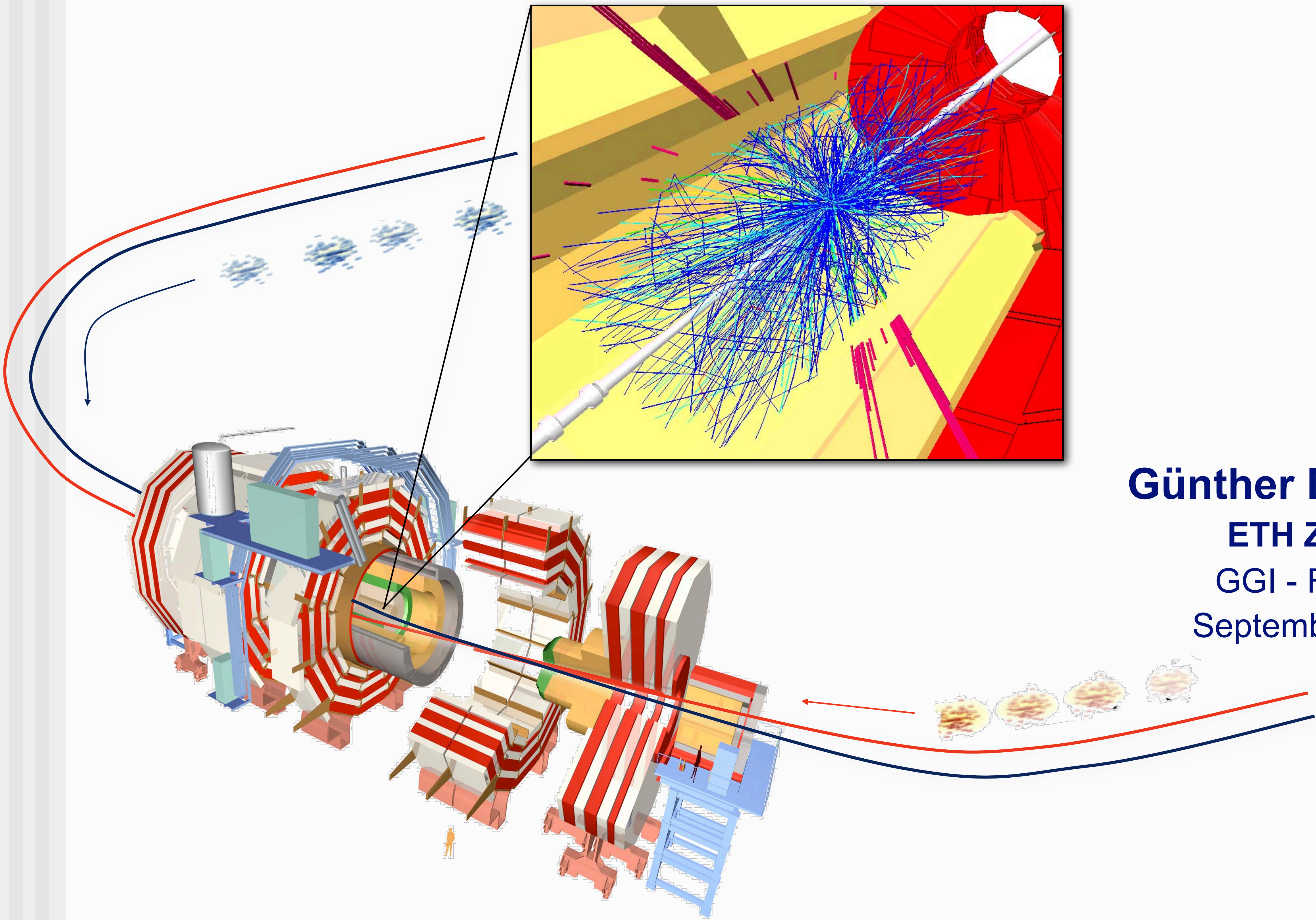
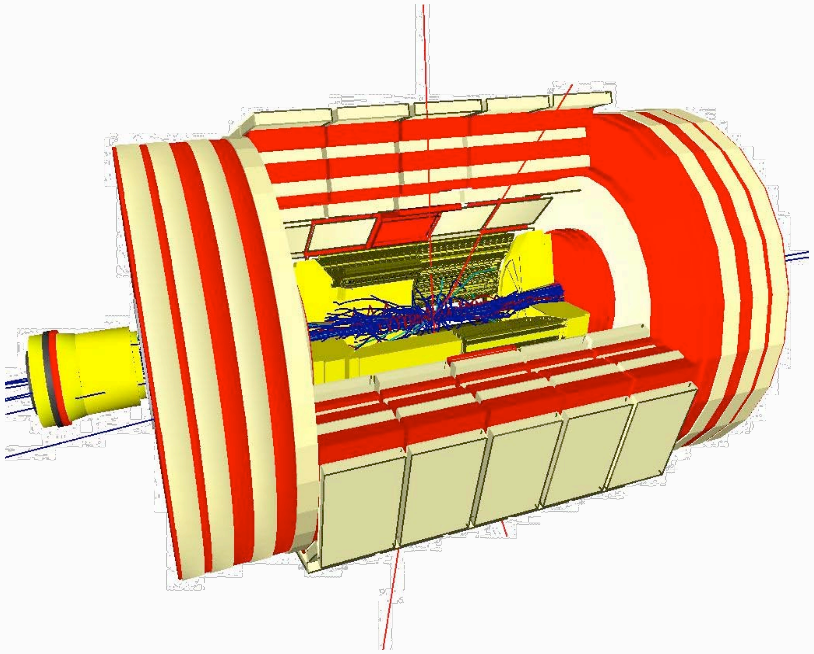
LHC Detectors : Part 2



Günther Dissertori
ETH Zürich
GGI - Firenze
September 2007

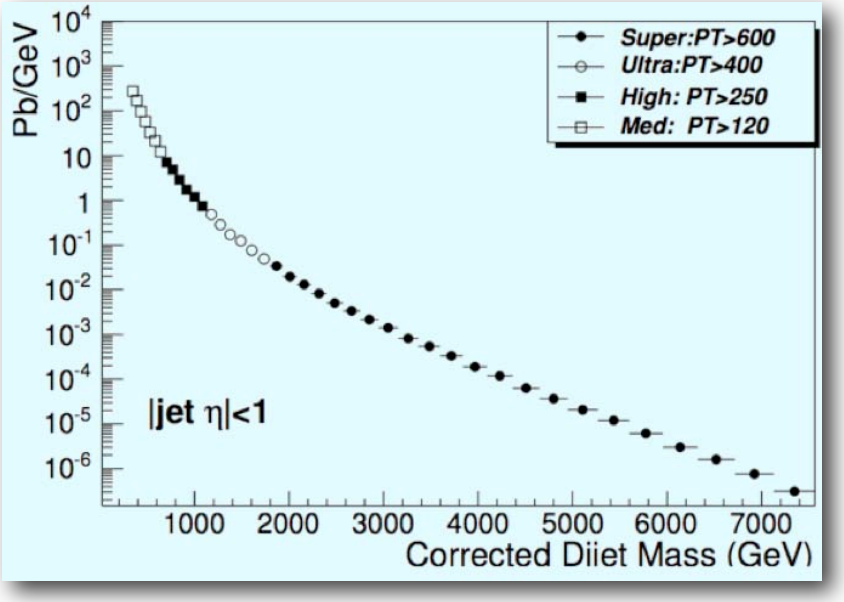
Outline

- What is measured, how and why?
  - Basic processes, rates
  - Resulting difficulties and requirements
  - Basic detector layout



- ATLAS and CMS
  - Overview
  - Construction status
  - Comparison

- Experimental issues
  - Some examples of experimental issues to be addressed
  - such as Jet Energy Calibration
  - and background estimations



Disclaimer 1 : I concentrate on multi-purpose detector ATLAS and CMS

Disclaimer 2 : Some slides or slide content taken from seminars/lectures of other LHC colleagues, eg. K. Jakobs, O. Buchmüller, L. Dixon, M. Dittmar, D. Froidevaux, F. Gianotti

The Detectors
ATLAS and CMS

ETH Institute for Particle Physics

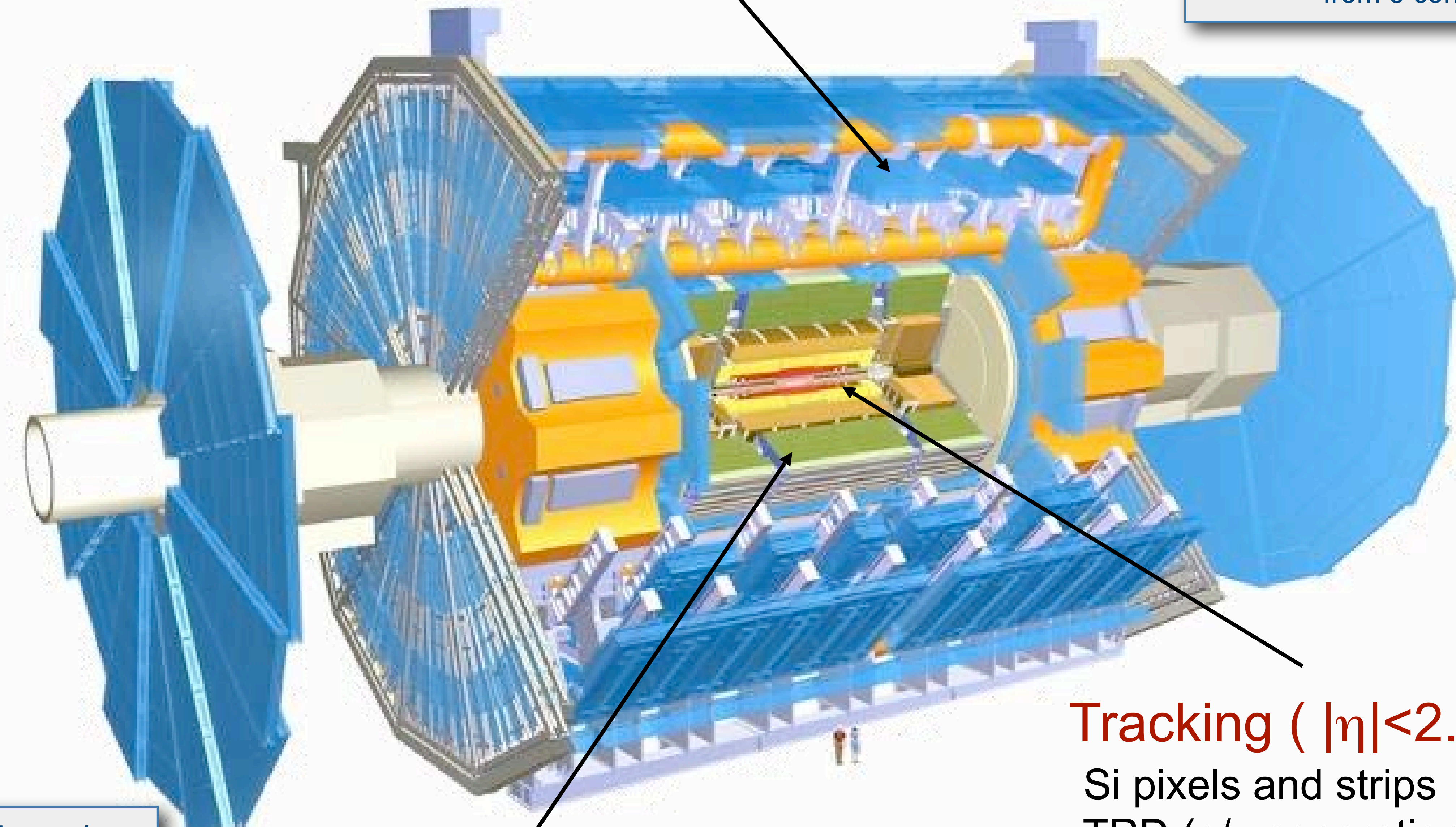
ATLAS

ATLAS

Muon Spectrometer ($|\eta|<2.7$)

air-core toroids with muon chambers

and …. 1900 physicists from
165 Institutions from 35 countries
from 5 continents



~10^8 electronic channels
~3000 km cables

Tracking ($|\eta|<2.5$, B=2T)

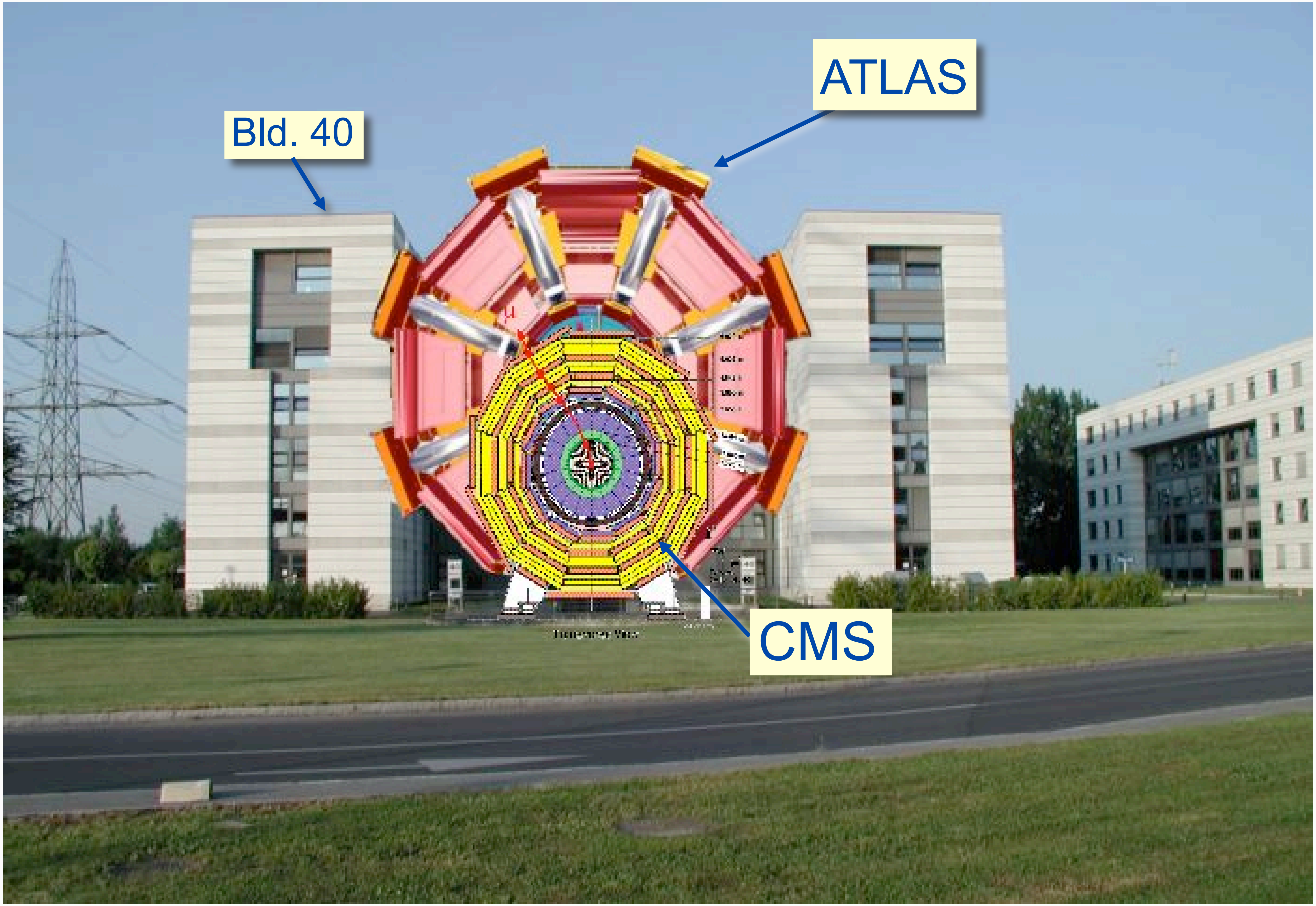
Si pixels and strips
TRD (e/π separation)

Calorimetry ($|\eta|<5$)

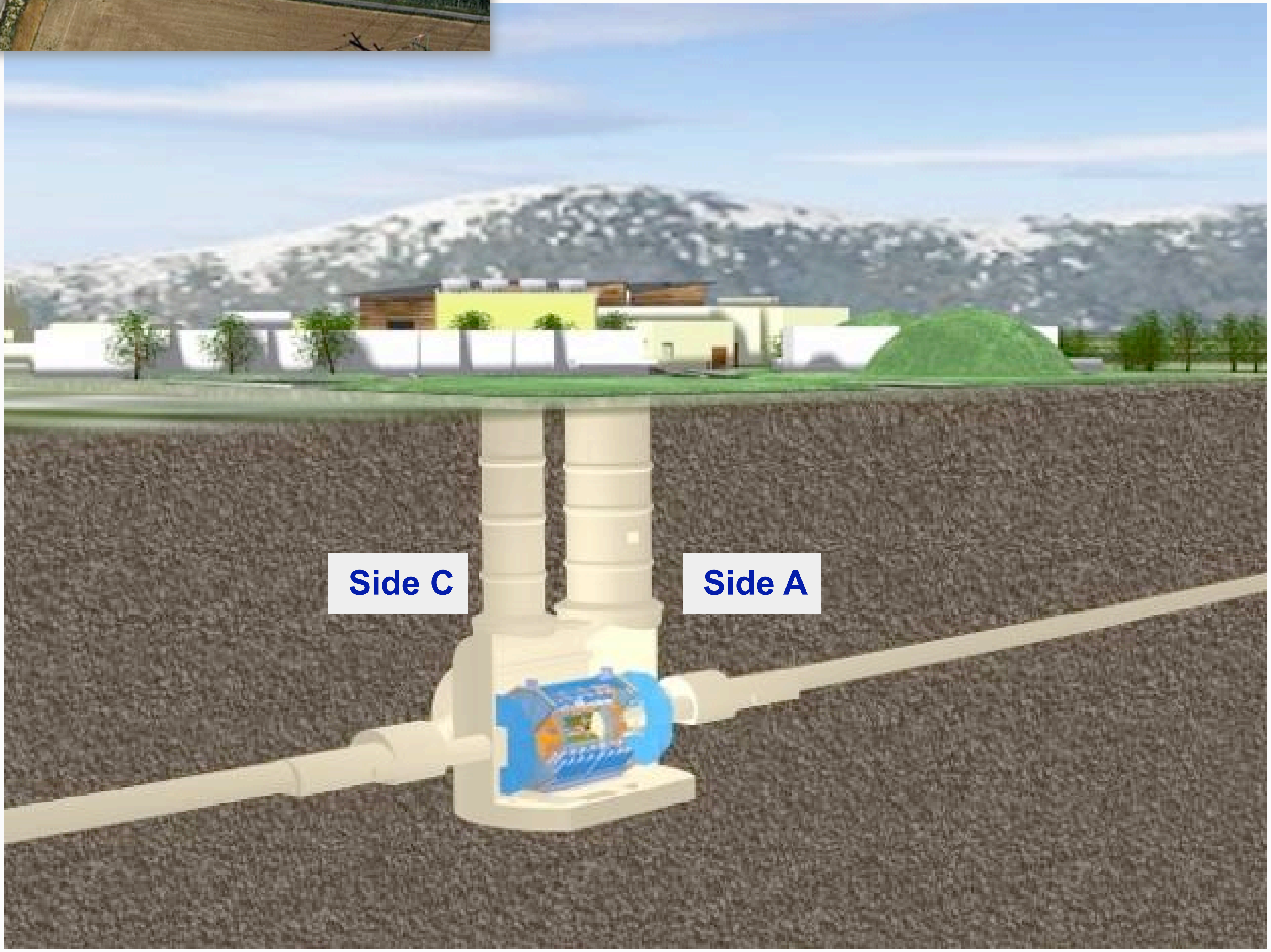
EM : Pb-LAr
HAD : Fe/scintillator (central),
Cu/W-Lar (fwd)

Diameter	25 m
Barrel toroid length	26 m
End-cap end-wall chamber span	46 m
Overall weight	7000 tons

Dimensions…



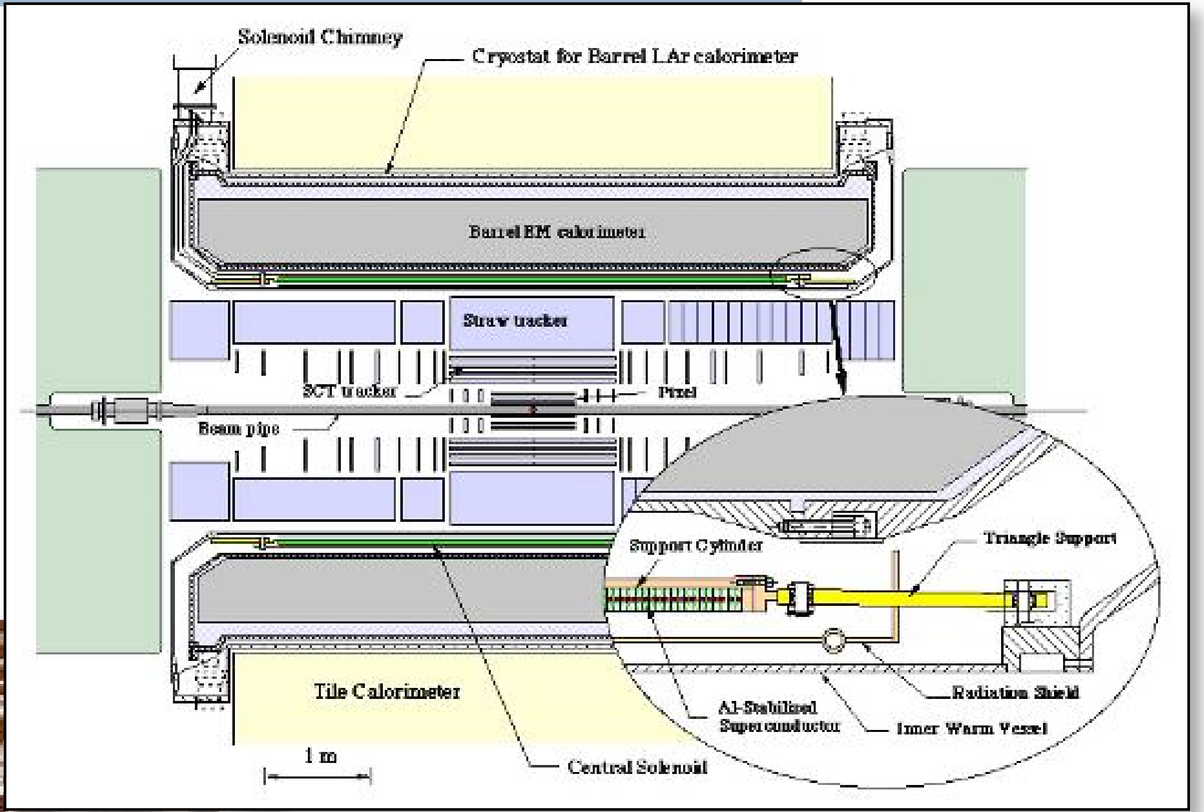
The Underground Cavern at Pit-1 for the ATLAS Detector



Length = 55 m
Width = 32 m
Height = 35 m

Magnet System : Central Solenoid

- 2T field with a stored energy of 38 MJ
- Integrated design within the barrel LAr cryostat



- Solenoid has been inserted into the Lar cryostat end Feb 04 and tested at full current (8 kA) during July 04

Solenoid

July – August 2006:

The solenoid has been fully commissioned *in-situ* up to 8.0 kA

The operation current is 7.73 kA for a field of 2.0 T

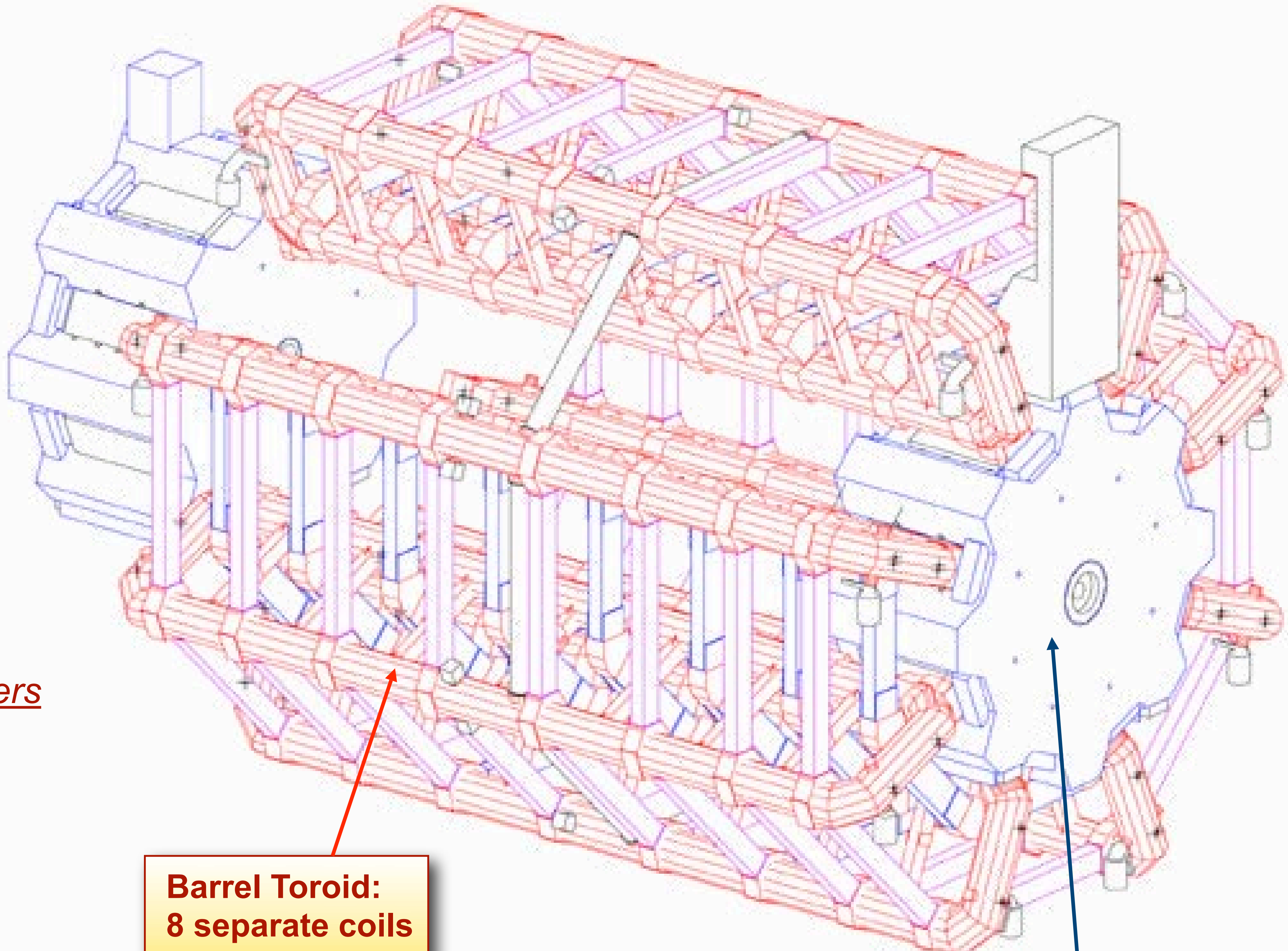
Successful accurate field mapping

1st August 2006: the solenoid is fully operational

Magnets : Toroid System

ETH Institute for Particle Physics

<u>*Barrel Toroid parameters*</u>
25.3 m length
20.1 m outer diameter
8 coils
1.08 GJ stored energy
370 tons cold mass
830 tons weight
4 T on superconductor
56 km Al/NbTi/Cu conductor
20.5 kA nominal current
4.7 K working point



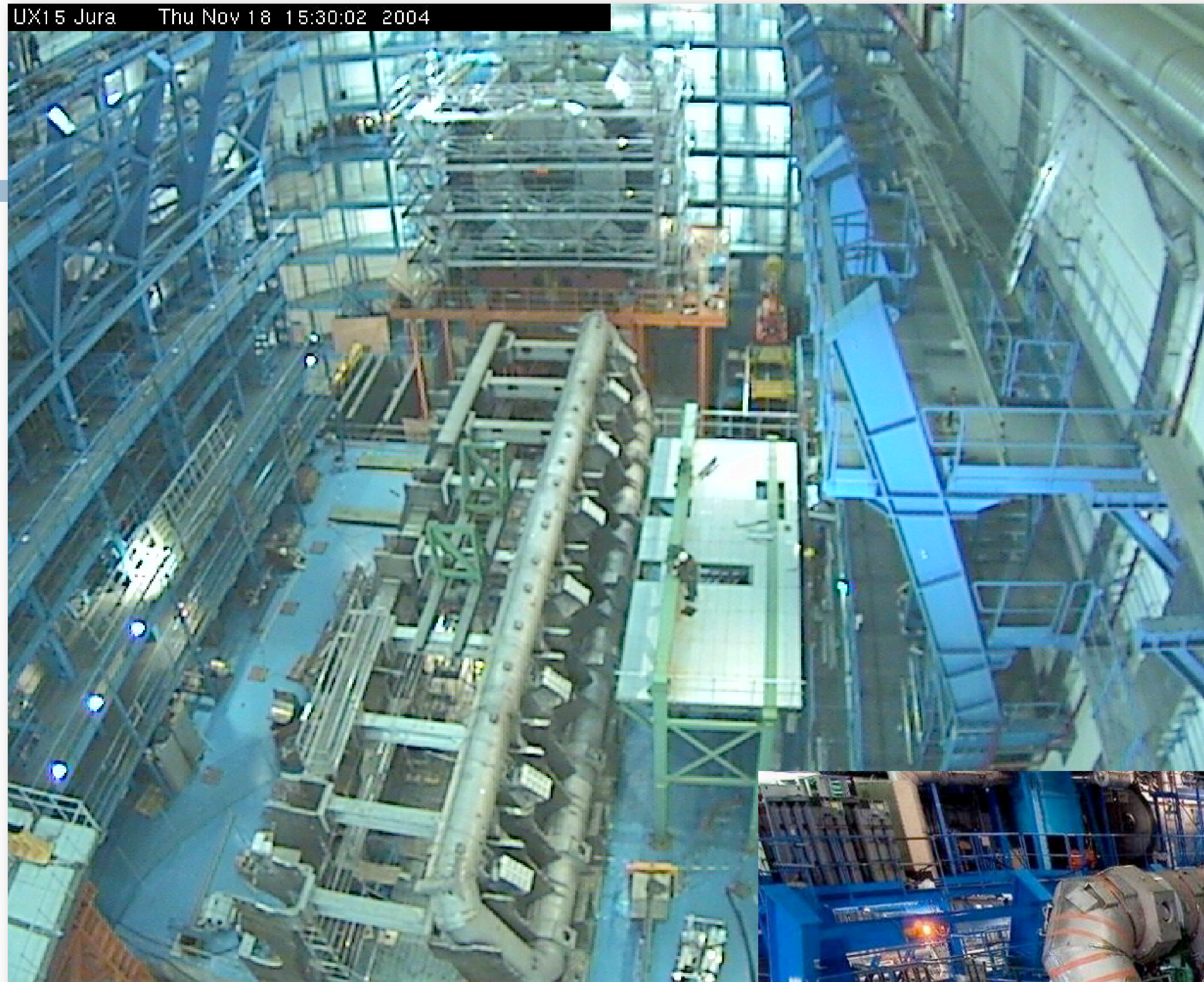
Barrel Toroid: 8 separate coils

End-Cap Toroid: 8 coils in a common cryostat

<u>*End-Cap Toroid parameters*</u>
5.0 m axial length
10.7 m outer diameter
2x8 coils
2x0.25 GJ stored energy
2x160 tons cold mass
2x240 tons weight
4 T on superconductor
2x13 km Al/NbTi/Cu conductor
20.5 kA nominal current
4.7 K working point

Barrel Toroid coil transport…

…and lowering into the
underground cavern



The first coil was installed in October 2004

The last coil was moved into position on 25th August 2005

… and tested!

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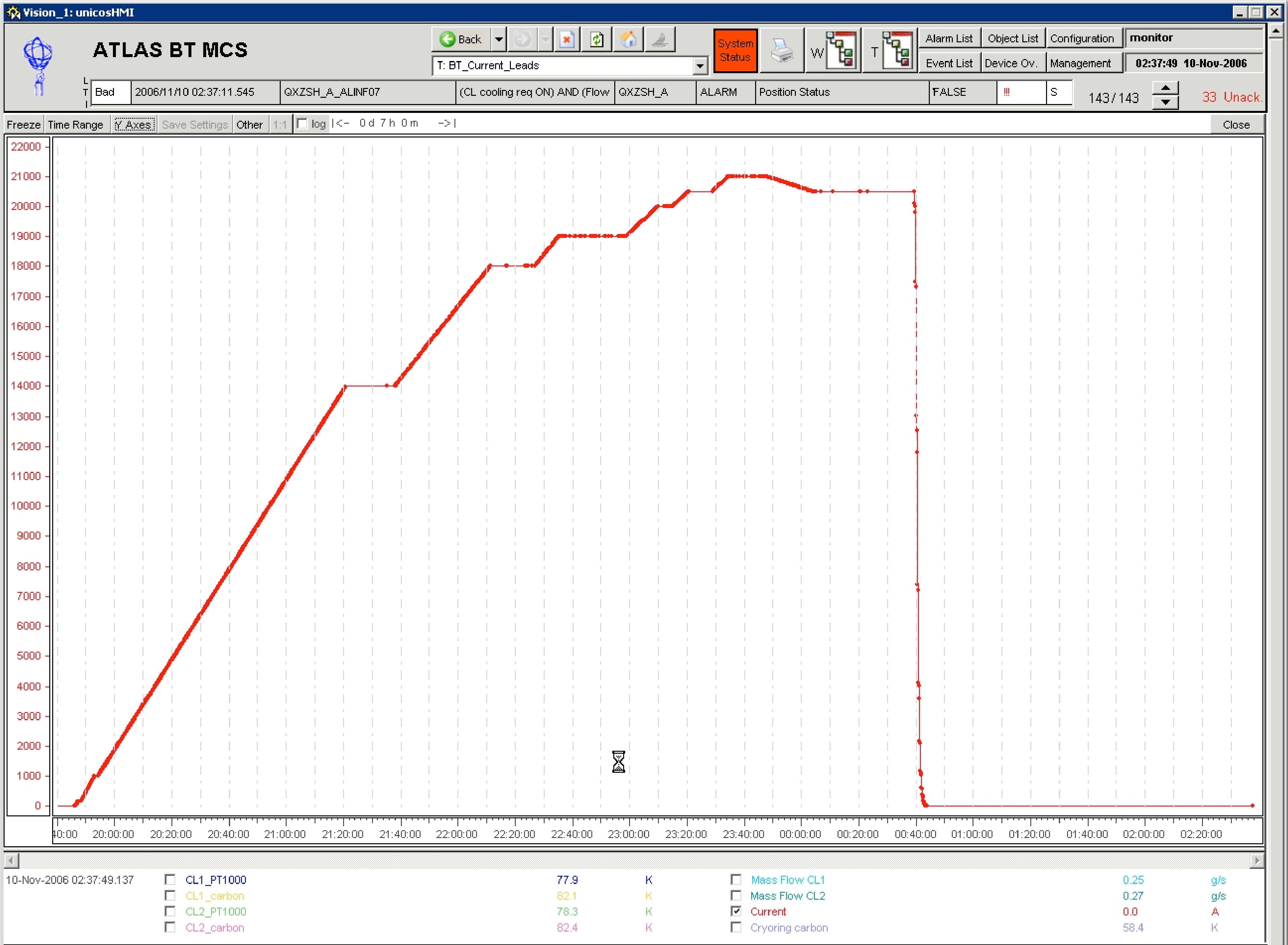
9 November 2006



In steps to 20.5 kA nominal current, to 21kA to prove margin, back to 20.5 kA, provoke quench, fast dump, very safe operation demonstrated!

ATLAS : most famous picture

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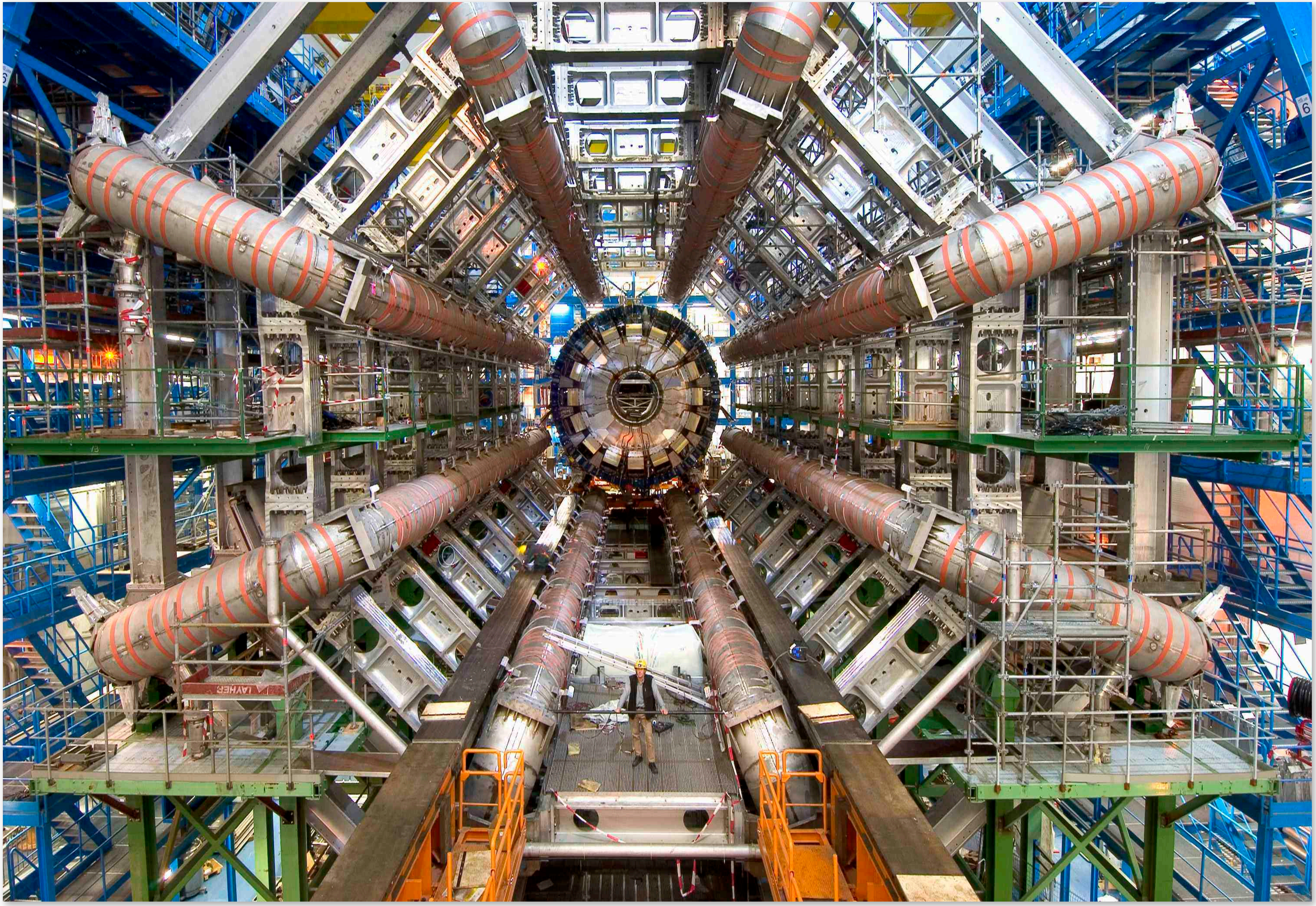
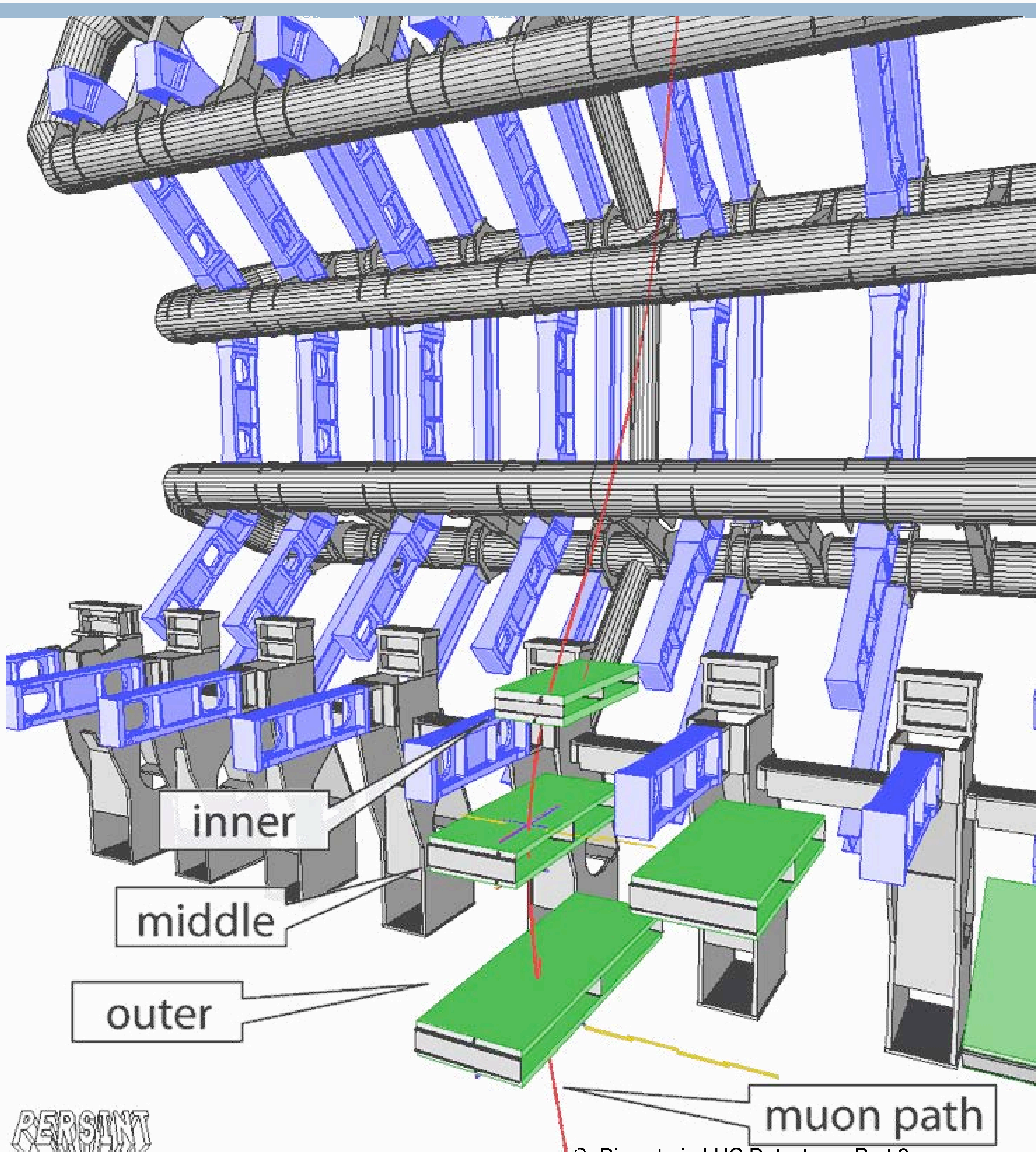


First bent muons seen!

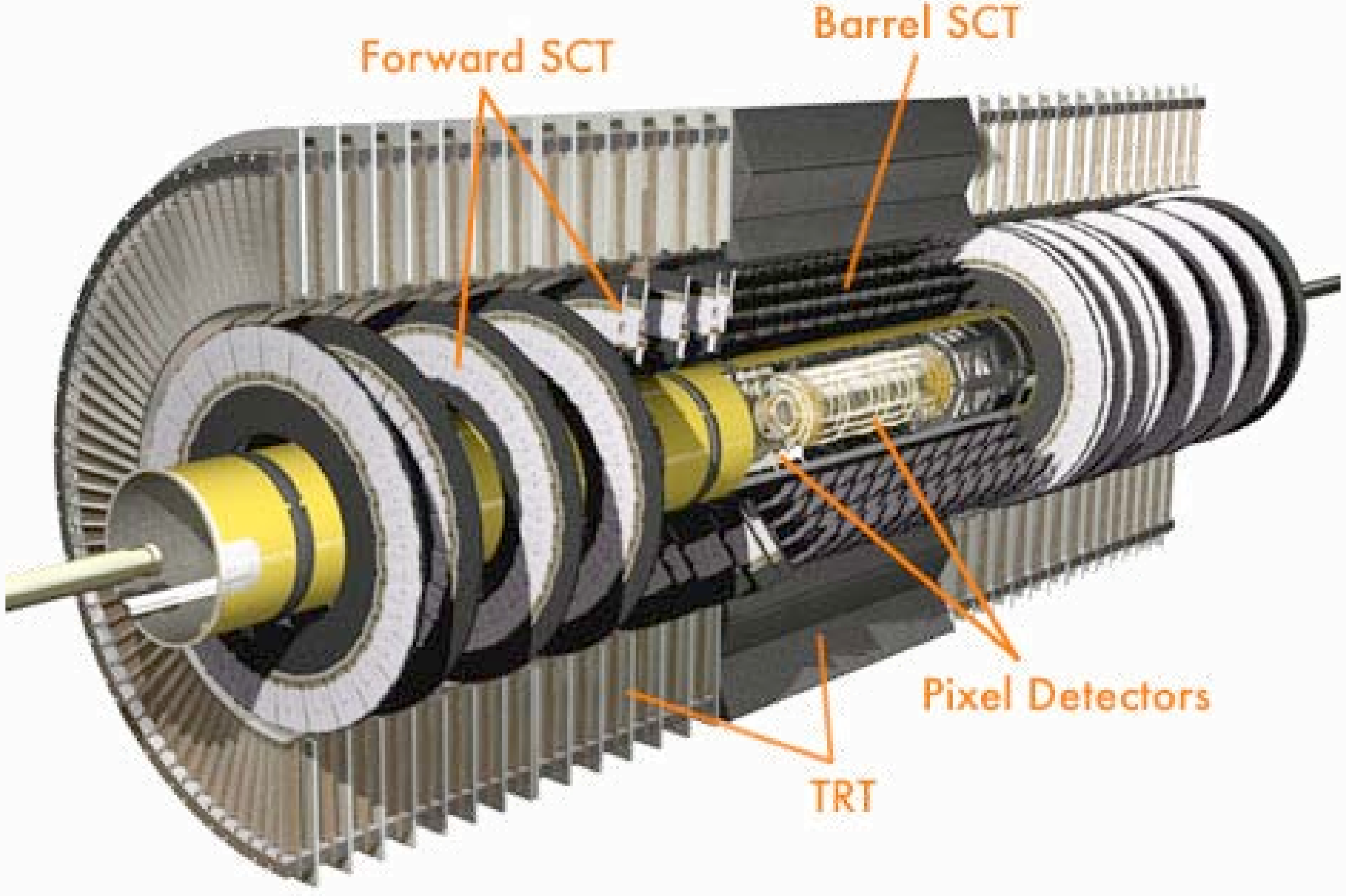


During stability test of the barrel toroid 18-19 Nov 06

7m

Inner Detector

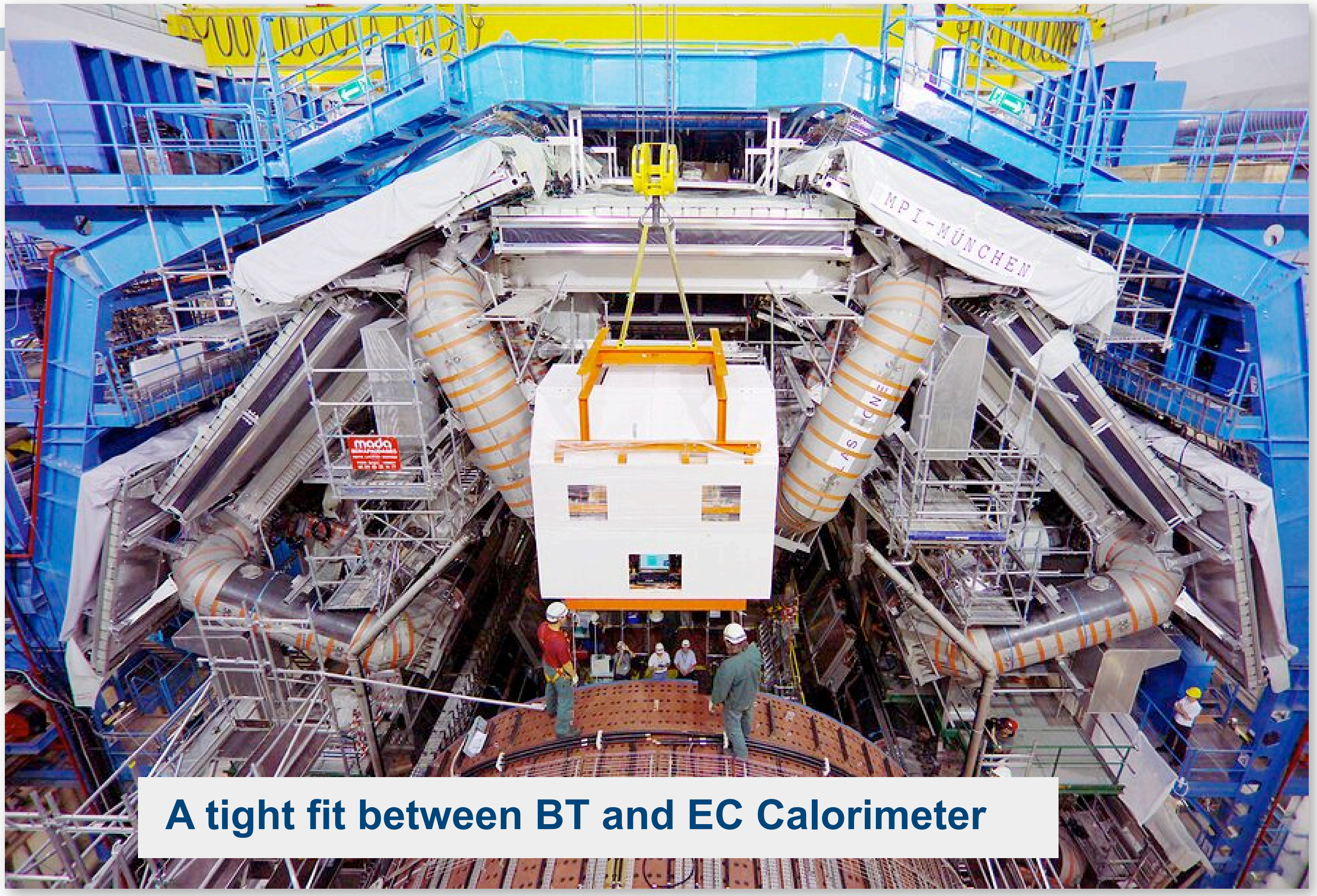
- The Inner Detector (ID) is organized into four sub-systems:



- Pixels (0.8 10^8 channels)
- Silicon Tracker (SCT) (6 10^6 channels)
- Transition Radiation Tracker (TRT) (4 10^5 channels)
- Common ID items

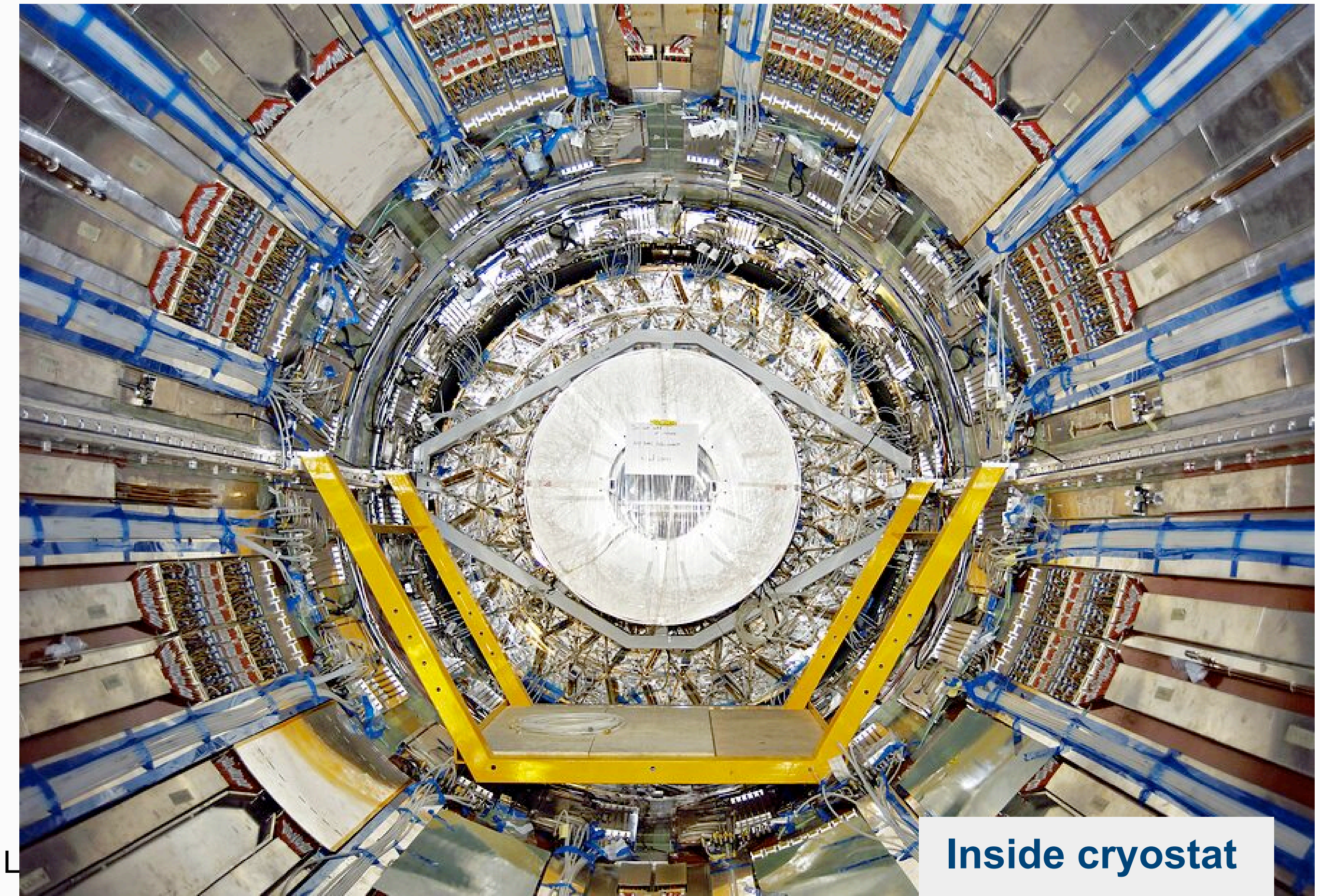
TRT+SCT barrel traveled to the pit, 24th Aug 2006

Through the parking area



A tight fit between BT and EC Calorimeter

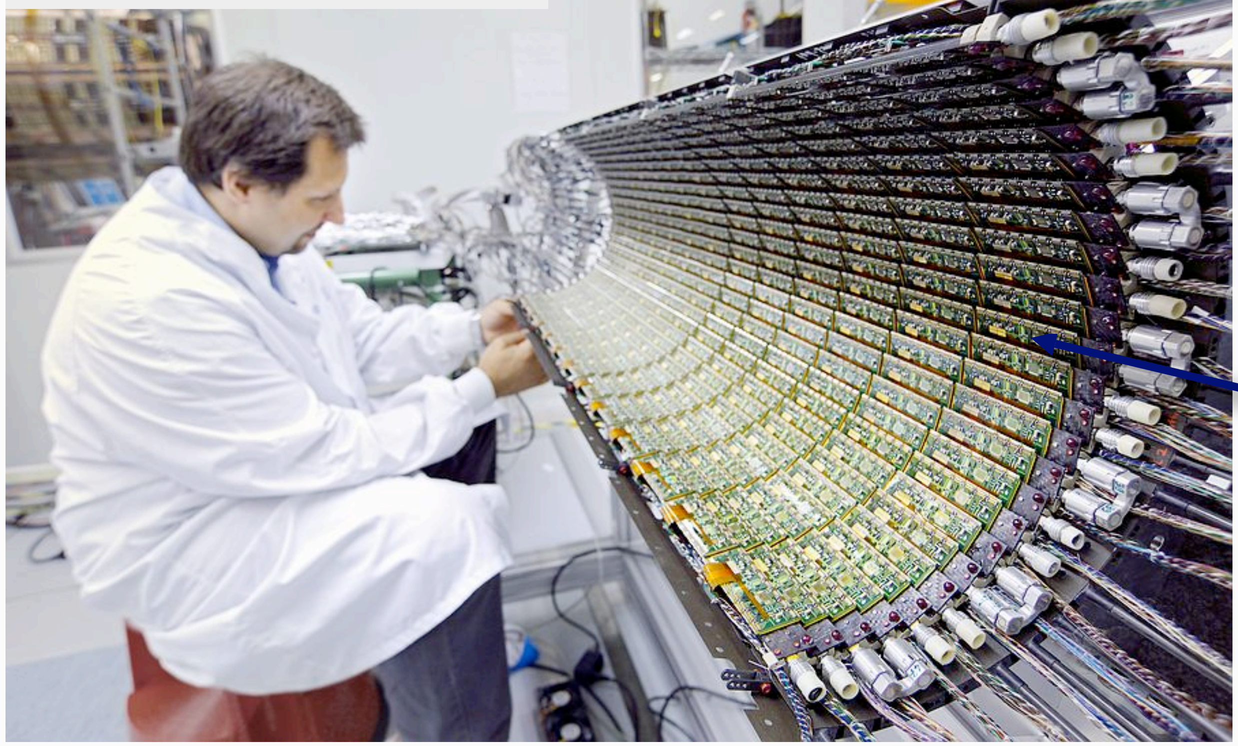
From the trolley to the support rails



Inside cryostat

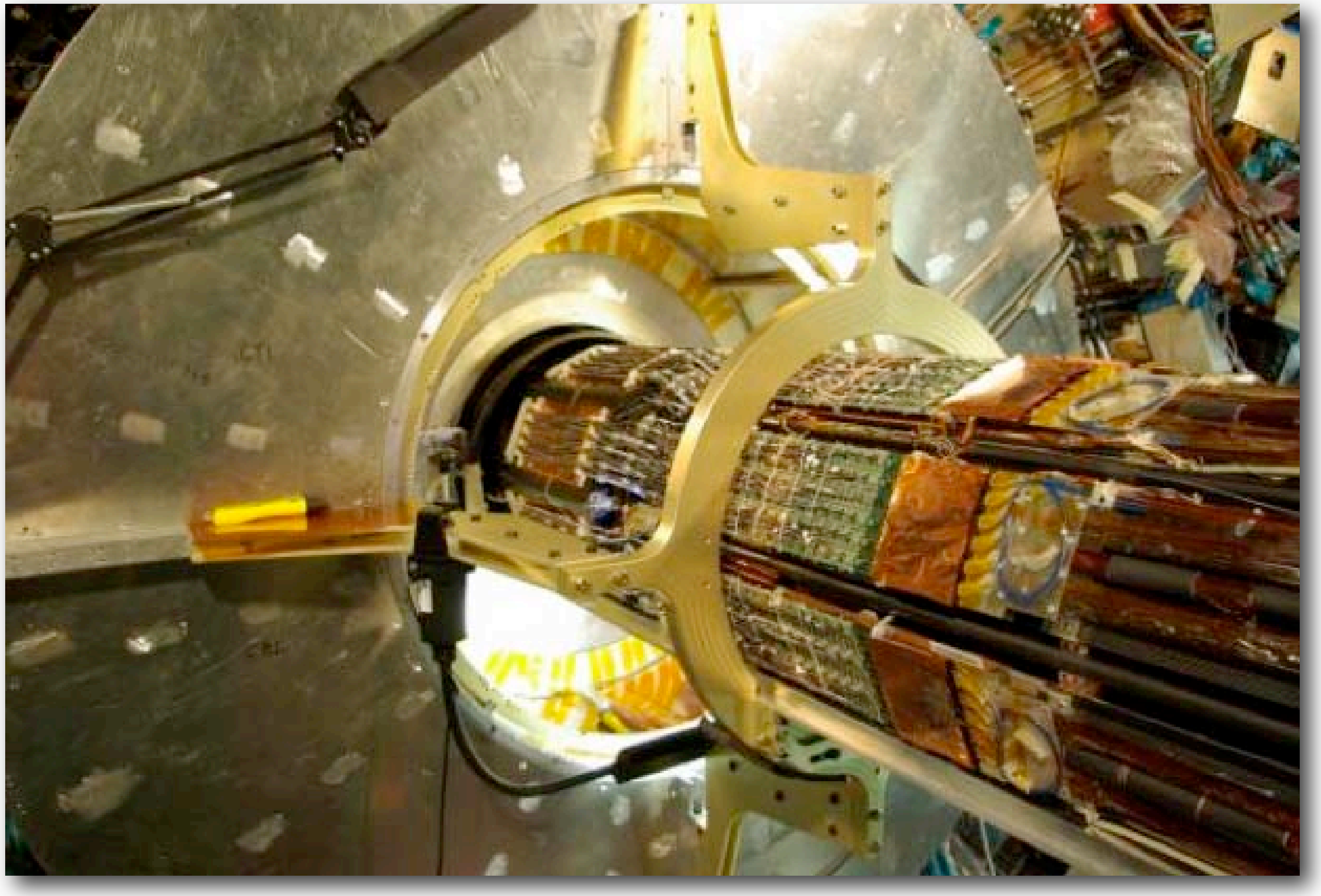
Pixel Detector

Pixel Layer-2 – half shell



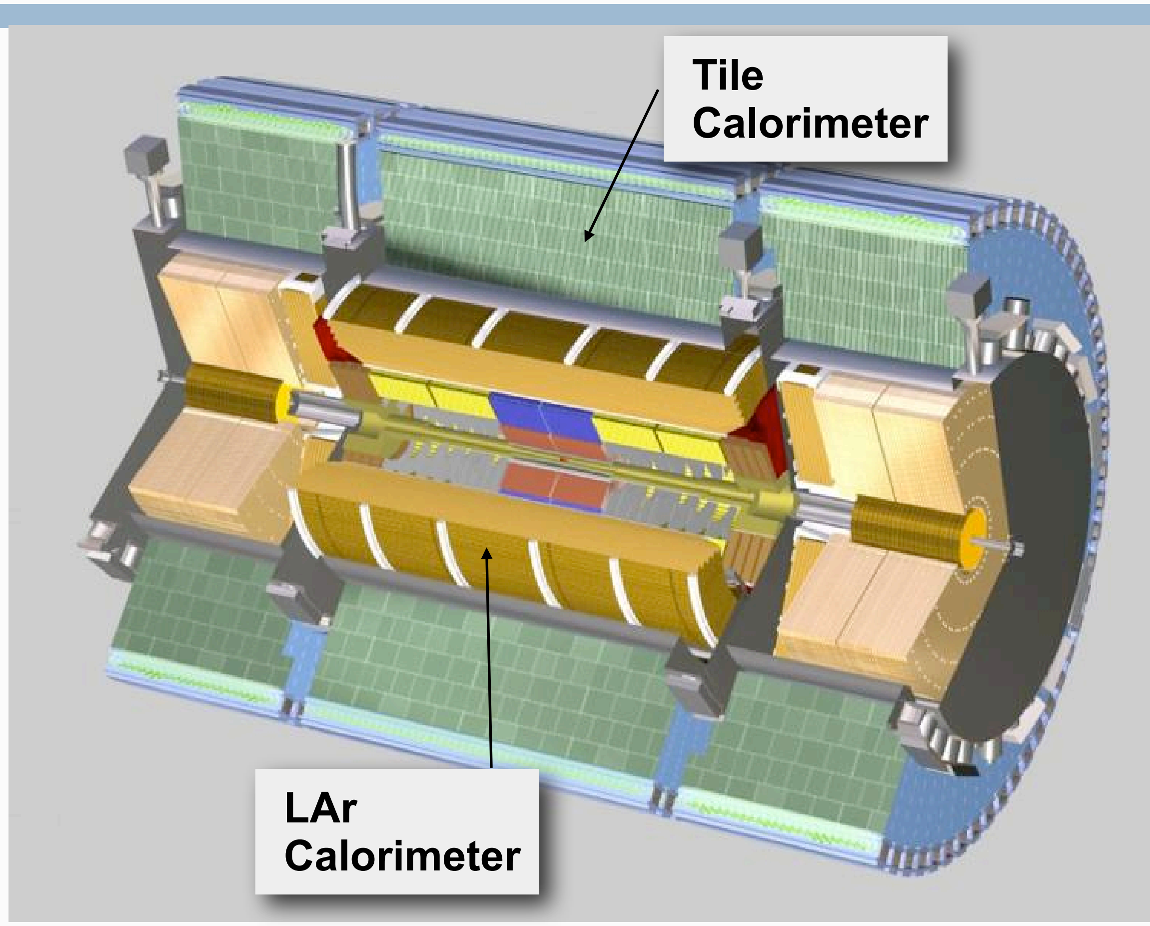
- All modules delivered with good yield
- Both EC integrated
- All barrel cylinders integrated

Each one of these modules contains ~45000 pixel sensors

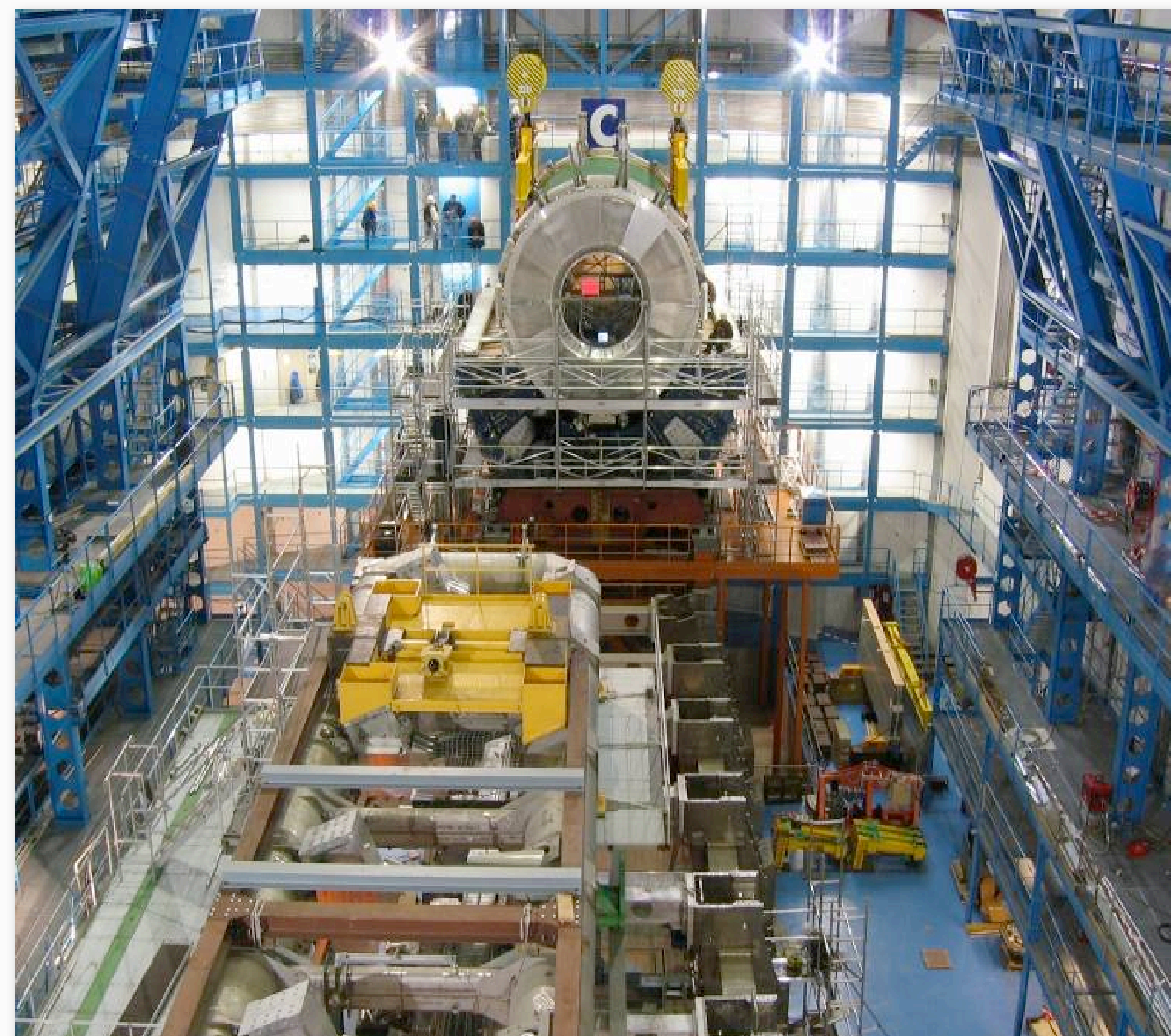


Pixel (+ beam pipe) insertion June 2007

LAr and Tile Calorimeters



- Oct 2004 : Barrel cryostat transported to the pit and lowered…

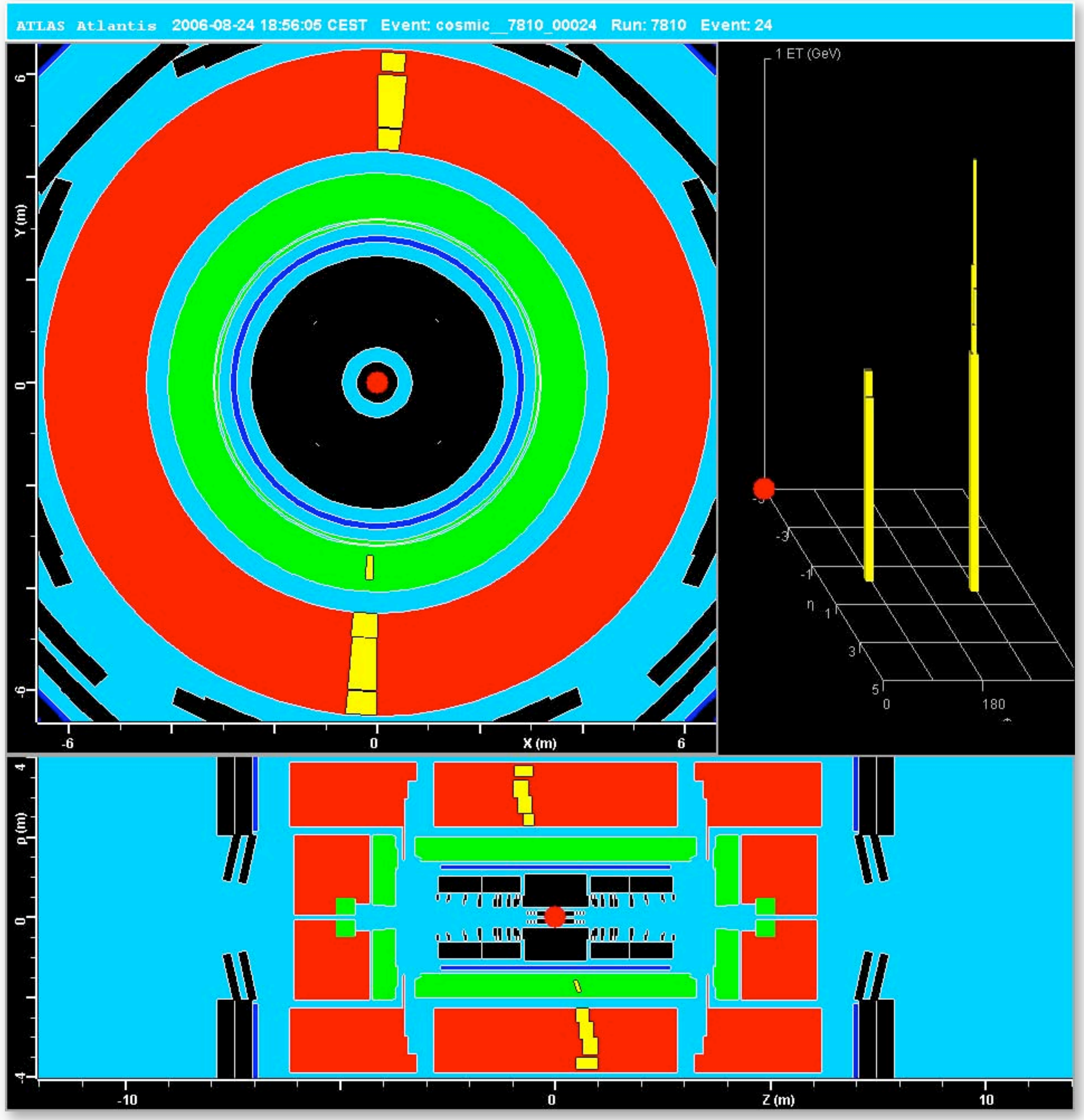


Barrel LAr and Tile Calorimeters

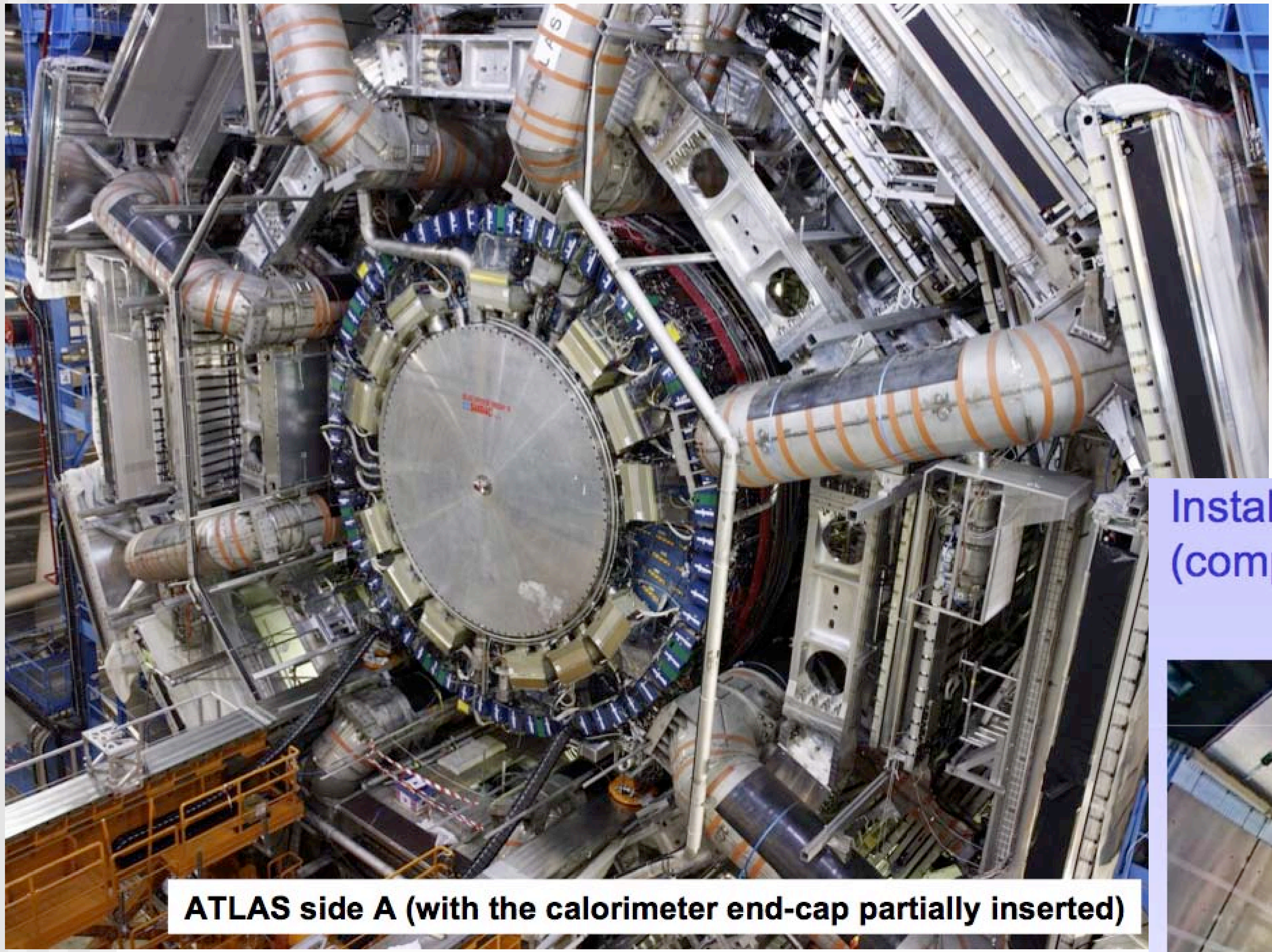
The barrel calorimeters are in their final position at the centre of the detector since November 2005

The final cool-down of the LAr cryostat took place over April and May 2006

Calorimeter barrel after its move into the center of the detector (4th November 2005)

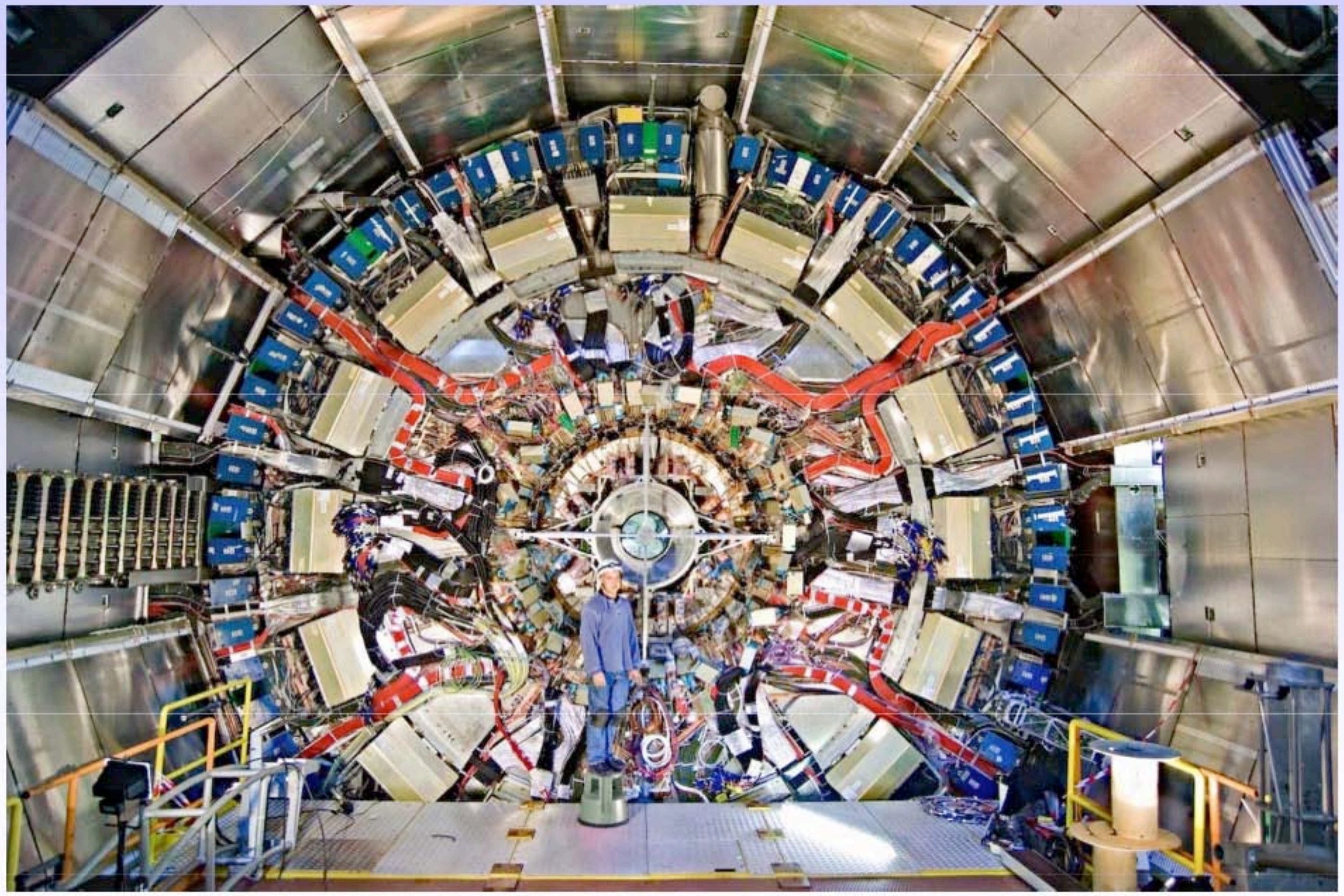


ATLAS : Preparations



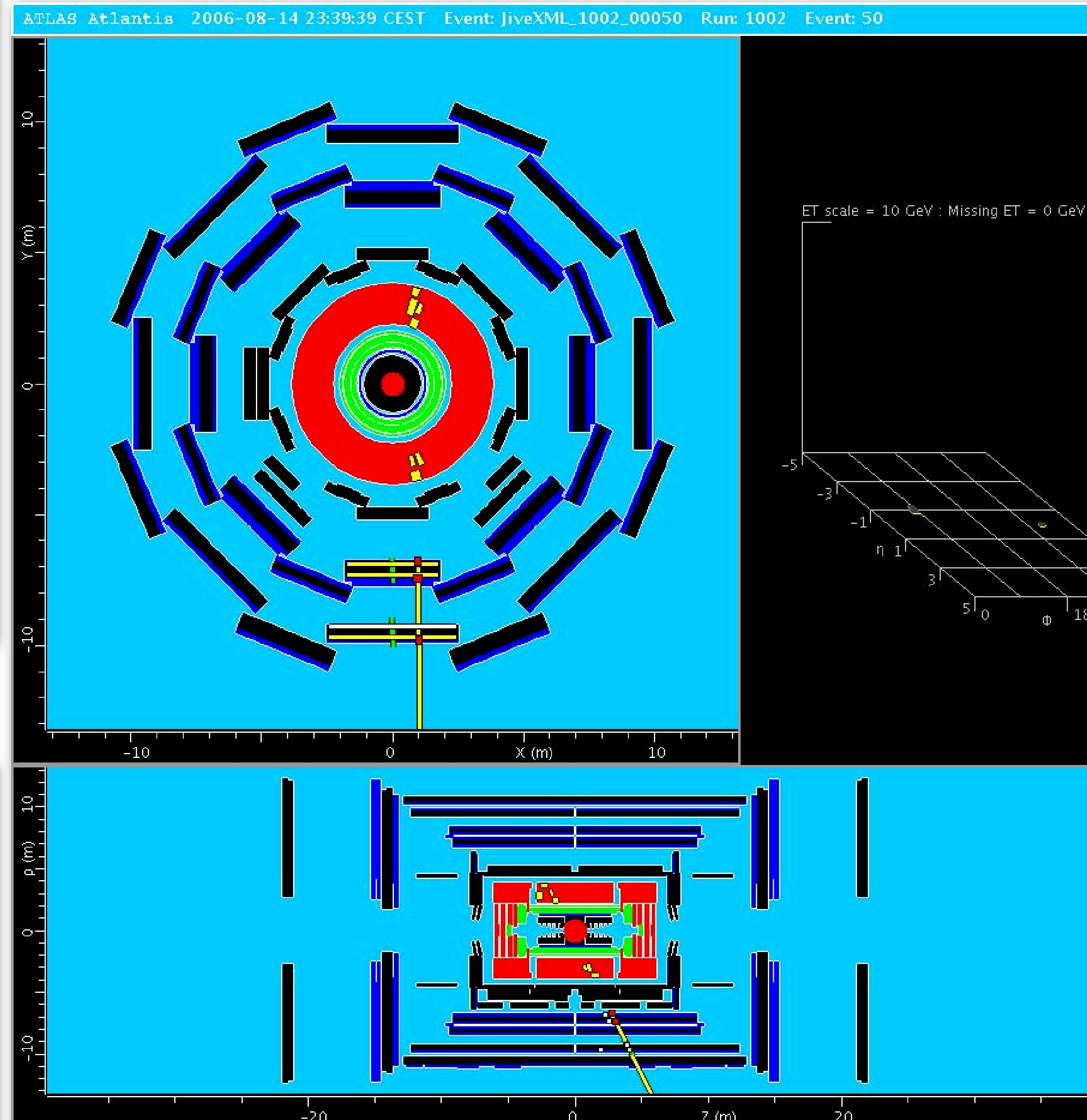
ATLAS side A (with the calorimeter end-cap partially inserted)

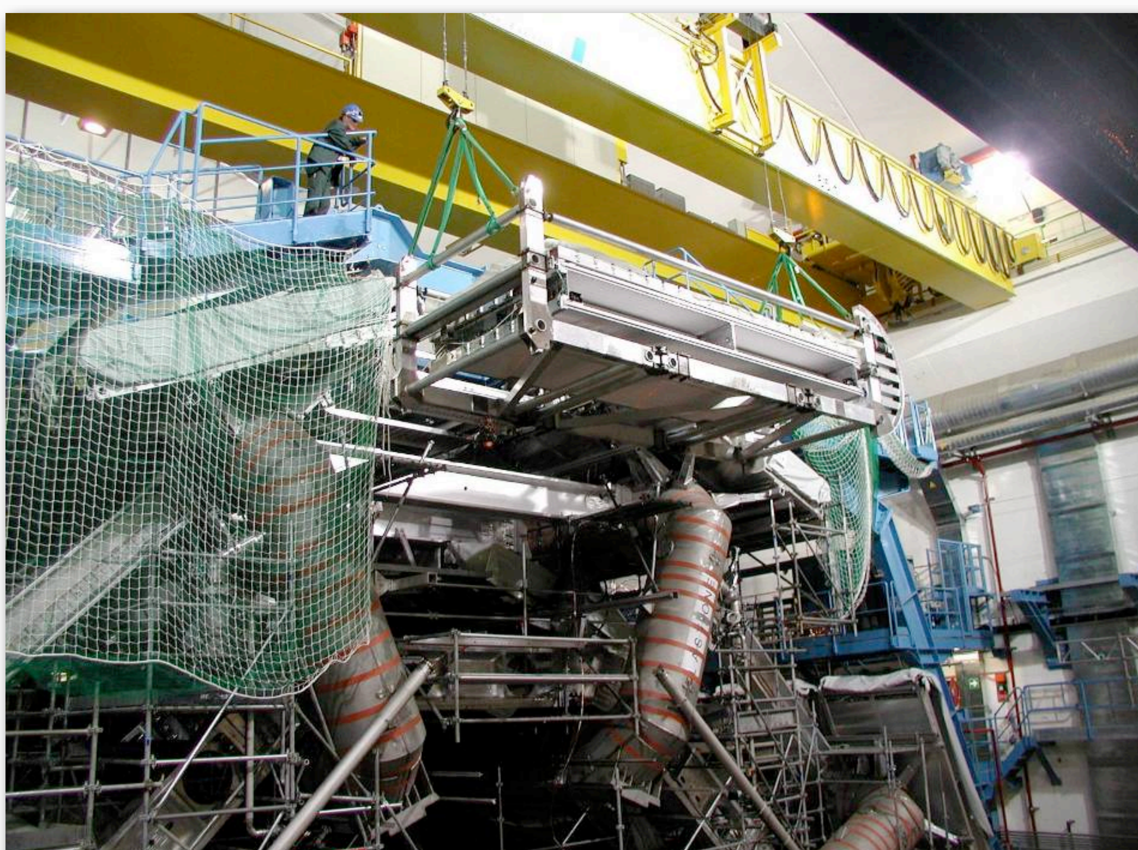
Installation of one of the ATLAS Endcap Tracking Detectors (completed on 29. May 2007)



Muon Stations : Barrel

Installation of barrel muon chambers (~700) started in Nov 2005 and is ~ completed

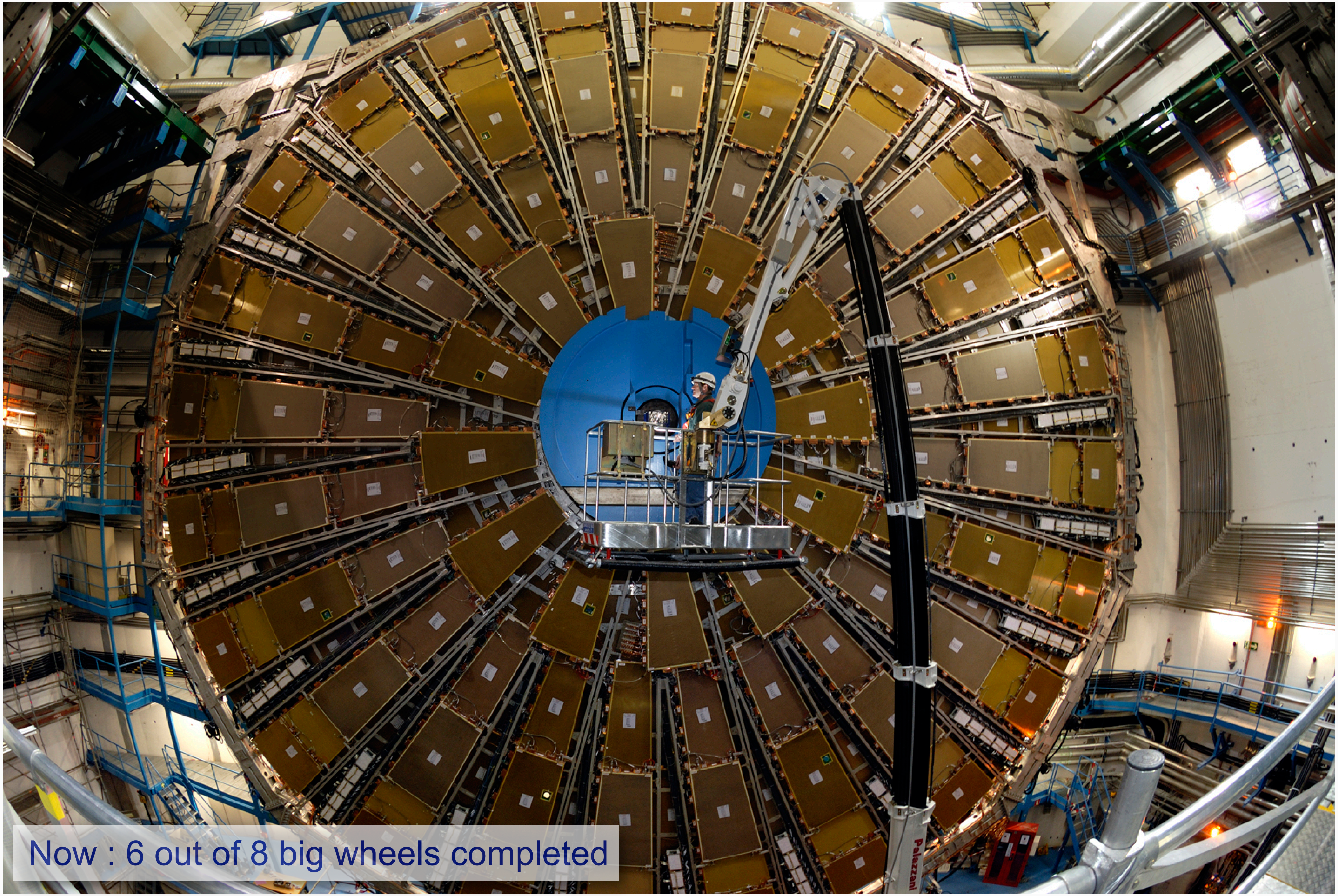




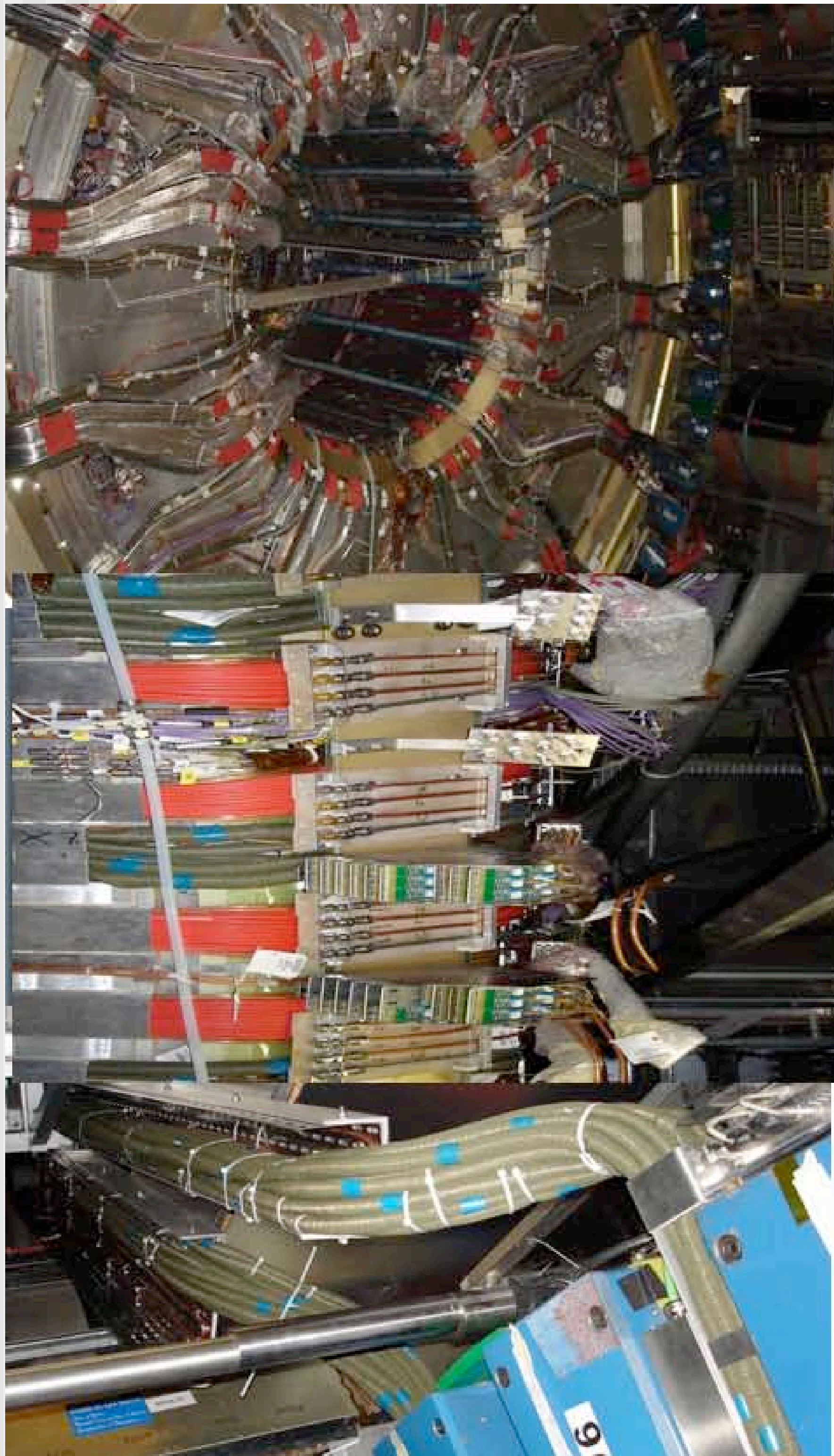
August 2006 :
first combined MDT + RPC + Tile Calorimeter cosmic ray muon run

Muon Stations : Endcaps

First TGC ‘Big-Wheel’ assembled in the cavern early September 2006.



ATLAS : Cabling



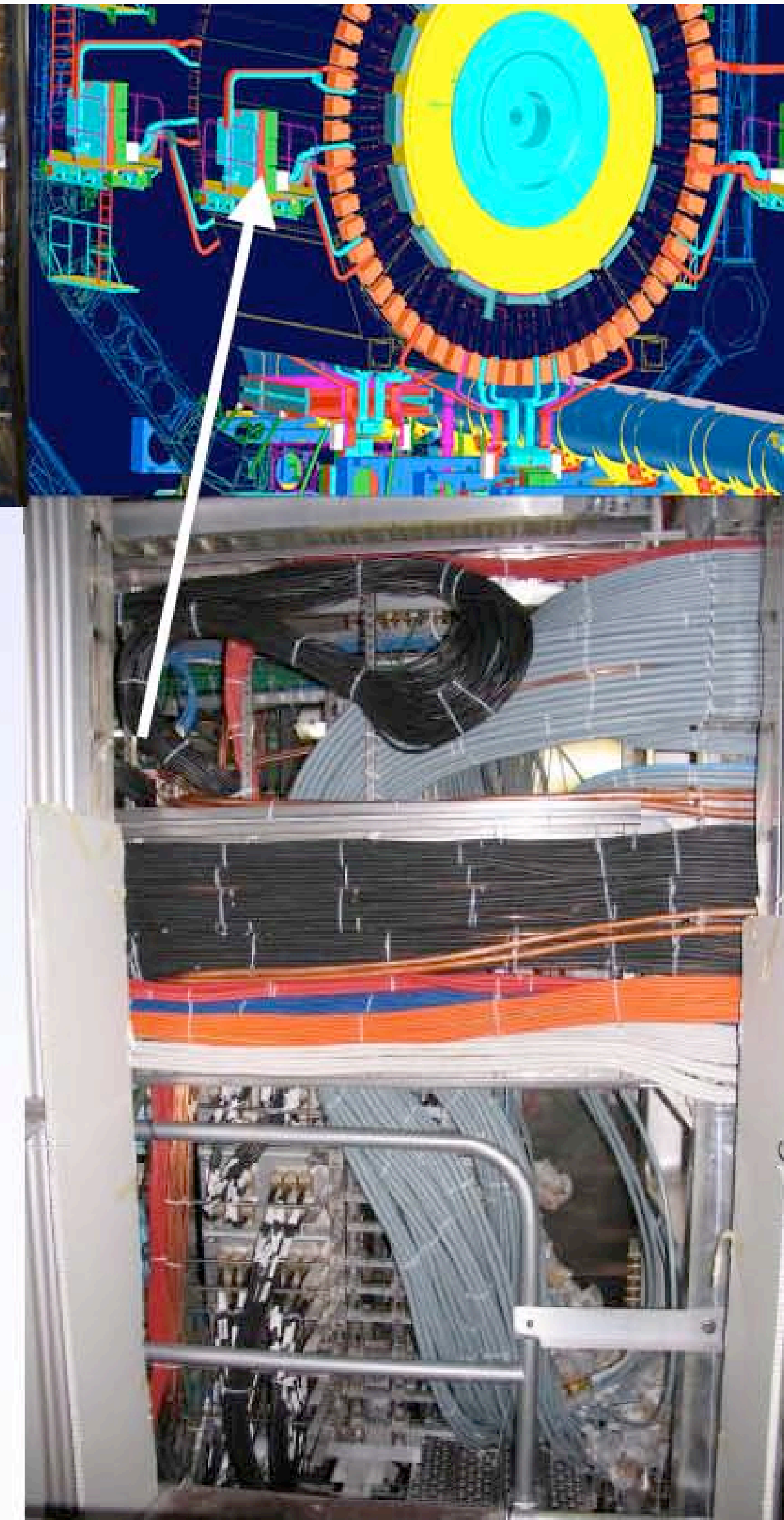
~ 800 man-months of installation work over

~18 months, ~ 45 people involved/day

- ✓ ~ 9300 SCT cable-bundles
- ✓ ~ 3600 pixel cable-bundles
- ✓ ~ 30100 TRT cables
- ✓ ~ 2800 cooling & gas pipes

All tested and qualified

K. Jakobs, CSS07



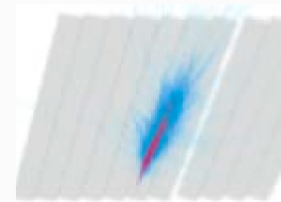
Similar huge effort in CMS....

CMS

Compact Muon Solenoid

ETH Institute for Particle Physics

Superconducting Coil, 4 Tesla



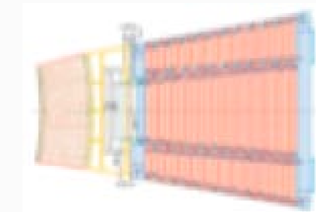
CALORIMETERS

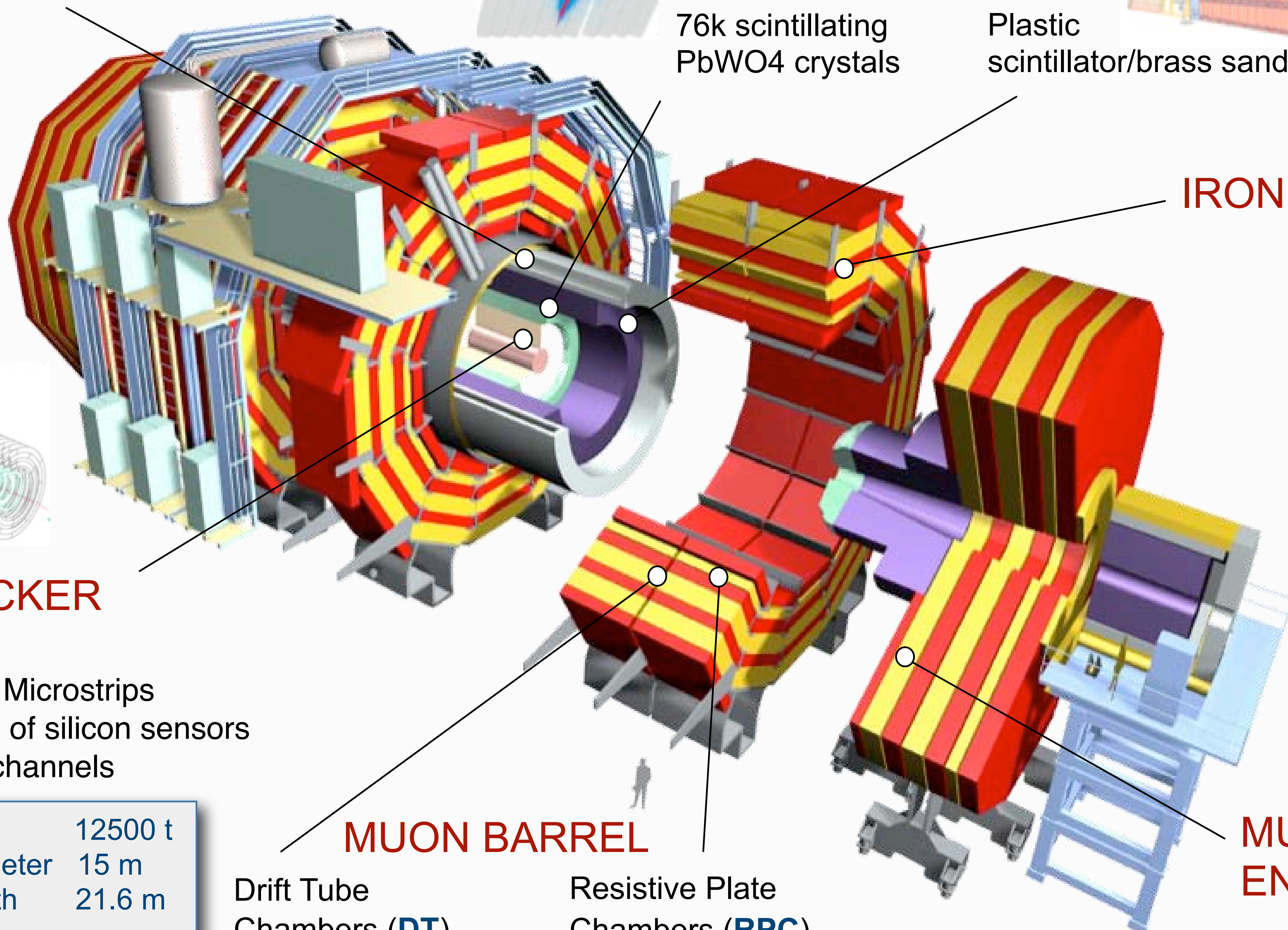
ECAL

76k scintillating PbWO4 crystals

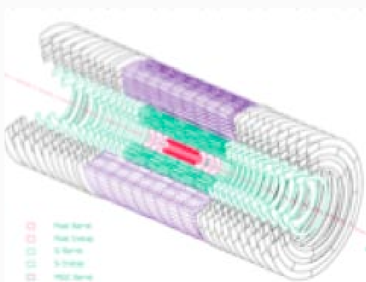
HCAL

Plastic scintillator/brass sandwich





IRON YOKE



TRACKER

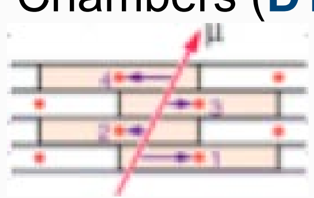
Pixels
Silicon Microstrips
210 m^2 of silicon sensors
9.6 M channels

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

2900 scientists from
182 Institutes from
38 countries

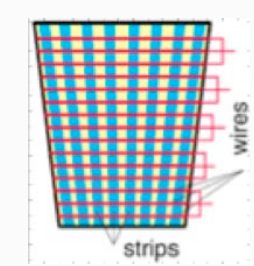
MUON BARREL

Drift Tube Chambers (**DT**)



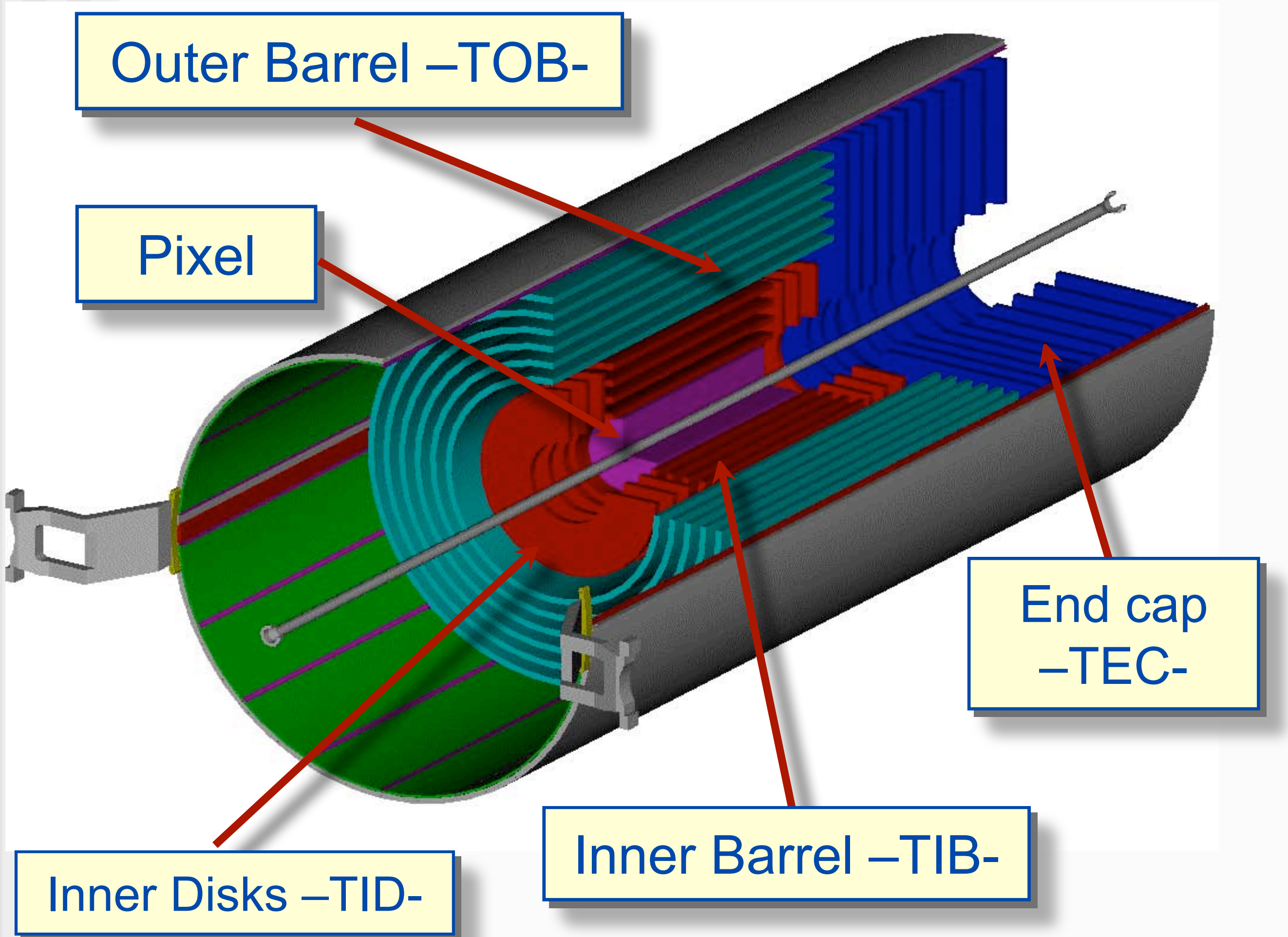
Resistive Plate Chambers (**RPC**)

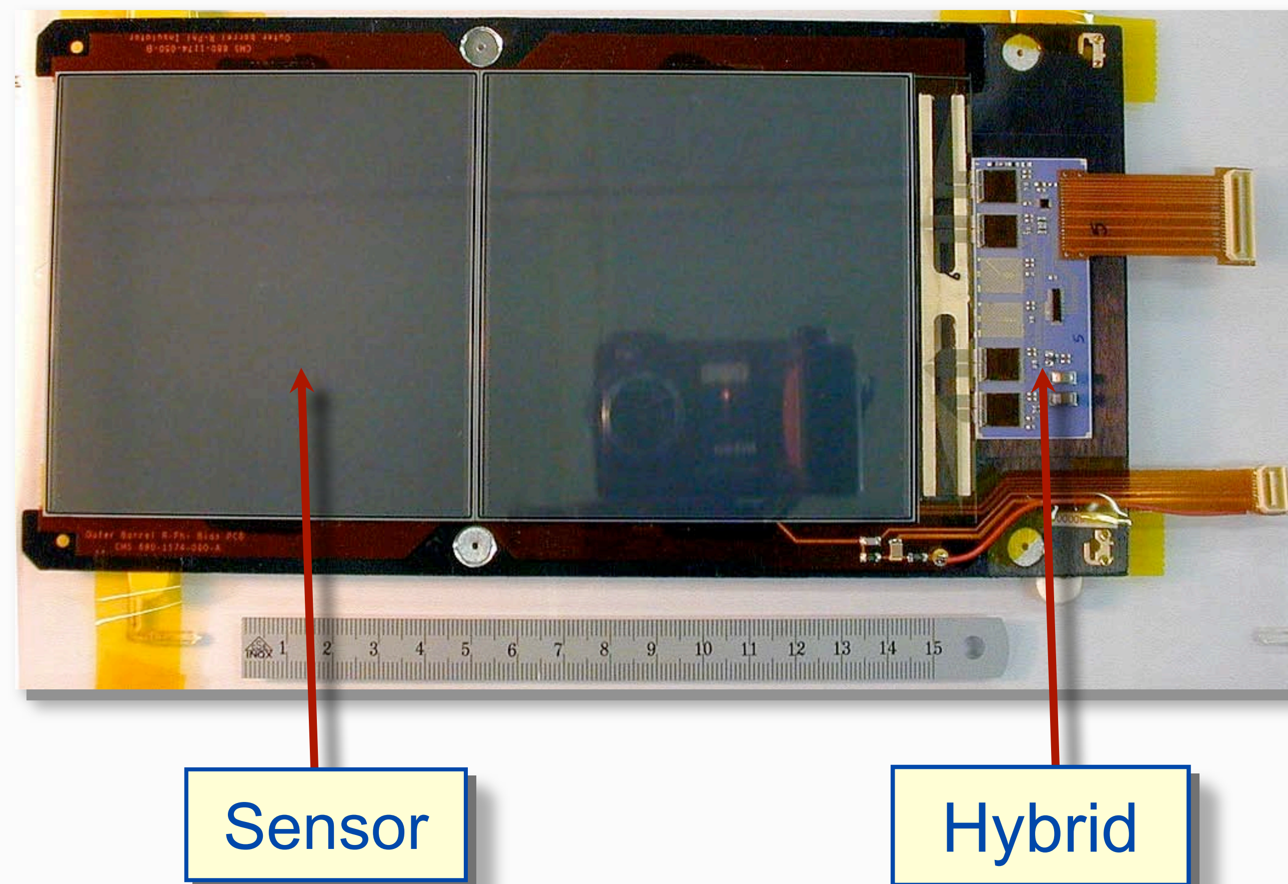
MUON ENDCAPS



Cathode Strip Chambers (**CSC**)
Resistive Plate Chambers (**RPC**)

Tracker



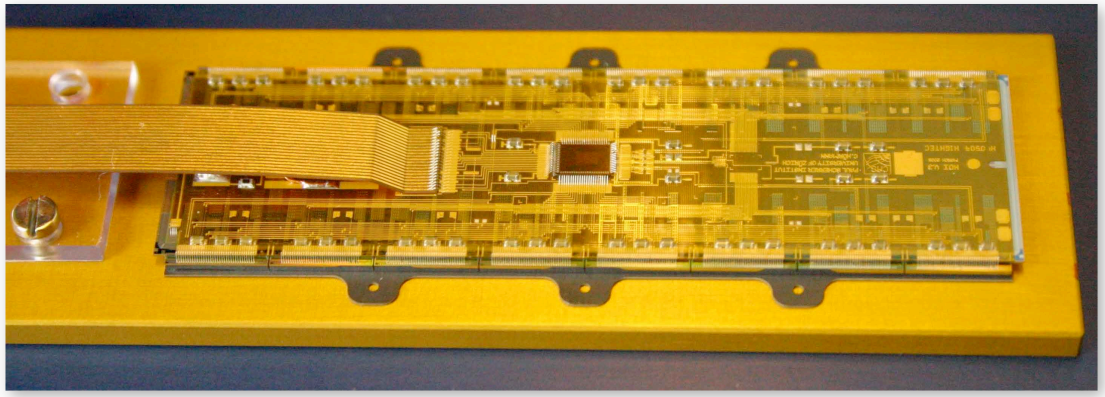


210 m^2 of silicon sensors

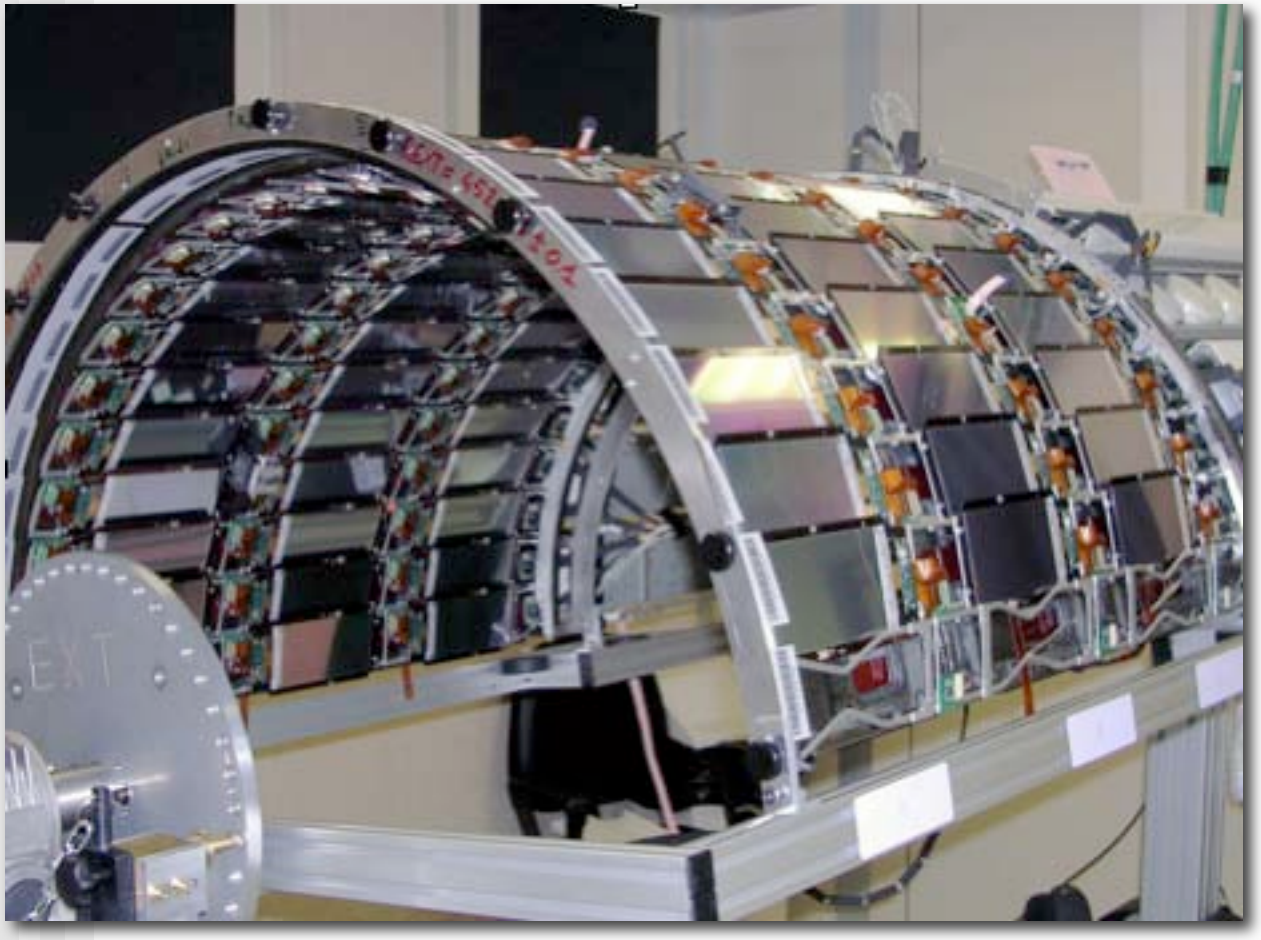
9,648,128 electronics channels

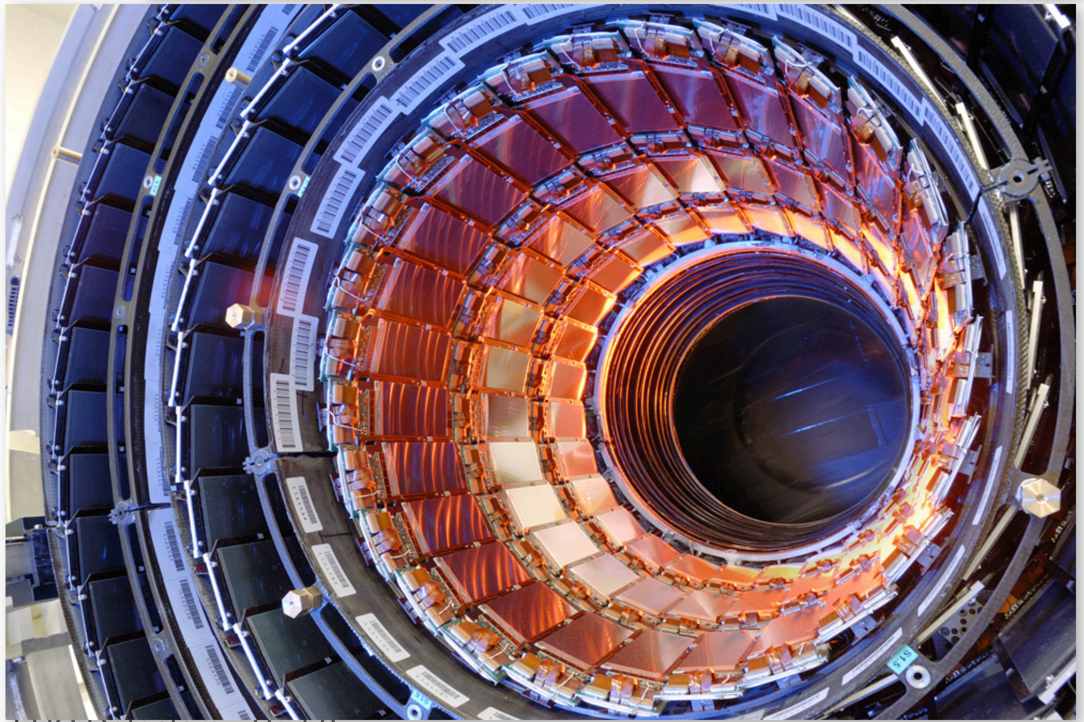
- All-Silicon Tracking
- Pixel : module production and testing under way. Full pixel to be installed in 2008.
- SI : all sensors produced and integrated in support tube, commissioned with cosmic muons, ready for installation in CMS later this year

Pixel module:



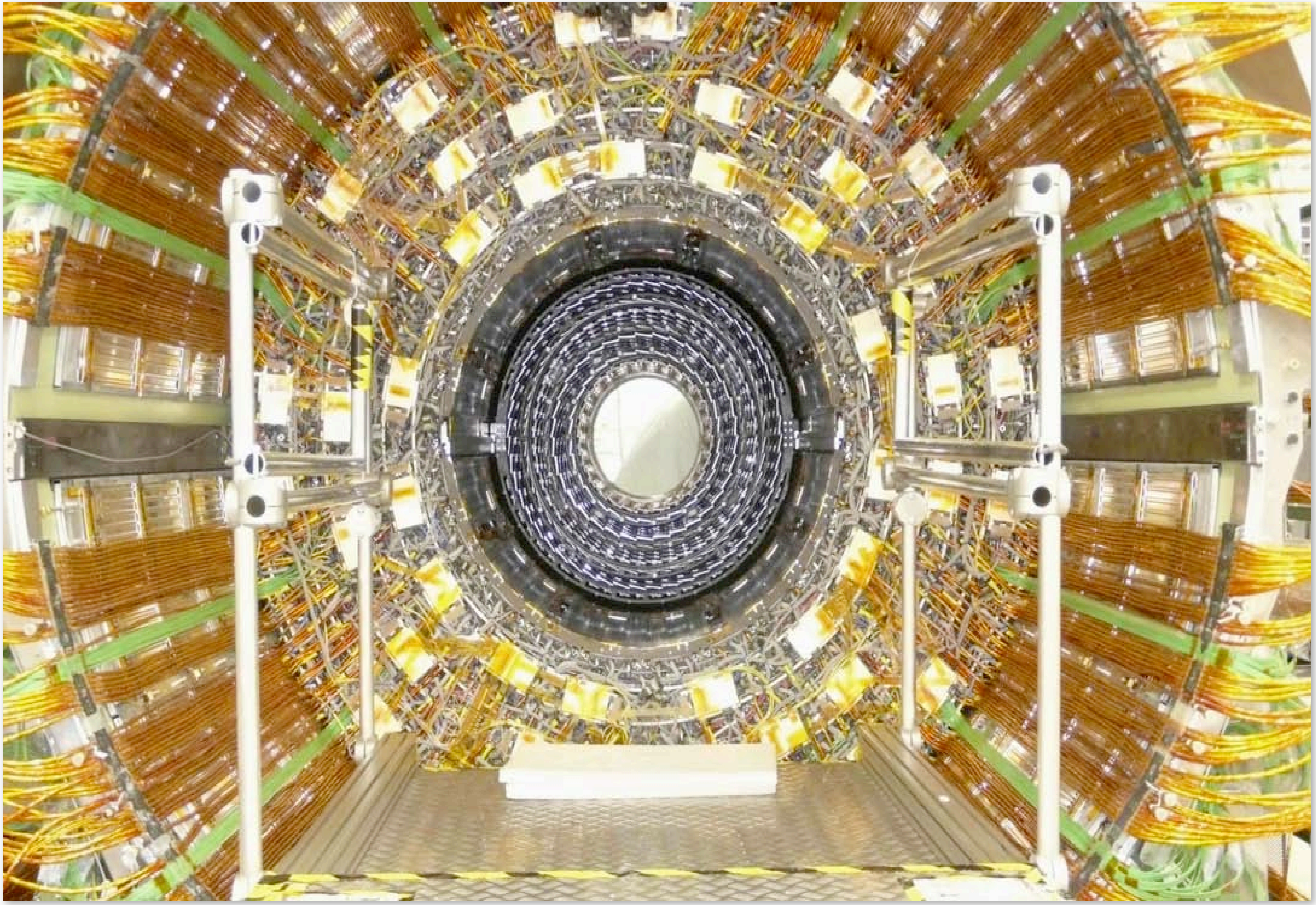
Tracker production





Tracker in CERN Tracker Integration Facility

View of the Inner and Outer Barrel in the Tracker Support Tube

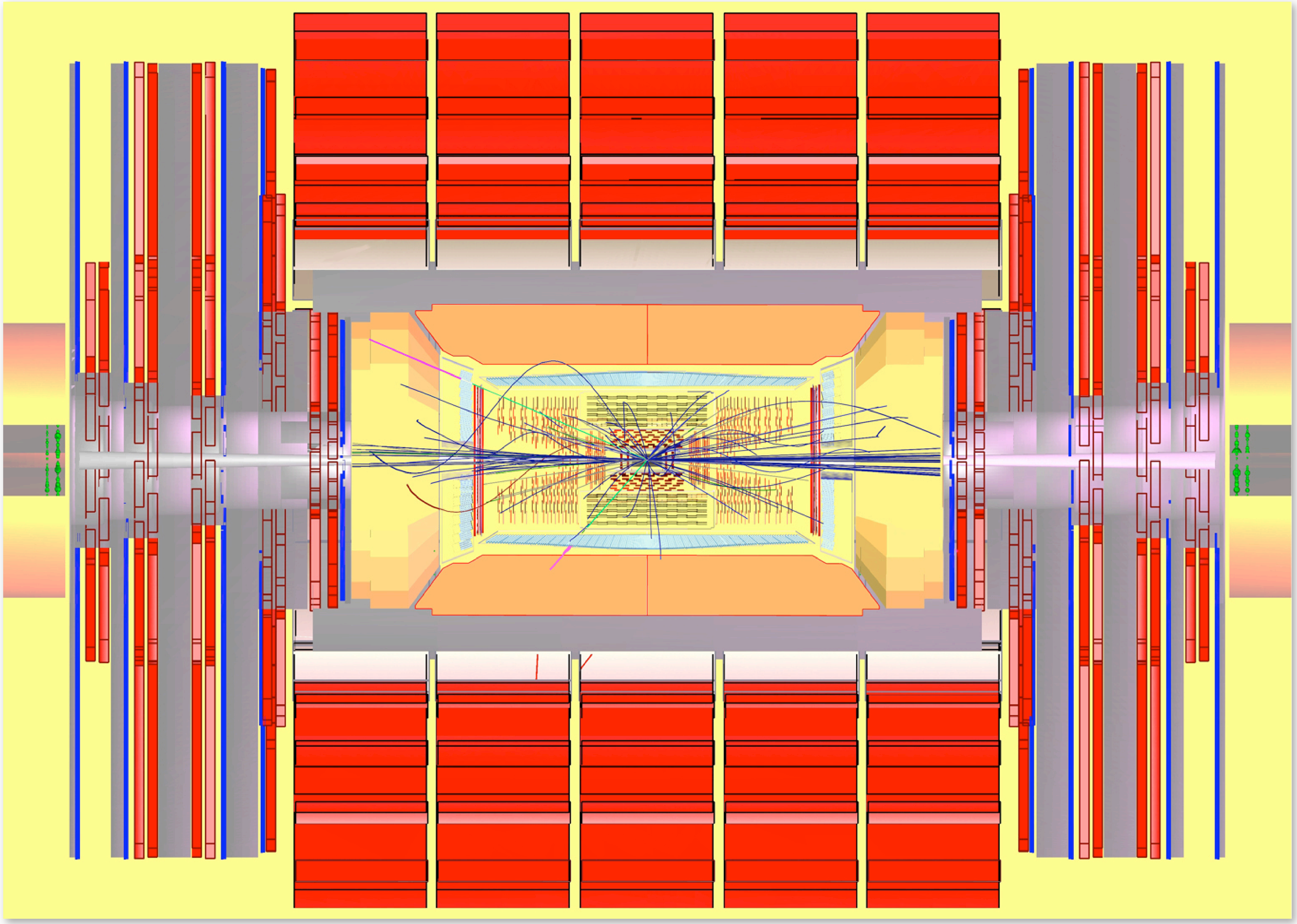


The CMS Crystal Calorimeter

ETH Institute for Particle Physics

Goal : Attain best possible precision

for the energy measurement of photons and electrons



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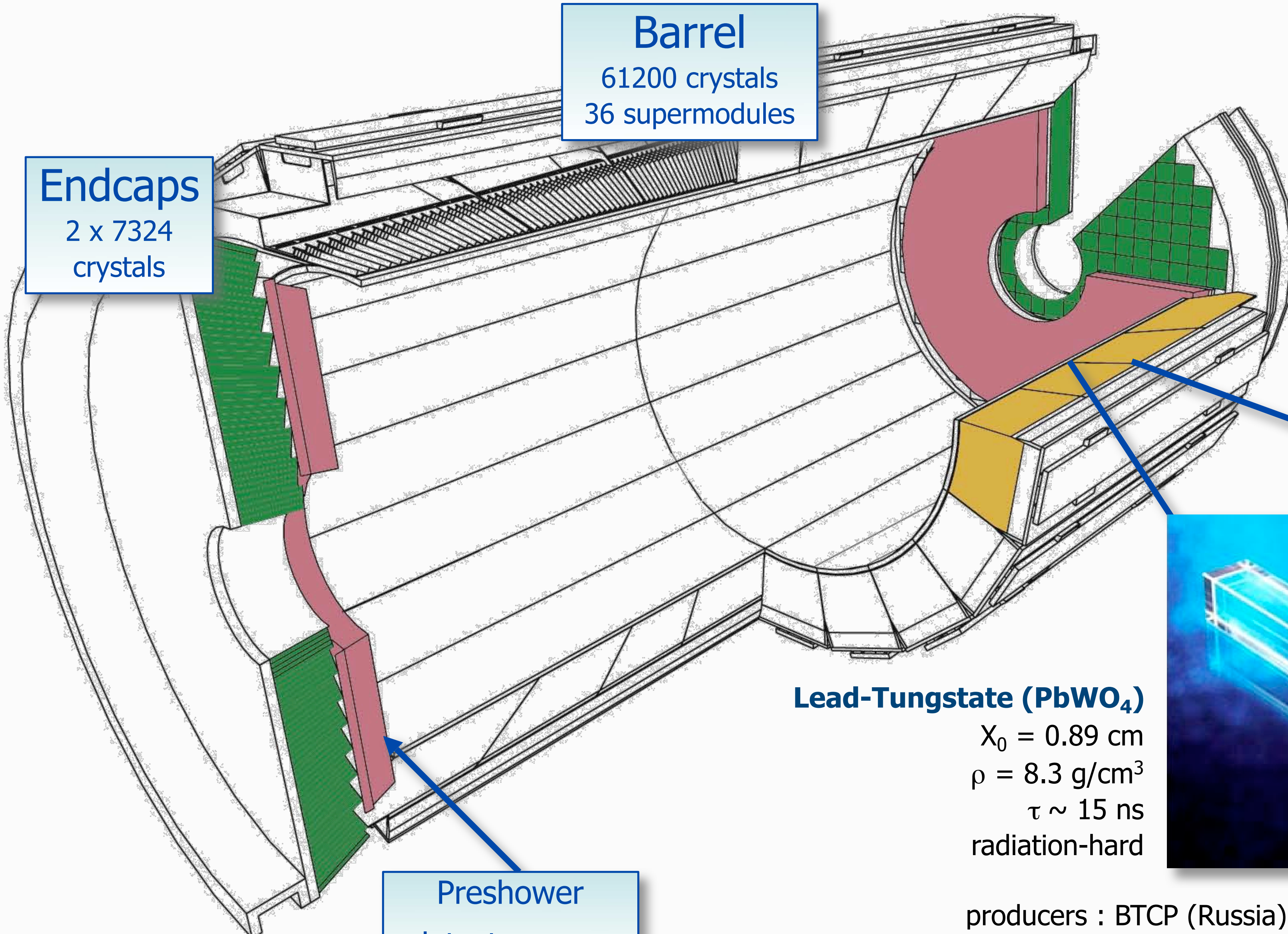
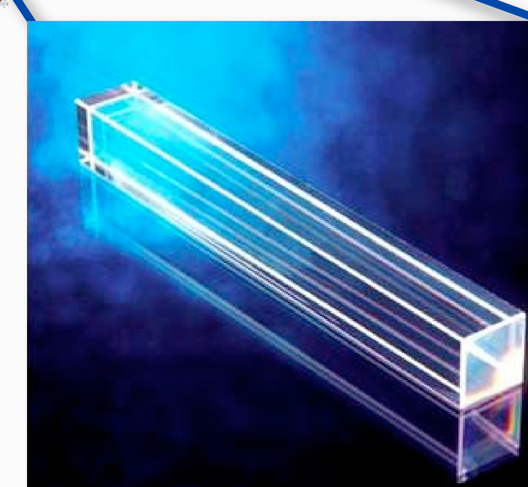


crystals : total volume 10.8 m^3
weight 90 tons

Lead-Tungstate ($PbWO_4$)
X_0 = 0.89 cm
ρ = 8.3 g/cm^3
$\tau \sim$ 15 ns
radiation-hard

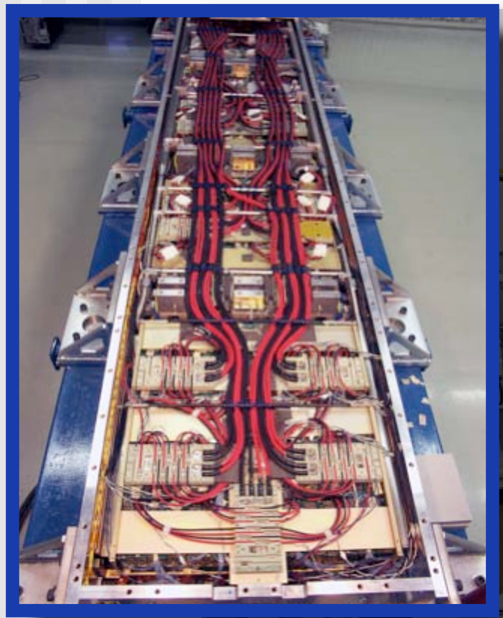


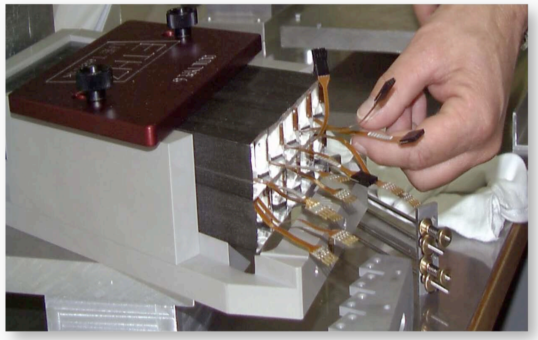
producers : BTCP (Russia) and SIC (China)

Goal for energy resolution : $$\frac{\sigma_E}{E} = \frac{3\%}{\sqrt{E}} \oplus \frac{0.15}{E} \oplus 0.5\%$$ i.e. 600 MeV resolution for Photon with E=100 GeV

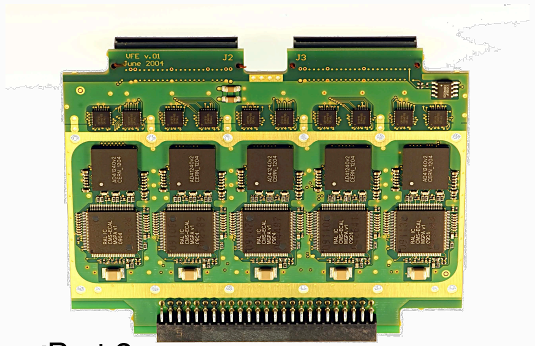
ECAL : Construction

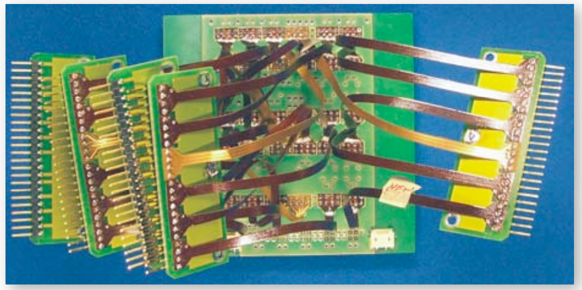
ECAL electronics integration centre:



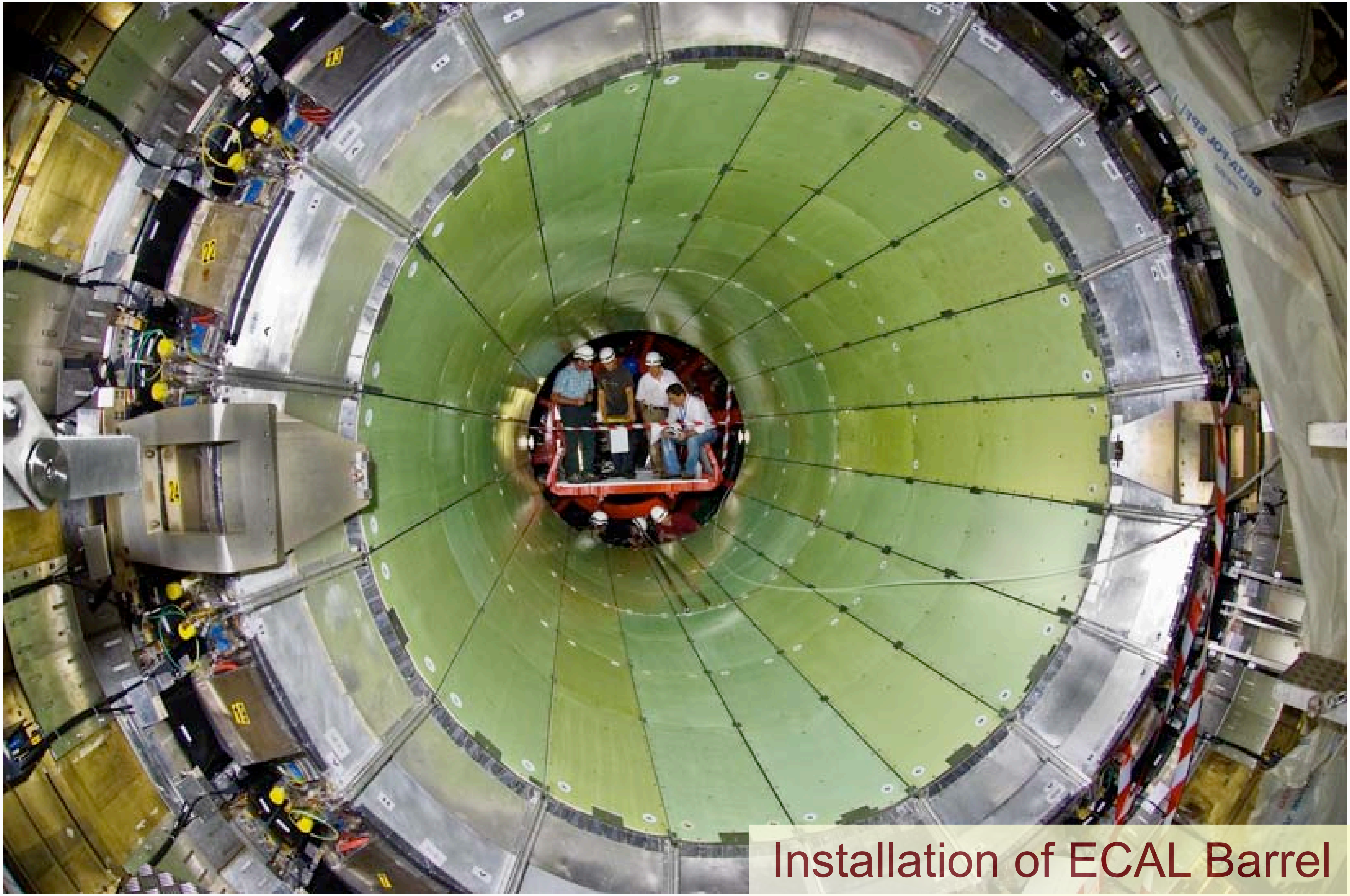


Barrel crystal production finished in March 07; Endcaps spring 2008.



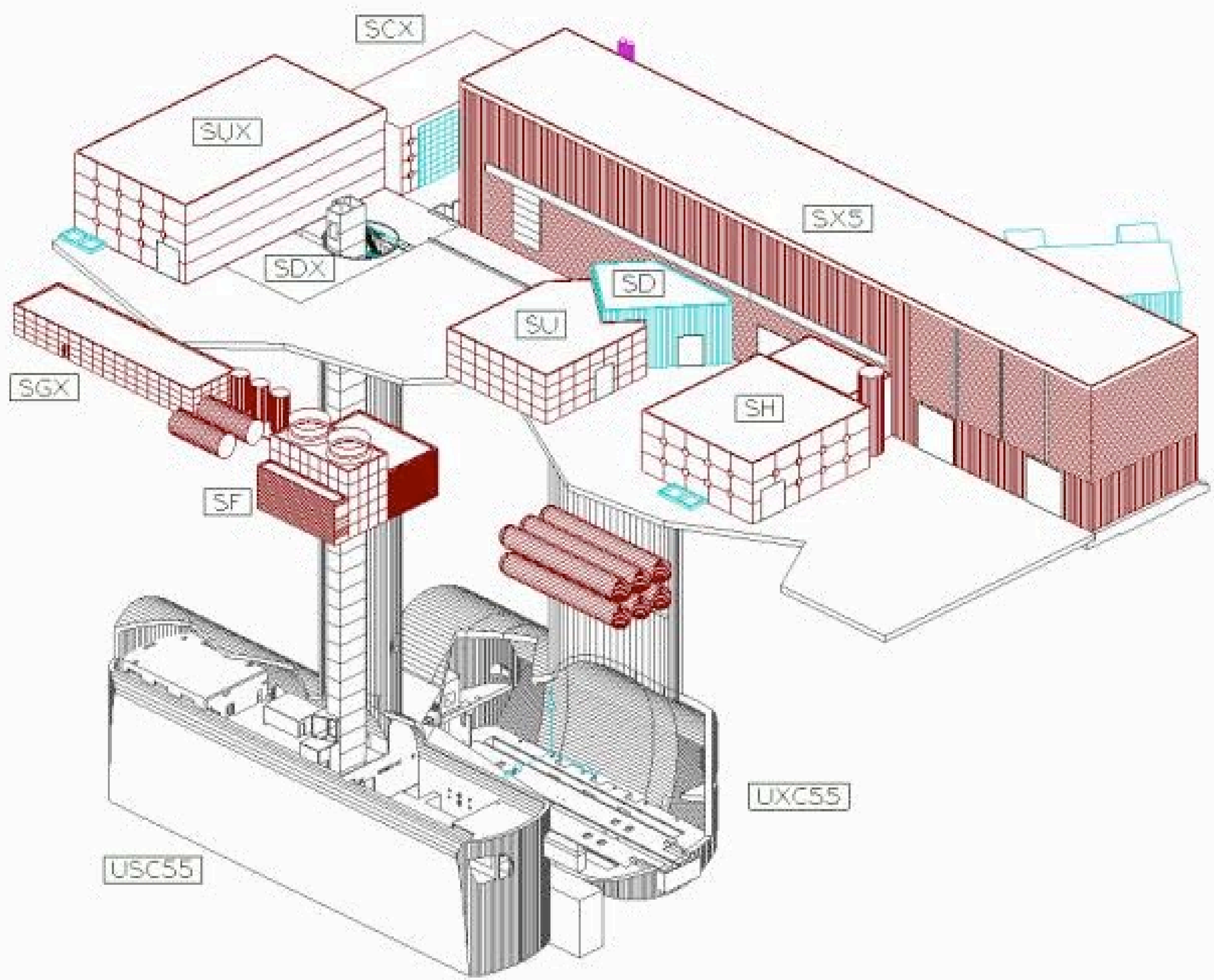


ECAL installation

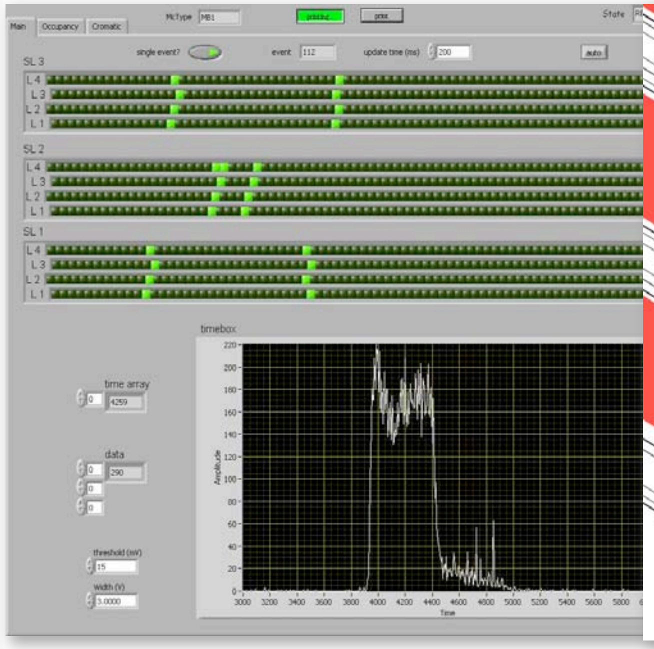


Installation of ECAL Barrel completed very recently!

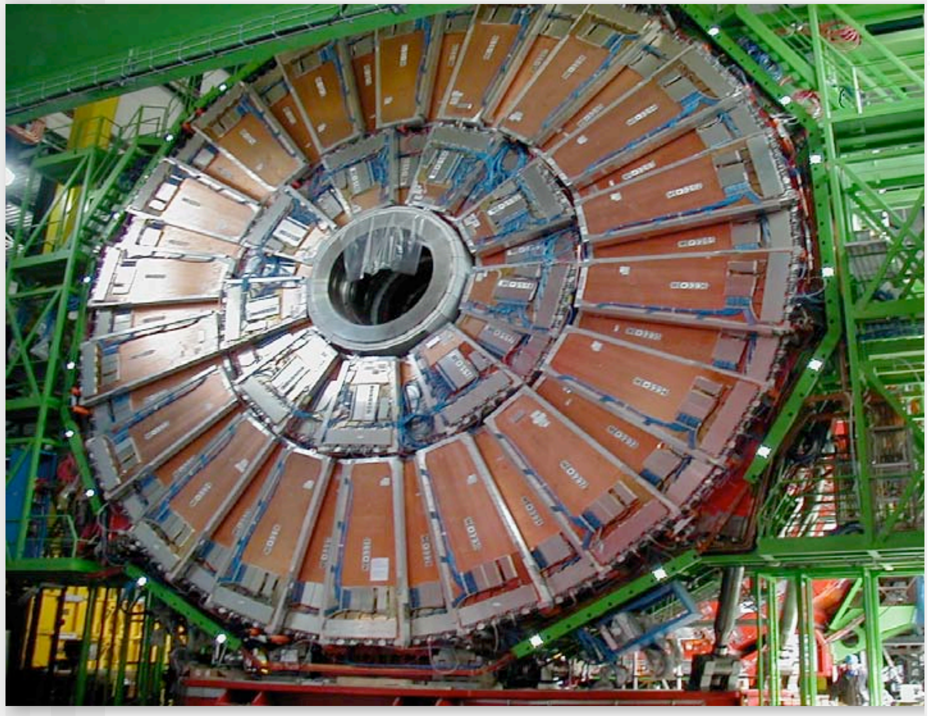
Experimental area : Point 5

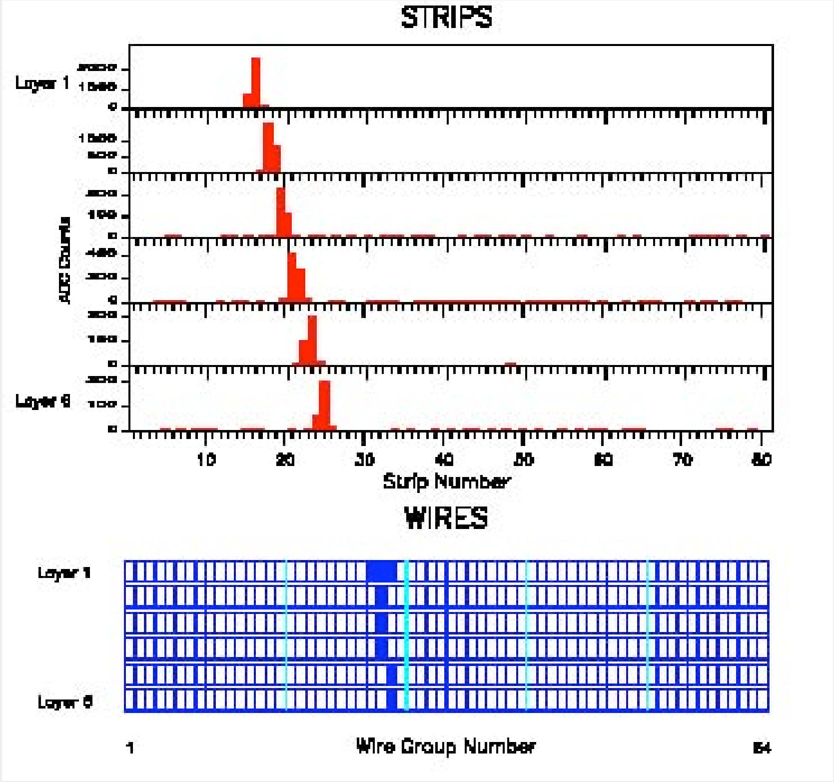


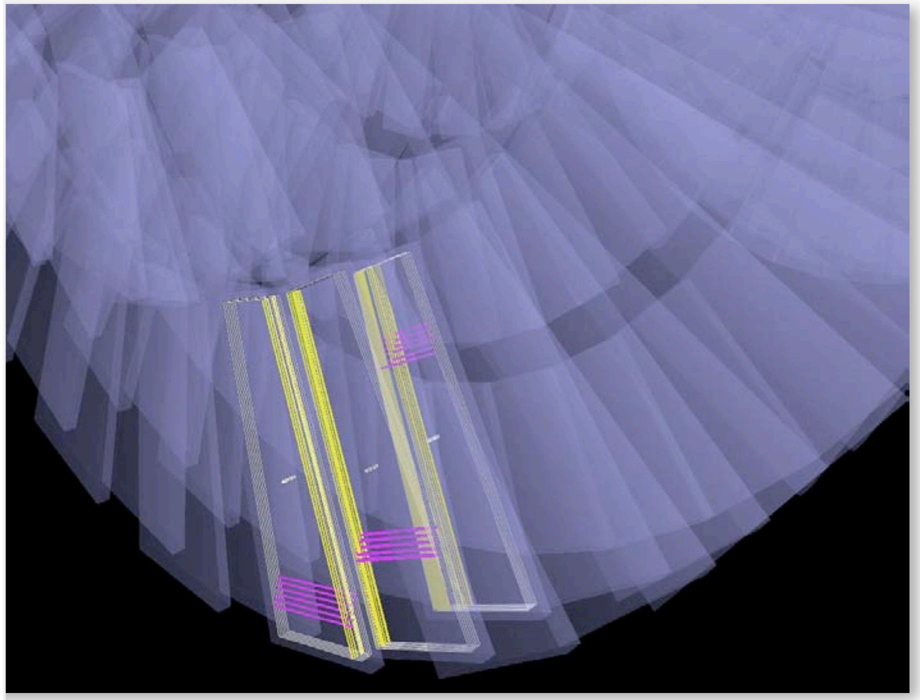
CMS : surface hall installations



Cosmic muon





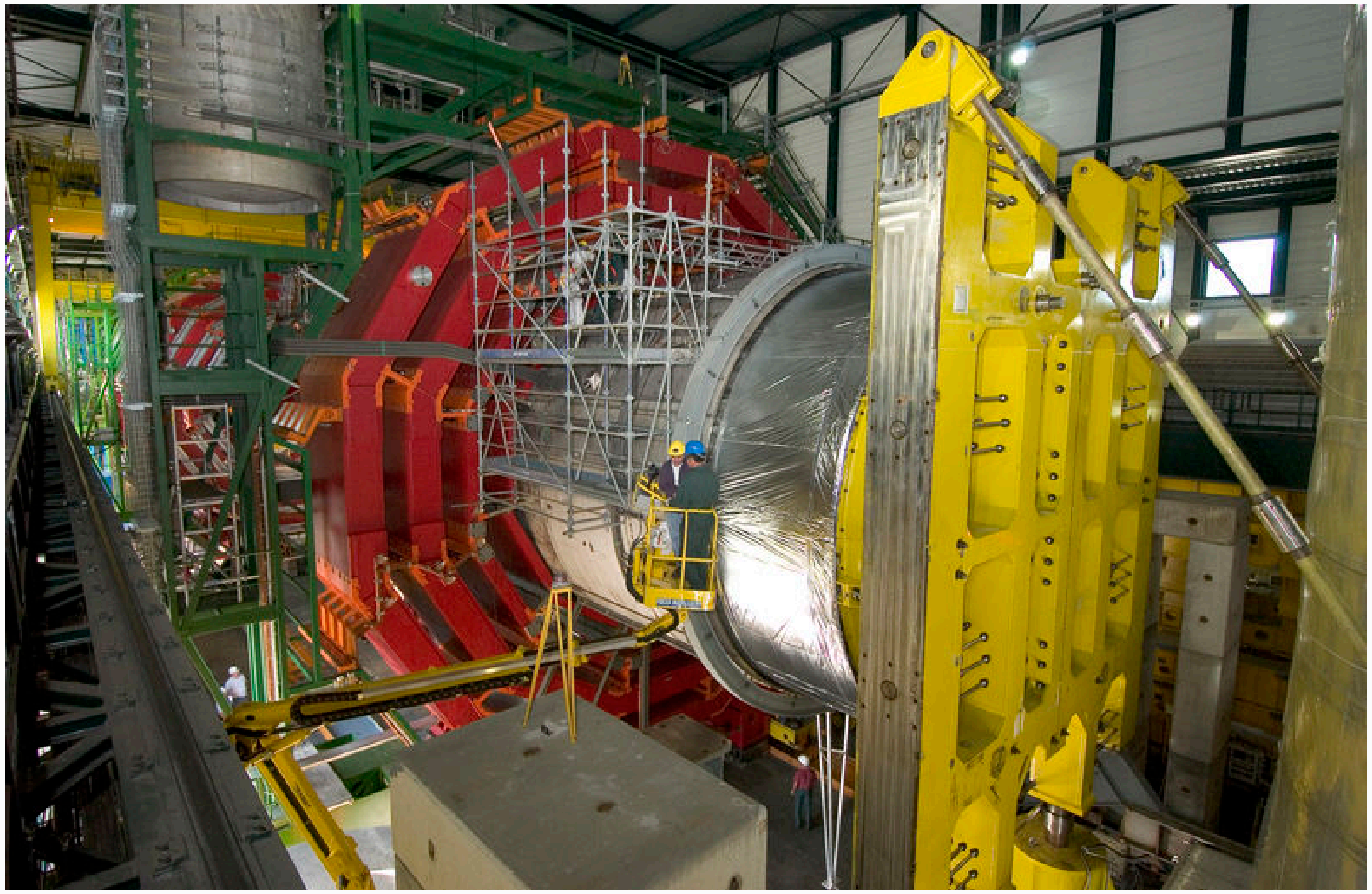


Comissioning of the muon system...

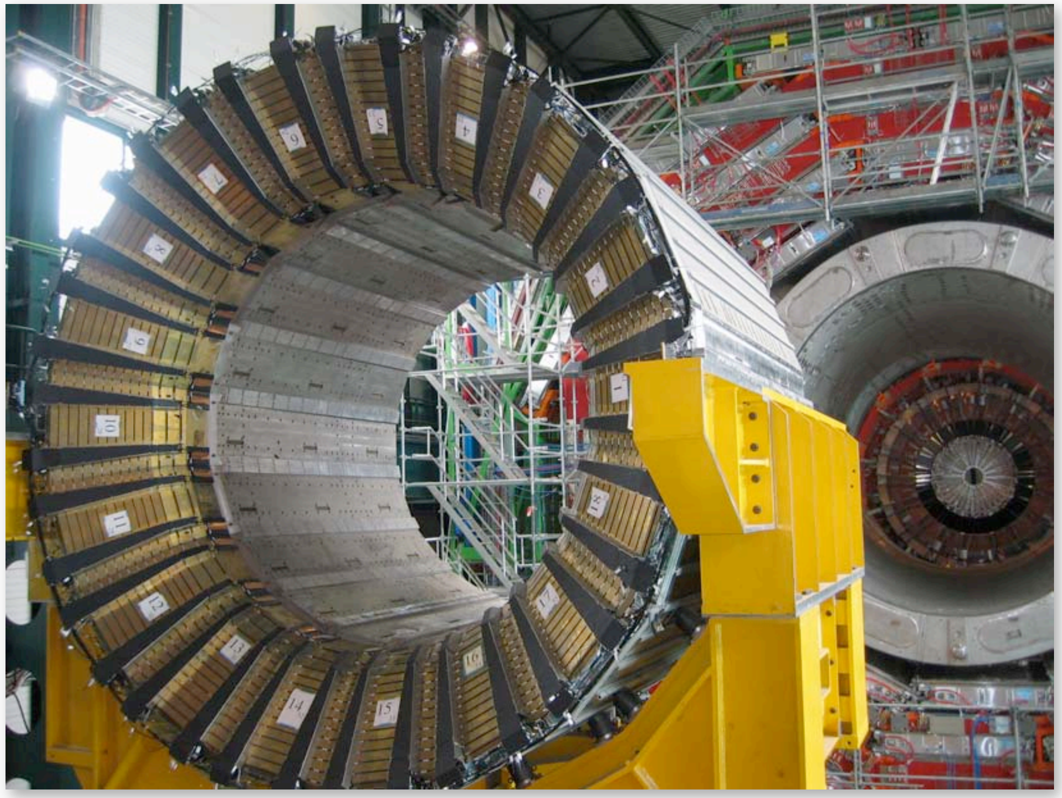
CMS : Magnet

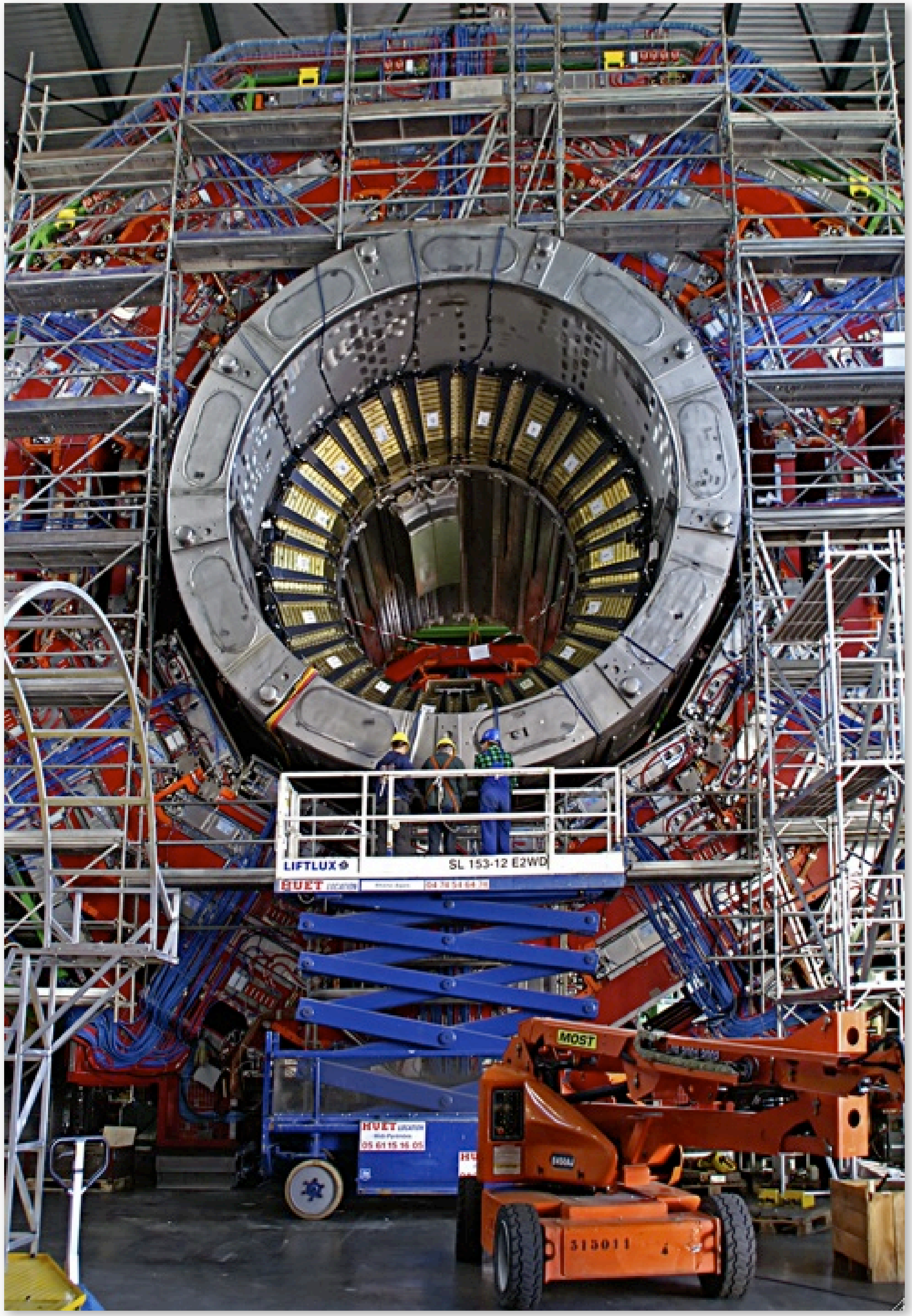
Magnet has been built out of 5 modules, connected and leak-tested.

Magnet Swivelling: Aug 05



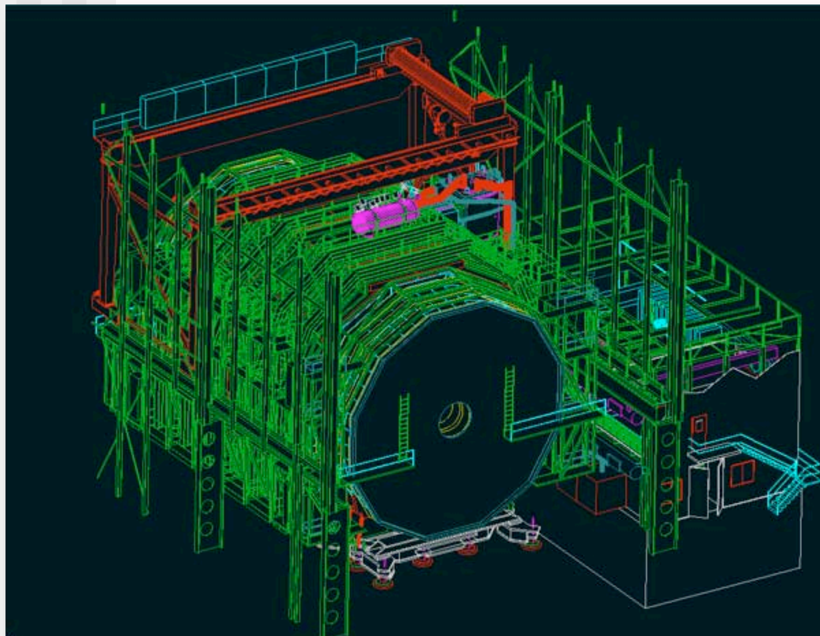
CMS : Preparations

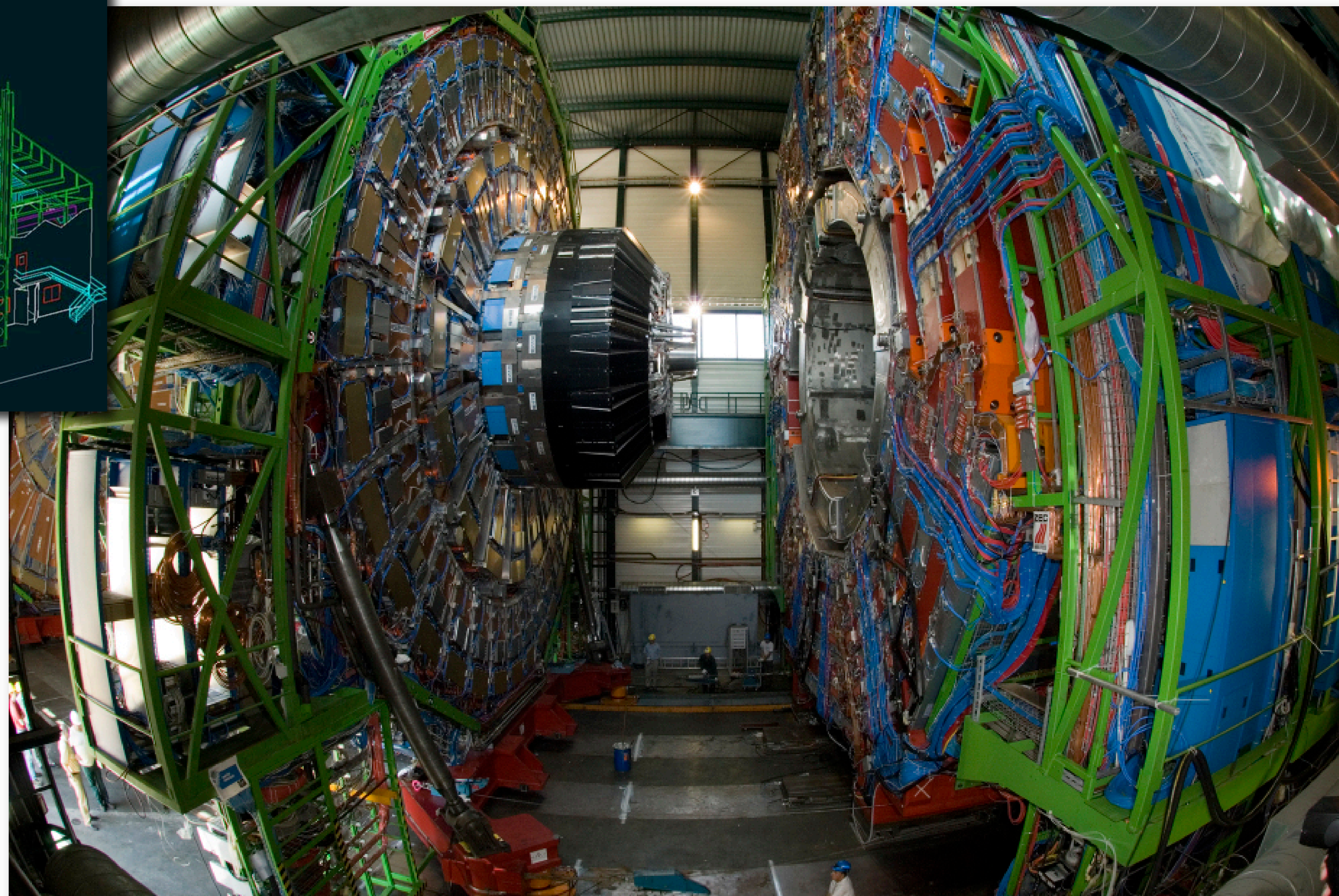




Closing CMS for the first time in July 2006

➪ Magnet Test and Cosmic Challenge (MTCC)





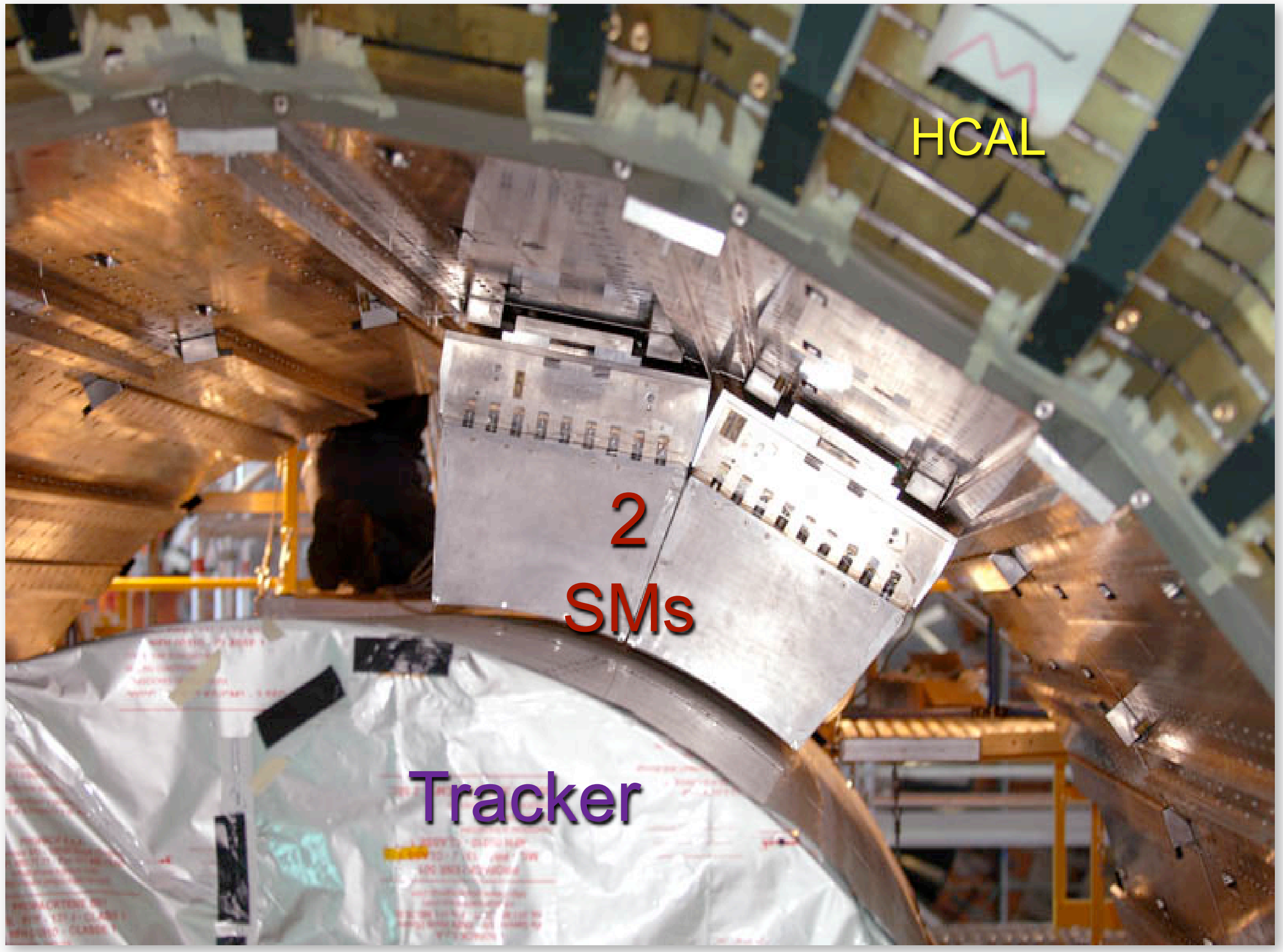
SC Magnet: 4 Tesla, l = 13 m, Ø = 6 m, weight > 10'000 tons

Magnet Test and Cosmic Challenge (MTCC)

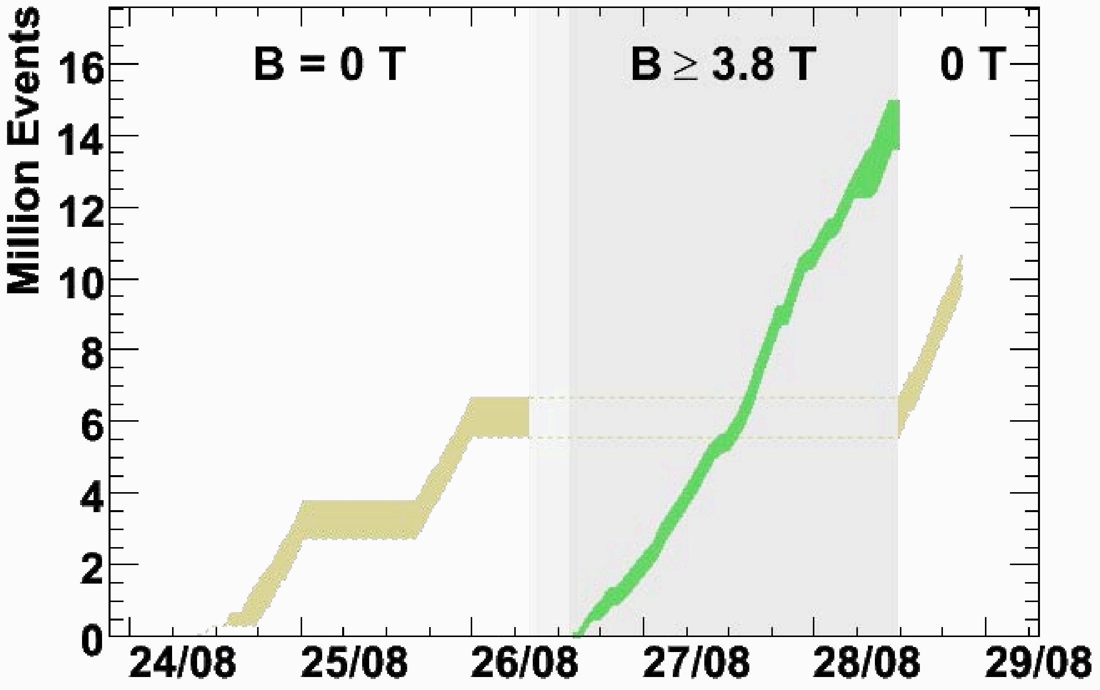
August 28: Stable magnet operation at 4 Tesla !

19.14 kA, 2.5 GJ stored energy, sufficient to melt 18 tonnes of gold

Muon system, HCAL, 2 ECAL SMs and part of tracker installed



Final DAQ for cosmic muon triggers:
~ 25 Million events



A big success !

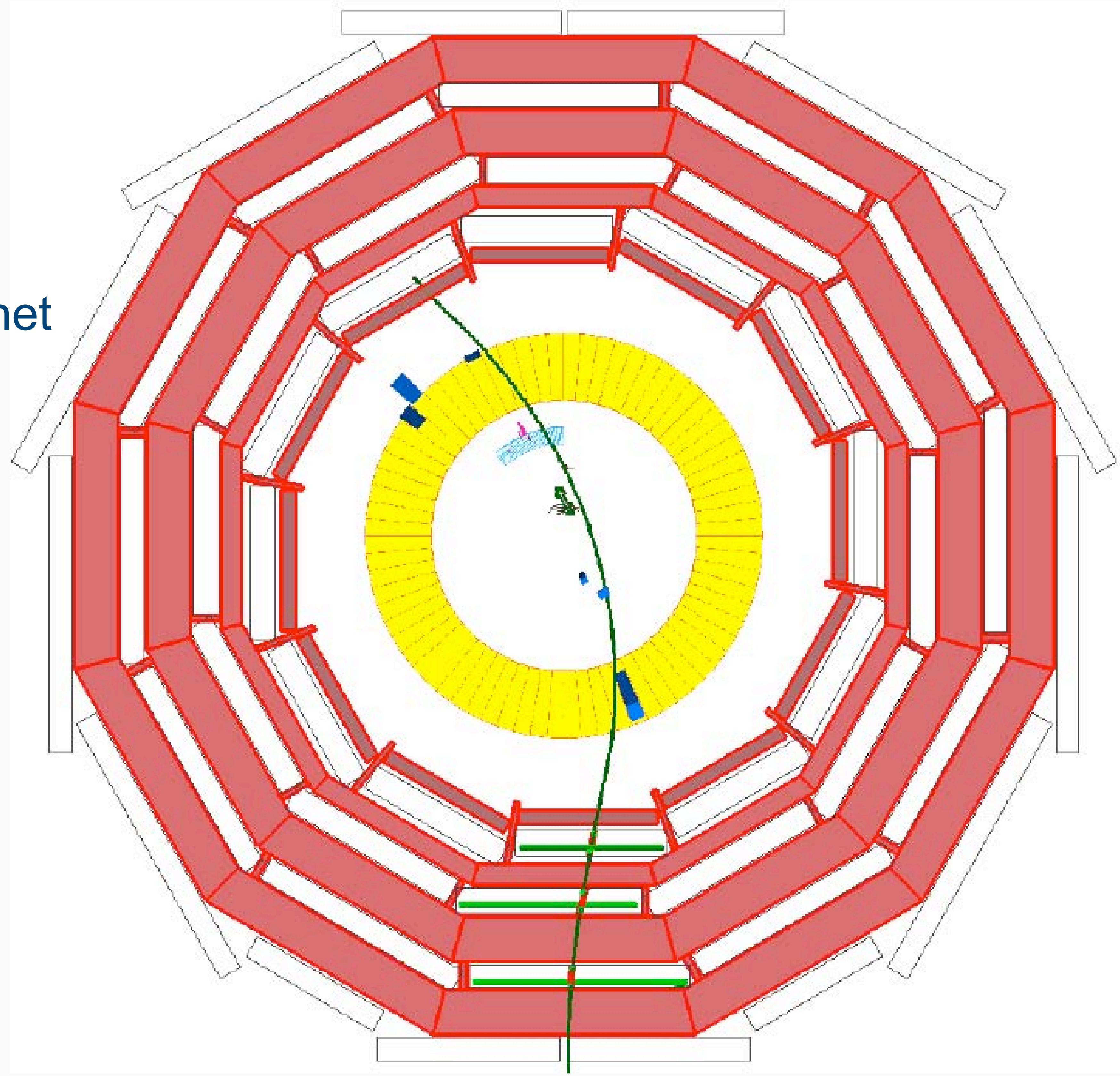
Field mapping done in October

Run 2605 / Event 3981/ B 3.8 T/27.08.06

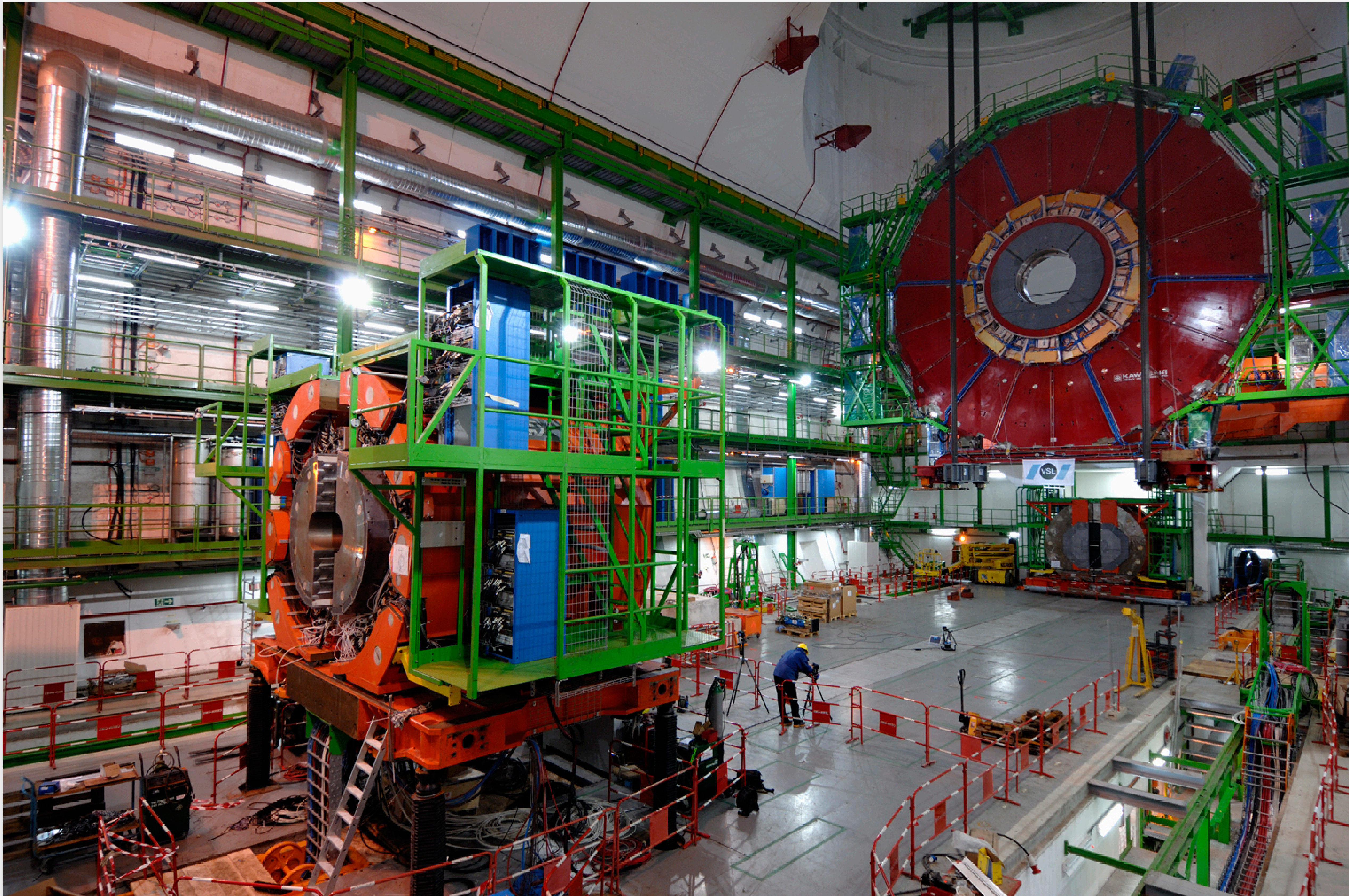
CERN PRESS RELEASE
13 September 2006

Mammoth CMS magnet reaches full-field at CERN

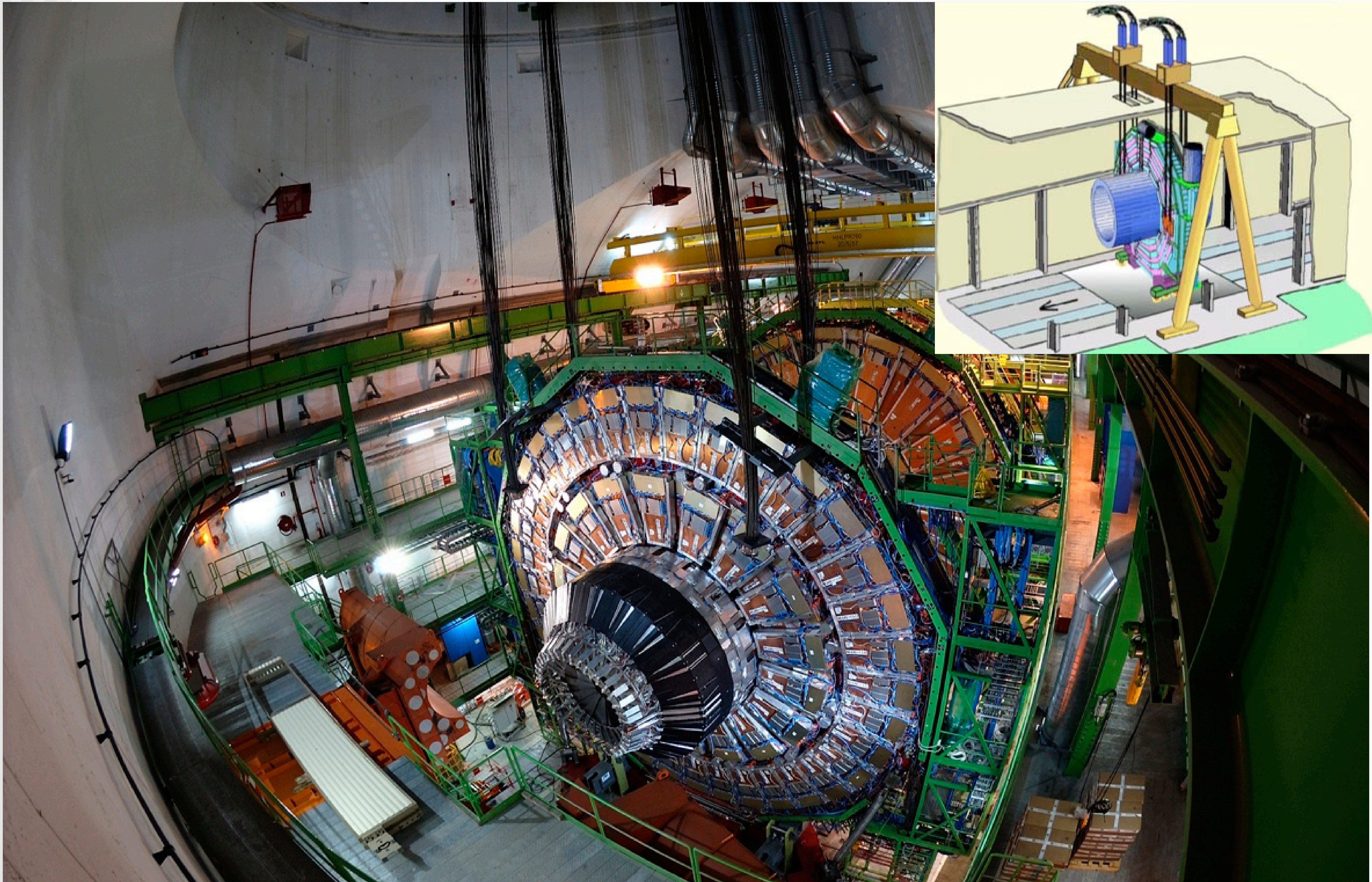
Tests show CMS detector will be ready for data



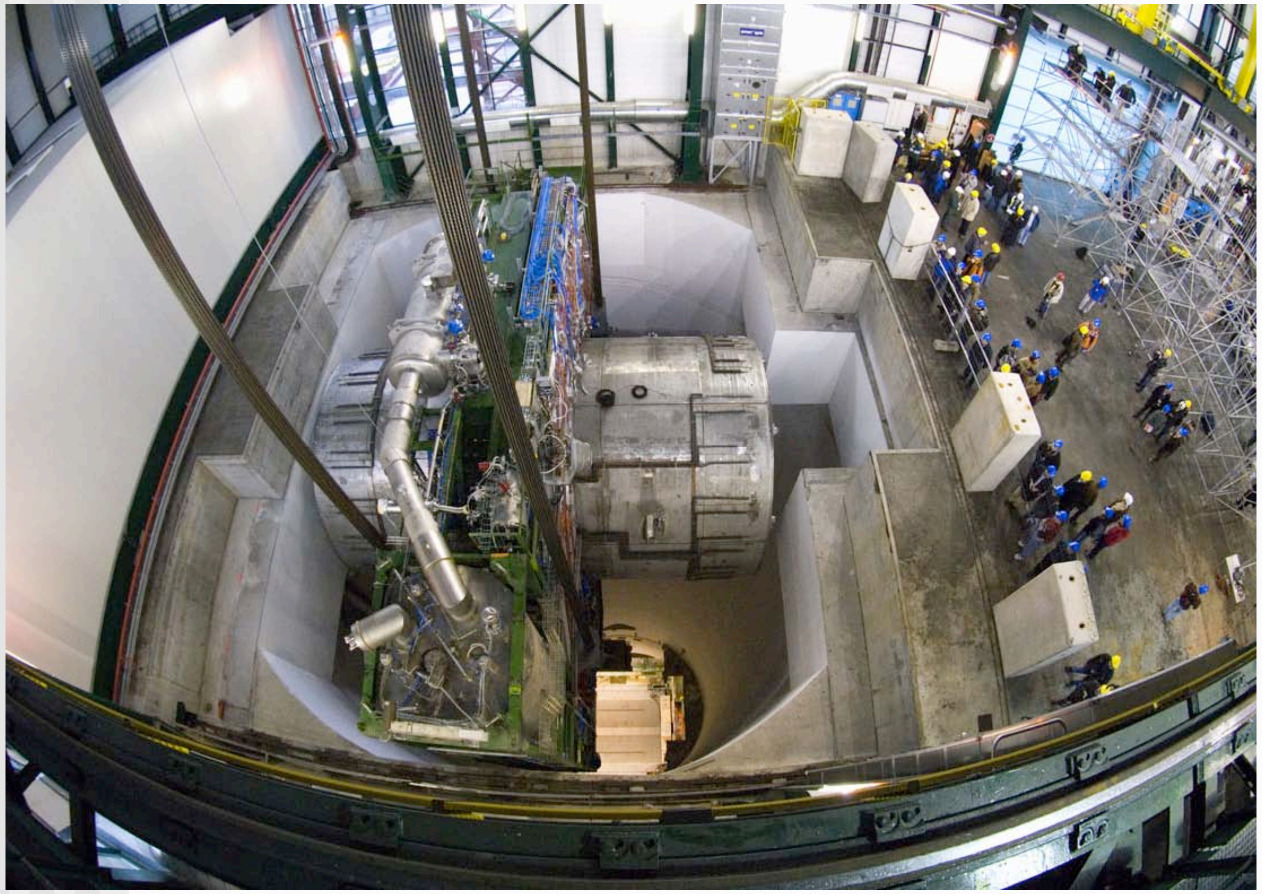
Heavy Lowering!

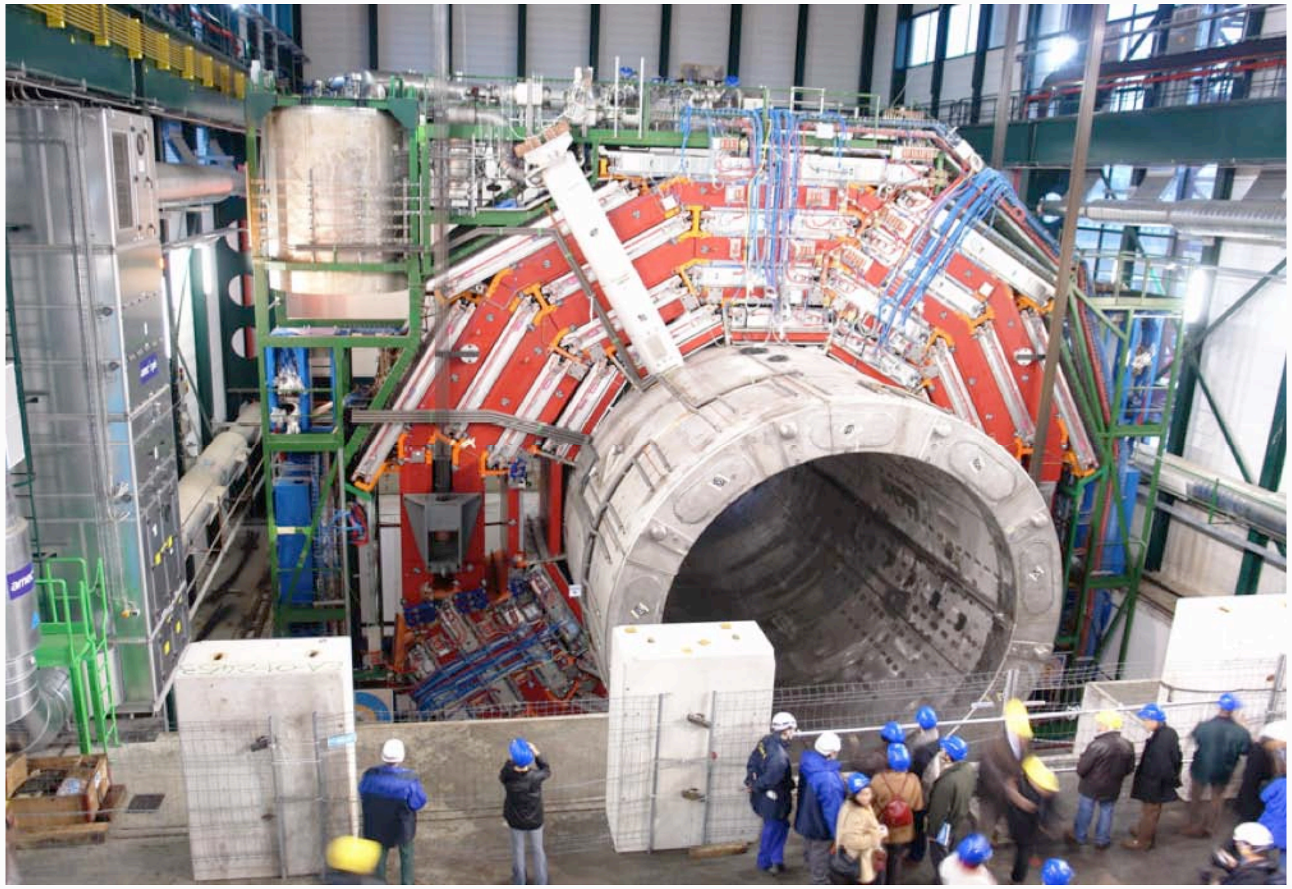


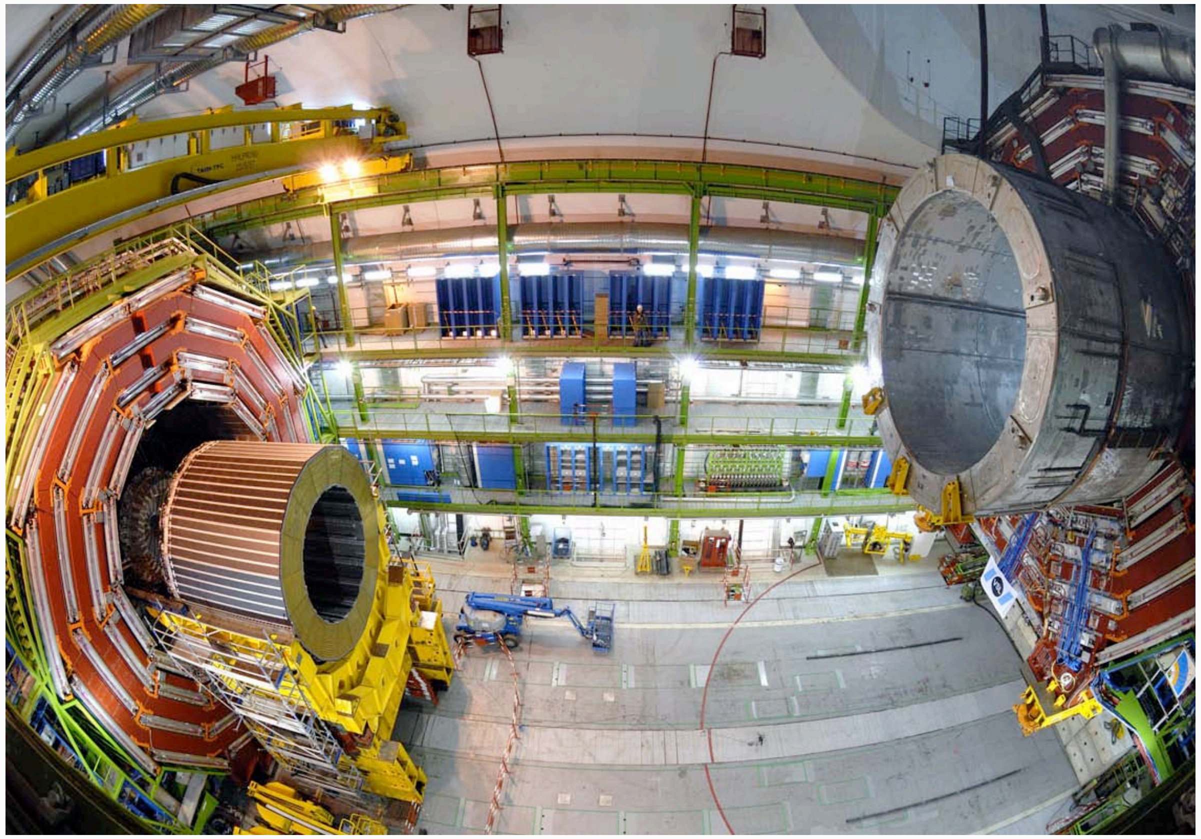
Heavy Lowering...



Heavy Lowering...







Now : Heavy Cabling Operations

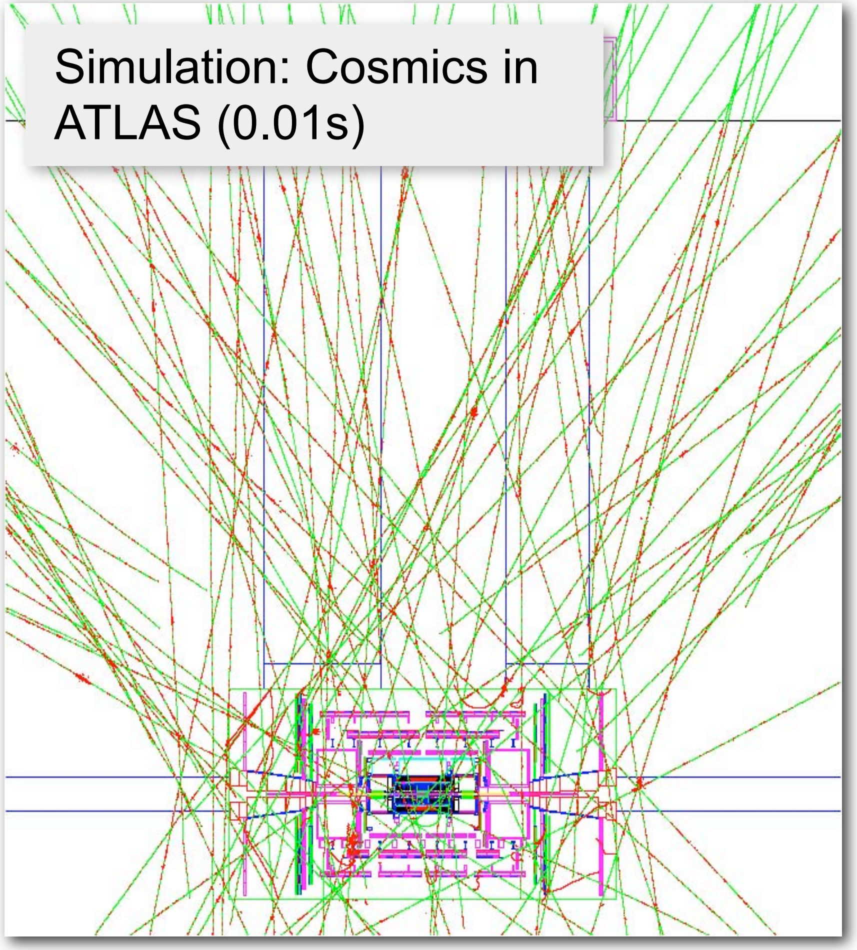
Comparison

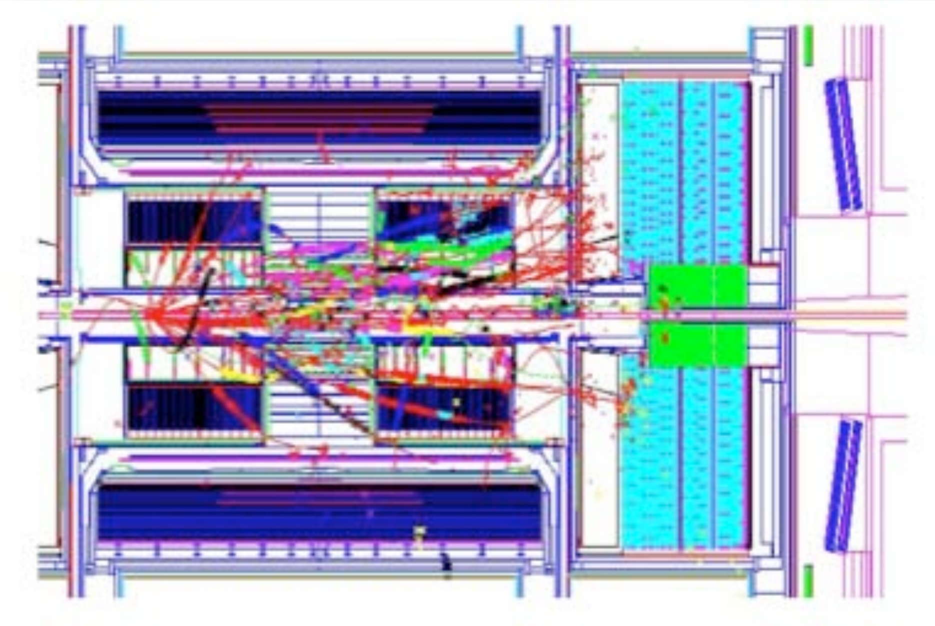
	ATLAS ≡ A Toroidal LHC ApparatuS	CMS ≡ Compact Muon Solenoid
MAGNET (S)	Air-core toroids + solenoid in inner cavity 4 magnets Calorimeters in field-free region	Solenoid Only 1 magnet Calorimeters inside field
TRACKER	Si pixels+ strips TRT → particle identification B=2T $\sigma/p_T \sim 5x10^{-4}\ p_T \oplus 0.01$	Si pixels + strips No particle identification B=4T $\sigma/p_T \sim 1.5x10^{-4}\ p_T \oplus 0.005$
EM CALO	Pb-liquid argon $\sigma/E \sim 10\%/\sqrt{E}$ uniform longitudinal segmentation	$PbWO_4$ crystals $\sigma/E \sim 2\text{-}5\%/\sqrt{E}$ no longitudinal segm.
HAD CALO	Fe-scint. + Cu-liquid argon (10 λ) $\sigma/E \sim 50\%/\sqrt{E} \oplus 0.03$	Cu-scint. (> 5.8 λ +catcher) $\sigma/E \sim 100\%/\sqrt{E} \oplus 0.05$
MUON	Air → $\sigma/p_T \sim 7$ % at 1 TeV standalone	Fe → $\sigma/p_T \sim 5\%$ at 1 TeV only combining with tracker

Commissioning

Detectors : Commissioning

- No Beam :
  - Cosmic Muons
  - Initial alignment/detector calibration (barrel)
  - Debugging, dead-channels mapping
- One Beam :
  - Beam-Halo Muons
    - Alignment/calibration in end-caps
  - Beam-Gas events
    - resemble pp, with soft spectrum (p_T < 2 GeV)
    - eg. first alignment of inner trackers to about 100 μm or better
- Two Beams :
  - very early low lumi : Min Bias interactions, QCD di-jet events
  - then : get quickly access to SM processes as standard calibration candles: W, Z, top production





Expted Detector Performance

- Construction quality checks and beam tests of series detector modules show that the detectors as built should give a good starting-point performance

	Expected performance day 1	Physics samples to improve (examples)
ECAL uniformity e/γ scale	~ 1% (ATLAS), 4% (CMS) 1-2 % ?	Minimum-bias, $Z \to ee$, $W \to e\nu$ $Z \to ee$
HCAL uniformity Jet scale	2-3 % < 10%	Single pions, QCD jets $Z (\to ll) +1j$, $W \to jj$ in tt events
Tracking alignment	20-500 μm in Rϕ ?	Generic tracks, isolated μ , $Z \to \mu\mu$

F. Gianotti

- However, a lot of data (and time …) will be needed at the beginning to
  - Commission the detector and trigger in situ
  - Reach the performance needed to optimize the physics potential
  - Understand "basic" physics at 14 TeV and normalize (tune) the MC generators
  - Measure backgrounds to new physics and extract "early" convincing signals

- Using in-situ calibration, control samples, and based on experience from previous exps: an educated guess :

Expted Detector Performance

"Isolated" electrons, photons: $\Delta E/E_{e,\gamma} =$ few % $/\sqrt{E}$ + 0.5%(goal)
excellent angular resolution, "high" efficiency and "small/negligible" backgrounds
for $p_t \geq 10$ GeV (?) and $|\eta| \leq 2.5$(?) $\delta\epsilon \approx 1\%$

"Isolated" (100 GeV?) muons: $\Delta p_t/p_t \approx 2 - 5\%$
excellent angular resolution "high" efficiency and "small/negligible" backgrounds
for $p_t \geq 10$ GeV (?) and $|\eta| \leq 2.5$(?) $\delta\epsilon \approx 1\%$

"Isolated(??)" jets: $\Delta E_t/E_t \approx 100 - 200\%/\sqrt{E} + 5\%$ (??)
good angular resolution and efficiency, but "difficult" systematics (nonlinearity)
for $p_t \geq 30$ GeV (??) and $|\eta| \leq 4.5$(??)

Missing transverse momentum: depends on final state!
in general a mixture between lepton and jet accuracies

Summary of Part 2

"Hofstadter's Law :
It always takes longer than you think,
even if you take into account Hofstadter's Law"

Douglas R. Hofstadter

Summary Part 2

- The Detectors
  - are designed to optimally exploit the physics offered by the LHC
  - and cope with the harsh conditions at the same time
- ATLAS and CMS
  - are both general purpose experiments
  - but are different in their overall layout and in their specific sub-detector (design) choices
  - Detector constructions and installations at full speed,
  - many sub-systems completed
- Preparations: We see the light at the end of the tunnel