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The CMS Muon Detector

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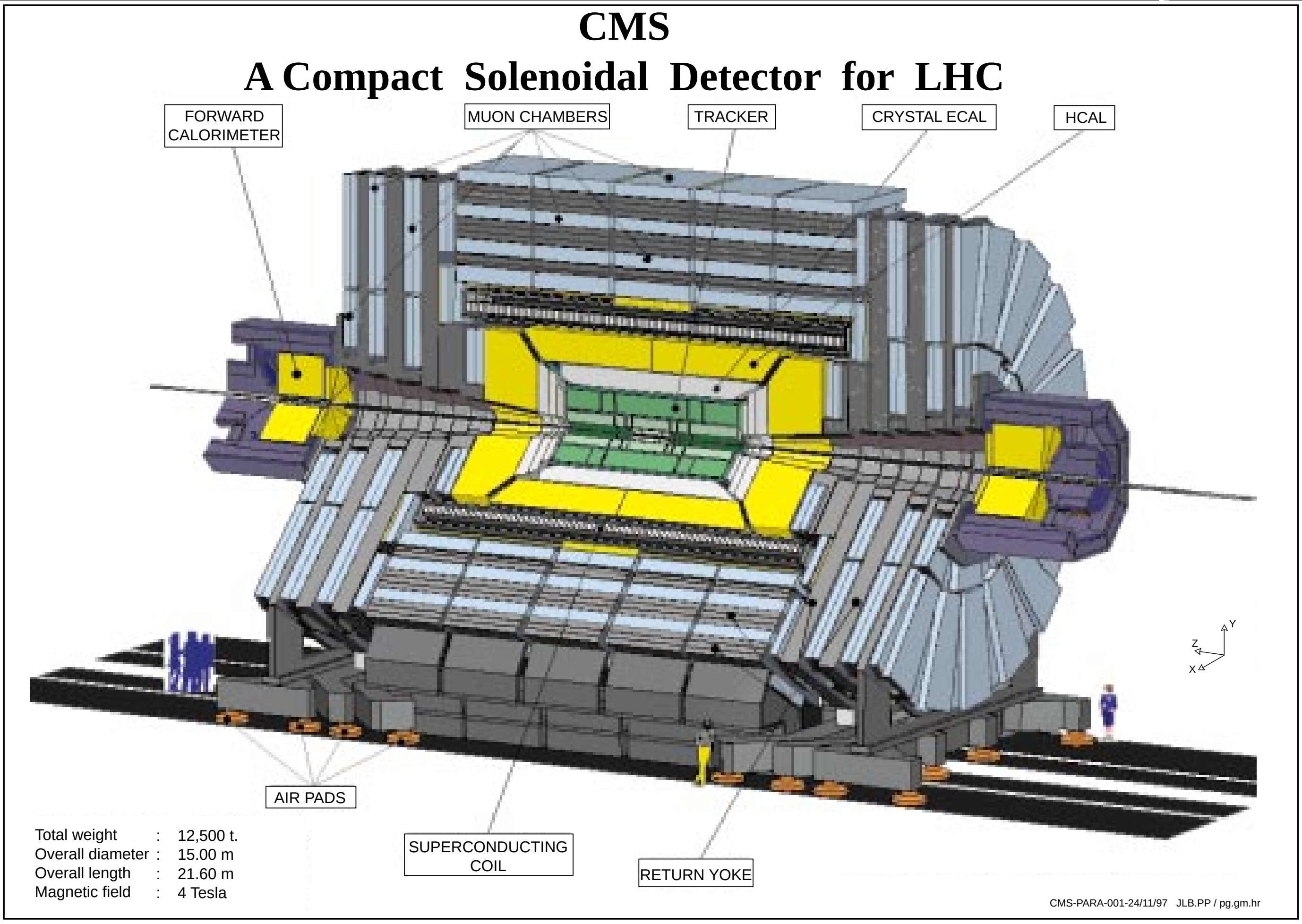
- General Overview
- Drift Tubes
- Cathode Strip Chambers
- Resistive Plate Chambers
- Global Muon Trigger
- Conclusions

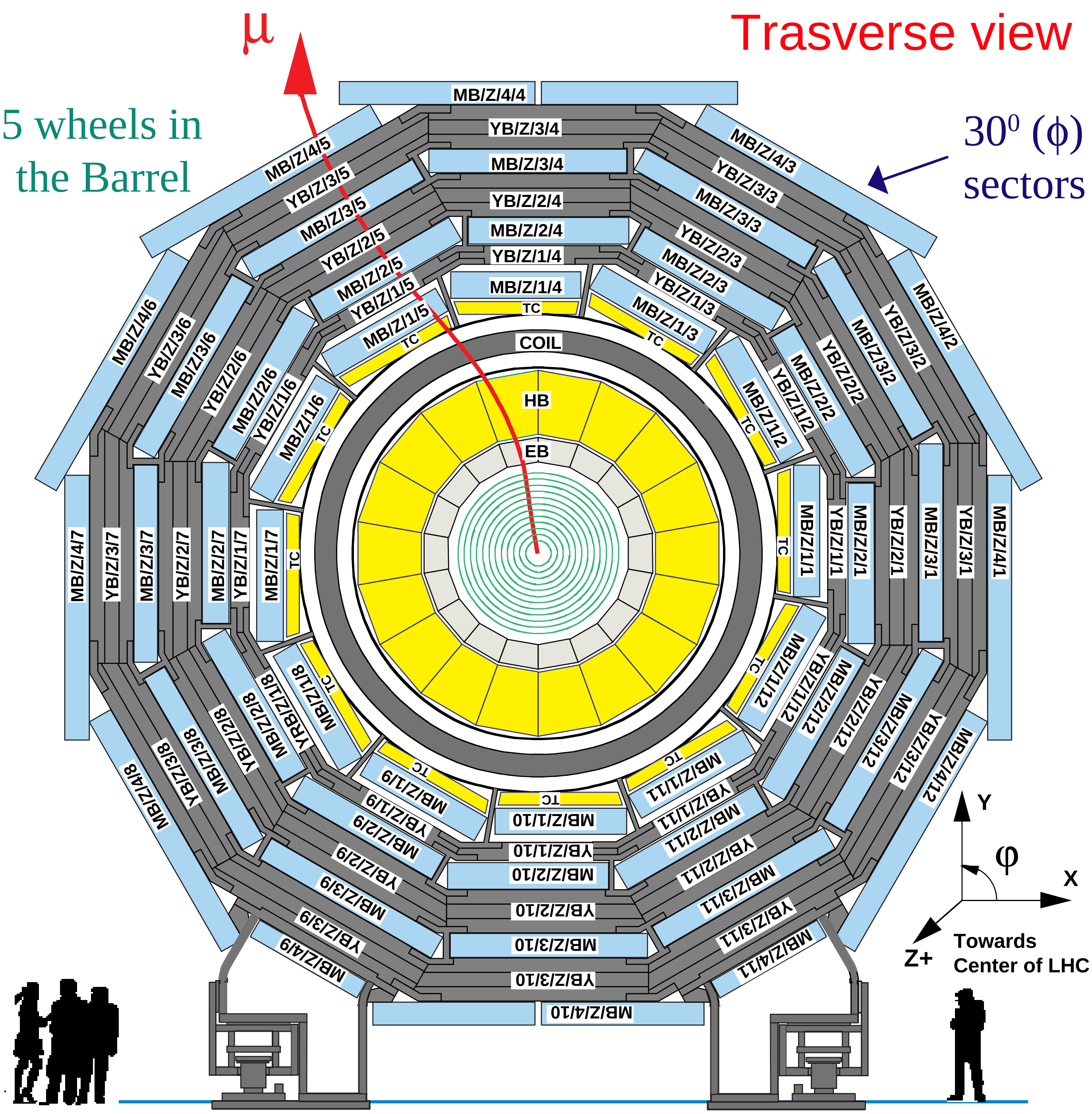
The CMS Muon Detector



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

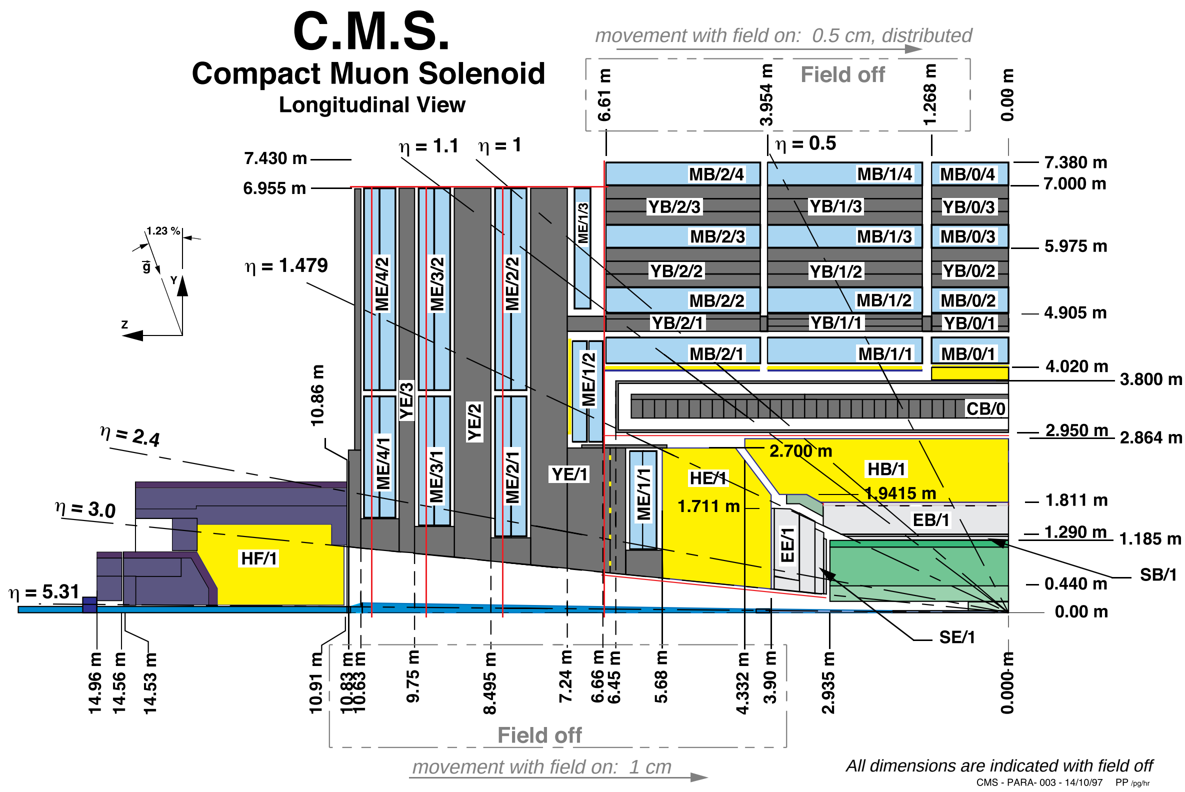
The CMS Muon Detector



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

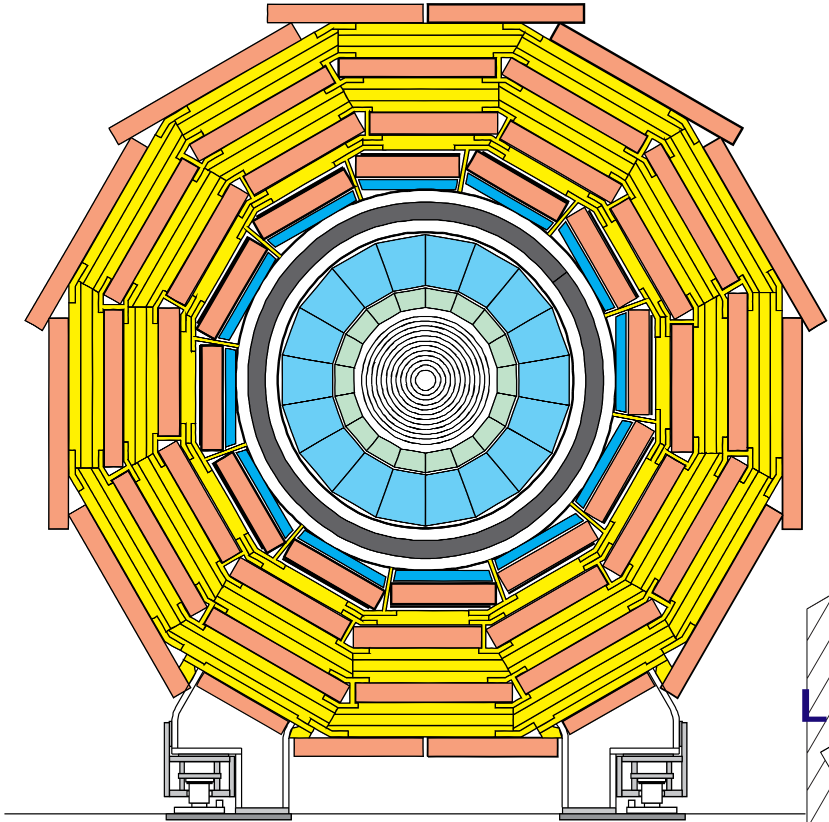
4 layers of Muon chambers covering up to |η|=2.4, providing ≥3 track segments along a muon track

Muon Detector Requirements



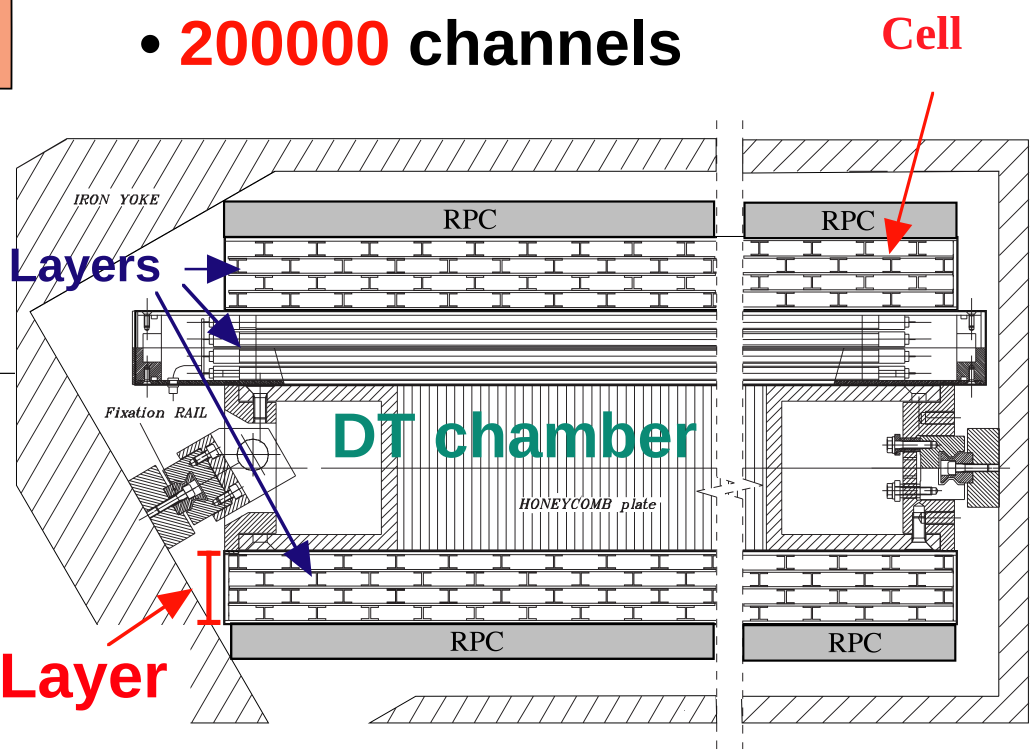
- Muon ID with at least 16 λ down to |η|=2.4
- Standalone transverse momentum res. 8-15% $\delta p_t/p_t$ (at 10 GeV), 20-40% $\delta p_t/p_t$ (at 1 TeV)
- Global momentum resolution 1.0-1.5 % $\delta p_t/p_t$
- Unambiguous BX identification
- Single and di-muon first level trigger with variable p_t thresholds down to |η|=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 ϕ-layers
  + 4 θ-layers
- MB4 = 8 ϕ-layers

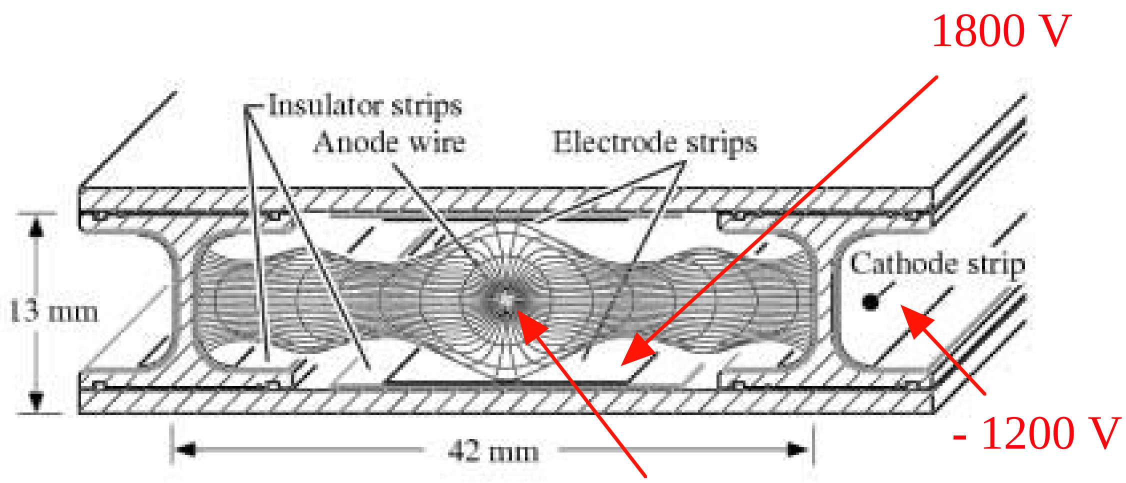
- 250 chambers
- 200000 channels



- wire pitch = 4.2 cm
- max. drift time = 380 ns

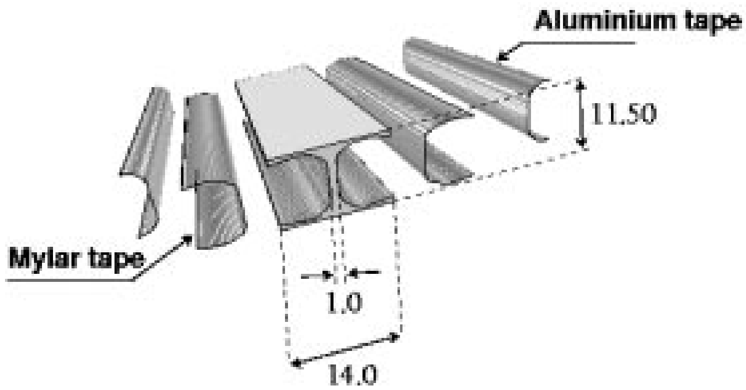
DT basic cell design

New design:



Nominal voltages

Gas mixture Ar(85%) + CO_2(15%)



Requirements

Single cell space resolution ≤ 250 μm

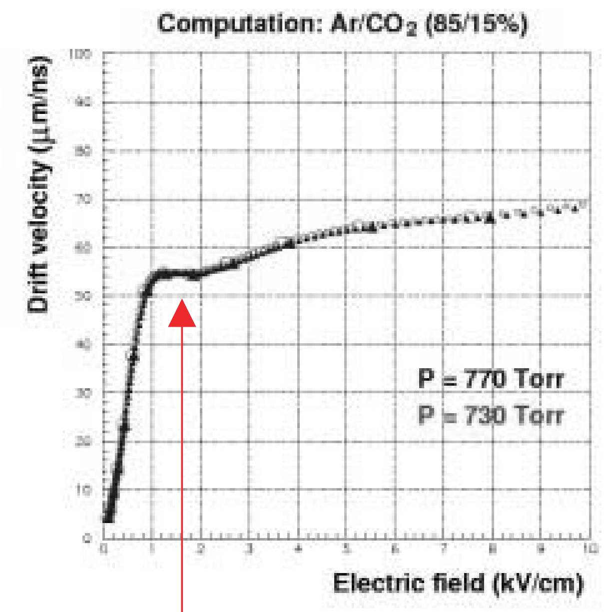
↓

Chamber space resolution ~ 100 μm

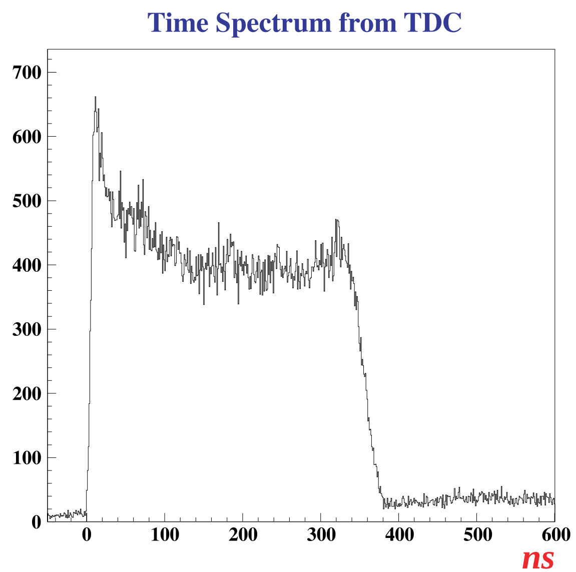
BX tagging efficiency ≥99%, trigger space res. 1-2 mm

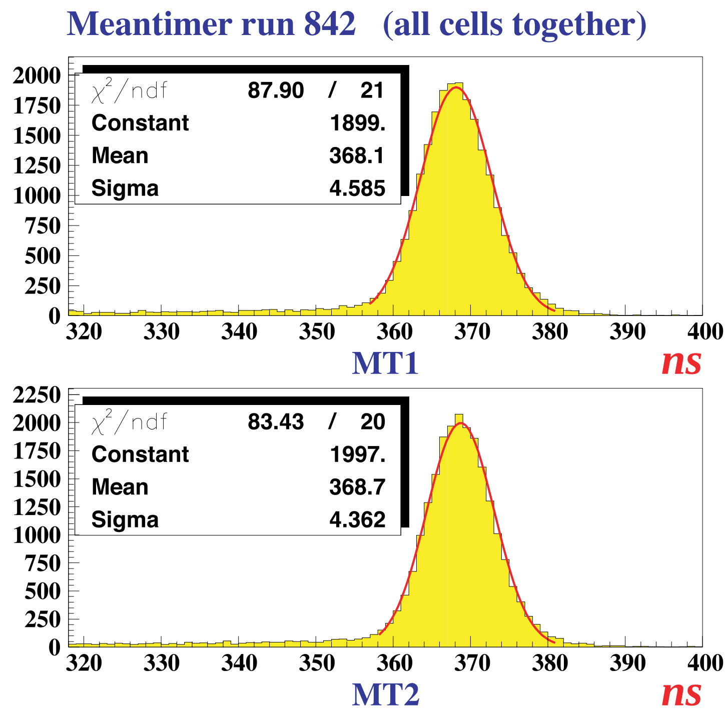
Drift Time

Simulation



test beam 2000





HV: 3600/1800/-1200 V

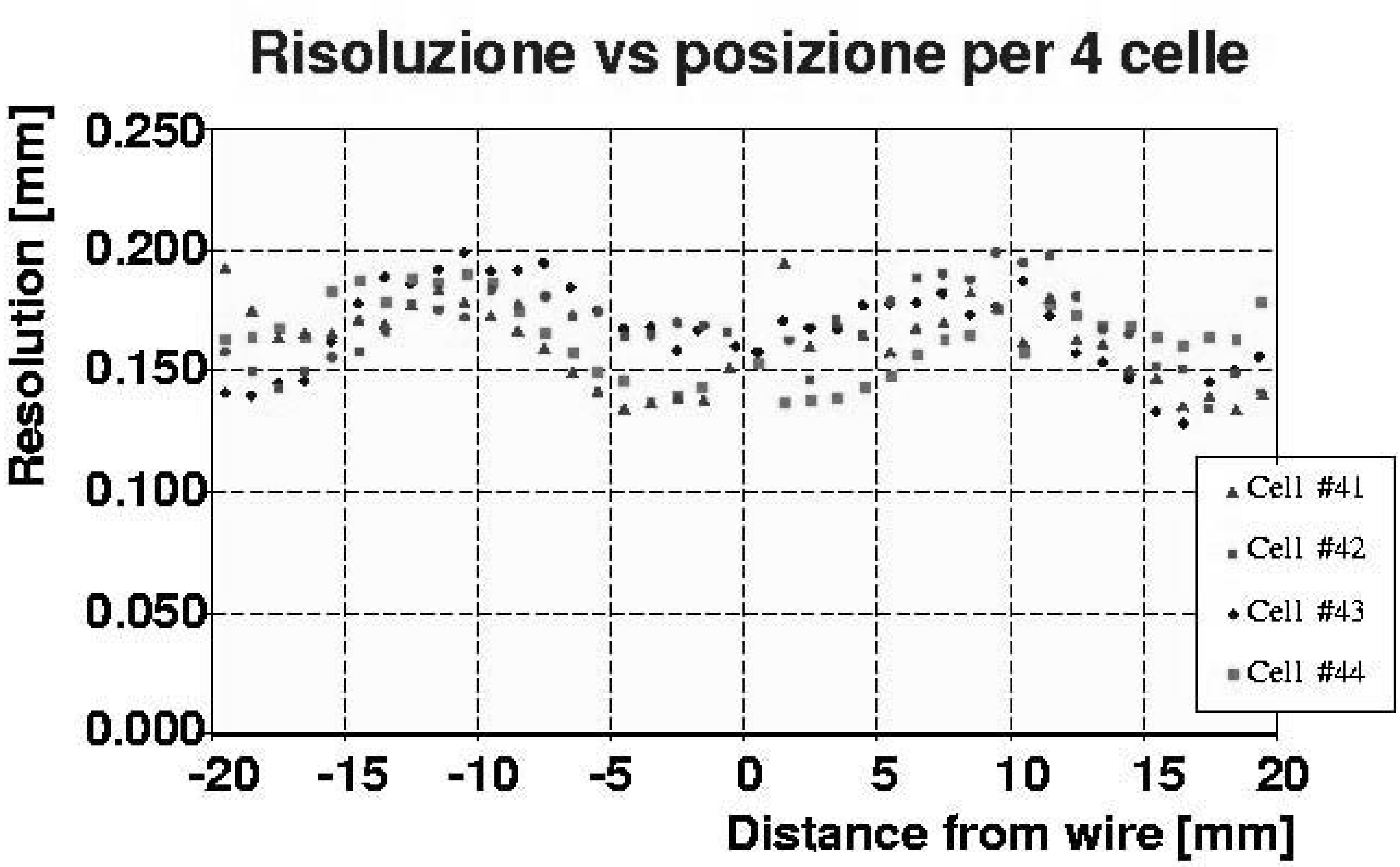
Preliminary:

v_{drift} = 57 µm/ns

Resol.= 208 µm

DT test beam results

Q4: Single wire resolution (test beam 1999)

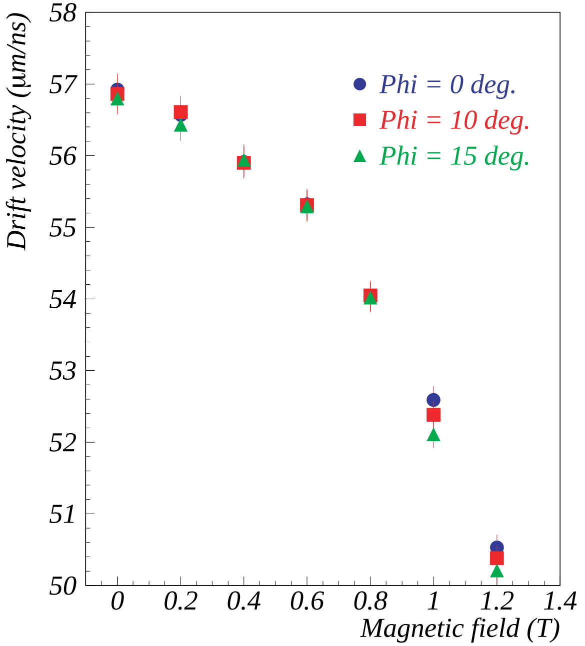


DT magnetic field effects

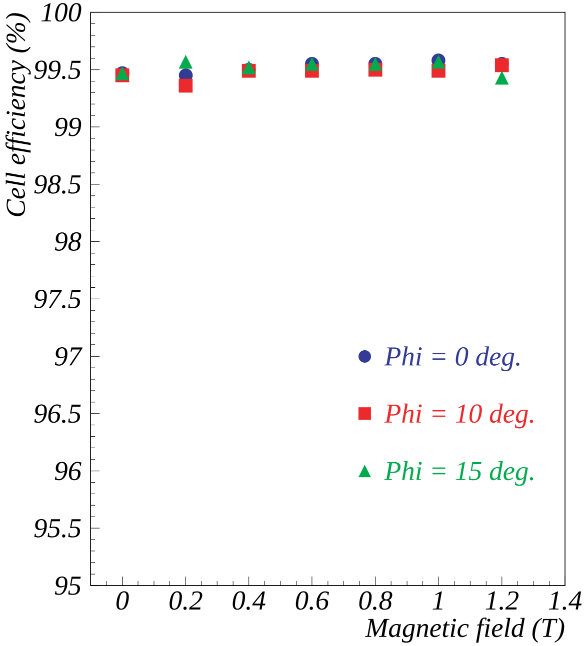
$$B_{perp} = B \cos(\phi)$$

$$B_{par} = B \sin(\phi)$$

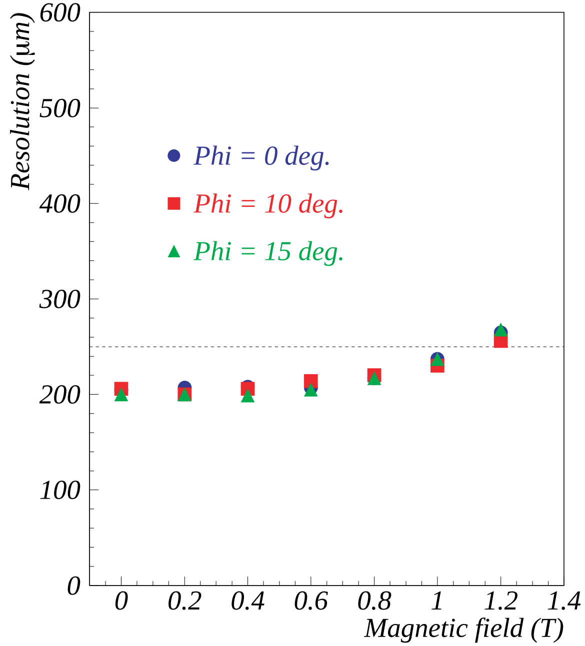
v_{drift} apparent



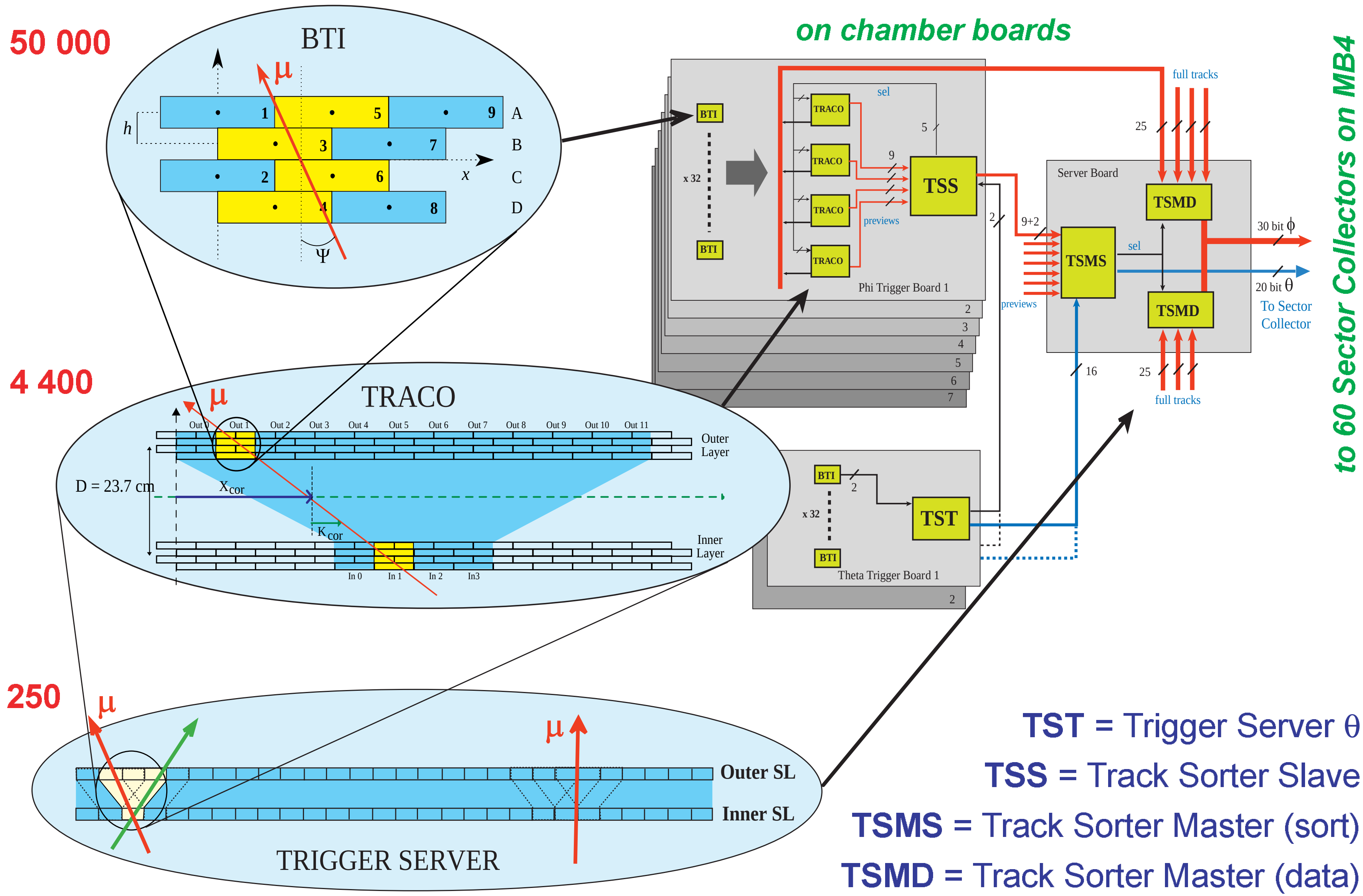
efficiency



resolution



DT Local Trigger



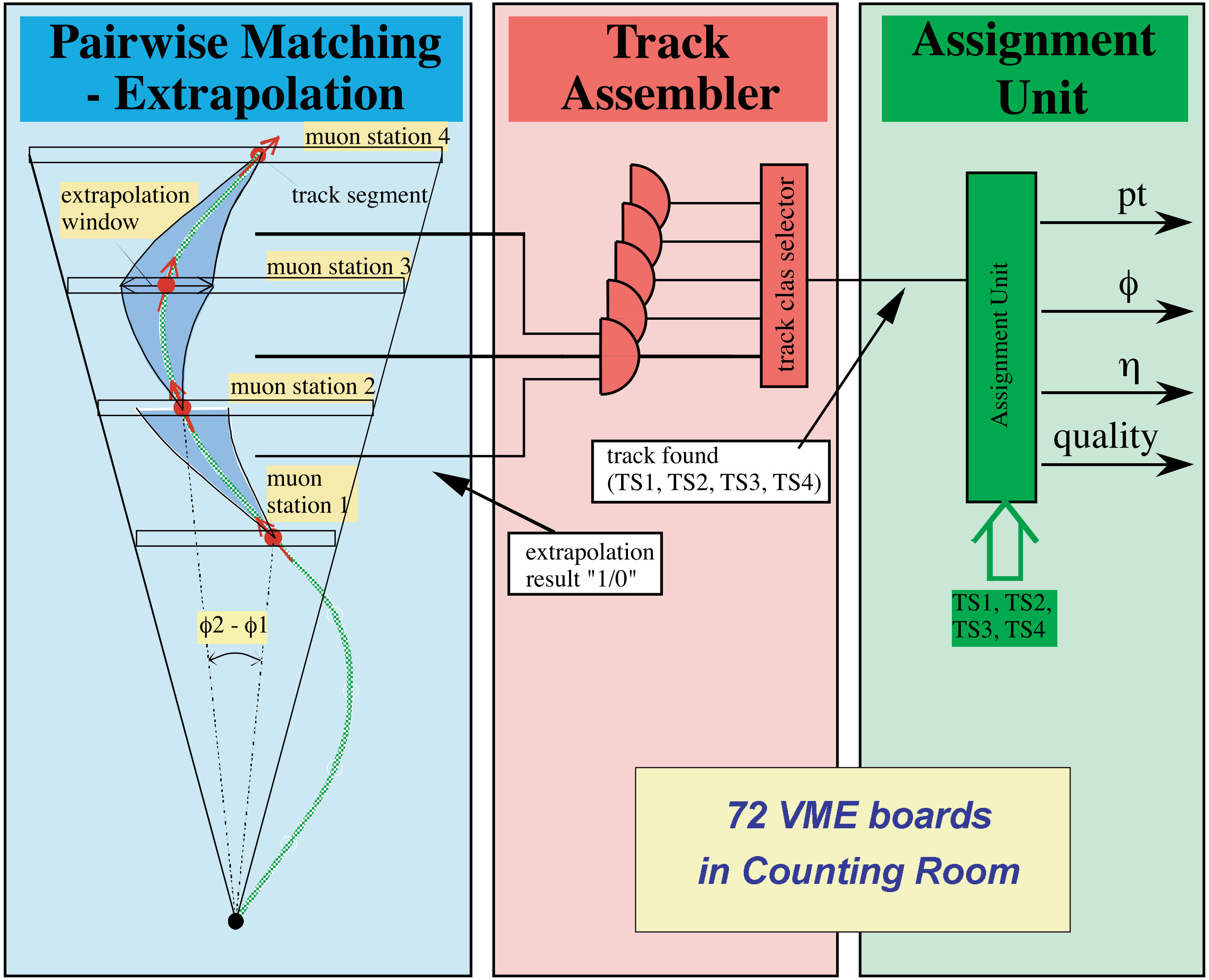
TST = Trigger Server θ

TSS = Track Sorter Slave

TSMS = Track Sorter Master (sort)

TSMD = Track Sorter Master (data)

Barrel track finder



72 VME boards in Counting Room

CSC layout

540 Chambers

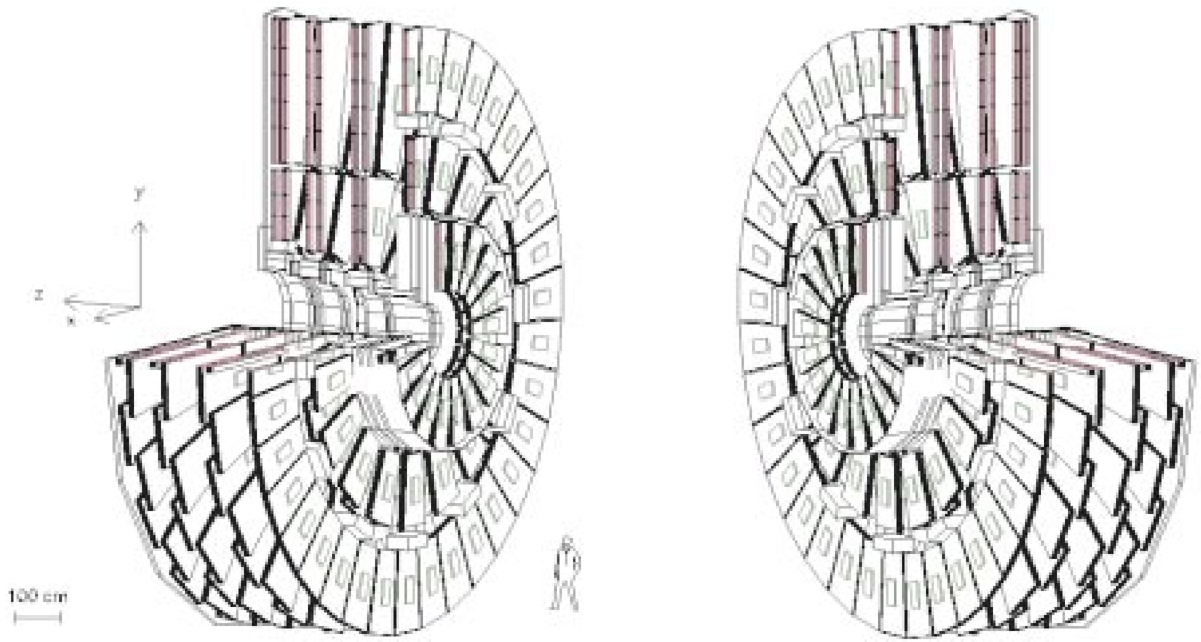
400,000 readout channels

Sensitive area 6,000 m^2 (all planes)

Offline spatial resolution ~100 μm

Trigger spatial precision ~1-2 mm

Trigger bunch-tagging efficiency ~99%

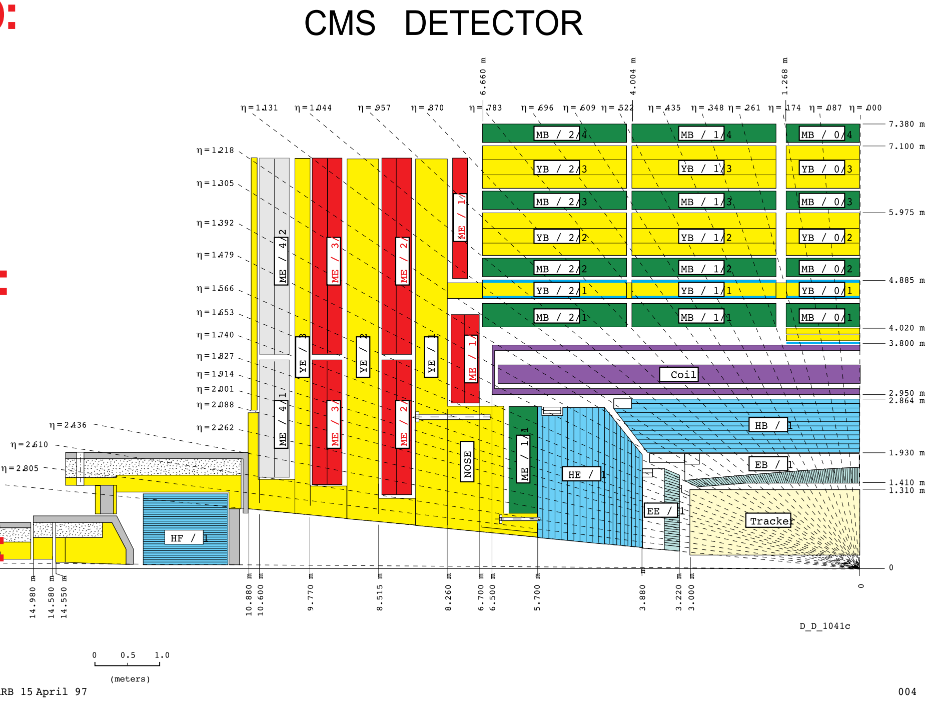


Endcap Muon System

Large 10^o ($3.4x1.5\ m^2$):
72 ME2/2 chambers
72 ME3/2 chambers
(72 ME4/2 chambers)

Small 10^o ($1.8x1.1\ m^2$):
72 ME1/1 chambers
72 ME1/2 chambers
72 ME1/3 chambers

Small 20^o ($1.9x1.5\ m^2$):
36 ME2/1 chambers
36 ME3/1 chambers
(36 ME4/1 chambers)



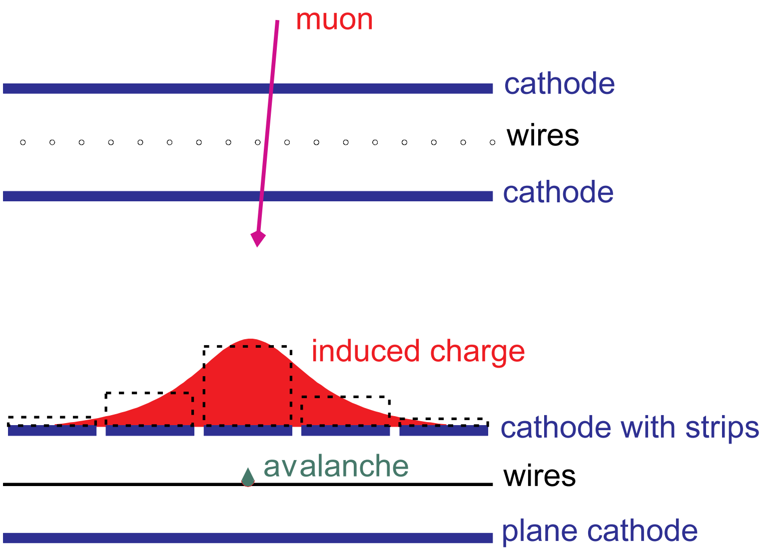
Environment

- **random hit rates**
  - up to 1000 Hz/cm^2
  - 20 kHz/channel
  - 4 times larger than mip signals
- **punch-through rates**
  - up to 100 Hz/cm^2
  - 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

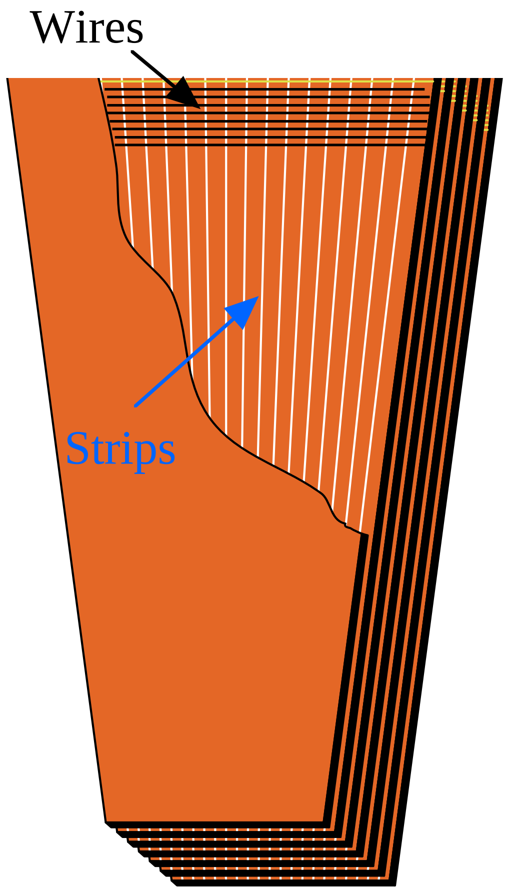
CSC conceptual design

CSCs will

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



Conceptual design of a CMS EMU CSC



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)

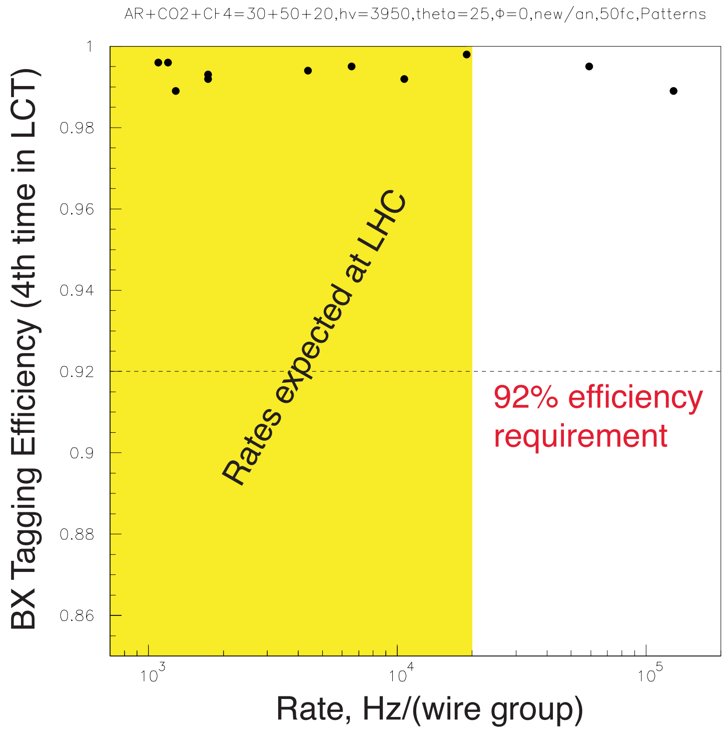
6.7 to 16.0 mm strip width
strips run radially to measure
ϕ-coordinate with ~100 μm precision

50 µm wires spaced by 3.2 mm
5 to 16 wires ganged in groups
wires measure r-coordinate

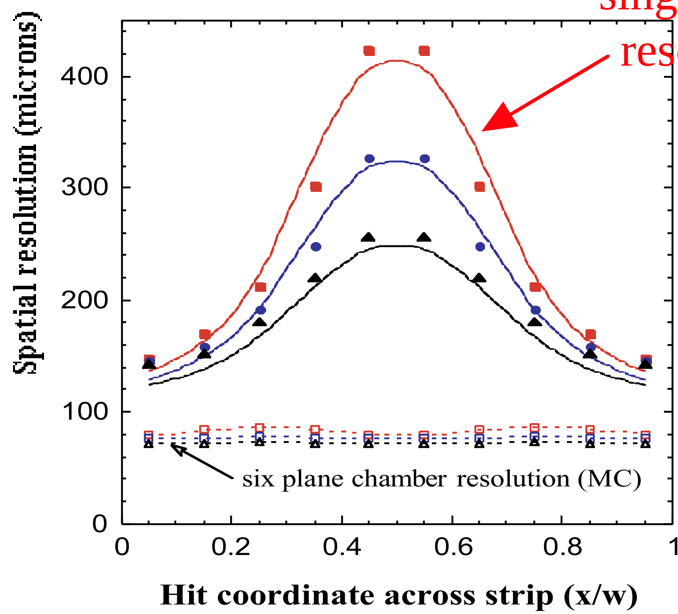
gas Ar(40%)+CO_2(50%)+CF_4(10%)
HV~3.6 kV ($Q_{cathode}$~110 fC, Q_{anode}~140 fC)

CSC time and space resolution

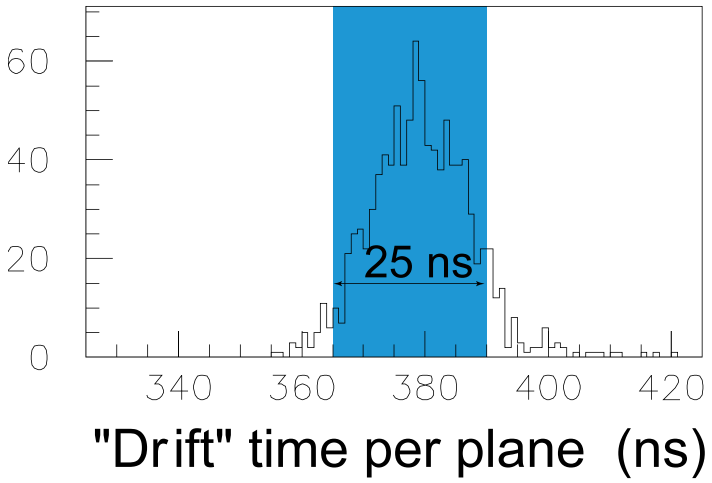
- **Bunch tagging ID efficiency ~99% at maximum LHC rates**



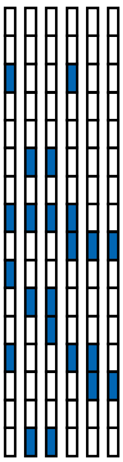
- **Spatial resolution <100 μm even for very wide strips:**
  - □ strip width = 16 mm
  - O strip width = 12 mm
  - Δ strip width = 8 mm



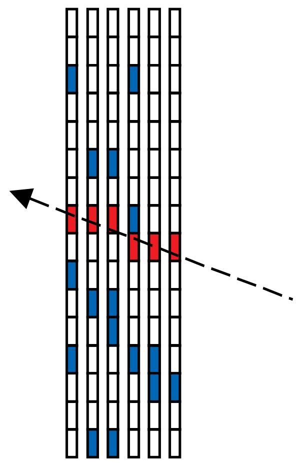
CSC Anode Trigger



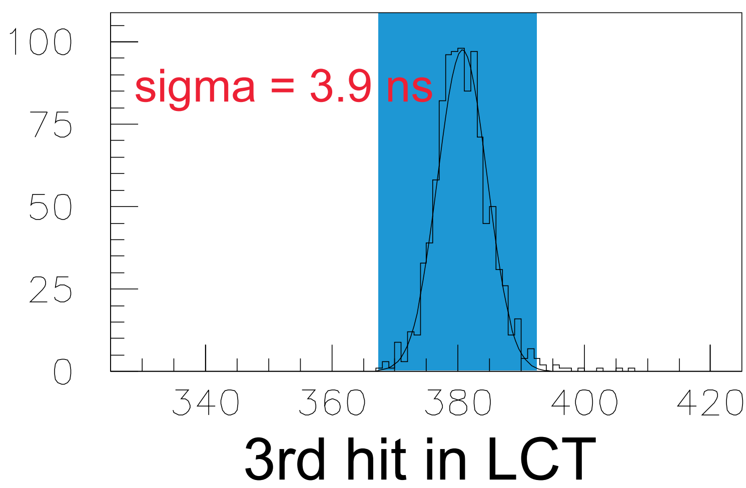
Time spread per plane is broad: drift, noise, fluctuations in cluster formations



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)



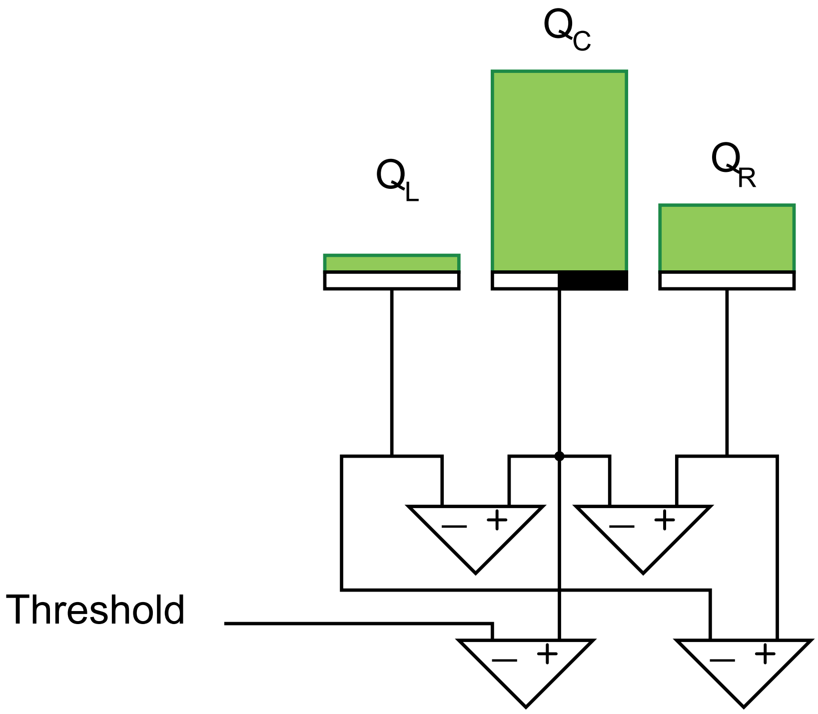
2nd (or 3rd) earliest hit in LCT has a much narrower distribution and can be used for reliable bunch crossing tagging



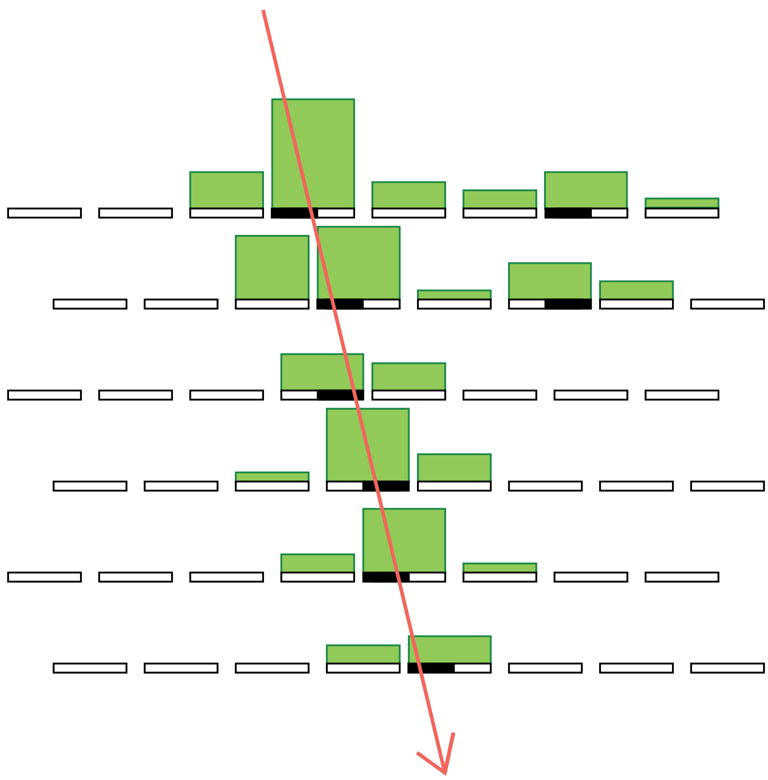
CSC Cathode trigger

First, hits are localized with precision of a half-strip:

- Q > threshold
- $Q > Q_{right}$
- $Q > Q_{left}$
- $Q_{right} > Q_{left}$



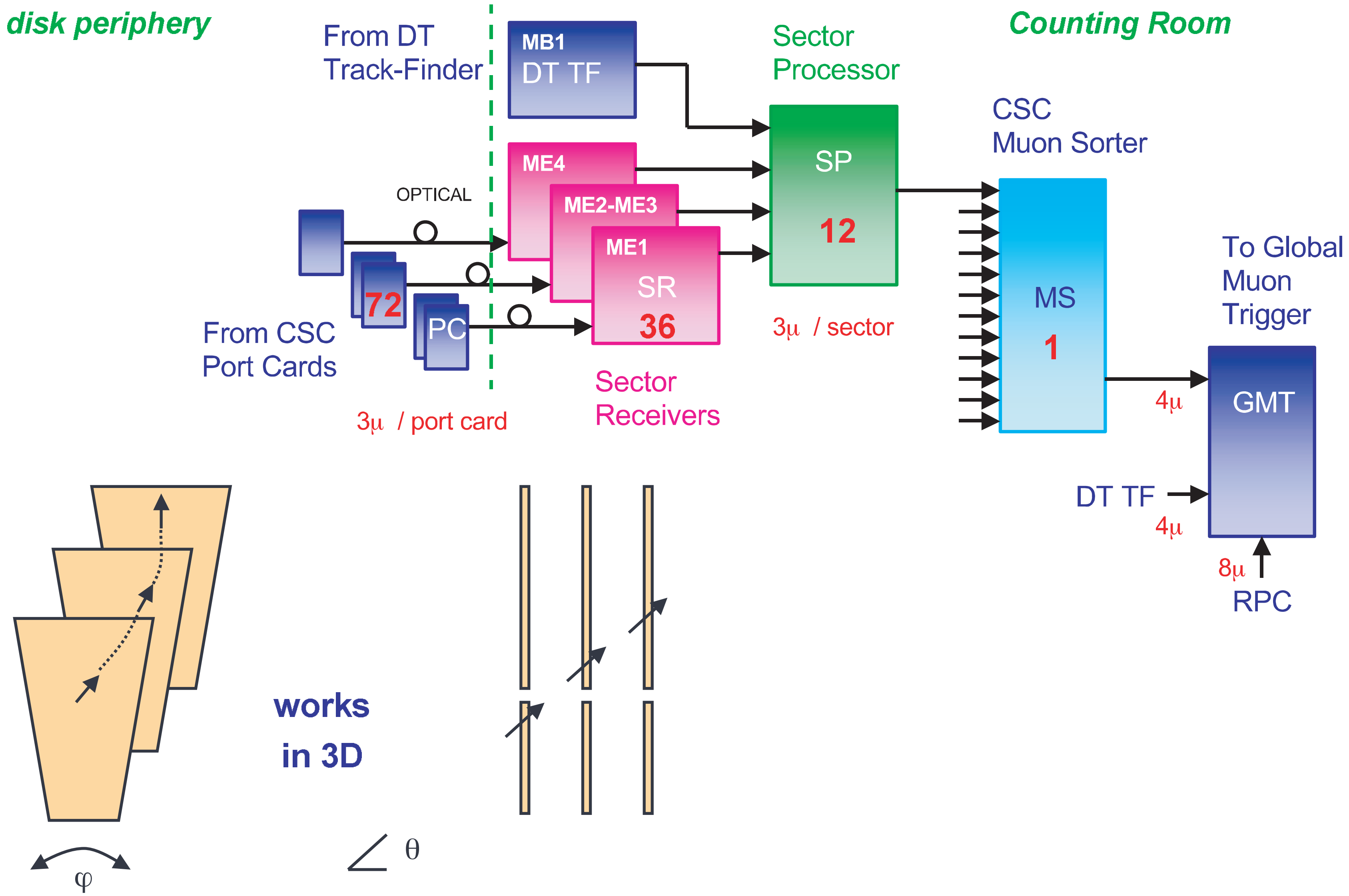
Then, a track-like pattern of half-strips is searched for (LCT-- local charged track).



Expected precision:

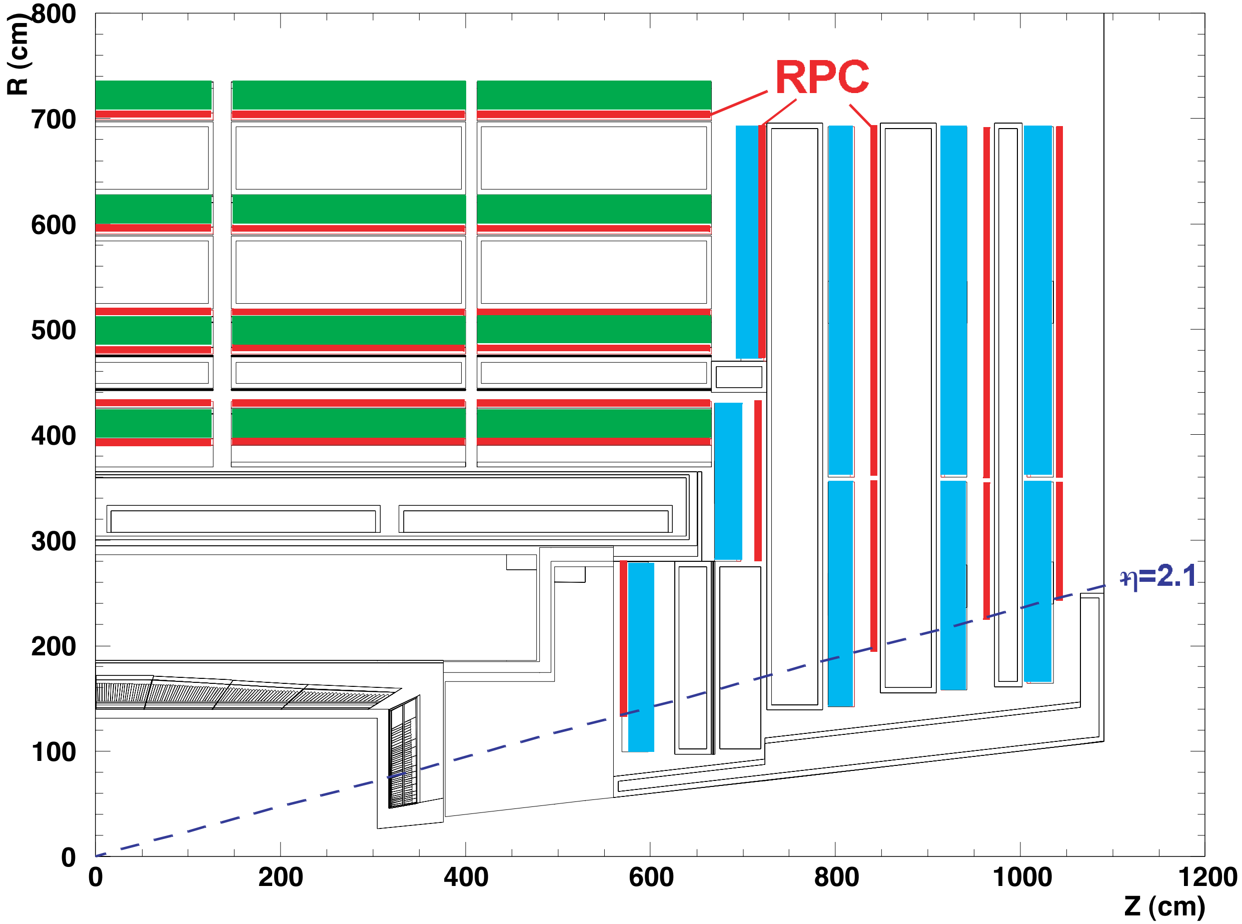
- (w/2)/sqrt(12)=0.14*w for normal incidence
- for wide-spread angles it should be even better

CSC Trigger



disk periphery
From DT
Track-Finder
MB1
DT TF
Sector
Processor
Counting Room
CSC
Muon Sorter
SP
12
ME4
ME2-ME3
ME1
SR
36
OPTICAL
72
PC
From CSC
Port Cards
3μ / port card
Sector
Receivers
3μ / sector
MS
1
To Global
Muon
Trigger
GMT
4μ
DT TF
4μ
8μ
RPC
works
in 3D
φ
θ

RPC layout



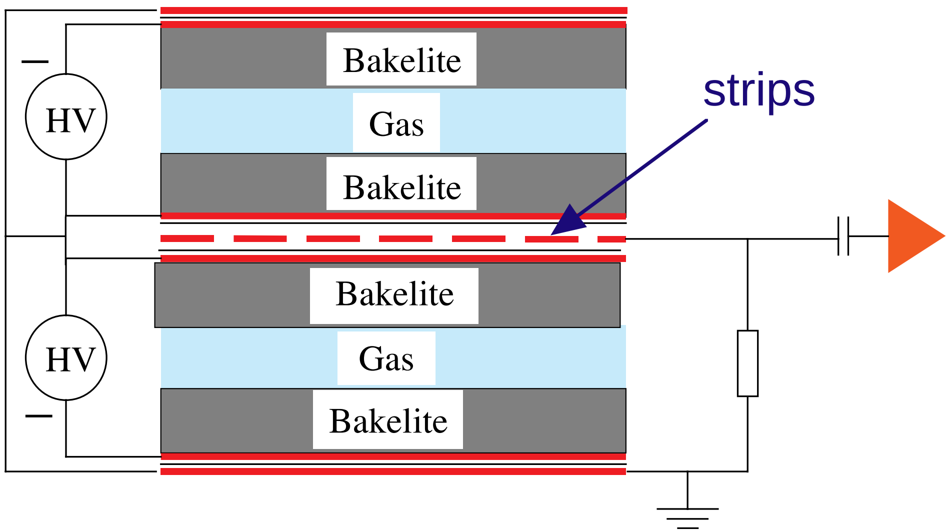
Barrel RPC:

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

Endcap RPC:

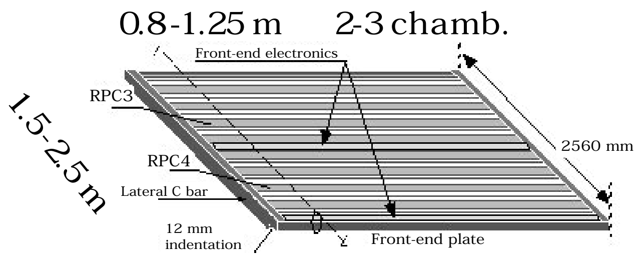
- RE 1,2,3,4 = 1 layers
- 540 trapezoidal chambers
- 80 000 radial strips

RPC double gap design

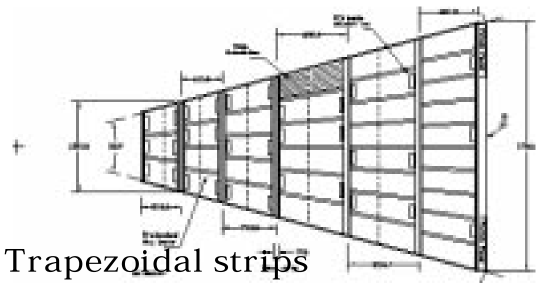


- 2 mm double gap
- bakelite resistivity: 2-5 x 10^{10} Ωcm
- bakelite thickness: 2 mm
- gas mixture: 95.5% $C_2H_2F_4$ + 4.5% iso-C_4H_{10}
- operating voltage: ~9 kV

strip pitch = Δη x Δφ ~ 0.1 x 5/16^0 = 20-100 cm x 1-4 cm



CMS barrel



Trapezoidal strips and chambers

CMS endcap

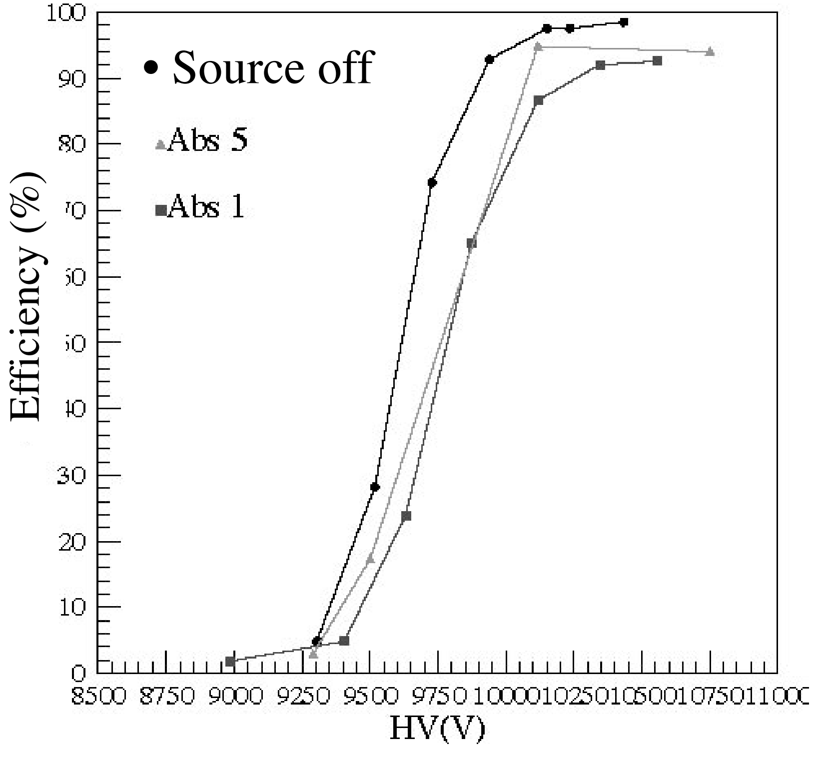
RPC efficiency and cluster size

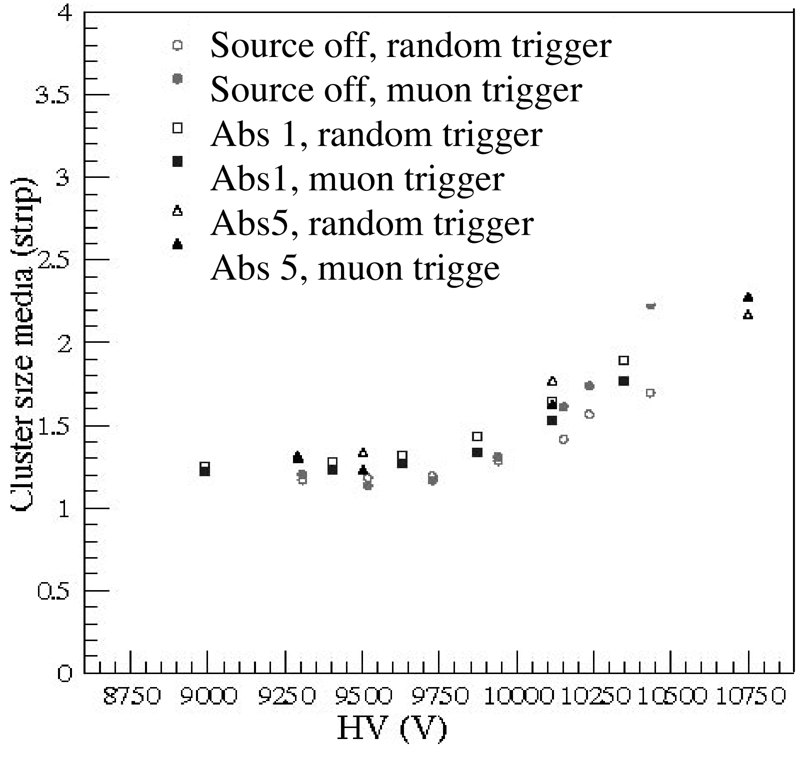
98.5% HV=10.4 kV

95% HV=10.1 kV

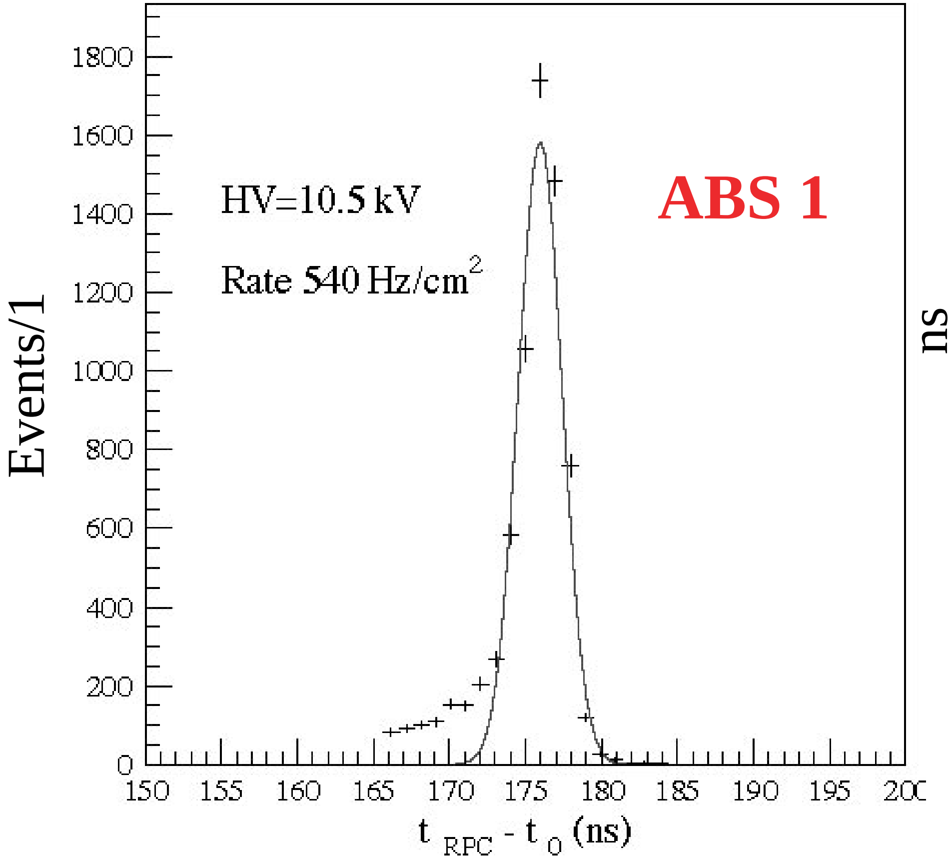
93% HV=10.5 kV

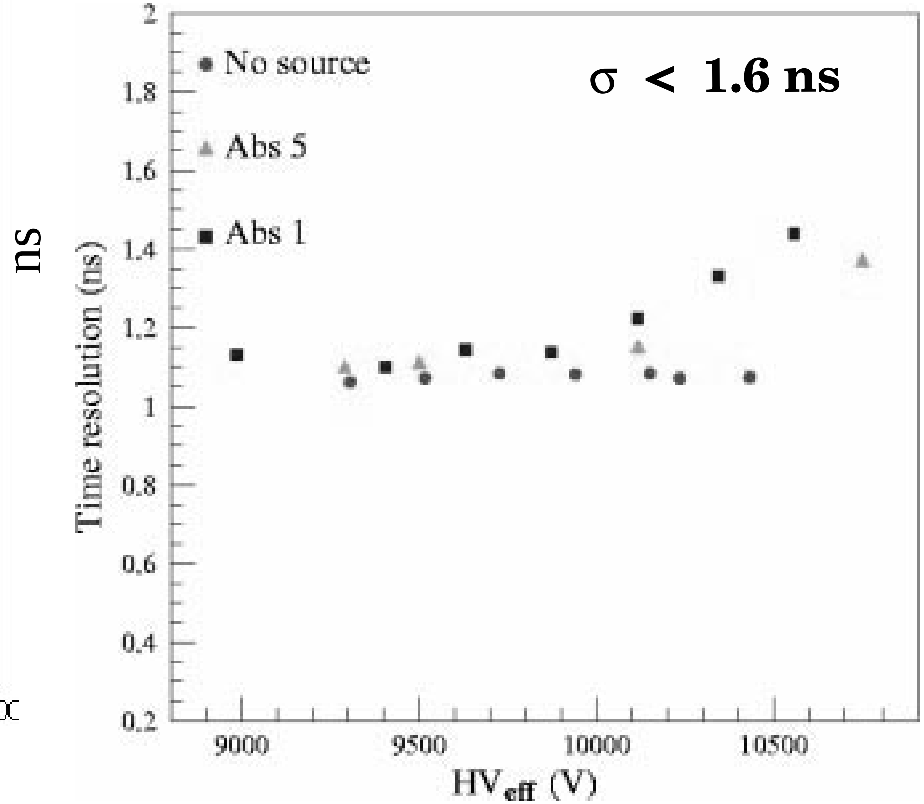
- **Cluster size < 2.3 strip**
- **Cluster with more than 7 strips < 5%**



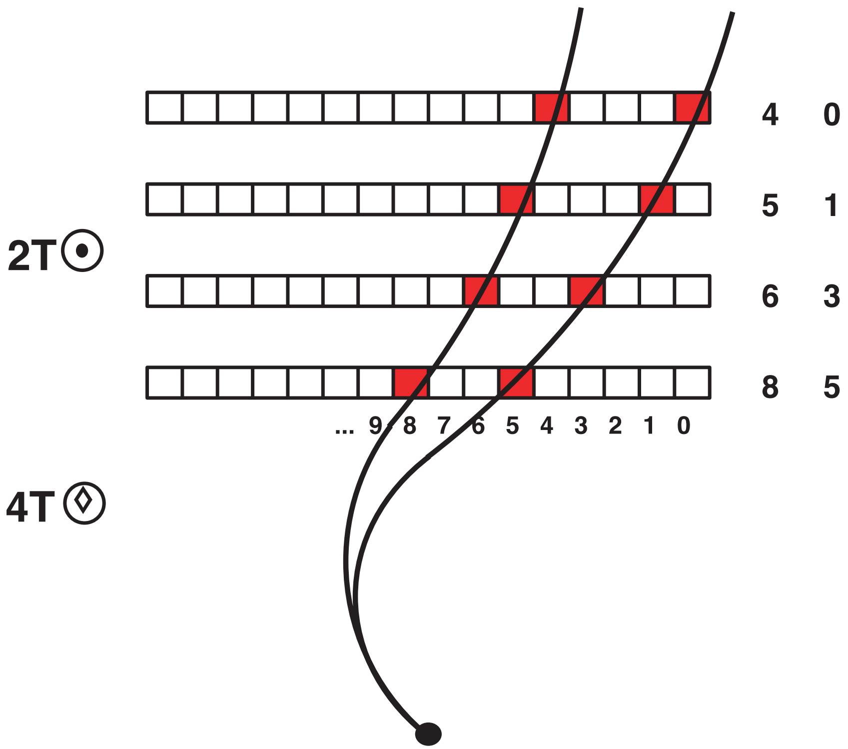


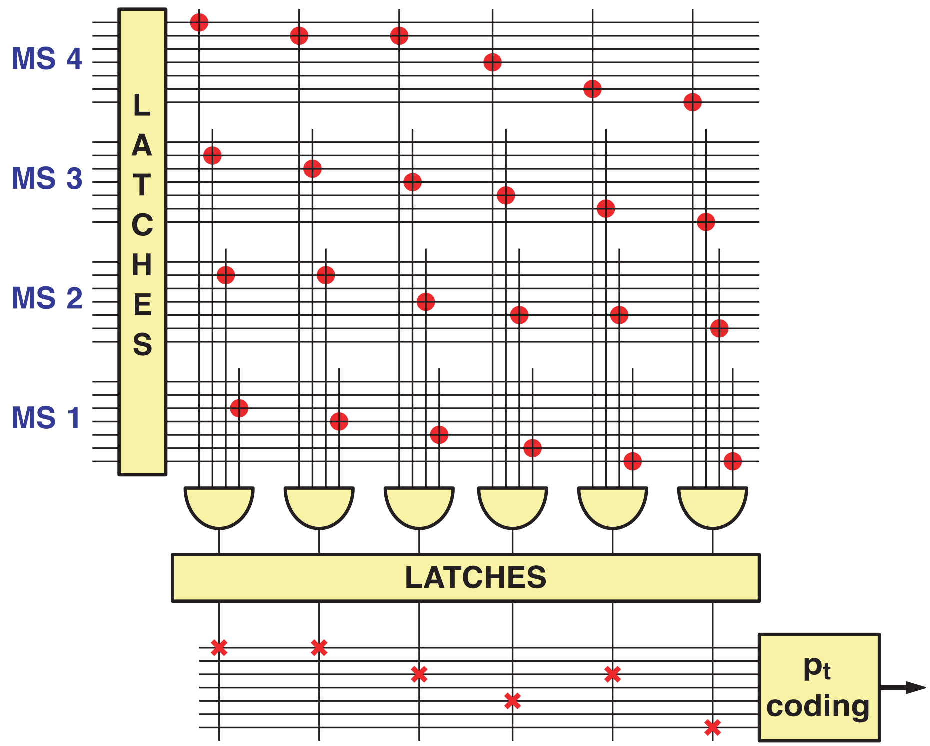
RPC time resolution





RPC Trigger algorithm



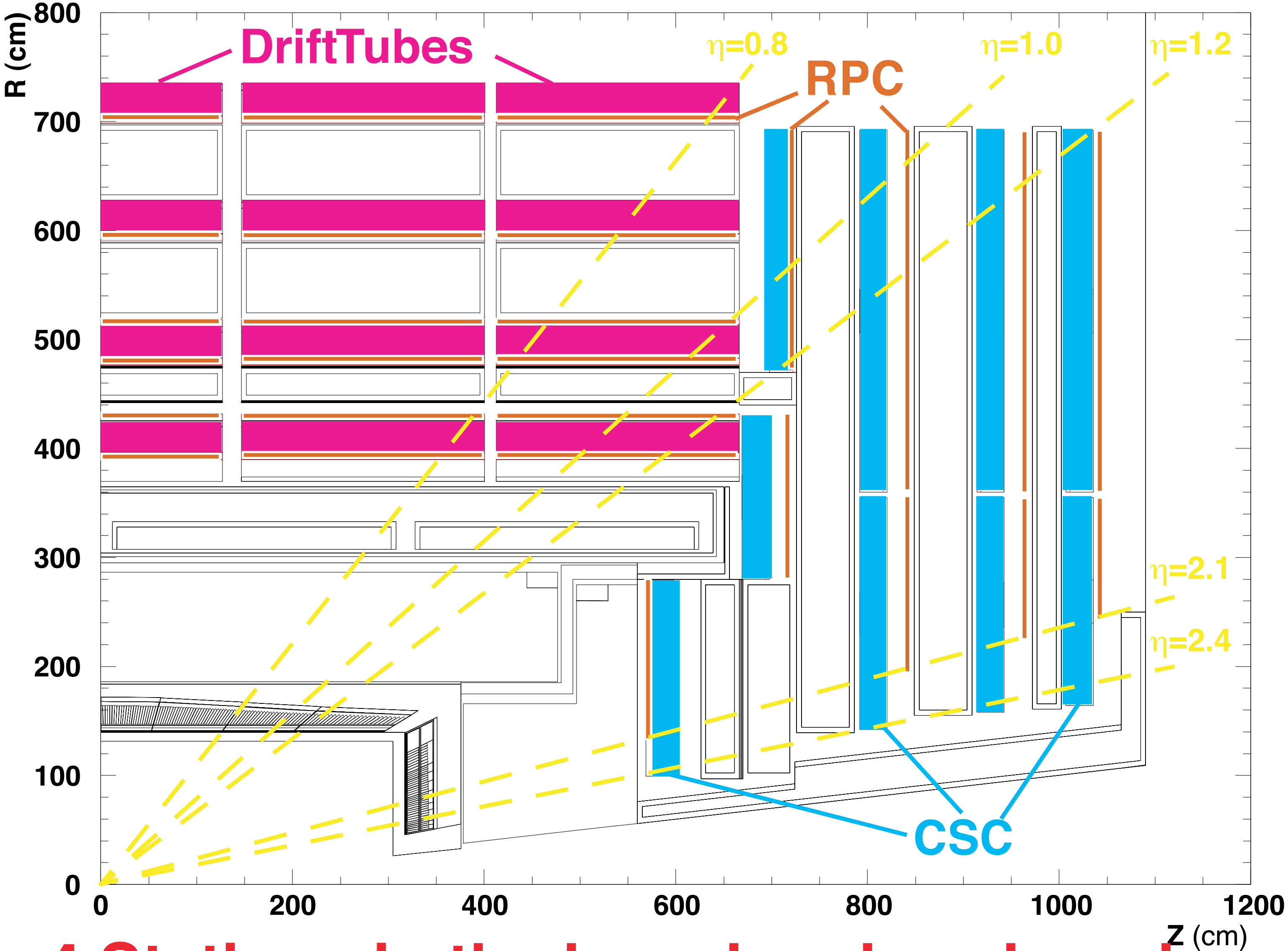


Pattern of hit strips is compared to predefined patterns corresponding to various p_T

PAttern Comparator (PAC) ASIC

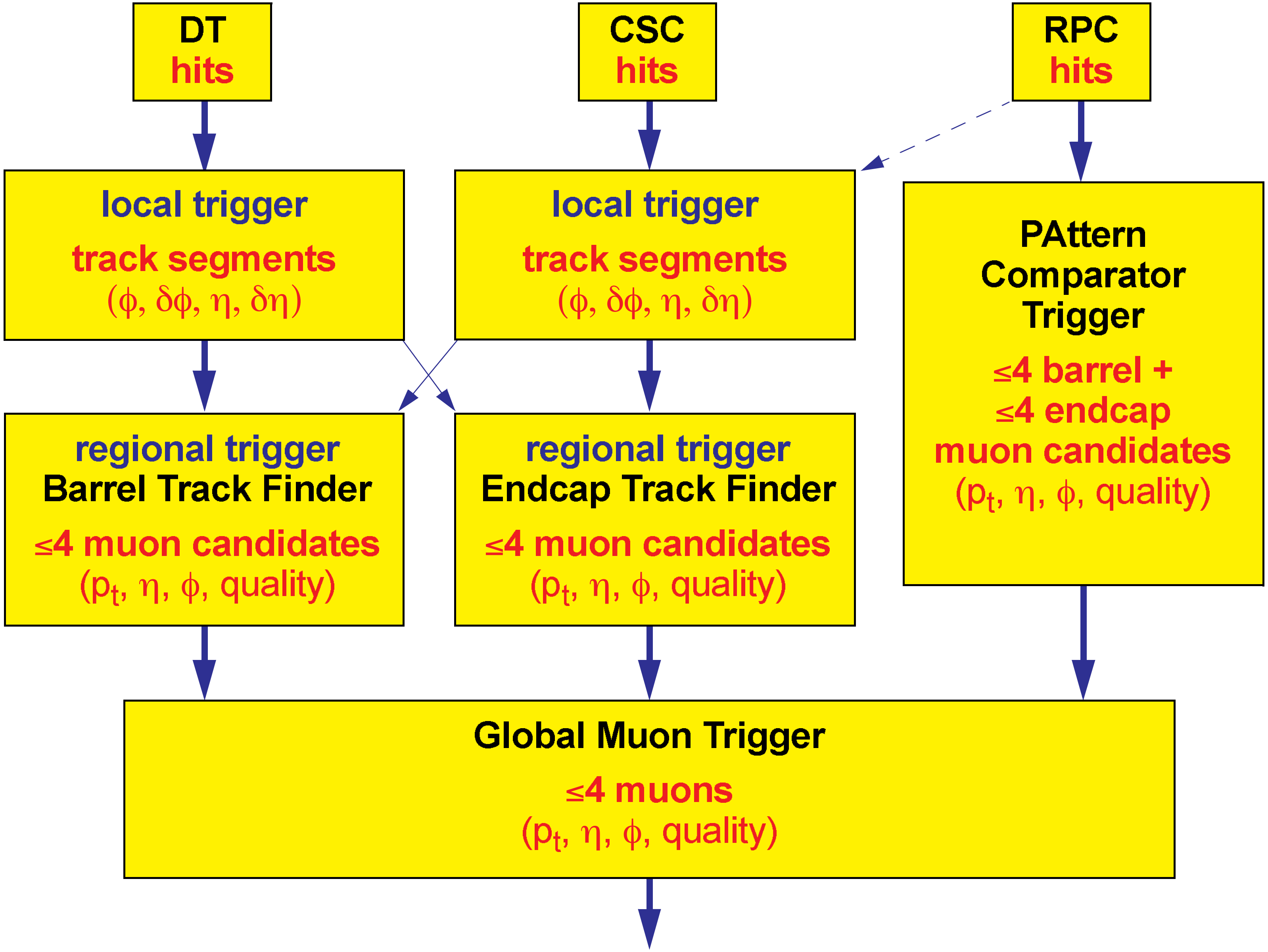
4752 ASICs *in Counting Room*

Muon Trigger geometry

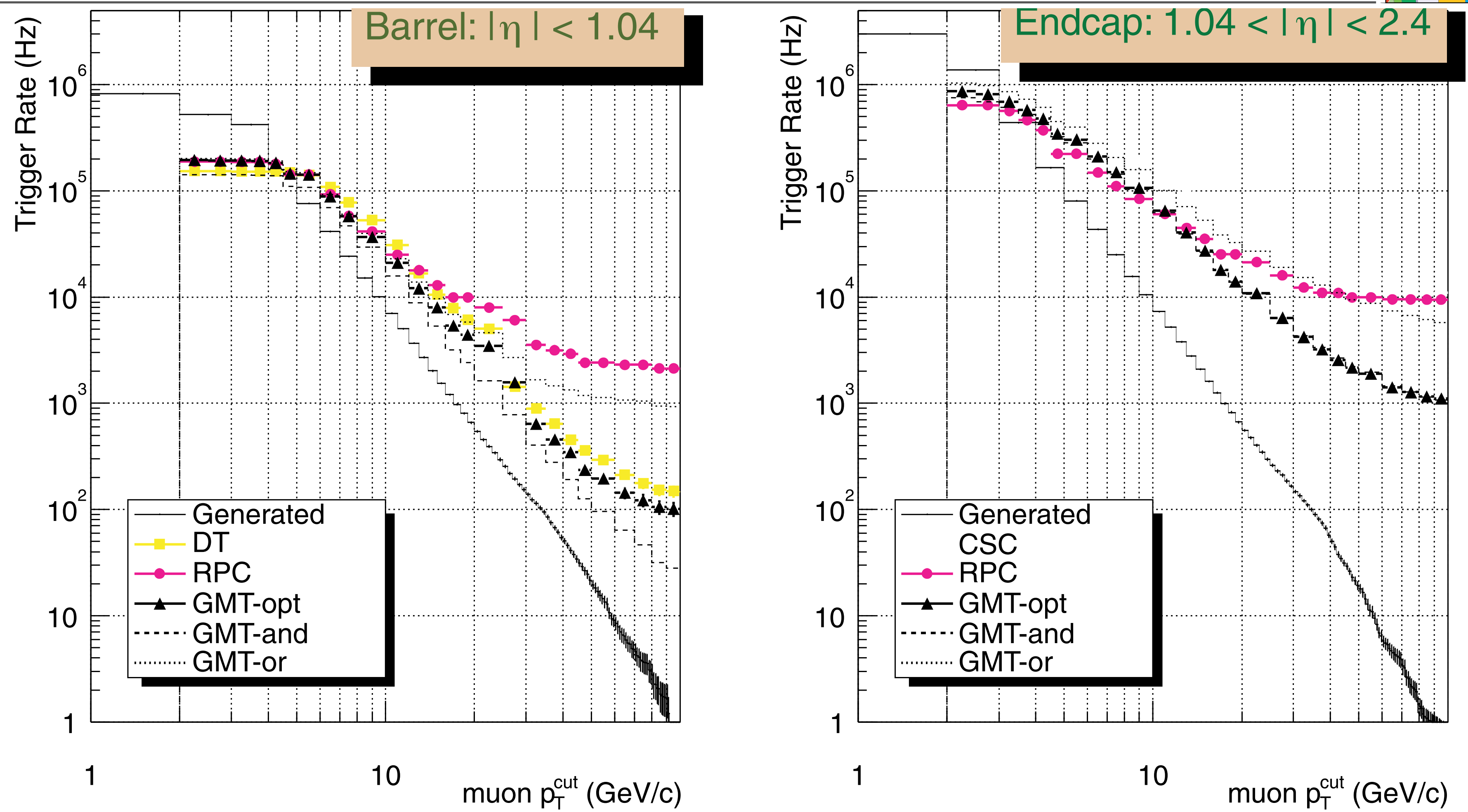


4 Stations in the barrel and each endcap

Global Muon Trigger

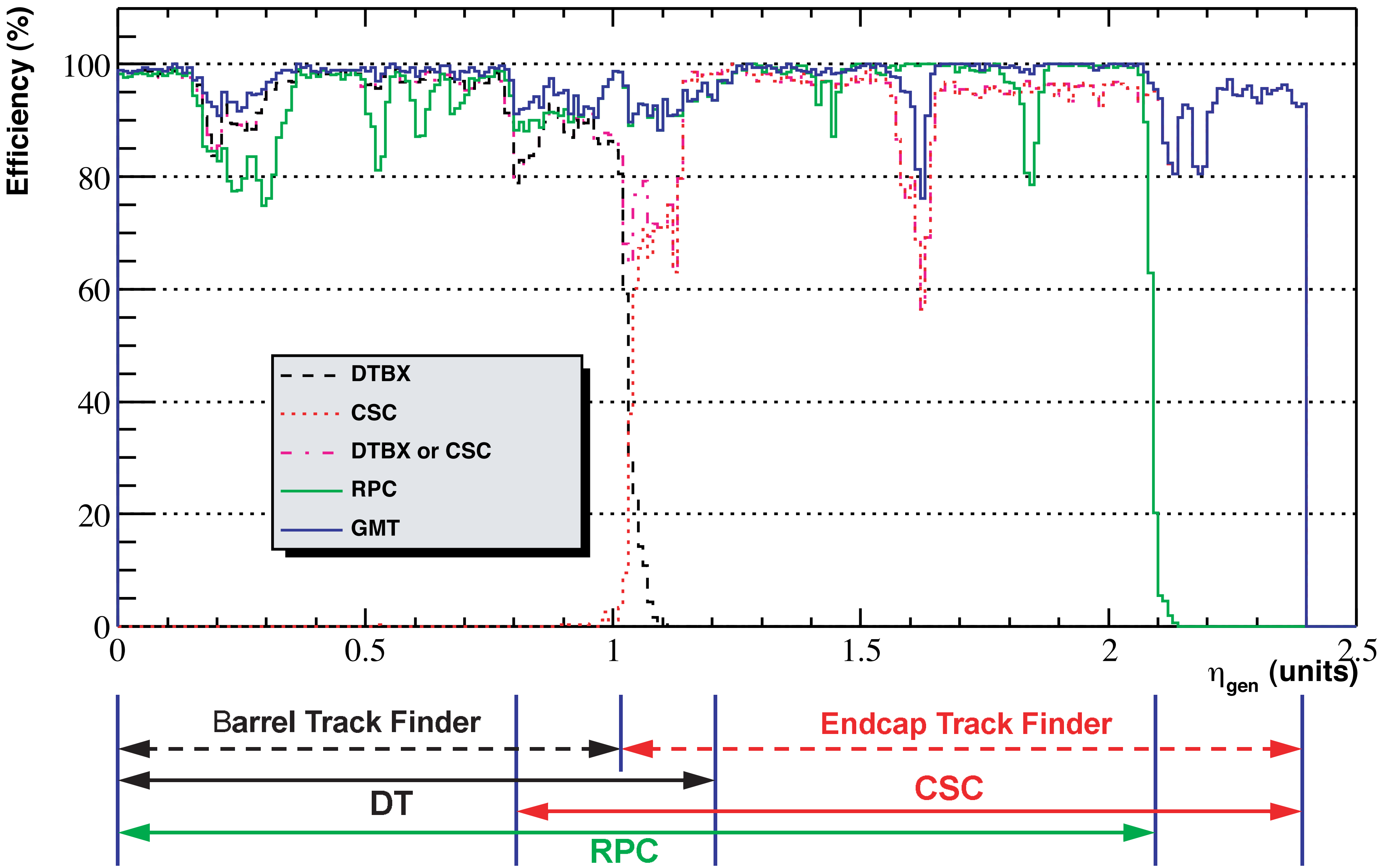


Muon Trigger rates vs. p_t

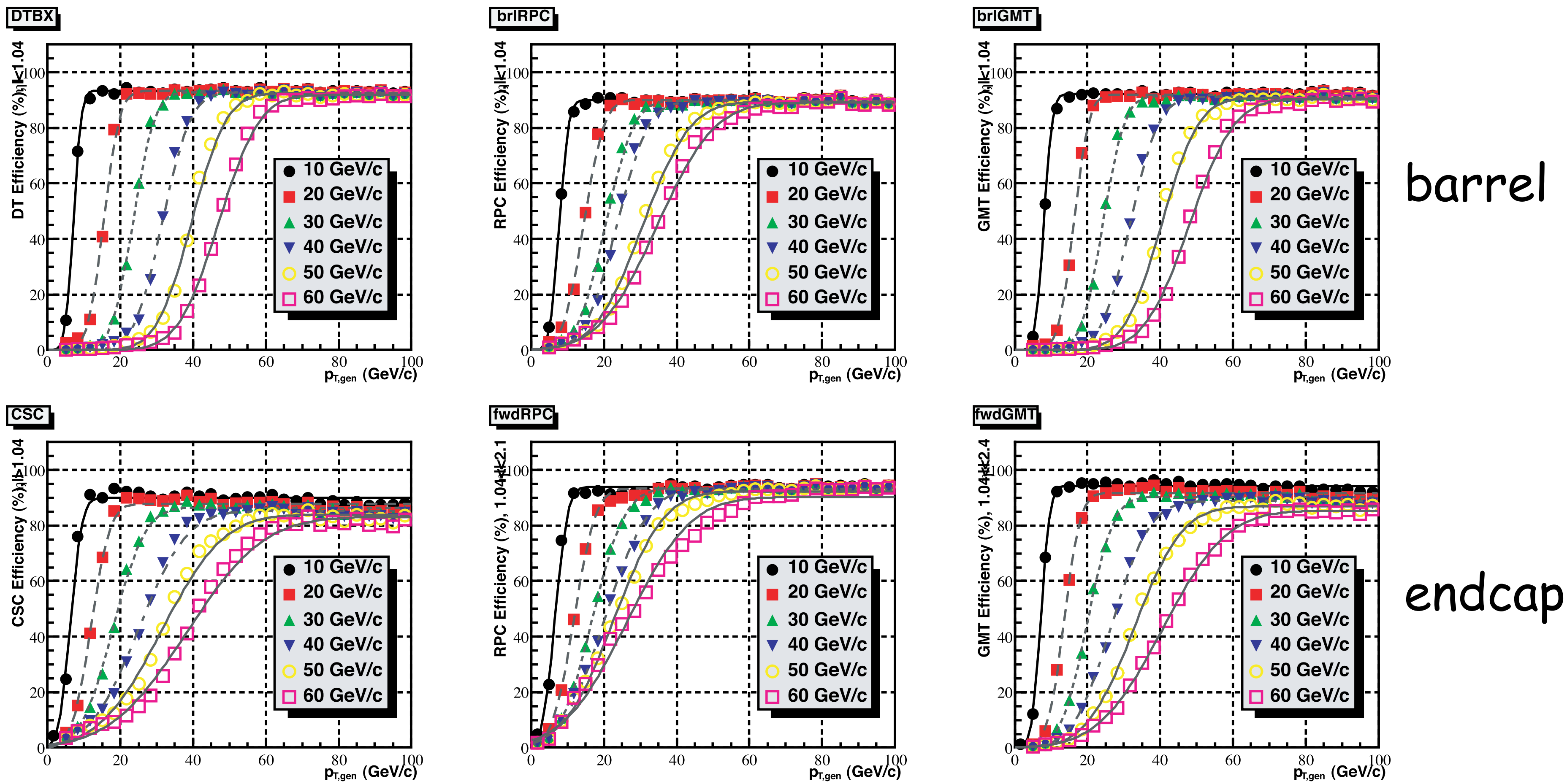


- Curves show individual DT, RPC & CSC & 3 Global Muon Trigger Combinations:
  - OR, AND, & optimized selection based on track quality & p_t information
- Single muon trigger rate is 8.1 kHz for a threshold of 25 GeV (90% efficient)
- Dimuon muon trigger rate is 2.8 kHz for thresholds of 8, 5 GeV (90%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

Global Muon Trigger Efficiency



Muon trigger rates turn-on curves



Conclusions

- **The CMS Muon detector will provide good muon identification with 4 independent measurements down to |η|=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**