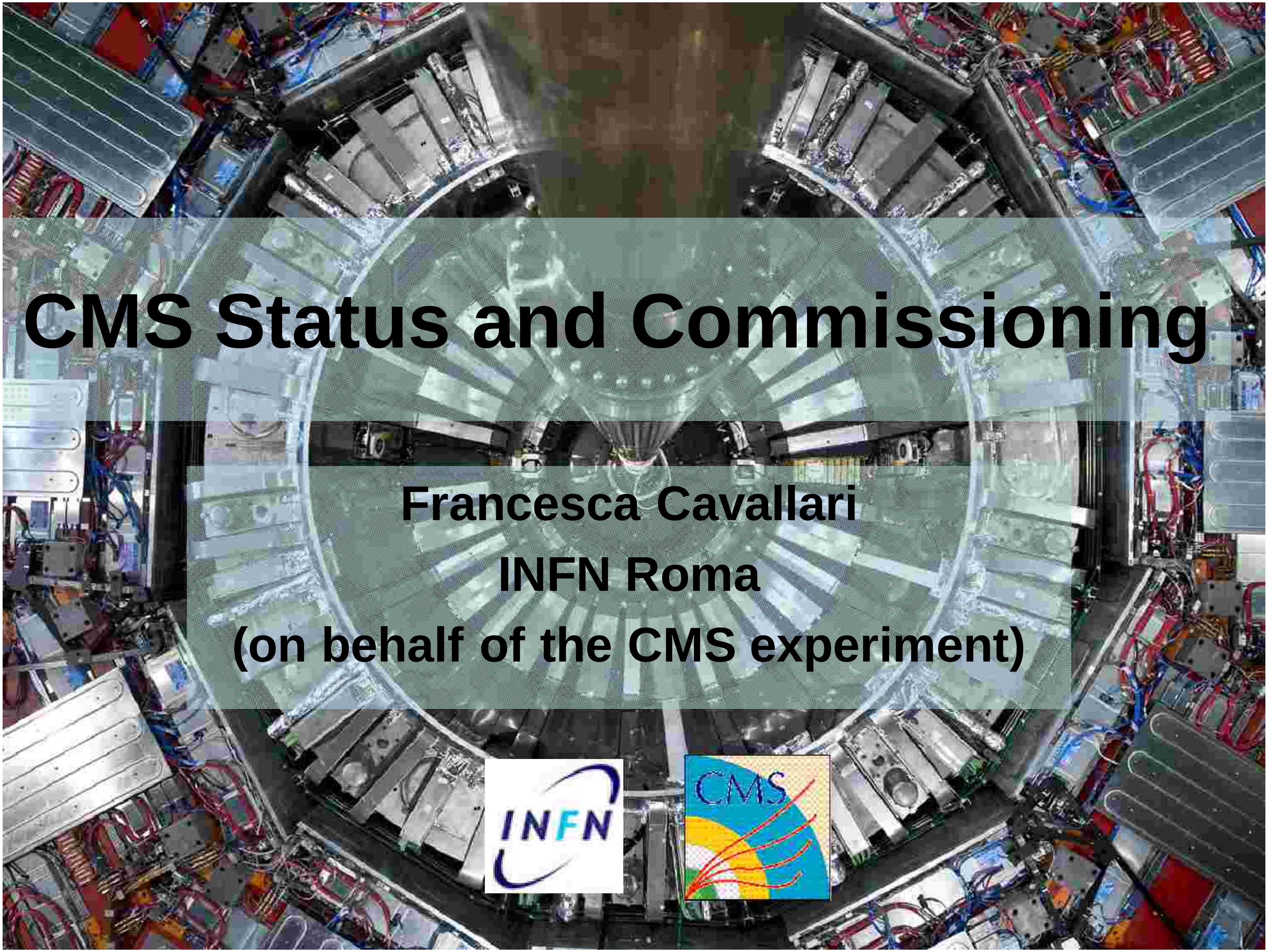


CMS Status and Commissioning

Francesca Cavallari
INFN Roma
(on behalf of the CMS experiment)

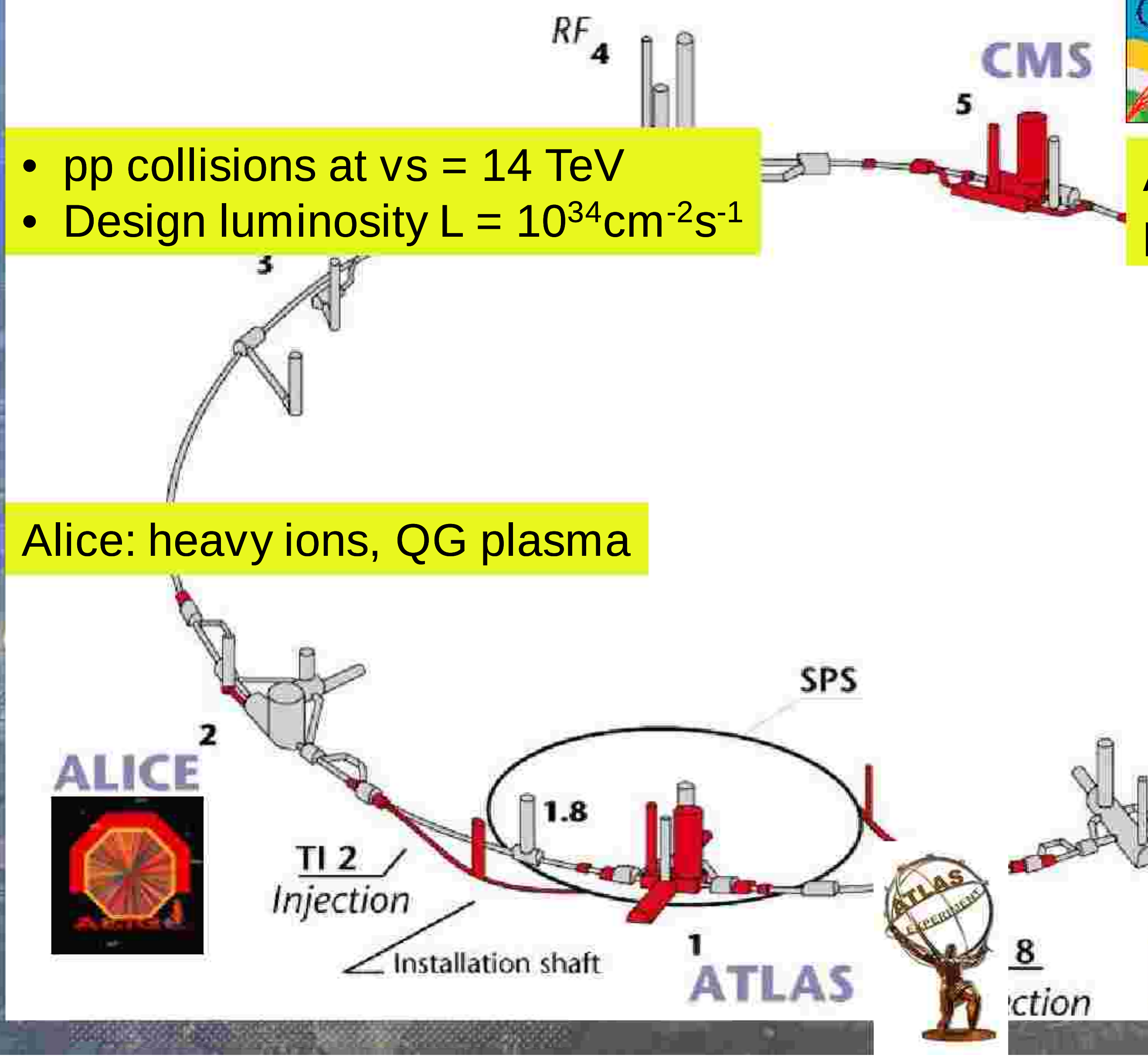
LHC

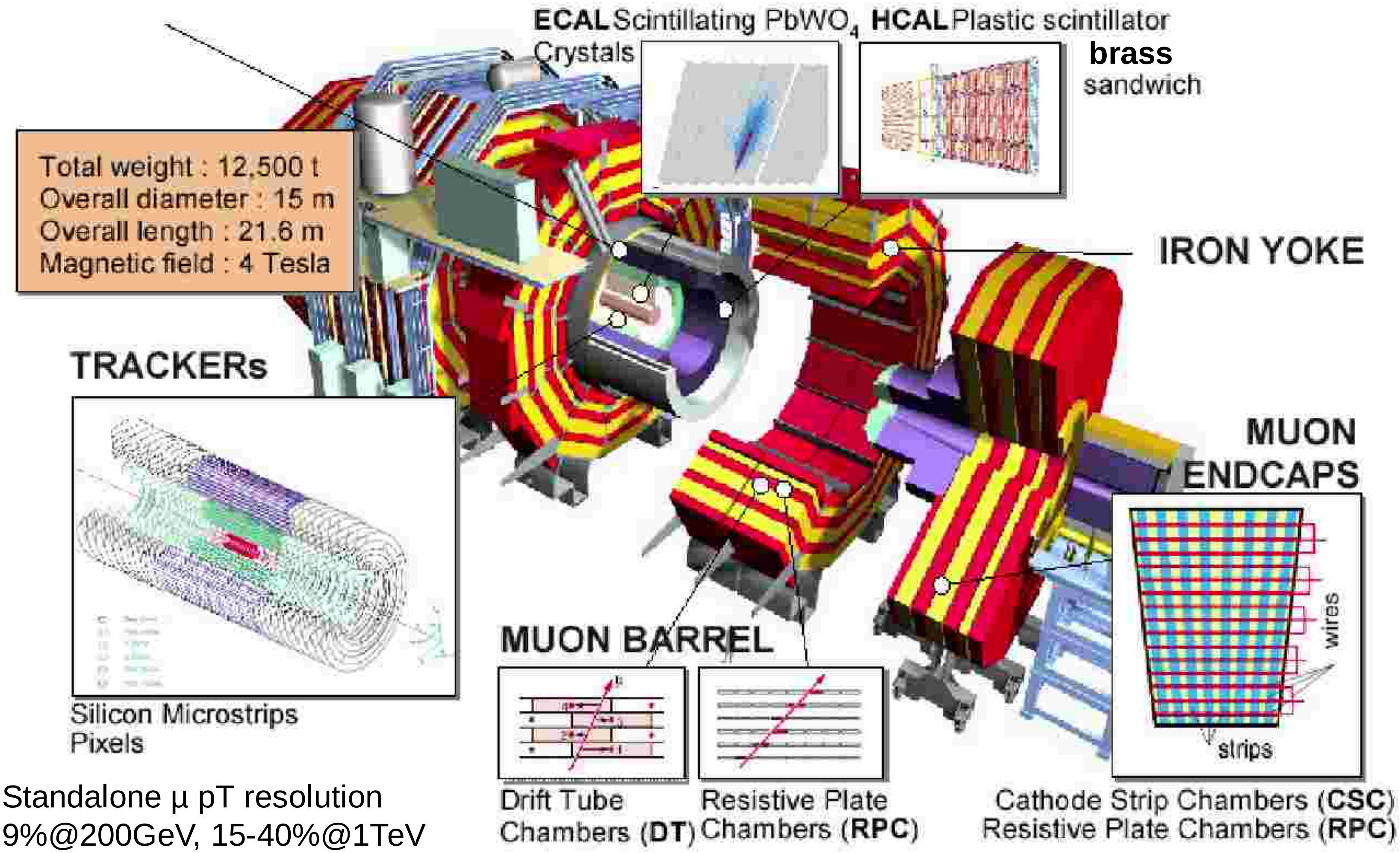
- pp collisions at $\sqrt{s}$ = 14 TeV
- Design luminosity L = $10^{34} cm^{-2} s^{-1}$

Atlas and CMS:
pp, general purpose

Alice: heavy ions, QG plasma

LHCb: pp, B physics





Standalone μ pT resolution
9%@200GeV, 15-40%@1TeV
Combined with tracker
1%@ low PT 5%@ 1TeV

- Compact solenoid (4T) containing the calorimeters and Si tracker
  Muon chambers embedded in the iron return yoke
  Excellent and compact crystal electromagnetic calorimeter
  Tile calorimeter for hadronic activity

CMS commissioning

Commissioning means:

– Efficiency: to make sure that everything works (eventually repair)
– Quality: to check and improve the detector performance (resolution / alignment and calibrations)
– Integration: from beautiful detectors to a working experiment (DAQ, trigger, data access)
– Tools: improve control and monitoring tools and develop expertise on realistic circumstances (Detector Control System and Data Quality Monitoring)

Cosmics and beam runs

- **4 global cosmics runs with B=0T**
- **300 Hz rate**
- **350 M events**

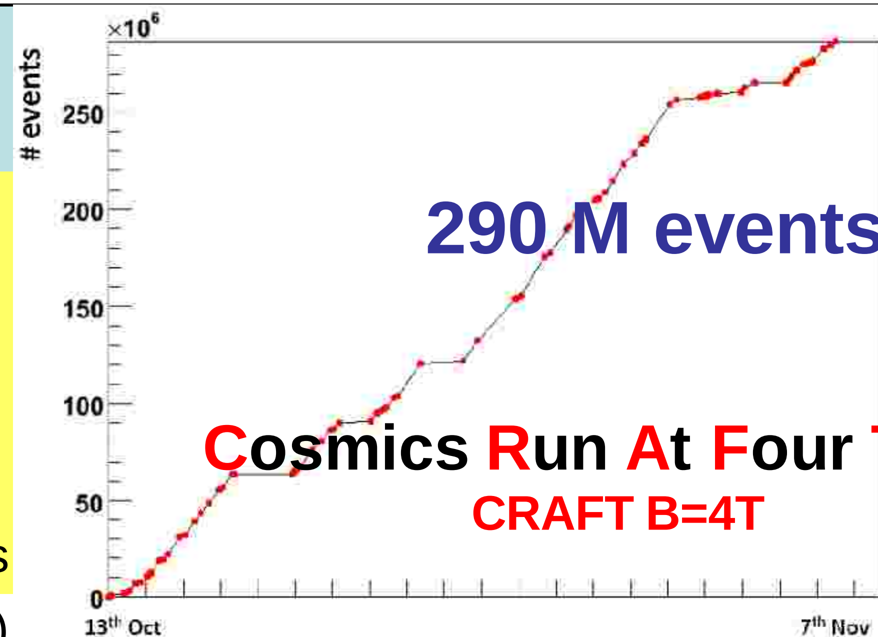
- **1 long cosmics run with B=3.8T**
- **4 weeks data taking (370M events)**
- **19 days with B=3.8T (290M events)**

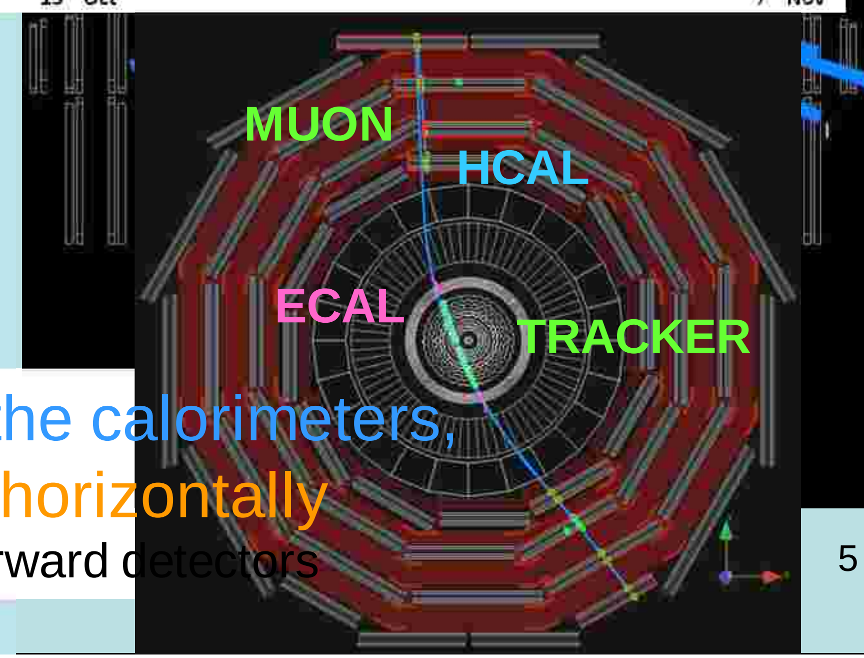
- 87% have a muon track in the chambers
- 3% have a muon track with tracker hits
- 30000 events have a track with pixel hits

On September 10th proton beams started to circulate in the LHC
We collected beam halo events (mostly muons coming parallel to the beam axis)
And beam splash events (single beam collisions with the collimators) **~2x10^9 protons on collimator ~150 m upstream of CMS**

350M events

CRUZET4

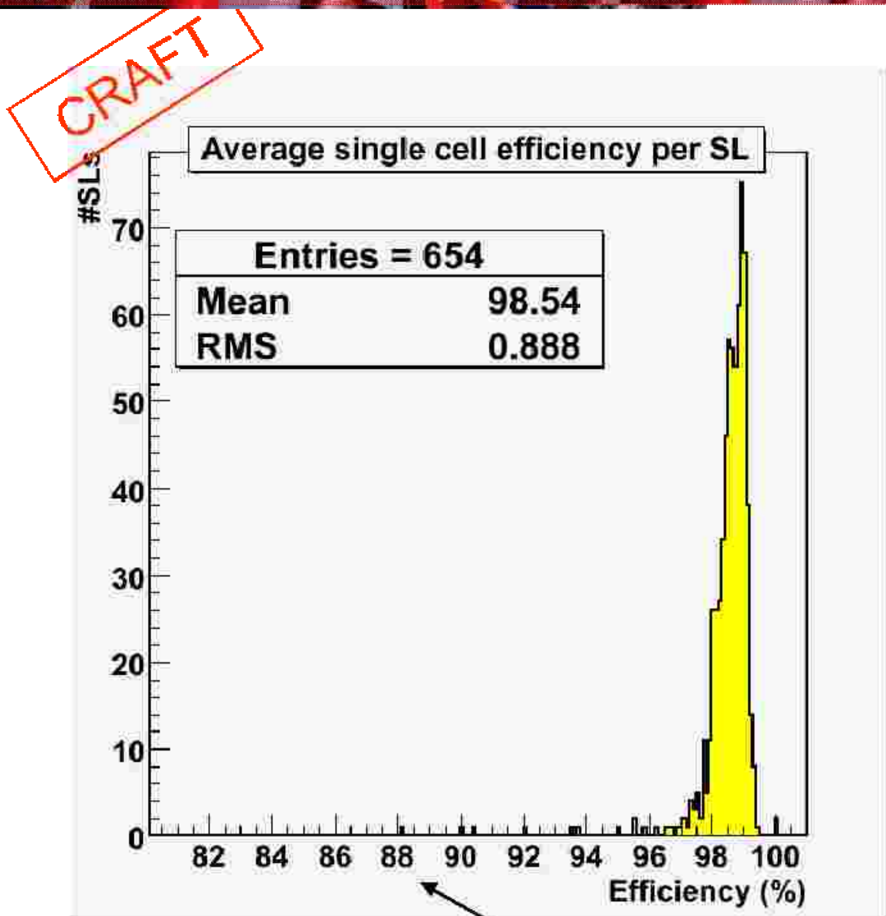


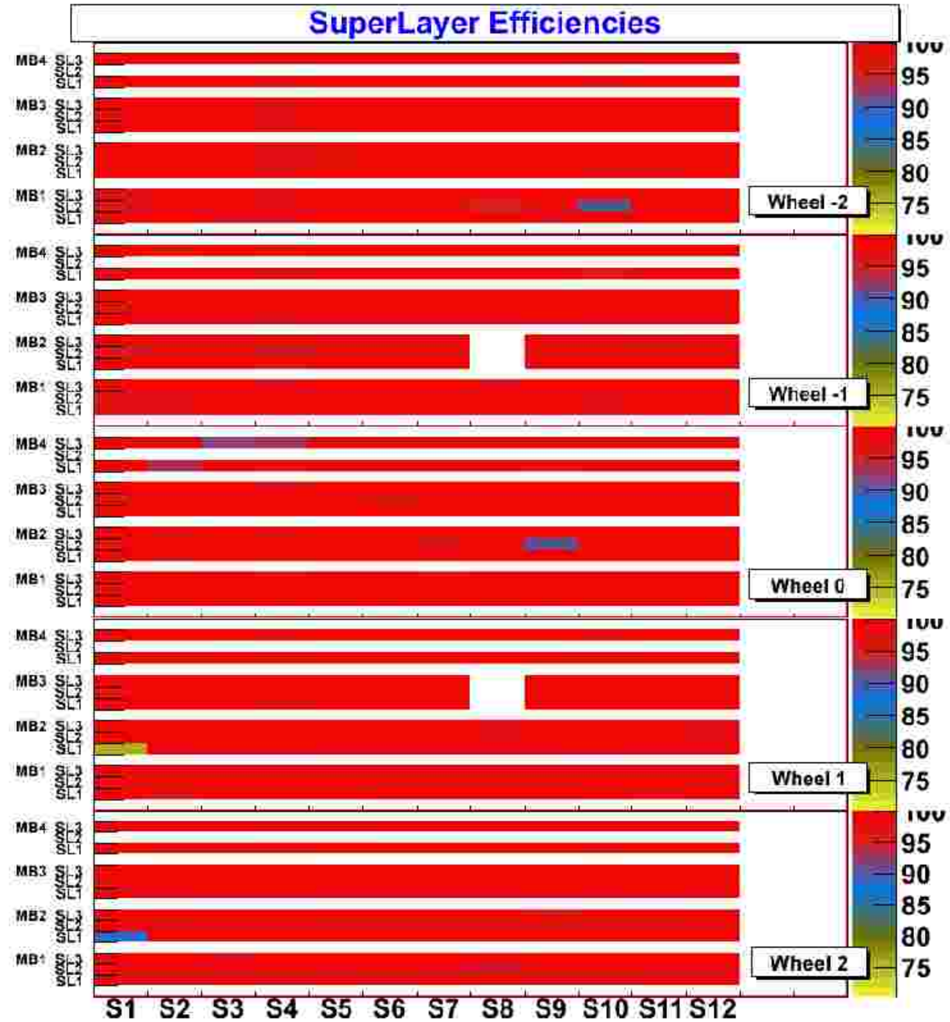


High energy deposit in the calorimeters, particles travelling horizontally
useful to commission forward detectors

CRUZET3
CRUZET2
CRUZET1

Muon Barrel: Drift Tubes efficiency

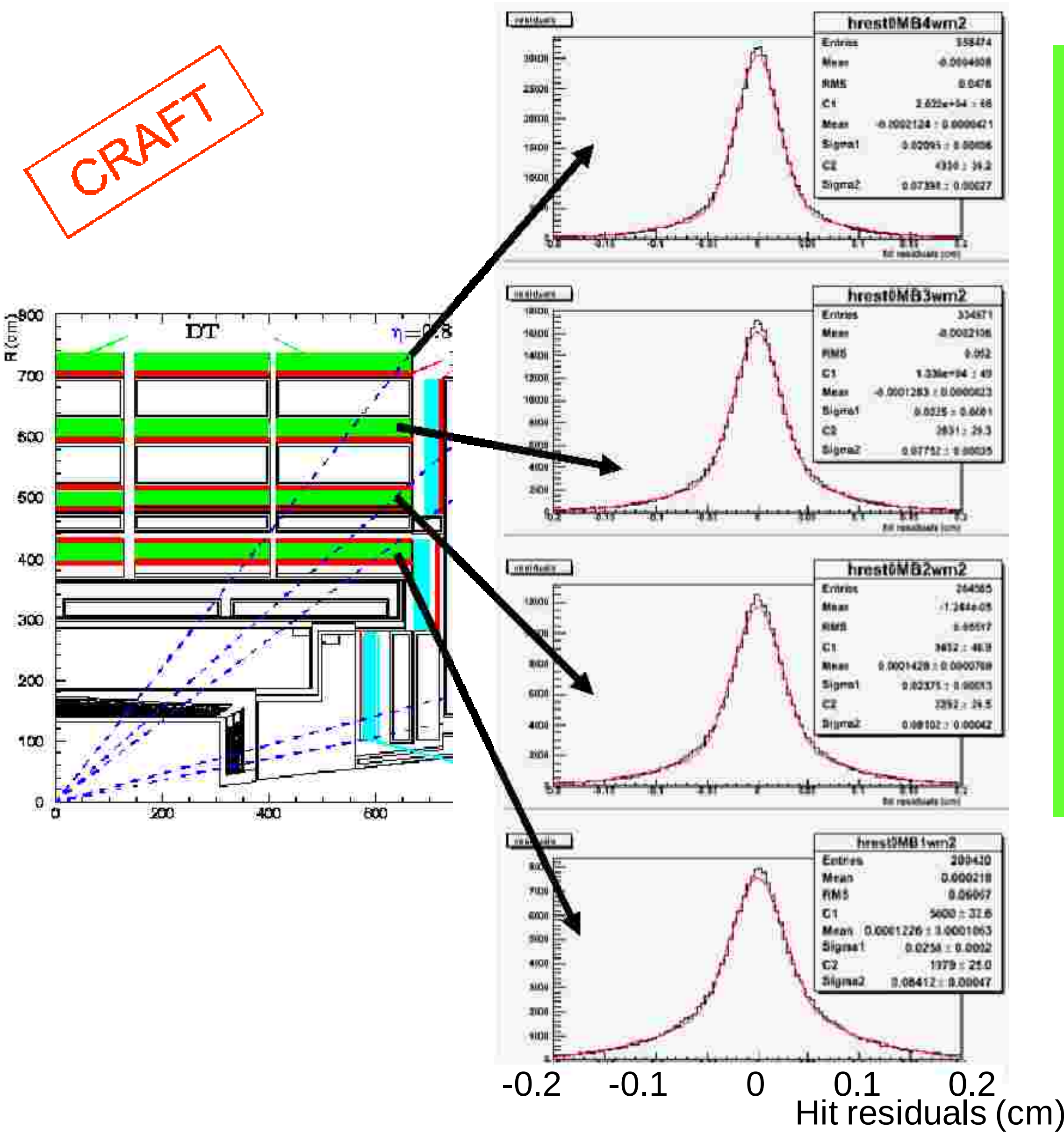




Drift Tubes layer efficiency. Lower values correspond groups of temporarily disconnected channels.

Muon Barrel: Drift Tubes Hit resolution

CRAFT



The hit resolution is computed from the residuals between the DT hits and the track segments in the muon spectrometer.

Typical values
s ~ 200 – 260 mm

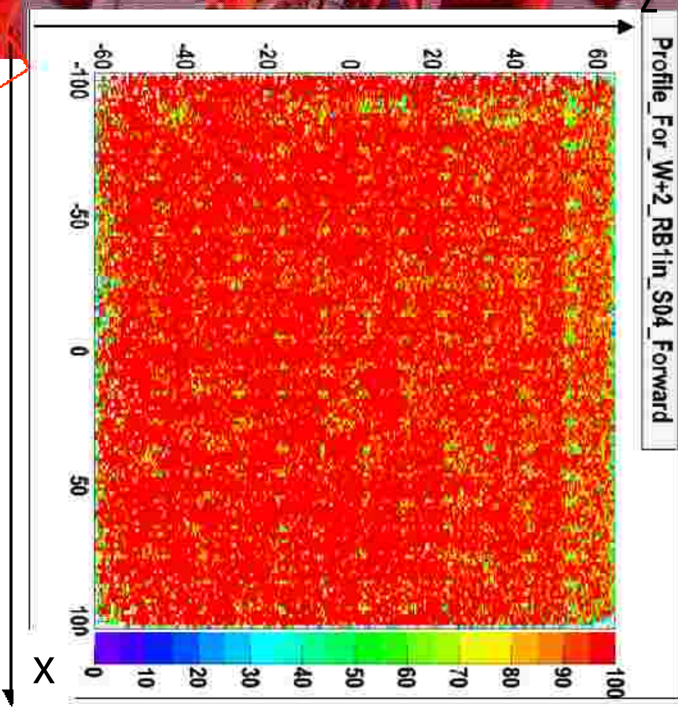
Good agreement with MC

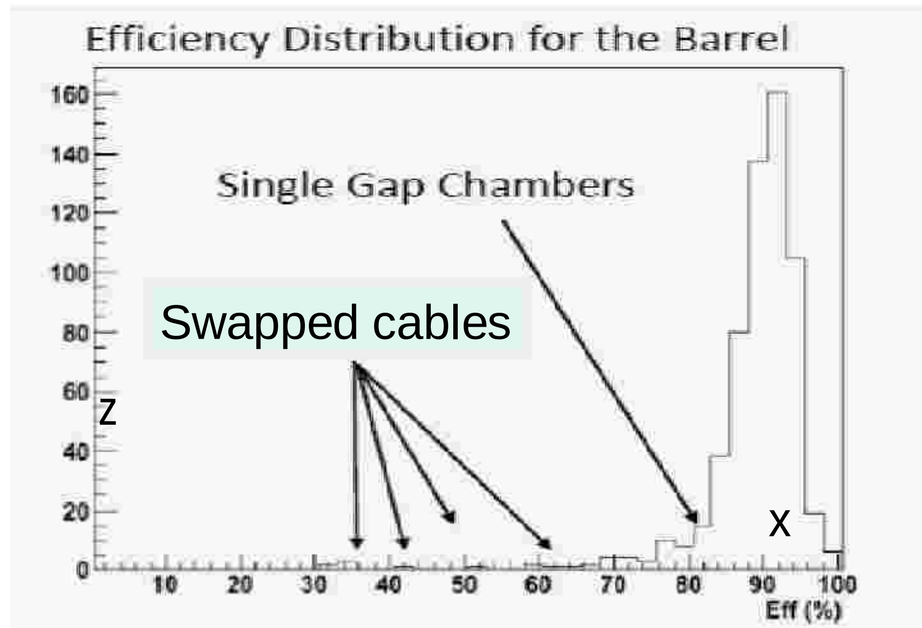
Magnetic field degrades the resolution in the inner chamber in the external wheels.

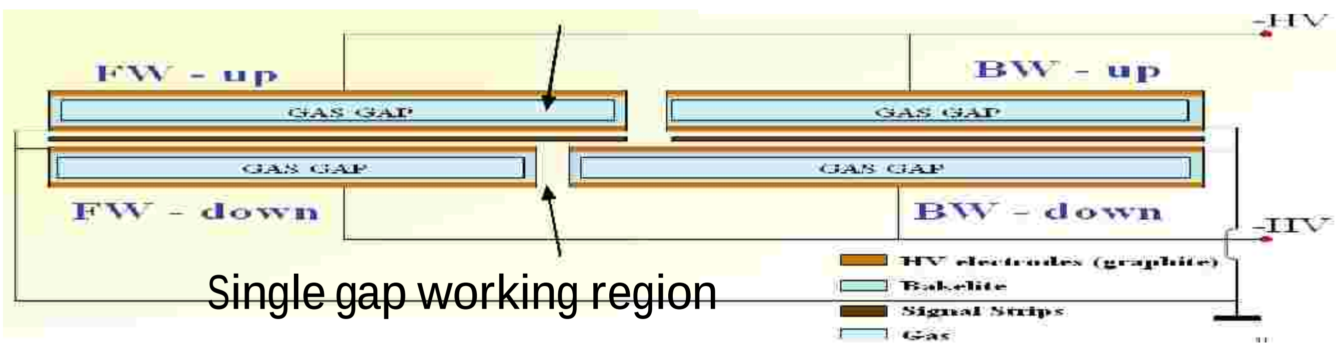
TALK

Muon Barrel: RPC efficiency

CRAFT





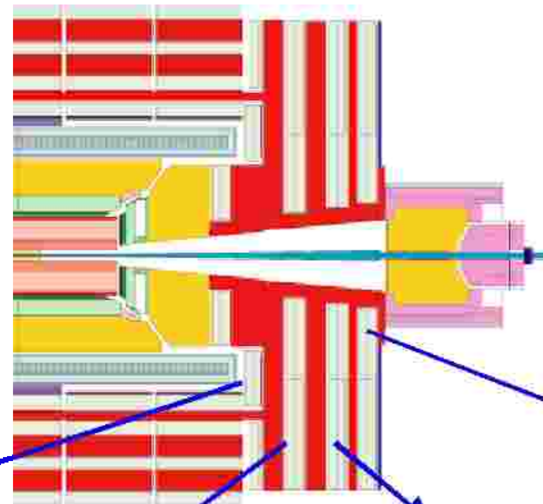


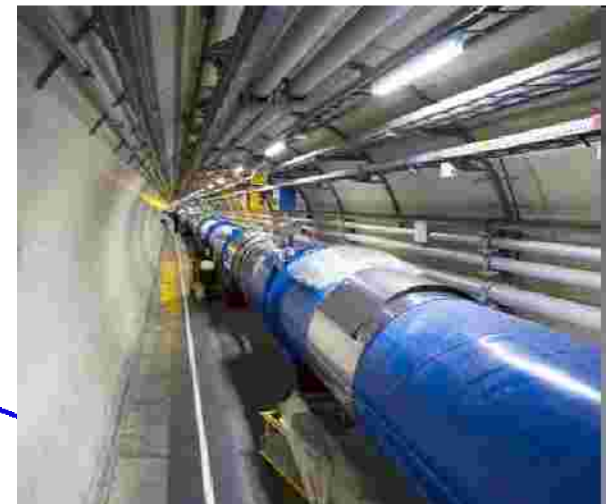
RPC efficiency vs impact point measured extrapolating DT segment on the RPC .
The low efficiency points (in step of 10 x 10 cm^2) are due to the spacers.
A slight degradation in efficiency is observed in the single gap zone.

POSTER

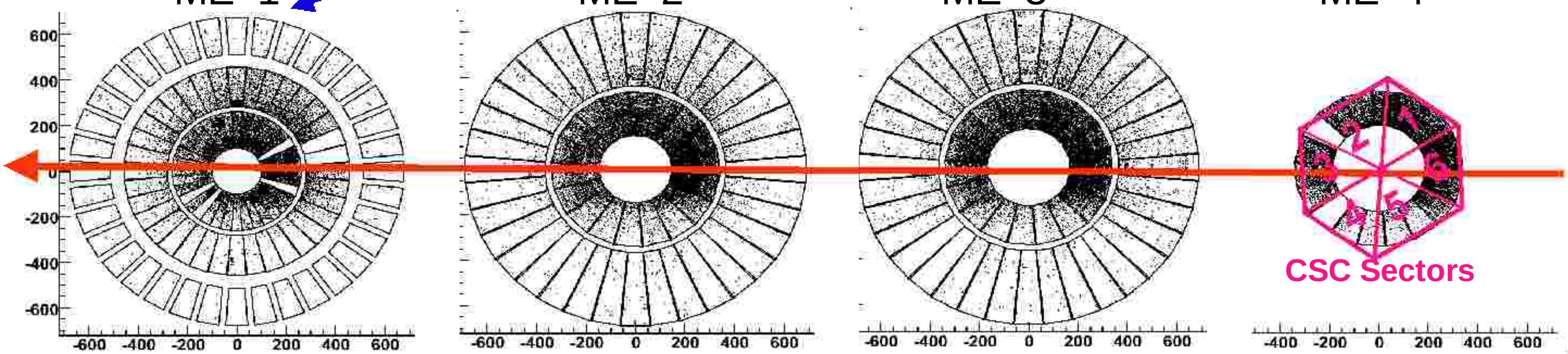
Muon Endcap: CSC occupancy

BEAM HALO





ME–1 ME–2 ME–3 ME–4



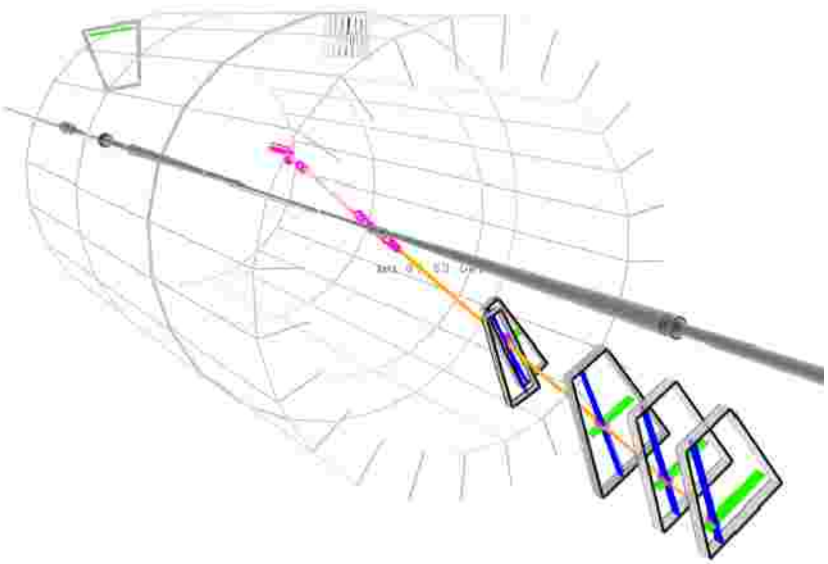
TALK

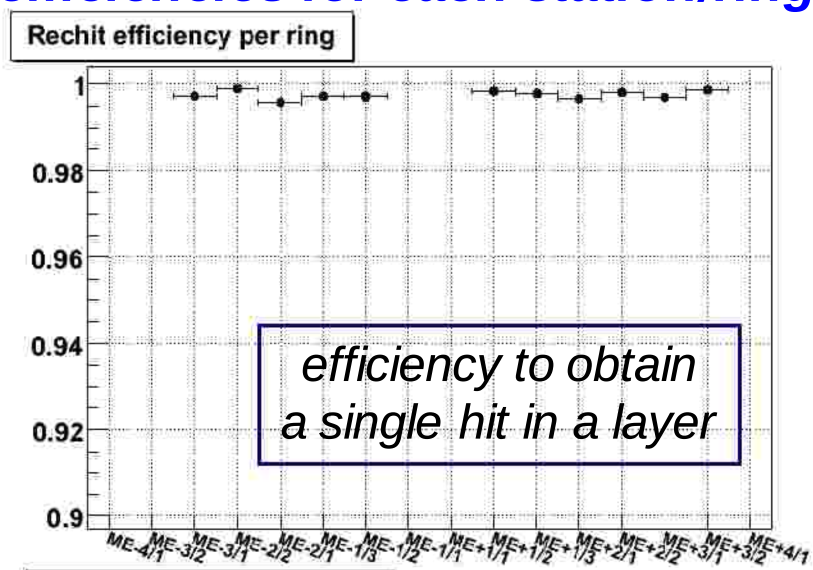
Muon Endcap: CSC efficiency

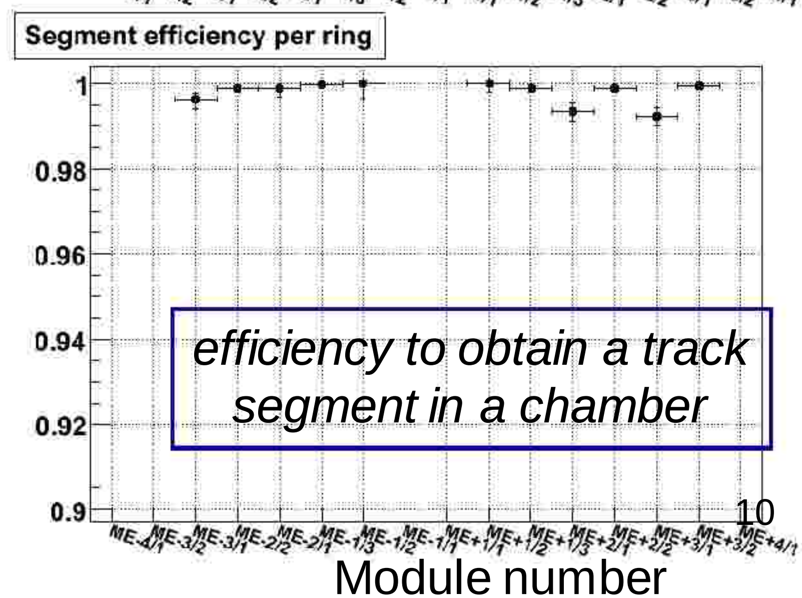
Average measured efficiencies for each station/ring.

CRAFT

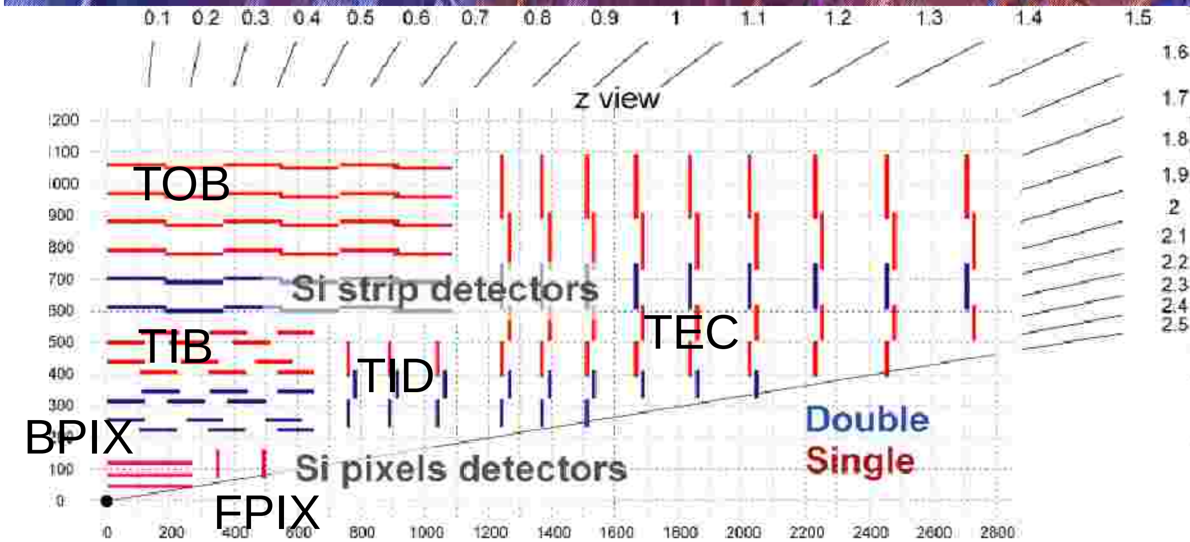
Endcap Muon CSC chambers performed well during cosmics run.







Tracker



The layout of the CMS inner tracker

13 layers in the Barrel
14 layers in the Endcaps
9.6M strips
66M pixels
More than 200 m^2 Si

Tracker status during cosmics run

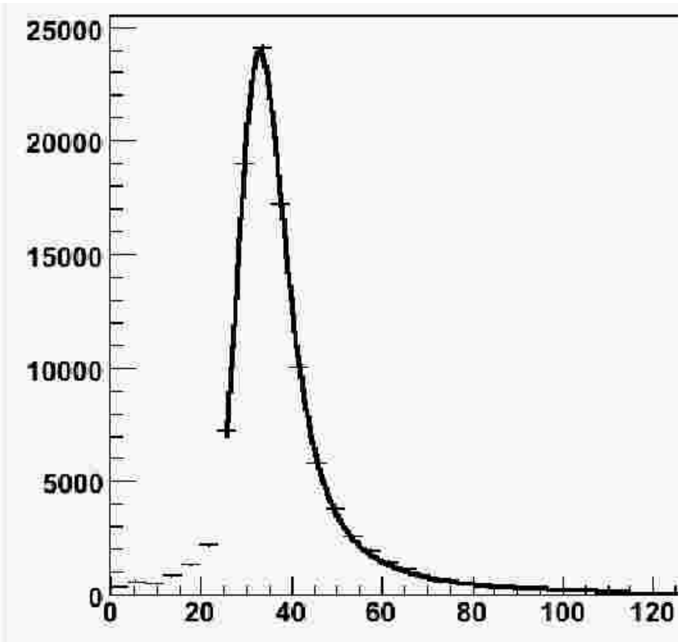
- Strip Tracker highly efficient.
- Pixel Barrel highly efficient
- Forward pixels 94% efficient during cosmic runs now repaired

TALK

Tracker: Strip efficiency

CRAFT

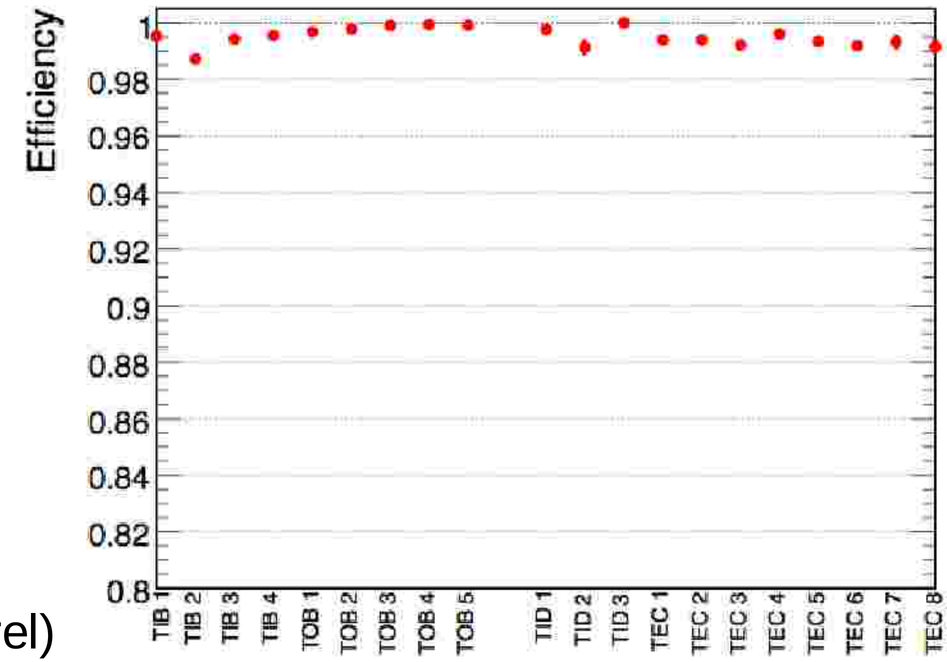
On track strip clusters Signal to Noise ratio corrected for track angle effect



Signal To Noise Ratio (Tracker Outer Barrel)

Signal To Noise Ratio around 30 for all detector parts.

Hit finding efficiency of Barrel and End-Caps layers (after masking of faulty modules)

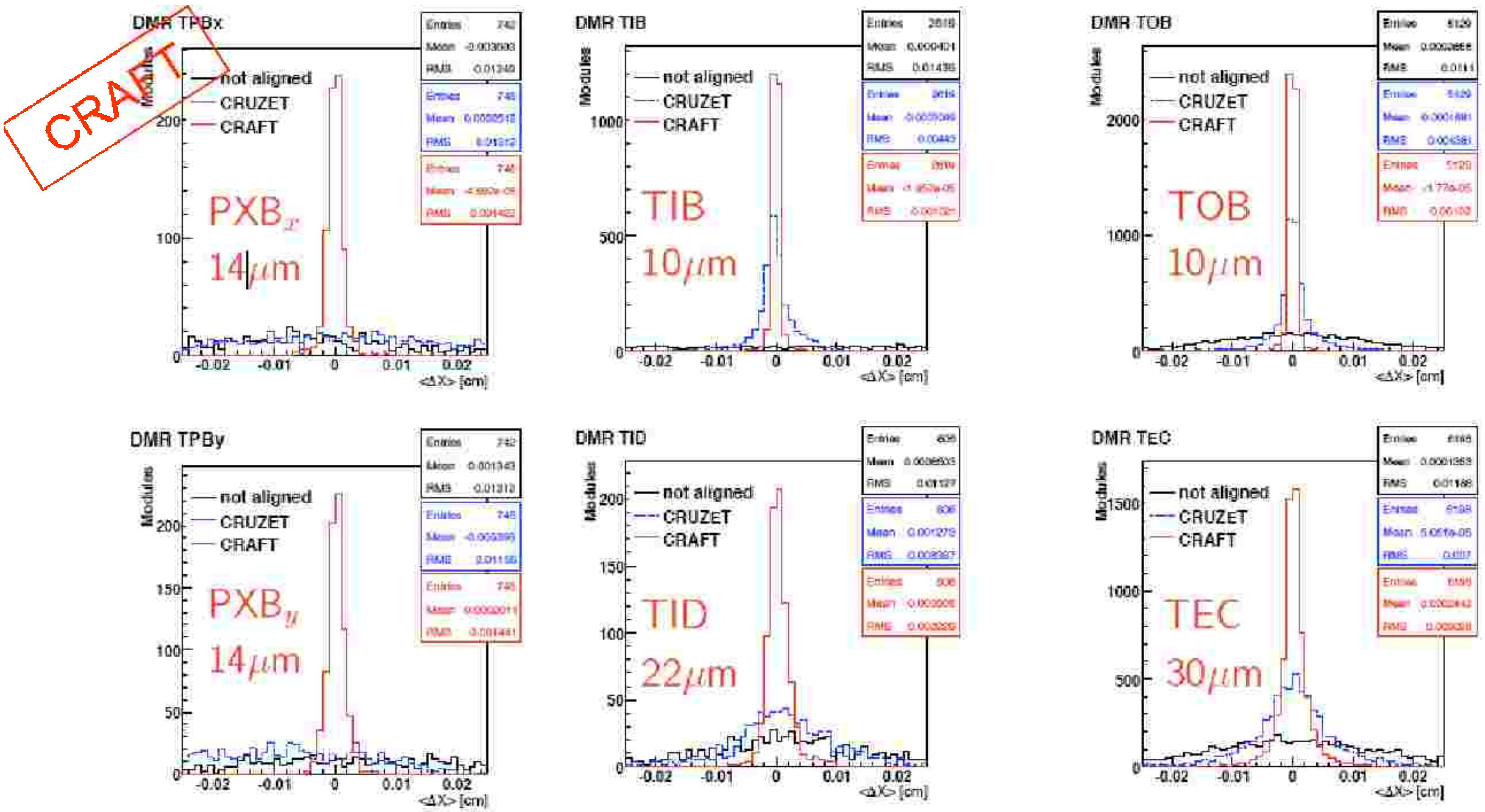


Tracker module

Tracker Alignment

•Distribution of Median of Residuals (cm)

Sensitive to remaining displacement of module in the measured coordinate



•Strip hit resolution in Tracker Barrel (after alignment) :

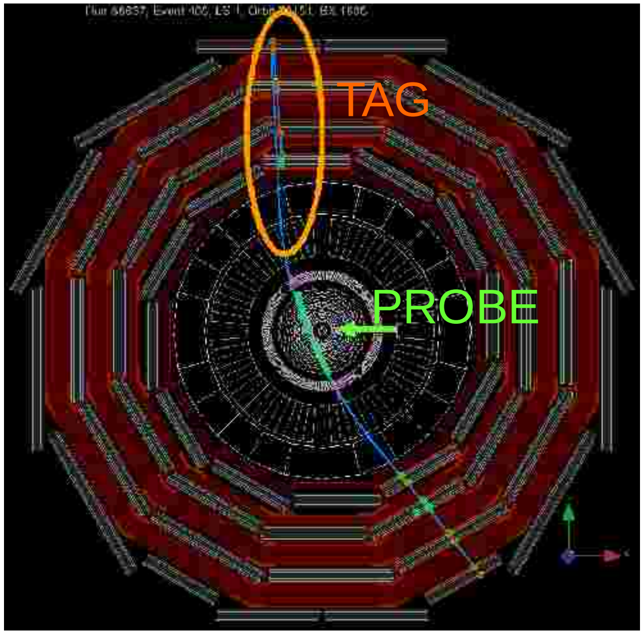
From comparison of measured and predicted differences hit positions in region of overlap of two modules in a same detector layer is as expected around 20-30 micron.

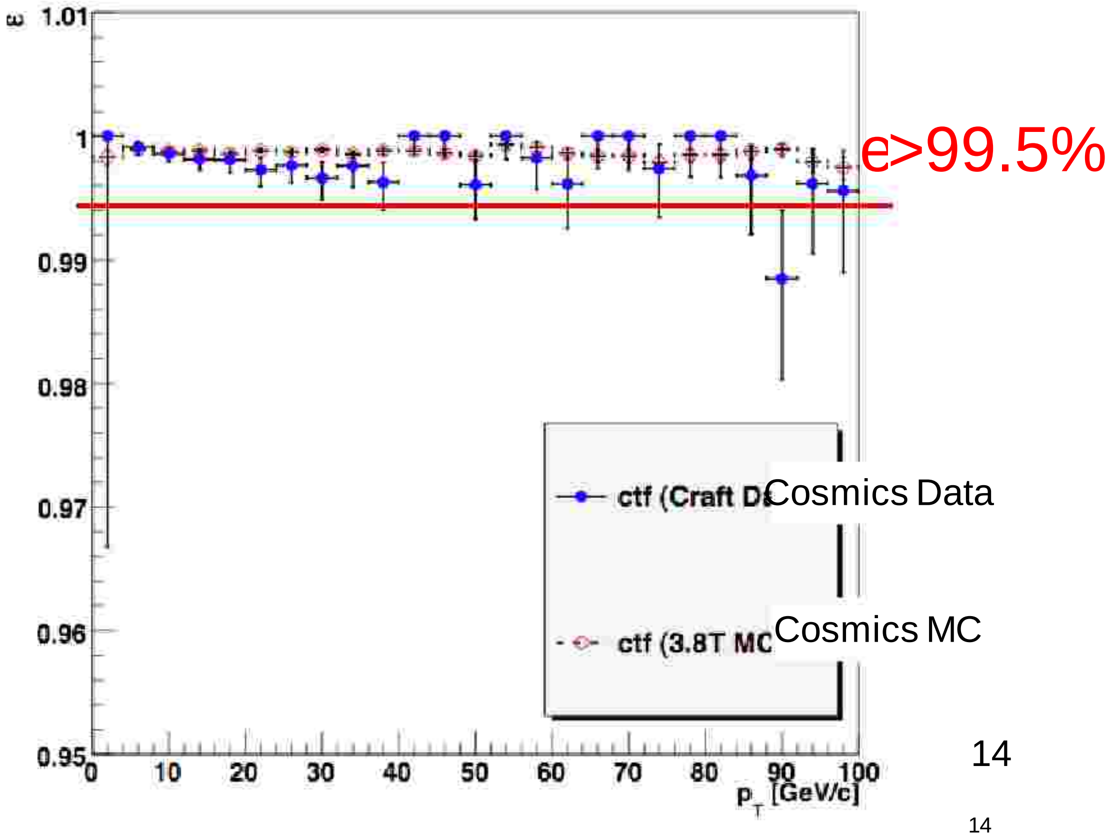
Tracker performance: cosmic tracks finding efficiency

CRAFT

Tag and Probe method

- Tag : Stand alone upper muons pointing to the Tracker near the origin (LHC-like tracks)
- Probe : Tracker muons





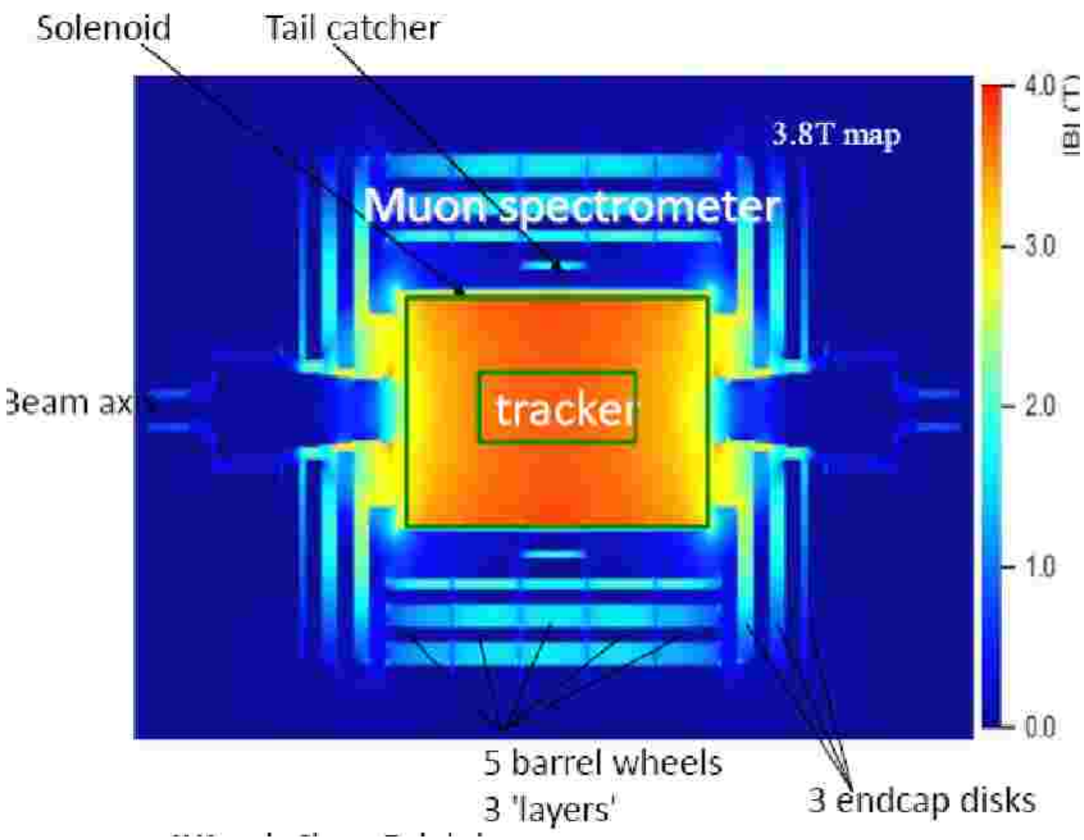
14

Magnetic field commissioning

- Magnetic Field mapped during Cosmics Run in the surface hall in 2006
- TOSCA model (finite element calculation)
- Many sensors

regions of interest:

1. Tracker
2. Muon Spectrometer



1) In the Tracker region TOSCA agrees with 2006 field at <0.1%. Probes confirm agreement.

Magnetic field commissioning

2) Muon spectrometer region complex

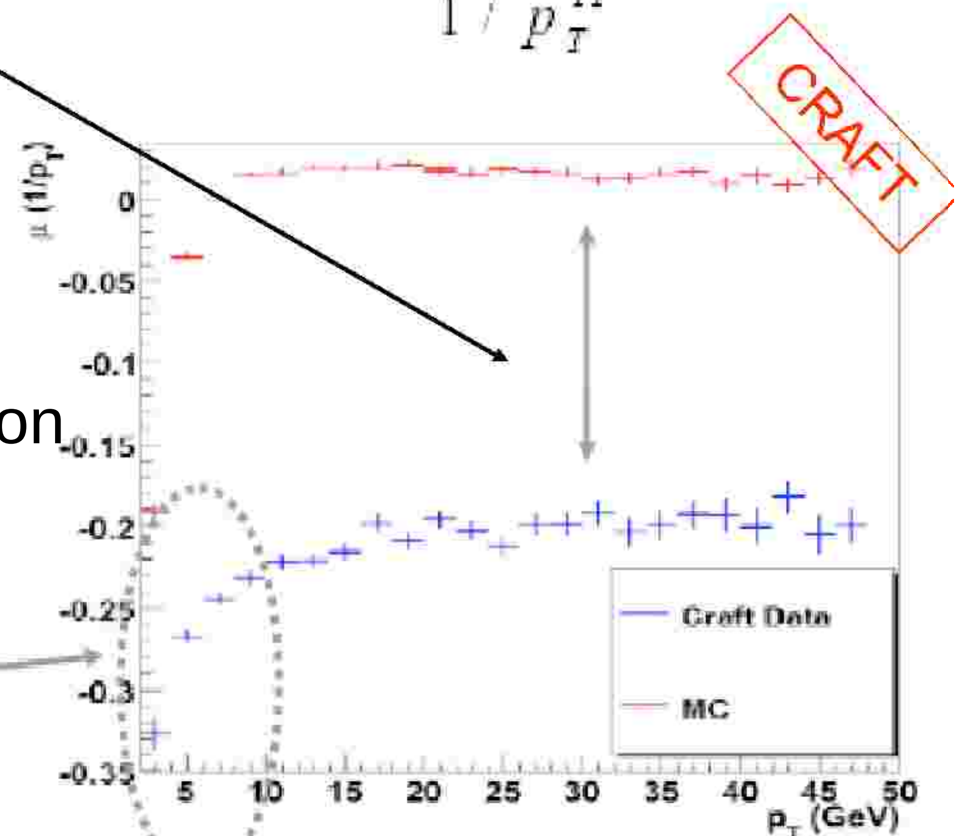
MUON p TRACKER p

$$R = \frac{1/p_T^{STA} - 1/p_T^{TT}}{1/p_T^{TT}}$$

- A disagreement of up to 20% was found in the outer layers.

- Problem solved extending the TOSCA radius in the calculation now corrected in the reconstruction software

Material effect

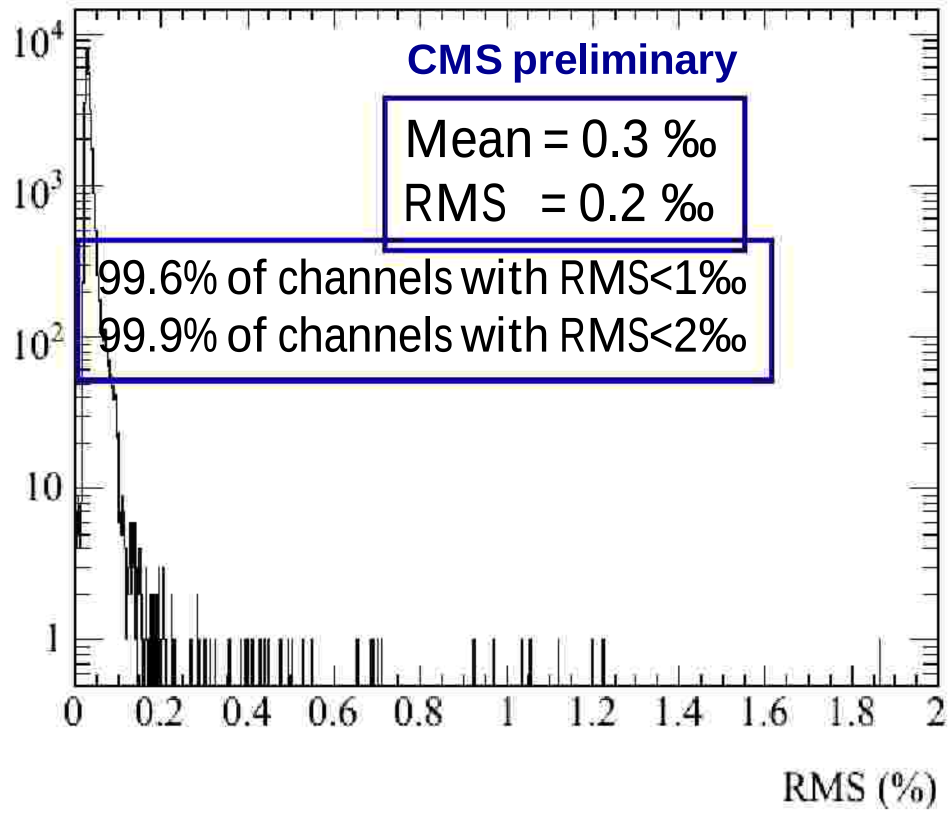


ECAL: stability

ECAL stability:
required Temperature, HV, LV stability achieved.

Under stable laser conditions, the ECAL LASER monitoring system is able to monitor the crystal response with a precision < 1‰
This precision is consistent with specifications (2‰)
needed to achieve the ECAL design resolution

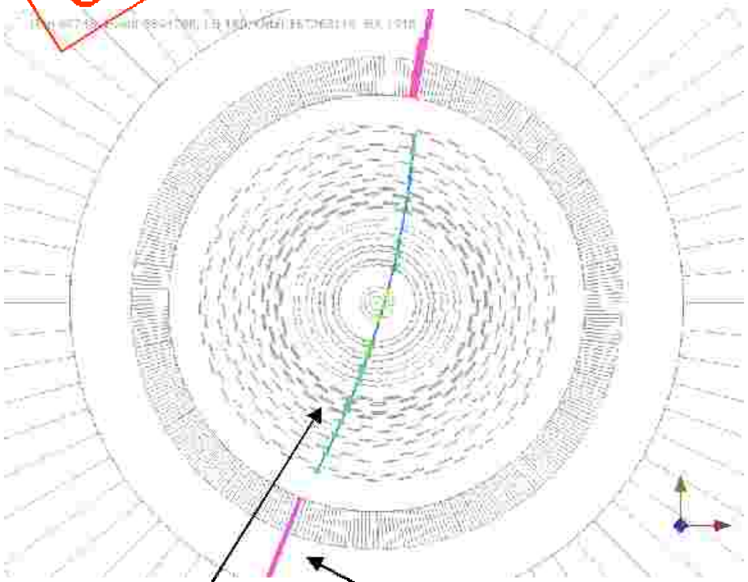
Stability of the crystal response to the Laser Calibration Signal

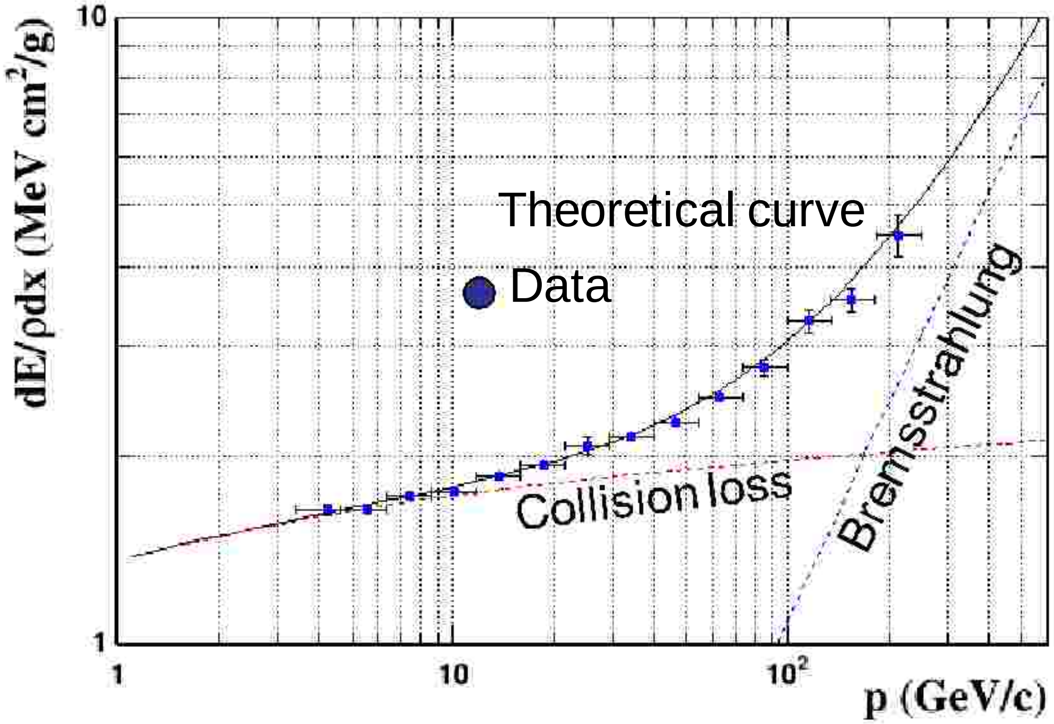


TALK 17

ECAL: stopping power

CRAFT





p measured in the tracker

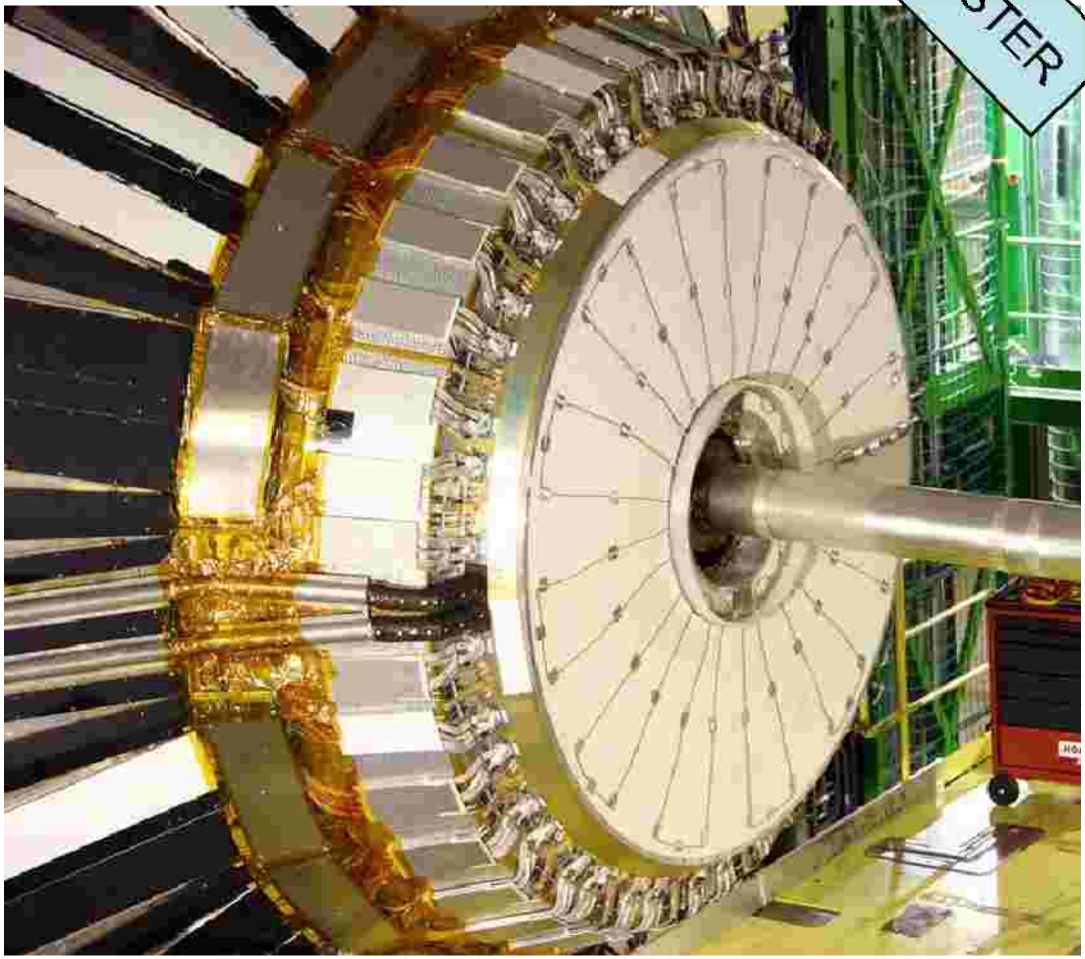
dE measured in the ECAL lower half

dE/?dx energy deposit matched to the track corrected for muon path length

Tracker momentum matches well with ECAL energy loss, ECAL energy scale is correct

ECAL preshower installed

POSTER

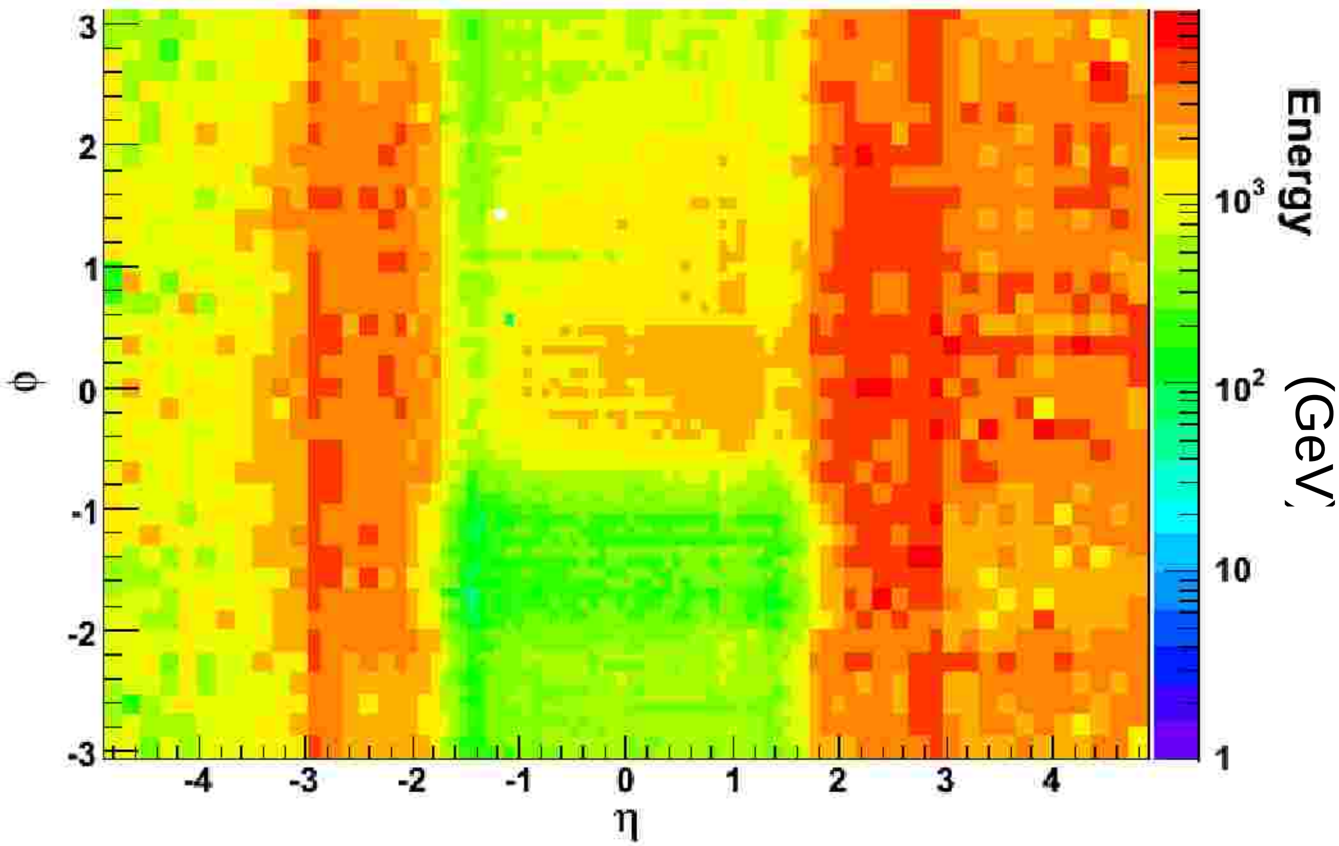


Last CMS detector to be installed. Preliminary commissioning show 99.9% functional.

Hadron Calorimeter

BEAM SPLASH

Average energy deposit during beam splash events in the HCAL



HCAL Barrel: Response to Muons

CRAFT

Event selection:

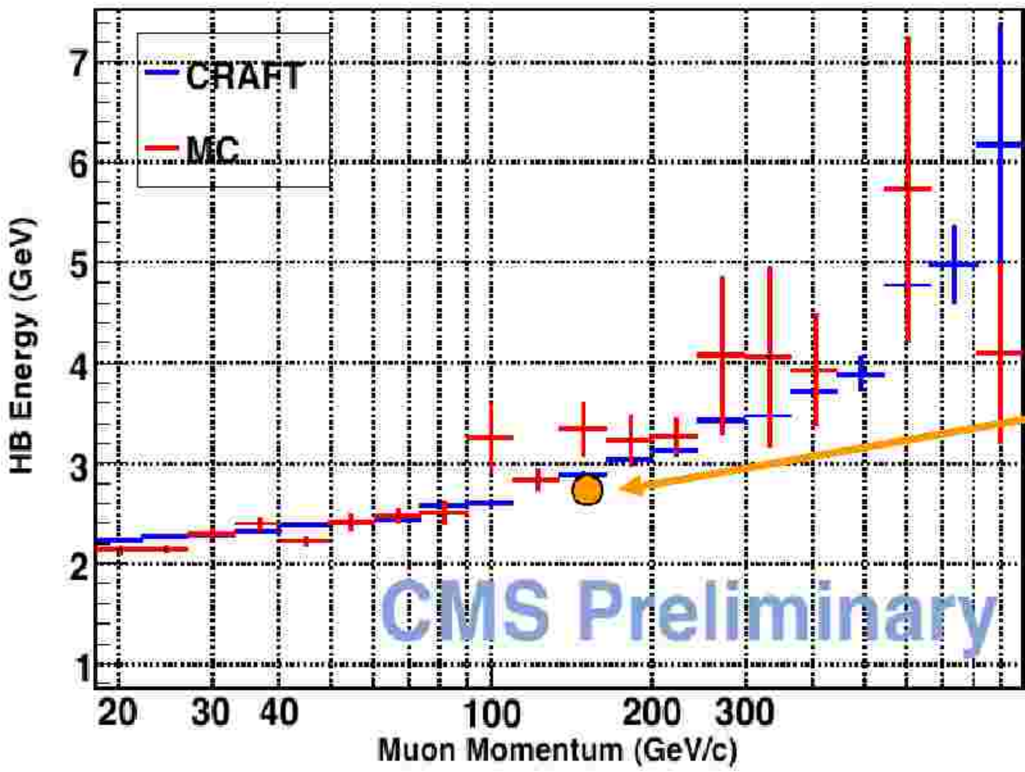
Muon track matching in DT and Tracker

20 GeV/c < P_{μ} < 1000 GeV/c

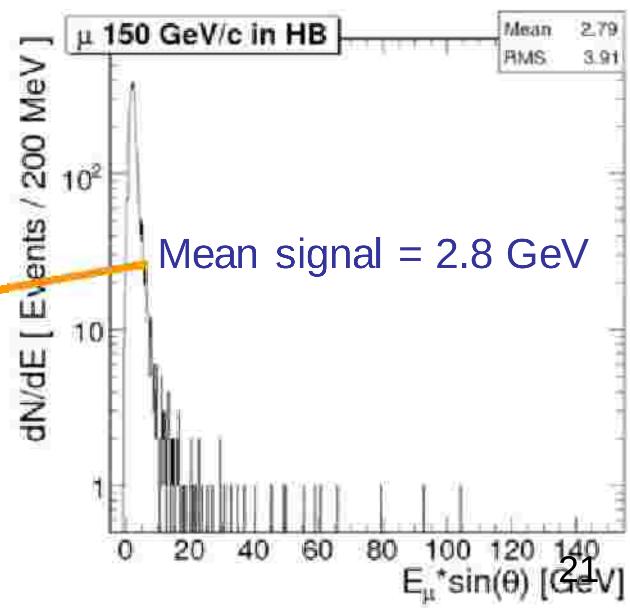
Cosmic muons data: 200 K events

MC: 15 K events

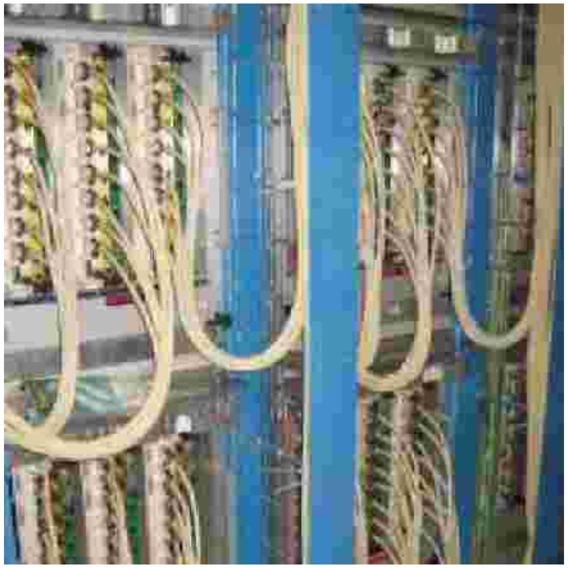
HCAL barrel energy:
signal corrected for muon path length in HCAL



HCAL Test Beam 2006
P_{μ} = 150 GeV/c



DAQ and Trigger system



DAQ

•All the detectors participated in cosmic global run. Cosmics data taking at 300 Hz.

•Detector calibration triggers mixed with data

•Stress tests are regularly done at 60 kHz

Trigger

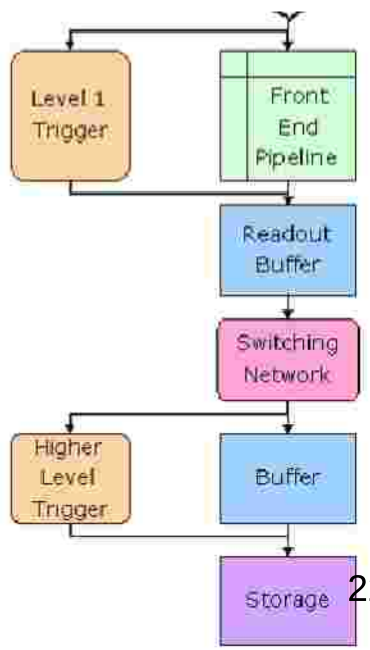
CMS Trigger system is organized in two levels: Level1 and High Level Trigger

- •During CRAFT data were read based on Level1 from Muons (DT, CSC, RPC) and Calorimeters.

•High Level Trigger

•Online startup filter farm successfully operated during CRAFT: 720 PCs, 7 instances of HLT process on each, 5000 processes in parallel

•Regular high frequency stress test



Data handling

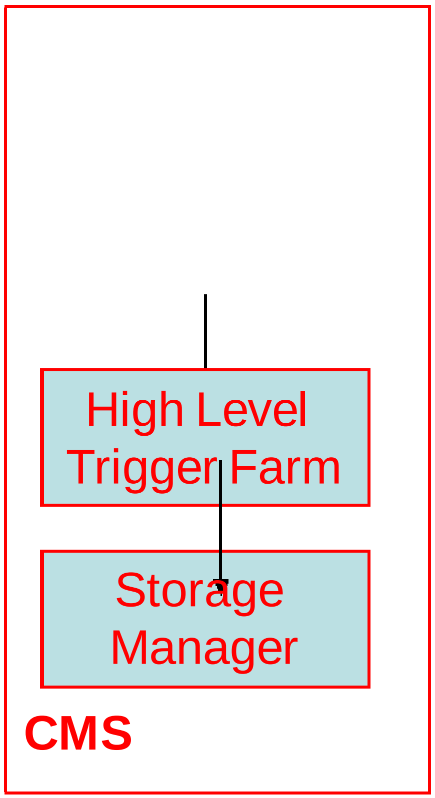
Data processing

•Most jobs and data made available for analysis after 6-8 hours.

Alignment & Calibrations

•Calibrations and alignment promptly produced and verified were inserted in the next data reconstruction.

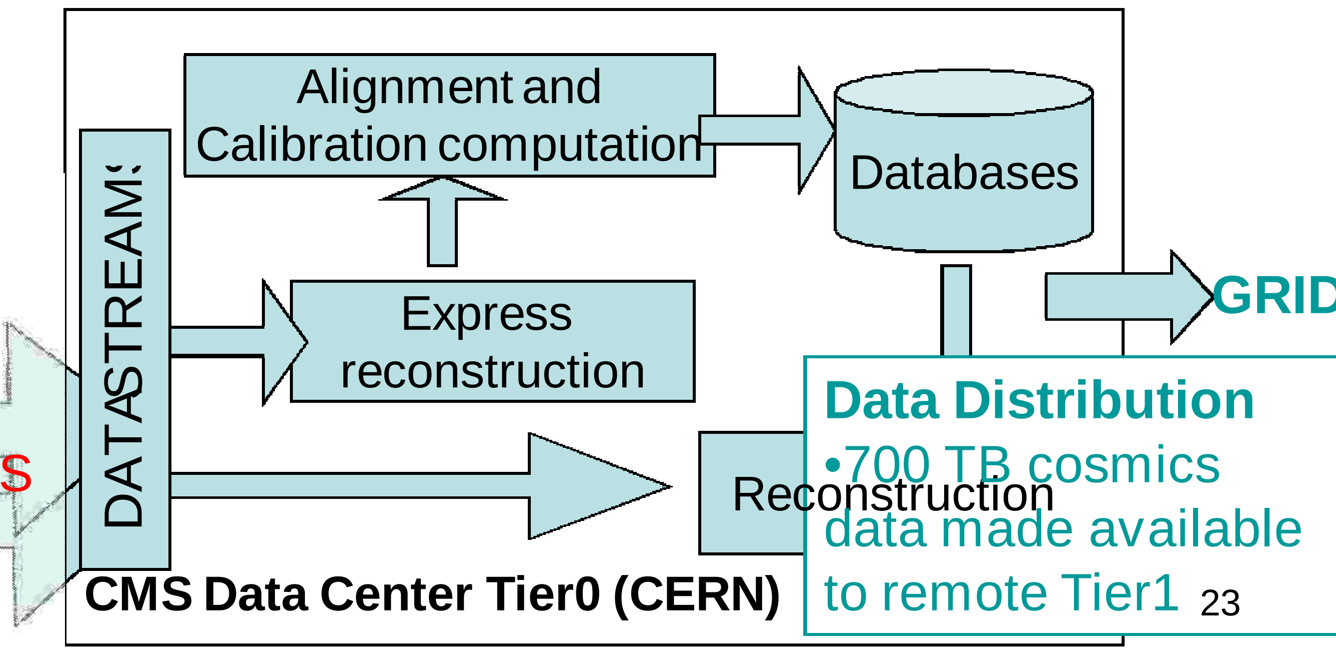
•2 re-reconstructions done



Data flow

Bandwidth to disk > 600 MB/sec.

Well established data workflow between CMS experimental site and CMS Tier0



Data Distribution

•700 TB cosmics data made available to remote Tier1

Conclusions

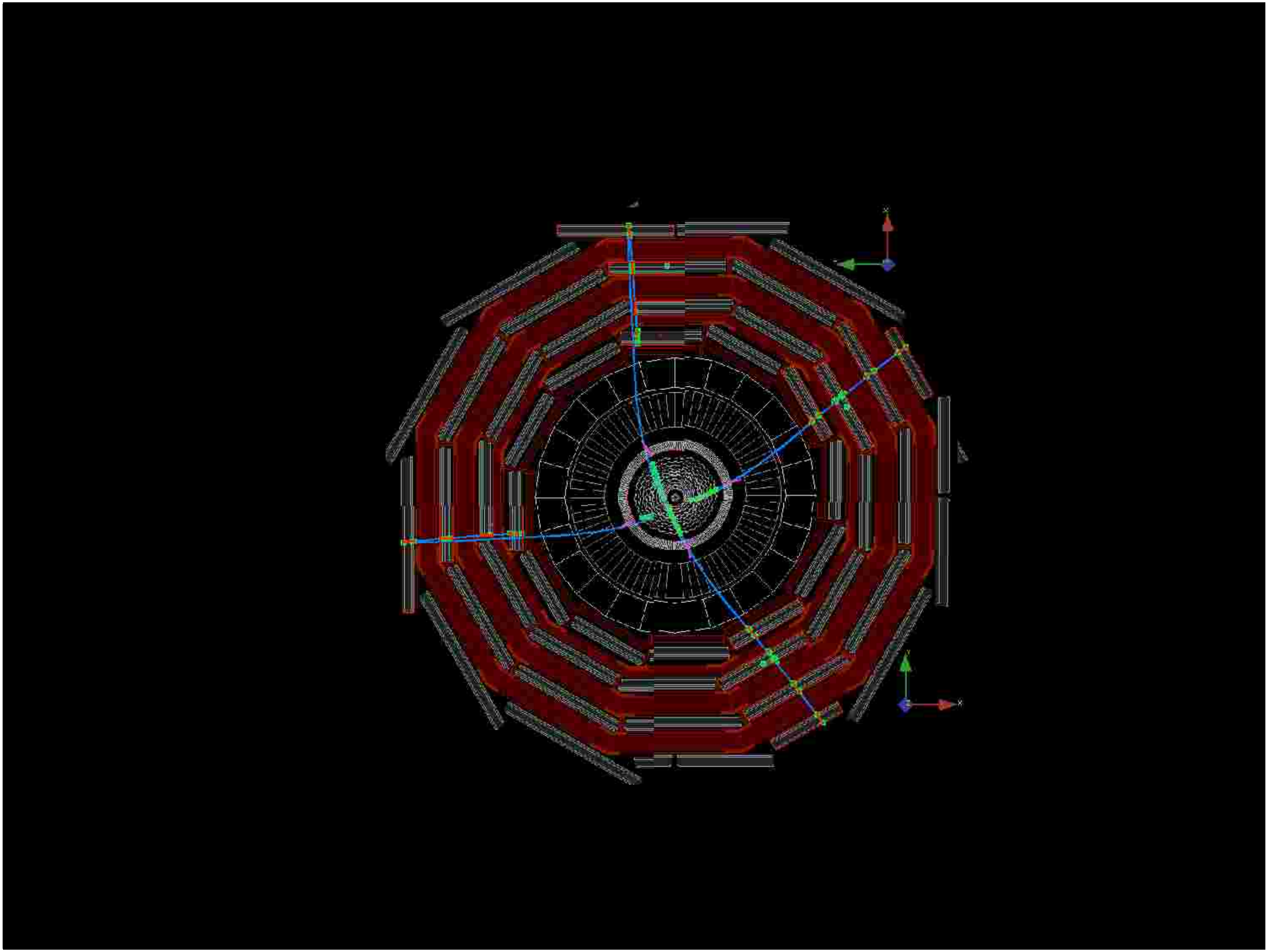
- The cosmics run at 4T was a very useful run to test the DAQ/trigger, online tools and data handling
- The data quality was so good that we could reach unexpected alignement accuracy
- Very useful data to spot problematic channels and repair
- Fundamental in the magnetic field understanding

- The CMS experiment has proved to be able to provide excellent data quality in realistic running conditions

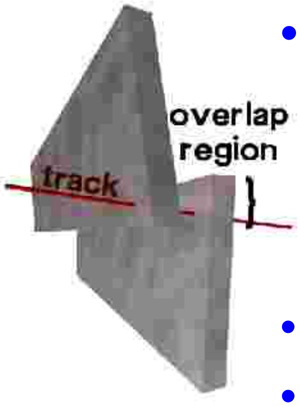
Preparation for beam

- few repairs and installations during shutdown
- recommissioning with global cosmics runs
- close experiment -> Cosmics run (july-august)
- collect cosmic muons to improve alignment/calibration and check reproducibility with respect to CMS opening/closing

•ready for beam

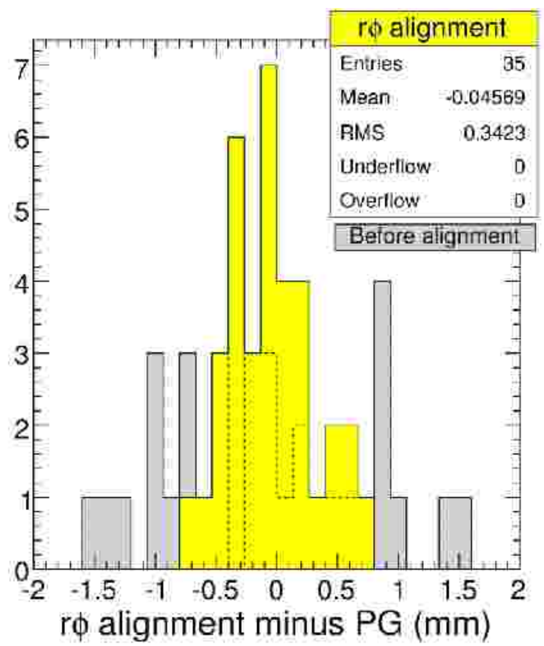


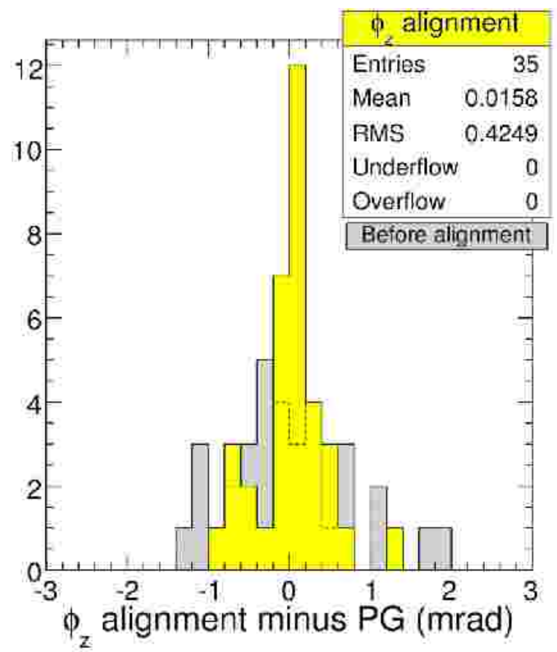
CSC Alignment with Beam-Halo Muons



- Select tracks that pass through overlap of two chambers
  - Determine relative position by requiring consistency between track segments
    - rf position
    - f_z : rotation in layer's plane
    - f_y : rotation around alignment pin axis
- Solve system for all chambers in a ring (must be consistent with a circle)
- Cross-check against Photogrammetry (210 µm rf , 0.23mrad f_z)

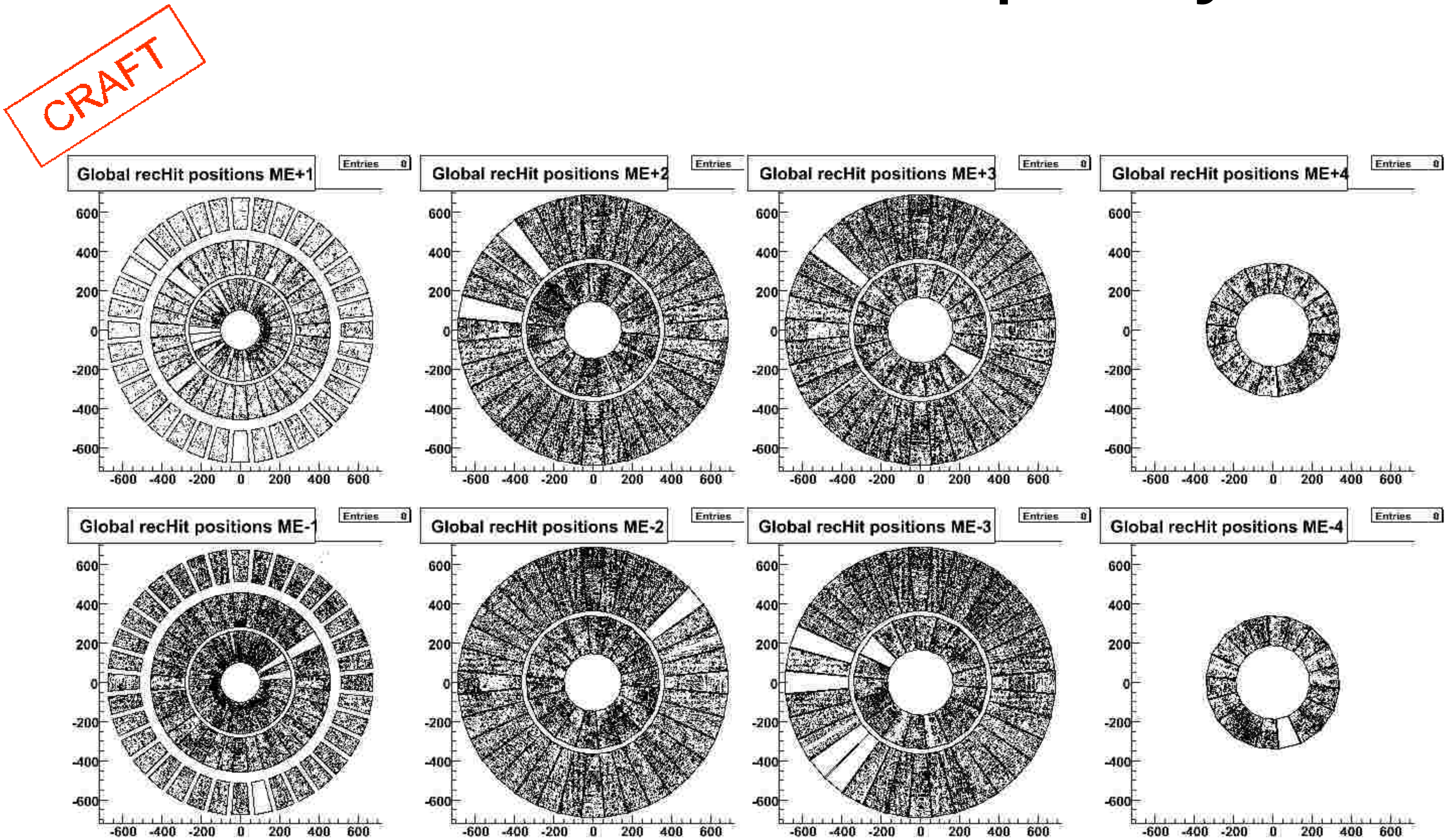
w.r.t





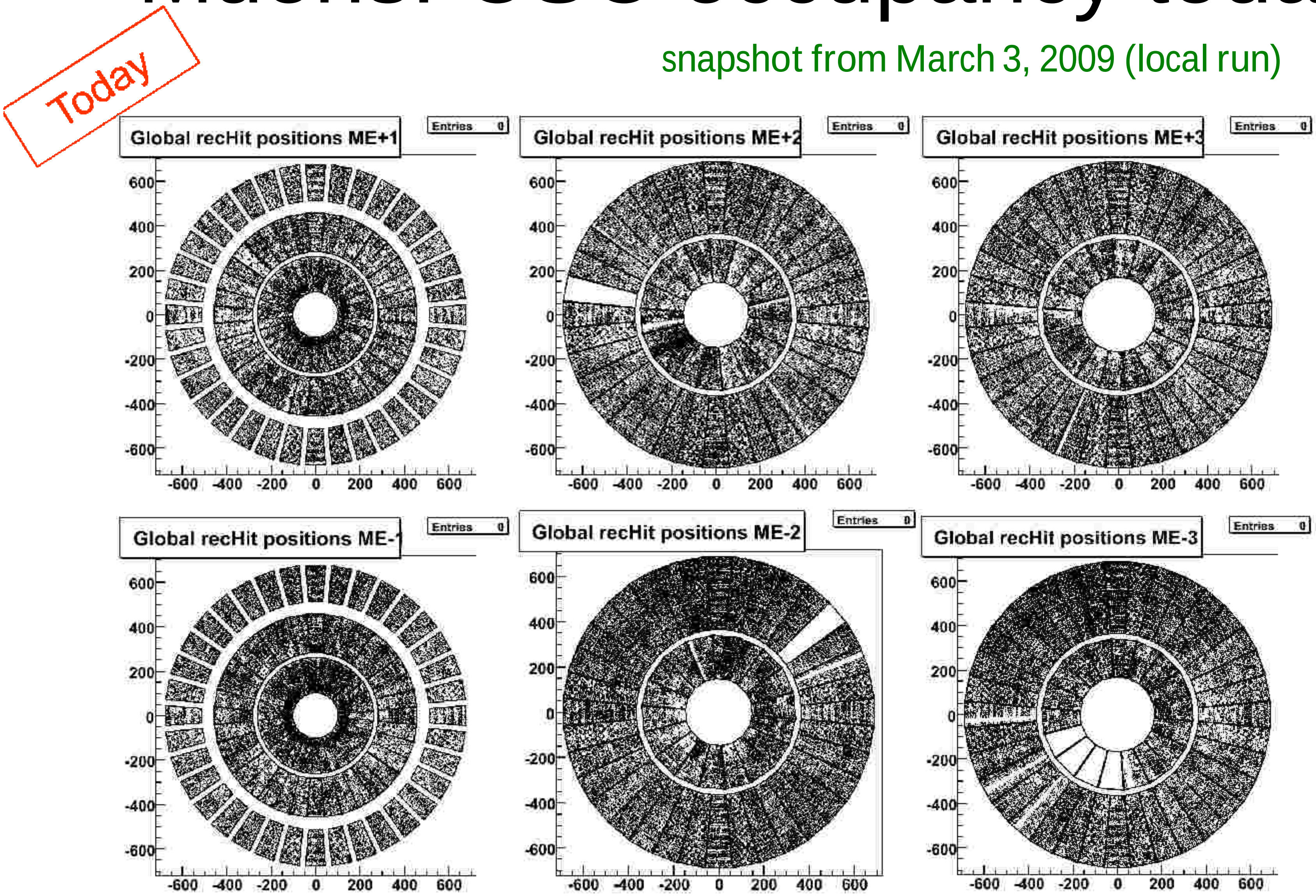
BEAM HALO

Muons: CSC occupancy

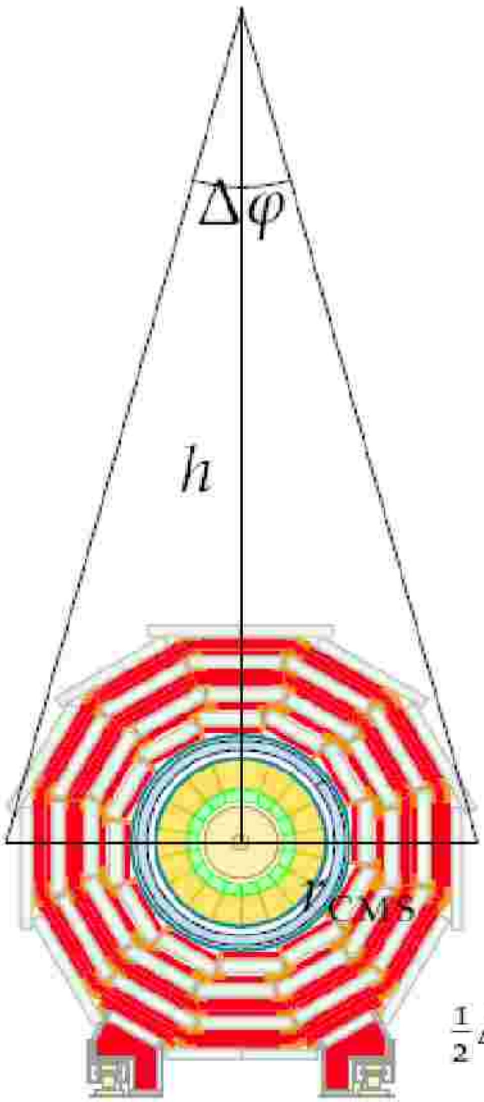


Muons: CSC occupancy today

snapshot from March 3, 2009 (local run)



Cosmic Shower Events

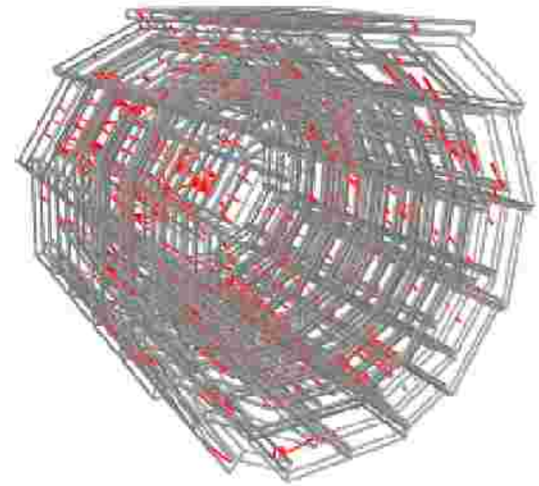


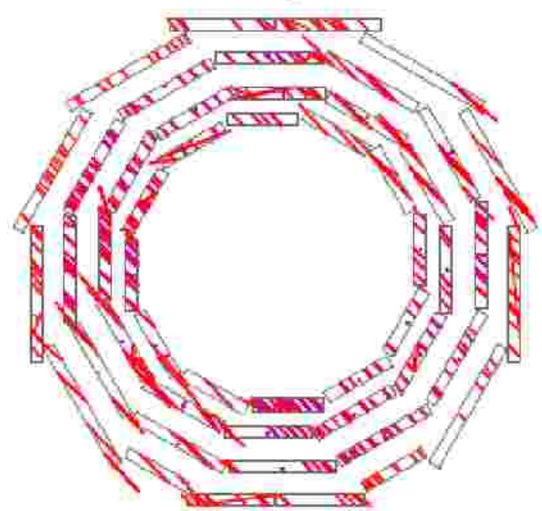
- 0.02% rate of events with >100 segments in ~10M cosmic events at 0T
- Event-by-event spread in phi compatible with multiple scattering ? all events compatible with ~parallel muon shower

$$\Delta\varphi \approx 0.01\pi$$
$$\Rightarrow \quad h \gtrsim 500\,\mathrm{m}$$

$$\tfrac{1}{2}\Delta\varphi \approx \tan\tfrac{1}{2}\Delta\varphi = \frac{r_{\text{CMS}}}{h}$$

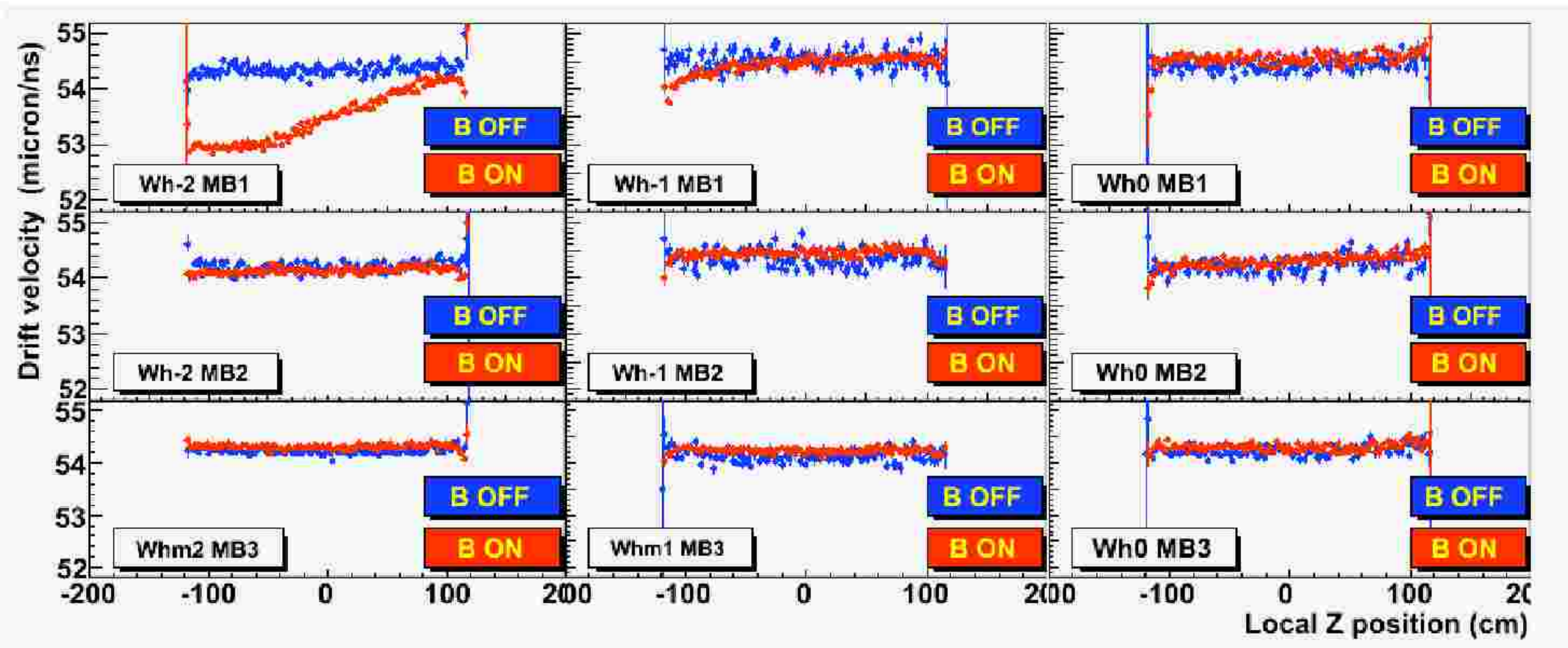
- Run 50908
- event 1057286
- 541 segments





Muon: Drift Tubes Drift Velocity

CRAFT

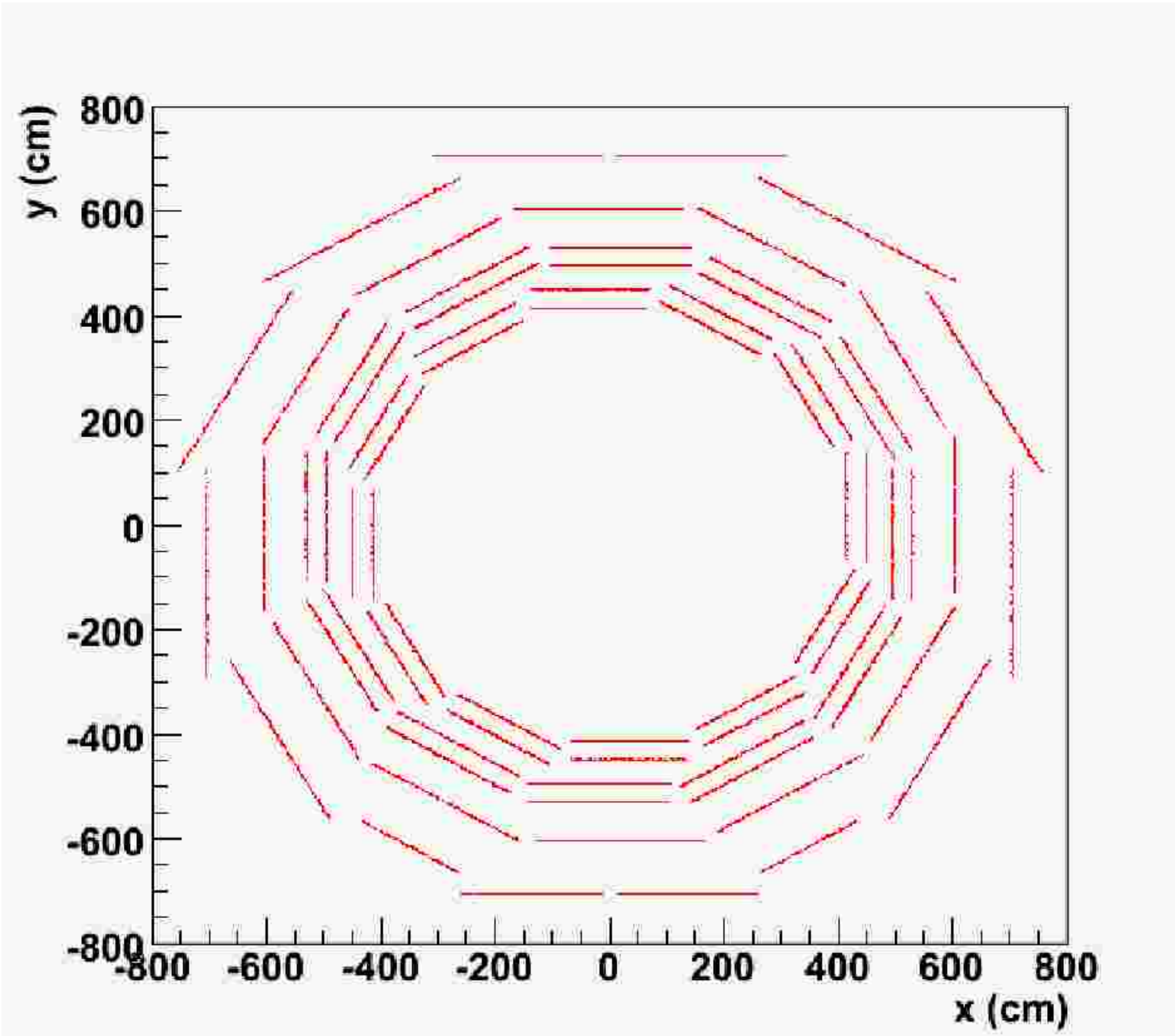


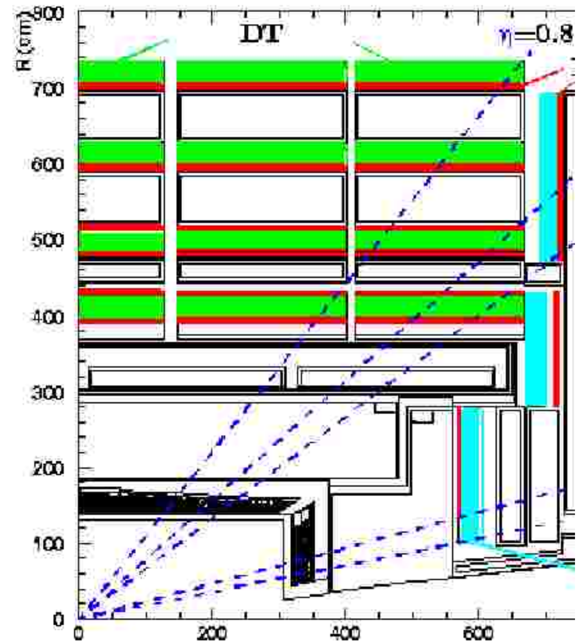
Innermost stations MB1 on wheels W-2/+2 have largest radial field. Maximum difference in drift velocity is 3%

31

Muon: RPC occupancy

CRAFT



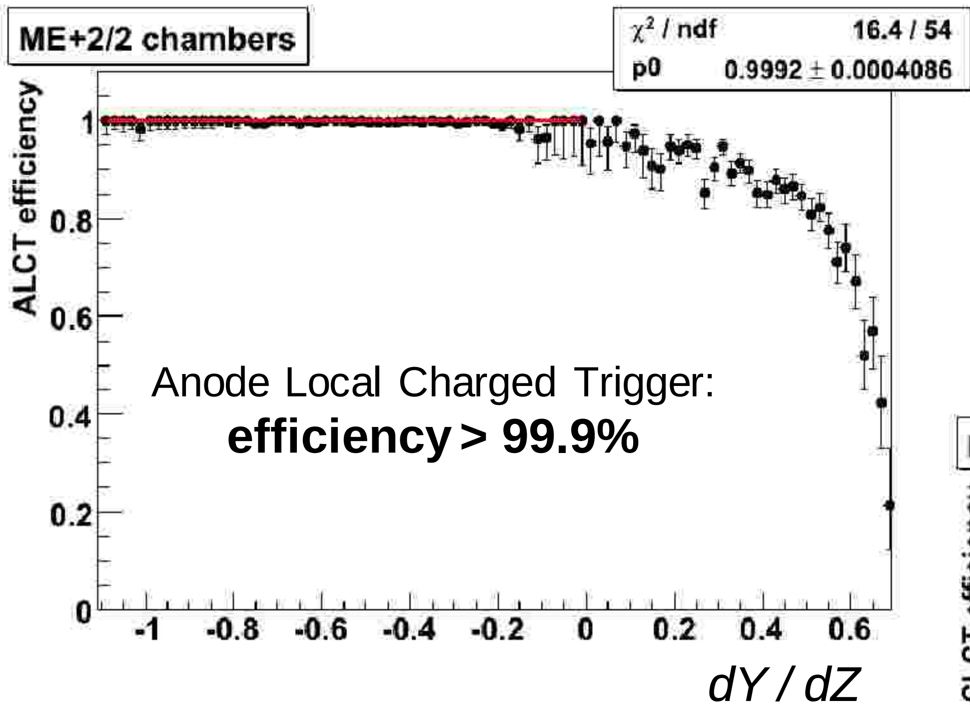


CSC efficiencies - background

- The CMS cathode strip chambers provide three-dimensional points in space called “rechits.”
- The readout of a chamber depends on the presence of a “local charged track” trigger – ALCT for anode wires and CLCT for cathode strips.
- Efficiencies are measured for a particular chamber by selecting cosmic ray muon tracks with trajectories similar to that of a muon coming from the interaction point.
- Quality requirements are placed on the track; and p > .
- The chamber to be “probed” must lie within the extent the track; the track is interpolated to that chamber, not extrapolated.
- Some chambers cannot be probed using cosmic rays.
- The track is propagated through the magnetic field and material.
- Fiducial requirements are placed on the interpolated point.

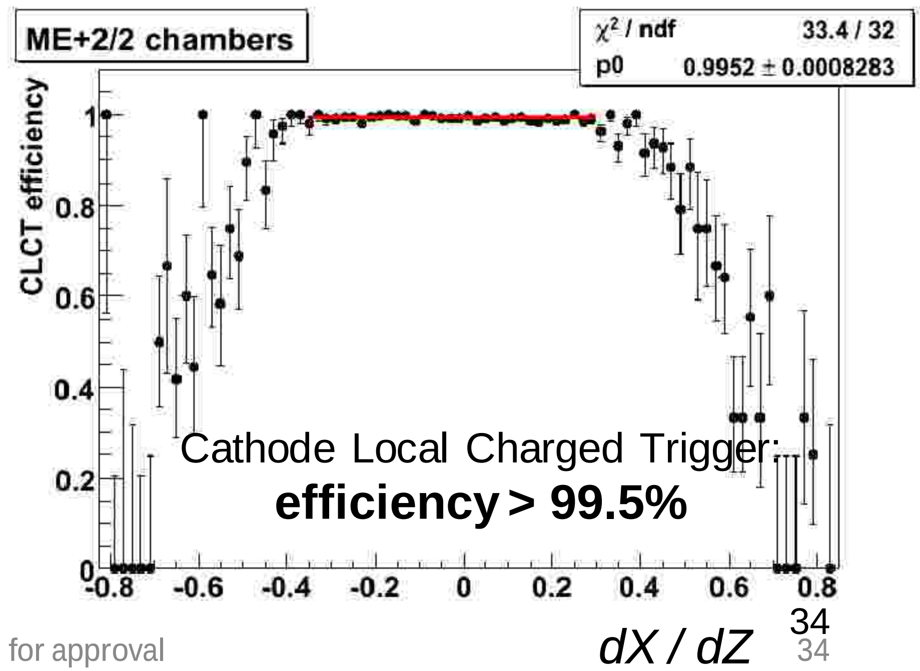
33

CSC local trigger efficiencies



These plots are made from all good chambers in ME+2/2.

"Local dY/dZ" determines the angle in the r-Z view, and "local dX/dZ" determines the angle with respect to a plan in r-Z (i.e., a fixed-   plane).

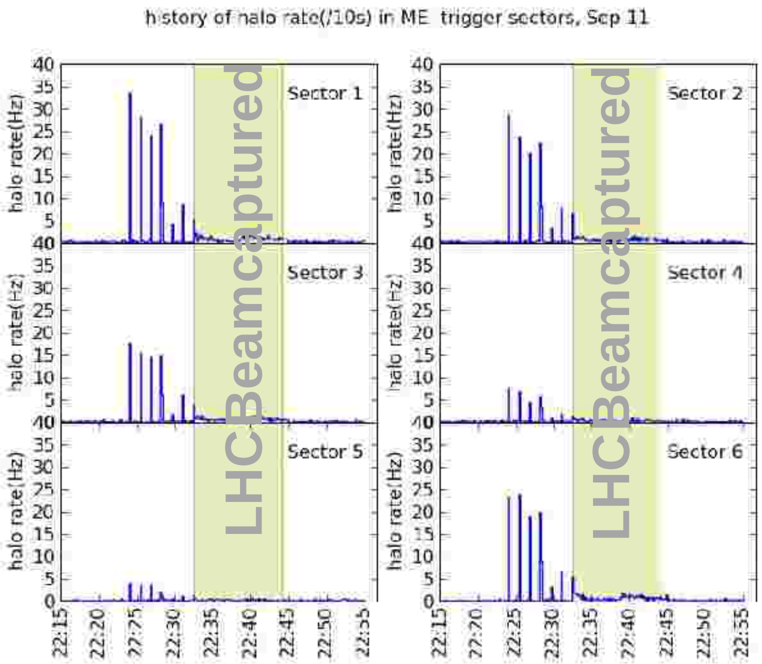


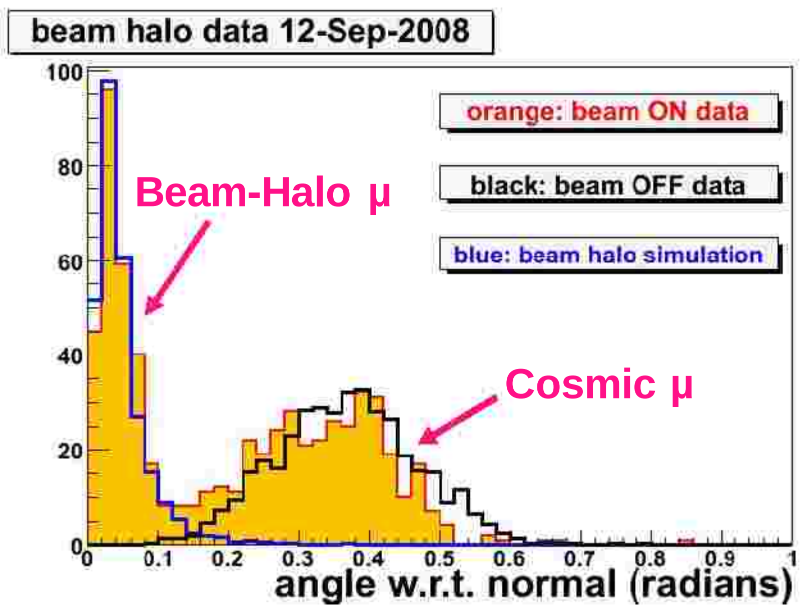
A cut |dX/dZ| < 0.2 is made when measuring ALCT efficiency, and a cut dY/dZ < -0.1 is made when measuring CLCT efficiency.

34

Muon: CSC rate in beam halo

- Halo Trigger Rate in YE- vs time
  - rate jumps preceding capture due to earlier capture attempts



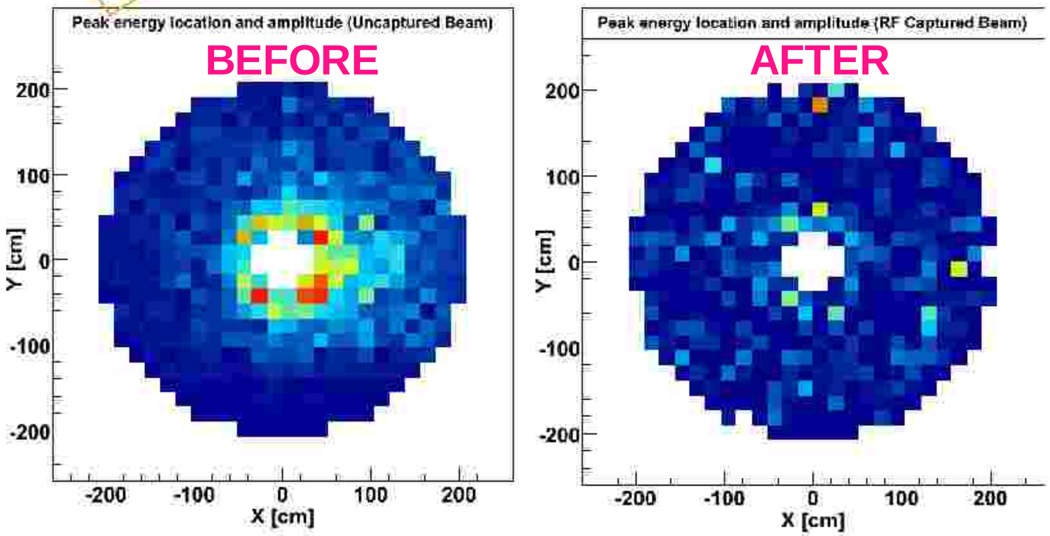


- Angles of reconstructed muon tracks w.r.t. plane perpendicular to beam
  - Arbitrary normalization of blue and black histograms (meant to guide the eye)

HCAL: HF in beam halo

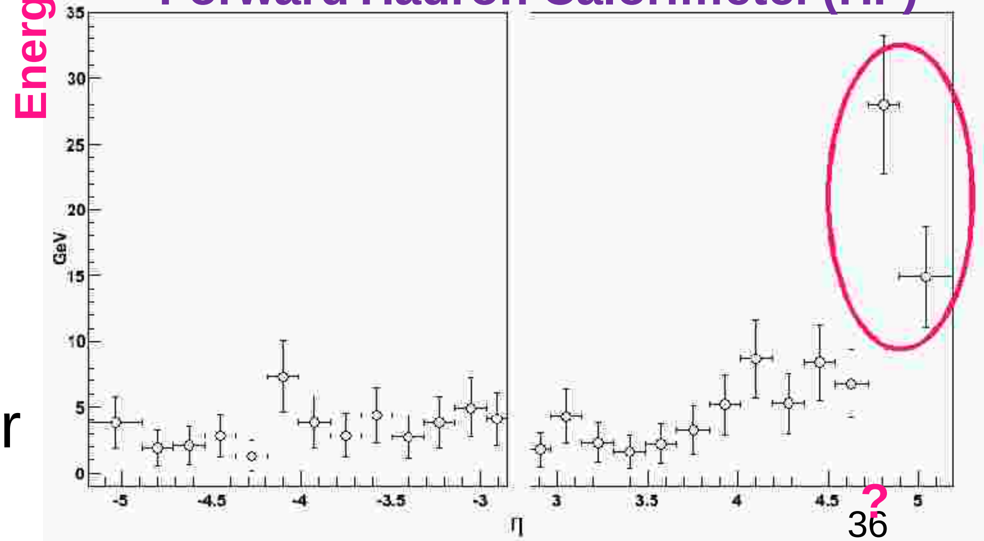
BEAM HALO

Endcap Hadron Calorimeter (HE)



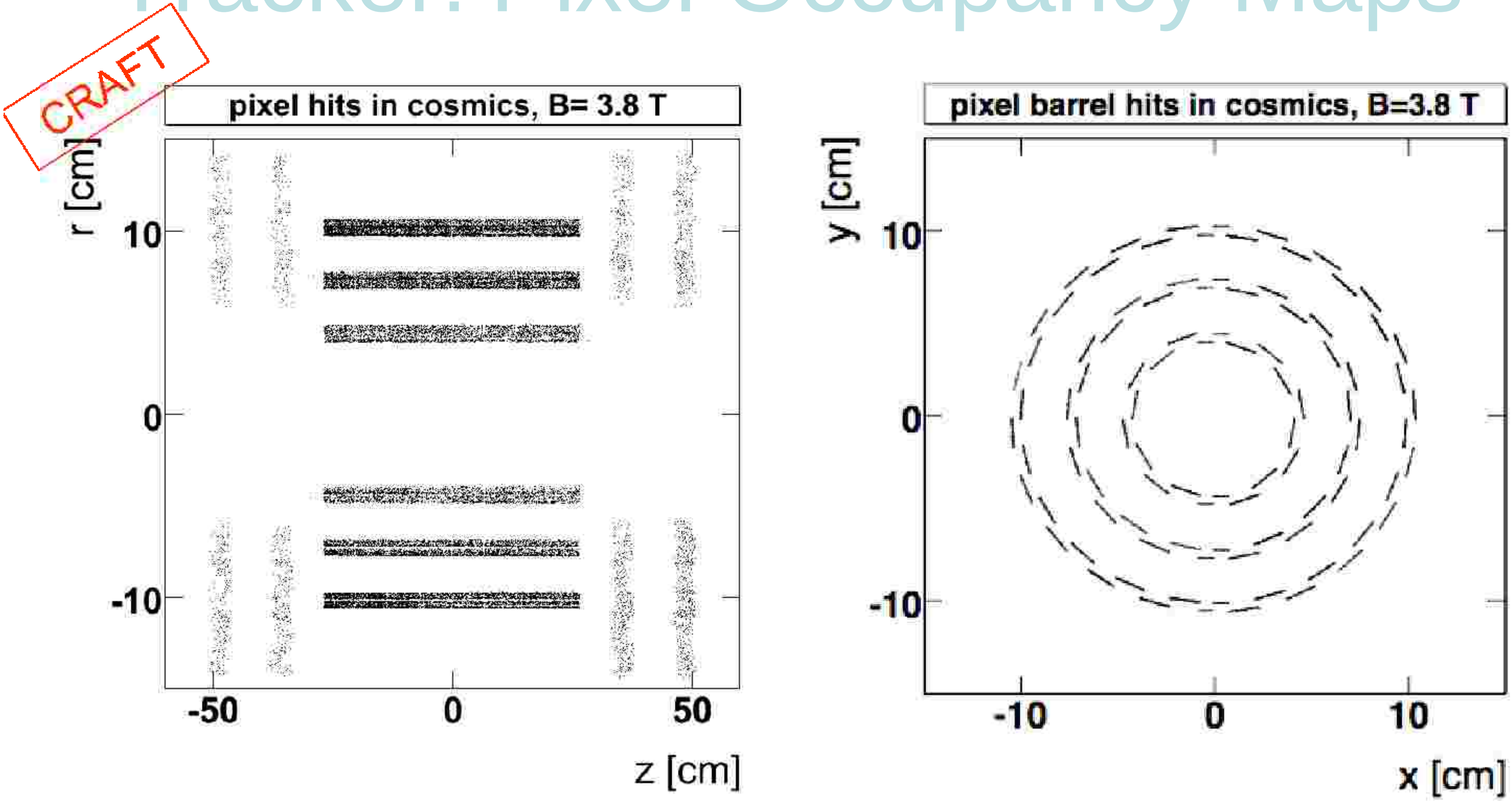
- HCAL Endcap Energy
  - BEFORE the RF capture, energy deposits due to not-focalized beam
  - AFTER the RF capture, the beam is quite clean

Forward Hadron Calorimeter (HF)



- Events triggered by the HF from LHC Beam 2
- Peak in energy deposition towards positive pseudorapidity is a signature of beam-gas interactions near or within the detector

Tracker: Pixel Occupancy Maps



- All detector parts included in the run

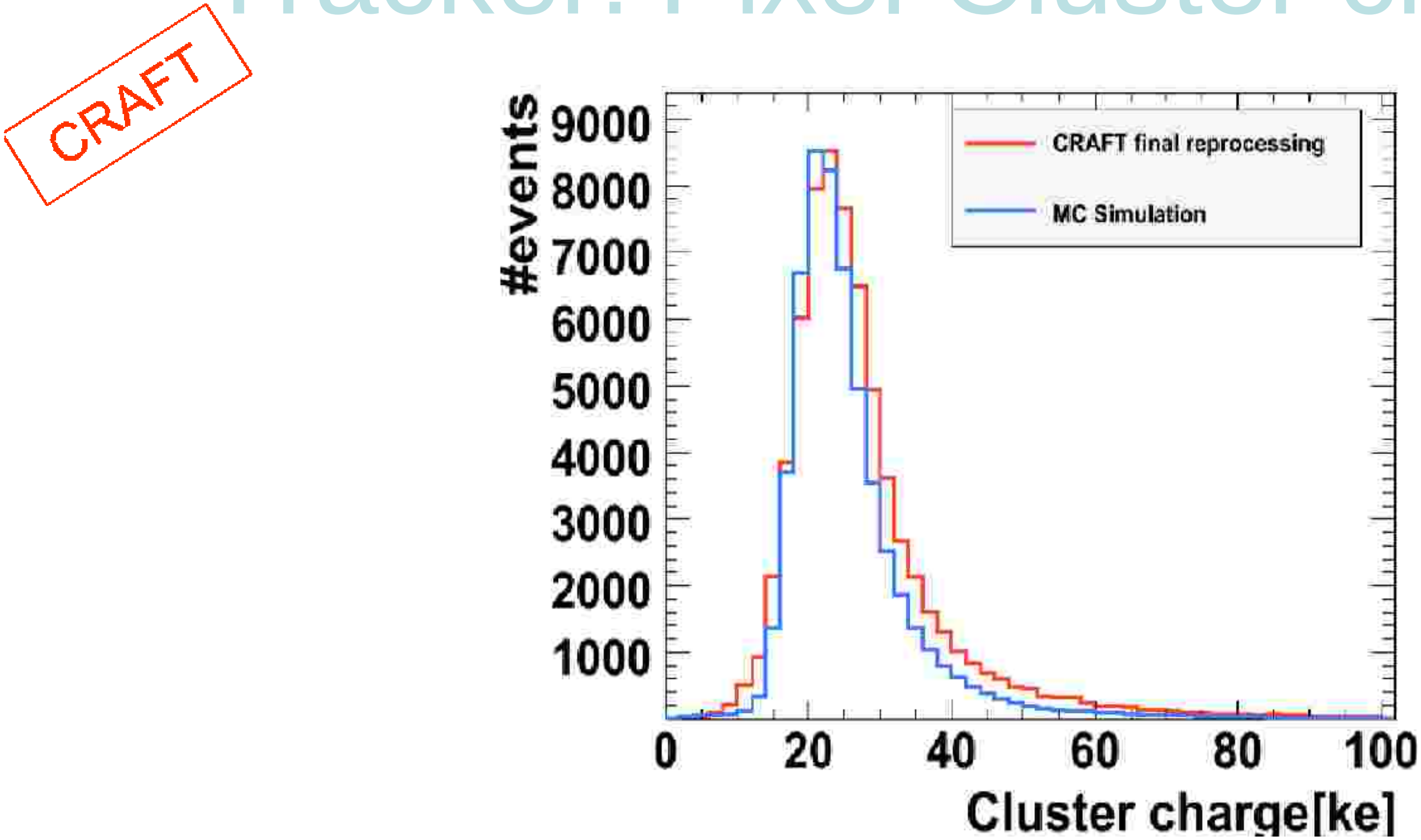
Strip Tracker: Hit resolution

CRAFT

- Strip hit resolution in TIB and TOB (after alignment) :
  - From comparison of measured and predicted differences of hit positions in region of overlap of two modules in a same detector layer
  - Resolution per layer is the mean over modules

Resolution (µm) vs track angle	0C-10C	10C-20C	20C-30C	> 30C
TIB12	24.3I 0.6	20.2I 0.6	24.6I 0.7	36.4I 0.8
TIB34	39.2I 0.6	26.2I 0.6	22.8I 0.6	34.1I 0.7
TOB14	56.0I 0.5	39.6I 0.4	35.1I 0.4	46.4I 0.5
TOB56	32.8I 0.5	27.5I 0.4	29.6I 0.5	41.5I 1.8

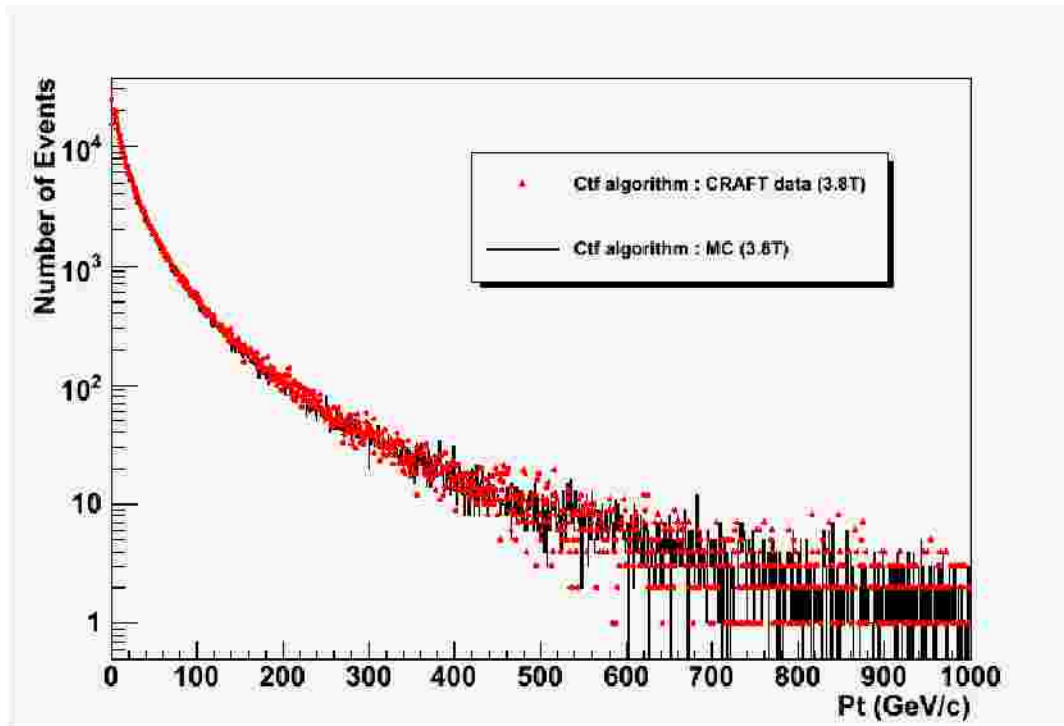
Tracker: Pixel Cluster charge



Total cluster charge is corrected for track impact angle w.r.t. the sensor
Clusters are associated to track and include more than one pixel
Data are calibrated at pixels level while MC includes ideal gain calibration w/o charge smearing

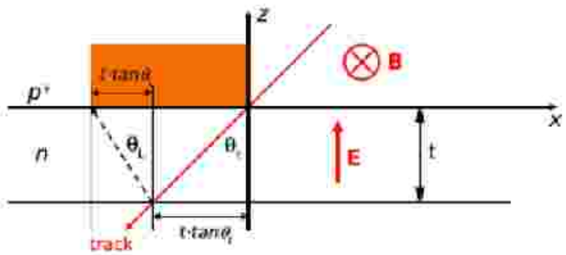
Tracker: Cosmic Tracks Momentum measurement

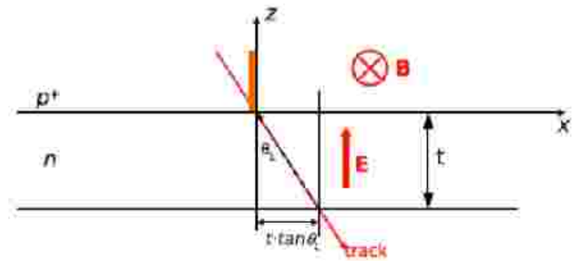
- Momentum distribution for high quality tracks after alignment
  - 8 hits
  - 1 hit in TIB L1/L2
  - 1 hit in TOB L5/L6
  - CRAFT data (red)
  - Monte Carlo simulation (black)

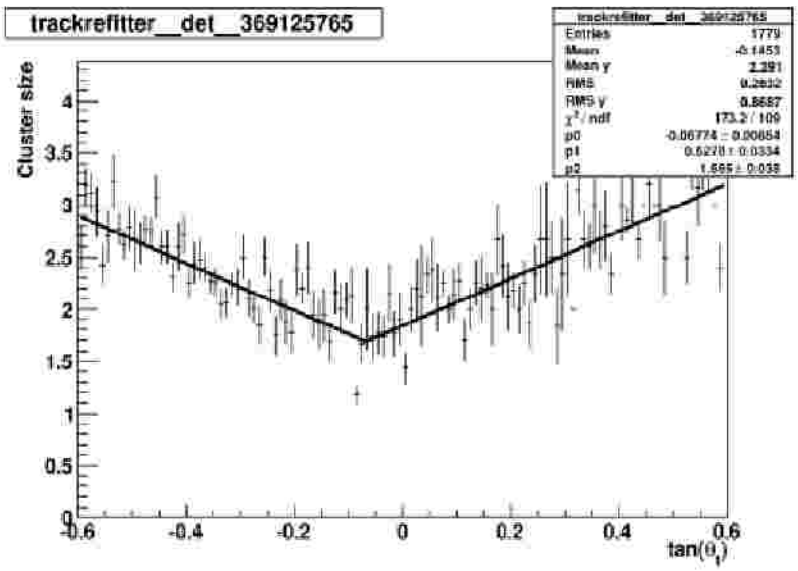


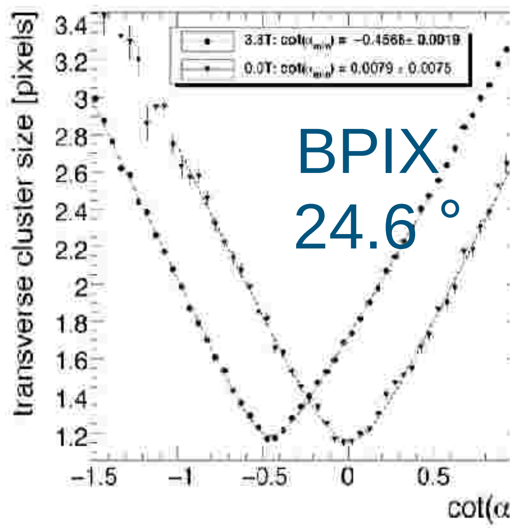
Tracker: Lorentz Angle Measurement

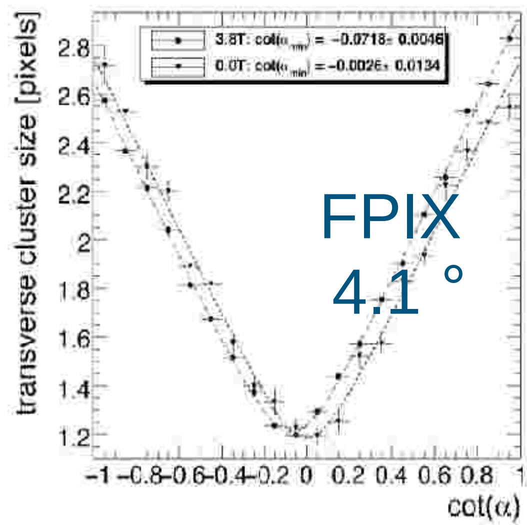
CRAFT











Charge carriers are affected by the Lorentz force in the 3.8T field
To determine the value of the Lorentz Angle, the spread of the drifting charge distribution is measured as a function of the track incidence angle.
The minimum corresponds to the Lorentz Angle.
Measured values will be used for future MC production.

Some consequences if LHC vs=10TeV

- Higgs search (WW* and ZZ* combined)
  - s $_{Bkgd}$ decreases less than s $_{Higgs}$
  - loss of a factor of a factor 2 in luminosity
  - with roughly ~200 pb^{-1}, reach sensitivity for a SM Higgs with m_H~160-170 GeV *(comparable to the current Tevatron sensitivity)*
- Discovery potential for new resonances (Z',W',...)

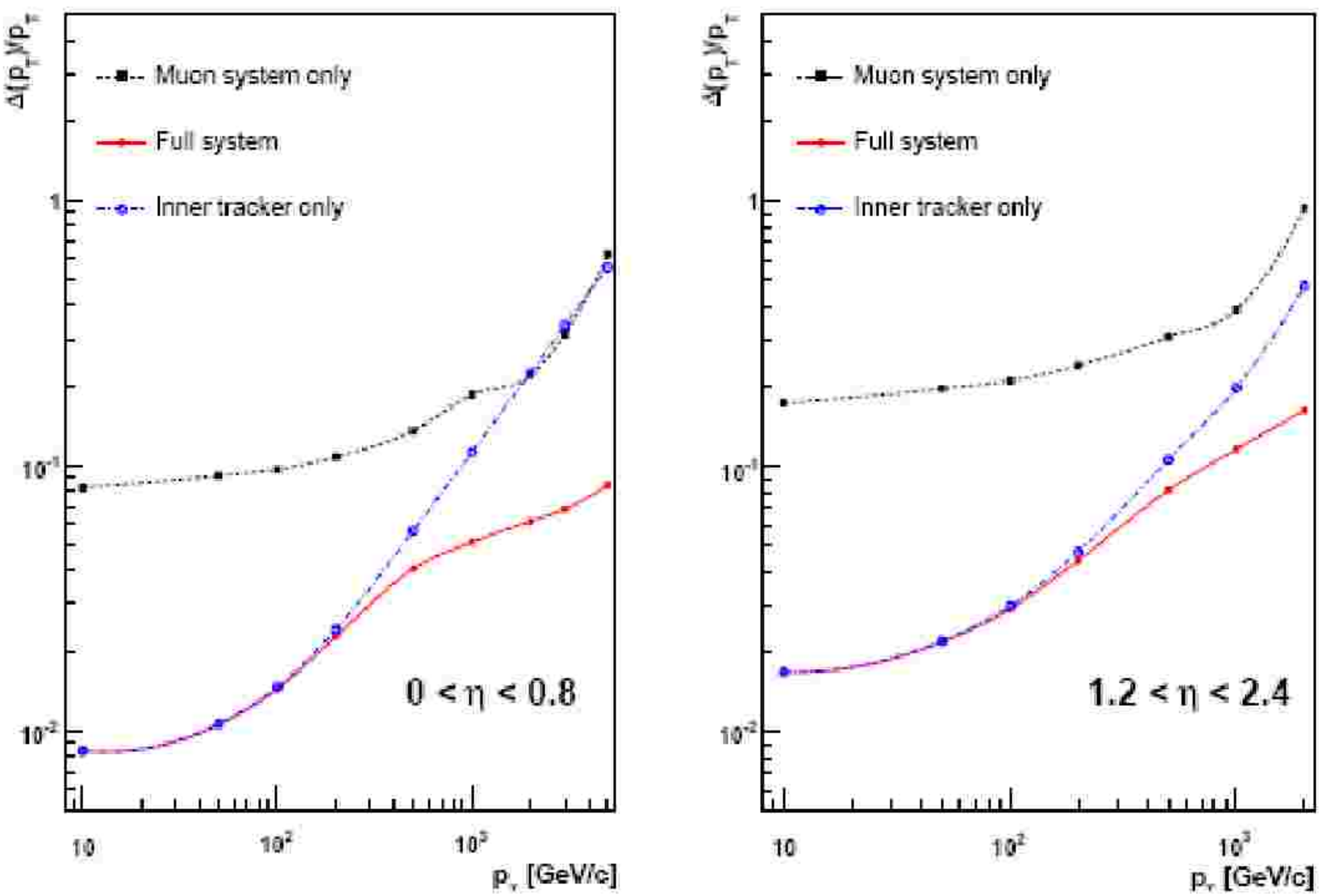
$M_{Z'}$ (TeV)	**(14 TeV) / 10TeV)**
1	2
2	3

- 100 pb^{-1}: good chances to discover Z' bosons at

  $M_{Z'}$ = 1 TeV

Integrated luminosity needed to reach 5s significance

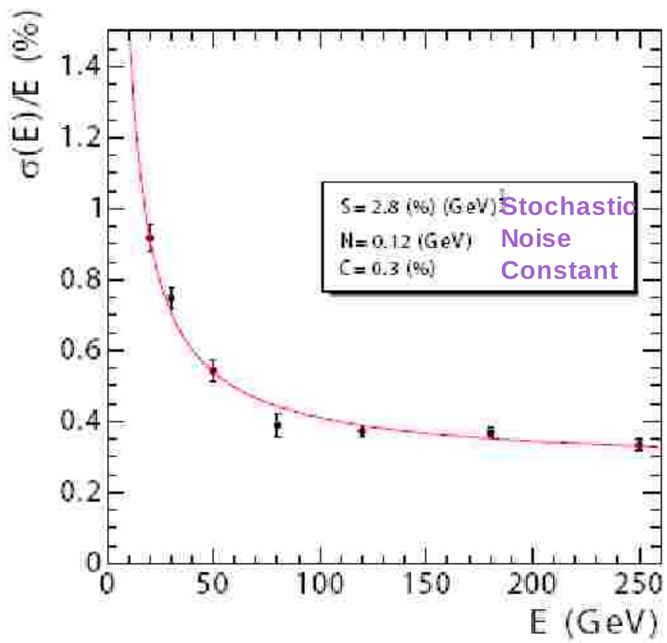
Momentum Resolution



Muon System contribution becomes important for µ with $p_T > 200$GeV

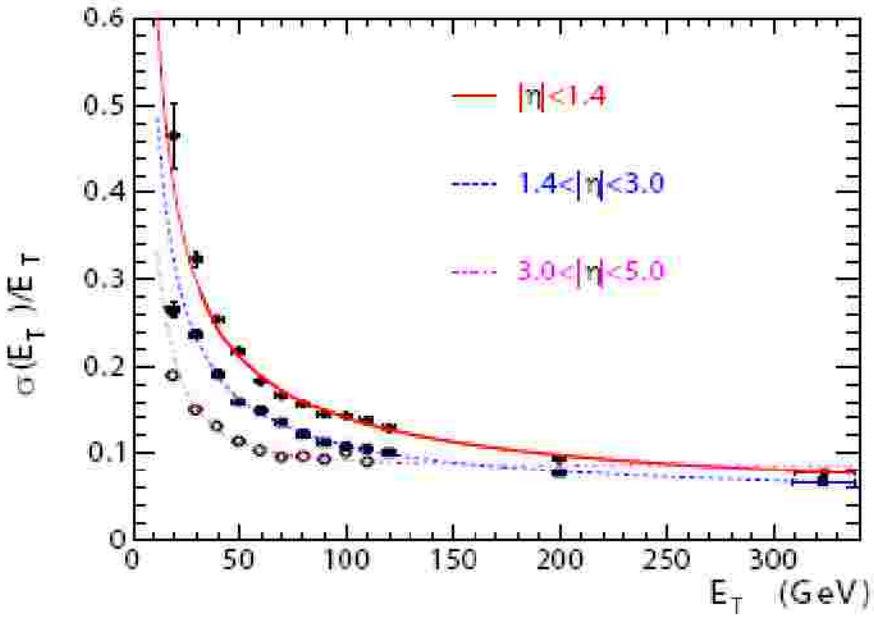
Energy Resolutions

ECAL Energy Resolution



Test Beam Result

Jet E_T Resolution



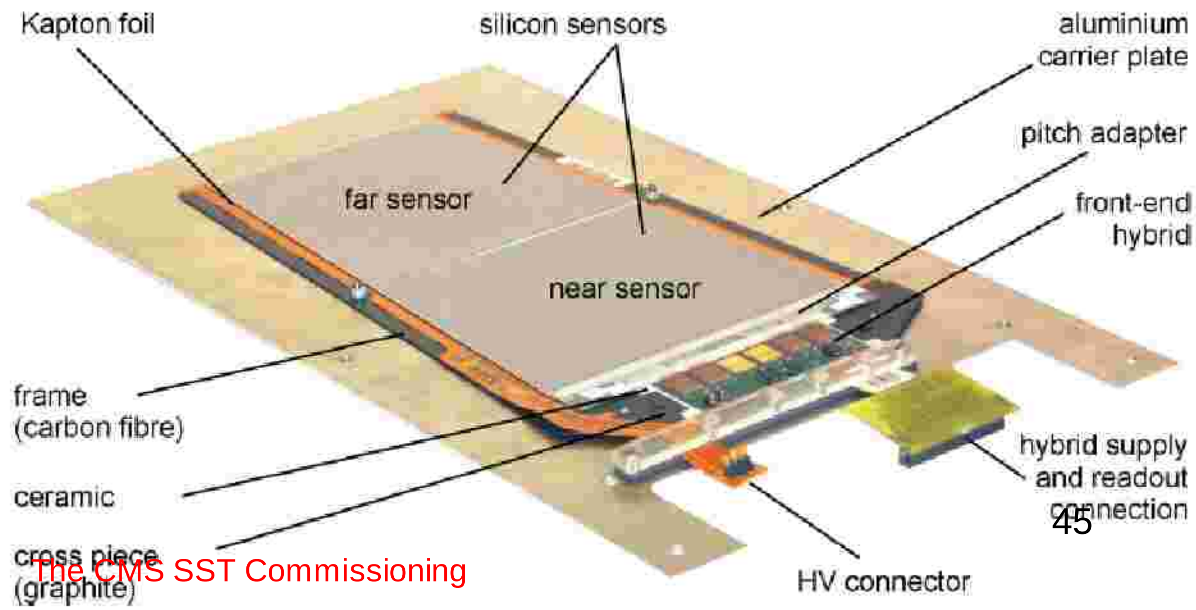
Jets reconstructed with cone algorithm (R=0.5)

SST: modules

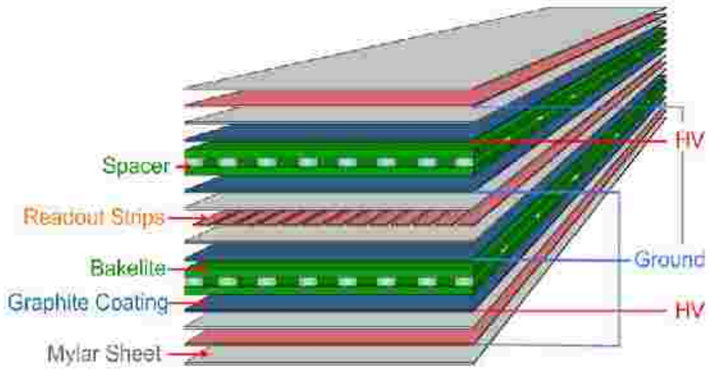
Modules are based on single-sided p+ strip on n-bulk devices

- 15,148 detector modules
  - 24,244 silicon micro-strip sensors (tolerant to a maximum fluence of 2.4 10^{14} 1-MeV-equivalent neutron per cm^2)
    - 15 different sensor geometries and two different thickness (320 and 500 m)
    - Double-Sided modules are made of two module of the same type glued back to back (one of them been tilted, stereo module)
- Readout electronics
  - 72,784 APV25 chips (tolerant to a maximum dose of ~ 70 kGy)

Modules have robust design and uniform mounting scheme



RPC



Ø Double gaps 2 mm width

Ø Bakelite bulk resistivity = 2-5 x 10^{10} Ωcm

Ø Gas mixture: 96.2% $C_2H_2F_4$+3.5%isoC_4H_{10}+0.3 SF_6

Ø Operated in avalanche mode

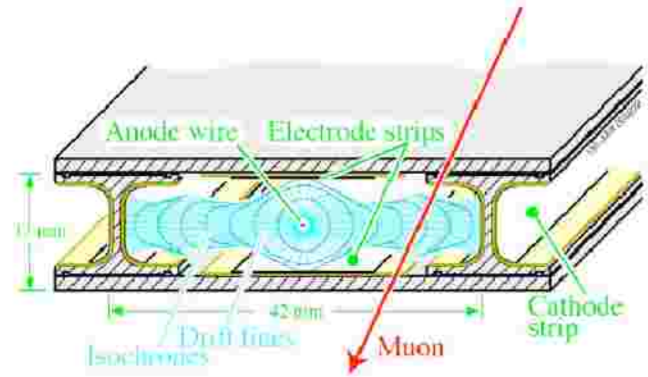
Forward Station

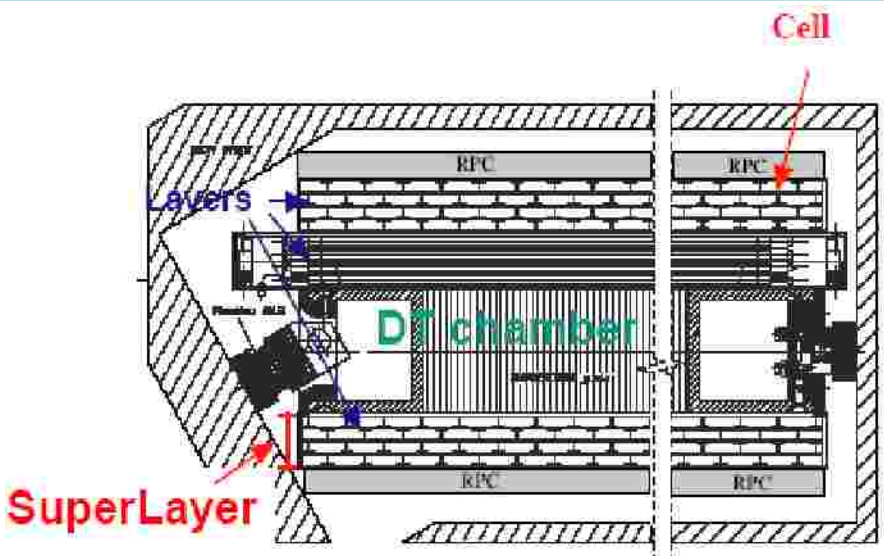
Barrel Station

- 912 stations
- 4632 sheets of bakelite
- total surface 3500 m^2
- 150.000 electronic channels

DT

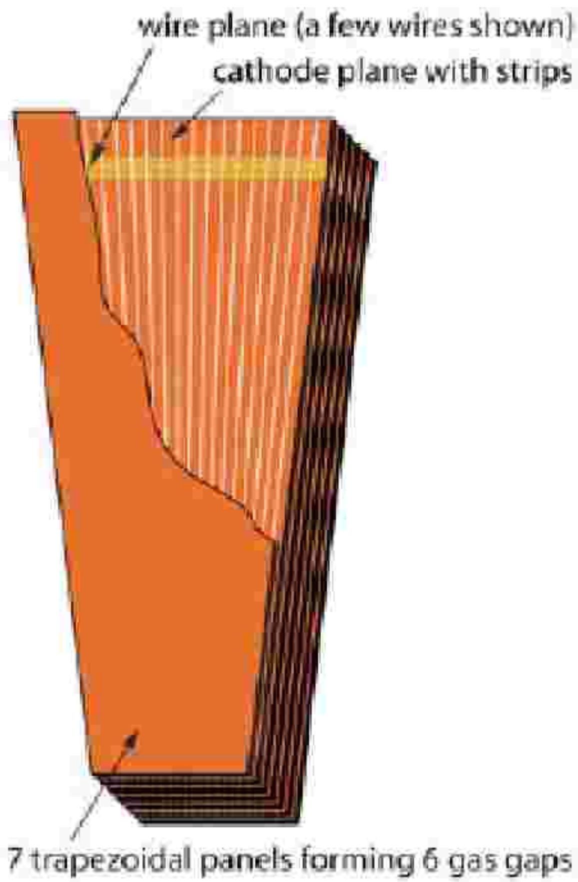
- a total of 172 000 DT cells
- gas mixture : 85% Ar + 15% CO_2
- hit position coming from the linear relation between the drift velocity (54.3 µm/ns) and the time of arrival on the anode wire
- hit resolution in rf : 200 to 250 µm
- segments reconstr.per superlayer , up to 4 hits

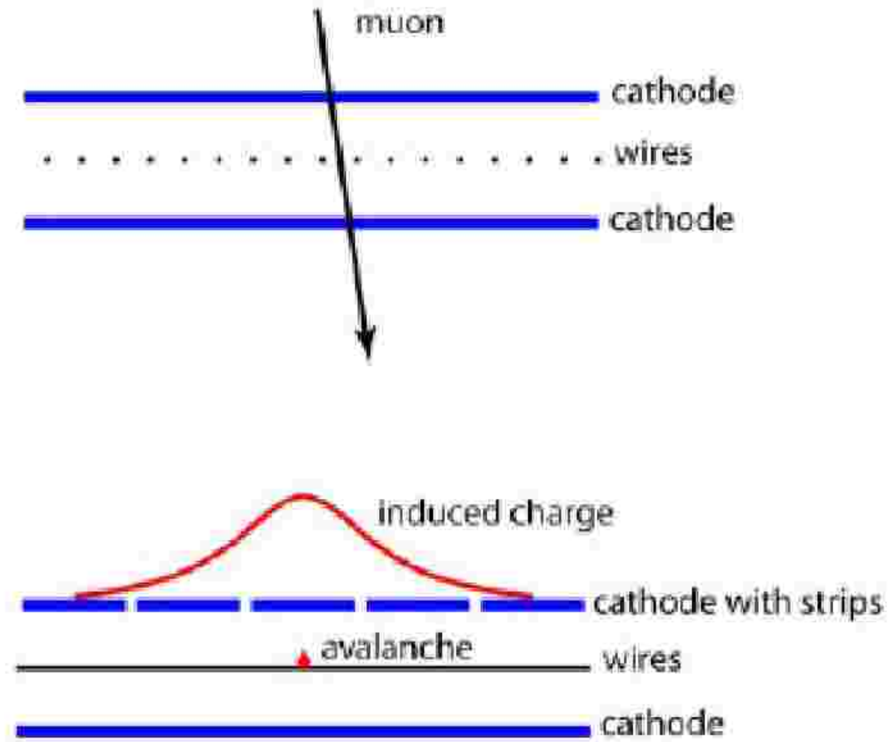




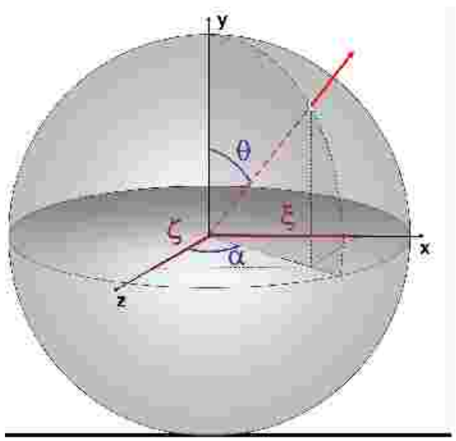
CSC

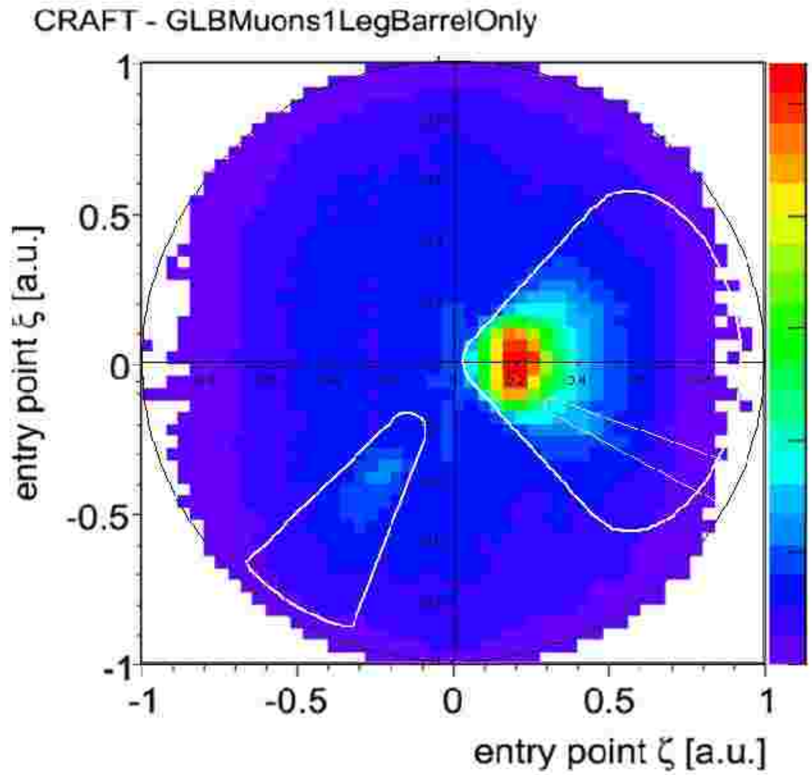
- 180 000 wire read-out channels
- gas mixture : 40% Ar + 50% CO_2 + 10% CF_4





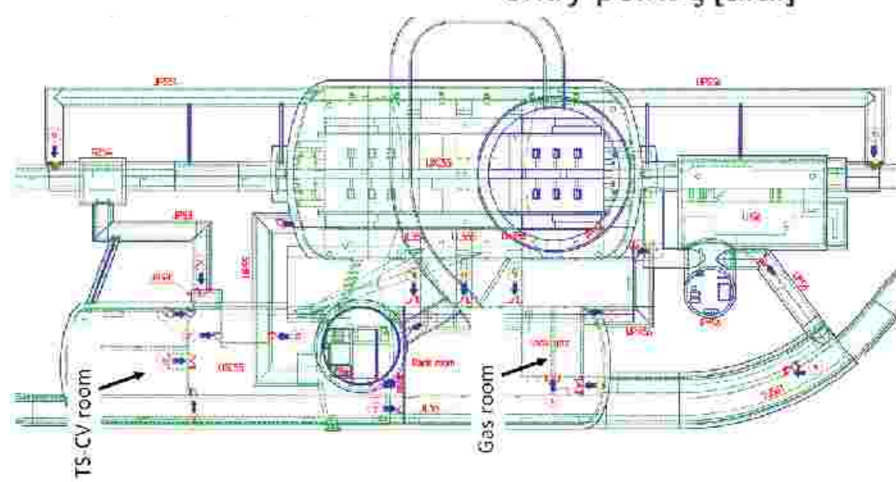
Angular Distribution of Cosmic





Reconstructed angles of cosmic rays indicate increased acceptance through the 2 access shafts of CMS

CMS is located 90m underground



49

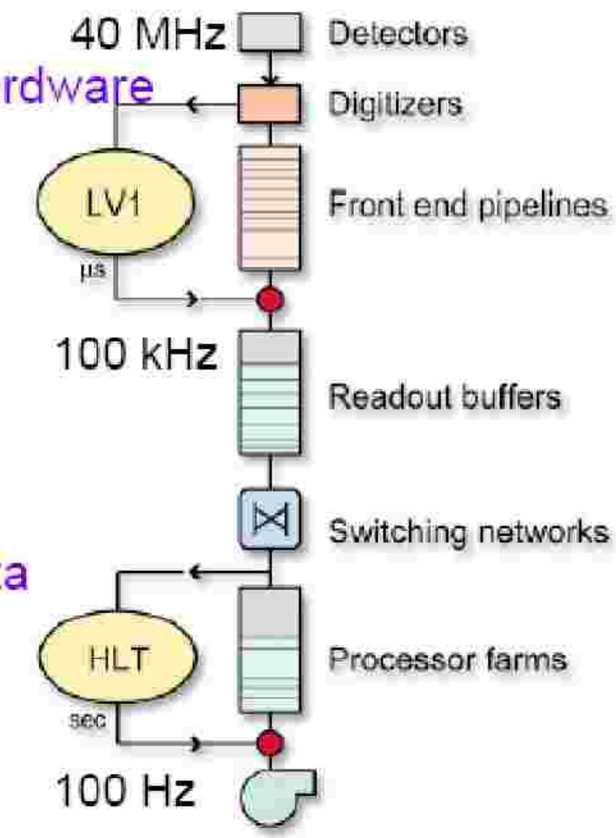
Trigger

CMS adopts an innovative (No Level-2 dedicated hardware) multilevel trigger design

- Level-1 Trigger: implemented on dedicated hardware
  - calorimeter and muon data (coarse granularity)
  - Dedicated hardware → minimum dead time
    - Input from detector: 40 Mhz
    - Output to DAQ ~100kHz

High Level Trigger (HLT): software running on a farm of commercial processors

- Uses as much as possible “off-line quality” data
  - Output: max rate for storage O(100) Hz
    1 event ~ 1MB



Tracker

Inner Barrel (4 layers, 2 DS)
& Disks (2x3 disks)

(TIB & TID)

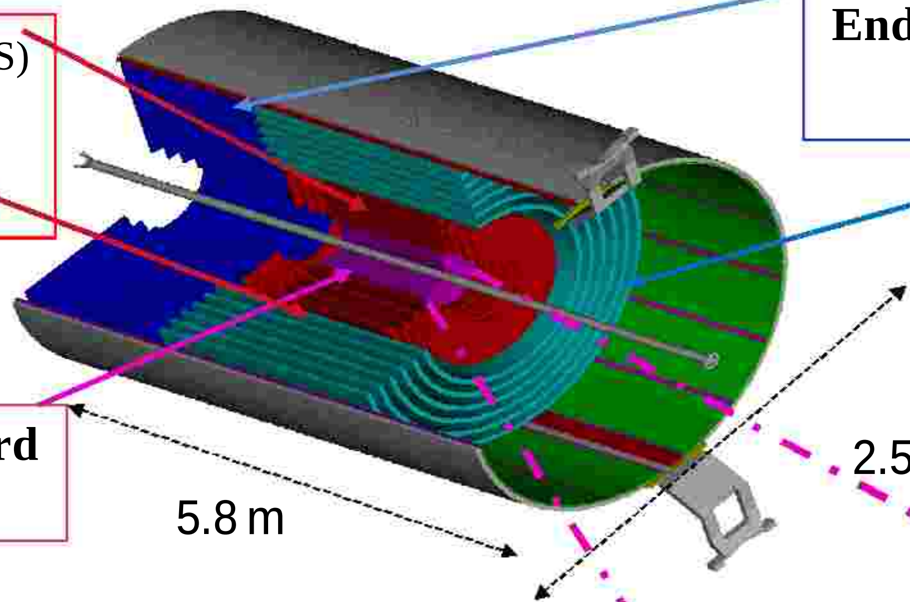
End Caps (TEC)

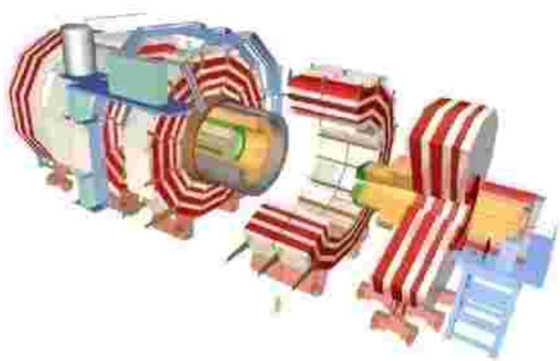
2x9 disks

Outer Barrel
(TOB)

6 layers (2DS)

Barrel (3 layers) & **Forward**
(2x2 disks) **Pixels**



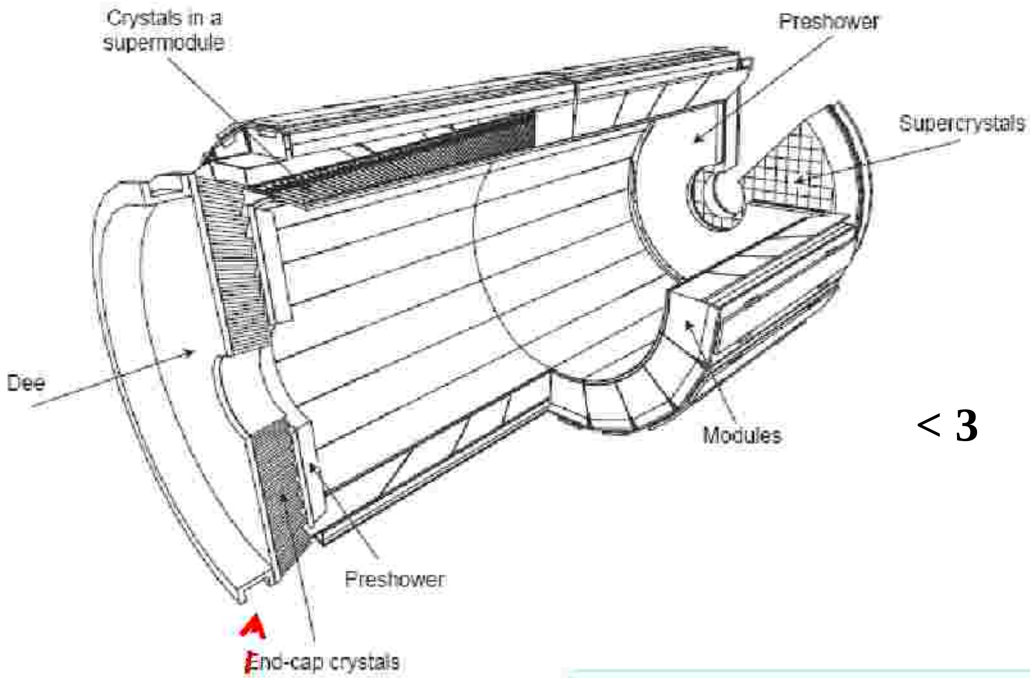


200 m^2 of silicon sensors

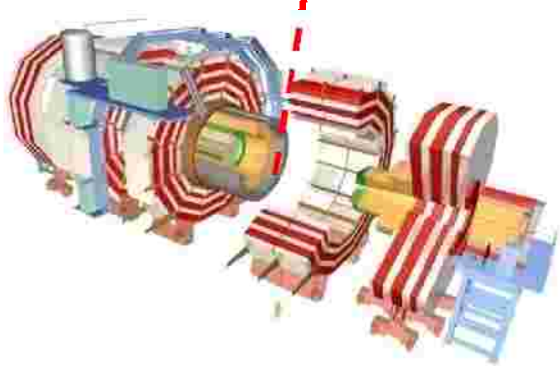
66 M pixels & **9.3** M strips

High granularity and radiation hardness

Electromagnetic Calorimeter



< 3



75k **$PbWO_4$ crystals** ~ 11 m^3 and 91 t

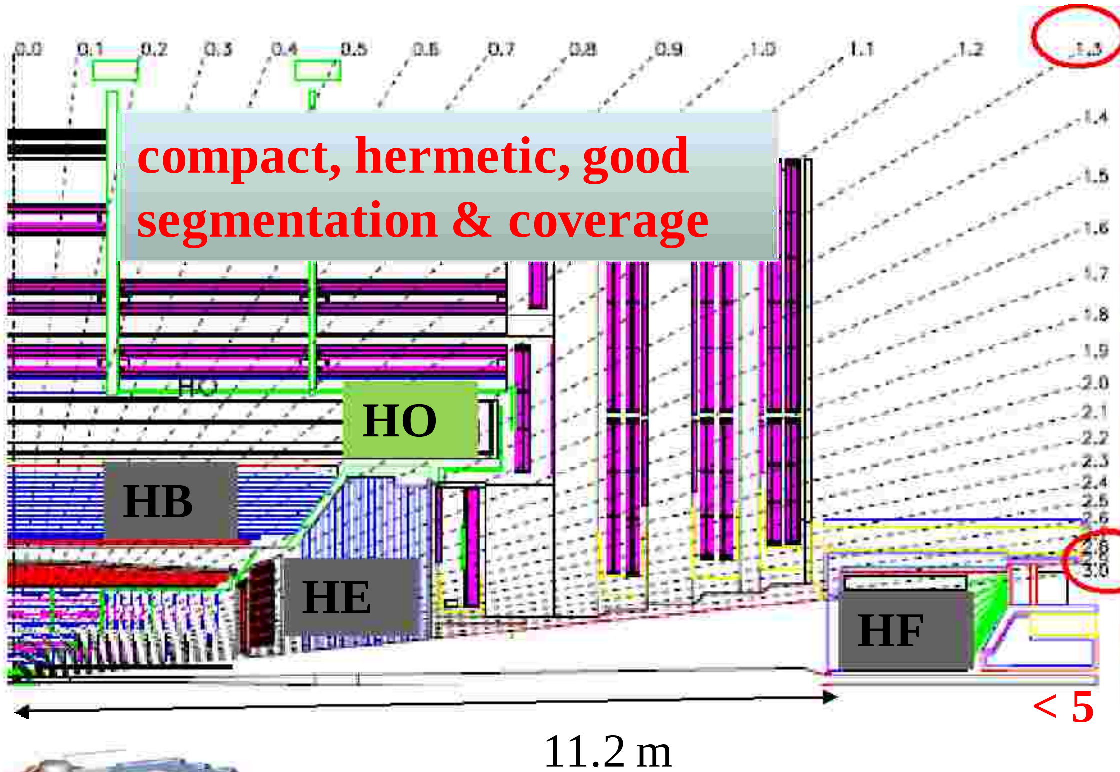
Density: 8.28 g/cm^3
X_0 : 0.89 cm
$R_{Moliere}$ 2.2 cm

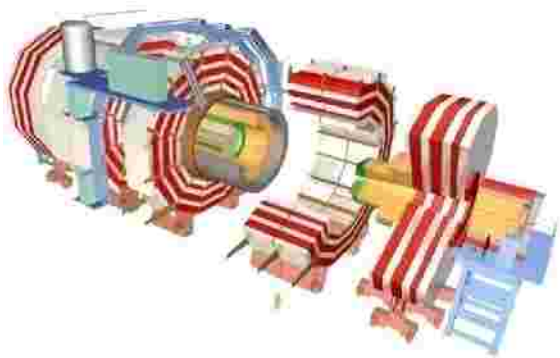
Fine granularity and compact calorimeter

Fast response (80% light output in 25ns)

Photo detectors: APDs in barrel & VPTs in endcaps

Hadron Calorimeter





Sampling type

HB & HE: brass absorber and scintillating tiles (˜ 70k tiles)

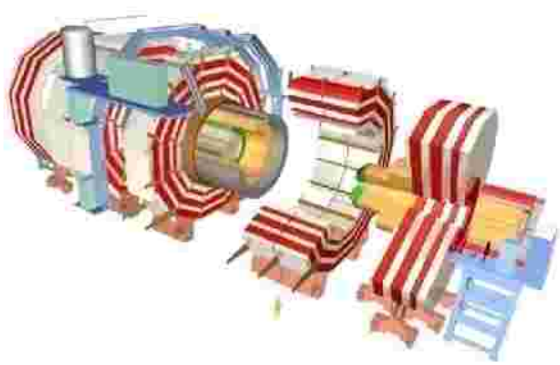
HO: barrel tail - catcher (outside the solenoid) for | |<1.26 à > 11 $_{int}$ in depth

HF: steel absorber and quartz fibres

Magnet

Huge magnet

Diameter: 6.3 m
Length : 12.5 m
Strong field: 4T
Nominal current: 19.14 kA
Stored energy 2.6 GJ
Operating temperature: 1.8 K

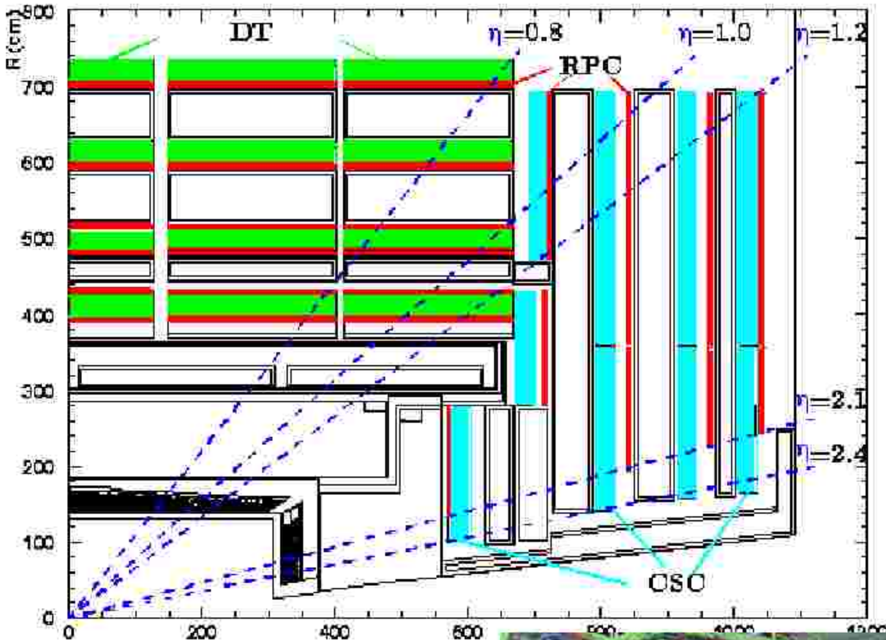


Huge iron return yoke

5 wheels and 2 endcaps

Total mass: 10.000 t

Muon spectrometer



468 **CSC** chambers
2.5M wires

250 **DT** chambers
172k DT cells

912 **RPC** chambers

3500 m^2 active surface

150k elect. channel

Robust, efficient and redundant muon system