# The ATLAS Level-1 Topological Trigger Performance

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# ATLAS trigger system

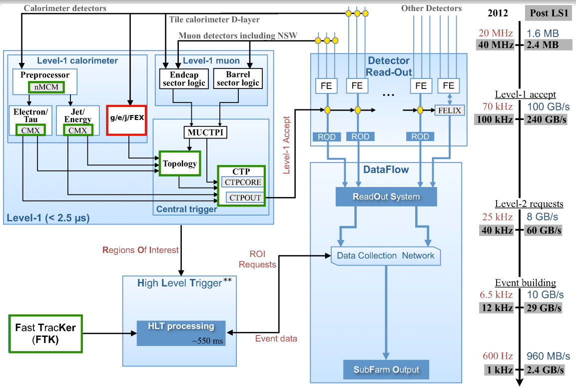



Fig. 1: Block diagram of the trigger and data acquisition system in 2016
- post **L**ong **S**hutdown 1, Phase 0, Run-2 new hardware
- post **L**ong **S**hutdown 2, Phase 1, Run-3 planned hardware*

* Weihao Wu - "The development of the Global Feature Extractor for the LHC Run-3 upgrade of the ATLAS L1 Calorimeter trigger"
** Mark Stockton - Errors detection, handling and recovery at the High Level Trigger of the ATLAS experiment at the LHCData intercommunication layer and control system of ATLAS High Level Trigger"

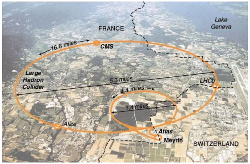



Fig. 2: CERN facility

**New conditions and requirements driving upgrade:**

- Bunch Crossing $50ns \rightarrow 25ns$
- luminosity up to $3x10^{34} cm^{-2} s^{-1}$
- increase trigger rates
- improve selection

# L1Calo upgrade

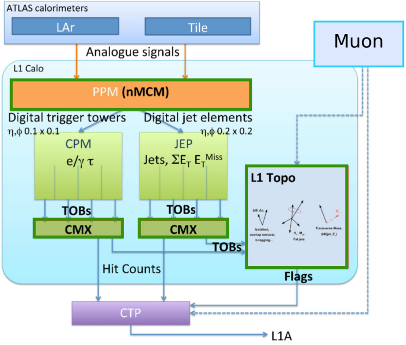



Fig. 3: Upgraded trigger system for Run-2

nMCM - **n**ew **M**ulti **C**hip **M**odule

CPM - **C**lustrer **P**rocessor **M**odule

JEP - **J**et **E**nergy **P**rocessor

CMX - **C**ommon **M**erger Module **EX**tended

CTP - **C**entral **T**rigger **P**rocessor

## New features

- new nMCM to improve timing, energy and reduce pile-up/noise influence
- increased bandwidth $40 \rightarrow 160 Mbit/s$ from JEM/CPM and between CMX modules
- position/energy of jets/electrons/taus in each **T**rigger **OB**jects (TOB)
- CMX sends TOBs to L1Topo, and provides legacy thresholding and multiplicities for CTP.
- connectivity to L1Topo (24 optical connections $6.4 Gbit/s$)
- interfacing muon trigger system with L1Topo

# L1Topo requirements

## Without upgrades

This would require:

- down-scaling triggers
- rising thresholds for different kind of triggers

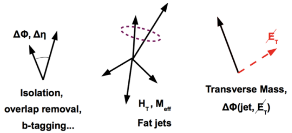
No gain from higher luminosity

## Limitations

- Level-1 system can accept events up to rate of $100kHz$
- higher trigger rates due to higher pile-up

## Remedy - topological calculations based on TOBs

- select events based on the geometric and kinematic relationships between trigger objects identified in earlier stages
- cuts on angular distributions - $\Phi, \eta, \Delta\Phi, \Delta\eta, \Delta R = \sqrt{\Delta\eta^2 + \Delta\Phi^2}$
- missing, invariant and transverse mass calculations
- compound triggers - $e/\gamma, jets, \mu, \tau, E_{\mathrm{T}}^{miss}$
- combining information both from calorimeter and muon system



# L1Topo requirements

## L1Topo in the ATLAS system

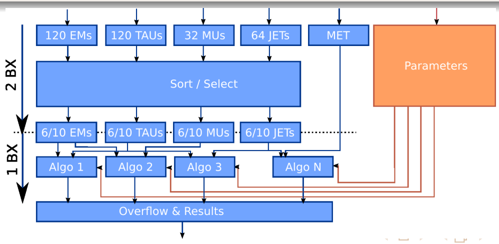
Receiving different types of **T**rigger **OB**jects (TOBs):

- muons, 32 TOBs
- electrons, 120 TOBs
- taus, 120 TOBs
- jets, 64 TOBs

Time constraints:

- execute topological algorithms in $75ns$ (VHDL)
- transmit decision algorithms to the Central Trigger Processor

Algorithms are configurable. Up to 128 algorithms. At the moment 107 trigger items implemented in processors.



# L1Topo - hardware

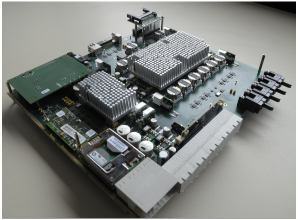


Fig. 4: L1Topo board

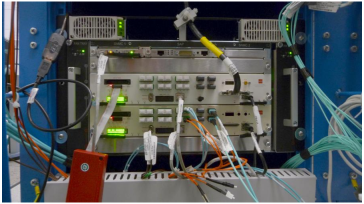


Fig. 5: L1Topo placed in the ATCA shelf

## L1Topo features

- ATCA shelf form factor blades
- 2 × Xilinx Virtex7 XC7V690T FPGAs per blade
- 80 multi-gigabit receivers per FPGA (up to 13 Gbit/s)
- Kintex7 FPGA for control and readout to DAQ (100kHz of accepted events)
- 22 layers PCB
- two L1Topo blades placed in the ATLAS trigger system

# L1Topo algorithm examples

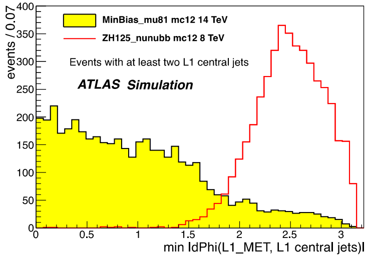



Fig. 6: $ZH \rightarrow \nu\overline{\nu}b\overline{b}$ - signal to background separation. Minimum bias (filled histogram) and ZH (open red histogram). Minimum azimuthal angular distance between Level-1 $E_{\mathrm{T}}^{miss}$ and Level-1 central jets with $p_T > 20GeV$ and $|\eta| < 2.5$ for events with at least two central jets.

## $ZH \rightarrow \nu\overline{\nu}b\overline{b}$ selection

- in Run-1 cut on $E_{\mathrm{T}}^{miss} > 40GeV$ in Level-1
- in Run-2 without additional cuts this trigger rate $> 100kHz$
- when $E_{\mathrm{T}}^{miss} > 50GeV$ and inclusive jet $p_T > 20GeV$ trigger rate $10kHz$ - still to much
- combination with topological quantity $|\Delta\phi(E_{\mathrm{T}}^{miss}, jets)| > 1$ allow to reduce trigger rate to $< 5kHz$

# L1Topo algorithm examples

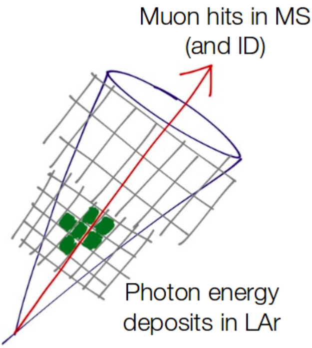



Fig. 7: Muon and photon detection in ATLAS detector - calorimeter, Muon Spectrometer and Inner Detector

**In search for lepton flavour violation ($\tau \to \mu\gamma, \tau \to \mu\mu\mu$)**

- individual $p_T$ cuts on $\mu$ and photon are not possible due to momentum distribution (either high mu pT and low photon pT or vice versa)
- angular distribution $\Delta R$ of $\mu$ and $\gamma$ can be used for event selection
- combination of $p_T$ and $\Delta R$ can be used to select signal events
- the information must be combined both from muon and calorimeter detector - possible within L1Topo

# Hardware/firmware commissioning

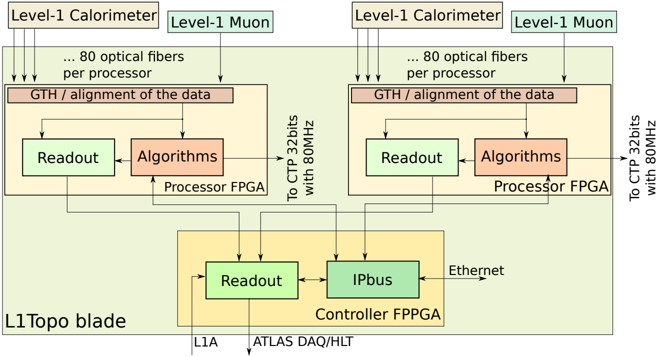



Fig. 8: L1Topo firmware and connectivity to other sub-systems

**Data aligned**

from calorimeter and muon system

**Triggers to CTP**

arriving in proper BC

**Readout is validated**

sustains 100 $kHz$ with 3 BC of data

**Slow control**

via IPbus is functional

# Algorithms - offline commissioning

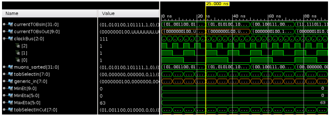


Fig. 9: VHDL simulation, events playback

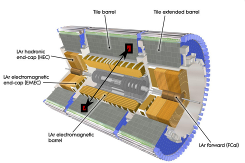



Fig. 10: Validation when no beam

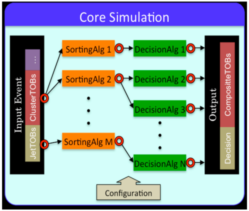



Fig. 11: Comparison with physics data

## Simulation and playback

All algorithms are validated in VHDL simulation. Test vectors are generated with scripts and saved results of simulation are checked. In the hardware a playback memories are available and can be filled with events containing particle signatures and again operation of algorithms can be verified.

## Stand alone tests

Sending artificial hot towers from calorimeter and muon system with different frequencies, angles, energies. This is extensively used to track down mistakes. Additionally cosmics can be used to check proper timing of events.

## Beam operation

Full emulation of algorithms is implemented and data collected during physics run containing algorithms results and all TOBs is used to validate proper behaviour of L1Topo.

# Algorithms - online commissioning. Preliminary results

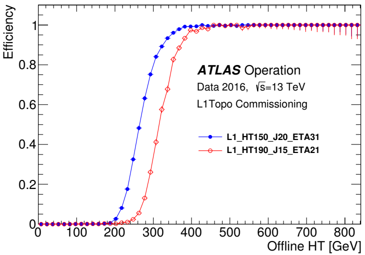



Fig. 12: Calculated efficiency turn-on curves for two L1Topo triggers HT150_J20_ETA31 (HT190_J15_ETA21) which require the transverse energy sum of jets with $p_T > 20(15) GeV$ and pseudo-rapidity $|\eta| < 3.1(2.1)$ to be above $150(190) GeV$. The efficiency of these triggers with respect to the full sample of events is shown as a function of the offline-reconstructed HT calculated using the appropriate selection of reconstructed jets.

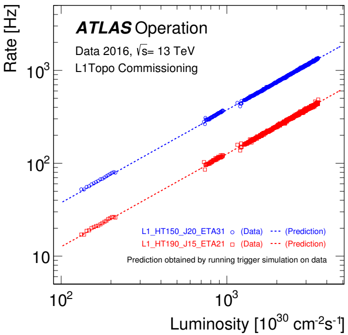



Fig. 13: Trigger rates as a function of the instantaneous luminosity of two L1Topo triggers based on the HT algorithm, which computes the transverse energy sum of jets. The online trigger rates are compared to the prediction obtained by running the trigger simulation on an un-biased data sample.

## Summary

- L1Topo hardware is validated
- control/readout firmware validation nearly finished, only minor modifications needed
- full machinery for algorithm commissioning and validation in place
- these various approaches allows for thorough and careful validation of L1Topo system
- preliminary results are promising but validation is still ongoing

**Good progress in commissioning of L1Topo system with promising preliminary results**