ATLAS Trigger Menu and Performance in Run I and Prospects for Run II

Olya Igonkina
(NIKHEF)
on behalf of ATLAS collaboration

- ATLAS experiment and ATLAS TDAQ system
- Trigger in Run I
- Preparation for Run II
**ATLAS Experiment**

*pp collisions at $\sqrt{s}=7-14$ TeV*

**Inner Detector**
- Pixel detector
- Silicon strip detector
- Transition radiation detector

**Calorimeter**
- Liquid Argon calorimeter
- Tile (Fe/Scintillator) calorimeter

**Muon Spectrometer**
- MDT, CSC (precision measurements)
- RPC, TGC (trigger chambers)

**Magnet system**
- 2T solenoid
- 0.5T toroid
3 level Trigger System

Minimum bias 40 mb

Standard Model Physics, ~20 nb

Rare processes, BSM, < pb

40 MHz

L1 hardware trigger
coarse Calo and Muon data

65 kHz

L2 software trigger:
detailed info in Region of Interest

5 kHz

Event Filter software trigger:
complete event data; latest calibration
+ alignment

400 Hz
ATLAS TDAQ system

**Typical 2012**

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

**Design**

- (20 MHz)
- ~1 sec
- ~60 ms
- ~40 ms
- ~60 ms
- L1 Accept 75 (100) kHz
- ROD
- Detector Read-Out
- FE
- Data Collection Network
- Event Builder
- Event Filter
- High Level Trigger

**ATLAS Event**

- 1.5 MB/25 ns
- 112 (150) GB/s
- ~ 100 GB/s
- ~ 7.5 GB/s
- ~ 600 MB/s
- CERN Data Storage
Multi-Purpose Experiment/Trigger

**Multi-Purpose trigger**

<table>
<thead>
<tr>
<th>Trigger</th>
<th>Threshold / GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>inclusive $\mu$</td>
<td>24</td>
</tr>
<tr>
<td>inclusive e</td>
<td>24</td>
</tr>
<tr>
<td>dimuon</td>
<td>13, 13 or 18, 8</td>
</tr>
<tr>
<td>dielectron</td>
<td>12, 12</td>
</tr>
<tr>
<td>ditau</td>
<td>29, 20</td>
</tr>
<tr>
<td>diphoton</td>
<td>20, 20</td>
</tr>
<tr>
<td>plus a couple of hundred others</td>
<td></td>
</tr>
</tbody>
</table>

- **Physics goals:**
  - SM, EW precision measurements
  - Higgs
  - Supersymmetry
  - Extra gauge bosons
  - Compositeness
  - Extra dimensions
  - B physics

**Publications**

- To date, 260 papers have been submitted with collision data
- Sustained rate of 2.5 papers/week during 2012
- In addition, 520 ATLAS CONF notes since the start of 2010

**Monitoring**
- Calibration
- Background samples

**Physics**
Trigger menu

<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>E/gamma</td>
<td>30000</td>
<td>2000</td>
<td>140</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>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>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>Total</td>
<td>65000</td>
<td>5500</td>
<td>400</td>
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</table>

**Complex trigger menu**

- 256 L1 selections
- >600 HLT selections

**Example**

<table>
<thead>
<tr>
<th>Subset of Photon triggers</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>g200_etcut , g120_loose</td>
<td>Very high pT photons, Z’</td>
</tr>
<tr>
<td>g30_g20_medium</td>
<td>H→γγ</td>
</tr>
<tr>
<td>g20_xe60, 3g15_loose</td>
<td>SUSY</td>
</tr>
</tbody>
</table>

**Stability:**

3 major trigger menu updates in 2 years
Primary triggers - always in

**Flexibility:**

Small weekly updates to menu
Tune prescales during LHC fill
Trigger Performance

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Efficiency vs transverse energy

Optimal distribution of available bandwidth is driven by physics requirements and priorities. Most bandwidth is given to the most generic triggers. Special data is recorded at low pileup: MinBias data at low pT jets for calibration, and low pT b-physics triggers and low pT jet triggers (for SUSY, boosted objects searches). See talk by D. Damazio.
LHC luminosity

2010-2011 - 5 orders increase in instant luminosity

2012 - doubled instant luminosity and pile-up conditions

Design values

\[ L = 1 \times 10^{34} \]

\[ \langle \mu \rangle = 25 \]

Pileup \( \langle \mu \rangle \): many overlapping interactions

Typical event \( \langle \mu \rangle = 20 \)
2012 challenges

- High Pile-up:
  - pile-up dependent variables revised and replaced
  - rolling upgrade of TDAQ system [more powerful hardware], rebalancing of L2/EF farms; improvement in software

- Higher instant luminosity → higher rate
  - higher thresholds
  - isolation requirements
  - tighter requirements, separation on signal and (prescaled) background triggers
  - using MultiVariant observables
  - topological selection at HLT
  - send some data (jets, Bphysics) to delayed stream
Fighting pile-up: MET triggers

One of the examples:
controlling MET trigger rate
1) tightening hardware thresholds
2) improving trigger MET software

Better L2 Algorithm

See talk by D. Damazio
Move offline cuts to trigger

Electron trigger

2011 data were used to prepare pile-up stable offline selections
2012: use them at trigger

Retuned electron ID
No energetic tracks around

Consider only tracks close to IP

2012 p-p Collision Data \( \sqrt{s} = 8 \text{ TeV} \)

\[ \int \! dt = 4.1 \text{ fb}^{-1} \]

Honorary mention: 2011 - 2012

IEEE-NSS 2013: ATLAS Trigger

Olya Igonkina
Towards Run II

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**Parameter** | **$E_{cm}$ [TeV]** | **# of bunches** | **Bunch separation [ns]** | **Peak lumi. [cm$^{-2}$s$^{-1}$]** | **Pile-up** | **Event size**
--- | --- | --- | --- | --- | --- | ---
Run 1 | 8 | 1380 | 50 | $\sim 7 \times 10^{33}$ | $\sim 35$ | $\sim 1.5$ MB
Run 2 | $\sim 13$ | 1380 - 2700 | 25 - 50 | $1.5 - 2 \times 10^{34}$ | up to 80 | 1.7 - 2.1 MB

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Excellent for physics, tough for trigger!
Trigger solutions

L1:

- Increase L1 rate to 100 kHz (75kHz in 2012)
- Double number of L1 items (256 in 2012, unlimited at HLT)
- Install L1 topological trigger
- Reduce rate in L1 muon (TGC logic); Increase efficiency (more RPCs)

HLT:

- Bring in FTK (fast hardware tracking)
- Merge L2 and EF into same nodes – less shipping of data
- More offline algorithms online
- Speed up code
- Increase output rate from 300Hz to 1kHz

Keep focus on physics!
New L1 hardware for topological cuts

**Example : using $\Delta\eta$ cut for $H\rightarrow\tau\tau$**

![Graph showing $\Delta\eta$ cut for Higgs]

**Example : using $\Delta\phi$ cut for Higgs from Vector Boson Fusion**

![Graph showing $\Delta\phi$ cut for Higgs]

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IEEE-NSS 2013: ATLAS Trigger
Fast TracKing

New hardware reconstructing tracks using hit LookUp Table to be installed during Run 2

Full tracking information in 40μs!

To compare with offline reco: 20 s @ 60 pileup events
Single lepton thresholds have to increase, but

Move from simple to complex objects

Move offline selections to online; HLT to L1

Move from “standard physics” to discoveries

Example: change in main electrons items

<table>
<thead>
<tr>
<th></th>
<th>Run I</th>
<th>Run II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single electron</td>
<td>$p_T &gt; 24$ GeV, medium, isolated OR $p_T &gt; 60$ GeV, medium</td>
<td>$p_T &gt; 28$ GeV, tight, isolated OR $p_T &gt; 60$ GeV, medium</td>
</tr>
<tr>
<td>Double electron</td>
<td>$p_T &gt; 12$ GeV, loose</td>
<td>$p_T &gt; 17$ GeV, loose</td>
</tr>
<tr>
<td>Electron + missing ET</td>
<td>$p_T &gt; 24$ GeV, medium + MET(EF) &gt; 30 GeV</td>
<td>$p_T &gt; 24$ GeV, medium, iso + MET &gt; 100 GeV</td>
</tr>
<tr>
<td>Electron + muon</td>
<td>$p_T(e) &gt; 12$ GeV + $p_T(\mu) &gt; 8$ GeV</td>
<td>$p_T(e) &gt; 17$ GeV + $p_T(\mu) &gt; 12$ GeV OR $p_T(e) &gt; 7$ GeV + $p_T(\mu) &gt; 24$ GeV</td>
</tr>
<tr>
<td>Background</td>
<td>fraction of $p_T &gt; 24$ GeV, medium, non-isolated</td>
<td>fraction of $p_T &gt; 24$ GeV, tight, non-isolated</td>
</tr>
<tr>
<td>Electron + jets</td>
<td></td>
<td>$p_T(e) &gt; 24$ GeV, iso + 4 $p_T(jet) &gt; 45$ GeV OR $p_T(e) &gt; 45$ GeV, iso + $p_T(jet) &gt; 30$ GeV</td>
</tr>
</tbody>
</table>
Conclusions

- The ATLAS trigger operated successfully in Run I, far beyond nominal design
  - Lots of operational experience, stability,
  - High performance, efficiencies measured on data, high flexibility
  - High pile-up LHC condition require pile-up safe algorithms
    - which can and are being deployed
- Preparing for new LHC challenge in Run II
  - Much more physics to come
  - More elaborate trigger system, both at hardware and software levels
    - new L1 topological selection
    - new fast tracking hardware system
    - new software algorithms and more complex trigger menu
- Even more challenging Run 3 ahead: more in “ATLAS Phase 1 TDAQ TDR”

Focus on physics