Performance and evolution of the ATLAS TDAQ system with $pp$ collisions at 7 TeV

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Introduction

• ATLAS Trigger & DAQ (TDAQ) system
  • System architecture
  • TDAQ operation in 2011

• Trigger performance
  • Challenges for the trigger
  • Signatures and performance
  • Improvements for 2012 data-taking

• Conclusion
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
ATLAS Trigger and DAQ system

- **Three level trigger system**
  - **Level-1**
    - Hardware-based trigger using calorimeter and muon detectors
    - Triggers the readout from the frontend electronics
    - 40 MHz → ~65 kHz
  - **Level-2**
    - Process data in Regions of Interest (RoIs) or other subset
    - ~65 kHz → ~5.5 kHz
  - **Event Filter**
    - Runs after the full event building
    - ~5.5 kHz → ~400 Hz
  - Events are written out into “streams” based on the trigger

**Design values**

- Level 1: ~2.5 μs
- Level 2: ~40 ms
- Event Filter: ~4 sec
- High Level Trigger: ~200 Hz
- ATLAS Event: 1.5 MB/25 ns
- ReadOut System: 112 (150) GB/s
- ~300 MB/s
- Data Collection Network: ~4.5 GB/s
- Event Builder: ~300 MB/s

Rol = Region(s) of interest: (η, φ)
High Level Trigger (HLT, =L2+EF)

- Step-wise execution of several algorithms
  - Algorithms calculate physical quantities from event data (Object reconstruction)
  - Separate algorithms apply selection criteria
    - If the object fails, stop the proceeding steps
- Most trigger selections run in the RoI-based mode at both L2 and EF

- Example: (execution steps in the electron trigger)
  - Step 1: Requests data from the calorimeters and checks the quality of the EM cluster
  - Step 2: Requests data from Inner Trackers and checks the quality of the electron candidate
  - If the selection fails at step 1, step 2 is not executed which reduces the execution time and data access rates
Data-taking in 2011/2012

- **2011 data-taking**
  - $\sqrt{s}=7$ TeV, 50 ns bunch spacing
  - $\mathcal{L} \sim 3.7 \cdot 10^{33}$ cm$^{-2}$s$^{-1}$, $\int \mathcal{L}dt \sim 5$ fb$^{-1}$
  - Continuous increase of the instantaneous luminosity ($2 \cdot 10^{32} \rightarrow 3.7 \cdot 10^{33}$ cm$^{-2}$s$^{-1}$) required improvements in the trigger selection to keep rates under control
  - Overall TDAQ efficiency: 94.9%
  - 2.7 PB of data recorded (4.7 M files)

- **2012 data-taking**
  - $\sqrt{s}=8$ TeV, 50 ns bunch spacing
  - $\mathcal{L} \sim 6.6 \cdot 10^{33}$ cm$^{-2}$s$^{-1}$, $\int \mathcal{L}dt \sim 4$ fb$^{-1}$ so far
  - Increased beam intensity
    - $\rightarrow$ Higher pile-up condition
      (additional $pp$ interaction per bunch crossing)
TDAQ operation in 2011 (1)

**L1, L2, EF rates in pp collision**
- High L1 trigger rate
- System was stressed in terms of bandwidth and data flow
- Operate at the margin to get the most out of the system

**Trigger rates in heavy ion collision**
- Low L1 trigger rate (<10 kHz)
- Large event size and complex processing at the HLT
- System was stressed in terms of computing power

Successful data-taking in both types of runs
TDAQ operation in 2011 (2)

- Evolution of the trigger selections
- DAQ system capability
  - Requirement on DAQ resources depends on the trigger menu
  - HLT farm increased by ~50% (16 new racks) in 2011
  - L2/EF sharing of XPU racks is configurable run by run

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</table>

(12 new racks replaced 16 old ones in 2012)
Readout System (ROS)

- Serves detector data fragments to L2 algorithms and Event Builder
- Performance can be limited by access rate, load or bandwidth
  - L2 algorithms must be aware of the limits
- Rolling replacement of old ROS PCs (75/153)
Challenges for trigger selections

• Luminosity increase
  • \( L = 2 \times 10^{32} \rightarrow 3.7 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1} \) in 2011 (6.5 \( \times 10^{33} \text{ cm}^{-2}\text{s}^{-1} \) in 2012)

• Pile-up condition
  • Average number of pile-up events \( \langle \mu \rangle : 8 \rightarrow 12 \) (~30 in 2012)
  • Need to understand the impact of pile-up on each trigger

• Physics requirements
  • Despite harsher operational conditions, a lot of pressure to increase the acceptance of the analysis

• Rate reduction at all three trigger levels
• Developments in the TDAQ system to overcome technical implementations
• Efficiency vs. rate with tighter selection criteria
Trigger signatures

Calorimeter-based triggers
• Electron/Photon
• Tau (Hadronic tau decay)
• Jet / b-jet
• Missing transverse energy
• Transverse energy sum
• Missing $E_T$ significance

Muon-based triggers
• Muon
• B-physics triggers

Combined triggers
• Require more than one signature in the event (e.g. lepton+ $E_T^{miss}$)
• Topological cuts on combination of objects (angular correlation, invariant mass cut, etc.)
Impact of pile-up on TDAQ resources

- CPU usage and event size increases with higher pile-up
  - Linear dependence is observed so far
  - Expect up to 1.65 MB/event at peak luminosity (at $<\mu>=35$)
  - Additional bandwidth to the storage system to meet the peak demand
Electron and photon triggers

- Electron triggers evolved in order to keep rates under control
  - L1 threshold tuning: 14 $\rightarrow$ 16 GeV and apply $\eta$-dependent thresholds
  - Hadronic leakage cut at L1
  - Tighter selection at the HLT
- Photon triggers stable for most of the year
- Re-optimized identification cuts for 2012
  - Robustness against pile-up
## Tau triggers

- Selects hadronically decaying tau lepton
  - Di-tau, tau+electron, tau+muon
  - $\tau + E_T^{\text{miss}}$
- Improvements for 2012 data-taking
  - Re-optimized selection cuts in order to be robust against pile-up
  - Multi-variate techniques (Boosted Decision Tree, Log likelihood) as used in offline identification
Jet

**ATLAS Preliminary**

Data 2011

- **Efficiency**
  - **Offline Jet $E_T$ [GeV]**
  - **Efficiency**
  - **ATLAS Preliminary**
  - **Data 2011**
  - **anti-$k_T$ $R=0.4$**
  - $|\eta_{\text{Jet}}|<2.8$
  - L1 Jet $E_T > 50$ GeV
  - L2 Jet $E_T > 70$ GeV
  - EF Jet $E_T > 75$ GeV

- **Normalised entries**
  - **ATLAS Preliminary**
  - **Data 2011**
  - **Trigger run offline**
  - **pp $\sqrt{s} = 7$ TeV**
  - **Efficiency**
  - **Normalised entries**
  - **L1 (0.2×0.2 towers)**
  - **L1.5 (0.2×0.2 towers)**
  - **L1.5 (0.1×0.1 towers)**
  - **L2 (all cells)**

- **Jet Efficiency**
  - **Jet Efficiency**
  - **Jet Efficiency**

**L2**

- **EF jets**

- **Rol-based algorithm on cells or full scan using L1 trigger towers (L1.5 jet)**

- **Anti-$k_T$ (FastJet) jets or cone jets**

- **Full scan using offline algorithms. Topological cluster as the input**
B-jet

- B-tagging using secondary vertex and the lifetime information
- Improvements in 2012
  - Better primary vertex reconstruction
  - Make use of new features in the HLT jet trigger
**Missing $E_T$**

- Most sensitive trigger to pile-up events
  - Measurement is done in a large area (full detector coverage)
- New developments done for 2012
  - TDAQ upgrade to calculate $E_T^{\text{miss}}$ at L2 (Update in the ROS software and calorimeter data format to readout calorimeter summary info)
  - 50% improvement in resolution, a factor $\sim 5$ rejection at L2
  - Possible to use topological cluster at the EF $\rightarrow$ better resolution

$E_T^{\text{miss}}$ significance: $E_T^{\text{miss}}/\sigma(E_T^{\text{miss}})$

$E_T^{\text{miss}}$ vs $\sum E_T$

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**ATLAS Trigger Operations**

- $\mathcal{L} = 7$TeV (Apr. 15, 2012)
  - 12 trains, 50ns [1051 bunches]
  - 9 trains, 50ns [423 bunches]
- $\mathcal{L} = 7$TeV (Oct. 25, 2011)
  - no trains [10 bunches]
Muon trigger

- L1 muon trigger
  - 2-station coincidence at 75 ns ($p_T > 10$ GeV)
  - 3-station coincidence at 50 ns ($p_T > 11$ GeV)
- Two types of algorithms at the HLT
  - Outside-in tracking
  - Inside-out tracking

\[ \text{Efficiency} \]

\[ \text{Entries / 30 ms} \]

\[ \text{Time [ms]} \]

\[ \text{ATLAS Preliminary} \]

\[ \text{Data 2011 $\sqrt{s} = 7$ TeV} \]

\[ |\eta| < 1.05 \]

\[ \text{L1_MU10 (2-station coincidence)} \]

\[ \text{L1_MU11 (3-station coincidence)} \]

\[ \text{EF outside-in: mean = 267 ms} \]

\[ \text{EF inside-out: mean = 1119 ms} \]
Low $p_T$ muon and B-physics triggers

- Di-muon triggers with invariant mass cuts
  - $p_T>4$ GeV
  - $B \to J/\Psi(\to \mu\mu) + X$
  - $B \to \mu\mu$

Changes in 2012
- New L1 di-muon trigger requiring at least one or both muons in the barrel region (effort to keep 4 GeV threshold)
Conclusion

• ATLAS TDAQ system operating successfully in 2011 and 2012 data-taking
  • LHC condition: $L=6.6 \text{ cm}^{-2}\text{s}^{-1}$, 30 pile-up events per crossing

• DAQ operation
  • Good performance for both pp and heavy ion collisions
  • Linear increase of CPU usage and data size against pile-up

• Trigger performance
  • Fully exploiting the system capability at all three levels
  • Selections were tightened in all signatures
  • Improvements for robustness against higher pile-up conditions for 2012 data-taking
Backup slides
L2 algorithm and the Readout System (ROS)

Readout Systems (ROS)
- Readout buffers hosted on PCs
- Respond to RoI data requests from L2 algorithms
- Also serve data to the Event Builder
- Performance can be limited by access rate, bandwidth and load