Muon Detectors in CMS

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Exploit full potential of LHC physics with muons

- Higgs decays (4µ, 2µ), SUSY (multi-lepton), top, Z’, B physics
- Quarkonia in Heavy Ion collisions

Requires reliable offline muon identification for η < 2.4

Muon trigger capability for η < 2.1, with p_T thresholds from a few GeV to 100 GeV

Precision $\Delta p_T / p_T$ measurements for muons with $p_T < 100$ GeV:

- ~2% resolution in combination with the central tracker
- ~10% standalone resolution

Muon sign determination with 99% confidence level up to the LHC kinematic limit ($p < 7$ TeV)
CMS Muon Detectors

Three technologies:

**Drift Tubes (DT)**
- Central coverage: $|\eta| < 1.2$
- Measurement and triggering
- 12 layers each chamber: 8 in $\phi$, 4 in $z$

**Cathode Strip Chambers (CSC)**
- Forward coverage: $0.9 < |\eta| < 2.4$
- Measurement and triggering
- 6 layers each chamber: each with $\phi$, $z$

**Resistive Plate Chambers (RPC)**
- Central and Forward coverage: $|\eta| < 2.1$
- Redundancy in triggering
- 2 gaps each chamber, 1 sensitive layer

Traditional technology for low occupancy

Designed for high B-fields and neutron backgrounds up to $1 \text{ kHz} / \text{cm}^2$
Quarter Cross-Sectional View

Rapidity coverage: $|\eta| < 2.4$

Muon momentum measurement uses return field of iron yoke
DT Barrel Muon System

4 stations in radius
5 wheels in z
250 drift chambers
Staggered in $\phi$
DT Chamber – XY View

2 superlayers in $\phi$
1 superlayer in $z$

Each superlayer has 4 layers of drift-tubes

Dimensions:

$27 \text{cm} \times 200 - 400 \text{ cm} \times 250 \text{ cm}$

$13 \text{ mm}$ resolution for single cell

$100 \text{ mm}$ resolution for chamber

Ar/CO$_2$ gas mixture

400 ns maximum drift time

250 $\mu$m resolution for single cell

100 $\mu$m resolution for chamber

Anode wire $+3.6 \text{ kV}$

Electrode $+1.8 \text{ kV}$

Cathode $-1.8 \text{ kV}$
DT Local Trigger

Bunch & Track Identifier (BTI) uses shift registers to search for patterns and to assign correct BX

Track Correlator (TRACO) correlates segments in inner and outer superlayers to improve measurement

Trigger Server chooses best 2 segments per chamber
CSC Endcap Muon System

2 endcaps
4 stations (disks) in z
2 or 3 rings in radius
540 chambers
6000 m² active area
2.5 million wires
0.5 million channels

Chambers overlap in $\phi$ and $\eta$
**Cathode Strip Chambers**

- Up to 3.4 m long, 1.5 m wide
- 6 planes per chamber
- 9.5 mm gas gap (per plane)

- 50 µm wires spaced by 3.2 mm
- 60 ns maximum drift-time per plane
- 5 to 16 wires ganged in groups
- Wires measure $r$

- 6.7 to 16.0 mm strip width
- Strips run radially to measure $\phi$
- 150 µm resolution for chambers (75 µm in station 1)

- Gas: Ar(40%) + CO$_2$(50%) + CF$_4$(10%)
- HV ~3.6 kV
- B-field up to 3 T in station 1
CSC Electronic Readout

100 ns pre-amp

SCA analog storage

ADC

Comparator (for trigger)

Time (50 ns/bin)

Amplitude

μ

Planes

Strips

γ-rays from n background

CMS Muon Detectors, H.I. Workshop, Feb. 2002

Darin Acosta
CSC Local Charged Track Trigger

Efficiency to get the right bunch crossing at the optimal phase is >98%
Resistive Plate Chambers

Double-gap design:
- 2 gaps with common pick-up
- Gap width: 2 mm
- Bakelite thickness: 2 mm
- Bakelite bulk resistivity: $1-2 \times 10^{10} \, \Omega \, \text{cm}$
- Gas mixtures: $C_2H_2F_4$ (95%), $i-C_2H_{10}$ (5%)
- Operating High Voltage: 8.5 – 9.0 kV
- Mode of operation: avalanche, not streamer
- 3 ns time resolution

![Graphs showing event distribution and intrinsic chamber delay for single and double gaps.](image)
RPC Muon System

- **612 total chambers**
- **Six barrel stations in radius**
  - Long strips in barrel ⇒ high intrinsic noise rate (~50 Hz/cm²)
  - Linseed oil applied to surfaces to reduce noise
  - Trigger makes use of all 6 stations
- **Four endcap stations in z**
  - Rate capability to 1 kHz/cm² using avalanche mode
CMS Muon Momentum Resolution

**Standalone**
Tracking Resolution—Muon System with Vertex Constraint

**Combined with Tracker**
Tracking Resolution—Muon System with Inner Tracker

- $\Delta p_T / p_T$ for different $p_T$ values:
  - $p_T = 1000$ GeV
  - $p_T = 100$ GeV
  - $p_T = 50$ GeV
  - $p_T = 25$ GeV
  - $p_T = 10$ GeV
CMS Level-1 Muon Trigger

RPC:
- Pattern Comparator Trigger applies coincidence logic along roads in $\eta$ and $\phi$
  \[ \Delta\eta \times \Delta\phi = 0.1 \times 0.005 \]

DT and CSC:
- “Track-Finders” apply tracking algorithms and swim track segments to next stations using fine $\phi$ information
  \[ \text{CSC Track-Finder swims in 3D to reduce backgrounds, handle non-axial B-field} \]

Global Muon Trigger:
- Combines DT and CSC muons with RPC patterns to reduce rate and improve efficiency
- Programmable $p_T$ thresholds from 1 to 140 GeV/c
- Single and di-muon trigger topologies
  \[ \eta, \phi \text{ topology selections, calorimeter isolation} \]
Level-1 Trigger Efficiency vs. $\eta$

Overall high efficiency over $|\eta| < 2.1$ when systems combined.
Minimum Trigger Threshold

**p_T vs. η**

Barrel: $p_T > 4$ GeV

- $p_T$ vs. $\eta$
- Efficiency:
  - $< 95\%$
  - $< 90\%$
  - $< 80\%$
  - $< 50\%$

- Error bars: $1\lambda = 16\text{cm Fe}$
  - $0.2\text{ GeV}$ (barrel)
  - $0.2\text{ GeV} \tan \theta$ (endcap)

**p vs. η**

Endcap: $p > 7$ GeV

- $p$ vs. $\eta$
- Efficiency:
  - $< 95\%$
  - $< 90\%$
  - $< 80\%$
  - $< 50\%$

- Error bars: $1\lambda = 16\text{cm Fe}$
  - $0.2\text{ GeV} / \sin \theta$ (barrel)
  - $0.2\text{ GeV} / \cos \theta$ (endcap)
Level-1 Trigger Rates

**pps, L = 10^{34}**

- Trigger Rate (Hz)
- |η| < 2.4

**Pb-Pb, L = 10^{27}**

- Integrated trigger rate (Hz)
- |η| < 1.5

**Sufficient p_T resolution to provide handle for rate reduction**
Conclusions

CMS has nearly hermetic and redundant muon coverage over the region $|\eta| < 2.4$ using 3 detector technologies

Designed to achieve LHC physics goals including heavy-ions

$p_T$ Resolution:
- $\sim 10\%$ standalone measurement
- $\sim 2\%$ when combined with tracker

Single and Di-muon trigger capability for $|\eta| < 2.1$ with $p_T$ thresholds from few GeV to 100 GeV

Mass production of chambers has already begun