CERN

Upgrade of ATLAS Hadronic Tile Calorimeter for the High Luminosity LHC

Kruger 2022: Discovery Physics at the LHC
Henric Wilkens, CERN

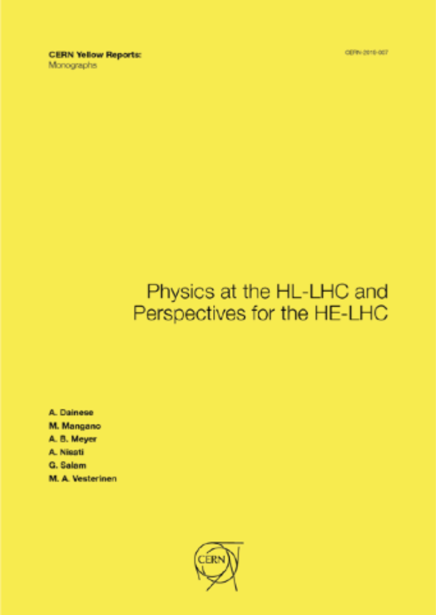
The High Luminosity LHC (HL-LHC)

HL-LHC approved by CERN council in June 2016:

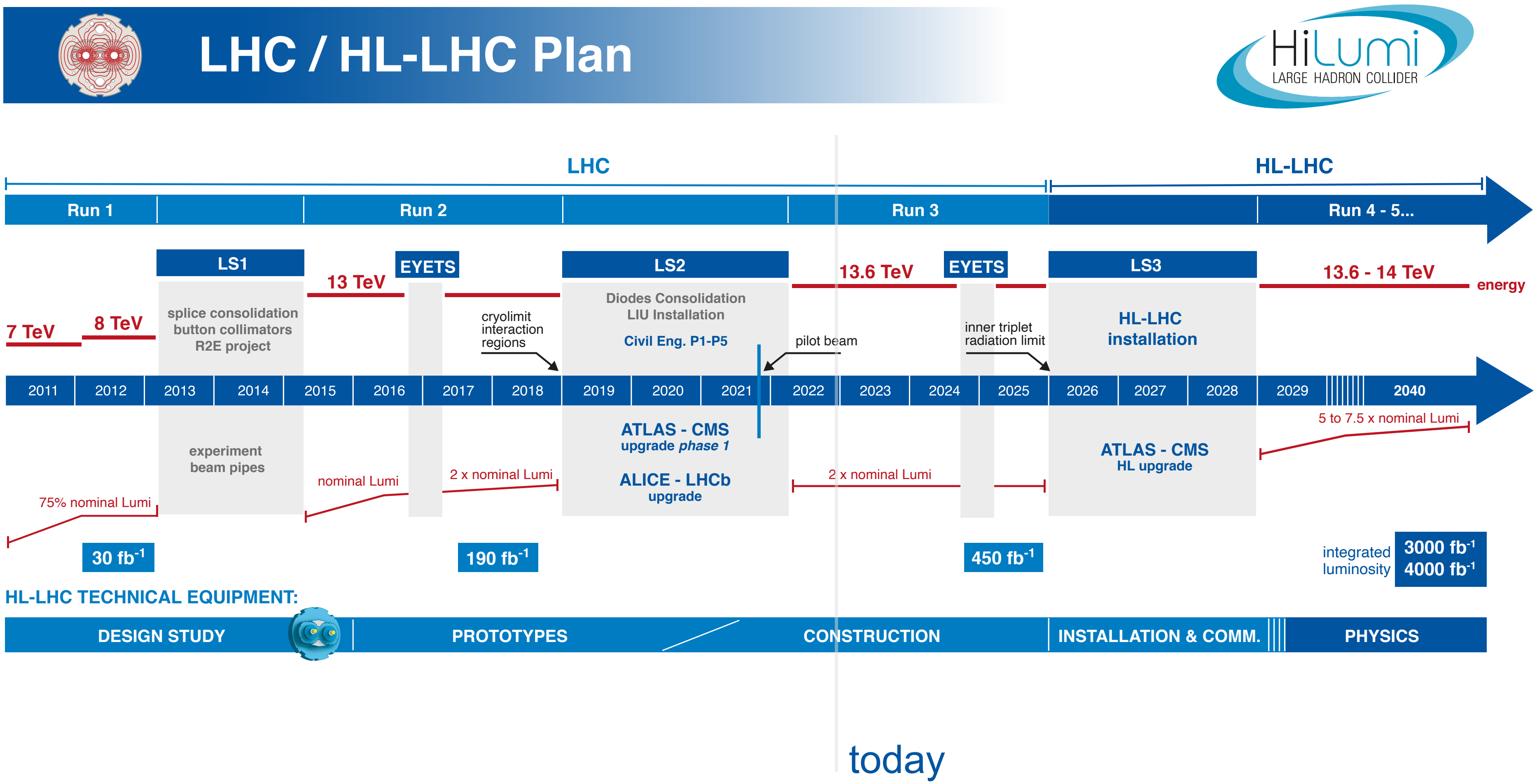
- “Europe’s top priority should be the exploitation of the full potential of the LHC, including the high-luminosity upgrade of the machine and detectors with a view to collecting ten times more data than in the initial design, by around 2030. This upgrade programme will also provide further exciting opportunities for the study of flavour physics and the quark-gluon plasma.” (European Strategy 2013)

- “Detector R&D programmes should be supported strongly at CERN, national institutes, laboratories and universities. **Infrastructure and engineering capabilities for the R&D programme and construction of large detectors**, as well as infrastructures for data analysis, data preservation and distributed data-intensive computing **should be maintained and further developed**.” (European Strategy 2013)

- There is a very wide physics program defined for HL-LHC:
  https://cds.cern.ch/record/2703572/files/94-87-PB.pdf

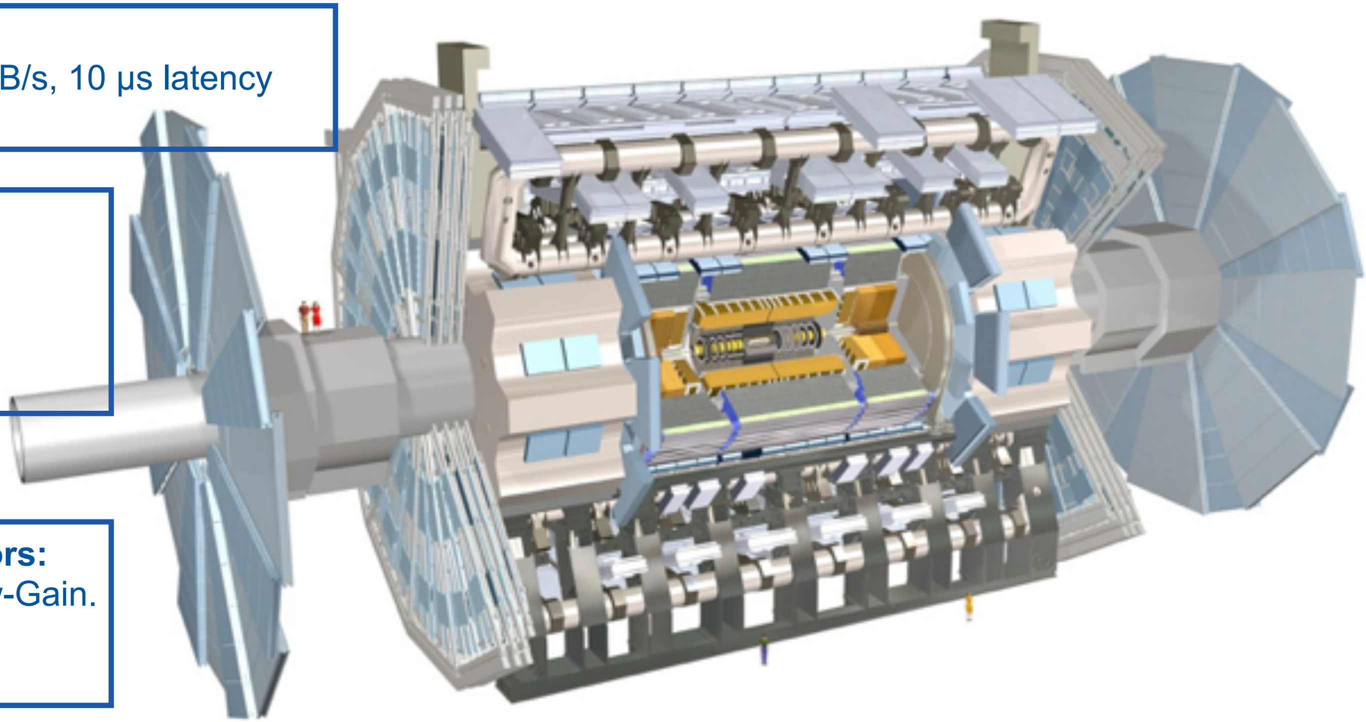


HL-LHC Time line



ATLAS Phase-2 Upgrade

Trigger and Data Acquisition:
- First level tigger at 1 MHz, 5.2 TB/s, 10 μs latency
- Event Filter 10 kHz, ~52 GB/s



Electronics upgrade:
- On/Off-detector electronics for Calorimeters and Muon systems
- 40 MHz readout and finer trigger segmentation.

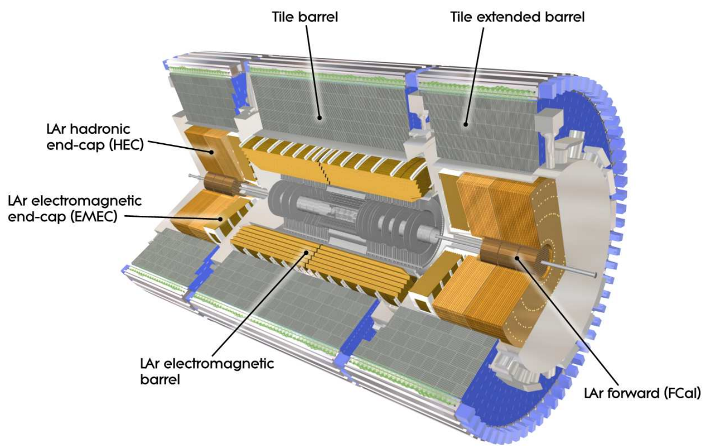
High Granularity Timing Detectors:
- 30 ps precision timing using Low-Gain.
- Improves pile-up separation and luminosity determination

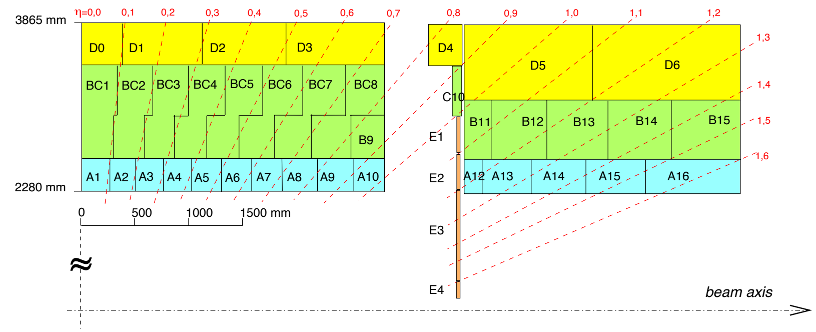
Additional upgrades:
- Luminosity detectors (1% precision),
- Zero degree calorimeter for Heavy Ion physics.

New muons chambers:
- Inner barrel with new RPCs, sMDTs and TGCs.
- Improves momentum resolution, trigger efficiency and fake rejection.

New Inner Tracker Detector:
- All Silicon.
- 9 layers for $|\eta|<4$.
- Reduced material budget.
- Finer segmentation.

Tilecal: the Barrel Hadronic Calorimeter

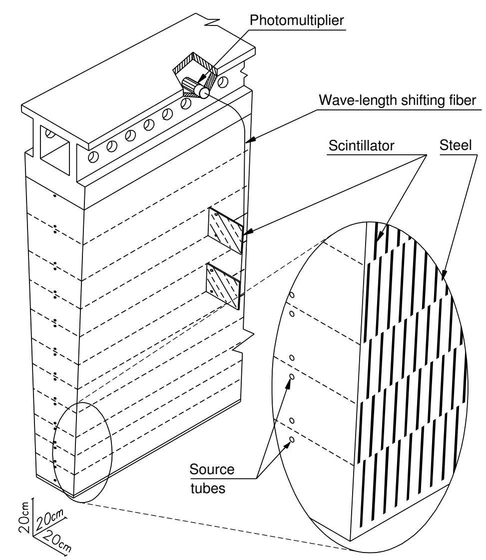




Tilecal pseudo projective cell layout

One long barrel (|η| <1.0) and 2 extended barrels 0.8<|η|<1.7, each composed of 64 modules in Phi.
Steel plates and plastic scintillators (the tiles) coupled to wavelength shifting fibres.
About 5000 pseudo-projective cells.
each cell readout by 2 PMTs (~10000 PMTs in total)
Dynamic range 10 MeV to 2 TeV per cell.

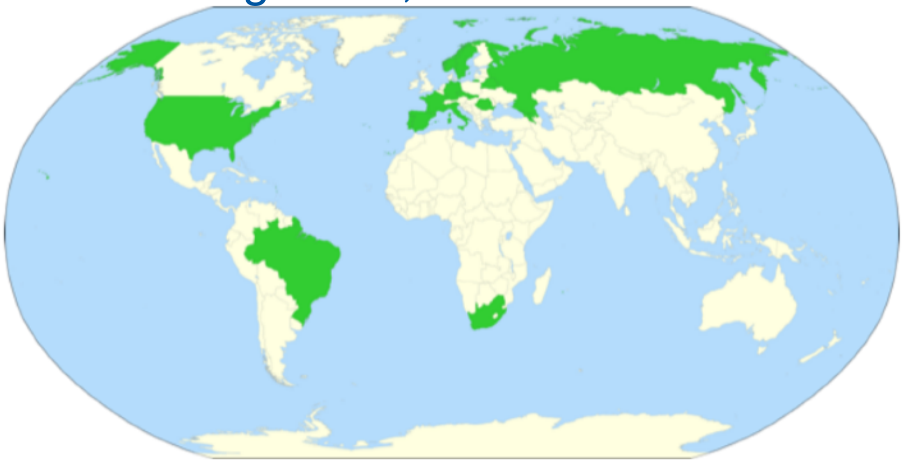
$$\frac{\sigma_E}{E} = \frac{50\,\%}{\sqrt{E[\mathrm{GeV}]}} \oplus 3\,\%$$



Take note about the Tilecal Performance and Calibration contribution by Michaela Mlynarikova

The Tilecal community

25 universities and institutions,
over 100 engineers, scientists and students



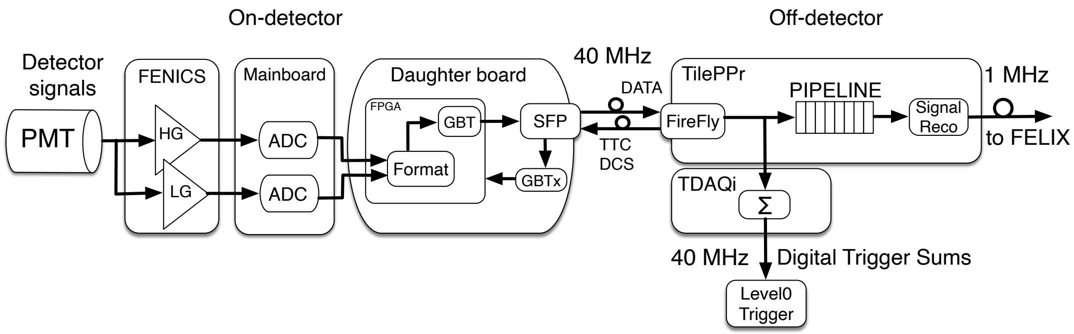
Tilecal's Upgrade

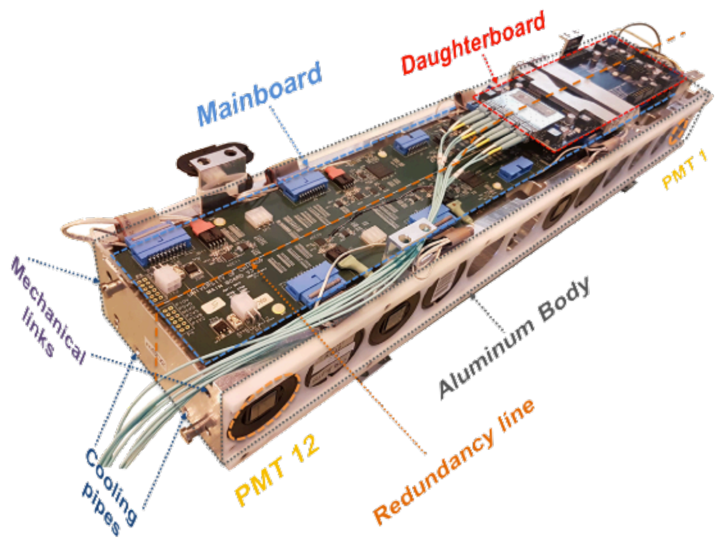
Motivated by:

- Lifetime of Tilecal extended decades (HL-LHC 2029-2040).
- Higher radiation environment (Luminosity x5-7 compared to nominal LHC)
- New triggering requirements

Upgrade of Tile calorimeter

- Active dividers on all PMT, replacement of 10% of the PMTs.
- Complete replacement of on and off-detector electronics.
- 40 MHz readout to off-detector electronics. 40 Tb/s over 6000 optical fibres.
- Improve reliability (full readout redundancy, new HV and LV systems) and maintainability (new mechanics).





The mini-drawer, the basic on-detector unit

The mechanics

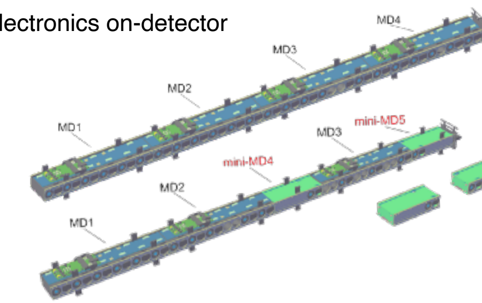
Currently Tile electronics housed in 1.75 m long drawers. They are quite cumbersome to extract to access electronics.

The upgrade mechanics consists of shorter modules (694 mm, 22 kg when equipped), which can be easily handled on the scaffolding. There are specific modules to accommodate the different geometries in the extended barrels, in totals 7 different types.

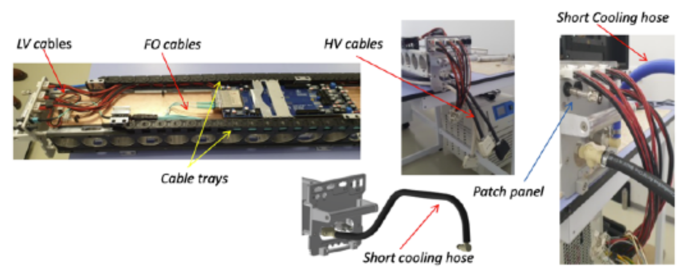
Associated are dedicated tooling for the mechanics insertion, extraction and new services (LV&HV cables, Fibre optics, cooling distribution)

Work on Tile electronics on-detector

new tooling



new mechanics for Barrel and Extended-Barrel



new services for the electronics

On-detector electronics: The PMT block

We will reuse 90% of the PMTs (Hamamatsu R7787), and use 10% of new R11187 in the most exposed region of the detector.

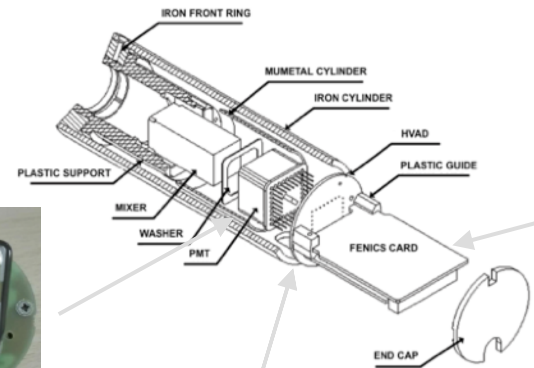
Dedicated test-benches operational at Bratislava, Pisa and CERN to test PMTs.

Passive HV dividers will be replaced with active dividers to provide better response stability at high anode currents.

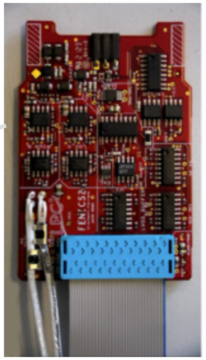
New front end, the FENICS:

- Pulse shaping at 2 gain (x0.4, x16), 0.2 pC to 1000 pC dynamic range.
- Current integration with 5 gains (0.02-13000 nA) for ^{137}Cs calibration and luminosity studies.
- Built-in Charge Injection system for ADC calibration.

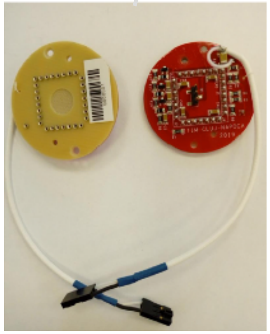
Dedicated test-benches to qualify the re-assembled PMT blocks are being prepared.



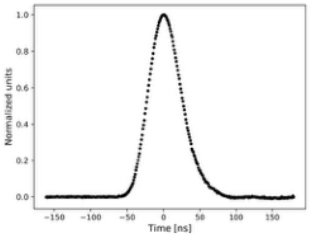
Hamamatsu PMT



New FENICS front end



New active HV dividers



Pulse shape in HG from 2022 test-beam data

On-detector electronics: The MainBoard

Receives and digitises the analog signals from the FENICS:

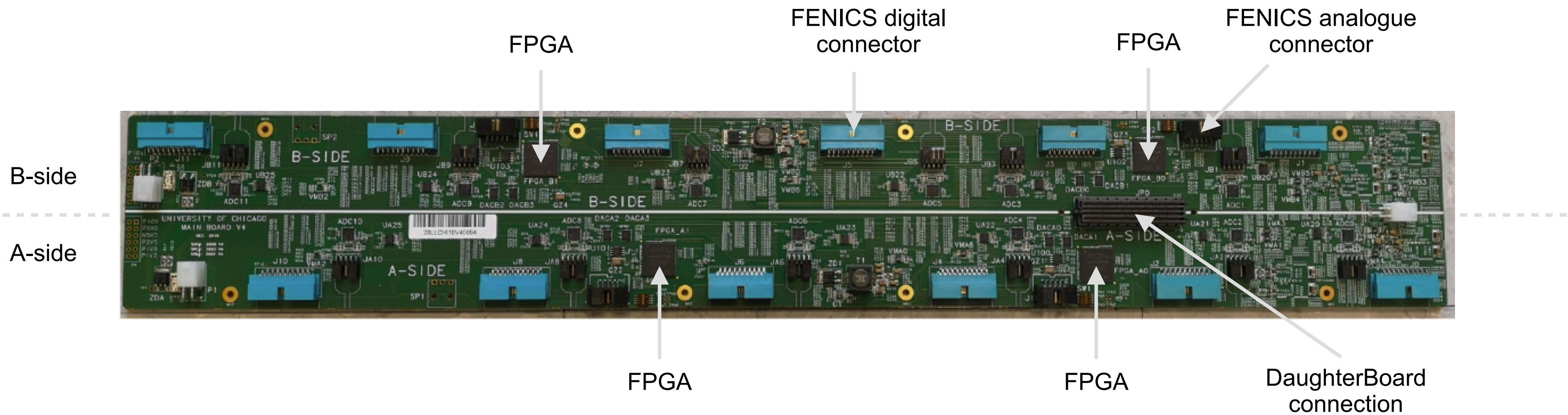
- 12 bit dual ADCs at 40 Msample/s for 2 gain signals.
- 16 bit ADC at 50 ksample/s for integrated signal readout.

Routes the high speed data to the DaughterBoard.

Distributes power (10 V), independently on each side (improves reliability)

Controls the FENICS.

Production in ongoing.



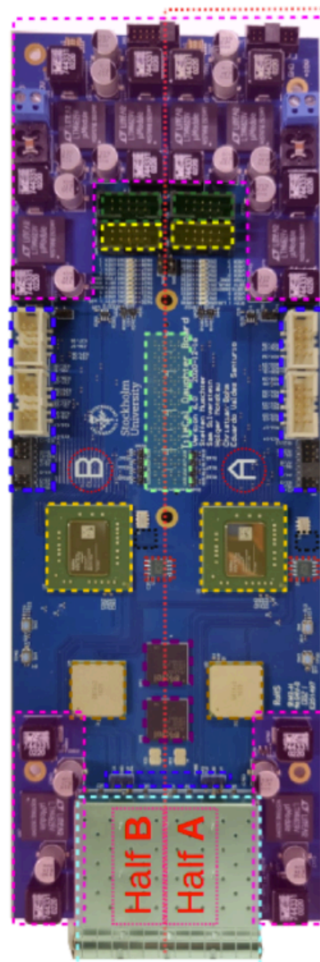
On-detector electronics: The DaughterBoard

Collects the digitised data from the MainBoard.

Interfaces to off-detector electronics through optical links.

Clock and commands recovery and distribution.

- Uses 2 GBTx chips for clock recovery and distribution
- 2 Kintex Ultrascale(+) FPGAs
- 2 QSFP high-speed optical modules
- Radiation testing and FPGA selection (in the Kintex Ultrascale family) ongoing.



Off-detector electronics

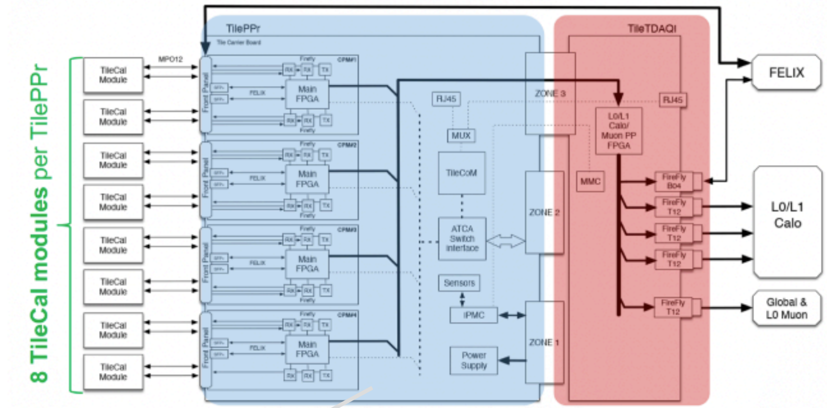
32 ATCA blades will readout the detector. They are located in 4 shelves, each reading π/2 of the detector in Φ.

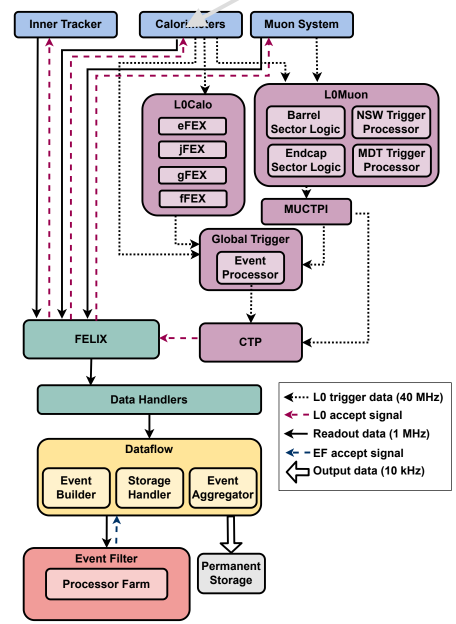
Each blade, the **TilePPr**, consists of a carrier board with 4 Advanced Mezzanine Card, the **CPMs**, connected to a Rear Transition Module, the **TDAQi**.

The TilePPr is controlled and monitored through the **TileCom** custom mezzanine.

A custom Gb ethernet switch provides the communication between the different components, the **GbE.**

These modules transmit timing and control to the On-detector electronics, process the data to compute energies and prepare trigger primitives for the Calorimeter, the Global and the Muon trigger systems.





TileCom

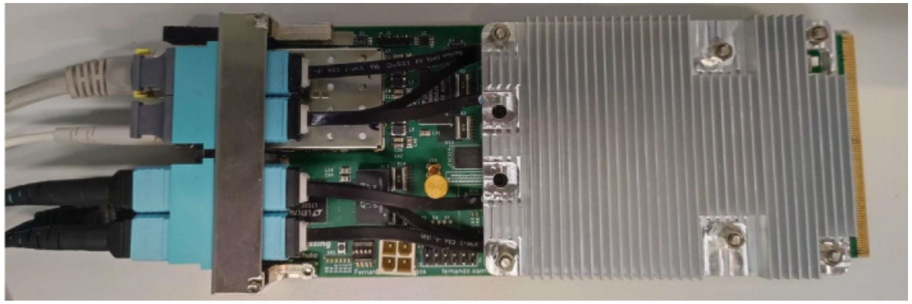
GbE

Off-detector electronics

The **Compact Processing Module** (CPM) processes data from 2 modules.

It connects to the Front-end through Samtec Firefly (2Rx +1Tx)x2 for each module.

It transforms the raw data into energy for up to 90 channels at 40 MHz on a Kintex UltraScale (KU115), through optimal filtering.



Compact Processing Module (CPM)

The **TDAQi** receives the cell energies from 4 CPMs synchronously from the CPMs.

It builds the trigger primitives, trigger towers or cluster in (η,Φ).

It sends the trigger objects synchronously to the electron/photon, jet and muon triggers systems.

For the Global trigger, it compares the cell energy with the noise thresholds and send cells above the noise cut (4 or 2 sigma)

It sends the calorimeter data to the FELIX system.

Trigger DAQ interface (TDAQi)

Powering Tilecal

The Radiation environment on detector requires Rad-Hard DC-DC converters.

200 V_{DC} is transformed to 10 V_{DC} to power the Point of Load regulators on the on-detector electronics boards.

The DC/DC converters are controlled by custom made AUX_Board located in the underground counting room.

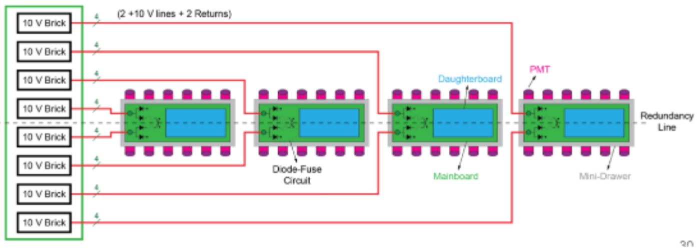
ELMB chip is used as CANbus interface to transfer monitored data.

There are strong constrains in terms of radiation tolerance, noise, power efficiency and reliability.

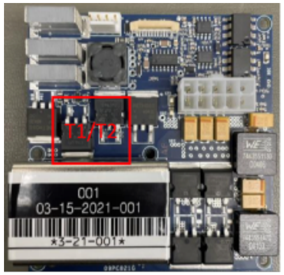
The High Voltage supplies are located in the underground counting rooms at 100 m of the detector.

Alleviates radiation issues and facilitates servicing.

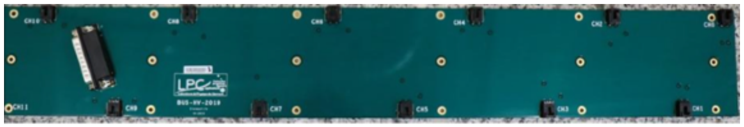
Good linearity of the supply chain to 100 μA, we expect 40 μA max. There is one HV channel for each PMT.



LV power distribution scheme.

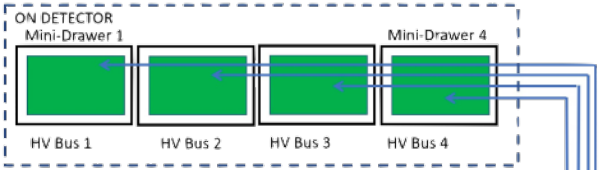


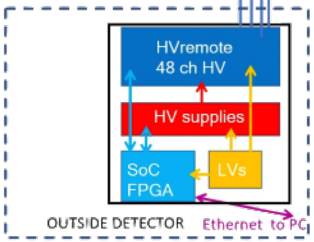
A low voltage brick



On-detector HV distribution board

prototype HV supply board





HV distribution scheme

Calibrations systems

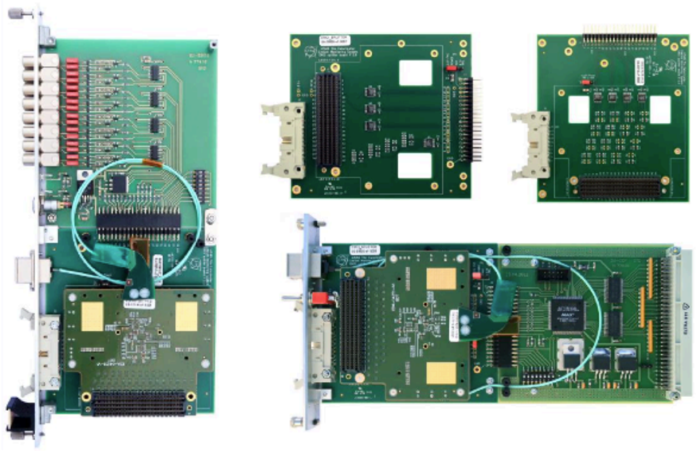
New Data Acquisition and control electronics is needed for the laser calibration system. We will also replace the pulsed laser and add a continuous light source to simulate pile-up. With it comes a redesign of the optical line.

New custom laser DAQ board.

Explorer One laser

For the Cesium system, the on and off-detector electronics will be replaced. The new electronics is designed around the CERN EMCI-EMP systems.

We are investigating new drive fluid (currently H2O+additive). Novec 649 and Novec 7200 are being investigated. The material compatibility studies are ongoing.



New Cs electronics prototype

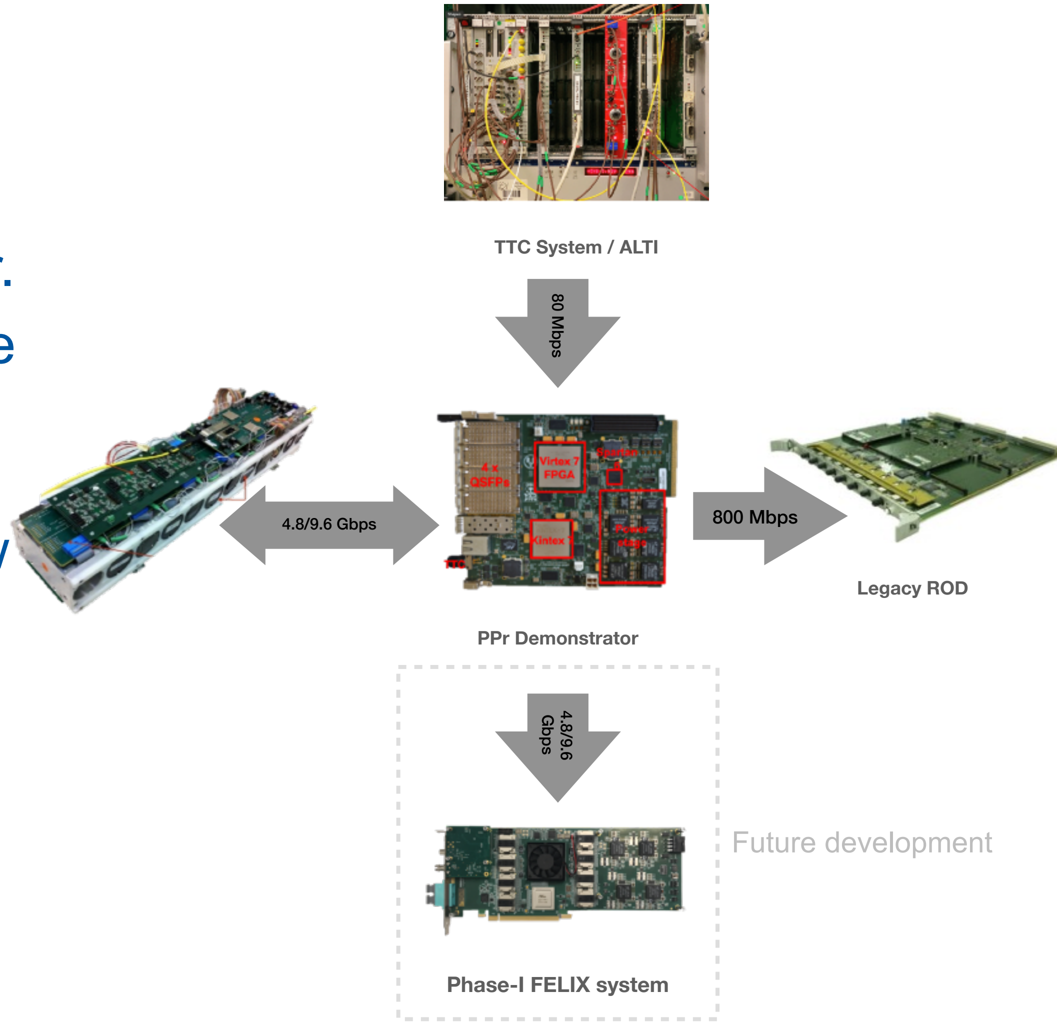
Phase-II demonstrator in ATLAS

Sumer 2019, we installed prototype mechanics / electronics in one of the Tilecal modules of the ATLAS detector.

It is made backward compatible with the current DAQ system.

It has proven a very useful exercise to learn about the new electronics and timely identify problems.

It is showing acceptable performance, and we decided to keep it in for Run-3.



Test-beam at the SPS

8 beam test campaigns were performed in the SPS-H8 beam line between 2015 and 2022 to validate the hardware and perform physics studies.

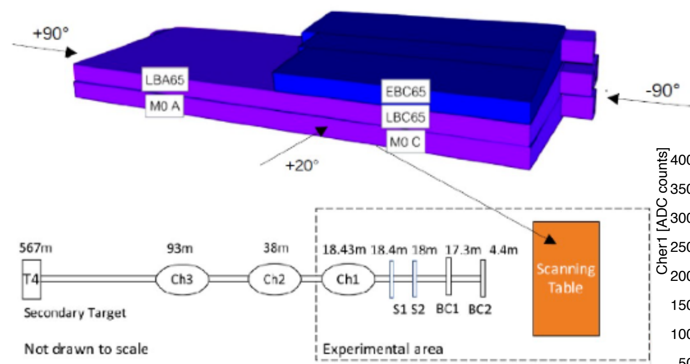
Different designs of the front-end electronics have been used over the years.

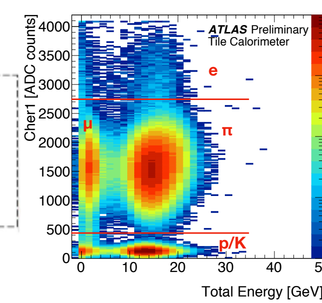
The setup is partially equipped with new electronics, the remainder with the current electronics.

We used electron, muon and hadron beams, of various energies and the detector positioned in different orientation.

Cherenkov detectors, part of the beam instrumentation allow for particle ID.

TileCal setup in the SPS-H8 beam-line.





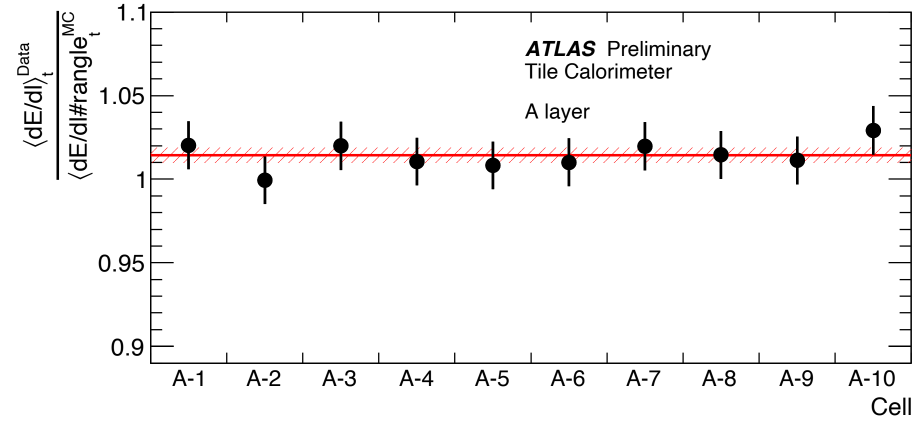
Selected TB results

On top, results from 160GeV/c Muons at 90º angle, with new electronics (May 2018 campaign).

The deposited energy is a function of the path length in each cell.

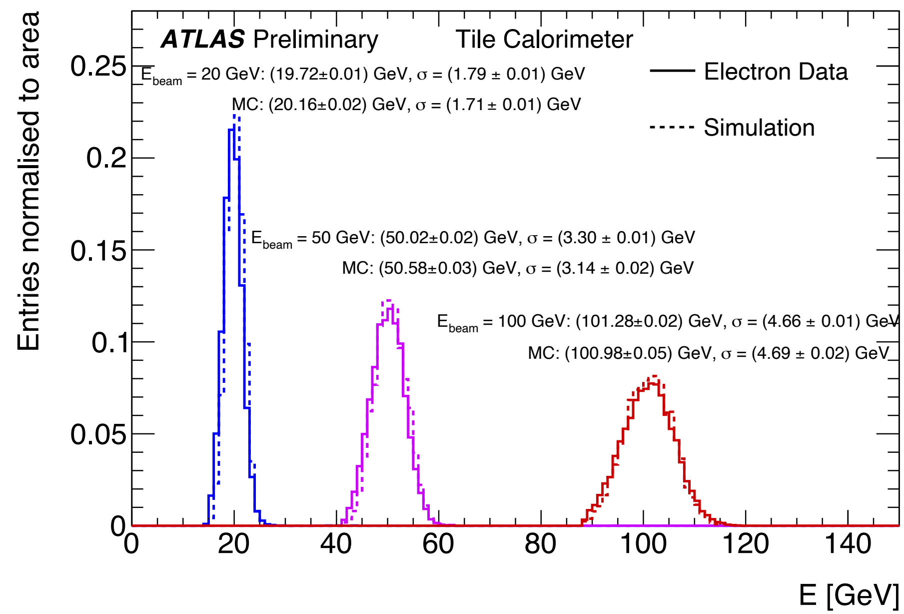
Layer uniformity within 1%, very good agreement of data and simulations.

It is similar in the two other layers (max deviation 1.4%).



Below, we use electrons to determine the calorimeter response (pC/GeV factors) at EM scale.

We could verify the response linearity and the energy resolution as function of the electron energy.



Selected TB results.

The hadron beams are used to check the response for hadrons and improve our understanding of jets and taus in ATLAS.

The beam composition is a mix with a majority of π, K and protons.

$$R^{E^{raw}} = \frac{\langle E^{raw} \rangle}{E_{beam}} \qquad \Delta\langle E^{raw} \rangle = \frac{\langle E^{raw} \rangle}{\langle E^{raw}_{MC} \rangle} - 1$$

Results for Kaon are dominated by statistical errors, while for pions electron contamination plays an important role.

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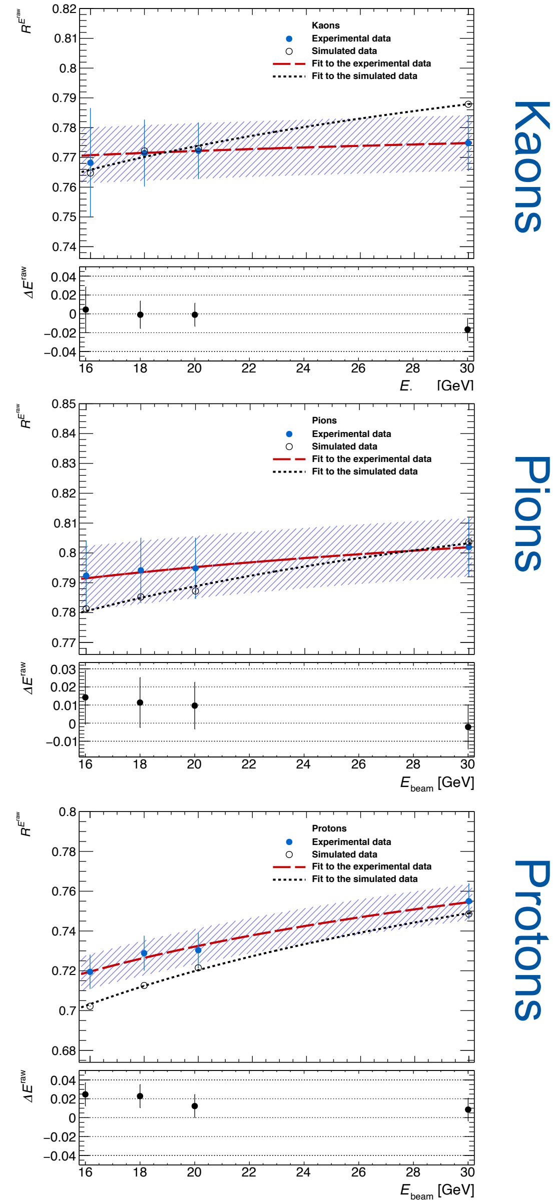

Conclusions

- The HL-LHC area will extend the detector lifetime by decades and bring new challenges:
  - A harsher radiation environment,
  - higher pile-up,
  - higher luminosity and read-out rates.
- For this we will replace all on- and off-detector electronics and 10% of the PMTs in LS3 (2026-2028).
- The TileCal upgrade project is well on track:
  - New mechanics and electronics more radiation hard, more reliable and easier to service.
  - New digital readout and trigger path, ready for 1 MHz first level trigger rate.
- We are operating prototype upgrade electronics on the current ATLAS detector, the demonstrator.
- Regular test-beam campaign throughout the project helped validate designs but also collect data to improve our understanding our detector and the physics underlying hadronic calorimetry.

Thanks for your attention

The contribution is open for questions

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