Run 2 ATLAS Trigger and Detector Performance

Oleg Solovyanov
IHEP NRC KI
On behalf of the ATLAS Collaboration
Outline

• LHC Run 2 Conditions
• ATLAS Detector Improvements
• ATLAS Detector Performance
• ATLAS Trigger Performance
HEP2018 ATLAS Talks

- ATLAS Highlights – Oliver Stelzer-Chilton
- SM Measurements with the ATLAS Detector – Bogdan Malescu
- Run 2 ATLAS Trigger and Detector Performance – Oleg Solovyanov
- Combination of ATLAS Higgs Boson Measurements – Fernando Monticelli
- ATLAS BSM Higgs Results – Leonor Cerda Alberich
- Searches for Supersymmetry and Exotics Physics in ATLAS – Jike Wang
- Recent ATLAS Results on Ultra-Peripheral Collisions in Heavy Ion Collisions at the LHC – Brian Cole
- Recent Results from the ATLAS Heavy Ion Program – Martin Spousta
- ATLAS Soft QCD Results – Tomas Sykora
- ATLAS Upgrades Plan and Progress (Physics Prospects) – Richard Polifka
- AFP Measurements and Prospects for Exclusive Diffraction, BSM Physics and Pomeron Structure – Ladislav Chitka
- Current and Expected Performance of Tracking and Vertexing with the ATLAS detector at the LHC and the HL-LHC – Alex Kastanas

Oleg Solovyanov - HEP2018
LHC Run 2 Conditions
LHC / HL-LHC Plan

Run 2: 13 TeV collisions during 2015-2018

Oleg Solovyanov - HEP2018
## LHC Run 2 Parameters

### Summary Table 2018 - 2017 - 2016

<table>
<thead>
<tr>
<th></th>
<th>2018</th>
<th></th>
<th>2017</th>
<th></th>
<th>2016</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Days</td>
<td>Ratio [%]</td>
<td>Days</td>
<td>Ratio [%]</td>
<td>Days</td>
<td>Ratio [%]</td>
</tr>
<tr>
<td>Phase</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Comm. &amp; Intensity ramp up</td>
<td>28</td>
<td>11.4</td>
<td>35</td>
<td>16.1</td>
<td>28*</td>
<td>11.3</td>
</tr>
<tr>
<td>Scrubbing</td>
<td>4</td>
<td>1.6</td>
<td>7</td>
<td>3.3</td>
<td>2</td>
<td>0.8</td>
</tr>
<tr>
<td><strong>25 ns Proton Physics</strong></td>
<td><strong>138</strong></td>
<td><strong>56.3</strong></td>
<td><strong>127</strong></td>
<td><strong>58.5</strong></td>
<td><strong>139</strong></td>
<td><strong>56.3</strong></td>
</tr>
<tr>
<td>Special Physics Runs</td>
<td>9</td>
<td>3.7</td>
<td>18</td>
<td>8.3</td>
<td>10</td>
<td>4</td>
</tr>
<tr>
<td>Setting up Pb-Pb ion run</td>
<td>4</td>
<td>1.6</td>
<td>-</td>
<td>-</td>
<td>6</td>
<td>2.4</td>
</tr>
<tr>
<td>Pb-Pb ion run</td>
<td>24</td>
<td>9.8</td>
<td>-</td>
<td>-</td>
<td>23</td>
<td>9.3</td>
</tr>
<tr>
<td>Machine Developments (MD)</td>
<td>20</td>
<td>8.2</td>
<td>18</td>
<td>8.3</td>
<td>21</td>
<td>8.5</td>
</tr>
<tr>
<td>Technical Stops (TS1 &amp; TS2)</td>
<td>13</td>
<td>5.4</td>
<td>8</td>
<td>3.7</td>
<td>12</td>
<td>5</td>
</tr>
<tr>
<td>Technical Stop Recovery</td>
<td>5</td>
<td>2</td>
<td>4</td>
<td>1.8</td>
<td>6</td>
<td>2.4</td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td><strong>245</strong></td>
<td><strong>217</strong></td>
<td><strong>100</strong></td>
<td><strong>247</strong></td>
<td><strong>100</strong></td>
</tr>
<tr>
<td>Integrated luminosity [fb⁻¹]</td>
<td>~ 60</td>
<td></td>
<td>50.2</td>
<td></td>
<td>39.7</td>
<td></td>
</tr>
</tbody>
</table>

* Did not fully include intensity ramp up – interleaved commissioning and interleaved intensity ramp up was as of 2017
# LHC Run 2 Records

<table>
<thead>
<tr>
<th>Category</th>
<th>Value</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak Stable Luminosity Delivered</td>
<td>$2.06 \times 10^{34}$ cm$^{-2}$s$^{-1}$</td>
<td>Fill 6358, 17/11/02 17:16</td>
</tr>
<tr>
<td>Maximum Average Events per Bunch Crossing</td>
<td>78.6</td>
<td>Fill 6358, 17/11/02 17:16</td>
</tr>
<tr>
<td>Maximum Stable Luminosity Delivered in one fill</td>
<td>769.9 pb$^{-1}$</td>
<td>Fill 6364, 17/11/06 03:35</td>
</tr>
<tr>
<td>Maximum Stable Luminosity Delivered in one day</td>
<td>881.9 pb$^{-1}$</td>
<td>Friday 20 October, 2017</td>
</tr>
<tr>
<td>Maximum Stable Luminosity Delivered for 7 days</td>
<td>5.248 pb$^{-1}$</td>
<td>Monday 16 October, 2017 - Sunday 22 October, 2017</td>
</tr>
<tr>
<td>Longest Time in Stable Beams for one fill</td>
<td>1 day, 13 hrs, 2 min</td>
<td>Fill 5045, 16/06/26 17:39</td>
</tr>
<tr>
<td>Longest Time in Stable Beams for one day</td>
<td>1 day, 0 min</td>
<td>Monday 27 June, 2016</td>
</tr>
<tr>
<td>Longest Time in Stable Beams for 7 days</td>
<td>5 days, 15 hrs, 5 min</td>
<td>Sunday 03 July, 2016 - Saturday 09 July, 2016</td>
</tr>
<tr>
<td>Fastest ATLAS Ready from Stable Beams</td>
<td>0 min</td>
<td>Fill 4495, 15/10/15 05:40</td>
</tr>
<tr>
<td>Fastest Turnaround to Stable Beams</td>
<td>2 hrs, 9 min</td>
<td>Fill 6156, 17/09/01 05:32</td>
</tr>
<tr>
<td>Maximum Colliding Bunches</td>
<td>2544</td>
<td>Fill 5880, 17/06/28 12:08</td>
</tr>
<tr>
<td>Maximum Charge per Bunch Colliding</td>
<td>$1.35 \times 10^{11}$</td>
<td>Fill 6194, 17/09/13 09:09</td>
</tr>
<tr>
<td>Maximum Charge per Beam Colliding</td>
<td>$3.08 \times 10^{14}$</td>
<td>Fill 6061, 17/08/09 23:45</td>
</tr>
<tr>
<td>Maximum Total Charge per Beam</td>
<td>$3.09 \times 10^{14}$</td>
<td>Fill 6061, 17/08/09 23:45</td>
</tr>
<tr>
<td>Average Specific Luminosity</td>
<td>$6.88 \times 10^{30}$ cm$^{-2}$s$^{-1}(10^{11}$ p$^{-2}$</td>
<td>Fill 6278, 17/10/07 00:14</td>
</tr>
</tbody>
</table>

- $2 \times 10^{34}$ cm$^{-2}$s$^{-1}$
- 5+ fb$^{-1}$/day
- 90+ fb$^{-1}$ total
- ~80 $\mu$
LHC Run 2 Conditions

ATLAS Online Luminosity

- **2011 pp** \(\sqrt{s} = 7\) TeV
- **2012 pp** \(\sqrt{s} = 8\) TeV
- **2015 pp** \(\sqrt{s} = 13\) TeV
- **2016 pp** \(\sqrt{s} = 13\) TeV
- **2017 pp** \(\sqrt{s} = 13\) TeV

**Delivered Luminosity (fb)**

- Jan
- Apr
- Jul
- Oct

**Month in Year**

**Peak Luminosity per Fill \(10^{36} \, \text{cm}^2 \, \text{s}^{-1}\)**

- 01/05
- 02/06
- 07/08
- 09/09
- 11/10
- 12/11
- 15/12

**Day in 2017**

**LHC Online Luminosity**

- **LHC Delivered All**
- **LHC Delivered Stable**
- **ATLAS Ready Recorded**

**Total Integrated Luminosity (fb)**

- **LHC Delivered**
- **ATLAS Recorded**
- **Good for Physics**

- Jan
- Jul
- Jan
- Jul
- Jan
- Jul

**Month in Year**

**Peak Interactions/BX**

- 01/05
- 02/06
- 07/08
- 09/09
- 11/10
- 12/11
- 15/12

**Day in 2017**

**ATLAS Online, 13 TeV**

- **LHC Online**
- \(L_{\text{int}} = 86.5\) fb

- 2015: \(\sigma_p = 13.4\)
- 2016: \(\sigma_p = 25.1\)
- 2017: \(\sigma_p = 38.1\)
- Total: \(\sigma_p = 32.0\)

**Mean Number of Interactions per Crossing**

- 0
- 10
- 20
- 30
- 40
- 50
- 60
- 70
- 80

**09/01/2018**
Luminosity Levelling

- The detector and high-level trigger reach their limits around $\langle \mu \rangle = 60$, hiccups started to happen.
- To provide stable operation and increase the integrated luminosity, ATLAS and CMS requested to level the instantaneous luminosity around $1.5 \times 10^{34}$ and $\langle \mu \rangle = 59$ at the end of September 2017.
- The target luminosity value for ATLAS is set by the ATLAS shift leader.
- The levelling procedure proved to be extremely successful and helped to ensure the stable operation, hence the increase of the integrated recorded luminosity.
LHC Crossing Angle Anti-Levelling

- Improves the integrated luminosity
- Decrease beams crossing angle in steps of -10 urad during stable beams
- Observed gain of 3-4% of integ. lumi.
LHC 8B4E Filling Scheme

- Special injection scheme to moderate e-cloud and heat-up
- 1/3 less bunches -> more pile-up to arrive to the same luminosity
- Concerns for calorimeters online pile-up correction
Heavy Ion Data Taking

- Pb-Pb run in 2015
- p-Pb data taking in 2016
- Xe-Xe pilot run in 2017
- 5 TeV pp reference run
- More details in two ATLAS presentations
  - Recent ATLAS Results on Ultra-Peripheral Collisions in Heavy Ion Collisions at the LHC – Brian Cole
  - Recent Results from the ATLAS Heavy Ion Program – Martin Spousta
- Next HI run in the fall 2018

Oleg Solovyanov - HEP2018
Special runs

- van der Meer scans for luminosity calibration
- Low-$\mu$ for W mass precise measurements
- High-$\mu$ for upgrade studies
- Xe-Xe ion pilot run
- 5 TeV pp reference run
- High $\beta^*$ at 900 GeV
- Sub-detector special runs
  - Muon alignment, LAr gain overlap, etc.

Oleg Solovyanov - HEP2018

09/01/2018 • 13
High-mass di-jet event with $m_{jj}=9.3$ TeV
• Several times more LHC design pile-up in Run-2, especially in 2017
• Sometimes up to maximum $<\mu>$ of 80
Detector Performance
The ATLAS Detector

Muon Spectrometer

Inner Detector

Calorimeters

Magnets

25 m

44 m
Detector improvements

• Many detector improvements during the year end technical stops in 2016 and 2017
• Three step read-out bandwidth upgrade in Pixel/IBL (ID)
• Dynamic front-end chip masking in SCT (ID)
• Read-out bandwidth increase in TRT (ID)
• Noise burst killer in LAr Calorimeter (Calo)
• Read-out CPU and bandwidth increase in Tile Calorimeter
• Noise killer in TGC (Muons), additional muon “feet” chambers
• New forward detector: AFP
AFP measures protons from diffractive processes that go down the beam pipe – provides interesting complementary physics program.

Data Analysis in progress

Current priority performance of Silicon Tracker (SiT) and Cherenkov time-of-flight (ToF)
Inner Detector

- **Pixel/IBL**
  - Hardware/Firmware/Software upgrades to cope with high $\langle \mu \rangle$ (FIFO flush at ECR)
  - Reduction of dead time (1.2%->0.2%)

- **SCT**
  - Very stable operation. Dynamic chip masking to cope with high $\langle \mu \rangle$

- **TRT**
  - Hardware and firmware upgrades to cope sustain high occupancy
  - Increase of bandwidth and compression ratio
Calorimeters

- **LAr**
  - Many special runs to study various aspects
  - While 8b4e is not optimal, the baseline correction works well

- **Tile**
  - Low number of dead channels
  - Doubling of read-out capacity (no busy)
  - Tile-Muon trigger to reduce fake muons in forward region
  - Calibration systems track calorimeter performance with precision

---

- Oleg Solovyanyev - HEP2018

09/01/2018 • 21
Muon Spectrometer

- Very smooth operation
- Rate reduction with EF/FI
- New “feet” trigger chambers to improve trigger coverage
- Effective noise killer in TGC
- Tile-Muon trigger in final commissioning to veto fake muons
Forward Detectors

- **LUCID**
  - Upgrades for Run 2
  - PMT calibration with Bi

- **ZDC**
  - Preparing for 2018
  - Quartz rods to be replaced

- **ALFA**
  - Special runs

- **AFP**
  - Both arms installed, taking data
Magnets

Operational statistics since start of physics data taking in September 2009
- Magnets off < 0.5% of operational hours
- ATLAS (and CMS) designed to survive some 150 load cycles up to 2025
- Need to extend the lifetime to at least 2035, yielding some 300 load cycles when using the present rate of runs per month
- Need to reduce the number of run cycles to arrive at a reasonable number in 2035, ~200 (30% more than designed for)
- New policy in place, limit the number of run downs on request
Luminosity Measurement (2016)

Main systematic uncertainties

<table>
<thead>
<tr>
<th></th>
<th>Moriond’17 (13TeV-008)</th>
<th>Final (13Tev-009)</th>
</tr>
</thead>
<tbody>
<tr>
<td>vdM calibration</td>
<td>1.7 %</td>
<td><strong>1.2 %</strong></td>
</tr>
<tr>
<td>Calibration transfer</td>
<td>1.6 %</td>
<td><strong>1.6 %</strong></td>
</tr>
<tr>
<td>Tracking efficiency</td>
<td>not cons'drd</td>
<td><strong>0.6 %</strong></td>
</tr>
<tr>
<td>Long-term consistency</td>
<td>2.5 %</td>
<td><strong>0.7 %</strong></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>3.4 %</strong></td>
<td><strong>2.2 %</strong></td>
</tr>
</tbody>
</table>

ATLAS Preliminary

\( \sqrt{s} = 13 \text{ TeV} \)

Tracking-efficiency correction (from Z T&P)

\( \mu \)-dependence: corresponds to a \(-9.5 \%\) correction at \( \mu \sim 40 \)
# Data Quality for Run 2

## 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>LAr</td>
</tr>
<tr>
<td></td>
<td>Tile</td>
<td></td>
<td>Tile</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>MDT</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>RPC</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CSC</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>TGC</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Solenoid</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Toroid</td>
</tr>
</tbody>
</table>

|                | 93.5         | 99.4              | 98.3    |
|                | 99.4         |                   | 99.4    |
|                | 100          |                   | 100     |
|                | 100          |                   | 100     |
|                | 100          |                   | 100     |
|                | 100          |                   | 97.8    |

**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 √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%.

## ATLAS pp 25ns run: April-October 2016

<table>
<thead>
<tr>
<th>Inner Tracker</th>
<th>Calorimeters</th>
<th>Muon Spectrometer</th>
<th>Magnets</th>
<th>Trigger</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pixel</td>
<td>SCT</td>
<td>TRT</td>
<td>LAr</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tile</td>
<td></td>
<td>Tile</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>MDT</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>RPC</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CSC</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>TGC</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Solenoid</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Toroid</td>
<td></td>
</tr>
<tr>
<td></td>
<td>98.9</td>
<td>99.9</td>
<td>99.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>99.3</td>
<td>98.9</td>
<td>99.8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>99.8</td>
<td>99.8</td>
<td>99.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>99.9</td>
<td>99.9</td>
<td>99.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>99.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>97.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>98.3</td>
<td></td>
</tr>
</tbody>
</table>

**Good for physics: 93-95% (33.3-33.9 fb⁻¹)**

Luminosity weighted relative detector uptime and good data quality efficiencies (in %) during stable beam in pp collisions with 25ns bunch spacing at √s=13 TeV between April-October 2016, corresponding to an integrated luminosity of 35.9 fb⁻¹. The toroid magnet was off for some runs, leading to a loss of 0.7 fb⁻¹. Analyses that don’t require the toroid magnet can use that data.

## ATLAS pp 25ns run: June 5-November 10 2017

<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>LAr</td>
</tr>
<tr>
<td></td>
<td>Tile</td>
<td></td>
<td>Tile</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>MDT</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>RPC</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CSC</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>TGC</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Solenoid</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Toroid</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>99.9</td>
<td>99.5</td>
</tr>
<tr>
<td></td>
<td>99.3</td>
<td>99.4</td>
<td>99.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>97.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>99.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>100</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>99.2</td>
</tr>
</tbody>
</table>

**Good for physics: 93.6% (43.8 fb⁻¹)**

Luminosity weighted relative detector uptime and good data quality efficiencies (in %) during stable beam in pp collisions with 25ns bunch spacing at √s=13 TeV between June 5 – November 10 2017, corresponding to a delivered integrated luminosity of 50.4 fb⁻¹ and a recorded integrated luminosity of 46.8 fb⁻¹. The toroid magnet was off for some runs, leading to a loss of 0.5 fb⁻¹. Analyses that don’t require the toroid magnet can use these data.
Trigger Performance
Trigger and DAQ in Run 2

- Calorimeter detectors
- Tile/TGC
- Muon detectors
- Preprocessor (nMCM)
- Electron/Tau CMX
- Jet/Energy CMX
- Endcap sector logic
- Barrel sector logic
- LITopo
- CTP
- CTPCORE
- CTPOUT
- Fast TracKer (FTK)
- High Level Trigger (HLT)
- Event Data
- Processors O(20k)
- Detector Read-Out
- ROD
- FE
- DataFlow
- ReadOut System
- Data Collection Network
- Data Storage (SFO)
- Region Of Interest
- ROI Requests
- ~30 MHz
- 100 kHz
- 1 kHz

[Oleg Solovyanov - HEP2018]
NEW: L1 Central Trigger Upgrade

- The L1CT has undergone a major Hardware / Firmware / Software upgrade for run II (more inputs, 256 → 512 items, multi-partitions...)

Diagram: L1CT -> L1Topo -> L1Calo -> Central Trigger Processor (CTP) -> L1Muon -> Muon to CTP Interface -> MuCTPI to L1topo -> Forward detectors
NEW: L1 Topological Trigger

- Topological cuts on angular distributions
- Combines calorimeters and muon spectrometer
- Missing, invariant and transverse mass calculations
- Execute algorithms in 75 ns
- Enabled, being validated
- Rate reduction up to 4
NEW: Fast TracKer (FTK)

- Provides full-track list with $p_T > 1$ GeV, $|\eta| < 2.5$ to HLT on L1 accept

- Full-level tracking information at the input to HLT for all level-1 triggered events
- Complex hardware system with ATCA and VME boards
- Custom ASICs and large FPGAs, associative memory and pattern recognition
- Building 8-layer tracks and writing data to ATLAS data stream
- System is being commissioned, full system in 2018
NEW: Fake Muon Trigger Rejection

- TMDB – Tile Muon Digitiser Board (9U VME)
- Digitise analogue trigger output from outer (D) layer of Tile Calorimeter
- Coincidence with Muon Chambers to reduce rate from fake muons
- Hardware installed, time alignment and calibration done

Oleg Solovyov - HEP2018
09/01/2018
Trigger Menu

- **Menu strategy**
  - Priority to primary physics triggers
  - Higher thresholds for higher lumi.
  - Keep L1<100 kHz, HLT<1 kHz (average in the run)

- **Luminosity levelling**
  - Set target lumi. at the beginning of the run to limit trigger rates

- **Change of pre-scales**
  - Start with strictest menu, relax and lower threshold as rates drop

### Table

<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>Single leptons</td>
<td>Single isolated $\mu$, $p_T &gt; 27$ GeV</td>
<td>20</td>
<td>26 (i)</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>Single isolated tight $\mu$, $p_T &gt; 27$ GeV</td>
<td>22 (i)</td>
<td>26 (i)</td>
<td>26</td>
</tr>
<tr>
<td></td>
<td>Single $\mu$, $p_T &gt; 52$ GeV</td>
<td>20</td>
<td>30</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>Single $\mu$, $p_T &gt; 61$ GeV</td>
<td>25 (i)</td>
<td>26</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>Single $\tau$, $p_T &gt; 170$ GeV</td>
<td>100</td>
<td>160</td>
<td>4.9</td>
</tr>
<tr>
<td>Two leptons</td>
<td>Two $\mu$, each $p_T &gt; 15$ GeV</td>
<td>$2 \times 10$</td>
<td>$2 \times 14$</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td>Two $\mu$, $p_T &gt; 25, 9$ GeV</td>
<td>20</td>
<td>$2 \times 15$ (i)</td>
<td>1.6</td>
</tr>
<tr>
<td></td>
<td>Two loose $\mu$, each $p_T &gt; 18$ GeV</td>
<td>$2 \times 15$ (i)</td>
<td>$2 \times 17$</td>
<td>1.6</td>
</tr>
<tr>
<td></td>
<td>One $\mu$ &amp; one $\mu$, $p_T &gt; 25, 9$ GeV</td>
<td>20</td>
<td>$2 \times 15$ (i)</td>
<td>1.6</td>
</tr>
<tr>
<td></td>
<td>One loose $\mu$ &amp; one $\mu$, $p_T &gt; 18, 15$ GeV</td>
<td>20</td>
<td>$2 \times 15$ (i)</td>
<td>1.6</td>
</tr>
<tr>
<td></td>
<td>Two $\tau$, $p_T &gt; 40, 30$ GeV</td>
<td>$2 \times 15$ (i)</td>
<td>$2 \times 17$</td>
<td>1.6</td>
</tr>
<tr>
<td></td>
<td>One $\tau$ &amp; one isolated $\mu$, $p_T &gt; 30, 15$ GeV</td>
<td>20 (i), 12 (i) (*jets plus topo)</td>
<td>$2 \times 15$ (i)</td>
<td>1.6</td>
</tr>
<tr>
<td></td>
<td>One $\tau$ &amp; one isolated $\mu$, $p_T &gt; 30, 15$ GeV</td>
<td>20 (i), 12 (i) (*jets plus topo)</td>
<td>$2 \times 15$ (i)</td>
<td>1.6</td>
</tr>
<tr>
<td>Three leptons</td>
<td>Three loose $\mu$, $p_T &gt; 25, 13, 13$ GeV</td>
<td>$2 \times 10$</td>
<td>$2 \times 12$</td>
<td>1.2</td>
</tr>
<tr>
<td></td>
<td>Three $\mu$, each $p_T &gt; 7$ GeV</td>
<td>$2 \times 10$</td>
<td>$2 \times 12$</td>
<td>1.2</td>
</tr>
<tr>
<td></td>
<td>Three $\mu$, $p_T &gt; 21, 2, 5$ GeV</td>
<td>$2 \times 10$</td>
<td>$2 \times 12$</td>
<td>1.2</td>
</tr>
<tr>
<td></td>
<td>Two $\mu$ &amp; one loose $\mu$, $p_T &gt; 2 \times 11, 13$ GeV</td>
<td>$2 \times 10$</td>
<td>$2 \times 12$</td>
<td>1.2</td>
</tr>
<tr>
<td></td>
<td>Two loose $\mu$ &amp; one isolated $\mu$, $p_T &gt; 2 \times 13, 11$ GeV</td>
<td>$2 \times 10$</td>
<td>$2 \times 12$</td>
<td>1.2</td>
</tr>
<tr>
<td></td>
<td>One photon</td>
<td>One photon</td>
<td>$p_T &gt; 145$ GeV</td>
<td>$2 \times 10$</td>
</tr>
<tr>
<td></td>
<td>Two photons</td>
<td>Two photons</td>
<td>$p_T &gt; 55, 35, 55$ GeV</td>
<td>$2 \times 10$</td>
</tr>
<tr>
<td></td>
<td>Two medium $\gamma$, $p_T &gt; 40, 30$ GeV</td>
<td>$2 \times 10$</td>
<td>$2 \times 12$</td>
<td>1.2</td>
</tr>
<tr>
<td></td>
<td>Two tight $\gamma$, $p_T &gt; 25, 25$ GeV</td>
<td>$2 \times 10$</td>
<td>$2 \times 12$</td>
<td>1.2</td>
</tr>
<tr>
<td>Single jet</td>
<td>Jet ($R = 0.4$), $p_T &gt; 460$ GeV</td>
<td>100</td>
<td>420</td>
<td>3.4</td>
</tr>
<tr>
<td></td>
<td>Jet ($R = 1.0$), $p_T &gt; 500$ GeV</td>
<td>100</td>
<td>460</td>
<td>3.4</td>
</tr>
<tr>
<td>$E_T^{miss}$</td>
<td>$E_T^{miss} &gt; 200$ GeV</td>
<td>50</td>
<td>110</td>
<td>4.4</td>
</tr>
<tr>
<td>Multi-jets</td>
<td>Four jets, each $p_T &gt; 125$ GeV</td>
<td>3</td>
<td>$3 \times 10$</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>Five jets, each $p_T &gt; 95$ GeV</td>
<td>100</td>
<td>44</td>
<td>9.3</td>
</tr>
<tr>
<td></td>
<td>Six jets, each $p_T &gt; 70$ GeV</td>
<td>100</td>
<td>44</td>
<td>9.3</td>
</tr>
<tr>
<td></td>
<td>Six jets, each $p_T &gt; 65$, $p_T &lt; 2.4$</td>
<td>100</td>
<td>44</td>
<td>9.3</td>
</tr>
<tr>
<td>$b$-jets</td>
<td>One $b$ ($m_b = 4.0$, $p_T &gt; 235$ GeV)</td>
<td>100</td>
<td>225</td>
<td>3.4</td>
</tr>
<tr>
<td></td>
<td>Two $b$ ($m_b = 6.0$, $p_T &gt; 185, 70$ GeV)</td>
<td>100</td>
<td>175</td>
<td>3.4</td>
</tr>
<tr>
<td></td>
<td>One $b$ ($m_b = 4.0, 73$ &amp; three jets, each $p_T &gt; 85$ GeV)</td>
<td>100</td>
<td>225</td>
<td>3.4</td>
</tr>
<tr>
<td></td>
<td>Two $b$ ($m_b = 73$) &amp; one jet, $p_T &gt; 65, 65, 160$ GeV</td>
<td>100</td>
<td>225</td>
<td>3.4</td>
</tr>
<tr>
<td></td>
<td>Two $b$ ($m_b = 60$, 73) &amp; two jets, each $p_T &gt; 45$ GeV</td>
<td>100</td>
<td>225</td>
<td>3.4</td>
</tr>
<tr>
<td>$b$-physics</td>
<td>Two $\mu$, $p_T &gt; 6.6$ GeV</td>
<td>50</td>
<td>6.6</td>
<td>3.4</td>
</tr>
<tr>
<td></td>
<td>plus dedicated $b$-physics selections</td>
<td>50</td>
<td>6.6</td>
<td>3.4</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>82</td>
<td>1320</td>
<td></td>
</tr>
</tbody>
</table>

- Oleg Solovyanov - HEP2018

09/01/2018 • 33
## Primary Triggers

<table>
<thead>
<tr>
<th>Main primary trigger</th>
<th>Trigger thresholds at HLT [GeV]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L≤1.5e34</td>
</tr>
<tr>
<td>single iso muon</td>
<td></td>
</tr>
<tr>
<td>single iso electron</td>
<td>E(_T) &gt; 26 (tight ID)</td>
</tr>
<tr>
<td>E(<em>T)(</em>{miss})</td>
<td>&gt; 110 (L1_XE50)</td>
</tr>
<tr>
<td>single jet</td>
<td>p(_T) &gt; 400</td>
</tr>
<tr>
<td>single photon</td>
<td>E(_T) &gt; 140 (loose ID)</td>
</tr>
<tr>
<td>di-muon for B-physics</td>
<td>p(_T)(m(_1), m(_2)) &gt; 6, 6 + topological/mass cuts</td>
</tr>
<tr>
<td>di-tau</td>
<td>p(_T)(t(_1), t(_2)) &gt; 35, 25 + jet requirement at L1</td>
</tr>
<tr>
<td>di-photon</td>
<td>p(_T)(g(_1), g(_2)) &gt; 20, 20 (with isolation &amp; tight ID), 35, 25 (medium ID)</td>
</tr>
<tr>
<td>four-bjets</td>
<td>p(_T)(bj(_1), bj(_2), bj(_3), bj(_4)) &gt; 35, 35, 35, 35 (Working Points: 70,70,85,85%)</td>
</tr>
</tbody>
</table>
2017 HLT CPU

- Operating with 40k CPU cores.
- From 336630 (25th Sep) running in over-allocation mode, 70k processing slots.
- Total CPU the product of L1 rate and Time/Event

μ ≠ L due to differing numbers of bunches.
Extrapolations by DAQ

Increasing $\mu$ results in approximately linear increases in:

- L1 Rate
- N Rols
- CPU/Rol

For equal lumi:

**CPU \propto \mu^2**

(as L1 rate constant for given L)

**The 2017 $1.7 \times 10^{34}$ menu could handle up to $<\mu> = 67$. This is without low-$p_T$ GSC multi-jet chains, with minimal loss to performance.**
HLT Rates Evolution

- 0.92kHz in the whole year. 1kHz before LHC’s 16L2 issue
HLT Rates During Run

**ATLAS Trigger Operation**

HLT Physics Group Rates (with overlaps)

pp Data June 2017, $\sqrt{s} = 13$ TeV

**Graph Details:**
- **Y-axis:** HLT Trigger Rate [Hz]
- **X-axis:** Time [h:m]
- **Legend:**
  - Physics stream
  - MET
  - Electron
  - Tau
  - Muon
  - Photon
  - Jet
  - B-physics
  - Combined

**Key Points:**
- The graph shows the rate of HLT triggers for various physics streams over time.
- The data is from pp collisions at a center-of-mass energy of 13 TeV.
- The rates decrease over time, indicating a possible reduction in trigger activity.

---

Oleg Solovyanov - HEP2018
Electron and Photon Trigger Performance

• High identification efficiency
• Energy response ($Z\rightarrow \text{ee}$) stable vs. $<\mu>$, correctly tracked by Monte Carlo

Oleg Solovyanov - HEP2018

09/01/2018 • 39
Jet Trigger Performance

- Sharp trigger turn-on curve
- Calibration with tracks
- Pile-up reduction with Jet Vertex Tagger

09/01/2018

Oleg Solovyanov - HEP2018
Great performance from L1Topo
High tau trigger efficiency and Monte Carlo agreement
• High trigger efficiency, stable against pile-up

"ATLAS Preliminary"

Data 2017, $\sqrt{s} = 13$ TeV, 15.4 fb$^{-1}$

$Z\rightarrow \mu\mu$

- L1_XE50
- HLT_xe110_pufit_L1XE50

"ATLAS Preliminary"

Data 2017, $\sqrt{s} = 13$ TeV, 15.4 fb$^{-1}$

$p_T (Z) > 150$ GeV

$Z\rightarrow \mu\mu$

- L1_XE50
- HLT_xe110_pufit_L1XE50
B-Jet Trigger Performance

- Stable performance in diverse pile-up conditions

[Graphs showing efficiency and fraction of jets passing online b-tagging as a function of mean number of interactions per crossing]
Muon Trigger Performance

- High reconstruction efficiency, stable against pile-up, well described by Monte Carlo

Oleg Solovyanov - HEP2018

09/01/2018 • 44
Computing

- Over 300k job slots
- More opportunistic resources like HPCs, Clouds and LHC@Home
- Large mixture of highly diverse jobs, multi-core, single-core, etc.

Impact of HPCs
Summary

• Incredible LHC performance in Run 2
• Collected great amount of data, 80 fb$^{-1}$ good for physics
• Challenging conditions, high luminosity and pile-up
• High data taking efficiency and data quality
• Several improvements made to deal with high trigger rates and high pile-up
• Excellent detector and trigger performance
• Robustness against high pile-up, sharp trigger turn-on
• All of the above thanks to the dedication and effort
• Looking forward for an exciting 2018 data taking!
One More Thing, or Two
Upgrades

• Phase-I upgrade in 2019-2020
  o Upgraded Trigger and DAQ, new Muon Small Wheel
  o EM calorimeter digital trigger information

• Phase-II upgrade in 2024-2025
  o New Inner Tracker (ITk)
  o New read-out and trigger electronics for calorimeters
  o New digital trigger system and data acquisition

• ATLAS talk
  o [ATLAS Upgrades Plan and Progress (Physics Prospects)] – Richard Polifka
Backup
The ATLAS Detector
Toroid Magnet Lifetime

ATLAS Toroid Run cycles per Operational_month in years 2009 - 2035

- LS1
- 300 needed for 2035! with present run policy
- 150 runs up to year 2025
- Here I want to go <200 in 2035
SCT Maximum Rates

**ATLAS** SCT Preliminary
\( \sqrt{s} = 13 \text{ TeV}, \) projection using 2017 data
With chip disabling

Interactions per bunch crossing, \( \mu \)

Maximum sustainable L1A rate [kHz]
TRT Bandwidth Limitations

- $\langle \mu \rangle = 66$: at 97 kHz L1 rate, TRT will use $\sim 92\%$ of S-Link bandwidth (effective occupancy with 8b4e bunch structure is less than with nominal structure)

- Expected improvement of $\sim 10\%$ by optimizing lossless data compression table (Huffman encoding) with high $\langle \mu \rangle$ data (former optimization with $\langle \mu \rangle = 40$ data)

- More aggressive “N-to-1 mapping” for readout compression on the way: be ready to run at $\langle \mu \rangle = 80$
The Level-1 Central Trigger System

- The L1CT team is responsible for:
  - **Central Trigger Processor (CTP)**: receives and processes the trigger inputs from L1Calo, L1Muon, L1Topo and forward detectors to form L1 trigger decision
  - **Muon to CTP Interface (MUCTPI)**: processes L1Muon inputs, resolves overlap between sectors, sends multiplicities for each $p_T$ threshold to the CTP and candidates $(\eta, \phi)$ positions to L1Topo
  - **RF2TTC**: interface to LHC clock distribution and beam picks-up
  - Support for the sub-detector TTC crates and timing-in

- The L1CT has undergone a major Hardware / Firmware / Software upgrade for run II (more inputs, 256 → 512 items, multi-partitions...)

![Diagram of L1CT system](image)
B-Tagging

\[ s = 13 \text{ TeV}, 32 \text{ fb}^{-1} \]

\( \text{OS } e\mu \text{ events} \)

**Mean b-tagged jet multiplicity**

- Jet \( p_T > 25 \text{ GeV} \)
- Jet \( p_T > 60 \text{ GeV} \)
- Jet \( p_T > 100 \text{ GeV} \)

\( tt\bar{t} \) candidates
**L1Topo Performance**

ATLAS Trigger Operations
Data 2017, $\sqrt{s} = 13$ TeV
Run taken on Jun 17, 2017

- L1: $2 \times p_T^{\mu} > 6$ GeV
- L1Topo: $2 \times p_T^{\mu} > 6$ GeV, $m_{\mu\mu} \in [2, 9]$ GeV, $\Delta R_{\mu\mu} \in [0.2, 1.5]$
First Xe-Xe Collisions on 12th October 2017
The Xe+Xe data are of great interest for Heavy Ion group. New system to measure azimuthal anisotropy in particle production and fluctuations → constrain initial geometry models. Uncertainties in number of binary collisions are smaller in smaller systems. Jet measurements benefit from lower UE and different “quenching configuration”.

Collected statistic:

- ~30M MB events collected.
  Comparison: ~50M MB events collected in 2010 Pb+Pb@2.76 TeV run.

Will allow to perform measurements of global event properties and some studies of hard processes (lower $p_T$ jets).