Run-2 ATLAS Trigger and Detector Performance

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on behalf of the ATLAS Collaboration

https://indico.cern.ch/e/hep2016

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Content

- Detector and Trigger performance
  - Upgrades done during Long Shutdown 1 (LS1, Feb’13 – Apr’15)
  - Detector Performance in 2015
  - Trigger Performance in 2015
  - Outlook for 2016

- Physics and Upgrade covered in
  - Wednesday
    - Hernan Wahlberg, First Atlas Results from Run2
  - Saturday
    - Giulio Aielli, ATLAS Upgrades for the Next Decades
  - + many other talks in parallel sessions
The ATLAS Detector

- Tile calorimeters
- LAr hadronic end-cap and forward calorimeters
- Pixel detector
- LAr electromagnetic calorimeters
- Transition radiation tracker
- Semiconductor tracker
- Solenoid magnet
- Muon chambers
- Toroid magnets
The ATLAS Detector

- Repairs and upgrades in all detectors during LS1
  - Prepare all detectors for 100 kHz readout rate (75 kHz in run-1)
  - Additional Pixel layer (IBL) and new beam pipe
  - Gas leak repairs for Transition Radiation Tracker (TRT)
  - Replacement of power supplies for LAr and Tile calorimeter
  - Repair of broken front-end electronics in all systems
  - Install remaining and new muon chambers
The ATLAS Detector

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  - Prepare all detectors for 100 kHz readout rate (75 kHz in run-1)
  - Additional Pixel layer (IBL) and new beam pipe
  - Gas leak repairs for Transition Radiation Tracker (TRT)
  - Replacement of power supplies for LAr and Tile calorimeter
  - Repair of broken front-end electronics in all systems
  - Install remaining and new muon chambers

- Fraction of operational channels

**ATLAS Detector Status**

<table>
<thead>
<tr>
<th>Module</th>
<th>Run-1</th>
<th>Run-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1 Muon Endcap</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>L1 Muon Barrel</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>L1 Calo</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>TGC</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>RPC</td>
<td>98%</td>
<td>100%</td>
</tr>
<tr>
<td>CSC</td>
<td>98%</td>
<td>100%</td>
</tr>
<tr>
<td>MDT</td>
<td>98%</td>
<td>100%</td>
</tr>
<tr>
<td>LAr Fwd</td>
<td>98%</td>
<td>100%</td>
</tr>
<tr>
<td>LAr HEC</td>
<td>98%</td>
<td>100%</td>
</tr>
<tr>
<td>Tile</td>
<td>98%</td>
<td>100%</td>
</tr>
<tr>
<td>LAr</td>
<td>98%</td>
<td>100%</td>
</tr>
<tr>
<td>TRT</td>
<td>96%</td>
<td>100%</td>
</tr>
<tr>
<td>SCT</td>
<td>96%</td>
<td>100%</td>
</tr>
<tr>
<td>Pixels</td>
<td>96%</td>
<td>100%</td>
</tr>
</tbody>
</table>
A new era for proton-proton collisions

A high-mass dijet event. This event was collected in September 2015: the two central high-\(p_T\) jets have an invariant mass of 8.8 \(\text{TeV}\), the highest-\(p_T\) jet has a \(p_T\) of 810 GeV, and the subleading jet has a \(p_T\) of 750 GeV. The missing ET for this event is 60 GeV.
A new era for proton-proton collisions

Run-1 vs Run-2

<table>
<thead>
<tr>
<th></th>
<th>Run-1 (8TeV)</th>
<th>Run-2 (13TeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak lumi [cm(^{-2}) s(^{-1})]</td>
<td>7.7 x 10(^{33})</td>
<td>5.1 x 10(^{33})</td>
</tr>
<tr>
<td>mean pileup</td>
<td>21</td>
<td>13</td>
</tr>
<tr>
<td>Integrated lumi [fb(^{-1})]</td>
<td>22.8</td>
<td>4.2</td>
</tr>
<tr>
<td>Data-taking eff.</td>
<td>93%</td>
<td>92%</td>
</tr>
</tbody>
</table>

**ATLAS pp 25ns run: August-November 2015**

<table>
<thead>
<tr>
<th>Inner Tracker</th>
<th>Calorimeters</th>
<th>Muon Spectrometer</th>
<th>Magnets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pixel</td>
<td>SCT</td>
<td>TRT</td>
<td>Solenoid</td>
</tr>
<tr>
<td>LAr</td>
<td>Tile</td>
<td>MDT</td>
<td>Toroid</td>
</tr>
<tr>
<td>93.5</td>
<td>99.4</td>
<td>98.3</td>
<td>100</td>
</tr>
<tr>
<td>99.4</td>
<td>100</td>
<td>100</td>
<td>97.8</td>
</tr>
</tbody>
</table>

All Good for physics: 87.1% (3.2 fb\(^{-1}\))

Luminosity weighted relative detector uptime and good data quality (DQ) efficiencies (in %) during stable beam in pp collisions with 25ns bunch spacing at \(\sqrt{s}=13\) TeV between August-November 2015, corresponding to an integrated luminosity of 3.7 fb\(^{-1}\). The lower DQ efficiency in the pixel detector is due to the IBL being turned off for two runs, corresponding to 0.2 fb\(^{-1}\). Analyses that don’t rely on the IBL can use those runs and thus use 3.4 fb\(^{-1}\) with a corresponding DQ efficiency of 93.1%.
Heavy-Ion data-taking
Heavy-Ion data-taking

Recorded 0.68 nb\(^{-1}\)
(expected 0.3-0.5 nb\(^{-1}\))

ATLAS Online Luminosity
\(|s_{NN}| = 5.0\) TeV

Total Delivered: 703.7 ub\(^{-1}\)
Total Recorded: 676.8 ub\(^{-1}\)

Data-taking eff.
96 %

Run: 286665
Event: 419161
2015-11-25 11:12:50 CEST
Inner Detector – Pixel, SCT and TRT

- **Pixel**
  - Operating smoothly
  - Overall status of Pixel improved compared to end of Run-1
  - New innermost layer (IBL) → see next slides

- **Silicon Strip Tracker (SCT)**
  - Stable and reliable throughout 2015
  - Performance comparable with Run-1
  - Very small drop in hit efficiency for 25ns beams
    - This is expected for bunches within a train
    - Intrinsic hit efficiency can be seen in first bunch
    - No impact on tracking performance

- **Transition Radiation Tracker (TRT)**
  - Proved to sustain 100 KHz at 50% occupancy
  - Still suffering from gas leaks
    - Currently ~150 liters per day
    - Xe gas replaced by (cheaper) Ar in the worst gas loops
  - Negligible impact on electron identification
  - For HI run changed full detector to Ar gas mix
IBL – Insertable B-Layer

- **New innermost layer for the ATLAS Pixel detector**
  - Increases the number of pixel layers from 3 → 4
    - 6M additional channels, 50×250 μm² pixel size (compared to 50×400 for Pixel)
    - 8×40 μm² resolution
  - 3.3 cm from the beam line including a new (smaller) beam pipe
  - Required complete removal of the ATLAS Pixel volume during Long Shutdown 1
  - Provides better tracking for ATLAS
  - But of course also some operational issues as with any new detector
IBL – Front-End current drift

- Increase of FE current observed during data-taking
  - Stopped IBL for 2 days in October for investigations

- Effect is due to irradiation
  - Understood to be a N-MOS transistor leakage due to defects built-up at the Silicon Oxide (STI) interface and cumulated by ionizing dose
  - Lab test confirms that effect will significantly reduce after a few additional Mrad of irradiation
**IBL – Mechanical Distortions**

- **Distortions due to temperature variations**
  - Bowing of \(\sim 10\mu m/K\) observed during cosmic ray commissioning in early 2015
  - Under normal operations conditions temperature is stable within 0.2K
    - No impact on tracking performance
  - Became a problem with the current drifts of the previous slide

- **Run-by-run alignment**
  - Correction applied on a run-by-run basis before bulk reconstruction
  - No significant effects on impact parameter resolution are observed
  - Not easily possible in the High-Level Trigger
    - For the moment mitigating effect by applying larger error scaling
IBL – Performance

- **IBL significantly improves impact parameter resolution**
  - About a factor two gain in impact parameter resolution for low-pT tracks

- **Impact of IBL distortion**
  - No significant impact after alignment correction
Tracking Performance and Material

- Material map of the Pixel detector
  - Using hadronic interactions
  - Using photon conversions
  - Simulation updated with improved geometry

- Tracking efficiency
  - 90% (85%) efficient for Loose (Tight Primary) selections for tracks above 5 GeV
Calorimeters and Jet reconstruction

- **Very stable operations for both LAr and Tile calorimeter**
  - Good for physics: 99.4% (LAr) and 100% (Tile) based on Data Quality
  - LAr using 4 instead of 5 sample readout to achieve 100 kHz
  - Performing even better than during run-1

- **In-situ jet energy-scale with full 2015 dataset**
  - Agreement between data and MC better than 2% up to 3 TeV
E/\gamma\text{ reconstruction performance}

- **Electron ID**
  - Likelihood (LH) combining LAr shower shapes, tracking, track-cluster matching and TRT PID
  - LH improves background rejection by \(~50\%) compared to cut-based ID with the same efficiency

- **Photon ID**
  - Using cut-based selection

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**Electron efficiency from Z**

![Electron efficiency from Z](image1)

**Photon reconstruction (MC)**

![Photon reconstruction (MC)](image2)

The lower efficiency in data than in MC mostly arises from a known mismodelling of calorimetric shower shapes in the GEANT detector simulation.
Tau reconstruction performance

- **Tau reconstruction**
  - Tau identification performed both at trigger and offline level using a multivariate discriminant combining calorimeter, tracking and lifetime observables [ATL-PHYS-PUB-2015-045]
  - Performance measured on $Z \rightarrow \tau\tau$ candidates
  - Good agreement between data and MC

![Tau BDT](ATL-PHYS-2015-1392)

![Z → ττ](ATL-PHYS-2015-1392)
Muon Detector and Performance

- **All Muon detectors operating well**
  - Readout operational at 100 kHz
  - Alignment already good to O(50μm) in the barrel and O(100μm) in the endcap

- **Performance studied with 2015 dataset**
  - Three main working points
    - Tight, medium, loose
  - Good agreement between data and MC
    - Remaining differences accounted for by scale factors

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![Muon efficiency from Z](image1)

**Muon efficiency from Z**

![Muon efficiency from J/psi](image2)

**Muon efficiency from Z and J/psi**

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**ATLAS Preliminary**

$\sqrt{s} = 13$ TeV, 3.3 fb$^{-1}$

**Data / MC**

- **FixedCutLoose**
  - Data
  - $Z \rightarrow \mu\mu$
  - $J/\psi \rightarrow \mu\mu$

**ATLAS Preliminary**

$\sqrt{s} = 13$ TeV, 3.3 fb$^{-1}$

**Data / MC**

- **Stat only**
- **Sys @ Stat**
Computing and Analysis

- **Grid utilized at full capacity**
  - Smooth operations
  - Running up to 200k jobs
  - Dominated by MC production

- **Tier0 reconstruction**
  - 15k jobs slots
  - Used for Grid jobs if not utilized by Tier0

- **Analysis dataset production**
  - New analysis model (xAOD) working extremely well
  - Producing O(100) analysis specific derived datasets
High-Level Trigger farm usage for Grid jobs

These are opportunistic resources. Data-taking, testing and commissioning always has priority!
Trigger Performance
Trigger environment in Run-2

- **LHC**
  - Energy increase 8→13 TeV results in **2-2.5 times** higher trigger rates
  - Peak luminosity increase 0.8→1.7e34 results in ~**2 times** higher trigger rates

- **Options to cope with increase in trigger rates**
  - Increase output rate → challenge for offline computing
  - Increase trigger thresholds → loose potentially interesting physics
  - Reduce fake (non-physics) triggers
  - Increase trigger rejection power → better hardware/software

- Will show some of the improvements on the next slides...
ATLAS Trigger/DAQ in Run-2

Level-1 Calo
- Preprocessor (nMCM)
  - Electron/Tau (CMX)
  - Jet/Energy (CMX)

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

Central Trigger
- MUCTPI
- L1Topo
- CTP
  - CTPCORE
  - CTPOUT

High Level Trigger (HLT)
- Processors O(20k)

Fast TracKer (FTK)

Detector Read-Out
- FE
- ROD

DataFlow
- ReadOut System
- Data Collection Network
- Data Storage (SFO)

Region Of Interest
- ROI Requests

Event Data

Calorimeter detectors
- Tile/TGC
- Muon detectors

~30 MHz

1 kHz

100 kHz
ATLAS Trigger/DAQ in Run-2

Level-1 Calo
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Region Of Interest
- ROI
- Level-1 Accept

Calorimeter detectors
- Tile/TGC
- Muon detectors

New or Improved for Run-2
- ~30 MHz
- 100 kHz
- 1 kHz
ATLAS Trigger/DAQ in Run-2

Merge of L2 and EF farms
- Simplification
- Dynamic resource sharing
- More flexible HLT algorithms
- Use offline algorithms where possible
**ATLAS Trigger/DAQ in Run-2**

**Central Trigger Processor (CTP)**
- More L1 Items (256 → 512)
- Many other improvements...

**Level-1 Topological Trigger**
- Allows for topological selections at L1 (angular cuts, invariant mass, combinations, ...)
- Crucial for maintaining low trigger thresholds at higher luminosities
- *Still under commissioning*
nMCM – new Multi-Chip Modules

- Major limitation during Run-1 were the high MET rates at the start of the bunch train (due to LAr pulse shape)
- nMCM allows for more flexible signal processing (ASIC→FPGA)
- Dynamic pedestal correction depending on position in bunch train resulting in dramatic rate reduction and linear lumi-scaling for MET triggers
New coincidences to reduce rate in muon endcap trigger due to fakes

- Tile D-layer and TGC (ongoing)
- TGC inner layer (ready)
Fast TracKer (FTK)
- Hardware track finder
- Using associate memory for pattern matching
- Operational for barrel by mid-2016

100 kHz
~30 MHz
1 kHz
## Trigger Menu and Rates at 5e33

<table>
<thead>
<tr>
<th>Trigger</th>
<th>Typical offline selection</th>
<th>Trigger Selection</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Level-1 (GeV)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Level-1 Peak Rate (kHz)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$L = 5 \times 10^{33}$ cm$^{-2}$s$^{-1}$</td>
</tr>
<tr>
<td>Single leptons</td>
<td>Single iso $\mu$, $p_T &gt; 21$ GeV</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>Single $e$, $p_T &gt; 25$ GeV</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>Single $\mu$, $p_T &gt; 42$ GeV</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>Single $\tau$, $p_T &gt; 90$ GeV</td>
<td>60</td>
</tr>
<tr>
<td>Two leptons</td>
<td>Two $\mu$'s, each $p_T &gt; 11$ GeV</td>
<td>$2 \times 10$</td>
</tr>
<tr>
<td></td>
<td>Two $\mu$'s, $p_T &gt; 19,10$ GeV</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>Two loose $e$'s, each $p_T &gt; 15$ GeV</td>
<td>$2 \times 10$</td>
</tr>
<tr>
<td></td>
<td>One $e$ &amp; one $\mu$, $p_T &gt; 10,26$ GeV</td>
<td>20 ($\mu$)</td>
</tr>
<tr>
<td></td>
<td>One loose $e$ &amp; one $\mu$, $p_T &gt; 19,15$ GeV</td>
<td>15, 10</td>
</tr>
<tr>
<td></td>
<td>Two $\tau$'s, $p_T &gt; 40,30$ GeV</td>
<td>20, 12</td>
</tr>
<tr>
<td></td>
<td>One $\tau$, one $\mu$, $p_T &gt; 30,15$ GeV</td>
<td>12, 10 (+jets)</td>
</tr>
<tr>
<td></td>
<td>One $\tau$, one $e$, $p_T &gt; 30,19$ GeV</td>
<td>12, 15 (+jets)</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>
</tr>
<tr>
<td></td>
<td>Three $\mu$'s, each $p_T &gt; 8$ GeV</td>
<td>3 $\times$ 6</td>
</tr>
<tr>
<td></td>
<td>Three $\mu$'s, $p_T &gt; 19,2,6$ GeV</td>
<td>15</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>
</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>
</tr>
<tr>
<td>One photon</td>
<td>one $\gamma$, $p_T &gt; 125$ GeV</td>
<td>22</td>
</tr>
<tr>
<td>Two photons</td>
<td>Two loose $\gamma$'s, $p_T &gt; 40,30$ GeV</td>
<td>2 $\times$ 15</td>
</tr>
<tr>
<td></td>
<td>Two tight $\gamma$'s, $p_T &gt; 25,25$ GeV</td>
<td>2 $\times$ 15</td>
</tr>
<tr>
<td>Single jet</td>
<td>Jet ($R = 0.4$), $p_T &gt; 400$ GeV</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Jet ($R = 1.0$), $p_T &gt; 400$ GeV</td>
<td>100</td>
</tr>
<tr>
<td>$E_T^{miss}$</td>
<td>$E_T^{miss} &gt; 180$ GeV</td>
<td>50</td>
</tr>
<tr>
<td>Multi-jets</td>
<td>Four jets, each $p_T &gt; 95$ GeV</td>
<td>3 $\times$ 40</td>
</tr>
<tr>
<td></td>
<td>Five jets, each $p_T &gt; 70$ GeV</td>
<td>4 $\times$ 20</td>
</tr>
<tr>
<td></td>
<td>Six jets, each $p_T &gt; 55$ GeV</td>
<td>4 $\times$ 15</td>
</tr>
<tr>
<td>$b$–jets</td>
<td>One loose $b$, $p_T &gt; 235$ GeV</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Two medium $b$'s, $p_T &gt; 160,60$ GeV</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>One $b$ &amp; three jets, each $p_T &gt; 75$ GeV</td>
<td>3 $\times$ 25</td>
</tr>
<tr>
<td></td>
<td>Two $b$ &amp; two jets, each $p_T &gt; 45$ GeV</td>
<td>3 $\times$ 25</td>
</tr>
<tr>
<td>$b$–physics</td>
<td>Two $\mu$'s, $p_T &gt; 6.4$ GeV</td>
<td>6, 4</td>
</tr>
<tr>
<td></td>
<td>plus dedicated $b$–physics selections</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>70</td>
</tr>
</tbody>
</table>
Trigger Menu and Rates at 5e33

- In total 400 L1 triggers and 1500 HLT triggers
  - Primary triggers, usually unprescaled
  - Support and background triggers, usually prescaled
  - Alternative triggers, using different algorithms
  - Backup triggers, using tighter selections
  - Calibration triggers, usually providing partially built events

- Aim was to keep primary physics triggers stable during 2015
  - Ensures continuity of trigger selection for physics analysis
  - At cost of slightly higher output rate than planned
## Trigger Menu and Rates at 5e33

<table>
<thead>
<tr>
<th>Trigger</th>
<th>Typical offline selection</th>
<th>Trigger Selection</th>
<th>Level-1 Peak Rate (kHz)</th>
<th>HLT Peak Rate (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Level-1 (GeV)</td>
<td>HLT (GeV)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$L = 5 \times 10^{33}$ cm$^{-2}$s$^{-1}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single leptons</td>
<td>Single iso $\mu$, $p_T &gt; 21$ GeV</td>
<td>15</td>
<td>20</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Single $e$, $p_T &gt; 25$ GeV</td>
<td>20</td>
<td>24</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>Single $\mu$, $p_T &gt; 42$ GeV</td>
<td>20</td>
<td>40</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Single $\tau$, $p_T &gt; 90$ GeV</td>
<td>60</td>
<td>80</td>
<td>2</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>
</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>
</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>
</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>
</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>
</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>
</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>
</tr>
<tr>
<td>Three leptons</td>
<td>Three loose $e$'s, $p_T &gt; 19, 11, 11$ GeV</td>
<td>15, 2 × 7</td>
<td>17, 2 × 9</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Three $\mu$'s, each $p_T &gt; 8$ GeV</td>
<td>3 × 6</td>
<td>3 × 6</td>
<td>&lt; 0.1</td>
</tr>
<tr>
<td></td>
<td>Three $\mu$'s, $p_T &gt; 19, 2 × 6$ GeV</td>
<td>15</td>
<td>18, 2 × 4</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Two $\mu$'s &amp; one $e$, $p_T &gt; 2 × 11, 14$ GeV</td>
<td>$2 \times 10$ ($\mu$'s)</td>
<td>$2 \times 10, 12$</td>
<td>0.8</td>
</tr>
<tr>
<td></td>
<td>Two loose $e$'s &amp; one $\mu$, $p_T &gt; 2 × 11, 11$ GeV</td>
<td>$2 \times 8, 10$</td>
<td>$2 \times 12, 10$</td>
<td>0.3</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>
</tr>
<tr>
<td>Two photons</td>
<td>Two loose $\gamma$'s, $p_T &gt; 40, 30$ GeV</td>
<td>2 × 15</td>
<td>35, 25</td>
<td>1.5</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>
</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>
</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>
</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>
</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>
</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>
</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>
</tr>
<tr>
<td></td>
<td>Two medium $b$'s, $p_T &gt; 160, 60$ GeV</td>
<td>100</td>
<td>150, 50</td>
<td>0.9</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>
</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>
</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>
</tr>
<tr>
<td>Total</td>
<td>plus dedicated $b$-physics selections</td>
<td></td>
<td></td>
<td>70</td>
</tr>
</tbody>
</table>
# Trigger Menu and Rates at 5e33

<table>
<thead>
<tr>
<th>Trigger</th>
<th>Typical offline selection</th>
<th>Trigger Selection</th>
<th>Level-1 Peak Rate (kHz)</th>
<th>HLT Peak Rate (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single leptons</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single iso $\mu$, $p_T &gt; 21$ GeV</td>
<td>15</td>
<td>20</td>
<td>7</td>
<td>130</td>
</tr>
<tr>
<td>Single $e$, $p_T &gt; 25$ GeV</td>
<td>20</td>
<td>24</td>
<td>18</td>
<td>139</td>
</tr>
<tr>
<td>Single $\mu$, $p_T &gt; 42$ GeV</td>
<td>20</td>
<td>40</td>
<td>5</td>
<td>33</td>
</tr>
<tr>
<td>Single $\tau$, $p_T &gt; 90$ GeV</td>
<td>60</td>
<td>80</td>
<td>2</td>
<td>41</td>
</tr>
<tr>
<td>Two leptons</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Two $\mu$'s, each $p_T &gt; 11$ GeV</td>
<td>2 x 10</td>
<td>2 x 10</td>
<td>0.8</td>
<td>19</td>
</tr>
<tr>
<td>Two loose $e$'s, each $p_T &gt; 15$ GeV</td>
<td>2 x 10</td>
<td>2 x 12</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<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>
</tr>
<tr>
<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>
</tr>
<tr>
<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>
</tr>
<tr>
<td>One $\tau$, one $\mu$, $p_T &gt; 30, 15$ GeV</td>
<td>12, 10 $[\mu]$</td>
<td>25, 14</td>
<td>0.5</td>
<td>10</td>
</tr>
<tr>
<td>One $\tau$, one $e$, $p_T &gt; 30, 19$ GeV</td>
<td>12, 15 $[\mu]$</td>
<td>25, 17</td>
<td>1</td>
<td>3.9</td>
</tr>
</tbody>
</table>

---

**Trigger Menu Evolution is prepared for up to 2e34**
Trigger rates during Run-2

- **Level-1 trigger rate**
  - ATLAS can run at 100 kHz
  - However, at low number of bunches, dangerous resonance frequencies could damage the IBL wire-bonds
  - Automatic fixed frequency veto protects IBL
  - Physics trigger menu not affected by this rate limitation

- **HLT trigger rate**
  - 1 kHz physics output rate
  - 4 kHz total output rate due to additional (partial event) rates from
    - Calibration and monitoring events
    - Data Scouting events
    - Bandwidth ~1.5 GB/s (80% for physics)
**Trigger-Level Analysis / DataScouting**

- **Di-jet resonance search**
  - Lowest unprescaled single jet is 360 GeV
  - Limits reach of standard di-jet resonance search
    - Current standard analysis applies $m_{jj} > 1.1$ TeV to avoid kinematic bias

- **Trigger-Level Analysis**
  - Only store reconstructed HLT jets instead of full ATLAS event
  - Can store much higher event rates
    - 2 kHz vs 200-300 Hz
  - Allows significant lower reach in di-jet masses
  - Look forward to first results at Moriond
Jet Trigger Performance

- Jet trigger improvements for Run-2
  - Using topo-cluster based offline jet reconstruction of the entire calorimeter
    - As opposed to two-step (partial → full) reconstruction in run-1
  - Implemented jet area pileup suppression
  - Good agreement between online/offline jet energy scale

---

**Jet Trigger Performance**

**HLT turn-on curves**

**Online vs Offline jets**

- offline jet $p_T > 120$ GeV, $0.0 < \eta < 0.8$
- Events passing HLT_j100 trigger

---

**ATLAS Preliminary**

$\sqrt{s} = 13$ TeV, 147.4 nb$^{-1}$
Muon Trigger Performance

- **Barrel (RPC) and Endcap (TGC) muon trigger**
  - Low barrel L1 trigger efficiency due to geometrical trigger chamber coverage
    - Worst in the ATLAS feet region
  - HLT close to 100% efficient compared to L1
  - Factor 3 speed improvement in muon full scan finding
    - To prevent efficiency loss from L1 for di-muon trigger signatures

---

**Barrel (RPC)**

- \( \mu \mu, |\eta^\mu| < 1.05 \)

**Endcap (TGC)**

- \( \mu \mu, 1.05 < |\eta^\mu| < 2.4 \)
Electron and Photon Trigger Performance

- **Improvements for Run-2**
  - New fast tracking algorithms
  - MVA energy calibration
  - Likelihood-based identification used for electrons (was cut-based in Run-1)

- **Performance in Run-2**
  - Single (isolated) electron triggers with minimum threshold of 24 GeV
  - Medium electron identification criteria (will move to tight selections for higher luminosities)
  - Photon triggers close to 100% efficient at threshold

[Ref]
Tau Trigger Performance

- Tau trigger based on offline BDT
  - Ensure performance close to offline
  - Tracking performed in two-stages with narrowing regions to save CPU
Missing Energy Trigger Performance

- Several 'flavours' of MET in use at the trigger
  - Default cell-based algorithms with two-sided two-sigma noise suppression
  - Topo-cluster based algorithm (tc)
  - Jet-based algorithm with soft object correction (mht)
  - + variants with different calibration and pileup subtraction

- Best performing MET algorithm is analysis dependent
  - Will maintain most of them as negligible impact for total rate and CPU cost
  - Important to compare performance for equal rate triggers

![MET turn-ons for equal threshold](image1)

![MET turn-ons for equal rates](image2)
Expected performance of the b-jet Trigger

- Run-2 b-jet trigger has been completely rewritten
  - Use same tagging algorithm as offline (MV2c20)
  - Track finding and primary/secondary vertexing heavily optimized for CPU
  - Will make heavy use of L1Topo and FTK
    - Reduce input rate by applying topological selection already at L1
    - Use FTK tracks for primary vertex finding

![Expected b-jet performance](image1)

![Expected b-jet performance using FTK](image2)

**ATLAS Preliminary**
- *t̅t̅* simulation
- $|\mathbf{s}| = 13$ TeV
- Jet $p_T > 55$ GeV, $|\eta| < 2.5$

**ATLAS**
- Simulation $t\bar{t}$ (H → b$b$) all hadronic
- HLT items w/ FTK
- HLT items no FTK
Plans for Year-End-Technical-Stop and 2016

- Repairs and upgrades continue
  - New readout readout system for 2nd layer of Pixel detector
    - To prepare for higher pileup
  - Repair a damaged bellow of the toroid endcap magnet
    - Requires opening of one side of ATLAS
  - Standard maintenance work on all detectors

- Full reprocessing of 2015 data and MC underway
  - Allows for a coherent Run-2 dataset

- During 2016 full commissioning of
  - Fast Tracker (FTK)
    - Provides full event tracking for the HLT
  - L1Topo
    - Topological selection at L1
Conclusions

- The restart after the long shutdown and data taking through out 2015 has been very successful

- Despite the challenging conditions, the data taking efficiency and system stability has already reached a level comparable to the end of Run-1

- ATLAS is ready for more data and higher luminosities in 2016

- Many physics results are presented this week
Backup
IBL – Bowing due to temperature variations

- Detailed investigation of IBL bowing
  - Full report available: https://cds.cern.ch/record/2022587
  - Bowing occurs in the -phi direction due to different thermal expansion coefficients of the bare stave and the polyimide flex bus line

**FEA simulation of bowing**

![IBL - Bowing due to temperature variations](image_url)
Pileup distributions

- Mean number of interactions for 25ns, 50ns in run-1 and run-2
Reconstruction improvements

- Reduction in reconstruction time during LS1
  - More than factor of 3 speed improvements, mainly in ID tracking
  - Crucial for handling the higher HLT output rate and higher pileup later in Run-2

![Graph showing reconstruction time improvements over software releases](image-url)
Level-1 Topological Processor/Trigger

- Completely new piece of Level-1 hardware
  - Programmable trigger selections (FPGA)
  - Receives input from L1Calo and L1Muon
  - Applies selection on trigger objects

- Possible selections
  - Angular cuts (DR, Df, Dh)
  - Invariant mass cuts
  - Object refinements
  - etc.

- Essential for higher luminosity
  - Will allow us to keep the L1 thresholds low while not exceeding 100 kHz

- In commissioning...
  - Very complex piece of hardware
  - First trigger algorithms working as expected
  - Will be used during 2016 data-taking
Muon Detectors

- **CSC**
  - New ATCA-based readout operating nicely at 100 kHz
    - Absolutely essential for trigger operations in Run-2
  - Several layers show sparking during collisions
    - Two chambers show several broken wires (1 out of 4 layers lost)
    - Low voltage has been reduced slightly to prevent sparking

- **RPC**
  - Extensive repair campaign for gas leaks in LS1
  - Commissioning of new trigger towers (feet region) is ongoing

- **TGC**
  - Added Inner station coincidence to reduce trigger rates (see later)
  - Implemented veto for noise bursts (relevant for lumi > 5e33)

- **MDT**
  - Double-link readout for innermost stations to prevent saturation during Run-1
  - Alignment based on Toroid-off run taken in July during LHC ramp up
    - Preliminary alignment already good to O(50μm) in the barrel and O(100μm) in the endcap
TGC EI/FI coincidence logic

- Significant rate reduction with minimal loss in efficiency
  - >98% efficient with 15% rate reduction at 2.5e33 (more at higher lumi)
Muon barrel trigger efficiency

- **RPC chambers in feet region**
  - Trigger electronics installed and commissioned
    - Was post-poned to LS1 during construction phase
  - Will be fully operational for 2016 data-taking
    - Will increase trigger efficiency in this region to 60-70%

\[ Z \to \mu \mu, p_T^{\mu} > 21 \text{ GeV}, |\eta^{\mu}| < 1.05 \]