CMS Road to Early LHC Physics

- my personal view -

S.Kunori / U. of Maryland

19-Nov-2007

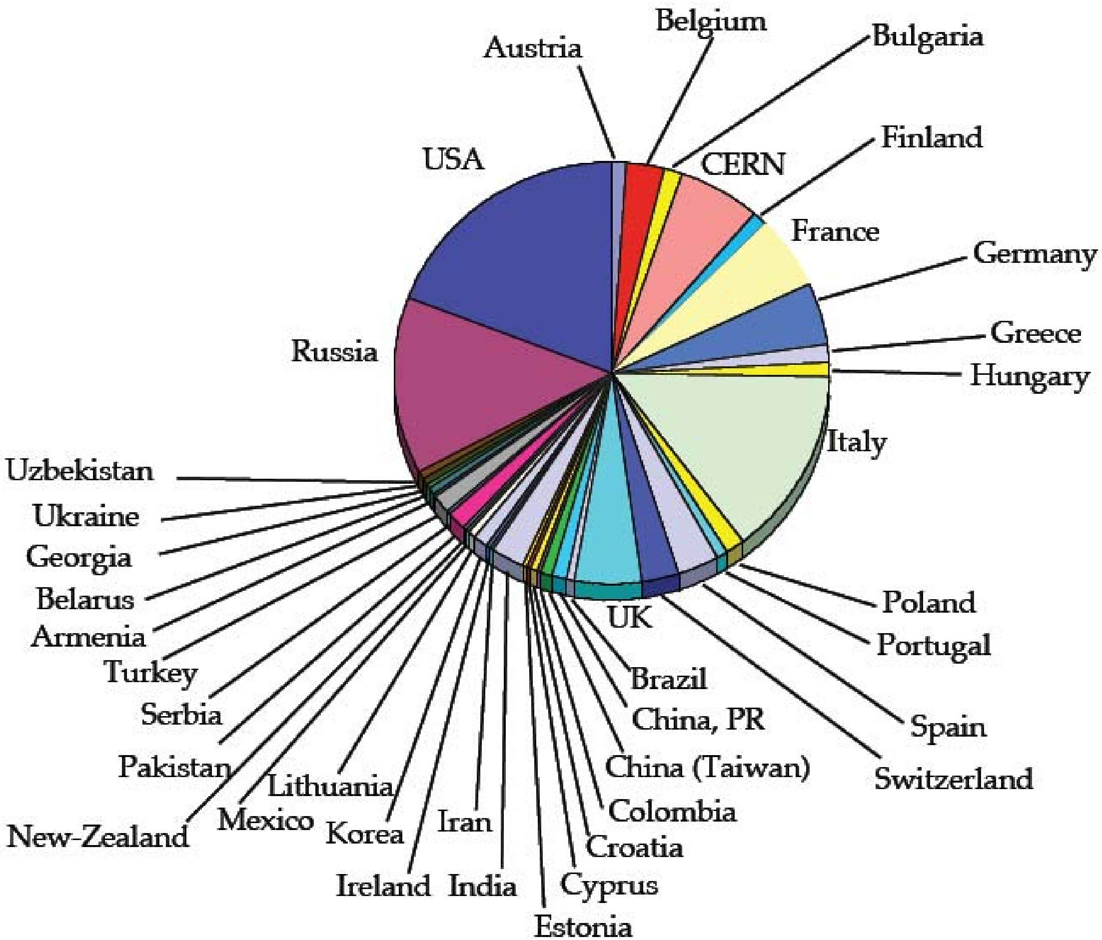
The CMS Collaboration

	Number of Laboratories
Member States	59
Non-Member States	67
USA	49
Total	175

	Nr of Scientific Authors
Member States	1084
Non-Member States	503
USA	723
Total	2310

Associated Institutes	
Number of Scientists	62
Number of Laboratories	9

Oct. 3rd 2007/gm



2310 Scientific Authors
38 Countries
175 Institutions

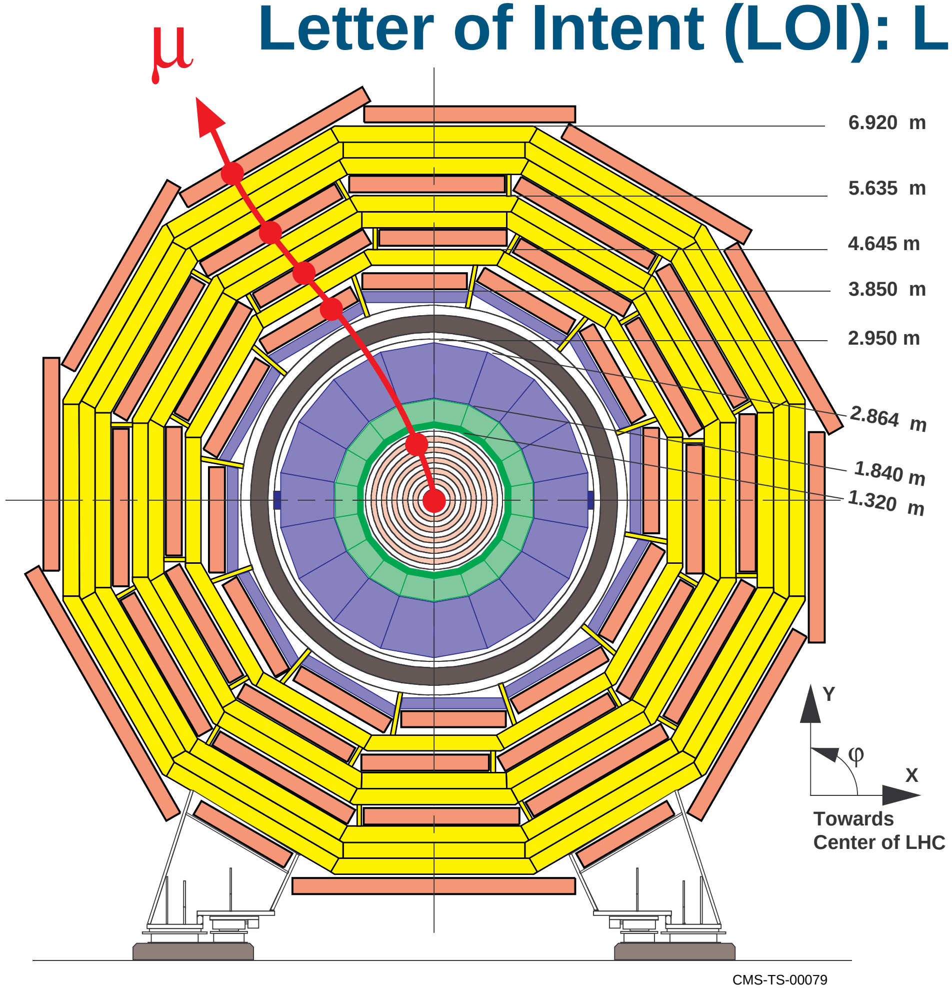
CMS Detector Design Priorities

Expression of Interest (EOI): Evian 1992

1. A robust and redundant Muon system
2. The best possible e/γ calorimeter consistent with 1.
3. A highly efficient Tracking system consistent with 1. and 2.
4. A hermetic calorimeter system.
5. A financially affordable detector.

Compact Muon Solenoid (CMS)

Letter of Intent (LOI): LHCC, 1 Oct 1992



Transverse View

solenoid as large as possible
barrel as long as possible

Strong Field 4T

Compact design

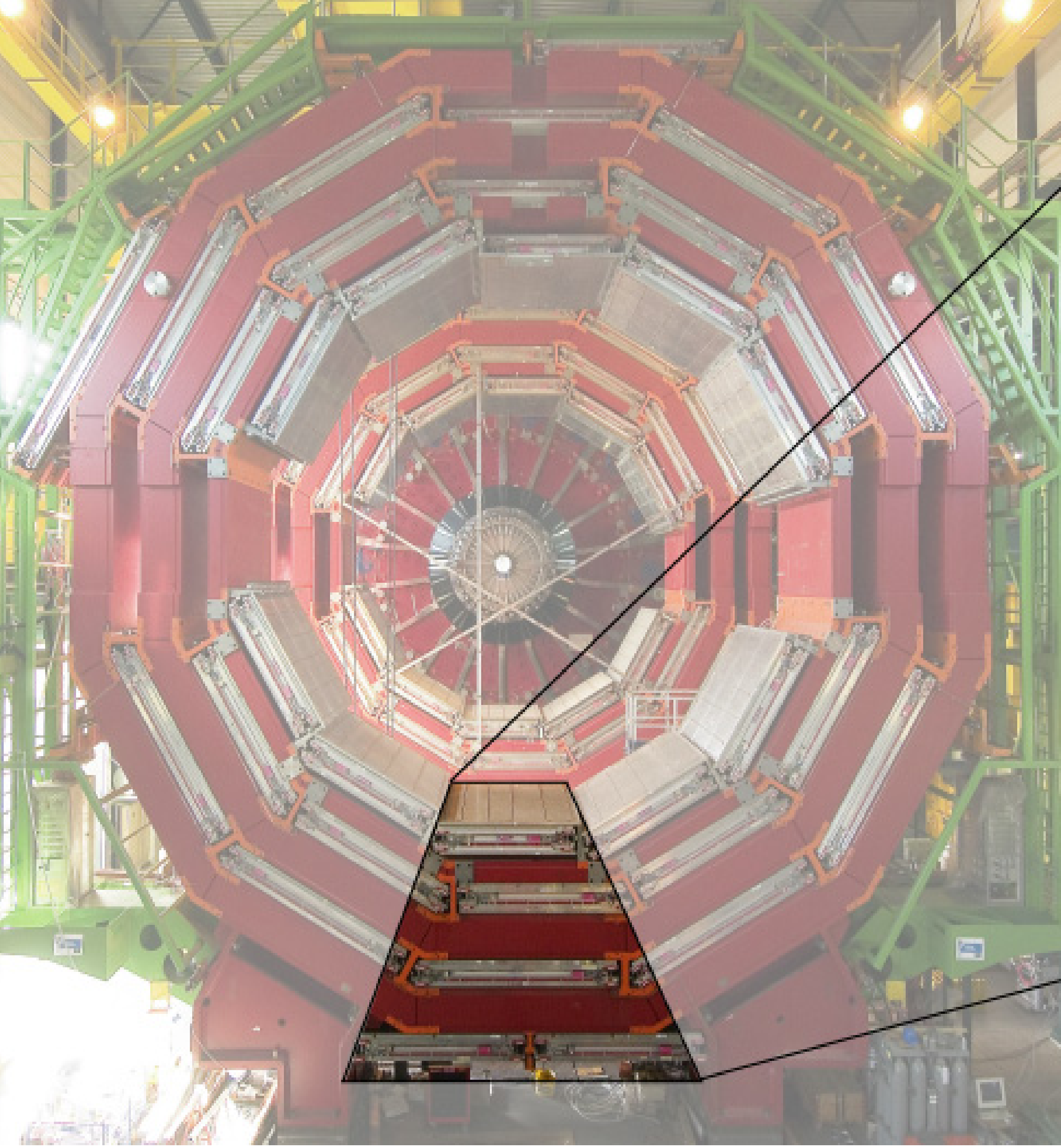
Solenoid for Muon P_t trigger in transverse plane

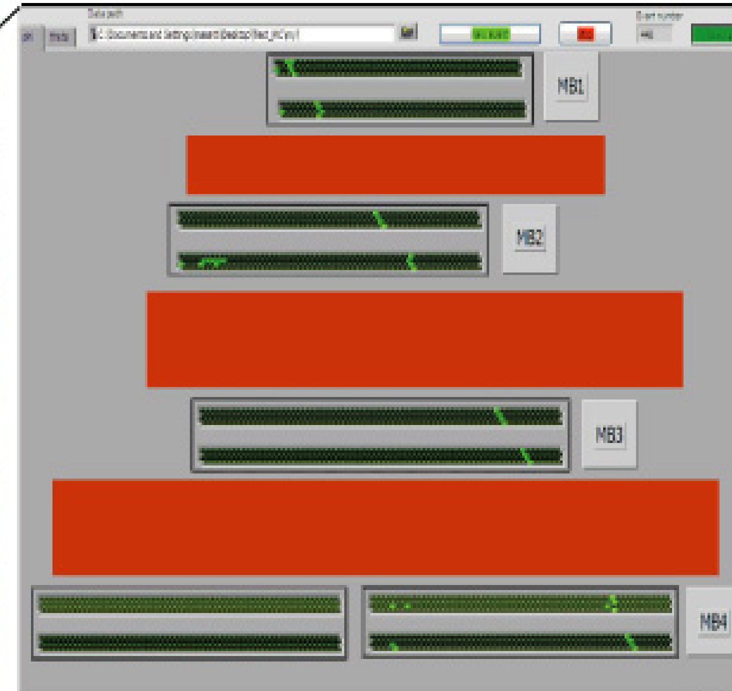
Redundancy: 4 muon stations with 32 r-phi measurements

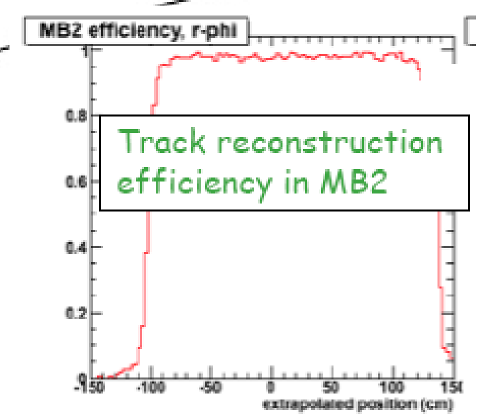
$\Delta P_t/P_t \sim 5\%$ @1TeV for reasonable space resolution of muon chambers (200μm)

Technical Proposal 1994
Technical Design Report
1997 Magnet, HCAL ECAL, Muon
1998 Tracker

December 2005
Cosmic Muons in CMS







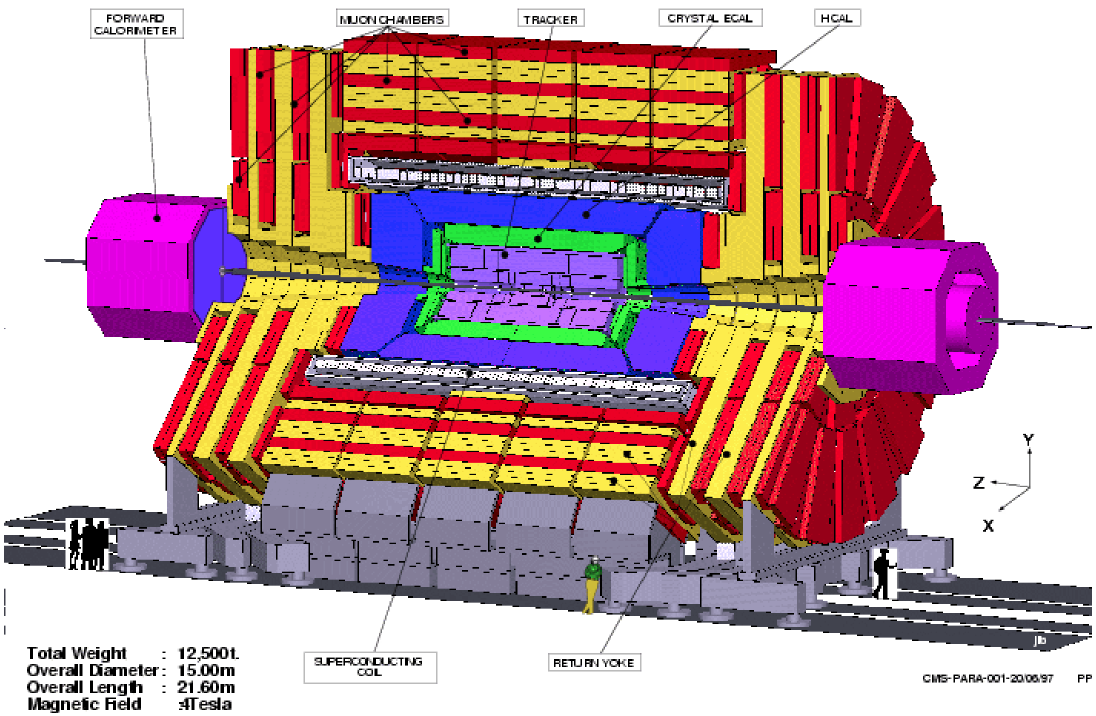
It Works!

Building 40 at CERN – 6 stories

Atlas: 22m ϕ x 44m L
7000 tons

CMS: 15m ϕ x 22m L
12500 tons

The CMS detector



Total weight	**12500 t**
Overall diameter	**15 m**
Overall length	**21.6 m**

All silicon tracker

- **micro strips (10M ch)**
- **pixel (60M ch)**

(5.4m long, 2.4m Φ: $|\eta| < 2.5$)

Hermetic calorimeter

- **ECAL: PbWO4 crystal**
- **HCAL: brass+scinti.**

($|\eta| < 3.0$)

in 4 Tesla solenoid

(12.5m long, 6m Φ in)

Robust muon system

- **DT+RPC (barrel)**
- **CSC+RPC (endcap)**

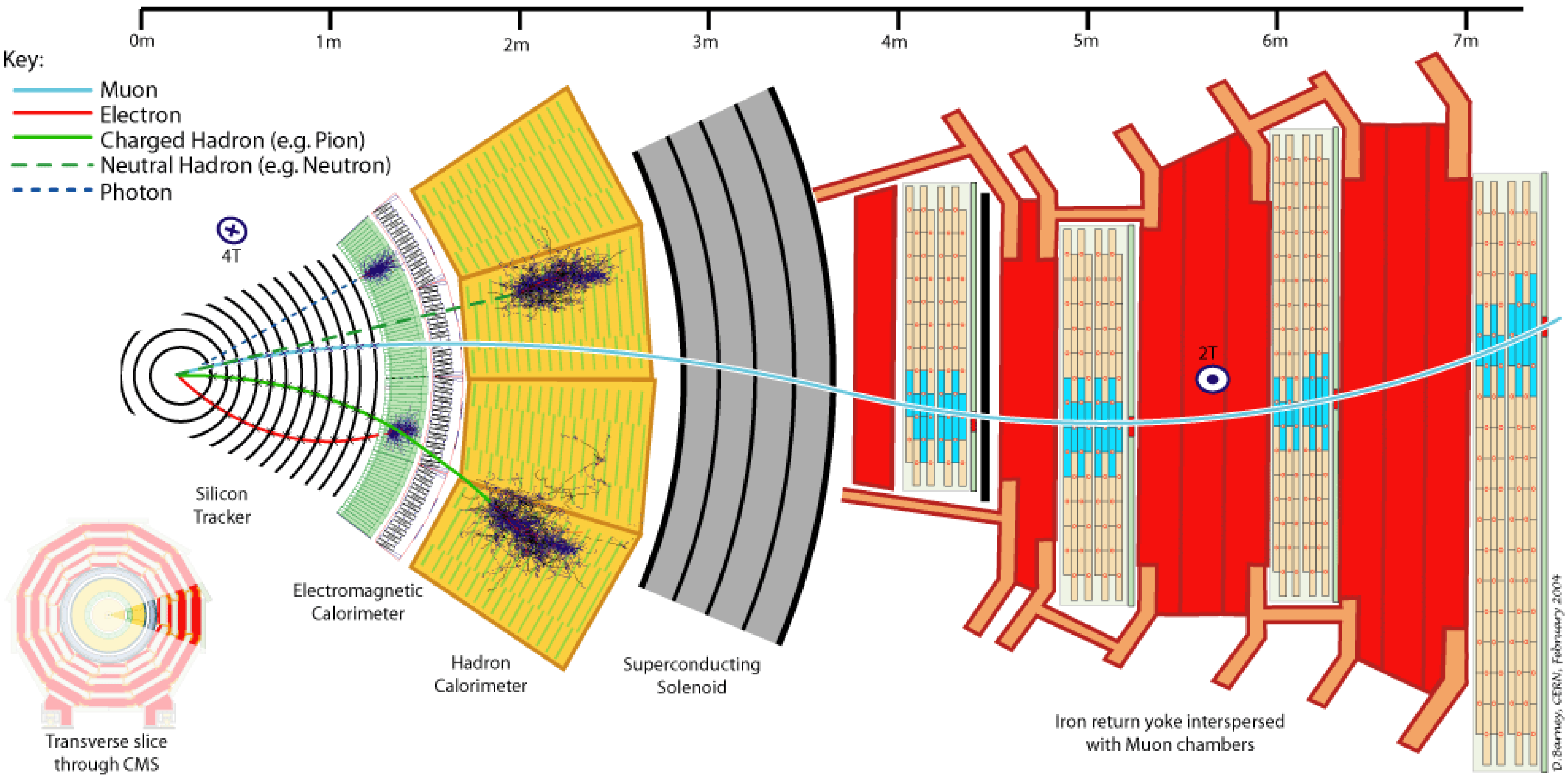
(in iron yoke: $|\eta| < 2.1$)

Fast cerenkov calor.

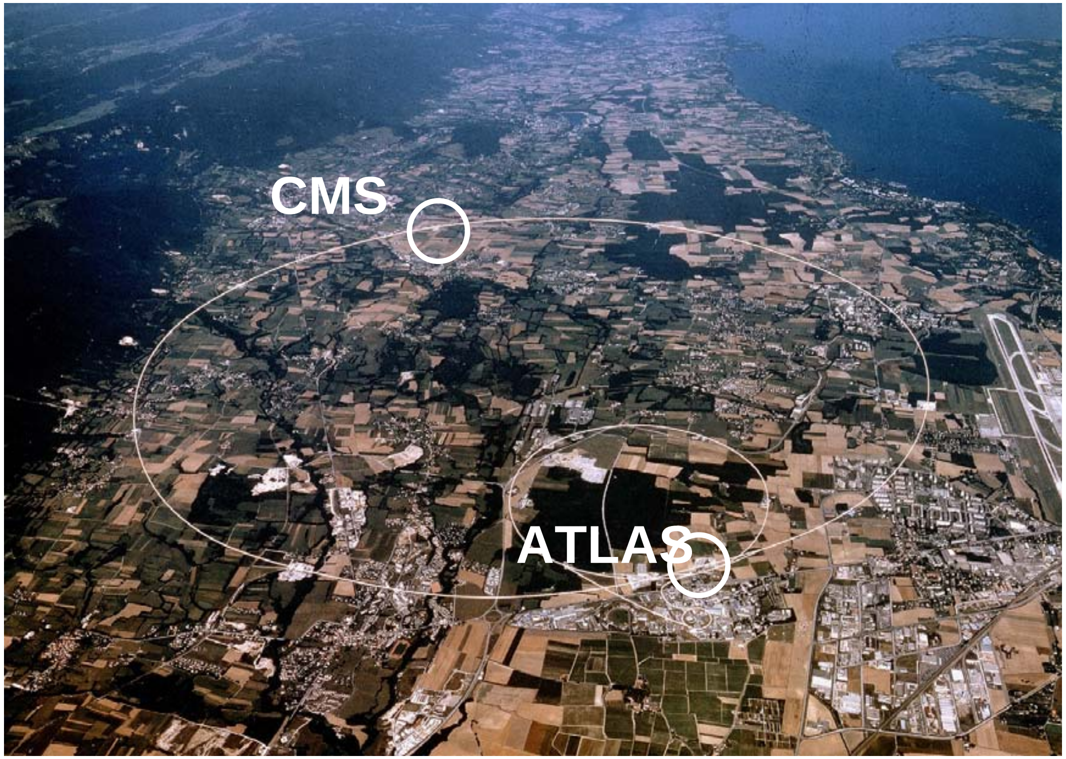
- **quartz fibber**

($3 < |\eta| < 5$)

The CMS detector



The LHC



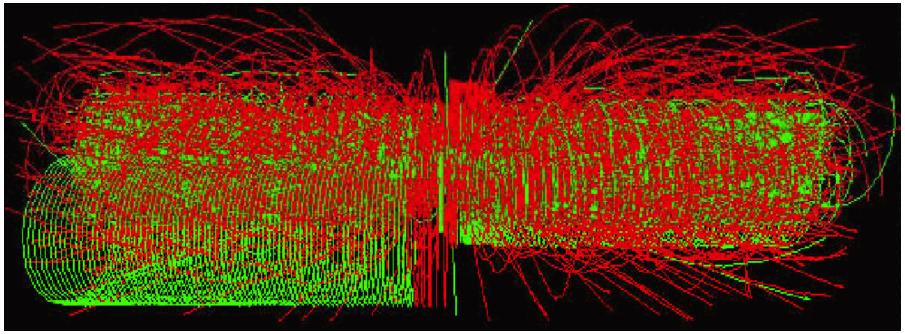
R = 4.5 Km
E = 7+7 TeV (pp)

crossing rate
=40MHz
(25nsec)

design luminosity
= $10^{34}cm^{-2}s^{-1}$

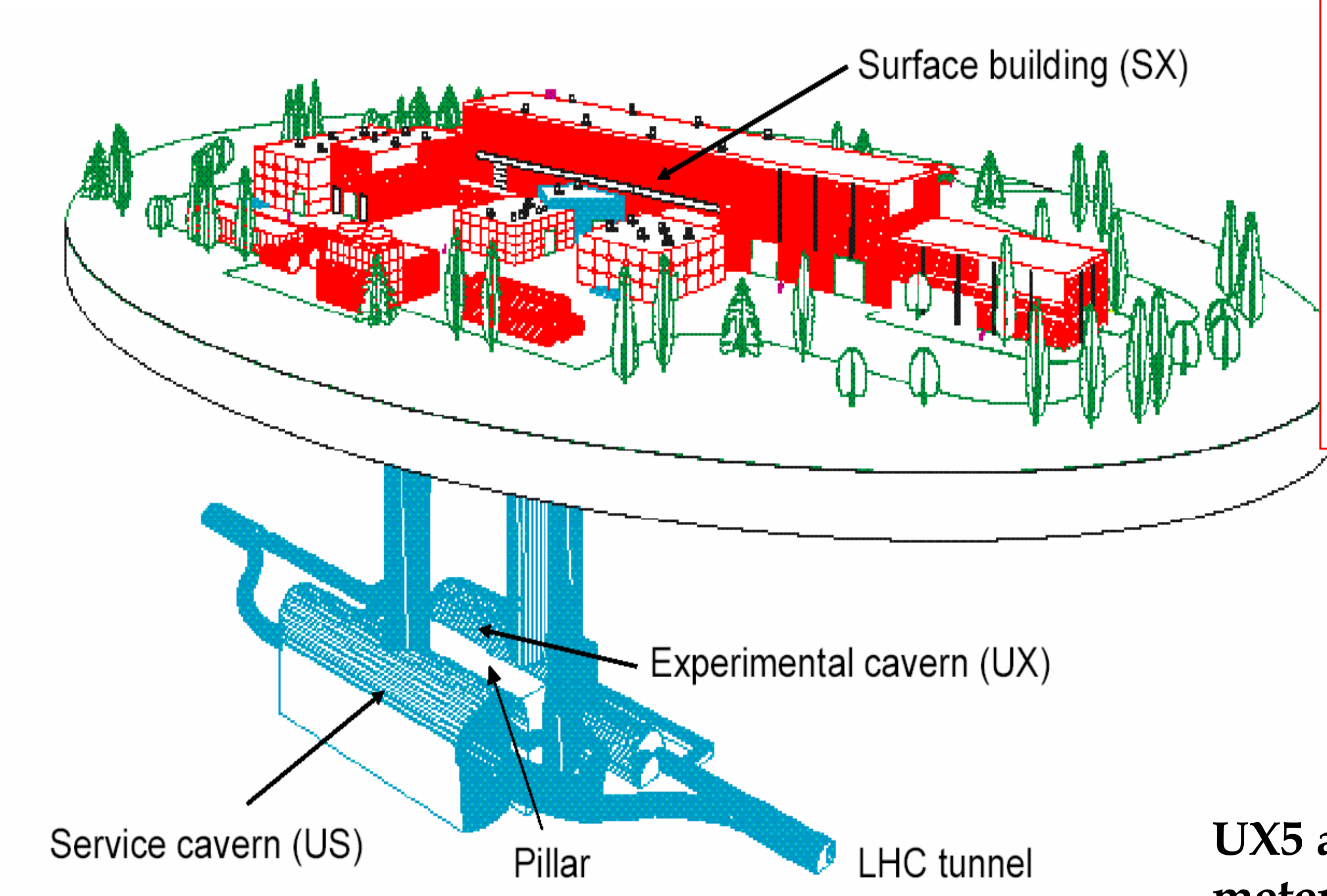
~20 pp interactions
per crossing
at design luminosity

First collision in 2008



h → 4 μ with 20 min. bias evt.

CMS at Cessy, France
(LHC Point 5)



Major assembly of the CMS detector was done in the surface building,
…
in parallel to construction of underground experimental hall.

UX5 about 100 meters underground

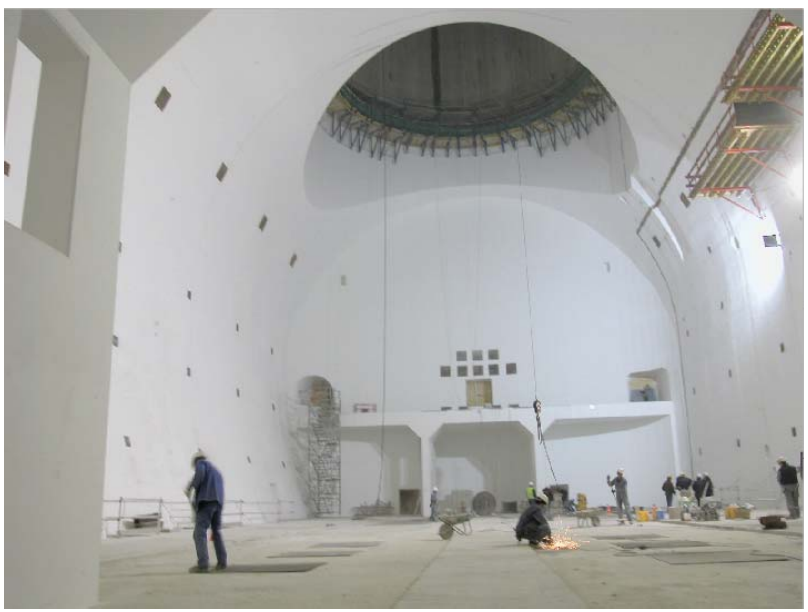
Surface buildings and main shaft

My slide from 2003

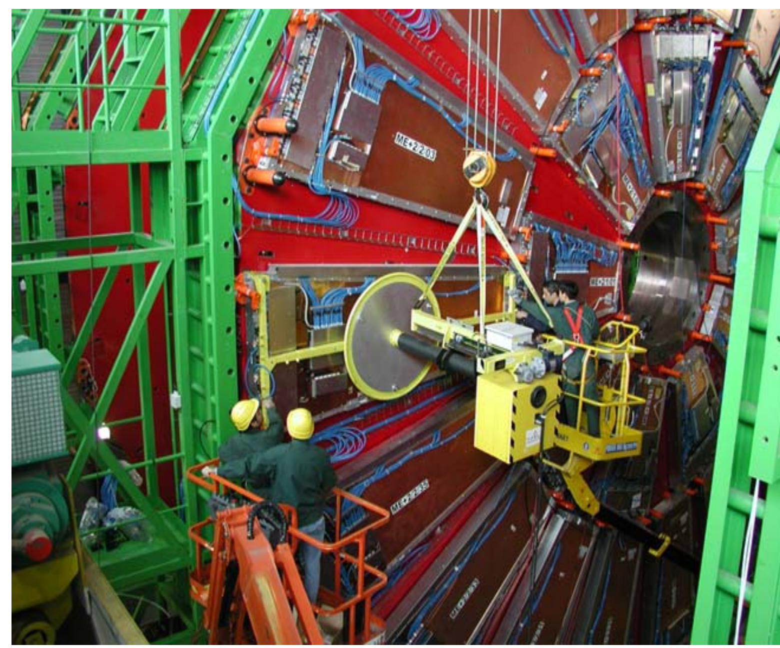
Installation of the first muon chamber

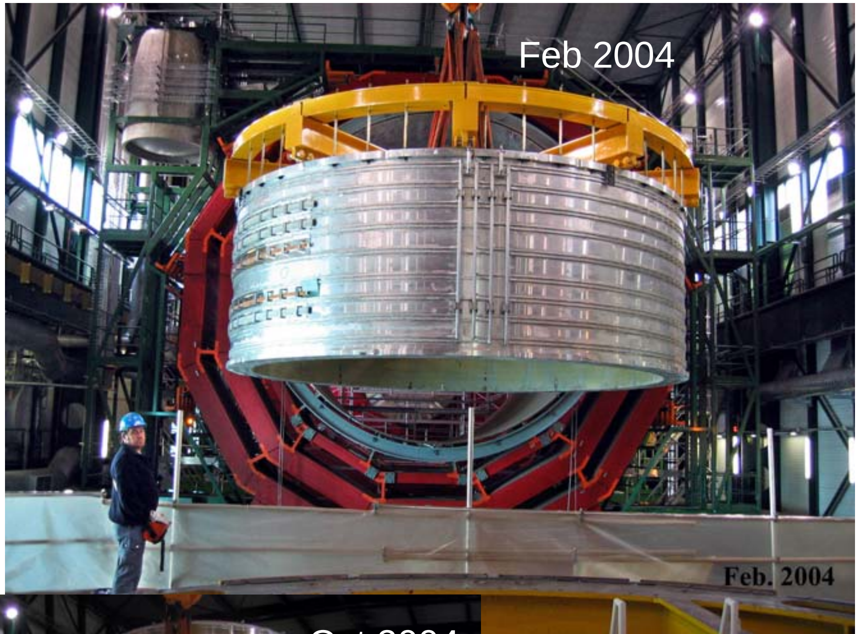
My slide from 2003

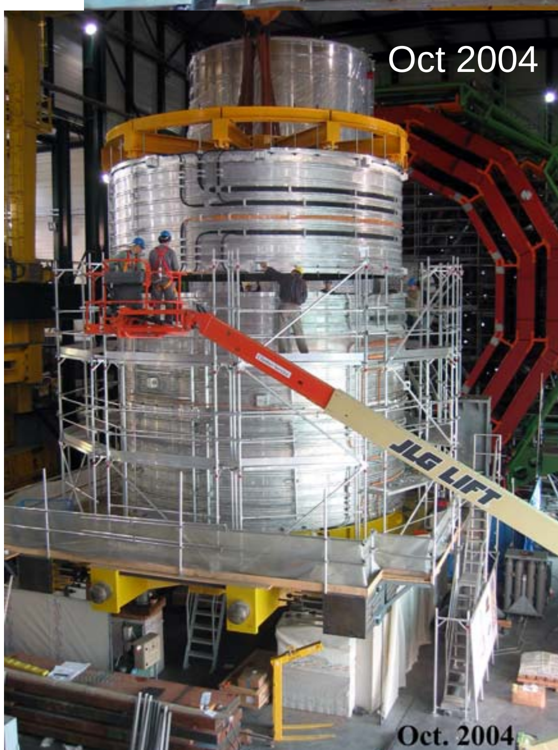
2005: Underground Cavern



2005: Muon Barrel (DT) and Endcap (CSC)







Superconducting Solenoid

Coil Insertion

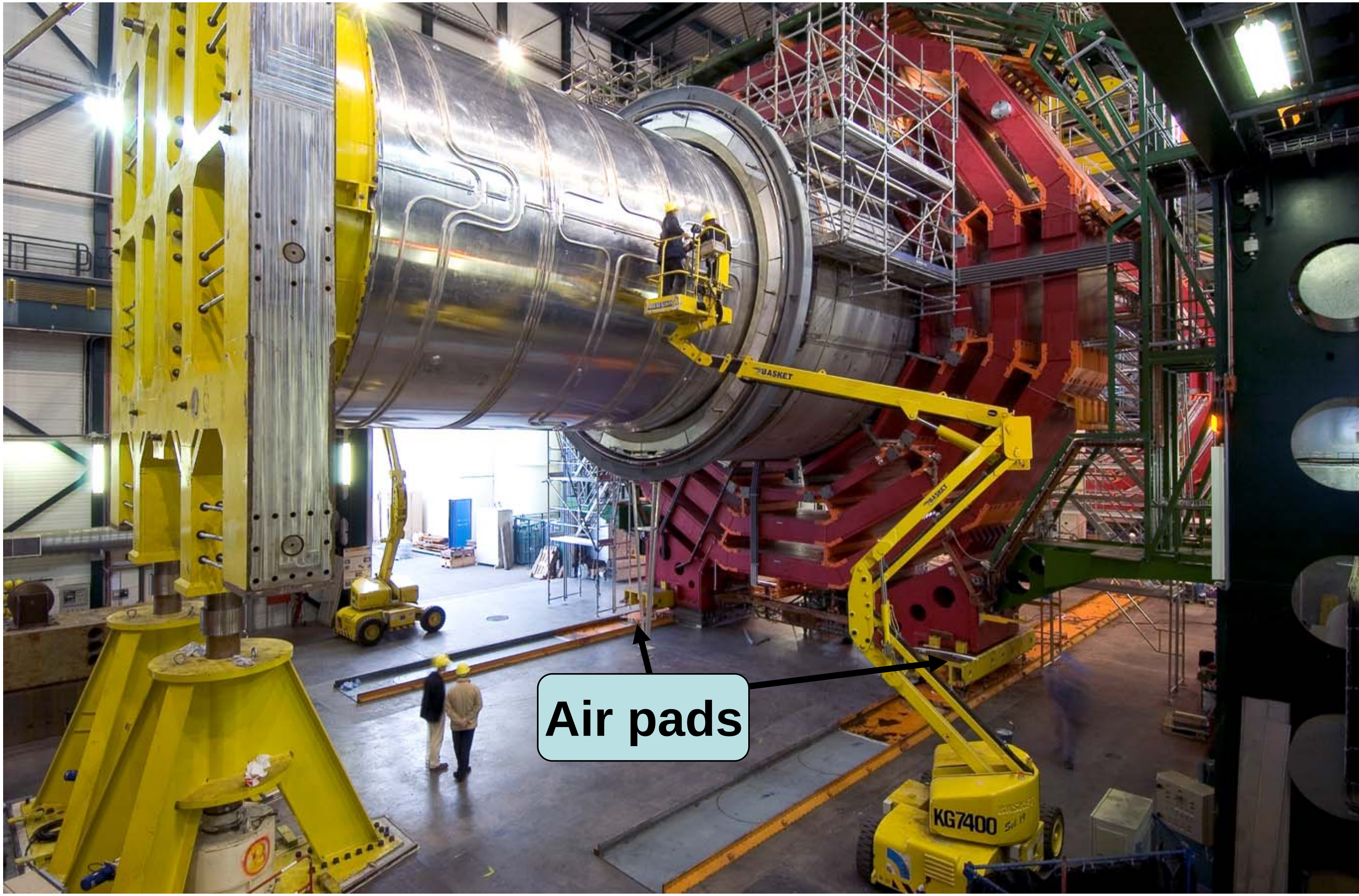
August 2005

The 220 ton cold mass was rotated in 15 min in the surface building.

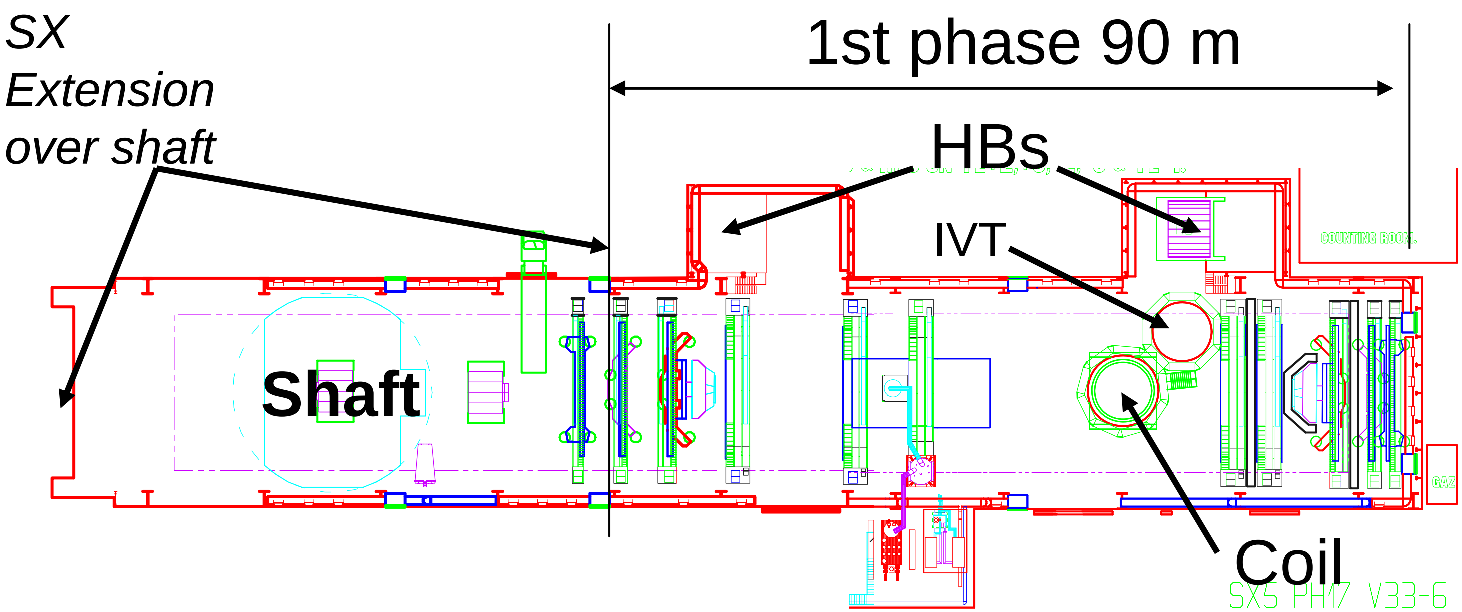
Moving YB0 with vac tank over the coil.

Ready to insert.

Inner VacTank/Screen Insertion in Sept 2005
These operations require a free length of 30 m min.



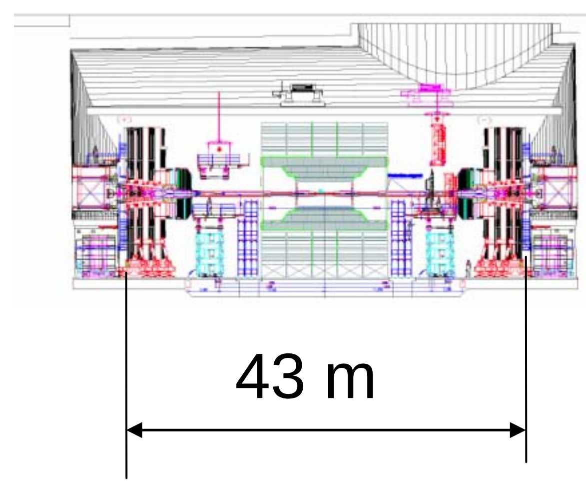
Coil swiveling in Surface Hall August 05



CMS Surface Assembly (A. Herve)

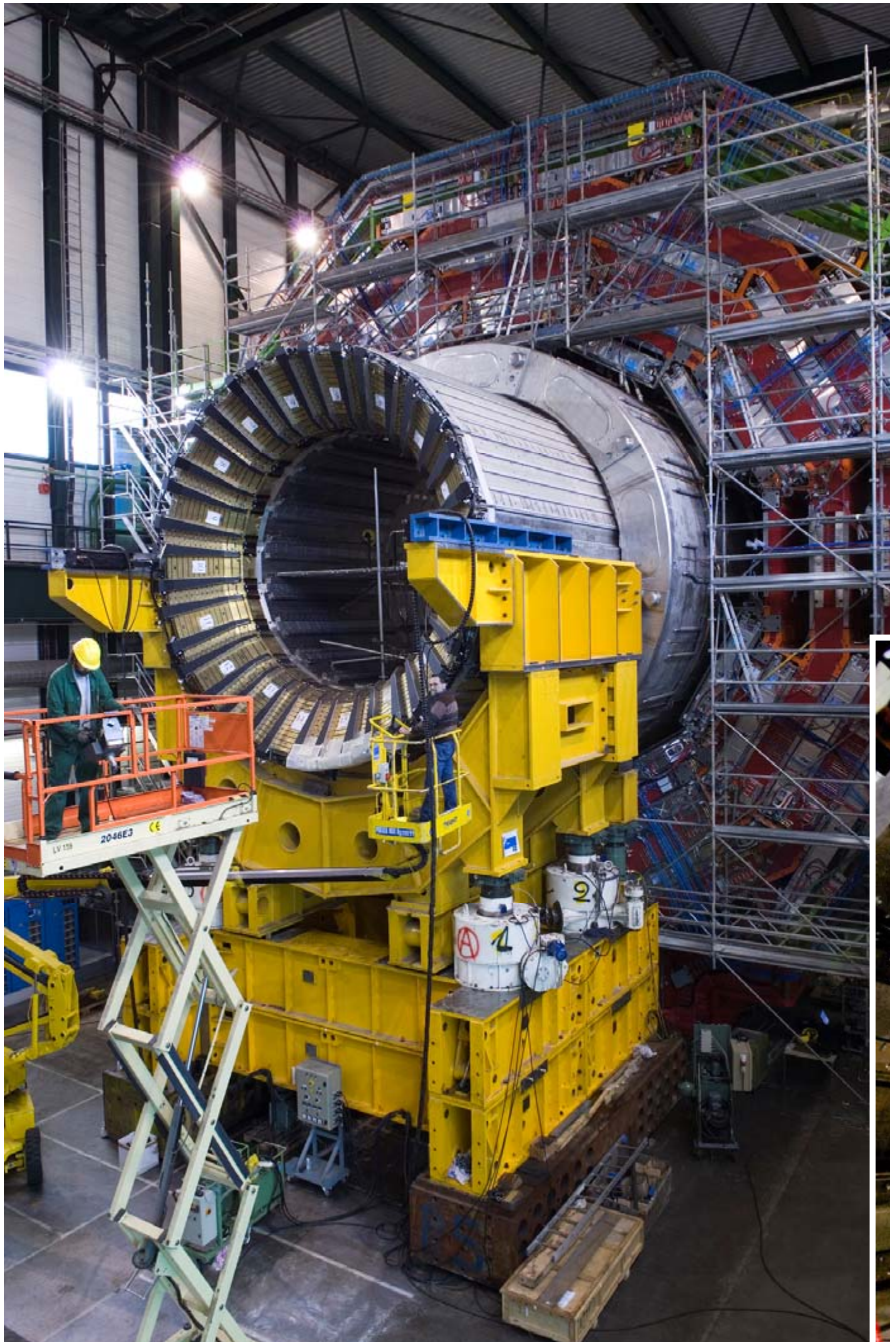
- These heavy construction activities cannot be done in a reasonable time, safely, in the underground hall.

- A much longer and wider underground hall, equipped with two 80-ton cranes, would be needed, and more time….



Same scale!

Underground hall Detector fully open

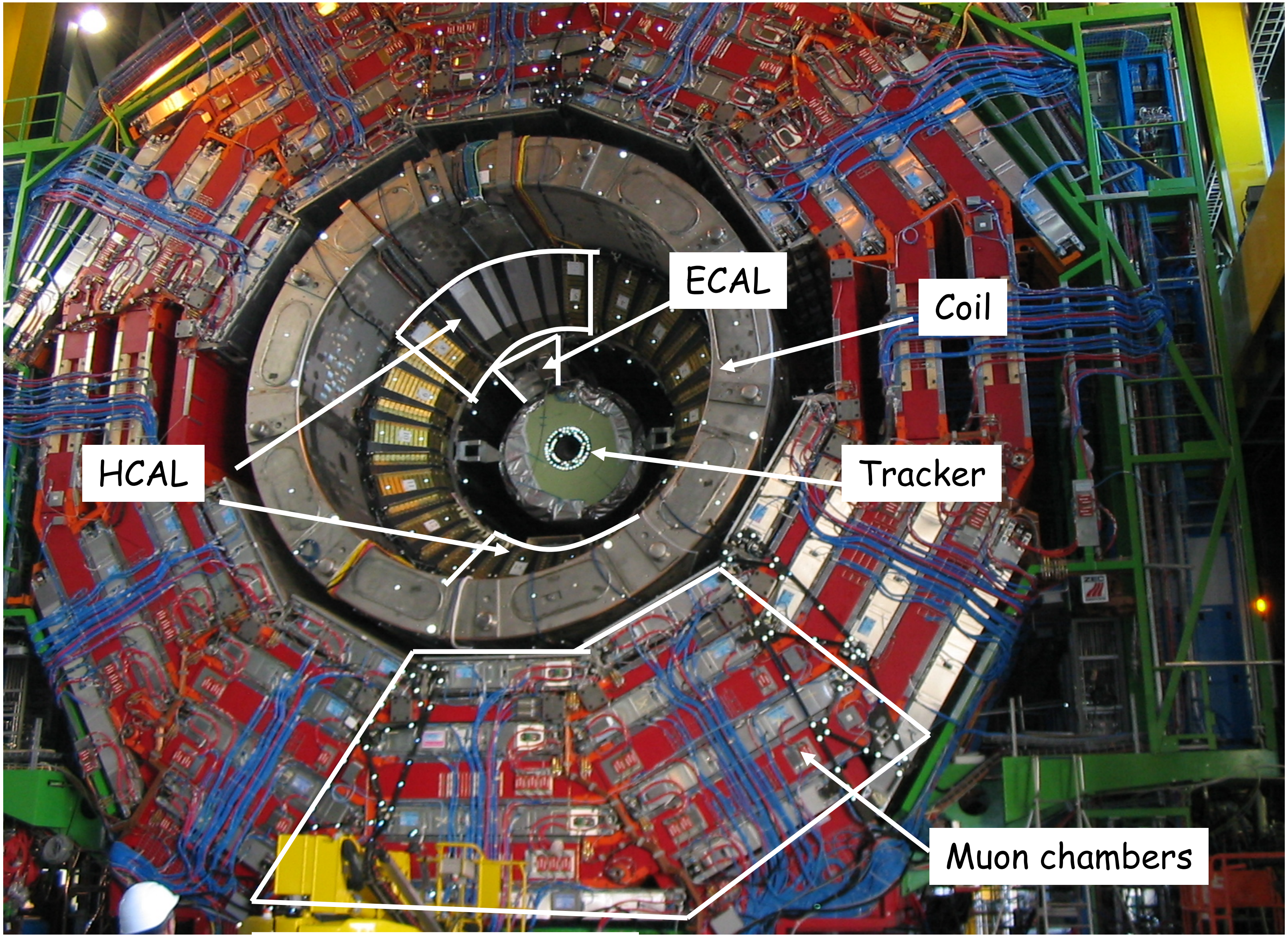


HCAL Barrel (HB) Insertion into the Magnet

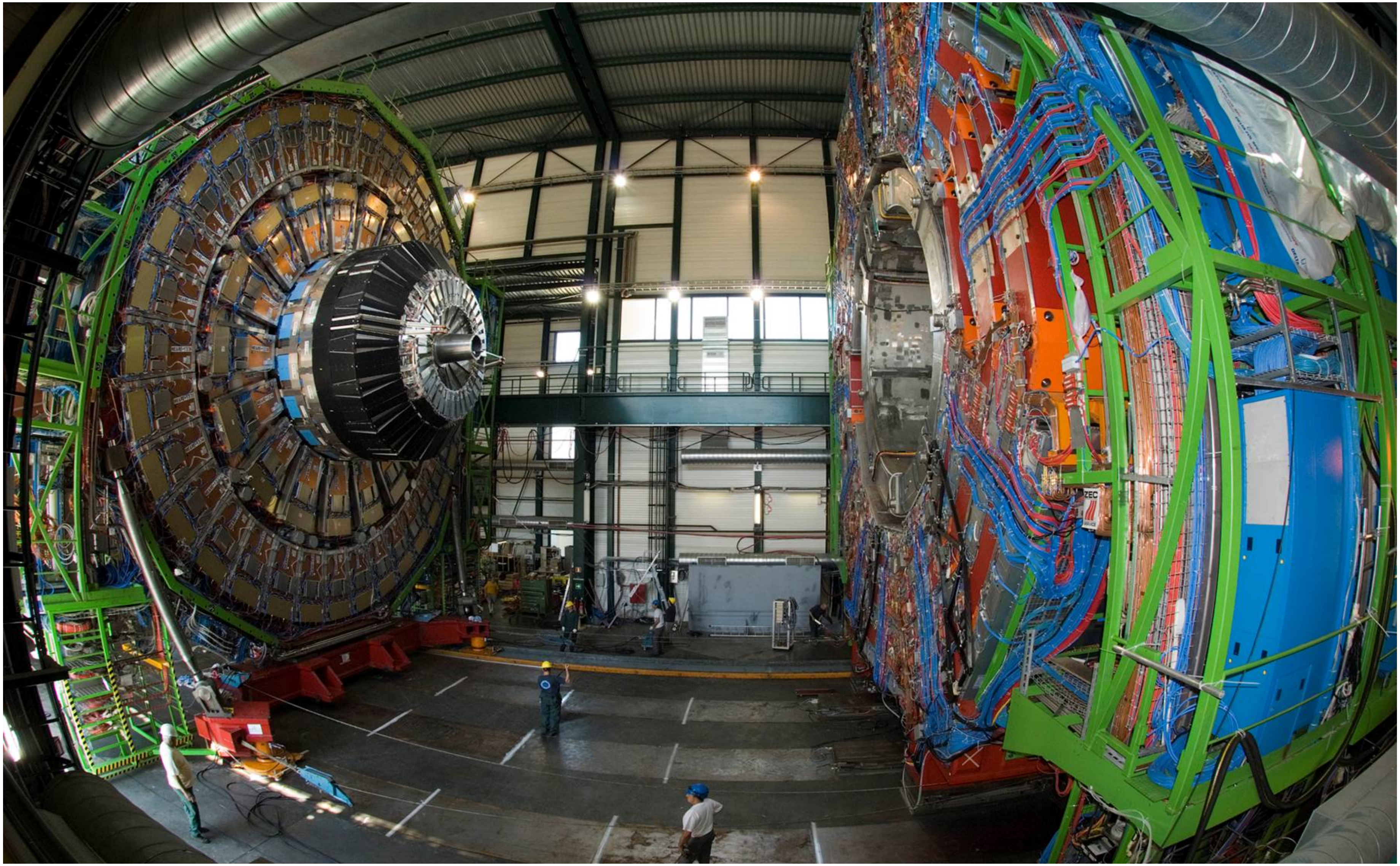
Two ECAL (EB) modules in HB

Barrel Ready for Cosmic Muon Runs

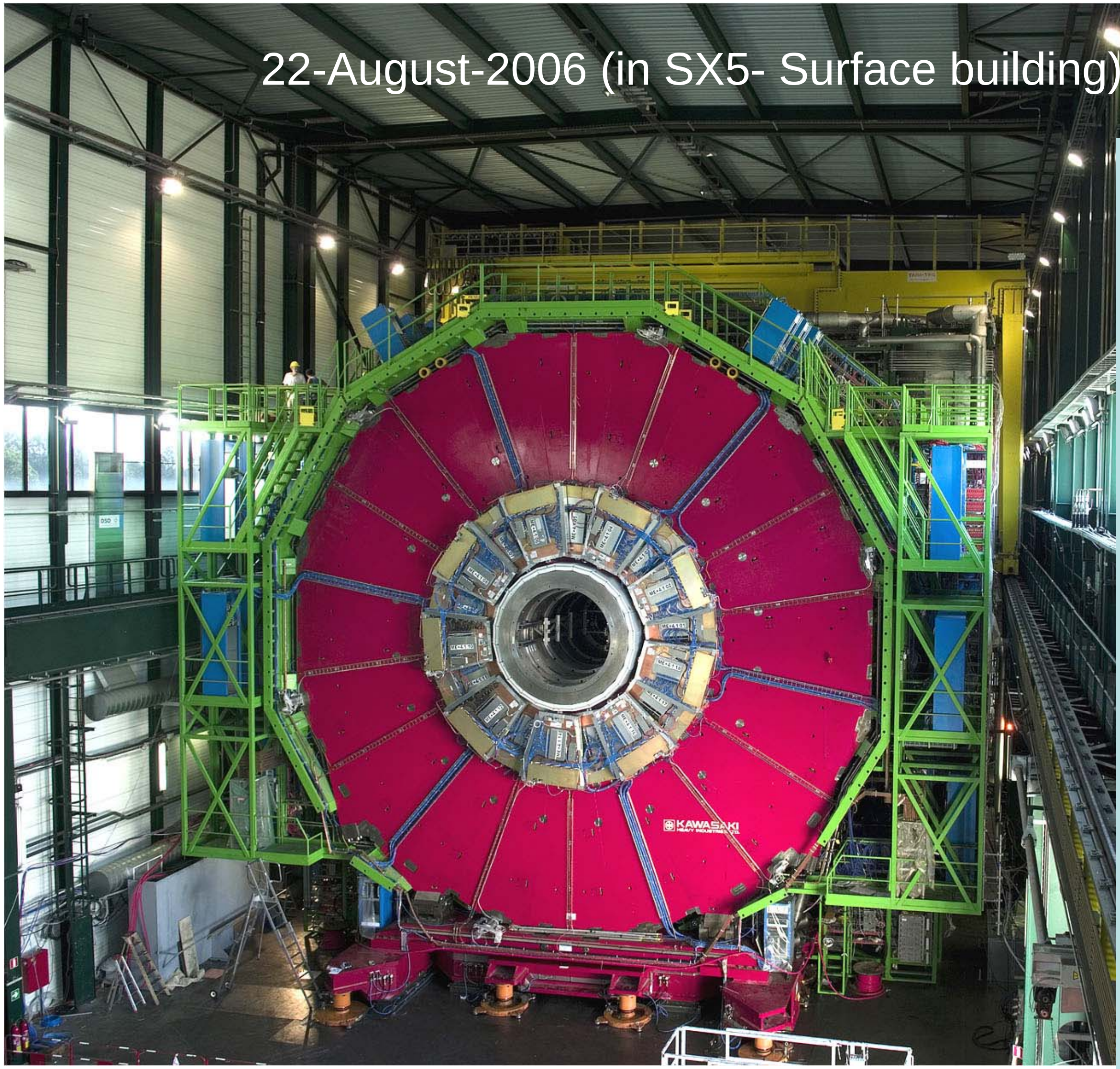
summer 2006



Endcap also ready for cosmic runs



CMS Detector – closed and reached 4T



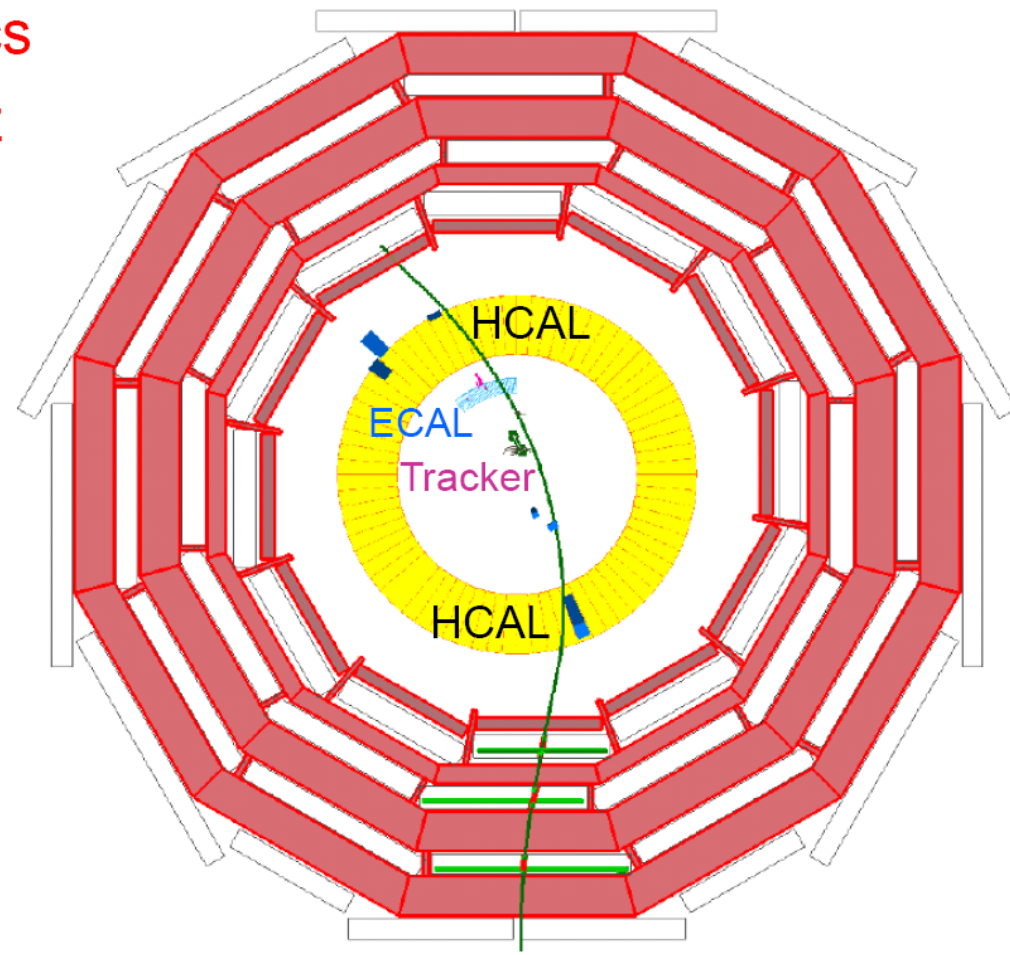
- Experiment closed first time
- Magnet commissioning and field mapping
- Combined operation of full chain: Detector – Electronics – DAQ – Trigger – Software
- Establish timing, calibration, operation procedures

→ MTCC 2006

Magnet Test and Cosmic Challenge

MTCC: Detectors synchronized and read-out!

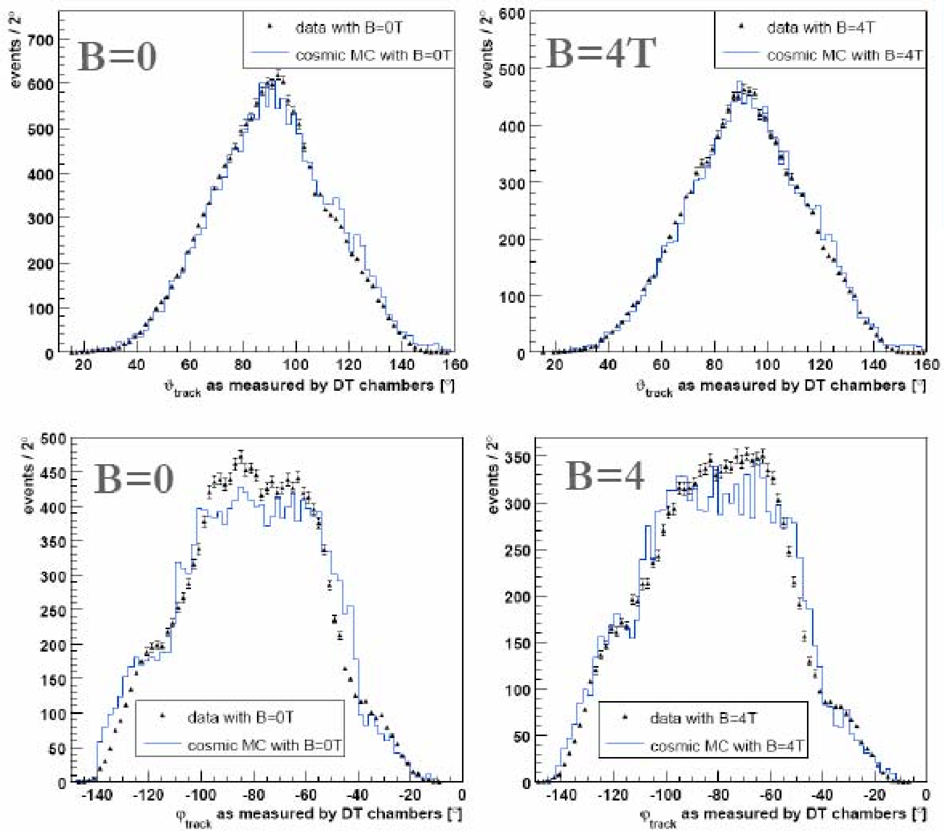
- Recorded ~200M cosmics
- Trigger rate up to 200 Hz
- Data very useful to measure detector performance, validate detector simulation and reconstruction algos, study noise
  - In fact it is still a treasure trove



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

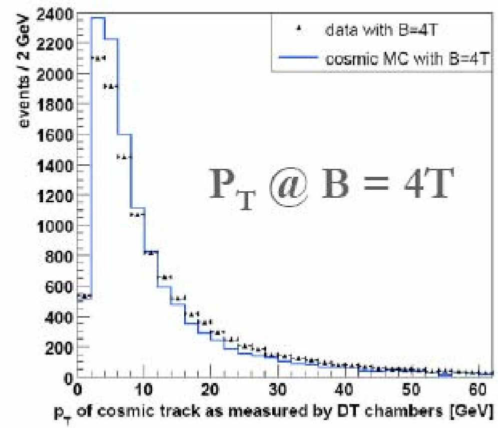
Cosmic Muons in MTCC

Track parameters are compared to Cosmic Muon MC:



←Very good match for θ (top).

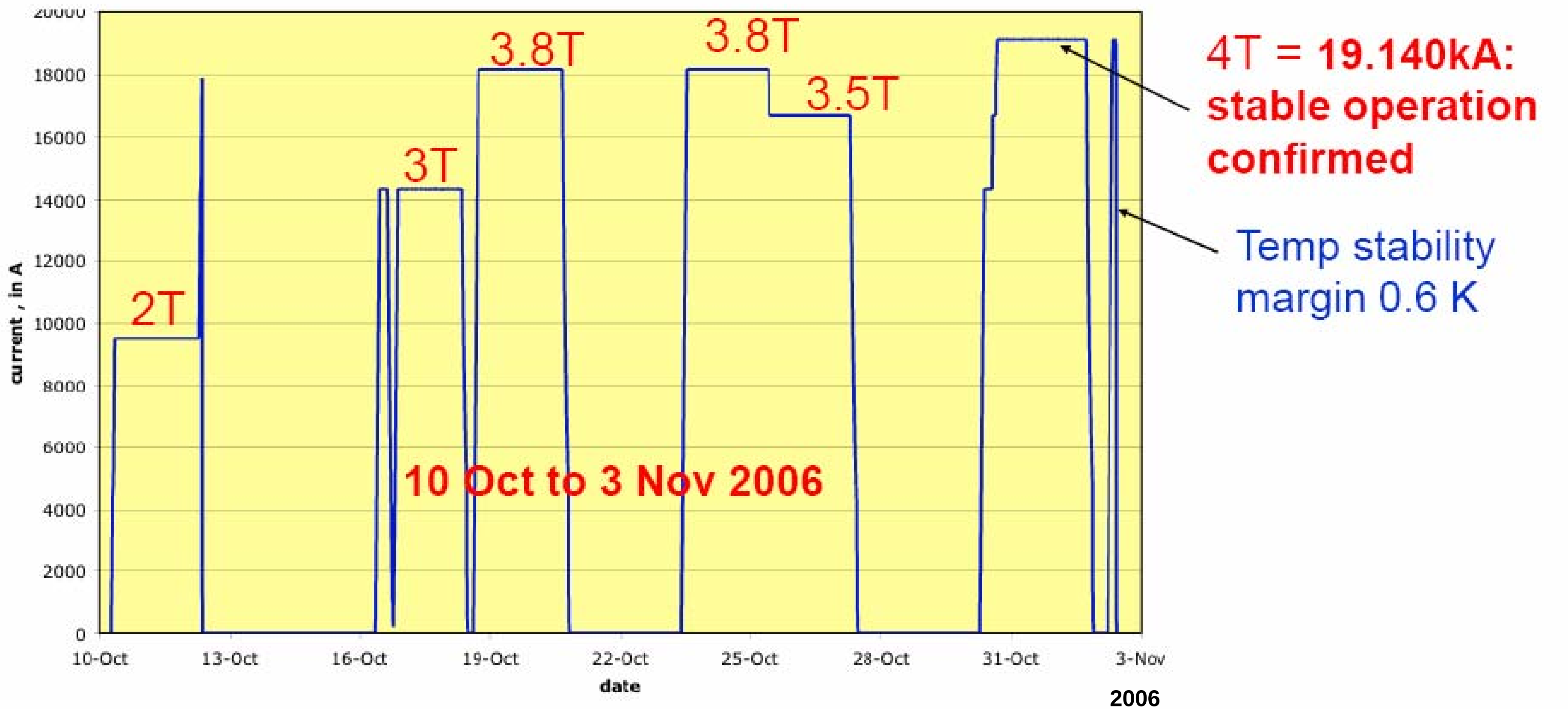
ϕ (bottom) is reasonably described by MC,



Transverse Momentum is also in reasonable agreement

Almost every aspect of final CMS from detector to off line software has to work to produce these plots

Operation of Magnet and Field Mapping



Field mapped at: 2.0, 3.0, 3.5, 3.8(twice) & 4.0 T with 0T references.
statistical precision of 10^{-4} achieved

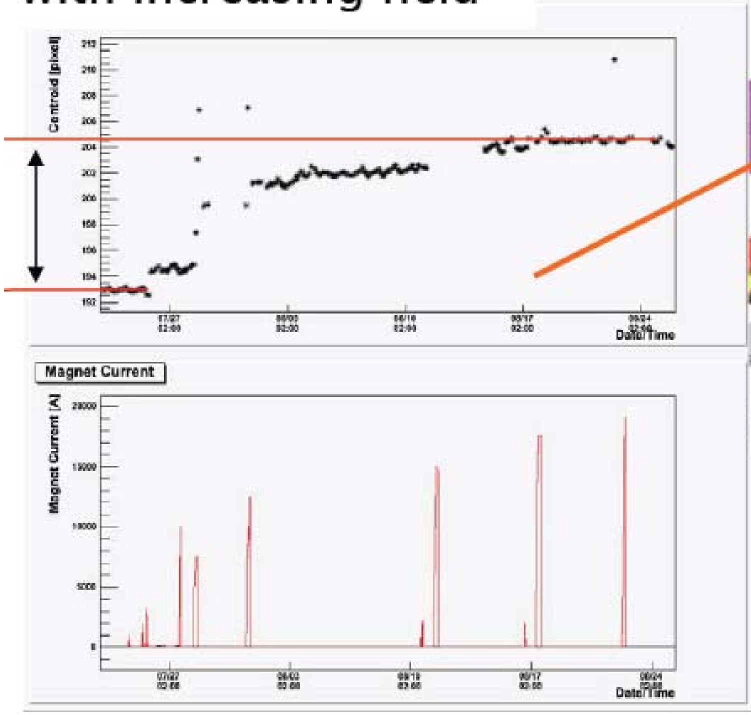
4T reached on 22/8/06

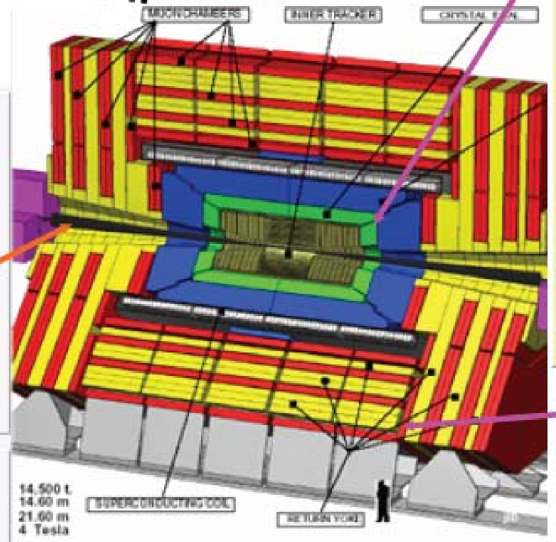
The detector deforms due to the magnetic forces

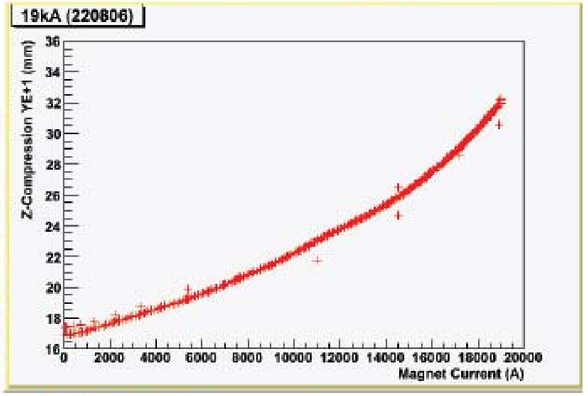
YB wheels steady compression with increasing field

~ 2.7 mm YB2 towards IP

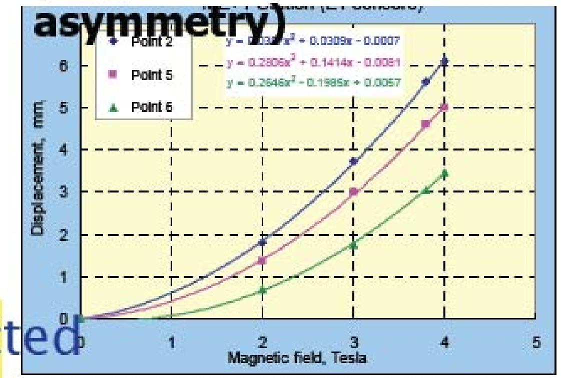
YE1 Nose moves in by 16 mm







YE1 Outer rim moves out by ~6 mm (top/bottom asymmetry)



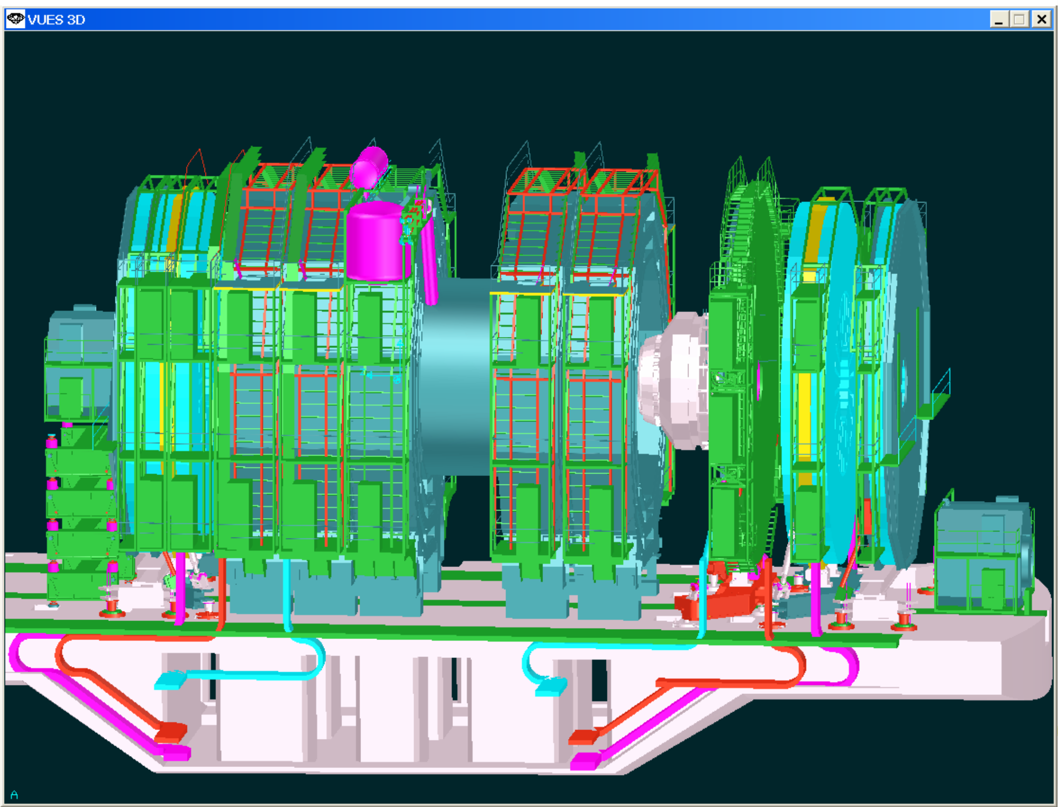
Preliminary

Yoke movements approximately as predicted

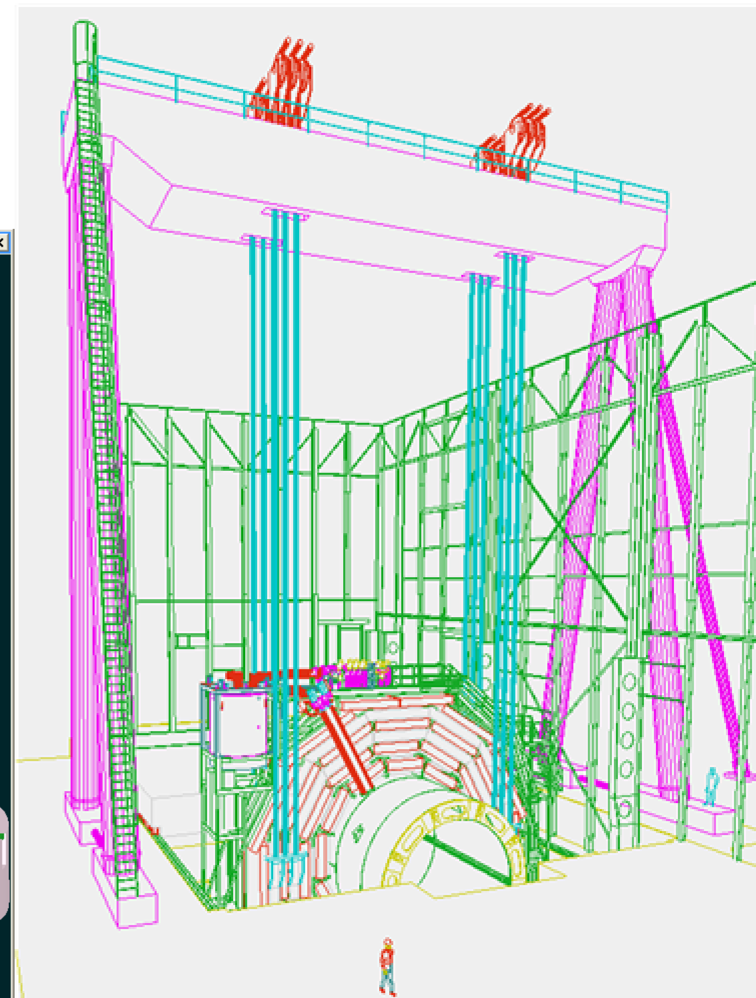
Lowering detector to underground

15 heavy objects (350-2000tons)

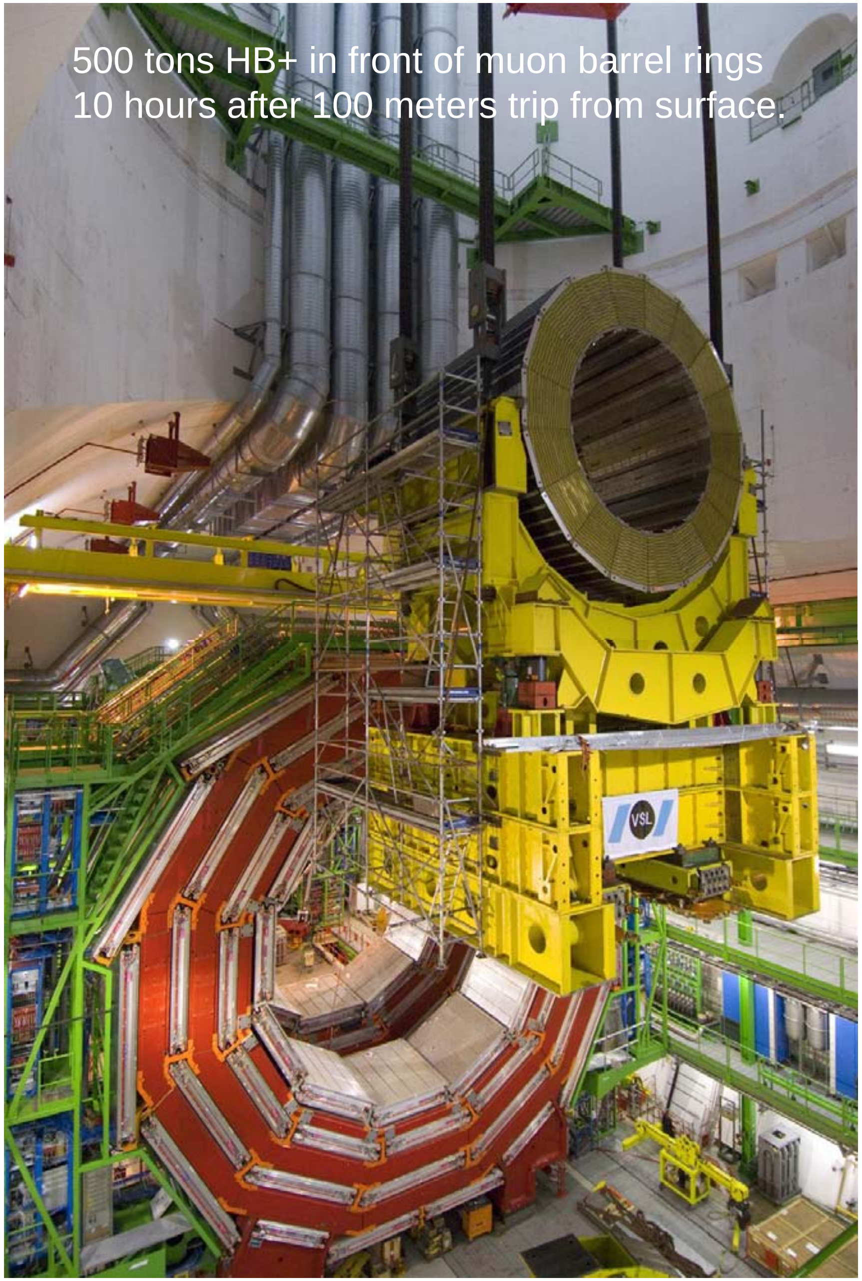
5 barrel rings
3+3 endcap disks
1+1 HB+/HB-
1+1 HF+/HF- ← First one Nov.2006



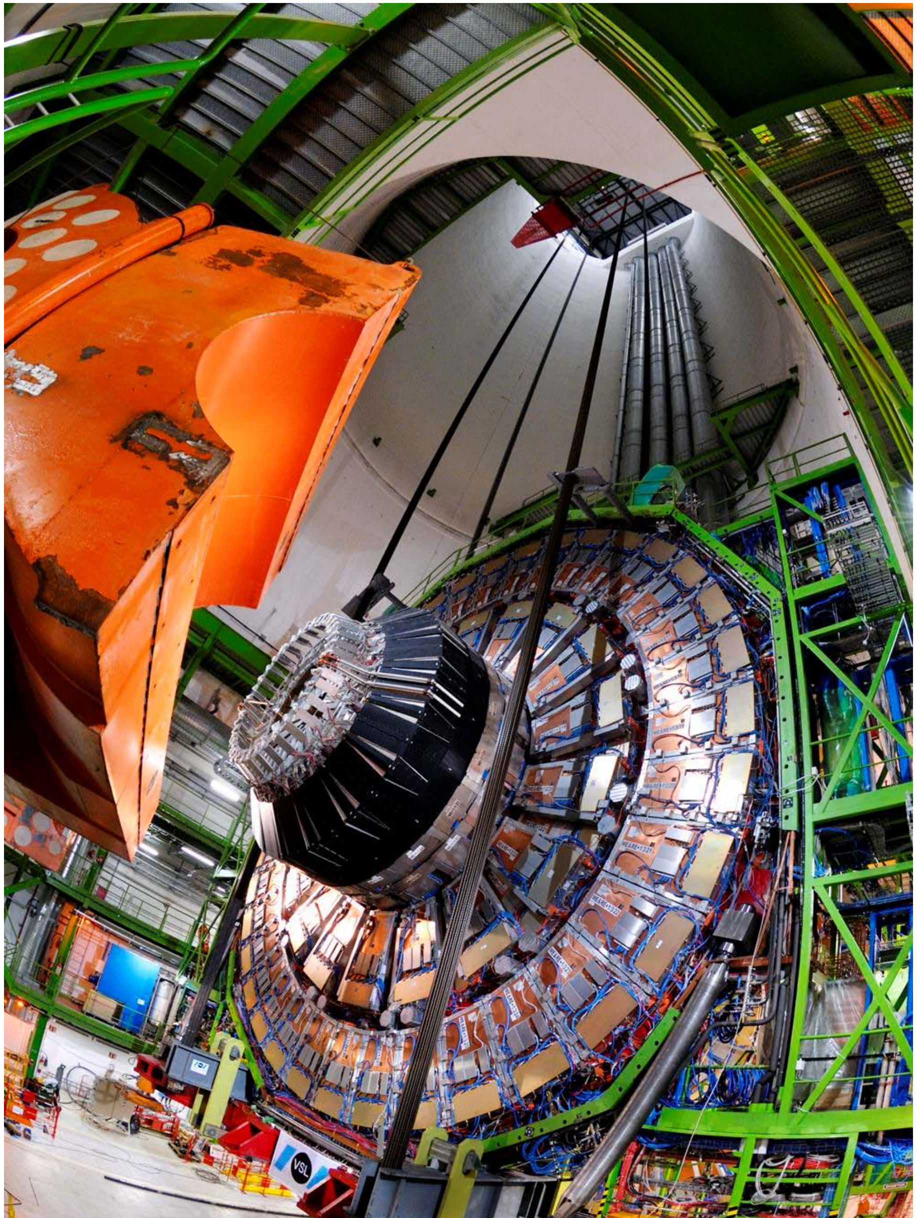
2000 ton crane

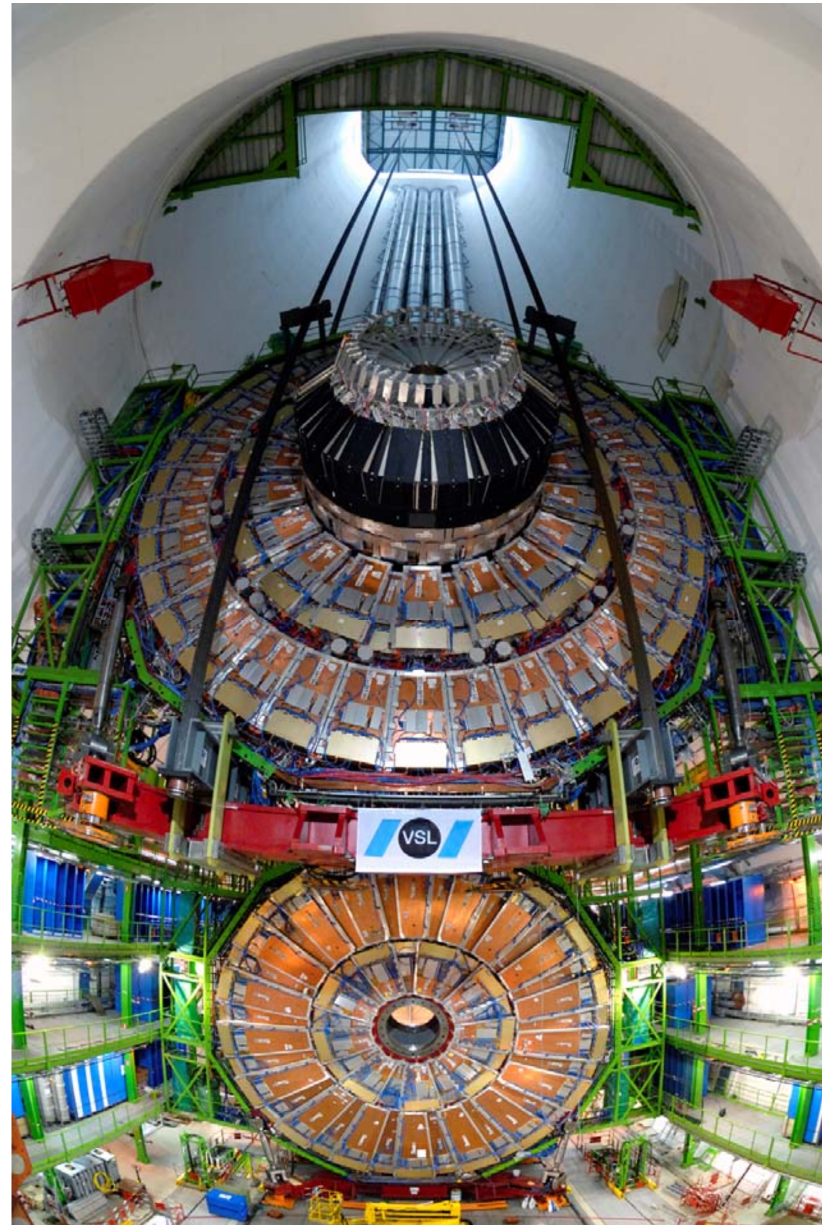


350 tons HF+ – First detector descended. (Nov 2006)

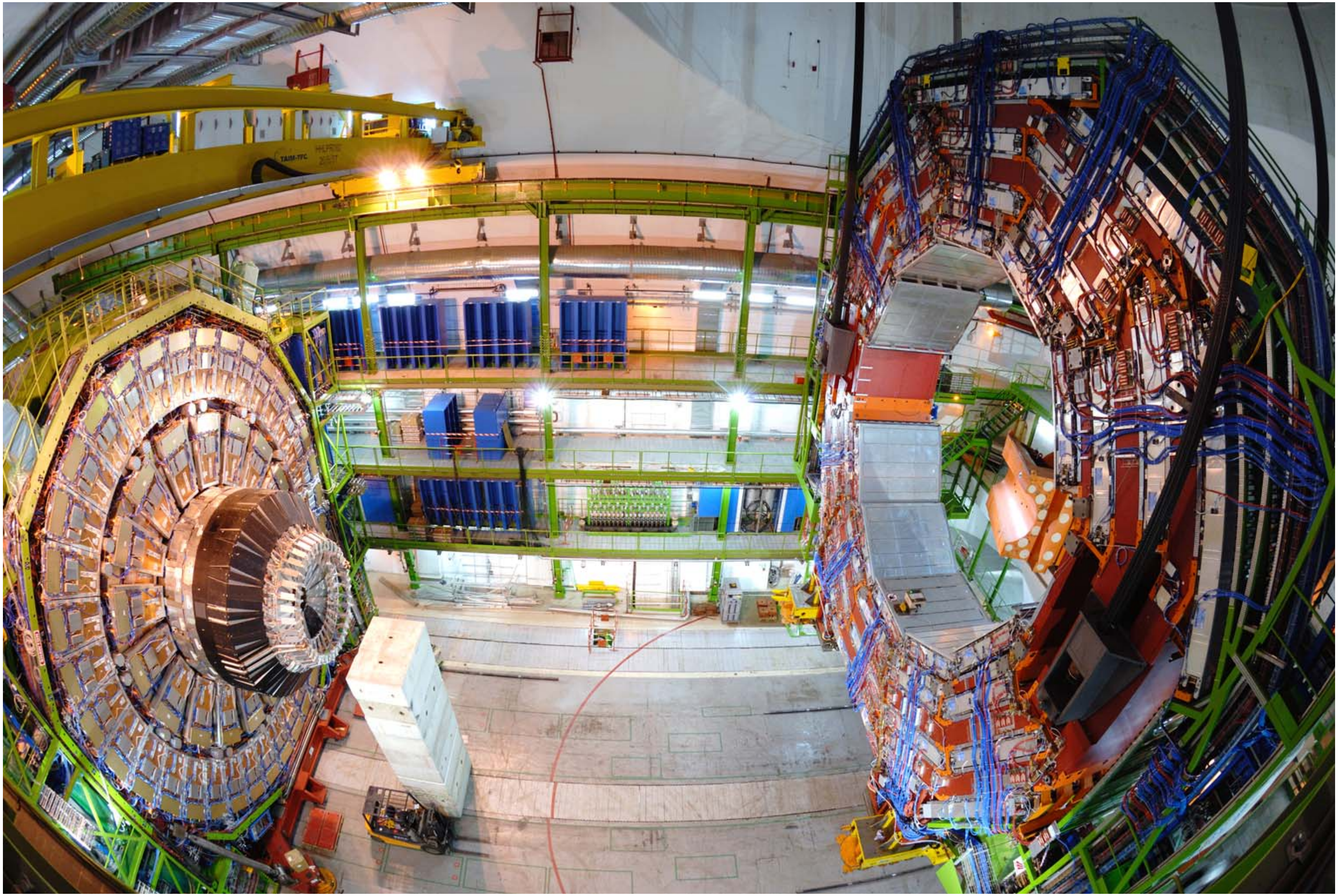


Commissioned YE+1 (endcap muon) with HE 9-Jan-07

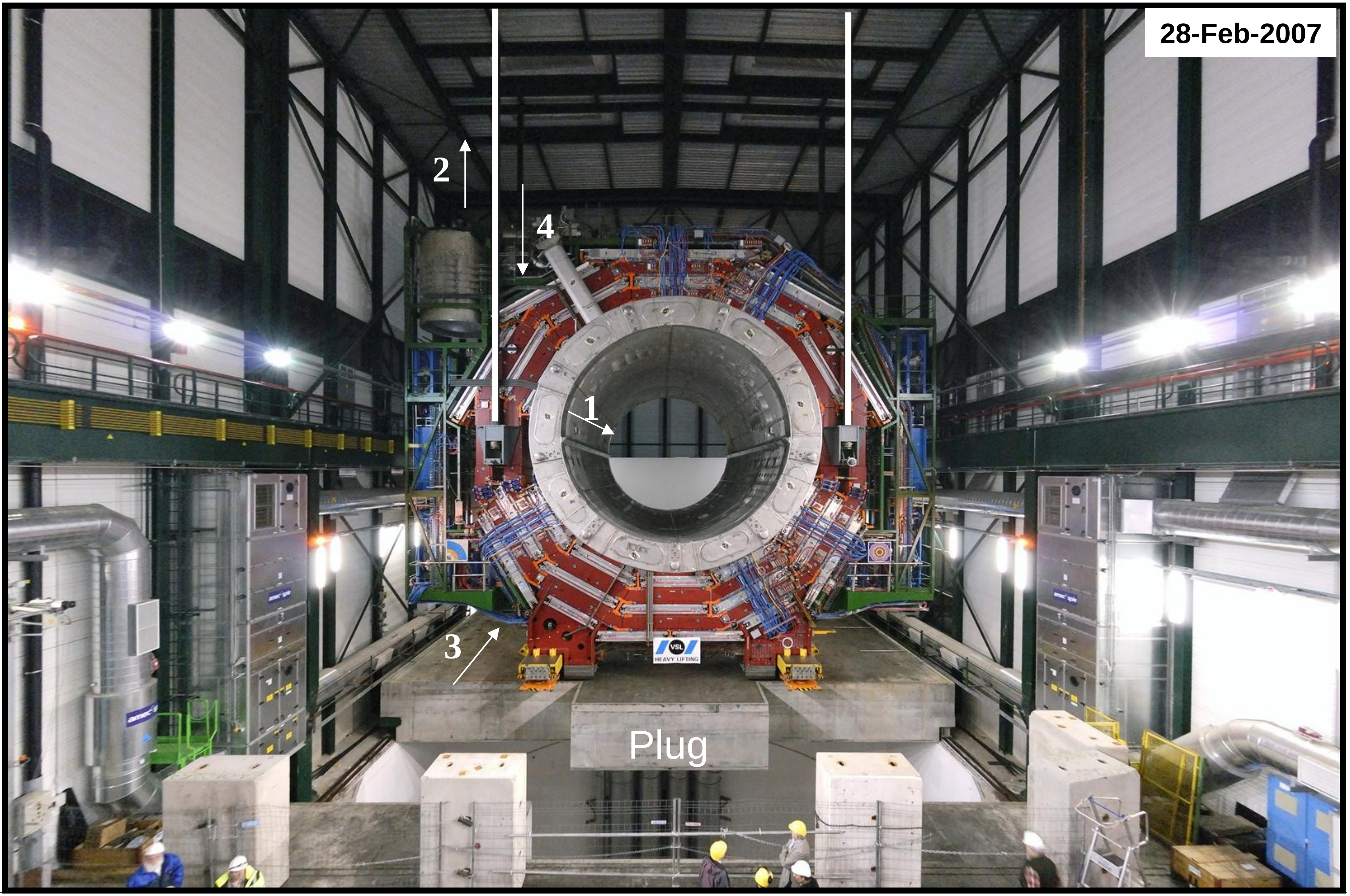


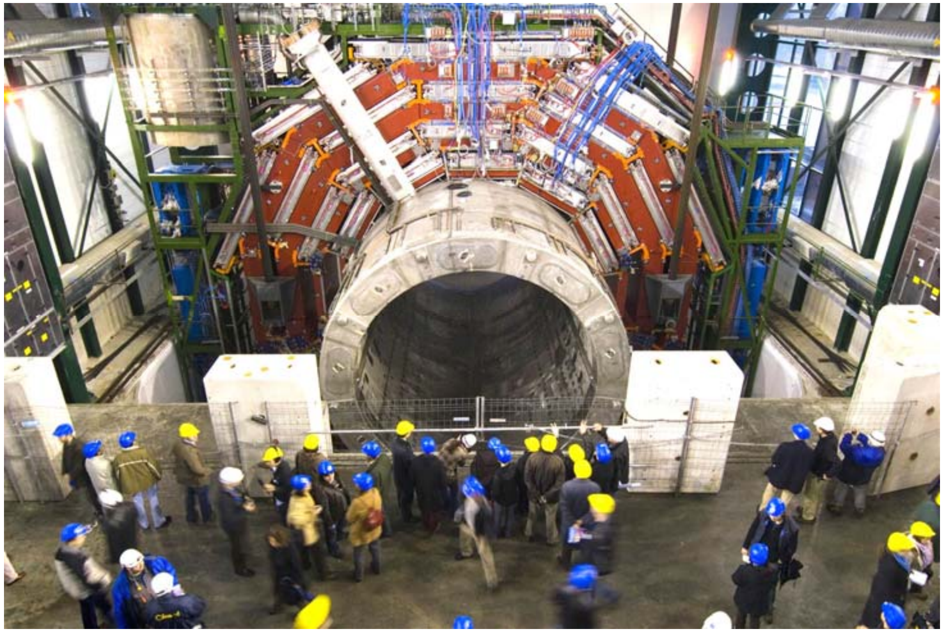


First Barrel Muon Ring YB+2 lowered   19-Jan-2007



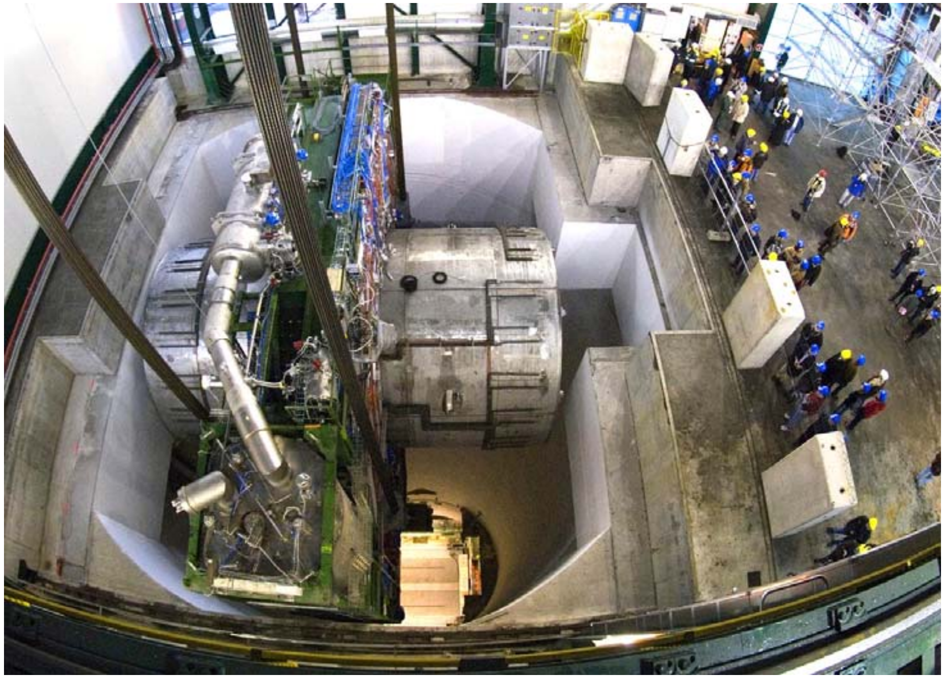
Opening plug under 2000-ton load



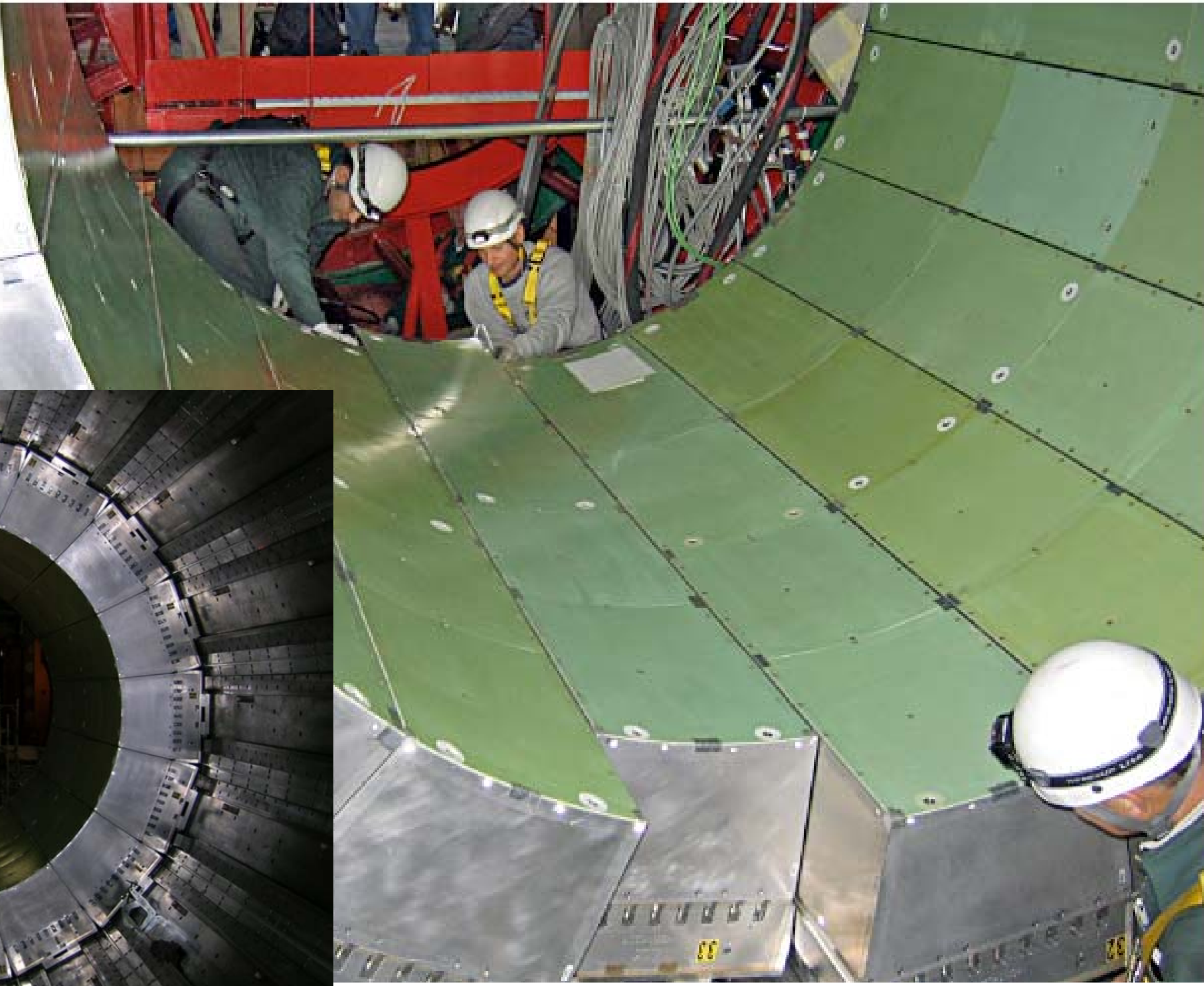


2000-ton YB0's 100 meter trip

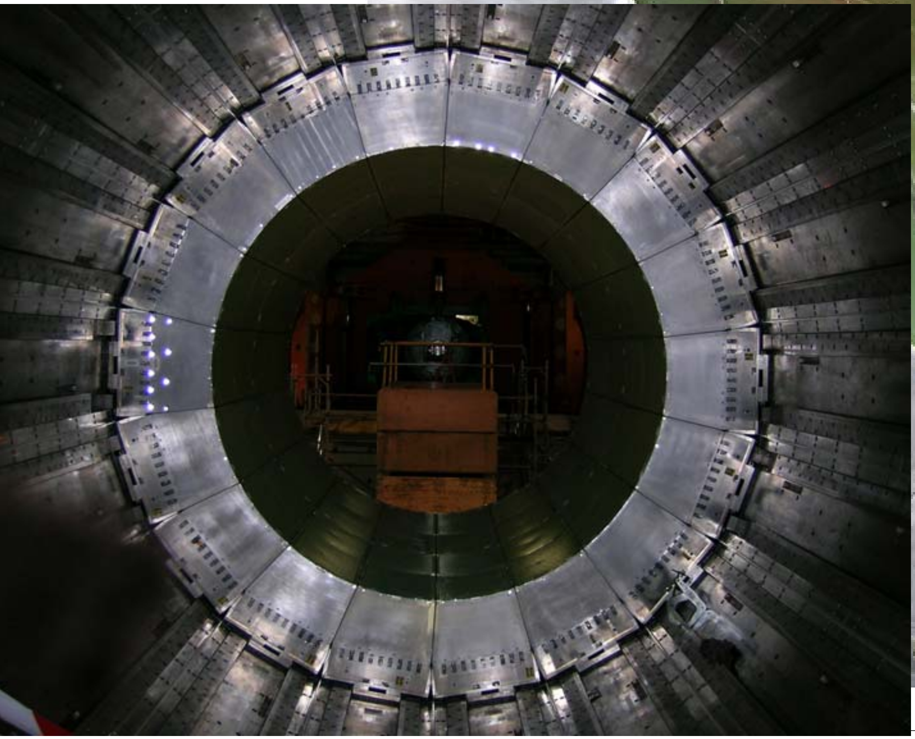
28-Feb-2007



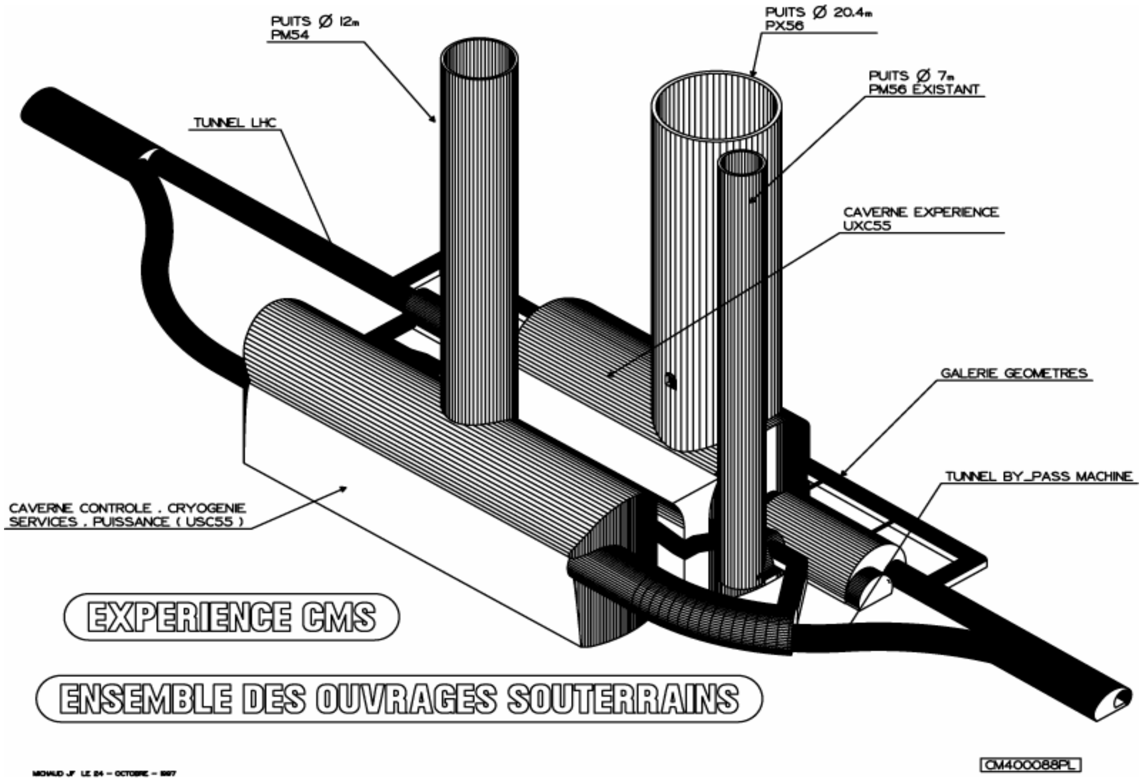
EB- Installation Completed



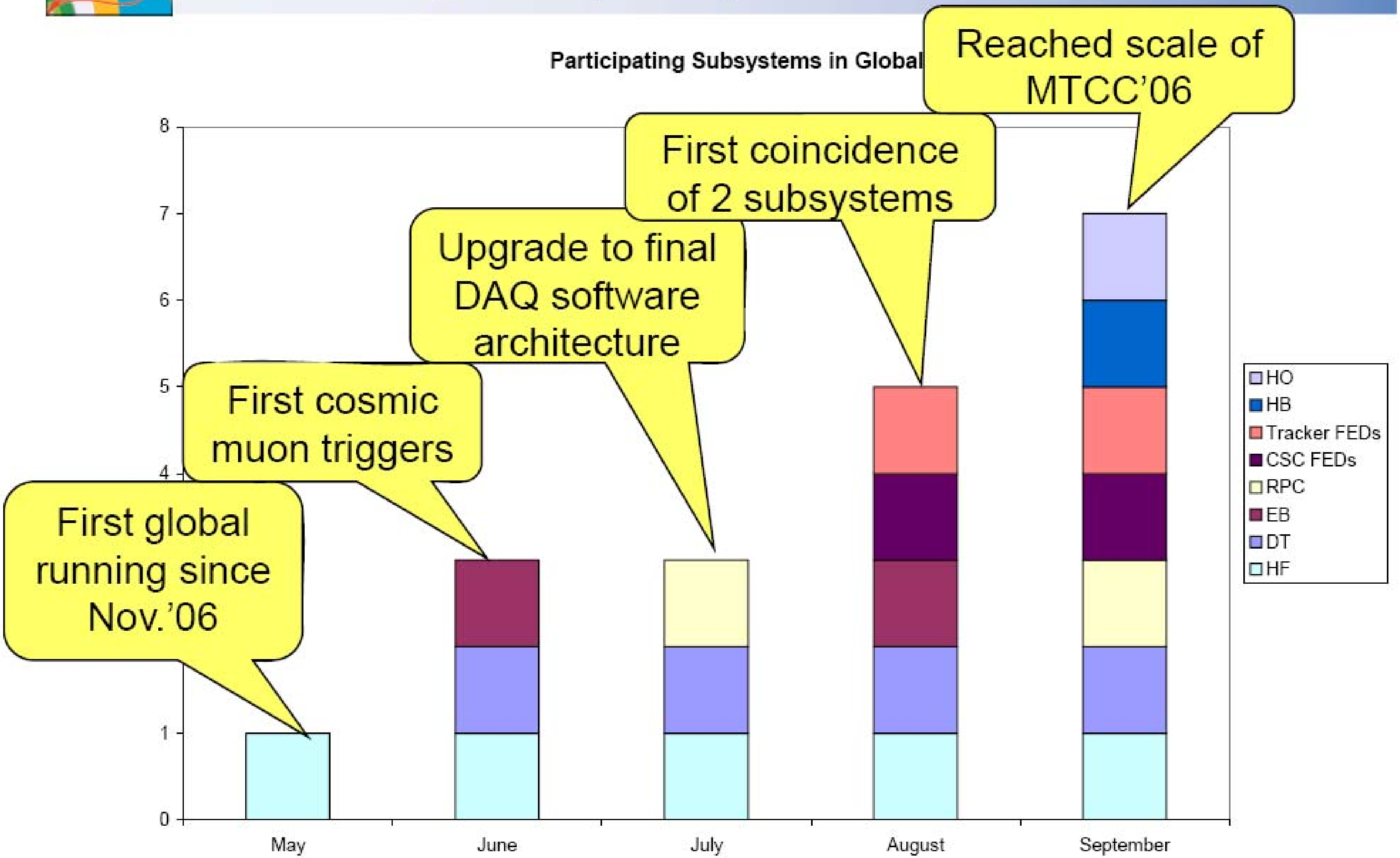
27-July-2007



Commissioning in UX5 -underground-



Increasing Complexity of the 2007 Global Runs



Snapshots from September Global Run

A little crowded in the underground control room, since systems are still expert driven

(Surface control room ready Jan'08)

But good camaraderie as run operations begin to take shape

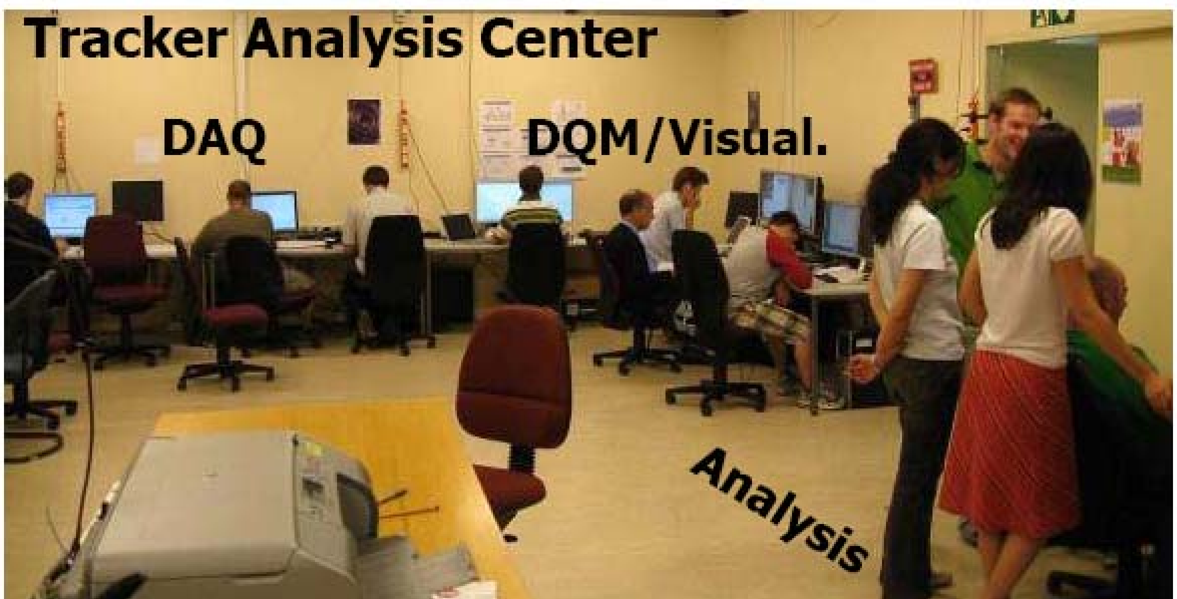
CMS Tracker Integration Facility

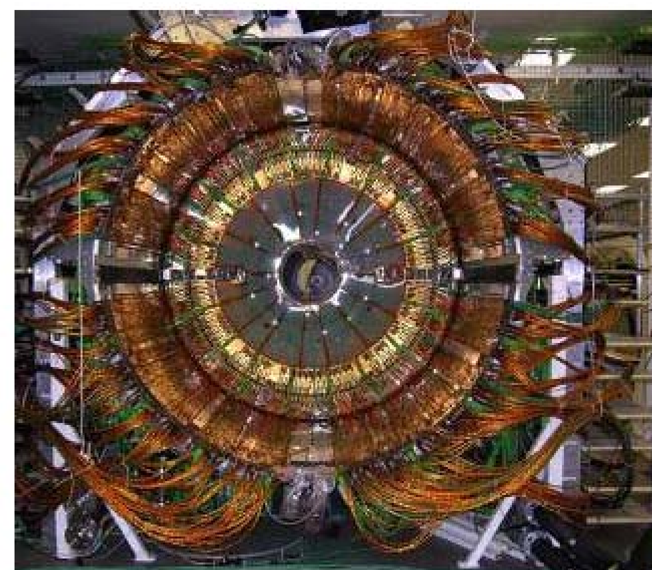
The silicon strip tracker connected and readout from January – July 2007 in dedicated surface facility.

- **Nearly 2M channels, more than CDF silicon vertex**

Gain operational experience, detector performance studies, alignment studies.

- **5M cosmic muon tracks collected @ T=15, 10, -1, -10, -15 °C**

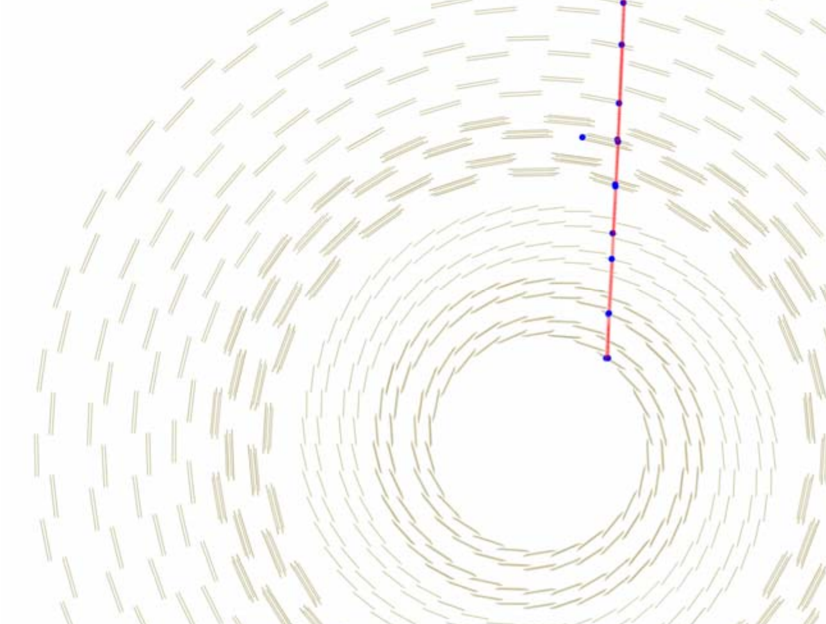


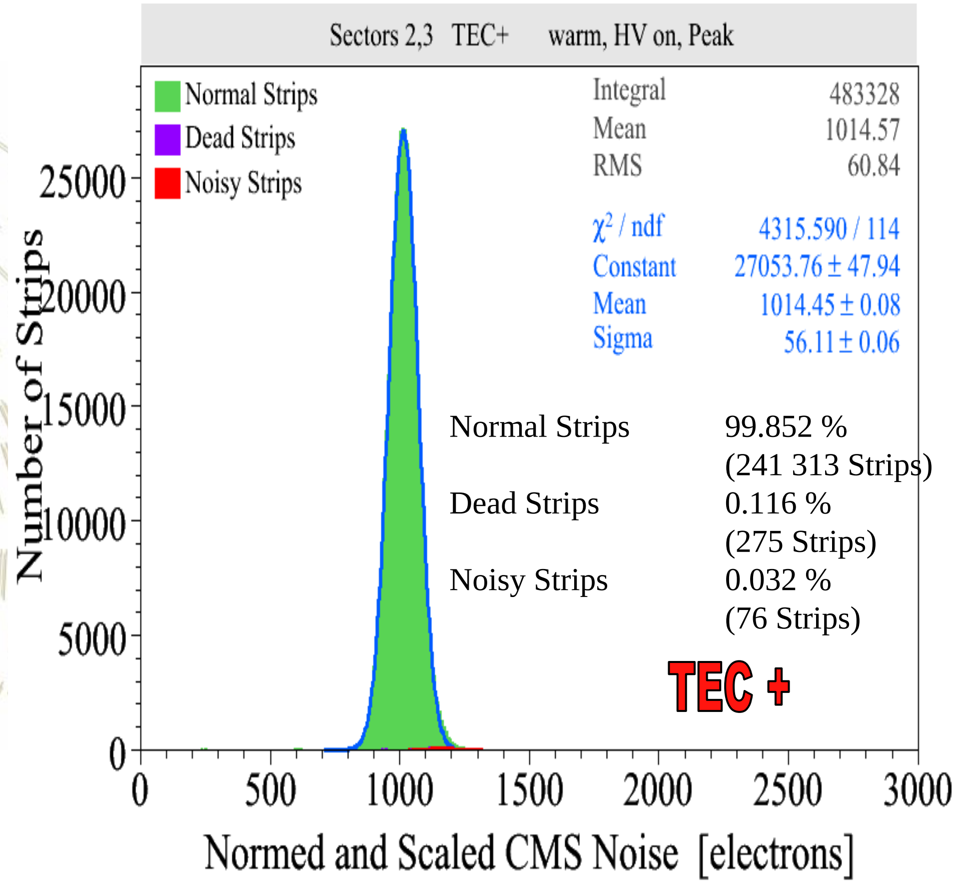


Cosmics in the Tracker

Example of Performance

A cosmic at -15°C
Validated clusters shown





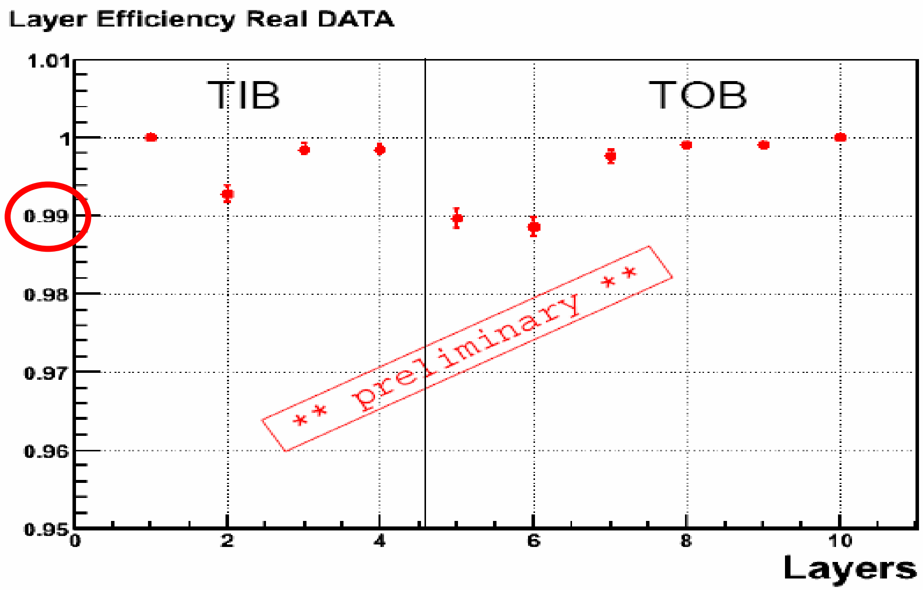
•The Quality of the CMS Tracker is Excellent:

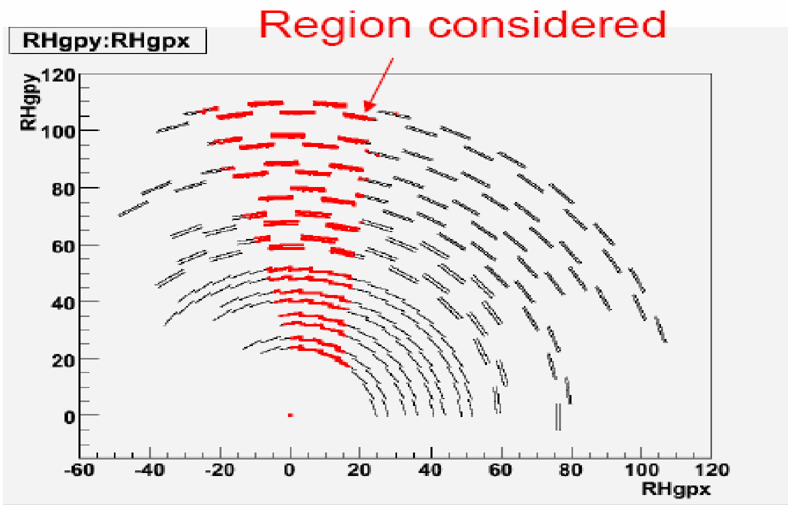
- Dead or Noisy Strips < 3 / 1000
- Signal:Noise > 25:1 in Peak Readout Mode
- Enormous experience gained in operating the Tracker at TIF

1st Measurements of Efficiency of Tracker

Real Data: Layer efficiency Summary

The alignment position error (APE) is set to 2 mm

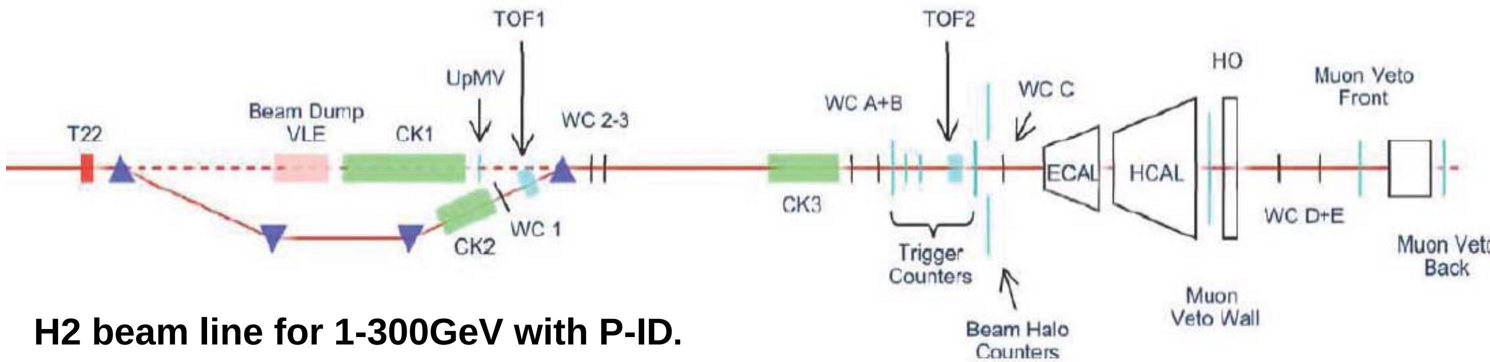




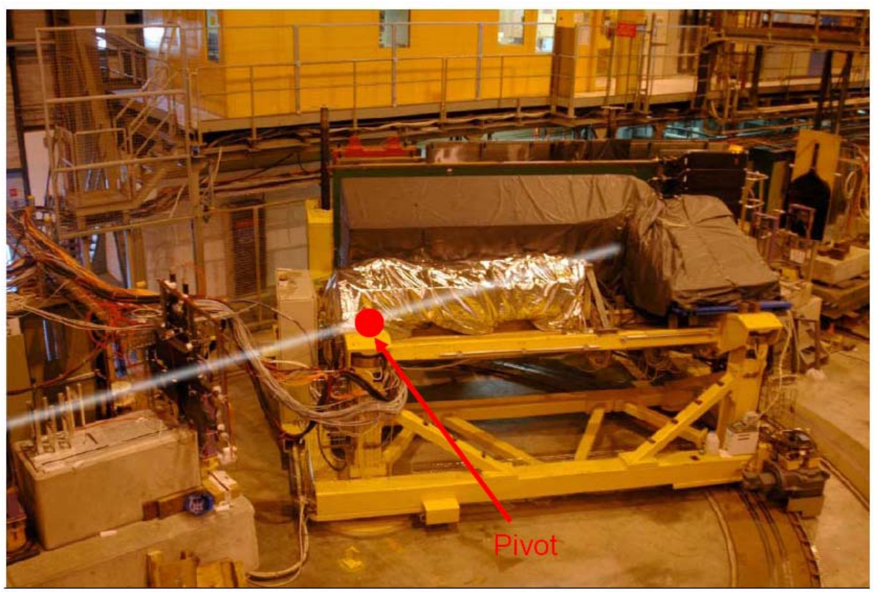
The layer efficiency in the region considered is more than 99.7% for single side layers and more than 99% for double side layers.
Further cross check need for double side layers.

02 May 2007 Daniele Benedetti - Università&INFN Perugia 14

TB2006: Calorimeter Response to Hadrons



H2 beam line for 1-300GeV with P-ID.



Pivot of table = IP at LHC

A phi slice of CMS calorimeter

HB: 2 wedges
8 ϕ segment
$\Delta\phi$ = 40 deg.

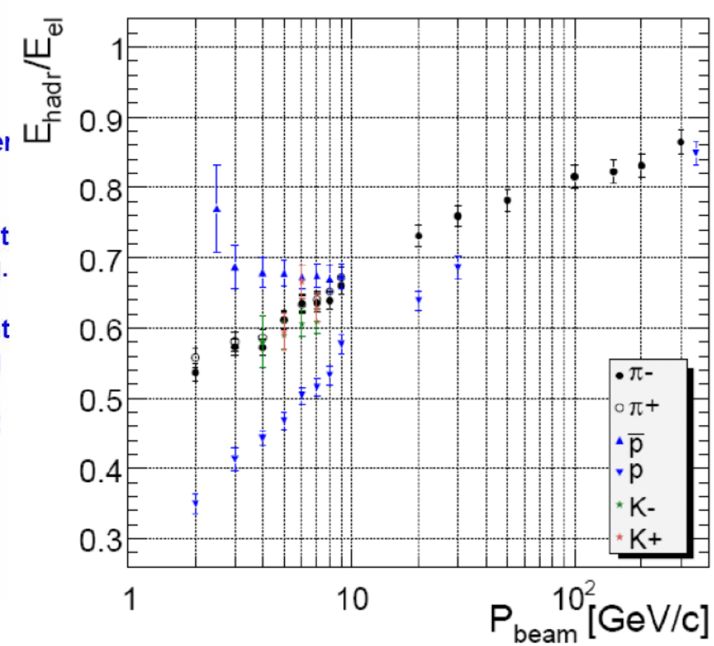
HE: 4 ϕ segment
$\Delta\phi$ = 20 deg

HO: Ring 0, 1, 2

ECAL: SM9

+ production electronics

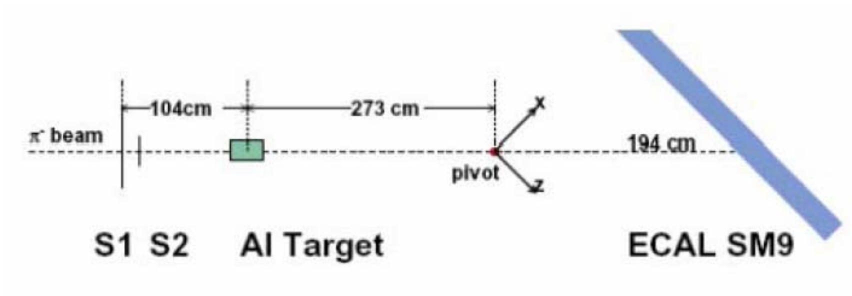
ECAL+ HCAL response



Tuning of hadron physics model in GEAN4 is in progress. (especially P<10GeV).

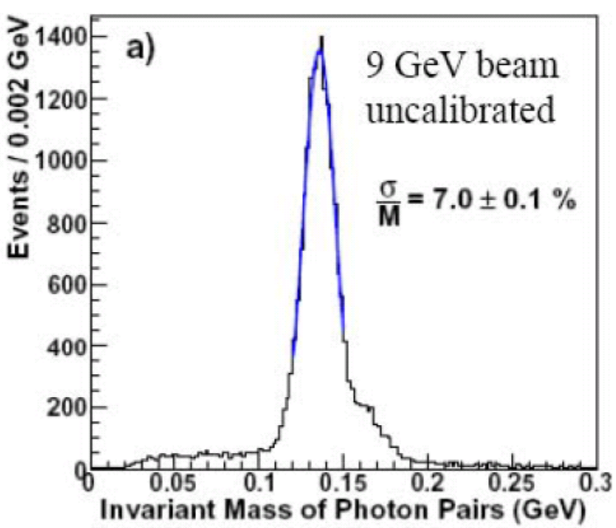
TB2006 - ECAL Crystal Calibration with π^0's

- Preparation for in-situ calibration with π^0's -

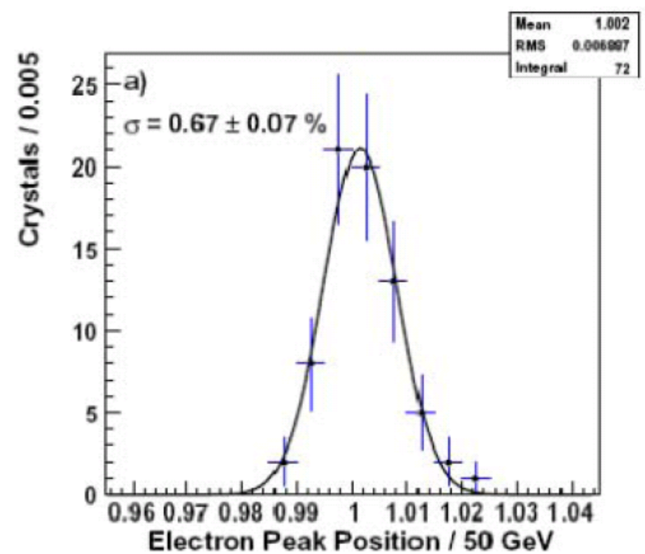


Crystals are calibrated with ~140 p0's/crystal.

Spread of peaks of reconstructed energy for 50GeV electrons centered at each crystal (total 72 crystals) is 0.67% - consistent with statistical expectation.



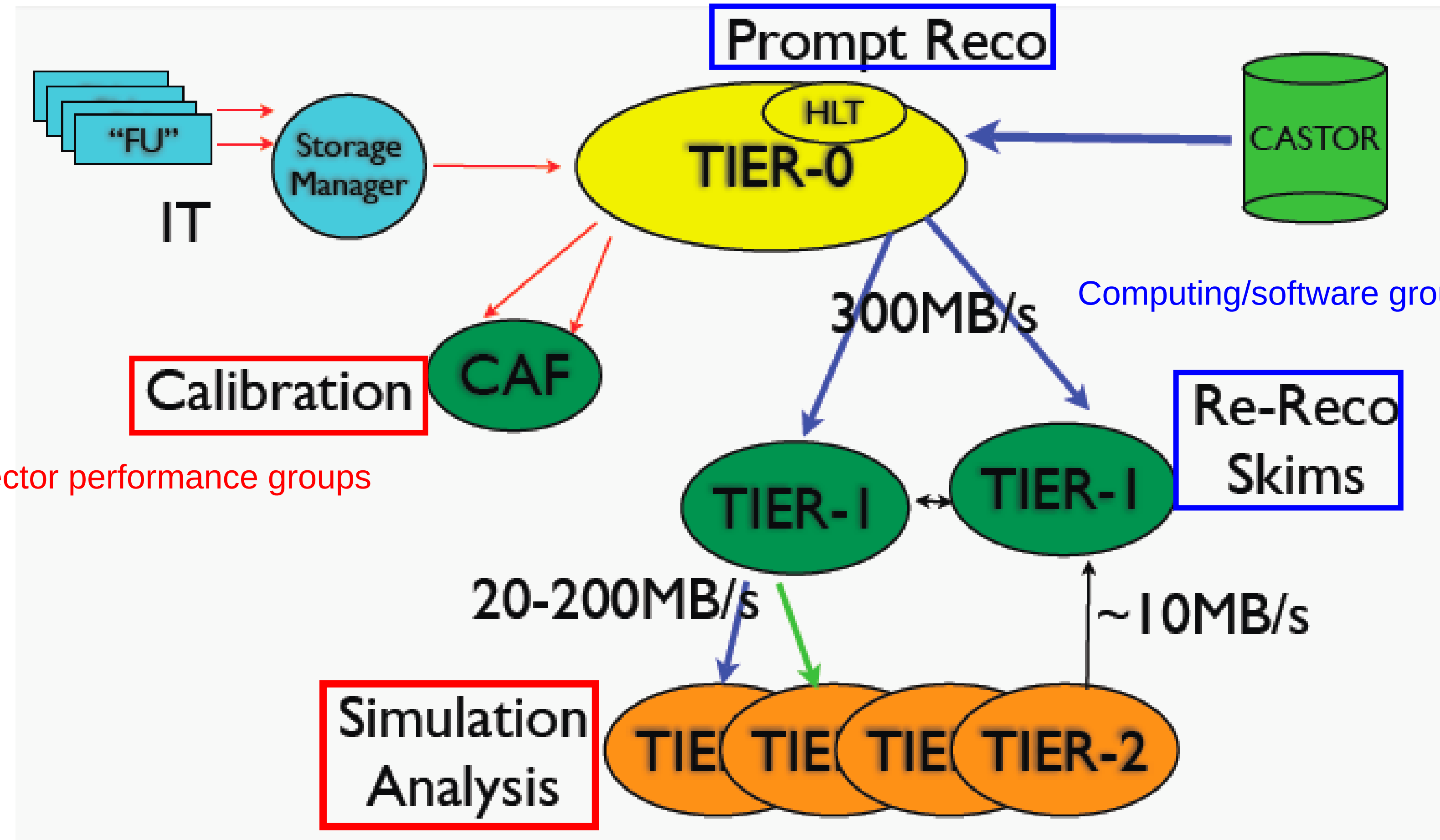
Raw π^0 mass



50 GeV electrons

CSA07: Computing Software and Analysis Challenge

Planning + Coordination + Execution (MC events)



Computing/software groups

Detector performance groups

Physics object groups
Physics groups

Data transfer

CSA07: Computing Software and Analysis Challenge

Commissioning of the data handling system: 50% of 2008 Goal
Software development program with analysis activities and users.

Service	2008 Goal	CSA07 Goal	CSA06 Goal	Status 2006
Tier-0 Reco Rate	150Hz - 300Hz	100Hz	50Hz	Achieved
Network Transfers between T0-T1	600MB/s	300MB/s	150MB/s	Achieved (6/7 cont.)
Network Transfers between T1-T2	50-500 MB/s	20-200 MB/s	10-100 MB/s	Achieved (15 sites)
Network Transfers T1-T1	100MB/s	50MB/s	NA	Not Attempted
Job Submission to Tier-1s	50k jobs/d	25k jobs/d	12k jobs/d	3k jobs/d
Job Submissions to Tier-2s	150k jobs/d	75k jobs/d	48k jobs/d	Achieved
MC Simulation	1.5 10^9 events/year	50M per month	NA	Not Attempted

100% 50% 25%

FNAL Involvement in CMS Operation

FNAL Remote Operation Center (ROC)

(remote monitoring during TB2007 data taking)

Role:

-Remote shifts in local time zone.

-Work with various local groups

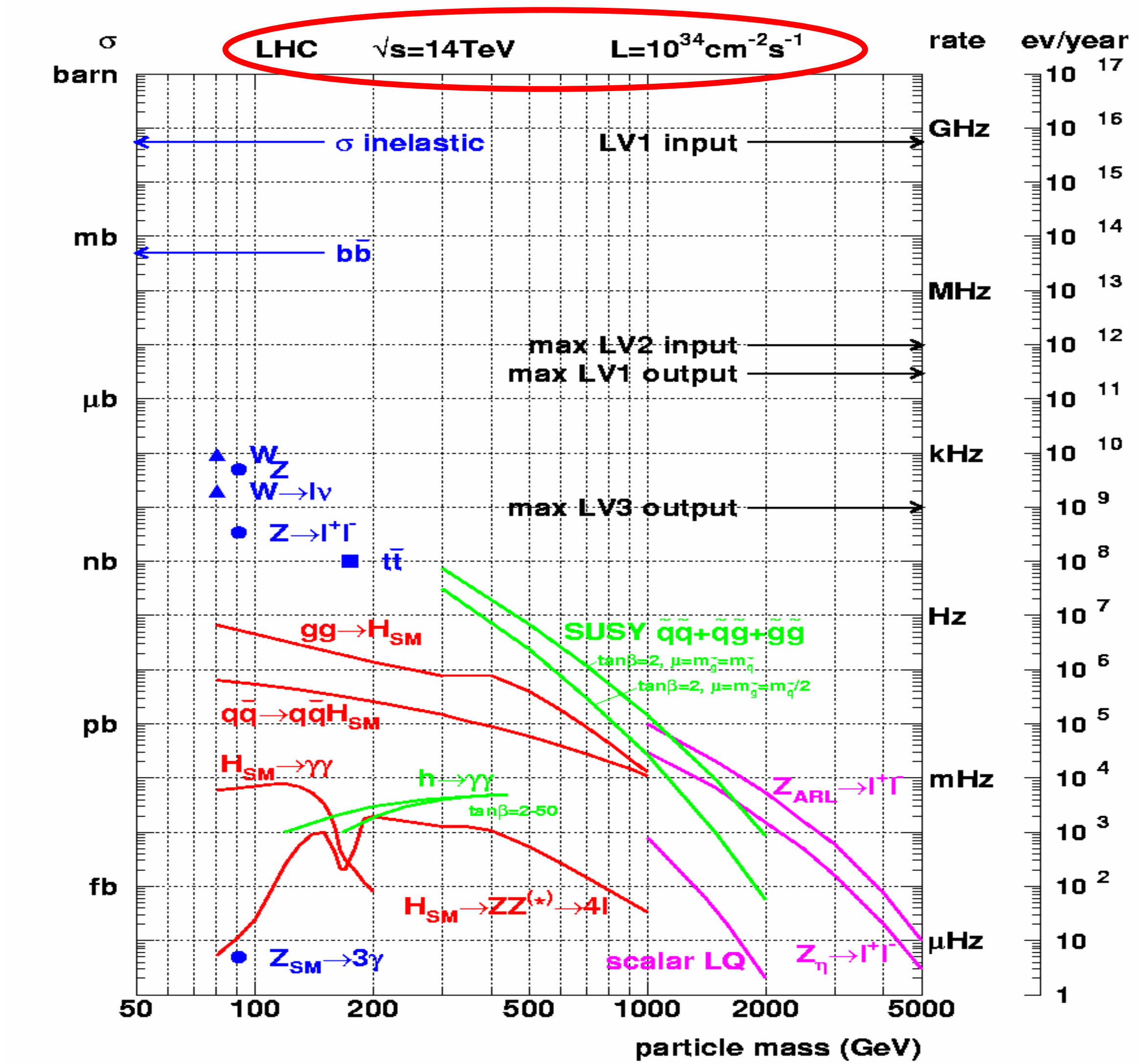
- **LHC Phyis. Center (LPC)-**
  - **software & analysis**
- **Detector groups-**
  - **detector commissioning**
  - **test beam**
- **Computing-**
  - **data operartion**
- **FNAL machine group-**
  - **LHC monitoring**

Being used during

- **Global runs**
- **Test beam data taking**
- **Tracker commissioning**
- **Data operation**

The FNAL ROC group delivered online/monitoring sw, based on experience with operation of CDF/Dzero at Tevatron.

Physics at LHC



Standard Model

Higgs
- **Origin of EW symmetry breaking? Mass?**

Top, b-quark, …

Beyond Standard Model

Supersymmetry (SUSY)
- **Dark matter**
- **Unify gauge couplings**

Extra dimension
Little Higgs
Technicolor
Heavy Z', W'
Black Hole
Quark substructure
:

Beam Commissioning

It will most likely take YEARS to reach design luminosity !!!

J.Wenninger
June 2007

Parameter	Phase A	Phase B	Phase C	Nominal
k / no. bunches	43-156	936	2808	2808
Bunch spacing (ns)	2021-566	75	25	25
N (10^{11} protons)	0.4-0.9	0.4-0.9	0.5	1.15
Crossing angle (μrad)	0	250	280	280
$\sqrt{(\beta^*/\beta^*_{nom})}$	2	$\sqrt{2}$	1	1
σ^* (μm, IR1&5)	32	22	16	16
L ($cm^{-2}s^{-1}$)	$6\times10^{30}-10^{32}$	$10^{32}-10^{33}$	$(1-2)\times10^{33}$	10^{34}

My guess

year	**2008**	**2009**	**2010**	**2011**
Luminosity	**O(100pb^{-1})**	**O(1fb^{-1})**	**O(10fb^{-1})**	**O(100fb^{-1})**
W→$\mu\nu$	**10^6**			
Z→$\mu\mu$	**10^5**			
tt→$\mu\nu X$	**10^4**			

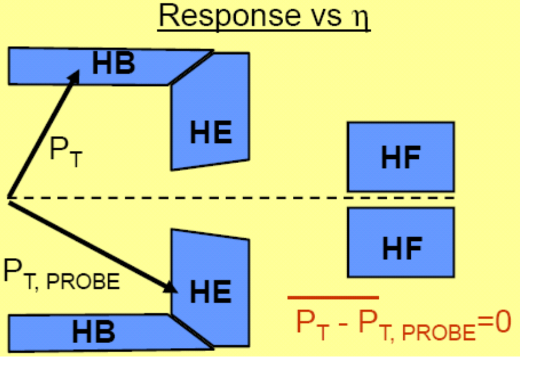
Comparable statistics to Tevatron

Use of Early Data

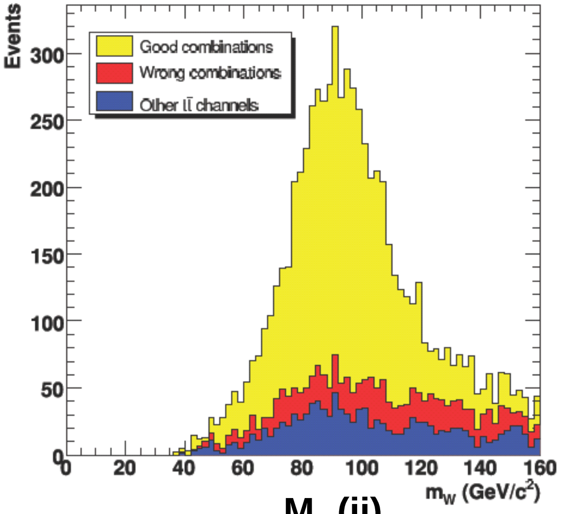
- **Measure Standard Model Processes at 14TeV**
  - **Background in search for new physics**
  - **With 10pb^{-1}**
    - **Measure W (10^5) and Z (10^4) cross section**
    - **Observe top production**
    - **…**
  - **With 100pb^{-1}**
    - **Measure top production (10^4)**
    - **…**
    - **→ good understanding of SM at 14TeV and start search for new physics**
  - **With 1fb^{-1}**
    - **Beyond Tevatron precision**
    - **May observe new physics**
- **Improve detector alignment and calibration**
  - **examples**
    - **100k Z→$\mu\mu$ with 100pb^{-1} for alignment**
    - **Dijet balance for calorimeter calibration**
    - **M(jj) in ttbar events for jet energy scale**
  - **Many processes**
    - **Triggers and software in preparation**

Calorimeter/Jet Calibration

Dijet balance

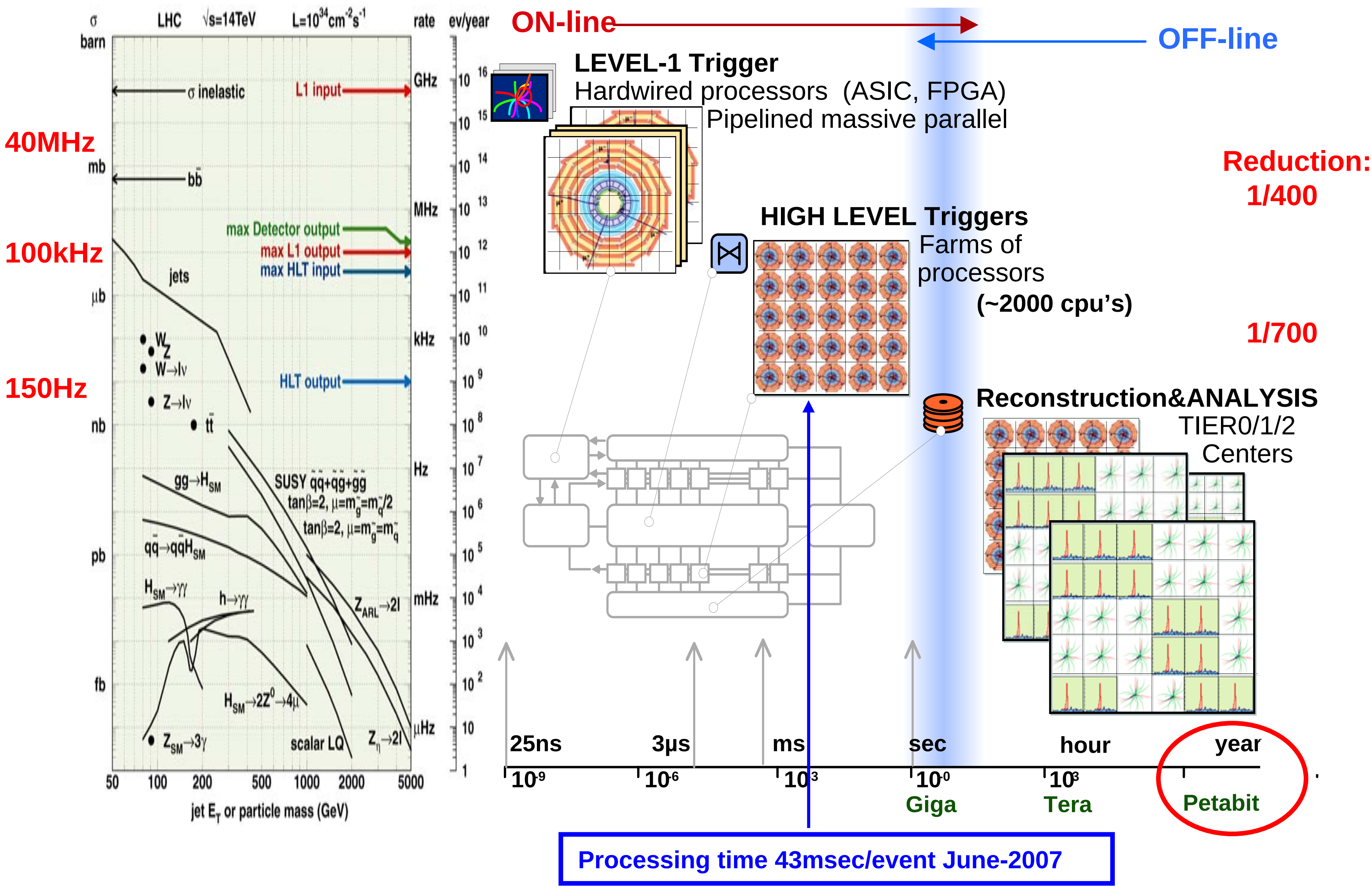


M_W(jj) from top decay



M_W(jj)

Physics Selection (Trigger)



- Example -

Preparation of trigger for dijet physics

- CMS jet trigger saves all high E_T jets & pre-scales the lower E_T jets.
  - ➔ Prescale means to save 1 event out of every N events.

	Path	L1 E_T (GeV)	L1 Pre-scale	L1 Rate (Hz)	HLT E_T (GeV)	HLT Rate (Hz)	ANA Dijet Mass (GeV)
L = 10^{32} 100 pb^{-1}	Low	**25**	2000	146	**60**	2.8	
	Med	**60**	40	97	**120**	2.4	**330**
	High	**140**	1	44	**250**	2.8	**670**

Mass values are efficient for each trigger, measured with prior trigger

L = 10^{33} 1 fb^{-1}

Add New Threshold (Ultra). Increase Prescales by 10.

Path	L1 E_T (GeV)	L1 Pre-scale	L1 Rate (Hz)	HLT E_T (GeV)	HLT Rate (Hz)	ANA Dijet Mass (GeV)
Ultra	**270**	1	19	**400**	2.6	**1130**

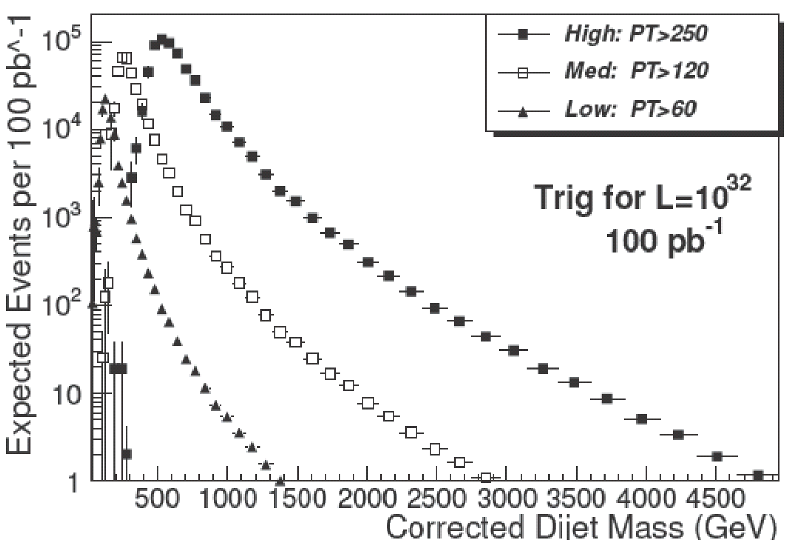
L = 10^{34} 10 fb^{-1}

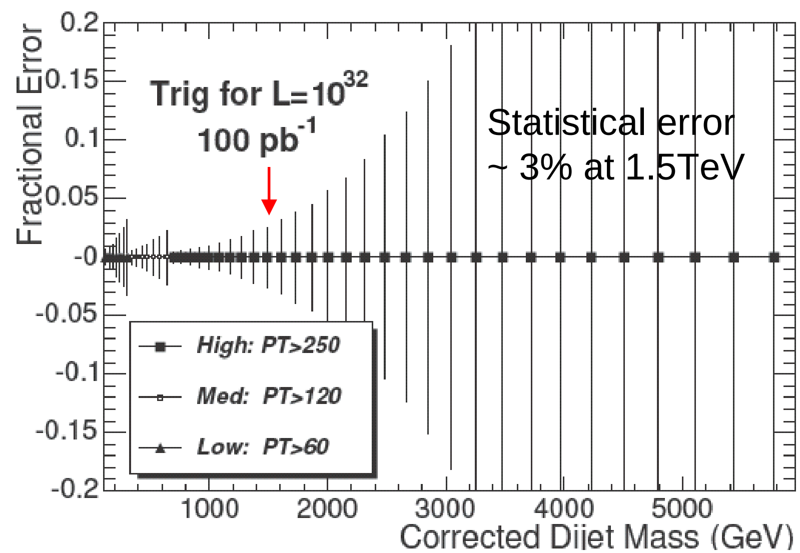
Add New Threshold (Super). Increase Prescales by 10.

Path	L1 E_T (GeV)	L1 Pre-scale	L1 Rate (Hz)	HLT E_T (GeV)	HLT Rate (Hz)	ANA Dijet Mass (GeV)
Super	**450**	1	14	**600**	2.8	**1800**

As luminosity increases new trigger paths are added

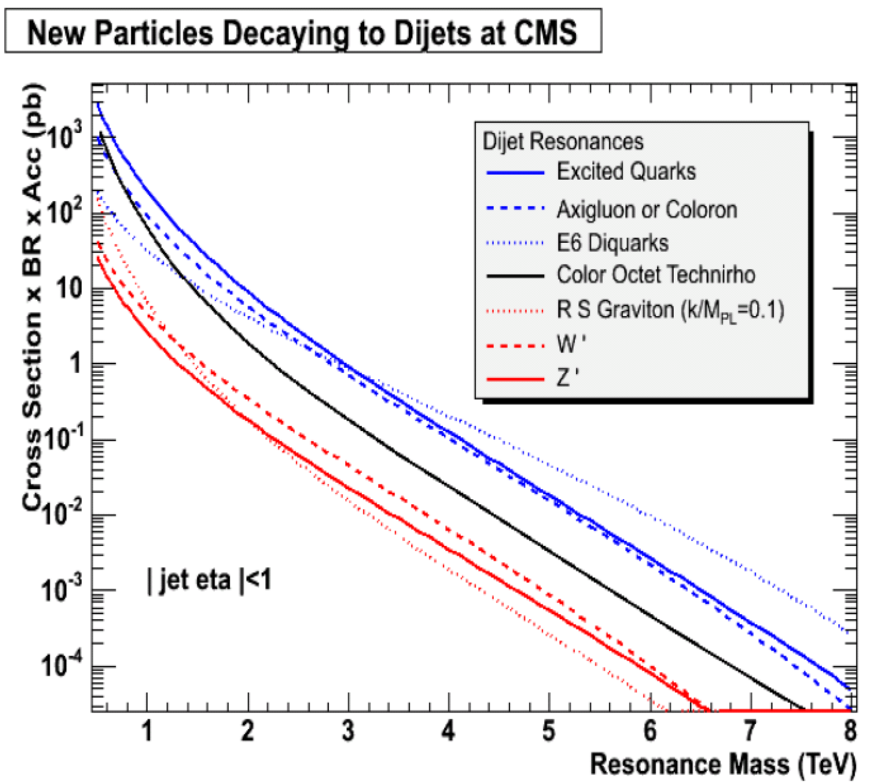
Each with new unprescaled threshold.

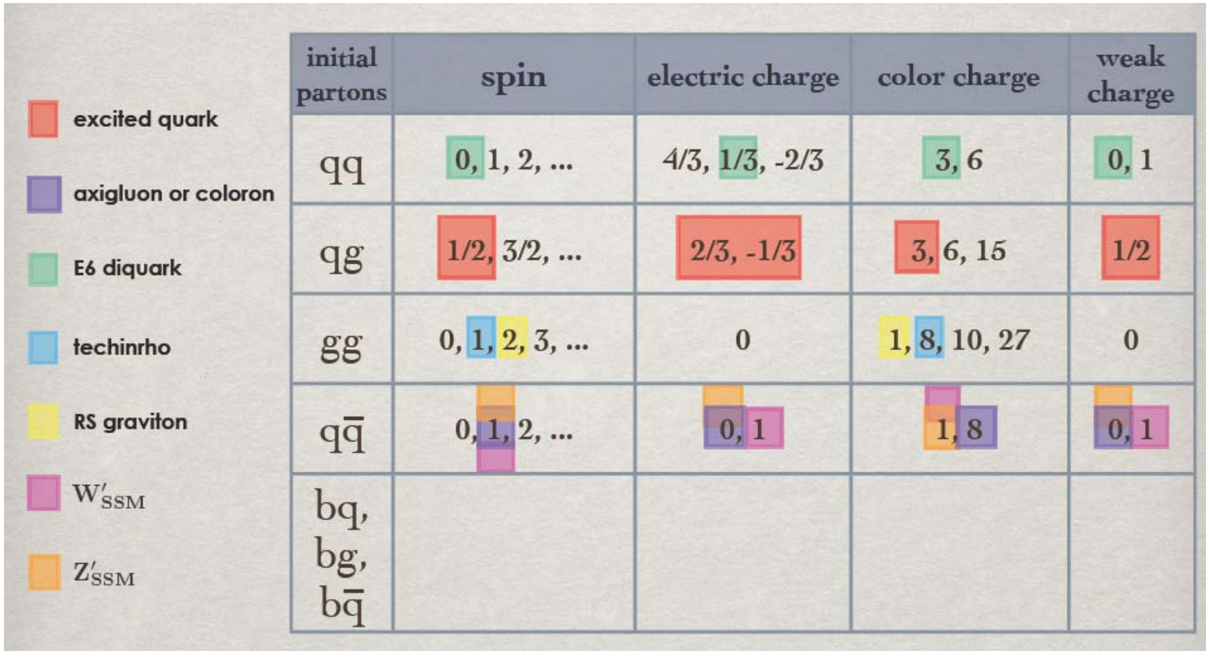




Topology-based analysis

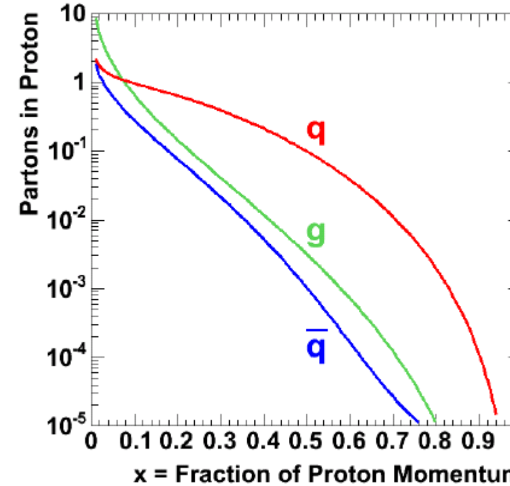
- Exclusive channels for discovery
  - e.g. H→μμμμ, H→γγ, H→jjττ
  - many channels to cover at LHC
- Inclusive channels (topology) for discovery
  - Dijet
  - Jets + MET
  - Lepton + jets+ MET
  - Dilepton + jets + MET
  - Deleptons
  - Photons
  - Others*
  - Develop model templates
    - to discriminate signal
  - Analysis groups
    - CMS + Theorists
    - Critical mass @ LPC/Fermilab

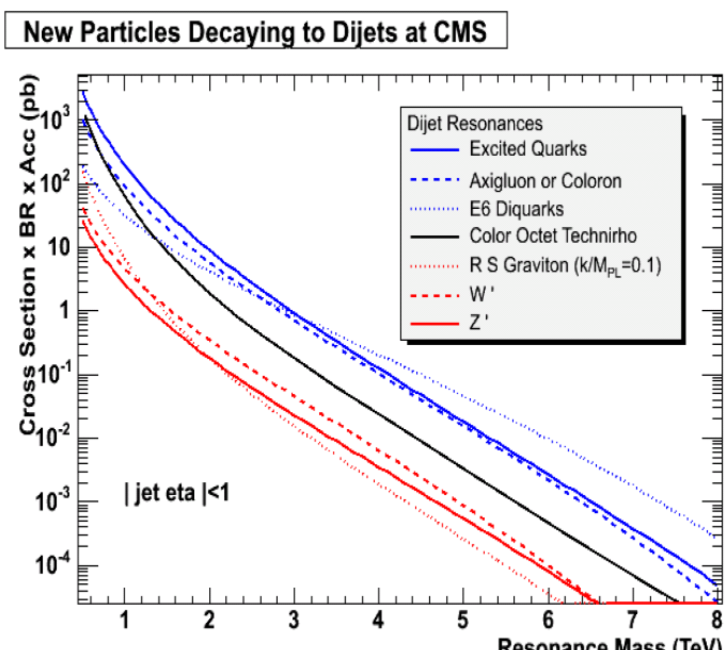




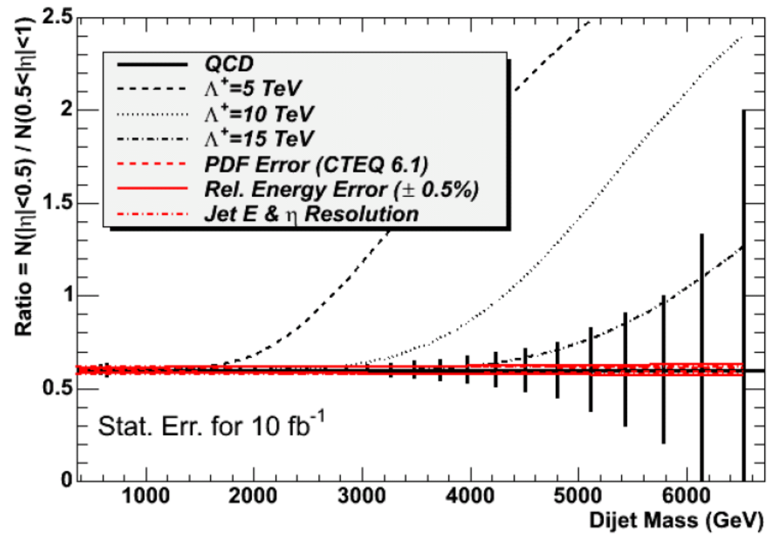
initial partons	spin	electric charge	color charge	weak charge
qq	0, 1, 2, ...	4/3, 1/3, -2/3	3, 6	0, 1
qg	1/2, 3/2, ...	2/3, -1/3	3, 6, 15	1/2
gg	0, 1, 2, 3, ...	0	1, 8, 10, 27	0
q$\bar{q}$	0, 1, 2, ...	0, 1	1, 8	0, 1
bq, bg, b$\bar{q}$				

X





Dijet Ratio – small systematic uncertainty



Preparation for Early Physics at LPC/Fermilab

US CMS Physics Workshop, Oct-2007

Conclusion

- **CMS is taking cosmic data with more and more elements in the underground collision hall.**
- **CMS detector will be closed for 4Tesla operation in spring 2008. It will be ready for pp data taking by mid-2008.**
- **If we have done a good job, then with 1fb^{-1} data, we might see something new.**