CMS

The CMS experiment at LHC

Compact Muon Solenoid

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GAS, Primorsko, 2007

Physics motivation

Physics motivation

- The SM is experimentally tested and confirmed with high precision
- All fundamental particles (quarks and leptons) and interaction carriers (γ, W,Z, g) are observed and
- their properties are under investigation
- However
  - ✓ One particle predicted by SM is still missing – the H-boson
  - ✓ Number of fundamental questions stay unanswered

Open Problems of SM

- The SM contains many apparently arbitrary features
  e.g. why there are 6 quarks?
- SM has a "missing element"
  i.e. mechanism to generate the observed masses of the known particles
  (Higgs mechanism)
- What is the origin of mass
  Why the Z-boson is massive whereas the related photon is massless?
- SM gives "nonsense" at very high energies
  $W_L W_L$ scattering probability becomes larger then 1 at energies above ~1 TeV
- SM is logically not complete
  Gravity is not incorporated

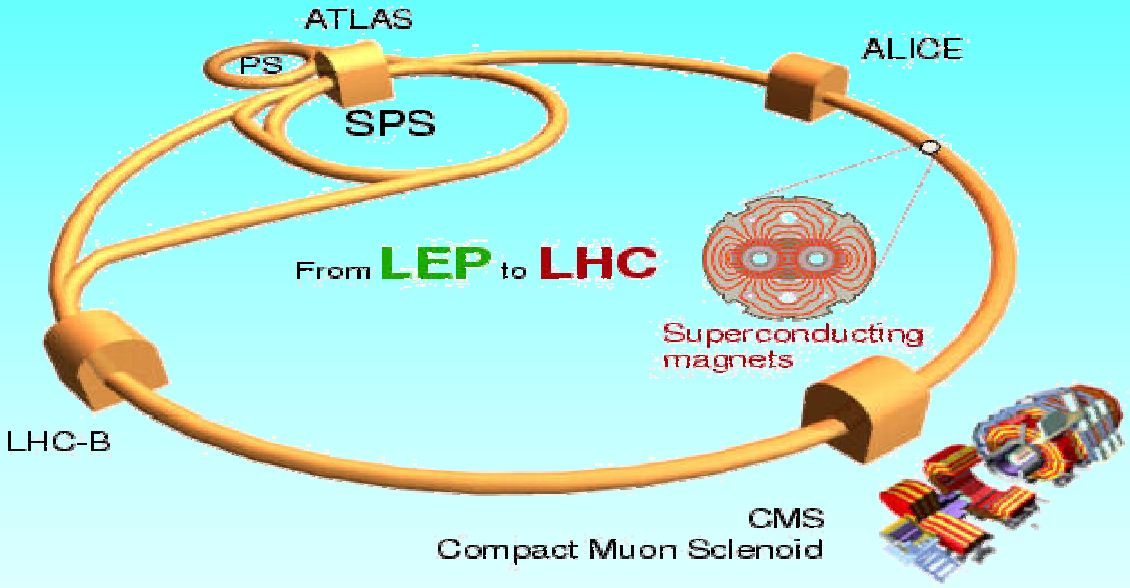
Beyond the SM

- The SM should be considered as a low energy phenomenological model
- Quest for a more fundamental theory (model) which incorporates the SM and answers the question is going on
  - ✓ GUT
  - ✓ Technicolor
  - ✓ SUSY
  - ✓ Extra Dimensions
  - ✓ Little Higgs
  - ✓ String theories
- In all of them many new features and particles are predicted
- This is so called "New Physics"

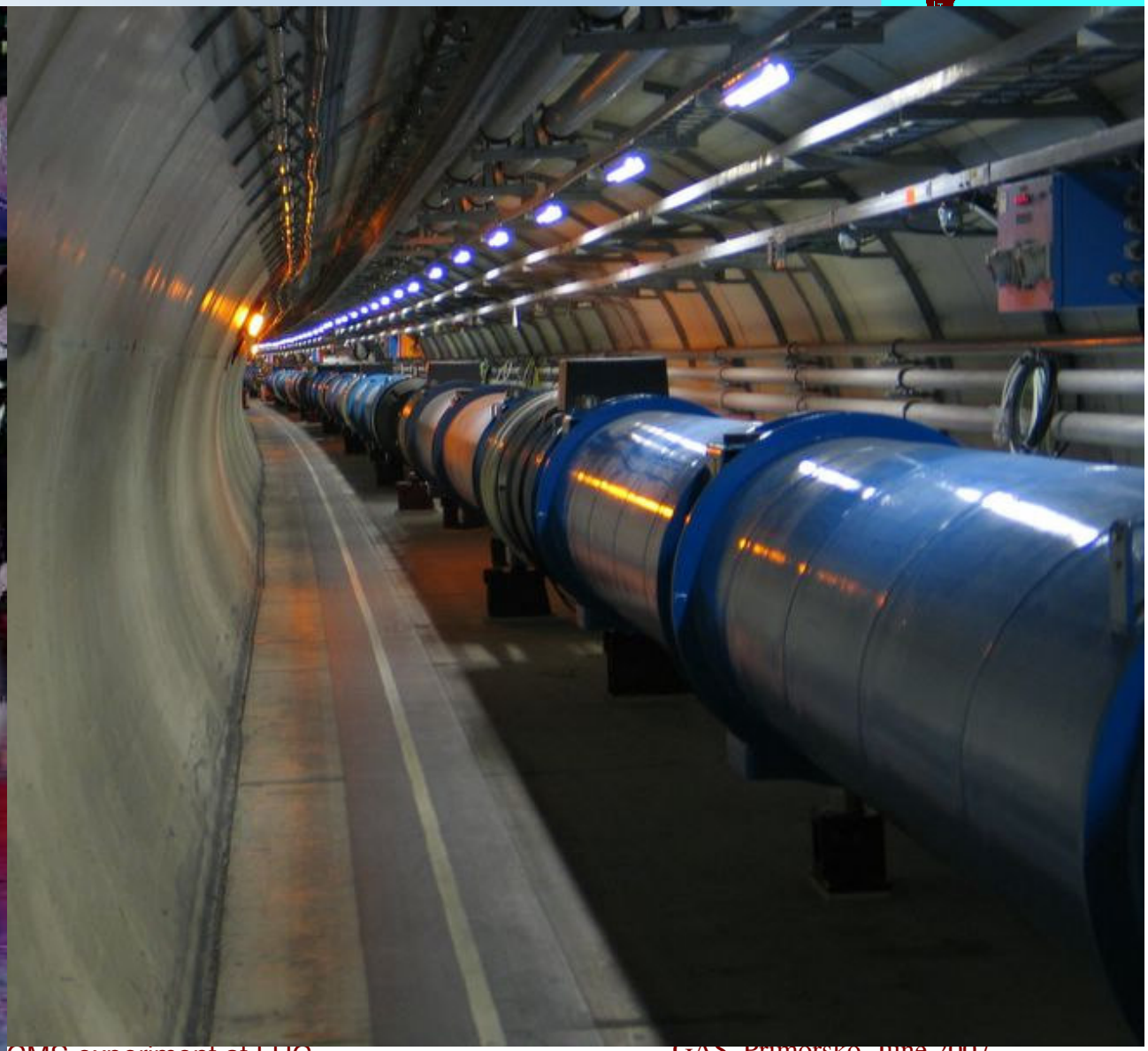
Need to
Find the Higgs
Find clues for the physics beyond the SM

The LHC program will address all these issues

The Large Hadron Collider (LHC)

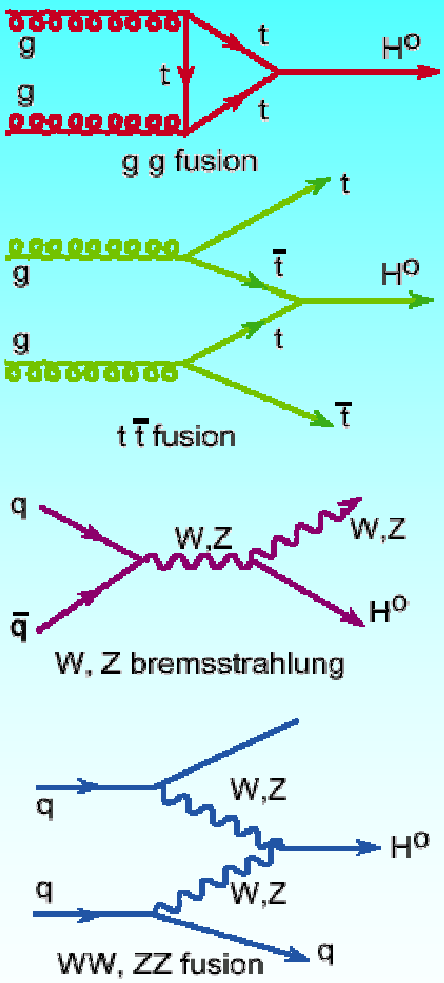


	Beams	Energy	Luminosity
LEP	e+ e-	200 GeV	10^{32} cm^{-2}s^{-1}
LHC	p p	14 TeV	10^{34}
	Pb Pb	1312 TeV	10^{27}

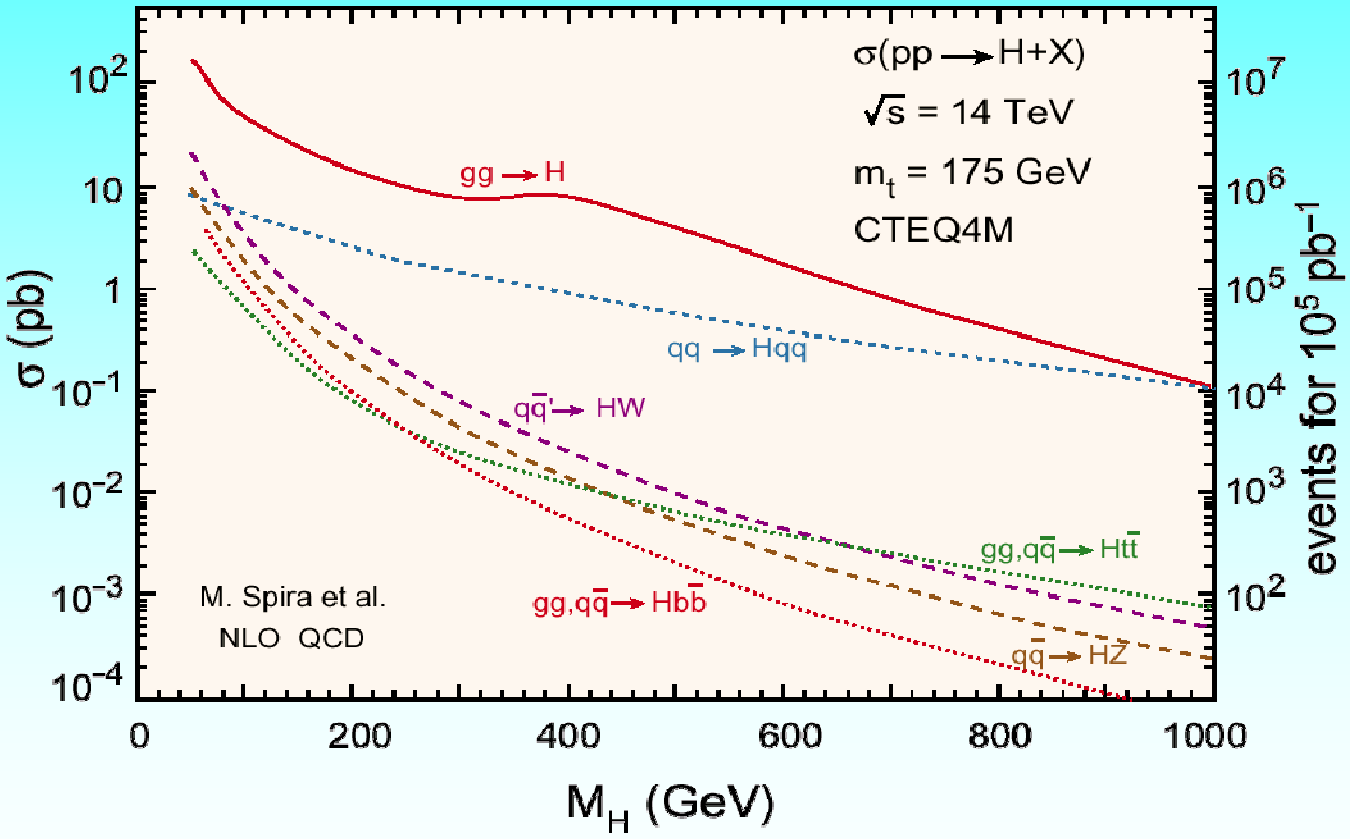


Detector requirements

Higgs production

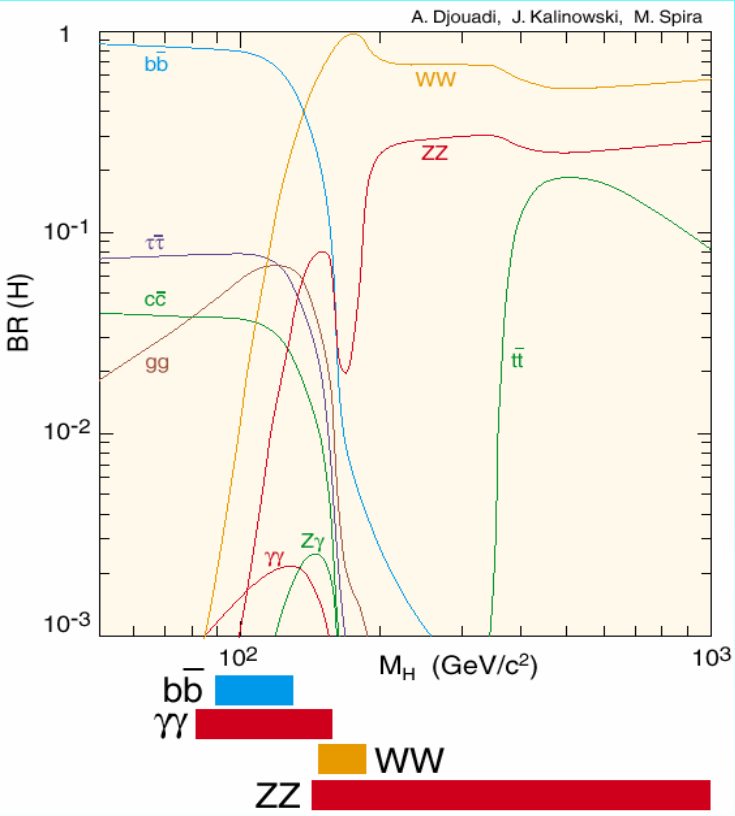


Production cross sections

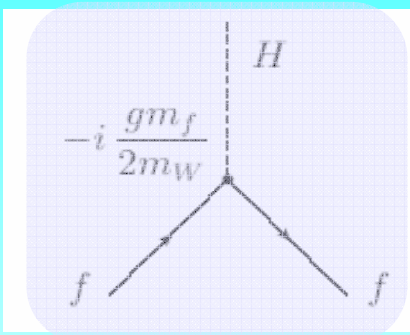


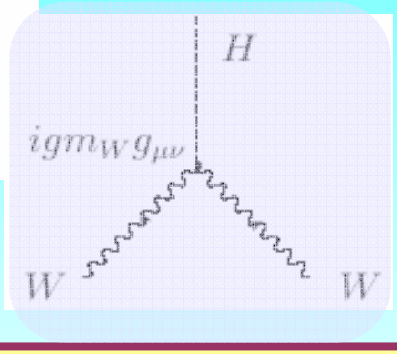
Higgs decays

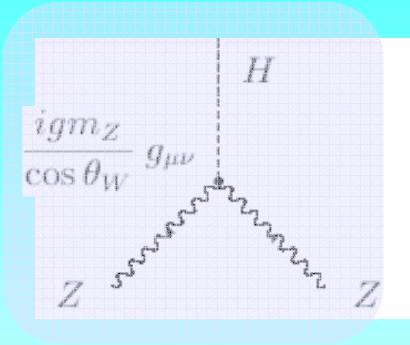
SM Higgs branching ratios



Higgs decays is proportional to the mass







Suitable search channels

80 GeV < m_H < 140 GeV H -> γγ, H -> bb
130 GeV < m_H < 700 GeV H -> ZZ(*) -> 4 ℓ (l = e, μ)
500 GeV < m_H < 1000 GeV H -> ZZ -> 2 ℓ + 2 Jets
500 GeV < m_H < 1000 GeV H -> ZZ -> 2 ℓ + 2 ν
800 GeV < m_H < 1000 GeV H -> WW-> ℓ + ν + Jets
800 GeV < m_H < 1000 GeV H -> ZZ-> 2 ℓ + 2 Jets

Supersymmetric particles

Standard Model	Supersymmetry
γ, Z^0, h^0, H^0	$\tilde{\chi}_1^0, \tilde{\chi}_2^0, \tilde{\chi}_3^0, \tilde{\chi}_4^0$
W^+, H^+	$\tilde{\chi}_1^+, \tilde{\chi}_2^+$
$e^-, \nu_e, \mu^-, \nu_\mu, \nu_\tau$	$\tilde{e}_R^-, \tilde{e}_L^-, \tilde{\nu}_e, \tilde{\mu}_R^-, \tilde{\mu}_L^-, \tilde{\nu}_\mu, \tilde{\nu}_\tau$
τ^-	$\tilde{\tau}_1^-, \tilde{\tau}_2^-$
u, d, s, c	$\tilde{u}_R, \tilde{u}_L, \tilde{d}_R, \tilde{d}_L, \tilde{s}_R, \tilde{s}_L, \tilde{c}_R, \tilde{c}_L$
b	$\tilde{b}_1, \tilde{b}_2$
t	$\tilde{t}_1, \tilde{t}_2$

SUSY-decays

$\tilde{q} \rightarrow \tilde{\chi}_2^0\, q$

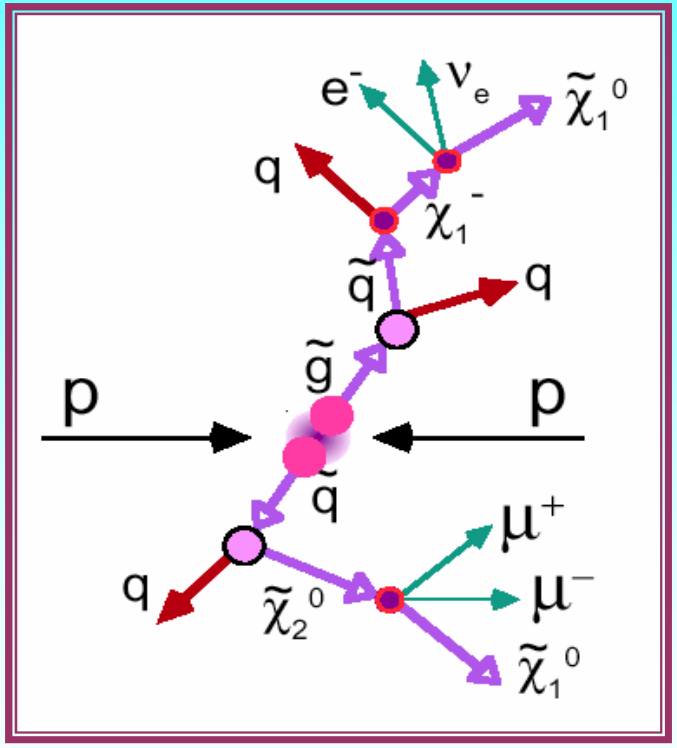
$\tilde{\mu}\, \mu$

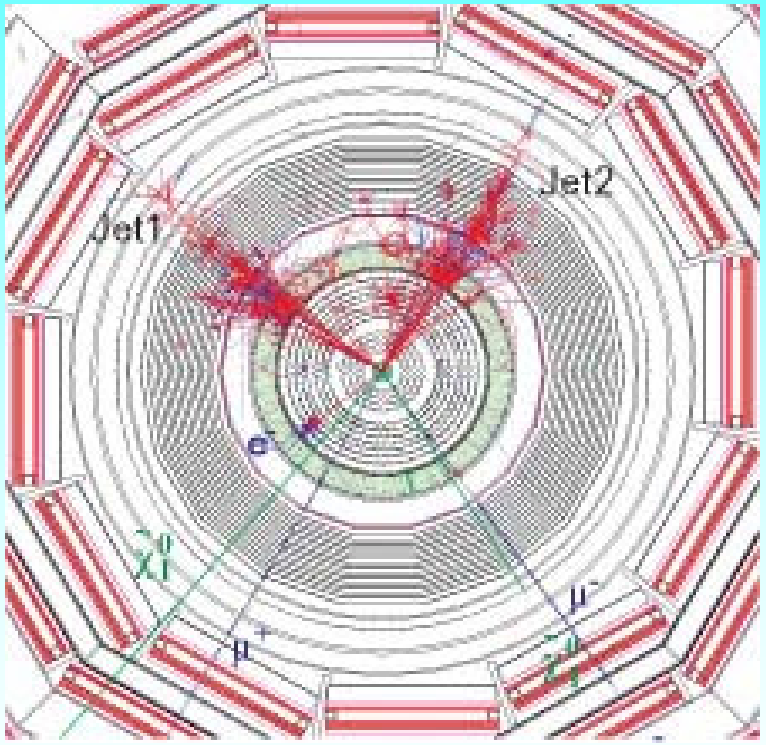
$\tilde{\chi}_1^0\, \mu$

$\tilde{g} \rightarrow q\tilde{q}$

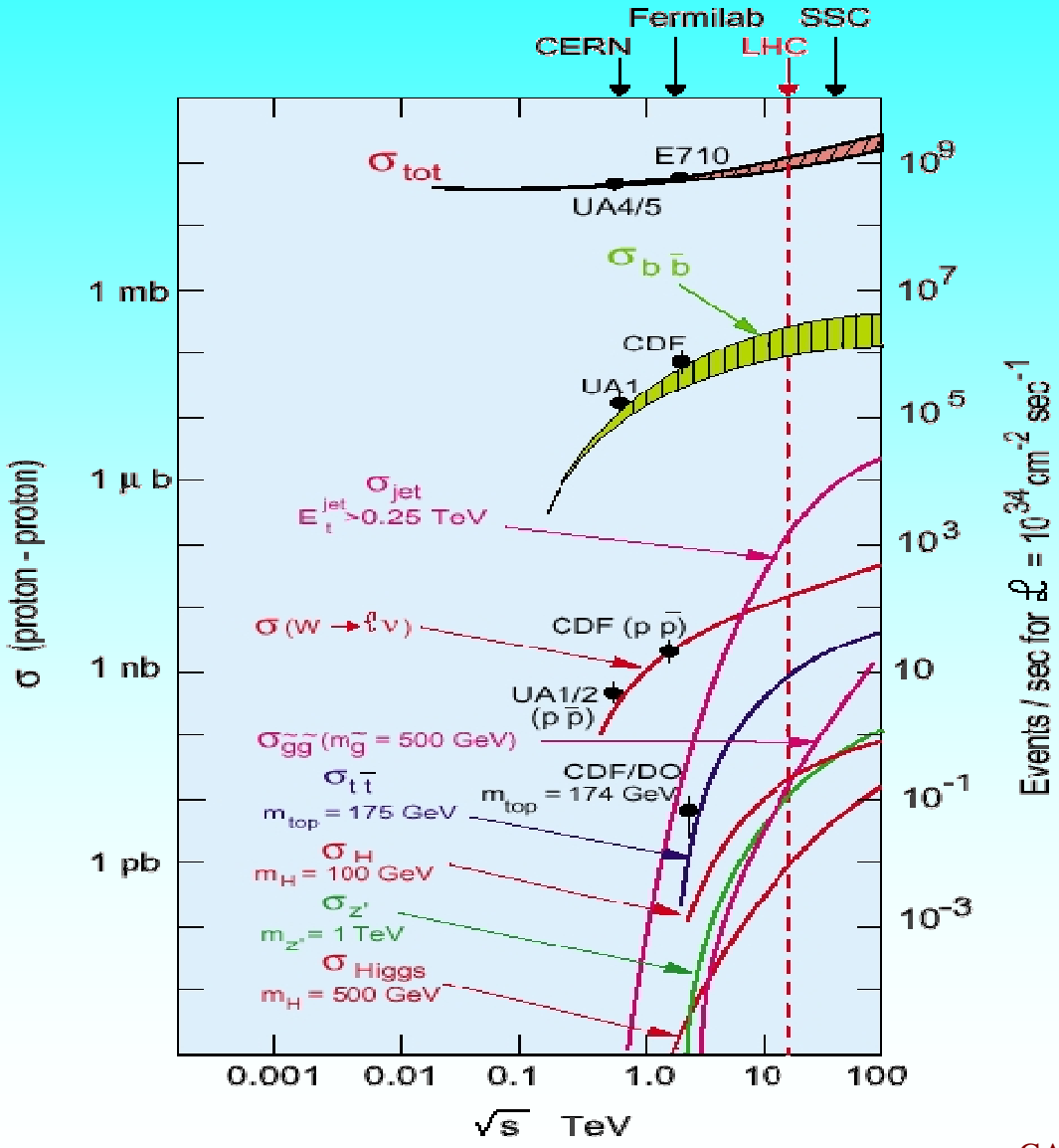
$\tilde{\chi}_1^{\pm}\, q$

$e\, \nu\, \tilde{\chi}_1^0$





pp cross-sections



Detector requirements

Very good muon identification and momentum measurement

trigger efficiently and measure sign of a few TeV muons

High energy resolution electromagnetic calorimertry

~ 0.5% @ E_T~50 GeV

Powerful inner tracking systems

factor 10 better momentum resolution than at LEP

Hermetic calorimetry

good missing E_T resolution

(Affordable detector)

Detector requirements

High Interaction Rate

pp interaction rate 10^9 interactions/s

data for only ~100 out of the 40 million crossings can be recorded per sec

Level-1 trigger decision will take ~2-3 ms

⇨ electronics need to store data locally (pipelining)

Large Particle Multiplicity

~ <20> superposed events in each crossing

~ 1000 tracks stream into the detector every 25 ns

need highly granular detectors with good time resolution for low occupancy

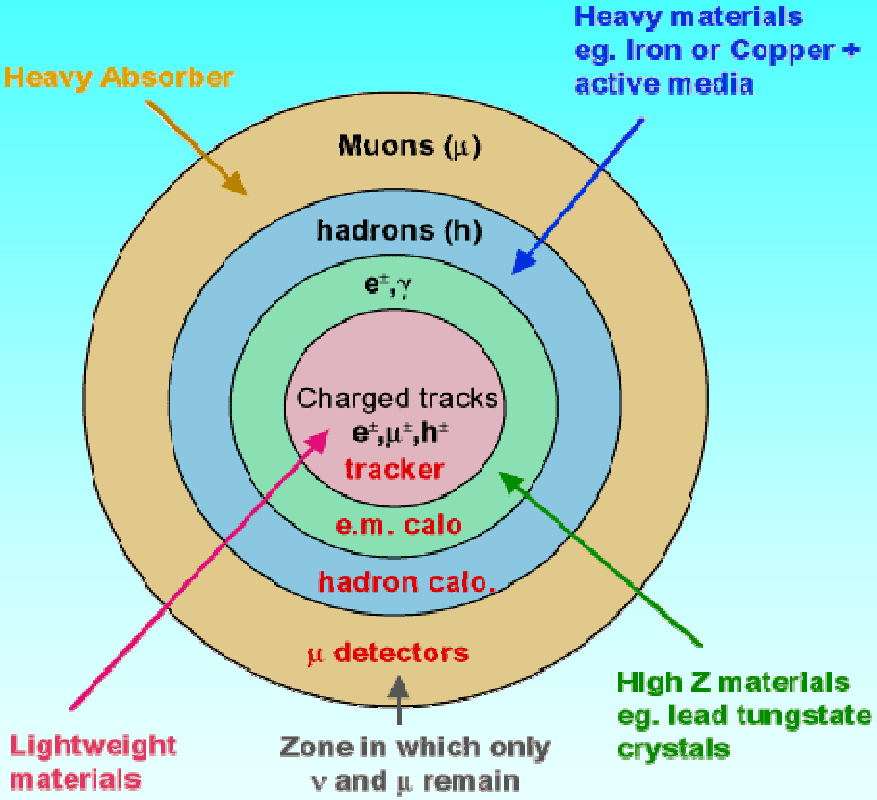
⇨ large number of channels

High Radiation Levels

⇨ radiation hard (tolerant) detectors and electronics

The CMS detector

Detector structure



Each layer identifies and measures (or remeasures) the energy of particles unmeasured by the previous layer

No single detector can determine identity and measure energies/momenta of all particles

The CMS detector

SUPERCONDUCTING COIL

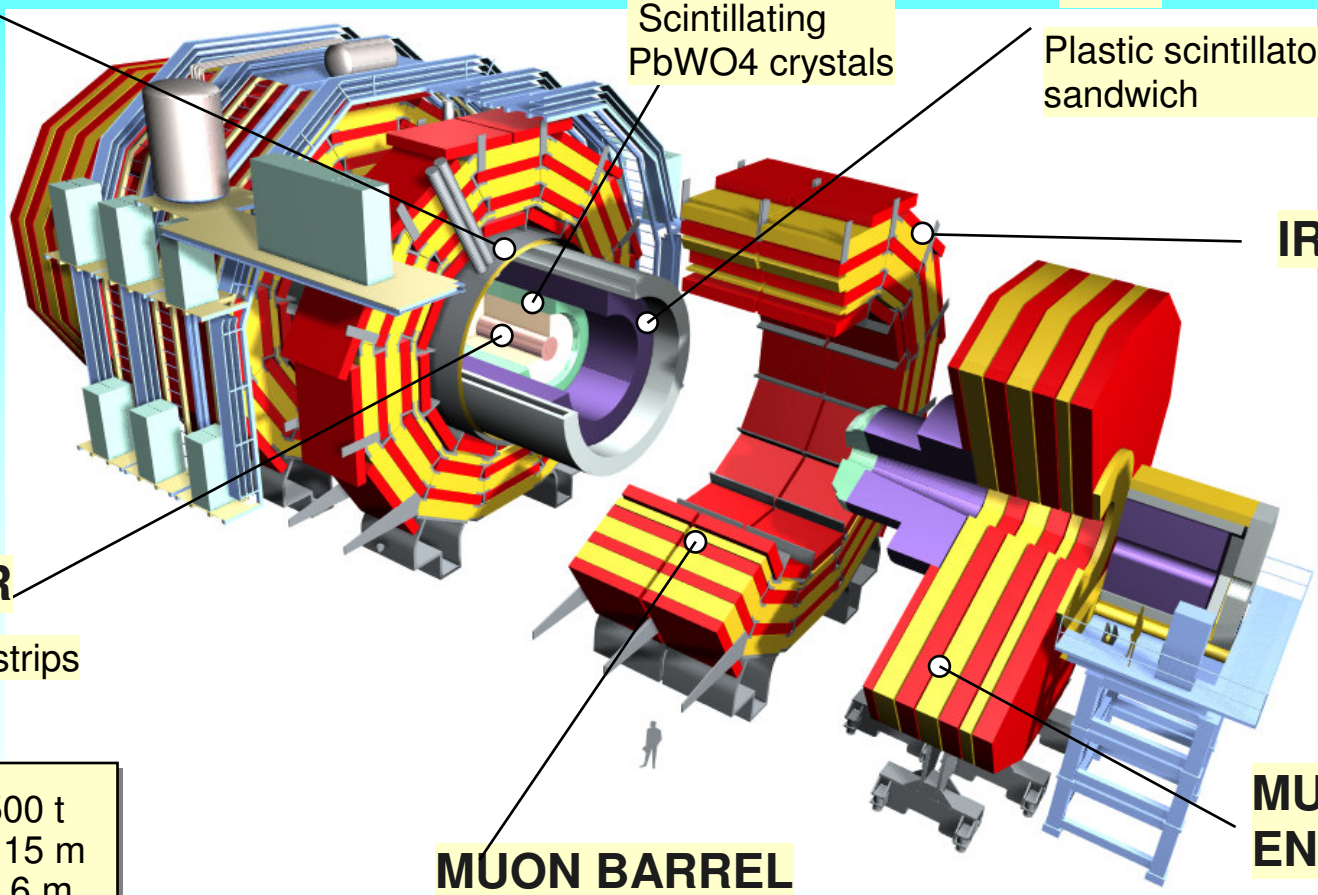
CALORIMETERS

ECAL

Scintillating PbWO4 crystals

HCAL

Plastic scintillator/brass sandwich



IRON YOKE

TRACKER

Silicon Microstrips
Pixels

MUON ENDCAPS

Cathode Strip Chambers (**CSC**)

Resistive Plate Chambers (**RPC**)

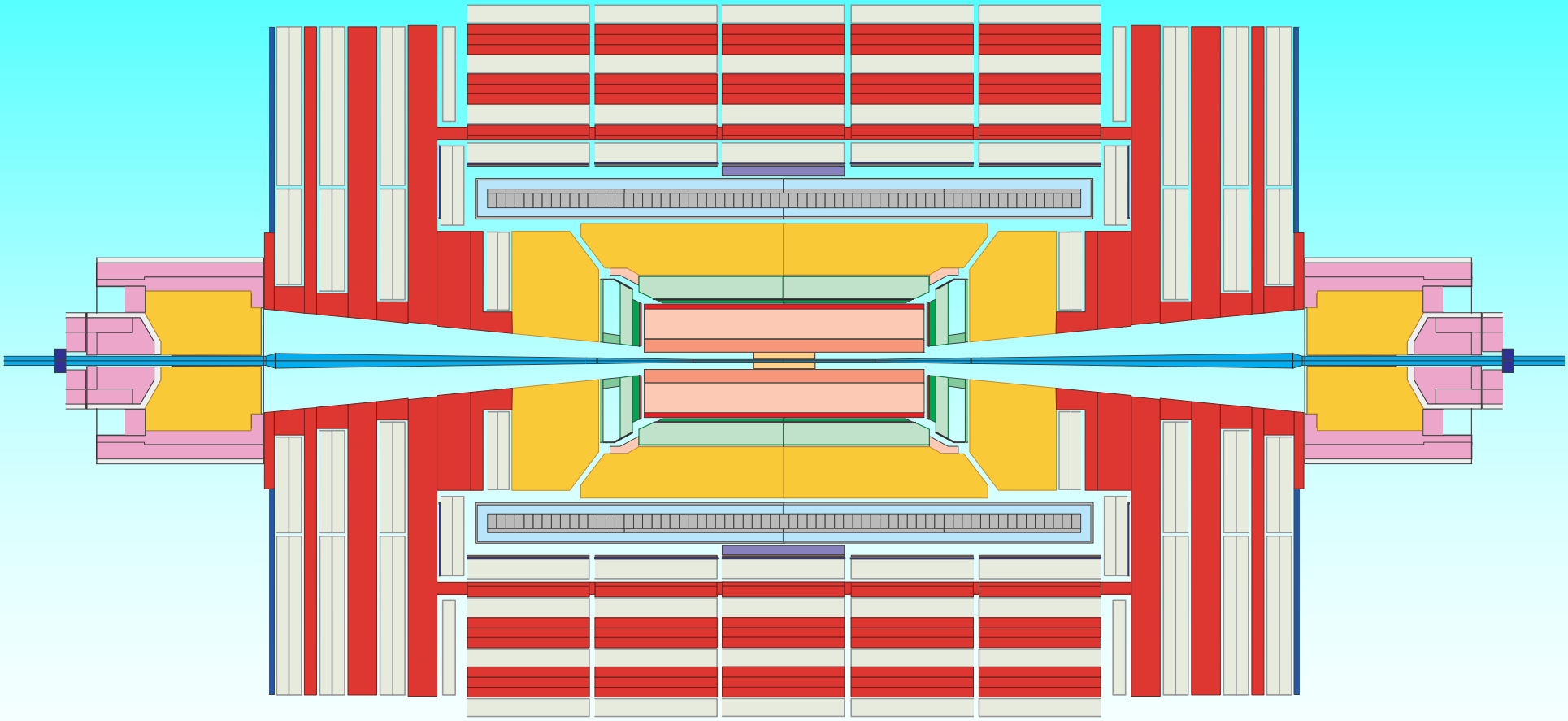
MUON BARREL

Drift Tube Chambers (**DT**)

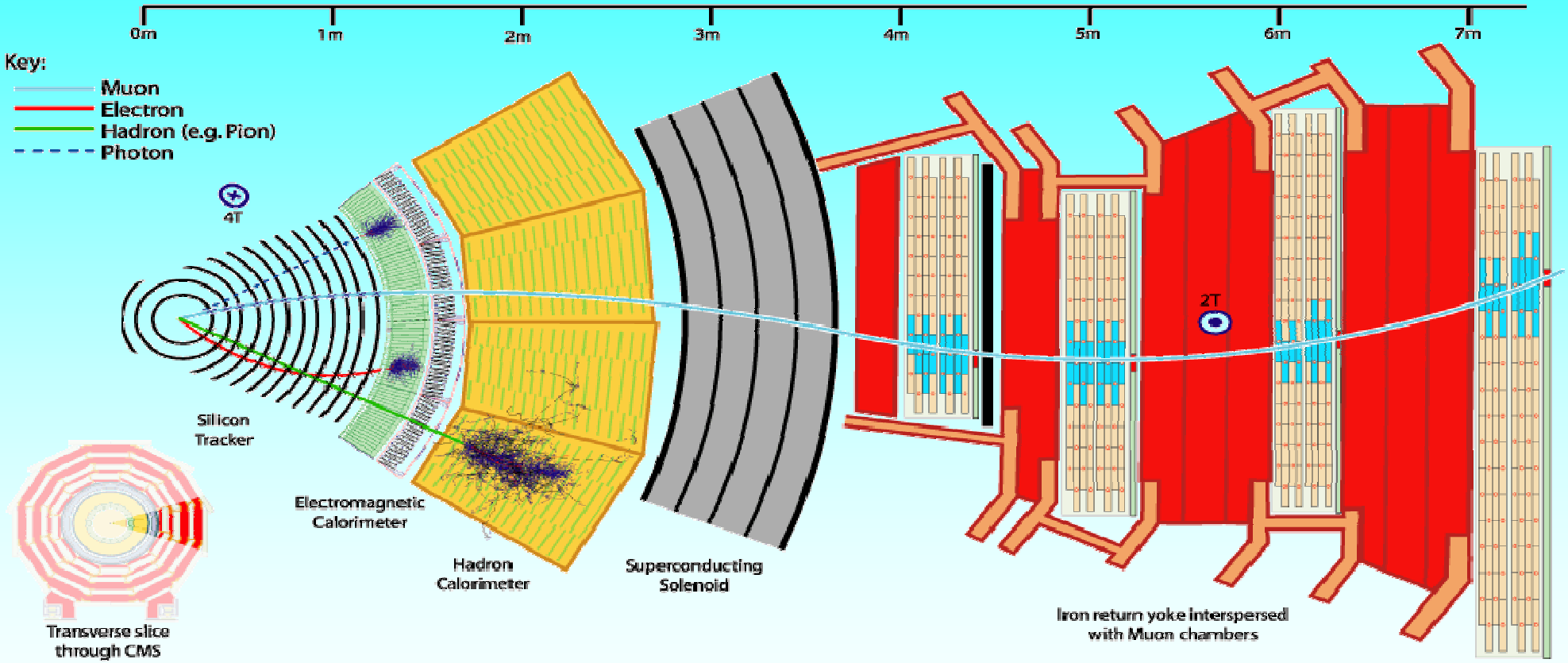
Resistive Plate Chambers (**RPC**)

Total weight : 12,500 t
Overall diameter : 15 m
Overall length : 21.6 m
Magnetic field : 4 Tesla

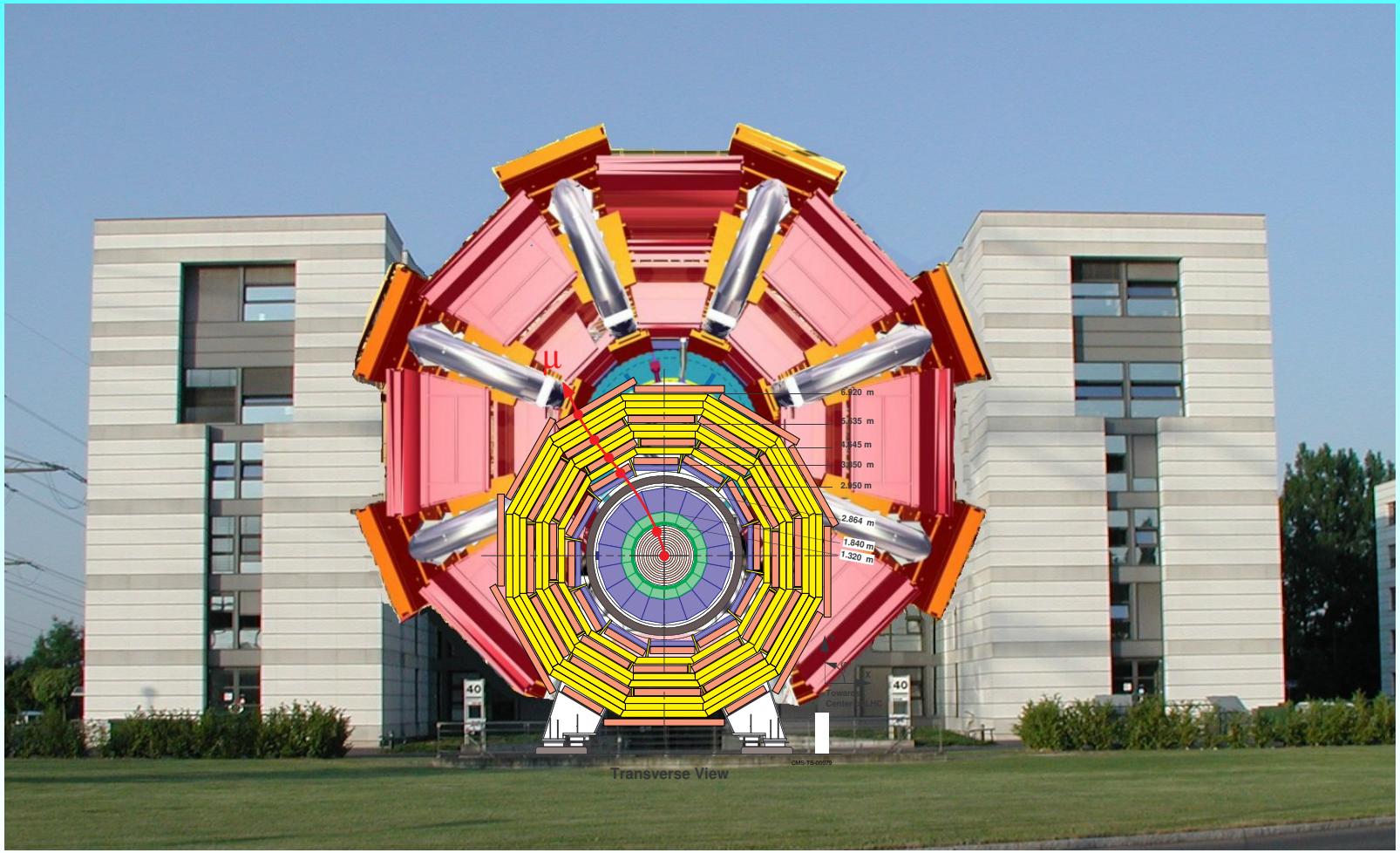
CMS Longitudinal view



CMS Detector Slice



Building 40 at CERN

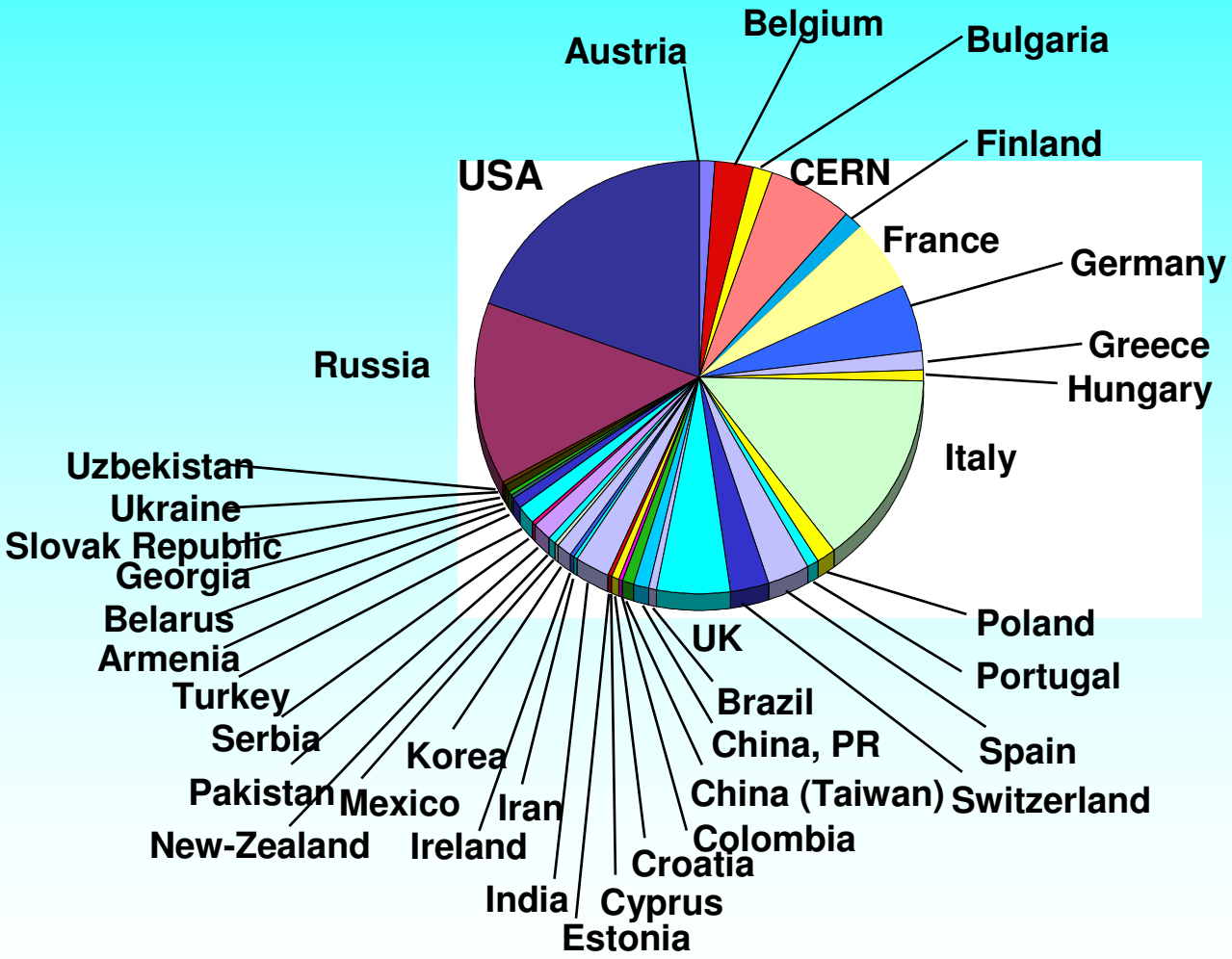


The CMS Collaboration

	Institutions
Member States	61
Non-Mem. States	64
USA	49
Total	174

	Scientists
Member States	1055
Non-Mem. States	428
USA	547
Total	2030

Associated Institutes	
Number of Scientists	46
Number of Laboratories	8

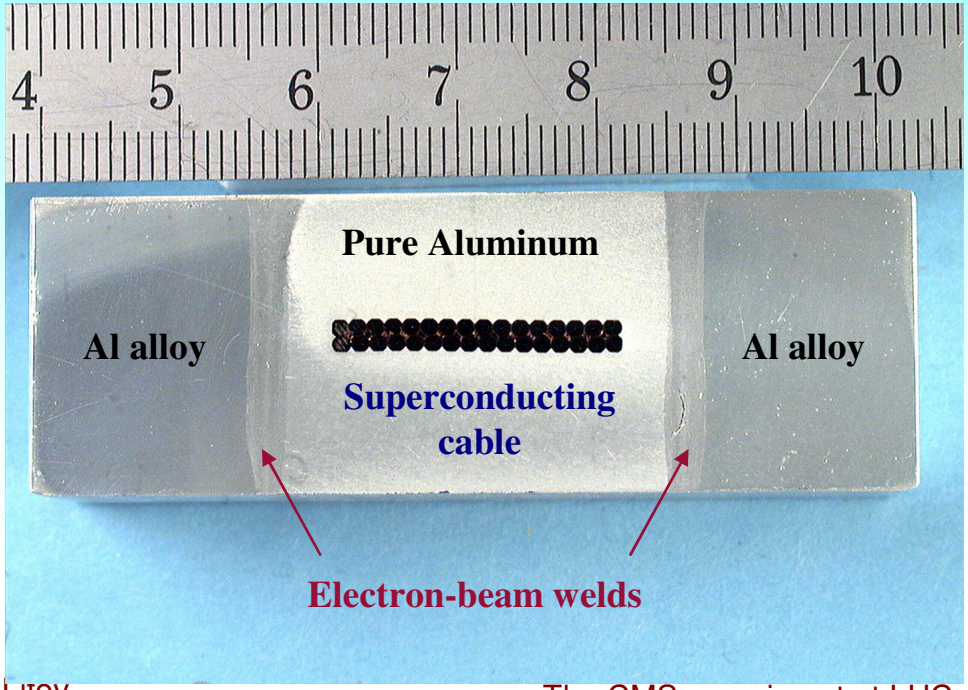


2030 Scientific Authors, 38 Countries, 174 Institutions

CMS Solenoid

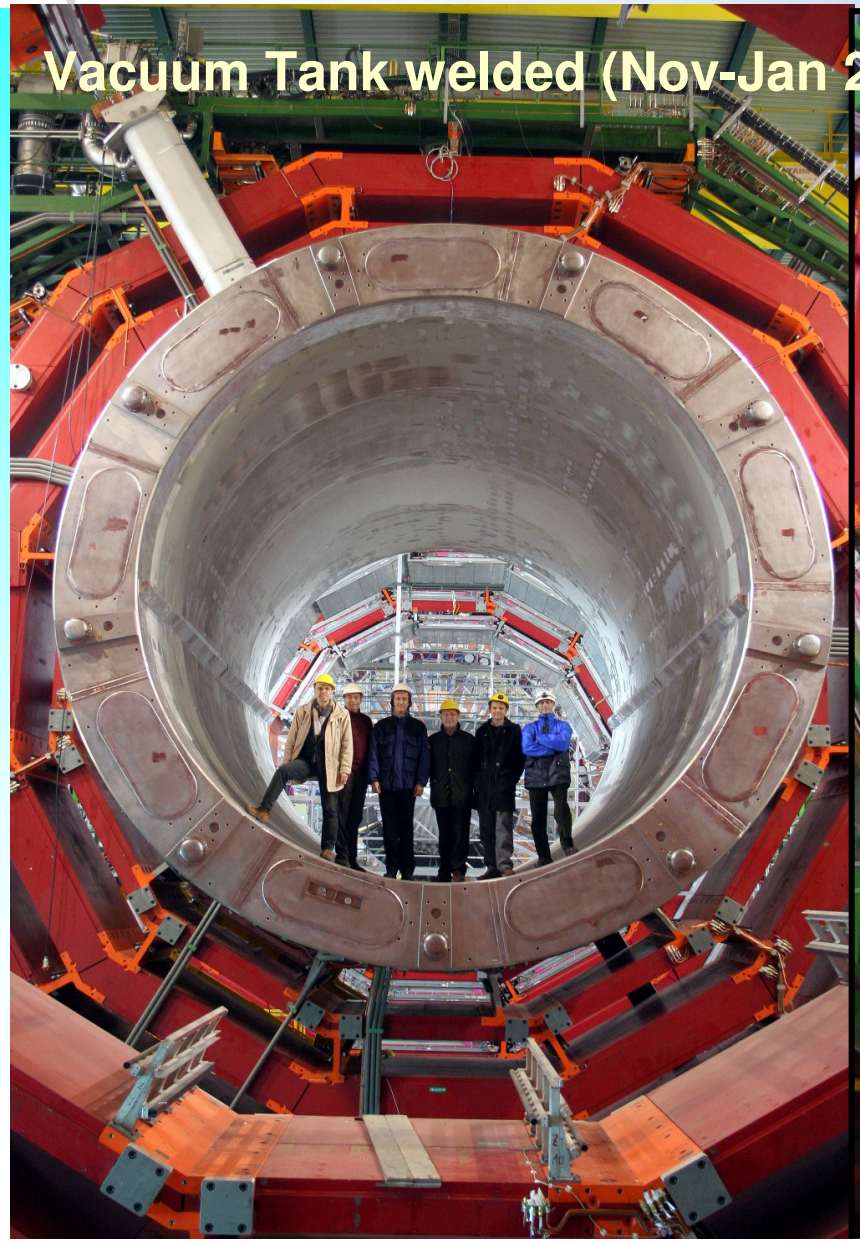
Magnet coil

CMS has the world's largest superconducting solenoid magnet. It provides a uniform magnetic flux density of 4 T at an operating temperature of 4.5 K, with a stored energy of 2.5 GJ, a nominal current of 19000 A.
Conductor: Al-reinforced Nb-Ti strands in copper coating.

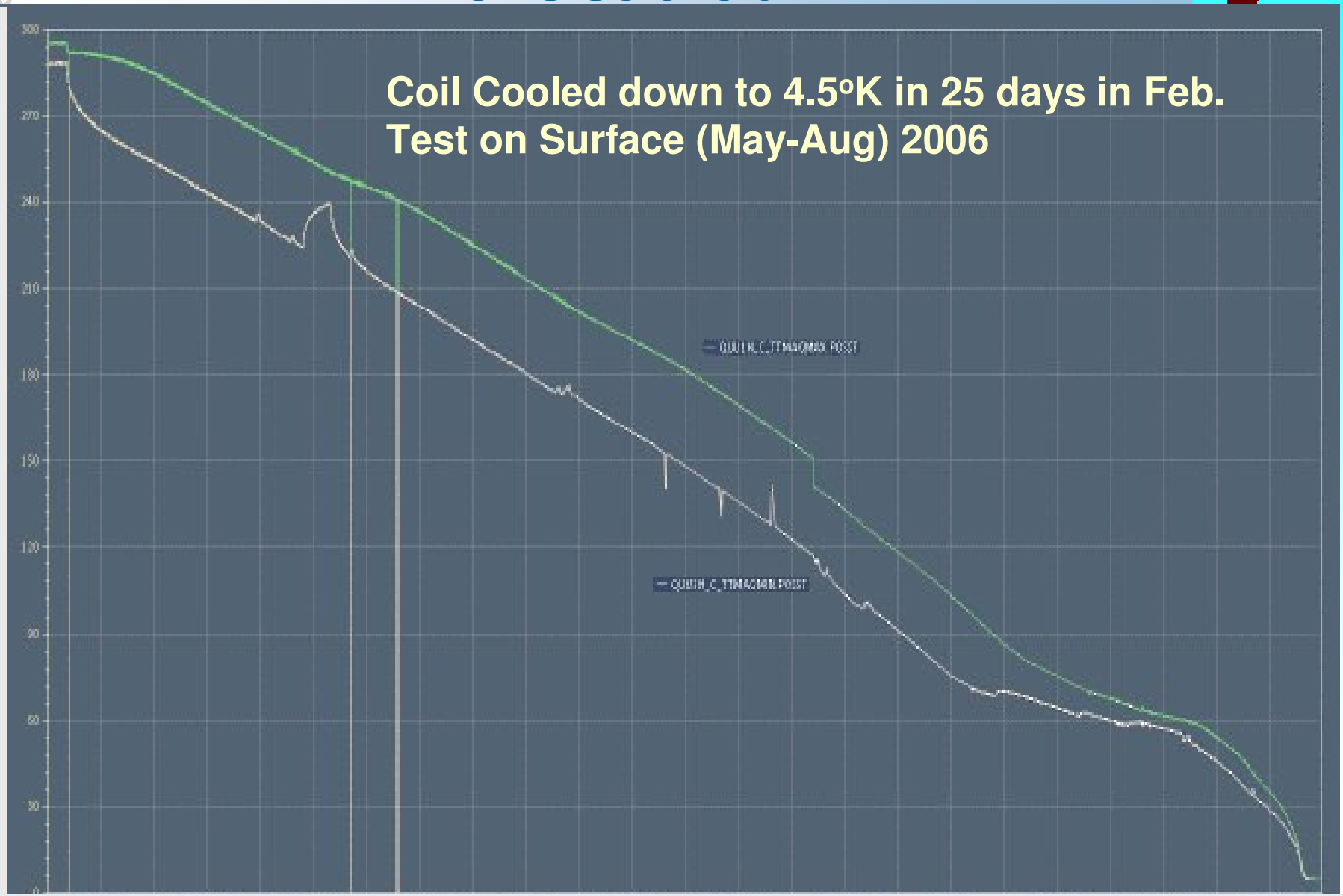


CMS Solenoid

CMS Solenoid

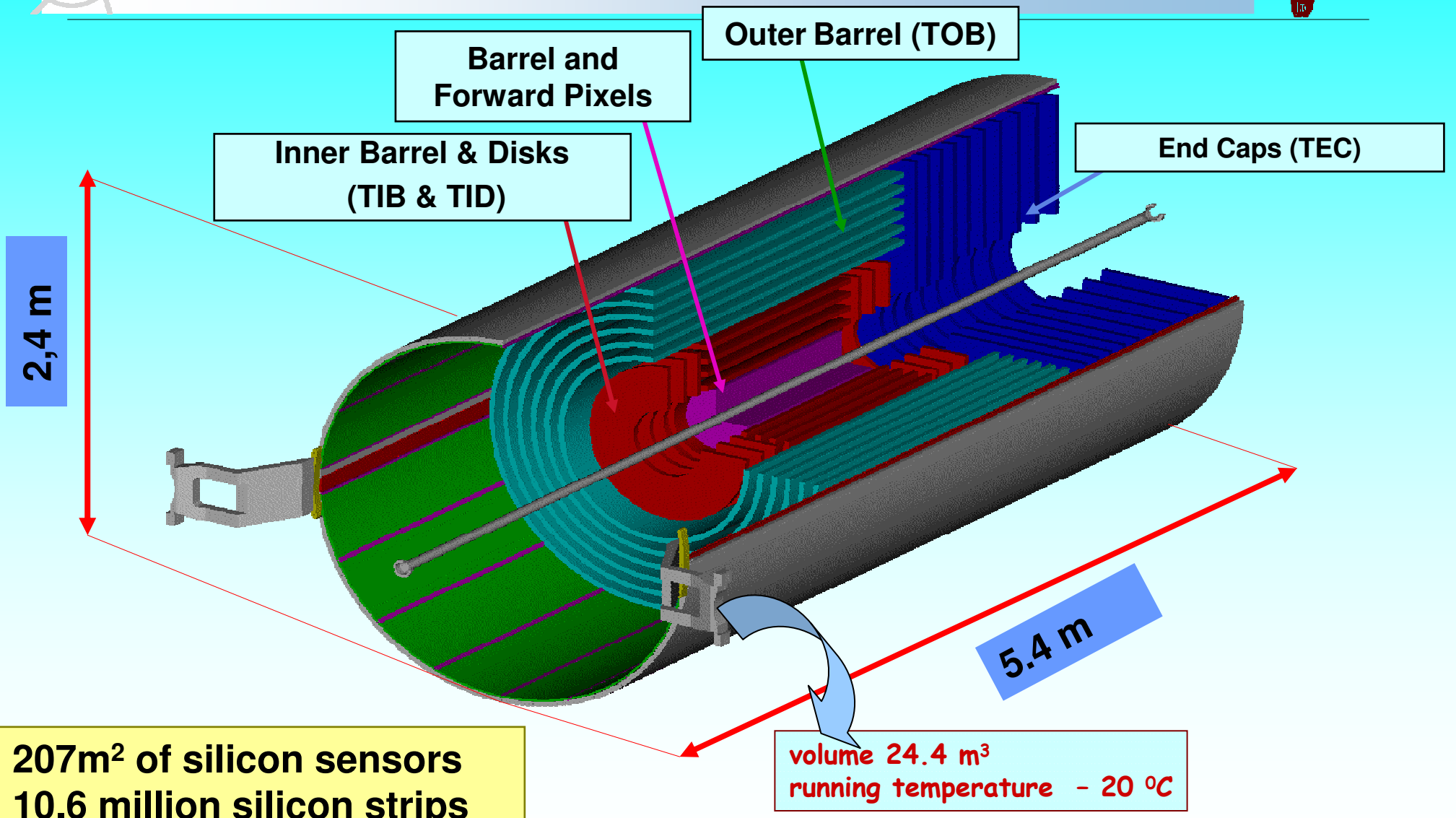


CMS Solenoid



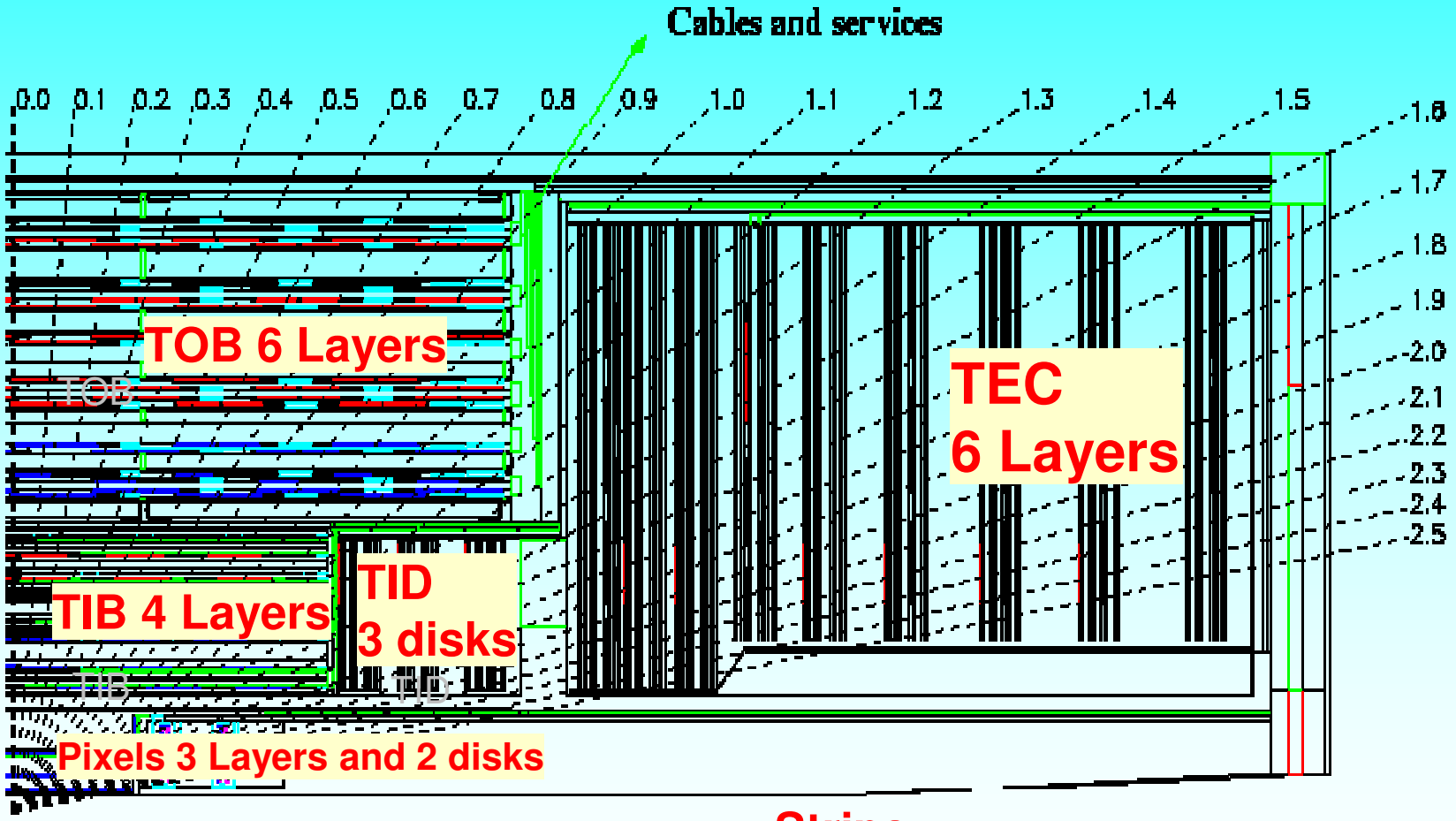
Central track detector

All Silicon Tracker



207m² of silicon sensors
10.6 million silicon strips
65.9 million pixels ~ 1.1 m²

Inner Tracker



Pixels:

100 μm x 150μm

rϕ and z resolution: 15-20 μm

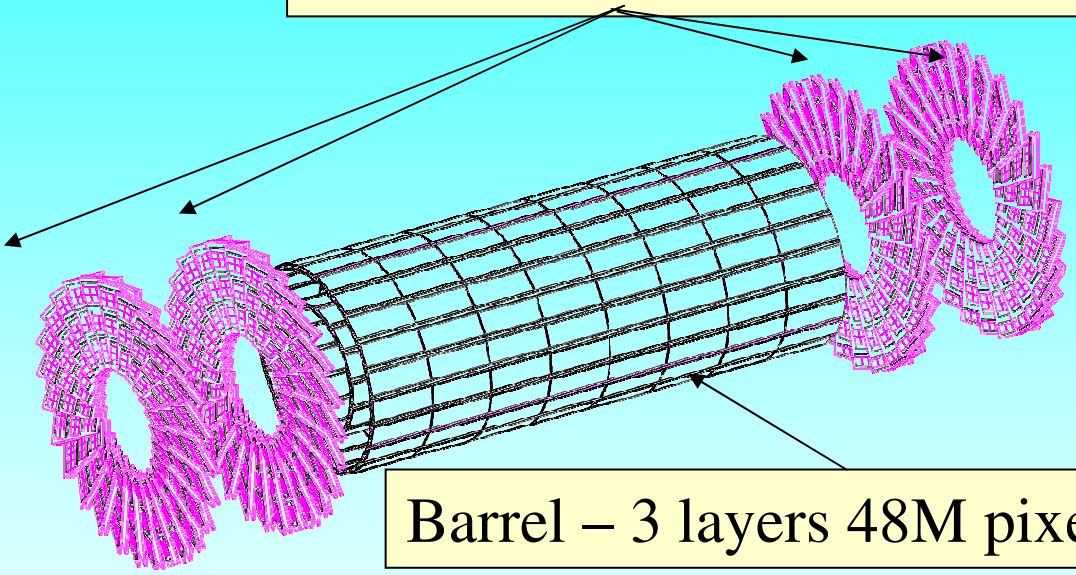
Strips:

Pitch: 80 μm to 180μm

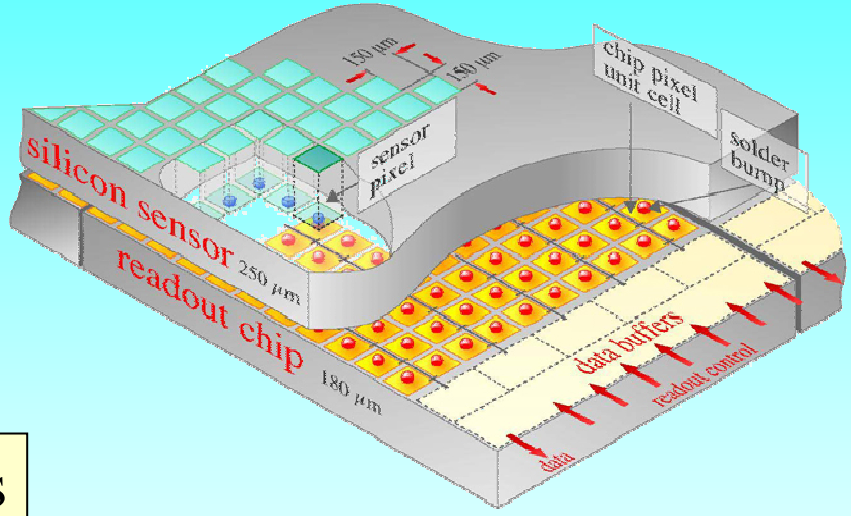
Hit Resolution: 20 μm to 50μm

Pixels Design

Forward – 4 disks, 16M Pixels



Barrel – 3 layers 48M pixels



LAYERS: R = 4.3cm 7.2cm 11.0 cm → Area Barrel = 0.78 m²

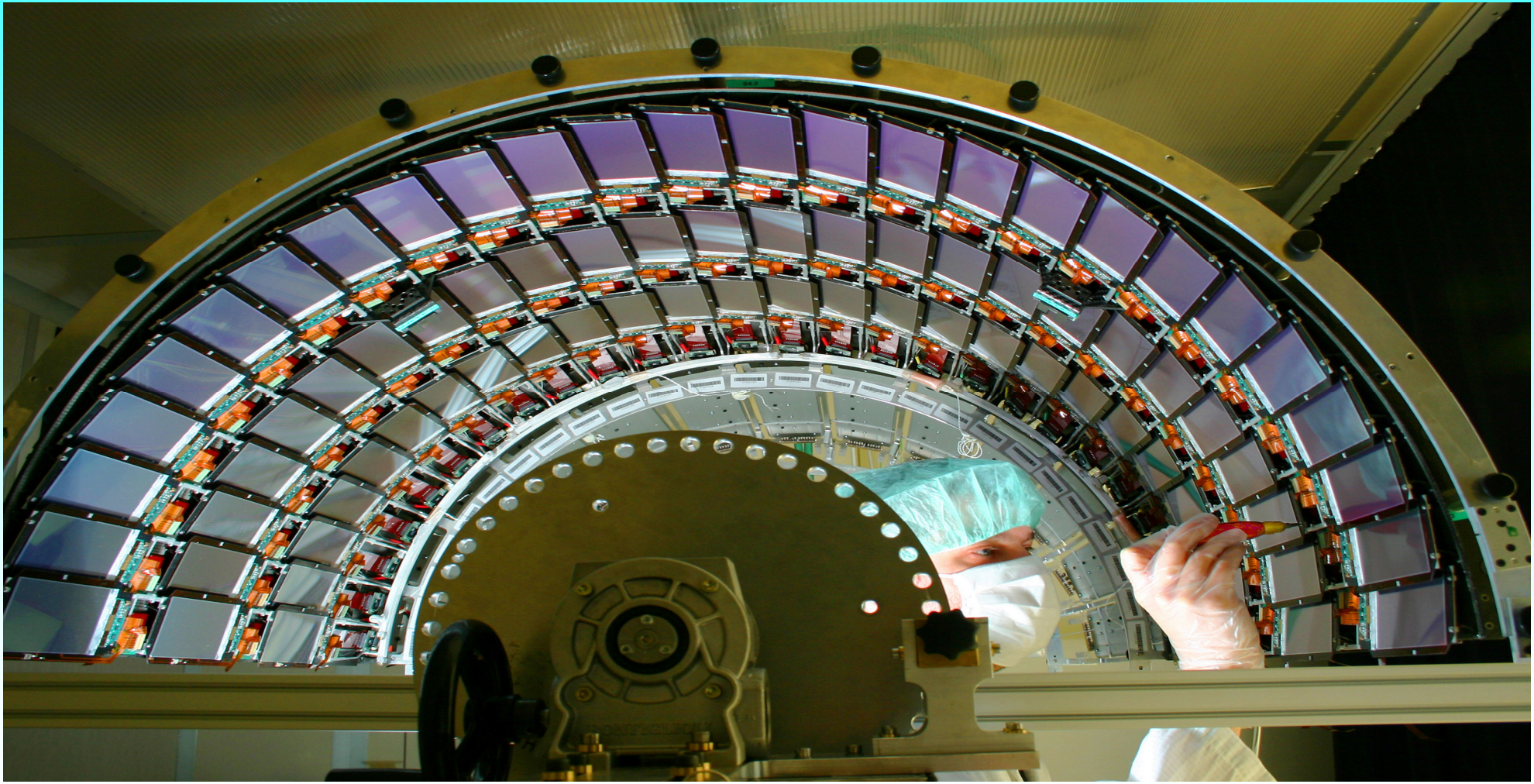
Disk = 0.28 m²

Total ~ 1.1 m²

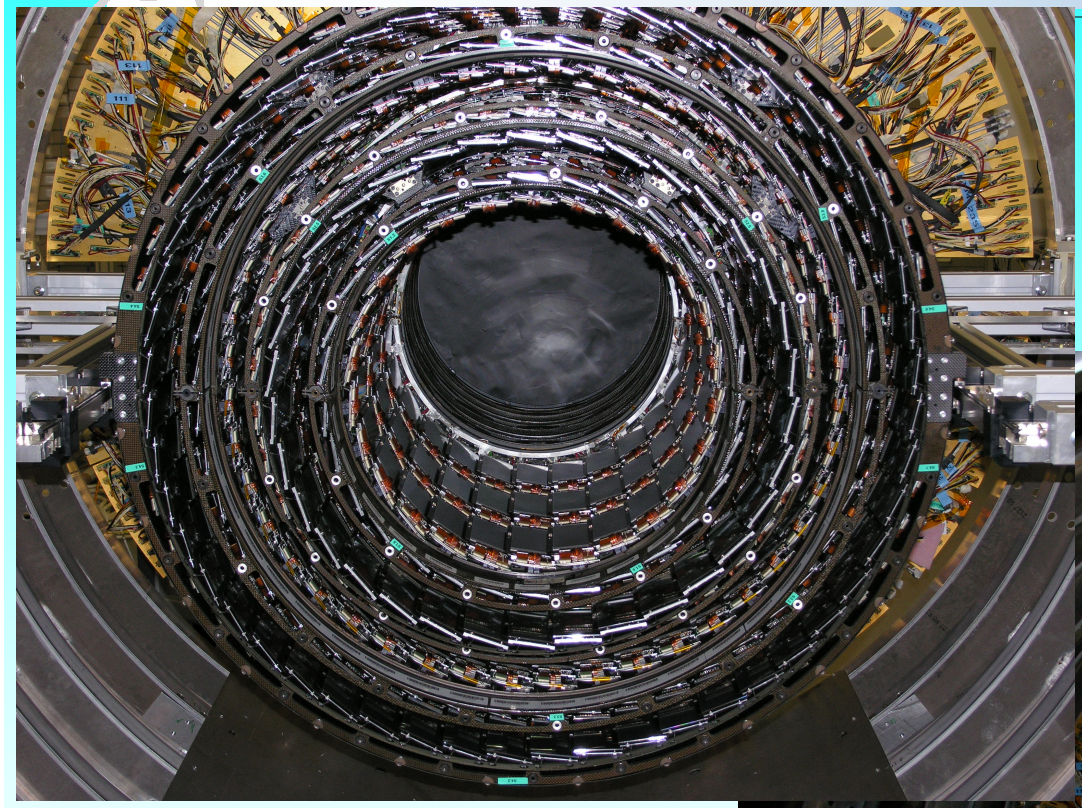
Installation +
Fluence limited
→ ΔT_{max} ~ 2 years

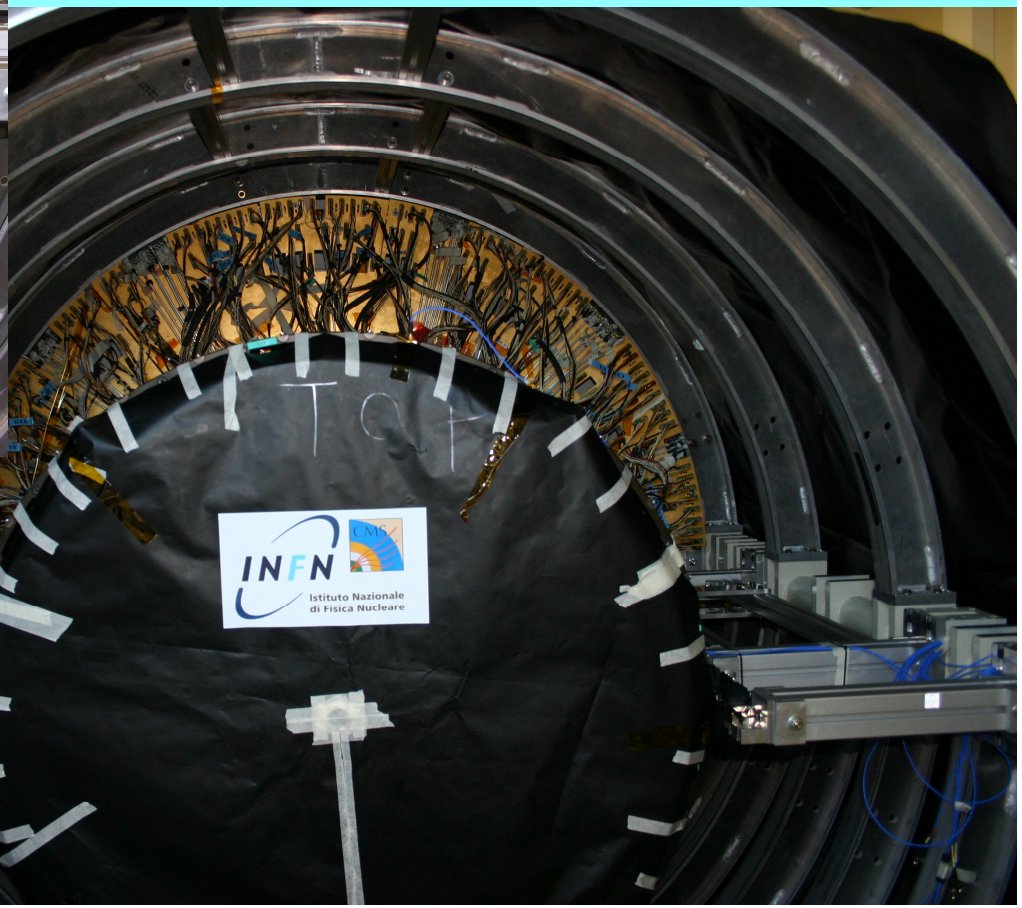
Cost limited !!
→ R_{max}

Installation of modules



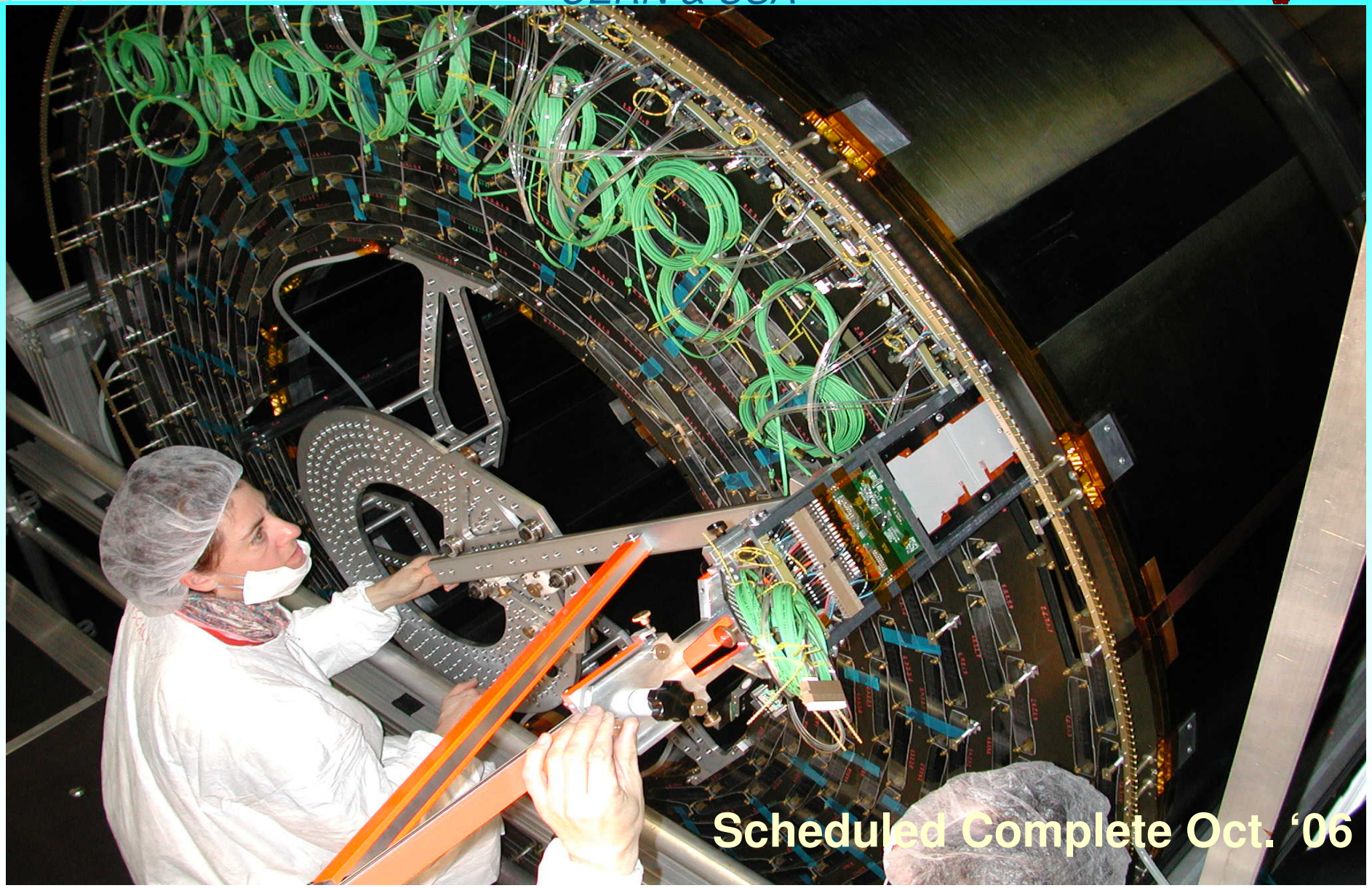
TIB



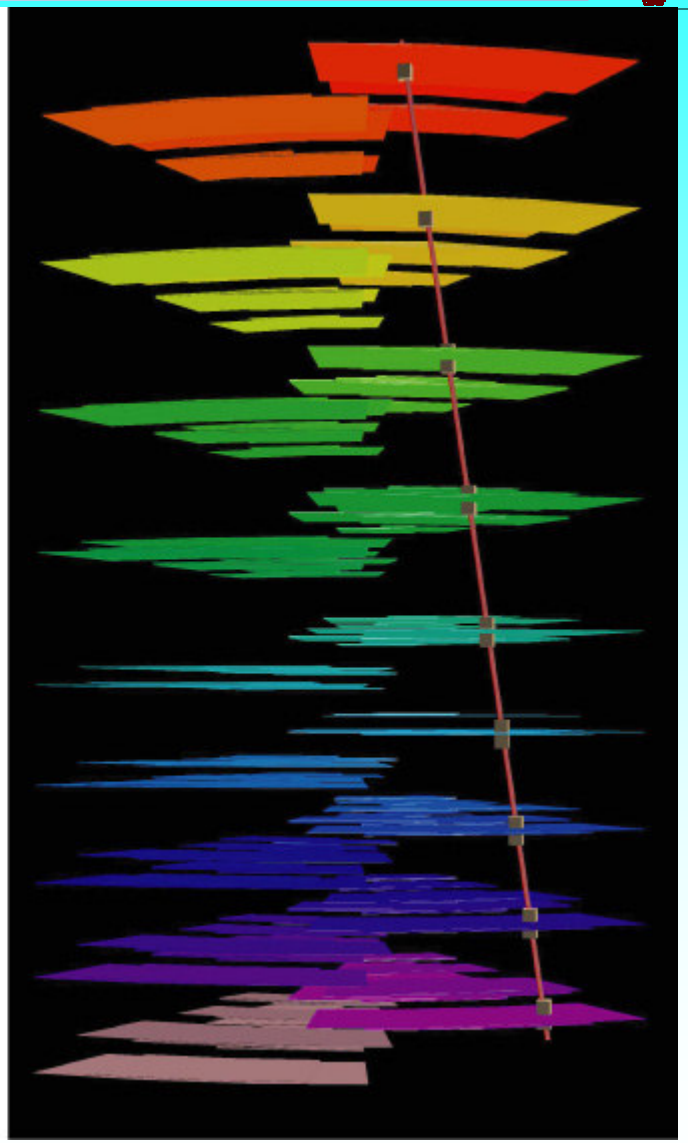


Tracker Outer Barrel (TOB)

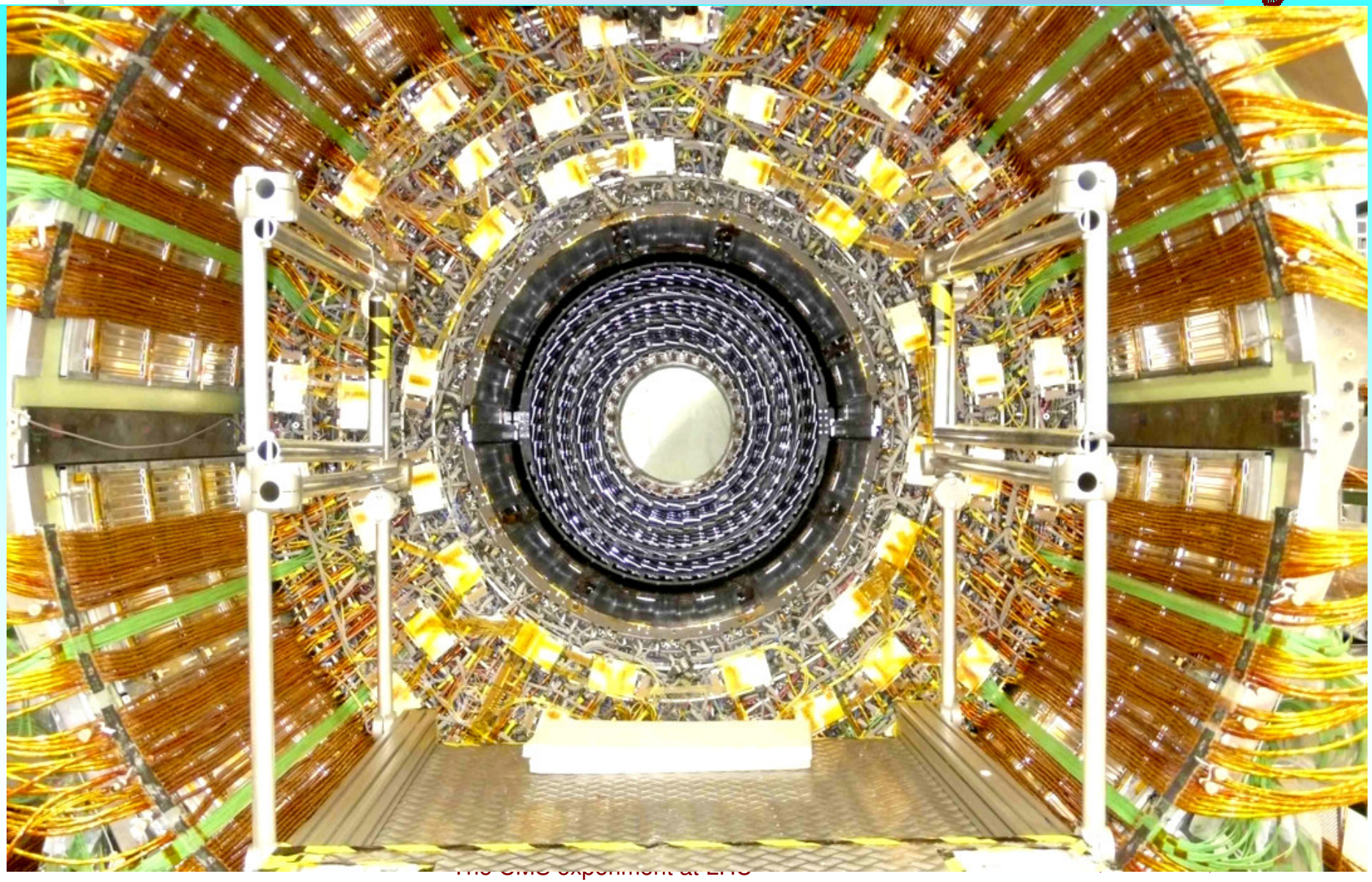
CERN & USA



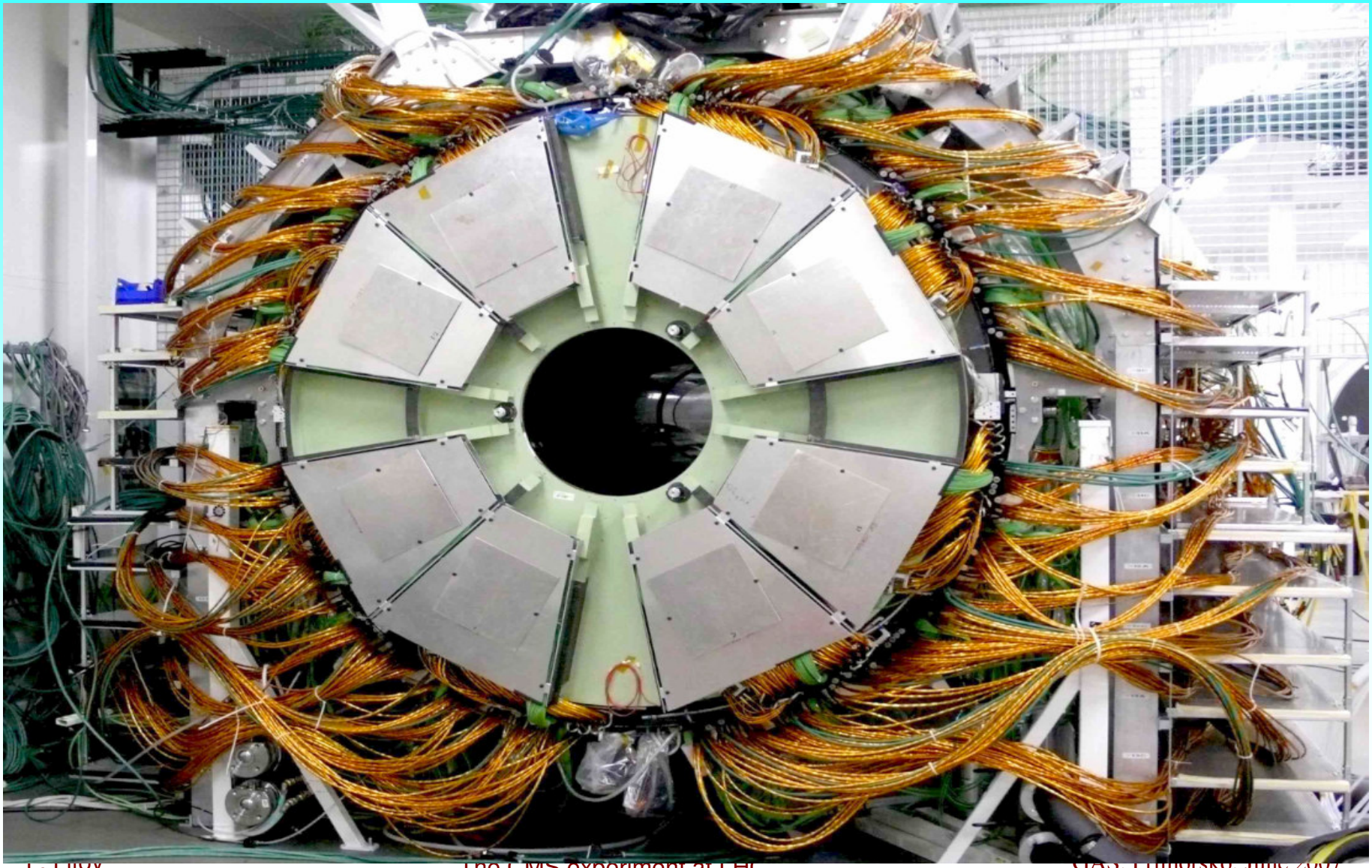
TEC Verification with Cosmics



Tracker Inner Barrel inserted in Outer Barrel

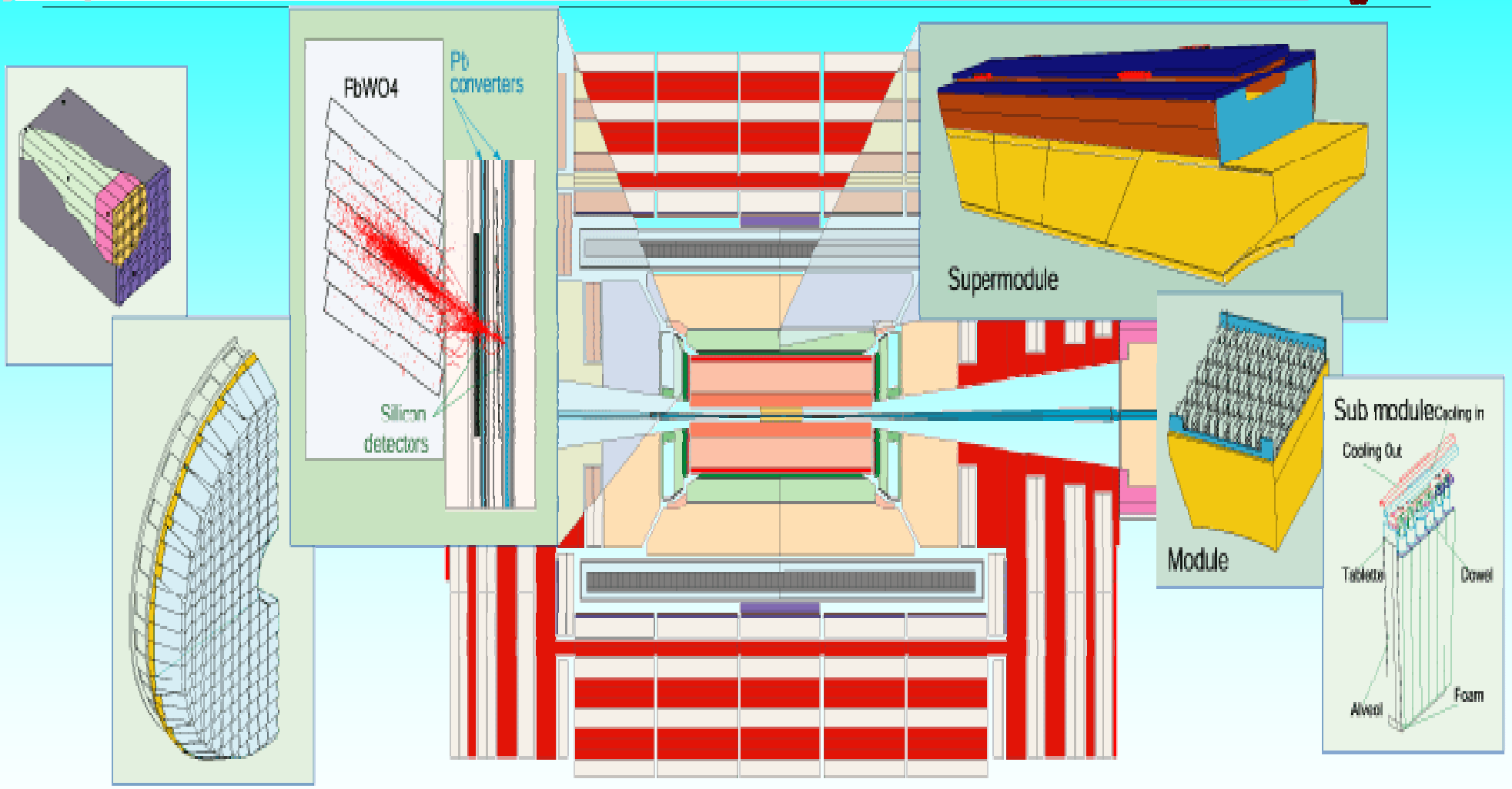


Si Strip Tracker Integrated into TST

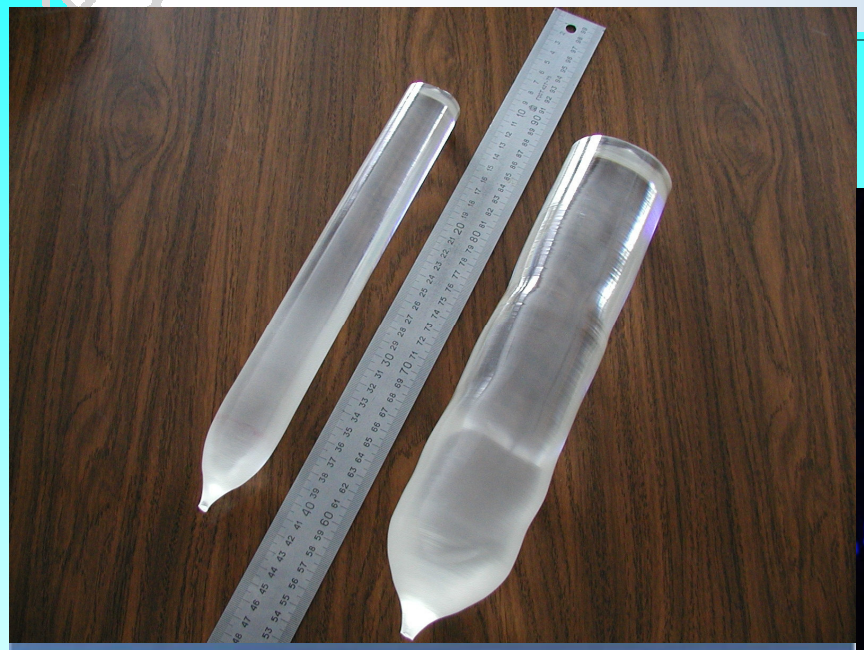


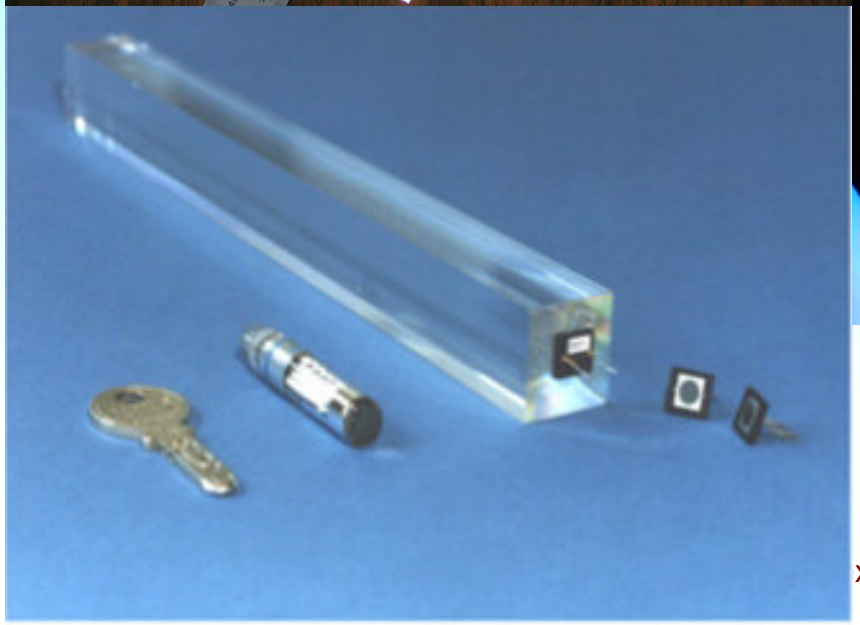
Electromagnetic calorimeter

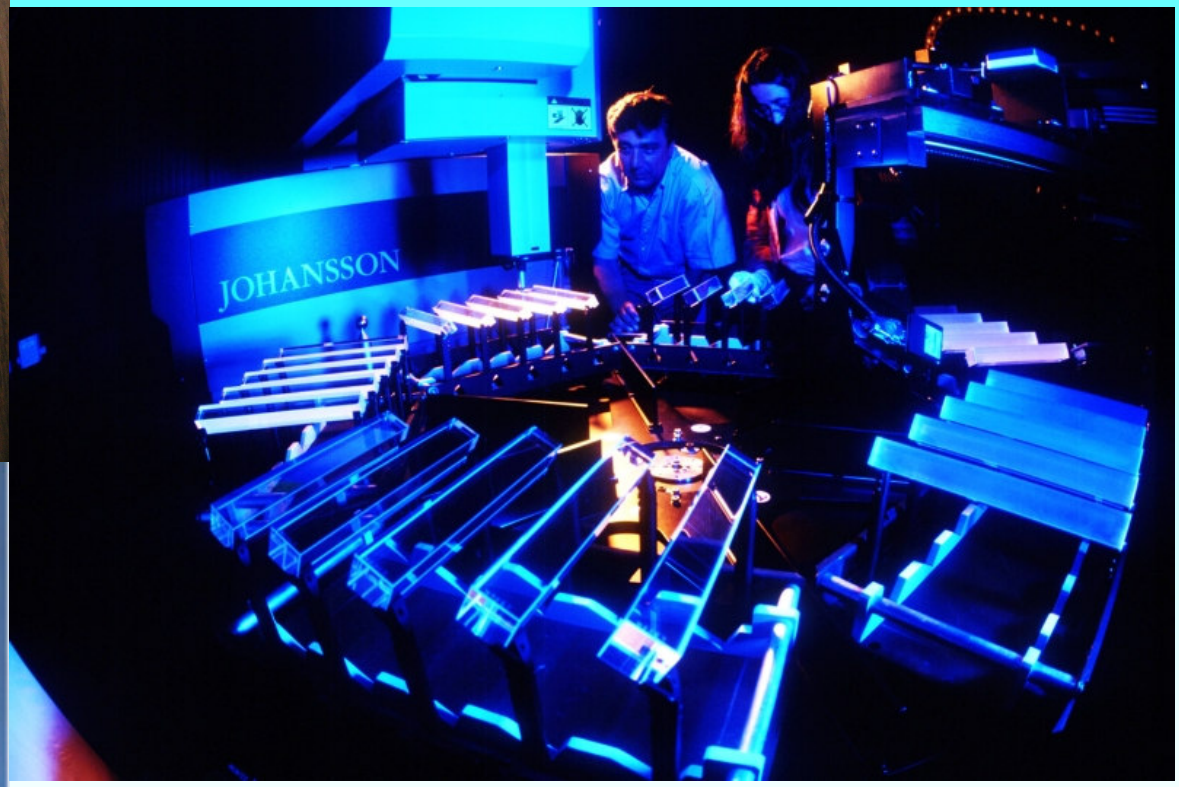
ECAL Overview



$PbWO_4$ crystals

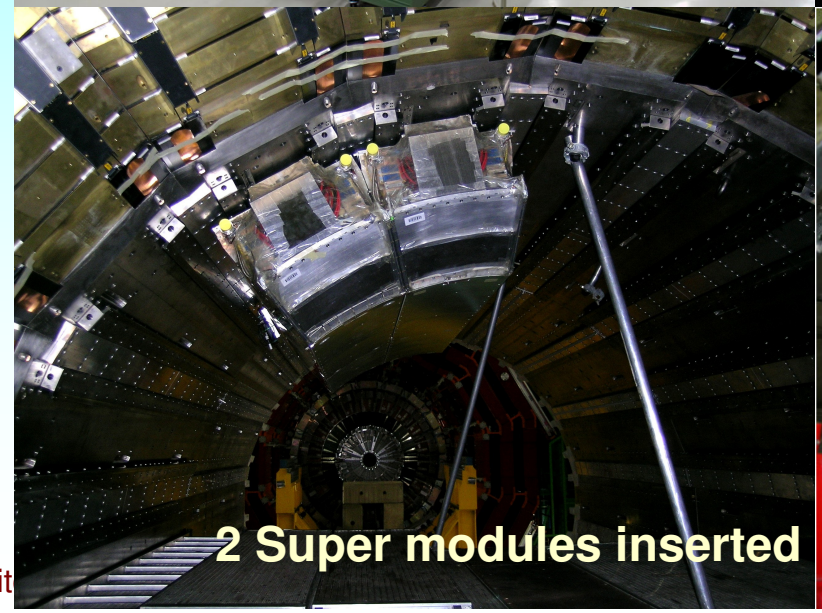






ECAL module

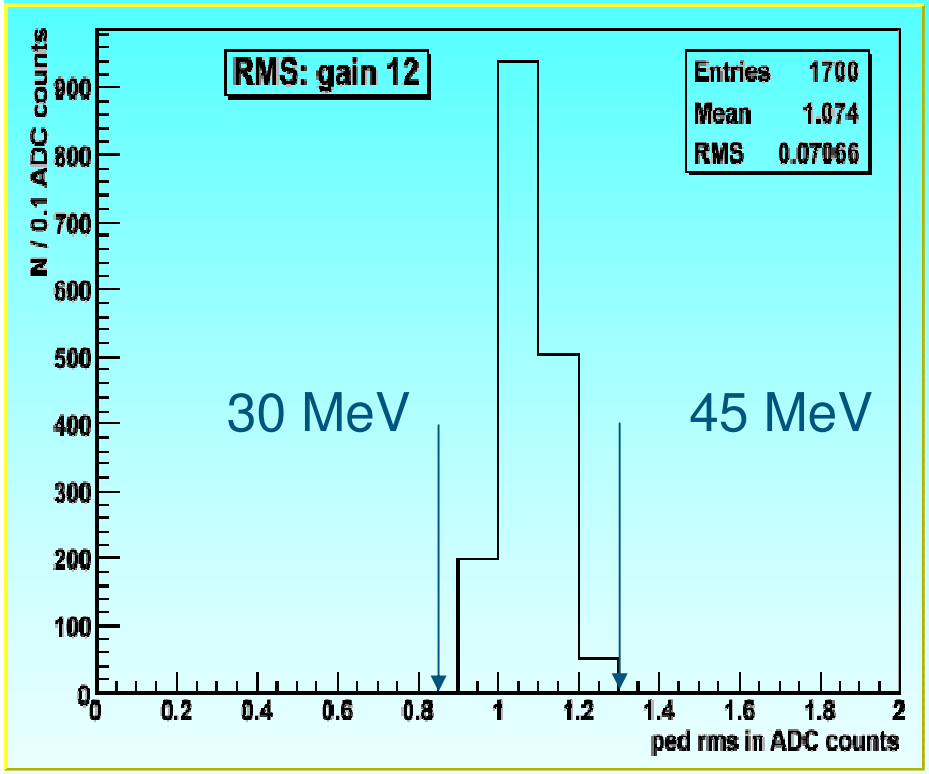
ECAL assembly



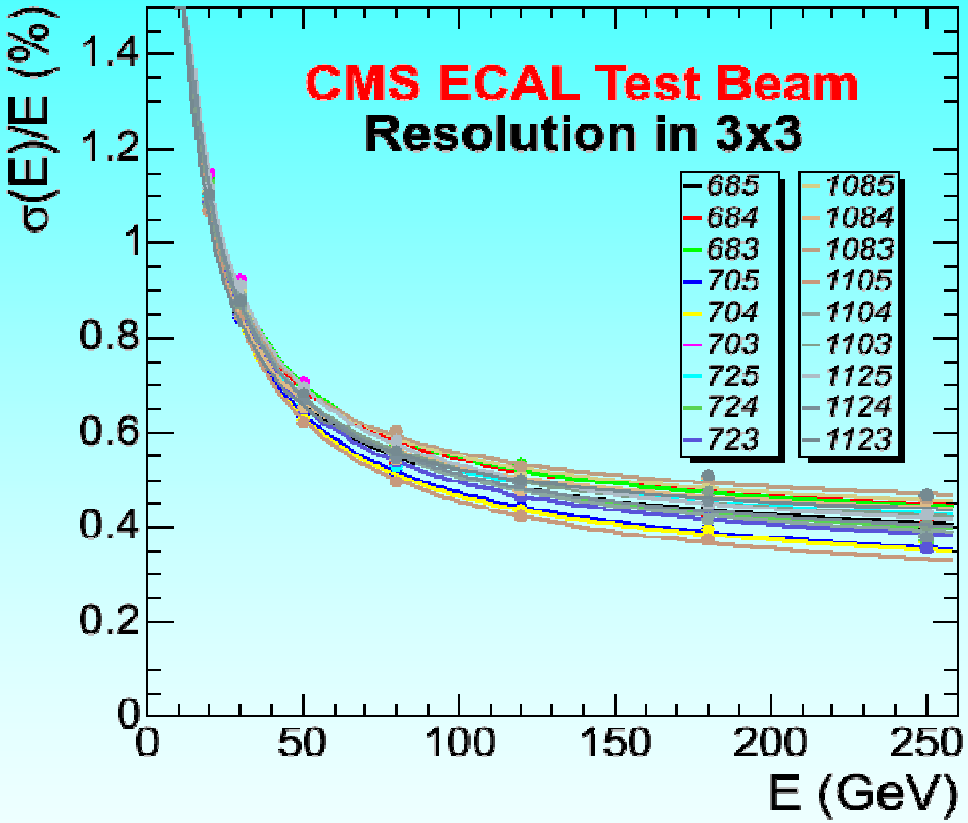
2 Super modules inserted

27 April for magnet test

ECAL performance



Noise distribution of the 1700 channels of SM13



Energy resolution: 2004 test beam 18 crystals

Hadron calorimeter

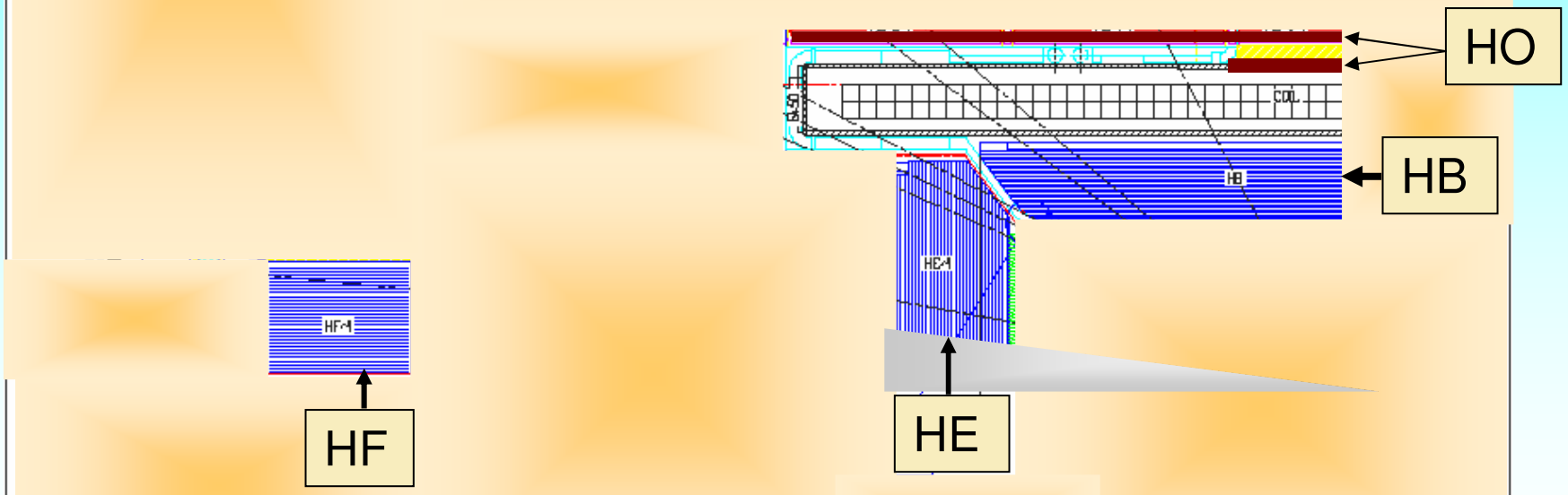
Hadronic Calorimeter: HCAL

Had Barrel: HB

Had Endcaps: HE

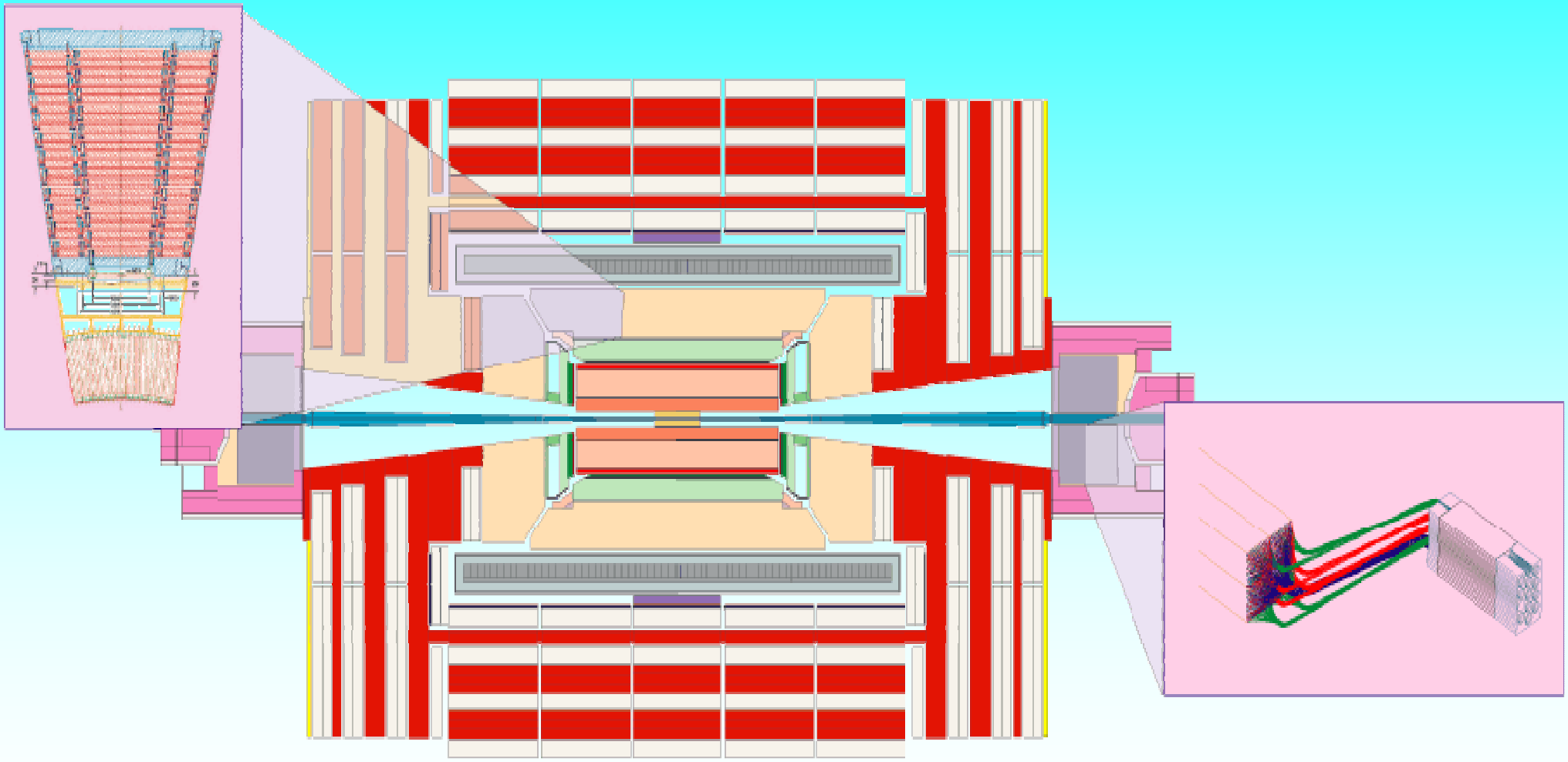
Had Forward: HF

Had Outer: HO

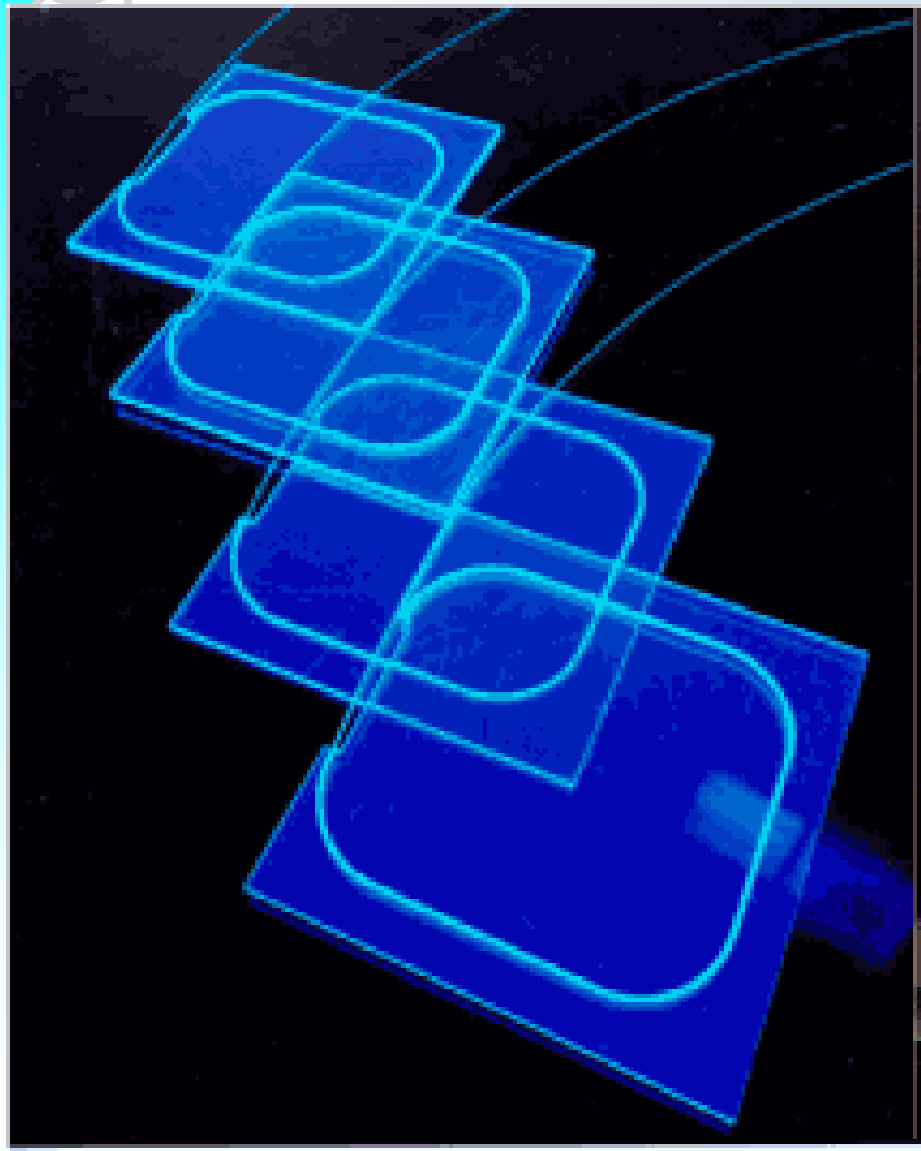


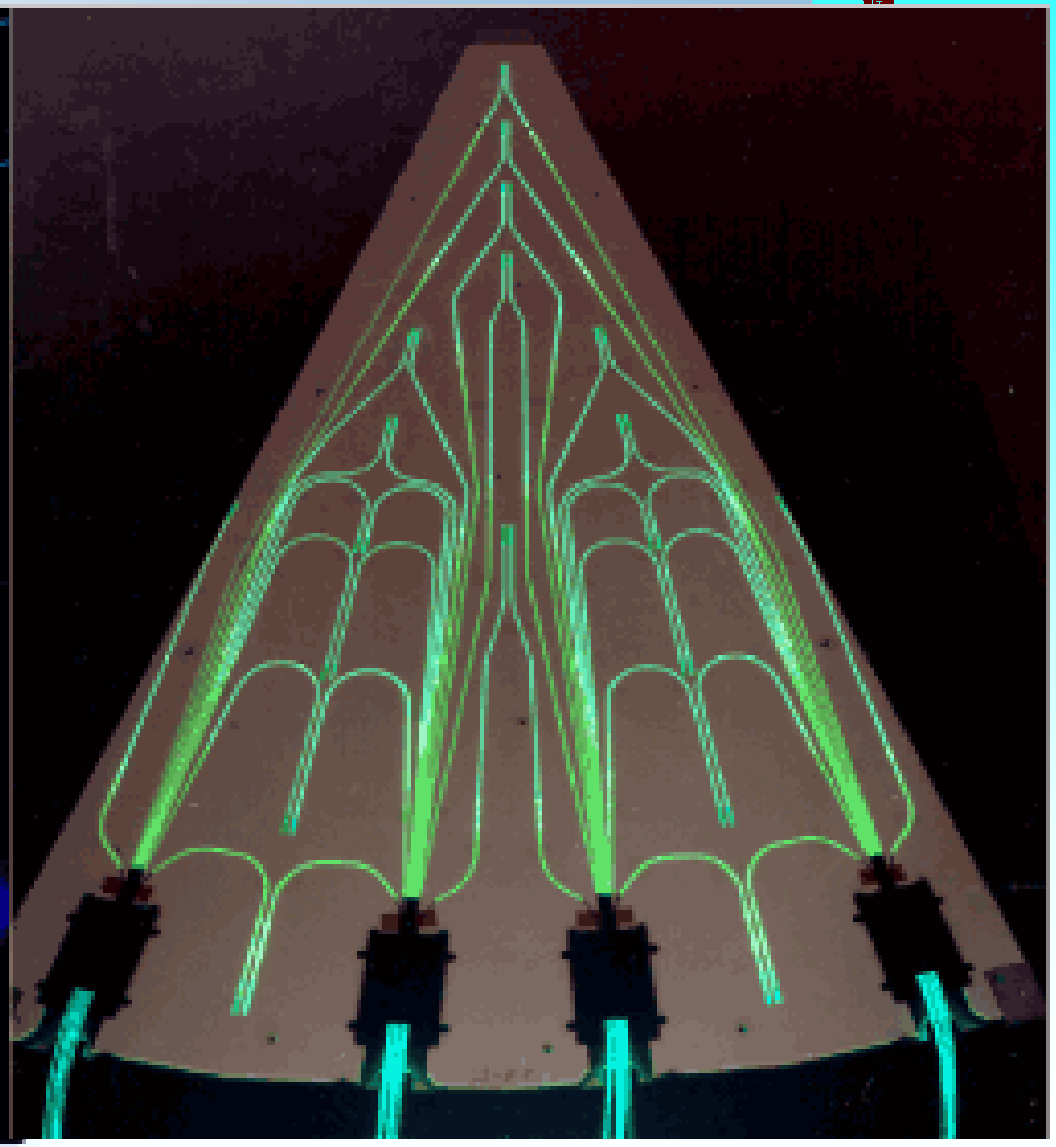
HB & HF: Brass Absorber and Scintillating tiles.
HO: Scintillator “catcher”. HF: Iron and Quartz fibers

HCAL overview

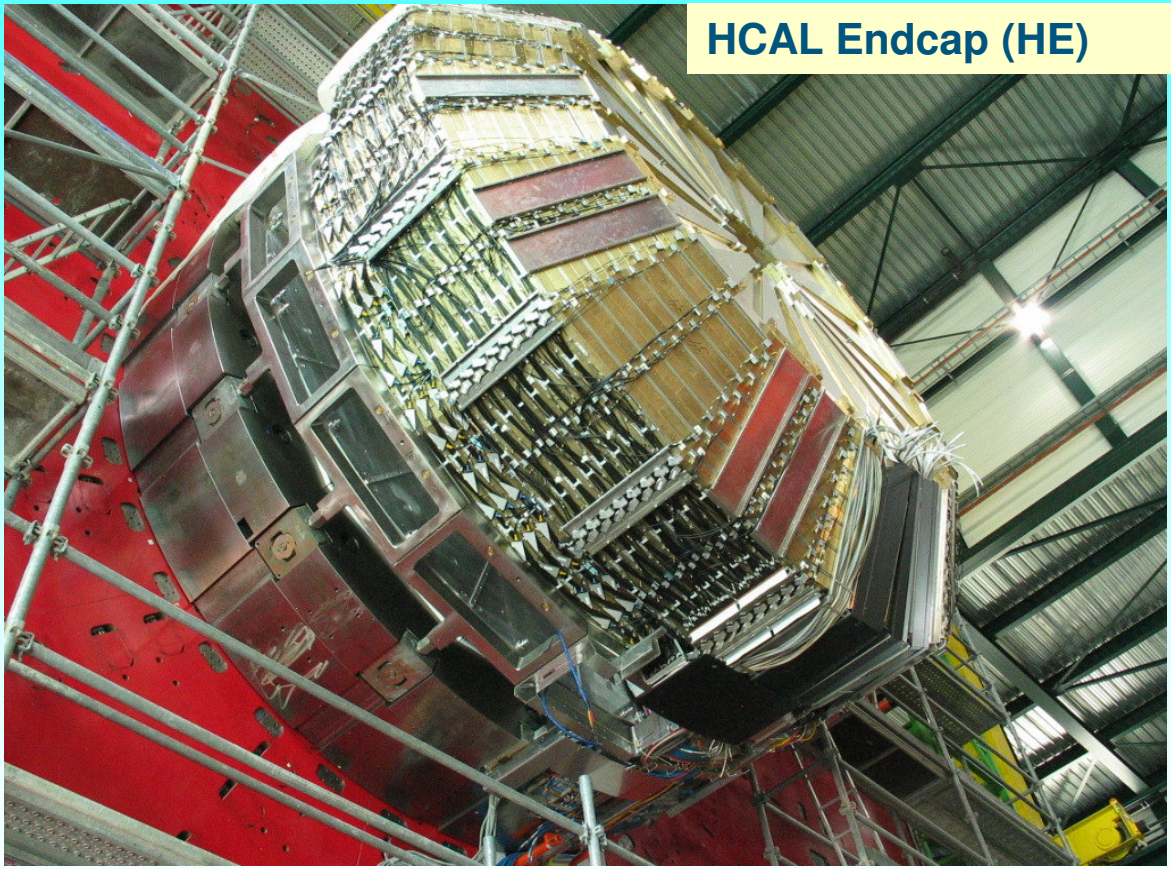


HCAL Scintillators



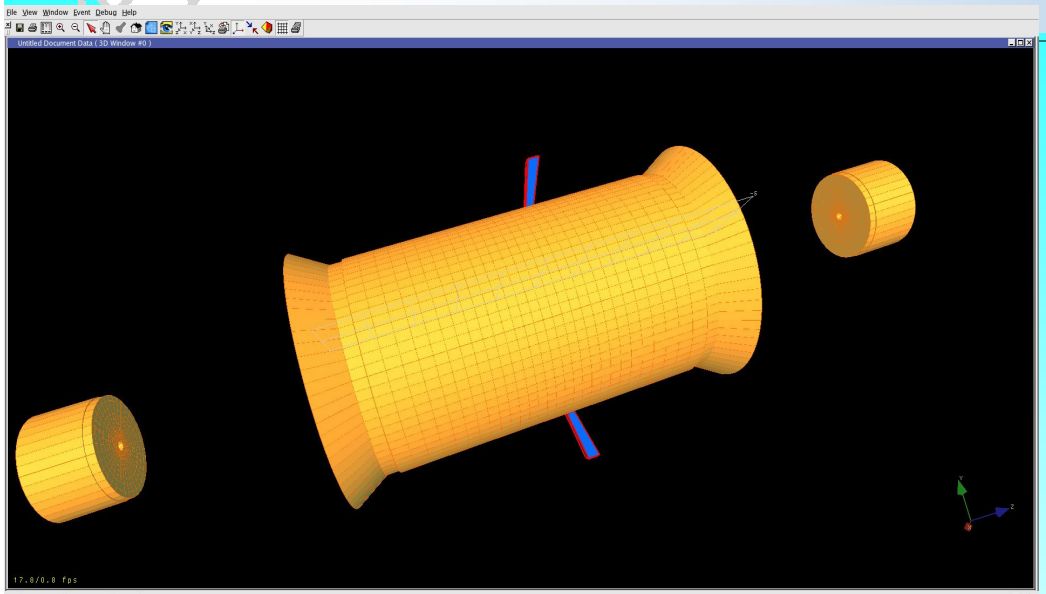


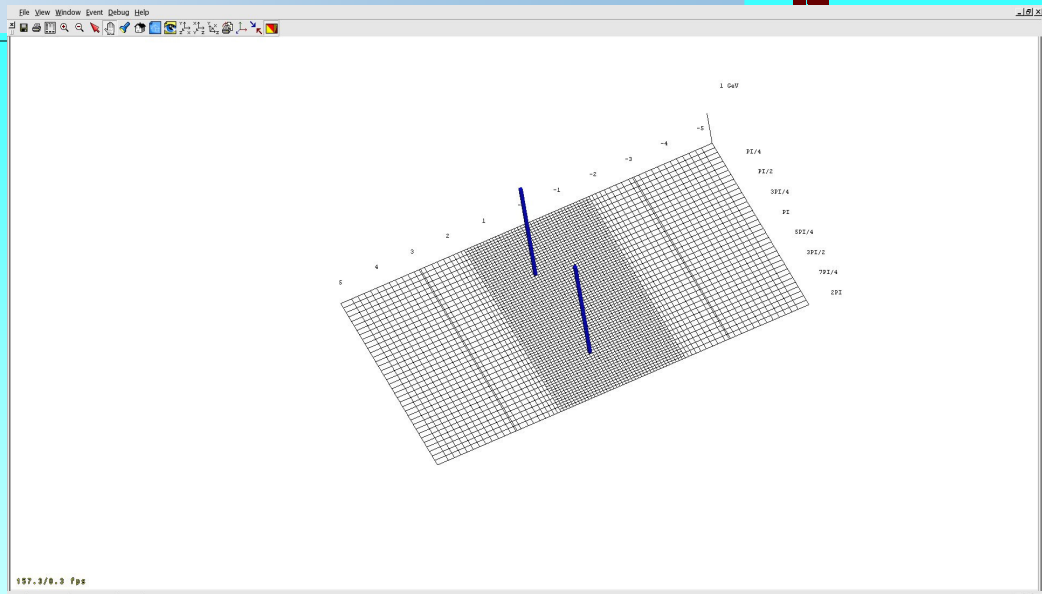
Hadron Calorimeter (HCAL) Complete

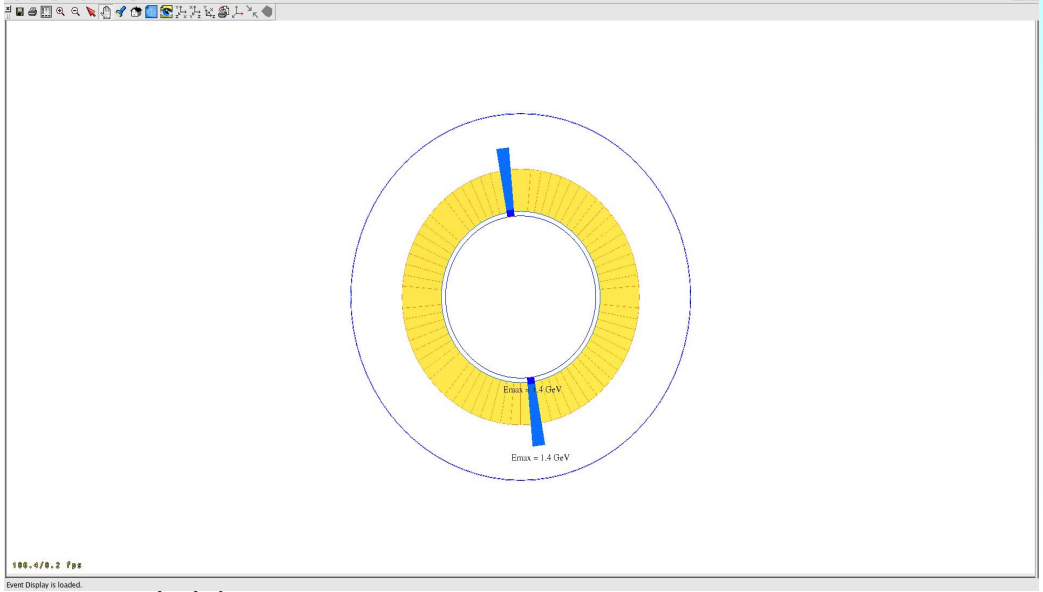


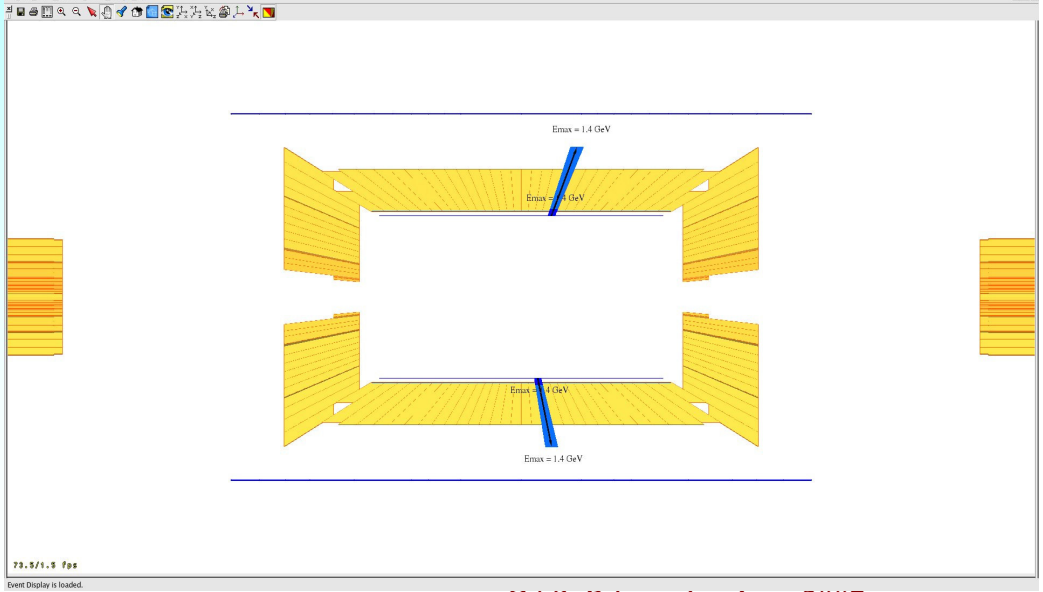
Assembly of 2 half barrels HB+ & HB- and two endcaps HE+ & HE- completed in 03 (brass+ scint)

Cosmic's in HCAL at SX5





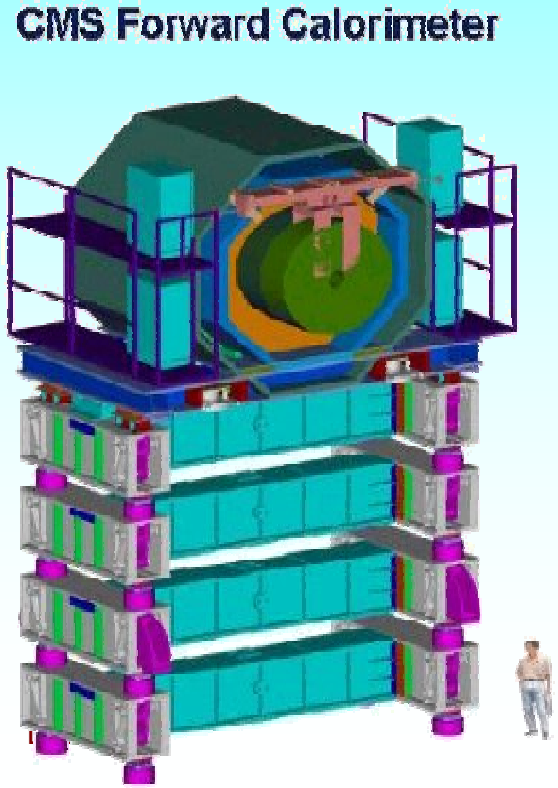


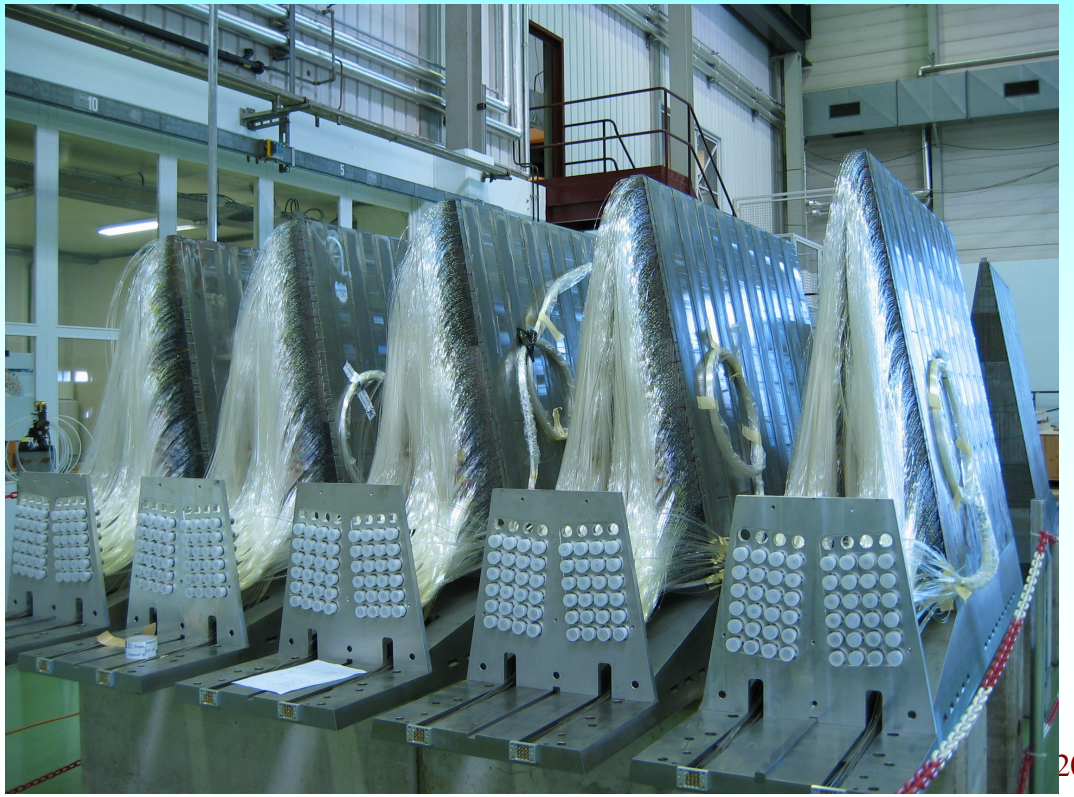


Hadronic Forward (HF) calorimeter

Steel absorbers, embedded quartz fibers // to the beam.
Fast (~10 ns) collection of Cherenkov radiation.

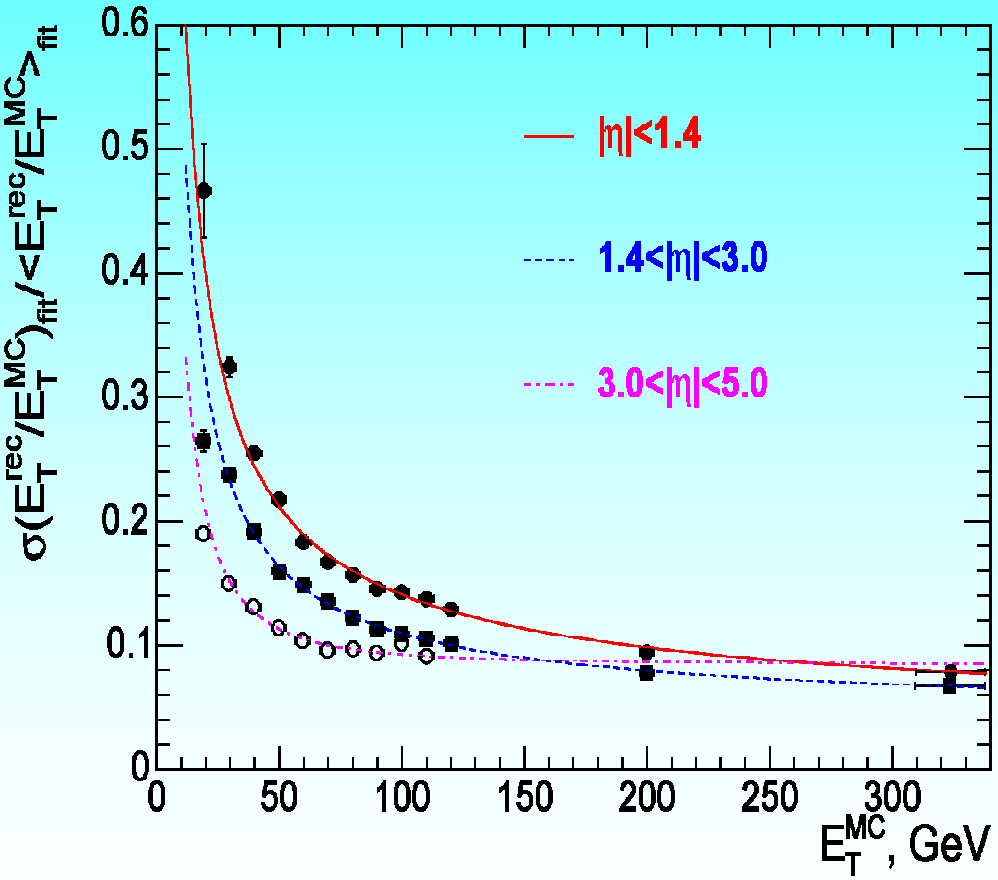
Coverage: $3<|\eta|<5$ $\Delta\phi$ x $\Delta\eta$ =10º x 13 η towers
Depth: 10 λ_{int}



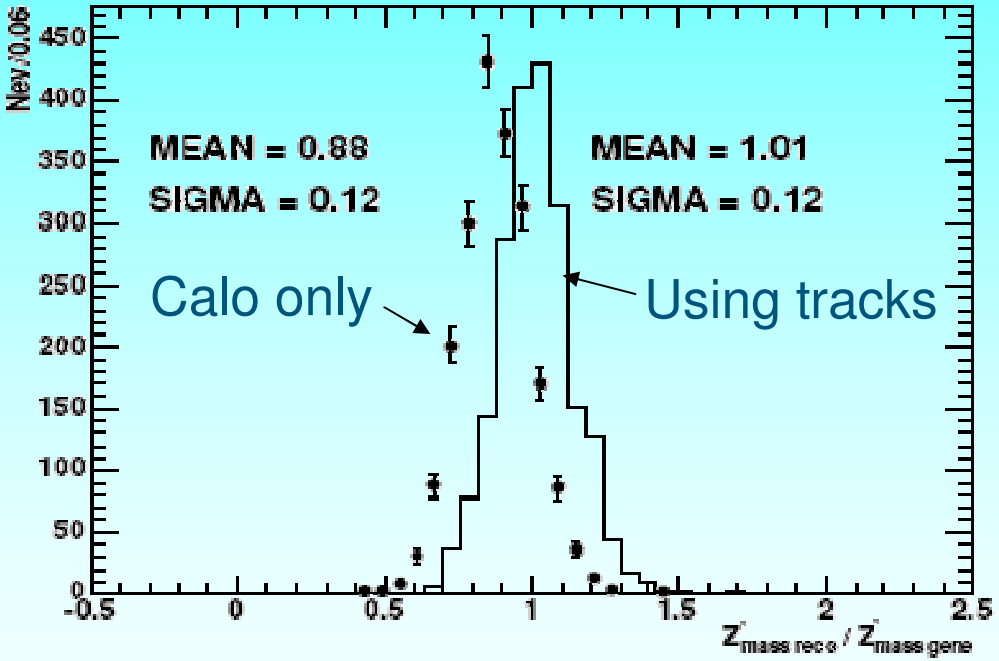


Jet Reconstruction and Resolutions

Jet E_T resolution



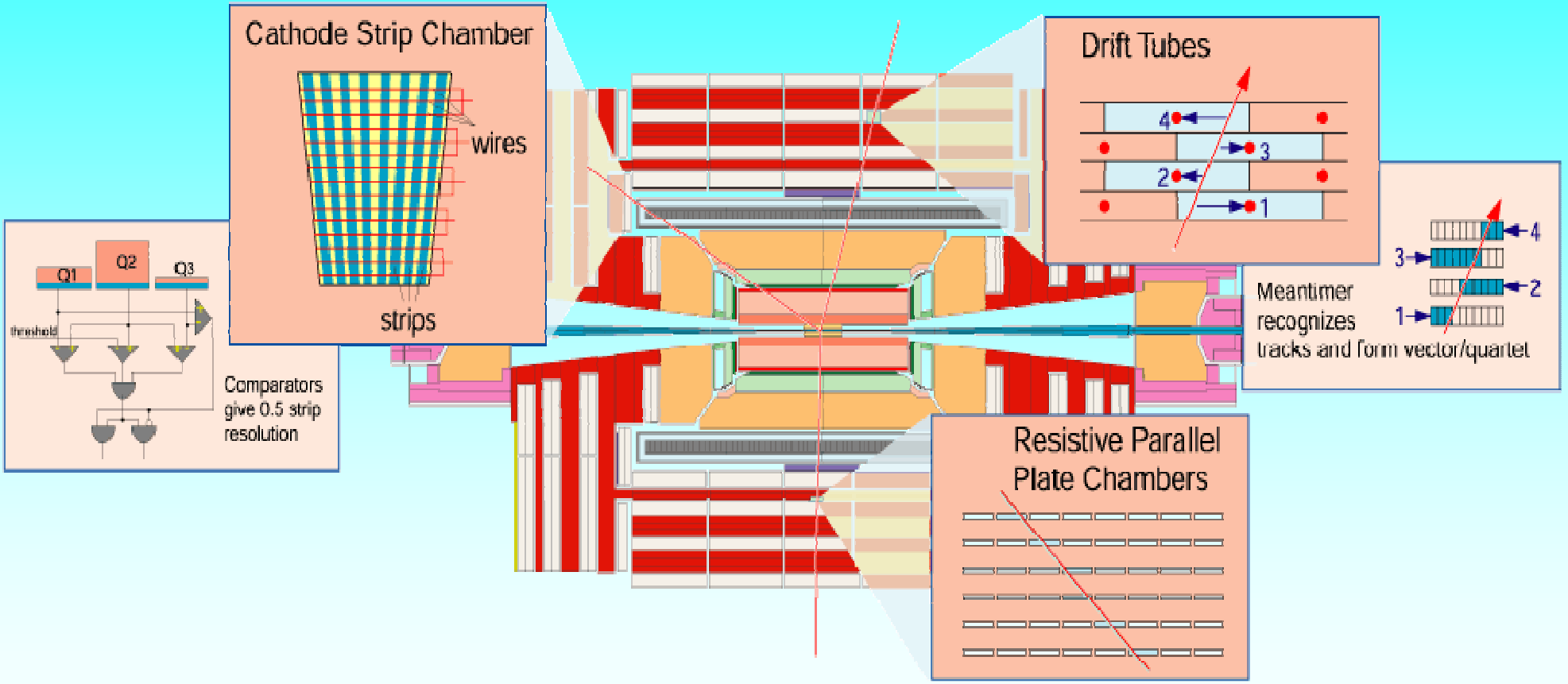
M_{jj} resolution at 120 GeV



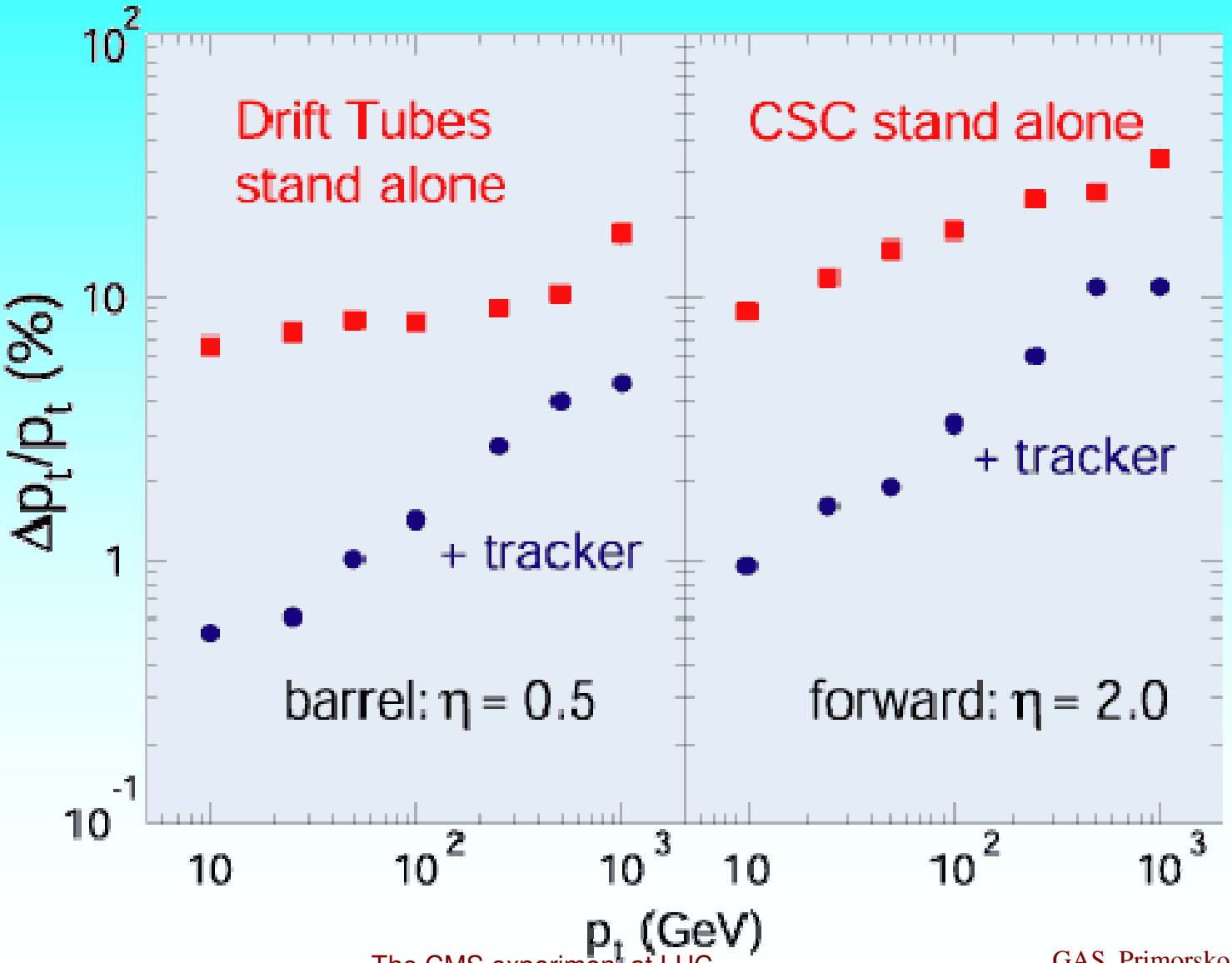
M_{jj} resolution ≤ 15%

Muon system

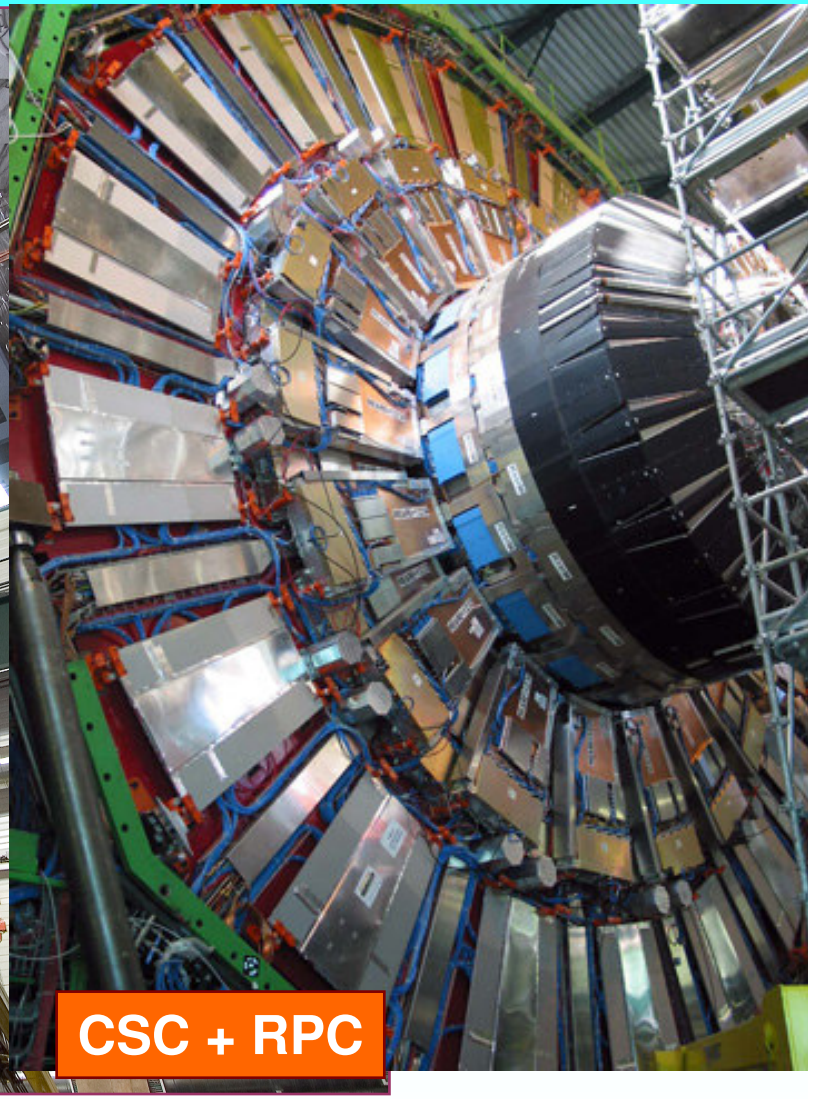
Muon system


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

Momentum Resolution

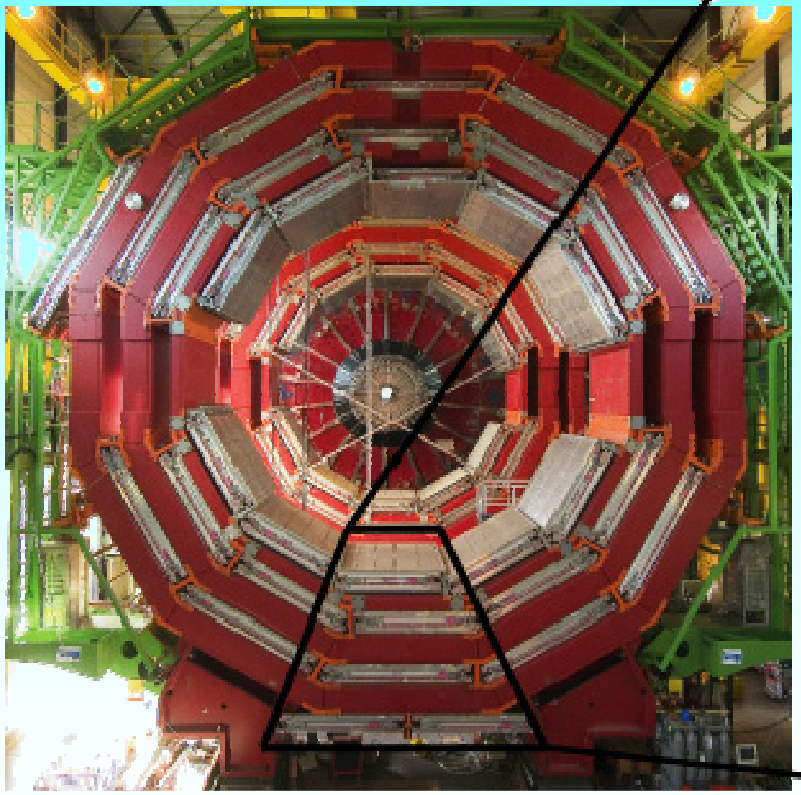


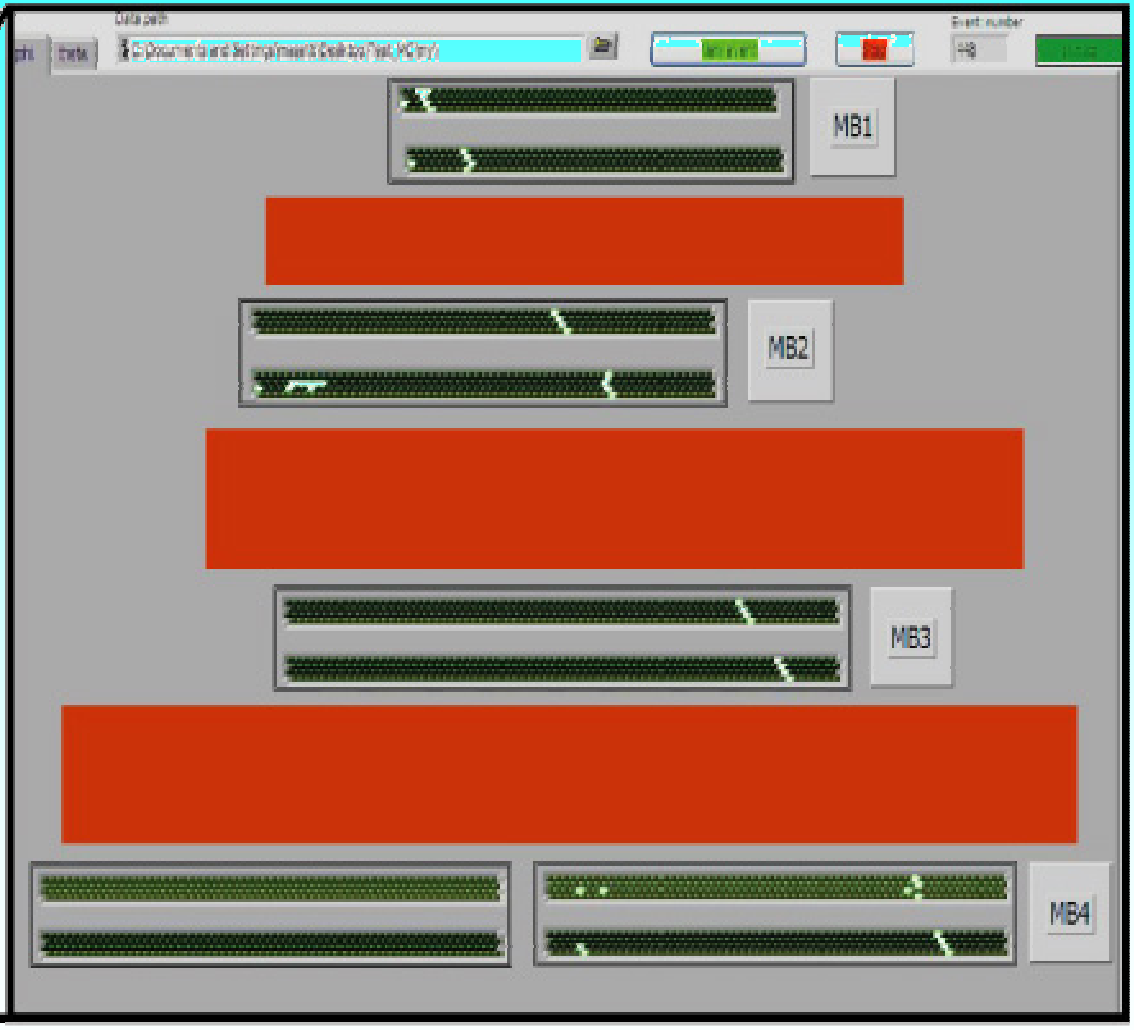
Muon system



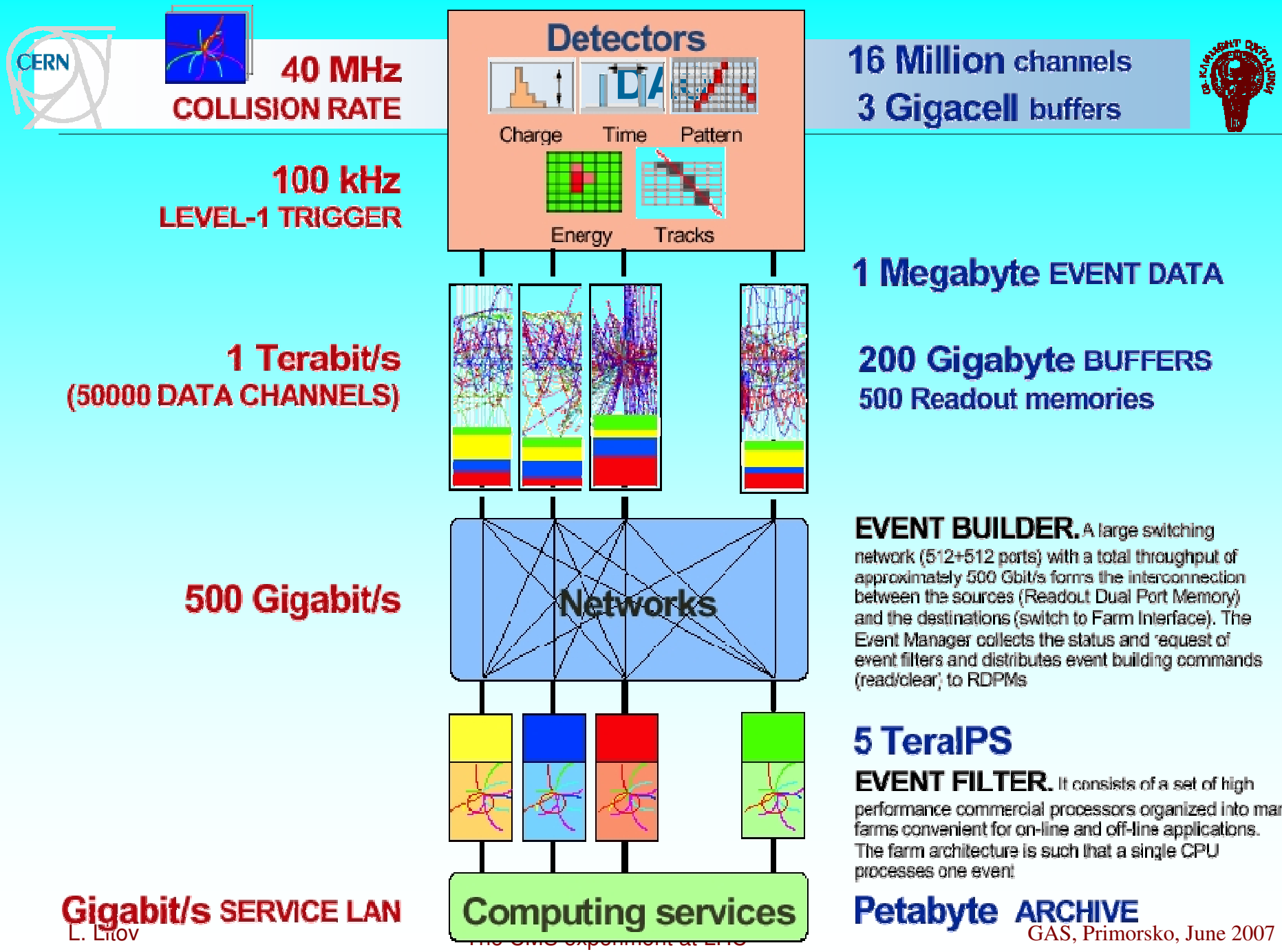
Muon system

First muon event at SX5



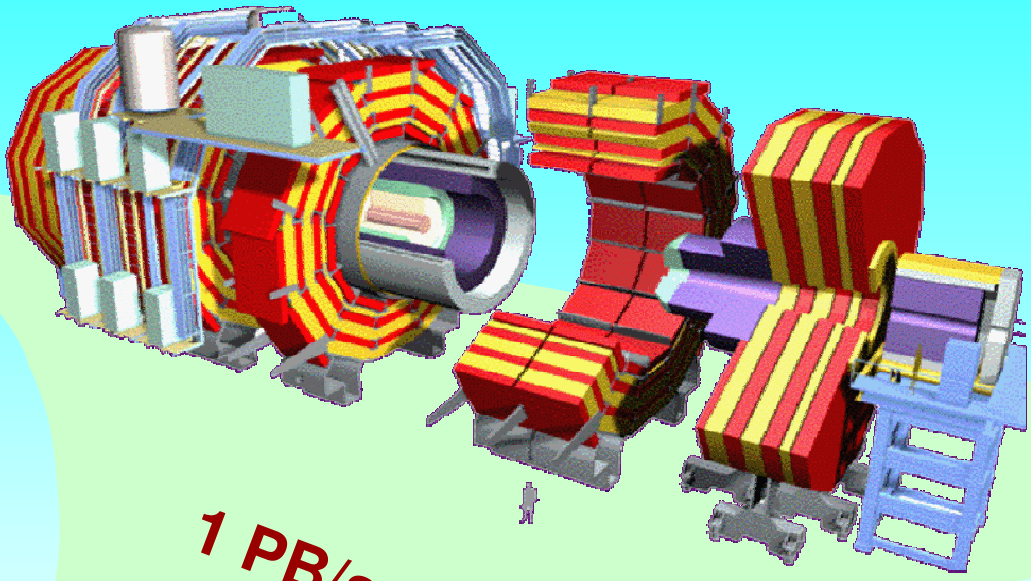


Trigger and DAQ


40 MHz
COLLISION RATE
Detectors
Charge
Time
Pattern
Energy
Tracks
16 Million channels
3 Gigacell buffers
100 kHz
LEVEL-1 TRIGGER
1 Megabyte EVENT DATA
1 Terabit/s
(50000 DATA CHANNELS)
200 Gigabyte BUFFERS
500 Readout memories
500 Gigabit/s
Networks
EVENT BUILDER. A large switching network (512+512 ports) with a total throughput of approximately 500 Gbit/s forms the interconnection between the sources (Readout Dual Port Memory) and the destinations (switch to Farm Interface). The Event Manager collects the status and request of event filters and distributes event building commands (read/clear) to RDPMs
5 TeraIPS
EVENT FILTER. It consists of a set of high performance commercial processors organized into many farms convenient for on-line and off-line applications. The farm architecture is such that a single CPU processes one event
Gigabit/s SERVICE LAN
Computing services
Petabyte ARCHIVE

DAQ Progress !

Data processing

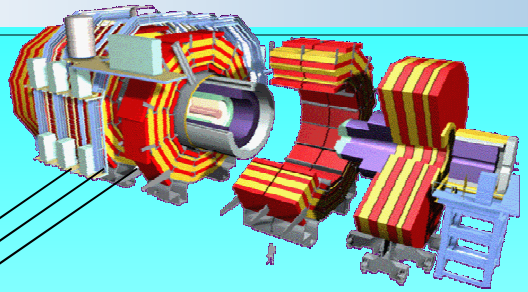


1 PB/sec

Filtering in real time:
Selection of interesting events and data compresion

1 PB per year

LCG



Level 0

Trigger system

0.1-1.5 GB/sec

CERN computing center

Level 1

~40Gb/sec

USA

France

CERN

Italy

…

1-2.5 Gb/sec

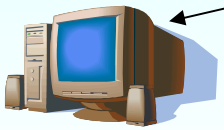
Level 2

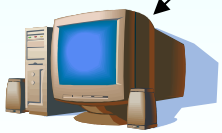
University

Laboratory

University

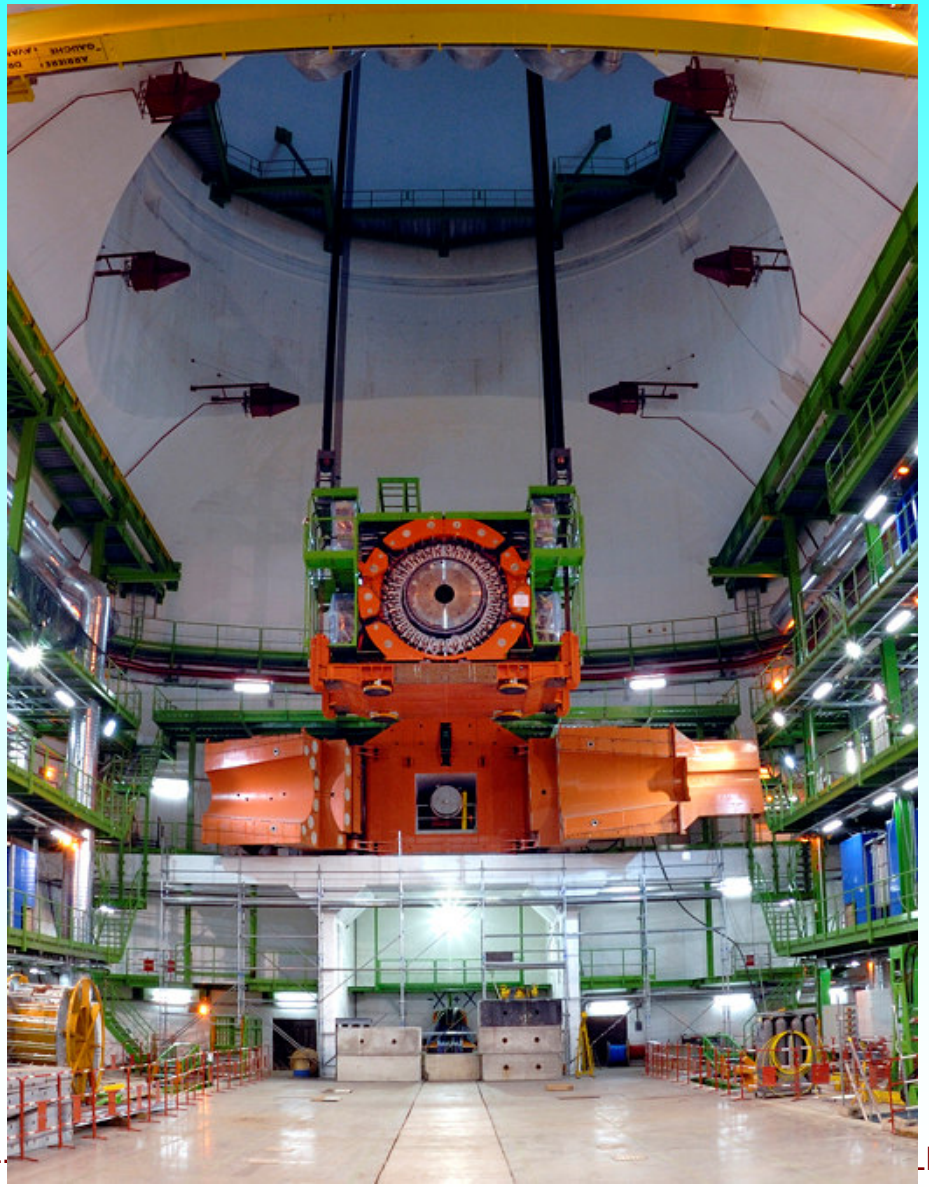
Level 3

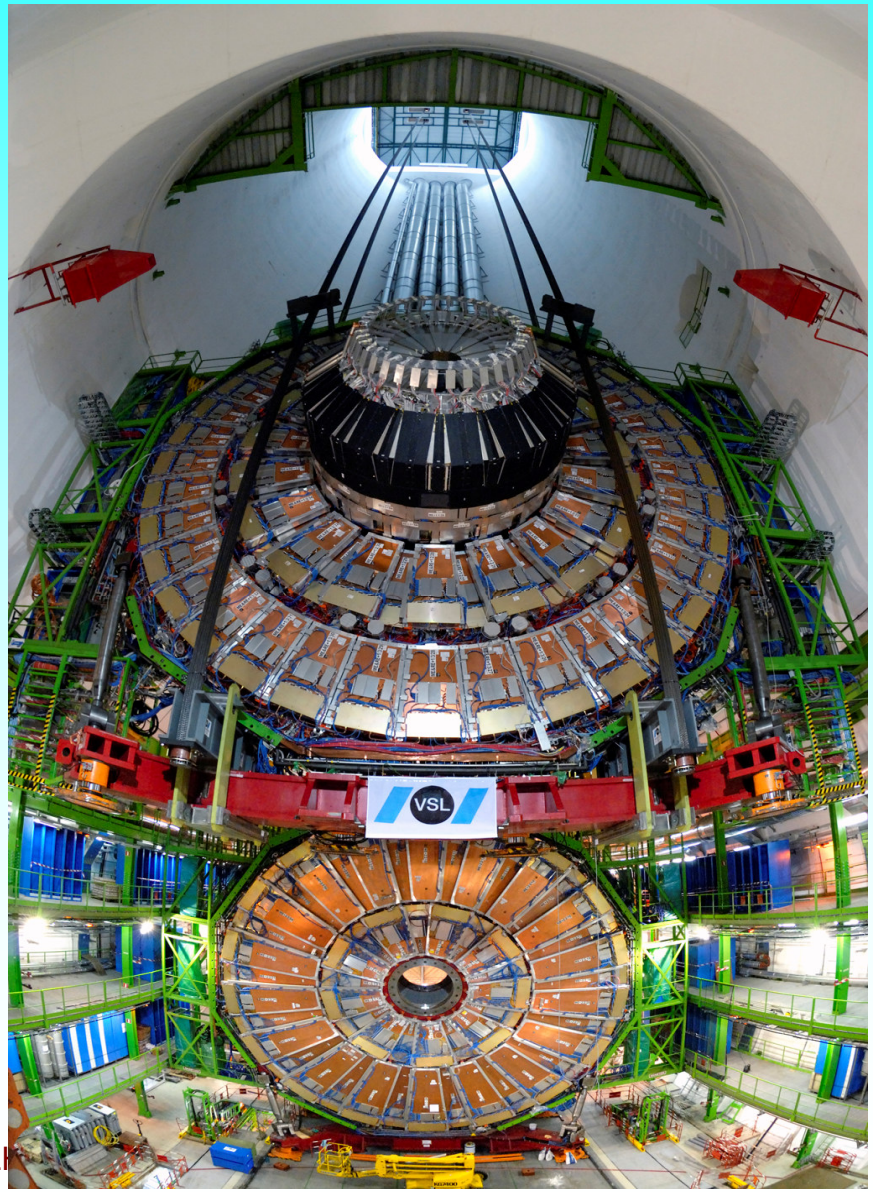




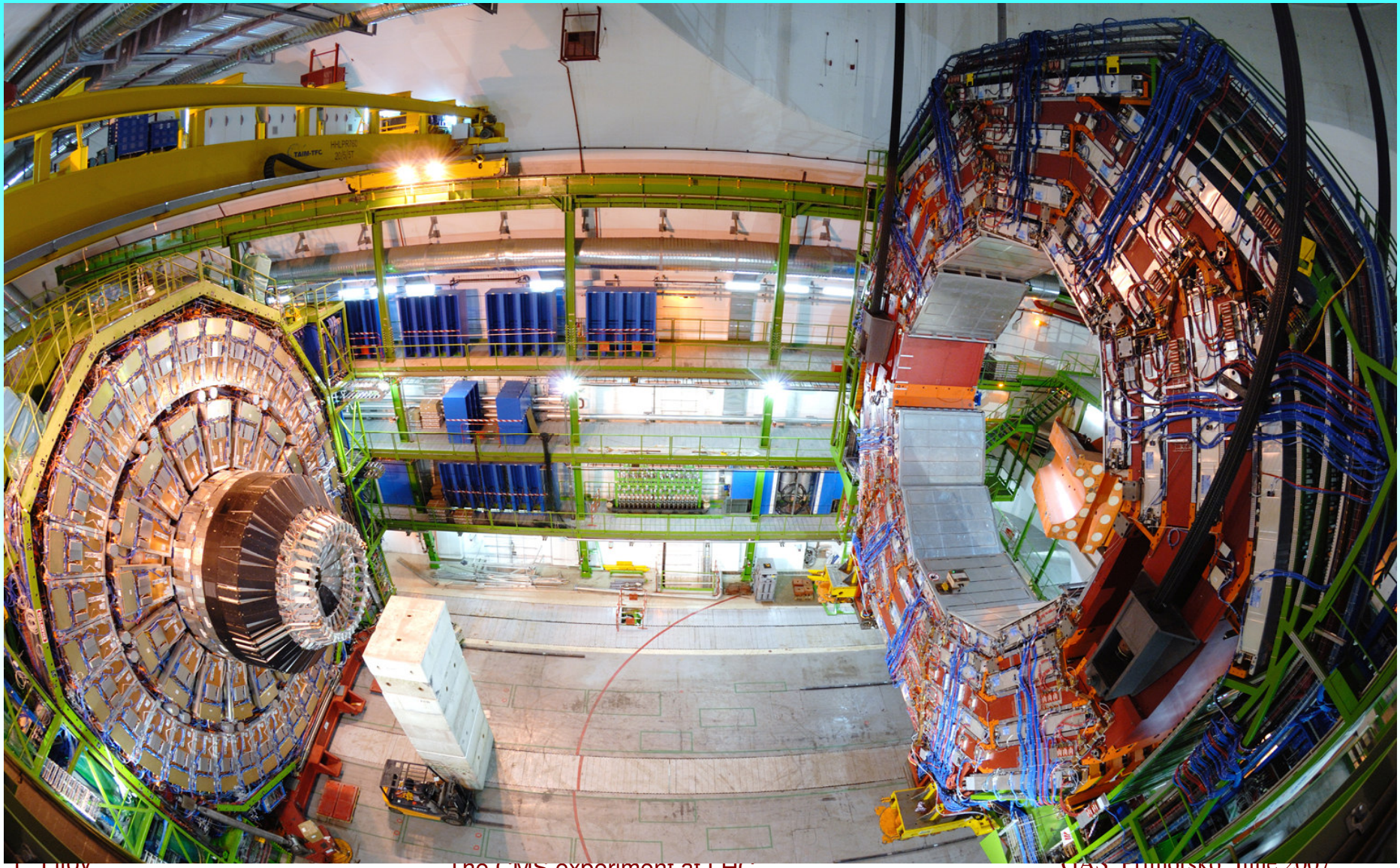
1-10 Gb/sec

HF and YE+1 Lowering (9 Jan)

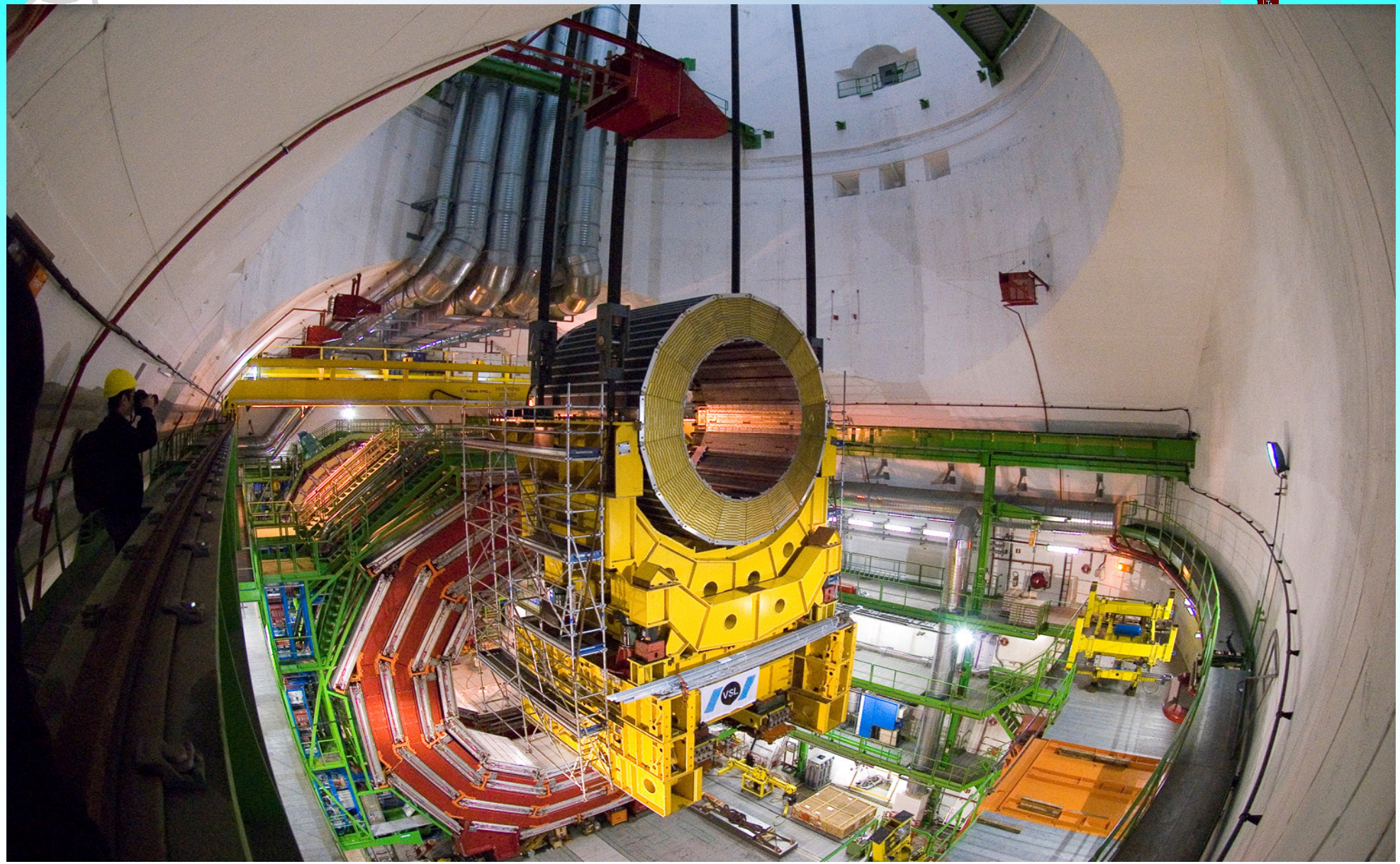




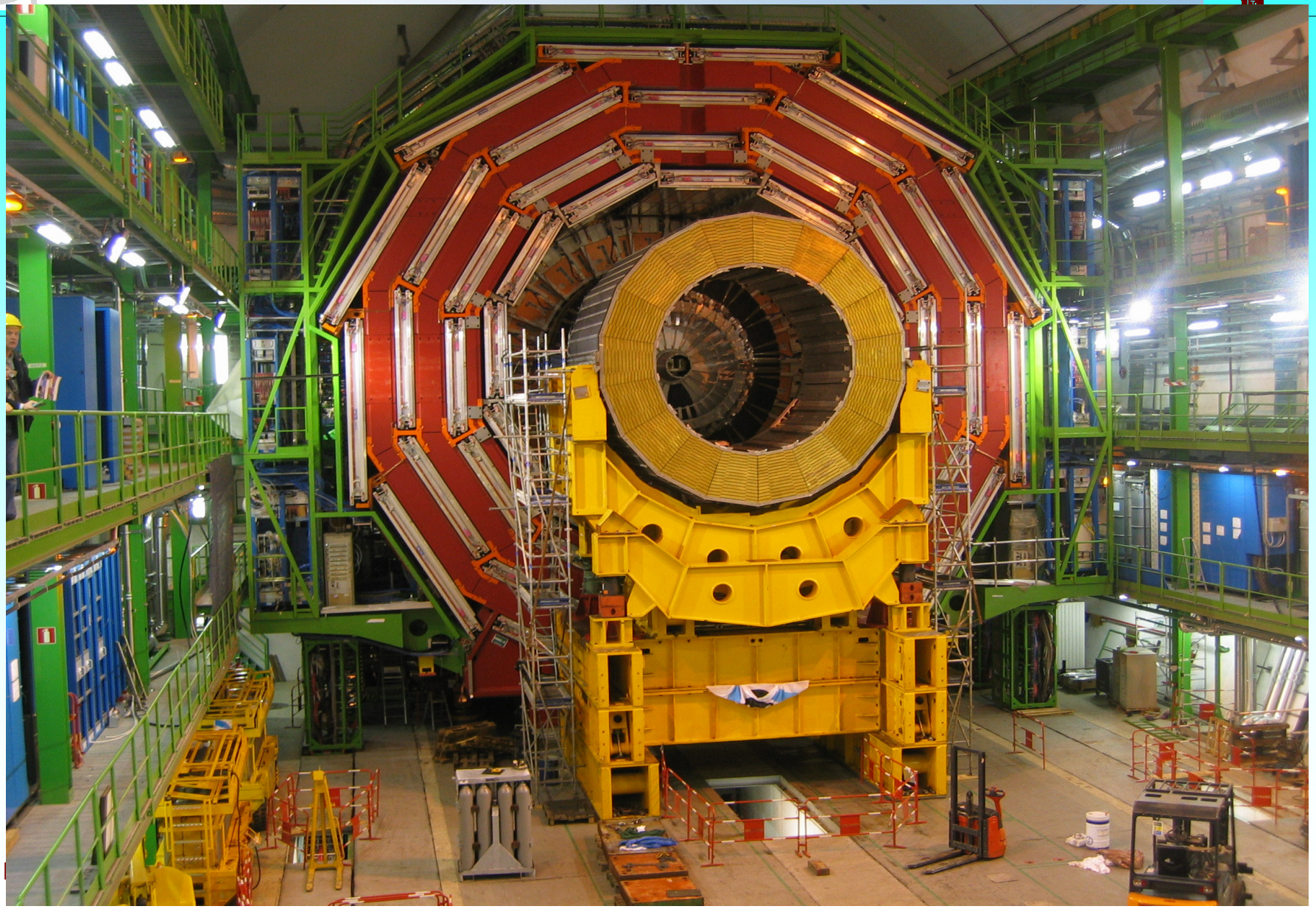
YB+2 Lowering (19 Jan)



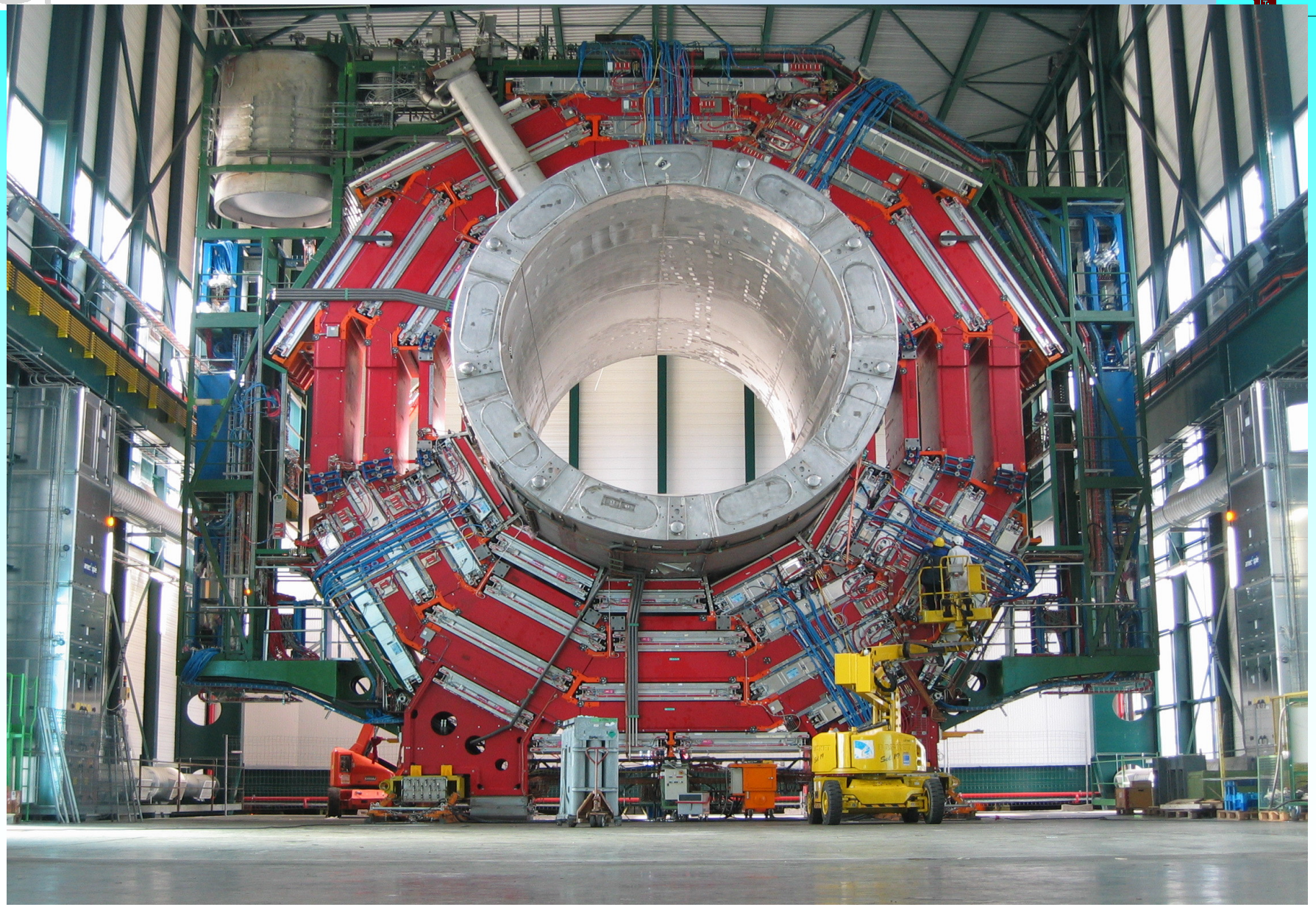
HB+ Lowering (13 Feb)



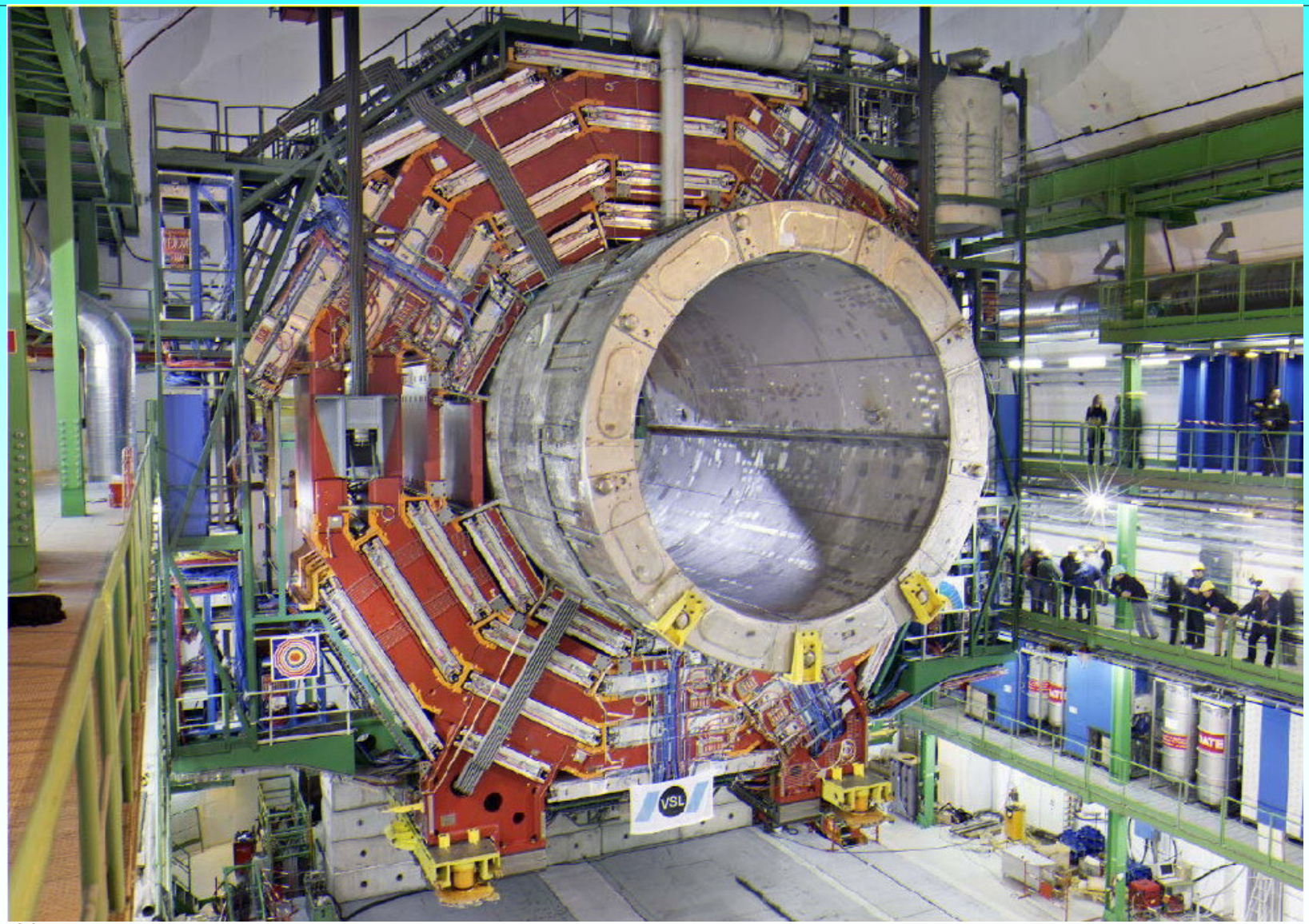
Situation in Cavern (23Feb)



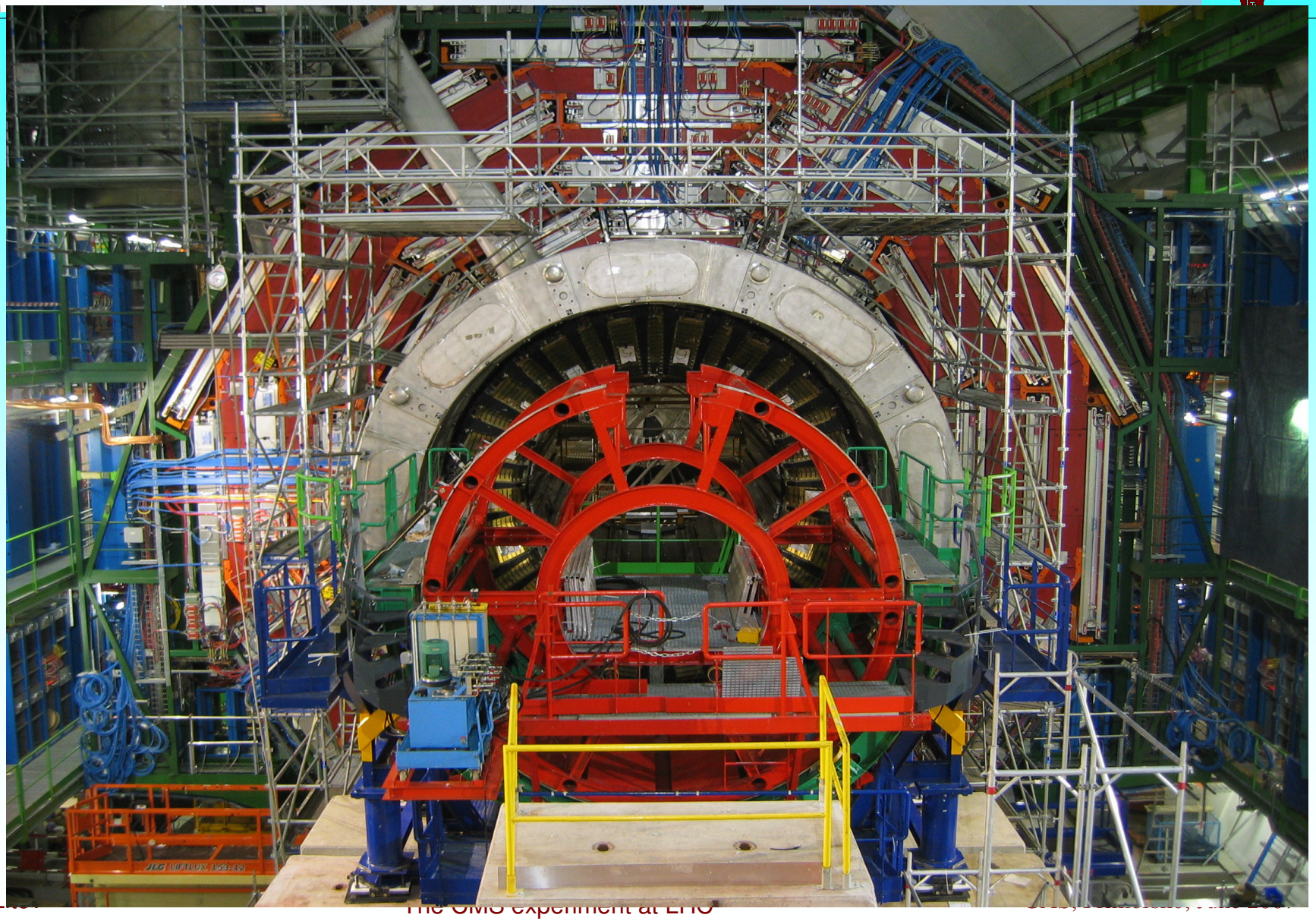
YB0 on Pithead Cover plate in SX5



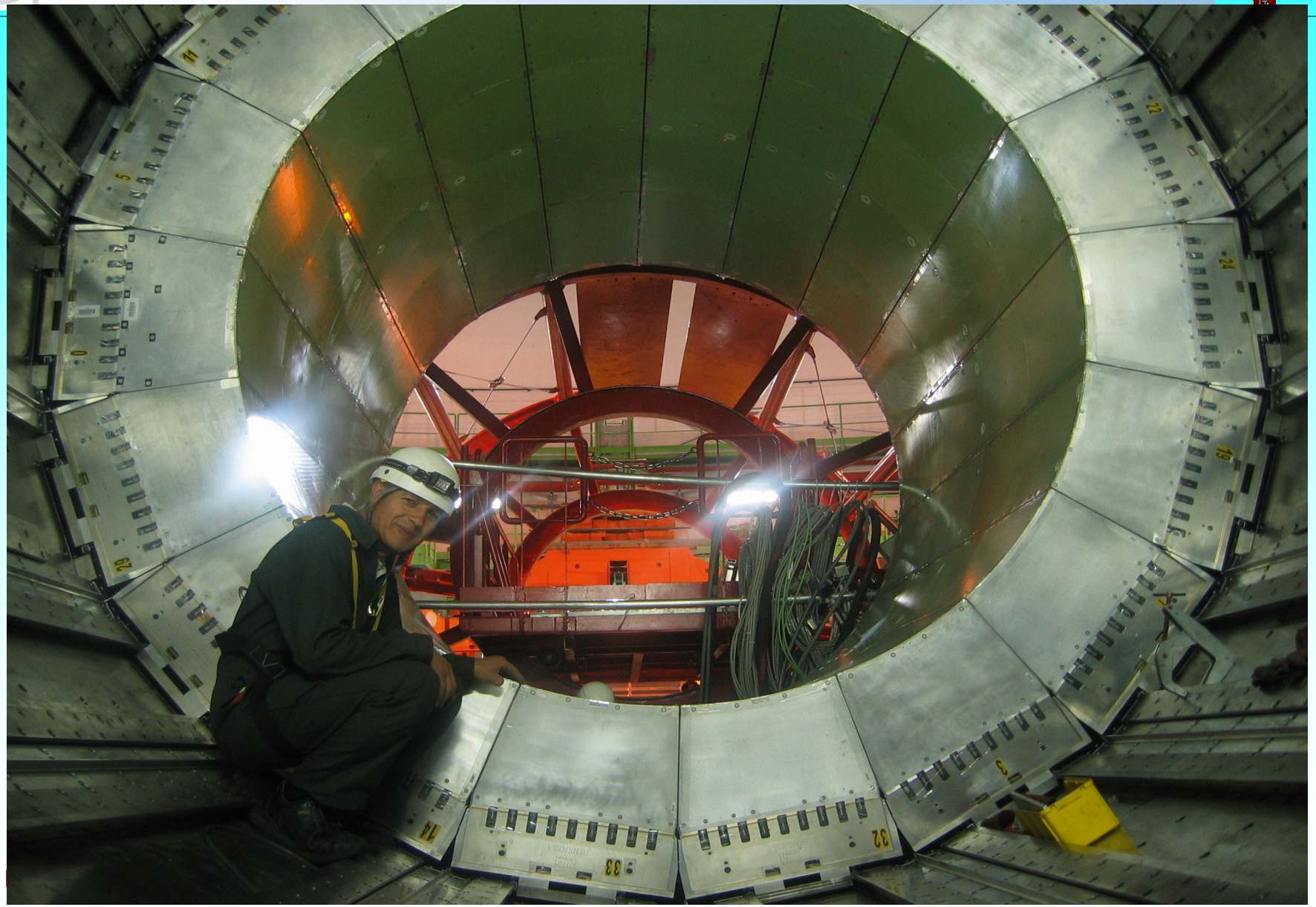
Lowering of W0



Situation in UXC

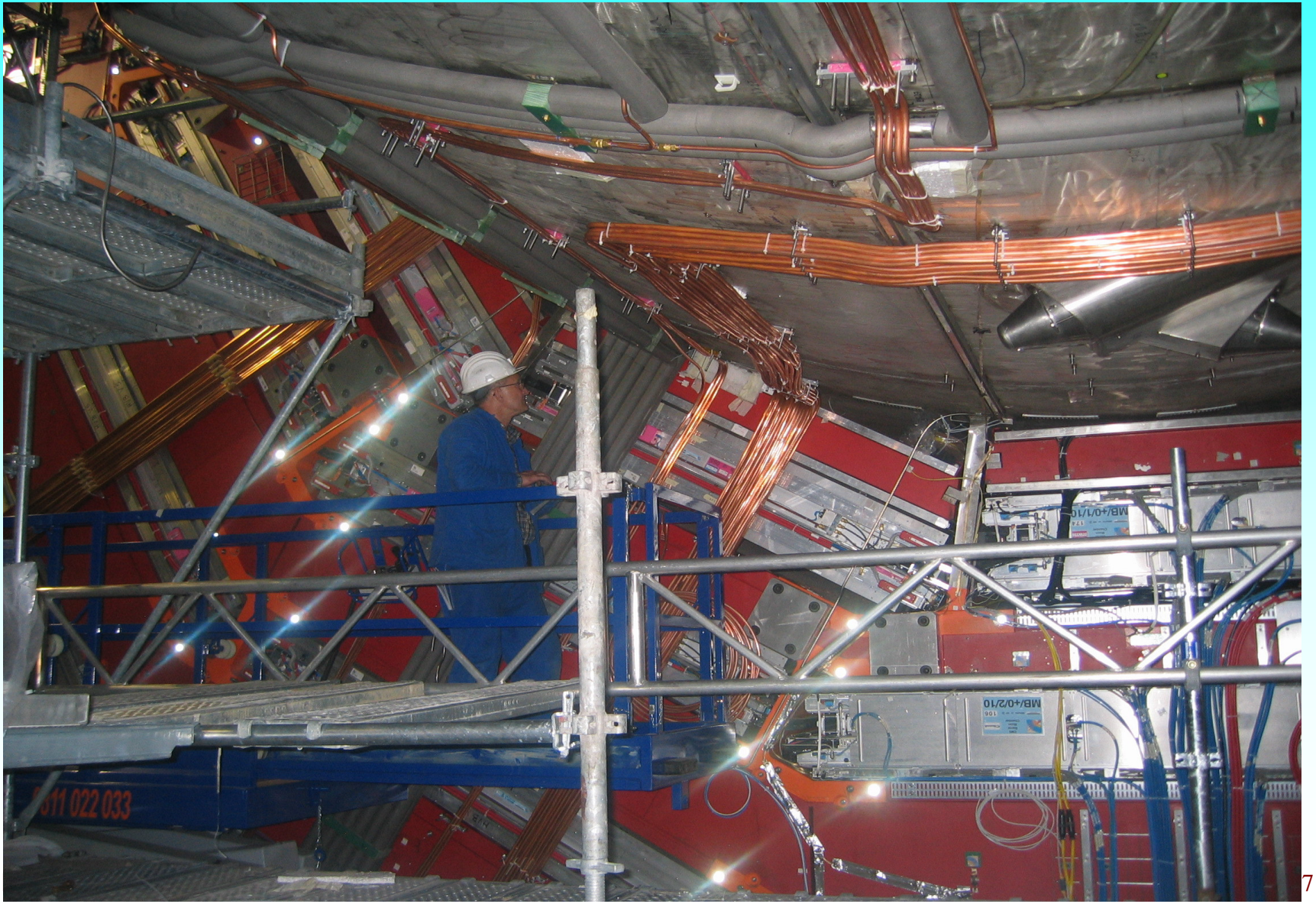


EB- Installation Completed (22 May)



Situation in SX

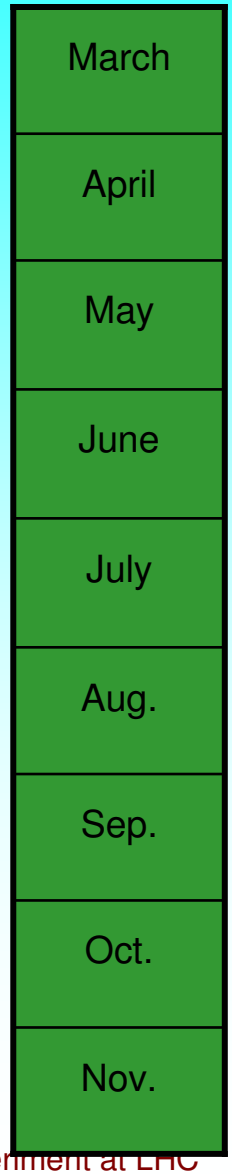
YB0 Services Installation



Overall CMS Schedule: v35.3

1) Detector Installation, Commissioning & Operation

2) Preparation of Software, Computing and Physics Analysis



First Global Readout Test

Barrel ECAL Inserted

HLT exercise complete

Pre-CSA07 Computing Software Analysis Challenge

Tracker Inserted

Trigger/DAQ Ready for System Commissioning

CSA07

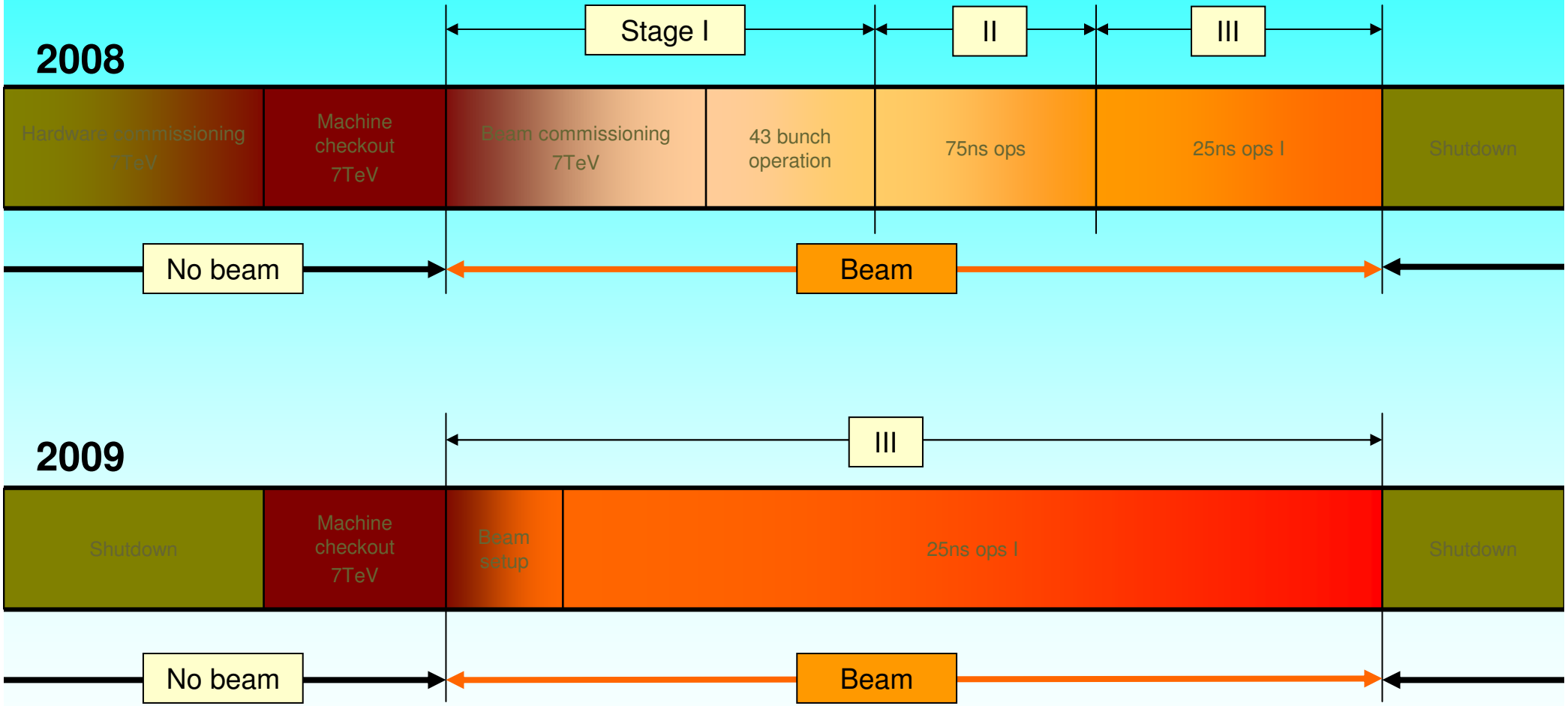
CMS Ready to Close

2007 Physics Analyses completed

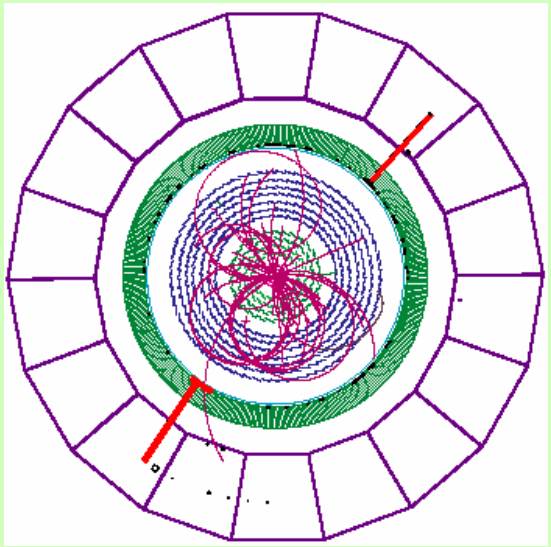
All CMS Systems Ready

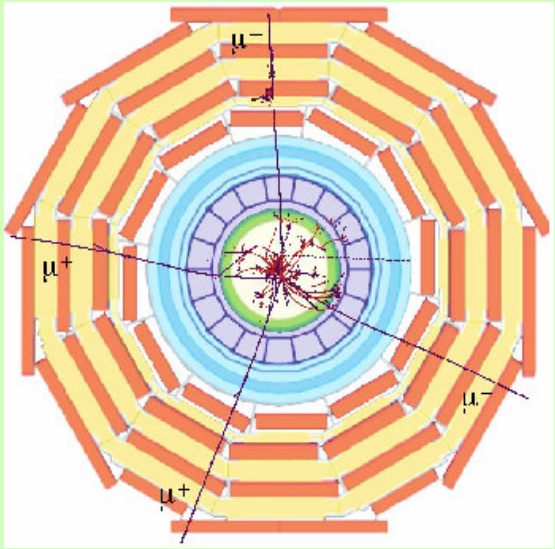
for Data Taking

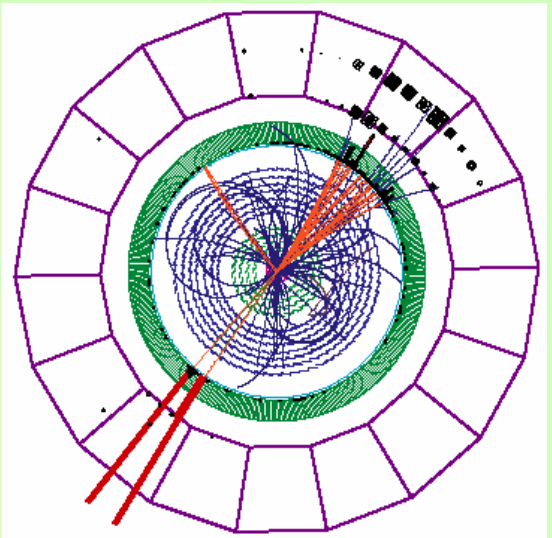
Beyond 2007

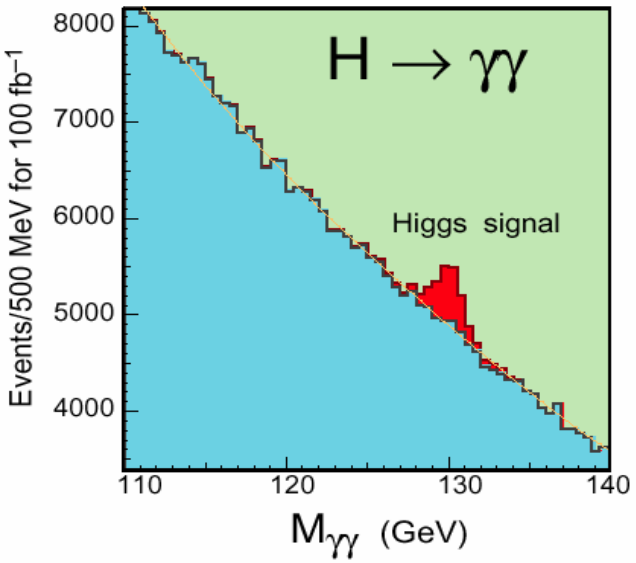

2008
Stage I
II
III
Hardware commissioning 7TeV
Machine checkout 7TeV
Beam commissioning 7TeV
43 bunch operation
75ns ops
25ns ops I
Shutdown
No beam
Beam
2009
III
Shutdown
Machine checkout 7TeV
Beam setup
25ns ops I
Shutdown
No beam
Beam

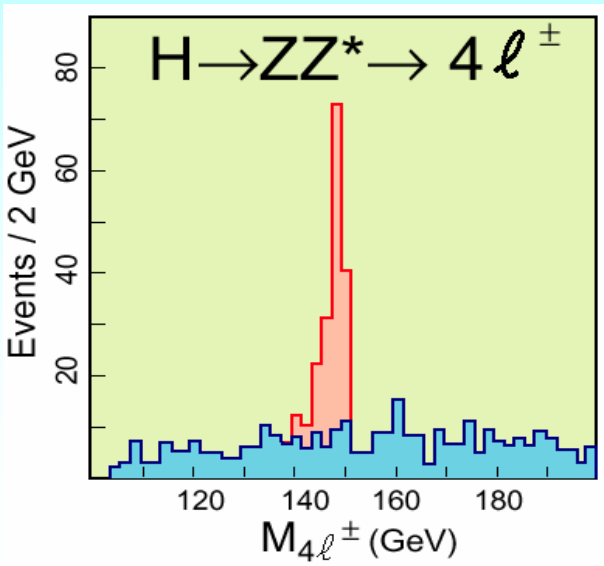
Higgs at CMS

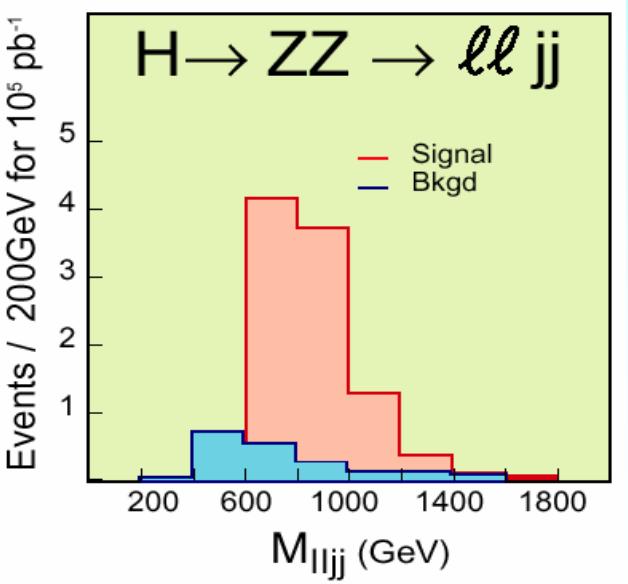



μ⁻
μ⁺
μ⁻
μ⁺

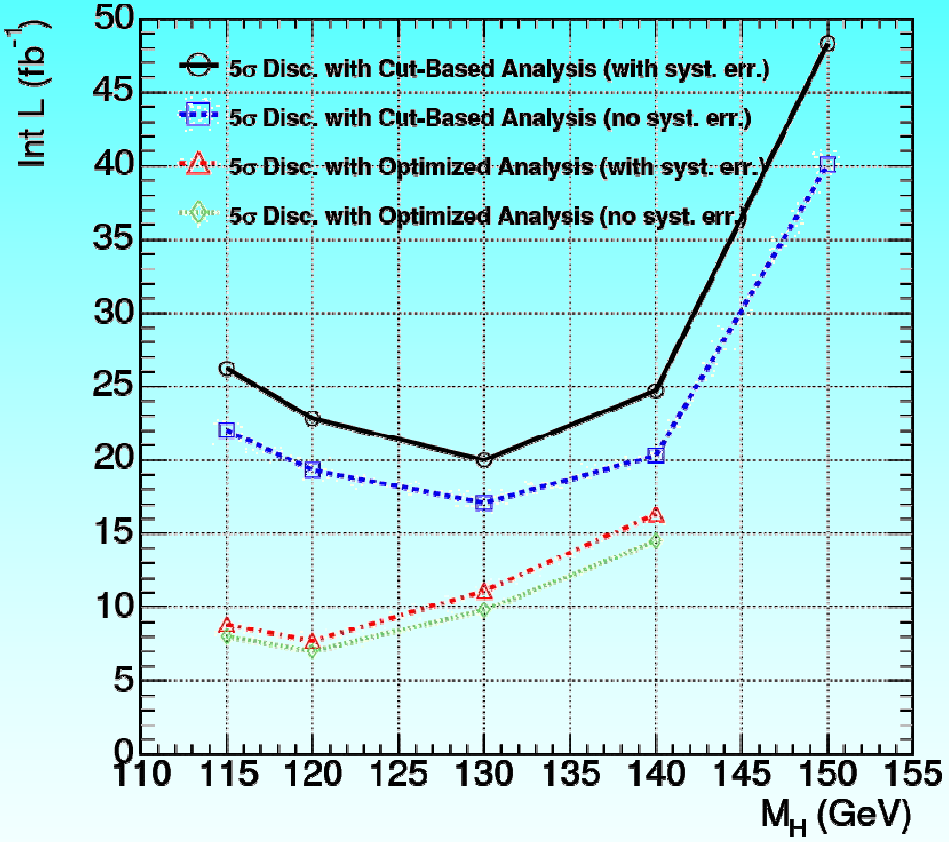


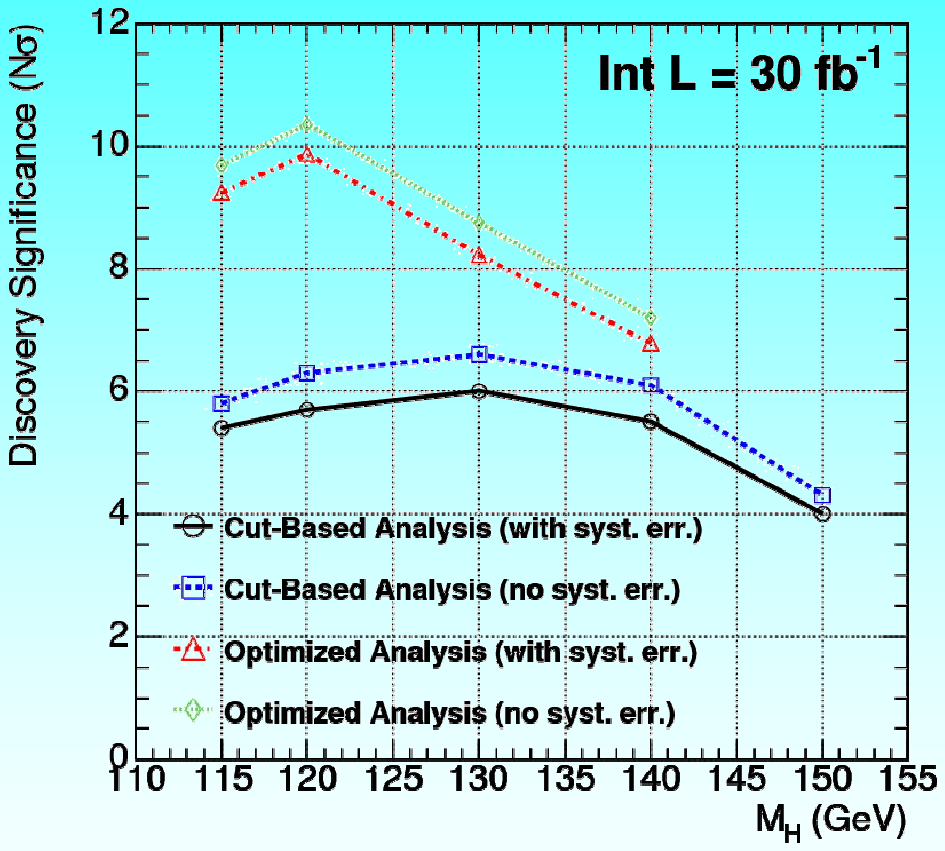

H → γγ
Higgs signal
Events/500 MeV for 100 fb⁻¹
8000
7000
6000
5000
4000
110
120
130
140
Mγγ (GeV)


H→ZZ*→ 4ℓ ±
Events / 2 GeV
80
60
40
20
120
140
160
180
M4ℓ ± (GeV)

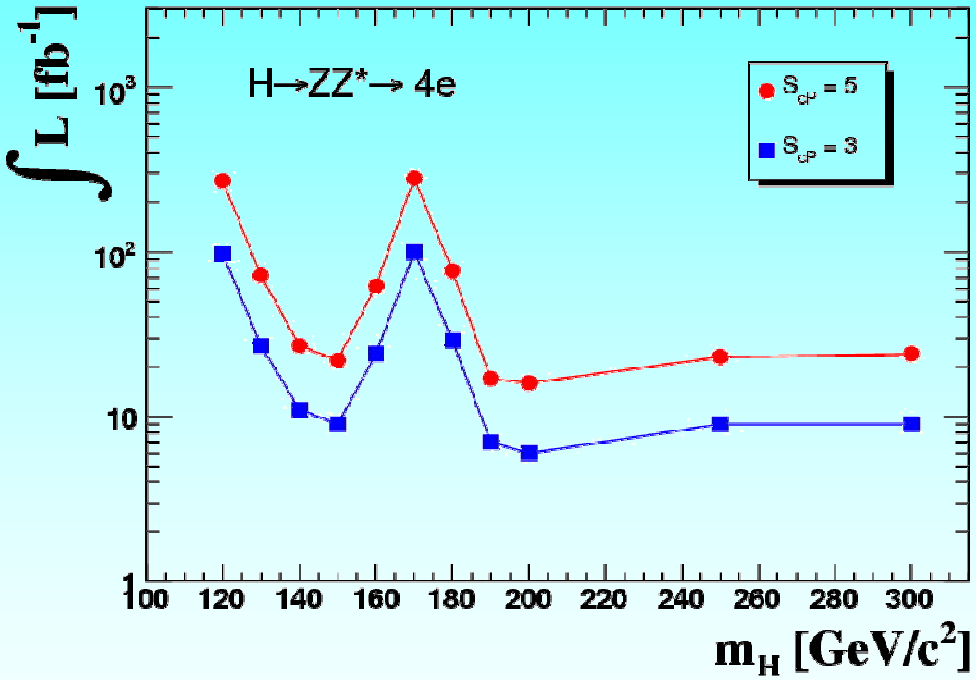

H→ ZZ → ℓℓ jj
Signal
Bkgd
Events / 200GeV for 10⁵ pb⁻¹
5
4
3
2
1
200
600
1000
1400
1800
MlIjj (GeV)

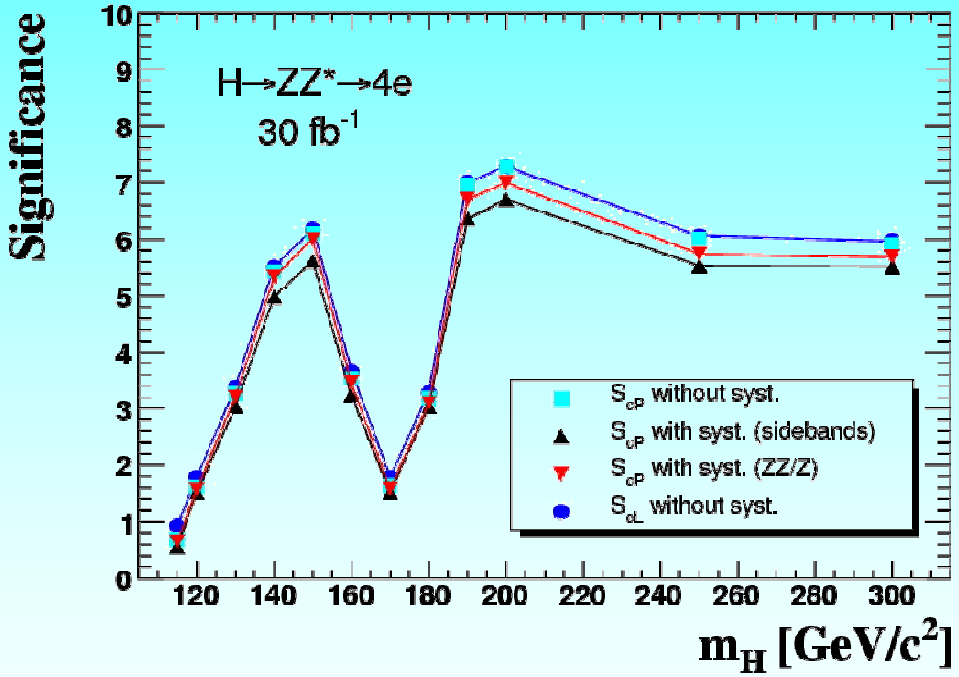
SM Higgs Boson Search H→ γγ



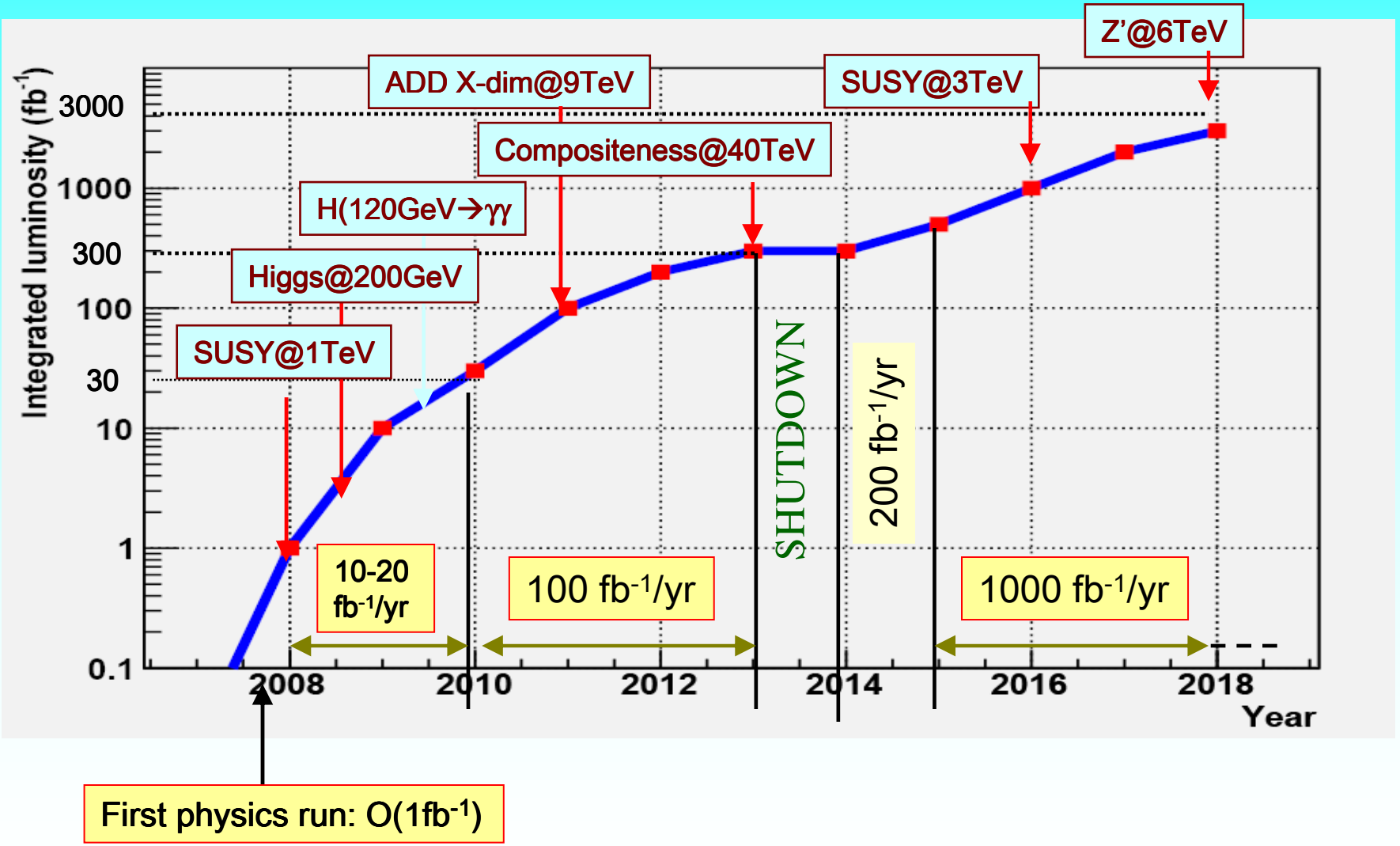


SM Higgs Boson Search

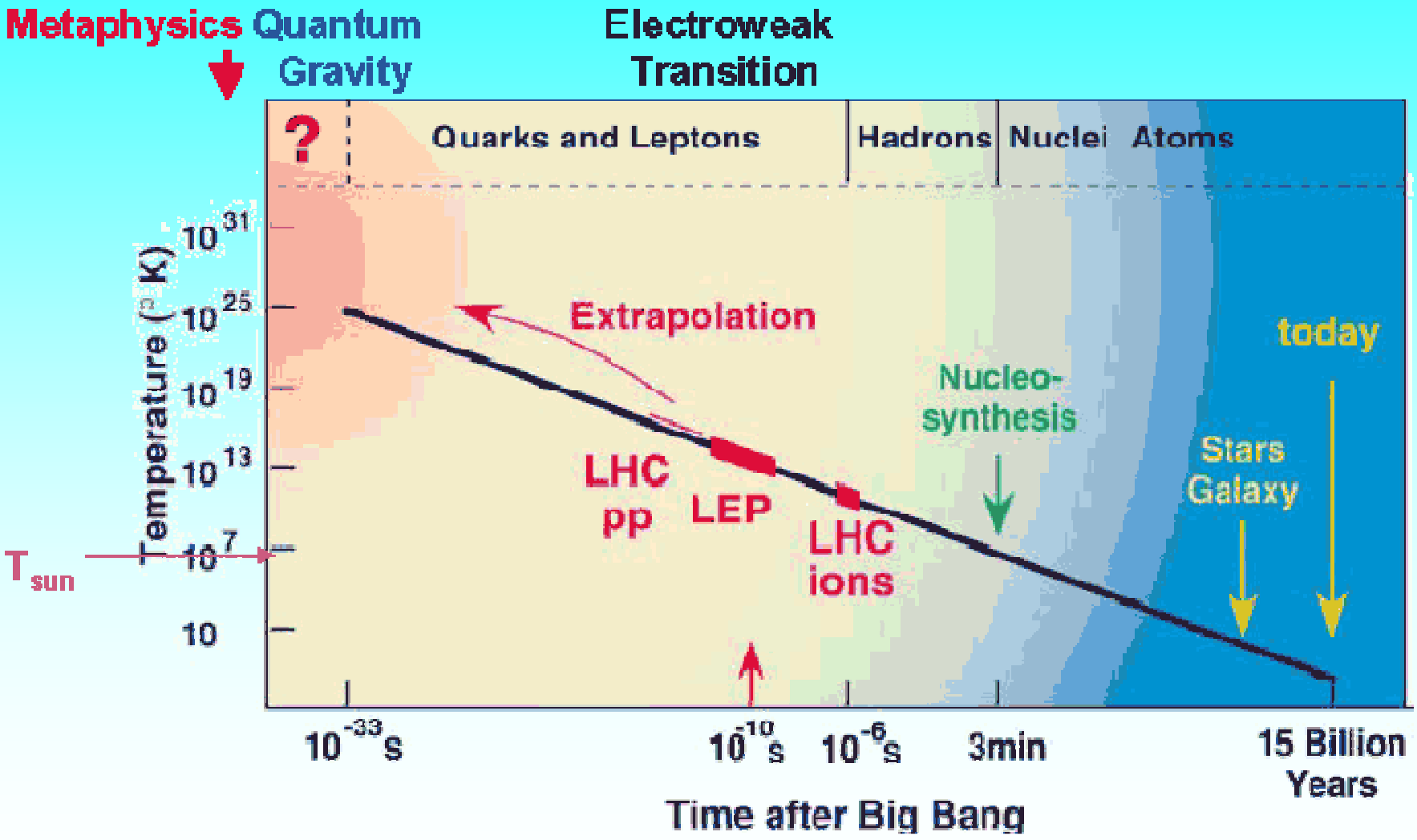




LHC Luminosity Profile



Back to the beginning



The Big Quest

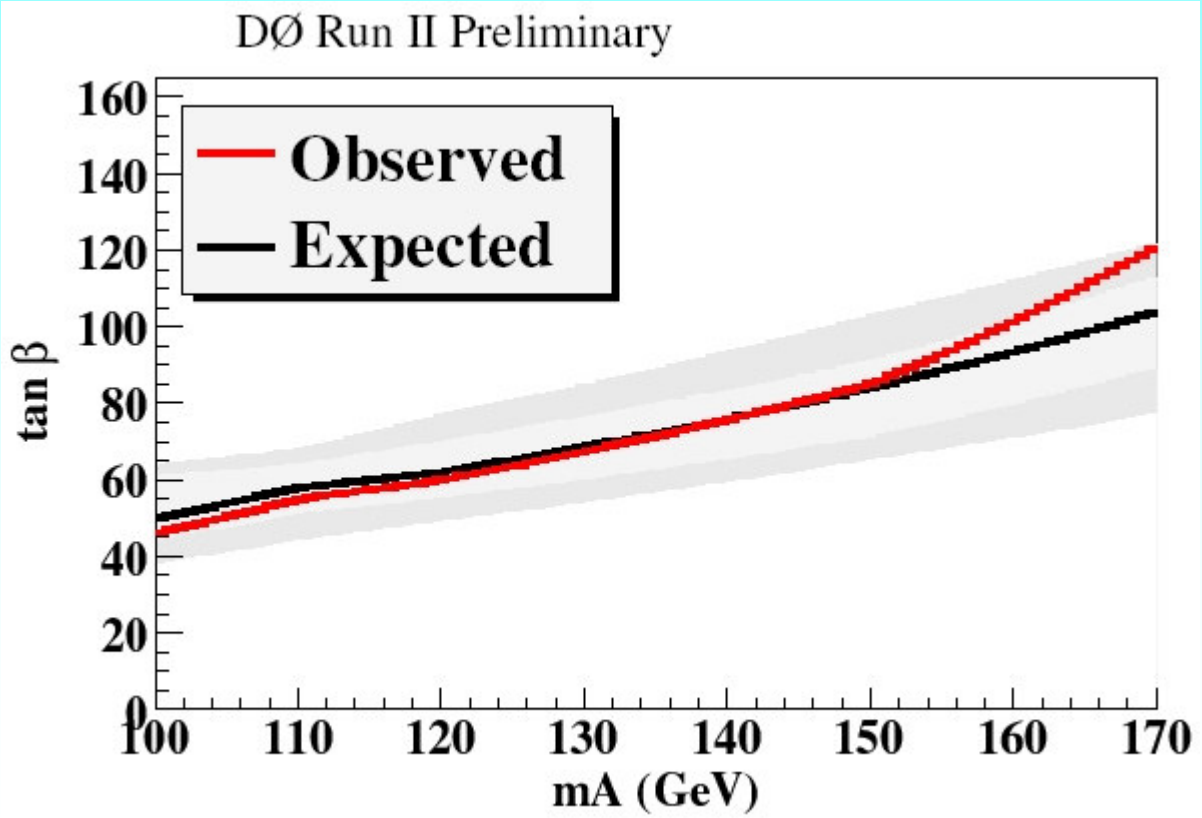
for secrets of the Universe

Starts 2008

Rumors from recent days

The D0 experiment at Fermilab Tevatron observes an excess at the level of 4-5 σ – a narrow resonance with mass ~ 180 GeV decaying in 4 b-jets

Probably this is a Higgs boson (SUSY A-boson)?!



Conclusions

- Higgs is still missing
  - Symmetry Breaking in the SM (and beyond!) still not understood
  - LHC and ATLAS/CMS designed to find it
  - Numerous challenges, mostly "solved"
- Physics at the LHC will be extremely rich
  - SM Higgs (if there) in the pocket
    - Now turning to measurements of couplings, etc.
  - Supersymmetry (if there) ditto
    - Can perform numerous accurate measurements
  - Large com energy: new thresholds
    - Compositeness, new bosons, large extra dimensions within reach
  - LHC++?
- Just need to build machine/experiments.