ATLAS Jet Trigger Update for the LHC Run II

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Ann Arbor, Michigan
2015-08-05
Outline

- ATLAS experiment at the LHC
- ATLAS Trigger & Jet Trigger
- Run I Jet Trigger Design & Performance
- Run II Jet Trigger Improvements & Performance
- Projected Jet Trigger Features
During 2013-2014, LHC was undergoing maintenance and upgrade to increase its energy, luminosity and bunch frequency (and pileup):

- Gives rise to a new physics environment for the detectors
- Factor 5x higher rate of interesting events is expected in Run II compared to Run I.
- **Trigger challenge**: Recording higher production of interesting events while maintaining good efficiency at low energy
- Higher output rate and latency are required from the trigger

Pseudorapidity: \( \eta = -\ln \tan \frac{\theta}{2} \)
ATLAS Trigger

Level 1 (L1): Hardware-based with coarse input granularity
- Finds position in eta and phi of high energy deposits (Region-of-Interest) and passes it to L2

Level 2 (L2): Software-based with fine input granularity around the Region-of-Interest

Event Filter (EF): Software-based with access to fine input granularity over the whole detector

Most notable upgrades:
- L1 output rate: 75 kHz → 100 kHz
- Recording rate: 400 Hz → 1 kHz
- Increased number of processors
- Upgraded readout system
- Redesigned dataflow network

L2 and EF merged into the High-Level Trigger (HLT)
- Runs on the same node all software algorithms
- Avoids repacking and unpacking the data between L2 and EF, saving time
- Can share resources between fast and detailed processings
ATLAS Jet Trigger

- The LHC is a hadron collider, coloured particles are the most prevalent high-energy objects
  - Seen as a collimated spray of particles, a jet
    - Detected as energy deposits in the calorimeters
  - Essential for QCD analyses and new physics searches to trigger on them with high performance
  - The main backgrounds are
    - Pileup jets at low energy
    - Non-collision jets at high energy

The ATLAS jet trigger main selection criteria are

- the transverse energy of a single jet
  e.g. j60 (one jet with $E_T > 60$ GeV)

- the transverse energy of multiple jets
  e.g. 4j100 (four jets with individually $E_T > 100$ GeV)

- the sum of the $E_T$ of all the jets in the event
  e.g. ht1000 ($H_T > 1000$ GeV)

- topological triggers, requiring angular separation

Complementary criteria, "jet cleaning", to remove non-collision jets
Run I Jet Trigger Algorithms

**Input to jet reconstruction algorithms**

**Trigger towers:**
- In an angular region, merges energy of all cells
- **Used at L1:** 0.2 x 0.2 in η x φ
- **Used at L2:** 0.2 x 0.2 over the whole calorimeters (L1.5)

**Cells**
- **Used at L2**

**Topological clusters (topoclusters):**
- 4-2-0 noise-suppressed 3-dimensional clusters
  - starts with a cell with signal to noise ratio greater than 4
  - adds all neighbouring cells with signal to noise ratio greater than 2
  - then adds all neighbouring cells
- **Used at EF**

**Jet reconstruction algorithms**

**L1 (latency: 2.5 µs):**
- 0.8 x 0.8 sliding window

**L2 (latency: 75 ms):**
- 3-iteration cone algorithm with R = 0.4
- anti-kT algorithm with R = 0.4 (L1.5)

**EF (latency: 1 s):**
- anti-kT algorithm with R = 0.4

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Jet Window (0.8 x 0.8)

Region Of Interest

Jet Element (0.2 x 0.2)

Trigger Tower (0.1 x 0.1)

\[
d_{ij} = \min \left( \frac{1}{k_{T_i}^2}, \frac{1}{k_{T_j}^2} \right) \frac{\Delta R_{ij}^2}{R^2}
\]

\[
d_{i\text{beam}} = \frac{1}{k_{T_i}^2}
\]
Run I Performance

The ATLAS Jet Trigger had an excellent performance throughout Run I considering the physics goals:

- We can note from the trigger efficiency versus the reconstructed jet transverse energy:
  - Plateau efficiencies are in good agreement with Monte Carlo
  - Curves at L2 and EF steeper than at L1 due to better input resolution
  - Turn-on region shifted wrt the applied threshold
  - Energy shifts between trigger and offline due to different jet calibration
A typical *jet trigger* in the Run II merged system include:
- At L1, running a sliding window algorithm
- At HLT, reading the cell information
- Building topoclusters (*most time-consuming*)
- Running anti-\(k_T\)

With the new readout system, the longer latency after L1 (0.25 s) and the optimization of cell unpacking and clustering allow to **build topoclusters over the whole calorimeters** (**Full Scan**) for every event passing L1:
- Uses best input (noise-suppressed), while avoiding the Region-of-Interest limited acceptance
- Allows to calculate event-level activity and make pileup corrections to the cluster energy
- L2 resources freed to implement more offline features

If building topoclusters over the full detector requires too much time (due to excessive rate), a partial scan of the detector was developed as a backup solution.
Partial Scan is an improvement over Region-of-Interest-based algorithms

- Accesses information limited to Region-of-Interests (with a configurable size), accesses all of them simultaneously (zero-suppressed)
- Avoids processing a deposit in overlapping regions twice
- Uses 3-7% of the total number of cells
- Finds the same number of jets as Full Scan

Good alternative to the more CPU-intensive Full Scan

6-10% of Full Scan
Run II Improvements - New triggers

- **Reclustering jets** in the trigger is possible
  - Takes anti-kt $R = 0.4$ jets as input and runs anti-kt $R = 1.0$ on them
  - Useful for jet substructure studies

- New type of trigger implemented: **datascouting**
  - Does not check for any criteria, few information about all reconstructed jets are saved for every accepted event (bandwidth = data x rate)
  - Only way to probe the exotics low dijet mass region

- Algorithms can process **partially-overlapping eta regions**
  - Decision depends on the order of association of jets and regions

- **For example**
  - Two possible ways of ordering:
    1. **red** doesn't work (because of last pair)
    2. **green** works

<table>
<thead>
<tr>
<th>Jets</th>
<th>Regions</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_T = 45$ GeV; $\eta = -3.0$</td>
<td>$E_T &gt; 25$ GeV; $0 &lt;</td>
</tr>
<tr>
<td>$E_T = 45$ GeV; $\eta = 4.0$</td>
<td>$E_T &gt; 40$ GeV; $2.5 &lt;</td>
</tr>
<tr>
<td>$E_T = 30$ GeV; $\eta = 2.6$</td>
<td>$E_T &gt; 40$ GeV; $2.5 &lt;</td>
</tr>
</tbody>
</table>

- Possible association found with Ford-Fulkerson algorithm [CJM-1956-045-5]
- Physics case: Higgs boson produced via vector boson fusion and with jet decay products
Run II Improvements - Calibration

- **Pileup subtraction**
  - Corrects the jet energy by subtracting the median energy of the event
  - Requires full detector information

- **Origin correction**
  - Corrects direction of the jet from the geometrical center of the detector to the primary vertex
  - Requires full event tracking

- **Jet Energy Scale (JES)**
  - Calibration constants are applied to bring jet energy to Monte Carlo particle jet energy
  - Offline derivation of JES constants from trigger jets themselves

- **Global Sequential Calibration (GSC)**
  - Residual calibration (improving only energy resolution, not average value) derived from global jet properties
  - To be used online: information from last electromagnetic and first hadronic calorimeter layers

- **In-situ calibrations**
  - Residual calibration derived from an energy-balance technique between a jet and a reference object

Shown above is the full calibration chain for offline jets.

**Goal for online:** applying as much of this chain as possible

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Run II Performance

Shown on this slide: anti-$k_T$ $R = 0.4$ full-scan jets with pileup subtraction and JES calibration applied, from run II first week of stable beam data (June 2015)

- The triggers show a great performance throughout the $E_T$ threshold range (j60 to j360)
  - Plateau efficiencies are in good agreement with Monte Carlo
- The triggers show also a great performance throughout the detector acceptance

100% efficiency with only 5 GeV difference

Calorimeters have better resolution in central region
Projected Features

Constant effort to improve the physical and technical performances

› Reimplementing the use of trigger towers as input after L1
  - To be used as backup triggers in case of high-rates

› Reimplementing jet cleaning (complementary trigger selection criteria)
  - Reduces rate of non-collision jets

› Implementing new jet global properties, trigger tracks, in the Global Sequential Calibration
  - Improves energy resolution at low energy

› Implementing jet grooming (characterizing jet substructure)
  - Helps to reduce rate of pileup jets
To cope with the increase of interesting events, the ATLAS Trigger has undergone major upgrades and is now ready for the coming years.

The Jet Trigger took opportunity of the new trigger system to maximize performance, while developing new features:
- New types of triggers
- Better jet calibration

The Run II data allows to assess appropriately the performance of all these improvements:
- Performance on early data confirms the expectations