PROCEEDINGS OF SCIENCE

ATLAS LAr Calorimeter Commissioning for LHC Run-3

Huacheng Cai, on behalf of the ATLAS Liquid Argon Calorimeter Group[a,*]

[a] *University of Pittsburgh,*
4200 Fifth Ave, Pittsburgh, PA 15260, USA

E-mail: huacheng.cai@cern.ch

The Liquid Argon Calorimeters are employed by ATLAS for all electromagnetic calorimetry in the pseudo-rapidity region $|\eta| < 3.2$, and for hadronic and forward calorimetry in the region from $|\eta| = 1.5$ to $|\eta| = 4.9$. They also provide inputs to the first level of the ATLAS trigger. After successful period of data taking during the LHC Run-2 between 2015 and 2018 the ATLAS detector entered into a long period of shutdown. In 2022 the LHC will restart and the Run-3 period should see an increase of luminosity and pile-up up to 80 interactions per bunch crossing.

To cope with this harsher conditions, a new trigger readout path has been installed during the long shutdown. This new path should improve significantly the triggering performances on electromagnetic objects. This will be achieved by increasing the granularity of the objects available at trigger level by up to a factor of ten.

The installation of this new trigger readout chain required also the update of the legacy system. More than 1500 boards of the precision readout have been extracted from the ATLAS pit, refurbished and re-installed. The legacy analog trigger readout that will remain during the LHC Run-3 as a backup of the new digital trigger system has also been updated.

For the new system 124 new on-detector boards have been added. Those boards that are operating in a radiative environment are digitizing the calorimeter trigger signals at 40MHz. The digital signal is sent to the off-detector system and processed online to provide the measured energy value for each unit of readout. In total up to 31Tbps are analyzed by the processing system and more than 62Tbps are generated for downstream reconstruction. To minimize the triggering latency the processing system had to be installed underground. The limited available space imposed a very compact hardware structure. To achieve a compact system, large FPGAs with high throughput have been mounted on ATCA mezzanines cards. In total no more than 3 ATCA shelves are used to process the signals from approximately 34000 channels. Given that modern technologies have been used compared to the previous system, all the monitoring and control infrastructure is being adapted and commissioned as well.

This contribution will present the challenges of the installation, the commissioning and the milestones still to be completed towards the full operation of both the legacy and the new readout paths for the LHC Run-3.

41st International Conference on High Energy physics - ICHEP2022
6-13 July, 2022
Bologna, Italy

[*] Speaker

https://pos.sissa.it/

PoS(ICHEP2022)667

1. Introduction

This proceeding describes the most recent status of the ATLAS Liquid Argon (LAr) calorimeter commissioning for LHC Run-3. In order to handle the increased instantaneous luminosity for Run-3 and the upcoming high luminosity LHC, a new trigger readout path has been installed. This new trigger readout path provides a higher granularity as a factor of 10 to implement more advanced trigger algorithms. The full commissioning work has been accomplished during the LHC long shutdown from 2019 to early 2022. The installation procedure for both frontend and backend electronics will be shown, as well as the data taken during the LHC pilot beam.

As one of the major calorimeter system of the ATLAS detector, the LAr calorimeter is composed by four major components, including EMB and EMEC as electromagnetic calorimeter for both barrel and endcap region, HEC as hadronic calorimeter for the endcap region, and FCAL as forward calorimeter. A schematic view of the different sub-detectors components is shown in Figure 1. For the most parts of the subdetector, the longitudinal segment comprises four layers, as a presampler, which measures the energy loss before calorimeter, a front layer with fine segmentation to distinguish π_0 from γ, a middle layer which is the deepest layer and takes most of the EM shower deposition, and a back layer which catches the tail of the EM shower.

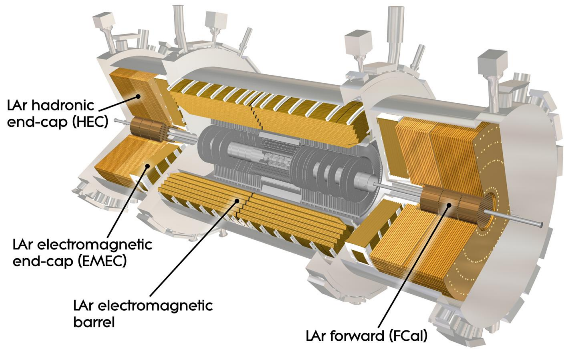

Figure 1: Cut-away view of the ATLAS Liquid Argon calorimeter system [1] [2].

2. Legacy analog trigger system

During the LHC Run-2, the operation of LAr was a huge success. The average data taking efficiency is above 99%, comparing to the overall data taking efficiency by ATLAS is 93%. The readout system used during the Run-2 is called legacy system, which is triggered by analog signals. Totally 1524 frontend boards (FEBs) are installed on the detector. Each FEB contains up to 128 channels, split by different gain scales (low/medium/high) and shapes. The triangular pulse will be shaped at 40MHz and stored in a buffer. The signal will be further sent to the level-1 calorimeter trigger (L1Calo) system. The trigger decision in the legacy system is based on 5.4k trigger towers (TT) built from 180k LAr cells, as shown on the left part of Figure 2. Once the TT energy satisfies certain threshold, an L1-accept (L1A) signal will be sent back to FEB, which will select the proper gain and transmit data to readout drivers (RODs), and further to ATLAS DAQ system for high level trigger (HLT) decisions.

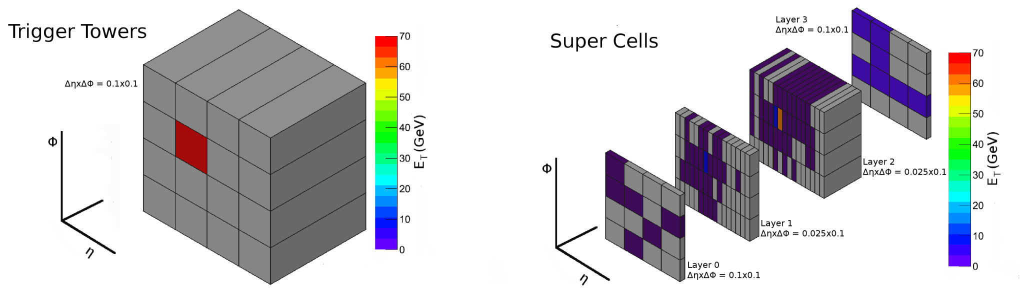

Figure 2: An electron with E_T = 70GeV as seen by the existing Level-1 Calorimeter trigger electronics (left), and by the proposed upgraded trigger electronics (right), in which the granularity is improved by a factor of 10 [3].

3. Digital trigger system

3.1 Motivation

Even with the expected increase of instantaneous luminosity and pile-up for Run-3, the sustainable L1 trigger rate for ATLAS remains the same as Run-2, which is 100 kHz at maximum, and 20 kHz for electrons and photons. Therefore new trigger algorithms are required. According to early studies, Figure 3 shows that the algorithms using shower shape variables such as R_η, $w_{\eta,2}$, f_3 can better distinguish electrons and jets, and remain at low E_T threshold at the same trigger rate of Run-2. However, as mentioned in Section 2, the energy in all four detector layers is summed, hence the shower shape information will be lost. Therefore, the concept of supercell is introduced for the Phase-I upgrade, as shown in the right part of Figure 2. Totally 34k supercells are summed by 180k LAr cells, which, compared to trigger towers, get finer granularity for triggering by a factor of 10. The resolution in the front and middle layers are increased, and E_T in each layer is retained to access the longitudinal shower shapes. Last but not least, instead of using analog signals, the Phase-I system moves to digitised signals, named as digital trigger system.

3.2 Electronics

In early Run-3, both legacy and digital trigger systems will be running concurrently in case of unforeseen issues. Figure 4 shows the sketch of the full electronic path, where the digital trigger system-related items are highlighted in red outlines and arrows. On the frontend electronics, the new layer sum boards (LSB) are installed for summing calorimeter cells into super cells. The baseplanes are replaced to handle the increased transmission of signals. LAr Trigger Digitizer boards (LTDBs) are the new boards on frontend dedicated to digital trigger, which digitise super cell signals and send them to backend electronics. And on the backend side, LAr Digital Processing Blades (LDPBs) will reconstruct transverse energy and send it to L1Calo Phase-I system.

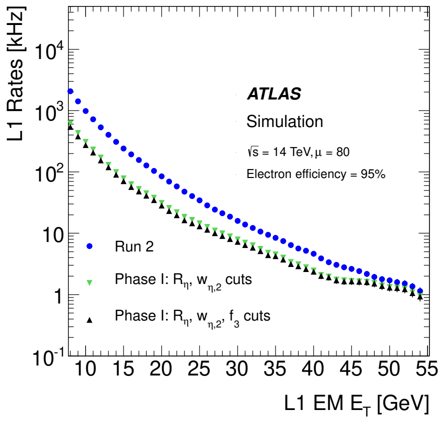

Figure 3: Level-1 trigger rates for a 95% electron efficiency as a function of the EM E_T threshold assuming Run-2 conditions (blue points) and for Run-3 conditions ($L = 3 \times 10^{34}$ cm^{-2}s^{-1}) for two sets of variables (green and black triangles) taking account of shower shapes, as measured from a sample of simulated minimum bias events with $<\mu>= 80$. [3].

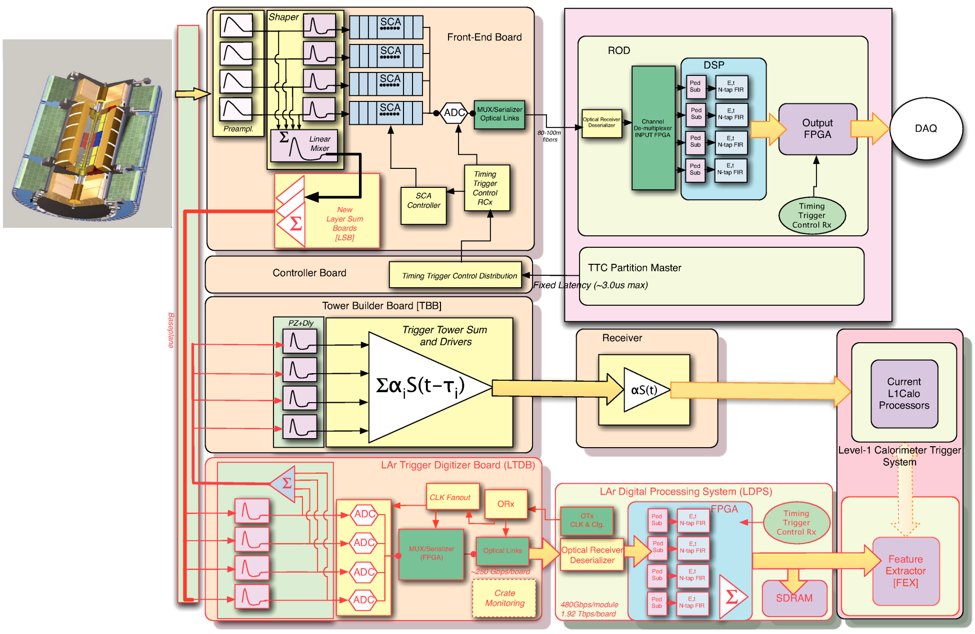

Figure 4: Schematic block diagram of the Phase-I upgrade LAr trigger readout architecture. The new components are indicated by the red outlines and arrows. [3].

3.3 Installation procedure

The frontend installation follows the procedure including exchange of 114 baseplanes, recabling for commissioning, boards reinsertion, installation for LTDB with commisioning and validation, and replacement for the cooling hose. Totally 124 LTDBs are installed, with 7 different flavours depending on the location. After each FEB refurbishment, calibration data for the legacy system are taken and compared to the reference recoded at the end of Run 2, in the level of pedestal ADC values, RMS in ADC counts, electronics noise and mean value of gains. No significant change is observed after the full Phase-I upgrade installation.

On the backend system, one LDPB comprises one LAr Carrier board (LArC), mounted with four LAr Trigger proOcessing MEzzanines (LATOMEs) and an Intelligent Platform management Controller (IPMC). 30 LArCs and 116 LATOMEs are being installed at the USA15 cavern distributed in three ATCA shelves. The LArC boards are responsible for global and local readout, providing trigger, timing, and control signals to LATOMEs. The LATOMEs are connected to LTDB with totally 5k fiber links, which transmit high speed input at 40 MHz. After reconstructing super cell E_T and assigning the collision bunch crossing ID (BCID), the LATOMEs transmit results to L1Calo system for trigger decisions. Furthermore, the IPMC boards control and manage the hardware, and are able to generate alarms to detector security controls.

3.4 Calibration

Both legacy system and digital trigger system are calibrated by daily and weekly calibrations, involving three substeps. The pedestal step is taken without injecting any pulse to the frontend, which is also used to study the electronic noise. In the ramp substep, pulses are generated with the peak ADC with respect to the pedestal as a function of E_T for the pulse. During this step, the saturation effect can be studied, where the saturation of the digital trigger system is found at 800 GeV, higher than for the legacy system where the saturation starts at 250 GeV. Finally the delay substep sends pulse samples by introducing delay between the injection and readout time. All calibrations are used to validate the robustness of the system. 7 LTDBs are found as faulty and have been replaced. Now the full system is validated and ready for physics data taking.

4. Pilot run results

In late 2021 and early 2022, LHC delivered pilot beam with proton-proton collisions at the center of mass energy at 900 GeV, as well as beam splashes. Both legacy and digital trigger systems participated in these tests. Beam splashes are used to align the timing for the full LAr system, where the legacy readout is aligned to ns level, and the digital trigger system is aligned at BCID level (25 ns). In the future, the alignment of digital trigger system will be improved by Optimal Filtering Coefficients (OFCs) and achieve in ps precision. The timing uniformity for both systems is shown in Figure 5. Figure 6 shows the good agreement between the supercell and summed cell energy obtained from the legacy system.

5. Summary

ATLAS LAr Phase-I upgrade has been completed successfully. Installations on both frontend and backend systems are finished, validated by various of calibration procedures, as well as LHC pilot runs. At the early stage of Run-3, the legacy system will be kept as the main readout to further commission and validate the digital trigger system. The full Phase-I calo trigger path should be operational by the end of 2022. During the LHC pilot runs, beam splashes showed good performance on both legacy and digital trigger system, including timing resolution and energy measurement. Regarding the official start for Run-3 at July 5th of 2022, the ATLAS LAr calorimeter is ready for physics data taking.

PoS(ICHEP2022)667

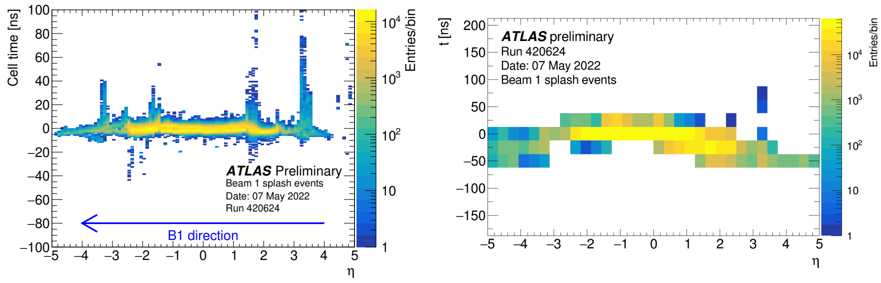

Figure 5: Time distributing in cell (left) and super cell (right) as a function of η in beam splash events from ATLAS Run 420624 selected by calorimeter triggers using the energy deposits in Endcap C (negative η) with the particles delivered by LHC Beam 1 (B1) and entered from the positive η (A) side [5].

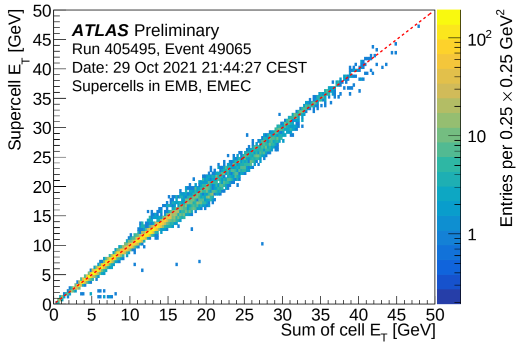

Figure 6: The measured super cell E_T from all layers of the LAr Electromagnetic Barrel (EMB) and Electromagnetic Endcaps (EMEC) are compared to the summed transverse energies from their constituent calorimeter cells, obtained through the main readout path. The data are from a single event of a beam splash run, where energy calculations are performed offline using optimal filtering with preliminary calibration constants. A good agreement is observed between the two readouts, as indicated by the y=x diagonal red line [4].

References

[1] ATLAS collaboration, *The ATLAS Experiment at the CERN Large Hadron Collider, JINST 3*, **2008** *S08003*.

[2] ATLAS collaboration, *ATLAS liquid-argon calorimeter: Technical Design Report, CERN-LHCC-96-04*.

[3] G. Aad et al. , *The Phase-I trigger readout electronics upgrade of the ATLAS Liquid Argon calorimeters, JINST 17* **2022** *P05024*.

[4] ATLAS LAr Calo Public Results during LS2, online URL: `https://twiki.cern.ch/twiki/bin/view/AtlasPublic/LArCaloPublicPilotBeam2021`

[5] ATLAS LAr Calo Public Results early 2022, online URL: `https://twiki.cern.ch/twiki/bin/view/AtlasPublic/LArCaloPublicBeamSplashMay2022`