PROCEEDINGS OF SCIENCE

The Phase-I upgrade of the ATLAS Level-1 Calorimeter Trigger

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The Level-1 Calorimeter Trigger (L1Calo) is a hardware-based pipelined system processing signals from the liquid-argon (LAr) and scintillating tiles (Tile) calorimeters and provides trigger signals to the Central Trigger Processor (CTP). It identifies events containing calorimeter-based physics objects, including electrons, photons, taus, jets, and missing transverse momentum. In preparation for Run 3, when the LHC is expected to run at higher energy and instantaneous luminosity, L1Calo and LAr are implementing a significant upgrade programme, in order to better perform in a challenging high-luminosity and high-pileup environment. The existing hardware will be replaced by a new system of feature extractor modules, which will process finer LAr granularity information and execute more sophisticated algorithms to identify physics objects.

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1. The ATLAS Level-1 Calorimeter Trigger

The ATLAS Level-1 Calorimeter Trigger is a pipelined system processing signals from the calorimeters using custom hardware processors based on FPGA technology. Its architecture is shown in Fig. 1: the bottom blocks represent the modules that were present in Run 1 and Run 2; on the top part, in yellow, the upgraded system is drawn. In Run 2, the Pre-Processor Modules (PPM) received 7200 analogue signals from LAr and Tile calorimeters, which were digitized in the new multi-chip modules (nMCM), processed and transmitted to two subsequent processors in parallel. The Cluster Processor Module (CPM) identified isolated electron, photon and τ lepton candidates from the $\Delta\eta\times\Delta\phi$=0.1×0.1 granularity energy deposits in a given calorimeter region; the Jet Energy Module (JEM) identified energetic jet candidates from $\Delta\eta\times\Delta\phi$=0.2×0.2 jet elements. The JEM also computed ΣE_T and E_T^{miss}. In both CPMs and JEMs a Region of Interest was defined using a sliding window algorithm, and isolation quantities were computed from the surrounding clusters. The CPM/JEM processors sent trigger objects (TOB) to the extended common merger modules (CMX), which merged trigger counts across modules and sent them to the Central Trigger Processor. TOBs were also forwarded to the Level-1 Topological Processor (L1Topo) to take decisions according to the topology of the events using TOBs and to forward the result to the CTP. The final Level-1 Accept (L1A) decision in the CTP was taken using information from calorimeter and muon trigger systems.

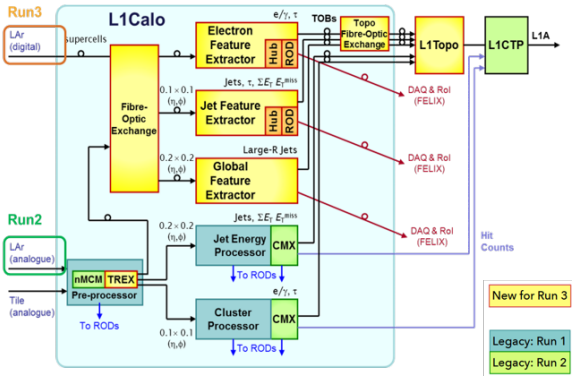

Figure 1: Level-1 Calorimeter system in Run 1 (blue boxes), Run 2 (green boxes) and Run 3 (yellow boxes). Adapted from [2].

1.1 The ATLAS Level-1 Calorimeter Trigger in Run 3

The L1Calo trigger system for Run 3 is required to cope with severe pileup levels that degrade the calorimeter resolution and isolation of single particles, leading to decreased trigger efficiency and to the necessity to use higher trigger thresholds to mitigate the resulting increase in rate. One of the main goals of the ATLAS trigger upgrade is to reduce the impact of pileup in order to maintain low thresholds which are important for electroweak physics. This will be possible using more refined processing of electromagnetic calorimeter information at higher granularity, which provides improved identification of isolated electrons, photons, jets and discrimination against pileup.
The Phase-I L1Calo trigger upgrade for Run 3 (Fig. 1) consists of three new Feature Extractor (FEX) systems: the electron FEX (eFEX, with functions similar to CPM), the jet FEX (jFEX, similar to JEM) and the global FEX (gFEX, that identifies large jets), which will replace the CPMs and JEMs. A Tile Rear EXtension (TREX), at the backside of the Tile PPMs, will provide the Tile digitised results to the FEXes via optical fibers, as well as to CPMs and JEMs via electrical signals. LAr signals digitization will be done at the Front End level and the LAr Digital Processing System (LDPS) modules will process LAr digital signals and calibrate them in real-time. A Fibre Optical

eXchange (FOX) plant will distribute and map the digitised data from the LDPS and the TREX to the FEXes. The FEX modules will reside in ATCA shelves. The TOBs and readout information will be collected in a custom ATCA hub board designed for the FEX system (HUB), which also acts as the shelf controller. The ReadOut Driver (ROD) on the HUB will collect and buffer data across shelves and will transmit them to the DAQ system. The L1Topo processor has also been redesigned for Run 3, in order to have more processing capabilities to make use of the improved input objects. It consists of three modules with two processor FPGAs each. The three FEXes and the muon trigger will provide TOBs containing information on position and energy to L1Topo through the TopoFOX fiber mapping module. L1Topo will then perform topological algorithms on these objects, as well as determine thresholds and multiplicity counts of calorimeter objects.

The Feature Extractor (FEX) system

The eFEX system covers the region of $|\eta|$<2.5 and consists of 24 modules located within two ATCA shelves, with each module containing four algorithm processing FPGAs (for the identification of isolated e, γ and τ candidates) and one control FPGA. The computed TOBs are then merged and sorted across the entire system. The jFEX system identifies jets, hadronically-decaying τ-leptons, E_T^{miss}, and ΣE_T in the range $|\eta|$<4.9. The system consists of one ATCA shelf, equipped with six jFEX modules. Small-radius jets are identified using a sliding-window algorithm. The gFEX has been designed such that the data from the entire calorimeter can be processed on a single module, thus permitting the use of full scan algorithms to facilitate identification of boosted objects and global observables such as E_T^{miss}, which are of particular interest in a number of searches for new physics.

2. Performance studies

One example of the effects of the 10-fold increase in granularity of LAr inputs can be seen in Fig. 2, which compares the energy deposition of an electron in the existing trigger system to that of Run 3. Figure 2 (right) shows the expected trigger rate reduction using the Run 3 system compared

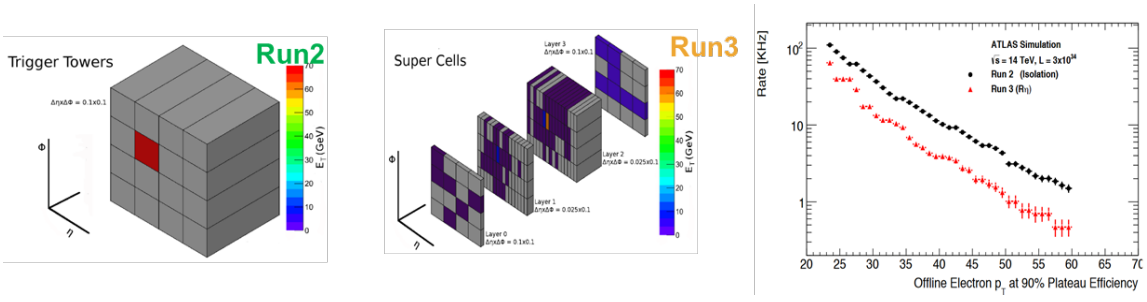

Figure 2: A 70 GeV electron as seen by the Run 2 (left) and by the upgraded Run 3 L1Calo system (center) [1]. Right: expected EM trigger rate reduction in Run 3 (red triangles) versus Run 2 (black dots) [2].

to the one in Run 2; this will allow to reduce the selection thresholds when needed.

Figure 3 demonstrates the expected improvements, thanks to the introduction of the eFEX system (a, b), the jFEX (c) and the gFEX (d), in terms of energy resolution and efficiency turn-on curves for different items.

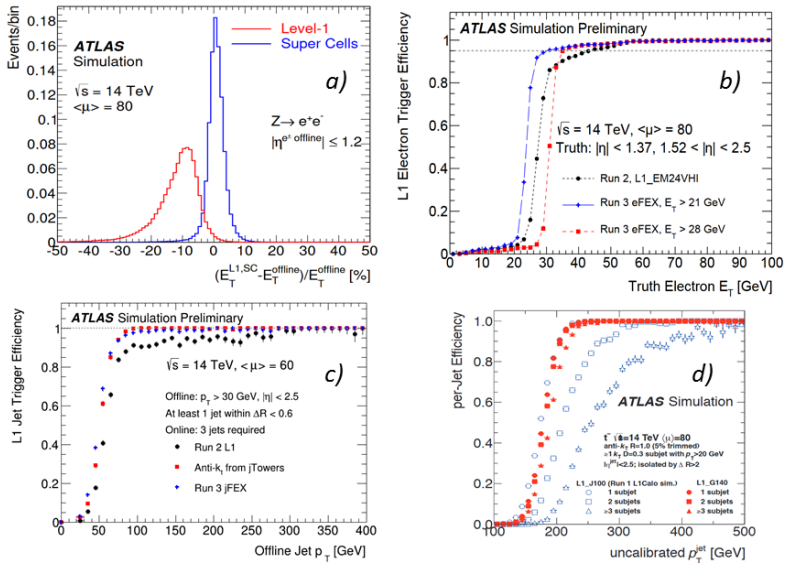

Figure 3: (a) eFEX improvements concerning the EM cluster energy resolution. (b) Improvement for the turn-on curves for electrons with the eFEX, (c) for jets with nearby jets with the jFEX and (d) for multiple L1Calo jets with the gFEX [1, 3, 4].

3. Commissioning strategy and installation plans

All the described modules were designed, produced and tested by 15 different institutes before being shipped to CERN where they are currently under final testing in the Surface Test Facility (STF). The STF aims to perform as many combined tests as possible before final commissioning in ATLAS and to demonstrate the full functionality within the system. Regular slice tests are being carried out there to perform both the internal L1Calo system-level tests and the integration with the neighbouring systems (calorimeters, CTP and data acquisition). After being fully validated at the STF, the production modules will be installed in the electronics cavern in P1.
At the start of LHC Run 3, during the commissioning of the upgraded L1Calo with collision data, the current legacy system will initially run in parallel and will provide input to the CTP; it will be decommissioned once the performance of the whole upgraded system will be fully validated.

References

[1] ATLAS Collaboration, Technical Design Report, ATLAS Liquid Argon Calorimeter Phase-I Upgrade, CERN-LHCC-2013-017, ATLAS-TDR-022

[2] ATLAS Collaboration, Technical Design Report for the Phase-I Upgrade of the ATLAS TDAQ System, CERN-LHCC-2013-018, ATLAS-TDR-023

[3] https://twiki.cern.ch/twiki/bin/view/AtlasPublic/L1CaloTriggerPublicResults

[4] ATLAS Collaboration, Technical Design Report for the Phase-II Upgrade of the ATLAS TDAQ System, CERN-LHCC-2017-020, ATLAS-TDR-029