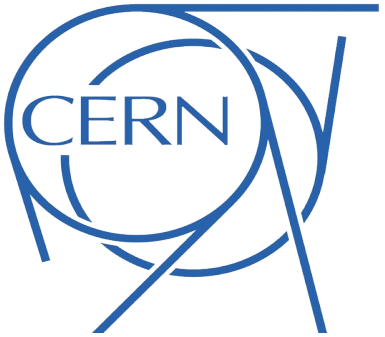
Upgrade of ATLAS Hadronic Tile Calorimeter for the High Luminosity LHC



Tibor Ženiš
Comenius University Bratislava

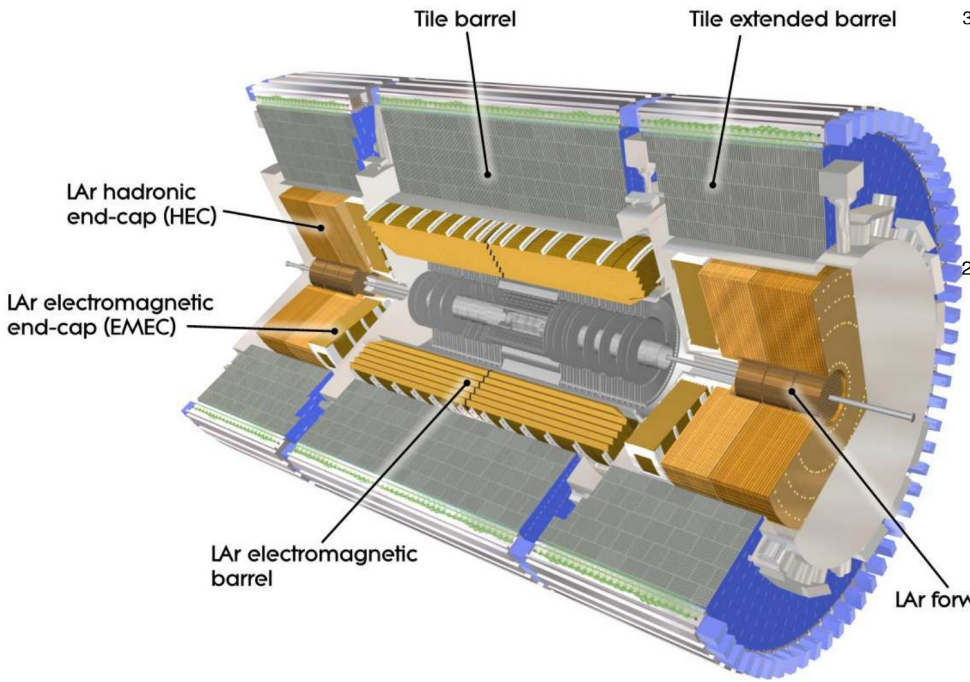
On behalf of the ATLAS Tile Calorimeter system

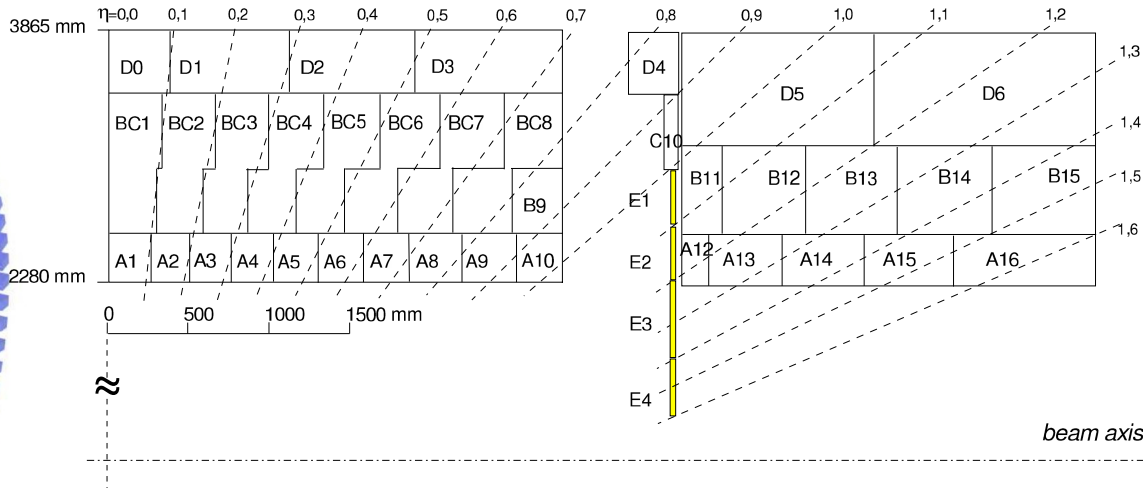
DIS2022: XXIX International Workshop on Deep-Inelastic Scattering and Related Subjects

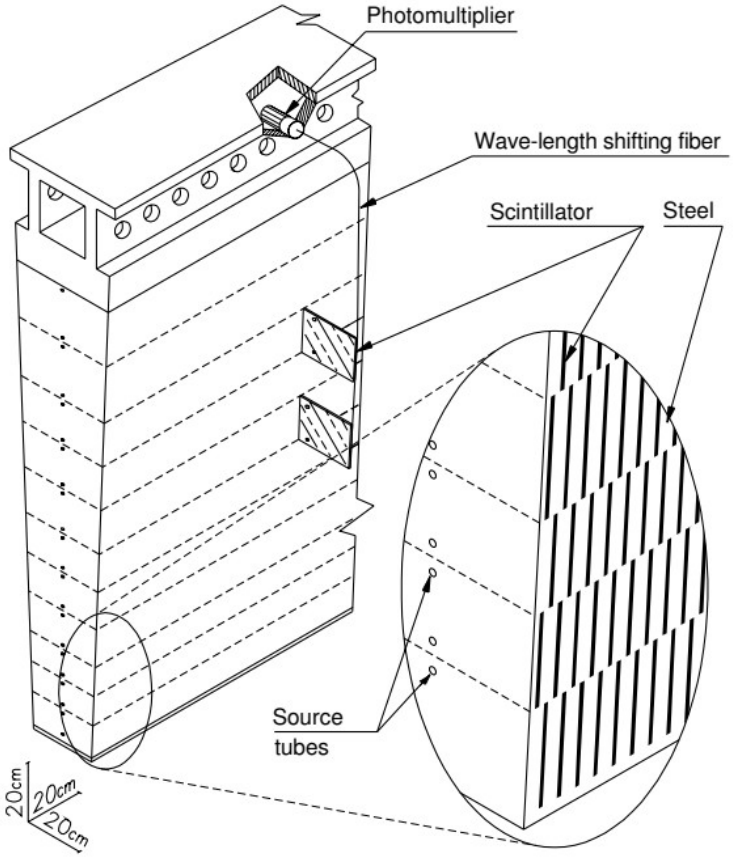
Overview

- The ATLAS Tile Calorimeter
- High-luminosity LHC and Tile upgrade
  - Mechanics
  - Electronics
  - High voltage
  - Low voltage
- Tile upgrade demonstrator
  - The demonstrator at test-beam
  - The demonstrator at ATLAS

The ATLAS Tile Calorimeter







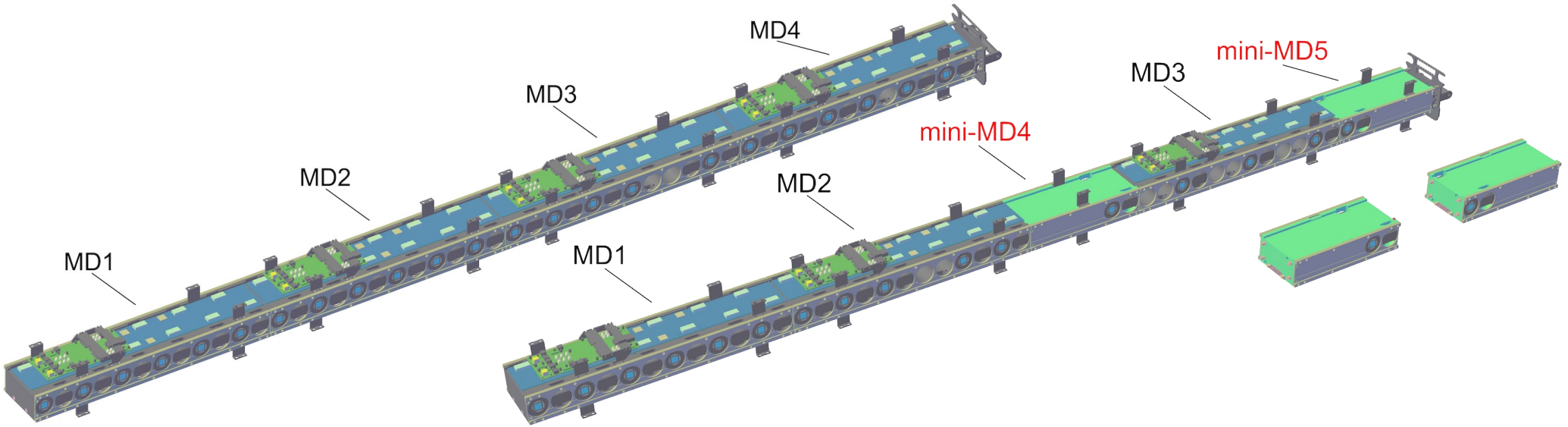
- **Central hadron ATLAS calorimeter.**
  - Two sides of Long Barrel (LBA, LBC) and Extended Barrels (EBA, EBC).
  - Three barrels (LBA+LBC, EBA, EBC), 64 modules each.
  - Coverage $|\eta| < 1.0$ (LB), $0.8 < |\eta| < 1.7$ (EB).
  - Measures jet energy and missing transverse energy. $\frac{\sigma}{E} = \frac{50\%}{\sqrt{E}} \oplus 3\%$
  - Constructed from steel plates and plastic scintillators – **tiles**.
  - Light readout with two optical fibers per tile.
  - Divided into ~5000 cells by grouping the fibers.
  - Two PMTs per cell, ~10,000 PMTs total.
  - Granularity: $\eta \times \varphi = 0.1 \times 0.1$ for the inner layers (A, BC), 0.2×0.1 for the outer layer (D).

Tile Phase-II Upgrade for HL-LHC

- **High-luminosity LHC:**
  - Installation during the LS3, 2025 – 2027.
  - Increase of peak luminosity, up to 4000 fb^{-1} integrated luminosity at the end.
  - High pile-up contribution, 50 $\rightarrow$ 200 collisions per bunch crossing.
- **Upgrade of the Tile Calorimeter:**
  - The scintillating tiles and optical fibers are built into the detector – cannot be modified.
  - Complete replacement of on-detector and off-detector electronics:
    - New mechanical structure for the on-detector electronics.
    - Improved LV and HV system.
    - Active dividers for all PMTs.
    - Replacement of 10% of PMTs, the most exposed ones.
    - New digital ATLAS trigger system up to 40 MHz.
    - Increased detector read-out bandwidth – 40 Tbps for the entire Tile.

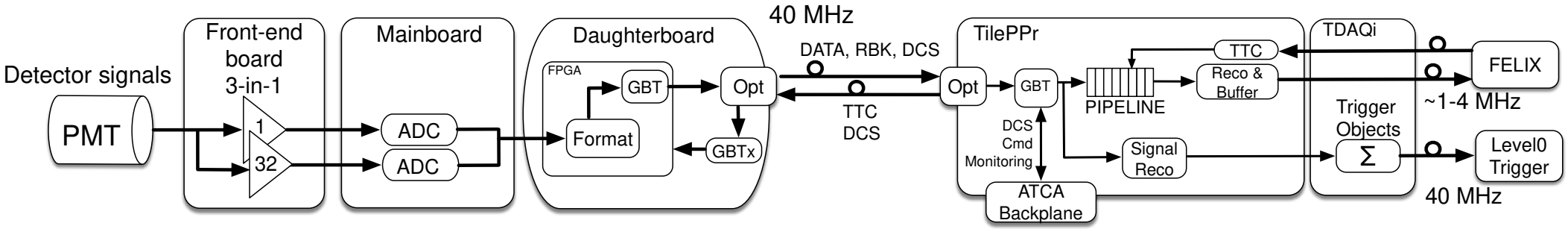
Tile Upgrade – Mechanics

- New Super-Drawer structure.
- Modules are split into 4 Mini-Drawers (MD).
  - Legacy modules have two drawers, 2 times bigger than MD.
  - Up to 12 PMTs per MD.
    - Independent 6 up PMTs and 6 down PMTs in one MD.
    - Independent electronics, readout and LV for each half of MD.
  - More segmentation for more reliability.
  - Smaller parts – easier to manipulate during installation and maintenance.
- Architecture fully validated, production has already started.
- Additional micro-drawer added for extended barrel modules.

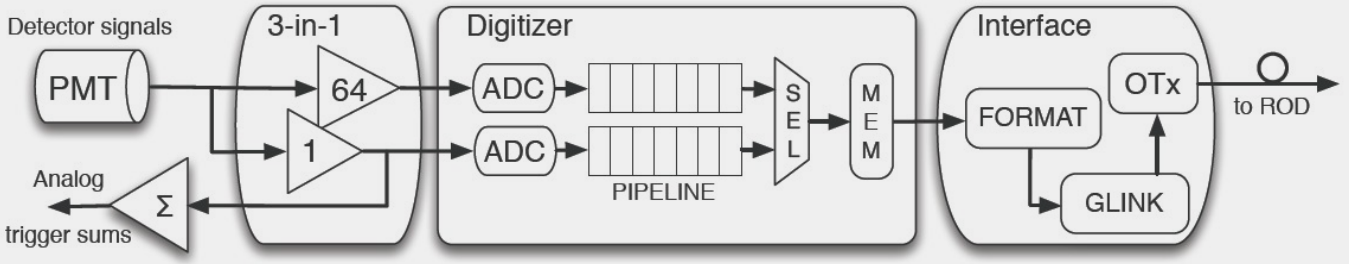


Tile Upgrade – Electronics

- On-detector electronics transmits full digital data at 40 MHz.
- Memory buffers (pipeline) are moved to off-detector electronics.
- Redundancy in data links and power distribution.
- Two signal paths with 1:32 gain ratio, 12 bit 40 MHz ADC each.
- Digital trigger output:
  - Allows more advanced trigger algorithms.
- New gain of integrators:
  - Better measurement of the instantaneous luminosity in full range.

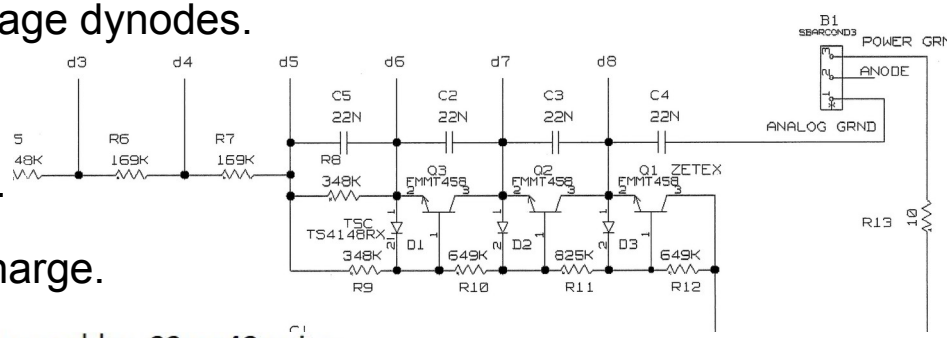


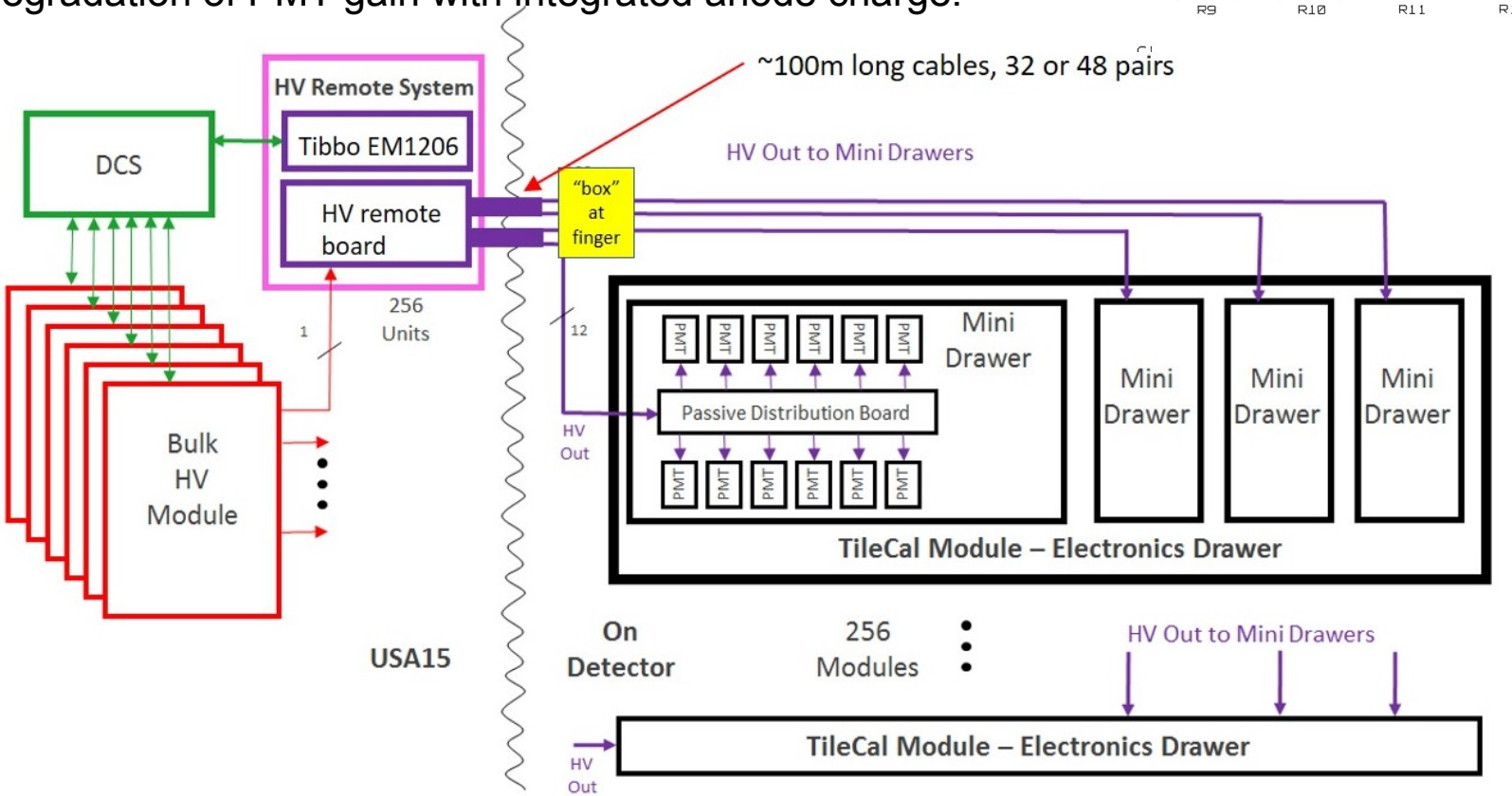
Legacy:
- Analog trigger output.
- Pipeline on detector.



Tile Upgrade – High Voltage system

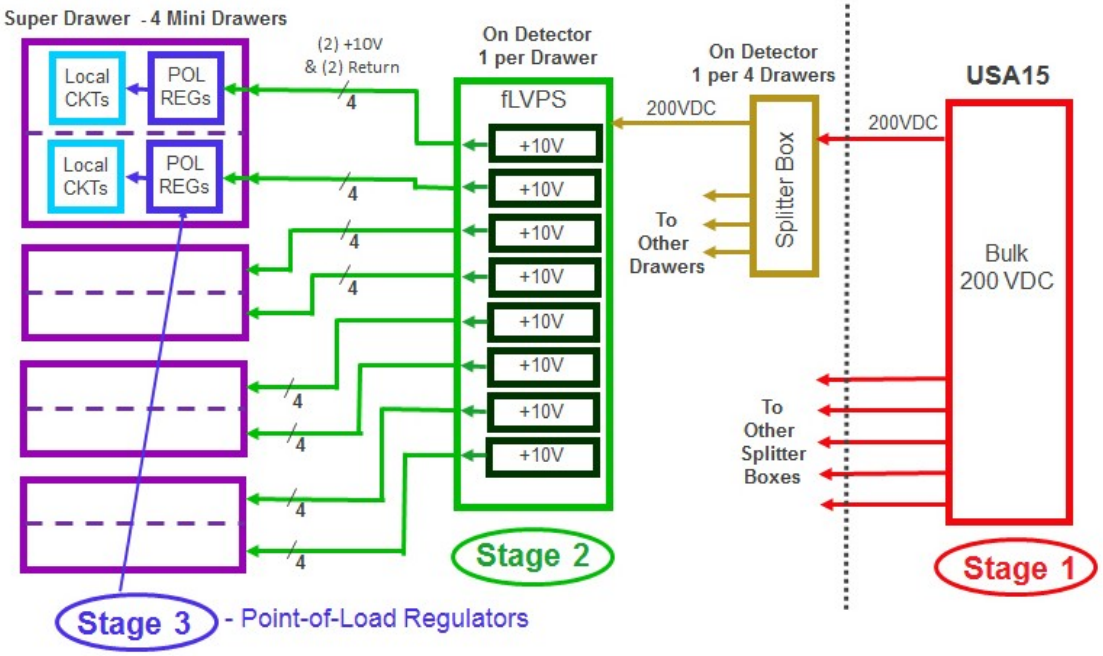
- HV regulation and distribution systems are moved off-detector – HV Remote System (100 m away).
  - Easy access during operation for maintenance.
  - Only passive distribution boards on-detector.
- New active dividers for PMTs with transistors for last stage dynodes.
  - Good linearity up to current of 100 μA.
- Replacement of 10% of PMTs, the most exposed ones.
  - Degradation of PMT gain with integrated anode charge.

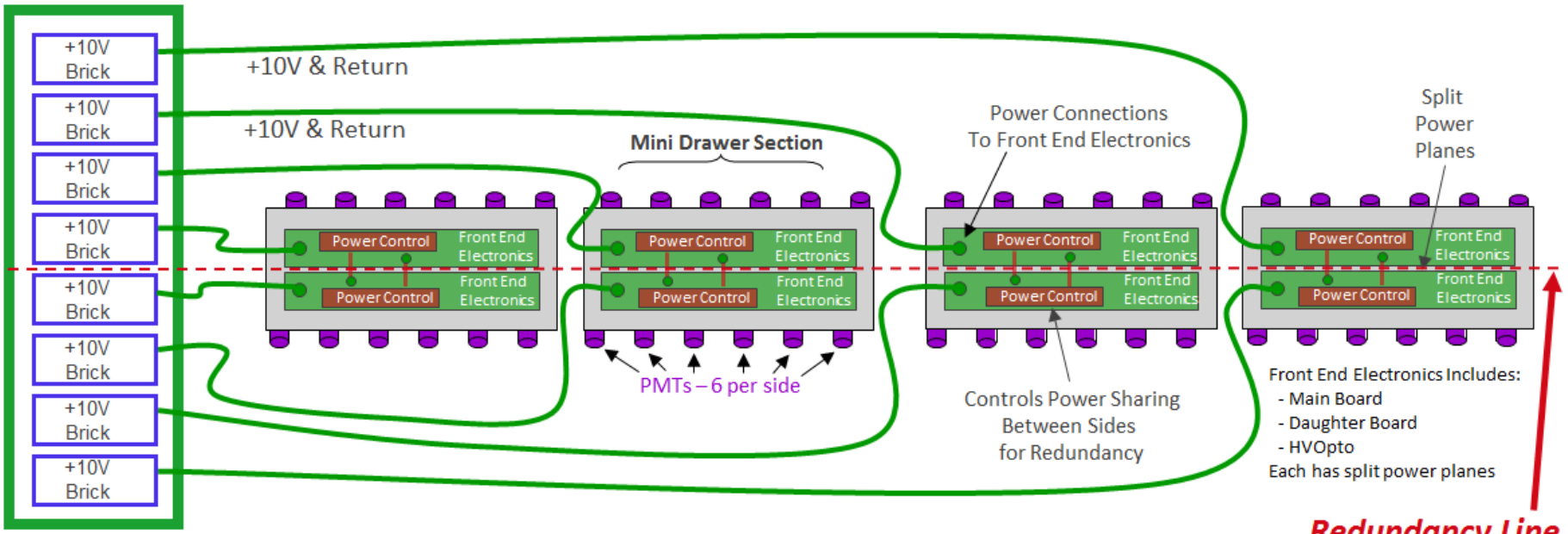




Tile Upgrade – Low Voltage power

- Three stage system.
  - Designed with better reliability, lower noise, improved radiation tolerance, reduced single points of failure.
- Single level (+10 V) DC brick.
  - 2 bricks per MD.
  - 8 bricks per module.
  - Redundant power distribution.





Tile Upgrade vs. legacy

- The upgrade was designed to:
  - Fulfill HL_LHC conditions.
  - New digital ATLAS trigger system.
  - Prevent malfunction of a full module:
    - Using experiences with the legacy.
  - Be easy to maintenance.

Upgrade	Legacy

• 4 independent minidrawers per module
  • Redundant LV on each MD
  • Redundant data output
  • Remote HV system, only passive distribution boards on detector
  • Easy to maintenance
	• Common module
	  • Common LV: 8 different voltage levels provided for a module
	  • single points of failure
	  • Common interface card
	  • HV regulation on detector
	  • No access during operation

• Active PMT dividers
  • Good linearity over 100 μA DC
	• Passive PMT dividers
	  • Non-linearity at % level from 1 μA DC

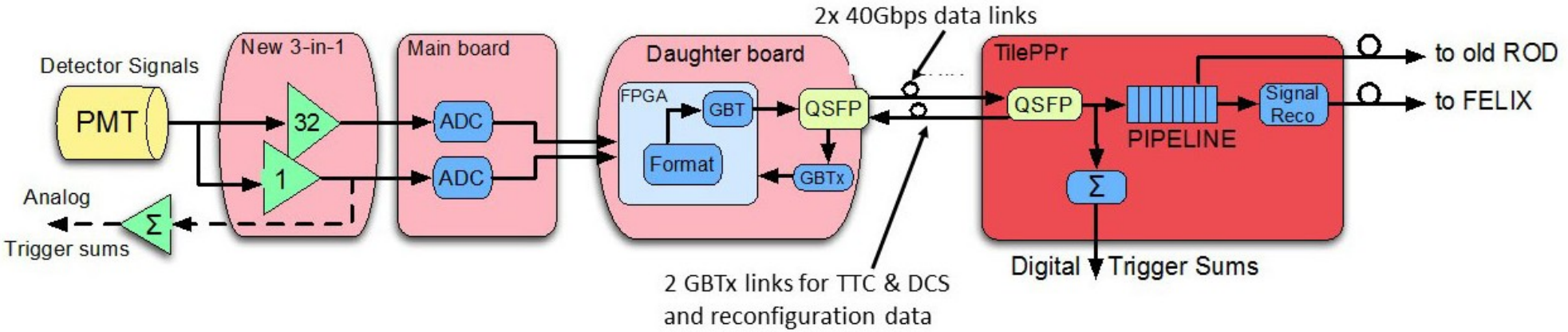
• 2-gains signal paths
  • ratio 1:32
  • 12 bit ADCs
	• 2-gains signal paths
	  • ratio 1:64
	  • 10 bit ADCs

• Off detector buffer memory	• On detector buffer memory
• Digital trigger output	• Analog trigger output
• 4.8 Gbps output bandwidth	• 800 Mbps output bandwidth

40 μA expected on the most exposed cells

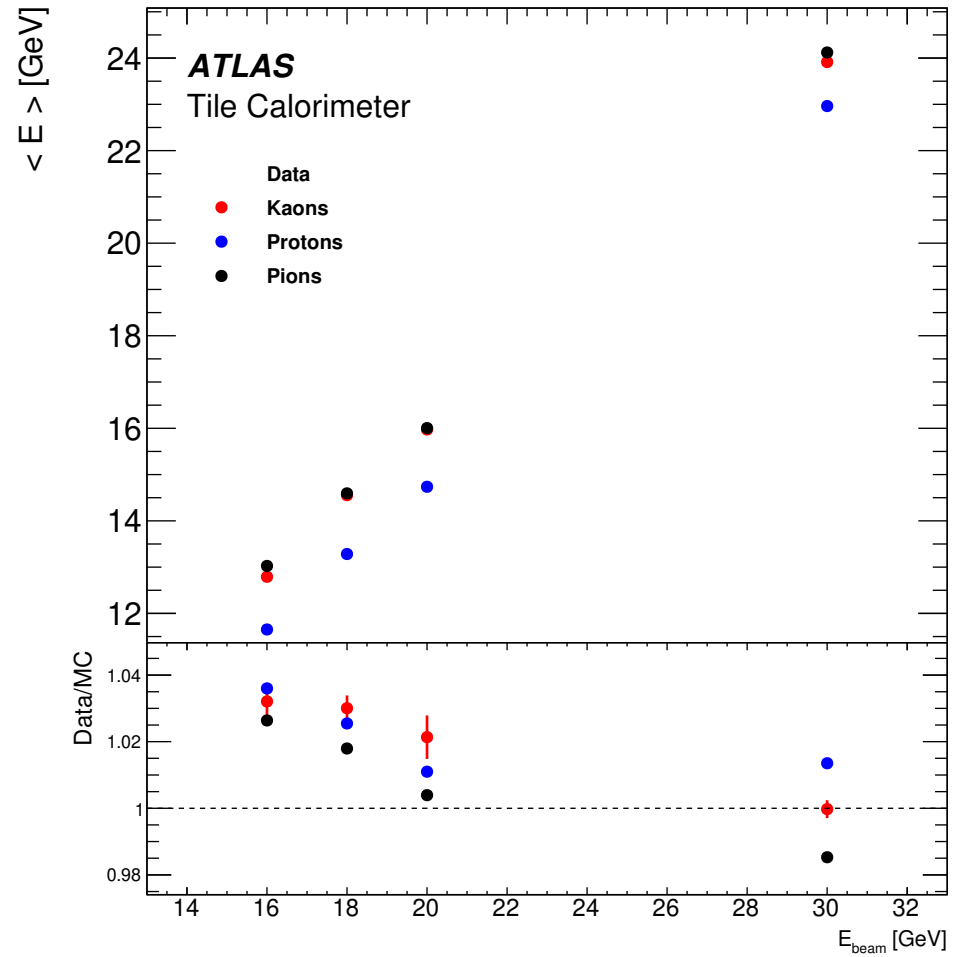
The Demonstrator Module

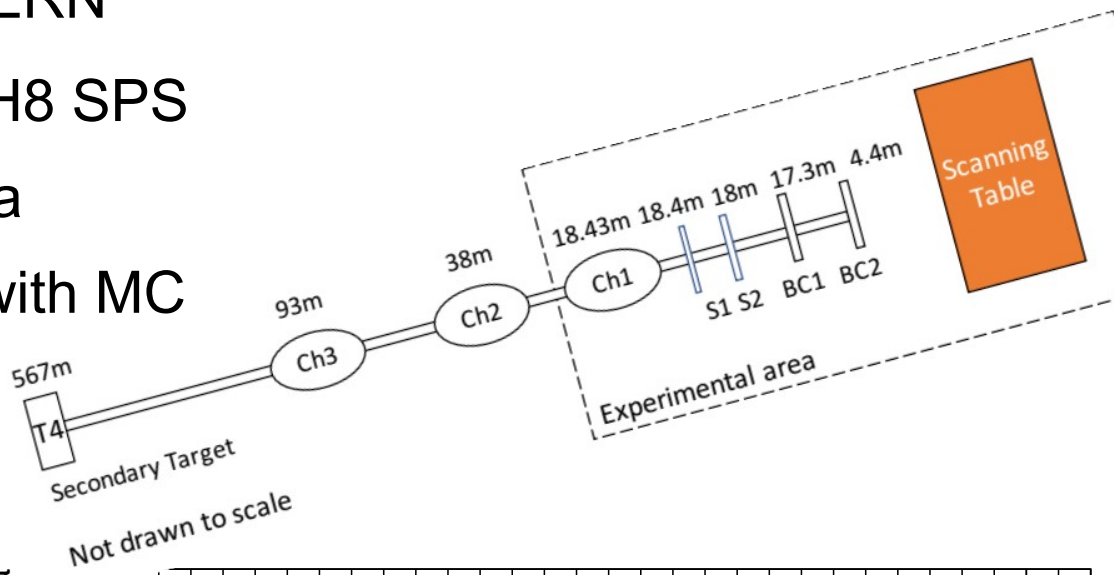
- Demonstrator module.
  - Project to operate backward-compatible upgraded electronics.
  - Inserted in ATLAS in July 2019.
  - Upgraded version of the electronics (upgraded 3-in-1 with 1/32 gain ratio, mainboard, daughterboard).
  - Analog adder cards for compatibility with current trigger system.
  - Demonstrator will be kept in ATLAS during RUN 3.
- Demonstrator PreProcessor.
  - Modified system to ensure compatibility with current TDAQ (Trigger & Data Acquisition) and TTC (Timing, Trigger and Control) system.
  - Demonstrator can be controlled and monitored by DCS (Detector Control System) like any other module.

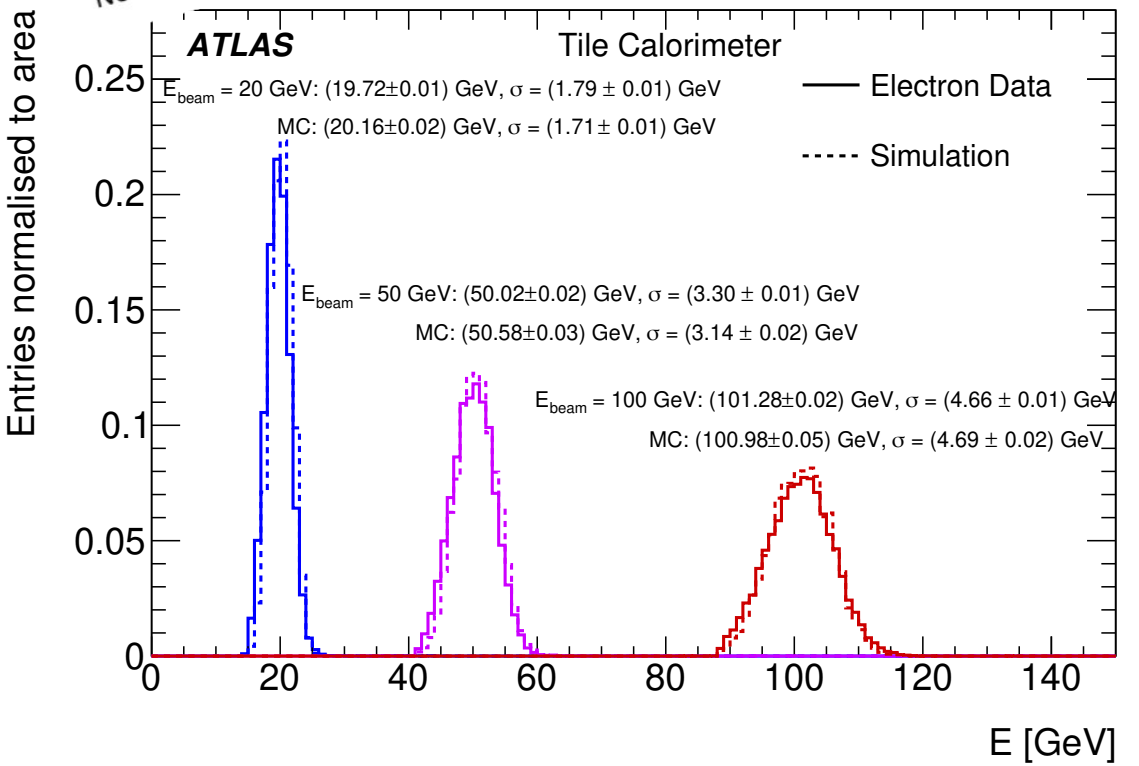


The Demonstrator at test-beam

- Results from particle-beams in CERN
  - 7 campaigns 2015 – 2018 at H8 SPS
  - various particles and momenta
- Good resolution and agreement with MC

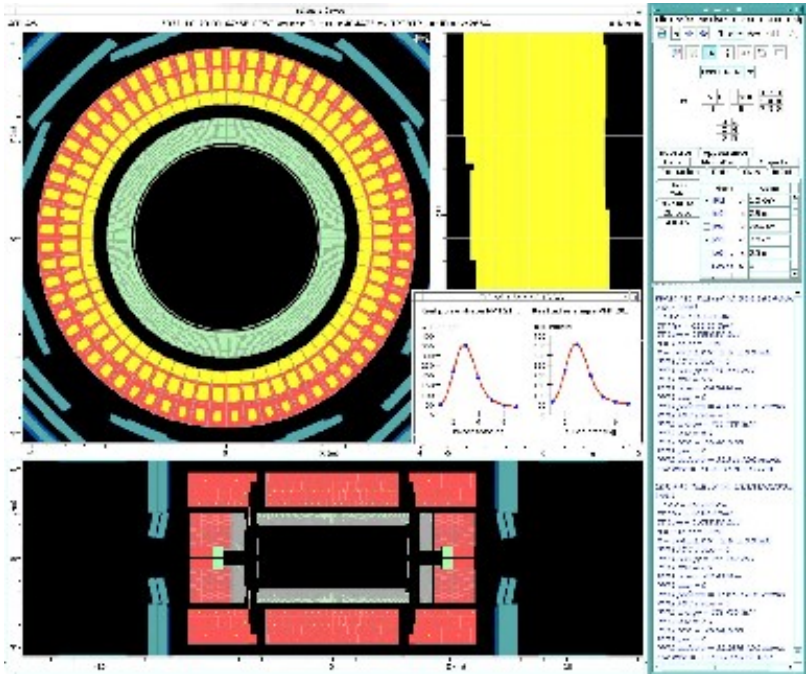






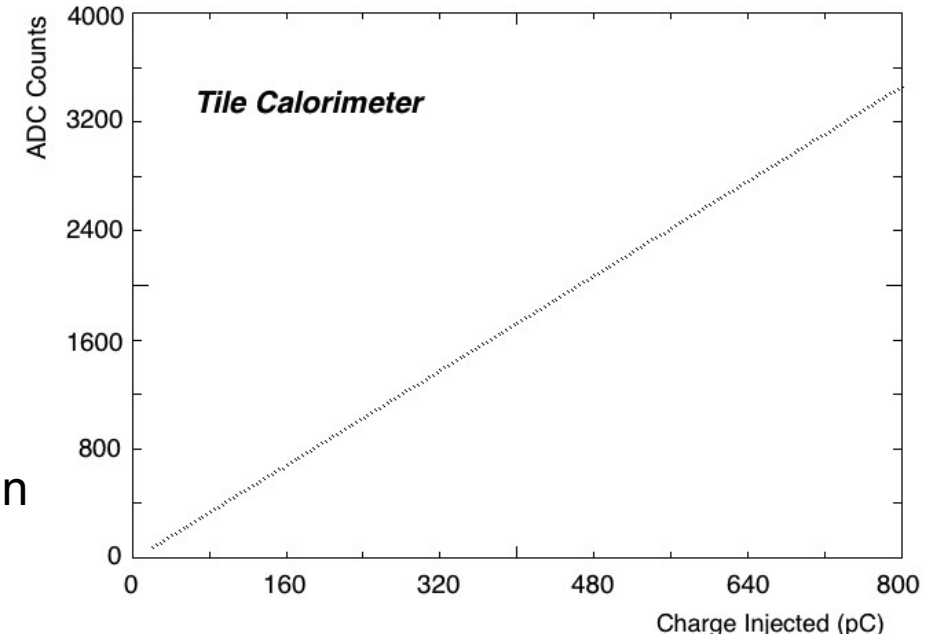
The Demonstrator at ATLAS

- Inserted into LBA14 module during July 2019.
- Powered (LV, HV) and monitored from DCS and calibrated using the TDAQ.
- Embedded into legacy calibration systems (pedestal, laser, charge injection system – CIS).
  - Stable performance, low noise and good CIS and laser signals.
- Commissioned trigger towers output system to ATLAS level 1 trigger.
- Recorded cosmic data and LHC splash events
  - **Tile demonstrator performs at least as good as legacy drawers.**



Splash event

CIS scan



Conclusion

- **The High-Luminosity LHC era will bring new challenges:**
  - higher luminosity,
  - higher pile-up,
  - higher radiations.
- **Upgrade of the Tile Calorimeter system is required and well on track:**
  - New mechanical structure and electronics, more robust.
  - New digital trigger system, higher rate.
- **The Tile demonstrator is fully operational:**
  - Test beam campaigns from 2015 to 2018 proved a good performance of the demonstrator.
  - Full integration of the Tile demonstrator in the current ATLAS DAQ and DCS systems, ready for RUN3 data.