Technical Challenges and Performance of the new ATLAS LAr Calorimeter Trigger

Chilufya Mwewa

Brookhaven National Laboratory

On behalf of the ATLAS Liquid Argon Collaboration

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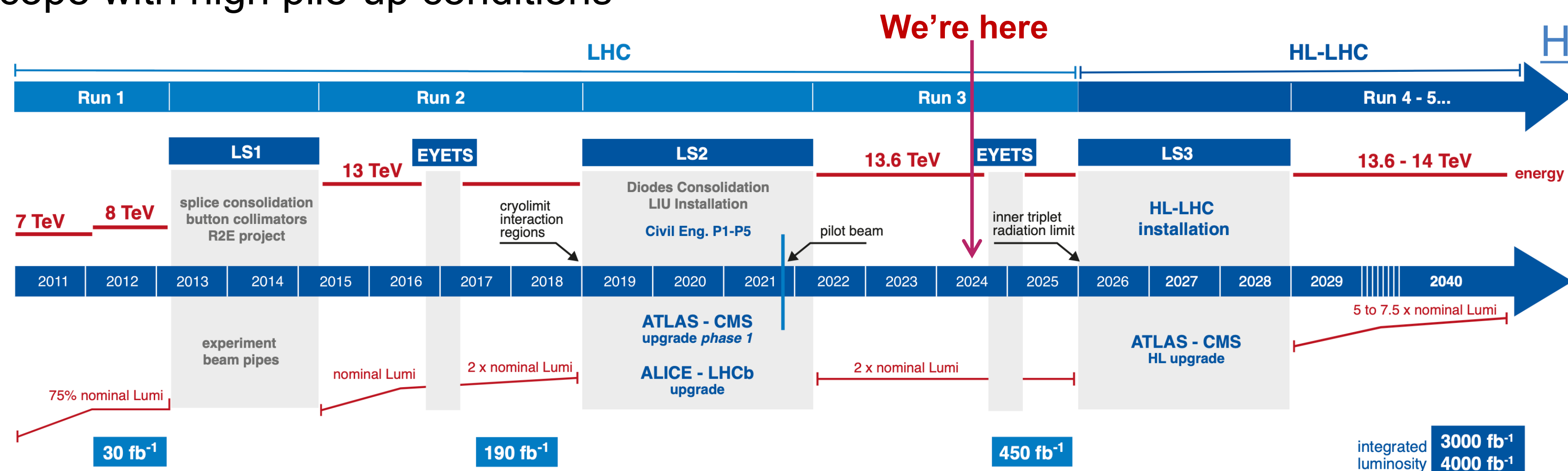
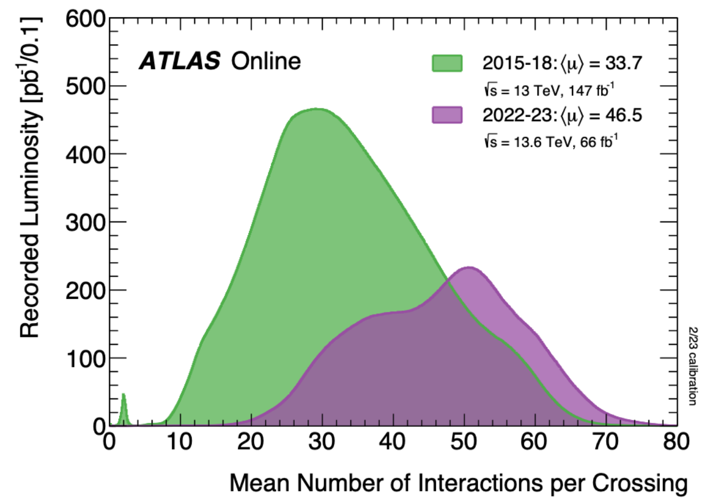
Introduction

- The Liquid Argon calorimeter (LAr) is an important tool for the ATLAS Physics program
- In Run 3 of the LHC, LAr has been equipped with a new digital trigger electronics system to cope with high pile-up conditions

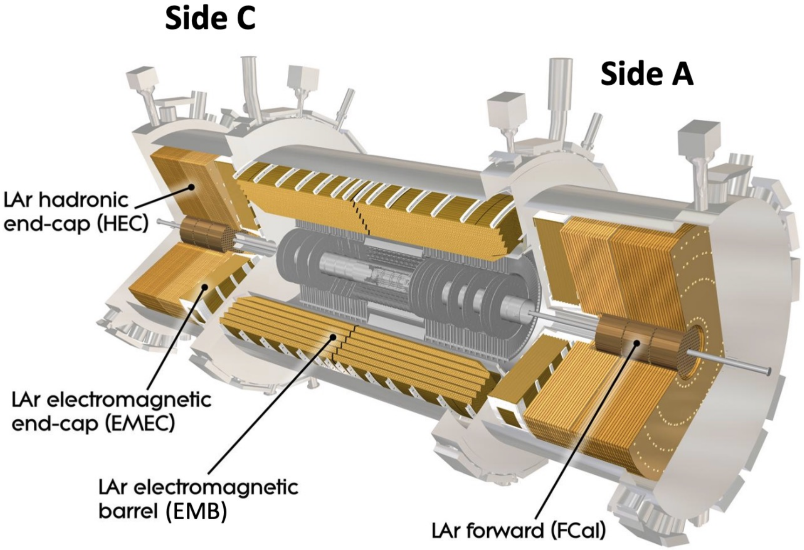


HL-LHC

- LAr analog trigger (legacy): operated until end of 2023
- LAr digital trigger: in full operation since the start of 2024 data-taking and will remain in place in HL-LHC era
- Overall good performance from the digital trigger in comparison to the legacy trigger
- Challenge: baseline shift from out-of-time pile-up



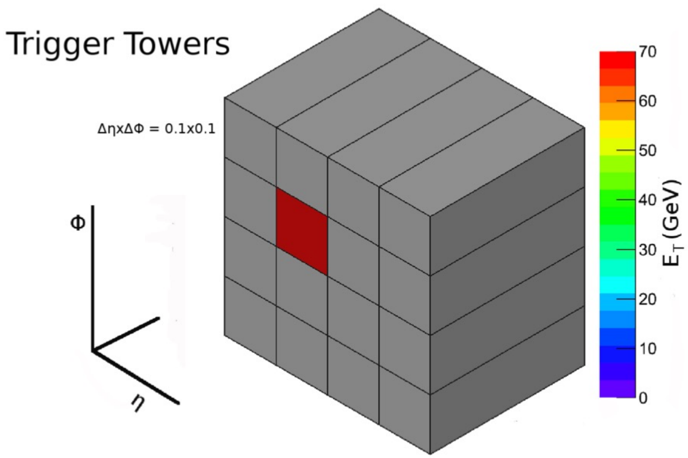
The ATLAS LAr Calorimetry System



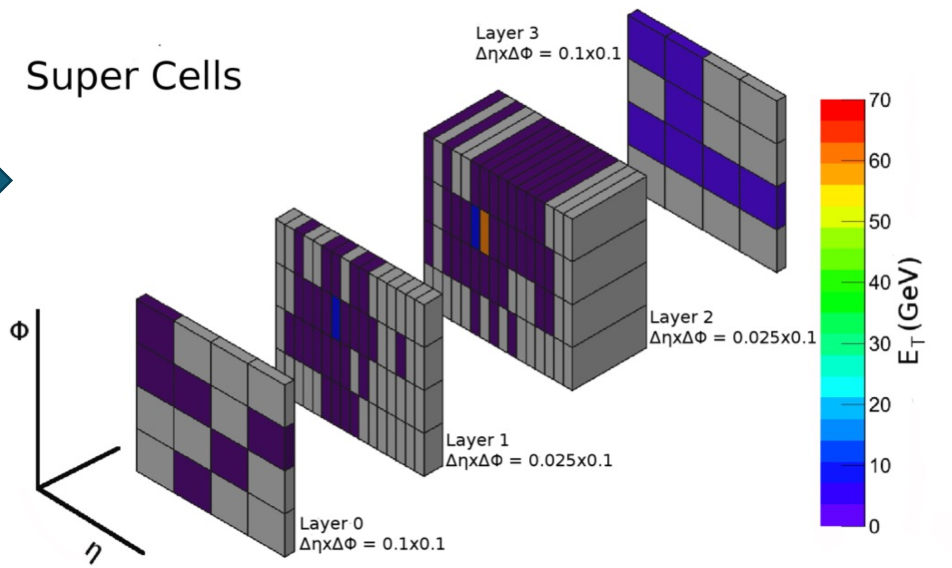
- Sampling calorimeter: Liquid argon as sampling material
  - See talk by Mary-cruz
- Uses lead (EMB+EMEC) or copper (HEC+FCal EM) or tungsten (FCal hadronic) as absorbers
- Each LAr partition has 3 layers (Front, middle, back)
- EMB and EMEC also have a pre-sampling layer
  - Used to correct for energy losses before the calorimeter
- Readout electronics are embedded in the LAr to readout pulses from particle showers
- LAr calorimeter cells are the smallest readout units (~180k in total)

Legacy and digital trigger overview

- In the legacy trigger system, calorimeter cells were grouped into Trigger Towers (TTs) of size $\Delta\eta\times\Delta\phi = 0.1\times0.1$
- In the digital trigger system, calorimeter cells are grouped into Super Cells (SCs) as small as $\Delta\eta\times\Delta\phi = 0.025\times0.1$
- Digital trigger system offers four-layer information and 10× granularity



Legacy trigger



Digital trigger

~5k trigger towers

~34K super cells

❖ 10 SCs per TT

LAr Readout Electronics

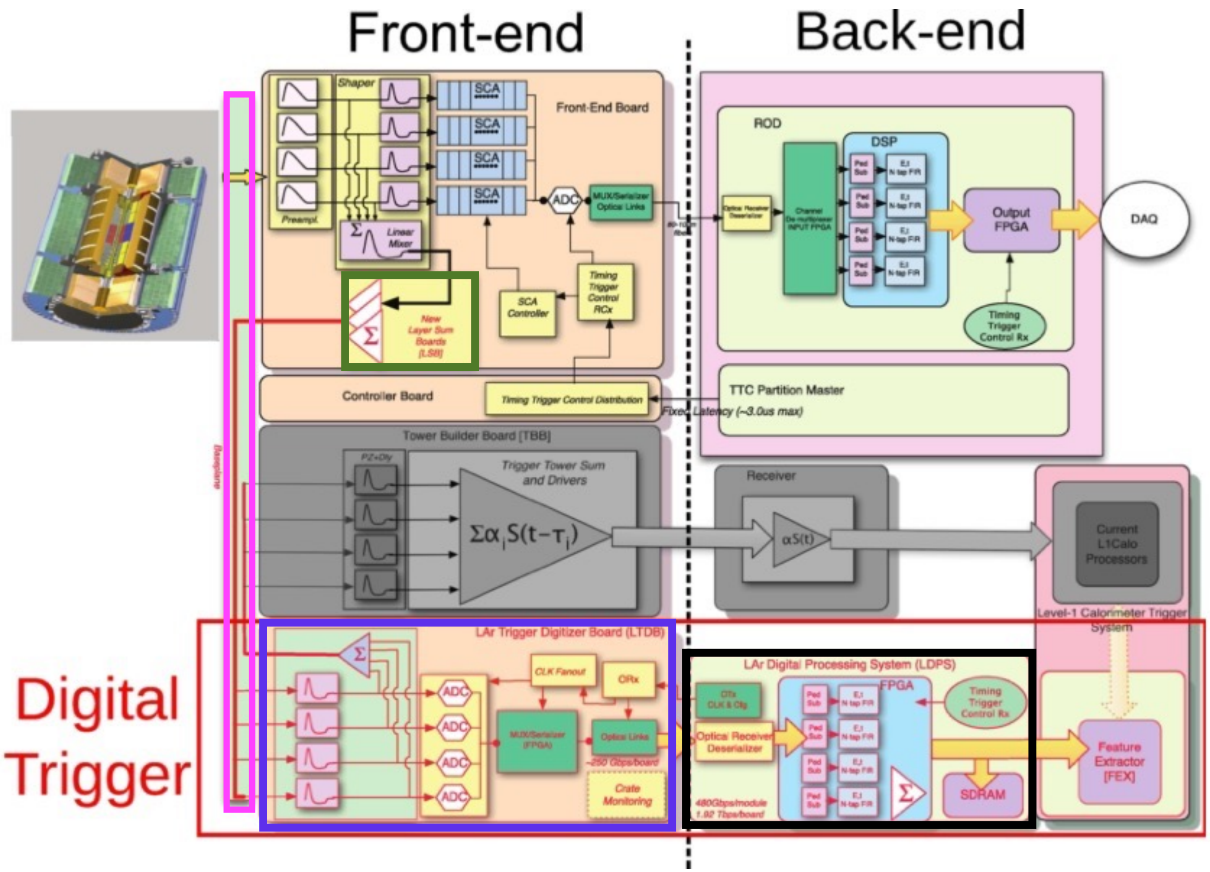
- **Analog trigger** is now decommissioned
- Front-end boards (FEBs) were refurbished and new digital trigger electronics were installed

New LSBs: sums analog cell signals, groups them into SCs, and sends them to LTDBs

New baseplanes: Transmit the increased number of signals from the FEBs to LTDBs

LAr Trigger Digitizer Boards (LTDBs): Digitize SC analog signals & sends them to LDPBs

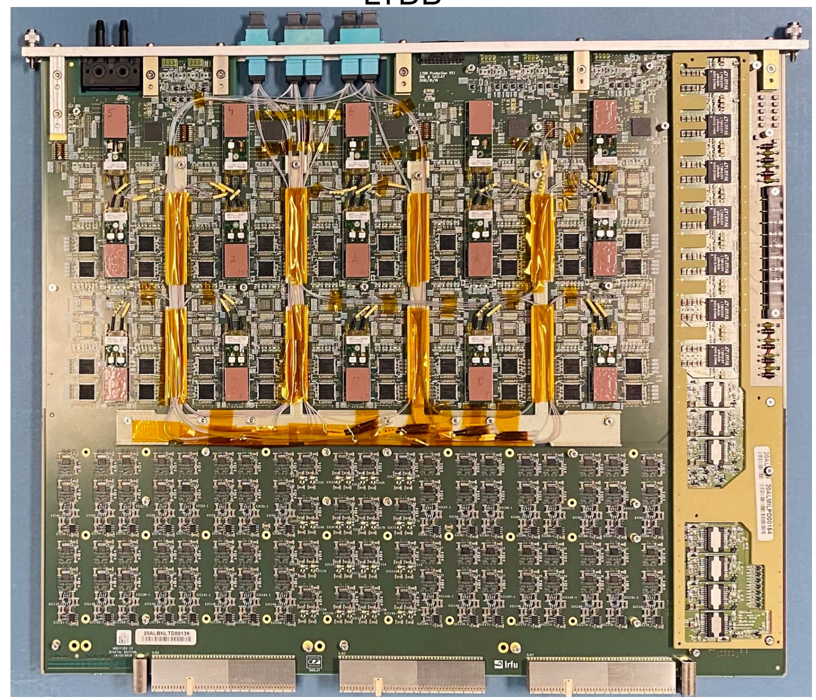
LAr Digital Processing Blade (LDPB): Computes SC energies (via LATOMEs) and sends them to the new L1 calorimeter (L1Calo) trigger system (FEXes)

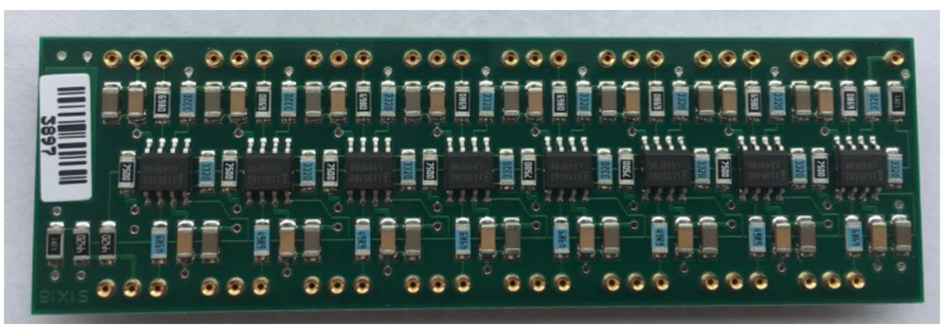


New Front – end Electronics

- **~1500 Front-end Boards (FEBs)**
  - refurbished and installed on the detector
- **114 baseplanes**
  - Link between LSBs and LTDBs
- **2328 Layer Sum Boards (LSBs)**
  - Sum analog signals (per layer), groups them into SCs, and transmits them to LTDBs

LTDB





LSB

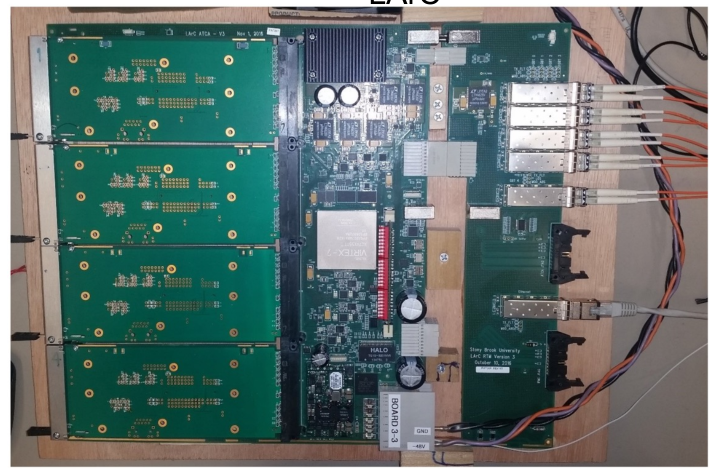
- **124 LAr Trigger Digitizer Boards (LTDBs)**
  - Digitize SC analog signals at 40 MHz
  - ~320 SCs processed per LTDB
  - Digitized SC signal is sent via 40 optical links to LDPBs on the back-end

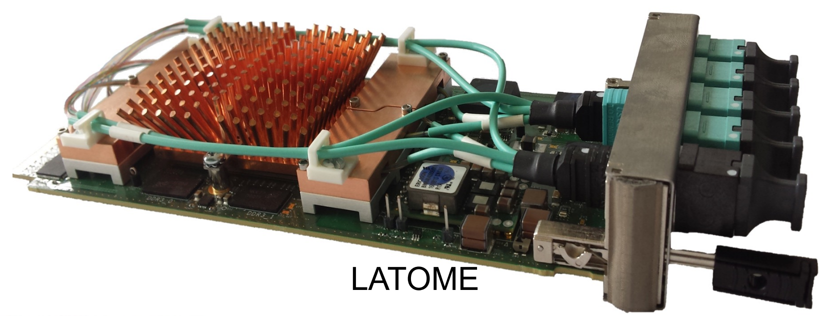
New Back – end Electronics

1 LDPB = 1 LAr Carrier (LArC) + 4 LAr Trigger processing MEzzanines (LATOMEs)

- **30 LAr Carriers installed**
  - Advanced Telecommunications Computing Architecture (ATCA) boards
  - Each LArC hosts 4 LATOMEs
- **116 LATOMEs installed**
  - Process digitized SC signals on Intel Arria 10 FPGAs
  - Transmits data, via 40 optical links, to the new L1Calo trigger system
- **Intelligent Platform Management Controllers (IPMCs)**
  - Plugged into each LArC for control and monitoring

LArC

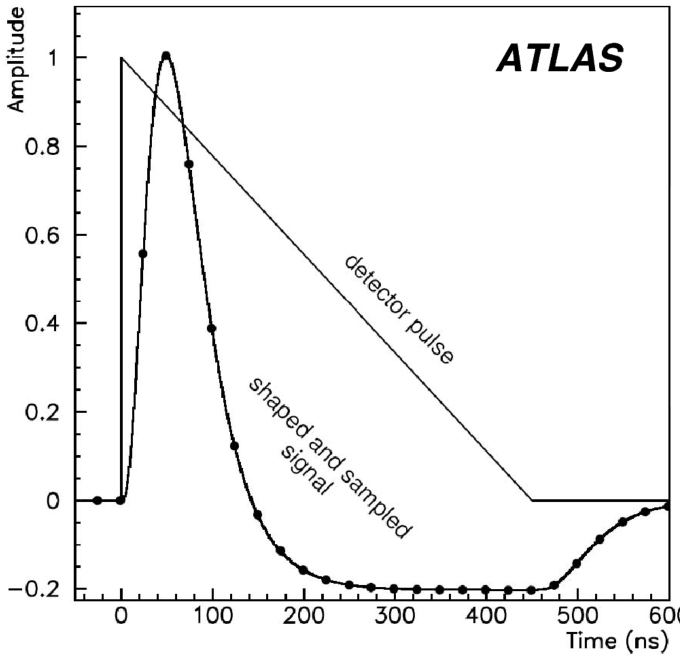




LATOME

Energy Computation

- When the liquid argon is ionized, ionization pulses are observed on calorimeter cells.
- Ionization current has a triangular shape and is proportional to the energy deposited.
- Signal is shaped and digitized by the front-end electronics
- Energy computation is then performed by the back-end electronics



- ❖ energy is estimated from the amplitude of the pulse, calibration constants and factors from test-beam data

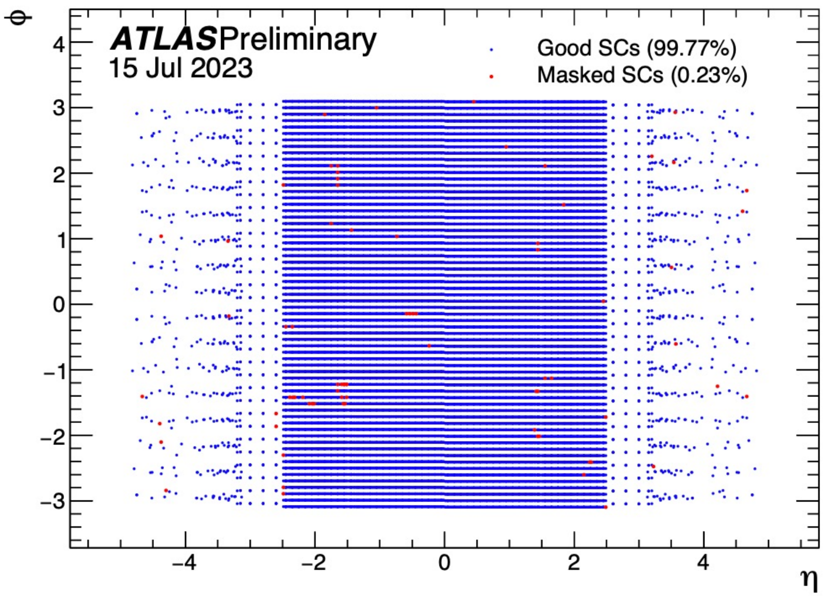
$$E_{\text{cell}} = F_{\text{DAC}\rightarrow\mu\text{A}} \cdot F_{\mu\text{A}\rightarrow\text{MEV}} \cdot \frac{1}{\frac{M_{\text{phys}}}{M_{\text{cali}}}} \cdot G_1 \cdot \sum_{i=1}^{N_{\text{samples}}} a_i (s_i - p)$$

- $F_{\text{DAC}\rightarrow\mu\text{A}}$: calibration board DAC to ionization current factor
- $F_{\mu\text{A}\rightarrow\text{MEV}}$: ionization current to energy conversion factor
- $M_{\text{phys}}/M_{\text{cali}}$: ionization to calibration pulse response
- G_1: gain
- $\sum a_i(s_i - p)$: amplitude; a= optimal filtering coefficients, S= digitized sample, p= pedestal

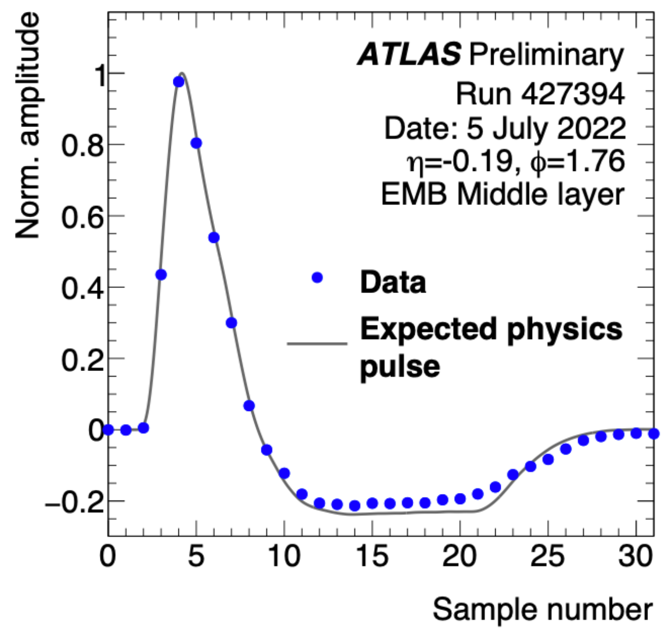
➢ Signal is sampled over a 100 ns time window
  - 1 sample every 25ns

Performance: SC coverage and Pulse Shape

- Digital trigger in full operation since the start of 2024 data-taking.
  - Performance plots not yet publicly available
- In 2023, digital trigger was used only for triggering on electrons and photons
- Commissioning since the start of LHC Run 3 (2022)

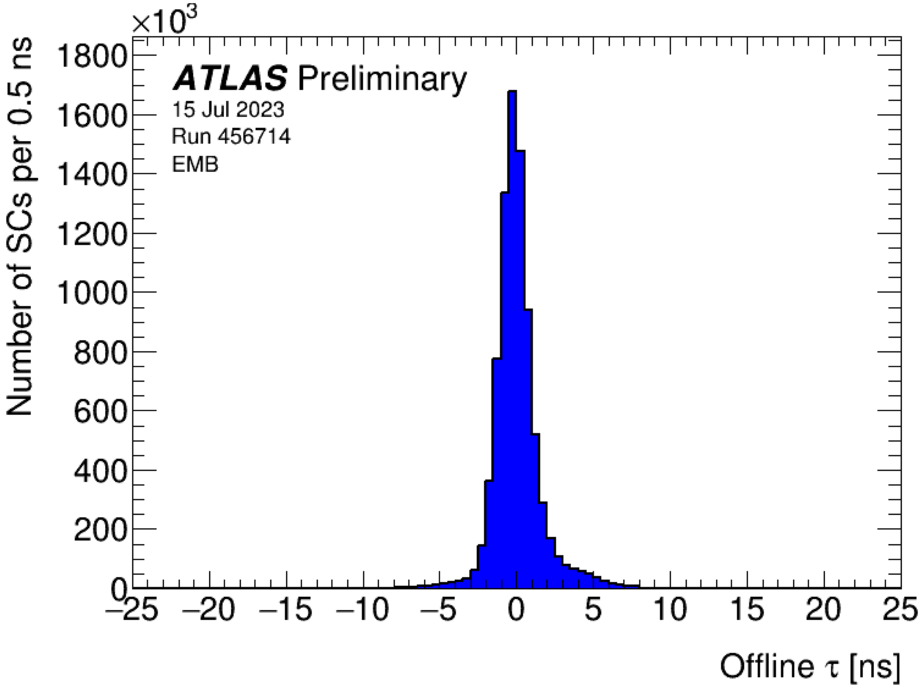


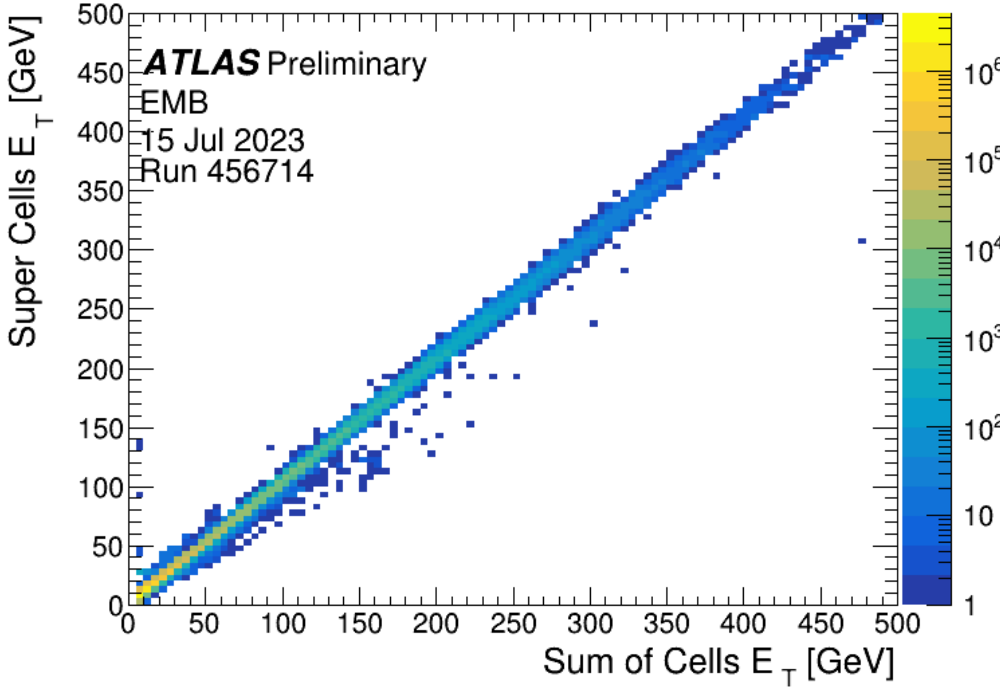
- Very good coverage for SCs: more than 99%
- Small fraction of problematic SCs
- ○ Note: Each point corresponds to one SC



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

Performance: Energy and Timing

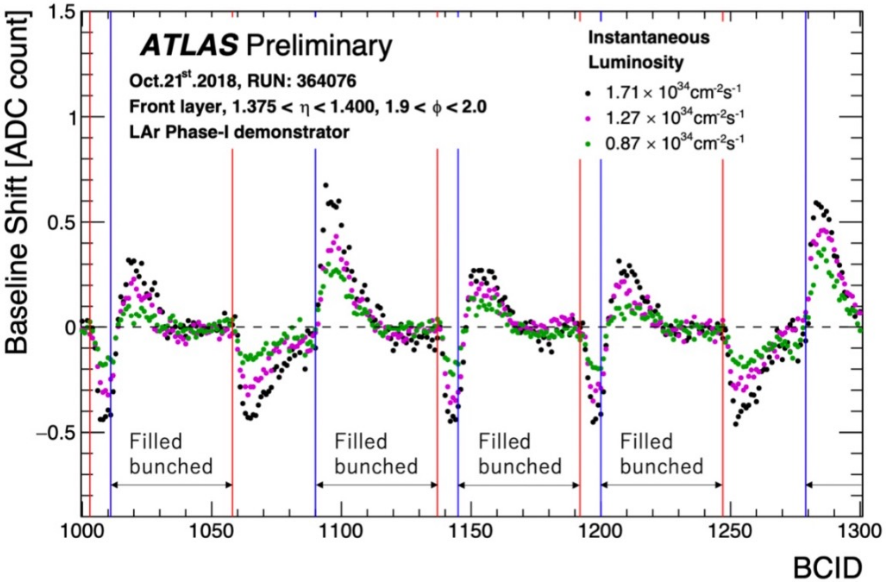


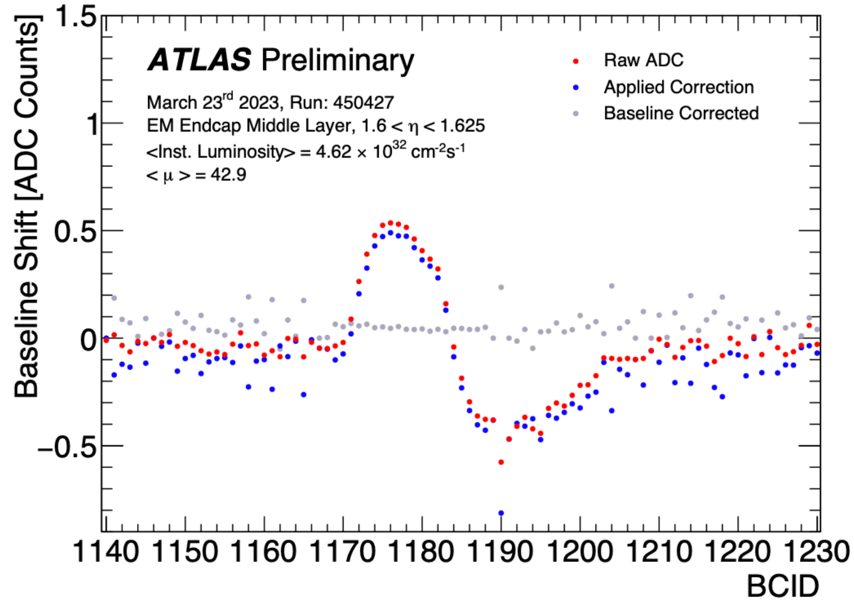


- τ: timing of the peak computed offline
- Narrow distribution centered at zero: overall good timing alignment
- Avoiding late or early triggers

- Super cell E_T (digital trigger) versus E_T from calorimeter cells (cell-by-cell)
- Very good agreement between the two

Challenges of the high pile – up environment

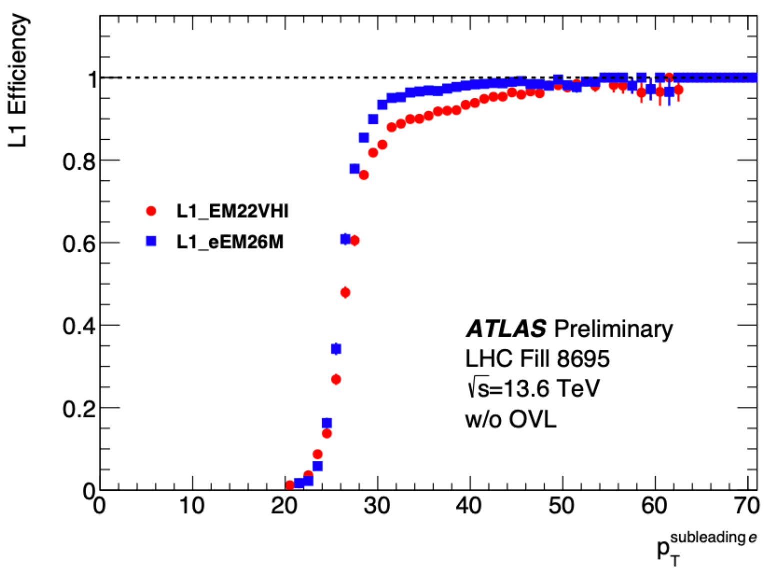


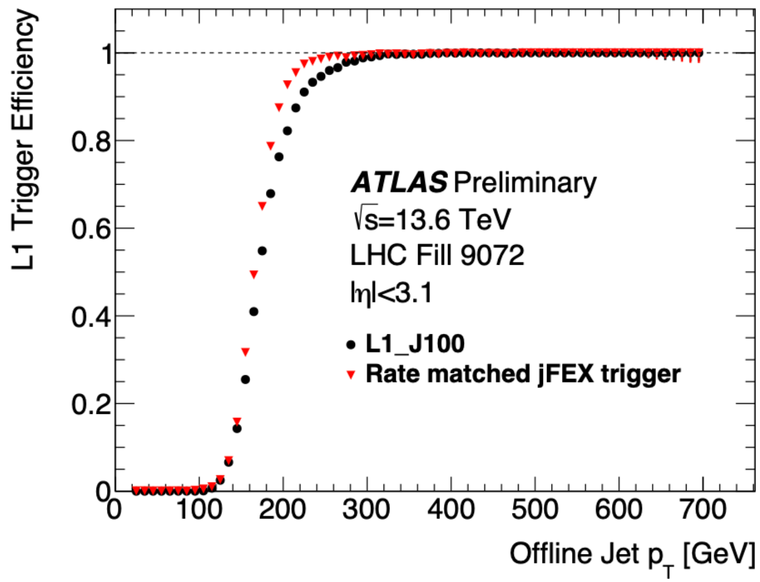


- LAr pulses are long since sampling is done over 100 ns
- Pulses can overlap due to out-of-time pileup, creating a baseline shift
  - Baseline: signal level when there’s no input. i.e zero-energy state of the calorimeter
- **A baseline correction** algorithm is implemented on the LATOME firmware
- Validated and deployed during high pile-up collision runs in 2023

Performance of the new L1Calo trigger

- The new ATLAS L1Calo trigger system uses fine granularity input from the LAr digital trigger to make trigger decisions with the same or better L1 output rate as the legacy system
- Uses 3 Feature EXtraction (FEX) processors;
  - eFEX: electromagnetic FEX
  - jFEX: jet FEX
  - gFEX: global FEX





- Sharper turn-on curves observed with the new L1Calo FEXes compared to the legacy triggers
- With the electron feature extractors (eFEX), ~10% reduction in L1 rate is observed compared to legacy
- With the jet feature extractors (jFEX), the same L1 rate is observed compared to legacy

Summary

- In Run 3 of the LHC, the ATLAS Liquid Argon calorimeter (LAr) has been equipped with a new digital trigger electronics system to cope with high pile-up conditions
- The LAr digital trigger provides the new L1Calo trigger with 10x more granular information than the legacy
- Full digital trigger system in operation since the start of 2024 data-taking and will remain in place for the HL-LHC
- Overall very good performance observed from both LAr and L1Calo!!

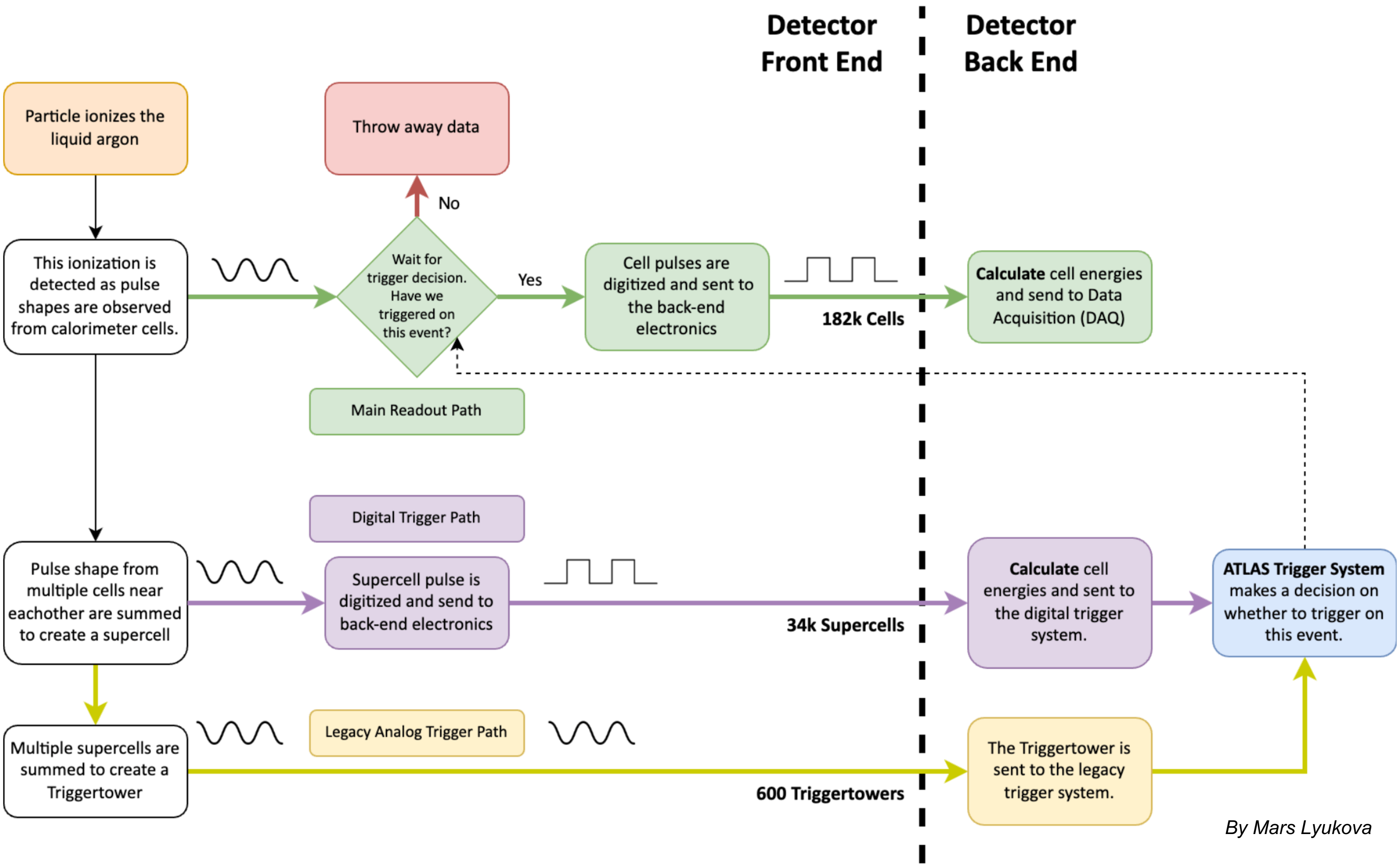
- The legacy analog trigger is now decommissioned
- Thanks to the remarkable work and commitment of the ATLAS LAr collaboration

Part of the LAr team in the ATLAS control room during 2022 data-taking

2024

Additional material

LAr Readout Electronics Overview



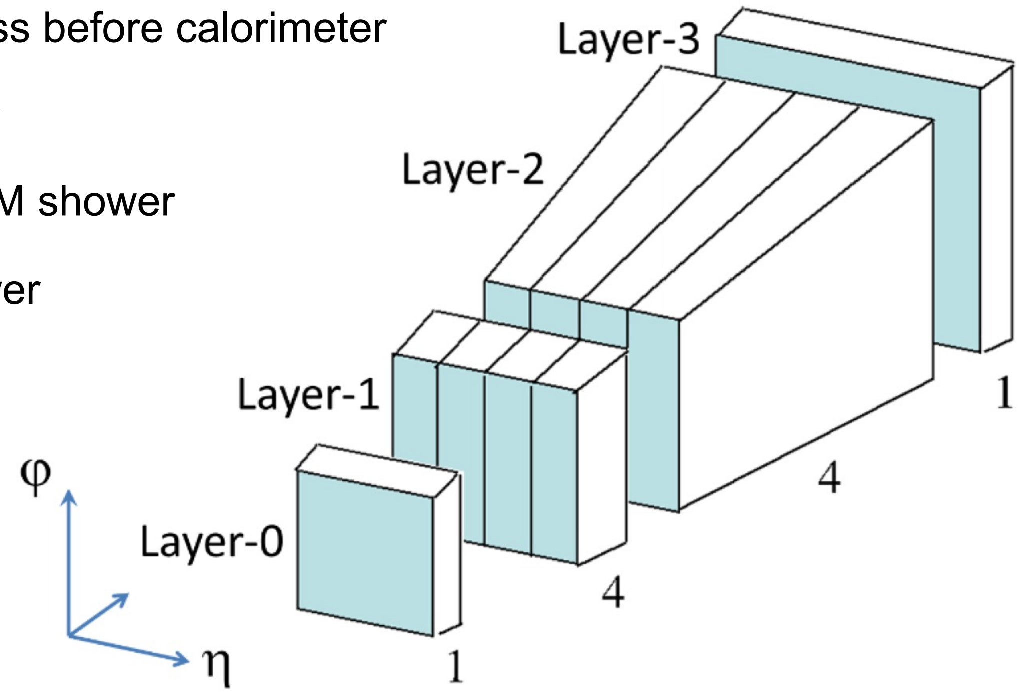
LAr Super Cells

Layer-0: presampler : measure energy loss before calorimeter

Layer-1: front layer : distinguish π^0 from γ

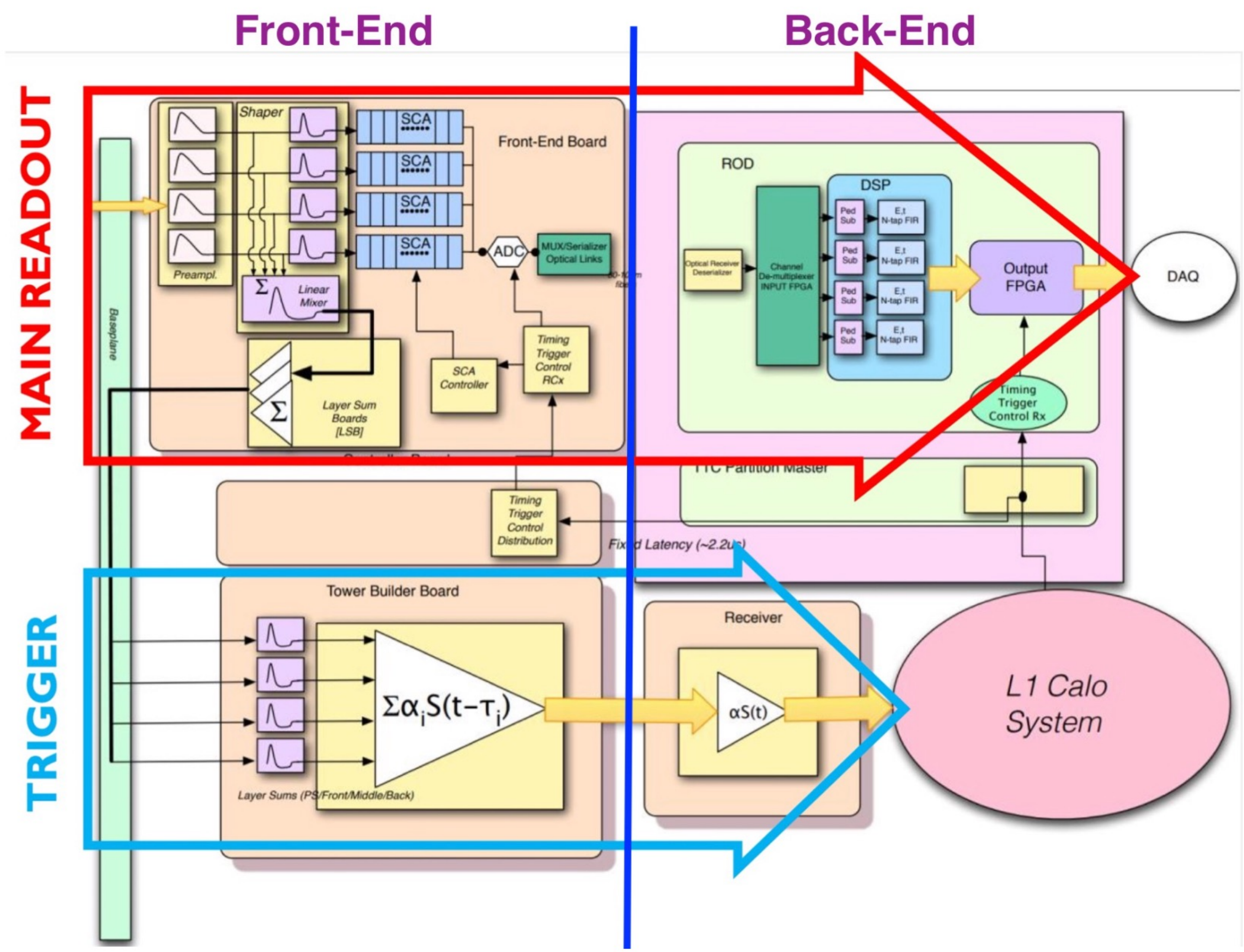
Layer-2: middle layer : contains bulk of EM shower

Layer-3: back layer : captures tail of shower



Legacy Trigger Electronics

- **Main readout path**: Front-End Boards send cell by cell information to Read Out Drivers (RODs)
- **Legacy trigger path**: Layer Sum Boards (LSBs) on the FEBs sent analog sums of cell information in each layer to Tower Builder Boards (TBBs) via baseplanes
- TBBs built analog trigger tower sums from all calorimeter layers and transmitted them to L1Calo receivers



Constants for energy computation

$$E_{\text{cell}} = F_{\text{DAC}\to\mu\text{A}} \cdot F_{\mu\text{A}\to\text{MEV}} \cdot \frac{1}{\frac{\text{M}_{\text{phys}}}{\text{M}_{\text{cali}}}} \cdot G_1 \cdot \sum_{i=1}^{N^{\text{samples}}} a_i \left(s_i - p\right)$$

$F_{\text{DAC}\to\mu\text{A}}$	=	sampling fraction, converts calibration board DAC counts to current
$F_{\mu\text{A}\to\text{MEV}}$	=	factor which converts ionisation current in the calorimeter to total deposited E, from test-beam studies
$\frac{\text{M}_{\text{phys}}}{\text{M}_{\text{cali}}}$	=	ratio of maxima of physical and calibration pulses with the same input current
G_1	=	cell gain - ADC to DAC from calibration pulse
a_i	=	Optical Filtering Coefficients (OFCs), derived from predicted pulse shape & noise autocorrelation
s_i	=	samples of the shaped signal digitised in a given electronic gain, measured in ADC counts
p	=	read-out electronic pedestal, measured for each gain