PROCEEDINGS OF SCIENCE

The phase-1 upgrade of the ATLAS level-1 calorimeter trigger

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The ATLAS level-1 calorimeter trigger 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, the level-1 calorimeter trigger is currently implementing a significant program of planned upgrades. The existing hardware will be replaced by a new system of feature extractor 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. The features of the upgraded level-1 calorimeter trigger and the plans for production, installation, and commissioning will be described and in addition, the expected performance of the system in Run 3 will be discussed.

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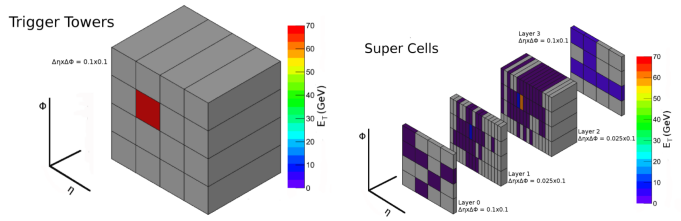


(a) LAr calorimeter trigger towers from Run 2

(b) LAr calorimeter supercells from Run 3

Figure 1: Increased granularity of LAr calorimeter in Phase I Upgrades [3]

1. The ATLAS level-one calorimeter trigger

The ATLAS experiment [1] is one of two general purpose experiments on the Large Hadron Collider (LHC). During Run 2 the LHC collided protons at a rate of 40 MHz. The ATLAS level-one trigger performs a real-time hardware-based selection of events which must reduce the event rate to 100 kHz. The level-one calorimeter trigger (L1Calo) receives inputs from the Liquid Argon calorimeter (LAr) and Tile calorimeter. L1Calo is a hardware-based system that identifies events containing calorimeter physics objects such as electrons, photons, taus, jets, and missing transverse energy ($E_{\mathrm{T}}^{\mathrm{miss}}$). The L1Calo system sends these trigger objects (TOBs) to the L1 Topological trigger (L1Topo) and then to the L1 Central Trigger (L1CTP) for the final event decision, or level 1 accept (L1A).

2. The L1Calo Phase I Upgrades

In Run 3 the LHC will reach significantly higher energies than ever before, with a center-of-mass energy at or near $\sqrt{s}$ = 14 TeV, and instantaneous luminosity reaching up to three times that in Run 2. With these increasingly challenging conditions come higher pileup levels, up to double those seen in Run 2 where the average was around $< \mu >= 30$ [2].

To cope with these intense conditions, the LAr calorimeter has been significantly upgraded with increased granularity and digitized outputs [3]. The granularity is roughly 10x higher in the LAr calorimeter supercells which significantly increases the resolution of the calorimeter data, as demonstrated in Figure 1.

To take advantage of these detector upgrades, L1Calo is currently implementing a significant program of planned upgrades. The existing hardware will be recommissioned and run at the beginning of Run 3, but will eventually be replaced by an entirely new system of feature extractor (FEX) modules, which will be commissioned in parallel with the legacy L1Calo trigger system. These FEXs process the finer-grained information from the calorimeters and execute more sophisticated algorithms for improved physics results.

The FEX modules consist of the electron, global, and jet Feature Extractors, or eFEX, gFEX, and jFEX respectively. The eFEX system consists of 24 ATCA modules with 4 Xilinx Virtex 7 processor FPGAs and 1 Xilinx Virtex 7 control FPGA on each module. The eFEX utilizes the full increased granularity of the LAr supercells and identifies electron, photon, and tau objects. Full

System	Modules	FPGAs	Function	Production	Installation
eFEX	24	4+1	electrons, photons, taus	in progress	1 module installed
gFEX	1	3+1 Soc	large-R jets, MET, SumE_T	done	done
jFEX	6	4+1 Soc	large/small-R jets, MET, SumE_T, taus	done	1 module installed
TREX	32	5+1 Soc	digitizes Tile trigger towers	done	done
HUB+ROD	8	1+1	clock source and data buffer for e/jFEX	done	2 modules installed
FOX	6	N/A	routes 7.5k + 1.5k fibers for FEXs	done	done

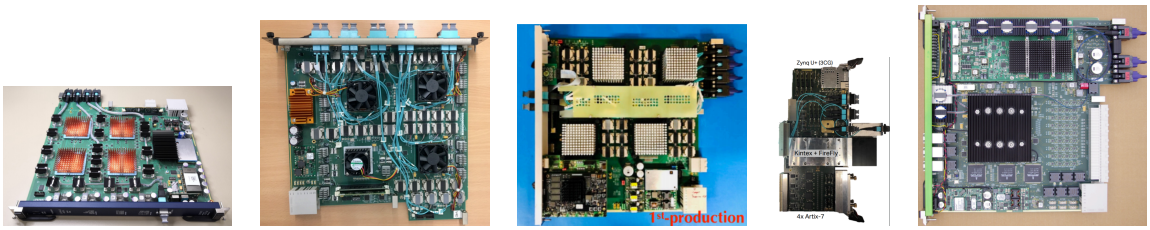
Table 1: New L1Calo phase I upgrade systems

production of the system is in progress. The gFEX system consists of 3 Xilinx Virtex Ultrascale+ FPGAs and 1 Zynq Ultrascale+ System on Chip on 1 ATCA module. The entire calorimeter is read out on one board, which identifies large radius jets, $E_{\mathrm{T}}^{\mathrm{miss}}$ and $\sum E_{\mathrm{T}}$. Full production and testing of the hardware is complete. The jFEX system is made up of 6 ATCA modules, each with 4 Xilinx Virtex Ultrascale+ FPGAs and 1 Zynq Ultrascale+ control FPGA. The jFEX identifies large and small radius jets, taus, $E_{\mathrm{T}}^{\mathrm{miss}}$ and $\sum E_{\mathrm{T}}$. Full production is completed and final testing of the hardware is near completion.

This program of upgrades also includes new infrastructure in the form of the Tile Rear eXtension (TREX) module, the Fiber Optic link eXchange (FOX), and the Front End Link eXchange (FELIX), and the HUB and Readout Driver (ROD) modules. The FELIX system provides the clock information to the FEX modules and readout from the FEX modules. The TREX system is 32 modules, which process all Tile trigger towers and provides digitized data to Legacy L1Calo system and the new FEX modules. The TREX provides a bridge between the legacy and phase I systems. Full production and testing of the hardware of this system is complete, and all boards have been installed in the ATLAS service cavern. The FOX distributes digitized data using 6 boxes which map 7.5k fibers from the LAr and Tile calorimeters to the FEXes. The Topo-FOX system maps 1.5k fibers from L1Calo and L1Muon to L1Topo. The HUB and ROD systems consists of 8 ATCA modules which send the clock and other signals to the eFEX and jFEX modules. They also collate and buffers data for one shelf of eFEX/jFEX modules. Production and hardware testing is complete for the HUB and ROD system. The new FEX and infrastructure systems are summarized in Table 1 and Figure 2.

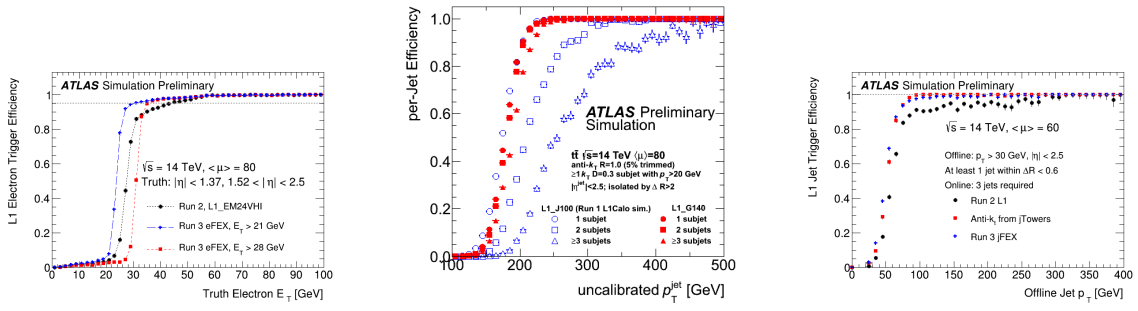
3. Expected Performance in Run 3

During Run 3 the high pileup levels expected lead to degradation of the calorimeter resolution and to the isolation of particles, which results in a decreased trigger efficiency and an increase



(a) eFEX **(b)** gFEX **(c)** jFEX **(d)** TREX **(e)** HUB+ROD

Figure 2: New L1Calo phase I upgrade systems



(a) eFEX electron events [4] **(b)** gFEX large radius jet events [5] **(c)** jFEX 3 jet events [4]

Figure 3: Run 3 FEX performance

in trigger rate. Part of the Phase I upgrades of the LAr calorimeter include increased granularity which allows for improved isolation performance and discrimination against pileup [3]. This helps to reduce the rate, and allows the L1Calo FEX modules to utilize algorithms which provide better performance overall, with a still manageable rate. Updated firmware algorithms in the FEX modules take advantage of the increased granularity of the calorimeters to provide better performance. The expected performance for Run 3 can be seen in comparison to Run 2 performance in Figure 3 for jFEX 3 jet events, eFEX electron events, and gFEX large radius jet events.

4. Installation and Commissioning

The installation and commissioning of the new L1Calo system is well underway at this point in time. The FELIX, FOX, TREX, and gFEX systems have been fully installed underground in the ATLAS service cavern, near the ATLAS detector. One module each of the eFEX and jFEX systems has been installed along with the corresponding HUB and ROD modules, and full installation of these systems is in progress. Commissioning is fully underway with a variety of connectivity and link tests, as well as mapping and readout tests. Integration with the LAr and Tile calorimeters, the TDAQ infrastructure, and the ATLAS control system are all in progress. Future tests will include those required for calibrating the system, as well as additional integration tests with the entire ATLAS detector. The upcoming pilot beams in the LHC will provide the first opportunity to test the newly installed system with particle beams.

References

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