Upgrade of the ATLAS Tile Calorimeter for the High-Luminosity LHC Era

Edward Nkadimeng

University of the Witwatersrand, Institute for Collider Particle Physics

on behalf of the ATLAS Tile Calorimeter System

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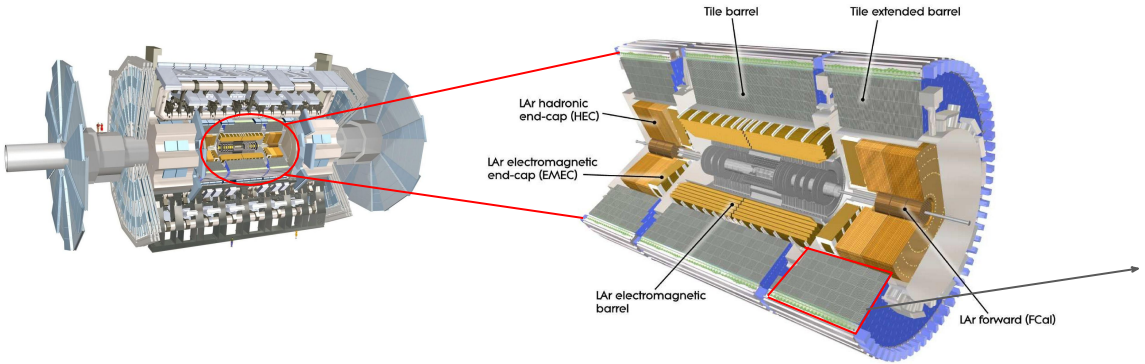
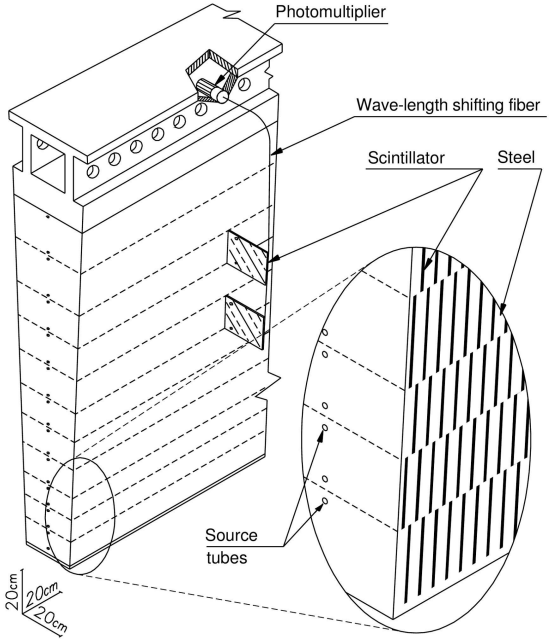
Tile Calorimeter (TileCal) in ATLAS





Central Hadronic Calorimeter - measures energy of hadrons, jets, hadronic decays of τ lepton and provides input signals to calorimeter and muon triggers

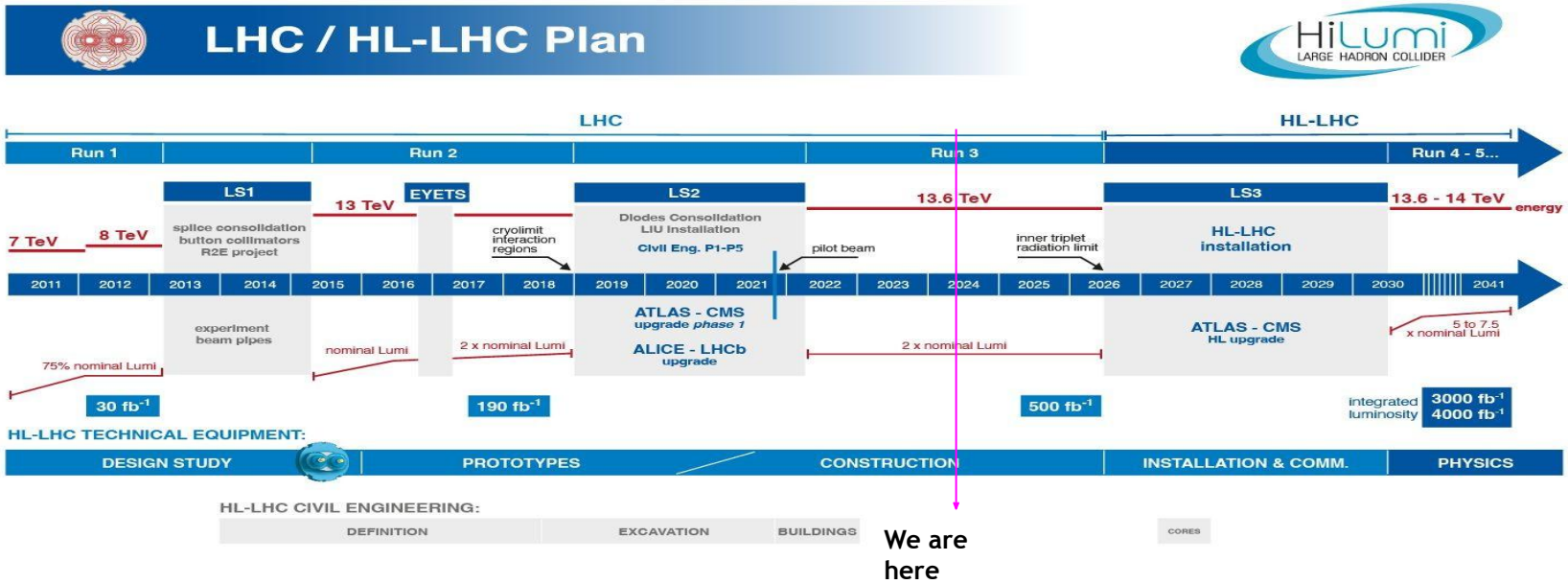
Operating principle - light collected from particle interactions fed to Photomultiplier Tubes (PMTs)

Sampling calorimeter with scintillator (active) and steel (passive)
Covers pseudo-rapidity $-1.7 < \eta < 1.7$

- one central Long Barrel (LB) - $|\eta| < 1.0$
- two end-cap Extended Barrels (EB) - $0.8 < |\eta| < 1.7$

★ 64 azimuthal **modules** cover full azimuth
★ 3 radial layers
★ ~ 460,000 plastic scintillators read out via fibers to 9852 PMTs

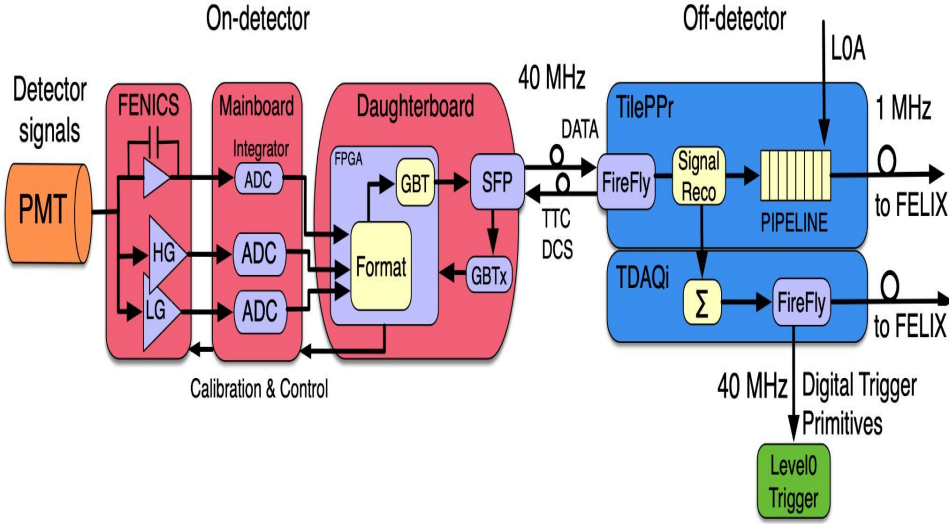
High Luminosity LHC era



- Run 3 program ended in June 2026
- Run 4 expected to start from 2030
  - Instantaneous luminosity increases → 5 - 7.5 x
  - 2500 - 3500/fb integrated luminosity in ~ 11 years → radiation tolerant components
  - Up to 200 pp interactions per bunch crossing → improvement of trigger and data acquisition systems

TileCal in HL-LHC era

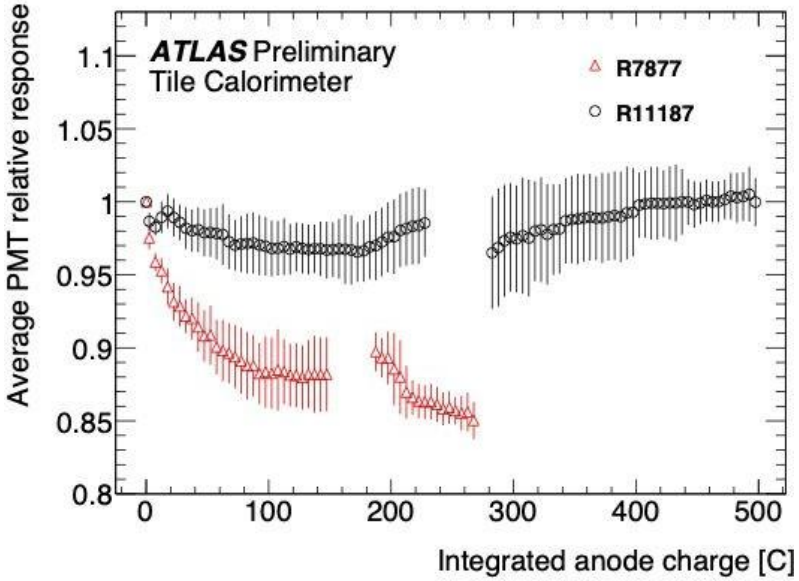
- Tile should operate until the end of Run 5 (2041)
  - modular drawers → accessible maintenance
  - redundant readout and power supply → avoid single point failures
- Higher PMT instantaneous current
  - new PMT → withstand large current
- Radiation damage→ Total Integrated Dose up to 244 Gy over 10 years
  - radiation tolerant components
- Adapt to new ATLAS Data acquisition (DAQ) and Trigger system
  - new readout and trigger interface
  - compatible with ATLAS FrontEnd LInkage eXchange (FELIX) system



PMTs for HL-LHC TileCal

NIM A 1045 (2023) 167660

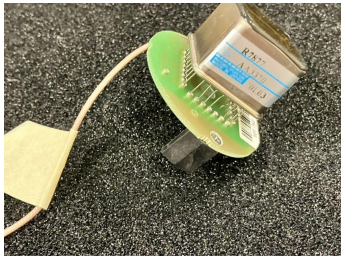
More PMT plots

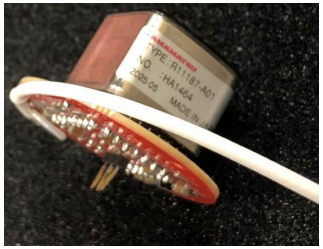


1000(~10%) most exposed PMTs are being upgraded from R7877 to R11187

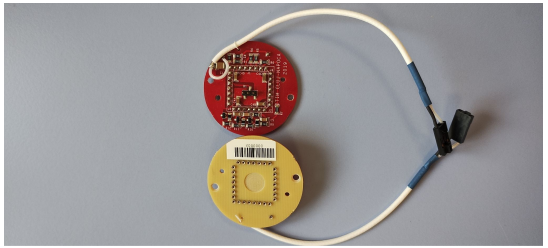
The new PMTs retain response at high integrated anode charge values expected in HL-LHC

R7877 PMT with passive high voltage (HV) divider attached to its bottom





R11187 PMT with active HV divider attached to its bottom

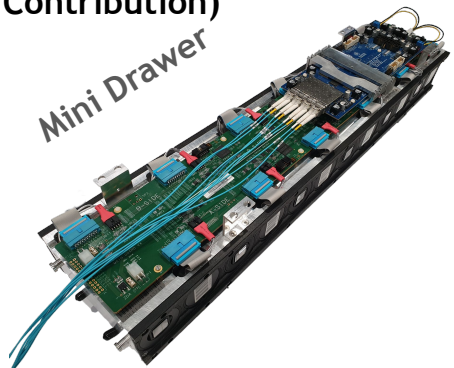


All passive HV dividers will be replaced by active dividers → withstand high instantaneous current

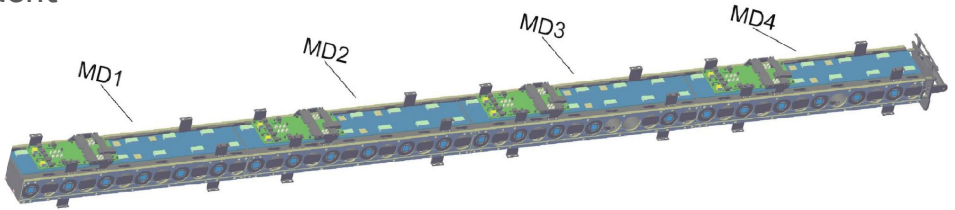
HL-LHC mechanics upgrade

Modular design focused on easy accessibility and independent power supply and readout of Mini Drawers (MD)

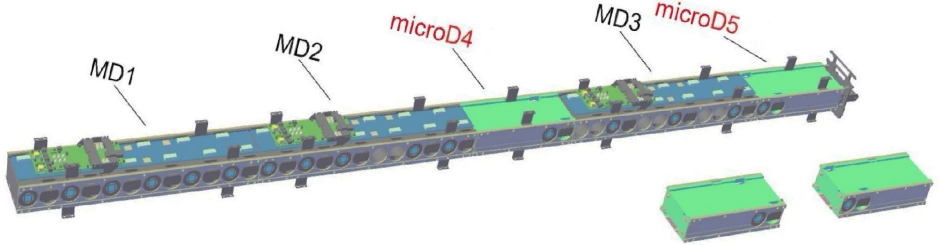
- 1 Super drawer split into
  - 4 MD for LB
  - 3 MD + 2 micro drawers for EB
- Two logical sides of MD. Each with
  - 6 PMTs + 6 FENICS
  - 1 Mainboard, 1 Daughterboard, 1 High Voltage(HV) board, and powered by 1 Low Voltage Power Supply(LVPS) **(WITS Contribution)**



Long Barrel Drawer



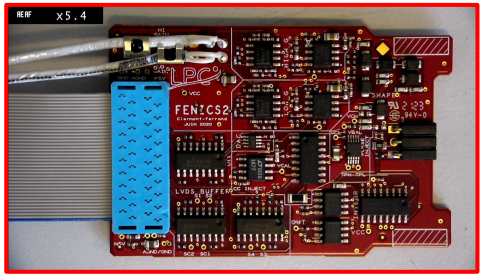
Extended Barrel Drawer

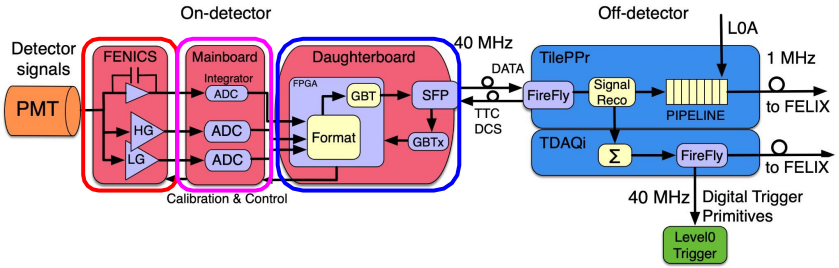


Electronics upgrade - on detector

FENICS
Shapes and amplifies the input PMT signal
9852 PMTs will be equipped with this card
Two gains 1:40 → dynamic range (0.02 - 1000)pC

Mainboard
Controls and provides LV to FENICS
Digitizes FENICS signals and sends to Daughterboard





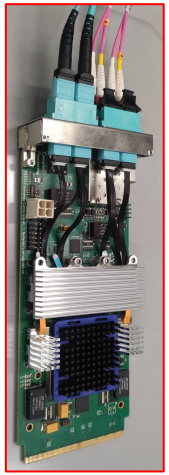
Daughterboard
Sends data to off detector with optical links @ 9.6 Gbps
Uses GBTx protocol

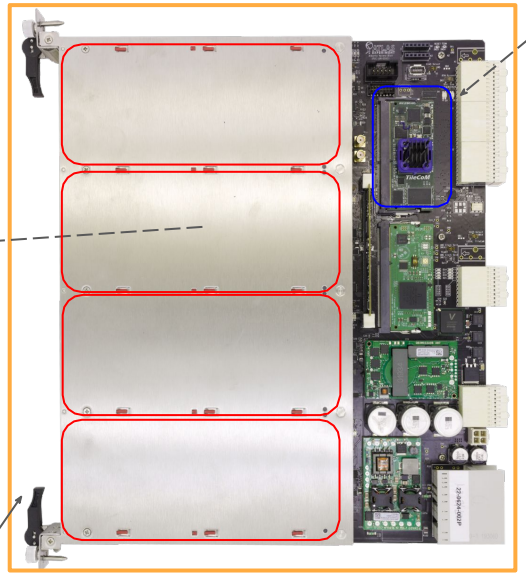
Electronics upgrade - off detector

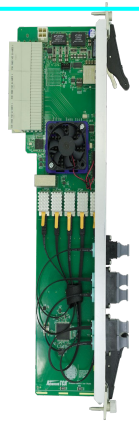
Tile Computer-on-Module
Controls the ATCA board

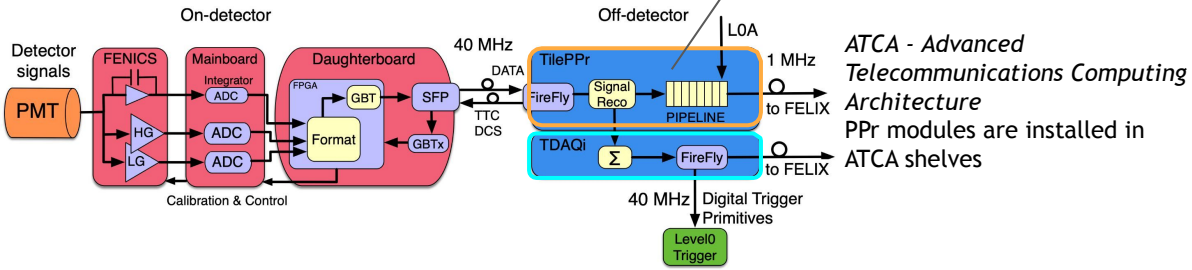
Compact Processing Module

- 1 CPM → 2 TileCal modules
- Reconstruct cell(s) energy and time per bunch crossing
- Stores data until events are selected by the L0 system









ATCA - Advanced Telecommunications Computing Architecture
PPr modules are installed in ATCA shelves

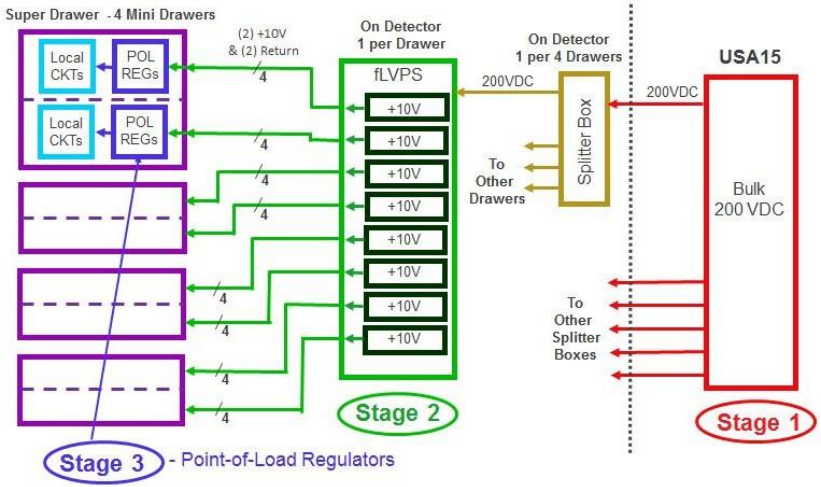
TDAQi

- Interface with ATLAS DAQ and trigger systems
- Computes trigger objects

Power supply systems

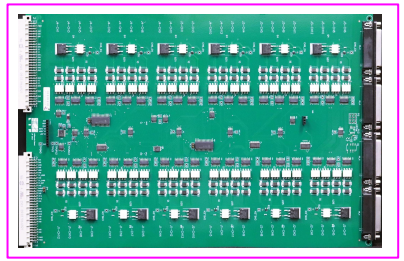
Low Voltage Power Supply

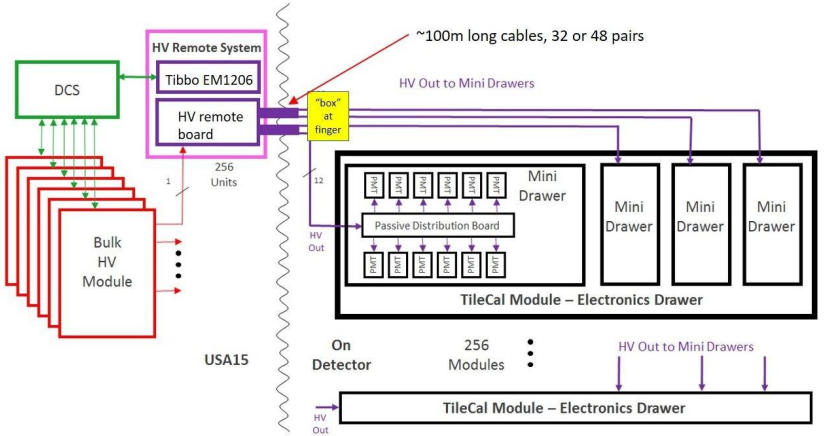
- On detector → high radiation → rigorous testing
- HL-LHC - Three stage power system



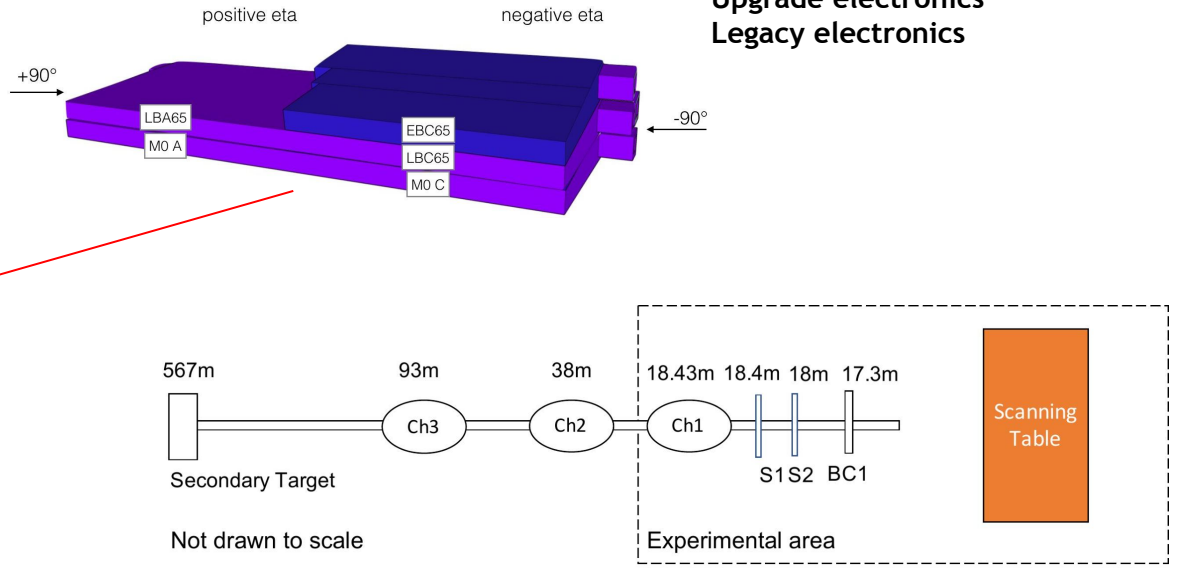
High Voltage Power Supply

- Located 100 m away from the detector
- 256 HV boards → 9852 PMT. Individual PMT HV control





Test Beam



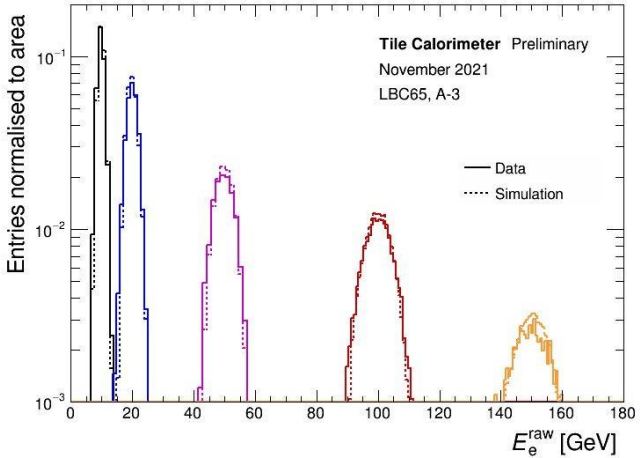
- 3 spare TileCal modules - 2 LB and 1 EB on CERN H8 beam line
- Test Beam studies important for validating response and testing of new components
- Uses tertiary beams of **e**, π, **K** from 400 GeV SPS proton beams
- Studies of module response to particles at various energy and angle
- Test Beam campaigns from 2015 - 2025

Ch3-1 *Cherenkov counters* ***S1, S2*** *Trigger scintillators* ***BC1*** *- Beam chamber*

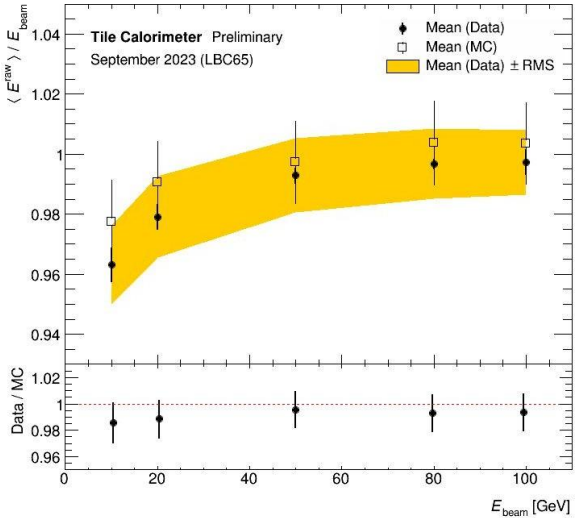
Demonstrator with new electronics operating in ATLAS.

Results from Test Beam - electrons

- 2021 Test Beam campaign data
- Electron response at energies 10, 20, 50, 100, 150 GeV
- Distribution of data and simulation agree



- 2024 Test Beam campaign data
- Agreement of electron response between data and simulation at energy range 10 - 100 GeV within 1%



Analysis of 2024 and 2025 electron data ongoing

Angular dependence of Tile Sampling Fraction (SF) with positron data and simulation ongoing

Conclusion

- Upgrades are underway for HL-LHC
- Results from demonstrator and test beam validate the new system
- Everything is on schedule for HL-LHC era
- HL-LHC installation phase starts after the end of Run 3
  - 2027: Assembly of super drawer surface electronics
  - 2028: Installation in the detector
  - 2029: Commissioning - cosmics run and calibrations

Fig: fLVPS at CERN

Fig: One layer being packed.

BACKUP