CMS as an example

Putting everything we learned together

Design a real detector

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

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?

(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)**

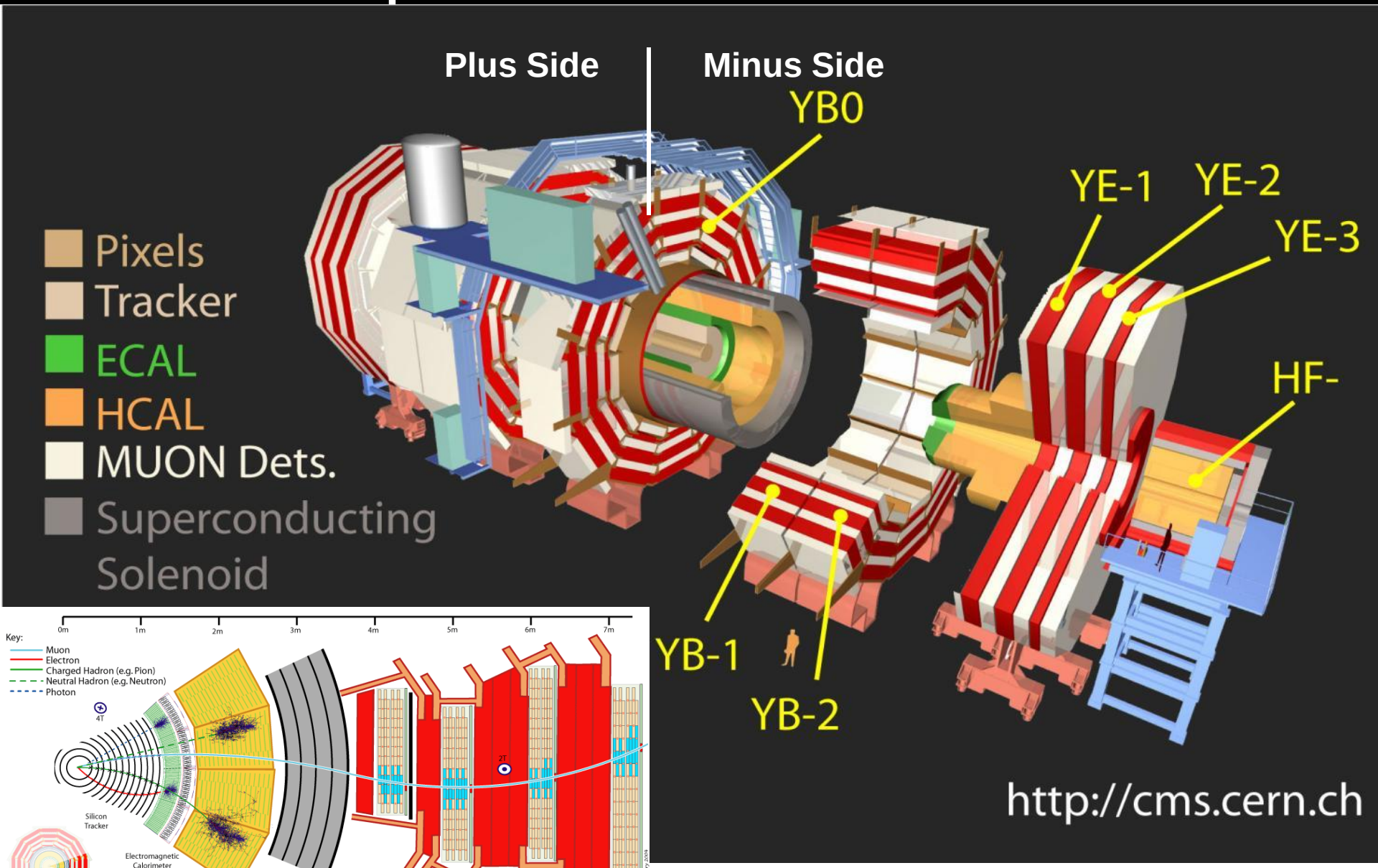
Large Particle Multiplicity

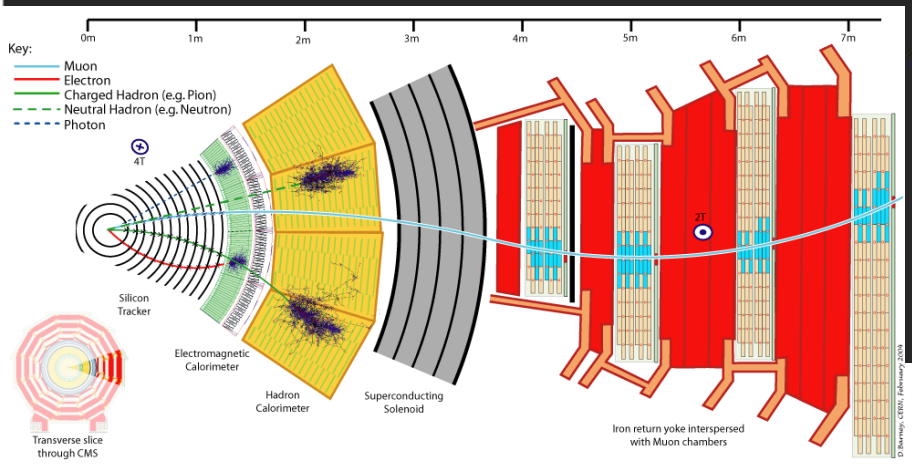
~ <20> superposed events in each crossing
~ 1000 tracks stream into the detector every 25 ns
need highly granular detectors with good time resolution for low occupancy
⇨ **large number of channels (~ 100 M ch)**

High Radiation Levels

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

Exploded View of CMS



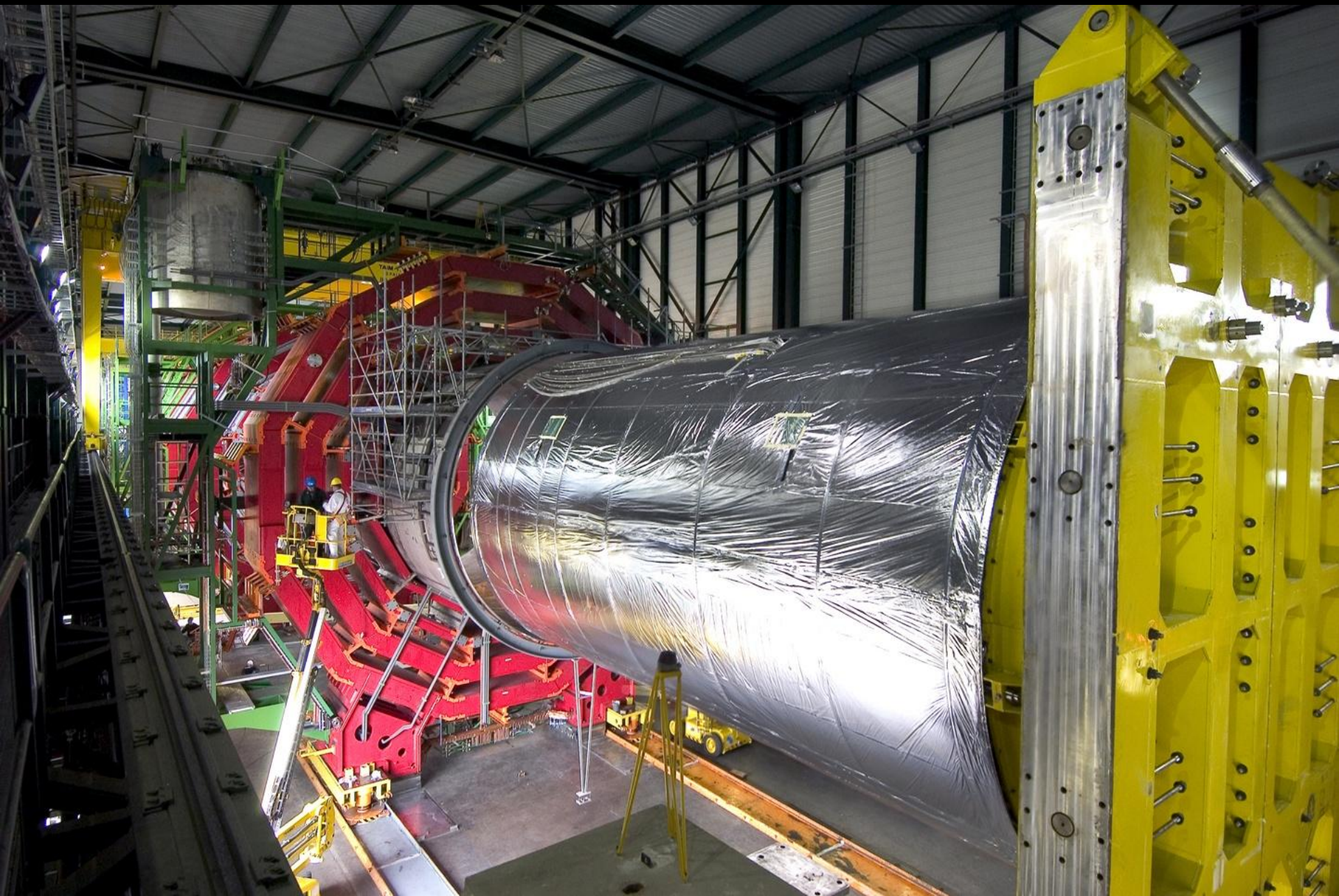


CMS Site at Point 5 (Cessy) in 2000

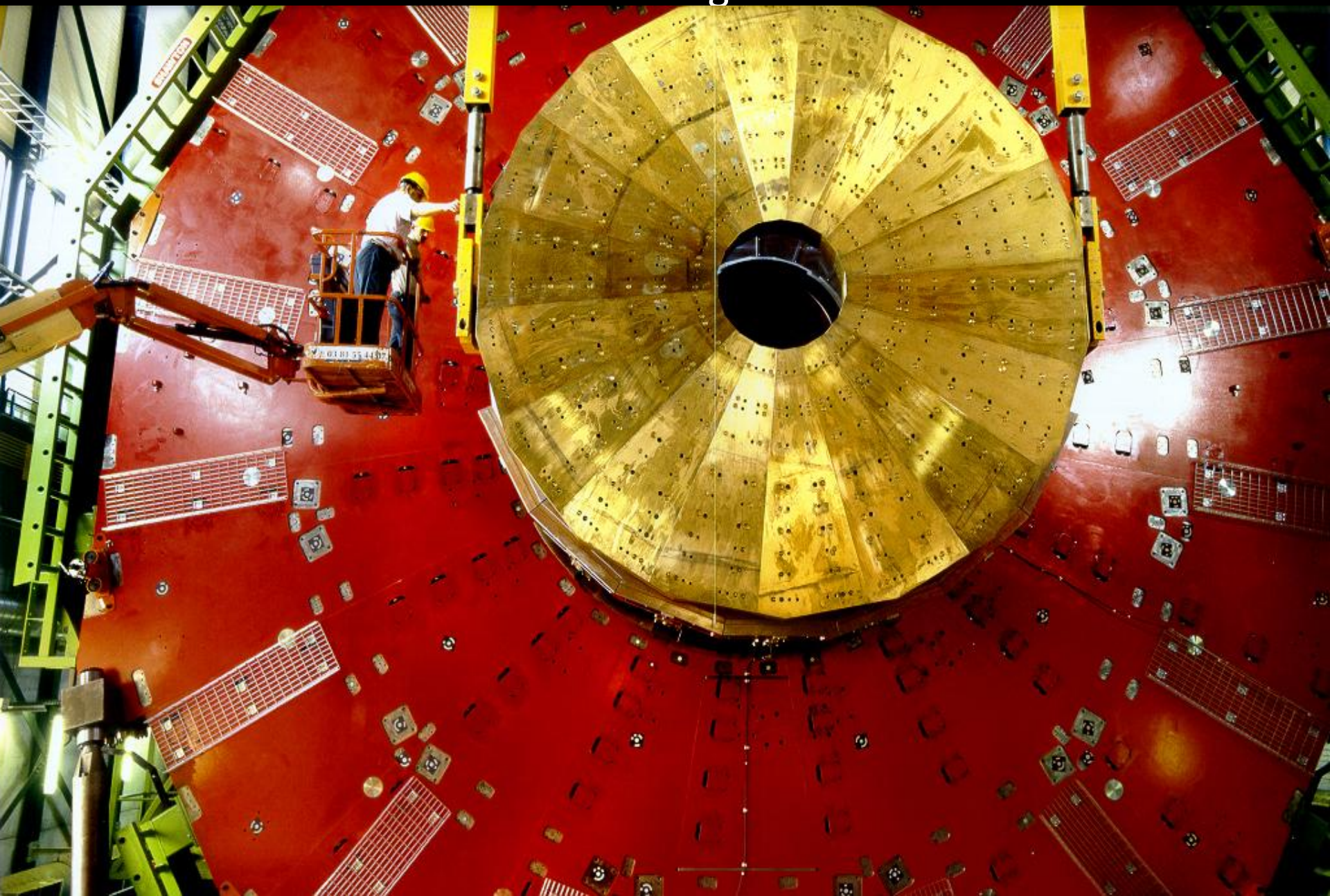
Hm, that‘s when I started with CMS!

Assembly of Iron Yoke

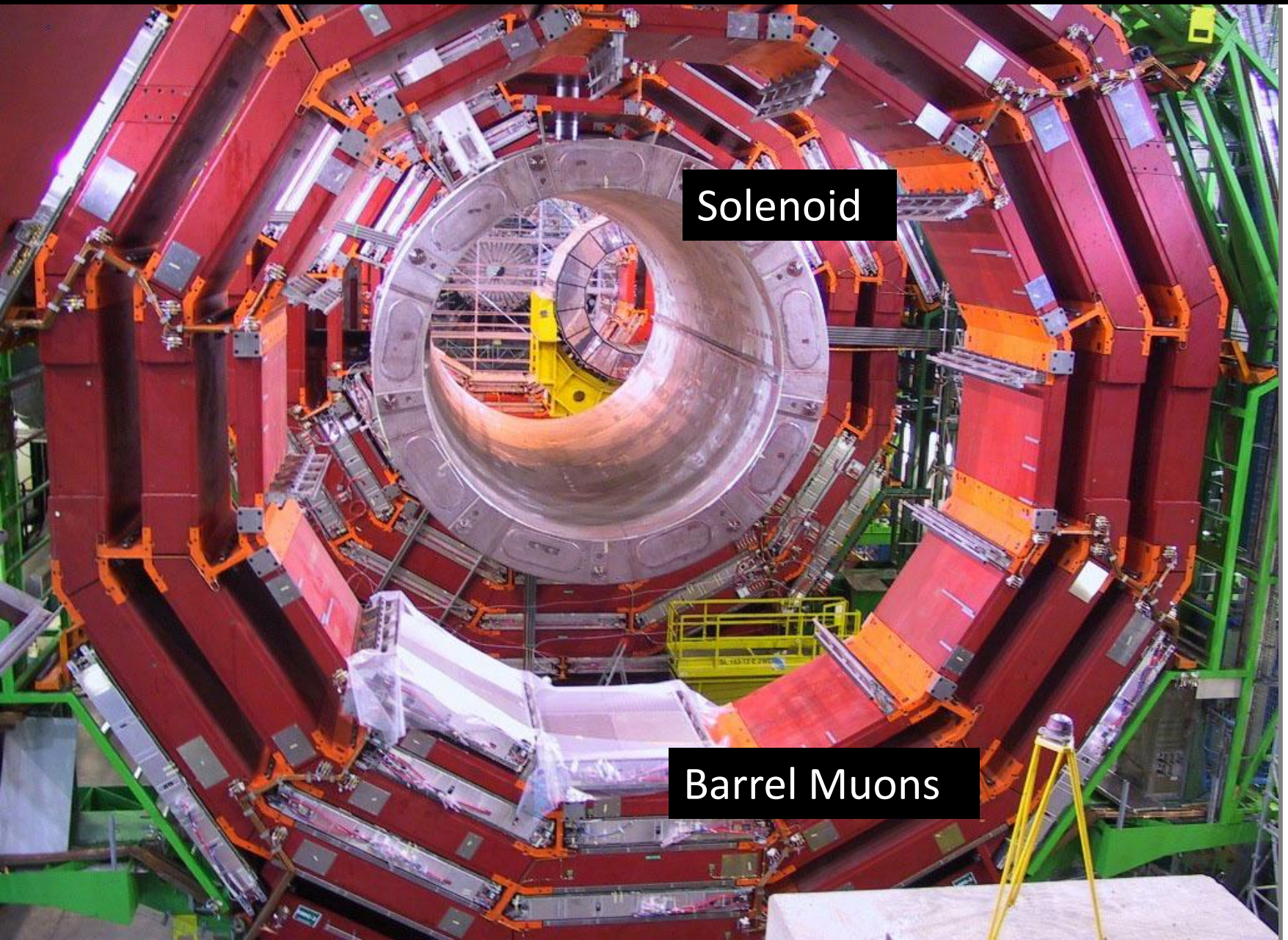
Swiveling of the Coil



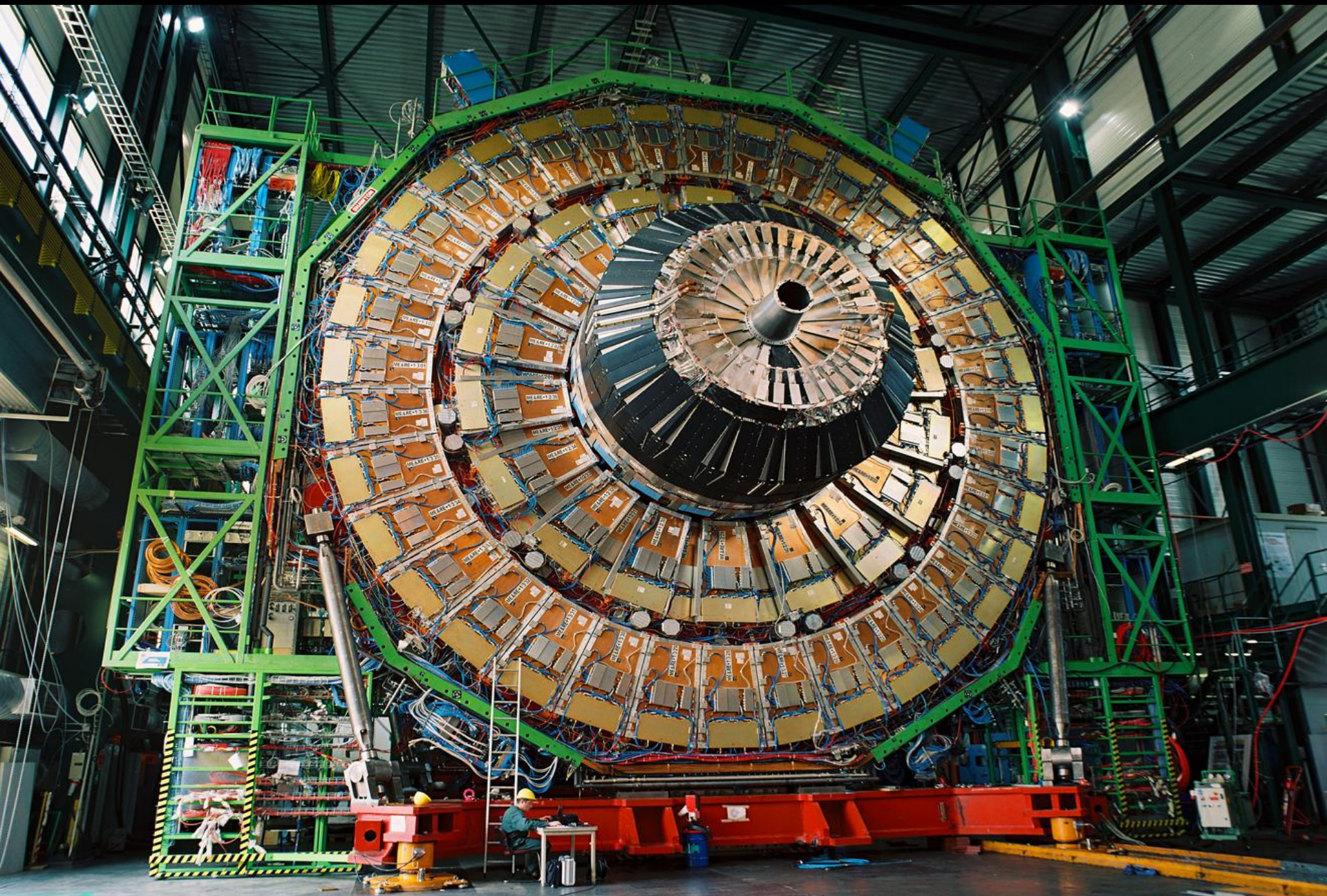
HCAL Endcap
Swords to Ploughshares !



CMS Surface Hall in Feb 2006



Surface Hall: Endcaps



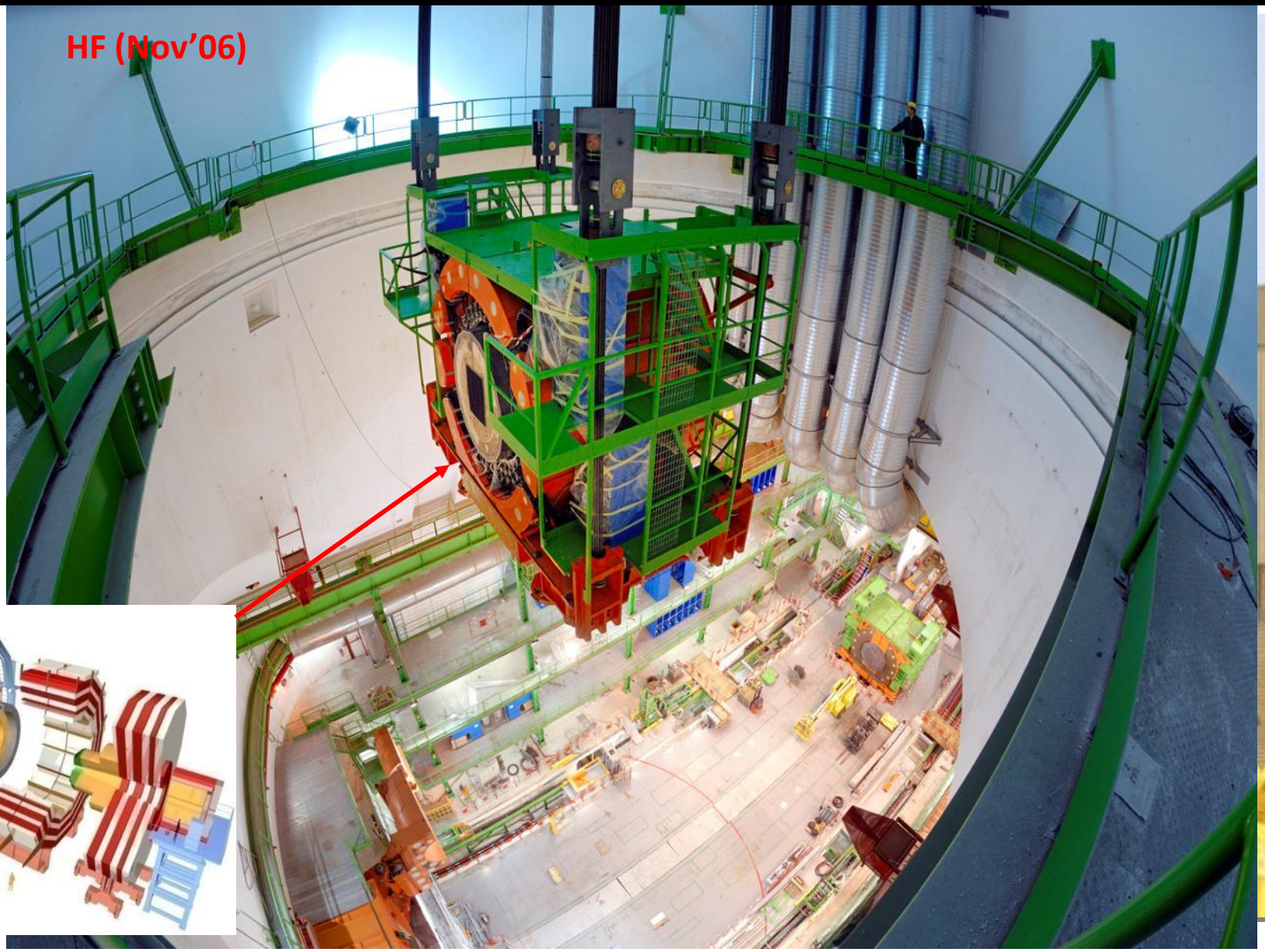
Closing CMS for the First Time – July 2006

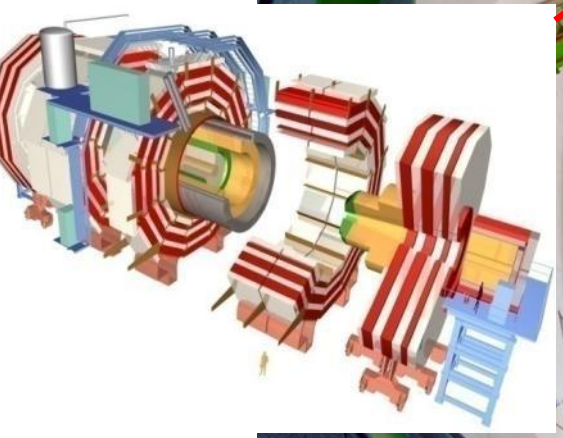
Experiment Cavern

2003

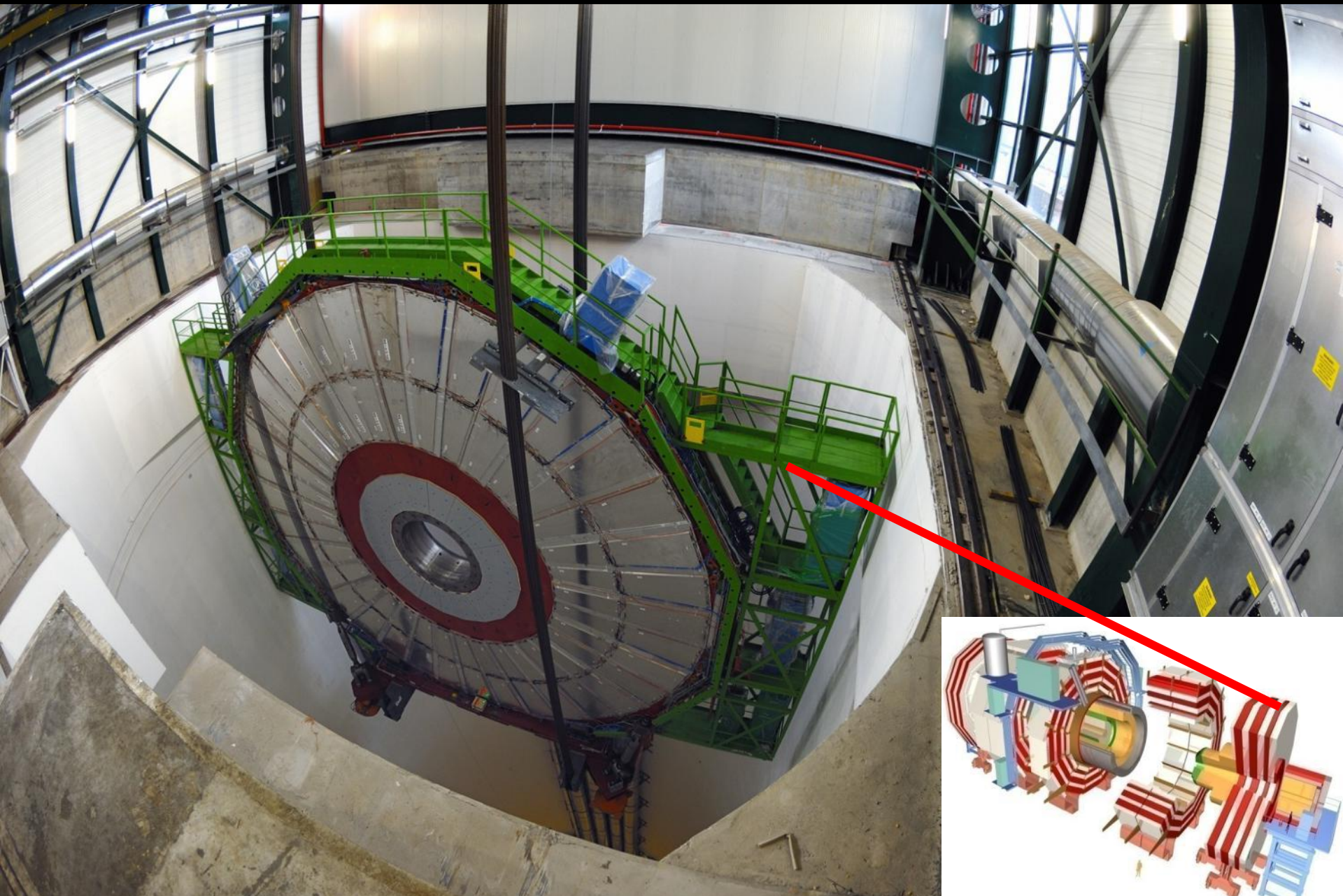
2004

Lowering of Heavy Elements

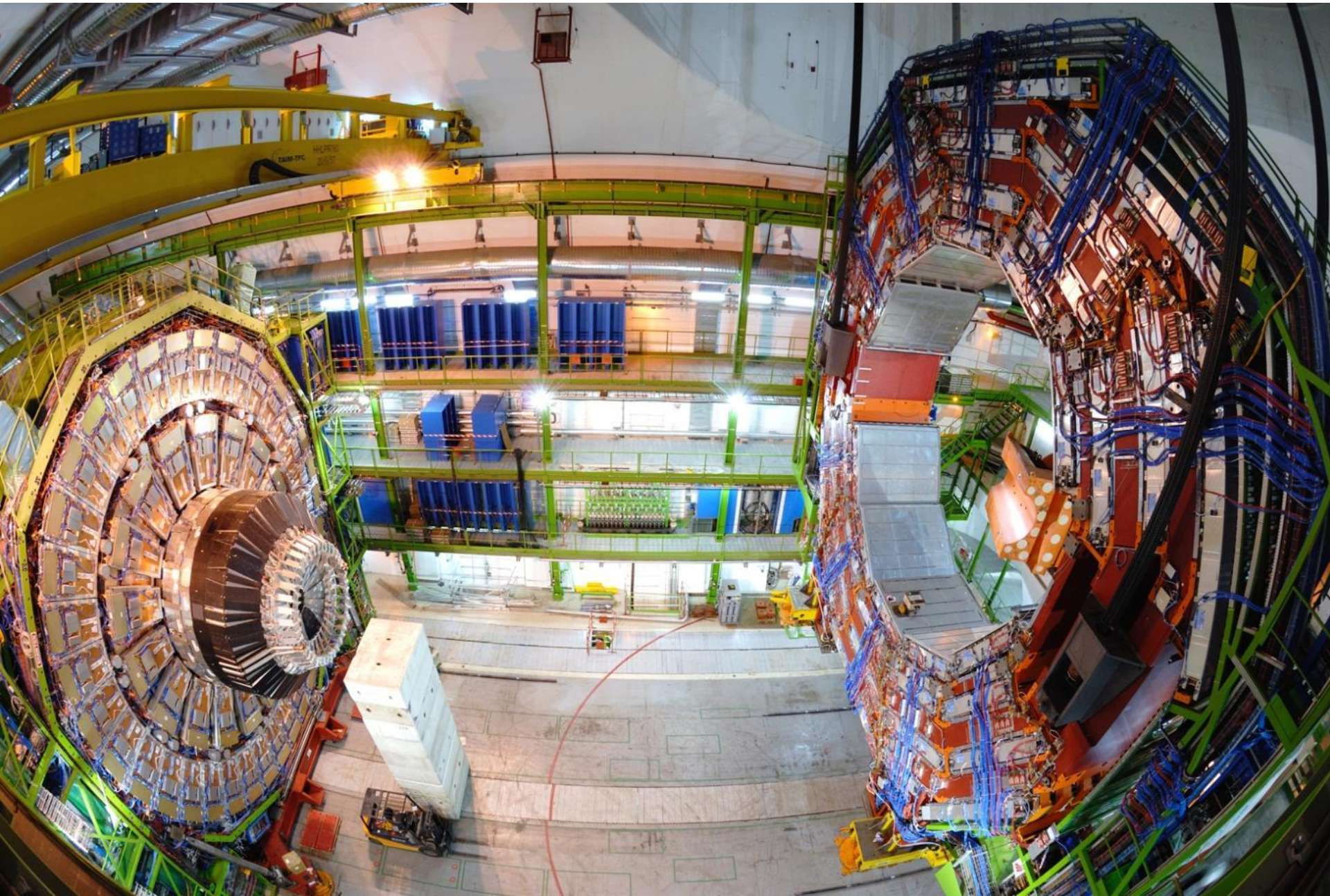




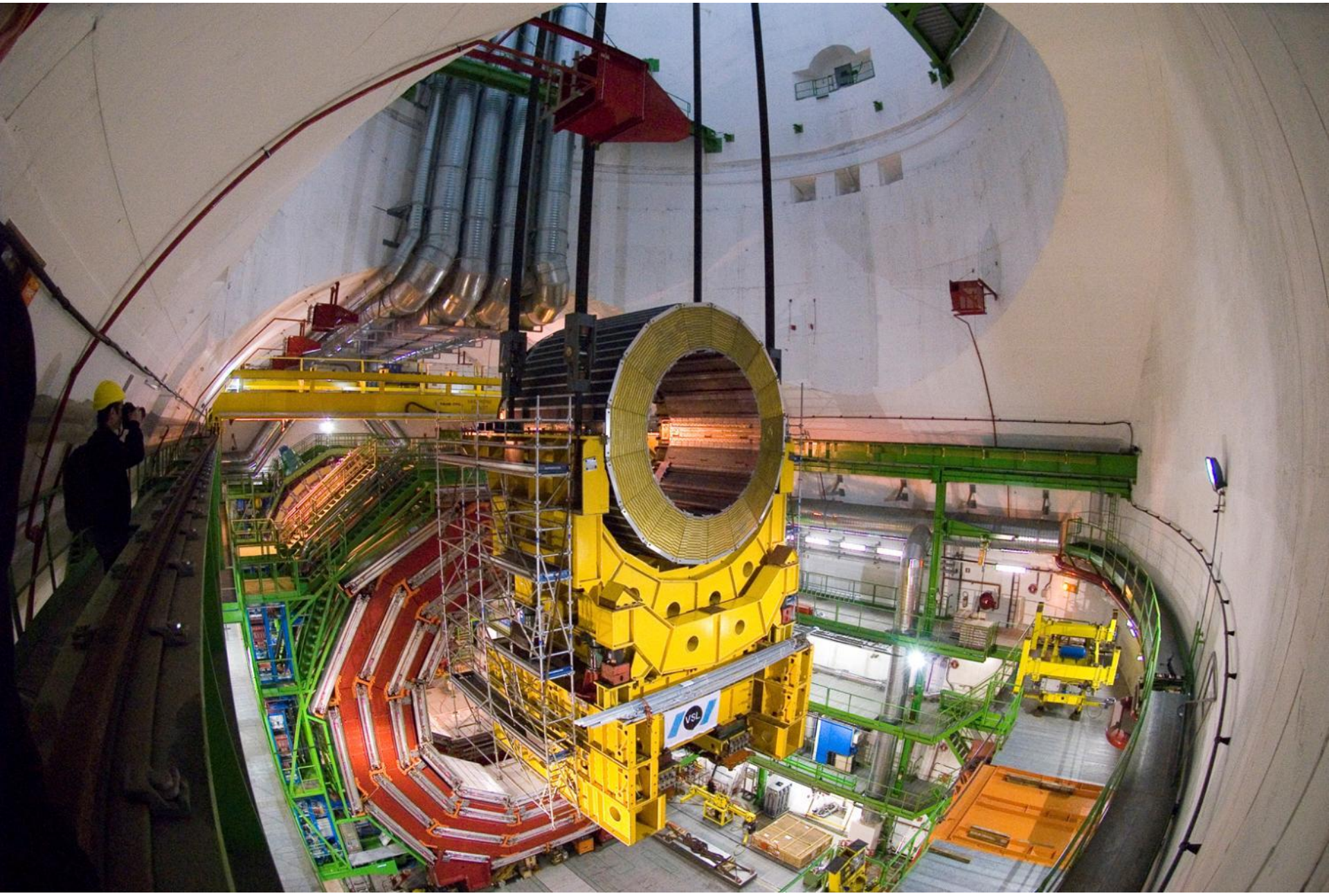
Start YE+3 lowering (30 Nov 2006)



YB+2 Lowering (19 Jan ‘07)

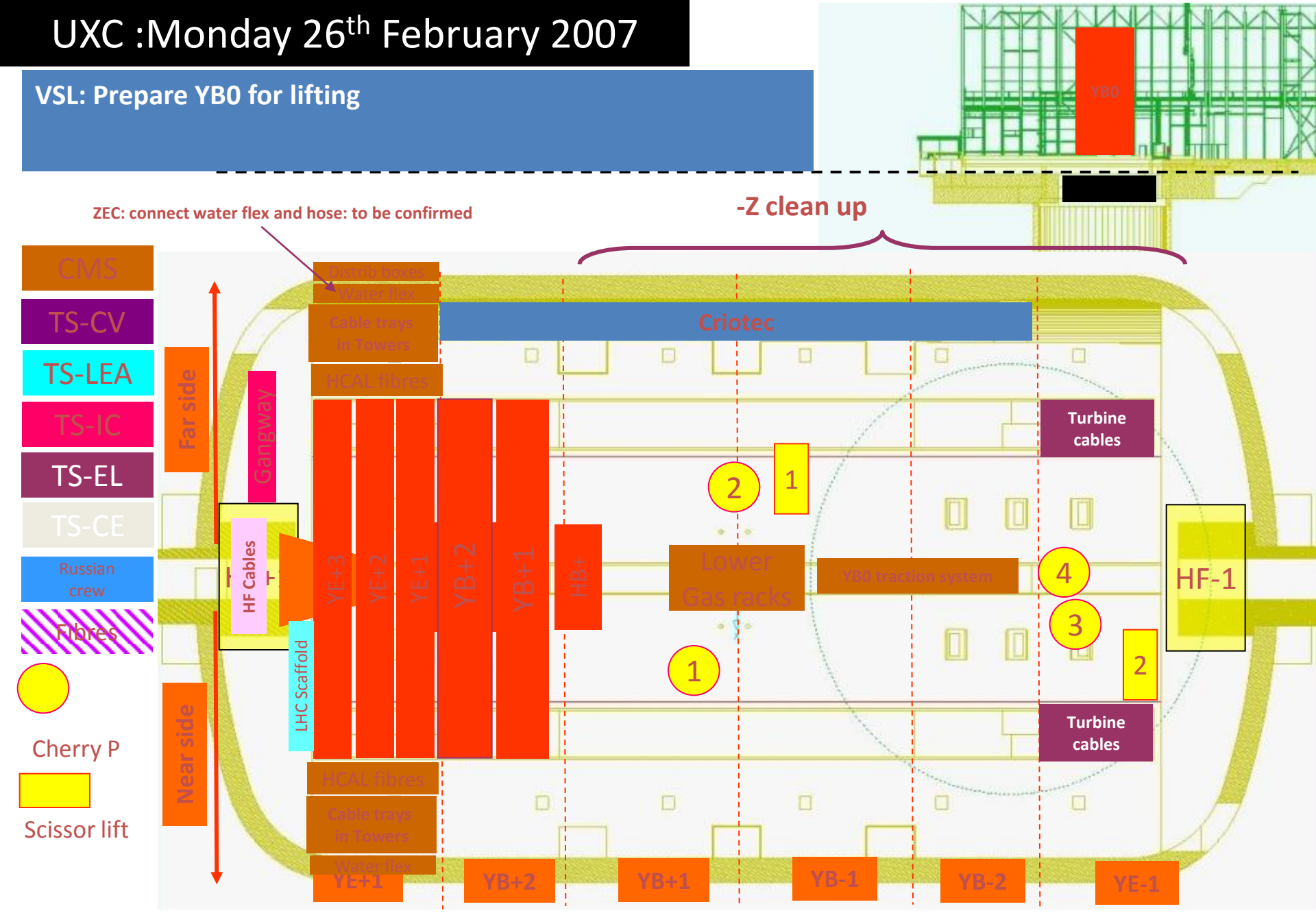


HCAL barrel+ Lowering (13 Feb ‘07)



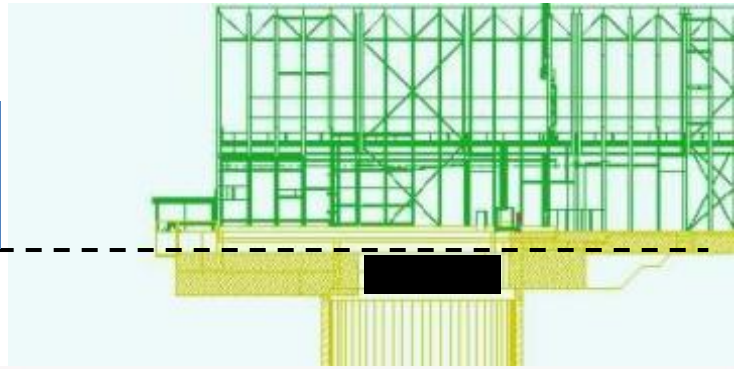
UXC :Monday 26th February 2007

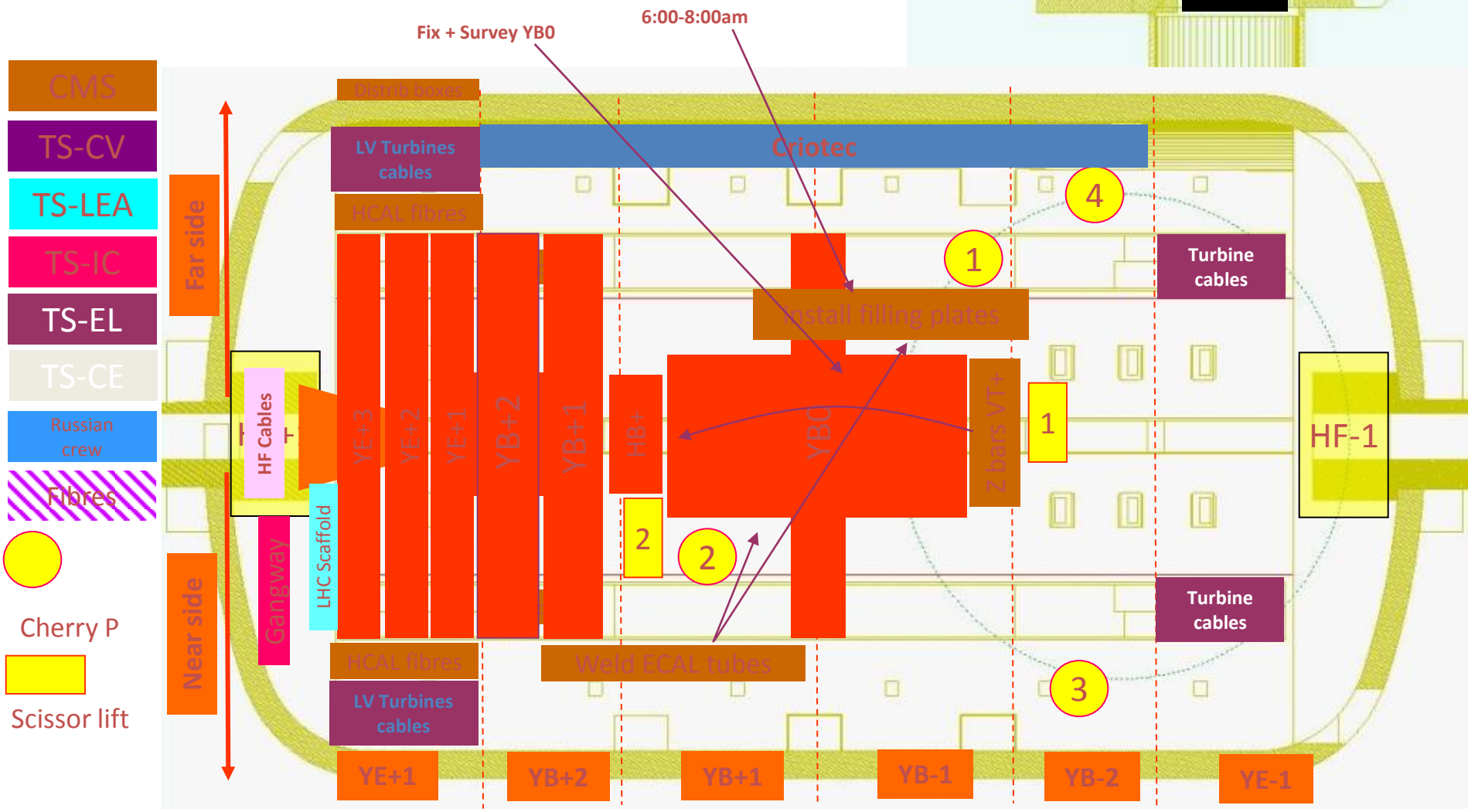
VSL: Prepare YB0 for lifting



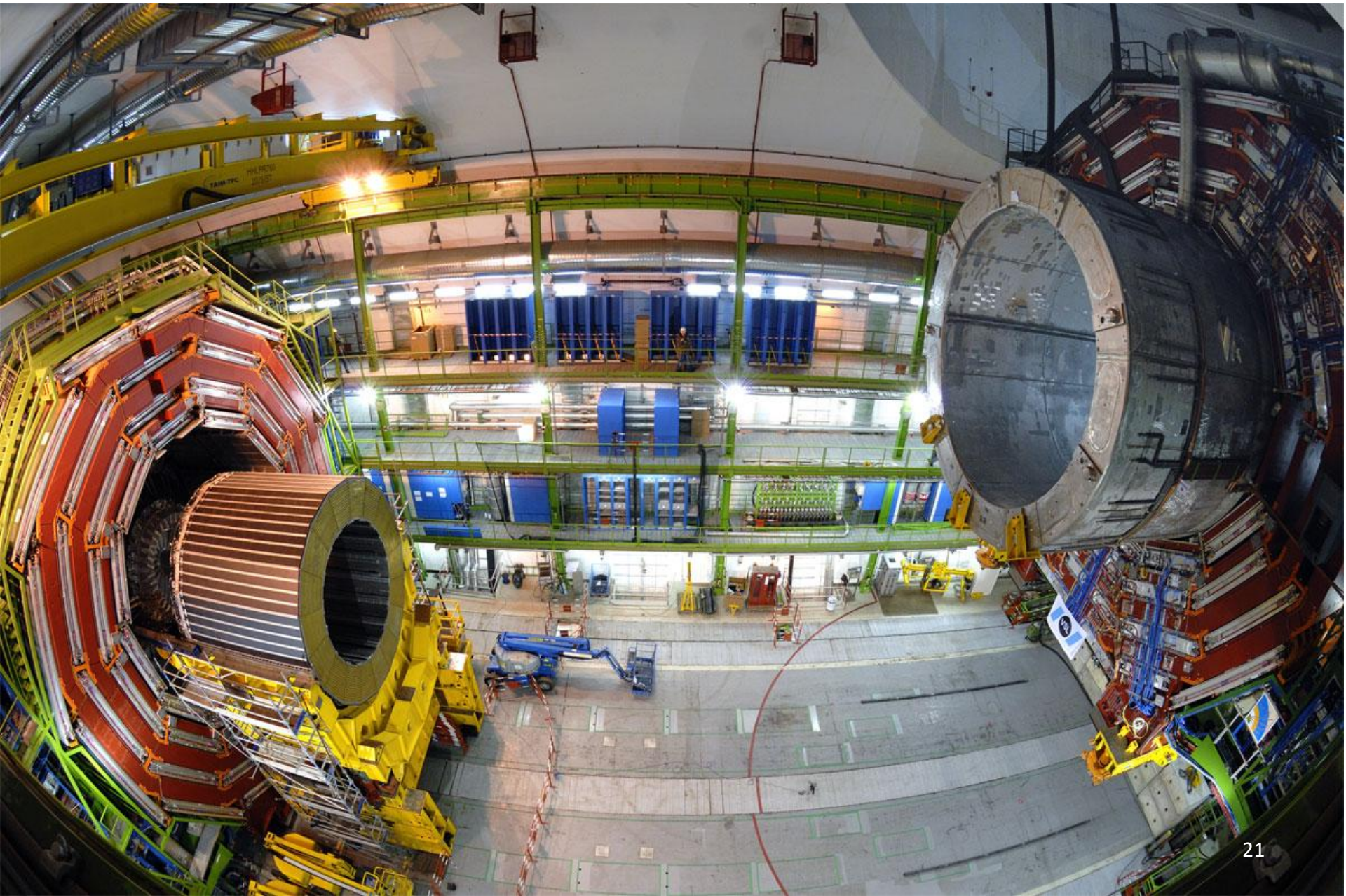
UXC: Friday 2 March 2007

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

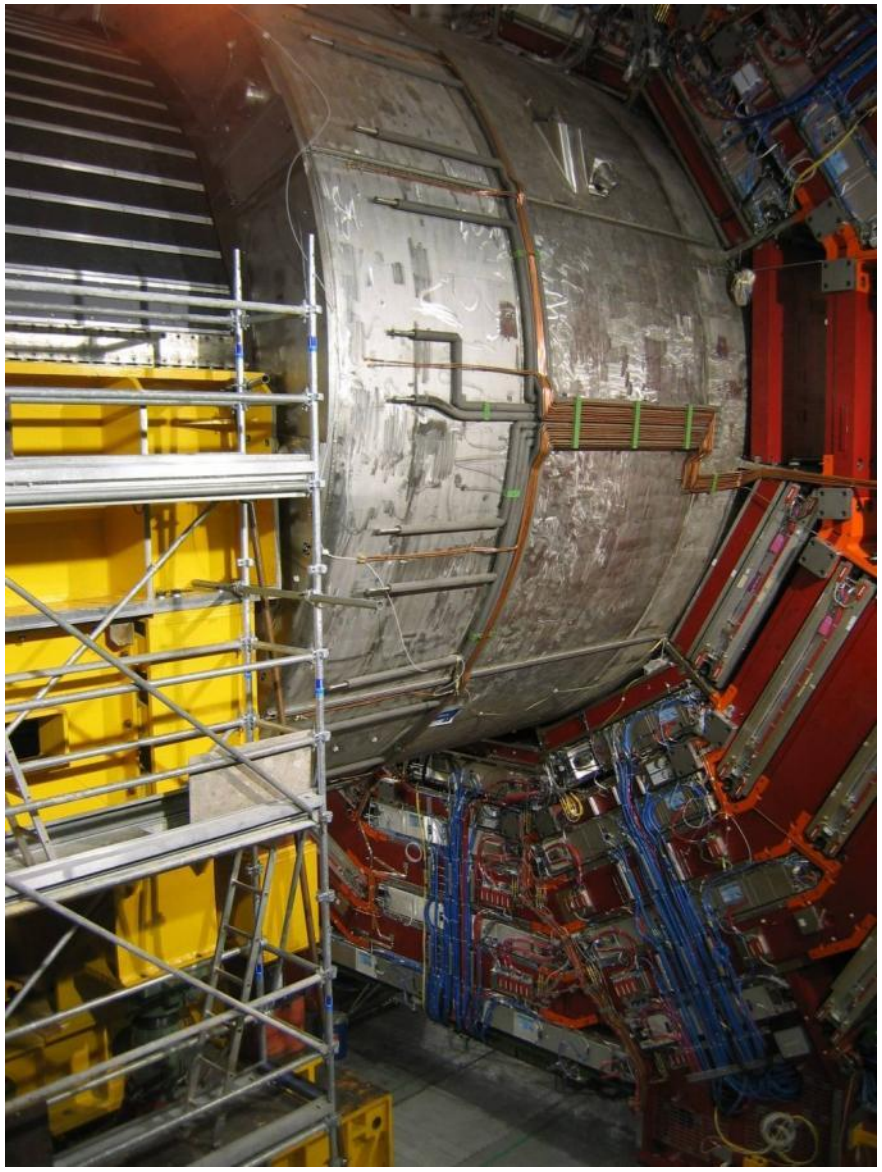


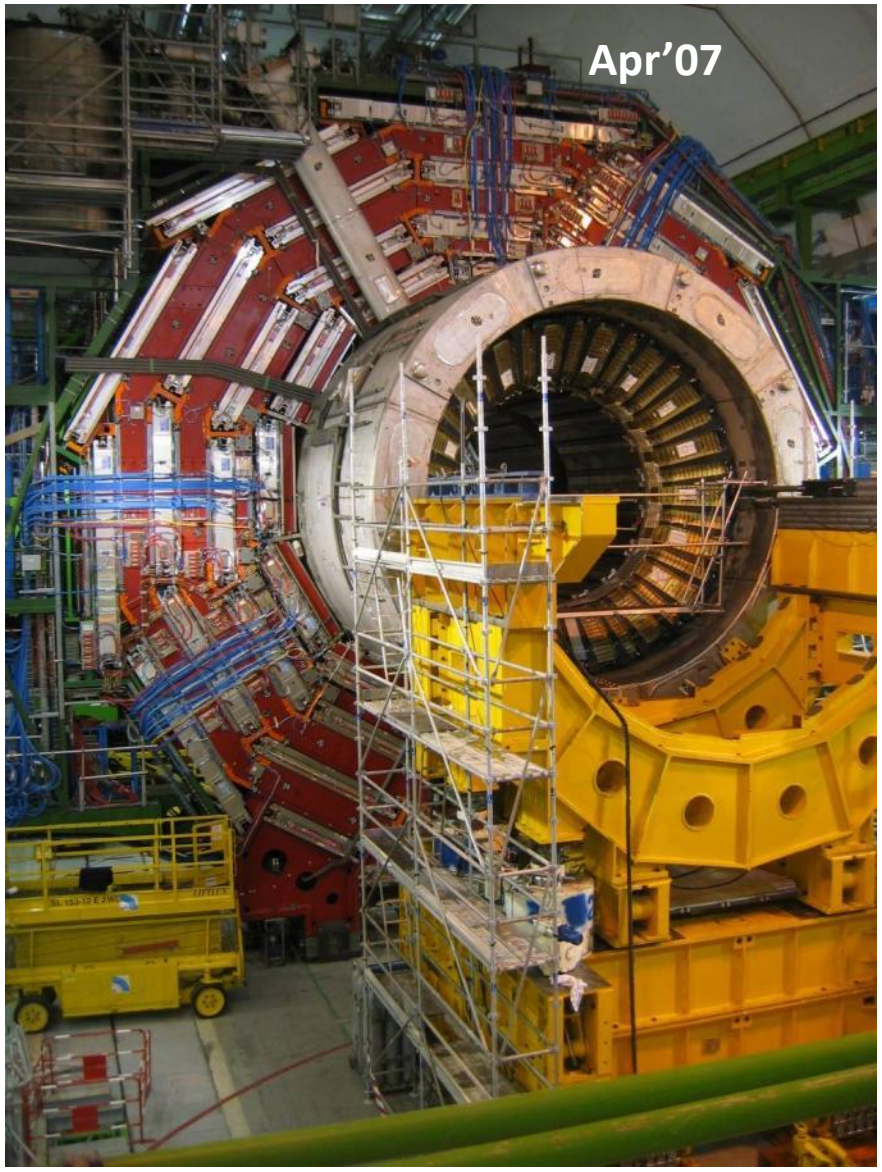


Central Wheel arriving

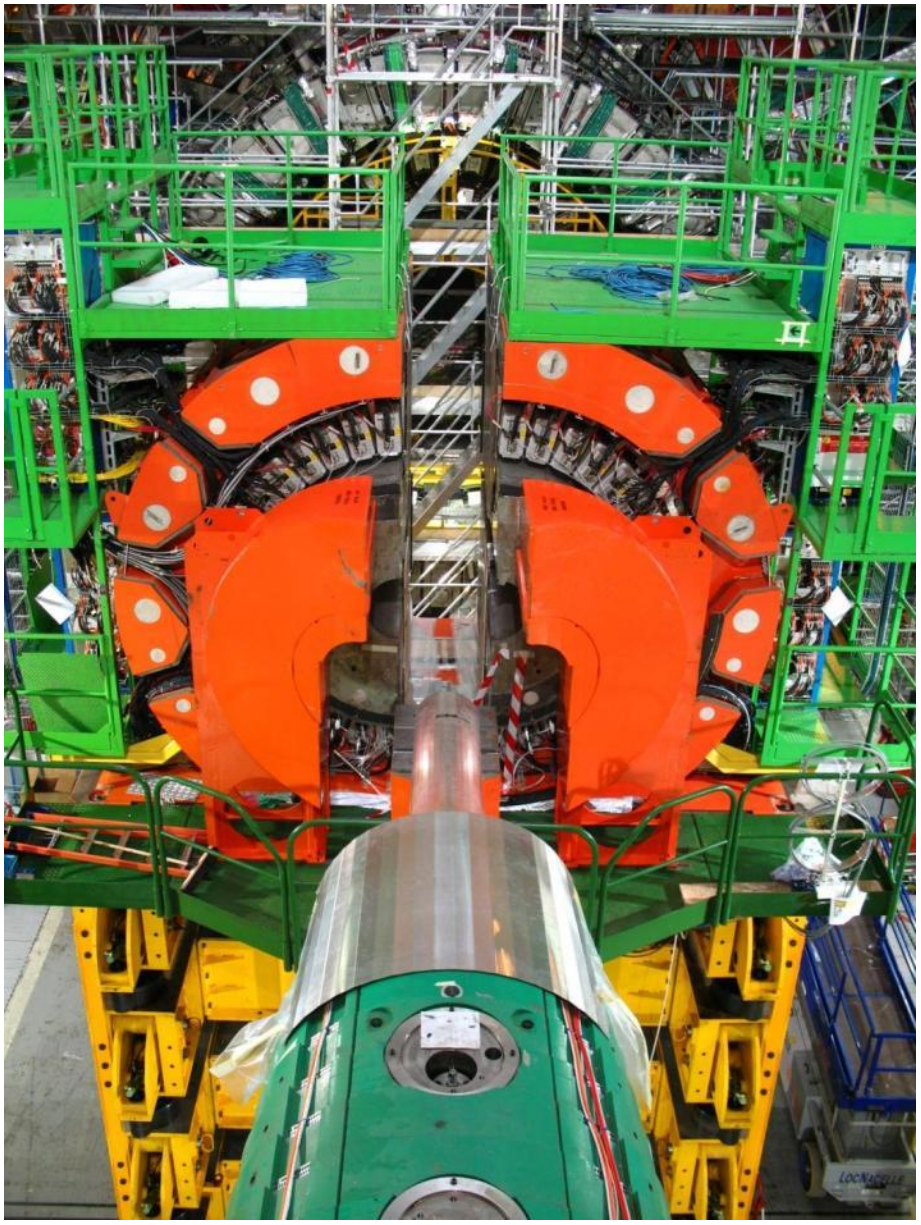


Insertion of HCAL Barrel

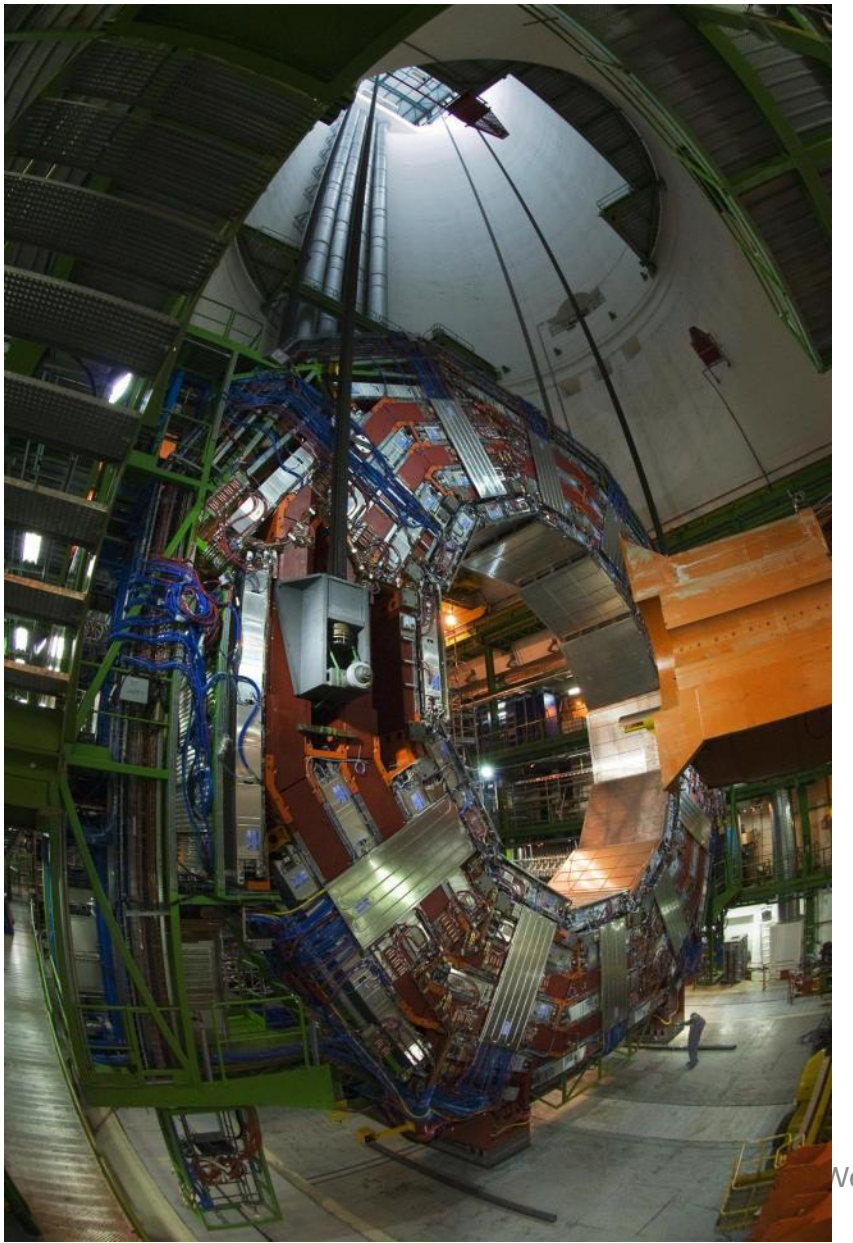


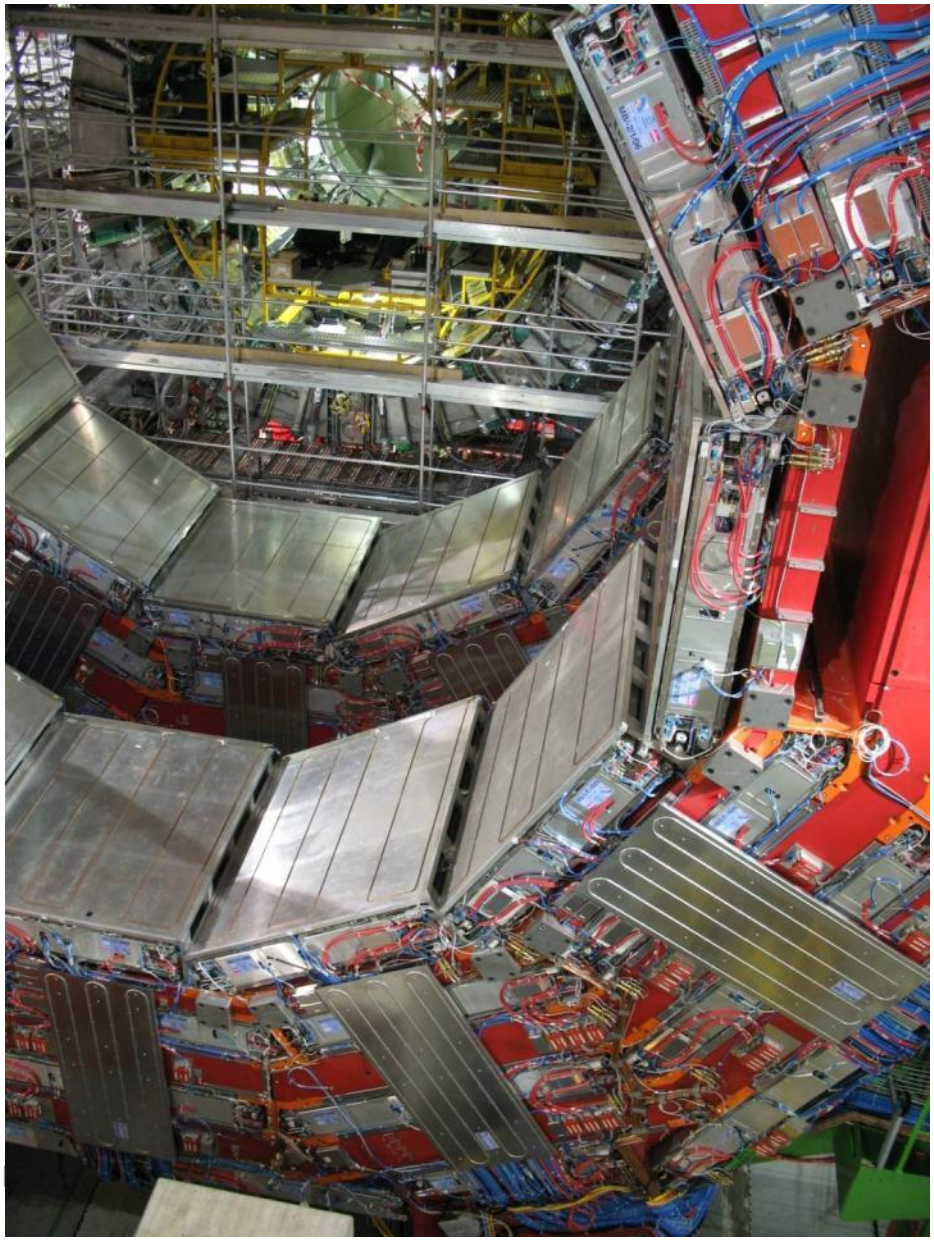


HF Raiser Test



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



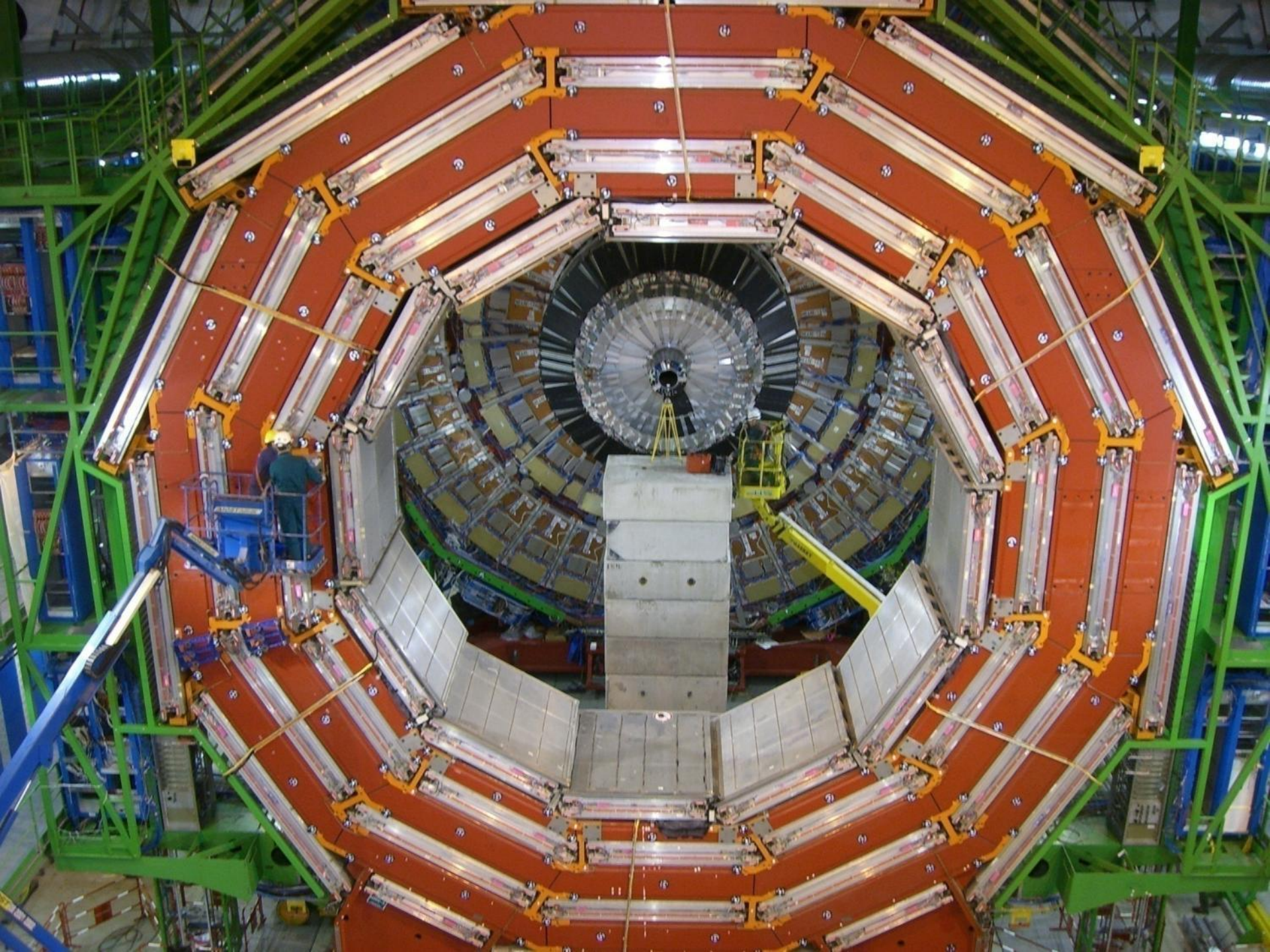


Drift Tubes – DT

Resistive Plate Chambers – RPC

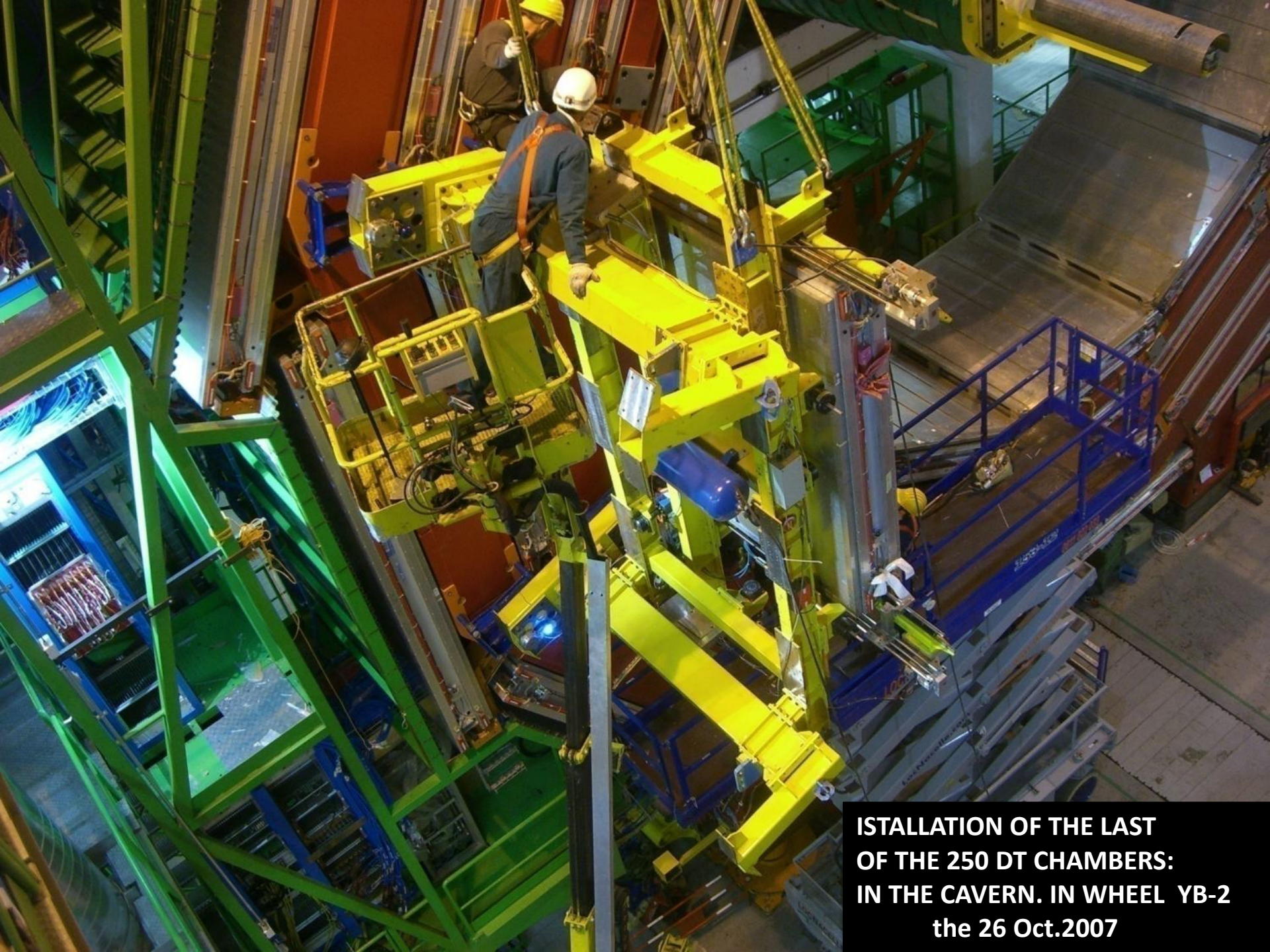
Cathode Strip Chambers – CSC

MUON DETECTORS



ARRIERE
DROITE
GAUCHE
AVANT

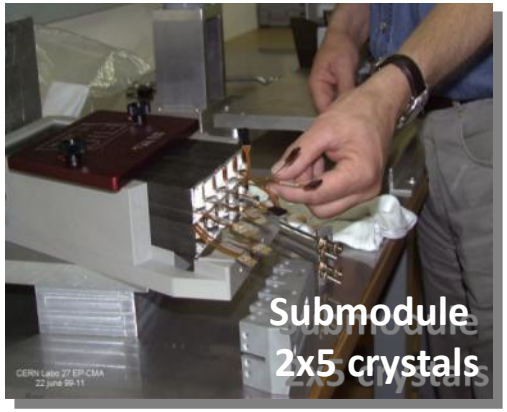
153-12
0611 022 033
LOCNACELLE

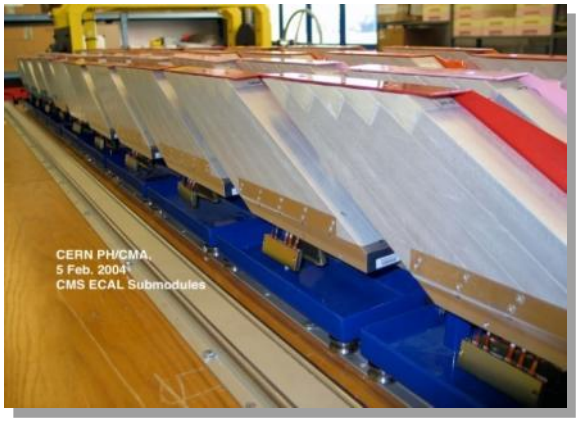


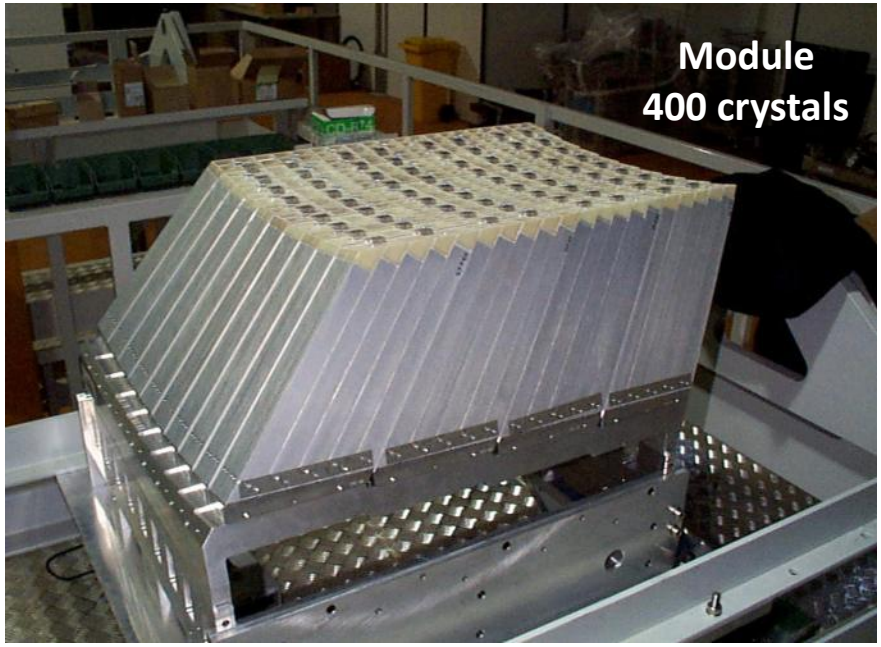
ISTALLATION OF THE LAST
OF THE 250 DT CHAMBERS:
IN THE CAVERN. IN WHEEL YB-2
the 26 Oct.2007

ELECTROMAGNETIC CALORIMETER

Assembly of ECAL

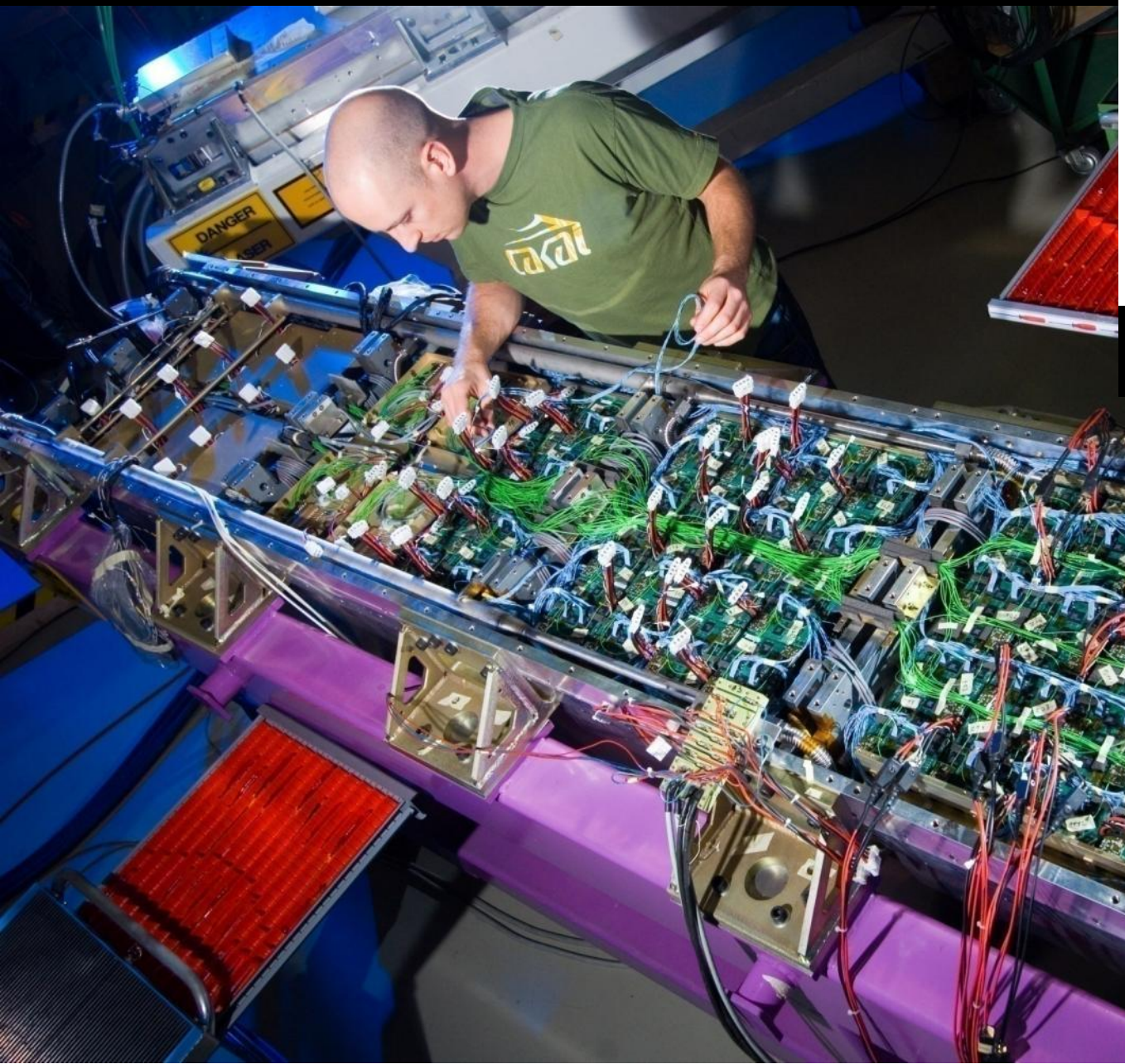


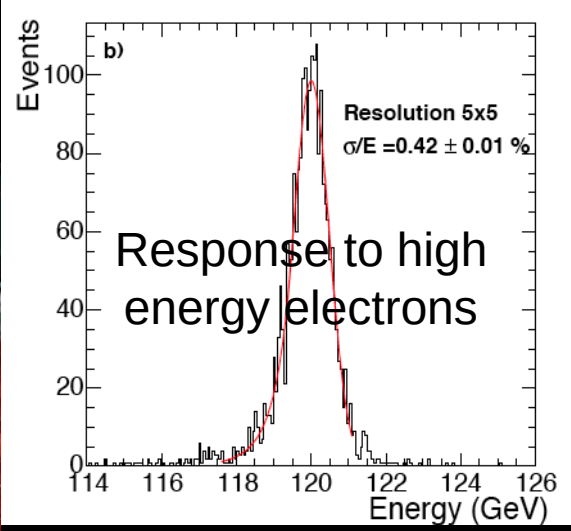




Total 36 Supermodules

ECAL: Assembly and Performance



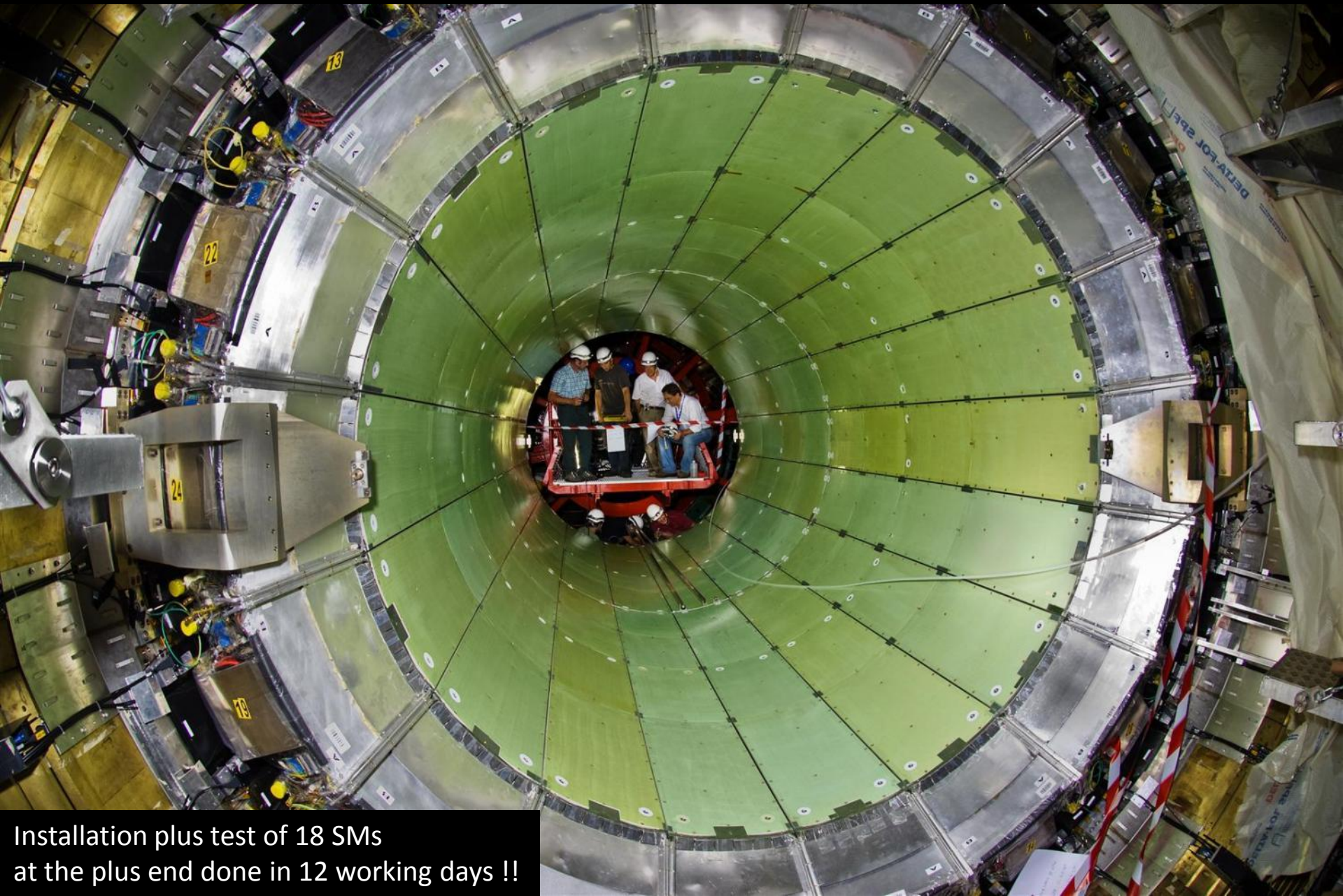


Temperature Stability: ≤ 0.1 °C
Light response stability: ≤ 0.1%

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

Next lecture

THE TRACKER

PIXEL

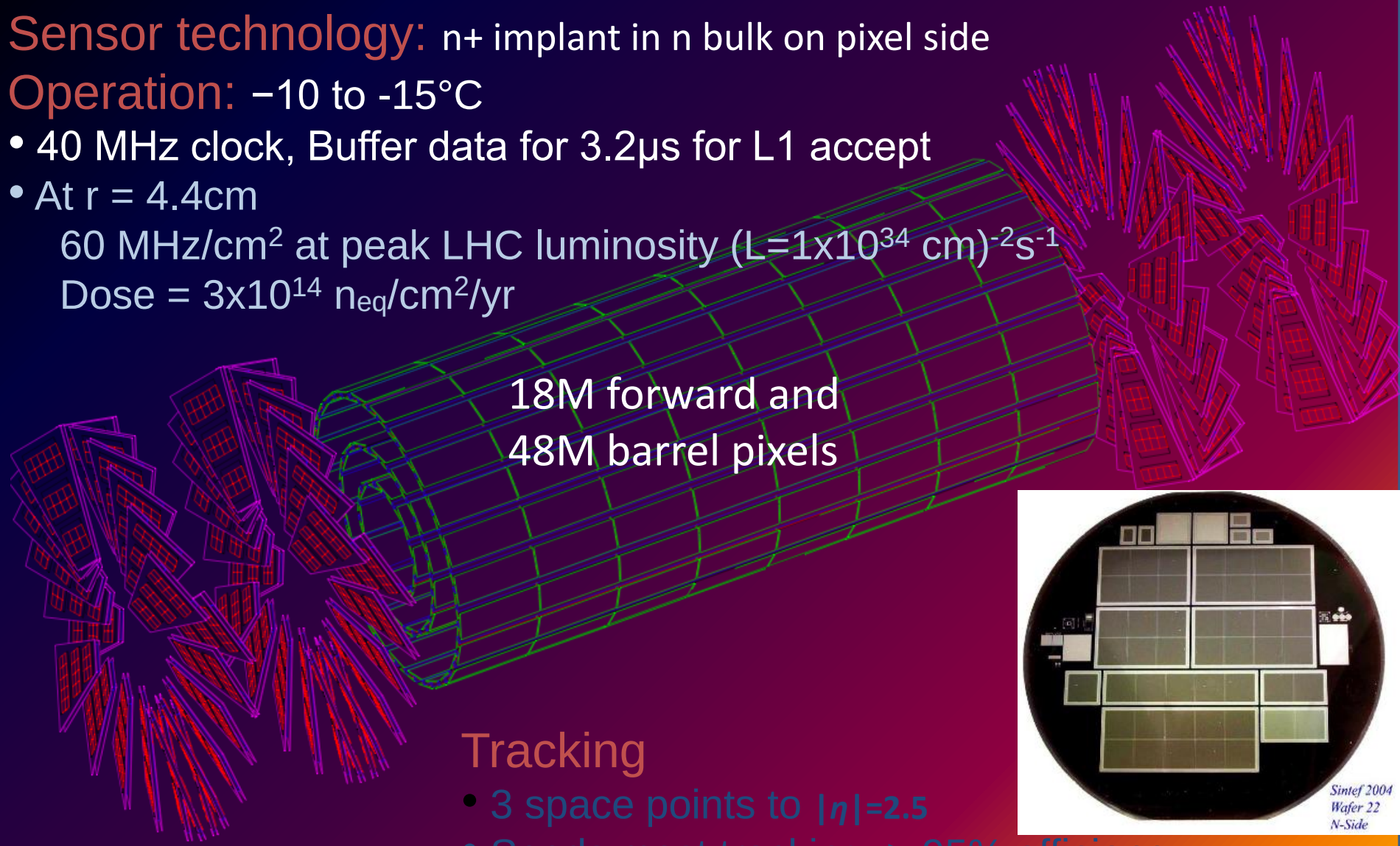
Sensor technology: n+ implant in n bulk on pixel side

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

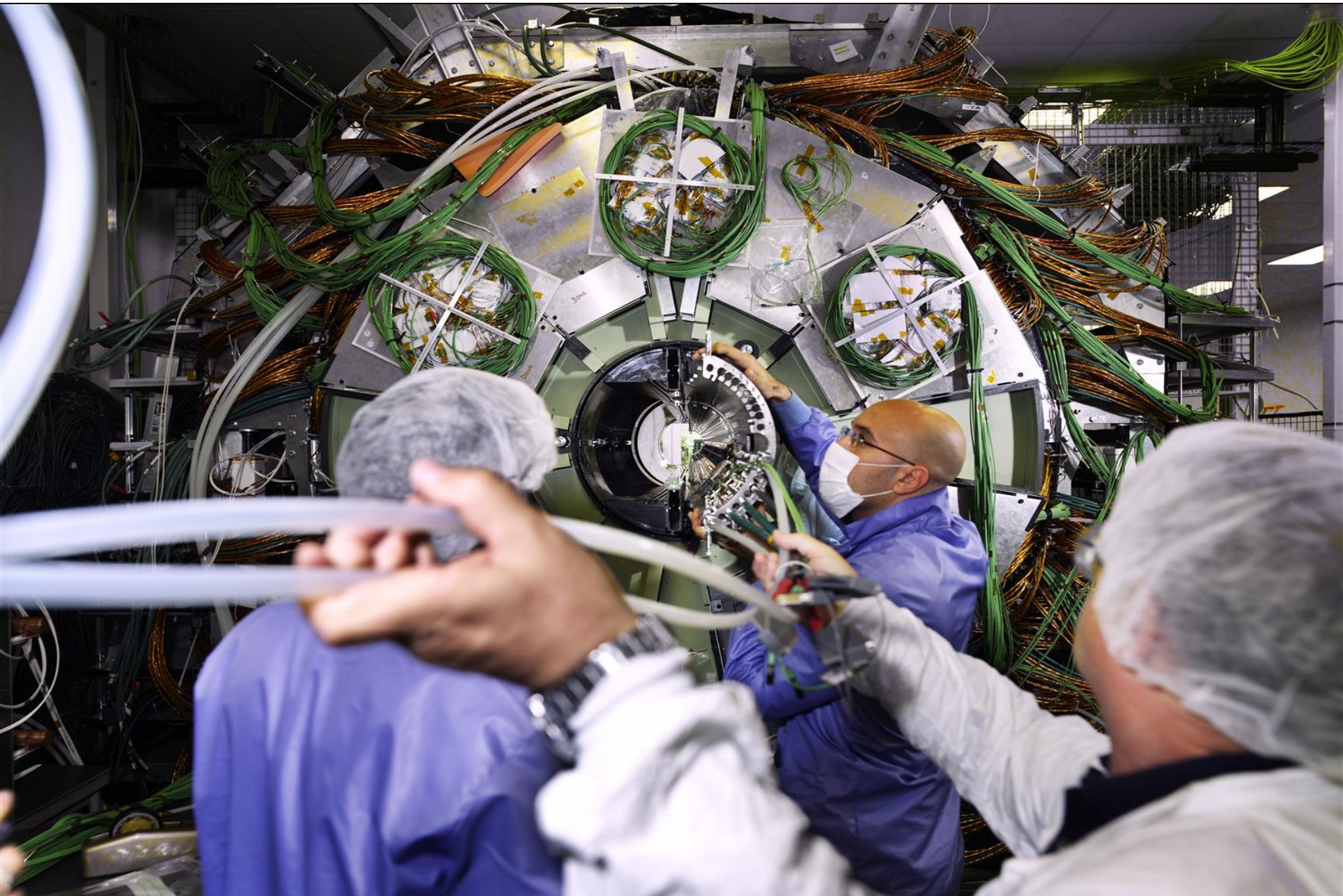
Tracking

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

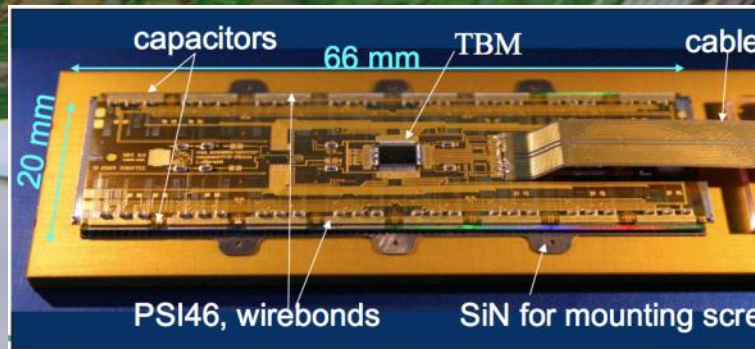
Half disc of Forward Pixels

Forward Pixel: 672 plaquettes required

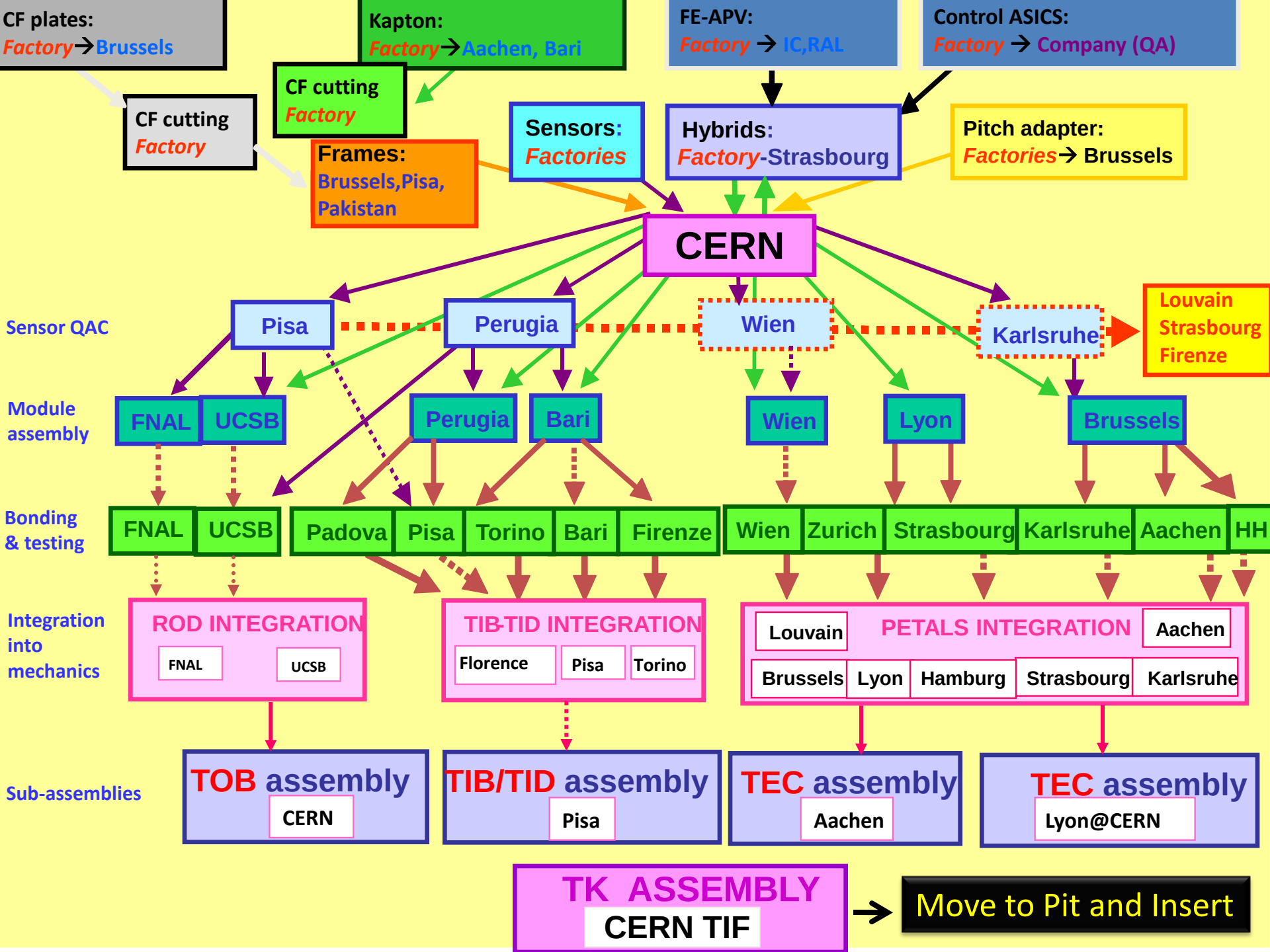
Pixel Test Insertion into Tracker



Pixel Barrel plus Endcaps READY

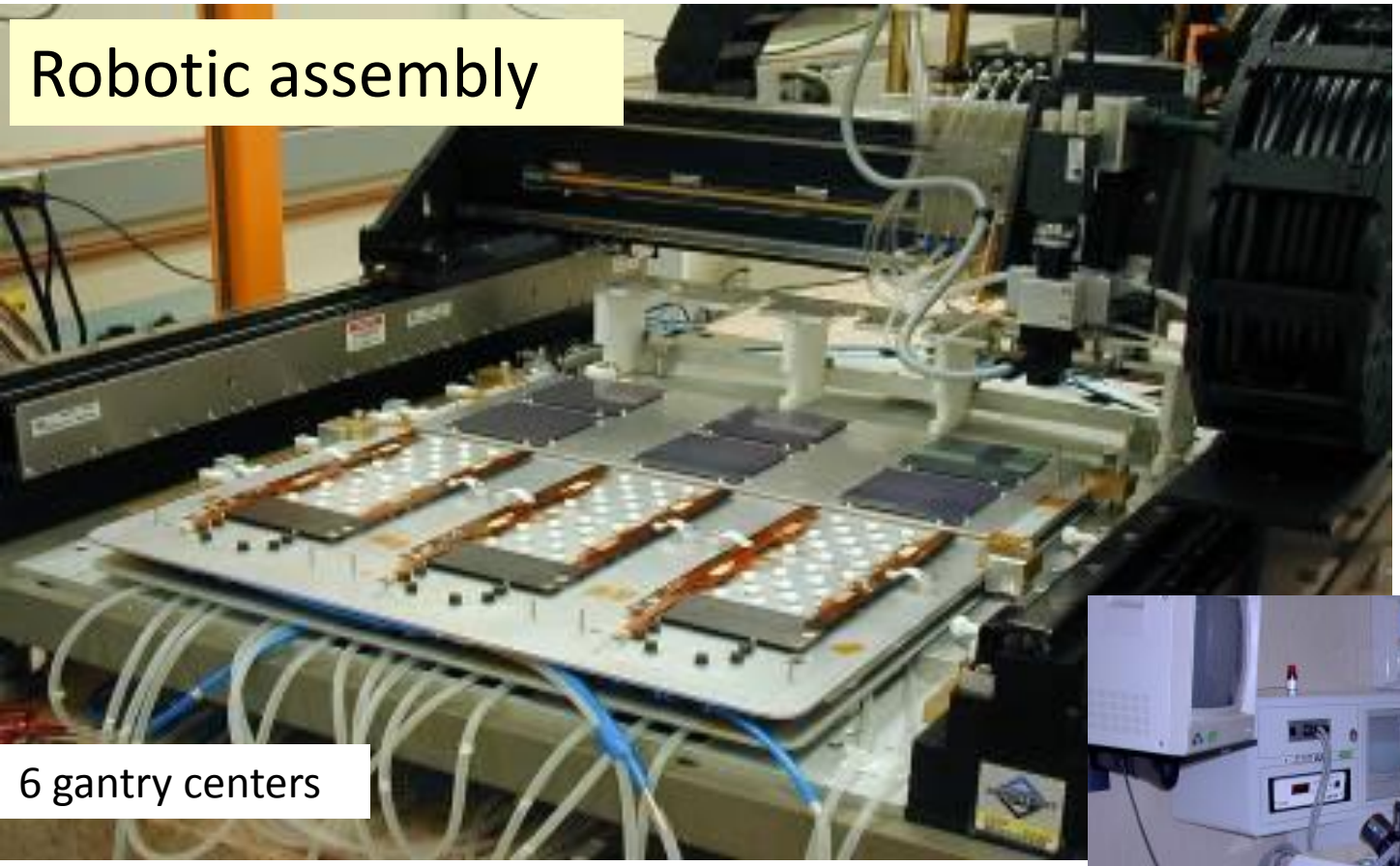


STRIP TRACKER

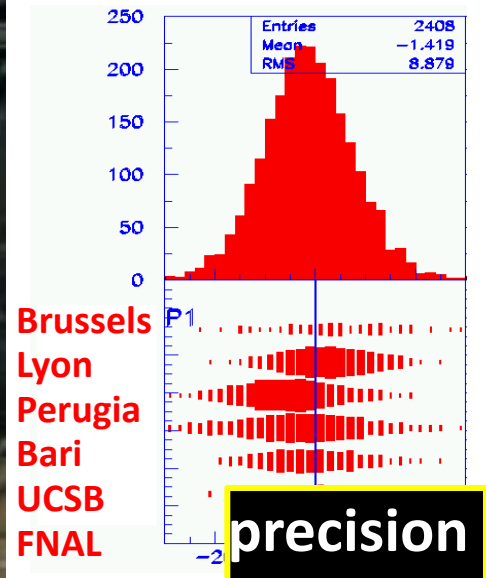

CF plates:
Factory→Brussels
Kapton:
Factory→Aachen, Bari
FE-APV:
Factory → IC,RAL
Control ASICS:
Factory → Company (QA)
CF cutting
Factory
CF cutting
Factory
Frames:
Brussels,Pisa,
Pakistan
Sensors:
Factories
Hybrids:
Factory-Strasbourg
Pitch adapter:
Factories→ Brussels
CERN
Sensor QAC
Pisa
Perugia
Wien
Karlsruhe
Louvain
Strasbourg
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

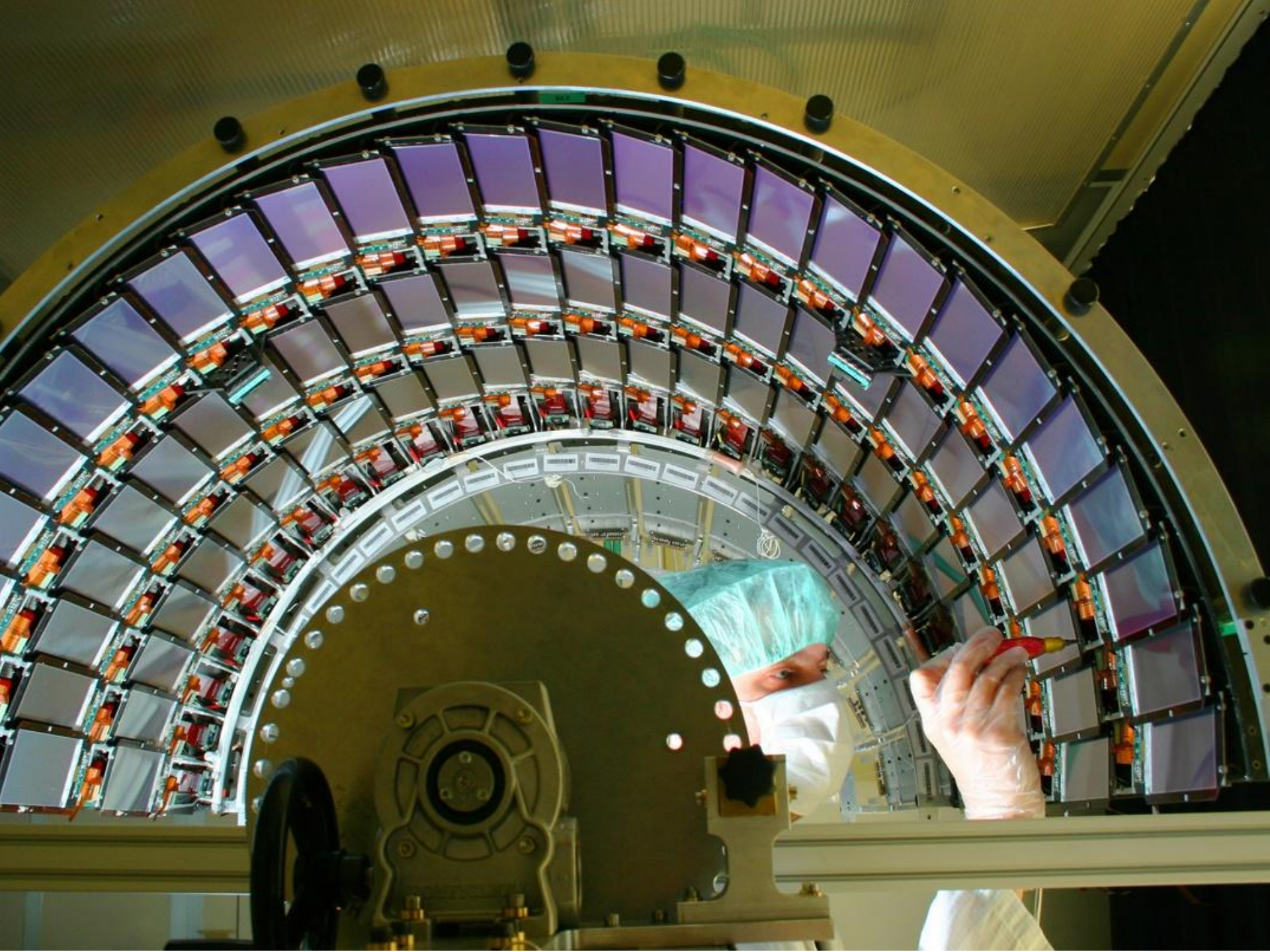


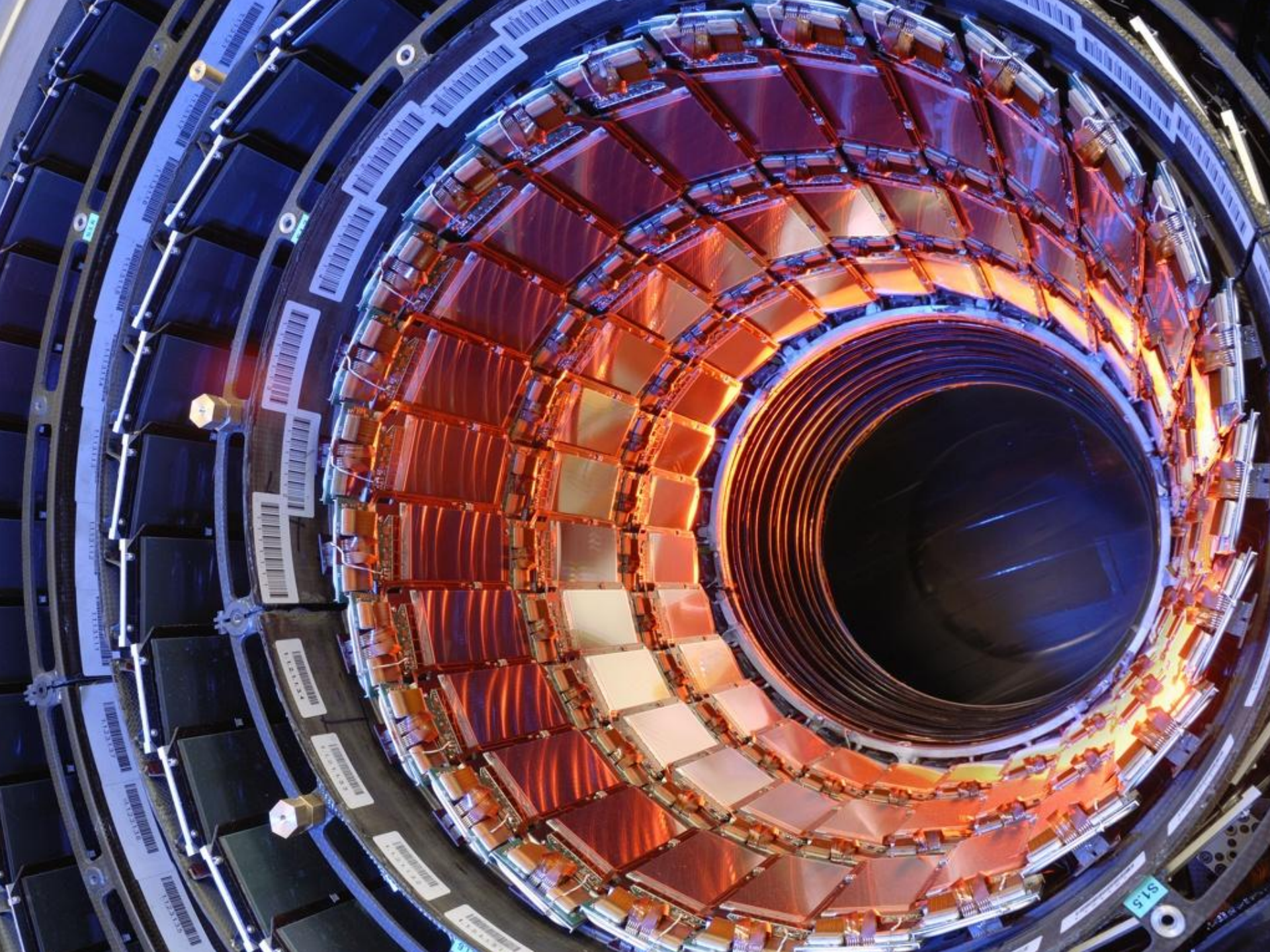
precision
$\sigma \approx 9\mu m$

13 bonding centers

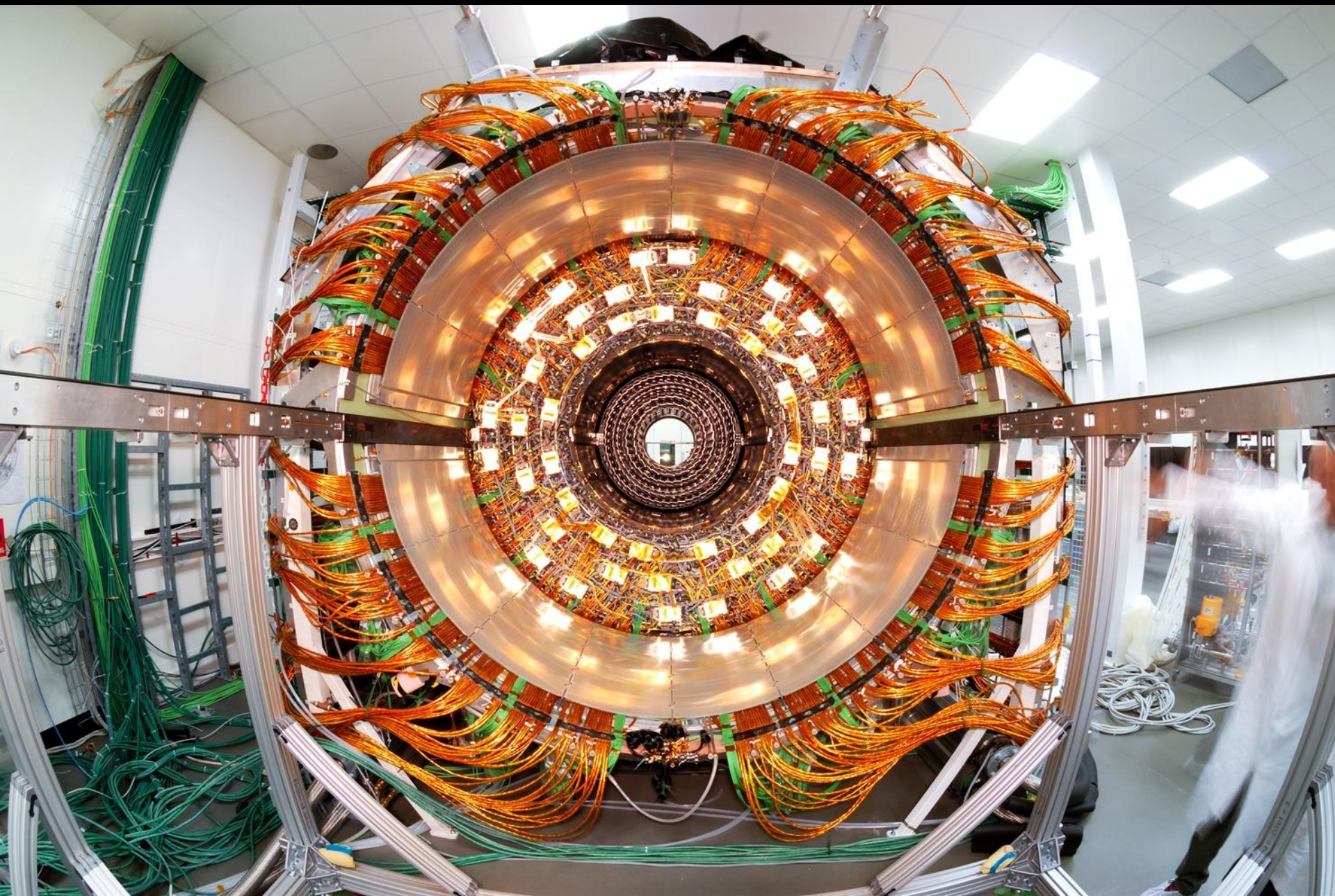
Intermediate Structures: Petals

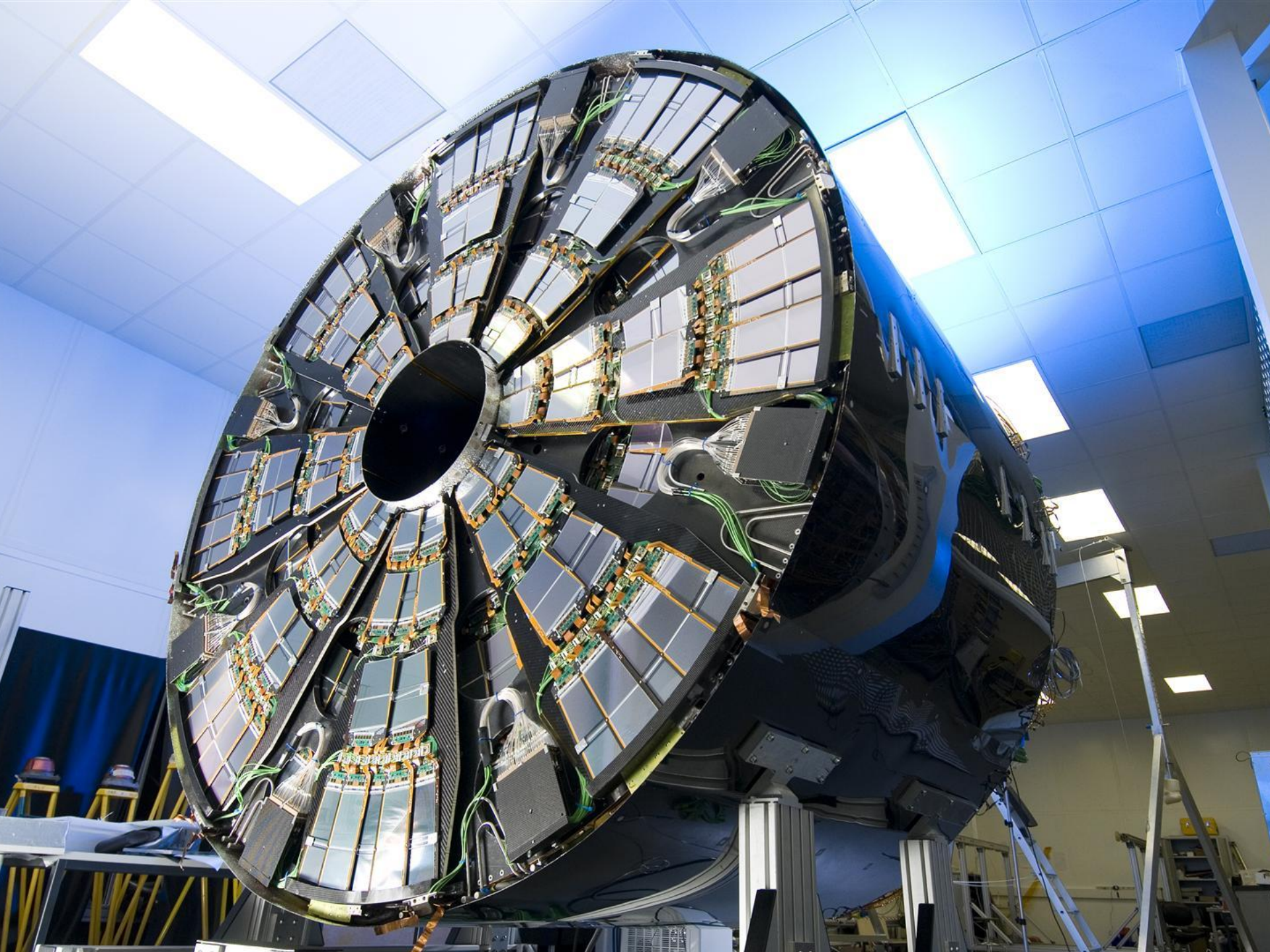
400 Different Pieces Makes one Petal, a Fairly Complicated Object: We needed 288 in total! We assembled 110 in Karlsruhe



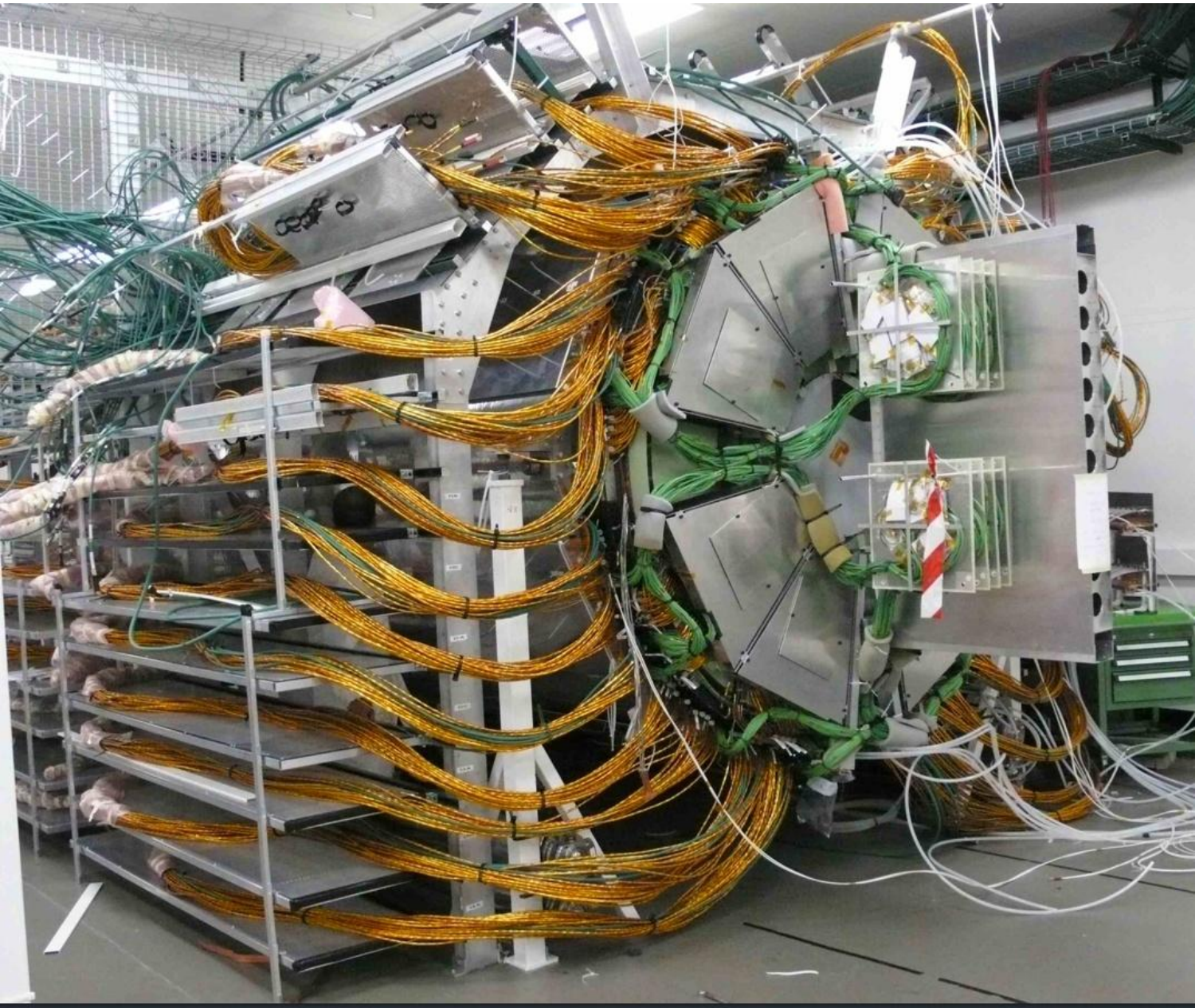


Si Tracker

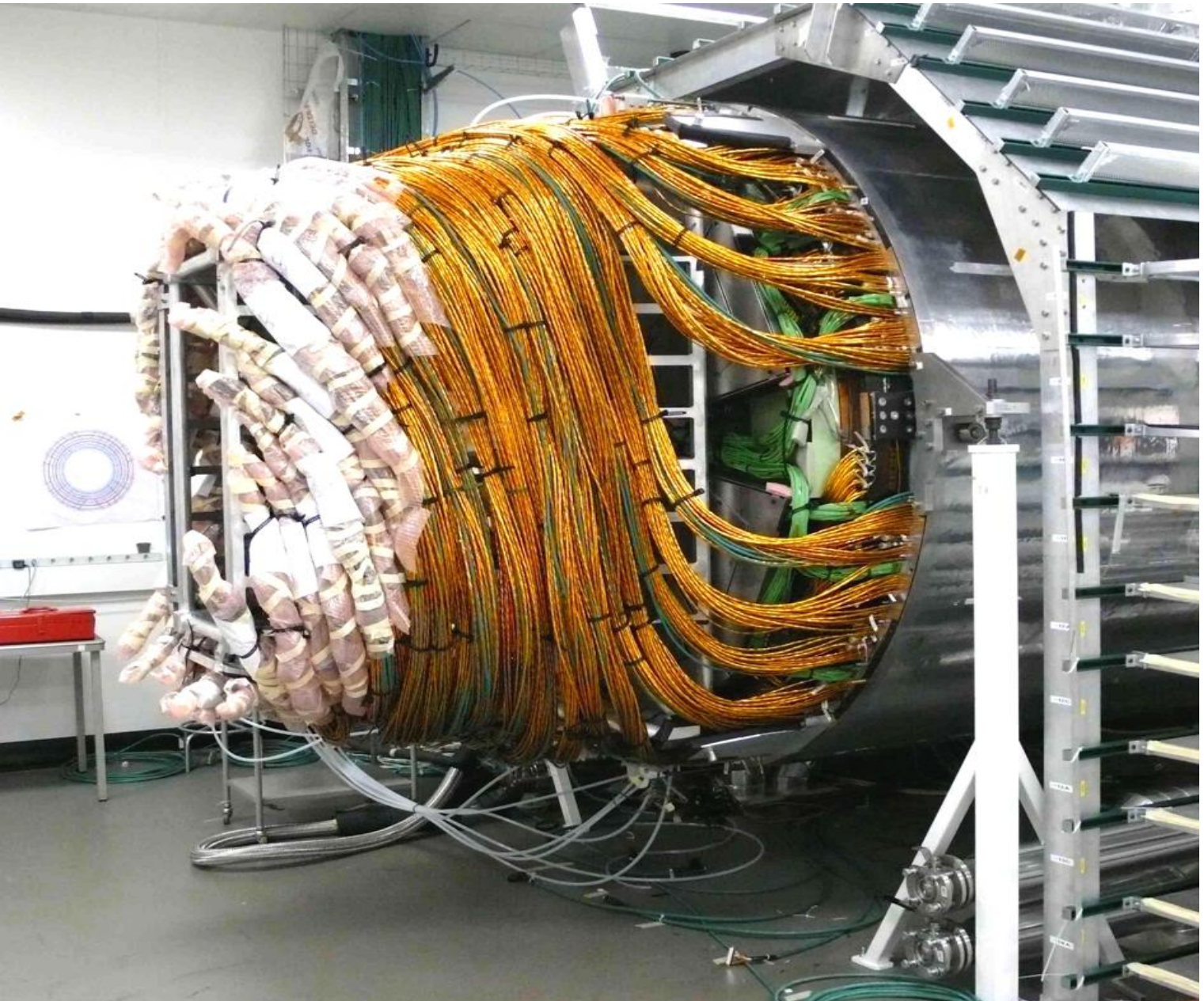




Optical Fibres Dressed onto the +End of the Tracker



Multiservice Cables Dressed



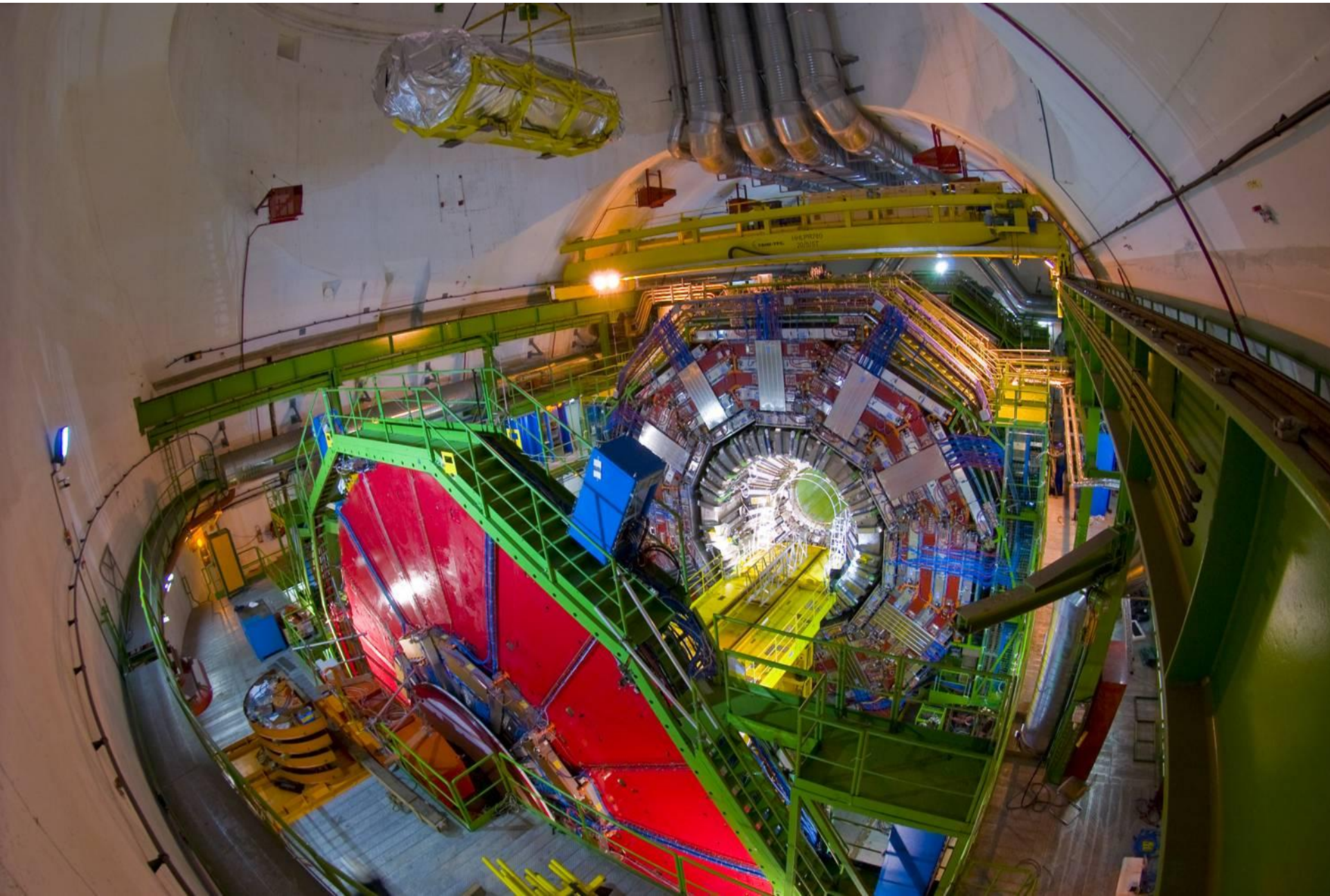
Tracker on the Way Down

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

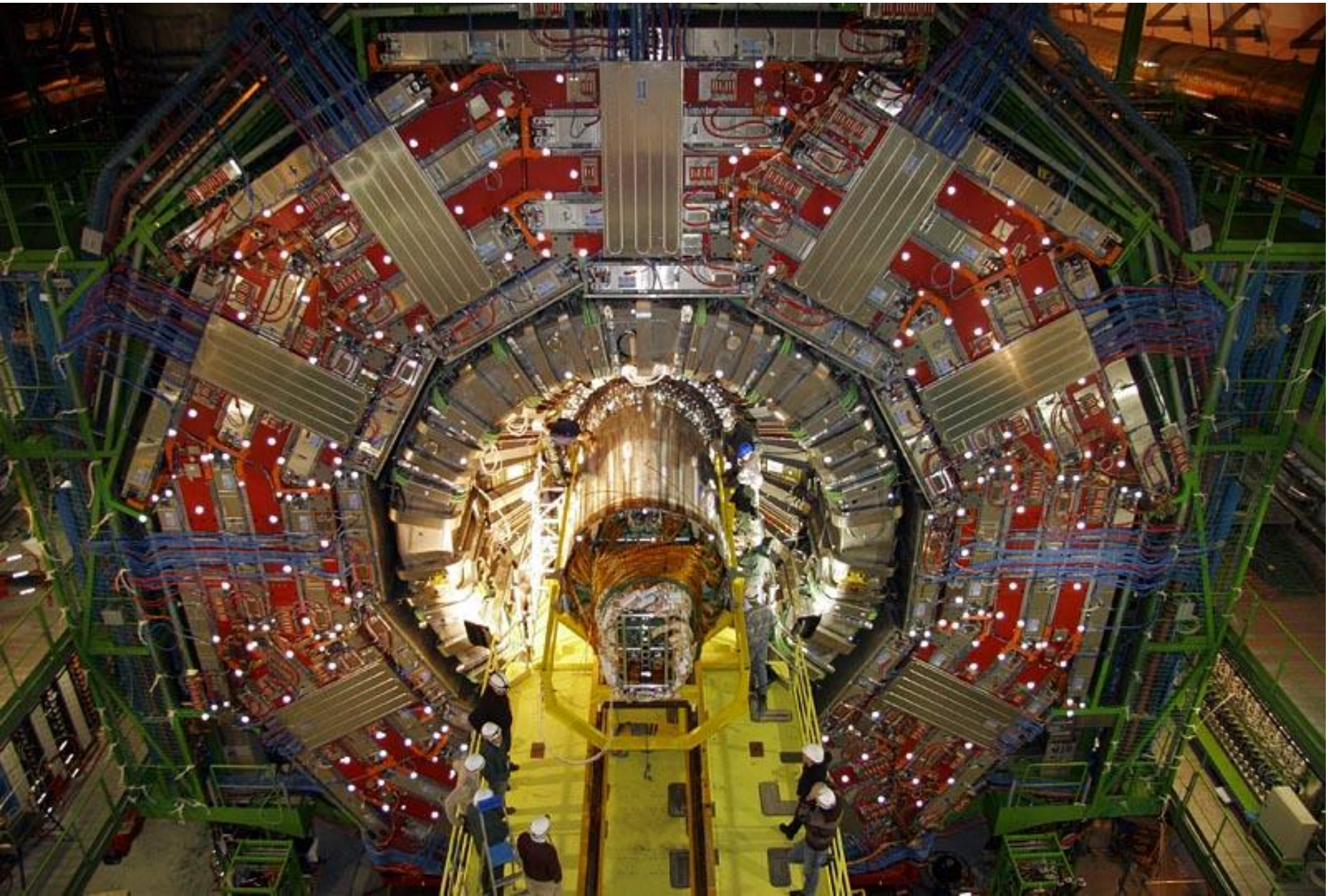
On the hook!

- Several frightened physicists, including me!

FLY IN



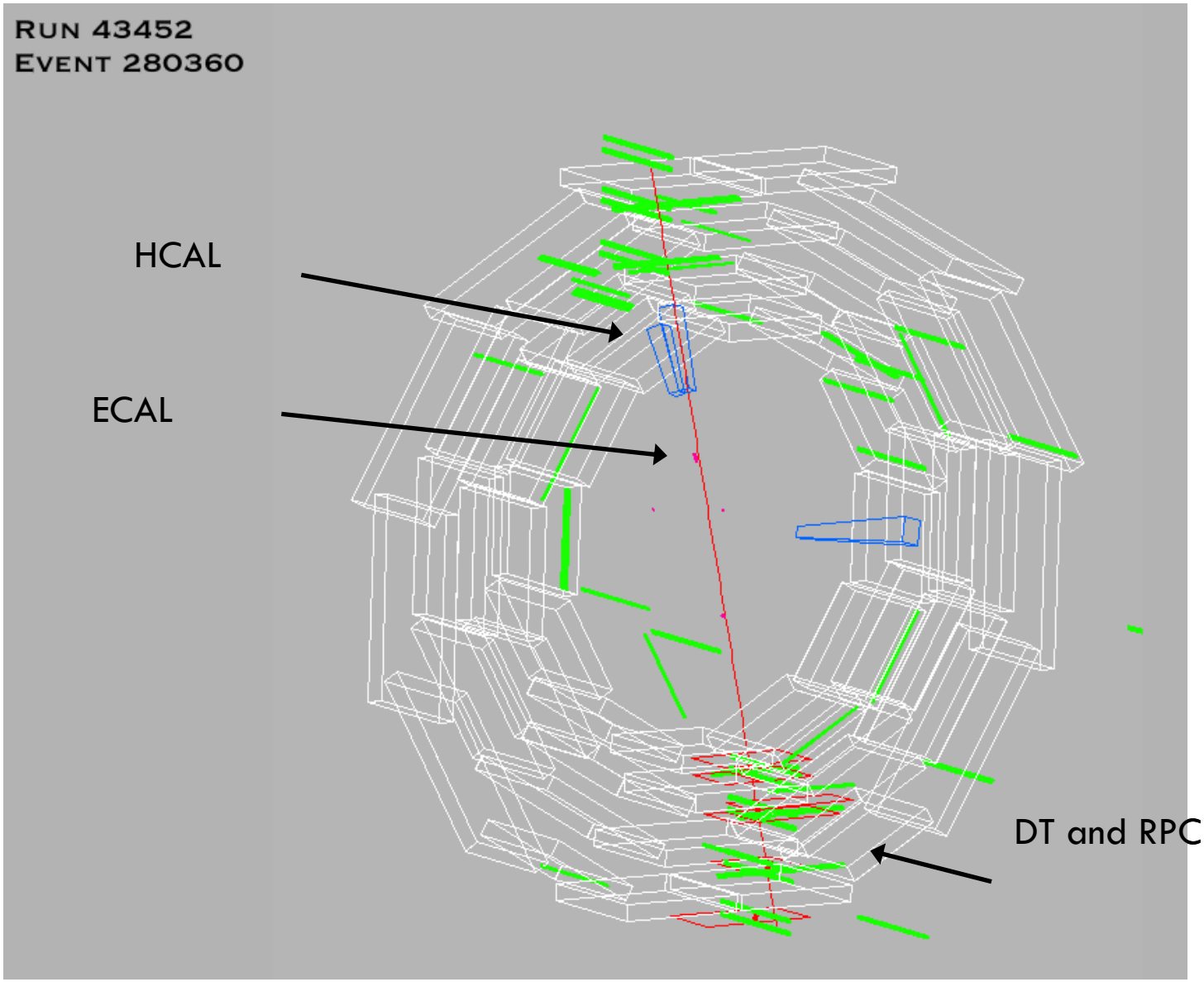
Insertion of the CMS Tracker into the Heart of CMS



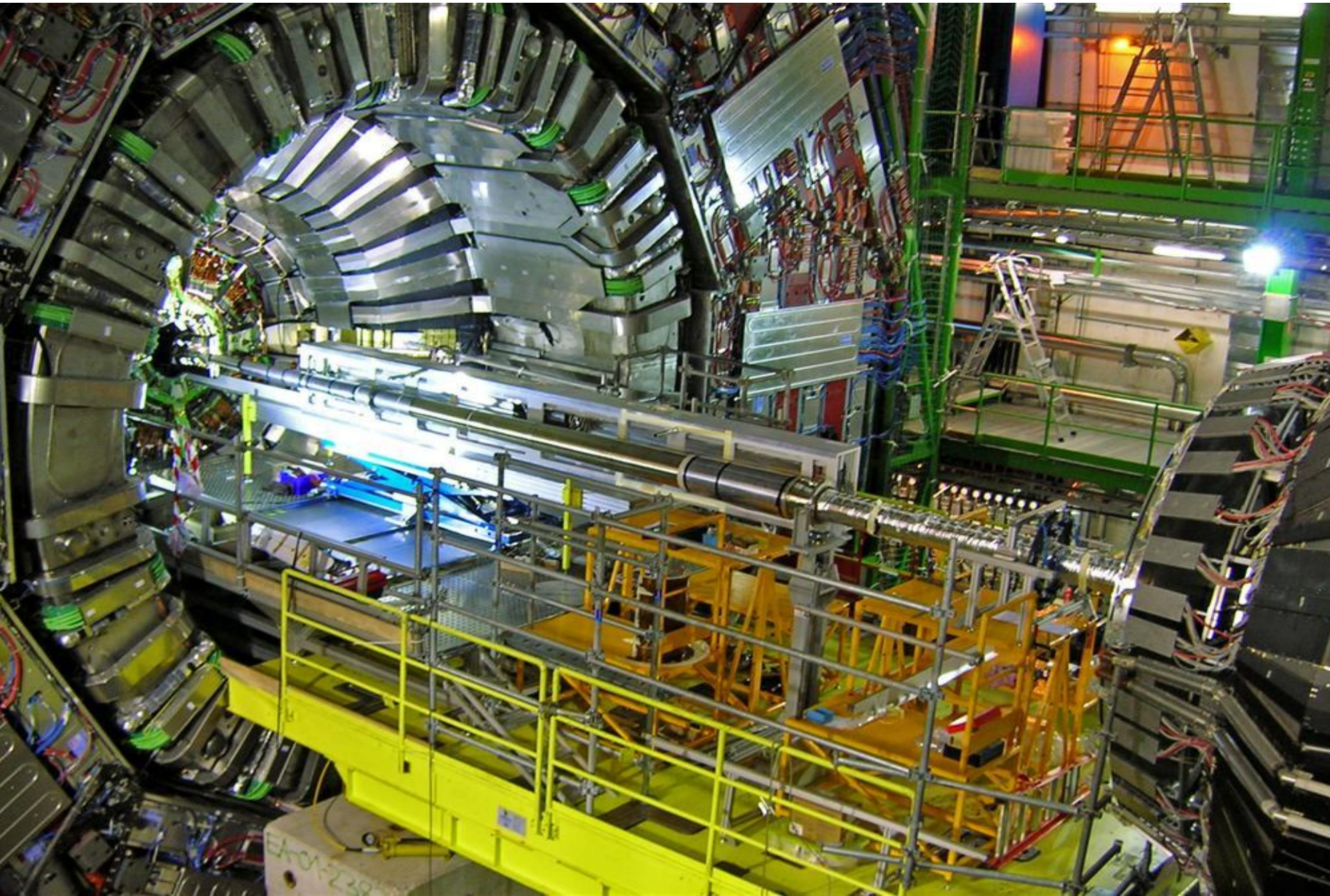
DONE, TRACKER IS IN(Sunday 15.12.07 01.30)

AT LAST

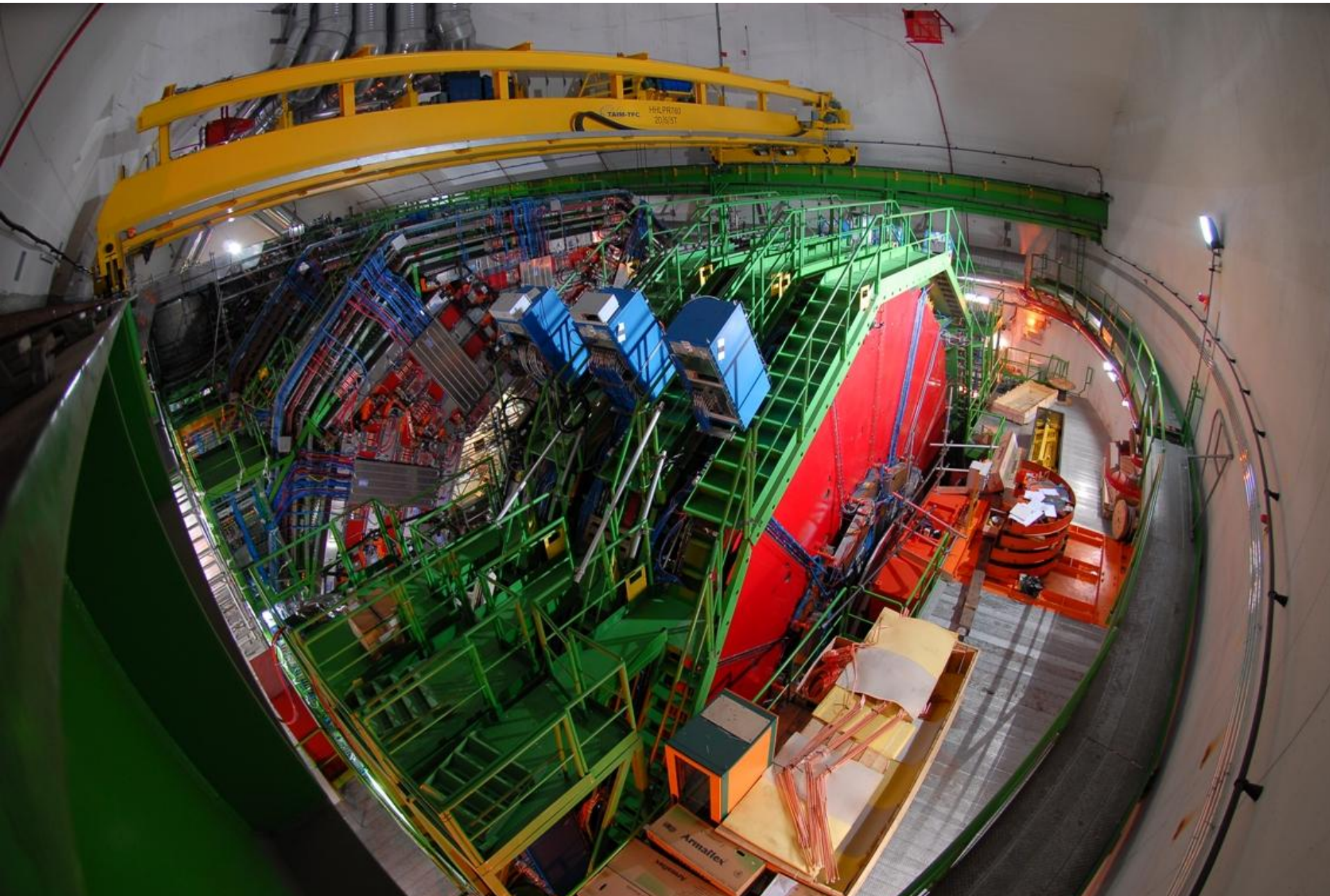
CRUZET: Cosmic Muon



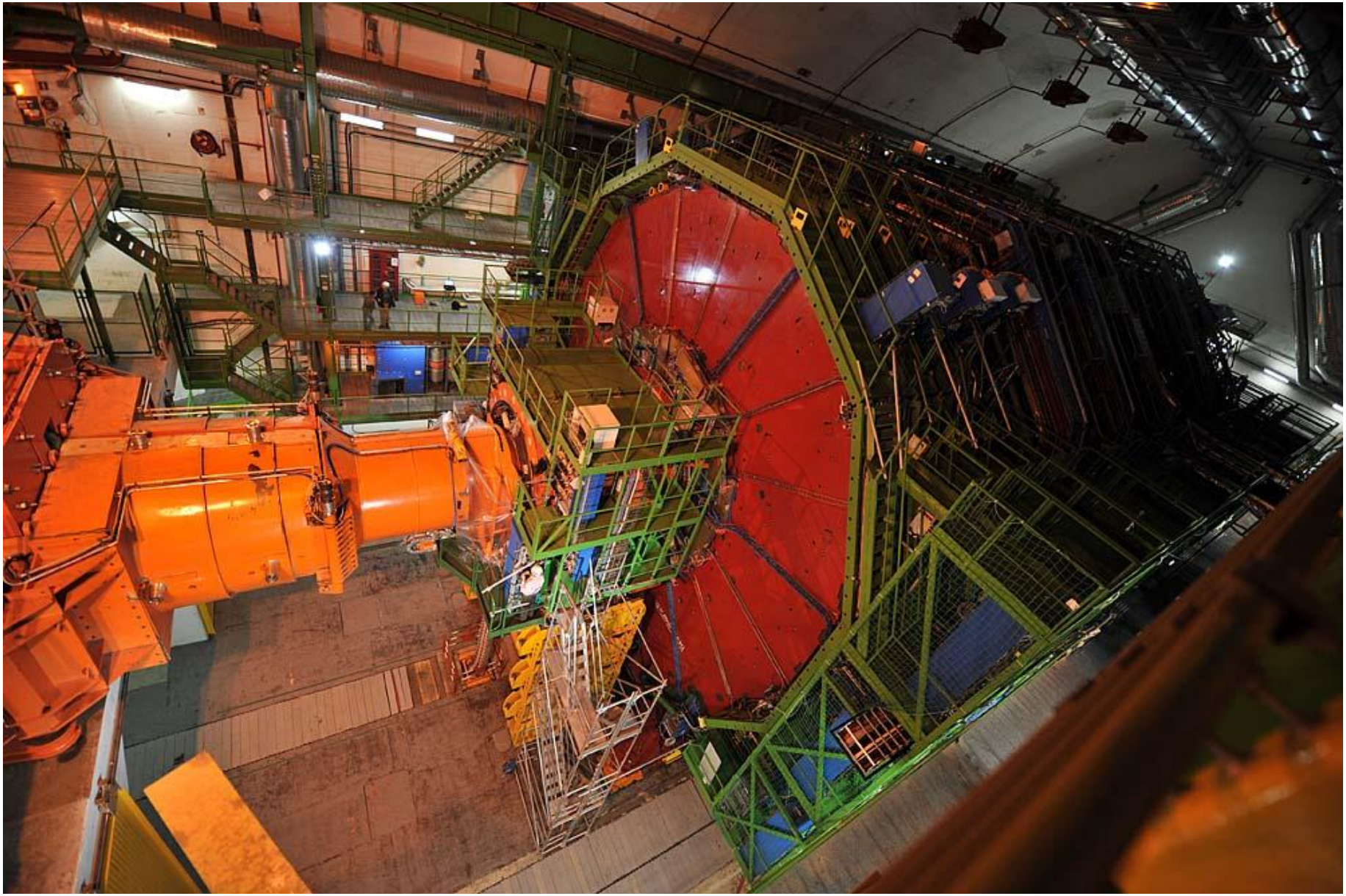
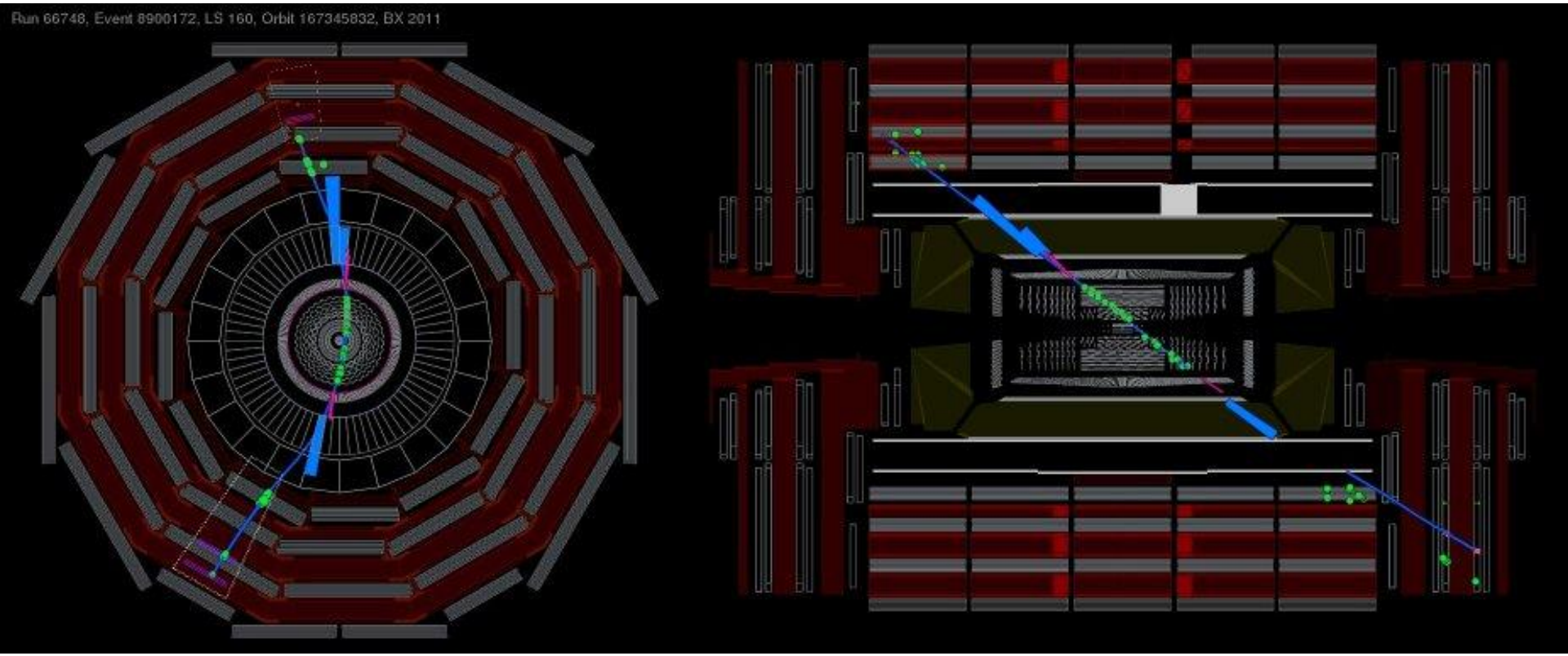
Beampipe



View from above



Final closure



CRAFT event Cosmic Ray Four Tesla 2008