Calorimetry triggering in ATLAS

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on behalf of ATLAS TDAQ collaboration

- ATLAS calorimeter
- ATLAS Trigger and DAQ overview
- Triggers for Electrons, Photons, Jets, Taus and Missing ET
- Results from cosmics and technical runs
- Preparation for data taking
ATLAS Calorimeters

- LAr electro-magnetic calorimeter
- LAr forward calorimeter
- LAr and Tile hadronic calorimeters
ATLAS is a multipurpose spectrometer with a multipurpose trigger:

- Electrons
- Photons
- Muons
- Jets
- Missing ET
- Taus

<table>
<thead>
<tr>
<th>Signature</th>
<th>L1 rate (Hz)</th>
<th>HLT rate (Hz)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum bias</td>
<td>Up to 10000</td>
<td>10</td>
<td>Pre-scaled trigger item</td>
</tr>
<tr>
<td>e10</td>
<td>5000</td>
<td>21</td>
<td>$b, c \rightarrow e, W, Z, $Drell-Yan, $t\bar{t}$</td>
</tr>
<tr>
<td>2e5</td>
<td>6500</td>
<td>6</td>
<td>Drell-Yan, $J/\psi, \Upsilon, Z$</td>
</tr>
<tr>
<td>$\gamma 20$</td>
<td>370</td>
<td>6</td>
<td>Direct photons, $\gamma$-jet balance</td>
</tr>
<tr>
<td>$2\gamma 15$</td>
<td>100</td>
<td>$&lt; 1$</td>
<td>Photon pairs</td>
</tr>
<tr>
<td>$\mu 10$</td>
<td>360</td>
<td>19</td>
<td>$W, Z, t\bar{t}$</td>
</tr>
<tr>
<td>$2\mu 4$</td>
<td>70</td>
<td>3</td>
<td>$B$-physics, Drell-Yan, $J/\psi, \Upsilon, Z$</td>
</tr>
<tr>
<td>$\mu 4 + J/\psi (\mu \mu)$</td>
<td>1800</td>
<td>$&lt; 1$</td>
<td>$B$-physics</td>
</tr>
<tr>
<td>j120</td>
<td>9</td>
<td>9</td>
<td>QCD and other high-$p_T$ jet final states</td>
</tr>
<tr>
<td>4j23</td>
<td>8</td>
<td>5</td>
<td>Multi-jet final states</td>
</tr>
<tr>
<td>$\tau 20i + xE30$</td>
<td>5000 (see text)</td>
<td>10</td>
<td>$W, t\bar{t}$</td>
</tr>
<tr>
<td>$\tau 20i + e10$</td>
<td>130</td>
<td>1</td>
<td>$Z \rightarrow \tau \tau$</td>
</tr>
<tr>
<td>$\tau 20i + \mu 6$</td>
<td>20</td>
<td>3</td>
<td>$Z \rightarrow \tau \tau$</td>
</tr>
</tbody>
</table>

Table 64. Subset of items from an illustrative trigger menu at $10^{31}$ cm$^{-2}$ s$^{-1}$.

All but muon and B-physics triggers are Calorimeter based triggers.
LHC bunch crossing 40 MHz

- ~23 interaction/bunch at high luminosity
  - ATLAS raw event size is ~ 1.5MB (140M channels)
    - if every event is stored - ~50 TB/sec
- The design output rate is 200 Hz which is limited by storage capacity

Have to achieve more that $10^5$ rejection at trigger level
**Trigger Challenge**

**Level 1:** Coarse calorimeter data and muon trigger chambers

- 40 MHz, 1 PB/sec
- 75 kHz, >100 GB/sec

**Level 2:** Full information from all detectors in regions of interest

- 1 kHz, 1.5 GB/sec

**Event Filter:** Reconstruction of complete event using latest alignment and calibration data

- 200 Hz, ~300 MB/sec

**Minimum bias, 70 mb**

**Standard Model Physics, ~20 nb**

**Rare processes, BSM, ≤pb**
**Level 1 trigger**

- **LVL1 Trigger**
  - Hardware based (FPGAs ASICs)
  - Coarse granularity calo/muon data
  - Maximum latency 2.5 μs
  - Output rate 75 KHz

Calorimeter L1 trigger accounts for 70% of total L1 bandwidth
Level 1 Calorimeter trigger

- Level 1 Calorimeter selects:
  - Electro-magnetic objects: (isolated EM only deposit) – electrons and photons
  - Hadronic objects: (isolated EM+HAD deposits) - taus
  - Jets: (high pT EM+HAD deposits)
  - Events with large missing transverse energy or sum of all Calo objects: (everything)
L1Calo readout

Readout data path

Real-time data path
Cosmics runs

- Real data comes from detector
- Allows to test L1 and data preparation for L2, EF
- Test software with real imperfect data

Very busy time in ATLAS control room
L1Calo trigger of cosmics rays
L1Calo energy correlation from cosmics data

- Both timing and energy scale of the signals were checked with cosmics data in addition to tests with pulses

Good correlation of L1Calo energies with calorimeter readout
LVL2 Trigger

- Software based
- Full granularity for all subdetectors, but only small region of interest is read and analysed (2% of all data per event)
- Fast rejection algorithms
- Mean event processing time - 40ms
- Output rate ~2 KHz
Level 2 trigger

- Electrons, Photons:
  - based on 2nd LAr sampling: study shape parameters of the EM cluster; track match
- Taus (narrow hadronic cluster):
  - take shape parameters from 2nd LAr sampling; use EM+HAD to estimate total energy, check EM and track isolation requirements;
- Jets:
  - measure total energy in the large cone (EM+HAD), advanced jet calibration
- Missing ET (event property):
  - Correct L1 ET on losses due to muons (from L2 muon reconstruction)
L2 Calibration

- Hadronic response of calorimeter is generally smaller than electromagnetic response. Calibrate difference to give an original energy of the jet. At L2:

\[ E_{\text{jet}} = w_{EM} * E_{EM} + w_{HAD} * E_{HAD} \]

- \[ w_i = a + b \log(E) \]

- More detailed calibration at EF/offline level

Dedicated calibration is applied to jet energy and missing ET measurements at all trigger levels. Tau uses jet calibration.
- MC or cosmics data are preloaded to readout buffer
- DAQ/HLT plays back data through the whole system except L1
- Loop permanently over preloaded data
- Allow running at high rate
In the ATLAS control room

Technical runs are also a very busy period
Results of technical runs

- test of DAQ/HLT system with realistic input rate
- test of trigger robustness and stability (in spite of small number of input MC events)
- test of time used by algorithms and spend on accessing data
- validation of output stream and data acquisition system
- test of time used to configure system
- validation of Data Quality control, tools, data taking procedures

Tests with complex menu for start-up are successful, Timing and performance is according to specifications

Data collection is 1/3 of total processing time

Actual time depends on algorithms included, trigger menu and prescales

First event, long configuration time
Data access is a critical component of trigger system, minimize the number of requests of data:

- use region of interest (2% of all data)
- re-use/cache data for different triggers (e.g. electron and tau found on the same spot);
- use early prescaling and early rejection
- optimize number of requests for data – better big block at once than many small blocks

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**Time for L2 tau clusterization**

- Tau & Egamma Rols overlap, part of data are already unpacked
- Tau only Rols
Event Filter (level3) trigger

- Event Filter Trigger
  - Software based
  - potential full event access
  - *Offline*-like algorithms
  - mean event processing time ~ 4 ms
  - output rate 200 Hz
  - data storage 300MB/s
EF performance

- Event filter runs most complex algorithms and provides accurate measurements of transverse energy of objects.
  - Optimize performance to provide highest possible efficiency at affordable rates
  - Use offline tools to benefit from offline development and precision
  - Can use differently tight cuts for different purposes and different pt regions
Preparing trigger menu for data

- Complex trigger menu includes
  - triggers for physics
  - triggers for commissioning, calibration
  - back-up triggers (what is actual rate?)
  - triggers for efficiency measurements
  - HLT pass-through triggers
  - minimum bias

Draft of menu for \(10^{31}, 14\text{TeV}\) run

<table>
<thead>
<tr>
<th>Stream</th>
<th>Total Rate (Hz)</th>
<th>Unique Rate (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>egamma</td>
<td>55</td>
<td>48</td>
</tr>
<tr>
<td>muon</td>
<td>35</td>
<td>29</td>
</tr>
<tr>
<td>jetTauEtmiss</td>
<td>104</td>
<td>89</td>
</tr>
<tr>
<td>minBias</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>express</td>
<td>18</td>
<td>0</td>
</tr>
<tr>
<td>calibration</td>
<td>15</td>
<td>13</td>
</tr>
</tbody>
</table>

Table 12: Summary of triggers for the first physics run assuming a luminosity of \(L \sim 10^{24} \text{cm}^{-2} \text{s}^{-1}\). For each signature rates and the motivation for this trigger are given.

Rates given are estimates based on MC simulation.
Preparing for data

- A lot of work went to understand and predict possible inefficiencies and biases at trigger level:
  - Effect of pile-up
  - Extra material in detector
  - Misalignment effects
  - etc
- Prepare to measure trigger efficiency from data:
  - using easy to reconstruct signals like Z->ee, ttbar
  - using well controlled background (fakes)
The calorimeter is one of the main components of ATLAS trigger system, used in triggers for more that 70% of the total bandwidth.

3 level trigger system has hardware and software components. All being installed and commissioning already now

Cosmics tests show beautiful calorimeter signal, used for time and energy scale calibration

Technical & cosmic runs give us the possibility to validate the HLT system and to establish procedures for algorithm tuning and data-taking

Trigger menus are becoming mature, they include triggers for different purposes, such as physics, calibration, alignment, commissioning. Also different menus are being developed for start-up, for 10 and 14 TeV runs, and for different instant luminosities (10$^31$, 10$^32$, 10$^33$ /s/cm$^2$)

preparation for data is ongoing, simulation of possible detector inefficiencies and systematics is applied in trigger studies
Very eager to get data, might happen in 2 months already!