# Phase-II Upgrade of the ATLAS Hadronic Tile Calorimeter for the High Luminosity LHC


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NRF iThemba LABS


**TIPP2023 Conference, CTICC**

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NRF
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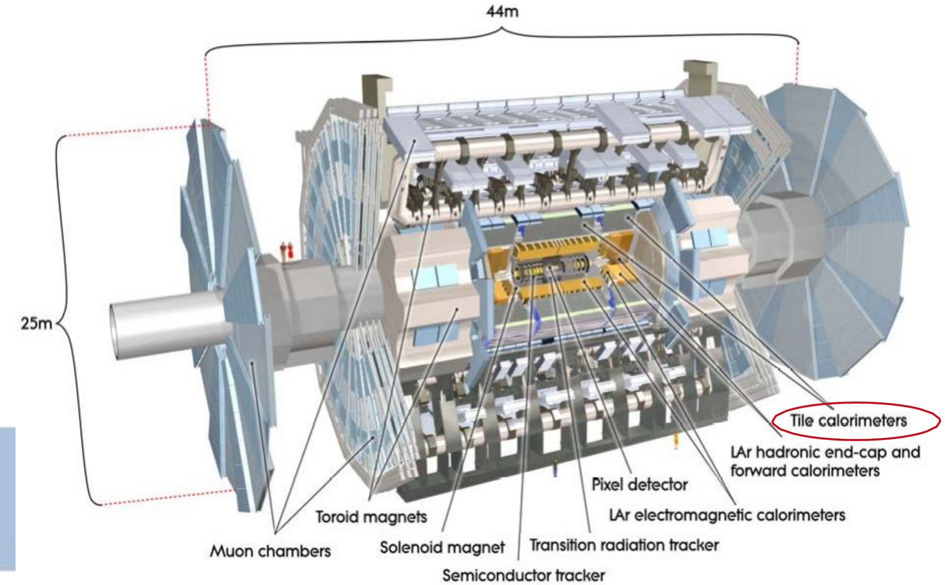
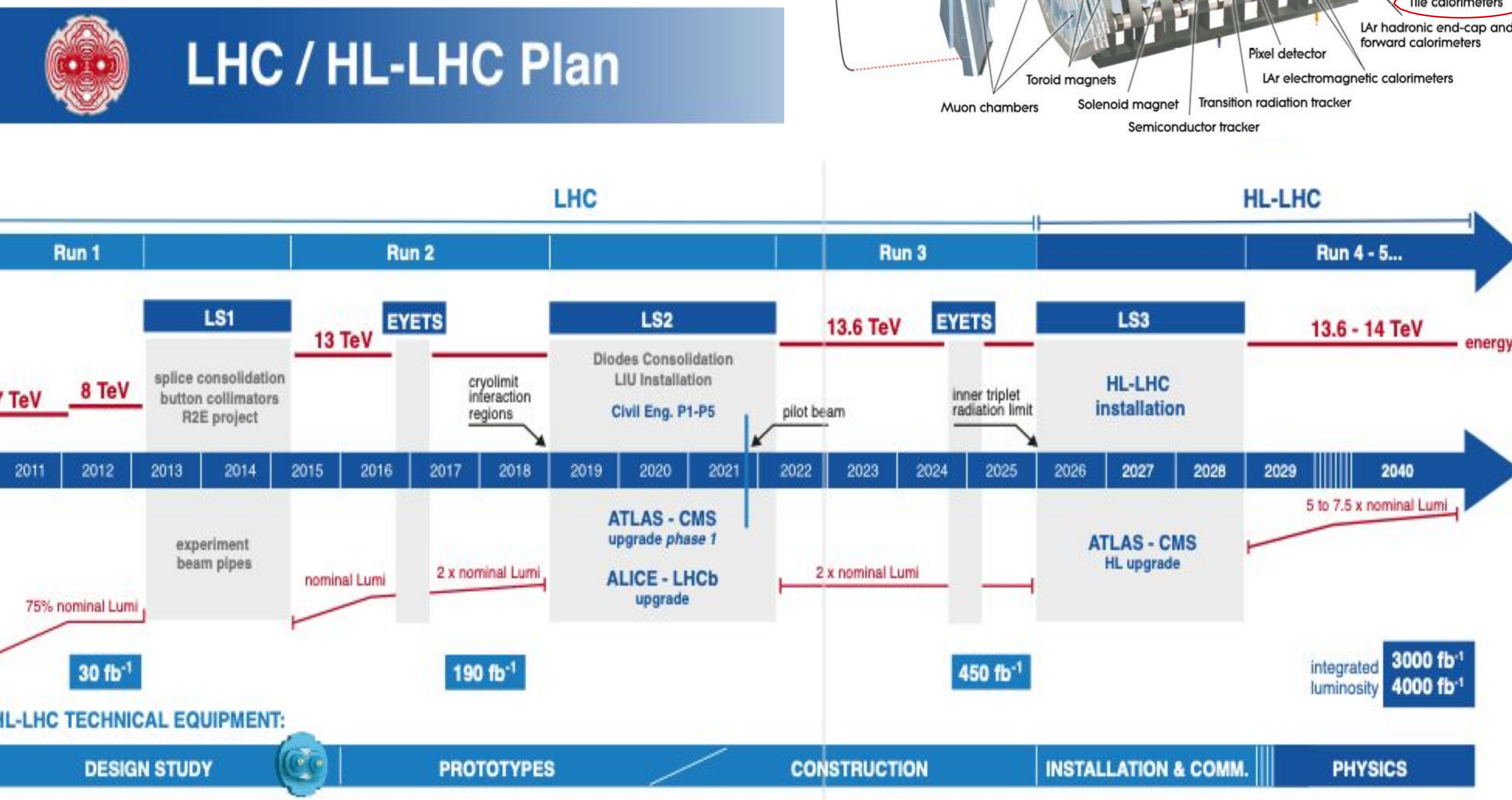
Laboratory for Accelerator Based Sciences

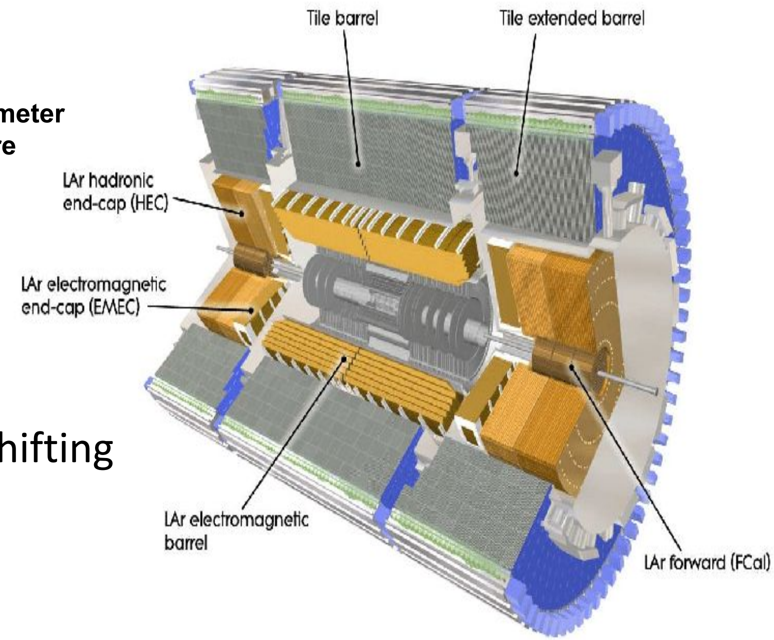

ATLAS EXPERIMENT

# HL-LHC Timeline



# Context




**TileCal Overview:**

- 256 modules in the detector, with ~10,000 readout channels.
- Steel absorber, plastic scintillator with wavelength-shifting fibers (WLS).

**Detector Configuration:**

- Long Barrel (LB) for $|\eta| < 1.0$ and 2 Extended Barrels (EB) for $0.8 < |\eta| < 1.7$.

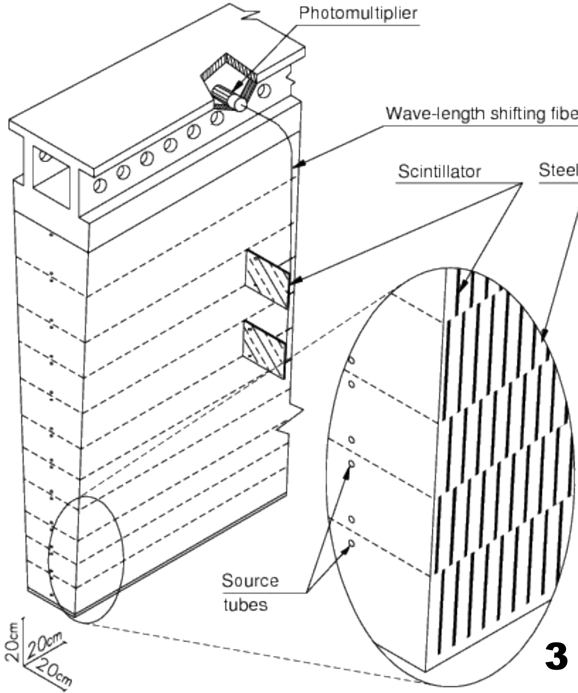
**Cell Structure:**

- Approximately 5000 pseudo-projective cells and each cell is read out by 2 PMTs.

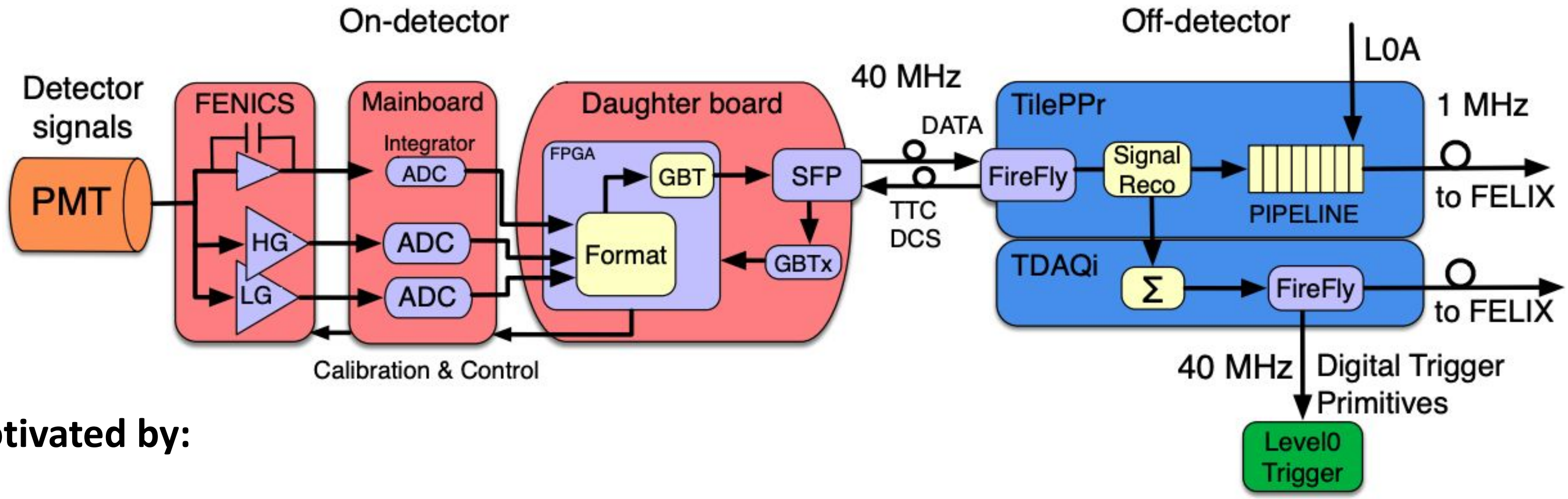
All on-detector and Off-detector electronics will be replaced

**Calibration Systems:**

- Charge Injection Scans (CIS), Cesium-137 (Cs) calibration and Laser-based calibration

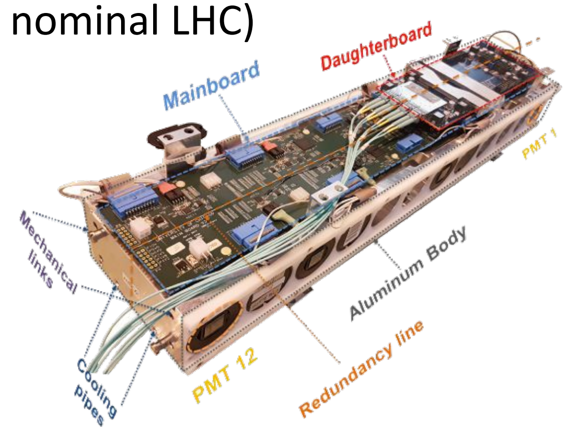


# TileCal P2-Upgrade Project




**Motivated by:**

- Lifetime of Tilecal extended (HL-LHC 2029-2040).
- Higher radiation environment (Luminosity x 5-7 compared to nominal LHC)
- There is a very wide physics program defined for HL-LHC: https://cds.cern.ch/record/2703572/files/94-87-PB.pdf




**New requirements:**

- 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.
- New HV and LV systems and new mechanics

1. ATLAS Tile Calorimeter Phase-II Upgrade Technical Design Report : https://cds.cern.ch/record/2302628/
2. Upgrade of Tile Calorimeter of the ATLAS Detector for the High Luminosity LHC Journal of Physics, DOI:10.1088/1742-6596/928/1/012024,2017.

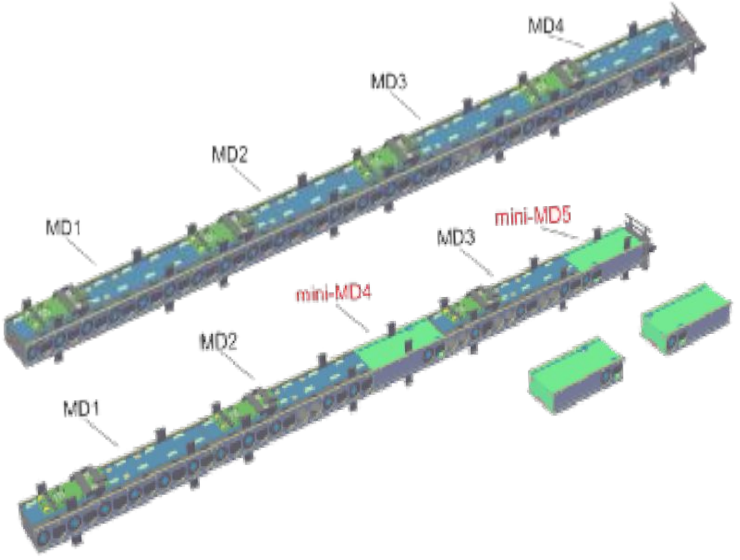
# Mechanics

- Current arrangement houses TileCal electronics within drawers measuring 1.75 m in length. However, extracting these drawers to access the electronics has proven to be a cumbersome process.

- Each mini-drawer is divided into two ‘independent sections for cell readout, accommodating 12 PMT blocks readouts for 6 TileCal cells.

- 1 Mainboard, 1 Daughterboard and 1 HV distribution is per minidrawer, while 1 LVPS is per whole module

- Specialized tools for inserting and extracting the mechanics, along with facilitating the integration of new services such as LV & HV cables, fiber optics, and cooling distribution.




Mechanics for Mini-drawers

Work on Tile electronics on-detector

# PMT blocks

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

- To enhance response stability at high anode currents, the current passive HV dividers will be substituted with active dividers.

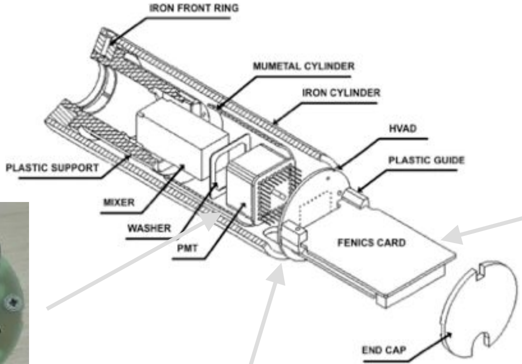
- **New front end card, the FENICS:**

- Pulse shaping occurs at two gains (x0.4, x16), enabling a dynamic range spanning from 0.2 pC to 1000 pC.

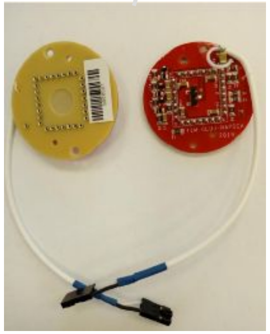
- Current integration with 5 gains (0.02-13000 nA) for 137Cs calibration and luminosity studies.

- Built-in Charge Injection system for ADC calibration but to calibrate the whole FE electronics.

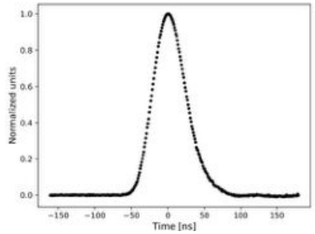
- Dedicated test-benches to qualify the re-assembled PMT blocks are being prepared at Clermont-Ferrand.




Hamamatsu PMT



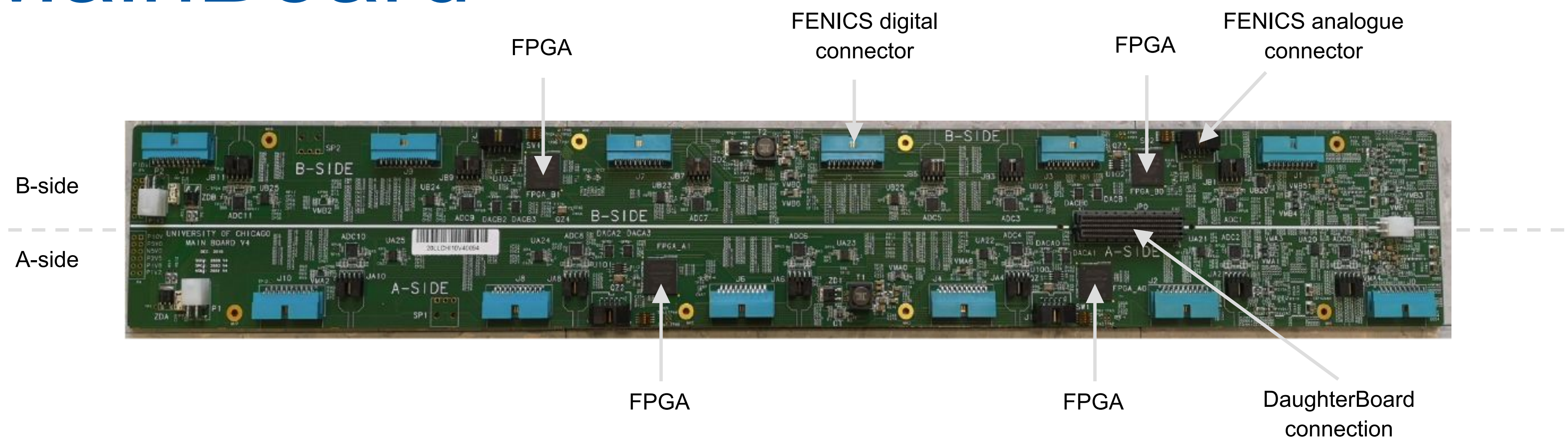
New active HV dividers




Pulse shape in HG from 2022 test-beam data

Test-benches to re-qualify

# MainBoard




- Receives and digitises the analog signals from 12 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) to all on detector electronics test bench is at U. Chicago.

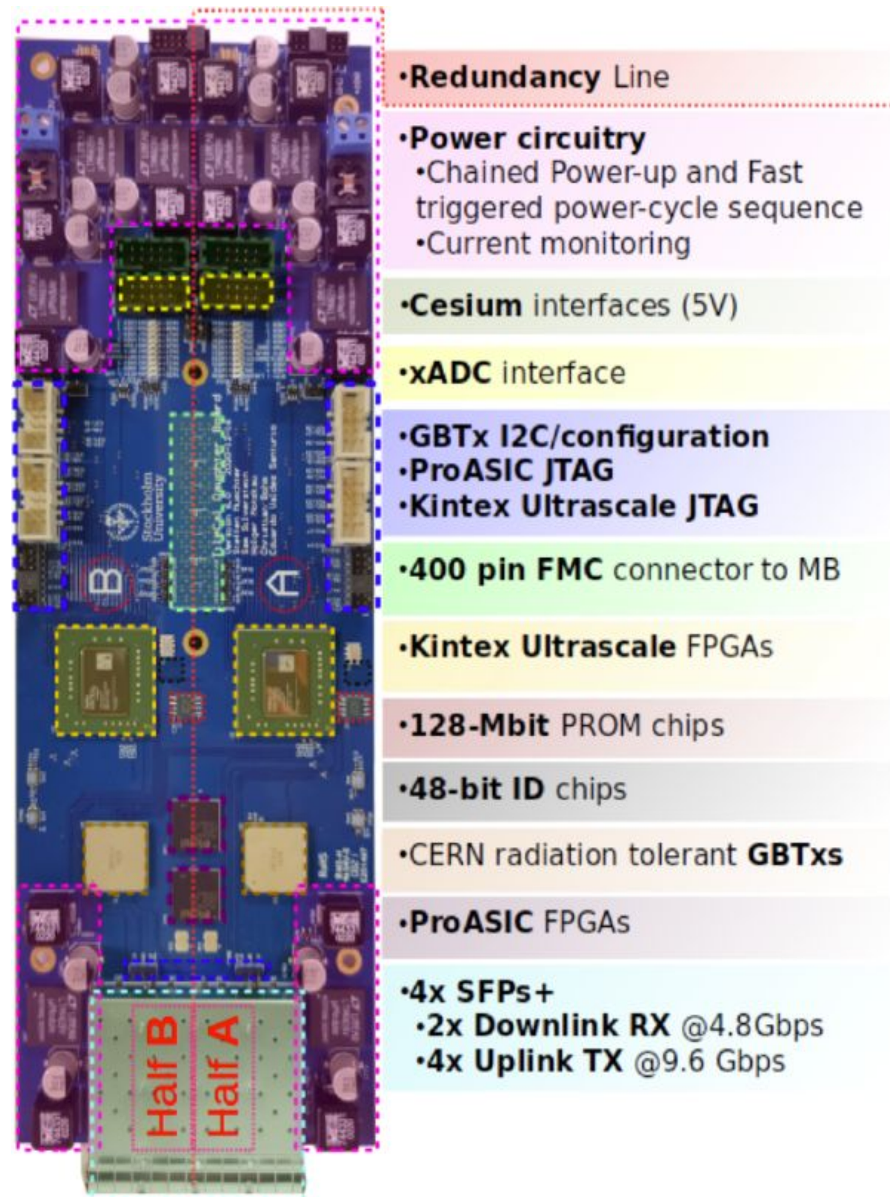
- Production is now close to complete (845 boards out of 896 boards).

Test bench for Mainboard

# Daughterboard

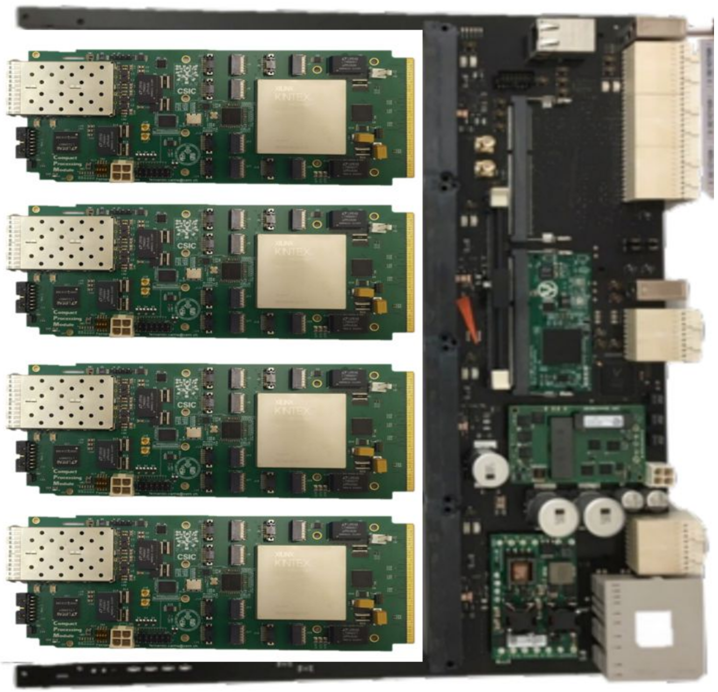
- **Collects the digitised data from the  MainBoard.**
    - High speed interfaces to off-detector electronics  through optical links.
    - Data transmission to preprocessors - 4 uplinks at 9.6Gbps
    - Uses 2 GBTx chips for clock recovery  and distribution -2 downlinks at 4.8Gbps
    - 2 Kintex Ultrascale FPGAs
    - 2 SFP high-speed optical modules

- **Design of v7 DB almost complete**
    - Larger package of FPGA's for improved pin-out
    - More simplified power scheme and fixing few bugs

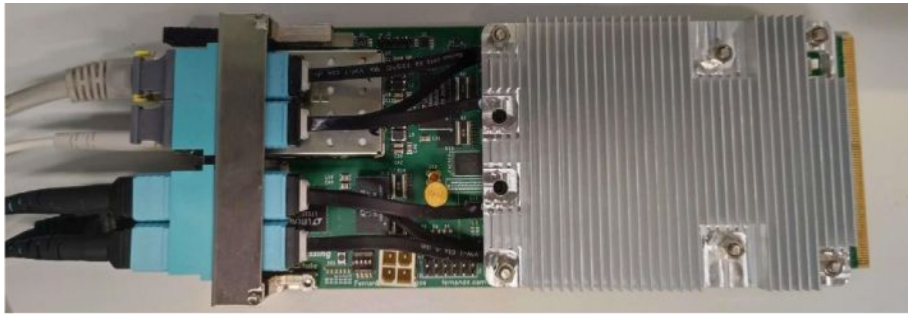


# Pre Processor: Off detector

- TilePPr is responsible for detector readout and trigger pre-processing
- Handling and pipeline of data from on-detector electronics
- Provides accelerator clock and configuration to the on-detector electronics.
- The TilePPr is controlled and monitored through the TileCoM custom mezzanine.
- PPr+TDAQi transmit timing and control to the On-detector electronics, process the data to compute energies and prepare trigger primitives for the Calorimeter
- 4 Compact Processing Modules undertake online energy reconstruction, calibration, and transmission to TDAQi.



ATCA carrier boards



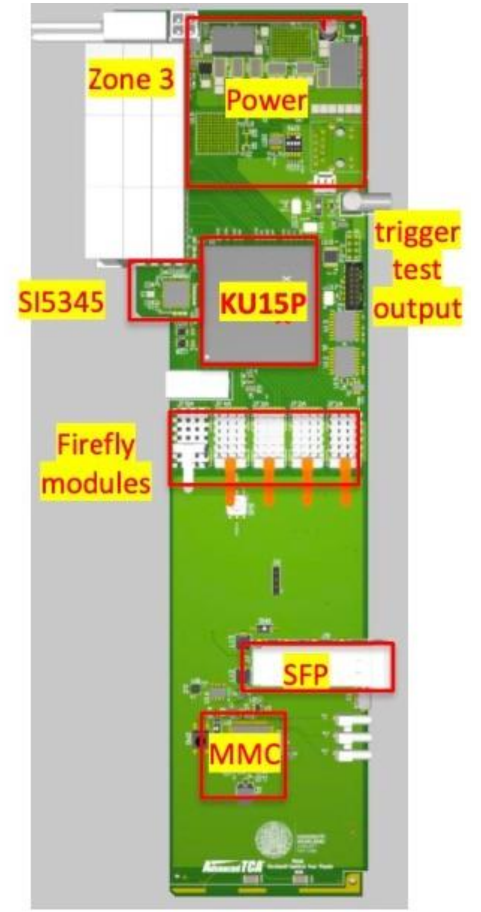
Compact Processing Module (CPM)

# Trigger DAQi

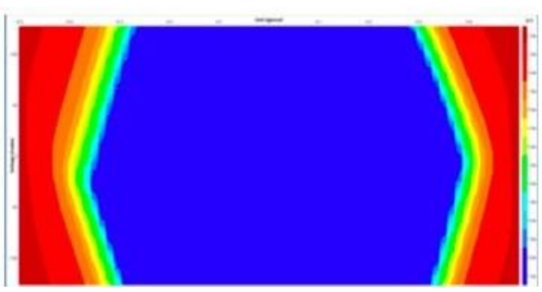
- TDAQi receives cell energies from 4 CPMs synchronously from the CPMs to FELIX system.

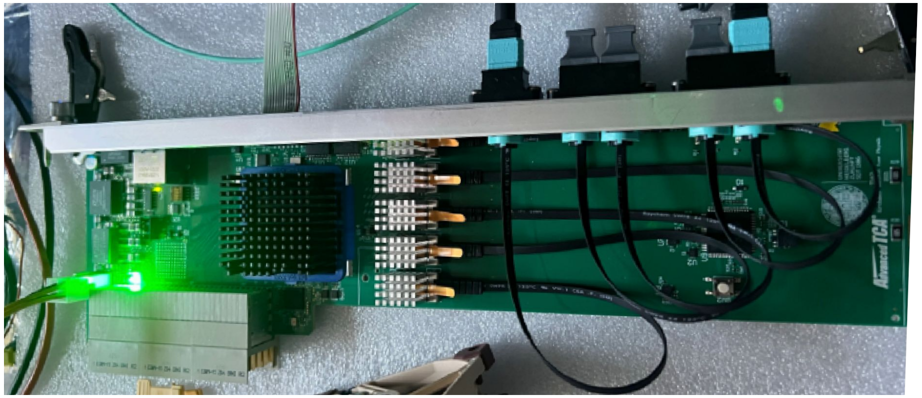
- Provides trigger primitives for the ATLAS trigger system for per bunch cross.
  - Interfaces with L0Calo, L0Muon and Global trigger

- TDAQi-v3 design complete
- Xilinx Kintex Ultrascale Kintex+ (XCKU15P)
- 1 FireFly B04 for FELIX (4 bi directional channels)
- 4 Firefly T12 for Trigger interfaces (12 TX channels)
- 1 SFP for debugging purposes



*TDAQi v3*

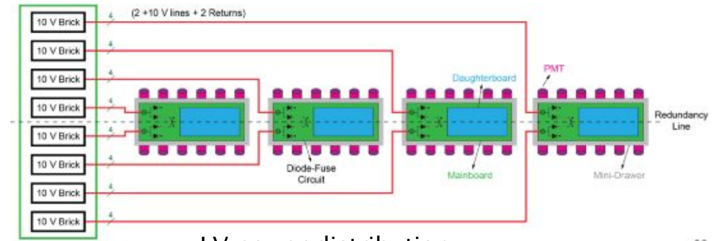

TDAQi v2 eye diagram at 9.6Gbps


Trigger DAQ interface (TDAQi)

# Low and High Voltage systems

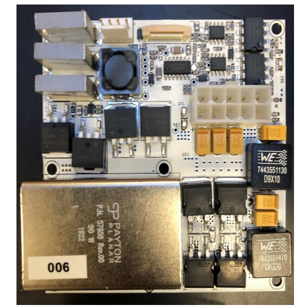
**Low Voltage**

- The Radiation environment on detector requires Rad-Hard DC-DC converters.
- 200 VDC is transformed to 10 VDC 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 constraints in terms of radiation tolerance, noise, power efficiency and reliability.




LV power distribution scheme.

Burn-in test bench



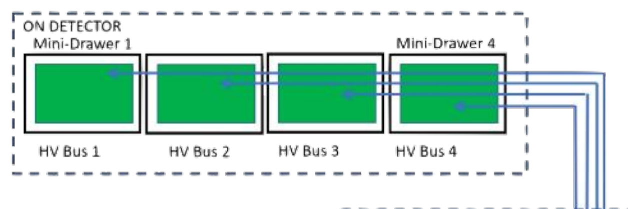
A low voltage brick

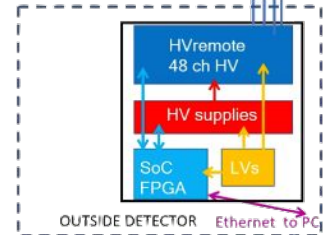
**High Voltage**

- The High Voltage supplies are located in the underground counting rooms at 100 m of the detector.
- Alleviates radiation issues and facilitates maintaining.
- Good linearity of the supply chain to 100 µA, we expect 40 µA max. There is one HV channel for each PMT.

On-detector HV distribution board

prototype HV supply board





# Calibration systems

## Cesium System

- New electronics based EMP/EMCI boards will be used with 3U and 6U custom boards for controlling the full Cs system and for data transfer to DCS.
    - Design of all boards is ready, all prototypes produced and under test.
    - EMP firmware development is in progress.
    - NIELs tests were performed last autumn, SEU tests were performed this spring, TID tests are running right now.

New Cs electronics prototype

## Laser System

- New Data Acquisition and control electronics is needed f the laser calibration system.

- Prototype of the ILANA board (laser control and new TDAQ interface) under validation tests at CERN

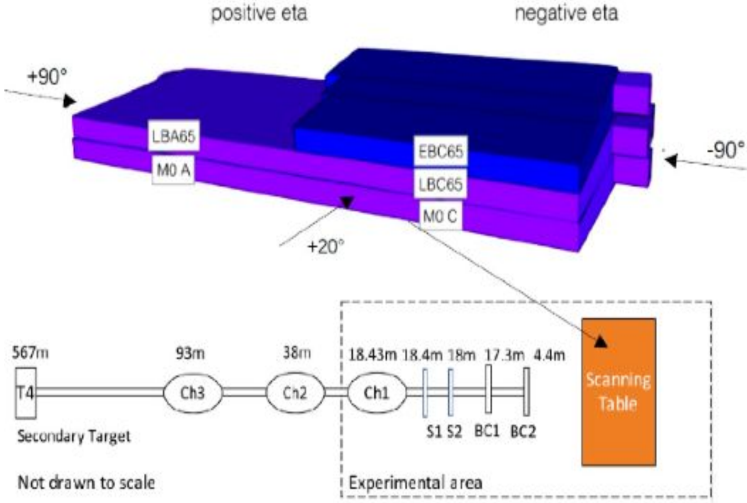

New custom laser DAQ board.

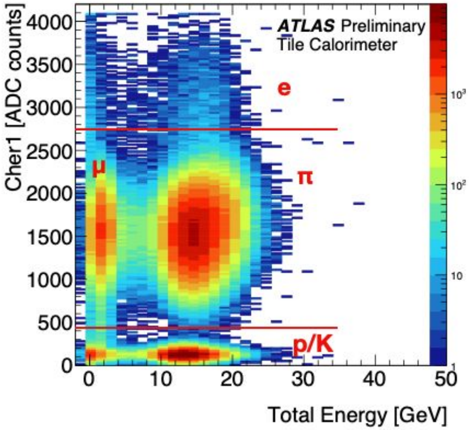

Explorer One laser

# Test-beam at SPS-H8 beam line

- 12 beam test campaigns were performed in the SPS-H8 beam line between 2015 and 2023 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.

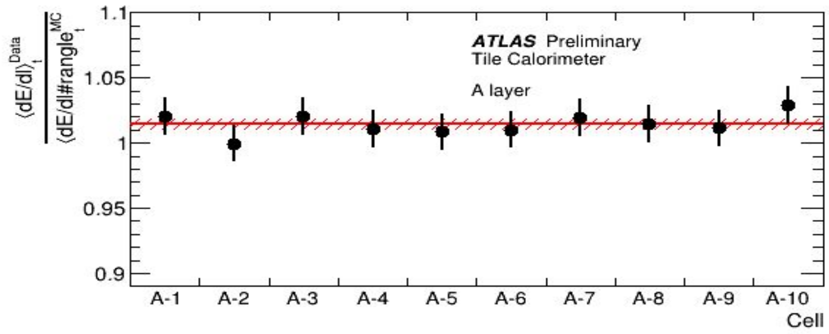


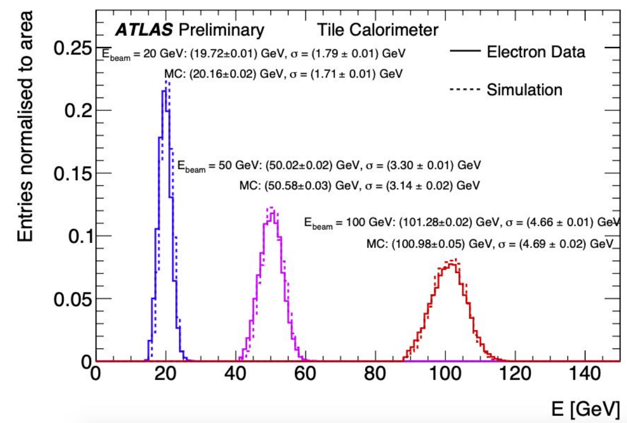

Cherenkov 1 signal vs. the energy measured in the calorimeter for 18 GeV particle beams

# Some Test Beam results

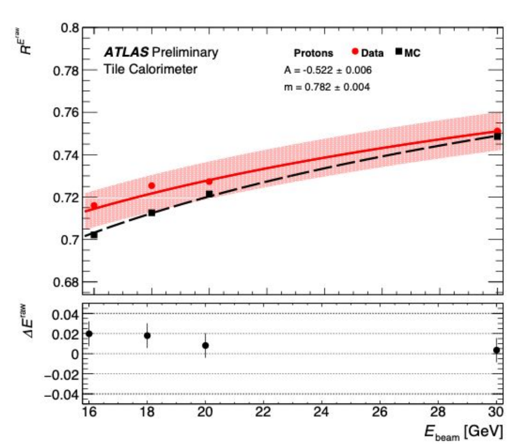
- **Muons results**
  - On top, results from 160GeV/c Muons at 90º angle, with new electronics (May 2018 campaign). The deposited energy is a function of the path  length in each cell.
  - Layer uniformity within 1%, very good agreement of data and simulations.

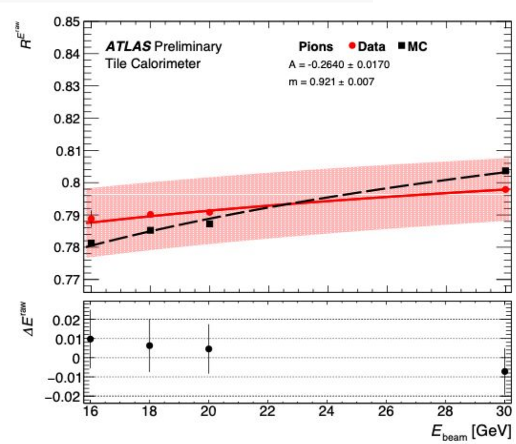



- **Electron results**
  - Electrons to determine the  calorimeter response (pC/GeV factors) at EM  scale.
  - We could verify the response linearity and the energy resolution as function of the electron energy.




- **Hadron 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.



# Summary

- The extended requirements of the HL-LHC demand an extension of the detector's lifespan, which comes with new challenges.

- A harsher radiation environment,  higher pile-up, higher luminosity and readout rates
- For this we will replace all on- and off-detector electronics and 10% of the PMTs in LS3 (2026-2028)
- 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.
- Regular test-beam campaigns throughout the project helped validate designs

# Thank You Very Much!

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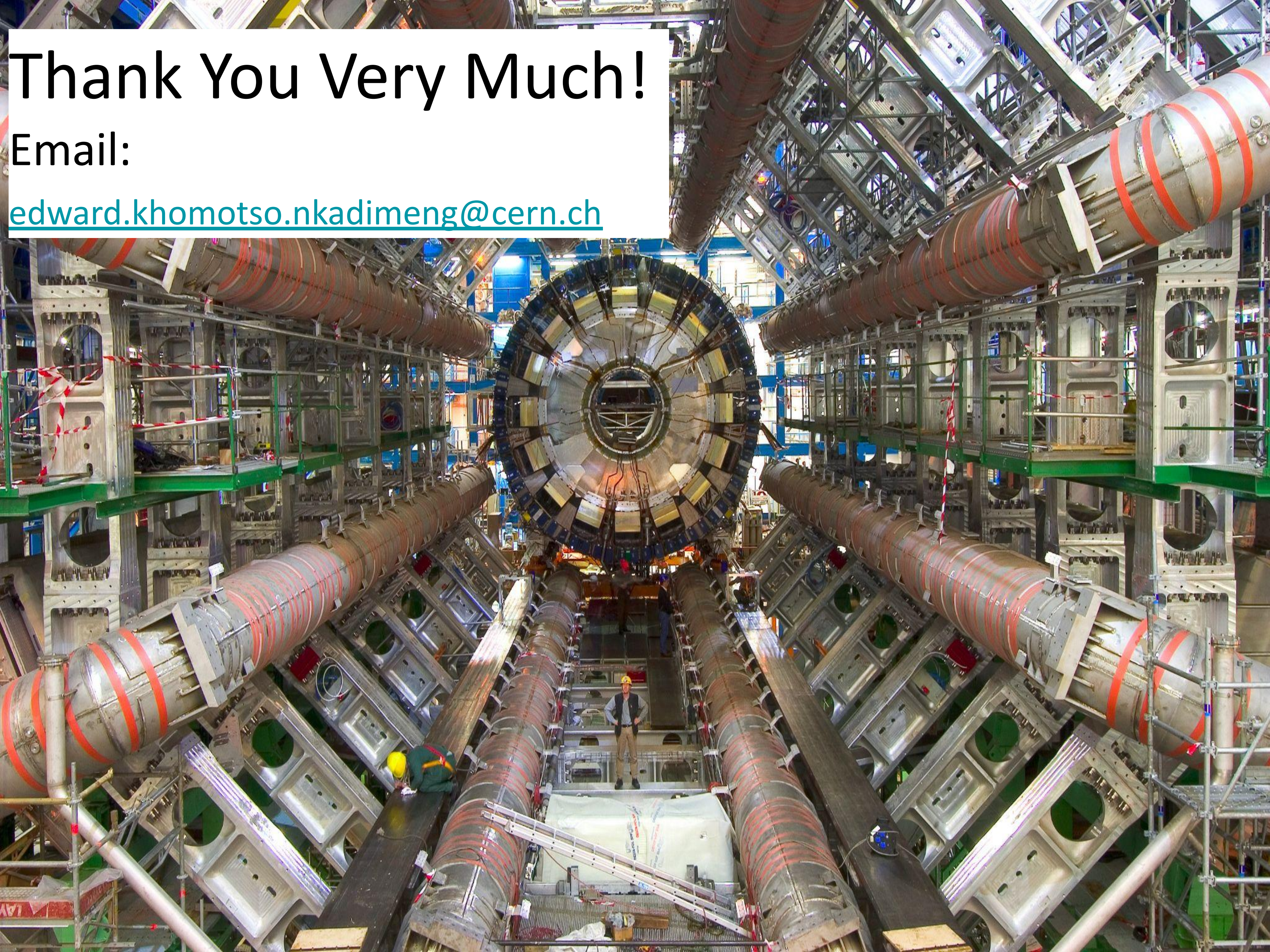

# Signal reconstruction

- **Signal Shaping and Sampling:**
  - The signal from the PMT undergoes shaping and is sampled every 25ns.
- **Phase Definition for Random Phase Pulses:**
  - Due to lack of synchronization between electronics and the clock, arriving pulses exhibit random phase relative to the clock.
  - To handle this, the phase is defined as the offset of sample number 4 from the pulse peak.
- **Reconstruction:**
  - Reconstruction involves determining amplitude A (energy), phase $T$ (timing), and quality factor QF.
- **Fit Method:**
  - One reconstruction method employs fitting the pulse using a specific formula.
- **Optimal Filter Method:**
  - Another method involves utilizing an optimal filter for the reconstruction process.