The ATLAS Level-1 Topological Processor: experience and upgrade plans

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ATLAS Trigger System

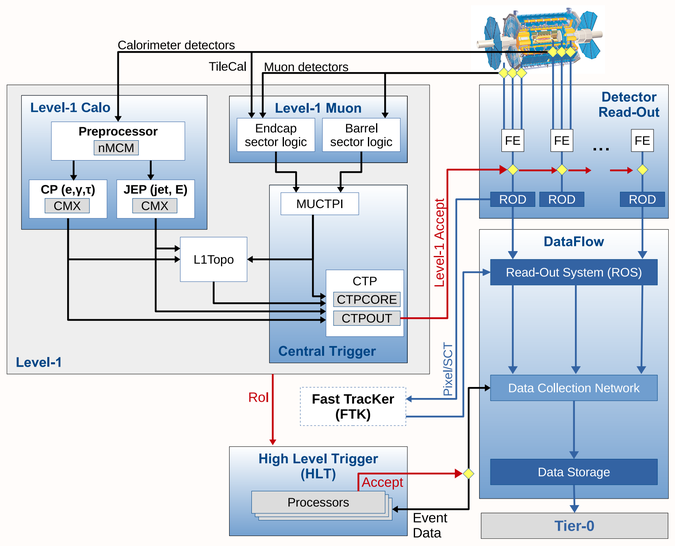


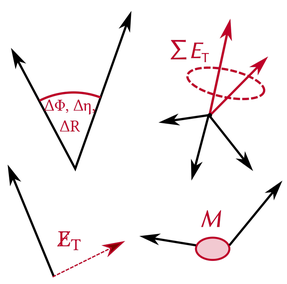
Figure 1: Schematic view of the ATLAS detector trigger system for Run 2 [1]

The ATLAS trigger system consists of two main parts, Level-1 Trigger and High-Level Trigger. The 40 MHz of proton-proton collisions are reduced to a rate of up to 100 kHz by the Level-1 Trigger and further processed by the High-Level Trigger. The Level-1 Topological Processor (L1Topo) gets inputs from the Level-1 Calorimeter Trigger (L1Calo) and the Level-1 Muon Trigger containing information on $jets$, e, γ, τ, μ and missing energy. It provides trigger decisions based on topological algorithms to the Level-1 Trigger.

Topological Algorithms

L1Topo system uses sorting and selecting algorithms based on E_t and η requirements. These objects are then combined into topological algorithms. A total of 114 topological triggers were implemented in 2018, such as,

- Angular Cuts: $\Delta\eta$, $\Delta\phi$, ΔR, object disambiguation
- Energy sums and large-radius jet clustering
- Invariant Masses
- Jet based E_t^{miss} correction



Hardware

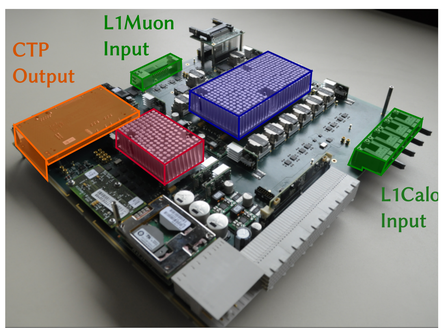


Figure 2: The L1Topo board used in Run 2.

Two identical modules process 1 Tbit/s of input data with a fixed latency of 200 ns. The input data are received via optical fibres, transformed into electrical signals and then directed into the FPGAs. Each module contains:

- Two Virtex7 FPGAs for algorithm processing
- A Kintex7 FPGA for module control and readout

L1Topo Validation

A bitwise simulation has been performed in order to validate hardware decision.

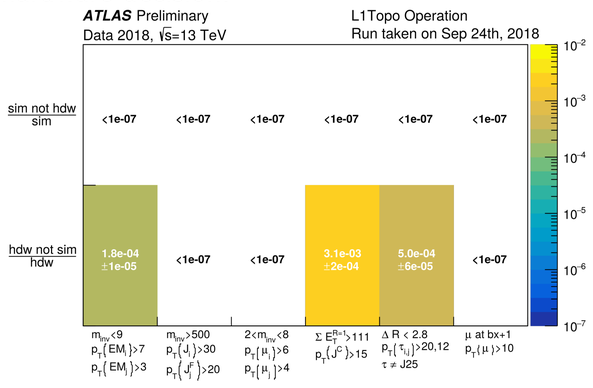


Figure 3: Agreement of $>$ 99 % observed between hardware and simulation decision for all algorithms used for physics analyses in Run-2 [1]

L1Topo Performance

L1Topo triggers allow to reduce the event rate without losing signal efficiency for a variety of challenging low p_T signatures and help recover higher efficiency compared to non-topological triggers. In general L1Topo trigger system provides good rate reduction while preserving signal efficiency!

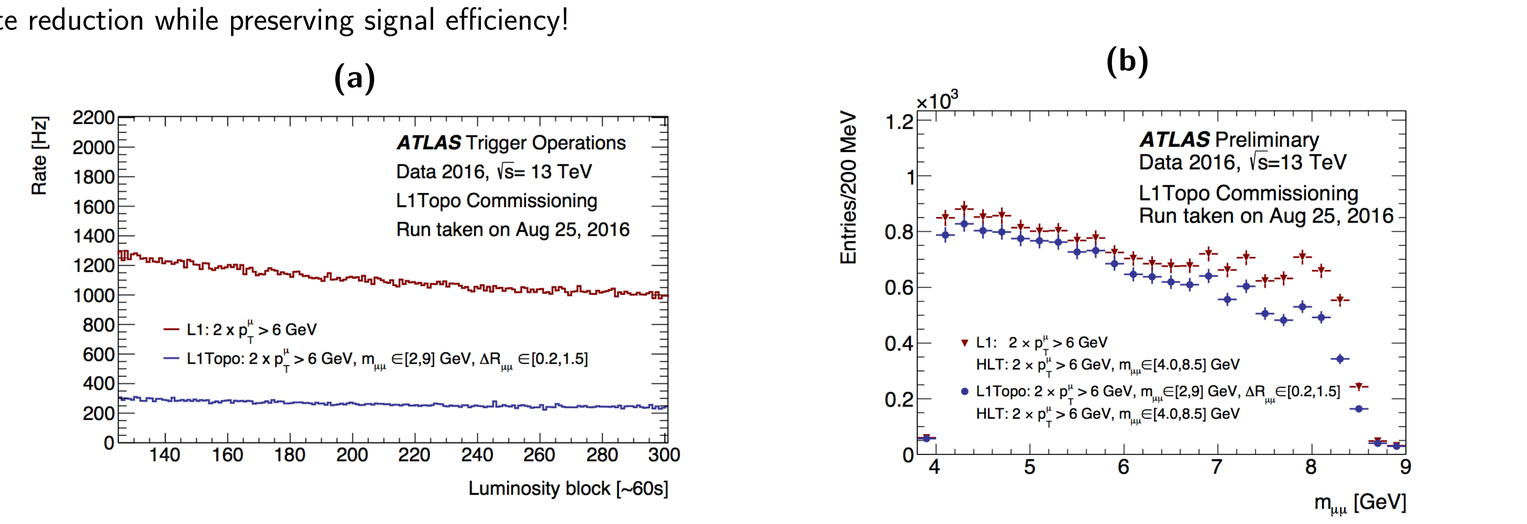


Figure 4: **B-physics example:** (a) Comparison of two di-muon selections in the Level-1. One only requires muons with $p_T > 6$ GeV (red), while the other applies a topological selection that also requires cuts on the invariant mass and angular separation of the muon pair (blue). (b) The number of events accepted by the HLT seeded by L1Muon and L1Topo selections is shown as a function of the di-muon invariant mass [2]

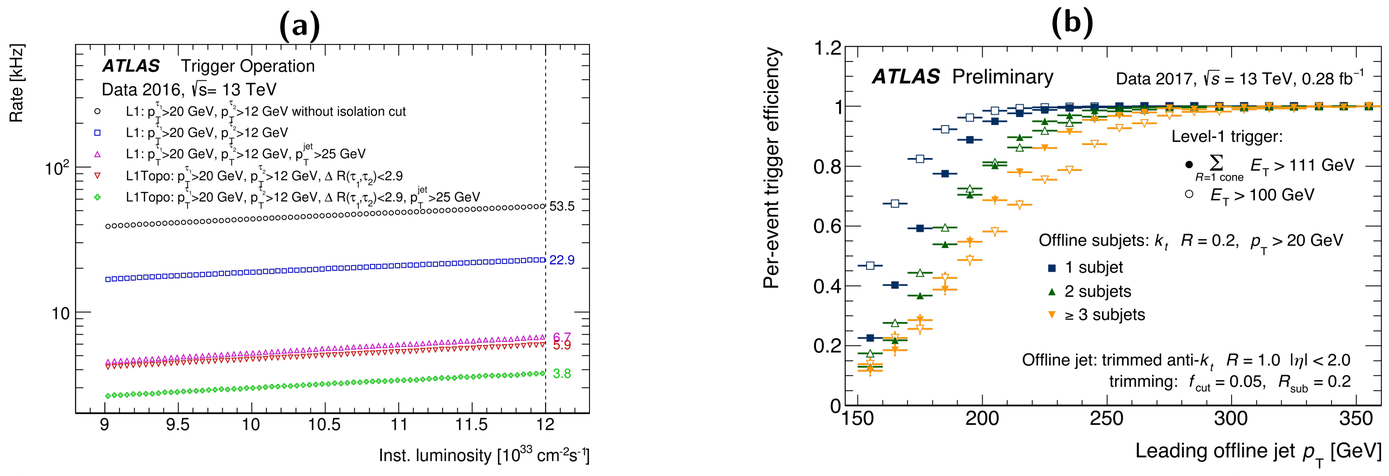


Figure 5: (a) $H \to \tau_{had}\tau_{had}$ **Triggers:** L1Topo requirement for $\Delta R(\tau_1, \tau_2) < 2.9$ reduces rate by about a factor of four (purple marker) without raising the threshold [3] (b) **Large-Radius Jet Clustering:** The scalar sum of transverse energies of smaller jets (solid markers) recovers efficiency for large-R jets with multiple subjets. [4].

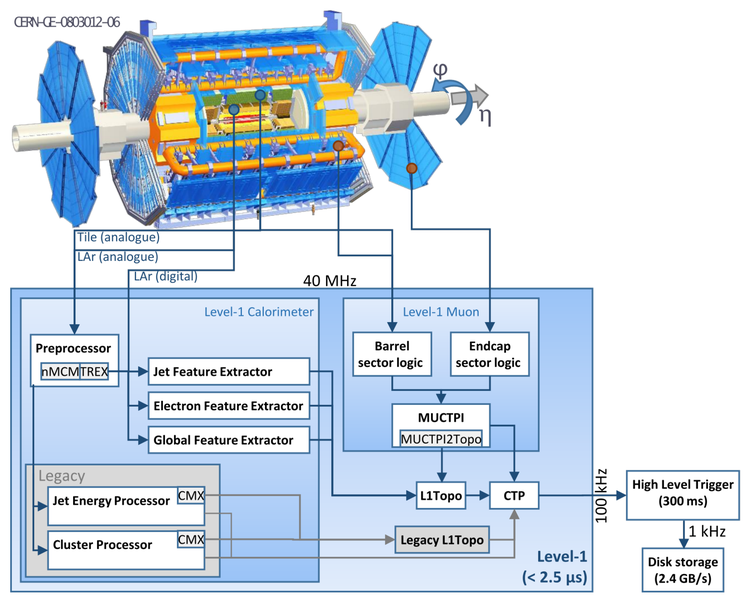
L1Topo in Run 3

During the Long Shutdown 2 (LS2) in the LHC program, the ATLAS detectors and trigger system are under preparation for the new beam conditions in Run 3.

Level-1 Trigger Upgrade

- L1Calo system introduced a new Feature Extractors (FEX) modules to build trigger objects with higher granularity
  - Electron Feature Extractor (eFEX)
  - Jet Feature Extractor (jFEX)
  - Global Feature Extractor (gFEX)
- In the L1Muon system, the End-Cap Sector Logic is upgraded and a new MUCTPI board will be installed. With the Run 3, muon candidates will have increased granularity and charge information.

Since the topological triggers are fed by the L1Calo and L1Muon system, the L1Topo hardware will need adapting to the new input formats from both systems.



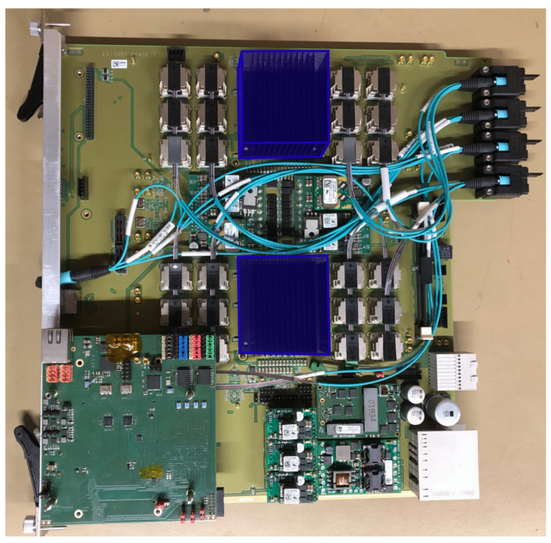


Figure 6: The L1Topo board planning to be upgraded in Run 3.

Level-1 Topo Upgrade

- Run 2 L1Topo is replaced by three new boards, each containing:
  - Two Xilinx UltraScale+ FPGAs for algorithm processing, 1 Tbit/s per FPGA
  - 118 input fibers and 24 output fibers
  - Phase1 Topo will have a control FPGA (Zynq, FPGA/Arm hybrid SoC)
- In addition to topological triggers, the new L1Topo will provide multiplicity triggers for L1Calo objects.
- The new system will run in parallel with the legacy Run 2 system in the beginning for commissioning.
- L1Topo algorithms will use charge information from L1Muon input.
- Multiple cuts on the different kinematics for the same object pairs/tuples applied simultaneously.

References

[1] The ATLAS collaboration, https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ApprovedPlotsDAQ
[2] The ATLAS collaboration, https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TriggerOperationPublicResults
[3] The ATLAS collaboration, The ATLAS Tau Trigger in Run 2, ATLAS-CONF-2017-061 https://cds.cern.ch/record/2274201?ln=en
[4] The ATLAS collaboration, https://twiki.cern.ch/twiki/bin/view/AtlasPublic/JetTriggerPublicResults