busy handling and data compression.
- Data are processed within 10 μs and transmitted to the High Level Trigger (HLT) system of ATLAS.

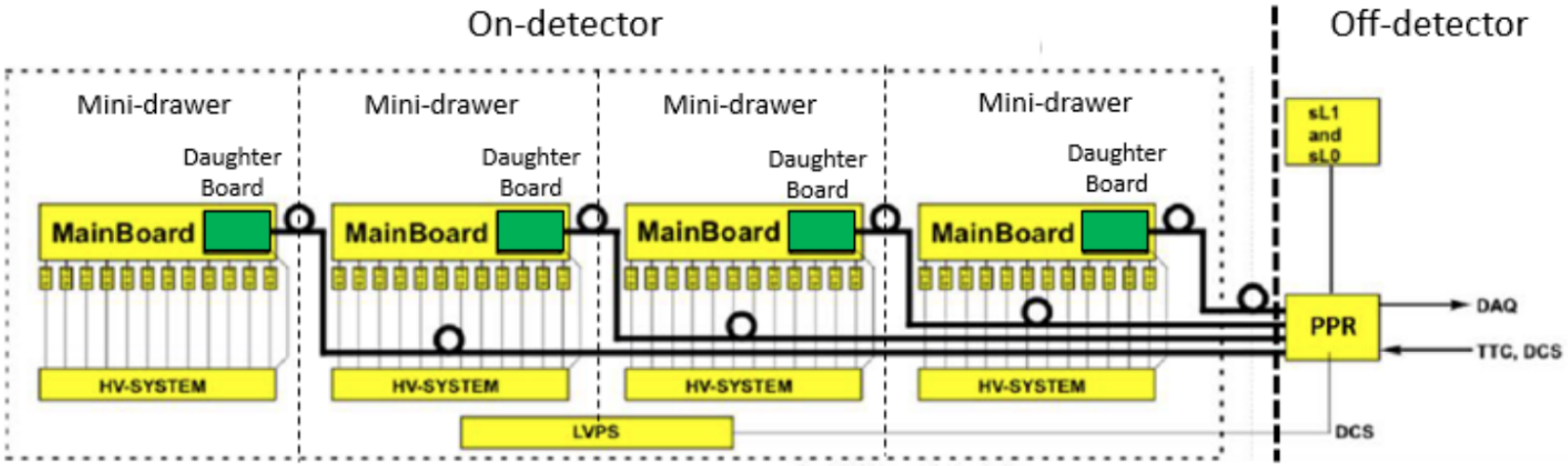


Upgrade phase

- At High Luminosity LHC (HL-LHC), the instantaneous luminosity will increase up to $7.5 \times 10^{34} \mathrm{cm}^{-2} s^{-1}$, producing about 200 p-p collisions per bunch crossing.
- Replacement of the current readout electronics (on- and off-detector) is mandatory as it is not compatible with new Trigger/DAq system.
- Trigger and data flow rates at HL-LHC require new upgraded readout.
- Detector components such as steel absorbers, scintillating tiles and fibers will not be replaced.

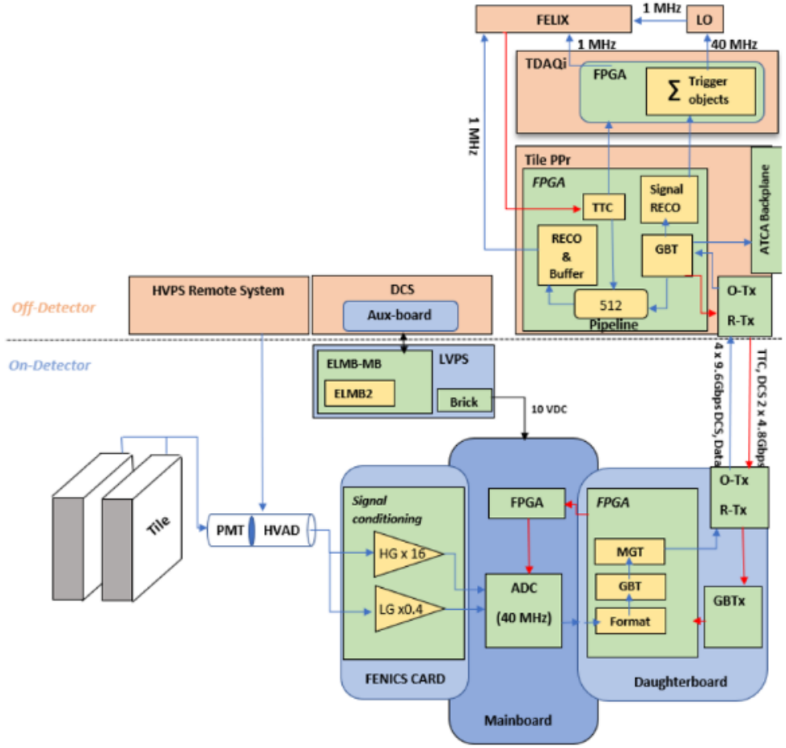
New TileCal readout system (on-detector)

- The PMTs from the barrel and extended drawers are located into 4 and 3 mini-drawers, respectively.
- A Main Board (MB) is placed on top of each mini-drawer structure.
- The MB receives the PMT analog signals from the front-end and digitizes them.
- The digitized data are sent to the Daughter Boards (DB).
- The DB synchronizes the digitized data and sends them to the Pre-Processor (PPr).



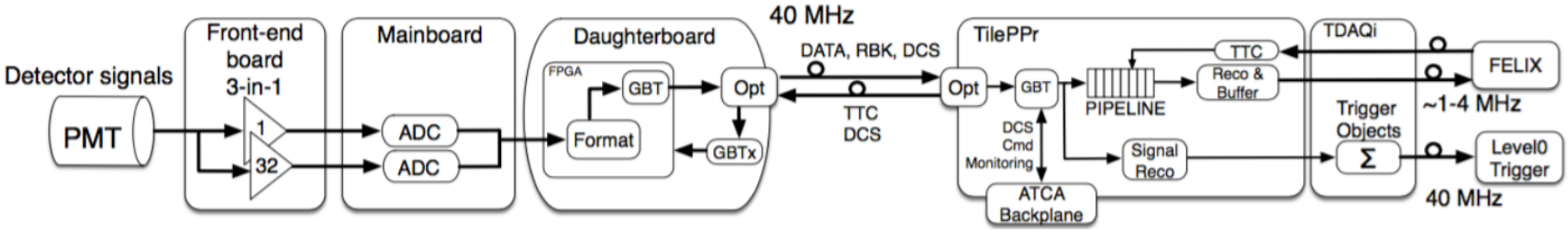
New TileCal readout system (on-detector)

- Front End board for the New Infrastructure with Calibration and signal Shaping (FENICS): amplification and shaping of the analog signals received from an individual PMT.
- Low Voltage Power Supplies (LVPS) improved in terms of reliability, lower noise and radiation tolerance.
- The timing, control and communication interface with the off-detector electronics is implemented with modern Field Programmable Gate Arrays (FPGAs) and high speed fibre optic links running up to 9.6 Gb/s.



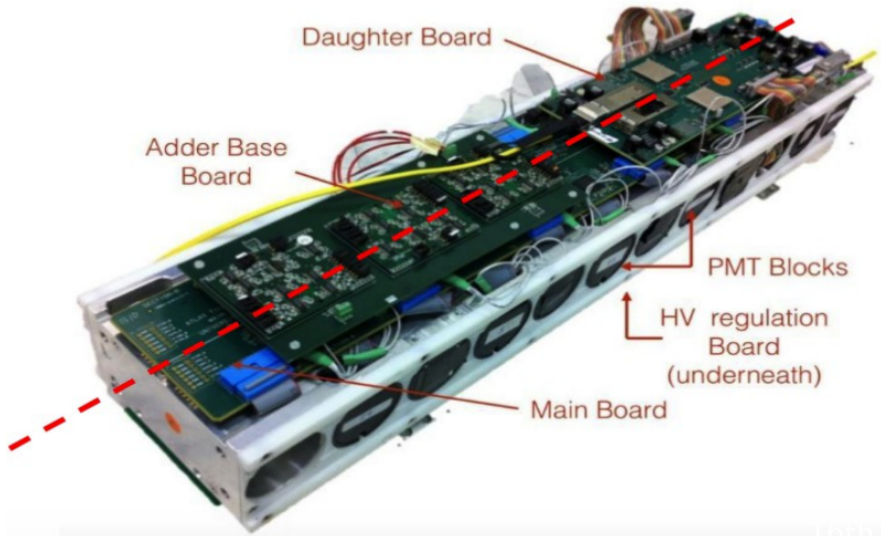
New TileCal readout system (off-detector)

- High Voltage system:
  - provides voltage of 600 – 900 V (remotely controlled) while ensuring the PMT response linearity requirement of better than 1%.
  - no radiation issues and accessible for maintenance.
- Data communication: digital trigger with a rate up to 40 MHz.
- The PPr, located off-detector, communicates with all the DBs, organizes data in pipelines, implements data reduction, and transmits the data selected by the trigger to FELIX (FrontEnd LInk Exchange), the future ATLAS digital DAQ and Trigger system.



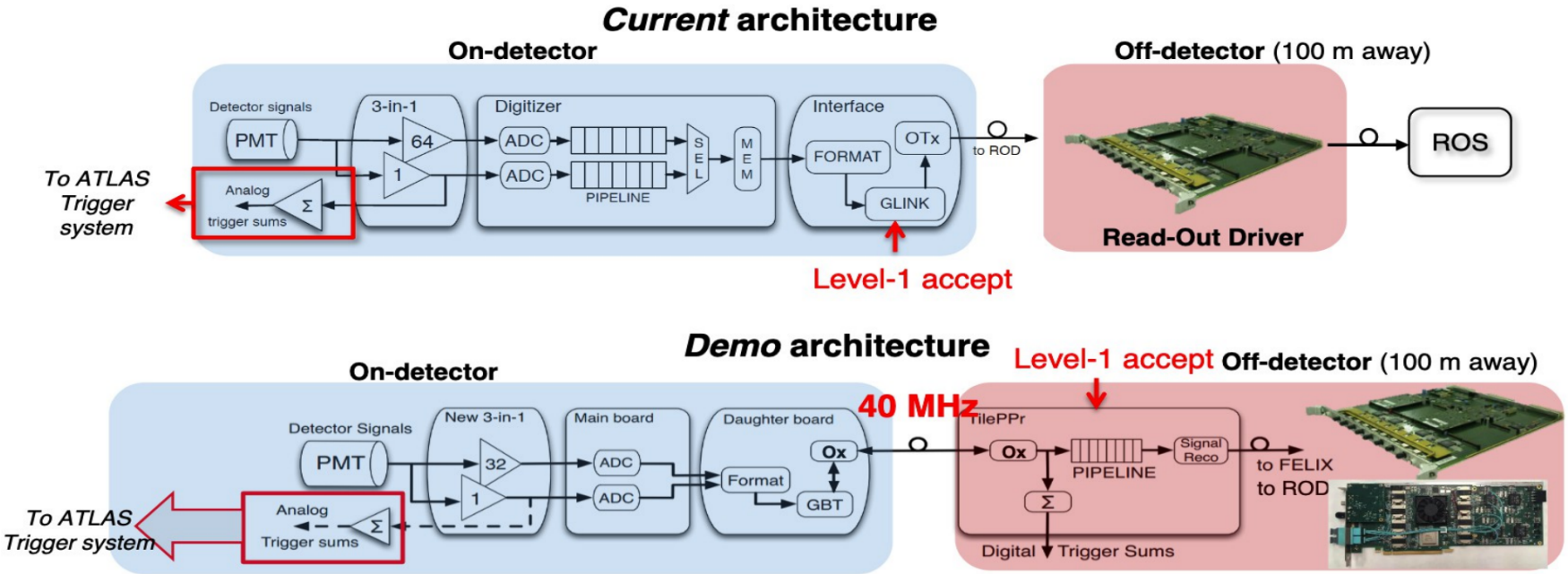
TileCal Demonstrator

- A special version of the upgrade electronics, called Demonstrator, was built to readout at the test beam a spare module of TileCal.
- Hybrid module that serves as a test case for the new components while ensuring compatibility with the current system.
- Equipped with an upgraded version of the current 3-in-1 card with a gain ratio 1/32
- Uses both MB and DB.
- Inserted into the detector in 2019 with the objective to keep it inside the detector during Run 3.



TileCal Demonstrator

- Clock and readout architecture as for HL-LHC.
- On-detector electronics transmit full digital data at 40 MHz.
- Memory buffer are moved to off-detector electronics.

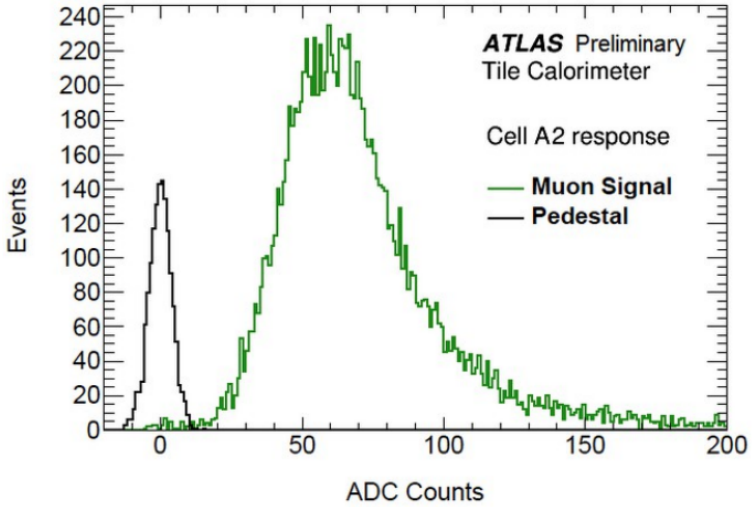


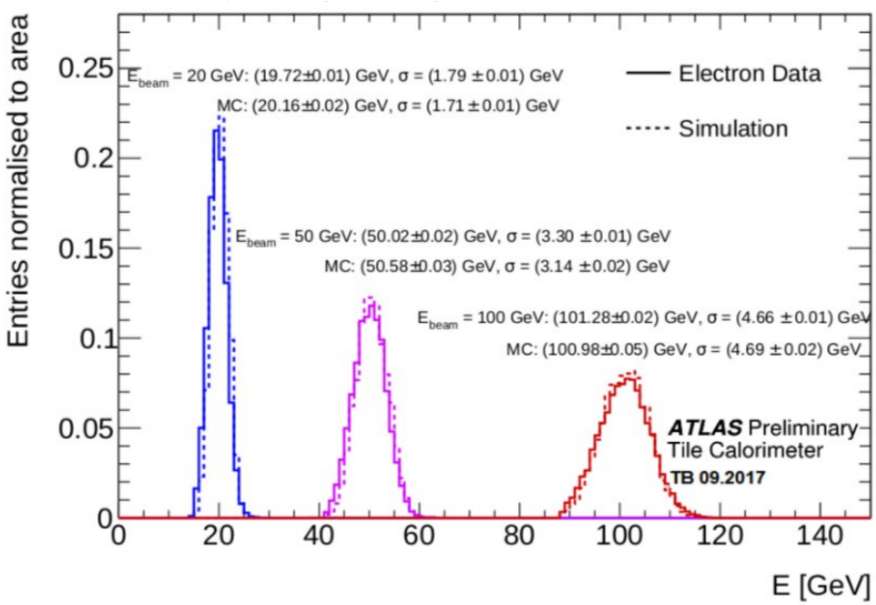
The TileCal Demonstrator

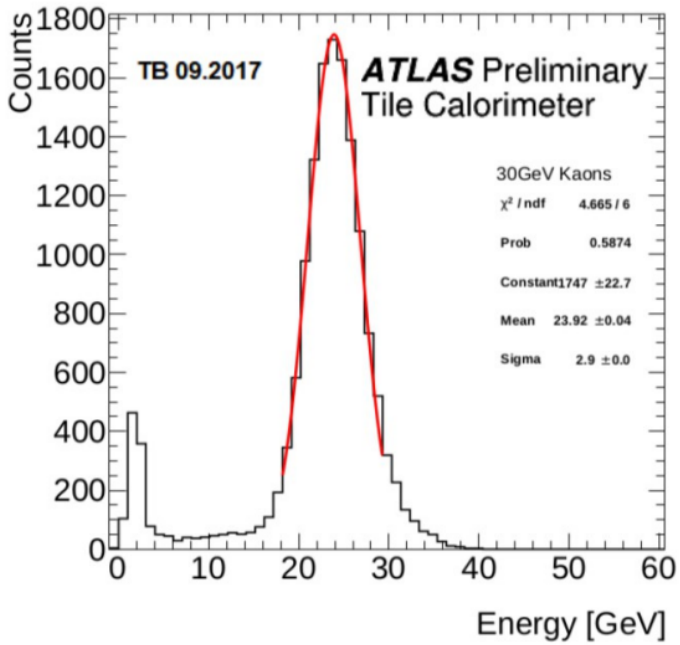
- The PMT output is shaped by a 7-pole passive LC shaper with 1 KHz - 12.5 MHz bandwidth.
- The shaped signal is amplified in parallel with two gains with 32:1 ratio.
- High-gain channel covers an input dynamic range of 0-25 pC suitable for processing the low energy particle signals.
- Low-gain channel covers an input dynamic range of 25-800 pC to process signals generated by high energy hadrons.
- Shaped signals are digitized with 12-bit in the MB and the combined bi-gain system achieves input dynamic range of 17 bits.

Test beam results

- Calibration with different electron energies.
- Low energy hadrons.
- Projective muons.







Conclusions

- Prototypes of all elements of the full TileCal readout chain for the HL-LHC upgrade are intensively tested exploiting a Hybrid Demonstrator module.
- Test beam campaigns from 2015 to 2021, proved the good performance of the new electronics.
- Test beam results are used for continuous tuning of the new versions of each component.
- TileCal new electronics performs at least as good as the current system.

Thank you!