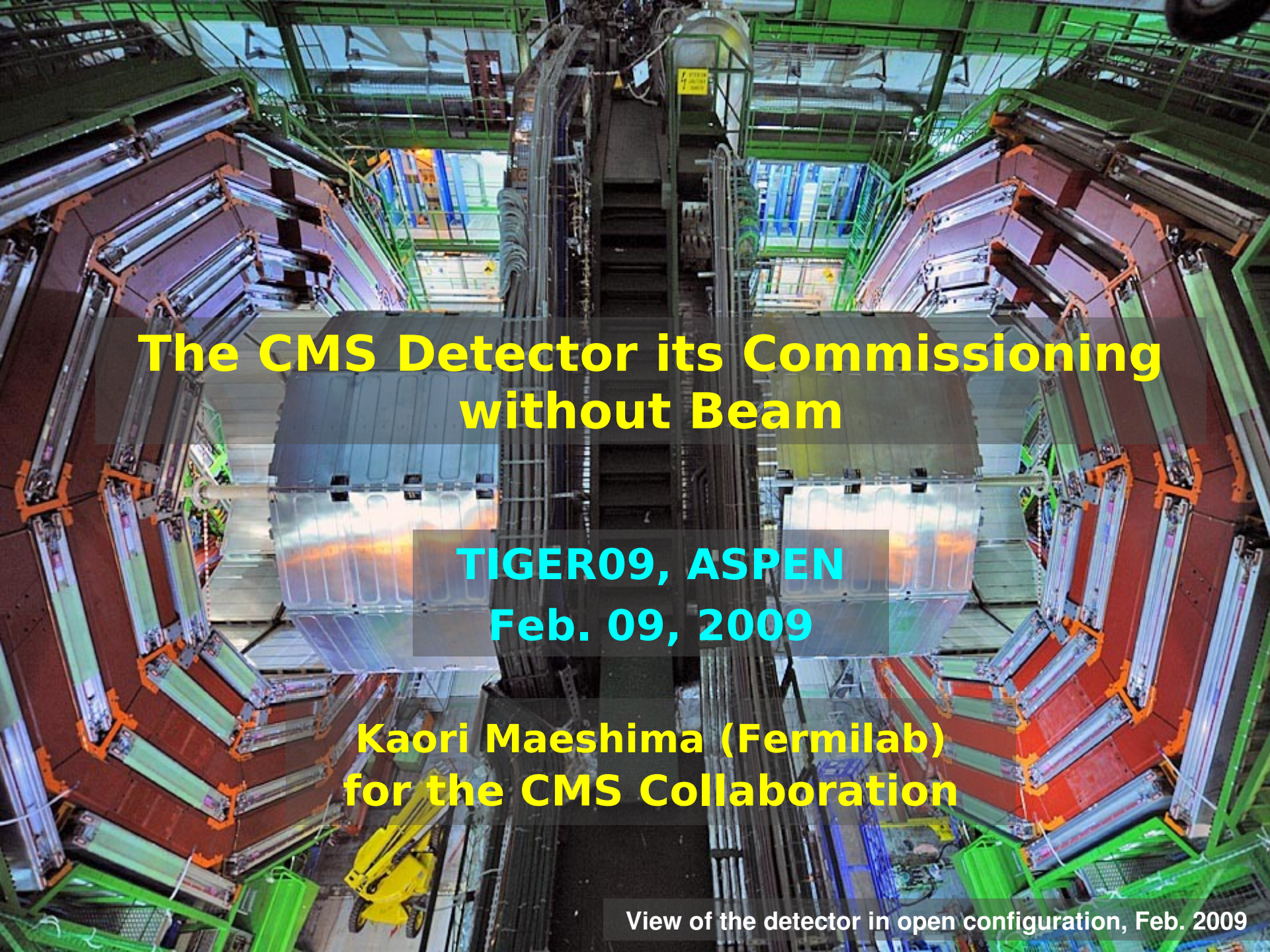


The CMS Detector its Commissioning without Beam

TIGER09, ASPEN
Feb. 09, 2009

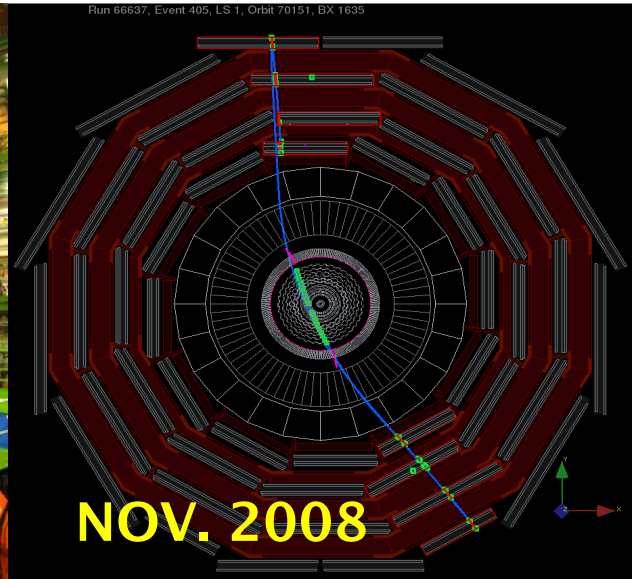
Kaori Maeshima (Fermilab)
for the CMS Collaboration

View of the detector in open configuration, Feb. 2009

Unique CMS Installation/commissioning – Challenge

- **Tight underground experimental hall construction schedule and size**
  - **2006: Magnet and detectors were assembled & tested (MTCC- magnet test cosmic challenge) in the surface assembly hall.**
  - **2007 (heavy lowering) : the heavy detector components must be lowered/installed in ~ 1 year time, in order to be ready for the 2008 LHC start-up schedule.**
  - **2008: lighter installation (tracker, pixel, endcap-ECAL, beam monitors, etc.) & commissioning/operation took place with increasing complexity step by step.**
    - **CRUZET (Cosmic RUn at Zero Tesla) 1-4**
    - **Run with beam** ← See Maria Chamizo Llatas' talk
    - **CRAFT (Cosmic Run At Four Tesla)**

Pictures taken at the CMS Underground Experimental Area



CMS detector

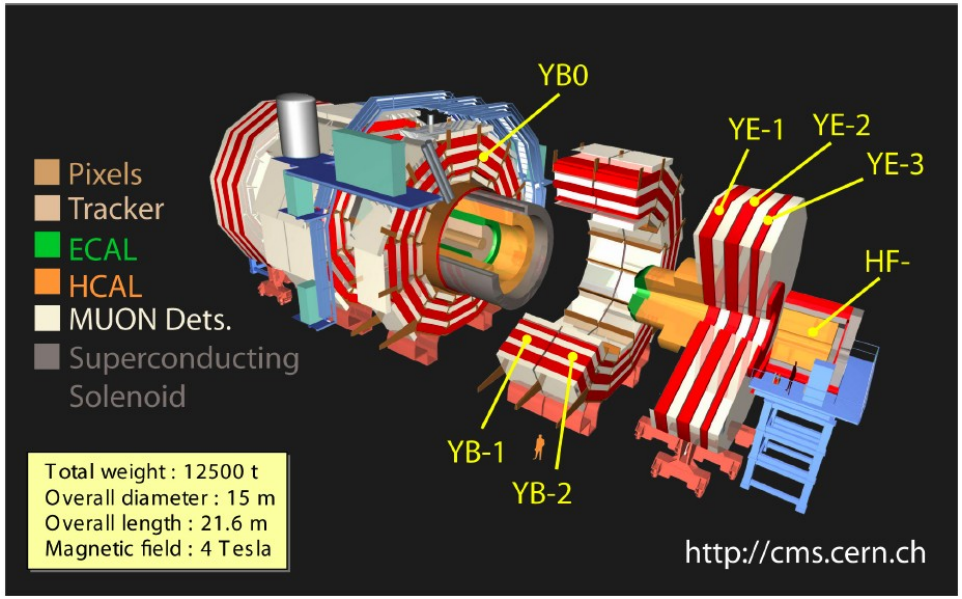
Super Conducting Solenoid

All central tracking and calorimetry inside the magnet
Enormous dimensions 13m long, 6m diameter
and strong field (4T)

Tracking System

Si-Pixel Detector with 66M pixels (100 *150 μm2)
3 Barrel layers at radius 4,7,11 cm
and 2*2 Endcap wheels

Si-Strip Detector with 10M strips in 10 layers and > 200 m2 of Silicon



Muon system

Redundant precision measurements inside an instrumented iron yoke
4 Stations of Drift Tubes (DT) in Barrel
- Endcap Cathode Strip Chambers (CSC)
Interleaved RPC trigger layers
(6 in the barrel, 3 in the endcaps)

Electromagnetic Calorimeter

Highly granular with ~ 83000 PbWO4 crystals
25 X0 for perp. passage

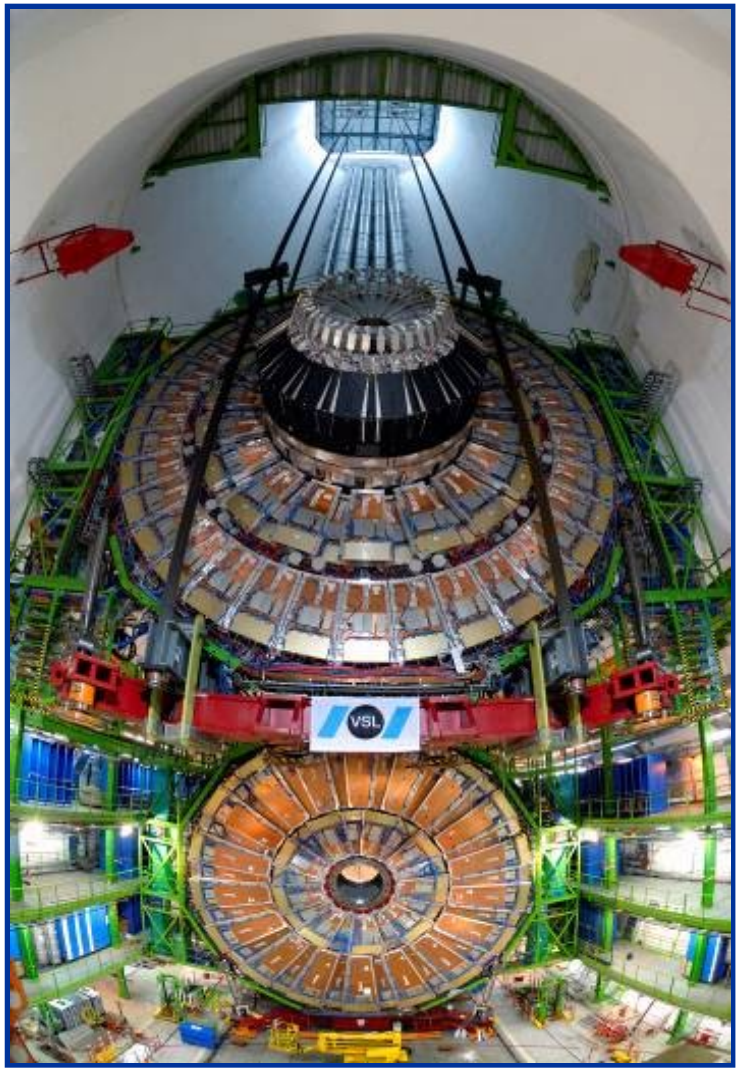
Hermetic Hadronic Calorimeter

with Barrel, Endcap (Brass-Scintillator)
and Forward (quartz fiber/steel) sections

Assembly and lowering

CMS is the first large HEP detector that has been assembled, cabled and tested on the surface and then brought underground

- Disentangle civil engineering underground from detector construction
- Less space requirements underground
- Heavy lowering is a mature and safe technique with careful planning/execution.
- Requires doubling some infrastructure on the surface for testing

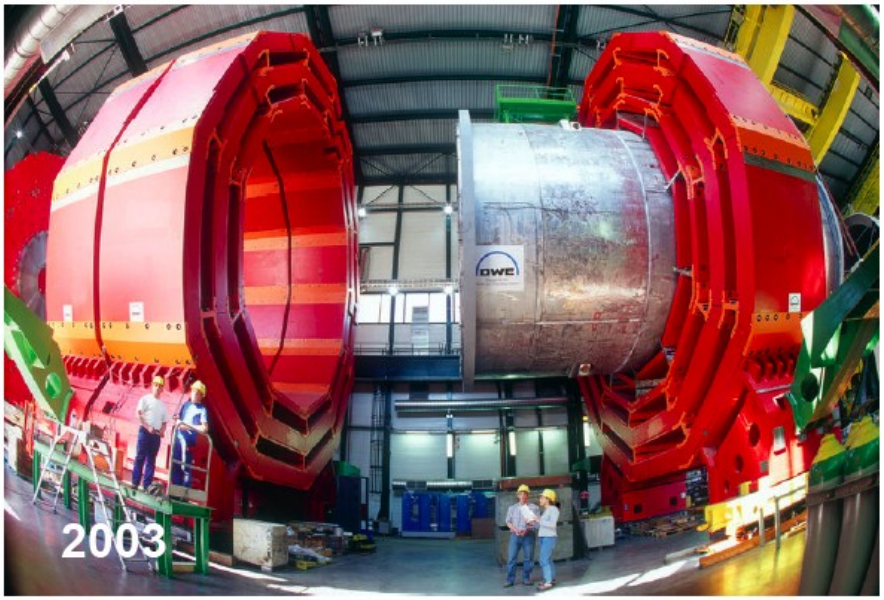


15 heavy lowerings of objects of 380 -1920 tons
YE1 most difficult: Mass 1430 tons, Nose of 465 tons out of plane of disk
–center of gravity in front of the plane.

Detector can be opened along the beam pipe

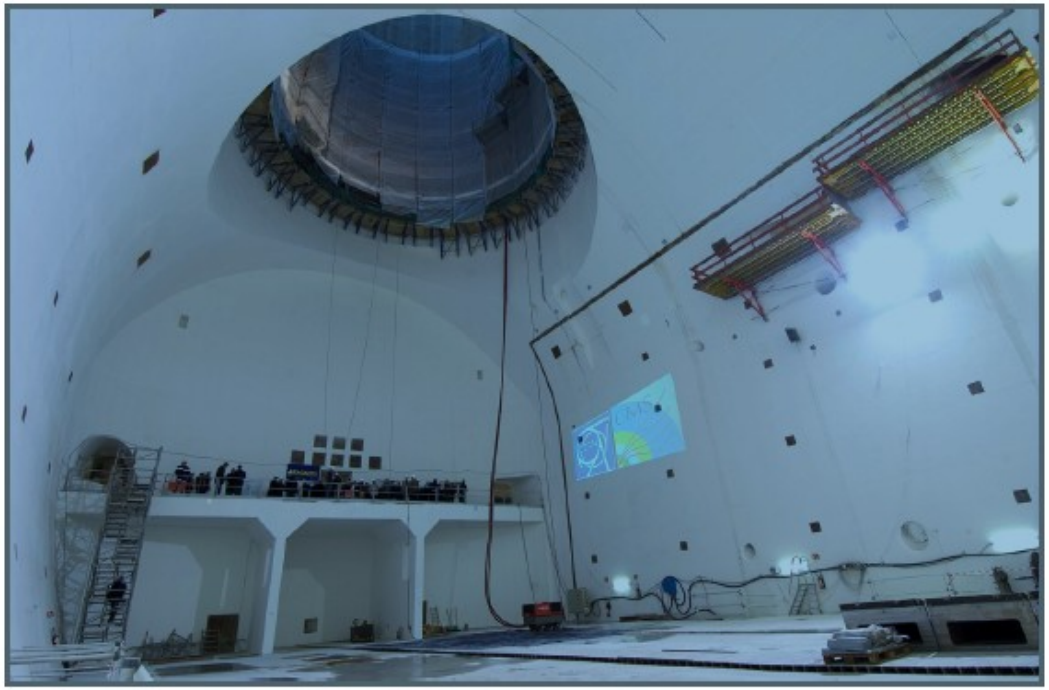
- Large pieces slide on air pads and grease pads
- Any single detector can be accessed and changed underground

Surface and Underground, 2003



Surface & Underground 2004/05

First elements of CMS were lowered
Into underground cavern in late 2006



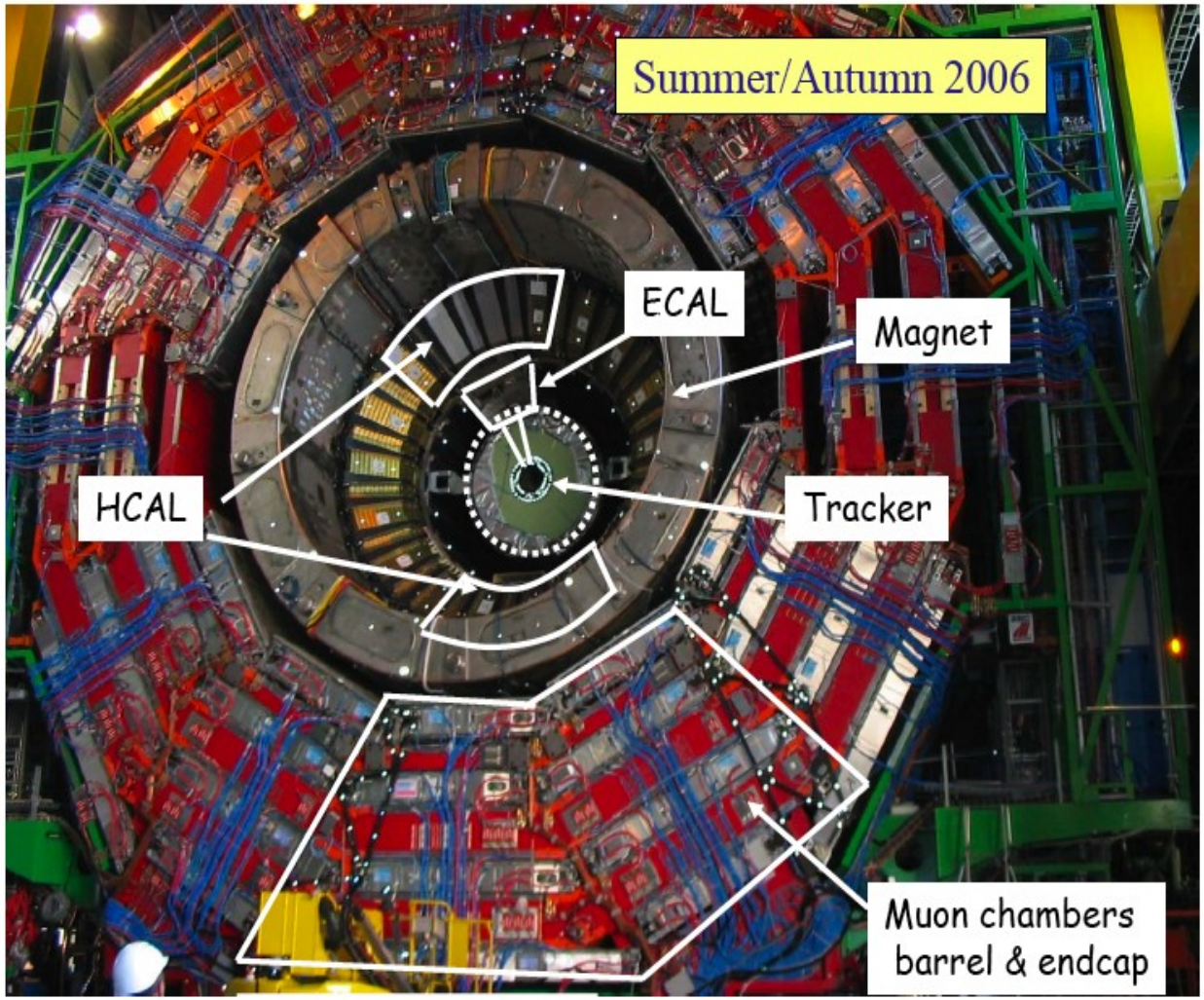
Magnet Test & Cosmic Challenge (MTCC), 2006

First CMS system test: June/November 2006

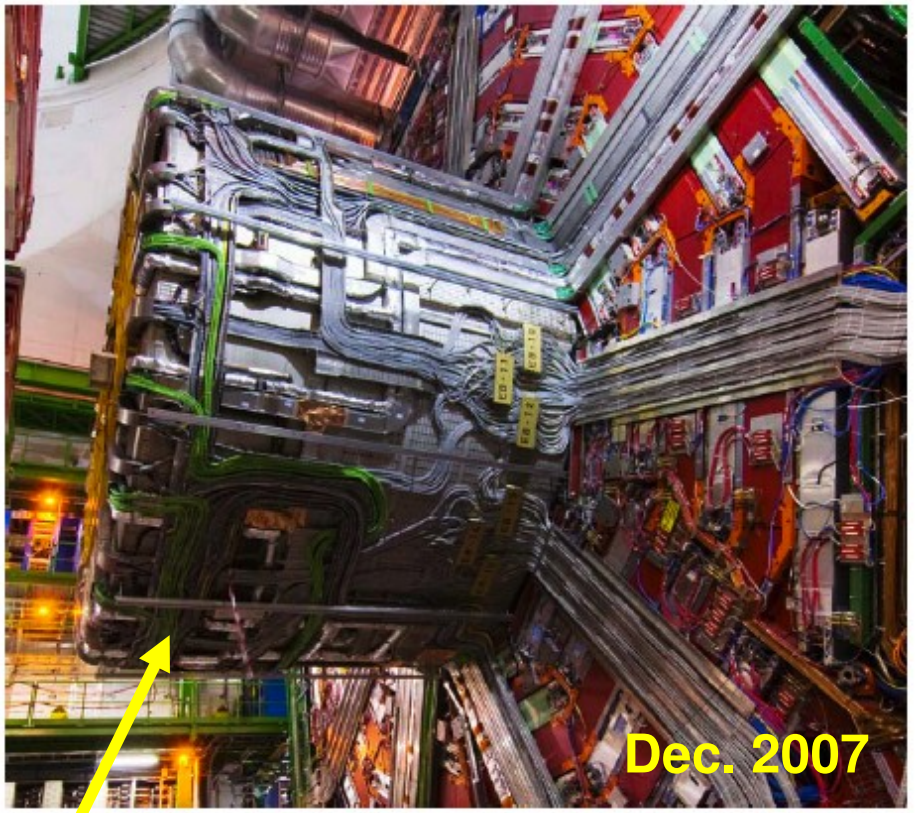
Surface testing and field-mapping of magnet

Parasitic system test, with elements of all subsystems plus central trigger & DAQ at nominal field

Investment in surface infrastructure, DAQ, rack & control rooms

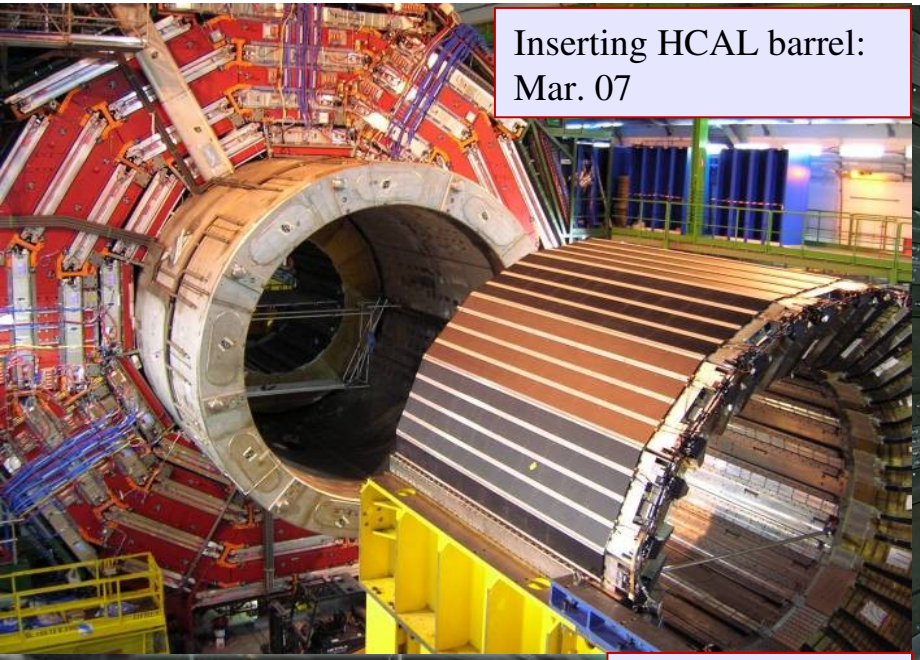


YB0 lowered on 28 Feb. 2007



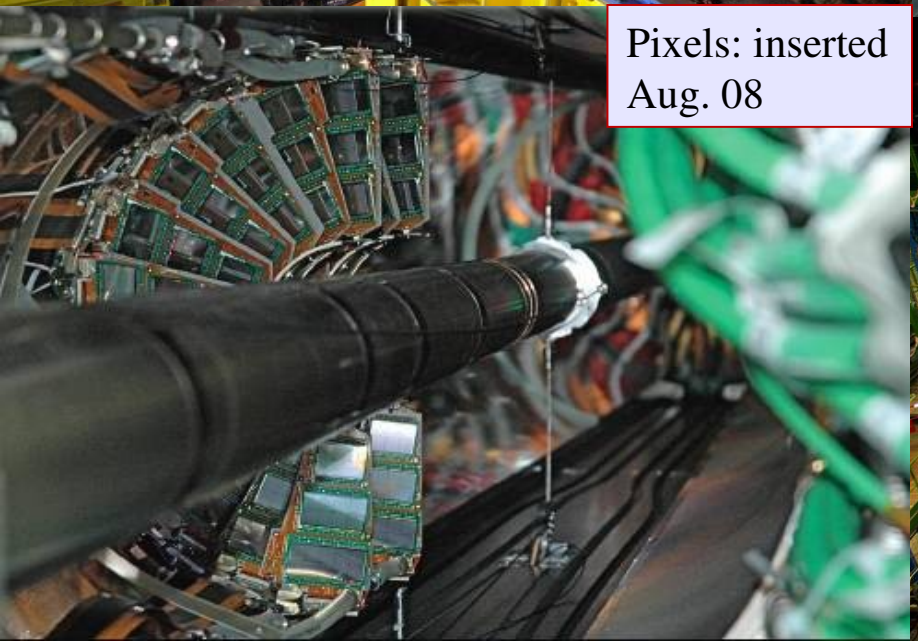
All services for Pixel, Tracker, ECAL and HCAL have to go over the vacuum tank
Approx.: 250 Km cables, pipes and fibers
6100 cables, 700 fibers,700 cooling pipes
50000 hours of work in 8 months
Peak times with ~100 people working in parallel

Installing Detectors Inside the Magnet

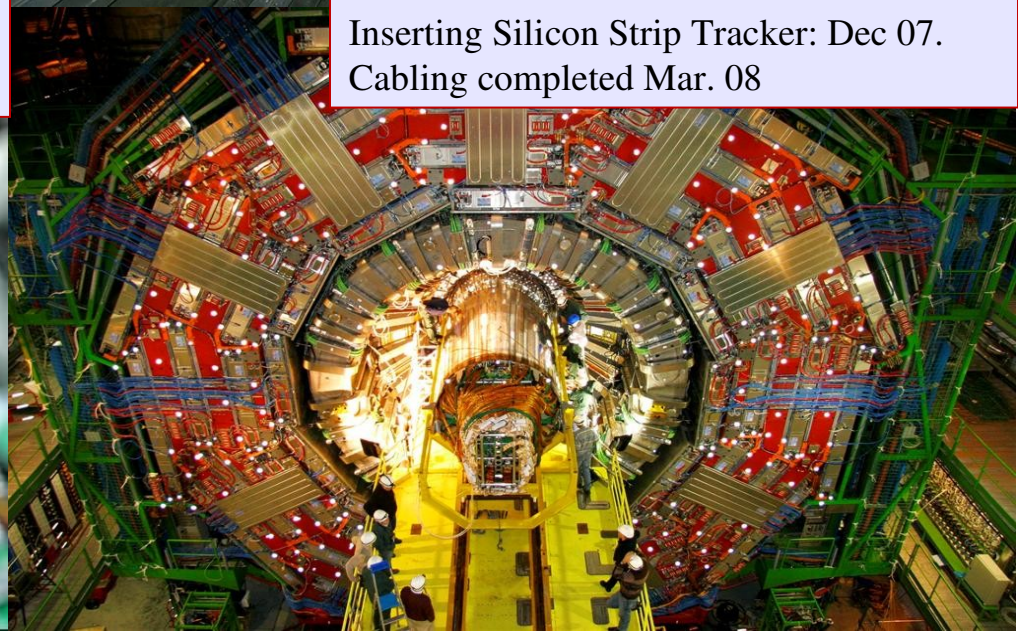


Inserting HCAL barrel: Mar. 07

Installing ECAL Barrel: ended July 07



Pixels: inserted Aug. 08



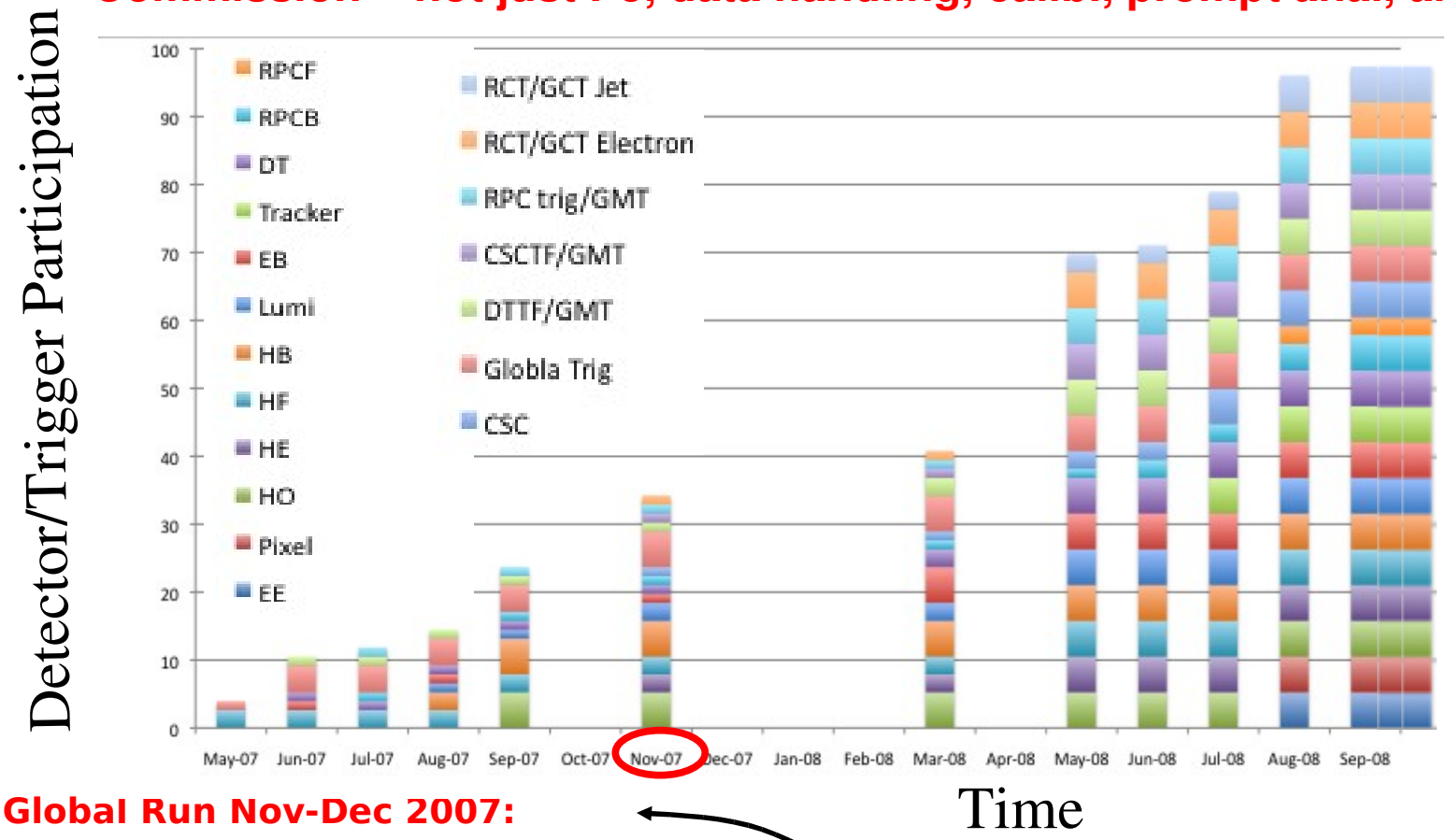
Inserting Silicon Strip Tracker: Dec 07. Cabling completed Mar. 08

CMS in September 2008

- CMS ready for beam, able to operate magnet at 3.8T
- Record long Cosmic Run at Full Field to better understand performance of the detector:

Commissioning: SubDetector operation ⟶ CMS as ONE

Commission - not just P5, data handling, calib., prompt anal, and more..

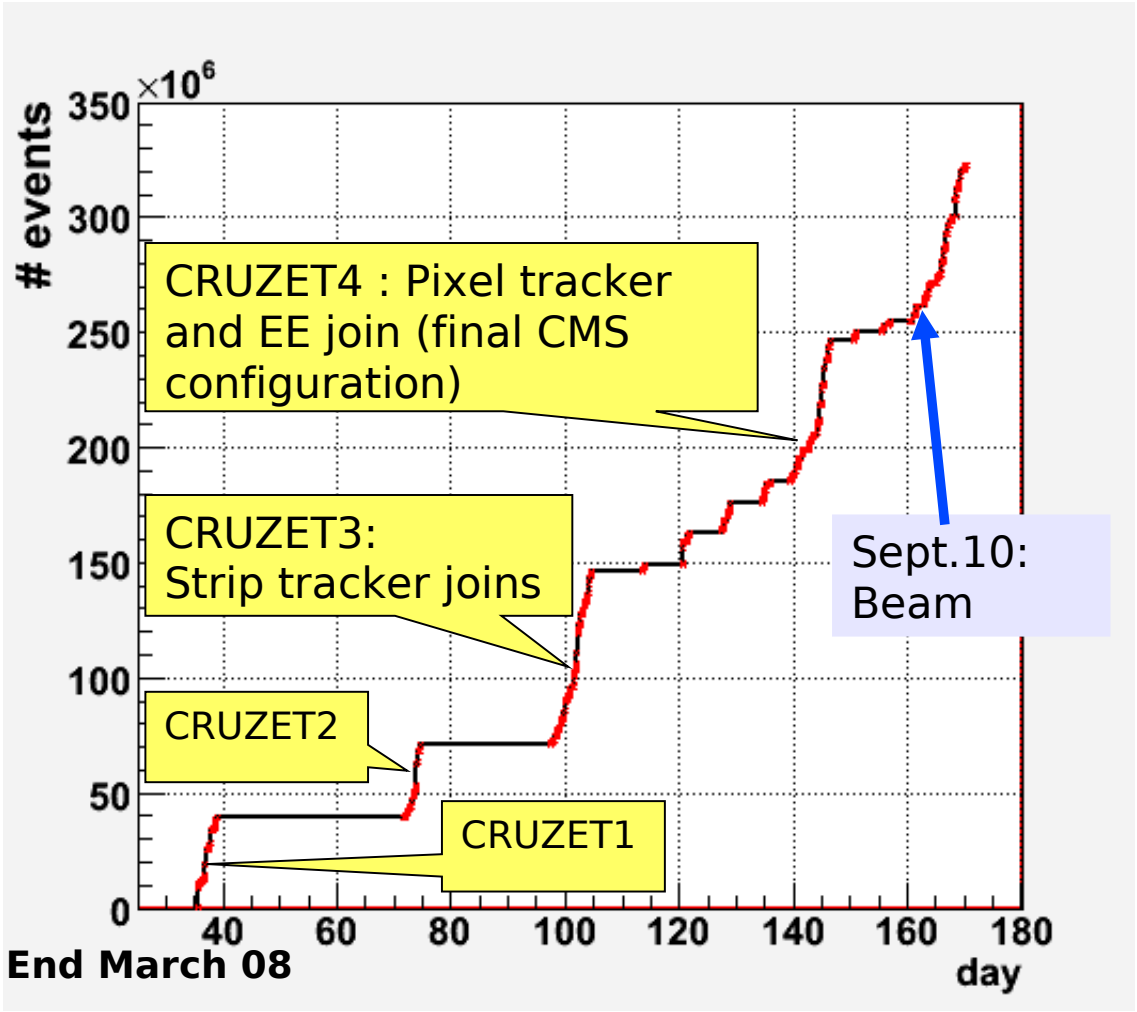


- **Global Run Nov-Dec 2007:**
  - **10M events in 8 days**
  - **3 TB data volume (raw, reco)**
- **CRAFT Oct-Nov 2008:**
  - **10M events in 10 hours, 2TB/hour**
  - **380 TB data volume (raw, reco, debug) and growing with more datasets**

Global Runs !!!!

CRUZET 1-4 ⟶ Getting Ready for Beam

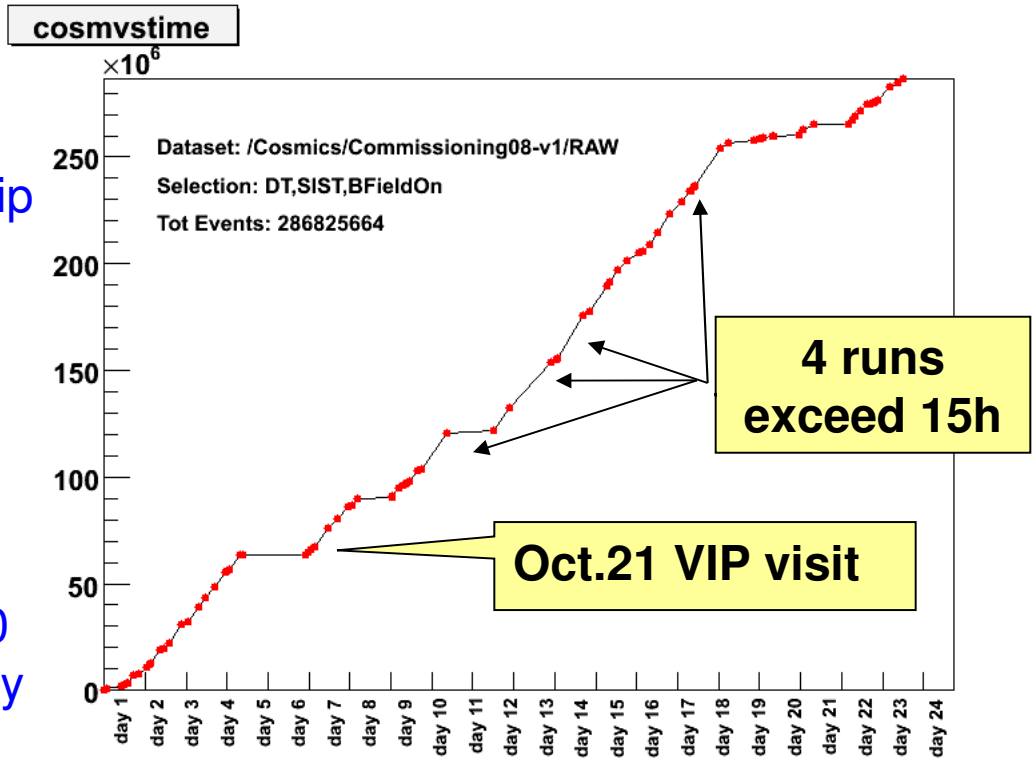
Increasing complexity, yet operate with higher stability



Cosmic Run at Four Tesla (CRAFT)

- Four weeks of continuous running (Oct. 13 – Nov. 11)
  - 19 days with magnet at the operational setting of B=3.8 T
  - Gained operational experience and learn places for future improvements

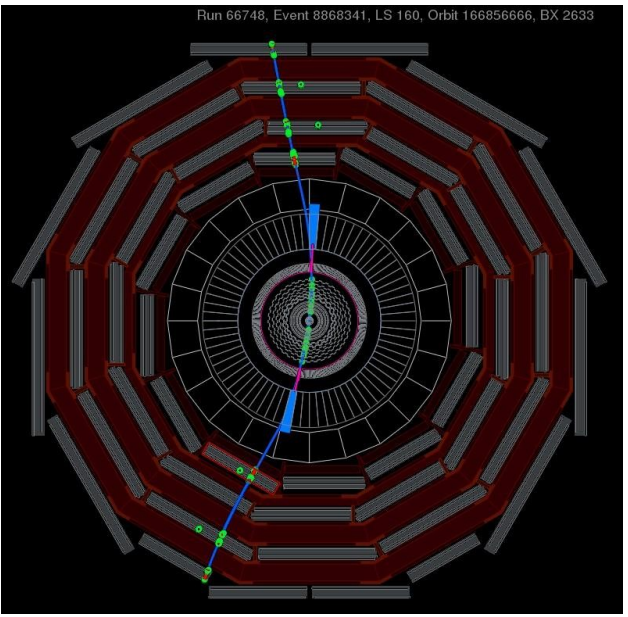
- Collected 370 M cosmic events, out of which 290 M with B = 3.8 T. Of those with magnetic field on:
  - 87% have a muon track reconstructed in the chambers
  - 3% have a muon track with strip tracker hits (~7.5 M tracks)
  - 3 x 10^{-4} have a track with pixel hits (~75K tracks)

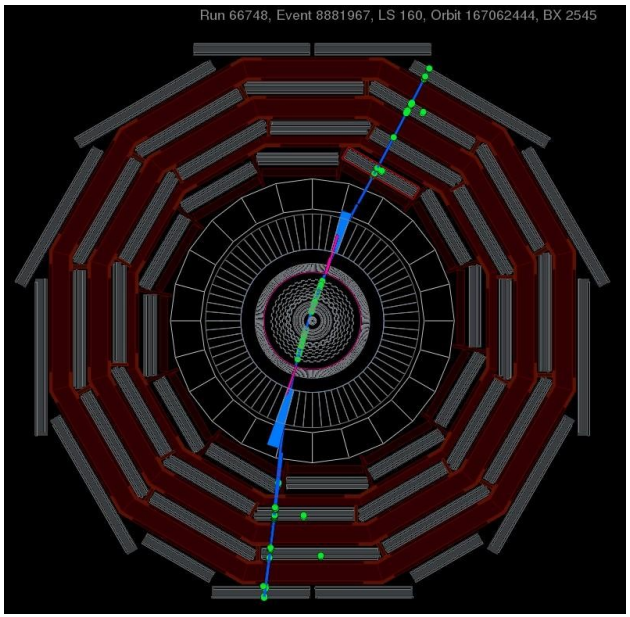


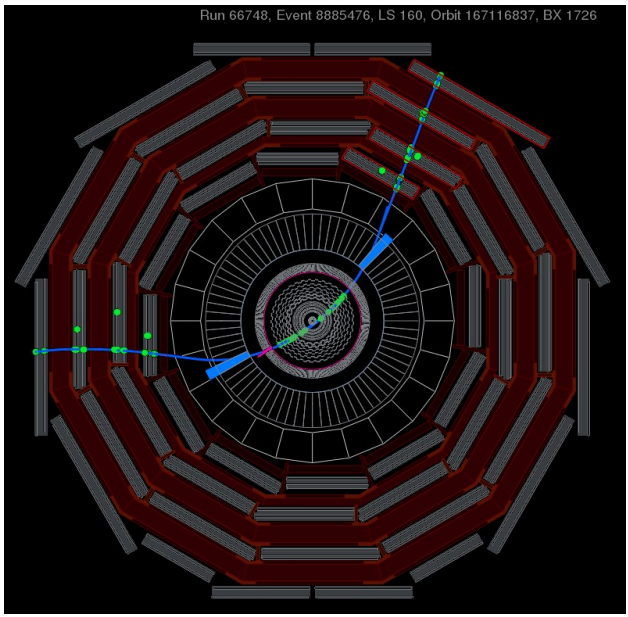
- Data operation performance
  - 600 TB of data volume transferred
  - Prompt reconstruction at Tier 0 completed with a typical latency of 6h

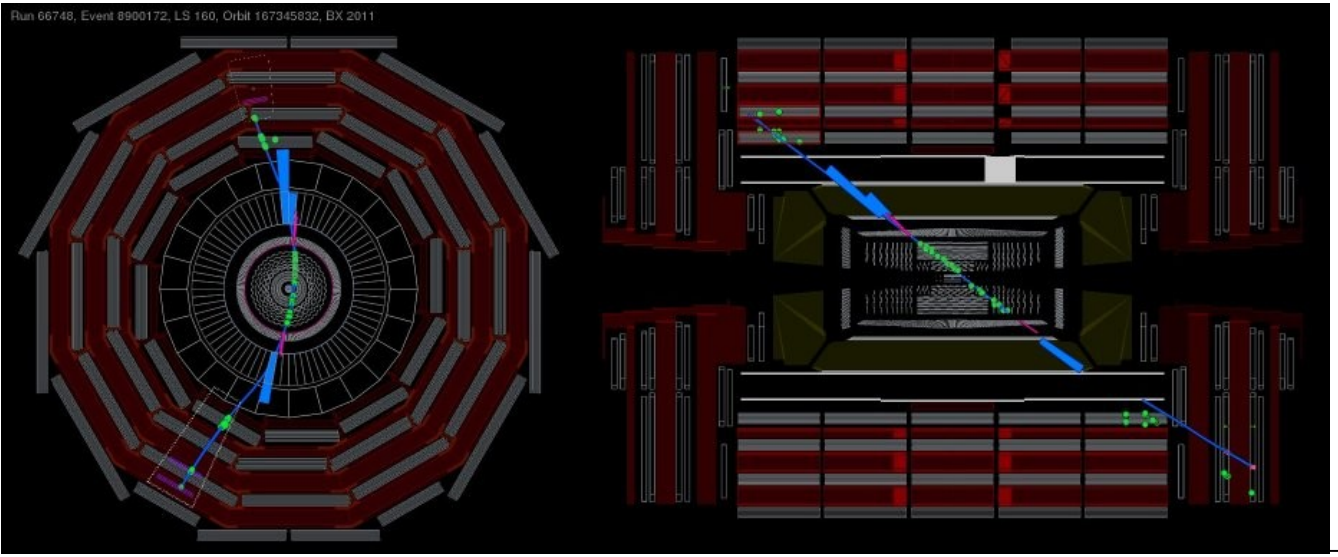
- Offline analysis of collected CRAFT data in in progress
  - finding many useful facts: eg. details of magnetic field affect.....

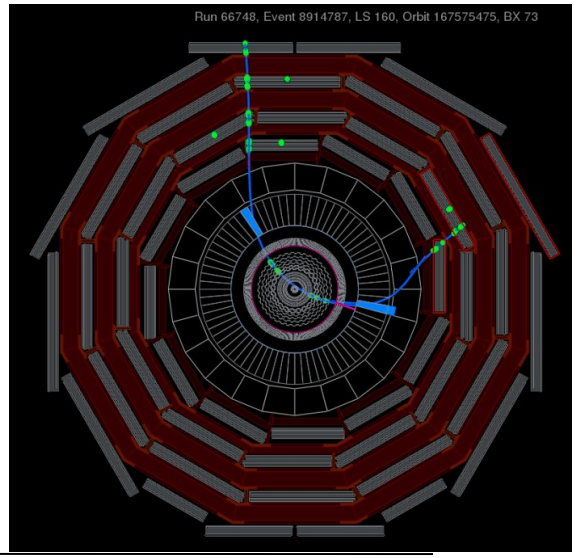
CRAFT - Cosmic Event Displays







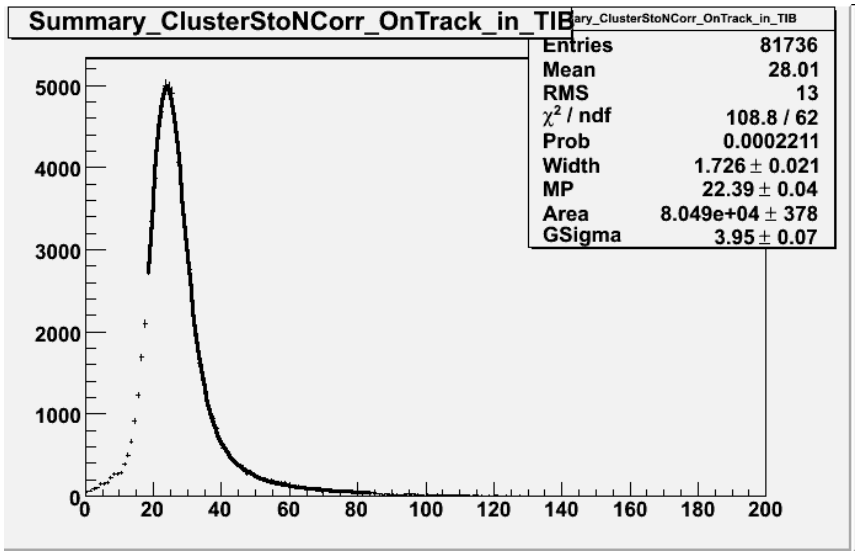




Operational Fraction of Strip and Pixel Tracker

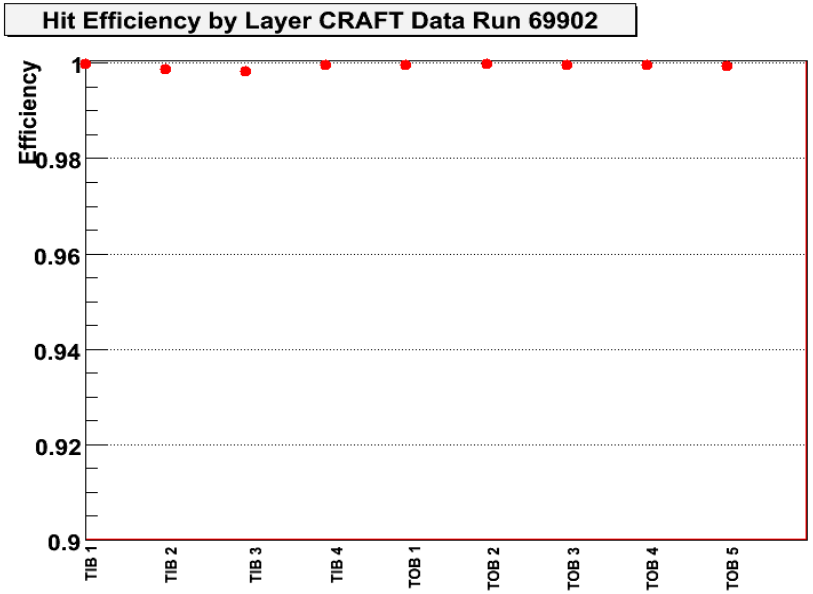
- **Strip Tracker**
  - **TOB: 98.2% (0.6% recoverable)**
  - **TIB/TID: 96.9 % (1% recoverable)**
  - **TEC+: 99.2%**
  - **TEC-: 97.8 % (1.7% recoverable)**
- **Pixels**
  - **Barrel pixels: 99.1%**
  - **Forward pixels: 94.0%**
    - **Dominated by some readout chips without bias voltage and others without low voltage**
    - **Reparation will be attempted during shutdown**

Tracker Performance: Signal/Noise & Efficiency



On track Strip clusters S/N ratio in peak mode of the read-out chip, corrected for the track angle

- **TOB thick sensors : S/N = 32**
- **TIB/TID thin sensors : S/N = 27/25**
- **TEC (mixed thickness) : S/N = 30**

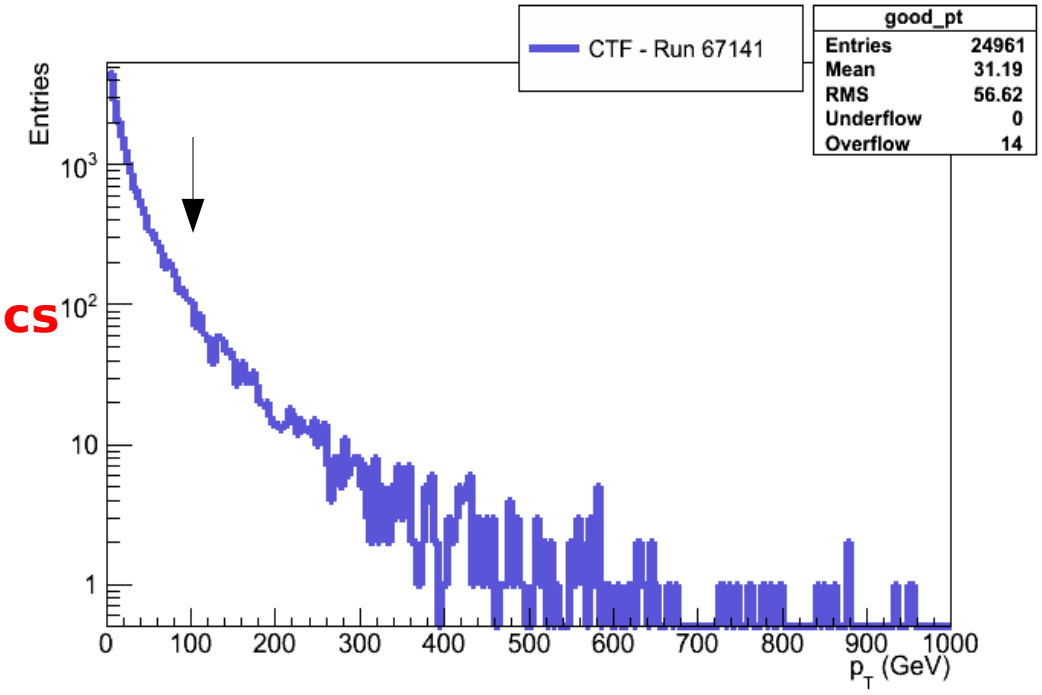


Track hit finding efficiency of TIB and TOB layers, excluding modules not in operation

Cosmic Tracking using Tracker

- **Three tracking algorithm used for track reconstruction, with different acceptance for cosmics:**
  - **Combinatorial Track Finder (CTF standard algorithm for collisions)**
  - **Road Search**
  - **Cosmic Track Finder**
- **Momentum distribution for high quality tracks (partial statistics)**
  - **8 hits**
  - **1 hit in TIB L1/L2**
  - **1 hit in TOB L5/L6**
  - **~70K tracks expected**

  out of full CRAFT statistics with P_T>100 GeV



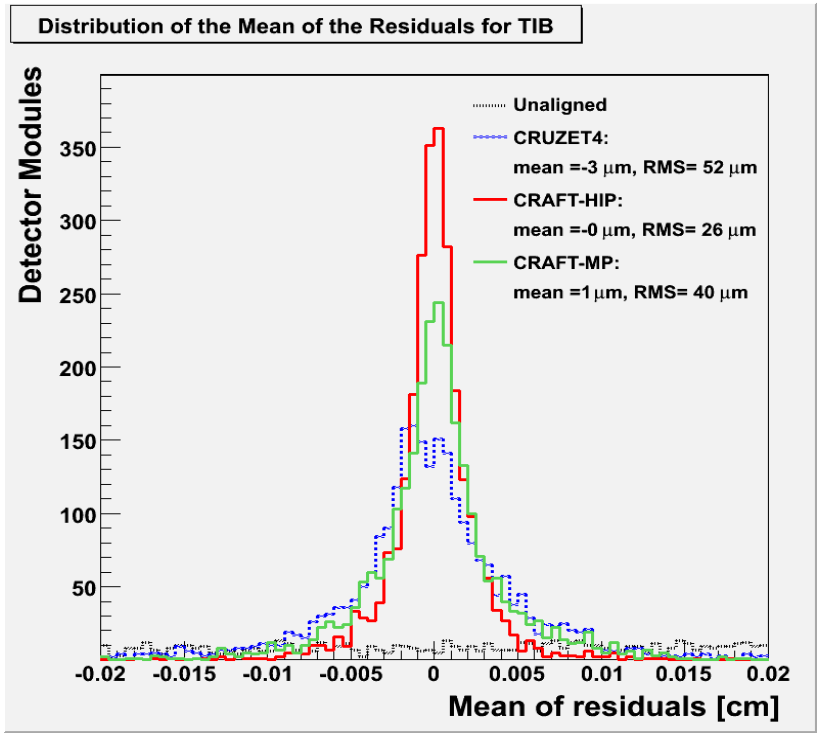
Tracker Barrel Alignment

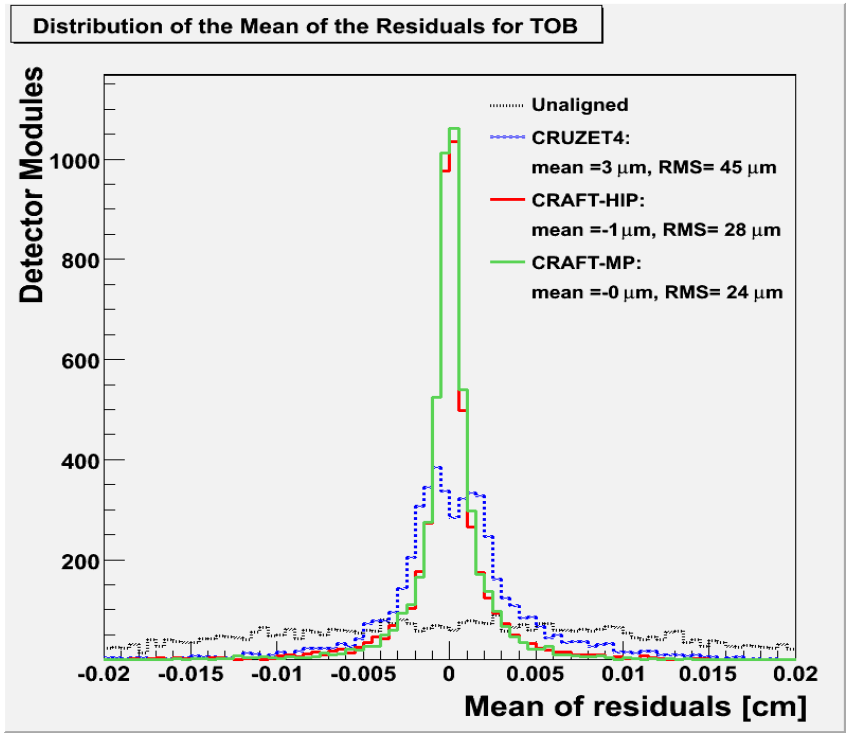
- Use 4M tracks for alignment and 1M for validation
- The second update on alignment constants delivered 1 day after CRAFT ended

Mean of residual distributions (cm), sensitive to module displacements

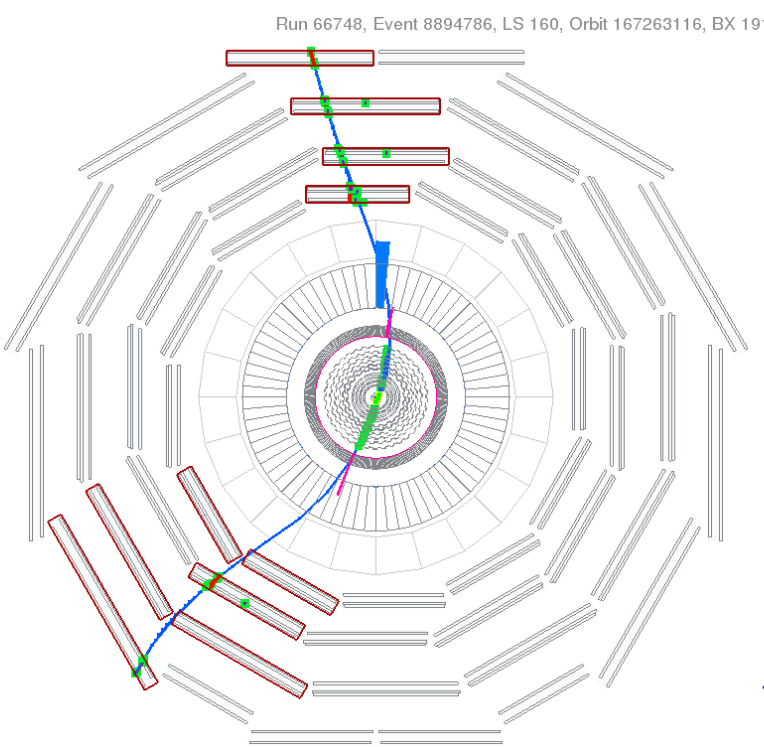
- Only modules with >30 hits considered
- Tracker Inner Barrel RMS = 26µm

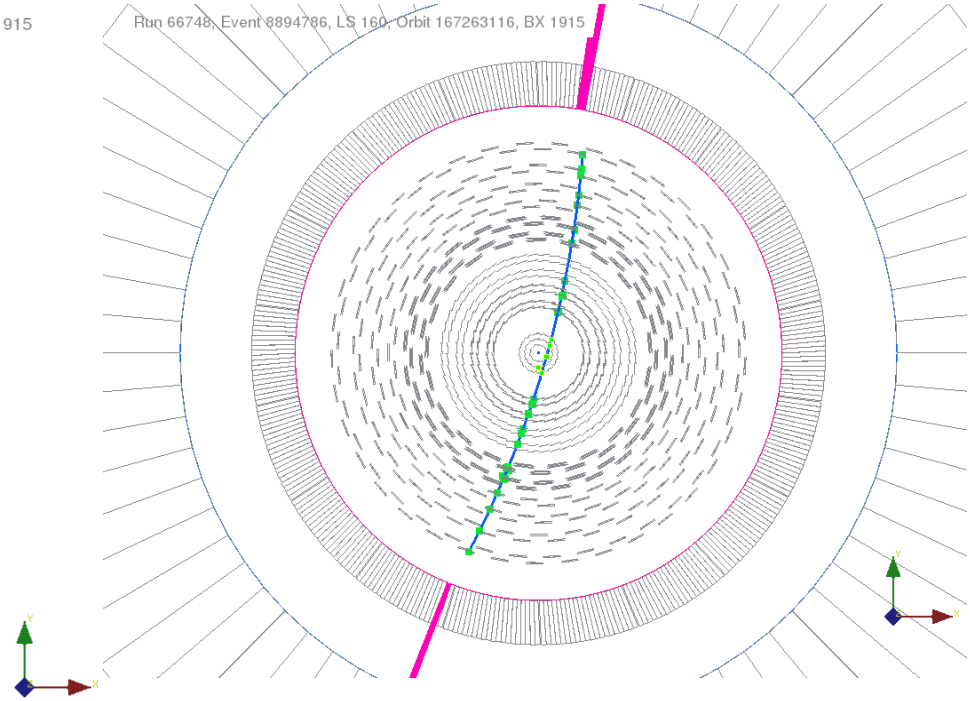
Tracker Outer Barrel RMS = 28µm





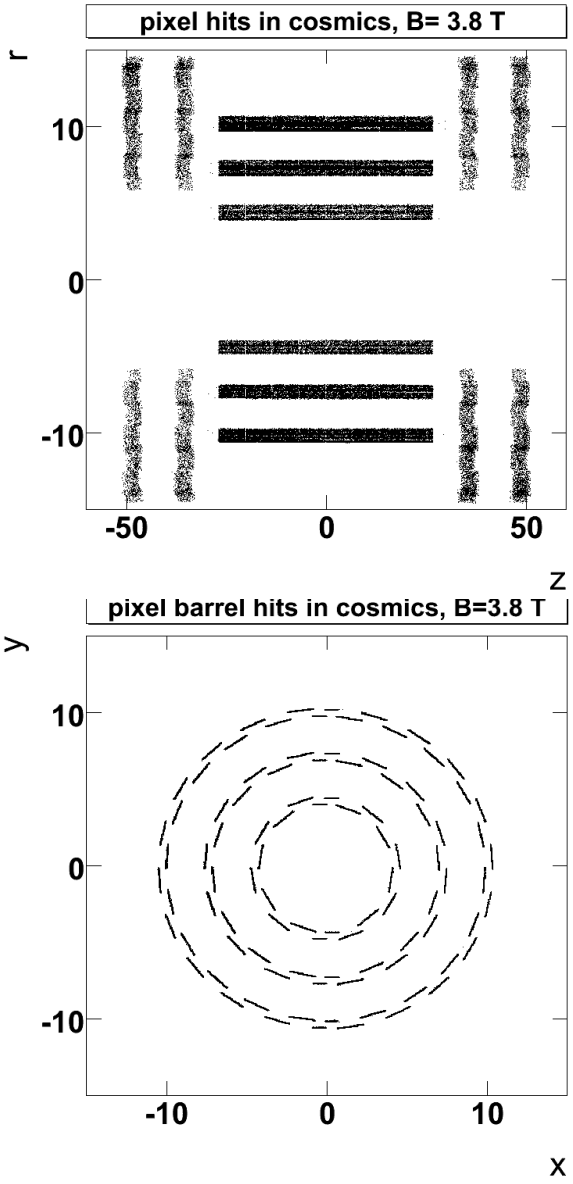
Muon Traversing Pixel Detector

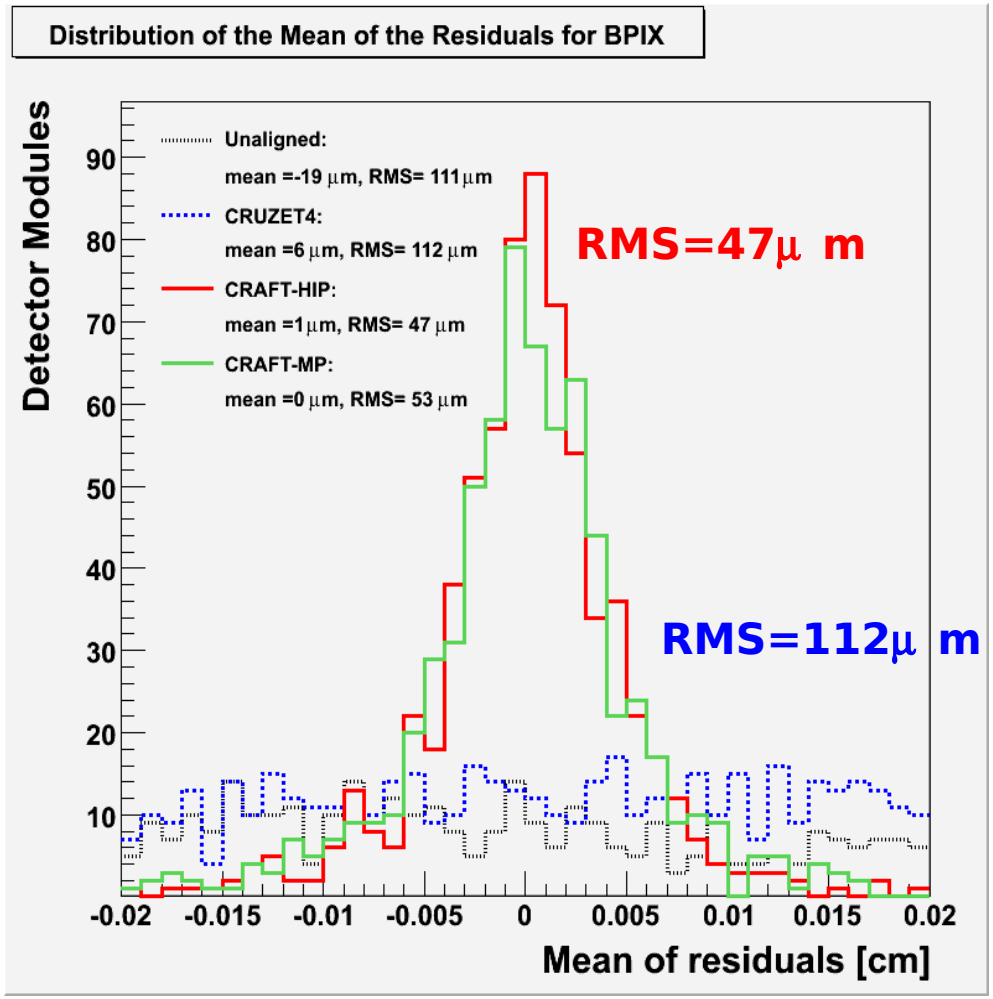




- ECAL in magenta, HCAL in blue, tracker and muon hits in green

Pixel Occupancy and Alignment

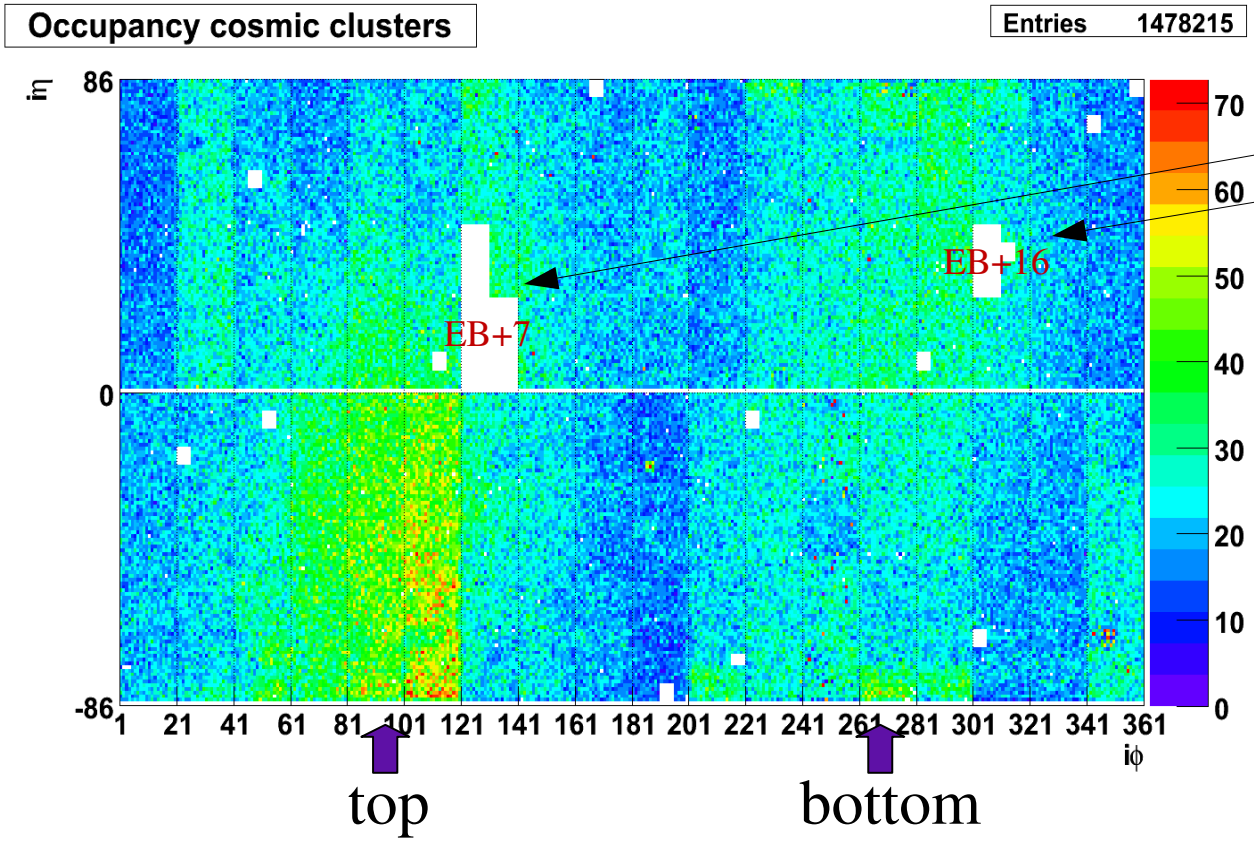




- ~75K tracks yielding 200-300 hits per module in Barrel
- Barrel aligned at module level and endcap at disk level

ECAL Barrel Occupancy

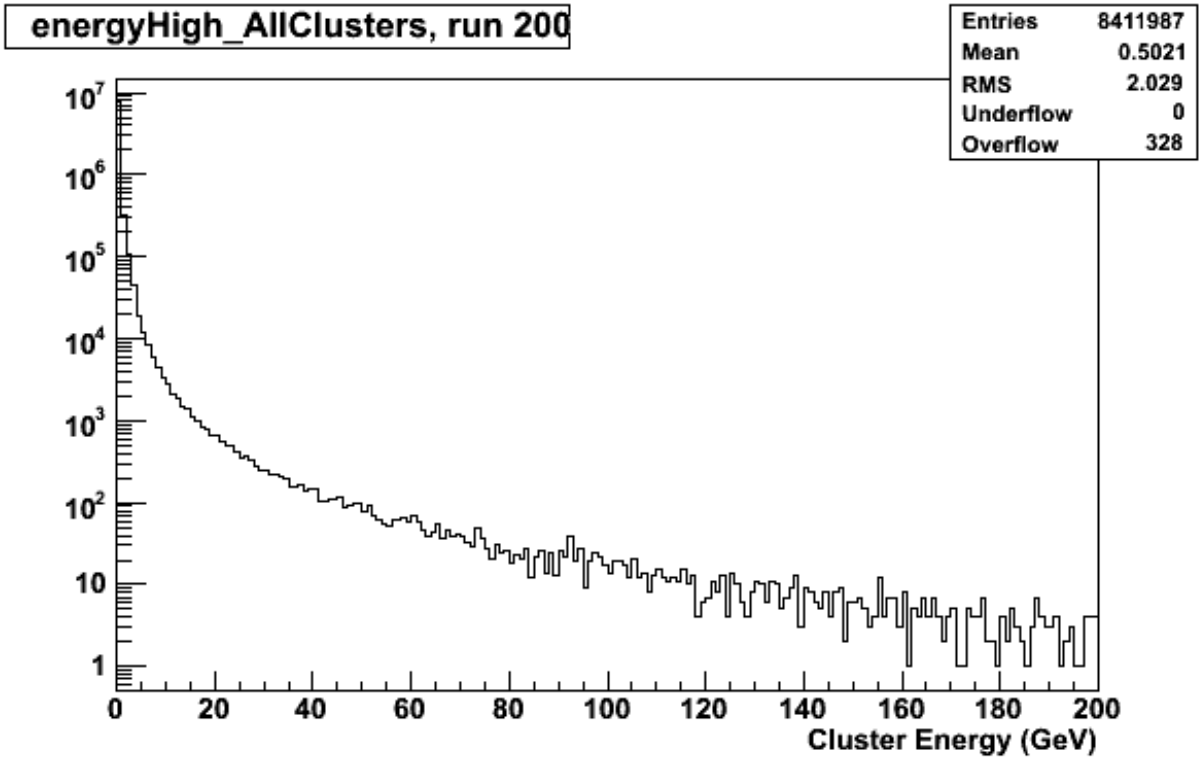
cosmic muon runs with the magnetic field at 3.8T
and the APD gain set to 200 (x4 the LHC conditions).
Clusters are seeded either from a single crystal
above 15 ADC counts (≈(130 MeV)
or from two adjacent crystals above 5 ADC counts (≈2x43 MeV).



LV problems
(being fixed now)

ECAL: Cosmic Energy spectrum

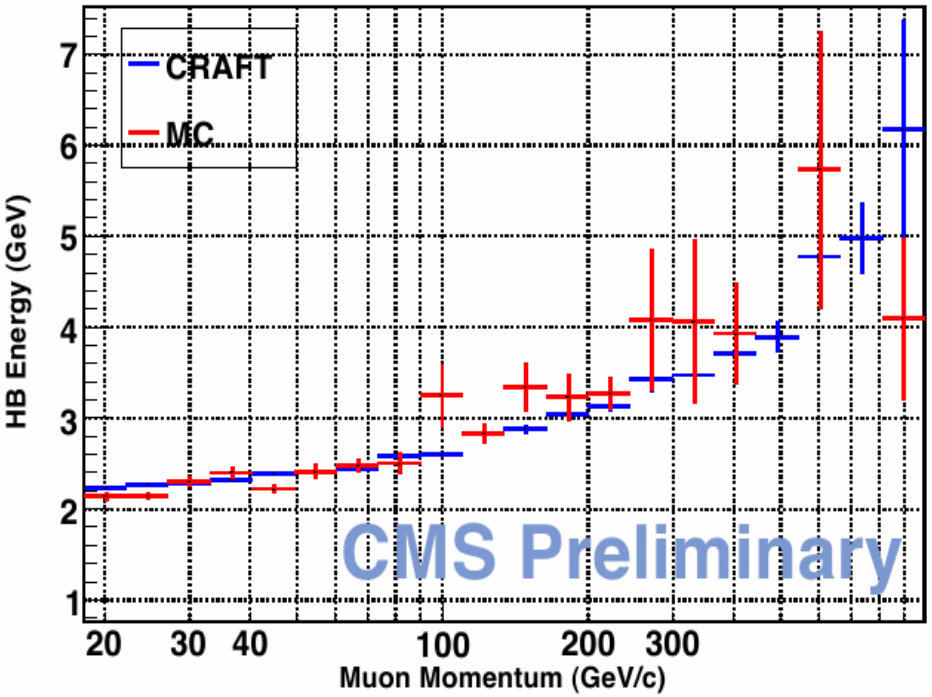
The figure shows the spectrum of energy deposits in the ECAL barrel in cosmic muon runs with the magnetic field at 3.8T and the APD gain set to 200 (x4 the LHC conditions). Clusters are seeded either from a single crystal above 15 ADC counts (≈130 MeV) or from two adjacent crystals above 5 ADC counts (≈2x43 MeV). Energy is obtained summing the energies of all the crystals belonging to a cluster.

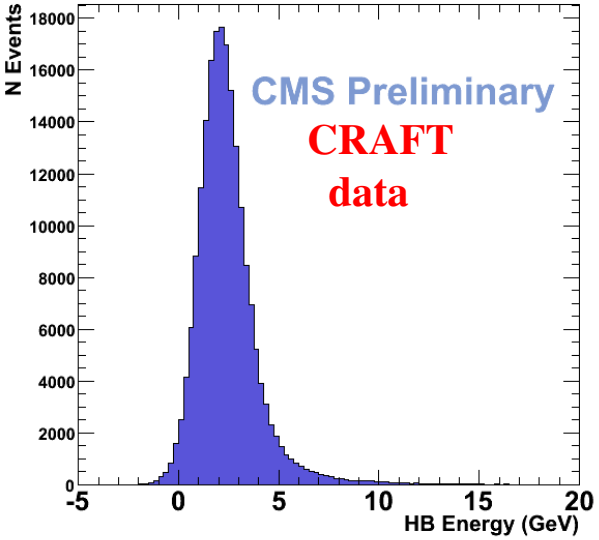


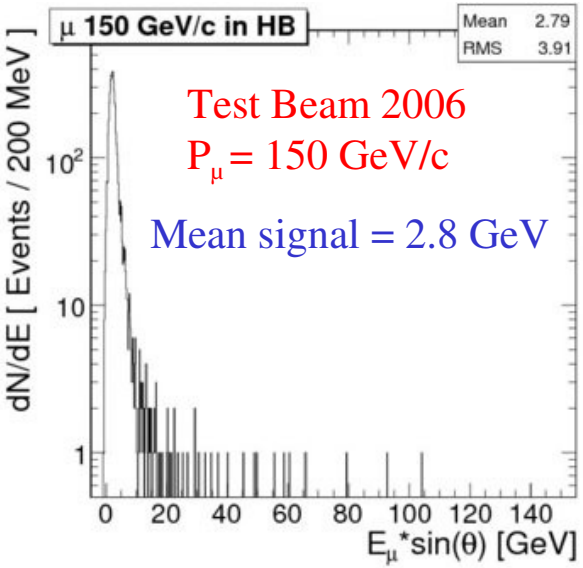
HCAL Barrel Muon Response

- **Event selection:**
  - Muon track matching in DT and Tracker
  - 20 GeV/c < P_μ < 1000 GeV/c
  - CRAFT: 200 K events
  - MC: 15 K events

HB energy: signal from HB towers corrected for muon path length in HB



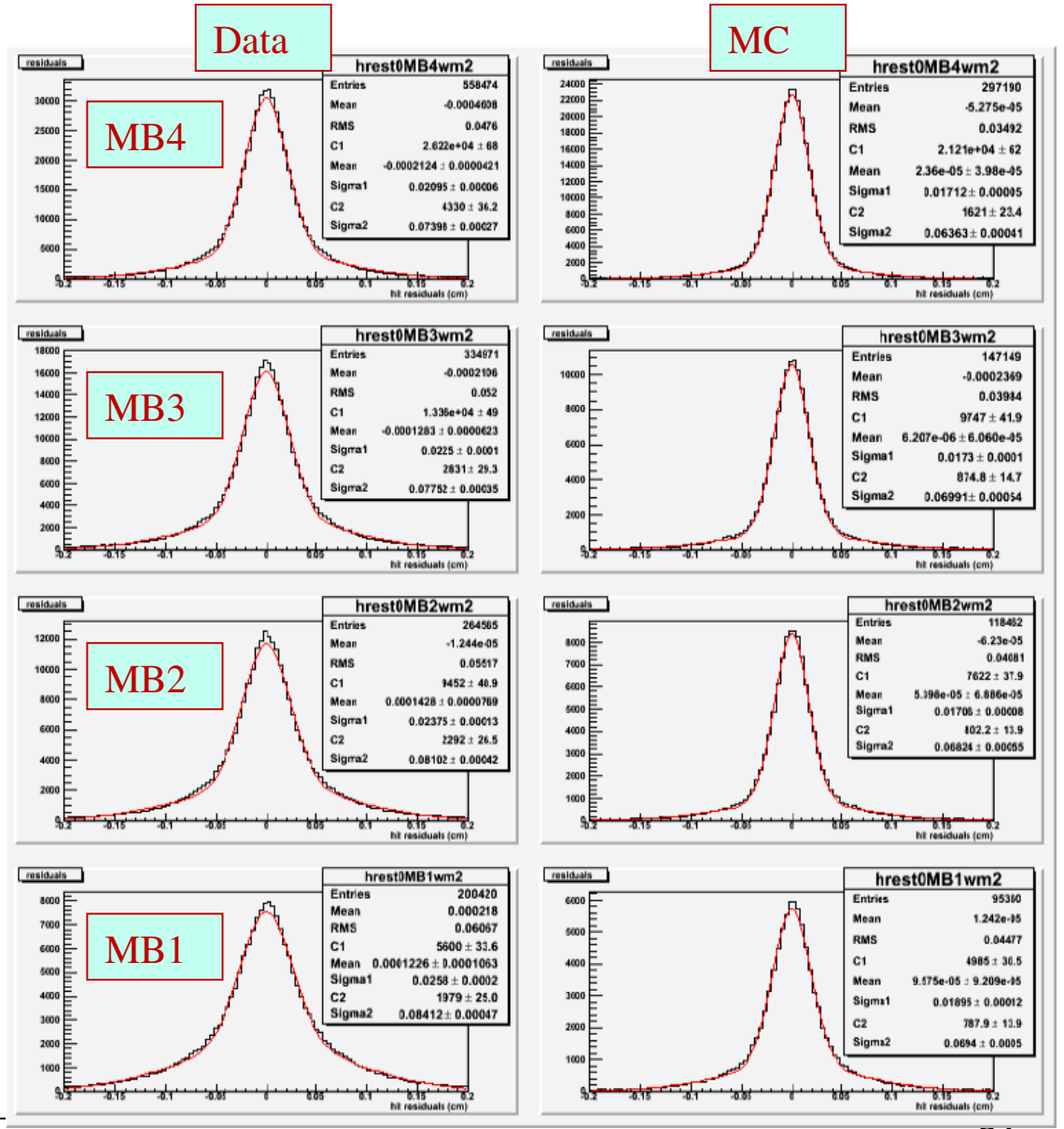




Drift Tube Barrel Muon System

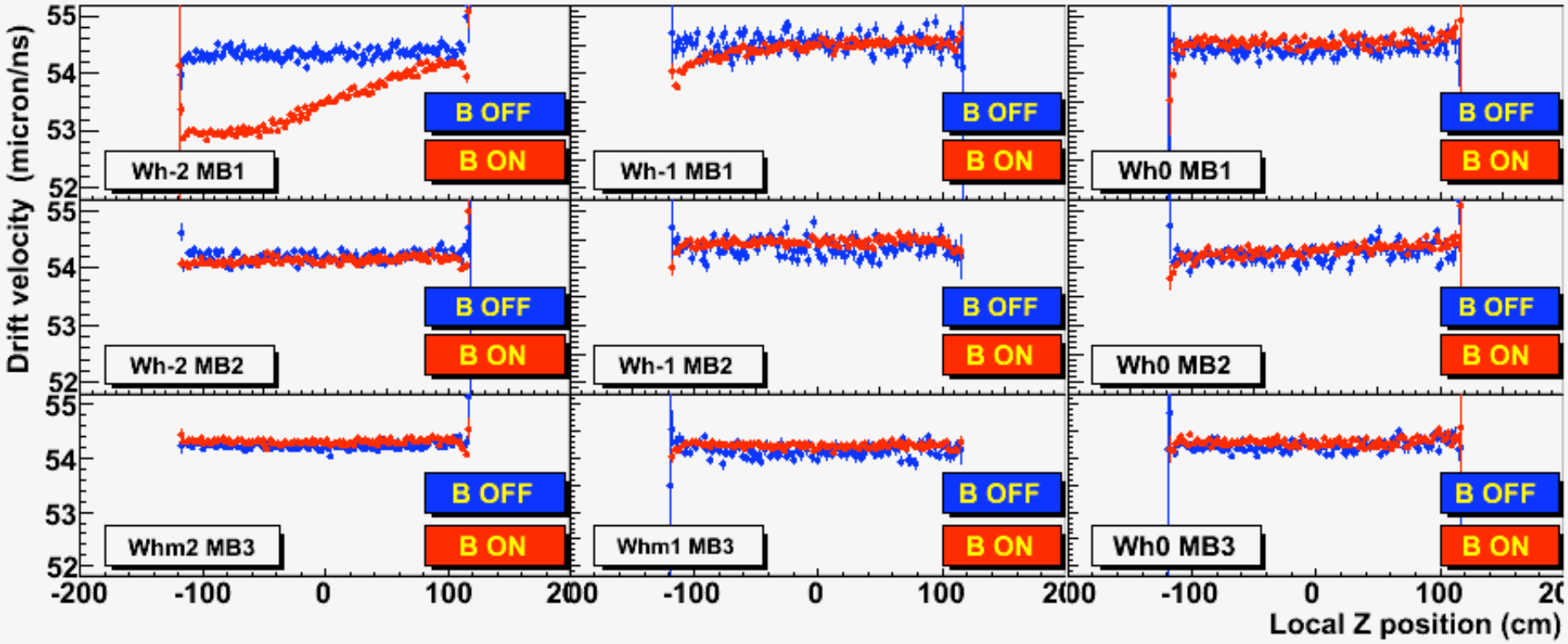
Residual Distributions

- Reasonable agreement between data and MC after cosmic muon arrival time fit
- Sigma ~ 200 – 260 μ m
- Sector 4 of wheel -2 is shown here
- B field degrades MB1 distribution in wheels +/-2



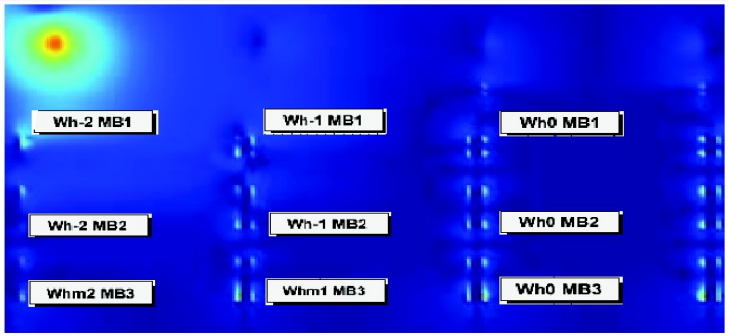
Drift Tubes – central muon chamber

Drift Velocity Along z-Axis with/without Field

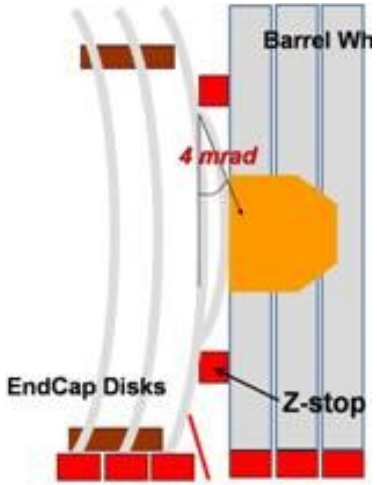


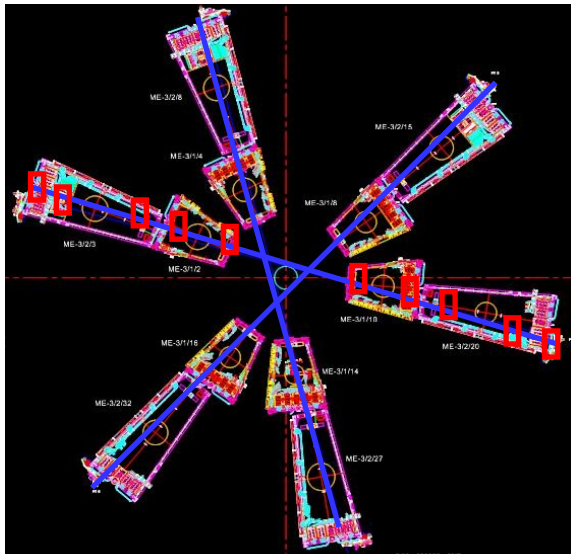
- Innermost stations on outer wheels have largest radial field
- Maximum difference in drift velocity is 3%

Br magnetic field map



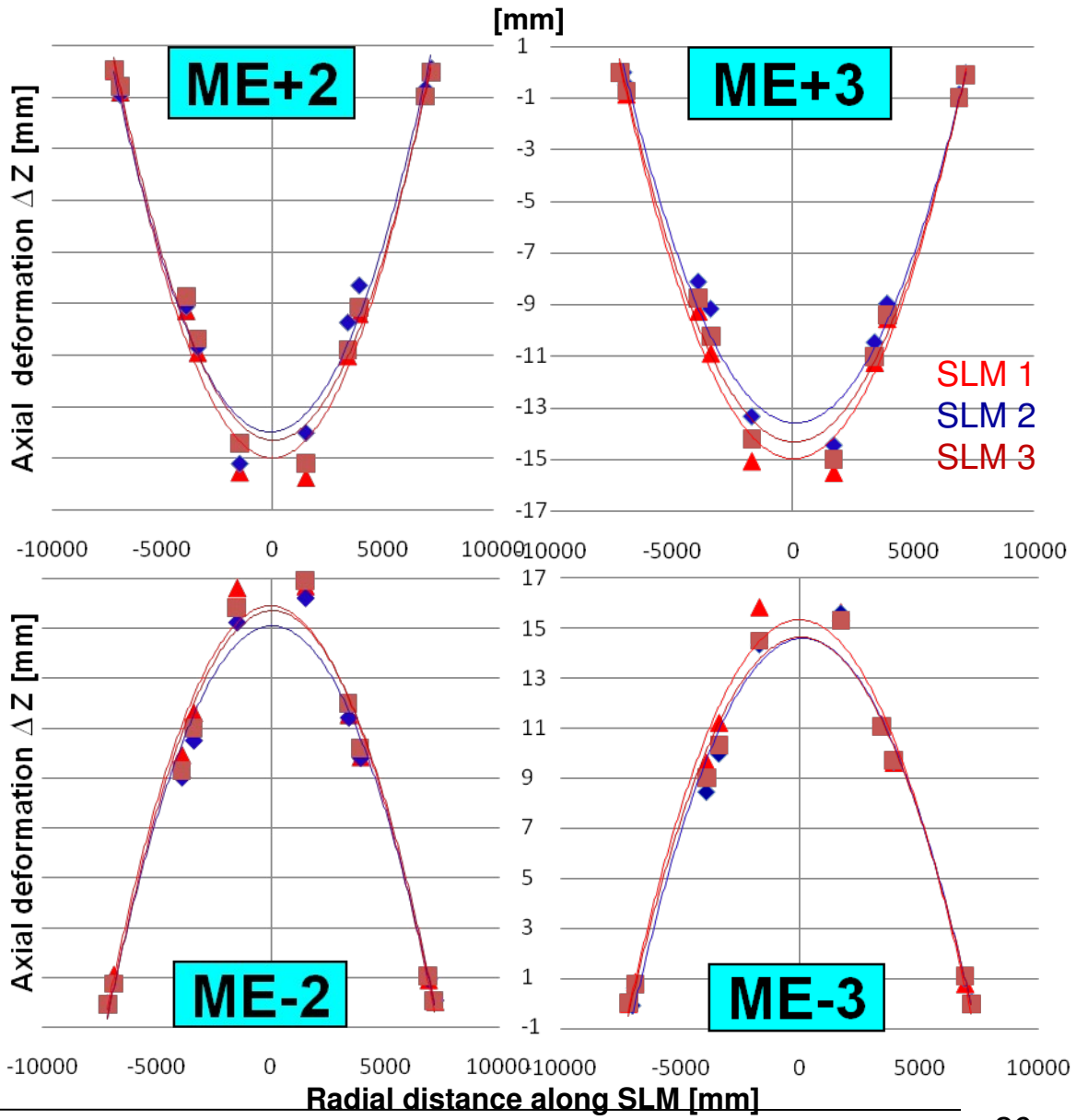
Measured Endcap Deformation at 3.8T



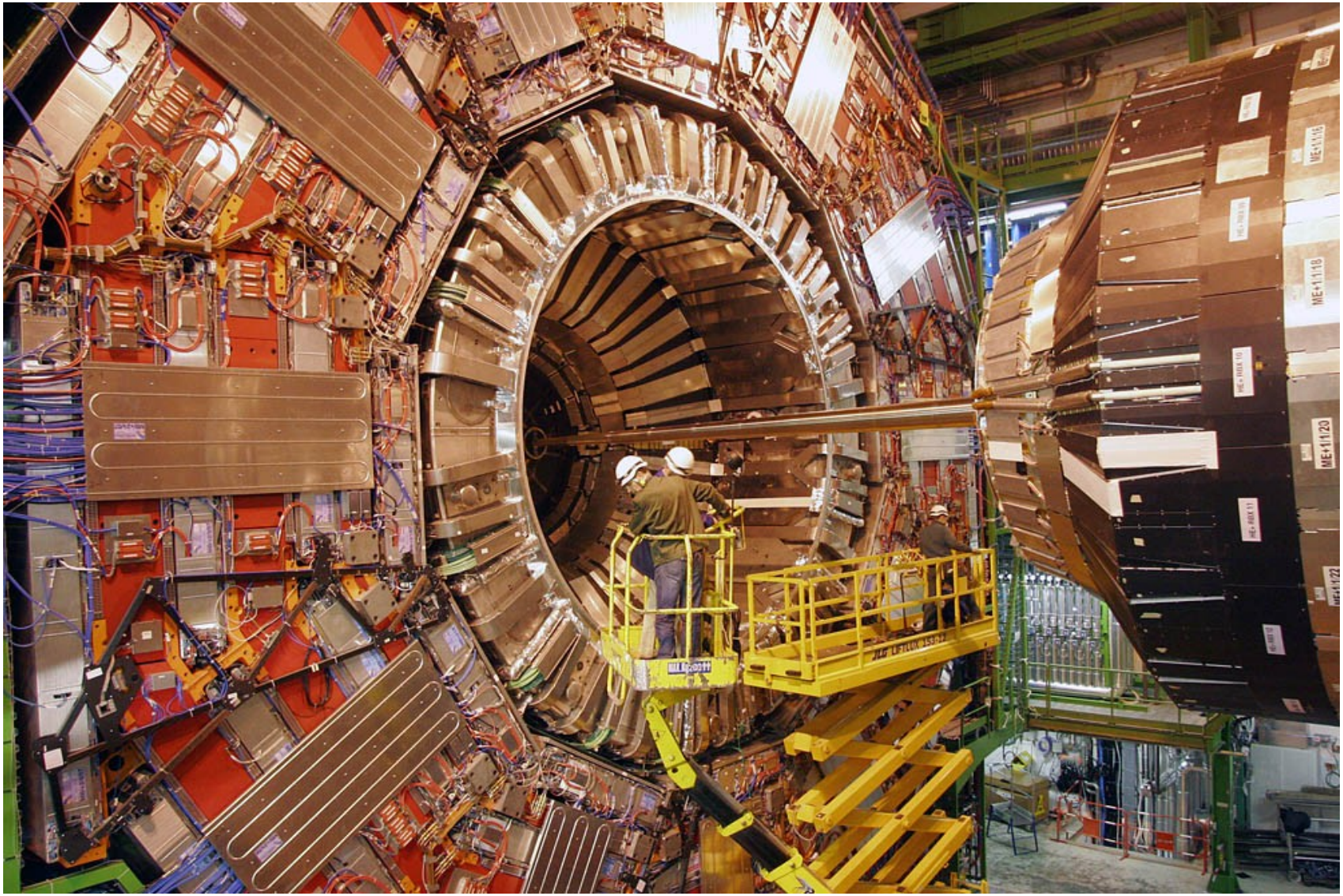


3 Straight Line Monitor (SLM) Laser Lines per Muon Endcap Station

10 optical CCD sensors per SLM



Opening CMS for 2008/09 shutdown



Activities during the winter shutdown and beyond

- Detector opening started on Nov 17th
  - Started a selected list of interventions/repairs for problematic channels (order of the percent)
  - CMS cooling system maintenance (done)
  - Installation of Preshower detector in February
- Continue the optimization of detector operations
  - Optimization of online system and procedures to eliminate possible sources of data taking inefficiency
  - Centralization and optimization of detector control system and monitoring
  - Consolidation of data quality monitor and certification
  - Improve monitoring and alarm system to ensure the high quality data taking
  - Aim to reduce the needed number of shift crew and experts at Point 5 to decrease long term manpower load for the sustainable operation.

Connecting the CMS CR and ROCs together

Remote Operation Centre (ROC) at FNAL has been a part of the routine CMS global operation since MTCC, 2006. Remote Centres extended to Meyrin and DESY in 2008.

Point5

FNAL ROC

CERN CMS CENTRE

- Efficient way to use manpower spread over the world. → Converge
- Crucial to have "tools" to communicate relevant information.
- Eg. Development of web-based-monitoring tool (WBM).

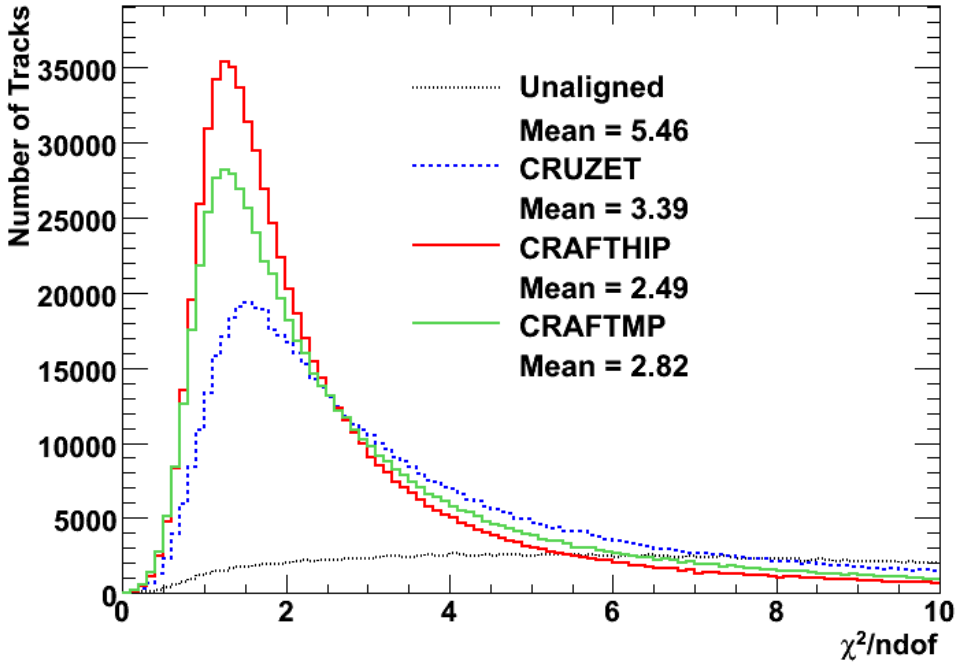
Summary

- Challenging installation and commissioning campaign was carried out successfully
  - All major components of the detector have been installed and commissioned
  - Preshower detector will be installed in February
- CMS was ready for beam in September 2008.
- Collected and exploited to maximum extent the beam data delivered.
- A one-month-long cosmic ray run with nominal magnetic field has been taken
- Commissioned and verified stability of operations (detector, magnet and operators)
- Exercised alignment, calibration algorithms, data handlings, reconstruction.....
- Measure the detector performance in-situ with magnetic field
- Perform cosmic measurements underground
- Still learning many more, from offline analysis of the collected data.
- Some problem fixes on detector components are currently being carried out
- No show stoppers.
- Key elements of the 2009 schedule has been defined.
- Expect to adjust the CMS schedule as we learn more the LHC schedule
- Global run sessions to be resumed in March
- First CRUZET09 in ~ May
- Detector will be closed, allowing enough time for CRAFT09
- CRAFT09 before LHC beam
- Run with beam → **physics!!!!!!**

Backup slides

Tracker Alignment

χ^2/ndof



- Using 4M tracks for alignment and 1M for validation
- “Unaligned” is the nominal geometry
- “CRUZET” is the geometry obtained from the B=0T runs using the Hits and Impact Point method and survey constraints
- “CRAFTHIP” is the geometry obtained from the Hits and Impact Point algorithm applied to CRAFT data, including survey constraints
- “CRAFTMP” is the geometry obtained from the Millepede algorithm applied to CRAFT data