The ATLAS Trigger Algorithms Upgrade and Performance in Run-2

Catrin Bernius (SLAC)

From Run-1 to Run-2

- The ATLAS trigger system operated successfully in Run-1 (2009-1012)

- In Run-2 (2015-2018), overall trigger rates have increased by a factor of ~5
  - A factor of ~2 due to the energy increase
  - A factor of 2-3 due to the luminosity increase

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<th>Year</th>
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  - Increased trigger thresholds → potential loss of interesting physics
  - Increased trigger rejection power → improved hardware/software
  - Increase output rate → challenge for offline computing
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Further luminosity & pile-up increase in 2017/18 while running with similar limitations from trigger & data acquisition system
- L1 (100 kHz) & HLT (1 kHz) trigger rates
- Output bandwidth
- Processing time of High Level Trigger (HLT)
Overview of the ATLAS Trigger System

- **Level-1**
  - **Hardware-based;** Input from calorimeters & muon system
  - Rate and latency limit set by detector & trigger hardware
  - Dead-time applied if limits are exceeded
    - Preventive veto to stop the front-end buffers from overflowing

- **High Level Trigger (HLT):**
  - **Software-based;** Access to all detectors including tracking
  - Average processing time set by HLT farm size
  - 1 kHz **average** output rate set by computing model (bandwidth, disk space, Tier0 size, …)
Overview of the ATLAS Trigger System

Level-1 Calo
- Pre-processor [nMCM]
  - CP (e, γ, τ)
    - CMX
  - JEP (jet, E)
    - CMX

Level-1 Muon
- Endcap sector logic
- Barrel sector logic

Central Trigger
- MUCTPI
- CTP
  - CTPCORE
  - CTPOUT

Fast TracKer (FTK)

High Level Trigger (HLT)
- Accept
- Processors O(28k)

Event Data

Read-Out System (ROS)

Data Collection Network

Data Storage

Tier-0

Calorimeter detectors
- TileCal/TGC

Muon detectors

DataFlow

Level-1 Accept

Pixel/SCT

ATLAS TDAQ design values & figures

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Level-1 Muon
- Barrel (RPC, $|\eta| < 1.05$)
- Endcaps (TGC, $1.05 < |\eta| < 2.4$)
- No $p_T$ measurement, only thresholds passed (and multiplicities)

Central Trigger Processor (CTP)
- Final trigger decision

Level-1 Calo: For triggering on any EM object: Electrons, Photons, Jets, Taus, Global event quantities ($M_{E_T}$)

L1Topo: Combines information from L1Calo and/or L1Muon into topological variables looking at absolute/relative location of trigger objects

See Kate Whalen’s talk on “Operation and Performance of the ATLAS Level-1 Calorimeter and Level-1 Topological Triggers in Run 2 at the LHC”
The ATLAS Trigger System: HLT

- High Level Trigger (HLT)
  - Input from Level-1 in form of a **Region-of-Interest (RoI)**
    - Geometrical region in $\eta \times \Phi$ with information about type of object (EM, MU, TAU,...) and passed thresholds ($p_T, E_T$)
    - More CPU/time expensive reconstruction algorithms can be run in RoI, e.g. tracking
  - Decision about the final event accept is made

**Fast TracKer (FTK)**
- Currently being installed, under commissioning in 2017
- **Hardware-based full event track finding** using associate-memory chips (pattern matching)
- Processes events at 100 kHz make fitted track available to HLT
- To replace/augment CPU-expensive software based tracking in the HLT
- Key feature for **high-luminosity** running
Electron & Photon Trigger Improvements

- **Electron triggers:**
  - L1 EM isolation tightened to keep single electron trigger threshold low
  - New data-driven smooth LH electron tunes using 2016 data
  - Sharp turn-on curves and good agreement with MC comparison

- **Photon triggers:**
  - Isolation at L1 and HLT for low-mass di-photon searches to keep thresholds low

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**ATLAS Preliminary**

Data 2016, \( \sqrt{s} = 13 \text{ TeV} \)

**L1 EM isolation optimisation**

Efficiency vs. Offline electron \( E_T \) [GeV]

**ATLAS Preliminary**

Data 2017, \( \sqrt{s}=13 \text{ TeV}, \) 1.8 fb\(^{-1}\)

**Trigger Efficiency**

Offline isolated electron \( E_T \) [GeV]

**HLT_e28_Ihtight_nod0_iVarloose**

- Data
- \( Z \rightarrow ee \) MC
Tau & Muon Trigger Improvements

- **Tau triggers (hadronic):**
  - L1Topo used by default for di-tau and lepton+tau triggers
  - Various improvements and changes to online tau energy scale corrections, online tau identification (BDT) to reflect offline changes, high-pT (> 400 GeV) selection for higher efficiencies

- **Muon triggers:**
  - $p_T$ determination using the Cathode Strip Chambers (CSC) to improve the resolution in the forward region (2.0 < $|\eta|$ < 2.4)
Jets - Global Sequential Calibration in Small-R Jets

- Jet trigger turn-on curves driven by relative HLT/offline jet resolutions
  - If online resolution closer to the offline → sharper turn-on curve
  - Sharper turn-on curve → less wasted rate below the plateau in the turn-on curve

- Small R-jet trigger (R = 0.4):
  - Global Sequential Calibration (GSC) calibration for majority of jet triggers
    - Applies additional Jet Energy Scale (JES) corrections using tracking and jet shape information
    - Reduces the flavor dependence of the response and improves the jet energy resolution
• Large-R jet trigger ($R = 1.0$):
  - Jets are wider $\to$ more susceptible to pile-up
  - Make use of offline grooming techniques to reduce the effects of pile-up
    ‣ **Trimming**:
      ★ Re-cluster jet constituents with $R = 0.2$ to form sub-jets
      ★ Remove sub-jets if $p_T^{\text{sub}}/p_T^{\text{jet}} < 4$
    ‣ Slightly altered from offline (5% → 4%) to recover lost efficiency
    ‣ Produces stable mass/$p_T$ vs pile-up
    ‣ As mass distribution is stable, can apply mass cuts and discriminate QCD vs W/Z/H/t
  - **Reduced pile-up dependence, improved resolution**
  - Brings online closer to offline $\to$ **sharper turn-on curve**
Missing Transverse Energy (MET)

- Pile-up mitigation is the main challenge for $E_T^{\text{miss}}$ triggers
  - In 2016: used $mht$ algorithm which is based on negative $p_T$ sum of all jets reconstructed by the anti-$k_T$ jet finding algorithm
  - New algorithm in 2017: PUFit which calculates $E_T^{\text{miss}}$ as the negative $p_T$ sum of all calorimeter topological clusters corrected for pile-up, pile-up estimated event-by-event and subtracted

  ▶ Excellent performance in high pile-up regimes
Conclusion

- Many improvements in algorithm performance and robustness across all signature groups to deal with increasing rates due to luminosity and pile-up increase
  - Only highlighted a few of them here!
- FTK currently being installed and commissioned in 2017 → further hardware improvement to the TDAQ System
- Run-1 and ongoing Run-2 have shown that ATLAS trigger system & strategy for event selection is very robust and able to adapt to the changing LHC conditions
  - Dedicated list of triggers (trigger menu) with various backups in place
    - See Heather Russell’s talk on “The ATLAS Trigger Menu design for higher luminosities in Run 2”
- Ready for the remaining two years of Run-2 Operations with increased luminosities and pile-up!