ATLAS LAr Calorimeter Commissioning for LHC Run-3

TWEPP 2023
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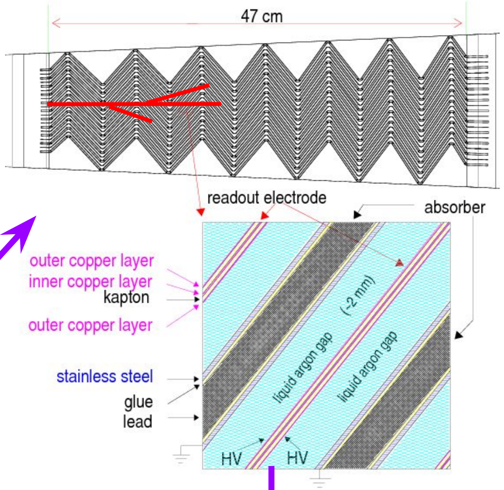
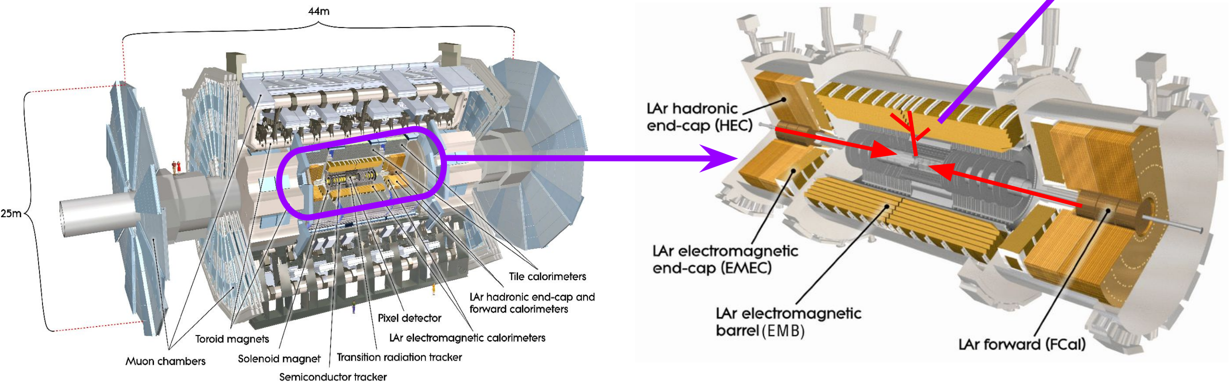
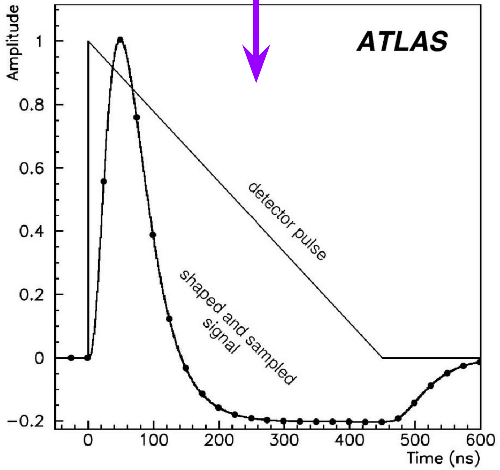
On behalf of the Liquid Argon Calorimeter Group

ATLAS Liquid Argon Calorimeter

- Used to measure the energies of electromagnetic particules (photons, electrons) and hadronic particules in forward region
- Provides signals of triggering
    - 40 million events per second
    - Electromagnetic shower ionised the liquid Argon
    - Induces triangular electric signal in electrode







LHC to HL-LHC

Increase in luminosity in two phases in 2022 and 2029 to reach the HL-LHC

- Run 3 μ = 50
- Run 4 μ = 200

Requires an upgrade of the detectors

- The triggering system for the ATLAS Liquid Argon Calorimeter (LAr) was replaced during phase-I

Phase-I of the LAr upgrade

A new LAr trigger system for high pile-up environment with a total of 34048 SCs.

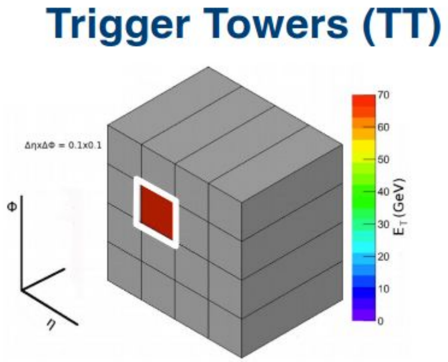
- Finer granularity than Trigger Towers.
- Better trigger energy resolution.
- Higher efficiency in selecting physics objects.

Trigger Tower (TT)

- No longitudinal segmentation
- Fixed size in $\Delta\eta \times \Delta\varphi = 0.1 \times 0.1$
- Up to 60 cells from 4 layers
- Only ~5.4k TT from 180k cells
- Analog trigger

Super Cells (SC)

- Lateral & longitudinal segmentation
- Increased granularity in Front and Middle to $\Delta\eta \times \Delta\varphi = 0.025 \times 0.1$
- Up to 8 cells from 1 layer
- ~34k SC from 180k cells
- Digital trigger



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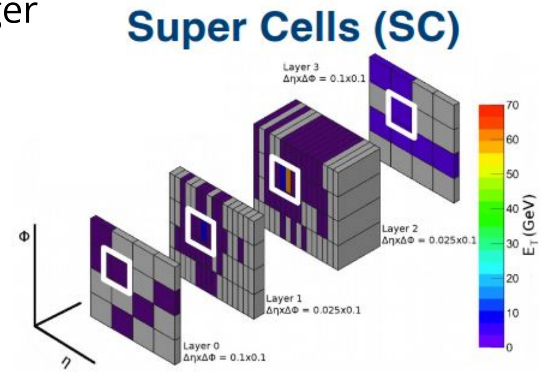


New electronics for Phase-I

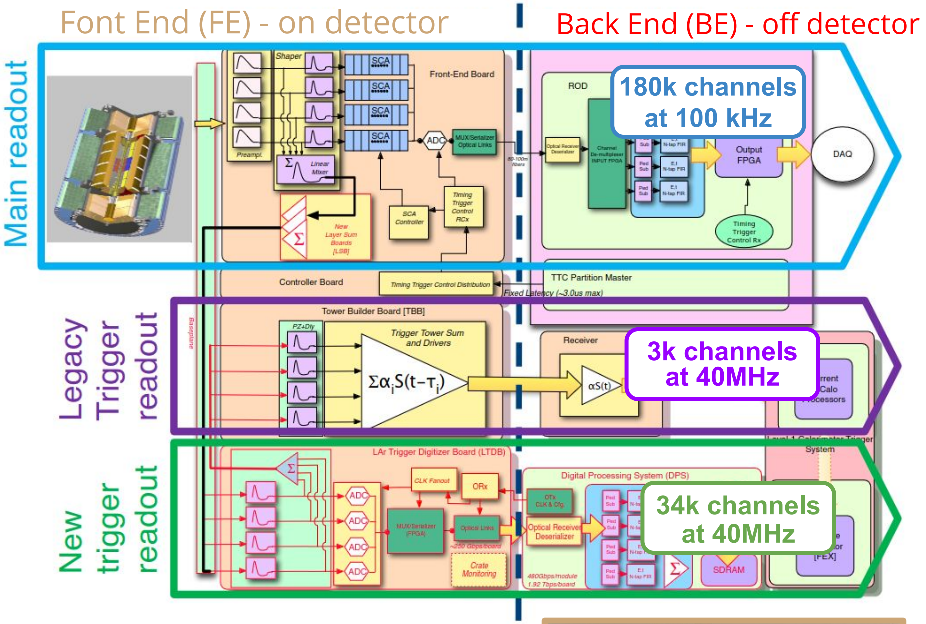
The entire readout system is affected by this upgrade

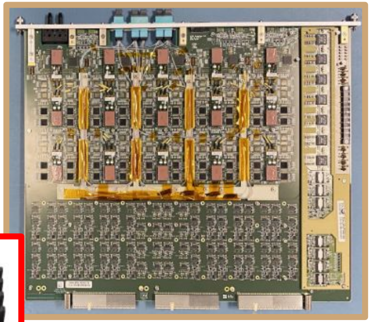
The front end electronics of the legacy trigger was dismantled then reassembled, some components replaced:

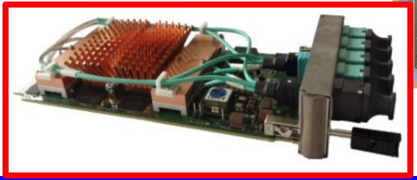
- Baseplane
- Front End Board
- Layer Sum Board

New cards added for the digital trigger

- LAr Trigger Digitizer Board
  - 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
- LAr Digital Processing System
  - LAr Carrier
  - LAr Trigger prOcessing MEzzanine
    - 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.







LTDB phase selection

To be able to decode the data received by the LATOME from the LTDB

- 320 MHz clk from PLL and GBTx clk should not be in phase

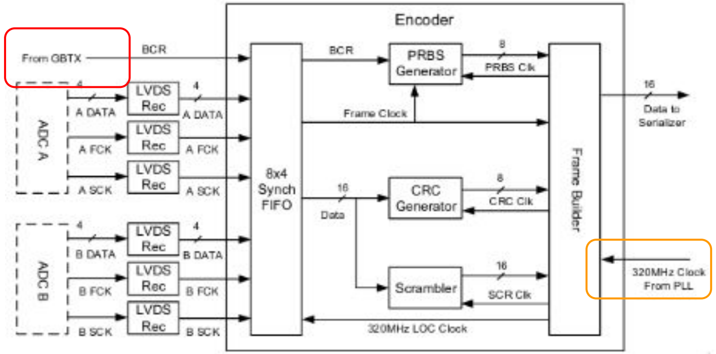
Develop a calibration to choose the delay between the 2 phases:

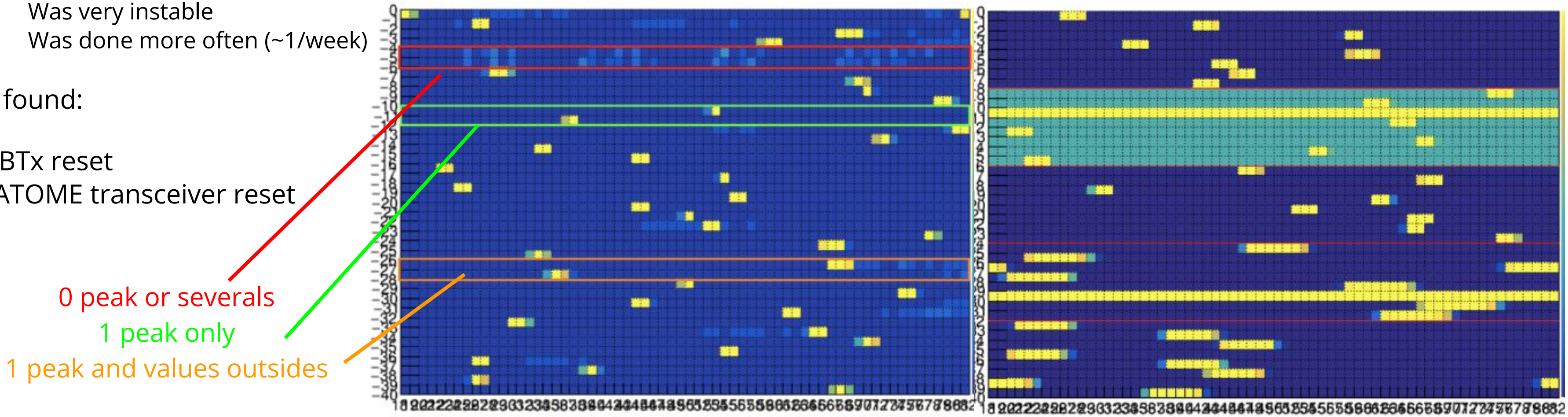
- Works per pair of fibers (1 LOCx2)
- For each delay → look at the number of errors received by the LATOME
  - If errors are received → delay is tagged as wrong
- 64 delays in total
- Should be done after each power cycle
  - Was very instable
  - Was done more often (~1/week)

Solution found:

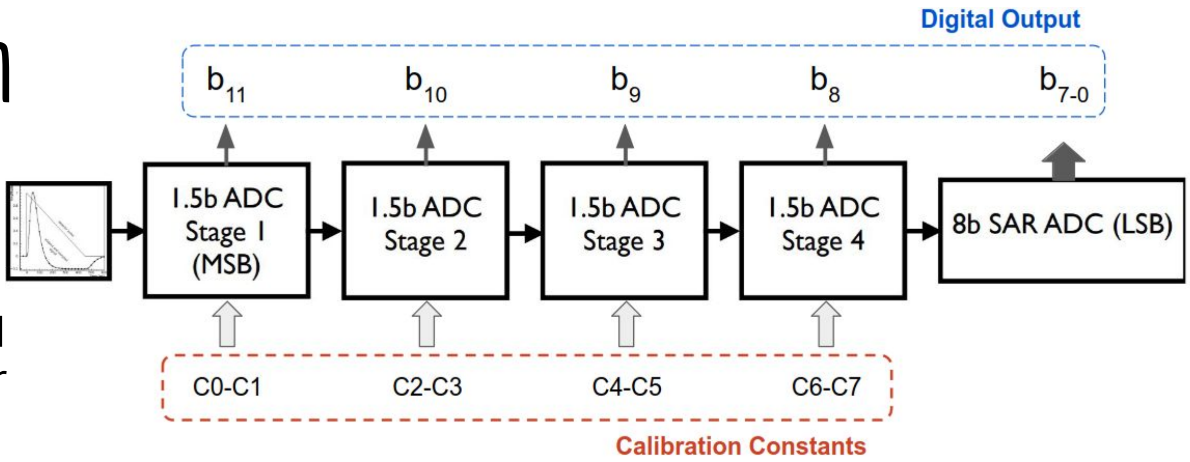
- GBTx reset
- LATOME transceiver reset

LOCic encoder

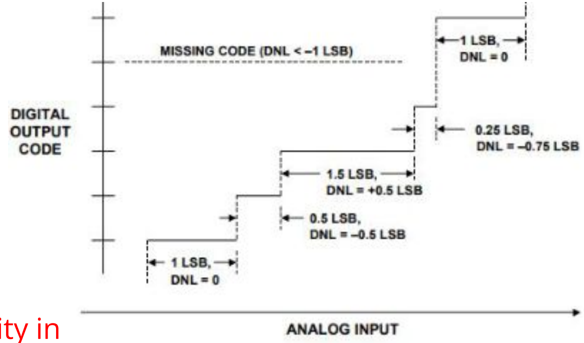




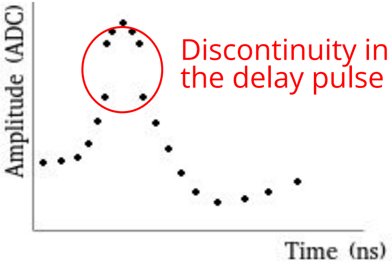
LTDB ADC calibration



- NevisADC is a pipeline ADC
  - 4 stage of 1.5 bit MDACs
  - 8 bit SAR ADC
- Calibration constants are loaded in the MDAC units to account for gain errors



- Miscalibration can cause Differential Nonlinearity (DNL) errors $\longrightarrow$ will be perceived as ADC jumps in the digitized signal
- DNL is nonlinearity of the code transitions of the converter It can be measured as the deviation of quantization steps from 1 LSB



The new calibration constants solve all ADC jumps !

LATOME firmware

Input: 5.12GHz/fiber
40 fibers

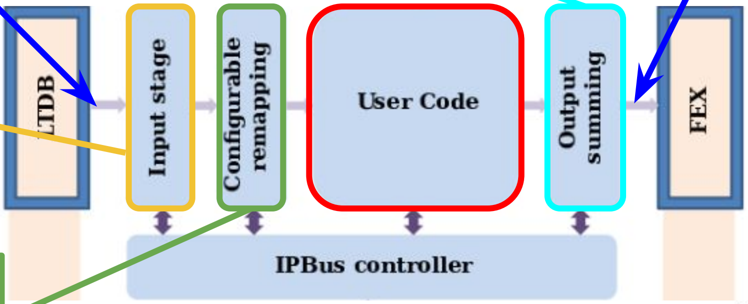
8 SCs x 16bit = 128 bit sent as 1 frame at 320MHz

Frequency is reduce to 240MHz
Mapping in function of SCs

Energy reconstruction
Bunch Crossing identification
Baseline correction
Saturation detection

Sum SCs for triggering

Output: 11.2GHz/fiber
40 fibers



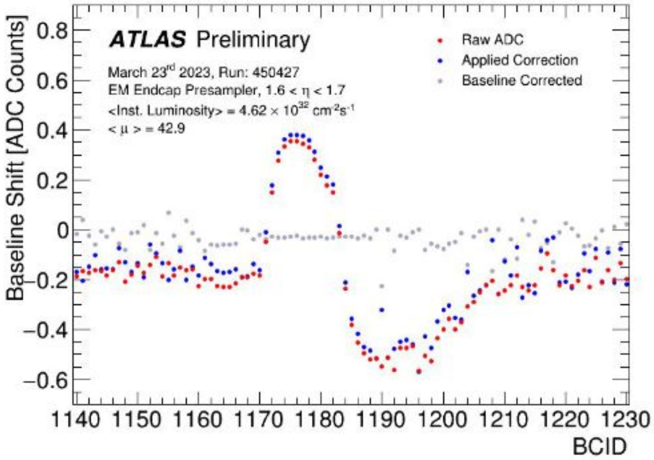
$$E_T = \sum_{i=0}^{3} \widetilde{A}_i (S_i - p - b)$$

$$E_{T}\tau = \sum_{i=0}^{3} \widetilde{B}_i (S_i - p - b)$$

Si ⟶ ADC samples from LTDB
P ⟶ Pedestal level (Cool DB)
b ⟶ Baseline correction
Ai and Bi ⟶ OFCs (Cool DB)

FPGA resource occupancy

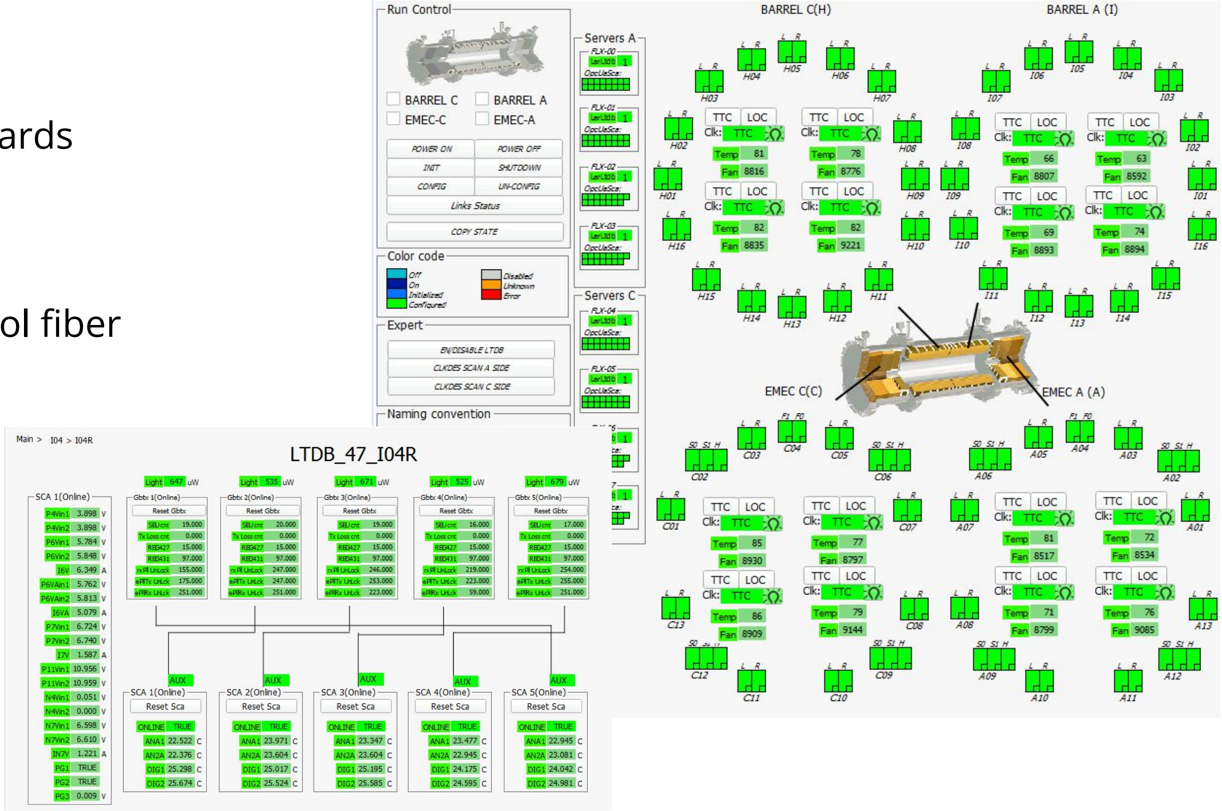
- 91% of logic unit
- 95% of block memory



Digital Trigger front end slow control & monitoring

LTDB 124 boards

- Control:
  - Configuration of all the boards
  - Calibration
  - General status
- Monitoring:
  - Optical power of the control fiber
  - Tension/current
  - Fan speed
  - FPGA temperature
  - SCA temperature/register
  - Data fiber status



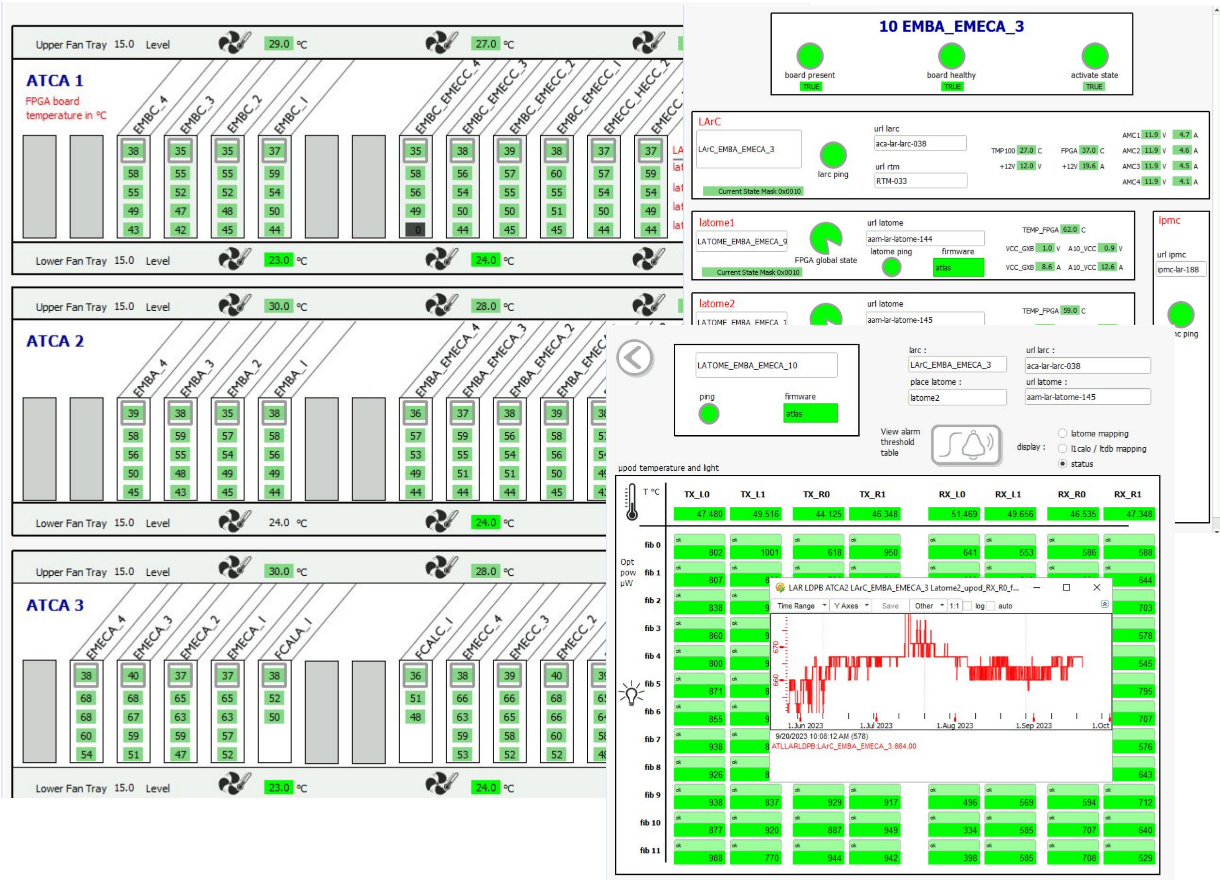
Digital Trigger back end slow control & monitoring

ATCA crate

- Fan speed level
- Region temperature (left, center, right)
- Rack temperature

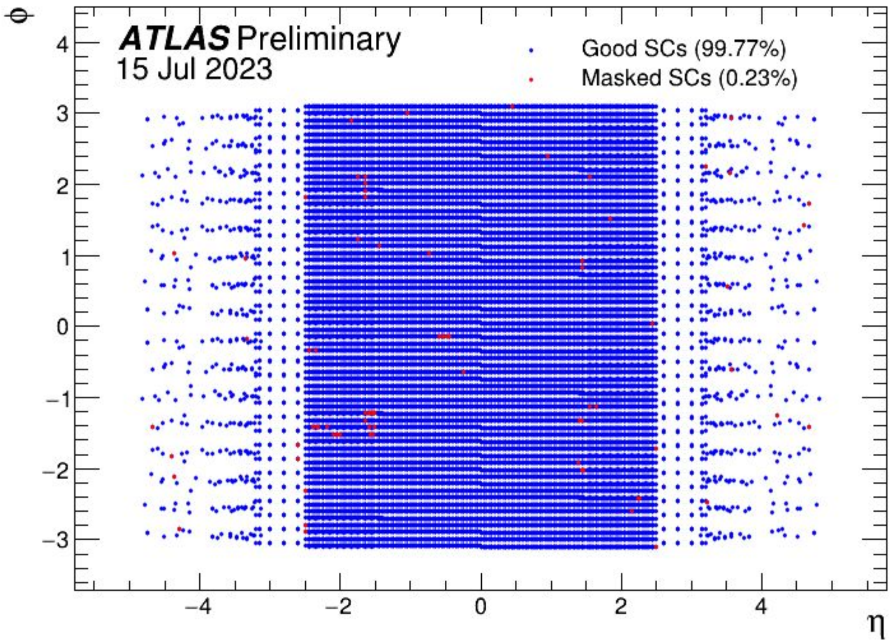
LDPB boards

- Monitoring:
  - State
    - ID
    - Ping
    - Firmware
  - Tension/current
  - FPGA temperature
  - Optical power data fiber



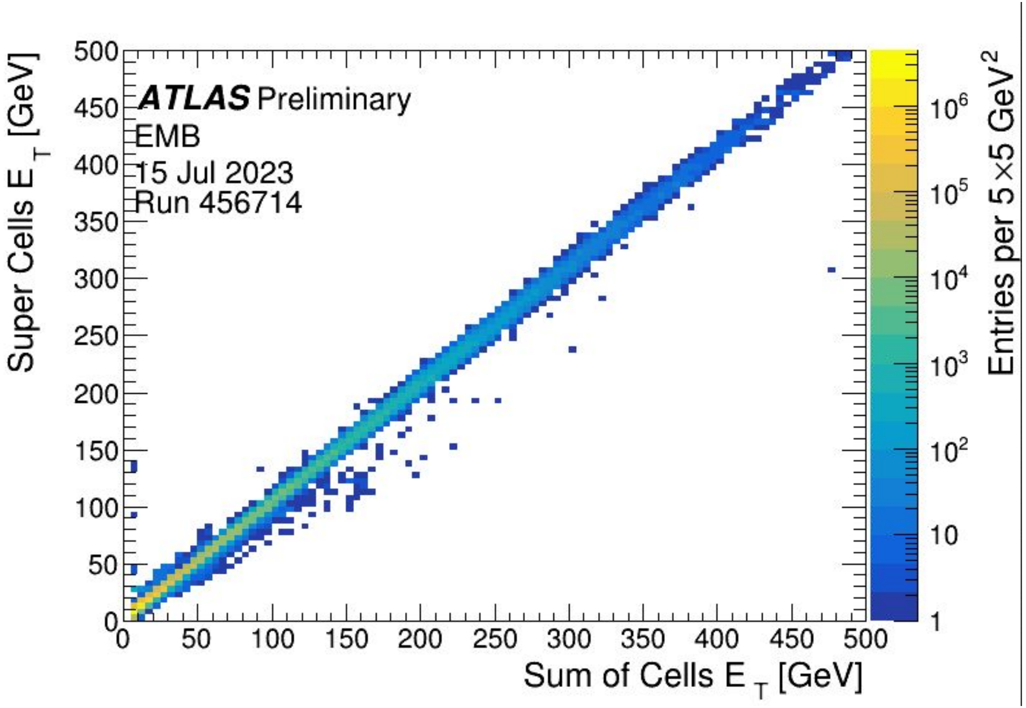
Digital Trigger status

- SC status reported on 15 July 2023 for a pp collision run at $\sqrt{s}$ = 13.6TeV
- 99.7% of SCs (33970 out of 34048) show (in blue) have no issues and return the expected timing and energy
- 78 SCs (in red) are dead, it comes from known problematic Digital Trigger Front End Board channels (LTDBs or with known calibration issues)



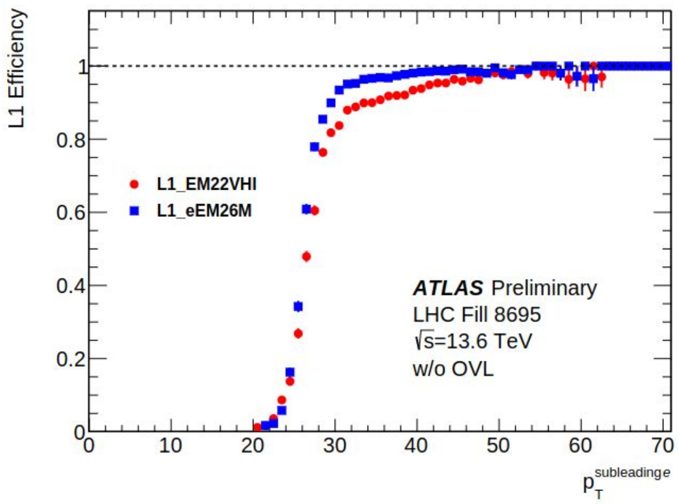
Energy comparisons DT - main readout

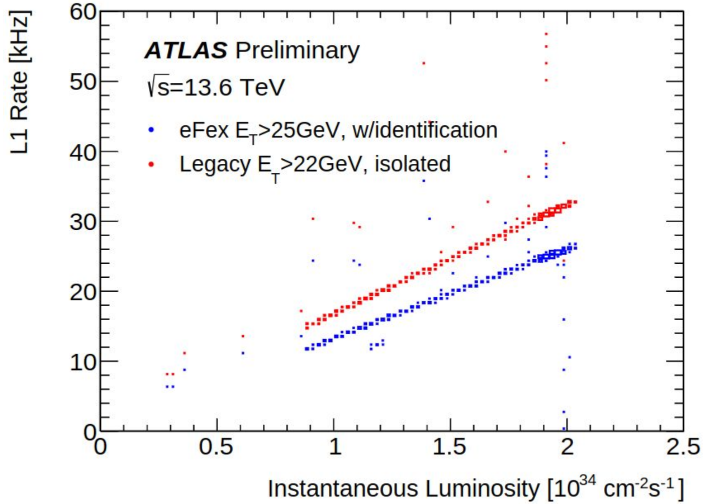
- Supercells transverse energies (*E_T*) are compared to the sum of the corresponding LAr cells in the main readout
- The data from the run with the pp collision at $\sqrt{s}$ = 13.6 TeV on 15 July 2023 is used for the comparison
    - Bad SCs are not included
    - A good agreement is observed between the two readouts



Phase-I trigger performance

- Cell energies correspond well between calorimeter cells and SCs
- The single electron triggers for the legacy system and the Phase-I system are compared
- Phase-I EM trigger item shows better performance:
  - Sharper efficiency turn-on curve
  - Lower trigger rate (~80% of legacy EM item) at the same ET threshold
- Phase-I EM items used as primary trigger now
- Plan to turned on the rest of the phase-I system beginning of 2024





Summary

- The LAr digital trigger system has been installed in the long shutdown 2 of LHC and is going to replace the legacy trigger system in 2024
    - Phase-I EM trigger item enabled since May 2023
- The main readout of LAr is also working well
- More than 99% of SCs are functional for the trigger system

Next step

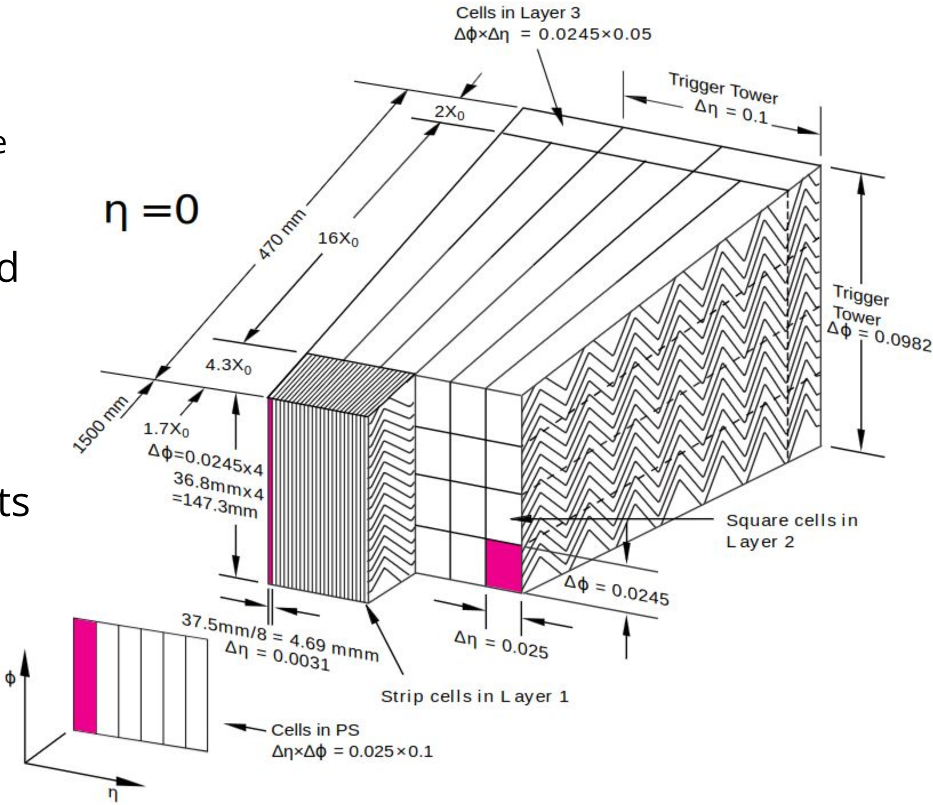
- Enable Phase-I trigger for all items and decommissioned the legacy trigger for the restart of run 3 in 2024

Thank you for your attention

Any questions ?

LAr calorimeter layers

- LAr cells are the readout units with the finest granularity
  - The size of LAr cells is varying in different parts of the calorimeters
  - In total there are **182418** LAr cells
- The readout units for the trigger are composed of the sum of LAr cell signals call trigger tower $\Delta\eta \times \Delta\varphi = 0.1 \times 0.1$
  - A new trigger system was introduced in Run 3 with a smaller units
- The barrel electromagnetic calorimeter consists of:
  - **Presampler**: correction of the energy loss caused by dead material
  - **Front layer**: fine granularity along η
  - **Middle layer**: most of energy deposit
  - **Back layer**: recovery of e/γ longitudinal energy leakage



Legacy readout electronics

The readout system is composed of front-end (on detector) and back-end (off detector) electronics.

<u>Front-end:</u>

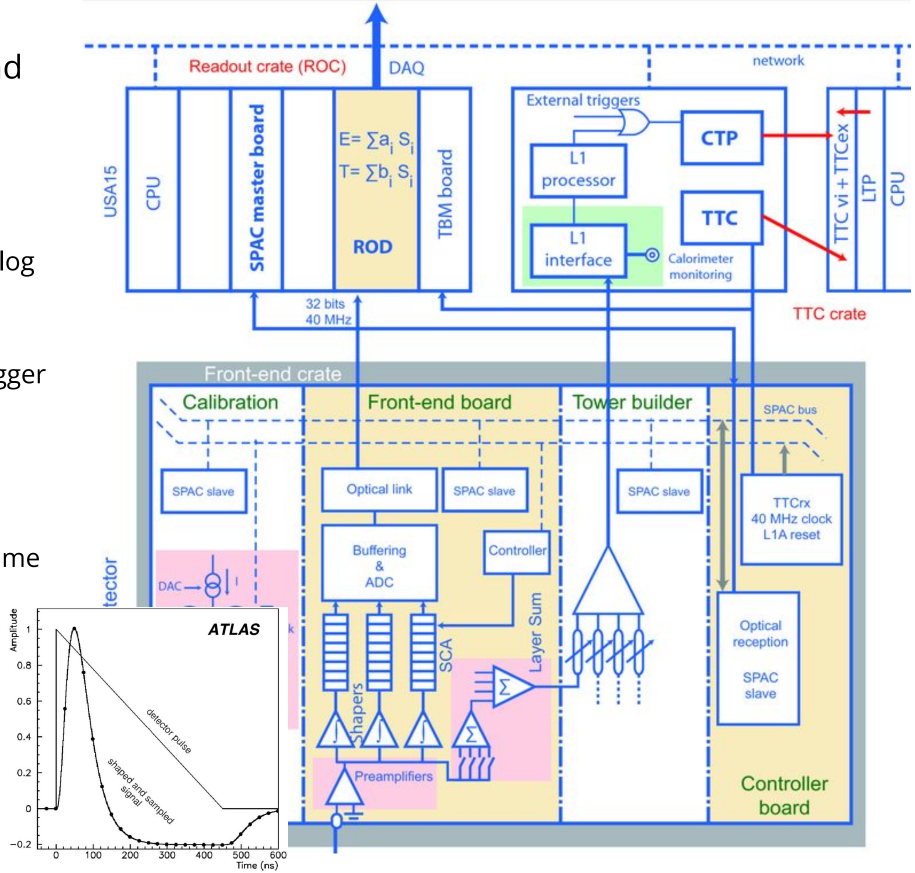
- **Front End Boards (FEBs):**
  - Analog signals from LAr cells are amplified, shaped to bipolar analog signals, and digitized using 12-bit ADC.
  - **Layer Sum Boards** (LSB) on FEBs sum the analog signals.
- **Tower Builder Boards (TBBs):**
  - Analog signal sums from LSB are received in TBB, which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

<u>Back-end:</u>

- **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 trigger towers are sent to L1Calo, which identifies physics objects and sends the results to the Central Trigger Processor (CTP).

Main readout: FEB → ROD

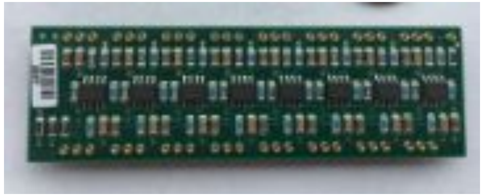
Legacy trigger: LSB → TBB → L1Calo



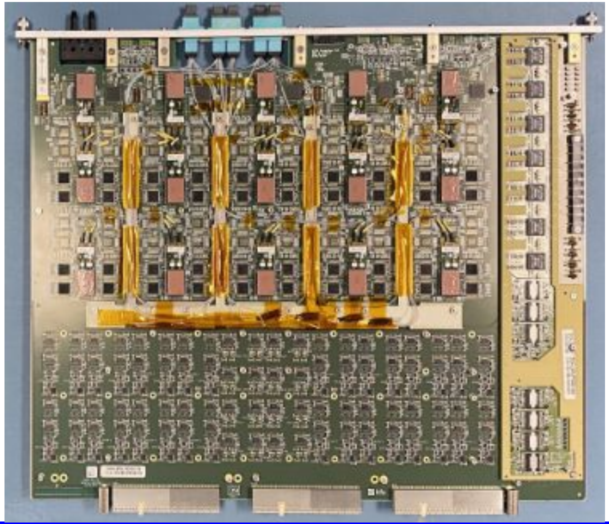
Front-end electronics

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

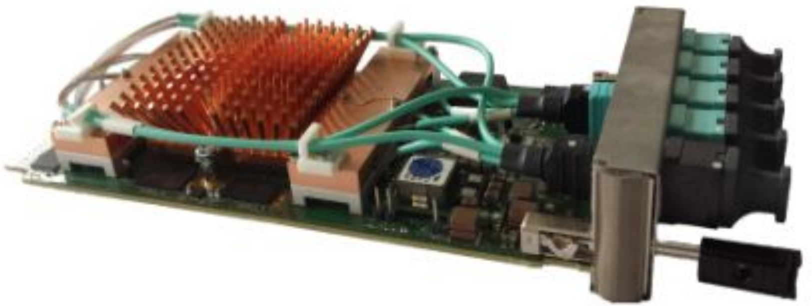
Layer Sum Board (LSB):
A plug-in card of the FEB provides a sum of analog signals for SCs. 2328 LSBs are replaced.



LAr Trigger Digitizer Board (LTDB):
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



Intelligent Platform Management Controller (IMPC):
Manage the power, cooling, and interconnect needs of intelligent devices.

LAr Trigger prOcessing MEzzanine (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):
Transmit data from LATOMEs to the readout system, distribute clocks and trigger signals synchronized to the LHC beam clock. 30 LArCs are installed.

Performance of the LAr calorimeter

These plots show the summed energies for a beam splash event from March 2023

- LAr cell energy sums distributed in a hypothetical tower grid with $\Delta\eta \times \Delta\phi = 0.025 \times 0.025$
- The particles were delivered by Beam 1 (B1) and entered from the positive η (A) side