# CMS
# Muon System

Emanuela Barberis
Northeastern University


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# Muons: physics signatures and calibration tools

Muons: clean signature at hadron colliders* for Standard Model precision measurements and searches for new physics. Unique identifiers for calibrating and aligning the detector.

Requirements on a muon system at the LHC:

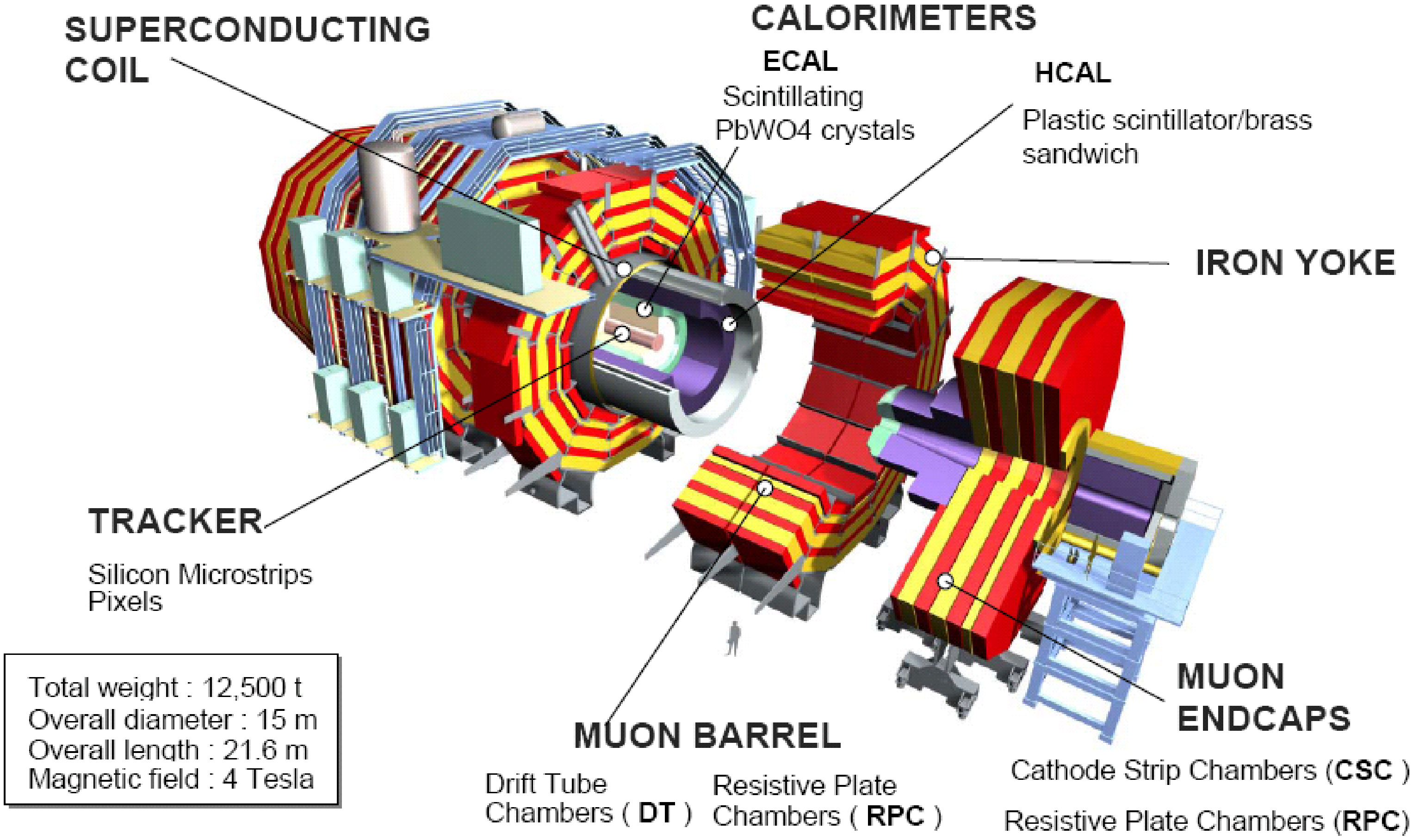
- Efficient triggering of muons over a large spectrum of momentum (up to the TeV scale) and a large area.
- Efficient, precise, and pure identification of muons over a large spectrum of momentum.
- Effective shielding and radiation hardness.
- Robust alignment procedures and system (large volume and high magnetic field).

* *incidentally the first several papers published by a "typical" Tevatron experiment in RunI and RunII involved muon final states.*

# The CMS Muon System

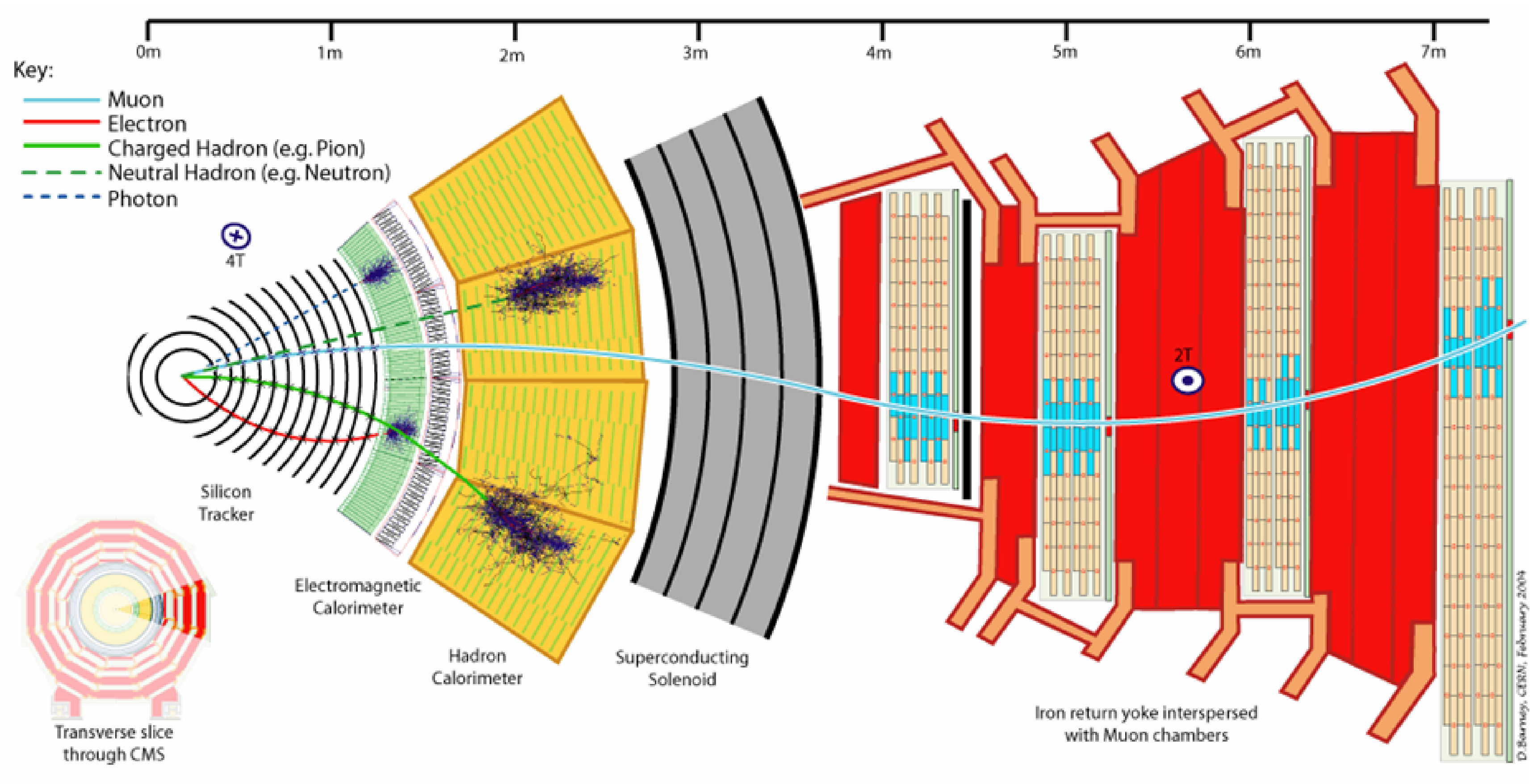
CMS Muon system: high resolution, radiation hardness, high rate capability, triggering w/o the need for external systems. Technology adapted to the LHC conditions.

3 types of gaseous chambers, with trigger capabilities, interleaved with the magnet return yoke layers.



# Muon Reconstruction in CMS

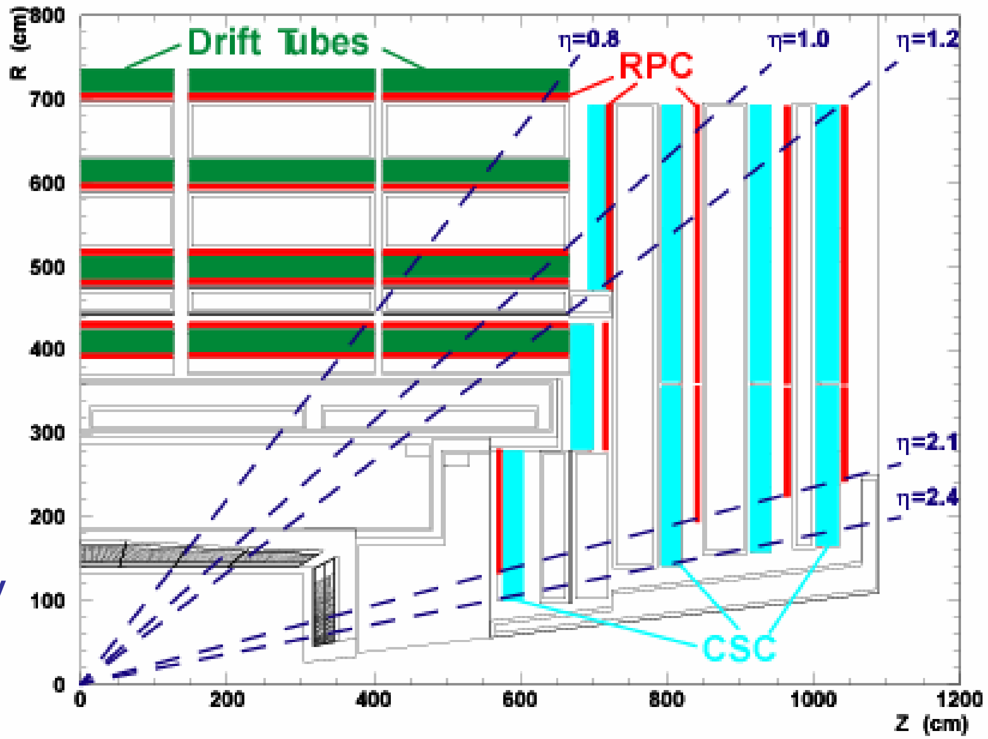
Bending in the transverse plane, independent tracking inside (Si tracker) and outside (muon spectrometer) the 4T coil.



# CMS Muon System design

Different geometry in central/forward region due to differences in background rates and magnetic field:

- Drift Tubes (DT) in the barrel.
- Cathode Strip Chambers (CSC) in the end-caps.
- Resistive Plate Chambers (RPC) in barrel and end-caps.

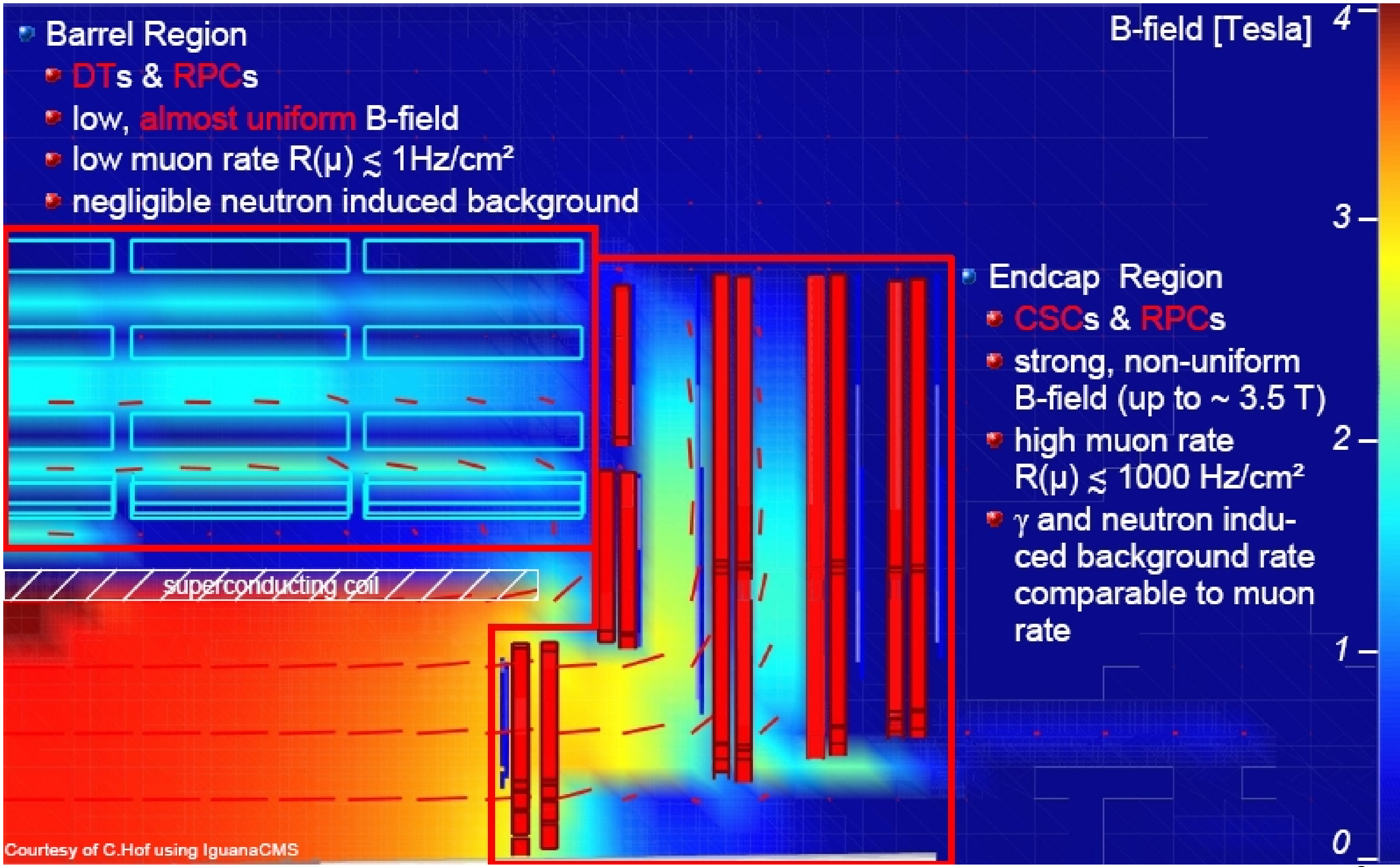



Longitudinal view: ¼ of CMS

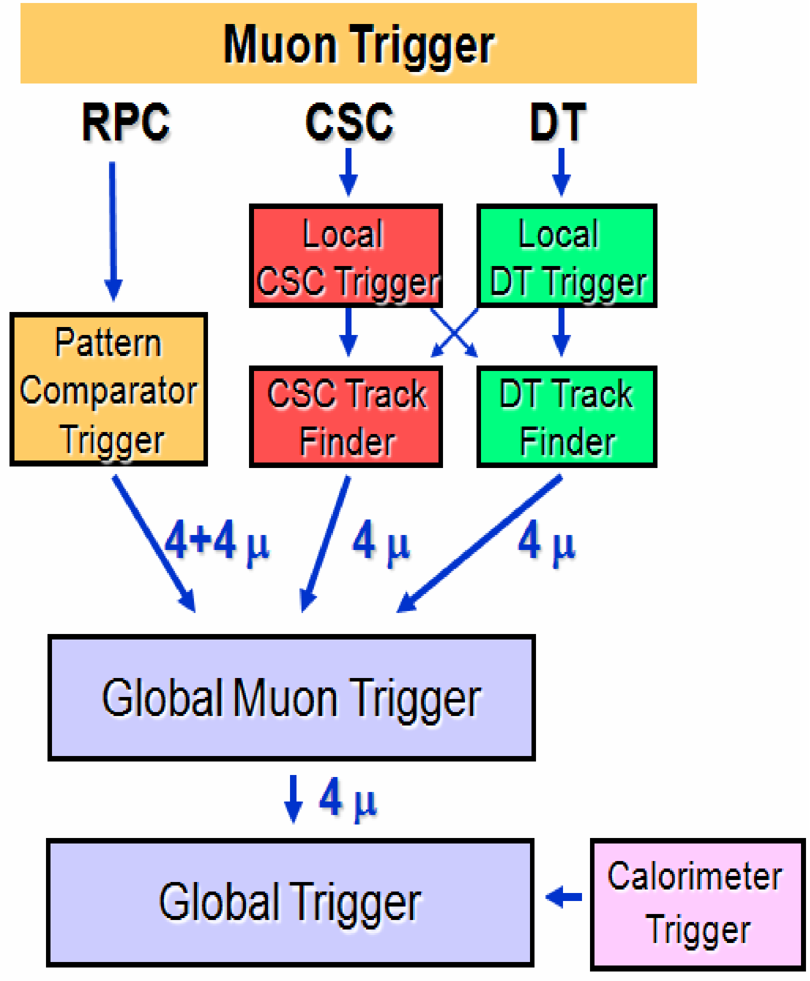
System requirements:

- $\mu$–ID up to $|\eta|=2.4$ (and up to $\lambda\sim16$)
- Standalone $\delta p_T/p_T \sim 20\text{-}40\%$ at 1 TeV (5-15% with central tracker)
- Unambiguous BX identification
- Single and double $\mu$ triggers up to $|\eta|=2.1$
- Alignment <100$\mu$m

# CMS Magnetic Field



# The CMS Muon Trigger



# CMS Muon System Installation


Installation at CERN - completed in October 2007

# CMS Muon System Commissioning

**Summer '06** ………………………………………… **Autumn '08**

| **MTCC** | **Commissioning** | **CRUZET** | **BEAM!** | **CRAFT** |
|---|---|---|---|---|
| "**M**agnet **T**est **C**osmic **C**ommissioning" | Moved underground | "**C**osmic **RU**n at **ZE**ro **T**esla" | | "**C**osmic **R**un **A**t **F**our **T**esla" |
| Above-ground | Magnet off | Magnet off | | Magnet at 4T |
| Magnet at 4T | Scale up to full detector operation | Full detector | | Full detector |
| Single trigger sector | | | | |

Local commissioning (within each subsystem): assess infrastructure readiness, development of internal diagnostics, testing of detector performance, internal timing, testing of local reconstruction.

Global commissioning: subsystems integration, synchronization, full testing of DAQ and trigger systems, global reconstruction.

# CMS Muon Central Barrel

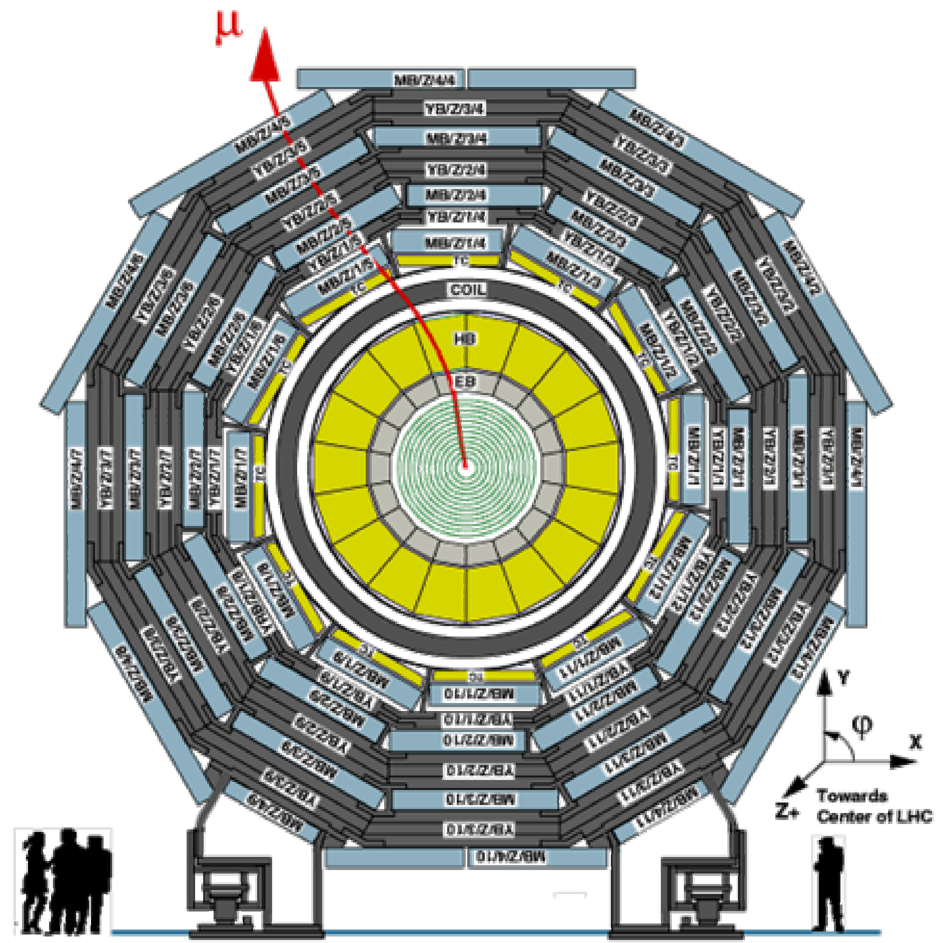
Low particle rates (<10 Hz/$cm^2$),
low, relatively uniform magnetic field

5 wheels, 30° sectors with 4 stations

Drift Tubes:
250 chambers (180k channels)
Resistive Plate Chambers:
480 chambers (75k channels)

DT economical for use in low rate region
Large wire spacing → long drift time →
slower response (<400 ns)

Good Resolution:
rΦ ~100 μm,   z ~150 μm,   Angle ~1 mrad

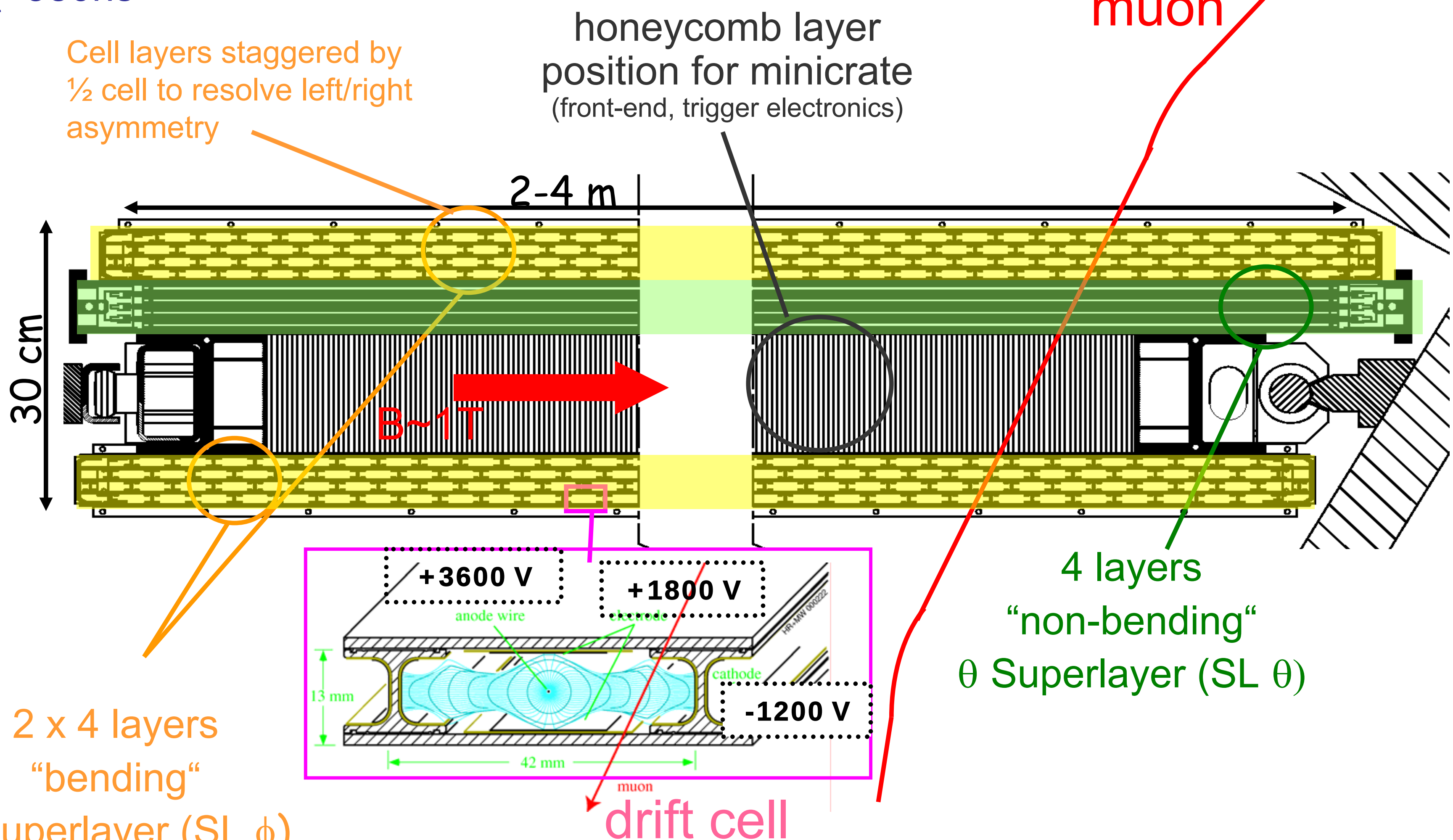



Z = -2, -1, 0, 1, 2 according to the Barrel wheel concerned

# CMS Muon Barrel Station

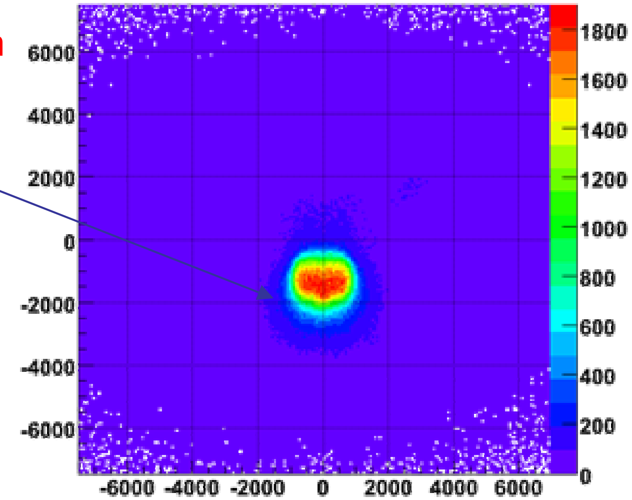
12 layers per chamber: 4 z, 8 (r,$\phi$)
Gas: Ar(85%) $CO_2$(15%), max $t_{drift}$=380ns

Cell resolution (r$\phi$) <250$\mu$m, chamber (r$\phi$) ~100$\mu$m
BX assignment efficiency >99%

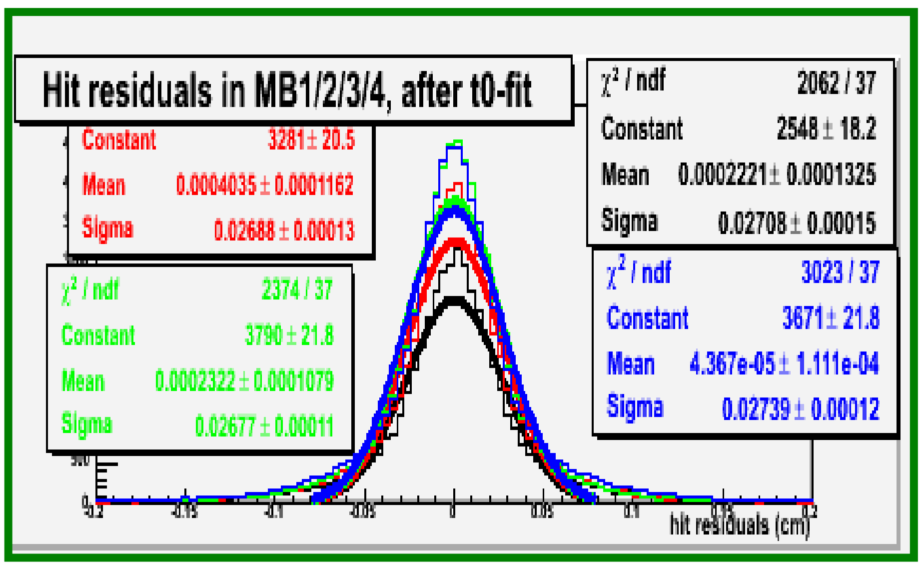


# Muon Barrel Performance

Cosmics tracks in the DT at 0T extrapolated to the surface (CMS coords). The shaft is clearly visible

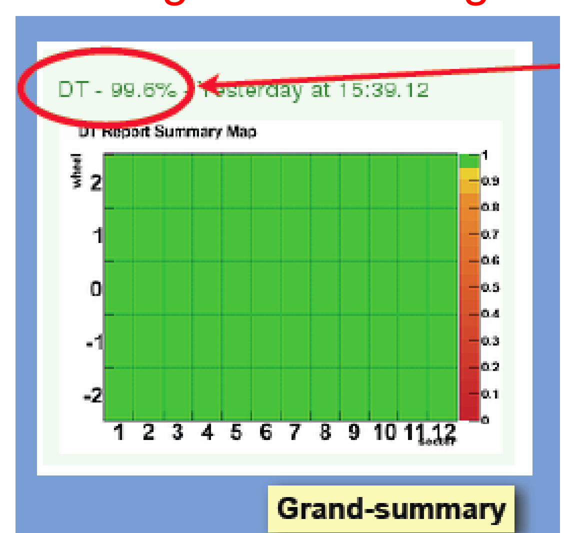



**MB1: 271 μm** **MB3: 268 μm**
**MB2: 269 μm** **MB4: 274 μm**




Hit residuals after the t0 fit in different DT stations averaged over the sectors

Status of the 12 DT sectors during commissioning: 99% working



# CMS Muon Forward End Cap

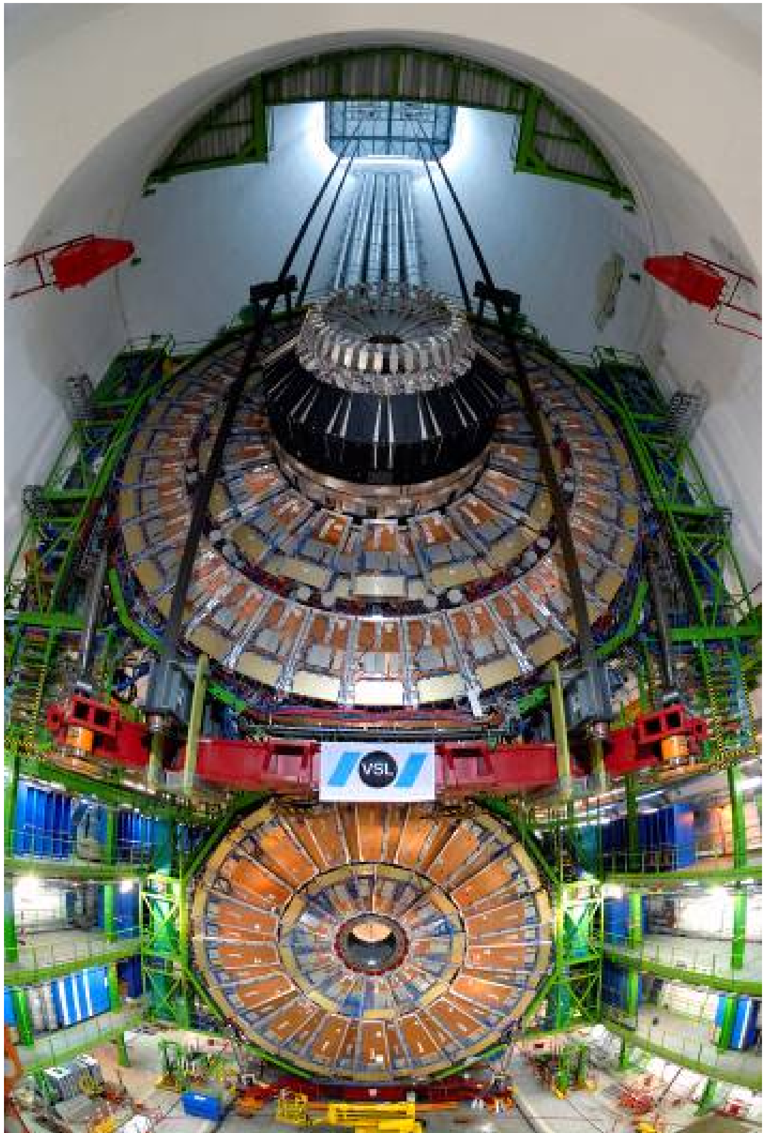
High rates (particle rate 100-1000 Hz/cm$^2$, punch-through ~ 100 Hz/cm$^2$), high and/or non uniform magnetic field

4 stations

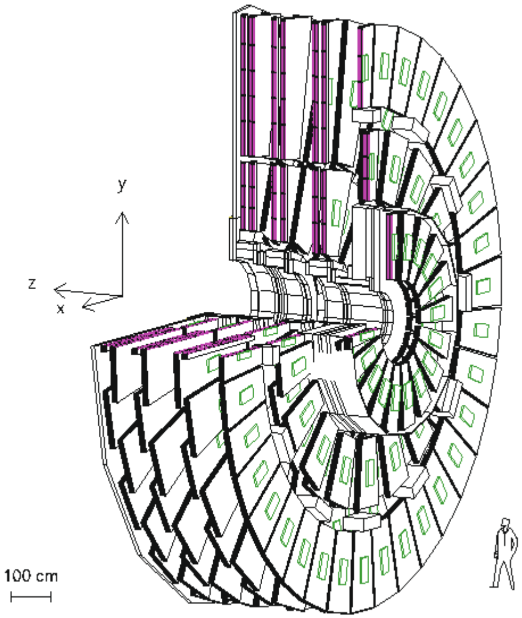
Cathode Strip Chambers:
486 chambers (450k channels)
Resistive Plate Chambers:
540 chambers (80k channels)

CSC have fast response (closely spaced wires), good in a high rate environment

Good Resolution:
r$\Phi$ ~75-150 $\mu$m,   4ns timing resolution (triggering)



# CMS Muon End Cap Station

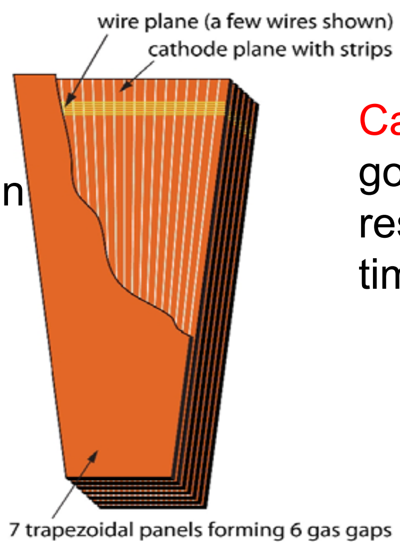



4 stations, 2 or 3 rings of trapezoidal chambers per station (finest segmentation closest to the IP)

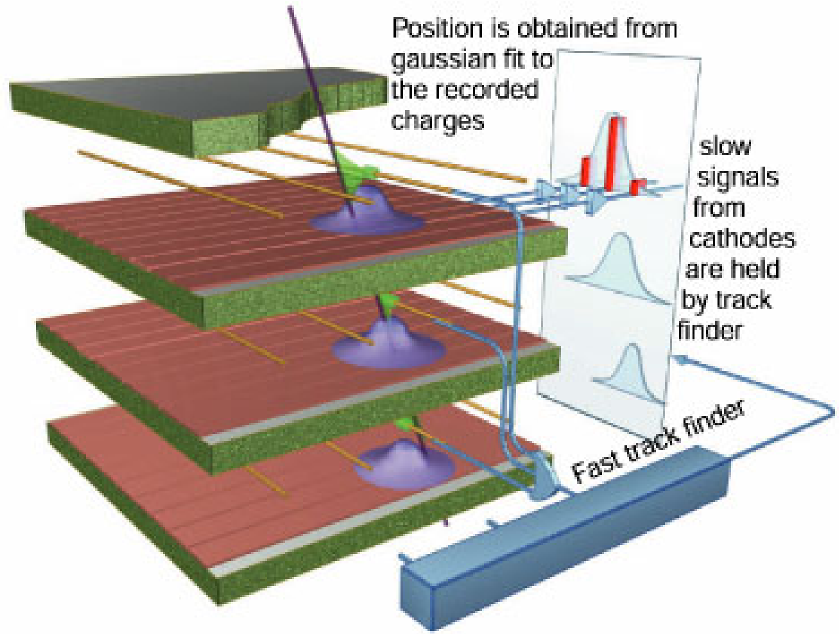
6 layers per chamber (6 gas gaps):
- radial, trapezoidal cathode strips
- azimuthal anode wires
- induced charges on strips - precise $\phi$ coordinate
- closely spaced wires - fast timing
- wires ganged in groups of 5 -16 for *r* coordinate

Gas: Ar (40%) $CO_2$ (50%) $CF_4$ (10%)

Anode wires:
fast timing (determine muon track segments and BX)
coarse radial position

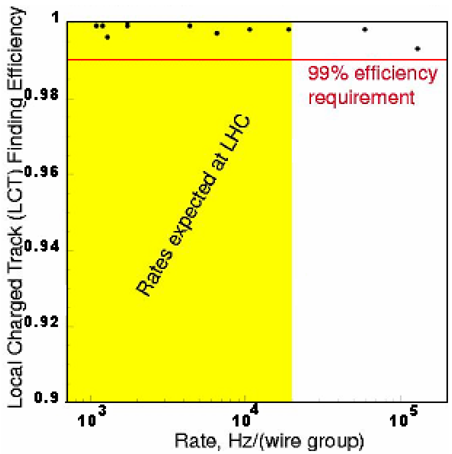



Cathode strips:
good spatial resolution, coarse timing



# Muon End Cap Performance

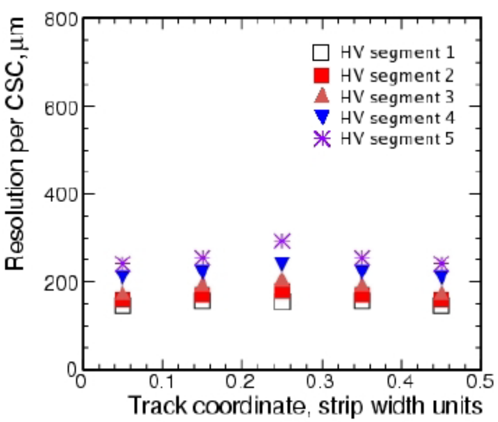
99% muon track trigger efficiency for chamber

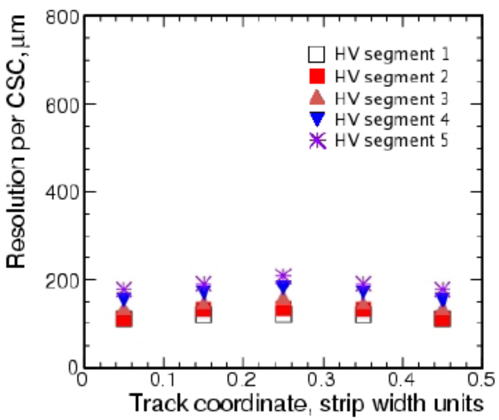


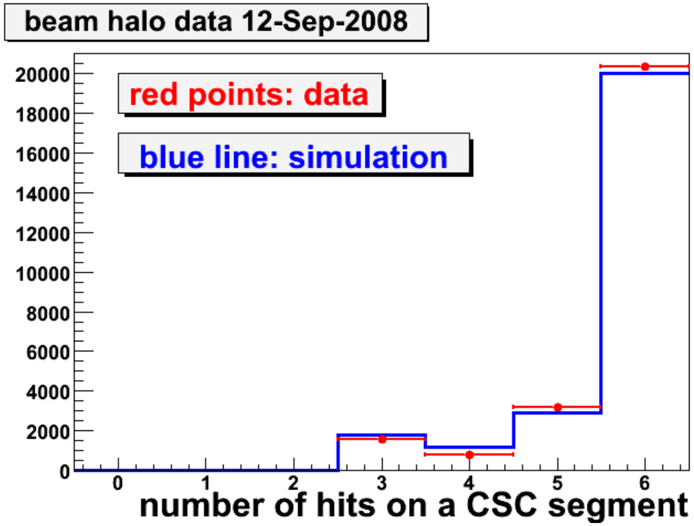


Global muon and local CSC reconstruction with beam-halo

CSC resolution (cosmic-ray data):
~80 $\mu$m (ME1) and ~150 $\mu$m (ME2/3/4)



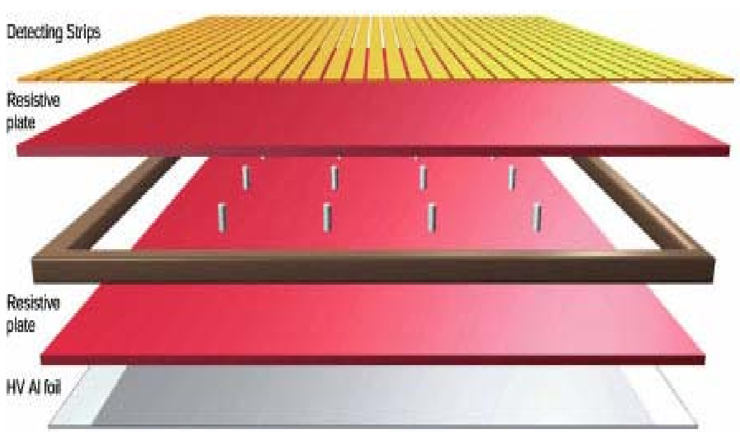



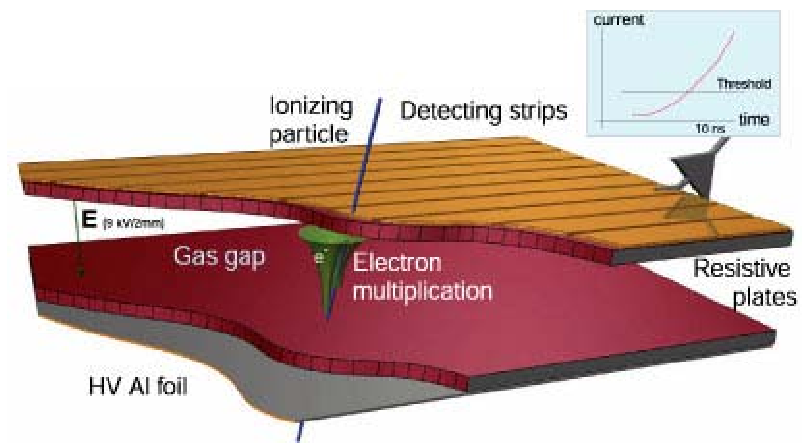



# Muon Resistive Plate Chambers

Dedicated to L1 triggering (trigger redundancy in DT/CSC muon system)

Relatively inexpensive, double gap (2mm) technology, operating in avalanche mode. Gas: 95% Freon, 5% Isobutane.



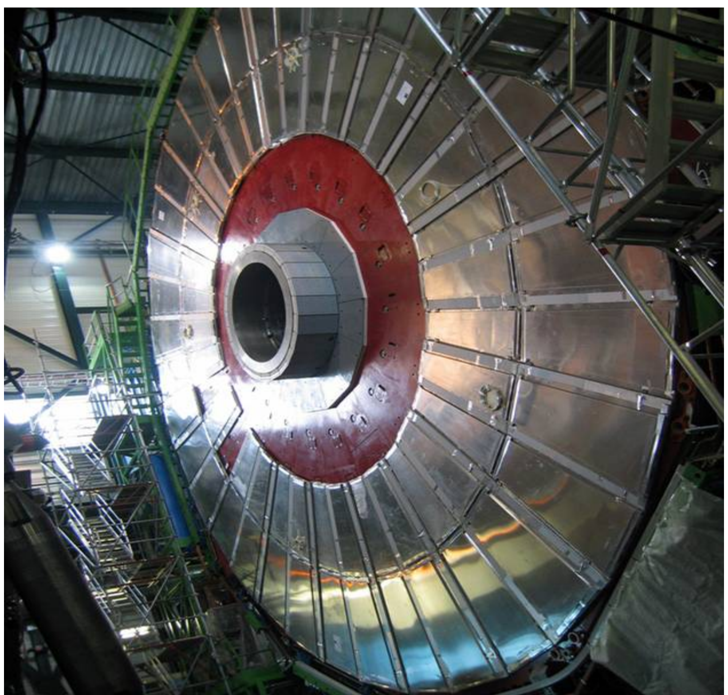

Fast response, good time resolution ($\sigma$<1.5 ns), precise BX assignment. The RPC trigger is based on the spatial and temporal coincidence of hits in 3 or 4 RPC muon stations. The pattern of hit strips is compared to predefined $p_T$ patterns.

Spatial resolution (r$\phi$) of ~1.5 cm, can be used to confirm DT/CSC signals in muon reconstruction

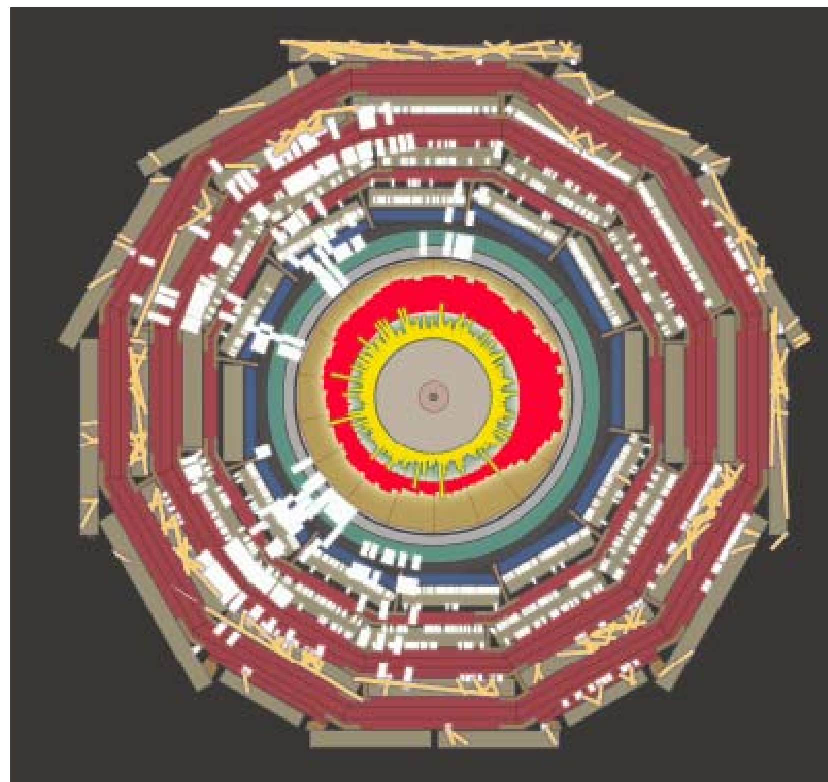
# CMS Muon RPC System

6 layers of RPC's embedded in the barrel iron yoke following the DT segmentation. The layers are dodecagons with $2\pi$ coverage. The chambers are rectangular, strips parallel to the beam.

Forward region instrumented with 4 layers of RPC's up to $\eta = 2.1$. The chambers are trapezoidal, radial strips.



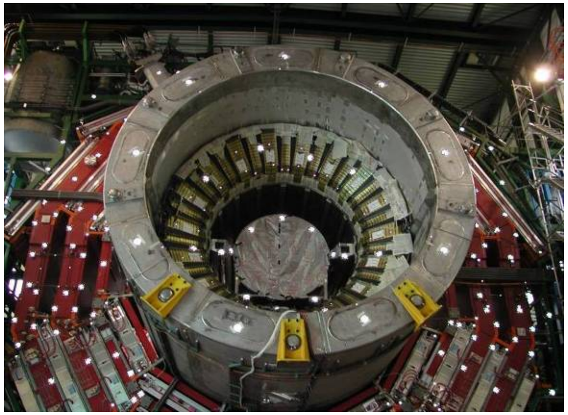
Beam event in the Barrel RPC

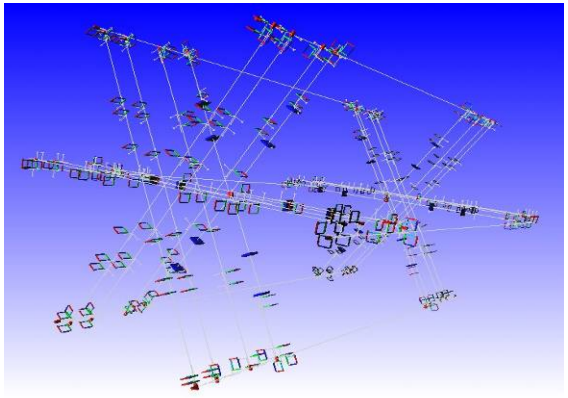


# CMS Muon Alignment

Significant deformations expected due to large field. Three complementary approaches:

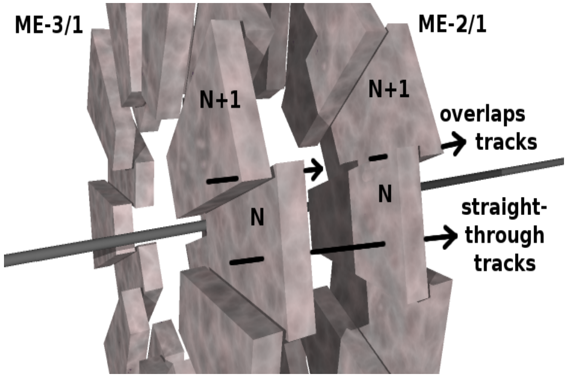
1) Starting point: photogrammetry of elements & detectors (B=0). Precision: ~1 mm rms





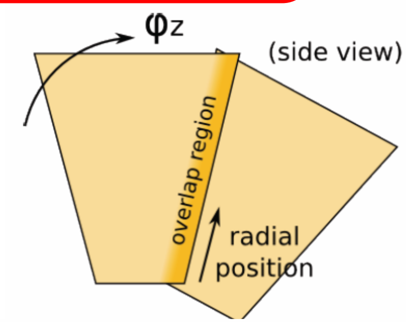
2) Optical system (analog/digital)
Barrel+endcap+link → global geometry
Reduce uncertainty to ~250 $\mu$m

3) Muon track-based alignment



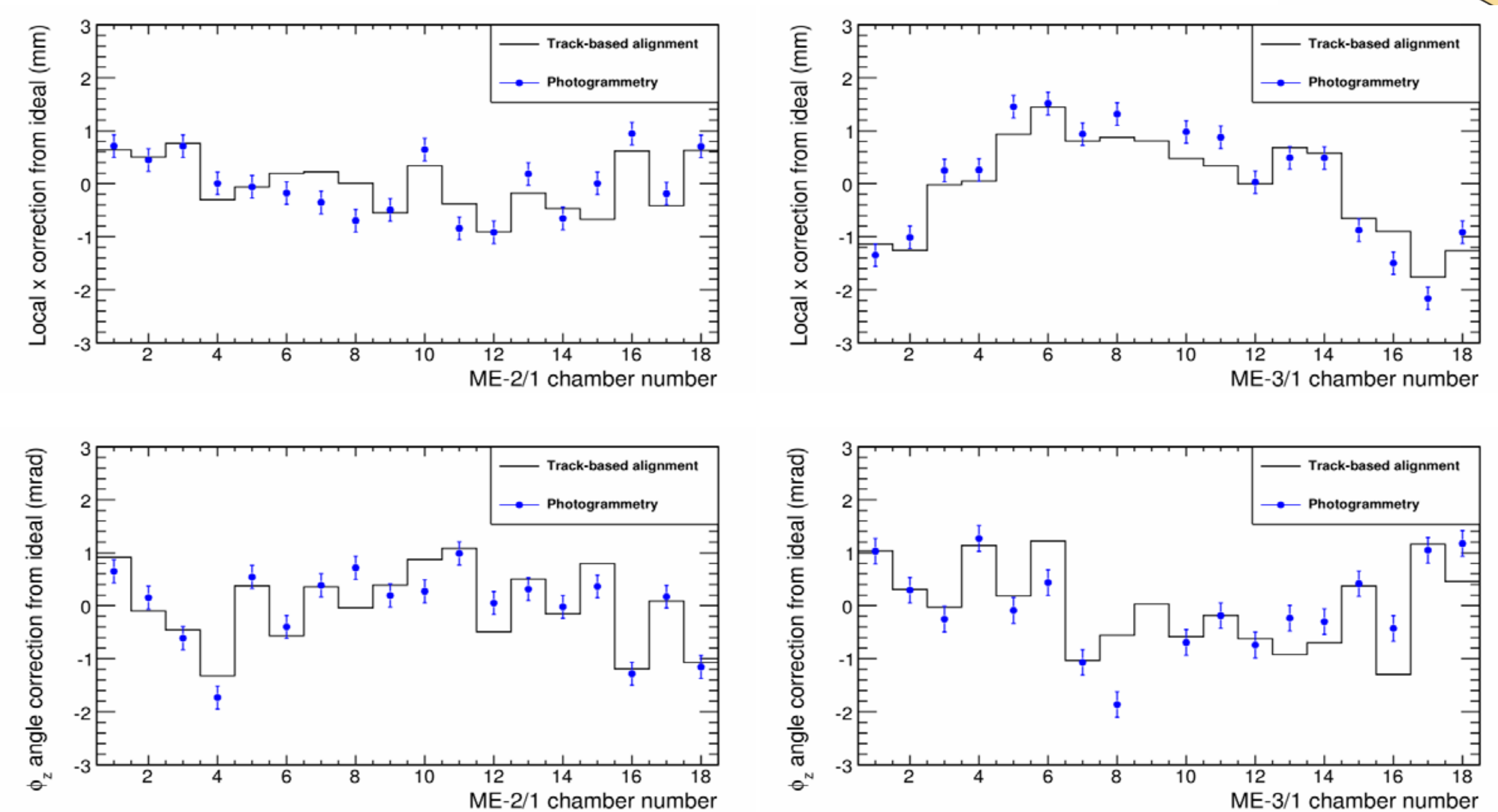
# CSC Chamber Alignment: Beam Halo

Example of cross-validation: beam-halo muons from 9min of captured LHC beam: good agreement of track-based alignment with photogrammetry for CSC alignment.




~phi displacement

phi rotation



# Cosmic-ray run at 4T: CRAFT

To conclude: a few more pictures from most recent commissioning