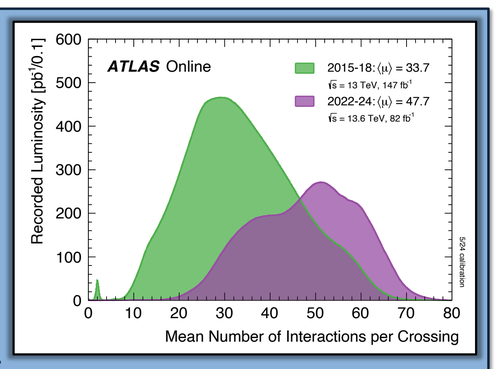
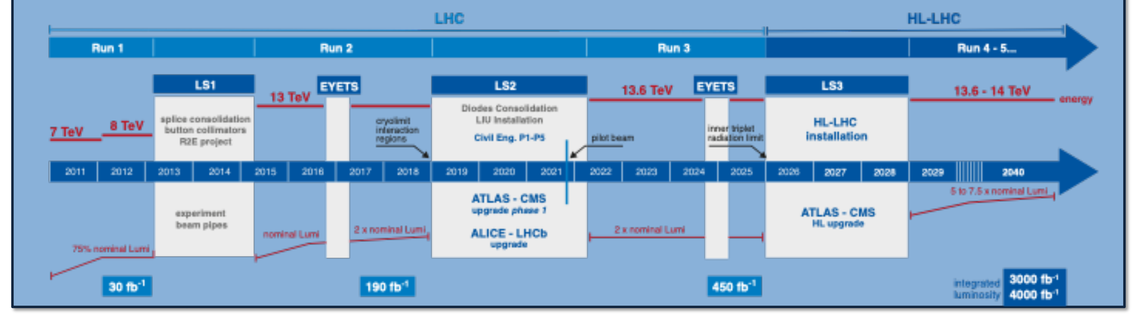
Technical Challenges and Performance of the new ATLAS LAr Calorimeter Trigger

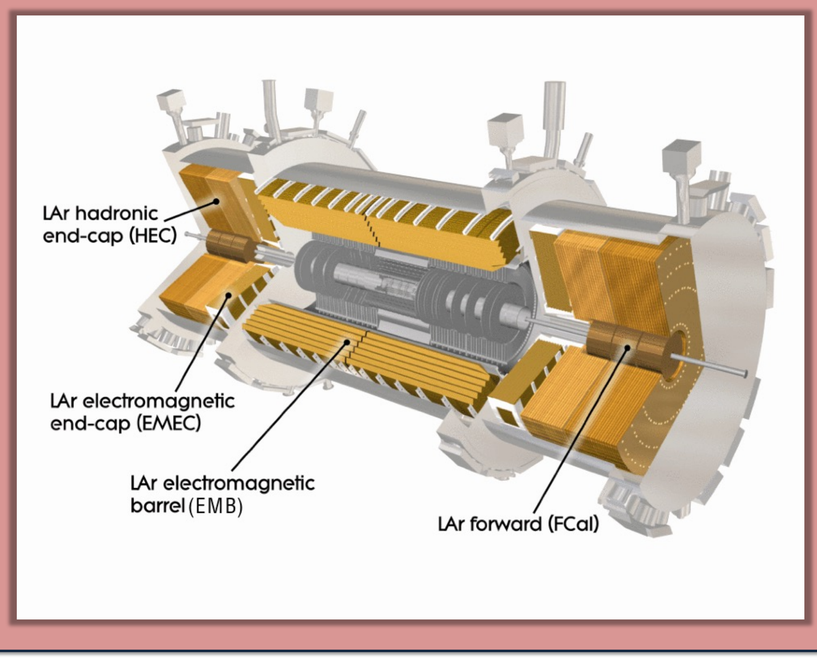
Sully Billingsley, cole.sullivan.billingsley@cern.ch

Introduction

- During Long Shutdown 2 of the LHC, the ATLAS Liquid Argon (LAr) Calorimeter was equipped with a new digital trigger system to cope with high pile-up conditions
- The analog trigger was decommissioned at the end of 2023
- Since the May 2023, the LAr digital trigger has been in full operation and has shown good performance in comparison to the legacy trigger







LAr Calorimeter

- Sampling calorimeter with liquid argon as active material

EMB $|\eta| < 1.5$
- Accordion geometry
- Lead plate absorber

EMEC $1.4 < |\eta| < 3.2$
- Accordion geometry
- Lead plate absorber

HEC $1.5 < |\eta| < 3.2$
- Parallel plate geometry
- Copper absorber

FCal $3.1 < |\eta| < 4.9$
- Rod and tube stucture
- Copper and tungsten absorbers

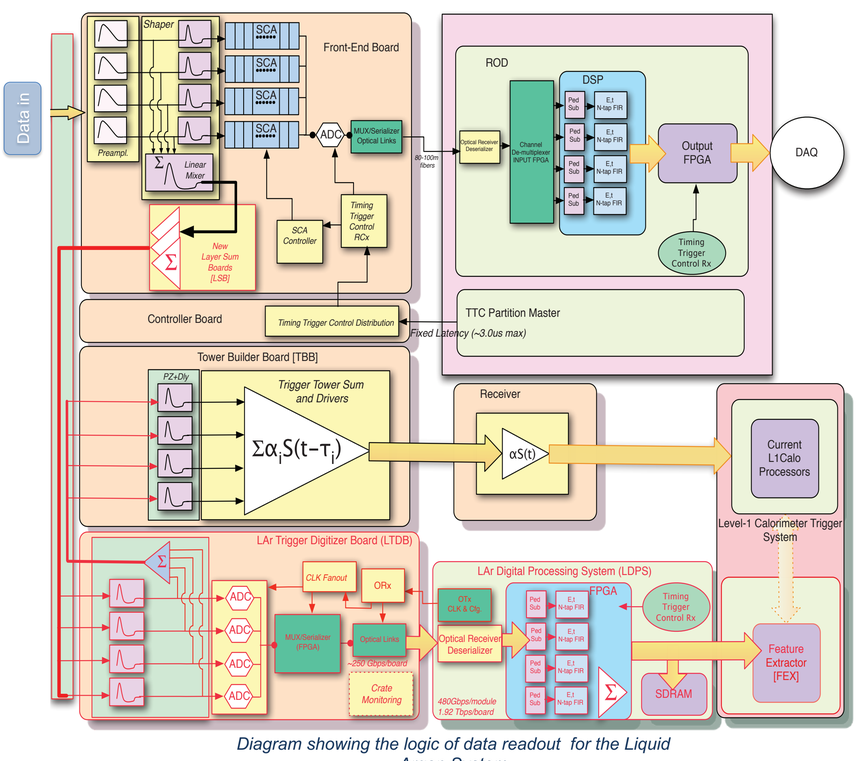


Diagram showing the logic of data readout for the Liquid Argon System

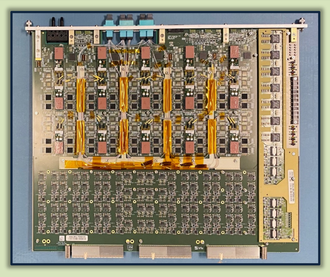
New Frontend (on-detector)

Front-end Boards (FEBs)
- 1524 in total
- Refurbished and installed on the detector

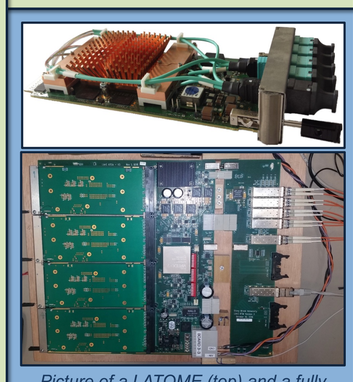
Layer Sum Boards (LSBs)
- 2328 in total
- Sums analog signals, groups them into Super Cells, sends signal to LTDBs through the baseplanes

LAr Trigger Digitizer Boards (LTDBs)
- 124 in total
- Digitizes analog Super Cell signal from LSB at 40 MHz
- Each LTDB processes about 320 Super Cells
- Digitized Super Cell signals are sent via 40 optical links to the LAr Digitial Processing Blades off-detector

Baseplanes
- 114 in total
- Link between all boards



Picture of an LTDB



Picture of a LATOME (top) and a fully loaded LDPB (bottom)

New Backend (off-detector)

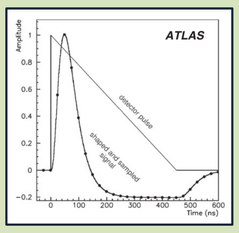
LAr Digital Processing Blade (LDPB)
- 30 were install
- Each is made up of:
  - 1 LAr Carrier
  - 1 Intelligent Platform Management Controller
  - 4 LAr Trigger prOcessing MEzzanines

Intelligent Platform Management Controller (IPMC)
- Connected to each LArC for control and monitoring

LAr Carrier (LArC)
- Advanced Telecommunications Computing Architecture (ATCA) boards
- Holds 4 LATOMEs and sends data to them

Energy Reconstruction

- When a particle ionizes the liquid argon, ionization pulses are collected in calorimeter cells.
- These pulses have a triangular shape and are proportional to the energy deposited.
- Signal is pre-amplified and shaped
- Cell energy is estimated from the amplitude of the pulse, calibration constants and factors from test-beam data
  - Pulse amplitude and time computed from $N_{samples} = 4$ digitized samples s_j using Optimal Filtering Coefficients (OFC) a_j and b_j and pedestal p from calibration
- Same energy computation procedure used for the main readout and digital trigger paths



$$A = \sum_{j=1}^{N_{samples}} a_j (s_j - p)$$

$$t = \frac{1}{A} \sum_{j=1}^{N_{samples}} b_j (s_j - p)$$

Equations for Amplitude and timing with respective OFCs

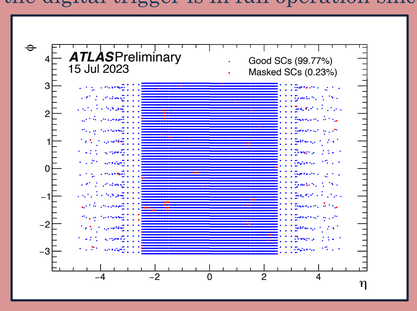
$$E_{cell} = F_{DAC \to \mu A} \cdot F_{\mu A \to MEV} \cdot \frac{1}{\frac{M_{phys}}{M_{cali}}} \cdot G_1 \cdot \sum_{i=1}^{N_{samples}} a_i (s_i - p)$$

calibration board DAC to ionization current factor; ionization current to energy factor; ionization to calibration pulse response; gain; amplitude; a= optimal filtering coefficients, S= digitized sample p= pedestal

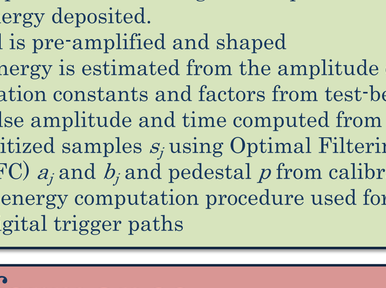
Equation for calculating cell energy

Performance

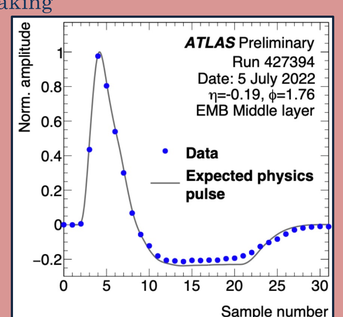
- Commissioning of the digital trigger started with the start of LHC Run 3
- In 2023, the digital trigger was used only for triggering on electrons and photons
- Now the digital trigger is in full operation since the start of 2024 data-taking



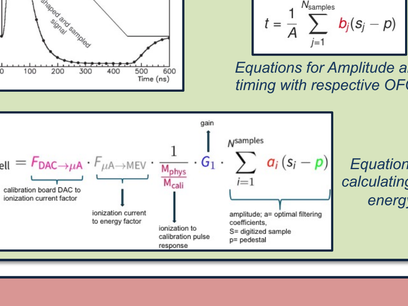
- > 99.7% coverage during high luminosity pp runs in 2023
- Very few problematic Super Cells and many have been recovered during the 2023 Year End Technical Shutdown



- Offline timing centered at zero showing good timing alignment
- Only SCs with E_T between 0 and 5 GeV is shown here



- Good agreement between SC pulse shape from data and the expected pulse shape from calibration



- Plot showing agreement between E_T reconstruction of Super Cells (digital trigger) and calorimeter cells (main readout)

Trigger Towers to Super Cells

- In the legacy trigger system, calorimeter cells were grouped into Trigger Towers (TTs) of size $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$
- In the digital trigger system, calorimeter cells are grouped into Super Cells (SCs) as small as $\Delta\eta \times \Delta\phi = 0.025 \times 0.1$
- Digital trigger system offers four-layer information and 10× granularity

~7,000 TTs

~34,000 SCs

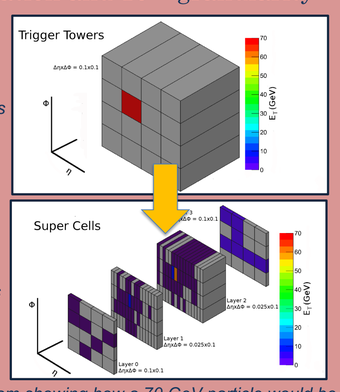
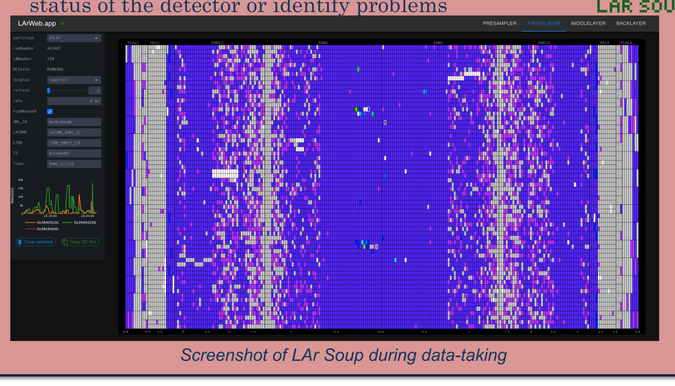


Diagram showing how a 70 GeV particle would be seen in the legacy trigger and the digital trigger

To reduce noise and monitor the new system LAr SuperCell Killer (LArSKill) and LAr Soup were developed

LAr SKill
- LArSKill monitors the pulse rate of all SuperCells.
- If a SuperCell is above the noisy rate threshold for an adequate amount of time, the SuperCell is masked for the Phase-I trigger path..
- LArSKill is running in ATLAS.
- Optimizing the energy and rate threshold for precise noise masking is currently underway.

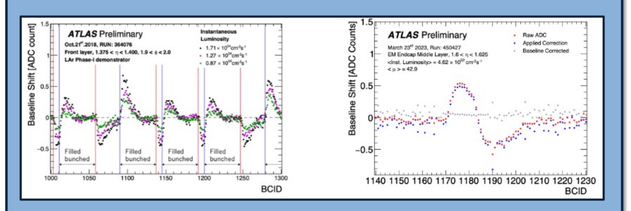
LAr Soup
- A web tool used to visualize the pulse rates of the digital trigger with additional features to help experts see the status of the detector or identify problems



Screenshot of LAr Soup during data-taking

Baseline Correction

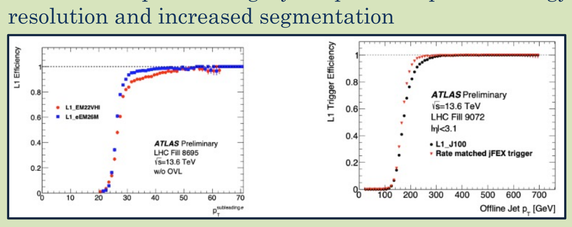
- LAr pulses overlap due to out-of-time pileup, creating a baseline shift
- A baseline correction algorithm is implemented on the LATOME firmware to correct potential energy measurement bias
- Calculated and updated regularly per Super Cell and Bunch Crossing ID (BCID)
- Validated and deployed during high pile-up collision runs in 2023



Plots showing the present bias when there are filled bunches and the effect of the baseline correction algorithm

Performance of L1Calo

- Now that LAr has upgraded its trigger readout L1Calo, who is upstream of the LAr system, can receive more granular information to make better L1 trigger decisions
- Uses 3 Feature EXtraction (FEX) processors
- When the digital trigger is compared to the legacy trigger for the single electron trigger:
  - Sharper turn-on curves observed with the new L1Calo FEXes
  - With the electron feature extractors (eFEX), ~10% reduction in L1 rate
- With the jet feature extractors (jFEX), the same L1 rate is observed compared to legacy in spite of improved energy resolution and increased segmentation



Plots showing the trigger efficiency of an L1 electron trigger (left) item and an L1 jet trigger item (right)

Conclusion

- The Digital Trigger has been operational since the start of 2024 data-taking
  - The Legacy trigger has been successfully decommissioned
- Very good performance has been measured by LAr and L1Calo

References

ATLAS Collaboration, ATLAS Liquid Argon Calorimeter Phase-I Upgrade Technical Design Report, CERN-LHCC-2013-017, ATLAS-TDR-022
ATLAS Collaboration, The Phase-I Trigger Readout Electronics Upgrade of the ATLAS Liquid Argon Calorimeters, arXiv:2202.07384
ATLAS Collaboration, Approved Liquid-Argon Calorimeter Plots, https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ApprovedPlotsLAr
ATLAS Collaboration, Approved Trigger Software Upgrade Plots, https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TriggerSoftwareUpgradePublicResults

On behalf of LAr Operations