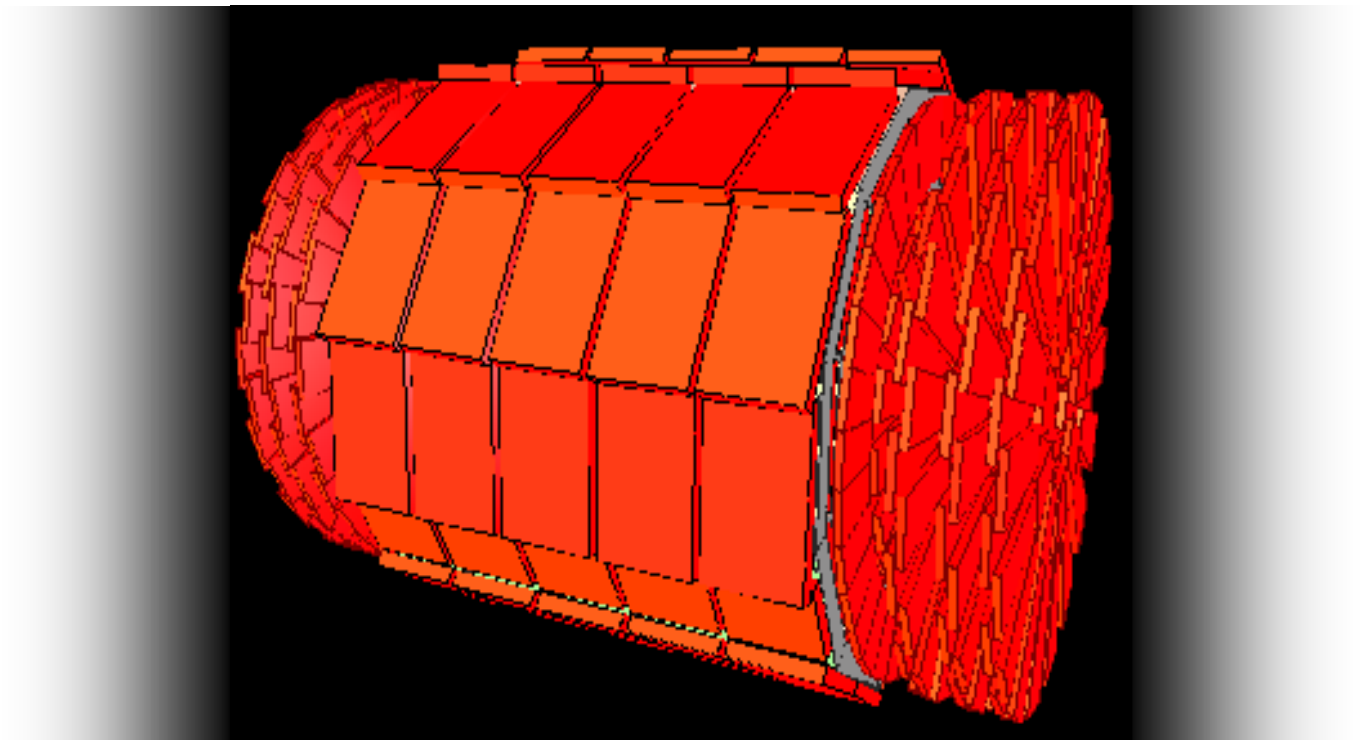
# Muon Detectors in CMS



Darin Acosta
University of Florida

# CMS Muon System Design Goals

**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 $\eta < 2.4$**

**Muon trigger capability for $\eta < 2.1$, 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

Traditional technology for low occupancy

### Cathode Strip Chambers (CSC)

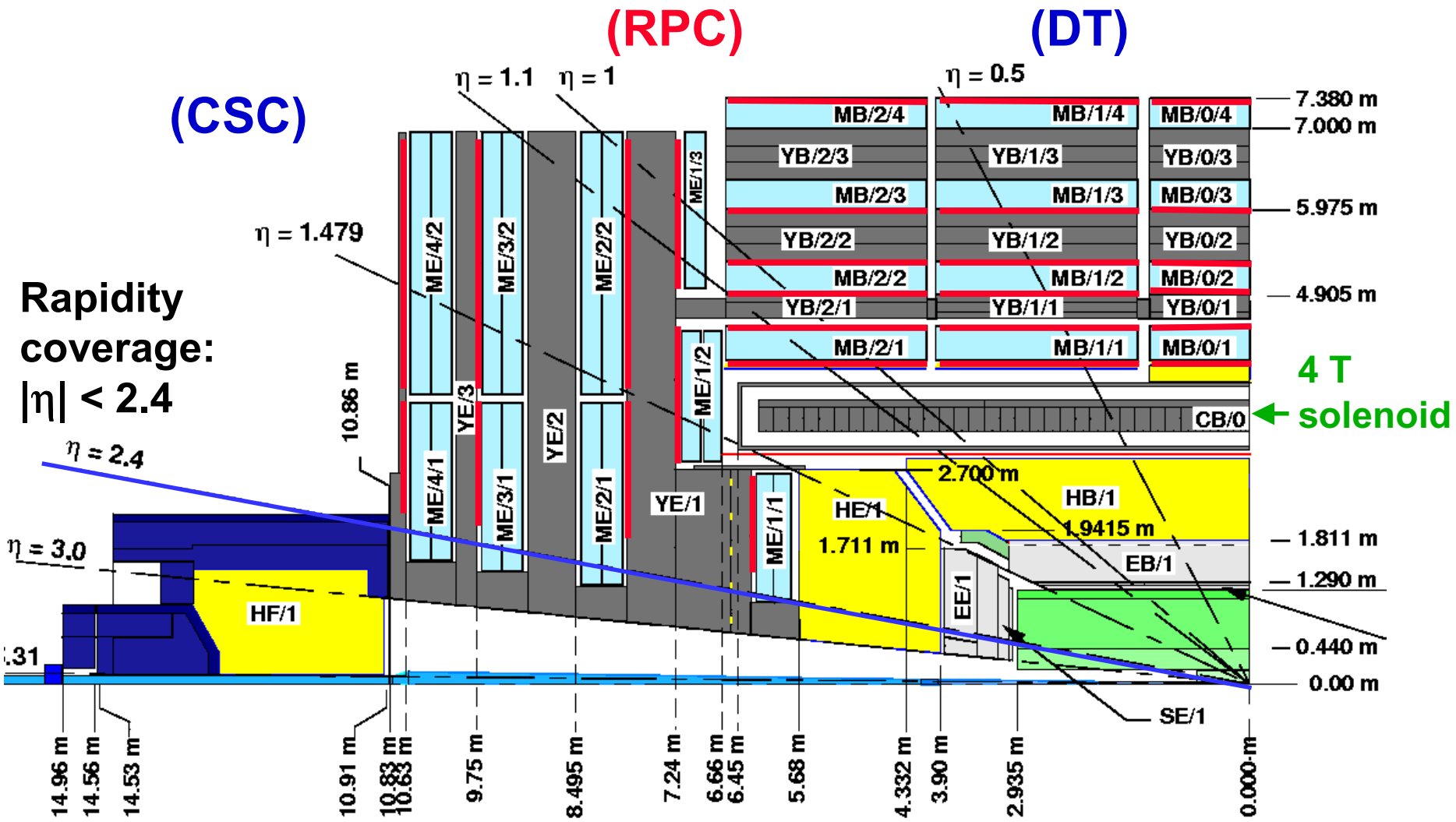
- Forward coverage: $0.9 < |\eta| < 2.4$
- Measurement and triggering
- 6 layers each chamber: each with $\phi$, z

Designed for high B-fields and neutron backgrounds up to 1 kHz / $cm^2$

### Resistive Plate Chambers (RPC)

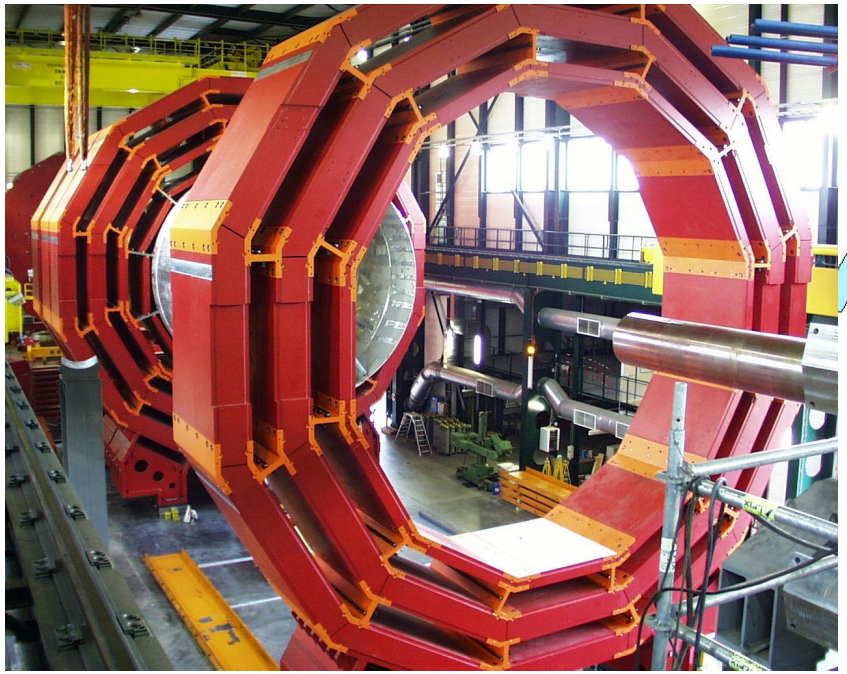
- Central and Forward coverage: $|\eta| < 2.1$
- Redundancy in triggering
- 2 gaps each chamber, 1 sensitive layer

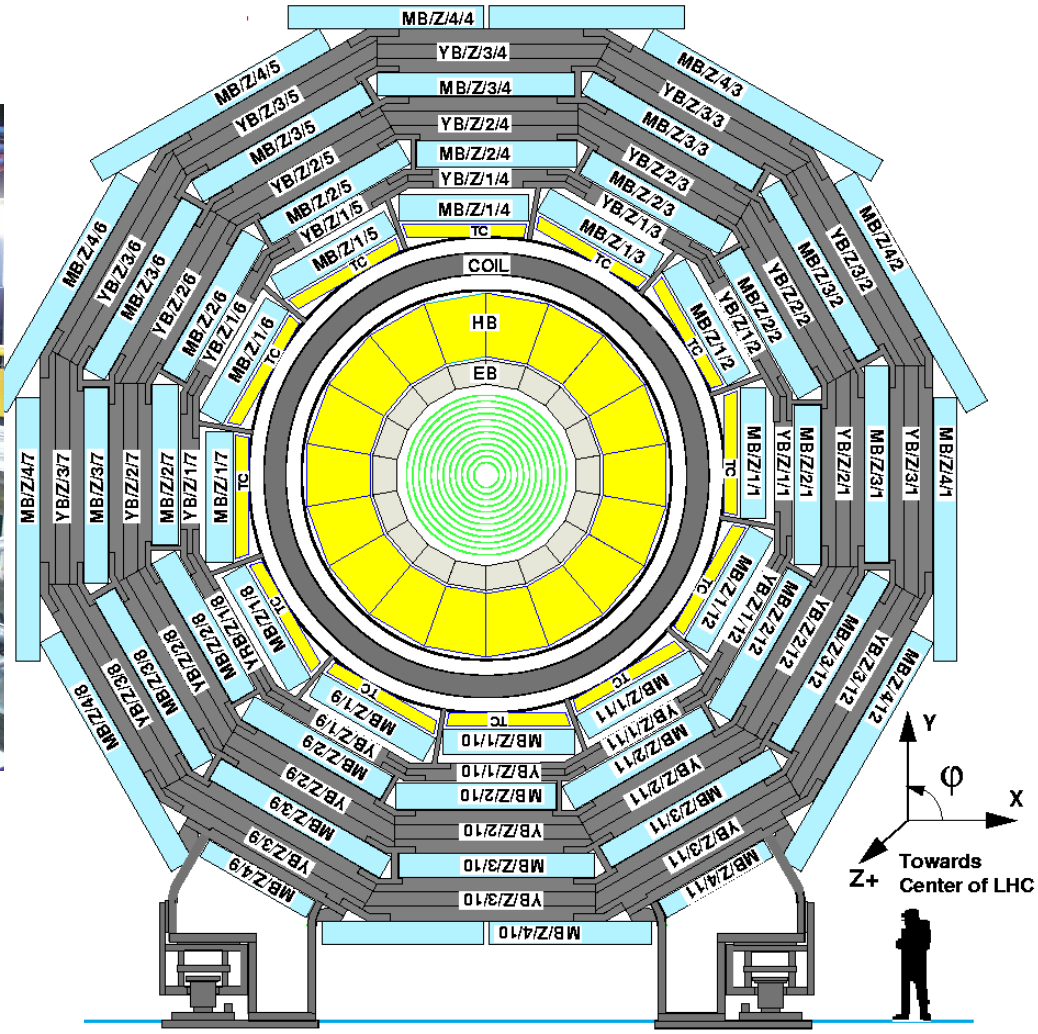
# Quarter Cross-Sectional View




**Muon momentum measurement uses return field of iron yoke**

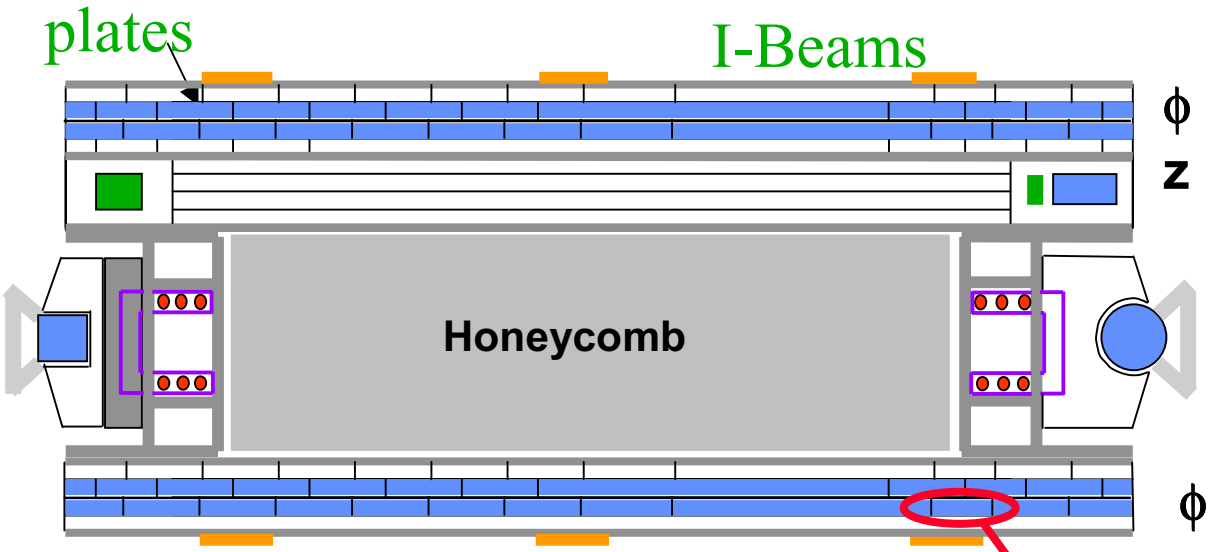
# DT Barrel Muon System






**4 stations in radius**
**5 wheels in z**
**250 drift chambers**
**Staggered in $\phi$**

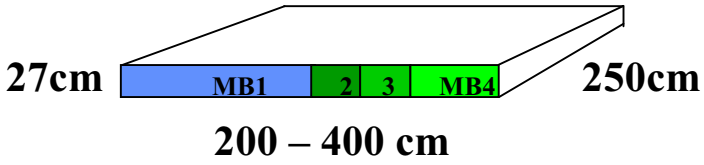
# DT Chamber – XY View

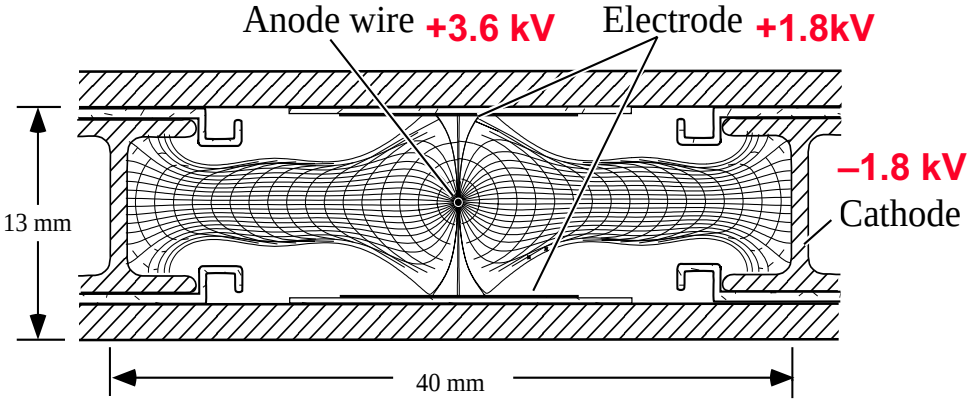



**2 superlayers in ϕ**
**1 superlayer in z**

**Each superlayer has**
**4 layers of drift-tubes**

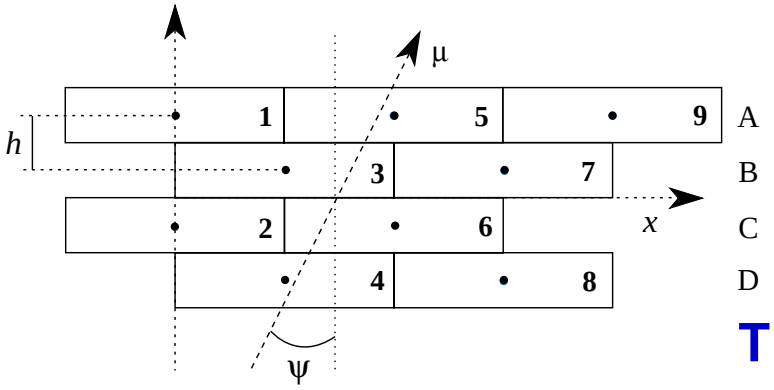
**Dimensions:**




**Ar/$CO_2$ gas mixture**
**400 ns maximum drift time**
**250 μm resolution for single cell**
**100 μm resolution for chamber**

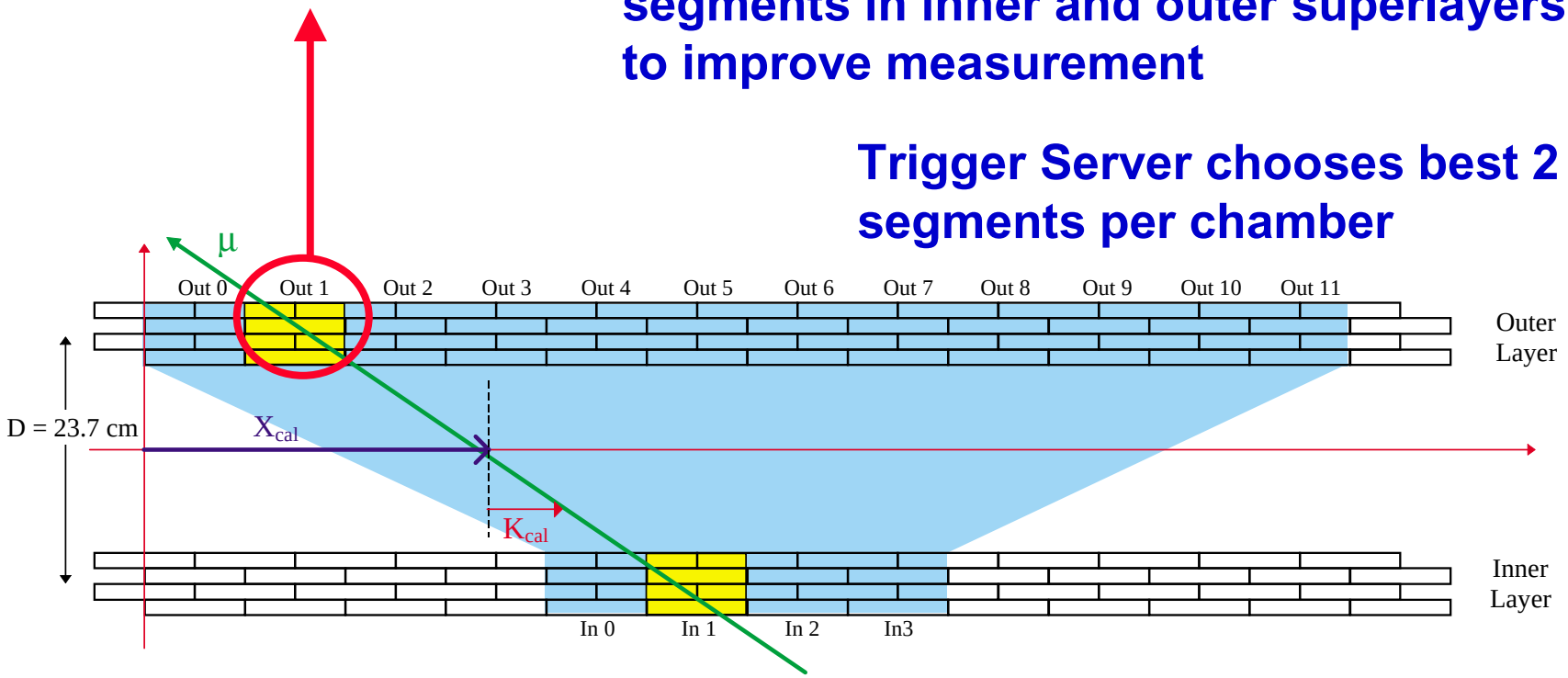
# DT Local Trigger



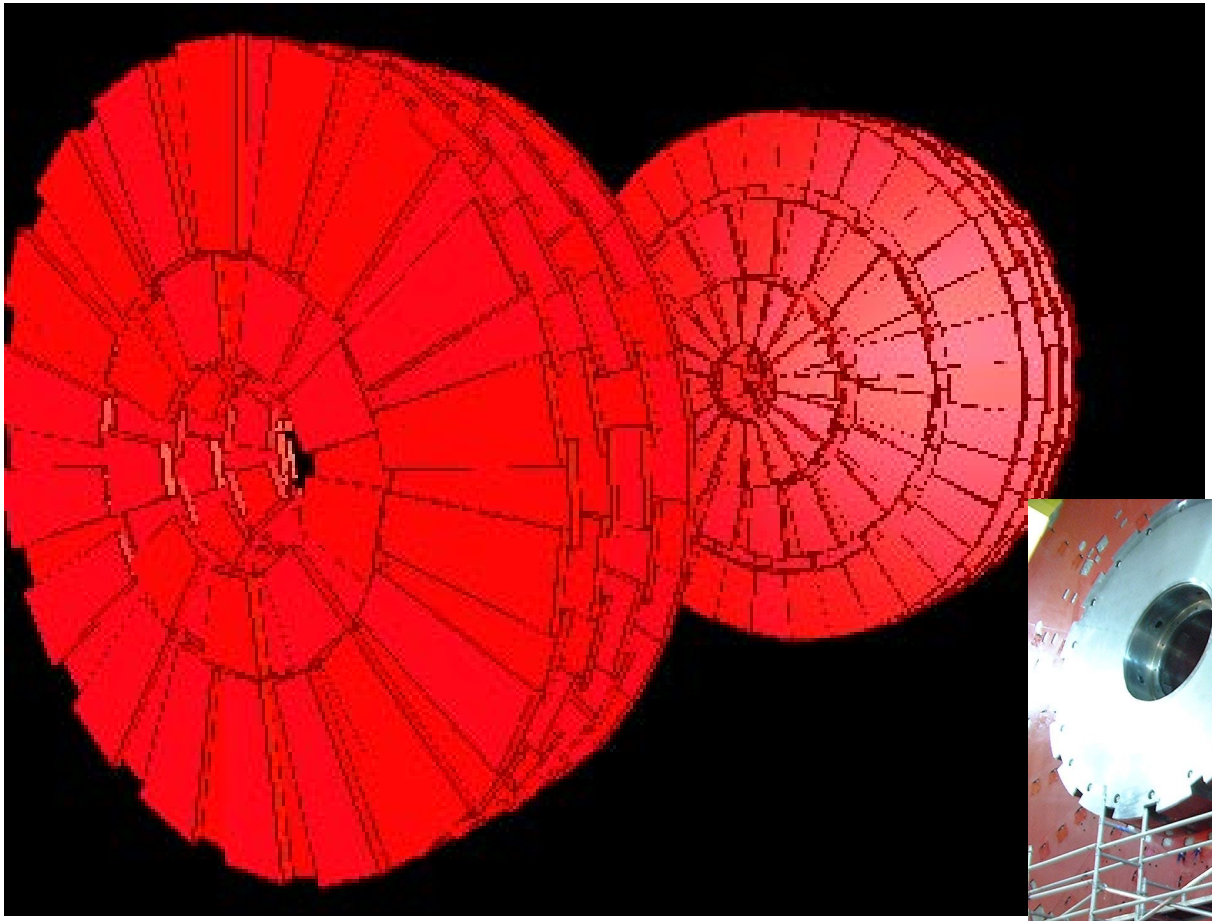

**Bunch & Track Identifier (BTI) uses shift registers to search for patterns and to assign correct BX**

**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 $m^2$ active area
2.5 million wires
0.5 million channels


Chambers overlap in $\phi$ and $\eta$

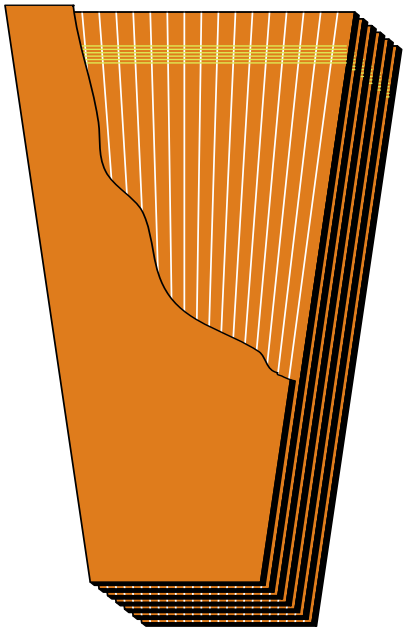
# Cathode Strip Chambers

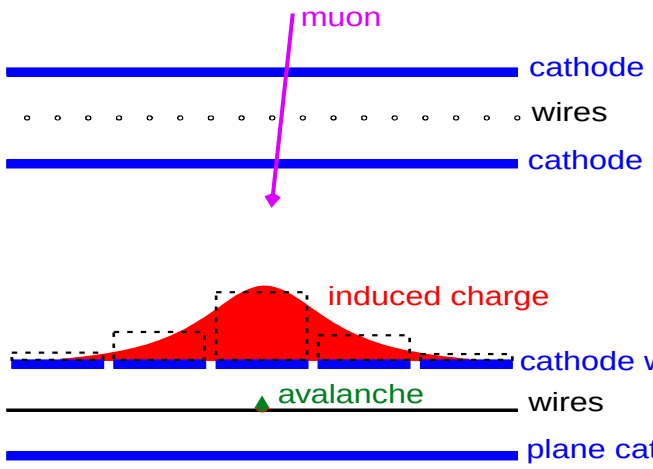
- Up to 3.4 m long, 1.5 m wide
- 6 planes per chamber
- 9.5 mm gas gap (per plane)

- 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

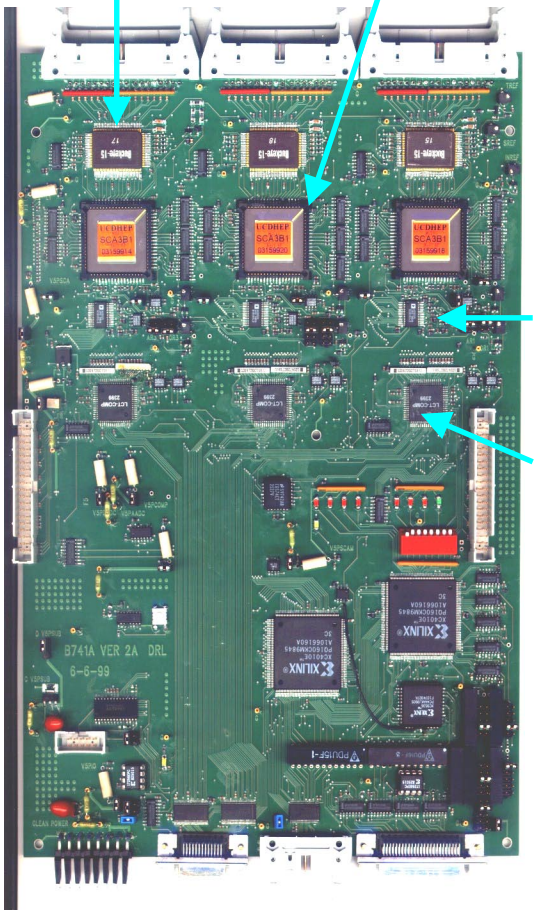
- 6.7 to 16.0 mm strip width
- Strips run radially to measure $\phi$
- 150 μm resolution for chambers (75 μm in station 1)

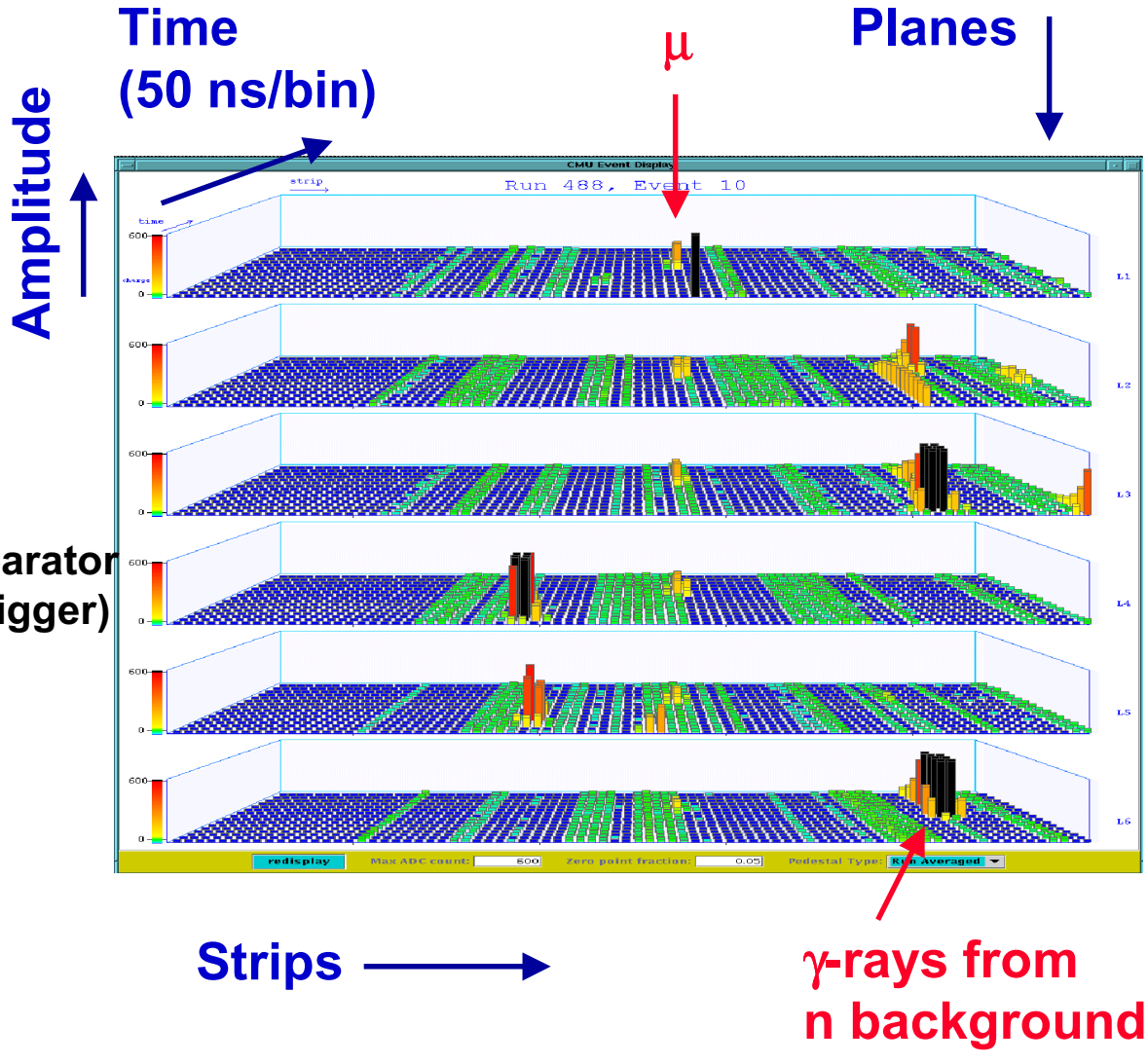
- Gas: Ar(40%)+$CO_2$(50%)+$CF_4$(10%)
- HV ~3.6 kV
- B-field up to 3 T in station 1





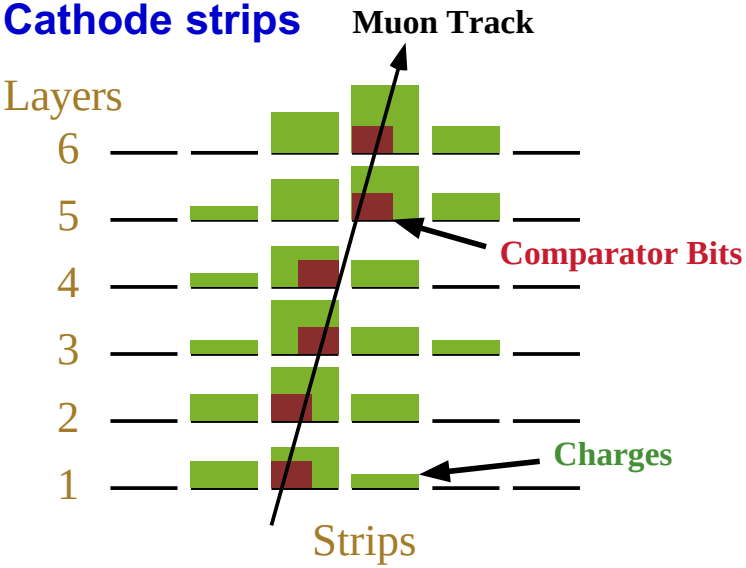
# CSC Electronic Readout



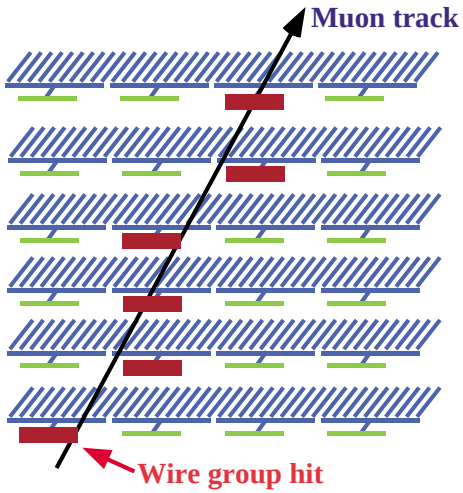



# CSC Local Charged Track Trigger

**Cathode strips**

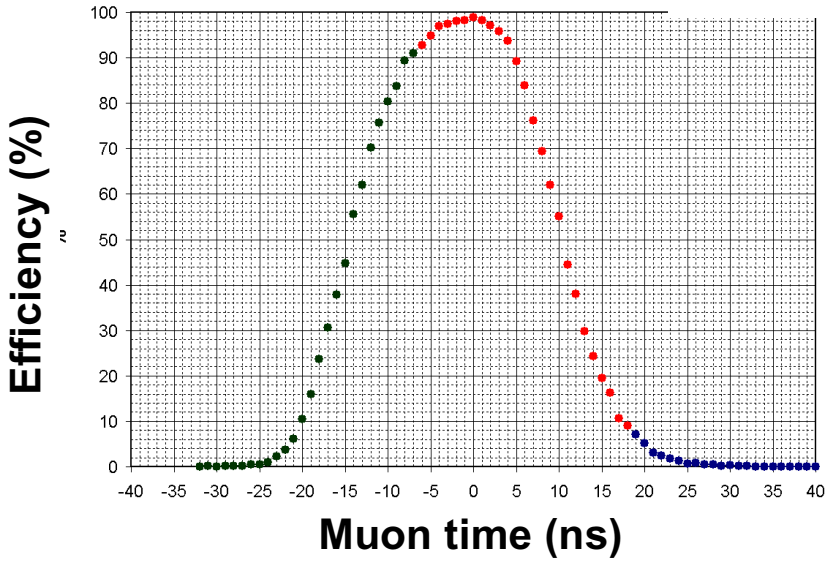



**Anode Wire Group Hits**




**~1 mm position resolution**

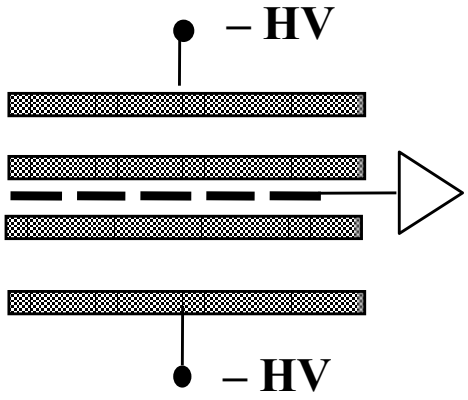
**Efficiency to get the right bunch crossing at the optimal phase is >98%**

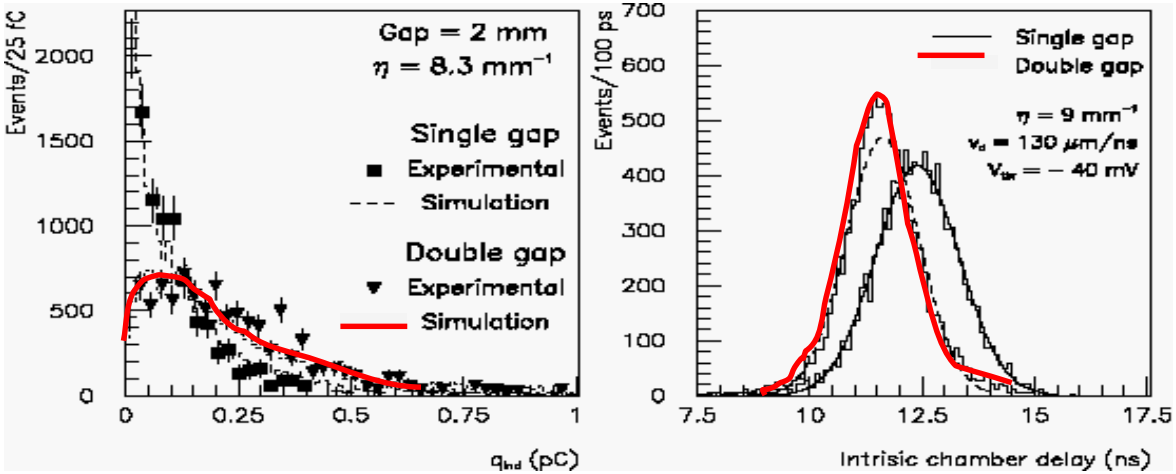


# Resistive Plate Chambers

## Double-gap design:

- 2 gaps with common pick-up
- Gap width: 2 mm
- Bakelite thickness: 2 mm
- Bakelite bulk resistivity: $1–2\times10^{10}\ \Omega$ 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

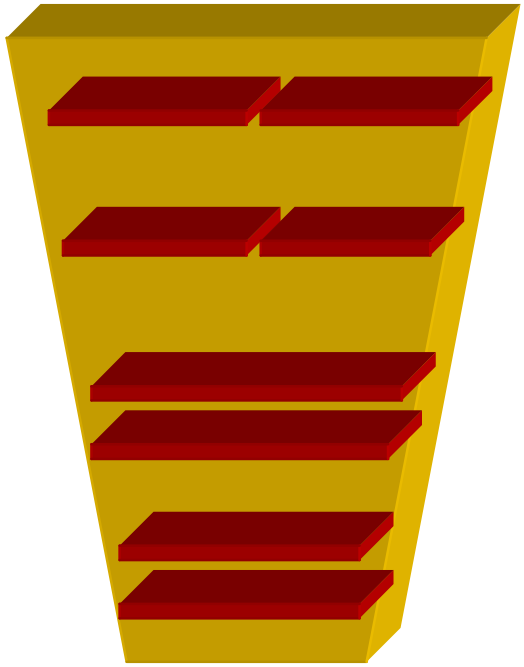


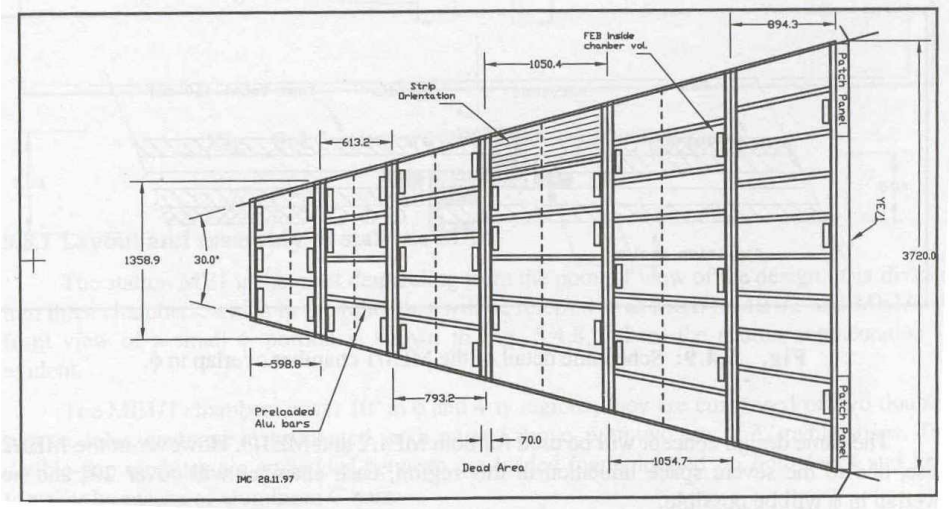



# RPC Muon System

- 612 total chambers
- Six barrel stations in radius
  - Long strips in barrel ⇒ high intrinsic noise rate (~50 Hz/cm$^2$)
  - 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/cm$^2$ using avalanche mode

Barrel sector



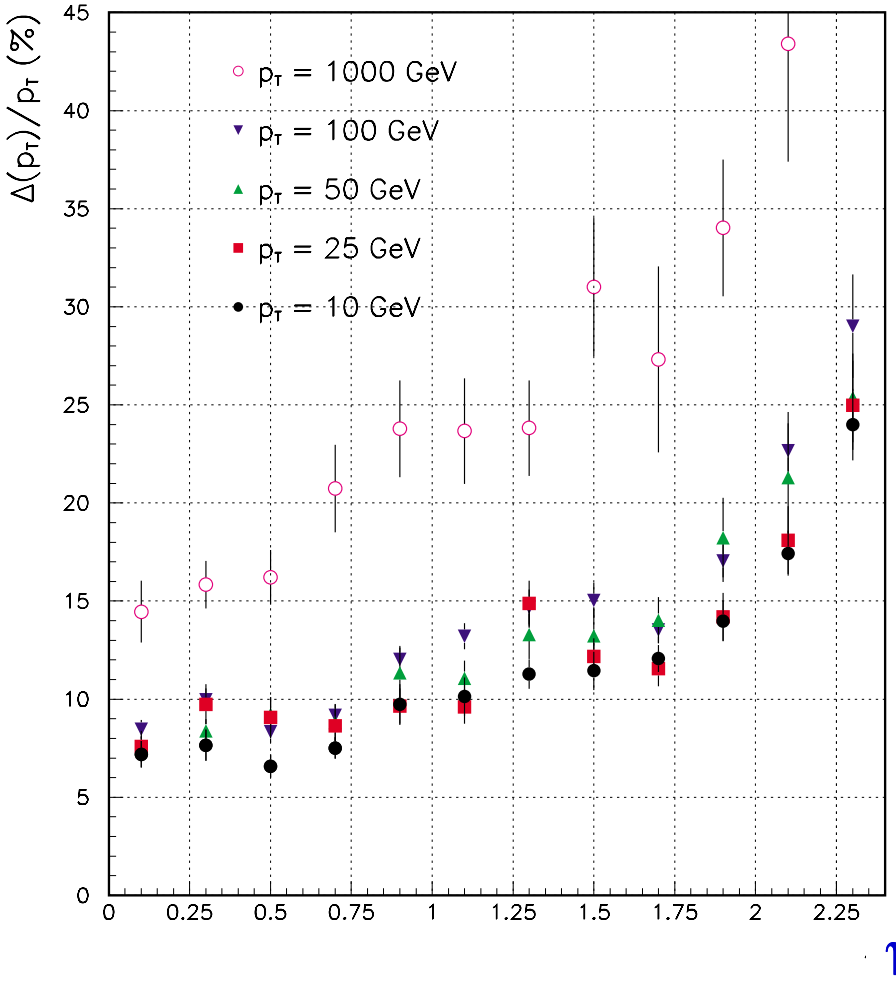



Endcap sector

# CMS Muon Momentum Resolution

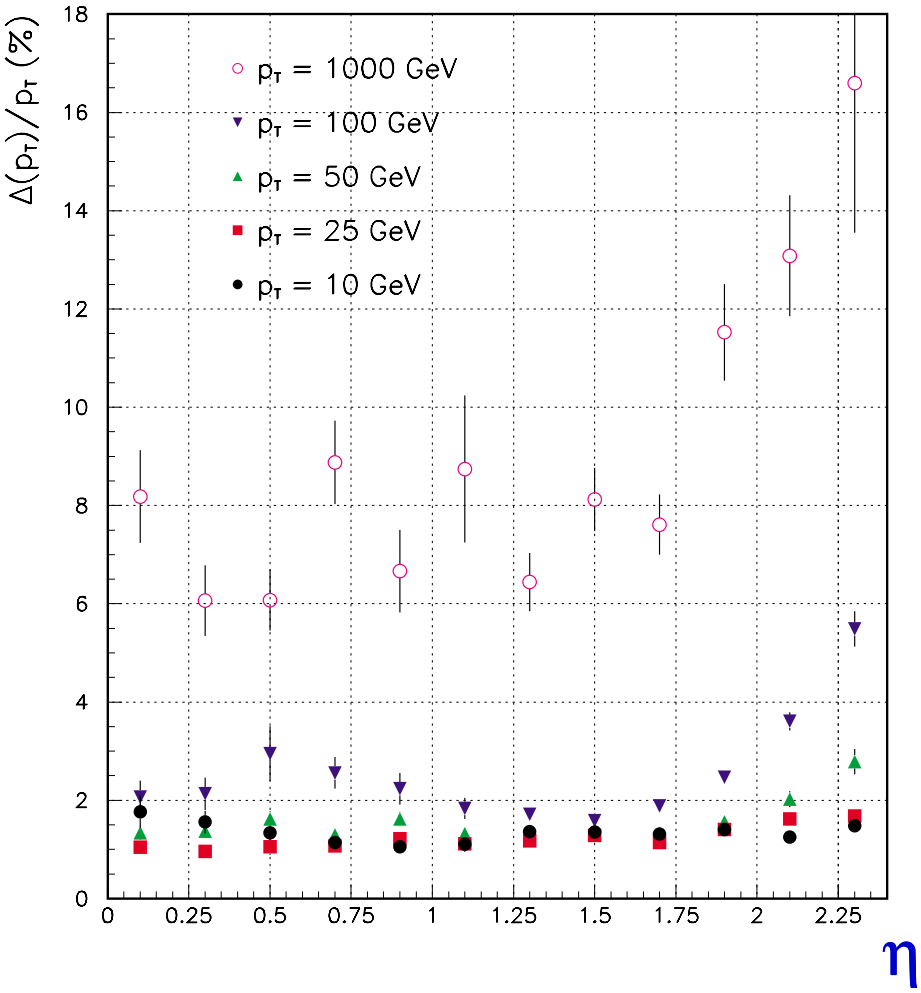
## Standalone

Tracking Resolution—Muon System with Vertex Constraint




## Combined with Tracker

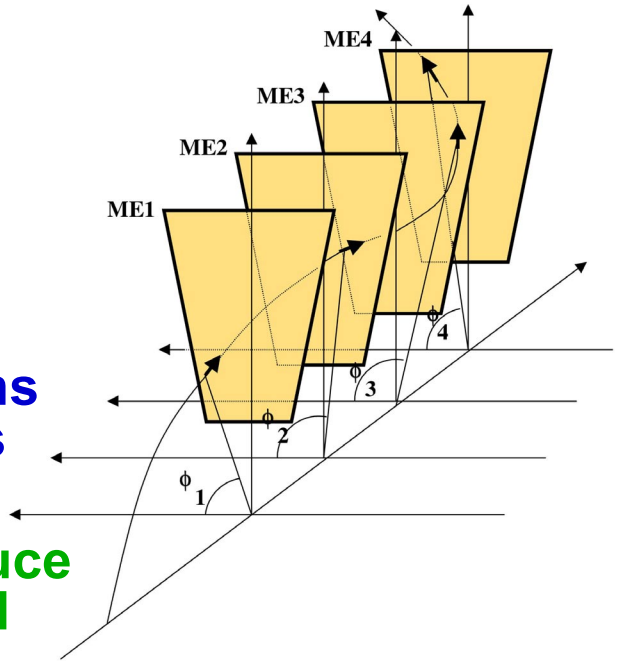
Tracking Resolution—Muon System with Inner Tracker



# CMS Level-1 Muon Trigger

## RPC:

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



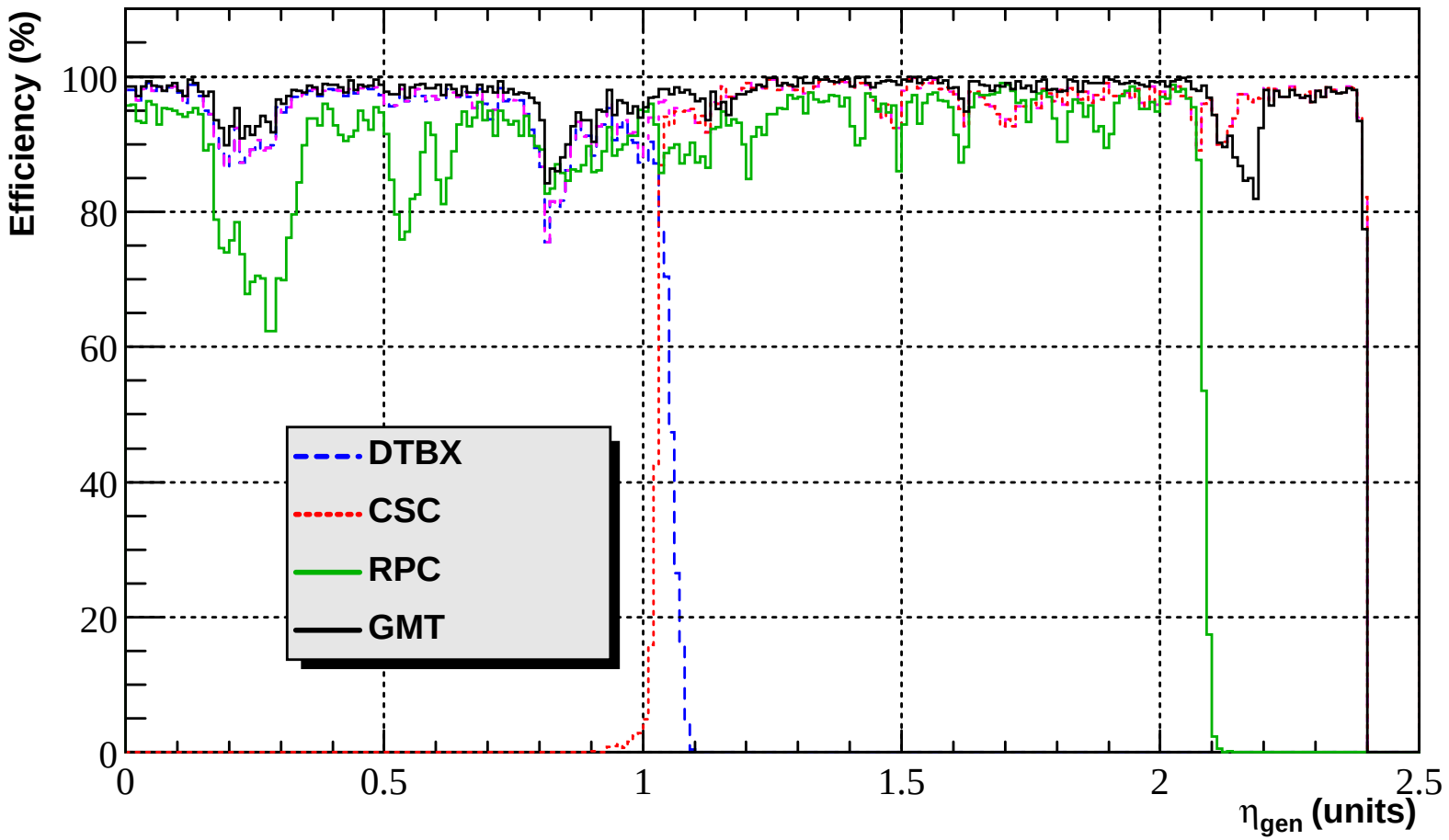

## DT and CSC:

- "Track-Finders" apply tracking algorithms and swim track segments to next stations using fine $\phi$ information
  - CSC Track-Finder swims in 3D to reduce backgrounds, handle non-axial B-field

## Global Muon Trigger:

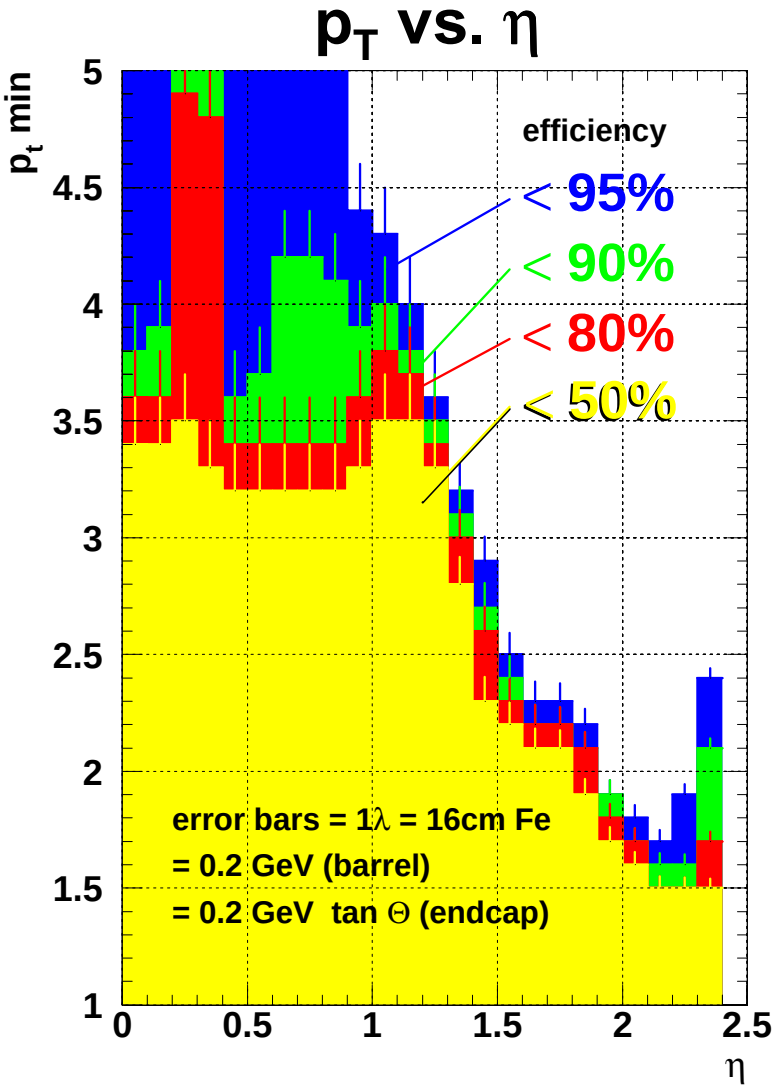
- Combines DT and CSC muons with RPC patterns to reduce rate and improve efficiency
- Programmable $p_T$ thresholds from 1 to 140 GeV/c
- Single and di-muon trigger topologies
  - $\eta$, $\phi$ topology selections, calorimeter isolation

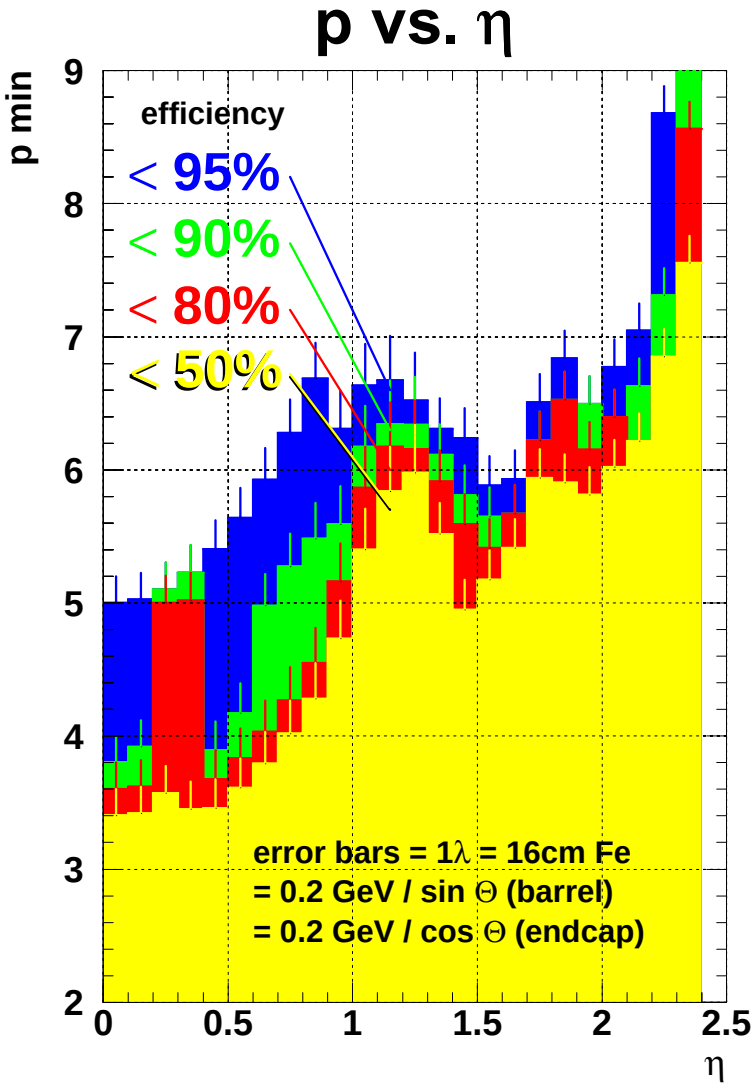
# Level-1 Trigger Efficiency vs. η




**Overall high efficiency over |η| < 2.1 when systems combined**

# Minimum Trigger Threshold



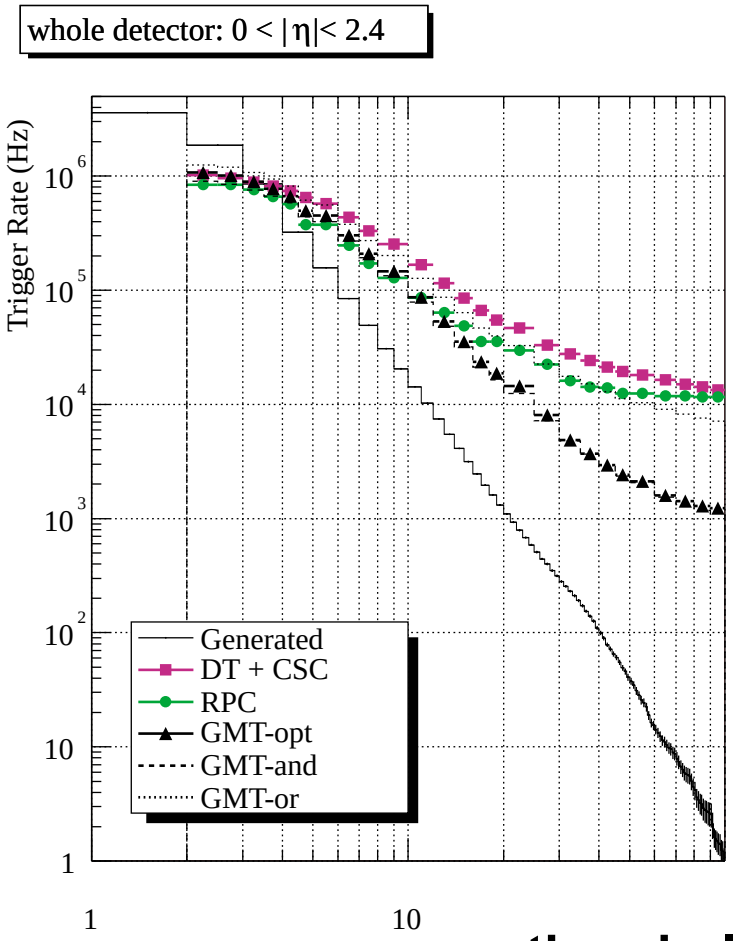




**Barrel: $p_T > 4$ GeV**

**Endcap: $p > 7$ GeV**

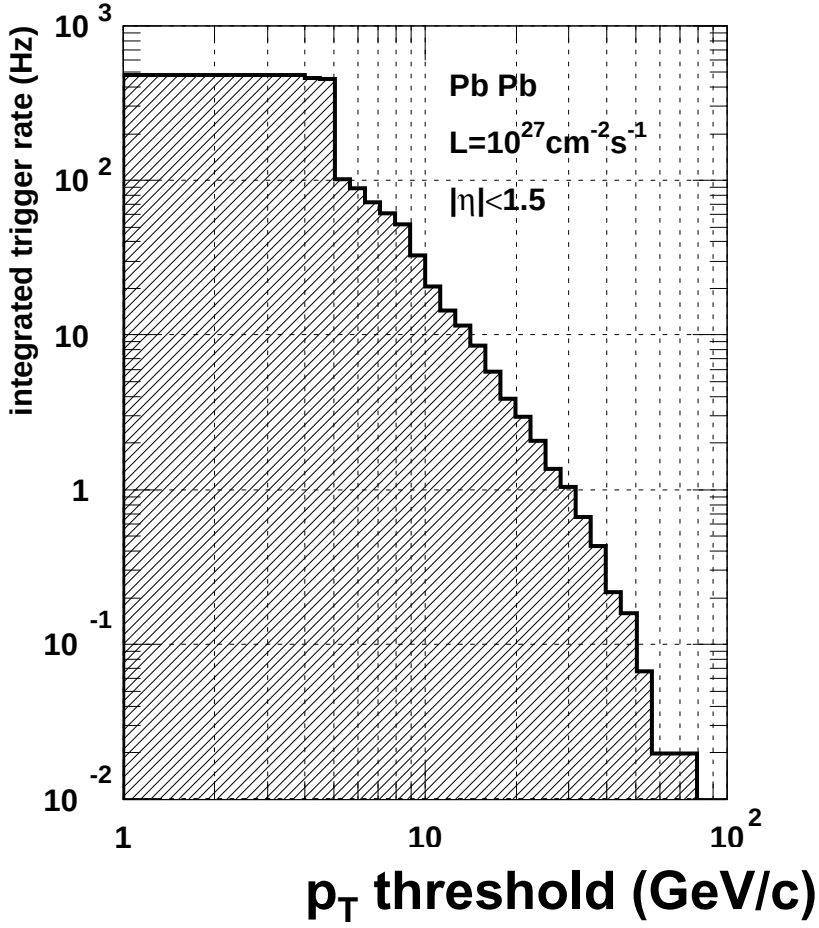
# Level-1 Trigger Rates

## *pp*, $L = 10^{34}$




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

CMS Note 1997/089




**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:**

- **~10% standalone measurement**
- **~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**