The CMS High Level Trigger

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on behalf of CMS collaboration
Outline

• HLT Description
• 2011 vs 2012: Challenges:
  – Pile Up
  – Particle Flow
  – Ecal Light Corrections
• Performance on Physics and HLT summary
• Data Parking/Data Scouting
• Conclusion
High Level Trigger

Level 1
(Jim Brooke talk)

High Level Trigger

~15 MHz

~100 kHz

Alignment, Calibration and Luminosity (Event Size ~kB)

Physics (Full Event Content), Scouting (Event Size ~kB)

Trigger Studies (Event Size ~kB)

Data Quality and Monitoring (Various Event Content)

LHC

FPGA and custom ASIC technology

software on a filter farm of commercial rack-mounted computers, comprising over 13000 CPU

500Hz LumiPixel
10 kHz Pi0/Eta
1.5 kHz EcalPhiSym
1.5 kHz RPCMonitoring

100 Hz Calibration

1 kHz Stream A
40 Hz Express
1.2kHz Data Scouting

10 kHz NanoDST

25 Hz Stream B
75 Hz DQM
1 kHz HLTDQMResults
150 Hz HLTDQM
20 Hz HLTMonitoring

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New Challenges

2011: $\mathcal{O}$ up to 3.5 Hz/nb
2012: $\mathcal{O}$ up to 6.5 Hz/nb
→ Code improved to reduce pile up dependence

Muon cross section at HLT with $p_T > 40$ GeV
→ Lower and flat in 2012 thanks to better track quality cuts
2012B trigger shows higher efficiency due to introduction of pileup corrections for isolation. Sharp turn on curve, efficiency plateau at ~90% and stable with Pile Up.
Purity of HLT paths

Purity is preserved with respect to pile up.

Above 80% purity in for muons.

⇒ Quite pure selection of objects at HLT
Particle Flow at HLT

Improve efficiency of algorithms via particle flow on the HLT farm as for offline

Particle flow algorithms:
- first implementation for Tau
- extension to Jets, Met, Missing HT

Particle flow algorithms:
→ Better resolution on object
→ Optimization of CPU consumption
→ Refine technics for pile up subtraction
**CPU & Cross Section**

- **Cross Section almost constant among a run (=with pile up)**
  - No degradation of signal/background wrt to pile up
  - A few paths with non linear increase with luminosity (working on them)

**HLT CPU time/evt grows linearly with Pile Up**

- > 5 Hz/nb use extension of HLT farm
- Current HLT farm [13k core] cope up to 8 Hz/nb
Single Electron Efficiency

Increase of luminosity → increase of transparency losses in Electromagnetic calorimeter of CMS.

Correction to compensate derived every week in 2012. Application to Endcap only so far.

→ Improvement: steeper turn on curve and keep lower threshold than 2011 thanks to corrections.
Photon Efficiency: $H \rightarrow \gamma\gamma$

Efficiency of HLT reconstruction for photons above 26 GeV as a function of offline $p_T$ & $\eta$.

Fully efficient at 30 GeV thanks to correction applied in endcap electromagnetic calorimeter.

$\rightarrow$ Crucial triggers for Higgs searches.
Run 2012A < run 2012B: change quality criteria of isolation tracks
Difference between barrel (|η| < 1.5) and endcap (|η| > 1.5): due to detector effects and different real tau purity

→ Very high performance which allow Higgs investigations
## HLT Menu @ 6Hz/nb

<table>
<thead>
<tr>
<th>(Unprescaled) Object</th>
<th>Trigger Threshold (GeV)</th>
<th>Rate (Hz)</th>
<th>Physics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Muon</td>
<td>40</td>
<td>21</td>
<td>Searches</td>
</tr>
<tr>
<td>Single Isolated muon</td>
<td>24</td>
<td>43</td>
<td>Standard Model</td>
</tr>
<tr>
<td>Double muon</td>
<td>(17, 8)</td>
<td>20 [30]</td>
<td>Standard Model / Higgs</td>
</tr>
<tr>
<td></td>
<td>[13, 8 for parked data]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single Electron</td>
<td>80</td>
<td>8</td>
<td>Searches</td>
</tr>
<tr>
<td>Single Isolated Electron</td>
<td>27</td>
<td>59</td>
<td>Standard Model</td>
</tr>
<tr>
<td>Double Electron</td>
<td>(17, 8)</td>
<td>8</td>
<td>Standard Model / Higgs</td>
</tr>
<tr>
<td>Single Photon</td>
<td>150</td>
<td>5</td>
<td>Searches</td>
</tr>
<tr>
<td>Double Photon</td>
<td>(36, 22)</td>
<td>7</td>
<td>Higgs</td>
</tr>
<tr>
<td>Muon + Ele x-trigger</td>
<td>(17, 8), (5, 5, 8), (8, 8, 8)</td>
<td>3</td>
<td>Standard Model / Higgs</td>
</tr>
<tr>
<td>Single PFJet</td>
<td>320</td>
<td>9</td>
<td>Standard Model</td>
</tr>
<tr>
<td>QuadJet</td>
<td>80 [50 for parked data]</td>
<td>8[100]</td>
<td>Standard Model / Searches</td>
</tr>
<tr>
<td>Six Jet</td>
<td>(6 x 45), (4 x 60, 2 x 20)</td>
<td>3</td>
<td>Searches</td>
</tr>
<tr>
<td>MET</td>
<td>120</td>
<td>4</td>
<td>Searches</td>
</tr>
<tr>
<td>HT</td>
<td>750</td>
<td>6</td>
<td>Searches</td>
</tr>
</tbody>
</table>
LHC will stop in 2013/2014: Recording additional events to be studied at that time:

**Vector Boson Fusion:** $M_{jj} > 650$ GeV, $\Delta\eta_{jj} > 3.5$

**MultiJet:** 4 Jet with $p_T > 50$ GeV

**HT and MHT:** For susy searches

**MuOnia:** low $M_{\mu\mu}$ (Jpsi, Psi`, ..)

**DoubleMu:** Mu13_Mu8

**TauParked:** $\tau\tau$ (with 3prong decays)

5% of parked data are promptly reconstructed for monitoring purpose

➔ On average 350 Hz of "core physics" is promptly reconstructed and 300 Hz of data is parked for future reconstruction
Data Scouting

Look at events not collected in main stream due to trigger constraints. Scouting approach:
Trigger: \( H_T > 250 \) GeV unprescaled
High rate (\(~1\) kHz) + reduced event content (i.e. store HLT jets, no RAW data)

→ Bandwidth (= rate x size) under control [a few MB/s]
→ Possibility to change stream A triggers in case something interesting is seen by “scouting”

Analyses in Data Quality Monitoring-like framework for:
Exotica: Dijet search
SUSY: Razor, \( \alpha_T \)
Conclusions

• HLT is serving many purpose:
  – Various streams for detector maintenance
  – Large flexibility to record specific events for physics searches

• HLT remarkably stable wrt PU
  – Many improvements in code/tuning of corrections
  – Allows us to use refined algorithms online
  – Current HLT Farm able to cope with 165 ms/evt @ 100 kHz L1
    \rightarrow \sim 8 \text{ Hz/nb} \text{ as instantaneous luminosity with no changes from current prescale setting at HLT}
  – Efficiencies high, turn-on’s sharp, rates stable

\rightarrow \text{ Ready to record more data to hunt for/to study new particles}
Back Up
High Level Trigger

The HLT: dedicated configuration of the CMS reconstruction software. We currently have \( \sim 13,000 \) cpu cores, and run \( \sim 20,000 \) event processors (exploiting the hyperthreading capability of the CPUs from 2011 and 2012).

The current machines are:

- 720 dual E5430 Xeon quad-core processors
- 288 dual X5650 Xeon six-core processors (with HyperThreading)
- 256 dual E5-2670 Xeon eight-core processors (with HyperThreading)

With a nominal input rate of 100 kHz, each process has available an average of \( \sim 160 \) ms to read the input data run all the trigger algorithms (\( \sim 400 \) currently) take the final accept/reject decision stream the data to the Storage Managers

Nominal output rate \( \sim 1 \) kHz
For comparison, offline reconstruction takes \( \sim 3 \) sec per event
# HLT farm evolution

<table>
<thead>
<tr>
<th></th>
<th>Original HLT System Dell Power Edge 1950</th>
<th>2011 extension Dell Power Edge c6100</th>
<th>2012 extension Dell Power Edge c6220</th>
</tr>
</thead>
<tbody>
<tr>
<td>Form factor</td>
<td>1 motherboard in 1U box</td>
<td>4 motherboards in 2U box</td>
<td>4 motherboards in 2U box</td>
</tr>
<tr>
<td>CPUs per motherboard</td>
<td>2x 4-core Intel Xeon E5430 Harpertown, 2.66 GHz, 16GB RAM</td>
<td>2x 6-core Intel Xeon X5650 Westmere, 2.66 GHz, hyper-threading, 24 GB RAM</td>
<td>2x 8-core Intel Xeon E5-2670 Sandy Bridge, 2.6 GHz, hyper threading, 32 GB RAM</td>
</tr>
<tr>
<td>#boxes</td>
<td>720</td>
<td>72 (=288 motherboards)</td>
<td>64 (=256 motherboards)</td>
</tr>
<tr>
<td>#cores</td>
<td>5760</td>
<td>3456 (+ hyper-threading)</td>
<td>4096 (+ hyper-threading)</td>
</tr>
<tr>
<td>cumulative #cores</td>
<td>5.6k</td>
<td>9.1k</td>
<td>13.2k</td>
</tr>
<tr>
<td>cumulative #CMSSW</td>
<td>5k instances</td>
<td>11k instances</td>
<td>20k instances</td>
</tr>
</tbody>
</table>

(CPU budgets are on 1 core of an Intel Harpertown)

**Per-event CPU budget @ 100 kHz:**

- **2009:** ~50 ms / evt
- **2011:** ~100 ms / evt
- **2012:** ~165 ms / evt
Dimuons Efficiency: H→WW

Very high efficiencies even for low threshold object

→ Crucial for exploring H→WW and H→ZZ production mode
**HLT Rates**

Luminosity = 6.6 Hz/nb

- **total HLT**
- “core”
- “parking”

Luminosity = 3 Hz/nb

**HLT rate for first 10h of long recent fill**
- Average “core rate = 380 Hz in range shown (6.6 - 3 Hz/nb) = 340Hz from 6.5 - 2.5Hz/nb, when fill is usually dumped by operator**

- Rate limit is set by offline resources, to 300-350Hz “core” physics on average.
- Goal: keep the average over the fill
  - If larger rates at the end → lower rates at start, with reduced physics acceptance
  - Physics like to have a constant set of thresholds throughout the data
HLT Operations

• Rate Monitoring:
  – Tools able to spot problems immediately during data taking.
  – Offline analysis identifies triggers with unexpected rate growth $> \text{instantaneous lumi}$

Data Certification:
• New, stream-lined certification process provides quicker feedback to operations.
• Improved HLT DQM utilities utilized by HLT secondary on-call

![Graph showing measured and predicted rates as a function of luminosity section.](image.png)