Commissioning of the ATLAS Liquid Argon Calorimeter for the LHC Run-3

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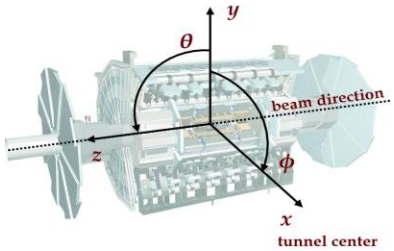
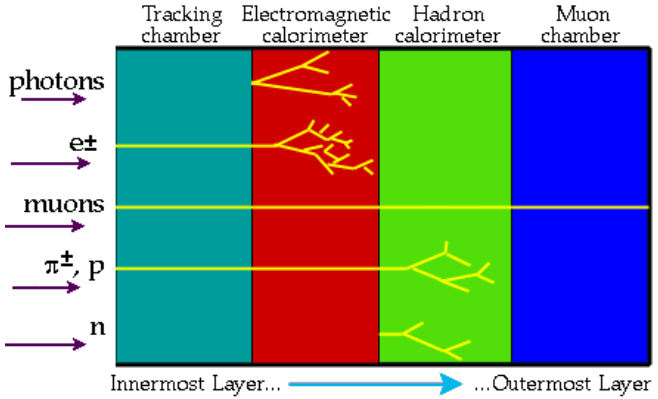
The Liquid Argon (LAr) Calorimeter

Technical Design report (TDR)

Measures the energy and position of electrons, photons and hadrons:

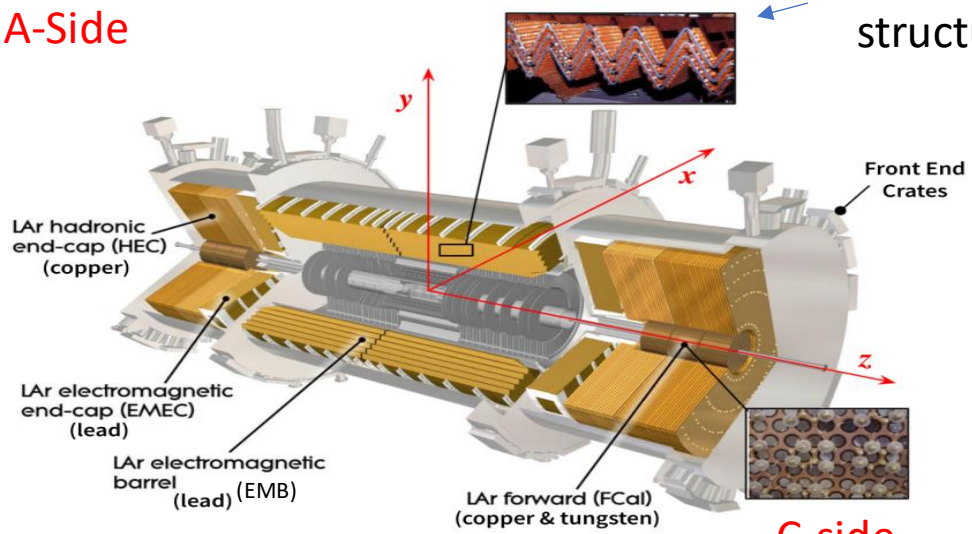
- Provides full coverage in ϕ with fine granularity
- ~180,000 readout channels
- Divided in four different detectors: Electromagnetic Barrel & Endcap, Hadronic Endcap and Forward Calorimeter
- One active material (LAr) and three passive materials: lead, copper & tungsten



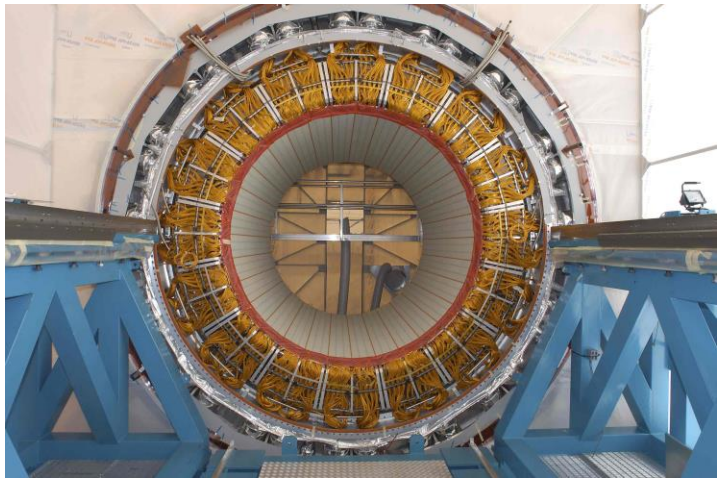


Honeycomb structure

A-Side



C-side

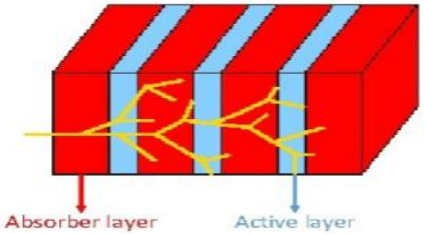


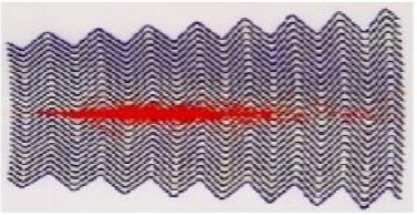
The Barrel Calorimeter

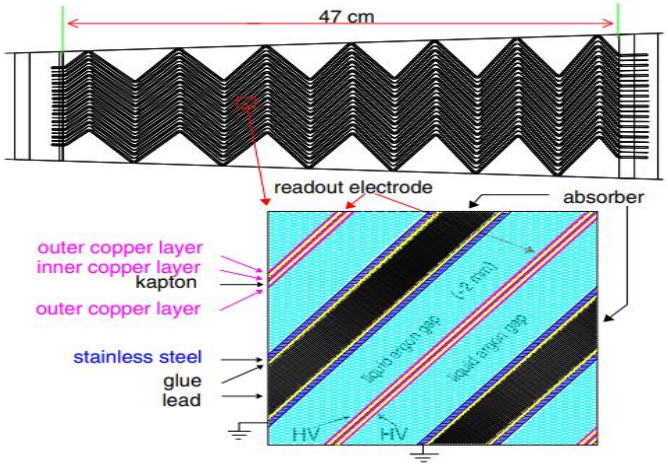
Operating principle

Three passive materials used: Lead (Electrogmagnetic calorimeter), Copper (Hadronic calorimeter) and Tungsten/Copper (Forward calorimeter)

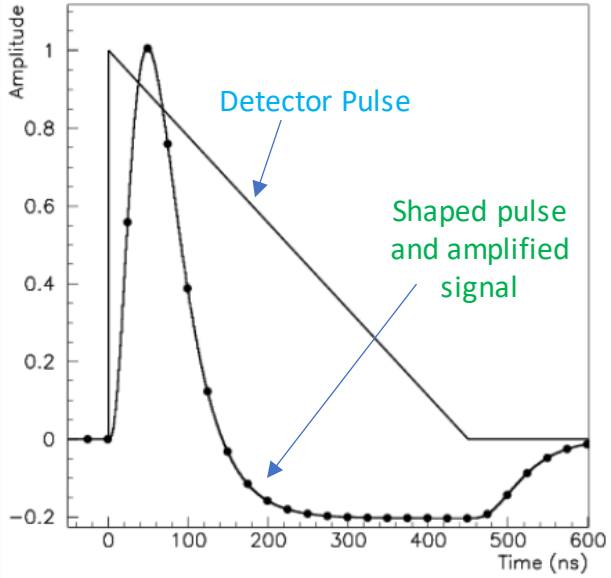
- Incoming particles interact with the absorber and lose part of their energy, initiating a shower of secondary particles
- These secondary particles ionize the active material (LAr)
- A high voltage of is applied on LAr gap (2 kV and 2.0 mm for the barrel region), and the ionisation electrons drift towards the electrodes
- By capacitive effect a signal is induced on the electrons and is read out by the electrodes







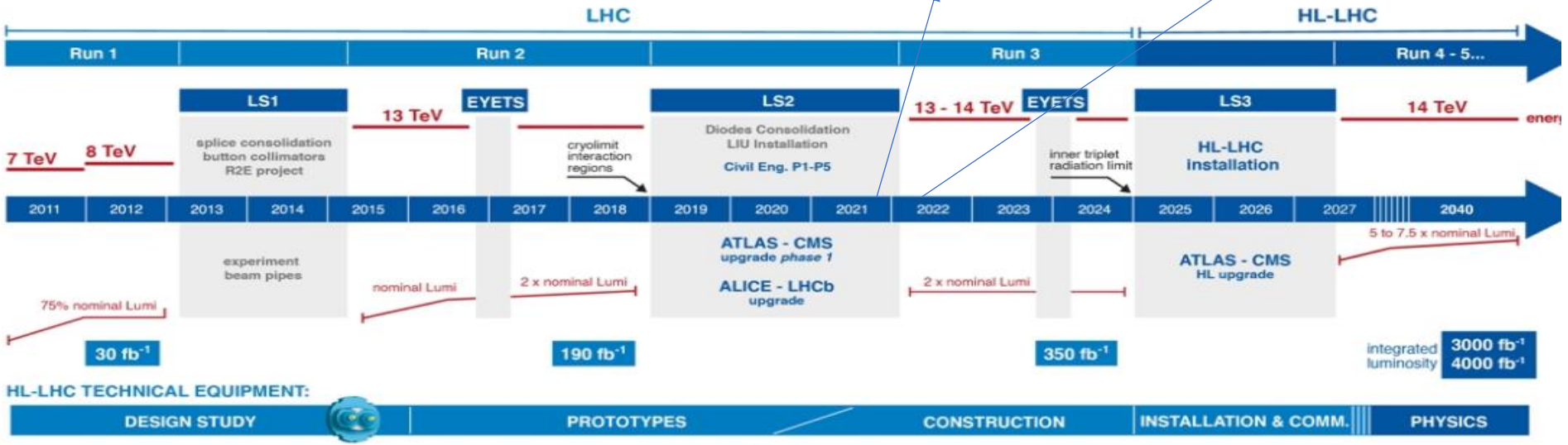
- The triangular detector pulses are shaped into bipolar ones
- The analog signal is sent to the Front-End electronics for sampling
- If the trigger system accepts the event, the signal is digitised and sent to the back-end for energy calculation



LHC Schedule towards Run-3

Feb 2022: Expected Start of Run-3

October 2021: Pilot Beam



	Run-2	Run-3	Increase
Inst. Lumi ($10^{34}\ cm^{-2}s^{-1}$)	1.9	3.0	~2
Avg. Pileup	36	80	>2
L1 trigger rate (kHz)	100	100	1
HL trigger rate (kHz)	1	1	1

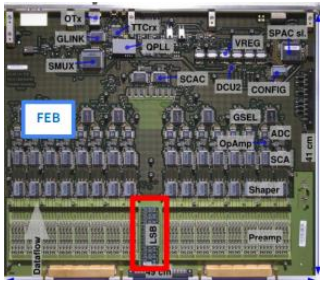
- Instantaneous luminosity and average number of interactions per bunch crossing (pile-up) will increase significantly in Run-3 conditions, while the Level-1 (L1) and High-Level Trigger (HLT) rate remain at Run-2 values
- The LAr Phase-I upgrade is aiming to maintain Run-2 performance in these new conditions

Overview of the Run-2 readout LAr Electronics

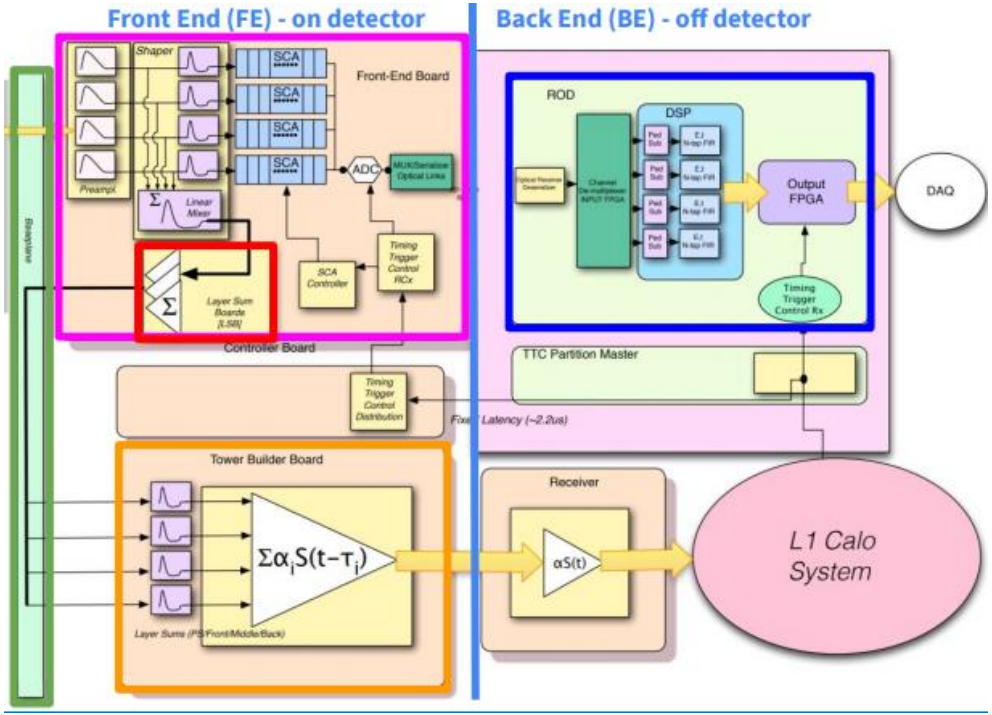
- The Front End Boards (FEBs) send digital samples of the shaped and amplified LAr ionization signal to the Read-out drivers (RODs) in the back-end

- The baseplane transmits the analogue sums from the FEBs to the Tower Builder Boards (TBBs)
  - The analogue sums from each of the four calorimeter layers are used to build the Trigger Tower energy sum
  - This information is then routed to the Level-1 trigger system

- All Front-end electronics are housed in Front-End crates (FEC), 58 in total, each containing a full set of boards
- Back-end electronics are in a separate cavern off-detector

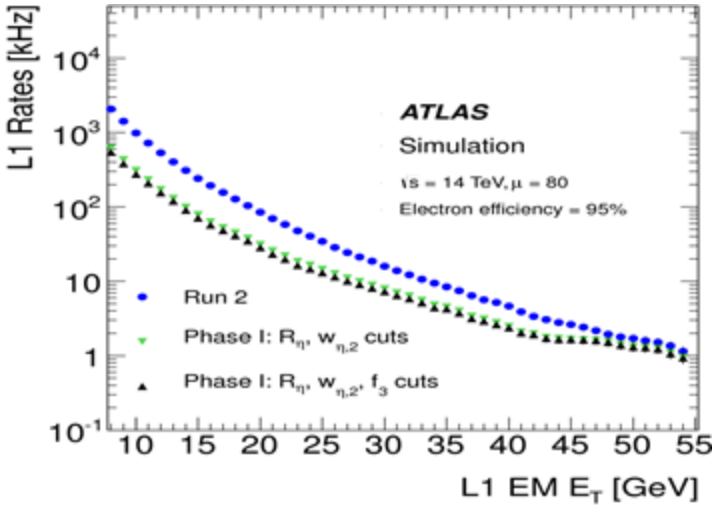


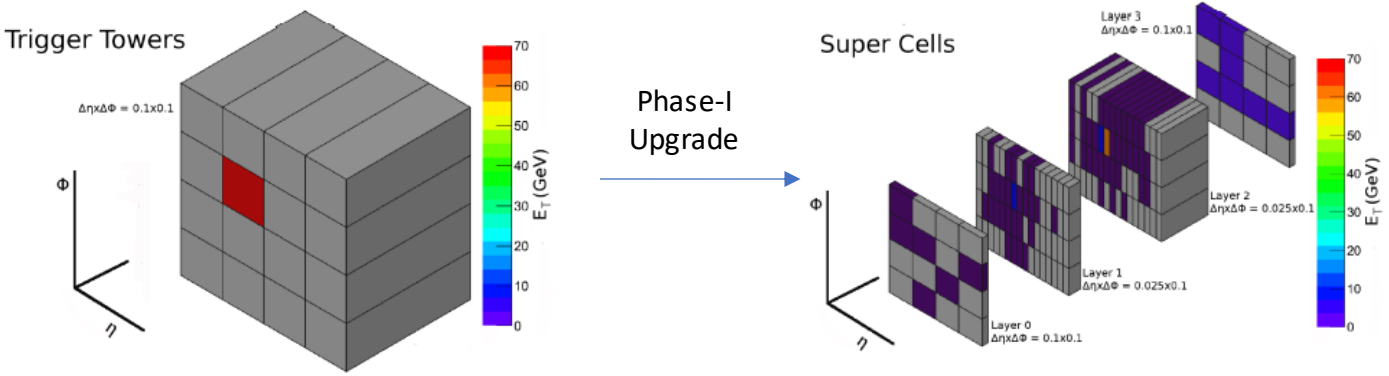
Front-end board



Phase-I Upgrade Motivation

- In order to maintain the Run-2 energy thresholds during Run-3 while keeping the same L1 rate, need to improve the background rejection at trigger level
- Throughout Run-2, up to 60 calorimeter cells (depending on the region) from various layers were grouped to form trigger towers of $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$, with a total of ~6000 towers used as input for the L1 trigger
- However, this setup does not provide longitudinal segmentation. As such, cannot use the shower shape information as a discriminant variable





70 GeV electron example

- Longitudinal segmentation is now available, with up to eight calorimeter cells used per layer
- Overall granularity increased to $\Delta\eta \times \Delta\phi = 0.025 \times 0.1$, with a total of ~34k supercells, increasing overall granularity by a factor ten
- Shower shape information allows for better bkg rejection at trigger level, as well as better pileup subtraction

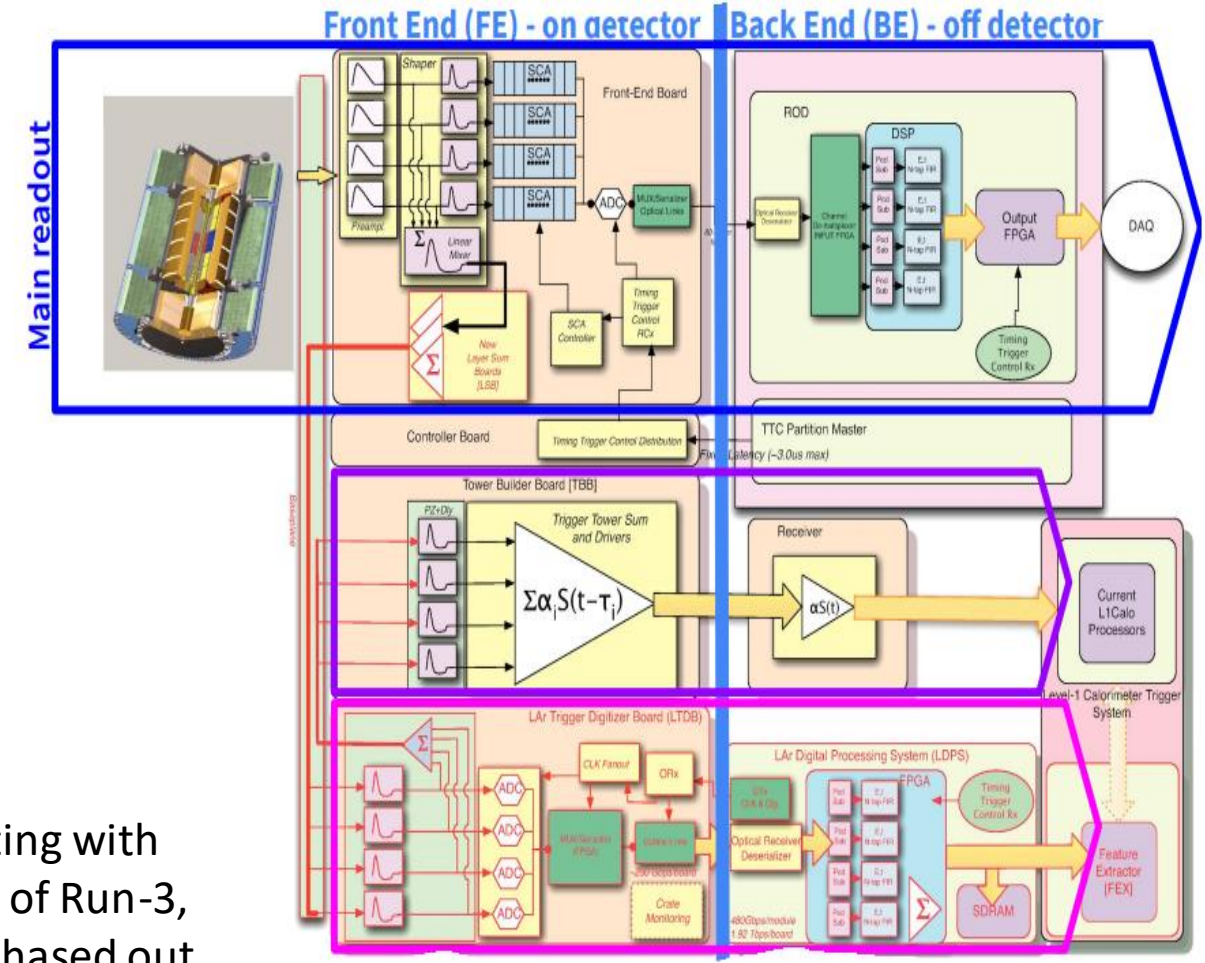
[Phase-I TDR]

LAr Phase-I Upgrade overview

Changes wrt Run-2 shown in red:

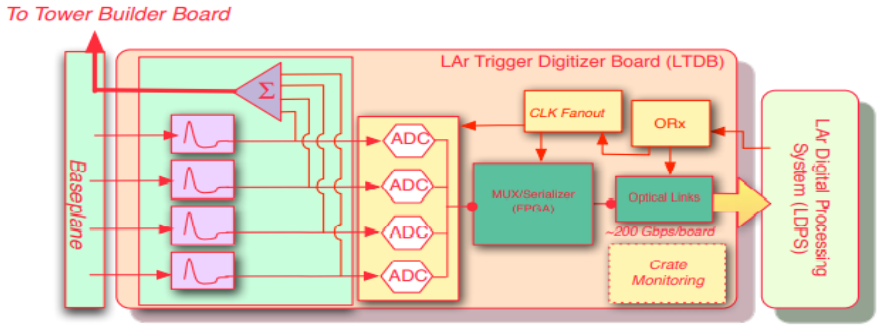
- New front-end component: **L**Ar **T**rigger **D**igitizer **B**oard (LTDB)
- New back-end (BE) component: **L**Ar **D**igital **P**rocessing **B**lade (LDPB)
- Baseplanes refurbished to add connections to the new phase-I components
- **Layer Sum Boards (LSBs)** replaced to build the more granular signals from the new supercells

The Legacy system will be co-existing with the new digital trigger at the start of Run-3, but is expected to be eventually phased out



Phase-I Front-End: LTDB

- Custom designed 12 bit ADC at 40 MHz
- Responsible for:
  - Digitizing of super cell analogue signals
  - Feeding back sums for the legacy trigger tower builder boards, as well as
  - Providing digitized signals to the phase-I back-end (LDPB) via optical fiber links
- 124 LTDBs in total, six different types adequated for each region, each one processing around 320 supercells

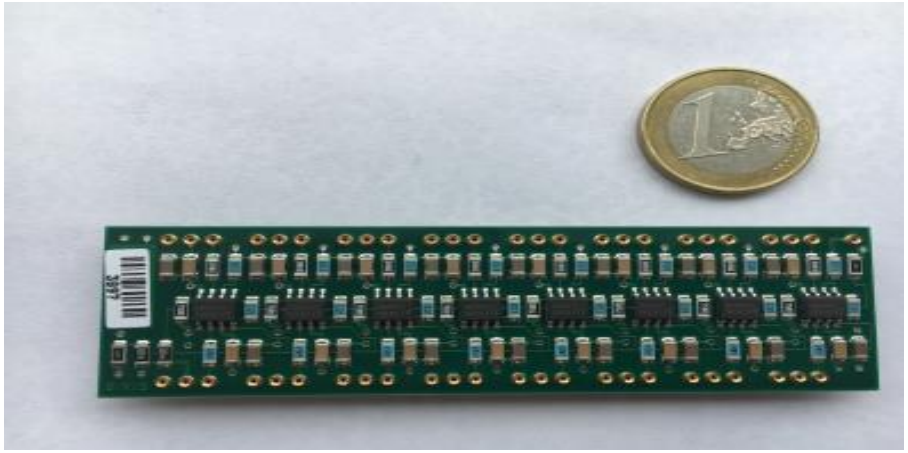


Installation status:

- All of the barrel LTDBs are already at CERN, and the large majority are installed (90%) (A-side is now complete)
- The endcap LTDBs are also at CERN and around 70% have been installed

Phase- I Front-End: Baseplane & LSB replacement

- Baseplane needed to be replaced in order to accommodate the demands of the new system:
  - Additional slots for the LTDBs
  - Route signals from the LSBs to the LTDBs
  - Route signals from the LTDBs to the TBBs
- The LSBs were replaced to be able to deal with the new sums provided by the supercells
- A total of 114 baseplanes and 2968 LSBs was needed

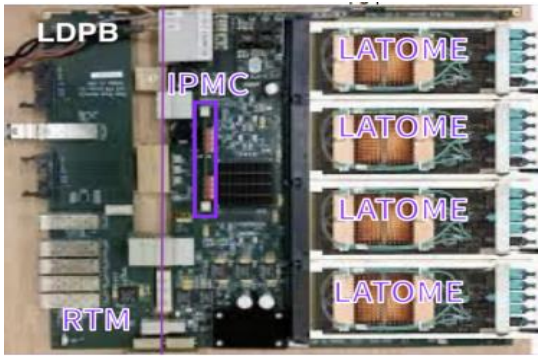


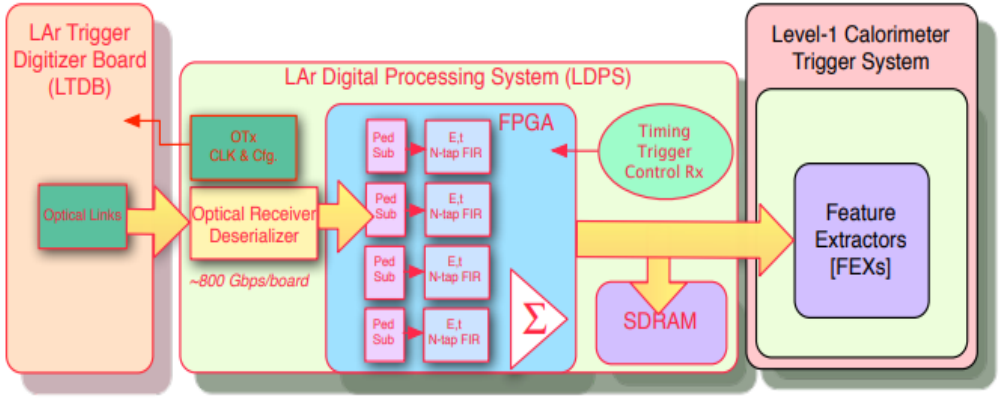
- Highly complex work as all FEBs had to be removed and refurbished
- Currently all new baseplanes and LSBs are already installed on the detector

LAr Phase-I Back-end: LDPB

Receives ADC from the LTDB, identifies bunch crossing and transmits them to the L1-Calorimeter trigger and and Data Acquisition system

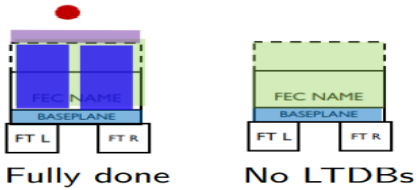
- Made up of a LAr Carrier (LArC) and four LAr Trigger PrOcessing MEzzanines (LATOME), as well as an Intelligent Platform Management Control (IPMC)
  - The IPMC manages sensor readings and the power of the boards, and acts as a safety mechanism



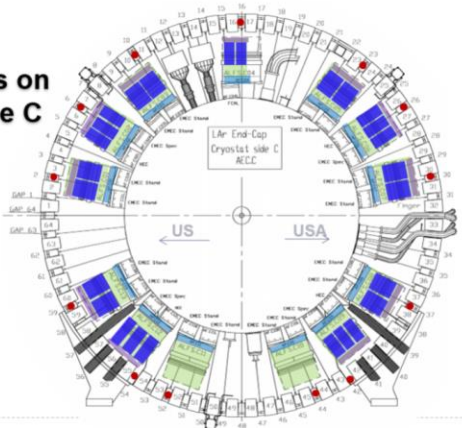


- 30 LArCs in total, with 116 LATOMEs, distributed across three Advanced Telecommunications Computing Architecture (ATCA) crate
- All LDPBs are already installed in ATCA crates, and the fiber connections to LATOMEs are still ongoing

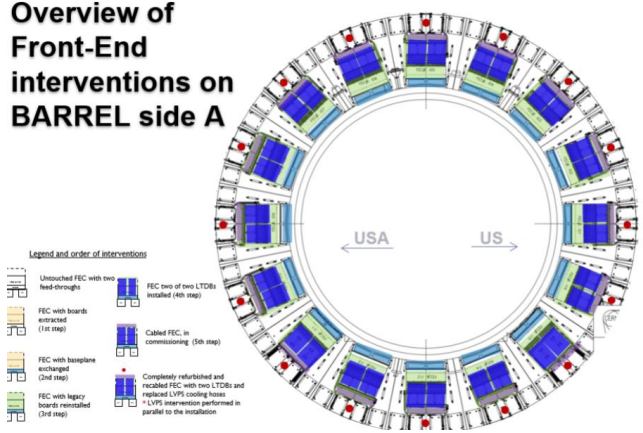
Front-End Installation Summary



Overview of Front-End interventions on ENDCAP side C

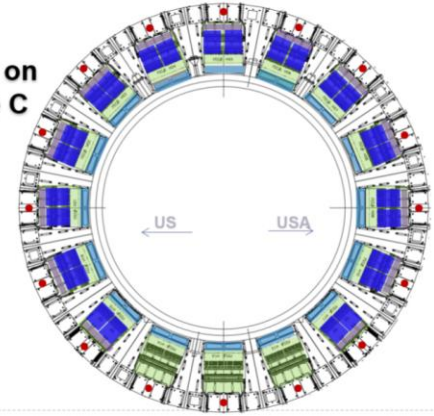


Overview of Front-End interventions on BARREL side A



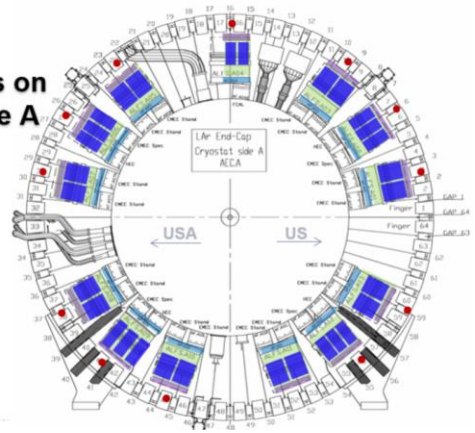
C-side still has two more crates to go

Overview of Front-End interventions on BARREL side C



A-side is now complete

Overview of Front-End interventions on ENDCAP side A



Back-End Installation Summary

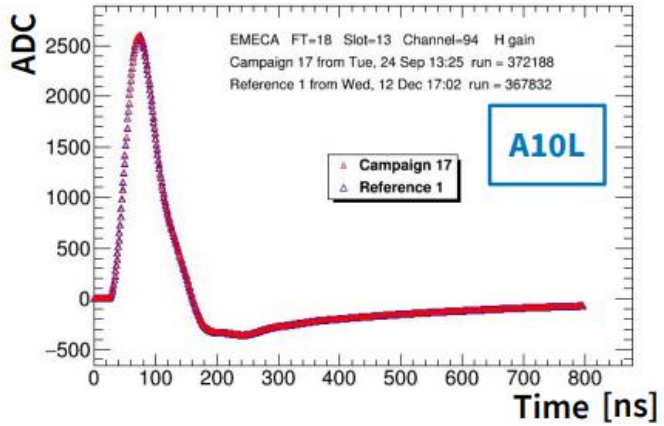
- Installation status closely follows that of the front-end (A-side already complete)
- 85% fiber from LTDB to LATOME connected, currently waiting for LTDB to be installed on the front end
- Monitoring and control system (DCS) in place, included in ATLAS control

ATCA Crate

Validation of the main readout path

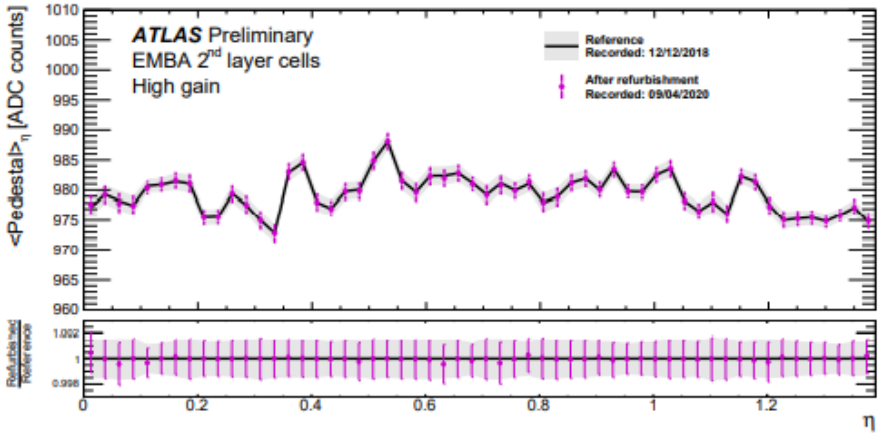
After replacing the LSB in the FEBs, need to verify that the calibration coefficients, pulse shape and noise level is consistent with previous values

- No significant changes observed in the calibration runs taken after the replacement

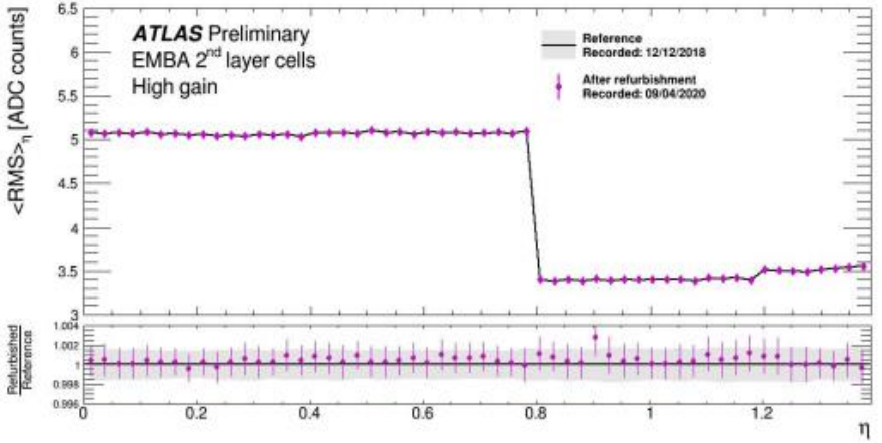


HFEC pulse shape

Pedestal value



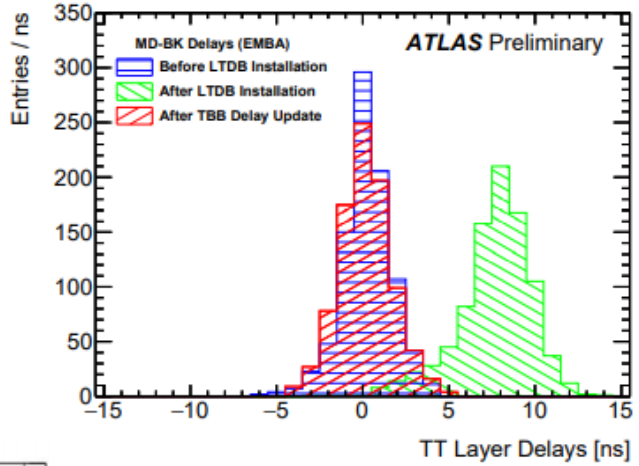
Noise level

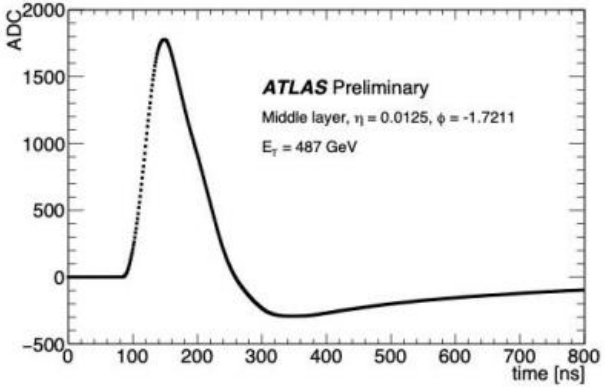


Validation of the legacy & digital trigger path

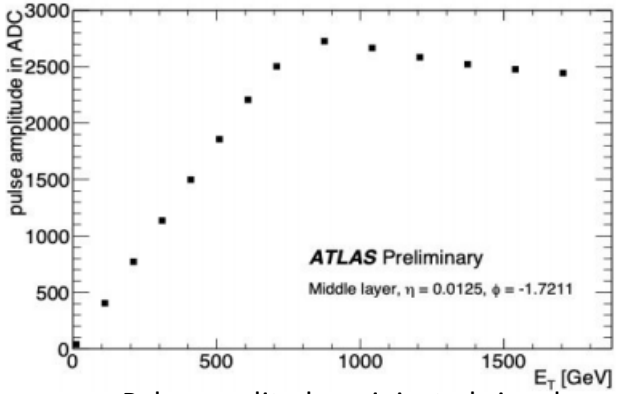
The legacy analog layer sums are now routed through the LTDB for some layers before arriving to the TBB

- The extra path length means the layers needs to be re-timed such that the signals arrive at the same time in the TBB
- Corrections to the TBB timing derived through the use of timing scans, currently done for the Barrel-A (Endcap A is in progress)





Pulse with the new digital trigger



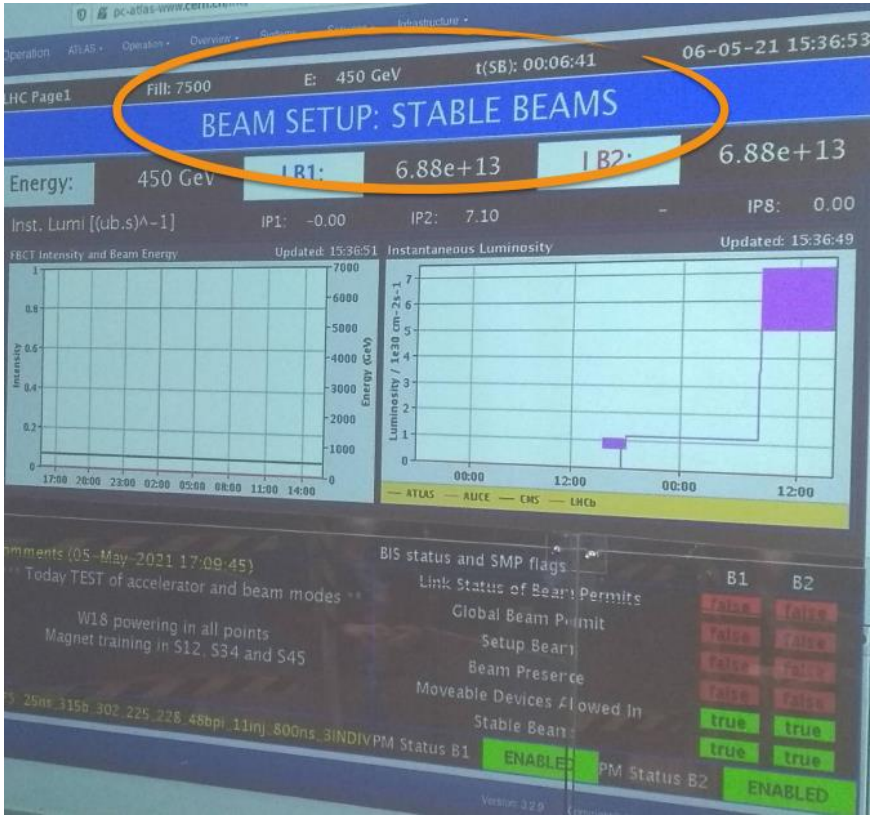
Pulse amplitude vs injected signal

Take data with the digital trigger enabled and verify the results:

- Validation of the LATOME energy computation by comparing to the offline energy
- Allows for validation of the full phase-I Front & Back end path
- Saturation at 700 GeV for supercells (255 for legacy)

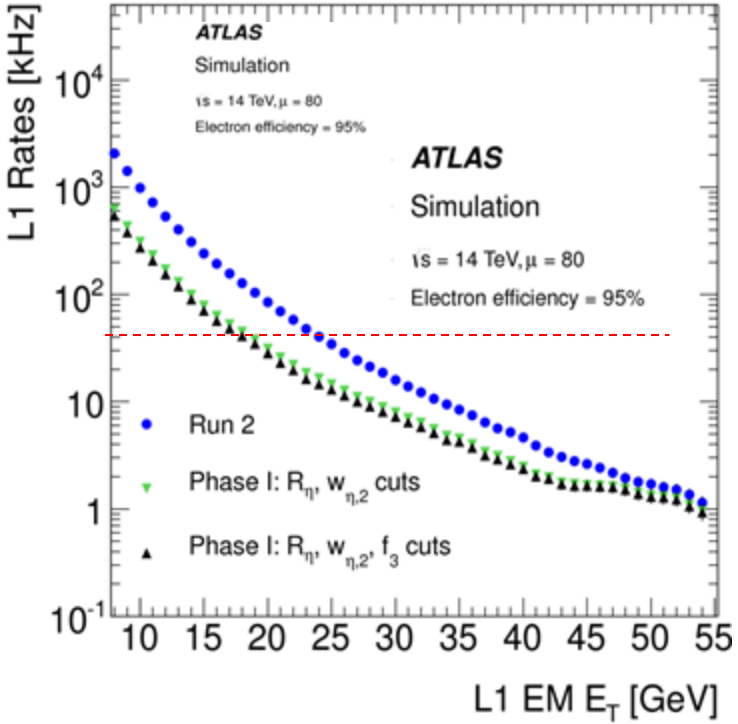
Conclusions and future plans

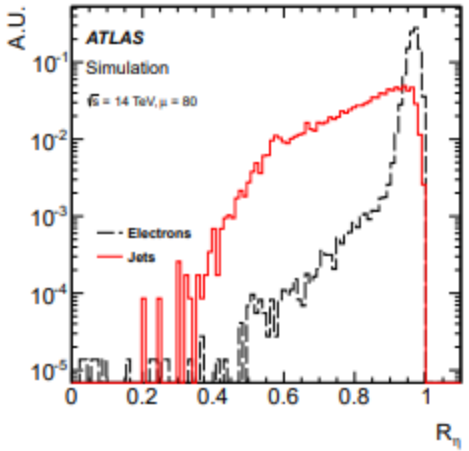
- Despite the ongoing pandemic and the delays it brought, installation is on track for October's pilot run and the start of Run-3:
  - A-side front and back end is finished and has mostly been validated barring some checks on the legacy trigger path
  - C-side is close to being done, and should be finished within the next month
  - Digital trigger Integration with ATLAS has been tested during various mock running situations and is progressing as expected

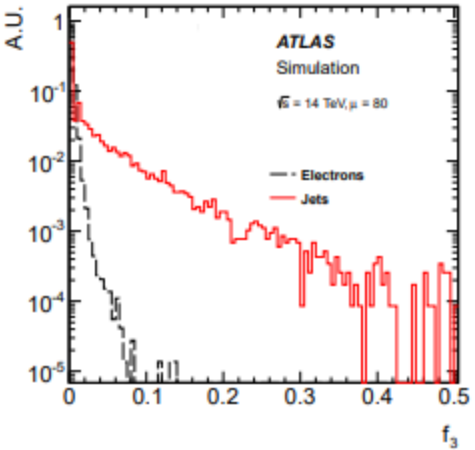


BACKUP SLIDES

Motivations for LAr Phase-I Upgrade



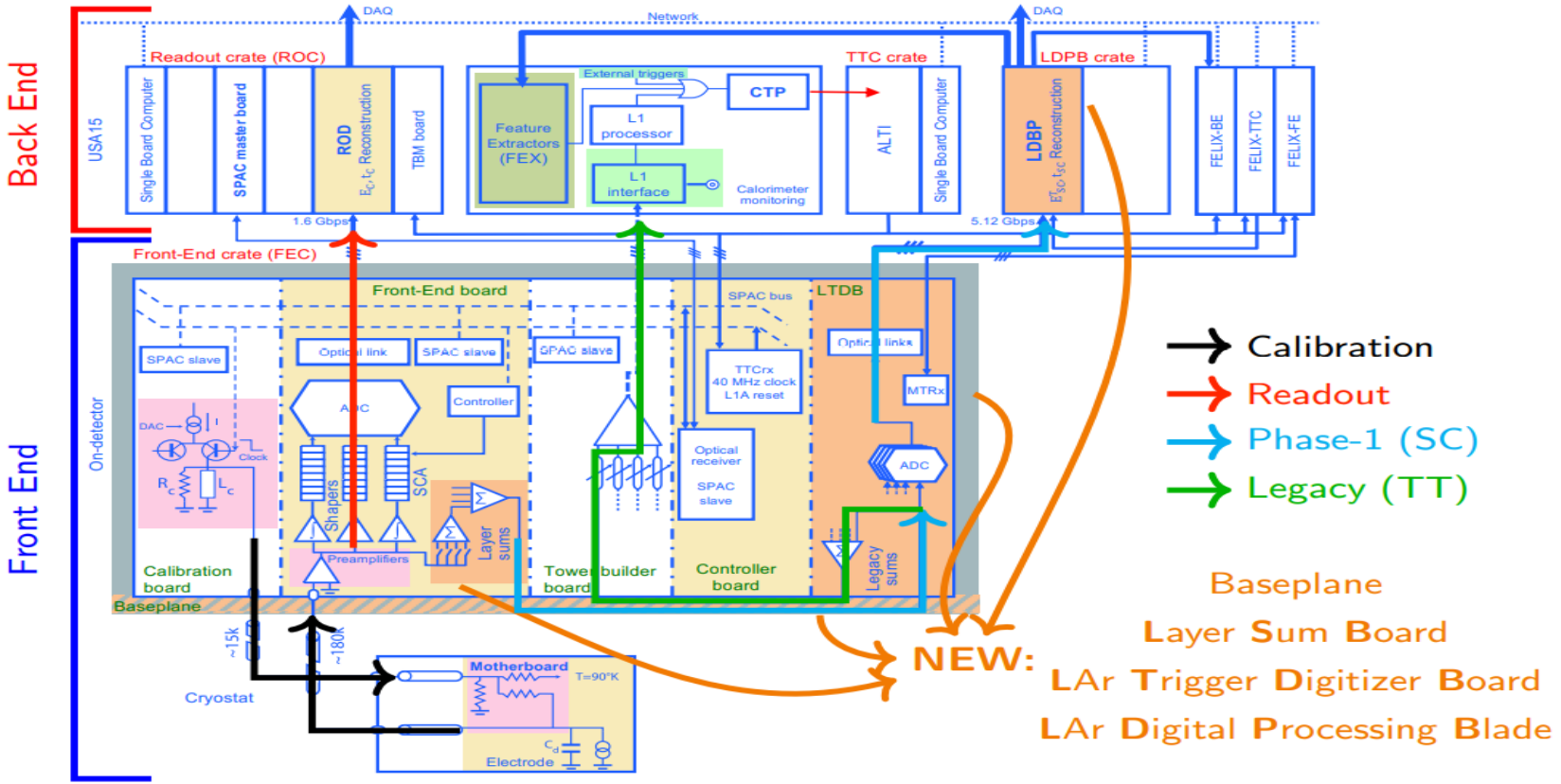




Shower shape variables

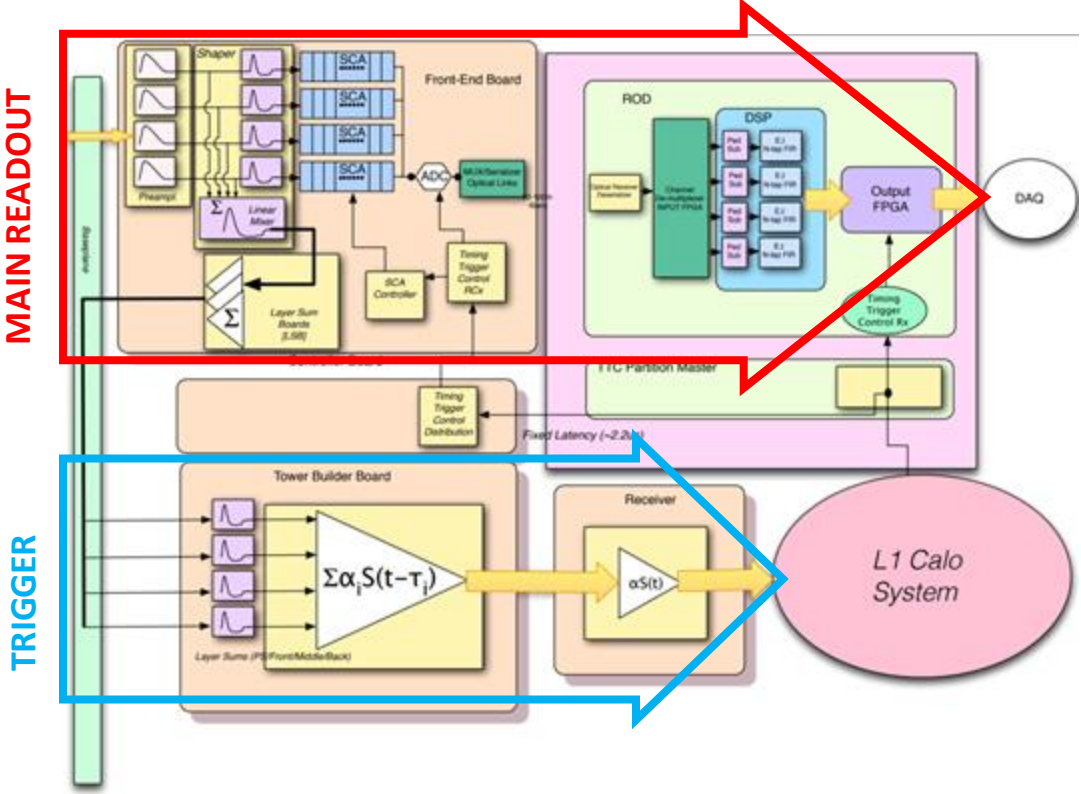
e.g. for a target L1 EM rate of 20 kHz, ~7 GeV lower ET thresholds if we use shower shape information w.r.t the Run 2 system

LAr digital trigger overview



Pre-Phase-I LAr readout electronics

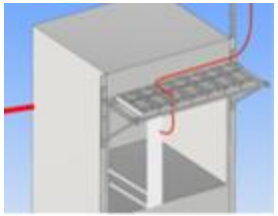
- **Main readout (FEBs)** sends digital samples (ADCs) of the shaped and amplified LAr ionization signal to the LAr back-end (RODs)
- FEBs also perform **analog sums of the cells in same layer for each trigger tower**
- Those analog sums are routed through the **baseplane** to other boards in the crates (Tower Builder Boards – TBBs)

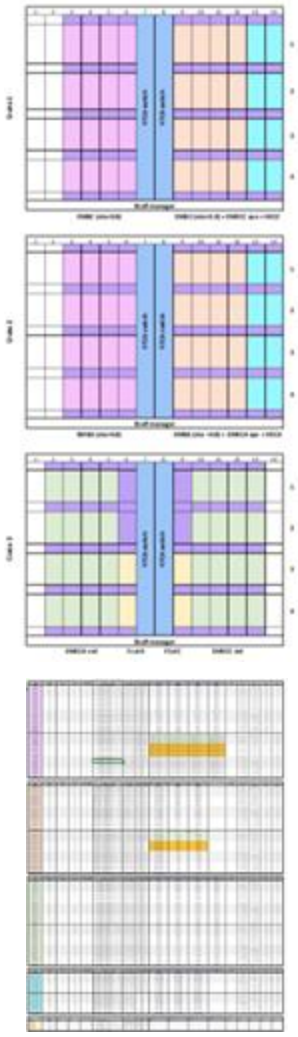


- The TBBs *build the **analog** trigger tower sums* from the four layer sums to make the TT energy sum and route it through thick cables to the *receivers* **for triggering**

Installation USA-15

- Lots of fiber routing from UX15
- Lots of fibers in USA15 (TTC, LTDB control, Felix…)
- PC installations, network….

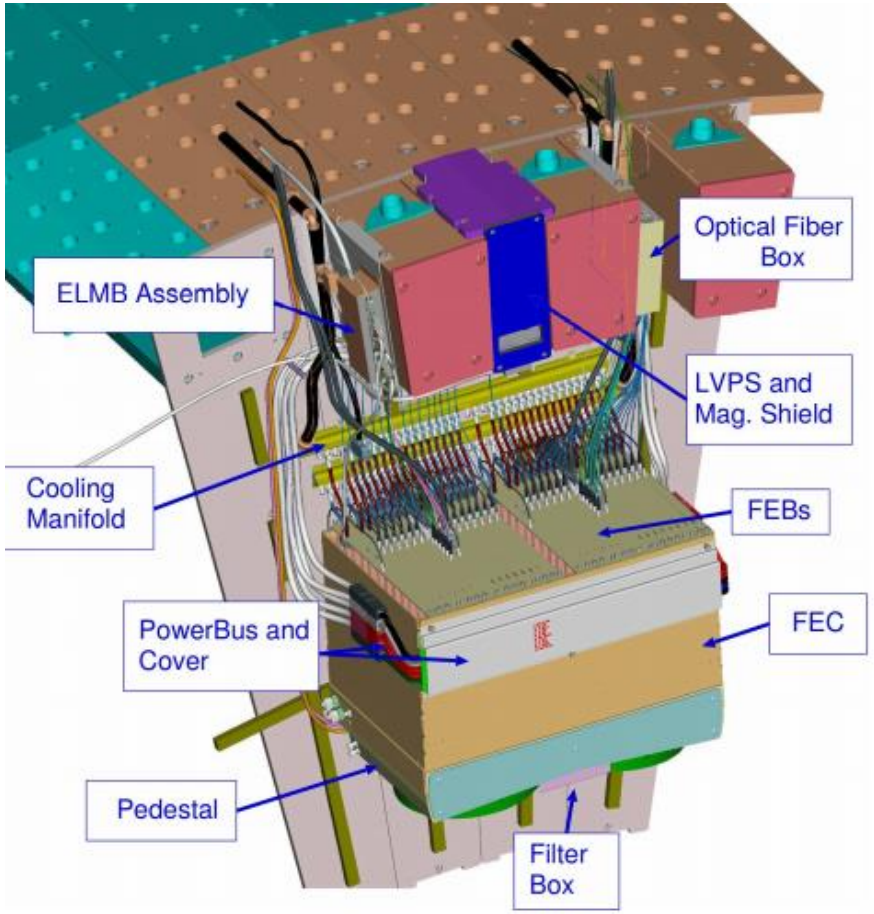




Front-End Crates

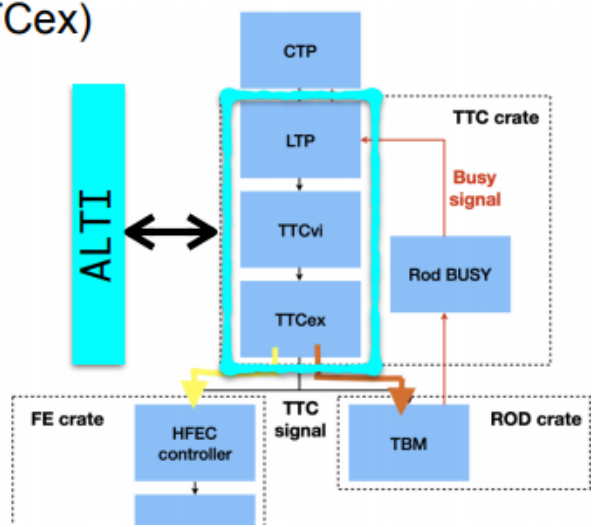
Contain most of the front-end electronics for readout and trigger:

- 116 Half Front-End crates (HFECs)
- Each HFEC contains a full set of boards (FEBs, Calibration, TBBs, controller)
- A total of 1524 FEBs, each covering one of the calorimeter layers (Presampler, Front, Middle and Back)



ALTI Migration

- **ALTI boards to replace 3 legacy TTC boards** (LTP, TTVvi & TTCex)
  - Distribute TTC signal for physics & calibrations
  - Offer more reliability and flexibility in operating the system
- **Installed ALTI boards on EMBA & EMBC**
  - ✓Calibration data w/ ALTI are consistent with those w/ LTP
  - Causality issue in sending pulse vs. issuing L1A results in calibrations runs failing sometimes, show-stopper in the long run => ALTI experts working on it



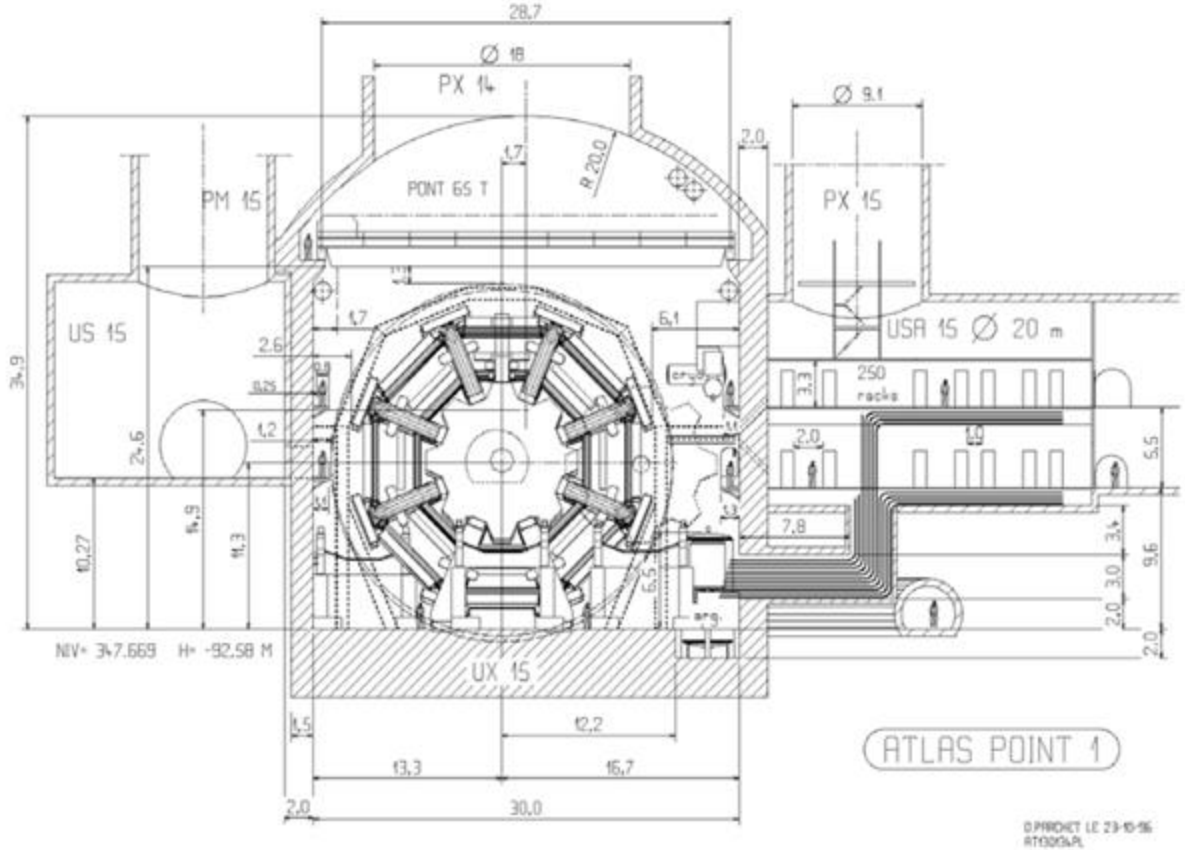


Figure 2. Cross section of the ATLAS experimental hall UX15, the electronics cavern USA15 and the US15 hall.

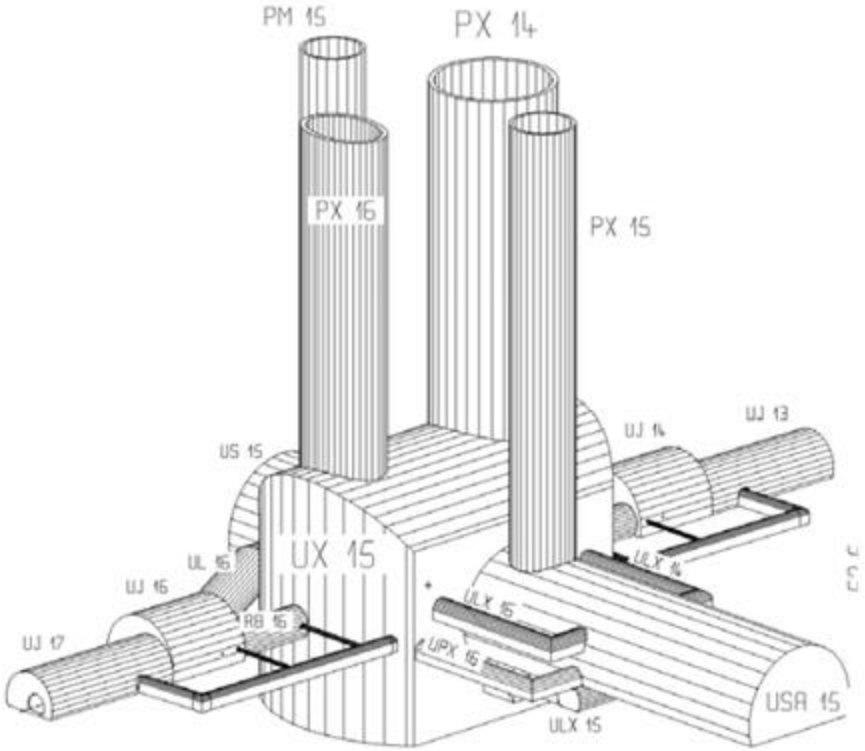
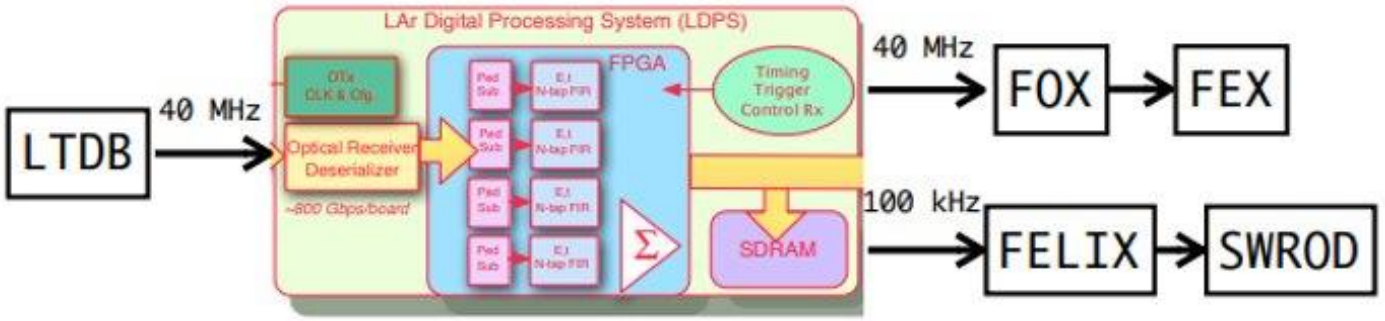
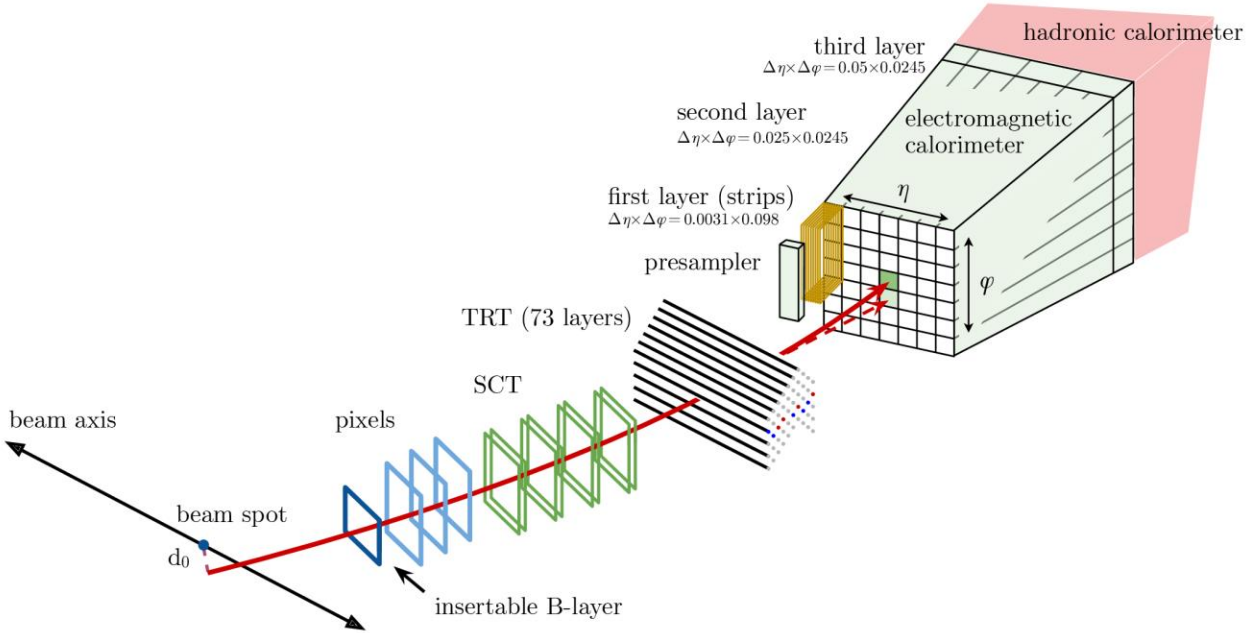


Figure 1. The caverns, access shafts and service tunnels that surrounds the ATLAS experimental cavern (UX15).


LAr Digital Processing System (LDPS)
LTDB
40 MHz
Optical Receiver Deserializer
~800 Gbps/board
FPGA
Timing Trigger Control Rx
SDRAM
40 MHz
FOX
FEX
100 kHz
FELIX
SWROD


hadronic calorimeter
third layer
$\Delta\eta\times\Delta\varphi = 0.05\times0.0245$
second layer
$\Delta\eta\times\Delta\varphi = 0.025\times0.0245$
electromagnetic calorimeter
first layer (strips)
$\Delta\eta\times\Delta\varphi = 0.0031\times0.098$
presampler
η
φ
TRT (73 layers)
SCT
pixels
beam axis
beam spot
d_0
insertable B-layer


LAR racks
Run Control
Private readout
DCS
ATCA with LDPBs
FELIX for LTDB config.