The Large Hadron Collider

Claudio Campagnari
UCSB

Protons and Champagne Mix as New Particle Collider Is Revved Up

By DENNIS OVERBYE
Published: September 10, 2008

BATAVIA, Ill. — Science rode a beam of subatomic particles and a river of Champagne into the future on Wednesday.

COMMENTS (139)

E-MAIL

PRINT

SINGLE PAGE

REPRINTS

SAVE

SHARE

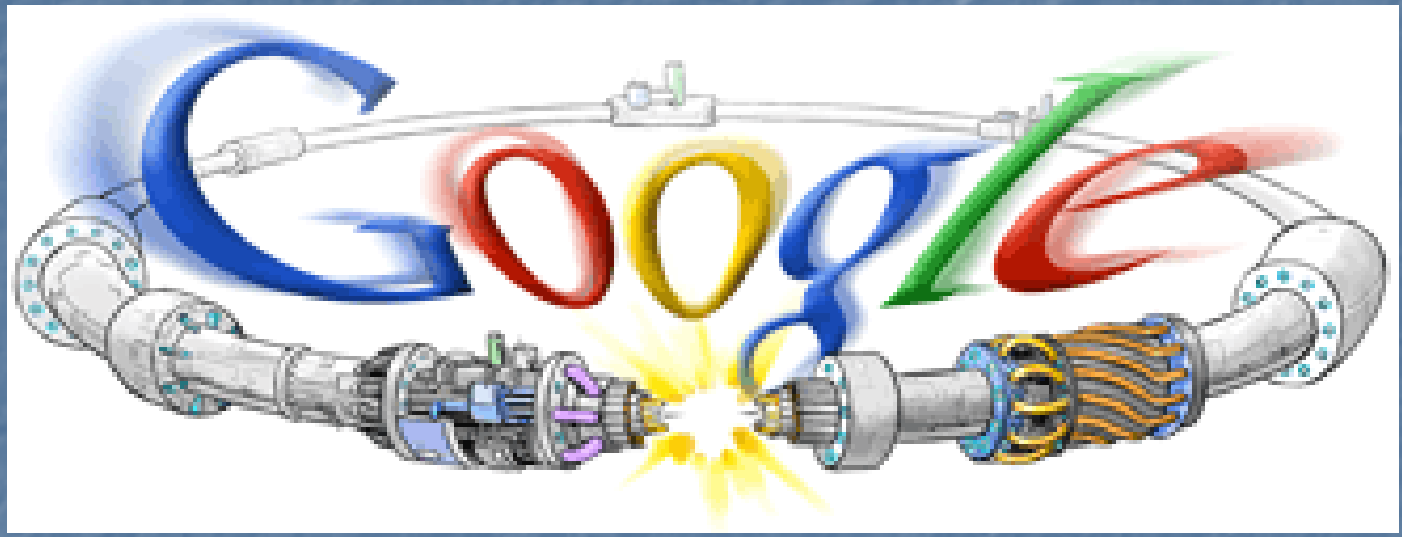
Enlarge This Image

Anja Niedringhaus/Associated Press

The entrance to the CERN laboratory near Geneva. After 14 years of labor, scientists

After 14 years of labor, scientists at the CERN laboratory outside Geneva successfully activated the Large Hadron Collider, the world's largest, most powerful particle collider and, at $8 billion, the most expensive scientific experiment to date.

More Articles in Science »


Google

What is the LHC

- A particle accelerator
  - We speed up protons (hydrogen nuclei) at 99.999999% of the speed of light
- We smash them together (collide)
- We see what happens!

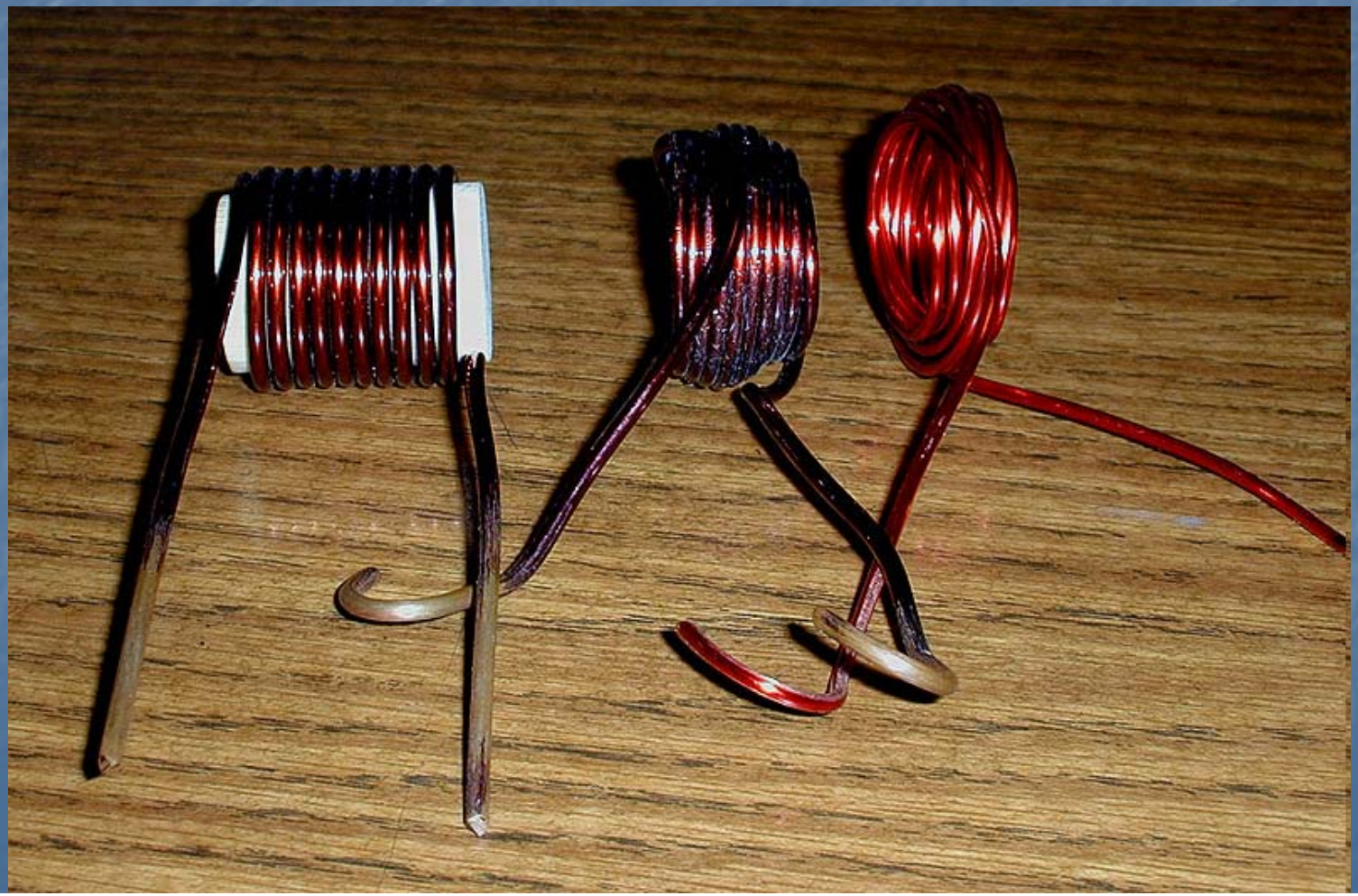
In a 17 mile long tunnel 300 ft below ground

What happens in the tunnel?

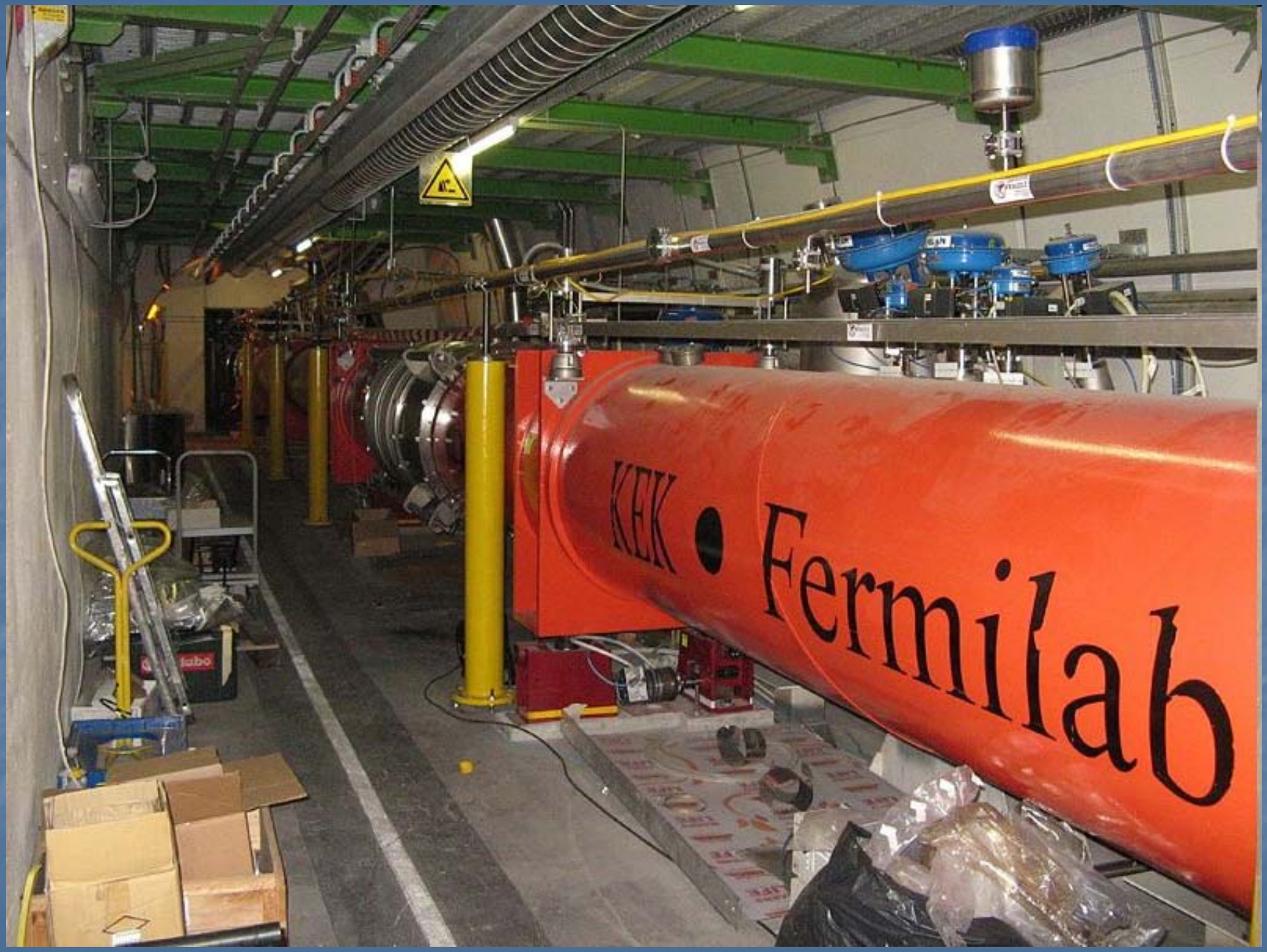
- Protons are put in the tunnel (injected) in bunches
  - Some bunches go clockwise, some bunches go anticlockwise
- Initially, every time they go around they get a little kick (accelerated)
- They quickly reach their final velocity
- Bunches are made to collide at a few points around the ring
- Experimenters place “detectors” around the collision points to study these collisions

What keeps the protons going round-and round?

Magnets!



Picture of the tunnel


KEK • Fermilab

- 9300 magnets
- Cooled to -271^0 C by 96 tonnes of liquid helium
- A 17 mile long vacuum pipe snakes through these magnets
- Protons go around the ring 11,000 times a second
- The size of the proton bunches is ¼ of that of a human air.

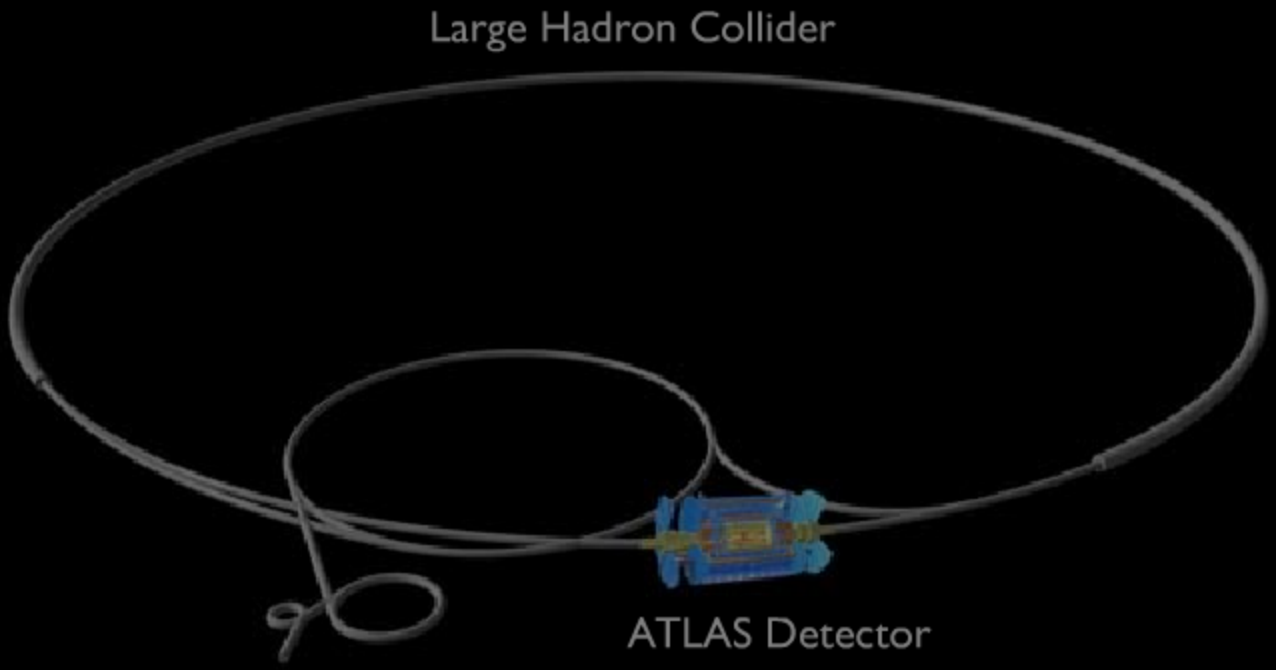
Why is it so big (and expensive)?

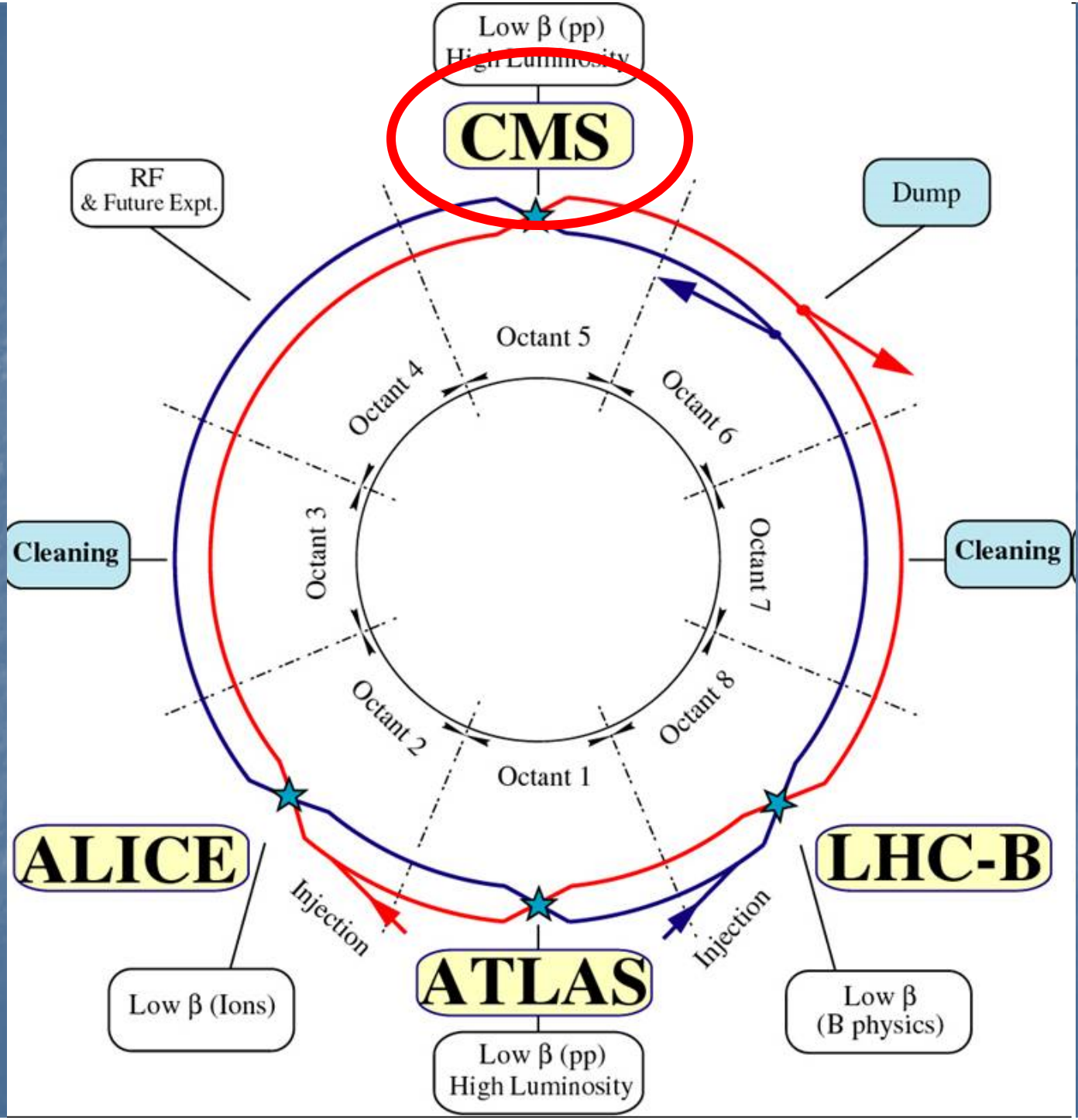
- The faster the protons go, the harder it is to bend them around
  - Need stronger and stronger magnets
  - LHC magnets are at the technological limit

What happens when the protons collide?

- They break up
- Their energy of motion can be transformed into production of new particles ($E=mc^2$)
- Detectors are placed all around the collision to “image” the debris that emerges
- From the patterns that are detected we learn about fundamental science (more later)

PLAY

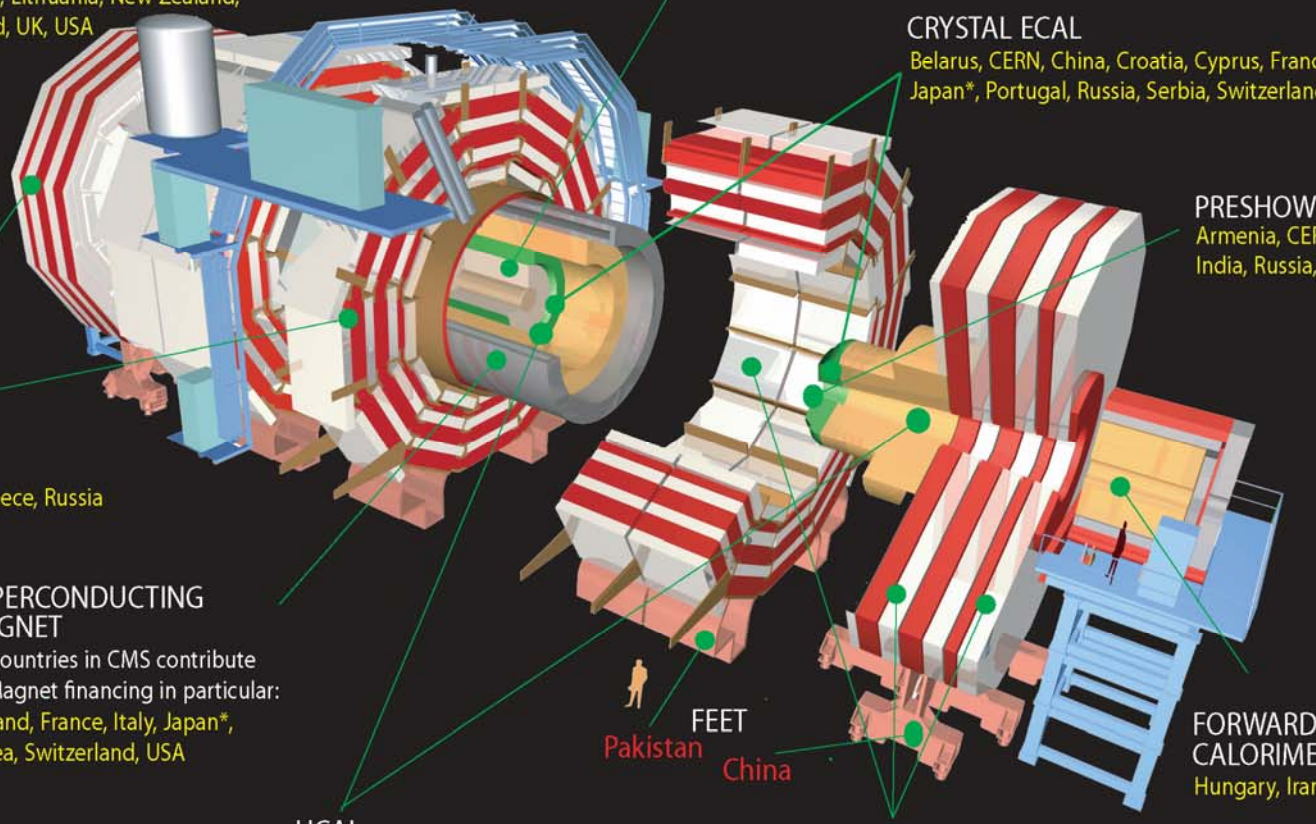



Low β (pp)
CMS
RF
& Future Expt.
Dump
Octant 5
Octant 4
Octant 6
Cleaning
Octant 3
Octant 7
Cleaning
Octant 2
Octant 8
Octant 1
ALICE
LHC-B
Injection
Injection
ATLAS
Low β (Ions)
Low β
(B physics)
Low β (pp)
High Luminosity

CMS Collaboration

June 2008

38 Countries, 183 Institutes, 3000 scientists and engineers (including 400 students)



TRIGGER, DATA ACQUISITION & OFFLINE COMPUTING
Austria, Brazil, CERN, Finland, France, Greece, Hungary, Ireland, Italy, Korea, Lithuania, New Zealand, Poland, Portugal, Switzerland, UK, USA

TRACKER
Austria, Belgium, CERN, Finland, France, Germany, Italy, Japan*, Mexico, New Zealand, Switzerland, UK, USA

CRYSTAL ECAL
Belarus, CERN, China, Croatia, Cyprus, France, Italy, Japan*, Portugal, Russia, Serbia, Switzerland, UK, USA

PRESHOWER
Armenia, CERN, Greece, India, Russia, Taiwan

RETURN YOKE
Barrel: Estonia, Germany, Greece, Russia
Endcap: Japan*, USA

SUPERCONDUCTING MAGNET
All countries in CMS contribute to Magnet financing in particular: Finland, France, Italy, Japan*, Korea, Switzerland, USA

FEET
Pakistan
China

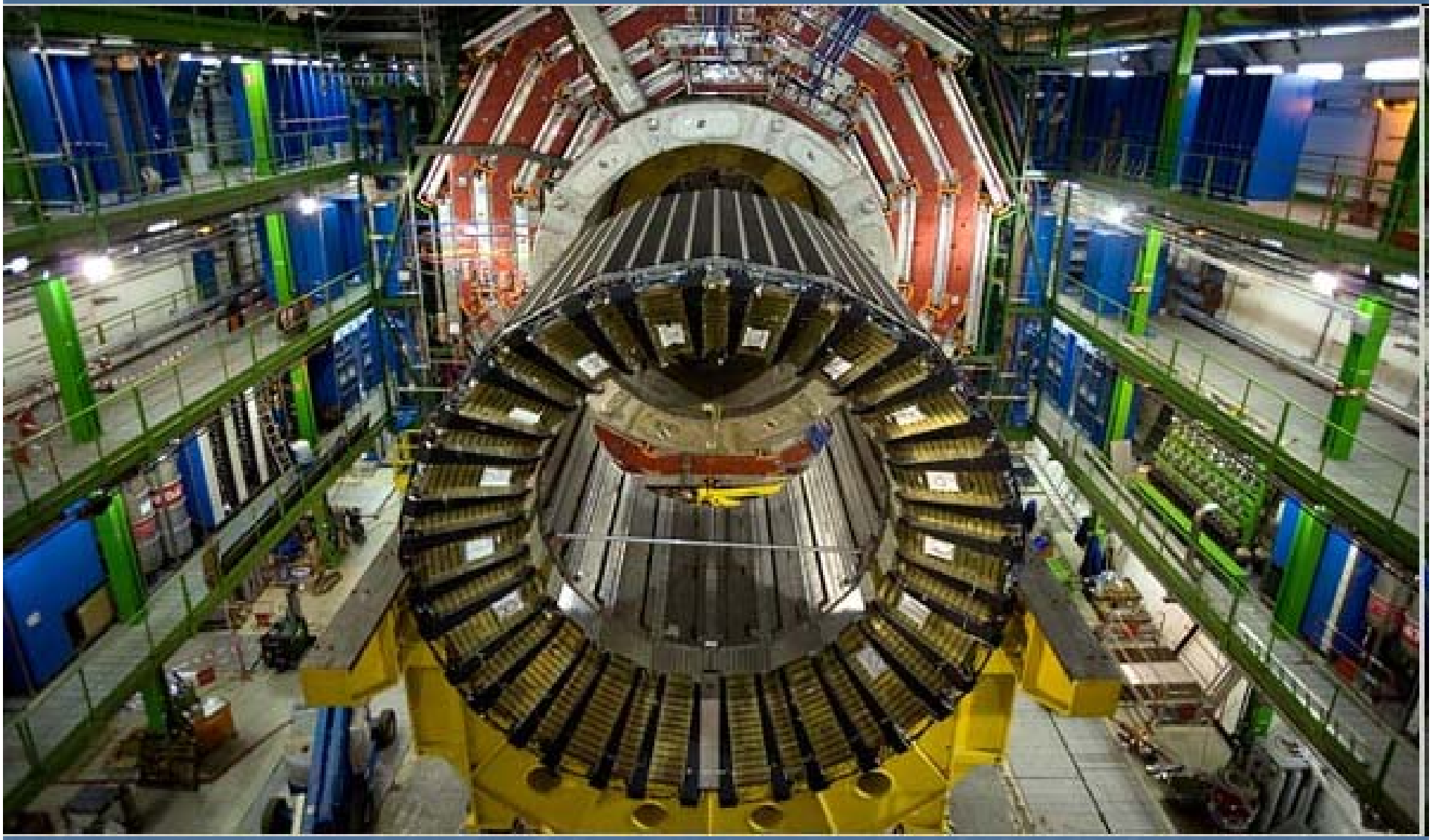
FORWARD CALORIMETER
Hungary, Iran, Russia, Turkey, USA

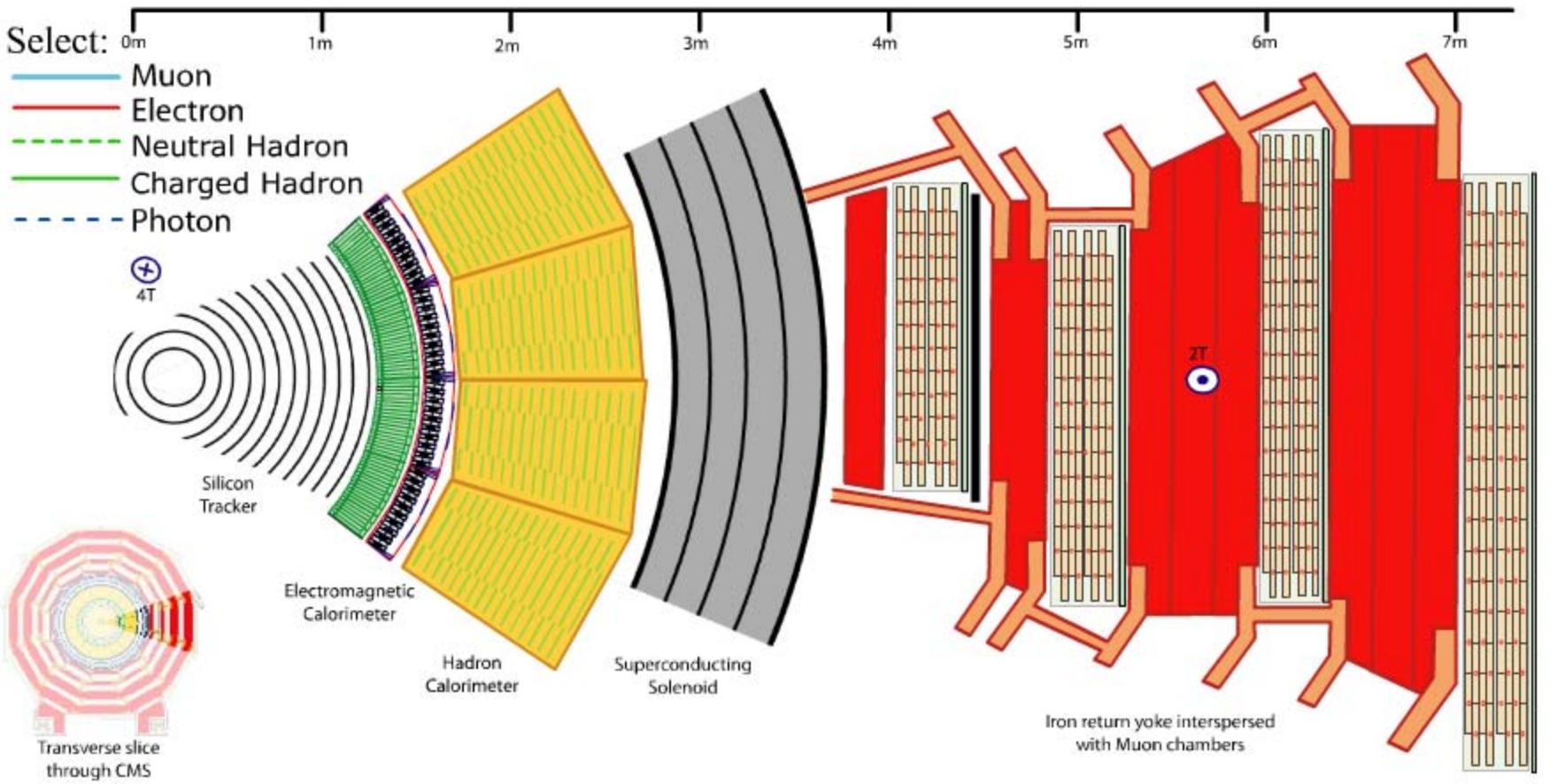
HCAL
Barrel: Bulgaria, India, Spain*, USA
Endcap: Belarus, Bulgaria, Georgia, Russia, Ukraine, Uzbekistan
HO: India

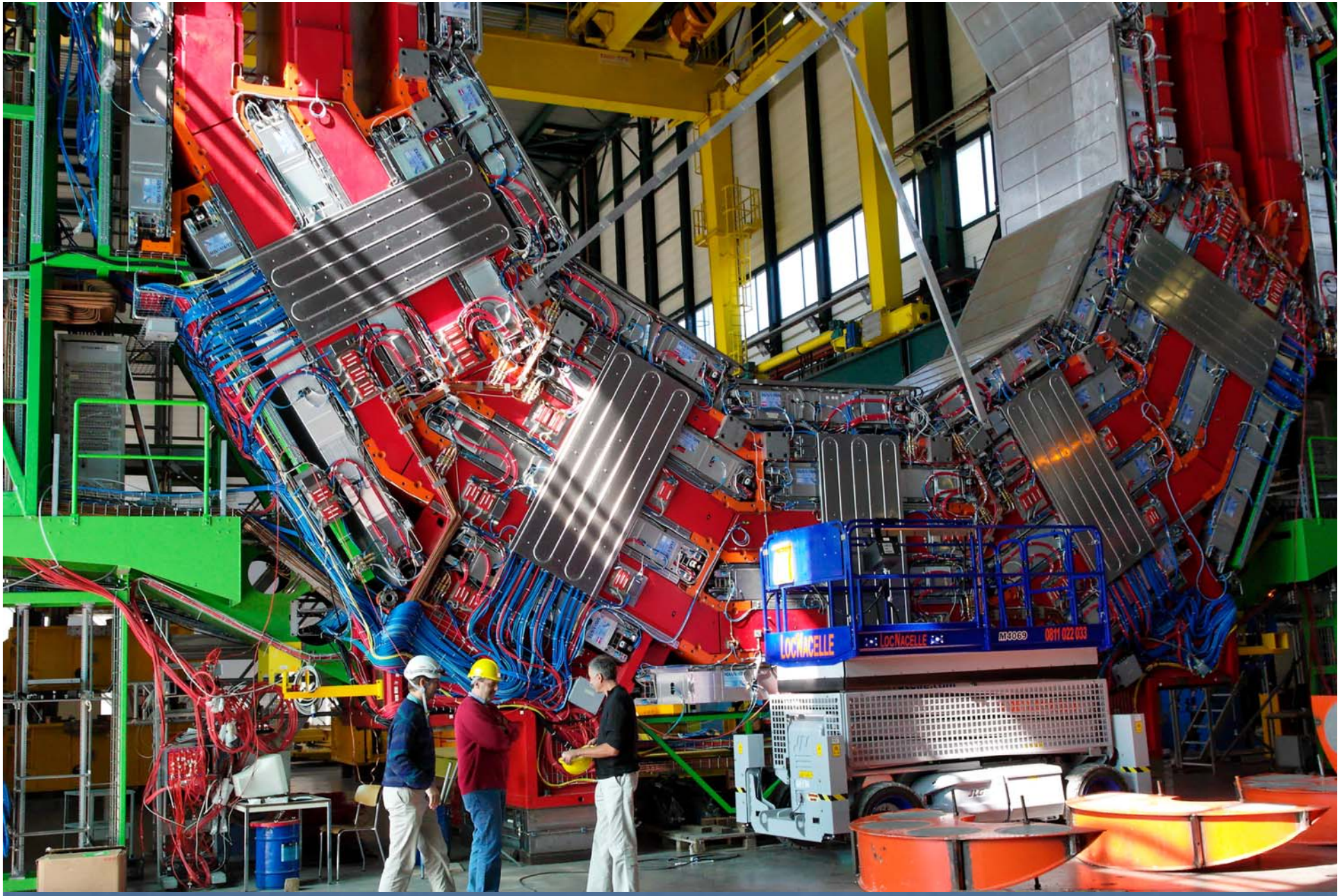
MUON CHAMBERS
Barrel: Austria, Bulgaria, CERN, China, Germany, Hungary, Italy, Spain,
Endcap: Belarus, Bulgaria, China, Colombia, Korea, Pakistan, Russia, USA

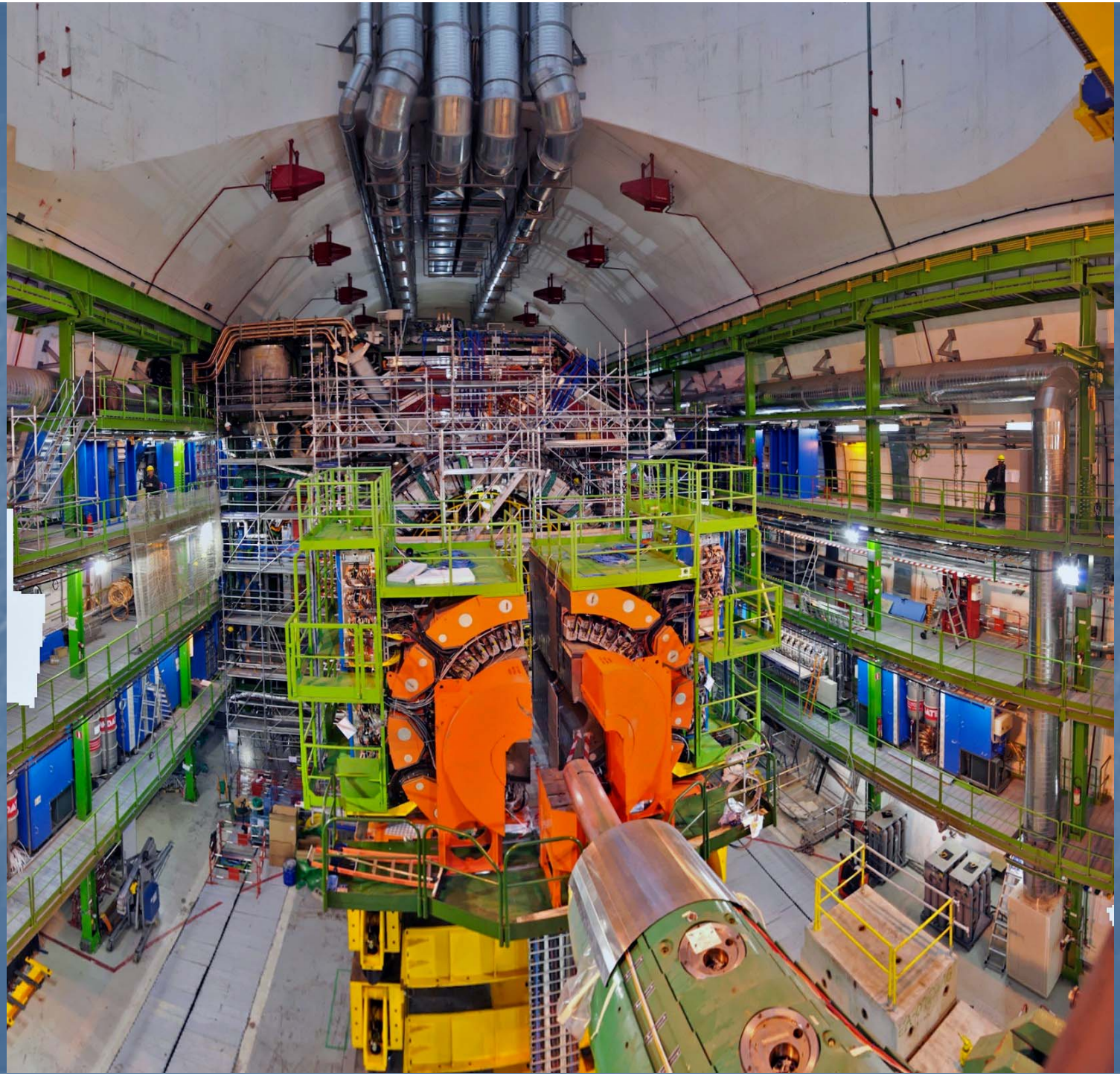
Total weight	: 12500 T
Overall diameter	: 15.0 m
Overall length	: 21.5 m
Magnetic field	: 4 Tesla

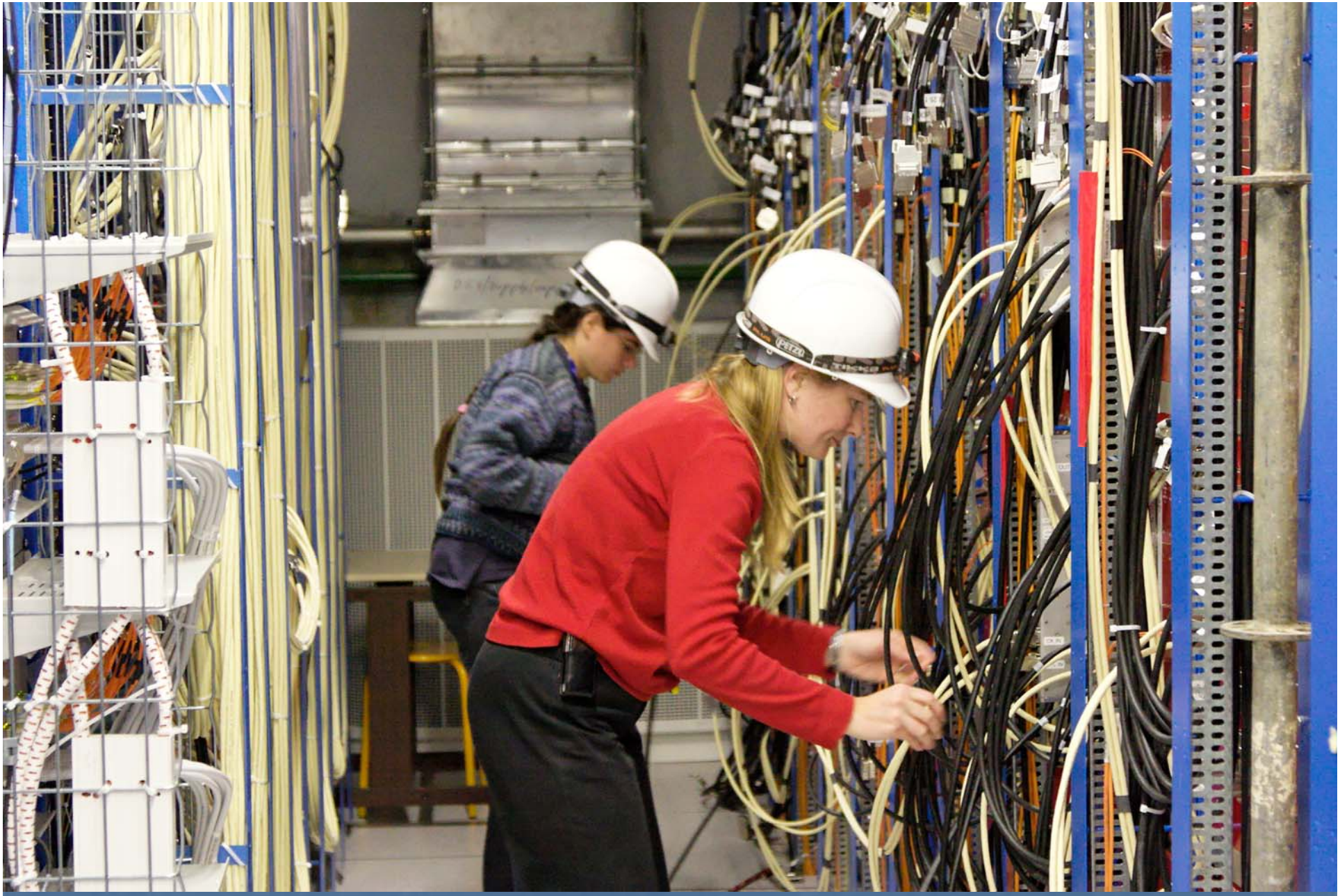
* Only through industrial contracts




Select:
0m
1m
2m
3m
4m
5m
6m
7m
Muon
Electron
Neutral Hadron
Charged Hadron
Photon
4T
2T
Silicon Tracker
Electromagnetic Calorimeter
Hadron Calorimeter
Superconducting Solenoid
Iron return yoke interspersed with Muon chambers
Transverse slice through CMS
D. Barney, CERN, 2004

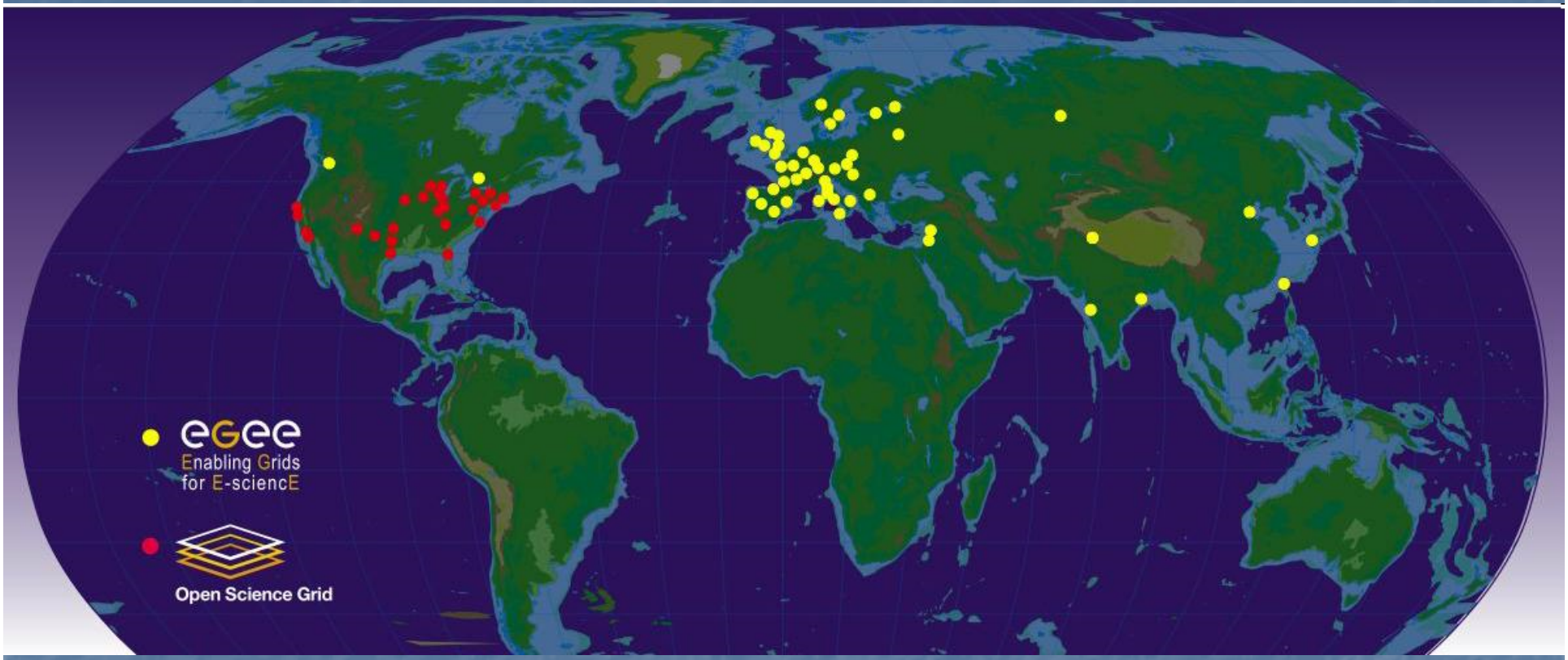

LOCNACELLE
LOCNACELLE
M3069
0811 022 033





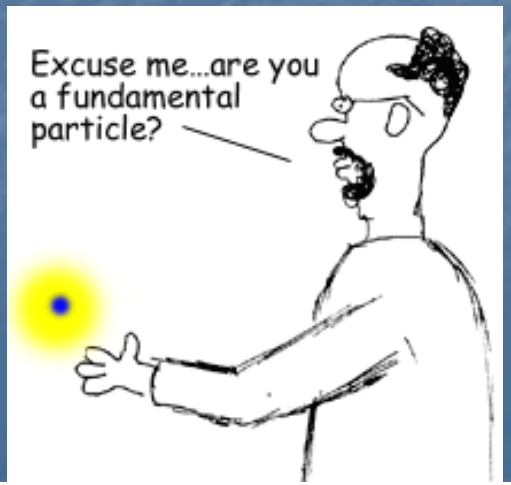
Fun facts about CMS

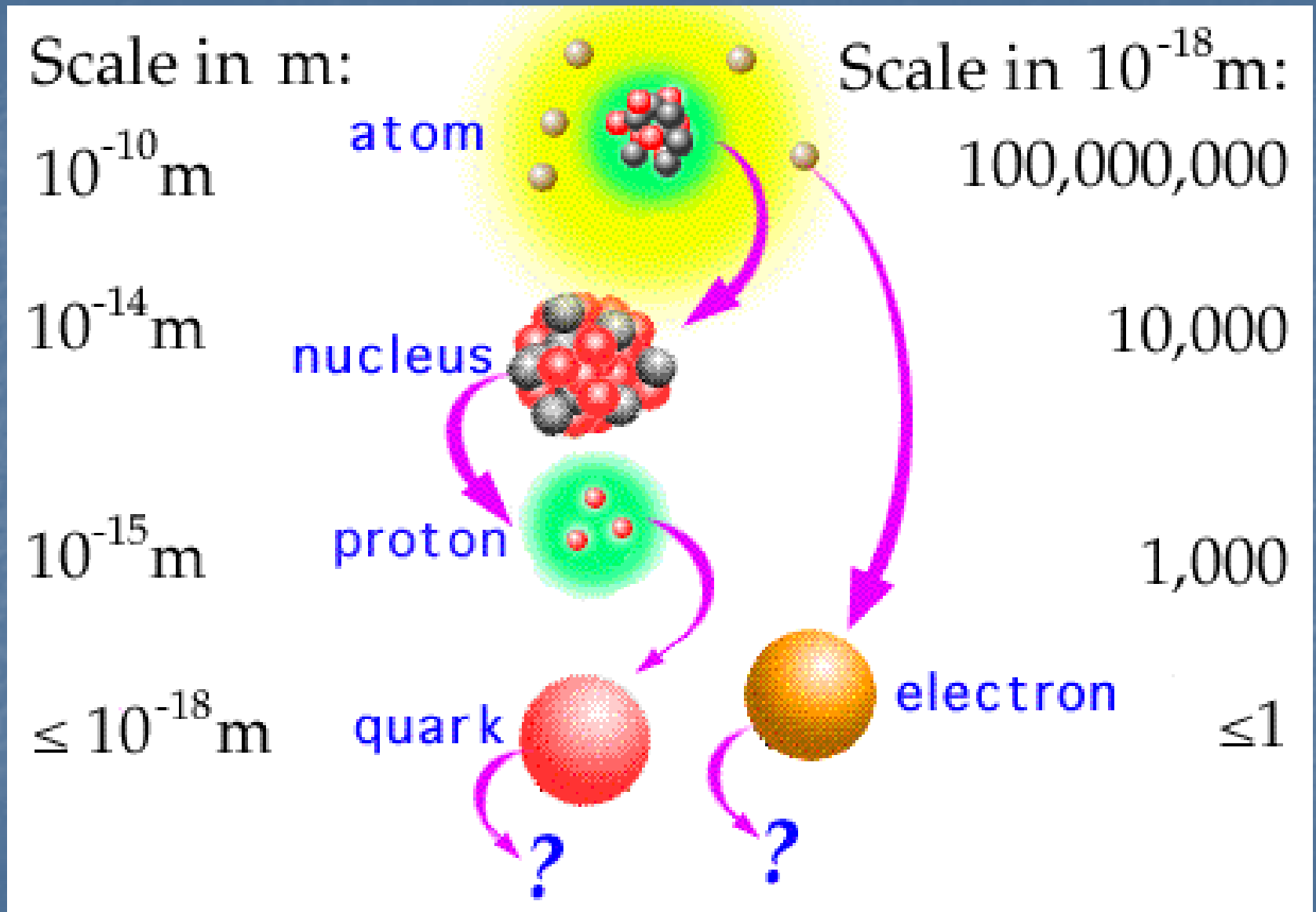
- Huge magnet 100,000 earth field
  - 12,000 tonnes
  - cooled to -268.5 degrees
  - stores enough energy to melt 18 tonnes of gold
  - twice as much iron as Eiffel tower
- 40 Million collisions/sec
  - But we can only record information from about 200..,..
  - Must decide in real time: “yes, this collision looks interesting” or “no, this one looks boring”
- About 1 GigaByte per second of data will flow out of the experiment
  - Then data is processed and even more information is added
  - Computer centers all over the world are tied together to handle this massive amount of data


eGee
Enabling Grids
for E-sciencE
Open Science Grid

Why?

- Try to answer some of the oldest and most basic questions of human civilization
  - What is matter (stuff) made of ?
    - The fundamental constituents of matter
  - How does it interact ?




Scale in m:
Scale in 10^{-18}m:
atom
10^{-10}m
100,000,000
10^{-14}m
nucleus
10,000
proton
10^{-15}m
1,000
electron
quark
$\leq 10^{-18}$m
≤1
?
?

The Standard Model (SM)

- We have a theory of fundamental particles and interactions
- It works extremely well
- But we know that it is incomplete

The Higgs (aka the God particle)

- The SM works great
- But it does not like mass very much
- Naturally the theory has mass=0 for everything
  - Not so great
- Cannot just put in mass by hand in the equations
- Must concoct “Higgs Mechanism”

Higgs Mechanism

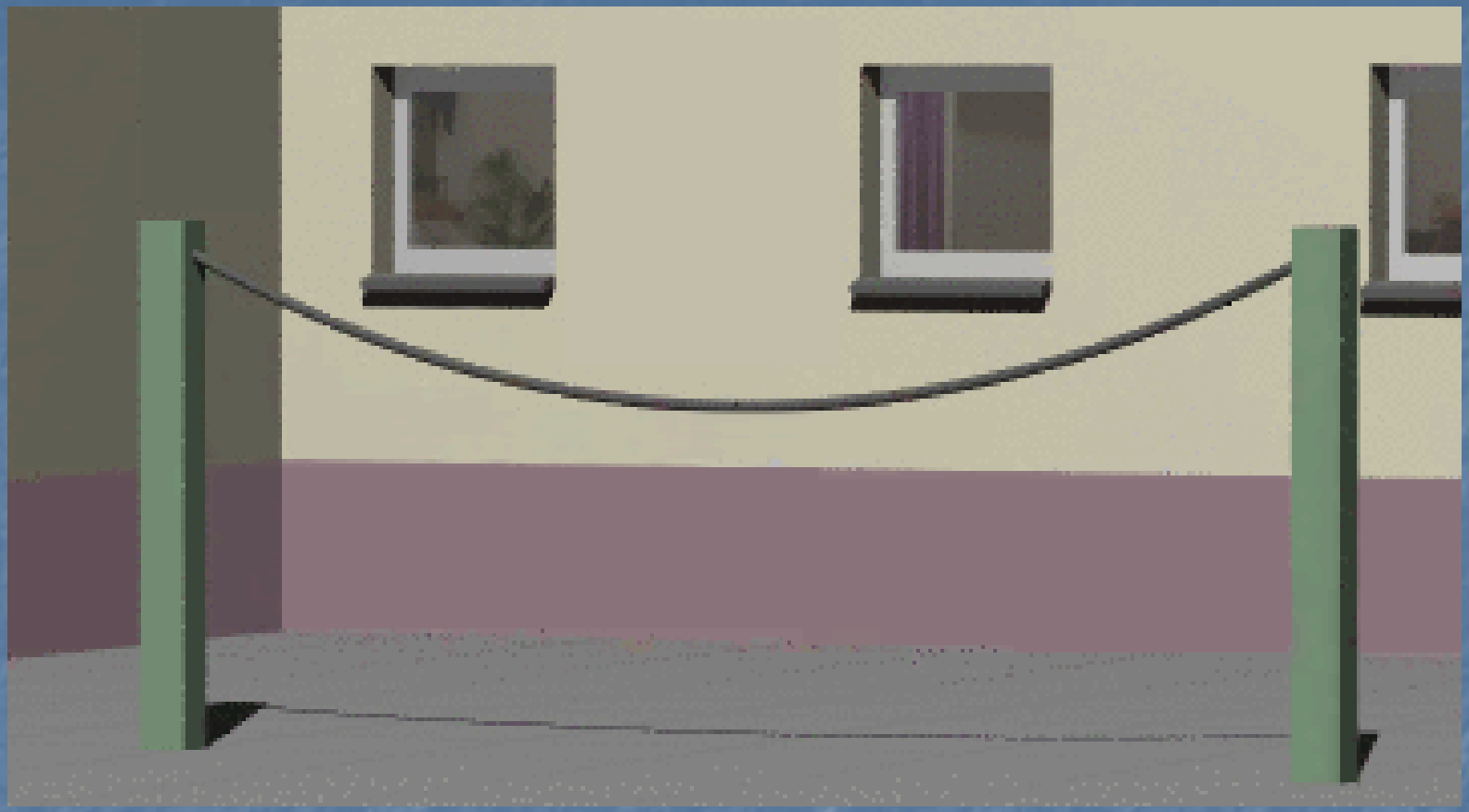
- Works
  - But all numbers have to be tuned to 19 decimal places to make it work!
- Predict the existence of a “Higgs particle”
- If true, we will make it and see it at the LHC
- If not, we will see what else is out there in its place

SuperSymmetry

- A beautiful mathematical theory.
- Theorists love it
- Predicts existence of many new particles, solves many problems
- We have seen no evidence for it
- We may see it at the LHC

Extra Dimensions

- The most fashionable theories of what happens at very short distance only work if there are more dimensions of spaces
- If the extra dimensions are just so, we could see first evidence for them



Surprises

- We are opening up a new energy regime
- There could be phenomena that none of us has thought of

Damage to atom smasher forces 2-month halt

From the Associated Press
September 21, 2008

GENEVA -- The world's largest atom smasher -- which was launched with great fanfare earlier this month -- has been damaged twice and will be out of commission for at least two months, its operators said Saturday.

CERN, the European Organization for Nuclear Research, said Saturday that a large amount of helium had leaked into the 17-mile (27-kilometer) circular tunnel deep under the Swiss-French border that houses the Large Hadron Collider.

The massive collider began operating Sept. 10 to the delight of physicists around the world, flinging protons around the circle at nearly the speed of light. But it had to be shut down only 36 hours later due to a failure of an electrical transformer.

That was repaired, but a CERN statement said a second failure took place midday Friday in the last section of the tunnel to undergo testing at high current, causing the large helium leak.

CERN spokesman James Gillies said the latest incident was several miles (kilometers) from the earlier damage. It is considered much more time-consuming to repair than the first malfunction.

"Preliminary investigations indicate that the most likely cause of the (Friday) problem was a faulty electrical connection between two magnets, which probably melted at high current leading to mechanical failure," said the statement Saturday.

- The LHC will have 1st collisions in May 2009
- In the meantime we continue debugging CMS and preparing our data analysis tools
- Will have 1st results next year
- I do not expect anything too exciting until 2010