ATLAS Trigger System

2011-2012 Performance and Evolution

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On behalf of the ATLAS collaboration

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The ATLAS Experiment

Inner Detector
- Pixel (pixel detector)
- SCT (silicon strip detector)
- TRT (transition radiation tracker)

Calorimeter
- LAr (EM calorimeter)
- Tile (Fe/Scintillator tile)

Muon Spectrometer
- MDT,CSC (precise momentum measurement)
- RPC,TGC (trigger chambers)

Magnet System
- 2 T solenoid
- 0.5 T toroid
TDAQ System

Design

Typical 2012
- 40 MHz (20 MHz)
- 75 (100) kHz
- ~65 kHz
- ~3 kHz
- ~5 kHz
- ~200 Hz
- ~400 Hz (avg.)

Trigger

Level 1
- <2.5 μs
- 40 MHz
- Regions Of Interest
- L1 Accept 75 (100) kHz
- ~40 ms ~60 ms
- EF Accept ~200 Hz

Level 2
- ~4 sec ~1 sec
- L2 Accept ~3 kHz

Event Filter

High Level Trigger

Data Collection Network

Event Filter Network

SubFarmInput

SubFarmOutput

Event Builder

Data-Flow

ReadOut System

DAQ

Detector Read-Out

Calo/Muon Detectors

Other Detectors

ROD

~100 GB/s

112 (150) GB/s

~300 MB/s

~600 MB/s

ATLAS Event

1.5 MB/25 ns

~4.5 GB/s

~ 7.5 GB/s

~100 GB/s
The ATLAS Trigger System

Three level trigger system
Based on Region of Interest (RoI) concept

Level 1:
- Fast, custom-build electronics finds and defines RoIs
- Muon and Calorimeters only
- Coarse resolution

Level 2:
- Dedicated, fast software algorithms
- Works on full-granularity RoI data

Level 3 (Event Filter):
- Software reused from offline
- Full event information available, but partly still RoI based

Nomenclature:
- **Chain**: one full L1→EF selection sequence
- **Menu**: full set of chains and prescale factors
  Typical menu has ~500 chains
Luminosity Challenge

LHC has had an extremely successful luminosity ramp up

Rapid changes in trigger to follow six orders of magnitude changes in luminosity during first years

In the last year luminosity increased mostly from more bunch luminosity

Challenge for trigger to keep efficiency and rejection stable in high pileup conditions
Frequent trigger changes complicate physics analyses
For 2011-2012 managed to run with just 3 base menus for p-p
Some trigger chains designated as extras in each menu dropped
as luminosity increases to keep bandwidth under control
Separate trigger menu for Heavy-Ion running
Trigger Menu Design and Rates

Optimal distribution of available bandwidth is critical
Driven by physics requirements and priorities
– extensive consultations with physics sub-groups
Most bandwidth given to most generic triggers

Approximate EF bandwidth assignment
- Single leptons (e/μ): ~50 Hz each
- Generic triggers: 5-15 Hz each
  examples: multi-jet, di-muon, ...
- Specialized triggers: ~1 Hz
  examples: long-lived particles, ...
- Supporting triggers: 20%

L1 and L2 bandwidth constraints also need to be considered

Rate distribution for $L_{\text{peak}} = 7 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$

<table>
<thead>
<tr>
<th>Group</th>
<th>Peak L1 rate</th>
<th>Peak L2 rate</th>
<th>Average EF rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>B-jets</td>
<td>5000</td>
<td>900</td>
<td>45</td>
</tr>
<tr>
<td>B-physics</td>
<td>7000</td>
<td>50</td>
<td>20</td>
</tr>
<tr>
<td>E/gamma</td>
<td>30000</td>
<td>2000</td>
<td>140</td>
</tr>
<tr>
<td>Jets</td>
<td>3000</td>
<td>1000</td>
<td>35</td>
</tr>
<tr>
<td>MET</td>
<td>4000</td>
<td>800</td>
<td>30</td>
</tr>
<tr>
<td>Muon</td>
<td>14000</td>
<td>1200</td>
<td>100</td>
</tr>
<tr>
<td>Tau</td>
<td>24000</td>
<td>800</td>
<td>35</td>
</tr>
<tr>
<td>Sum</td>
<td>65000</td>
<td>5500</td>
<td>400</td>
</tr>
</tbody>
</table>

About 150 Hz of additional B-physics and jet triggers recorded for later processing in 2013

Group overlap accounted for in the sum
Muon Triggers

Muon trigger at $p_T > 18$ GeV in 2011
Tightened L1 trigger mid 2011 due to out-of-time hits with 50ns beam

Changes for 2012:
- Additional shielding installed in detector
- Raise to $p_T > 24$ GeV
- Track isolation required (pileup robust)
- Di-muon raised from 2x10 to 2x13 GeV

Efficiencies measured in $Z \rightarrow \mu\mu$ to <1%

Barrel trigger eff. vs $p_T$

Endcap trigger eff. vs pileup

Isolation eff. vs pileup
Electron Triggers

**Design:** Inclusive 25 GeV and 2x15 GeV electron triggers – Requires HLT ~ offline

**Changes during 2011:**
- Hadronic veto at L1
- Retuned HLT&Offline electron ID

**Changes for 2012:**
- Raised L1 threshold
- Retuned electron ID for high pileup
- Track isolation required (pileup robust)

2011 trigger vs pileup

2012 trigger vs pileup
Hadronic $\tau$ Triggers

$\tau$ triggers mostly used in combination with 2$^{\text{nd}}$ $\tau$ (had/lep) or MET trigger

Tuned for $H\rightarrow\tau\tau$ and $H^{+}\rightarrow\tau\nu$

Significant improvements for 2012:

- Much improved pileup robustness
- Smaller cone sizes, $\Delta z$ track cuts
- EF now uses multi-variate selection to increase rejection power significantly

$\tau$ track isolation vs pileup

2011 trigger vs pileup

2012 trigger vs pileup
Photon Triggers

Many users of photon triggers

- Di-photon (2x20 GeV) trigger essential for $H \rightarrow \gamma \gamma$, at >99% eff.
- Kept stable during 2011

Retuned for 2012:

- Loosened pileup sensitive selection, but raised $p_T$ thresholds
- 2x20 GeV trigger with somewhat tighter photon identification
- Added 3-photon triggers
Jet Triggers

Many signals rely on jet triggers
Have triggers for various sizes of jets and both with and without b-tag
Evolution away from RoI based triggers

Improvements for 2012:
- Full scan reco of L1 towers for anti-kt jets at L2
- Hadronics scale for HLT jets
- Noise thresholds adjusted for high pileup
- More advanced b-tagger (Multi-variate, multi-jet vertex)

Improvements from L2 fullscan:

![Jet efficiency vs p_T](chart)

![Efficiency vs Sixth jet E_T](chart)
Missing Energy Triggers

Trigger MET sums over calorimeter cells above noise threshold
Strong pileup effect seen in 2011

L1 improvements for 2012:
1. Pileup effectively increases noise, particularly in the forward calorimeters → noise threshold per tower was raised
2. L1 rate reduced by factor 10-20
3. Little effect on resolution seen

L1 “noise” width vs pileup
Missing Energy Triggers

HLT improvements for 2012:
- Cell-based MET sum implemented in readout system for fast L2 decision
  *Factor ~5 L2 rejection vs none in 2011*
- New EF algorithm summing calibrated clusters instead of all cell energies
  (closer to offline definition as well)
- Noise cuts adjusted for high pileup

MET trigger looser in 2012 than 2011 despite higher luminosity and pileup

**EF MET Resolutions**

**Acceptance Improvement**
Summary and Outlook

- The ATLAS trigger operating successfully in 2011-2012
  - Efficiency losses due to the trigger are typically less than few %
  - Efficiencies are measured accurately using data
- Handling challenge of excellent LHC performance
  - Luminosity increased by factor 30 since end of 2010
  - Pileup increase by almost a factor 10 since end of 2010
- Significant improvements deployed for 2012
  - Retuned selection for high pileup conditions
  - More advanced HLT selection algorithms
  - Trigger thresholds only raised minimally w.r.t. 2011 despite twice the luminosity and beyond design pileup conditions
- Now planning for $\sqrt{s}=13-14$ TeV and $L>10^{34}$ cm$^{-2}$s$^{-1}$
Backup
B-physics Triggers

Large sample of low-$p_T$ di-muon events collected for B-physics
Main trigger: di-muon with mass cut

Improvements for 2012:

- New “Barrel-only” low-pt muons at L1 keeps lowest threshold for best muons
- Delayed processing stream (lifts EF output limit)
B-jet Triggers

B-tagging of jets available in the trigger
Mostly used in multi-jet triggers
Can reduce trigger rates by factor 10-50

Improvements for 2012:
- More advanced tagger incl. secondary vtx finding
- Factor 4-5 better light jet rejection
- Pileup robust primary vertex determination
- Full use of HLT jets
# Main Unprescaled Triggers

<table>
<thead>
<tr>
<th>Offline Selection</th>
<th>Trigger Selection</th>
<th>L1 Peak (kHz)</th>
<th>EF Ave (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L1</td>
<td>EF</td>
<td>(L_{\text{peak}} = 7 \times 10^{33})</td>
</tr>
<tr>
<td>Single leptons</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single muon (p_T &gt; 25) GeV</td>
<td>15 GeV</td>
<td>24 GeV</td>
<td>8</td>
</tr>
<tr>
<td>Single electron (p_T &gt; 25) GeV</td>
<td>18 GeV</td>
<td>24 GeV</td>
<td>17</td>
</tr>
<tr>
<td>Two leptons</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 muons (p_T &gt; 15) GeV</td>
<td>2x10 GeV</td>
<td>2 x 13 GeV</td>
<td>1</td>
</tr>
<tr>
<td>2 muons (p_T &gt; 20,10) GeV</td>
<td>15 GeV</td>
<td>18.8 GeV</td>
<td>8</td>
</tr>
<tr>
<td>2 electrons, each (p_T &gt; 15) GeV</td>
<td>2x10 GeV</td>
<td>2x12 GeV</td>
<td>6</td>
</tr>
<tr>
<td>2 taus (p_T &gt; 45,30) GeV</td>
<td>15,11 GeV</td>
<td>29,20 GeV</td>
<td>12</td>
</tr>
<tr>
<td>Two photons</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 photons, each (p_T &gt; 25) GeV</td>
<td>2 x 10 GeV</td>
<td>2 x 20 GeV</td>
<td>6</td>
</tr>
<tr>
<td>2 loose photons, (p_T &gt; 40,30) GeV</td>
<td>12,16 GeV</td>
<td>35, 25 GeV</td>
<td>6</td>
</tr>
<tr>
<td>Single jet</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jet (p_T &gt; 360) GeV</td>
<td>75 GeV</td>
<td>360 GeV</td>
<td>2</td>
</tr>
<tr>
<td>MET</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MET &gt; 120 GeV</td>
<td>40 GeV</td>
<td>80 GeV</td>
<td>2</td>
</tr>
<tr>
<td>Multi-jets</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 jets, each (p_T &gt; 55) GeV</td>
<td>4x15 GeV</td>
<td>5x55 GeV</td>
<td>1</td>
</tr>
<tr>
<td>b-jets</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(b + 3) other jets (p_T &gt; 45) GeV</td>
<td>4x15 GeV</td>
<td>4x45 GeV+btag</td>
<td>1</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>&lt;75</td>
<td></td>
<td>~400</td>
</tr>
</tbody>
</table>