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ATLAS LAr Calorimeter Commissioning for LHC Run 3

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The Liquid Argon (LAr) calorimeter detector in ATLAS is instrumental in measuring the energy deposits of particles traveling through the detector and for identifying electrons, photons, and jets. As Run 3 introduces higher luminosity, LAr must adapt to the increased radiation and pileup conditions to preserve acceptable trigger thresholds. During the second Long Shutdown, new boards were installed on- and off-detector as a part of the Phase-I upgrade, resulting in a ten fold granularity improvement and increased precision for data sent to the Level-1 Calorimeter (L1Calo) trigger. The Phase-I upgrade is compatible with the planned high-luminosity LHC (HL-LHC). We present an overview of the Phase-I upgrade for LAr and its performance for the start of Run 3.

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1. Introduction

The Liquid Argon (LAr) calorimeter records energy deposits to assist in identifying leptons, photons, jets, and measuring the particle's energy within the pseudorapidity region $|\eta| < 4.9$ [1]. It is composed of an electromagnetic section, the Electromagnetic Barrel Calorimeter (EMB) and Electromagnetic Endcap Calorimeter (EMEC), a hadronic section, the Hadronic Endcap Calorimeter (HEC), and a section with electromagnetic and hadronic calorimetry, the Forward Calorimeter (FCal).

The Phase-I upgrade during the Long Shutdown 2 (LS2) introduced the Digital Trigger system. The system was designed to accommodate an instantaneous luminosity of $\mathcal{L} = 3 \times 10^{34}\text{cm}^{-2}\,\text{s}^{-1}$, center of mass energy $\sqrt{s} = 13.6\,\text{TeV}$ and pile-up of $\langle\mu\rangle = 80$ [3]. This was an anticipated increase from Run 2, which has reached peak instantaneous luminosity of $\mathcal{L} = 1.9 \times 10^{34}\text{cm}^{-2}\,\text{s}^{-1}$ with $\sqrt{s} = 13\,\text{TeV}$ and peak interactions of $\langle\mu\rangle \approx 55$ [2]. To account for the expected increase of collisions and pile-up, new boards were installed during the LS2 to improve the granularity and precision of trigger information sent to the Level-1 Calorimeter (L1Calo) trigger system [3]. The installation introduced a new on-detector board, the LAr Trigger Digitizer Board (LTDB), and new off-detector boards, collectively called the LAr Digital Processing System (LDPS). This upgrade introduces a new readout path, called the Digital Trigger readout. Monitoring software LArSoup and LArSKill were developed to visualize and monitor the rates within the digital trigger readout path, allowing efficient operation of ATLAS and preventing noisy high rates from reaching the L1Calo trigger. The new electronics are compatible with the Phase-II upgrade for the High-Luminosity LHC (HL-LHC) scheduled to be installed during the Long Shutdown 3 (LS3).

2. LAr Digital Trigger Upgrade

The Digital Trigger boards send data with improved granularity compared to the analog legacy readout. During Run 2, cell energies were summed in Trigger Towers, forming an area of $\Delta\eta \times \Delta\Phi = 0.1 \times 0.1$ extending in a single longitudinal block. For Run 3, the longitudinal axis has been split to four layers with varying $\Delta\eta \times \Delta\Phi$ in each layer, forming Super Cells. The Super Cells in the presampler and back layers retain the $\Delta\eta \times \Delta\Phi = 0.1 \times 0.1$ area of the Trigger Towers. Super Cells in middle two layers now have a size of $\Delta\eta \times \Delta\Phi = 0.025 \times 0.1$. Figure 1 shows a simulation of the energy deposit of a 70 GeV electron as seen by both the Trigger Towers and Super Cells where the energy deposit as seen by Super Cells is shown to have higher level of detail. The increased granularity and access to layer information allows us to better observe the electromagnetic shower shape of the electron and allows for improved algorithms within L1Calo.

2.1 Digital Trigger Boards

The Digital Trigger upgrade introduced a new digital readout path while the legacy trigger path is maintained to preserve the analog trigger functionality during commissioning. There are 124 LTDBs added to the on-detector to receive analog Super Cell information from the new Layer Sum Boards (LSBs) installed on the Front End Boards (FEBs). The LTDBs transmit data in the digital trigger pathway while maintaining compatibility with the legacy analog trigger path. In the legacy path, the LTDBs send the analog data, with the help of newly installed baseplanes, to the Tower

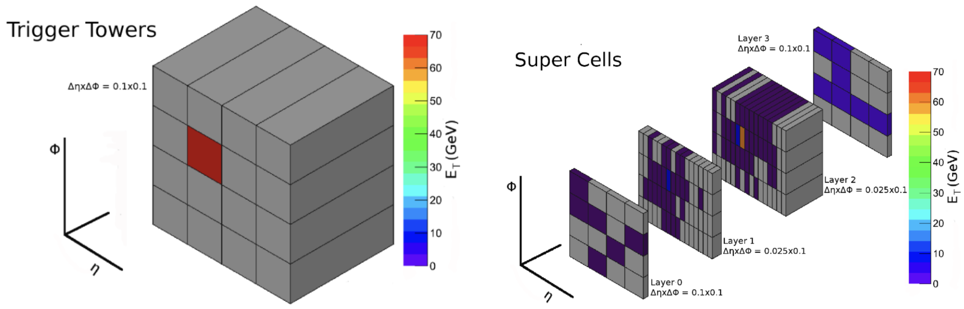


Figure 1: Electron with 70 GeV of energy as seen by both the TriggerTower and supercells. [4]

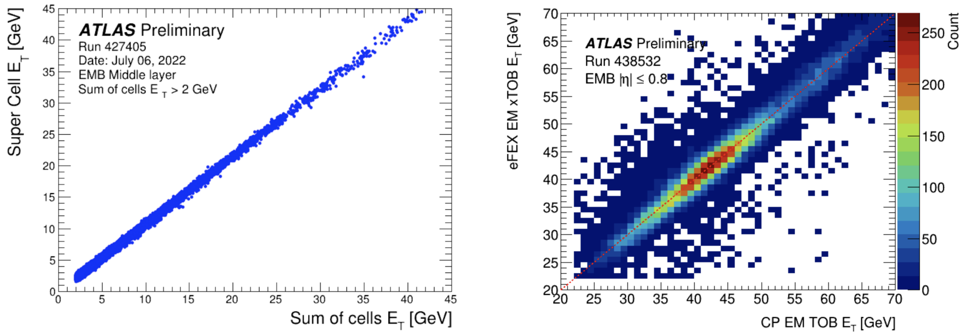
Builder Boards (TBBs) to reconstruct the Trigger Towers sent to L1Calo. In the digital readout path, the LTDBs digitize the Super Cell data and sends the samples to the off-detector LAr Digital processing Board (LDPB) within the LDPS at a 40 MHz bandwidth. There are 30 LDPBs in total to reconstruct the transverse energy, E_{T}, and calculate the bunch crossing timing of each Super Cell, τ. This calculation is done using FPGAs with an optimal filter algorithm and is forwarded to the Level-1 feature extractors (FEXs) within the L1Calo digital trigger system [5]. Each LDPB contains an ATCA format compliant LAr Carrier (LArC), up to four LAr Trigger Processing Mezzanines (LATOMEs) for a total of 116 LATOMEs, and one Intelligent Platform Management Controller (IPMC).

2.2 Energy Validation

The digital trigger boards were tested intensively to verify the readout is accurate and to calibrate the energy scale per Super Cell. One method was to compare the online digital trigger energy calculation with the offline calculation for accuracy as seen in Figure 2a. The transverse energy E_{T} from each Super Cell calculated during running is compared with the offline precision calculation of the summed E_{T} from corresponding calorimeter cells. In the figure, Super Cells with known issues are masked, and events must have energy greater than 5 GeV. The Super Cells must also pass a timing criteria $-8\,\mathrm{ns} < \tau < 16\,\mathrm{ns}$ for $10\,\mathrm{GeV} < E_{\mathrm{T}}$, or $-8\,\mathrm{ns} < \tau < 8\,\mathrm{ns}$ for $0\,\mathrm{GeV} < E_{\mathrm{T}} \leq 10\,\mathrm{GeV}$. The straight line indicates consistency between the digital trigger energy calculation and the offline data [6]. The digital trigger was also validated against the online legacy triggers. Figure 2b shows that the energy deposits received by L1Calo in the legacy path are consistent with the energy calculation received from Super Cells in the digital path. The L1_EM22VHI trigger, corresponding to electrons with transverse momentum $p_{\mathrm{T}} > 20\,\mathrm{GeV}$, is used in the L1Calo legacy and electron Feature Extractor (eFEX) readout with strict selection criteria. The trigger objects (TOBs) originating from electrons and photons in the eFEX path are matched in the $\eta - \phi$ plane, within a radius of $\Delta R < 0.15$ to the leading and subleading electrons in the legacy path [7]. The correlation is seen to be accurate in the figure, indicating good agreement between TOBs generated from L1Calo eFEX and objects in L1Calo legacy calculations.

2.3 Monitoring Digital Trigger Rates

The digital trigger readout path is monitored to ensure noisy Super Cell data is not sent to L1Calo. As the LDPB reconstructs the energy and deposition time of each Super Cell, it also



(a) (b)

Figure 2: (a) The measured Super Cell transverse energies (E_T) for all layers of the LAr Electromagnetic Barrel (EMB) are compared to the summed transverse energies from their constituent calorimeter cells, obtained through the main readout path. [6]. (b) Correlation of the L1Calo transverse energies measured by the legacy Cluster Processor (CP) system and the Phase-I electron Feature Extractor (eFEX) for the inner ElectroMagnetic Barrel (EMB) $|\eta| < 0.8$. The correlation is measured in data recorded in ATLAS Run 438532 using electrons from Z $\rightarrow$ ee decays. [7].

calculates the rate that each Super Cell has reconstructed energy values above a certain configurable threshold. This enables the LAr Super Cell Killer (LArSKill) to autonomously monitor if any of the rates are above a predetermined programmable value. If so, LArSKill communicates to the LDPS that the energy of the Super Cell with the high rate should be ignored by the L1Calo FEXs. Each LATOME within the LDPS is monitored in parallel by LArSKill, allowing for quick response times and increased efficiency compared with manual intervention. A visualization of the rates is generated by LArSoup so that LAr Experts and ATLAS Control Room shifters may manually intervene according to the observed rates. Historical data is recorded so that when problems arise during a run, the visualization of rates during that time may be quickly presented.

3. Conclusion

The LAr Digital Trigger upgrade introduced the new digital trigger readout path to provide data with higher granularity and precision to the L1Calo trigger in anticipation of the higher luminosity rates of Run 3. This upgrade is running successfully at the start of Run 3 and continued development of the new system is ongoing. The trigger granularity is improved ten fold, and is expected to improve background rejection and efficiency in identifying leptons and other particles without having to raise trigger energy thresholds. The algorithms implemented at the L1Calo trigger level may now incorporate the EM shower shape alongside energy, similar to algorithms used in High Level Trigger (HLT) and offline calculations. The digital readout was validated against the legacy trigger path alongside offline calculations of energy and is found to be consistent. Monitoring tools, LArSKill and LArSoup, were developed to aid in solving problems that arise during running. These upgrades are consistent with the future Phase-II HL-LHC plans.

References

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