The CMS Magnet Test and Cosmic Challenge

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On behalf of the CMS Collaboration

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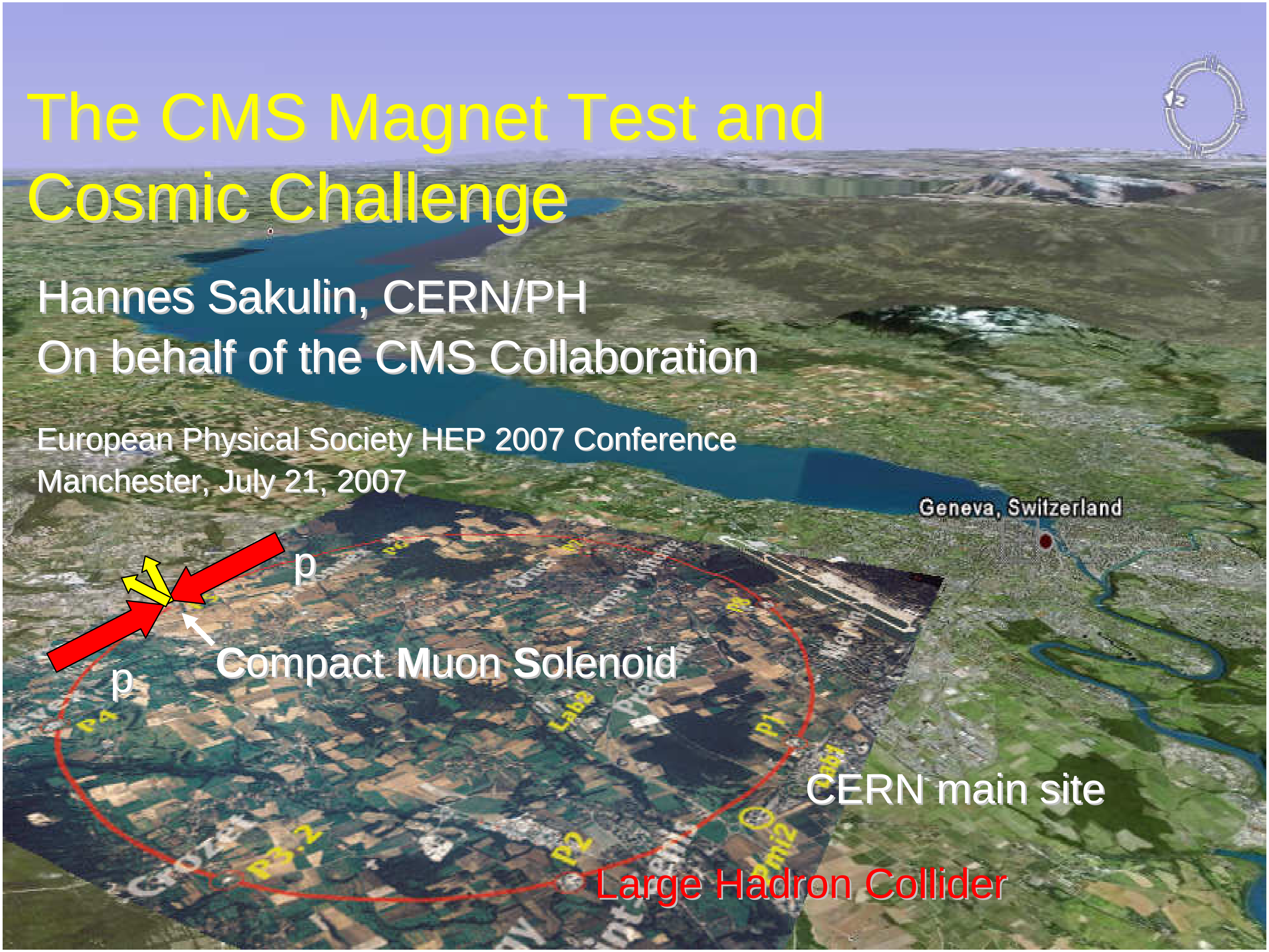
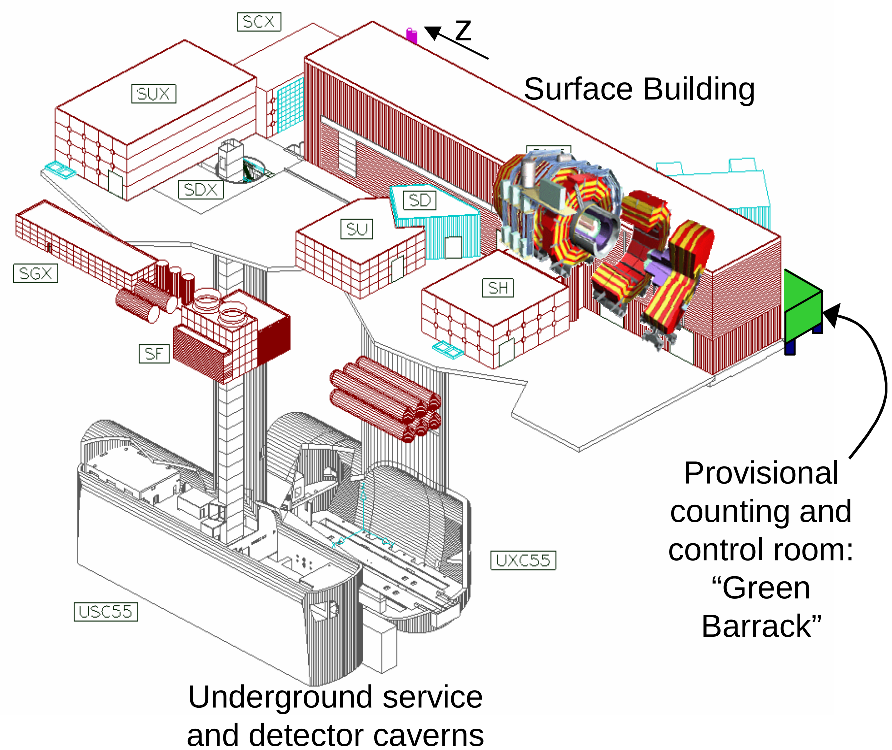


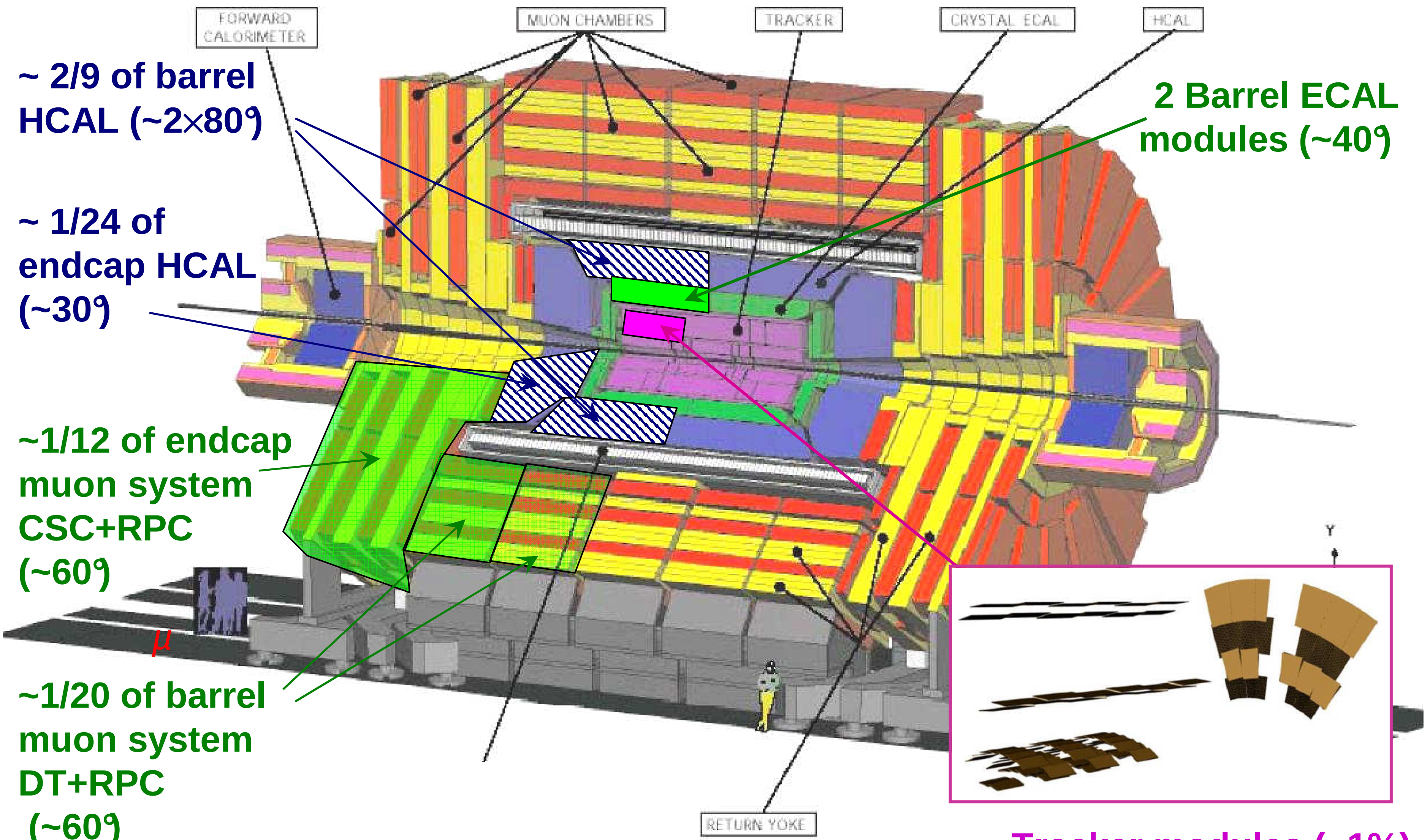
CMS Magnet Test and Cosmic Challenge

- Since 2000: Have been assembling CMS in a surface building
  - Modular design: 5 wheels and 6 endcap disks
    that can be (and partly have been) lowered, separately
  - Assembly of yoke, installation of detectors, solenoid, service, cabling
  - Cope with civil engineering schedule

- In 2006: Major parts of commissioning on the surface
  - **Magnet Test**
    - Closing and opening of CMS
    - Coil commissioning to 4 Tesla
    - Obtain detailed field map
  - In parallel: **Cosmic Challenge**
    - Operate ~1/20 of CMS integrated with central services, trigger, DAQ
    - Take combined data with cosmic muons
  - Two Phases
    - Phase 1: operate (parts of) all participating CMS detectors
    - Phase 2: Field mapping, operate without tracker and ECAL



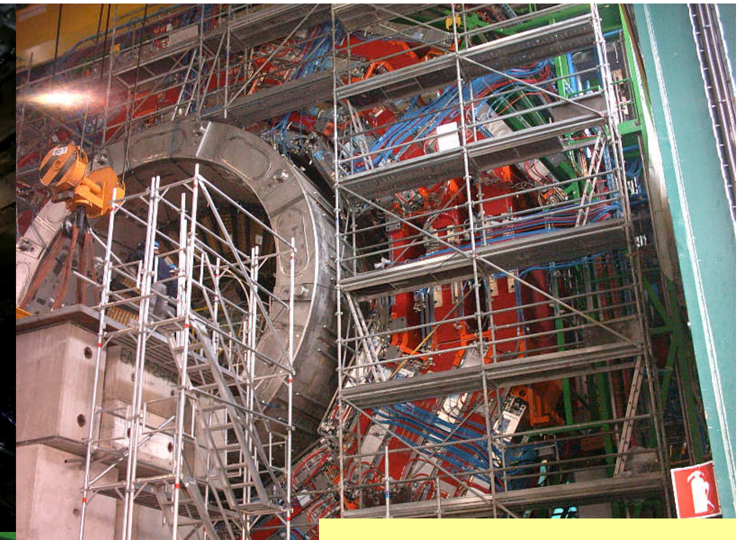
Cosmic Challenge detector

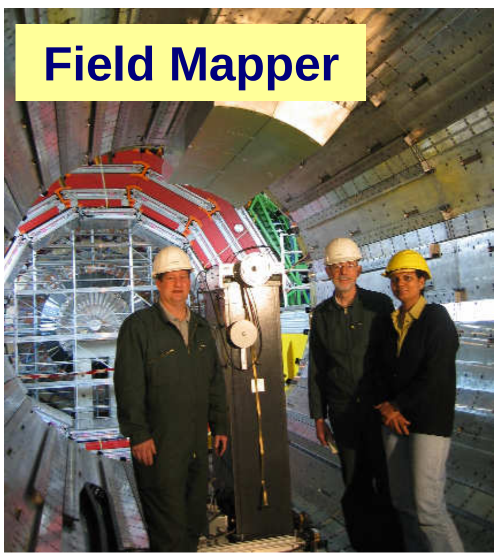


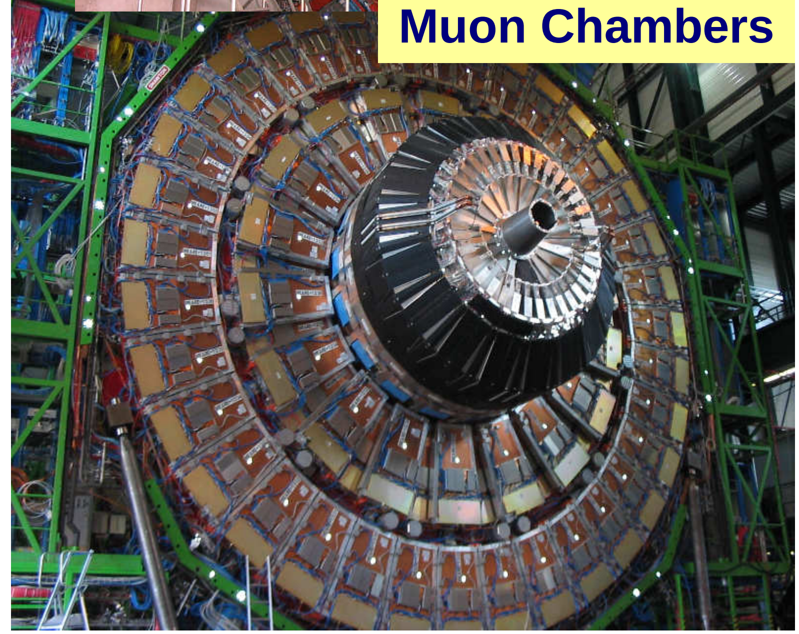
Tracker modules (~1%)

parts of: inner barrel layer 2&3, outer barrel layer 1&5, endcap disk 9

Installation



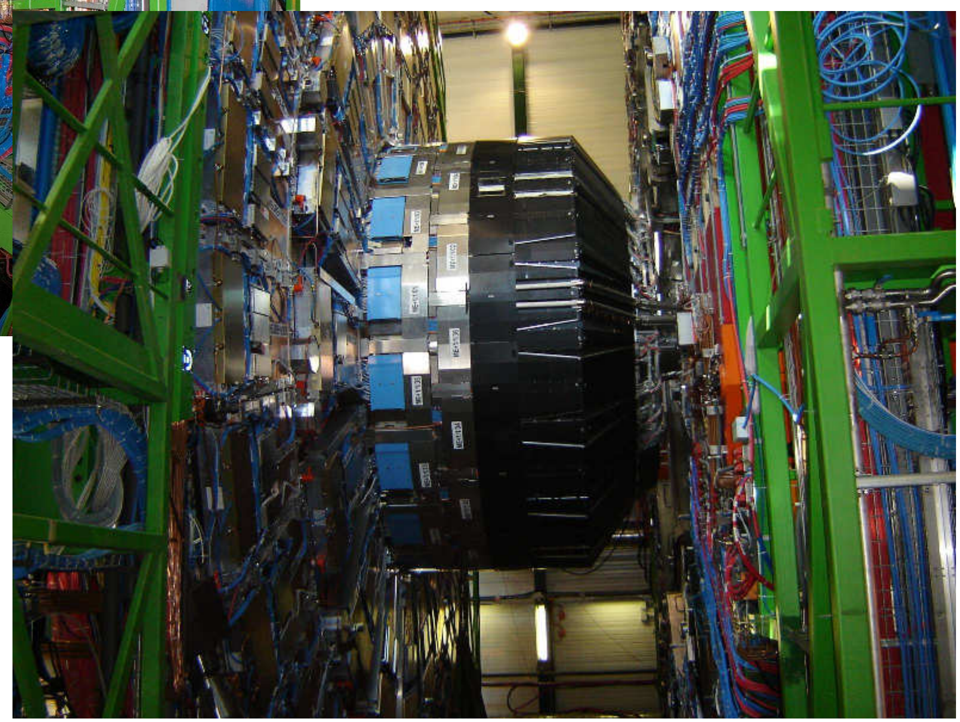




Closing and Opening CMS

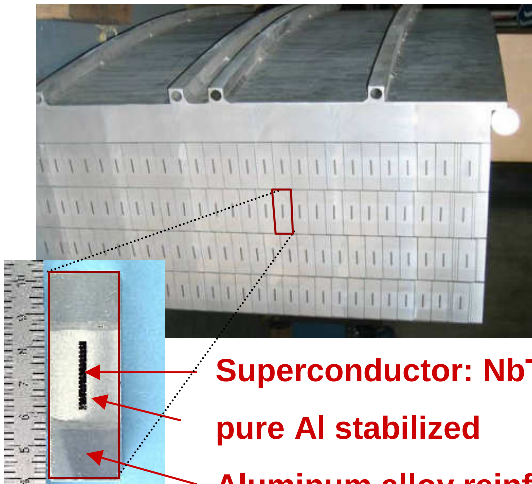
Closed CMS without major problems

Air-pads and grease pads used to move the 5 barrel wheels and 6 endcap disks



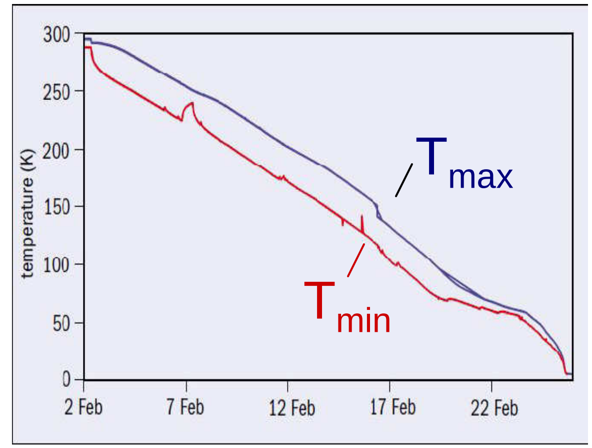
Commissioning of 4T superconducting coil

4-layer coil winding



2005: insertion into cryostat

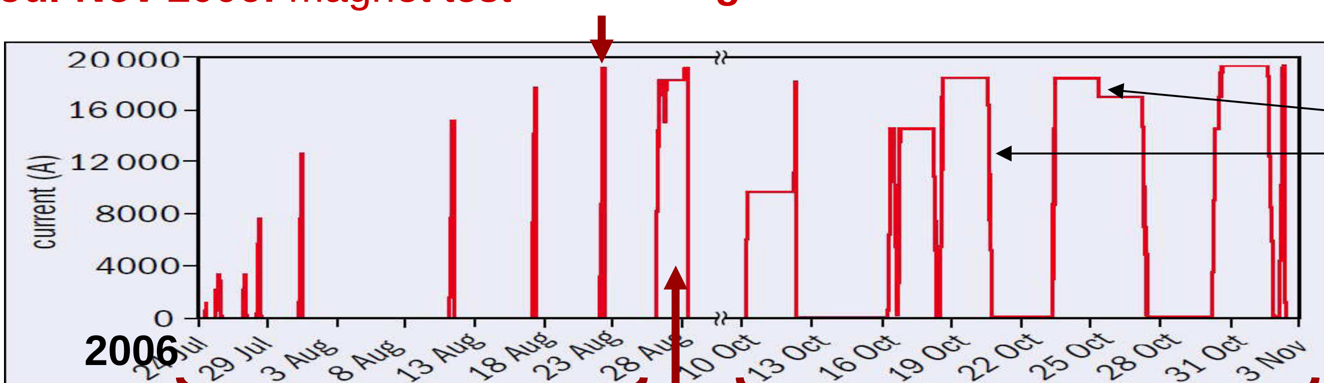
Feb 2006: smooth cool-down to 4K



Coil contraction of ~27 mm during cool-down

Jul-Nov 2006: magnet test

22 Aug 2006: Reached B=4T !



Tested slow and fast magnet discharge

Tests with increasing magnet currents

Cosmic Challenge phase I

Field Mapping & Cosmic Challenge phase II

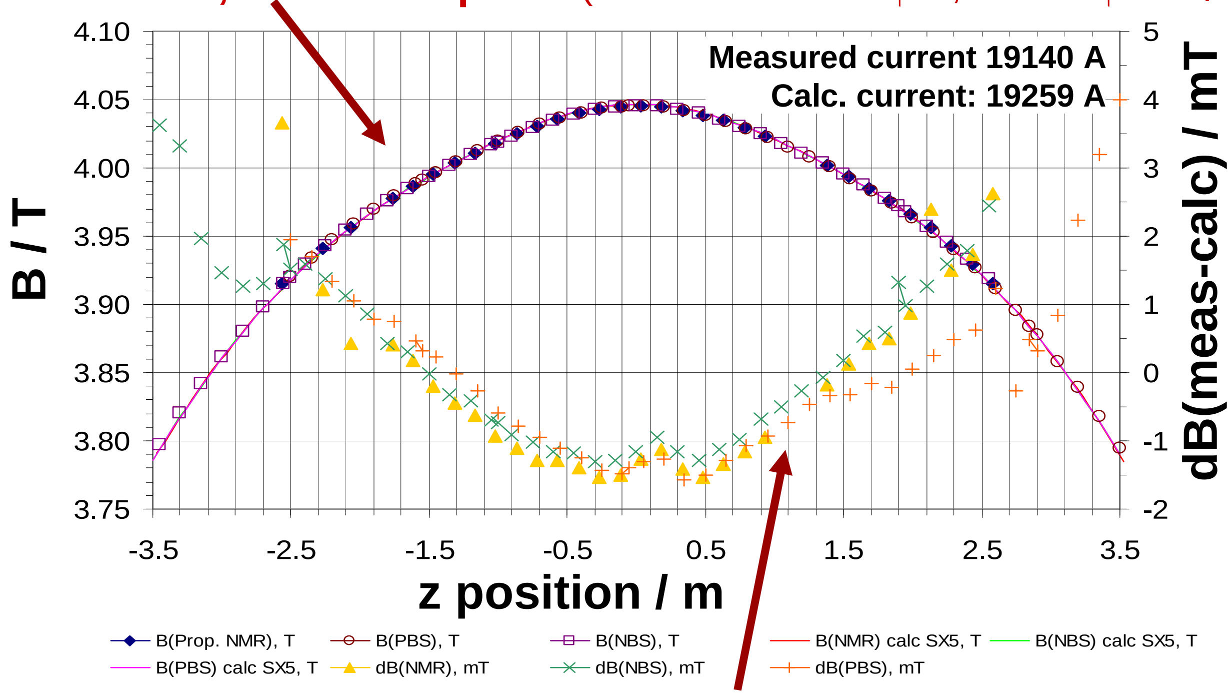
Field Mapping

during Phase 2

- 10 Hall sensors
- 2 NMR probes at r=0m, r=1.72m (≈HCAL inner radius)
- Map entire volume inside HCAL
  - 48 positions in phi
  - 142 positions in z
  - ~50 hours per map
- Field mapping performed at 0T, 2T, 3.5T, 3T, 3.8T, 4T

Field Mapper: non-magnetic device on special rails, air-driven mechanics (*B*-field!): *O*(10^{-4}) precision at 4T

NMR and Hall probe measurements & TOSCA Simulation at r=1.72m, horizontal plane (NMR and NBS at ϕ=0, PBS at ϕ=180)



PBS: positive B sensor, NBS: negative B sensor

Very good agreement between measurement and simulation !

Cosmic Challenge: Trigger System

- Most components of final trigger system tested
- Two alternative setups
  - "Full" trigger chain
    - Local Triggers ⇨ Regional Triggers ⇨ Global Muon Trigger / Global Trigger
    - Trigger decision and Trigger Control in Global Trigger
  - Local Trigger Setup
    - Trigger decision in regional muon and calorimeter triggers
    - Trigger distribution and Trigger Control in Local Trigger Board
- Successfully synchronized entire trigger system
  - More difficult with cosmic muons than at LHC

Main Triggers used (plus many others for dedicated studies)

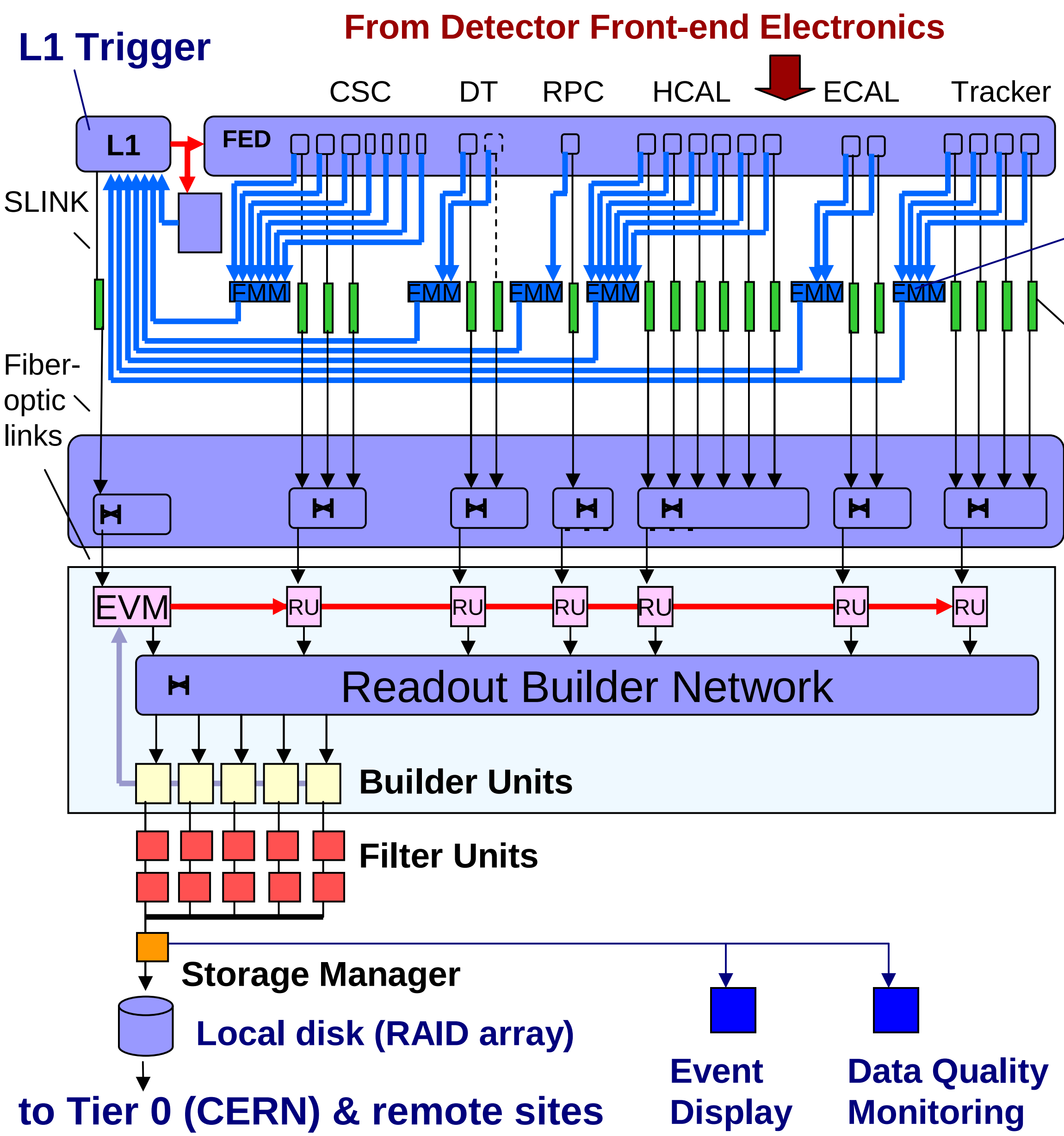
- **DT Inclusive**: ≥ 2 chambers (same sector & wheel)
- **DT Pointing to center of detector** (constraint on η segments)
- **CSC**: Single chamber (≥ 4/6 layers) or two-chamber coincidence
- **RPC**: ≥ 5/6 planes (single wheel)
- **RPC pointing**: ≥ 5/6 planes in wheel 1 or 2, pointing to center
- **HCAL**: Coincidence of Minimum Ionizing Particle (MIP) signals in upper and lower part of HCAL Barrel (HB) detectors

Trigger Rate (cosmics)

100 .. 300 Hz

(final CMS: 100 kHz)

Cosmic Challenge: Central DAQ System



Scaled-down setup of final hardware and software

Front-end Drivers (18 / 650)
(MTCC / final CMS)

Trigger Throttling System
1 Fast Merging Module per detector (5/52)
custom-built compact PCI

Front-end Readout Links (19 / 500)
custom-built compact PCI

Myrinet Super-Fragment-Builder
1 super-fragment per detector (6/72)

Gigabit Ethernet Event Builder
Single slice (1 / 8)
1 Event Manager
1 Readout Unit per detector (6 / 72x8)
5 Builder Units (5 / 288x8)

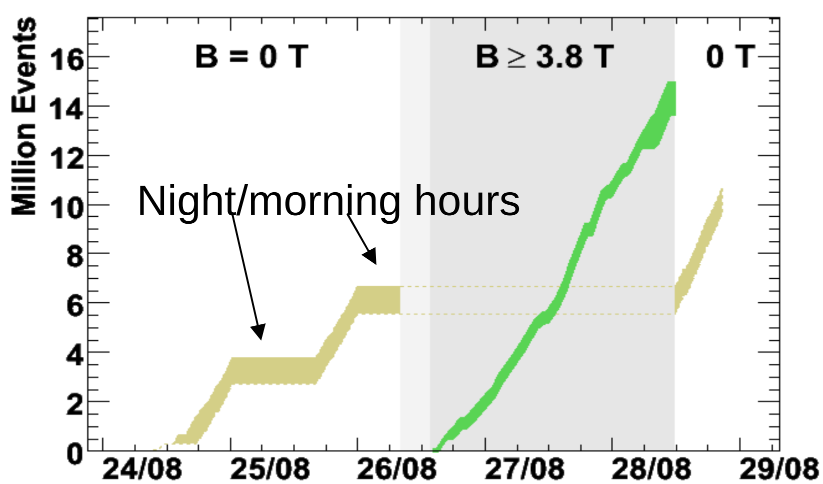
Filter Farm
10 Filter Units (10 / 288x8)
1 Storage Manager (1/8)

Commercial PCs

Event Size
200 kB (final CMS: 1MB)

Data Taking with central DAQ

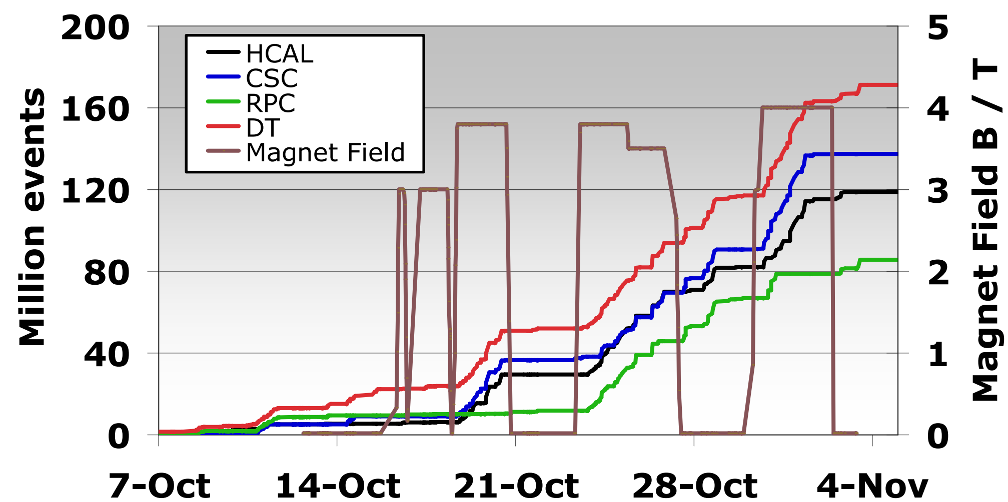
- All software for detectors, trigger, DAQ controlled by Run Control System
- All software monitored using common Monitoring Infrastructure
- Operated round-the clock (when field was on)
- Good data taking efficiency
  - effort of shift crew to keep error recovery time short
  - flexible central DAQ system: possibility to quickly disable subsystems or individual FEDs at start of run („masking“)



Phase 1 (with Tracker and ECAL)

15 + 10 Mio events with / without field

5k + 6.5k „central“ tracks (hitting MTCC tracker)

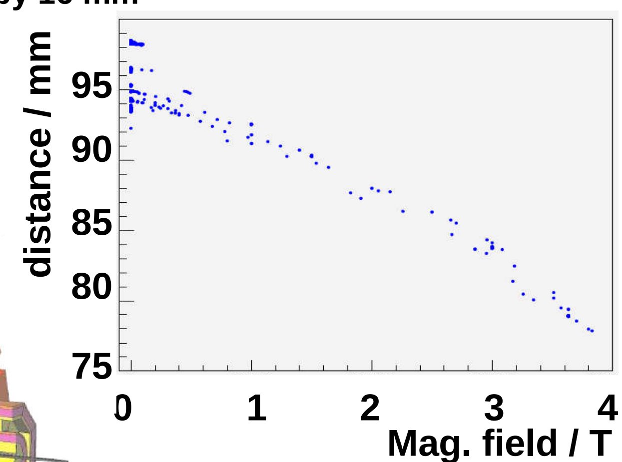


Phase 2 (without Tracker and ECAL)

~100 Mio events for global reconstruction and dedicated sub-detector studies

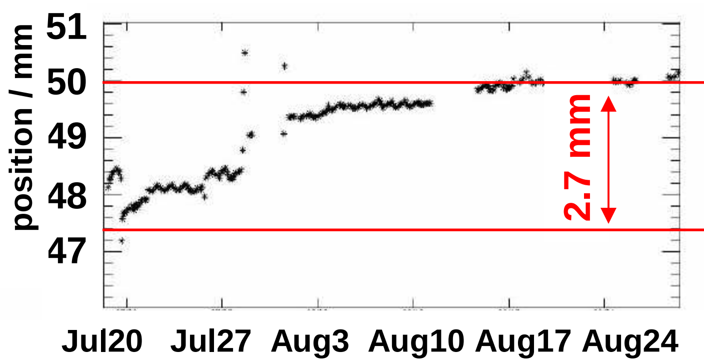
Selected observations: Alignment

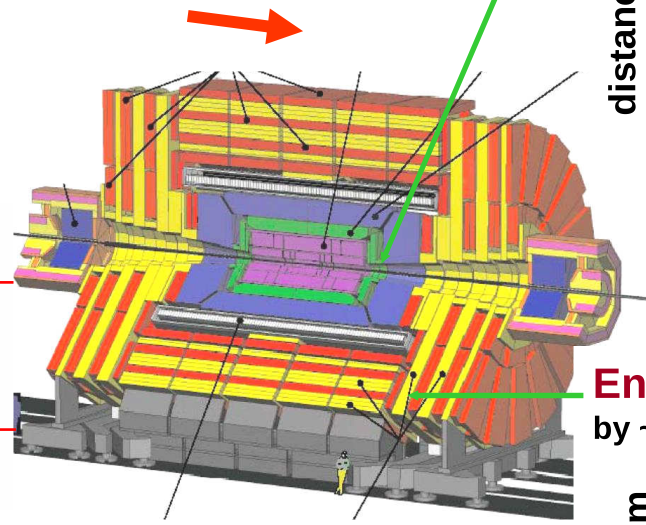
Endcap 1 nose moves in by 16 mm



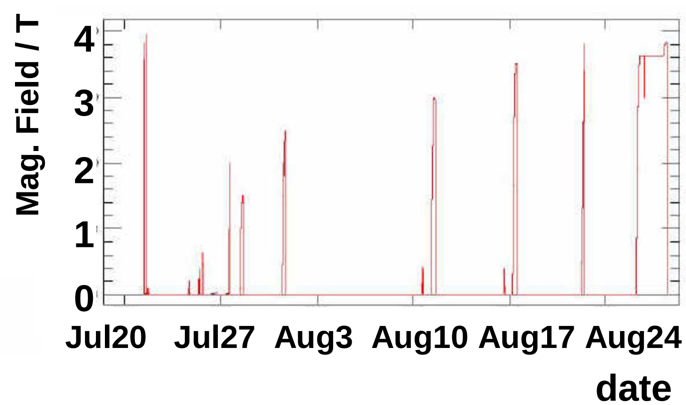
wheel 2 moves ~ 2.7 mm towards Interaction Point

Permanent longitudinal shrinkage of barrel yoke due to first magnetization

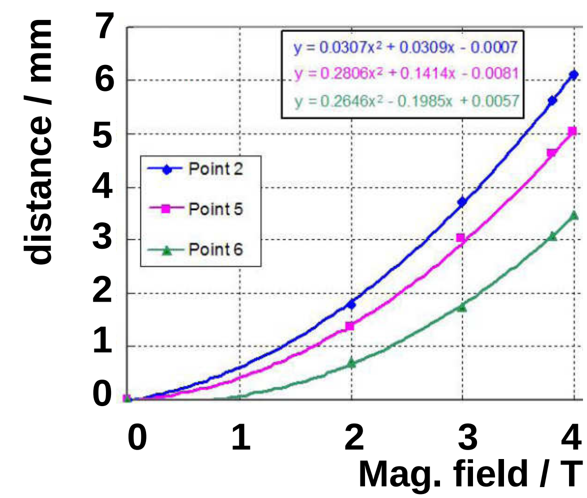




Endcap 1 outer rim moves out by ~6 mm (top/bottom asymmetry)



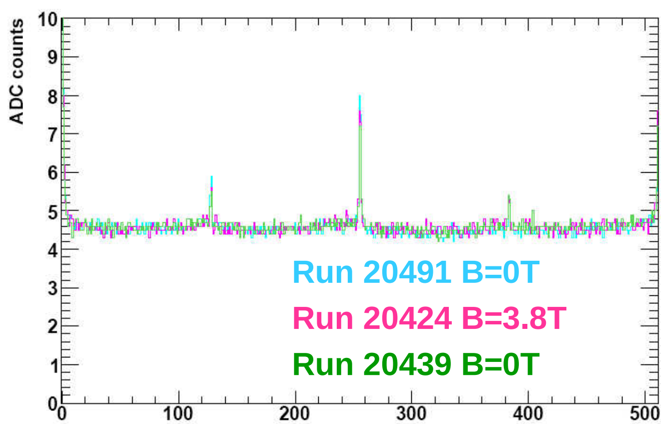
Yoke movements approximately as predicted



Selected results

Tracker

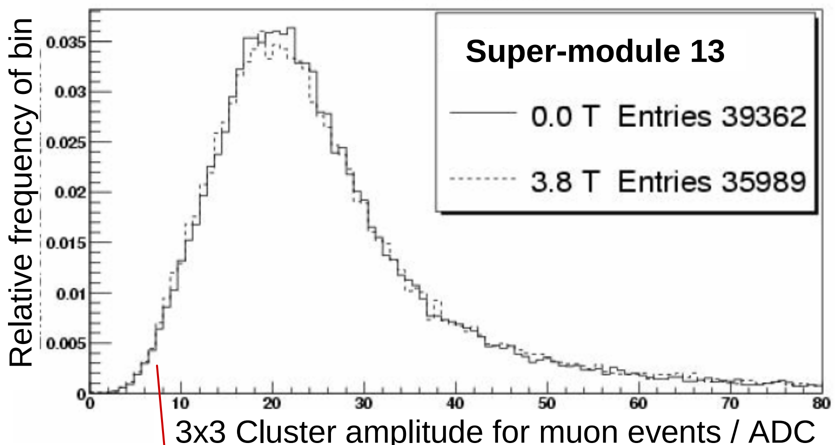
- ~ 10k tracks reconstructed – mostly triggered by ‘pointing’ triggers
- Signal to noise ratio as expected: 28 (34) for thin (thick) sensors
- Pedestals and electronic noise not significantly influenced by B-field:



TOB Module 6180 noise

ECAL

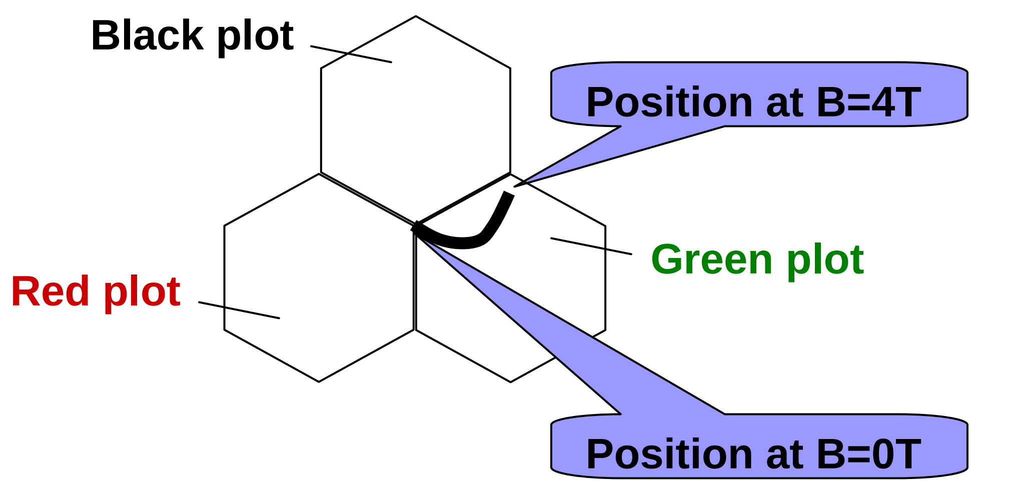
- Observed muons in coincidence with Tracker and muon chambers (special muon selection for MTCC)



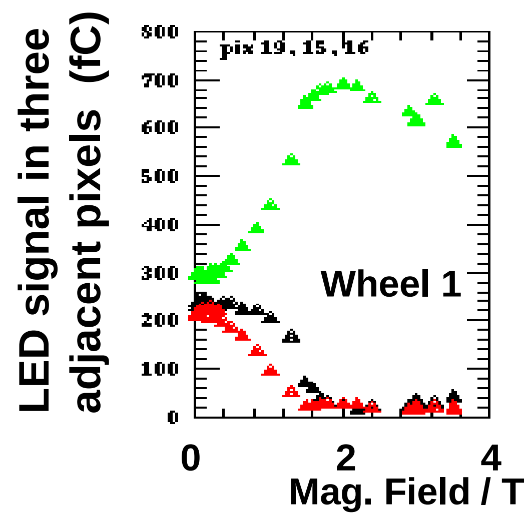
- Channel electronics noise exactly as envisaged: 40 MeV
- Pedestal r.m.s unchanged by B-field

Selected results: **HCAL**

- Muon signals observed in all parts of HCAL using DT and CSC triggers
- Used HCAL to generate MIP triggers
- Problem found in HCAL Outer Barrel (HO): Increased cross-talk between **H**ybrid **P**hoto-**D**iode pixels in magnetic field
  - Cause: angle of field to HPD axis found to be 25° (55°) different from simulation in wheels 1 and 2 (wheel 0)
  - Solution: move Hybrid Photo-Diode boxes deeper into gap (different field conditions)



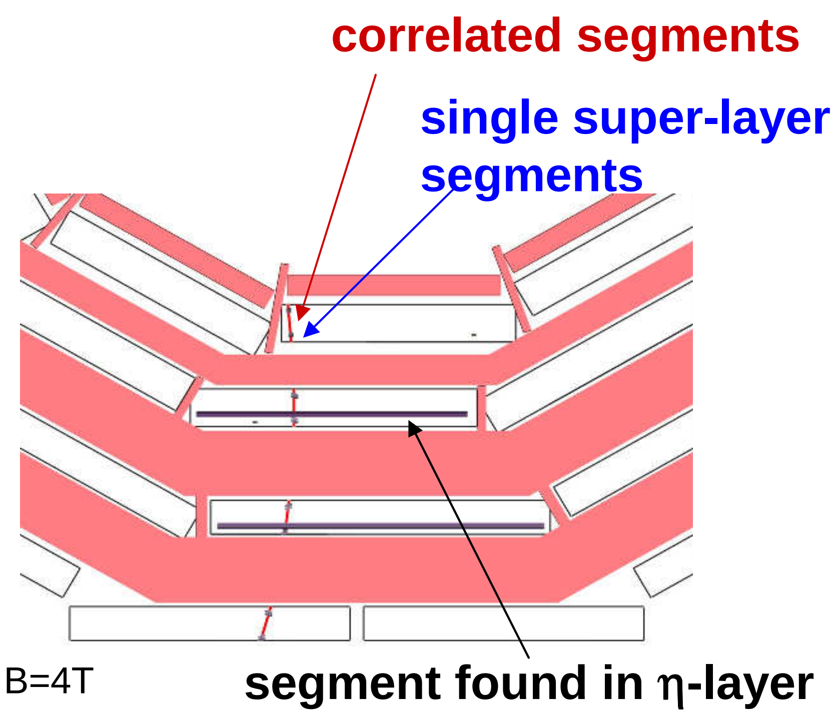
LED signal moves away from corner of three adjacent pixels of Hybrid Photo-Diode



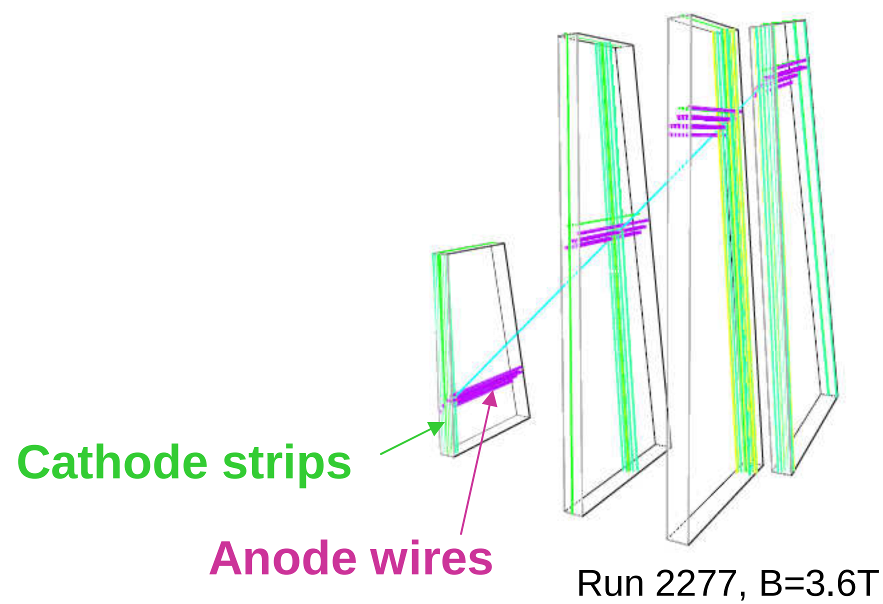
Selected results: **Muon Systems**

- All three muon systems successfully used, both in trigger and reconstruction
  - Modified track-finding algorithms without vertex constraint
- Many dedicated studies
  - E.g. Influence of B-field on drift velocity in drift tubes

More details:
presentation by M. Fernandez (Friday)

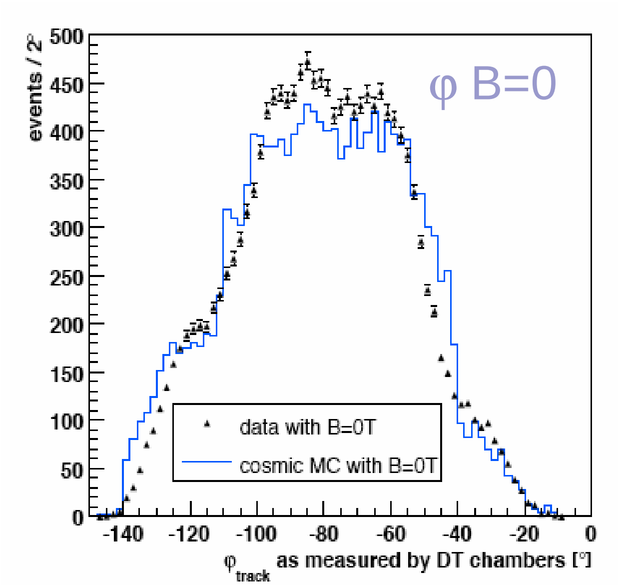


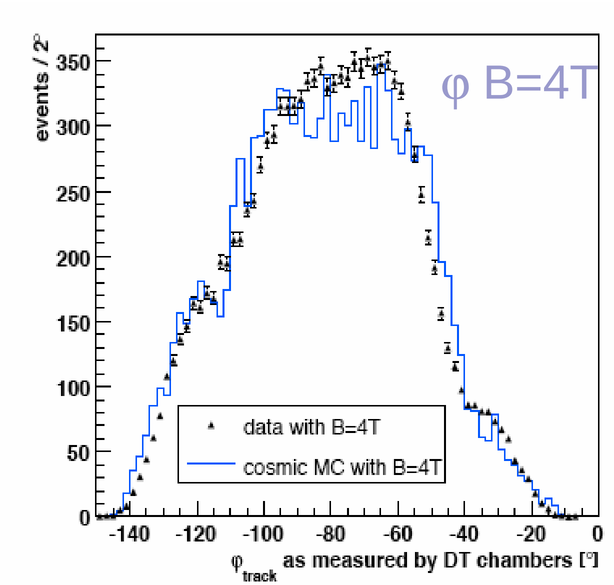
Drift Tube event display



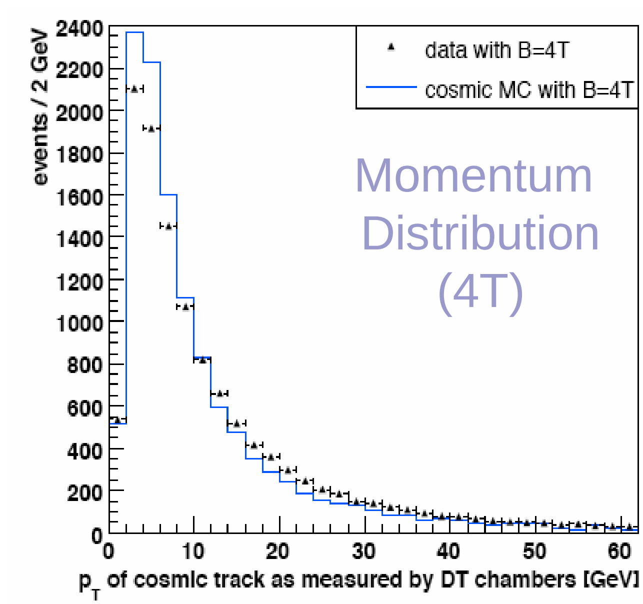
Cathode Strip Chamber event display

Muon spectra





Azimuthal distribution measured by DTs.



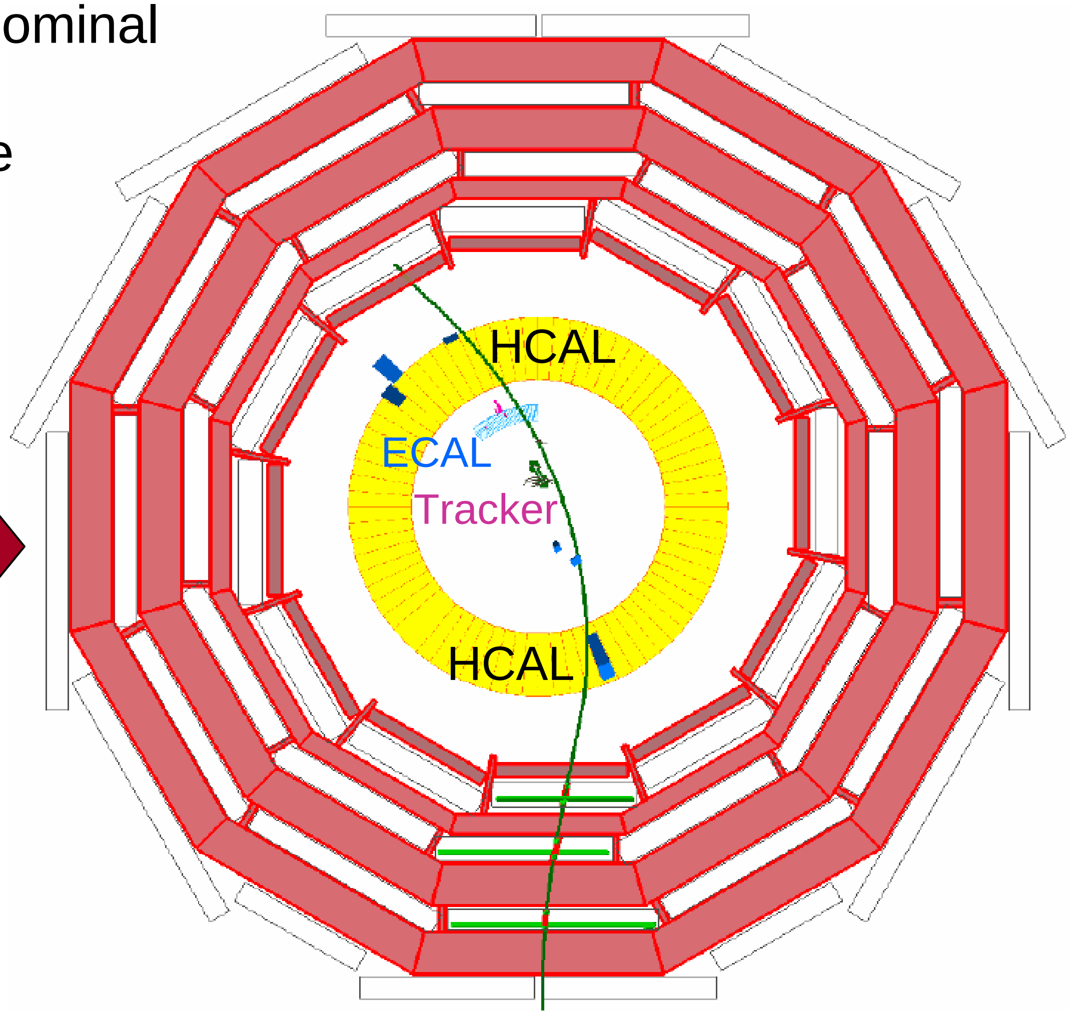
Cosmic muons data normalized to Monte Carlo simulation

Reasonable agreement between data and simulation.

Almost every aspect of final CMS from detector to CMSSW software had to work to produce these plots.

Summary

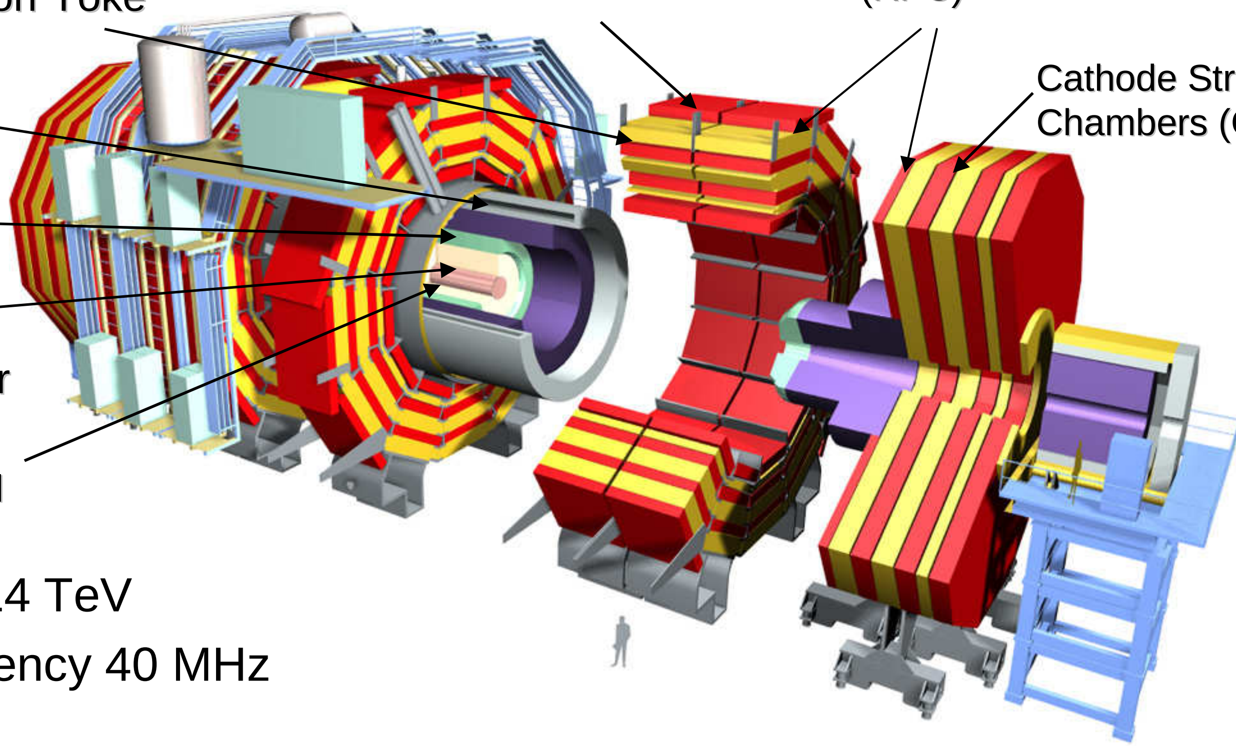
- Stably operated the magnet at nominal field strength of 4T
- Mapped the magnetic field in the entire volume inside HCAL with high precision
- Successfully integrated and operated ~ 1/20 of CMS
- Took cosmic muon data with all detectors at B=4 T
- Performed many dedicated studies
- Found some problems that are now being corrected
- CMS Collaboration performed very well as a team !!!



Run 2605 / Event 3981 / B=3.8 T / 27.08.06, 22h
Muon traversing DT, RPC, HCAL, ECAL, Tracker

BACKUP SLIDES

The Compact Muon Solenoid Experiment



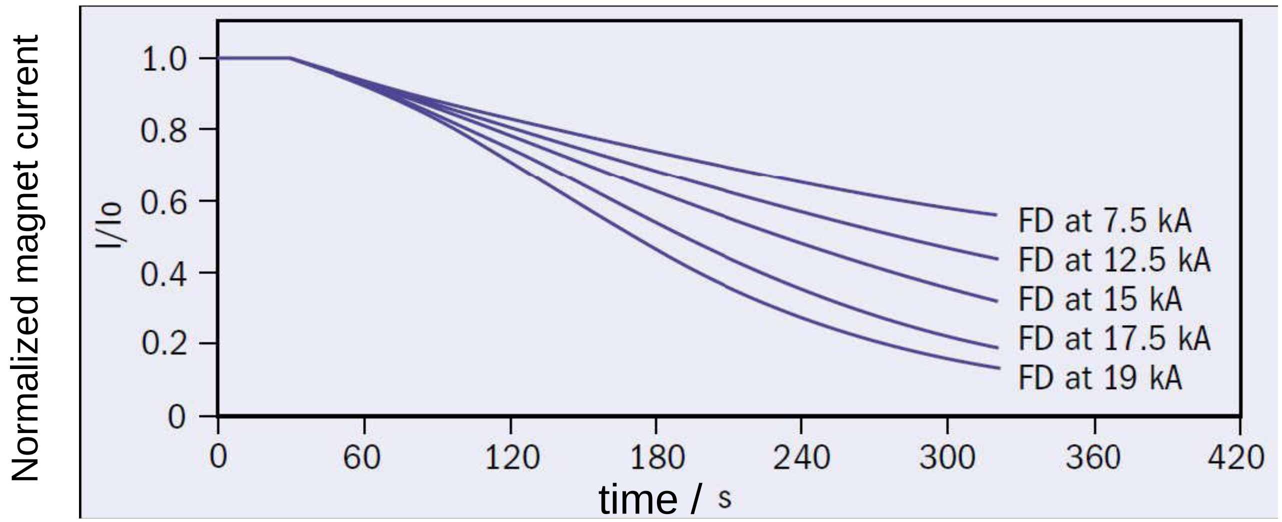
LHC

- p-p collissions, E_{CM}=14 TeV
- Bunch crossing frequency 40 MHz

CMS

- Multi-purpose detector
- Broad physics programme
- 55 Mio. Channels to read out
- 1 MB event size after zero suppression

Magnet fast discharge behavior

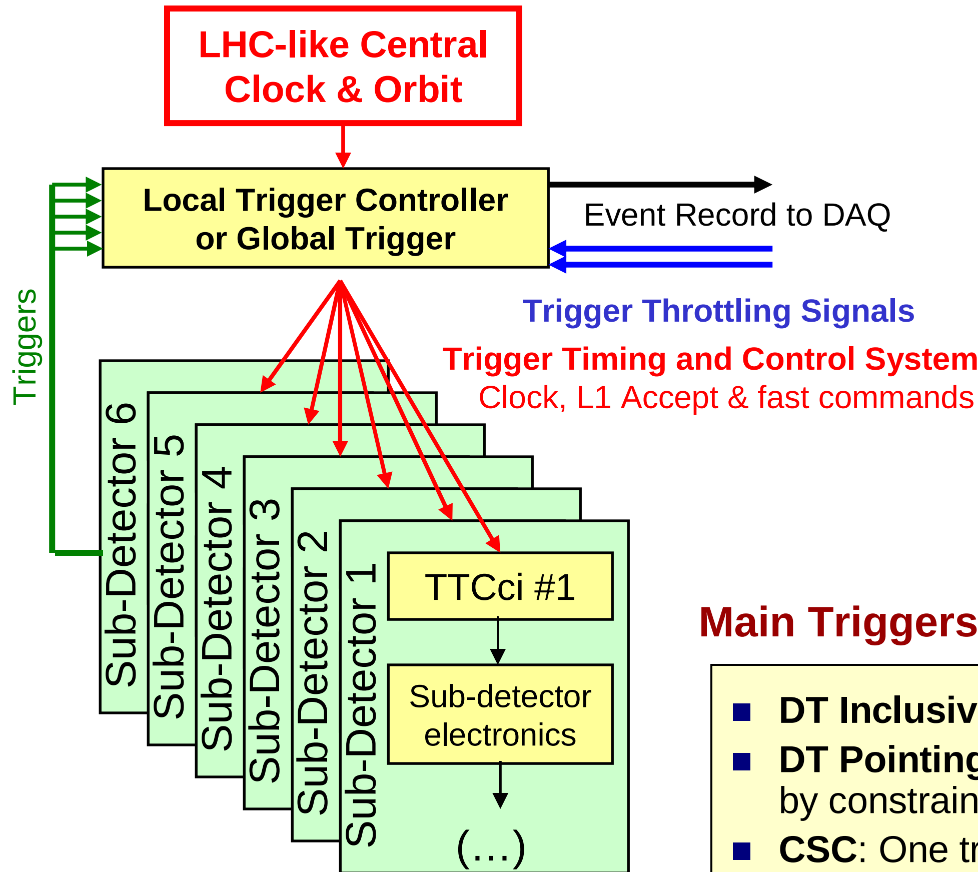


Tested fast discharge from several initial currents

Normalized magnet current during a fast discharge triggered at t=30 s

- Discharge through external dump resistor banks
- Magnet turns into normal conductor (quench)
  - Internal resistance increases up to 0.1 Ω (at I_0=19 kA)
- Average cold mass temperature increases to T=70 K (at I_0=19kA)
  - Inductive coupling with mandrel protects against high thermal gradients
  - Difference of 32.3 K between hottest and coldest part of cold mass
- Up to 3 days needed to re-cool coil

Cosmic Challenge: Trigger System



- **Local Trigger Controller used for most of MTCC**
  - Trigger signals from local or regional triggers
- **Global Trigger and Global Muon Trigger used at the end of MTCC phase 2**
  - Full trigger chain for DT and CSC triggers
- **Major effort to synchronize system**
  - ✓ Detector data to triggers
  - ✓ Trigger w.r.t. each other
  - ✓ DT and CSC triggers (overlap region)
  - More difficult with cosmics than at LHC

Trigger Rate (cosmics)

100 .. 300 Hz (final CMS: 100 kHz)

Main Triggers used (plus many others for dedicated studies)

- **DT Inclusive**: ≥ 2 chambers in same sector & wheel
- **DT Pointing**: above + select tracks pointing to center of detector by constraint on η segments
- **CSC**: One track stub in any chamber with ≥ 4 out of 6 layers
- **RPC1**: ≥ 5 out of 6 planes in wheel +1
- **RPC2**: ≥ 5 out of 6 planes in wheel +2
- **RPC pointing**: ≥ 5 / 6 planes in wheel +1 or +2, pointing to center
- **HCAL**: Coincidence of Minimum Ionizing Particle (MIP) signals in upper and lower part of HCAL Barrel (HB) detectors

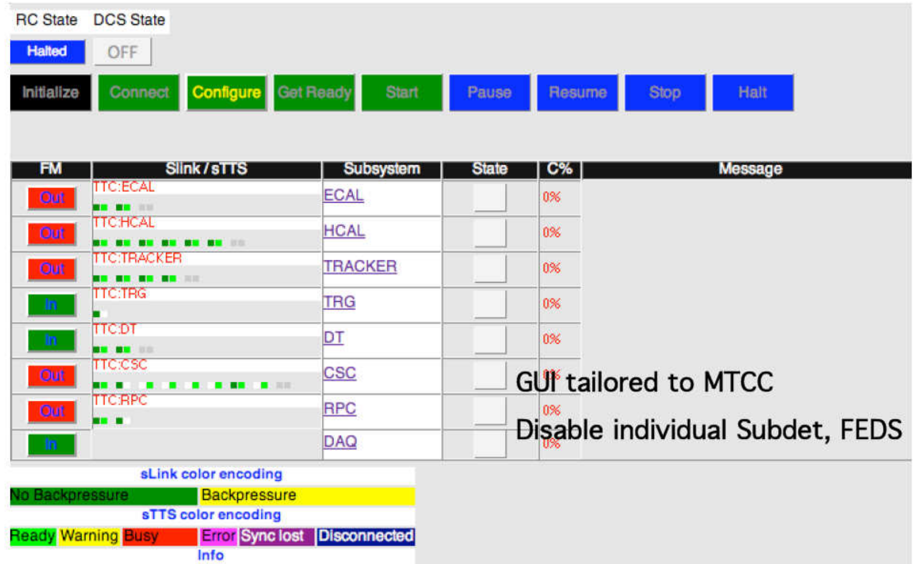
Run Control and Monitoring System

Run Control Display

Control of all online software (Detectors, Trigger, DAQ)

Driven by state machine

Masking: possibility to disable individual subsystems / FEDs before start of run



GUI tailored to MTCC

Disable individual Subdet, FEDS

MTCC-Run 2251 Evt-No 40170 Trg-Rate 26.6Hz (eff 37.5%) Trg-Input DT(HW0).or.CSC(HW1)

FRL-FBO-RU summary

	CTC	TK				ECAL		HCAL						CSC/TF			DT/TF		RPC
expected FED ID	815	53	55	57	59	600	601	700	701	702	703	704	705	750	751	760	770	780	790
received FED ID	815	53	55	57	59	0	0	700	701	702	703	704	705	750	751	760	770	0	0
CMCversion	cf01001e	cf01001e	cf01001e	cf01001e	cf01001e	cf01001e	cf01001e	cf01001e	cf01001e	cf01001e	cf01001e	cf01001e	cf01001e	cf01001e	cf01001e	cf01001e	cf01001e	cf01001e	0
FED clk [MHz]	80.14	80.14	80.14	80.14	80.13	0	0	31.99	32	32	31.99	31.99	31.99	62.48	62.49	78.11	40.07	0	0
LFF time	0.000s	0:14:17	0:02:30	0:14:17	0:14:20	0.000s	0.000s	0.000s	0.000s	0.000s	0.000s	0.000s	0.000s	0.001s	0.000s	0.000s	0.000s	0.000s	0.000s
BXNumber	3062	687	401	687	687	0	0	3062	3062	3062	3062	3062	3062	3064	3064	3064	0	0	0
triggerNum	40133 0x9ce5	40134 0x9ce6	40134 0x9ce6	40134 0x9ce6	40134 0x9ce6	0 0x0	0 0x0	40133 0x9ce5	40133 0x9ce5	40133 0x9ce5	40133 0x9ce5	40133 0x9ce5	40133 0x9ce5	40133 0x9ce5	40133 0x9ce5	40133 0x9ce5	40134 0x9ce6	0 0x0	0 0x0
triggerCount	40133 0x9ce5	40134 0x9ce6	40134 0x9ce6	40134 0x9ce6	40134 0x9ce6	0 0x0	0 0x0	40133 0x9ce5	40133 0x9ce5	40133 0x9ce5	40133 0x9ce5	40133 0x9ce5	40133 0x9ce5	40133 0x9ce5	40133 0x9ce5	40133 0x9ce5	40134 0x9ce6	0 0x0	0 0x0
slinkBadCRC	0	0	714	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
fedBadCRC	0	0	359	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
backpressure	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
myrfbStatus	running	running	running	running	running	running	running	running	running	running	running	running	running	running	running	running	running	running	running
myrfb occupancy	0%	83%	46%	83%	83%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
myrbadEvtNo	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
instance/[slot]	0/[1]	12/[1]	13/[2]	14/[3]	15/[4]	10/[13]	11/[14]	4/[6]	5/[7]	8/[10]	9/[11]	6/[8]	7/[9]	1/[2]	3/[3]	2/[4]	16/[6]	17/[7]	18/[9]
Detector FMM	n.a.	R_8	R_8	R_8	R_8	off	off	R_8	R_8	R_8	R_8	R_8	R_8	R_8 R_8 R_8	R_8 R_8	R_8 R_8	R_8	off	off
Merger FMM	n.a.	R_8				off		R_8						R_8			R_8		off
	CTC	TK				ECAL		HCAL						CSC/TF			DT/TF		RPC
RU last evtNo	n.a. (0)	n.a. (4)				n.a. (3)		n.a. (2)						n.a. (1)			n.a. (5)		n.a. (6)
myrfbStatus	n.a. (0)	n.a. (4)				n.a. (3)		n.a. (2)						n.a. (1)			n.a. (5)		n.a. (6)
gaveToMyrinetFB	n.a. (0)	n.a. (4)				n.a. (3)		n.a. (2)						n.a. (1)			n.a. (5)		n.a. (6)
myrfb occupancy	n.a. (0)	n.a. (4)				n.a. (3)		n.a. (2)						n.a. (1)			n.a. (5)		n.a. (6)
Host (RU inst)	.n.a.	rubu28 (inst 3)				rubu27 (inst 2)		rubu26 (inst 1)						rubu25 (inst 0)			rubu29 (inst 4)		rubu30 (inst 5)
RU avg frag Size	n.a.	175.9 +/- 0.00 kB (n=34)				0.0 +/- 0.00 kB (n=0)		76.9 +/- 0.02 kB (n=64)						5.4 +/- 4.89 kB (n=57)			8.6 +/- 0.28 kB (n=64)		0.0 +/- 0.00 kB (n=0)
RU avg throughput	n.a.	5920.1kB/s (dt=1s)				0.0kB/s (dt=1s)		4869.3kB/s (dt=1s)						307.1kB/s (dt=1s)			542.8kB/s (dt=1s)		0.0kB/s (dt=1s)

Expert Monitoring Page

monitoring information from XDAQ monitoring infrastructure

tailored to MTCC