The ATLAS Electron and Photon Trigger Performance in Run 2

D. A. Maximov
on behalf of the ATLAS collaboration
The International Conference “Instrumentation for Colliding Beam Physics” (INSTR-20)

BINP SB RAS, Novosibirsk, Russia
NSU, Novosibirsk, Russia

28 February 2020
Electron propagation through the ATLAS detector

All plots and results shown are from “Performance of electron and photon triggers in ATLAS during LHC Run 2” paper, Eur. Phys. J. C 80 (2020) 47
The ATLAS trigger system

L1 Trigger ($|\eta| < 2.5$)

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

Based on ATL-DAQ-SLIDE-2019-628
Level-1 trigger performance

- L1_EM22VHI trigger (blue line) was used for the most part of the Run 2 data-taking
- Single-electron triggers consume about 20% of the total L1 and HLT available rate

**ATLAS**
\[ \sqrt{s} = 13 \text{ TeV} \]

L1 Rate [kHz]

- L1_EM20VH
- L1_EM20VHI
- L1_EM22VHI
- L1_EM24VHI
- L1_2EM10VH

Instantaneous Luminosity \([10^{33} \text{ cm}^2 \text{ s}^{-1}]\)

pp data: 2018 0.5 fb \(^{-1}\)

**ATLAS**
\[ \sqrt{s} = 13 \text{ TeV} \]

L1 Trigger Efficiency

pp data 2017, \(\sqrt{s} = 13 \text{ TeV}\)

L1 Trigger Efficiency

**ATLAS**
\[ \sqrt{s} = 13 \text{ TeV} \]

Single-electron triggers consume about 20% of the total L1 and HLT available rate.
Trigger reconstruction of photons and electrons

Fast step — on each EM RoI defined by L1

- Use calorimeter and inner detector information within the RoI only
- Photons don’t use tracking information
- Initial selection of the photons and electrons
- Achieve early background rejection

Precision step

- Precision online algorithms are similar to offline, with some exceptions such as:
  - No bremsstrahlung-aware re-fit of electron tracks
  - No electron and photon topo-clusters
  - Online algorithms use $\langle \mu \rangle$ for pile-up, number of primary vertices — offline

ATL-DAQ-SLIDE-2019-628
Ringer algorithm

- Used from 2017 on to trigger electrons (Fast Calorimeter step) with $E_T > 15\text{GeV}$
- Uses lateral shower development
- Calculates concentric ring energy sums in each calorimeter layer
- Normalized ring energies fed into multilayer perceptron neutral networks
- Event selection efficiency kept at the same level
- Reduces input candidates to the tracking: significantly reduces CPU demand
- 50% CPU reduction for the lowest $p_T$ unprescaled single electron trigger
Photon trigger evolution and performance

- Single photon trigger had a threshold of 120 GeV (2015) and 140 GeV (2016–2018), more details in the backup

- Bootstrap method used to calculate the efficiency
- Total uncertainties dominated by systematics, in total $O(1\%)$ for $E_T$ 5 GeV above threshold
Efficiency is calculated wrt offline tight identification and isolated electrons, measured with “Z tag and probe” method.

Sharper turn on in 2015 (lower $E_T$ threshold), inefficiencies in 2016 (likelihood calorimeter only selection).

2017 data driven likelihood selection, introduction of Ringer algorithm.

The error bars indicate statistical and systematic uncertainties combined in quadrature.
Heavy ion collisions

- Events with a lot of activity in the detector
- Event is characterised by collision centrality, accounted by \( \sum_{FCal} E_T \)
  
  \[ (3.1 < |\eta| < 4.9) \]
- Centrality affects trigger efficiency
- Introduced underlying event (UE) subtraction into egamma trigger to minimize efficiency dependence on centrality, allows to use standard identification variables

D. A. Maximov (BINP, NSU)
Photon trigger in heavy ion data taking

- Photon trigger efficiency evaluated with respect to offline-reconstructed photons measured by bootstrap method
- Efficiency shown with and without subtraction of the underlying event
Run 3 upgrades: L1 Trigger — LAr Super cells

- More fine-grained in lateral and longitudinal directions
- Improve energy resolution and backgrounds discrimination

Electron (70 GeV $E_T$) seeing with finer granularity

- $E_T > 21$ GeV has the same event rate as in Run 2
- $E_T > 28$ GeV has half event rate

(from L1CaloTriggerPublicResults)
Conclusions

- Electron and photon trigger performed well during Run 2
- Significant complication of experimental environment from 2015 to 2018 requires trigger chains modification and development/adoption of new algorithms (Ringer)
- Using of adapted offline reconstruction algorithms (GSF, Superclusters) for future data-taking is expected to improve energy and momentum resolution at trigger stage
- Run 3 upgrades are in progress:
  - planned to extend $\eta$ coverage of the HLT to include forward regions
  - L1 Trigger: LAr Super cells
  - \ldots and others
References


3. Level-1 Calorimeter Trigger Public Results, https://twiki.cern.ch/twiki/bin/view/AtlasPublic/L1CaloTriggerPublicResults

Backup
High Level Trigger sequence

Level 1 Calo

Fast Calorimeter Reconstruction (Shower Shape Quantities)
Fast Calorimeter Selection

Fast

High-Level Trigger Sequence (2015-2018)

Precision

Precise Calorimeter Reconstruction
Energy Calibration
Calibrated $E_t$ Selection
Precise Photon Reconstruction
Precise Photon Selection

Fast

High-Level Trigger Sequence (2017-2018) for $E > 15$ GeV

Precision

Precise Calorimeter Reconstruction
Energy Calibration
Calibrated $E_t$ Selection
Precise Track Reconstruction
Precise Electron Reconstruction
Precise Electron Selection

Fast

Efficient Selection (Ensemble of NNs)
Fast Track Reconstruction
Fast Electron Reconstruction

Ringer

D. A. Maximov (BINP, NSU)
'Offline' Electron and photon reconstruction and identification

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

Photons
- Identification based on calorimetric variables
- Two identification working points: 'loose' and 'tight'
- 'loose': second EM layer + Hadronic calorimeters
- 'tight': 'loose' + first EM calorimeter

Using Supercluster to improve electron and photon energy reconstruction in cases with Bremsstrahlung or pair production
Performance measurement techniques — electrons

Z tag-and-probe method

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

- \( N_{all} \) — number of produced electrons,
- \( N_{trig} \) — number of triggered electron candidates,
- \( N_{offline} \) — number of isolated, identified and reconstructed offline electron candidates
- \( \epsilon_{offline} \) — offline efficiency

Trigger efficiency computed with respect to offline electron definitions
Performance measurement techniques — photons

Bootstrap method

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

- \( \epsilon_{\text{trig}} \) — HLT efficiency with respect to offline selection

- \( \epsilon_{\text{HLT|BS}} \) — HLT efficiency on bootstrap sample
  bootstrap sample collected by L1-only triggers or by loose, low-\( E_T \) photon triggers

- \( \epsilon_{\text{BS}} \) — Bootstrap sample efficiency
  with respect to offline selection
  computed on events selected by special 'random' trigger
Performance measurement techniques — photons

Z radiative decay method used for diphoton triggers

Tag electrons/muons

- Fired lowest $p_T$ unprescaled single and double electron/muon trigger
- Opposite charge, same flavour lepton pair
- Medium offline identification requirement fulfilled, FCLoose isolation

Probe photon

- Tight photon candidate
  - $\eta < 2.37$ $E_T > 10$ GeV
  - Satisfy isolation of interest
- Cut on $m_\ell\ell$ and $m_\ell\ell$ to avoid ISR photons

ATLAS pp data 2017
$\sqrt{s} = 13$ TeV
$Z \rightarrow \ell\ell\gamma$
Photon trigger efficiency

ATLAS
pp data 2018, $\sqrt{s} = 13$ TeV

Radiative Z
Bootstrap

$g_{25\_medium}$
$g_{35\_medium}$

Trigger Efficiency vs. $E_T$ [GeV]
Level-1 trigger performance

**ATLAS**

<table>
<thead>
<tr>
<th>Trigger</th>
<th>L1 Rate [kHz]</th>
<th>Instantaneous Luminosity [$10^{33}$ cm$^{-2}$s$^{-1}$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1_EM20VH</td>
<td>60</td>
<td>10</td>
</tr>
<tr>
<td>L1_EM20VHI</td>
<td>45</td>
<td>20</td>
</tr>
<tr>
<td>L1_EM22VHI</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>L1_EM24VHI</td>
<td>20</td>
<td>40</td>
</tr>
<tr>
<td>L1_2EM10VH</td>
<td>10</td>
<td>50</td>
</tr>
</tbody>
</table>

**L1 Trigger Efficiency**

<table>
<thead>
<tr>
<th>Trigger</th>
<th>E$_T$ [GeV]</th>
<th>Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1_EM20VH</td>
<td>20</td>
<td>0.86</td>
</tr>
<tr>
<td>L1_EM20VHI</td>
<td>30</td>
<td>0.88</td>
</tr>
<tr>
<td>L1_EM22VHI</td>
<td>40</td>
<td>0.9</td>
</tr>
</tbody>
</table>

**ATLAS**

<table>
<thead>
<tr>
<th>Trigger</th>
<th>L1 Rate [kHz]</th>
<th>Instantaneous Luminosity [$10^{33}$ cm$^{-2}$s$^{-1}$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1_EM20VH</td>
<td>45</td>
<td>10</td>
</tr>
<tr>
<td>L1_EM20VHI</td>
<td>30</td>
<td>20</td>
</tr>
<tr>
<td>L1_EM22VHI</td>
<td>20</td>
<td>30</td>
</tr>
<tr>
<td>L1_EM24VHI</td>
<td>10</td>
<td>40</td>
</tr>
<tr>
<td>L1_2EM10VH</td>
<td>5</td>
<td>50</td>
</tr>
</tbody>
</table>

**ATLAS**

<table>
<thead>
<tr>
<th>Trigger</th>
<th>L1 Trigger Efficiency</th>
<th>E$_T$ [GeV]</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1_EM20VH</td>
<td>0.86</td>
<td>20</td>
</tr>
<tr>
<td>L1_EM20VHI</td>
<td>0.88</td>
<td>30</td>
</tr>
<tr>
<td>L1_EM22VHI</td>
<td>0.9</td>
<td>40</td>
</tr>
</tbody>
</table>

**ATLAS**

<table>
<thead>
<tr>
<th>Trigger</th>
<th>L1 Rate [kHz]</th>
<th>Instantaneous Luminosity [$10^{33}$ cm$^{-2}$s$^{-1}$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1_2EM15VH</td>
<td>60</td>
<td>10</td>
</tr>
<tr>
<td>L1_2EM20VH</td>
<td>45</td>
<td>20</td>
</tr>
<tr>
<td>L1_2EM15VHI</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>L1_2EM24VHI</td>
<td>20</td>
<td>40</td>
</tr>
<tr>
<td>L1_2EM10VH</td>
<td>10</td>
<td>50</td>
</tr>
</tbody>
</table>

**L1 Trigger Efficiency**

<table>
<thead>
<tr>
<th>Trigger</th>
<th>E$_T$ [GeV]</th>
<th>Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1_EM20VH</td>
<td>20</td>
<td>0.86</td>
</tr>
<tr>
<td>L1_EM20VHI</td>
<td>30</td>
<td>0.88</td>
</tr>
<tr>
<td>L1_EM22VHI</td>
<td>40</td>
<td>0.9</td>
</tr>
</tbody>
</table>

**ATLAS**

<table>
<thead>
<tr>
<th>Trigger</th>
<th>L1 Trigger Efficiency</th>
<th>E$_T$ [GeV]</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1_EM20VH</td>
<td>0.86</td>
<td>20</td>
</tr>
<tr>
<td>L1_EM20VHI</td>
<td>0.88</td>
<td>30</td>
</tr>
<tr>
<td>L1_EM22VHI</td>
<td>0.9</td>
<td>40</td>
</tr>
</tbody>
</table>
## Photon trigger evolution and performance

<table>
<thead>
<tr>
<th>Trigger type</th>
<th>2015</th>
<th>2016</th>
<th>2017–2018</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single photon</td>
<td>g120_loose (EM22VHI)</td>
<td>g140_loose (EM22VHI)</td>
<td></td>
</tr>
<tr>
<td>Primary diphoton</td>
<td>g35_loose_g25_loose (2EM15VH)</td>
<td>g35_medium_g25_medium (2EM20VH)</td>
<td></td>
</tr>
<tr>
<td>Loose diphoton</td>
<td></td>
<td></td>
<td>2g50_loose (2EM20VH)</td>
</tr>
<tr>
<td>Tight diphoton</td>
<td>2g20_tight (2EM15VH)</td>
<td>2g22_tight (2EM15VH)</td>
<td>2g20_tight_icalovloose (2EM15VHI)</td>
</tr>
</tbody>
</table>

![Graph: Instantaneous Luminosity vs Rate](attachment:image.png)

**ATLAS pp data 2015-2018**

<table>
<thead>
<tr>
<th>Rate [Hz]</th>
<th>Instantaneous Luminosity [$10^{33}$ cm$^2$s$^{-1}$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary single-photon triggers</td>
<td></td>
</tr>
<tr>
<td>○ 2015</td>
<td></td>
</tr>
<tr>
<td>□ 2016</td>
<td></td>
</tr>
<tr>
<td>△ 2017</td>
<td></td>
</tr>
<tr>
<td>▲ 2018</td>
<td></td>
</tr>
</tbody>
</table>

**ATLAS pp data 2015-2018**

<table>
<thead>
<tr>
<th>Rate [Hz]</th>
<th>Instantaneous Luminosity [$10^{33}$ cm$^2$s$^{-1}$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary diphoton triggers</td>
<td></td>
</tr>
<tr>
<td>○ 2015</td>
<td></td>
</tr>
<tr>
<td>□ 2016</td>
<td></td>
</tr>
<tr>
<td>△ 2017</td>
<td></td>
</tr>
<tr>
<td>▲ 2018</td>
<td></td>
</tr>
</tbody>
</table>
Photon trigger evolution and performance

- Bootstrap method used to calculate the efficiency
- Total uncertainties dominated by systematics, in total $O(1\%)$ for $E_T$ 5 GeV above threshold
DiPhoton trigger evolution and performance
Electron trigger evolution and performance

<table>
<thead>
<tr>
<th>Trigger type</th>
<th>2015</th>
<th>2016</th>
<th>2017–2018</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single electron</td>
<td>e24_lhmedium (EM20VH)</td>
<td>e26_lhtight_nod0ivarloose (EM22VHI)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>e120_lhloose</td>
<td>e60_lhmedium_nod0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>e200_etcut</td>
<td>e140_lhloose_nod0</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>e300_etcut</td>
<td></td>
</tr>
<tr>
<td>Dielectron</td>
<td>2e12_lhloose (2EM10VH)</td>
<td>2e17_lhvloose_nod0 (2EM15VH)</td>
<td>2e17_lhvloose_nod0 (2EM15VH)</td>
</tr>
</tbody>
</table>

![Graph showing the rate vs. instantaneous luminosity](image)
Single Electron trigger evolution and performance

**Graphs and Data:**

- **Graph 1:**
  - Title: Single electron trigger combination
  - Description: Offline tight, isolation FCTight
  - Data: pp data 2015-2018, √s = 13 TeV
  - Efficiency plotted against E_T [GeV]
  - Data/MC ratio shown

- **Graph 2:**
  - Title: Single electron trigger combination
  - Description: Offline tight, isolation FCTight
  - Data: pp data 2015-2018, √s = 13 TeV
  - Efficiency plotted against η
  - Data/MC ratio shown

**Legend:**

- Data points for 2015, 2016, 2017, and 2018 are shown.

**Notes:**

- Data from ATLAS with a run of 13 TeV on pp collisions from 2015 to 2018.
- Trigger efficiency and data/MC ratio are shown across different bins of E_T and η.
DiElectron trigger evolution and performance

**ATLAS**

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

**Instantaneous Luminosity**

- $10^{33}$ cm$^{-2}$s$^{-1}$

**Rate [Hz]**

- **L1 no-iso**
- **L1 iso**

2015

2016

2017

2018

**Dielectron triggers**

**Trigger Efficiency**

- **offline loose, isolation FCLoose**

**$E_T$ [GeV]**

20

40

60

80

100

120

140

2

0.5

0.55

0.6

0.65

0.7

0.75

0.8

0.85

0.9

0.95

1

**$\eta$**

-2

-1

0

1

2

0.55

0.65

0.7

0.75

0.8

0.85

0.9

0.95

1

**Dielectron triggers**

- **L1 non-iso**
- **L1 iso**

2015

2016

2017

2018

**Trigger Efficiency**

- **Offline loose, isolation FCLoose**

- **$\mu$**
Electron trigger in heavy ion data taking

ATLAS
PbPb data 2018, 1.3 nb$^{-1}$
$\sqrt{s_{NN}} = 5.02$ TeV

- Trigger electron $E_T > 20$ GeV, loose
- Trigger electron $E_T > 15$ GeV, lhloose

Trigger Efficiency

D. A. Maximov (BINP, NSU)