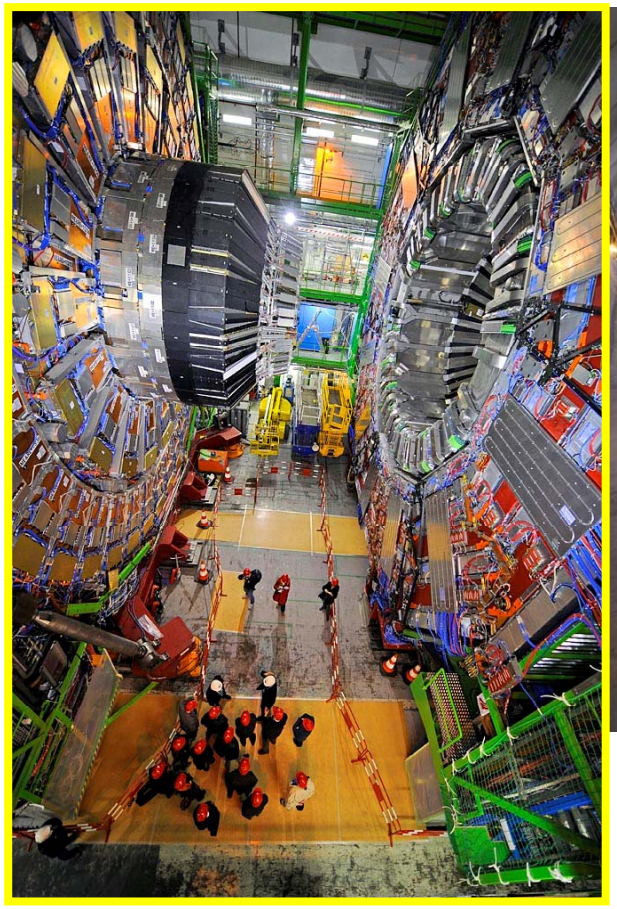
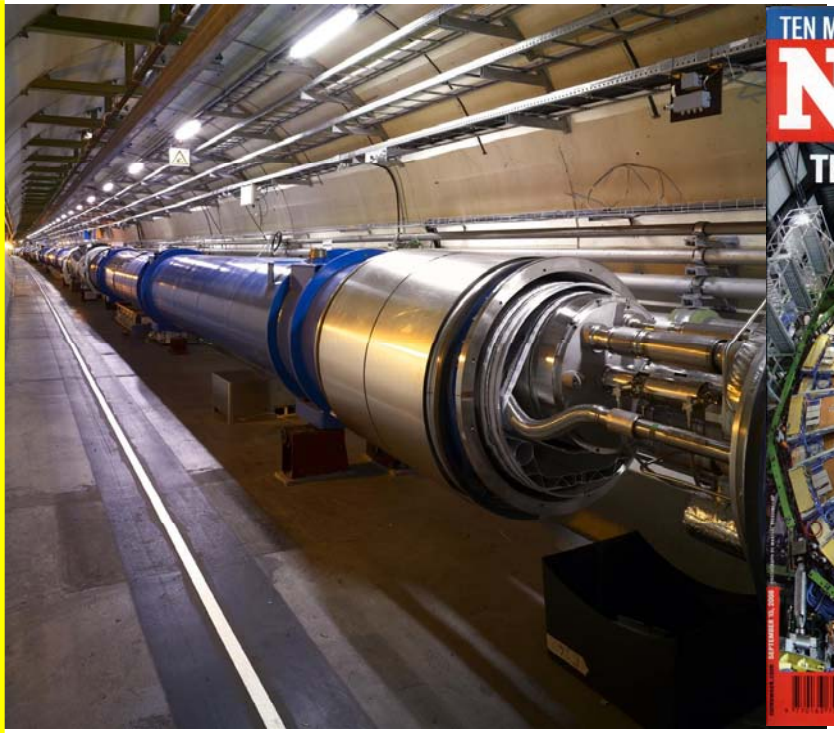
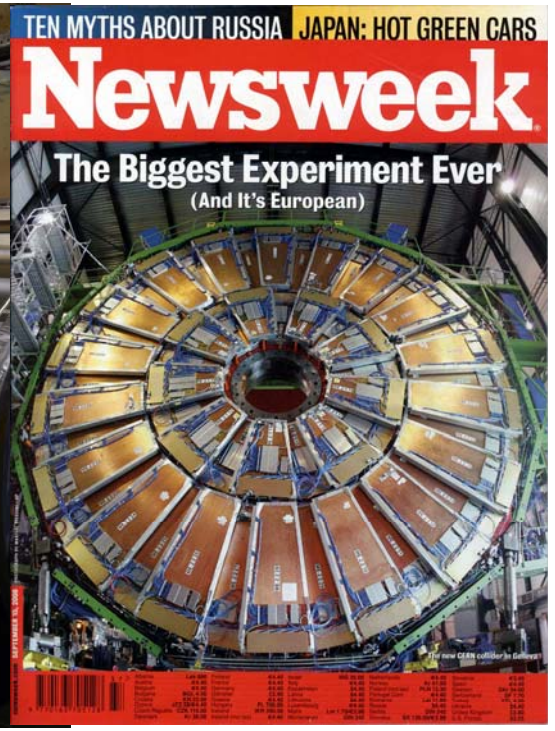






The CMS Experiment at CERN-LHC

Introduction
Construction, Installation and Commissioning of CMS
Outlook

AAAS
ADVANCING SCIENCE, SERVING SOCIETY

15 Feb. 2009
Chicago

T. Virdee
CERN/ImperialCollege

Charge to CMS (ATLAS)

The Standard Model is a beautiful theory and arguably one that is most precisely tested
BUT we know it is not the whole truth !

Search for New Particles/New Symmetries/New Forces?

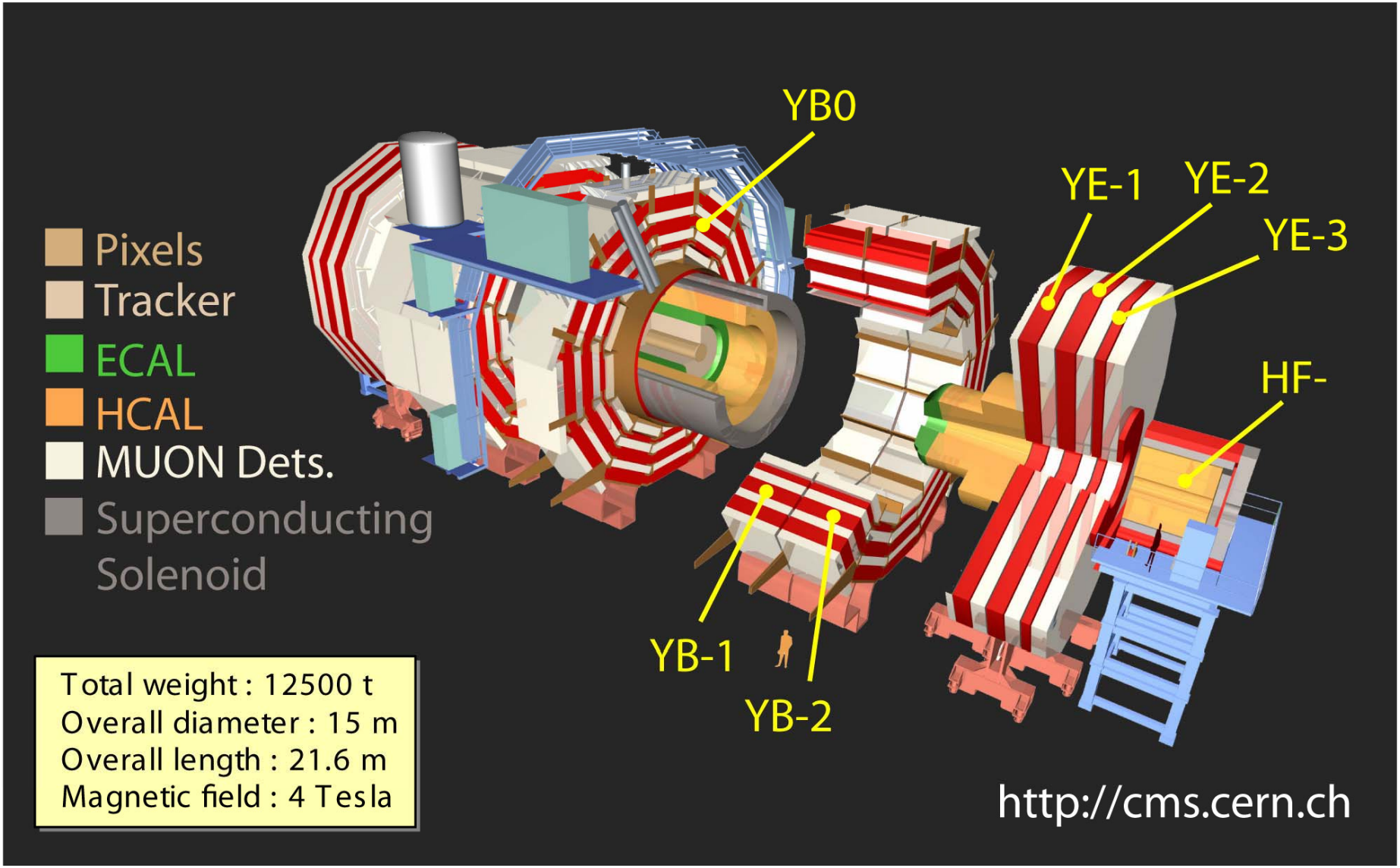
⇨ **Origin of Mass -** Higgs boson(s)

⇨ **Supersymmetric particles** - a new zoology of particles, dark matter particle? …

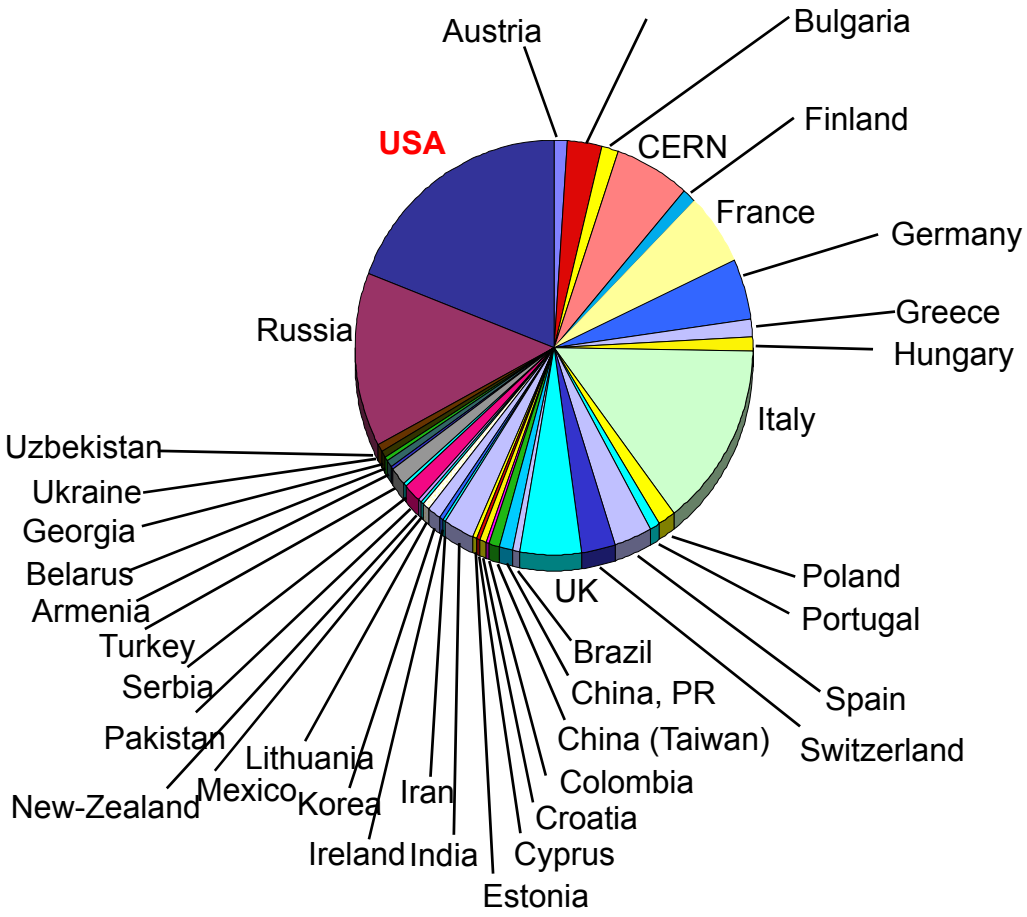
⇨ **Extra space-time dimensions:** gravitons, micro-black holes, Z' etc. ?

⇨ **The Unexpected !!**

The CMS Detector



CMS Collaboration



38 countries, 184 Institutions with
about 2800 scientists and engineers (~ 670 Ph.D. students)

US constitutes the largest national group

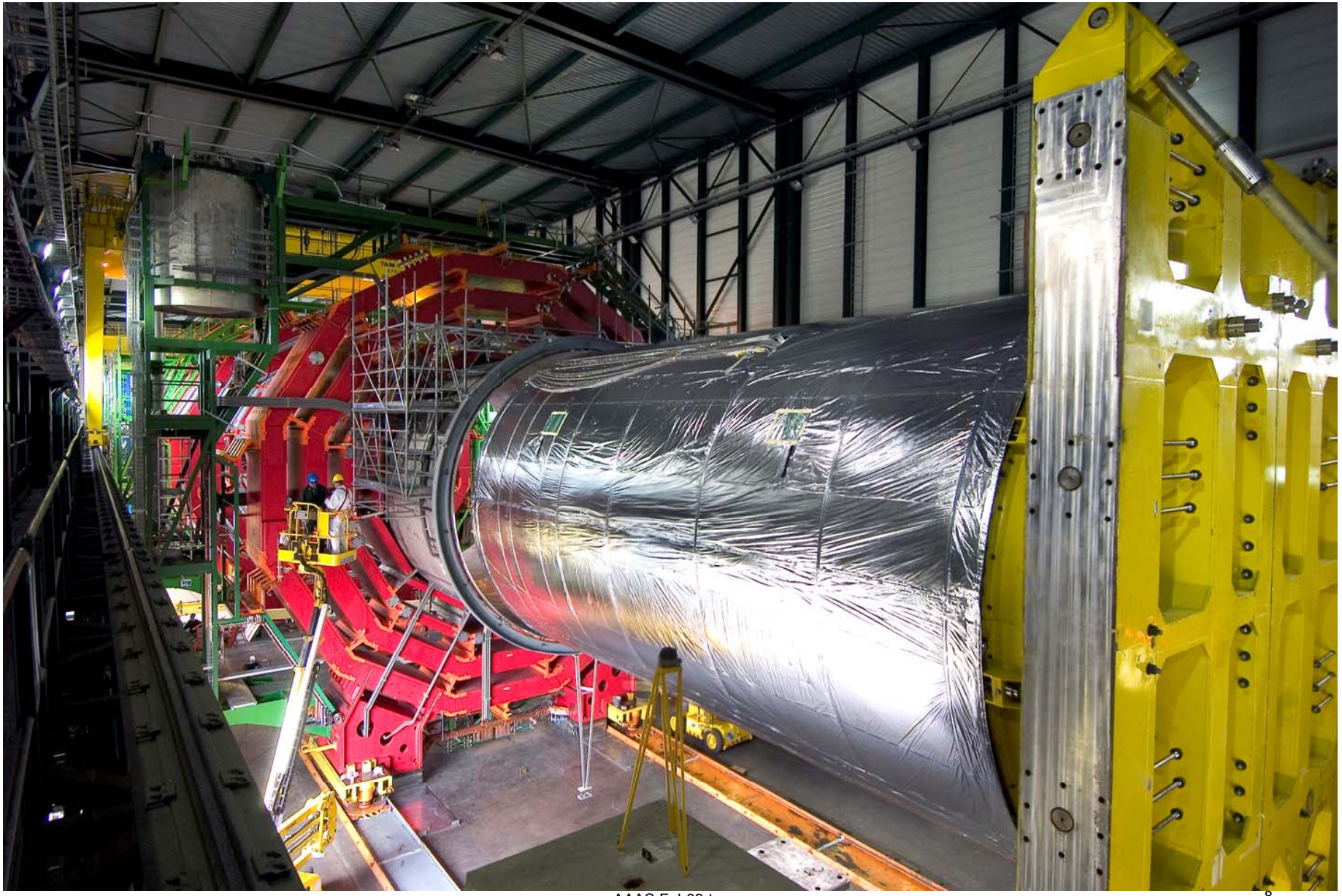
Construction and Installation of CMS

1998 - 2008

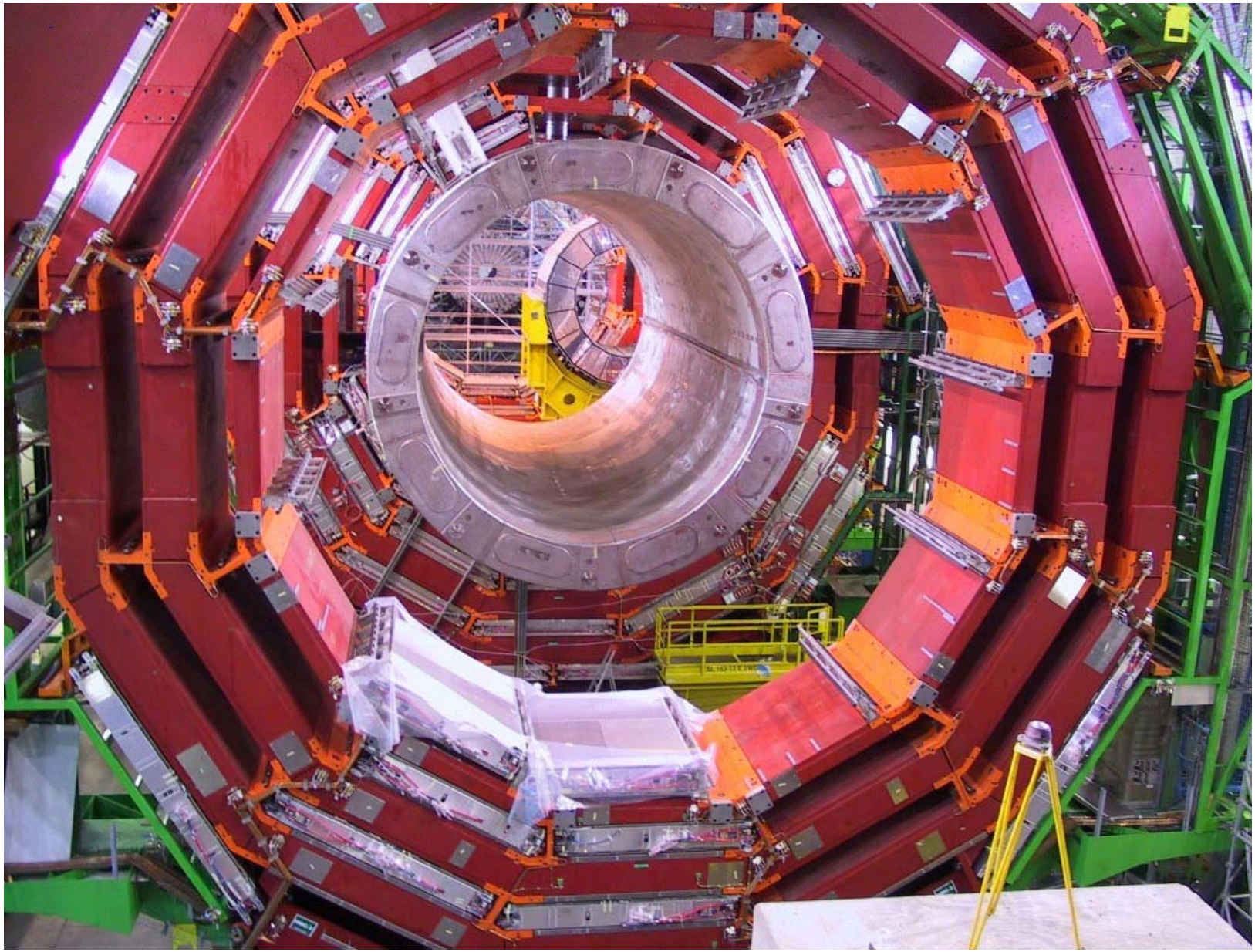
CMS Site in Cessy in 2000

Assembly of the Iron Yoke (2003)

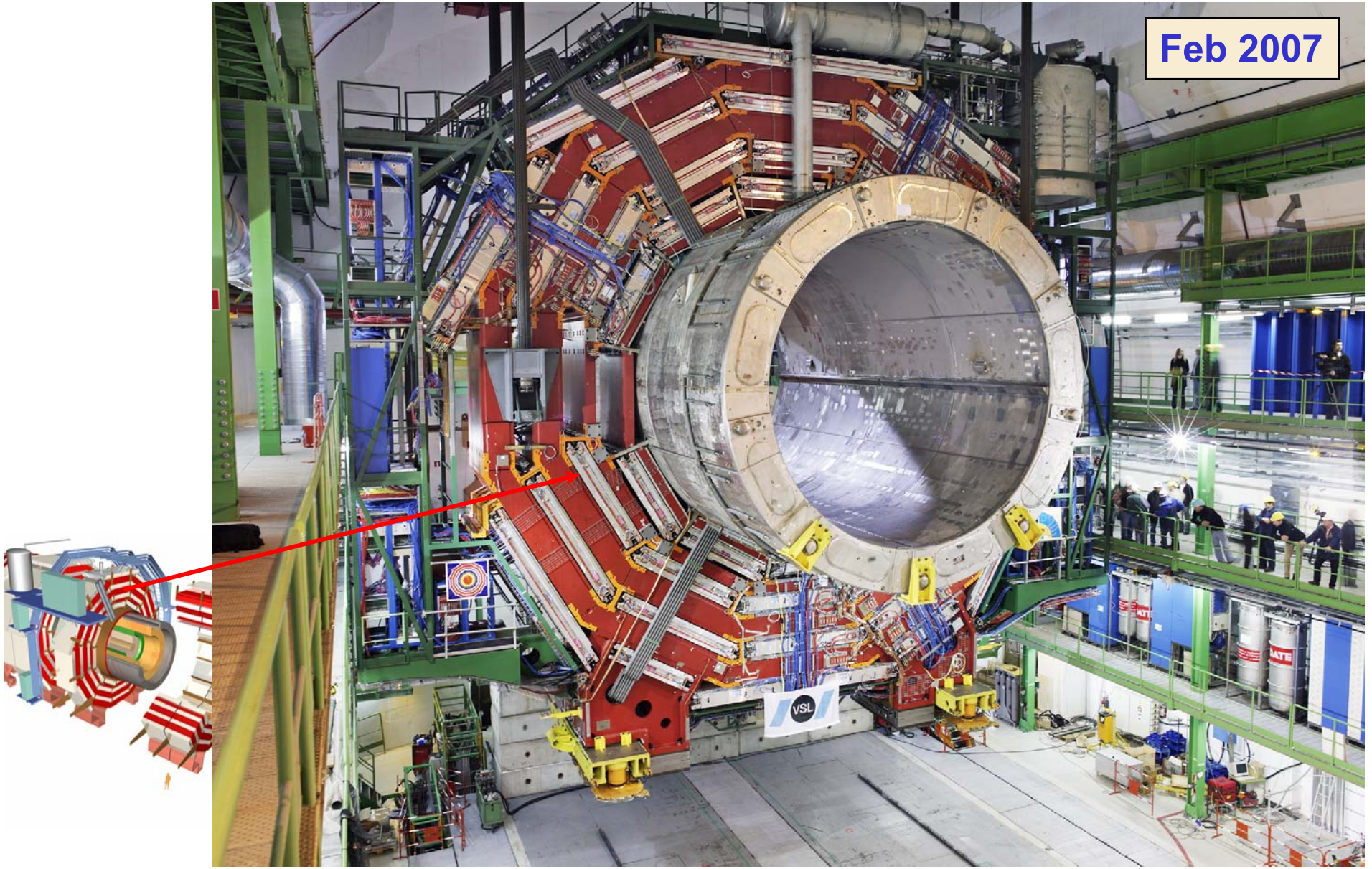
Assembly of the Solenoid (2005)



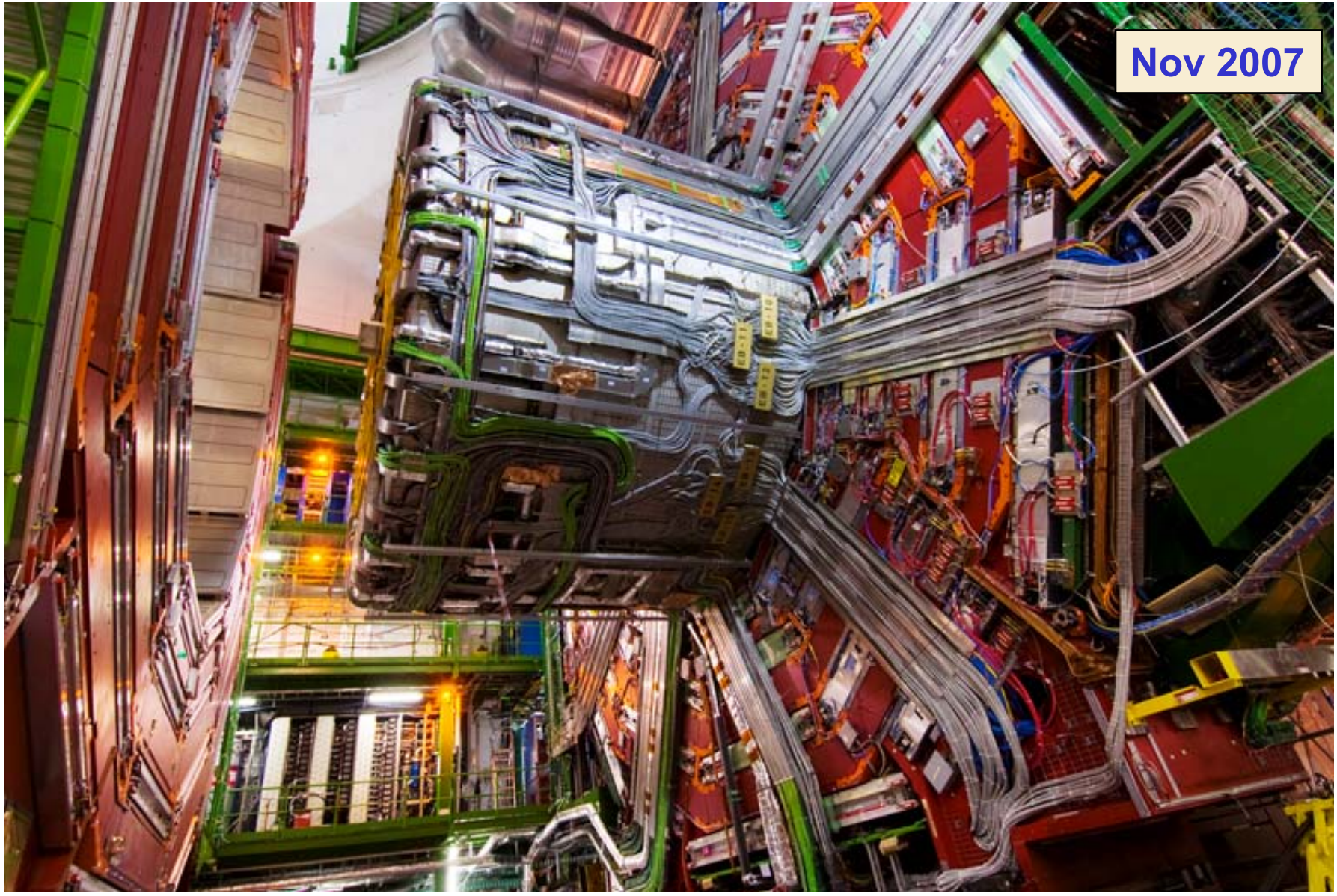
CMS Surface Hall in 2006



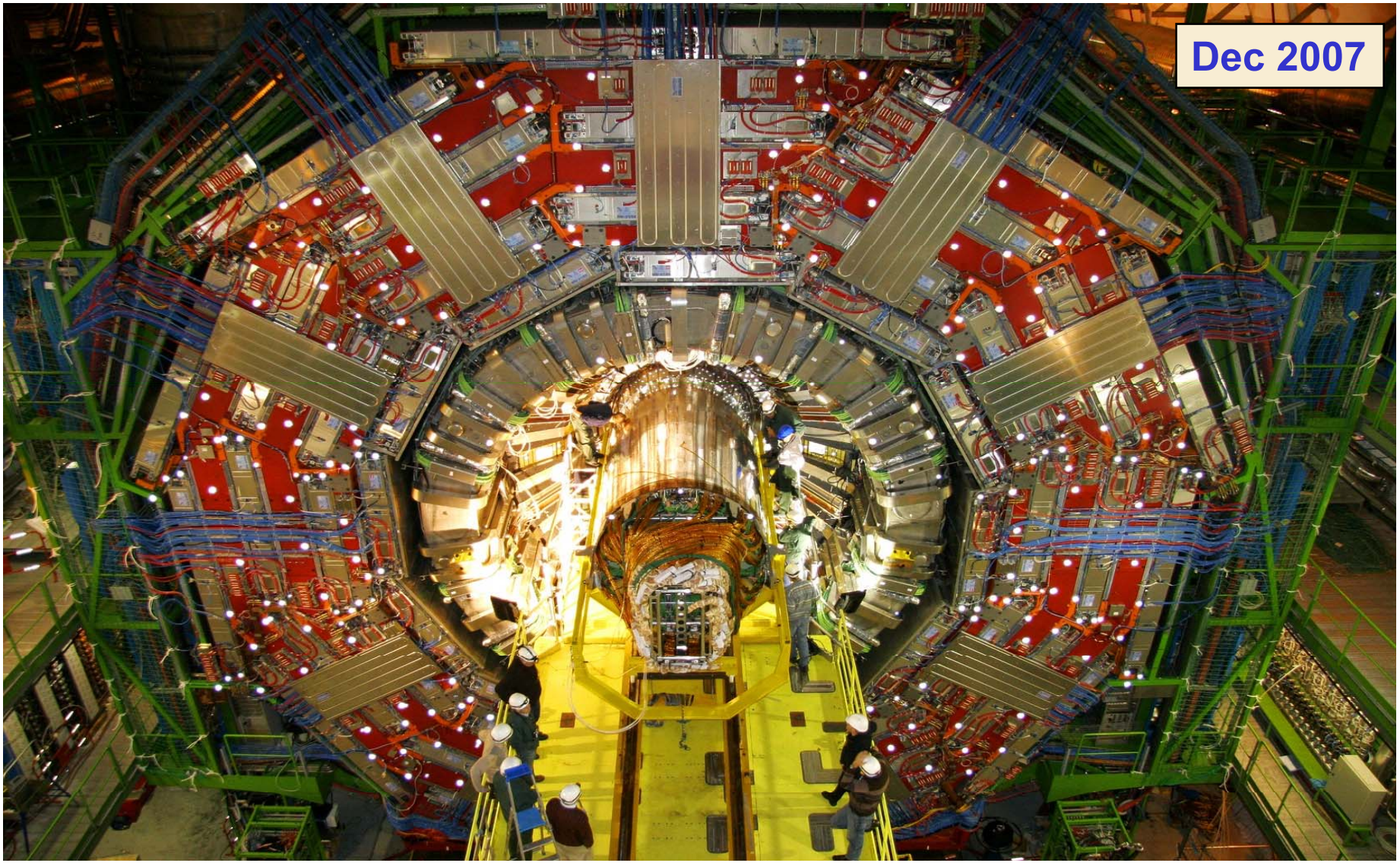
Lowering of the Experiment
Nov06-Jan08



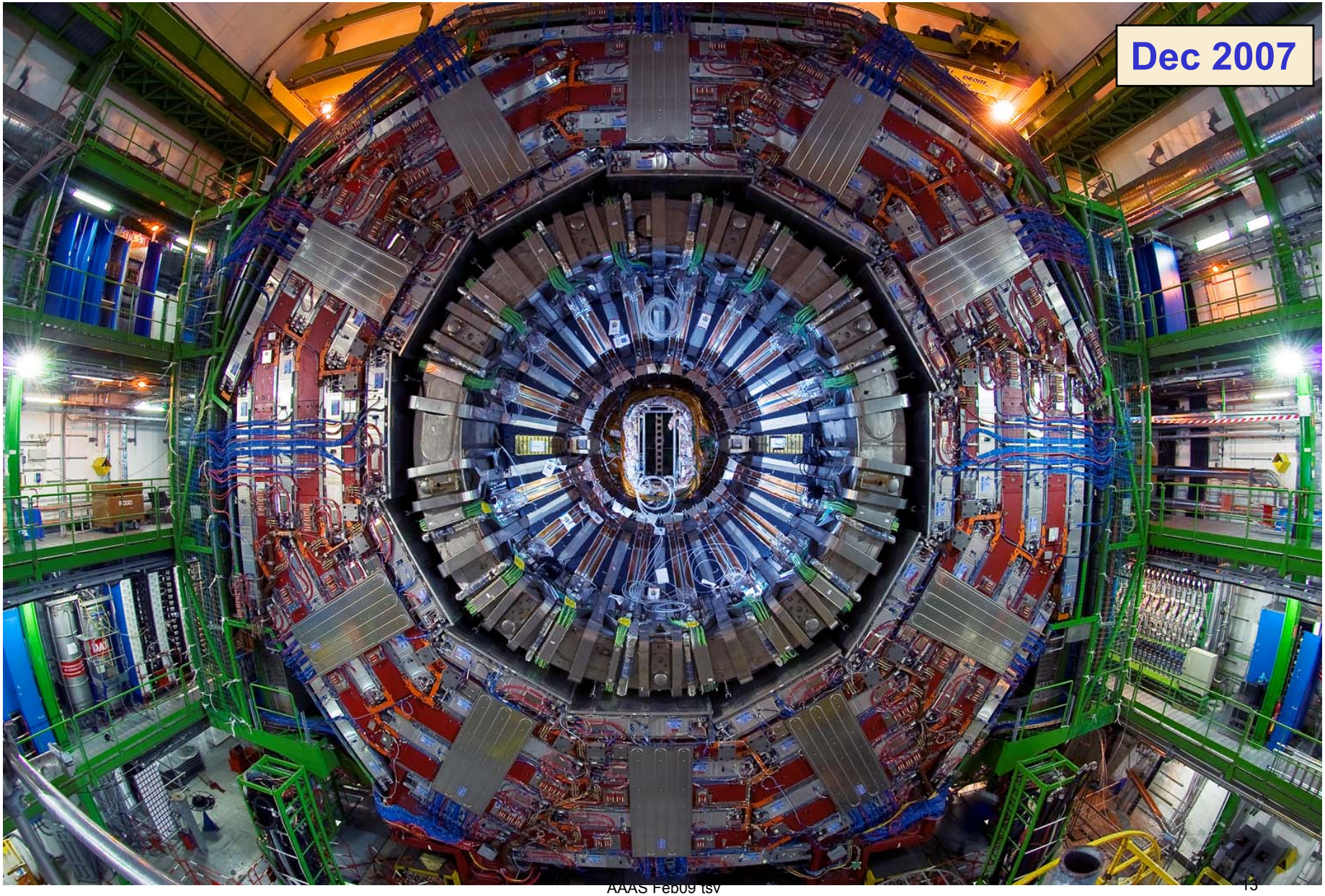
Completion of Services on the Central Element



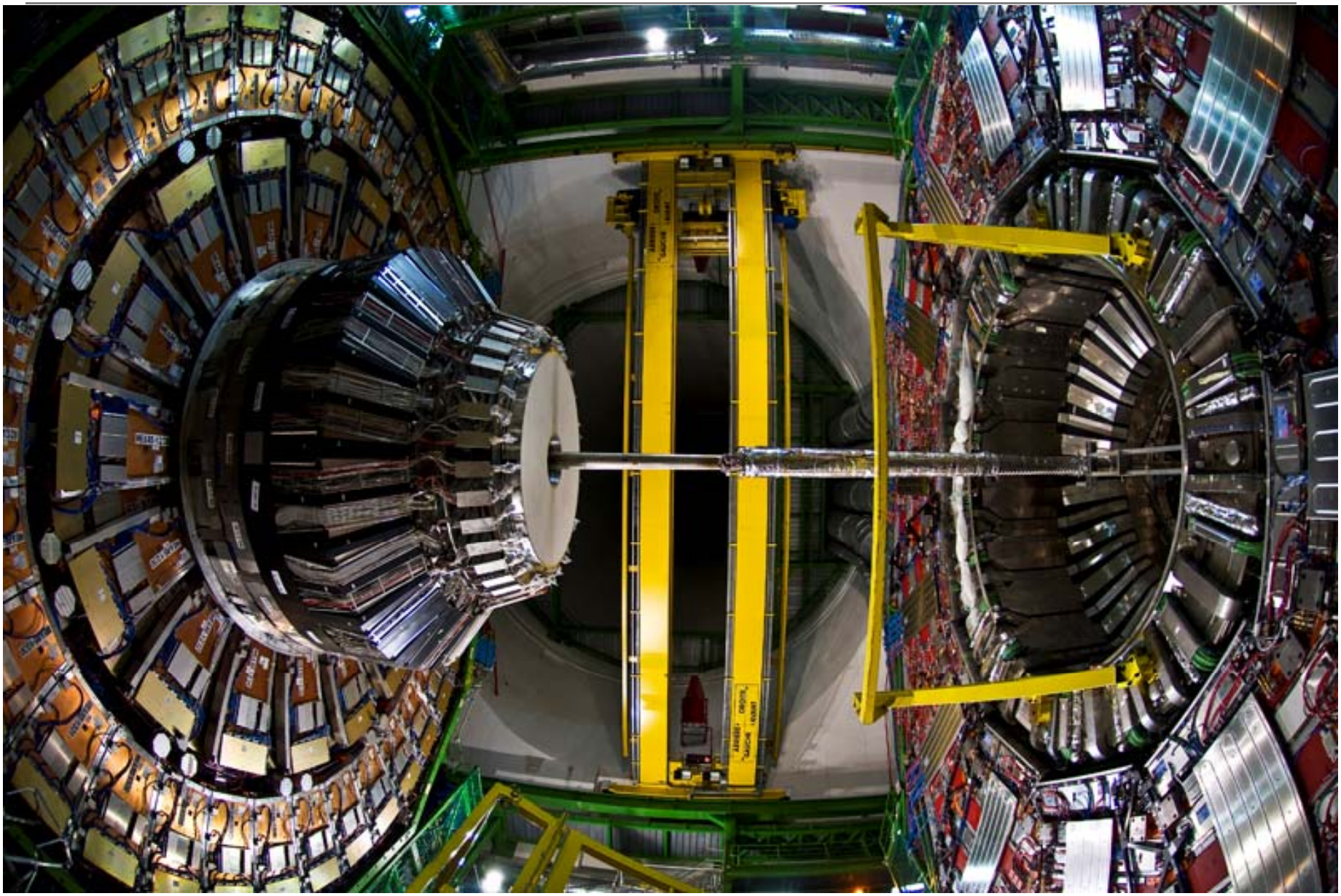
Insertion of the Si-Strip Tracker



CMS after Installation of Si Strip Tracker



Insertion of the Beam-pipe



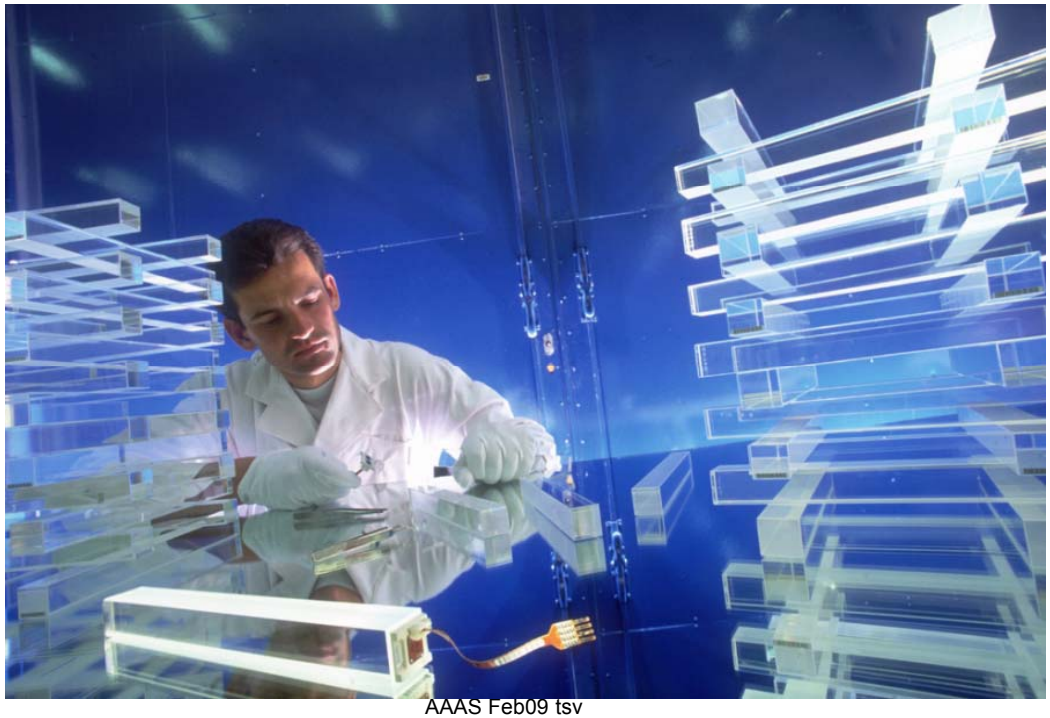
Closure of the Experiment

Challenging Detectors - An Example

Lead Tungstate Scintillating Crystals Electromagnetic Calorimeter

Driving Physics Design Goal

Measure precisely the energies of photons from a decay of the Higgs boson.



Timeline for Lead Tungstate Crystals

Idea (1993 – few yellowish cm^3 samples)

→ **R&D** (1993-1998: improve rad. hardness: purity, stoechiometry, defects)

→ **Prototyping** (1994-2001: large matrices in test beams, monitoring)

→ **Mass manufacture** (1997-2008: increase production, QC)

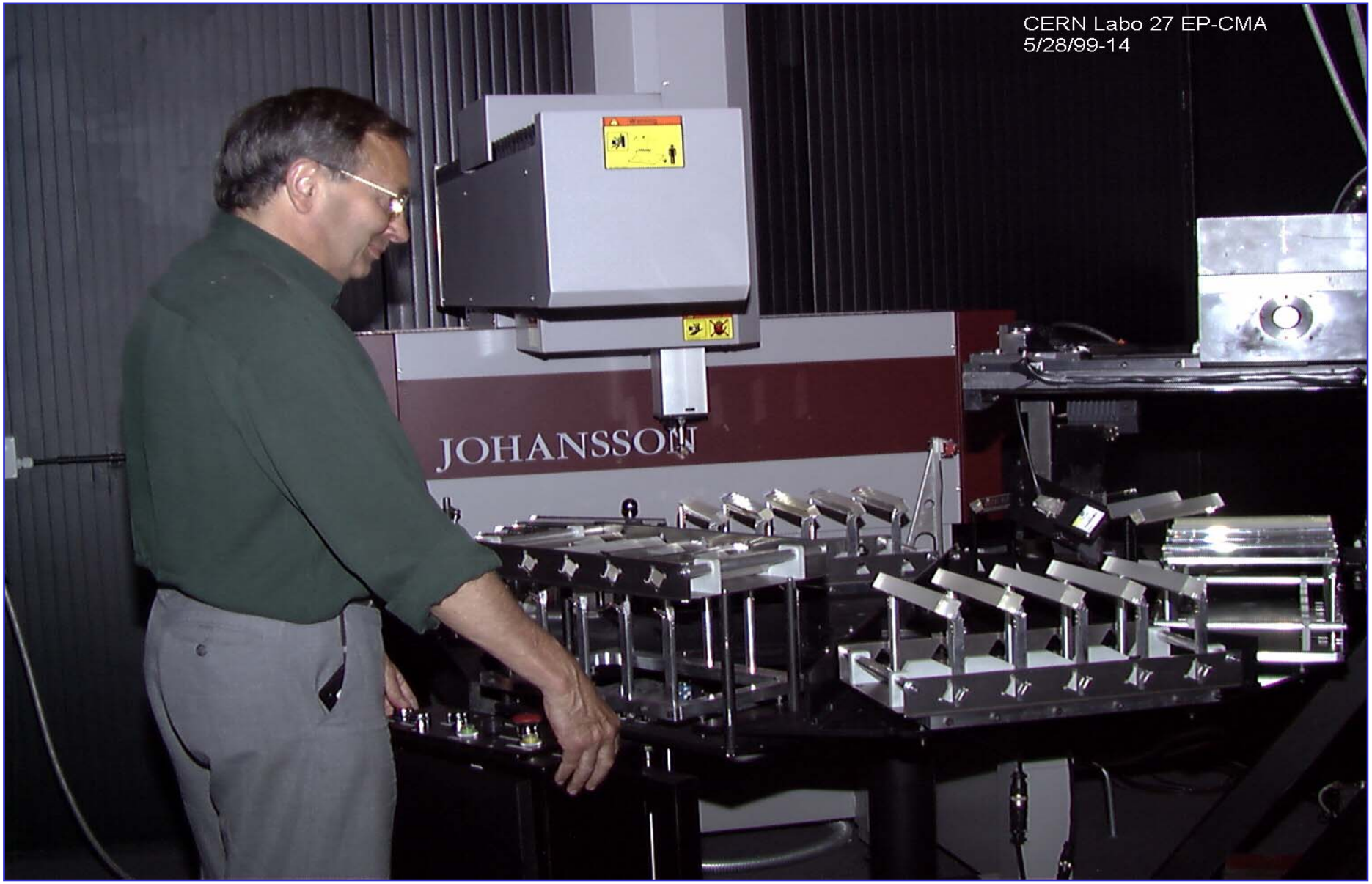
→ **Systems Integration** (2001-2008: tooling, assembly)

→ **Installation and Commissioning** (2007-2008)

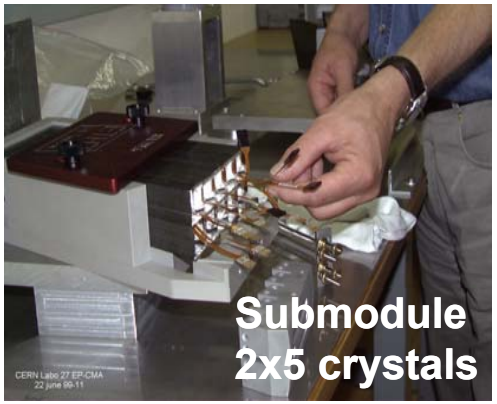
→ **Data Taking** (2008 onwards)

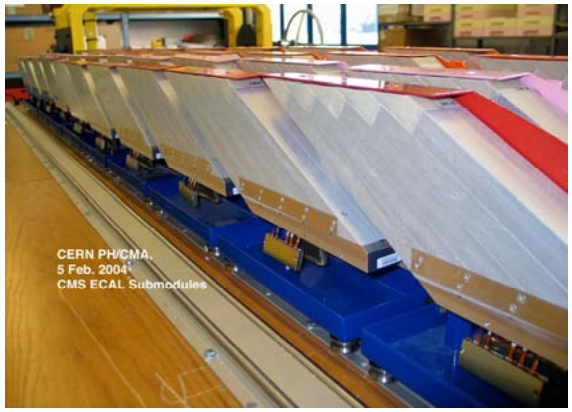
$\Delta t \sim 15$ years !!!

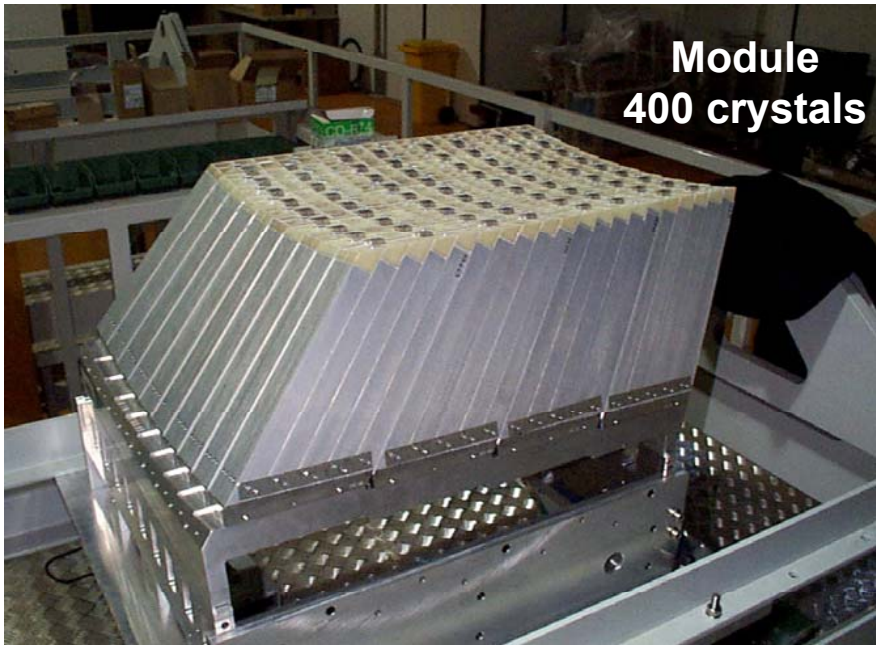
Production of Crystals

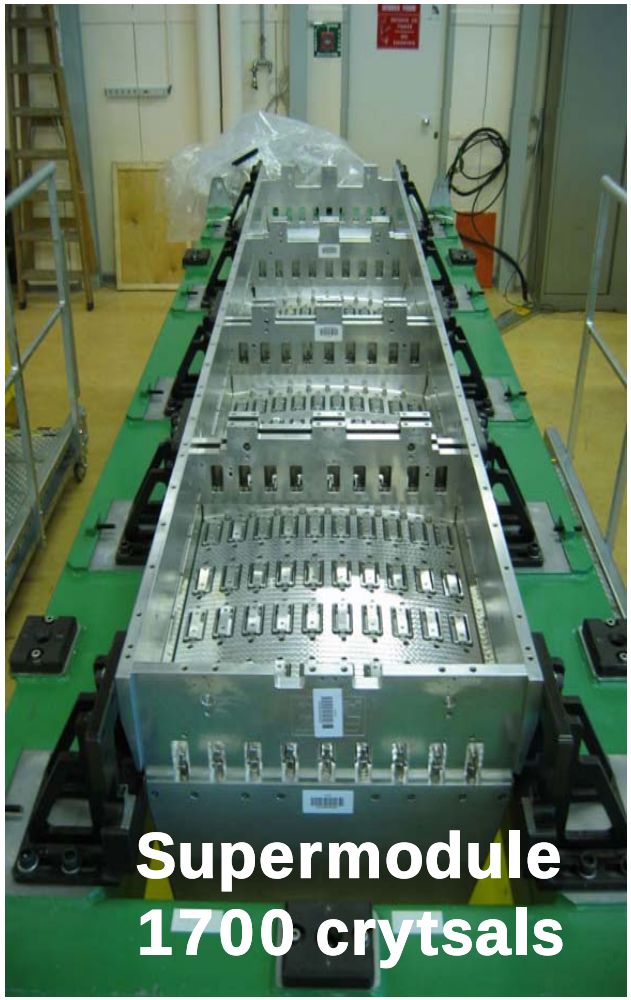


Assembly of ECAL





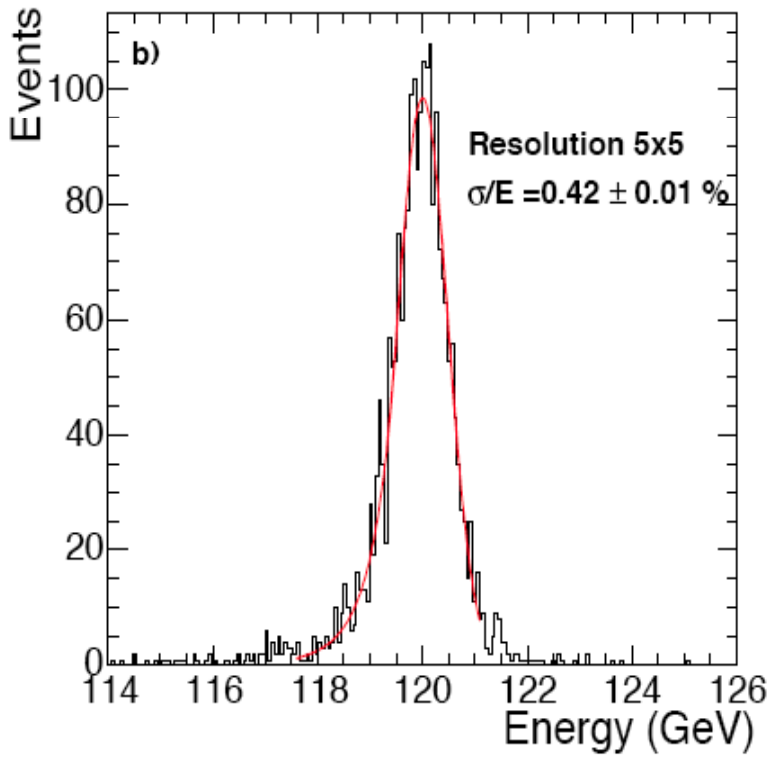




Total 36 Supermodules

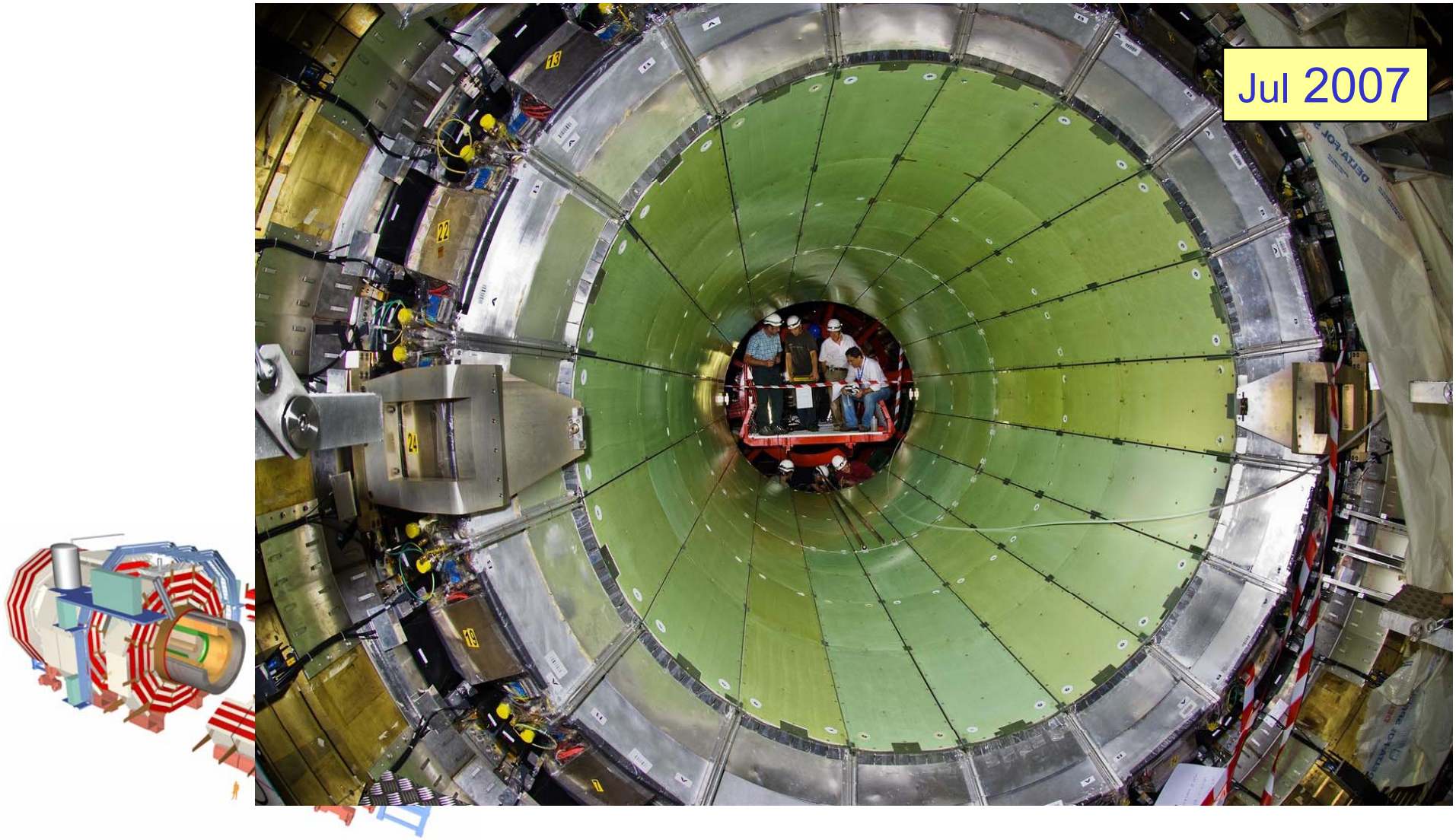
Integration of Electronics and Performance

Response to high energy electrons



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

Installation of Barrel ECAL



Commissioning CMS

Cosmics and First LHC Beam

Exercising the LHC Worldwide Computing Grid

Prompt Reconstruction

TIER-0

CASTOR

CAF

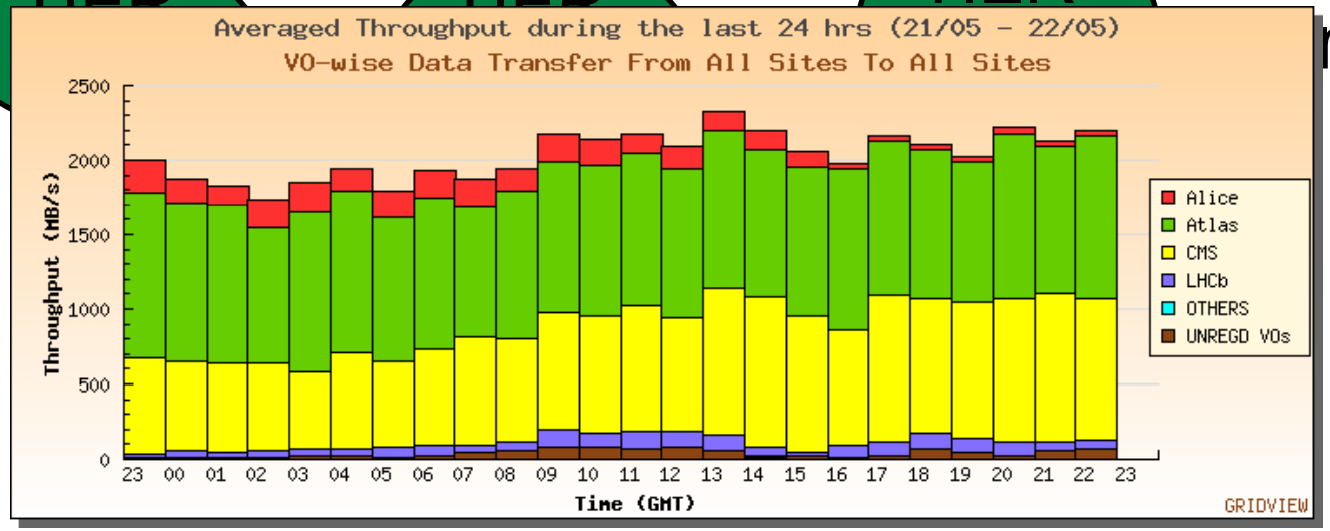
Calibration
Express-Stream
Analysis

600MB/s

50-500MB/s

TIER-

Re-Reco
ms



First Beams

After almost 20 years of design and construction CMS started taking data with LHC beams.

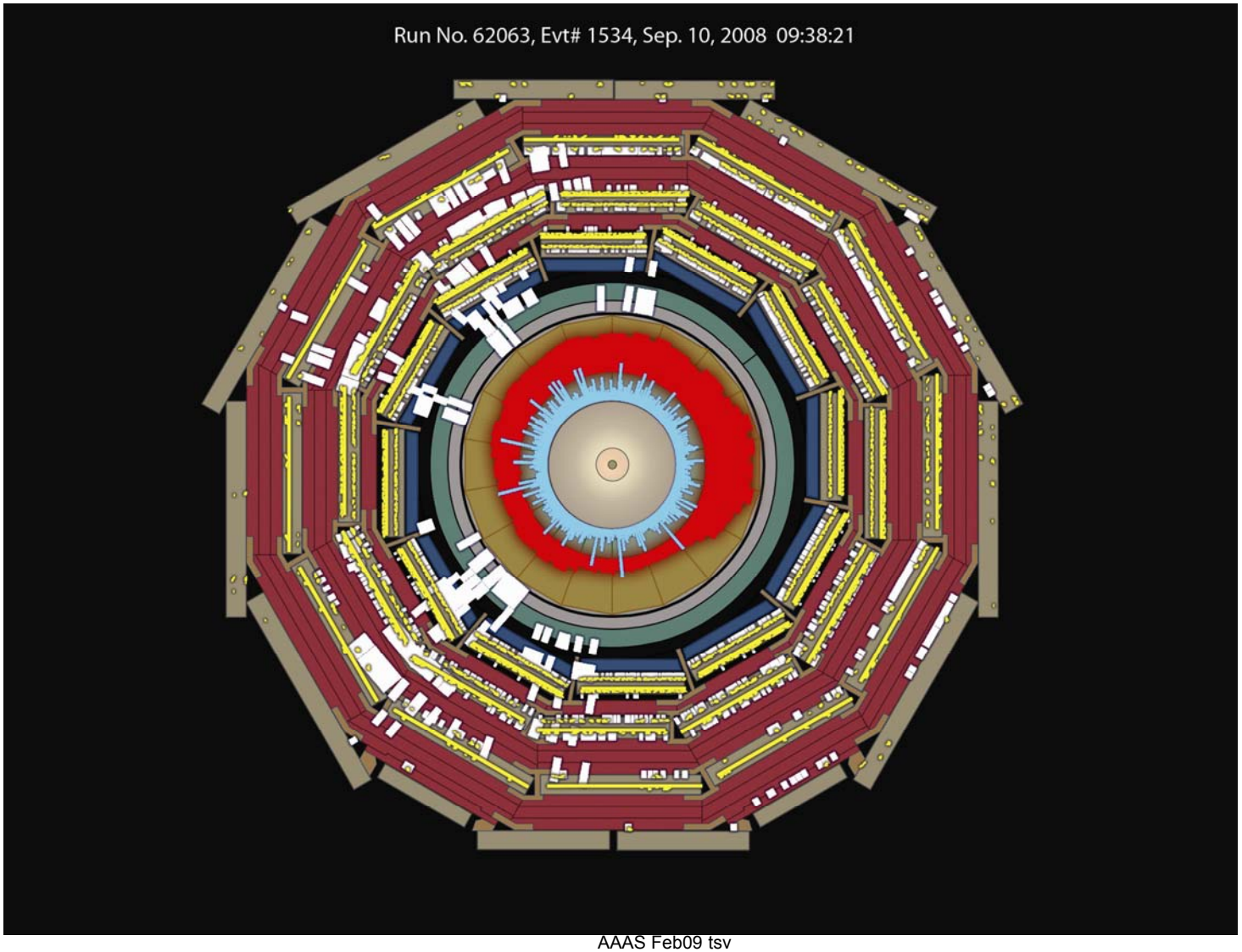
(Much appreciation for the work of the accelerator folks)

- **Sun/Mon/ Tues, 7-8-9 Sept.**
  - **Single shots of Beam 1 onto collimator 150m upstream of CMS**
  - **Allowed synchronization of trigger, splash events**

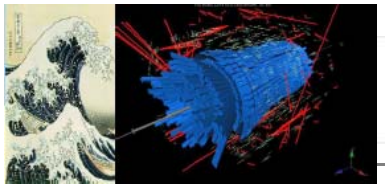
- **Wed., 10 Sept.**
  - **Spectacular splash events observed when beam onto collimators, 100-1000 TeV observed in ECAL-HCAL**
  - **Halo muons observed once beam started passing through CMS**
  - **Ciculating beams were "clean"**

First Events: Collimators Closed

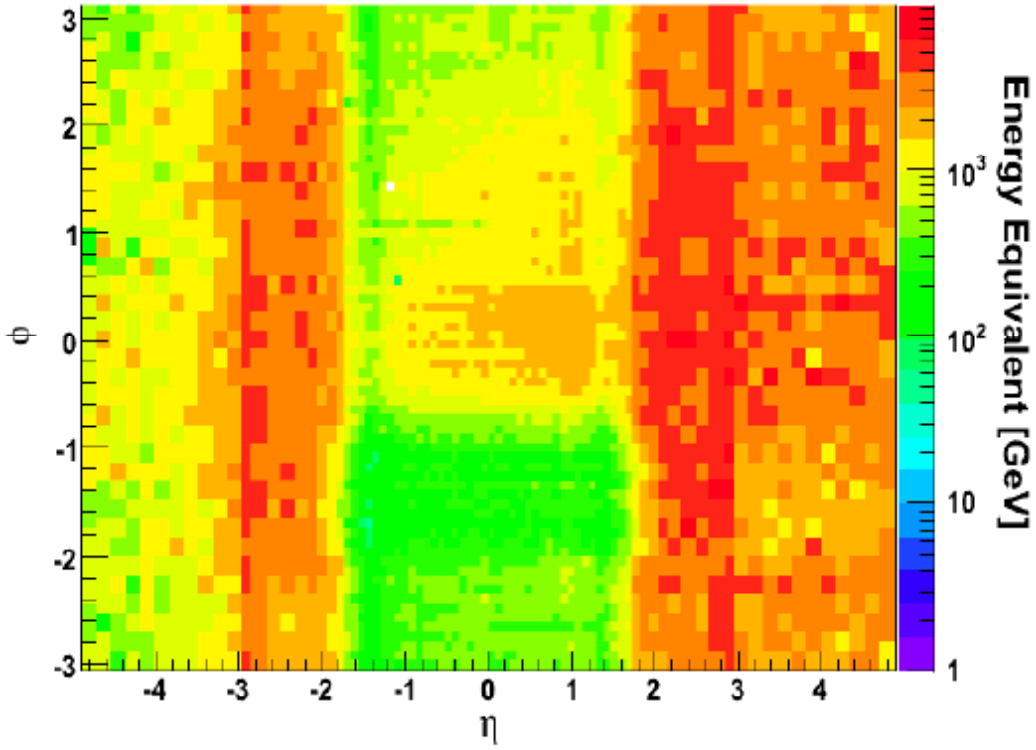
~2.10^9 protons on collimator ~150 m upstream of CMS



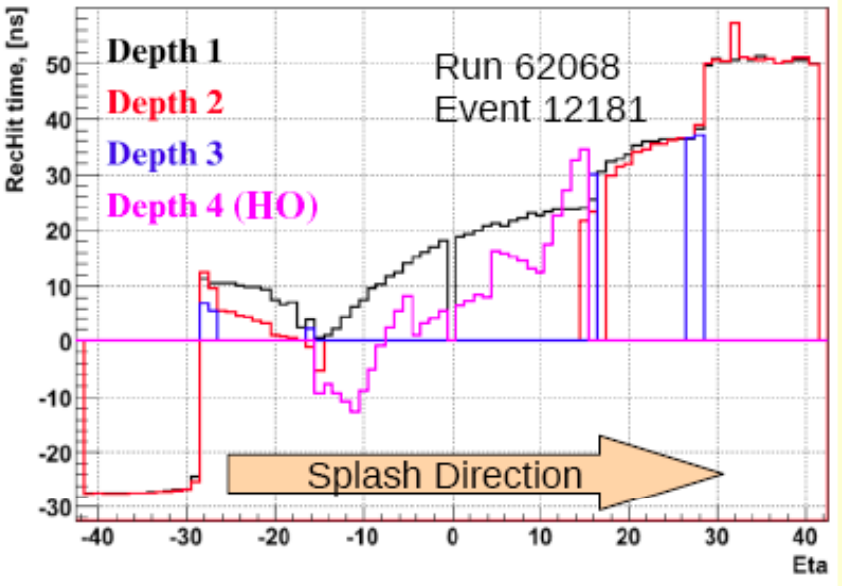
10 Sept. 2008

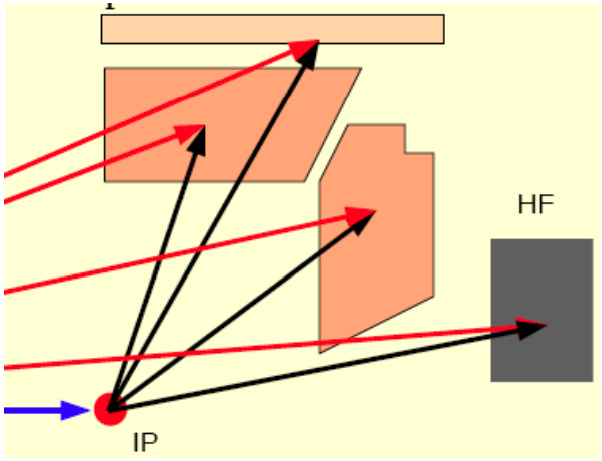


An Example: Timing in HCAL

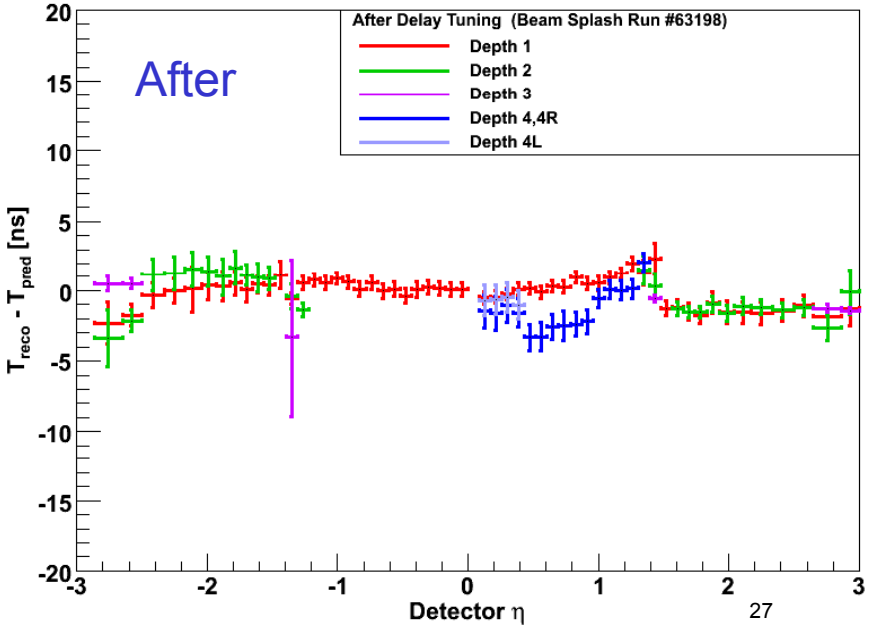


Before

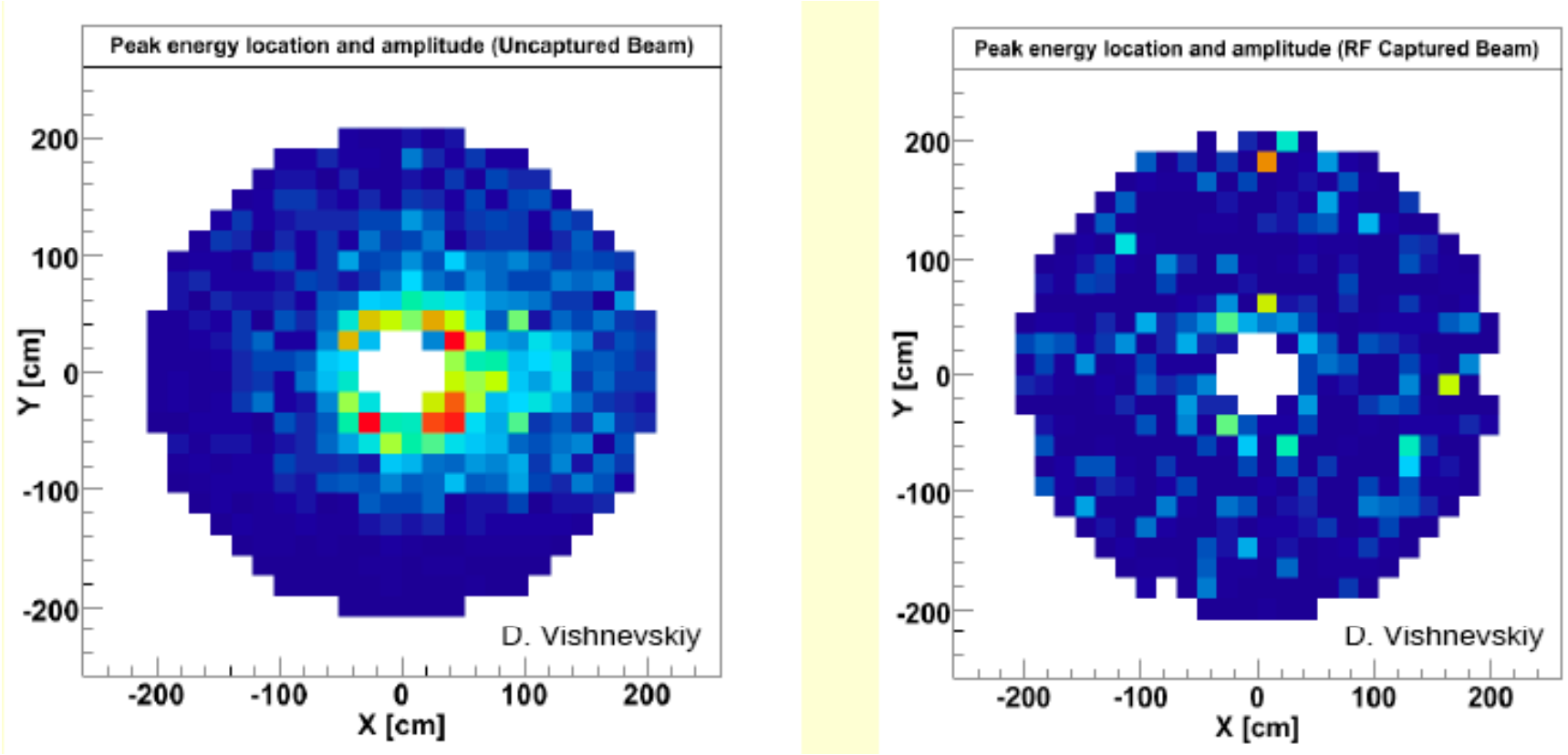




After



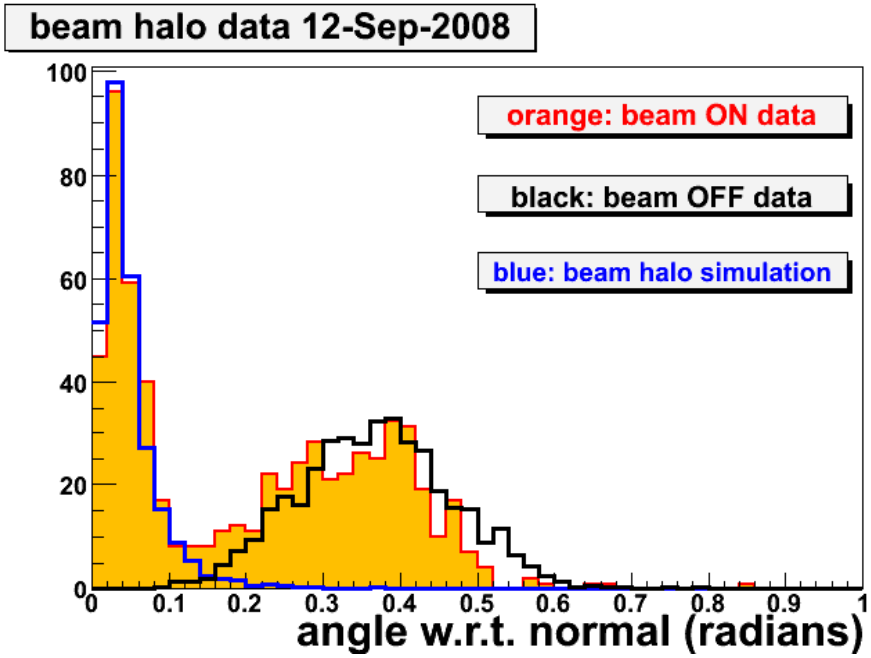
Circulating Beam: Beam Halo Events

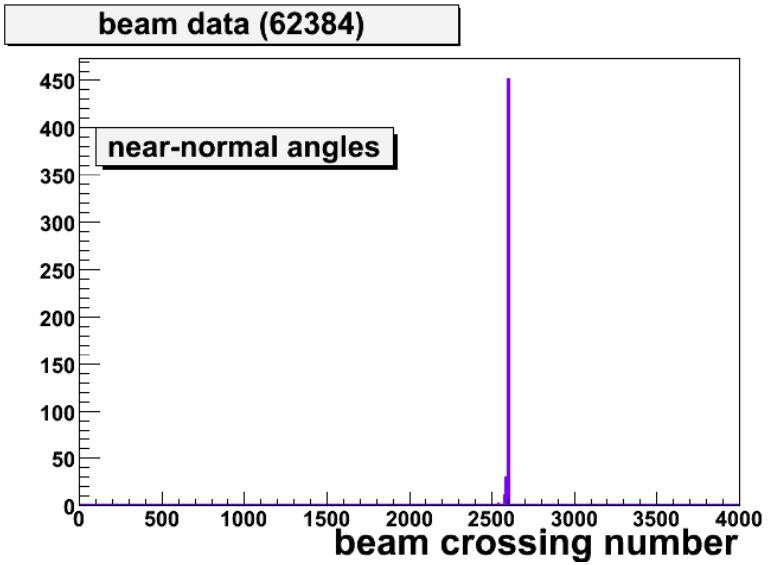


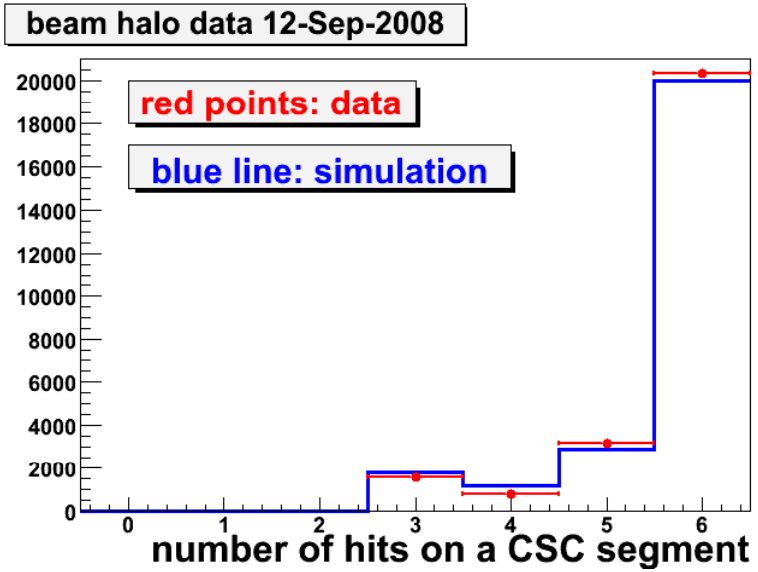
HCAL Endcap: un-captured (lhs) and captured beam (rhs)

Muon CSCs: Single Beam

Reconstructed track angle w.r.t. the transverse plane







Reasonable description of beam ON data: combination of

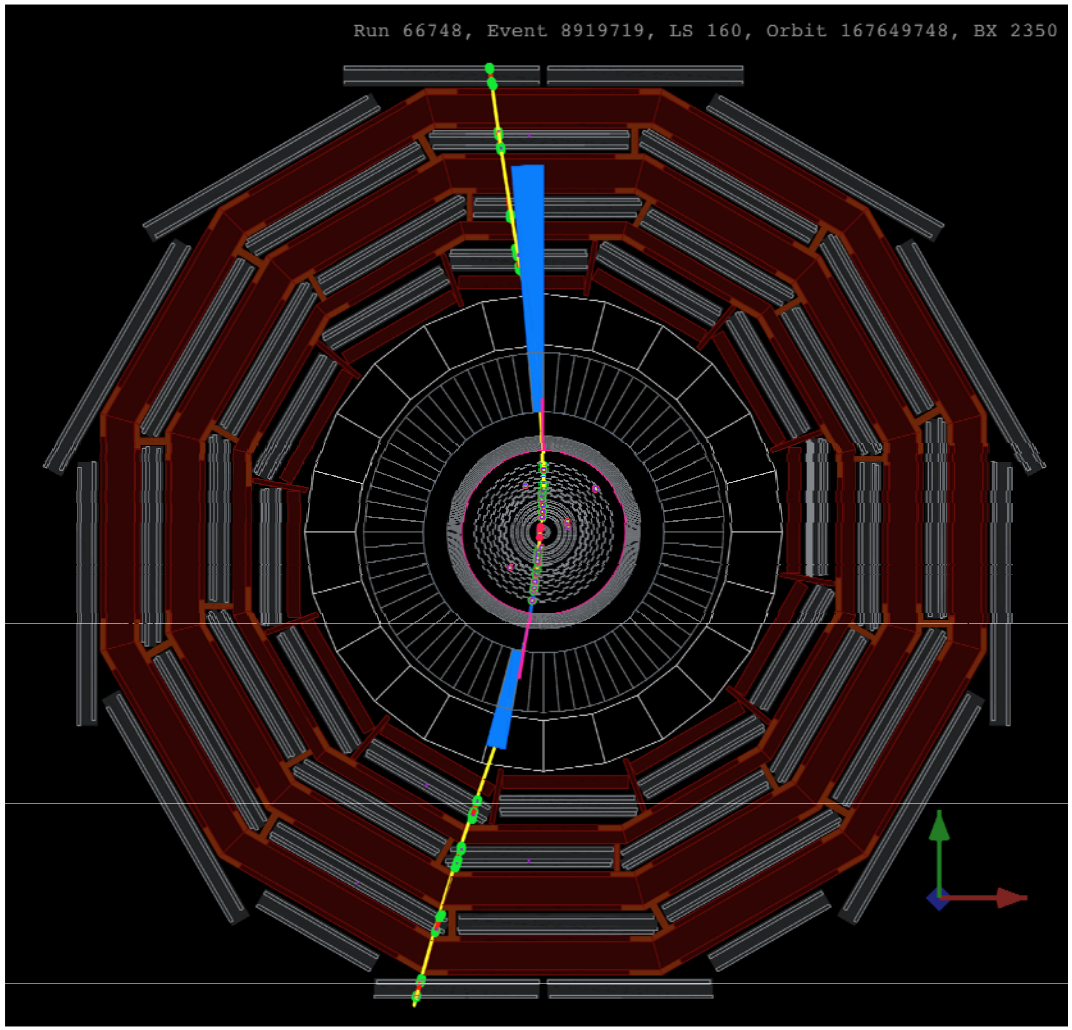
- **beam halo**
- **cosmic rays**

Continuous Operation of CMS

CRAFT: Cosmics Run at Four Tesla

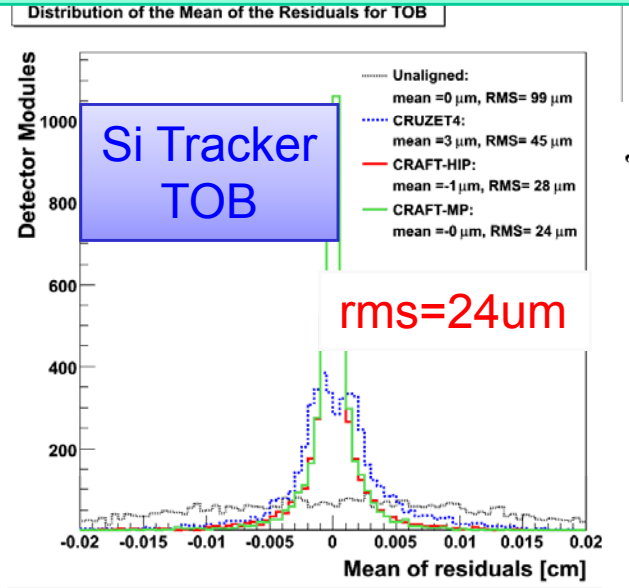
Ran CMS for 6 weeks continuously to gain operational experience

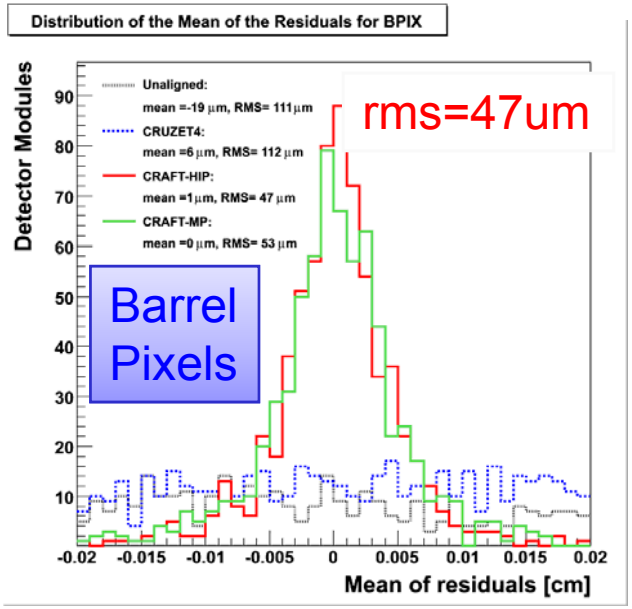
Collected 300M cosmic events with tracking detectors and field (≈ 70% live-time). About 400 TB of data distributed widely.



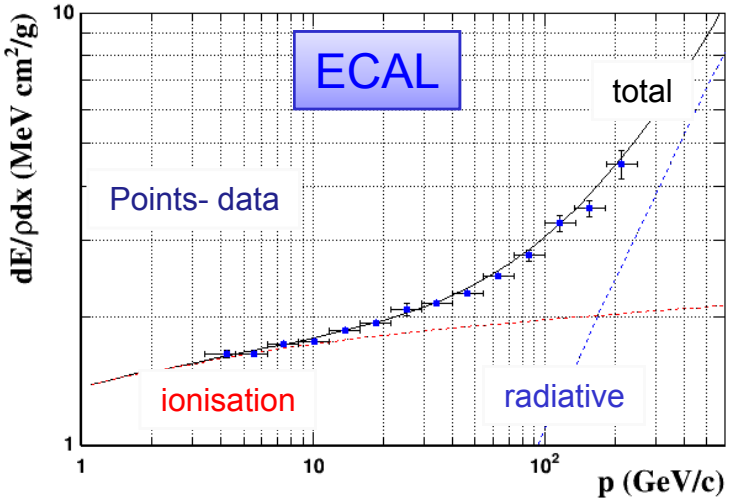
CRAFT Results: Some Examples

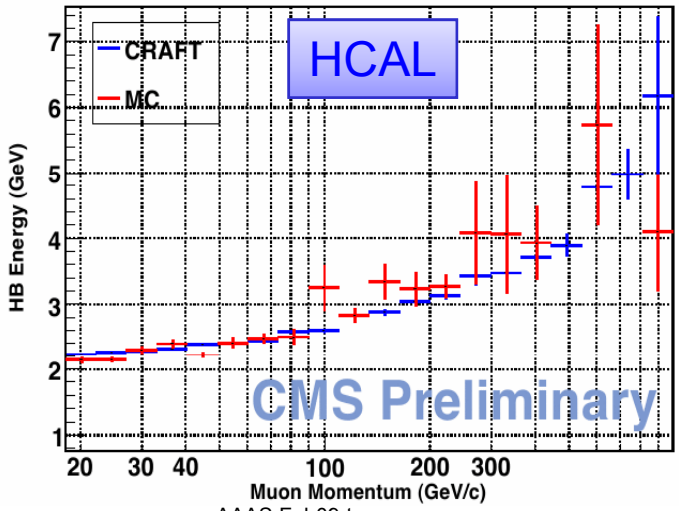
Alignment in Inner Tracker



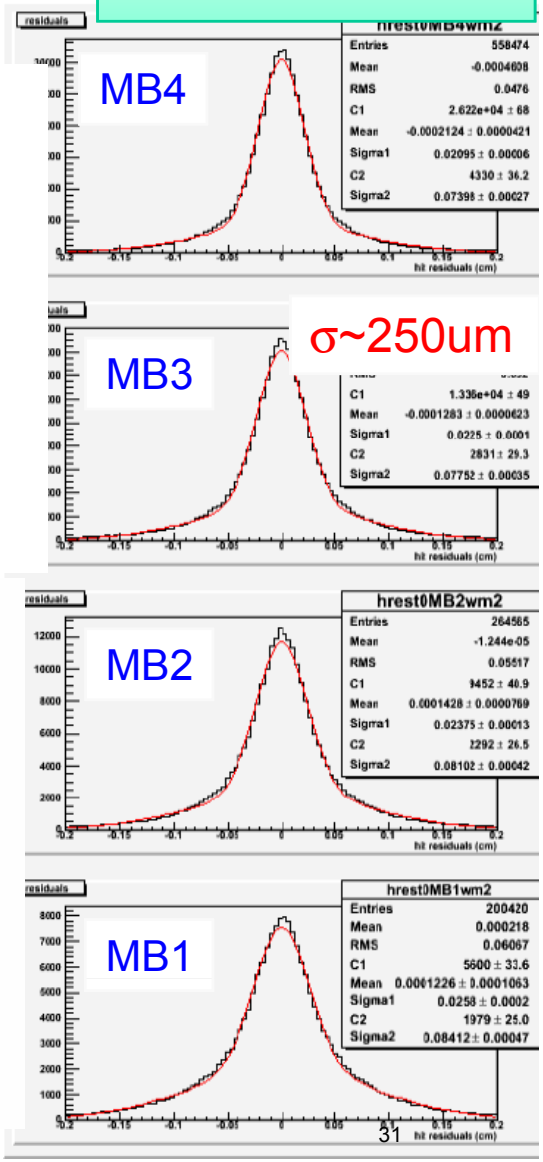


Energy deposited by muons





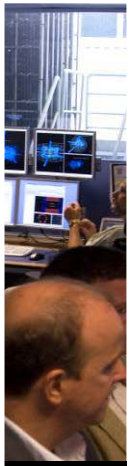
Muon Chambers Point Resolution



Distributed Operations

CMS Remote Operations Centre at Fermilab

CMS Experiment Control Room



High definition permanently-running video links between operations centres

CMS Centre at CERN: monitoring, computing operations, analysis

Conclusions on CMS

After almost 20 years of design, construction and assembly CMS started taking data with LHC beams in September 2008.

After the LHC incident CMS ran continuously for 6 weeks in October/November 2008.

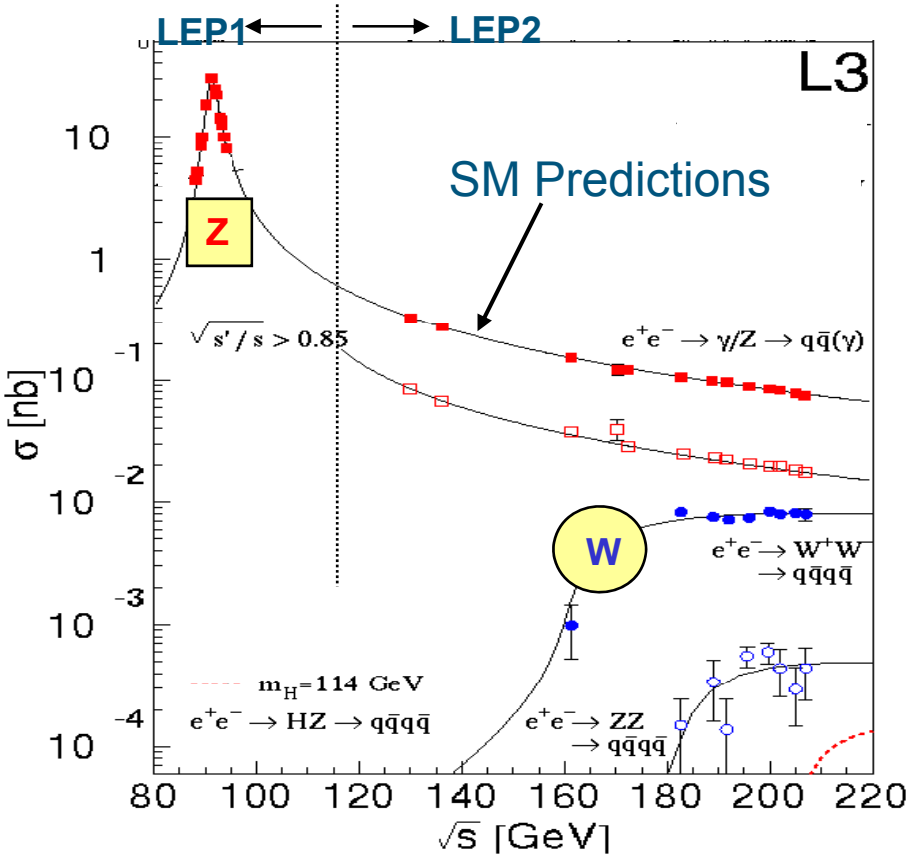
All indications are that sub-detectors, online, offline, computing and analysis systems are performing well and according to specification.

CMS is now an operational experiment and is ready for high energy collisions !

Successes of the Standard Model

LEP, SLC and the Tevatron: established that we really understand the physics at energies up to $\sqrt{s} \sim 100$ GeV

And any new particles have masses in the range of hundreds of GeV – and in some cases TeV.



Although the Standard Model is a beautiful theory and arguably one that is most precisely tested
we know it is not the whole truth !

Questions for the SM (I)

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

Higgs mechanism ? If so measurements suggest m_H<200 GeV/c^2.

Other physics ? Answer will be found at the Terascale.

Why is weak interaction not so obvious as electromagnetism in our everyday life ? More precisely: why is $M_\gamma = 0$, $M_Z \sim 90$ GeV/c^2

2. SM without Higgs (or equivalent) gives nonsense at LHC energies

The probability of some reactions becomes greater than 1 ??

The SM solution: introduce the Higgs boson.

3. Supersymmetry?

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 a new symmetry (Supersymmetry) is the answer, it must show up at *O*(TeV)

Questions for the SM (II)

4. Nature's favouritism… why is there more matter than anti-matter?

5a. Unified Theory? SM is logically incomplete

Does not incorporate gravity.

Superstring theory ? ⇨ dramatic concepts: supersymmetry, extra space-time dimensions ?

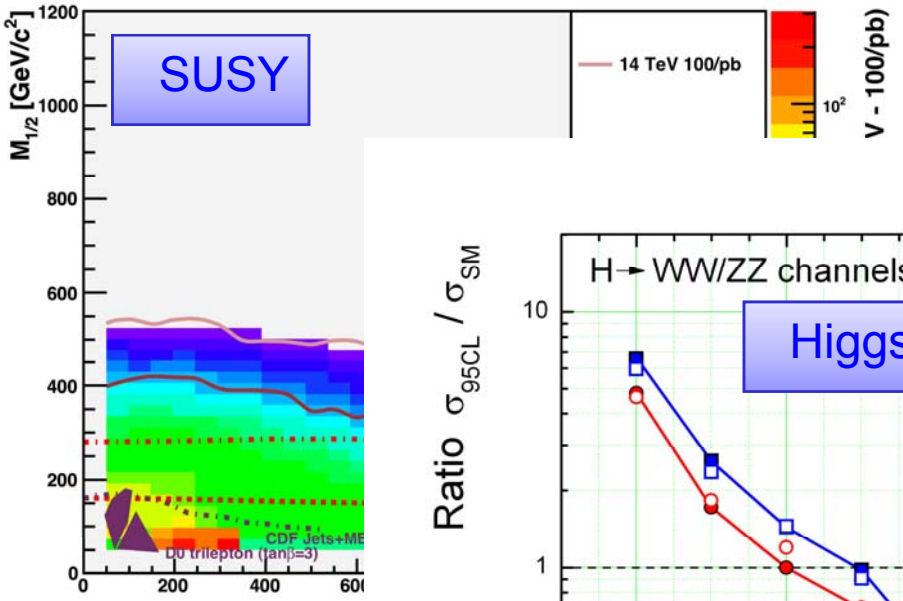
5b. Unified Theory? SM contains too many (arbitrary) parameters

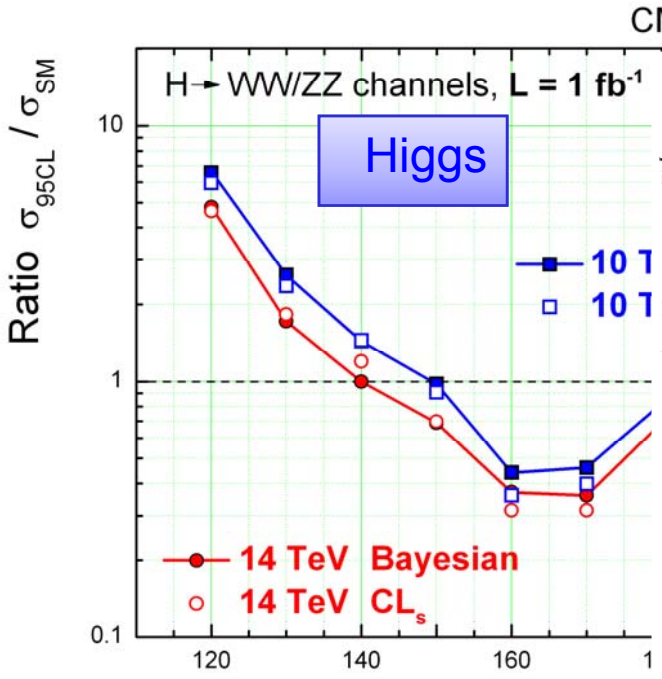
A more complete theory (unified theory?) should give these from first principles ?

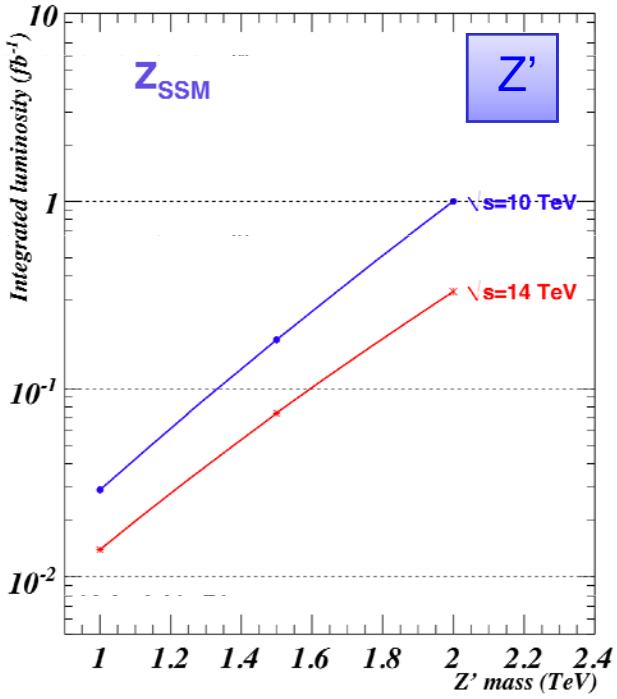
CMS (LHC) experiments are designed to tackle and make progress in answering these questions

First Few Hundred pb^{-1} @ 10 TeV

Signals and backgrounds are scaled from 14 TeV
Plots are indicative of CMS reach



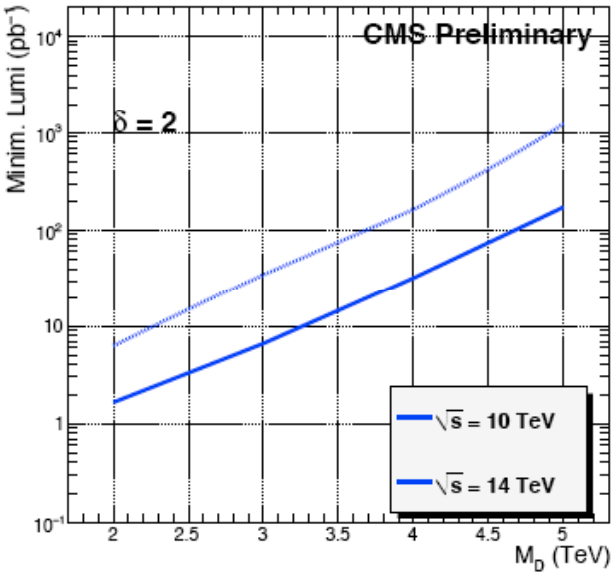


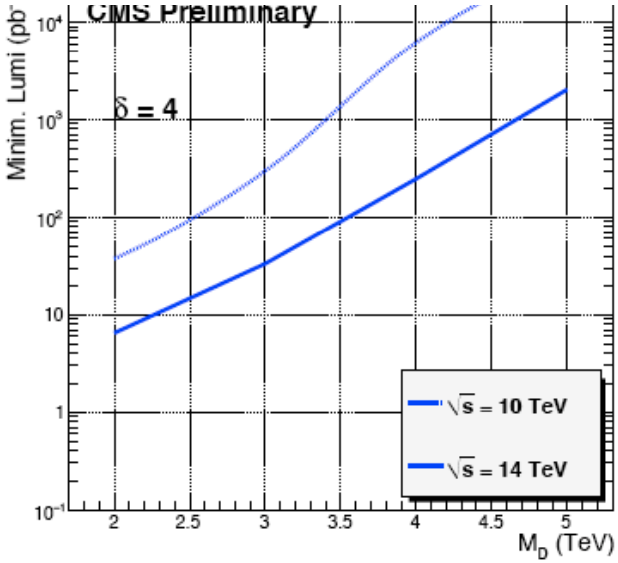


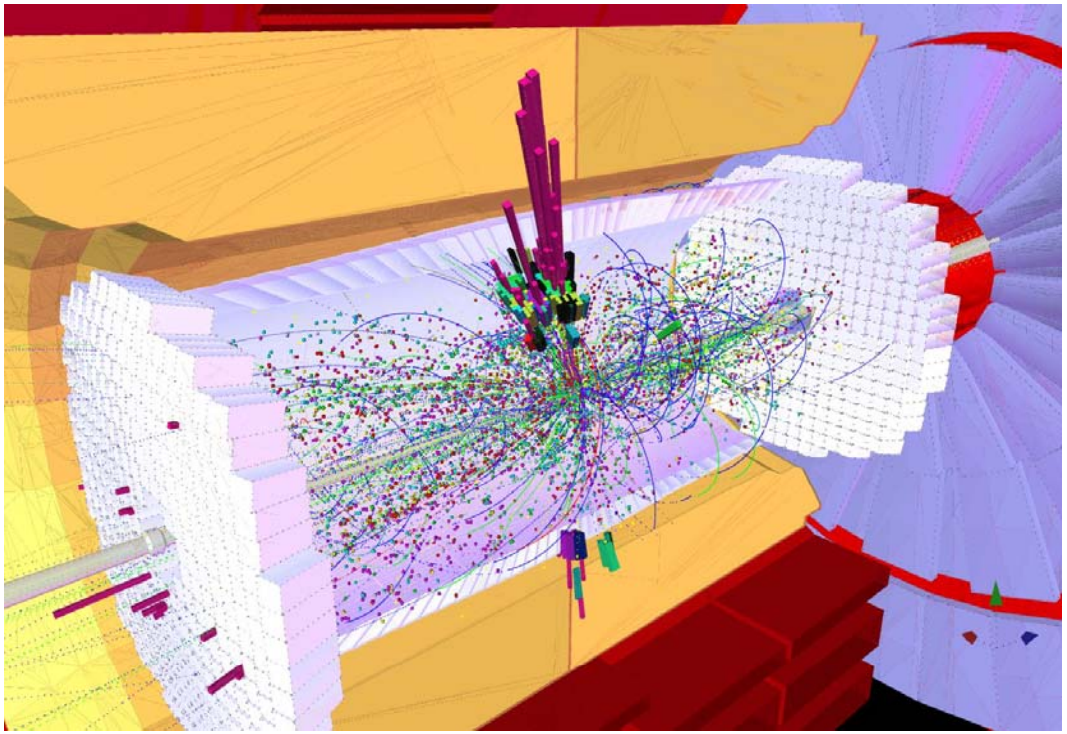
With 200 pb^{-1}, reach current Tevatron sensitivity for Higgs

Extra Dimensions

ADD monojets



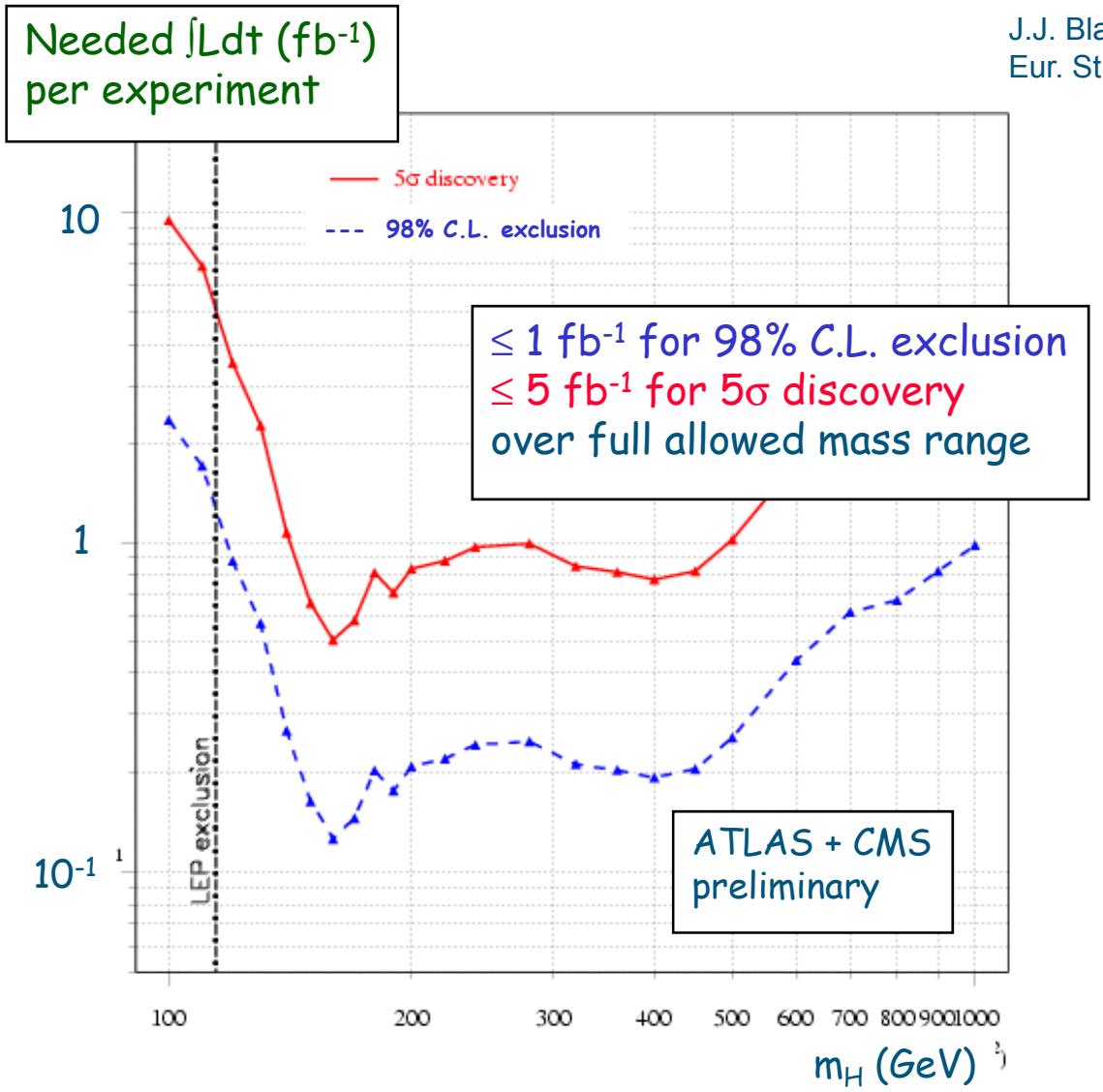




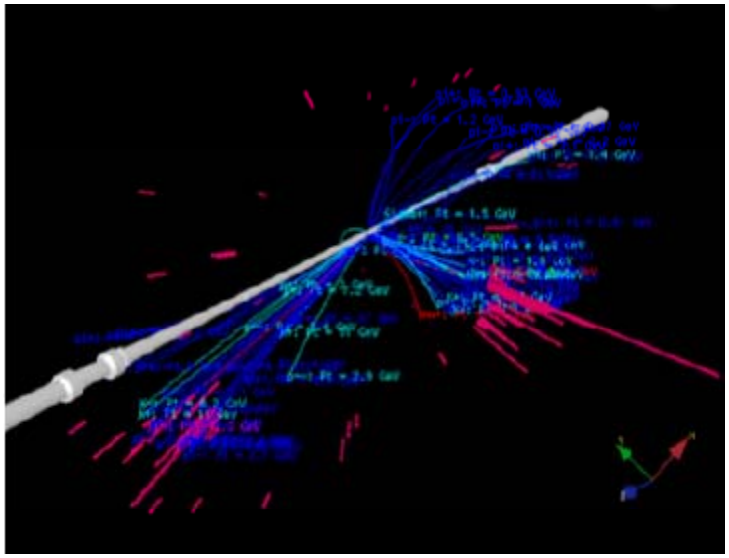
Plots are indicative of CMS reach

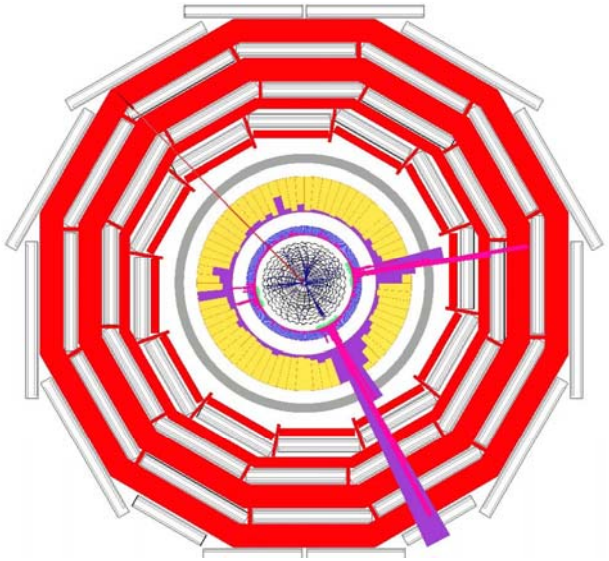
ATLAS +CMS: SM Higgs @14 TeV

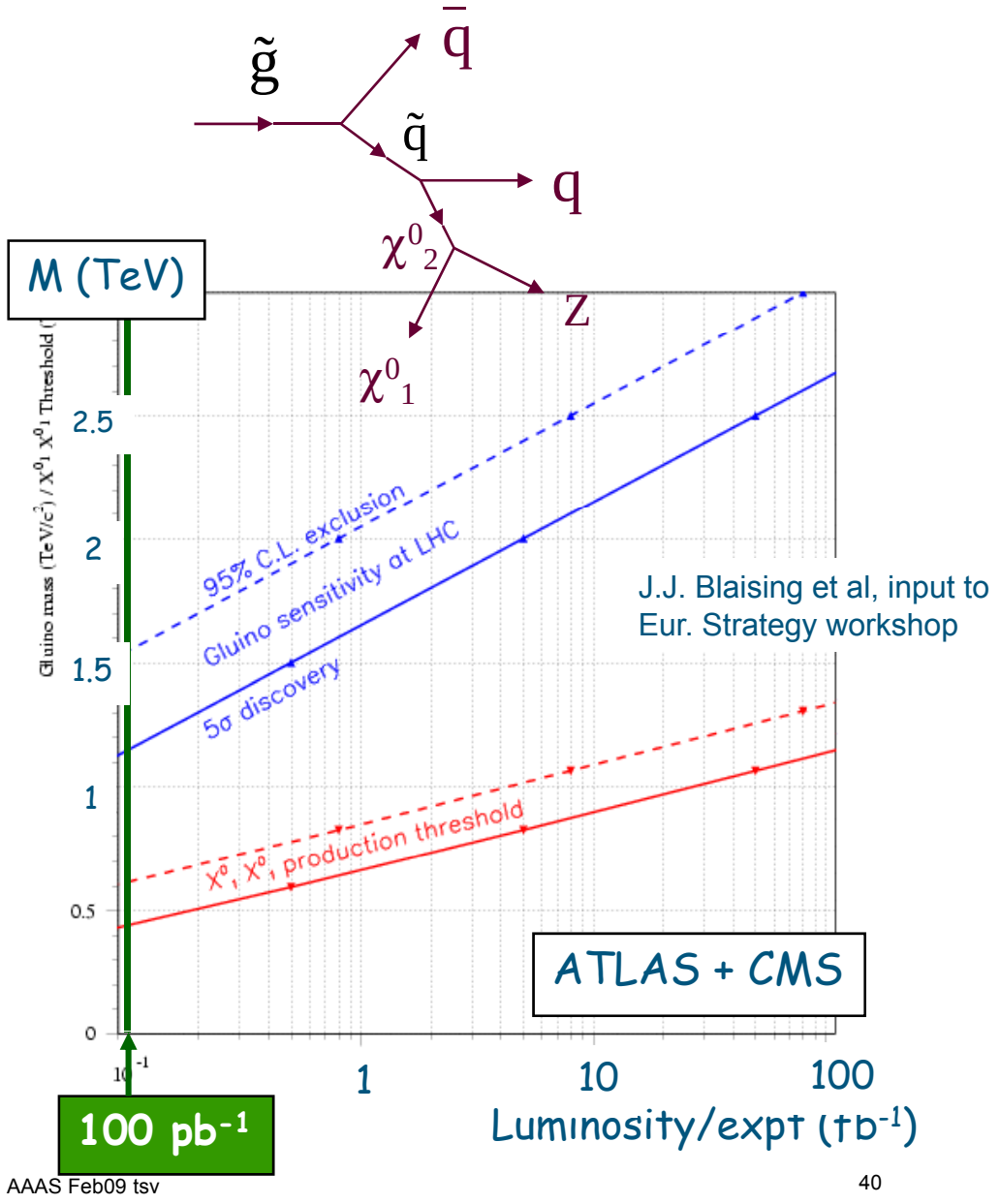
J.J. Blaising et al, input to Eur. Strategy workshop



ATLAS + CMS: Supersymmetry @ 14 TeV



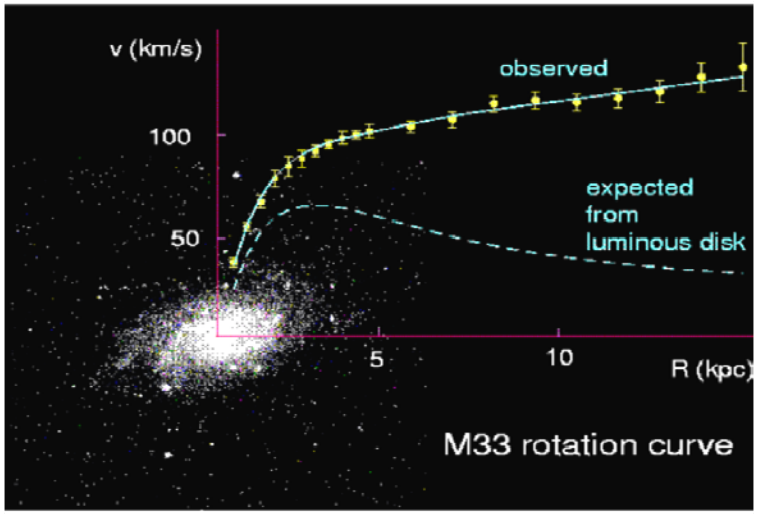


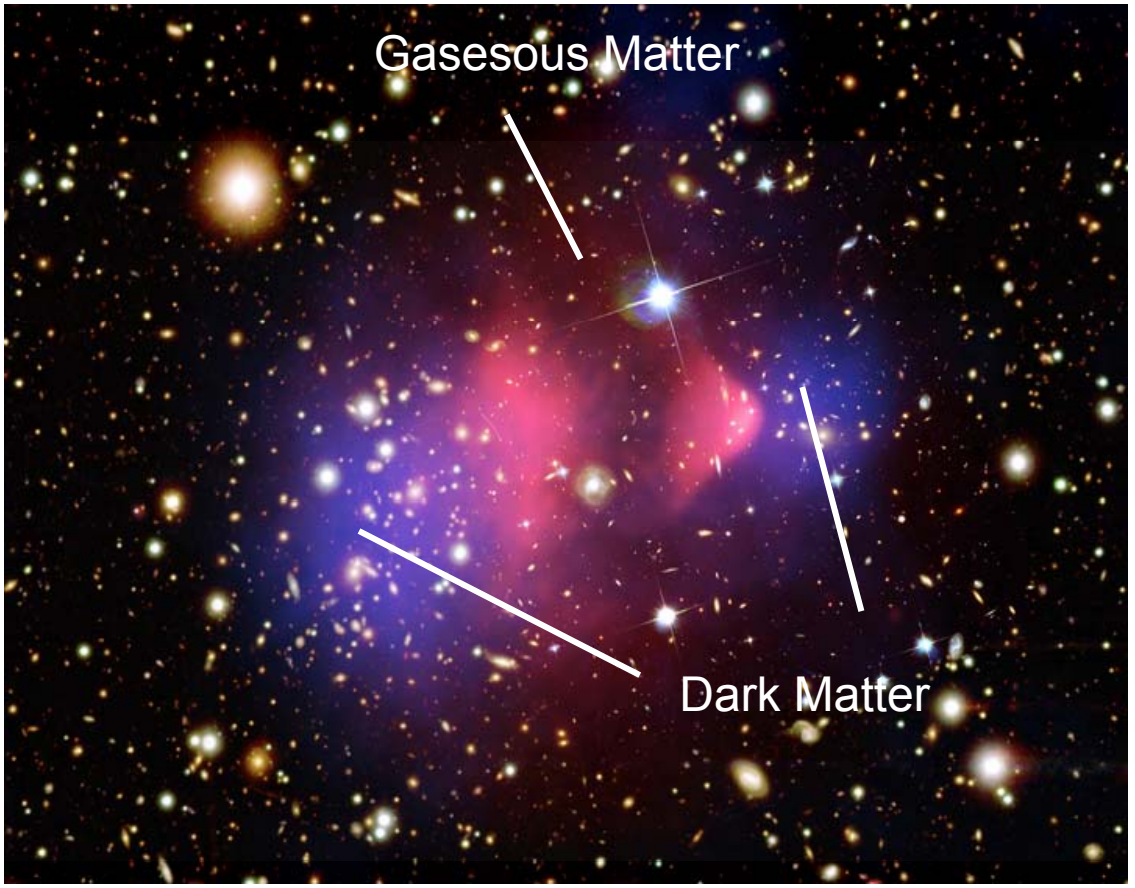


J.J. Blaising et al, input to Eur. Strategy workshop

Dark Side of the Universe: Dark Matter

Dark (invisible) matter!

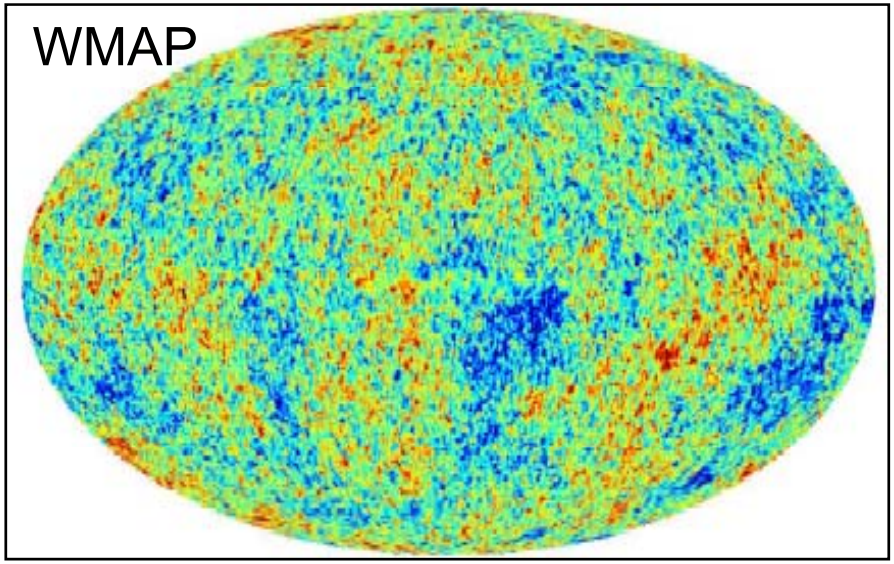




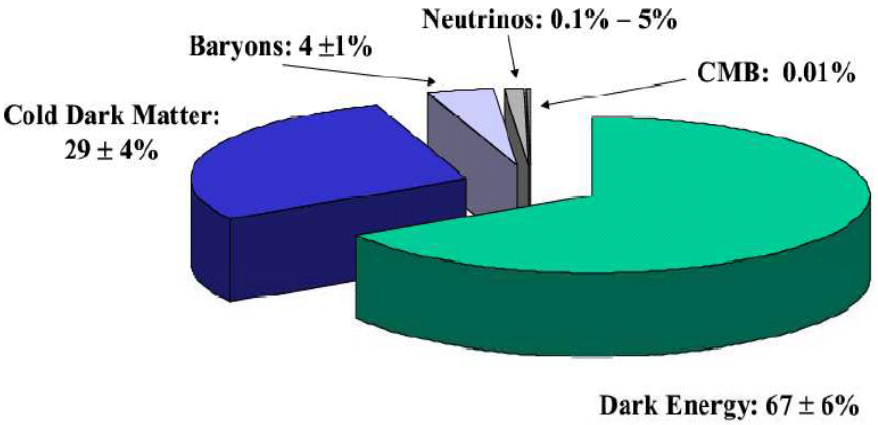
Dark Matter appears to be a weakly interacting massive particle

Lightest SUSY particle has these properties !

Dark Side of the Universe: Dark Energy



"The Standard Model of Cosmology"
Concordance Model



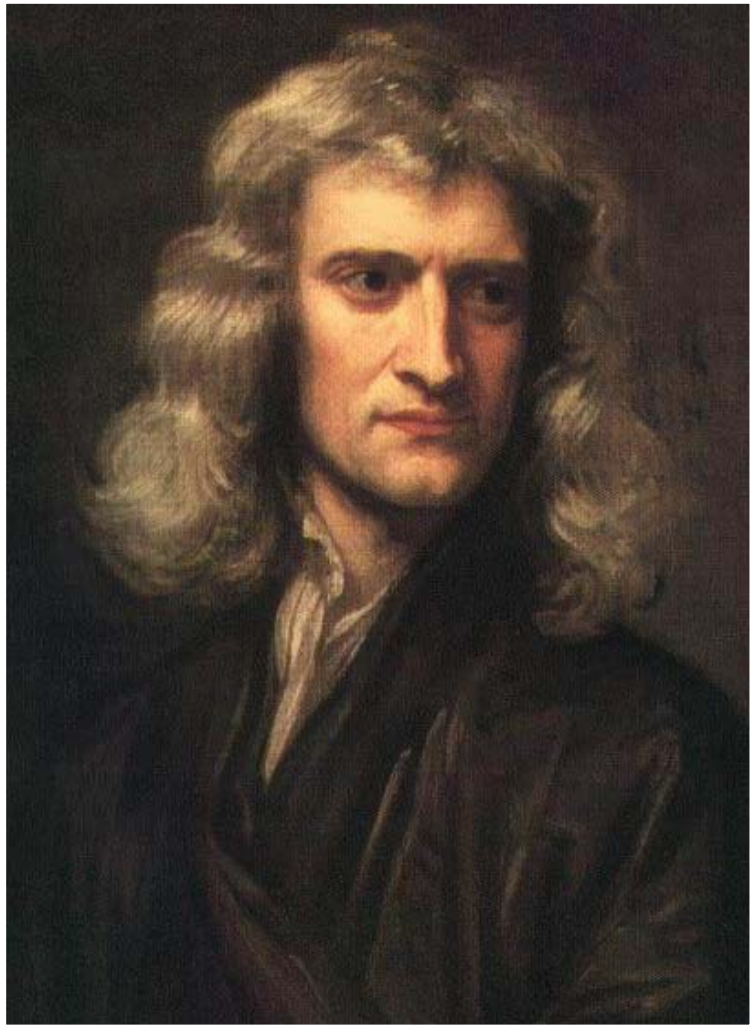
It appears that the rate of expansion of the universe is accelerating !!
Dark Energy?
Remnant of some elementary scalar field analagous to the Higgs field?

Conclusions

- The LHC project (the accelerator and experiments) was conceived & designed to attack fundamental questions in particle physics (and science).
- The LHC accelerator and the experiments are unprecedented in complexity and will operate in an unprecedented environment.
- The accelerator and experiments have required a long and painstaking effort on a global scale. Driven by the science (at the frontier of knowledge), we have had to push many technologies to their limits in a truly worldwide collaboration.
- Unique and unparalleled scientific instrument(s) - a powerful microscope as well as a powerful "telescope"
- Plan: collisions at high energy in Q4-09, and run for much of 2010.

Only experiments reveal/confirm Nature's inner secrets.
All expectations are that what we find at the LHC will reform our understanding of nature at the most fundamental level.

Epilogue



To me there has never been a higher source of earthly honour or distinction than that connected with Advances in Science.

Sir Isaac Newton