ATLAS LAr Calorimeter Commissioning for LHC Run-3

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on the behalf of ATLAS Liquid Argon Collaboration

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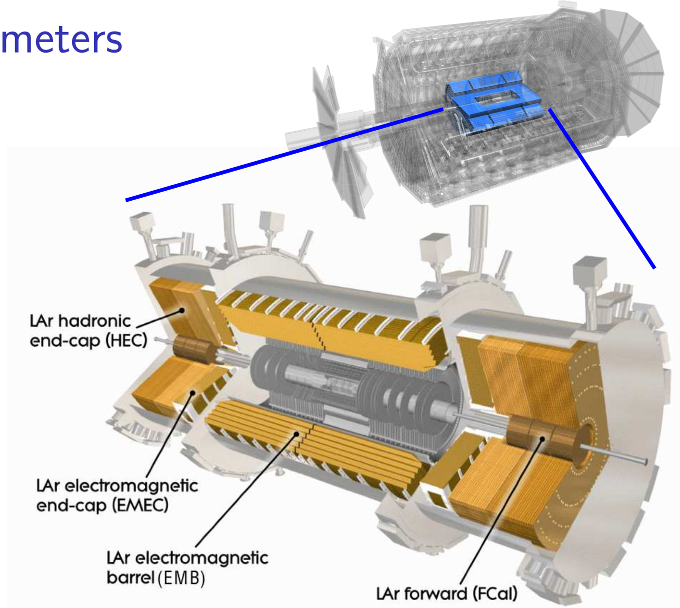
ATLAS Liquid Argon calorimeters

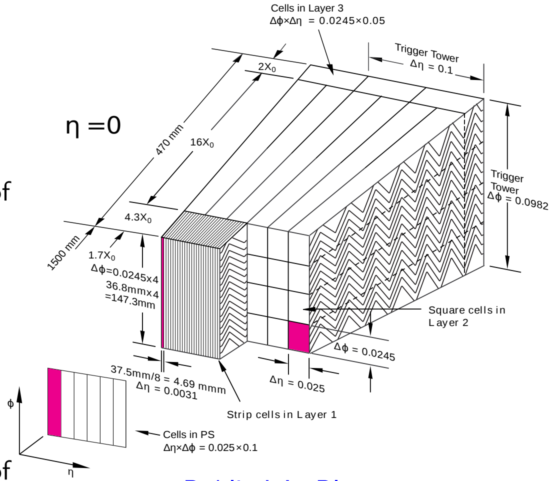
- Measurement of energies of electrons, photons, jets and estimation of missing transverse momentum.
- Particles ionizing the atoms of argon in liquid phase (LAr) produce currents for the signal readout.
- Pb (EMB and EMEC), Cu (HEC and FCAL), W (FCAL) are used as absorbers.
- Overall η coverage is -4.9 $< \eta <$ 4.9.



ATLAS Schematics

LAr cells and sampling layers

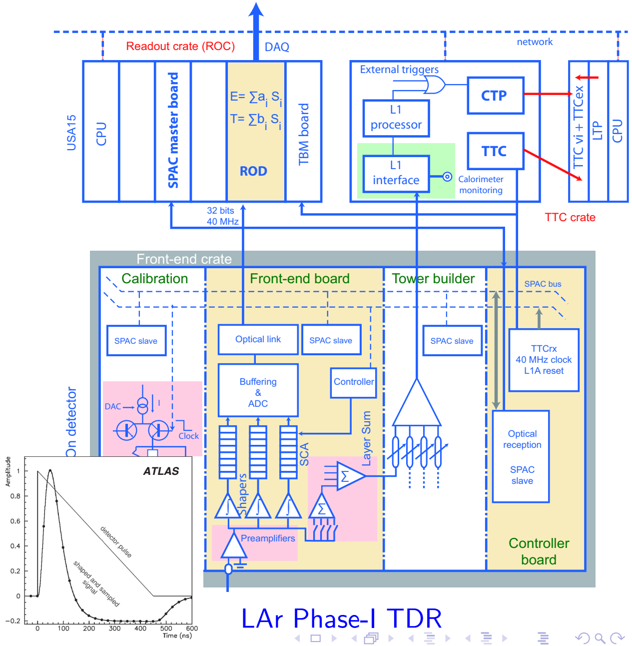
- LAr cells are the readout units with the finest granularity.
  - The size and shape of LAr cells are variable in different parts of the calorimeters.
  - Total 182418 LAr cells.
- The barrel electromagnetic calorimeter consists of
  - **Presampler**: correction of the energy loss caused by dead material.
  - **Layer 1**: fine granularity along η for good separation of π^0/γ.
  - **Layer 2**: most of energy deposit.
  - **Layer 3**: recovery of e/γ longitudinal energy leakage.
- The readout units for the trigger are composed of the sum of LAr cell signals.
  - A new trigger system is introduced for Run 3.



Public LAr Plots

Legacy readout system

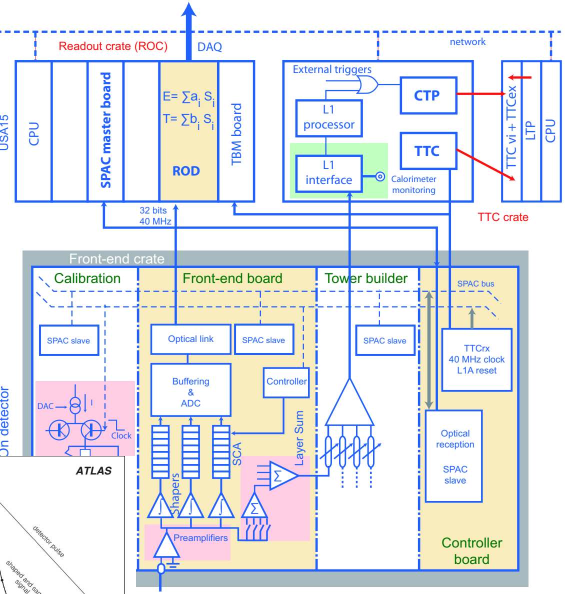
- The readout system is composed of front-end (on detector) and back-end (off detector) electronics.
- Front-end:
  - **Front End Boards (FEBs)**: Analog signals from LAr cells are amplified, shaped to bipolar analog signals, and digitized using 12-bit ADC. Layer Sum Boards (LSB) on FEBs sum the analog signals.
  - **Tower Builder Boards (TBBs)**: Analog signal sums from LSB are received in TBB, which forms trigger towers with a granularity of $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$.

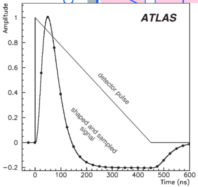


LAr Phase-I TDR

Legacy readout system

- The readout system is composed of front-end (on detector) and back-end (off detector) electronics.
- Back-end:
  - **Read Out Drivers (RODs)**: RODs receive digital signals from FEBs and compute the energy, time phase, and quality of the signal.
  - **Level-1 calorimeter (L1Calo) system**: Analog signals from TBBs are sent to L1Calo, which identifies physics objects and sends the results to the Central Trigger Processor (CTP).
- Main readout: FEB $\rightarrow$ ROD
- Legacy trigger: LSB $\rightarrow$ TBB $\rightarrow$ L1Calo

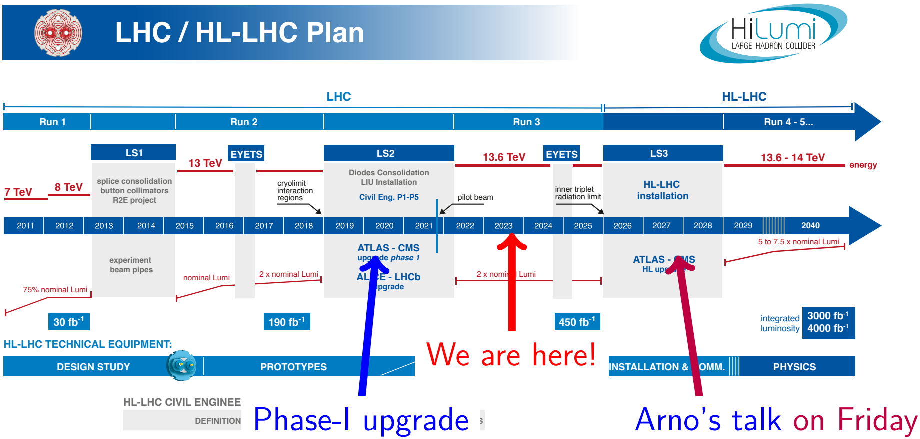




LAr Phase-I TDR

Toward high luminosity with high pilepup

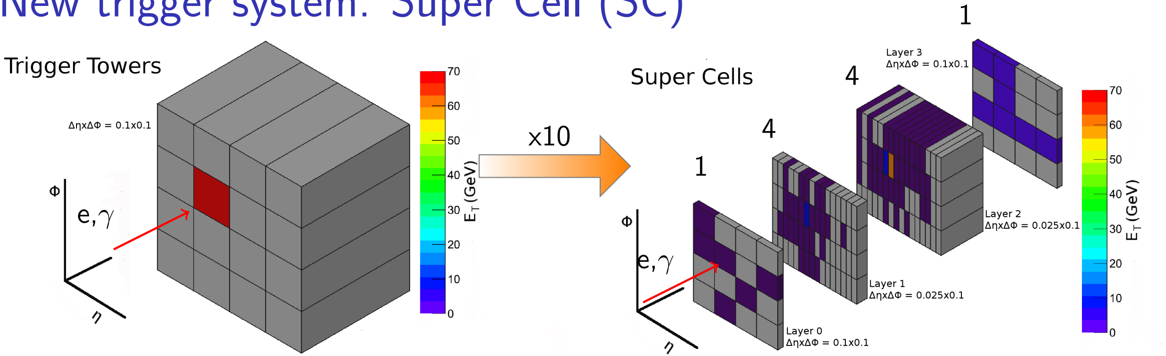
LHC/ HL-LHC Plan



- To cope with the environment of higher pileups in Run 3 ($<\mu> = 80$) and Run 4 ($<\mu> = 200$), we need to upgrade our trigger system.

New trigger system: Super Cell (SC)

LAr Phase-I TDR

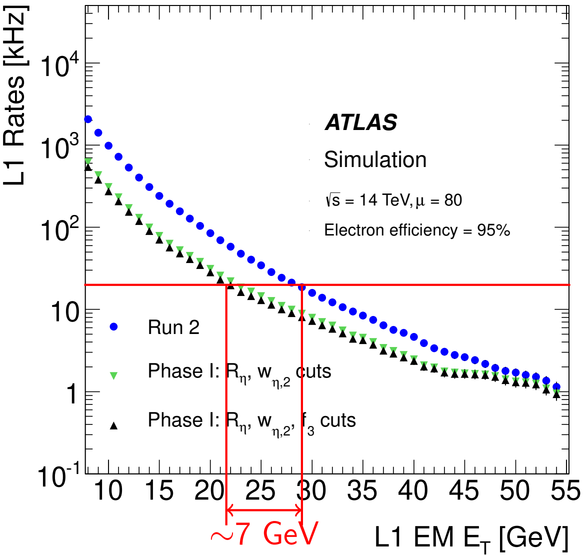


- A new LAr trigger system for high pile-up environment with a total of 34048 SCs.
  - Finer granularity than Trigger Towers.
- Pros:
  - Better trigger energy resolution.
  - Higher efficiency in selecting physics objects.
- Cons:
  - The existing system is not capable of the transmission of a huge amount of data (∼25Tbps).

Improvement on trigger performance

- A simulation of trigger rates was performed for the legacy and Phase-I systems.
- The Phase-I trigger item can have a 7 GeV lower cut on the electron E_T at a 20kHz trigger rate.
- Lower energy cuts can keep more physics signatures in a high luminosity environment.

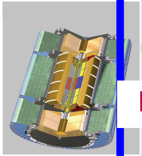
LAr Phase-I TDR

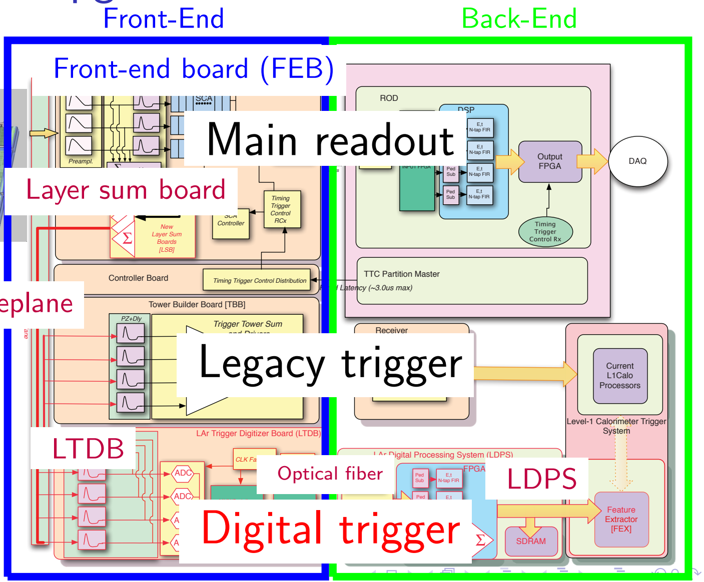


New electronics for Phase-I upgrade

LAr Phase-I TDR

- **Digital trigger**:
  - A new data stream is needed for the implementation of the Super Cell.
- **Front-end**:
  - Layer sum board
  - Baseplane
  - LAr trigger digitizer board
- **Back-end**:
  - LAr trigger processing mezzanine
  - LAr carrier
  - Intelligent platform management controller
- Optical fibers for connecting front-end to back-end

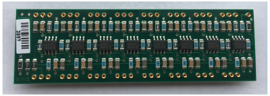




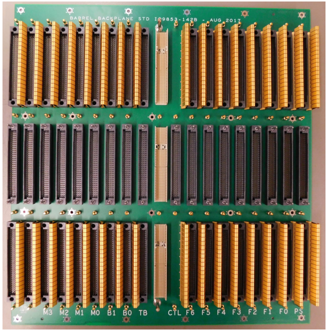
Front-end electronics

2022 JINST 17 P05024

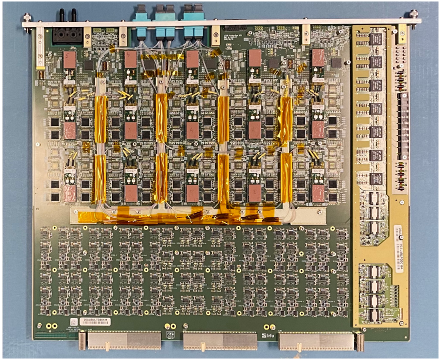
- Layer Sum Board (LSB):
  A plug-in card of the FEB provides a sum of analog signals for SCs. 2328 LSBs are replaced.



- Baseplane:
  New baseplanes provide an additional slot for LTDB and distribute analog signals of SCs from FEBs to LTDB.



- LAr Trigger Digitizer Board (LTDB):
  LTDBs send analog signals to Tower Builder Board, digitize analog signals, and send digital signals to the back-end. A total of 124 LTDBs are installed.



Back-end electronics: LDPS

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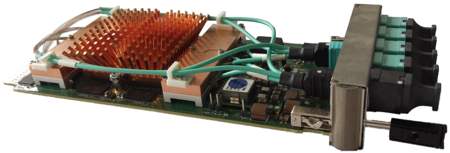
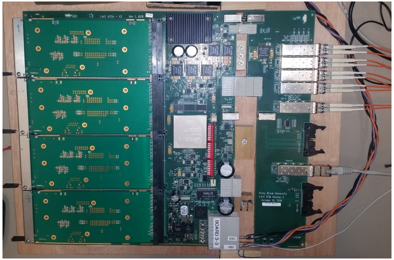
- LAr Trigger prOcessing MEzzanine (LATOME):
  A LATOME receives ADC counts from a LTDB via 40 optical fibers with the speed of 5.12 Gbps for each fiber, computes energy and pulse timing in a FPGA and sends energy to Feature Extractors. 116 LATOMEs are installed.



- LAr Carrier (LArC):
  LArCs transmit data from LATOMEs to the readout system, distribute clocks and trigger signals synchronized to the LHC beam clock. 30 LArCs are installed.

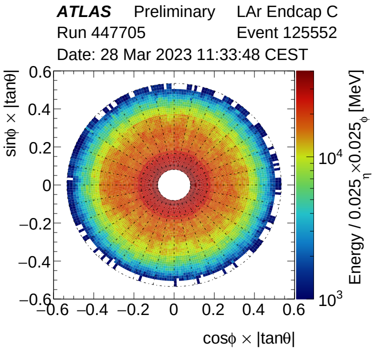


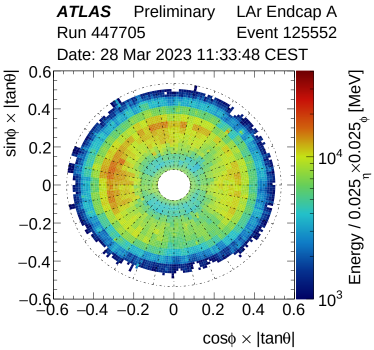
- Intelligent Platform Management Controller (IPMC):
  IPMCs manage the power, cooling, and interconnect needs of intelligent devices.

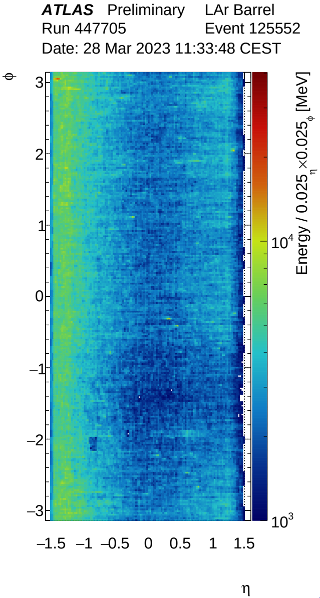
LAr performance

LArCaloPublicBeamSplashMay2023

- A beam splash was recorded in March 2023.
- These plots show an event with energy deposited in all the LAr cells.
  - LAr cell energy sums are in a hypothetical tower grid of $\Delta\eta \times \Delta\phi = 0.025 \times 0.025$ with Beam 1 (B1) coming from the positive η (A) side.



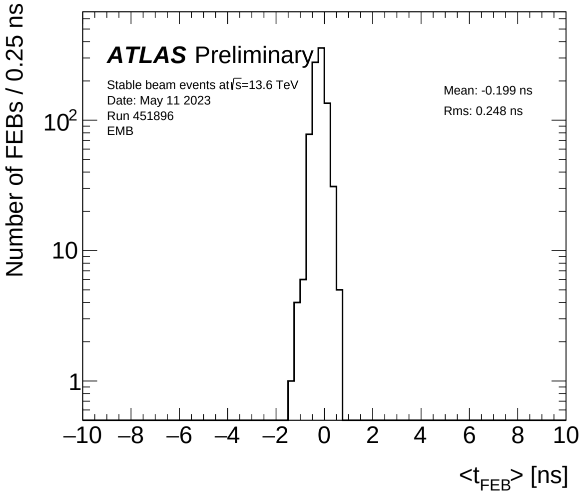




FEB offset timing

- The average time per FEB was measured with collision data in the stable beam at $\sqrt{s} = 13.6$ TeV in May 2023.
  - The average time for one FEB is the result of a Gaussian fit on the time distribution from pulses reconstructed from medium and high gain for all channels of this FEB.
- All FEBs are well aligned since the distribution is centered at zero and no significant outliers are observed.

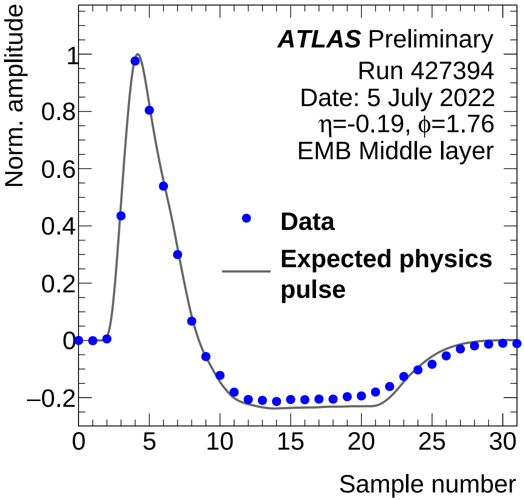
LArCaloPublicStableBeam2023



Super cell pulse shape

- Pulse shapes of SCs are measured with the first stable beam collision data at $\sqrt{s} = 13.6$ TeV in early July 2022.
- The expected physics pulse is extracted using preliminary conversion parameters from a calibration pulse obtained with an injected calibration charge.
- The sampling points of the measured pulse shape on the pulse peak matched well with the expected physics pulse.

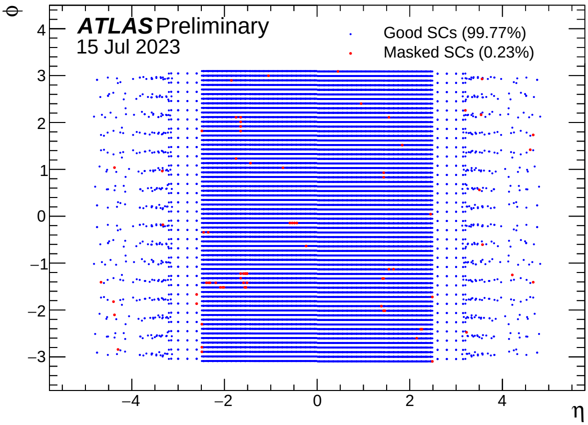
LArCaloPublicStableBeam2022



SuperCell status

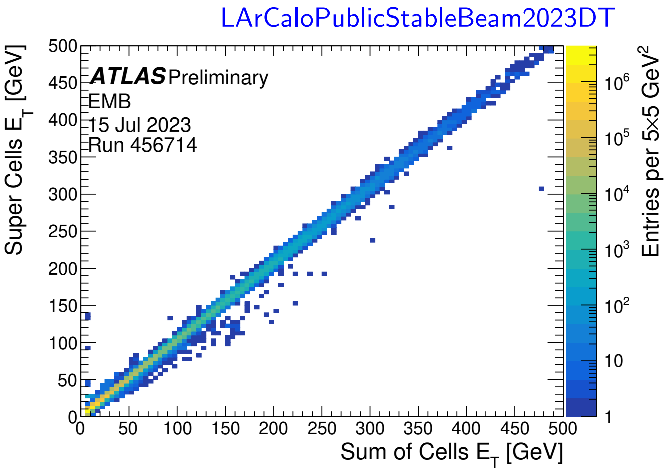
LArCaloPublicStableBeam2023DT

- The SC status is reported on 15 July 2023 for the runs with the pp collision at $\sqrt{s} = 13.6\text{TeV}$.
- 78 SCs shown in red have other issues related to their associated LTDBs or with calibration issues.
- More than 99% of SCs (33970 out of 34048) SCs in good status are shown in blue.



Energy comparisons with main readouts

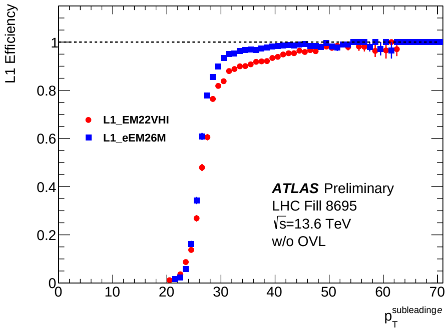
- Supercell transverse energies (E_T) are compared to the sum of energies from the corresponding LAr cells in the main readout.
- The data from the run with the pp collision at $\sqrt{s} = 13.6$ TeV on 15 July 2023 is used for the comparison.
  - Bad SCs are excluded from the comparison.
  - The results show good agreement between the data streams of the main readout stream and the trigger.

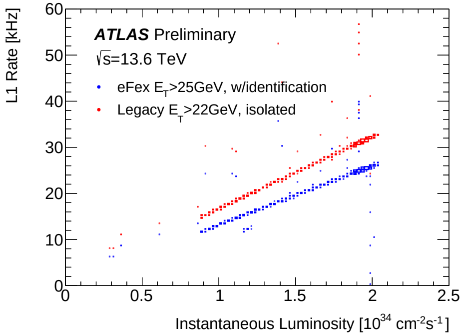


Performance of trigger rate

- The single electron triggers for the legacy system (red) and the Phase-I system (blue) are compared.
- Efficiencies along subleading electron p_T from $Z \to e^+ + e^-$ events are measured.
- The Phase-I EM item shows better performance:
  - Shaper trigger efficiency turn-on curve.
  - Lower trigger rate (80% of legacy EM item).
- The Phase-I EM item is used as the primary trigger now.

L1Calo Public Results





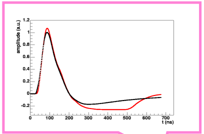
Summary

- The LAr digital trigger system has been installed in long shutdown 2 of LHC and is working well towards full replacement of the legacy trigger system.
- The main readout of LAr is also working well.
- More than 99% of SCs are functional for the trigger system.
- ATLAS is running with the Phase-I EM trigger item and the legacy EM trigger item has been disabled since May.

Back up

Energy reconstruction

LArCaloPublicResultsDetStatus



ADC to DAC (Ramps)

Pulse Samples

$$E_{\text{cell}} = F_{\mu\text{A}\rightarrow\text{MeV}} \cdot F_{DAC\rightarrow\mu\text{A}} \cdot \frac{1}{\frac{\text{M}_{\text{phys}}}{\text{M}_{\text{cali}}}} \sum_{i=1}^{M_{\text{ramps}}} R_i \left[\sum_{j=1}^{N_{\text{samples}}} a_j \left(s_j - p \right) \right]^i$$

Cell energy

Sampling fraction

Calibration board

Optimal Filtering Coefficients

Pedestals

The above formula describes the LAr electronic calibration chain (from the signal ADC samples to the raw energy in the cell. Note that this version of the formula uses the general M_{ramps}-order polynomial fit of the ramps. We use a linear fit as the electronics are very linear, and we only want to apply a linear gain in the DSP in order to be able to undo it offline, and apply a more refined calibration. In this case, the formula is simply:

$$E_{\text{cell}} = F_{\mu\text{A}\rightarrow\text{MeV}} \cdot F_{DAC\rightarrow\mu\text{A}} \cdot \frac{1}{\frac{\text{M}_{\text{phys}}}{\text{M}_{\text{cali}}}} \cdot R \left[\sum_{j=1}^{N_{\text{samples}}} a_j \left(s_j - p \right) \right]$$