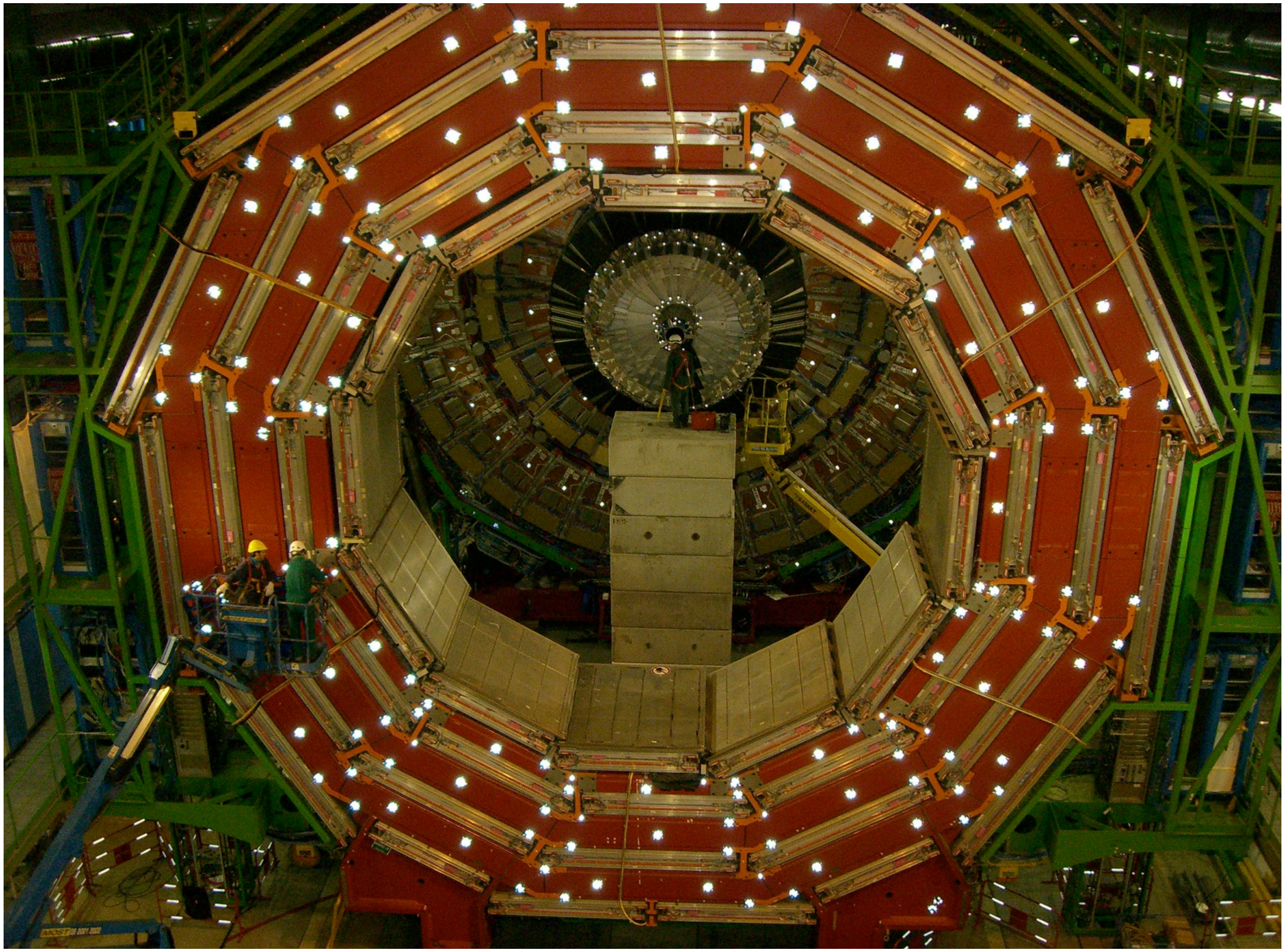
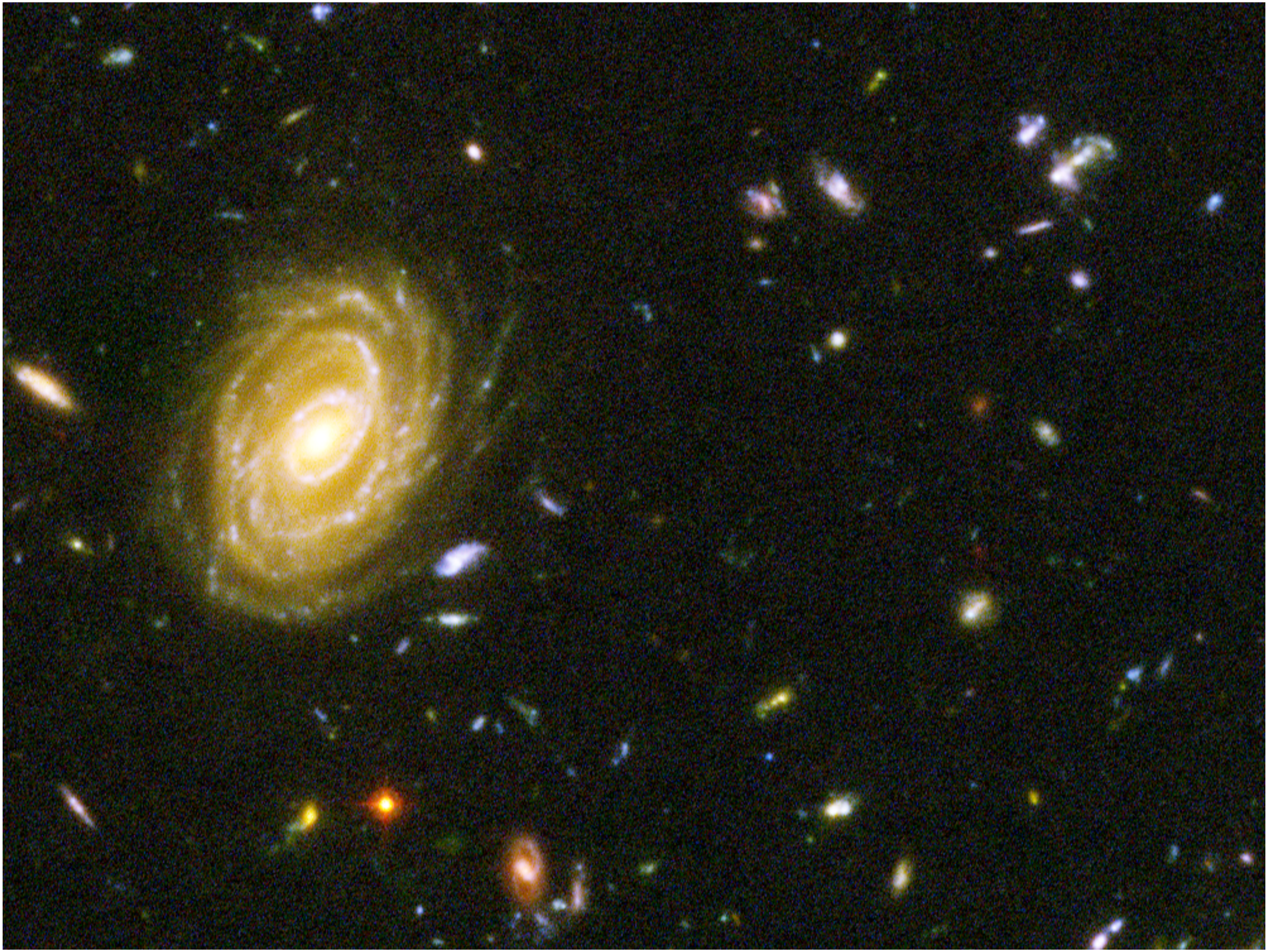


The Detector at the Large Hadron Collider

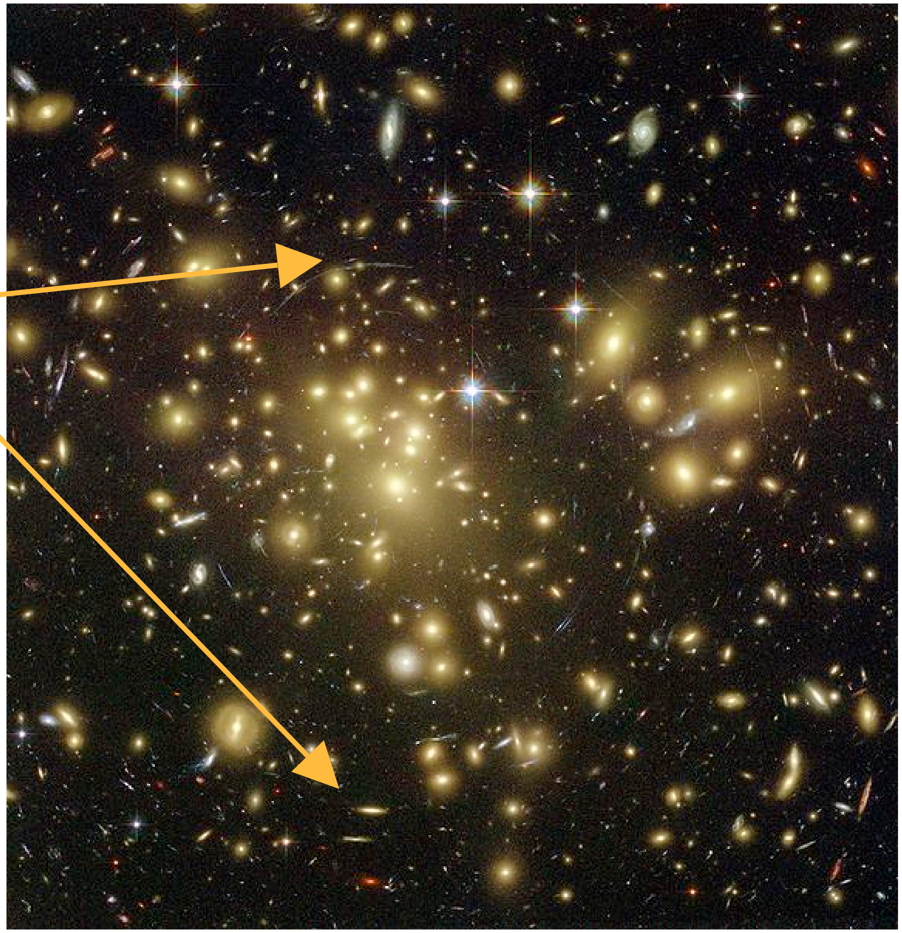
Ritchie Patterson

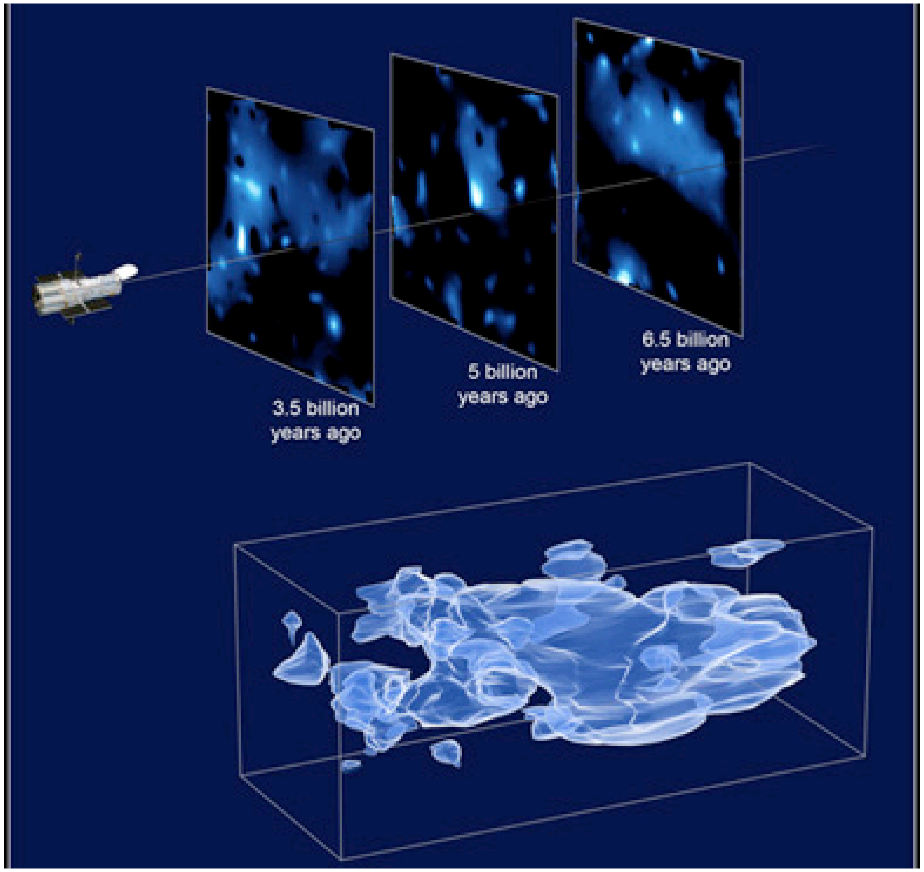
CIPT
July 13, 2009



Dark Matter

Dark matter seems to cause the lensing arcs in this Hubble image



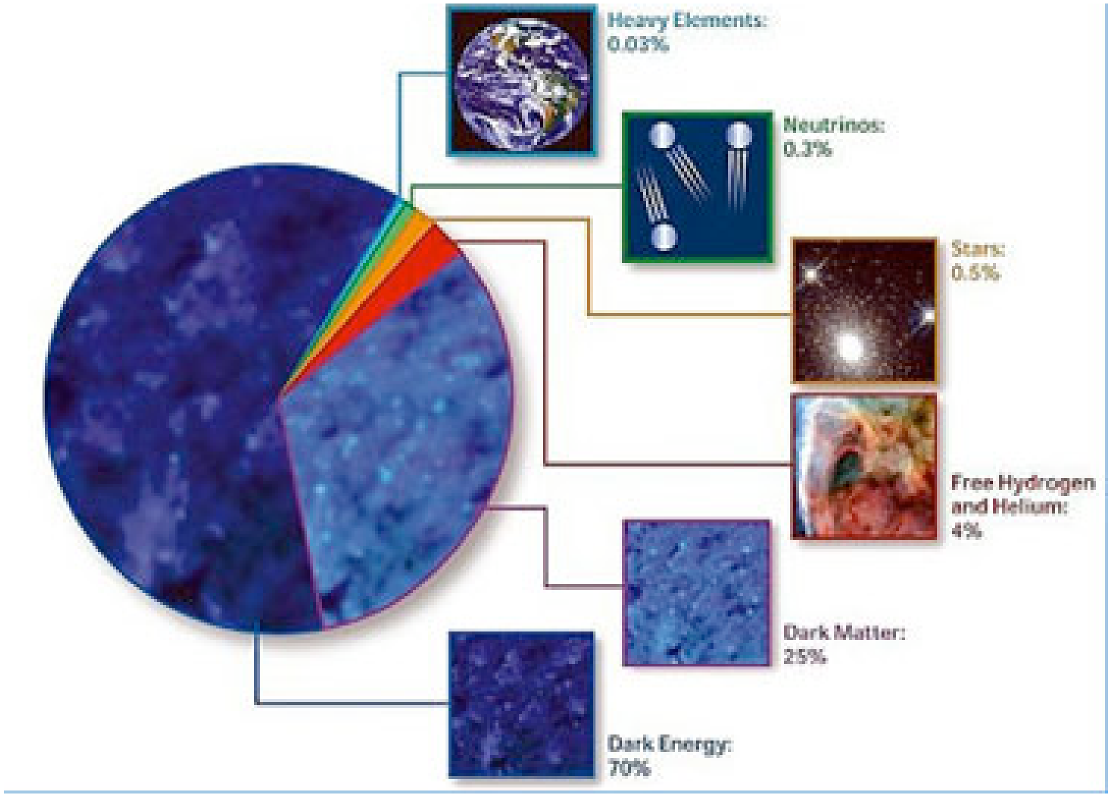


Massey et al (Caltech) used arcs like these to create a map of the dark matter in a section of the sky. (2007)

What we know about Dark Matter

Not much.

- It exerts gravitational force -- ie, has mass
- It is widely distributed, but not uniformly (this rules out very light particles such as neutrinos).
- It rarely interacts with the particles we know -- the quarks, electrons, neutrinos, etc. (that's why we can't see it.)



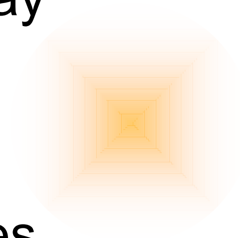
It's not any of the particles we know.

- 13.7 billion years ago there was a giant explosion
- 10^{-20} seconds later, the universe was a hot soup of particles
- No planets, no stars, not even atoms
- Instead, particles and radiation in *thermal equilibrium*

Thermal equilibrium?

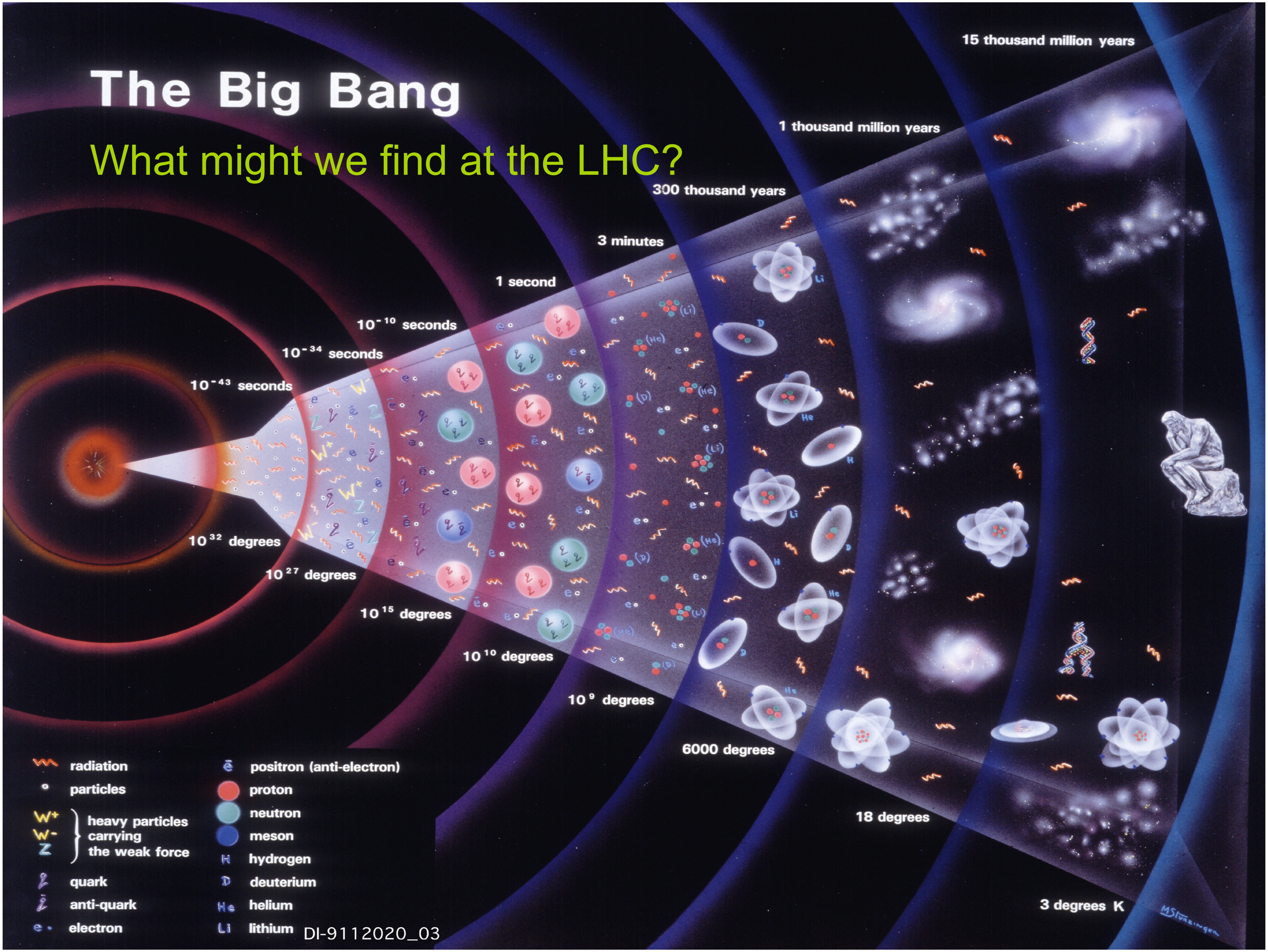
- We know $E = mc^2$
- Equivalence of energy and mass
- Turn energy (radiation) into matter and back again
- Particle $\rightarrow$ radiation $\rightarrow$ particle
- In balance

- Then the universe cooled
- Radiation no longer had enough energy to produce heavy particles and most decayed away
- Atomic nuclei formed



- Then stars and galaxies
- And planets
- And you and me

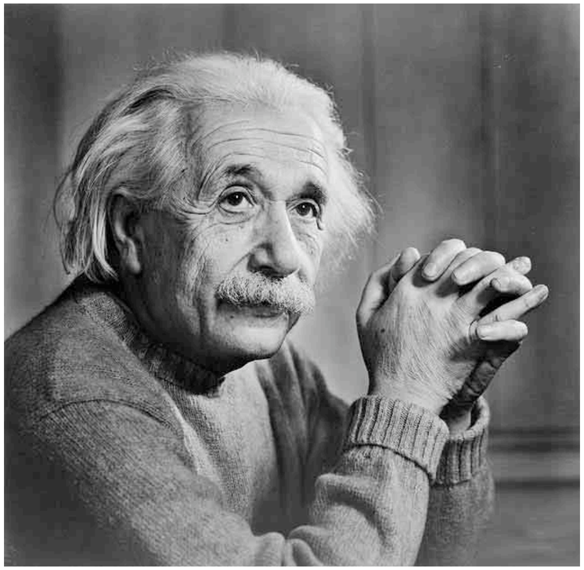
- Some heavy particles may have remained as dark matter
- The others disappeared, as *E* became too small to create mc^2.
- These may be recreated only when enough energy is available
- In nature
- Or at the Large Hadron Collider


The Big Bang
What might we find at the LHC?
15 thousand million years
1 thousand million years
300 thousand years
3 minutes
1 second
10^{-10} seconds
10^{-34} seconds
10^{-43} seconds
10^{32} degrees
10^{27} degrees
10^{15} degrees
10^{10} degrees
10^{9} degrees
6000 degrees
18 degrees
3 degrees K
radiation
particles
W^{+}
W^{-}
Z
heavy particles carrying the weak force
quark
anti-quark
electron
positron (anti-electron)
proton
neutron
meson
hydrogen
deuterium
helium
lithium
DI-9112020_03

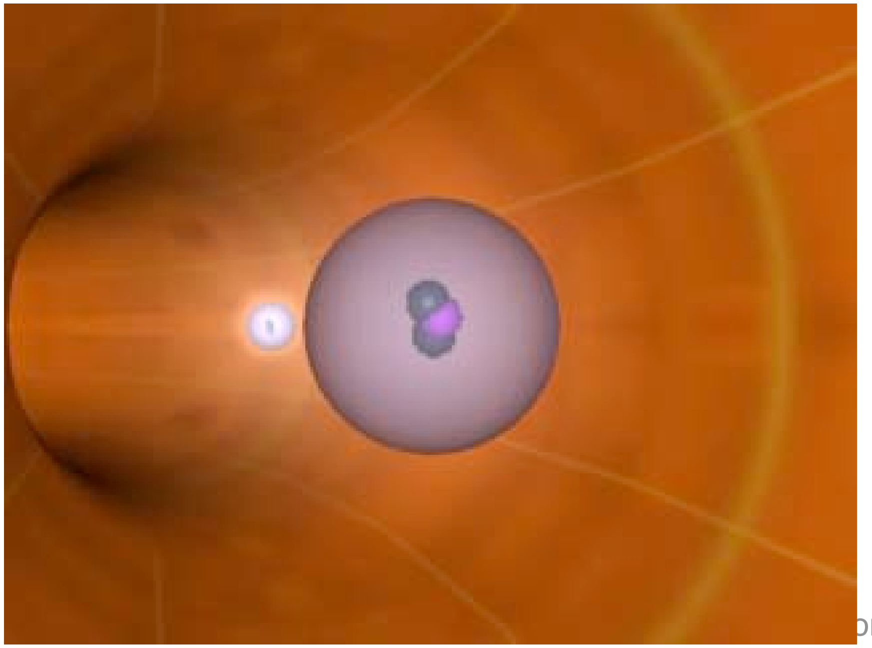
The Driving Questions

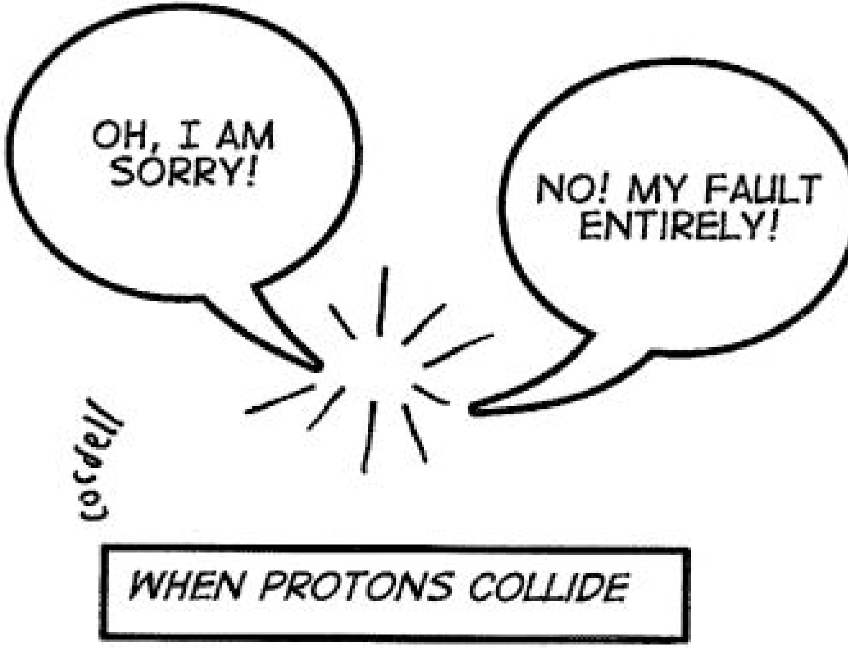
- What is the dark matter?
- Where did the antimatter go?
- Why do particles have mass?
  - What is the Higgs particle?
- What keeps the Higgs mass in check?
- What is dark energy?

How does it work?



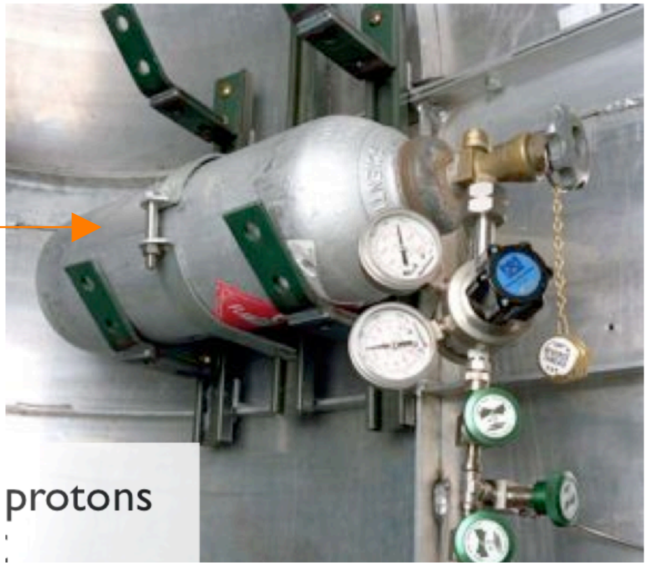
- $E = mc^2$ again
- Accelerate particles to near the speed of light and smash them together. Their kinetic energy and mass energy combine to create heavy particles.
- At the LHC, protons are accelerated and the quarks inside them collide. The total energy is E = 14 TeV.

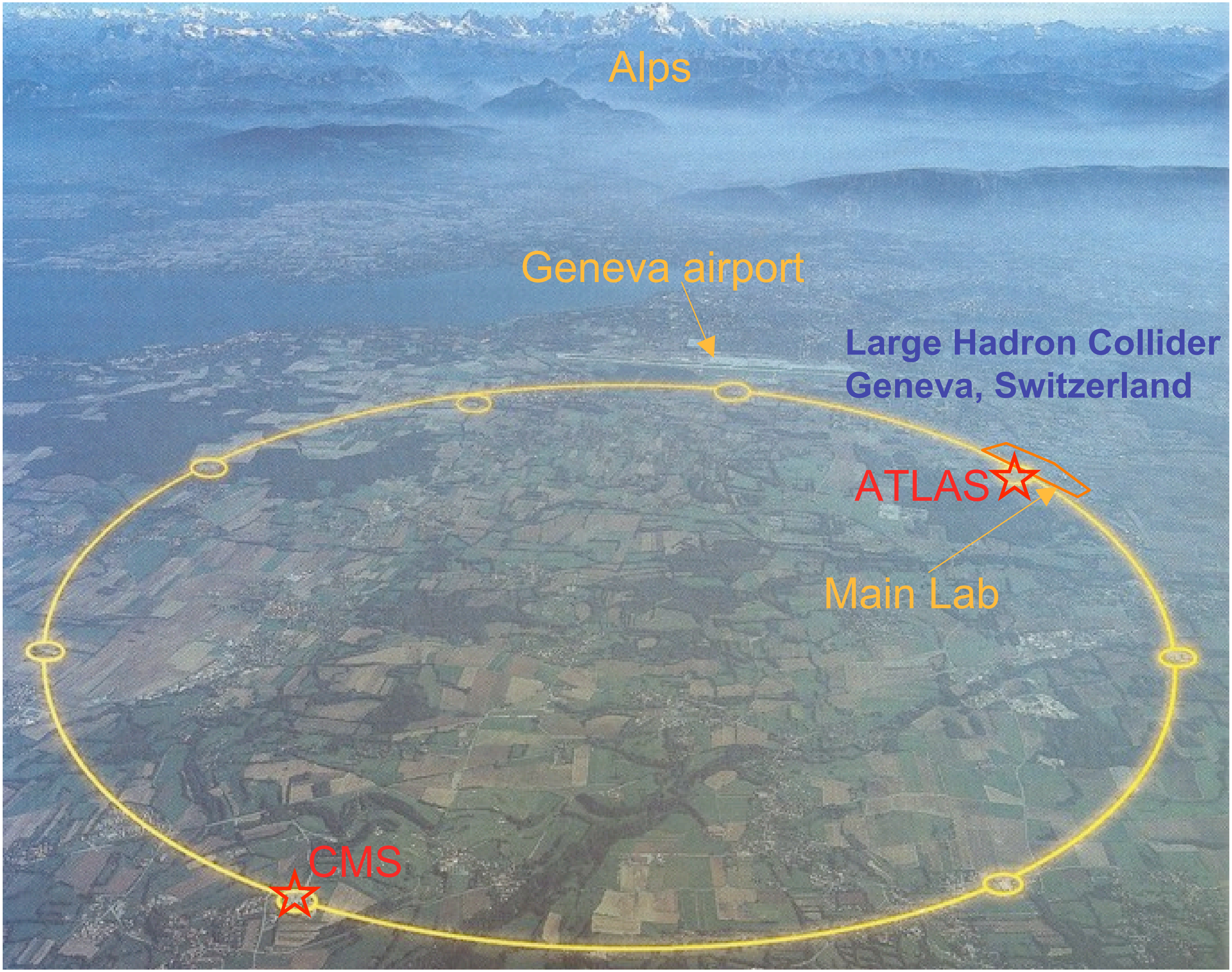


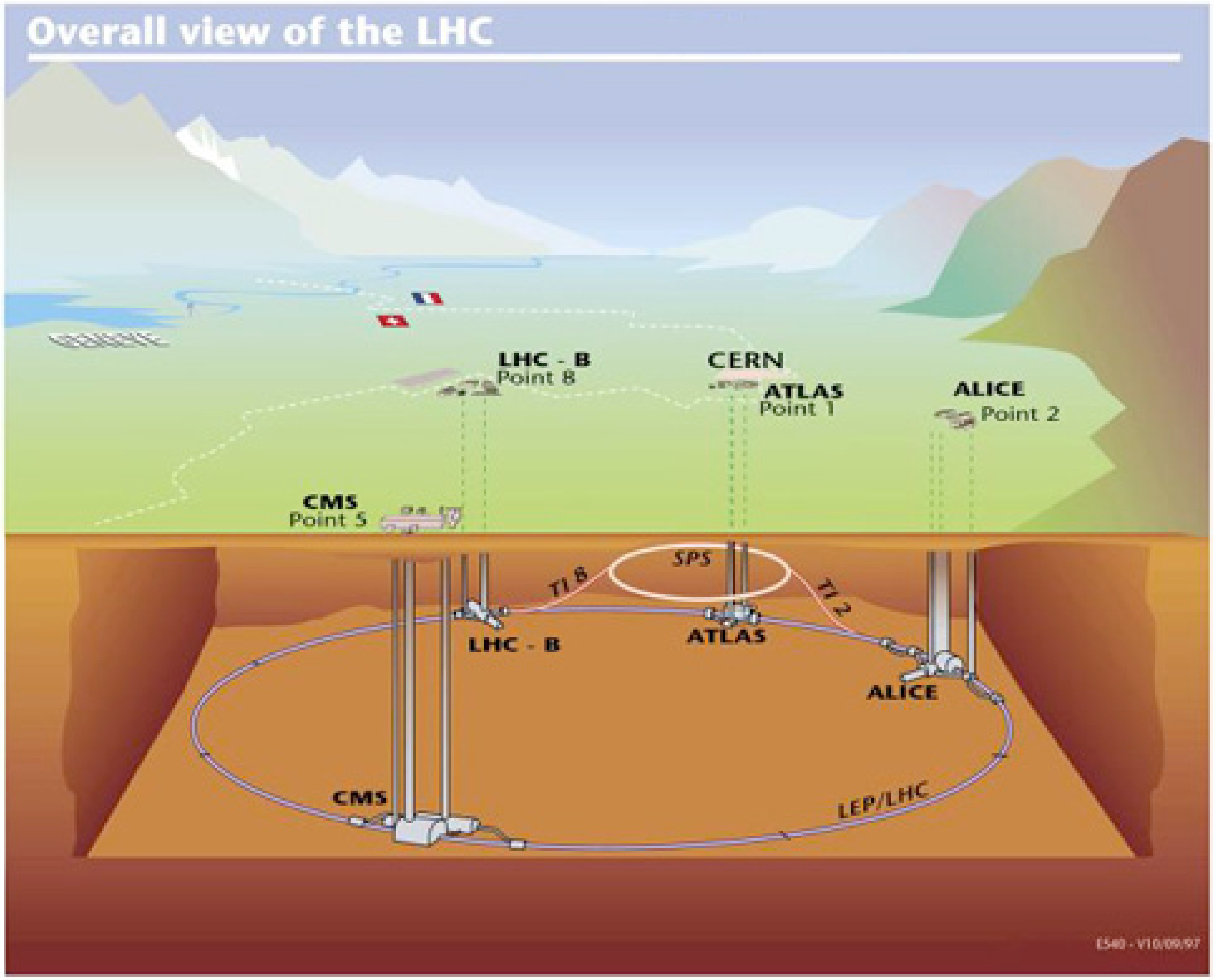


What do you need?

- Lots of protons to smash together
  - Proton source
- Mechanism for accelerating them
  - Protons at the LHC travel at 99.99% of the speed of light
  - Racetrack
- Detector to observe, and disentangle the collision products

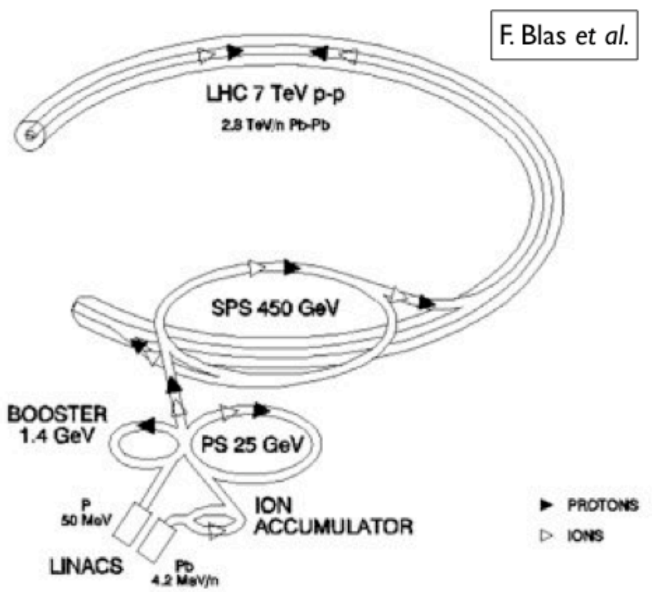


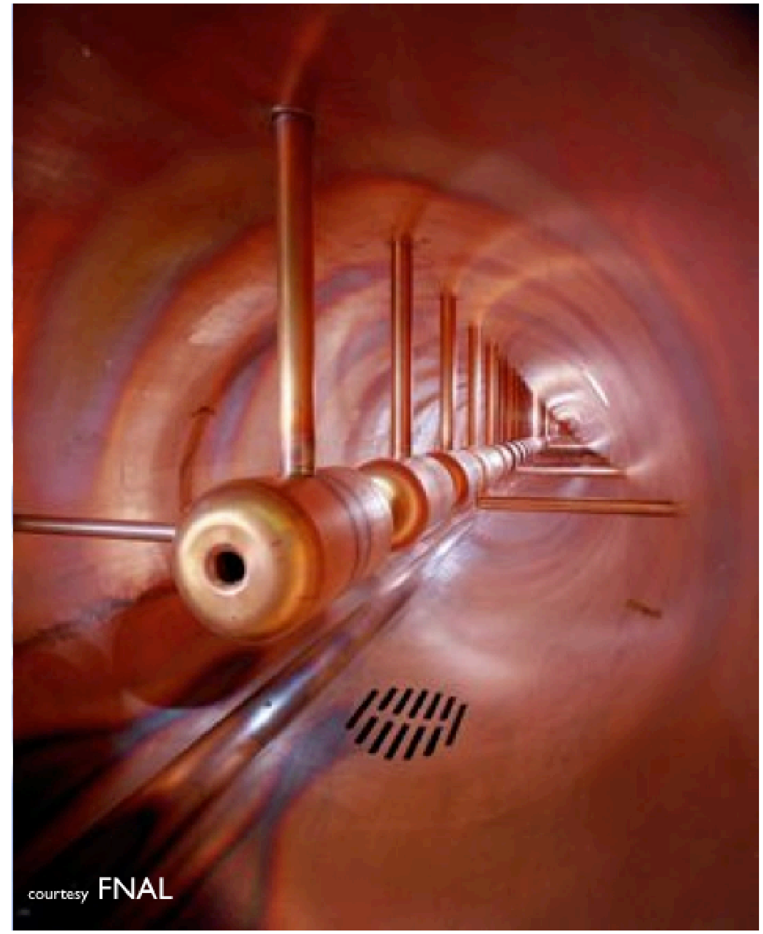

Alps
Geneva airport
Large Hadron Collider
Geneva, Switzerland
ATLAS
Main Lab
CMS


Overall view of the LHC
LHC - B
Point 8
CERN
ATLAS
Point 1
ALICE
Point 2
CMS
Point 5
SPS
TI 8
TI 2
LHC - B
ATLAS
ALICE
CMS
LEP/LHC

Parts of the Racetrack

Electric and magnetic fields accelerate and steer the beams





- Beams are in 2808 bunches, each with 1.15 x 10^{11} protons
- Total energy in each beam is 360 MJ (equivalent to 60 kg TNT)

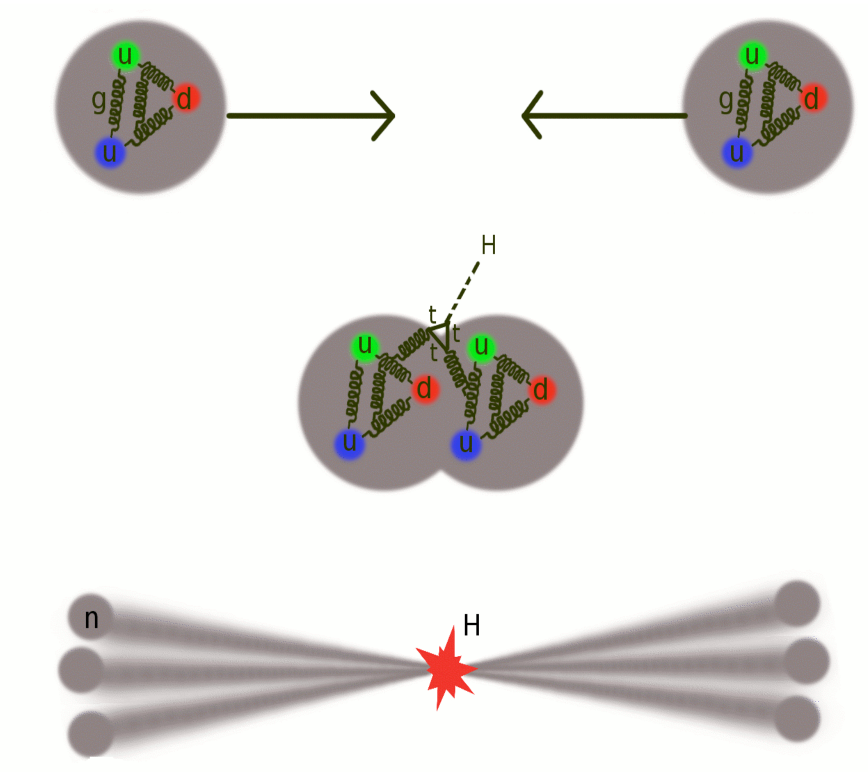
LHC Steering Magnet

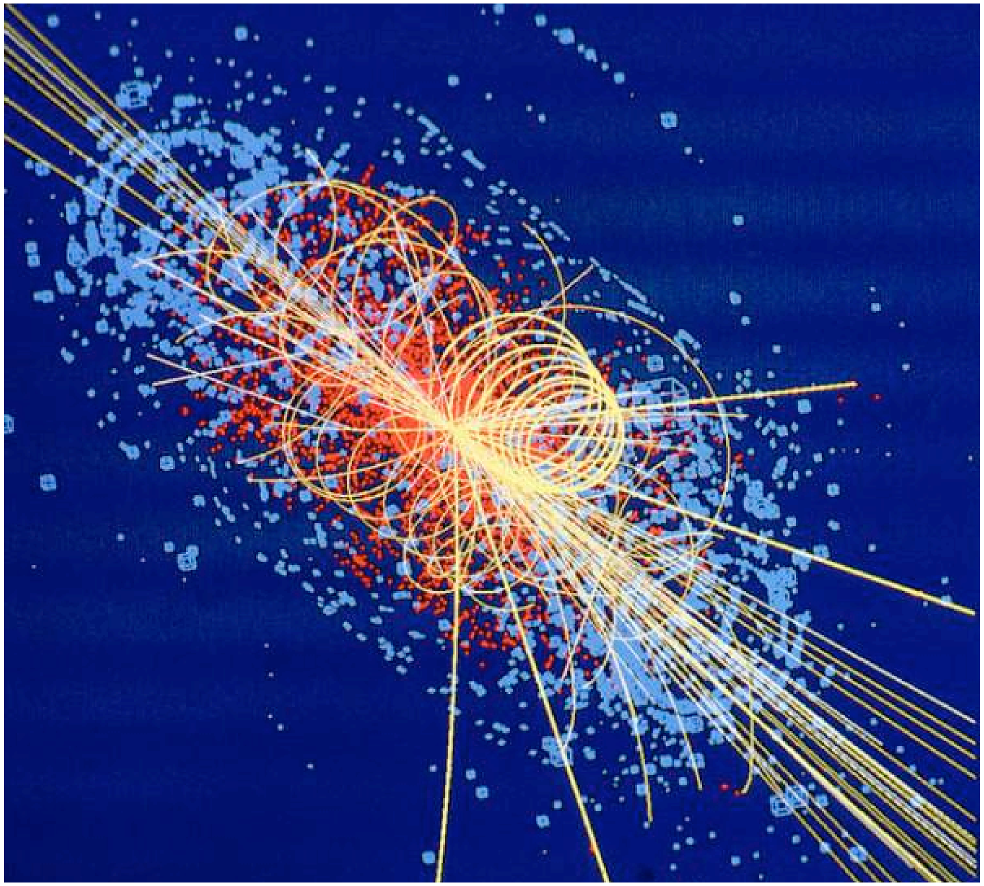
The last one being lowered into place

The magnets

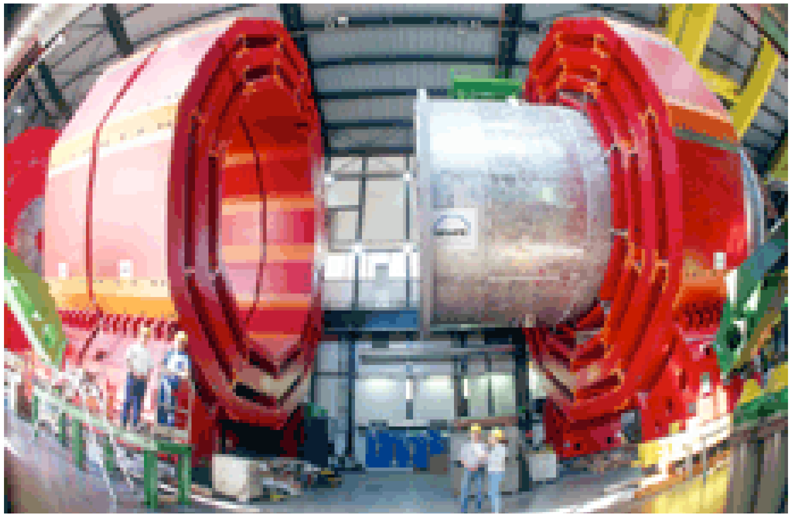
- Steer the protons around the 17 mile circular track
- Are superconducting with a field of 8.3 Tesla
- Use 96 tons of superfluid helium

Proton-proton collision

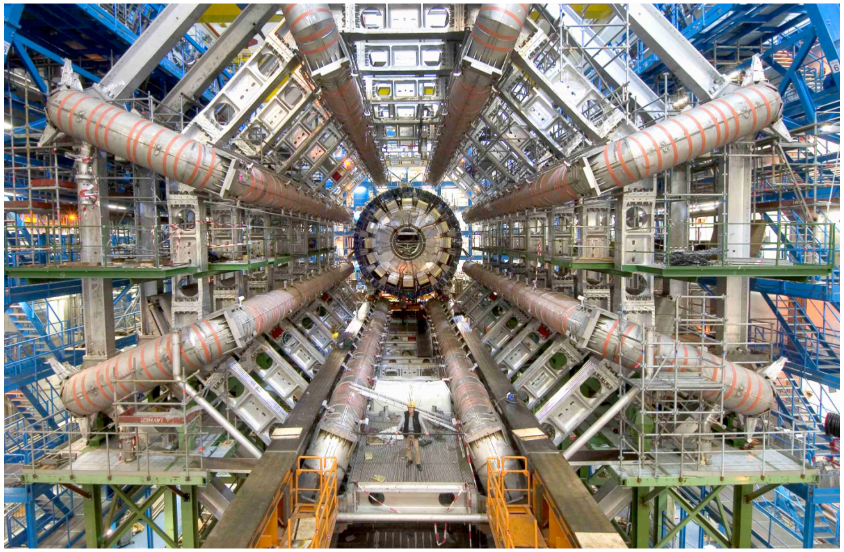




Particle detectors



- Heavy particles produced in the collisions typically decay within 10^{-24} seconds into particles we know and love: e, mu, pi, K
- The detector records traces of these well-known and well-understood particles.

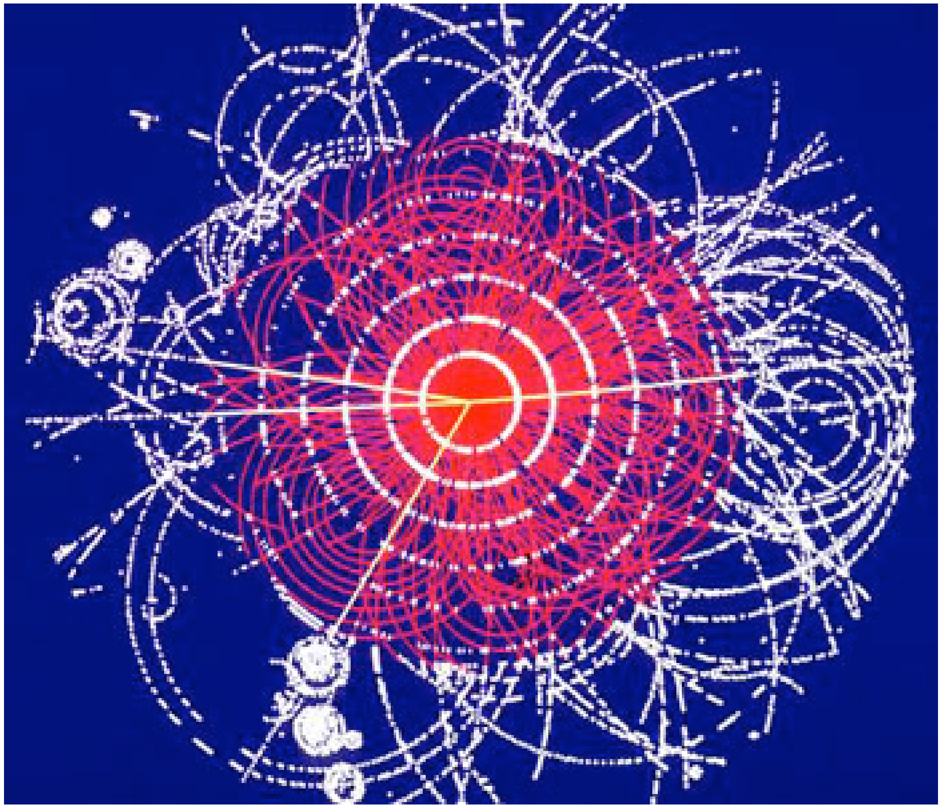


What do we want from our detector?

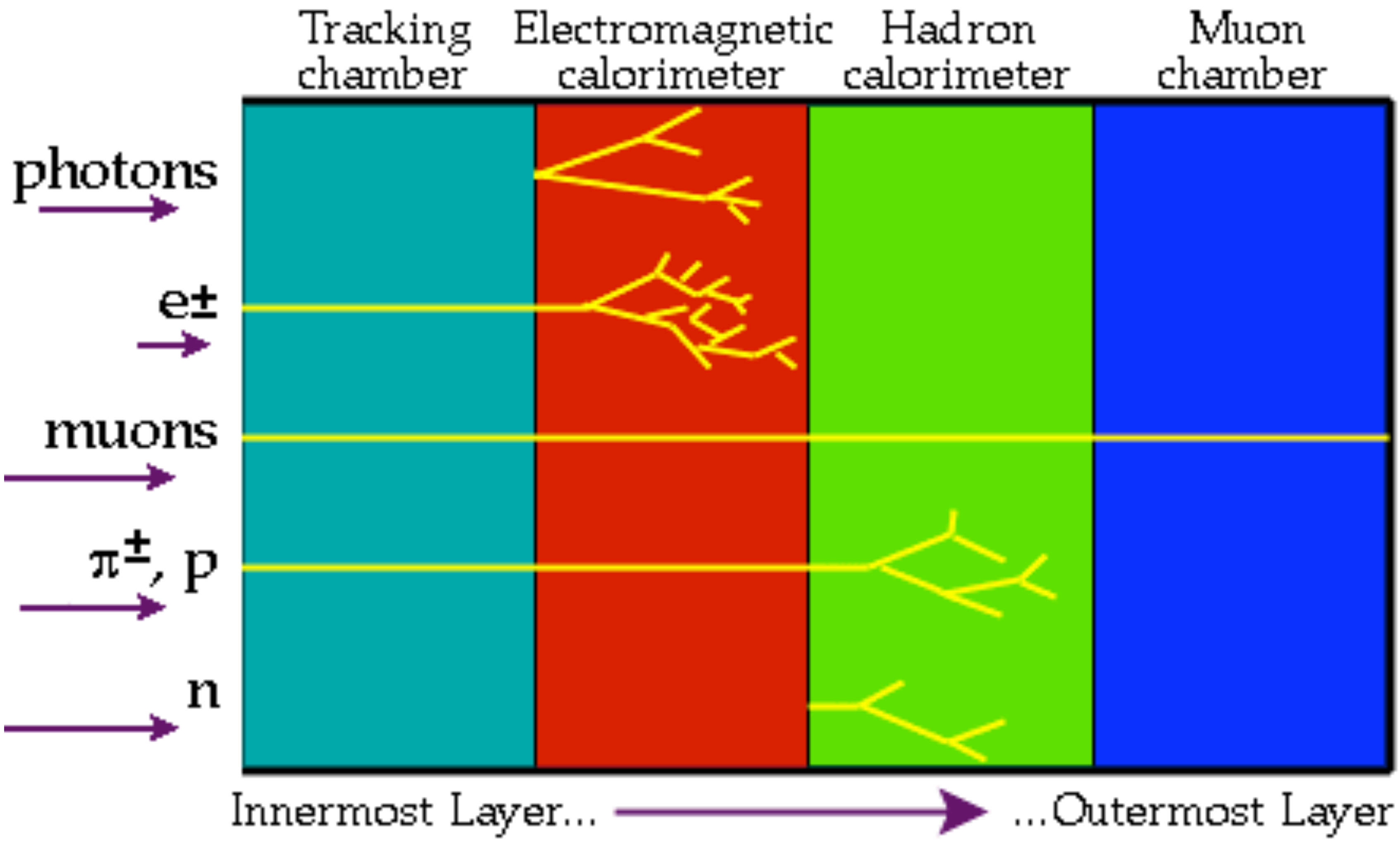
Imagine that a bomb explodes mid-air, and you want to study the fragments to find out everything you can about the bomb.

What properties of the fragments would you want to measure?

- Direction of motion of each fragment just after explosion
- Speed (or momentum) of each fragment
- Mass of each fragment

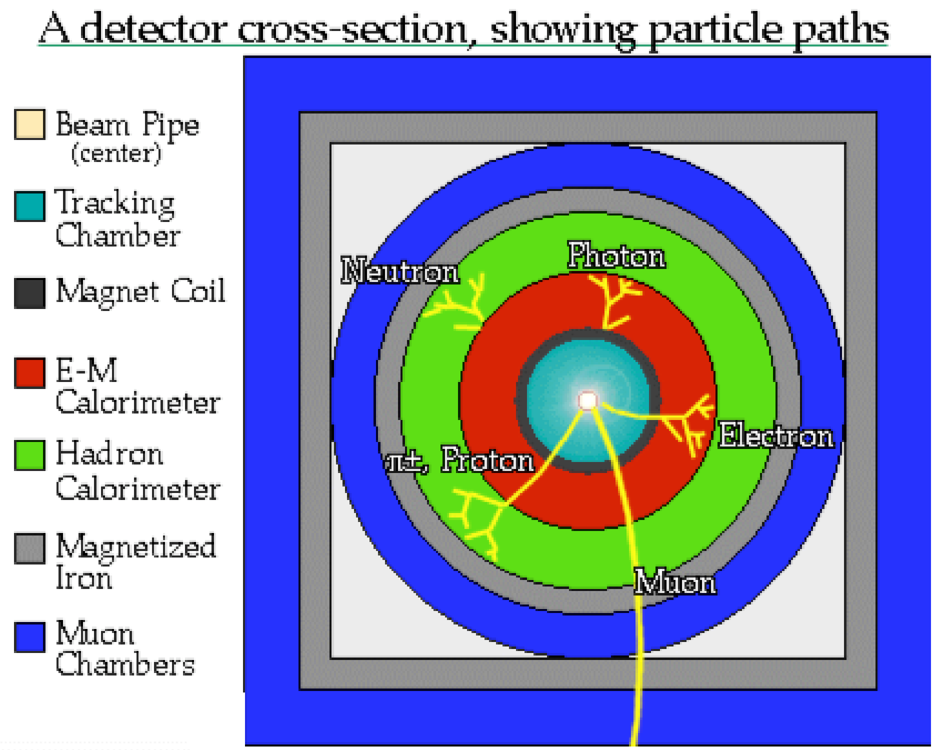


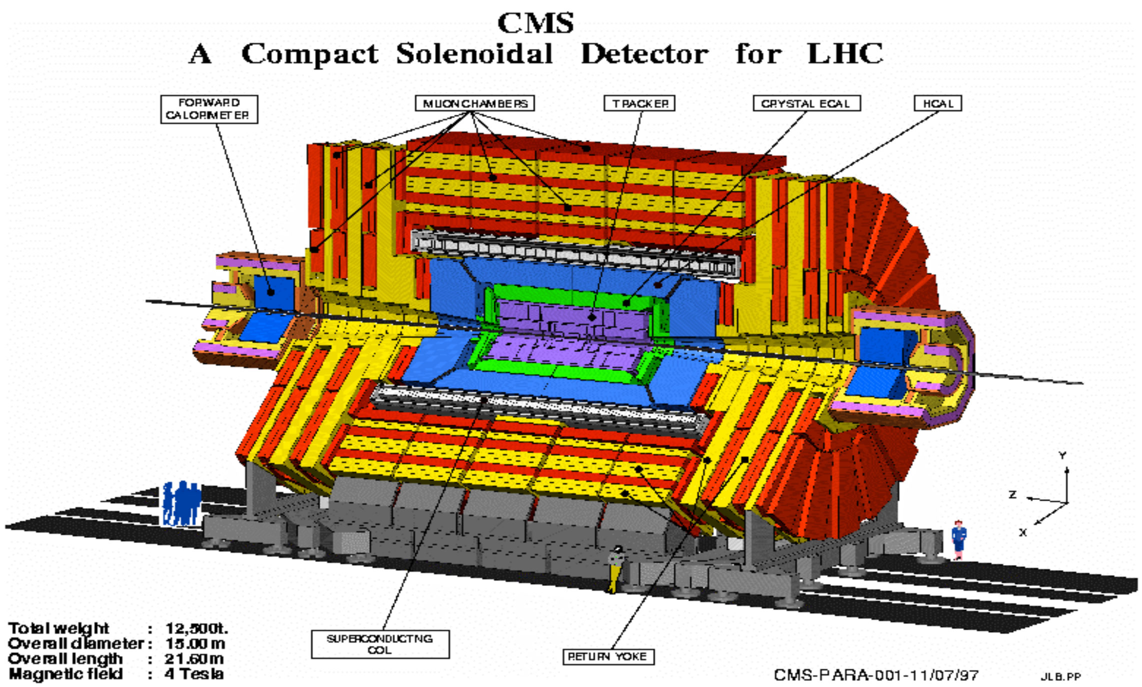
Each particle species leaves a distinct trail



CMS Detector at the LHC

- CMS stands for “Compact Muon Solenoid”
- Weighs 12,500 tons
- Six stories tall

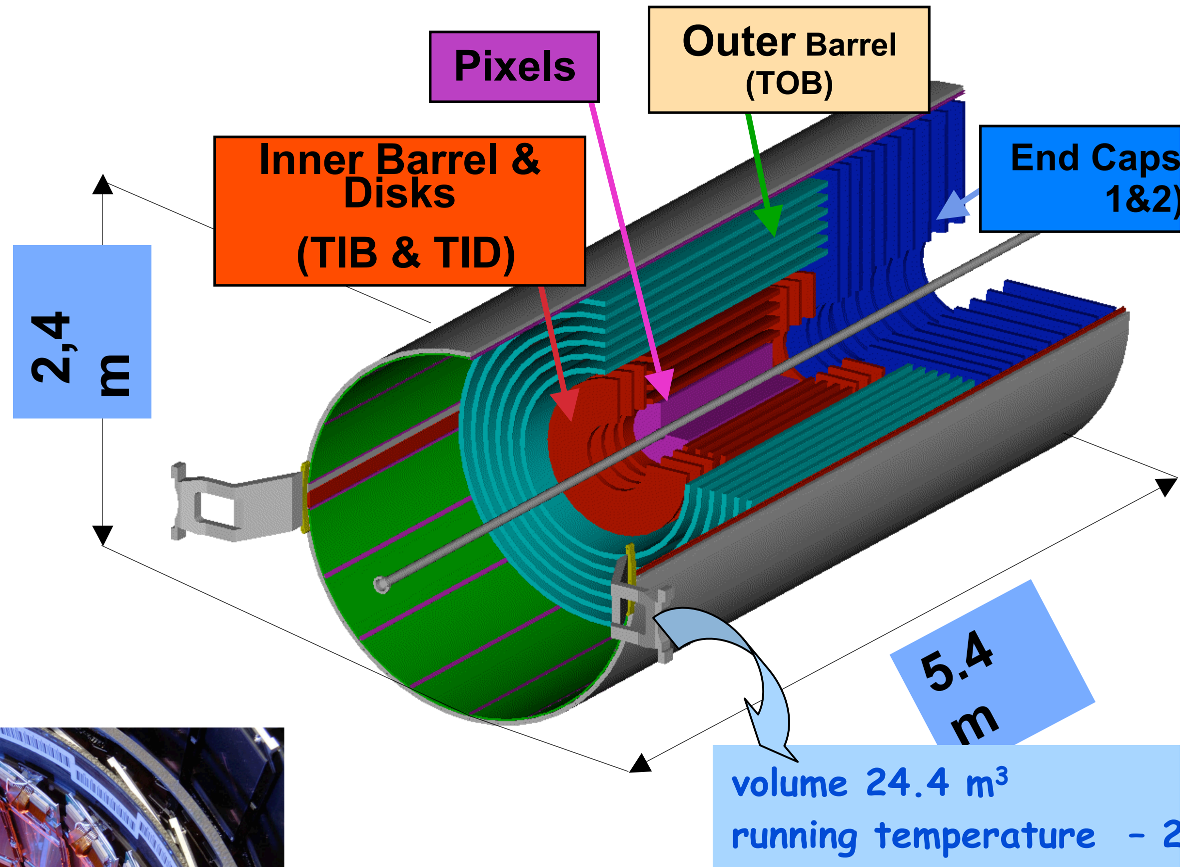


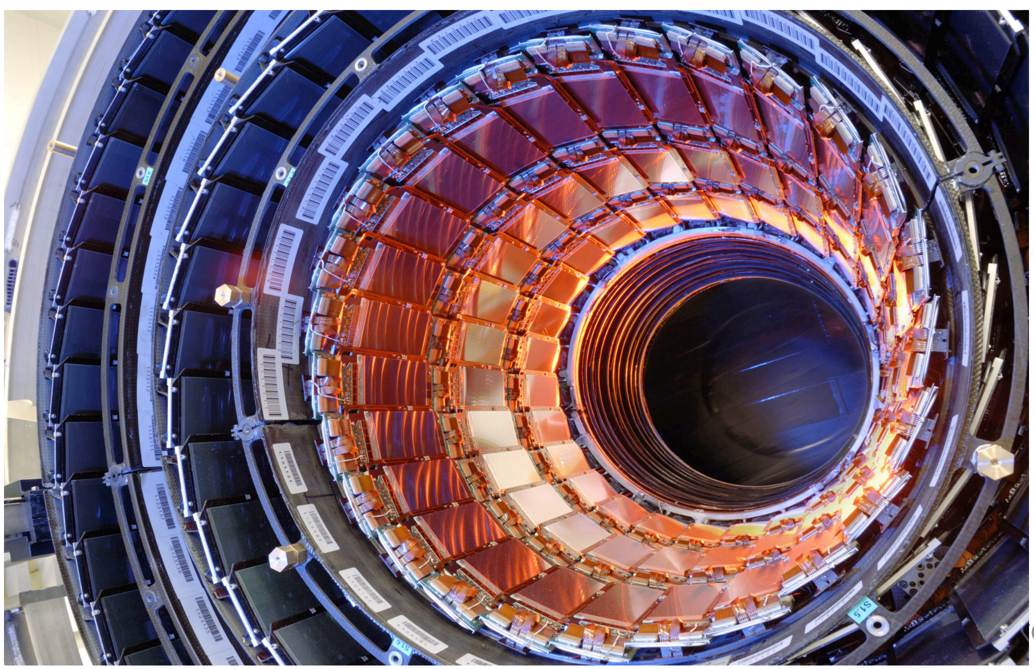


CMS is “compact” because its diameter is 60% that of ATLAS, the other big LHC detector. But CMS weighs 1.7 times more.

CMS Tracker

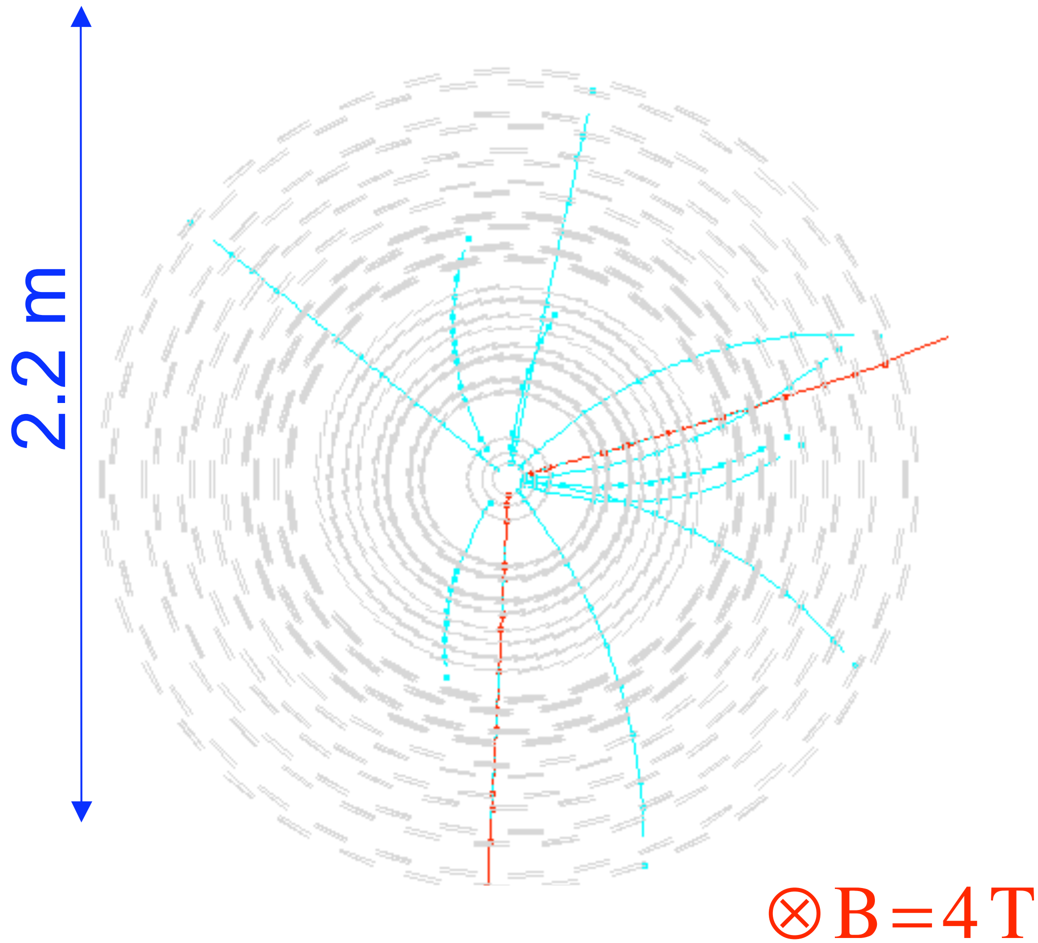
- Solid state detector
- Charged particles produce a signal (or "hit") on each layer
- Resolution is 10-60 microns per hit





Immersed in 4Tesla solenoidal magnetic field … Why?

Particles in the tracker



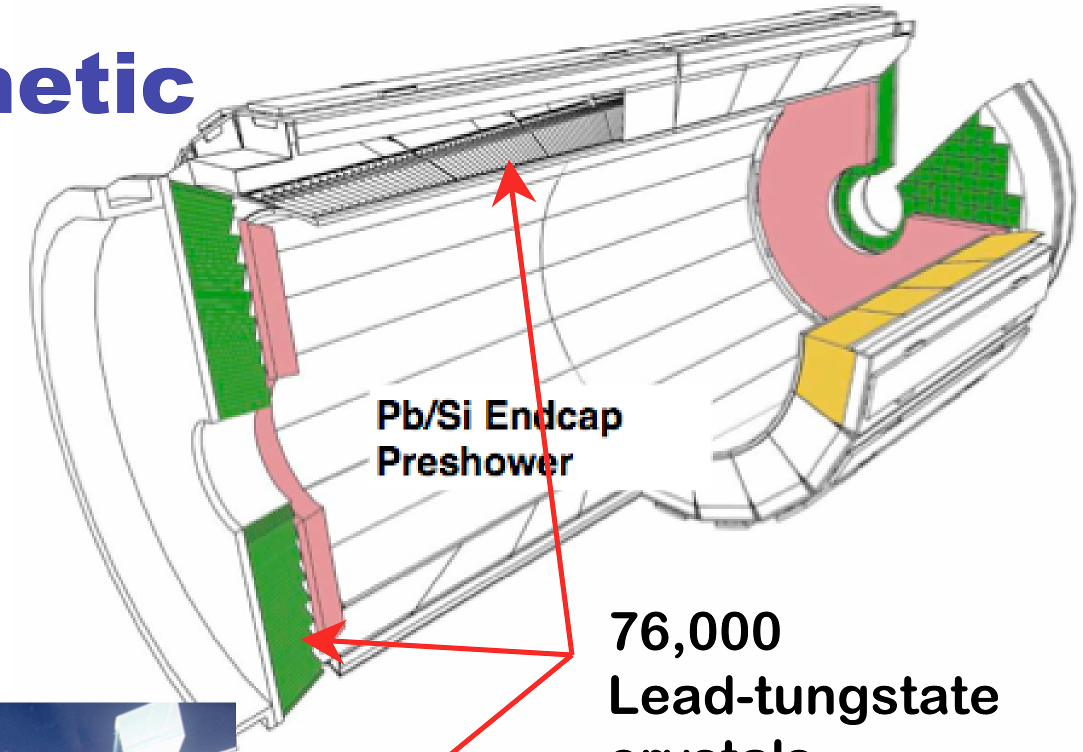
Which particle(s) have the greatest momentum?

The smallest?

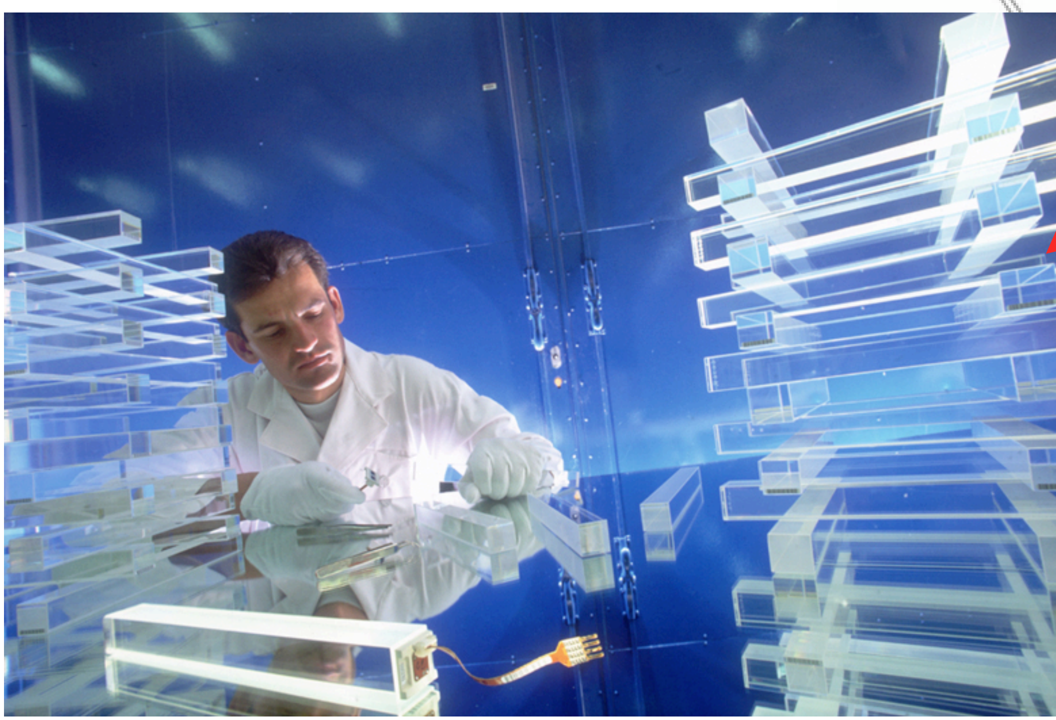
Which have positive electric charge?

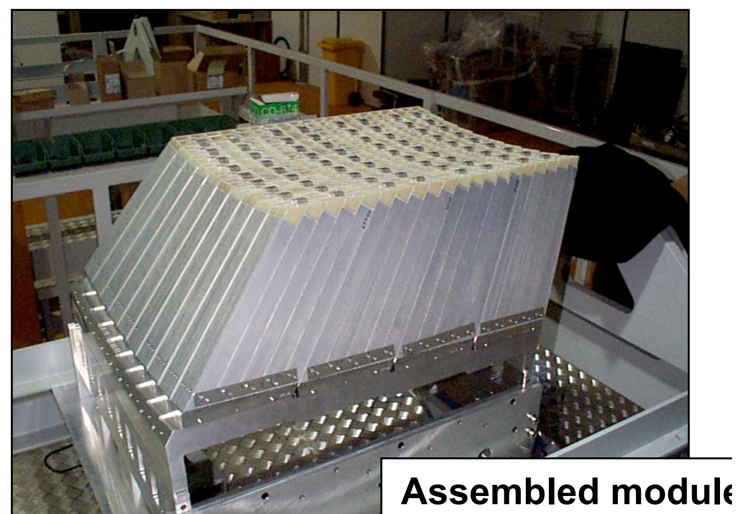
Electromagnetic Calorimeter

Absorbs electrons and photons to measure their energies



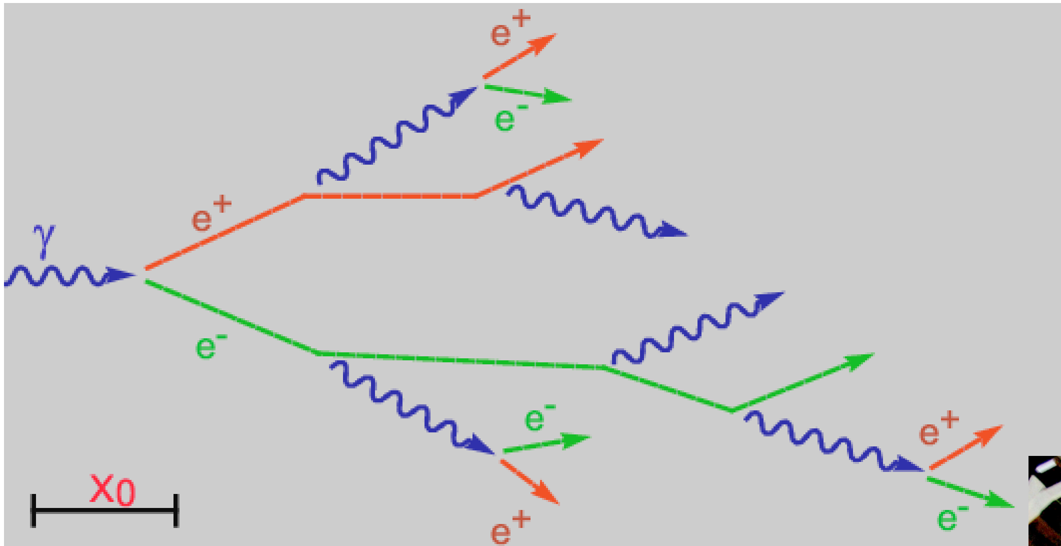
76,000 Lead-tungstate crystals



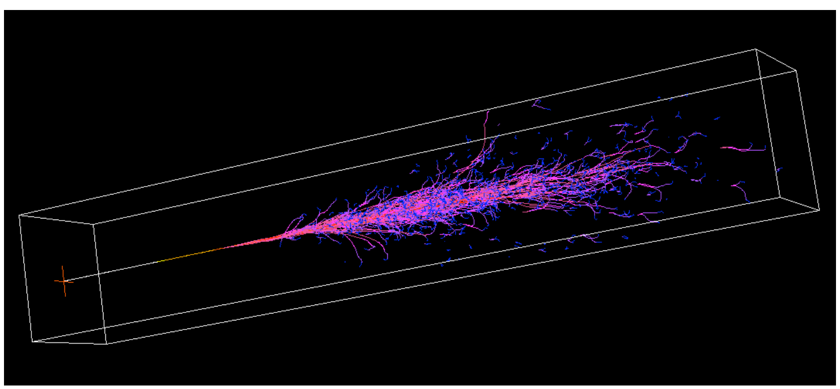


Assembled module

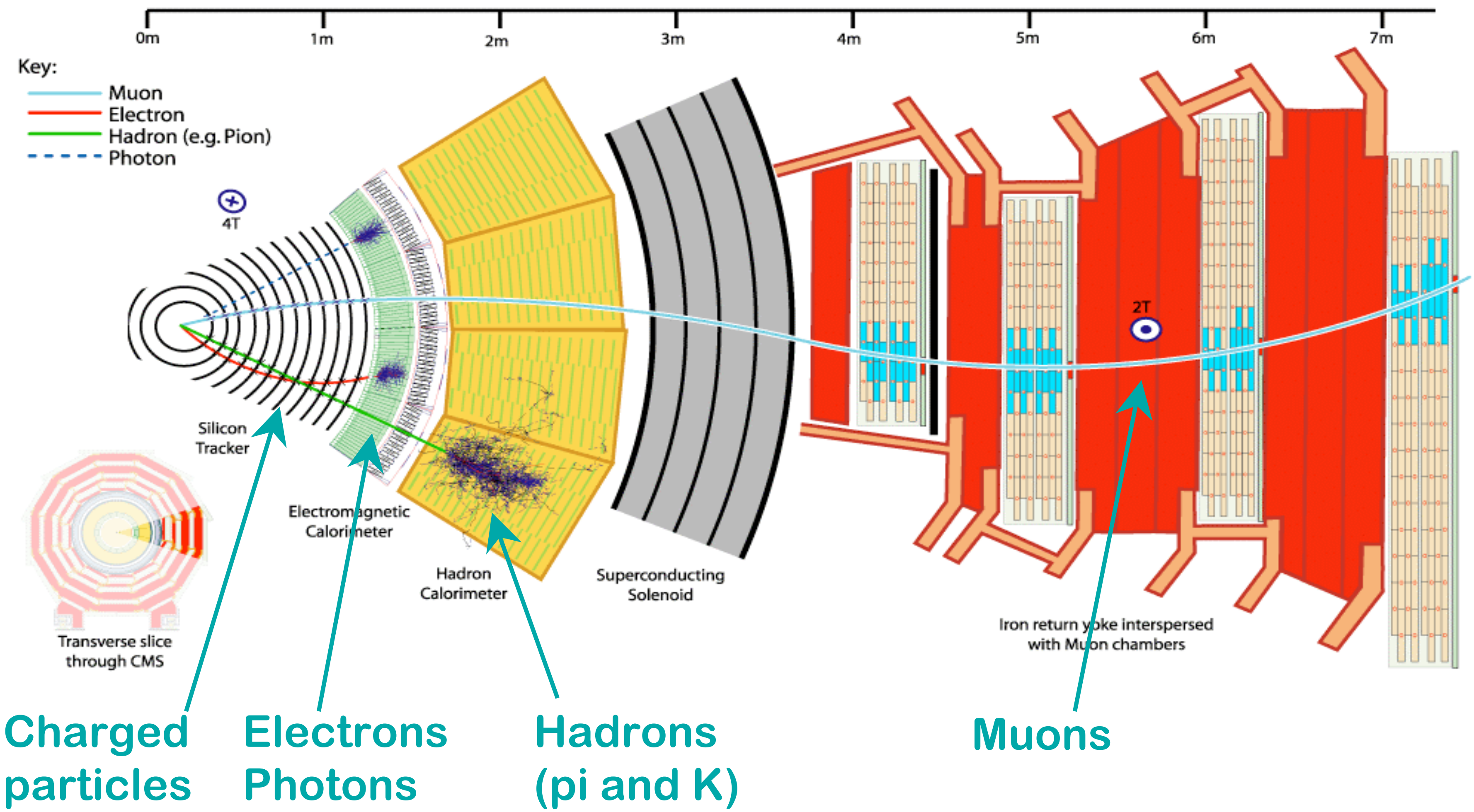
Electromagnetic showers



- Electrons and photons "shower" in the crystals
- Shower particles produce scintillation light, detected at the back of the crystal

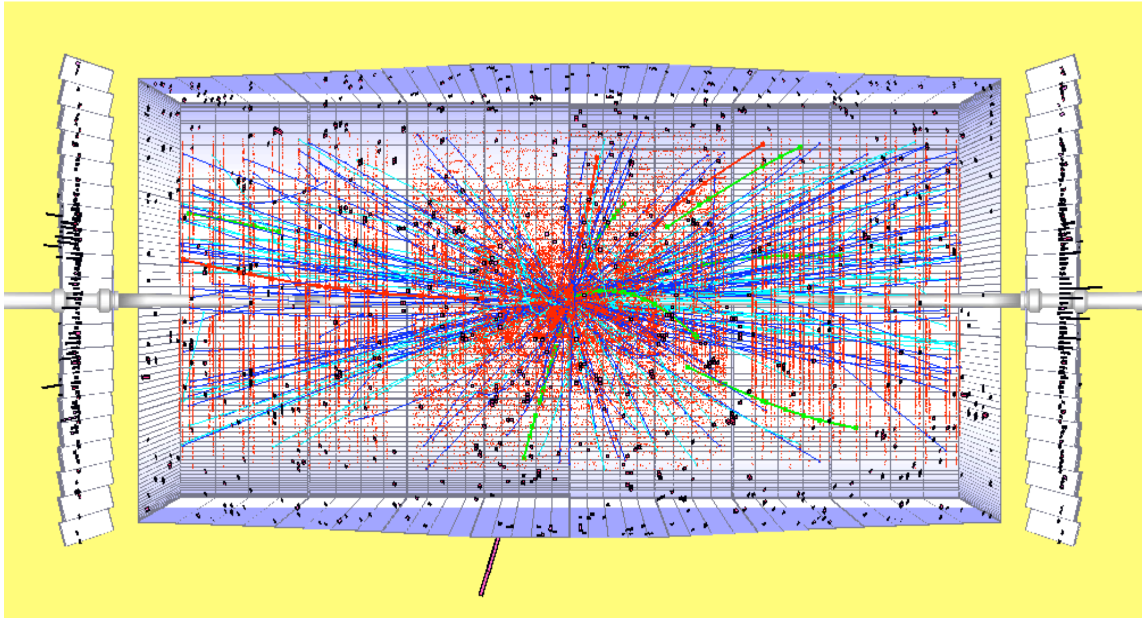


Slice of CMS


0m
1m
2m
3m
4m
5m
6m
7m
Key:
Muon
Electron
Hadron (e.g. Pion)
Photon
4T
2T
Silicon Tracker
Electromagnetic Calorimeter
Hadron Calorimeter
Superconducting Solenoid
Iron return yoke interspersed with Muon chambers
Transverse slice through CMS
Charged particles
Electrons Photons
Hadrons (pi and K)
Muons

Computing

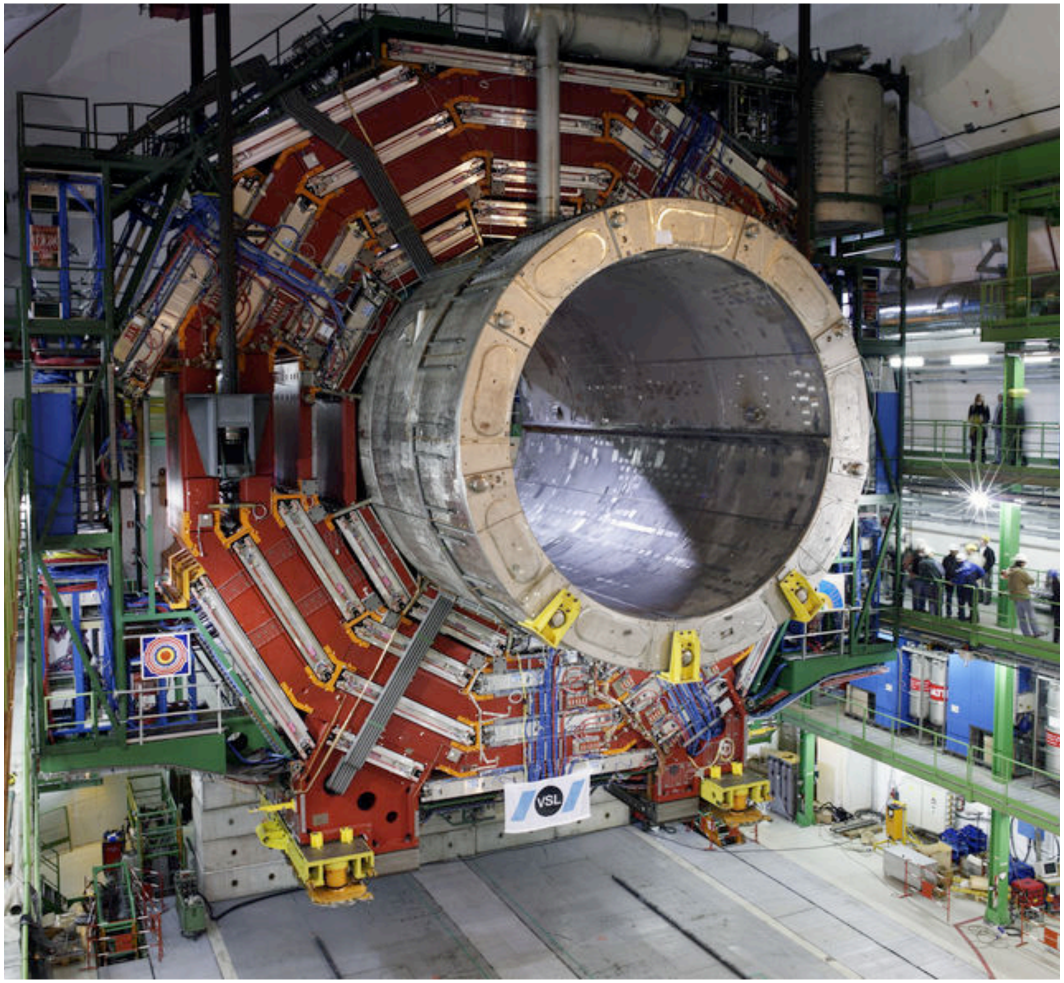
- 15 Petabytes of data per year
- Tiered computing structure
- Achieved data transfer rates of 110 Gbps
  - the world record



CMS Cavern

92 meters underground

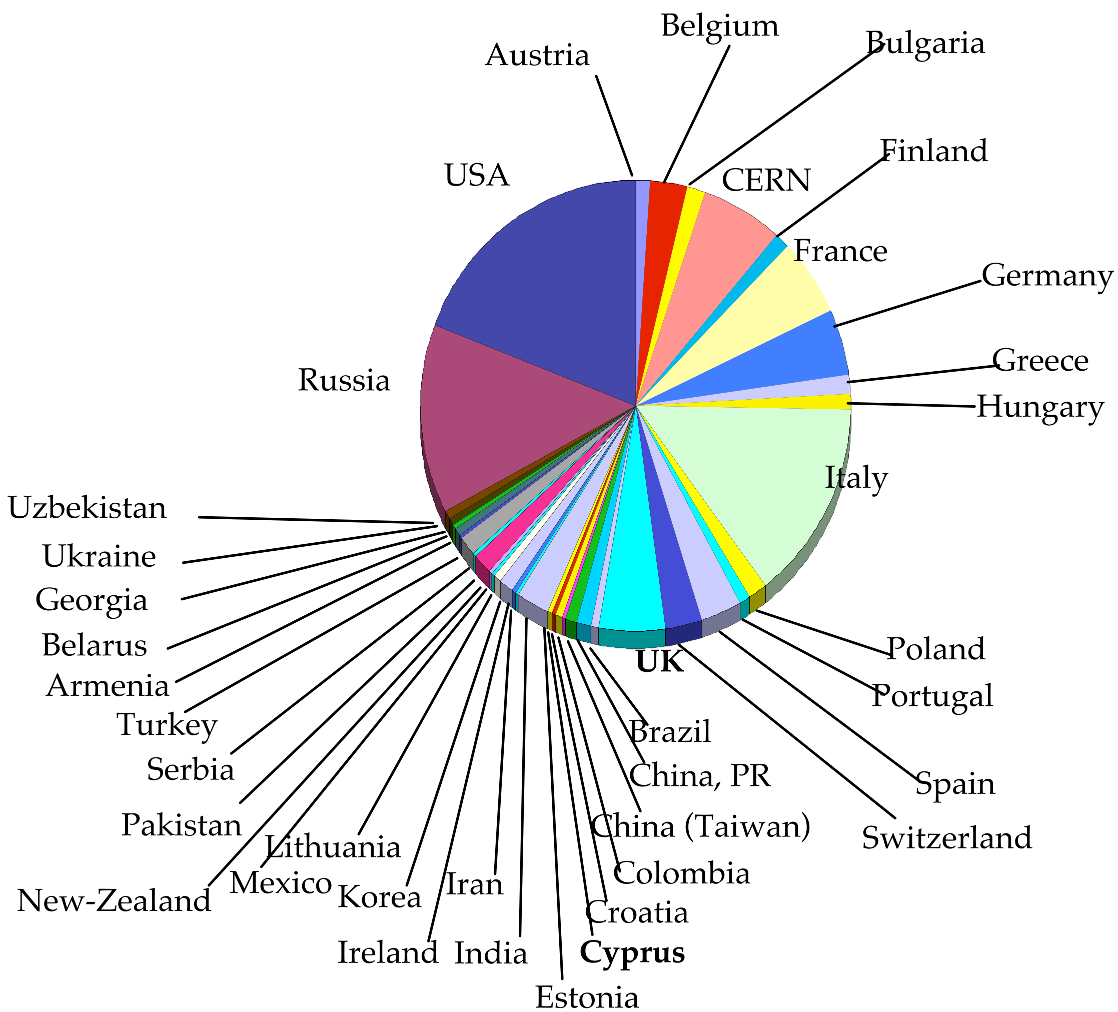
Installing CMS



- Components were built on the surface and then lowered via crane.
- This is the largest one, weighing more than 2000 tons.
- After lowering, they move on air pads.

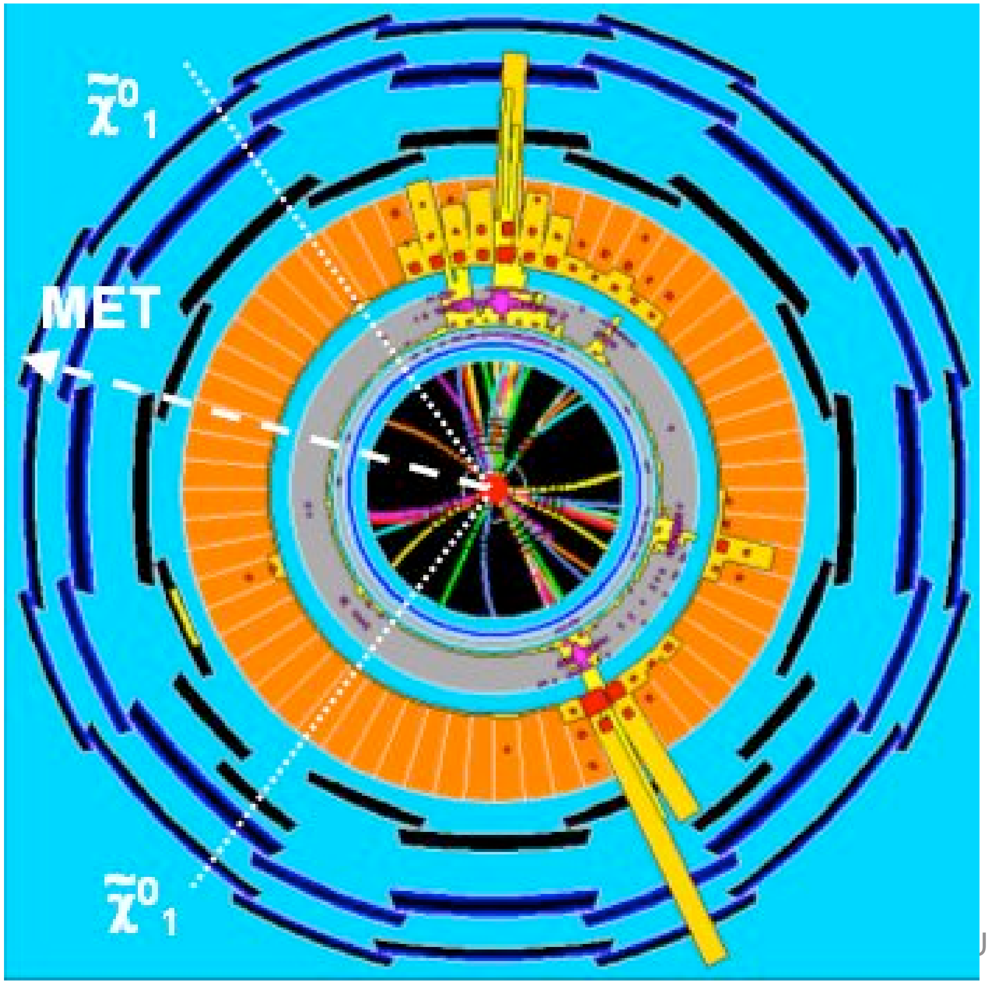
The CMS Collaboration

- CMS was approved in 1994
- 2300 Scientific Authors
- 175 Institutions
- 38 Countries



Finding Dark Matter

- Leaves no trace in detector
- Find via momentum imbalance of detected particles: $\sum p \neq 0$



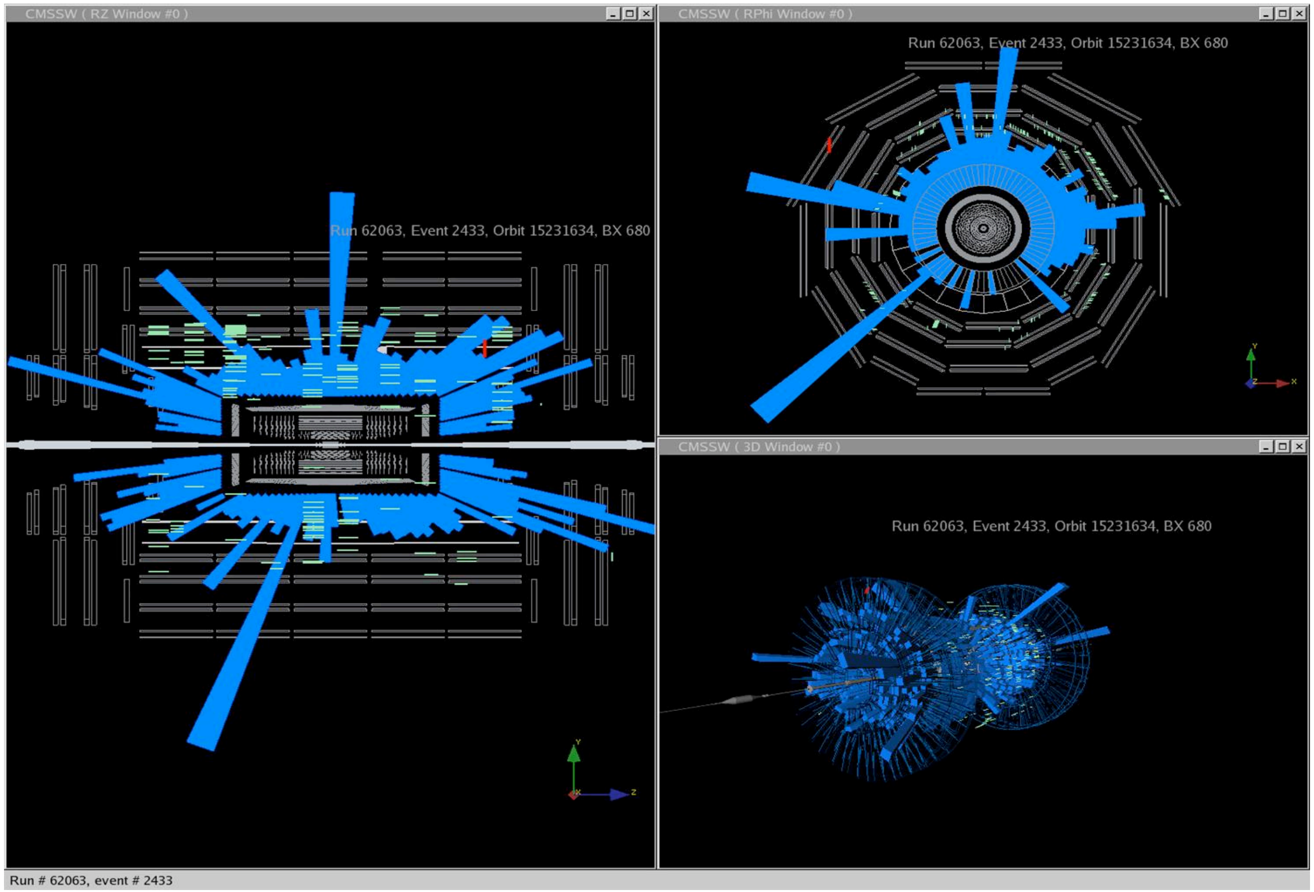
This is a simulation of dark matter in ATLAS

This event is modeled based on a candidate theory called supersymmetry.

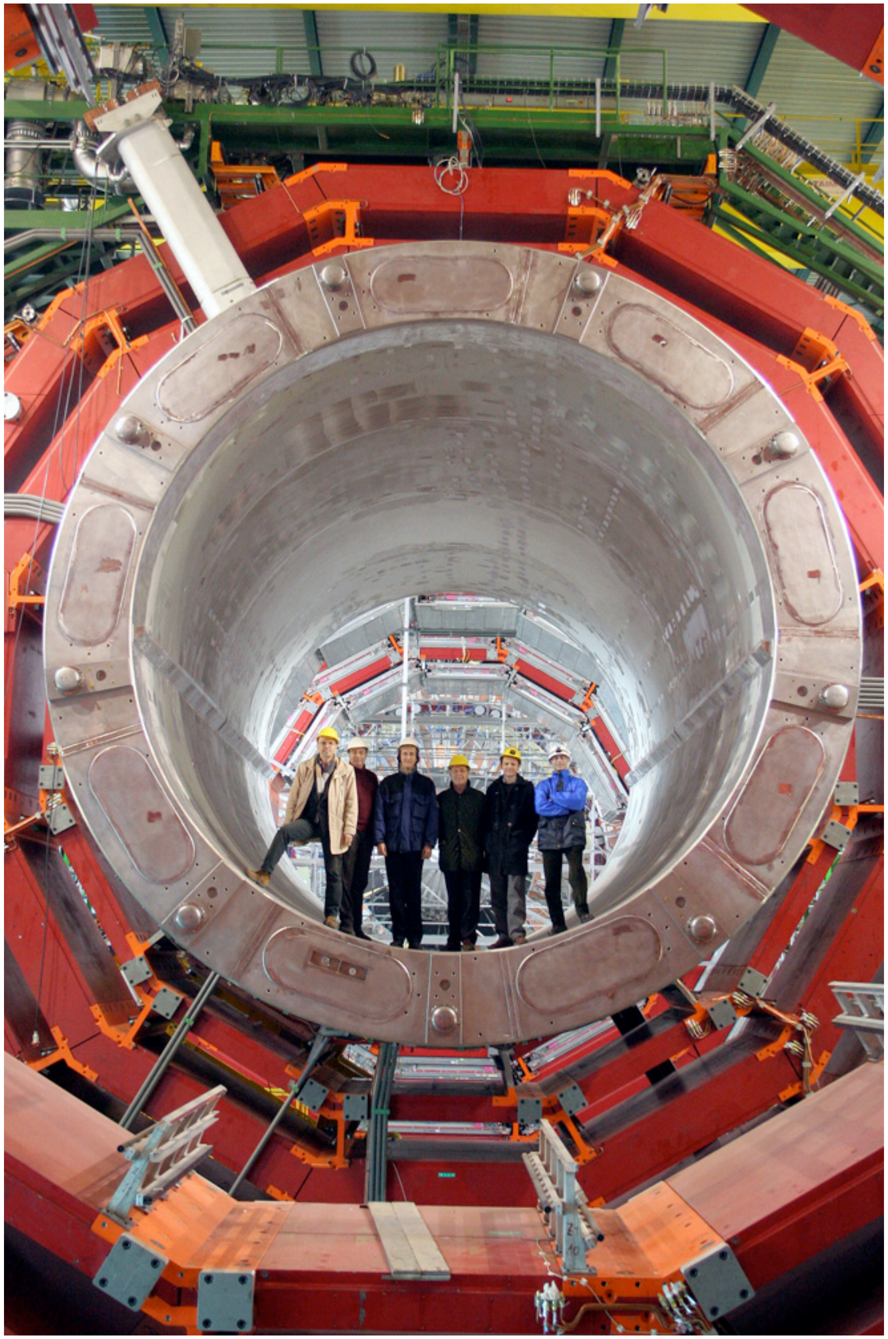
Other theories give similar momentum imbalance.

First Beam September 10, 2008

CMS detects beam fragments



Then, an LHC equipment failure caused a shutdown, and one year of repairs.



Conclusions

The LHC will begin operation again this fall.

CMS and ATLAS are ready to go.

They will explore energies not seen since moments after the big bang.