Status of the CMS Experiment

DESY Seminar 7.10. & 8.10. 2008
Wolfram Zeuner

- Design Criteria and Engineering Solutions
- Construction and Assembly
- CMS Commissioning
- LHC Beam Commissioning and Operation
- CMS Beam Operation
- Outlook
- Summary

Design Criteria for Physics

- **Muon triggering and identification**
  - High efficiency & low contamination
  - Hermetic detector coverage
  - di-muon mass resolution < 1% at 100GeV/c2.
  - charge determination for muons with momentum ~ 1 TeV/c2
  - $\Delta pT/pT \sim 5\%$

- **Central tracking system**
  - high resolution
  - good reconstruction of secondary vertices
  - to detect the decays of long-lived b quarks & τ-leptons

- **Electromagnetic calorimetry**
  - Hermetic and highly granular
  - di-photon mass resolution < 1% at 100 GeV/c2.
  - High energy resolution, ~ 0.5% @ ET ~ 50 GeV

- **Hermetic calorimetry system**
  - good resolution for
  - detecting and measuring "missing" ET
  - reconstructing the mass of jet-pairs.

Engineering Solutions

- **Muons**

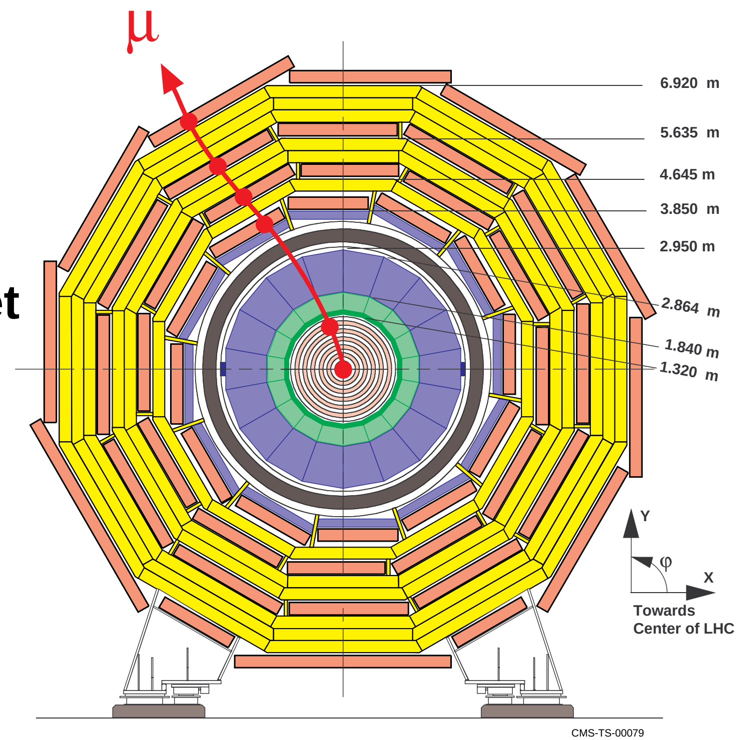
  Redundant precision measurements inside an instrumented iron yoke

  4 Stations of 32 r-φ measurements - Barrel Drift Tubes (DT)
  24 r-z measurements – Endcap Cathode Strip Chambers (CSC)
  Interleaved RPC trigger layers (6 in the barrel, 3 in the endcaps)
  Precision alignment system to link barrel and endcap

  →Very Compact Muon System with independent momentum measurement if iron is saturated

- **Super Conducting Solenoid**
  All central tracking and calorimetry inside the magnet

  Enormous dimensions 13m long, 6m diameter
  Strong field (4T) with very large BL^2
  Stored energy at full field 1.6 GJ
  Magnet can be thick

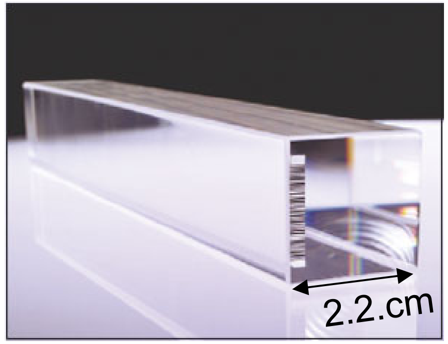


Transverse View

Engineering Solutions

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

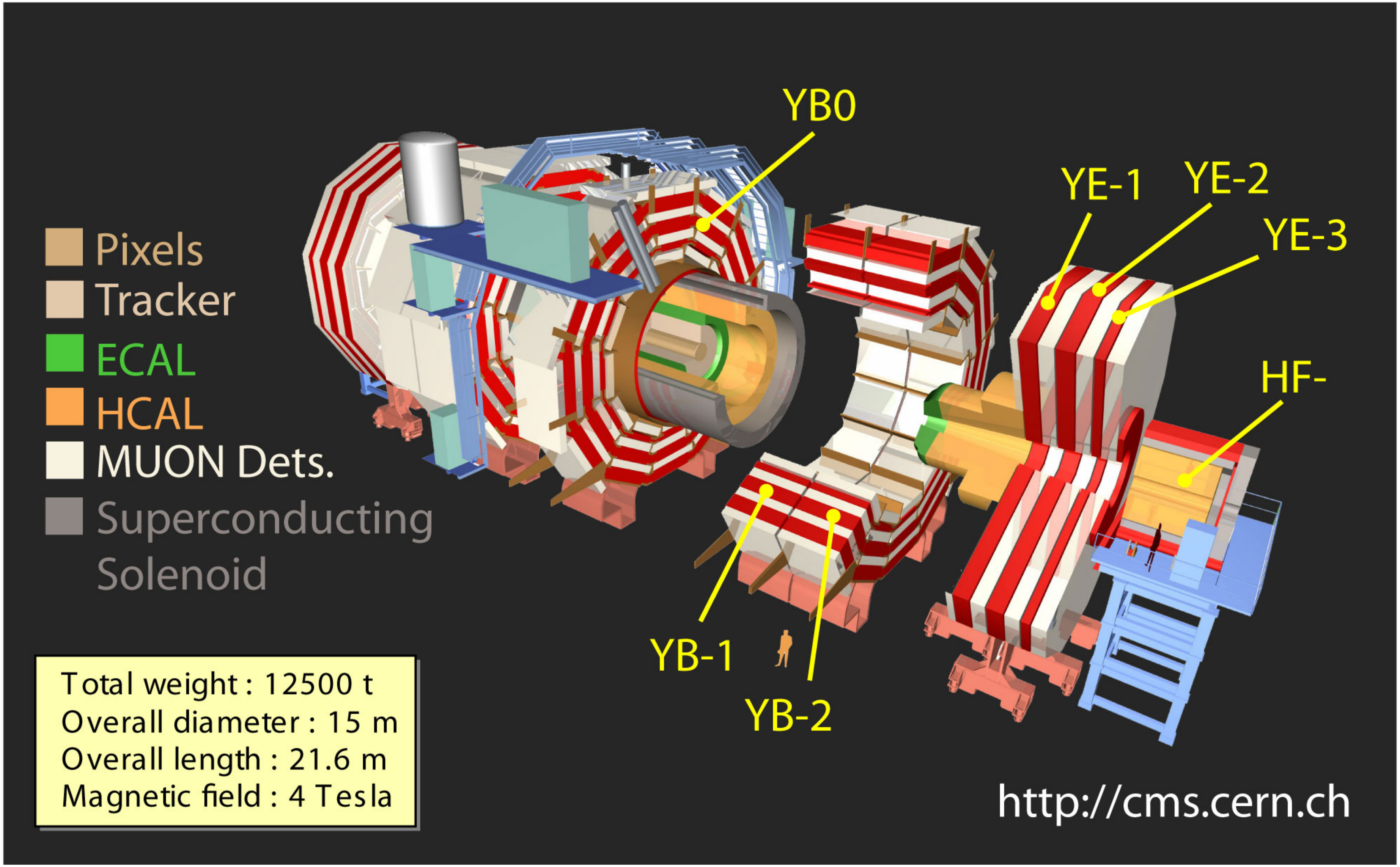
Si-Strip Detector with 10M strips in 10 layers and
> 200 m^2 of Silicon



Electromagnetic Calorimeter
Highly granular with ~ 83000 $PBWO_4$ crystals
25 X0 for perp. Passage

Hermetic Hadronic Calorimeter with Barrel, Endcap and Forward sections (Brass-Scintillator)

Engineering Solutions



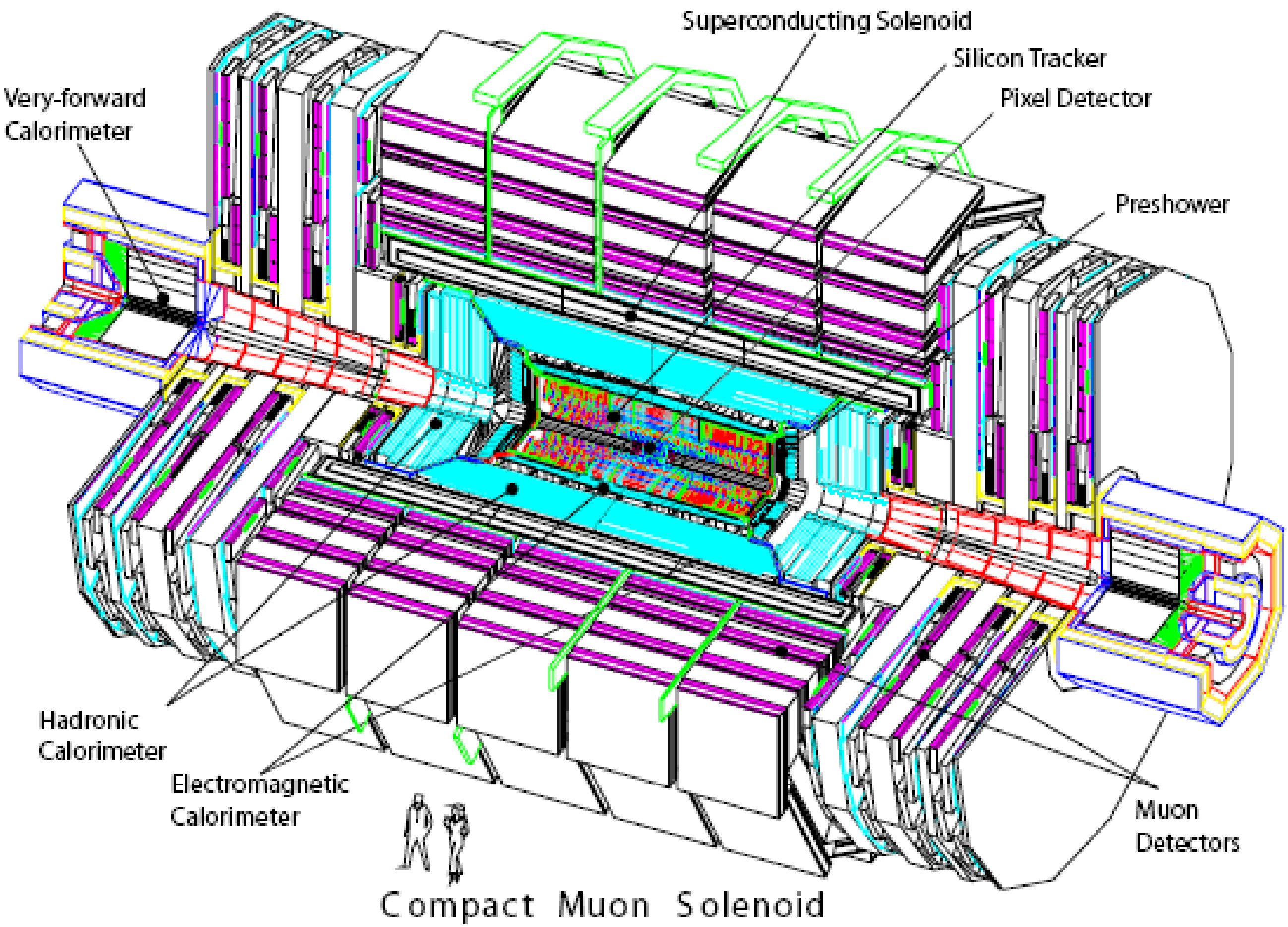
Engineering Solutions

- The iron yoke is built in slices along the beam axis
  - Barrel part in 5 wheels
  - Central wheel fixed to the solenoid – YB0
  - Endcap part 3 disks each end
  - 4th disk planned for highest luminosities
- Forward hadron calorimeter on each end

- 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

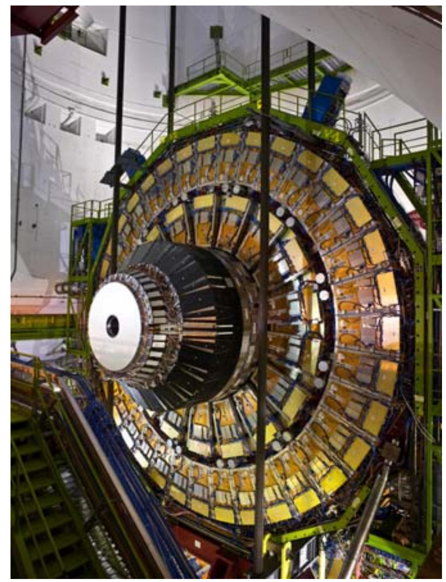
- CMS is the first large HEP detector that has been assembled, cabled and tested on the surface and then brought underground
  - Very interesting concept for future detectors
  - Disentangle civil engineering underground from detector construction
  - Much less space requirements underground
  - Heavy lowering is a very mature and safe technique
  - Requires doubling some infrastructure on the surface for testing

Engineering Solutions



13 Heavy Lowerings
Masses between
400 tons and 1920 tons

YE1 most difficult:
Mass 1430 tons
Nose of 465 tons out of plane of disk – center of gravity in front of the the plane.



Assembly Sequence

SURFACE : *independent of underground Civil Engineering*

2000-2007

*construct magnet barrel yoke & pre-cable
* prepare solenoid vac tanks
* construct endcap yoke & pre-cable
* assemble hadron calorimeters
* install muon chambers (barrel+endcap) in yoke
* assemble coil & insert in vac tank
* insert HCAL inside coil

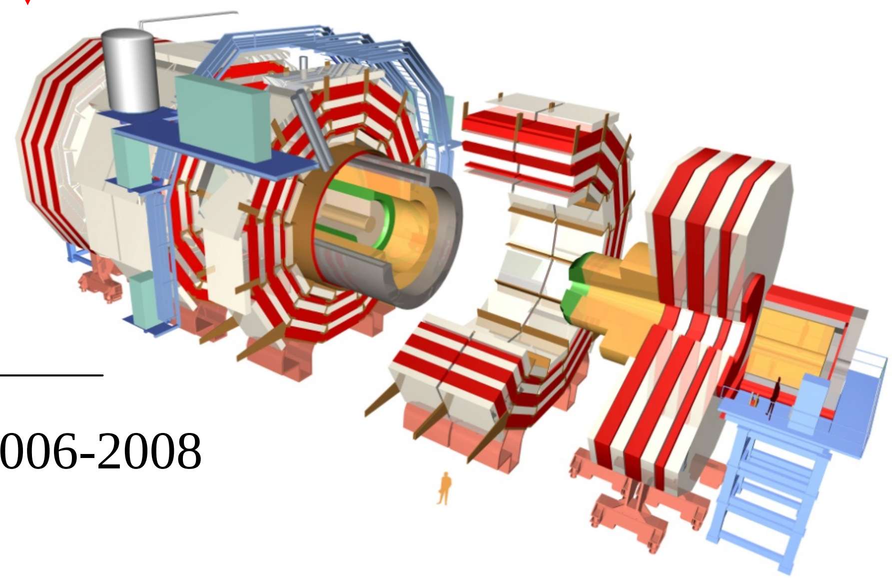
• Test magnet + parts of all subsystems

2006-2008

*separate elements and lower sequentially

UNDERGROUND:

* re-install HCAL
* install ECAL barrel & cable central wheel
* install Tracker & cable
* install beampipe & bake-out
* install ECAL endcaps
* close & finish commissioning

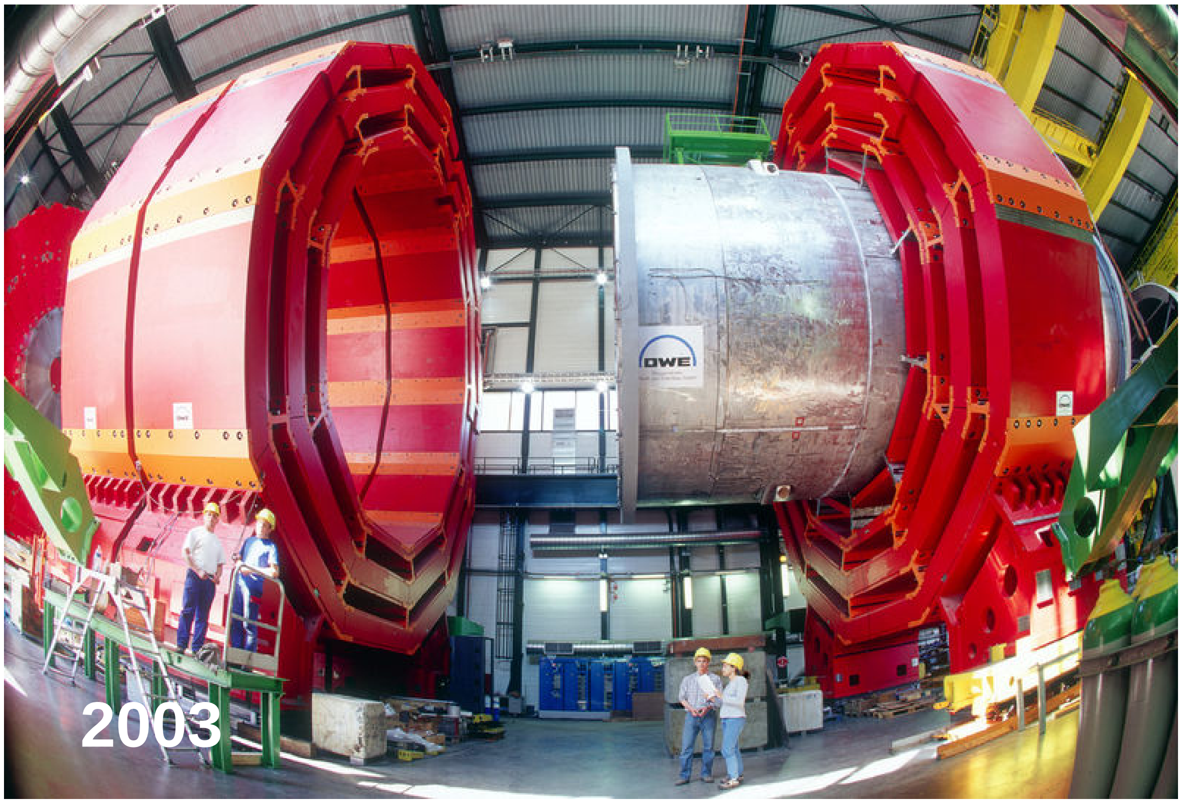


15 heavy lowerings of objects of 380 tons -1920 tons

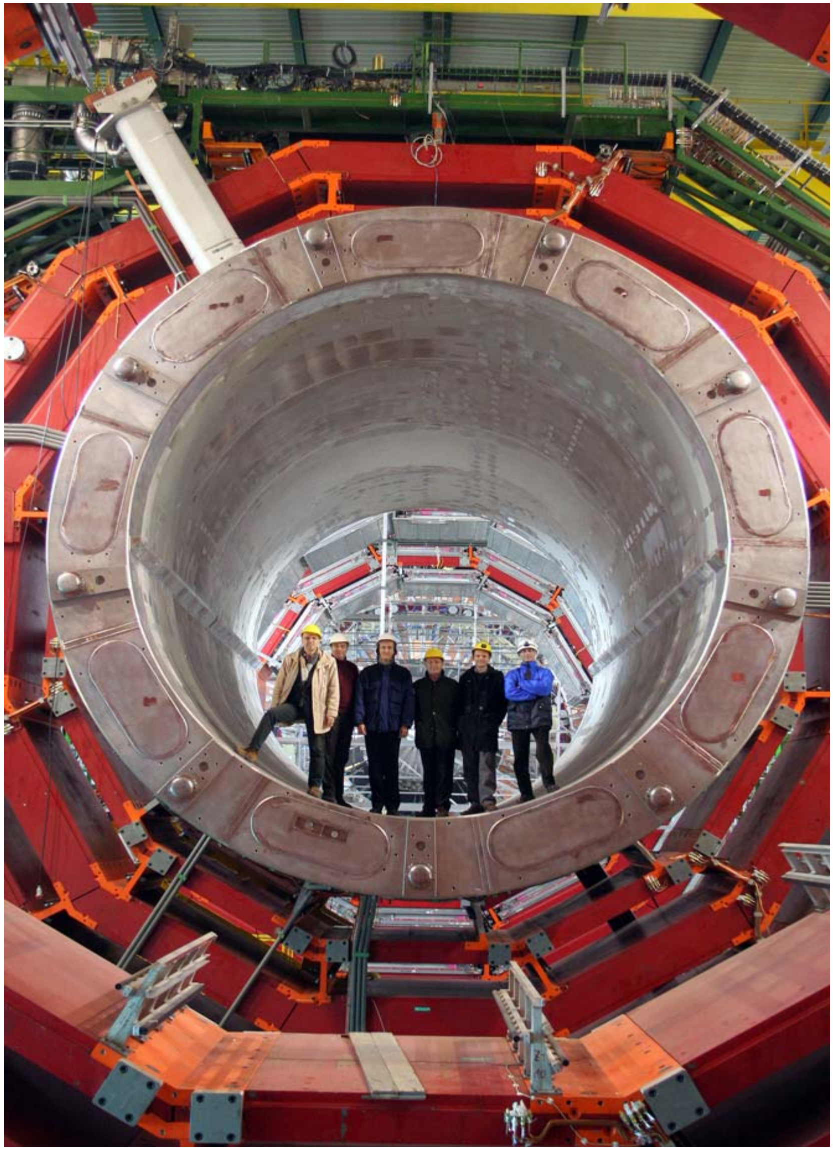
Surface & Underground 2001/02

Assembly of solenoid vac tank

Surface and Underground 2003/04



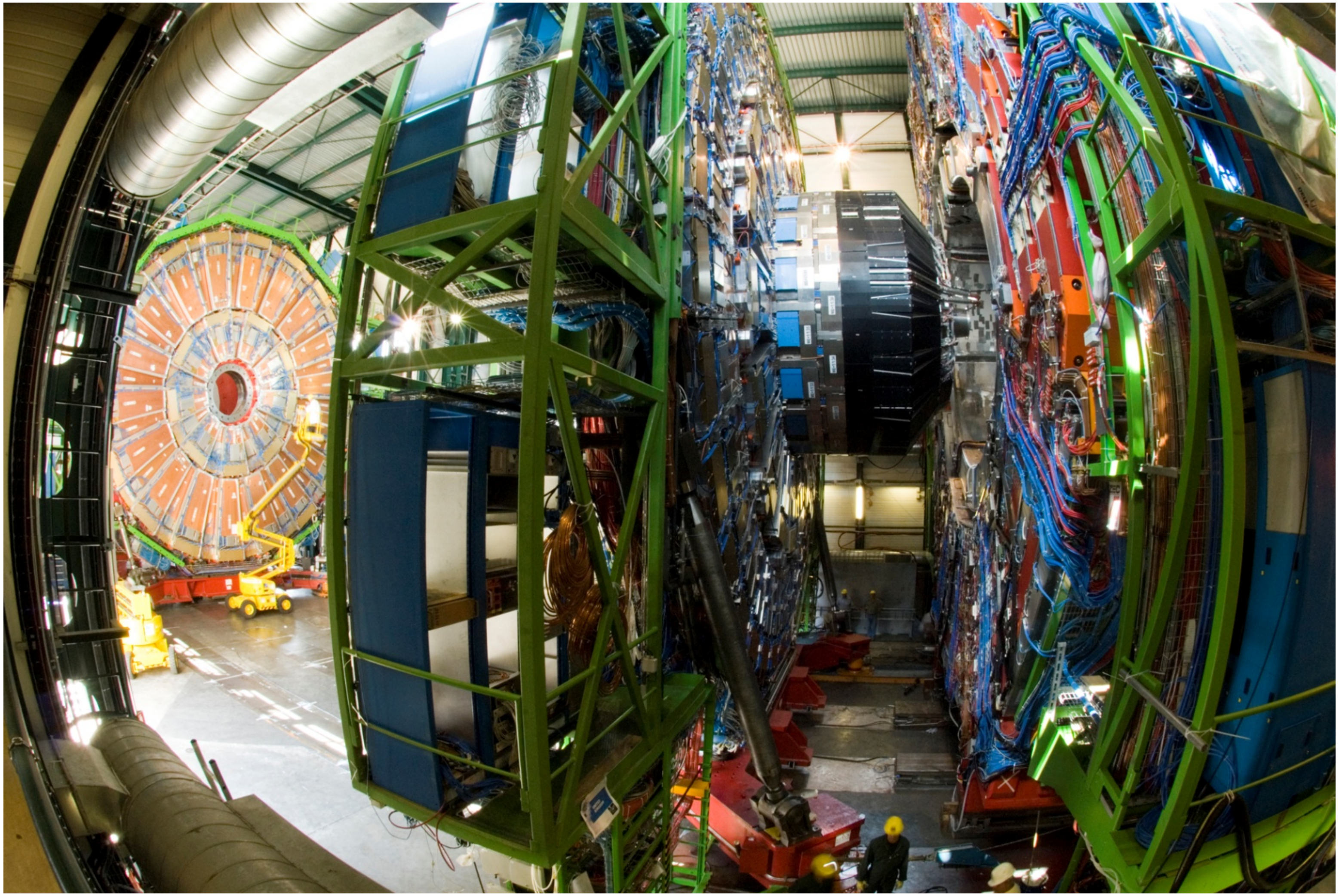
Surface & Underground 2004/05



Due to severe geological problems, underground hall (UXC) was ready to receive CMS only in 2006

Summer 2006 First Closure of CMS

Preparation of magnet test and field mapping at the surface



Review and trial installation for HCAL, ECAL and Tracker

First complete exercise of moving system – Air pads, grease pads and locking system (w/o beam pipe)

Worked ok, 3 days to close/open endcap

Magnet Test & “Cosmic Challenge” 2006

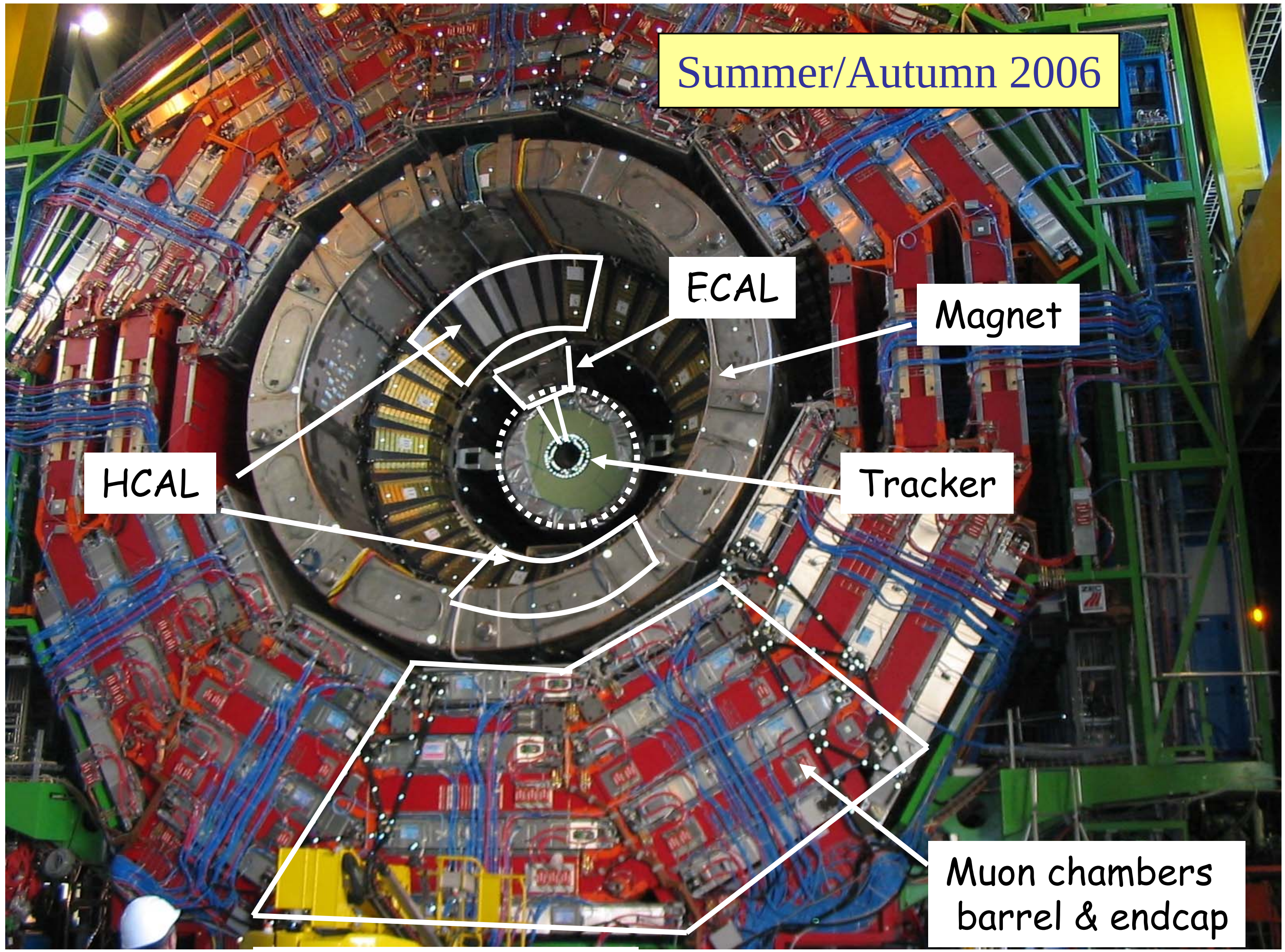
1’st CMS system test

Surface testing and field-mapping of magnet

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

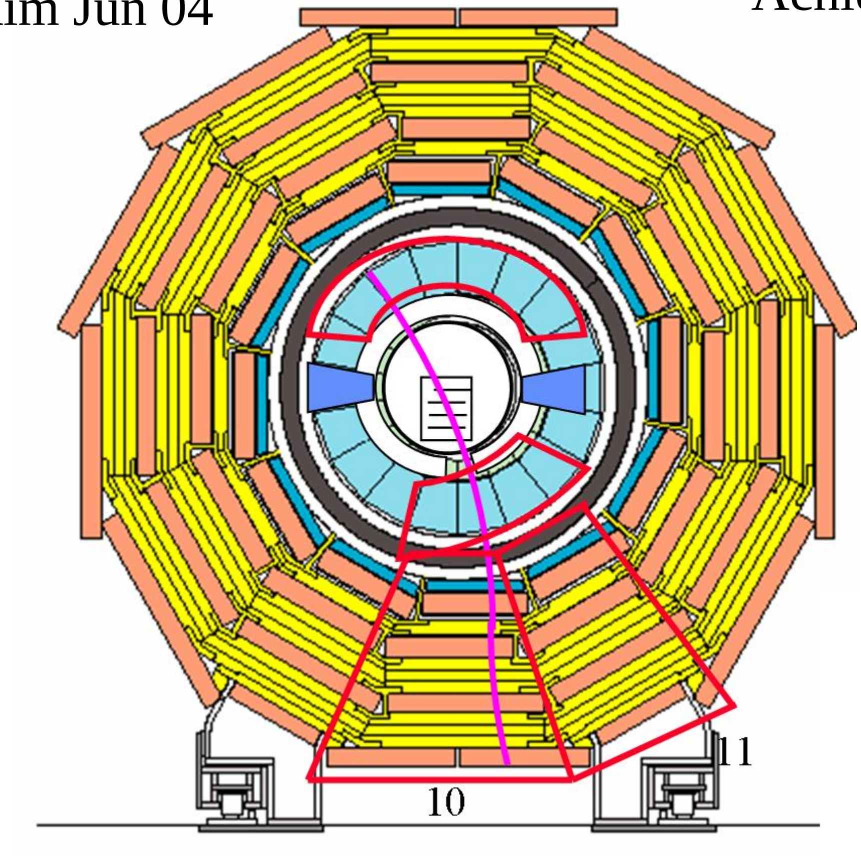
(Investment in surface infrastructure, DAQ, rack & control rooms)

MTCC project in its own from June 2004 – Aug. 2006

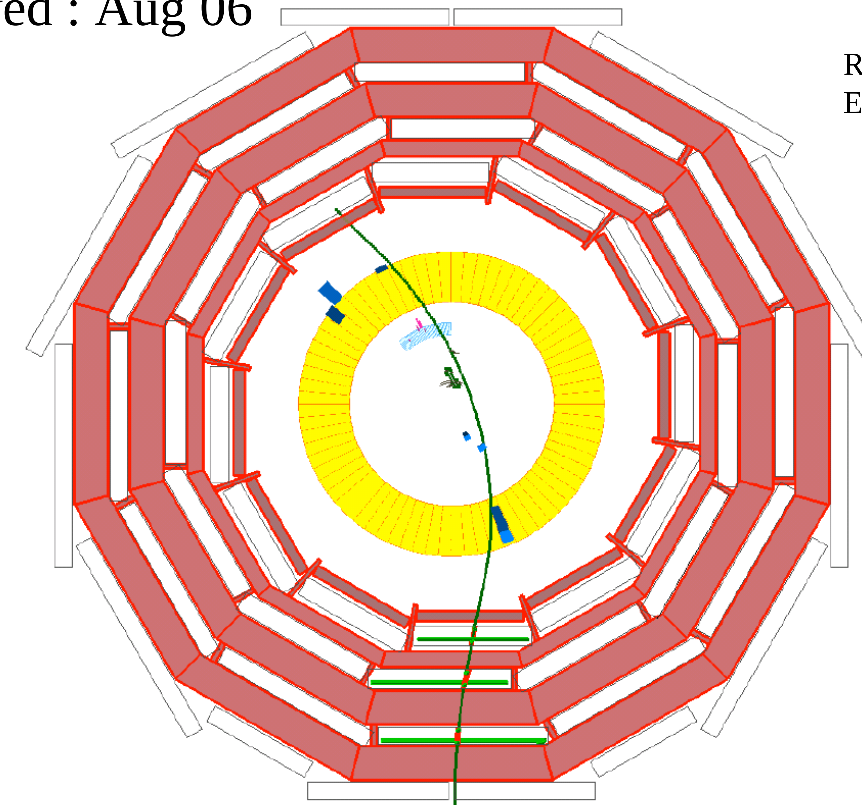


MTCC August 2006

Aim Jun 04



Achieved : Aug 06

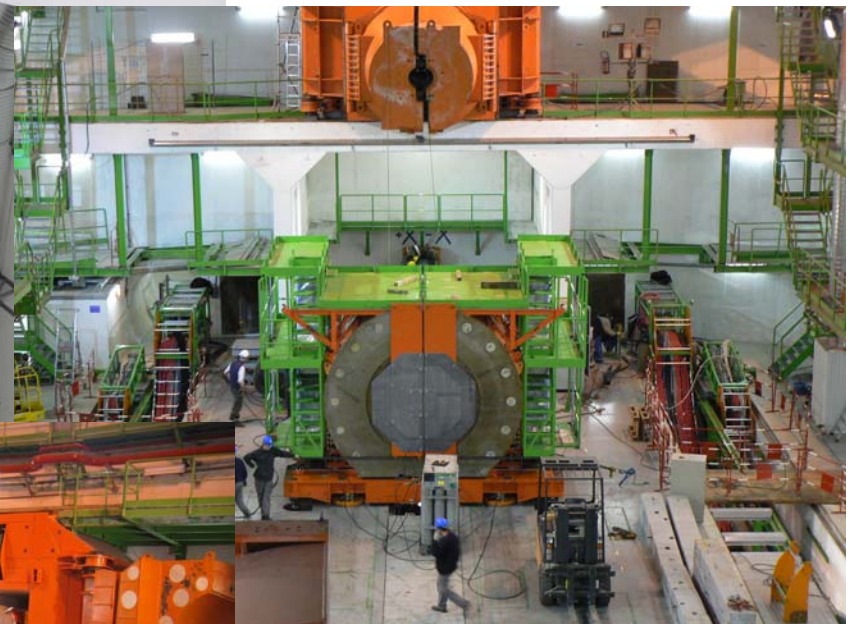


Run 2605
Evt 3981

Phase I : offline /quasi-online event display

3 recon TK clusters
Uncalibrated recon hits in ECAL
Recon Hits in HCAL
DT digis, recon segments & track propagation

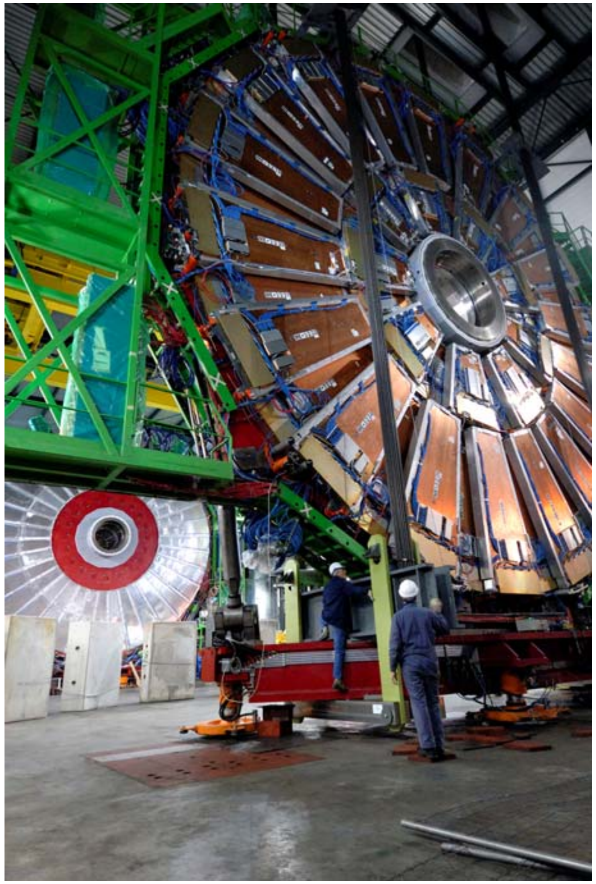
Assembly from Surface to Underground
HF – October 2006



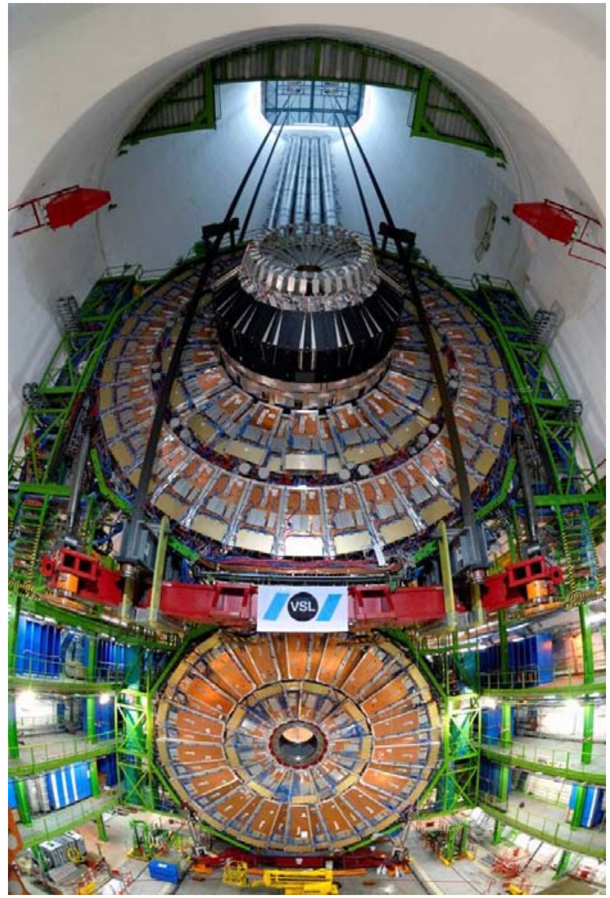
Both HFs in their garage;
cable chains connected;
local commissioning;
started

Assembly from Surface to Underground
Endcap Disks – “Plus End”

YE+3
30.11.2006

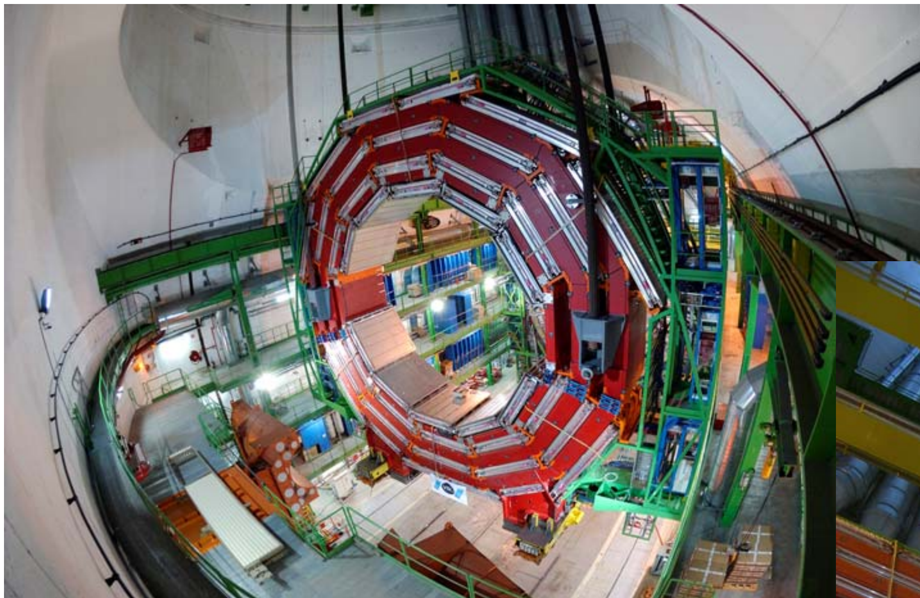


YE+2
12.12.2006



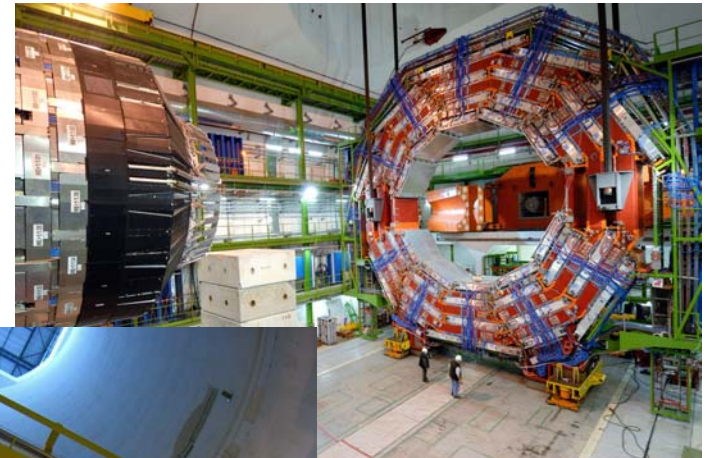
YE+1
9.1.2007

Assembly from Surface to Underground Barrel Wheels – "Plus End"



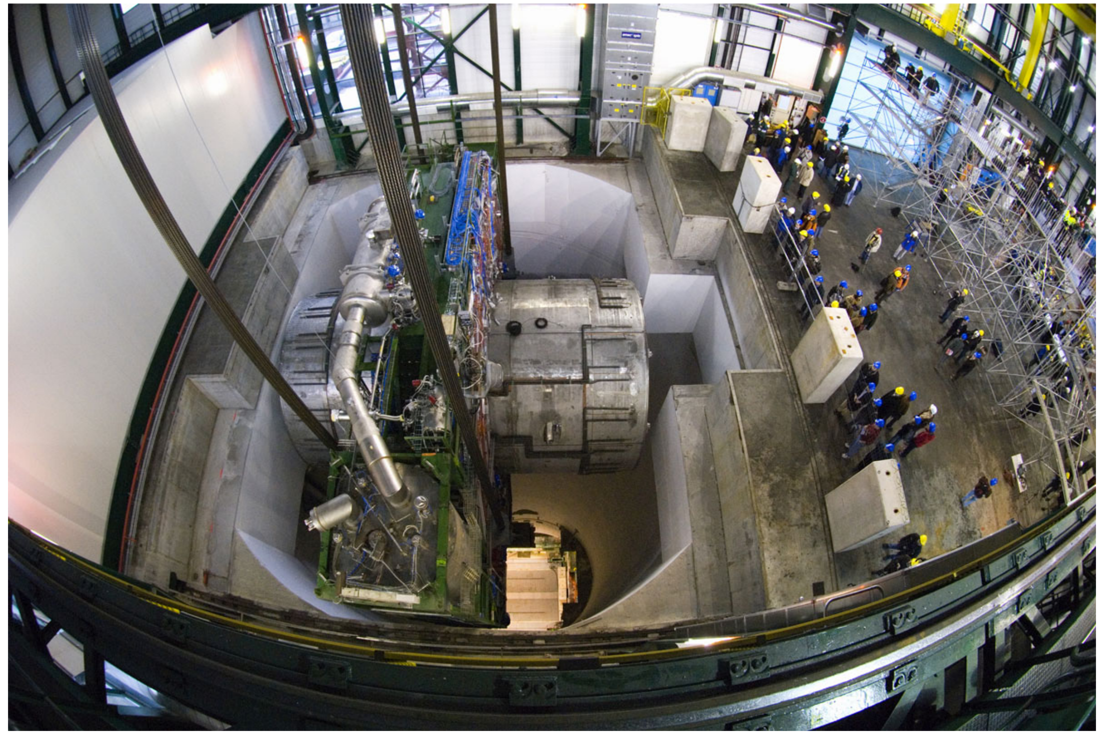
YB+2
19.1.2007

YB+1
4.2.2007



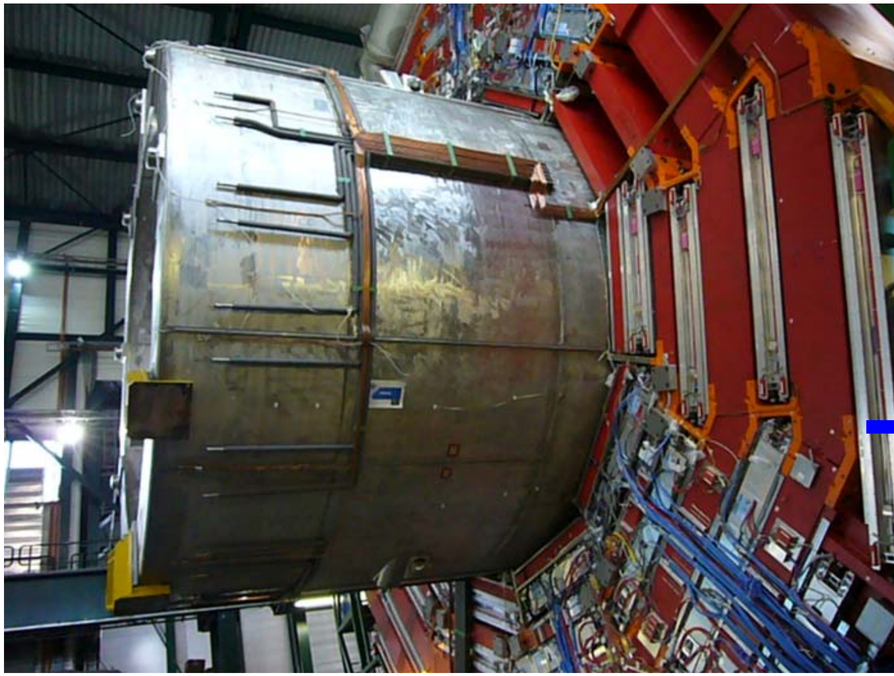
Insertion of horizontal DTs and HOs finished for YB+2 and YB+1 on Feb.8 2007

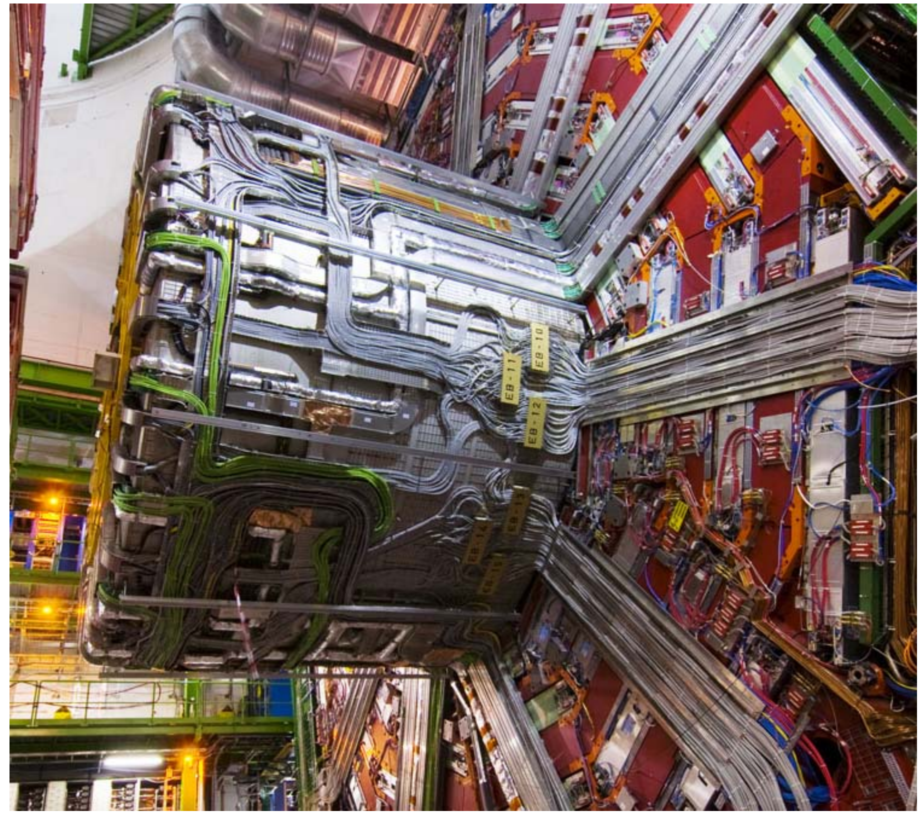
YB0 – 28.2.2007



YB0

50000 hours of work in 8 months





All services for Pixel,Tracker, ECAL and HCAL have to go over the vacuum tank
Approx.:
250 Km cables, pipes and fibres
6100 cables, 700 fibres,700 cooling pipes

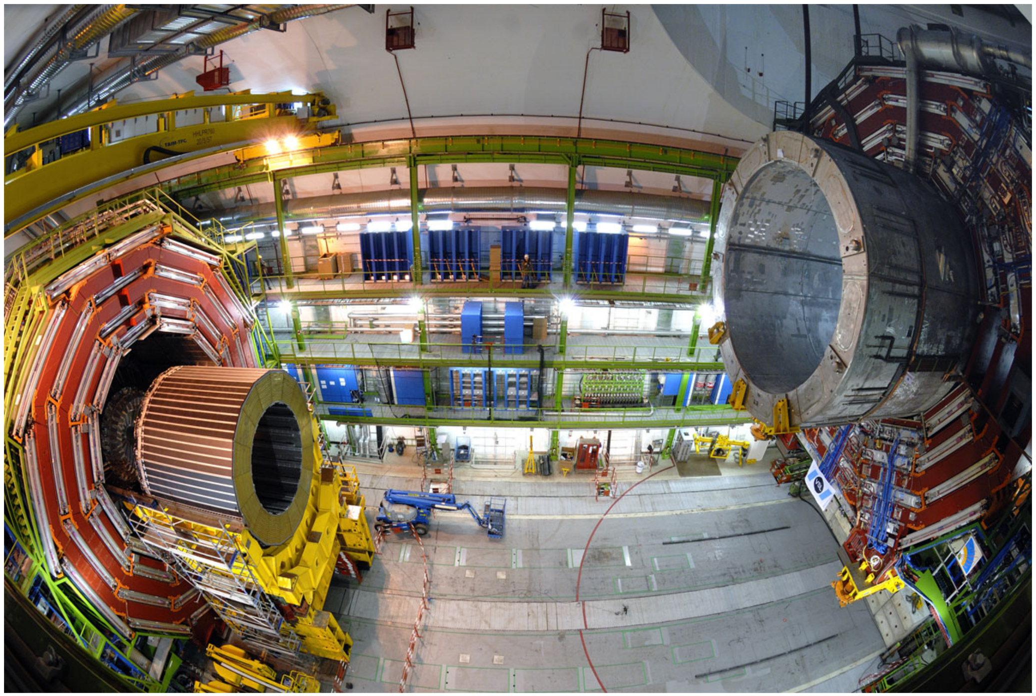
Peak times with ~100 people working in parallel

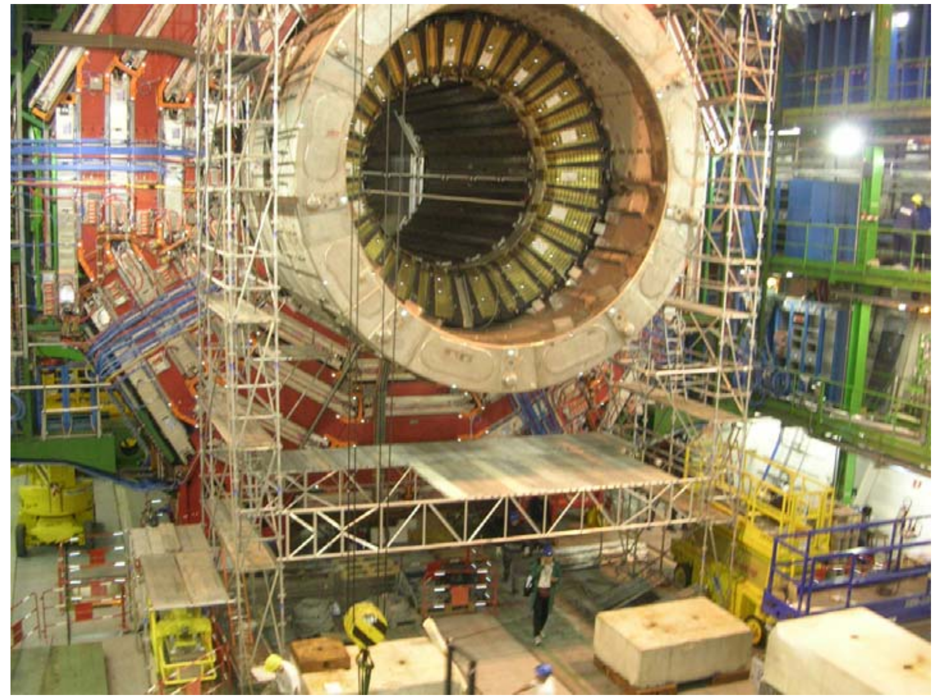
YB0

Much less spectacular with thermal shield…

- Difficult to install
- Necessary to shield DTs from heat of cables

HCAL

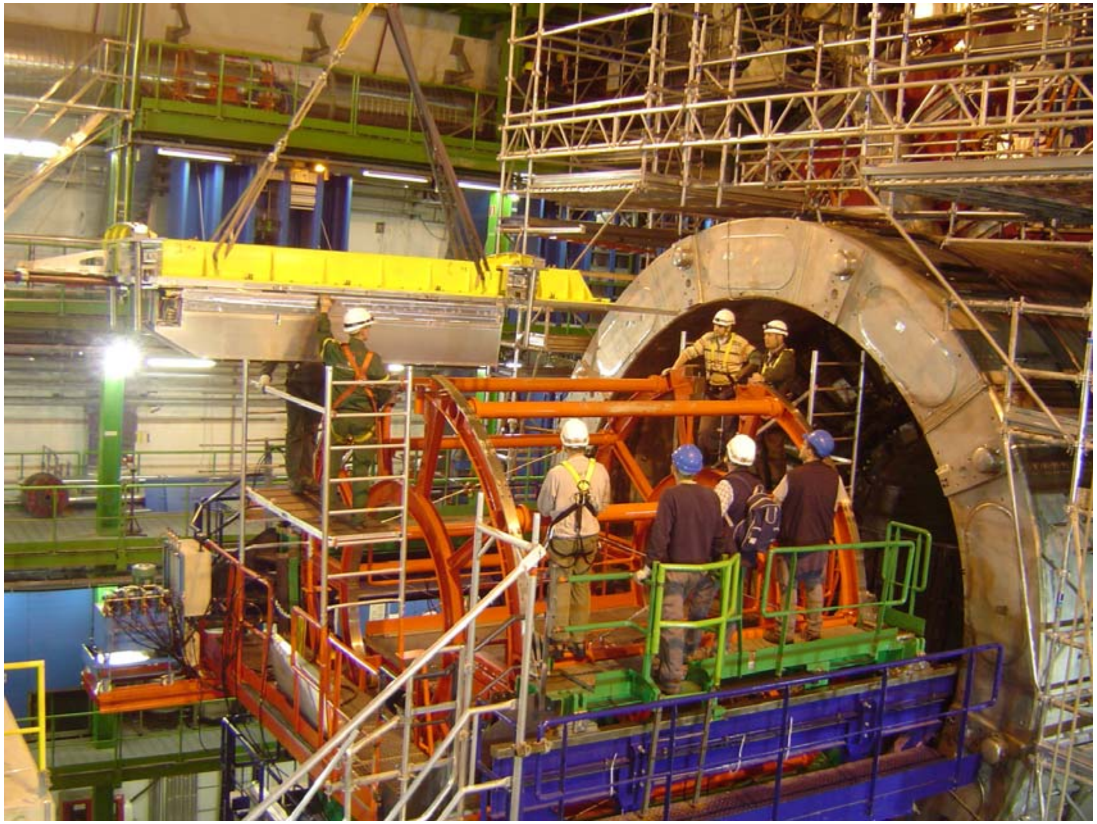


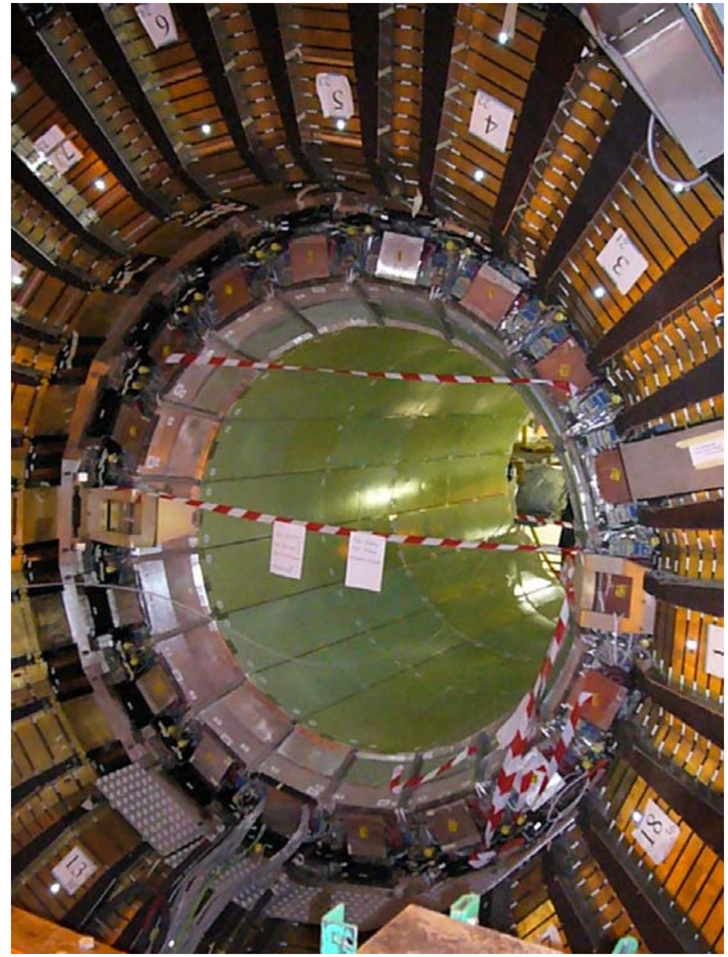


Insertion finished end of March 2007

- HCAL is too heavy to be installed on the surface and lowered with YB0
- Installed in ½ barrels from each end

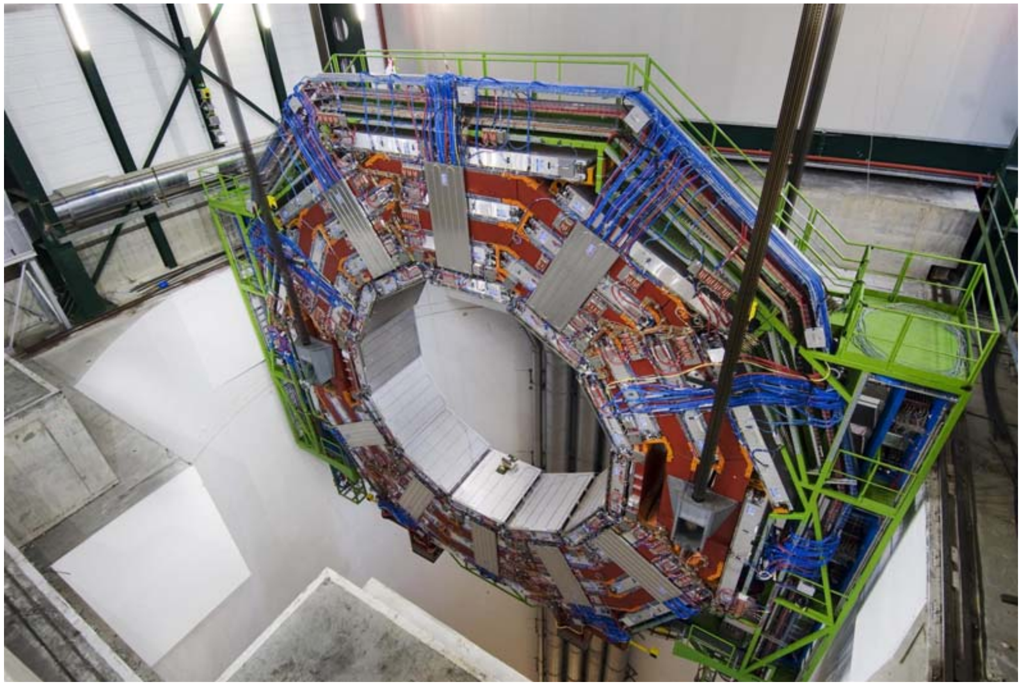
Barrel ECAL





Installation of 2 ½ Barrels with 18 supermodules each on both ends of CMS
All 36 Supermodules installed end of July 2007

Lowering the other end
YB-1 & YB-2



- Lowering October 12 & 17 2007
- October 26 2007 Muon Barrel Installation finished

Tracker Installation

- **In autumn 2007 it was realized that the standard installation sequence would move tracker installation into 2008 – expect problems to finish in time**

Nov 2007 – Strategic decision to change order of installation

I) Lower YE-3
II) Install Tracker
III) Lower YE-2
IV) Lower YE-1

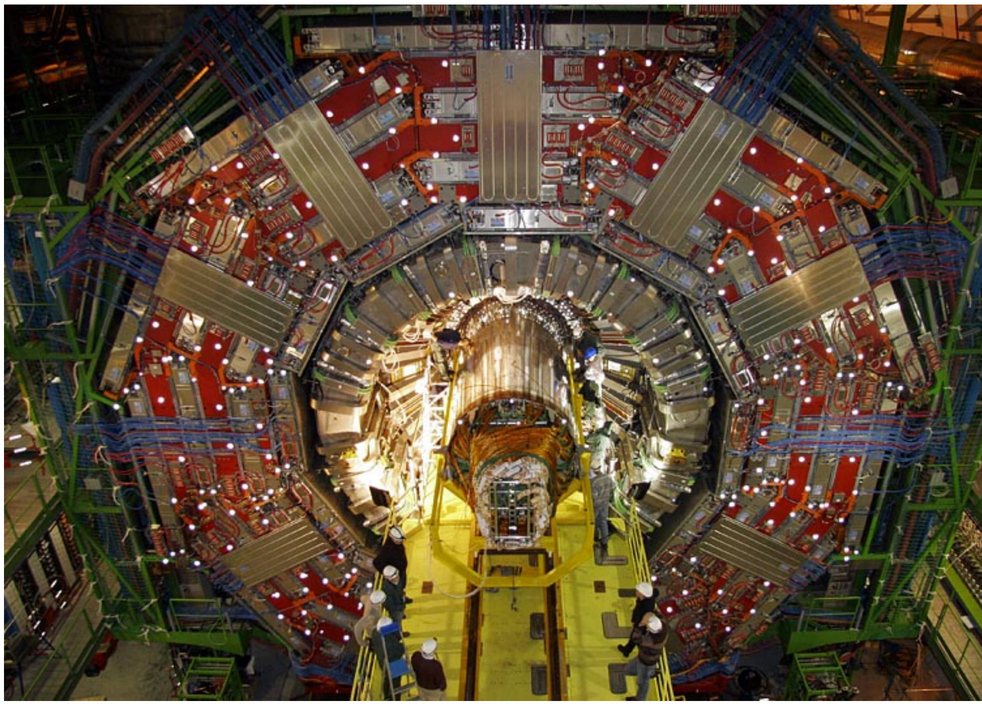
Required reordering of disks on the surface – dance of the disks

YE-3 lowered begin of Dec. 2007

With lowering of YE-1 on Jan 22, 2008 CMS heavy lowering finished

Si-Strip Tracker Installation

Pre-cabling of services to patch panels inside the solenoid vacuum tank simultaneous with Si-strip Tracker surface pre-commissioning.
Speeded up the final connections, completed in 4 months

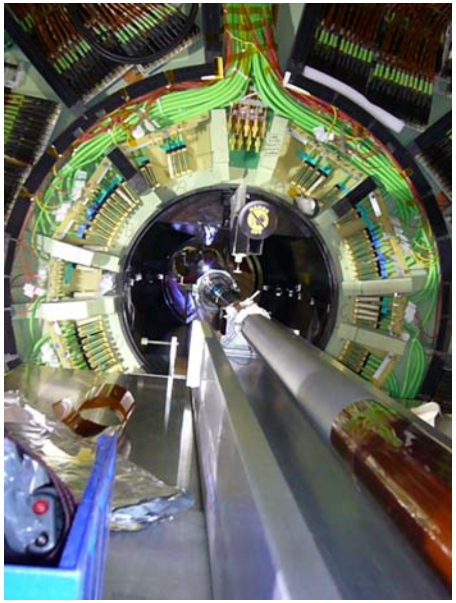


Dec. 2007 – Tracker installed

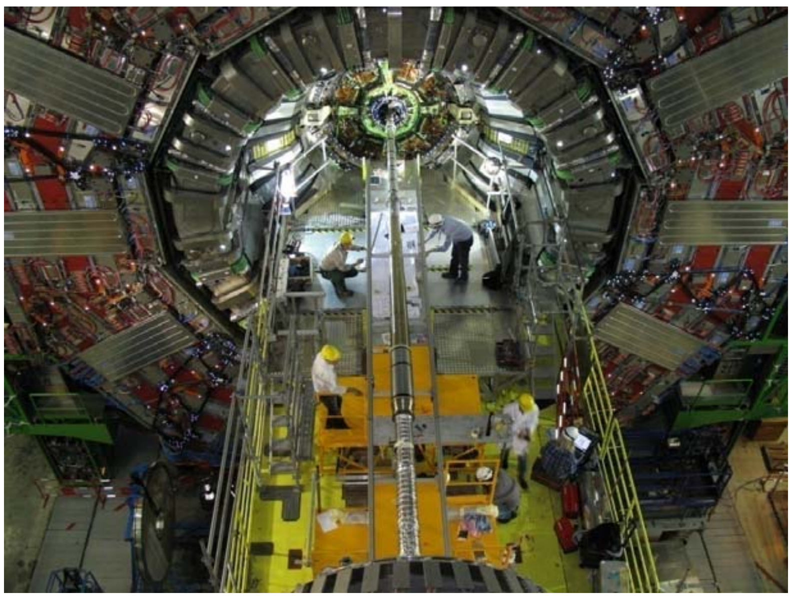
Apr. 2008 Connection completed

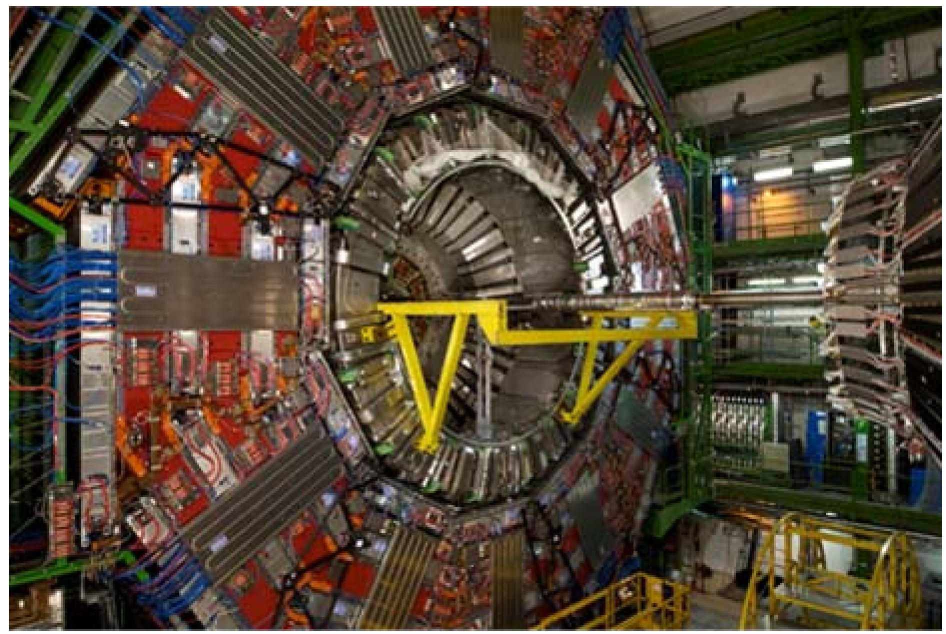
Beam Pipe Installation 18.4. – 10.6.

Overall 44m in 9 pieces



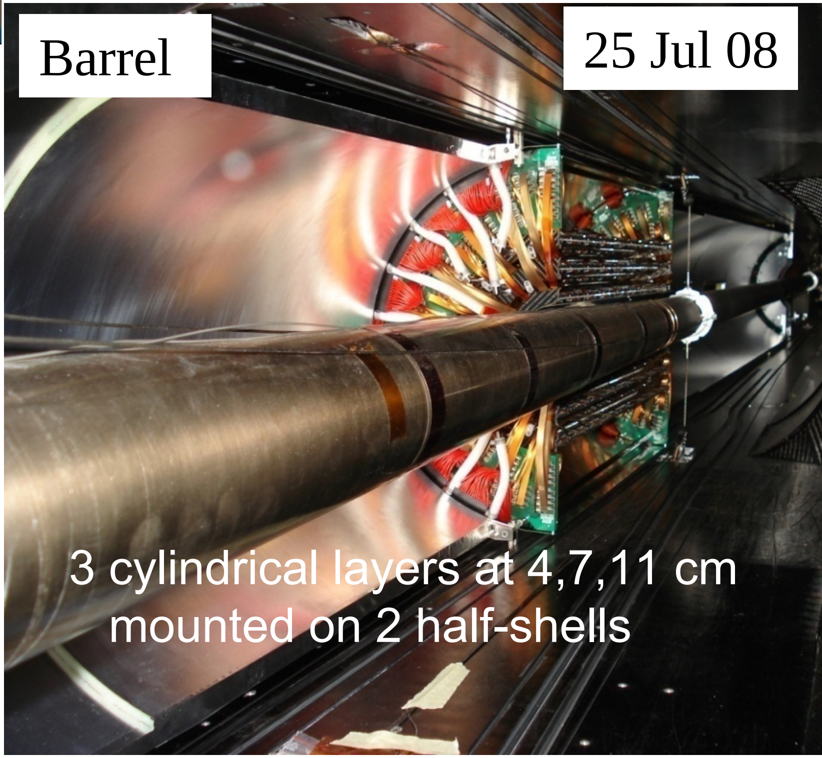
4m long Be central section braised to conical stainless steel cones connecting to endcap cones

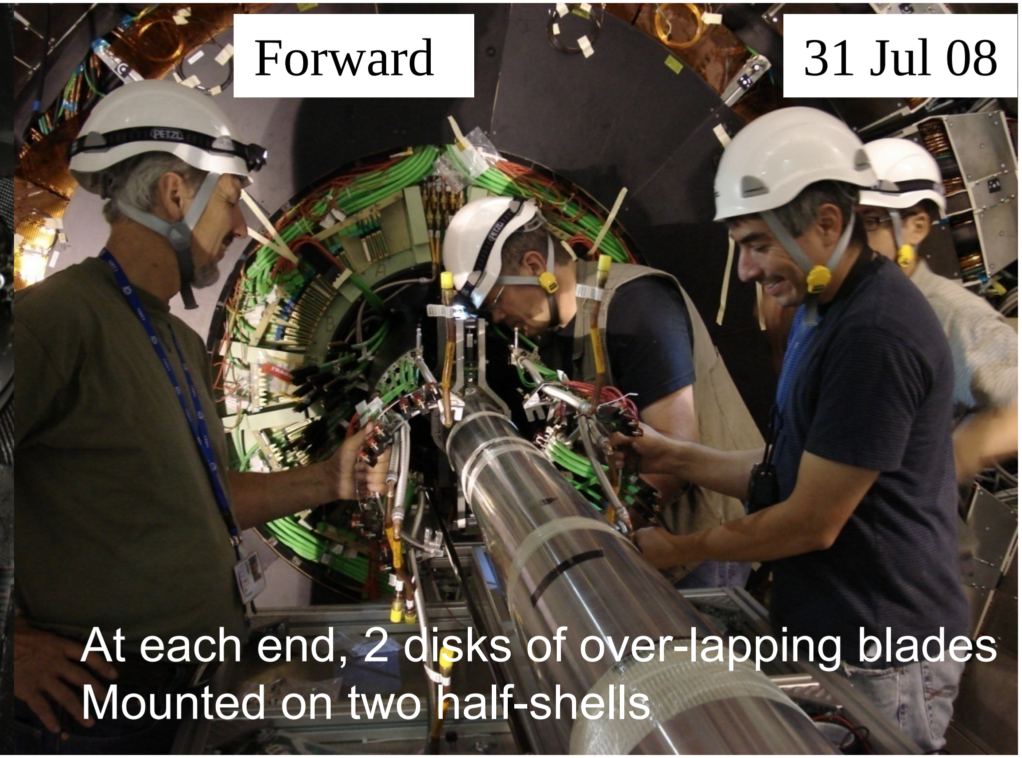




Endcap disks closed along beampipe for bakeout bakeout complete 25 Jun

Pixel Tracker Installation





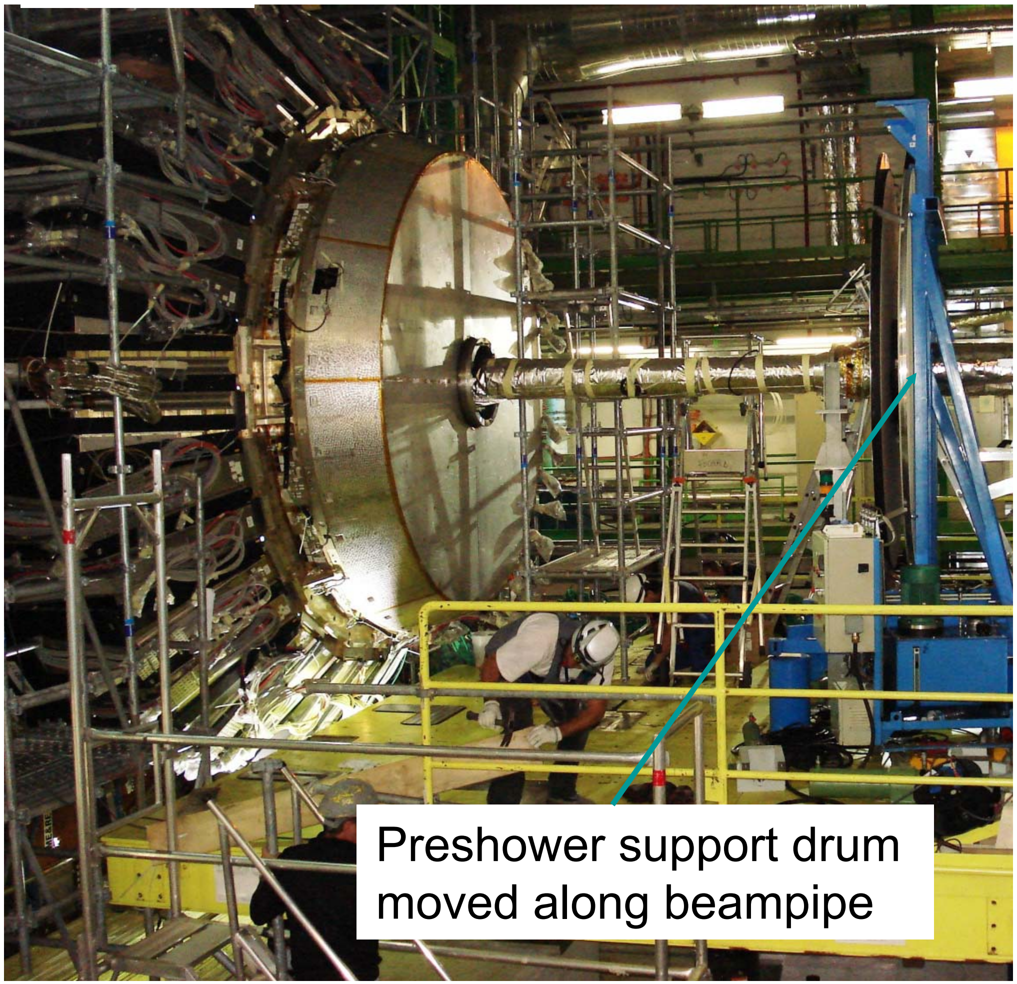
66 mega pixels!!

BCM1 monitor installed just behind forward pixel
Diamond based flux monitor

ECAL Endcap Installation

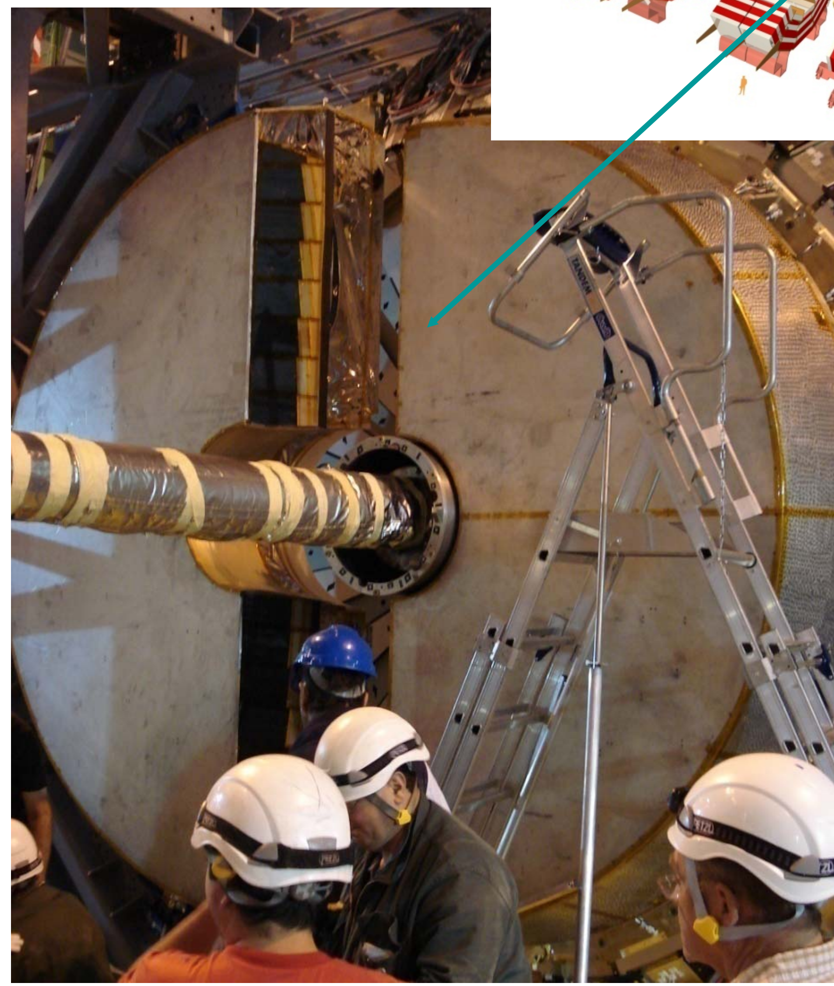
Preshower only missing component
of low lumi version of CMS
Installation foreseen during shutdown

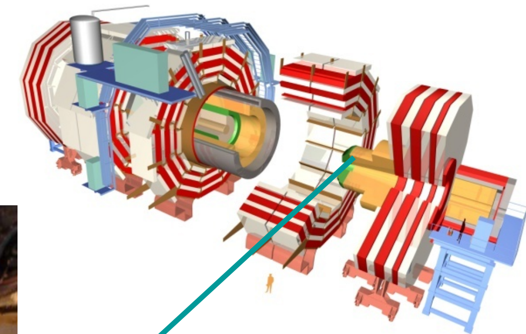
24 Jul 08



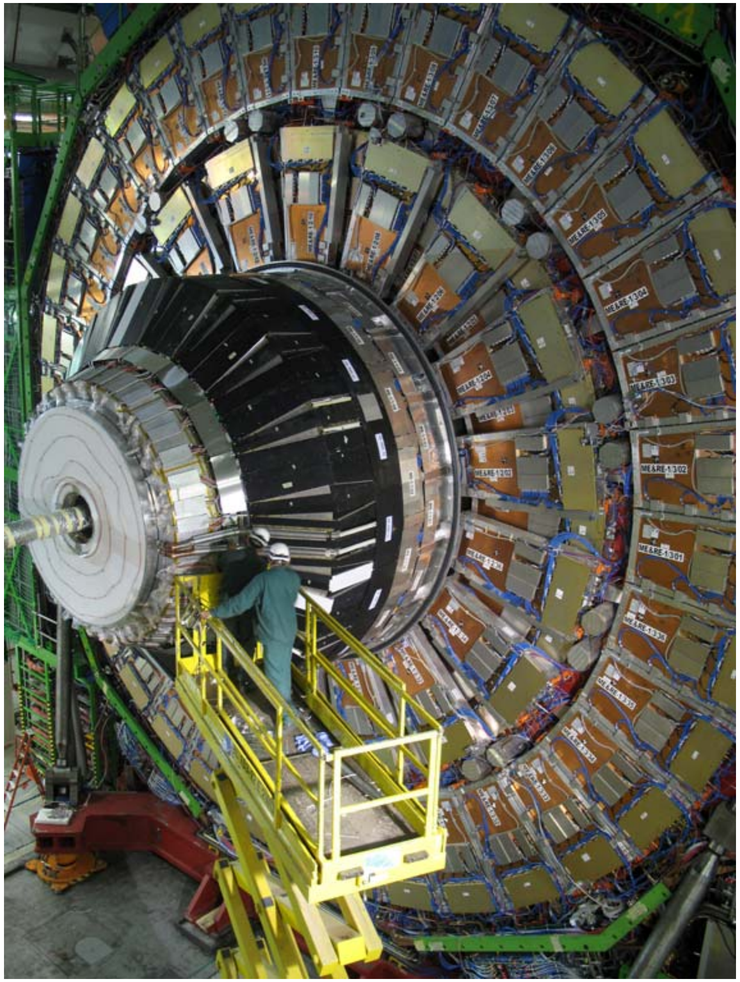
Preshower support drum
moved along beampipe

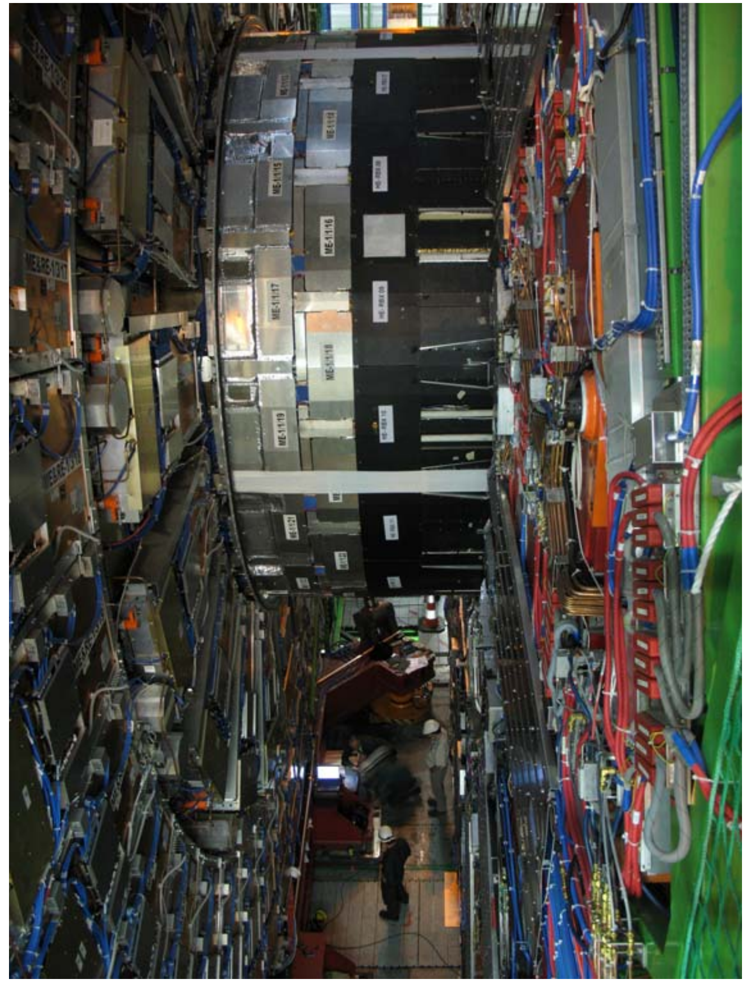
31 Jul 08





Closure of the Yoke

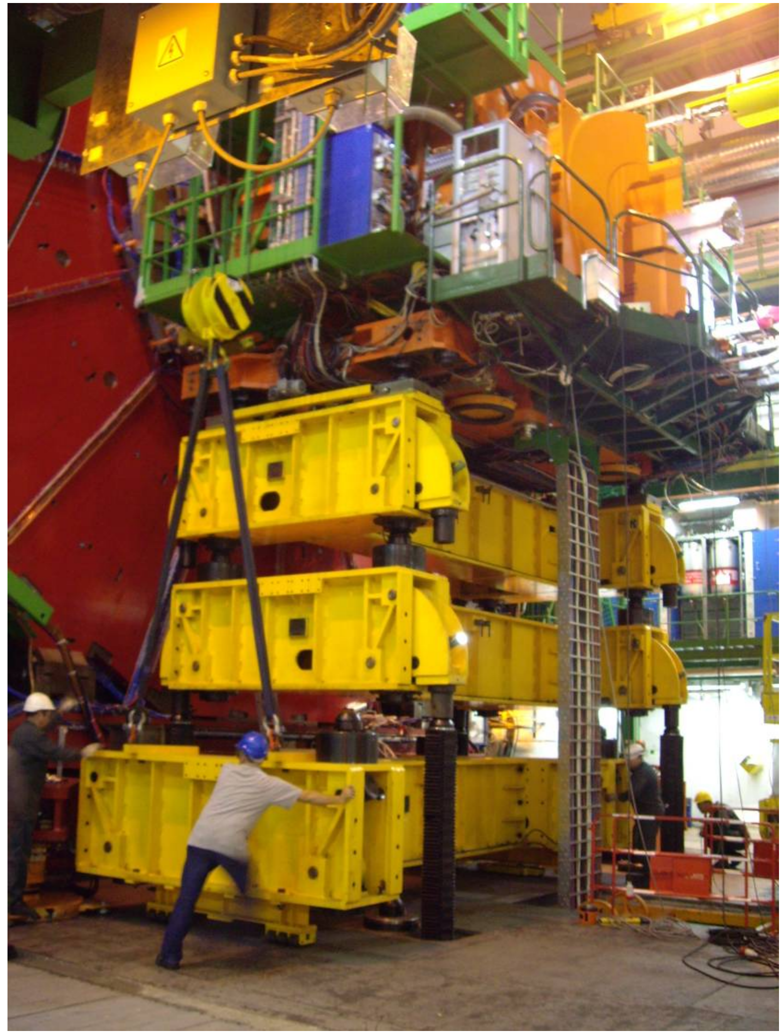




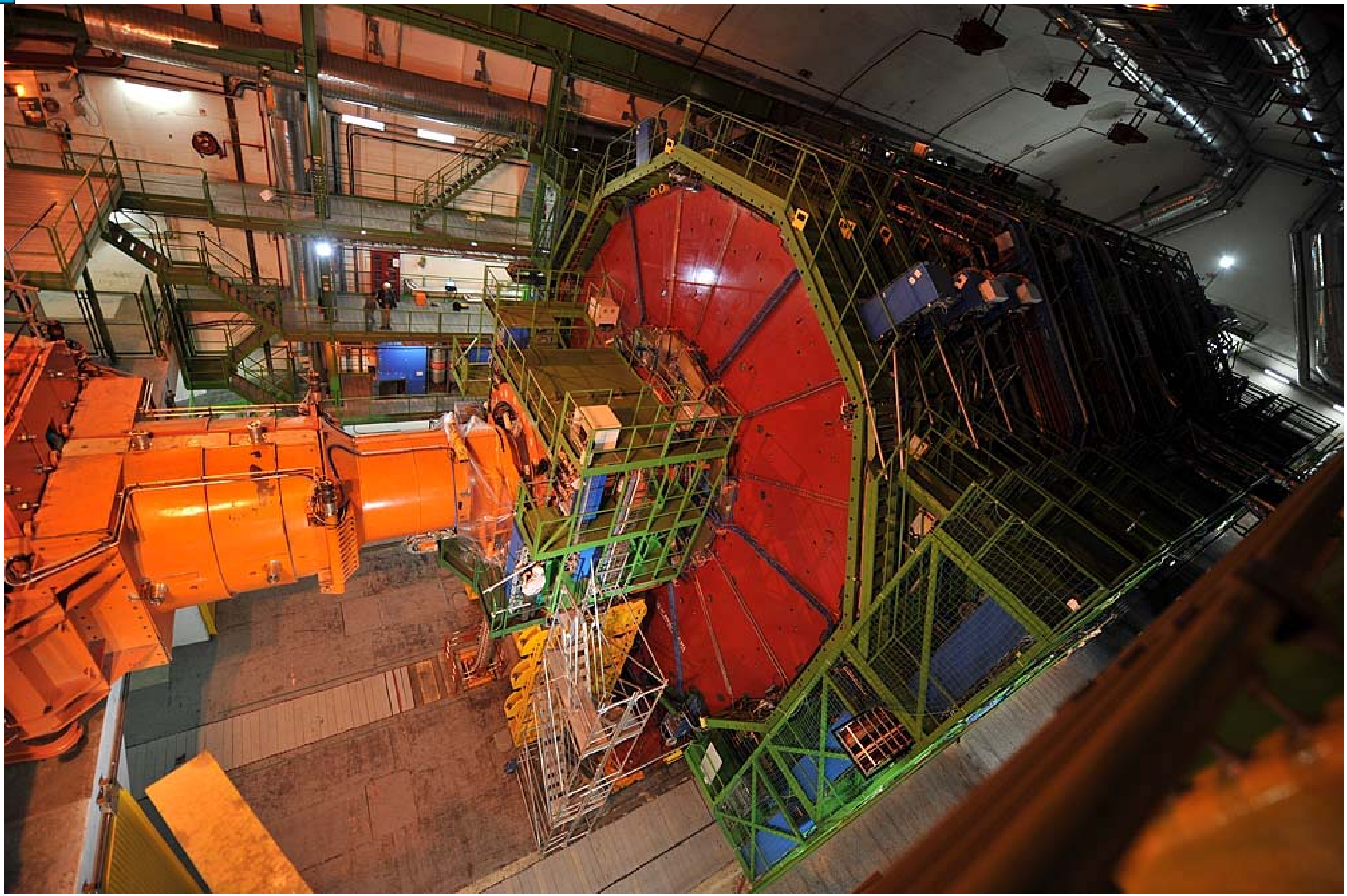
First closure with beam pipe in place - very delicate min. clearance ~4cm
Done by Aug. 25

HF preparation and raising

Minus end
Installed prior to raising
1/8 CASTOR
½ TOTEM T2
BCM2



Closing of Rotating Shielding



Sept 3, 2008 20:30 CMS was closed

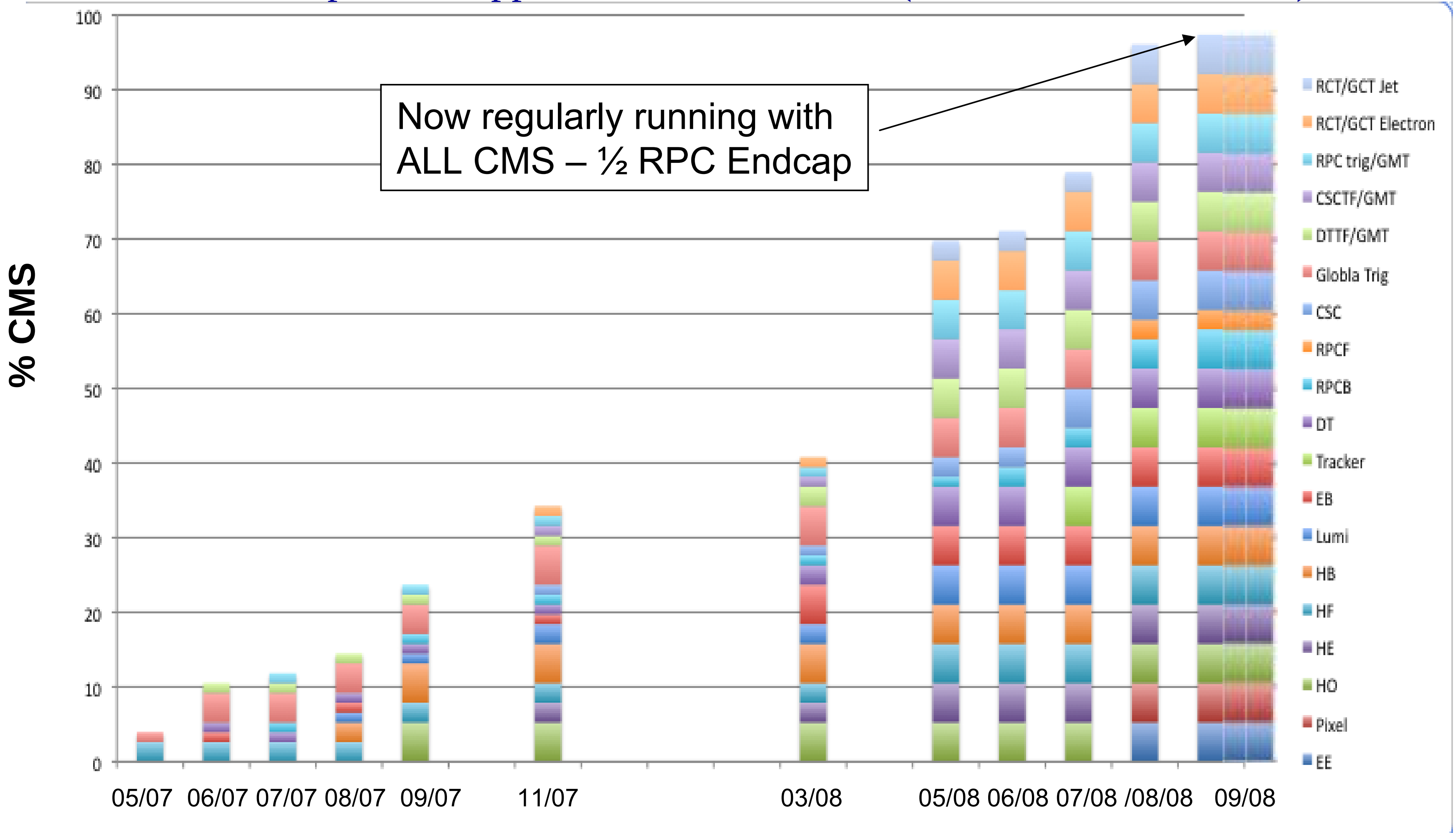
CMS Commissioning

- Global run exercises started in May 2007
- Parallel and parasitic to installation of components and infrastructure
- Since May 2008 high priority global runs with quickly increasing participation
  Still parallel to major installations → complicated planning
- Regular exercises with 24/7 operation – CRUZET
- Since Sept. 2008 regular running with all components (except ½ RPC Endcap)
- First splash events seen from collimators 150m left from CMS on Sept. 5-7
- To be prepared for first beam 24/7 operation since Sept. 8

CMS Commissioning

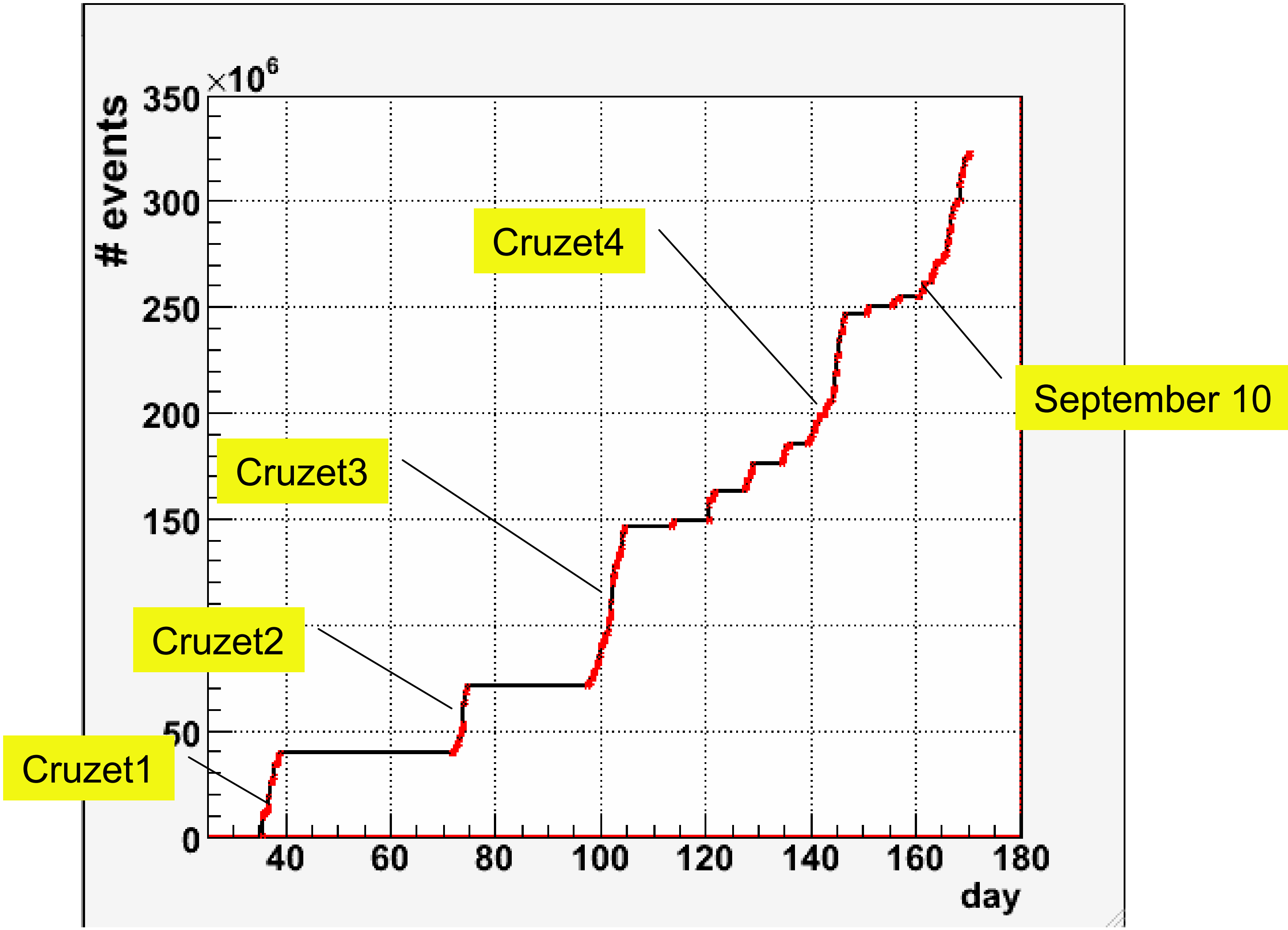
Participation of systems in global runs:

Subdetector and trigger considered separately. Total - 19 items, each equally weighted box size represents approx. fraction included (25%, 50%, 75%, 100%)

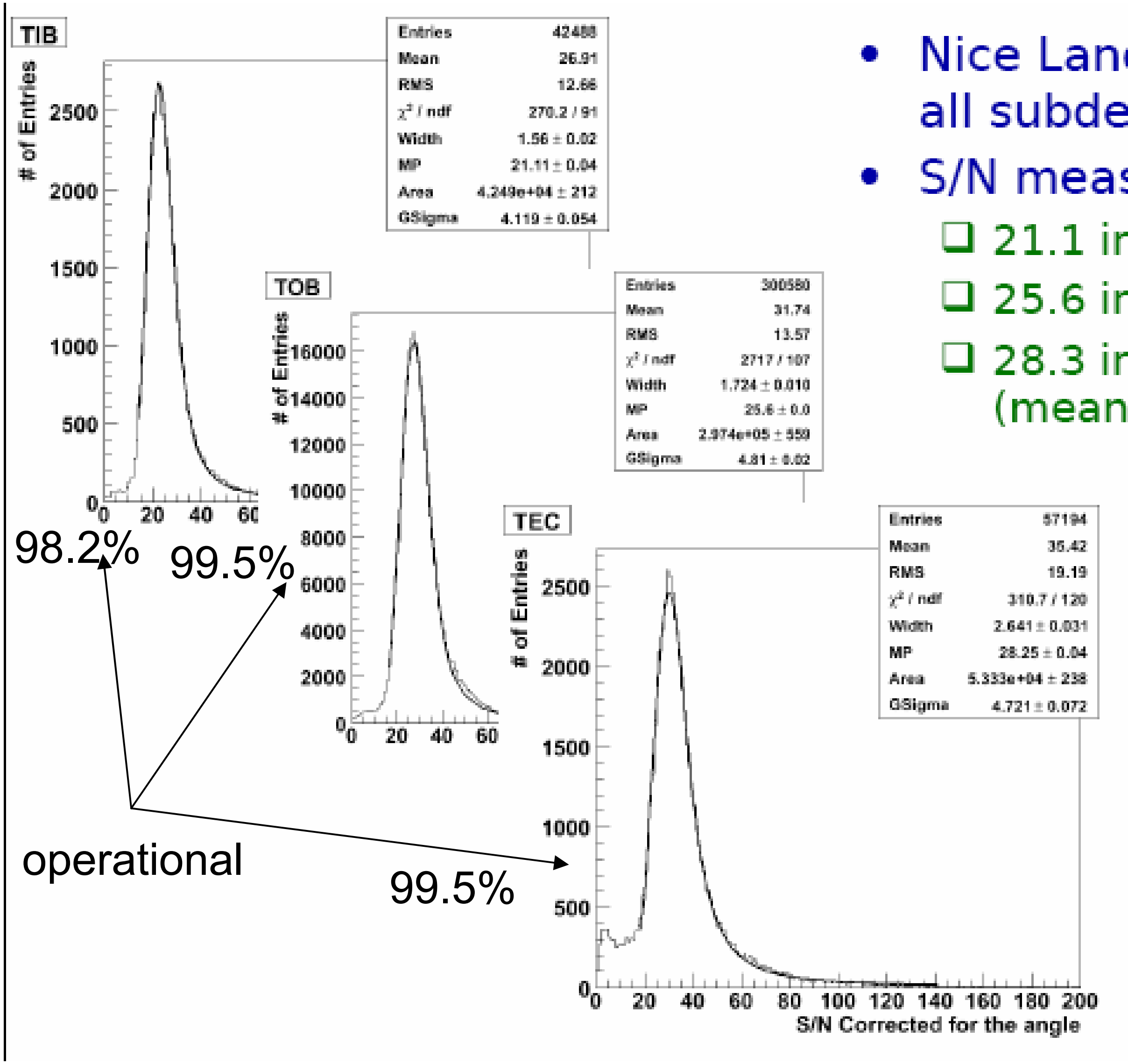


CMS Commissioning

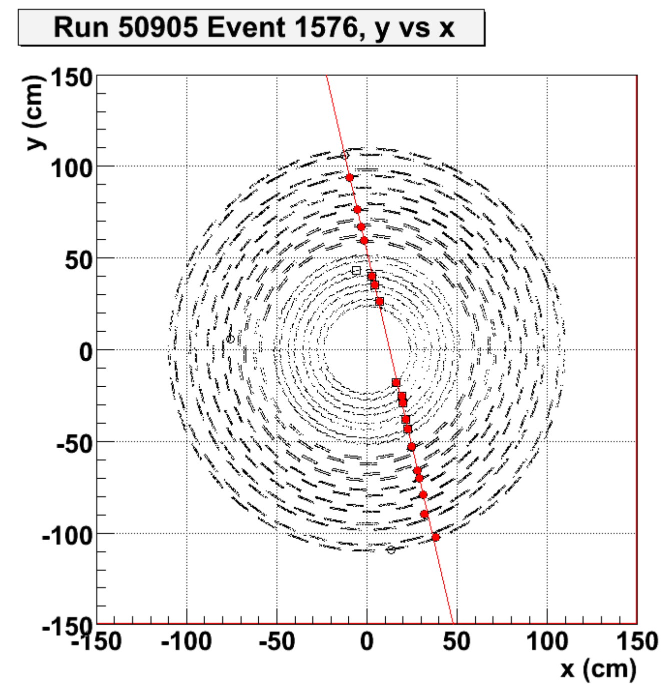
Large Datasets from global runs prior to beam



Tracker Commissioning

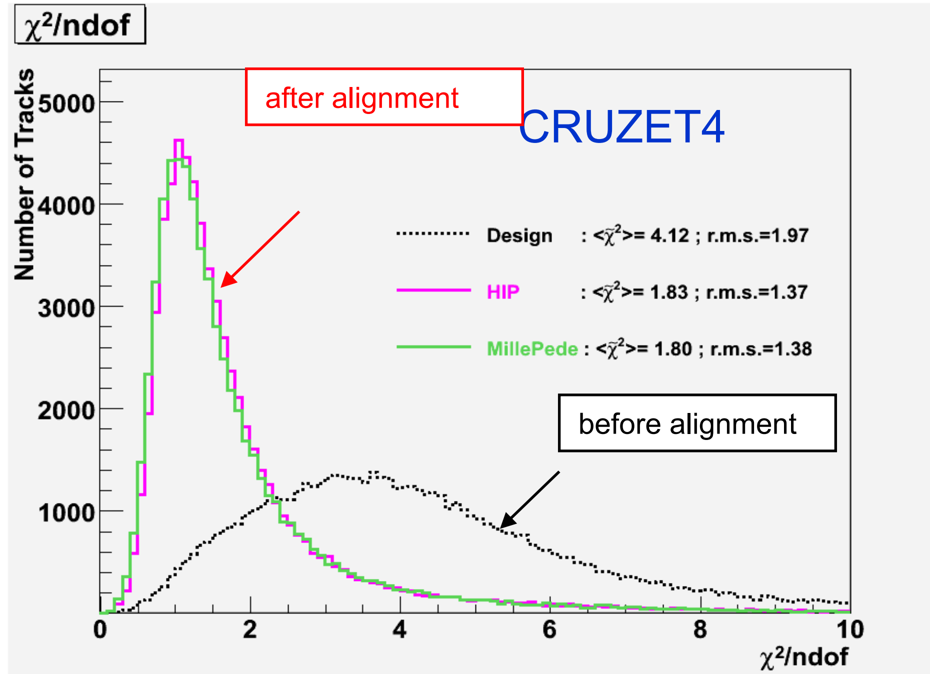


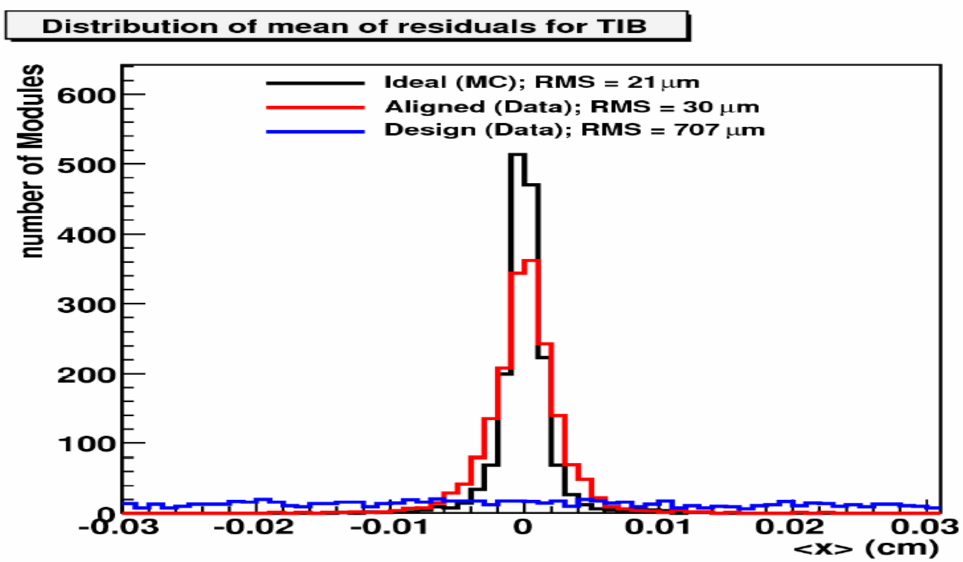
- Nice Landau shape obtained in all subdetectors.
- S/N measured:
  - ❑ 21.1 in TIB
  - ❑ 25.6 in TOB
  - ❑ 28.3 in TEC
    (mean over all geometries)



Tracker Alignment

- Alignment constants for CRUZET3 and CRUZET4 obtained with cosmic muons using two algorithms (HIP & MillePede)
  - ➔ considerable improvement of track quality after alignment (consistently with both algorithms)
  - ➔ centering and narrowing of residual distributions at module level clearly seen

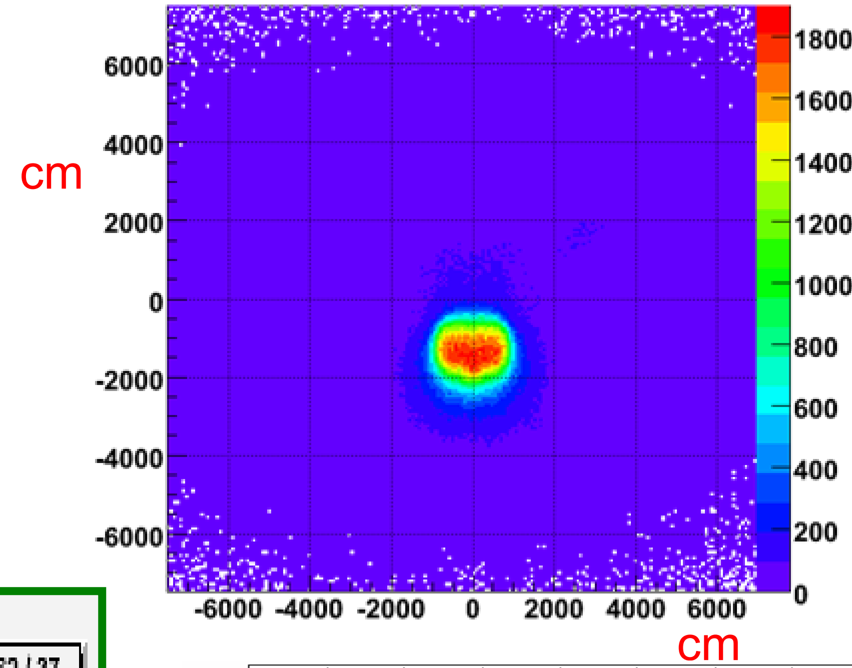




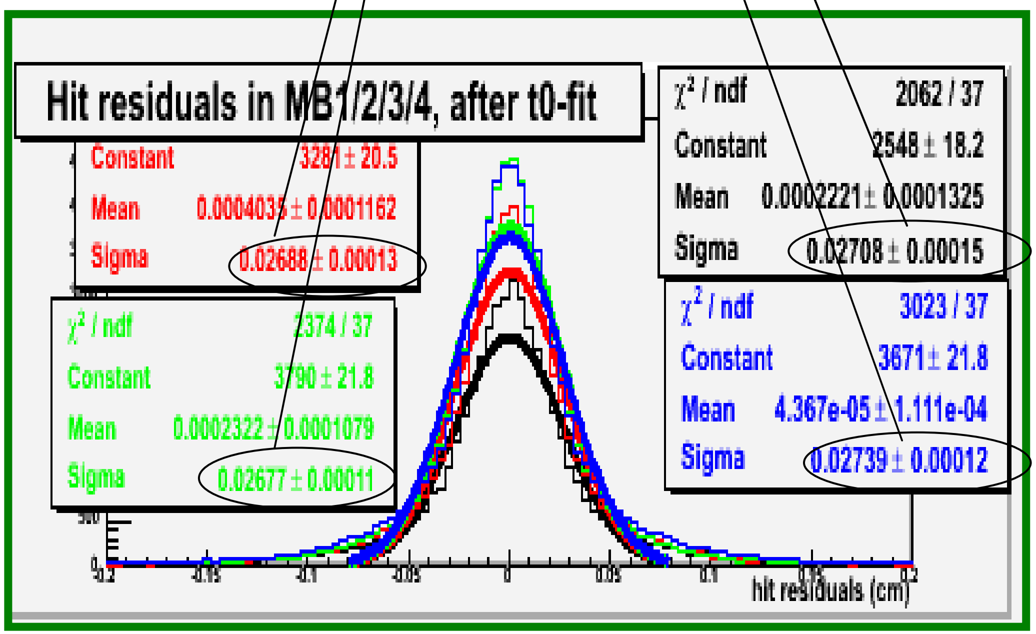
DT Commissioning

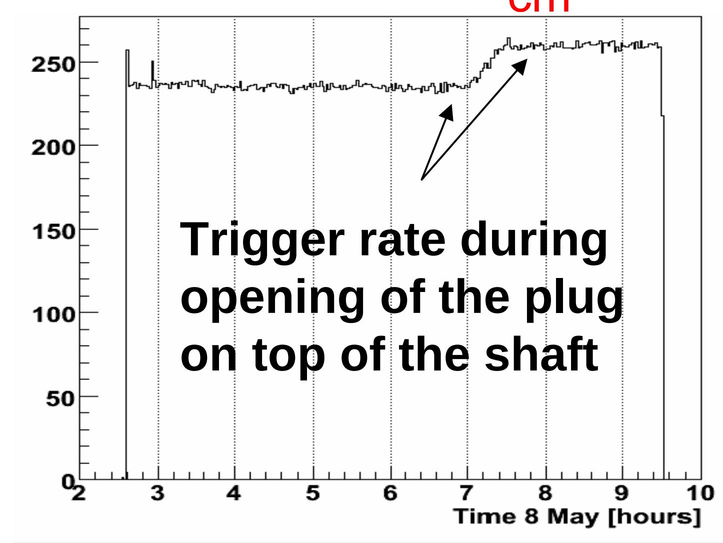
Cosmics tracks extrapolated to the surface (CMS coords)

Can clearly see the shaft !



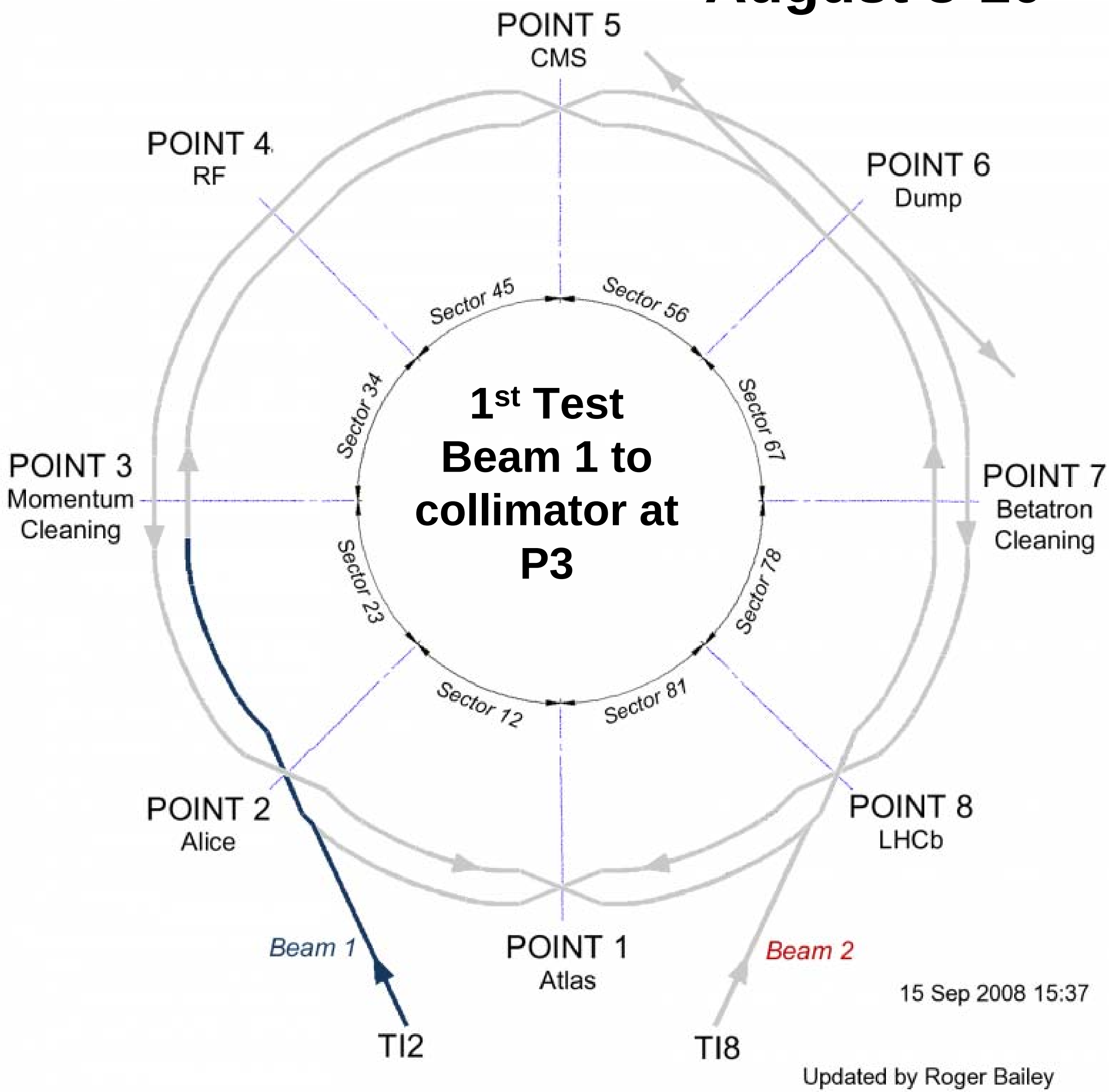
MB1: 271 μm
MB2: 269 μm
MB3: 268 μm
MB4: 274 μm

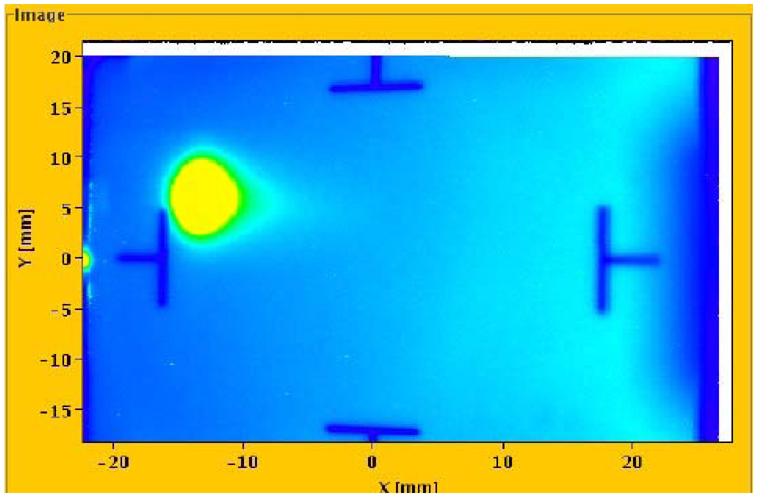




LHC Beam Commissioning

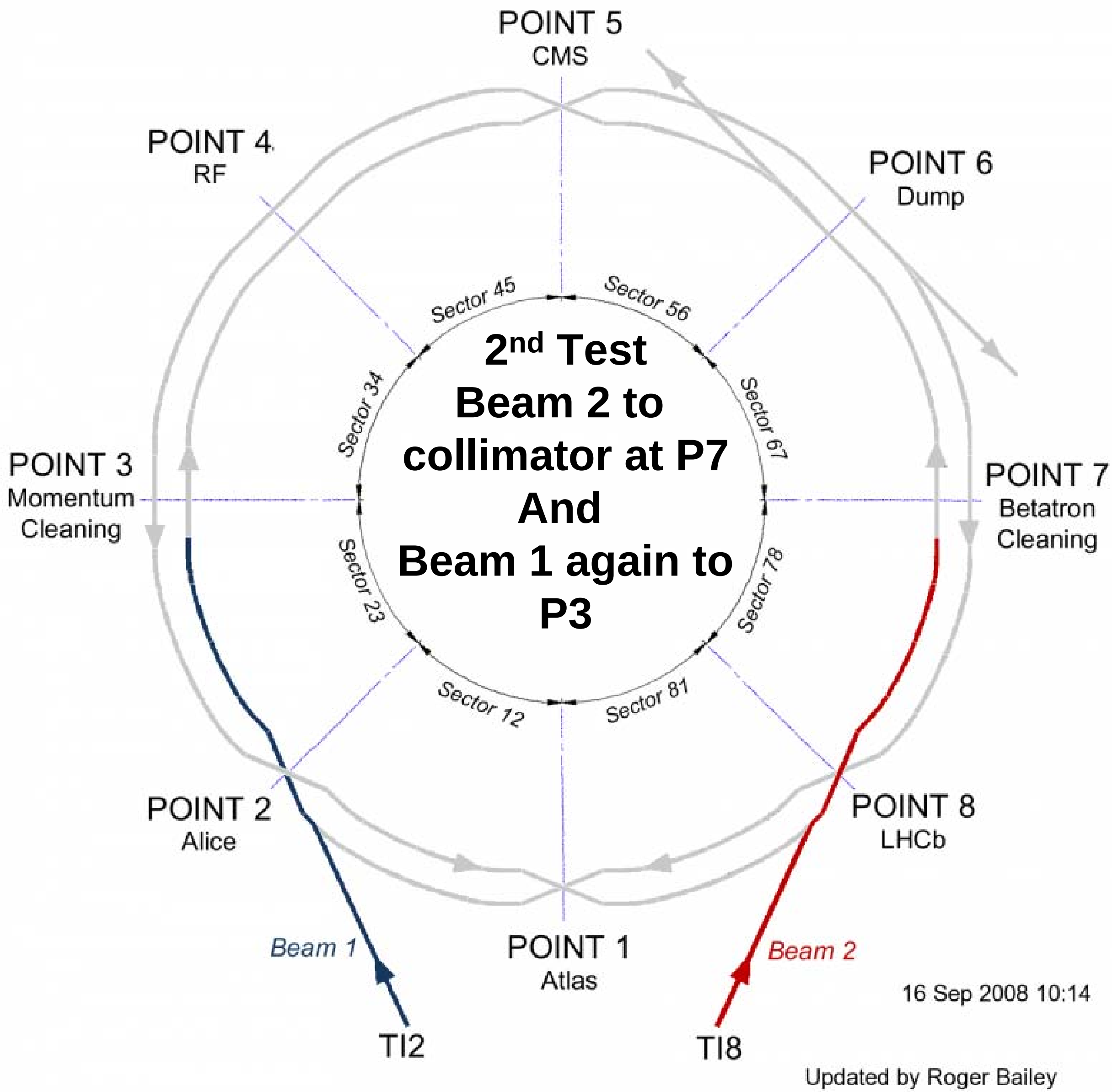
August 8-10



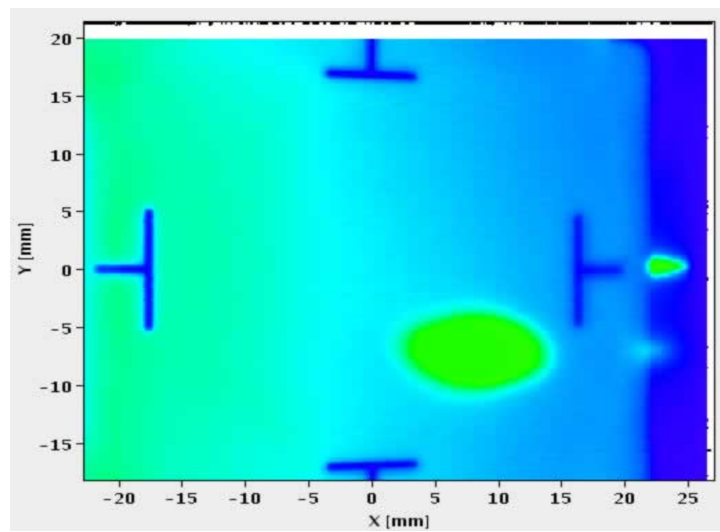


LHC Beam Commissioning

August 22-24

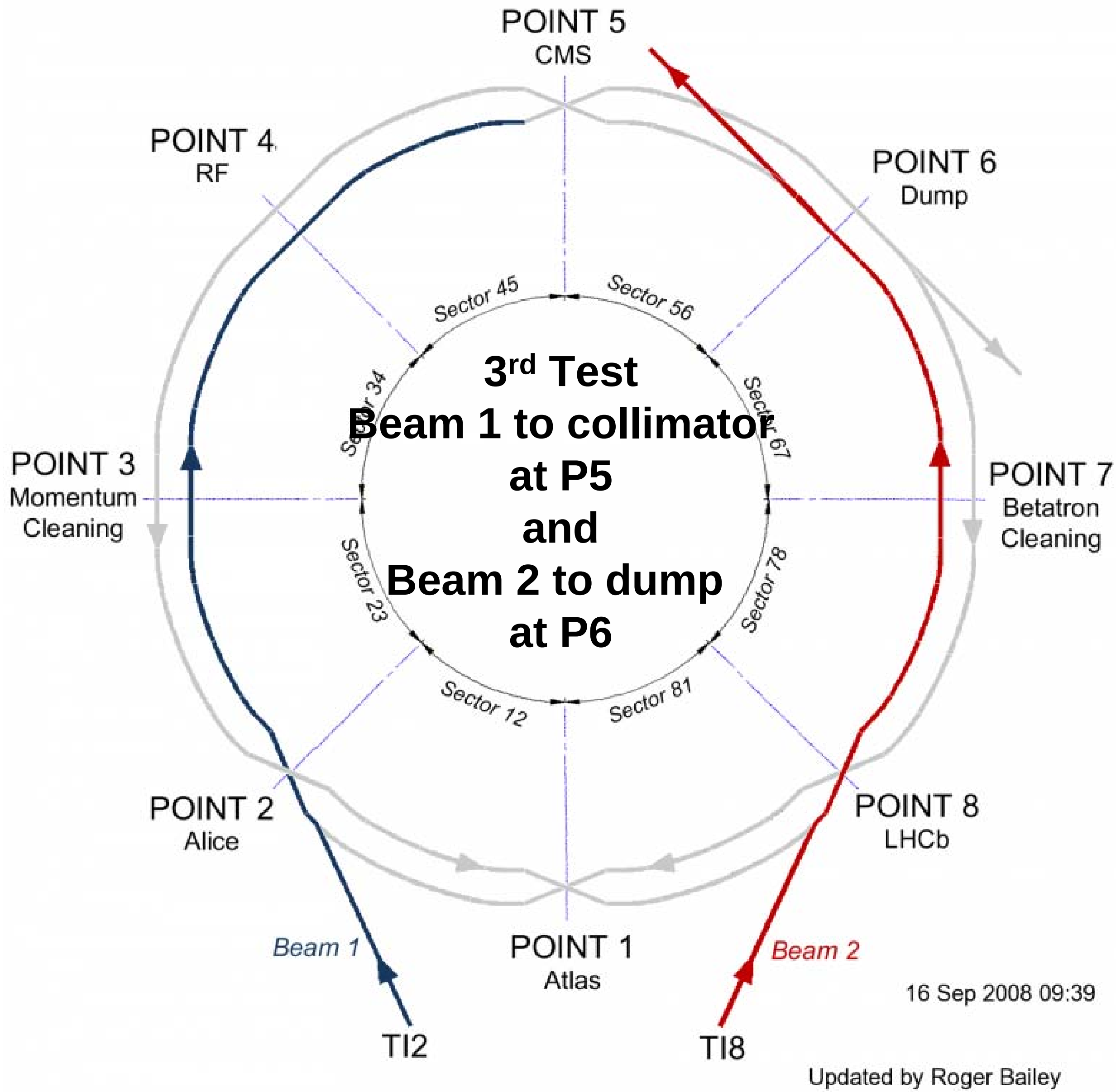


Beam 2



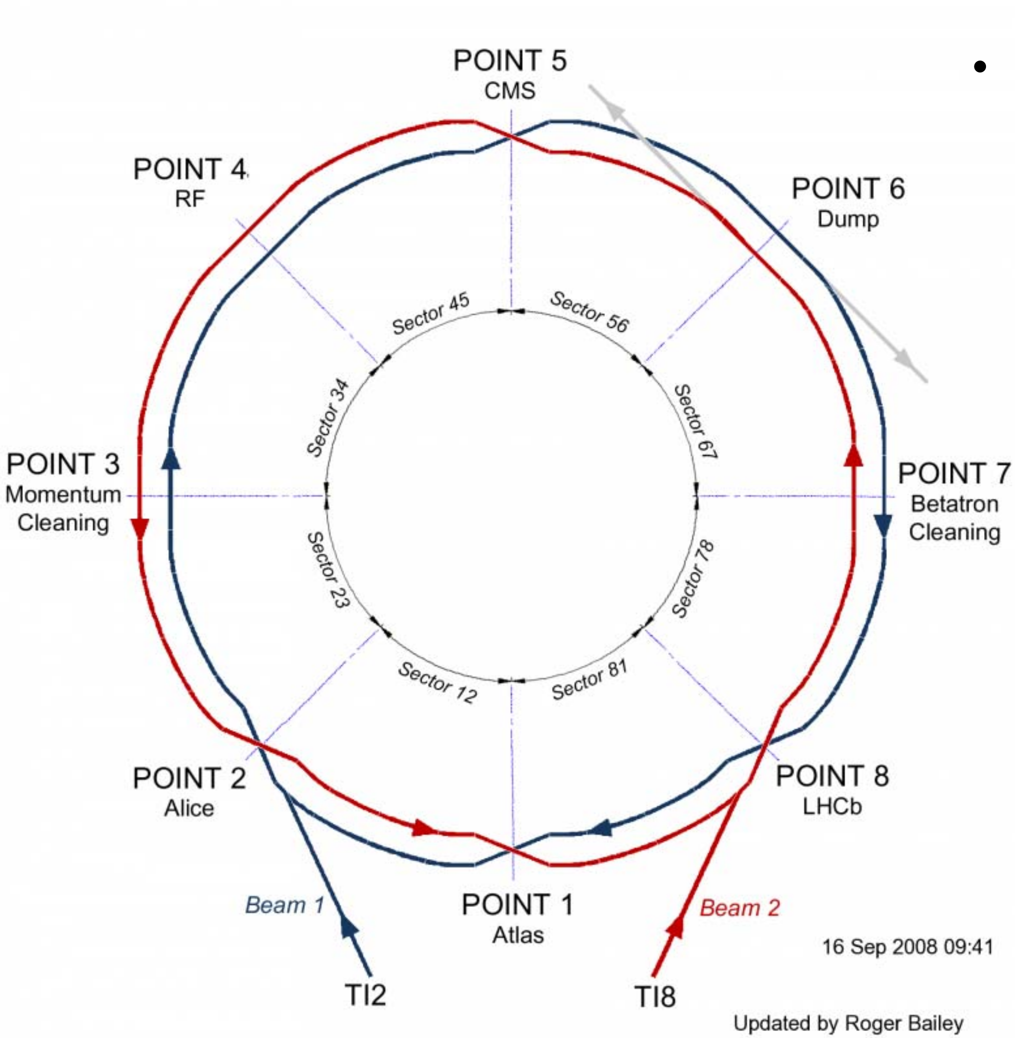
LHC Beam Commissioning

Sept. 5-7



3rd Test
Beam 1 to collimator at P5
and
Beam 2 to dump at P6

LHC Beam Operation Sept. 10



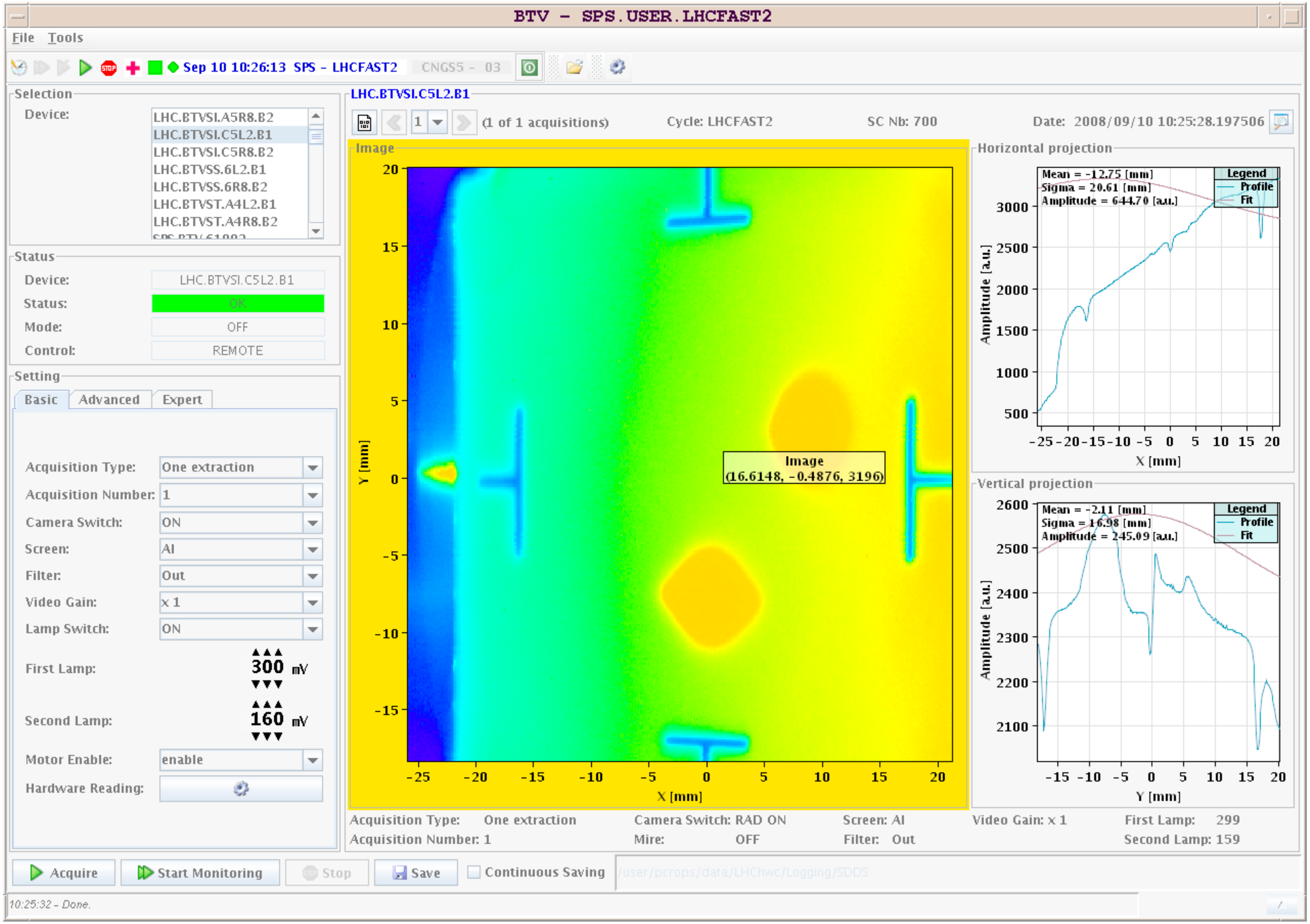
- Achieved
  - **Beam 1** injected IP2
  - Threaded around the machine in 1h
  - Trajectory steering gave 2 or 3 turns

  - **Beam 2** injected IP8
  - Threaded around the machine in 1h30
  - Trajectory steering gave 2 or 3 turns
  - Q and Q' trims gave a few hundred turns

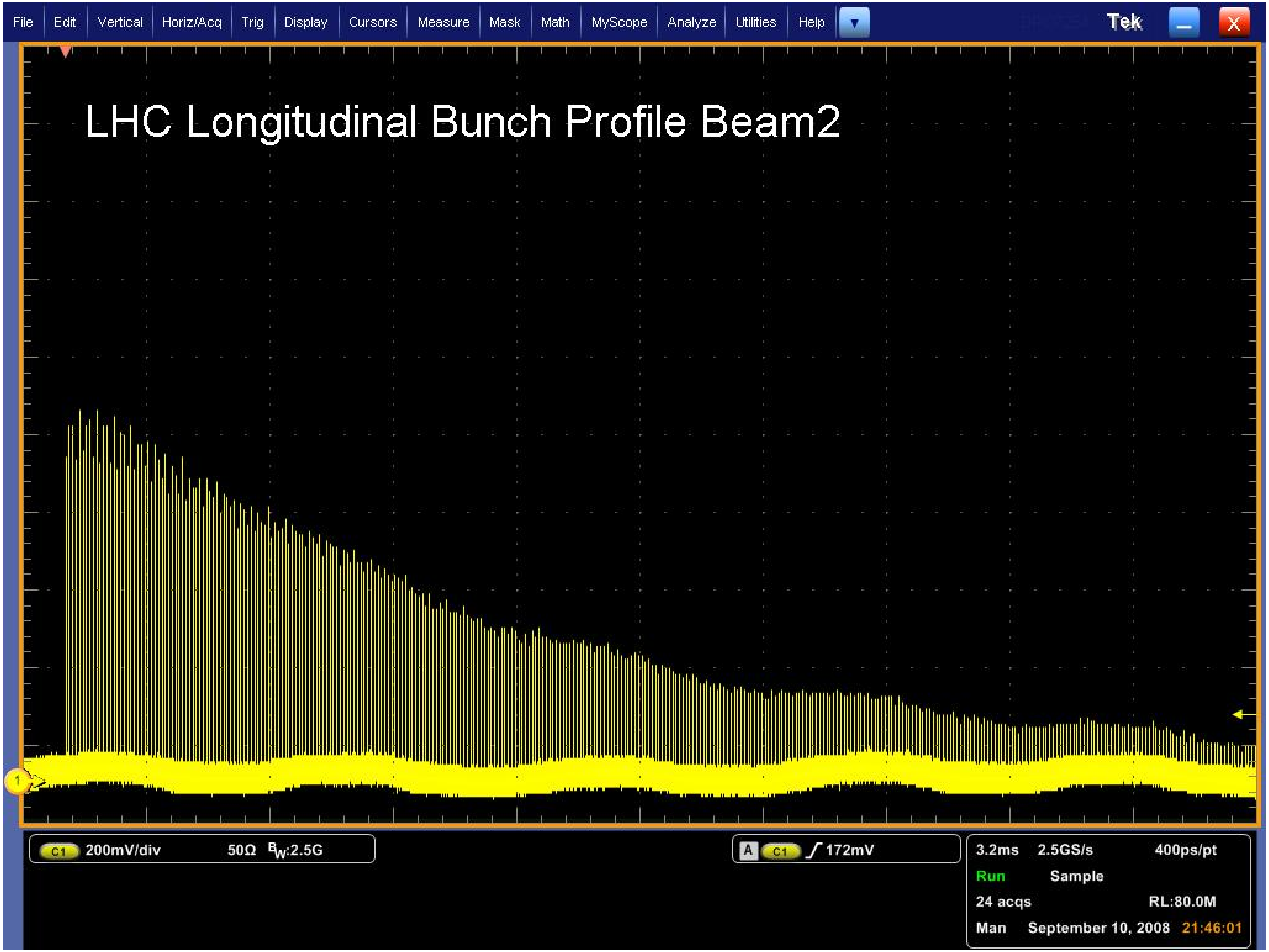
  (R. Bailey at CMS Pleanry)

LHC Beam Operation Sept. 10-12

Beam 1 turn 1 & 2



LHC Beam Operation Sept. 10-12

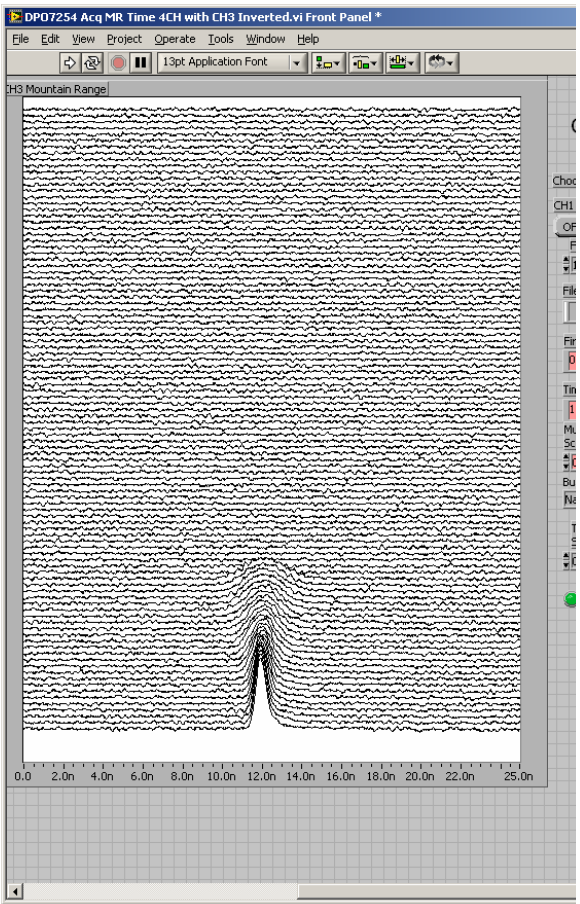


R. Bailey at CMS Plenary, Sept. 08

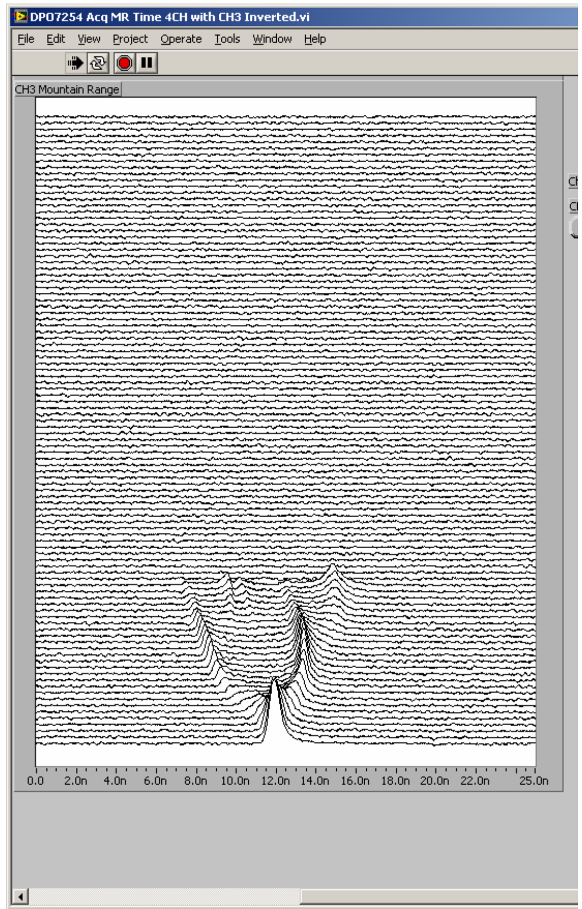
LHC Beam Operation Sept. 10-12

Beam diagnostics

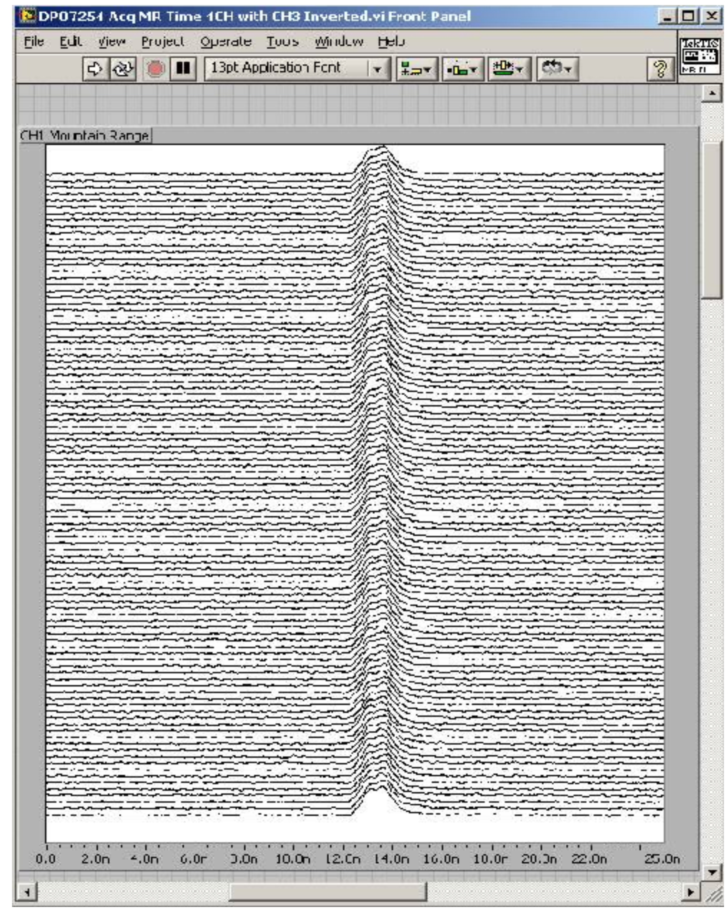
No RF beam de-bunches



RF – wrong injection phase



**RF captured,
correct injection phase**

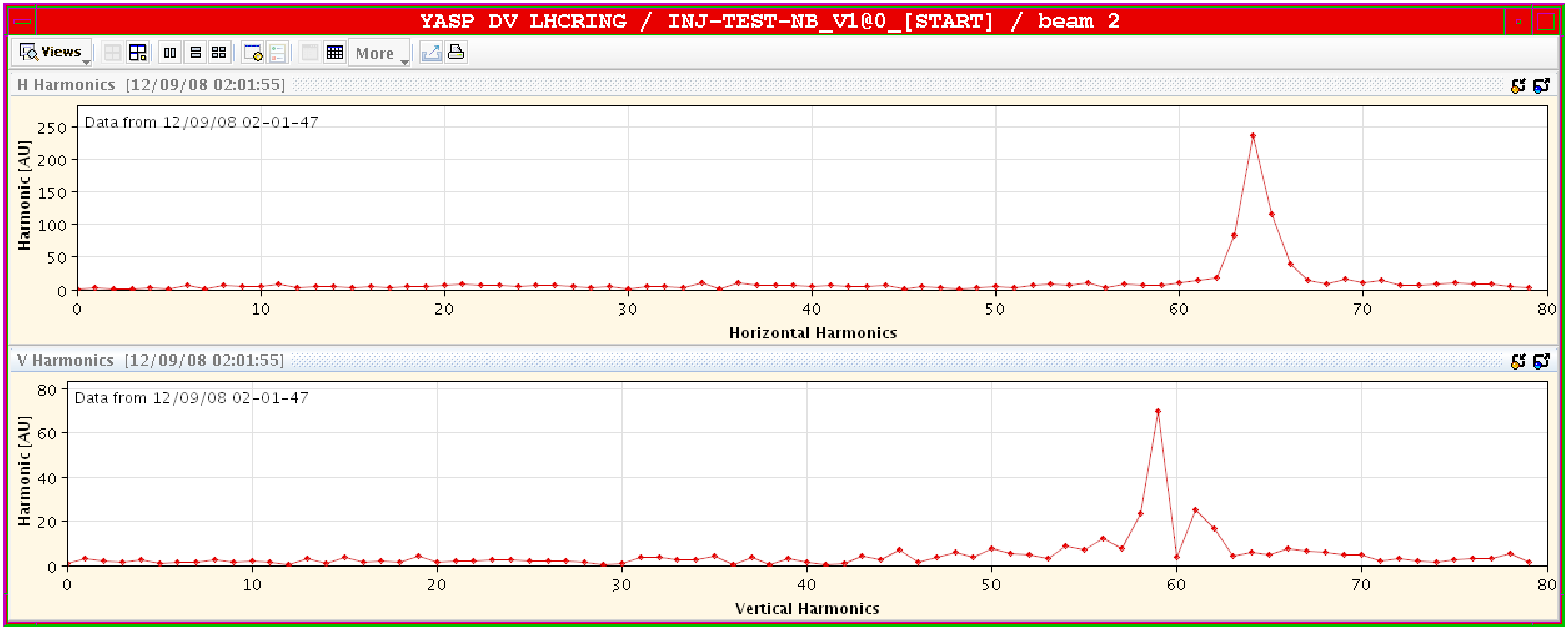


L. Evans at LHCC Plenary, Sept. 08

LHC Beam Operation Sept. 10-12

Beam diagnostics

Integer Tunes



Incidents 12.9. & 19.9.

- 12.9. 23:30, 12MVA transformer failed at P8
- Cryogenics failed at P8 (Sec. 7-8 & 8-1)
- Transformer replaced Sept 13 &14
- Recovery took a few days, ready for beam Sept. 18

- 19.9. Midday, an incident happed in Sector 3-4
  during commissioning magnets without beam
  Details still under investigation
  Sector has to be warmed up
  Some magnets have to be brought to surface
  Impossible to restart before the winter-shutdown

- Restart of LHC foreseen for May 2009

September 19th - Incident in LHC sector 34

Press Release

Geneva, 20 September 2008. During commissioning without beam of the final LHC sector (sector 34) at high current for operation at 5 TeV, an incident occurred at mid-day on Friday 19 September resulting in a large helium leak into the tunnel. Preliminary investigations indicate that the most likely cause of the problem was a faulty electrical connection between two magnets which probably melted at high current leading to mechanical failure. CERN's strict safety regulations ensured that at no time was there any risk to people….

A full investigation is underway, but it is already clear that the sector will have to be warmed up for repairs to take place. This implies a minimum of two months down time for the LHC operation. For the same fault, not uncommon in a normally conducting machine, the repair time would be a matter of days.

Further details will be made available as soon as they are known.

CMS Beam Operation

- Sunday/Monday 7/8 Sept.
  - Single shots of Beam 1 (clockwise) onto collimator 150m upstream of CMS
  - BPTX synchronized (beam timing)

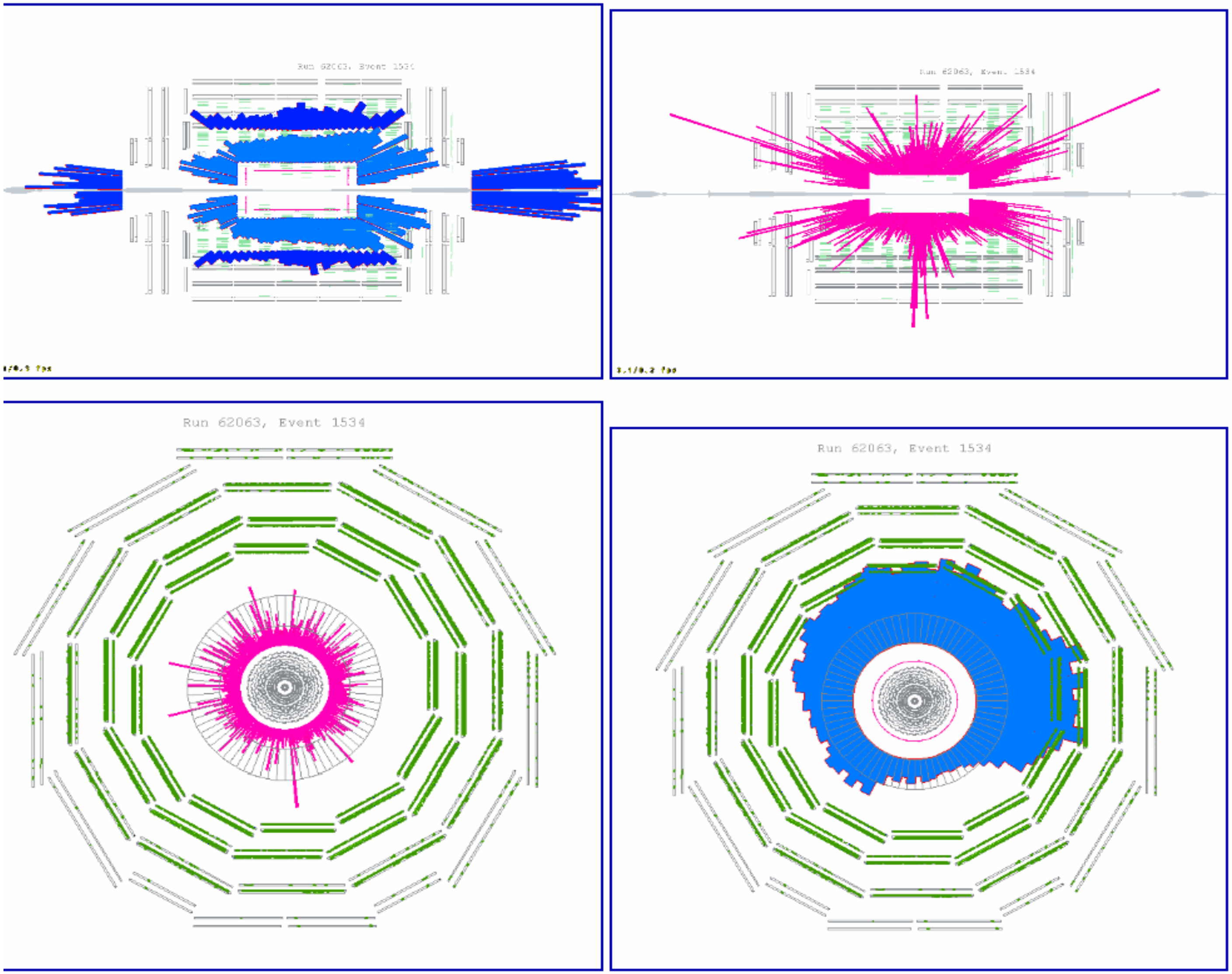
- Tuesday Sept. 9
  - 20 shots of Beam 1 onto collimator

- Wednesday Sept. 10 – Friday Sept. 12
  - Splash events with closed collimators
  - Halo Muon events once beam went through CMS

First Events Collimator Closed

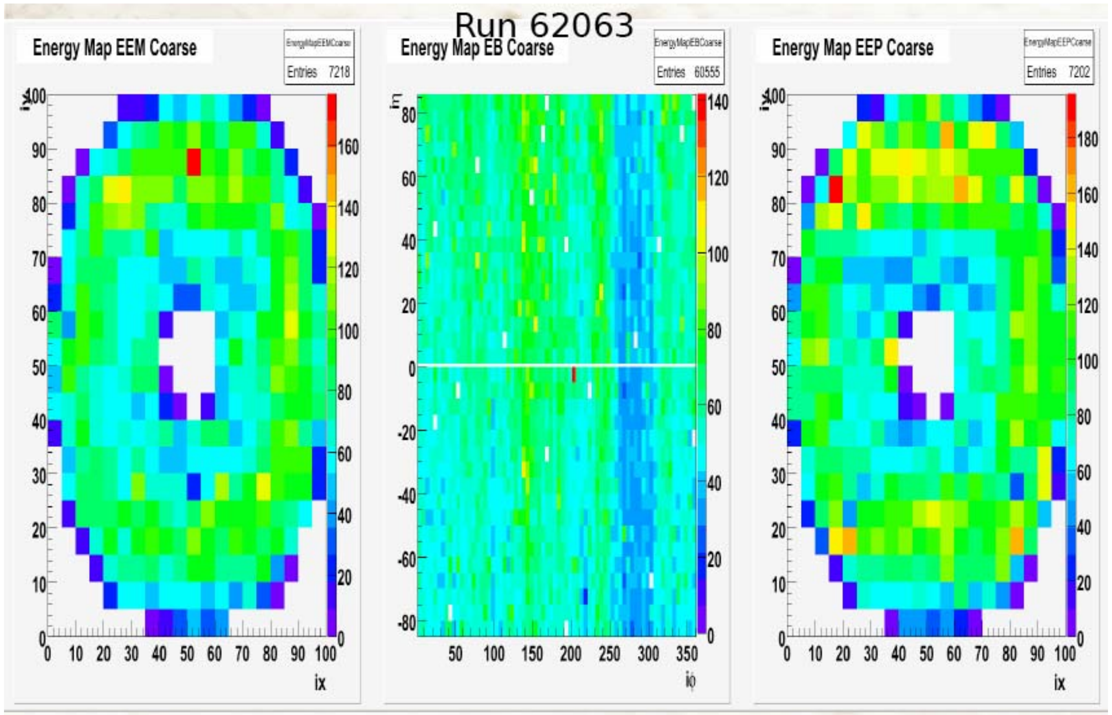
~2.10^9 protons on collimator ~150 m upstream of CMS

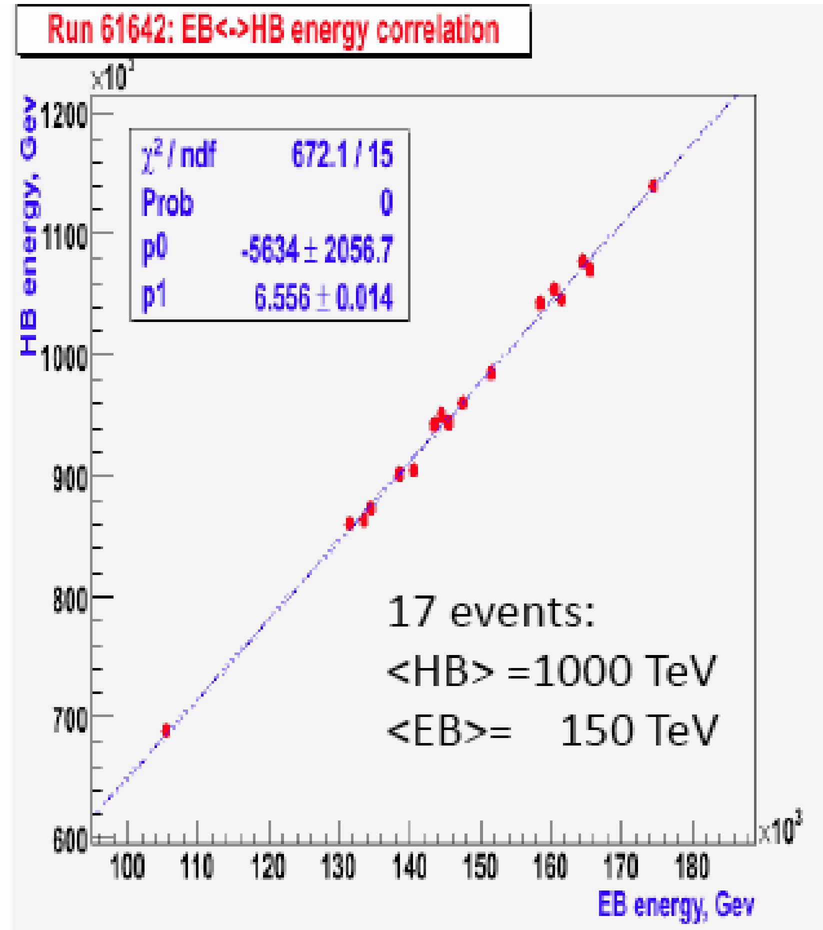
ECAL- pink; HB,HE - light blue; HO,HF - dark blue; Muon DT - green; Tracker Off



Calorimeters Collimators Closed

ECAL Energy Map



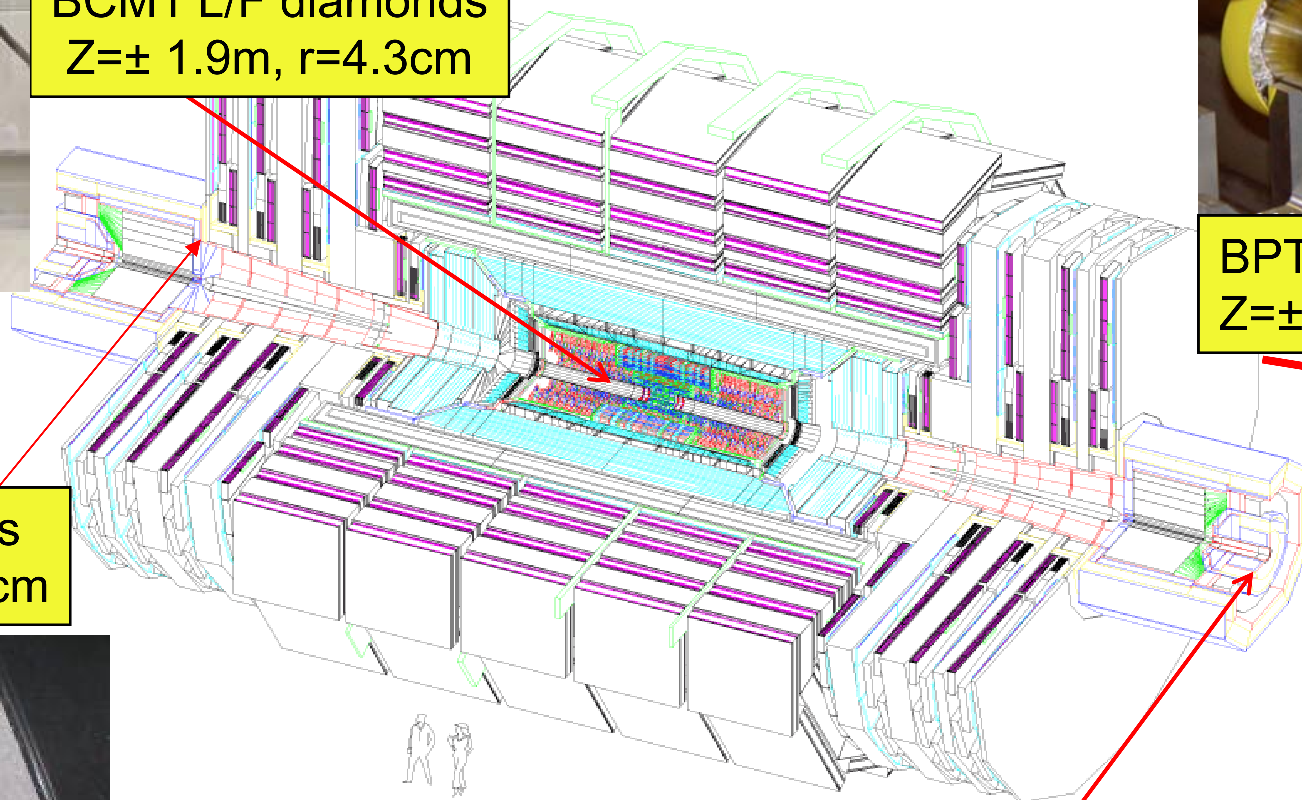


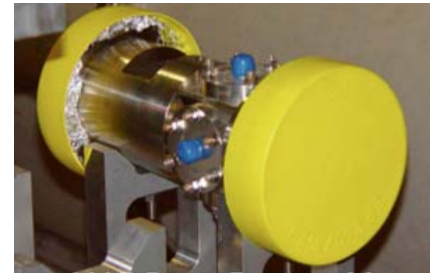
Beam Radiation Monitoring

Ready just in time

In addition: 18 RADMON detectors + TLD-Alanine passives

BCM1 L/F diamonds
Z=± 1.9m, r=4.3cm



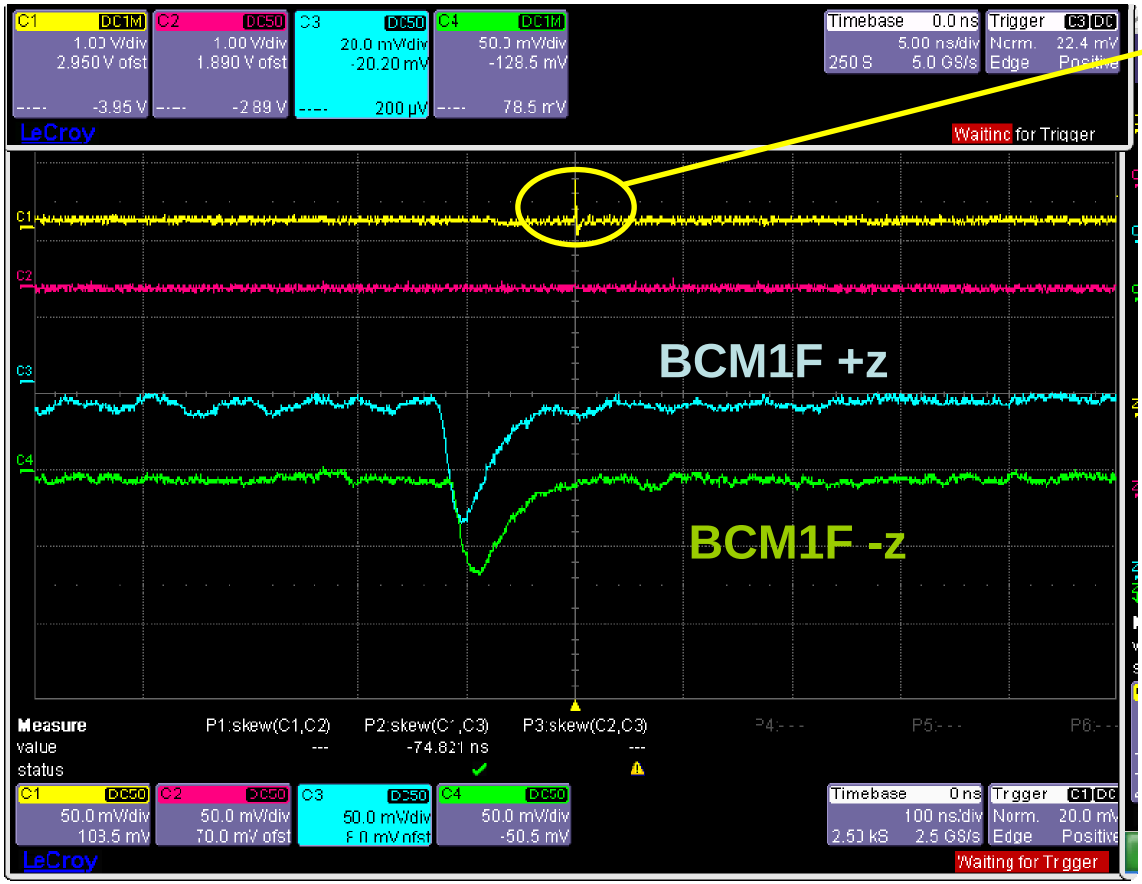


BPTX beam pickup
Z=± 150m

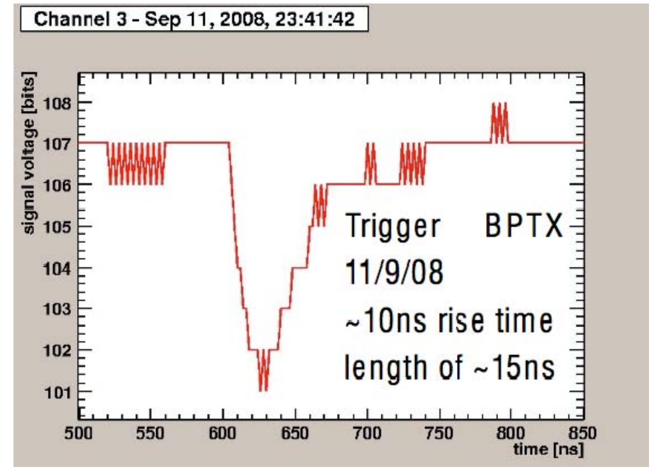
BSC1: scintillators
Z=± 10.9 m, r=4.3cm

BCM2 diamonds &
BSC2 scintillators
Z=± 14.4m, r=29cm
Triggers beam dump

Beam Radiation Monitor

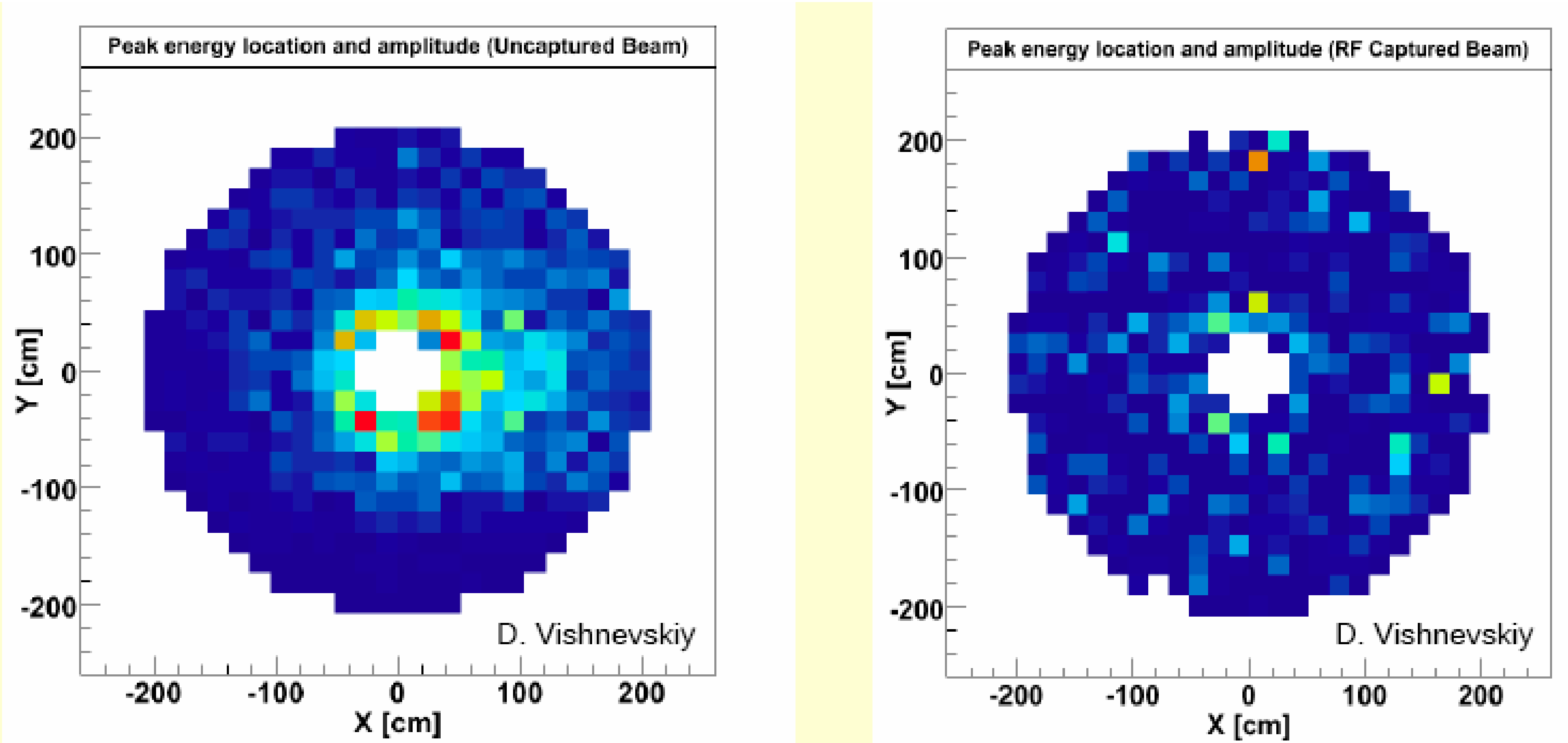


BPTX Trigger



Beam 1 arrives at +z counter ~15ns before on -z

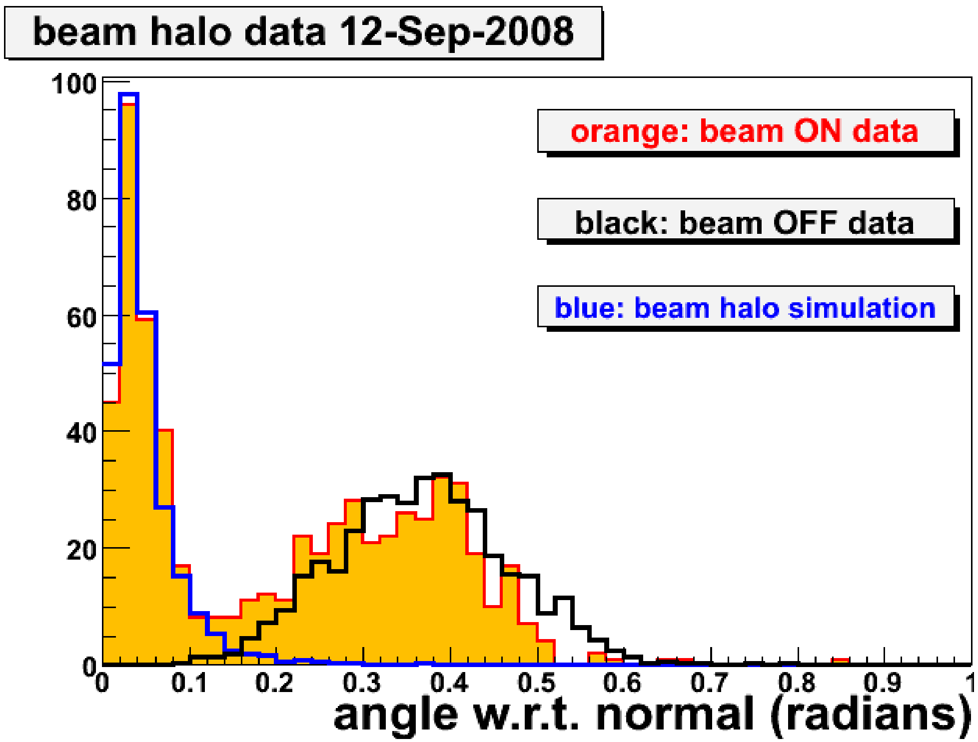
Circulating Beam

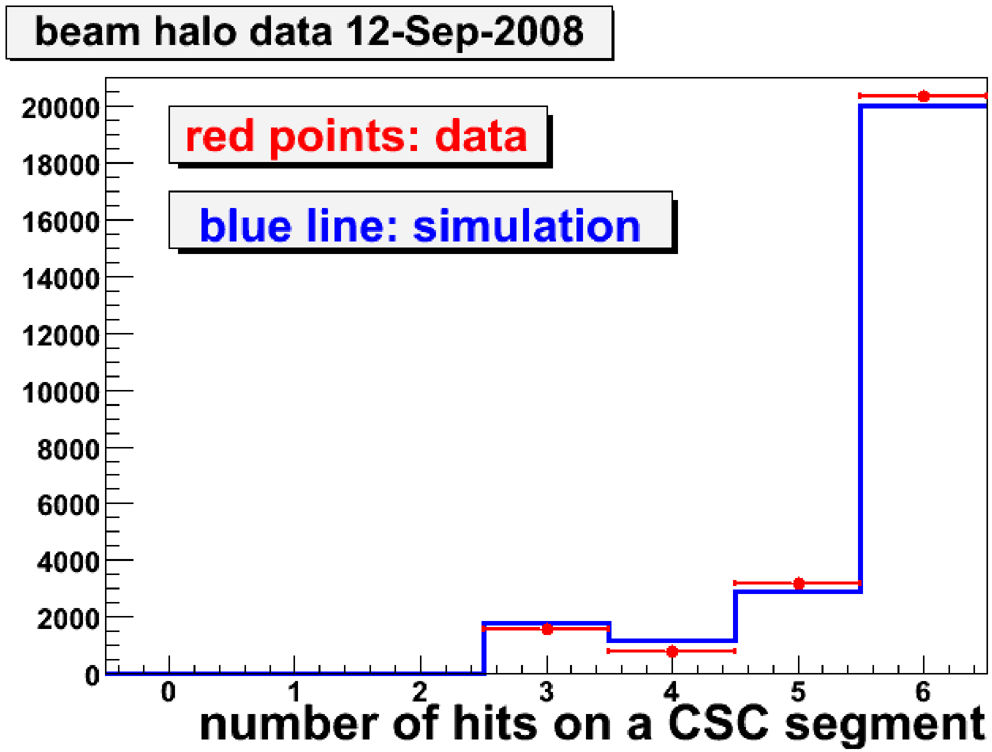


HCAL Endcap: Reduction of beam halo when beam was captured by RF

Circulating Beam CSC-Muon Detector

Reconstructed track angle
w.r.t. the transverse plane





Reasonable description of beam ON data: combination of

- beam halo
- cosmic rays

Whats next

- Fringe Field problems found in the region between HF and Rotating Shield
  Very large forces on the table and support of CASTOR
  Dangerous because CASTOR is close to beam pipe and
  Beam pipe is supported from CASTOR table
  Not yet understood from calculations

- Remove CASTOR and investigate experimentally by ramping the magnet
- Fix problems as they show up

- ~2 weeks cosmics run 24/7 with full field “CRAFT”

- Mid Nov start shutdown
- “CMS Perfectionism” has to be balanced against risks and the machine schedule
- Pre-shower Endcap should be installed – construction is ongoing but well advanced

- Next years running period will start with the complete CMS in its initial configuration

Summary

After almost 20 years of design and construction CMS started data taking with LHC beam

- The low luminosity detector minus the Pre-shower is ready

- All components have shown to be working including DAQ, Trigger and Computing

The setback of LHC came very untimely and is very unfortunate

Summary

However,
There are still issues in CMS to be solved or improved

- Understanding of the fringe field in the forward region
- Finalization and installation of the Pre-shower detector
- Some left out repairs and cut edges due to the rush of the assembly in summer

In spring 2009,
we will restart with a complete and even better CMS detector expecting exciting physic to be discovered.
You will hear from us !!!