The CMS Muon Detector

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• General Overview

• Drift Tubes

• Cathode Strip Chambers

• Resistive Plate Chambers

• Global Muon Trigger

• Conclusions
The CMS Muon detector is made of 3 different sub-detectors to ensure redundancy and robustness:

- Drift Tubes (DT) in the barrel region
- Cathod Strip Chambers (CSC) in the endcap region and
- Resistive Plate Chambers (RPC) as dedicated trigger detectors in both the barrel and the endcap
The CMS Muon Detector

5 wheels in the Barrel

30° (φ) sectors

Z = -2, -1, 0, 1, 2 according to the Barrel wheel concerned

4 layers of Muon chambers covering up to |η|=2.4, providing ≥3 track segments along a muon track
• Muon ID with at least 16 $\lambda$ down to $|\eta|=2.4$
• Standalone transverse momentum res. 8-15% $\delta p_t/p_t$ (at 10 GeV), 20-40% $\delta p_t/p_t$ (at 1 TeV)
• Global momentum resolution 1.0-1.5 % $\delta p_t/p_t$
• Unambiguous BX identification
• Single and di-muon first level trigger with variable $p_t$ thresholds down to $|\eta|=2.1$
• Correct charge assignment up to $p=7$ TeV
• Ability to withstand the highest radiation and interaction background foreseen at the LHC
Drift Tubes layout

- MB1,2,3 = 8 \(\phi\)-layers + 4 \(\theta\)-layers
- MB4 = 8 \(\phi\)-layers
- 250 chambers
- 200000 channels

- wire pitch = 4.2 cm
- max. drift time = 380 ns
DT basic cell design

New design:

Nominal voltages
- 1800 V
- 3600 V
- -1200 V

Requirements
- Single cell space resolution ≤ 250 μm
- Chamber space resolution ~ 100 μm
- BX tagging efficiency ≥99%, trigger space res. 1-2 mm

Gas mixture
- Ar(85%) + CO₂(15%)
**DT time resolution**

**Drift Time**

Simulation
test beam 2000

**Time Spectrum from TDC**

- Meantimer run 842 (all cells together)
  - $\chi^2$/ndf: 87.90 / 21
  - Constant: 1899.1
  - Mean: 368.1
  - Sigma: 4.585

- $\chi^2$/ndf: 83.43 / 20
  - Constant: 1997.4
  - Mean: 368.7
  - Sigma: 4.362

**Preliminary:**
- $v_{\text{drift}} = 57 \mu m/\text{ns}$
- Resol. = 208 $\mu m$

**HV:** 3600/1800/-1200 V
Q4: Single wire resolution (test beam 1999)


\[ B_{\text{perp}} = B \cos(\phi) \]

\[ B_{\text{par}} = B \sin(\phi) \]

\( v_{\text{drift apparent}} \)

\( \text{efficiency} \)

\( \text{resolution} \)

![Graphs showing drift velocity, cell efficiency, and resolution vs. magnetic field for different \( \phi \) values]
DT Local Trigger

50 000

4 400

250

TST = Trigger Server θ
TSS = Track Sorter Slave
TSMS = Track Sorter Master (sort)
TSMD = Track Sorter Master (data)
Barrel track finder

Pairwise Matching - Extrapolation

Track Assembler

Assignment Unit

72 VME boards in Counting Room

extrapolation window

muon station 4

track segment

muon station 3

muon station 2

muon station 1

\( \phi_2 - \phi_1 \)

72 VME boards in Counting Room
CSC layout

540 Chambers
400,000 readout channels
Sensitive area 6,000 m² (all planes)
Offline spatial resolution ~100 μm
Trigger spatial precision ~1-2 mm
Trigger bunch-tagging efficiency ~99%
Endcap Muon System

Large 10° (3.4x1.5 m²):
72 ME2/2 chambers
72 ME3/2 chambers
(72 ME4/2 chambers)

Small 10° (1.8x1.1 m²):
72 ME1/1 chambers
72 ME1/2 chambers
72 ME1/3 chambers

Small 20° (1.9x1.5 m²):
36 ME2/1 chambers
36 ME3/1 chambers
(36 ME4/1 chambers)

Environment

- random hit rates
  up to 1000 Hz/cm²
  20 kHz/channel
  4 times larger than mip signals
- punch-through rates
  up to 100 Hz/cm²
  penetrate through all six planes of a chamber
- B-field
  3.5 T and uniform in ME1/1
  0-1 T and very non-uniform in some others
CSC conceptual design

CSCs will
- satisfy the performance requirements,
- while operating in the CMS/LHC environment

Conceptual design of a CMS EMU CSC

Wires
- trapezoidal chambers
- length up to 3.4 m
- width up to 1.5 m
- 6 planes per chamber
- 9.5 mm gas gap (per plane)

Strips
- 6.7 to 16.0 mm strip width
- strips run radially to measure
- \( \phi \)-coordinate with \( \sim 100 \mu \text{m} \) precision

- 50 \( \mu \)m wires spaced by 3.2 mm
- 5 to 16 wires ganged in groups
- wires measure \( r \)-coordinate

- gas \( \text{Ar}(40\%)+\text{CO}_2(50\%)+\text{CF}_4(10\%) \)
- HV\( \sim 3.6 \text{ kV} \) (\( Q_{\text{cathode}} \sim 110 \text{ fC} \), \( Q_{\text{anode}} \sim 140 \text{ fC} \)
CSC time and space resolution

- Bunch tagging ID efficiency ~99% at maximum LHC rates
- Spatial resolution <100 µm even for very wide strips:
  - □ strip width = 16 mm
  - ○ strip width = 12 mm
  - Δ strip width = 8 mm

single-plane resolution
CSC Anode Trigger

Time spread per plane is broad: drift, noise, fluctuations in cluster formations

A pattern of anode hits, or LCT for Local Charged Track, consistent with a muon track (i.e., pointing back to IP) is searched for (to ensure time overlap, signals are shaped to last 150 ns)

2nd (or 3rd) earliest hit in LCT has a much narrower distribution and can be used for reliable bunch crossing tagging

sigma = 3.9 ns
**CSC Cathode trigger**

First, hits are localized with precision of a half-strip:
- $Q > \text{threshold}$
- $Q > Q_{\text{right}}$
- $Q > Q_{\text{left}}$
- $Q_{\text{right}} > Q_{\text{left}}$

Then, a track-like pattern of half-strips is searched for (LCT--local charged track).

Expected precision:
- $(w/2)/\sqrt{12} = 0.14\ast w$ for normal incidence
- for wide-spread angles it should be even better
CSC Trigger

Disk periphery

From DT Track-Finder

MB1 DT TF

Sector Processor

SP 12

3μ / sector

From CSC Port Cards

ME4 ME2-ME3 ME1 SR 36

3μ / port card

Sector Receivers

CSC Muon Sorter

MS 1

To Global Muon Trigger

GMT

DT TF 4μ

8μ RPC

works in 3D

θ

φ
RPC layout

Barrel RPC:
- RB 1,2 = 2 layers
- RB 3,4 = 1 layer
- 480 rectangular chambers
- 75,000 strips || beam

Endcap RPC:
- RE 1,2,3,4 = 1 layers
- 540 trapezoidal chambers
- 80,000 radial strips
**RPC double gap design**

- 2 mm double gap
- bakelite resistivity: $2-5 \times 10^{10} \Omega$ cm
- bakelite thickness: 2 mm
- gas mixture: $95.5\% C_2H_2F_4 + 4.5\%$ iso-$C_4H_{10}$
- operating voltage: ~9 kV

**Strip pitch**

$$\Delta \eta \times \Delta \phi \sim 0.1 \times 5/16^0 = 20-100 \text{ cm} \times 1-4 \text{ cm}$$

**CMS barrel**

Trapezoidal strips and chambers

**CMS endcap**
RPC efficiency and cluster size

98.5% HV=10.4 kV
95% HV=10.1 kV
93% HV=10.5 kV

- Cluster size < 2.3 strip
- Cluster with more than 7 strips < 5%

![Graph showing efficiency and cluster size](image)
RPC time resolution

HV=10.5 kV
Rate 540 Hz/cm$^2$

ABS 1

σ < 1.6 ns
RPC Trigger algorithm

Pattern of hit strips is compared to predefined patterns corresponding to various $p_T$

PAttern Comparator (PAC) ASIC

4752 ASICs in Counting Room
Muon Trigger geometry

4 Stations in the barrel and each endcap
Global Muon Trigger

- DT hits
  - local trigger
    - track segments
      - $(\phi, \delta\phi, \eta, \delta\eta)$
  - regional trigger
    - Barrel Track Finder
      - $\leq 4$ muon candidates
        - $(p_t, \eta, \phi, \text{quality})$

- CSC hits
  - local trigger
    - track segments
      - $(\phi, \delta\phi, \eta, \delta\eta)$
  - regional trigger
    - Endcap Track Finder
      - $\leq 4$ muon candidates
        - $(p_t, \eta, \phi, \text{quality})$

- RPC hits
  - PAttern Comparator Trigger
    - $\leq 4$ barrel + $\leq 4$ endcap muon candidates
      - $(p_t, \eta, \phi, \text{quality})$

- Global Muon Trigger
  - $\leq 4$ muons
    - $(p_t, \eta, \phi, \text{quality})$
**Muon Trigger rates vs. $p_t$**

- Curves show individual DT, RPC & CSC & 3 Global Muon Trigger Combinations:
  - OR, AND, & optimized selection based on track quality & $p_t$ information
- Single muon trigger rate is 8.1 kHz for a threshold of 25 GeV (90% efficient)
- Dimuon muon trigger rate is 2.8 kHz for thresholds of 8, 5 GeV (90% efficient)
Global Muon Trigger Efficiency

Efficiency (%)

0 20 40 60 80 100

0 0.5 1 1.5 2 2.5

η_{gen} (units)

Barrel Track Finder

Endcap Track Finder

DT

RPC

CSC

DTBX

CSC

DTBX or CSC

RPC

GMT
Muon trigger rates turn-on curves
Conclusions

• The CMS Muon detector will provide good muon identification with 4 independent measurements down to $|\eta|=2.4$

• The Muon detector will provide unambiguous BX identification and single and di-muon first level triggers with very high efficiency

• Test-beam results have proven that the CMS Muon detector will be able to meet the requirements even at the highest LHC luminosities

• The production of DTs, CSCs and RPCs has started and the detectors will be operational for the first physics runs of LHC, foreseen in the summer of 2006