The Performance of the Muon, Electron and Photon Triggers at ATLAS

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Preface

Why are the electron, photon and muon triggers important?

ATLAS Preliminary

$H \rightarrow \gamma \gamma, m_H = 125.09 \text{ GeV}$

$\sqrt{s} = 13 \text{ TeV}, 139 \text{ fb}^{-1}$

ATLAS Public Results
40 MHz of p-p collisions are reduced to a rate of 100 kHz by the Level-1 (L1) Trigger. After further processing by the High-Level Trigger (HLT), the final event recording rate is of ~1 kHz.

**L1 Trigger:**
Fast and coarse, hardware-based trigger

- **L1 Calo** calorimeter trigger for Electrons, Photons, Jets, taus, Missing ET
- **L1 Muon** to trigger on Muons
- **L1 Topo** topological Processor using information from L1CALO and L1Muon

Sends Region-of-Interest (RoI) to HLT for the final decision and data-storage

**HLT Trigger:**
Software-based trigger

- Fast reconstruction inside the given RoI
- Precise measurements, using offline based reconstruction tools
Electron/Photon Trigger

- L1 trigger
  - uses calorimeter information in the central ($|\eta| < 2.5$) region to build an EM RoI consisting of $4 \times 4$ trigger towers, with granularity $0.1 \times 0.1$ in $\eta$ and $\varphi$
  - A sliding–window algorithm identifies a local energy maximum from the four possible pairs of nearest neighbour towers in a $2 \times 2$ central region

Electrons HLT
- Fast Calorimeter reconstruction:
  - Neural-network-based (Ringer) algorithm for electrons with $E_T > 15$ GeV
  - Shower shape-based selection for electrons $< 15$ GeV
  - Tracks reconstructed in the Inner Detector matched to electromagnetic clusters
- Precision reconstruction:
  - Identification based on a likelihood discriminator
  - ‘loose’, ‘medium’, ‘tight’ working points defined

Photons HLT
- Fast Calorimeter reconstruction:
  - Calorimeter-only selection
- Precision Reconstruction:
  - Rectangular cuts on calorimeter shower shapes
  - ‘Loose’, ‘Medium’ and ‘Tight’ identification working points
  - No tracking used for photons at HLT

arXiv:1909.00761
Ringer Algorithm

- Since 2017
- Use lateral shower development
- Concentric ring energy sums in each calorimeter layer
- Transverse energy in each ring normalised to total transverse energy in the RoI
- Ring energies fed into multilayer perceptron (MLP) neutral networks

Ringer increases fast calorimeter step reconstruction time, but reduces input candidates to the tracking significantly reduced CPU demand
50% CPU reduction at the HLT for the lowest $p_T$ un-prescaled single electron trigger

arXiv:1909.00761
Trigger performance is evaluated using tag and probe method using $Z \rightarrow ee$ events
- Tag: lowest un-prescaled single-electron trigger
- Probe: used to measure the trigger efficiency, opposite charge to tag
- Single electron trigger combination: un-prescaled single-electron triggers with lowest thresholds
- Efficiency is measured in respect to offline electron

**Sharper turn on in 2015:** Lower threshold, no isolation, looser identification

**Inefficiencies in 2016:**
- MC-based Likelihood in precision calorimeter step
- 2017-2018: data-driven likelihood Id, introduction of Ringer algorithm
- Pileup dependency reduced towards end of Run 2
Photon Trigger Performance

- Trigger efficiency:
  - measured using Z radiative decay method using \( Z \rightarrow ll\gamma \)
- Tag and probe selection:
  - tag: electrons or muons from lowest \( p_T \) un-prescaled single and double leptonic trigger
  - probe: tight photon candidate

Slightly lower efficiency in 2017-2018 due to the tightening of photon ID
Sharp turn on and small dependency on pileup
Muon Trigger

- Muon Spectrometer (MS) in toroidal field (2 - 7.5 Tm)
- L1 Muon trigger:
  - Only some part of MS information
  - L1 trigger acceptance: $|\eta| < 2.4$
- HLT:
  - Uses full MS information for track segments and tracks reconstructed in the Inner Detector (ID)
  - Combined muons then formed from the muon segments and ID tracks

Muon Trigger Sequence:

1. L1 RoI
2. Fast MS Tracking
3. Fast ID tracking + MS-ID comb
4. Precision MS tracking
5. Precision ID tracking + MS-ID comb
Muon Trigger Performance

Muon trigger efficiency in the Barrel

- The efficiency loss in the barrel is essentially due to uncovered detector regions - eg the ATLAS supporting legs
- HLT is 100% efficiency relative to L1
- Almost no pileup dependency

Muon trigger efficiency in the Endcap

Muon Trigger
Electron, Photon Triggers Upgrade in Run 3

L1 CALO
- The Run-3 LAr calorimeter's trigger digitised readout improved with finer granularity
- New suite of L1 hardware designed to take advantage of this
  - Finer granularity of the super cells allows to use shower shapes closer to offline
  - Better resolution
  - Sharper trigger turn-on

Same rate − 0.5 x rate

Trigger public page
Muon Upgrade in Run 3

- The chambers of the muon innermost layer will be replaced with higher granularity detectors, New Small Wheels (NSW), provide precise tracking information.

- Rate reduction by NSW is due to requiring additional inner coincidence of the big wheel to reject fakes, and also to re-calculate the $p_T$ only with few % drop in efficiency, ~50% rate reduction is expected for L1 MU20.
Summary

- Good understanding of the electron, muon and photon trigger performance during Run 2

- All measurements show stable performance during Run 2 and efficient triggering of electrons, muons and photons.

- Many ongoing efforts to improve trigger performance toward Run 3

  - Aim to get closer to offline selections than in Run 2
  - Multithreading techniques for HLT
Backup
References

- Web References
  - https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TriggerPublicResults
  - https://twiki.cern.ch/twiki/pub/AtlasPublic/EgammaTriggerPublicResults
  - https://twiki.cern.ch/twiki/bin/view/AtlasPublic/L1MuonTriggerPublicResults
  - https://twiki.cern.ch/twiki/bin/view/AtlasPublic/MuonTriggerPublicResults
L1 Electron/Photon Trigger

Trigger performance is evaluated using tag and probe method using $Z \rightarrow ee$ events

Tag: lowest un-prescaled single-electron trigger
Probe: used to measure the trigger efficiency, opposite charge to tag

ATLAS
pp data 2017, $\sqrt{s} = 13$ TeV

arXiv:1909.00761
Electron/Photon HLT Reconstruction

arXiv:1909.00761
Trigger performance is evaluated exploiting tag and probe method using $Z \rightarrow \mu\mu$ events or $J/\psi \rightarrow \mu\mu$ at lower $p_T$.

Efficiency is measured in respect to offline muon.

- Efficiency is about 90% in the endcap and nearly 70% in the barrel.
- The efficiency loss in the barrel is essentially due to uncovered detector regions - e.g., the ATLAS supporting legs.