The CMS Muon System

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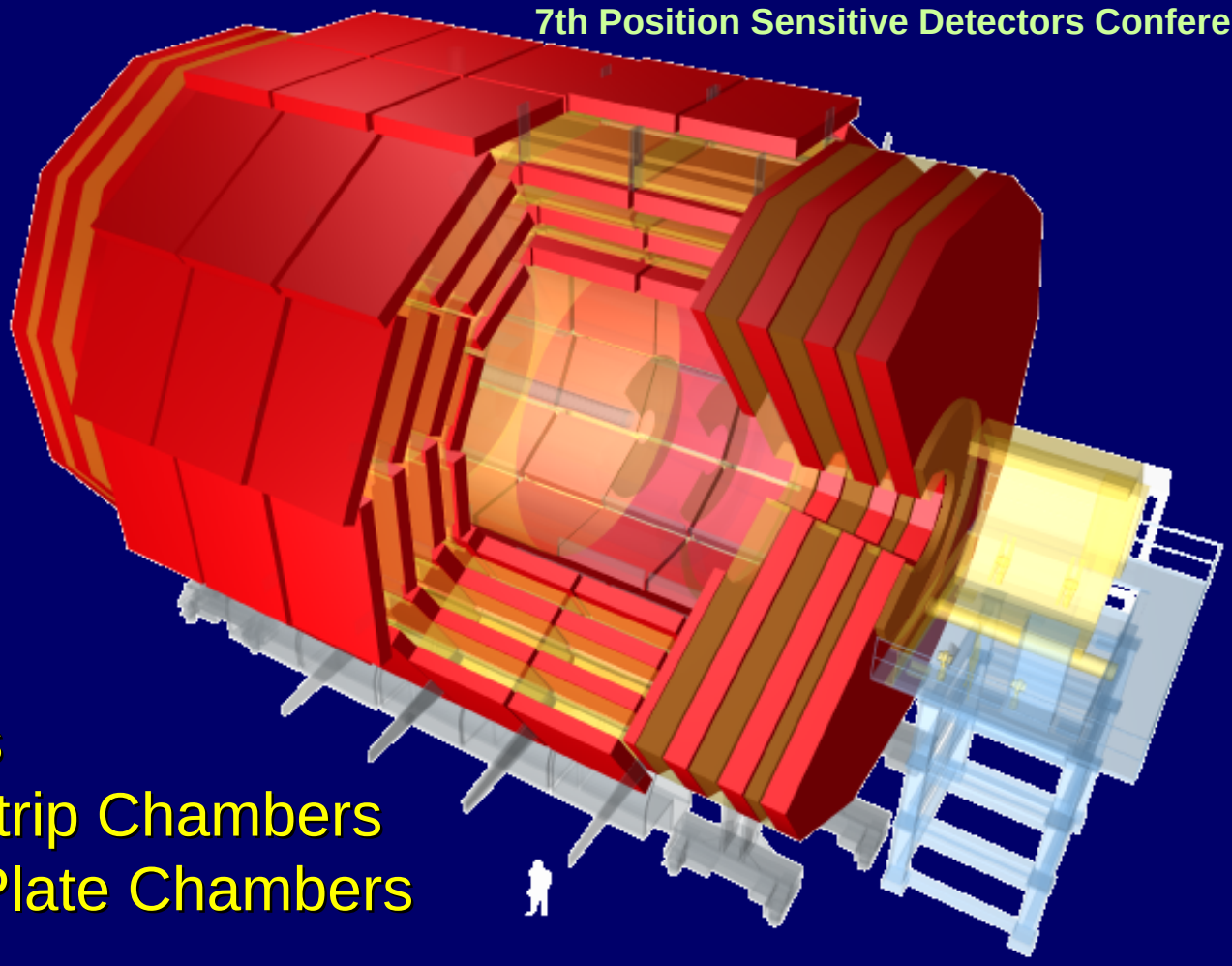
CIEMAT – Madrid

7th Position Sensitive Detectors Conference



Drift Tubes
Cathode Strip Chambers
Resistive Plate Chambers

Requirements from LHC & CMS

The Large Hadron Collider (LHC) at CERN

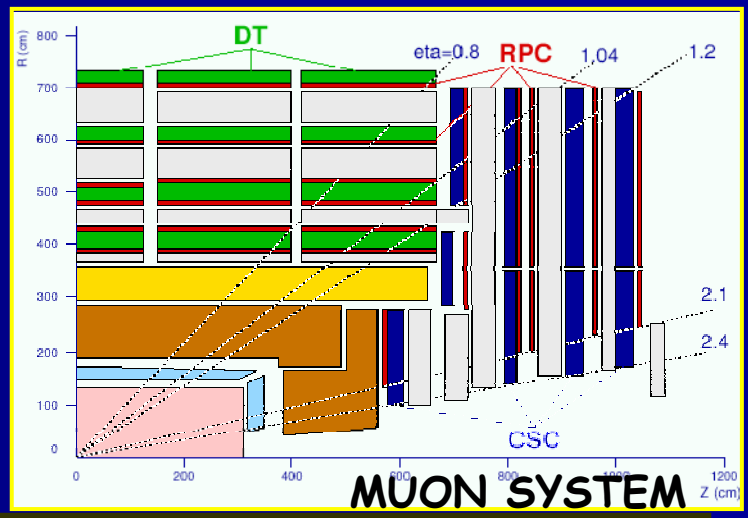
7 TeV proton – proton colliding beams every 25ns (40MHz), Luminosity $10^{34}cm^{-2}s^{-1}$

The Compact Muon Solenoid detector (CMS)

Muon Detector: Four concentrical stations interleaved with the iron return yoke of a 4 Teslas superconducting magnet

Muon Detector Requirements

- ✓ Muon identification
- ✓ Muon momentum measurement
  - Charge assigment: 99% CL up to 7 TeV
  - Resolution stand alone
    - 8 - 15% at $\delta p_T/p_T$ 10 GeV
    - 20 - 40% at $\delta p_T/p_T$ 1 TeV
- ✓ Trigger single and multi muon with unambiguous bunch crossing identification



System Conditions

	Endcap ($0.9 < \eta < 2.4$)	Barrel($\eta < 1.3$)
Particle Rates	100-1000 Hz/cm^2	< 10 Hz/cm^2
Magnetic Field	Uniform axial > 3 T in ME1/1 Highly non-uniform radial field up to 1T	Low values

Muon System

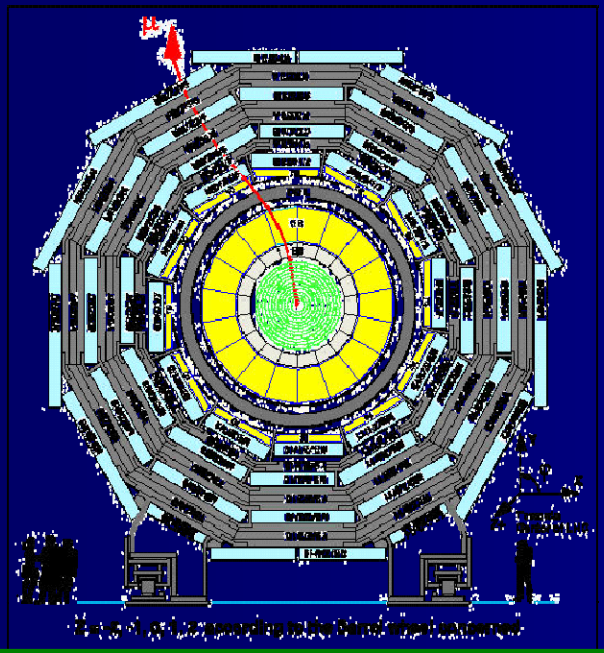
Three gaseous detectors chosen

- Drift Tubes (DT) - Cathode Strip Chambers (CSC)	Excellent position resolution Precise measurement of the muon position and momentum. Providing Level-1 Trigger
- Resistive Plate Chambers (RPC)	Excellent time resolution Dedicated to provide redundant and complementary information for the Level-1 trigger

BARREL

250 stations (in the iron magnet return yoke)
5 wheels
4 Layers: MB1,MB2,MB3,MB4
A station: 1 DT and 2 RPCs on MB1,MB2
1 DT and 1 RPC on MB3,MB4

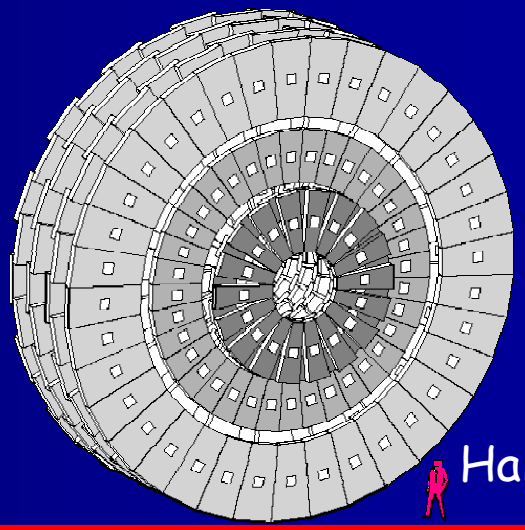
CMS Transversal View



ENDCAP

Each endcap:
4 planes, 2-3 rings/plane

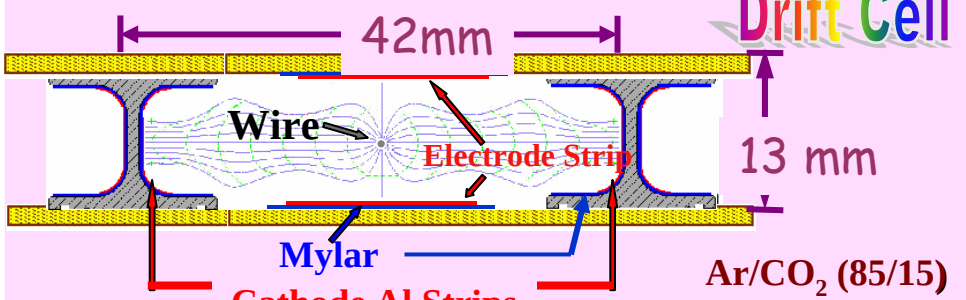
Proposed initial System:
CSCs: NO ME4/2
➔ 468 Chambers
RPCs:3 planes up to $\eta = 1.6$
➔ 432 Chambers



Half endcap

Drift Tube Chamber (DT)

Drift Cell



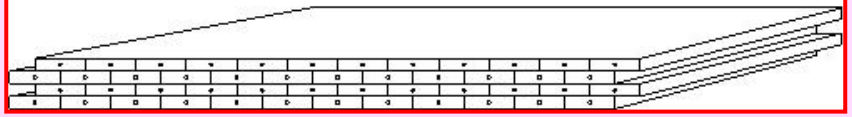
Ar/CO_2 (85/15)
3.6/1.8 /-1.2 kV (W/S/C)

Tmax:	< 400 ns
Drift Velocity:	~ 55µm/ns
Single Cell Resolution	< 250 µm

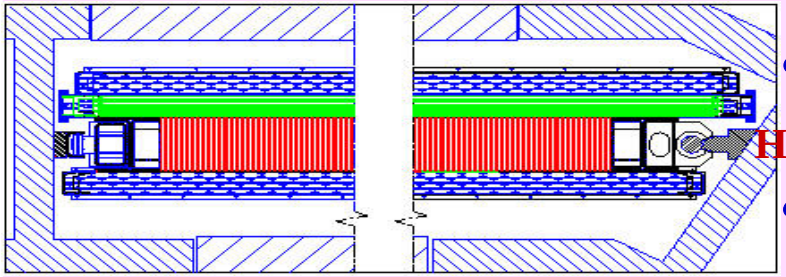
Chamber Resolution:	RΦ 100µm, θ 150µm
	Angle: 1mrad

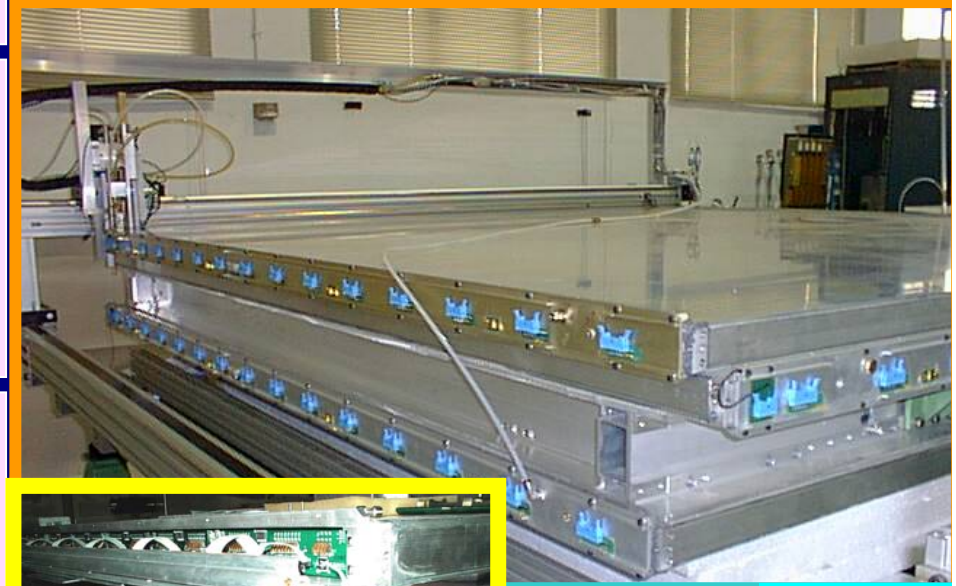
Superlayer

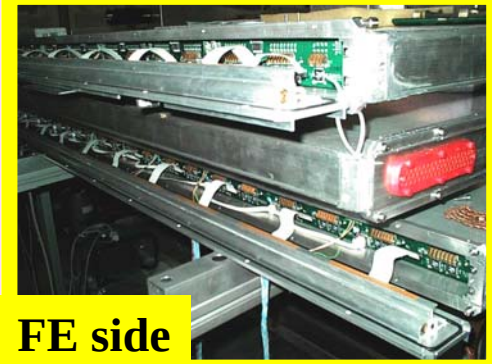
4 Layers = 1 *Superlayer* (SL)



Chamber







FE side

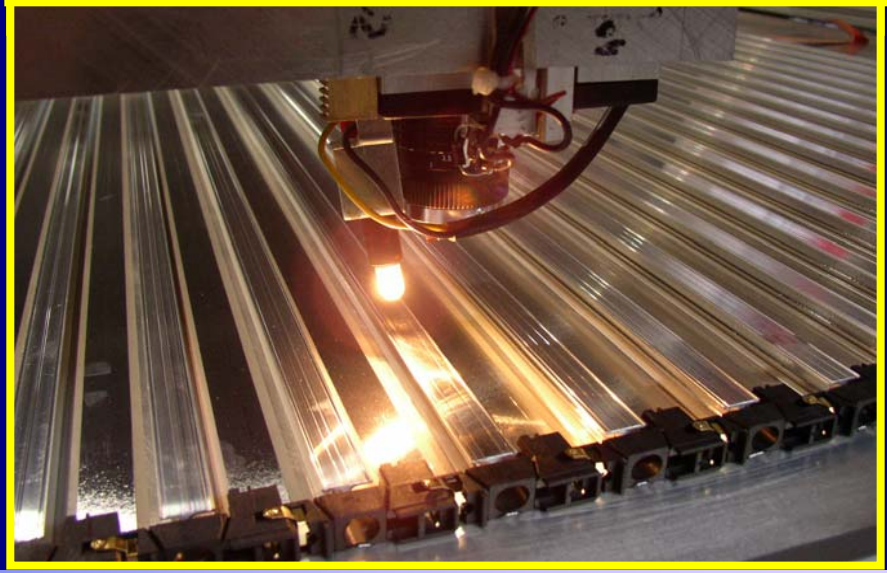
HV side

250 Chambers 172200 Readout Channels

Mechanical Assembly of Superlayers

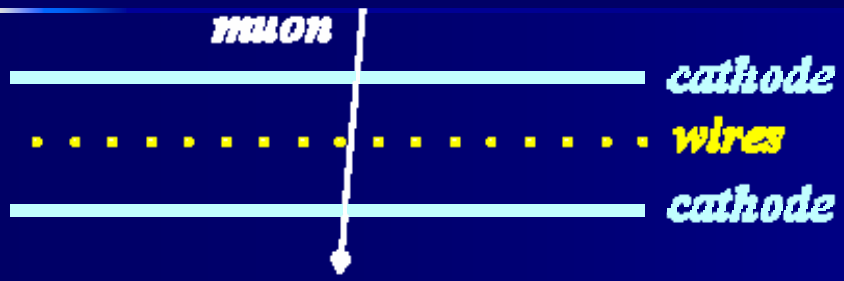
GLUEING

Wire positioning and measurement
(precision of 100 μm required by trigger)



Cathode Strip Chamber (CSC)

Wire spacing ~3mm

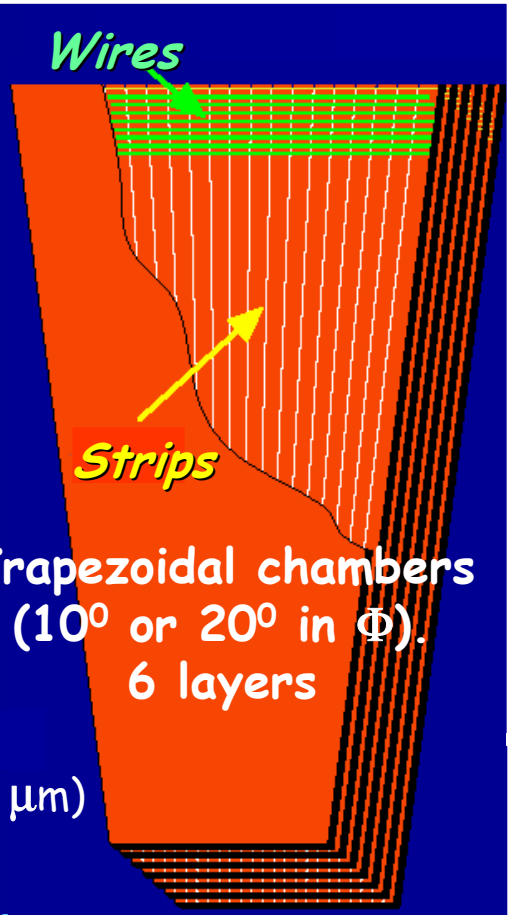


HV wires ~ 3.6 kV

Gas: Ar(40%) + CO2 (50%) + CF_4(10%)

Strip pitch 8.4-16mm

Gas gap 9.5mm



Trapezoidal chambers (10^0 or 20^0 in Φ). 6 layers

CSC Chambers

Radial cathode strips ➡ Precise Φ measurement (75-150 μm)

Wires orthogonal to strips
(except for ME1/1 rotated 25^0 to compensate Lorentz Effect)

➡ Precise timing measurement (BX). Chamber: ~4.5ns

➡ Coarse measurement of the radial position. 16-54mm
(5-15 wires readout together)

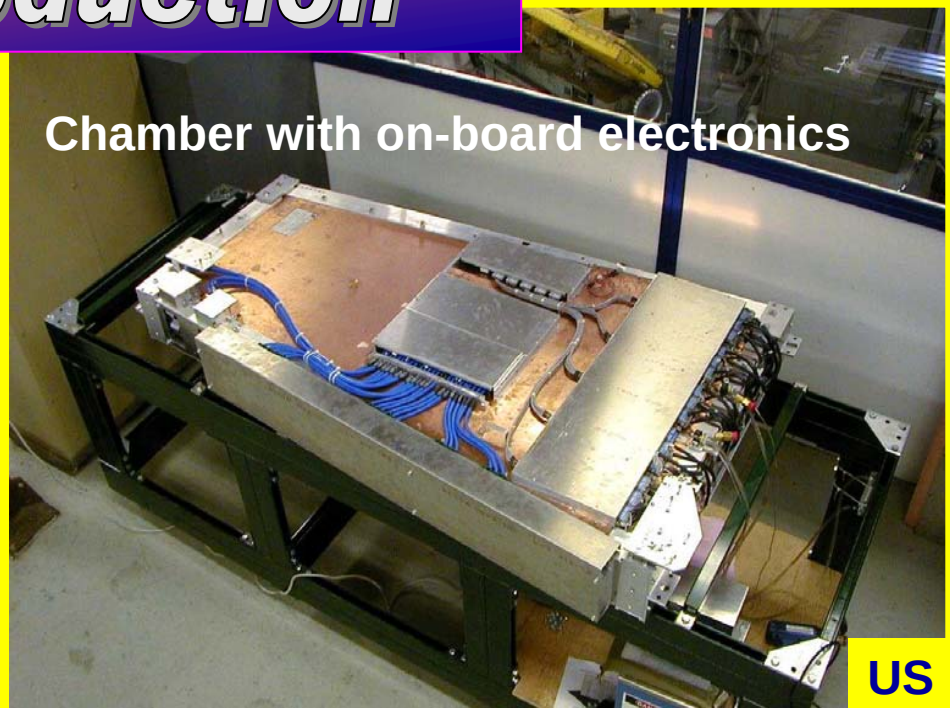
CSC production

PNPI

IHEP

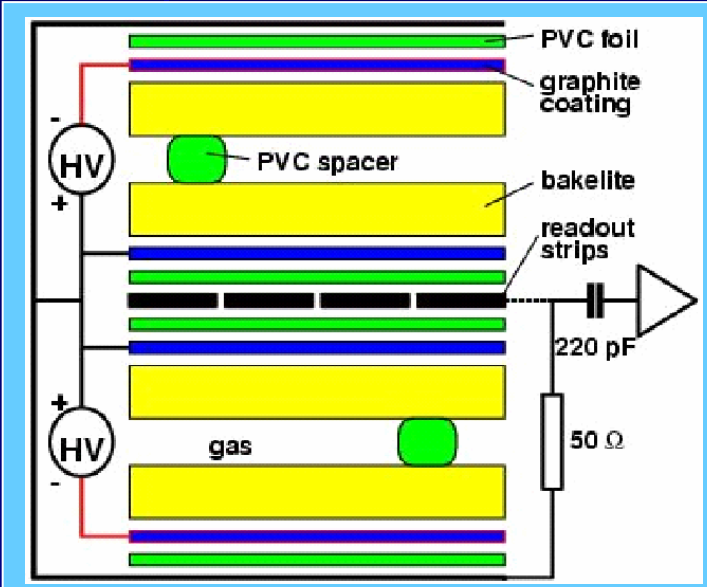
Dubna

Chamber with on-board electronics



US

Resistive Plate Chamber (RPC)



Avalanche in the gas produce a fast charge in the pick-up electrode

High resistivity electrodes (bakelite)
(prevents surface sparking damages)

Low ρ ~10^{10} Ωcm (better rate capability)

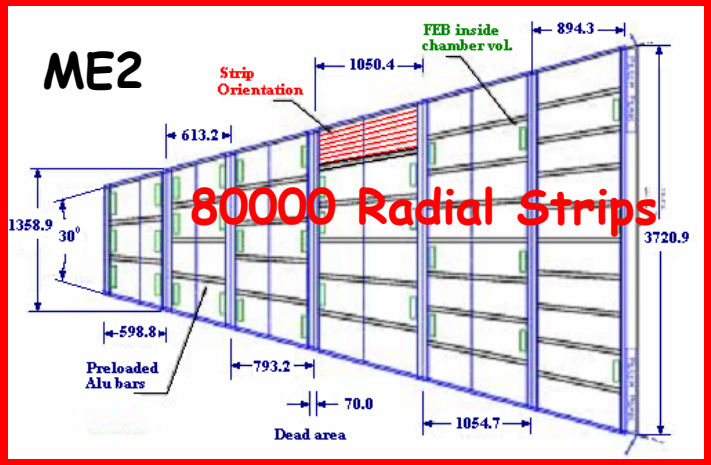
Proportional Mode (Low gain)
(Streamer mode limited Rate Capability ~ 100Hz/cm^2)

Double gap with a common pick-up strip in the middle.
(Increase total charge collected)

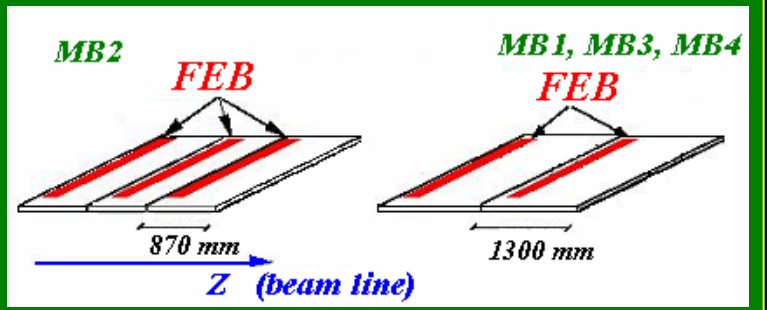
Efficiency	> 95 %
Time resolution	< 3 ns
Cluster size	< 3 strips
Rate capability	~ 1KHz/cm^2
Operational plateau	300 V
Noise	< 10Hz/cm^2
Fraction of Streamers	<10%

Gap:2mm
Gas:96.2% $C_2H_2F_4$ + 3.5% iC_4H_{10} + 0.3% SF_6

ENDCAP



Barrel



75000 Strips parallel to beam line

Endcap RPC Chamber

Stocking and test area at CERN

RPC Test Setup

Coupling to DT

DT Local Trigger

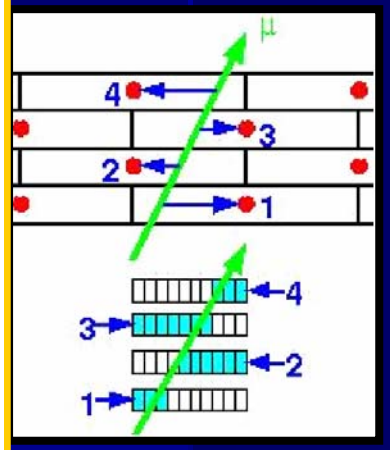
Bunch and Track Identifier (BTI)

Find muon tracks on a SL and identify BX

Based on a meantimer technique:

$$MT1 = 0.5 * (T1 + T3) + T2$$
$$MT2 = 0.5 * (T2 + T4) + T3$$

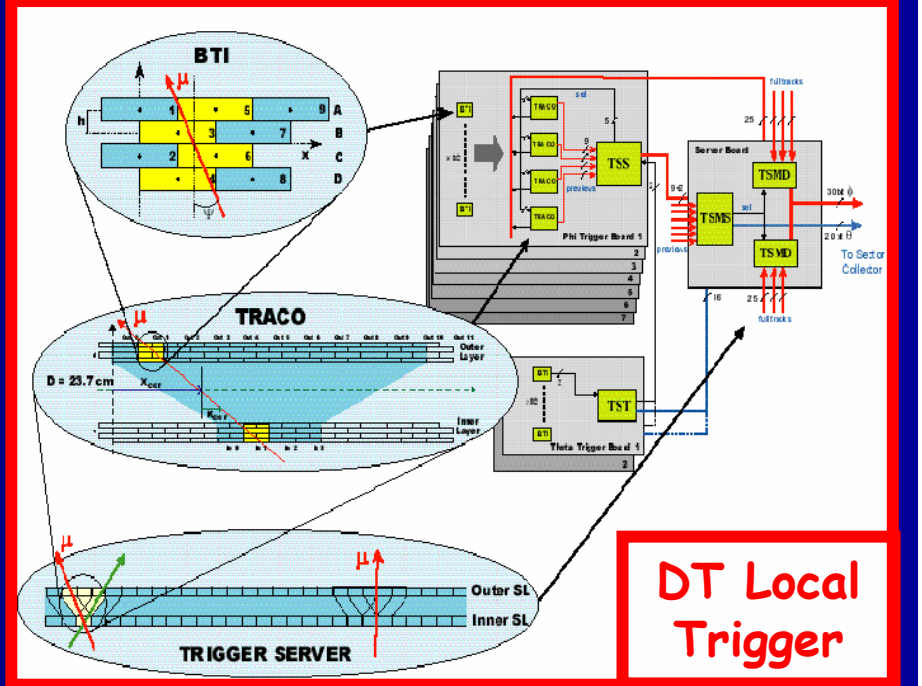
MT=Tmax (independent on the track angle and position)



- Signals are shifted in the registers
- BTI looks for coincidences every clock period (≥3 planes hitted)
- At a time T=Tmax after muon crossing the drift times are aligned, i.e. the hits form an image of the muon track,

Allows efficient BX identification:

Position = 1.14 mm
Angle = 60mrad



TRAck COrrelator (TRACO)

Combines the segments from the 2 Φ SLs
Reduces noise
Improves angular resolution to 10mrad

Trigger Server (TS)

Collects the TRACO combinations and the η segment, and selects the 2 best segments for the DT Track Finder

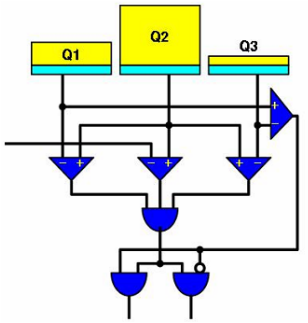
CSC Local Trigger

A ***Local Charged Track (LCT)*** is formed when a coincidence of ≥ 4 hit *strips* (**CLCT**) or *wires* (**ALCT**) in different layers, belonging to a predefined road, occurs.

Cathode trigger

Optimized to measure Φ precisely (for p_T)

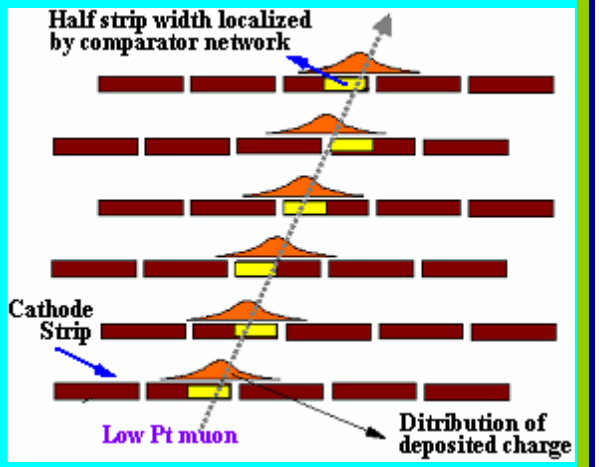
Comparator network.



Compares strip charge:
- with a threshold
- with the neighboring strips (n-1,n+1)

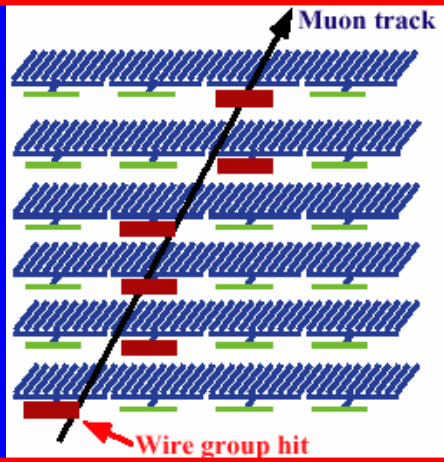
→ Localize hits to within a half-strip (in a layer)

By combining 6 Layers (1 chamber)
→0.15-strip ~1-2mm



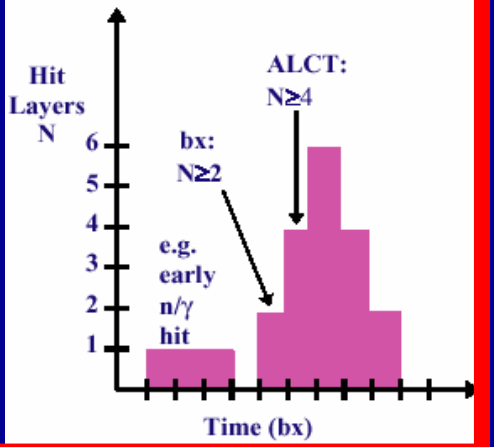
Anode trigger

Efficient BX ID



LCT trigger processor looks for coincidences of hits every 25 ns within predetermined patterns

For each spatial pattern, a low level coincidence (≥ 2 layers) is used to establish timing, and a higher level coincidence (≥ 4 layers) to establish a muon track.

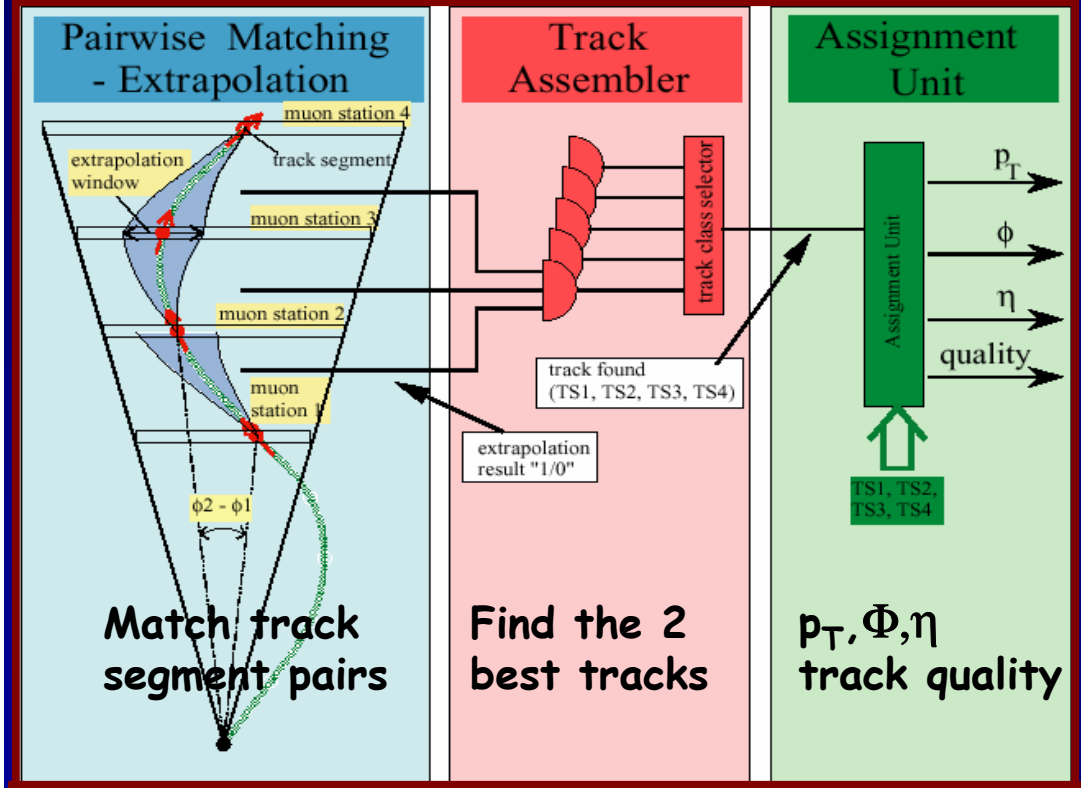


ALCT + CLCT → Time + Location + Angle → Send to CSC Track Finder

Track Finder

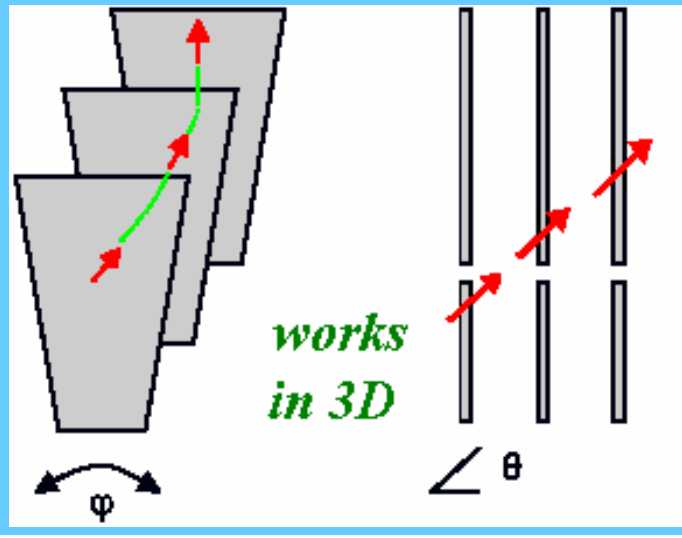
The Track Finder Connects track segments coming different stations into a full track and assigns p_T,Φ,η, and quality

DT Track Finder (DTTF)



Then the DT sorter select the 4 best candidates

CSC Track Finder



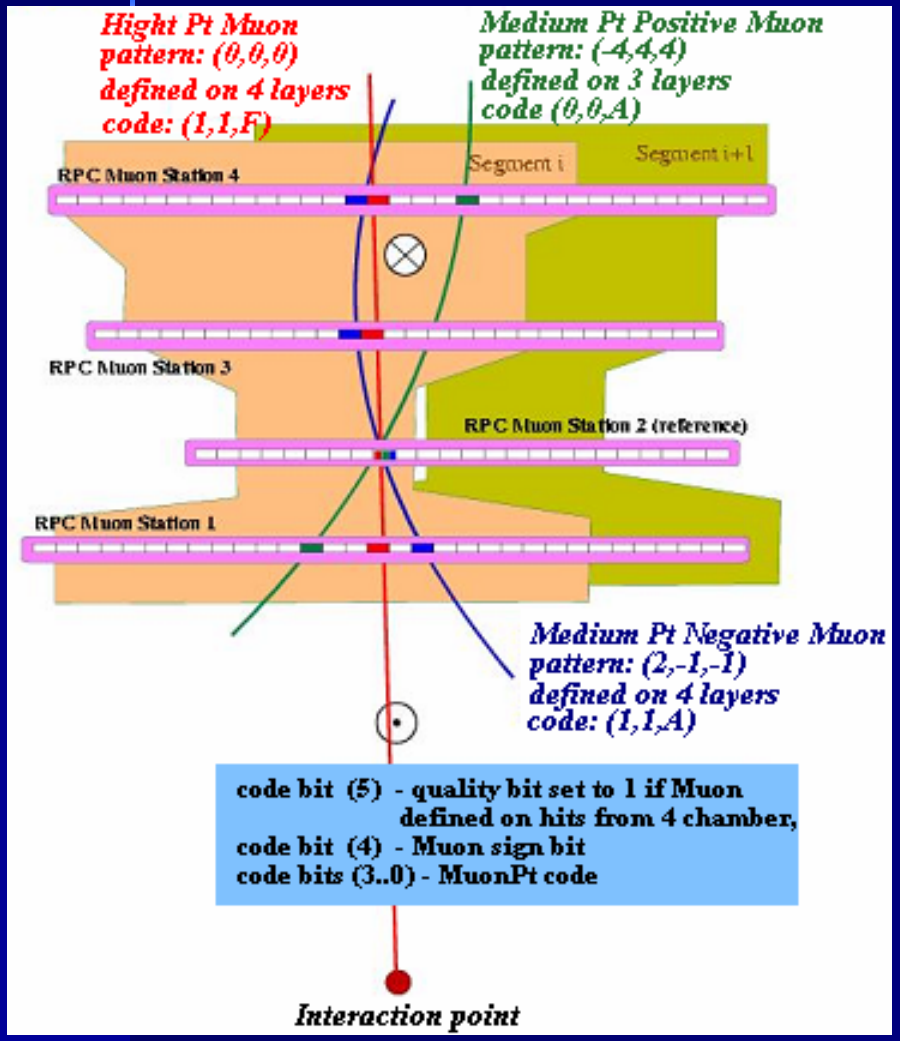
3-D info profiting from non-axial B in the endcap used to achieve maximum background rejection

Then the CSC sorter select the 4 highest quality candidates.

GLOBAL MUON TRIGGER

RPC Trigger

Pattern Comparator Trigger (PACT)



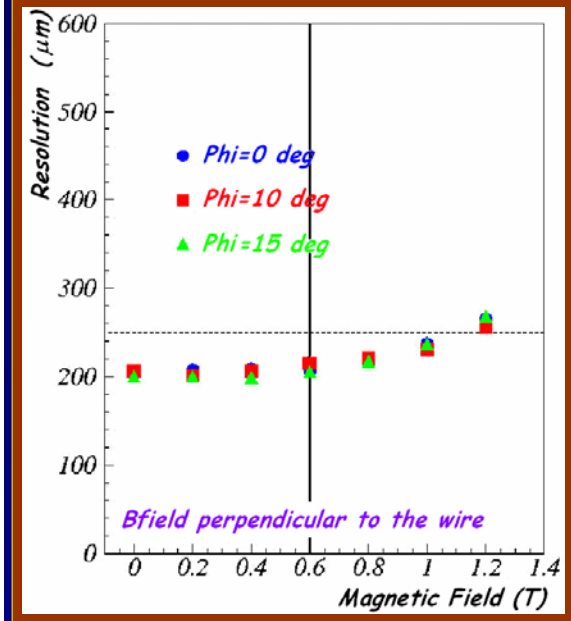
It is based on the spatial and the time coincidence of hits coming from the muon stations.

It looks for predefined patterns, each pattern associated to a p_T value

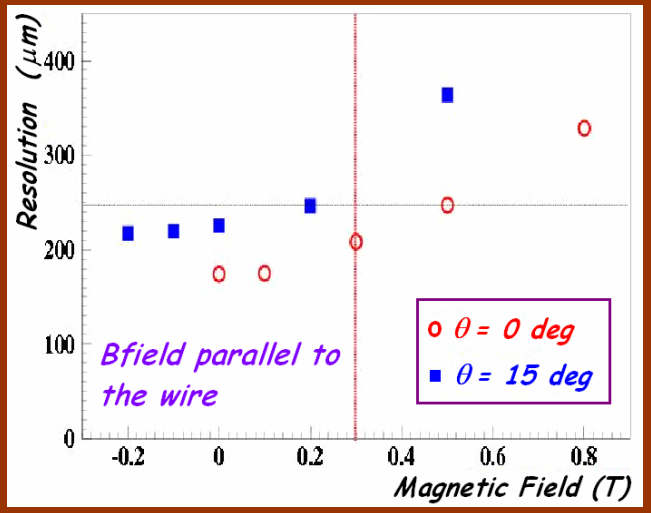
If matching is found

p_T, η and Φ is assigned
Bx identification
(from the RPC signals arrival time)

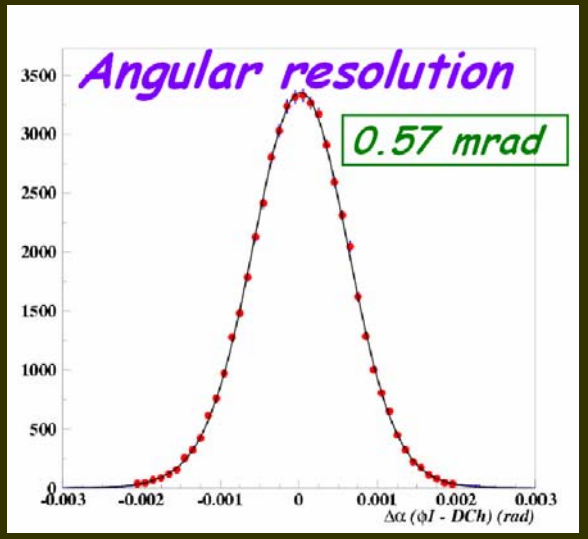
Some DT performance results



Single Cell Resolution < 250μm for Bfield conditions at CMS

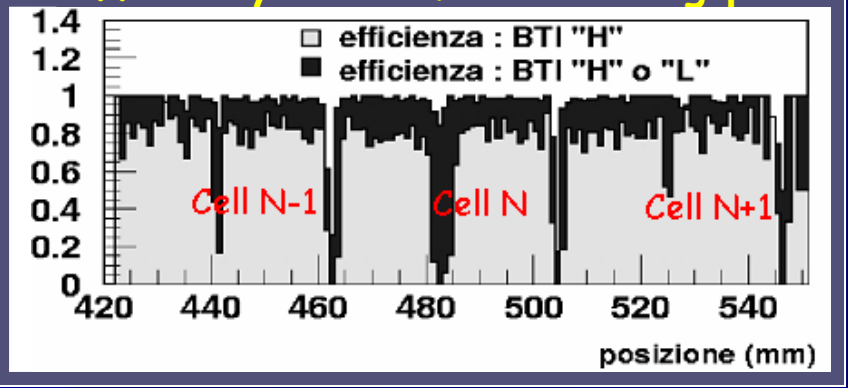


Single chamber

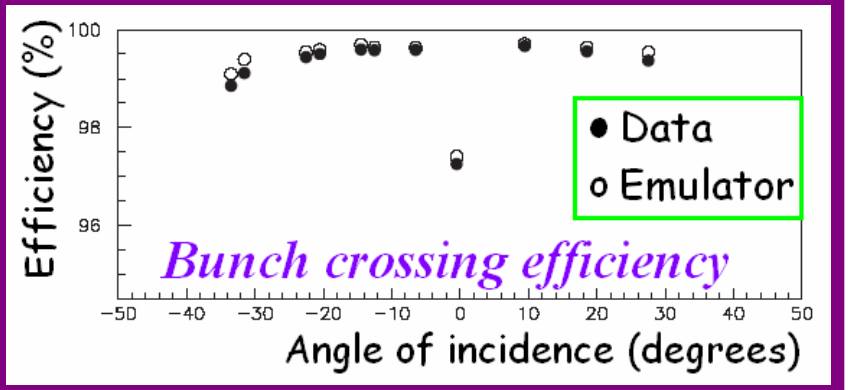


BTI

Efficiency vs chamber crossing point

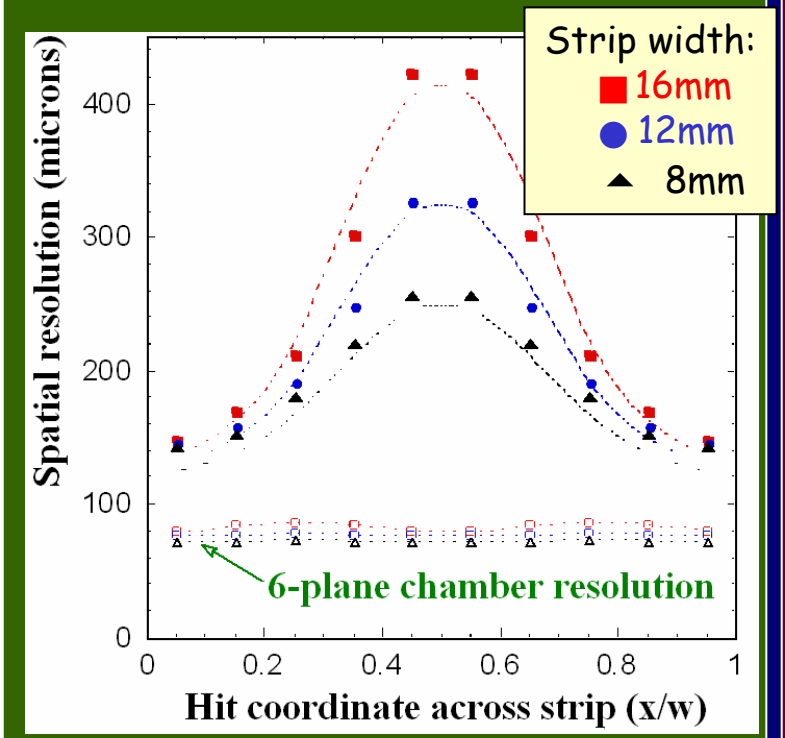


TRACO

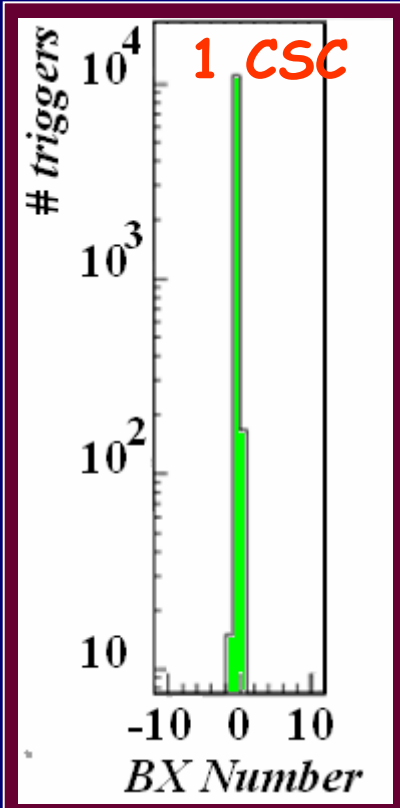


Some CSC Performance results

RESOLUTION

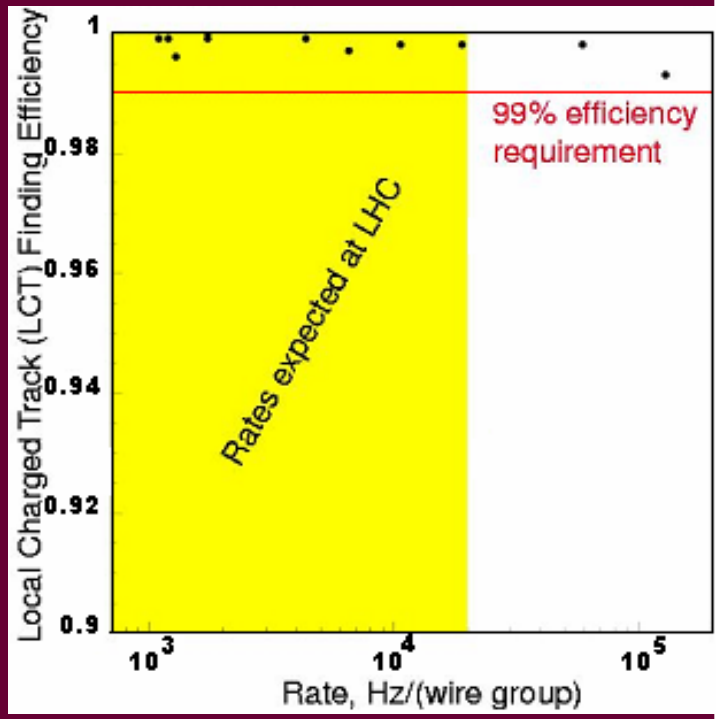


Spatial resolution per plane
150-400 μm
Resolution per chamber
≤ 100 μm



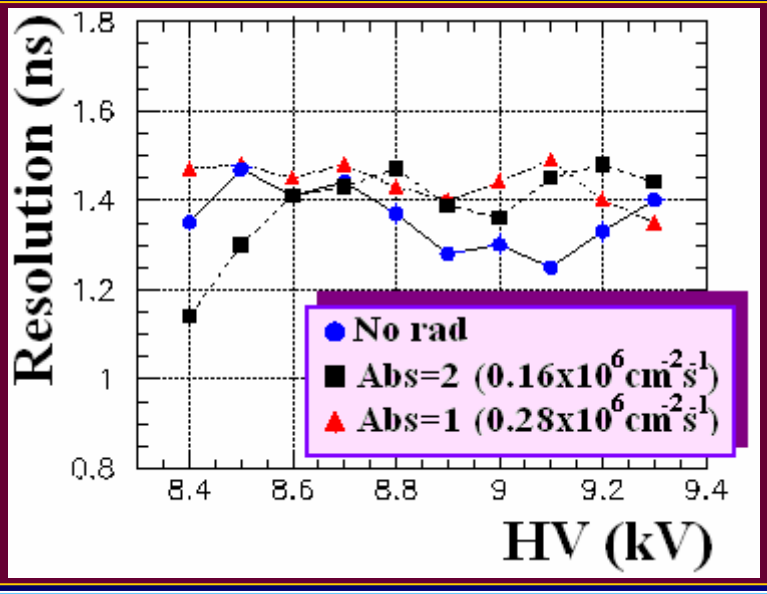
If only 1 CSC:
BX tagging
Eff:98.7%

ANODE TRIGGER



LCT Finding Efficiency
> 99%

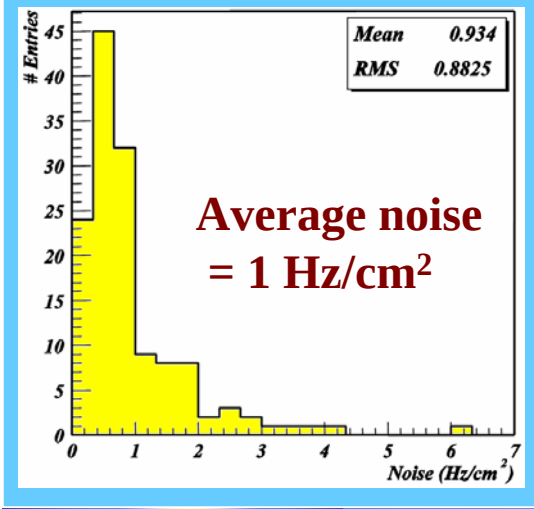
Some RPC performance results



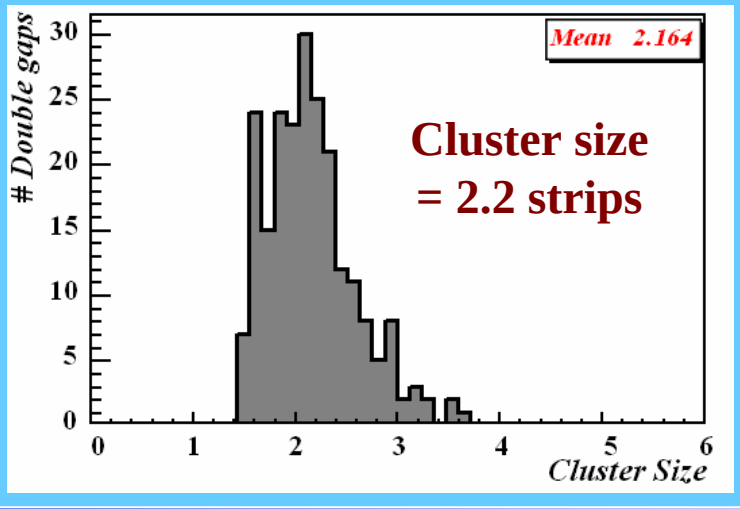
Time Resolution
(under gamma irradiation)

Results on 250 chambers

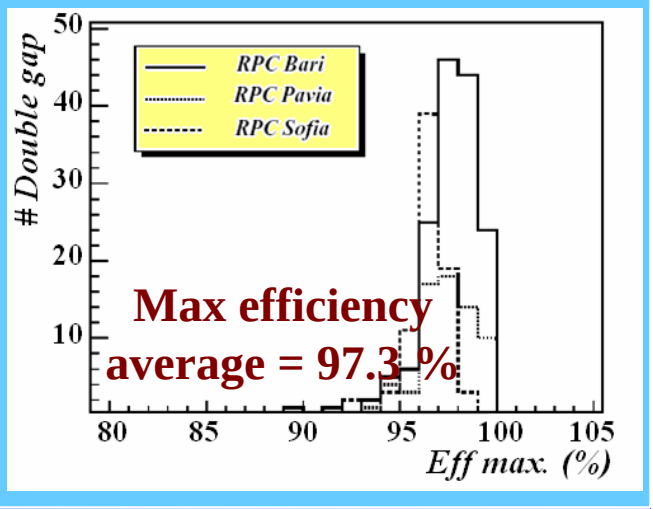
HV=9.6 kV



Average noise
= 1 Hz/cm^2



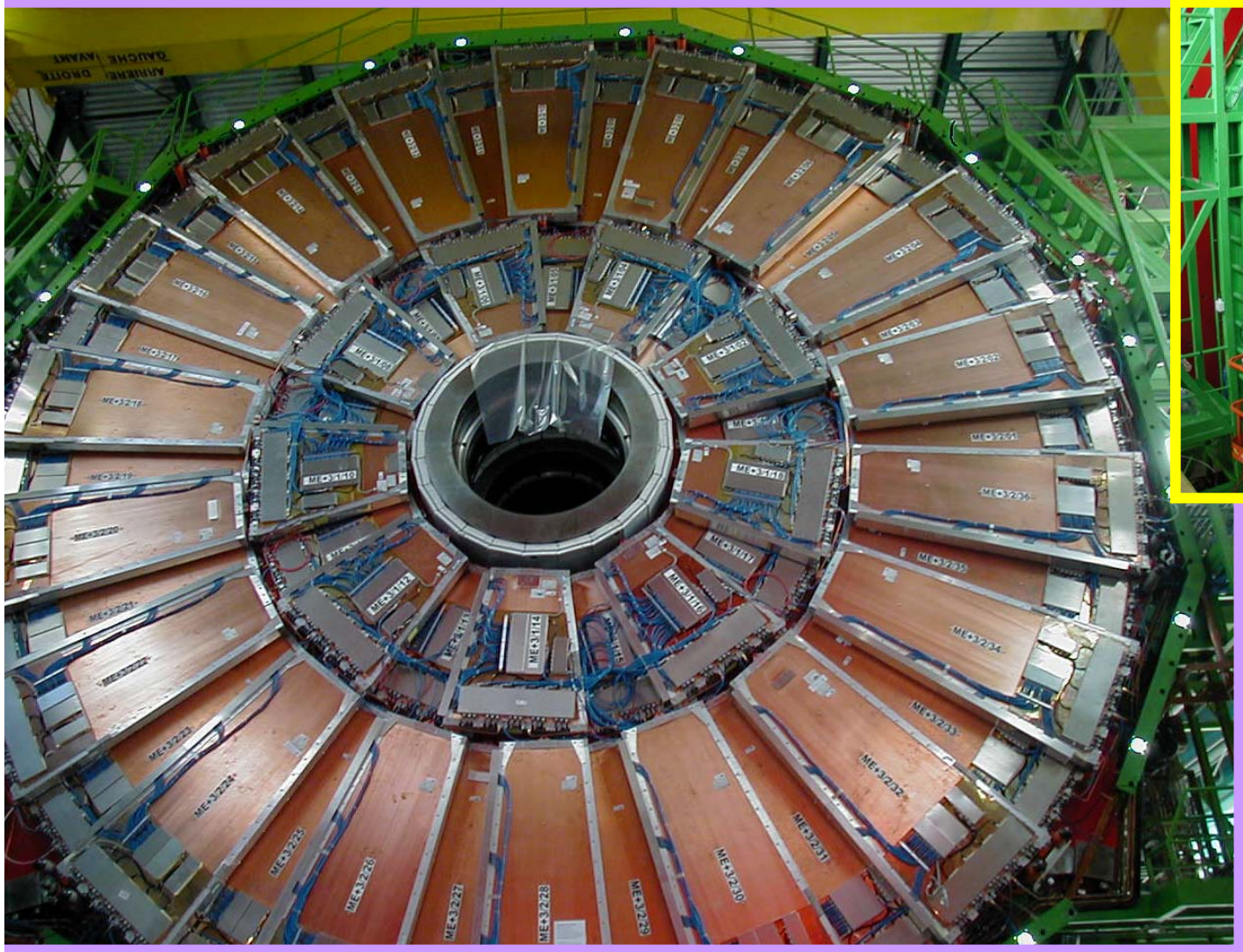
Cluster size
= 2.2 strips

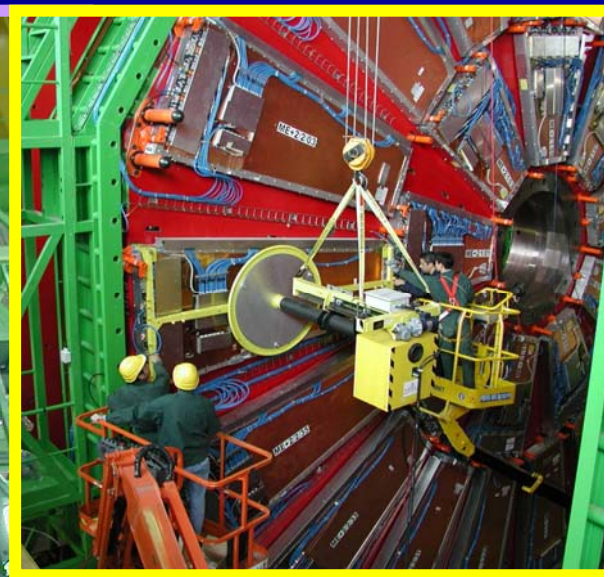


Max efficiency
average = 97.3 %

DT+RPC Installation and Comissioning

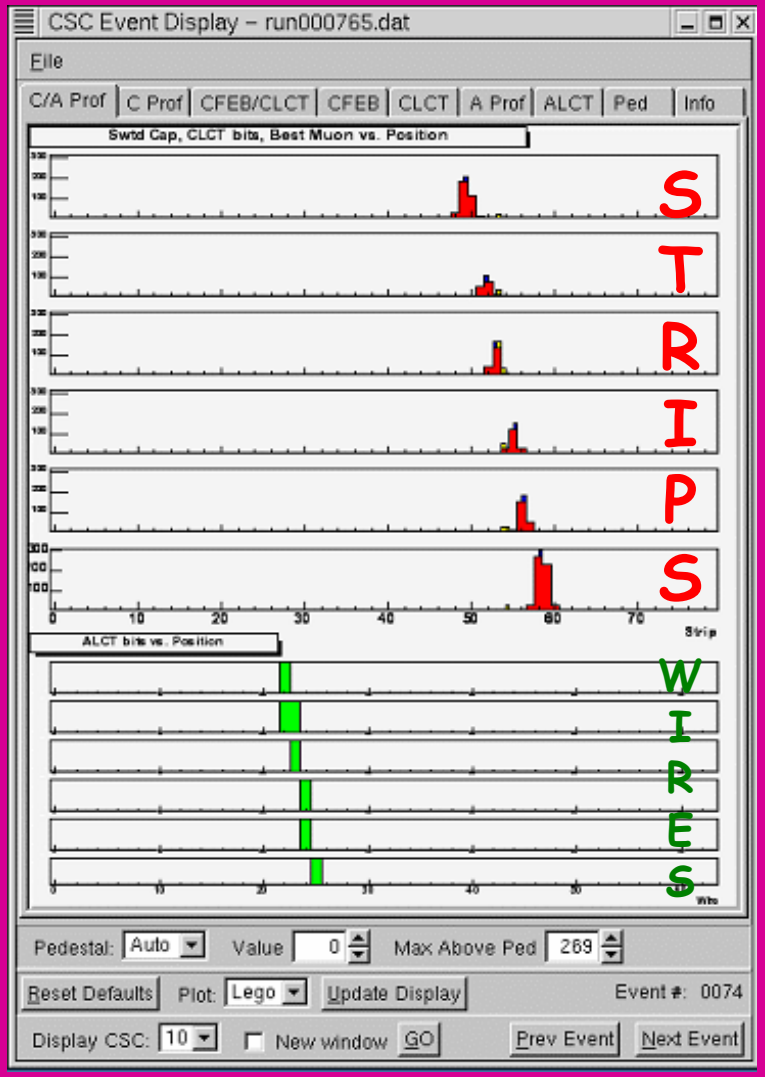
CSC Installation and Comissioning



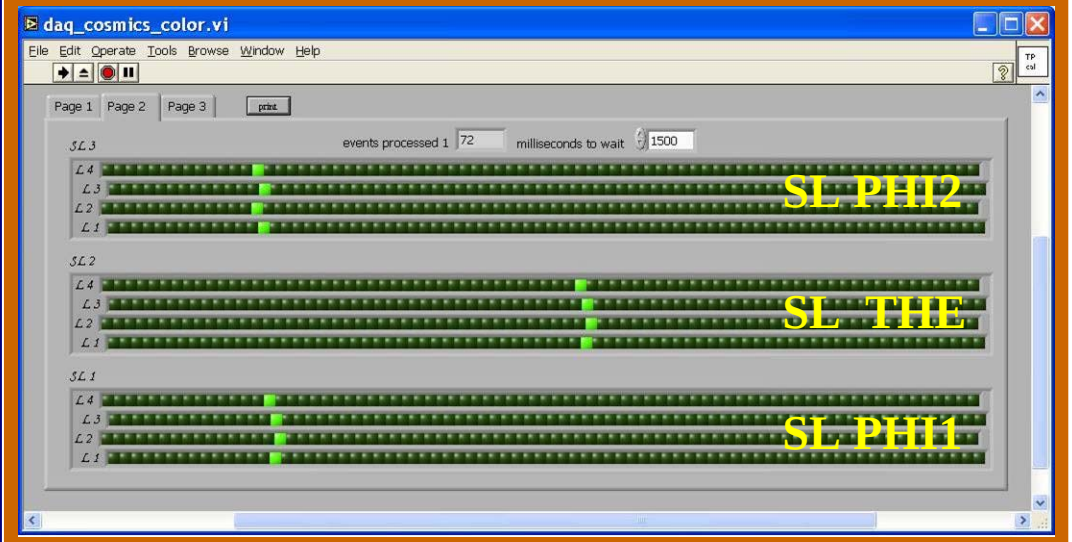


First muons (cosmics) at CMS

Single muon track in one CSC

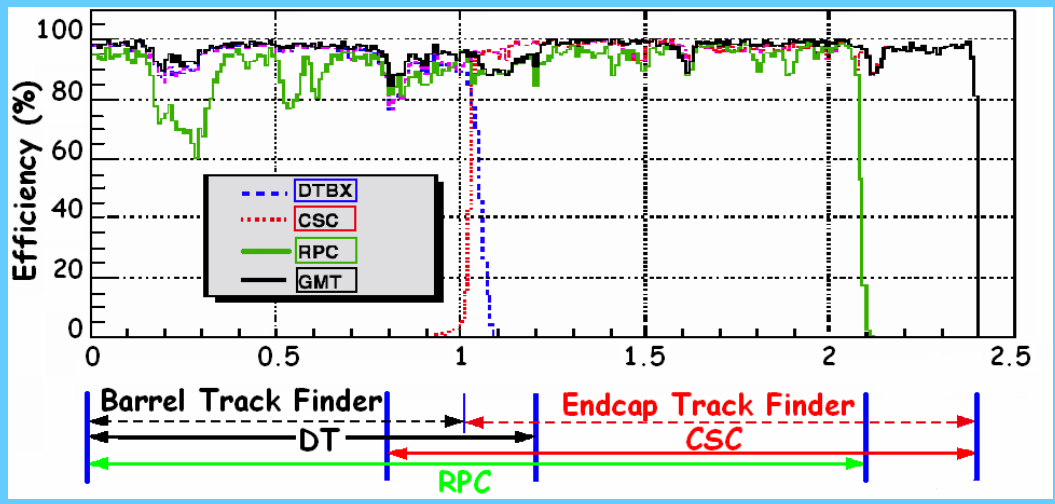


Single muon track in one DT

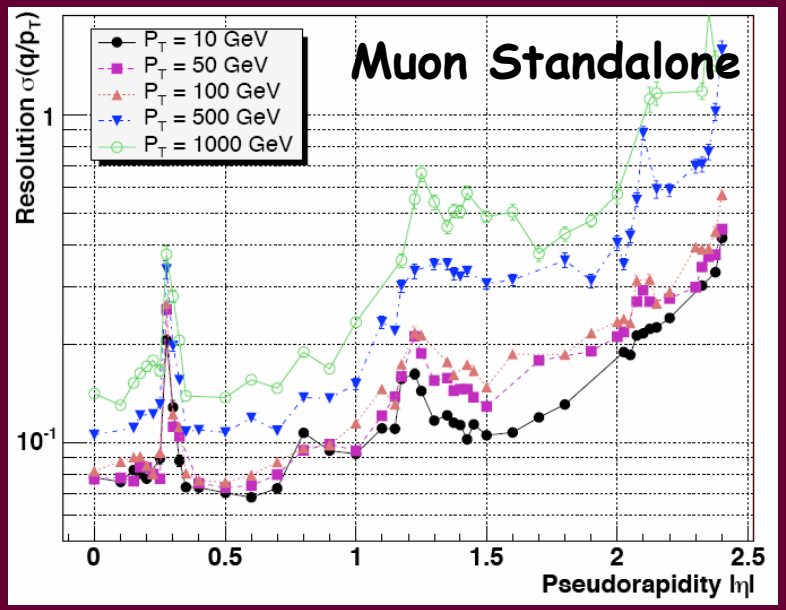


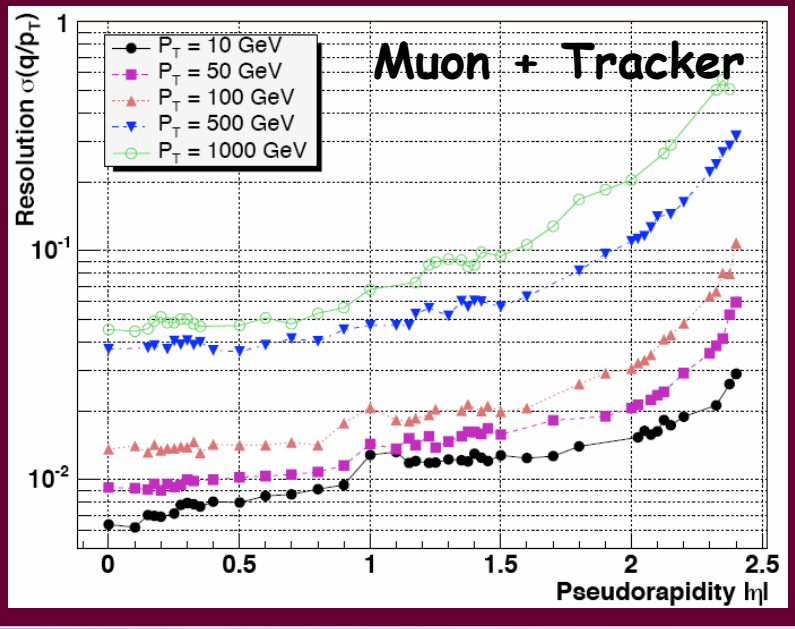
Expected muon system performance at CMS

Trigger Efficiency



$1/P_T$





We expect to get it running for 2007