Real time data analysis with the ATLAS Trigger at the LHC in Run-2

Hugo Beauchemin, on behalf of the ATLAS Collaboration

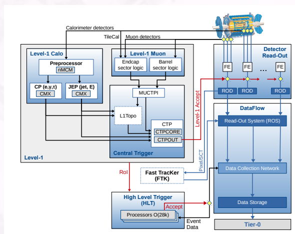
Challenges with Data-Taking at the LHC During Run-2

During Run-1 of the LHC, the ATLAS trigger system operated efficiently at instantaneous luminosities of up to 8 × 10^{33} cm^{-2} s^{-1} and primarily at center-of-mass energies of 7 and 8 TeV. In Run-2, the center-of-mass energy increased to 13 TeV, enhancing the total proton-proton (pp) cross section, and therefore the trigger rate, by more than 100%. In addition, changes in the beam parameters resulted in an increase of the instantaneous luminosity by a factor of up to about 3, with a number of pp-interactions per bunch-crossing (in-time pile-up) reaching 80 in 2017. Finally, a reduction of the bunch spacing from 50 ns to 25 ns added interactions from neighboring bunch-spacing (out-of-time pile up). While these changes to the beam aimed at producing a large enough dataset for probing new physics at the TeV scale and performing measurements at an unprecedented precision, they made the Run-1 trigger menu completely unsustainable. **To preserve the physics program of the experiment, a significant upgrade of the ATLAS trigger system was needed for Run-2.**

Run-2 Improvements to the ATLAS Trigger System

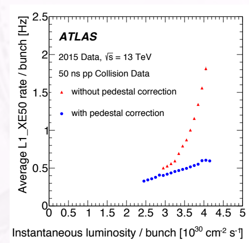
Improvements of the hardware, firmware and software parts of the trigger system must aim at a better rate control and processing time per event, higher reconstruction and identification efficiencies with respect to offline selections, and resolution effects closer to offline measurements. Some of the most striking improvements include [1]:

- 4th RPC chambers electronic: To recover some muon trigger acceptance lost near detector feet and elevator shafts (2.8% and 0.8% respectively).
- New Fast TracKer (2018): Fast tracking reconstruction at L1 [2].
- L1-Topo: Two FPGA-based processor modules added to refine calculation and perform selections at L1.
- High-Level Trigger: Merge L2 and EF farms for more flexibility, simplify hardware and software, and remove rate limitation between fast and precision processing to use the resources for better trigger efficiency.
- Read-Out System: Upgraded to deal with higher readout and output rates.



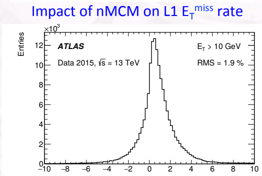
Sketch of the ATLAS TDAQ system in Run-2

- Trigger Processor: Upgrade CTP to double the trigger and bunch-group selections, and communicate with L1-Topo. A new FPGA-based module (nMCM) was used in L1CALO to digitalize and calibrate the analogue signal. It allowed for a bunch-by-bunch pedestal subtraction that significantly reduce the rate of L1 Jets and E_T^{miss} triggers, linearized the rate as a function of the luminosity and the position of bunches in a train, and improve the bunch-crossing identification.



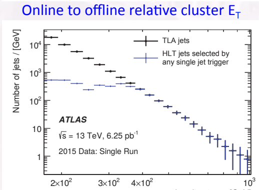
Impact of nMCM on L1 E_T^{miss} rate

- TGC coincidence: A new trigger logic was introduced to suppress the L1 trigger rate in the muon end-cap region due to particles not originating from the interaction point (60% rate reduction in this region).
- Calorimeter clustering : Harmonizing online with offline, topocluster reconstruction directly after L1 has been possible thanks to a new caching mechanism that bought enough CPU time to do it.



Online to offline relative cluster E_T

- Trigger menu: The improvement to the overall system allowed a 30% increase in the L1 accept rate compared to Run-1, and an HLT output of ~1kHz (was 400 Hz in Run-1). The menu has been optimized for several luminosity ranges, maximizing the physics output.
- Event streaming: There is now only one Physics stream, reducing storage and CPU resources by 10%. A new stream also allows for partial event storage and therefore allows for **Trigger-Level Analyses** at lower thresholds.



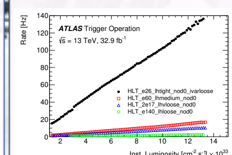
Low Jet-p_T spectrum recovered by TLA

Examples of Real Time Data Analyses

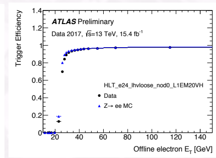
ELECTRON TRIGGER:

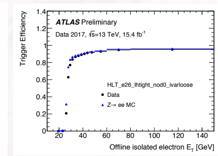
New Multivariate techniques have been used to calibrate electrons and to implement a likelihood discriminant improving the efficiency and purity of electron identification.

Required to keep the E_T threshold low enough to store as many W, Z and H as possible.



Rate dominated by the single electron trigger (W bosons)



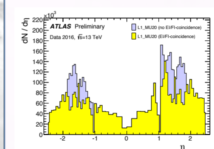


Tight electron selections allow to collect lower p_T electron, at an efficiency cost for higher offline electron p_T.

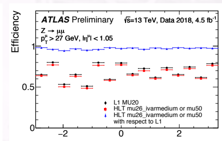
MUON TRIGGER:

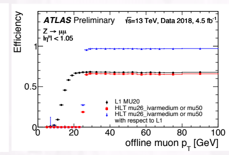
The coincidence logic and isolation selections reduce the L1 trigger rate with negligible efficiency loss. Background is not the most limiting factor; L1 acceptance is.

New L1 instrumentation has a direct impact on efficiency of muon selections.



L1 muon rate reduction by TGC coincidence decision.



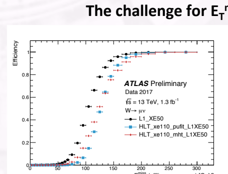


Most of the inefficiency comes from uninstrumented regions at L1. With respect to L1, HLT is essentially perfect.

E_T^{miss} TRIGGER:

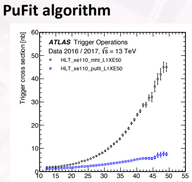
E_T^{miss} is a global quantity, highly sensitive to resolution, defects in the detector, and pile-up leading to very high rate. Thanks to L1 improvements, the E_T^{miss} threshold is kept low enough for the distortion with respect to offline being mostly due to HLT.

The challenge for E_T^{miss} is to be robust against pile ➔ PuFit algorithm



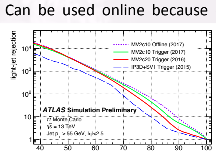
Right: With its event-by-event fit to estimate pile-up (μ), the PuFit algorithm reaches a close to linear dependence on μ.

Left: PuFit even has a slightly better efficiency than the offline-like jet-based "mht". L1 is not affecting results.



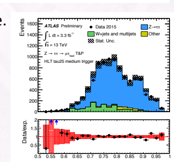
Multivariate Analyses:

Can be used online because of improvements in processing time.



Right: BDT algorithms to separate b from light and c-jet improve tagging performance.

Right: BDT are also used in tau reconstruction, enhancing the signal-to-background ratio.



Take-home Message

Large statistic data samples constitute one of the key ingredients for exploring new physics and performing high-precision measurements. To do this, the LHC luminosity is continually increased. This constitutes a challenge for data-taking. Thanks to improvements to the ATLAS Trigger and DAQ system, ATLAS succeeds in selecting the relevant physics events with high efficiency and close-to-offline performances, while coping with the objects rate increases.

References

[1] The ATLAS Collaboration, *Performance of the ATLAS Trigger System in 2015*, Eur. Phys. J. **C77** (2017) 317.

[2] The ATLAS Collaboration, *Technical Design Report Fast Tracker (FTK)*, ATLAS-TDR-021.

For other results, see: https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TriggerPublicResults