CMS L1 Trigger

Commissioning with cosmic rays

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Outline

- LHC and CMS
- Two levels of CMS trigger: L1 and HLT
- Cosmic ray runs
- Results from cosmic ray runs
  - L1 trigger emulator studies
  - Synchronization of L1 triggers
  - Efficiencies of L1 triggers
  - Resolutions of L1 triggers
- Synchronization from LHC beam
- Summary
LHC and CMS

LHC (Large Hadron Collider)
- collides protons to protons with 14 TeV design center-of-mass energy
- first beams circulated in September 2008
- expected first collisions: end of 2009

CMS (Compact Muon Solenoid)
- multi-purpose experiment
- tracker, electromagnetic and hadronic calorimeters, and muon detectors
CMS Trigger system consists of two levels:

- **Level-1 trigger (L1)**
  - **input rate:** 1 GHz
  - **output rate:** 100 kHz
  - **custom made hardware processors**

- **High Level trigger (HLT)**
  - **input rate:** 100 kHz
  - **output rate:** 100 Hz
  - **PC farm using reconstruction software and event filters similar to the offline analysis**
The L1 trigger is based on the calorimeter and muon detectors.

At L1 we trigger on:
- 4 highest $E_T e^+/\gamma$
- 4 highest $E_T$ central jets
- 4 highest $E_T$ forward jets
- 4 highest $E_T$ tau-jets
- 4 highest $P_T$ muons

For each of these objects the rapidity, $\eta$, and $\phi$ are also transmitted to GT so HLT can seed on them.

In addition we trigger on
- inclusive triggers: $E_T, ME_T, H_T, MH_T$
- minimum-bias and zero-bias

3.2 $\mu$s latency
- cable propagation leaves 1 $\mu$s for processing
Cosmic ray runs

- CMS has collected over 300 million cosmic ray events
  - without good trigger, only very low chances to see cosmic ray muons or high-$E_T$ “jets” or “electrons”

- Cosmic ray runs help preparing for physics running
  - synchronization between trigger and data
  - trigger rates from cosmic rays and from noise
  - trigger efficiencies
  - resolutions between trigger and reconstructed objects
Trigger shifter monitoring tools

Cosmic ray runs are good opportunity to test and improve

- online software
- trigger monitoring tools
- train people for real data taking

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L1 trigger emulator

- Software that emulates bit by bit the L1 trigger subsystems
  - *it uses the same input as hardware*
  - *it produces the same output as hardware, with identical format*
  - *it uses the same configuration as the hardware*

- Excellent agreement between data and emulator
L1 trigger emulator continued

Note: the GCT data is mainly noise, thus the structures are not important!
Synchronization of muon triggers

Bunch crossing differences between L1 muon candidates created by the same cosmic muon

★ synchronization as good as one can expect from cosmic rays

★ CSC trigger timing: dashed line shows the situation before last modification

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Synchronization between L1 muon and CALO triggers

Bunch crossing differences between L1 muon candidates and calorimeter triggers

★ synchronization as good as one can expect from cosmic rays

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Efficiency of muon triggers

**DTTF trigger efficiency**
- trigger efficiency wrt stand-alone tracks
- holes: sectors masked due to hardware problems

**DTTF trigger efficiency vs $p_T$**
- masked sectors removed
- good agreement between data and MC
Efficiency of muon triggers continued

CSCTF efficiency
- tracker track extrapolated to endcap
- look for matching CSC trigger with 2 or more stations in coincidence

RPC occupancy
- during 2008 cosmic ray run
- endcaps fully ready in 2009 runs

![CSCTF Efficiency Chart](chart1.png)

![RPC Occupancy Chart](chart2.png)
**Efficiency of CALO triggers**

- E/gamma trigger efficiency turning curve
  - muon triggered events
  - reconstructed muon passing close to ECAL supercluster

**Jet trigger efficiency**
- E/gamma triggered events
  - *mainly noise with large electromagnetic fraction*

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Muon phi, eta resolution

DTTF phi resolution
- difference wrt stand-alone track
- **bottom sectors**: LHC-like muon direction
  - **observed sigma=0.021**
  - **expected sigma~0.02**

DTTF eta resolution
- difference wrt stand-alone track
- **red plot**: eta TF not fully operational in 2008 running
- **blue plot**: commissioned eta TF in 2009 running
Muon phi, $p_T$ resolutions continued

CSCTF resolutions
- require a muon on both top and bottom part of the detector
- compare the muon on bottom part to reconstructed track

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E/\gammaeta, \phi resolution

**Eta, phi correlations**
- L1 trigger object matched to closest reconstructed super cluster

**Eta, phi resolutions**
- muon triggered events
- reconstructed muon close to super cluster
- granularity of L1 e/\gamma trigger: 0.35x0.35

\*resolution width as expected
L1 synchronization to LHC beam

**Beam splash events**
- Measurement of the time delay between the Beam Pickup (BPTX) trigger and previously synchronized CSC beam halo trigger

**Circulating beams**
- Synchronization of BPTX trigger with CSC halo trigger
- CSC beam halo spread into two BX due to imperfect internal synchronization (cosmic data limitation)

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Summary

- Experience from cosmic ray runs has proved that L1 trigger runs stably and reliably

- We have performed several analysis from the L1 trigger data from cosmic rays
  - L1 trigger emulator studies
  - Synchronization of L1 triggers
  - Efficiencies of L1 triggers
  - Resolutions of L1 triggers
  - Results show good performance of the L1 trigger

- CMS L1 trigger is ready and looking forward to collision data
HLT trigger

Purely software based
  runs on a farm of commercial PCs

Less strict time constraints than L1 trigger
  average processing time 40 ms

Algorithms executed in order of increasing complexity
  Finer granularity precise measurements
  Clean particle signatures
  Kinematics, effective mass cuts and event topologies
  Track reconstruction and detector matching
  Event reconstruction and analysis

Execution of path stopped unless evidence for signal is found
L1 trigger