CMS Commissioning:
The Magnet Test & Cosmic Challenge (MTCC)

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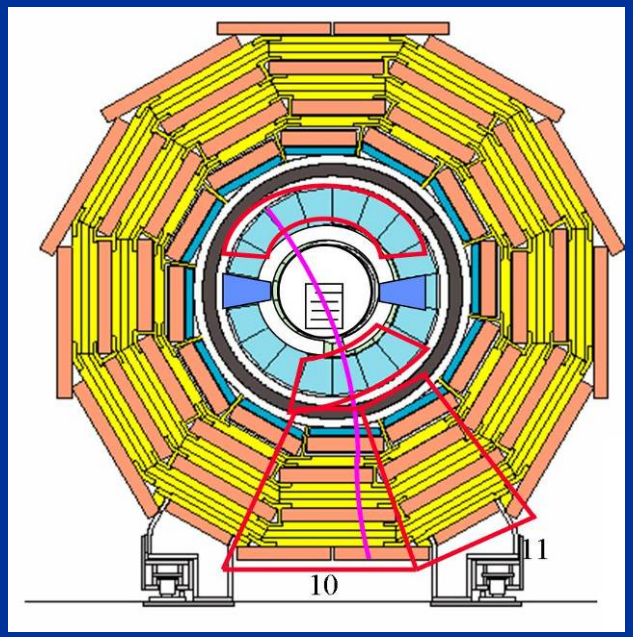
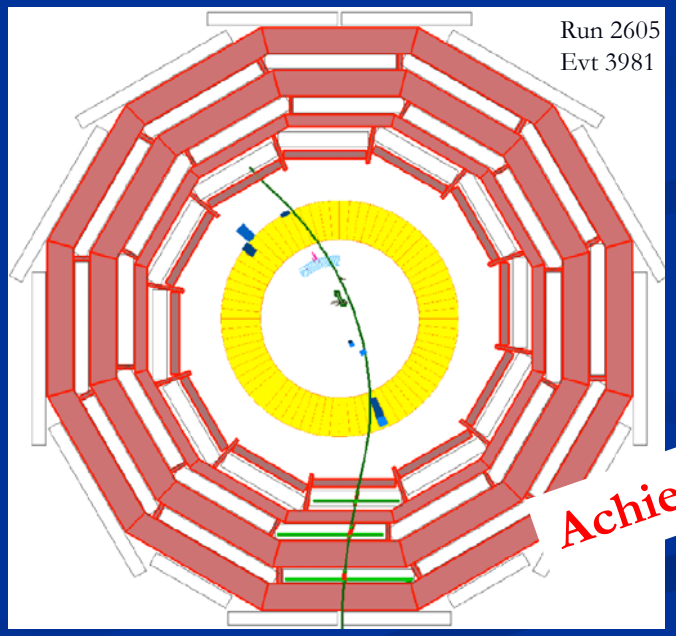
Special thanks for the material to A. Ball, G. Bruno, D. Campi, S. Cittolin, T. Christiansen, P. de Barbaro, G. Franzoni, A. Gaddi, A. Herve, K. Hoepfner, F. Loddo, K. Maeshima, I. Osborne, T. Rodrigo, A. Sharma and hundreds more for the work behind the scenes..

The MTCC planning and goals

- Surface activities have been planned since 1996 to cope with underground schedule. Main objective being the Magnet Test: closure of the yoke, coil commissioning and mapping of the magnetic field.
- The activities plan was then extended to including slice tests done in parallel for muon systems and the HCAL with local DAQ readout and self triggering.
- By early 2004 the plan was finally extended to running one fraction (~1/20) of CMS with all detectors (except tracker pixels) participating, with central controls, trigger and readout systems, and with central services, trying to have as much as possible of such components as in their final design: the original plan became **"The Magnet Test and Cosmic Challenge".** MTCC is split in two phases due to incopatibility of field mapper with ECAL & Tracker

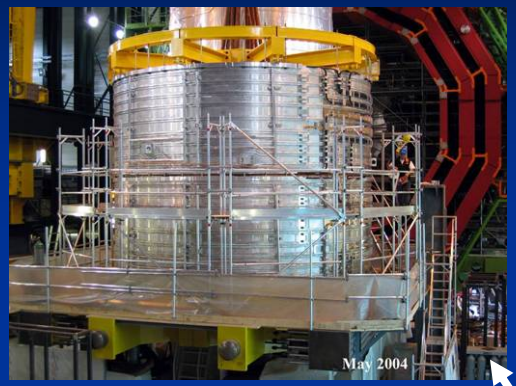




Phase I accomplished in August 2006, phase II will be in October 2006

Infrastructure Activities Towards MTCC

In surface hall @ LHC Interaction Point 5



Oct 2004: starting to make modules connections

Installation of the five Coil modules

Thermal Shield assembly

Coil Swivelling

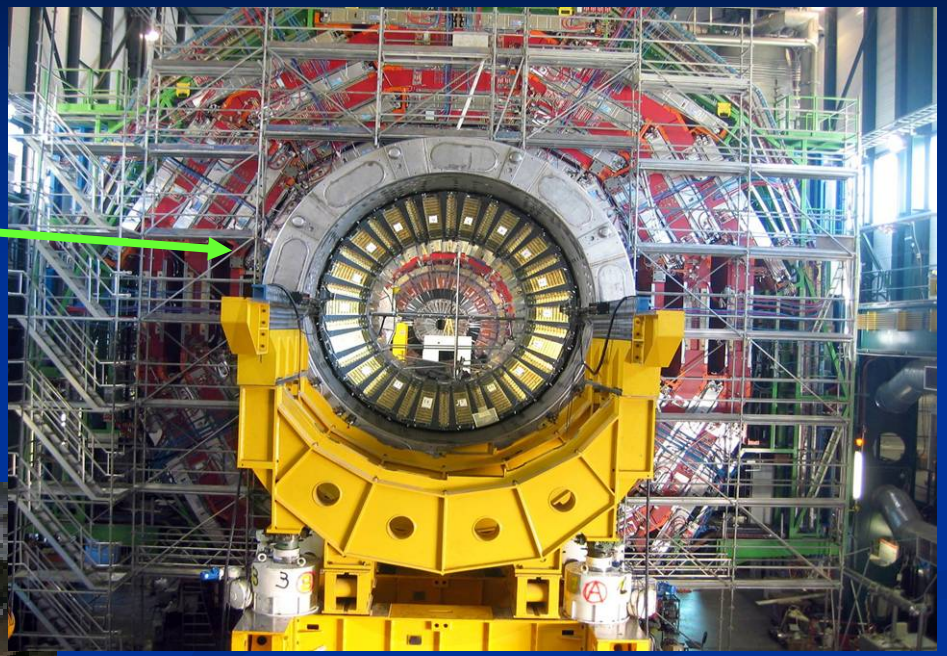
Infrastructure Activities Towards MTCC cont'd:

Coil insertion in central Barrel wheel

Inner vacuum tank insertion

Infrastructure Activities Towards MTCC cont'd:

Coil Vacuum tank closed
by welding at the two ends

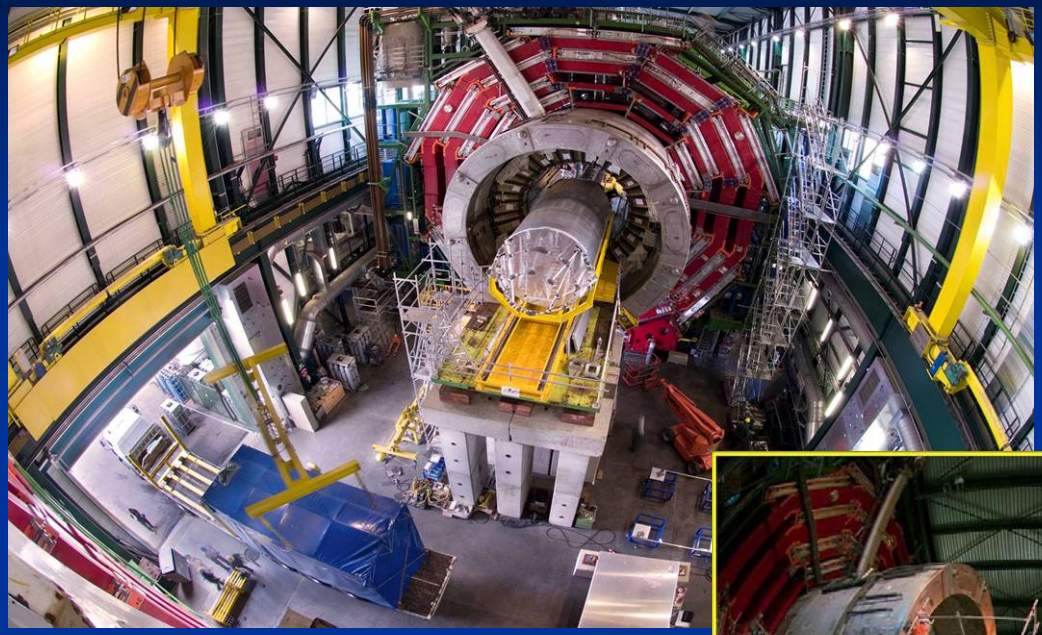


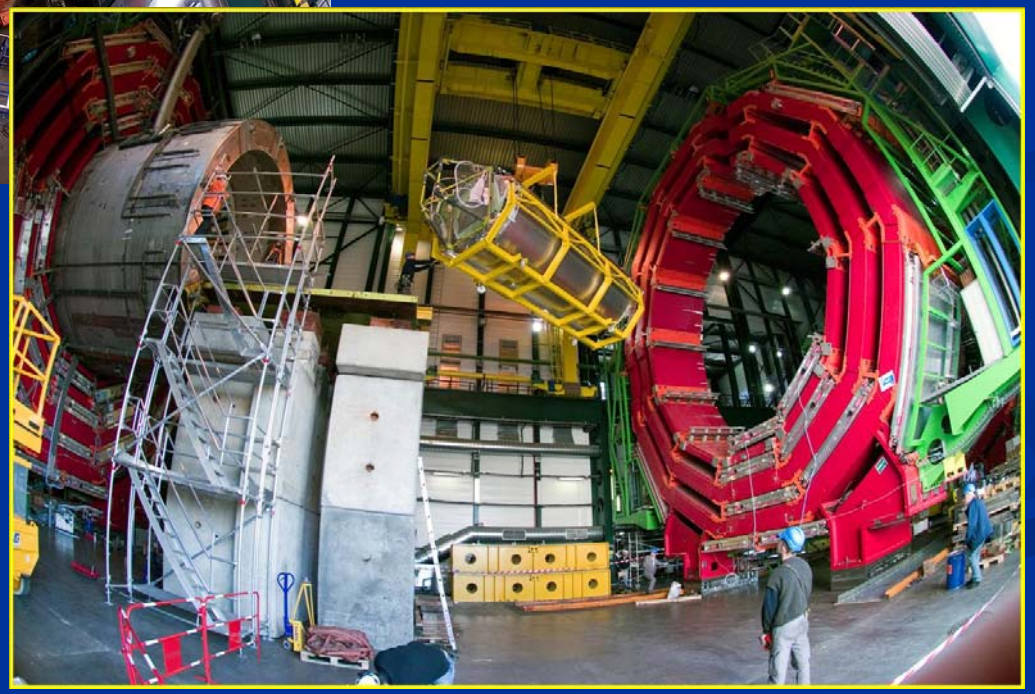
HCAL Barrel insertion

Two ECAL supermodules insertion (May 2006)

Many lessons learned from infrastructure work, e. g. ~ 2 weeks for inserting first HCAL Barrel module, ~ 3 days for the second module!

Infrastructure Activities Towards MTCC cont'd:





Many lessons learned from dummy Tracker tube insertion adjustments on insertion procedure

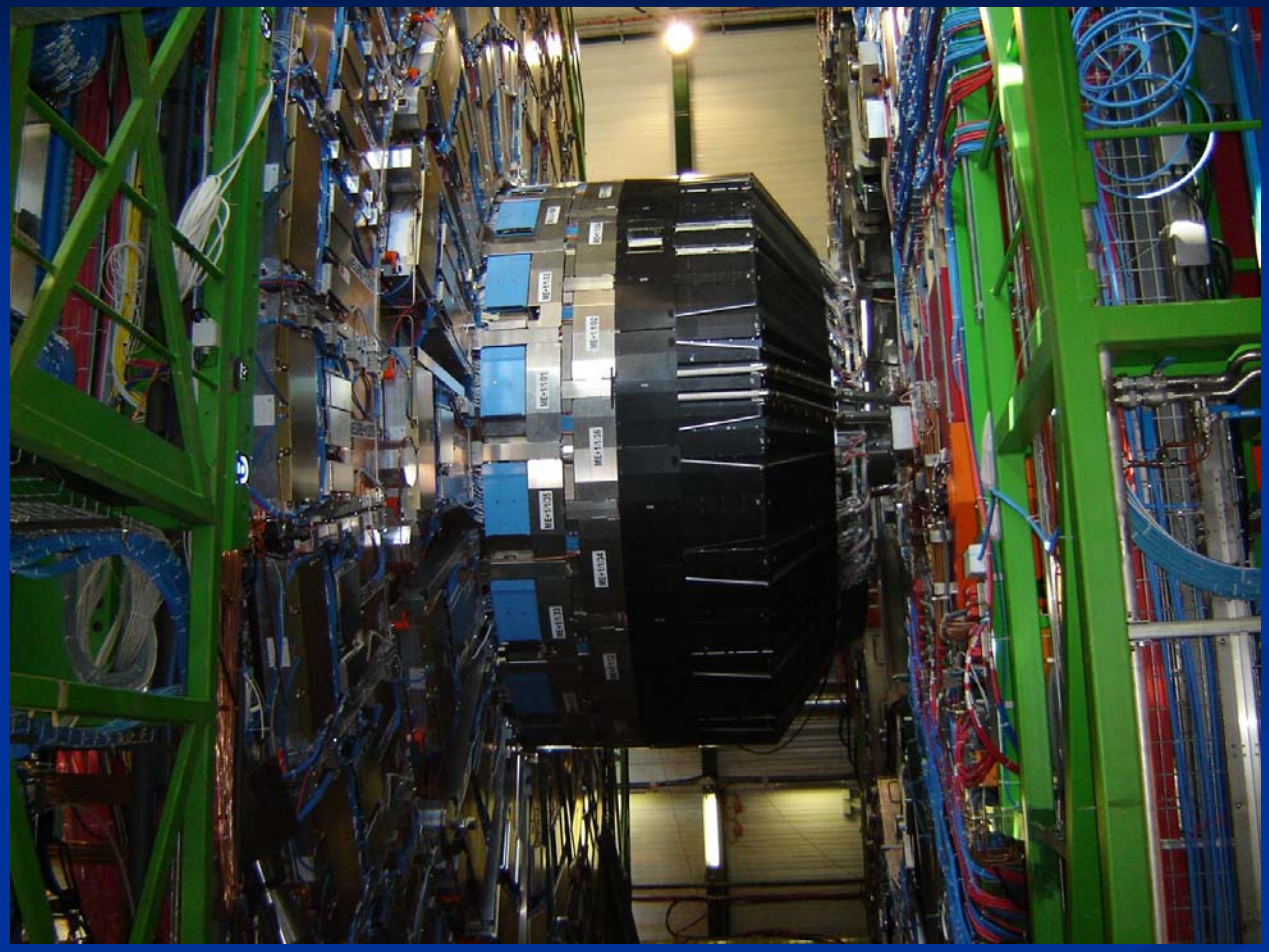
Infrastructure Activities Towards MTCC cont'd:

Closure of first Endcap + Disk

Instructive exercise with closuring and opening, we can now open and access the Tracker in three days.

Air pads used to move the 11 CMS elements

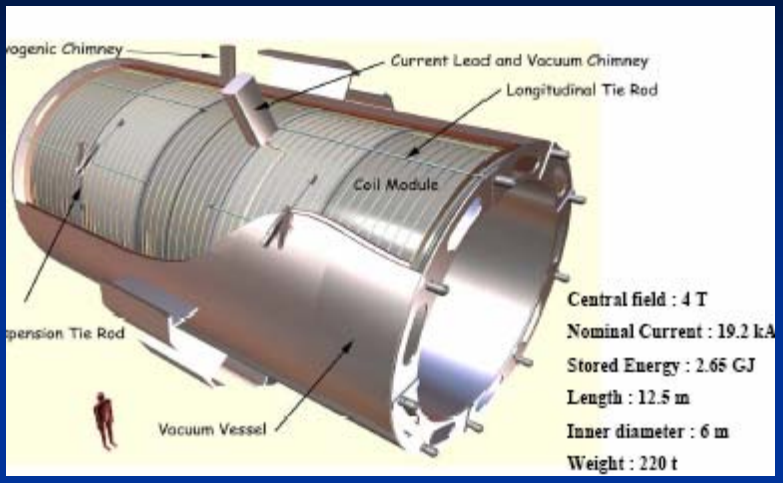
Infrastructure Activities Towards MTCC cont'd:



Repeated surveys measuring four points on x axis allowed for adjustments and alignment of 1mm wrt the ideas axis

The Magnet Test

The Superconducting Solenoid



Coil Cross Section and cooling pipes for liquid He

Reinforced superconductor structure (pure Al and Al alloy)

February 2006: exceptionally smooth cool down to 4.2 K:

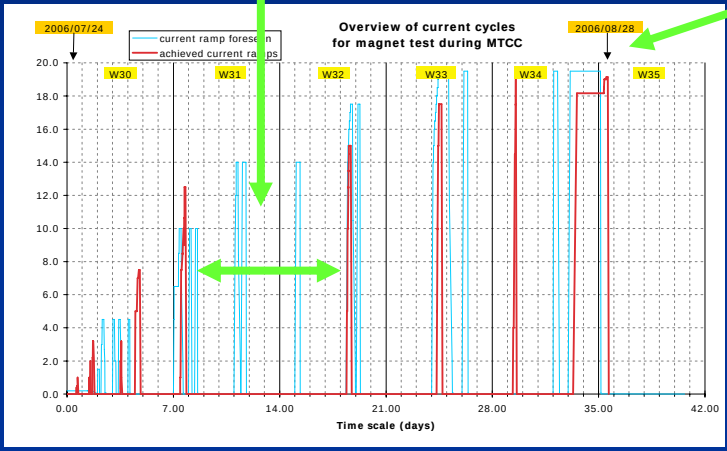
- No leaks exist in the cold mass and its circuits (despite the some 540 welds).
- Coil contraction was measured during cool down (half length and diametral mean contraction~27mm)
- Stability of the solenoid axis during shrinkage was monitored (no axial or radial displacements)

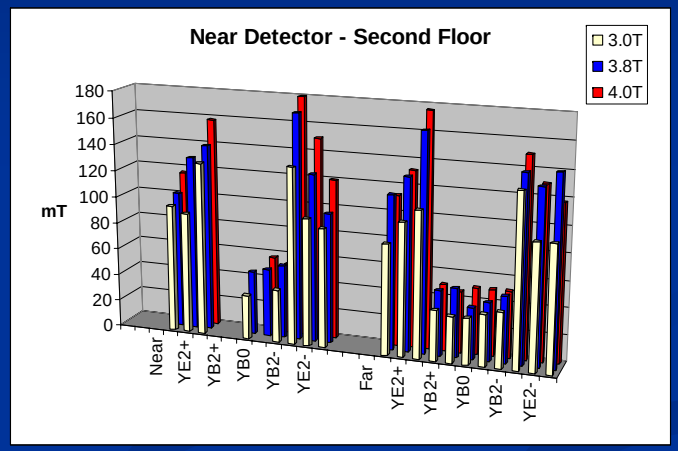
Current Cycles, Aug 2006

Mounting new pressure relief valve

Nominal 4T value reached on Aug 22nd

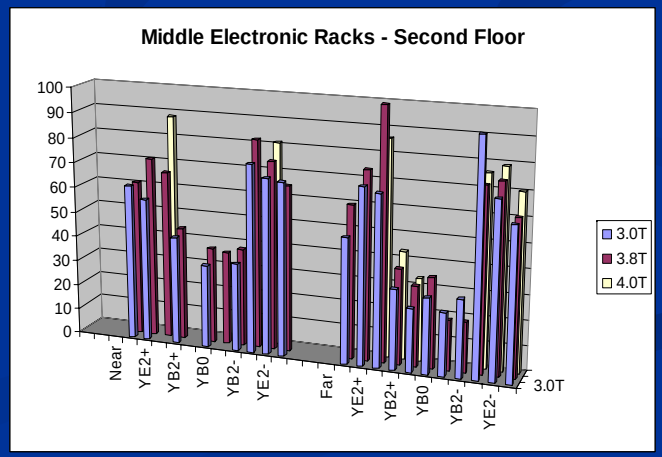
3 days for the Cosmic Challenge with field at 3.8 T and 4T



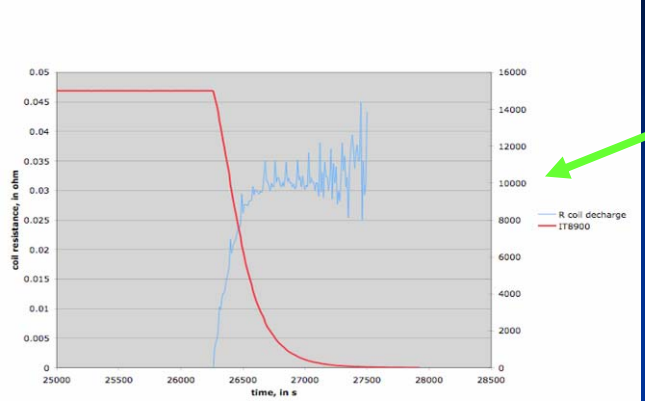


Fringe field was close to expected near detector and somewhat larger further away

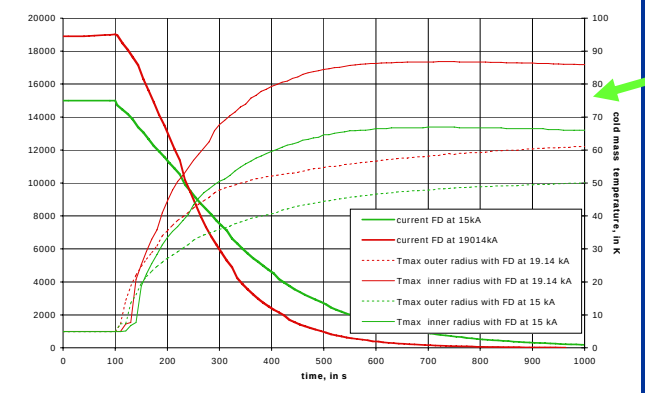
⇒ adjusting design for materials in underground cavern (e.g. aluminum rack doors instead of steel, larger pillar wall)



Fast Discharges



Current & Coil Resistance during FD: solenoid warms up and becomes conductor (energy is dumped in external resistor)

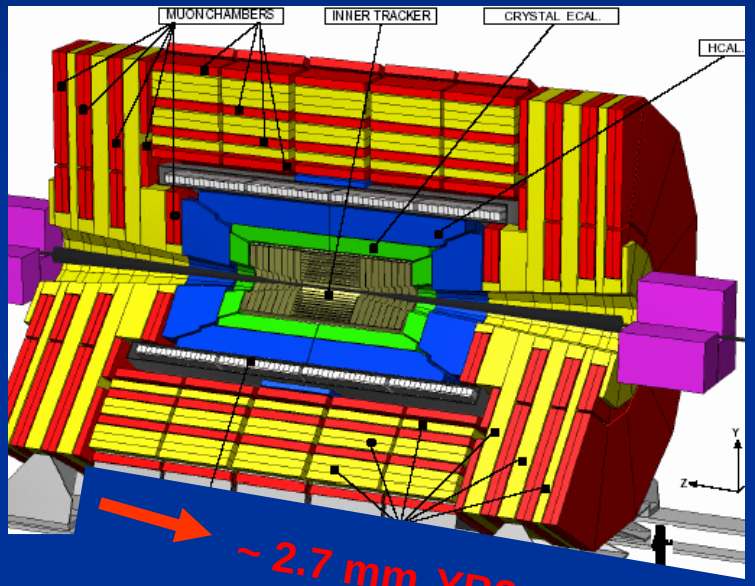


Current and coil maximum temperatures during two FDs (at 19.14KA and 15 KA): reaches ~80K => rather slow recovery

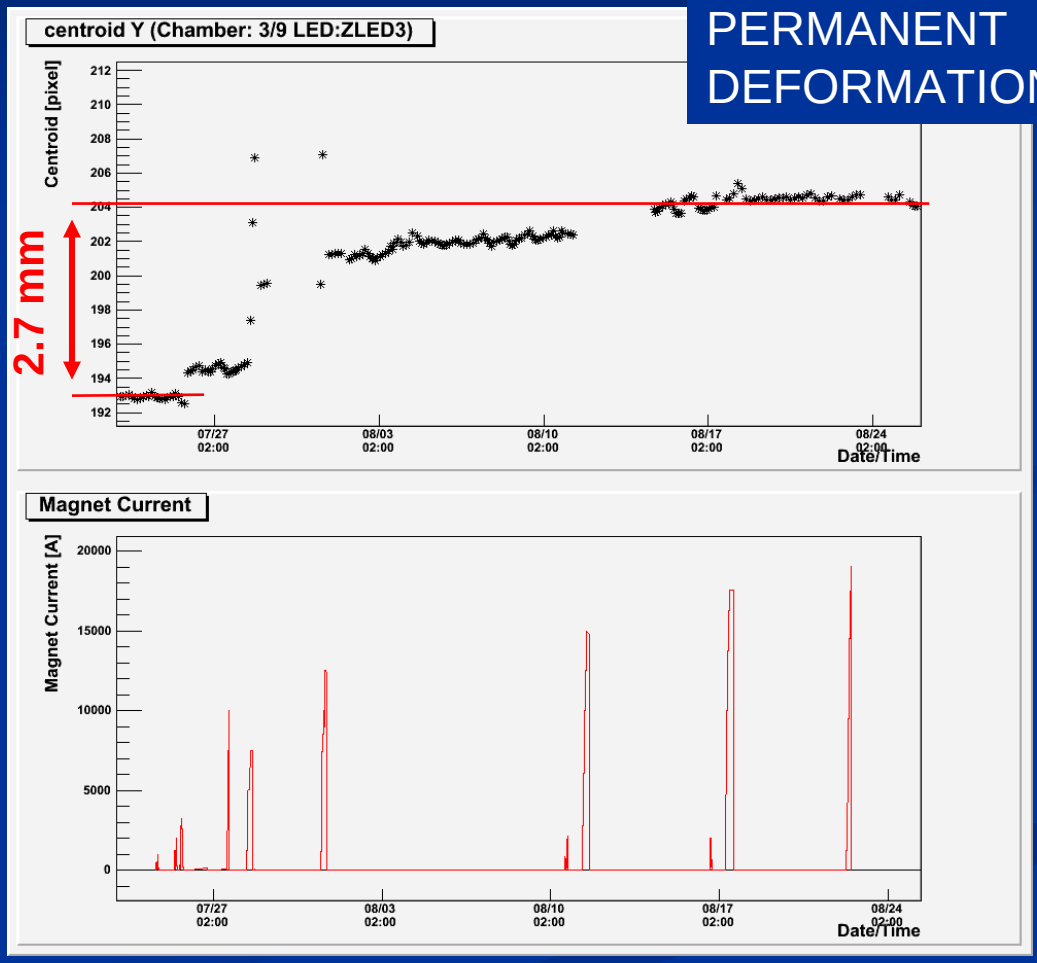
High pressure He is released through relief valves during first of five fast discharges. A very small amount of He was lost in the last F.D (video of He released with first fast discharge available though the CMS Times web site: http://cmsinfo.cern.ch/outreach/CMStimes/2006/09_04/index.html .

Yoke Distortion with Field

Magnetic actraction force ~ 10000 tons

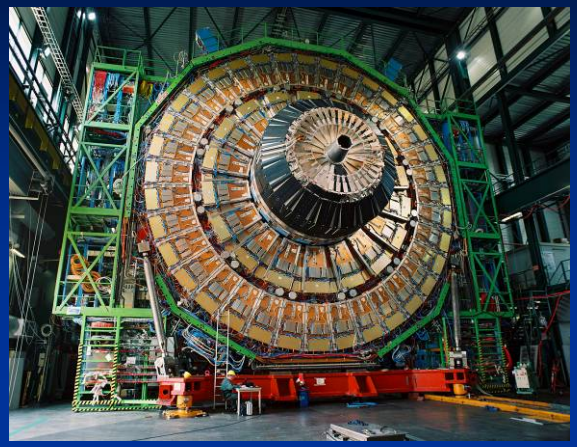


PERMANENT DEFORMATION

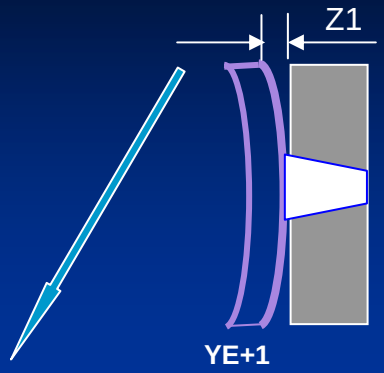


The analysis of hardware alignment data just started

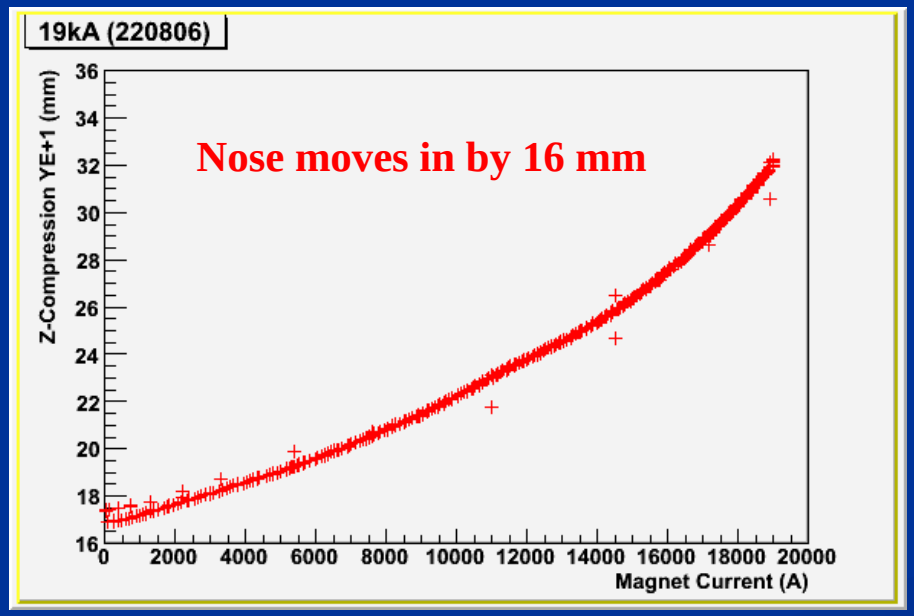
YE1 Disk compression

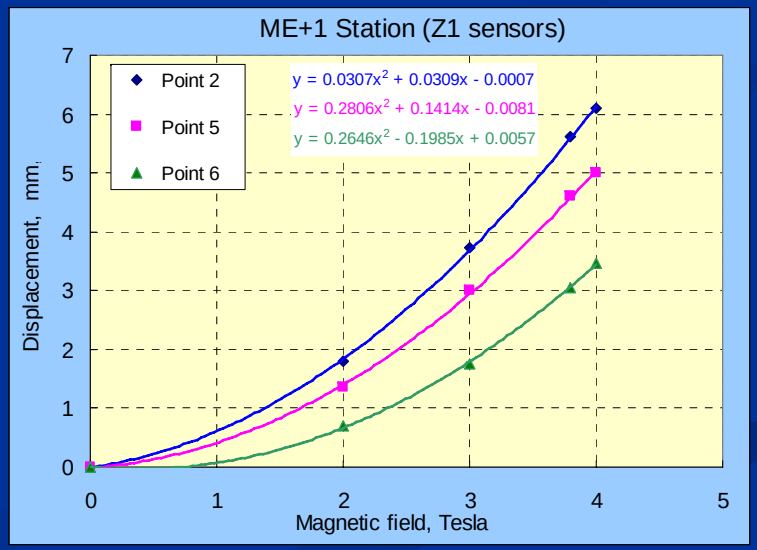


With Field @ 4 Tesla



Outer rim moves out by 6 mm
(a top/bottom an asymmetry is observed)





The Cosmic Challenge

Participating Detectors

End-cap CSC

- 3 stations with 60º trigger sector each
- On positive end-cap
- 36 chambers (~8% of total)

End-cap RPC

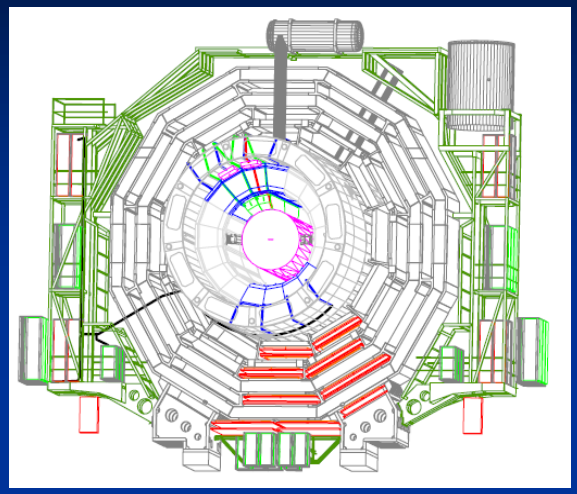
- Chambers on 1 station available

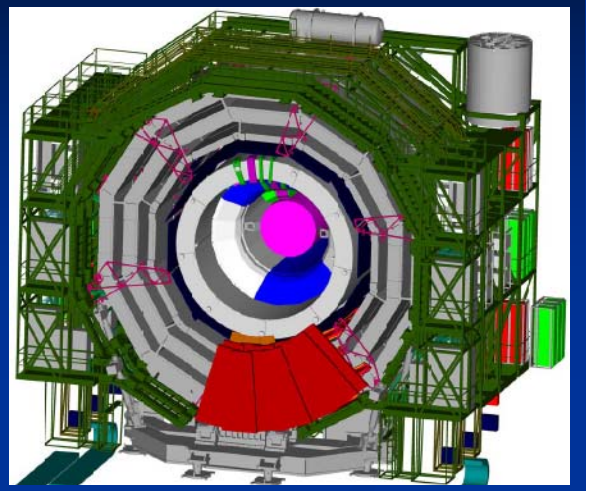
Barrel DTs

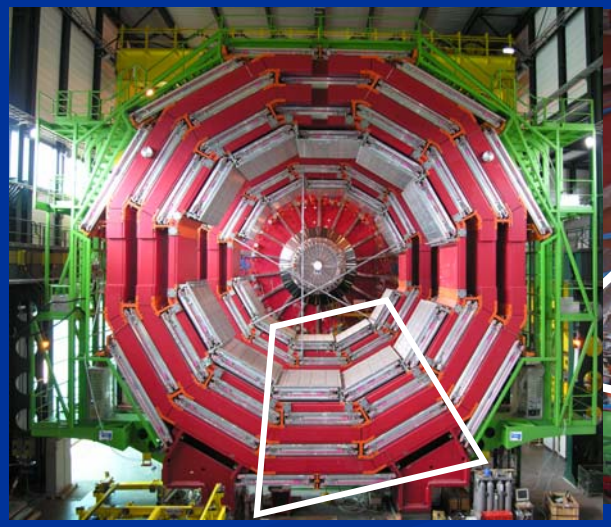
- 3 sectors with 4 stations each in 2 wheels
- On positive side, YB+2 (2 sect), YB+1 (1 sect)
- 14 chambers (~5% of total)

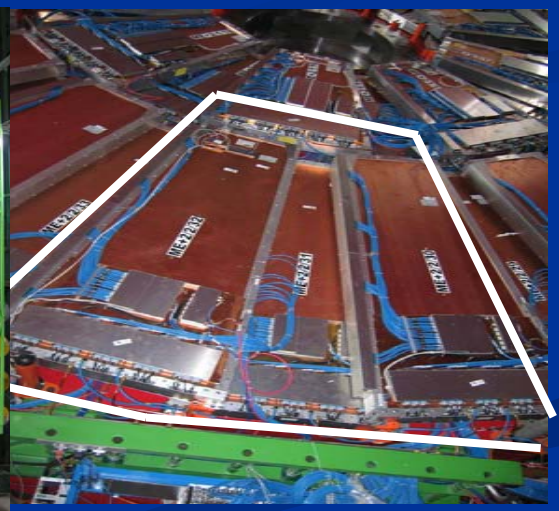
Barrel RPC

- Same sectors as for DT available

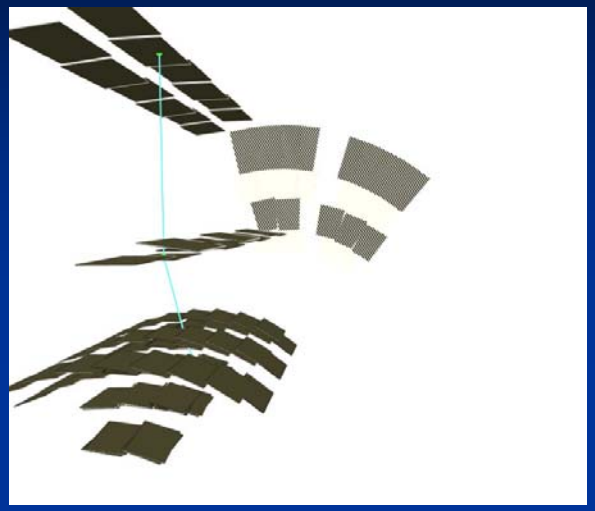








Participating Detectors cont'd



Tracker:

While tracker is getting ready for 25% test, an "mtcc" tracker was assembled for MTCC:

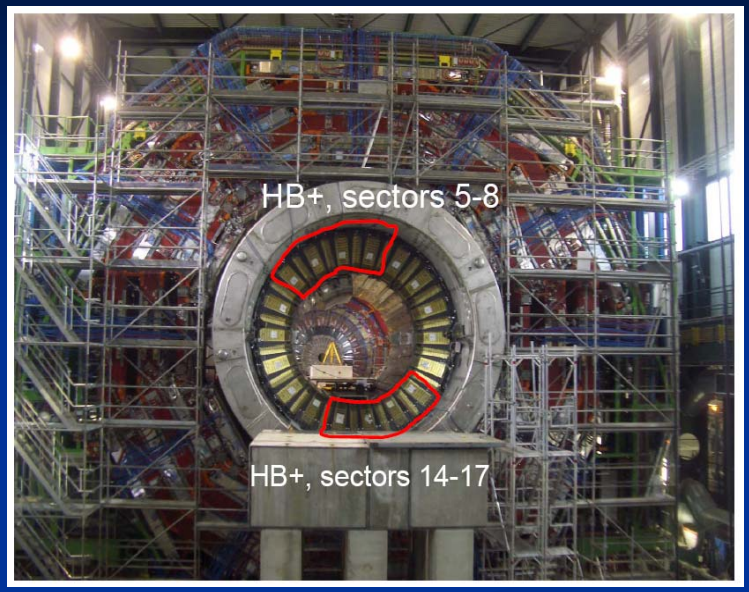
- 4 RODs in outer barrel (24 modules)
- 2 layers in inner barrel (75 modules)
- 2 petals in endcap (34 modules)
- 133 modules total = 1% of final system
- Installed in final geometry

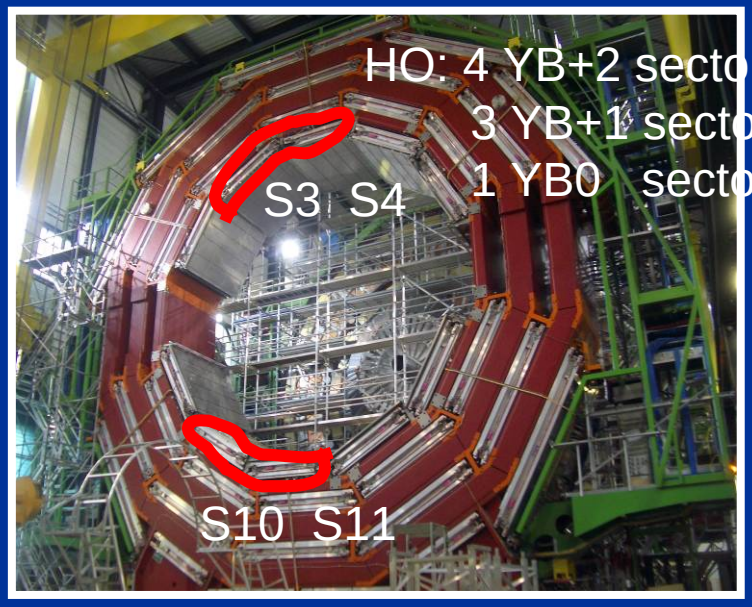
ECAL:

- Two Supermodules in barrel (original plan was one supermodule)

Participating Detectors cont'd

HCAL:
Different sectors in Barrel,
Outer Barrel and Endcap

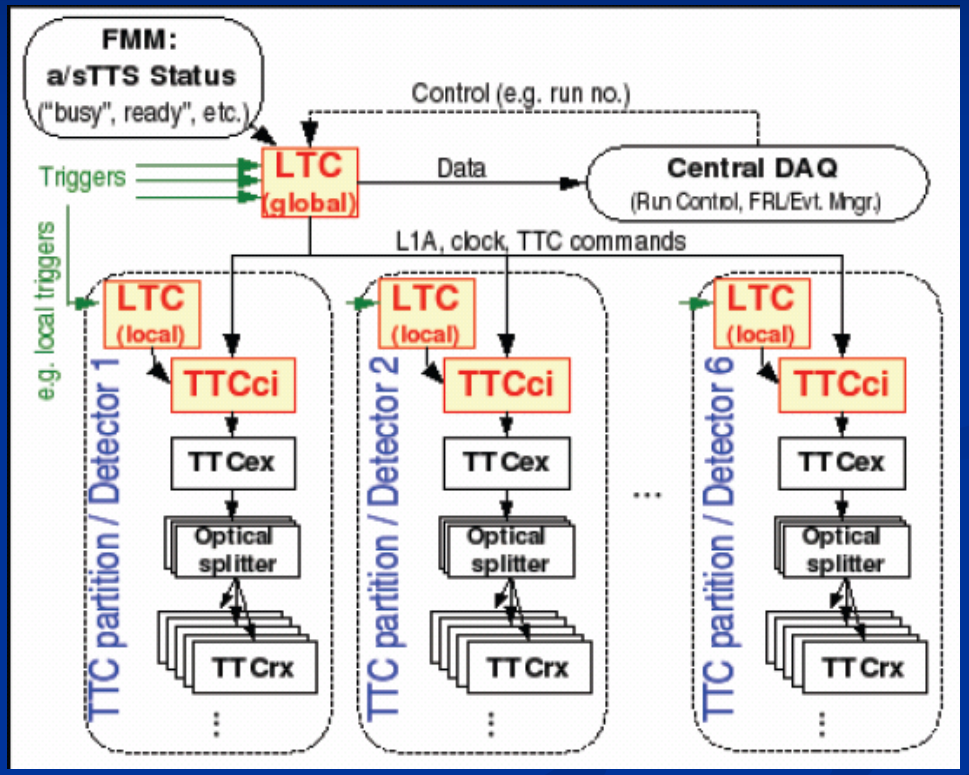




Trigger

- All detectors equipped with a Local TTC Control (LTC)
- One additional LTC used as Central Trigger Control, controlling through final TTC system

  - Level 1 Triggers provided as OR's between 5 Trigger inputs from the three muon systems
  - Up to six partitions controlled by the LTC, one for each sub-detector through six TTCci (TTC boards)
  - LTC listens to the Trigger Throttling System providing the status information from all front-end electronics (e.g. in order to block triggers in case any of the detector front-ends being "busy") and from its own DAQ readout system
  - LHC-like central clock



- Final TTC & TTS worked
- All Triggers synchronized w.r.t. each other
- All detector readouts synchronized w.r.t. Trigger

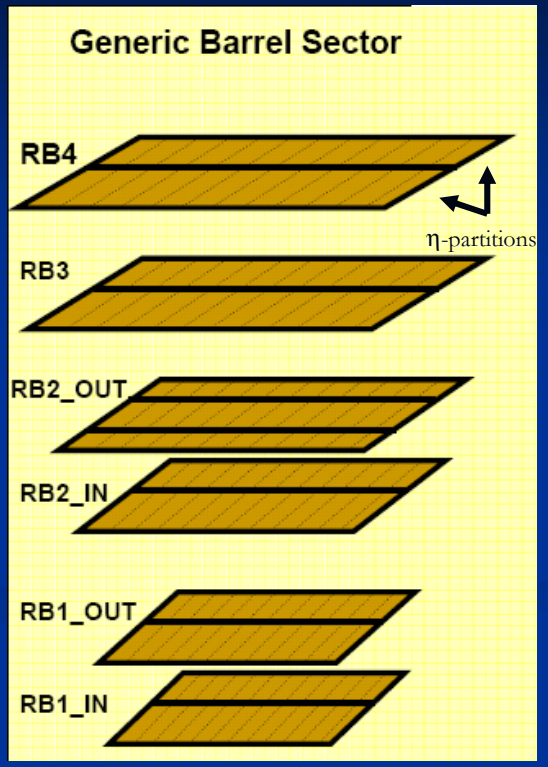
Trigger Inputs

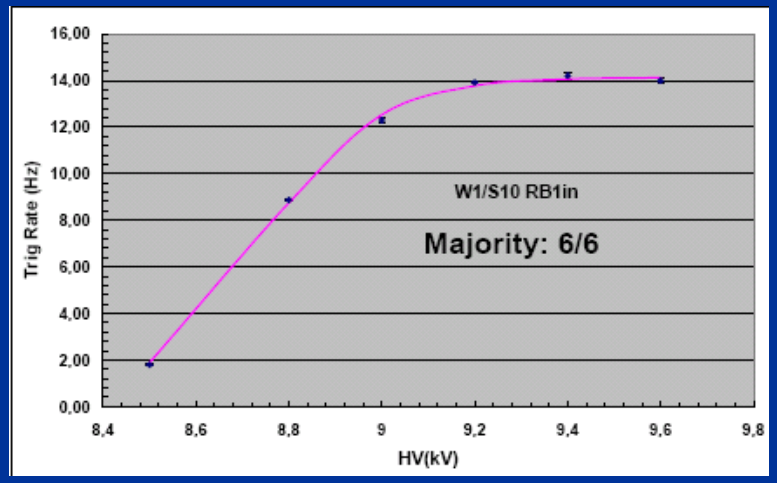
RPC

- RPC-Trigger Board with "pointing to the tracker" pattern
- Technical Triggers from RPC Balcony Collector Boards (RBC)

=> more efficient for cosmics

  - 1 RBC/2 sectors => 2 RBC in MTCC (one per wheel)
  - Vetoes coincidences in η-partitions in same layer (spurious)
  - Produces sector triggers with configurable ORs between layers
  - Requires ORs to be in coincidence
  - Introduce latencies for synchronization

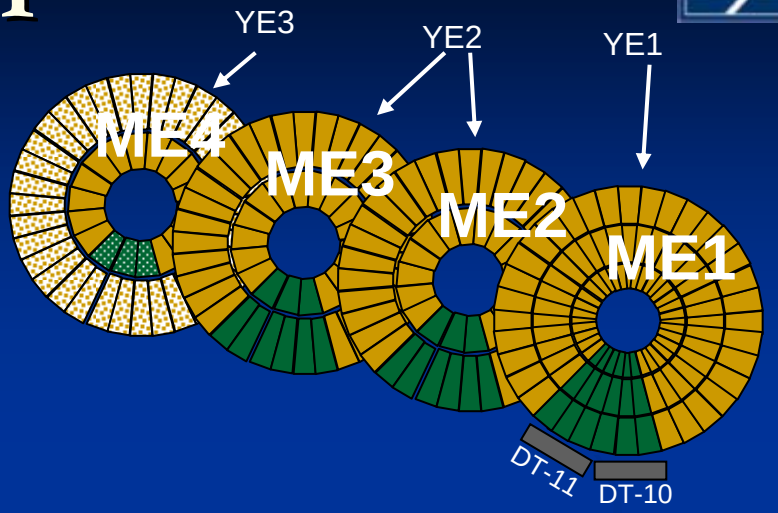




Trigger rates with 6/6 layers ~ 14 Hz/Wheel
Trigger rates with 5/6 layers ~ 30 Hz/Wheel

Trigger Inputs

CSC

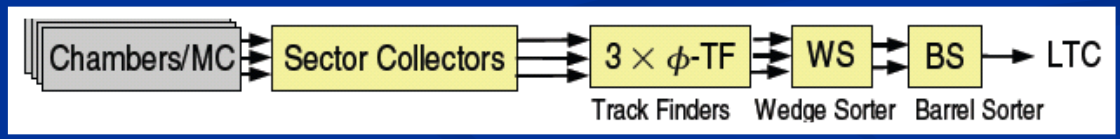


•Requirements within one station:
- •Coincidence between segments in anode wires and cathode strips
- • Segment quality varies (minimum hits required: 2, 3 or 4 out of 6 layers)

•Required coincidences in any 2 stations (10M events collected with this configuration) or single LCT from any sinlge station (ME1 usually)

•Trigger rate ~ 100Hz

DT:



- • High quality (and consistent with each other) segments in two superlayers, configurable to "pointing to the tracker" topology
- • Track Finder: r-ϕ track projection, tracks selected using look up tabels
- • Coincidences in 2 out of 3 chamber**s** ~ 55 Hz/sector
- • Pointing to Tracker ~ 13 Hz (total)

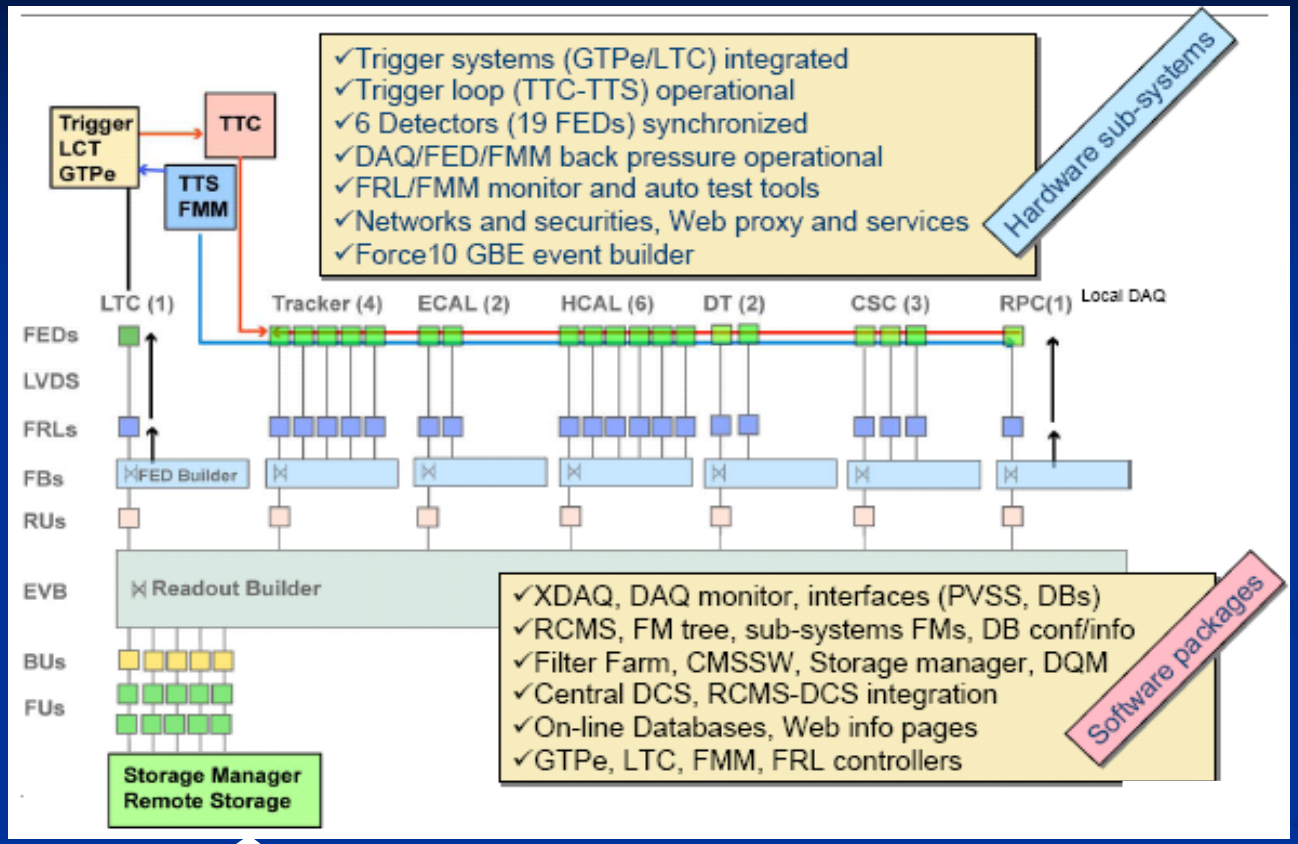
Triggers synchronization

- Relative latencies studies were carried out before the MTCC phase one start-up.
- Synchronization scheme worked well with other systems and within own system chambers chambers

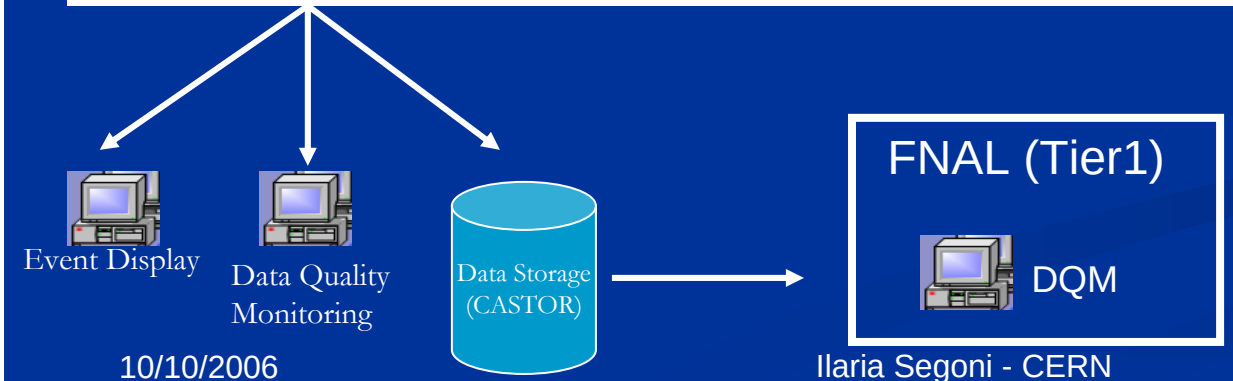
DT:

- Very good synchronization with Trigger obtained with B off, then compensated for magnetic field (in first layer shift in BX occupancies due to changes in drift time)

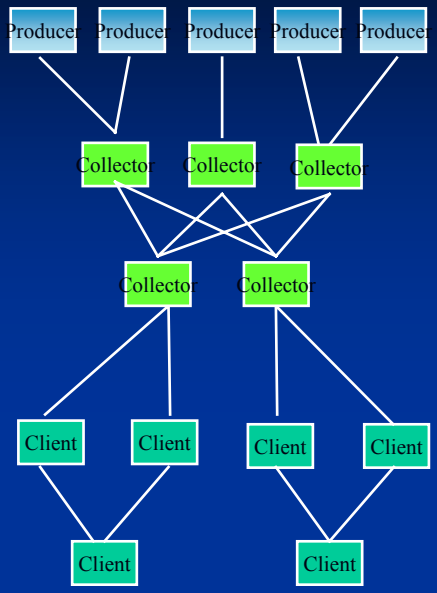
Data Acquisition



All software used (for DAQ, raw data processing and for online/offline reconstruction) is the new CMS software (CMSSW)



Data Quality Monitoring



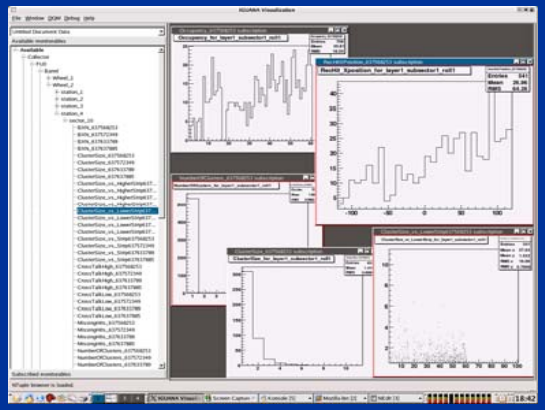
DQM architecture:

"DQM PRODUCERS": applications that process the (event) data and produce the "monitorable" (collection of histograms, scalars, messages)

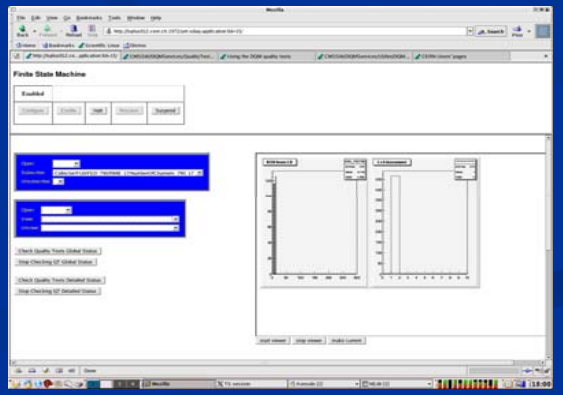
"DQM COLLECTORS": applications that perfom producer-client connection tasks: tell Clients which information is available, receive the requests for information from clients, transfer the requested information from producers and send it to clients

"DQM CLIENTS": applications that retrieve and process the information produced by the producers, (e.g. displaying, running automated quality tests).

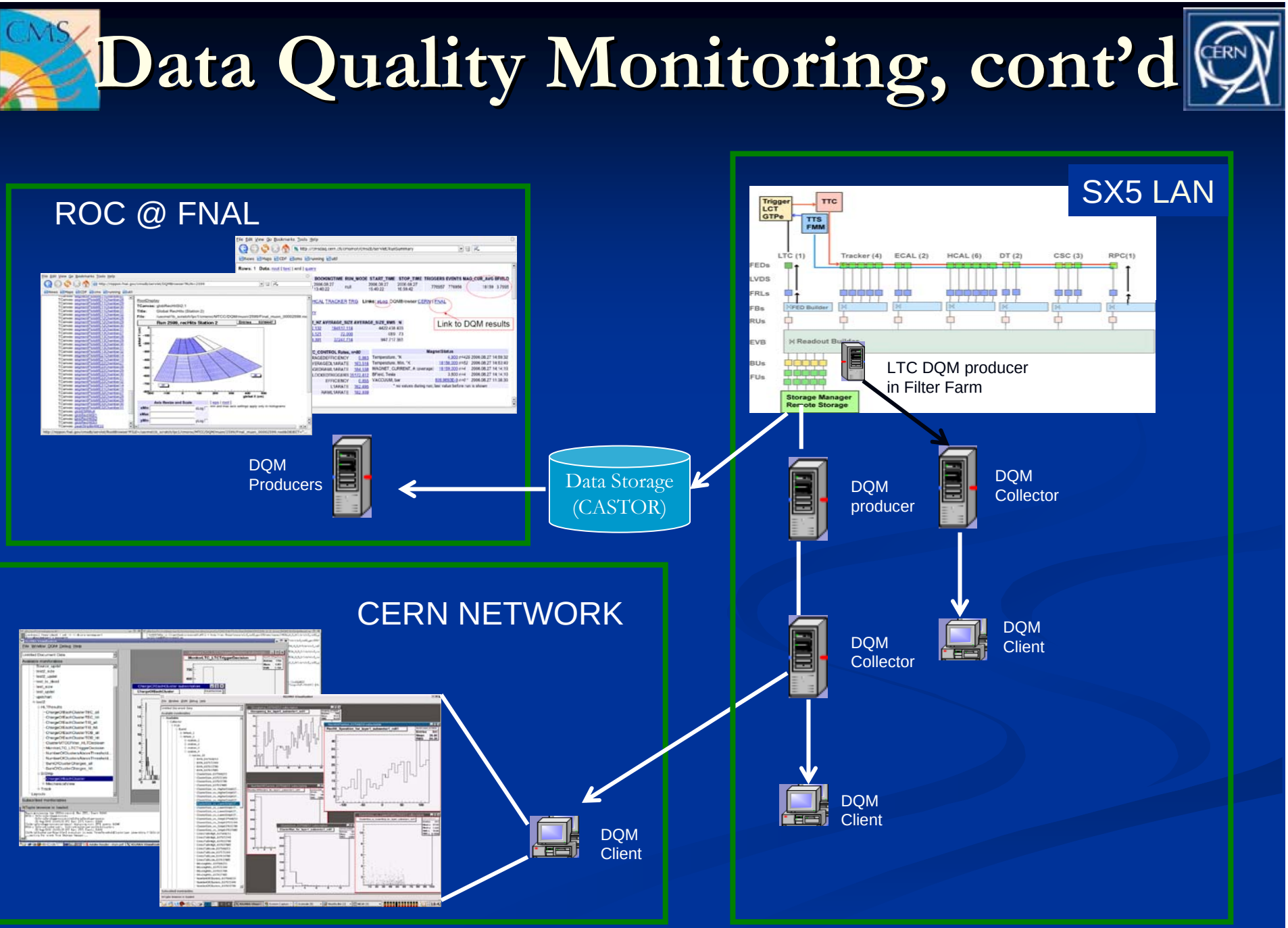
Client GUI for local operation mode



Client GUI with web interface

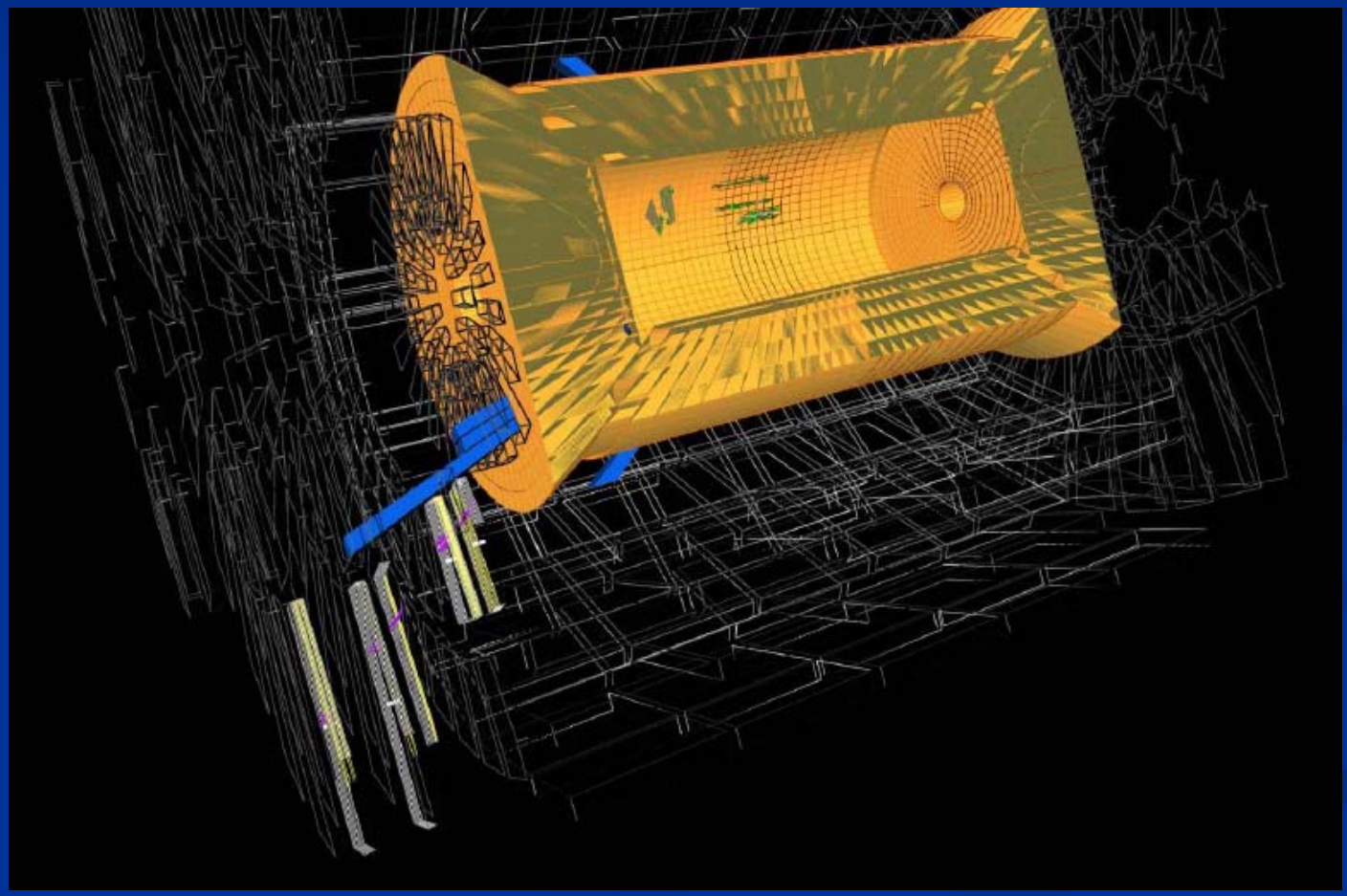


Data Quality Monitoring, cont'd



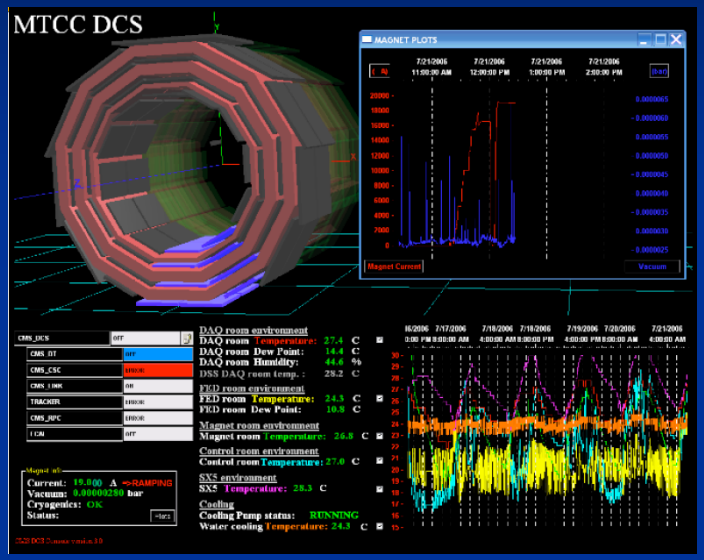
Event Display

- Full CMS geometry from engineering description or from Geant 4 simulation, event hits, segments, tracks, energy deposits
- Run on-line from Storage Manager during MTCC



Control Tools

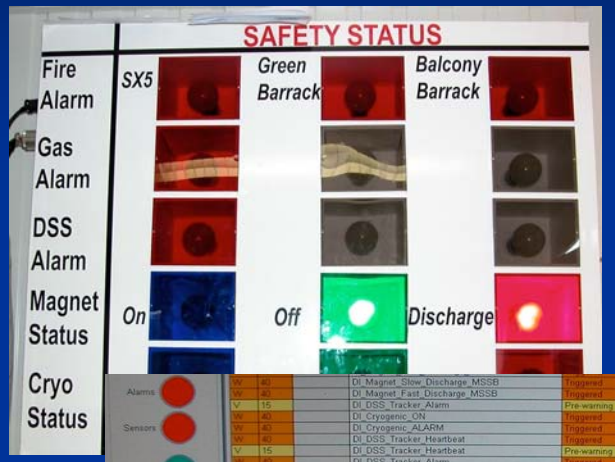
Central DCS



- Subsystems centrally managed by DCS (e.g. when power cut occurred)
- DSS successfully handles gas and cooling failures

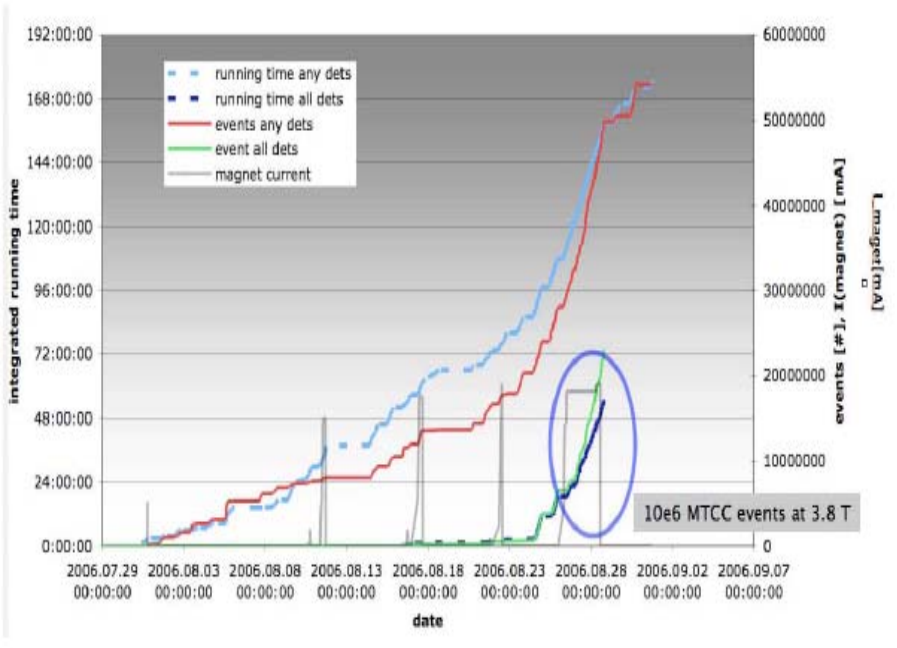
Lessons learned from power cut: introduce auto restart capabilities

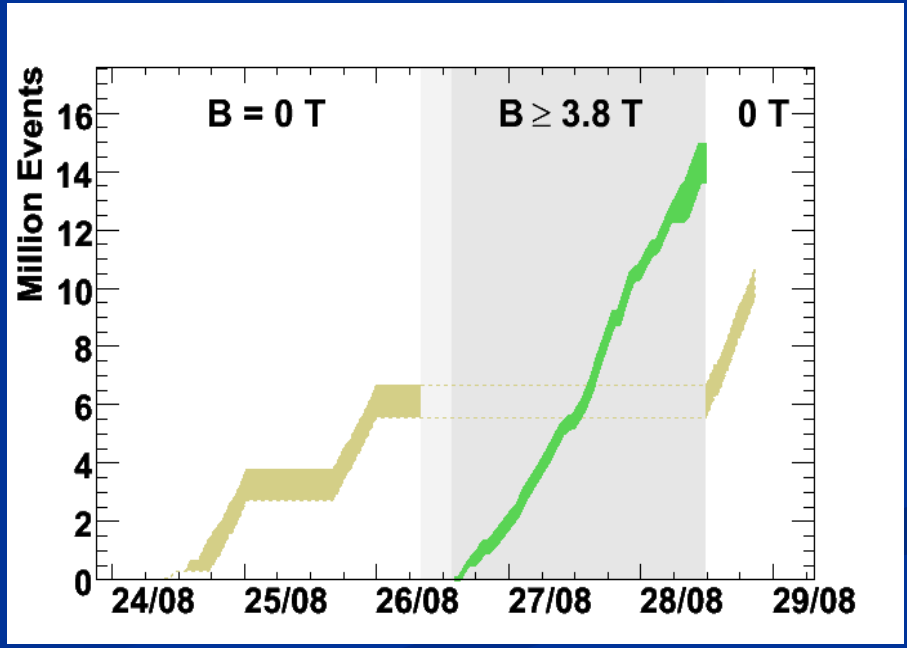
DSS



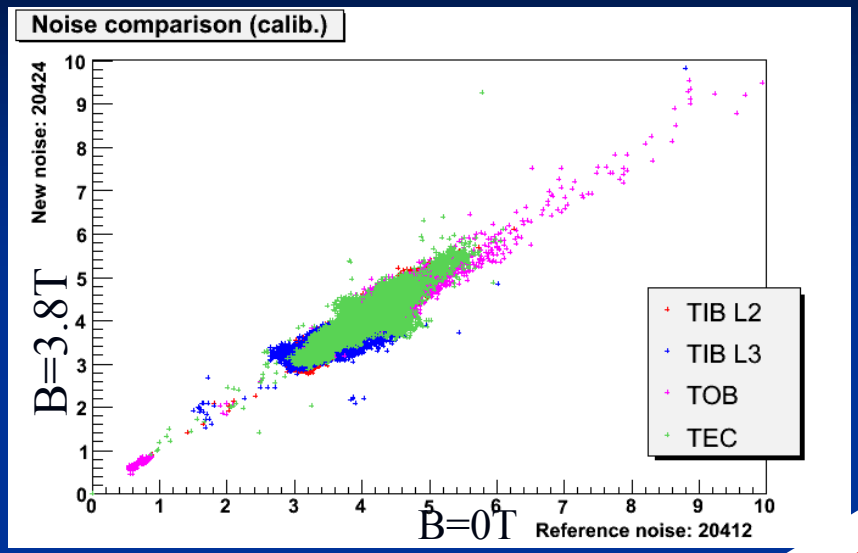
Data Acquisition:~ 50M events!

- ~170 h data taking sessions, 50M events taken, 25M good events (with at least DT, ECAL and Tracker data), 10K events with good tracks reconstructed in Tracker
- 90% Data taking efficiency
- Event size ~170Kb
- Max Trigger rate~200Hz
- Shift crew ~ 20 people at the time





Preliminary studies Tracker

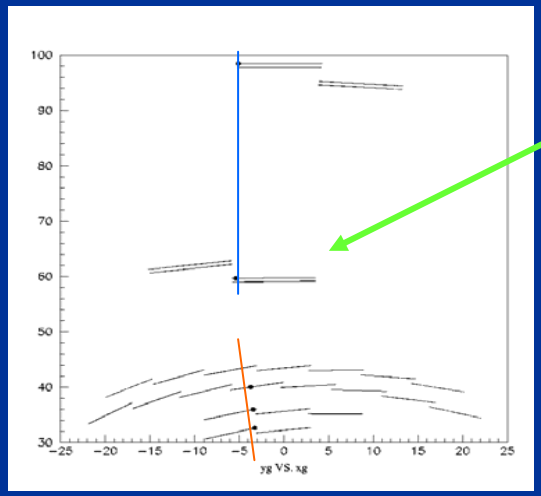


Noise and pedestal values ~unchanged in magnetic field.

Estimate 6k (4.5k) "tracks" with field on (off)

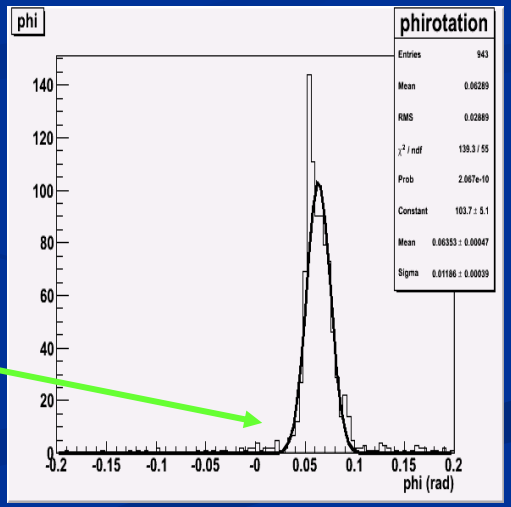
Preliminary

B=0T



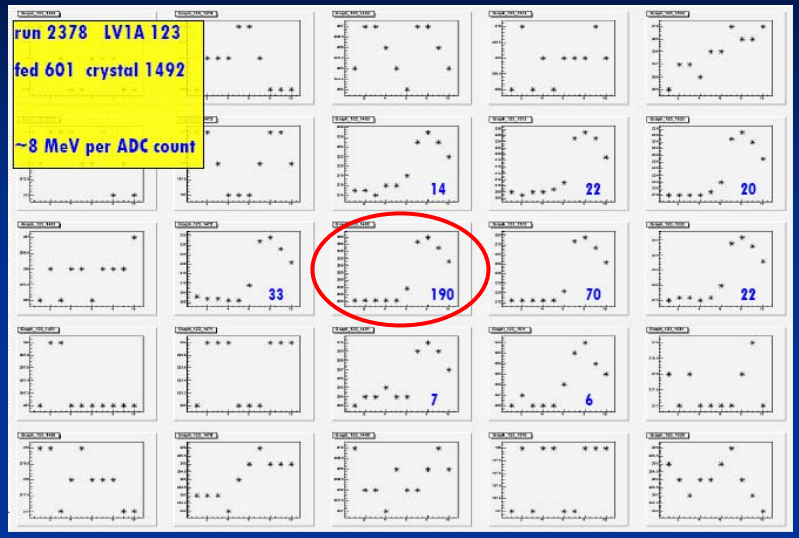
Track extrapolation to evaluate TIB-TOB relative rotation:

$\langle\phi\rangle$ = (63,57 ± 0,27) mrad

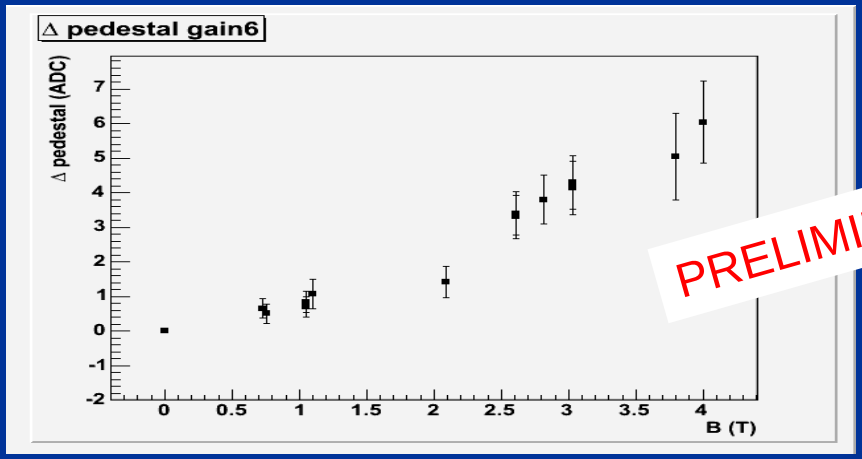


Preliminary studies: ECAL

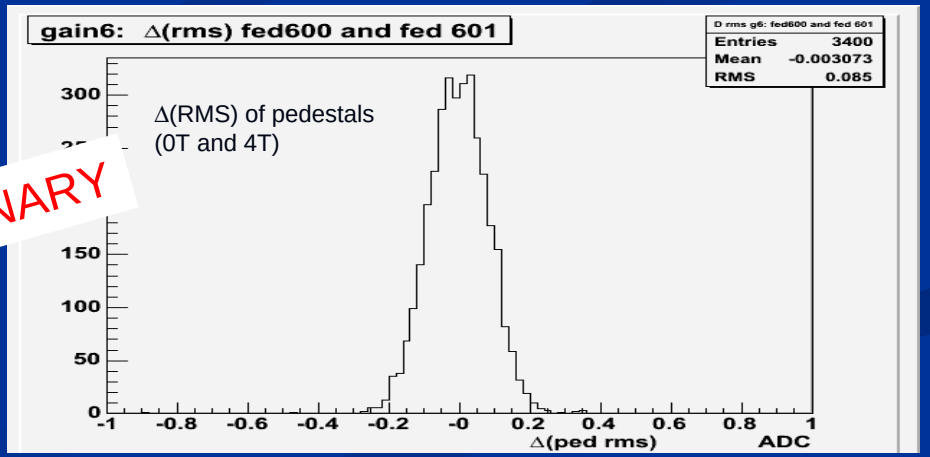
Clear muons are found in crystal expected from DT Track extrapolation (pulse shape is shown for the 25 crystals around the expected location)



Pedestal mean increases with magnetic field while noise is unchanged, currently under study.

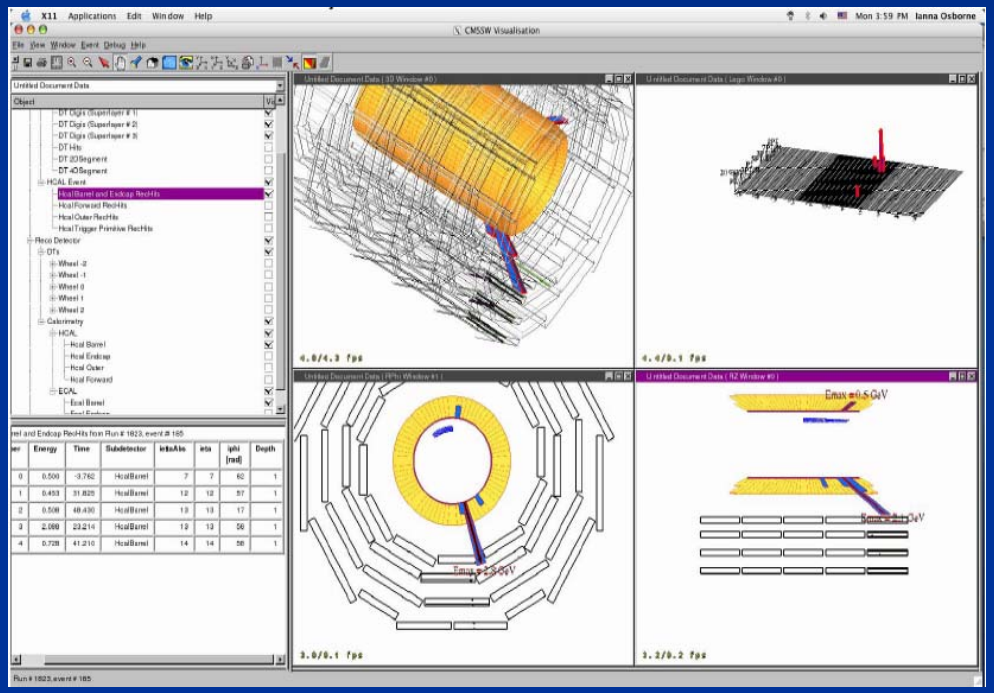


PRELIMINARY



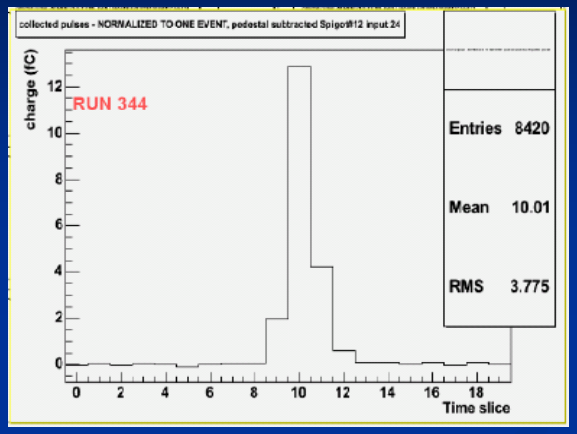
Preliminary studies: HCAL

Matching energy deposits consistent with muons are found when extrapolating tracks from DT

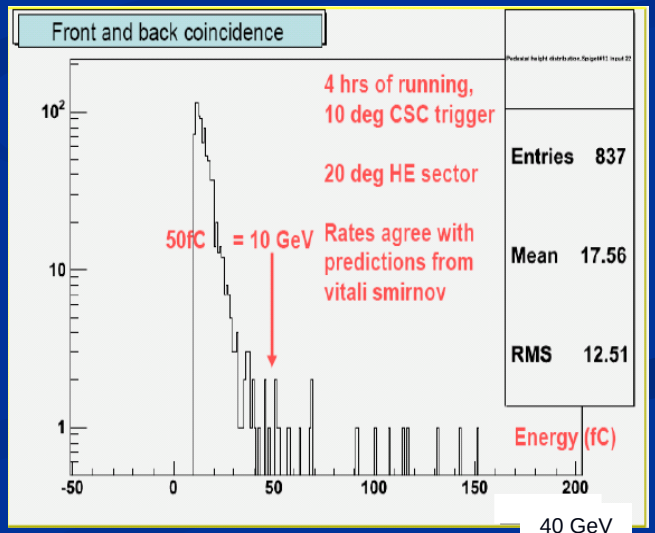


Pedestal and Noise are not affected by MagneticField

Muon pulse shape corrected by trigger jitter (max energy time slice forced to bin 10)

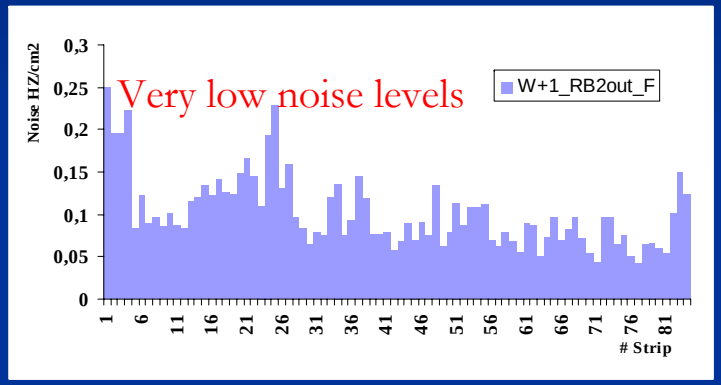


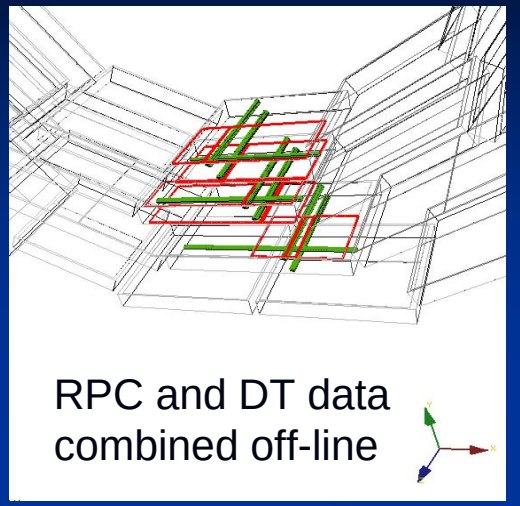
Muon energy spectrum is consistent with expectations



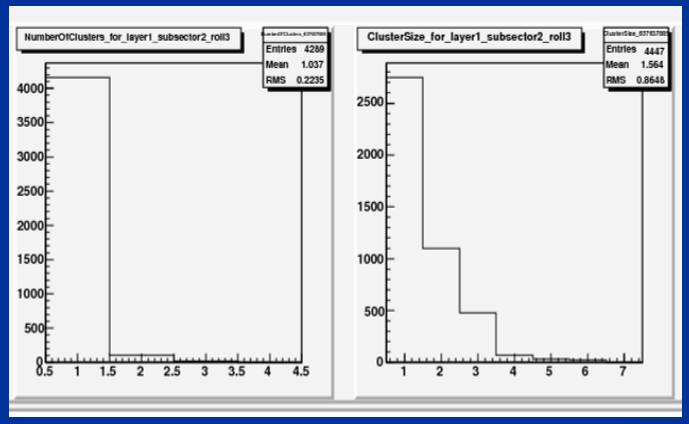
Preliminary studies: Muons

RPC were read out through Trigger Board local diagnostic readout => off-line data format conversion and merging with global DAQ data used to analyze events, will not be necessary in phase II

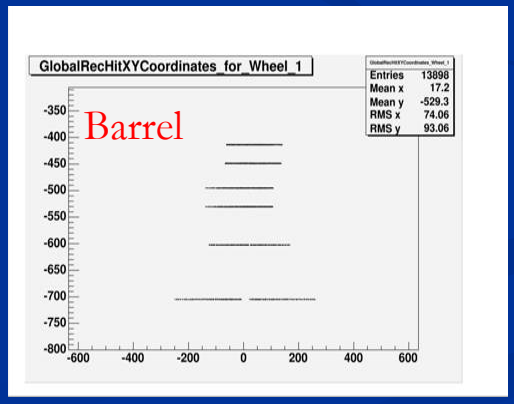


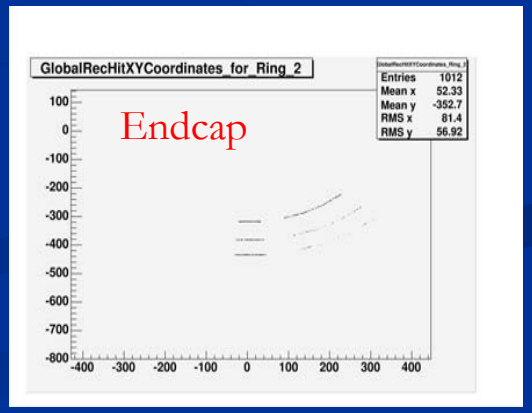


Average cluster size is just below 2, as expected



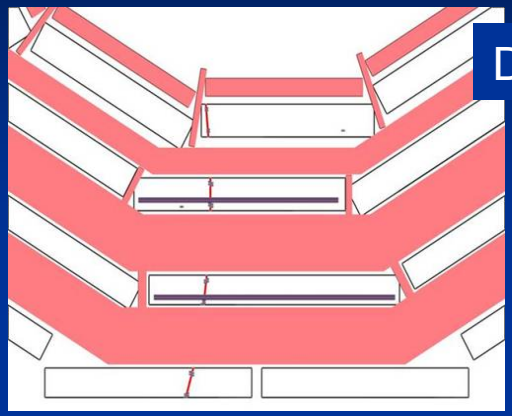
Chamber illumination, xy view of reconstructed hits

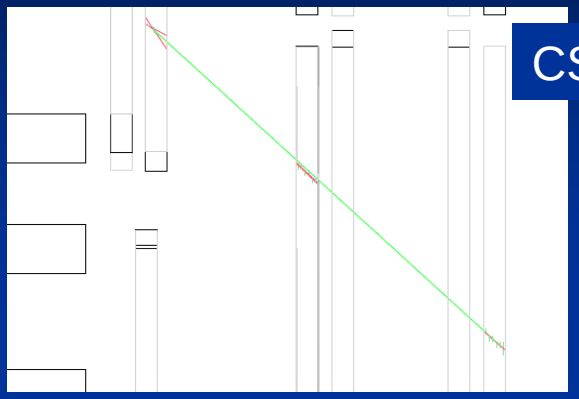


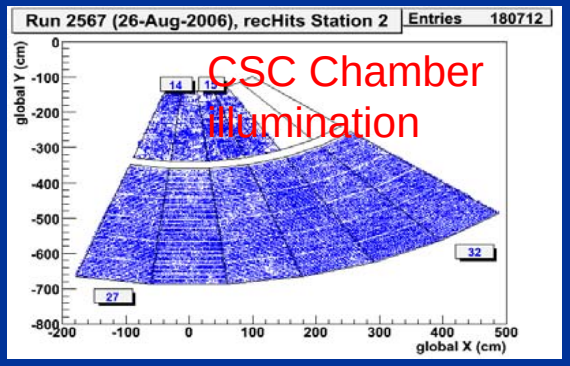


Preliminary studies: Muons

High statistics accumulated for studying local and global tracking with B on and off







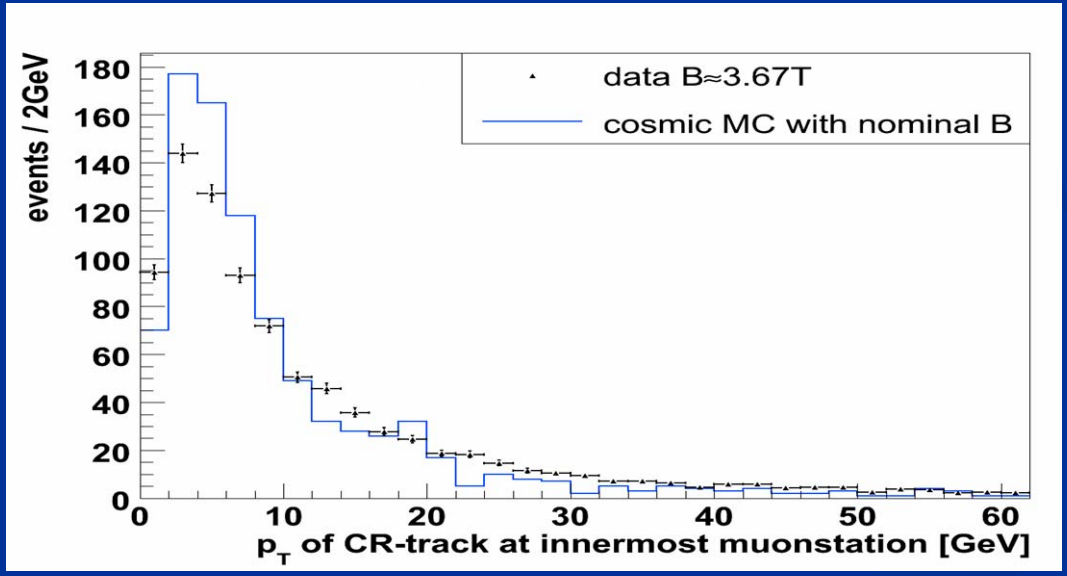
- Studies on track resolution are ongoing, preliminary measurements confirm expectations and will soon be made public

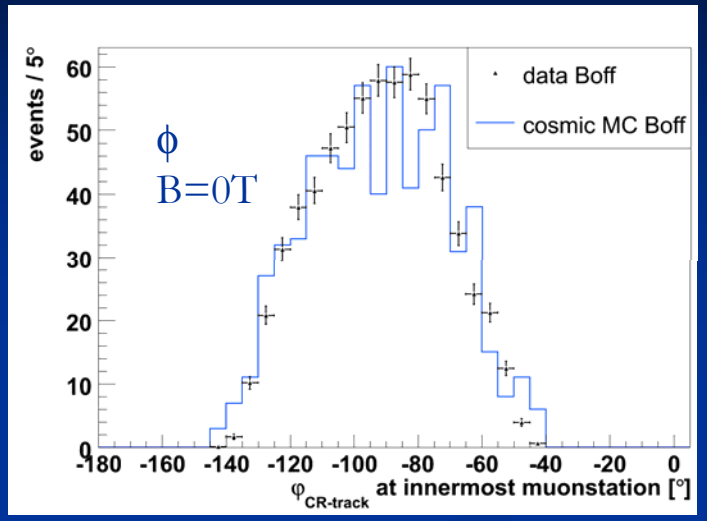
- Studies on alignment using DT data and Hardware alignment data @ B=0, are being done. So far excellent agreement

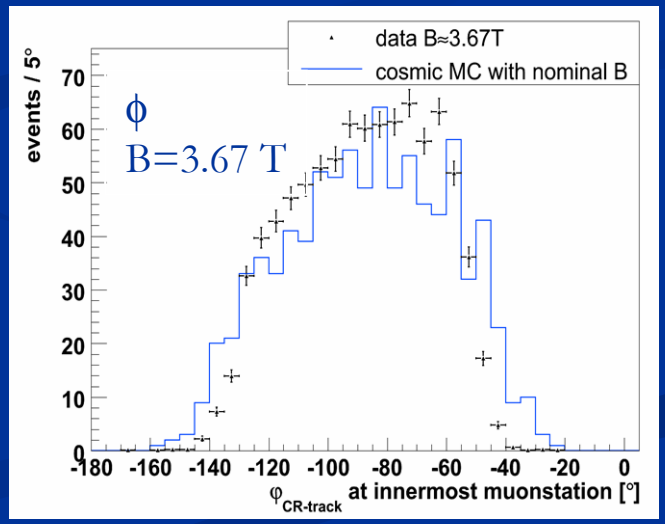
Preliminary Monte Carlo Comparisons

Track P_T and ϕ evaluated at innermost muon station are reasonably described by simulation.

Data normalized to MC statistics







Conclusions

Phase I of Magnet Test and Cosmic Challenge was a great success in all its aspects:

- Closure of the yoke
- Coil cooled, commissioned and run at maximum expected field of 4T
- One slice (~1/20) of CMS run with central Trigger (using final controls and throttling systems, central DAQ, all central services)
- Central controls and monitoring successfully operating




Plans

CMS is now preparing for MTCC phase II:

- Mapping of the magnetic field at different values (to allow installation of field mapper, ECAL and Tracker will not participate). Mapping precision ~ 10^{-4}

October 9 16 23 30

Long plateau at 2T to commission Field Mapping procedure

Measurements at:
2 T, 3.8 T, 3.5 T, 3.0 T, 3.8 T, 4 T
⇒ we'll then be able to extrapolate between 3T and 4T

Plans

During phase II, in parasitic way w.r.t the field mapping:

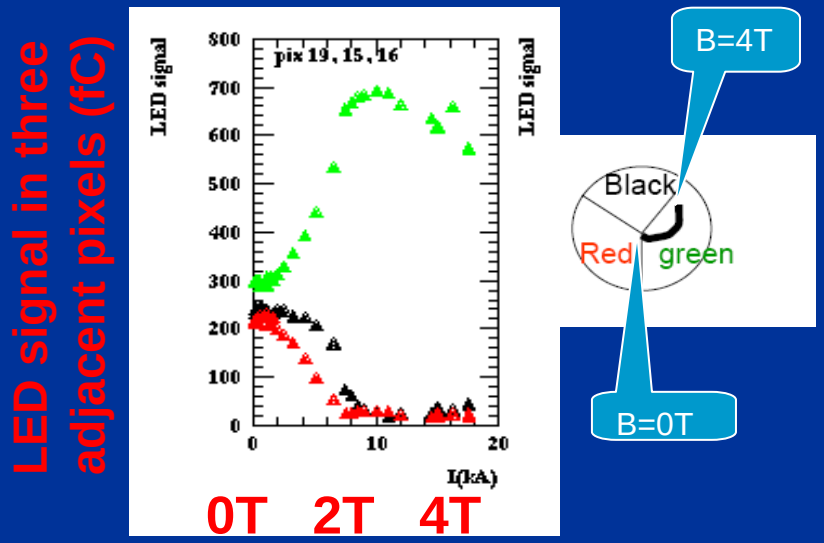
- Integration and commissioning of final Global TTC Control system, using Global Muon Trigger and Regional Calorimetry Trigger
- Global DAQ as in phase one + RPC FED
- Additional software components in the Filter Farm (raw data processing, DQM, possibly simple filtering algorithms)
- More detector commissioning studies (large data samples for alignment, Lorentz angle measurements, combined muon detectors reconstruction, cross talk studies for HCAL)

- Phase II will end as soon as the Magnetic field measurements are completed.
- The final fast discharge will prepare the cold mass for the warm up process.
- Infrastructure works will then be central CMS activity with the beginning of heavy lowering into the cavern.
- The commissioning task force is planning a new phase of the Cosmic Challenge to be done underground

Back Up Slides

Problems Encountered with Magnetic Field

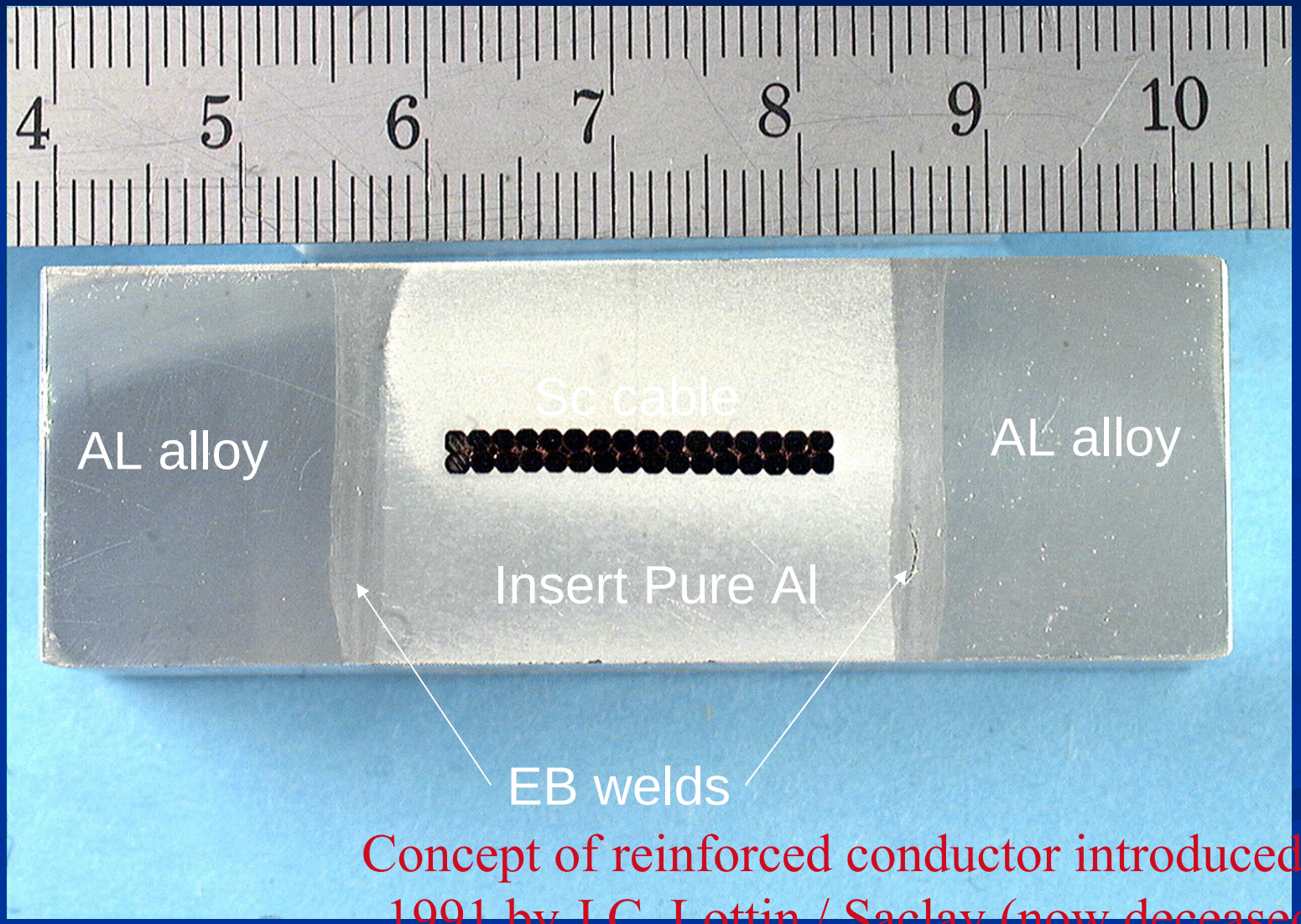
Alignment: due to insertion of ferrite inductors, electronic card for the syncronization of video-cameras used in the barrel alignment modules (MABs) failed. Now replaced by air-core inductors (3 modified cards already mounted)



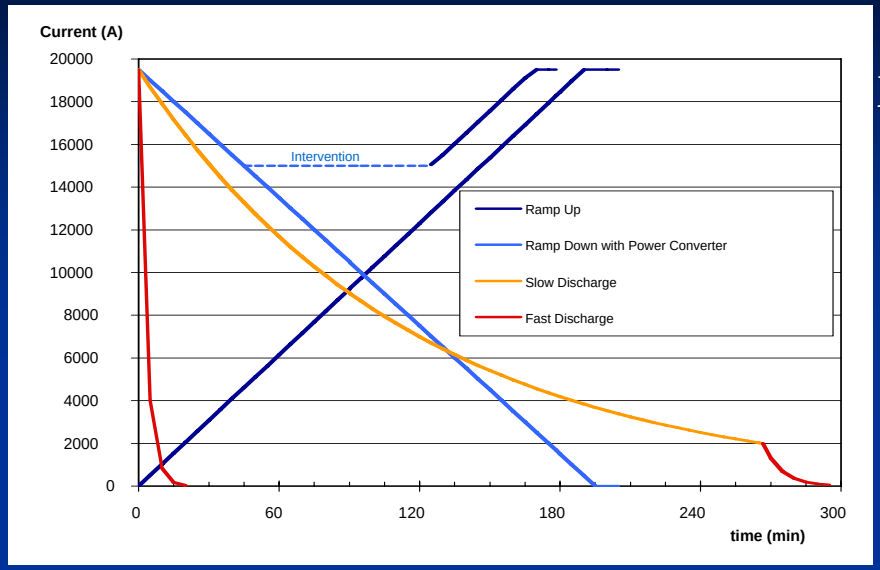
HCAL: Magnetic field angle HO HPD axis was 25 degrees different from simulation
=> Cross Talk
In MTCC II

- tests with displaced HPD box, to limit effect to ≤10%
- Try re-directing field using soft iron wedges.

Cross Section of CMS Reinforced Conductor



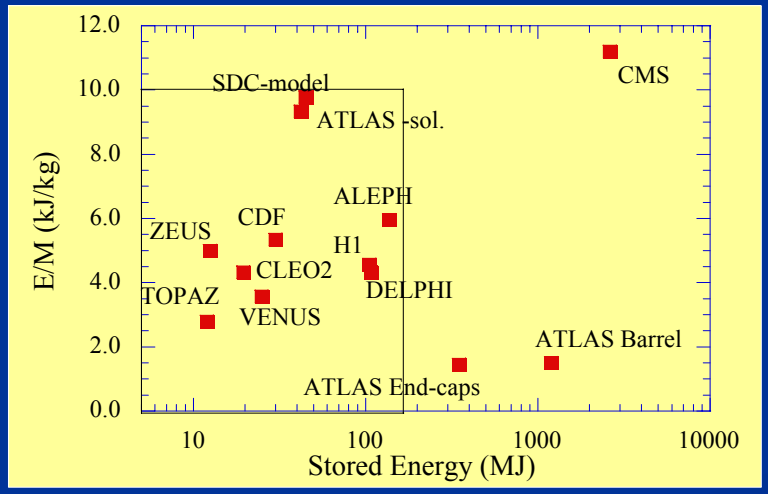
Concept of reinforced conductor introduced in 1991 by J.C. Lottin / Saclay (now deceased)



Magnet rump up & discharge possibilities

Slow discharge: cold mass remains at 4.2 K

Fast discharge: cold mass is warmed up to ~70K => longer recovery



Specific Energy of the CMS Coil (kJ/kg of cold mass), the expected value for CMS has been reached!

Stored Magnetic Energy ~ B^2

Overview of the CMS Experiment