ATLAS Jet Trigger Update for the LHC Run II

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On behalf of the ATLAS Collaboration

LIP - Lisbon
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20-24 April 2015
Introduction: The Large Hadron Collider (LHC) at CERN

- Circular accelerator with 27 km perimeter
- Proton-proton collider
  - Can also collide heavy ions

<table>
<thead>
<tr>
<th>Run-1</th>
<th>Maintenance</th>
<th>Run-2</th>
<th>...</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>2012</td>
<td>2013</td>
<td>2014</td>
</tr>
</tbody>
</table>

During Run-1

<table>
<thead>
<tr>
<th>Centre of mass energy</th>
<th>7 TeV to 8 TeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bunch spacing</td>
<td>50 ns</td>
</tr>
<tr>
<td>Interactions per bunch crossing</td>
<td>20</td>
</tr>
<tr>
<td>Peak luminosity</td>
<td>$0.7 \times 10^{34}$ cm$^{-2}$s$^{-1}$</td>
</tr>
</tbody>
</table>

For Run-2

<table>
<thead>
<tr>
<th>Centre of mass energy</th>
<th>13 TeV to 14 TeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bunch spacing</td>
<td>25 ns</td>
</tr>
<tr>
<td>Interactions per bunch crossing</td>
<td>$\sim 43$</td>
</tr>
<tr>
<td>Peak luminosity</td>
<td>$1.6 \times 10^{34}$ cm$^{-2}$s$^{-1}$</td>
</tr>
</tbody>
</table>

ATL-DAQ-PROC-2014-032
Introduction: The ATLAS experiment

Multi-purpose experiment designed to probe the Standard Model and search for new physics at very high energies

**Muon Spectrometer:** $|\eta| < 2.7$
Air-core toroids and gas-based muon chambers
$\sigma/pT = 2\% @ 50\text{GeV}$ to $10\% @ 1\text{TeV}$ (ID+MS)

**EM calorimeter:** $|\eta| < 3.2$
Pb-LAr Accordion
$\sigma/E = 10\%/\sqrt{E} \oplus 0.7\%$

**Hadronic calorimeter:**

- $|\eta| < 1.7$ Fe/scintillator
- $1.3 < |\eta| < 4.9$ Cu/W-Lar
$\sigma/E_{\text{jet}} = 50\%/\sqrt{E} \oplus 3\%$

**Inner Tracker:** $|\eta| < 2.5$, $B = 2\text{T}$
Si pixels/strips and straw detector
$\sigma/pT = 0.05\% pT (\text{GeV}) \oplus 1\%$

- $10^8$ electronic channels
- $1.6 \text{ MB per event (64 TB/s)}$
- 3-level trigger reducing $40\text{ MHz}$ collision rate to $400 \text{ Hz}$ of events to tape
Jet: Spray of collimated particles

- Initiated by quarks or gluons
- Most common high $p_T$ objects produced at the LHC
  - Important for a wide range of physics analyses
- The energy deposits are aggregated by the reconstruction algorithms and calibrated to provide the jet momentum measurement
The ATLAS Trigger and DAQ systems: Run-1

- Reduce the accepted events by a factor of $10^5$
  - Most interesting physics have small cross-section relative to total p-p cross-section
  - Limited bandwidth to disk data storage

Run-1:

Organized in 3 levels:
- **L1**: Hardware based
  - Coarse granularity.
  - Finds high $p_T$ objects positions
  - Provides seeds for next levels
- **L2**: Software based
  - Full granularity
  - Regions of interest based
- **EF**: Software based
  - Offline like algorithms
  - Can access the full event

- L2 and EF in different farms
  - Extra data transfer

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The ATLAS Trigger and DAQ systems: Run-2

- Improve the trigger capability for Run-2
  - Better exploit available computing capacity and output rate from the HLT
  - New L1 topological processor and fast tracking at HLT:
    - will allow angular and mass jet selection and rejection of pileup jets
  - Improved data flow architecture
    - L1 output rate raised to 100 kHz (increased energy and luminosity)
    - L2 and EF merged; 250 ms to take a decision for jets
    - Read Out System upgrade; bandwidth increase 10x, memory per channel 5x
Jet trigger: Run-1

- Selects events containing high $p_T$ hadronic jets

Typical chain for single Jet trigger

- **L1:**
  - Sliding window algorithm
  - Calorimeter towers (trigger towers)

- **L2:**
  - Readout Regions of Interest
  - Simple cone algorithm
  - Cells as constituents

- **EF:**
  - Full calorimeter scan
  - Offline algorithms available

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ATLAS Jet Trigger

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Run-1 Jet trigger efficiency:

- The ATLAS jet trigger demonstrated excellent performance throughout Run-1
- EF turn-on curves considerably steeper than corresponding L1 curves
  - Improved $E_T$ resolution, compared to the offline reconstructed jets
  - Monte Carlo simulates the data well

Efficiency turn-on curves for various single inclusive jet triggers

Naming convention: L1_jX and EF_jX, where X is the $E_T$ trigger threshold in GeV
Jet trigger: Run-2

- Selects events containing high $p_T$ hadronic jets

Typical chain for single Jet trigger

- **L1:**
  - Sliding window algorithm
  - Calorimeter towers (trigger towers)

- **HLT** generic jet chain:
  - Prepare detector data (Cell unpacking)
  - Process cell Clustering and Jet maker
  - Evaluate the event (Hypothesis)

Topological Clustering algorithm:

- Iterative 3D calorimeter cell clustering
  - based on signal/noise
- Applies noise suppression
- Most time-demanding step

Jet reconstruction uses $Anti-k_\perp$ algorithm [1]

- Fast, collinear and infrared safe and regular shape algorithm

Jet trigger: Run-2

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Jet event rate increase by a factor of five
  - higher energy, luminosity and pileup
- Better exploit available computing capacity
  - HLT algorithms optimization
  - Data reduction through the use of a partial calorimeter readout scheme
## Algorithm optimization

- The cell unpack and retrieval time was reduced by a factor of 7
  - More efficient full calorimeter readout
- The cell clustering time was reduced by a factor of 2
  - Pre-fetching, code inlining and the introduction of more efficient data structures

![Graph showing time improvements over software releases](image-url)
**Data reduction: Partial calorimeter readout scheme**

- Reads at once all the cells around the L1 positions, removing any overlap
- Works as a full calorimeter readout with low activity regions suppression
  - zero-suppressing algorithm
- Increases system flexibility to adapt to different requirements

![Graph showing ATLAS Preliminary Simulation results]
**Partial Scan:** Data and processing time reduction

- The Partial Scan reads out 3.5 to 7% of the calorimeter cells.

- The cell clustering in the Partial Scan takes 6 to 10% of the time required by the complete calorimeter processing.

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**ATLAS Preliminary Simulation**

- **Full Scan**
  - <no. cells> = 187652
  - <time> = 98.1 ms

- **Partial Scan (η×φ=1x1)**
  - <no. cells> = 6489
  - <time> = 6.3 ms

- **Partial Scan (η×φ=1.5x1.5)**
  - <no. cells> = 13392
  - <time> = 9.7 ms

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**ATLAS Jet Trigger**

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Partial Scan: Comparing partial to full reconstruction

- The full calorimeter readout gets the best resolution
- The $E_T$ of the most central jet differs by less than 0.5% from full scan trigger jets, for jets above 100 GeV
Conclusions:

- The jet trigger has shown excellent performance during the first data taking.
- The ATLAS TDAQ introduced important improvements to better exploit Run-2:
  - Significant optimizations were achieved during shut-down:
    - Cell unpacking becomes seven times faster.
    - Cell clustering processing time was reduced by a factor of two.
  - A partial calorimeter readout scheme was developed:
    - Zero-suppressing algorithm that filters the low activity regions.
    - Speeded up jet reconstruction by a factor of 10 without much loss of physics performance.
- The ATLAS jet trigger will collect crucial data to calibrate the detector and allow many unique physics measurements. We are ready to face the challenges of the LHC Run-2!
Thank you!
Backup slide: Topological Cluster