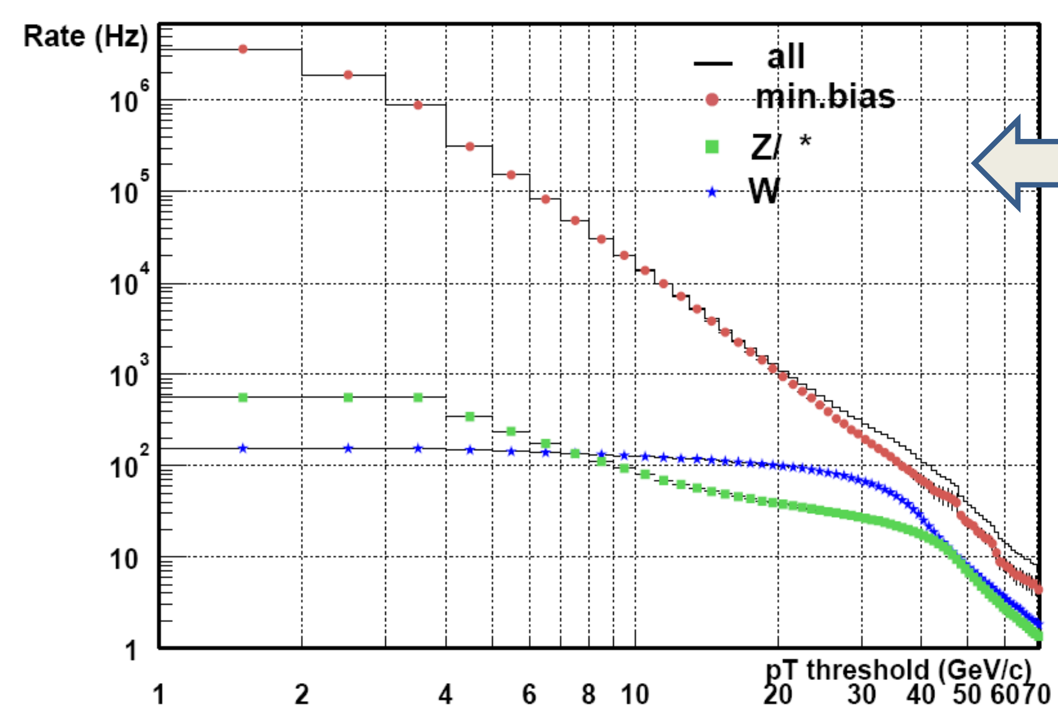
The Muon System of the CMS Experiment at LHC

S. Marcellini – INFN Bologna, Italy,
on behalf of the CMS Experiment

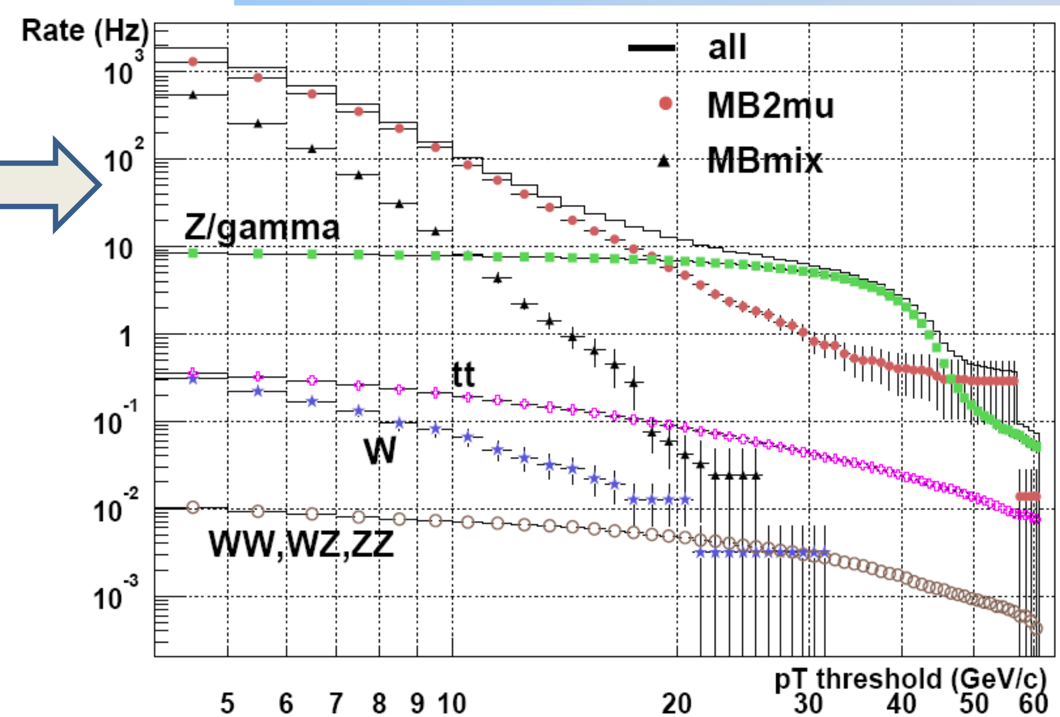


Single Muon rate
@ L = 10^{34} $cm^{-2}s^{-1}$
vs p_t threshold

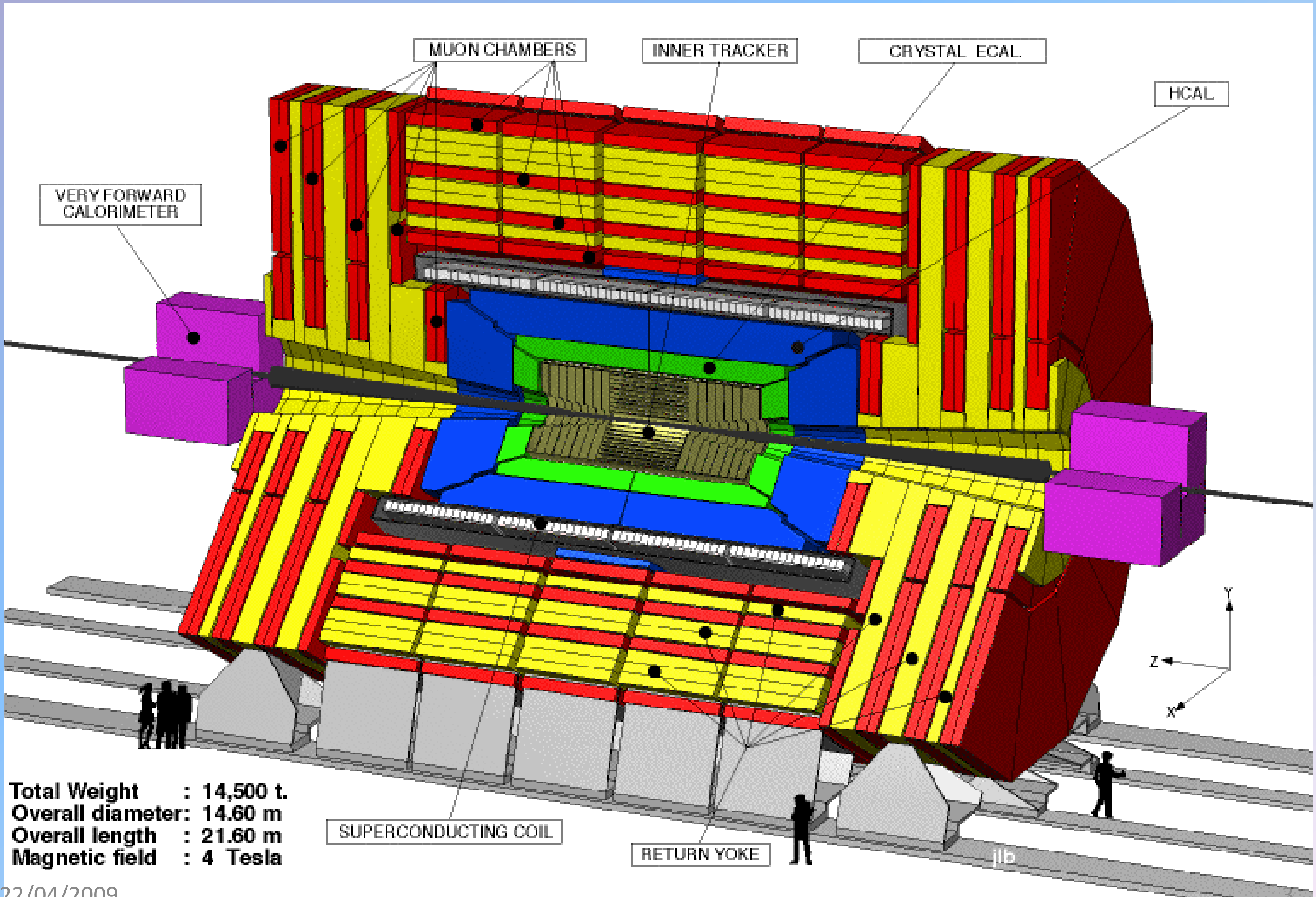
Good p_t resolution already at trigger level to avoid large feed-through from low p_t muons

Di-Muon rate
@ L = 10^{34} $cm^{-2}s^{-1}$
vs p_t threshold
(~ 1% or less than single muon rate

Single muon ghost rate below 0.5 % not to overcome real di-muon rate



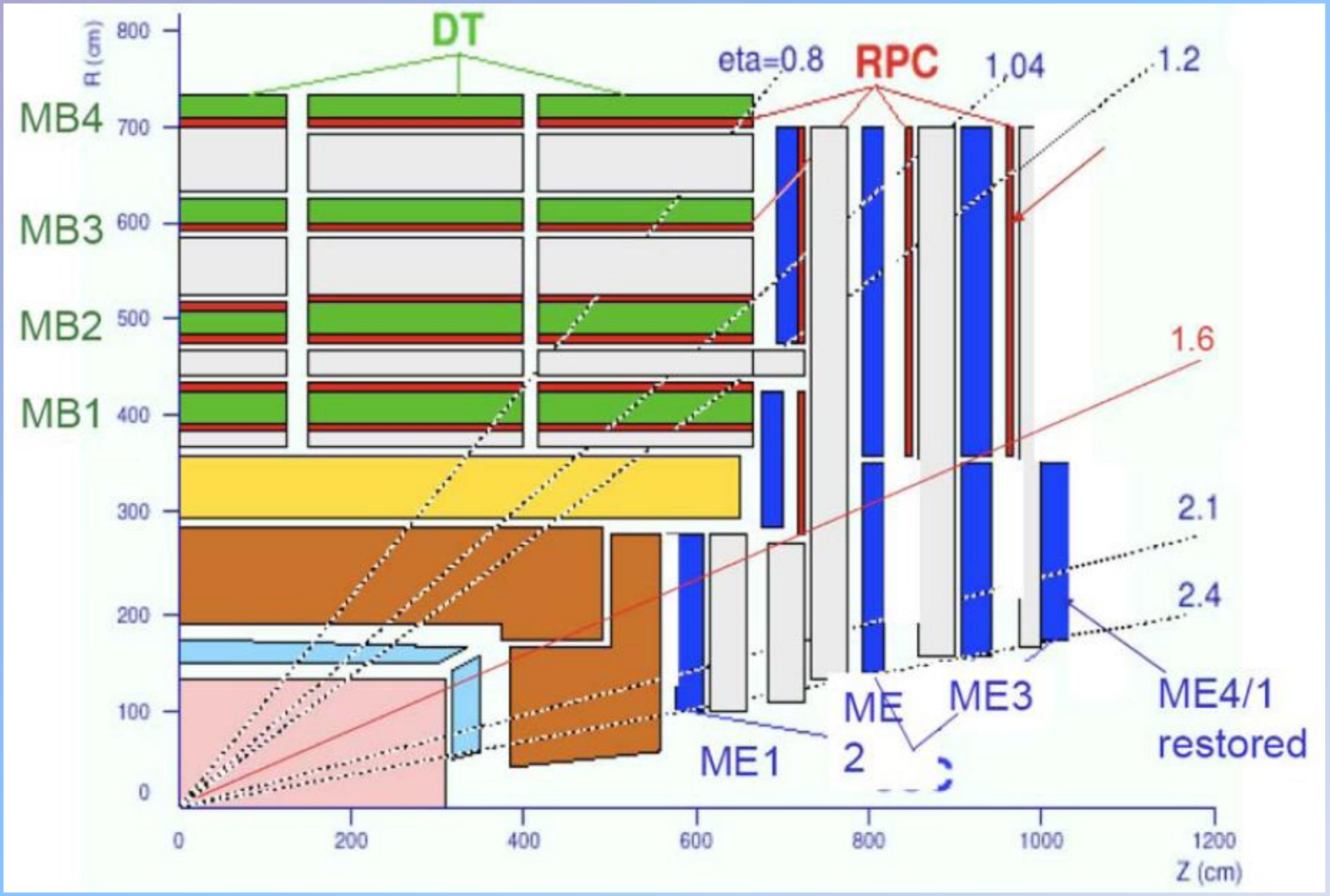
Red: Muon chambers
Yellow: A lot of Iron ! –> Compact Muon Solenoid



The Muon system has to:

Provide **independent muon tracking** to improve muon reconstruction, especially at high momenta

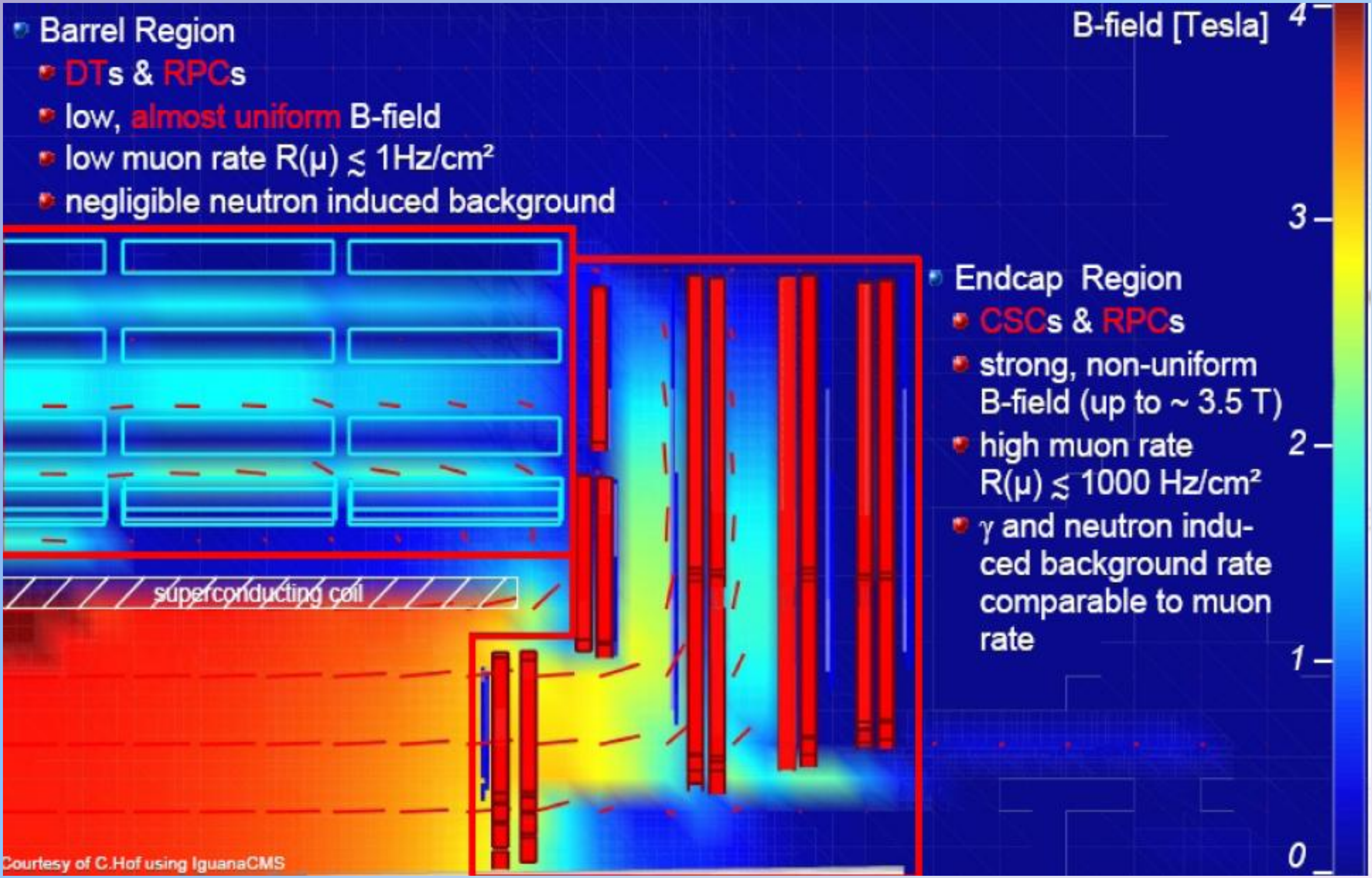
Provide a robust, redundant, independent **Level-1 trigger** for muons, apply thresholds in muon momentum at trigger level, and perform BX identification.



Barrel: Drift-Tubes (DT), Resistive-Plate-Chambers (RPC)

End-Caps: Cathode-Strip-Chambers (CSC), Resistive-Plate-Chambers (RPC)

B-Field and rate conditions in the Muon System



Muon Detector Constraints

Barrel: Particle rate ~ 1-10 Hz/cm^2
Low magnetic field

End-Caps: Particle Rate ~ 100-1000 Hz/cm^2
High and non-uniform magnetic field

Muon Trigger: BX identification and trigger on single and multi-muons from ~ few GeV to 100 GeV with well defined p_t threshold

Momentum Resolution:

- **Stand alone**

dp_t/p_t = 8 - 15% at p_t = 10 GeV

dp_t/p_t = 20 - 40% at p_t = 1 TeV

- **Global**

dp_t/p_t = 1 - 1.5% at p_t = 10 GeV

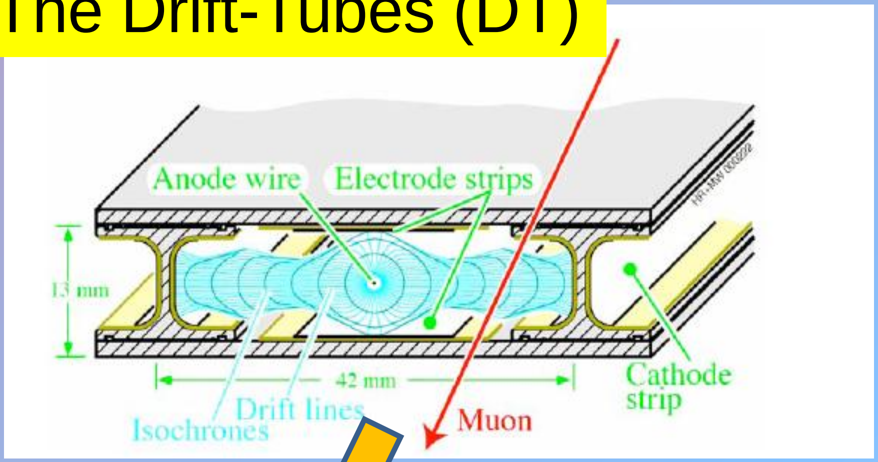
dp_t/p_t = 6 - 17% at p_t = 1 TeV

Correct Charge Assignment: up to 7 TeV

Muon Trigger Requirements

- Geometrical coverage up to η=2.4
- 128 BX Latency = 3.2 μs
- No Dead-time allowed: every BX must be processed
- Output Rate: ~ 30 KHz –> reduction factor > 10^3
- Ghost Rate < 0.5 %
- p_t threshold should be set in the range ~ 4 – 50 GeV

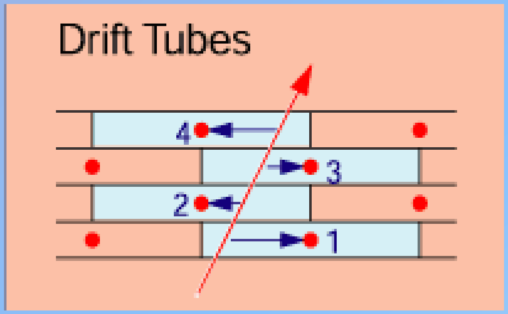
The Drift-Tubes (DT)



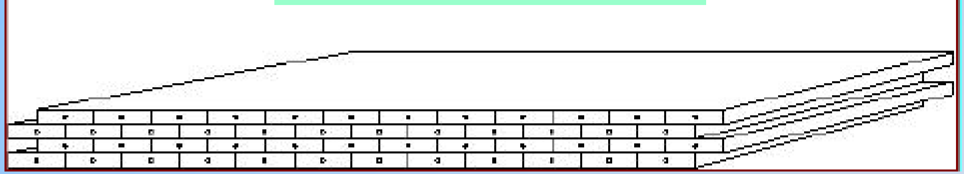
V_{drift} ~ 55 μm/ns -> Max drift time ~380 ns

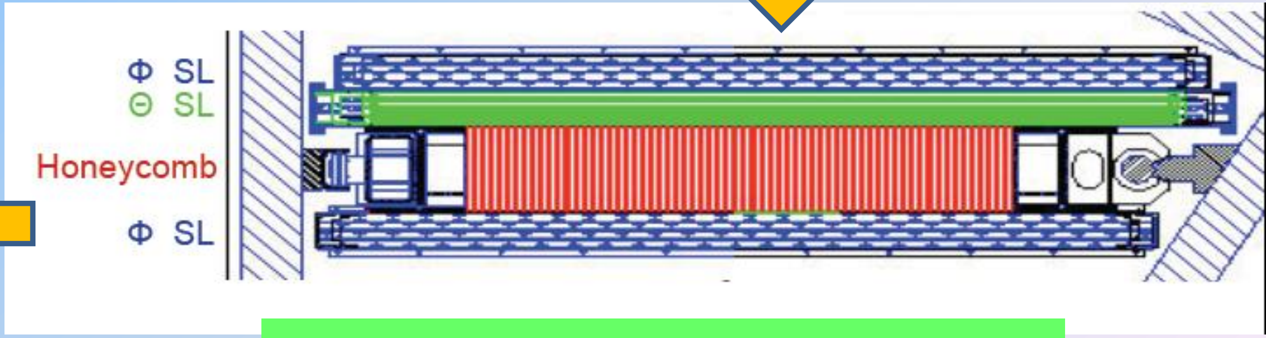
Single wire resolution ~ 250 μm

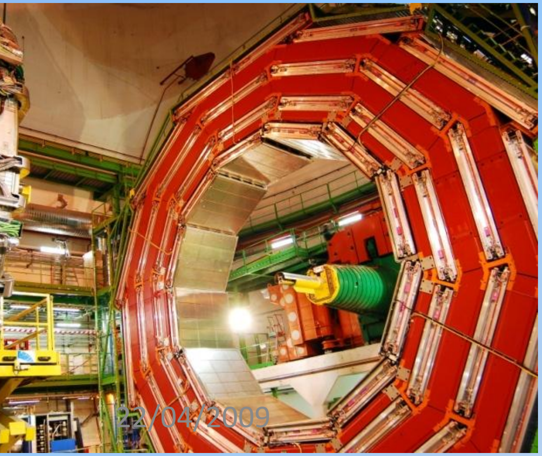
Local reconstruction (r-ϕ) ~ 100 μm



Arranged in layers

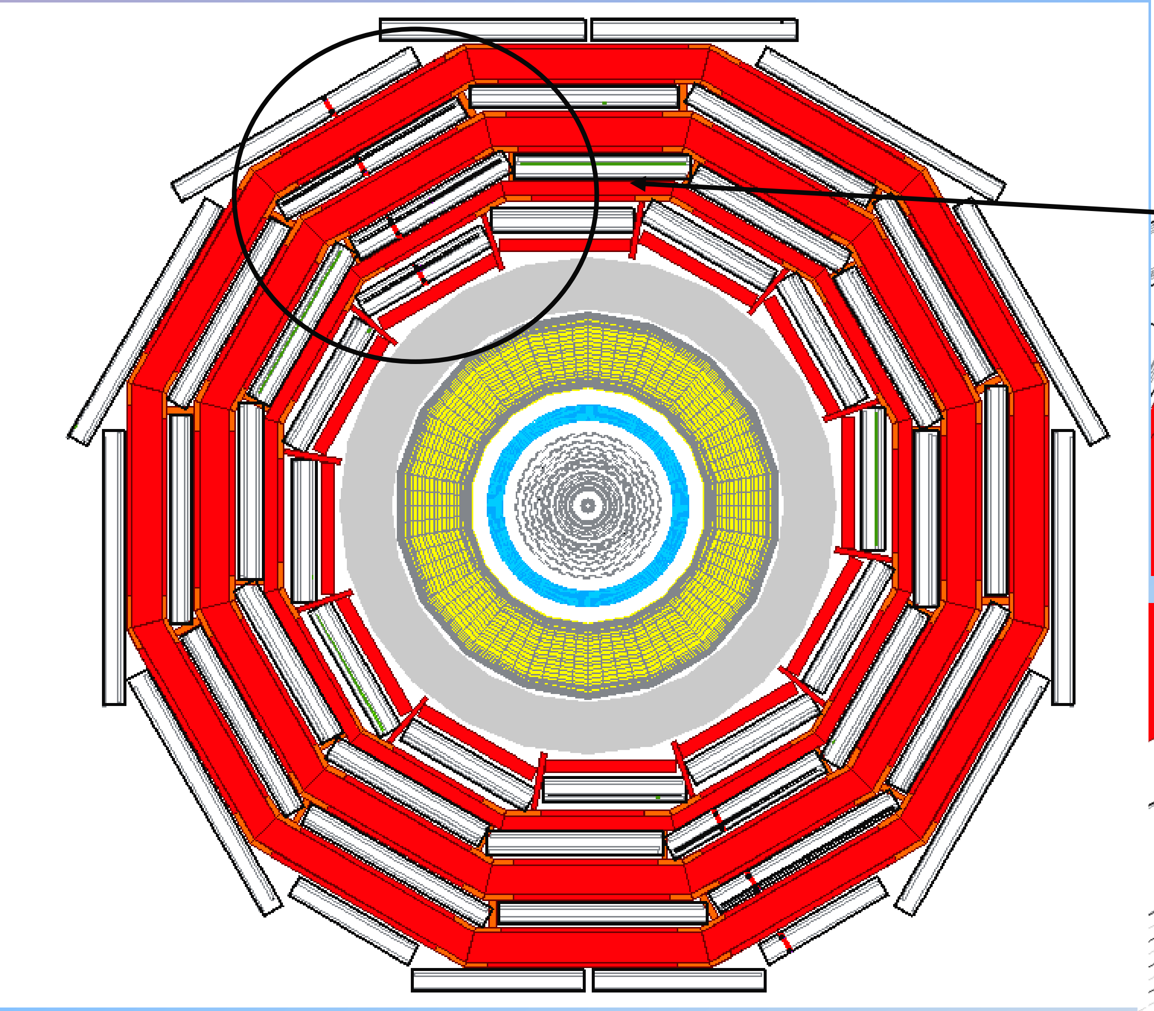
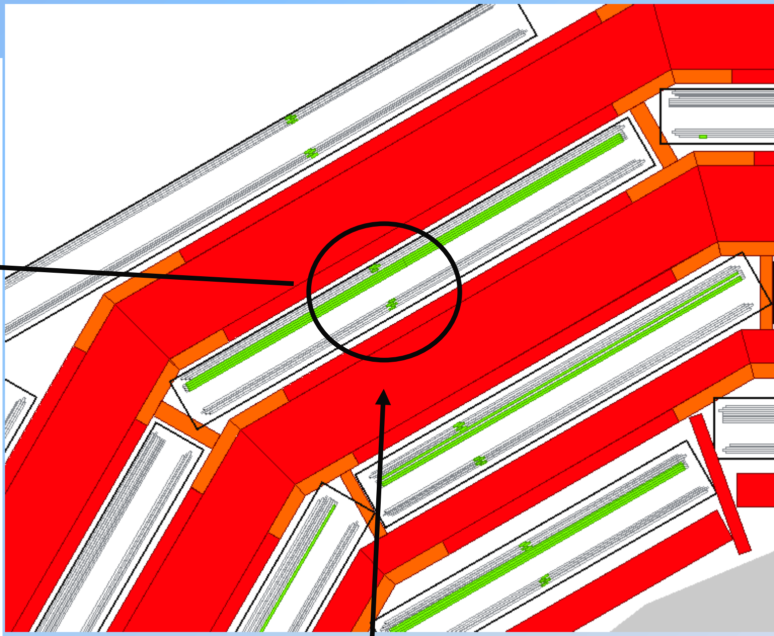
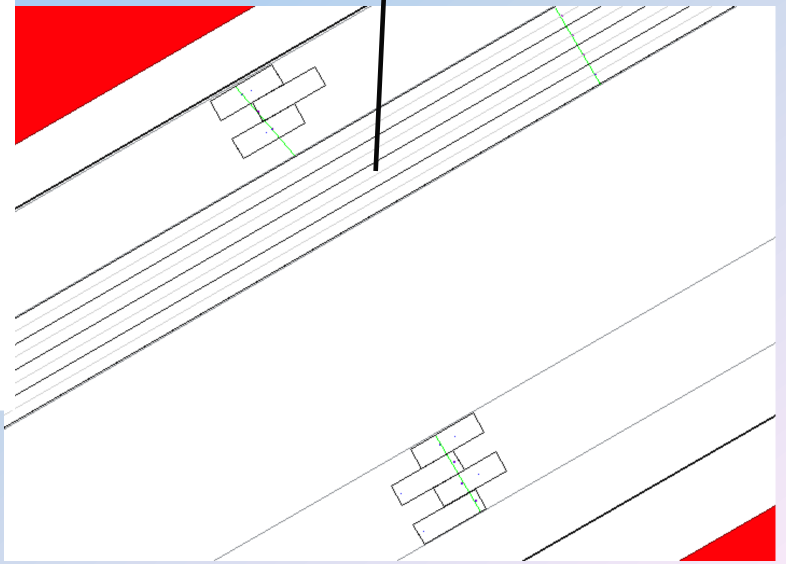




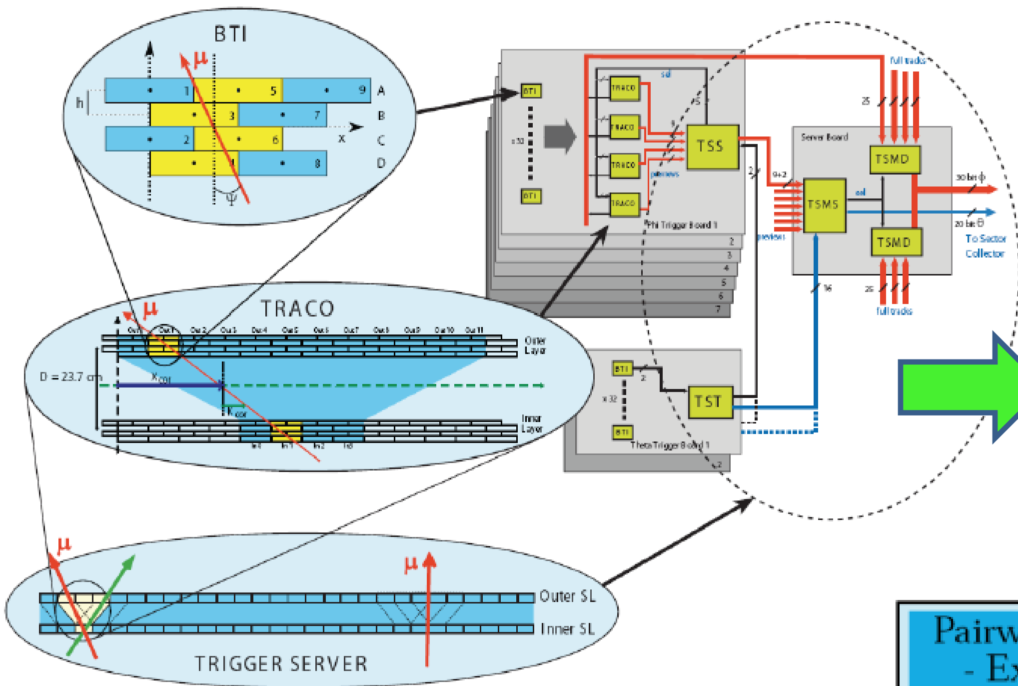


250 **chambers** like this in the barrel

DT Hits from cells to tracks

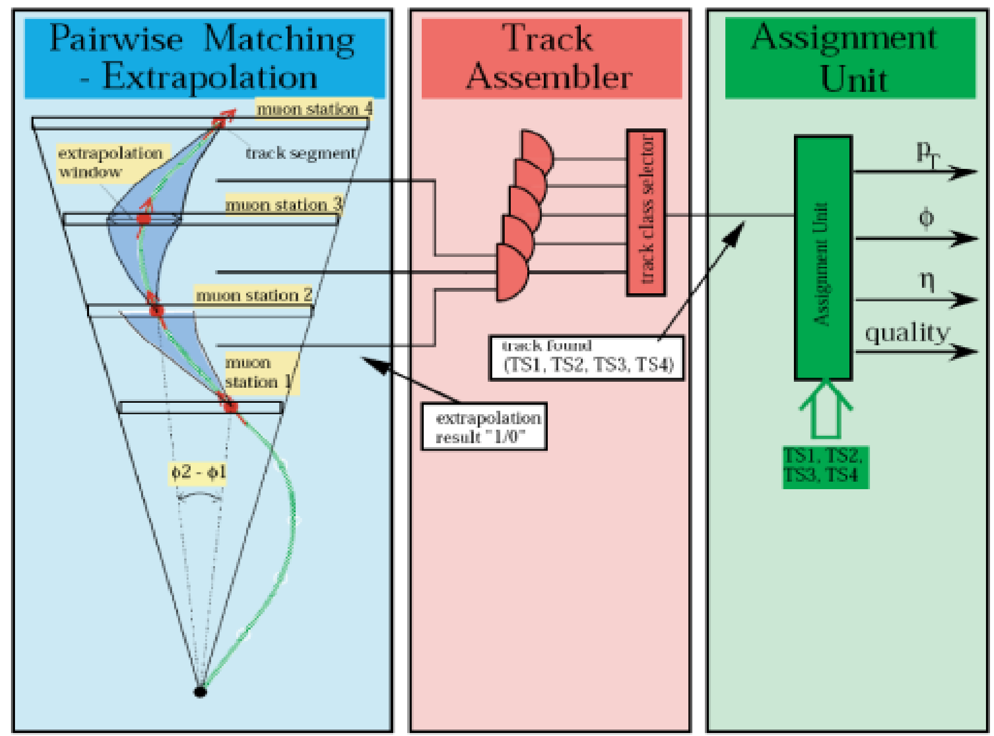




The Drift-Tubes Trigger



- Search for hit alignment in each muon station.
- Up to 2 muon segments per station for each BX
- A ghost suppression mechanism to remove fake or wrong candidates
- Performed by electronics on the chambers

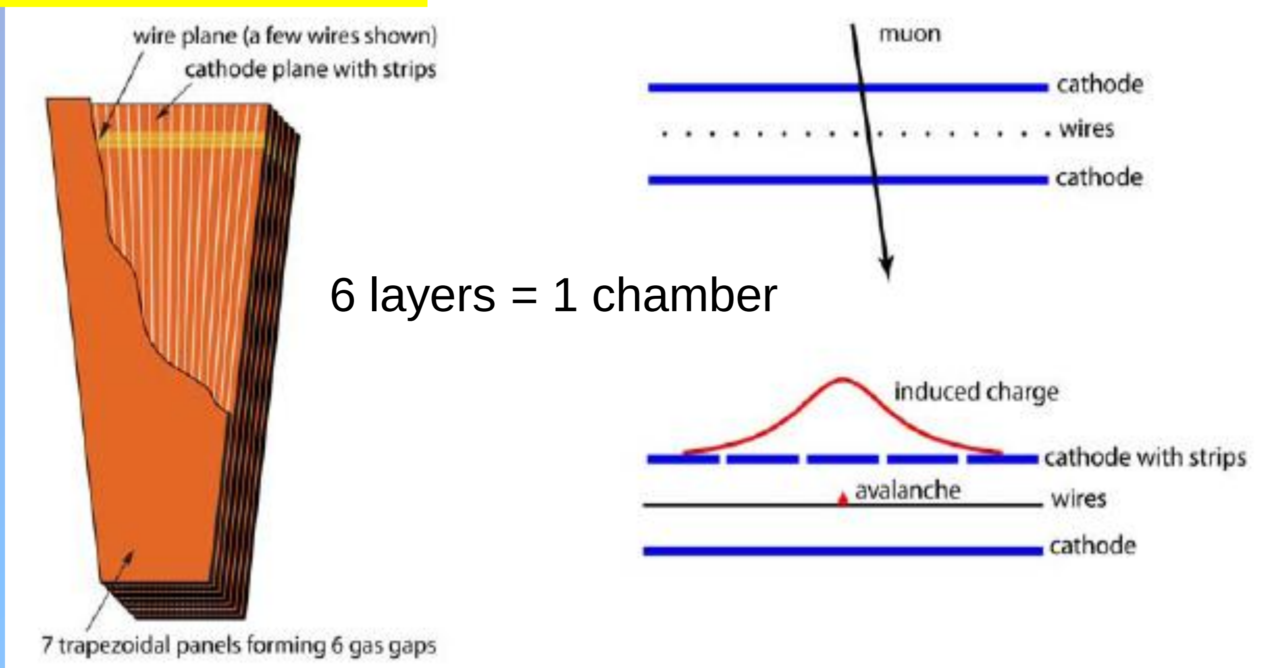
- Trigger segments from each station are matched together according to proper Look-up-Tables
- p_t, position and charge are assigned



The Cathode Strip Chambers (CSC)

High B-field,
High particle rate

Drift Tubes are not suitable
(too long drift path).



6 layers = 1 chamber

Multiwire Proportional Chambers:

6 planes/chamber – 540 chambers in total

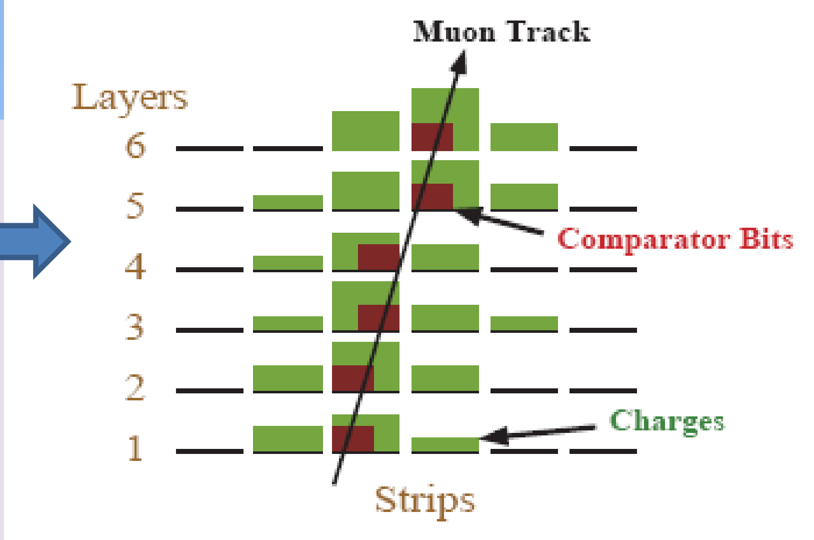
ϕ measured from fit to the induced charge

r and BX id from the signal on the wire

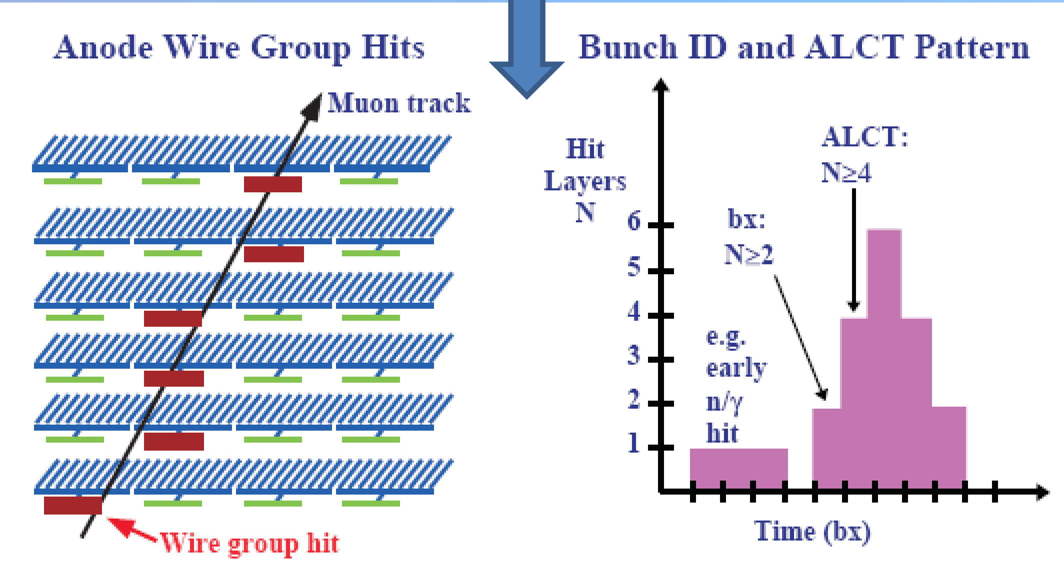
ϕ resolution ~ 100 μm

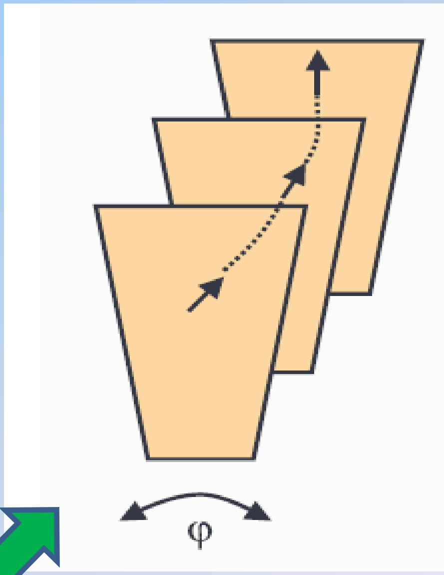
The CSC Trigger

Cathode view: 6 layers provide a good (~ 1 mm) measurement of position in r-ϕ



Anode view: optimized for BX identification (~ 4.5 ns precision) the coincidence of ≥ 4 layers define a muon segment





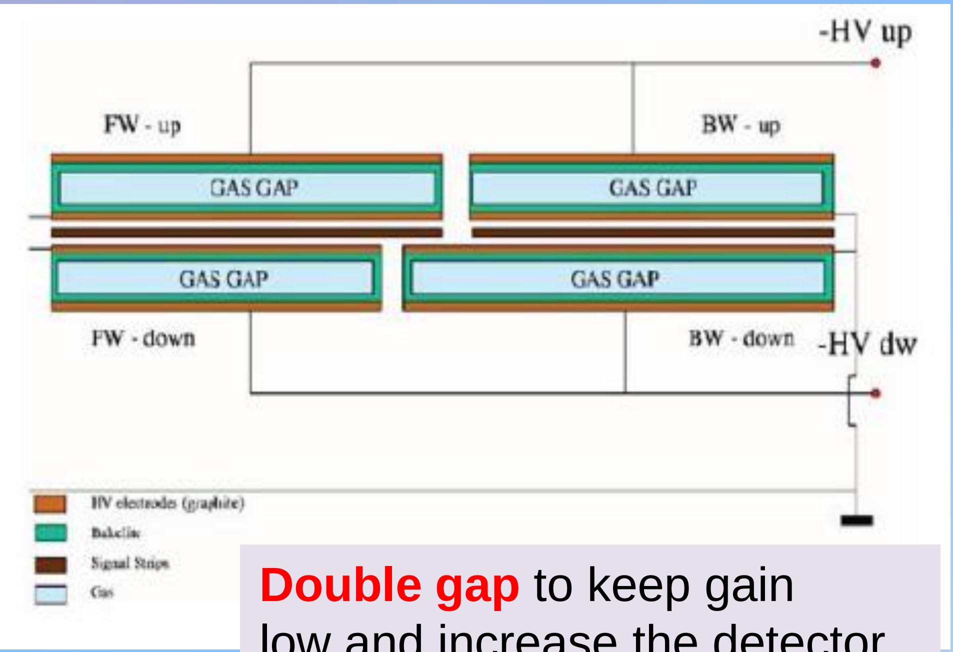
Track Finder =reconstruct tracks using 3-D spatial information Assigns pt, Φ and η

Select the 4 highest quality candidates and sends them to the **Global Muon Trigger**

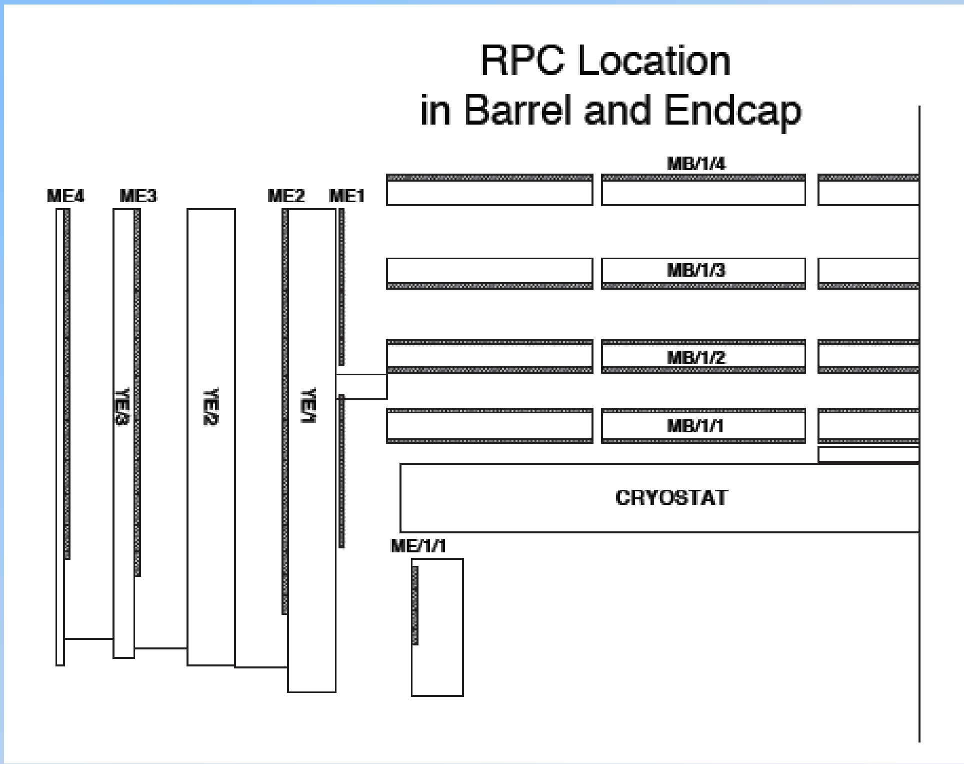
The Resistive Plate Chambers (RPC)

480 (barrel) and 432 (end-caps) chambers

Avalanche mode: lower gain (to cope with high rate) and higher amplification



Double gap to keep gain low and increase the detector efficiency (OR of the two gaps)

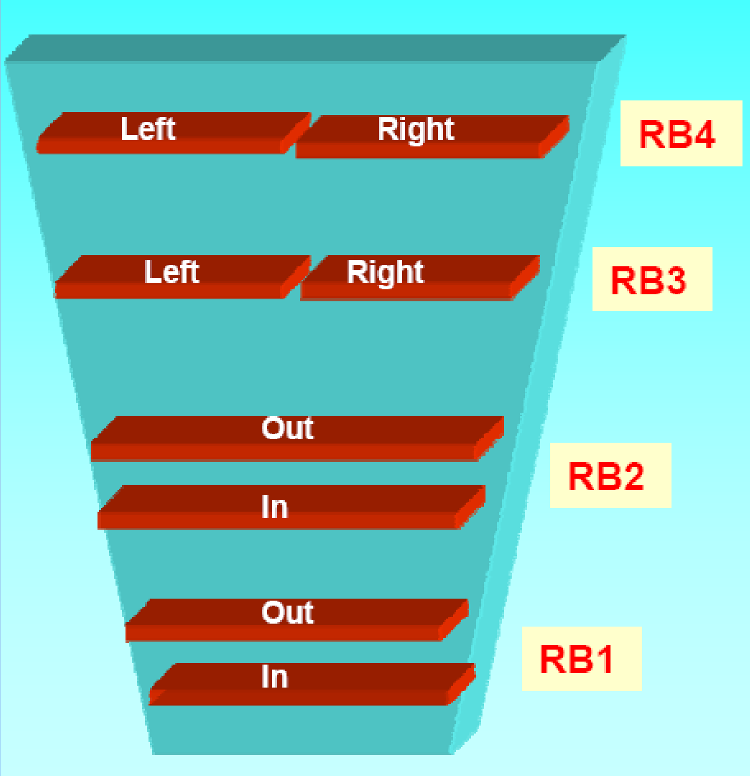


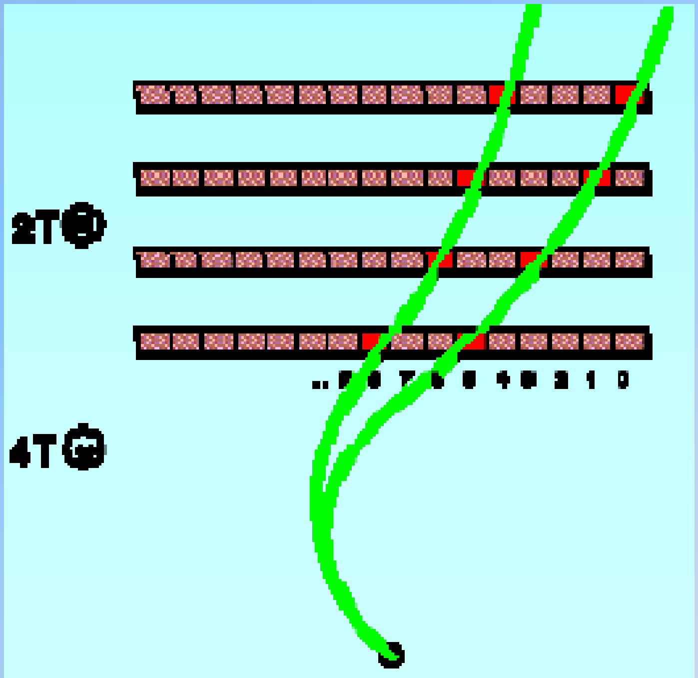
Fast detectors for the first level trigger of the experiment

Considerably good space resolution

Able to work in areas with background ~ 10^3 Hz/cm ^{2}

The RPC Trigger





Example: RPC in the barrel

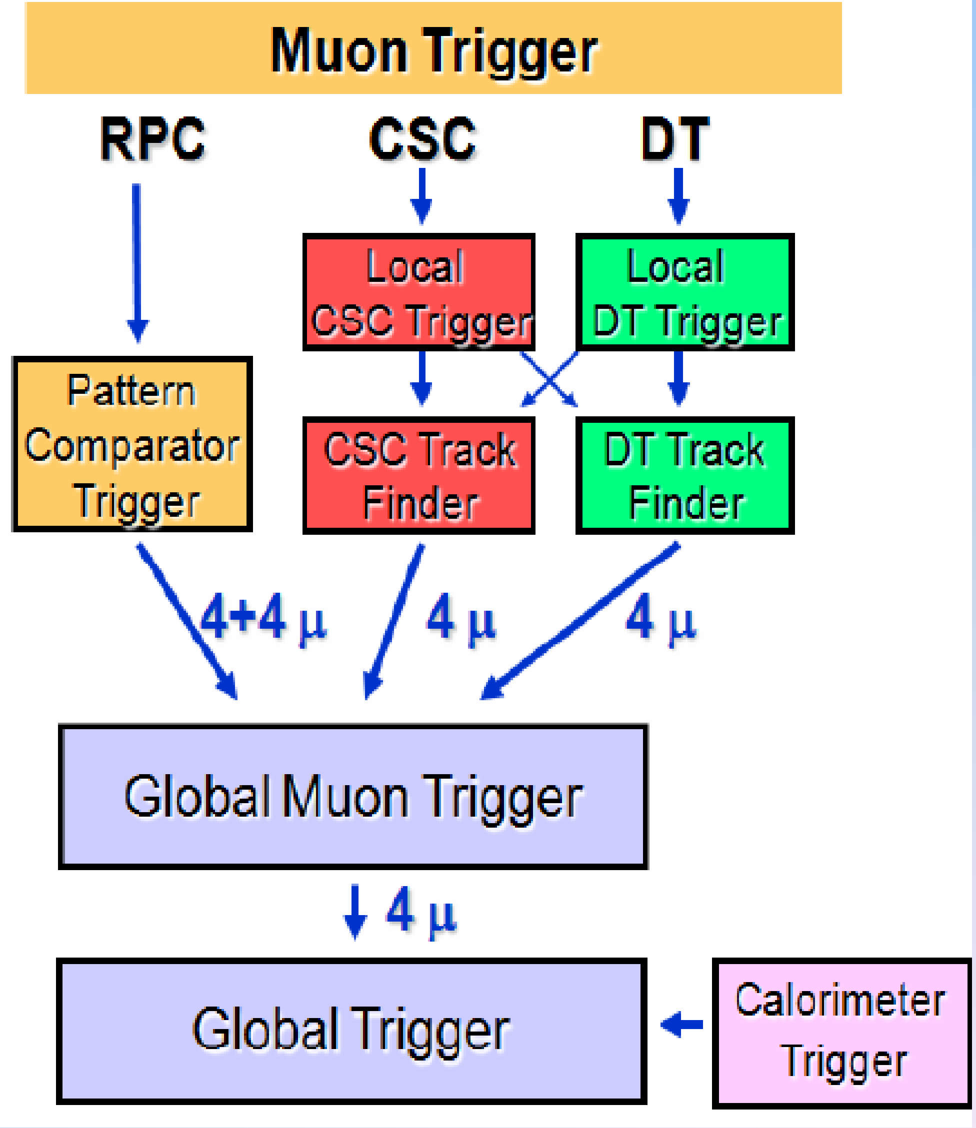
Pattern Comparator: compares each pattern of hit strips to pre-defined patterns corresponding to various p_t

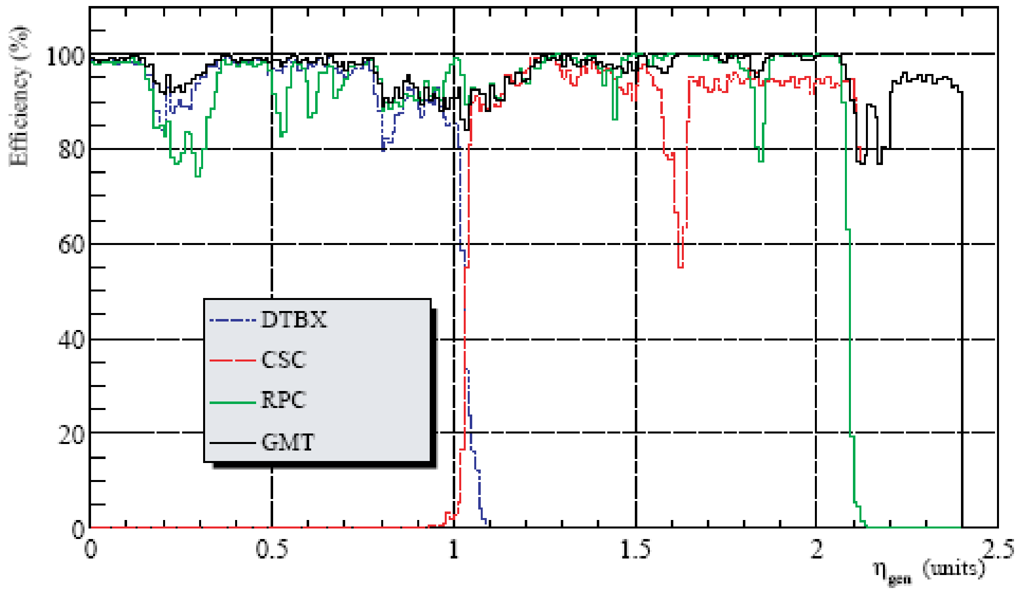
RPC Muon Sorter: selects 4 highest pt muons from barrel, and 4 from end-caps, and delivers them to the Global Muon Trigger

The CMS Muon trigger

RPC, CSC and DT provide muon candidates independently

The **Global Muon Trigger** selects up to **4 muon candidates** for each BX, taking into account the quality of the candidates from each sub-system



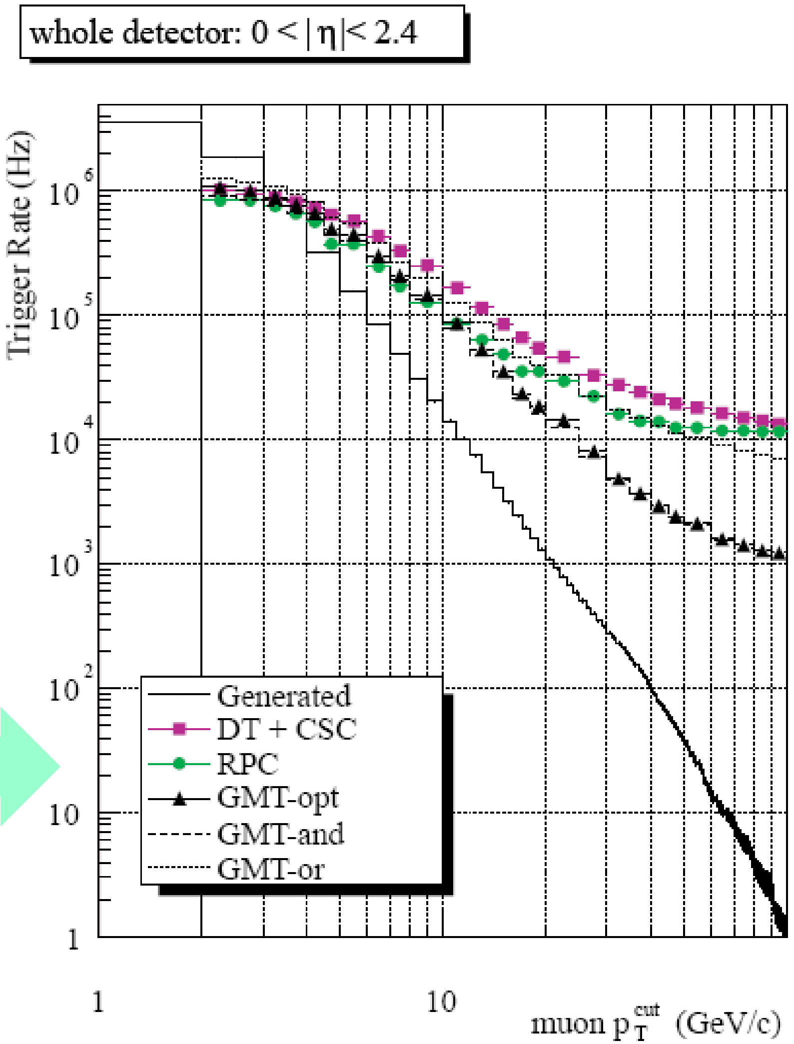


GMT efficiency vs η

GMT single muon rate @ L = 10^{34} $cm^{-2}s^{-1}$

P_t cut > 10 GeV –> Rate ~ 10 KHz

At LHC start-up, with much lower Lumi,
P_t cut = 3-4 GeV



Alignment

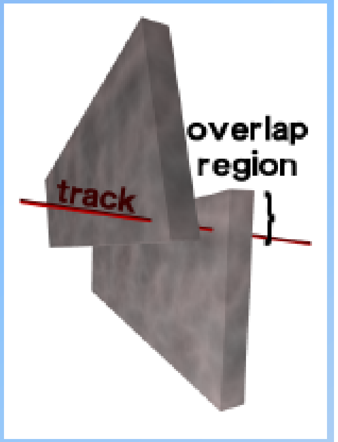
The Structure is not rigid:

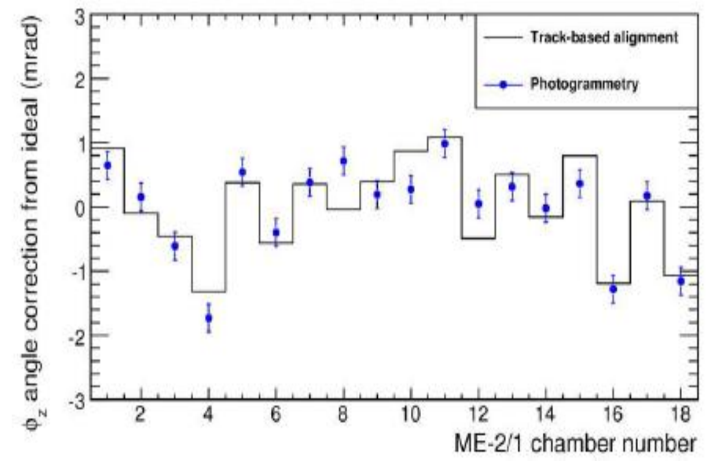
1 – 3 cm due to magnetic field
5 – 15 mm due to gravity (weight)
500 μm due to changes of temperature and humidity

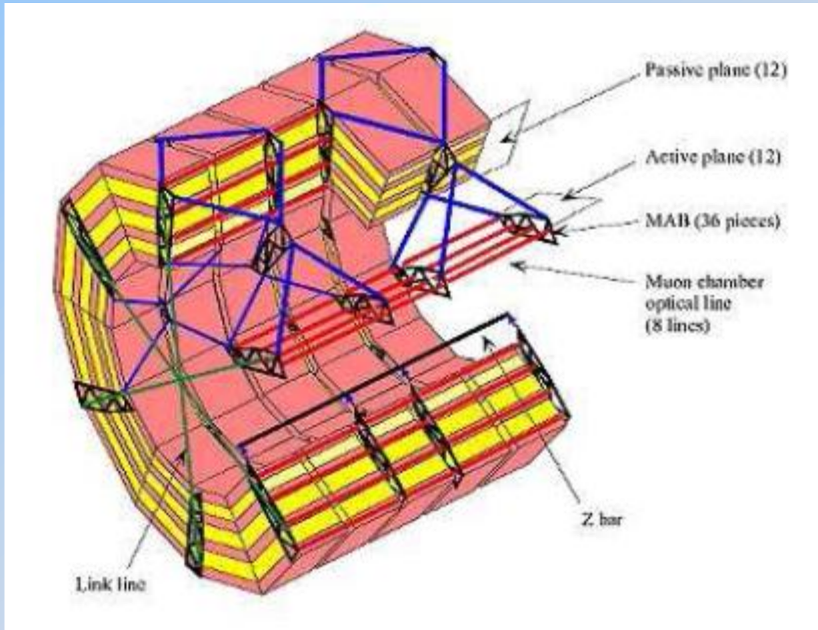
Maximum allowed uncertainty on alignment
(not to degrade momentum measurement) : **200 μm** in the r-ϕ projection

Alignment is based on several techniques:
- Optical system
- Tracking
- CSC align. done with beam halo muons

(results OK with only 9 minutes of real beam !)

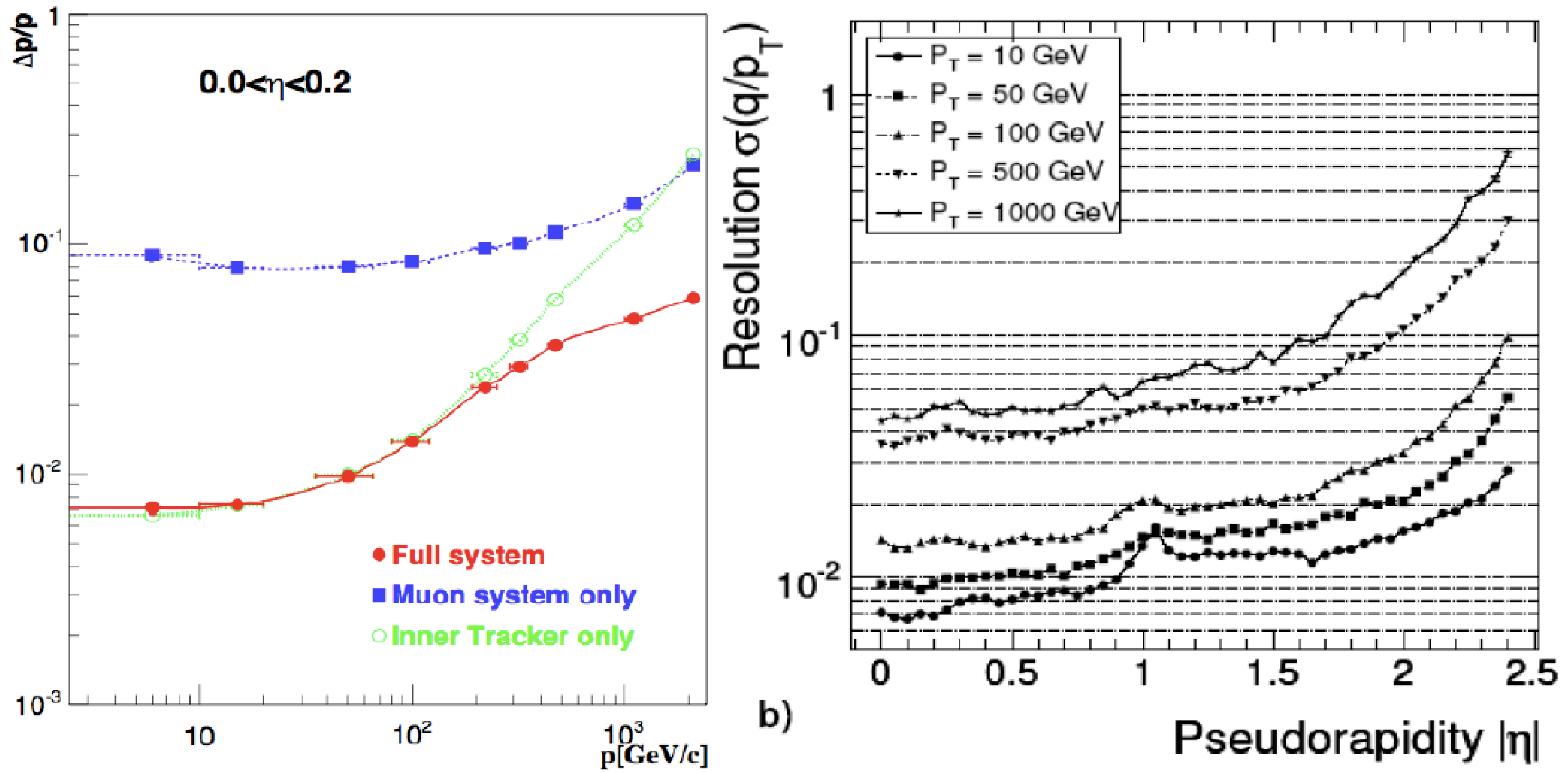




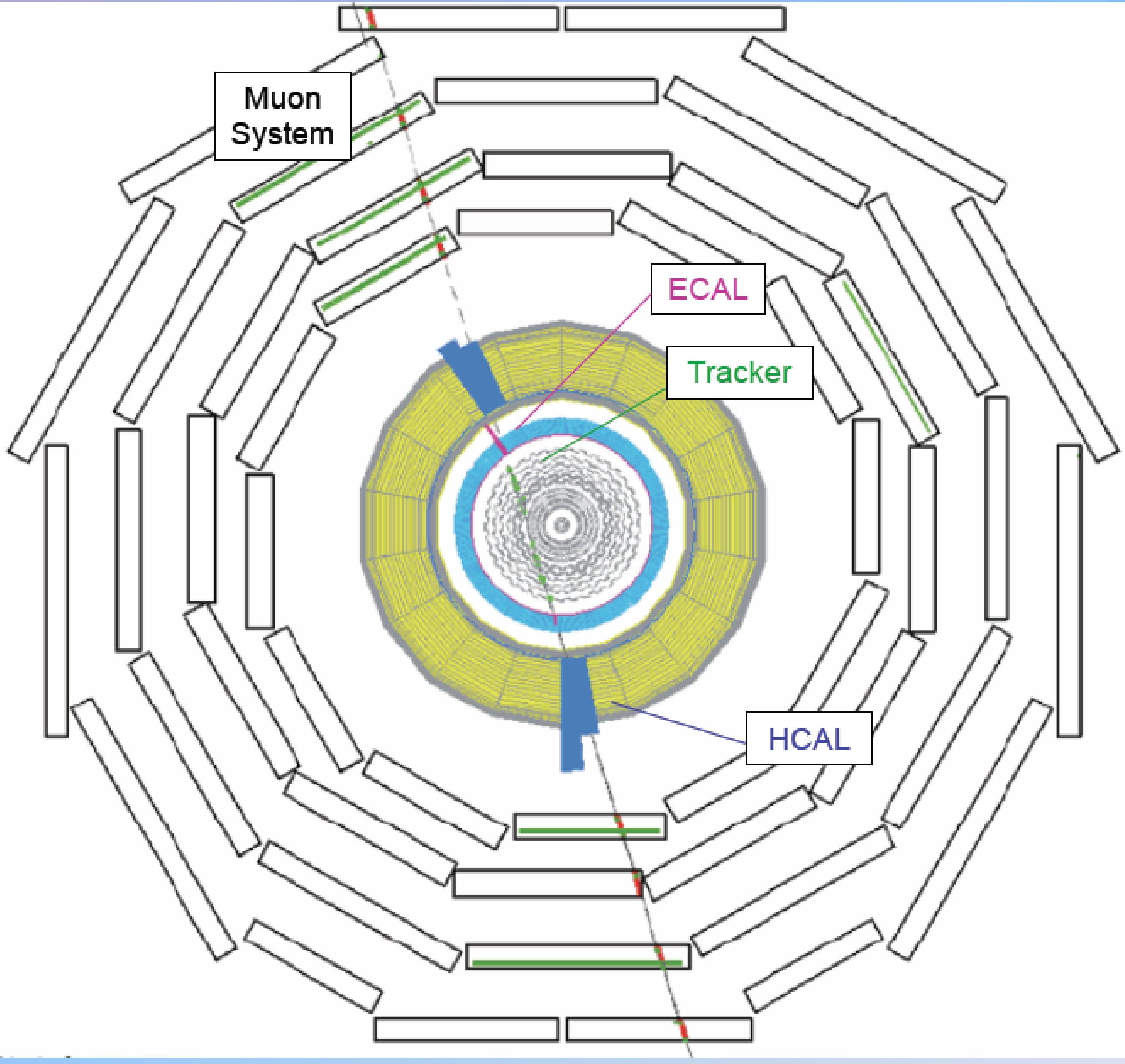


Muon Momentum Resolution

- Tracker only for p up to ~ 100 GeV
- Tracker + Muon for p > 100 GeV

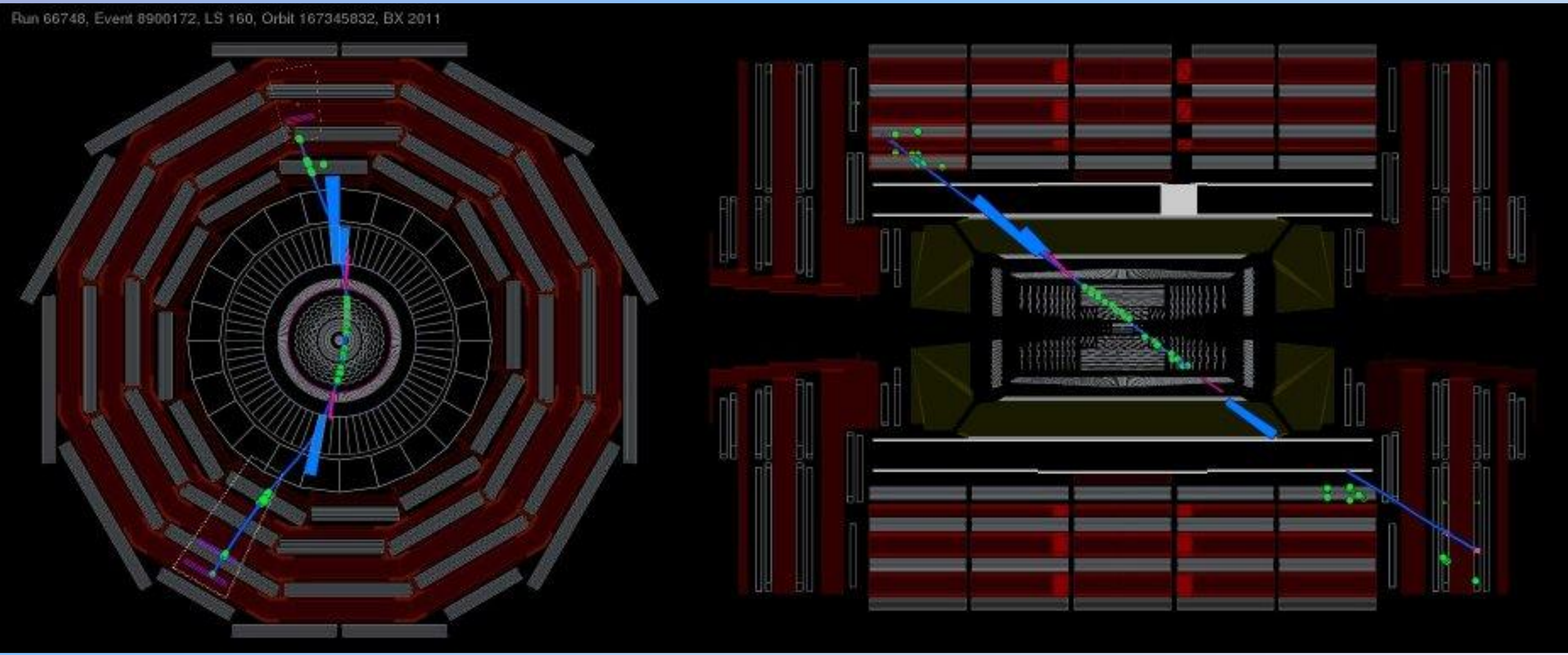


In 2008 a long period of cosmics data-taking with the full detector on
More than 300 M events with B=0 T, and more than 360 M events with B=3.8 T

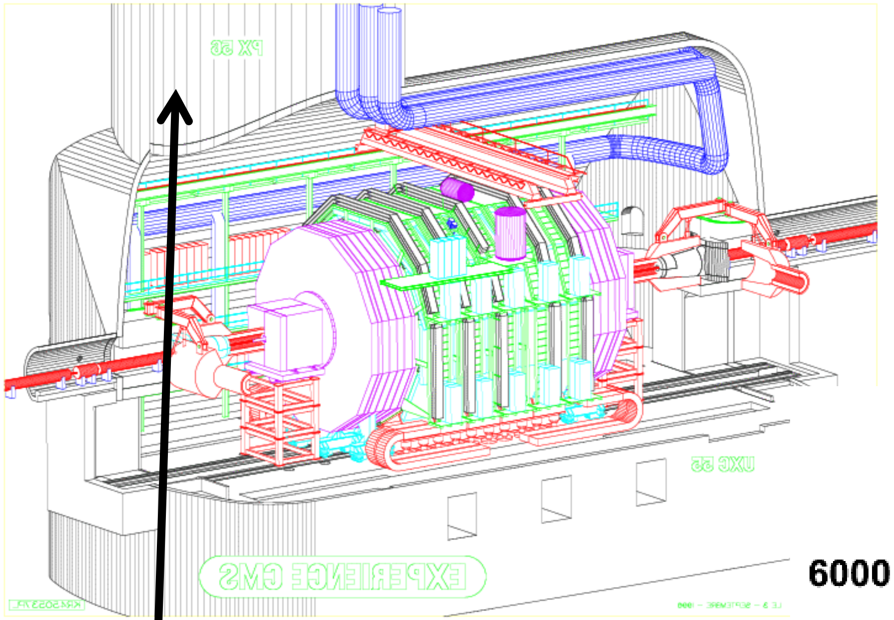


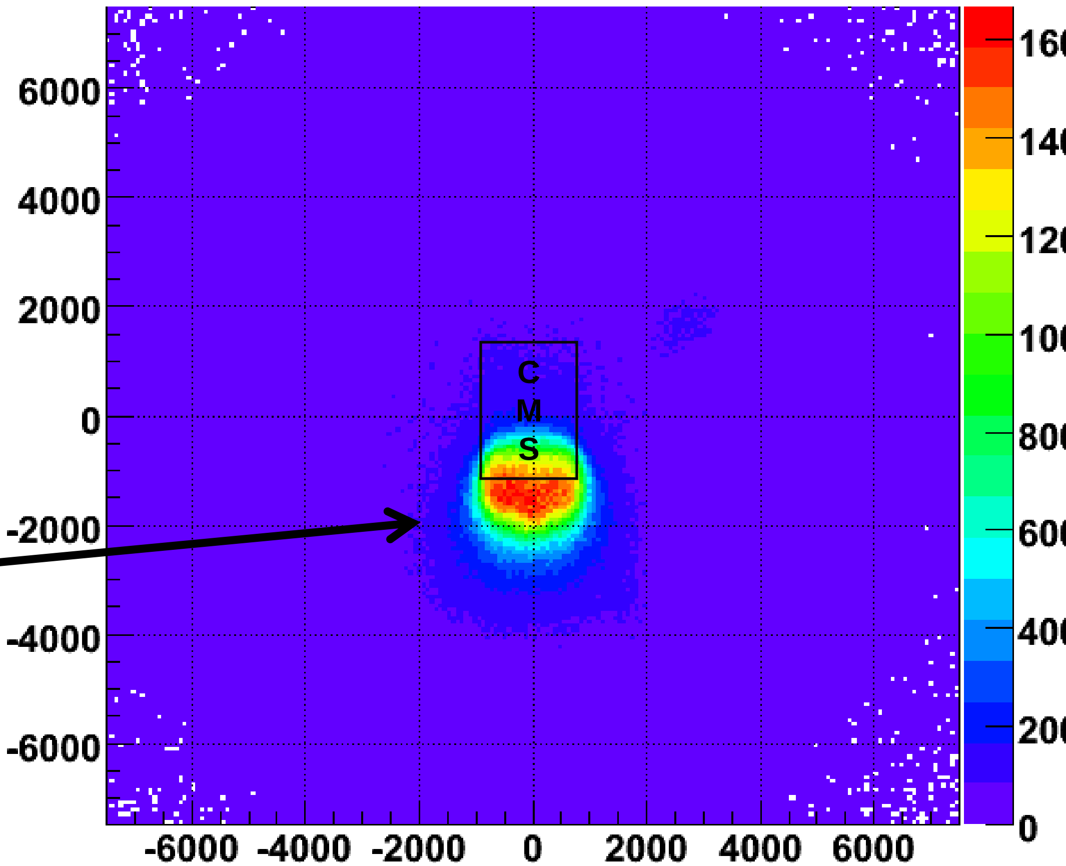
- Di-muon Trigger:
  - Drift-Tube coinc. in top+bottom, each ≥ 2 station segments
- Muon signals traced through
  - muon system
  - Tracker TOB+TIB
  - ECAL
  - HCAL
- Global track fit
- Excellent data - being used for alignment

Global Runs with B-Field = 3.8 Tesla



Muons arriving at the CMS detector, extrapolated at the surface

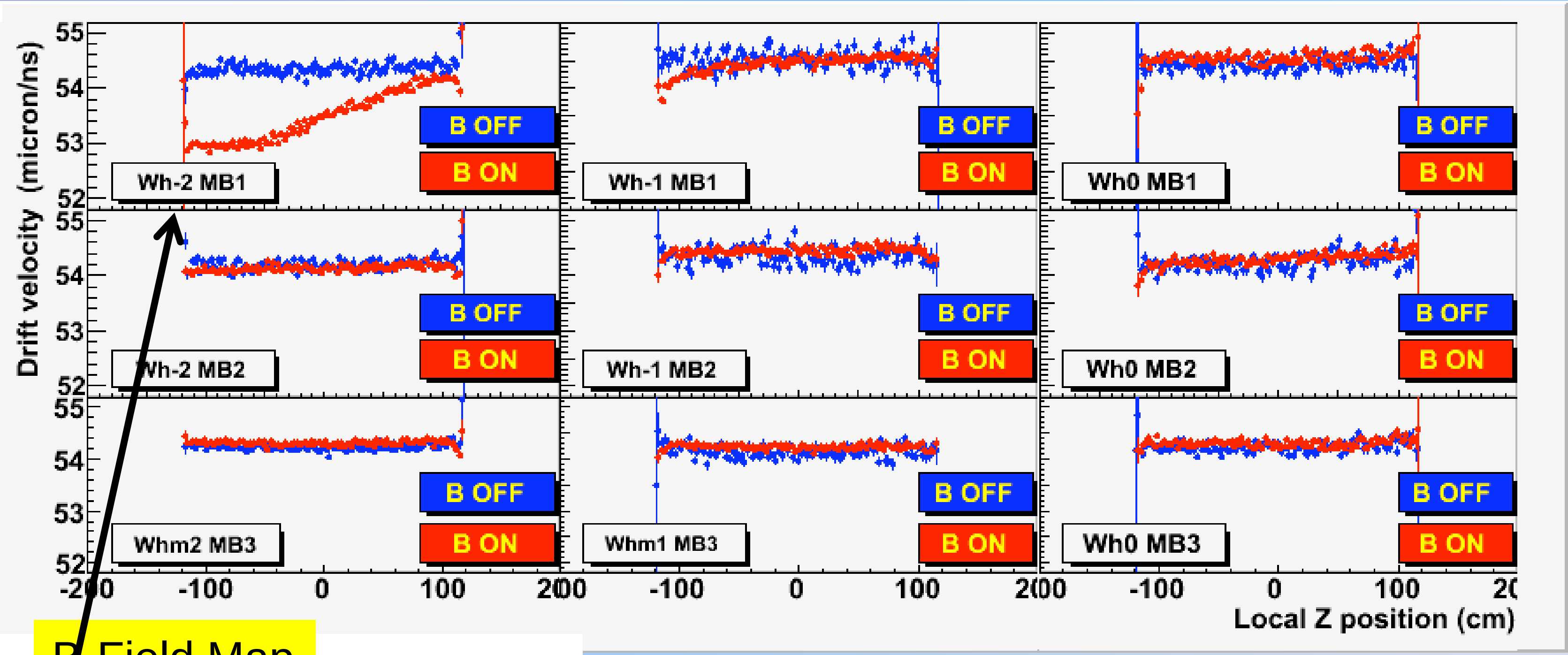




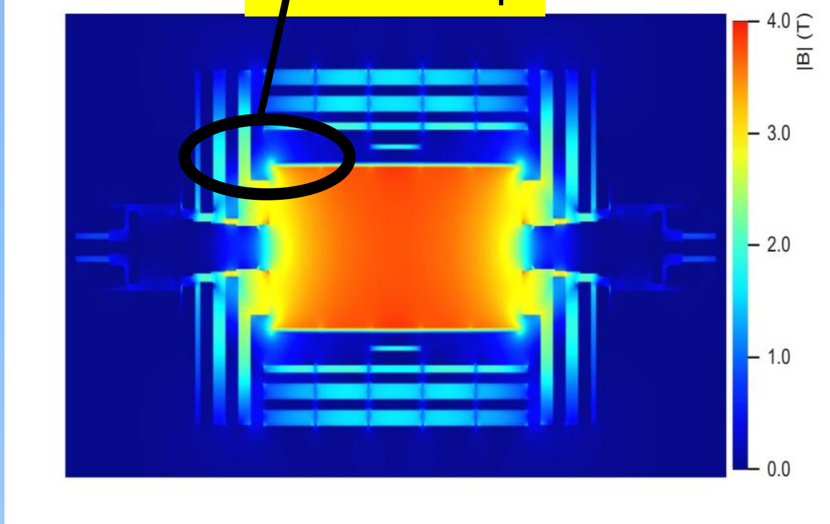
Muons from the shaft

Drift velocity in the Drift Tubes: key parameter for the muon trigger and reconstruction

Innermost chambers in outermost wheels affected by B-field with a deviation up to 3%



B-Field Map

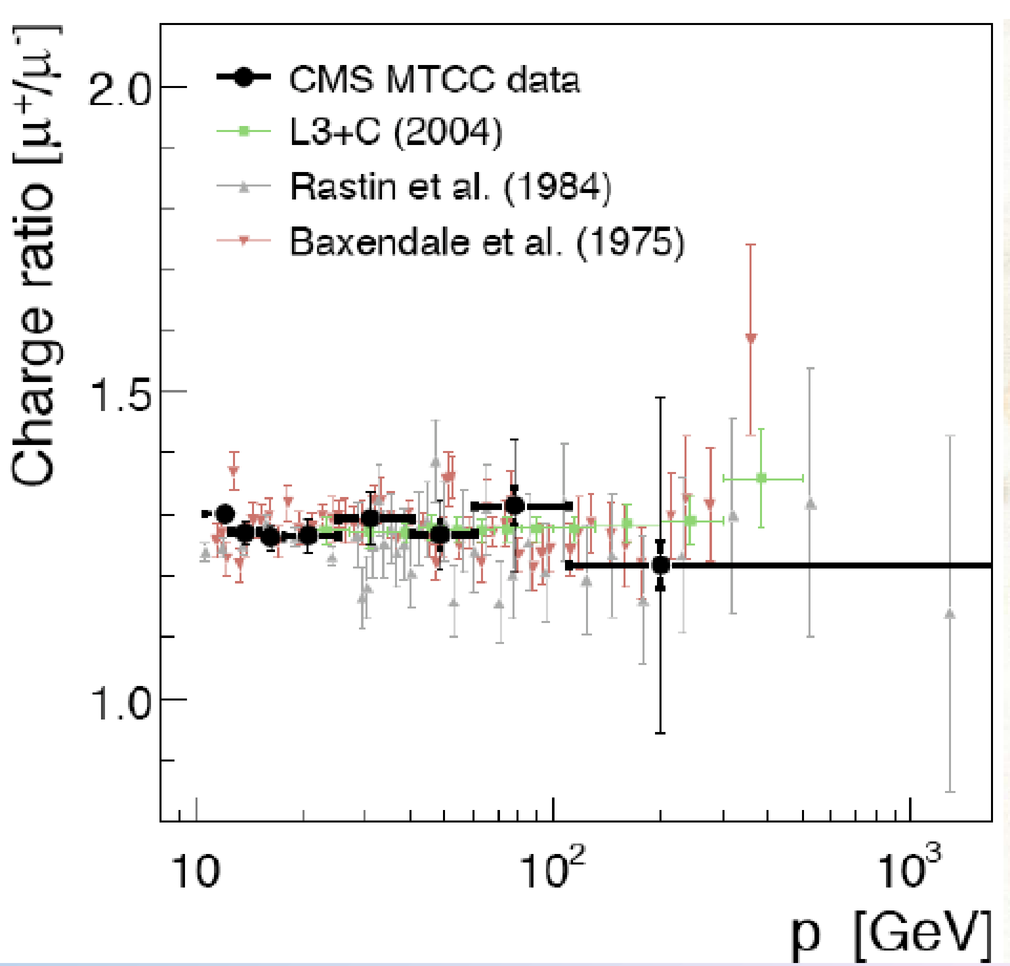


First Physics Measurement in CMS

Charge ratio: μ^+ / μ^-

Good agreement with previous measurements.

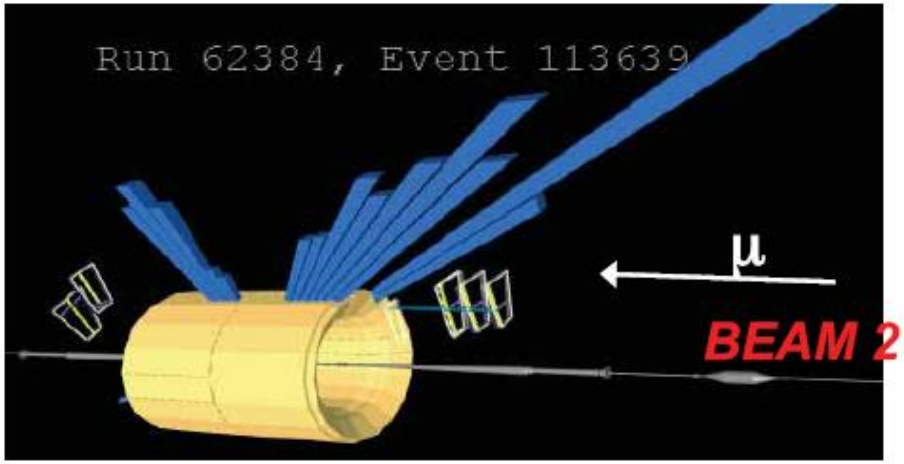
A good exercise to gain experience with the CMS detector



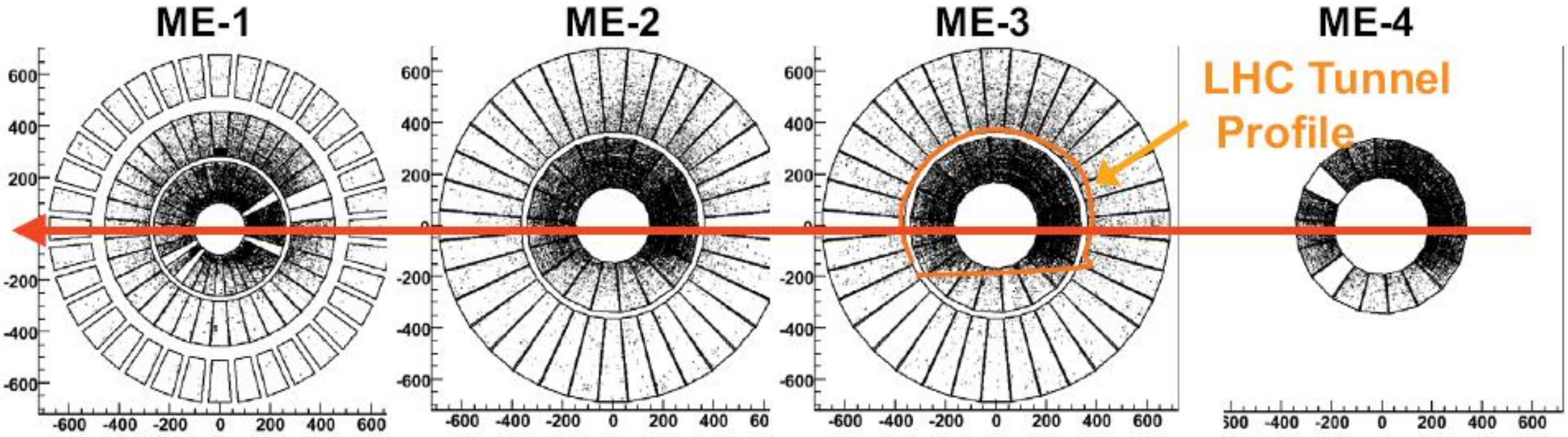
Something Happened on September 10, 2008 !

Muons from beam halo in CSC

Beam Halo: Muons outside of beam-pipe, arising from decays of pions created when off-axis protons scrape collimators or other beamline elements

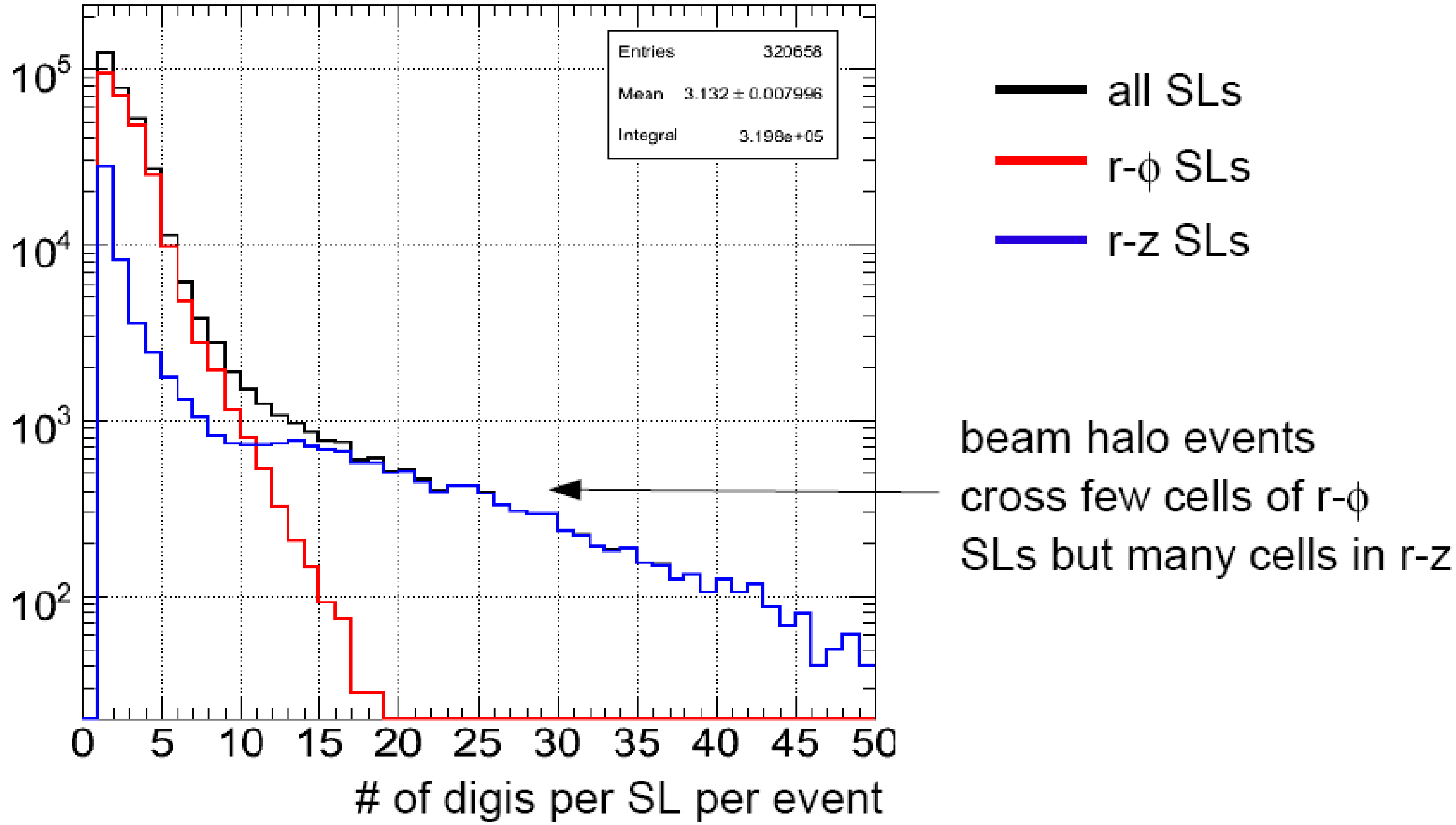


CSC Hit Distribution from Beam Halo Events

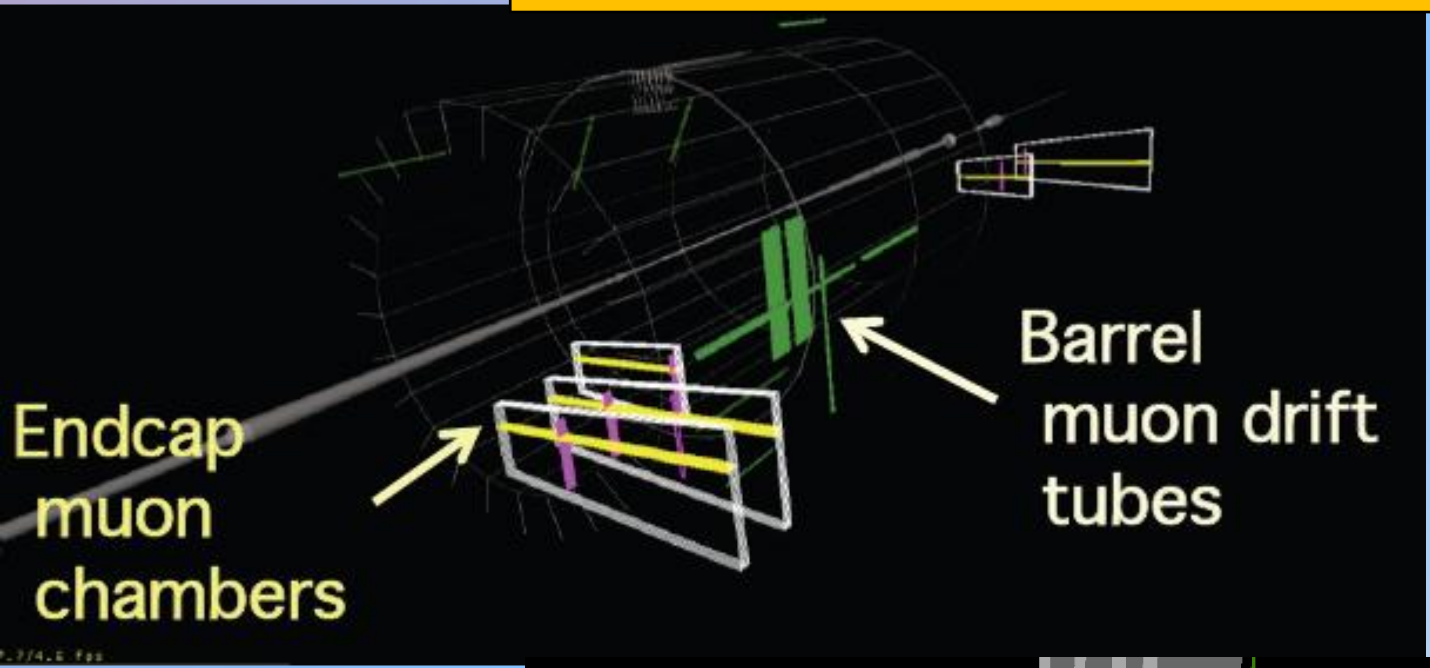


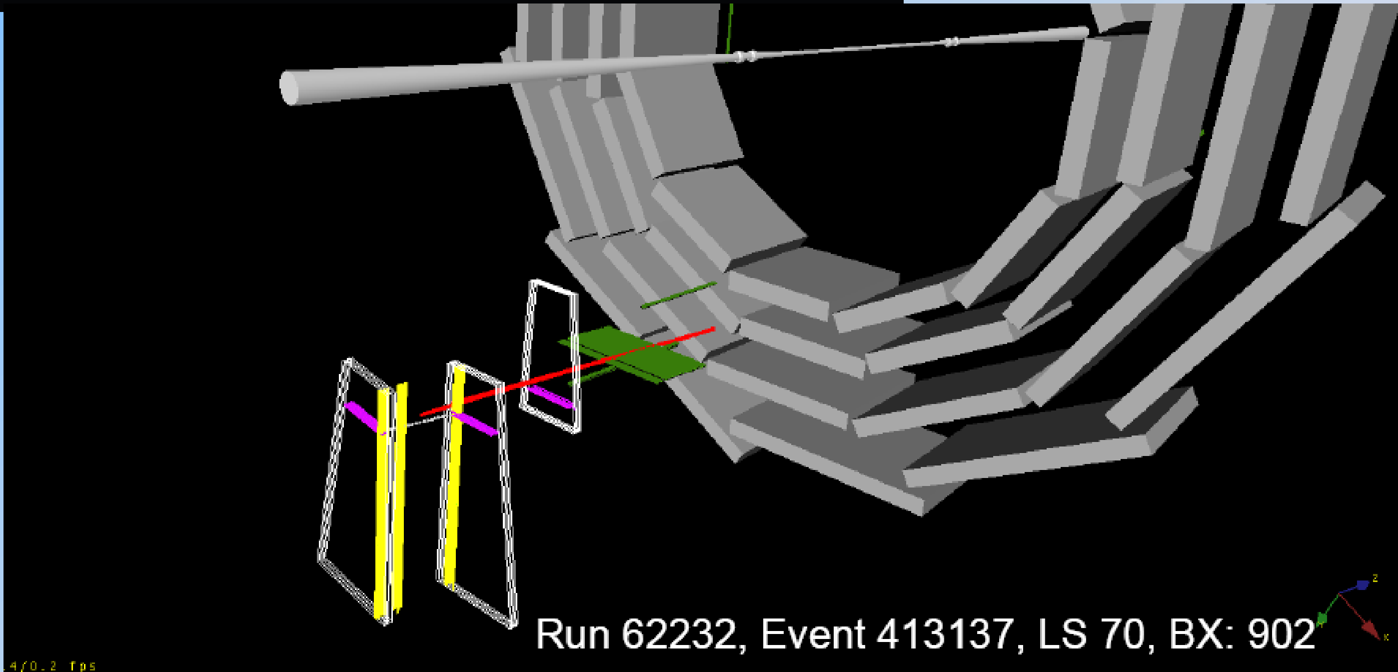
Beam Halo in DT system

- MB1 station: occupancy per SL in each event



Beam Halo both in CSC and DT





Conclusions

Cosmic Muons data provided a very important tool to debug and understand the detector.

The CMS muon detector is now in the “re-commissioning” phase after some detector intervention.

Further cosmic muons global runs will get the detector fully ready for LHC collisions late this year.

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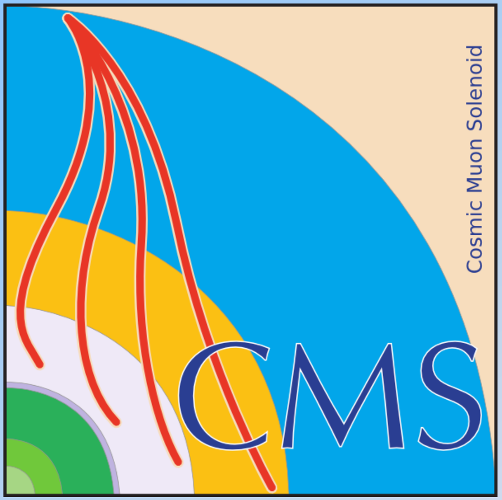

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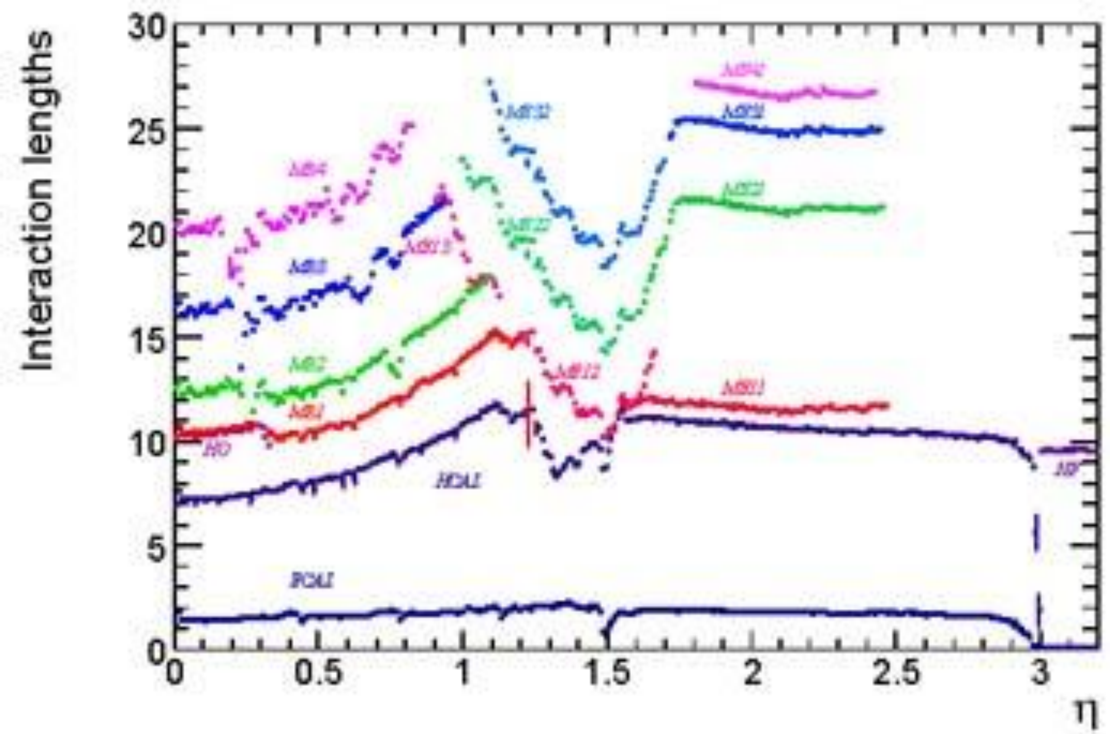
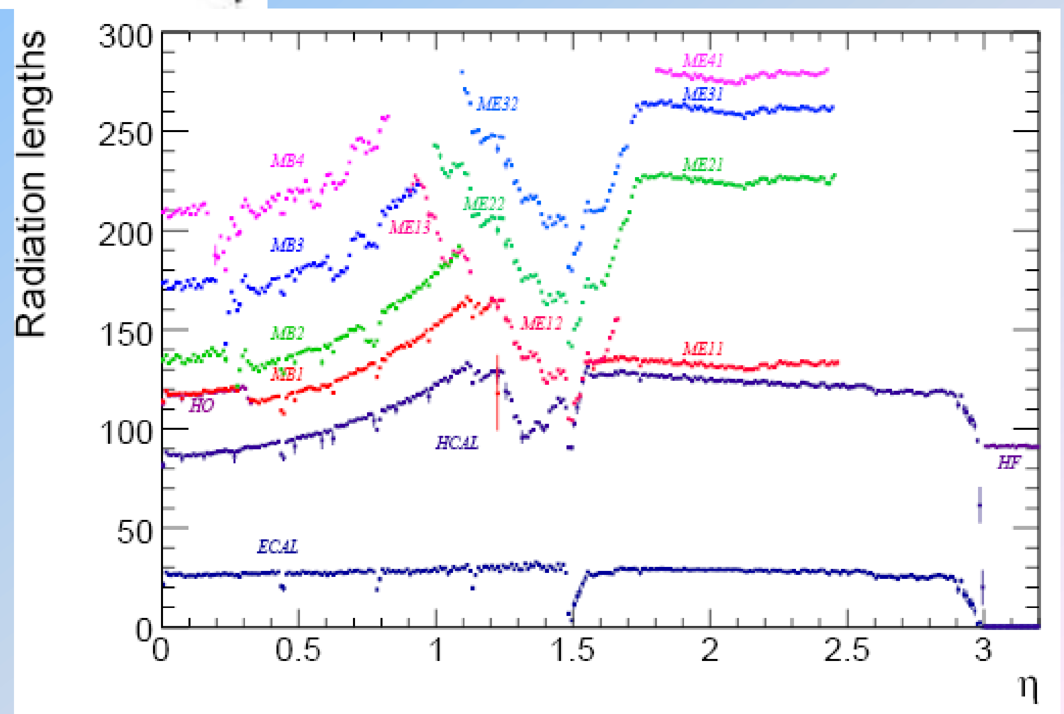
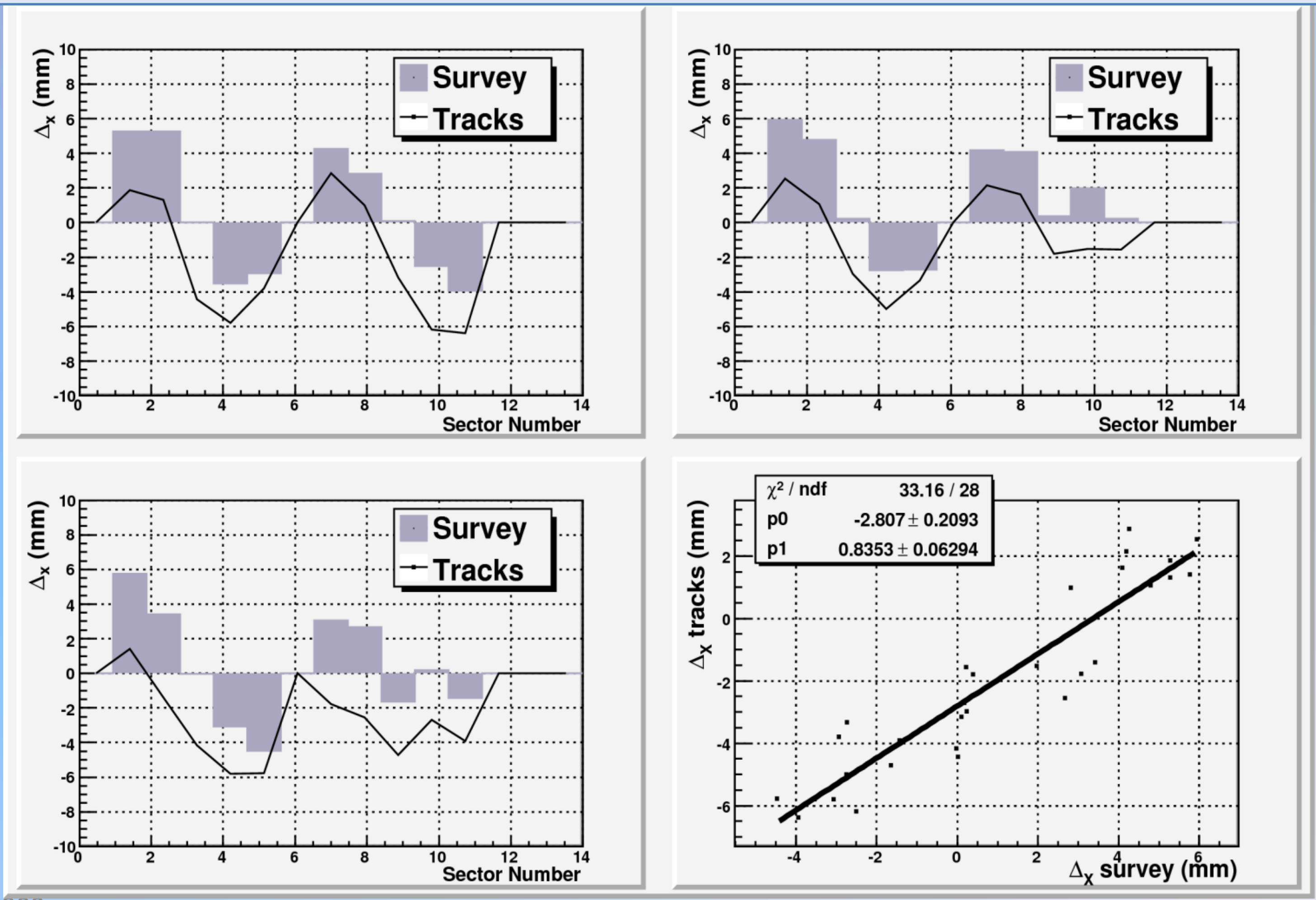
Back-Up Slides

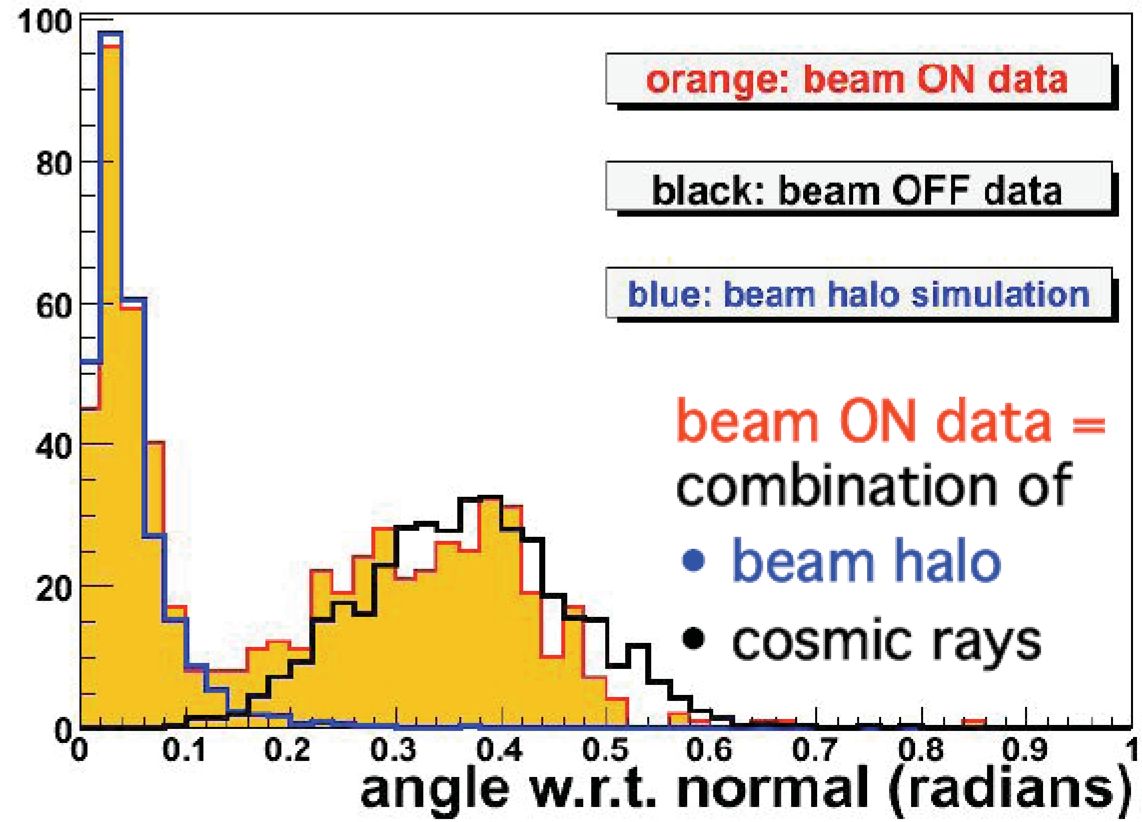

Interaction lengths
30
25
20
15
10
5
0
0.5
1
1.5
2
2.5
3
η


Radiation lengths
300
250
200
150
100
50
0
0.5
1
1.5
2
2.5
3
η
ME41
ME31
ME32
ME21
MB4
ME22
ME13
MB3
ME12
MB2
ME11
MB1
HO
HCAL
HF
ECAL

CRAFT results : alignment (barrel)

Results of the alignment in the rϕ plane using both photogrammetry and tracks alignment, shown here per individual chambers :





- Beam halo muons parallel to beam tangent (small angle)
- Cosmic Ray muons pass through the CSCs at a more oblique angle
- Beam-on distribution consists of two pieces, one resembling cosmic rays and the other matching the beam halo simulation.