The CMS Muon Trigger

Outline:
- CMS trigger system
- Muon Lv-1 trigger
- Drift-Tubes local trigger
- Performance tests
CERN Large Hadron Collider

- start-up 2007
- target luminosity $10^{34}$/cm$^2$/sec
- initially $2\times10^{33}$/cm$^2$/sec
- pp interaction rate 700MHz
- bunch Xing frequency 40MHz = 1 every 25ns
- events/"active Xing"=23
- Physics Selectivity
- need 1:10$^{11}$ for exploring Higgs sector
CMS at LHC

the **Compact Muon Solenoid detector**
- omni-purpose with emphasis on muon detection
- cylinder Diam=16m, Lenght=25m, weight=14000ton
- $2\times10^7$ electronics channels

**CMS collaboration**
- 150 institutes worldwide
- 1900 scientists

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Many interesting Physics channels produce high-pt leptons. For instance:

- **Standard model Higgs**
  - $H \rightarrow ZZ^* (4 \text{ leptons})$
  - $H (< 2M_W) \rightarrow b \bar{b} (\text{lepton} + X)$

- **SUSY Higgs**
  - $h, H, A \rightarrow \tau \tau (\text{lepton} + X) \text{ or } \mu \mu$

- **Other new particles**
  - $Z' \rightarrow \text{dileptons}$
  - $\text{Leptoquark decays}$

- **Top physics**
CMS Trigger System Overview

Level-1. Specialized processors
- Particle identification: high $p_T$ electron, muon, jets, missing $E_T$
- Local pattern recognition and energy evaluation on prompt macro-granular information from calorimeter and muon detectors

High trigger levels.
- Network and CPU farms
- Clean particle signature
- Finer granularity precise measurement
- Kinematics, effective mass cuts & event topology
- Track reconstruction and detector matching
- Event reconstruction and analysis

System Lv-1 Output

40 MHz

Up to 100 kHz

$\approx 100$ Hz

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40 MHz Synchronous digital system
no deadtime: every BX is analysed
at Lv-1 only calorimeters and muon detectors
CMS Muon Detectors

Muon stations in the iron yoke

Barrel:
- Drift Tubes
- Resistive Plates
  (double gap)

End-Cap:
- Cathode Strip Chambers
- RPC

4 Stations in the barrel and each endcap

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Drift Tubes Chambers

(Aachen, Bologna, Padova, Madrid, Torino)

Each DT Chamber comprises 4 layers of DT cell in r-\(\phi\), 4 in r-\(z\) and further 4 in r-\(\phi\).

(No r-\(z\) layer in the fourth station)

Nominal Operating Parameters
- Nominal Mixture: Ar - CO\(_2\), (85% -15%)
- Nominal voltages: strips at 1800V, wires at 3600, I-Beams at -1200V
- Gain (nominal): \(9.10^4\)
- Typical charge: 1pC
architecture of the Lv-1 Muon Trigger

- **tasks of the LV-1 muon trigger:**
  - muon identification
  - transverse momentum measurement
  - bunch Xing identification
- **2 independent trigger systems in the barrel (DT+RPC)**
- **2 independent trigger systems in each end-cap (CSC+RPC)**
CMS trigger system: location of devices

- **Local trigger electronics**
  - On detector
  - DT/CSC Muon Segment generation
  - RPC Muon Hit generation

- **Regional trigger electronics**
  - In Underground shielded room
  - DT/CSC Muon Track Finder
  - RPC Muon Pattern Logic
DT local trigger overview

A single large synchronous 40 MHz digital system of 55000 ASICs
Two best muon segments on output from each chamber:

- Higher quality
- Higher Pt

Output at fixed latency after the "parent" BX
30 BXs pipeline (drift included)
DT local trigger: MiniCrate

- Local trigger electronic boards hosted in a MiniCrate inserted in the chamber mechanical structure
  - Fewer cable connections
  - Reliability issue
  - Access to ASICs for test and configuration via
    - JTAG
    - Custom Parallel Interface

Highly compact 16-layer-boards with a 100-line bus interconnection

TRACO ASICs  TSS ASICs  TSM: 3 pASICs

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DT local trigger: Robustness

- Highly segmented system (SORT TREE):
  - 4 to 6 Trigger Boards with 32BTIs, 4TRACOs, 1TSS
  - Each TRACO covers 20cm of a DT ch. (Rϕ)
- Trigger Server Board has 3 pASICs with redundant functionalities, which have separate power- and control- lines
During LHC running for the CMS Muon barrel it is predicted:
- Total neutron flux $3 \times 10^{10} / \text{cm}^2$ in 10 years
- Flux of $>20 \text{MeV n}$ $1 \times 10^9$
- Total Ionizing Dose 0.01 Krad

All on-chamber electronic components passed irradiation tests also using a high intensity 60 MeV proton beam
- Single-Event-Effect Xsec measured for each active component
- Single Event Upset rate for the whole DT system estimated in a few instances per year of LHC running

**pASIC irradiation test at the CRC of UC Louvain (Belgium)**
System integration tests have been carried out for over a year. A full DT chamber equipped with MiniCrate has been exposed to the muon 40MHz bunched beam @ the CERN H6 beamline from May 24 to June 1, 2003.

About 15’000’000 triggers were collected in 7 angular orientations (-30deg to +45deg) and 17 different BTI-TRACO-TSS-TSM configurations. Analysis of these data will allow thorough characterization of the performance and fine tuning of the simulation. They can also be used as input patterns for testing the DT Track Finder.

Preliminary results are in agreement with expectations:
- ≈98% efficiency of finding a muon segment at the correct bx
- <1mm segment position uncertainty
- 5 to 20 mrad segment direction uncertainty, depending on segment quality (two or one super-layer used)
DT regional trigger: Track finder processor

(Vienna)

- Accepts DT segments from 4 stations in a sector + neighbours
- Accepts also CSC segments in “overlap” $\eta$ region
- Combines segments into full tracks
- Assigns $Pt, \eta, \phi$, quality to each muon track

Pairwise Matching - Extrapolation
- Track finder processor
- Accepts DT segments from 4 stations in a sector + neighbours
- Accepts also CSC segments in “overlap” $\eta$ region
- Combines segments into full tracks
- Assigns $Pt, \eta, \phi$, quality to each muon track

72 VME boards in Counting Room

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Lv-1 DT trigger: expected performance

- **Chamber local trigger** has a very efficient and configurable filter against fake and duplicate track segments
- **Reliable dimu trigger**

### Efficiency for 2\textsuperscript{nd} track
- Efficiency for 2\textsuperscript{nd} track in open pairs: 98%
- Prob. of correct ID of both tracks in open pairs: 95%
- Prob. of generating a fake 2\textsuperscript{nd} track (in one muon events): < 4%

Regional trigger has a sharp rise of the efficiency to identify a muon above a Pt threshold as function of generated Pt

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**global muon trigger: expected performance**

- System simulation on single muon generated events show:
  - 96% efficiency for finding at least one muon in $0<|\eta|<2.4$
  - 0.2% "ghost" dimuons

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**Efficiency (%)**

![Graph showing efficiency of muon trigger systems with different components: DTBX, CSC, RPC, GMT.](image-url)
Lv-1 Muon trigger rates

iso-rate curves (KHz); |η|<2.1

ε_W 90%
ε_Z 99%
ε_{H(150)} \rightarrow ZZ^* \rightarrow 4μ 98%

ε_W 82%
ε_Z 97%
ε_{H(150)} \rightarrow ZZ^* \rightarrow 4μ 98%

working points selected as examples

\[ L = 2 \times 10^{33} \text{cm}^{-2}\text{s}^{-1} \]

50KHz DAQ / 4 KHz for μ, μμ

\[ L = 10^{34} \text{cm}^{-2}\text{s}^{-1} \]

100KHz DAQ / 8 KHz for μ, μμ

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summary

- The CMS trigger system consists of
  - a Lv-1 trigger implemented with custom electronics
  - a High-Level trigger selection running in CPU farms
- The Lv-1 system has to select 1 in $\approx 10^3$ LHC bunch Xings with no dead time and an output rate <100KHz
- The Muon Lv-1 trigger utilizes signals from 3 independent detectors (DriftTubes and ResistivePlateCh in the CMS barrel; CathodeStripCh and RPC in the end-caps)
- The DriftTubes Lv-1 local trigger is a large synchronous 40 MHz digital system of 55000 ASICs in minicrates on the DT chambers. It provides:
  - muon track segment position and Pt measurement
  - bunch Xing identification
- the Minicrate electronics has performed very successfully in a test with the CERN “LHC-like” 40 MHz bunched beam