The ATLAS Electron and Photon Trigger Performance in Run-2

Daniela Köck
on behalf of the ATLAS collaboration

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Overview

Introduction
The ATLAS trigger system in a nutshell, Ringer algorithm
offline electron and photon reconstruction

electron and photon trigger efficiency measurements
Z tag-and-probe method, Z radiative decay method, Bootstrap method

Performance of electron and photon triggers during Run-2
Level-1 performance, electron and photon trigger evolution,
trigger in heavy ion collisions

Conclusions and Outlook
The ATLAS Electron and Photon Trigger Performance in Run 2

Daniela Köck (dkoeck@cern.ch)

The ATLAS trigger system in a nutshell

- **Fast steps**
  - Level 1 (L1)
  - Hardware
  - Calorimeter/Muon chambers

- **Precision steps**
  - Energy Calibration
  - Calibrated $E_T$ selection
  - Precise Track Reconstruction
  - Precise Electron Reconstruction

**Level-1**

- 2x2 trigger tower cluster as RoI in EM calorimeter
- $\mathbf{V}$: varying $E_T$ threshold within -2 and +3 GeV of nominal threshold
- $\mathbf{H}$: veto on hadronic leakage
- $\mathbf{I}$: $E_T$ dependent isolation of cluster in EM calorimeter

- $\mathbf{V}$: $E_T$ dependent isolation of cluster in EM calorimeter
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- Fast Calorimeter Reconstruction
- Fast Track Reconstruction
- Fast Electron Reconstruction
- Fast Electron Selection

- Precise Calorimeter Reconstruction
- Energy Calibration
- Calibrated $E_T$ selection
- Precise Track Reconstruction
- Precise Electron Reconstruction
- Precise Electron Selection

- ~40 MHz
- ~100 kHz
- ~1 kHz

- Fast Calorimeter Reconstruction
- Fast Track Reconstruction
- Fast Electron Reconstruction
- Fast Electron Selection

- Level 1 (L1)
  - Hardware
  - Calorimeter/Muon chambers

- Energy threshold and multiplicity
  - 2g20
  - e26
  - lhtight
  - lghtight
  - icalov

- iso selection
  - 2g20
  - lhtight
  - icalov
Ringer algorithm

- used from 2017 on to trigger electrons (Fast Calorimeter step) with $E_T > 15$ GeV
- 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 for the lowest $p_T$ unprescaled single electron trigger)*
`Offline’ electron and photon reconstruction and identification

Electrons

- Identification based on a likelihood discriminator
- ‘loose’, ‘medium’, ‘tight’ working points considered
- using GSF (Gaussian-Sum Filter) as a generalisation of the Kalman fitter; better account for energy loss in Inner Detector

using Supercluster to improve electron and photon energy reconstruction in cases with Bremsstrahlung or pair production

Photons

- identification based on calorimetric variables
- two identification working points, ‘loose’ and ‘tight’
- ‘loose’ relying on shower shapes in the second electromagnetic calorimeter layer and hadronic deposits
- ‘tight’ including first layer of electromagnetic calorimeter
**Performance measurement techniques - electrons**

**Z tag-and-probe method**

- **Tag electron**
  - Tight offline identification requirement fulfilled
  - Fired lowest $p_T$ unprescaled single electron trigger

- **Probe electron**
  - Opposite charge to Tag electron
  - Invariant mass of Tag and Probe within Z-mass window

$$\epsilon_{\text{total}} = \epsilon_{\text{offline}} \times \epsilon_{\text{trig}} = \left( \frac{N_{\text{offline}}}{N_{\text{all}}} \right) \times \left( \frac{N_{\text{trig}}}{N_{\text{offline}}} \right)$$

compute trigger efficiency with respect to offline electron definitions

**systematic uncertainties**

- given by varying tag definition, Z-mass window and background subtraction method
- central value is average of variations
Performance measurement techniques - photons

Tag electrons/muons

Fired lowest $p_T$ unprescaled single and double electron/muon trigger

-/+ opposite charge, same flavour lepton pair

ID medium offline identification requirement fulfilled, FCLoose isolation

Probe photon

tight photon candidate

$\eta < |2.37|\ E_T > 10\text{ GeV}$
satisfy isolation of interest

cut on $m_{ll}$ and $m_{ll\gamma}$ to avoid ISR photons

Z radiative decay method

ATLAS Preliminary

pp data 2017

$\sqrt{s} = 13\text{ TeV}$

$Z \rightarrow l\bar{l}\gamma$
Performance measurement techniques - photons

**Bootstrap method**

\[
\epsilon_{\text{trig}}^\gamma = \epsilon_{\text{HLT}|BS} \times \epsilon_{\text{BS}}
\]

- High Level Trigger efficiency with respect to offline selection
- High Level Trigger efficiency on bootstrap sample
  - based on Level-1 only triggers or loose and low \( E_T \) photon triggers
- Bootstrap sample efficiency with respect to offline selection
  - computed on events selected by special ‘random’ trigger

- large, uncontrolled background contamination (main source of uncertainty)
- systematic uncertainty as difference between data and simulated \( H \to \gamma\gamma \) events
Level-1 trigger performance

- Linear increase of rate with instantaneous luminosity
- Single Level-1 EM triggers: raise of threshold by 2 GeV leads to 25% decrease in rate
- Rate reduction of ~44% per leg by including electromagnetic calorimeter isolation at Level-1, efficiency decrease up to 5%
Photon trigger evolution and performance

<table>
<thead>
<tr>
<th></th>
<th>2015</th>
<th>2016</th>
<th>2017</th>
<th>2018</th>
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</thead>
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<tr>
<td><strong>Single photon</strong></td>
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<td>\textit{g140_loose}</td>
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<td>\textit{g35_medium_g25_medium}</td>
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<td><strong>Tight diphoton</strong></td>
<td>\textit{2g20_tight}</td>
<td>\textit{2g22_tight}</td>
<td>\textit{2g20_tight_icalovloose}</td>
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reoptimisation of ‘tight’ photon selection at the end of 2017

→ BSM physics, high $E_T$ photons
→ Higgs to diphoton
→ low mass diphoton searches
Photon trigger evolution and performance

- bootstrap method used to calculate the efficiency
- total uncertainties dominated by systematics, in total O(1%)
- efficiency in 2016 rises faster due to lower pile-up conditions
Photon trigger evolution and performance

- efficiency measured with radiative Z decay method
- lower efficiency in 2017-2018 due to medium instead of loose online ID
- no pseudorapidity or pile-up dependency in efficiency
**Electron trigger evolution and performance**

<table>
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<th>2017-2018</th>
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</thead>
<tbody>
<tr>
<td><strong>Single electron</strong></td>
<td>e24_lhmedium (EM20VH) e120_lhloose e200_etcut</td>
<td>e26_lhtight_nod0_ivarloose (EM22VHI) e60_lhmedium_nod0 e140_lhloose_nod0 e300_etcut</td>
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<tr>
<td><strong>dielectron</strong></td>
<td>2e12_lhloose (2EM10VH)</td>
<td>2e17_lhvloose_nod0 (2EM15VH)</td>
<td>2e17_lhvloose_nod0 (2EM15VHI) 2e24_lhvloose_nod0 (2EM20VH)</td>
</tr>
</tbody>
</table>

**Diagram:**

- **ATLAS Preliminary**
- **pp data 2015-2018**
- **$\sqrt{s} = 13$ TeV**

**Legend:**
- Lowest unprescaled single electron trigger
- 2015
- 2016
- 2017
- 2018

**Axes:**
- **Rate [Hz]**
- **Instantaneous Luminosity [cm$^{-2}$s$^{-1}$] $\times 10^{33}$**
Performance of the Ringer algorithm

Evaluation of Ringer performance in 2017

Comparing Ringer and cut-based selection at fast reconstruction

Nearly unchanged efficiency behaviour in single electron case

50% CPU reduction for the lowest $p_T$ unprescaled single electron trigger
Performance evolution of single electron trigger

sharper turn on in 2015
lower $E_T$ threshold, no isolation, looser identification
inefficiencies in 2016 below 60 GeV observed
due to LH calorimeter only selection in precision calorimeter step
2017 data driven likelihood selection, introduction of Ringer algorithm
pile-up dependency reduced towards end of Run-2
residual dependency due to isolation requirements
The ATLAS Electron and Photon Trigger Performance in Run 2

photon trigger in heavy ion data taking

- photon trigger efficiency evaluated with respect to offline-reconstructed photons
- efficiency shown with and without subtraction of the underlying event
Conclusion and Outlook

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

established methods to measure trigger efficiencies, several improvements during Run-2 to adapt to changing conditions

Many ongoing efforts to improve the electron and photon trigger performance and CPU usage in Run-3

Aim to get closer to offline selections than in Run-2

moving towards multi-threading on trigger level

update of Level-1 Calo electronics with improved granularity, will lead to improved background rejection and better efficiencies
References

[1] 'Electron and photon reconstruction and performance in ATLAS using a dynamical, topological cell clustering-based approach'
The ATLAS Collaboration, ATL-PHYS-PUB-2017-022
[3] 'Performance of Ringer in Trigger egamma for WCC12018'
   https://twiki.cern.ch/twiki/pub/AtlasPublic/EgammaTriggerPublicResults/HLT_e28_lhtight_nod0_ivarloose_L1EM24VHIM_et.png
[4] 'Performance of photon triggers for Pb+Pb collisions at 5.02 TeV'
   https://twiki.cern.ch/twiki/pub/AtlasPublic/EgammaTriggerPublicResults/PhotonTriggerPerformance_vsFCal_Prelim.png
BACKUP
Daniela Köck (dkoeck@cern.ch)

The ATLAS Electron and Photon Trigger Performance in Run 2

electron reconstruction
Datasets and simulated samples

**p-p collision data**
- 2015 - 3.2 fb⁻¹
- 2016 - 32.9 fb⁻¹
- 2017 - 43.9 fb⁻¹
- 2018 - 58.5 fb⁻¹

**Pb - Pb collision data**
- one month in 2015 and 2018
- centre of mass energy per nucleon pair 5.02 TeV

**Pb - p collisions**
- at 5.02 TeV and 8.16 TeV per nucleon pair in 2016

**Heavy Ion reference data**
- from 5.02 TeV p-p collisions in low pile-up conditions

<table>
<thead>
<tr>
<th>process</th>
<th>generators</th>
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<tbody>
<tr>
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<td>PYTHIA v8.186</td>
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<td>PYTHIA v8.186</td>
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<td>J / ψ → ee</td>
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**Z tag and probe method**

**tag electron**

matched to lowest unprescaled single electron triggers

tight ID, $E_T > 27$ GeV

$|\eta| < 2.47$, outside the transition region

**probe electron**

15 GeV around Z-mass peak

opposite sign to tag electron

**systematic uncertainties**

• given by varying tag definition, Z-mass window and background subtraction method

• central value is average of variations

• systematic on central value is standard deviation of all variations

• statistical error on central value is average over statistical uncertainty of variations
The ATLAS Electron and Photon Trigger Performance in Run 2

trigger inefficiencies

- inefficiency sources for 2017 single electron chain mainly electron identification for tight and isolated trigger

Daniela Köck (dkoeck@cern.ch)
Trigger reconstruction and identification of photons and electrons

2×2 trigger tower cluster as RoI in EM calorimeter

**Level 1**
- **V**: varying $E_T$ threshold within -2 and +3 GeV of nominal threshold
- **H**: veto on hadronic leakage
- **I**: $E_T$ dependent Ecal isolation of cluster

**e/γ trigger**
- precision reconstruction with sliding window algorithm
- no usage of superclusters
- use of average number of interactions per crossing instead of number of primary vertices

**Photon trigger**
- fast algorithm uses only 2nd layer of EM calo, selection on cluster $E_T$ and shower shape parameters
- online ID use same cluster shower shapes as the offline ID (without fudging), three working points: 'loose', 'medium' (only used online), 'tight'
- calorimeter only isolation possible
- no tracking information

**Electron trigger**
- fast calorimeter reconstruction cut-based and neural-network ringer algorithm
- precision selection relying on likelihood discriminant, four working points: $Ih/loose, Ih/loose, Ih/medium, Ih/tight$
- additional isolation requirement possible ($ivar/loose$)
- differences w.r.t. offline:
  - trigger reconstruction with poorer resolution than offline
  - no momentum loss due to bremsstrahlung taken into account

Daniela Köck (dkoec@cern.ch)
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