Performance of the CMS High-Level Trigger

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Overview

- Introduction
- Commissioning Triggers (referenced to other ICHEP contributions)
- Physics Triggers Performance:
  - Electrons
  - Muons
  - Jets
  - Missing Transverse Energy (MET) objects
- Rates and CPU Performance
- Conclusions
The CMS Detector

The CMS Detector

**Introduction**

**Commissioning**

**e/\gamma**

**Muon**

**Jet**

**MET**

**Rates/cpu**

**Conclusions**

**The CMS Detector**

**SOLENOID**

3.8 T B-field

**TRACKER**

**MUON BARREL**

Silicon Strips

Pixels

**ECAL**

Scintillating PbWO$_4$

**Crystals**

**CALORIMETERS**

**HCAL**

Plastic scintillator/brass sandwich

**MUON ENDCAPS**

Resistive Plate Chambers (RPC)

Cathode Strip Chambers (CSC)

**Azimuthal angle:** $\phi$

**Polar angle:** $\theta$

**Pseudorapidity:** $\eta = -\ln \tan \left( \frac{\theta}{2} \right)$

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The CMS High Level Trigger (HLT) System

- Full CMS event rate reduced in two steps, Level-1 (L1) Trigger and HLT.
- L1: uses custom-designed, programmable electronics
- The HLT:
  - receives input directly from L1.
  - Software based; offline-quality algorithms running in real time on a ~5K processor filter farm.
  - Combines the traditional Level-2 and Level-3 steps into a single step and uses full granularity data.
  - Internally, it works in several stages:
    First stage: only calorimeters and muon system information; second stage: selection including reconstruction of full tracks in the tracker; intermediate stage: use of partial tracker information
Currently, the HLT trigger menu consists of about 150 triggers, which include physics and commissioning.

Smooth running and excellent performance of the HLT system during the first months of LHC operations at $\sqrt{s} = 7$ TeV.

- Background and L1 rate optimally brought down.
- Quality data successfully delivered for analysis.

In the following slides:

Plots of HLT performance in Spring 2010 proton-proton collision data taken at $\sqrt{s} = 7$ TeV (L1 max rate 50 KHz)
Commissioning Triggers

- A fraction of the bandwidth (close to 30% at start-up) is reserved for calibration triggers to ensure complete understanding of the detector performance.

- Data collected by these triggers are used for providing new calibration and alignment constants for use by offline reconstruction algorithms.

**MORE on Commissioning/Alignment/Calibration triggers**
- Parallel talk *Operation of the CMS detector with first collisions at 7 TeV at the LHC*, Salle 252A, 24 July 2010, Advances in Instrumentation and Computing for HEP:
  http://indico.cern.ch/contributionDisplay.py?sessionId=58&contribId=1196&confId=73513

- Poster: *Commissioning, Performance, and Calibration of the Electromagnetic Calorimeter of CMS*
Photon and Electron Triggers

- **Common stage for Photons and Electrons:**
  - Angular matching of energy deposits (clusters) in the Electromagnetic Calorimeter (ECAL) with $e/\gamma$ candidates at L1.
  - Form super-clusters (group of clusters; bremsstrahlung/conversions recovery)
  - $E_T$ cut applied
  - ECAL super-cluster shape consistent with an electromagnetic object
  - Calorimetric (ECAL+HCAL) isolation

- **Photons**
  - Tight track isolation in a solid cone

- **Electrons:**
  - Matching with hit pairs in pixel detectors
  - Electron track reconstruction
  - Angular matching of ECAL cluster and full track
  - Loose track isolation in a hollow cone
Performance of Photon and Electron Triggers

Trigger efficiency for selected offline superclusters matched to L1 objects to pass a photon trigger with a threshold of $E_T > 15$ GeV, plotted vs. the supercluster $E_T$.

Efficiency for offline reconstructed electrons, which have passed a photon trigger with a threshold of $E_T > 15$ GeV, to pass an electron trigger with similar $E_T$ threshold.
Muon Triggers

First Stage:
- Confirm L1 “seeds”: refit hits in the muon chambers with full granularity
- Reconstruction in L1 regions of interest
- Kalman filter iterative technique

Second Stage:
- Inclusion of tracker hits
- Regional tracker reconstruction
- Combine 1\textsuperscript{st}-stage objects to charged particle tracks in the tracker.
  - $p_T$ resolution much better compared to 1\textsuperscript{st} stage

Optional: Isolation in calorimeters (at 1\textsuperscript{st} Stage) and tracker (at 2\textsuperscript{nd} Stage)
Performance of Muon Triggers

- Efficiency for a high-quality offline reconstructed muon matched to L1 object to pass the HLT single muon trigger with a threshold of $p_T > 3$ GeV, plotted as a function of $p_T$
- Events collected with the minimum bias trigger
- Lower than expected efficiency due to time calibration at start-up
Jet-MET Triggers

- **Jet Triggers:**
  - Use calorimeter “towers” (HCAL + projection on ECAL)
  - Energy deposits above certain threshold
  - Use an “iterative cone algorithm” with a cone of radius:

  \[ R = \sqrt{\left( \Delta \phi \right)^2 + \left( \Delta \eta \right)^2} = 0.5 \]

- **MET Trigger:**
  - Algebraic sum of transverse energies of calorimeter objects plus muons
  - Can be used in combination with one or more jet requirement.
Performance of Jet Triggers

Efficiency for offline reconstructed jets to pass HLT jet triggers of different $p_T$ thresholds, namely 15, 30, and 50 GeV, plotted versus $p_T$. 

![Graph showing efficiency versus $p_T$ for different jet triggers.](image)
Efficiency for events recorded with a jet trigger of threshold $p_T > 6$ GeV to pass a trigger with a threshold of MET $> 20$ GeV

Efficiency for events passing an L1 trigger of threshold MET $> 20$ GeV to pass an HLT trigger with a threshold of MET $> 45$ GeV
Extrapolations accurate within 20% for most triggers (used for HLT development)
Monte Carlo predictions, using a Minimum Bias sample, match the observed rates except for those triggers susceptible to detector noise or significant cosmic muons component (e.g. HLT L1-pass-through muon triggers)
Study performed on a Minimum Bias sample of collected data (average pile up \(~ 1.5\) event/xing).

Filter farm machine specs:
- Processors: 2 Quad Core Intel® Xeon® 5430
- 2.66 GHz nominal frequency
- 16 GB of memory

Average CPU time budget at 100KHz (50KHz) of input rate is 50 ms (100 ms)

Blue curve corresponds to full pixel detector unpacking for tracking.
Conclusions

■ Full understanding of the evolution of trigger rates and CPU timing with instantaneous luminosities allowed optimal operation of the HLT.

■ Performance of Electron/Photon, Muon, and Jet/Met triggers were studied extensively.
  ■ In general, efficiency curves in very good shape at startup.
  ■ There is mostly agreement with expectations from simulation.
  ■ Discrepancies with simulation understood.

■ Outlook: the LHC machine constantly making progress towards higher instantaneous luminosities, the CMS HLT will keep adjusting quickly and optimally to these changes.
Backup: Trigger Efficiency for Photon Trigger
**Backup:** Monte Carlo Comparison for Jet Triggers

Efficiency for an offline reconstructed jet to pass an HLT trigger with a threshold of $p_T > 15$ GeV, for both data and simulation, as a function of angular variables.
Backup: Efficiency of Jet Triggers

Efficiency for an offline reconstructed jet to pass an HLT trigger with a threshold of $p_T > 15$ GeV and its corresponding L1 seed as a function of corrected and uncorrected $p_T$. 

![Graph showing efficiency vs. corrected and uncorrected $p_T$ for jets.](image)
Backup: Efficiency of Jet Triggers using muon dataset