The ATLAS Run-2 Trigger: Design, Menu, Performance and Operational Aspects

ICHEP 2016

Joana Machado Miguéns
University of Pennsylvania

on behalf of the ATLAS Collaboration

August 4th 2016
Introduction

- Trigger system decides online whether or not to keep an event
  - drives physics potential of ATLAS!

- Trigger operated very efficiently in Run-1

- Challenging environment in Run-2
  - increase of luminosity, pile-up and centre-of-mass energy
  - need sophisticated trigger strategies to get the physics out within the given rate budget

- Fundamental modification and upgrade of the Trigger system after Run-1
  - challenging commissioning phase at the start of Run-2

- Will give overview of the ATLAS trigger in Run-2
The ATLAS Run-2 Trigger

Joana Machado Miguéns (UPenn)

ICHEP, Chicago, 08.04.2016
Level-1 Trigger (L1)

- 40 MHz → 100 kHz rate reduction with a fixed latency of 2.5 μs
- Fast custom-made electronics find regions of interest (RoIs) using calorimeter and muon data with coarse information
- L1Calo, L1Muon and L1 Central Trigger (CTP) components upgraded
Trigger and DAQ system

High Level Trigger (HLT)
- Single farm for better resource sharing and overall simplification
- Fast offline-like algorithms running mostly in L1 RoIs
- Average 200 ms latency
- Full upgrade of readout and data storage systems
- \( \sim 1 \) kHz of physics (full event building) output rate achieved
- Partial event building used for Trigger Level Analysis, detector monitoring and calibrations

Joana Machado Miguéns (UPenn)
The ATLAS Run-2 Trigger
ICHEP, Chicago, 08.04.2016
Trigger menu strategy

- Menu defines list of L1 → HLT trigger chains with prescale factors
  - events out of the HLT are written into data streams
  - primary triggers make up bulk of Main Physics stream
    * support, alternative and backup triggers also included
  - calibration triggers run at high rate but store only part of the event
- Menu composition driven by physics priorities of ATLAS
  - high acceptance for BSM searches & Higgs/SM precision measurements
  - need to respect L1, HLT and Tier-0 processing limitations
## Trigger menu design and evolution

*Over 2000 trigger chains running online and covering a large variety of physics objects and processes!*

<table>
<thead>
<tr>
<th>Trigger</th>
<th>Typical offline selection</th>
<th>Trigger Selection</th>
<th>Level-1 (GeV)</th>
<th>HLT (GeV)</th>
<th>Level-1 Peak Rate (kHz)</th>
<th>HLT Peak Rate (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single leptons</td>
<td>Single iso $\mu$, $p_T &gt; 21$ GeV</td>
<td>15</td>
<td>20</td>
<td>7</td>
<td>130</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Single $e$, $p_T &gt; 25$ GeV</td>
<td>20</td>
<td>24</td>
<td>18</td>
<td>139</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Single $\mu$, $p_T &gt; 42$ GeV</td>
<td>20</td>
<td>40</td>
<td>5</td>
<td>33</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Single $\tau$, $p_T &gt; 90$ GeV</td>
<td>60</td>
<td>80</td>
<td>2</td>
<td>41</td>
<td></td>
</tr>
<tr>
<td>Two leptons</td>
<td>Two $\mu$'s, each $p_T &gt; 11$ GeV</td>
<td>$2 \times 10$</td>
<td>$2 \times 10$</td>
<td>0.8</td>
<td>19</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Two $\mu$'s, $p_T &gt; 19, 10$ GeV</td>
<td>15</td>
<td>18, 8</td>
<td>7</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Two loose $e$'s, each $p_T &gt; 15$ GeV</td>
<td>$2 \times 10$</td>
<td>$2 \times 12$</td>
<td>10</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>One $e$ &amp; one $\mu$, $p_T &gt; 10, 26$ GeV</td>
<td>20 ($\mu$)</td>
<td>7, 24</td>
<td>5</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>One loose $e$ &amp; one $\mu$, $p_T &gt; 19, 15$ GeV</td>
<td>15, 10</td>
<td>17, 14</td>
<td>0.4</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Two $\tau$'s, $p_T &gt; 40, 30$ GeV</td>
<td>20, 12</td>
<td>35, 25</td>
<td>2</td>
<td>22</td>
<td></td>
</tr>
<tr>
<td></td>
<td>One $\tau$, one $\mu$, $p_T &gt; 30, 15$ GeV</td>
<td>12, 10 (+jets)</td>
<td>25, 14</td>
<td>0.5</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>One $\tau$, one $e$, $p_T &gt; 30, 19$ GeV</td>
<td>12, 15 (+jets)</td>
<td>25, 17</td>
<td>1</td>
<td>3.9</td>
<td></td>
</tr>
<tr>
<td>Three leptons</td>
<td>Three loose $e$'s, $p_T &gt; 19, 11, 11$ GeV</td>
<td>$15, 2 \times 7$</td>
<td>$17, 2 \times 9$</td>
<td>3</td>
<td>&lt; 0.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Three $\mu$'s, each $p_T &gt; 8$ GeV</td>
<td>$3 \times 6$</td>
<td>$3 \times 6$</td>
<td>&lt; 0.1</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Three $\mu$'s, $p_T &gt; 19, 2 \times 6$ GeV</td>
<td>15</td>
<td>18, 2 × 4</td>
<td>7</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Two $\mu$'s &amp; one $e$, $p_T &gt; 2 \times 11, 14$ GeV</td>
<td>$2 \times 10$ ($\mu$'s)</td>
<td>$2 \times 10, 12$</td>
<td>0.8</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Two loose $e$'s &amp; one $\mu$, $p_T &gt; 2 \times 11, 11$ GeV</td>
<td>$2 \times 8, 10$</td>
<td>$2 \times 12, 10$</td>
<td>0.3</td>
<td>&lt; 0.1</td>
<td></td>
</tr>
<tr>
<td>One photon</td>
<td>one $\gamma$, $p_T &gt; 125$ GeV</td>
<td>22</td>
<td>120</td>
<td>8</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Two photons</td>
<td>Two loose $\gamma$'s, $p_T &gt; 40, 30$ GeV</td>
<td>$2 \times 15$</td>
<td>35, 25</td>
<td>1.5</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Two tight $\gamma$'s, $p_T &gt; 25, 25$ GeV</td>
<td>$2 \times 15$</td>
<td>$2 \times 20$</td>
<td>1.5</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Single jet</td>
<td>Jet ($R = 0.4$), $p_T &gt; 400$ GeV</td>
<td>100</td>
<td>360</td>
<td>0.9</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Jet ($R = 1.0$), $p_T &gt; 400$ GeV</td>
<td>100</td>
<td>360</td>
<td>0.9</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>$E_T^{miss}$</td>
<td>$E_T^{miss} &gt; 180$ GeV</td>
<td>50</td>
<td>70</td>
<td>0.7</td>
<td>55</td>
<td></td>
</tr>
<tr>
<td>Multi-jets</td>
<td>Four jets, each $p_T &gt; 95$ GeV</td>
<td>$3 \times 40$</td>
<td>$4 \times 85$</td>
<td>0.3</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Five jets, each $p_T &gt; 70$ GeV</td>
<td>4 × 20</td>
<td>5 × 60</td>
<td>0.4</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Six jets, each $p_T &gt; 55$ GeV</td>
<td>4 × 15</td>
<td>6 × 45</td>
<td>1.0</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>$b$-jets</td>
<td>One loose $b$, $p_T &gt; 235$ GeV</td>
<td>100</td>
<td>225</td>
<td>0.9</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Two medium $b$'s, $p_T &gt; 160, 60$ GeV</td>
<td>100</td>
<td>150, 60</td>
<td>0.9</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>One $b$ &amp; three jets, each $p_T &gt; 75$ GeV</td>
<td>$3 \times 25$</td>
<td>$4 \times 65$</td>
<td>0.9</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Two $b$ &amp; two jets, each $p_T &gt; 45$ GeV</td>
<td>$3 \times 25$</td>
<td>$4 \times 35$</td>
<td>0.9</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>$b$-physics</td>
<td>Two $\mu$'s, $p_T &gt; 6, 4$ GeV</td>
<td>6, 4</td>
<td>6, 4</td>
<td>8</td>
<td>52</td>
<td></td>
</tr>
<tr>
<td></td>
<td>plus dedicated $b$-physics selections</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>70</td>
<td>1400</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Menus designed for different peak luminosities
- Primary triggers kept stable within a menu (desirable for analysis)
- Able to adjust to changing conditions during LHC ramp-up
- Maximize physics output and optimize resource usage

← Main primary triggers used in 2015 shown for illustration
Trigger menu online

- Trigger rate predictions and HLT farm performance studies essential for all menu developments and validation of HLT algorithms
  - special dataset collected upon data-taking condition changes to provide rate predictions
  - full trigger menu run offline over this dataset for algorithm validation
- Menu deployed with different prescale sets depending on luminosity
  - as luminosity decreases throughout the fill the bandwidth usage is optimized by increasing the rate of supporting triggers
Monitoring trigger rates online

- Trigger rates are measured **online** and closely monitored.
- Rate **predictions** are based on luminosity scaling using previous data.
- Deviations from expectations or changes in rates indicate problems.
- Distributions of HLT-level quantities monitored online
- Automatic DQ checks applied based on standardised histogram analyses and comparisons to reference histograms
- Performance of the HLT tracked via red, yellow and green DQ flags
- Similar procedure followed offline to declare data good for physics
Trigger performance - muons

- New coincidence logic at L1 suppresses fake muon triggers
- Coverage improved with installation of new chambers
- \( \sim 100\% \) HLT efficiency wrt L1
Trigger performance - jets and $E_T^{\text{miss}}$

- Speed of clustering algorithms improved by factor 2 and timing of data unpacking improved by factor 7 compared to Run-1
  - full calorimeter unpacked for jet reconstruction at the HLT
- Sharp efficiency turn-on curves for jet triggers in large $p_T$ range
  - excellent agreement between energy scale of HLT and offline jets
- Pile-up mitigation is main challenge for $E_T^{\text{miss}}$ triggers
  - $mht$ algorithm based on $p_T$ sum of HLT jets currently default

\[ \begin{align*}
\text{Efficiency} & \quad \text{Offline central jet } p_T \text{ [GeV]} \\
\text{Data 2016} & \quad \text{Data 2015} \\
\text{HLT}_{\text{j25}} \text{ (L1 random)} & \quad \text{HLT}_{\text{j60}} \text{ (L1_J20)} \\
\text{HLT}_{\text{j110}} \text{ (L1_J30)} & \quad \text{HLT}_{\text{j175}} \text{ (L1_J50)} \\
\text{HLT}_{\text{j380}} \text{ (L1_J100)} & \quad \text{L1_XE50}
\end{align*} \]

\[ \sqrt{s} = 13 \text{ TeV}, 135 \text{ pb}^{-1} \]
\[ \text{data16} \]
\[ \mu > 21.5 \]

Joana Machado Miguéns (UPenn)
Trigger performance - electrons, photons and taus

- Likelihood-based identification for electrons - new in Run-2!
- Cut-based id for photons
- BDT-based id for taus
Summary and conclusions

- LHC Run-2 conditions pose a challenge to the ATLAS trigger system
- Hardware and software modified and improved during the shutdown
- Well designed menu ensures physics goals of the experiment are met
- Trigger successfully commissioned in 2015
- Smooth trigger operations in 2016 despite the very challenging LHC conditions
- New studies show overall great performance of the trigger
- Further improvements ahead
  - use of L1Topo
  - commissioning of FTK

**ATLAS trigger system ready to exploit the full potential of the LHC!**
Back-up
Trigger performance - tracking

- Tracking (HLT only) includes two stages
  - fast tracking - tracks and spacepoints seed next stage
  - precision tracking - offline-like
- Multiple stage tracking used to reconstruct $\tau$ and $b$-jet tracks
- Timing improved by $\times 3$

![Graph showing processing time per RoI vs. Normalised Entries](image)

![Graph showing $d_0$ resolution vs.Offline $p_T$ vs. $z_0$ resolution vs. Number of offline tracks](image)