ATLAS Jet Trigger Update for the LHC Run II

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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.
ATLAS Trigger

Run I

- **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

Run II

- **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
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.

Trigger chain example: L1_j50 → L2_j70 → EF_j75

EF_j75 centred at ~110 GeV, ~30% relative difference.
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 \textit{(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 \textit{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

Large difference at low $E_T$, mitigated by larger Region-of-Interest
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**

<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

Shown above is the **full calibration chain** for offline jets.

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

- **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
Run II Performance

- 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

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)

- 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
Summary

- 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.