Operation of the enhanced ATLAS First Level Calorimeter Trigger at the start of LHC Run-2
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L1Calo in the ATLAS experiment

Fig. 1: CERN facility

Fig. 2: ATLAS experiment

Fig. 3: Calorimeters (electromagnetic and hadronic)
Introduction

L1Calo upgrade
Calibration and system performance
Monitoring during Run-2

Introduction

Fig. 4: Block diagram of data acquisition system at 2015
- post Long Shutdown 1 (LS1), Phase 0, Run-2 new hardware
- post Long Shutdown 2 (LS2), Phase 1, Run-3 planned hardware

New conditions and requirements driving L1Calo upgrade

- bunch crossing $50\text{ns} \rightarrow 25\text{ns}$
- luminosity $1.6 \times 10^{34} \text{cm}^{-2} \text{s}^{-1}$
- improving selection and physics statistics
**nMCM**

**Fig. 5 :** nMCM module to improve quality of digitized calorimeter signals

**Fig. 6 :** Improved efficiency for missing $E_T$ and improvements also for jet triggers

**New Multi Chip Module (nMCM) for improved processing of calorimeter signals**

- adaptive resources (Spartan 6)
- 2x faster signal sampling
- pile-up suppression (FIR filters)
- noise filtering (FIR filters)
- pedestal correction
- improved clocking
- internal signal generation
- all required 2048 nMCM modules have been built and integrated into L1Calo
Features

- CMM only merged multiplicities. CMX sends Trigger OBjects (TOBs) to L1Topo, and provides legacy thresholding and multiplicities for CTP.
- position/energy of jets/electrons/taus in each TOB
- significantly more of thresholds possible (28 → 97)
- increased bandwidth 40 → 160Mbit/s from JEP/CPM and between CMX modules
- connectivity to Topological processor (L1Topo) (24 optical connections 6.4Gbit/s)
CMX - Common Merger Module - eXtended

Fig. 8: Jet energy summing (Missing $E_T$, sum $E_T$, missing energy significance $X_S$), CPM/JEM thresholding and hit-counting

**Current status**

CMX system is commissioned it has better threshold granularity of triggers and new fast connections to L1Topo are fully operational.
New more demanding conditions for data taking - they could cause

- reduction of physics event rate due to increased luminosity and limited system capabilities
- rising thresholds for different kind of triggers - more background

Remedy - topological calculations based on TOBs

- select events based on the geometric and kinematic relationships between objects identified in earlier stages
- cuts on angular distributions - $\Delta \Phi, \Delta \eta, \Delta R = \sqrt{\eta^2 + \Phi^2}$
- missing, invariant and transverse mass calculations
- compound triggers - $e/\gamma, jets, \mu, \tau, E_T^{miss}$
- combining information both from calorimeter and muon system
Fig. 9: L1Topo board
Fig. 10: L1Topo placed in the ATCA shelf

L1Topo features

- ATCA shelf form factor
- $2 \times$ Xilinx Virtex7 XC7V690T FPGAs
- 80 multi-gigabit receivers per FPGA (up to 13 Gbit/s)
- Kintex7 FPGA for control and data transmission
- two L1Topo blades placed in the ATLAS trigger system
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L1Topo - algorithms

Fig. 11: Efficiency L1Calo derived MET (black) and L1Topo corrected MET (colors)

Fig. 12: $ZH \rightarrow \nu \bar{\nu} b \bar{b}$. Signal to background separation, possible only with topological trigger

Algorithms summary

- up to 128 algorithms (107 trigger items in Topological processors)
- improvements in B physics, $H \rightarrow \tau \tau$, $ZH \rightarrow \nu \bar{\nu} b \bar{b}$, electron/photon triggers
- all algorithms are implemented and simulated
- maximum latency of algorithms 100ns
- currently the algorithms are under commissioning
Different aspects of calibration

- **Analogue path**
  - variable gain amplifiers (calibration and $E_T$ scaling)
  - timing adjusted in pre-processor to align signals in time
  - reduce influence of different length of differential cables (30 - 70m)

- **Bunch Crossing ID (BCID)**
  - digitized signal has to be properly located in time/BCID (FIR filter)
  - should be insensitive to pile-up effects
  - small miss-timing can lead to wrong energy estimation
  - large mistiming will cause hit loss

- **Energy**
  - pedestal subtraction
  - noise filtering
Timing calibration

- calibration runs with pulser - which mimics beam collisions
- beam splashes - rough estimation
- fit physics signals with known shapes

These allow the determination of timing corrections on the level of $2\text{ns}$ accuracy

**Fig. 13**: Electromagnetic end-cap Inner Wheel

**Fig. 14**: Electromagnetic barrel

**Fig. 15**: Forward calorimeter 1-3,4

Performance of auto-correlation filters together with properly calibrated system in terms of BCID efficiency
Energy Calibration

- Each tower is calibrated individually.
- ADC values are proportional to $E_T$ ($1FADC \approx 0.25\text{GeV}$), for precise $E_{textT}$ reconstruction corrections are required.
- Dedicated pulser weekly runs:
  - Different amplitudes
  - Comparison between L1Calo Trigger Towers and calorimeter readout
  - Offline analysis permits the calculation of calibration factors based on this proper gain values are set in the hardware.
  - Also permits localization of cause of dead/noisy channels.

**Fig. 16**: L1_XE35 as function of BCID for a single train. Pedestal correction off.

**Fig. 17**: L1_XE35 as function of BCID for a single train. Pedestal correction on.

**Fig. 18**: Total L1_XE35 per-bunch rate as function of the per-bunch instantaneous luminosity for three runs (-pedestal correction disabled).
Monitoring - main features

Functionalities provided with monitoring tools

- delivers important information about the state of the L1Calo system: hit maps, energy distributions,
- provides detailed information about hardware
- monitors firmware, readout, transmission errors, online software, decoding, simulation
- real-time L1Calo data path simulated is compared to data (offline/online)
- only minor differences between offline and online monitoring (code re-usability)
- constantly used by experts/shiflers to determine the status of the L1Calo ATLAS system

Fig. 19: Monitoring connectivity to other subsystems. Crucial in the process of commissioning new subsystems into the ATLAS detector.
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Monitoring during Run-2

Upgrades
- provides channel-wise and trigger independent rates and spectra
- improved Pre-Processor Modules rate-metering and histogramming
- new hardware incorporated into the monitoring (CMX, L1Topo)
- major Detector Control System extensions (CMX,L1Topo)

![Fig. 20: Information read-out from L1Topo](image1)

![Fig. 21: Information read-out from CMX](image2)

Distribution of the transverse energy for EM candidates identified within the cluster processor system of the Level-1 Calorimeter Trigger
Summary

- L1Calo trigger system in Run-2 provides new functionalities and possibilities. It ensures better physics statistics while reducing background.

- nMCM boards built to improve timing, energy and reduce pile-up/noise influence.

- Exchange CMM with CMX boards to cope with increased amount of data, extend the trigger capabilities and adopt TOB philosophy.

- New topological processors (L1Topo) for real-time event selection based on geometrical and kinematic quantities is nearing the end of commissioning.

- Calibration procedures are established.

- Monitoring has been extended to serve for newly installed modules and allows for online/offline L1Calo system quality assessment.

Further programmes to improve the trigger performance are being prepared (Phase I): Reinhard Schwienhorst - The Phase-1 Upgrade of the ATLAS First Level Calorimeter Trigger.
Thank you
Backup slides