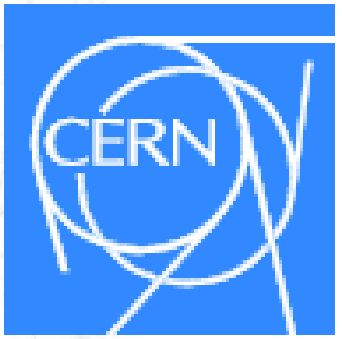
CMS – an Introduction

Frank Hartmann



A try to share the feeling we have these days when working in the cavern and preparing the last stages

Questions for the Standard Model and Beyond

LEP, SLC and Tevatron: established the understanding of physics at energies up to √s ~ 100GeV

Now, what about new particles with masses above 200-300 GeV – or even TeV?

1. SM has an unproven element: the generation of mass

Higgs mechanism ? other physics ?

Answer will be found at $\sqrt{s}$ ~ 1 TeV e.g. why $M_\gamma = 0$, $M_Z \sim 90$ GeV/c^2

2. SM without Higgs gives nonsense at LHC energies

At $\sqrt{s}$ > 1 TeV probability of $W_L W_L$ scattering > 1 !!

The SM solution: Higgs exchange cancels bad high energy behaviour.

Even if the Higgs exists, all is not 100% well with the SM alone:

Next question is "why is the (Higgs) mass so low"?

If SUSY is the answer, it must show up at O(TeV)

Recent: extra dimensions. Again, something must happen in the *O*(1-10) TeV scale if the above issues are to be addressed

Questions for the Standard Model and Beyond

3. SM is logically incomplete
Does not incorporate gravity.
Superstring theory ? Supersymmetry, extra space-time dimensions ?

4. SM contains too many (arbitrary) parameters

So, here‘s the GOAL: ➔ **Experimentally**
New particles/new symmetries/new forces?

⇨Higgs boson(s), Supersymmetric particles, Z’, …
Extra space-time dimensions: gravitons, black holes, Z’ etc. ?

(CMS) Design Criteria

Very good muon identification and momentum measurement

Trigger efficiently and measure sign of TeV muons dp/p < 10%

High energy resolution electromagnetic calorimetry

~ 0.5% @ E_T ~ 50 GeV

Powerful inner tracking systems

Momentum resolution a factor 10 better than at LEP

Hermetic calorimetry

Good missing E_T resolution

(Affordable detector)

Transparency from the early 90's

Experimental Challenge

LHC Detectors (especially ATLAS, CMS) are radically different from the ones from the previous generations

High Interaction Rate

pp interaction rate **1 billion interactions/s**
Data can be recorded for only ~10^2 out of 40 million crossings/sec
Level-1 trigger decision takes ~2-3 μs
⇨ **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 (~ 100 M ch)**

High Radiation Levels

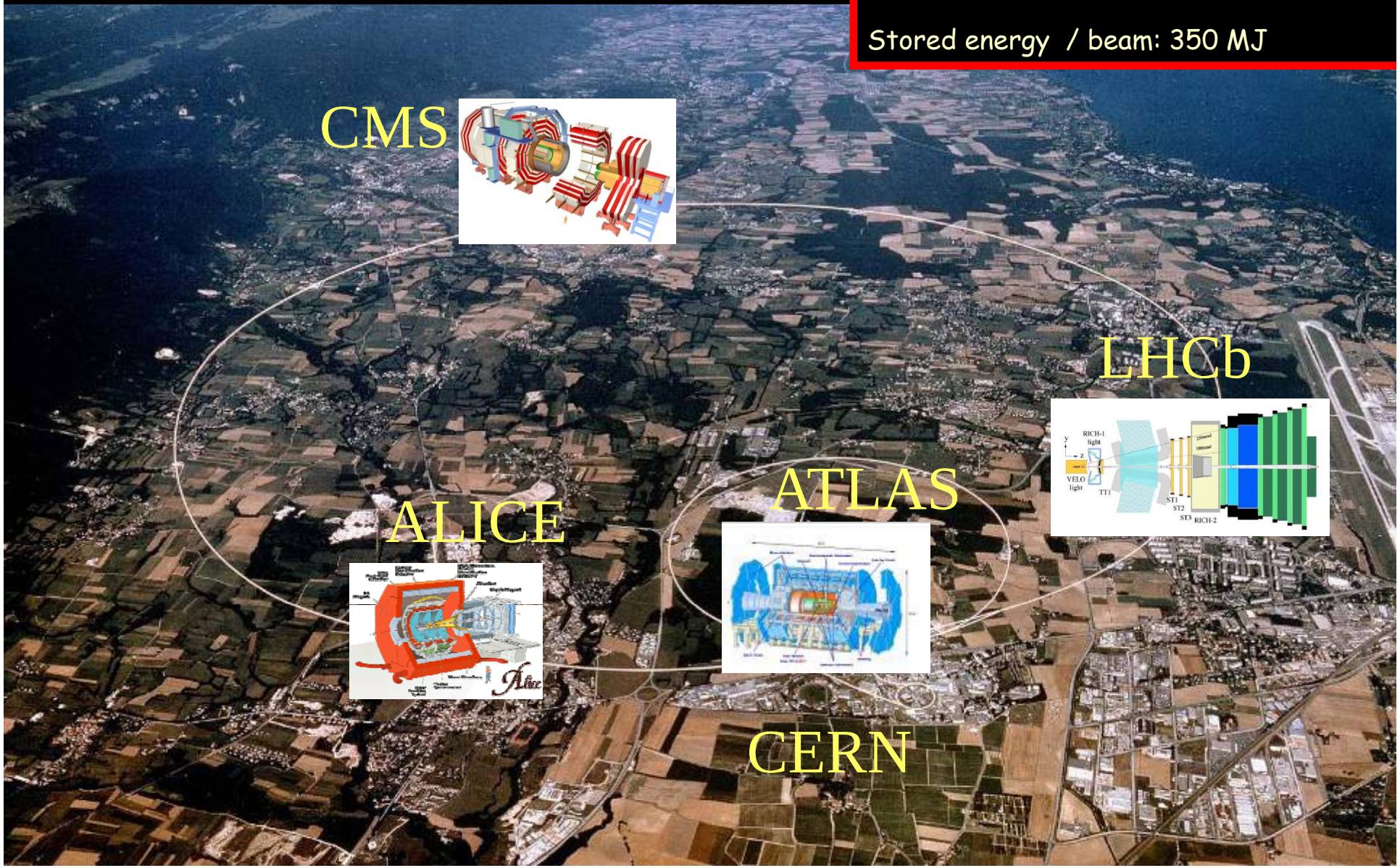
⇨ **radiation hard (tolerant) detectors and electronics**

LHC, CERN's Flag Ship and its Detectors

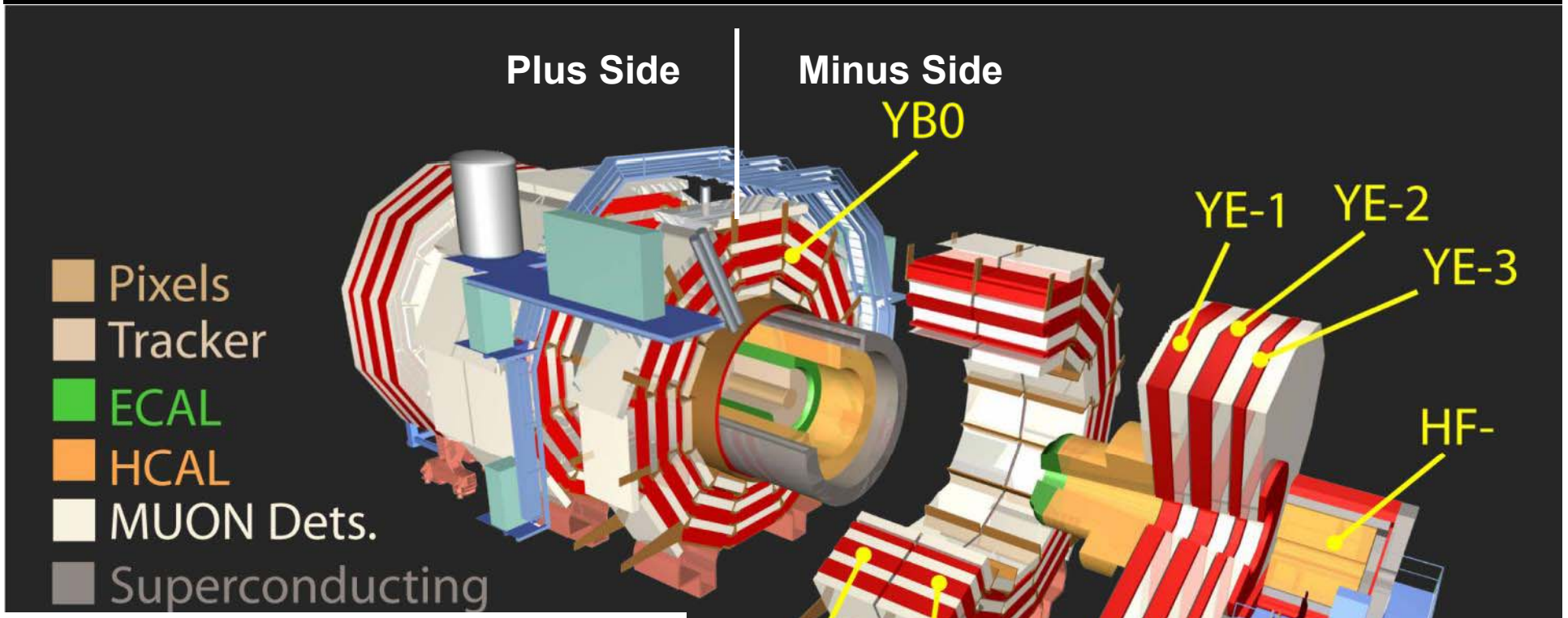
25 ns bunch spacing ⇒ 2835 bunches with 10^{11} p/bunch

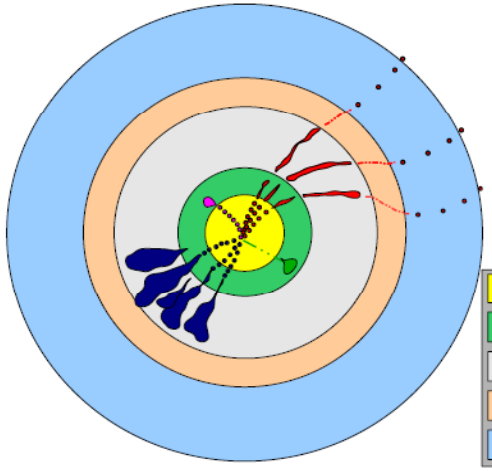
Design Luminosity:
$10^{34}cm^{-2}s^{-1}$ ⇒100 fb^{-1}/year

Stored energy / beam: 350 MJ



Exploded View of CMS





muon
photon
electron
quark jet

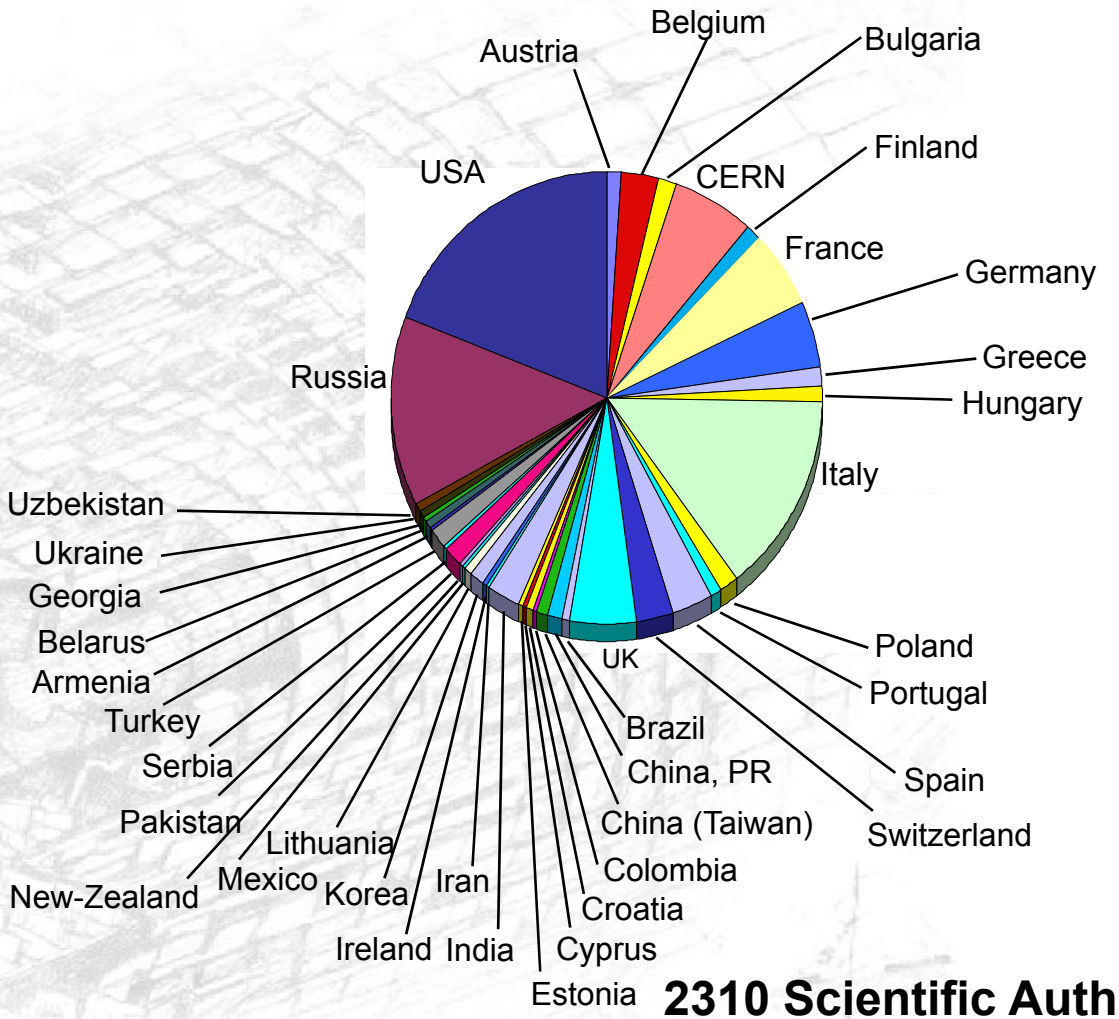
- Tracking
- Electron Calorimeter
- Hadron Calorimeter
- Solenoid
- Muon chamber

The CMS Collaboration

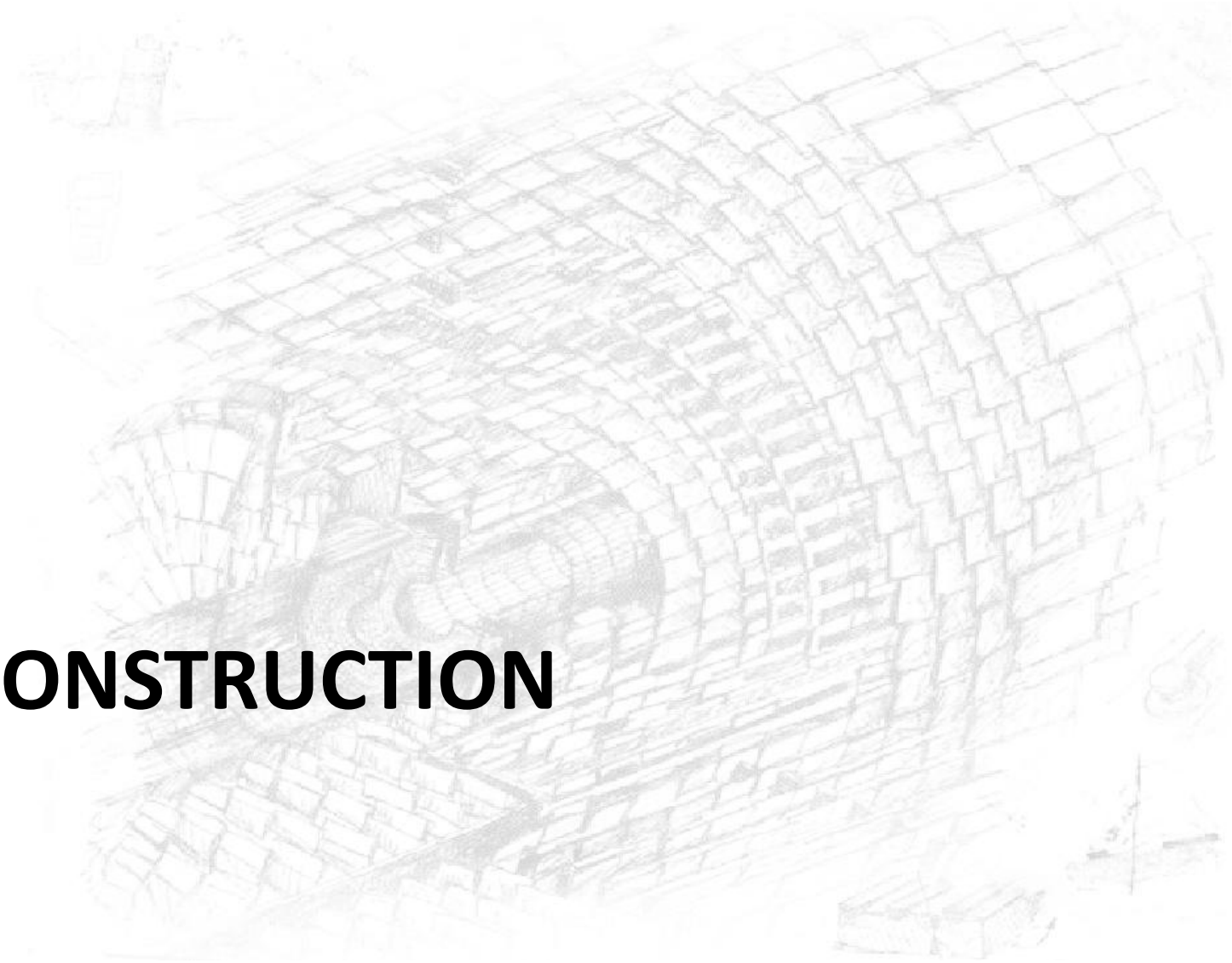
	Number of Laboratories
Member States	59
Non-Member States	67
USA	49
Total	175

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

Associated Institutes	
Number of Scientists	62
Number of Laboratories	9



2310 Scientific Authors
38 Countries
175 Institutions

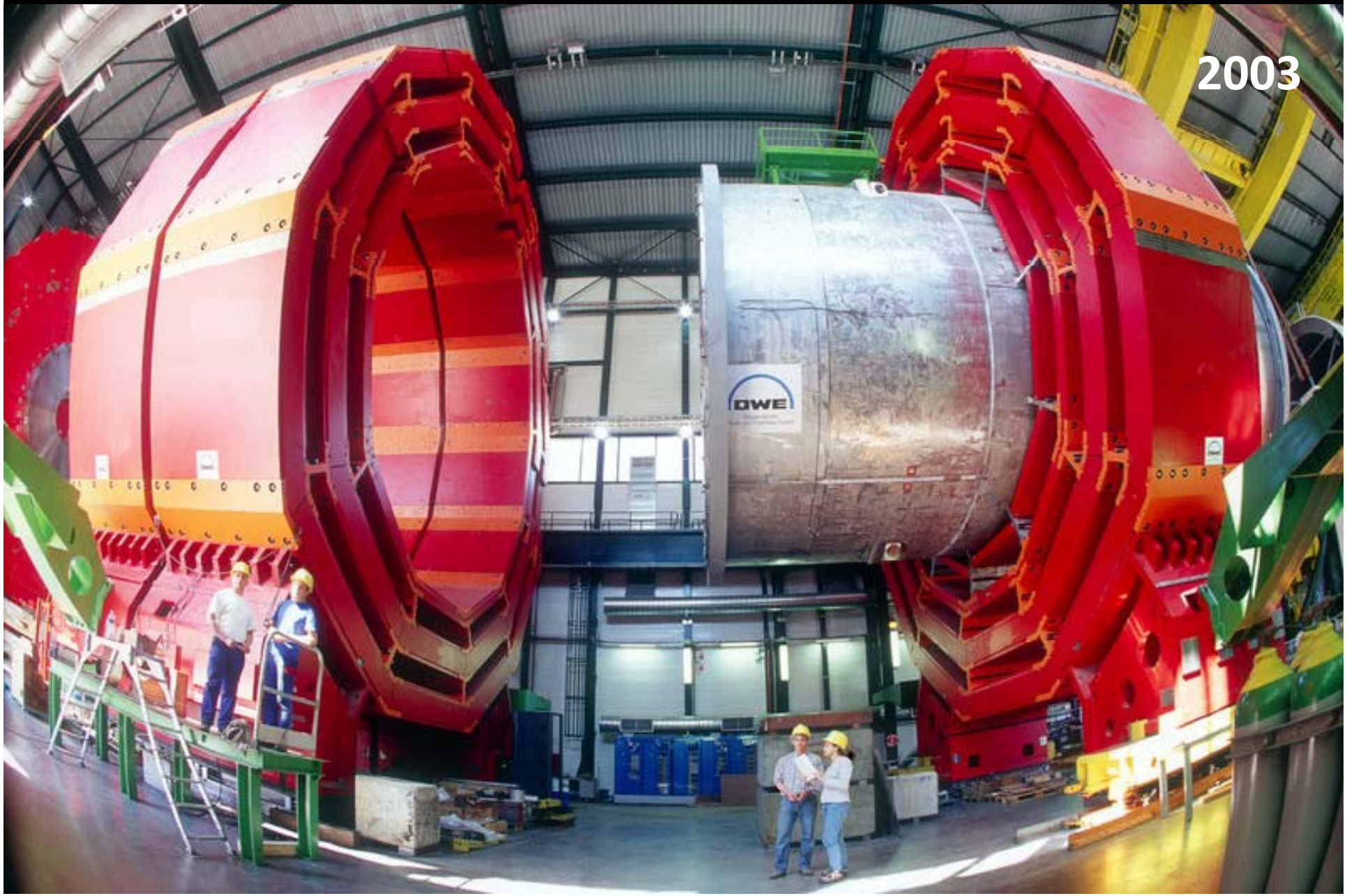


CONSTRUCTION

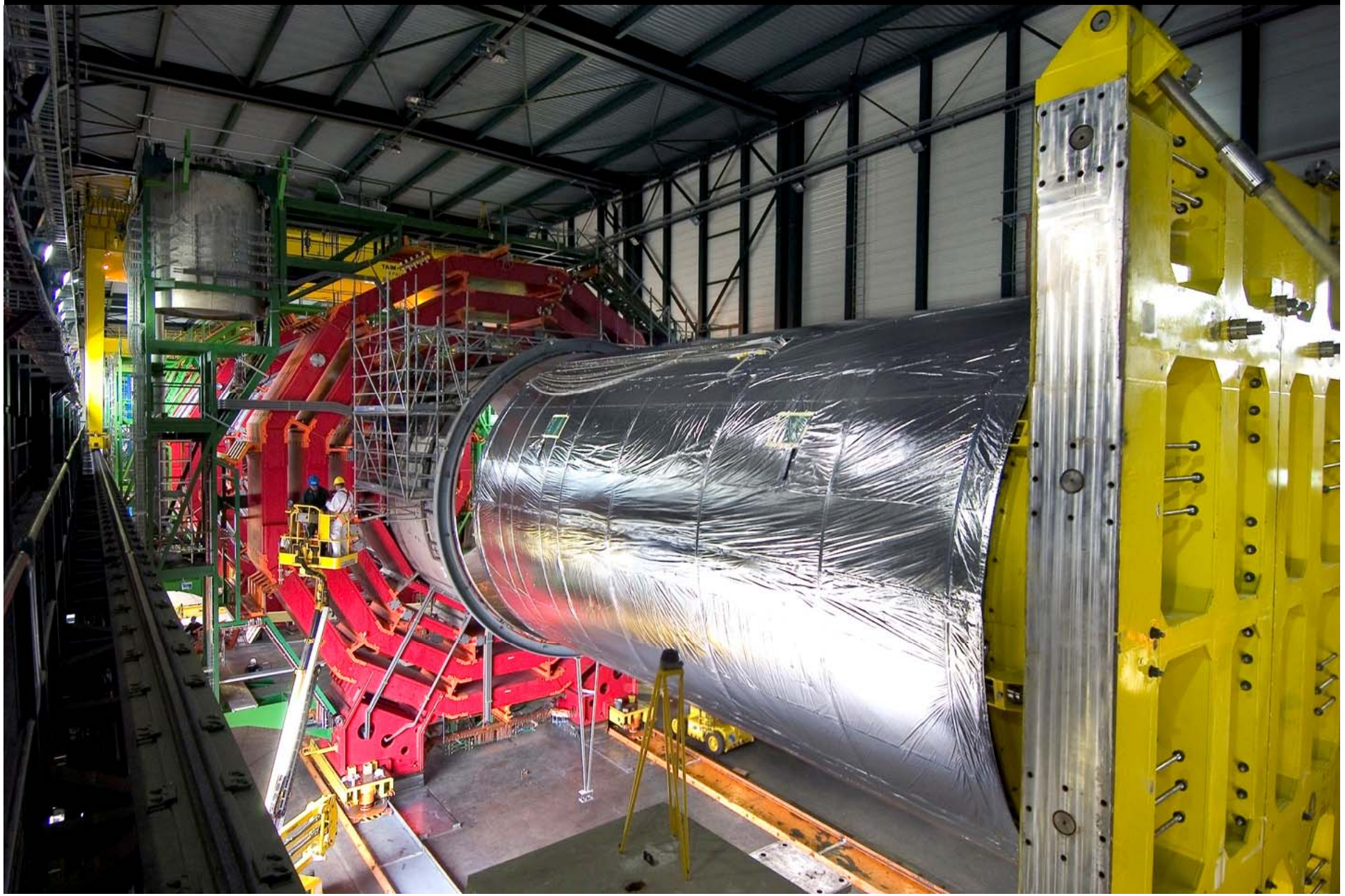
CMS Site at Point 5 (Cessy) in 2000

Hm, that‘s when I started with CMS!

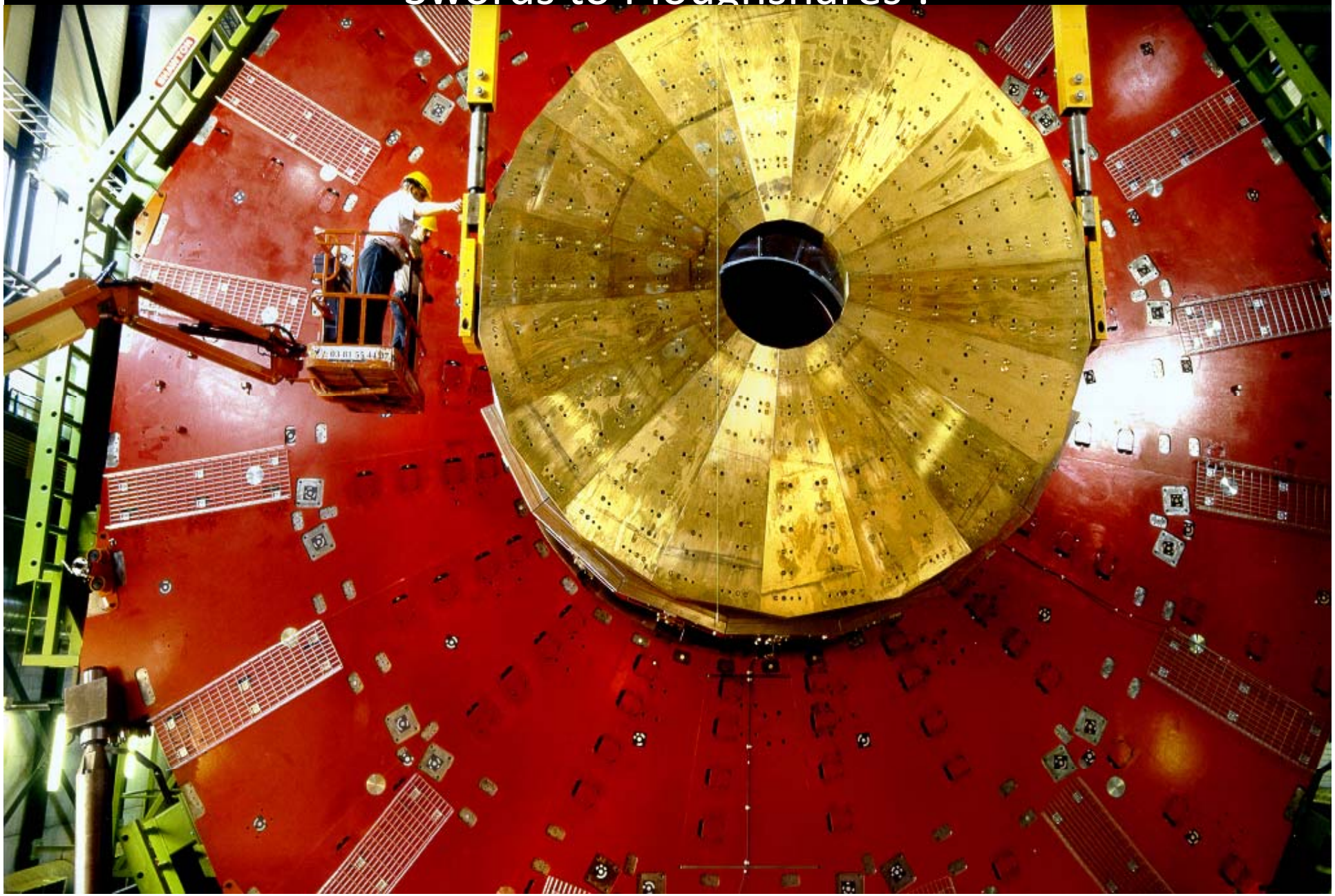
Assembly of Iron Yoke



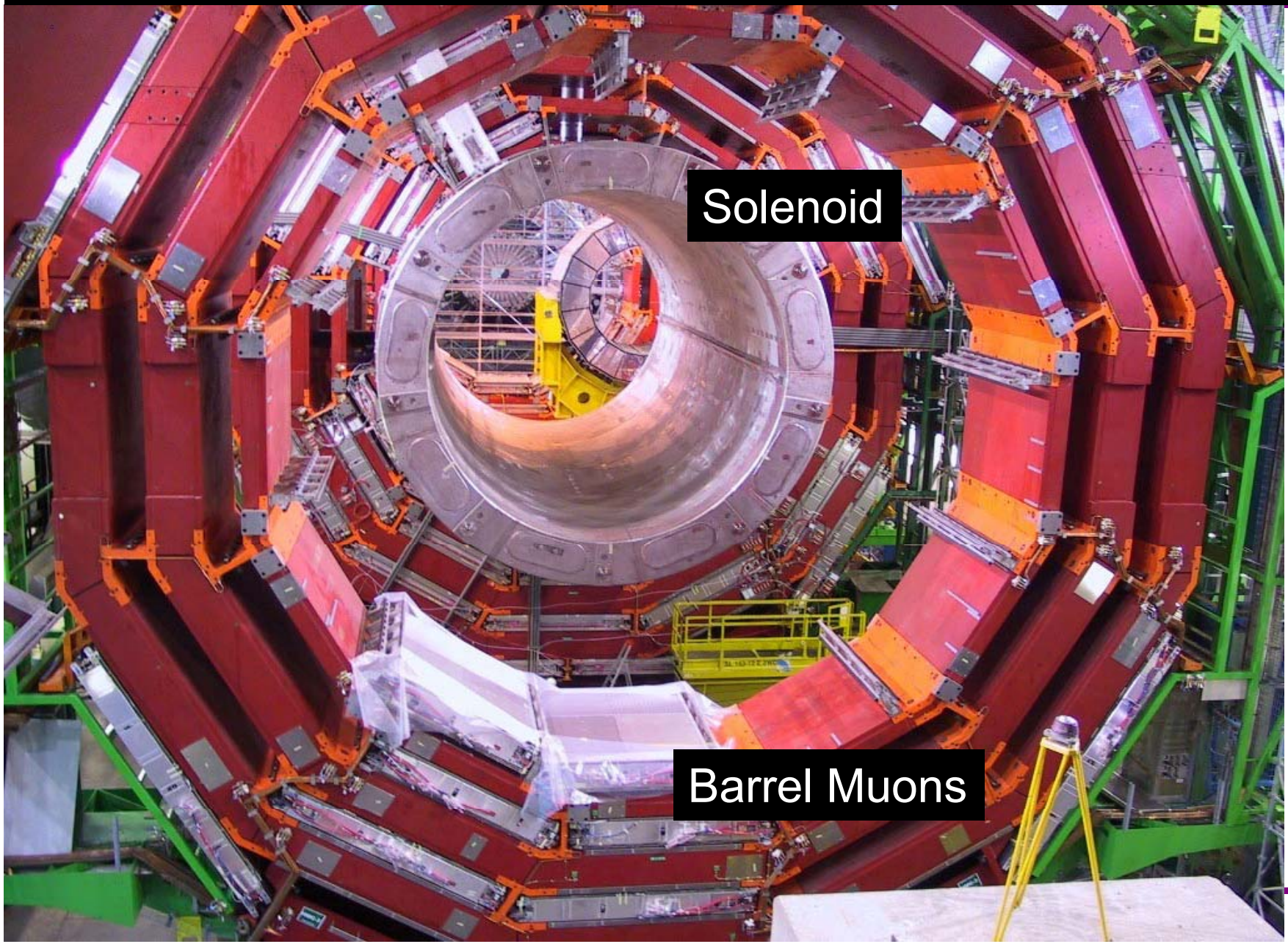
Swiveling of the Coil



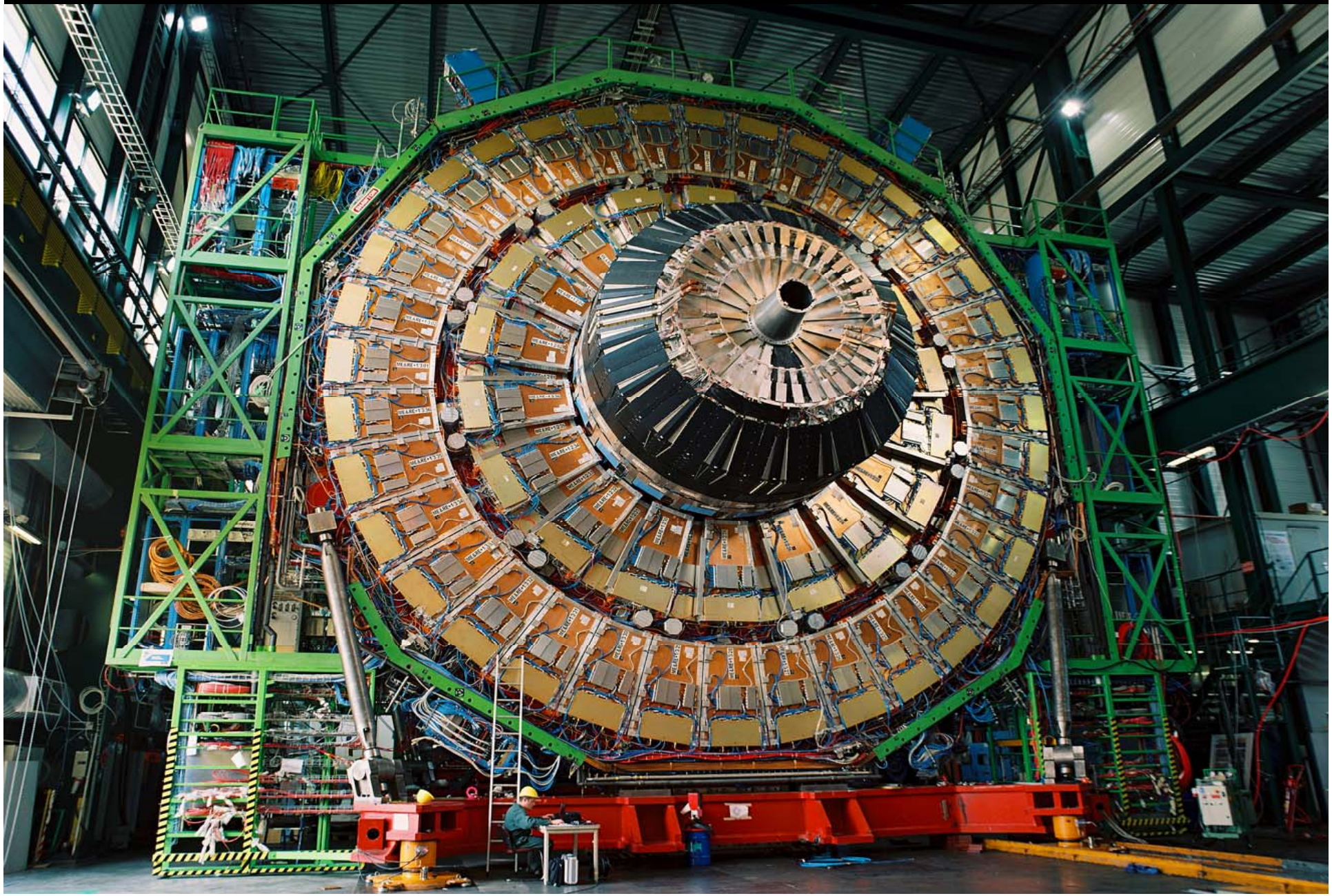
HCAL Endcap
Swords to Ploughshares !

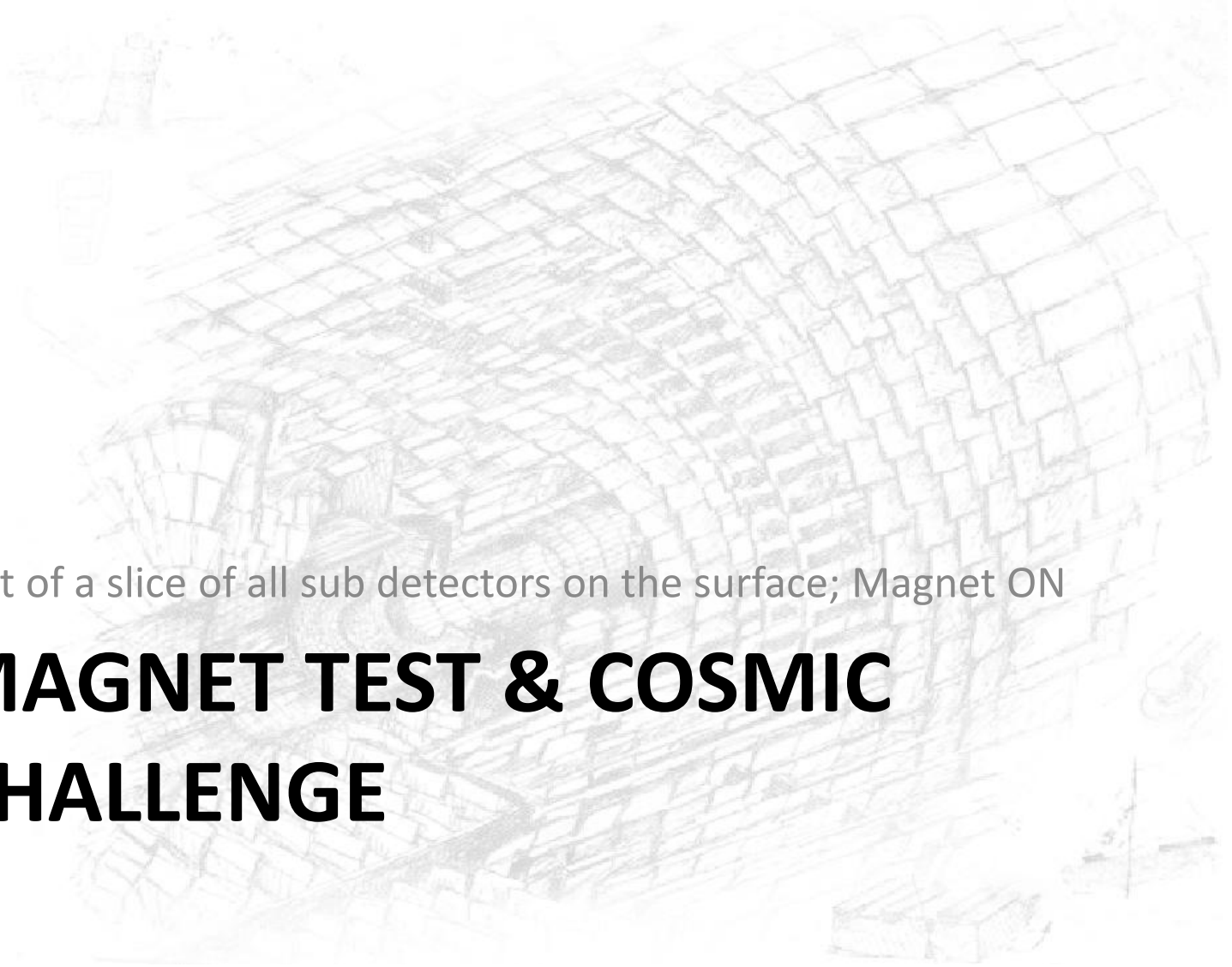


CMS Surface Hall in Feb 2006



Surface Hall: Endcaps



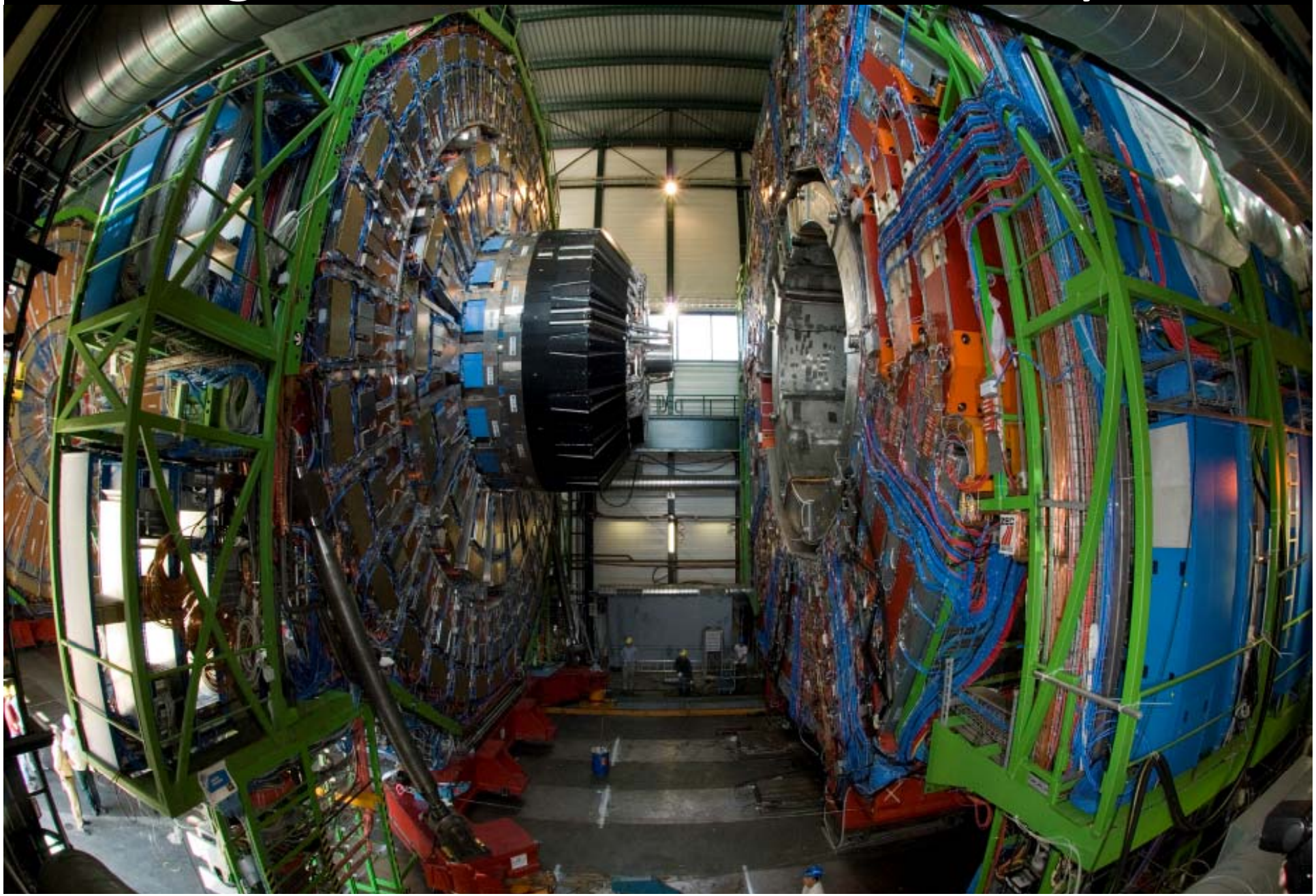


Test of a slice of all sub detectors on the surface; Magnet ON

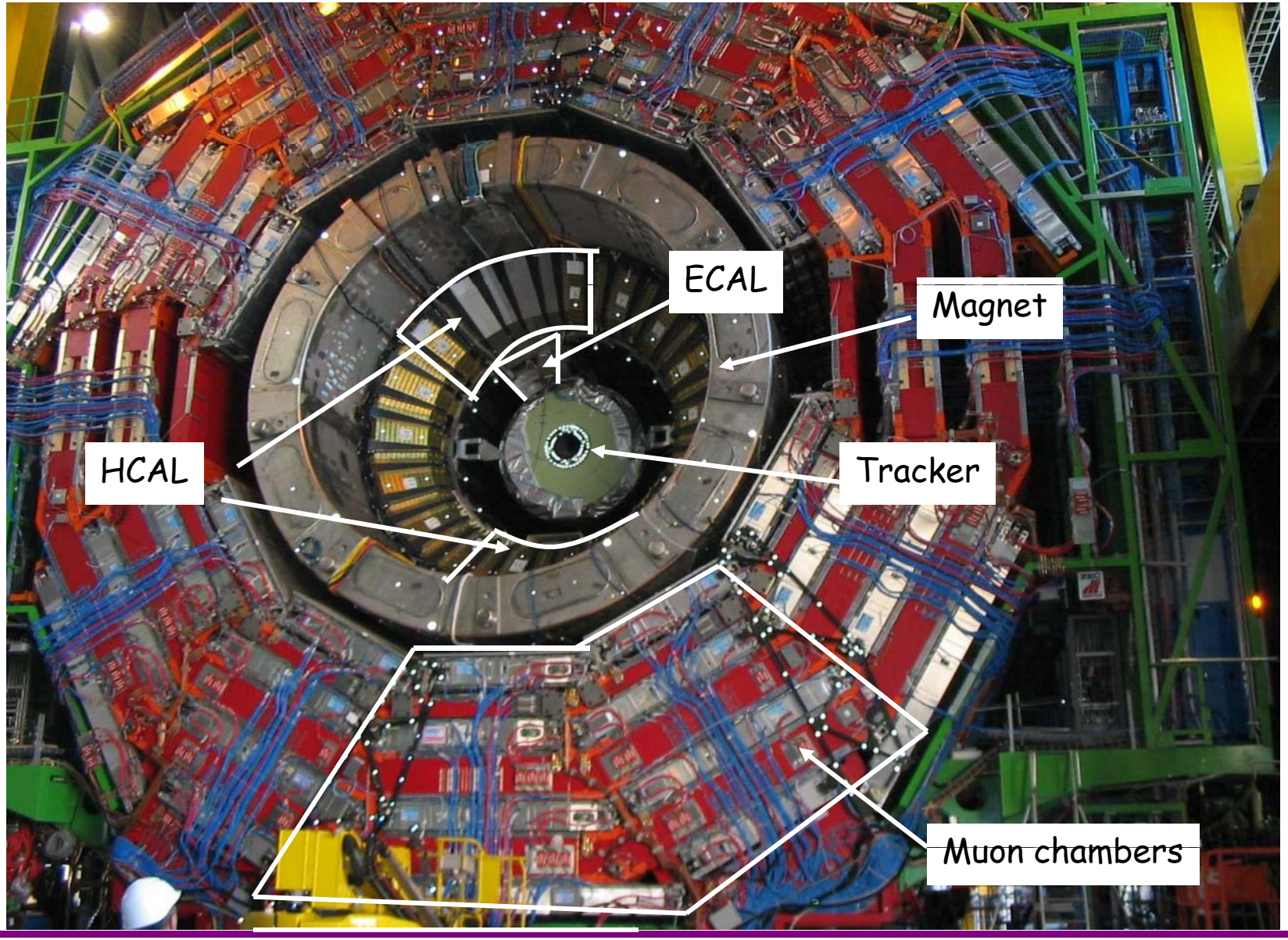
MAGNET TEST & COSMIC CHALLENGE

The Dummy Tracker, That was FUN

Closing CMS for the First Time – July 2006



Magnet Test & Cosmic Challenge



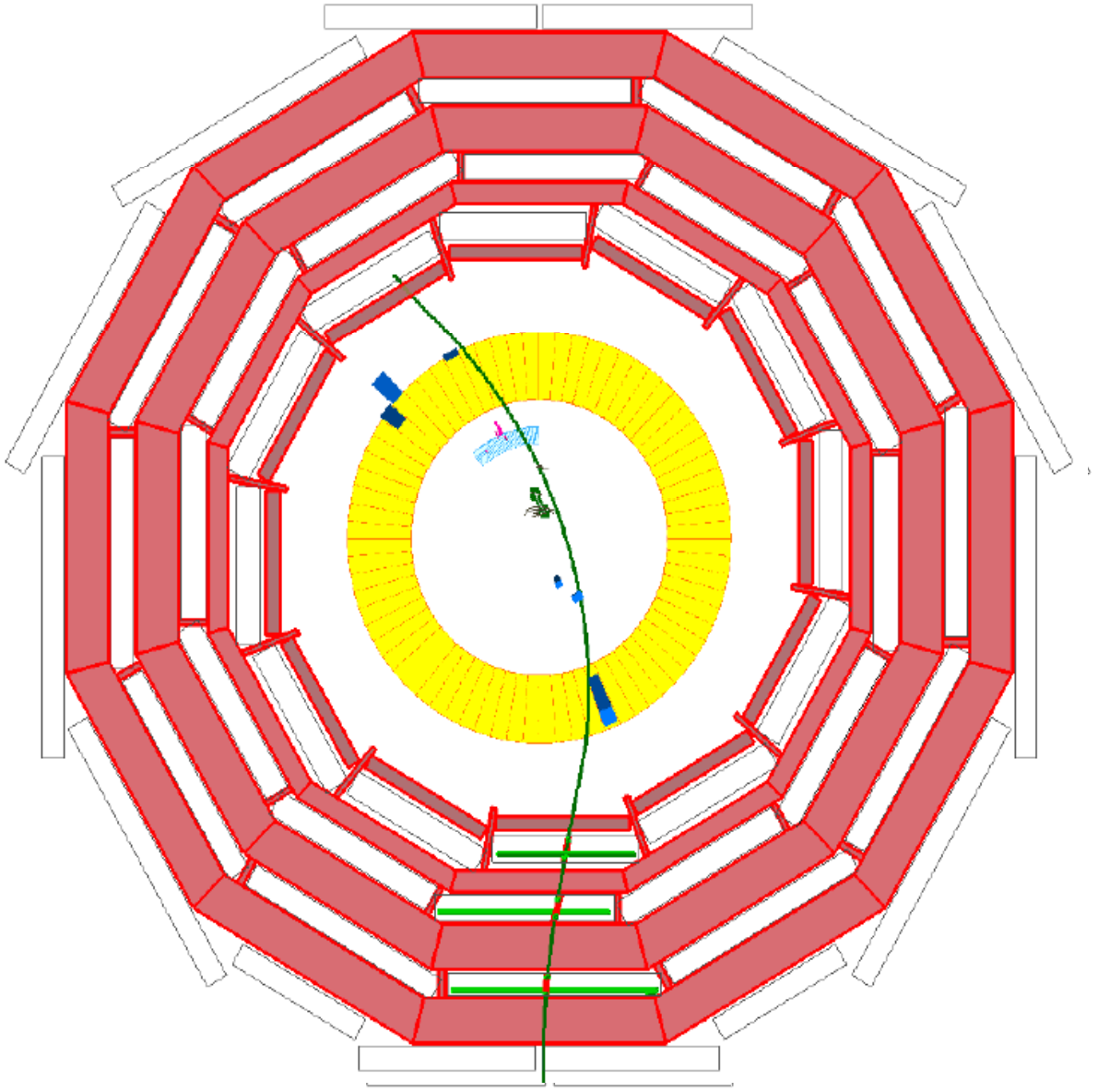
Run 2605 / Event 3981/ B 3.8 T/27.08.06

CERN PRESS RELEASE
13 September 2006

Mammoth CMS magnet reaches full-field at CERN

Tests show CMS detector will be ready for data

~~4T operation also tested~~



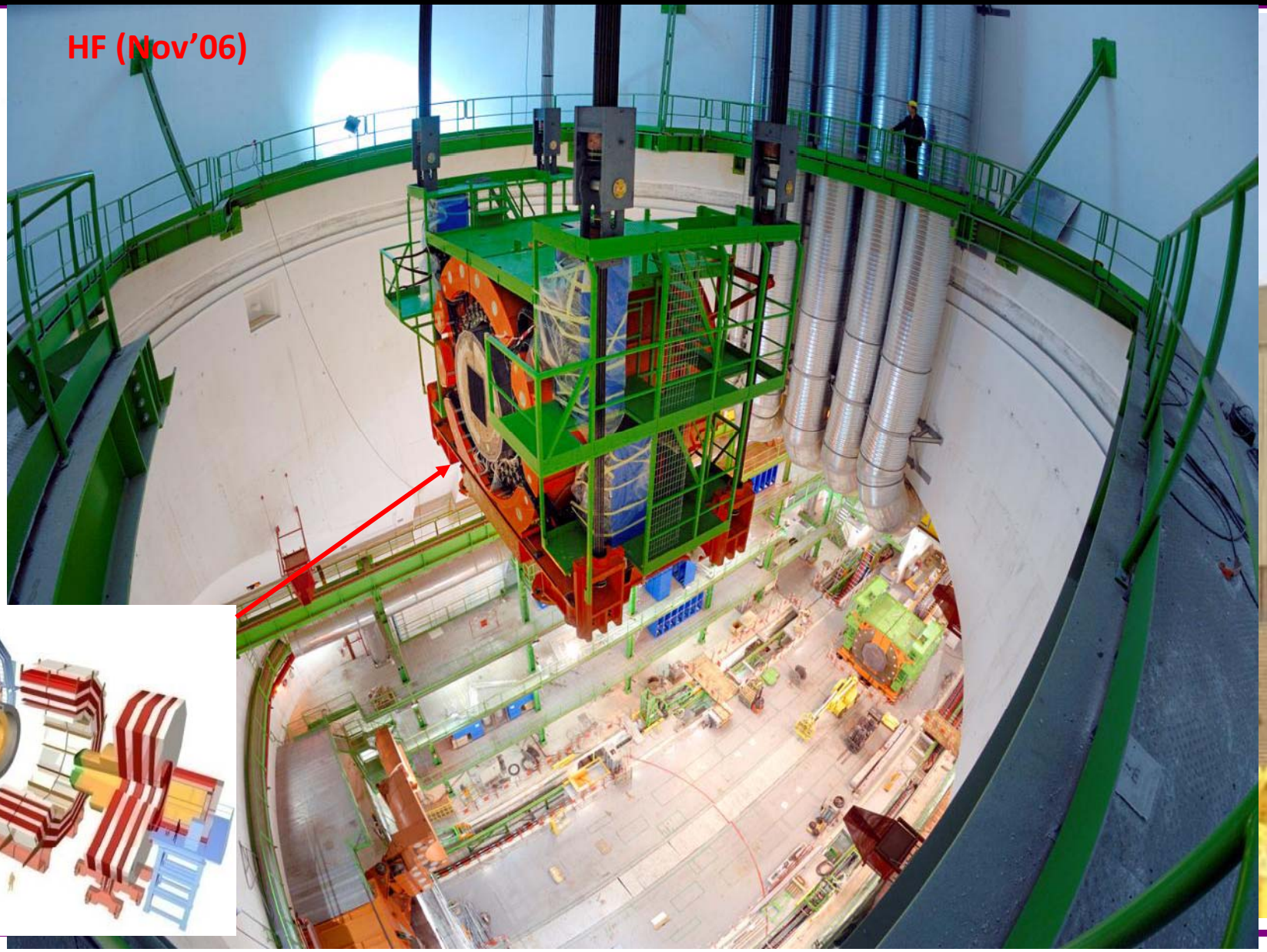
ALL SLICES DOWN

Experiment Cavern

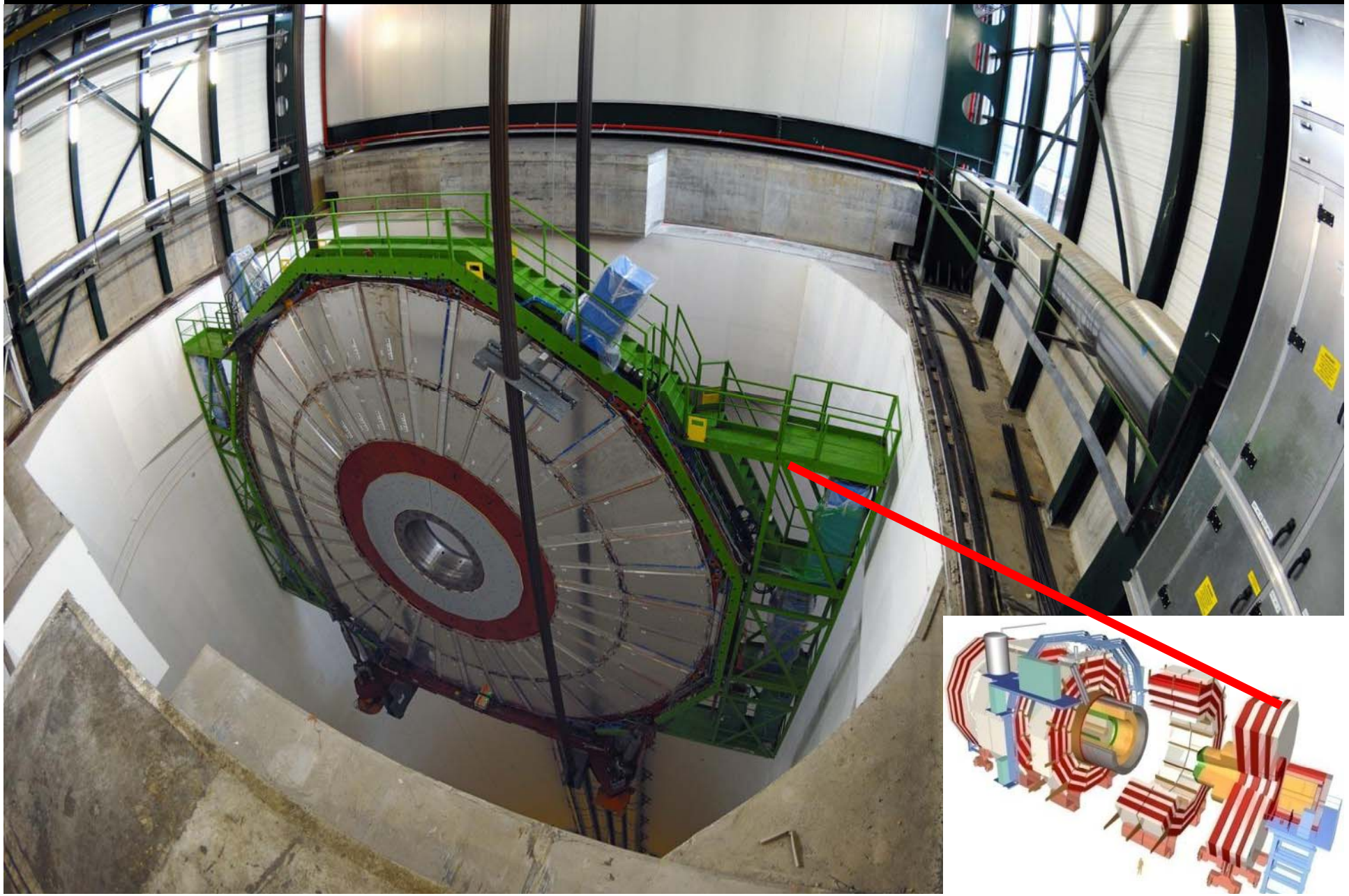
2003

2004

Lowering of Heavy Elements

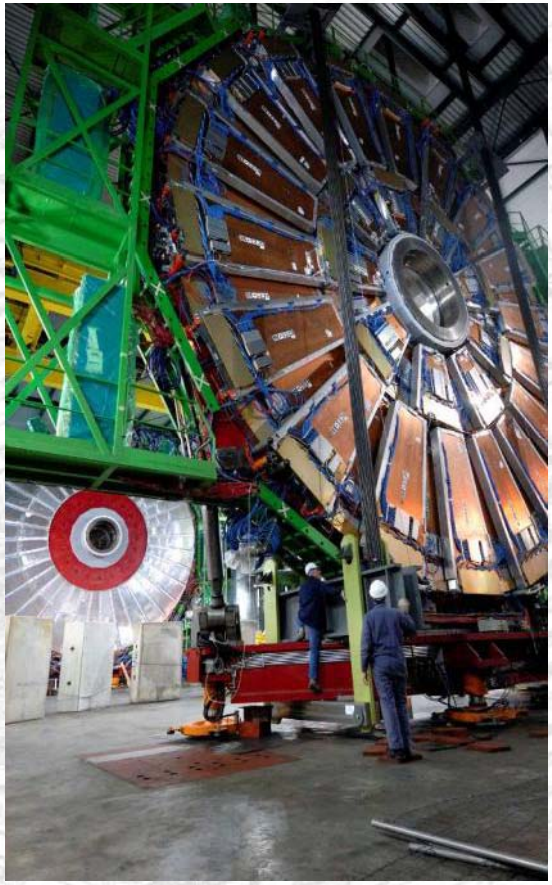


Start YE+3 lowering (30 Nov 2006)

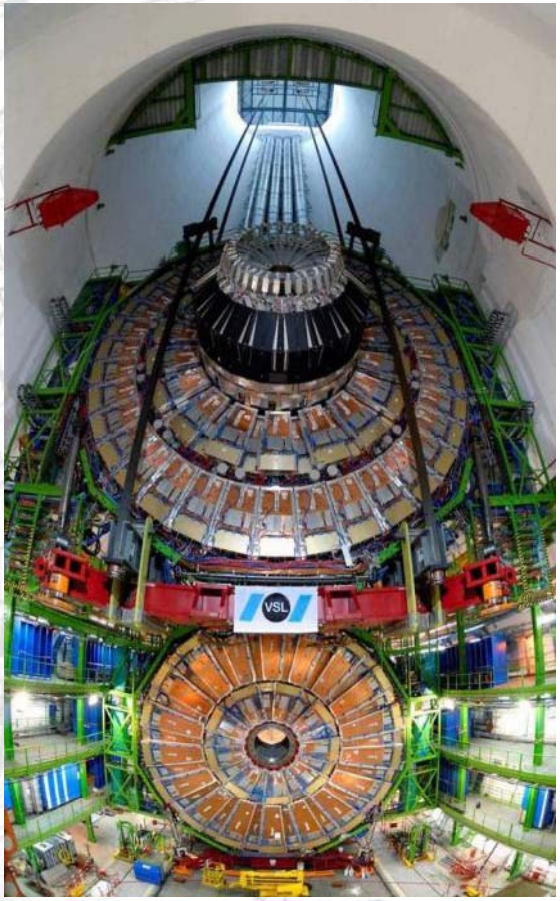


Heavy Lowering: +z Endcap Disks

YE+3
30.11.2006

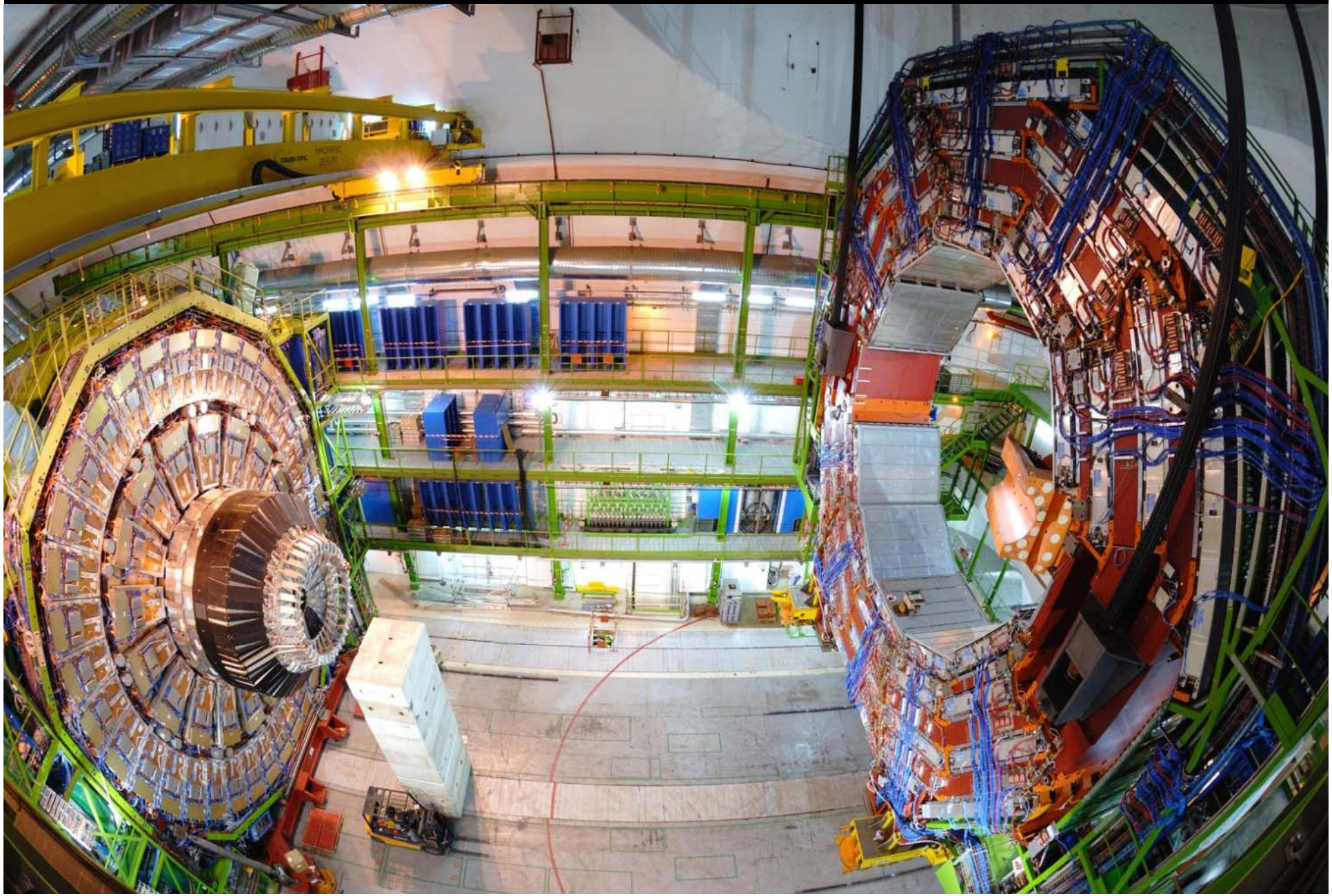


YE+2
12.12.2006

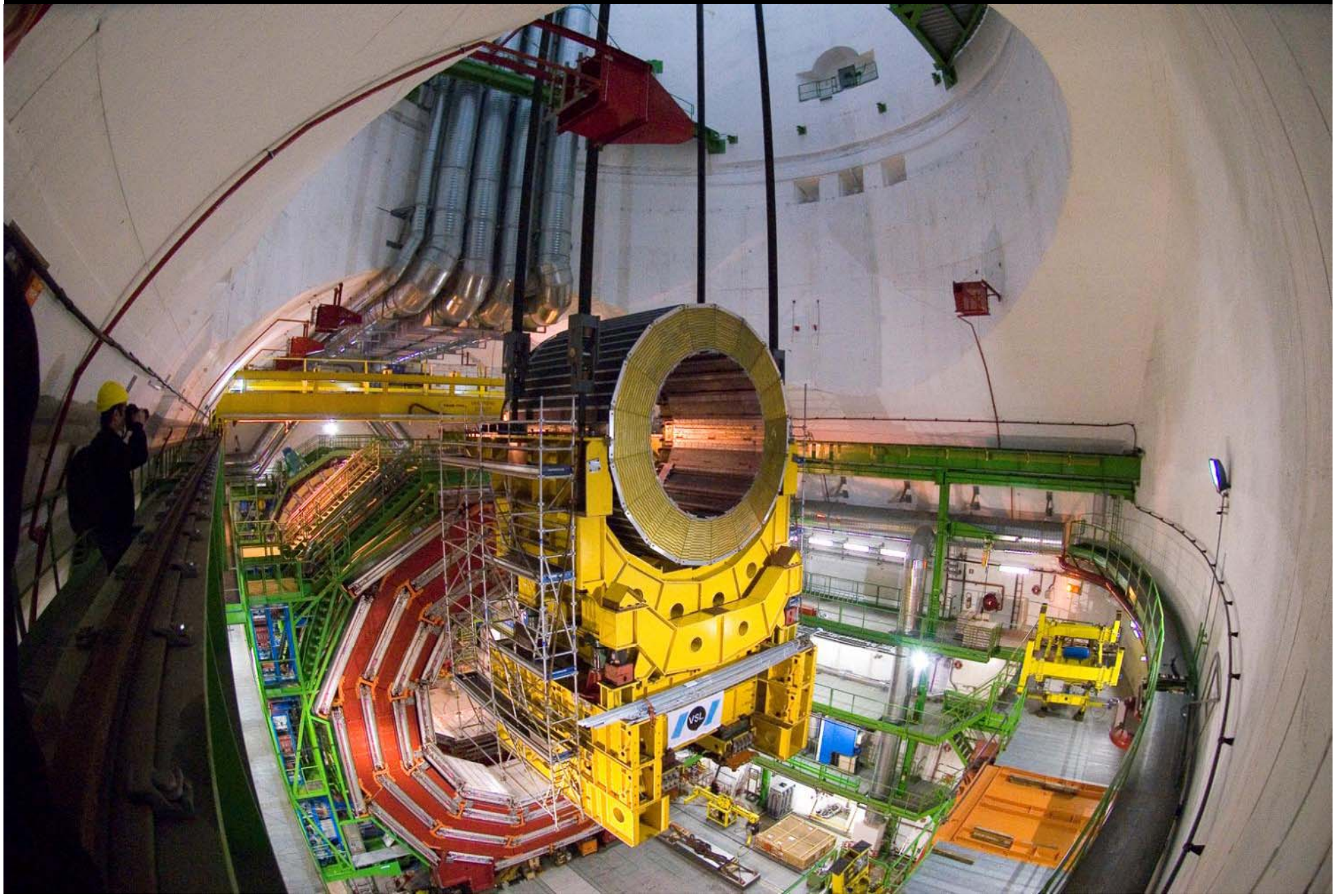


YE+1
9.1.2007

YB+2 Lowering (19 Jan ‘07)

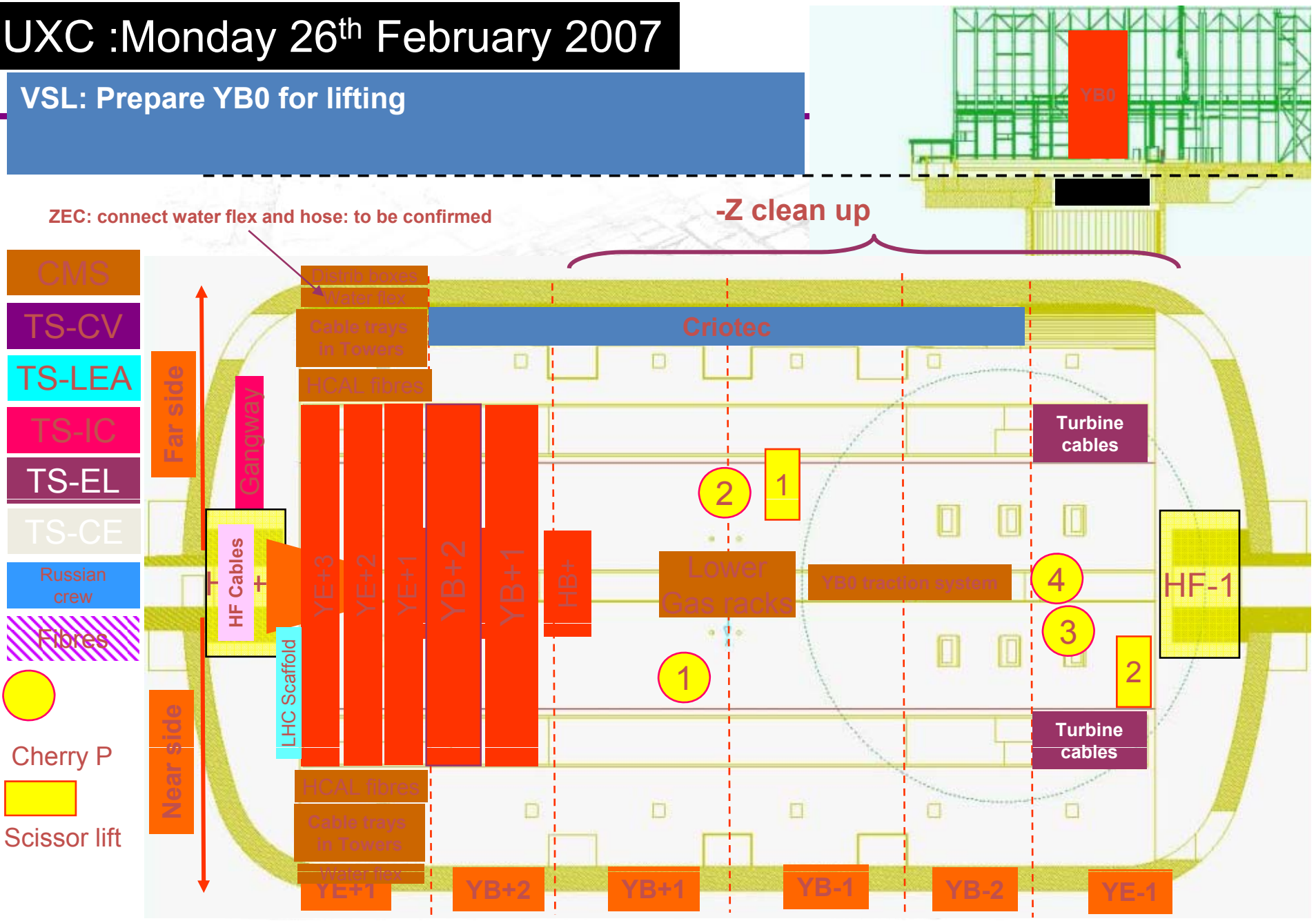


HB+ Lowering (13 Feb ‘07)



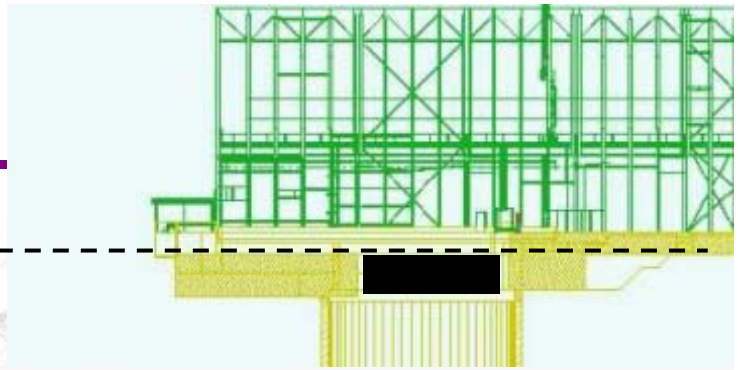
UXC :Monday 26th February 2007

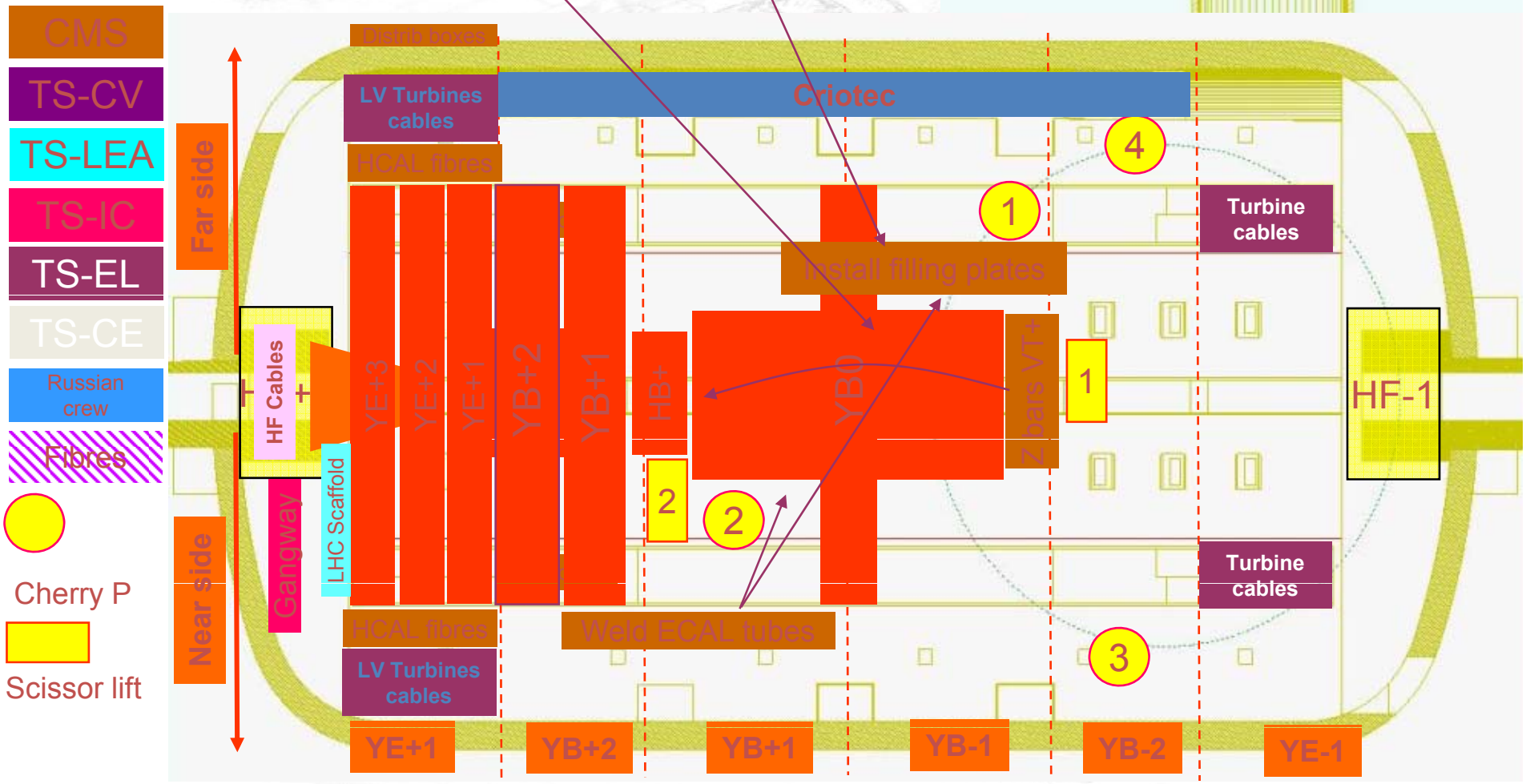
VSL: Prepare YB0 for lifting



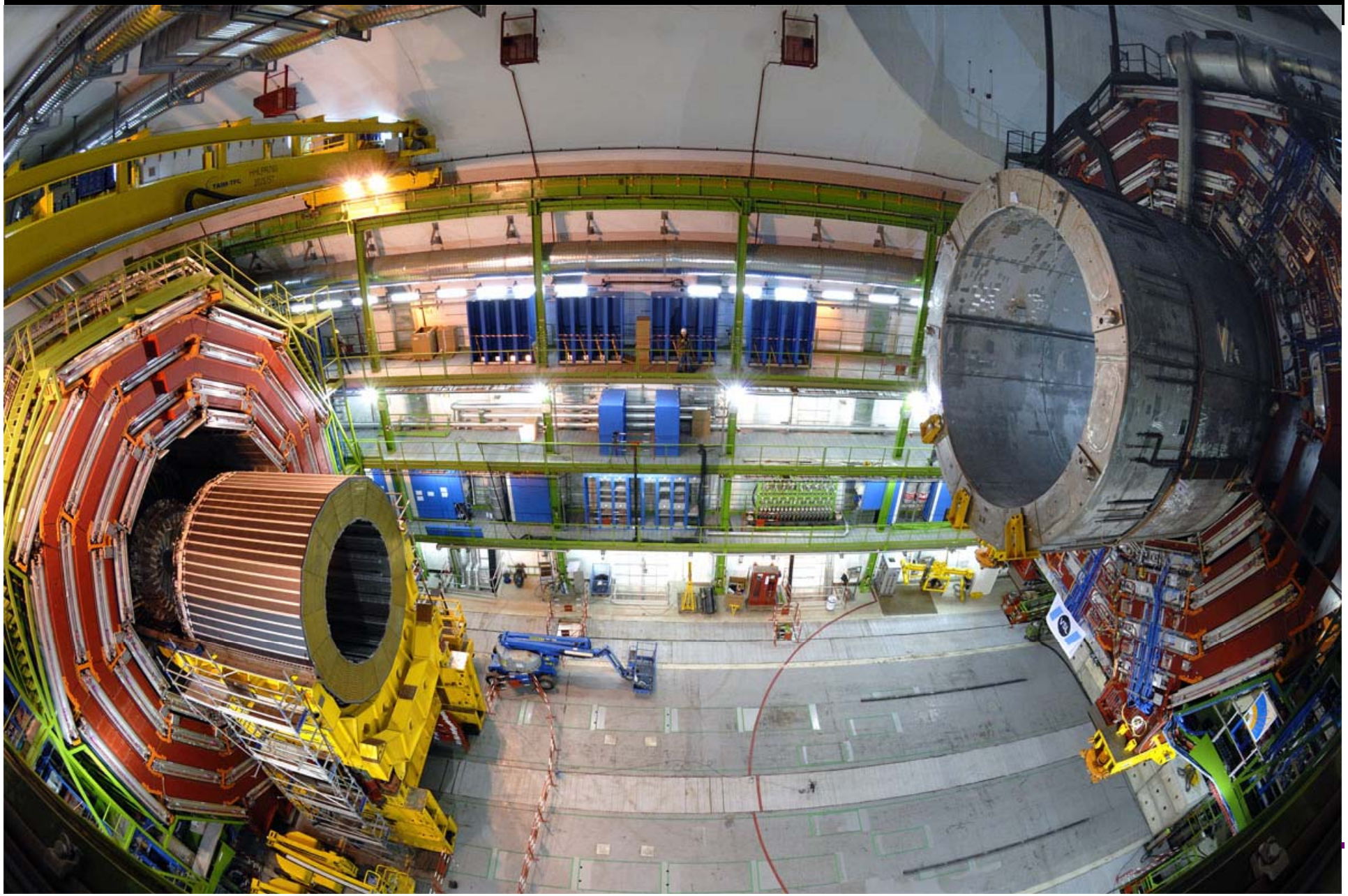
UXC: Friday 2 March 2007

VSL: Switch lifting tooling YB0 to HB-
PH-CMI: Close Plug

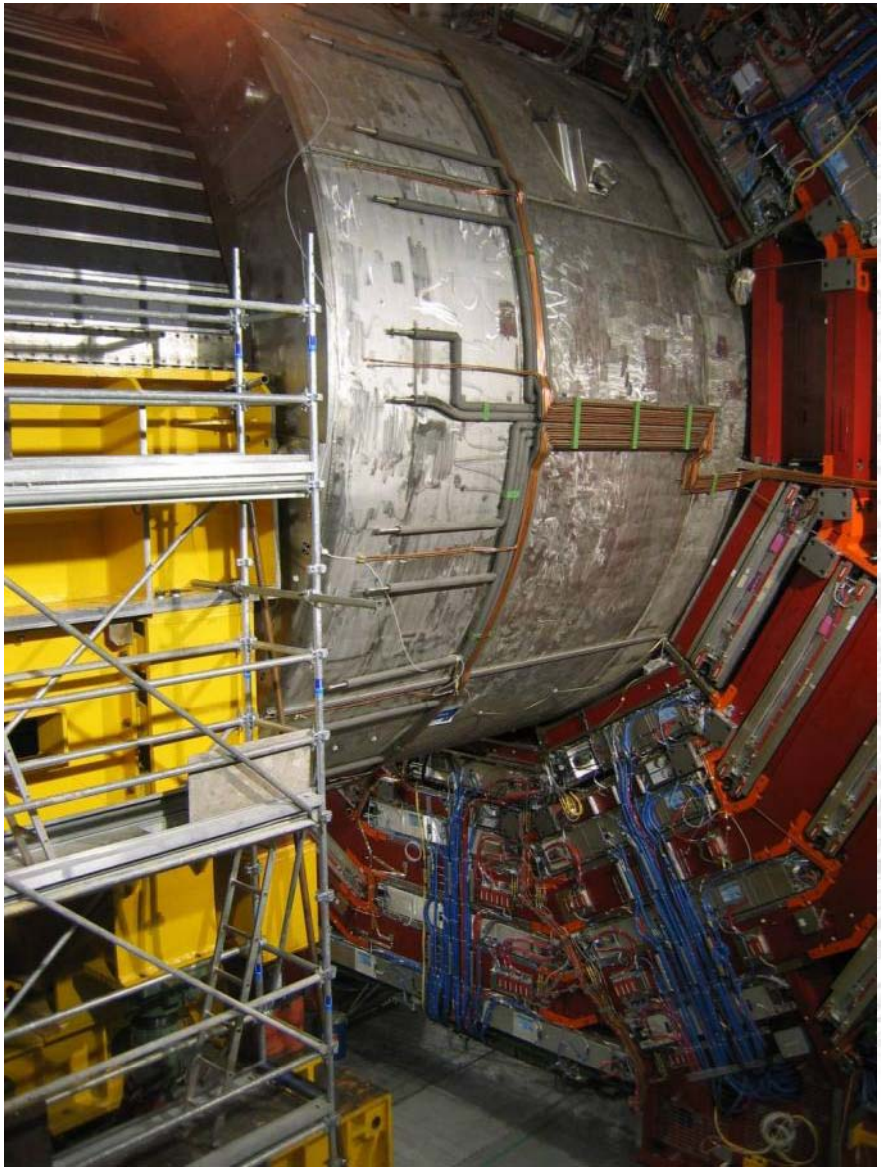


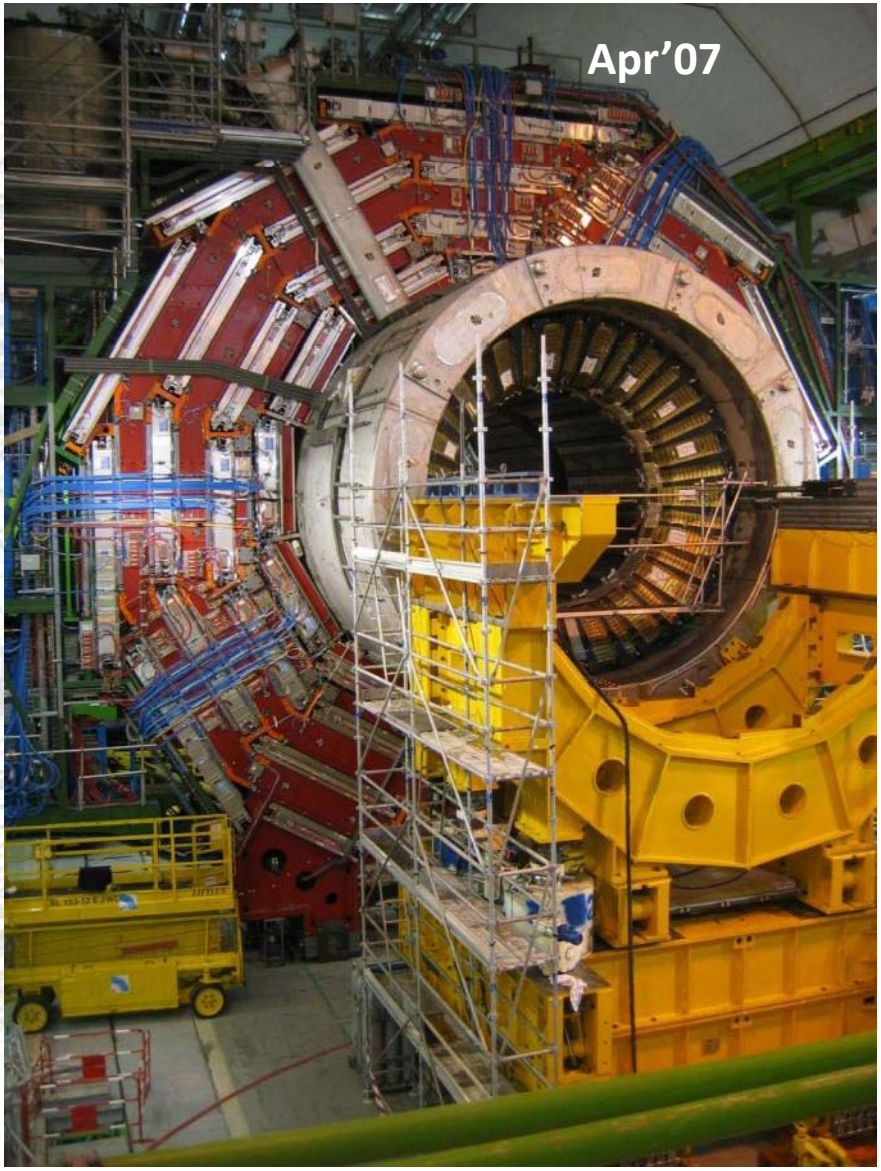


Central Wheel arriving in the Dungeon

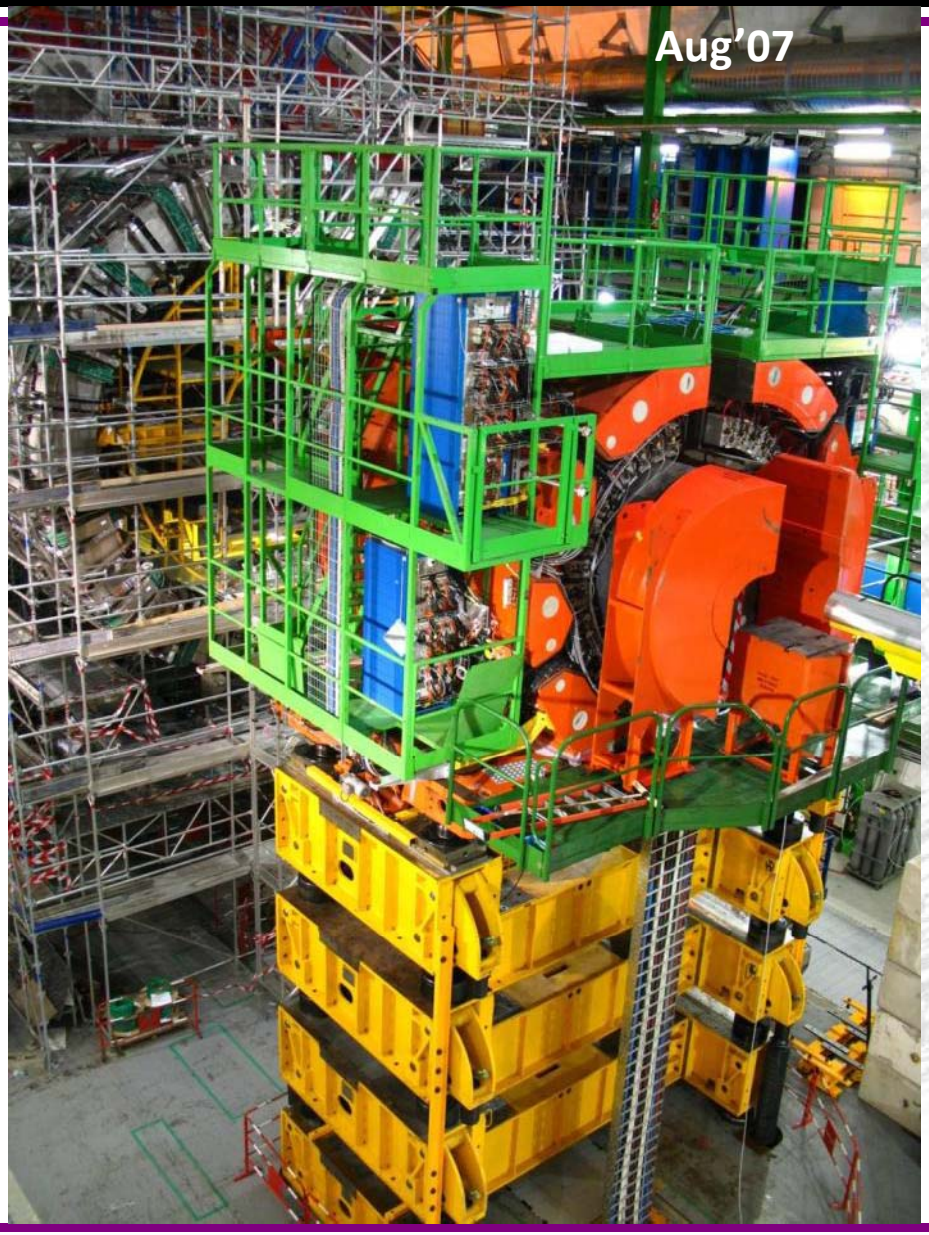


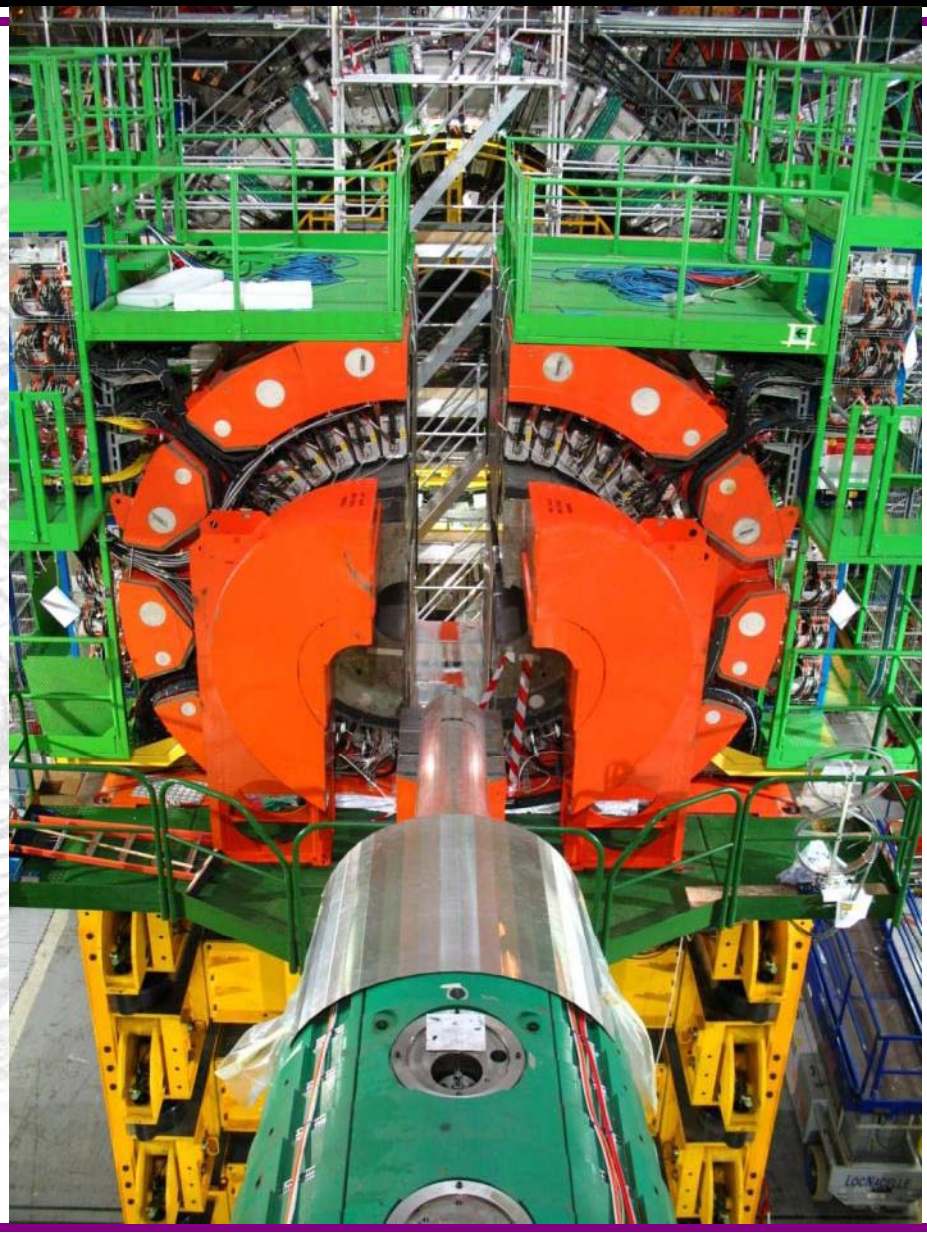
Insertion of HCAL Barrel



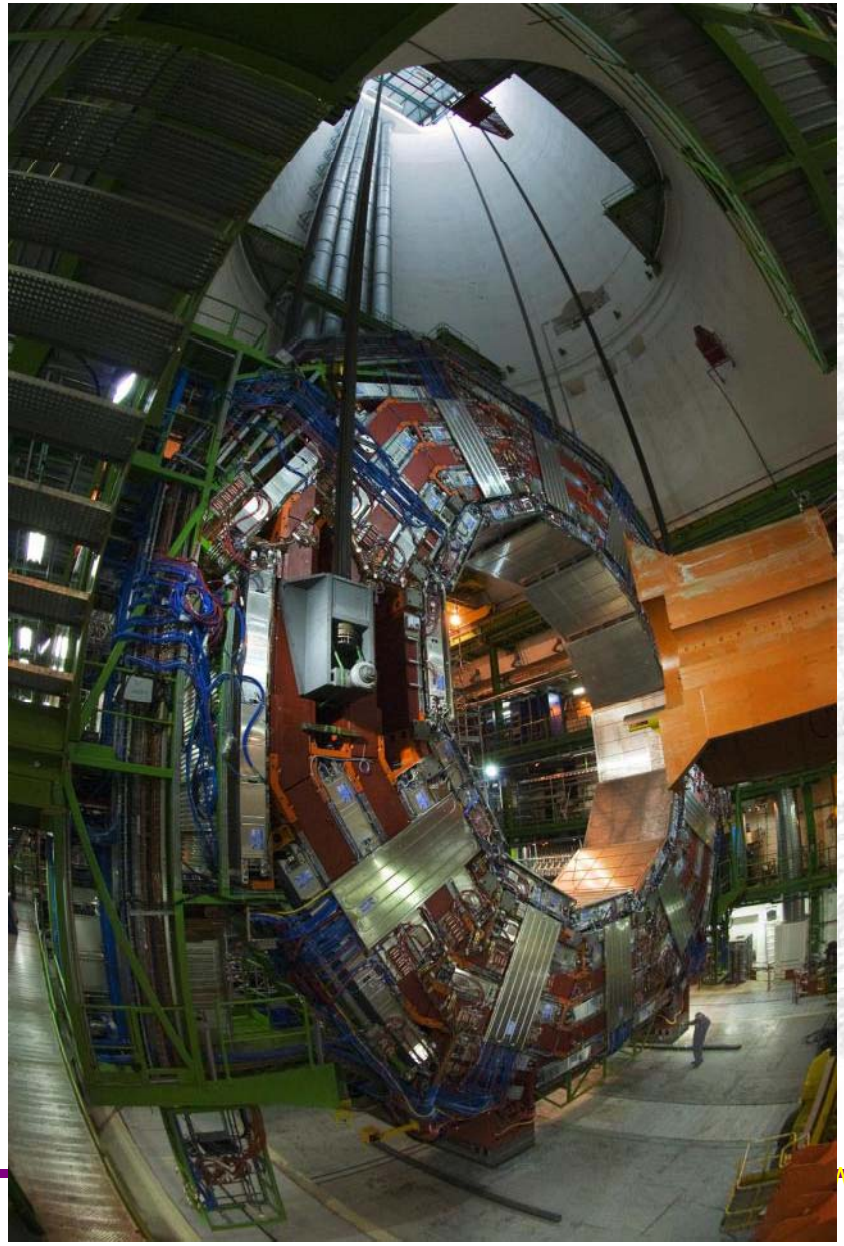


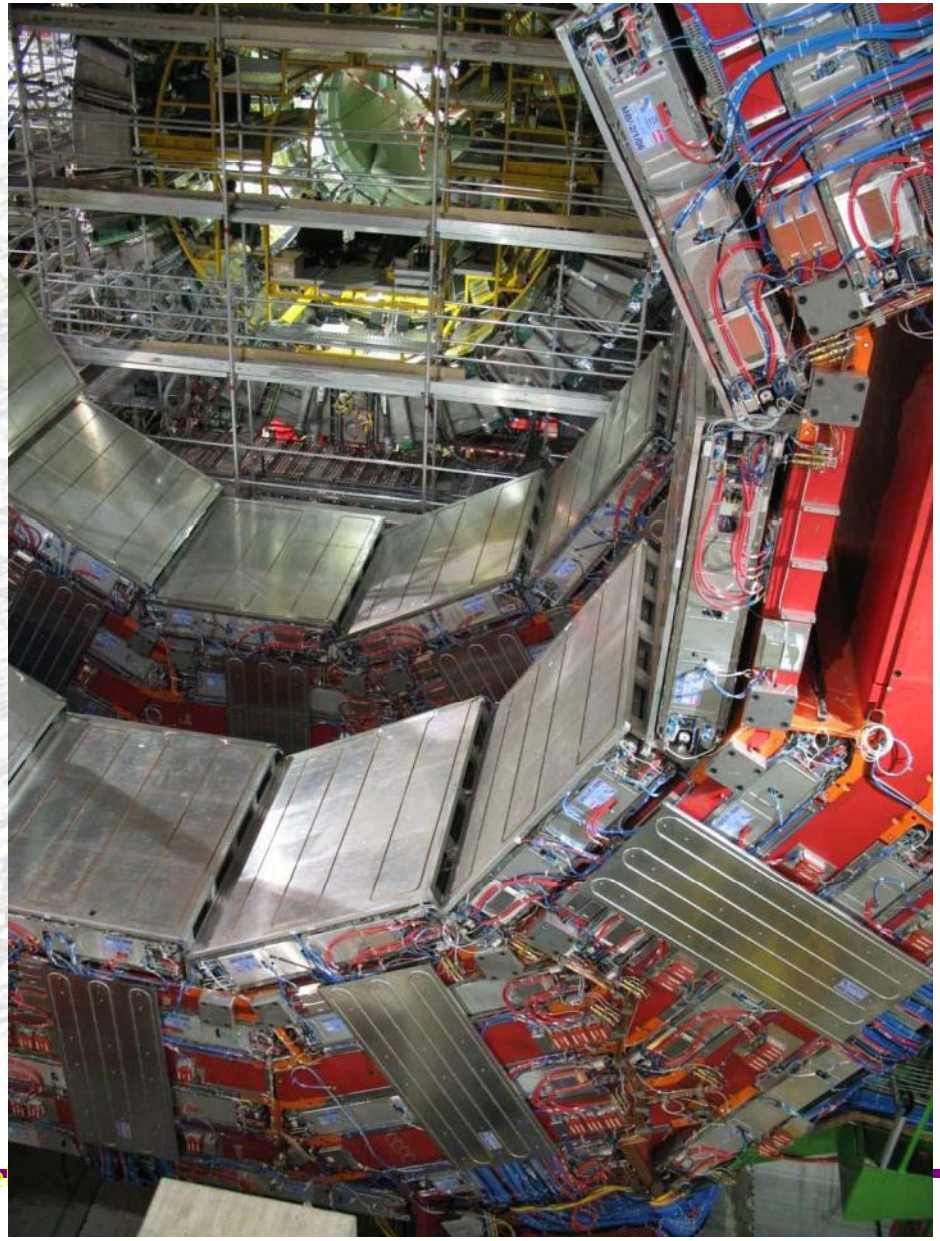
HF Raiser Test



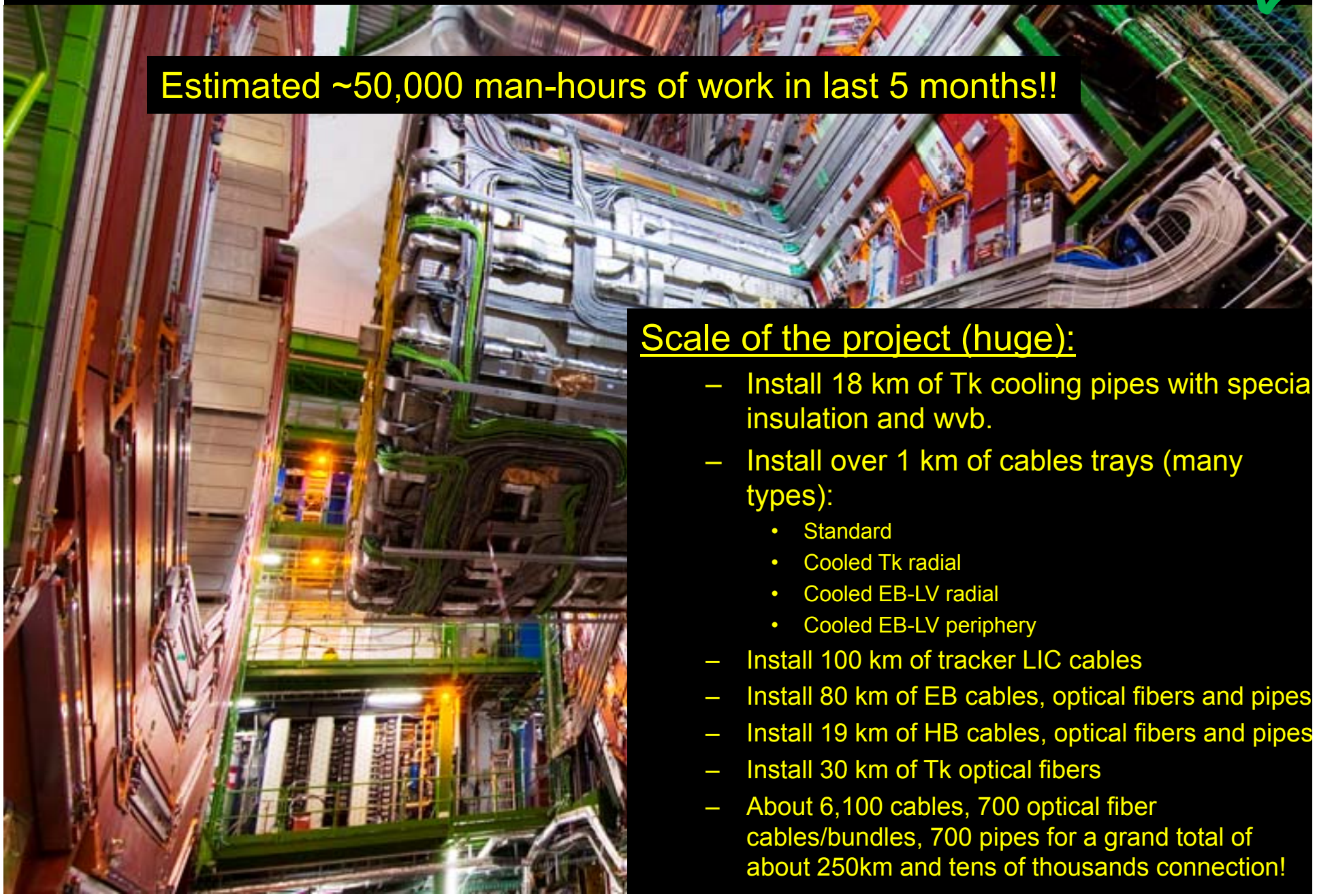


Lowering of YB-1 and YB-2 (October)





Completion of Services on YB0 Nov. '07 ✓

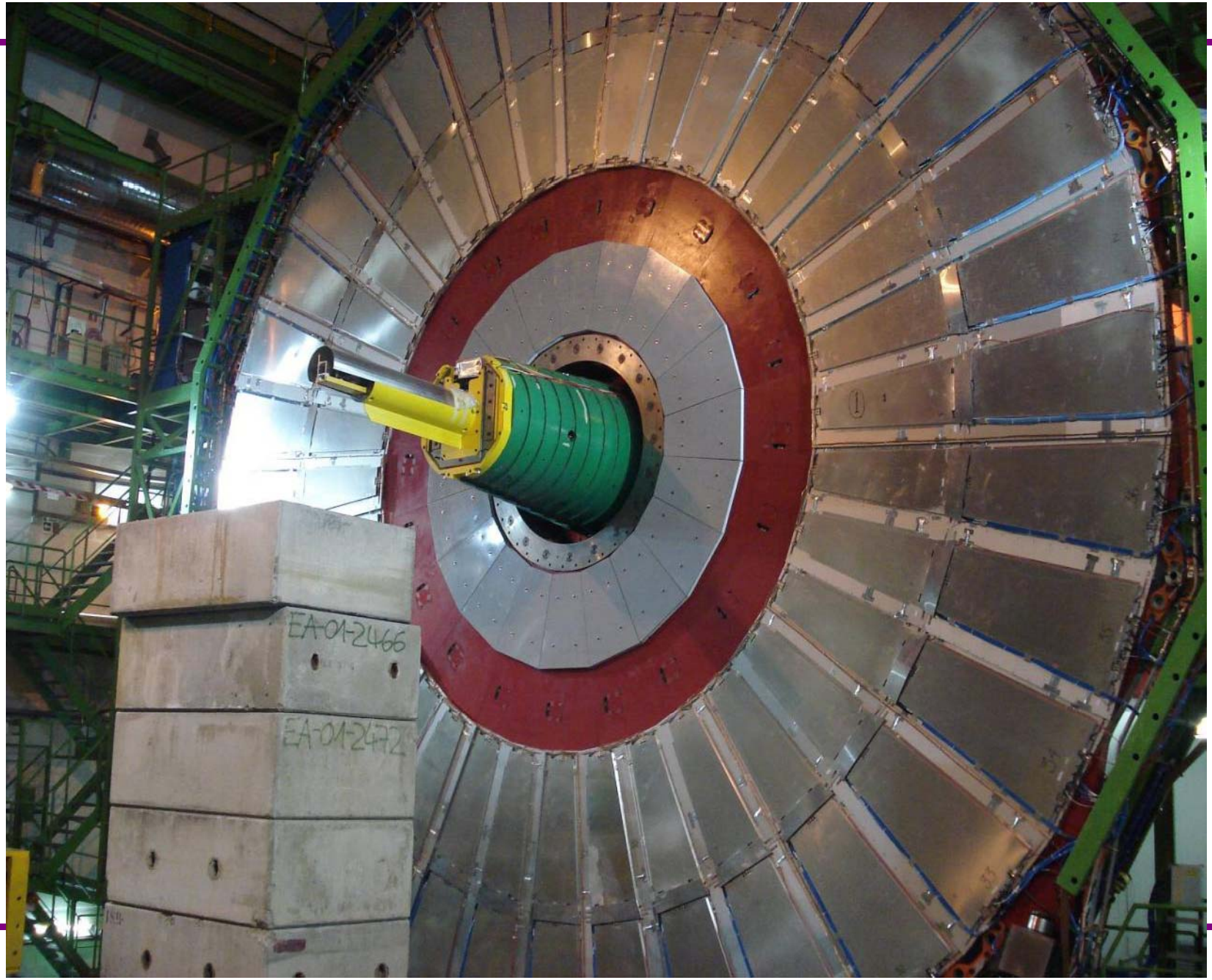


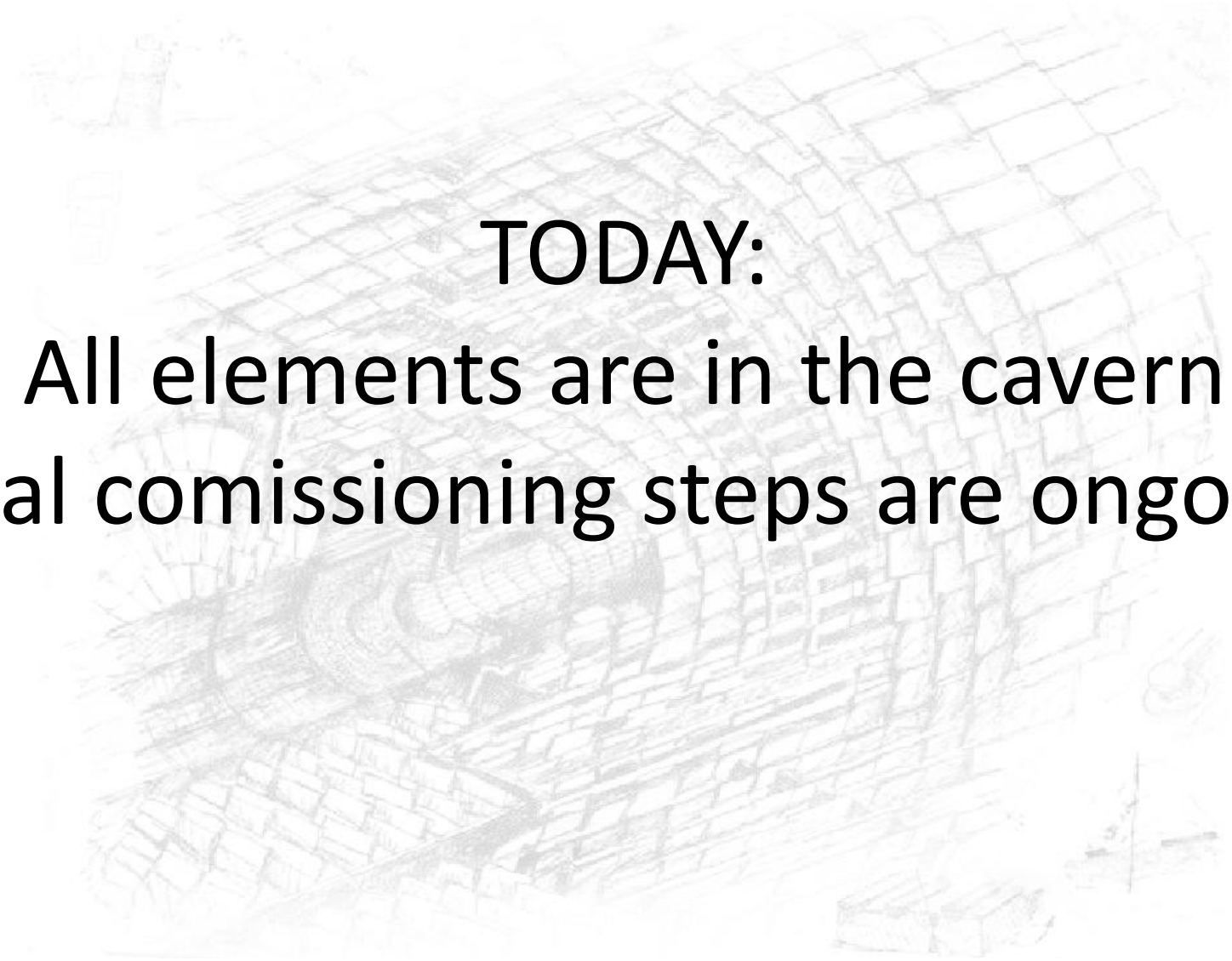
Estimated ~50,000 man-hours of work in last 5 months!!

Scale of the project (huge):

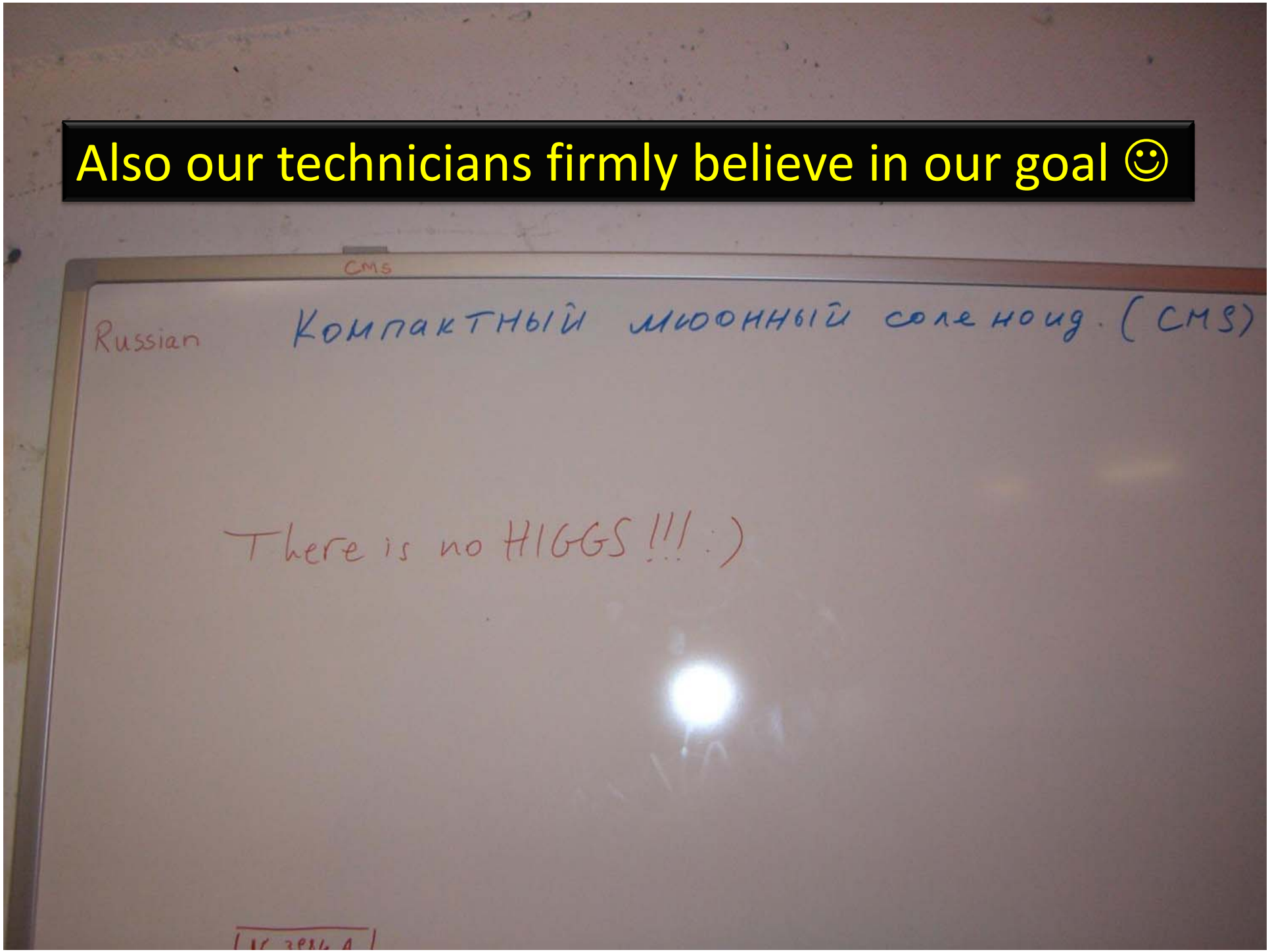
- Install 18 km of Tk cooling pipes with specia insulation and wvb.
- Install over 1 km of cables trays (many types):
  - Standard
  - Cooled Tk radial
  - Cooled EB-LV radial
  - Cooled EB-LV periphery
- Install 100 km of tracker LIC cables
- Install 80 km of EB cables, optical fibers and pipes
- Install 19 km of HB cables, optical fibers and pipes
- Install 30 km of Tk optical fibers
- About 6,100 cables, 700 optical fiber cables/bundles, 700 pipes for a grand total of about 250km and tens of thousands connection!

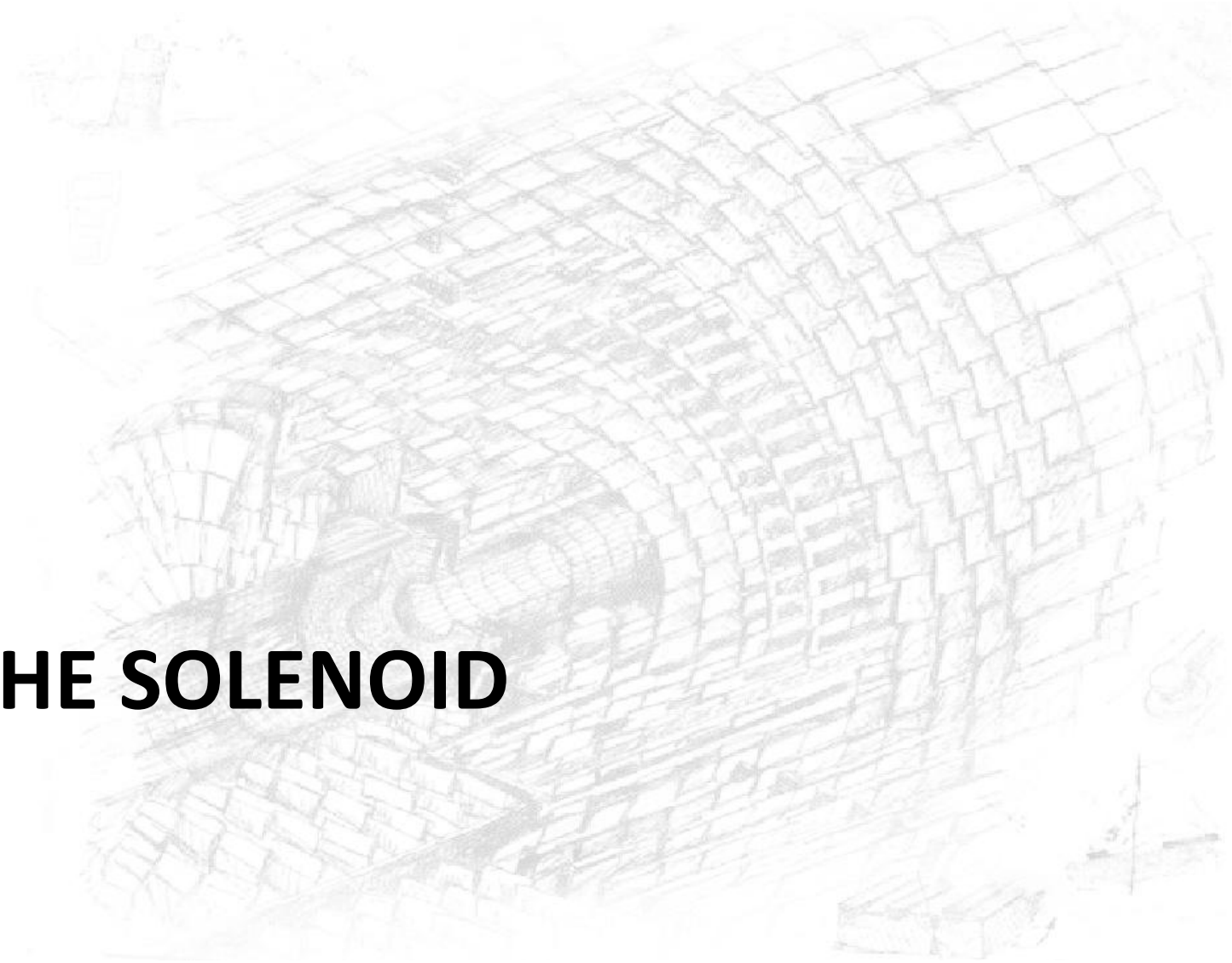
YE-3 lowered and moved over FIN





TODAY:
All elements are in the cavern
final comissioning steps are ongoing


Also our technicians firmly believe in our goal ☺
CMS
Russian
Компактный мюонный соленоид. (CMS)
There is no HIGGS !!! :)



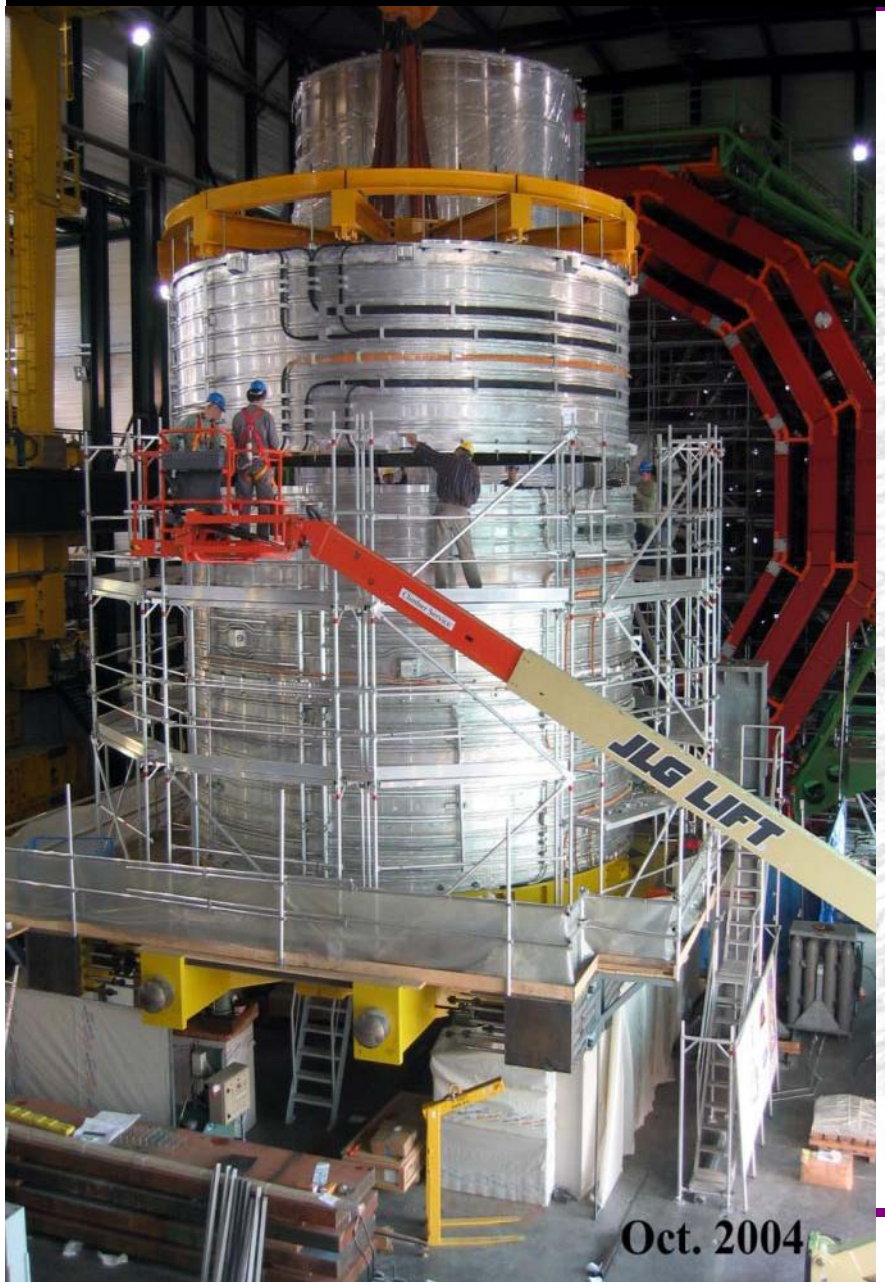
THE SOLENOID

Winding of the Coil

- Passive protection by Quench-Back effect
- Al stabilized NbTi conductor (insert of CMS)
- Indirectly cooled at 4.5 K by thermo siphon circuits
- Inner winding vacuum impregnated with epoxy resin

Central magnetic induction	4 T
Nominal current	20 kA
Stored energy	2.7 GJ
Magnetic Radial Pressure	64 Atmospheres!

Assembly of the Coil



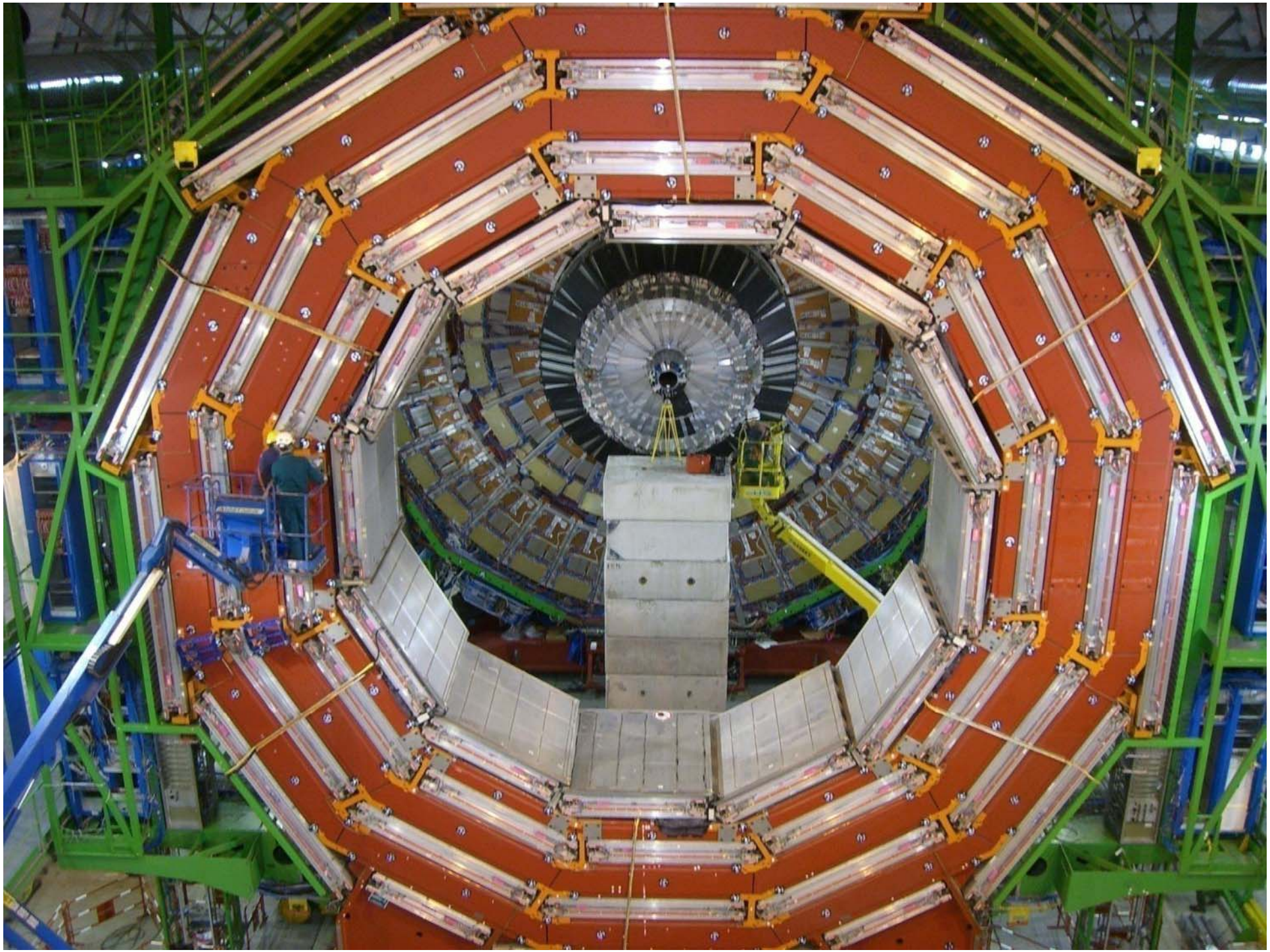
Swiveling was shown earlier.

Drift Tubes – DT

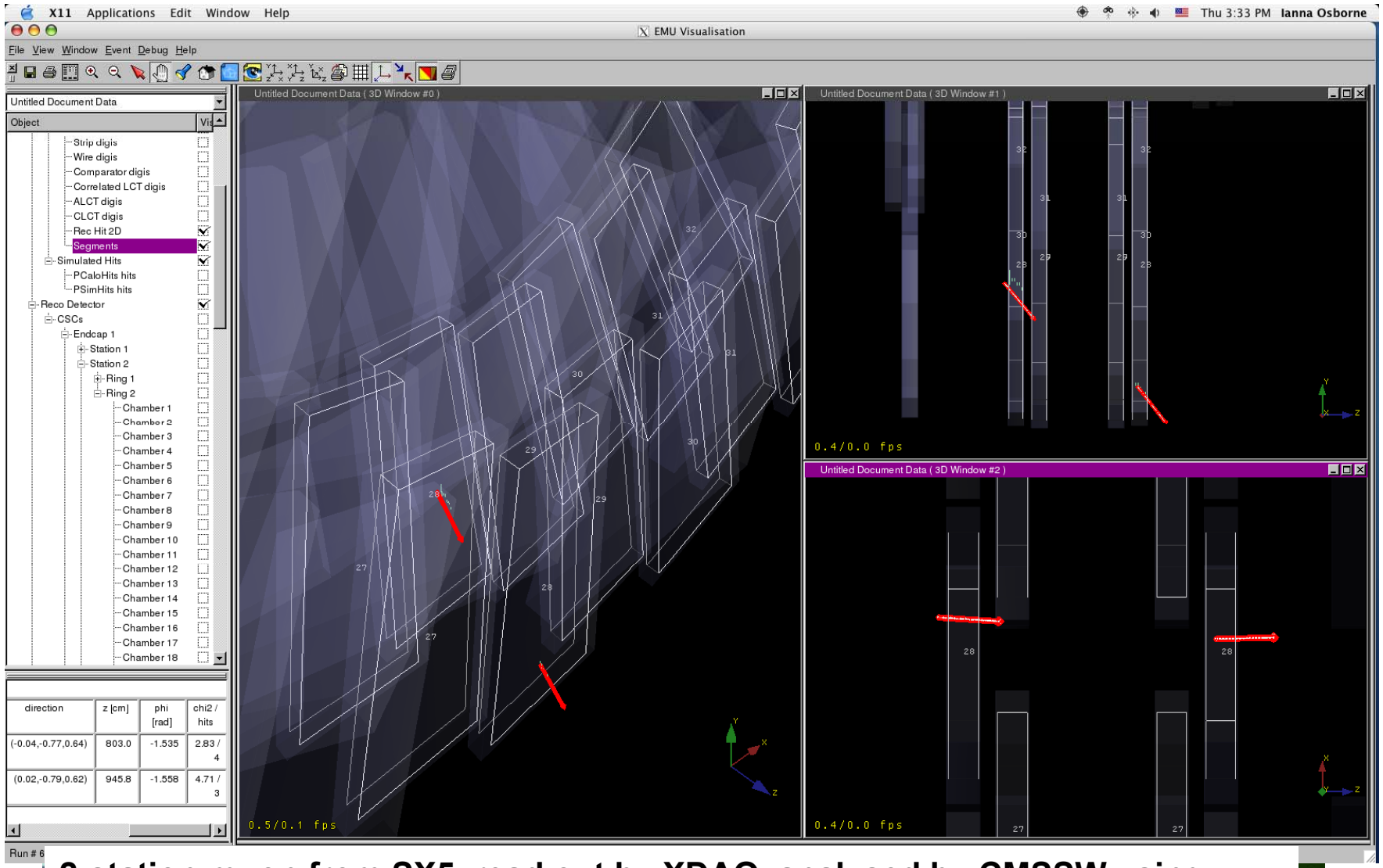
Resistive Plate Chambers – RPC

Cathode Strip Chambers – CSC

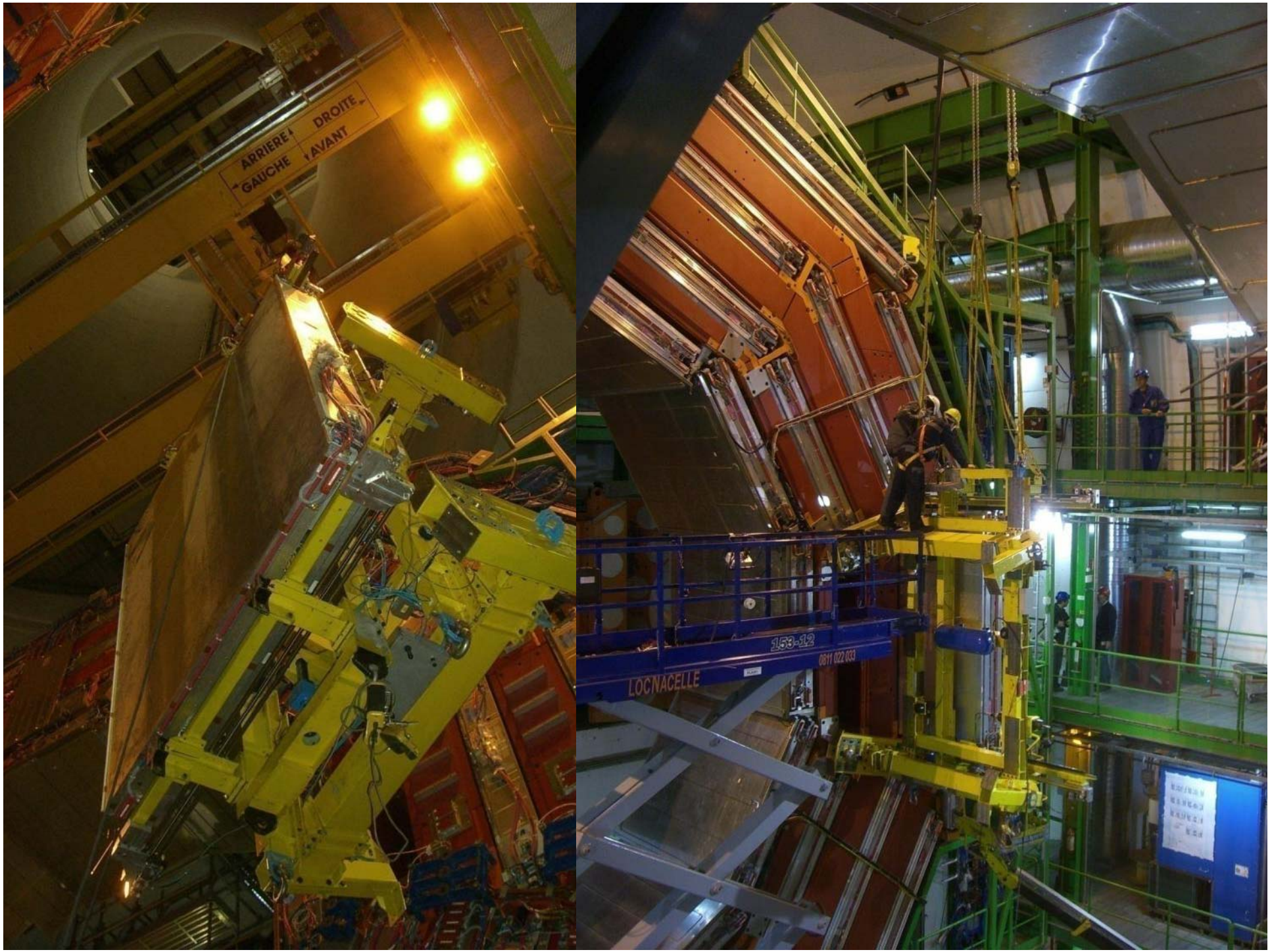
MUON DETECTORS

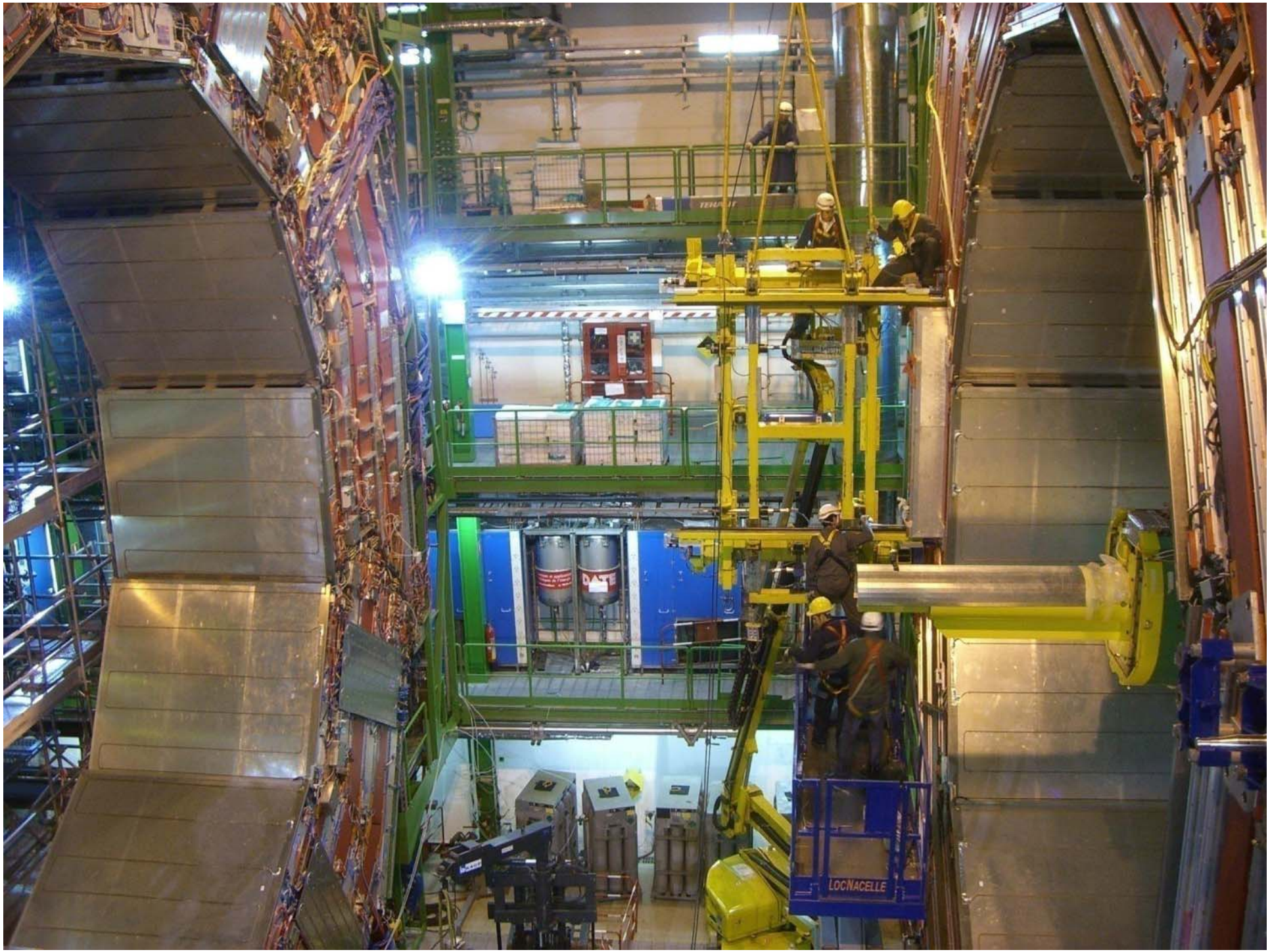


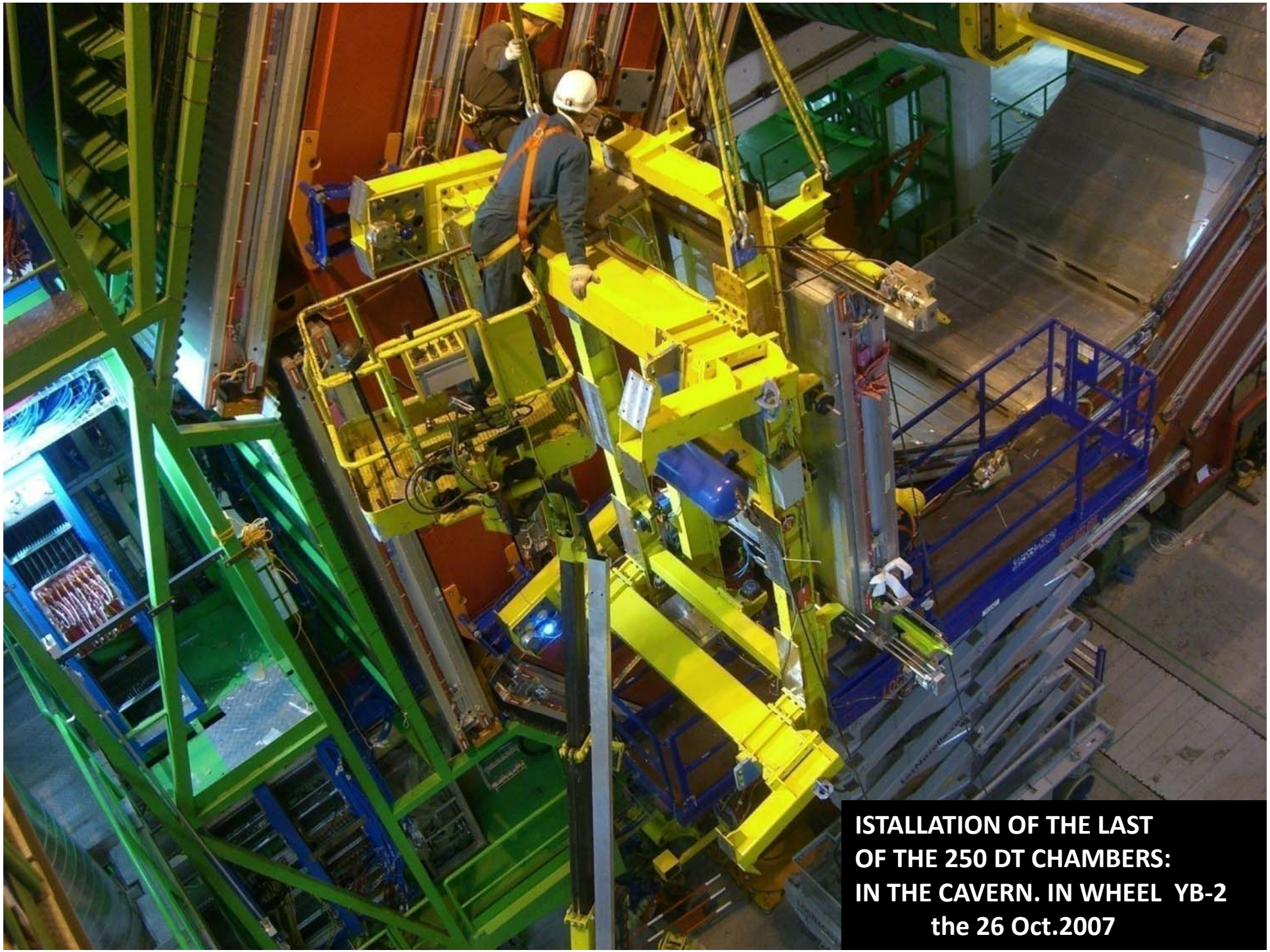
Cosmic Muon may 2006



2-station muon from SX5, read out by XDAQ, analysed by CMSSW using alignment data bases, …,. Displayed on IGUANA Event Display. May 2006


ARRIERE
DROITE
GAUCHE
AVANT
LOC'NACELLE
1.53-1.2
0811 022 033

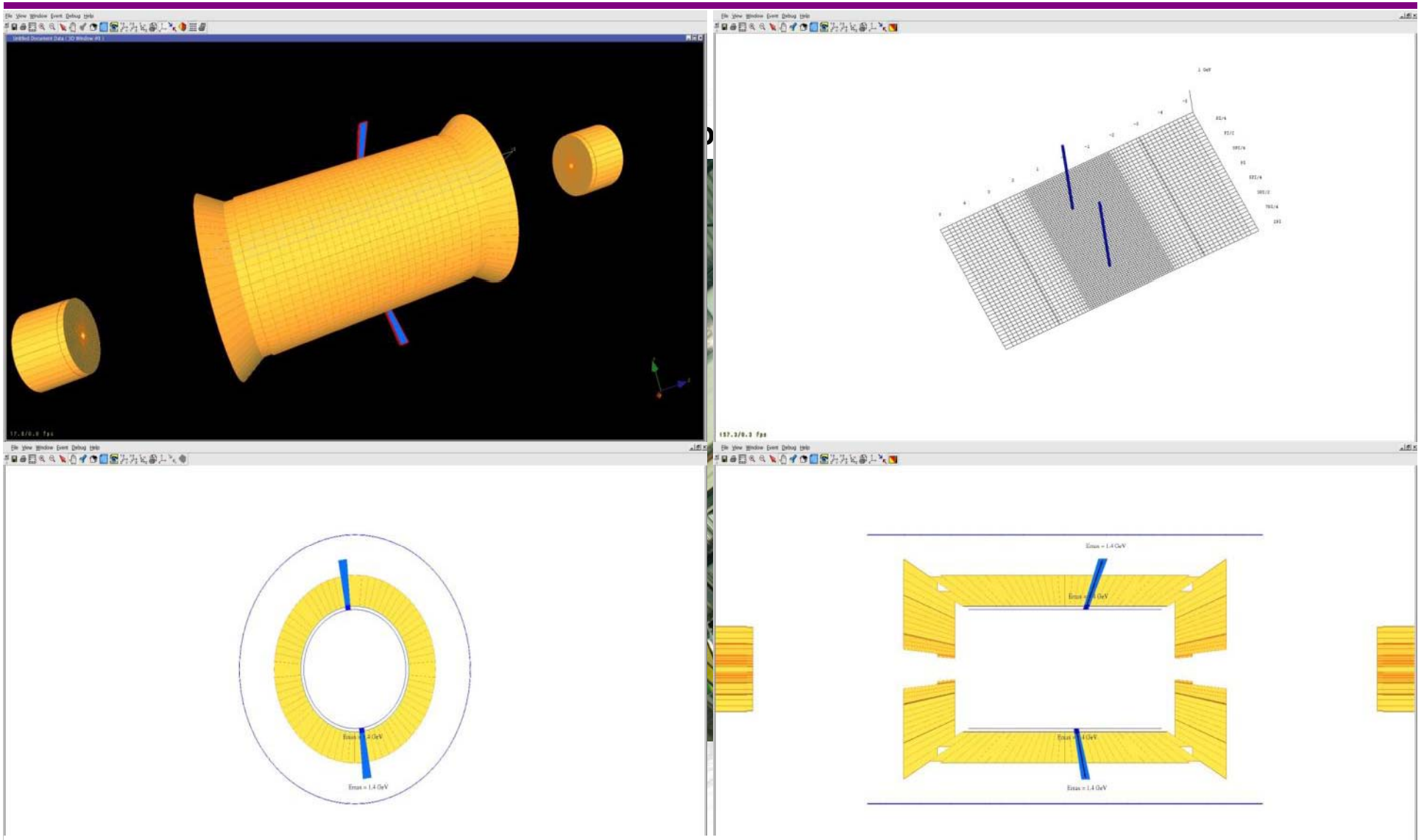

LOCNACELLE



ISTALLATION OF THE LAST
OF THE 250 DT CHAMBERS:
IN THE CAVERN. IN WHEEL YB-2
the 26 Oct.2007

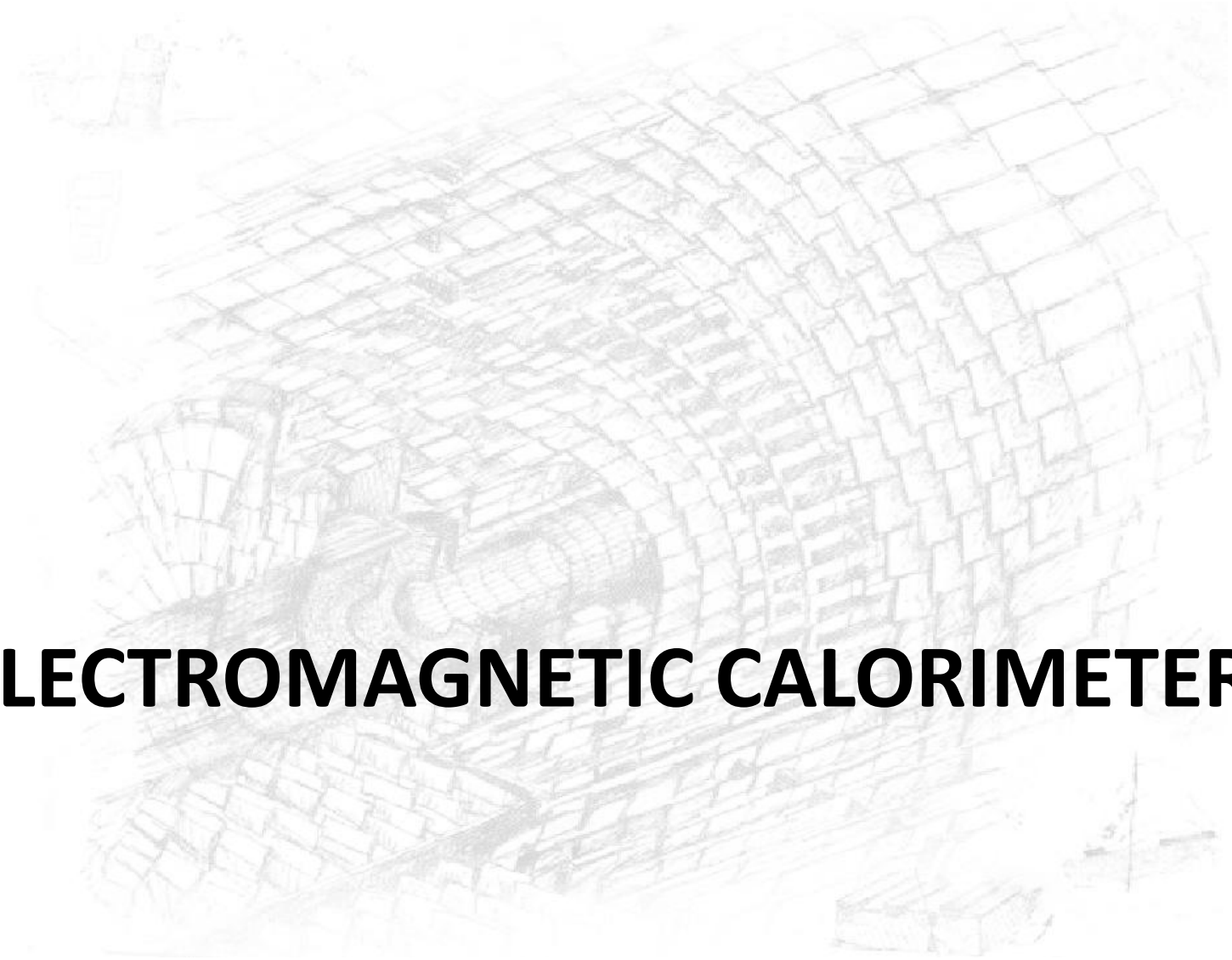
HADRONIC CALORIMETER

Hadronic Calorimeter (HCAL) at SX5



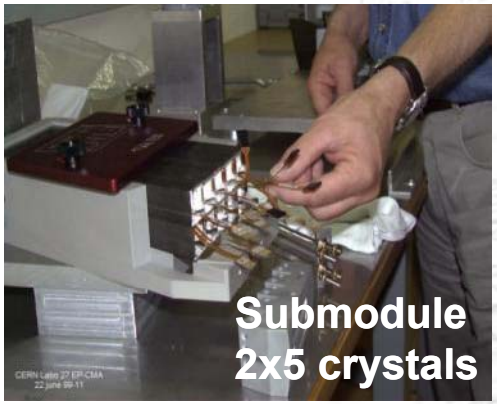
Assembly of 2 half barrels HB+ & HB- and two endcaps HE+ & HE- completed in 2003 (brass+ scint)

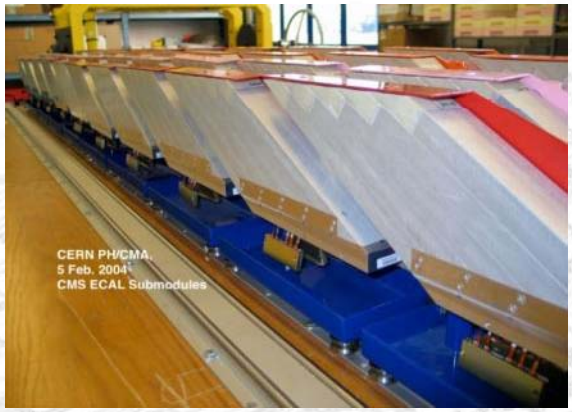
HB- insertion complete on 27 April 2006 on surface

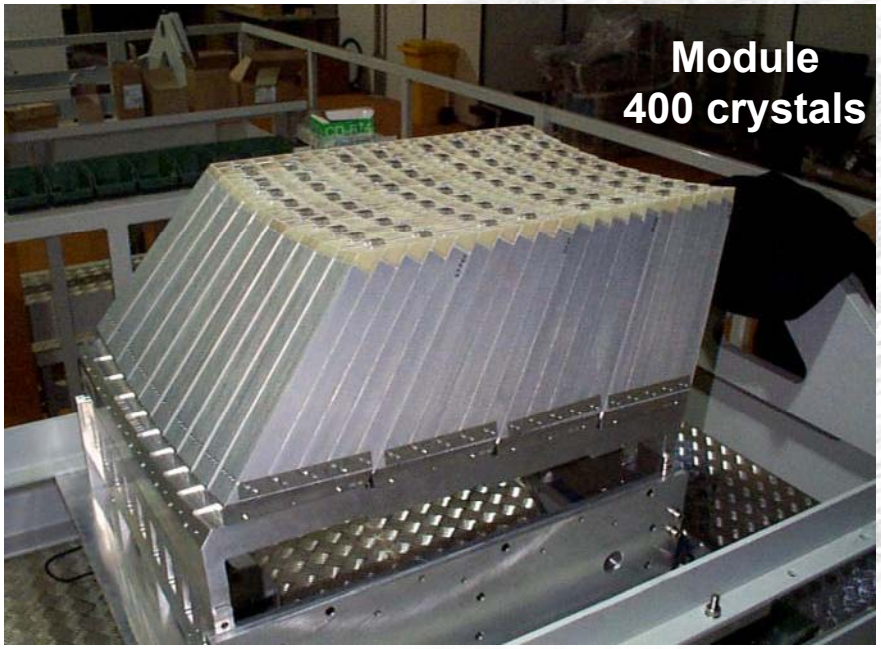


ELECTROMAGNETIC CALORIMETER

Assembly of ECAL

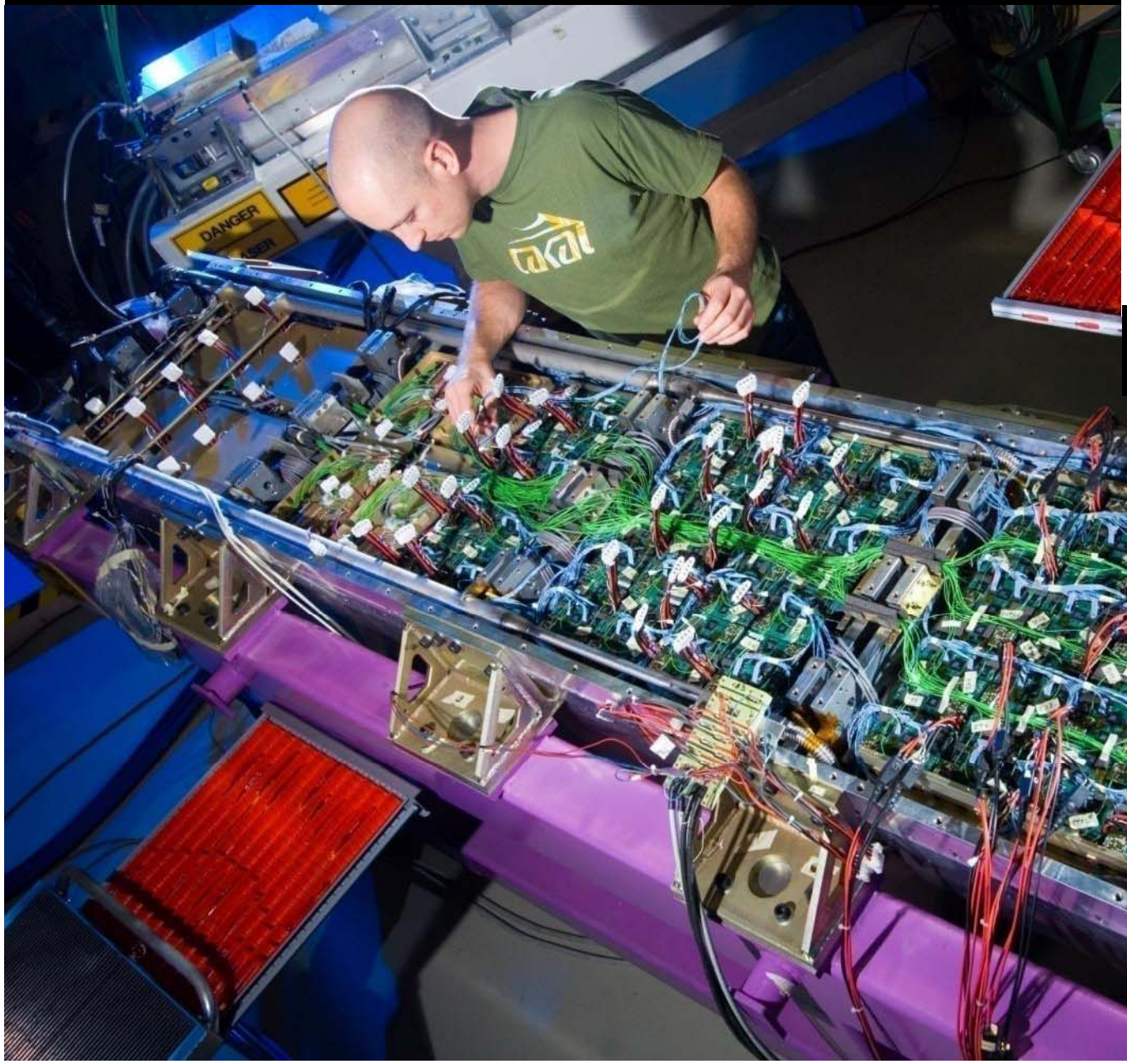


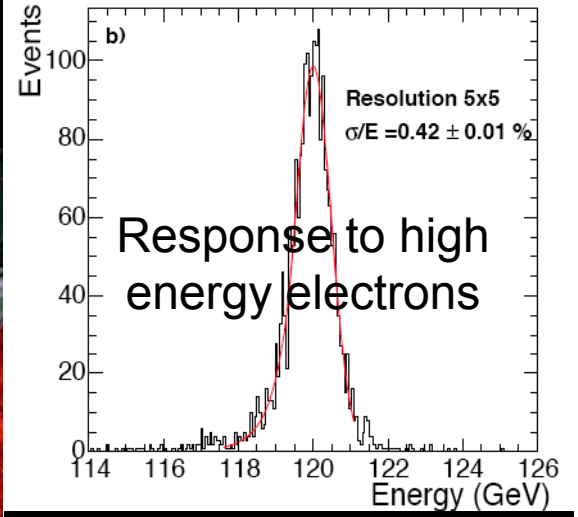




Total 36 Supermodules

ECAL: Assembly and Performance



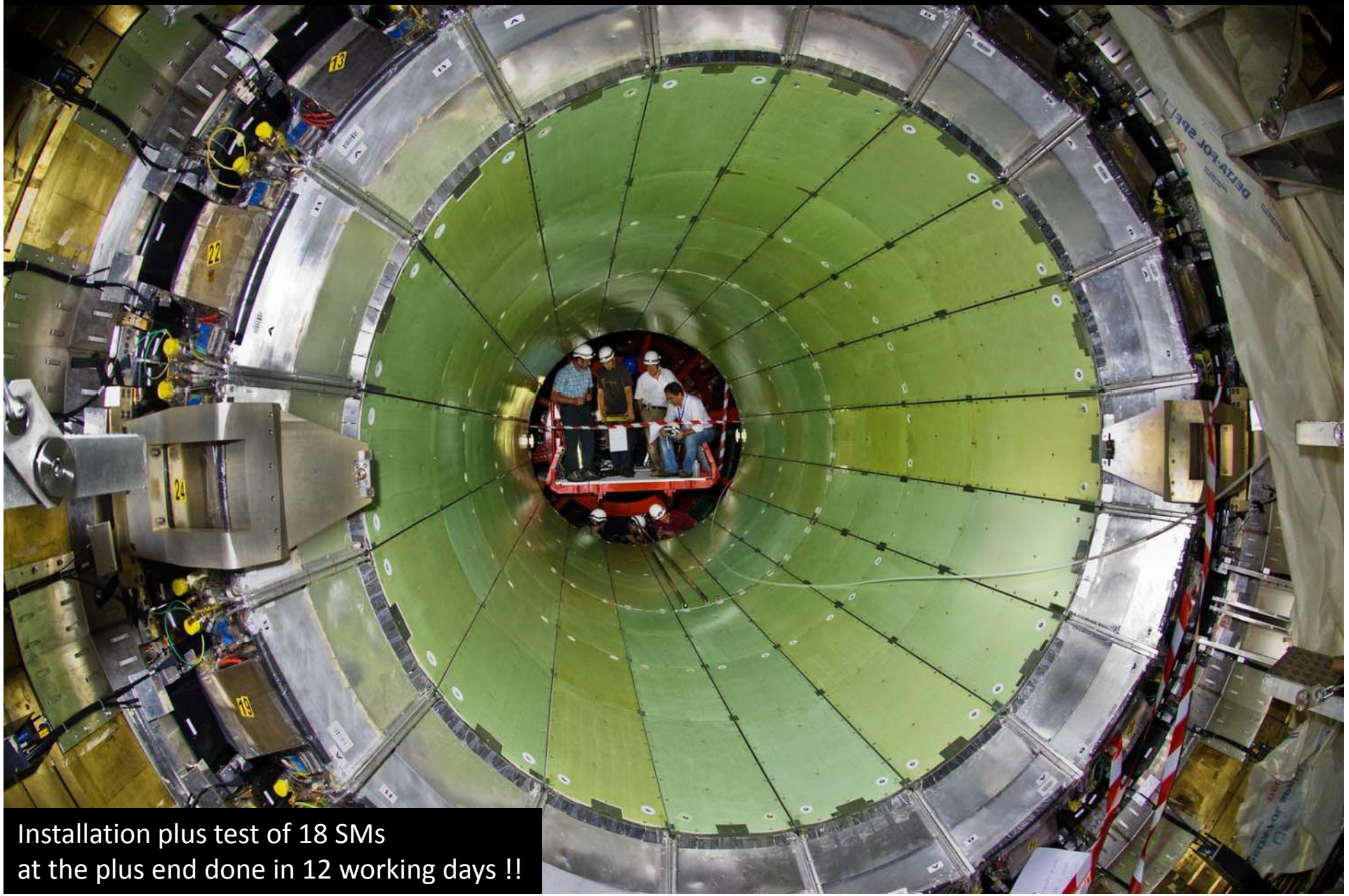


Temperature Stability: ≤ 0.1 °C
Light response stability: ≤ 0.1%

Insertion of Barrel ECAL

ECAL Barrel competed

Jul'07



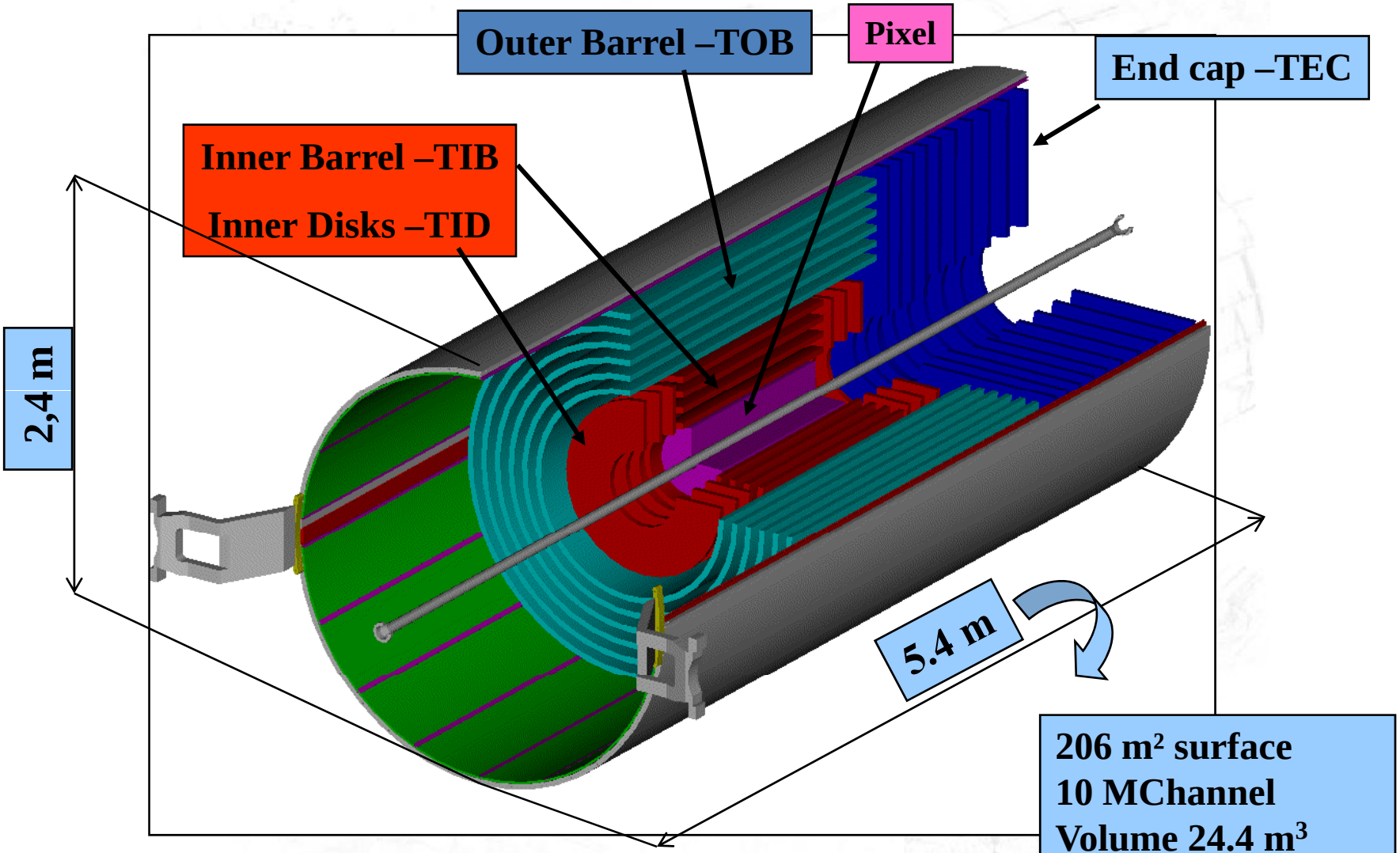
Installation plus test of 18 SMs
at the plus end done in 12 working days !!

66 Million Pixel

10 Million Strips

THE TRACKER

The Inner Tracker of CMS



PIXEL

PIXEL

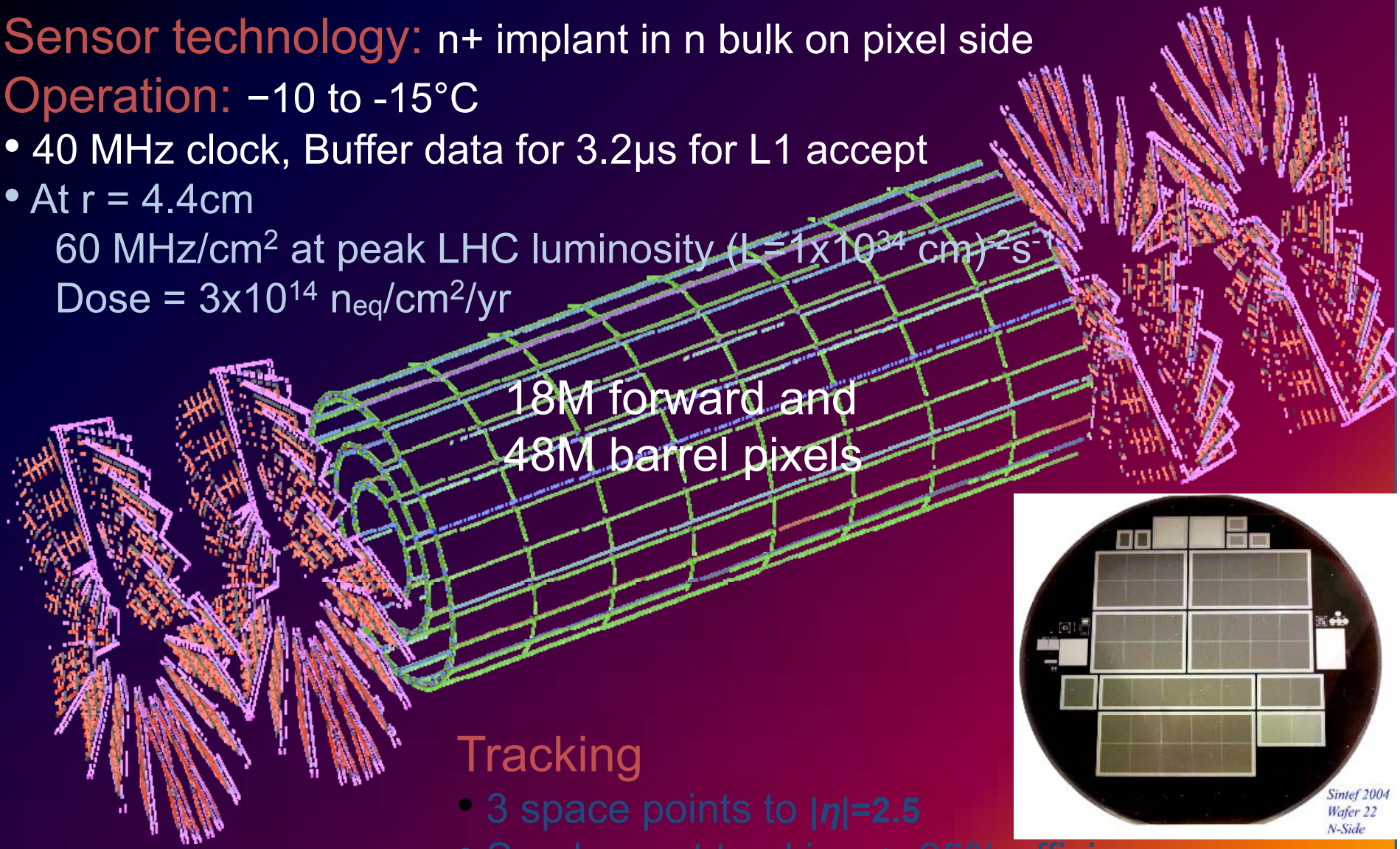
Sensor technology: n+ implant in n bulk on pixel side

Operation: −10 to -15°C

- 40 MHz clock, Buffer data for 3.2μs for L1 accept
- At r = 4.4cm

  60 MHz/cm^2 at peak LHC luminosity ($L=1x10^{34}$ cm)$^{-2}s^{-1}$

  Dose = $3x10^{14}$ n_{eq}/cm^2/yr



18M forward and
48M barrel pixels

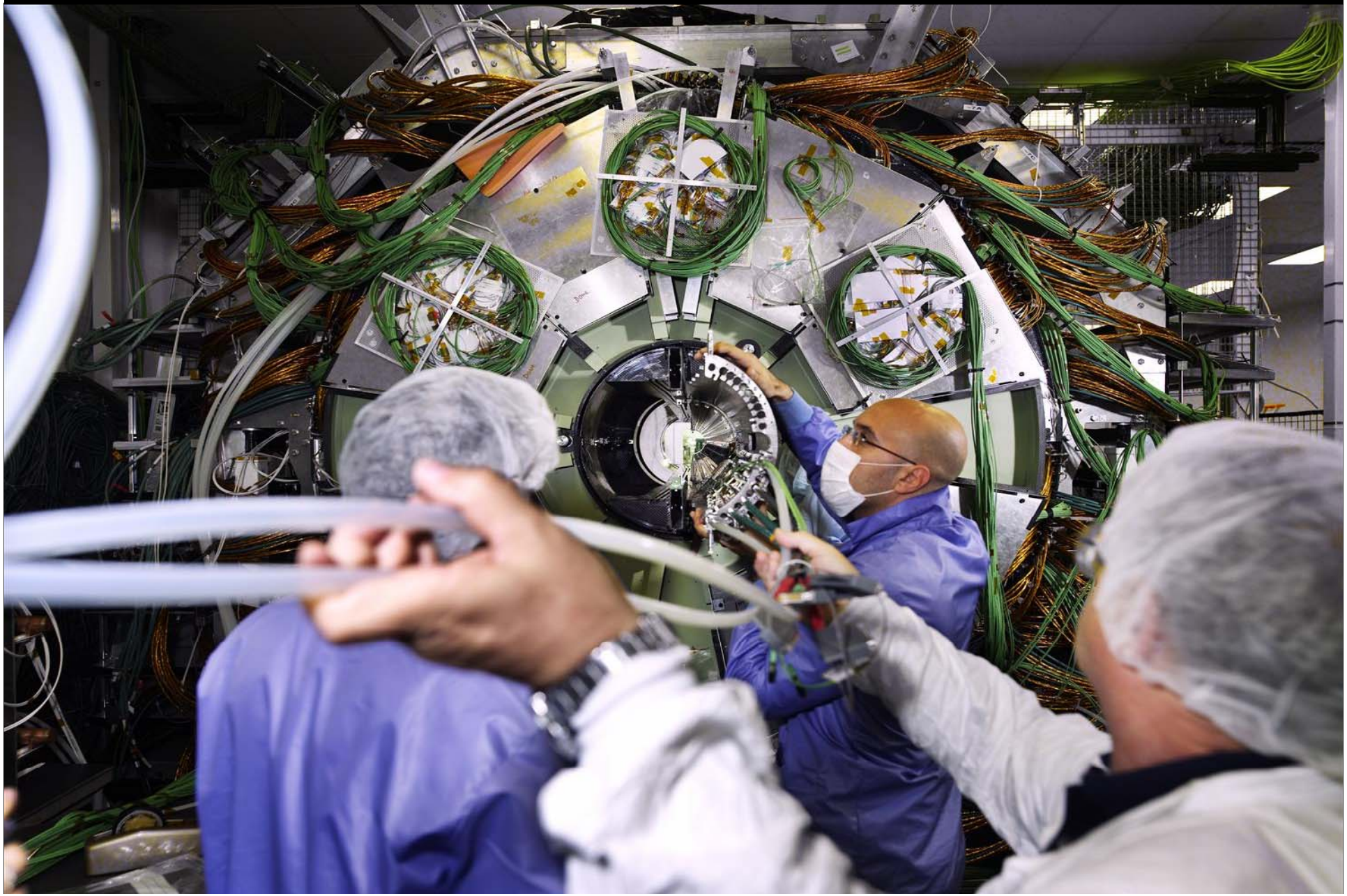
Tracking

- 3 space points to $|\eta|=2.5$
- Seeds most tracking > 95% efficiency
- Vertexing
- Standalone in High Level Trigger (HLT)

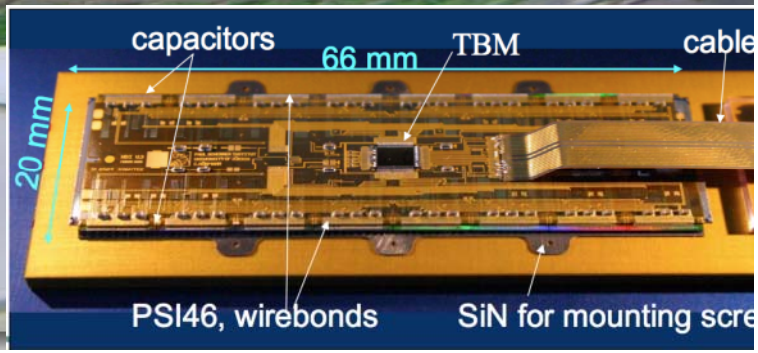
Half disc of Forward Pixels

Forward Pixel: 672 plaquettes required

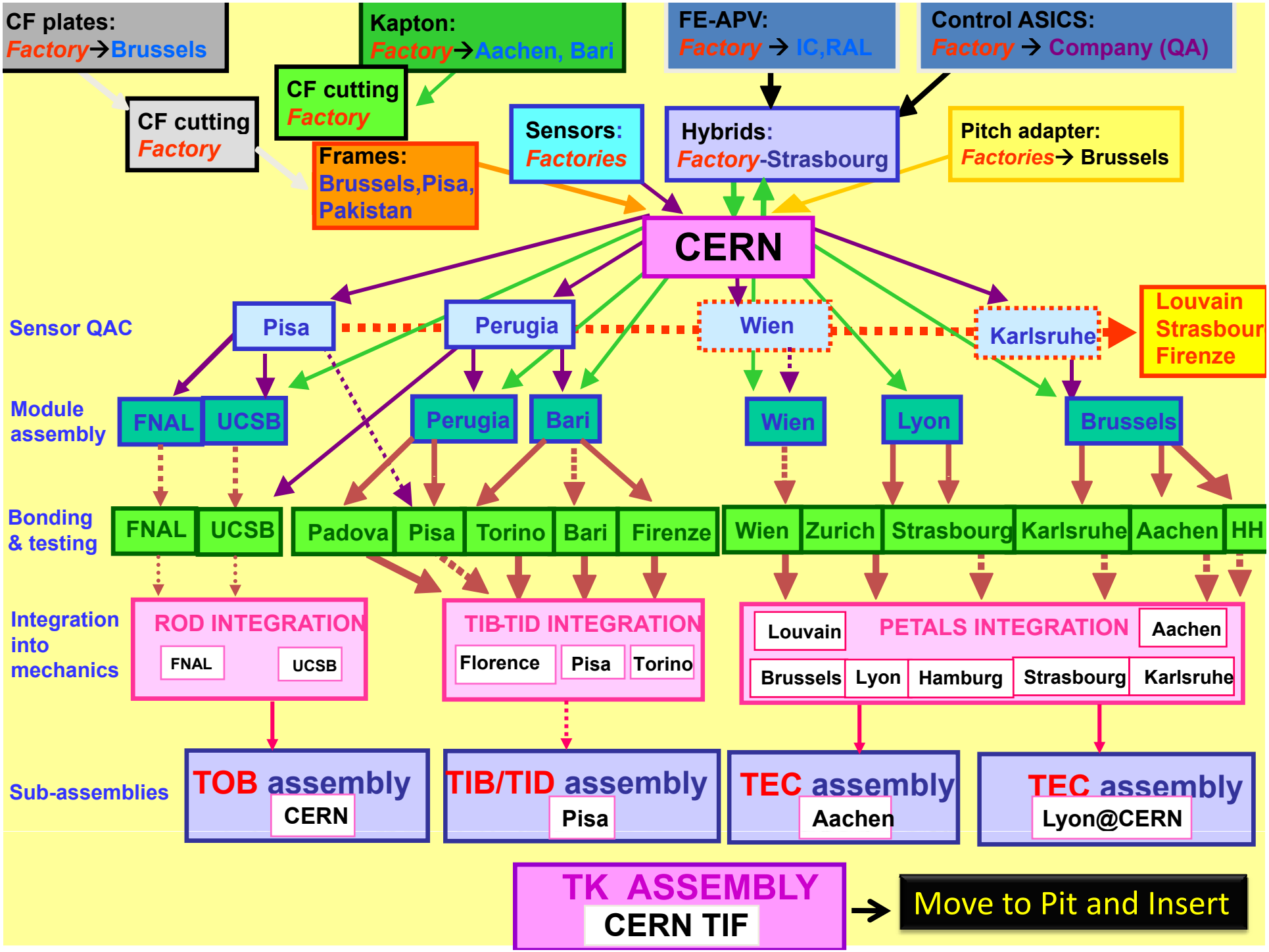
Pixel Test Insertion into Tracker



Pixel Barrel plus Endcaps READY

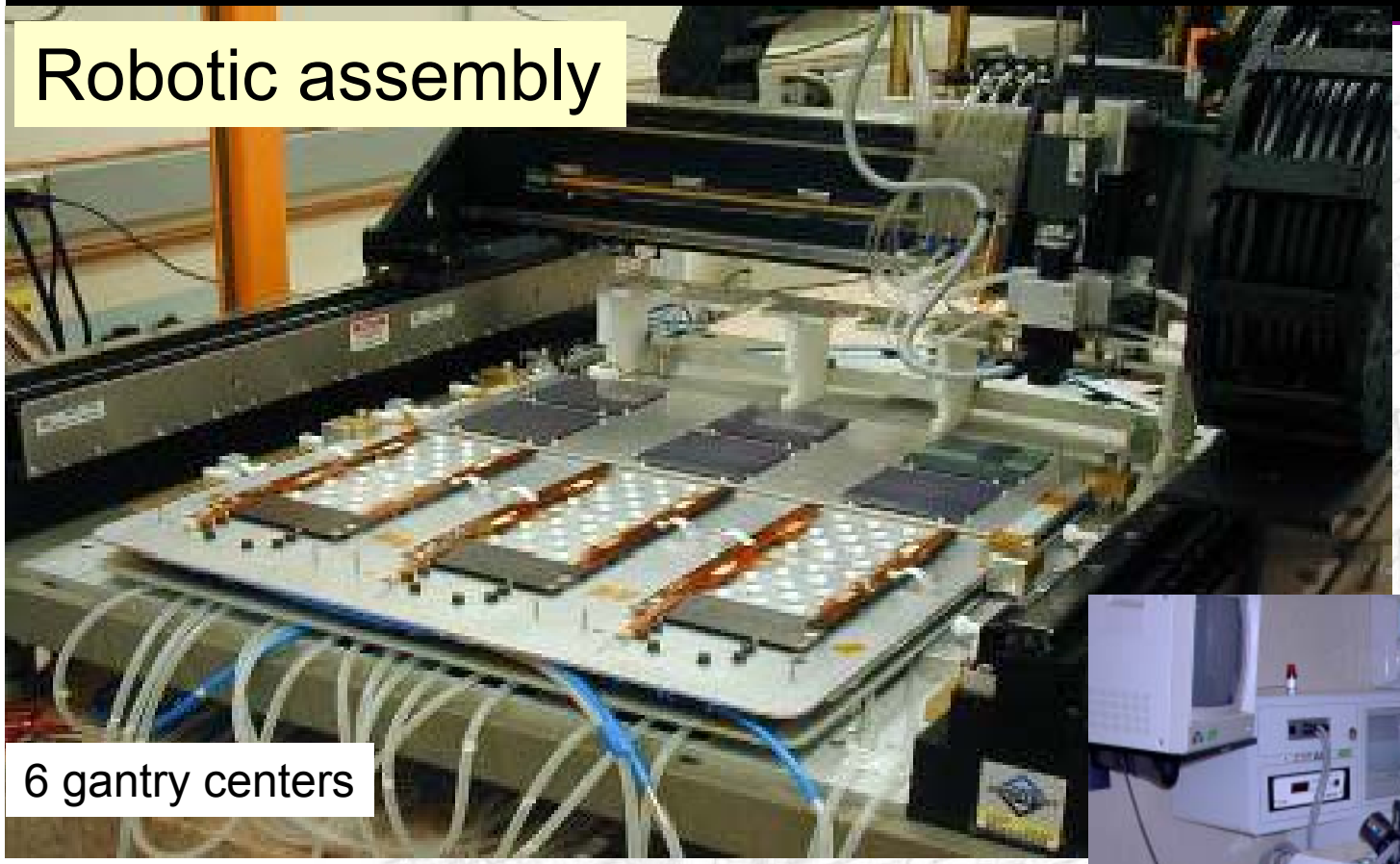


STRIP TRACKER

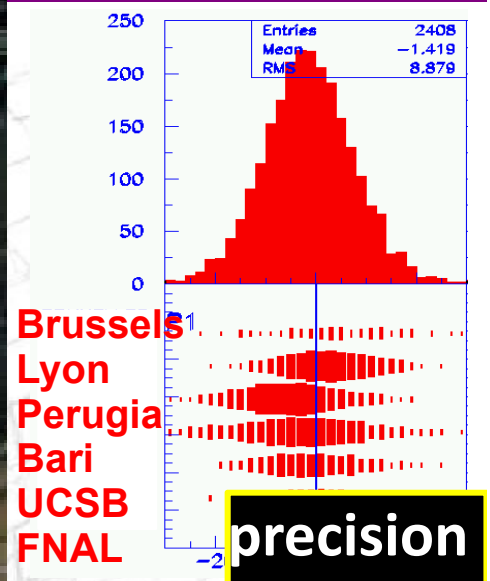

CF plates:
Factory→Brussels
Kapton:
Factory→Aachen, Bari
FE-APV:
Factory → IC,RAL
Control ASICS:
Factory → Company (QA)
CF cutting
Factory
CF cutting
Factory
Frames:
Brussels,Pisa,
Pakistan
Sensors:
Factories
Hybrids:
Factory-Strasbourg
Pitch adapter:
Factories→ Brussels
CERN
Sensor QAC
Pisa
Perugia
Wien
Karlsruhe
Louvain
Strasbour
Firenze
Module
assembly
FNAL
UCSB
Perugia
Bari
Wien
Lyon
Brussels
Bonding
& testing
FNAL
UCSB
Padova
Pisa
Torino
Bari
Firenze
Wien
Zurich
Strasbourg
Karlsruhe
Aachen
HH
Integration
into
mechanics
ROD INTEGRATION
FNAL
UCSB
TIB-TID INTEGRATION
Florence
Pisa
Torino
PETALS INTEGRATION
Louvain
Aachen
Brussels
Lyon
Hamburg
Strasbourg
Karlsruhe
Sub-assemblies
TOB assembly
CERN
TIB/TID assembly
Pisa
TEC assembly
Aachen
TEC assembly
Lyon@CERN
TK ASSEMBLY
CERN TIF
Move to Pit and Insert

Module Production and Test

Robotic assembly



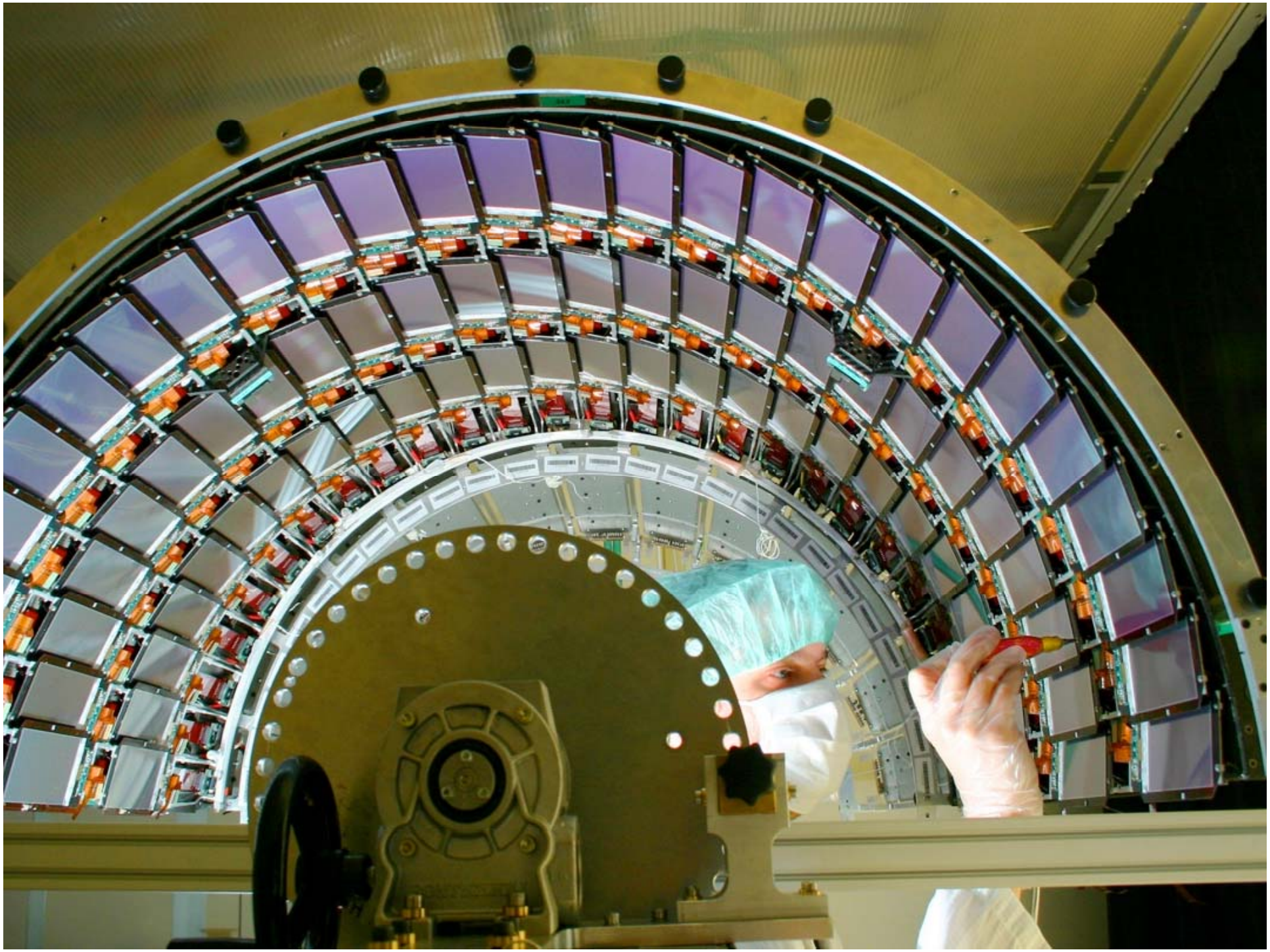
6 gantry centers

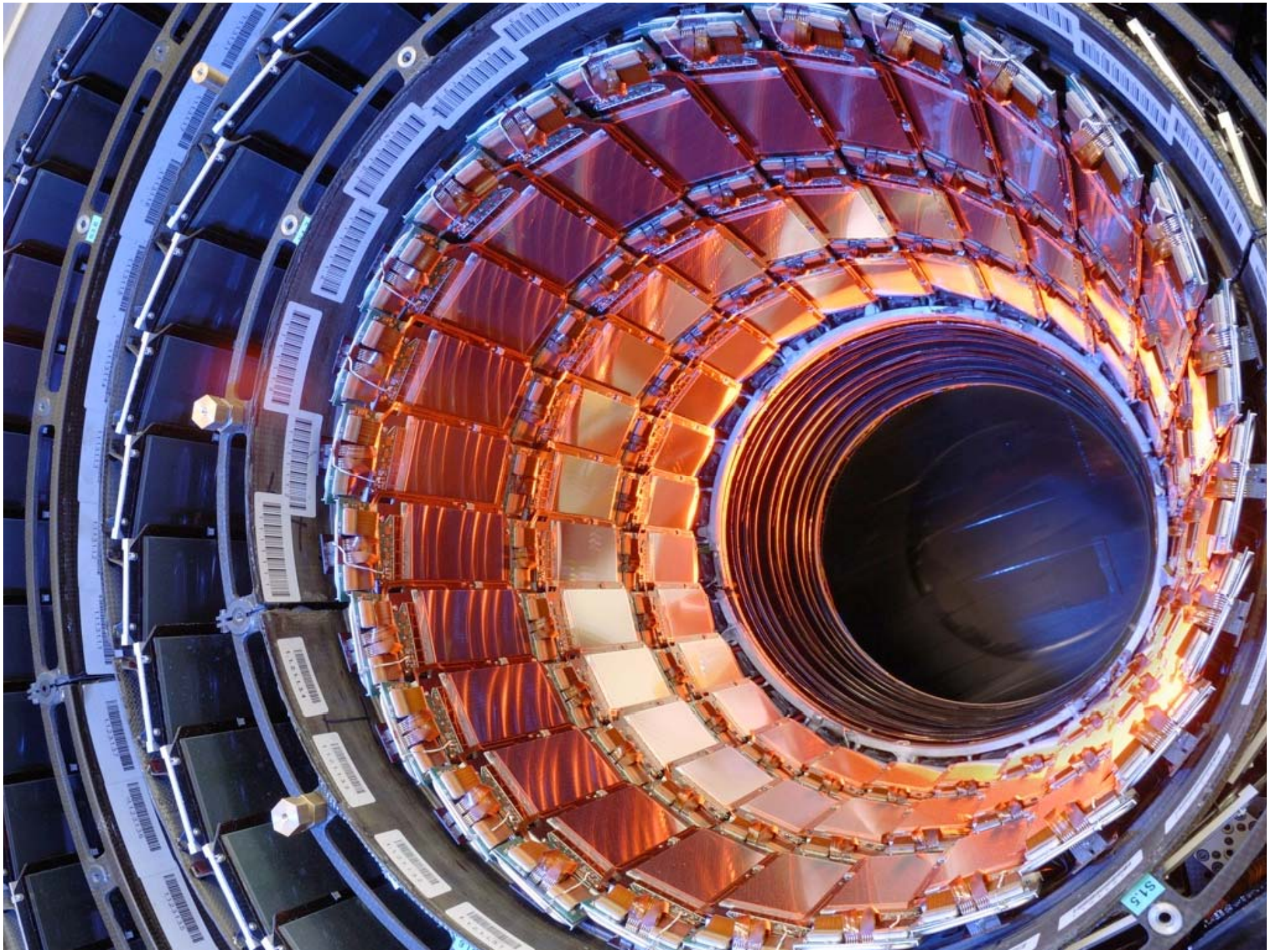


precision
$\sigma \approx 9\mu m$

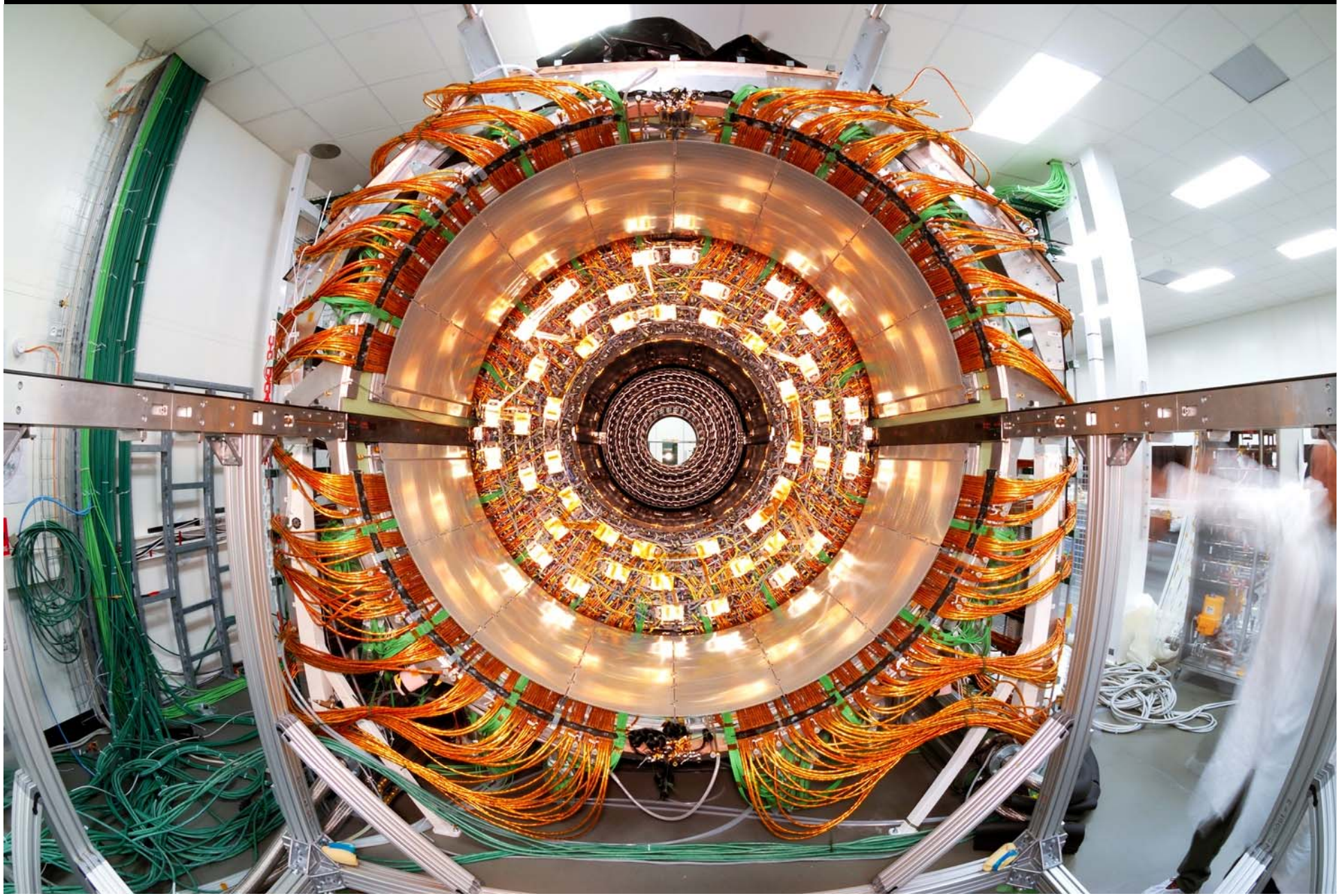
13 bonding centers

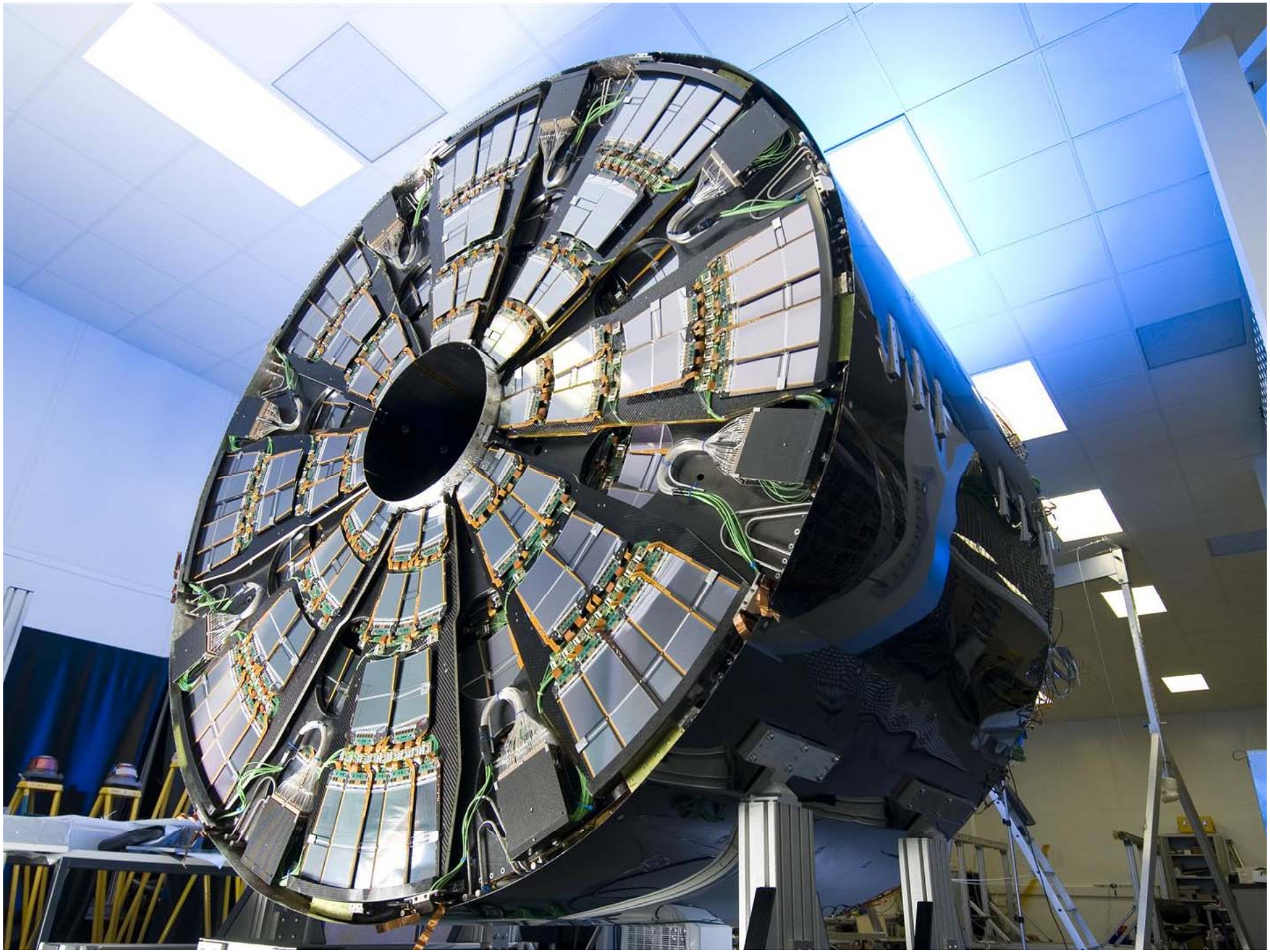
400 Different Pieces Makes one Petal, a Fairly Complicated Object: We needed 288 in total! We assembled 110 in Karlsruhe



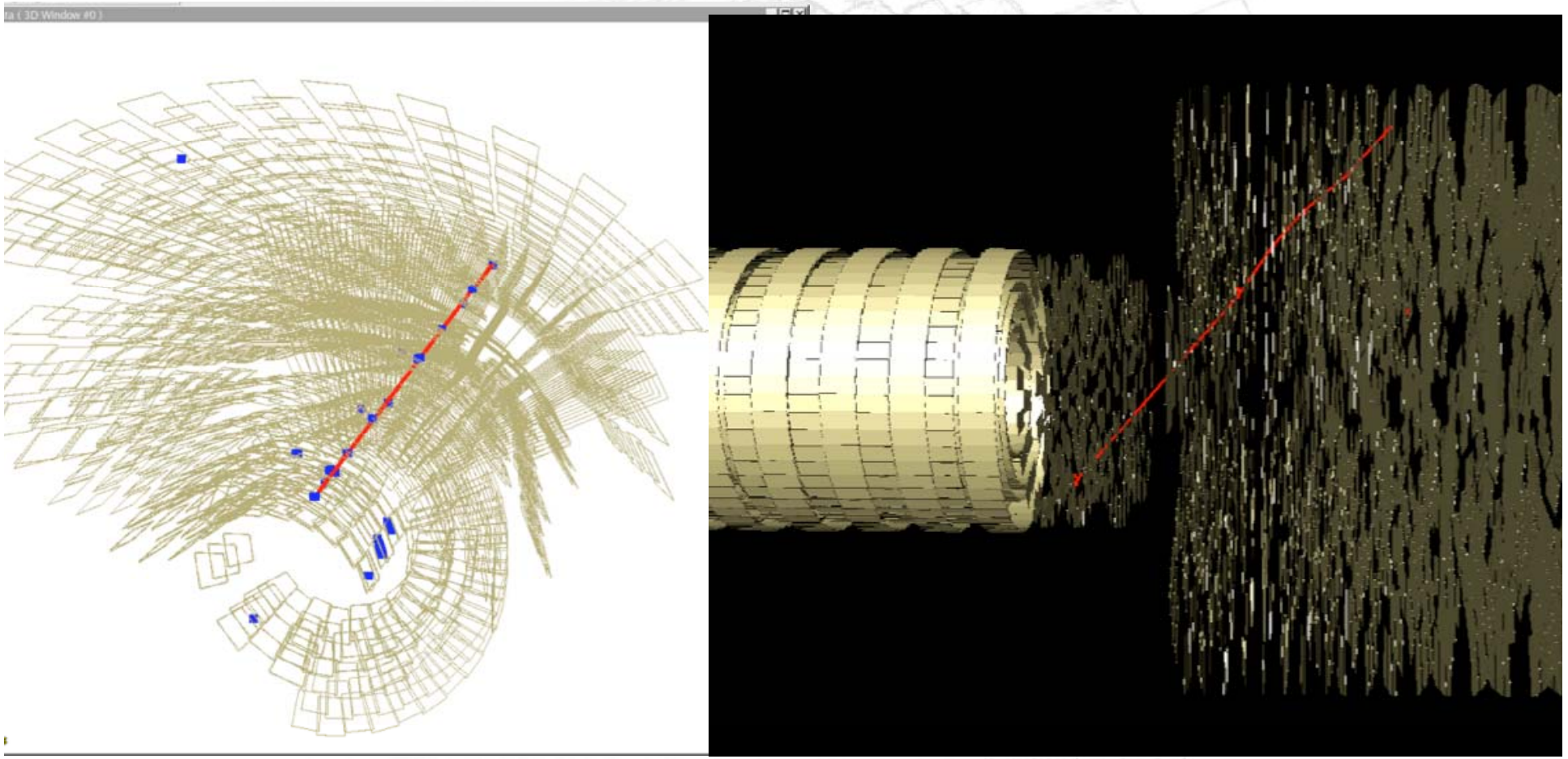


Si Tracker

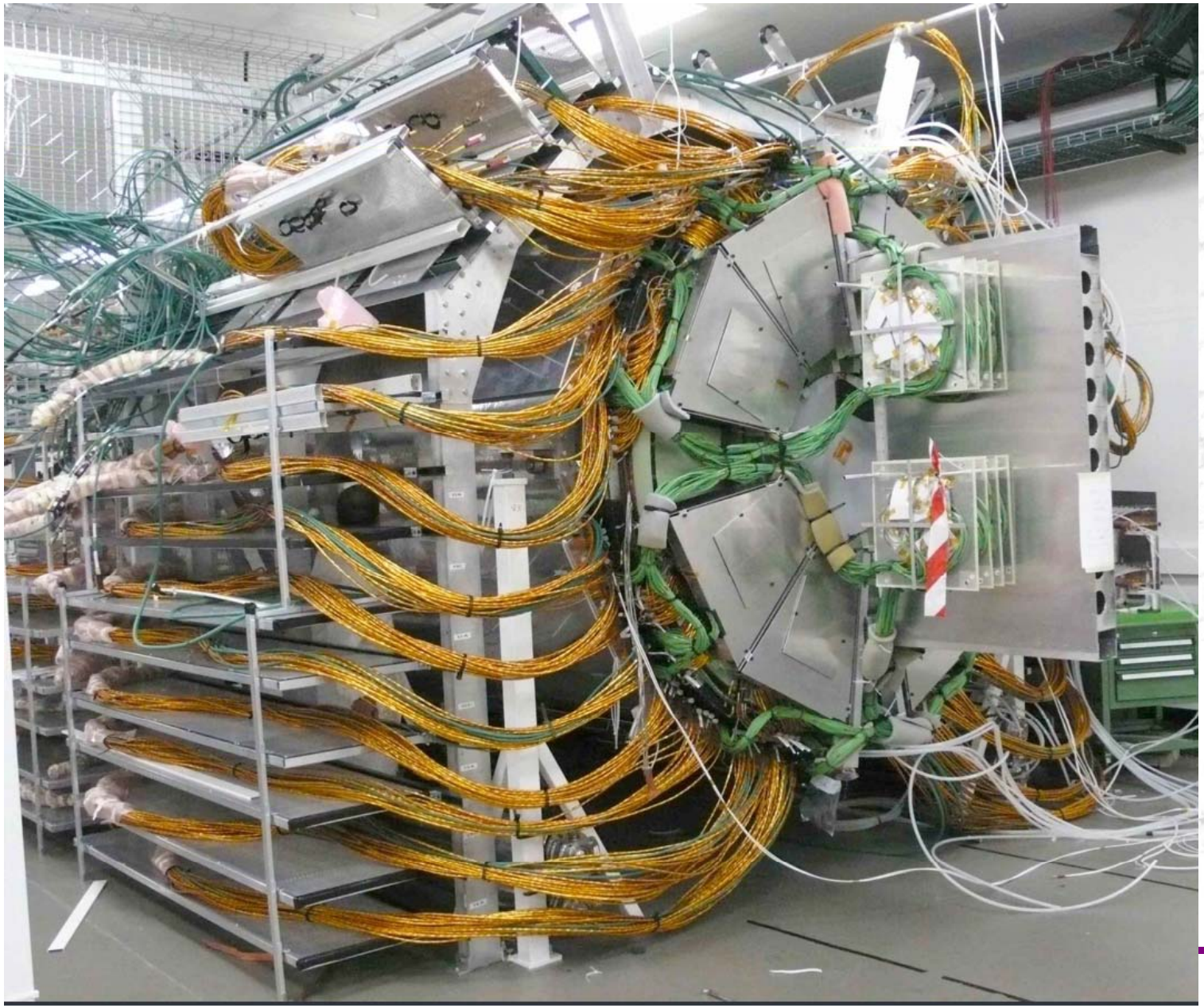




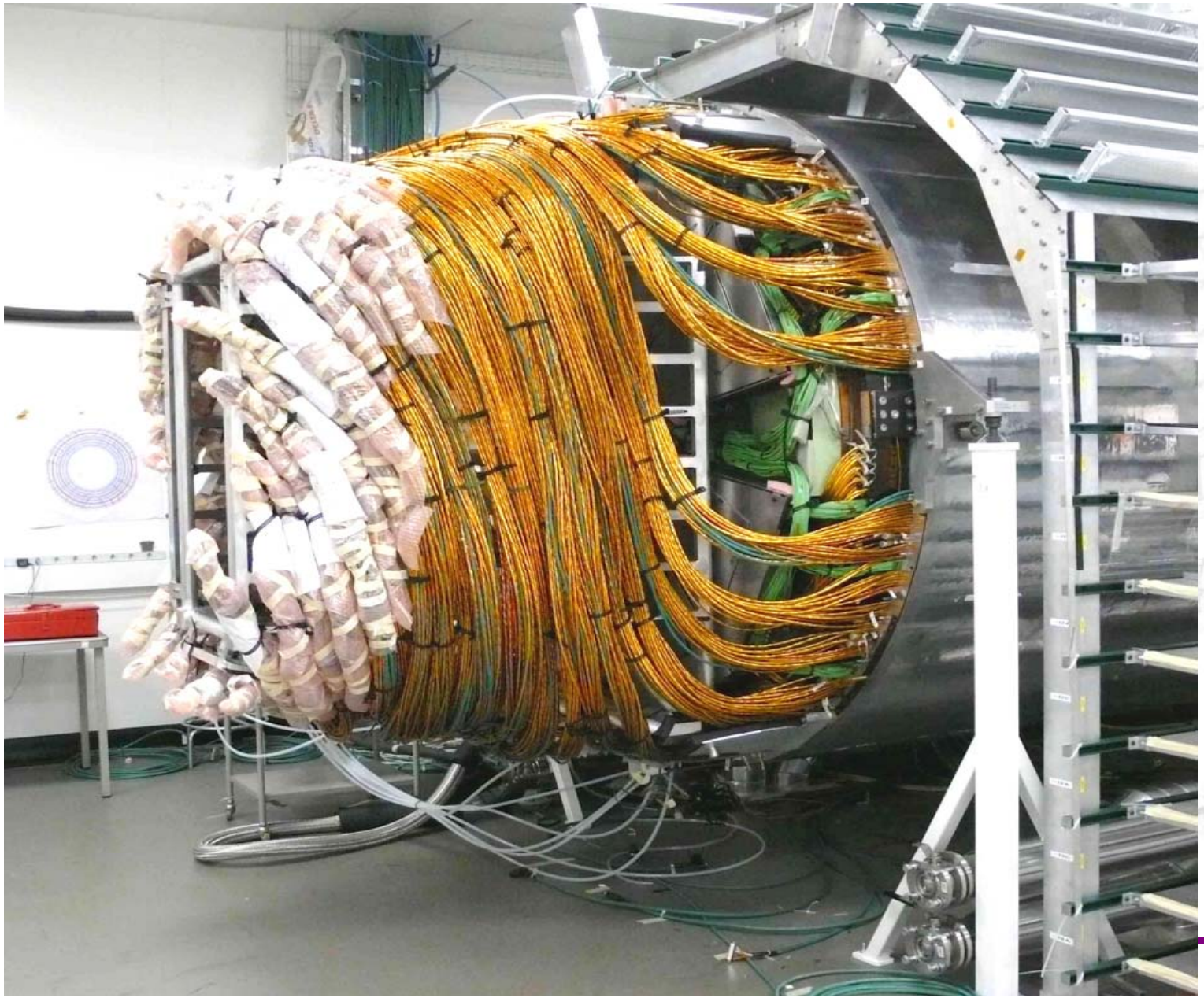
Reconstructed Cosmic Ray Tracks



Optical Fibres Dressed onto the +End of the Tracker



Multiservice Cables Dressed



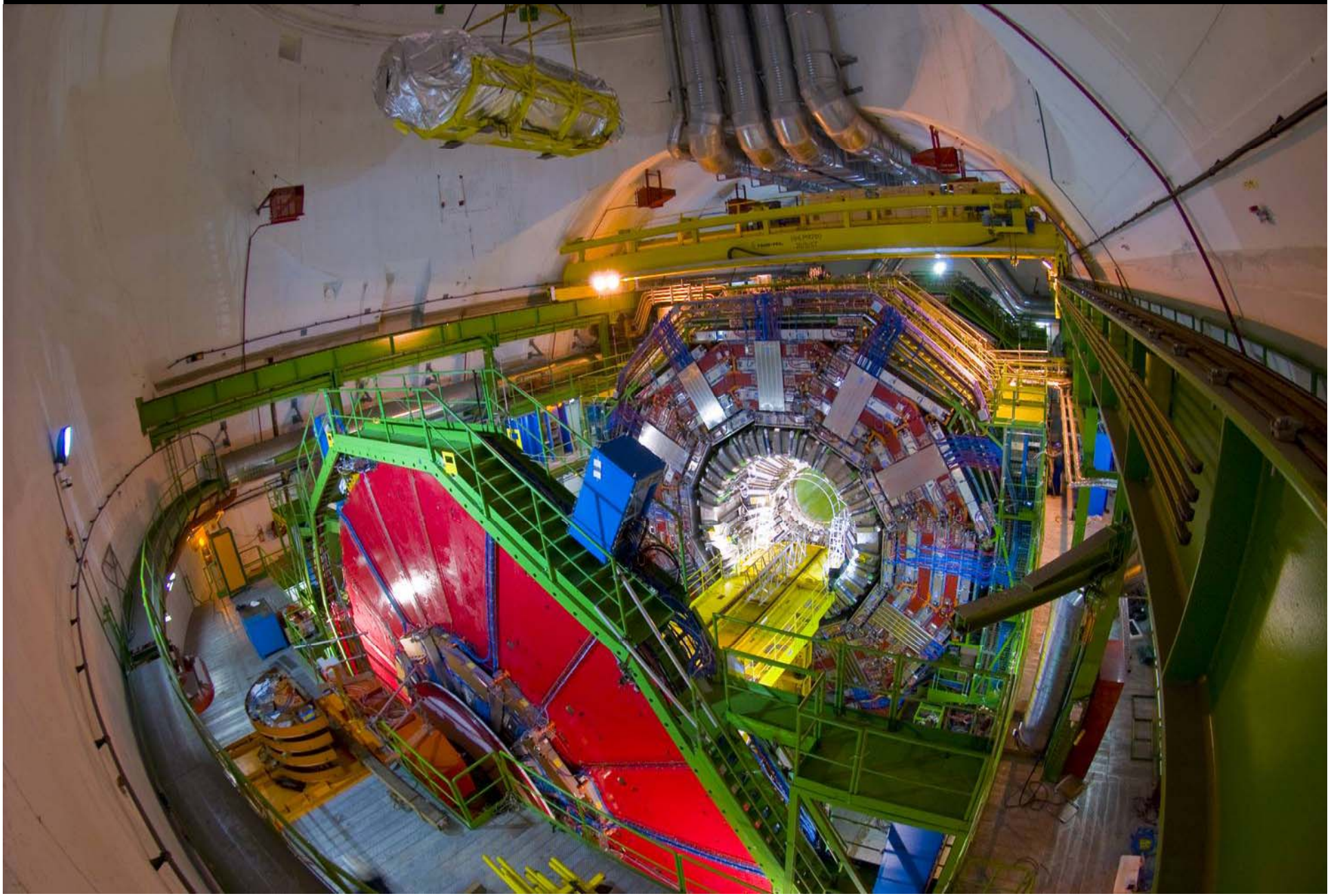
Tracker on the Way Down

- 6.5 tons
- 100 MCHF
- 2000 man years
- 100 m deep shaft below
- Not insured ;-)

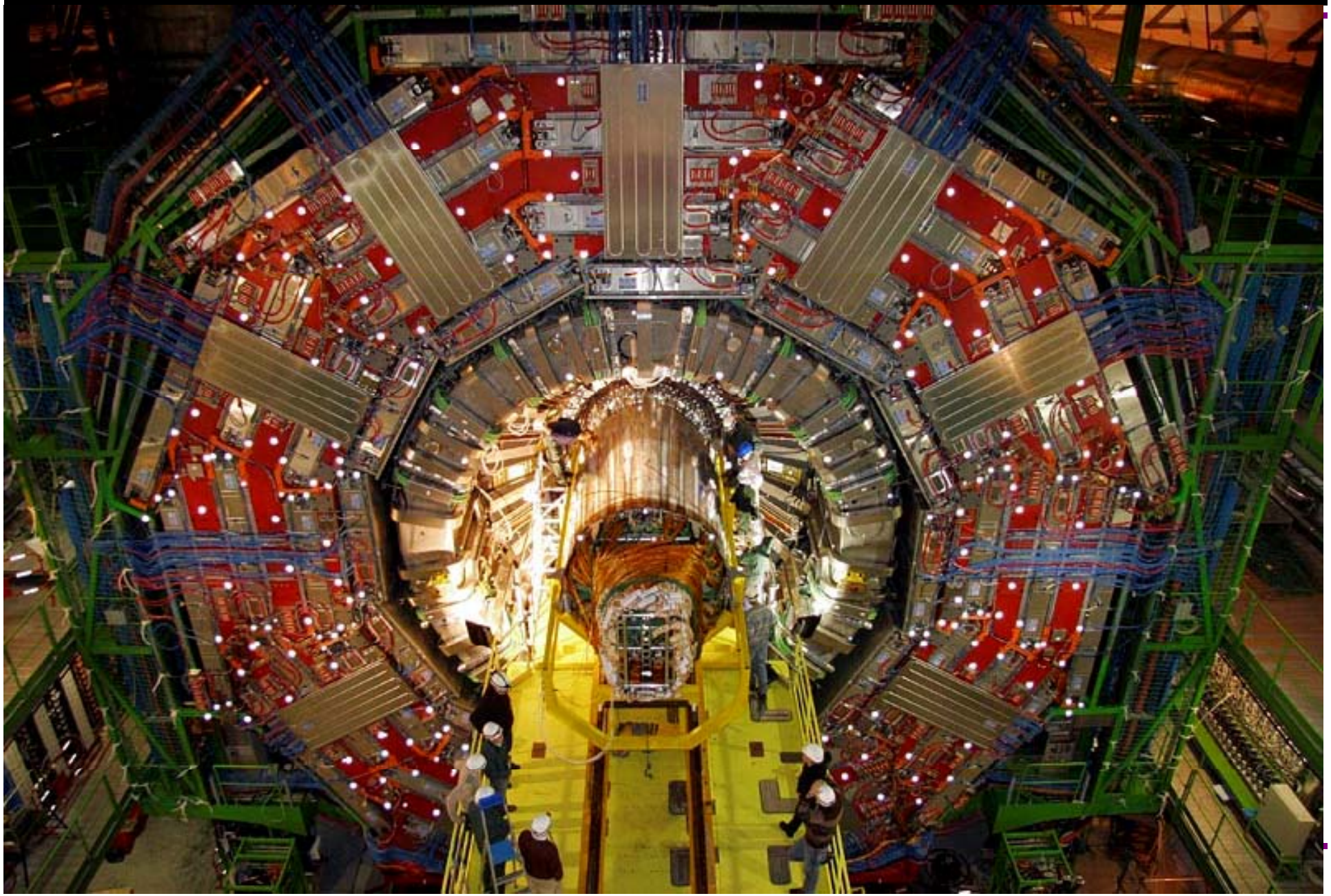
On the hook!

- Several frightened physicists, including me!

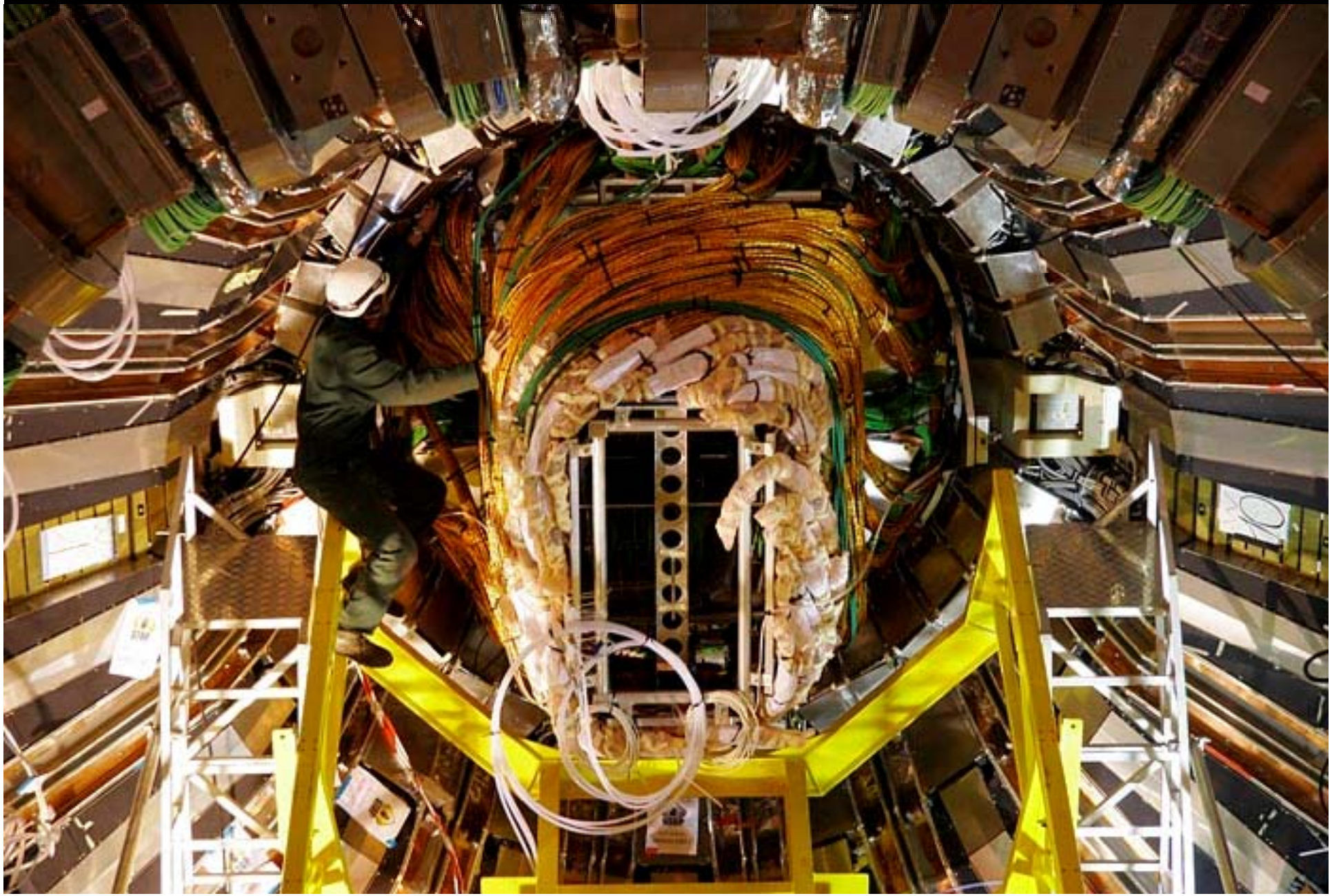
FLY IN



Insertion of the CMS Tracker into the Heart of CMS

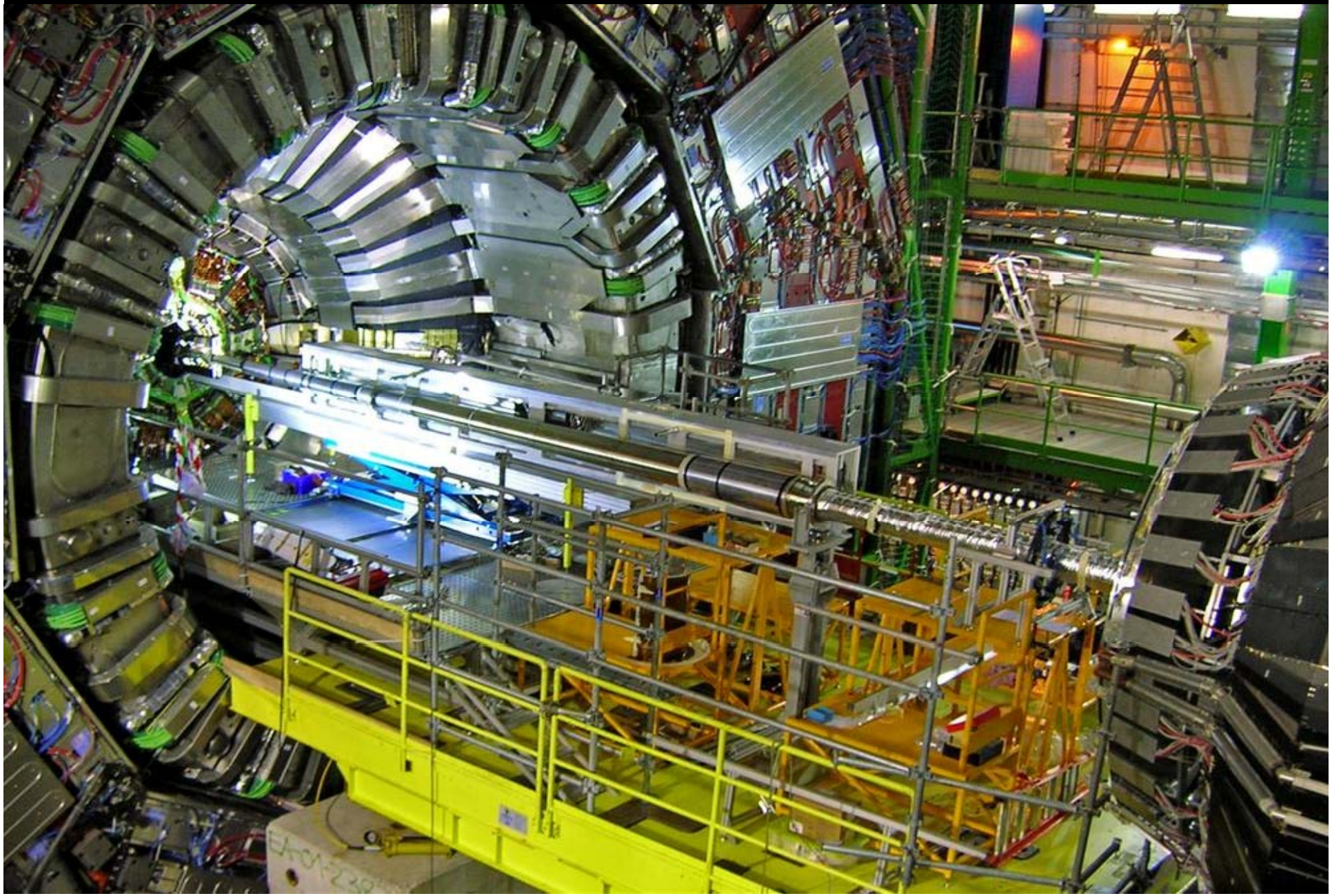


DONE, TRACKER IS IN(Sunday 15.12. 01.30)

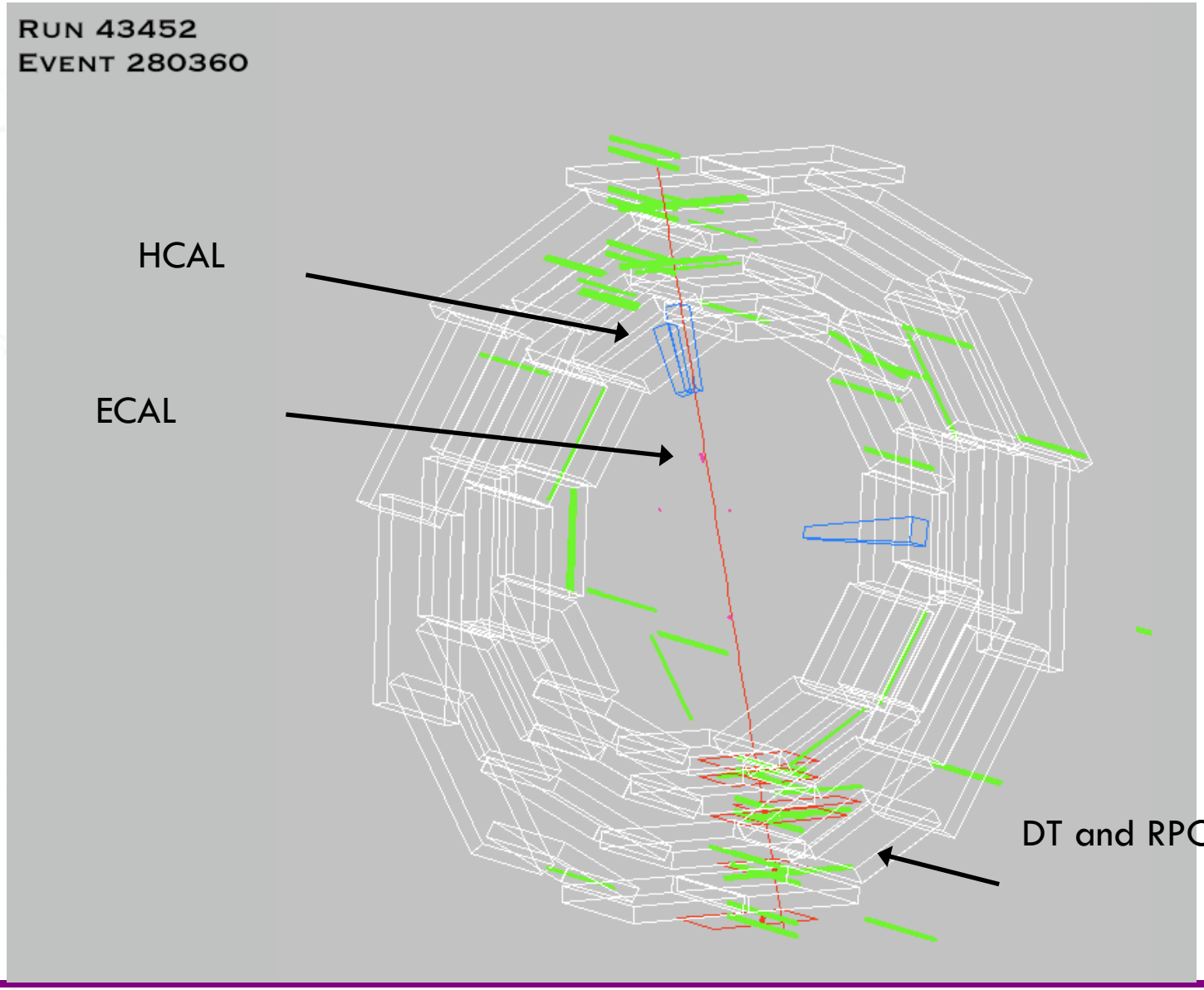


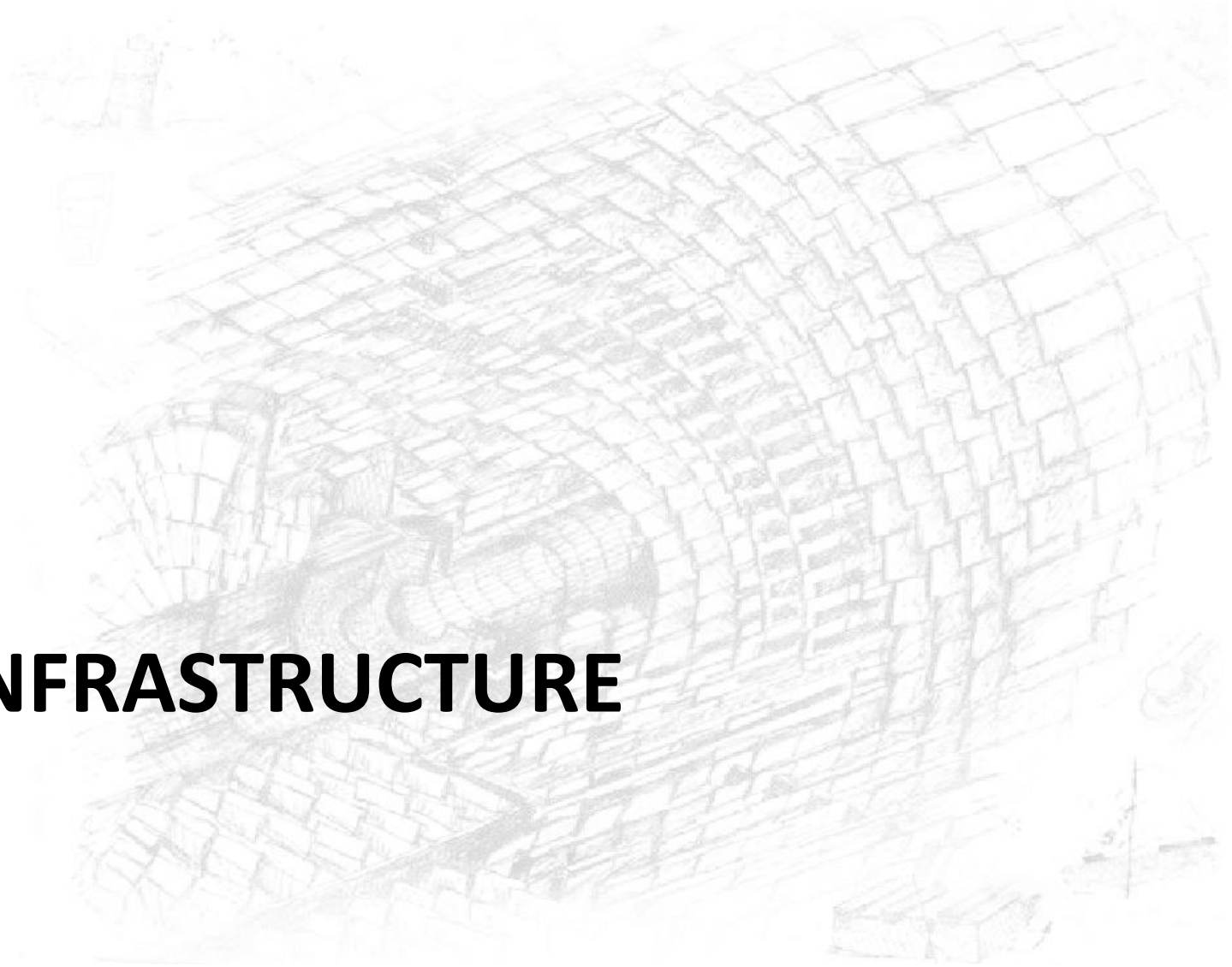
LAST PIECES

Beampipe



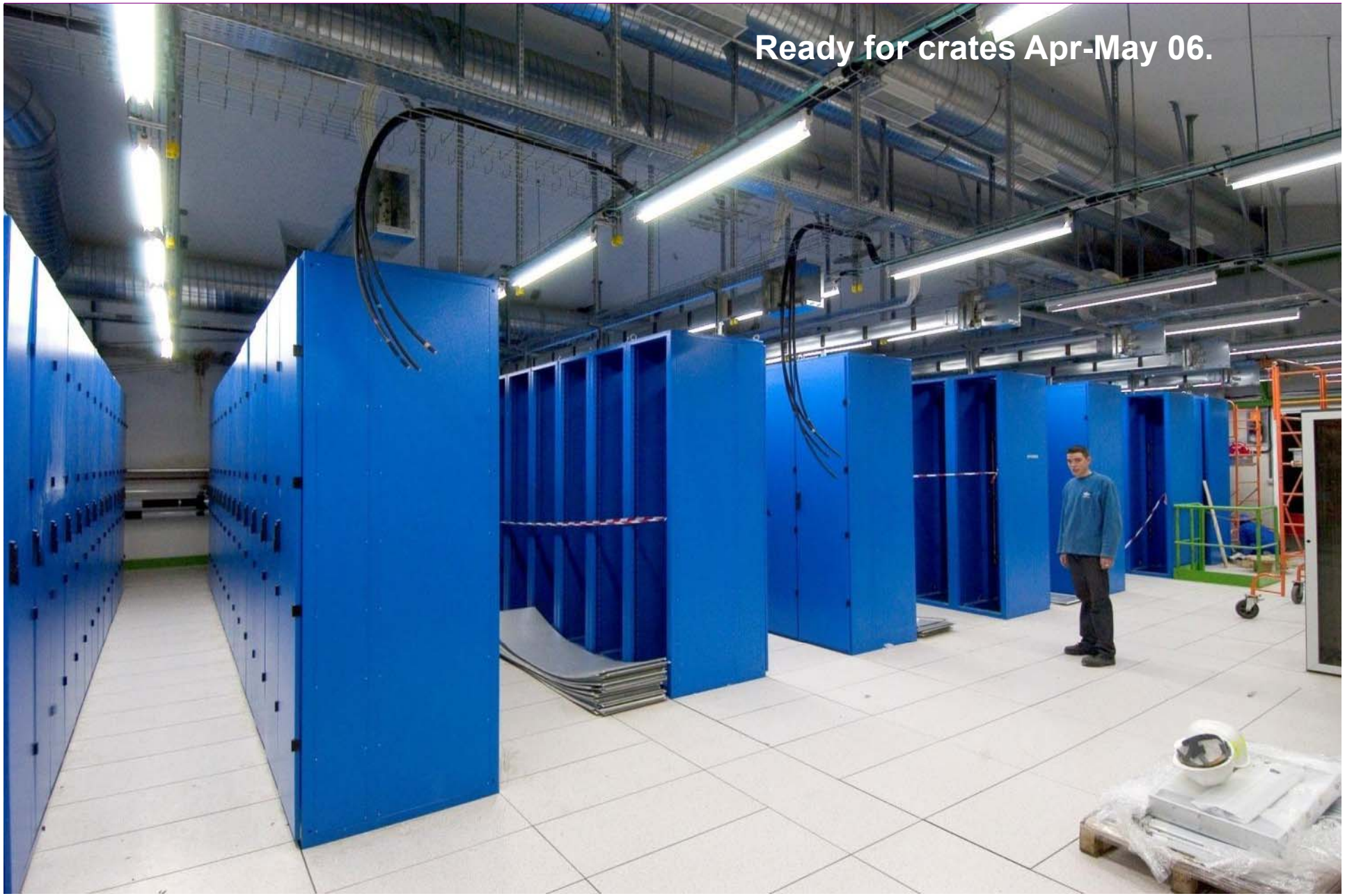
CRUZET: Cosmic Muon





INFRASTRUCTURE

Civil Engineering Overview (mid 2006)



and today …

Slides and pictures „borrowed“ from

- CMS Outreach
- CMS Week Plenaries, mostly Virdee and Ball
- Tracker slides from myself, M.Krammer & J, Incandela
- Thx to M. Hoch for nice actual Tracker Photos