Physics with Muons in CMS

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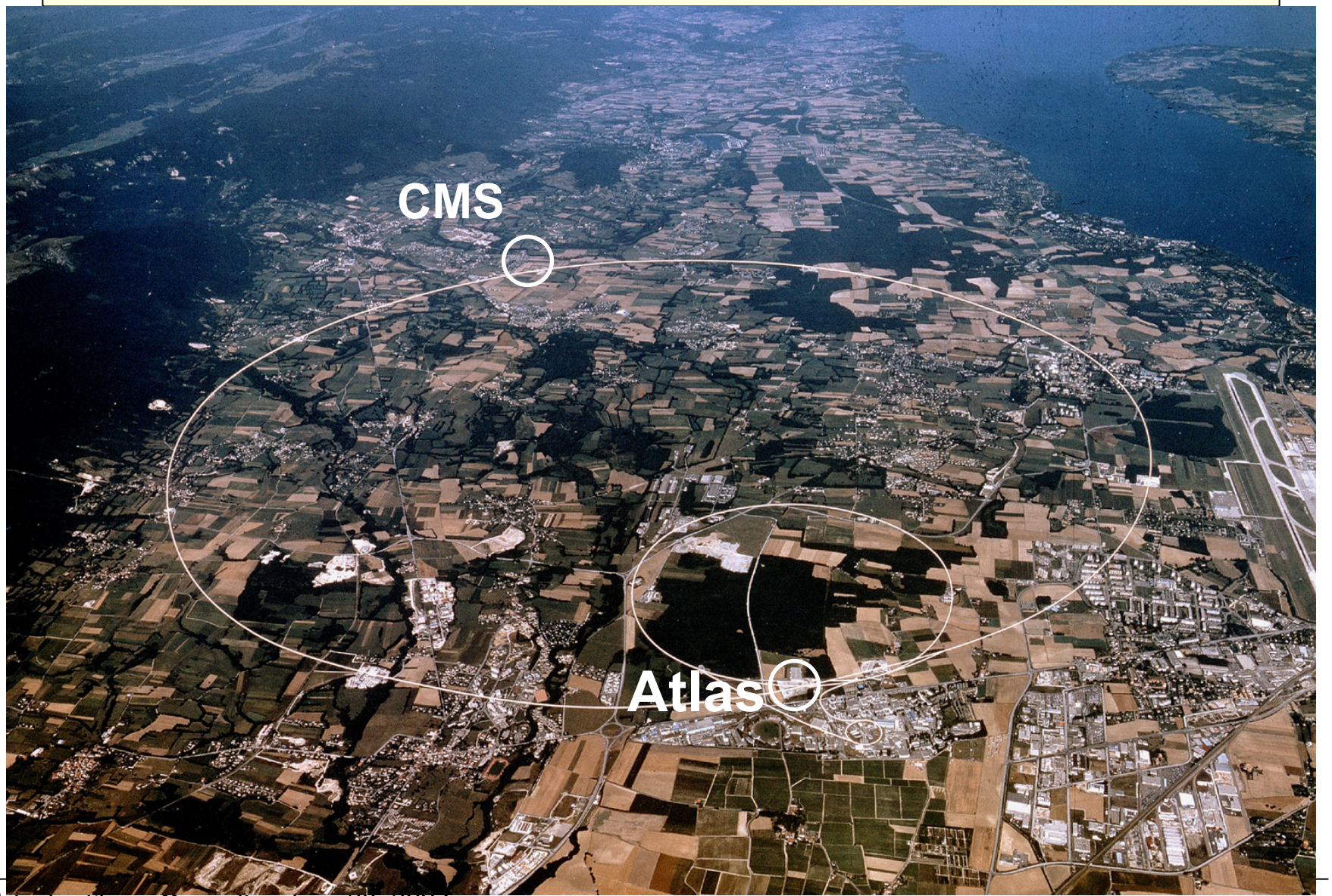
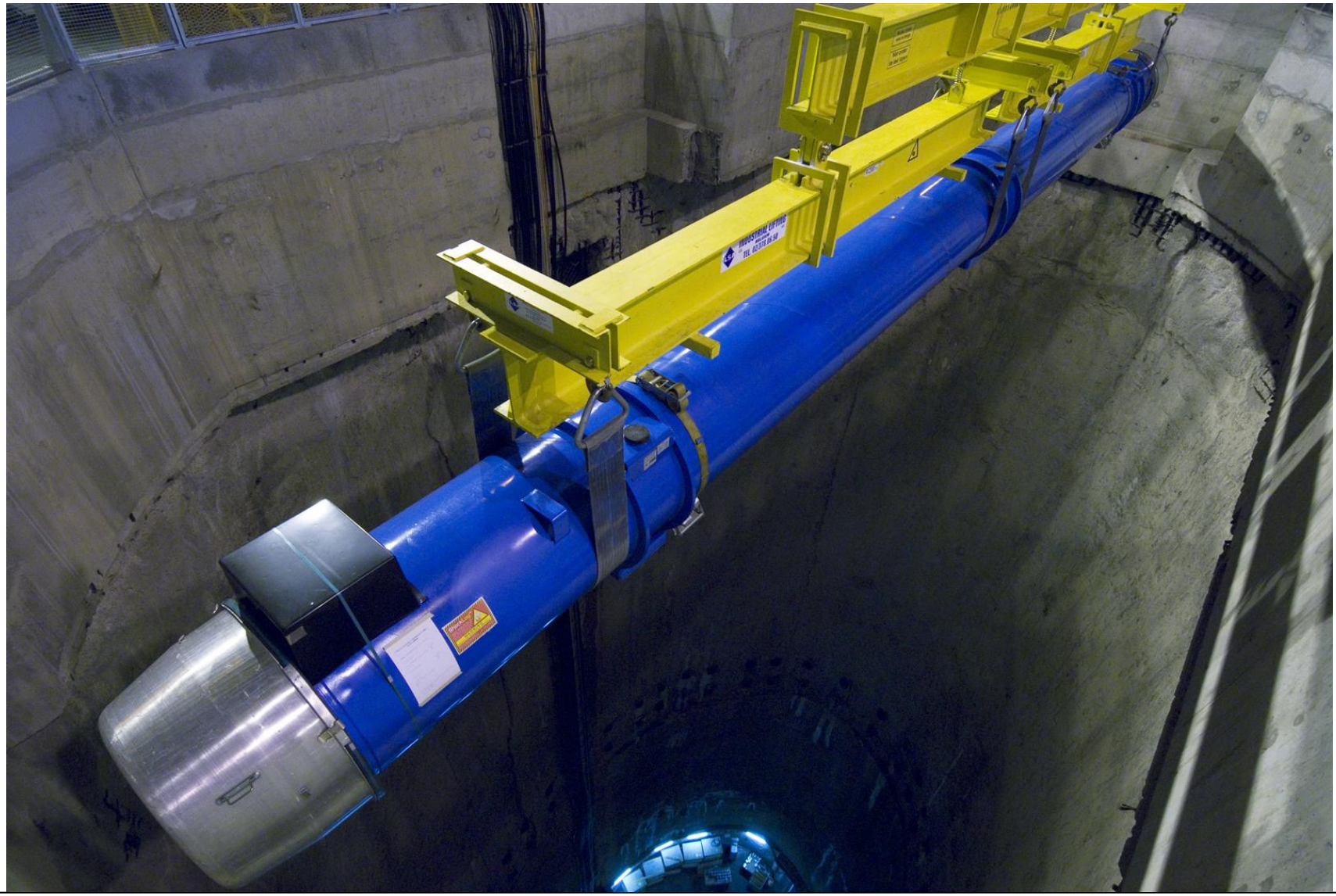
University of Florida

LHC, ATLAS and CMS



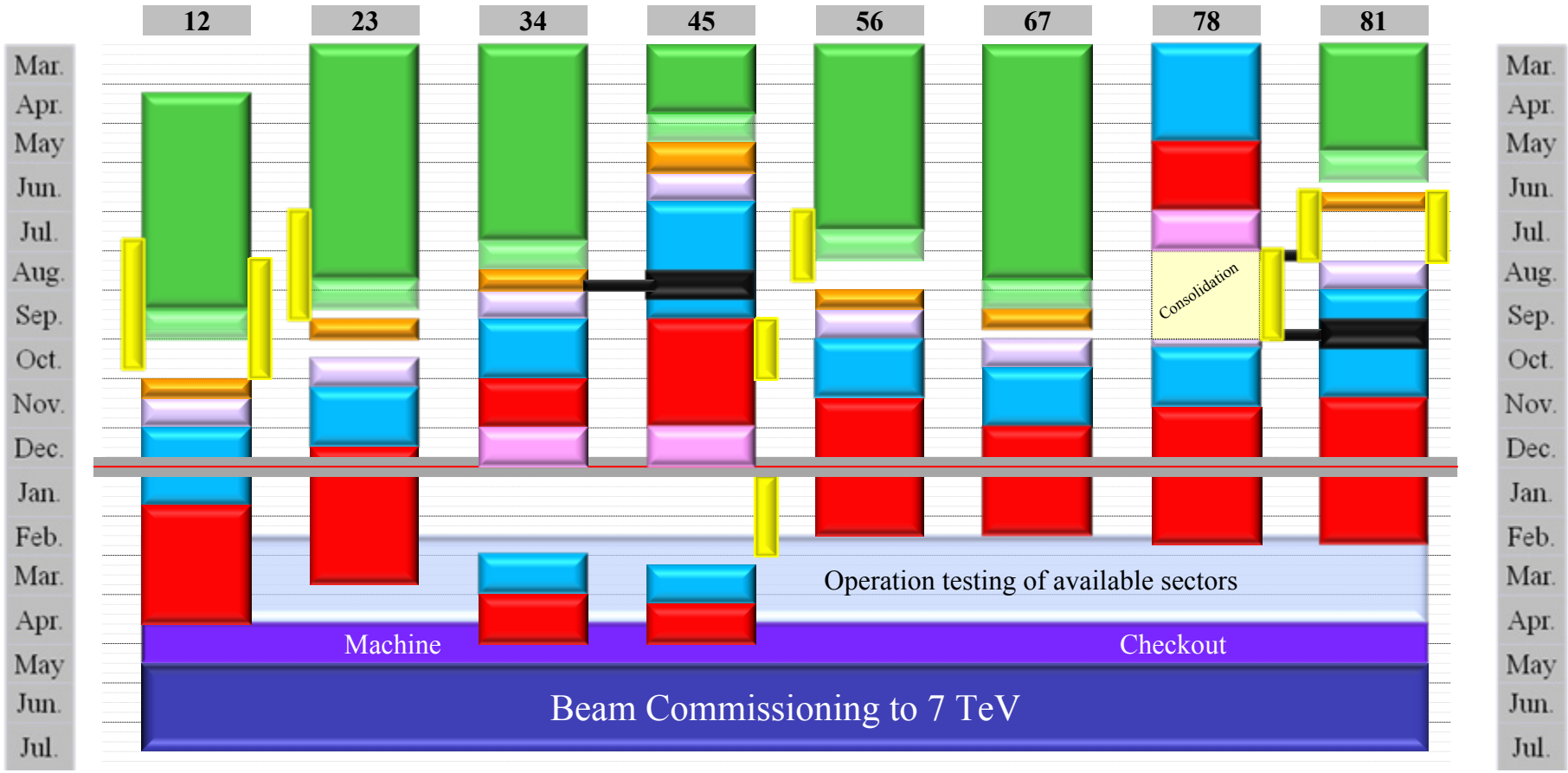
LHC Machine nearing completion: Descent of Last Dipole (#1232) April 07



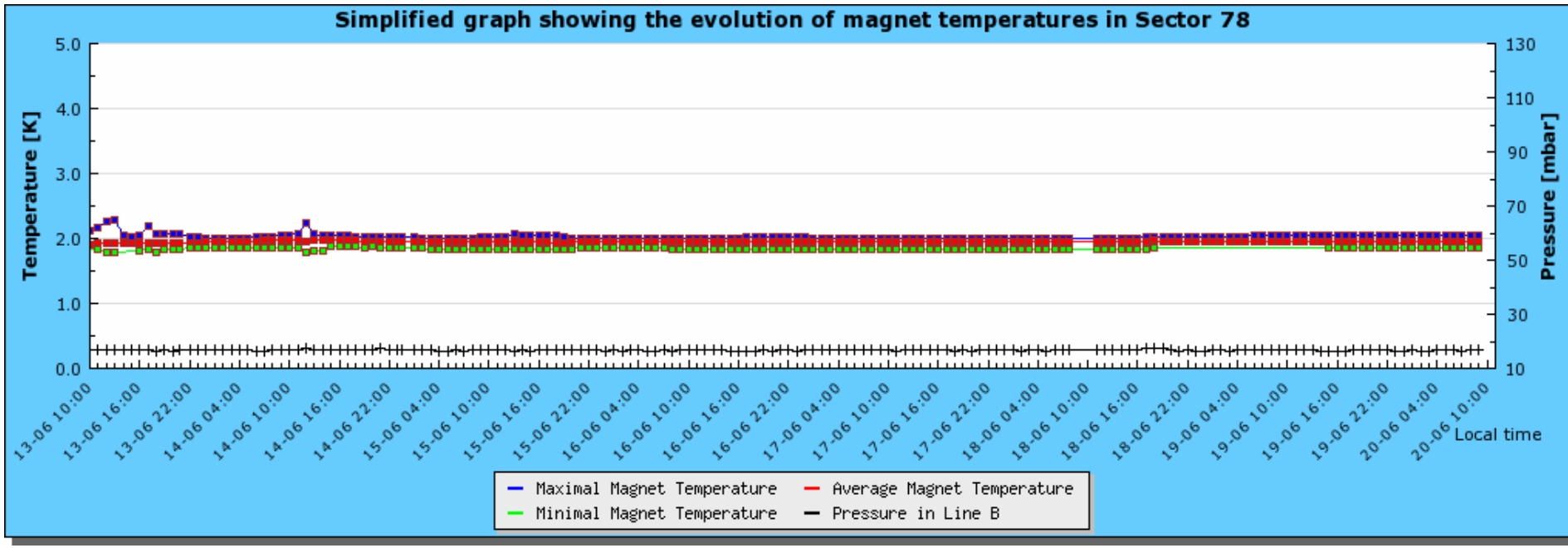
LHC Schedule update (slides from M. Lamont, June 2007)

- **Engineering run** originally foreseen at end 2007 now precluded by delays in installation and equipment commissioning.
- **450 GeV operation** now part of normal setting up procedure for beam commissioning to high-energy
- **General schedule** being reassessed, accounting for inner triplet repairs and their impact on sector commissioning
  - **All technical systems commissioned to 7 TeV operation, and machine closed April 2008**
  - **Beam commissioning starts May 2008**
  - **First collisions at 14 TeV com July 2008**
  - **Pilot run pushed to 156 bunches for reaching 10^{32} $cm^{-2}s^{-1}$ by end 2008**
- **No provision in success-oriented schedule for major mishaps, e.g. additional warm-up/cool-down of sector**

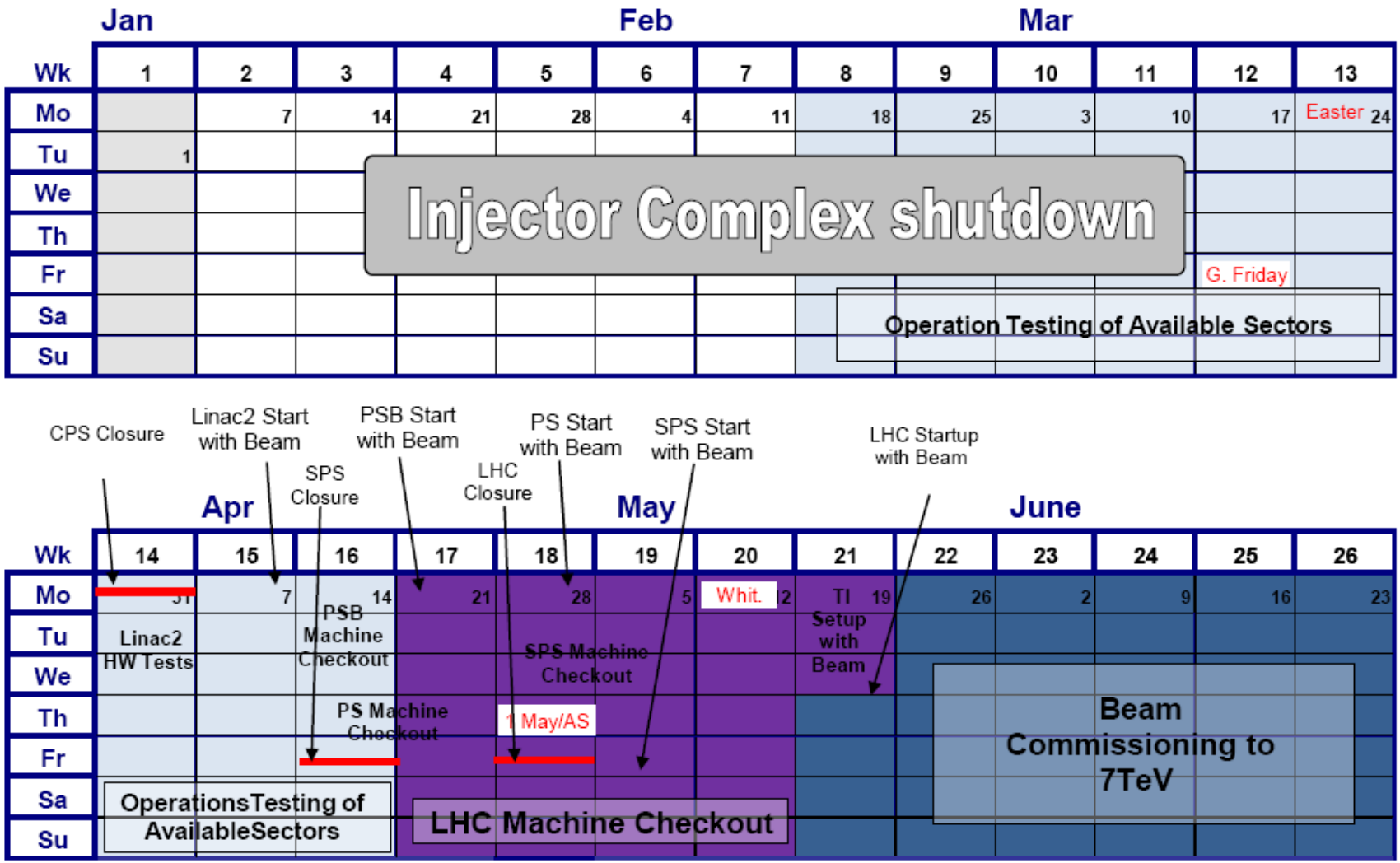
LHC Commissioning Schedule



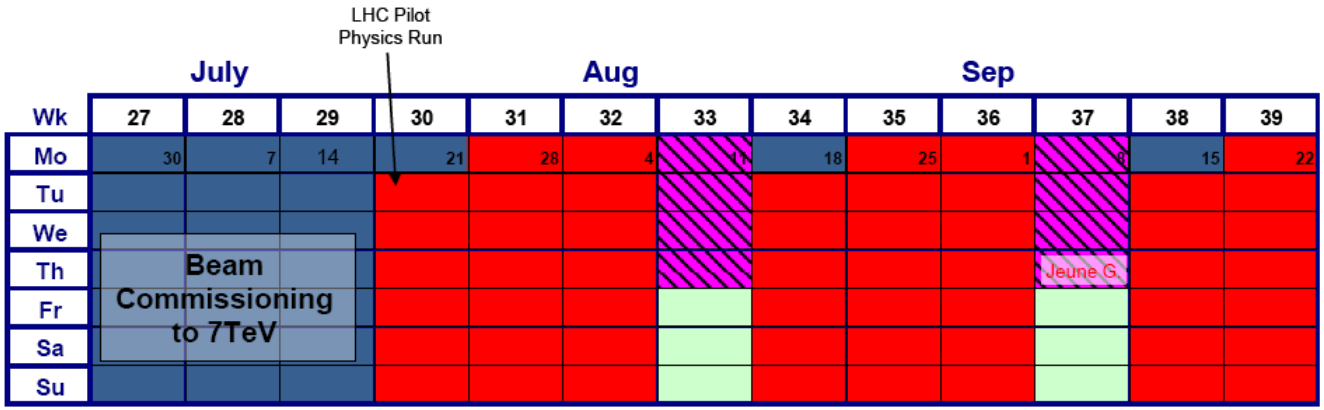
Sector 78 cool-down (June 2007)

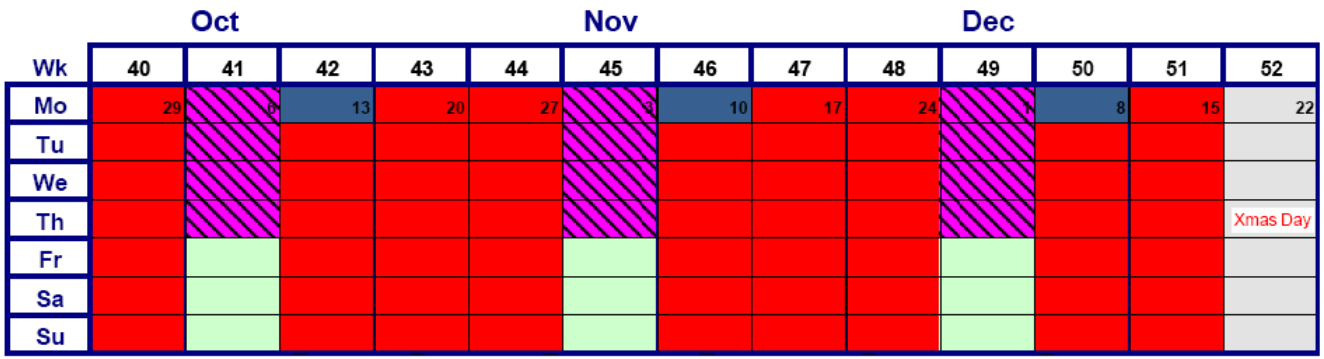


2008 LHC Accelerator schedule



2008 LHC Accelerator schedule





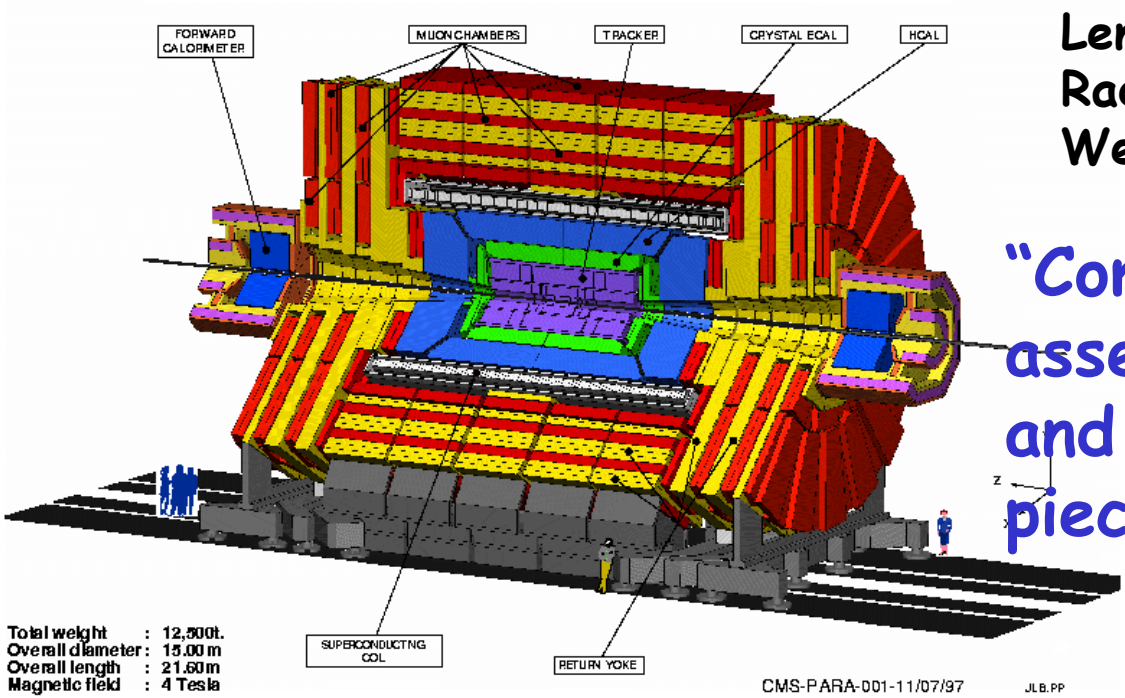
LHC Physics

LHC Machine Development

LHC Setup with beam

LHC Technical Stop

2008 integrated luminosity:
(0.1 – 1.0) inv.fb (my guess, GM)



CMS

Length : ~22 m
Radius : ~7 m
Weight : ~ 12500 tons

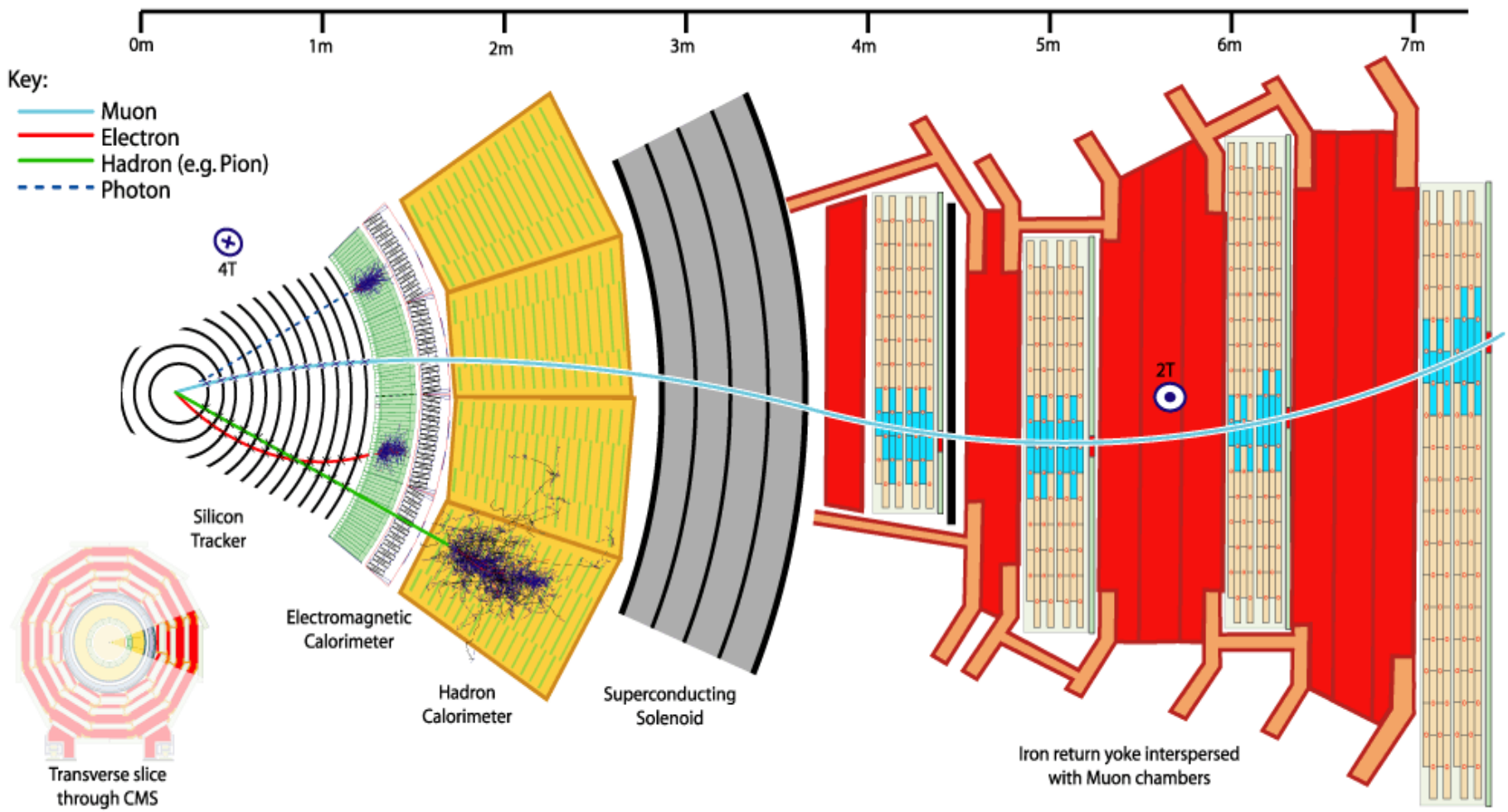
"Compact" and modular: assembled at the surface and lowered in the cavern piece by piece

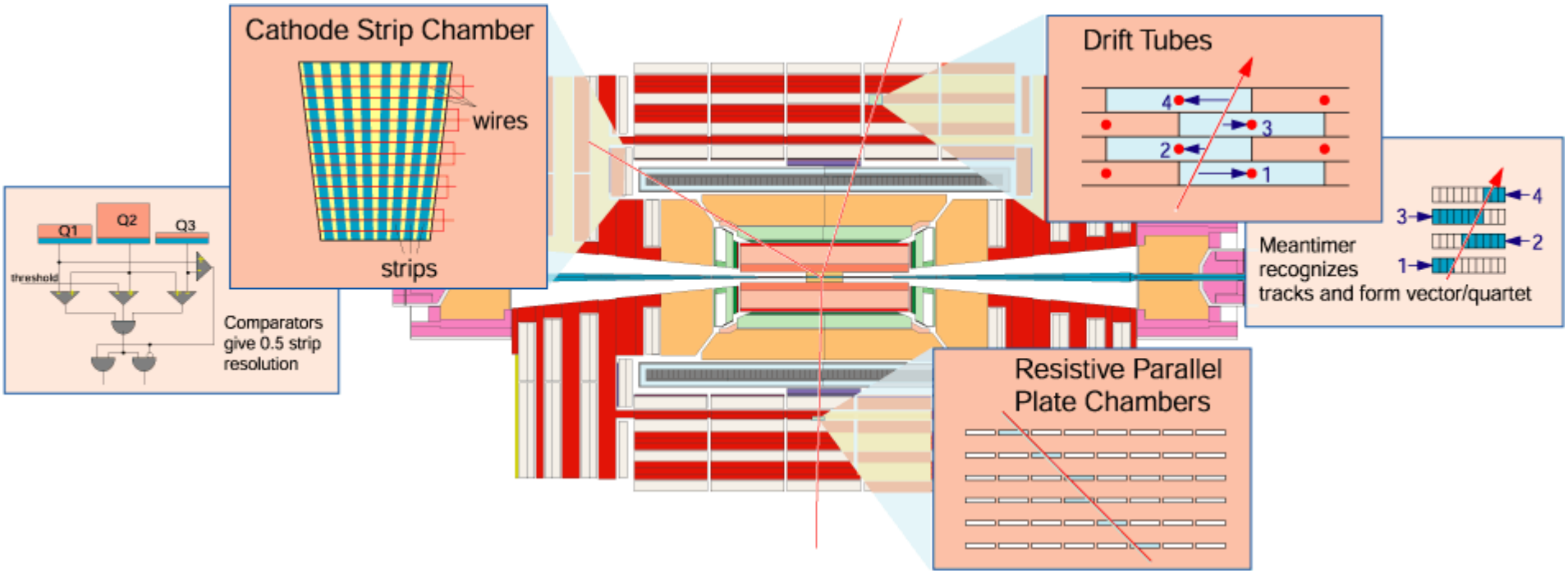
- Tracking ($|\eta|<2.5$, B=4T) : Si pixels and strips

- Calorimetry ($|\eta|<5$) :
  -- EM : $PbWO_4$ crystals
  -- HAD: brass/scintillator (central+ end-cap), Fe/Quartz (fwd)

- Muon Spectrometer ($|\eta|<2.5$) : return yoke of solenoid instrumented with muon chambers: Drift Tubes (DTs) in Barrel, Cathode Strip Chambers (CSCs) in Endcaps, Resistive Plate Chambers (RPCs) in Barrel and Endcap

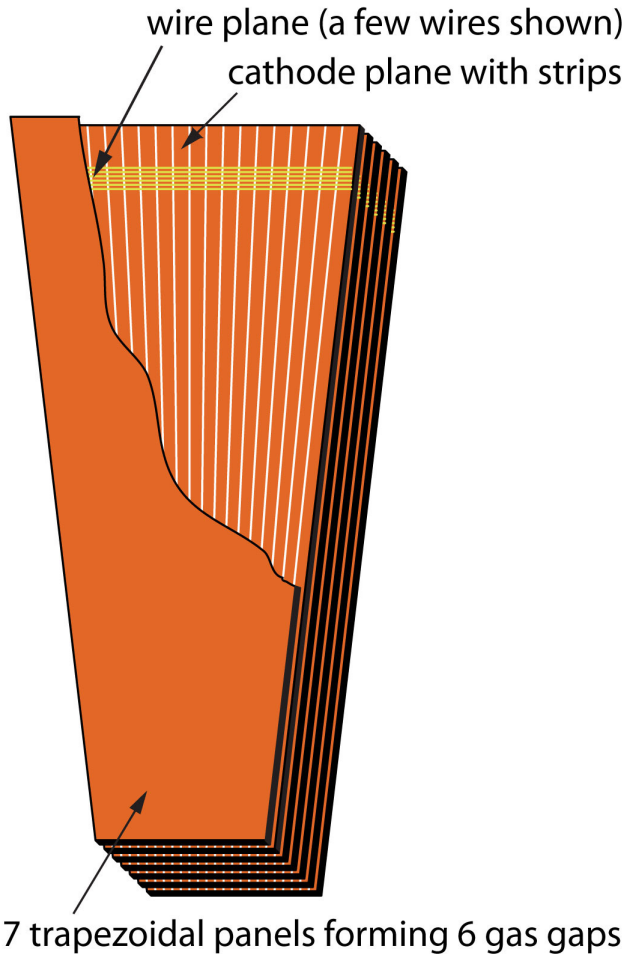
Detection of different particles in a slice of CMS

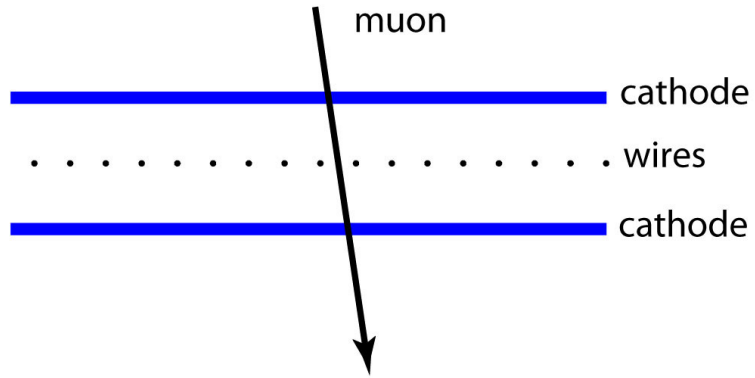


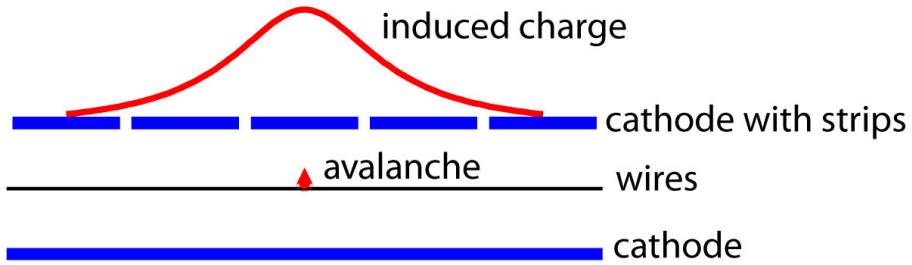

Cathode Strip Chamber
wires
strips
Q1
Q2
Q3
threshold
Comparators
give 0.5 strip
resolution
Drift Tubes
4
3
2
1
Meantimer
recognizes
tracks and form vector/quartet
Resistive Parallel
Plate Chambers

CSCs: principles of operation

- Ionization in chamber → avalanche at anode wire → induced charge on cathode strips → hit coordinate reconstruction from charge distribution on strips







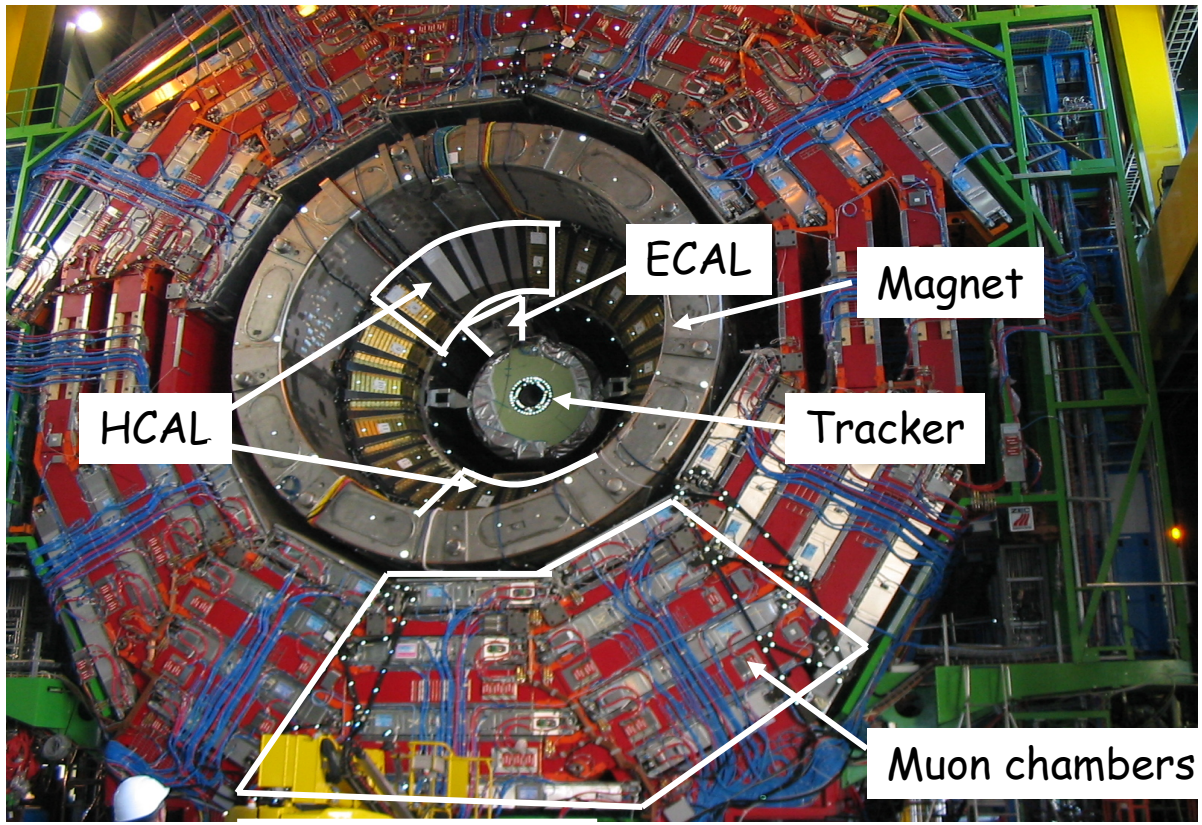
CMS Magnet and Muon Spectrometer have been assembled and tested on the surface The end cap disks were closed in July 2006

Beginning of CMS Commissioning after assembly in the surface hall: July-November2006

CMS Magnet Test and Cosmic Challenge (MTCC)

Cosmics run of a ~full detector slice (few percent of CMS coverage) inside 4T field.

Very successful, lots of data from detectors, still continue

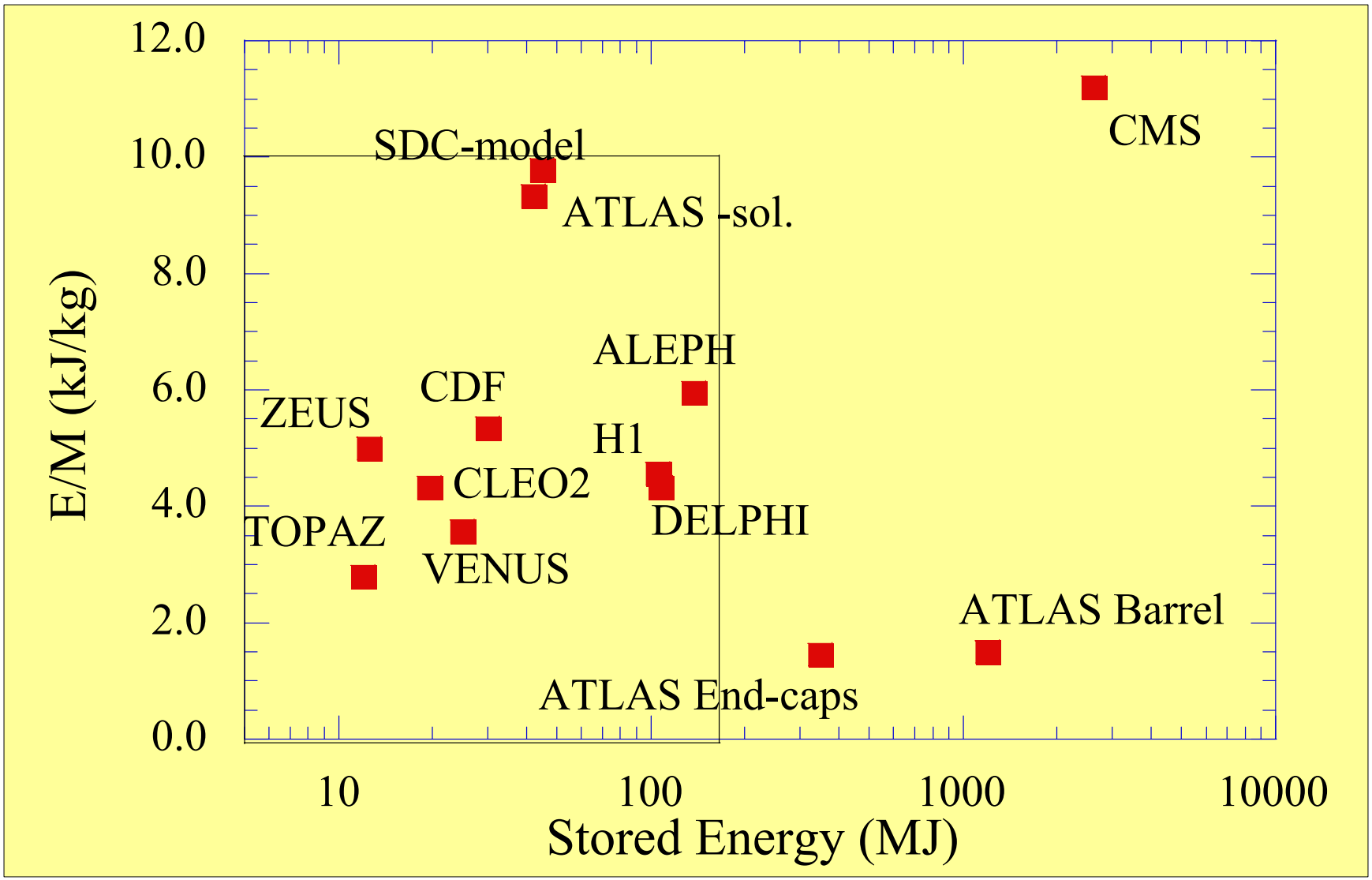


CMS magnet

- **Superconductive solenoid**
- **Magnetic length 12.5 m**
- **Diameter 6 m**
- **Magnetic field 4 T**
- **Nominal current 20 kA**
- **Stored energy 2.7 GJ:**

  largest ever in a single magnet

Specific Energy of the CMS Coil (kJ/kg of cold mass)

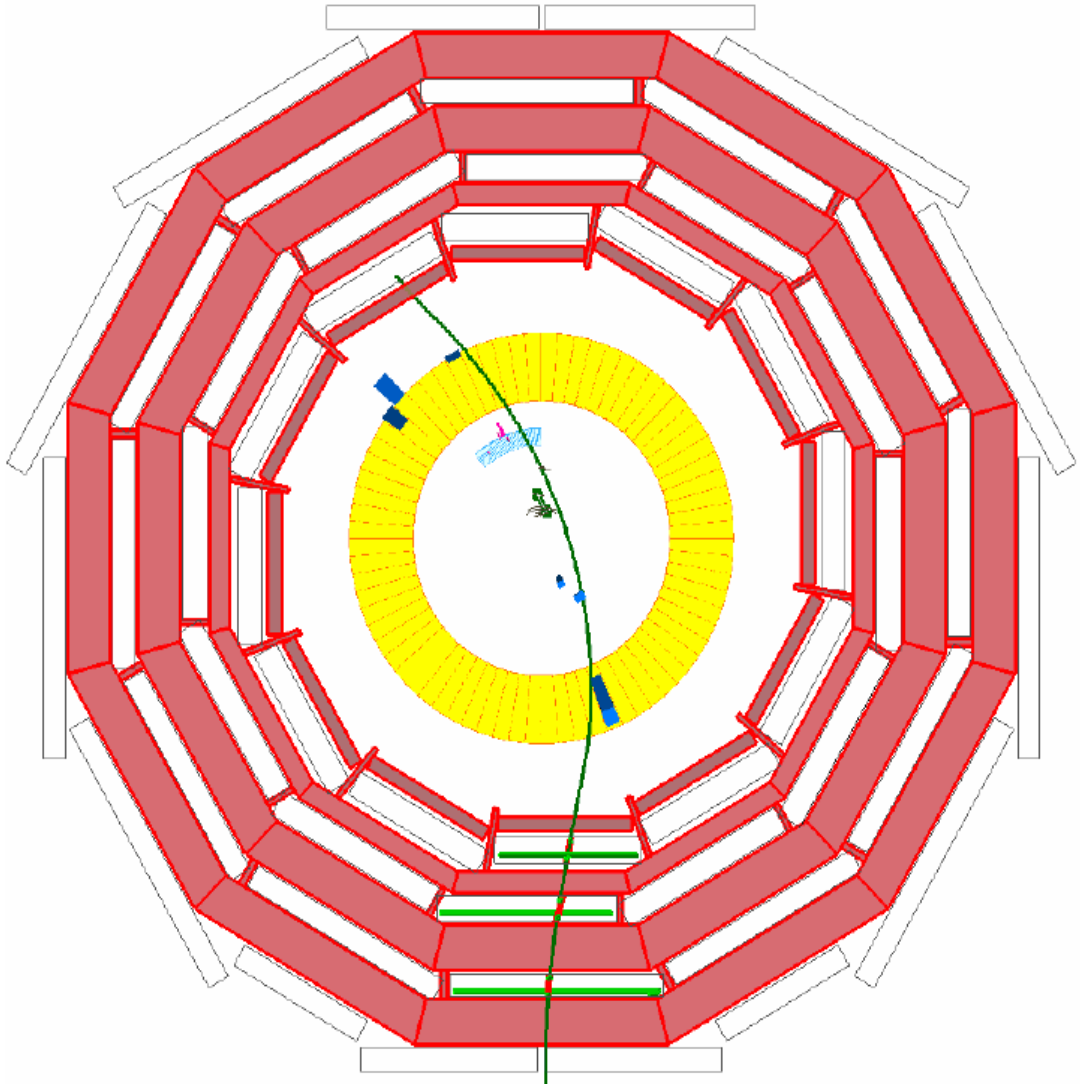


Run 2605 / Event 3981/ B 3.8 T/27.08.06

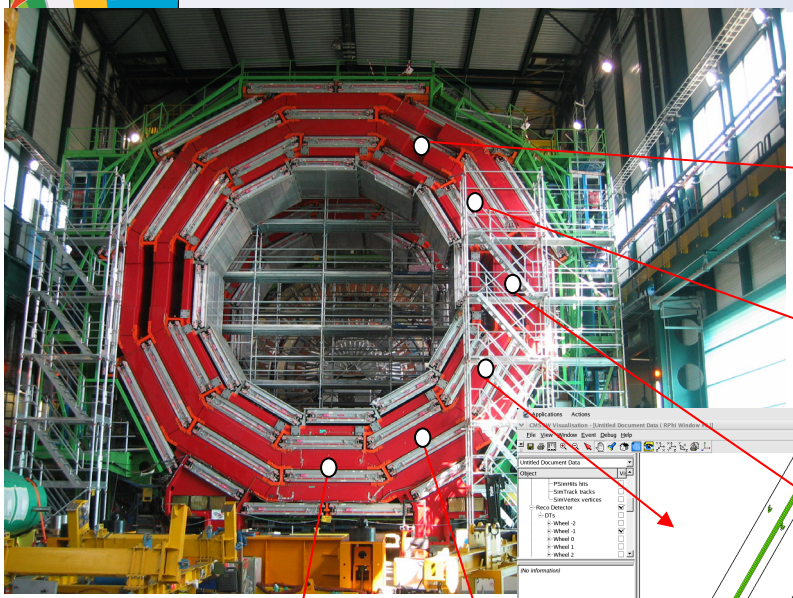
CERN PRESS RELEASE
13 September 2006

Mammoth CMS magnet reaches full-field at CERN

Tests show CMS detector will be ready for data

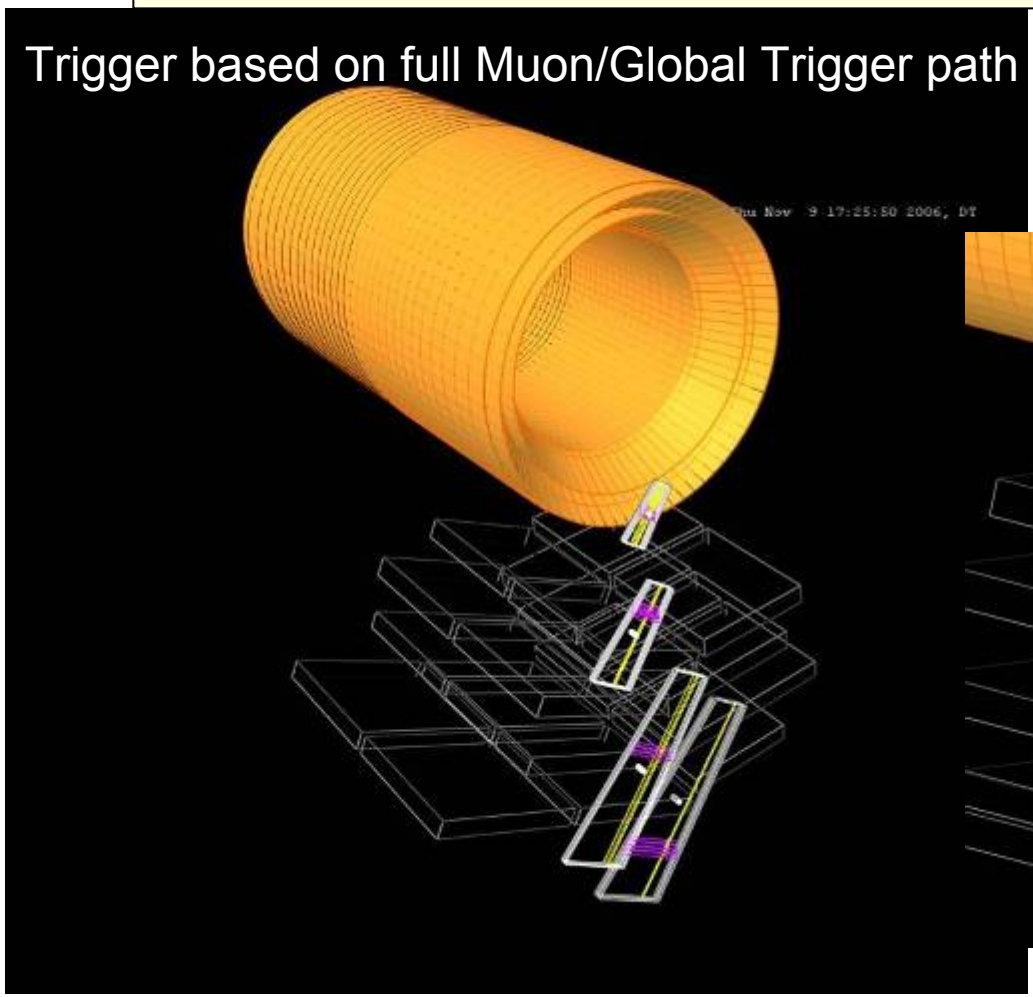


Muon Commissioning: MB-1 Stations in SX5

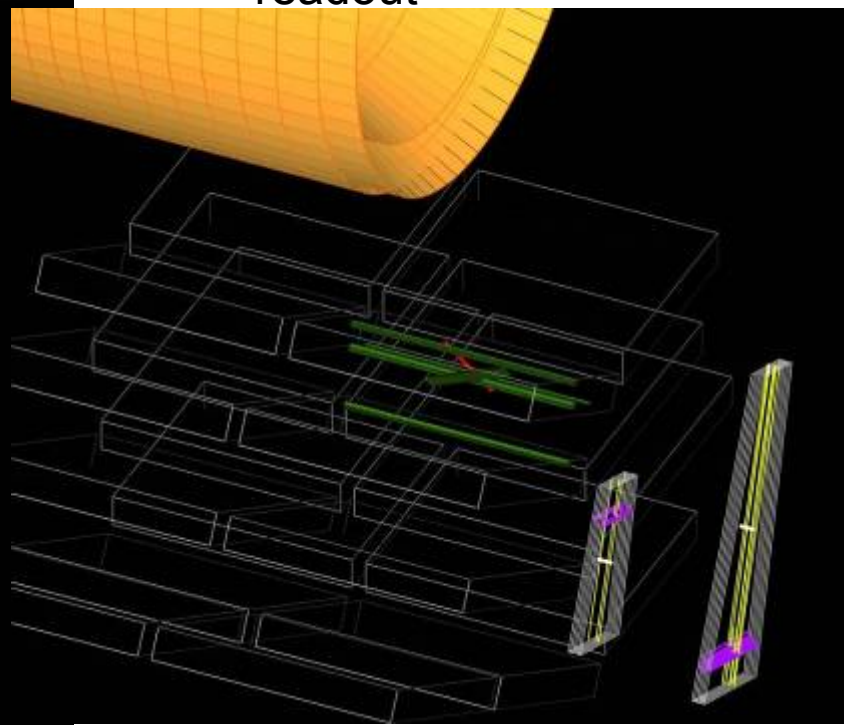


SX5: YB-1 DTs commissioned using cosmics

Cosmic Muons detected by CSCs

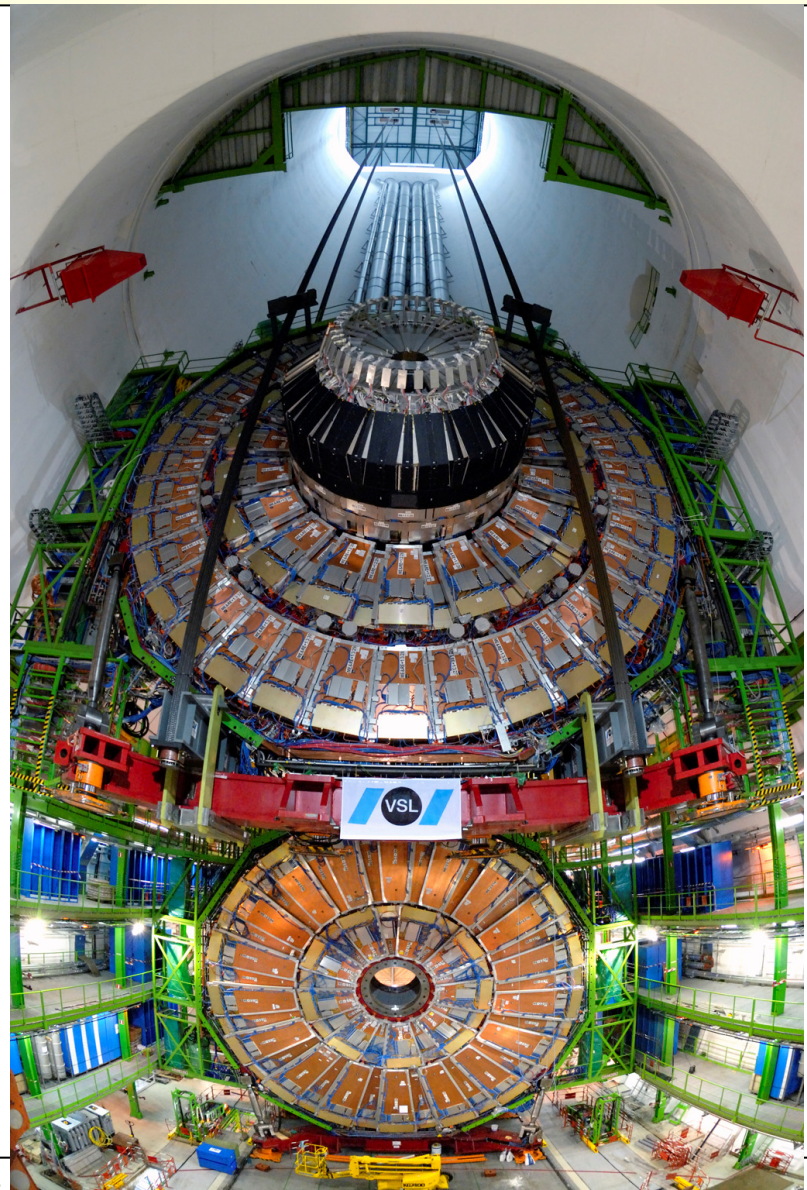


CSC/DT–GMT–GT trigger integration, with Global DAQ readout

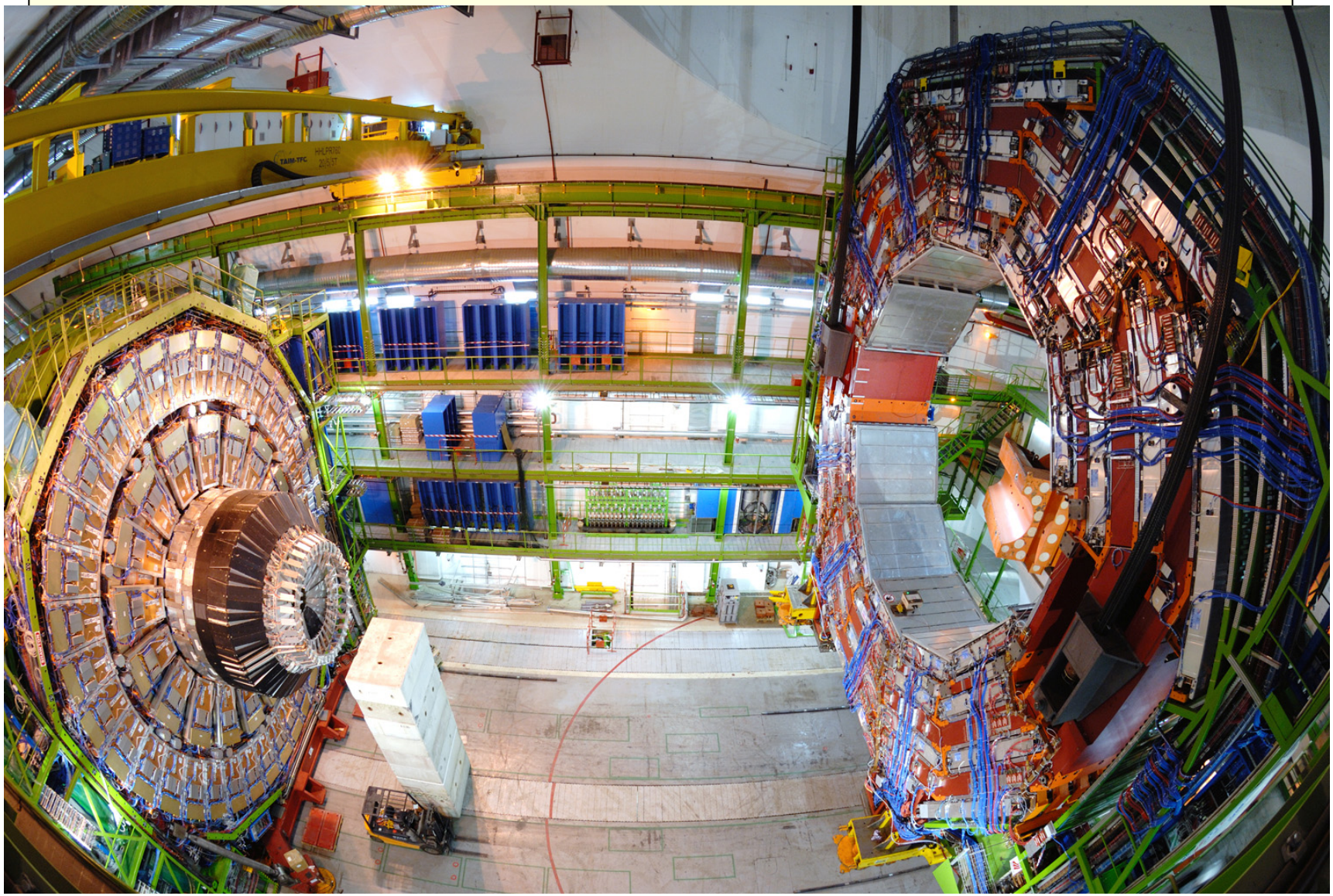


CSC+DT triggered event
(using GMT+GT)

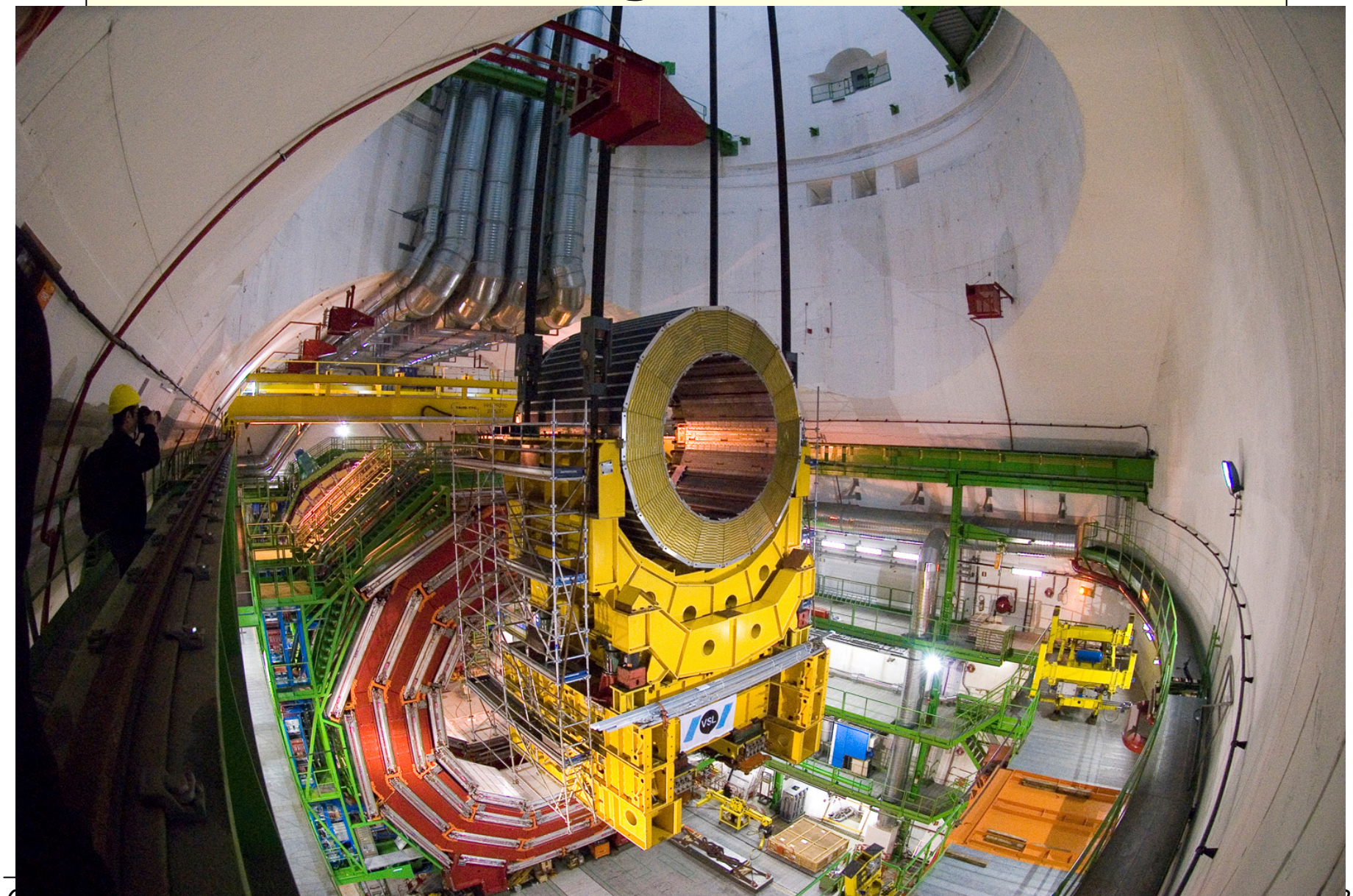
YE+1 Lowering (9 Jan 2007)



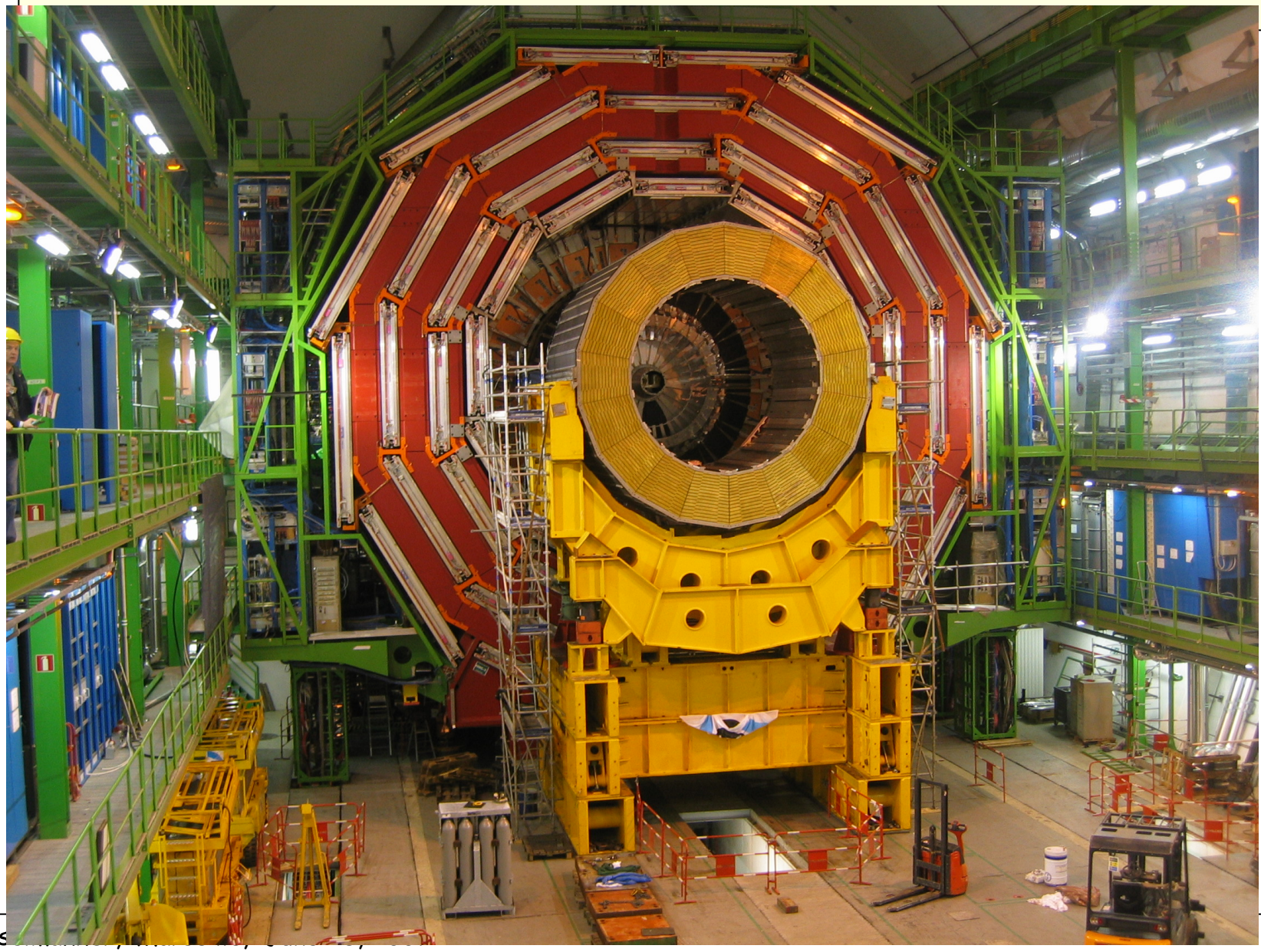
YB+2 Lowering (19 Jan, 2007)



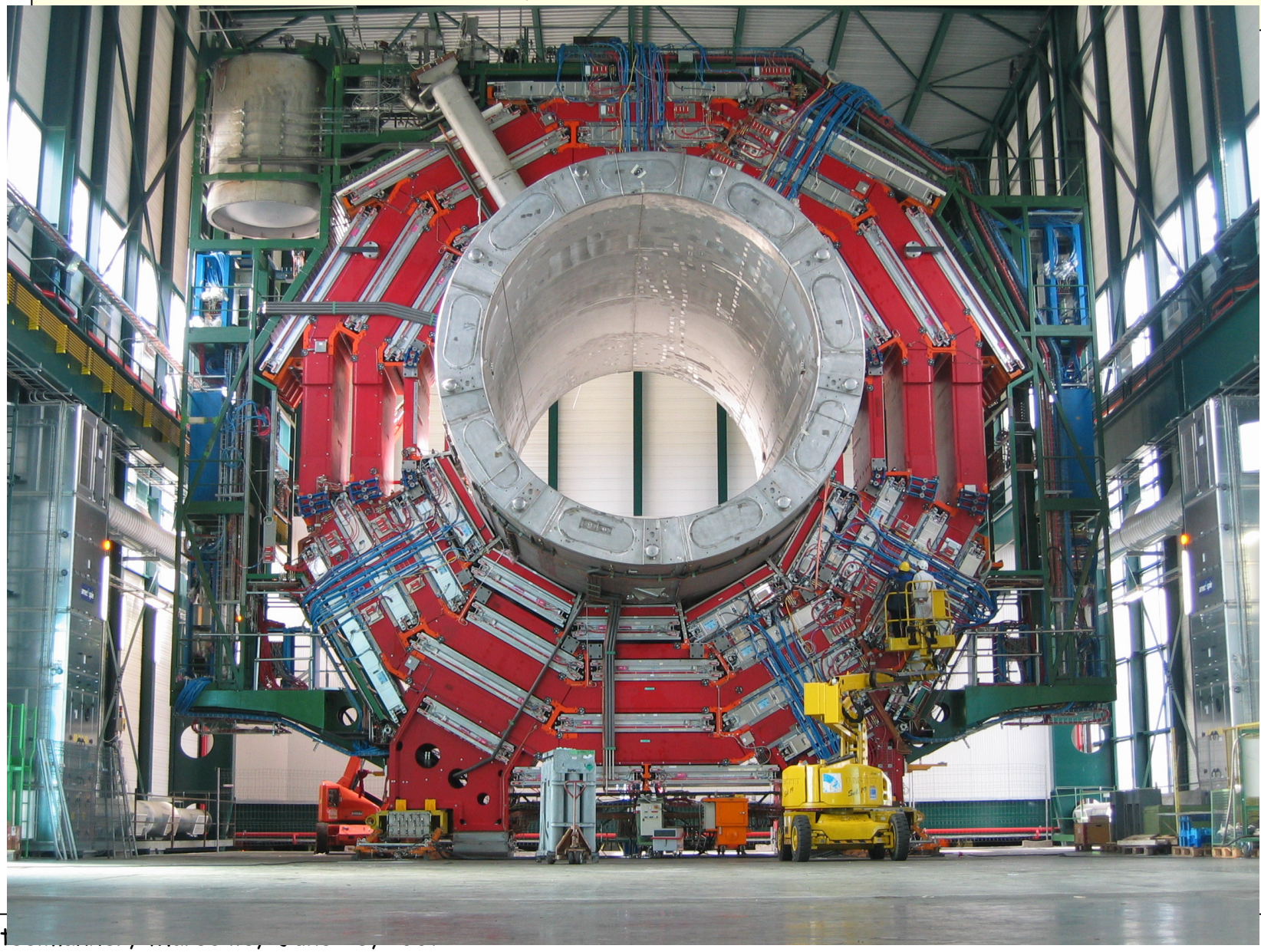
HB+ Lowering (13 Feb, 2007)



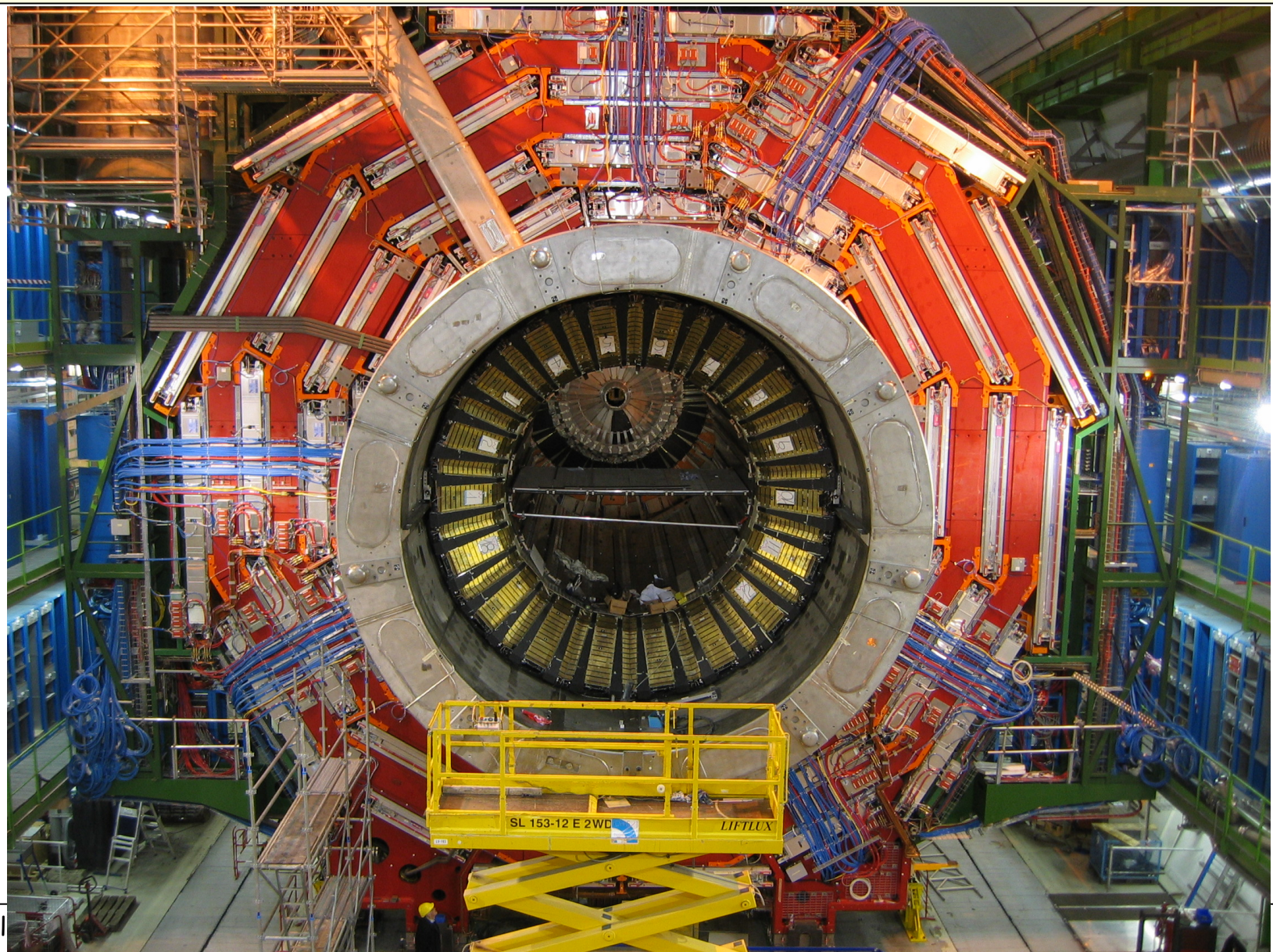
Situation in Cavern (23Feb, 2007)



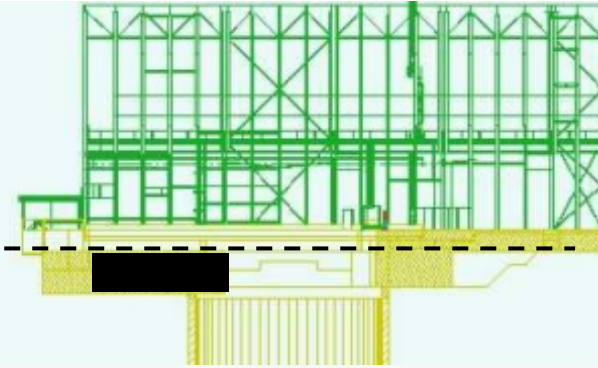
YBO (central piece of CMS) in SX5



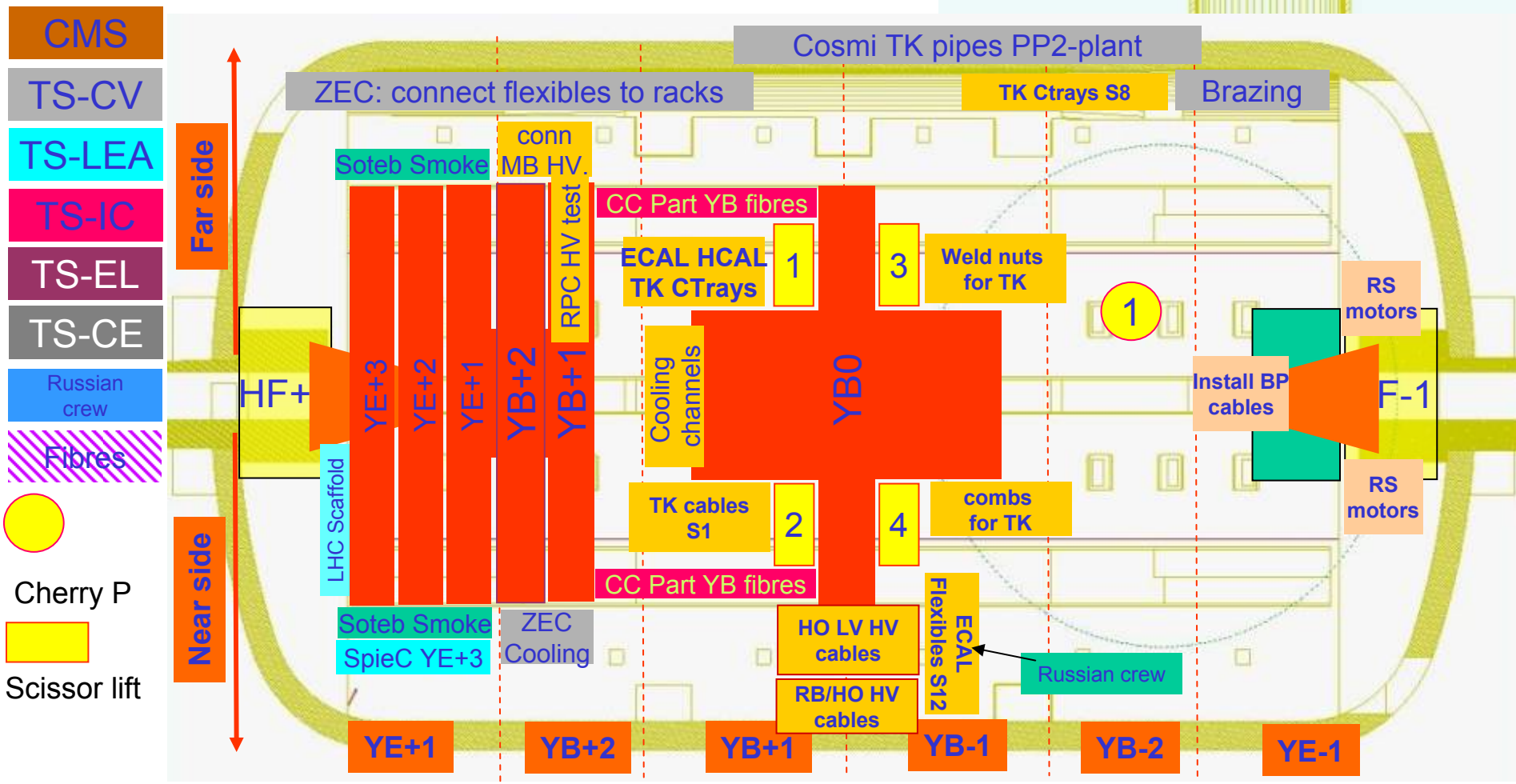
Situation in the Cavern after 1st Phase of Heavy Lowering (9 Apr)



CMS: Current situation (June 2007) in UX5 (underground detector hall)



ZEC: Leak test on YEs



Media Interest

CORRIERE DELLA SERA

Data 26-03-2007
Pagina 23
Foglio 1 / 2

Un superacceleratore al Cern di Ginevra per catturare il bosone di Higgs

E ora i fisici cercano la «particella di Dio»

Pronto il sistema che ricrea il Big Bang in laboratorio

BBC NEWS

OPEN The News in 2 minutes

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Last Updated: Wednesday, 28 February 2007, 13:49 GMT

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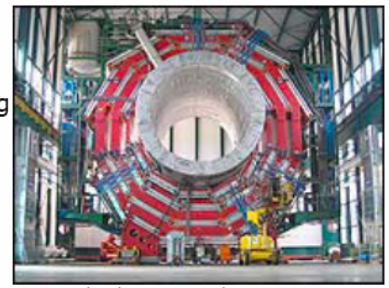
'It's like stepping on to a film set'

Construction of the Large Hadron Collidor, a giant underground particle accelerator, is reaching a major milestone as a key piece of machinery is lowered into the ground. BBC News Science Correspondent David Shukman reports from the scene.

It's like stepping onto the set of a James Bond film.

Or possibly something involving Austin Powers.

Everything here is on a vast scale; many tens of thousands of cables woven together, silicon sensors by the thousand, towering shapes of steel, impossibly complicated engineering and science.



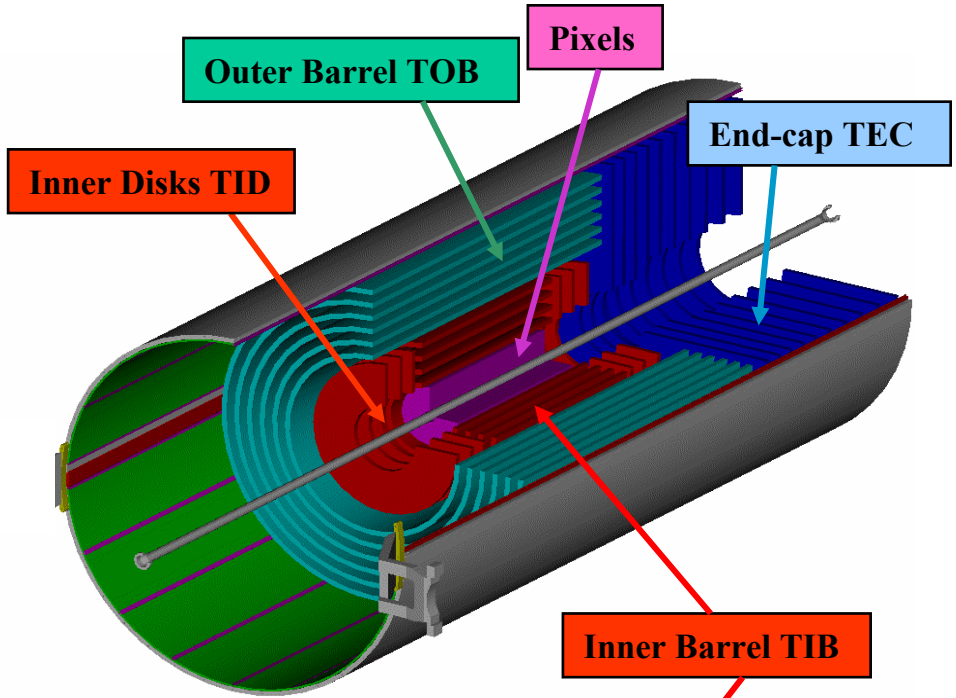
YB0 is the biggest and most impressive element of the CMS

La tension monte au CERN dans la course au boson de Higgs

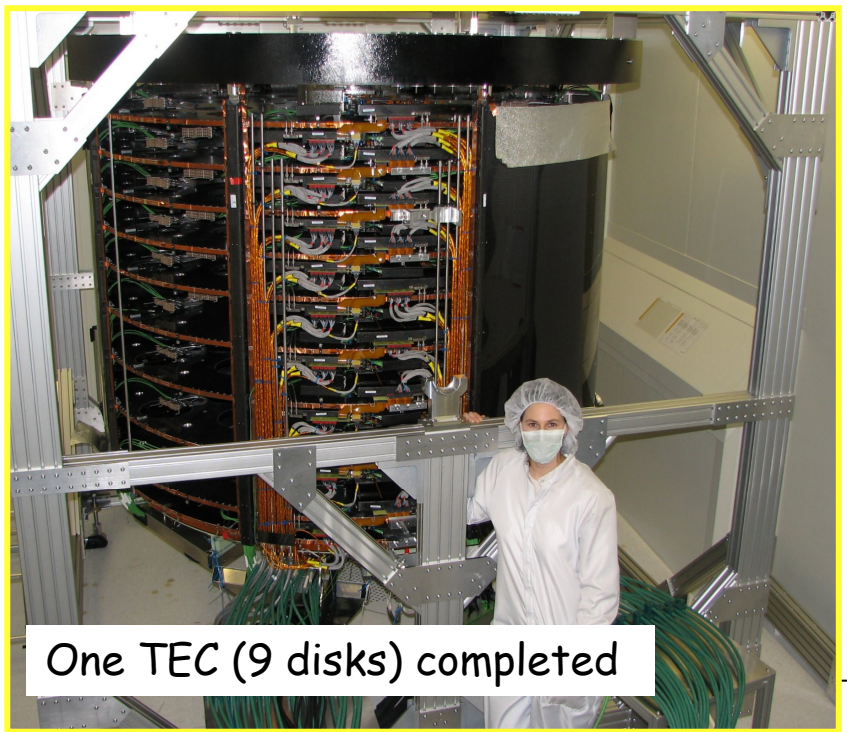
LE MONDE | 23.03.07 | 17h39 • Mis à jour le 23.03.07 | 17h39
CESSY (AIN) ENVOYÉ SPÉCIAL

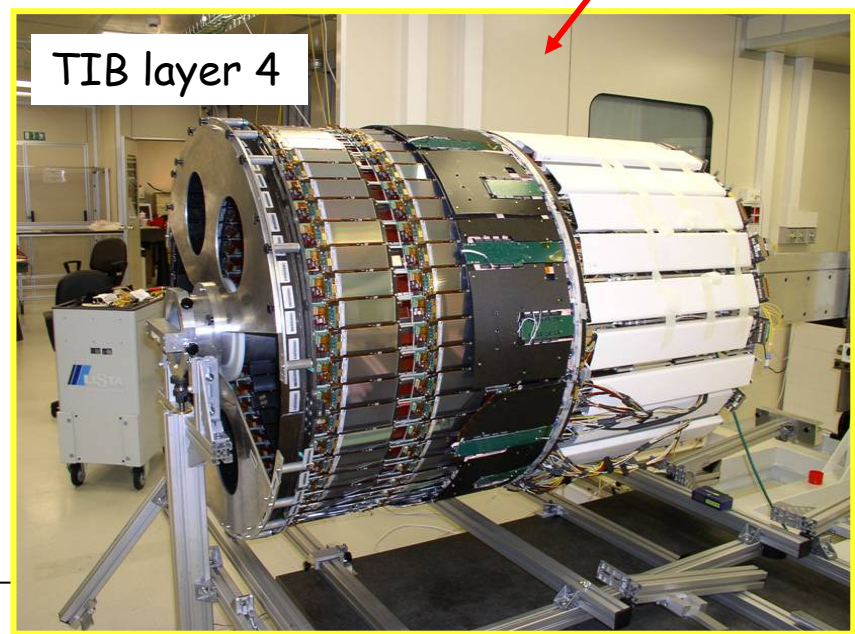
Les solennités ne s'éternisent pas au CERN (Organisation européenne pour la recherche nucléaire). En deux petites heures arrachées de haute lutte au planning du chantier, des discours calibrés, des visites chronométrées ont rendu hommage, jeudi 22 mars, à l'élégance compacte et aux performances hors du commun de CMS. ….

Inner tracker:
~ 220 m^2 of Si sensors
10.6 million Si strips
65.9 million Pixels



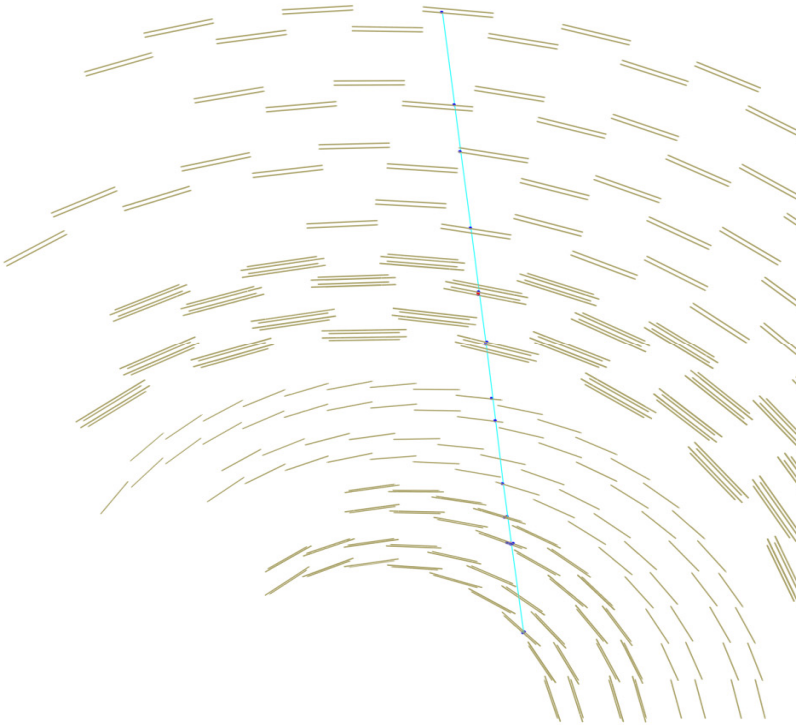
- Integration progressing well
- To be inserted in September 2007

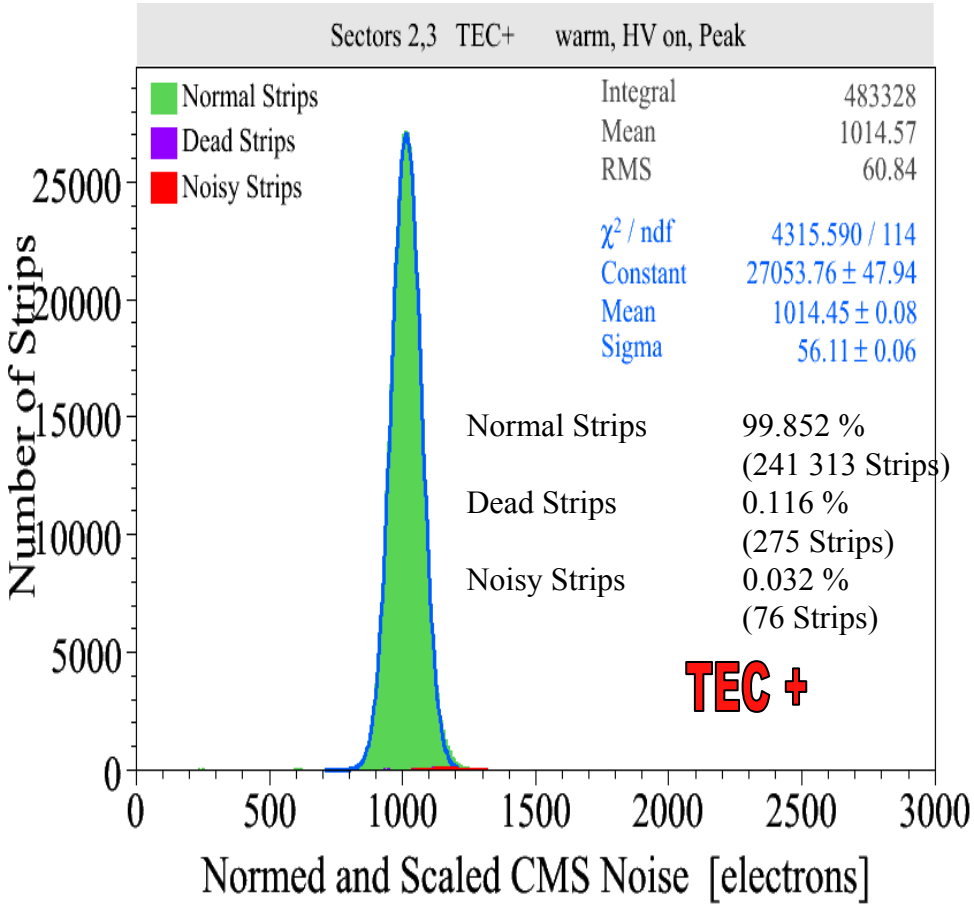

One TEC (9 disks) completed



Cosmics in the Tracker

Example of Performance



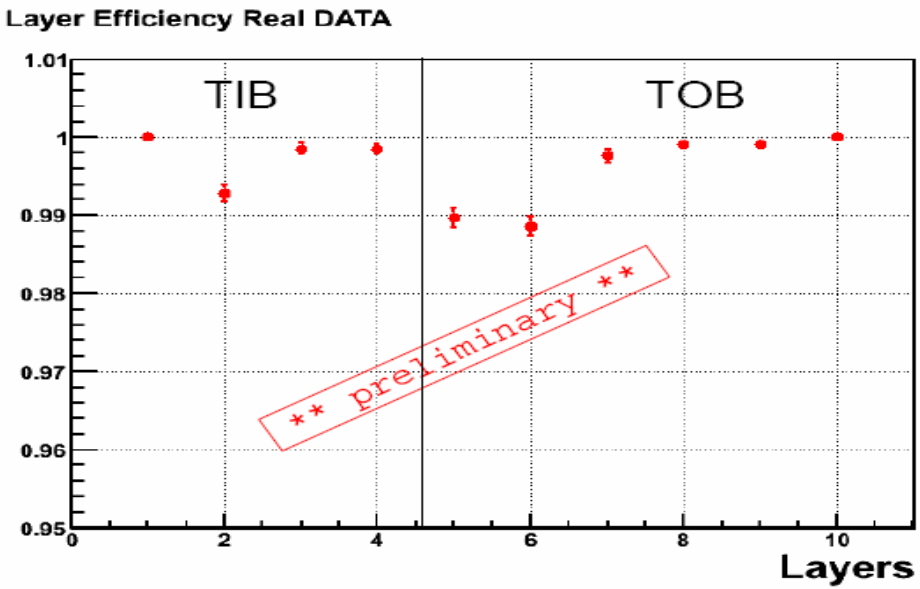


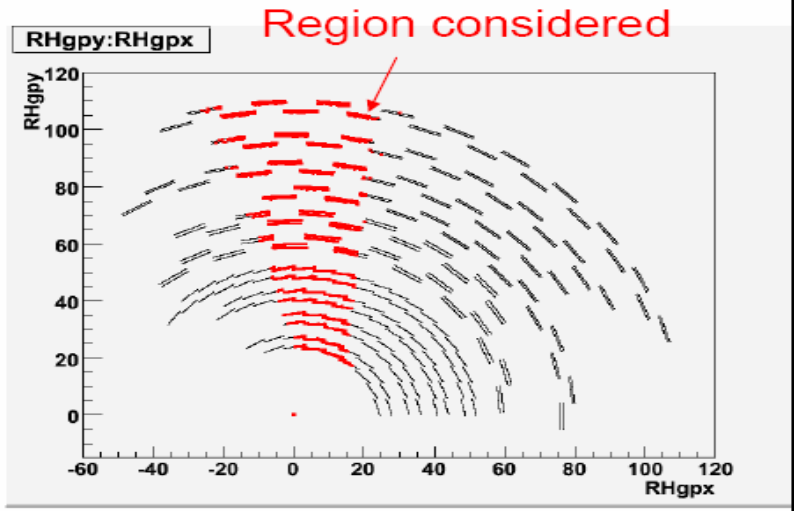
- **The Quality of the CMS Tracker is Excellent:**
- Dead or Noisy Strips < 3 / 1000
- Signal:Noise > 25:1 in Peak Readout Mode

1st Measurements of Efficiency of Tracker

Real Data: Layer efficiency Summary

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





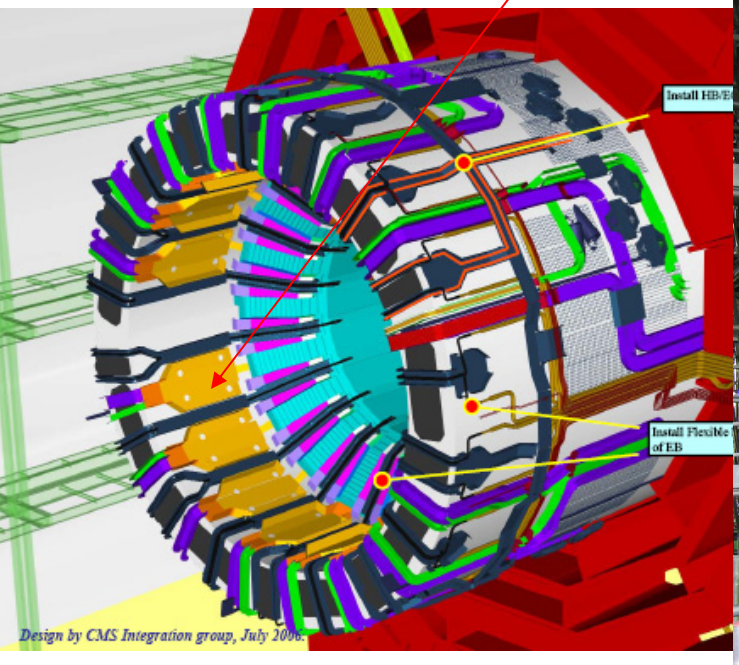
The layer efficiency in the region considered is more than 99.7% for single side layers and more than 99% for double side layers.
Further cross check need for double side layers.

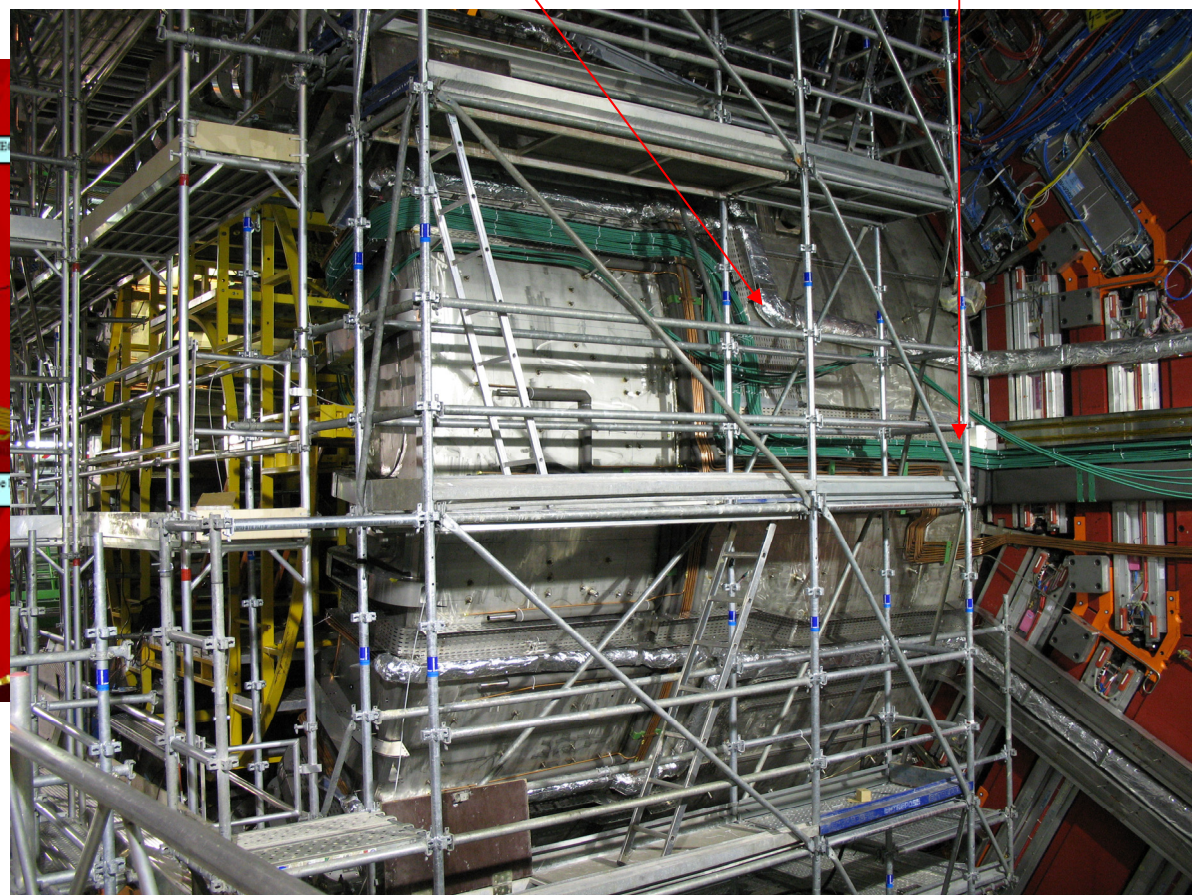
Installation of Services on YB0

The critical path, up to Tracker Insertion (in Sept), goes through the installation of services on YB0

+ end: Tracker patch panels (PP1s), & pipes installed and insulated, tracker cables being installed, then instal ECAL SMs in July, L0 scint, then ECAL/HCAL services

- end: tracker patch panels &ECAL, L0 scint. installed, start tracker pipes installation last week, then tracker cabling, ECAL/HCAL services





Pixels

Barrel

Module production: 600 out of 800 modules produced
Support Tube OK
12 module system test being conducted
Material budget expected to smaller than in simulation
Commissioning system ready by early autumn, final system one side by Nov and the second in January.

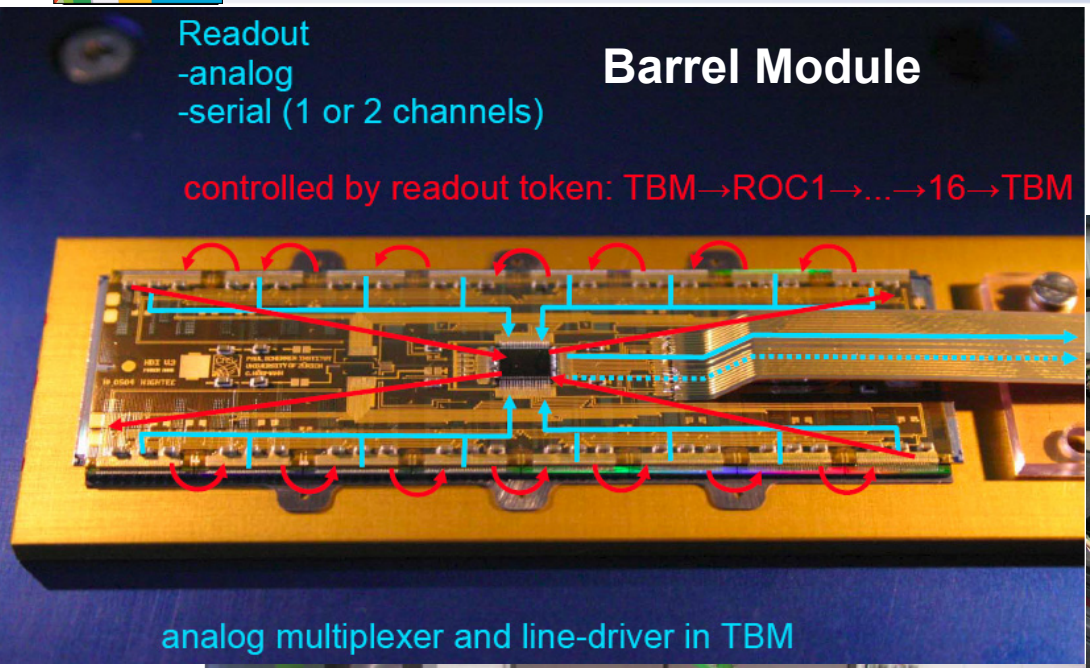
Endcap

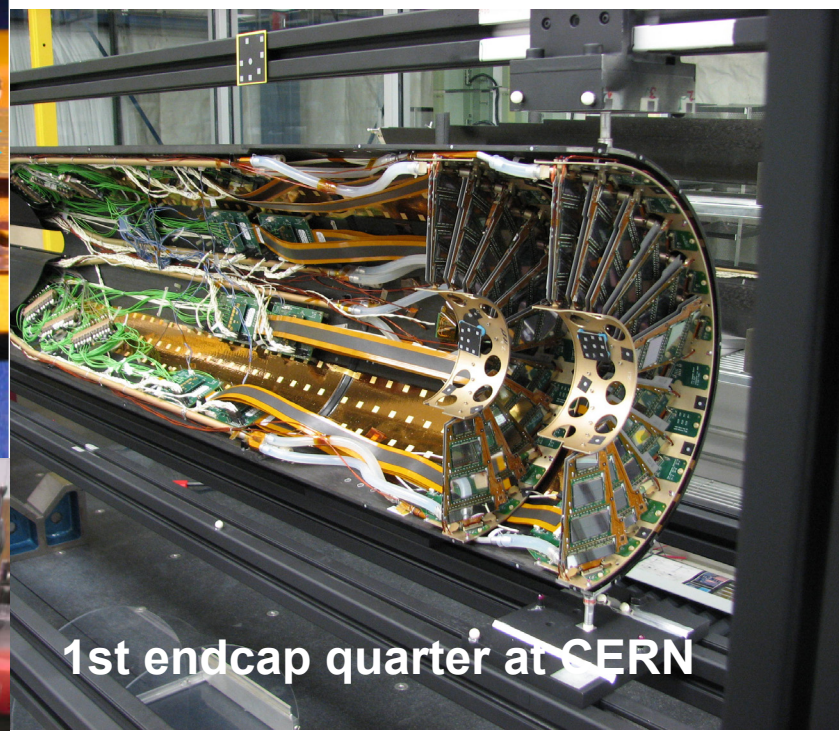
1st quarter delivered to CERN in May, the last quarter by Sept/Oct

Concern

Time needed to install

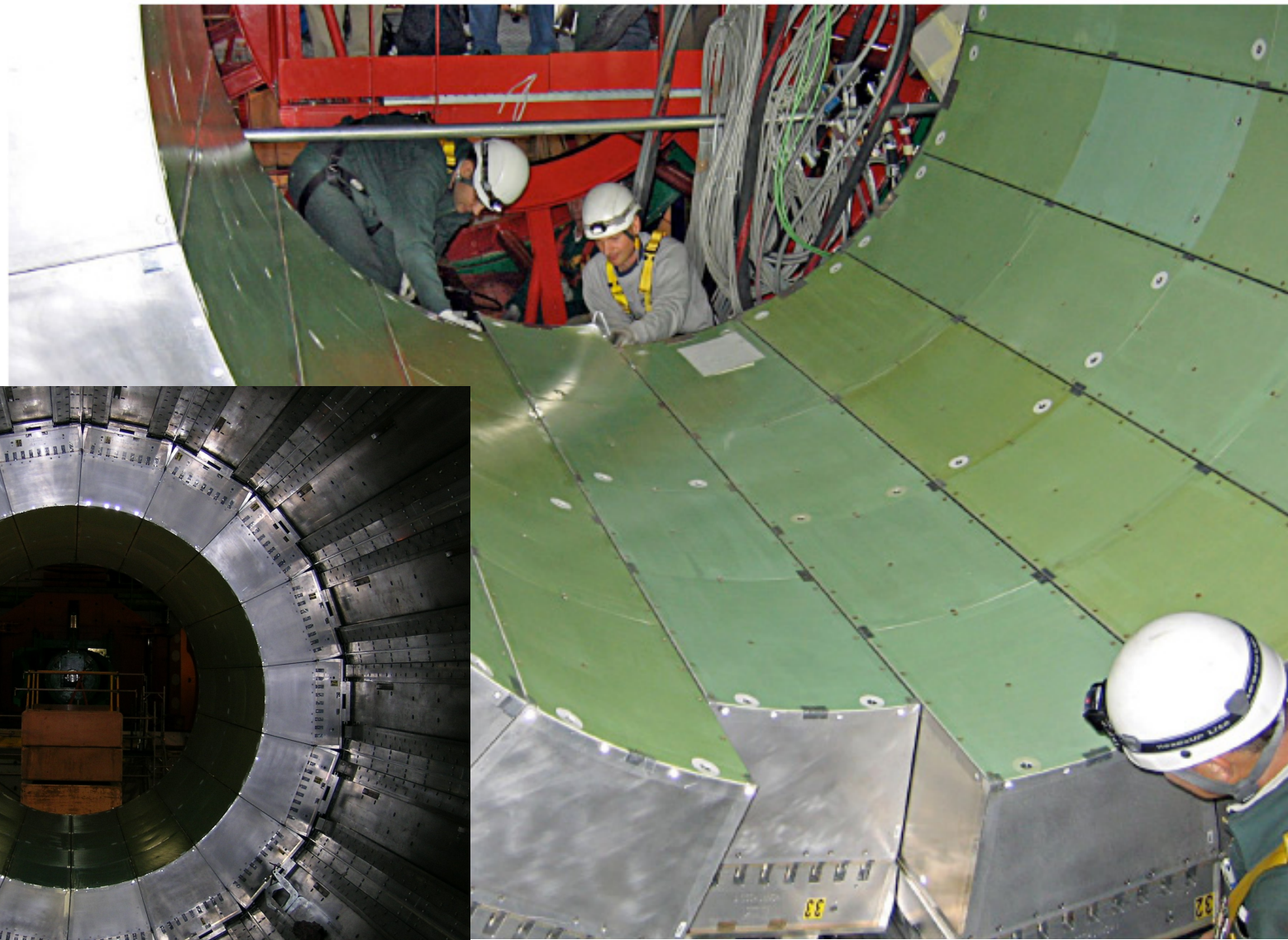
Pixels


Readout
-analog
-serial (1 or 2 channels)
Barrel Module
controlled by readout token: TBM→ROC1→...→16→TBM
analog multiplexer and line-driver in TBM


1st endcap quarter at CERN

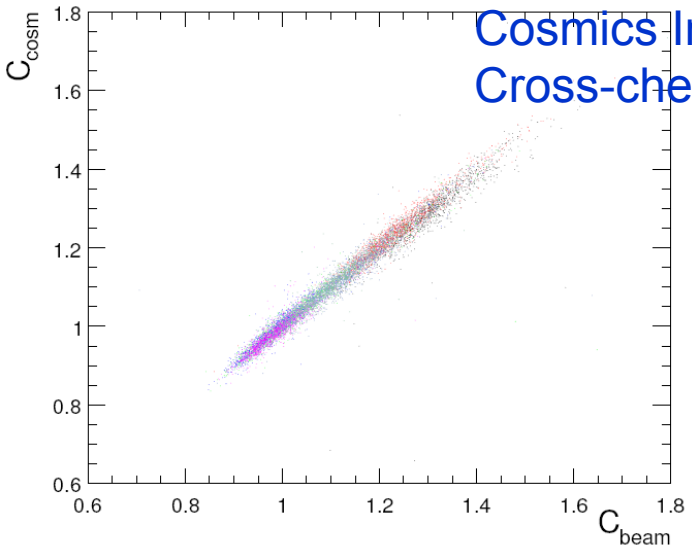

Barrel Support Tube

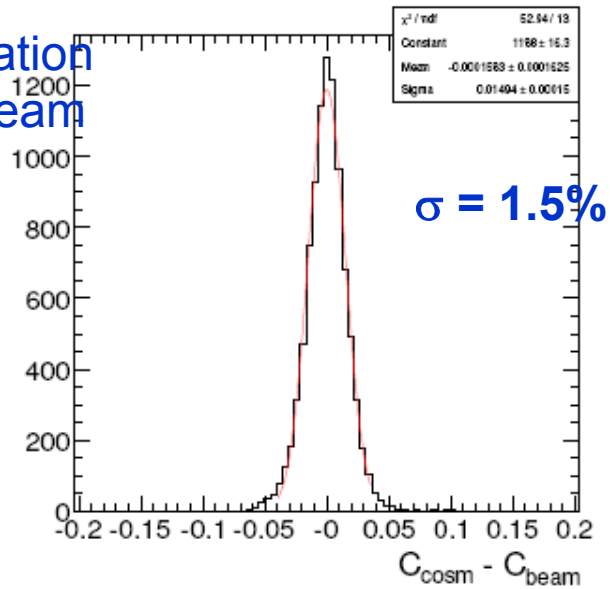
EB- Installation Completed



ECAL EB Calibration

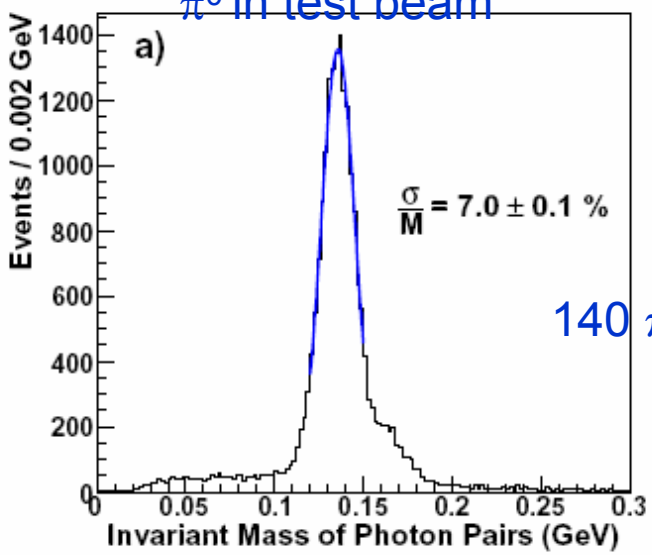
Cosmics Intercalibration
Cross-checked in beam



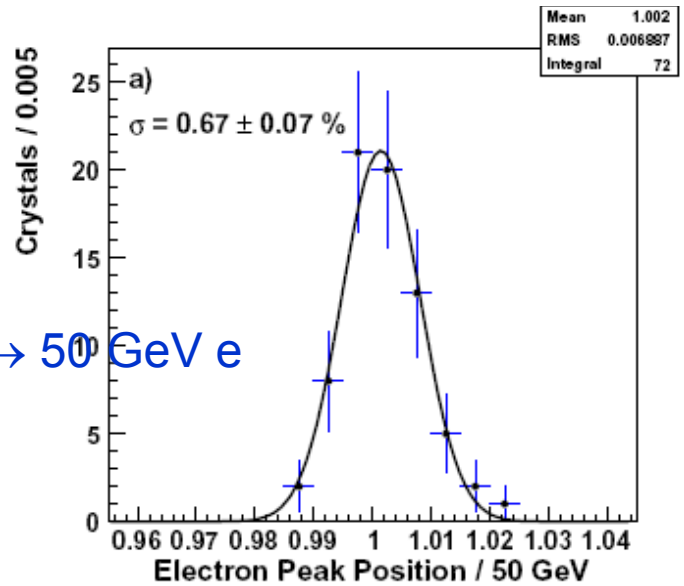


$\sigma = 1.5\%$

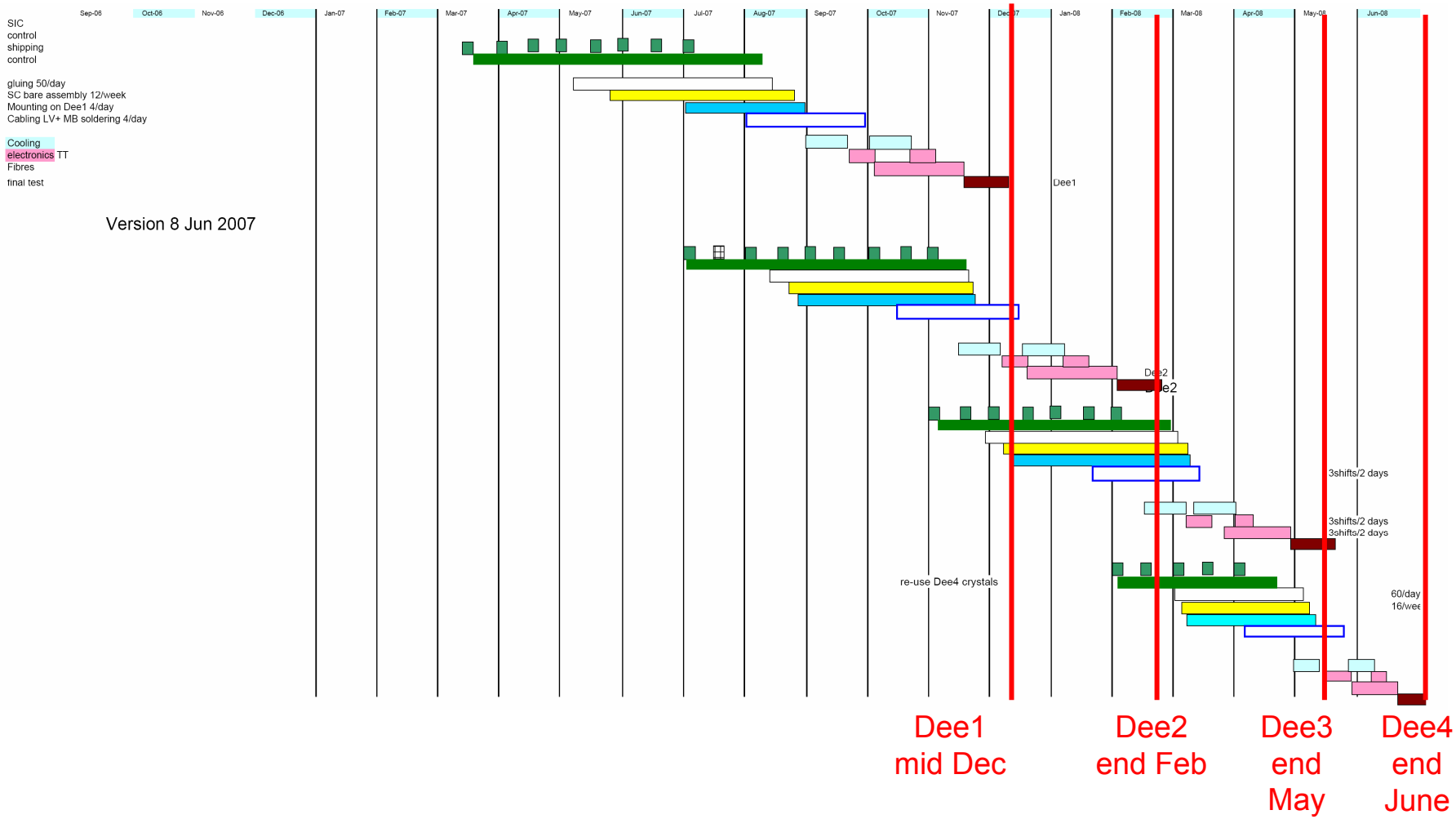
π^0 in test beam



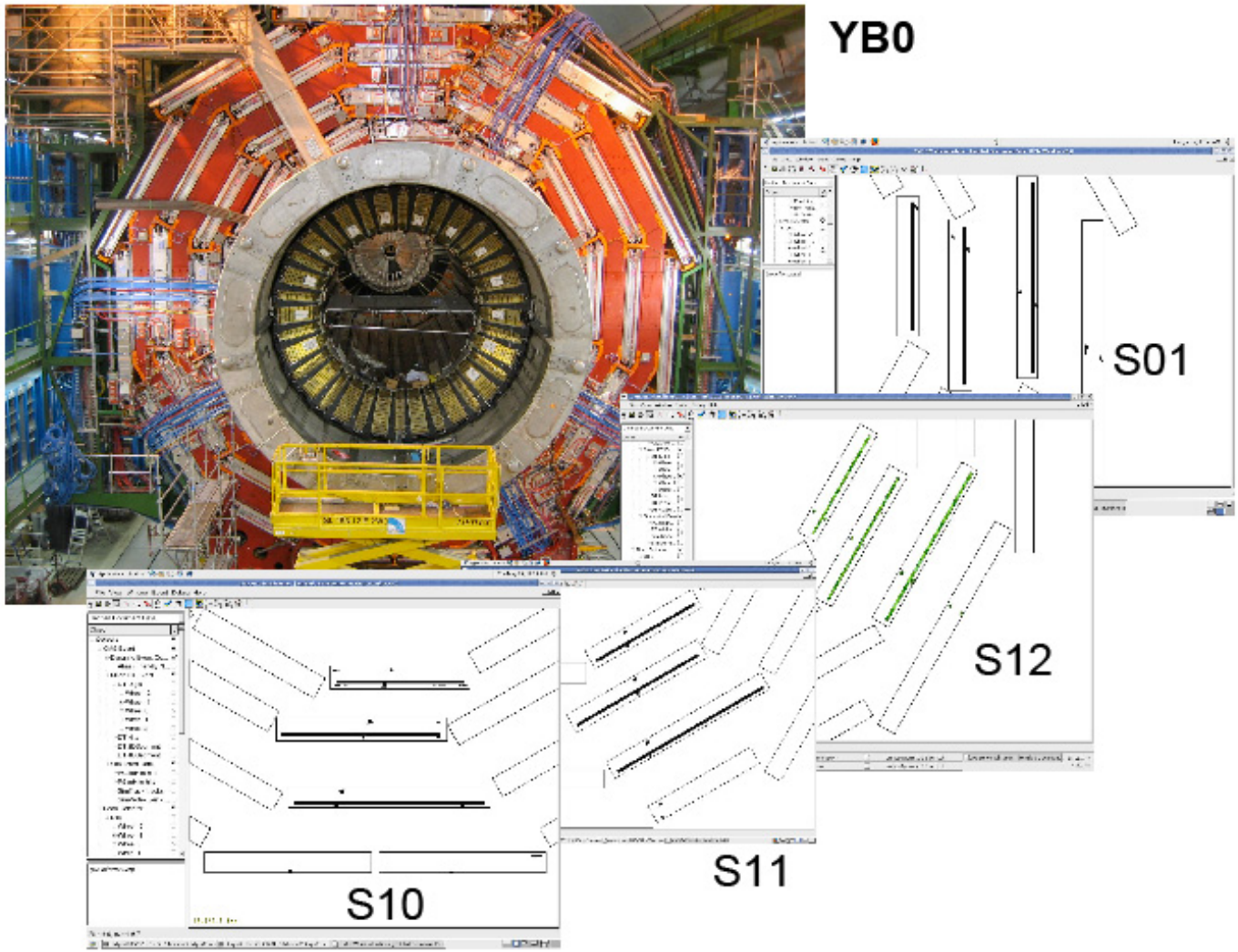
140 π^0/ crys → 50 GeV e



ECAL Endcap Schedule



Muon Commissioning: MB0 Stations in the cavern



1) Detector Installation, Commissioning & Operation

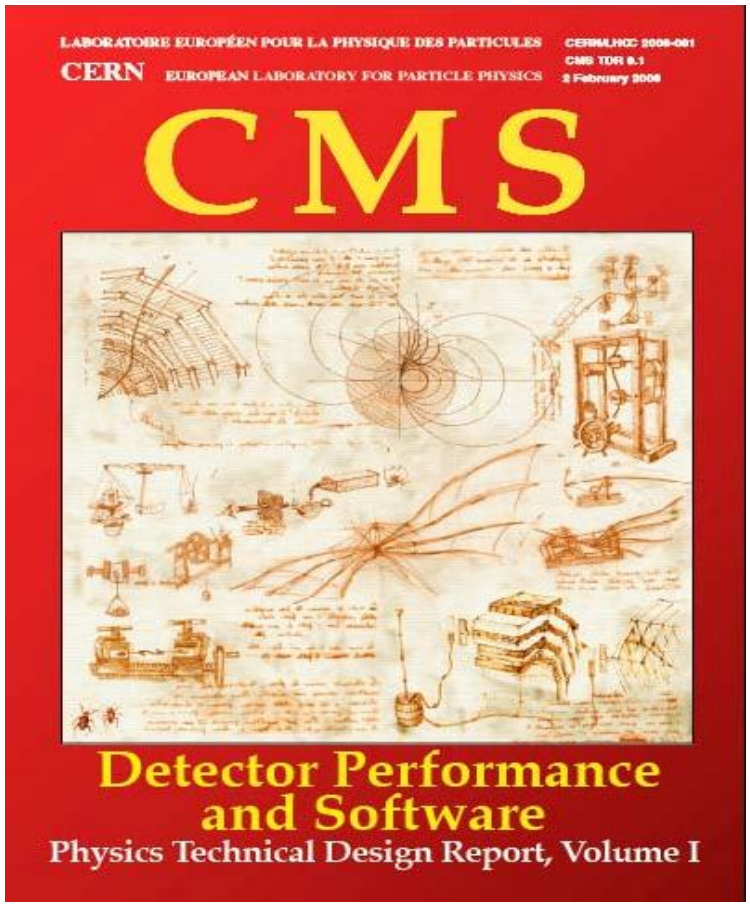
2) Preparation of Software, Computing & Physics Analysis

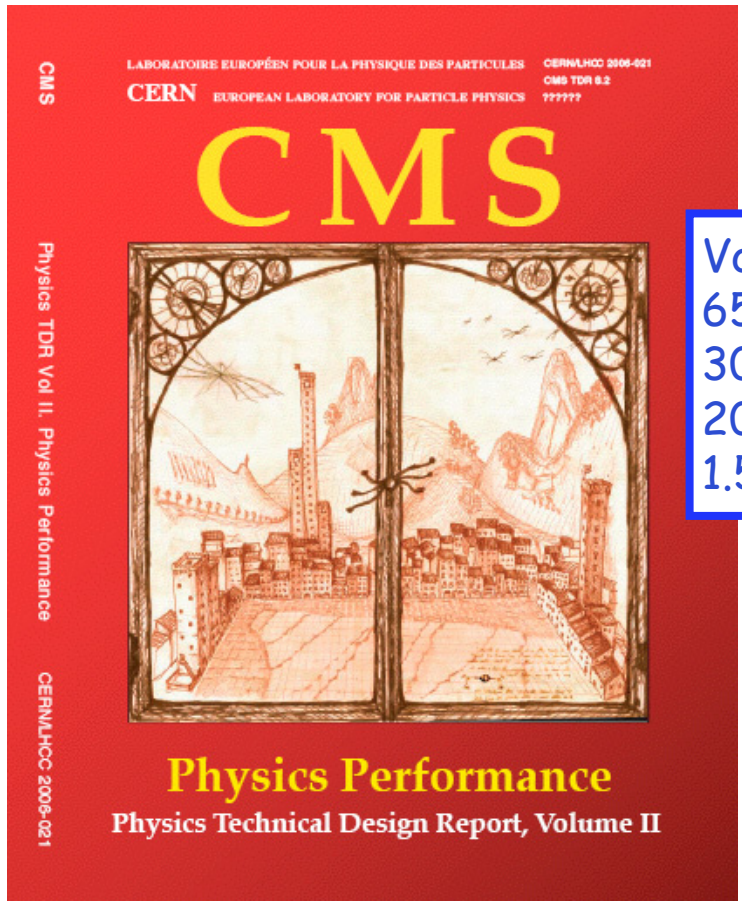
	June	HLT Exercise
Barrel ECAL Inserted	July	Pre CSA07
	Aug	S/w Release 1_6 (CSA07, CCR1)
Trigger/DAQ Ready Commissioning	Sep	CSA07
Tracker Inserted	Oct	S/w Release 1_7 (CCR2, HLT Validation)
CMS Cosmic Run (CCR) Phase 1 Test Magnet at low current Tracker cabled & Commissioned Last Heavy Element Lowered	Nov	2007 Physics Analyses Completed
CMS Cosmic Run Phase 2 (YB0)	Dec	S/w Release 1_8 (Lessons of '07)
CMS Cosmic Run Phase 3	Jan	
Beam-pipe Closed	Feb	S/w Release 2_0_x (Production of startup MC samples)
Pixels installed CMS Cosmic Run Phase 4 (4T)	Mar	MC Production for Startup

Overall Plan & Physics

- **Global priorities:**
  - Detector completion and commissioning
  - Detector Performance
  - Physics Objects
  - Physics Analysis
- **Physics-wise: focus on discovery**
  - **Standard Model studies: a necessary step**
    - Obviously, lots of good physics there as well
    - But priority is in preparing for the main physics (new) that the LHC is conceived for
- **And, to do physics we also need to:**
  - Complete and commission trigger
  - Complete software
  - Deploy computing model – and use it effectively

CMS Physics Technical Design Reports





Volume II
650 pages
308 figures
207 tables
1.50 Kg

http://cmsdoc.cern.ch/cms/cpt/tdr/

CERN/LHCC 2006-001
February 2006

CERN/LHCC 2006-021
June 2006

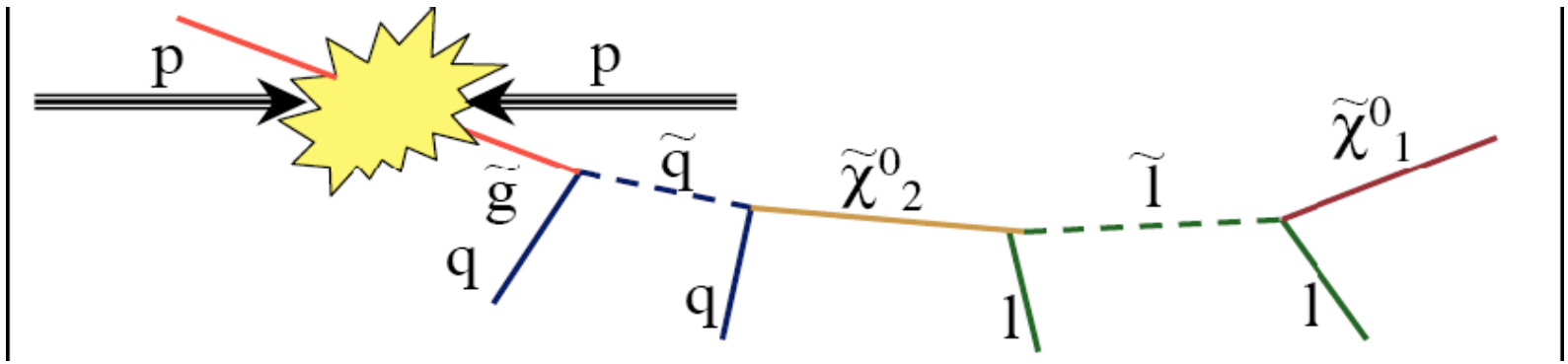
What New Physics can we probe early?

Major discoveries are possible with low luminosity

- **A number of possible signals both from the SM and from beyond**
  - **SUSY: <500 GeV sparticles: large production cross section, spectacular signatures.**
  - **Higgs: can exclude large range of masses**
  - **Extra dimensions: significant reach Z' etc**
  - **Compositeness: reach multi-TeV very fast**
- **Of course, all these signals can be claimed only after the Standard Model channels are adequately measured**
  - **QCD jets**
  - **b-quark production**
  - **Drell-Yan**
  - **W + Z production (plus jets); multibosons (WW, WZ, ZZ)**
  - **Top quark**

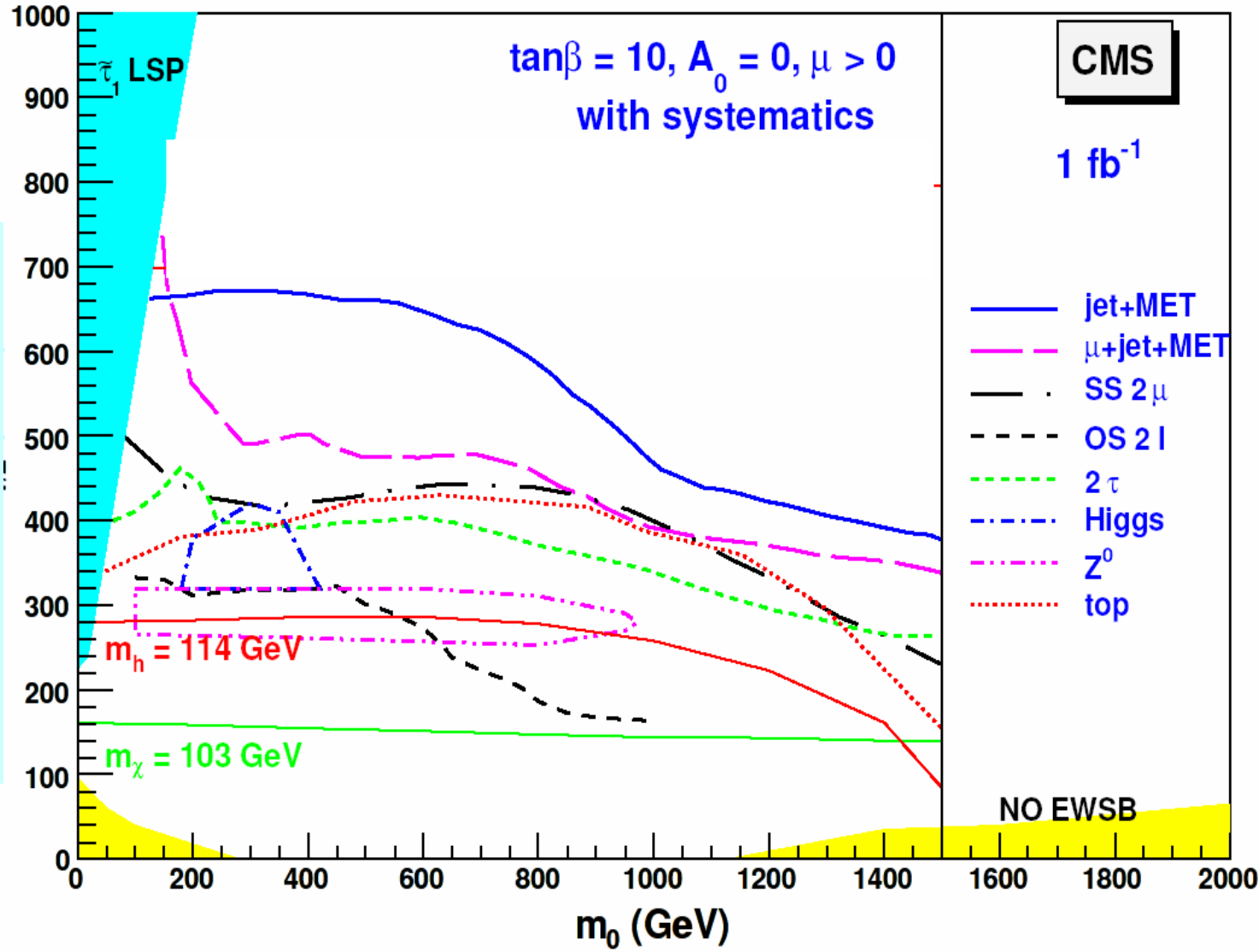
Direct Search for SUSY particles

- Susy Particles at LHC will be produced in strong interactions: large cross section make early discovery possible
- The production is followed by a SUSY+SM cascade.



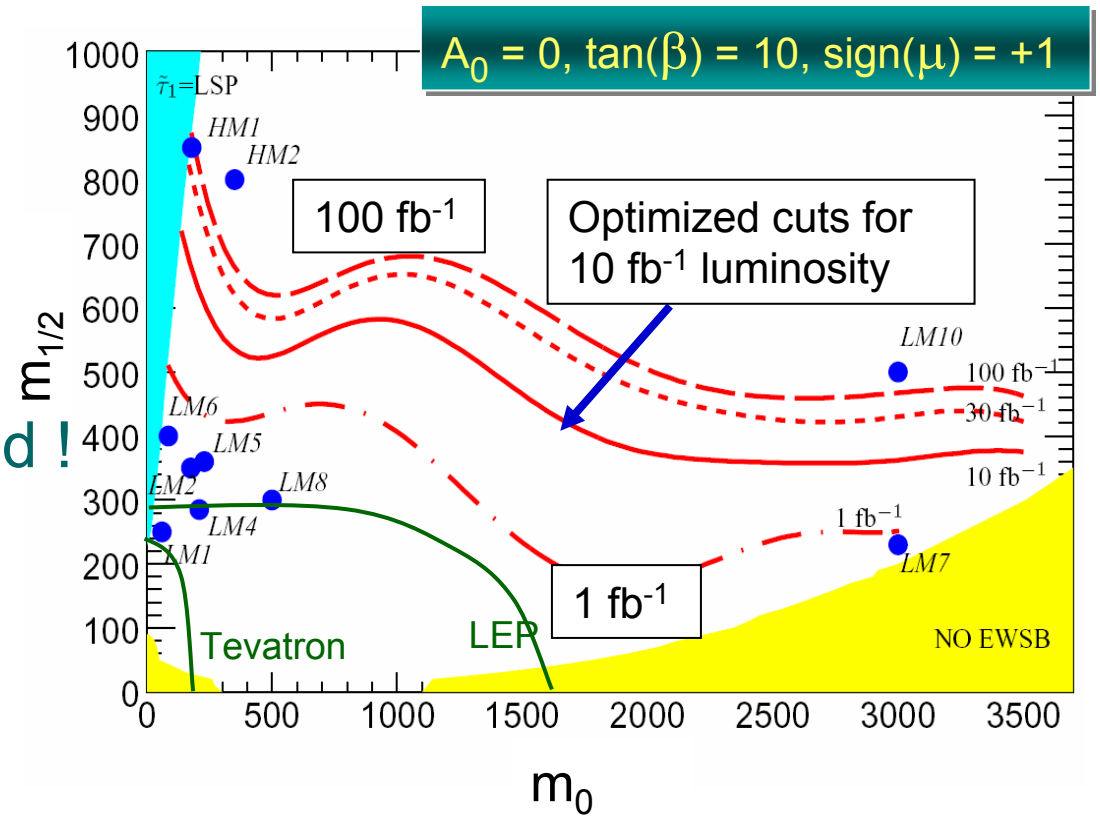
Discovery Physics: SUSY: need to understand missing Et !!!

1fb^{-1}
5 sigma discovery reach.



My favorite channel: Same-Sign Muons

- Trigger on two muons, Clean and efficient
- Low,low SM background !
  1.5 events at 10 fb-1,
  Systematic uncertainty ~20%
- Possibility to measure directly SUSY contribution (Low SM background)

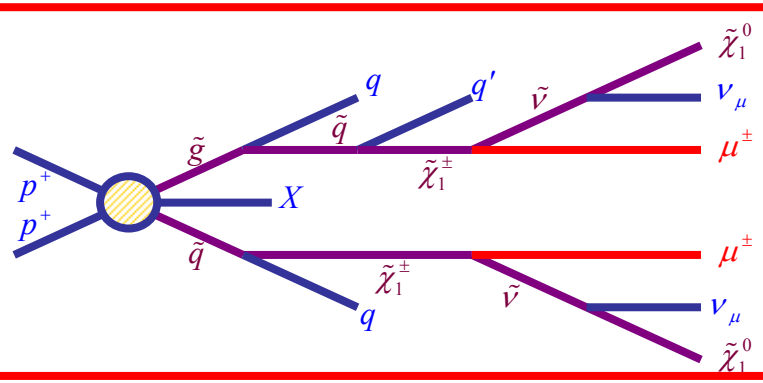


Sample(s)	Events	Sample	Events	Sample	Events
SM	1.5	LM5	61	LM10	4
LM1	341	LM6	140	HM1	4
LM2	94	LM7	82	HM2	2
LM4	90	LM8	294		

SUSY 2SS Muons production

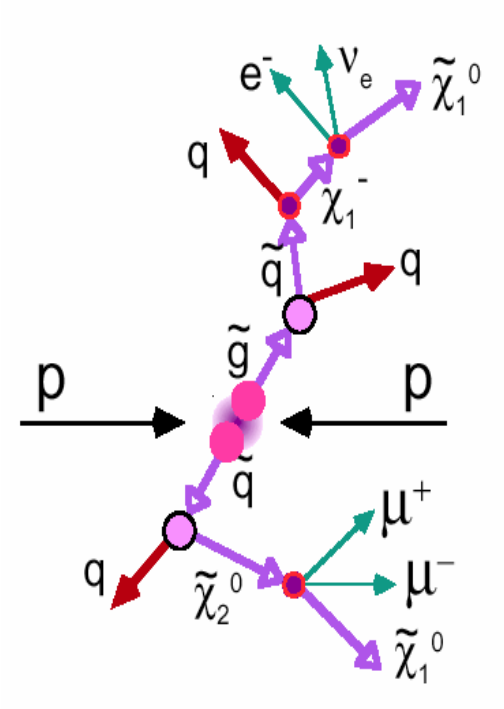
- Gluino dominantly decays via ~g → q qbar $\tilde{X}^{\pm}_1$ unless this decay is kinematically suppressed.
  - Br(~g → q qbar $\tilde{X}^{\pm}_1$) ~ 0.5
- Chargino decays via $\tilde{X}^{\pm}_1$ → $\tilde{X}^{0}_1$ ν_l l, where is l=e/μ
  - Br($\tilde{X}^{\pm}_1$ → $\tilde{X}^{0}_1$ ν_μ μ) ~ 0.22
- Hence, fast isolated lepton will be contained in ~2*0.5*0.22~1/5 of all produced gluino events
- We may expect ~(0.5)^2*(0.22)^2~1% of the total number of gluino pair events to contain 2 leptons. Half of the dilepton events from chargino decays of gluino contain a like-sign lepton pair.
- Muons: trigger is clean and easier to understand especially at start up

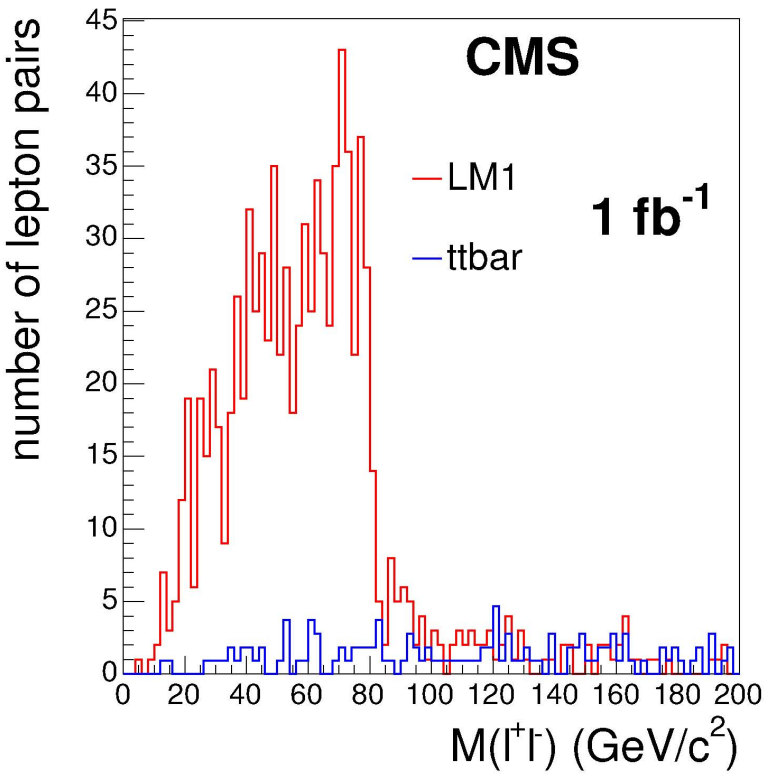
Example of 2 same-sign muon production in ~g~q event



If we are very lucky…

Squarks & gluinos





For some sets of SUSY parameters low energy SUSY may have spectacular signatures! (Leading edge in two opposite sign muons)

With our powerful computing we can simulate even a discovery paper…

6 December 2008

Evidence for squark and gluino production in pp collisions at $\sqrt{s}$ = 14 TeV

CMS collaboration

Abstract

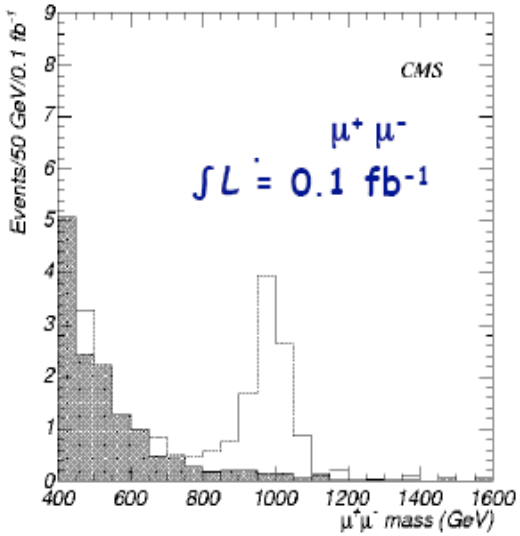
Experimental evidence for squark and gluino production in pp collisions $\sqrt{s}$ = 14 TeV with an integrated luminosity of 97 pb^{-1} at the Large Hadron Collider at CERN is reported. The CMS experiment has collected 320 events of events with several high E_T jets and large missing E_T, and the measured effective mass, i.e. the scalar sum of the four highest P_T jets and the event $\not{E}_T$, is consistent with squark and gluino masses of order of 650 GeV/c^2. The probability that the measured yield is consistent with the background is 0.26%.

Submitted to *European Journal of Physics*

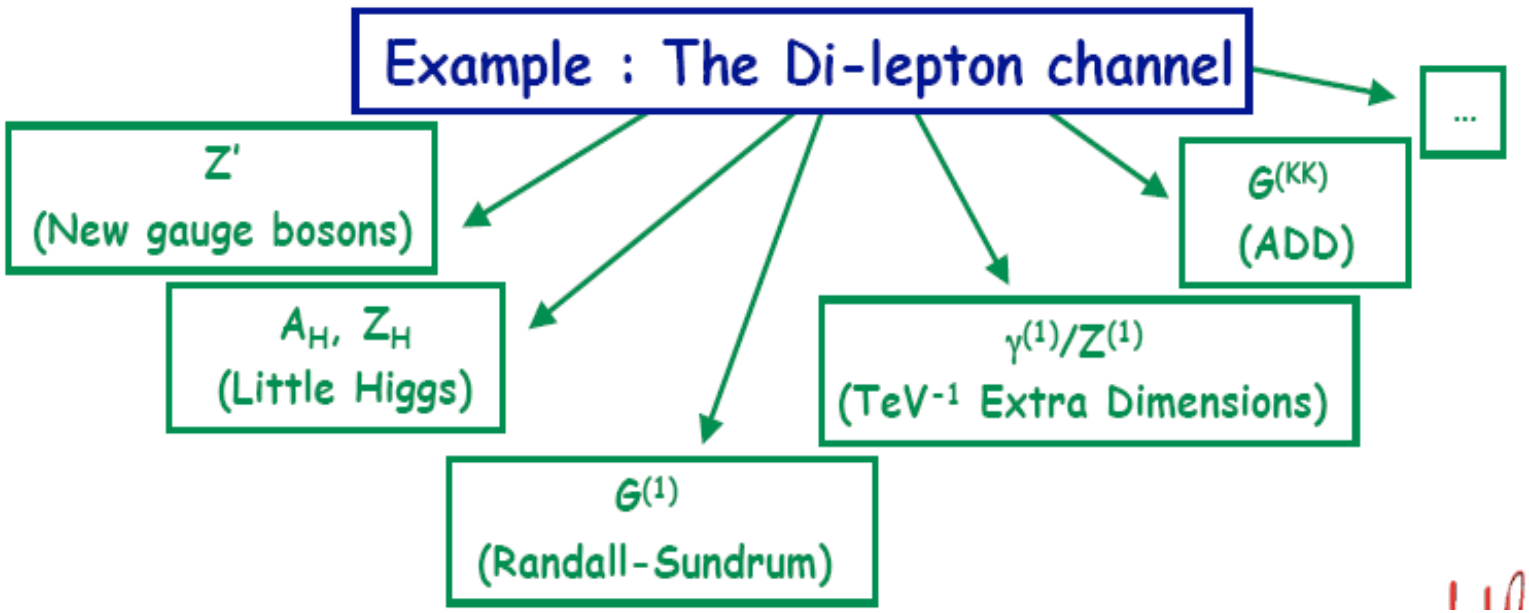
Courtesy A. De Roeck

One more example of an "easy" discovery: a ~1TeV di-lepton resonance

May be seen very early: first weeks

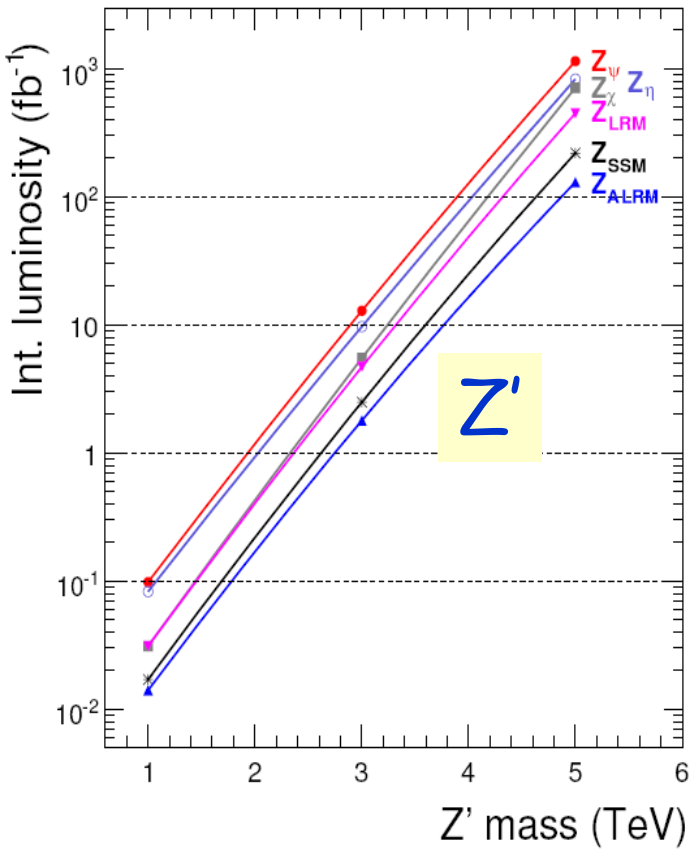


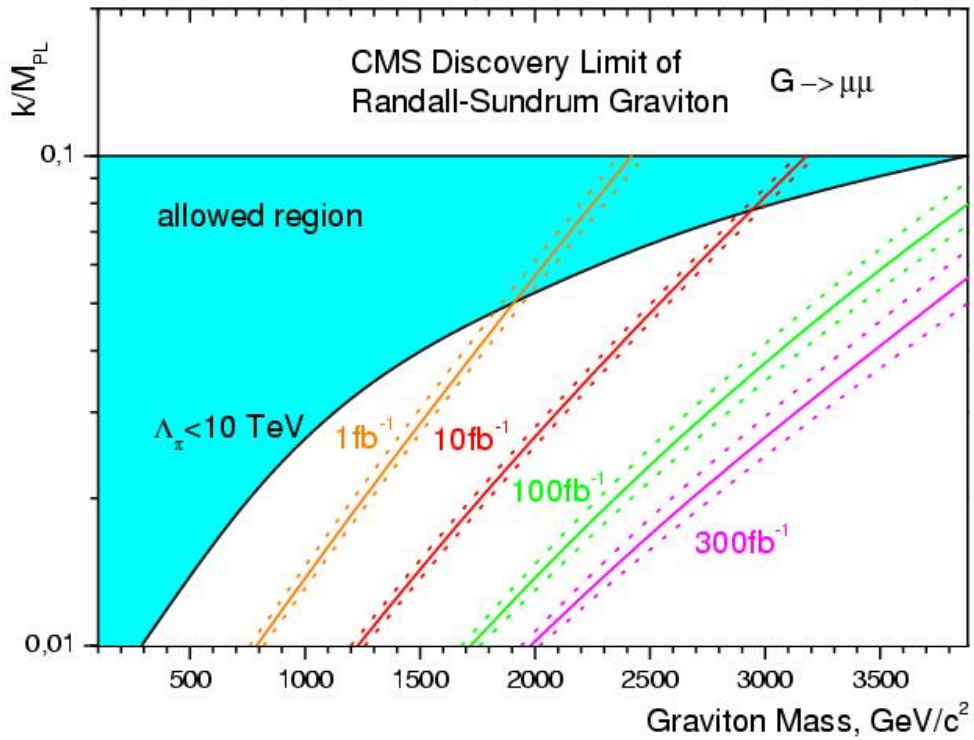
$pp \rightarrow \mu\mu + X$



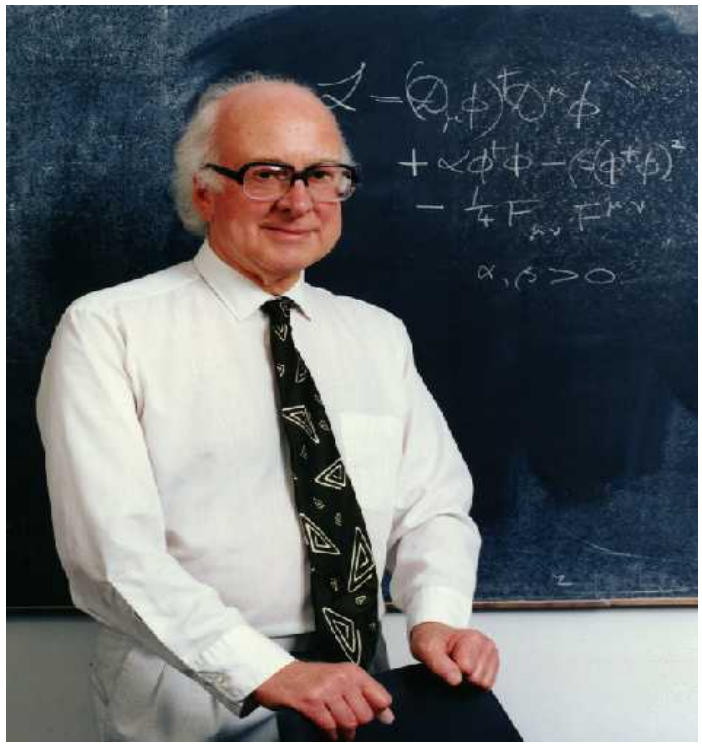
Extra dims: Z′/Randall-Sundrum

- **With 1fb^{-1}: Z′ reach: 2-2.5 TeV**
- **Most of relevant RS parameter space covered already with 1 fb^{-1}**





Do we have a chance to discover Higgs early?

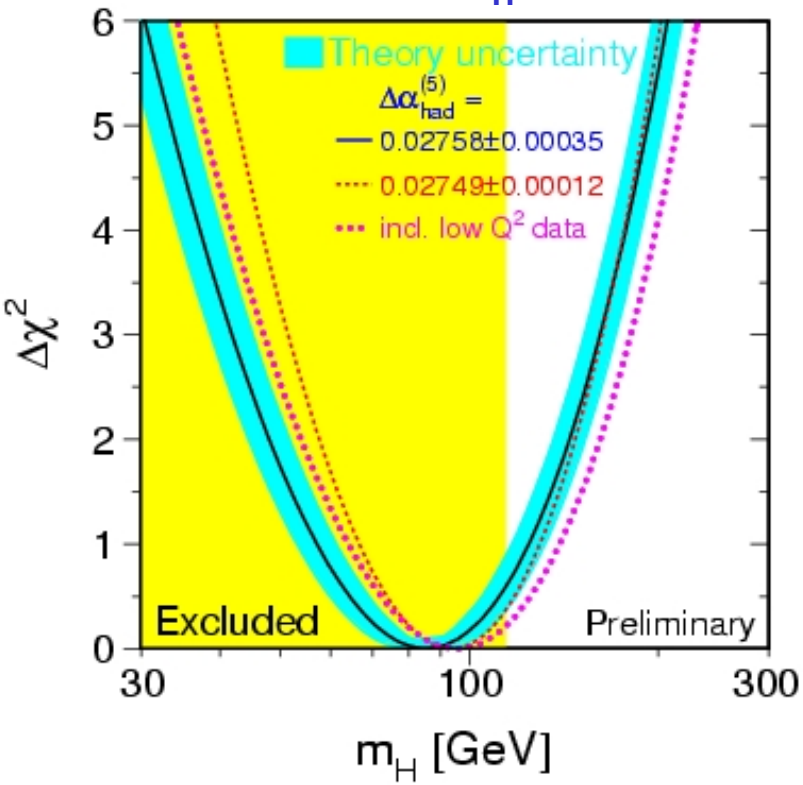


SM Higgs mass constraints from the data and theory

Experiment

Indirect constraints from precision EW data :
M_H < 166 GeV (2006, ICHEP06)
or with renormalized probability, M>114GeV
M < 200 GeV

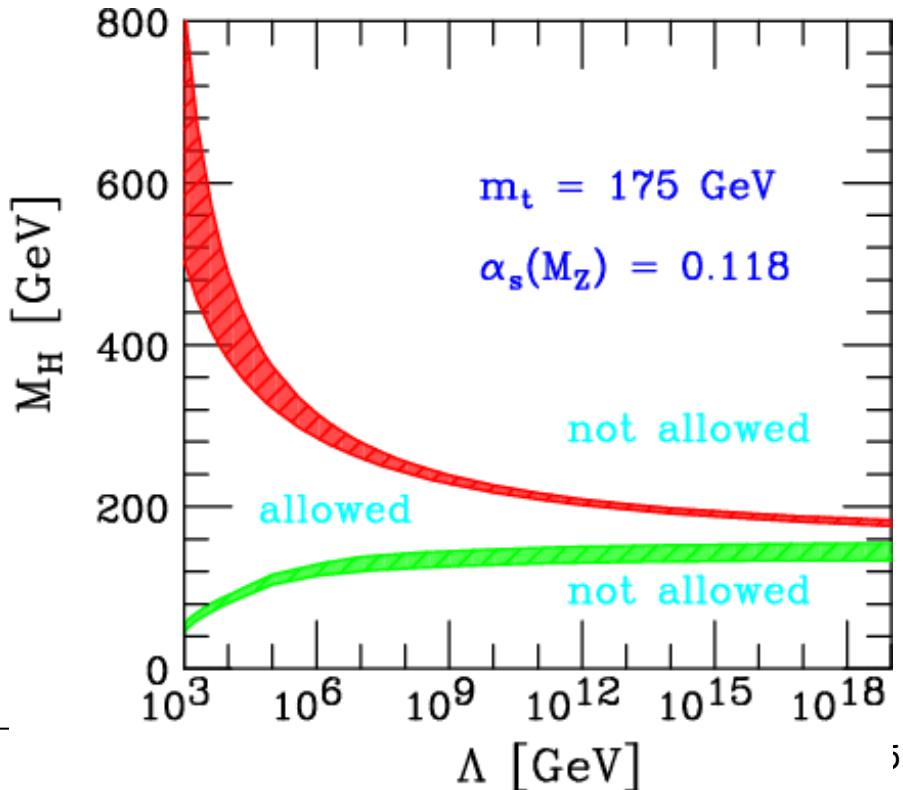
Direct limit from LEP: M_H > 114.4 GeV



SM theory

The triviality (upper) bound and vacuum stability (lower) bound as function of the cut-off scale Λ

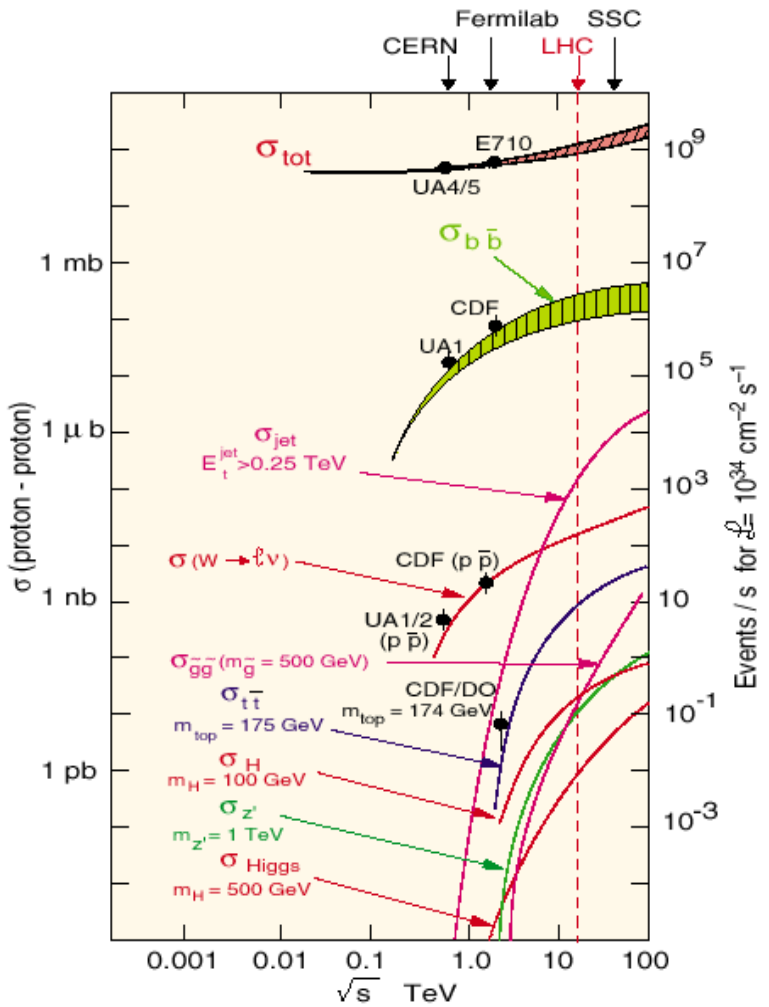
"triviality" :
Higgs self-coupling remains finite



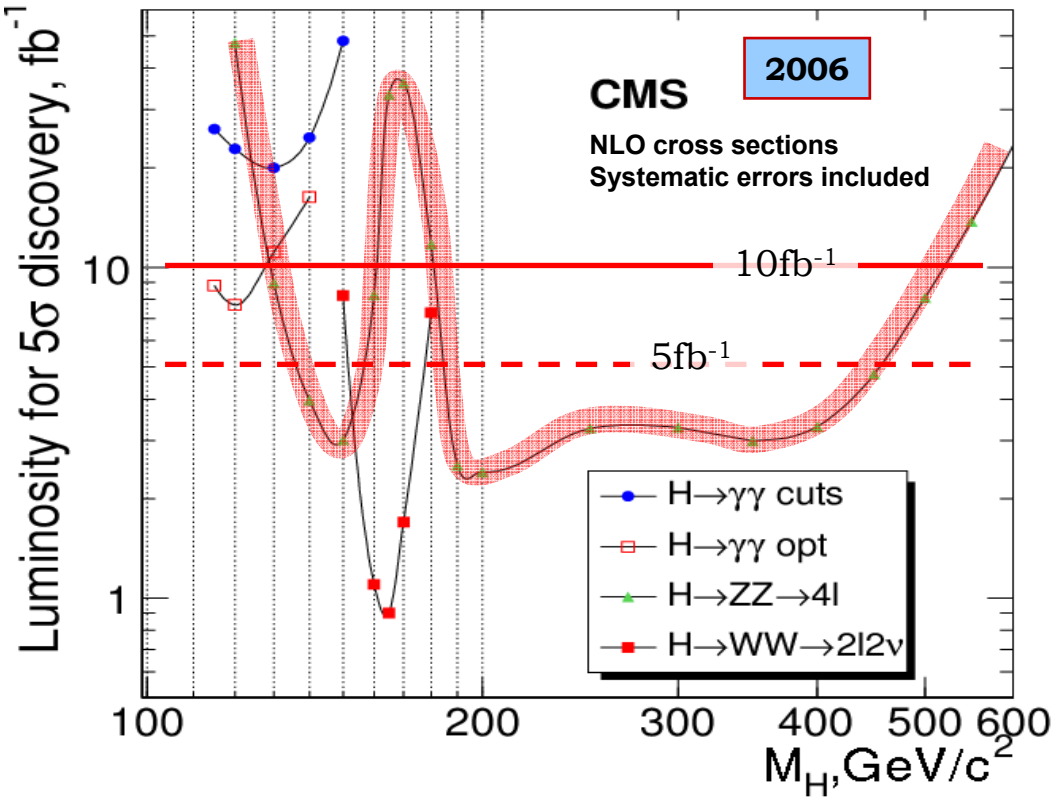
Cross sections and rates at 10^{32} cm^{-2}s^{-1}

At Luminosity (10^{32} cm^{-2} s^{-1})

SM Higgs (115 GeV/c^2):	→0.001 Hz
t t production:	→0.1 Hz
W→ ℓ ν:	→1 Hz
bb production:	**→ 10^4 Hz**
Inelastic:	→10^7 Hz



Standard Model Higgs discovery



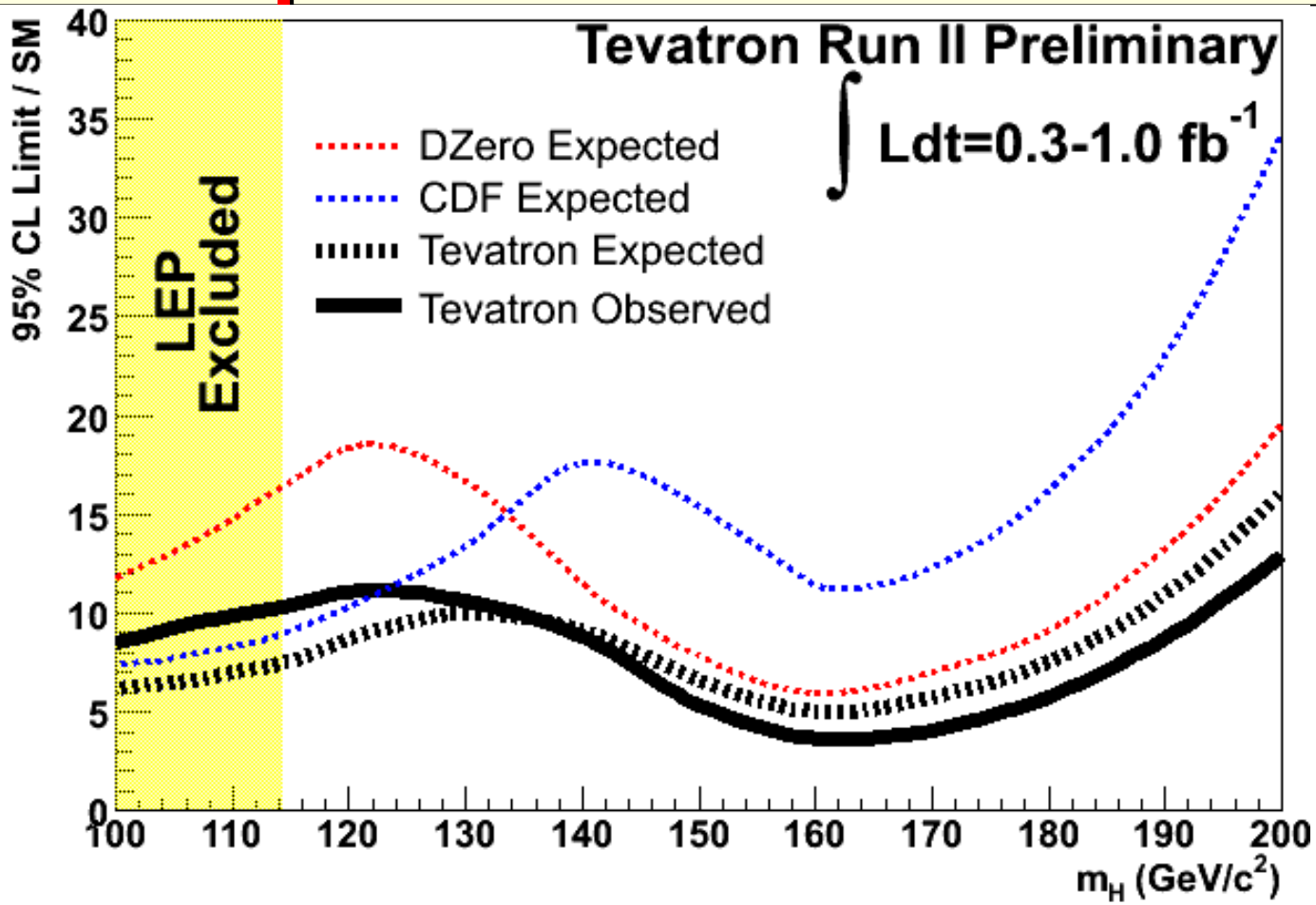
NLO cross sections
Systematic errors included

Benchmark luminosities:

- 0.2 fb^{-1}: exclusion limits will start carving into SM Higgs x-section
- 1 fb^{-1}: discoveries become possible if M_H~165 GeV
- 5 fb^{-1}: discoveries possible if 140 GeV < M_H < 500 GeV
- 10 fb^{-1}: SM Higgs is discovered (or excluded) in full range

Higgs at Tevatron: a competition to LHC?

m_H (GeV)	Limit/SM Exp.	Obs.
115	7.6	10.4
130	10.1	10.6
160	5.0	3.9
180	7.5	5.8



with few times greater integrated luminosity it will be possible to exclude or get an "evidence" for the higgs in some mass regions at Tevatron

Conclusion

- The construction of CMS is nearing completion
- The “low luminosity” detector will be ready for operations in 2008
- Detailed simulations prove that detection of muons provide a convenient tool for search of Higgs→ 4mu, SUSY, Z’ etc.