Analysis of initial performance of the ATLAS Level-1 Calorimeter Trigger

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On behalf of the Level-1 Calorimeter Trigger collaboration

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- LHC & the ATLAS detector
- Trigger system
- Level-1 calorimeter trigger
- Commissioning & Cosmic rays
The Large Hadron Collider - LHC

- pp collisions at $\sqrt{s} = 14$ TeV
- Bunch crossing: 25 ns
- $10^{11}$ protons per bunch
- Initial luminosity: $L_0 = 10^{31}$ cm$^{-2}$s$^{-1}$
  $(L = 50$ pb$^{-1}$/year$)$
- Low luminosity: $L_0 = 10^{33}$ cm$^{-2}$s$^{-1}$
  $(L = 10$ fb$^{-1}$/year$)$
- Nominal luminosity: $L_0 = 10^{34}$ cm$^{-2}$s$^{-1}$
  $(L = 100$ fb$^{-1}$/year$)$
- First collisions: Very soon….

- 4 Detectors:
  - ATLAS & CMS: p-p collisions, Standard Model and beyond
  - LHCb: p-p collisions, B physics, CP violation
  - ALICE: ion-ion/p-ion collisions, quark-gluon plasma
**The ATLAS detector**

### Specifications
- **Length**: 44 m
- **Diameter**: 22 m
- **Weight**: 7000 t

### Inner Detectors
- **Pixel Semi-Conductor Tracker (SCT)**
- **Calorimeters**
  - **Electromagnetic**
  - **Hadronic**
- **Muon spectrometers**
  - Monitored Drift Tubes (MDT)
  - Cathode Strip Chambers (CSC)
  - Resistive Plate Chambers (RPC)
  - Thin Gap Chambers (TGC)

### Interaction Point
- **Solénoïd 2T**
- 8 toroidal magnets

### Detector Component Resolution and η Coverage

<table>
<thead>
<tr>
<th>Detector component</th>
<th>resolution</th>
<th>η coverage</th>
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</thead>
<tbody>
<tr>
<td>Tracking</td>
<td>$\sigma_p/p_r = 0.05%$, $p_r &lt; 1%$</td>
<td>$</td>
</tr>
<tr>
<td>EM calorimetry</td>
<td>$\sigma_E/E = 10%/\sqrt{E} \pm 0.7%$</td>
<td>$</td>
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<tr>
<td>Hadronic calorimetry (jets)</td>
<td>$\sigma_E/E = 50%/\sqrt{E} \pm 3%$</td>
<td>$</td>
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<tr>
<td></td>
<td>$\sigma_E/E = 100%/\sqrt{E} \pm 10%$</td>
<td>$3.1 &lt;</td>
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<tr>
<td>Muon spectrometer</td>
<td>$\sigma_{p_T}/p_T = 10%/p_T @ p_T = 1 TeV$</td>
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</table>
Cross sections & rates

- p-p inelastic cross section: 70 mb
- 23 collisions / bunch crossing \((10^{34} \text{ cm}^{-2}\text{s}^{-1})\)
  \(\Rightarrow\) pile-up
  \(\rightarrow 10^9 \text{ interactions/s (high luminosity)}\)

- Need stringent selections to keep only interesting events:
  - Search for processes with small cross-sections
  - Rejection power \(10^{12}\) \((H\rightarrow\gamma\gamma \text{ 120 GeV})\)
  - Looking for a needle in a haystack…

- Technological constraints:
  - Event size: 1.5 Mb
  - To tape: 300Mb/s

⇒ Have to reduce the acquisition rate from 40 Mhz to 200 Hz
**Trigger strategy**

**L1**
- Dedicated hardware (ASICS & FPGAs)
- Calorimeters & muons
- Latency < 2.5 μs
- L1A 75 kHz

**L2**
- ~500 dual CPUs
- Full granularity
- Regions of Interest (~2%)
- Latency ~40 ms
- L2A 2kHz

**Event Filter (L3)**
- ~1600 dual CPUs
- Access to full event & calibration constants
- More detailed reconstruction
- Use Offline algorithms
- Latency ~1s
- 200 Hz
3 sub-systems
- L1 - Calorimeters (L1Calo)
- L1 - Muons
- Central Trigger Processor (CTP)

Signature identification
- e/\gamma, \tau/h, jets, \mu
- Multiplicities per \pT threshold
- Isolation criterion
- Missing \ET, total \ET, jet \ET

**CTP**
- Receive & synchronize trigger information
- Generate level-1 trigger decision (L1A)
- Deliver L1A to other sub-detectors
L1 Calorimeter - Architecture

- L1Calo partitioned into 3 sub-systems
  - Pre-Processor (PPr)
    - Receive & sample signal from calorimeters
    - Coarser granularity (Trigger Towers)
    - Noise filter
    - Bunch crossing identification (BCID)
    - Determine final $E_T$ value

- Processors JEP & CP
  - Physics algorithms
  - Search for and identify:
    - isolated leptons, taus
    - jets
  - Compute $E_T$ total, missing,…

- Real time transmission to CTP
- DAQ + RoIs at each L1A (75kHz)
Trigger towers (TT)

- Analogue summation of calorimeter cells
- 3584 x 2 (EM+HAD) trigger towers

<table>
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<tr>
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<th>$\Delta \eta \times \Delta \phi$</th>
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<tr>
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<tr>
<td>$3.2 &lt;</td>
<td>\eta</td>
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</table>
## Pre-Processors - Energy reconstruction

### Receivers (Rx)
- Input signal conditioning to L1 ($2.5V \rightarrow 250GeV$)
- Variable gain amplifier (VGA)
- $E \rightarrow E_T$ Conversion (Hadronic layers only)
- Local signal monitoring

### Sampling
- 40 Mhz, Flash-ADC 10 bits
- 1 ADC = 250 MeV
- Pedestal 40 ADC

### Bunch crossing identification (BCID)
- Finite impulse response filter (FIR)
- Peak finder (linear/saturated)
- Assign $E_T$ to the ‘correct’ bunch crossing

### $E_T$ calibration
- Look-Up Table (LUT)
- Pedestal subtraction, noise suppression
- ADC (10b) $\rightarrow$ GeV (8b) conversion

### Transmission to processors & DAQ
Regions of Interest (RoI)

- Processors input is a matrix of tower energies
- Algorithms look for physics signatures (sliding window)
- RoI’s sent to Level-2 trigger

Criteria for $e/\gamma$ or $\tau/h$ candidate:
- EM or Had. cluster $> E_{\text{threshold}}$
- Total $E_T$ in EM Isolation Ring $\leq$ EM isolation thresh.
- Total $E_T$ in Had. Isolation Ring $\leq$ Had. isolation thresh.
- Local $E_T$ Maximum compared to neighbor windows.

- $e/\gamma$ only:
  - Had. core $\leq$ core isolation threshold

Jet candidate
- Coarser granularity 0.2x0.2 (jet element)
- Digital summation EM + Had.
- Sliding, overlapping windows (3 sizes)

Missing energy

See next talk by Andrea Neusiedl
Installation & Commissioning

- **System fully installed since end of 2007**
  - Hardware production achieved
  - Last modules installed
  - Cabling finalized

- **Commissioning**
  - Hardware/software testing
  - Calibration procedures with calorimeters
  - Several integration & data taking campaigns

- **Cosmic muons**
  - Proved to be very useful
  - Acquisition chain understanding
    - Analogue & digital parts
    - Calorimeters - L1Calo comparisons
  - Assess system stability
  - Triggering on muons
    - Proof that L1Calo is behaving correctly
Event display of a cosmic muon

Run 29576

EM calorimeter

Tile calorimeter

L1Calo - Had

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Pedestal & Noise

- Pedestals set to 40 ADC counts
- Sensible RMS ~ 400 MeV
- Nearly all channels behaving correctly (>99%)
L1Calo reconstructed $E_T$ vs calorimeter precision readouts
Cosmic muons
Reasonable correlation achieved
Very crude calibration applied, still room for improvement
EM & Hadronic cluster Energy

- $E_T$ for Cluster Processor RoIs
- 8 $E_T$ thresholds for $e/\gamma$ & $\tau/h$
- Show the thresholds are working
- Steps between thresholds correspond to
  - Different pre-scale settings
  - HLT algorithms at Level-2
Trigger rates

- Long overnight cosmic runs
  - 1 luminosity block = 5 minutes
- Stable trigger rate at level of few Hz
- Capability to separate good events from background
- Rate monitoring tools
  - Very useful to spot hot channels
Conclusions

System fully installed since end of 2007
- Cabling, Hardware & signal testing,…
- Technical & integration runs with other sub-detectors

Cosmic runs
- Providing trigger in all the last campaigns
- Very useful for debugging
- More control over the system (stability, rates…)
- Proved capability to trigger reliably

Toward the first collisions…
- Preparing for beam
- Fully operational L1Calo trigger
  - >99% working channels
  - Timing will be crucial
- Focusing on calibration procedures
  - See poster by Rainer Stamen
- Performance
  - Trigger efficiency
  - Correction for misbehaving channels
Beam splash
Average offset from L1A timing in EM layer
Timing calibration

- Internal timing of L1Calo trigger is achieved
- Input timing realized in pre-processors
- Not a trivial task
- Several strategies depending on signal origin:
  - calibration
  - cosmic rays
  - collisions
- Different setup & automatic procedures
  - Setup coarse/fine timing
  - Ensure signals are correctly sampled (3rd sample at maximum)
  - Signal shape with 1 ns sampling step

- LAr EMB timing from pulser run
- Coarse timing ok
- Focusing on fine tuning
Calorimeters

- Electromagnetic calorimeter
- Hadronic calorimeter – End cap
- Forward calorimeter

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Central Trigger Processor (CTP)

- **Receive, synchronize** and **align** trigger information
- **Other signals:**
  - Random trigger
  - Calibration
  - Minimum bias events (MBTS)
- **Generate the level-1 trigger decision (L1A)**
  - Programmable trigger menu
  - Latency 100 ms (4BC)
- **Deliver the L1A to the other sub-detectors**

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160 entries 256 items