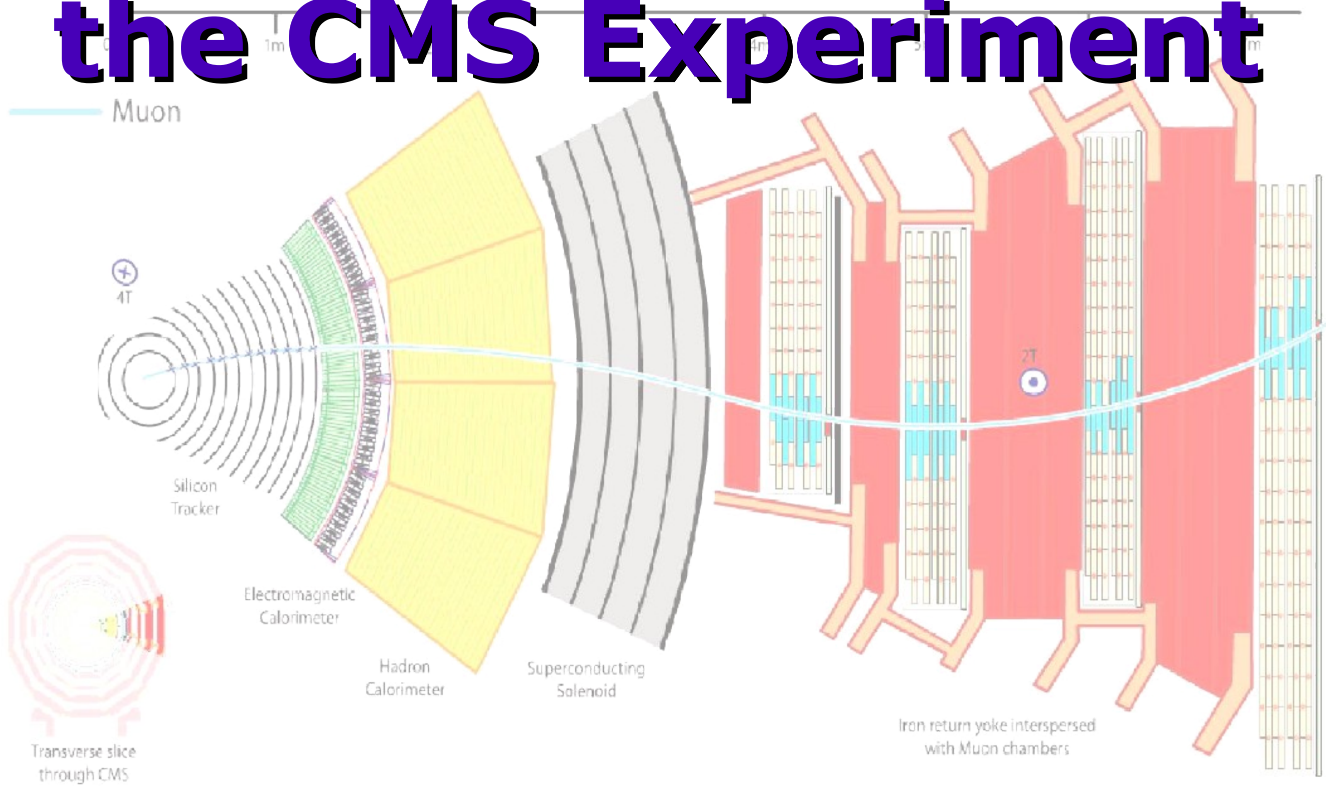
IPRD06 – October 2nd, 2006

The Drift Tube System of the CMS Experiment



G. Cerminara on behalf of the CMS collaboration

University and INFN Torino

Overview

- The CMS muon spectrometer and the Drift Tube (DT) system
  - the CMS tracking strategy
  - design of the muon spectrometer
  - design of the barrel DT system
- Performance of the DT chambers
- Status of the DT system: installation and test with cosmics
  - chamber commissioning
  - Magnet Test & Cosmic Challenge

CMS Tracking Strategy

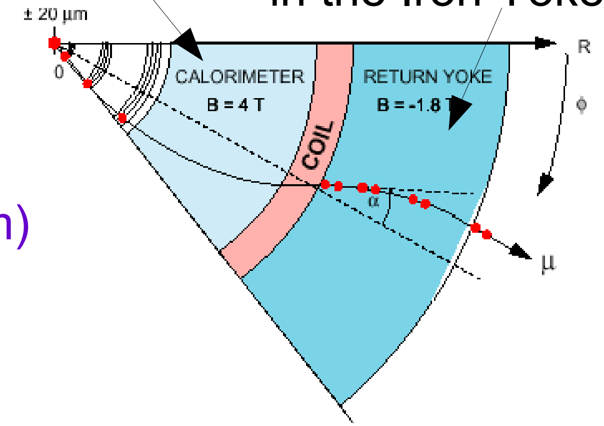
- Magnet: Superconducting Solenoid
- Bending in the transverse plane (ϕ)
  - Independent tracking inside (Si tracker) and outside (muon spectrometer) the coil
  - Vertex constraint in the transverse plane ($\sigma_{xy} \sim 20\mu m$)
- Muon spectrometer in the iron return yoke
  - Good p_T resolution at high transverse momenta:

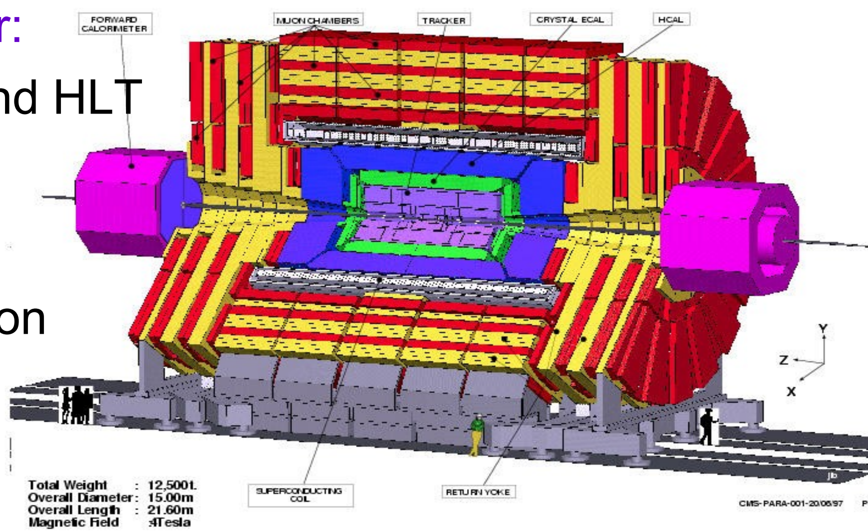
    goal $\sigma_{pT}/p_T \sim 10\%$ @ 1 TeV/c
  - Must provide a reliable and robust trigger:
    - p_T standalone measurement @ L1 and HLT
    - coverage of the solid angle:

      $|\eta| < 2.1$ for the trigger
    - fast reconstruction and trigger decision
    - precise BX assignment
    - redundancy and robustness also in high background environment

B=4T for r <3m

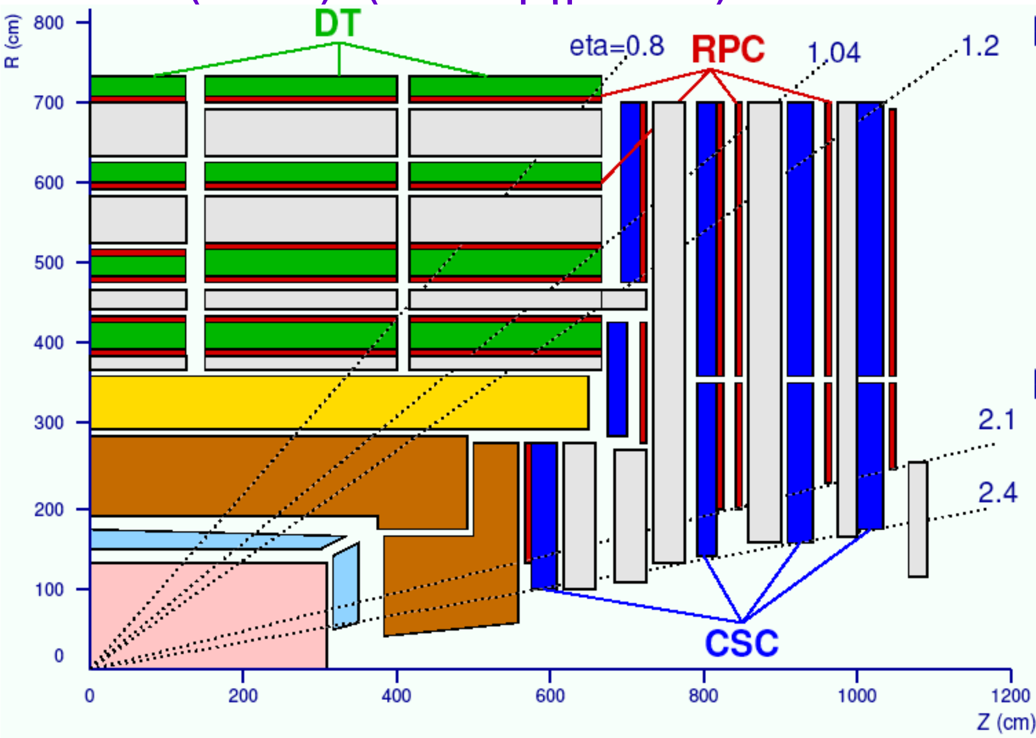
B~1.8 T in the Iron Yoke





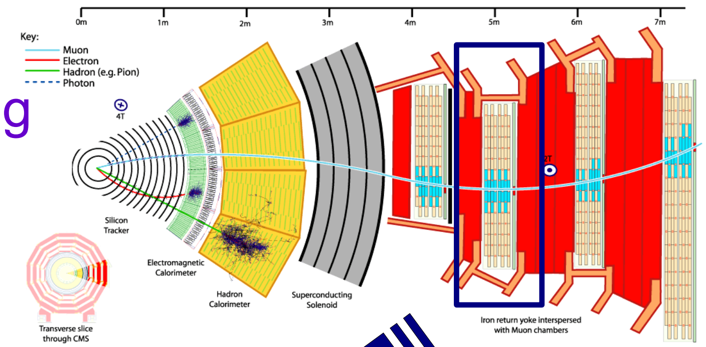
The Muon Spectrometer

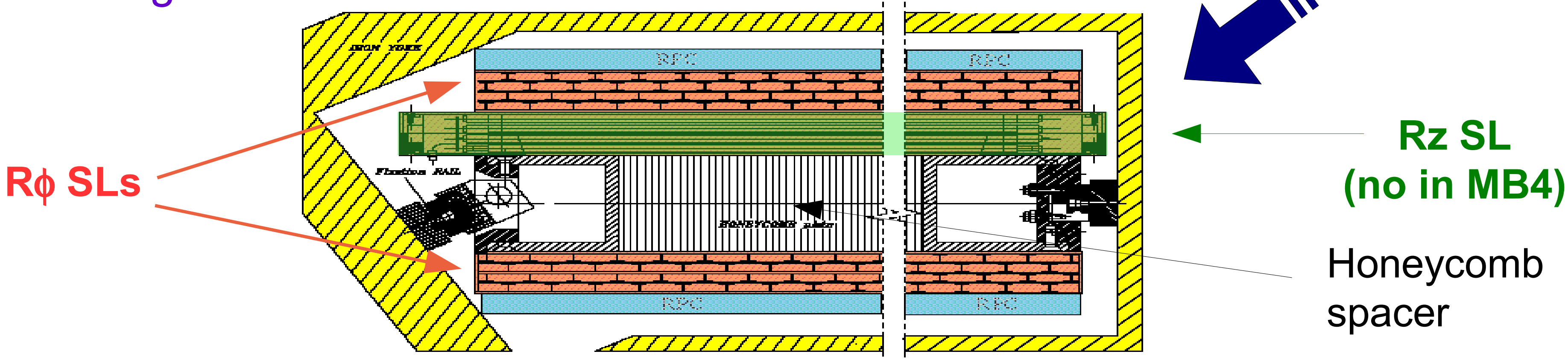
- Muon spectrometer uses 3 types of gas detectors with trigger capabilities
  - Barrel & Endcaps: **Resistive Plate Chambers** (RPC) ($|\eta| < 2.1$)
    - good time resolution: $\sigma_t \approx 2$ ns → BX assignment
  - Endcaps: **Cathode Strip Chambers** (CSC) ($0.8 < |\eta| < 2.4$)
    - $\sigma_x \approx 100 – 240\mu m$ / layer
  - Barrel: **Drift Tubes** (DT)
    - pseudorapidity coverage: $|\eta| < 1.2$
    - 4 stations of chambers
    - 250 chambers → $O(10^5)$ channels
    - $\sigma_x \approx 200\ \mu m$ / layer



Drift Tube Chambers

- Each DT chamber is composed by:
  - 2 SuperLayers (SL) measuring the bending coordinate → Rϕ SLs
  - 1 SuperLayer (SL) measuring the track angle w.r.t. the beam line → Rz SLs

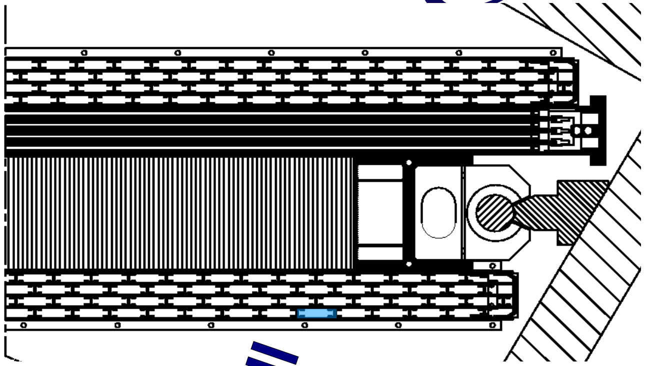


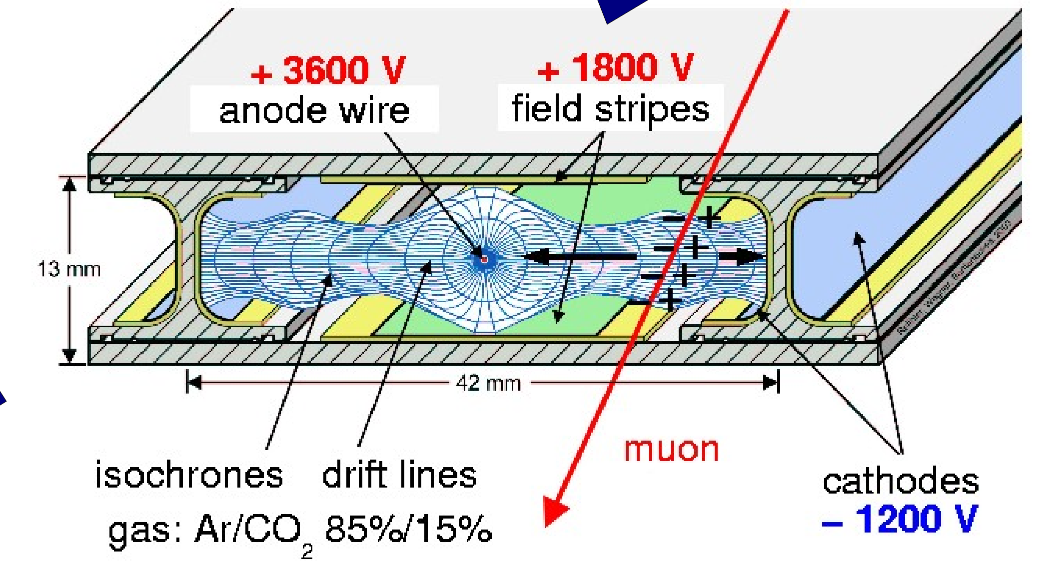


- Each SL is a quadruplet of cell layers staggered by half a cell
  - Layer structures allows to:
    - improve resolution w.r.t. the single cell & measure the segment angle
    - minimize the effect of soft δ-rays decoupling the effect on each layer (2 mm thick Al walls)
    - generate trigger within the chamber (autotrigger) → see next slides

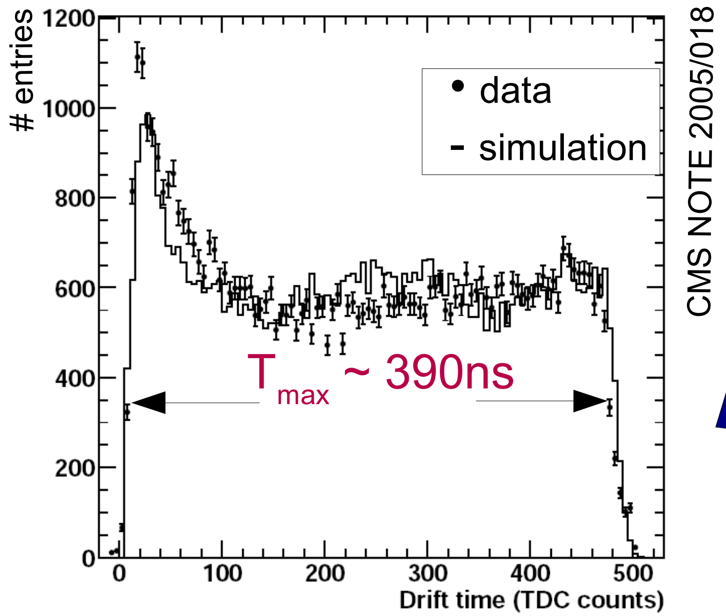
Drift Tube Cell

- Drift cell: 13 x 42 mm² cell
  - Ar/CO_2 (85%/15%) gas mixture:
    - good quenching properties and saturated drift velocity
  - Field shaping obtained with central stripes:
    - good linearity of space-time relation:





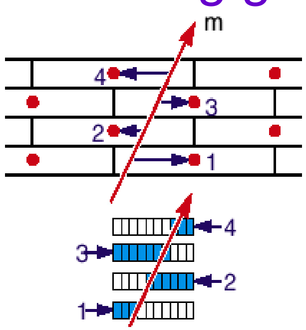
V_{drift} ~ 54 μm/ns



1 TDC count = 0.7812 ns

DT Level-1 “Local” Trigger

- Muons and calorimeters take part to the CMS Level-1 decision
  - Level-1 reduces the rate from 40MHz to 100kHz (max input for HLT)
- Local (chamber level) trigger: electronics installed on-chamber
  - Find segments at SuperLayer level (Bunch and Track Identifier, BTI) using generalized mean timer technique:



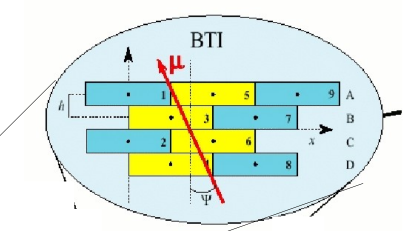
Meantimers recognize tracks and form vector / quartet.

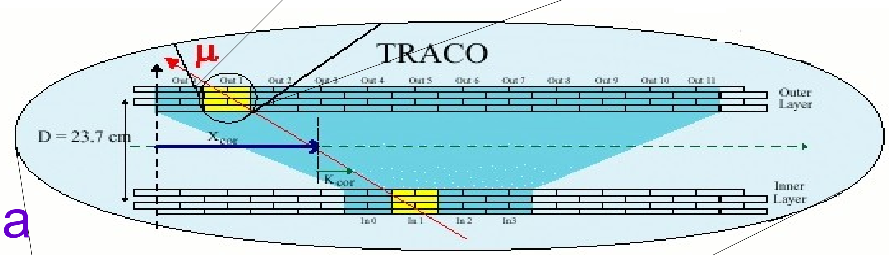
from geometry:

$$\frac{(t_1+t_3)}{2}+t_2=T_{MAX}$$

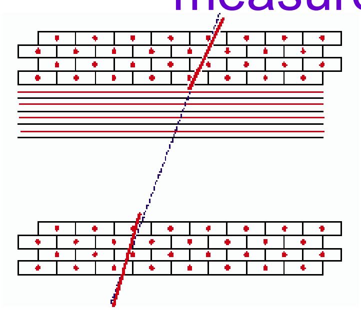
meantimer

The BTI also assign a Bunch Crossing to each segment



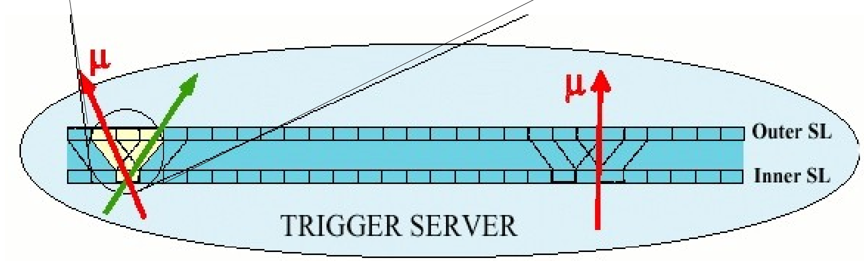


  - Correlate SL segments providing a measurement of position and direction



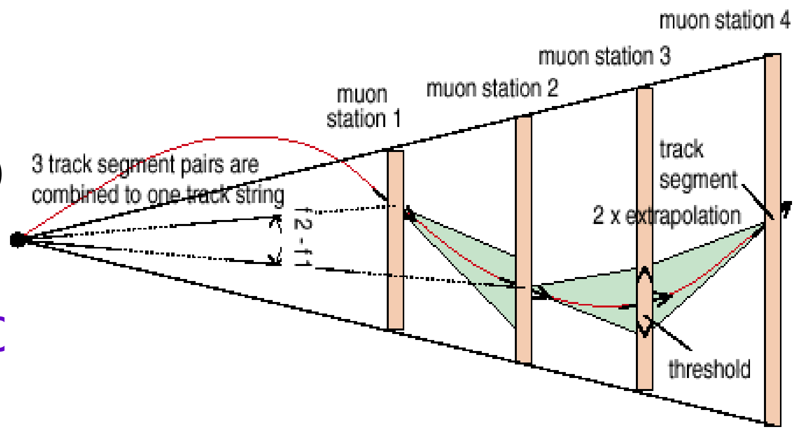
Correlator combines them into one vector / station.

Track Correlator, TRACO



DT Level-1 “Regional” Trigger

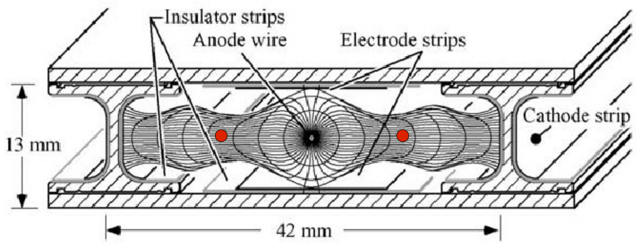
- “Regional” (subsystem) level (FPGAs)
  - DT Track Finder
    - combine segments into track; assign p_T (Based on Look Up Tables)

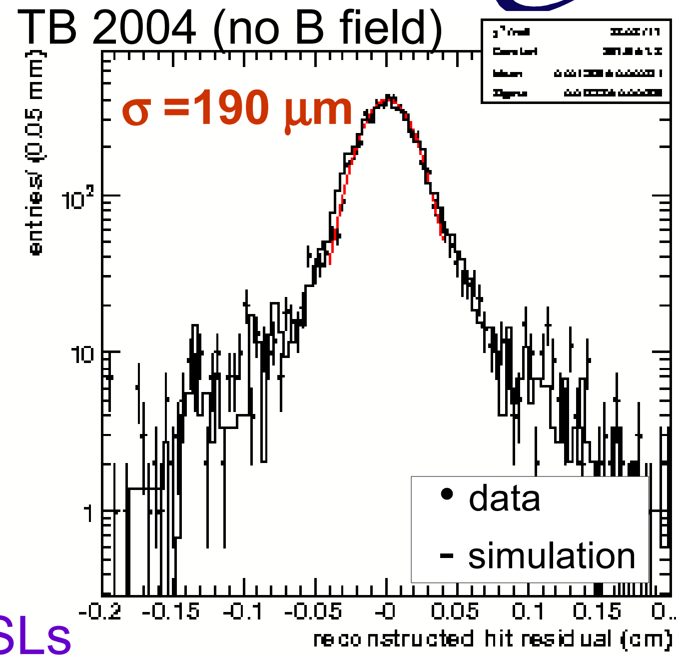


- Global Muon Trigger
  - Combines candidates from DT, CSC,RPC
    - Exploits complementarity of systems
  - Delivers 4 best muons to the Global Trigger
    - Each with p_T, position, angle, BX, quality
  - Efficiency: ~97%
  - p_T resolution: 17-22% depending on η (muons from W decays)
  - Decision time: 128BX = 3.2 μs

Reconstruction

- Local reconstruction in DT chambers is performed in steps:
  - the drift time is converted in a drift distance from a wire in a cell:

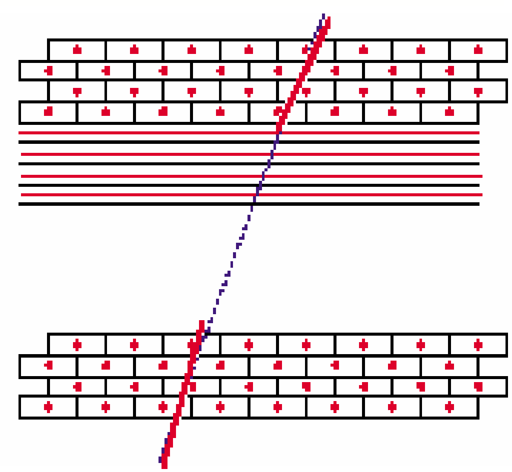




  - cell hits are used to fit 2D segments independently in $R\phi$ (up to 8 hits) and RZ SLs (3-4 hits)
  - the two projections are combined to build a 3D segment in the chamber (which will be used in the track fit)
    - Resolution on the segment position

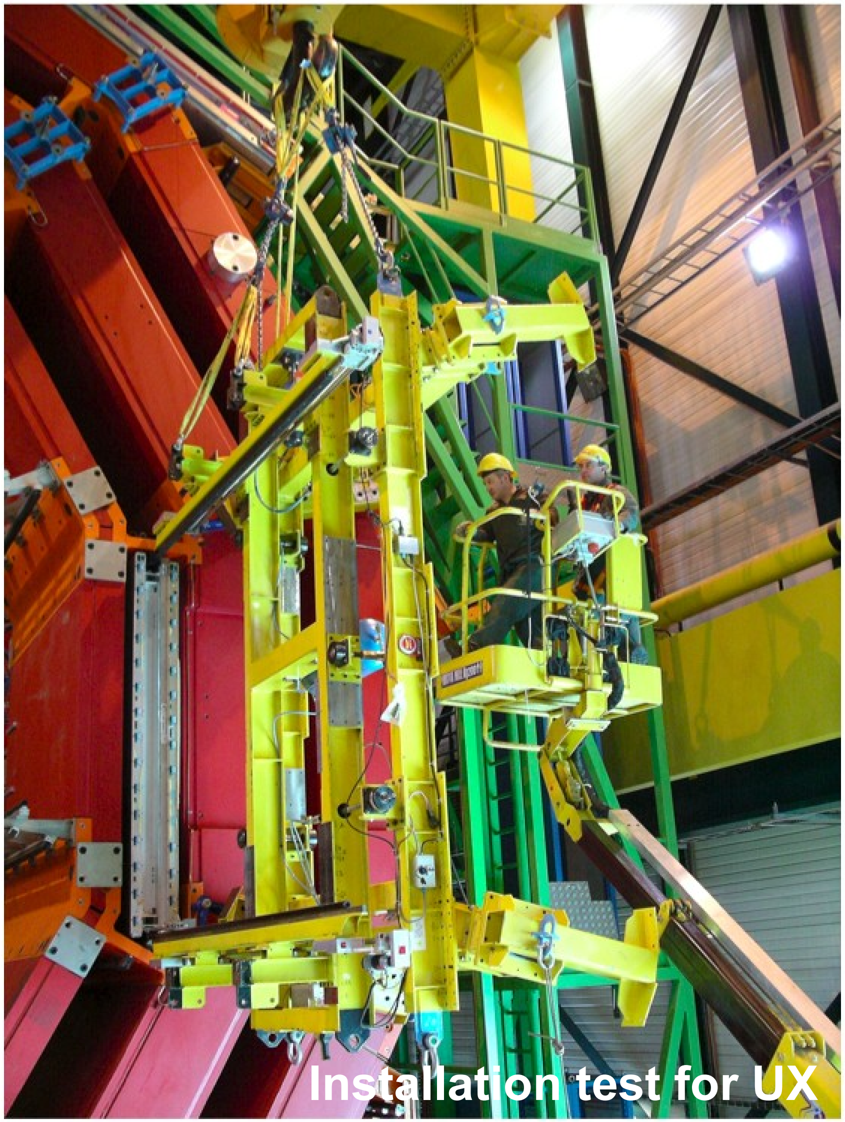
      $\sigma_{R\phi} \sim 70\ \mu m$
    - Resolution on the segment direction

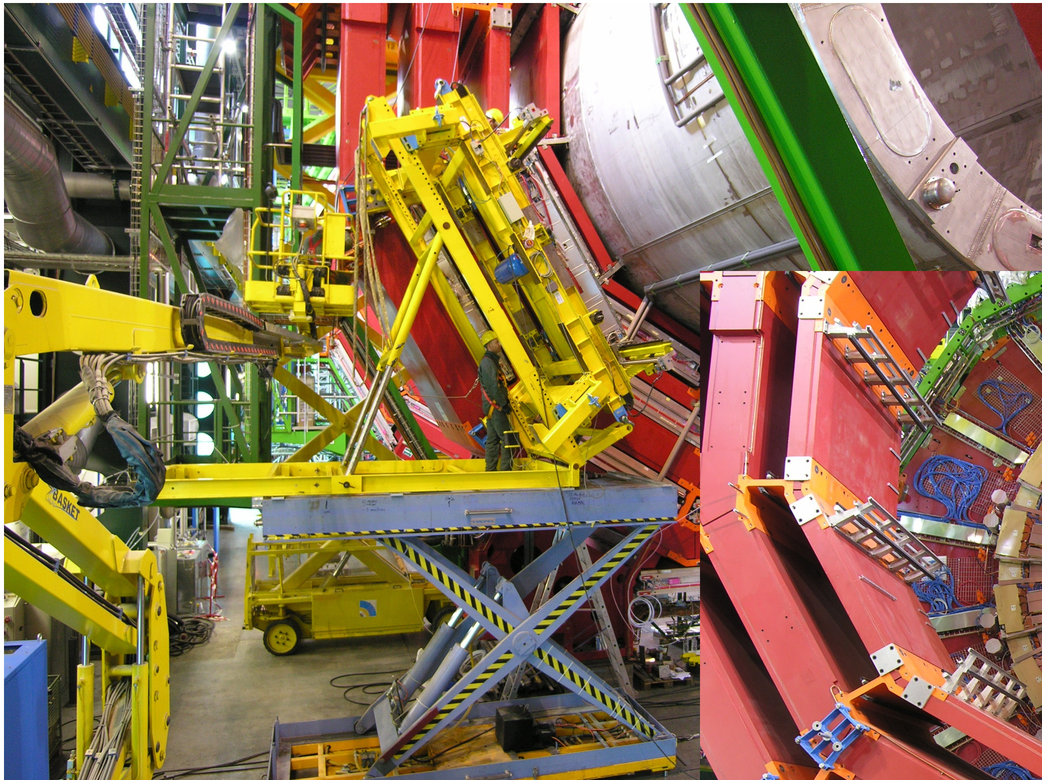
      $\sigma \sim 0.5$ mrad in $R\phi$ projection

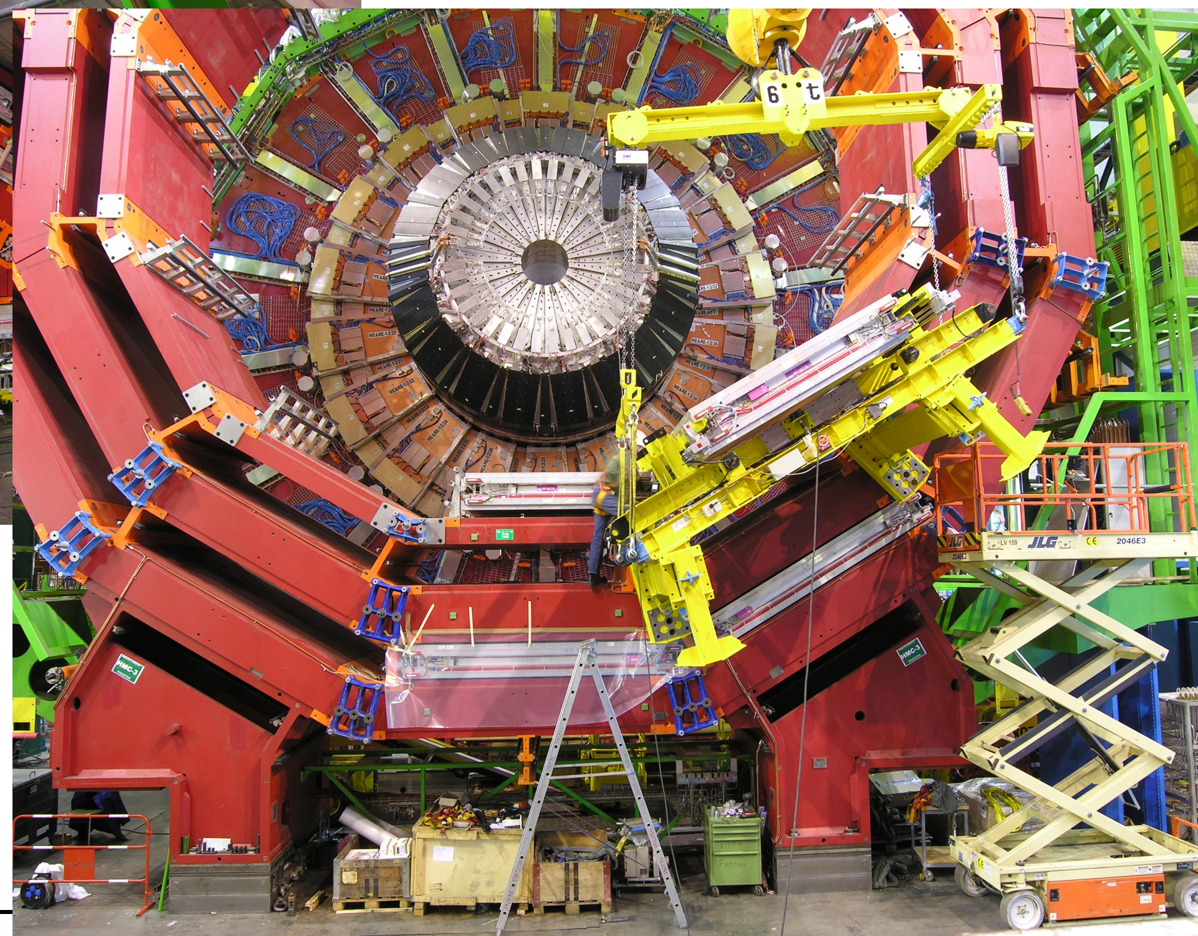


Status of DT Installation

- Production is completed since March 06:
  - 250 DT chambers + spares built (construction sites: Aachen, Madrid, Padova and Torino)
- Installation in CMS is on-going at surface installation point:
  - installed 146/250 chambers → 70% of chambers which can be installed on surface
  - end of installation foreseen by end of 2006
- Lowering of the first wheel in the experimental hall is foreseen for November 06




BASKET

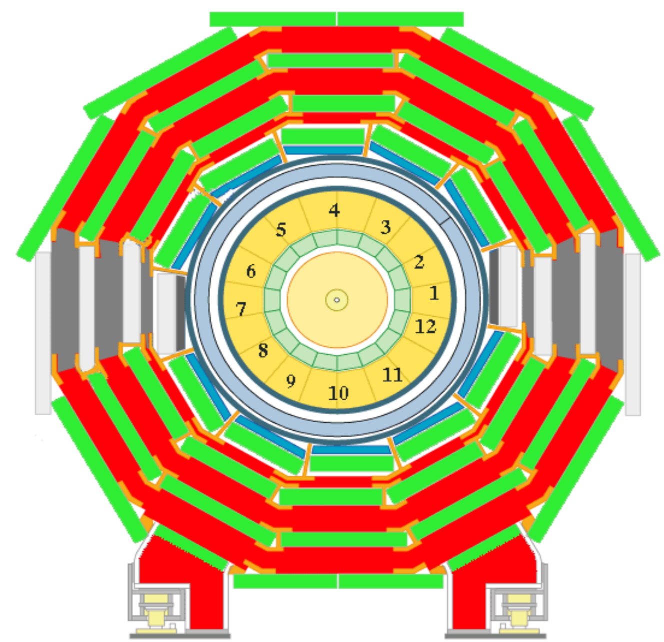

6 t
JLG
2046E3

Commissioning of the Chambers

- Chambers functionality is tested through all the production chain:
  - with cosmics at production sites
  - after the shipping to CERN (where the chamber is dressed with trigger and read-out electronics)
  - after the installation in CMS → **commissioning**
- Commissioning of the chambers is ongoing since May 2005. Goals:
  - certify that the chamber is operational with final on-chamber electronics before cabling to the tower racks electronics
    - Dedicated test of on-chamber electronics (minicrate) (Read-out and L1 local trigger)
    - Test of chamber functionality with cosmic muons:
      - 1 chamber at a time in auto-trigger mode

Status of the DT Commissioning

- Not all the chambers will be tested on surface
  - vertical sectors will be installed and commissioned underground (iron slabs needed for hanging the wheel during lowering procedure)
- Commissioning is going on in parallel with the installation:
  - 137 chambers in 3 and 1/2 wheels tested up to now
    - ~55% of all DT chambers
  - the chamber performance is as expected :
    - The number of interventions due to chamber problems is low (<2% of commissioned chambers required interventions)
    - No long term HV problems observed
  - most of the interventions done during commissioning concern the electronics



DT Commissioning Results

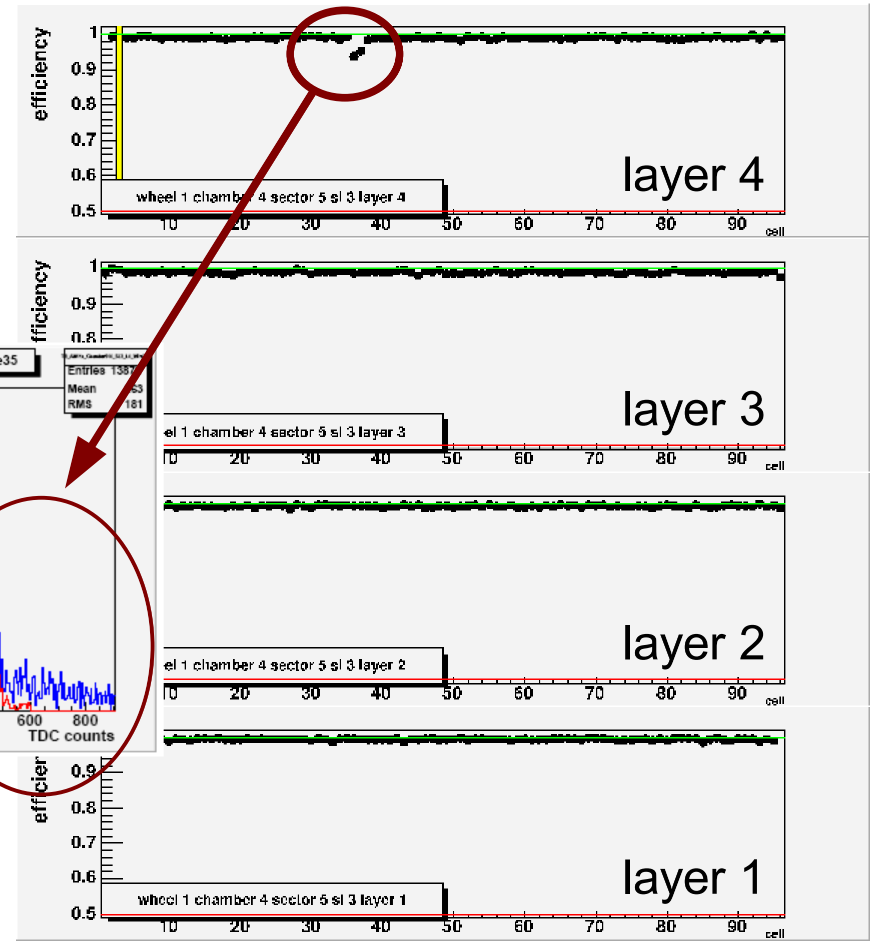
- The analysis of the cosmic data can be used to characterize the chamber behaviour looking for:
  - disconnected and dead channels → << 0.1% well below the requirement (mainly disconnected for HV problems at construction sites)
  - Noisy channels → chambers commissioned with very low discrimination thresholds but noise is under control

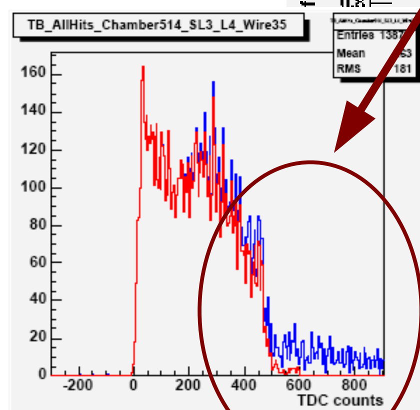
- NOTE: the cosmic data taking (in auto-trigger mode) can not be used for fine test the DT resolution:
  - local trigger electronics (BTI and TRACO) is designed for bunched muons and the BX assignment introduces a jitter in the drift-time measured for cosmics muons (~ $25/\sqrt{12}$ ns ~ 390 μm jitter...)

Chamber Efficiency

- Cell efficiency and drift-time distributions are the main tool to evaluate the chamber behaviour:
  - example: allow to find field problems in the cell volume
- The cell efficiency is on-average > 99% for all the commissioned chambers

MB4 Chamber SL3





Cell #

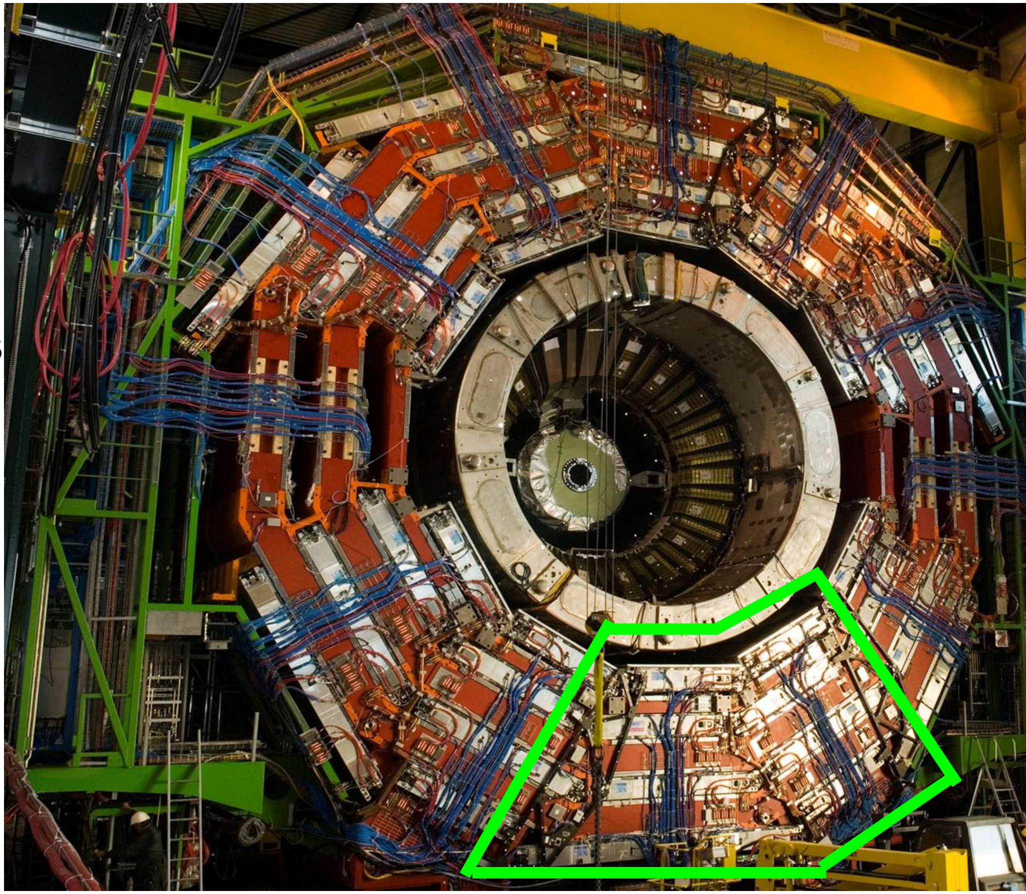
Disconnected cathode: →
long tail in drift time distribution
and lower efficiency

Magnet Test & Cosmic Challenge

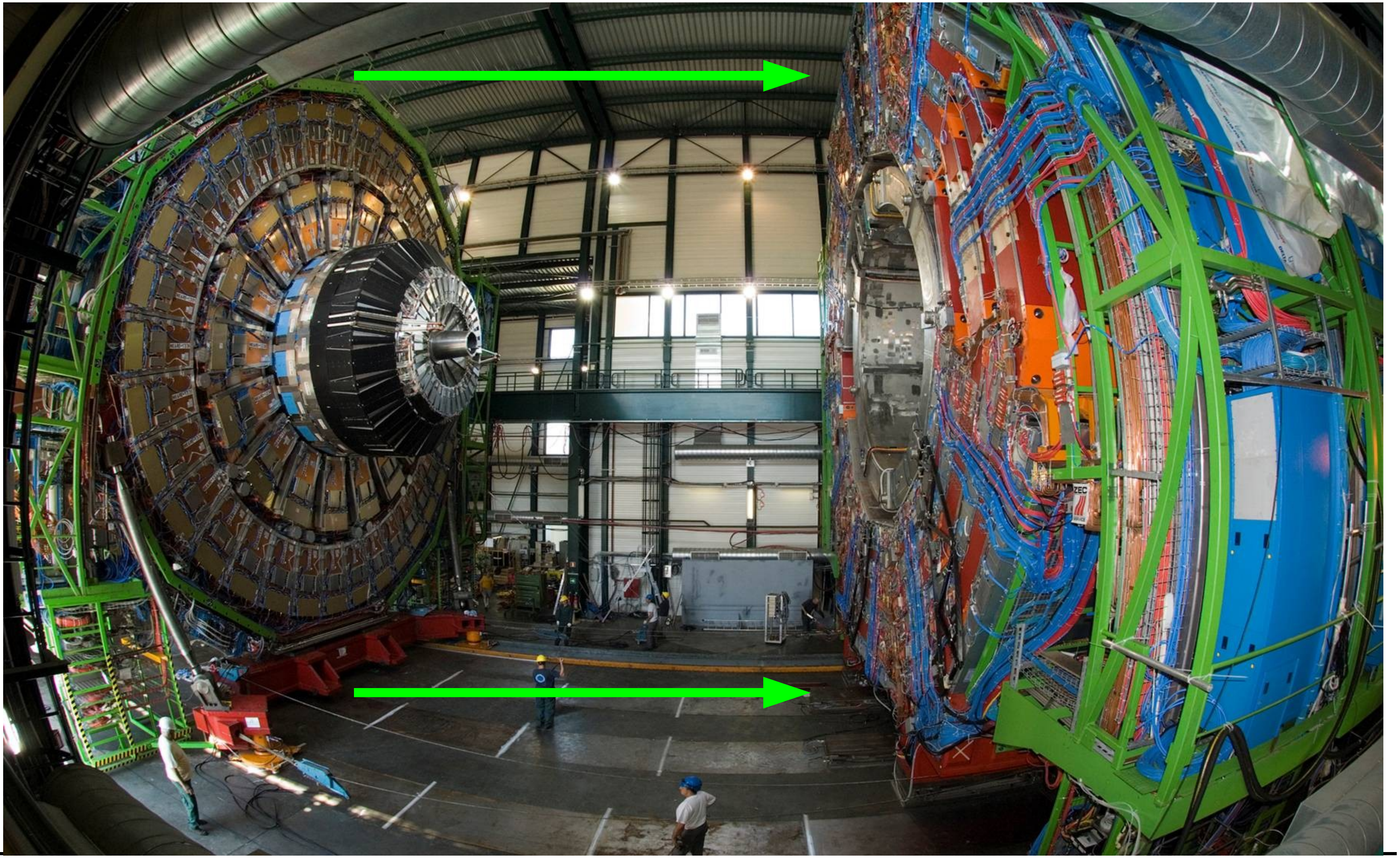
- Main effort during the summer up to end of October 06
- Combined cosmic data taking of ALL CMS sub-detectors with/without B field
- DT setup:
  - 3 sectors → 14 chambers
    - 2 sectors in Wheel+2
    - 1 sector in Wheel +1

~5% of the DT system = ~10k channels

  - final read-out and trigger electronics
  - integrated with the Global CMS DAQ system

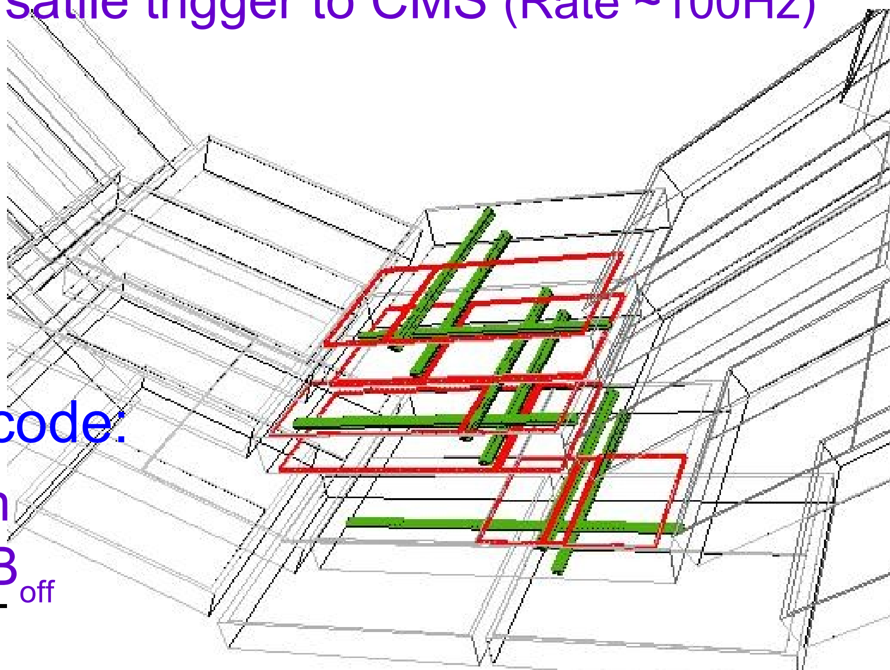


Closing CMS!



MTCC: the DT Challenge

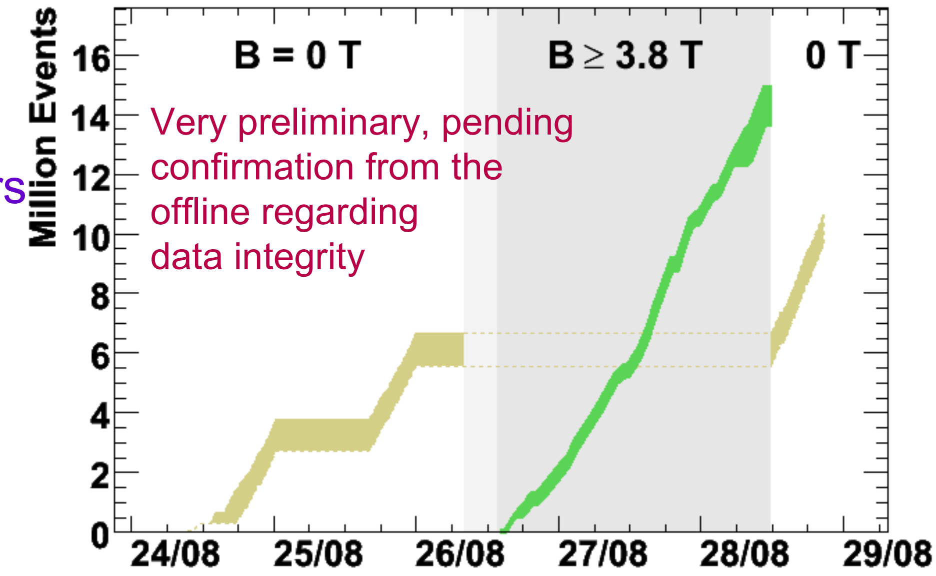
- First time operating 3 sectors over an extended period of time:
  - chambers have been working smoothly and stably for more than 4 months
- First time running with CMS magnetic field on:
  - chambers behave as expected
  - they can deal without problem with fast magnet discharges
- Operation of the entire Level-1 trigger chain:
  - succeeded to provide stable and versatile trigger to CMS (Rate ~100Hz) For example dedicated triggers for:
    - tracks pointing to the tracker
    - tracks crossing different sectors (for alignment studies)
  - optimization during the running
- Important test of the reconstruction code:
  - DT segment reconstruction code run on the proto filter-farm with B_{on} and B_{off}



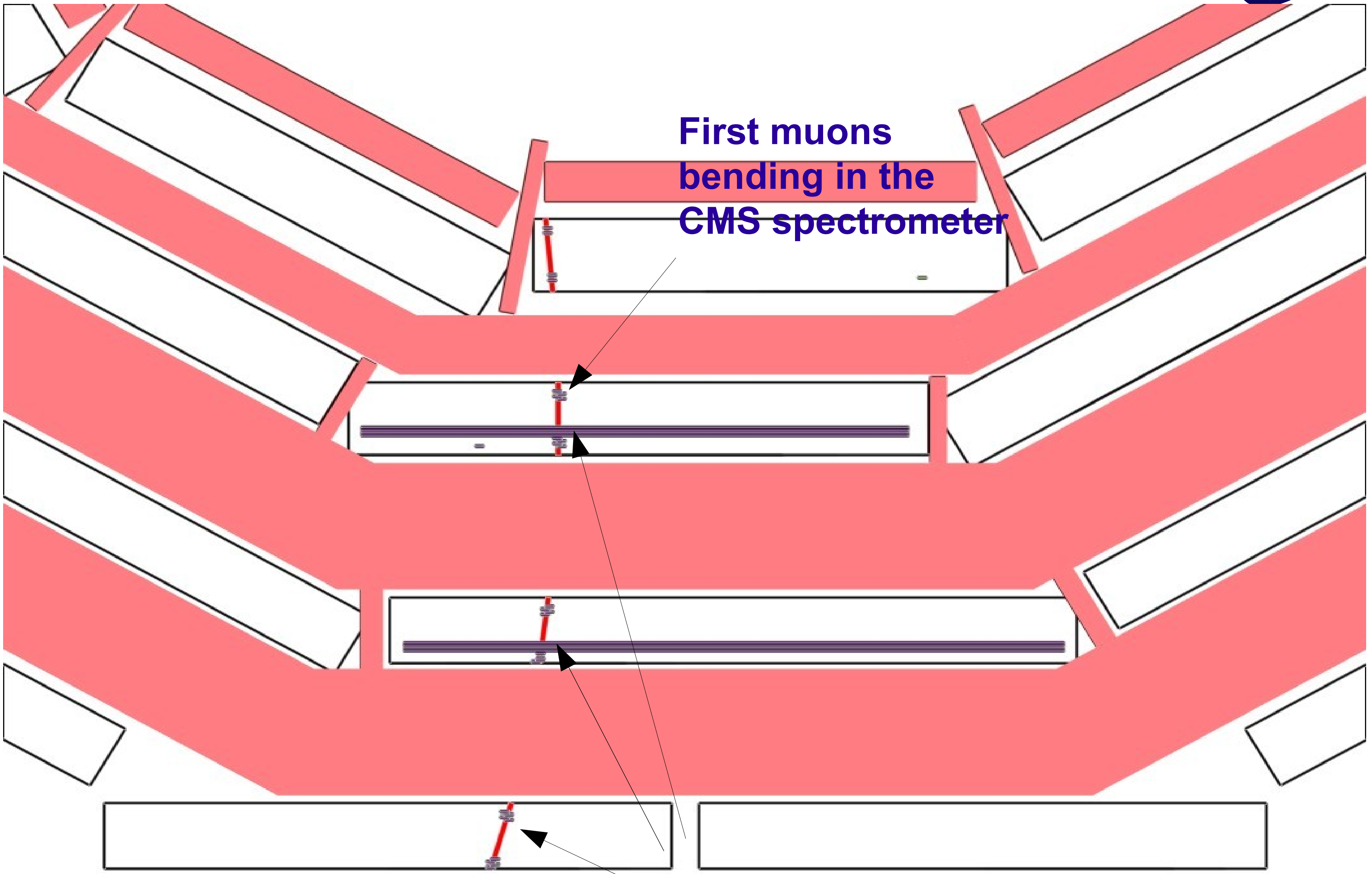
The MTCC Data

- The analysis of MTCC data is still on-going...detailed results will come later..
  - preliminary plot shows successful data taking with several subdetectors a very encouraging result:
    - about 25M triggers from DTs
- Very important lessons from this data taking:
  - integration of DAQ and trigger of different sub-detectors
  - a lot of work still needed to scale the control of 14 chambers to the whole DT system:
    - DQM tasks to be scaled/automated
    - Detector Control and Configuration need improvements
- An important result: we can see real muons crossing CMS

Global Runs with Muon Barrel trigger and at least ECAL and tracker readout



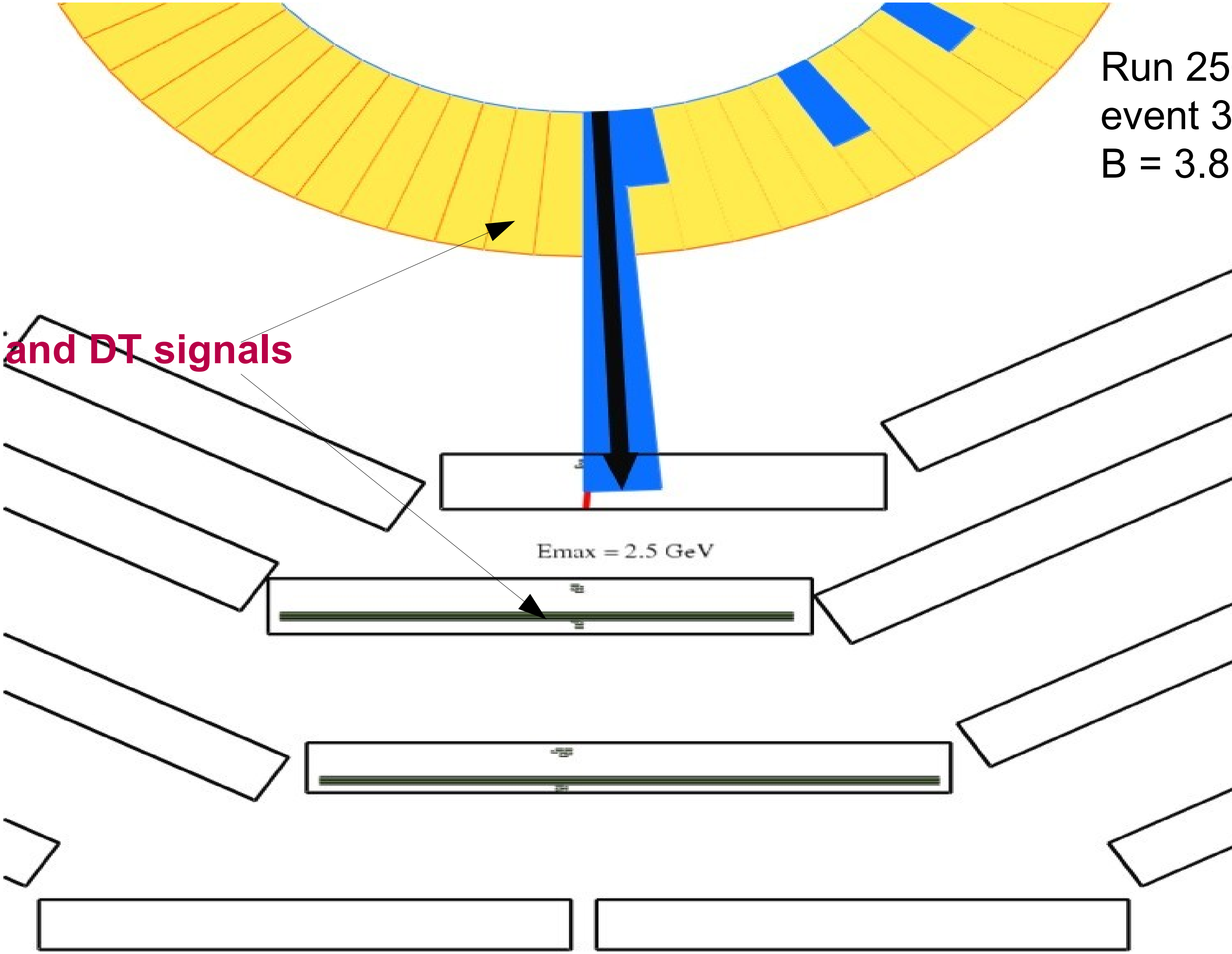
Some (nice) Event Display



Some (nice) Event Display

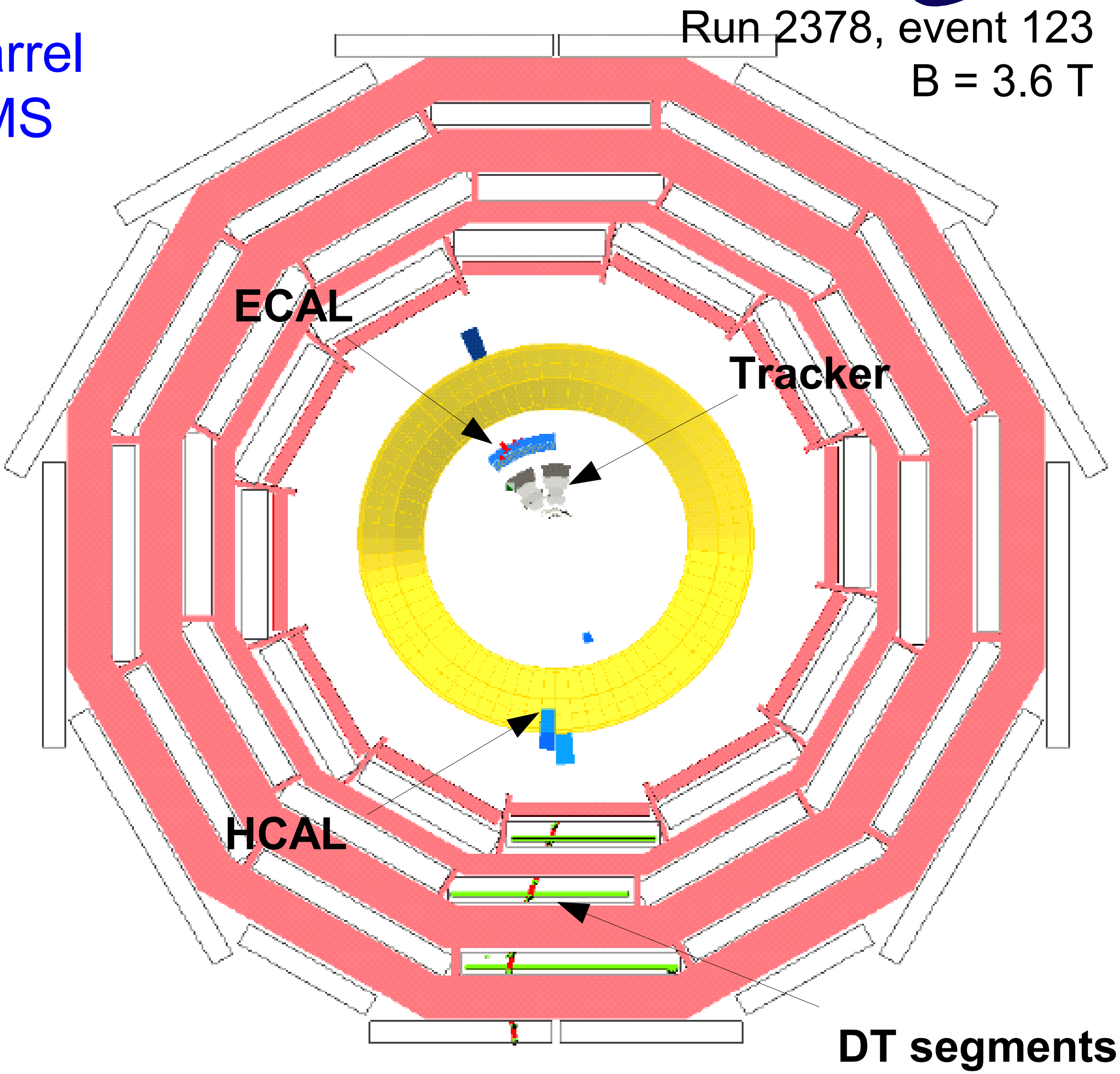
Run 2565,
event 333095
B = 3.8 T

HCAL and DT signals



Some (nice) Event Display

- A muon track in the barrel passing through all CMS sub-systems



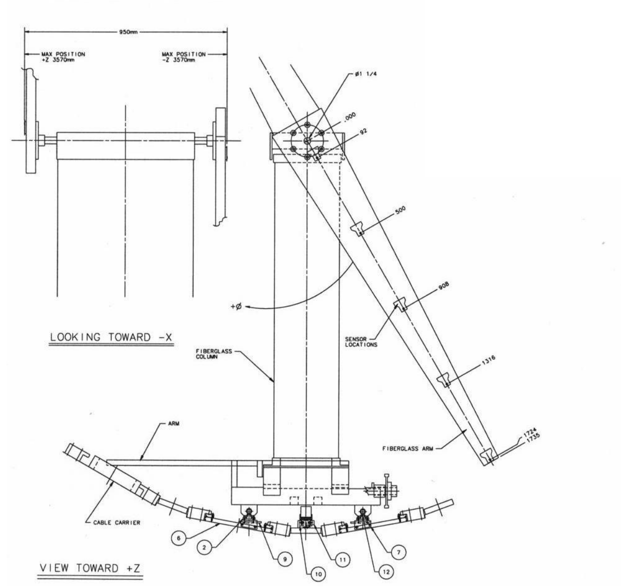
Summary

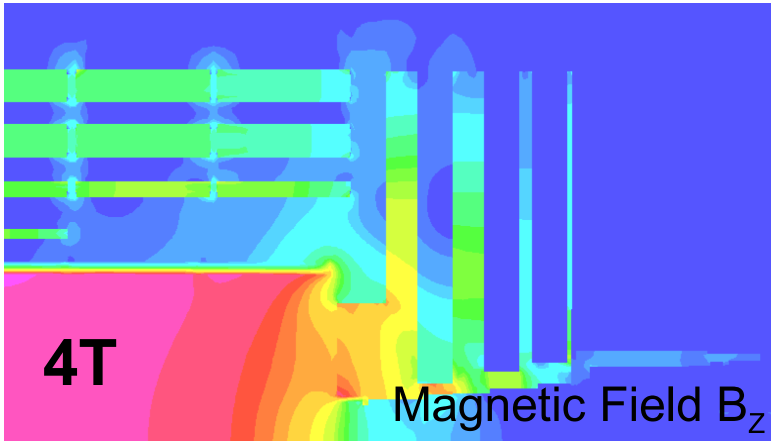
- The Drift Tube system of the CMS experiment is getting ready for LHC start-up
- The commissioning is on-going in parallel with chamber installation:
  - design performance of chambers and electronics achieved
- The Magnet Test & Cosmic Challenge is on-going:
  - final electronics and trigger tested
  - many useful lessons on the way of the start-up...
  - excellent results also for the DT subsystem:
    - the system can be run smoothly for long periods (also with B field on)
    - millions of trigger provided to the experiment
    - millions of data acquired → data analysis is on-going

Backup Slides

Magnetic Field

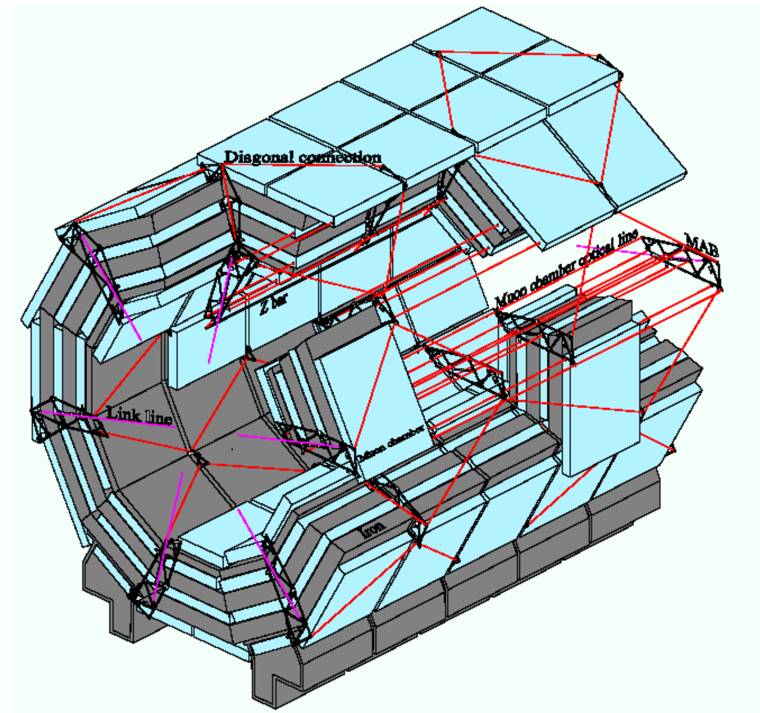
- Superconducting Solenoid
  - r = 3m, L=14m
  - B = 14T within the solenoid
  - B ~ 1.8T in the iron return yoke
- Great bending power
- Independent measurement inside / outside
- A lot of material within chambers
- Field measurement:
  - During Magnet Test (2006)
    - Rotating arm instrumented with Hall and NMR probes:
      - Δr = 20 cm, Δz = 5 cm
  - NMR probes inside the solenoid for on-line monitoring





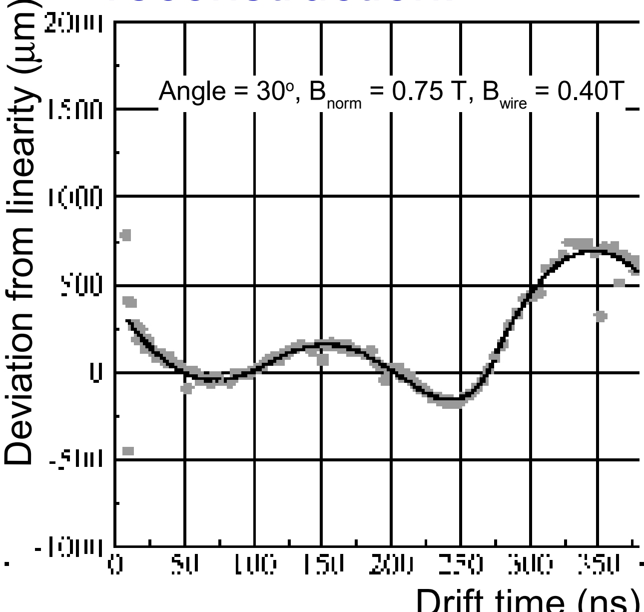
Muon System Alignment

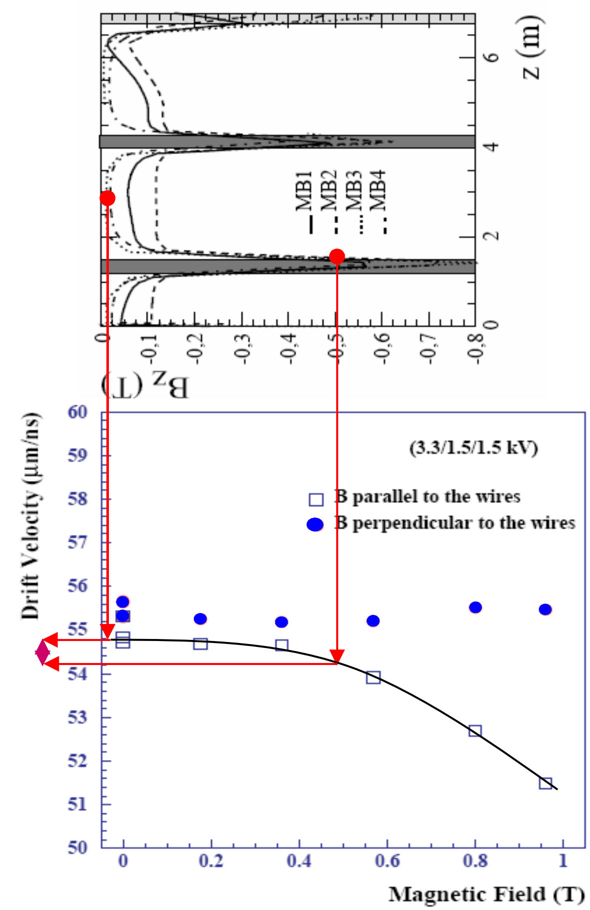
- Chamber alignment is fundamental
  - chamber resolution ~100 μm
  - movements due to B_{on}/B_{off} : *O*(1cm)!
- Optical alignment system
  - rigid structures + optical links (LED, laser, CCD)
  - link system for alignment with tracker
  - performance:
    - $\sigma_{r\phi}$ ~150 μm (same sector)
    - $\sigma_{r\phi}$ ~210 μm (between sectors)
- Alignment with tracks
  - Problem: knowledge of material and magnetic field
    - Only muons with p_T > ~50 GeV/c are usefull

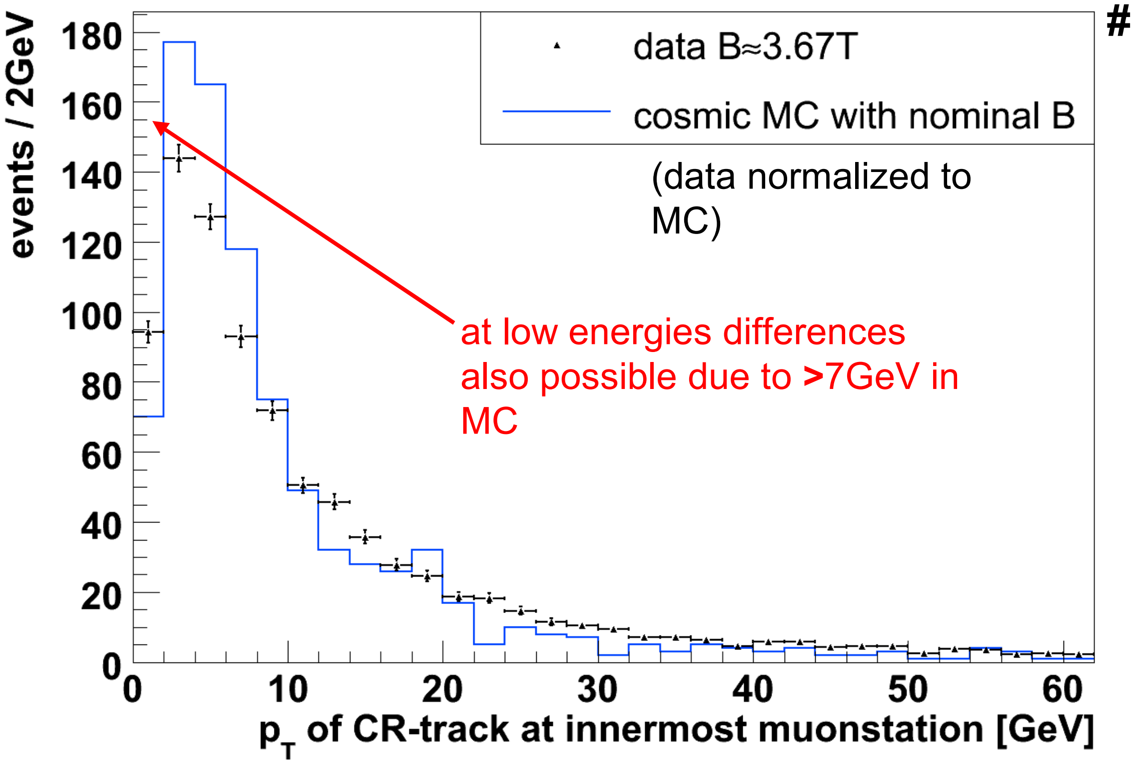


Performance

- Cell non-linearities are small (< 100 μm) but not negligible:
  - more important in regions close to anode and cathode
  - enhanced effect for big impact angles and residual component of the magnetic field along the wire
- The drift velocity is affected by the residual magnetic field in the cell volume
- A parametrization of the cell response based on a GARFIELD simulation can be used in the reconstruction: $x = f(t_{drift}, \alpha, B_{wire}, B_{norm})$

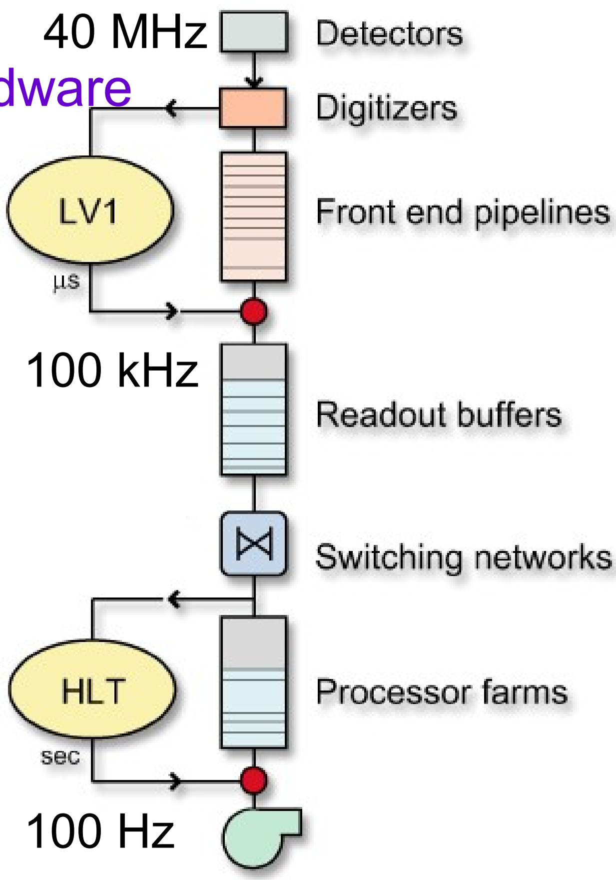





#
events / 2GeV
180
160
140
120
100
80
60
40
20
0
0
10
20
30
40
50
60
p_T of CR-track at innermost muonstation [GeV]
data B≈3.67T
cosmic MC with nominal B
(data normalized to MC)
at low energies differences also possible due to >7GeV in MC

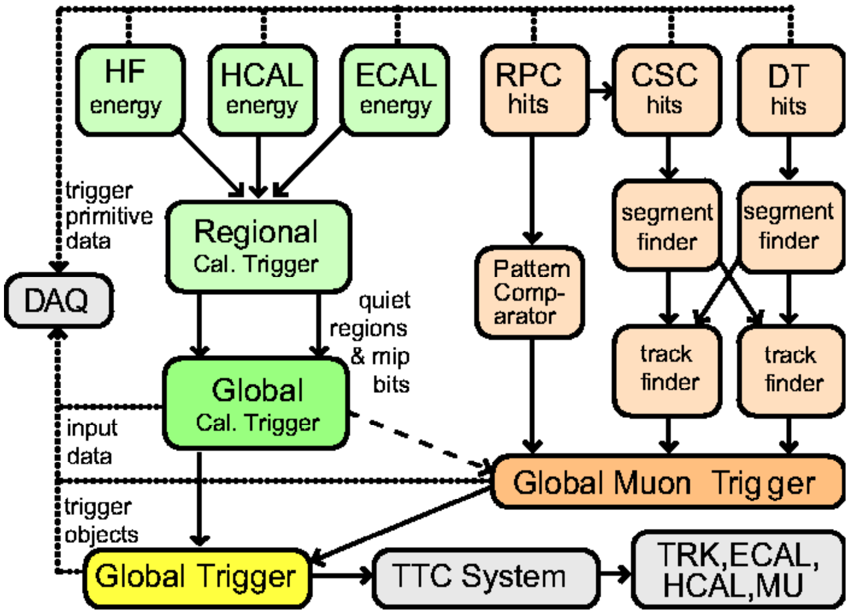
CMS Trigger Design

- 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



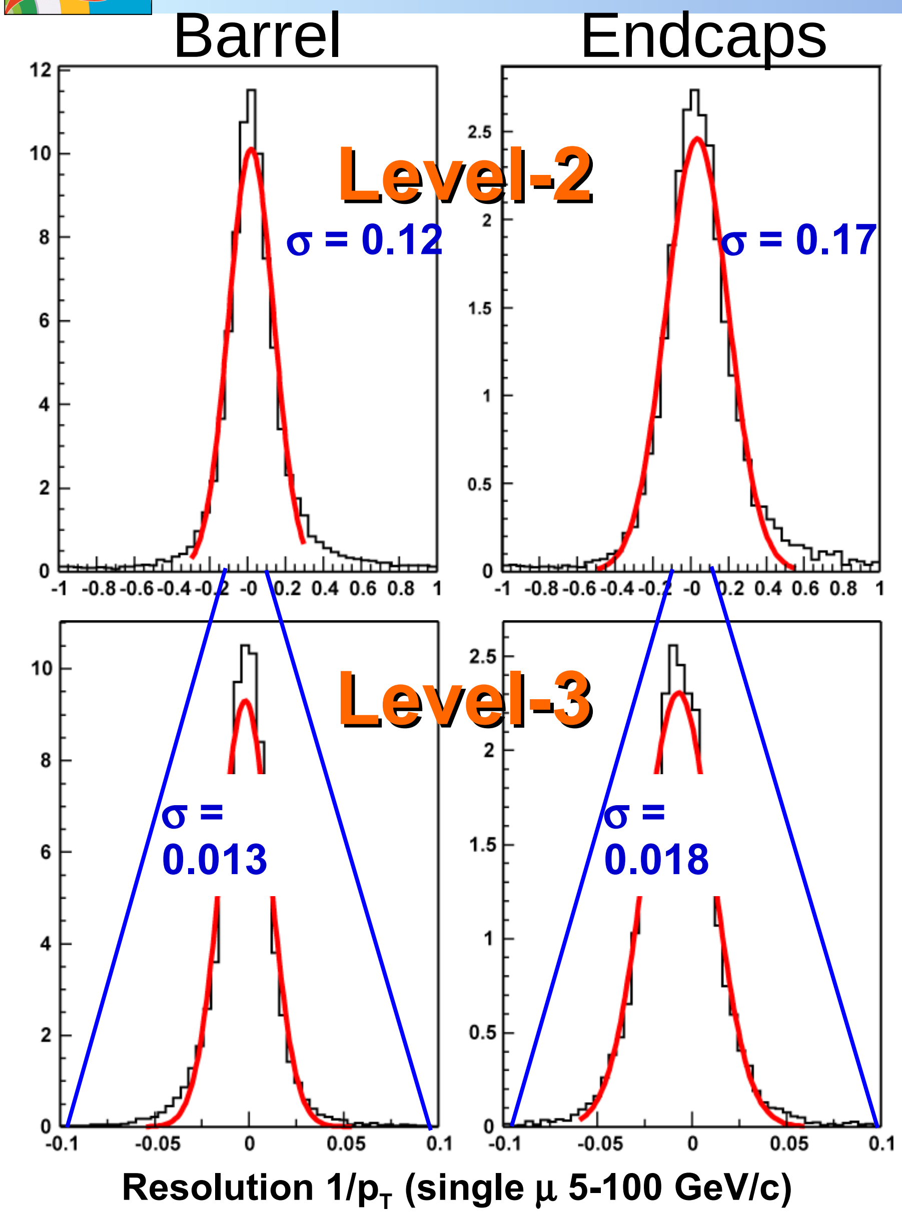
L1 Trigger General Design

- Implemented on custom hardware
  - minimal dead time
- Synchronous, pipelined (25 ns)
  - delayed by 3.2 μs = 128 BX including propagation (~1-2 μs)
- Max output ≡ max DAQ input
  - Design: **100 kHz**; at startup: 50 kHz
- 2 Subsystems
  - **Calorimeter Trigger**
  - **Muon Trigger**
  - Result: jet, e/γ, μ, τ jet candidates; E_T^{miss}, ΣE_T



- No local decisions; selection by the "**Global Trigger**"
  - 128 simultaneous, programmable algorithms, each allowing:
    - Thresholds on single and multiple objects of different type
    - Correlations, topological conditions, Prescaling

HLT Performance: Resolution



- Good resolution
- Tails under control
  (very important for trigger rates)

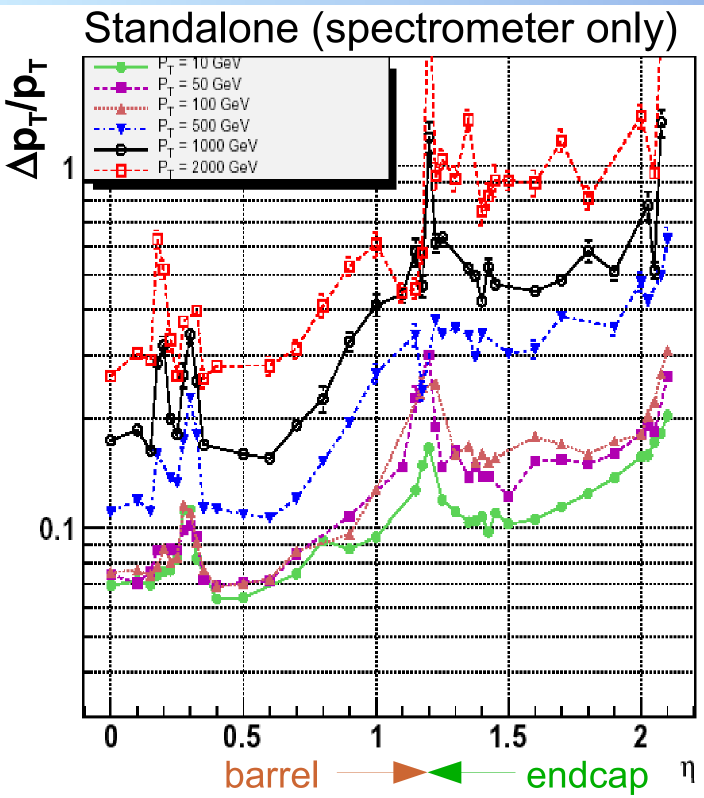
Level-2

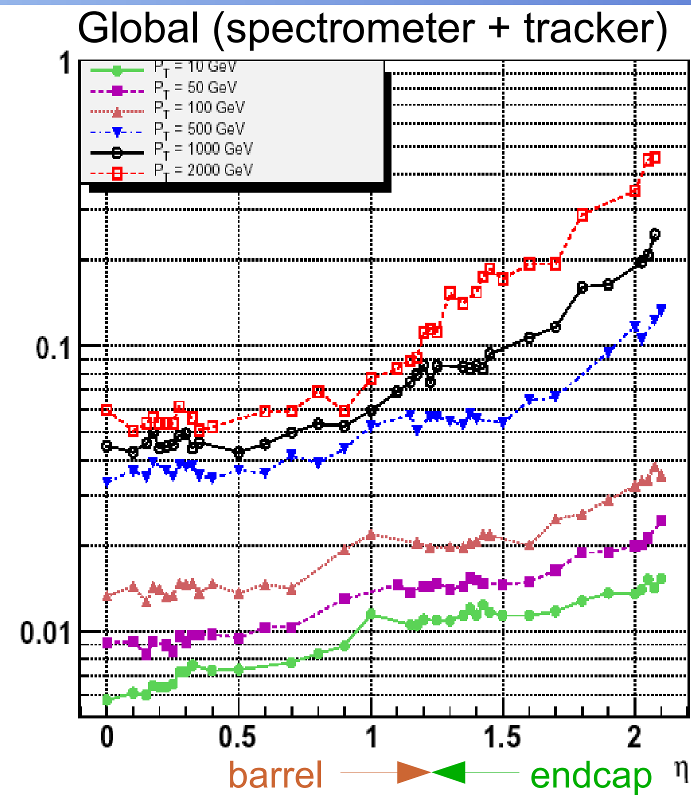
resolution x 10

Level-3

- Big improvement using tracker hits

Off-line Performance: Resolution





- η dependency due to solenoidal B field
- High p_T muons (~1TeV):
  - showering in the chambers → difficult Local Reconstruction
  - energy loss → bias

  New reconstruction strategies under study