Tau Workshop in Pisa 08/06/2007

High Level Trigger in CMS: Overview

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Formidable task: Trigger Rejection $4 \times 10^5$

Bunch crossing rate 40MHz → permanent storage rate ~ 150 Hz
Level 1 Trigger:
Hardwired processors
High Level Triggers:
Farm of processors

Level-1 Trigger Requirements:
Output: 100 kHz (50 kHz for initial running)
Latency: 3 msec for collection, decision, propagation
HLT designed to output $O(10^2)$ Hz
CMS DAQ/Trigger System

Farm of ~ 1000 CPUs

- **Builder Units**
  - Event Builder
- **Filter Units**
  - Unpacking, RecHit, HLTAlgos

**HLT supervisor**
- Apply dynamic prescales in luminosity block boundaries

Output capacity of Storage Manager

- 1 GB/s (peak), **250 MB/s** (mean)
- 1-2 MB/event: ~150 Hz

- Smaller event size at startup → could go to higher rates
Level 1 trigger Data-Flow

Calorimeter Trigger

- HF
- HCAL
- ECAL
  - Regional Calorimeter Trigger
  - Global Calorimeter Trigger

Muon Trigger

- RPC
- CSC
- DT
  - Pattern Comparator Trigger
  - Local CSC Trigger
  - CSC Track Finder
  - DT Track Finder

40 MHz pipeline, latency < 3.2 μs

MIP + ISO bits

e, J, E_T, H_T, E_T^{miss}

4 μ (with MIP/ISO bits)

Seeds for the HLT:
L1 provides p_T & location in detector

max. 100 kHz L1 Accept
High Level Trigger

Runs on large CPU farm

Code as close as possible to offline reconstruction

Selection must meet CMS physics goals

• Output rate to permanent storage limited to $O(10^2)$ Hz

Reconstruction on demand

• Reject as soon as possible

• Trigger “Levels”:

  Level-2: use calorimeter and muon detectors

  Level-2.5: also use tracker pixel detector

  Level-3: includes use of full information, including tracker

  “Regional reconstruction”: e.g. tracks in a road or region
Online Selection Group Activities
Crossing rate:
\[ R_{\text{bunch}} = 40 \text{ MHz} \]

Mean Rate of events:
\[ R_{\text{Hz}} = \sigma_T \cdot \mathcal{L} = 79.3 \text{ mb} \cdot 2 \cdot 10^{33} \text{ cm}^{-2}\text{s}^{-1} = 159 \text{ MHz} \]

Number of events per bunch crossing:
\[ N_{\text{evt}} = \frac{R_{\text{Hz}}}{R_{\text{bunch}}} = 4 \text{ events/crossing} \]

Not all bunches full in the LHC (only 79.5%)
\[ \mu = \frac{N_{\text{evt}}}{0.795} = 5 \]

**Trigger requirements**

**Maximum Output Rate L1:** 100 KHz

(Goal ~17 KHz with security factor)

**Estimated Output Rate HLT:** 100-150 Hz
## Tau Trigger Tables for $2 \times 10^{33}$ cm$^{-2}$s$^{-1}$ Luminosity

<table>
<thead>
<tr>
<th>Trigger</th>
<th>L1 Threshold (GeV)</th>
<th>L1 Rate (kHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inclusive Tau</td>
<td>100</td>
<td>2.2 ± 0.2</td>
</tr>
<tr>
<td>Double Tau</td>
<td>60</td>
<td>3.0 ± 0.2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Trigger</th>
<th>Threshold (GeV)</th>
<th>Rate [Hz]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Double Pixel TauJet</td>
<td>100 Single Tau@L1 or 66 Double Tau@L1</td>
<td>4.1+-1.1</td>
</tr>
<tr>
<td>Double Tracker TauJet</td>
<td>100 Single Tau@L1 or 66 Double Tau@L1</td>
<td>6.0+-1.1</td>
</tr>
<tr>
<td>Electron-TauJet</td>
<td>16, 52</td>
<td>~0</td>
</tr>
<tr>
<td>Muon-TauJet</td>
<td>15, 40</td>
<td>0.1+-0.06</td>
</tr>
<tr>
<td>TauJet-MET</td>
<td>93, 65</td>
<td>0.5 +- 0.1</td>
</tr>
</tbody>
</table>
## HLT Trigger Table for $\mathcal{L} = 2 \cdot 10^{33} \text{ cm}^{-2}\text{s}^{-1}$

<table>
<thead>
<tr>
<th>Trigger</th>
<th>Threshold (GeV)</th>
<th>Prescale</th>
<th>Rate [Hz]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Electron</td>
<td>26</td>
<td></td>
<td>23.5+- 6.7</td>
</tr>
<tr>
<td>Double Electron</td>
<td>12, 12</td>
<td></td>
<td>1.0 +- 0.1</td>
</tr>
<tr>
<td>Relaxed Double Electron</td>
<td>19, 19</td>
<td></td>
<td>1.3 +- 0.1</td>
</tr>
<tr>
<td>Single Photon</td>
<td>80</td>
<td></td>
<td>3.1 +- 0.2</td>
</tr>
<tr>
<td>Double Photon</td>
<td>30, 20</td>
<td></td>
<td>1.6+-0.7</td>
</tr>
<tr>
<td>Relaxed Double Photon</td>
<td>30, 20</td>
<td></td>
<td>1.2+-0.6</td>
</tr>
<tr>
<td>Single Photon Prescaled</td>
<td>23</td>
<td>400</td>
<td>0.3+-0.02</td>
</tr>
<tr>
<td>Double Photon Prescaled</td>
<td>12, 12</td>
<td>20</td>
<td>2.5+-1.4</td>
</tr>
<tr>
<td>Relaxed Double Photon Prescaled</td>
<td>19, 19</td>
<td>20</td>
<td>0.1+-0.03</td>
</tr>
<tr>
<td>Single Muon</td>
<td>19</td>
<td></td>
<td>25.8+-0.8</td>
</tr>
<tr>
<td>Relaxed Single Muon</td>
<td>37</td>
<td></td>
<td>11.9+-0.5</td>
</tr>
<tr>
<td>Double Muon</td>
<td>7, 7</td>
<td></td>
<td>4.8+-0.4</td>
</tr>
<tr>
<td>Relaxed Double Muon</td>
<td>10, 10</td>
<td></td>
<td>8.6+-0.6</td>
</tr>
<tr>
<td>Double Pixel TauJet</td>
<td>100 SingleTau@L1 or 66 DoubleTau@L1</td>
<td></td>
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<tr>
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<td></td>
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<td>15, 40</td>
<td></td>
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</tr>
<tr>
<td>TauJet-MET</td>
<td>93, 65</td>
<td></td>
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<th>Trigger</th>
<th>Threshold (GeV)</th>
<th>Prescale</th>
<th>Rate [Hz]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single jet</td>
<td>400</td>
<td></td>
<td>4.8 +- 0.02</td>
</tr>
<tr>
<td>Single jet Prescale 1</td>
<td>250</td>
<td>10</td>
<td>5.2+-0.02</td>
</tr>
<tr>
<td>Single jet Prescale 2</td>
<td>120</td>
<td>1000</td>
<td>1.6+-0.008</td>
</tr>
<tr>
<td>Single jet Prescale 3</td>
<td>60</td>
<td>100000</td>
<td>0.4+-0.002</td>
</tr>
<tr>
<td>Dijet</td>
<td>350</td>
<td></td>
<td>3.9 +- 0.02</td>
</tr>
<tr>
<td>Trijet</td>
<td>195</td>
<td></td>
<td>1.1 +- 0.01</td>
</tr>
<tr>
<td>Fourjet</td>
<td>80</td>
<td></td>
<td>8.9 +- 0.2</td>
</tr>
<tr>
<td>Acoplanar Dijet</td>
<td>200, $\Delta\phi$ (dijets)&lt;2.1</td>
<td></td>
<td>0.2+-0.008</td>
</tr>
<tr>
<td>Single jet-MET acoplanar</td>
<td>100, 80, $\Delta\phi$ (jet,MET)&lt;2.1</td>
<td></td>
<td>0.1+-0.02</td>
</tr>
<tr>
<td>Single jet - MET</td>
<td>180, 80</td>
<td></td>
<td>3.2+-0.07</td>
</tr>
<tr>
<td>Dijet – MET</td>
<td>155, 80</td>
<td></td>
<td>1.6+-0.03</td>
</tr>
<tr>
<td>Trijet – MET</td>
<td>85, 80</td>
<td></td>
<td>0.9+-0.07</td>
</tr>
<tr>
<td>Fourjet – MET</td>
<td>35, 80</td>
<td></td>
<td>1.7+-0.2</td>
</tr>
<tr>
<td>MET</td>
<td>91</td>
<td></td>
<td>2.5+-0.2</td>
</tr>
<tr>
<td>$H_T$ – MET</td>
<td>350, 80</td>
<td></td>
<td>5.6+-0.2</td>
</tr>
<tr>
<td>$H_T$ - Single Electron</td>
<td>350, 20</td>
<td></td>
<td>0.4+-0.1</td>
</tr>
<tr>
<td>B-jets (leading jet)</td>
<td>350, 150, 55 : 1,3,4-jet event cuts</td>
<td></td>
<td>10.3 +- 0.3</td>
</tr>
<tr>
<td>B-jets (second jet)</td>
<td>350, 150, 55</td>
<td>1,3,4-jet event cuts</td>
<td>8.7 +- 0.3</td>
</tr>
</tbody>
</table>

**TOTAL**                      | 118.3+-7.2     |
HLT Rate Summary Plot in PTDR II

[Graph showing HLT rate summary in PTDR II, with various categories and their respective rates.]
During MTCC phase 2 online application of a possible HLT algorithm

**Goal:** online selection of events with one local DT segment and a CSC segment \(\rightarrow\) selection of events in the DT/CSC overlap region in a dedicated data stream

Small fraction (<1/3) of overlap events successfully selected.

Express stream with prescale (1%)

“B” stream selecting muons in CSC/DT overlap (~25%)
What is the CPU performance of the HLT?

- Implement **L1 emulator, HLT algorithms** in CMSSW: Integration
- Implementation of **2E33 Trigger Menu**; recover ORCA functionality
- Determine **CPU-performance** for 1E32 Trigger Menu
- CMS beginning to discuss startup issues:
  - What HLT do we need at startup?

What triggers are required for commissioning & early physics?

- Detector, object-id and physics commissioning triggers (+calib/alignment)
- Implementation of startup, pilot-run trigger menus
- Determine CPU-performance for early Trigger Menus
**“Global” vs. “Regional”**

- **All algorithms** (except for Jets) **regional** by now
  - Seeded by previous levels (L1, L2, L2.5)

- Can benefit significantly by doing **regional data-unpacking** and **local reconstruction**

- Have started planning (& development) of **regional unpacking** and **RecHit** across subdetectors

- Only some local reconstruction envisioned for HLT exercise at this point.
  - Rest must continue work beyond HLT exercise

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**“Local”: using one sub-detector only**

**“Regional”: using small (η, φ) region**
HLT exercise Status

L1 Emulator in CMSSW √

HLT Algorithms in CMSSW √

Trigger menus for various luminosity settings
  • Focus on first year of operation √
  • Develop menu for L = 10^{32} \text{ cm}^{-2} \text{ s}^{-1} (underway)
    • L1 sets thresholds with 16.7 kHz output rate
    • HLT improves on object ID to reduce rate to 150 Hz
  • Pileup effect on trigger is negligible at this level

Study HLT performance
  • Special emphasis on HLT path timing
  • Include modules from unpacking up to storage manager
  • However, run in offline mode for the moment

Submit document to LHCC (June 18)
Muon L1 Emulator

orca 8.13.0

cmssw 1.3.0pre6

Reaching ~99% of ORCA efficiency!
## Global data-unpacking times

First (still preliminary) results on data-unpacking:

<table>
<thead>
<tr>
<th>Detector</th>
<th>Unpacking time (ms)†</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECAL</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>HCAL</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>CSC</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>RPC</td>
<td>?</td>
<td>Code now available</td>
</tr>
<tr>
<td>DT</td>
<td>?</td>
<td>Code now available</td>
</tr>
<tr>
<td>PS</td>
<td>?</td>
<td>Code almost ready</td>
</tr>
<tr>
<td>Pixels</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>SiStrips</td>
<td>140</td>
<td></td>
</tr>
</tbody>
</table>

Muon, Calorimeter unpacking invoked at “L2” modules

Tracker unpacking not invoked till “L3” modules (~x10 less often)

Digi2Raw & Raw2Digi code used

† Pentium IV, 3 GHz machine
## HLT CPU times

<table>
<thead>
<tr>
<th>Trigger</th>
<th>Global unpacking (ms)</th>
<th>L2+L3 processing (ms)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>eγ</td>
<td>17 (L2) + 15 (L3)</td>
<td>60 (RecHit) + 30 (algorithm)</td>
<td>~120</td>
</tr>
<tr>
<td>μ</td>
<td>13 (L2) + 19 (L3)</td>
<td>35 (L2 propagator) + 63 (rest)</td>
<td>~130</td>
</tr>
<tr>
<td>jets</td>
<td>17 (L2)</td>
<td>32 (RecHit) + 5 (algorithm)</td>
<td>~50</td>
</tr>
<tr>
<td>τ</td>
<td>23 (L2) + 5 (L3)</td>
<td>90</td>
<td>~120</td>
</tr>
<tr>
<td>τ-τ</td>
<td>23 (L2) + 15 (L3)</td>
<td>100</td>
<td>~140</td>
</tr>
</tbody>
</table>

- Individually measured numbers
- Overlaps with L1 skimmed samples being examined
Global Timing in 131HLT4 (28/05)

Goal: 40 ms

Preshower and SiStrip unpacking times missing
Average Time per HLT path

B-jets and Tau triggers!

pathTimeSummary
Entries 58
Mean 31.68
RMS 15.71
Underflow 0
Overflow 0
Switching from CHLEP to ROOT Matrix
Gain a factor of 2 in all tracking-related code
Projections of improvements will be included in HLT note by scaling appropriate modules in 15x vs 13x

Magnetic field – L2 muon propagator
Propagator makes now longer steps in regions where the magnetic field is almost homogeneous.
HLT-only propagator will not be in time for HLT exercise:
Go from one muon station to another in just one step, instead of using many small steps using helices

Regional data-unpacking, regional RecHit:
Some first prototypes (EGamma) delivered
EGamma numbers to be updated
Online Selection Group Plans
Participate in **CSA07** with Trigger Menu  
(HLT-exercise + updates)

Deploy HLT algorithms in on-line environment

Prepare for cosmics
Will be used to test the HLT-exercise algorithms in a "online enviroment"

We propose to setup and maintain such a playback configuration as a validation testbed fro HLT relevant developments, using some of our machines at Cessy (Can be operated from anywhere at CERN!).
Rates at $10^{31-33}$ cm$^{-2}$s$^{-1}$

Assume in 2008:
- L1T Out $< 5 \cdot 10^4$ Hz
- HLT Out $< 1.5 \cdot 10^2$ Hz

Cannot trigger on all minbias
Jet & SoftLepton triggers operational at $10^{31}$ cm$^{-2}$s$^{-1}$
Isolated electron triggers operational at $10^{32}$ cm$^{-2}$s$^{-1}$
All triggers operational at $10^{33}$ cm$^{-2}$s$^{-1}$
**Level-1 at Startup**

- **Minbias**

  Hadron Calorimeter Feature bits
  - Program HB, HE & HF feature bits to ID towers with energy over noise
  - HF feature bits are passed through by RCT to GCT
  - On GCT count +h and –h active towers, Trigger on their correlation
  - These are ORed in 4x4 by RCT and forwarded to GMT via GCT
  - On GMT count active trigger towers to trigger on HF $E_T$ rings
  - Implemented on GCT - but to get minbias efficiently one needs HF $E$ rather than $E_T$
  - Beam Scintillation counters, Any TOTEM elements

- **Normal L1 trigger lines are operated for trigger commissioning**
  - Will operate eGamma, jet, … triggers with low thresholds (above noise) and muons with no threshold (any muon segment found)

- **Rate limit at 25 kHz (2 DAQ slices) input - 1 GB/s output**
  - Minbias trigger without prescale written to tape
Validate L1T (run L1 Emulator) and run simple HLT algorithms
- HLT algorithms could be calorimeter and muon based
  Don’t bother unpacking and reconstructing tracks?
- Apply thresholds (none applied at L1)
  Stream data by trigger type
- Calibration triggers
  ECAL: $\pi^0$
  Jets: $\gamma + \text{Jet}$
  Tracks: $J/\psi \rightarrow \mu\mu$, isolated $\pi^{\pm}$
- Prescale minbias

Output bandwidth limit 1 GB/s (mean 250 MB/s)
Rate limit 500-1000 Hz full events, 1-2 MB/event $\rightarrow$ 150 Hz
- Multi-terabyte output buffer can hold all 2007 data
  in the control room (few days of operation at most!)
- Leisurely transfer to T0/Castor for reconstruction
Inclusive leptonic W and Z samples will be needed across early physics analyses

- Calibration & Alignment
- Lepton Efficiency Calculation
- Luminosity Measurement/Cross Check
- Jet Energy Scale, MET resolution, UE resolution, etc
- Absolute MET scale via W(νe) and Z(ττ)

Baseline L1 triggers are capable of accepting most of produced W/Z

- HLT is a different story: 10 Hz each of W(νe) and W(μν) each at $10^{33}$ cm$^{-2}$s$^{-1}$ – already saturates 20% of the bandwidth and may require quite strict HLT quality cuts – these triggers may easily blow up!

J/Ψ and Υ serve as another standard candle

- Need special (prescaled) triggers