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MAY 4, 2009

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THE PLOT

- Antimatter is stolen from CERN's Large Hadron Collider and hidden in Vatican City.
- Countdown to Vatican annihilation begins.
- Race through Rome to avert death and destruction.

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HOLLYWOOD'S CERN

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REAL-LIFE CERN

Near Geneva, Switzerland

Not top secret

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CERN

- European Laboratory for Particle Physics
- Founded in 1954
- 20 member countries
- More than 9,000 scientists
- Over 100 nationalities
- More than 1,000 from U.S. universities and labs

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HOLLYWOOD'S LARGE HADRON COLLIDER

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THE REAL LHC

- The world's most powerful particle accelerator
- 16.8 miles around, 330 feet underground

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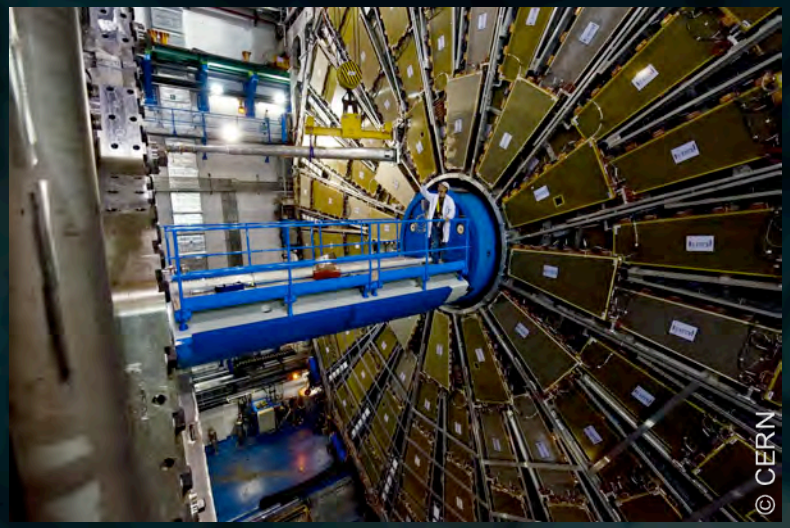
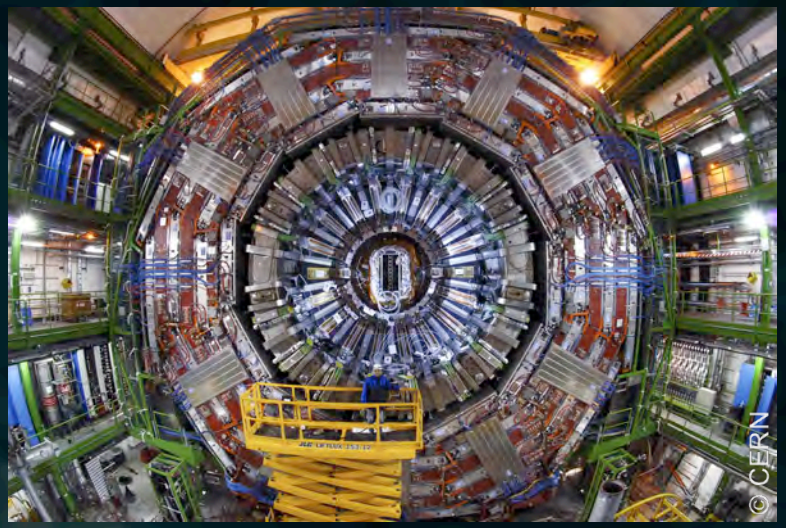
THE LHC

Will smash particles into each other…



…to solve some of the universe's biggest mysteries



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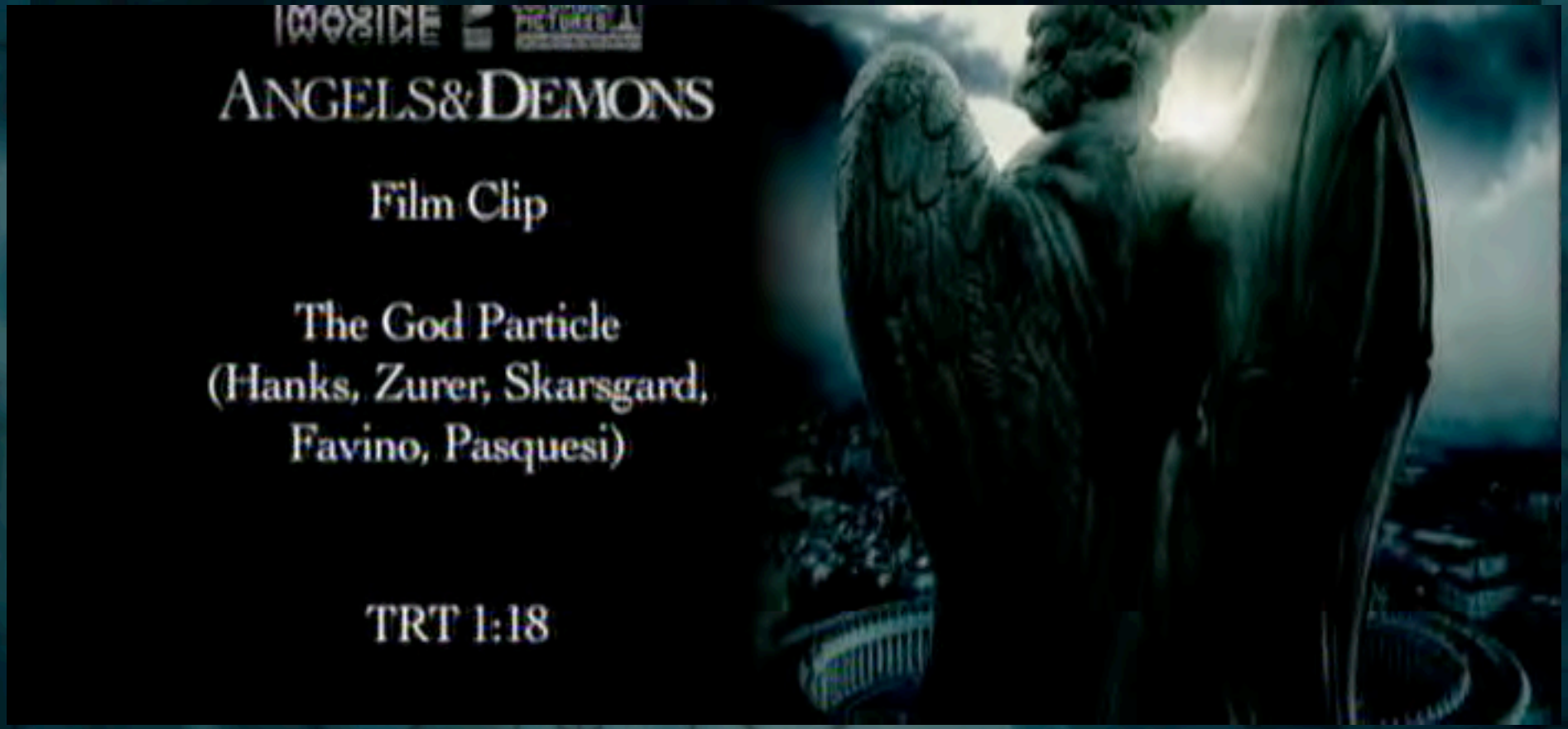
ANTIMATTER



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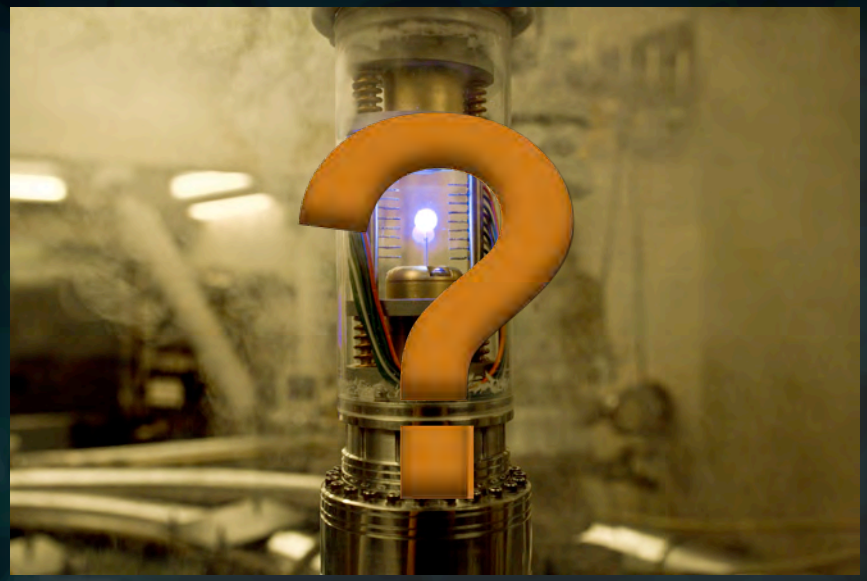
ANTIMATTER

- It's real
- It's produced at the Large Hadron Collider
- Enough of it could destroy Rome
- What is it?



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WHAT IS MATTER?

Particles in various combinations

Quarks


up


charm


top


down


strange


bottom

Leptons


electron


muon


tau


electron neutrino


muon neutrino


tau neutrino

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BUILDING A UNIVERSE

electron

proton

neutron

Multiply by billions and billions and billions and billions…

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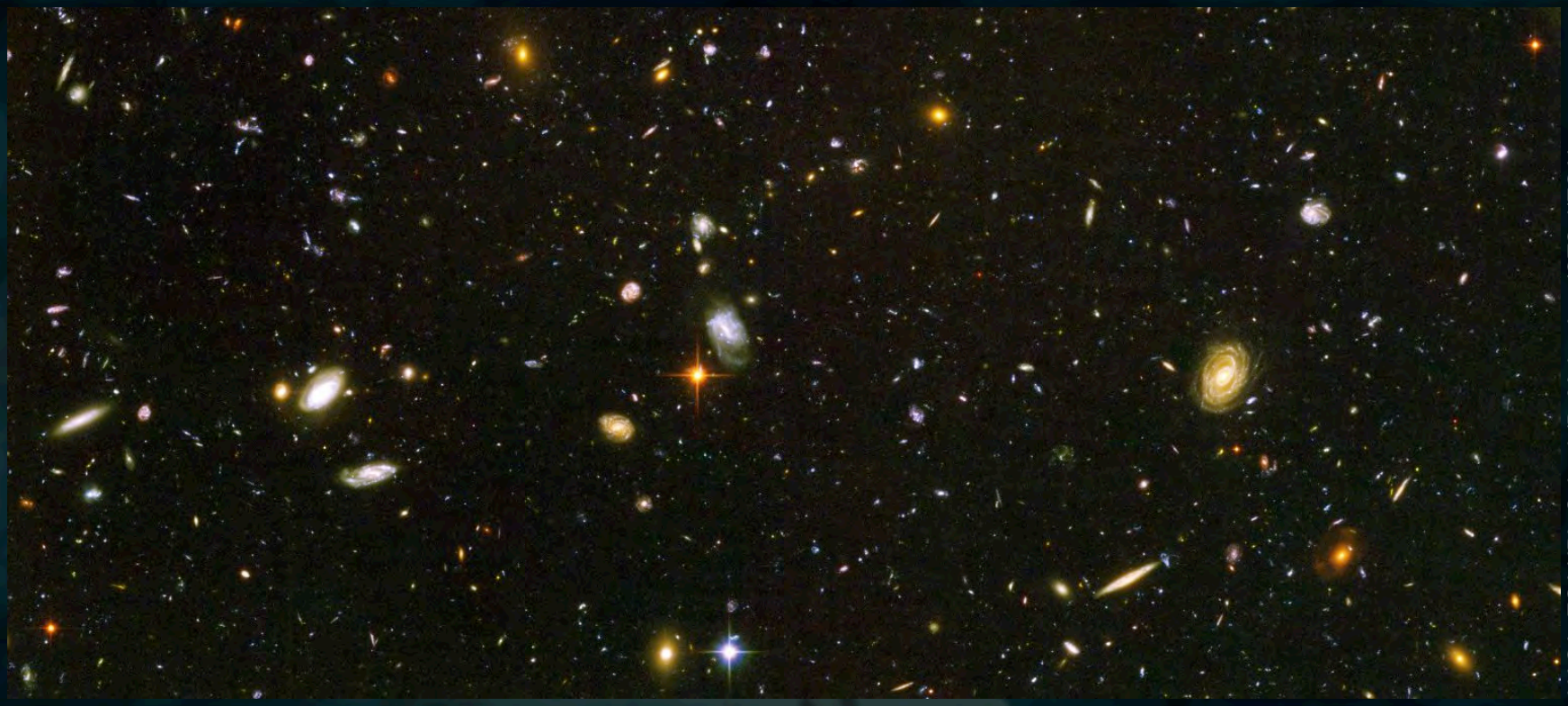
BUILDING A UNIVERSE



NASA, ESA/JPL-Caltech/B. Mobasher (STScI/ESA)

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WHERE DOES ANTIMATTER FIT?

For every particle


up


electron


down


electron neutrino

There is an antiparticle


anti-up


positron


anti-down


Anti-electron neutrino

Particles and antiparticles have opposite electric charge

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CAN WE MAKE ANTIMATTER?

We can, and do


SLAC National Accelerator Laboratory


Fermilab

In particle accelerators

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CAN WE MAKE ANTIMATTER?

Nature can, too

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MATTER VS. ANTIMATTER

Anti-Tom Hanks

Would look very much like

Tom Hanks

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MATTER VS. ANTIMATTER

But were they to meet…

$E=mc^2$

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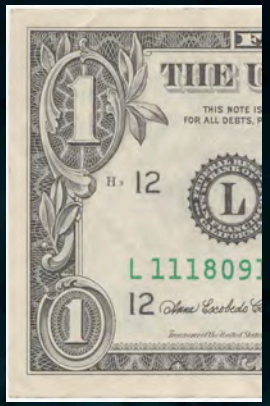
ANGELS & DEMONS & ANTIMATTER

- Rome is threatened by ¼ gram of antimatter
- Annihilation of ¼ g matter + ¼ g antimatter = 10,000 kilotons of TNT
- More than enough to destroy the Vatican



¼ gram

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ANTIMATTER'S NO THREAT

- We make *very* little antimatter, a particle accelerator like Fermilab (in Illinois) creates 2 nanograms of antiprotons per year

- It would take 109 million years to make ¼ gram

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ANTIMATTER'S NO THREAT

- It's not portable

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ANTIMATTER CAN'T BE USED FOR

- **Power**
  - Have to make every single antiparticle
  - More energy goes in than is produced
- **Spaceships**

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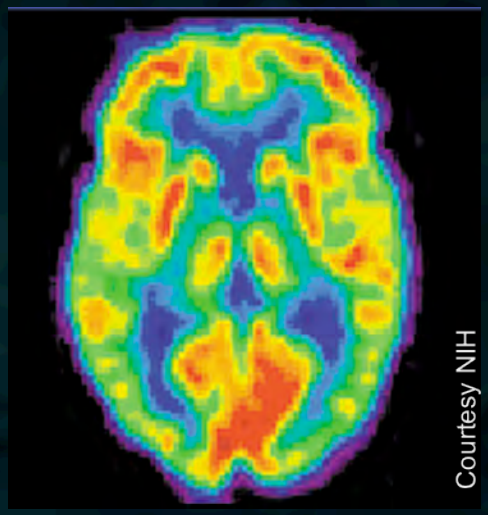
ANTIMATTER CAN BE USED FOR

Positron Emission Tomography Scans



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ANTIMATTER CAN BE USED FOR

- Solving some of the biggest mysteries in science

- Why do we exist?
- Why do we have mass?
- What is most of the universe made of?

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THE MYSTERY OF ANTIMATTER

- We exist because there is almost no antimatter around
- It wasn't always that way

NASA/STScI/G.Bacon

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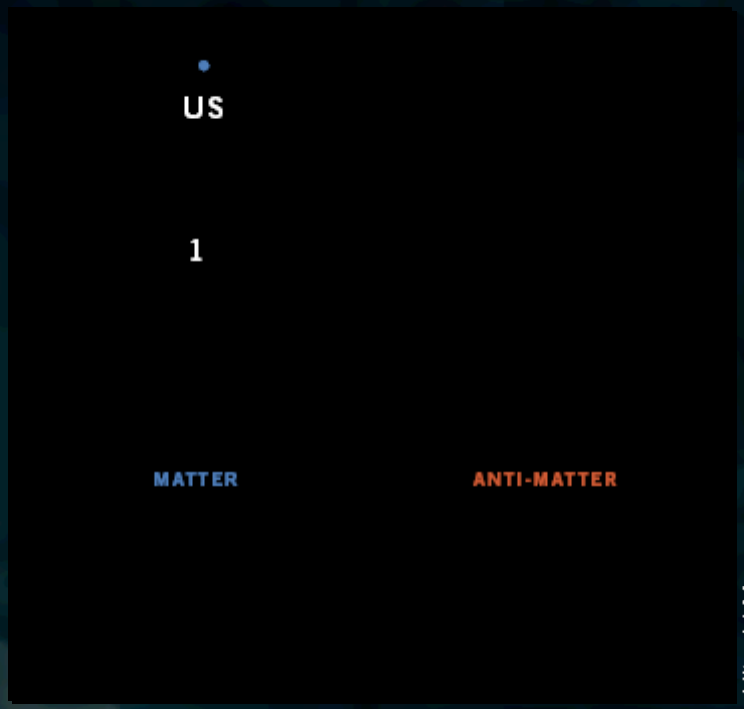
THE BIG BANG

- 14 billion years ago, the Big Bang produced equal amounts of matter and antimatter
- Everything should have annihilated
- Instead…



Hitoshi Murayama

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WHAT HAPPENED TO THE ANTIMATTER?

- After 40 years of research we know:
- Some particles behave differently from their antiparticles
- The difference is very slight – not enough
- There must be another explanation

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MYSTERIES: WHY DO WE HAVE MASS?

- One possibility: Higgs field
- Predicted in 1964
- Still unconfirmed

- Can prove it by finding the Higgs Boson
  - "Angel?"

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WHAT'S A HIGGS BOSON?

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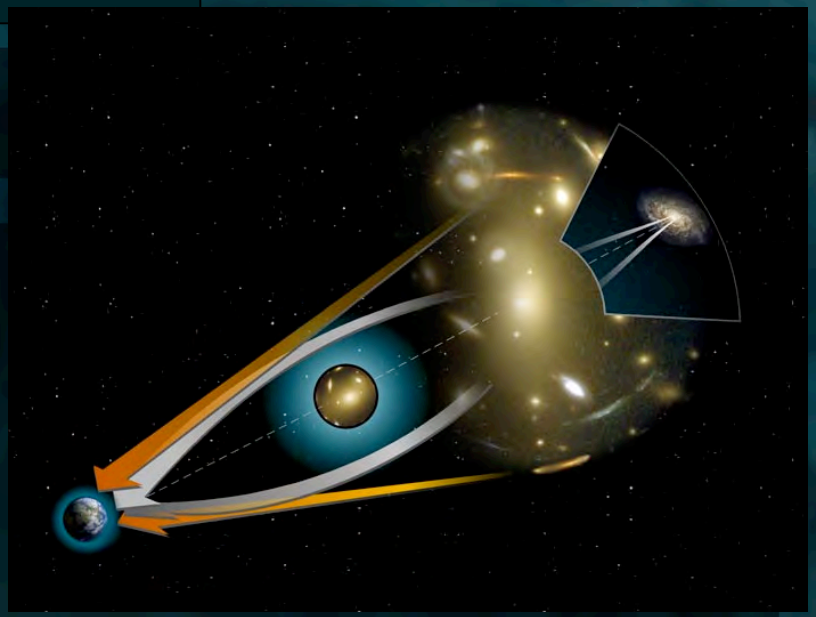
OTHER MYSTERIES: DARK MATTER

The Bullet Cluster (1E 0657-56). Two galaxies colliding. Red shows concentration of visible matter. Blue shows dark matter inferred by gravitational lensing.



Gravitational lensing

What is dark matter composed of?

- *Supersymmetric* particles perhaps? The lightest supersymmetric particle predicted by theory has all the right properties!

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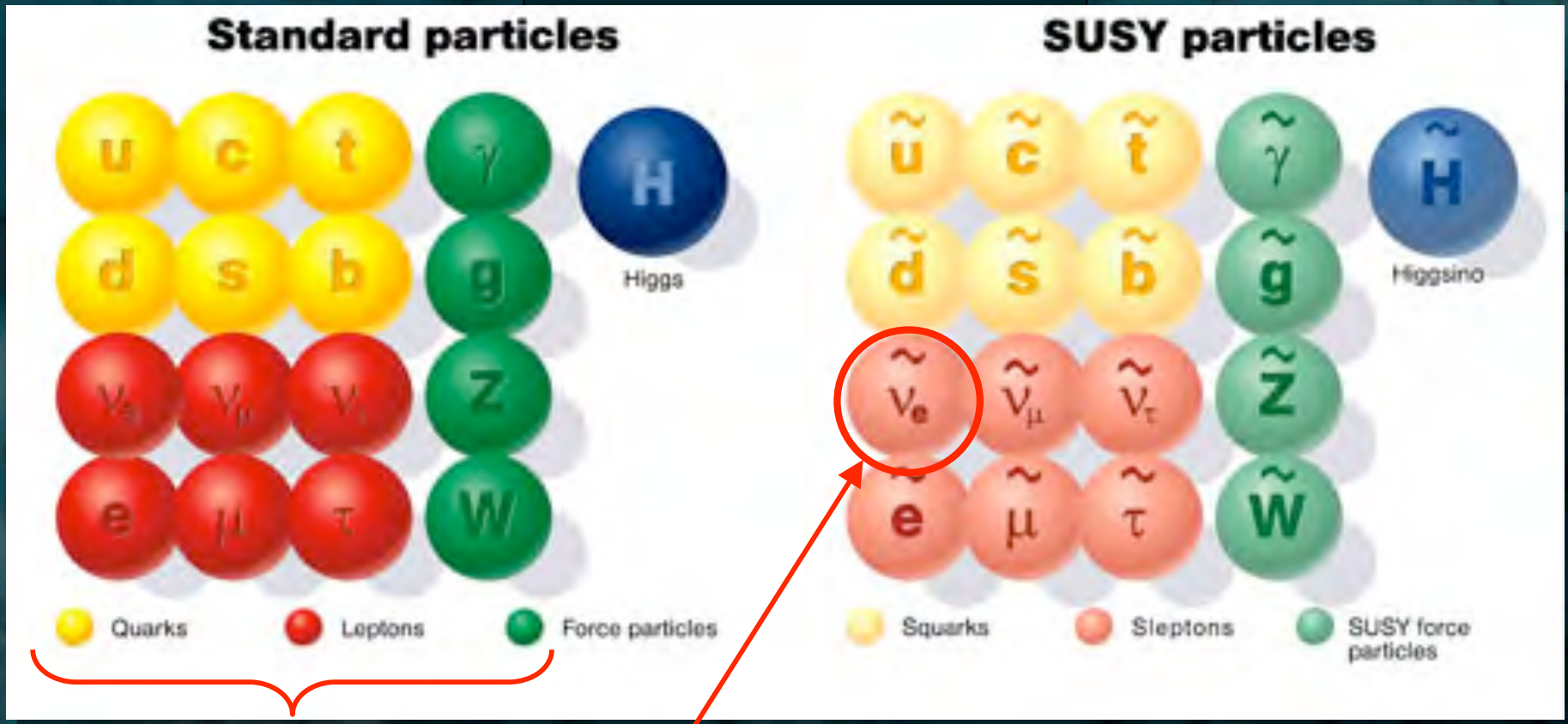
SUPERSYMMETRY "ANGEL?"



The 'Standard' particles which have been discovered

Possible candidate for the dark matter particle

Could LHC be the first accelerator to discover a corresponding world of 'Supersymmetric' particles?

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EXTRA DIMENSIONS CAN ALSO OFFER A SOLUTION!

- Since appears to contain gravity, string theory provides hope for unification of all forces.
  - But these theories work only in 10 or 11 space-time dimensions!
- Extra dimensions may be curled up (radius R) & too small to be detectable

- To sense any extra dimension, size of probe must be smaller or about size of R
  - A tightrope walker is one-dimensional: can only move forward or back, & not around the rope, but an ant can also circle the rope, therefore lives in & senses an extra dimension.
- If gravity operates in all dimensions, can explain its weak coupling in 4 dimensions
  - suggests using elementary particles to probe any “large” extra dimensions
- “Large” extra dimensions can give quantum gravity at the LHC Energies

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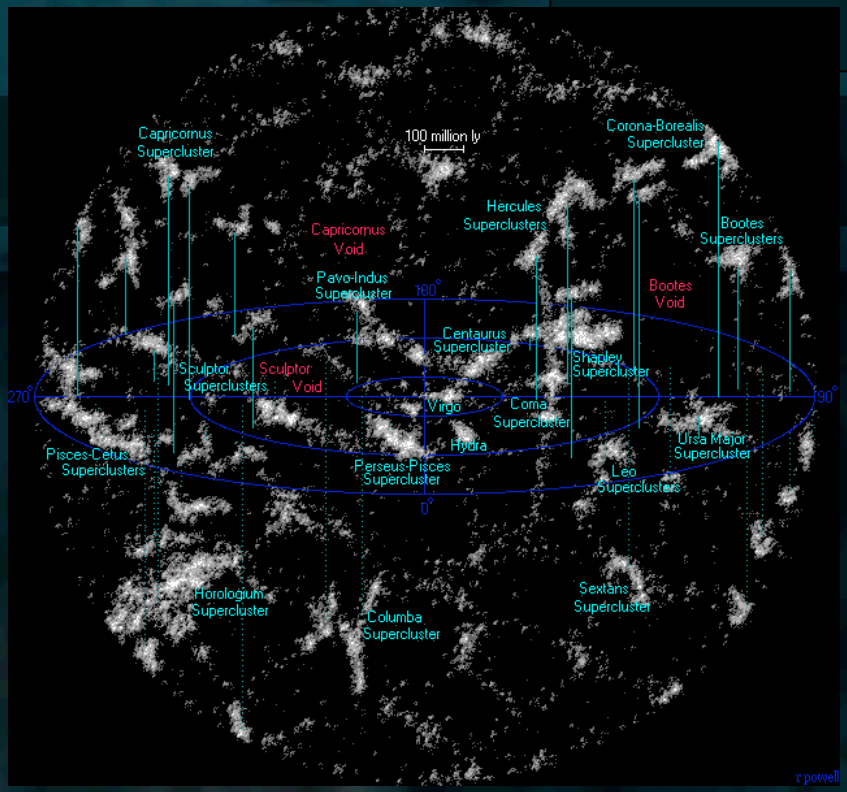
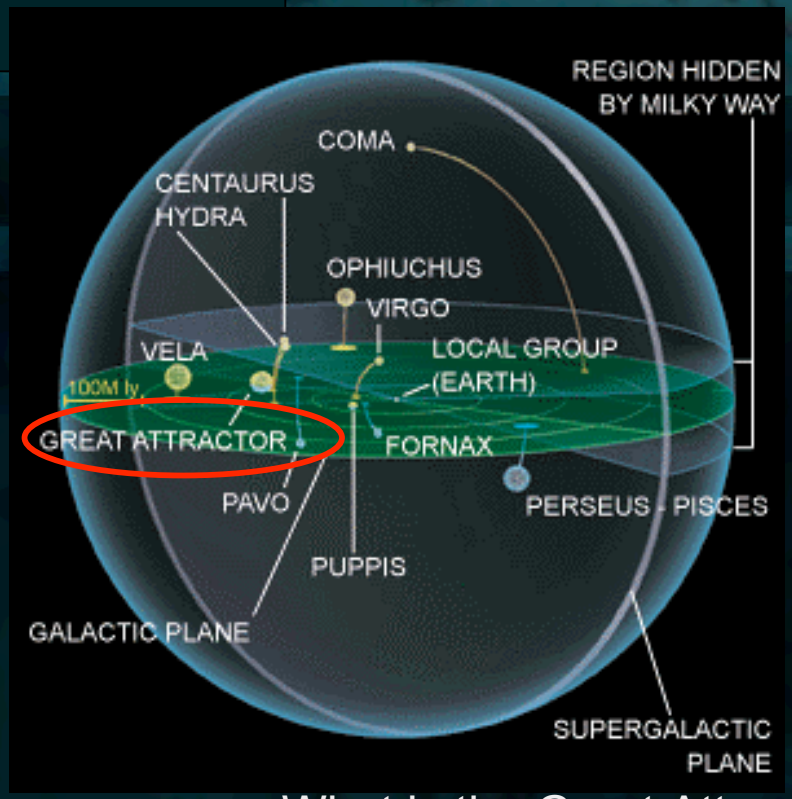
WHY THE LHC?





Why are there huge voids and clusters of galaxies in outer space?

Could the LHC find new forces and extra 'hidden' dimensions ?

What is the Great Attractor ?
It corresponds to the pull of 10^{16} suns

Only 10% can be accounted for with the visible stars and galaxies

Is the rest due to Dark Matter Particles ?

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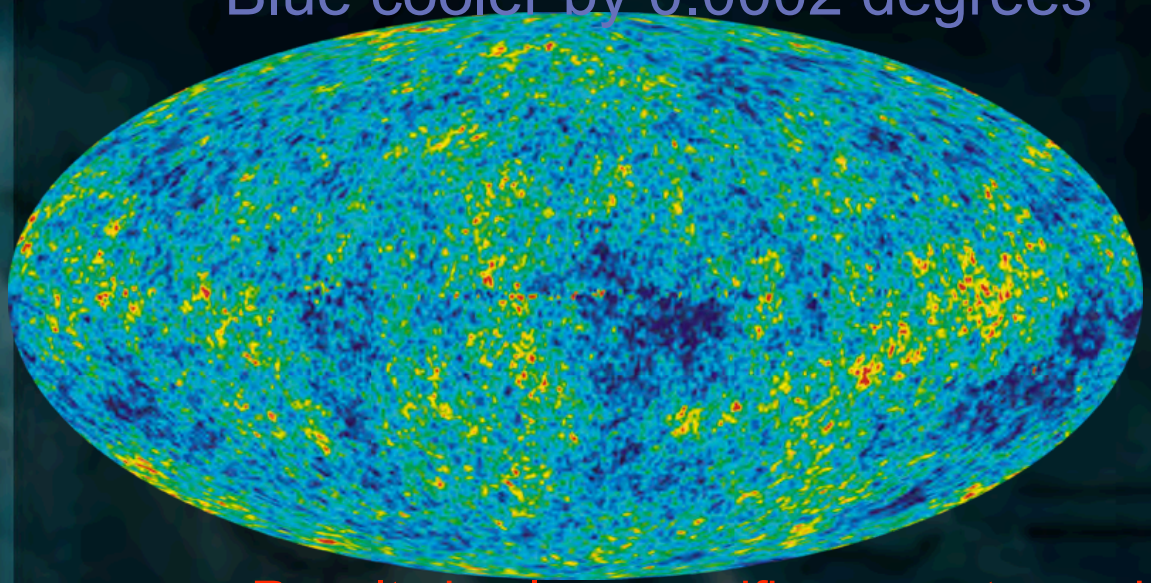
WHY THE LHC?

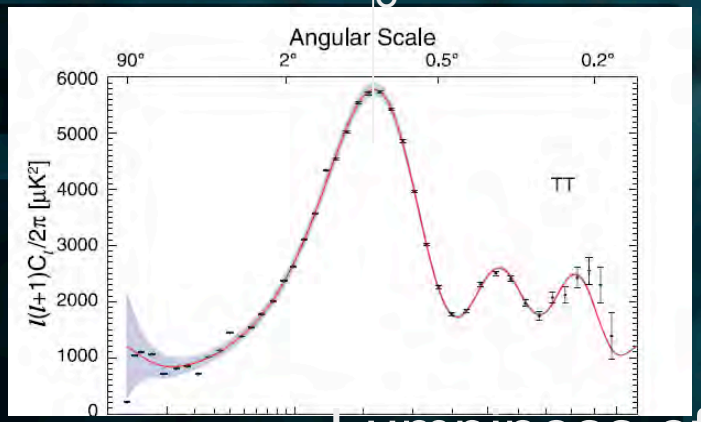
Wilkinson Microwave Anisotropy Probe (WMAP)
Measurements of the 2.7K microwave background

Tiny fluctuations on the 2.7K microwave background

Red warmer by 0.0002 degrees

Blue cooler by 0.0002 degrees





Lumpiness of temperature variations at an angular scale of ~1 degree

Results imply a specific geometry and density for the Universe

Caused by phase transitions during evolution of the universe (like water ➔ ice)

LHC studies the phase transition where particles shifted from massless to massive

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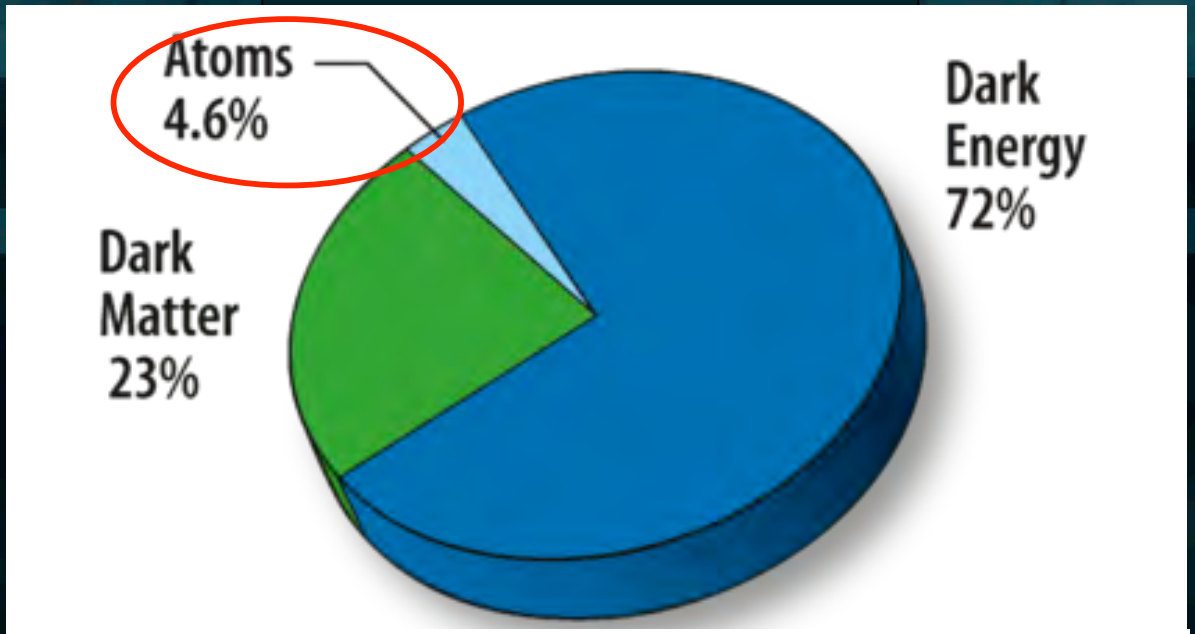
WHY THE LHC?



The calculated makeup of the Universe
We only understand 4.6% of it
after 100s of years of trying !!

Don't know what Dark Matter is

Don't know what Dark Energy is but SOMETHING is accelerating the expansion of our Universe

Supersymmetry ?
The 'Neutralino' particle at the LHC ?

A new force field particle, like the Higgs, at the LHC ?

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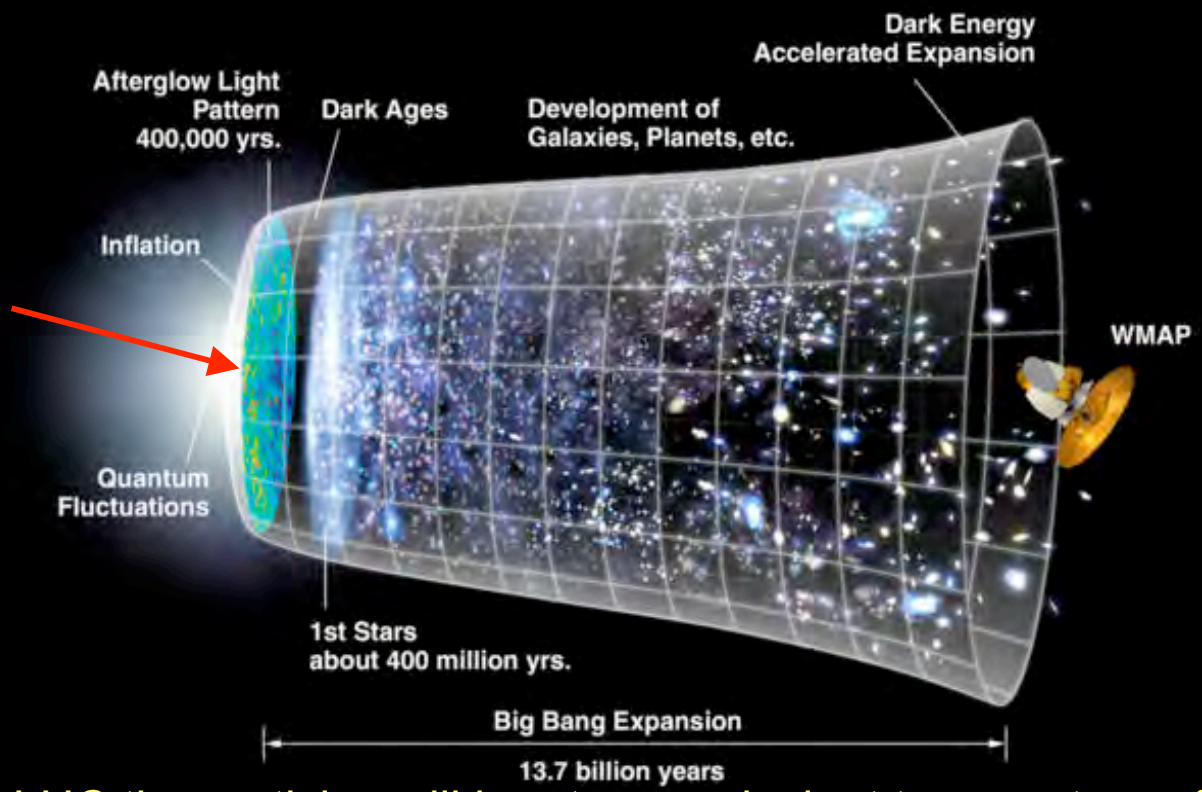
WHY THE LHC?

The LHC will recreate the conditions prevailing in the first moments of the Universe after the Big Bang

LHC ~10^{-10} seconds after the Big Bang

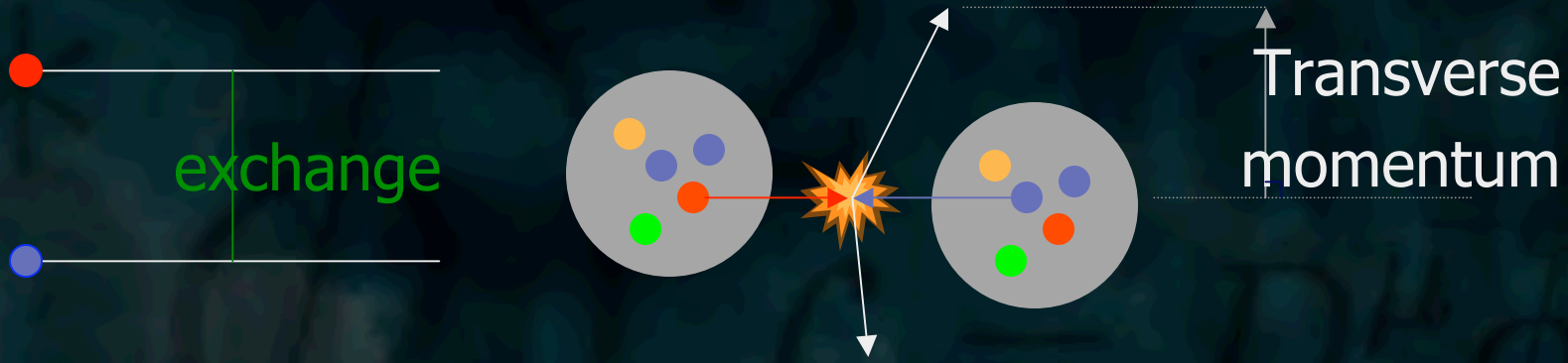


At the LHC the particles will be at an equivalent temperature of 10^{16} K
= 10 thousand, million, million degrees = hot !!

The sun is only 16 million degrees at its core
(and only a piddly 6000 degrees on its surface)

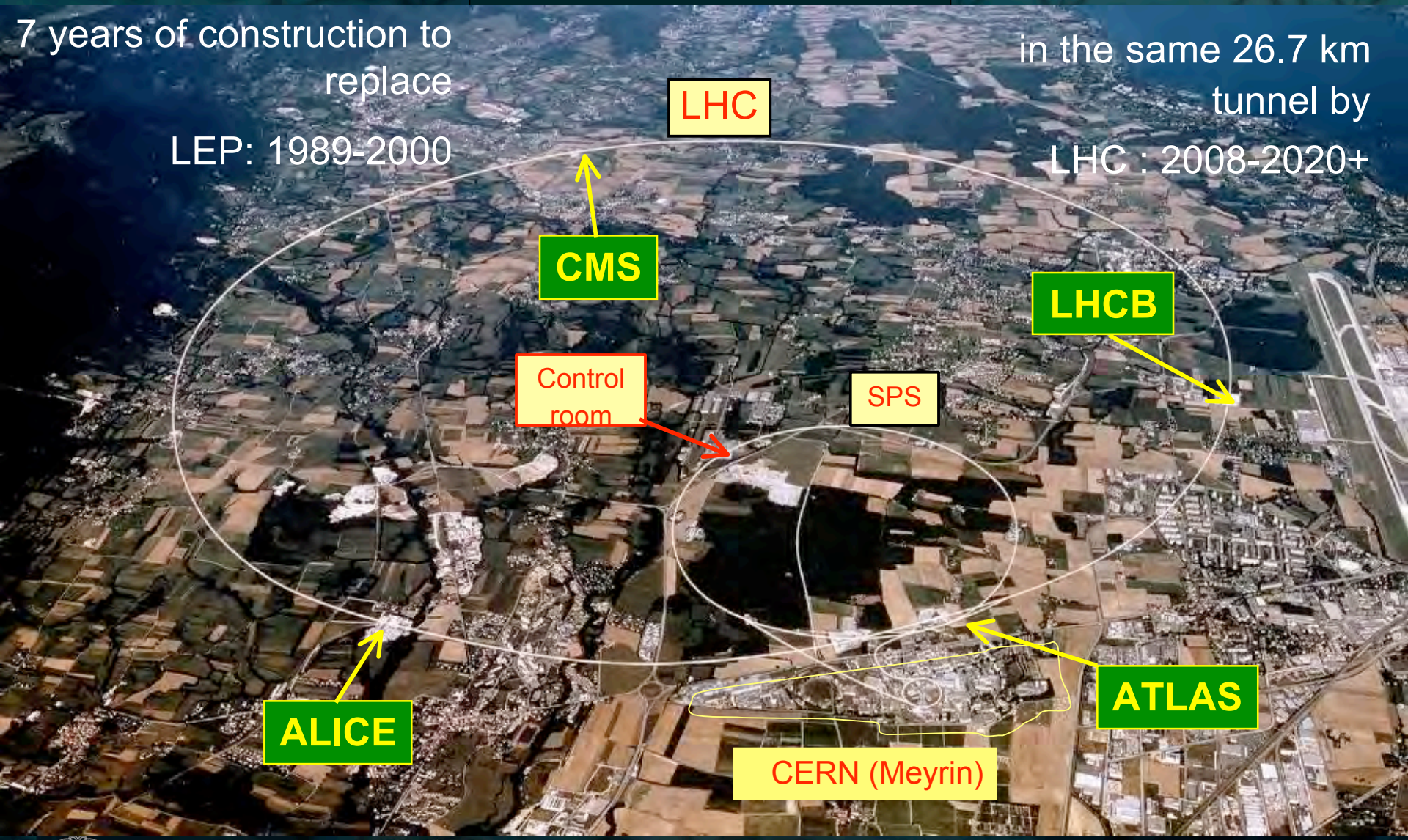
PROTON-PROTON COLLISIONS

- Proton beams can be accelerated to very high energies, and can then be made to collide with other protons.

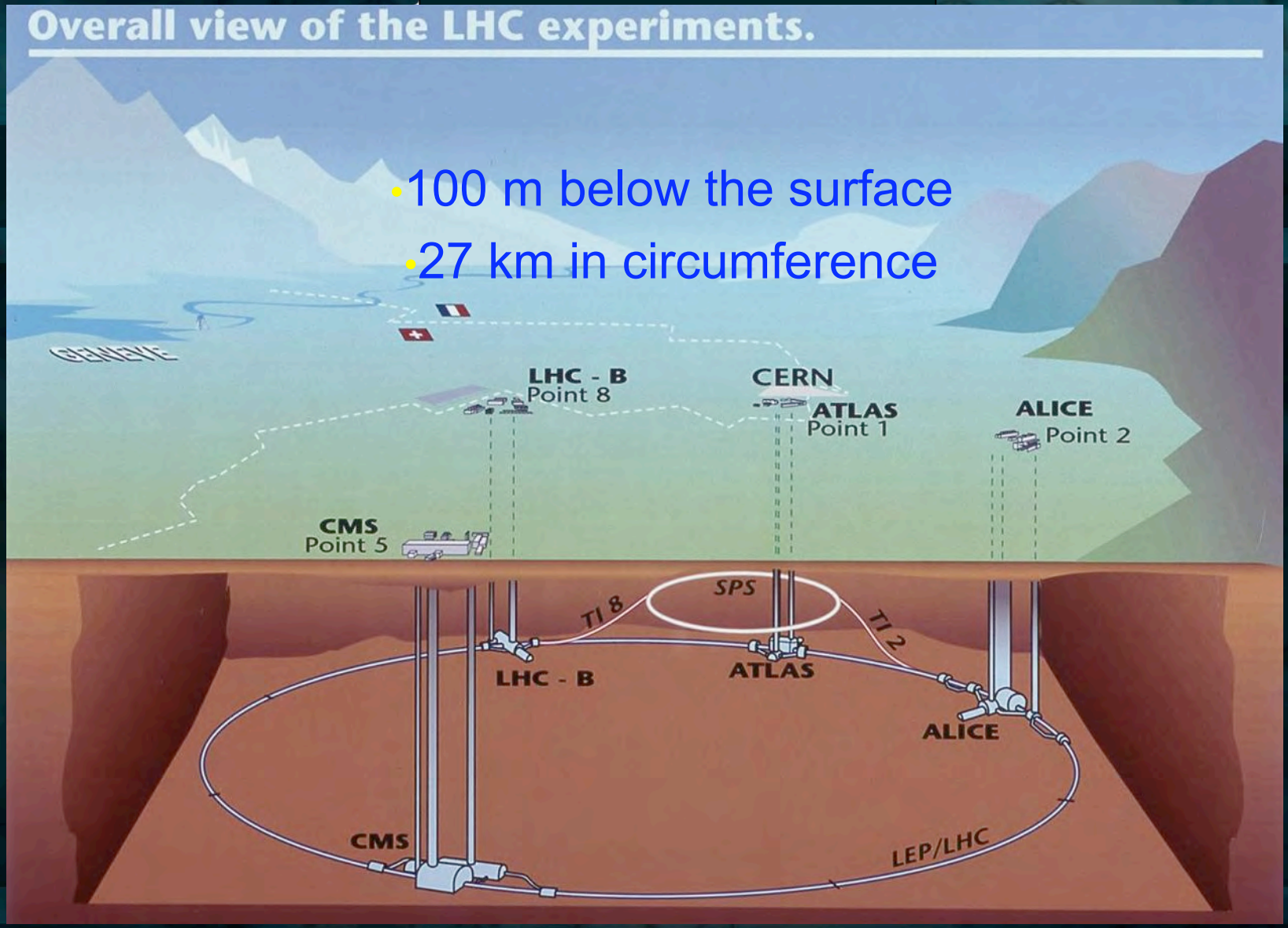


- But the collision energy is shared among the many constituents – the “partons” (quarks and gluons) – of the “hadrons”

THE CERN & LHC COMPLEX



THE PARTICLE ACCELERATOR



- 100 m below the surface
- 27 km in circumference

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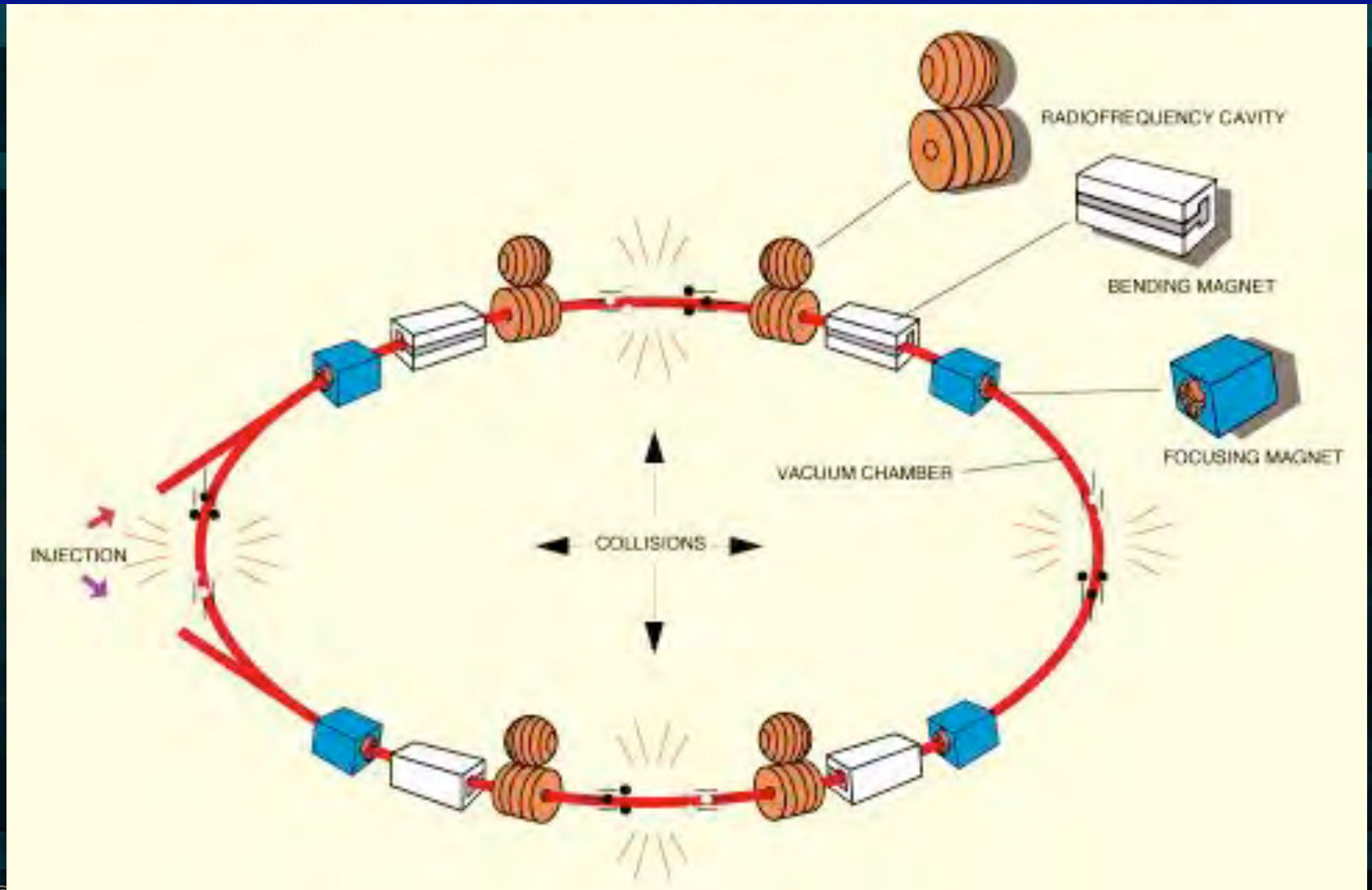
THE LARGE HADRON COLLIDER

3 principal components of an accelerator



THE LARGE HADRON COLLIDER

The LHC tunnel – with bending magnets as far as the eye can see

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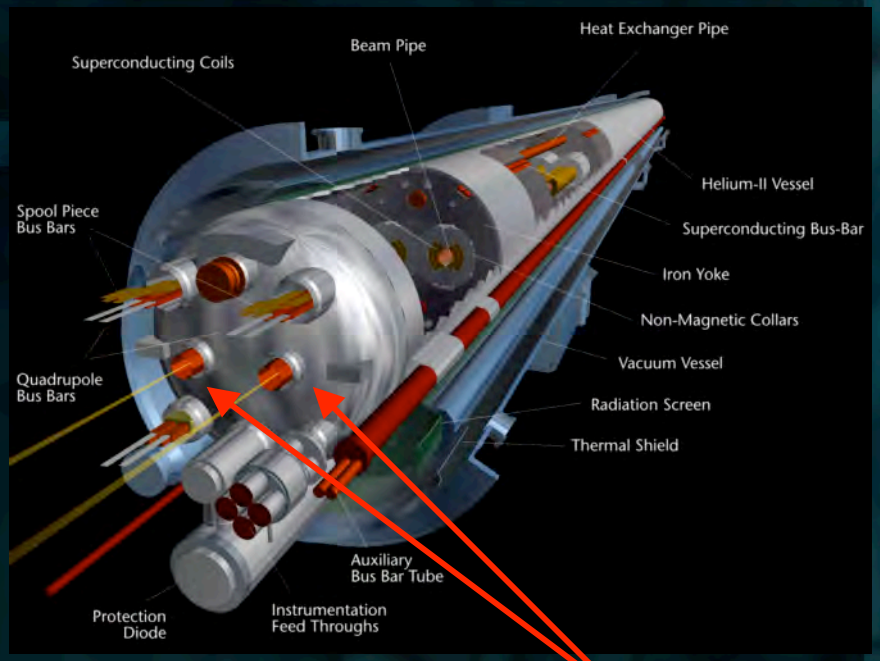

Beam pipes

The LHC dipole bending magnets

Protons guided around tunnel by 1232 of these superconducting magnets

Each 15m long, the magnets are the most complex components of the LHC

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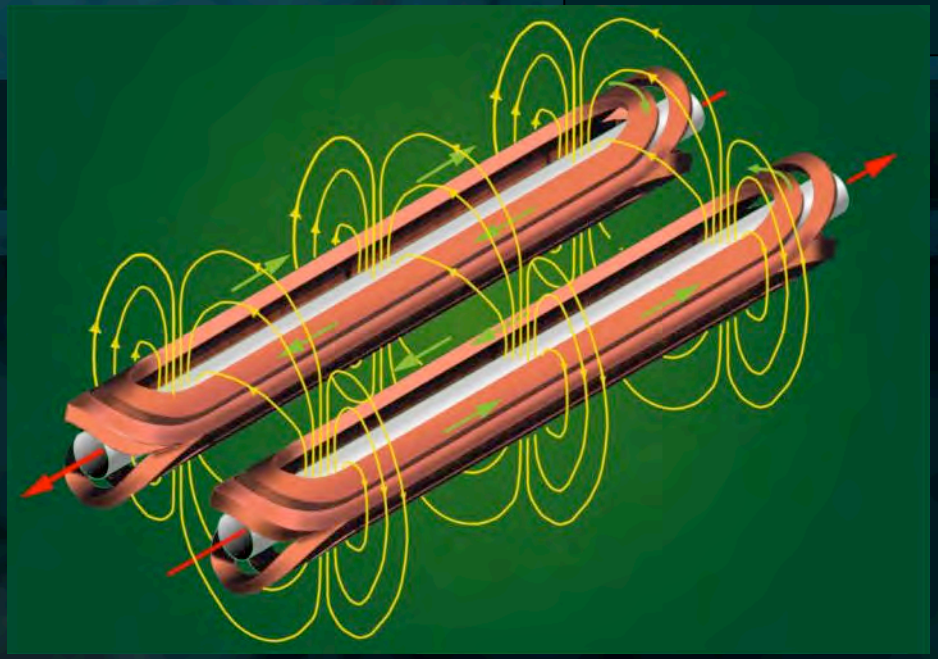
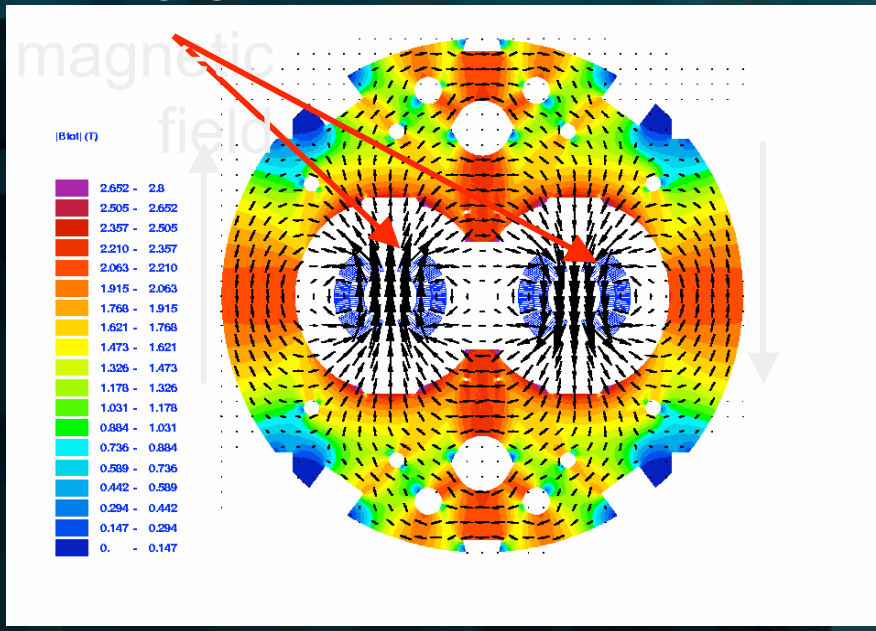


Counter rotating proton beams
2-in-1 magnet design

8.3T



The LHC dipole magnets

11500 amp current flows, without resistance, in the superconducting coils

Current generates the huge magnetic field of 8.3T (200,000 times the earth's) to bend the protons around the LHC tunnel

Beam energy equivalent to 80kg of TNT !

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THE LARGE HADRON COLLIDER

Lowering one of the 1232 15m long dipoles 100m down into the LHC

There are another 8000 magnets of different types as well

1st magnet lowered in March 2005

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THE LARGE HADRON COLLIDER

A set of radiofrequency cavities
Accelerating field 5 Million Volts per meter
Frequency 400 MHz

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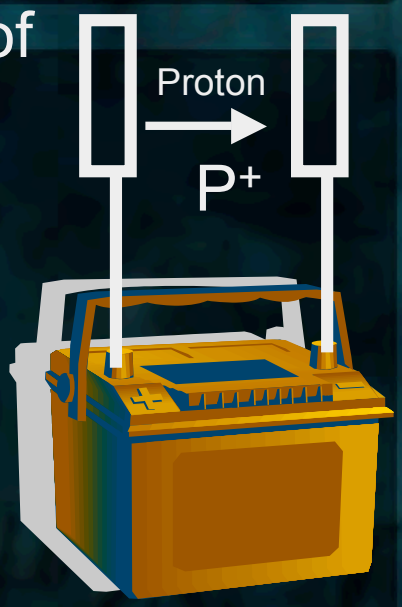
THE LARGE HADRON COLLIDER

- The power of the LHC accelerator is enormous.

- Imagine using a car battery of 12V to accelerate a proton. The proton would gain a kinetic energy of
- $E = q \cdot \Delta V = 1 \cdot 12 = 12$ eV



- We now need some Greek:
  - 1 keV = 1000 eV = 1 Thousand electron volts
  - 1 MeV = 10^6 eV = 1 Million electron volts
  - 1 GeV = 10^9 eV = 1 Billion electron volts
  - 1 TeV = 10^{12} eV = 1 Trillion electron volts

- The LHC accelerates protons to 7 TeV on 7 TeV
- You would need 1.17 Trillion car batteries to compete!

Result ➔

ONE OF THE FASTEST RACETRACKS ON THE PLANET

Several thousand billion protons traveling at 99.9999991% of the speed of light will travel round the 27km ring over 11000 times a second 100 m underground

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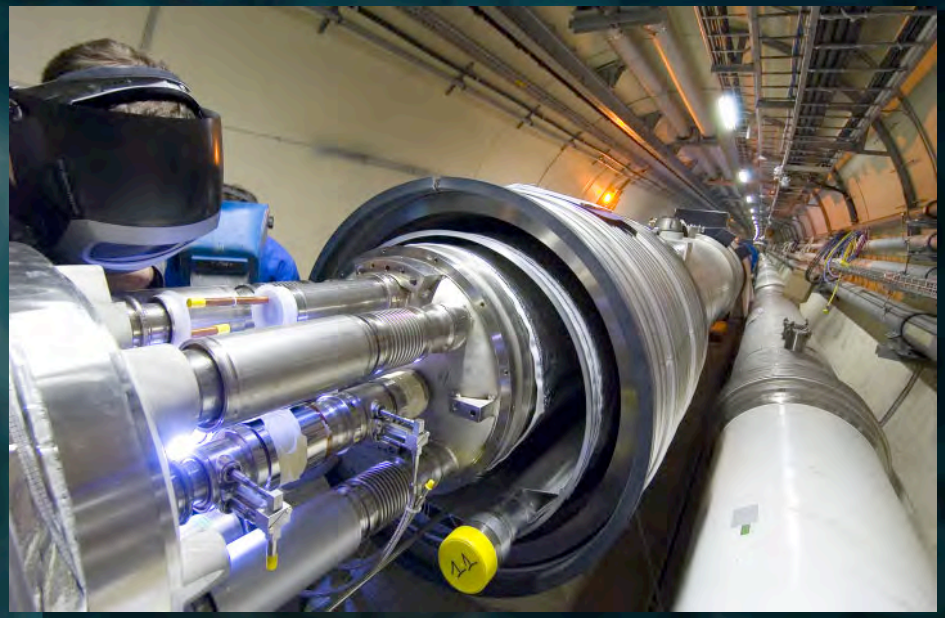
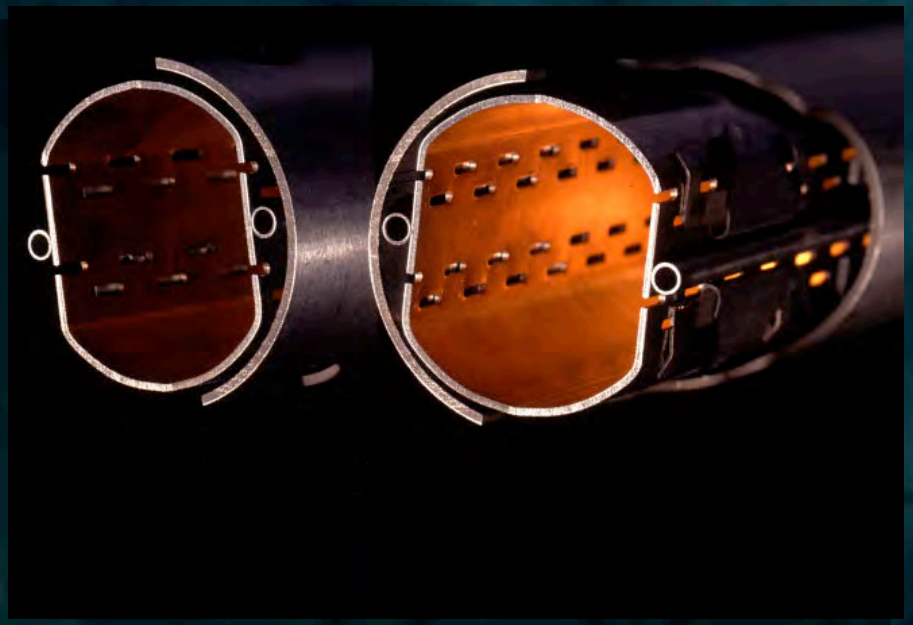
THE EMPTIEST SPACE IN THE SOLAR SYSTEM…





To accelerate protons to almost the speed of light, we need a vacuum similar to interplanetary space. The pressure in the beam-pipes of the LHC will be about ten times lower than on the moon.

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ANGELS&DEMONS
Lecture Night
THE SCIENCE REVEALED

ONE OF THE COLDEST PLACES IN THE UNIVERSE…

With a temperature of around -271 degrees Celsius, or 1.9 degrees above absolute zero, the LHC is colder than interstellar space.

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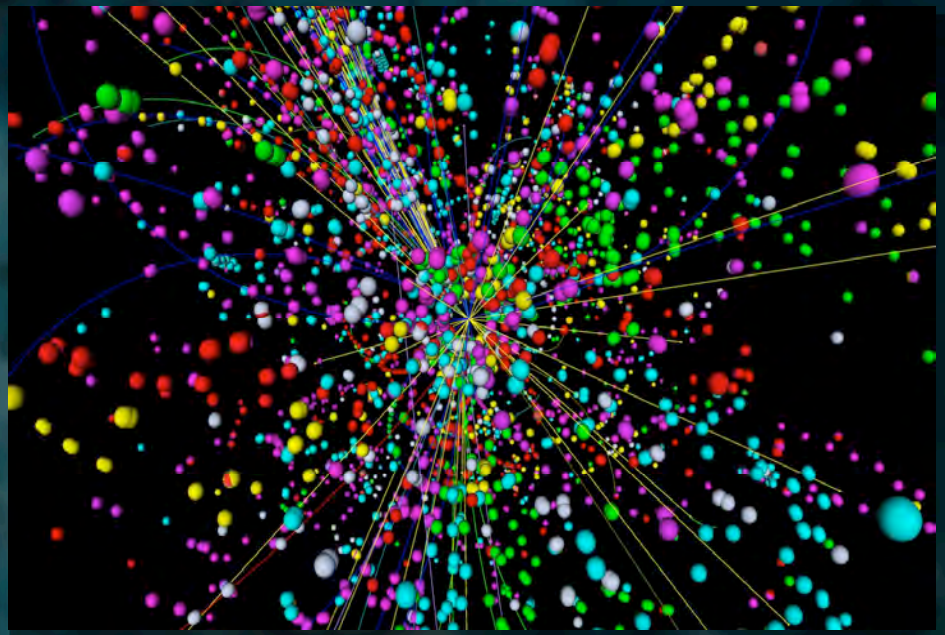
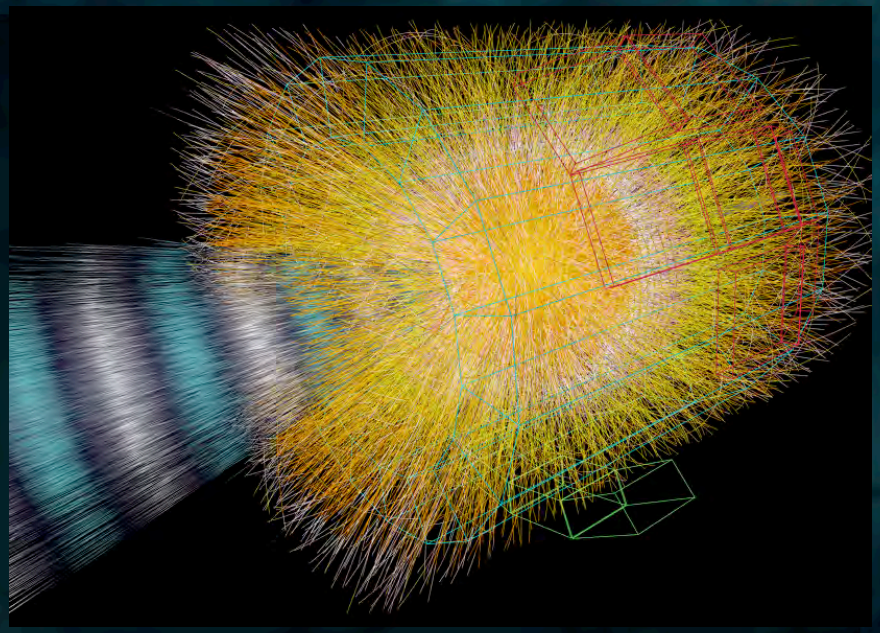
ONE OF THE HOTTEST PLACES IN THE GALAXY…



Simulation of a collision in the CMS experiment



Simulation of a collision in the ALICE experiment

When two beams of protons collide, they generate within a tiny volume, temperatures more than a billion times those in the very heart of the Sun.

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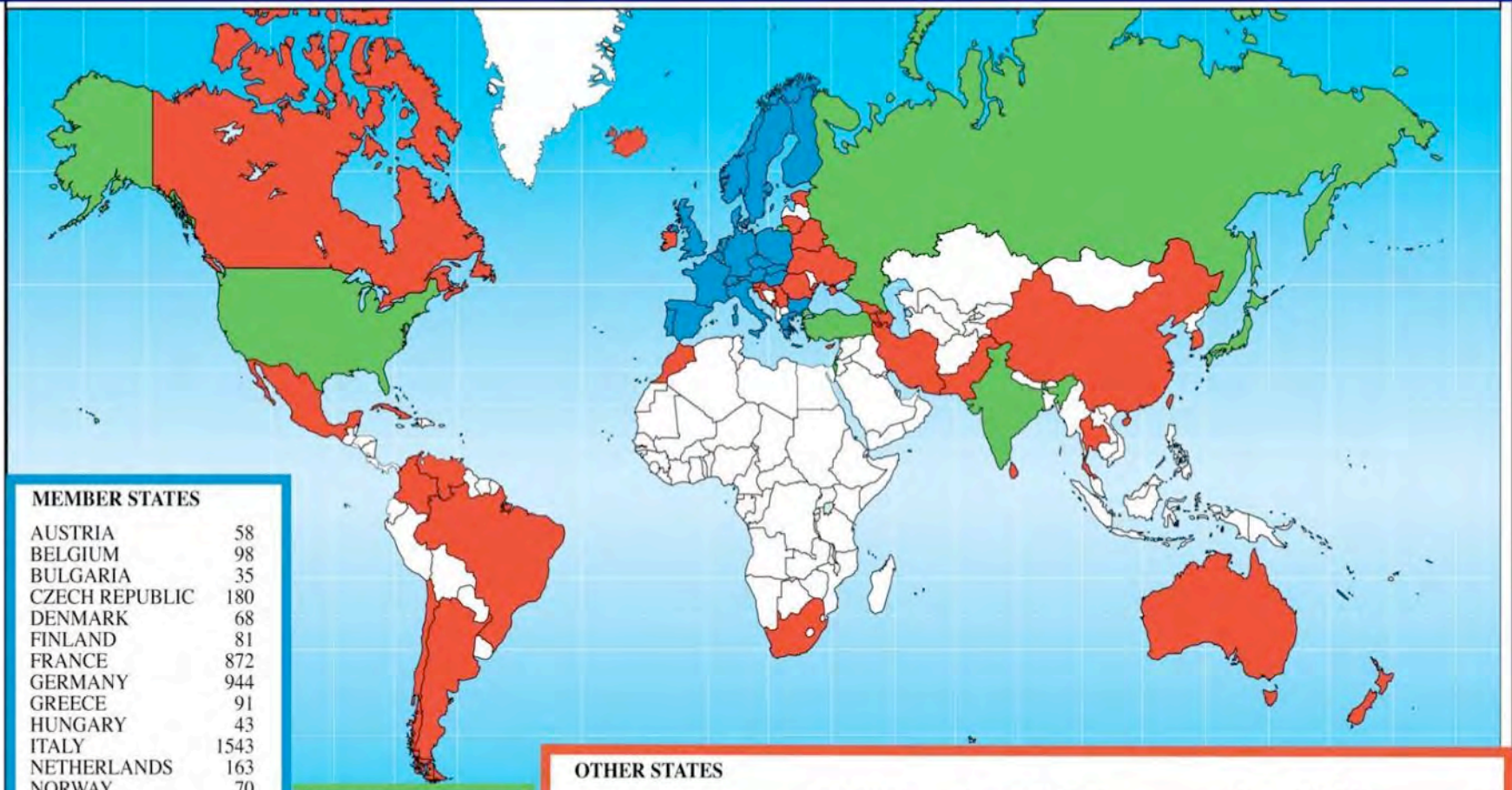
Distribution of All CERN Users by Nation of Institute on 5 February 2008



MEMBER STATES

AUSTRIA	58
BELGIUM	98
BULGARIA	35
CZECH REPUBLIC	180
DENMARK	68
FINLAND	81
FRANCE	872
GERMANY	944
GREECE	91
HUNGARY	43
ITALY	1543
NETHERLANDS	163
NORWAY	70
POLAND	175
PORTUGAL	109
SLOVAKIA	46
SPAIN	270
SWEDEN	74
SWITZERLAND	344
UNITED KINGDOM	645

5909

OBSERVER STATES

INDIA	93
ISRAEL	64
JAPAN	182
RUSSIA	940
TURKEY	35
USA	1278

2592

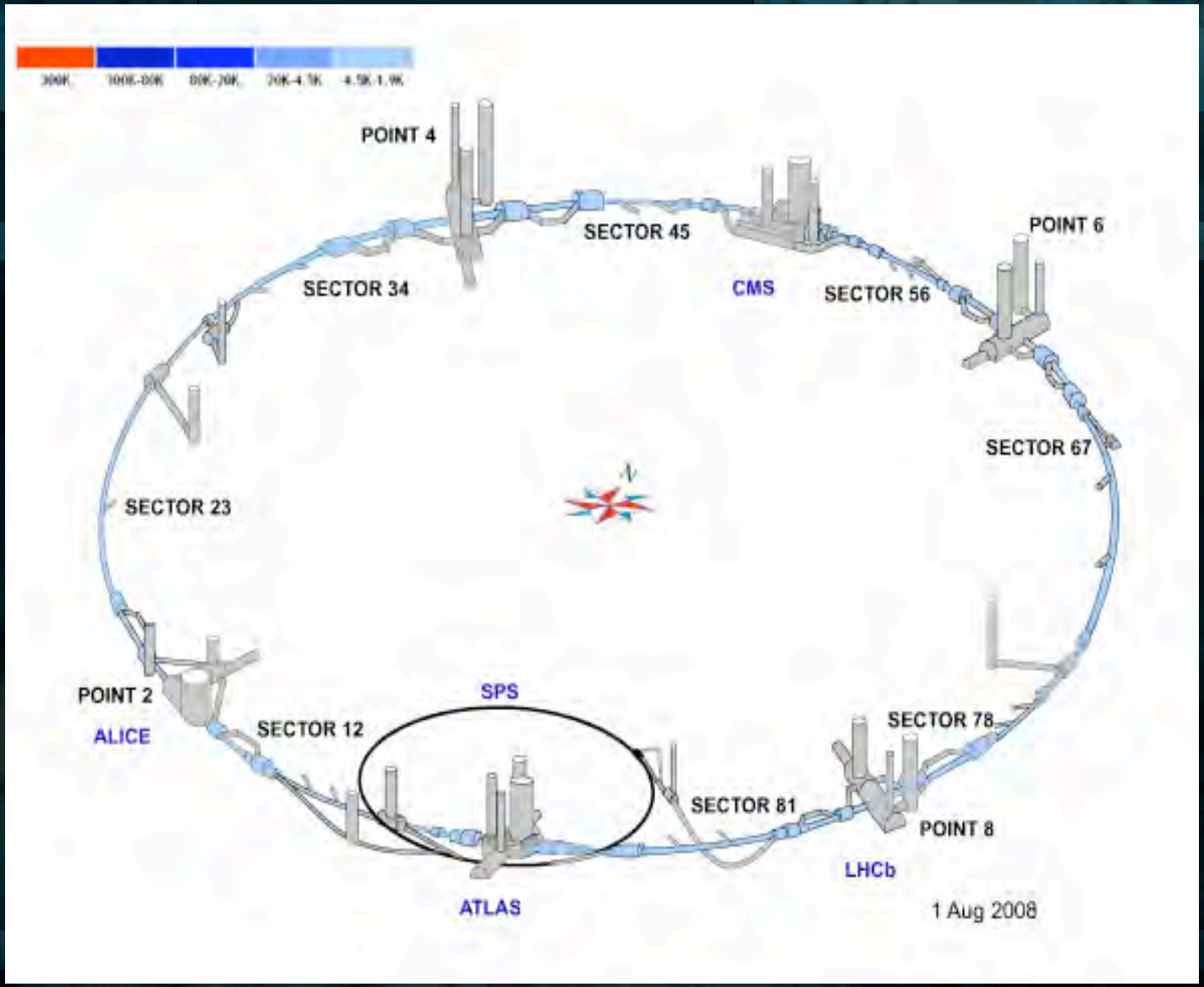
OTHER STATES

ARGENTINA	8	CROATIA	17	MEXICO	23	TAIWAN	40
ARMENIA	17	CUBA	3	MONTENEGRO	1	THAILAND	1
AUSTRALIA	13	CYPRUS	6	MOROCCO	6	UKRAINE	17
AZERBAIJAN	1	ESTONIA	10	NEW ZEALAND	7		
BELARUS	23	GEORGIA	9	PAKISTAN	23		
BRAZIL	68	ICELAND	1	ROMANIA	46		
CANADA	119	IRAN	6	SERBIA	16		
CHILE	4	IRELAND	14	SLOVENIA	16		
CHINA	60	KOREA	44	SOUTH AFRICA	2		
COLOMBIA	5	LITHUANIA	5	SRI LANKA	1		

632

COOLDOWN OF THE LHC ACCELERATOR

LHC was cold in August



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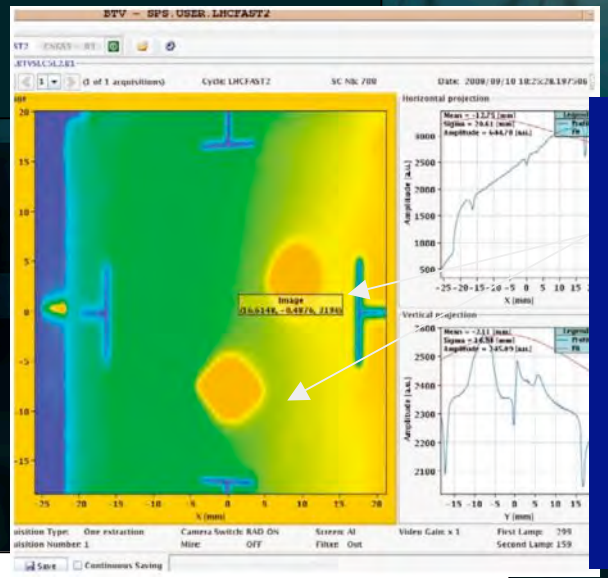
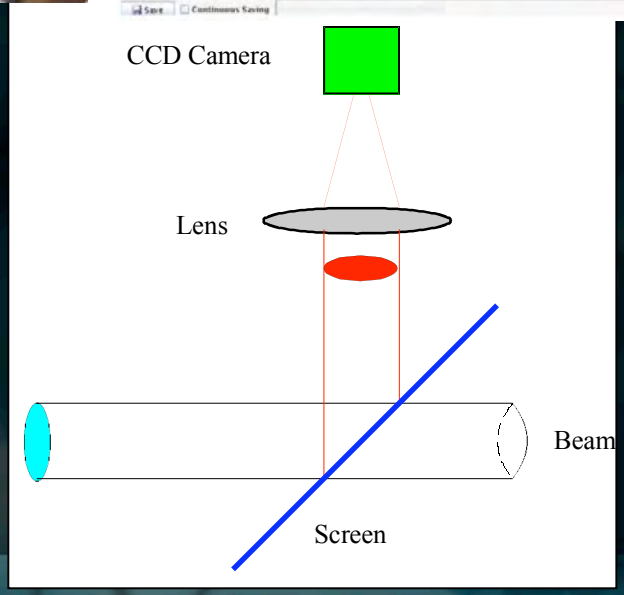
FIRST BEAMS AROUND THE LHC

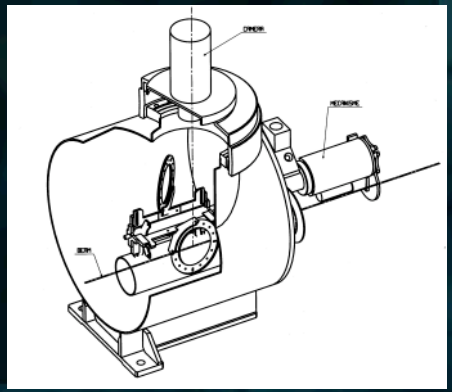
Joyous faces on 10 Sep 2008



Beam (a single proton bunch) enters and does a complete circle around the LHC ring

Fluorescent screen to detect the beam – like that in a CRT television



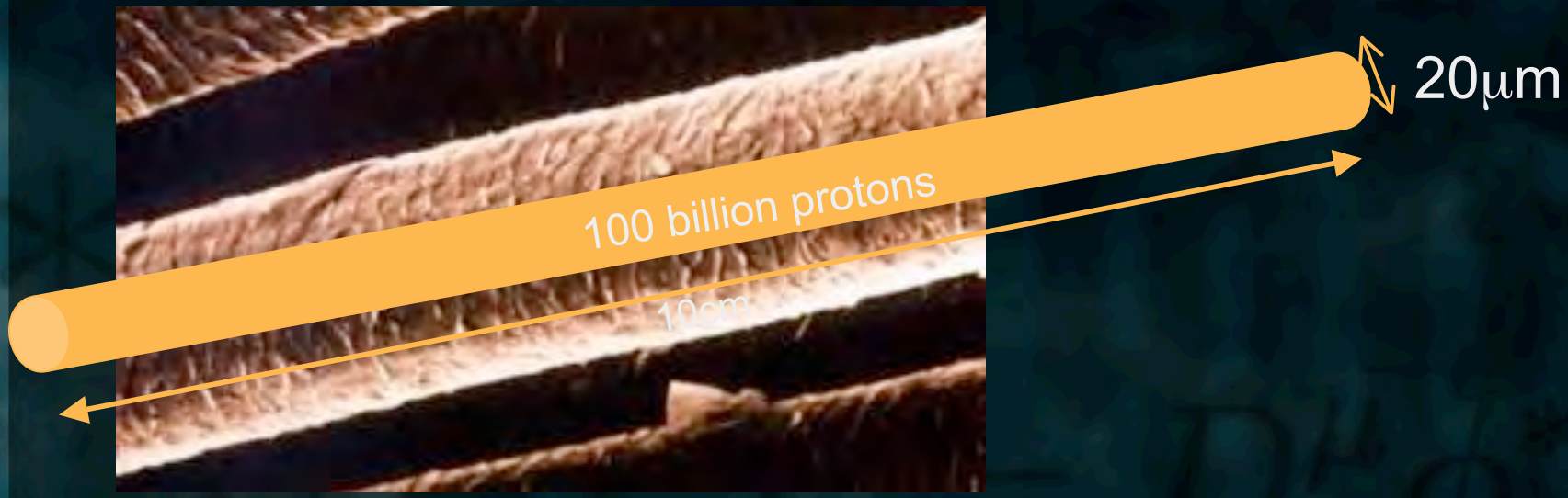


THE LARGE HADRON COLLIDER

Inside the 2 beam pipes the Protons are BUNCHED together

There are ~100 billion protons in each bunch

2835 bunches in each beam pipe circulate around the ring



An entire bunch is only 20μm across (but spread over a length of ~10cm)

- a width of about a fifth of a human hair !

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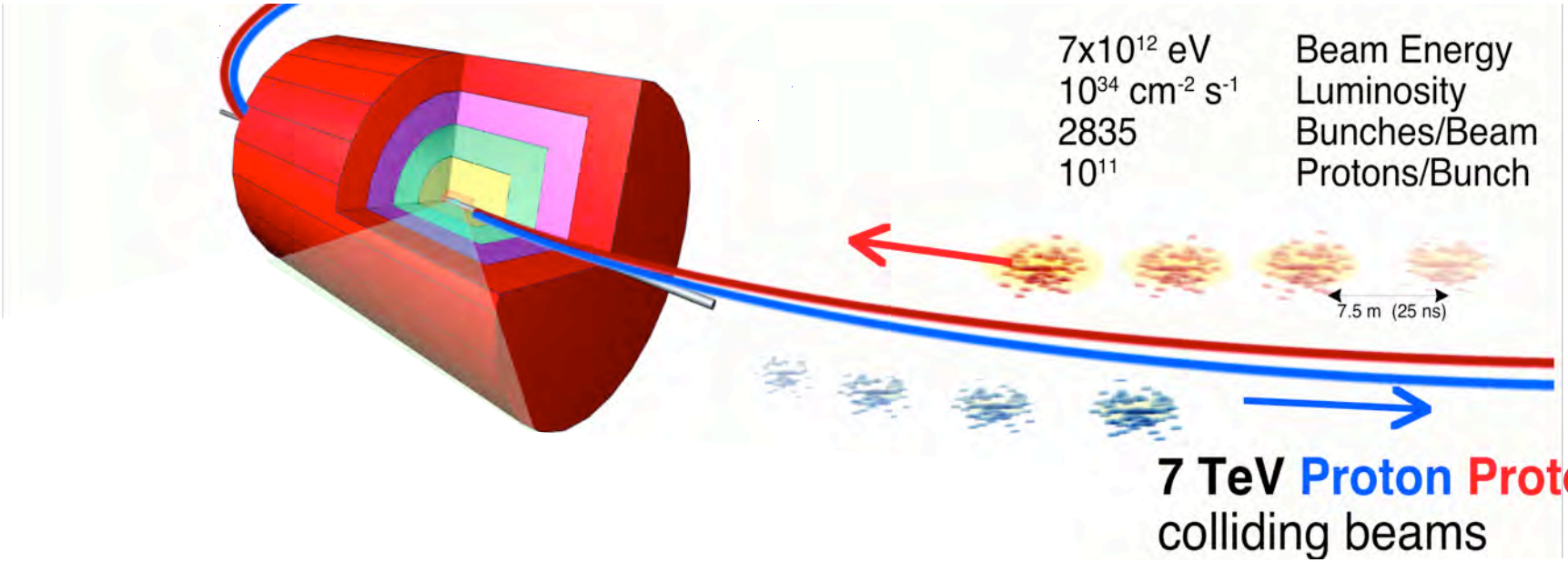
THE LARGE HADRON COLLIDER

To get protons to collide
Aim one bunch of protons straight at the other

This is harder than firing two needles at each other
from opposite shores of Lake Monona
and ensuring they hit head on !

THE ENVIRONMENT: COLLISIONS AT LHC



One per day?

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EXPERIMENTAL CHALLENGE "DEMONS"

- **High Interaction Rate**
  - **1 billion proton-proton interactions per second**
- **Large Particle Fluxes**
  - **~ 1000 tracks stream into the detector every 25 ns**

  ⇨ a large number of channels (~ 100 M ch)
- **High Radiation Levels**

⇨ radiation hard (tolerant) detectors and electronics

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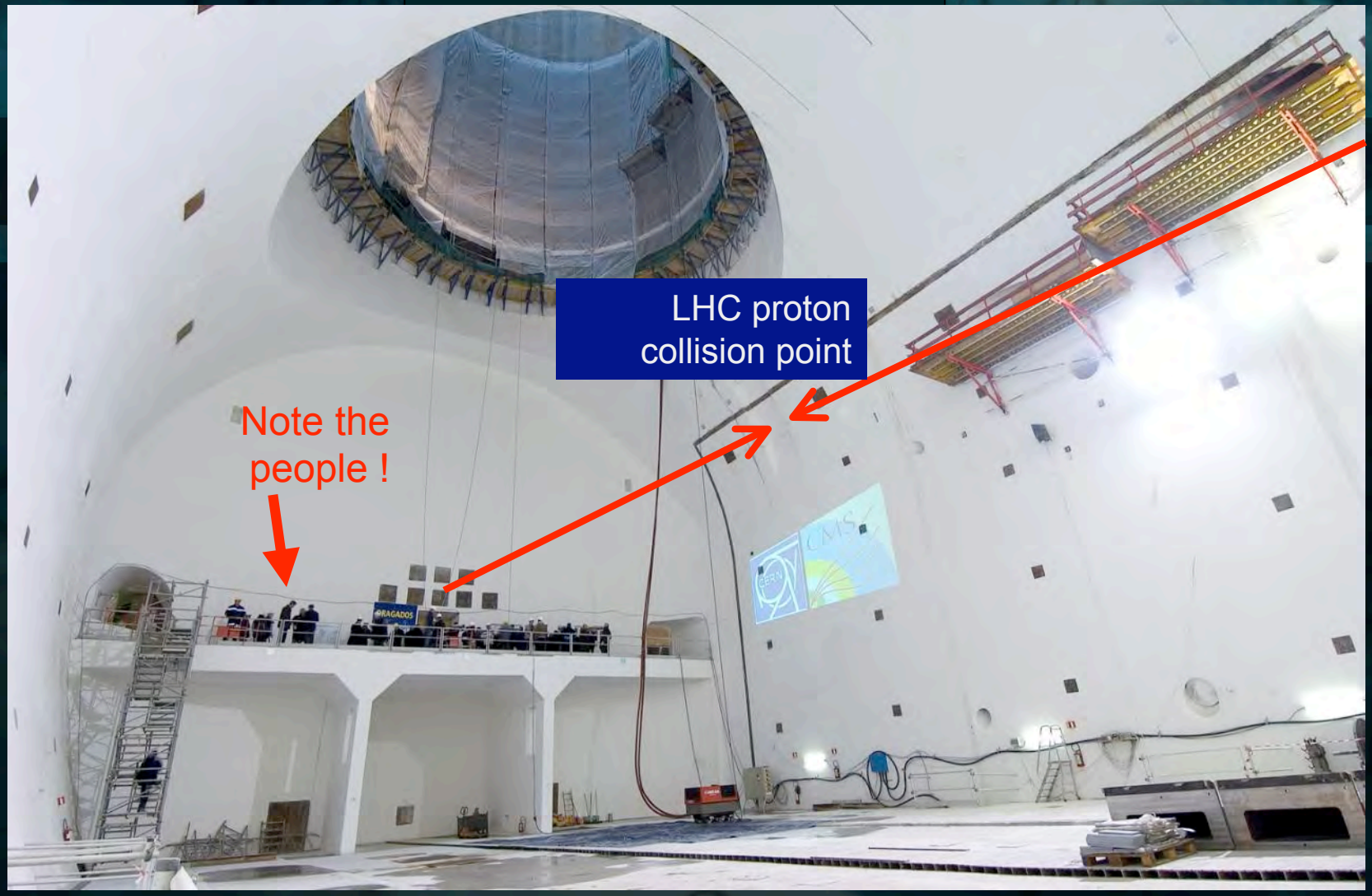
COMPACT MUON SOLENOID



The CMS Underground cavern before installing the experiment

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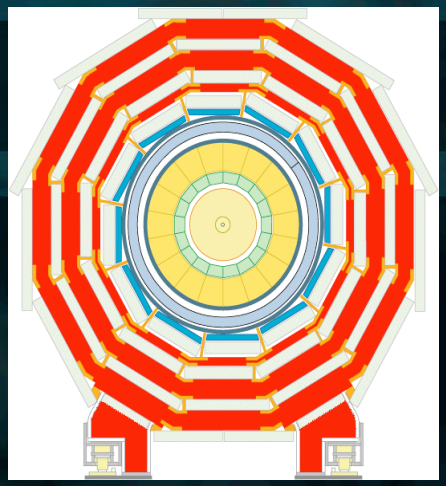
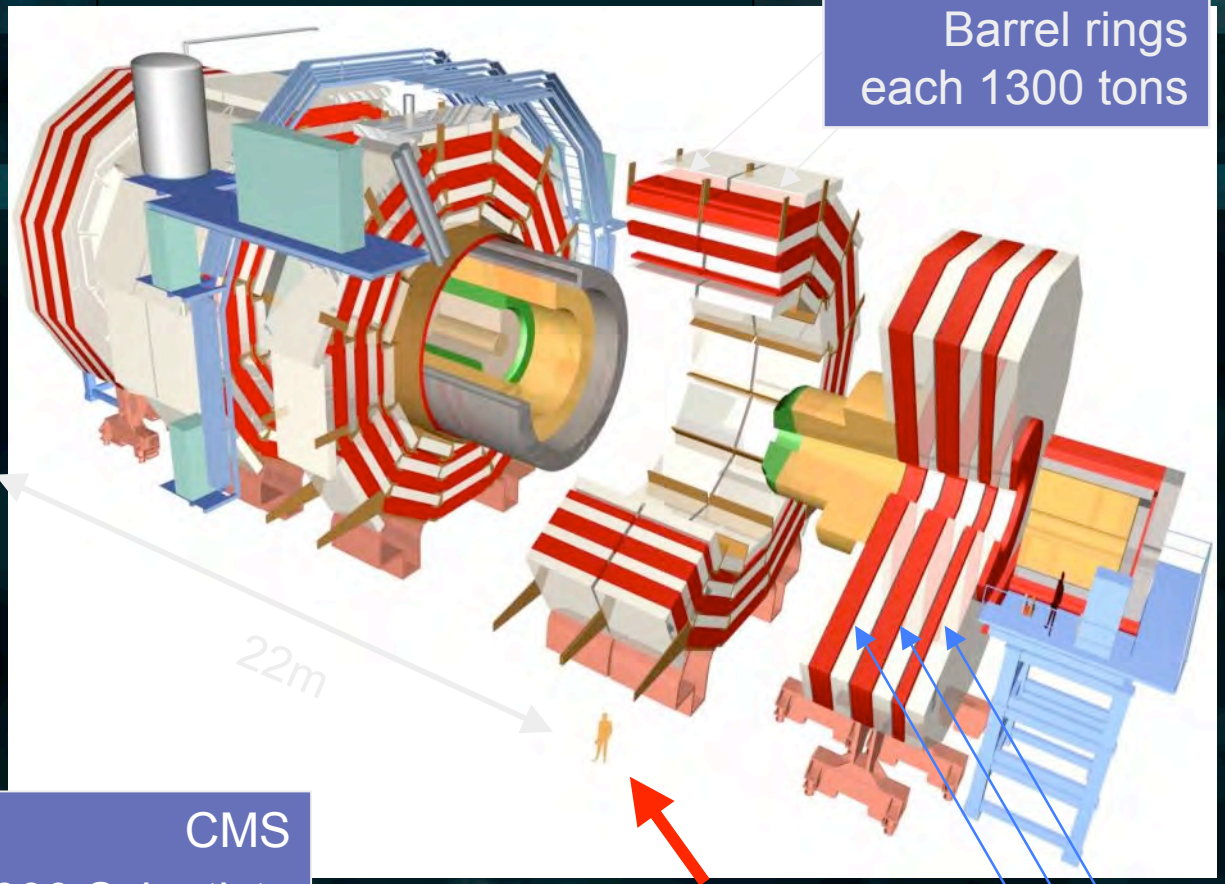
COMPACT MUON SOLENOID



12500 tons
As much iron as the Eiffel Tower !



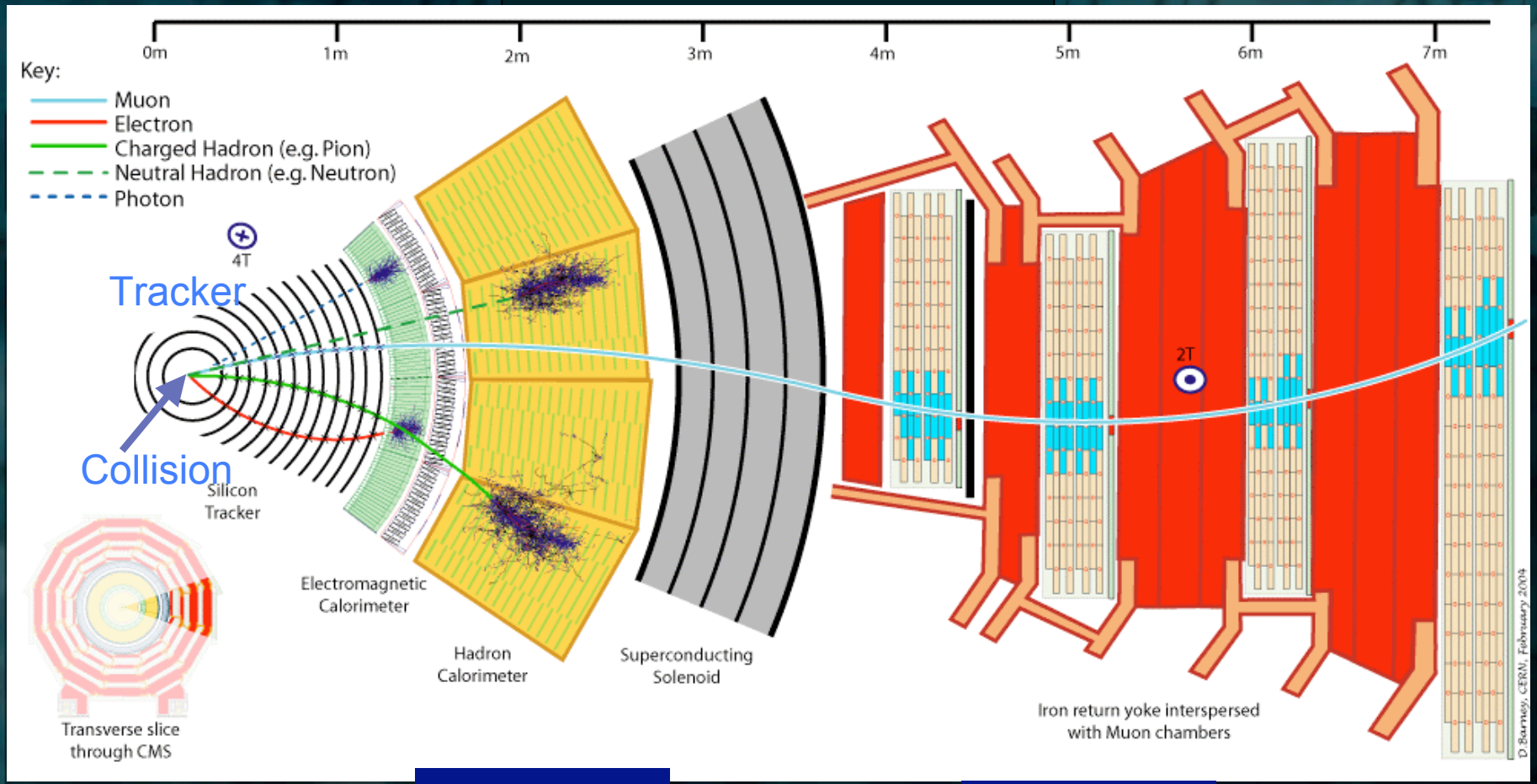
Barrel rings each 1300 tons

CMS
2930 Scientists
184 Institutions

Note the person !

Endcap disks

PARTICLE INTERACTIONS IN CMS



Electrons
Photons

Pions
Protons
Neutrons

3.8T
Solenoid

Iron return
Muons

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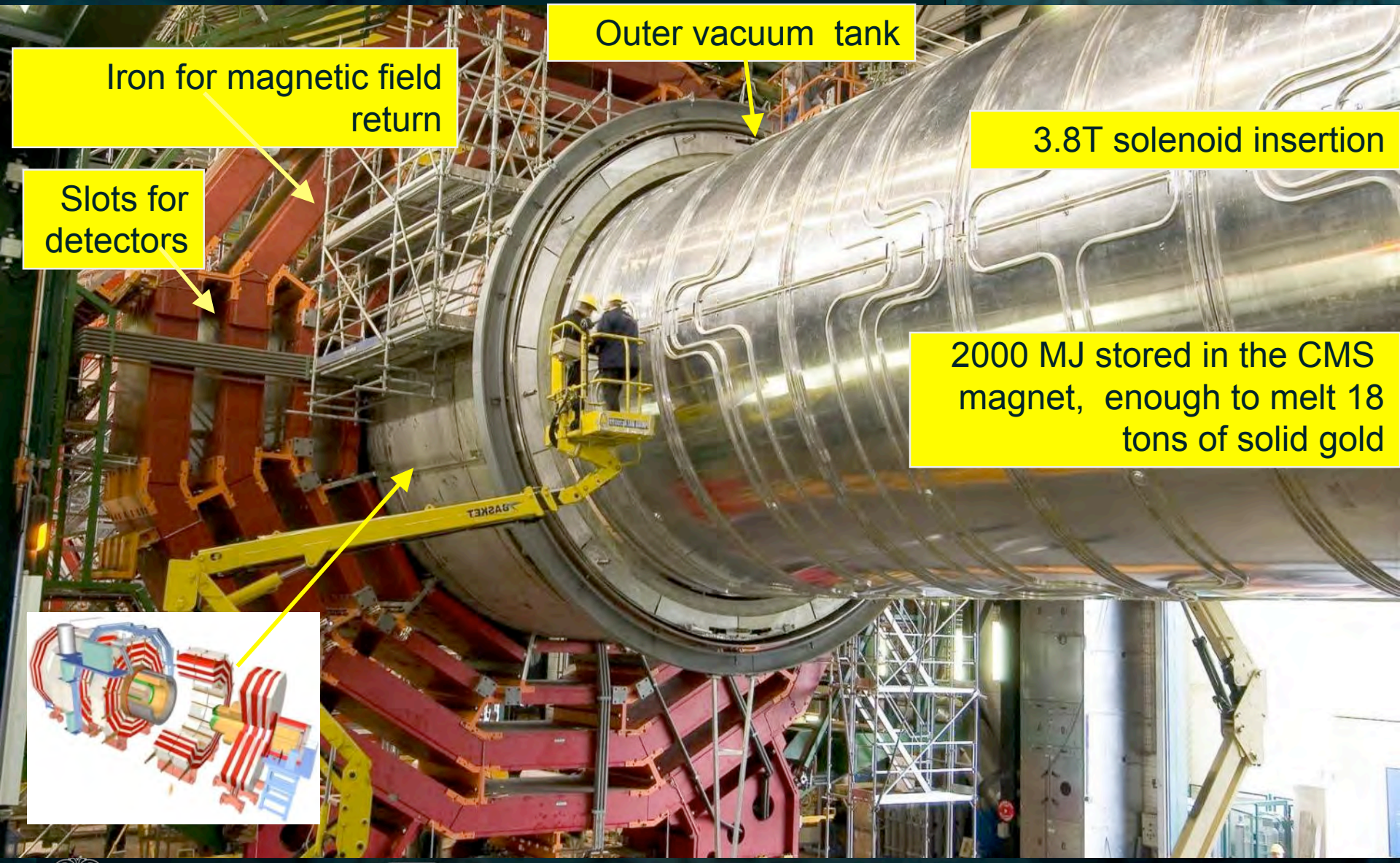
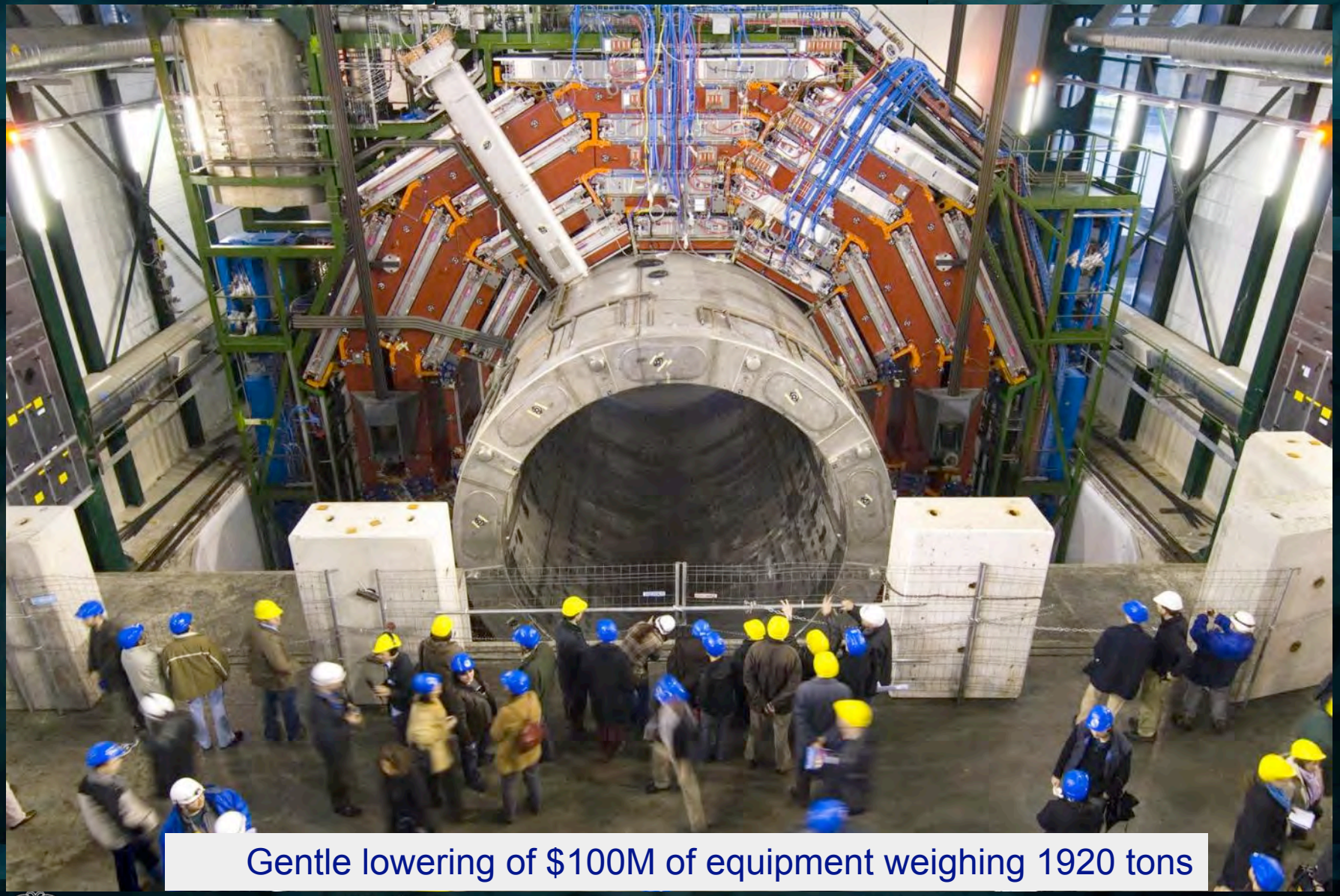
COMPACT MUON SOLENOID



COMPACT MUON SOLENOID



Gentle lowering of $100M of equipment weighing 1920 tons

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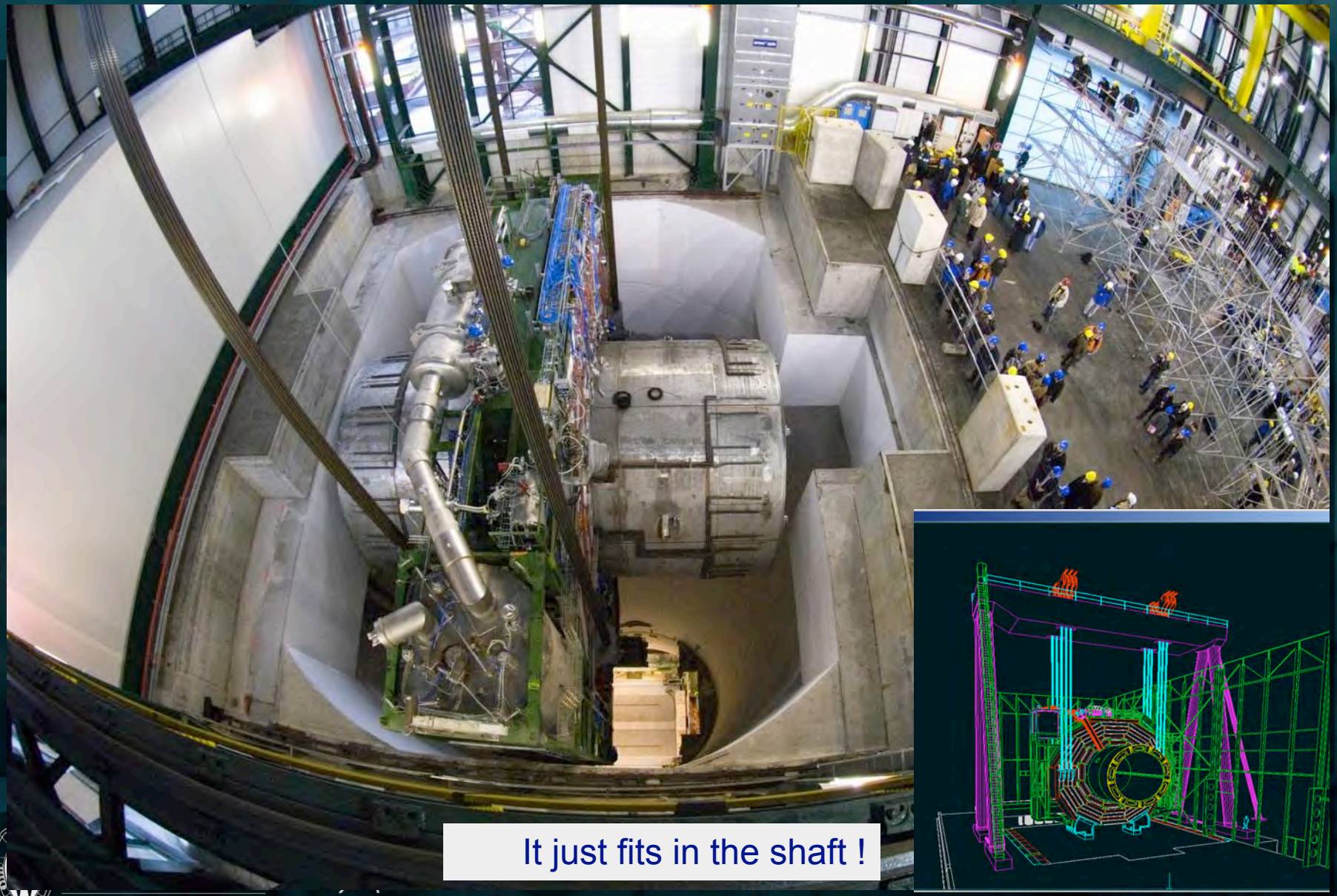
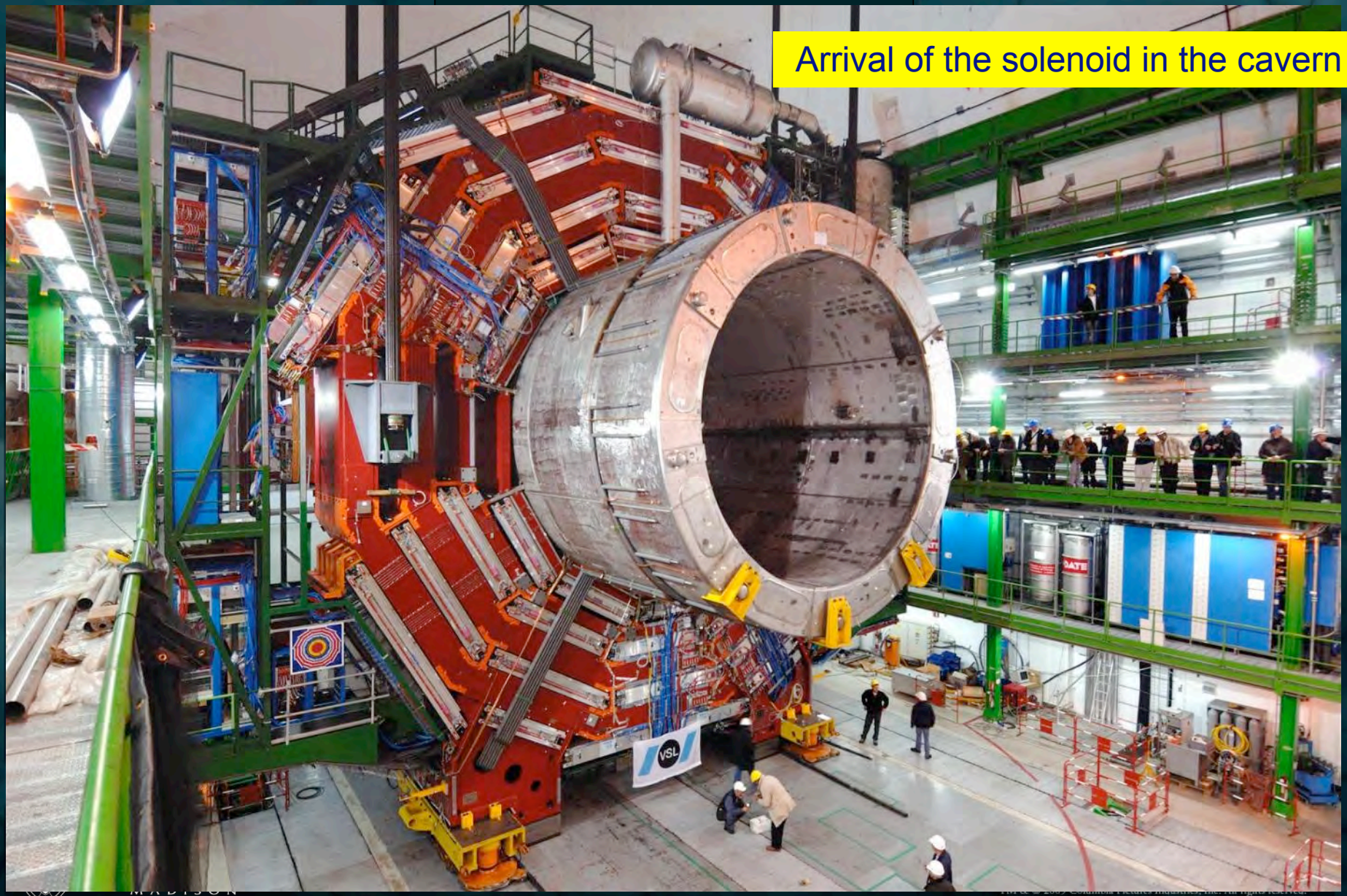
COMPACT MUON SOLENOID

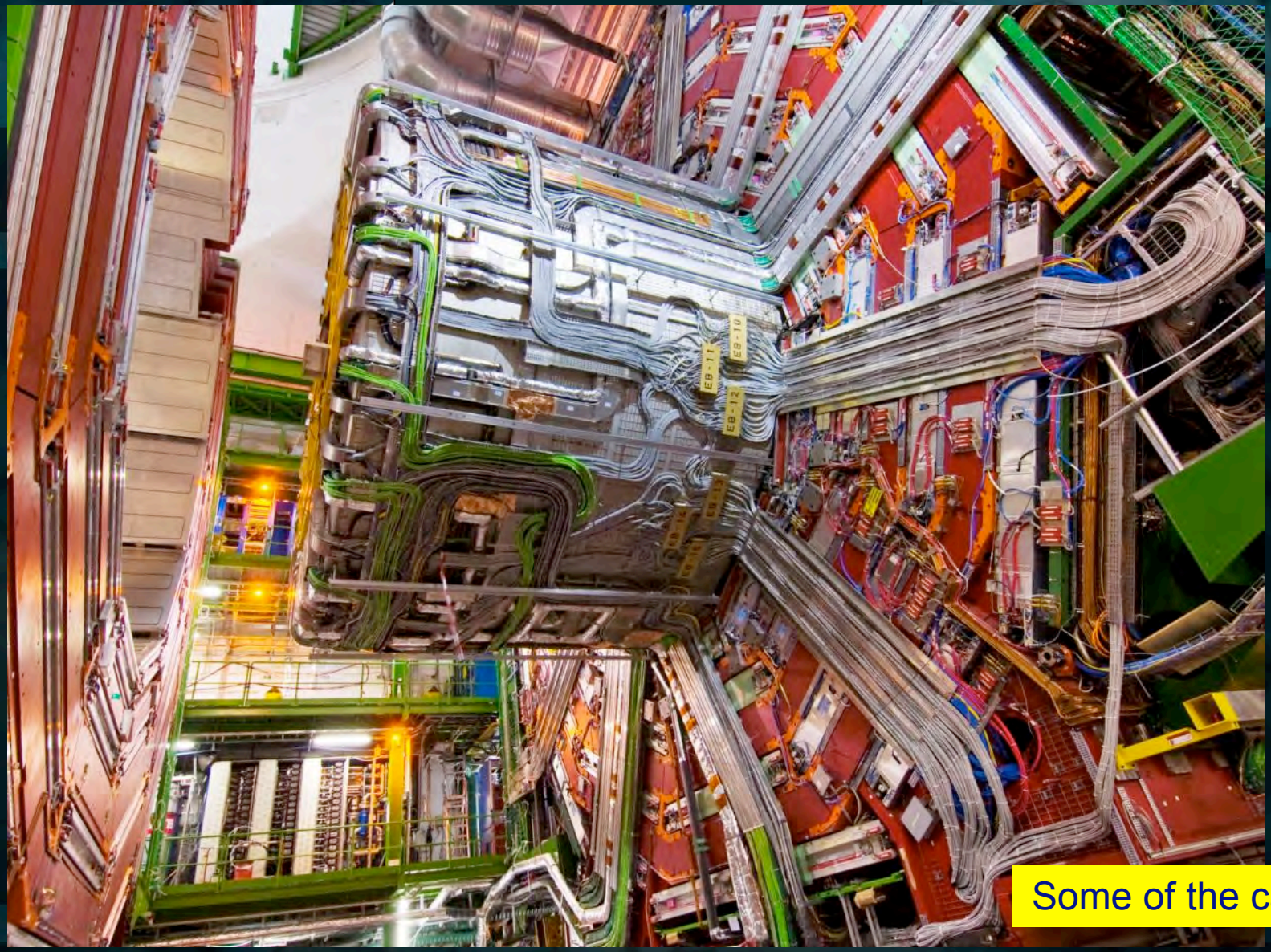


It just fits in the shaft !

COMPACT MUON SOLENOID



COMPACT MUON SOLENOID



Some of the cabling !

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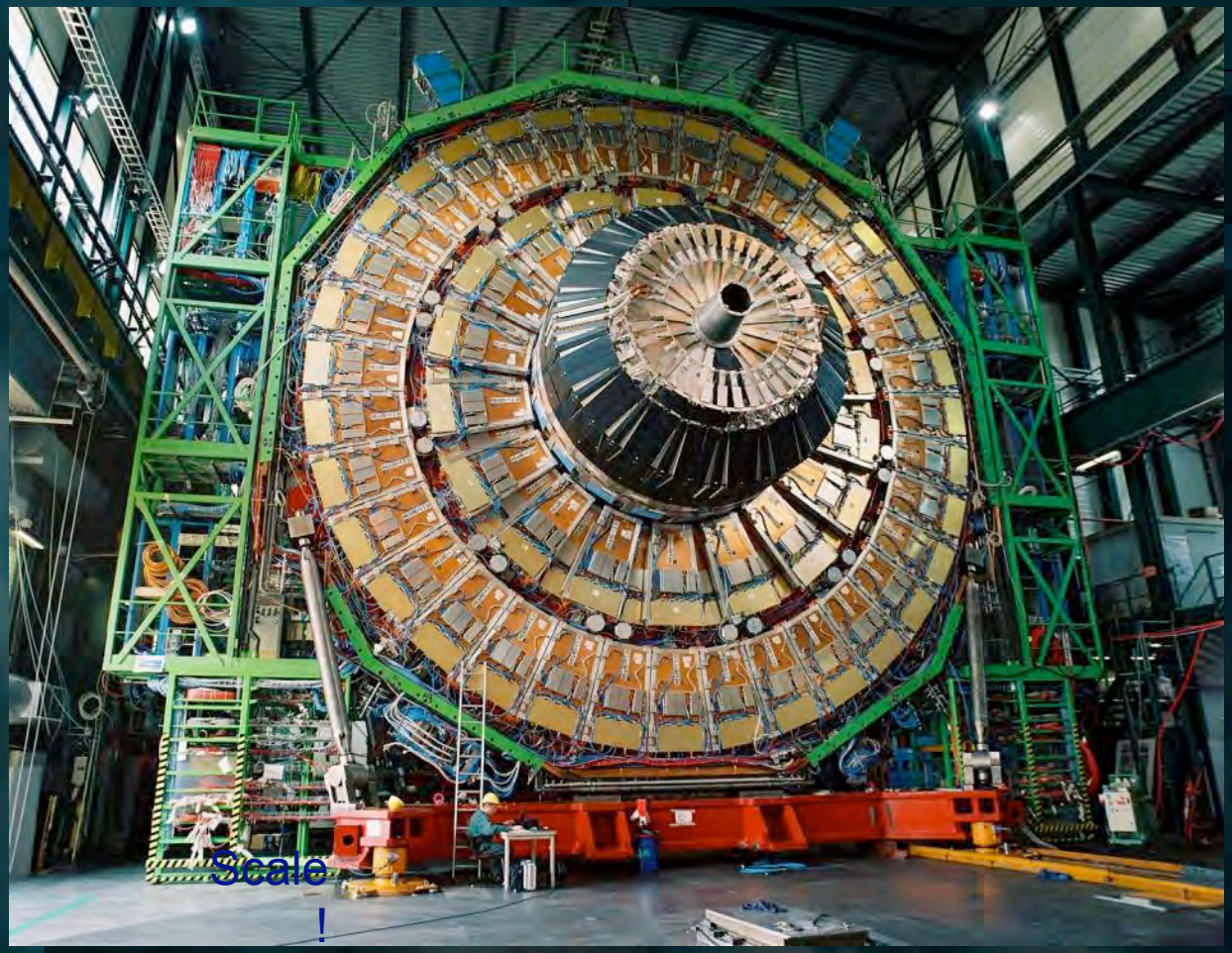
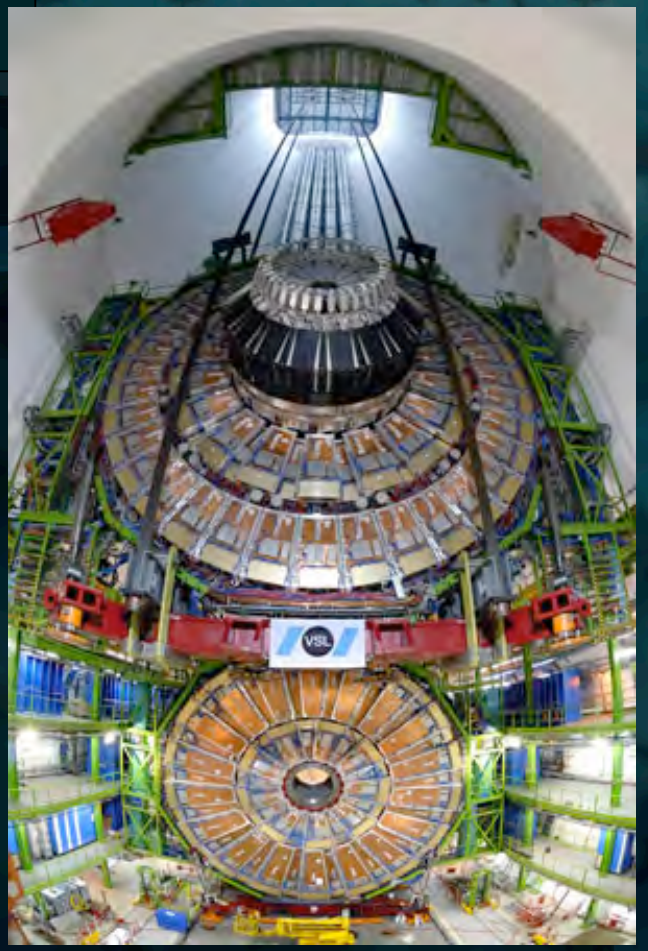
COMPACT MUON SOLENOID





A beautiful view of an Endcap disk with its Muon chambers – Wisconsin Contrib.

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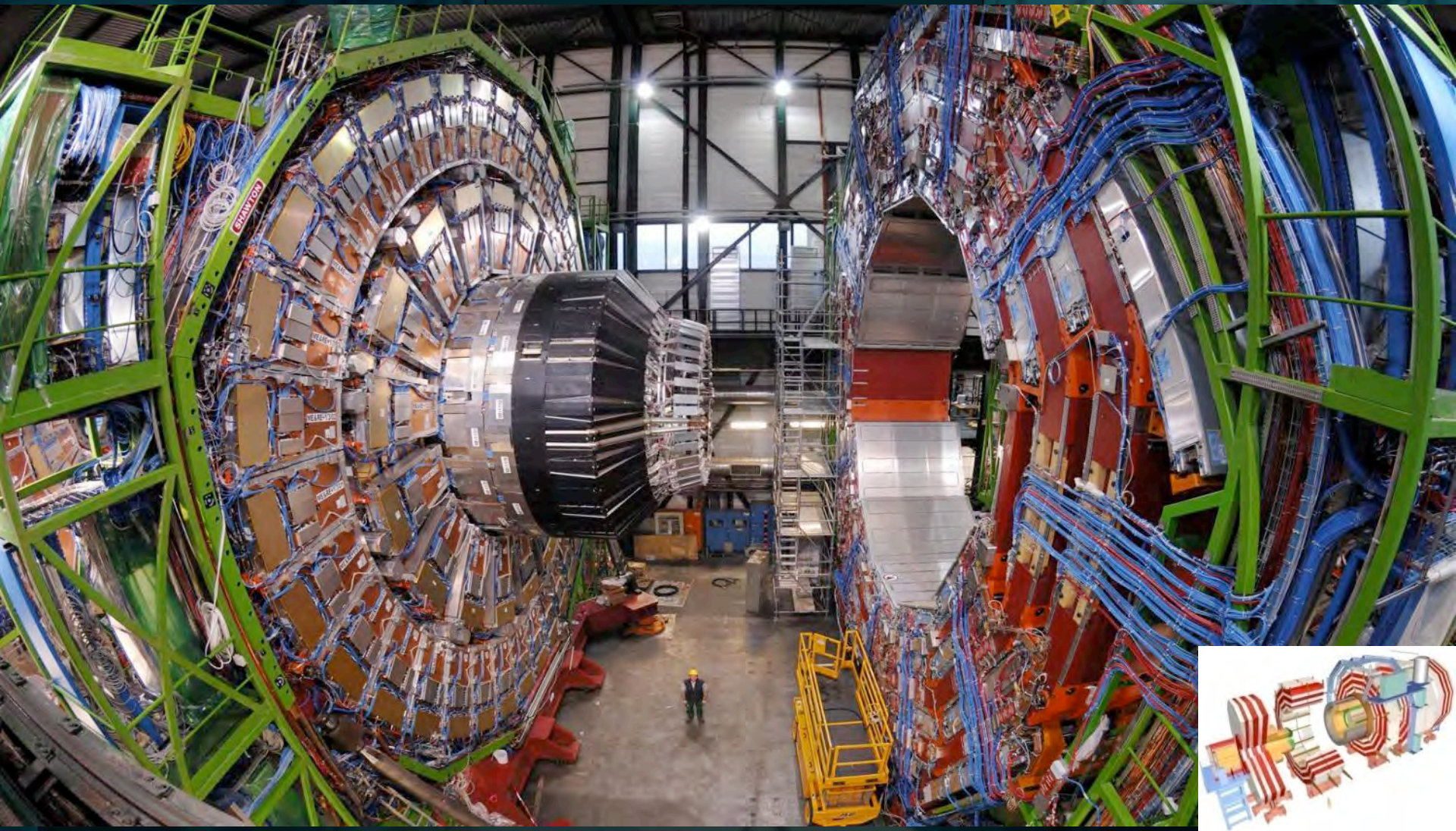
CMS - COMPACT MUON SPECTROMETER



Nearing completion underground

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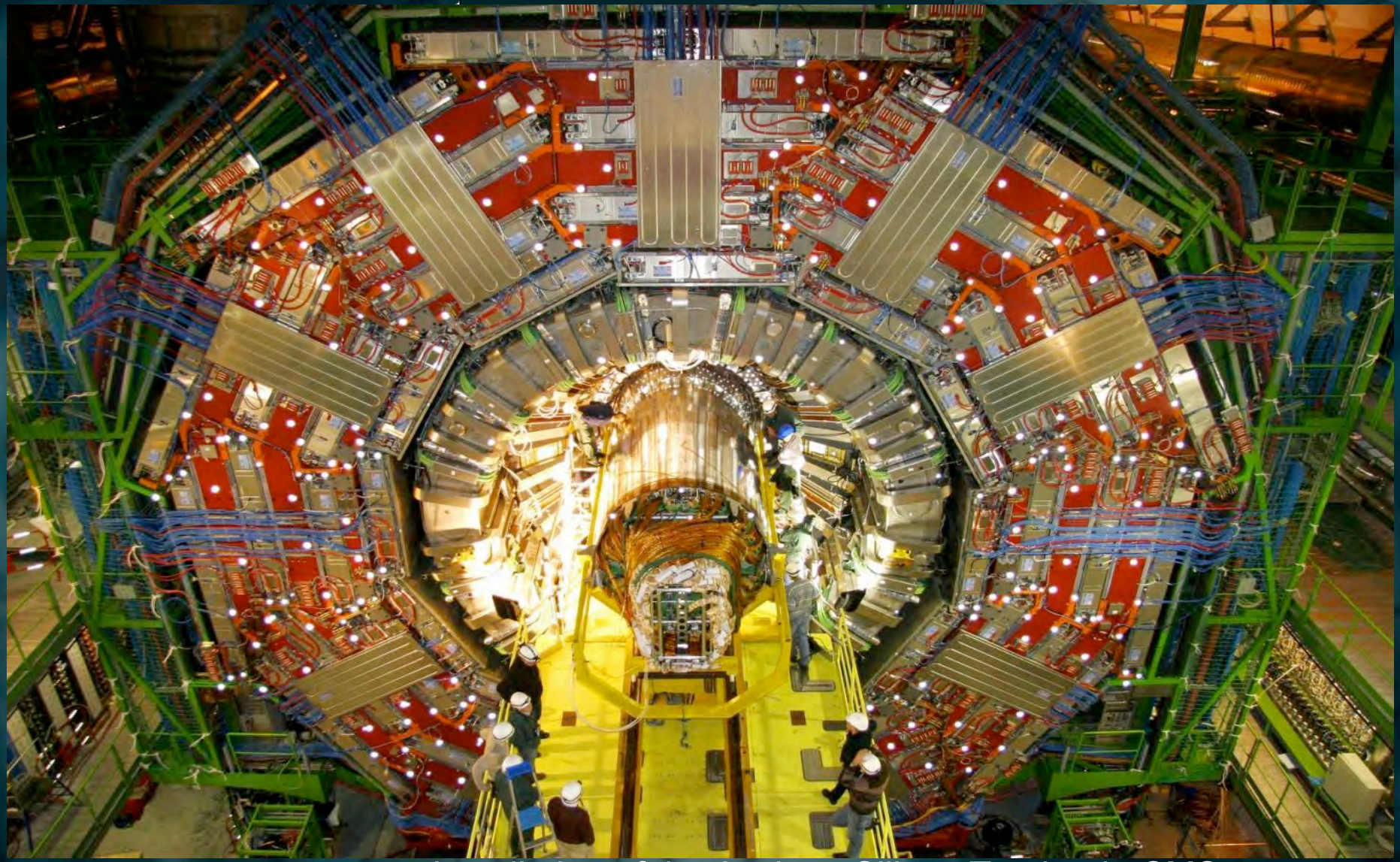
COMPACT MUON SOLENOID



Installation of the 6m long Silicon Tracker in CMS

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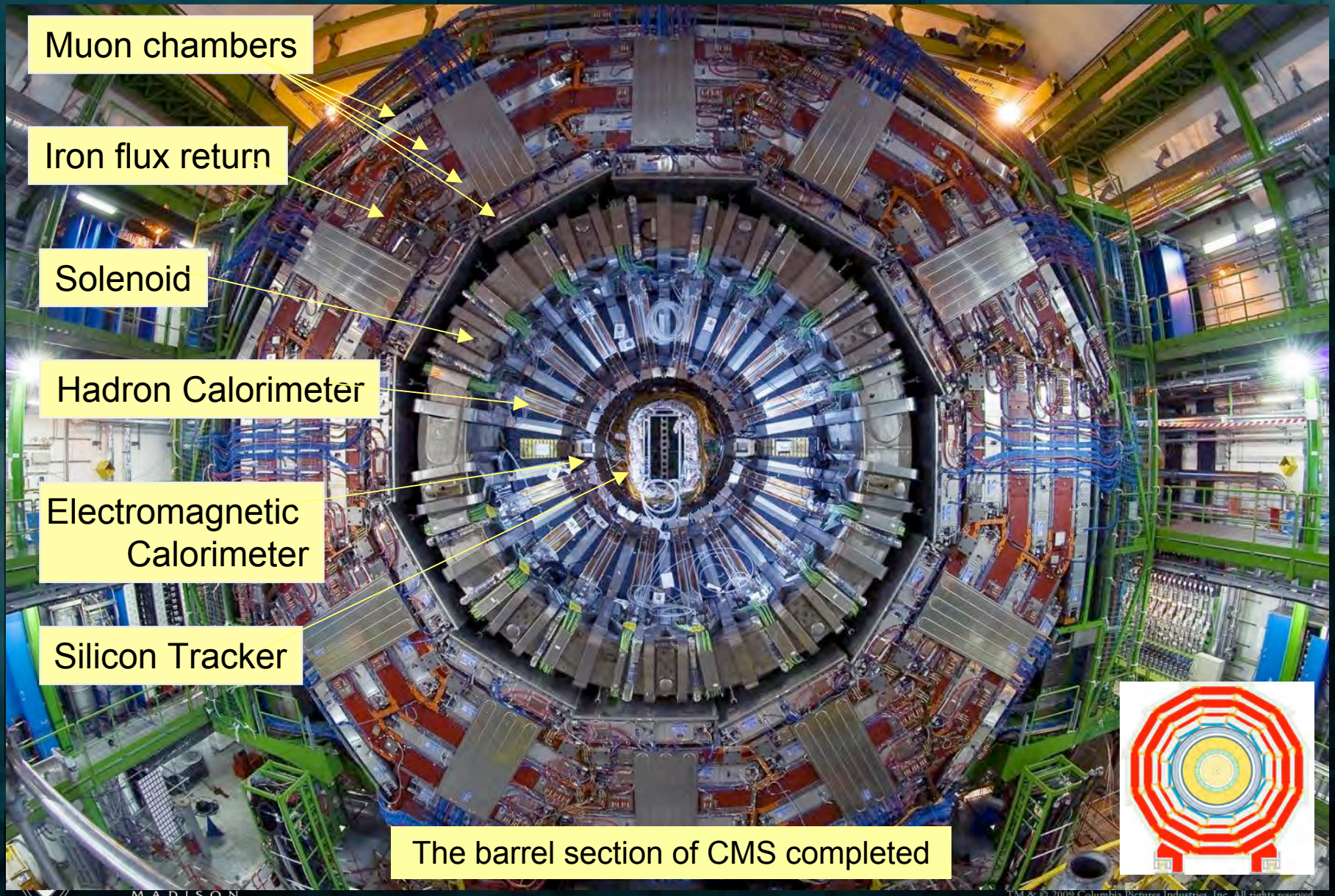
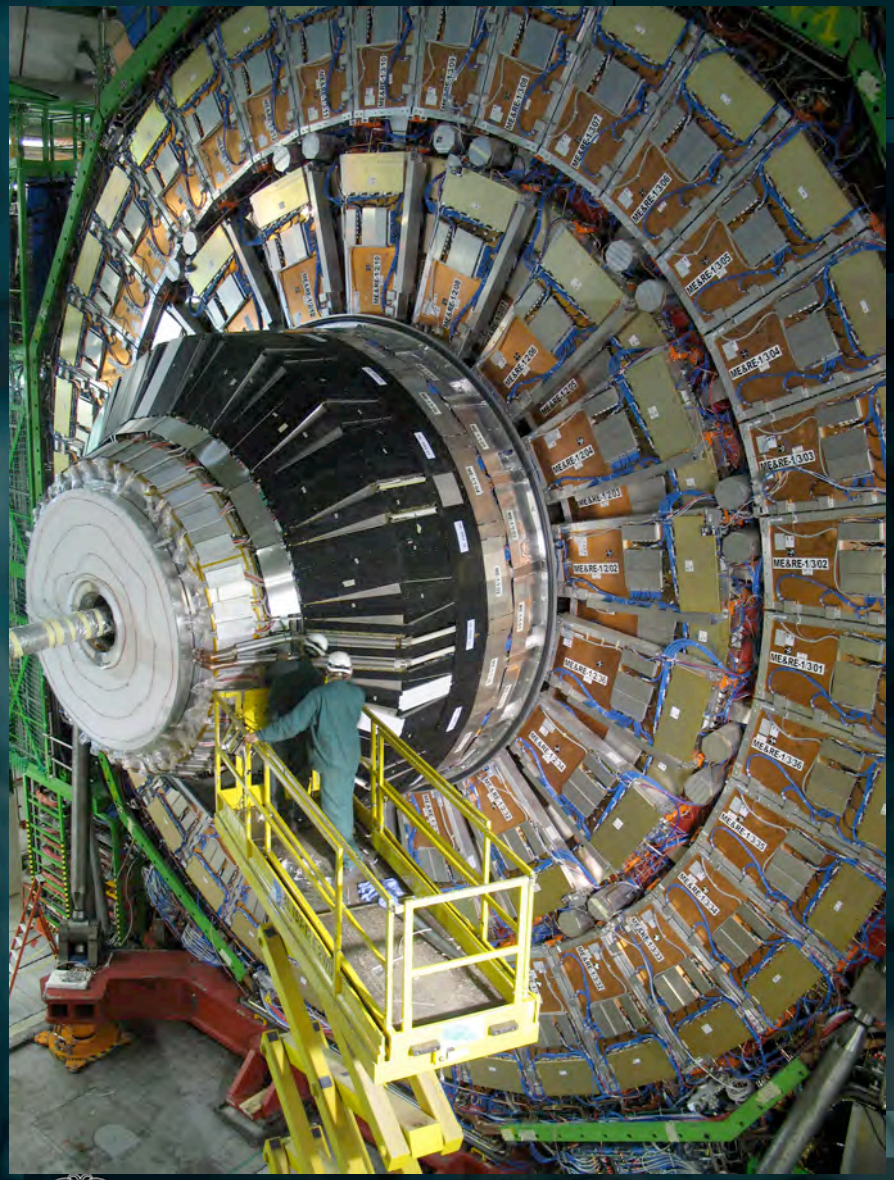
COMPACT MUON SOLENOID



CMS MINUS END & CLOSURE



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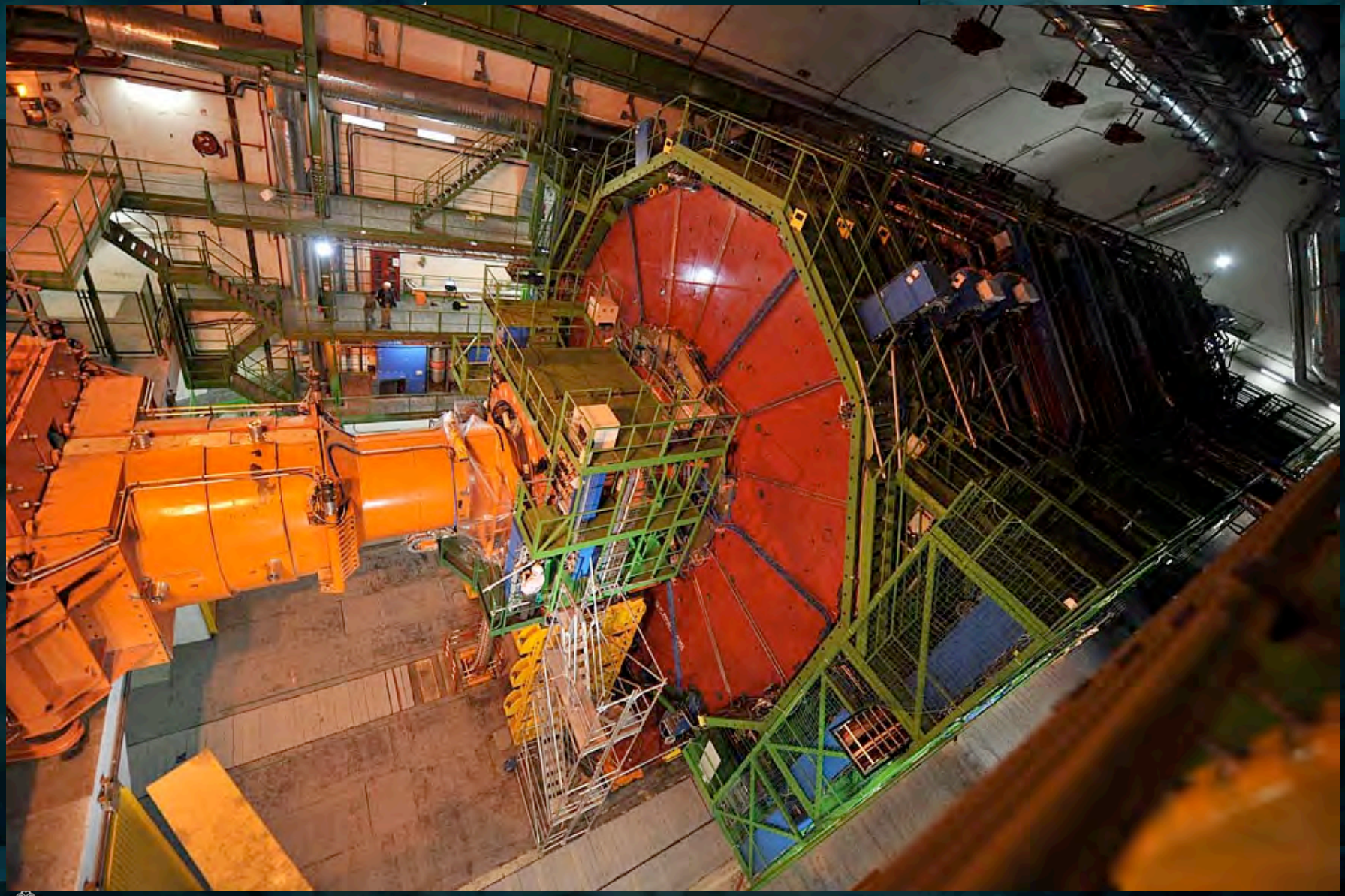
FINAL CLOSURE



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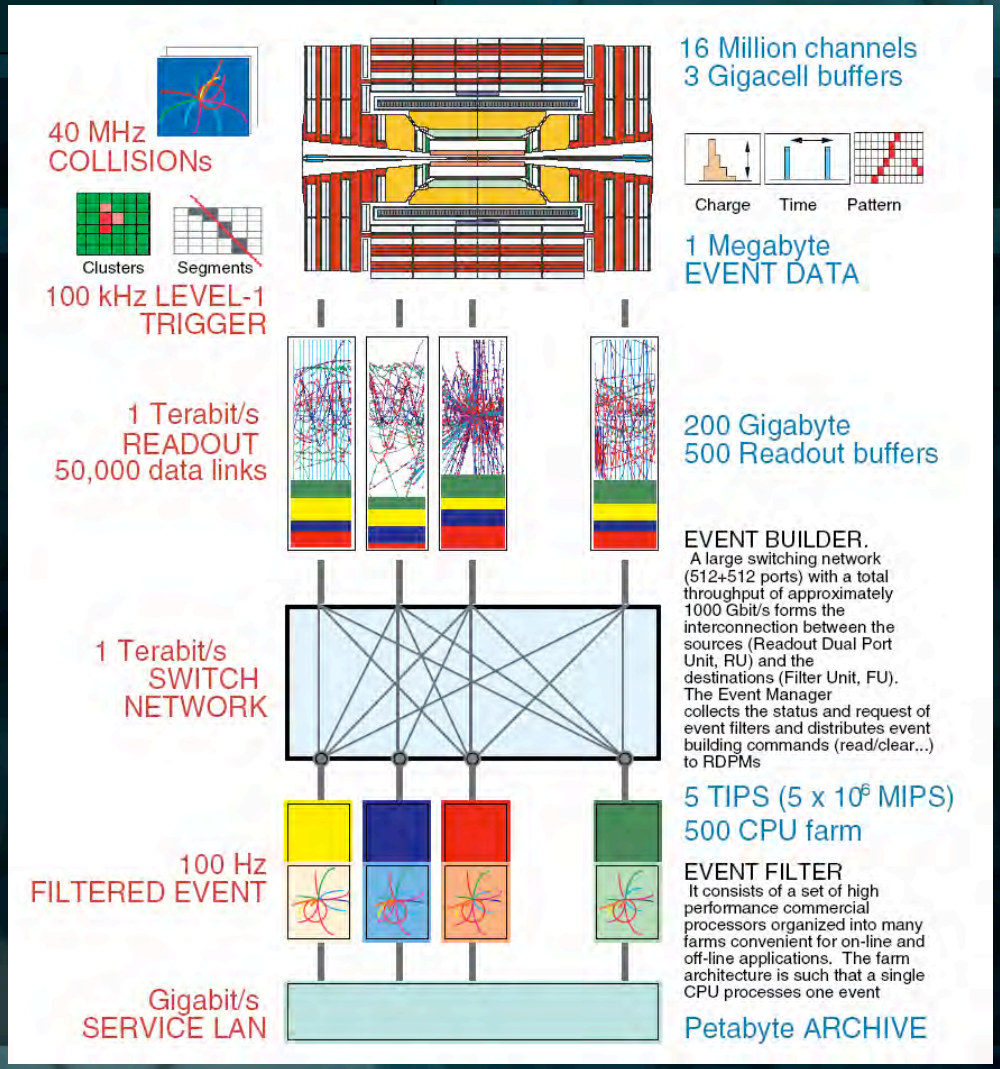
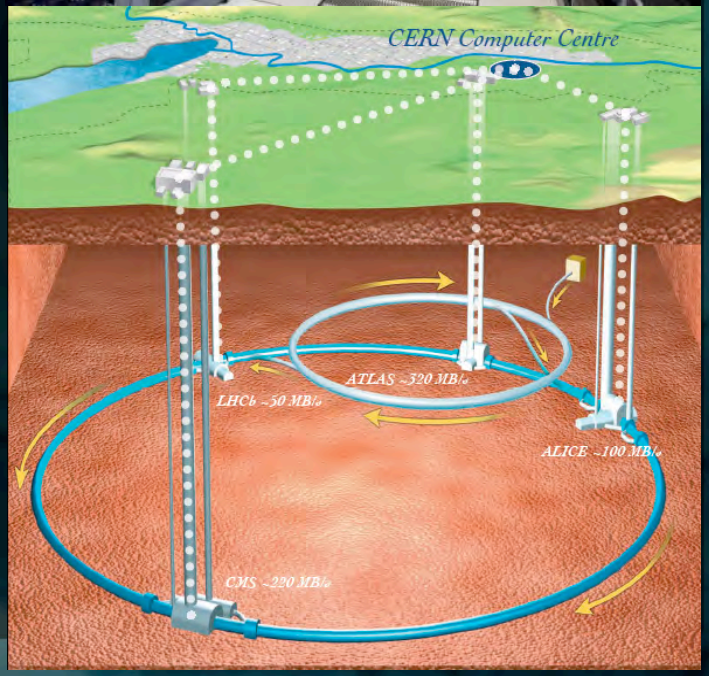
STORING DATA FROM COLLISIONS

- During one second of CMS running, a data volume equivalent to 10,000 Encyclopaedia Britannicas is recorded
- The data rate handled by the CMS event builder (~500 Gbit/s) is equivalent to the amount of data currently exchanged by the world's Telecom networks
- The total number of processors in the CMS event filter equals the 4000 workstations at CERN today



STORING DATA FROM COLLISIONS

- All 4 experiments at the LHC send their data continuously to the CERN computer centre for storage and processing
- The data are shipped from the experimental underground caverns to computers on the surface
- From the surface, the data are sent overland by high speed links to the CERN computer center



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The LHC will spit out the equivalent of 15 million CDs of data EACH YEAR = 15 million Gigabytes = 15 Petabytes

Equals a pile of CDs 15 km high 1.5 times the height of Mount Everest

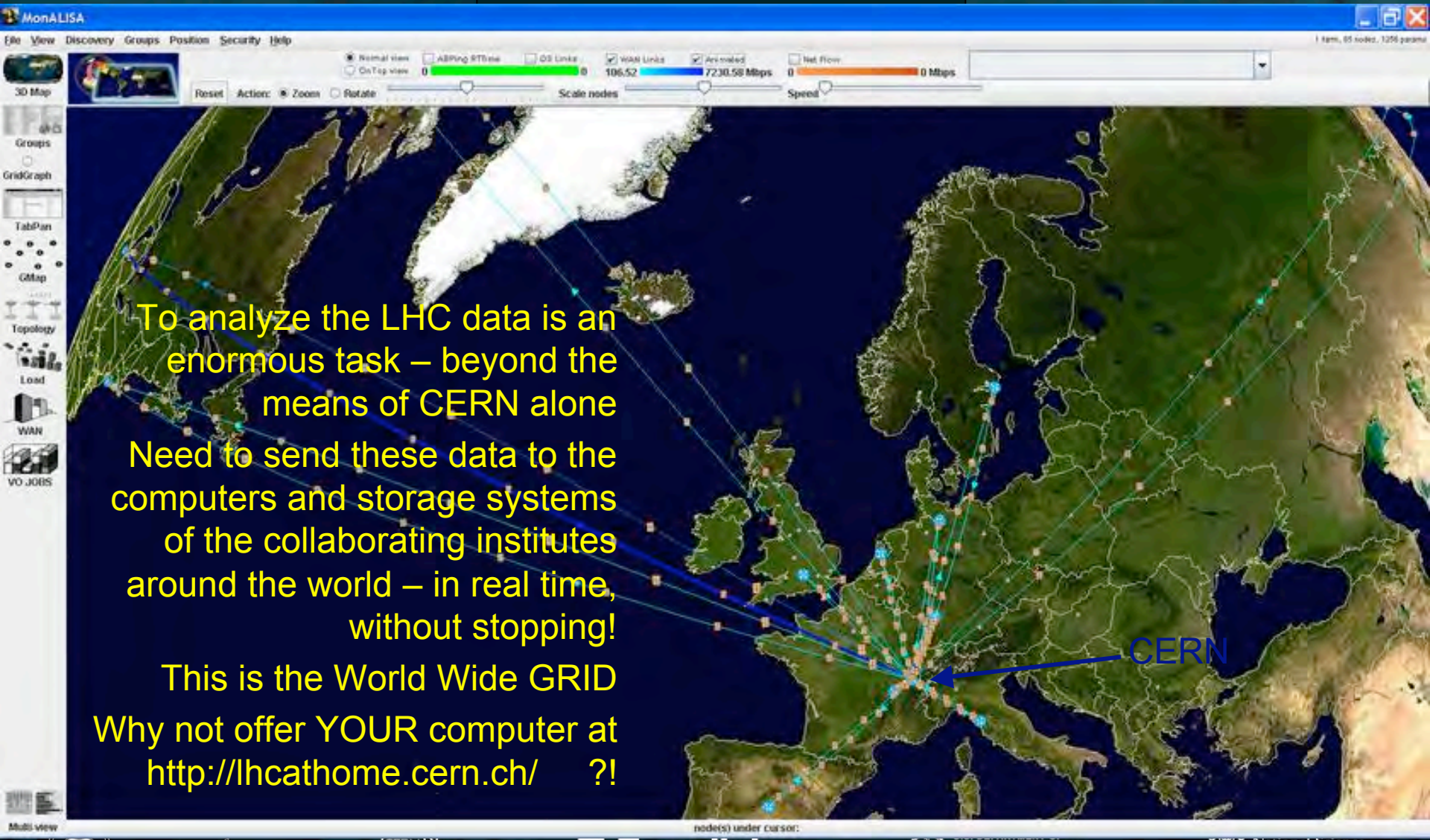
If these were DVDs it would take you 40 million years to watch all the movies

And you would probably need to buy a new DVD player on the way!

Mount Everest
~10 km high

MADISON

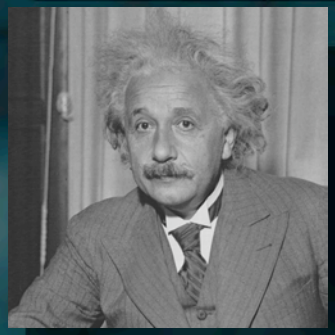
ANALYZING DATA FROM COLLISIONS



RESEARCH & SOCIETY

Fundamental research has always been a driving force for innovation

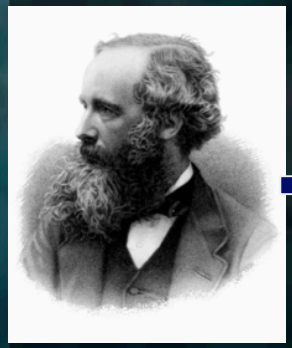
A. Einstein



Relativity

100% SCIENCE

For GPS to work, we have to take into account the correction due to time dilation. Otherwise, there would be a position error of around 10m after just 5 minutes of travel-time!



J.C. Maxwell

Electromagnetism

100% SCIENCE

Telephones use electromagnetic waves to communicate

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MEDICAL TREATMENT

Accelerators: developed in physics labs are used in hospitals

Hadron Therapy

Around 9000 of the 17000 accelerators operating in the World today are used for medicine.

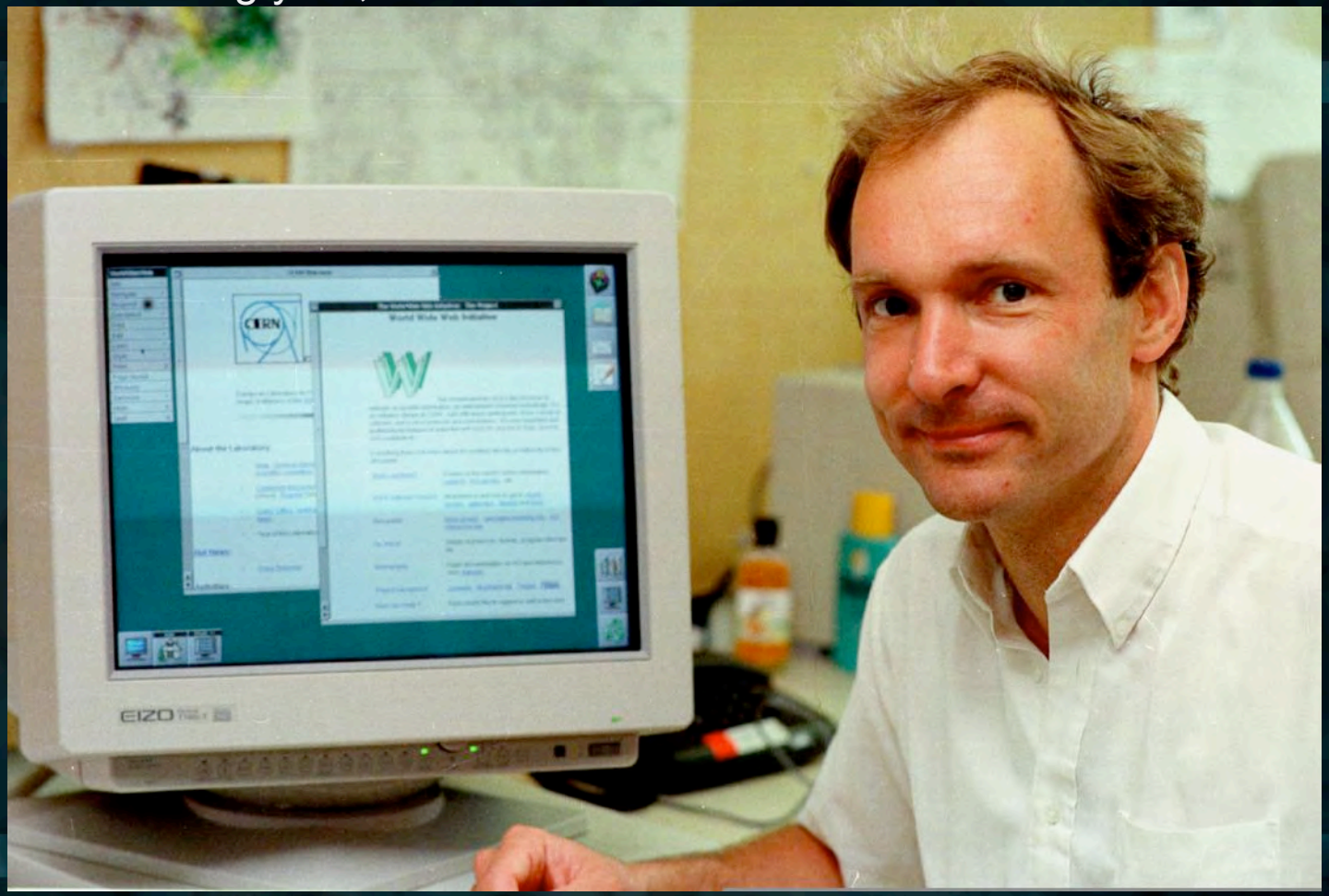
MEDICAL DIAGNOSTICS

Detectors: developed in physics labs are used for medical imagery

PET (Positron Emission Tomography) is a very important technique for localising and studying certain types of cancer using the Fluor-18 isotope produced by particle accelerators. PET uses antimatter (positrons).

OTHER BENEFITS…WWW !

- Twenty years ago an event at CERN changed the world forever: Tim Berners-Lee handed a document to his supervisor Mike Sendall entitled "Information Management : a Proposal". "Vague, but exciting" is how Mike described it, and he approved it to go forward. The following year, the World Wide Web was born.



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IMPACT OF SCIENTIFIC RESEARCH

- "No one can predict what new applications will be born of basic research: new treatments in our hospitals; new sources of efficient energy; new building materials; new kinds of crops more resistant to heat and drought.
- It was basic research in the photoelectric effect that would one day lead to solar panels. It was basic research in physics that would eventually produce the CAT scan. The calculations of today's GPS satellites are based on the equations that Einstein put to paper more than a century ago...."

-- President Barack Obama,
Speech to National Academy of Sciences, April 27, 2009

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CONCLUSIONS

- The LHC is the world's largest and most complex scientific instrument ever.
- First collisions expected this Fall
- It promises to open up hitherto unreachable areas of particle physics
- Just as Albert Einstein revolutionized physics 100 years ago, in 1908, could we be at the threshold of a new revolution in our understanding of the Universe with the LHC?

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THANK YOU

For more information

www.uslhc.us

www.fnal.gov

www.cern.ch

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ADDITIONAL MATERIAL

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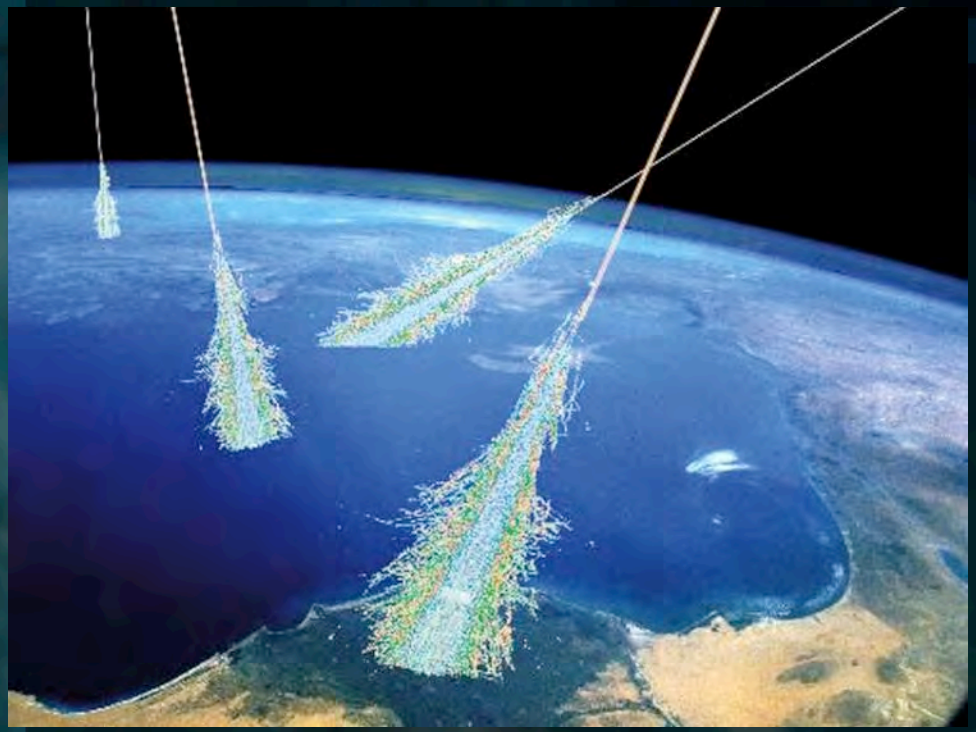
IS THIS DANGEROUS?

Cosmic Rays



The LHC collides particles with 14 TeV in the center of mass frame which corresponds to 10^{17} eV collision with a fixed target.

Cosmic rays from outer space routinely bombard the earth and its atmosphere with up to 10^{20} eV.

3×10^{22} cosmic rays with energies above 10^{17} eV are estimated to have collided with the earth since its formation.

The LHC running over 10 years have been repeated billions of times in the sun already!

WHAT ABOUT BLACK HOLES?

Some speculative theories predict the formation of microscopic black holes at the LHC.

The microscopic black holes that *might* be created at LHC are so small they evaporate instantly according to Steven Hawking & other theorists

No time to accrete matter.

But what if Hawking's wrong?

Cosmic rays reach much higher energies than the LHC and have been having collisions for billions of years – any black holes created have not done much damage.

Black holes don't suck everything in.

– Only stuff inside the Schwarzschild radius.

– The Schwarzschild radius of a 1 TeV black hole is about 10^{-18} m

– that's about 1/1000th of the size of a proton.

– There's nothing around such a black hole for it to suck in!

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