The ATLAS Trigger System: Ready for Run-2

Junpei Maeda (Kobe University) on behalf of the ATLAS Collaboration

Challenging data-taking conditions in ATLAS Run-2

The ATLAS trigger system operated successfully in Run-1.

It selected events online at $\sqrt{s}$ up to 8 TeV between 2009 and 2013, with high efficiencies for a wide range of ATLAS physics program.

Trigger rates are expected to increase by a factor of 5~6 in Run-2.

	Energy	Bunch-spacing	Inst. Lumi.	Collisions per x-ing
Run-1	8 TeV	50 ns	8×10^{33} cm^{-2}s^{-1}	25~30
Run-2	13 TeV	25 ns	1.5×10^{34} cm^{-2}s^{-1}	40~45

- the center-of-mass energy (more high-p_T jets): a factor of ~2.5 increase
- the peak luminosity: a factor of ~2 increase

Upgrades to the ATLAS trigger system were mandatory and implemented during LHC shutdown to deal with the increased trigger rates while maintaining efficiencies to select physics processes of interest.

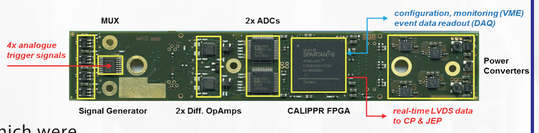
Level-1 Trigger upgrades

New Central Trigger Processor (CTP) features:

- increased the number of Level-1 items (512 in Run-2)
- Output rate increased to 100 kHz

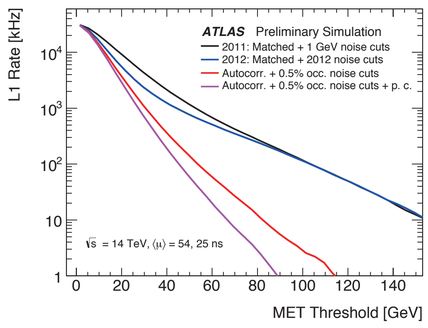
Level-1 Calorimeter Trigger:

New Multi-Chip Modules (x2000)



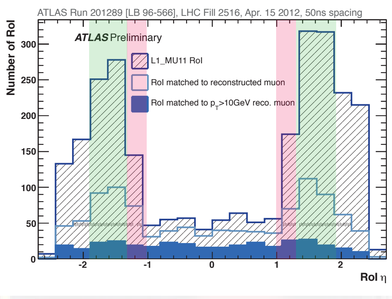
- Limitation was the Level-1 $E_{T,miss}$ rates which were significantly higher at the beginning of a bunch train.
- New multi-chip modules (ASIC→FPGA) allow more flexible signal processing with dynamic pedestal subtraction.
- Improved noise filters (matched→auto-correlated)

→ Significant reduction in Level-1 $E_{T,miss}$ rates



Increases in the number of definable Level-1 calorimeter trigger thresholds:

- Doubling the number of trigger threshold increases flexibility for trigger selections

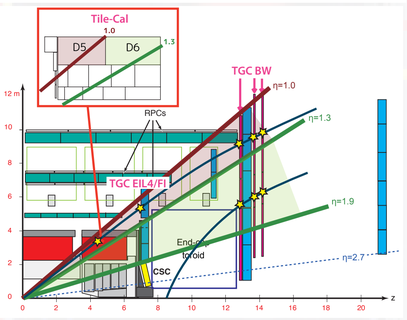


Level-1 Muon Trigger:

New coincidence logic

- In Run-1, many Level-1 muon triggers in the endcap region were caused by low p_T out-of-time protons generated in toroids and shieldings. This effect increases in 25 ns bunch spacing, i.e. the Level-1 trigger rate increases in Run-2.
- New strategy: coincidence with detectors placed before the endcap toroid
  - $1.0 < |\eta| < 1.3$: coincidence with Tile calorimeter or EIL4 Thin Gap Chamber (TGC)
  - $1.3 < |\eta| < 1.9$: coincidence with FI TGC

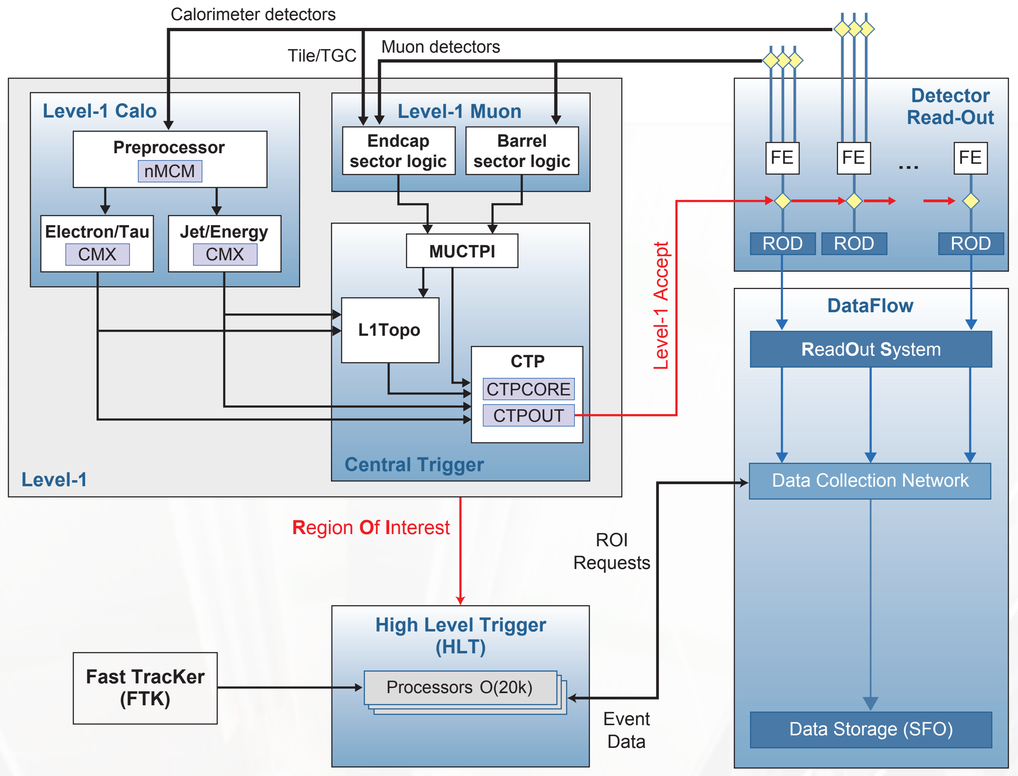
→ ~50 % rate reduction for Level-1 muon with $p_T > 20$ GeV, $1.0 < |\eta| < 1.9$ at 25 ns



New trigger chambers in the feet of the barrel region

→ ~4 % acceptance gain for Level-1 muons

ATLAS Run-2 Trigger/DAQ system



Level-1 Trigger

- custom electronics to determine Regions-of-Interest (RoI) in the detector based on coarse calorimeter and muon detector information
- Rate reduction from ~30 MHz to 100 kHz
- Latency 2.5 μs

High-Level Trigger (HLT)

- Software algorithms using RoIs or full detector event information, running on PC farm
- Event building in parallel
- Rate reduction from 100 kHz to ~1 kHz (up to 1.5 kHz)
- Latency 0.2 s

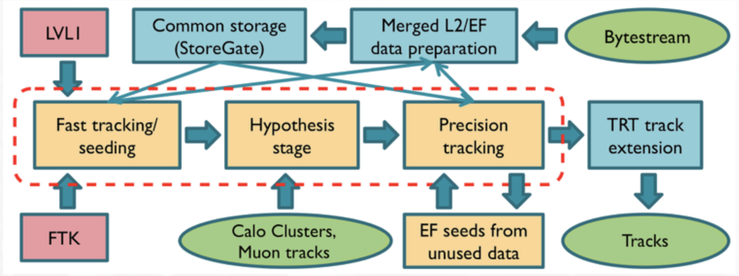
High-Level Trigger (HLT)

In Run-2, higher-level trigger farms and Event Builder farms are merged to a unique HLT farm for simplification and dynamic resource sharing.

- efficienct coupling between HLT selection steps reducing duplication of CPU usage and network transfer of detector data
- advanced multi-threaded processing for optimial memory usage
- allows flexible combination of fast and detailed processing in several steps (e.g. tracking, clustering and trigger decisions)

HLT algorithms: Major rewrite to be closer to offline reconstruction algorithms

- large reduction of code and commissioning duplications
- easier calibration of triggers along with offline selections
- usage of real-time pile-up information
- Increase in physics acceptance after analysis selections (e.g. tau trigger)



offline-like tracking and clustering run straight after Level-1

The performance has been improved!

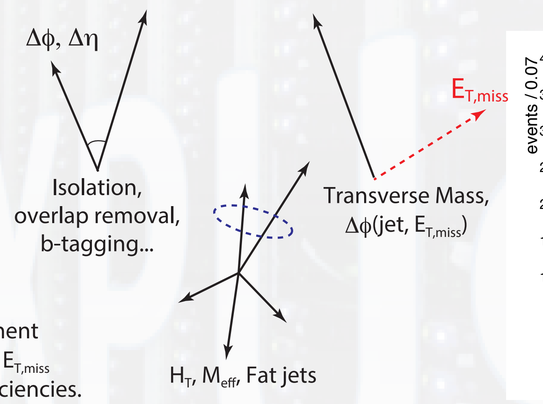
0.2 s average event processing time

Maximum output rate: ~2 kHz

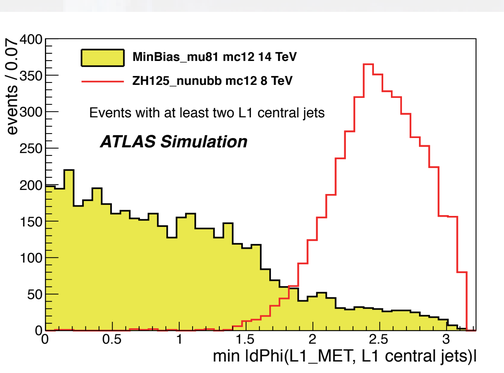
New Level-1 Topological Trigger Module:

- Performs topological selection on Level-1 physics objects at the LHC bunch crossing rate.
- Decisions on FPGA within Level-1 latency (200 ns)
- Variety of algorithms, e.g. angular separation, invariant mass, global quantities like H_T (sum of jet E_T)
- Essential to final states with $E_{T,miss}$, jets, and taus

→ Low thresholds for multi-object final states possible



Example: Minimum dϕ (L1 $E_{T,miss}$ - L1 central jets) requirement in SM Higgs ZH→ννbb analysis allows to lower $E_{T,miss}$ threshold (70 GeV→50 GeV), while keeping efficiencies.



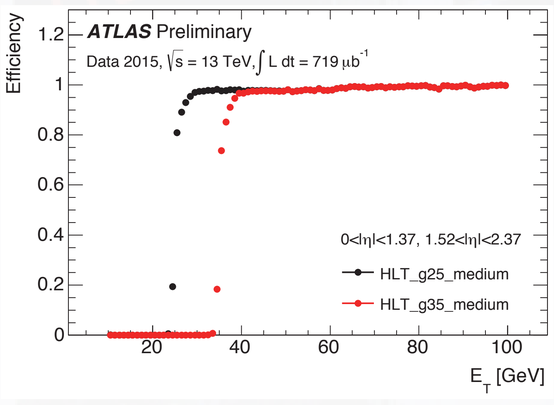
Performance of main physics triggers in the first 13 TeV collision data

The ATLAS Trigger: *Trigger Menu strategy for bandwidth allocation has been designed to maximize physics coverage.*

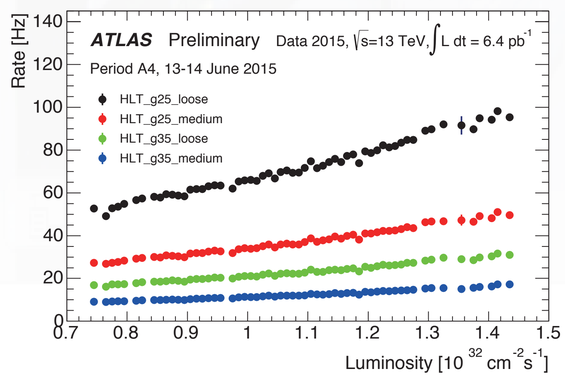
- More flexible with more L1 items than in Run-1.
- Most of the bandwidth is allocated to generic physics triggers, e.g. single electron muon, jet triggers etc.
- More analysis specific triggers as well as multi-object final state triggers (including L1Topo items) to keep low thresholds to preserve efficiencies at affordable rates.
- Based on physics objects (signature), such as photons, electrons, muons, jets, $E_{T,miss}$ etc.
- A huge set of triggers including for the validation and monitoring purpose have been implemented! (~500 types of selections at Level-1, and ~1000 triggers at HLT)

Photon trigger:

Efficiency of single photon triggers requiring a transverse energy (E_T) greater than 25 GeV and 35 GeV as a function of photon transverse energy.

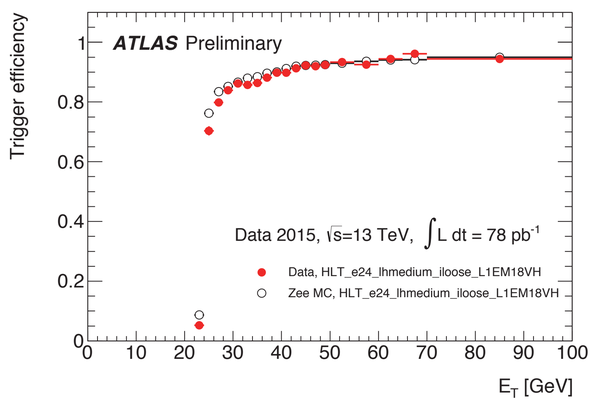


Output rates of single photon triggers as a function of the instantaneous luminosity.

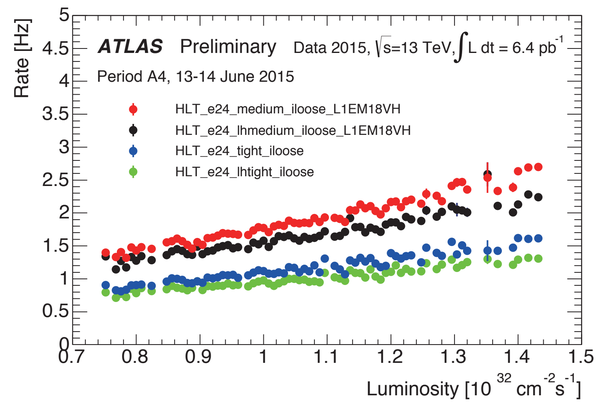


Electron trigger:

Efficiency of one of single electron triggers, as a function of the transverse energy (E_T). The efficiencies were measured with a tag-and-probe method using Z→ee decays.

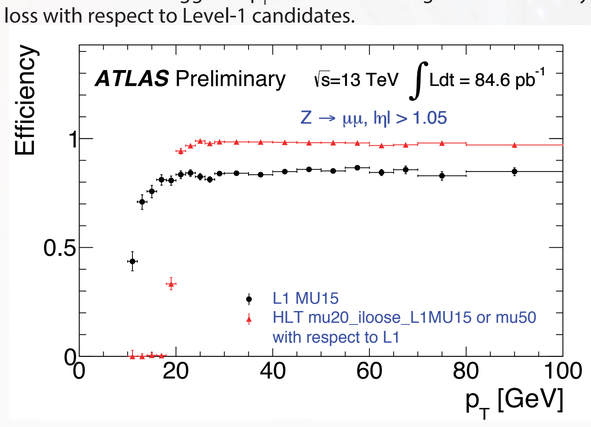


Output rates of single electron triggers as a function of the instantaneous luminosity. Medium-quality identification criteria will move to tight selections for higher luminosities.



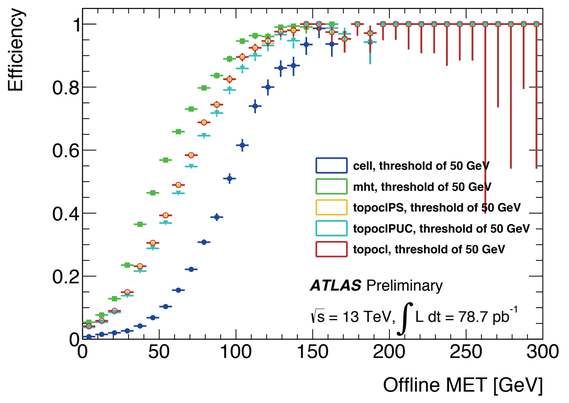
Muon trigger:

Efficiency of Level-1 trigger of $p_T > 15$ GeV and HLT trigger of $p_T > 20$ GeV or 50 GeV with respect to candidates passed by Level-1. The HLT trigger of $p_T > 20$ GeV is no significant efficnecy loss with respect to Level-1 candidates.



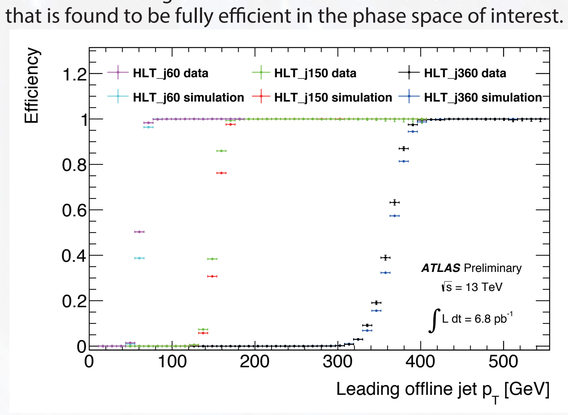
$E_{T,miss}$ trigger:

Missing transverse momentum trigger efficiency turn-on curves for a threshold of 50 GeV as a function of offline reconstructed $E_{T,miss}$ reference for different algorithms.



Jet trigger:

Comparison of trigger efficiency turn-on curves between data and MC simulation for three typical thresholds. Each efficiency is determined using events retained with a lower threshold trigger that is found to be fully efficient in the phase space of interest.



Summary

Many upgrades have been implemented in the ATLAS trigger system to cope with the increased trigger rates due to larger center-of-mass energy and higher luminosity.

Trigger commissioning with 13 TeV collisions is well advanced based sophisticated diagnostic tools. Comprehensive trigger strategies are in place to make use of the new resources and to exploit the full physics potential of ATLAS in Run-2.

Results are available on https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TriggerPublicResults

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