The phase-1 upgrade of the ATLAS Level-1 Calorimeter Trigger

Abstract
The ATLAS Level-1 Calorimeter Trigger (L1Calo) is a hardware-based system that identifies events containing calorimeter-based physics objects, including electrons, photons, taus, jets, and missing transverse energy. In preparation for Run 3, when the LHC will run at higher energy and instantaneous luminosity, L1Calo is currently implementing a significant programme of planned upgrades. The existing hardware will be replaced by a new system of feature extractor (FEX) modules, which will process finer-granularity information from the calorimeters and execute more sophisticated algorithms to identify physics objects; these upgrades will permit better performance in a challenging high-luminosity and high-pileup environment.

ATLAS Level-1 Calorimeter Trigger system evolution
L1Calo is a pipe-lined system processing signals from the liquid-argon and tile calorimeters and provides trigger signals to the Central Trigger Processor (CTP). Since the start of the ATLAS operation, the initial L1Calo system underwent several important upgrades.

- Multi-Chip Module (MCM) with pre-processing ASIC replaced by new FPGA-based version (MCM).
- Cluster Processor (CP) and Jet Energy Processor (JEP) calculate and send trigger objects in addition to simple counts.
- New L1Topo module for topology-based decisions uses trigger objects and forwards the result to the CTP.

The ATLAS experiment is planning an upgrade to the TDAQ system for the Phase-I period (Run-3, from 2021 to 2024) to address the new challenging accelerator machine conditions, namely an increase in luminosity to ~2.5E34/cm²s and to maintain the sensitivity to electroweak physics without being affected by the increased number of pile-up events. The upgraded system makes use of higher granularity and runs better-performing trigger algorithms than currently employed.

Feature Extractors (FEX)
- eFEX: isolated e- & & candidates
- gFEX: large radius jets, ETmiss, centrality, etc.

Systems with similar characteristics:
- ATCA modules with FPGAs
- Large optical input bandwidth
- Large processing capacity

Input data and algorithm (jFEX example)
The inputs to the L1Calo in Run-2 are Trigger Towers (TT) that are formed by analogue summation of calorimeter cells across the longitudinal layers in a region of $\Delta$R $\approx$ 0.1 x 0.1. The Phase-1 upgrade increases the granularity of the LAr trigger inputs to ten Super Cells per trigger tower as shown:

- Three new Feature Extractor (FEX) systems: electron FEX, jet FEX and global FEX (identifies large jets).
- The digitised data will be distributed by a new Fibre Optical eXchange plant (FOX).
- New Tile Rear Extension (TREX), provides the Tile digitised results to the FEX processors as well as to CP and JEP.
- The current legacy system will initially run in parallel and will be decommissioned after the performance of the FEX processors has been validated.

Firmware development (eFEX example)

Fibre mapping

TREX: VME rear transition module in Pre-Processor Module (PPM) provides the Tile digitised results to the FEX processors and maintain the legacy trigger path to CP and JEP systems.

R�D: ReadOut Driver, collects & transmits to DAQ system

L1Topo: Re-design of Run-1 Topo based on JFEX framework. 3 ATCA modules with 2 Xilinx Ultrascale+ FPGAs per module.

ROD on HUB

gFEX & eFEX

HUB: Control and clock hub in eFEX and L1Topo ATCA shelves

FOX & TopoFOX: Fibre mapping

L1Calo commissioning

Individual module test example:
- ATCA shell: 2 HUBs & 12 HTMs
- Test Module: 24 HTMs
- MGT link stability as a function of drive voltage (max -333 mV, min -191 mV)
- Margin of ~5 in voltage attenuation

TDQA Surface Test Facility (STF)
Aimed to perform as many tests as possible for each module before final commissioning: full functionality demonstrated within system

- Build vertical slice through system
- Internal L1Calo system-level tests
- Soak tests with bit-wise simulation
- 4 CERN standard ATCA shelves for eFEX, eFEX/gFEX, Topo, LAr, Muon trigger
- VME Crate for ATCA, L1Calo and TTC (Timing and Trigger Control, 6U)
- DAQ (FELIX + SW ROD)
- Legacy DCs for PPMs (TREX)
- DCs machine from Central DCs for ATCA
- In use for tests since Feb’19

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