The upgraded ATLAS Trigger and DAQ system for the second LHC run

Kevin Black
Boston University
on behalf of the ATLAS collaboration
ATLAS Experiment

- ATLAS covers a huge breath of physics topics that consists of many different types of final state topologies
  - b-physics, W and Z, top quark, Higgs boson, SUSY and exotic searches
- Many orders of magnitude between total pp cross-section and physics of interest
- Must deal with additional pp interactions from the same bunch crossing (in time pile-up) and other bunch crossings (out of time pile-up)
ATLAS Detector

- Muon Detectors
- Tile Calorimeter
- Liquid Argon Calorimeter
- Toroid Magnets
- Solenoid Magnet
- SCT Tracker
- Pixel Detector
- TRT Tracker
Trigger and DAQ

- Data Acquisition System (DAQ)
  - gather the data information from the front end electronics from the detector
  - puts the data from all the different detectors together and builds individual events
  - Stores the data to be sent to permanent storage
  - provides control, configuration and control
- Trigger
  - Multi-tiered system that decides which events to record
Environment Changes

- Rate increases by \(~5\)
  - \(~x\ 2\) for increase in energy
  - \(~x\ 2-3\) for increase in luminosity
- Additional pp interactions from the same bunch crossing (in time pile-up) and other bunch crossings (out of time pile-up)
DAQ and Trigger Evolution

- Run 1 - Three level system
  - Level 1- Custom Hardware utilizing calorimeter and muon spectrometer data looking for ‘regions of interest’ (ROI) to base L1 decision and examine in more detail
  - Level 2- fast software processing data in ROI (projective tower in \( \eta \) and \( \phi \))
  - Event Filter (EF) - close to offline reconstruction driven by ROI but with possibility of examining the full event
DAQ and Trigger Evolution

- Run 2- Two level system
- Level 1- Similar to Run 1 but with many upgrades
- Merged L2/EF in single CPU farm to take advantage of common tools and results from L2 in final stage

<table>
<thead>
<tr>
<th>Stage</th>
<th>Functionalities</th>
<th>Components</th>
<th>Latency</th>
<th>Rate reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level-1 (L1)</td>
<td>Fast custom-made electronics finds regions of interests using Calorimeter/Muon data with coarse info</td>
<td>L1Calo, L1Muon, L1Topo, Central Trigger Processor</td>
<td>&lt; 2.5 µs</td>
<td>40 MHz → 100 kHz</td>
</tr>
<tr>
<td>High-Level Trigger (HLT)</td>
<td>Fast algorithms in Rol, or offline-like ones with full-event info on PC farm</td>
<td>(FTK,) HLT farm (average)</td>
<td>~0.2 s (average)</td>
<td>→ 1 kHz</td>
</tr>
</tbody>
</table>
Level 1 Trigger

- Level 1

- Central Trigger processor issues L1 trigger decision based on inputs from L1 calorimeter trigger, L1 muon central trigger processor, forward detectors, and (run 2) the L1 topological trigger.

- MuCPTI sends muon candidates (6 $P_T$ thresholds) from the endcap and barrel on detector trigger electronics.

- Calorimeter Trigger finds electron, photon, tau, jets, as well as sum $E_T$ and missing $E_T$ passing candidates to the central trigger processor.
L1 Muon Improvements

- L1 trigger formulated by Resistive Plate Chambers (RPC) in barrel, and Thin Gap Chambers (TGC) in endcaps

- L1 rates were dominated by low $P_T$ particles produced in the end-cap toroid or cryostat from particles not associated with hard scattering from proton-proton collision of interest

- Run 2 has several improvements to reduce the endcap rates
L1 Muon Improvements

- Options to reduce rates for Run 2
  - Reduce rate in endcaps by requiring coincidence with tile-calorimeter and additional coincidence with inner wheel TGC
  - Exclude zero-field region (reduction of < 5% acceptance)
- Increased acceptance in barrel (~4%) by additional RPC chambers in feet region (being commissioned)
L1 Calorimeter

- 3 main components

- Pre-processor that digitizes analogue inputs, identifies bunch crossing, and channel by channel calibration

- Cluster processor - sliding window algorithm for electron, photon, and tau candidates

- Jet processor - selection of jet candidates, calculation of energy sums, missing energy calculation

- new Multi Chip Module in preprocessor

  - dynamic pedestal subtraction for pileup (huge reduction in missing transverse energy trigger rates)
L1 Topological Trigger

- In Run 1, L1 triggers could be single item or logical AND of two items but could not use detailed properties to combined items.

- In Run 2, a topological processor has been introduced. This allows topological properties of the event to be calculated from Calorimeter and Muon processor.
Central Trigger Processor Improvements

- Increase in inputs (160 -> 320) inputs + 192 for L1 Topological trigger and forward detectors
- 256->512 trigger items at L1
- Increased Latency from addition of L1 topological trigger saved by direct input into CTP core processing
- Improved monitoring and web based configuration
FTK

- L1 does not use inner detector (huge number of channels and time consuming tracking)
  - Run 1 - tracking done at L2 software driven by region of interest found by L1 calorimeter or muon trigger
  - Run 2 - dedicated hardware to prepare tracks for HLT for full detector
    - saves most time consuming part of Run 1 CPU consumption at L2
    - tracks of $P_T > 1$ GeV for full detector

First Slice Integrated in the Fall 2015 - full detector Fall 2016
FTK approach: pattern recognition

1. Given a collection of hits in an event, we gang them together to form coarse “superstrips” – about 1 mm wide.

2. Build a pre-calculated lookup table of all coarse paths (“patterns”) that a charged track might take through the tracking layers. For full ATLAS detector, we expect about 1 billion such patterns.

3. Load these patterns into specialized hardware – Associative Memories – that can simultaneously compare the event with ALL stored patterns and quickly return only those that match.
**DAQ Upgrade**

<table>
<thead>
<tr>
<th>Links</th>
<th>3</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Memory per link (MB)</td>
<td>64</td>
<td>682</td>
</tr>
<tr>
<td>Output Bandwidth (MB/s)</td>
<td>266</td>
<td>1600 (3200 possible)</td>
</tr>
<tr>
<td>Max Input Bandwidth (MB/s)</td>
<td>480</td>
<td>2400</td>
</tr>
</tbody>
</table>

- New Read Out System (ROS) with new CPU and readout cards
- 4 times greater link density from front end to CPU farm
- 40 GbE data connection to each PC
- In Run 1 - two data flow networks for L2/EF merged to one data flow network for merged HLT
Improvements at HLT

- Merger of HLT CPU means dynamic resource sharing

- Still have algorithmically different stages can share common software and results between L2+EF (i.e. skip combinatorial tracking and refine tracks at EF stage)

- where possible HLT code utilizes offline code to improve performance and minimize duplication

- See Ben Sowden’s talk for details of tracking code improvement

<table>
<thead>
<tr>
<th>Signature</th>
<th>HLT Reconstruction methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tracking</td>
<td>FastTracking + offline tracking</td>
</tr>
<tr>
<td>E/gamma</td>
<td>FastTracking + offline tracking + LH/cut-based ID</td>
</tr>
<tr>
<td>Muon</td>
<td>Fast muon reco (L2MuonSA) + offline reco (3rd chain)</td>
</tr>
<tr>
<td>Jets</td>
<td>Topo-clusters, AntiKt</td>
</tr>
<tr>
<td>MET</td>
<td>Topo-clusters (no track correction)</td>
</tr>
<tr>
<td>Taus</td>
<td>Calo-based preselection, tracking, BDT ID</td>
</tr>
<tr>
<td>b-jets</td>
<td>offline b-tagging</td>
</tr>
</tbody>
</table>

ATLAS Preliminary Simulation

- Full Scan $<\text{time}> = 98.1$ ms
- Partial Scan ($1\times1$) $<\text{time}> = 6.3$ ms
- Partial Scan ($1\times1.5$) $<\text{time}> = 9.7$ ms

Events / 20 ms

Cell clustering time per event [ms]
First Results
Summary

• Many new additions to ATLAS TDAQ as well as merged HLT

• Critical improvements have been added to keep bandwidth under control with increased rejection and use of topological information

• Taking data successfully and ready for increased luminosity

• Run 1 had a long commissioning time - Run 2 is starting fast with high instantaneous luminosity expecting soon at 13 TeV
Backup
L1 Calorimeter Improvements

- new Multi Chip Module in preprocessor
  - dynamic pedestal subtraction for pileup (huge reduction in MET rates)
- improved jet energy resolution
- New Merger Module
  - input to L1 topological trigger
  - increase # of thresholds by x2
FTK approach: track fitting

4. Restore full-resolution hits inside each matched pattern.

Ultimately, we need to create a list of tracks with:
- $\chi^2$ (track quality)
- Curvature ($\sim 1/p_T$)
- Phi
- Impact parameter, etc

5. Because our patterns are narrow, we have very few hits inside of them. The remaining combinatorial problem can be solved via the brute-force method – i.e., trying out every combination.

6. For each combination, perform a linearized fit to arrive at final track parameters. Since these fits involve only scalar products, they can be performed VERY quickly in modern FPGA chips: 1 fit / ns

This pattern has two combinations:

Finally, we apply a $\chi^2$ cut to remove bad tracks, perform duplicate removal, and send all final tracks to LVL2 trigger.