Commissioning the Phase-1 LAr Upgrade

ATLAS
EXPERIMENT

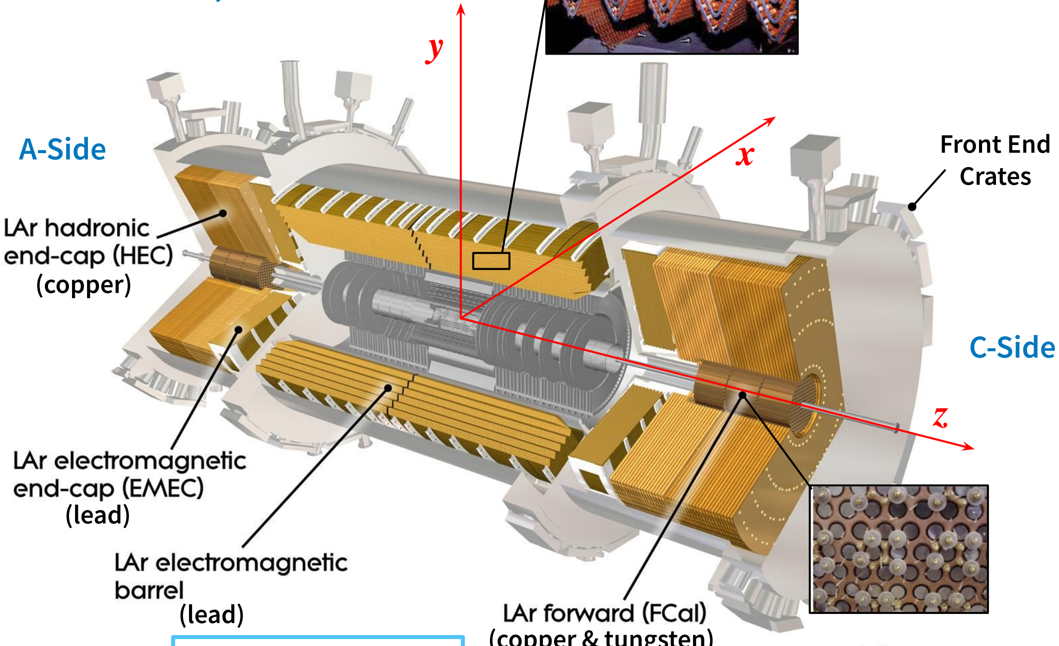
Ellis Kay - The University of Victoria

On behalf of the ATLAS Liquid Argon Calorimeter Group

University of Victoria

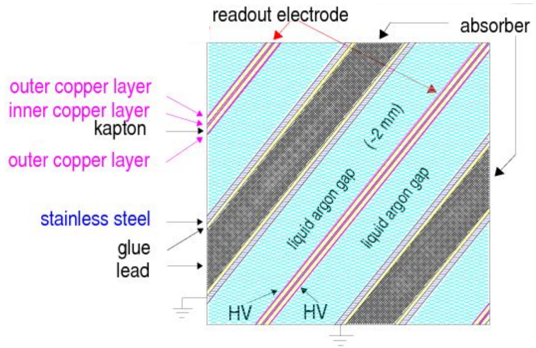
The Liquid Argon Calorimeter

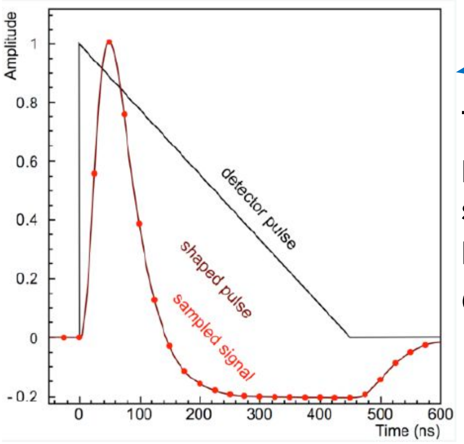
- Liquid Argon (LAr) sampling calorimeter with fine granularity & full coverage in ϕ
  - ~180,000 channels



CERN-LHCC-96-041

$$\eta = -\ln\tan\left(\frac{\theta}{2}\right)$$



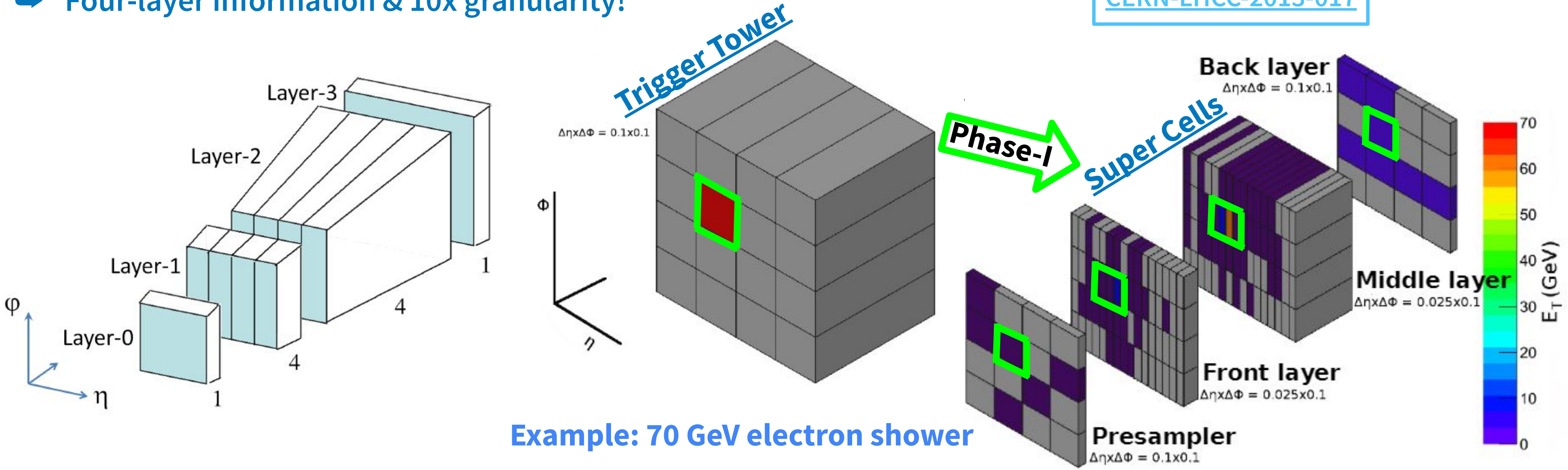


Triangular ionisation pulse amplified & shaped (CR-RC^2), bipolar shape sampled @ 40 MHz

Upgrade Motivation: Super Cells

- Instantaneous luminosity and pileup will increase for Run 3, while L1 rate stays the same
  - Need to improve background rejection at trigger level
- Currently cells in different calorimeter layers are grouped into 5.4k trigger towers $\Delta\eta\times\Delta\phi = 0.1\times0.1$
  - Shower shape information is lost, cannot be used as discriminating variable
- Phase I upgrade will group cells into ~34000 ‘Super Cells’ (SCs)
  - Four-layer information & 10x granularity!

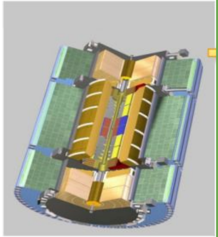
CERN-LHCC-2013-017



Example: 70 GeV electron shower

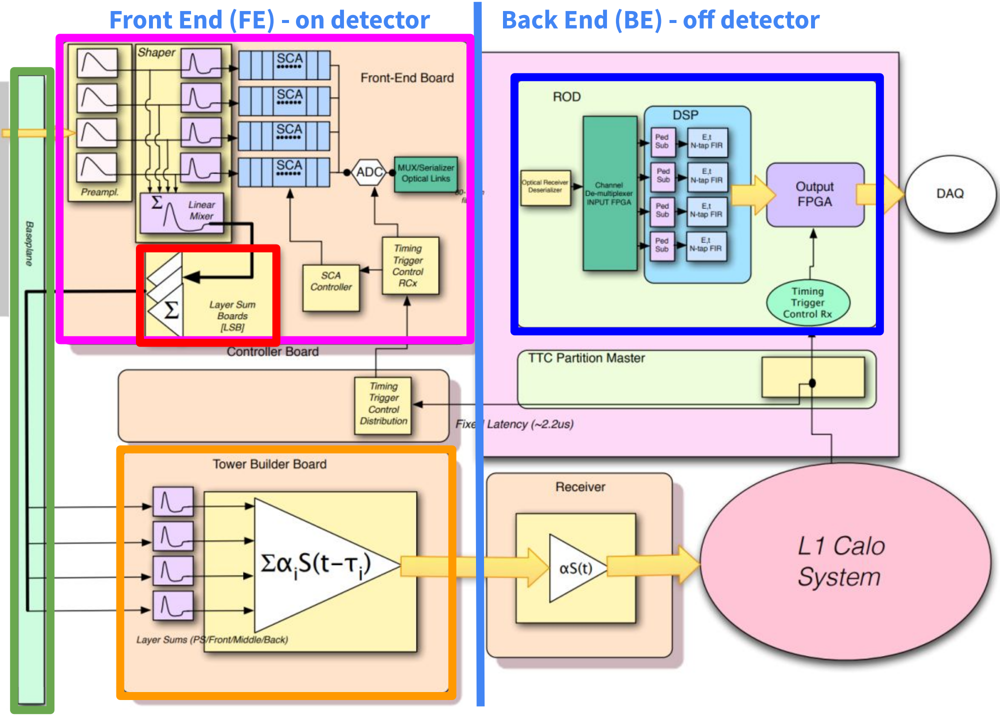
LAr Electronics Schematic

- Front End Boards (FEBs) send digital samples (ADCs) of the shaped & amplified LAr ionization signal to the back-end (Readout Drivers, RODs)
  - Also perform analogue sums of the cells in same layer for each Trigger Tower with Layer Sum Boards (LSBs)

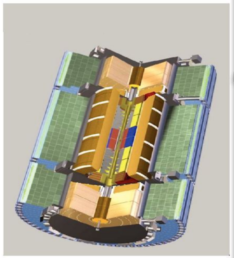


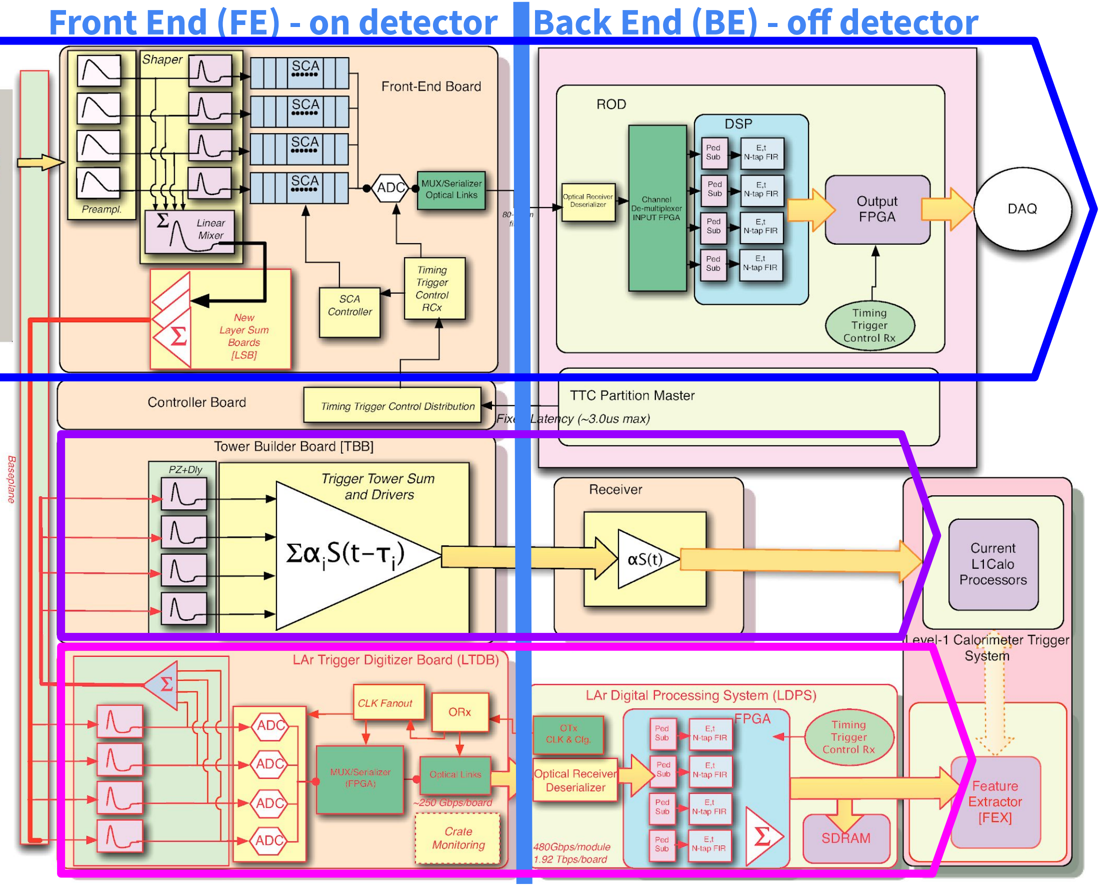
- Analogue sums are routed through the baseplane to Tower Builder Boards, TBBs

- TBBs use the analogue sums from each of the four calorimeter layers to build the Trigger Tower (TT) energy sum, then route it to lowest level trigger (L1Calo) receivers for triggering



Phase-I Schematic





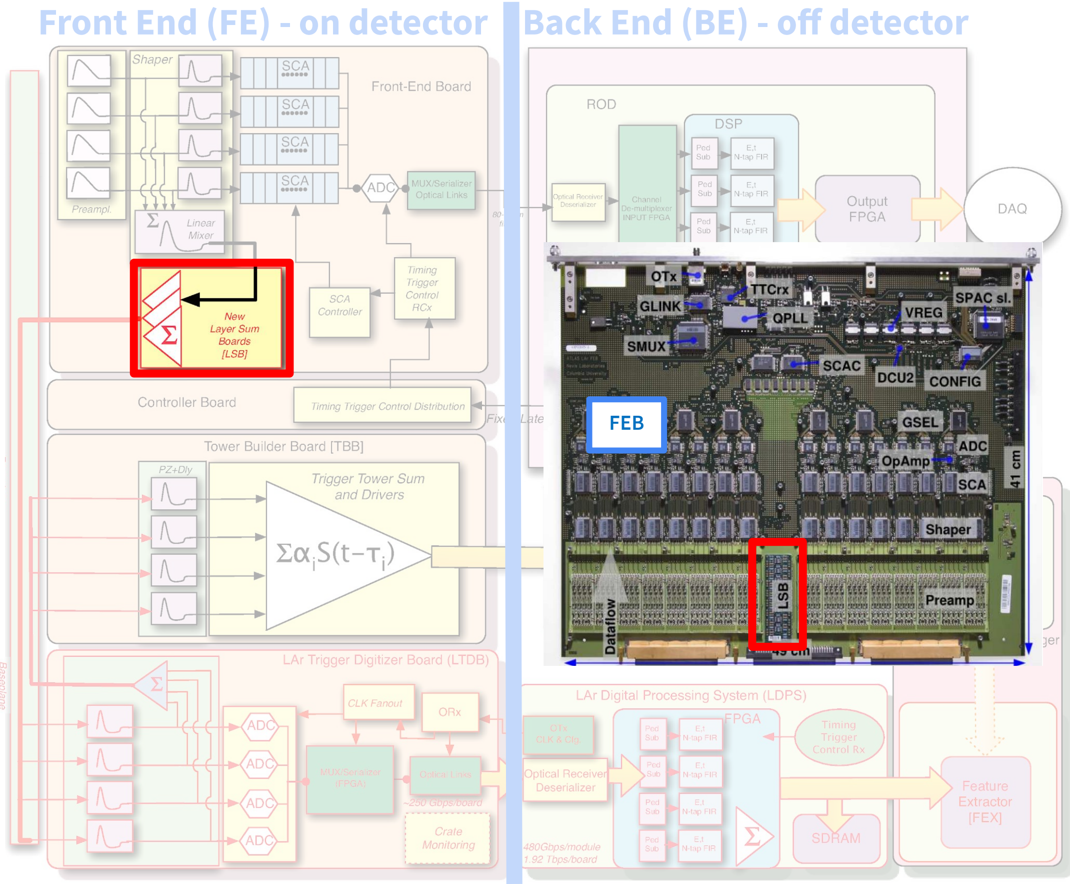
- ➡ Changes, shown in red, must be made to meet the demands of the increased granularity of the new trigger system
- ➡ The legacy system is still maintained
  - ➡ Both systems should work concurrently
- ➡ Compatible with phase-II plans
  - ➡ See phase-II poster this week

Layer Sum Board Replacement

- Layer Sum Boards (LSB): mezzanine board on the FEB, sums signals of calorimeter cells in each layer
- Super Cells (SCs) require finer sums than the old trigger towers
  - Must exchange LSBs on FEBs
- Every FEB must be removed from the cavern and refurbished
  - Cooling plates replaced with newly manufactured ones
  - Simultaneously replacing ageing cooling hoses on all FEBs (as well as LVPS)

STATUS

☑ All LSBs replaced
☑ All cooling plates & hoses replaced

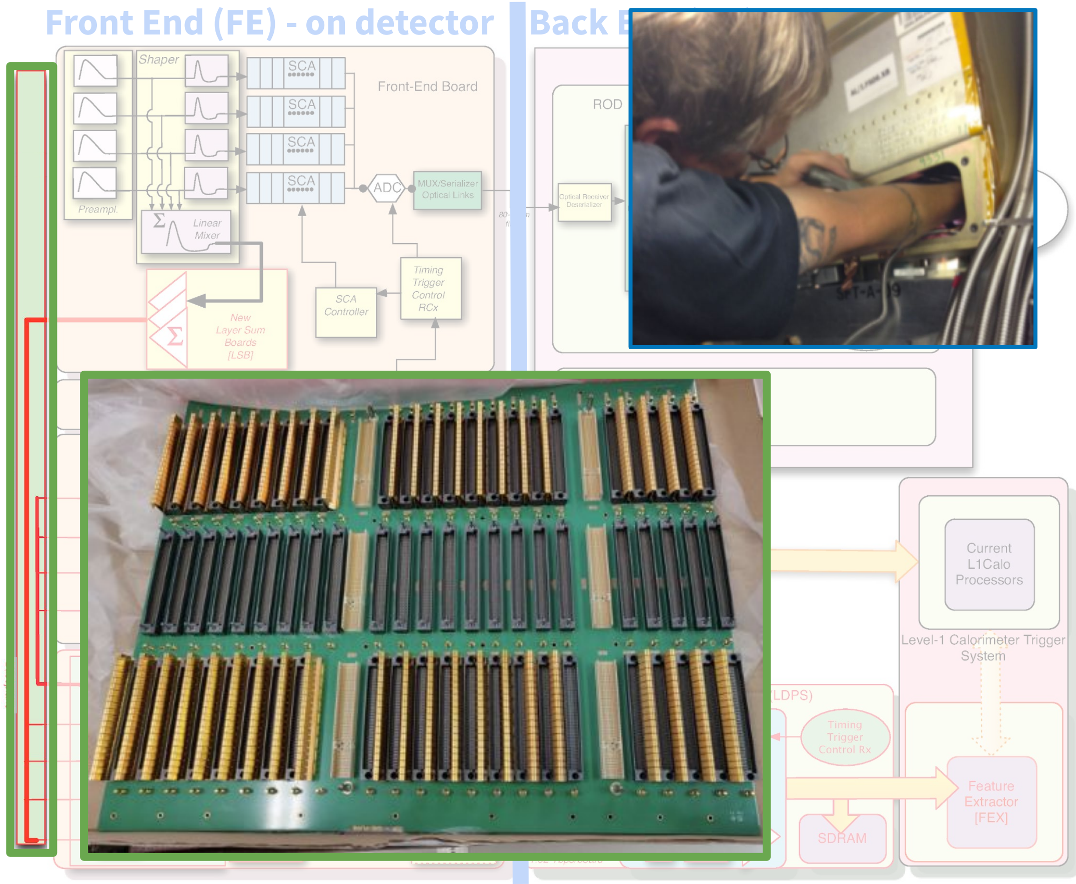


Baseplane Replacement

- ➟ New baseplanes are needed to meet the demands of the upgraded system
  - ➥ Additional slot for the new LAr Trigger Digitiser Board (LTDB)
  - ➥ Routing SC sums LSB → LTDB
  - ➥ Routing legacy sums LTDB → TBB
- ➟ Replacement is complicated work in a restricted space
  - ➥ Requires removal of all boards first

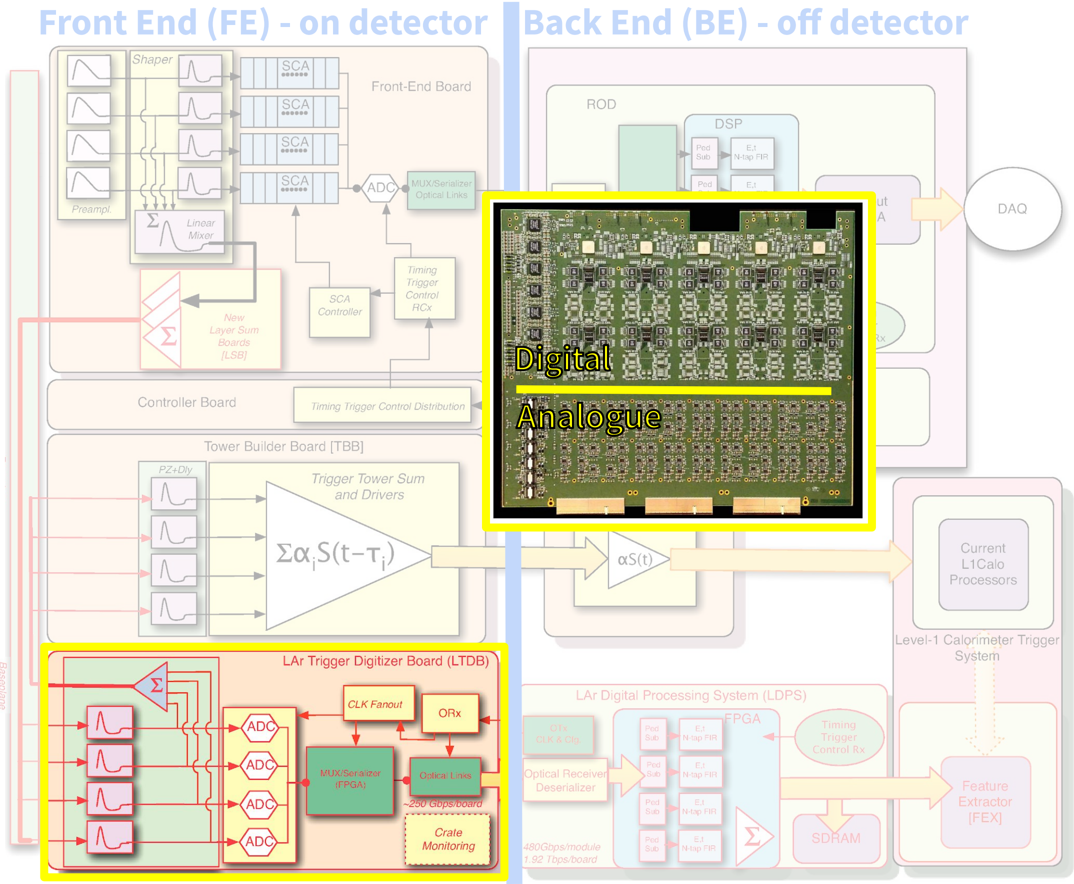
STATUS

☑ All baseplanes are complete & installed on the detector



LAr Trigger Digitiser Board Installation

- LAr Trigger Digitiser Board (LTDB): NEW board, digitises SC signals & sends them to phase-I back-end, reroutes layer sums to legacy trigger readout path
    - 124 LTDBs in total, processing up to 320 SC signals each
    - 7 ‘flavours’ depending on location: 1 for barrel, 6 for end-cap

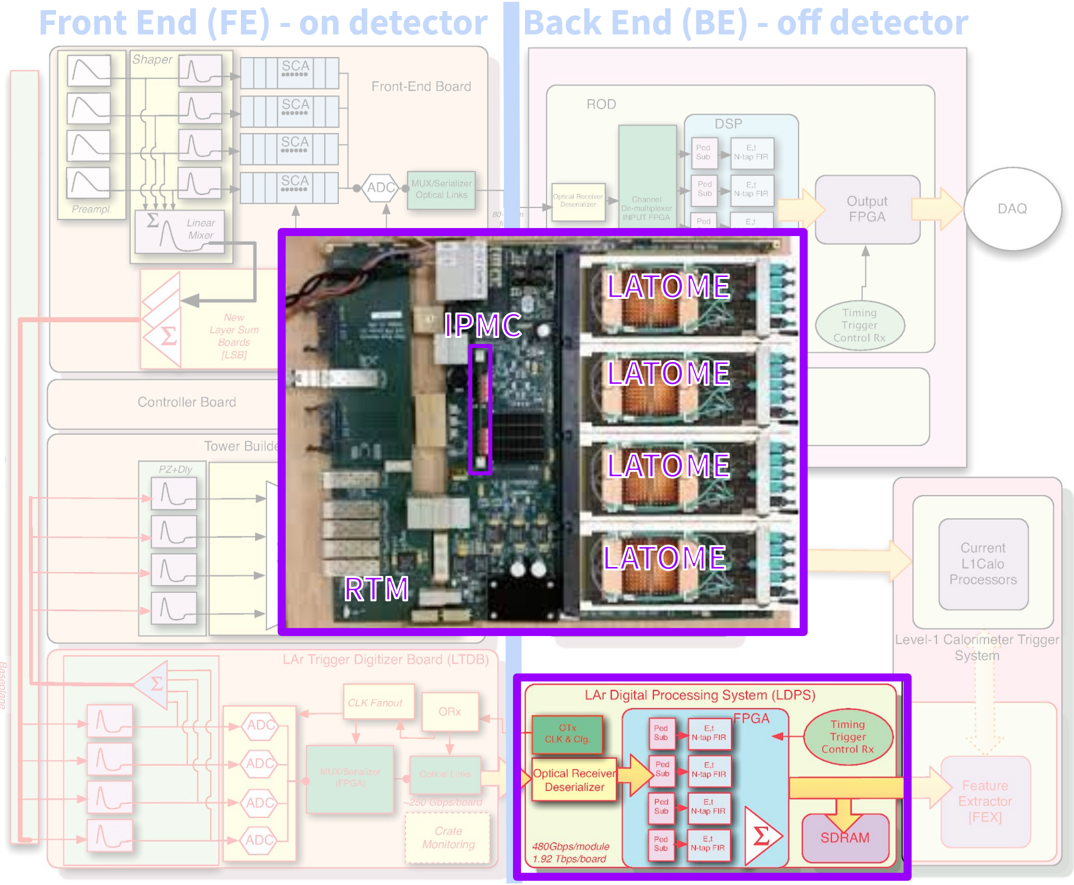


STATUS

- ☑ All barrel LTDBs are manufactured, tested & at CERN, ~90% are installed (pending access)
- ☐ All end-cap LTDBs are manufactured & undergoing tests, ~70% are installed

LAr Digital Processing Blade

- LAr Digital Processing Blade (LDPB): reconstructs deposited energies & transmits them to L1 calorimeter trigger system (@ 40 MHz) and TDAQ system (@ 100 kHz)
  - Consists of a LAr Carrier (LArC) and 4 LAr Trigger prOcessing Mezzanines (LATOMEs)
  - 30 LArC in total, with 116 LATOMEs
  - Distributed across 3 ATCA crates

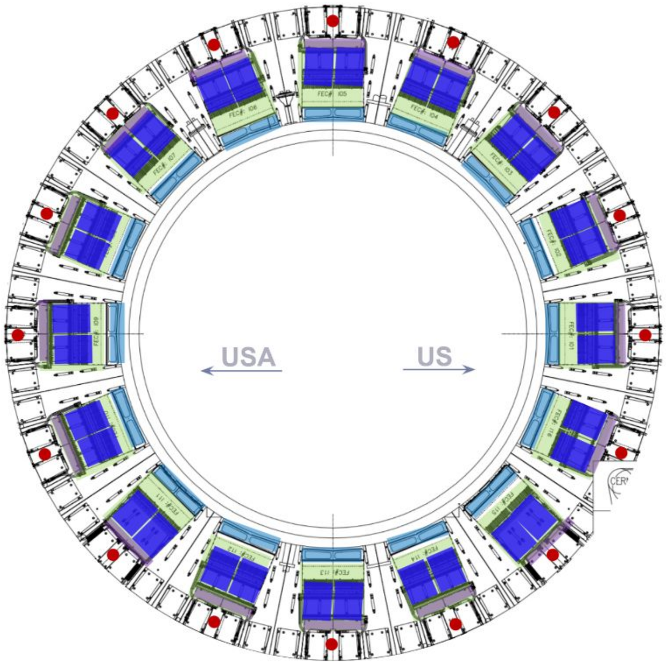


STATUS

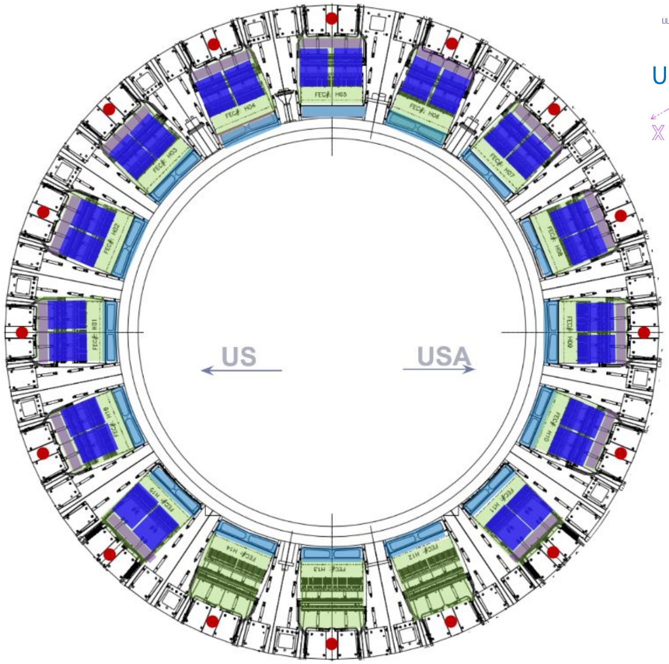
- ☑ All LDPBs installed in ATCA crates
- ☐ Fibre connection to LATOMEs proceeding alongside LTDB installation

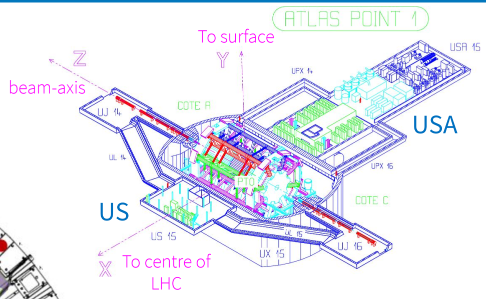
Installation Status: Barrel

A Side



C Side

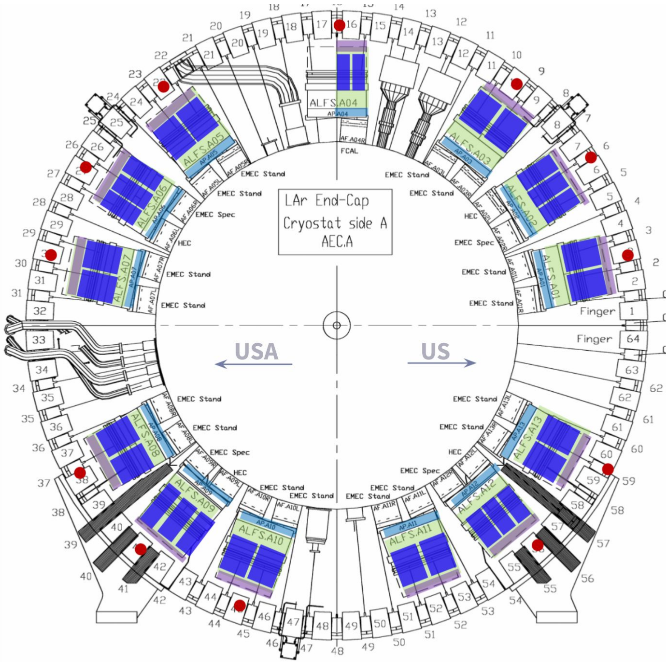




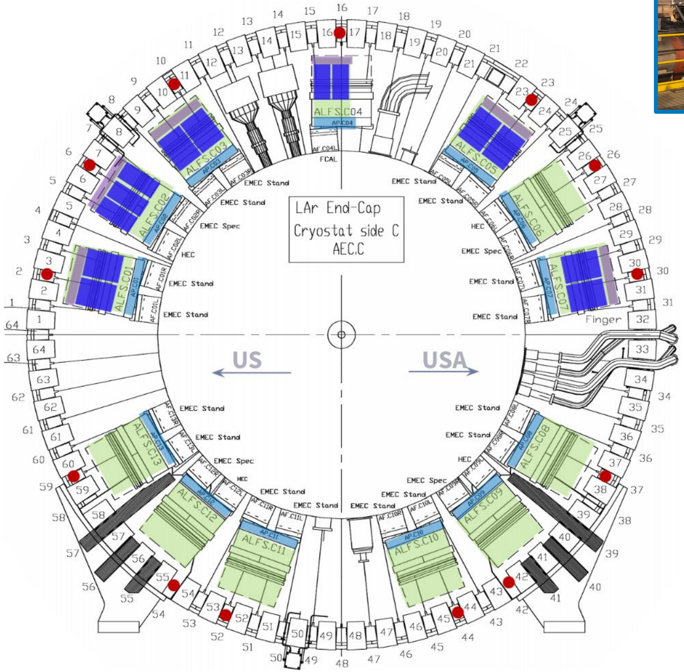
- Baseplane exchanged
- Re-cabled for commissioning
- Boards reinserted
- LTDB installed
- LVPS cooling hose replaced

Installation Status: End-Cap

A Side



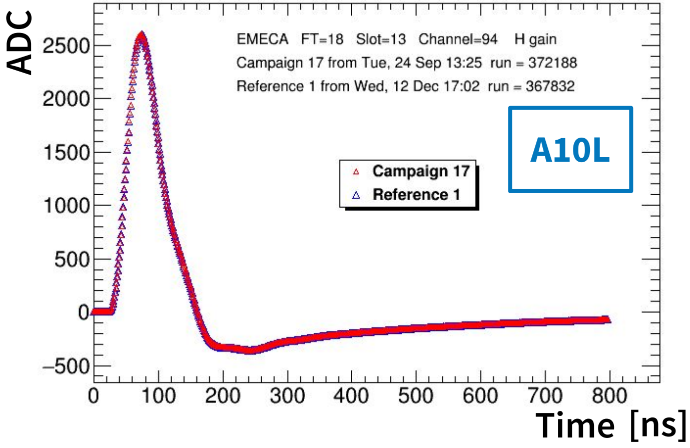
C Side

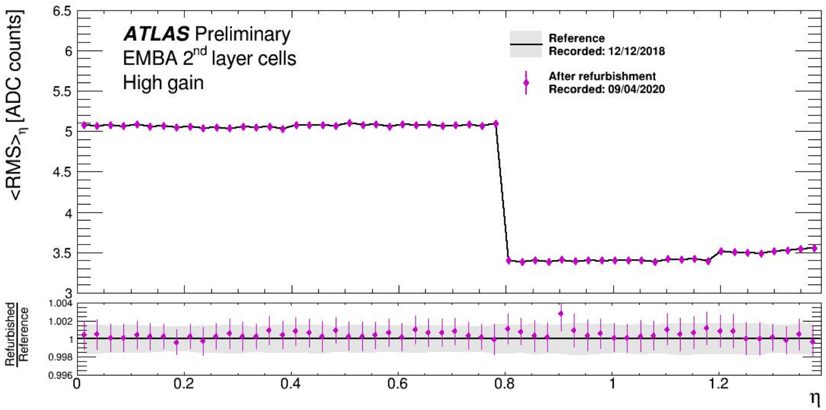


- Baseplane exchanged
- Re-cabled for commissioning
- Boards reinserted
- LTDB installed
- LVPS cooling hose replaced

Main Readout Path Validation

- Validation of refurbished crates (FEBs with exchanged LSBs & new baseplanes)
  - Not all FEBs were returned to their original position
- Starting with low level checks - ‘ping’ & connectivity scans
- Take regular set of calibration runs, compare results to reference runs taken at the end of run-2
  - Pedestal: read detector output with no input signal → noise (from RMS), autocorrelation
  - Delay: pulse with an increasing time delay → full pulse shape
  - Ramp: inject signals of increasing current (DAC) → gain slope from DAC vs ADC fit

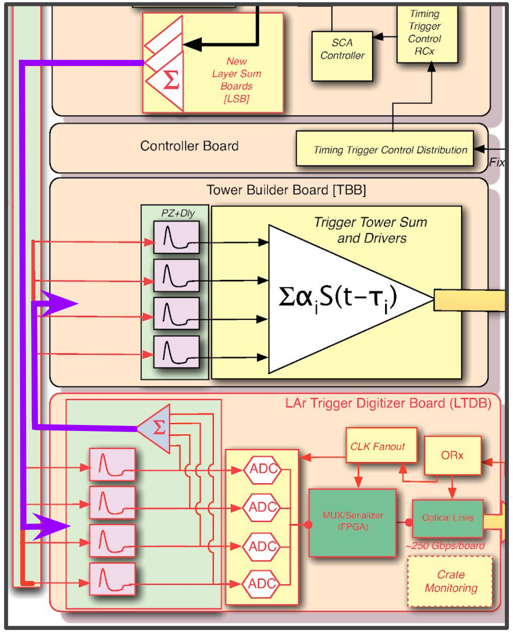




Legacy Trigger Path Validation

- Must ensure that the LSBs & baseplanes are correctly installed, with LTDBs routing <u>some</u> of the legacy analogue sums to the TBBs

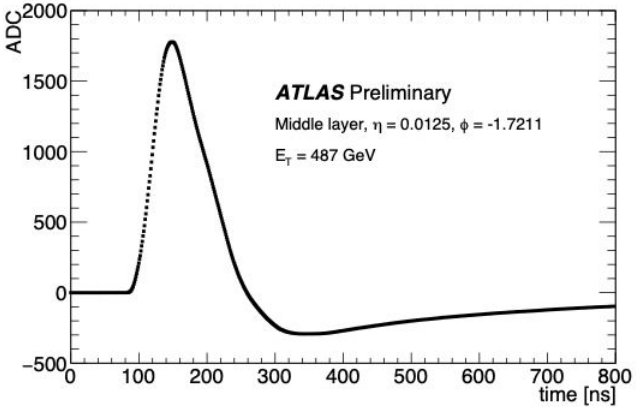
- Use L1Calo+LAr gain & timing scans to check connectivity, measure delay between sums from different layers
  - No major issues found so far, scans taken regularly with the installation of each LTDB
  - Timing scans give expected results: up to 10 ns timing difference between some layers, attributable to the increased path through the LTDB
  - Delays are updated for the TBBs based on the results of these scans

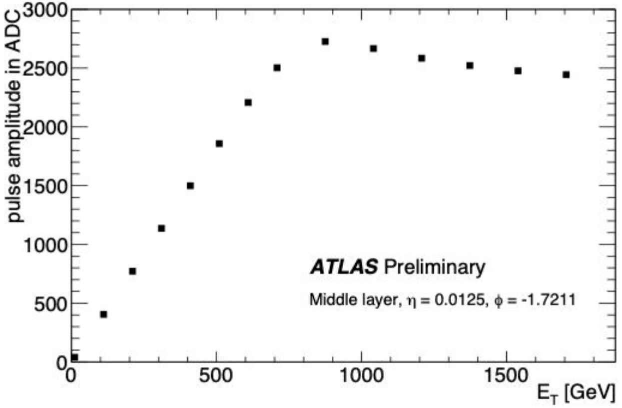


Digital Trigger Path Validation

- Validate data from the full phase-I front-end & back-end path
- Configure LTDBs & LDPB to take data
- Overnight pedestal/pulsed runs to monitor stability of the system
  - Automatically plot pedestal value / peak sampling / RMS of peak etc. for each enabled LATOME
- Full pedestal, delay & ramp sets
  - Obtain calibration constants which are used for energy reconstruction
  - Compute energy (E_T) offline & compare this to E_T computed by LATOMEs

$$E_T = \sum_{i=1}^{4} a^{(5-i)}(data_i - Pedestal)$$





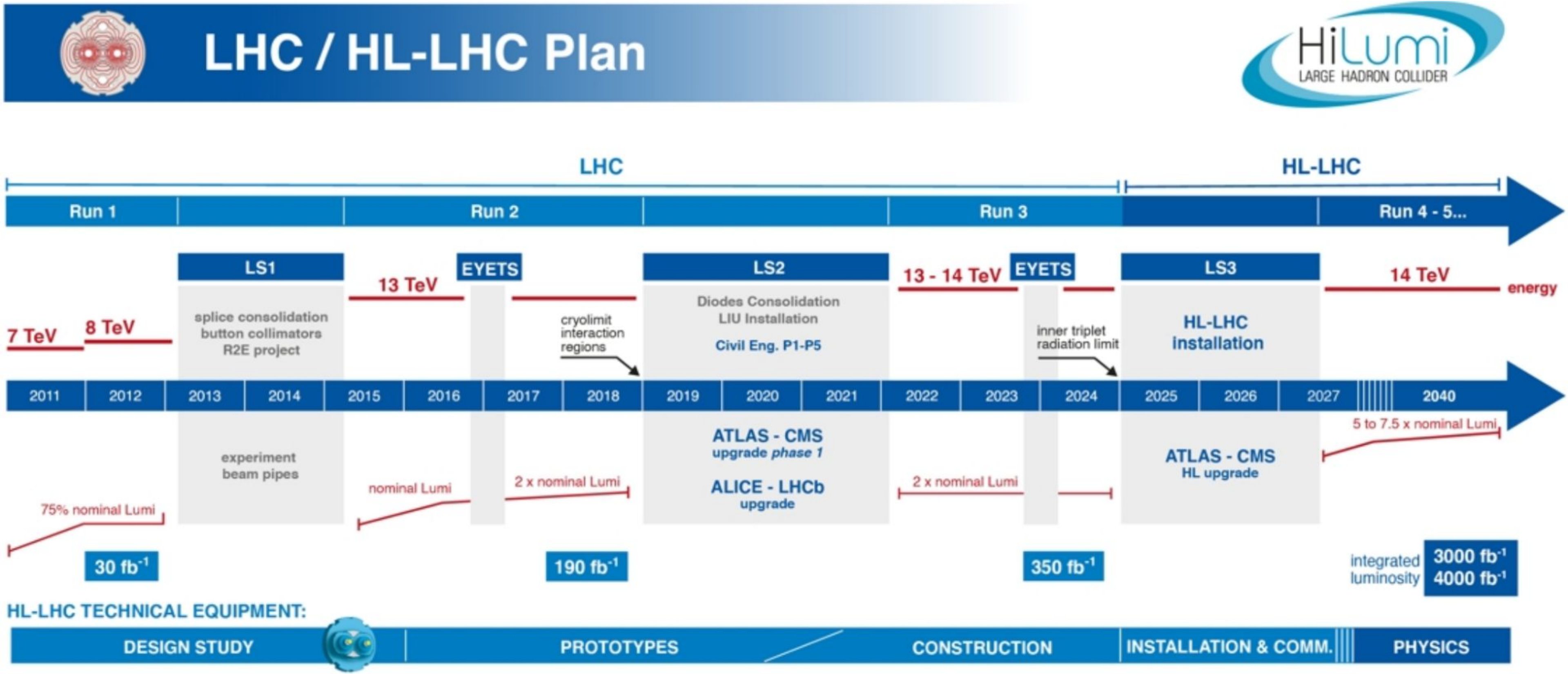
Conclusions & Next Steps

- Excellent progress has been made in the LAr installation, despite the challenges brought by the ongoing pandemic
  - All FEBs refurbished, all baseplanes installed, all LTDBs manufactured and most installed
  - All LDPB installed in ATCA crates, fibre connections & front-end installation happening in parallel
- The main readout path is validated immediately as crates go online
  - So far our system is stable! No major deviations from end of run-2
- Working with L1Calo experts, the legacy trigger is checked now that new LTDBs participate in this path for some layers
  - Observe the expected timing differences in these cases, apply delays accordingly & recover layer-layer timing
- Taking calibration runs for the new phase-I hardware, reading out supercell data
  - Checking connectivity, mapping of SCs, calibration constants, energy… established automatic processing of data & threshold values/criteria for validating crates

Will use these tools to sign off all installed crates & prepare for some real data in upcoming pilot runs and Run 3 from March next year!

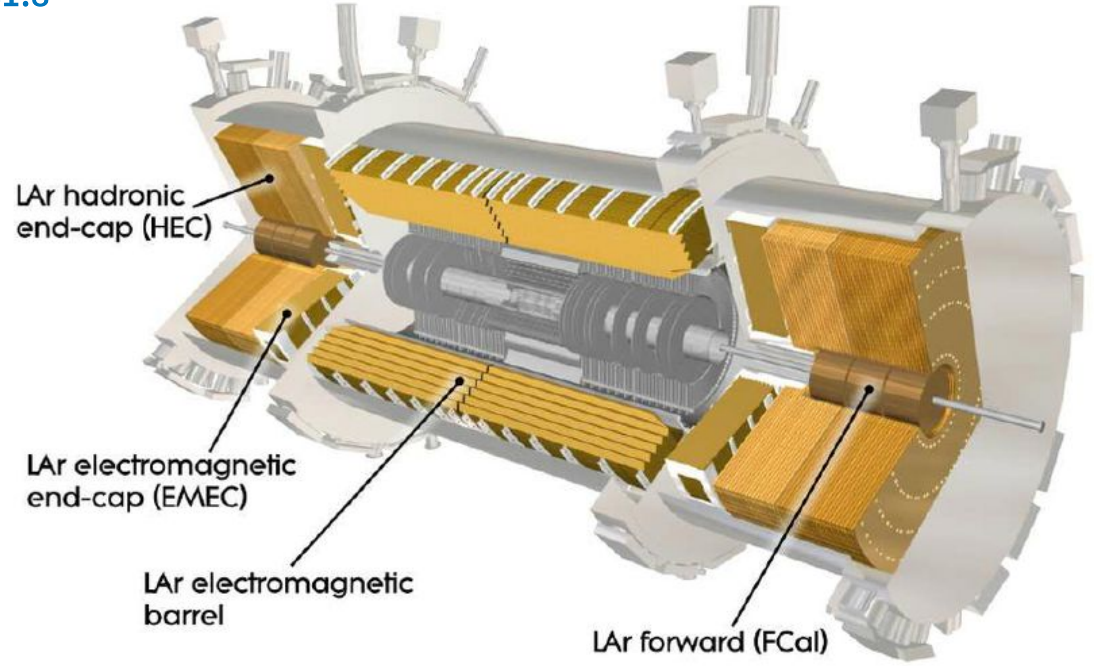
Backup

LHC Schedule



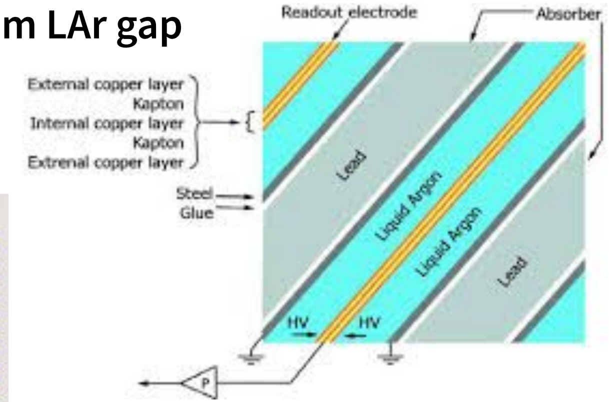
Liquid Argon Calorimeter

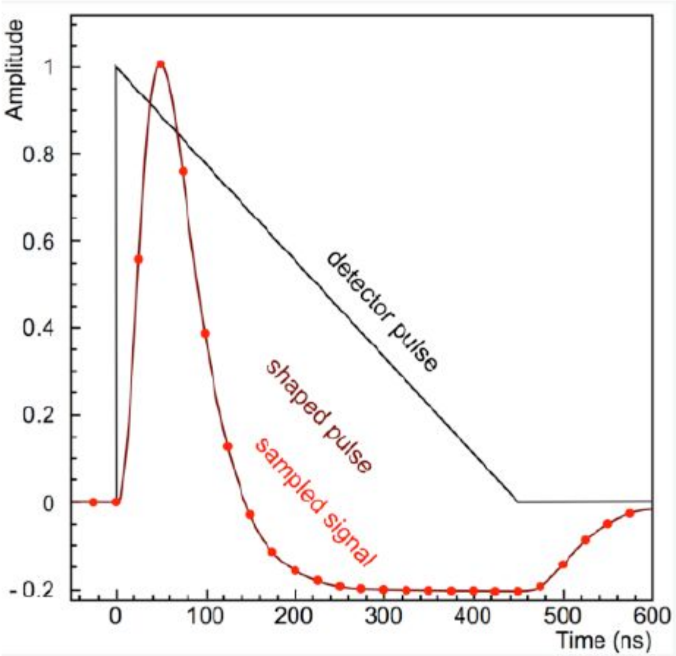
- Sampling calorimeter with full coverage in ϕ
- Electromagnetic Barrel + End-Caps (EMB+EMEC) $|\eta|<3.2$
  - Accordion shaped Pb absorbers with Cu/kapton electrodes
  - 3 longitudinal layers + presampler for $|\eta|<1.8$
- Hadronic End-Cap (HEC) $1.5<|\eta|<3.2$
  - Cu absorbers and Cu/kapton electrodes
  - 4 longitudinal layers
- Forward Calorimeter (FCal) $3.1<|\eta|<4.9$
  - Cu absorbers (EM) / W absorbers (had)
  - 3 longitudinal layers
- ~180 k channels
- Housed in cryostats at -88° C

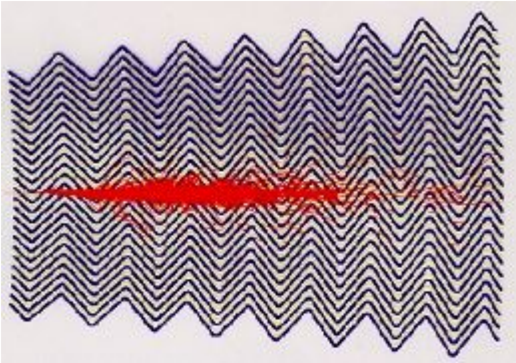


Principle of Operation

- ➟ Ionisation electrons drift to electrodes due to HV applied to 2.1 mm LAr gap
- ➟ Incoming particle creates EM shower & ionises LAr
- ➟ Current is produced and read out by electrodes

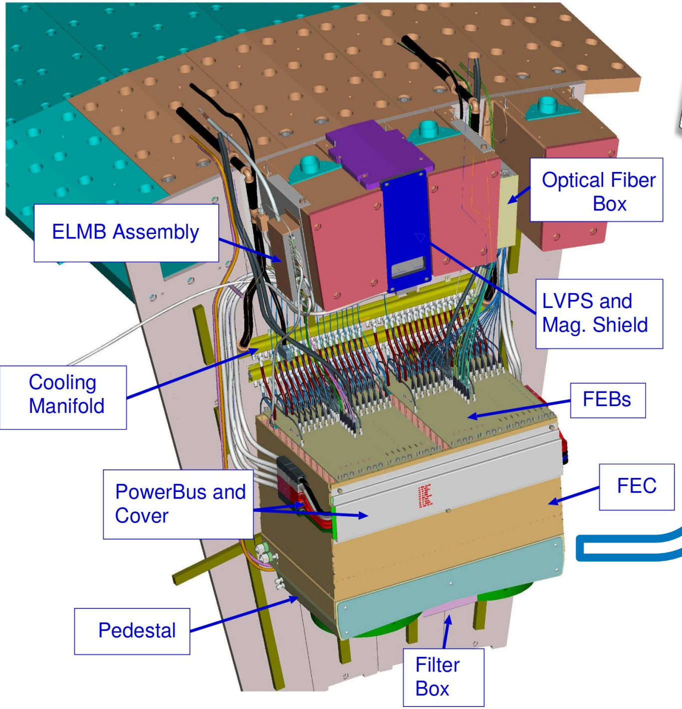




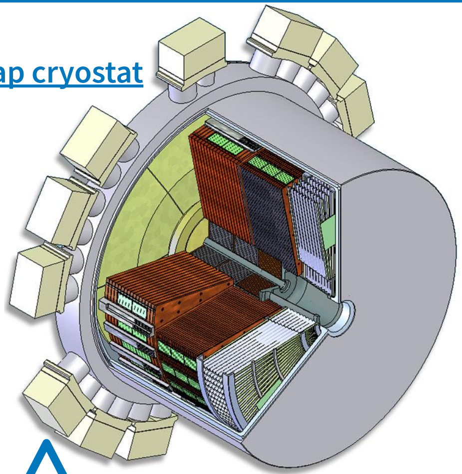


- ➟ Signal amplified & shaped (CR-RC^2)
- ➟ Sampled signal stored in analogue memory awaiting trigger decision @ 40 MHz & digitisation
- ➟ E_T deposited in given cell computed & sent to DAQ

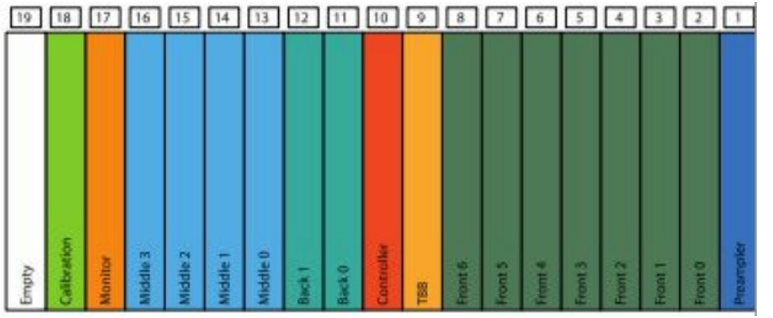
Front End Crates



Endcap cryostat



baseplane slot assignment example

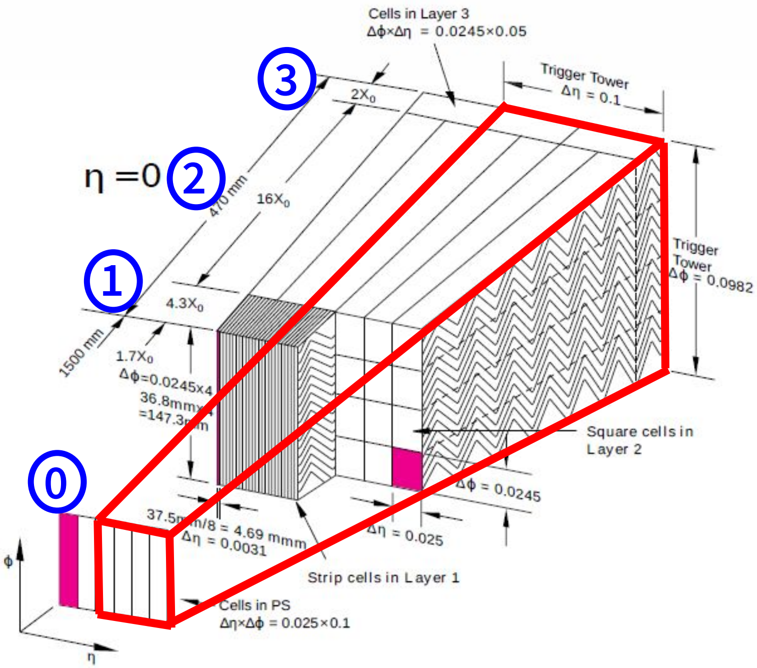


- 58 crates = 116 Half Front-End Crates (HFECs)
  - Each HFEC has a baseplane connected by a feedthrough (FT)
  - One HFEC contains a full set of boards
    - FEBs, Calibration boards, TBBs, Controller boards
- 1524 FEBs
  - Each covering a dedicated calorimeter layer
    - Presampler, front, middle, back
  - 128 channels each

Calorimeter Geometry

- Total of ~22 X_0 (avg. distance for EM particle to lose all but 1/e energy)
- Four layers with different spatial resolutions
- Presampler (0) measure energy loss before calorimeter, $\Delta\eta = 0.025$
- Front (1) distinguish π^0 from γ, 4.3 X_0, $\Delta\eta = 0.0031$
- Middle (2) contain bulk of EM shower, 16 X_0 , $\Delta\eta = 0.025$
- Back (3) capture tail of shower (+ leakage), 2 X_0 , $\Delta\eta = 0.05$
- ~5.4k Trigger Towers (TTs) $\Delta\eta \times \Delta\phi = 0.1 \times 2\pi/64$ (~0.1)

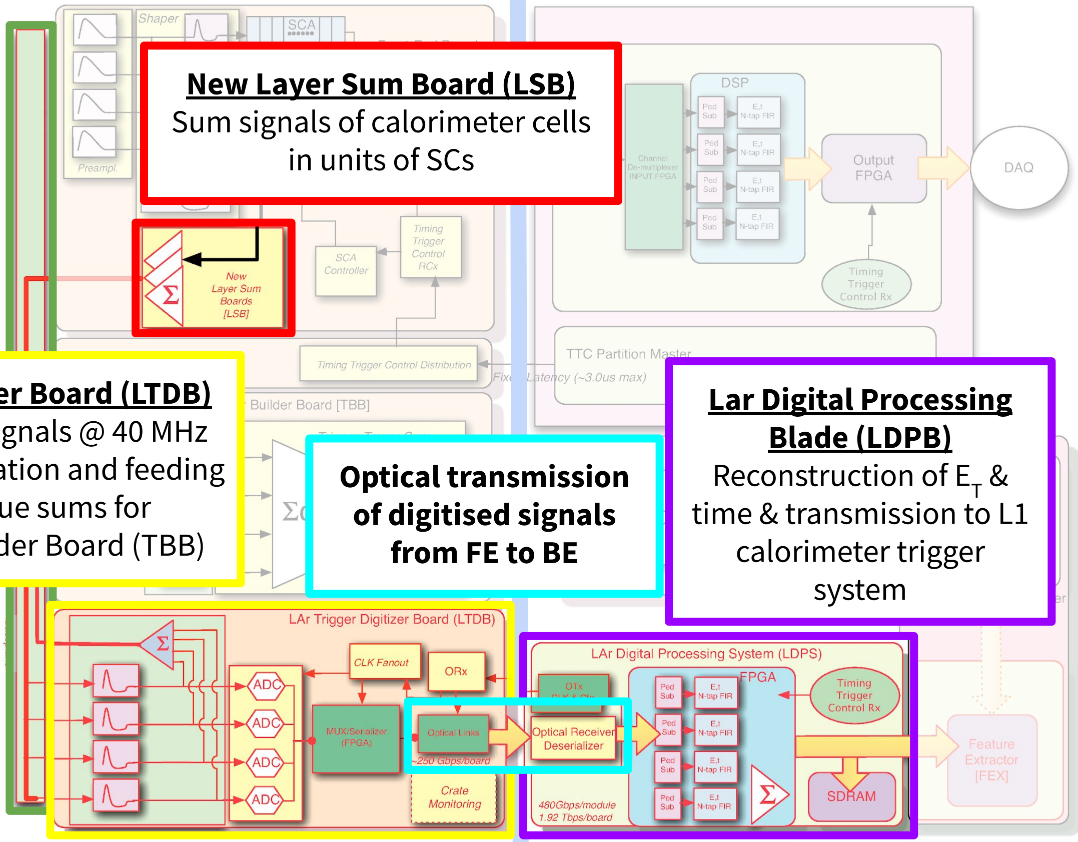
<u>Example: EM Barrel</u>



Phase-I Schematic

Baseplane
Transmission of increased number of signals from FEB

New Layer Sum Board (LSB)
Sum signals of calorimeter cells in units of SCs



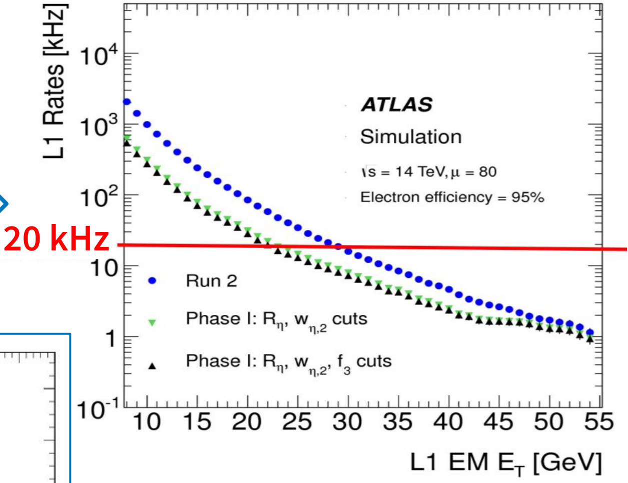
LAr Trigger Digitiser Board (LTDB)
Digitisation of SC signals @ 40 MHz to send to BE, recreation and feeding back of analogue sums for (legacy)Tower Builder Board (TBB)

Optical transmission of digitised signals from FE to BE

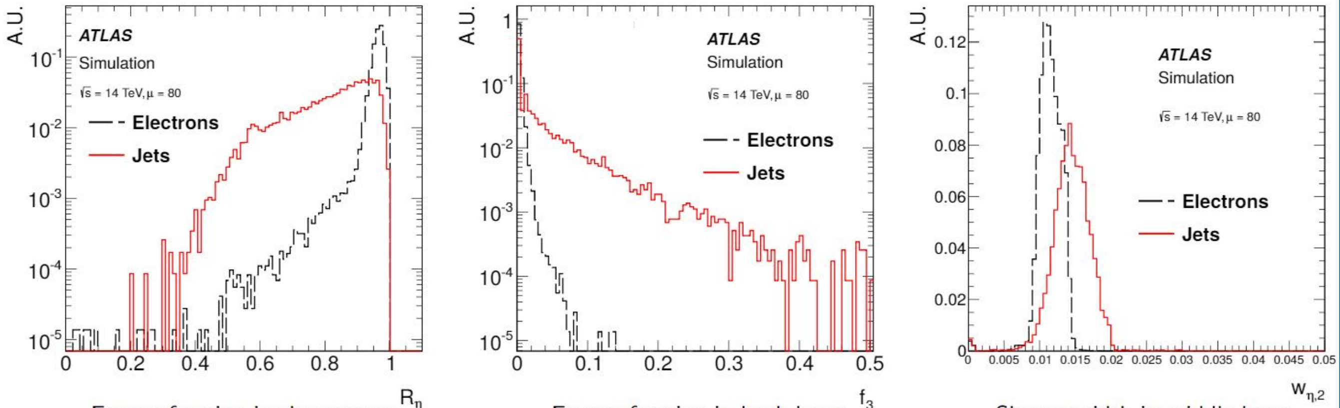
Lar Digital Processing Blade (LDPB)
Reconstruction of E_T & time & transmission to L1 calorimeter trigger system

Expected Supercell Performance

- Shower shape variables may be used to discriminate between jets and electrons at L1 trigger level
  - Improved jet background rejection for electron ID
- E_T threshold can be lowered by 7 GeV @ 20 kHz



Shower shape variables



Energy fraction in shower core

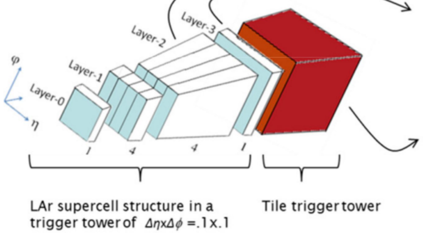
$$R_\eta = \frac{E^{(2)}_{T,\Delta\eta\times\Delta\phi=0.075\times0.2}}{E^{(2)}_{T,\Delta\eta\times\Delta\phi=0.175\times0.2}}$$

Energy fraction in back layer

$$f_3 = \frac{E^{(3)}_{T,\Delta\eta\times\Delta\phi=0.2\times0.2}}{E^{(1)}_{T,\Delta\eta\times\Delta\phi=0.075\times0.2}+E^{(2)}_{T,\Delta\eta\times\Delta\phi=0.075\times0.2}+E^{(3)}_{T,\Delta\eta\times\Delta\phi=0.2\times0.2}}$$

Shower width in middle layer

$$w_{\eta,2} = \sqrt{\frac{\Sigma\left(E^{(2)}_T\times\eta^2\right)_{\Delta\eta\times\Delta\phi=0.075\times0.2}}{E^{(2)}_{T,\Delta\eta\times\Delta\phi=0.075\times0.2}} - \left(\frac{\Sigma\left(E^{(2)}_T\times\eta\right)_{\Delta\eta\times\Delta\phi=0.075\times0.2}}{E^{(2)}_{T,\Delta\eta\times\Delta\phi=0.075\times0.2}}\right)^2}$$

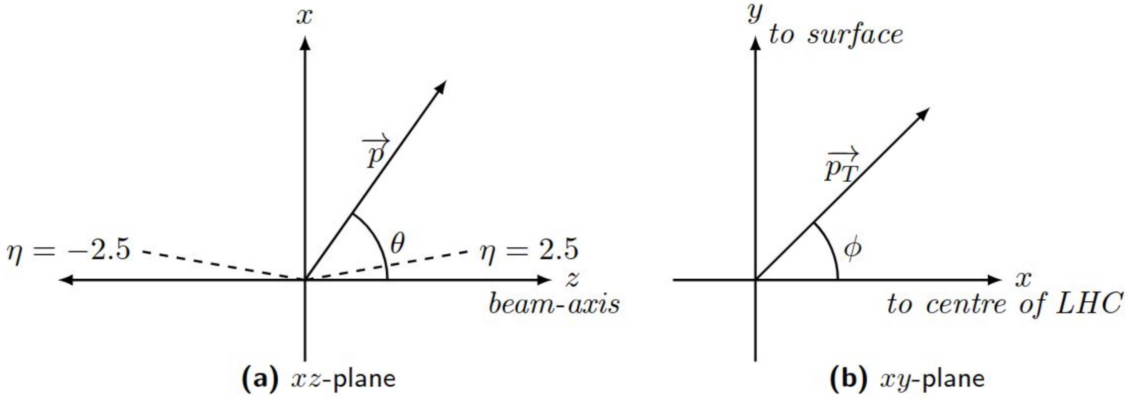


$$R_\eta = \frac{E_{3\times2}}{E_{7\times2}}$$

$$f_3 = \frac{E_{S3}}{E_{Tot.}}$$

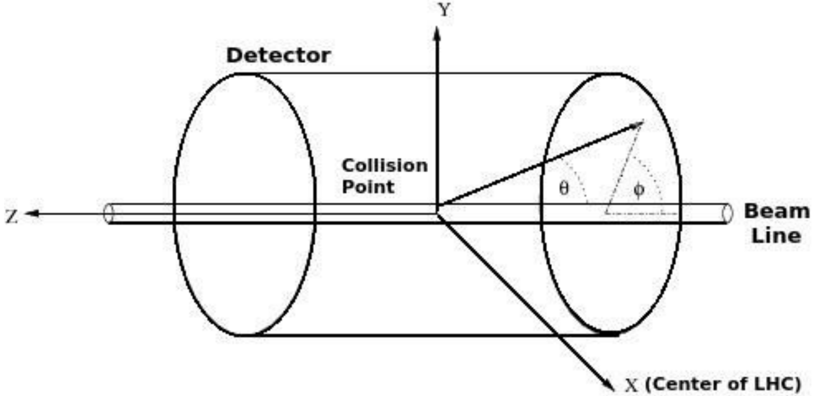
$$R_{Had} = \frac{E_{Had}}{E_{Tot.}}$$

The LHC Coordinate System



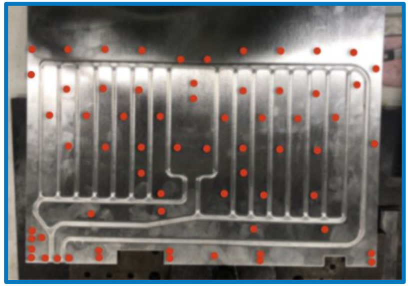
$$\eta = -\ln \tan\left(\frac{\theta}{2}\right)$$

$$\Delta R = \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2}$$

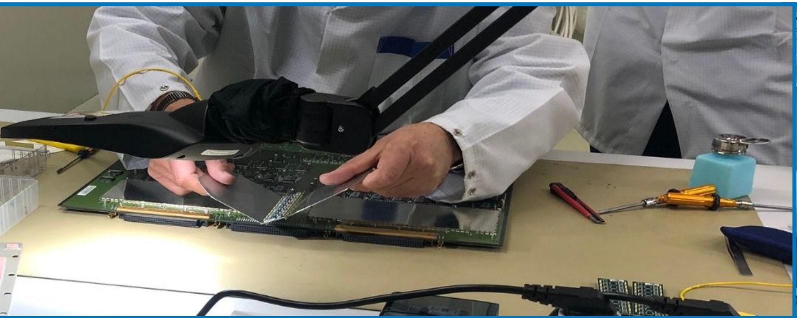


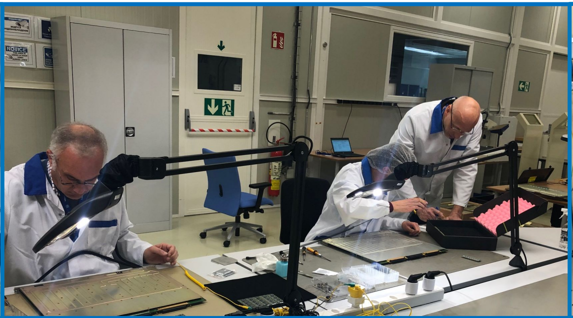
FEB & LSB Refurbishment

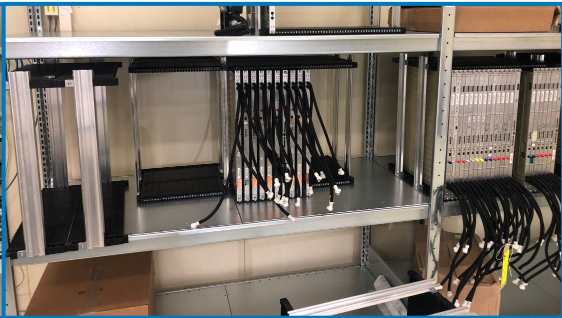
- LSB exchange is a long and arduous process
  - Cooling plate removed, ~50 small screws involved
  - LSB exchanged
  - Re-installation of brand new cooling plates
  - Leak test



- Very slight radioactivity of boards means refurbishment must take place on site lab at P1 (ATLAS)
- Process running very smoothly
  - Target of 50+ FEBs/week achieved

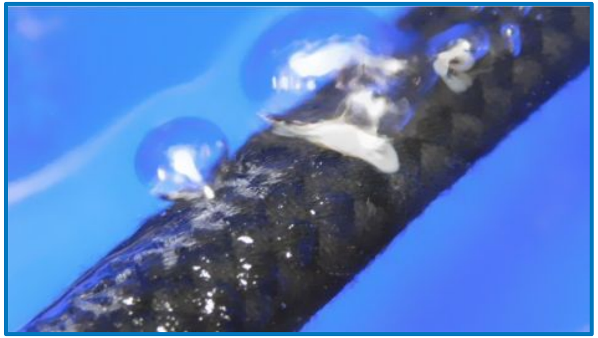






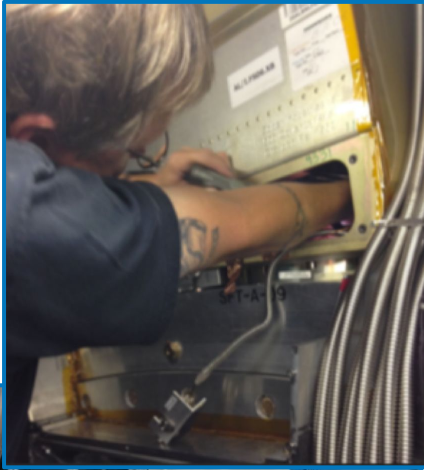
Cooling Hoses

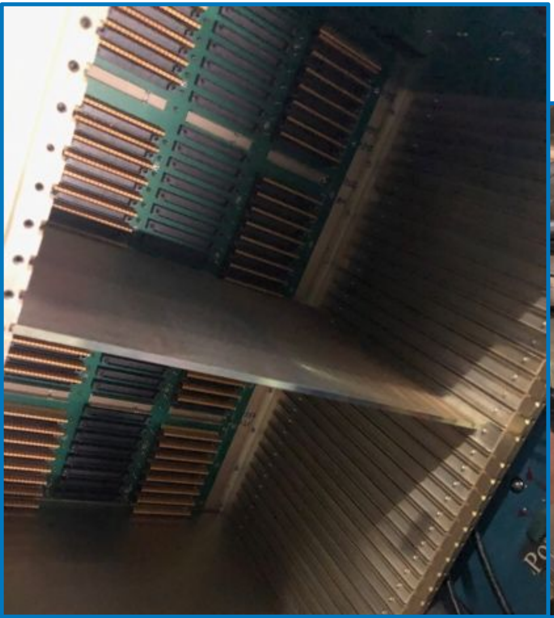
- Cooling hoses for all FEBs had to be replaced
  - Ageing rubber losing flexibility & grip on connector
  - Replaced refurbished FEBs - some re-installed FEBs were re-extracted to undergo replacement
- Same hoses are used in FEC LVPS & also need replacement
  - Caused some leaks in the past
- Cooling hose replacement is included in the installation process, without disrupting the schedule

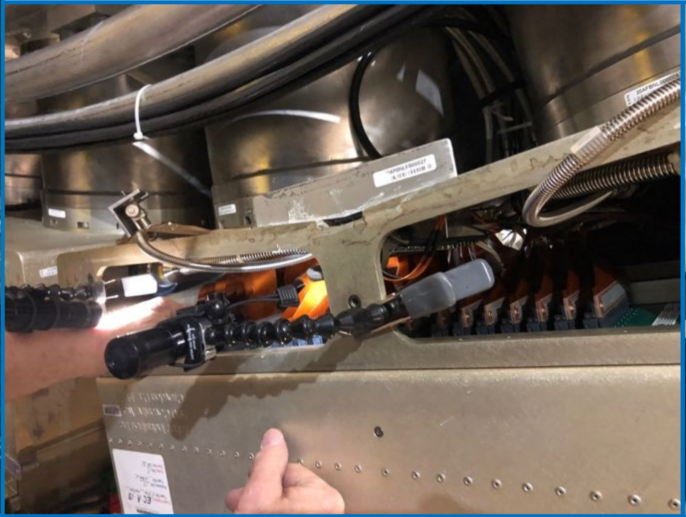


Baseplane Replacement

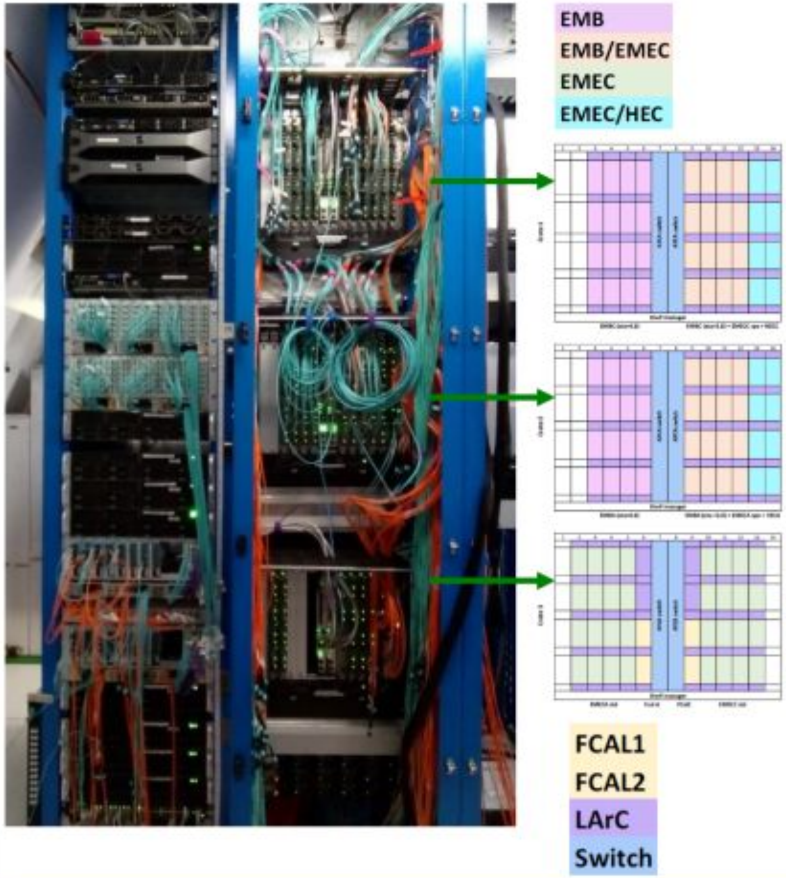
- Replacement is quite complicated work in restricted space
  - Requires removal of all boards first, which are sent to the surface by crane







Back-End Installation



EMEC Special Crates

- Recent change informed by phase-I special crate layout
- EMEC+HEC mixed crates previously defined as 3 crates with 3 controller boards
  - Now only space for 2 due to LTDB's
- HEC FEBs will have to be controlled by the controller boards which previously only controlled EMEC FEBs
  - Assignments of boards to TTC and SPAC (Serial Protocol for the Atlas Calorimeter) must be changed accordingly
- EMEC+HECFCAL TTC crate merged into one