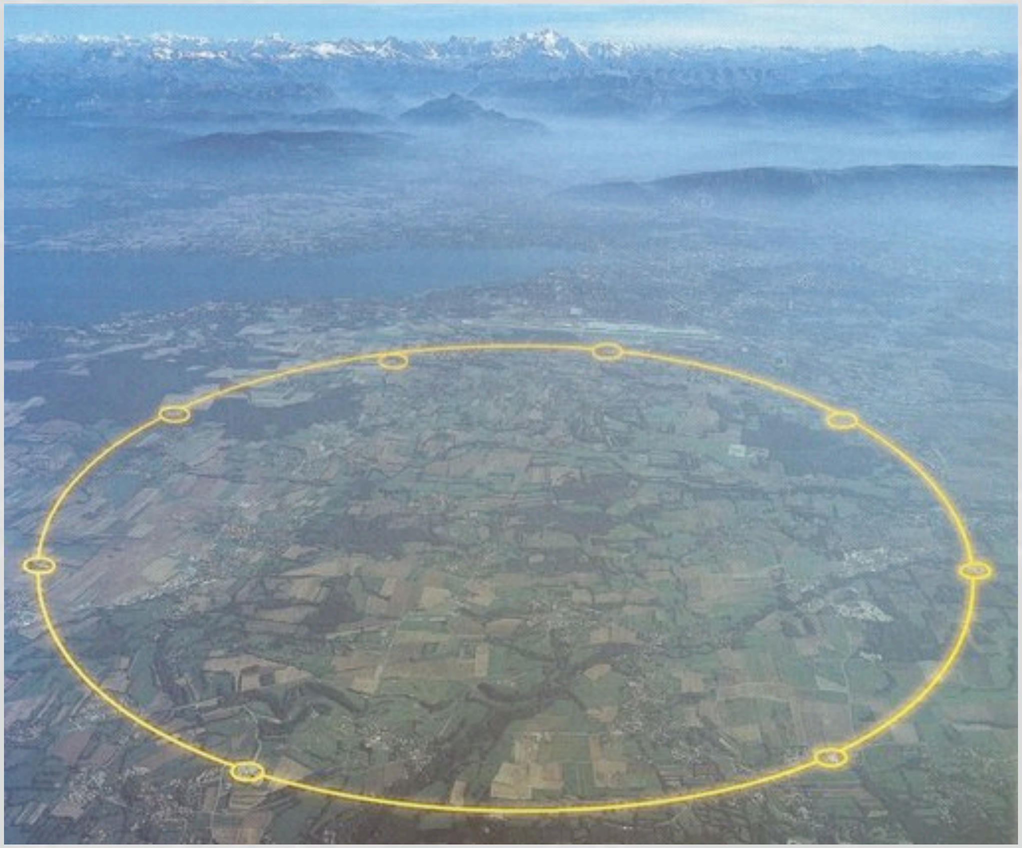
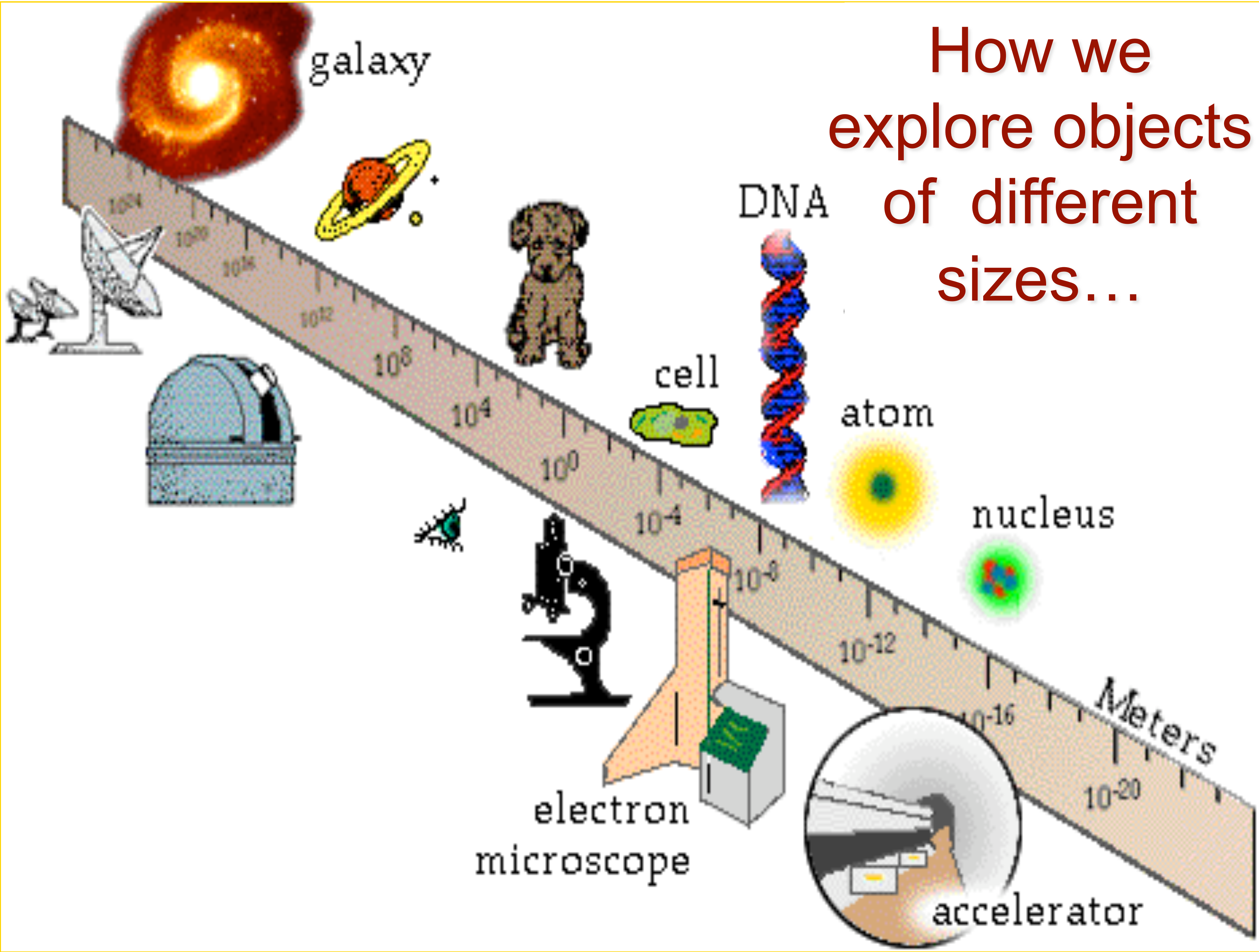
# Particle Physics in the Age of the Large Hadron Collider



We shall not cease from exploration
And the end of all our exploring
Will be to arrive where we started
And know the place for the first time.

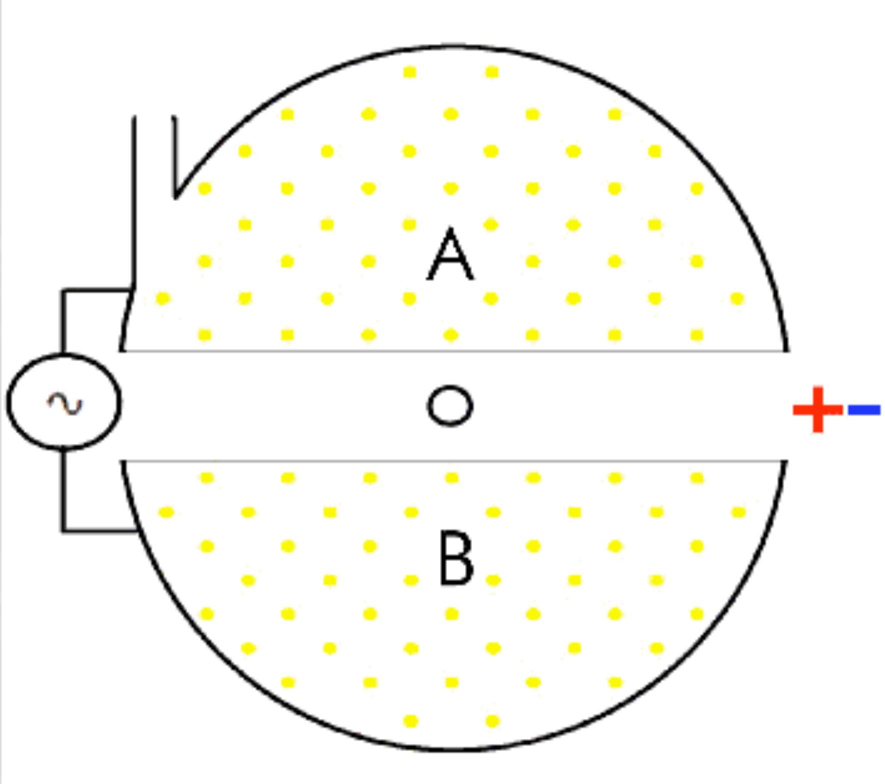
T.S. Eliot

# How we explore objects of different sizes…

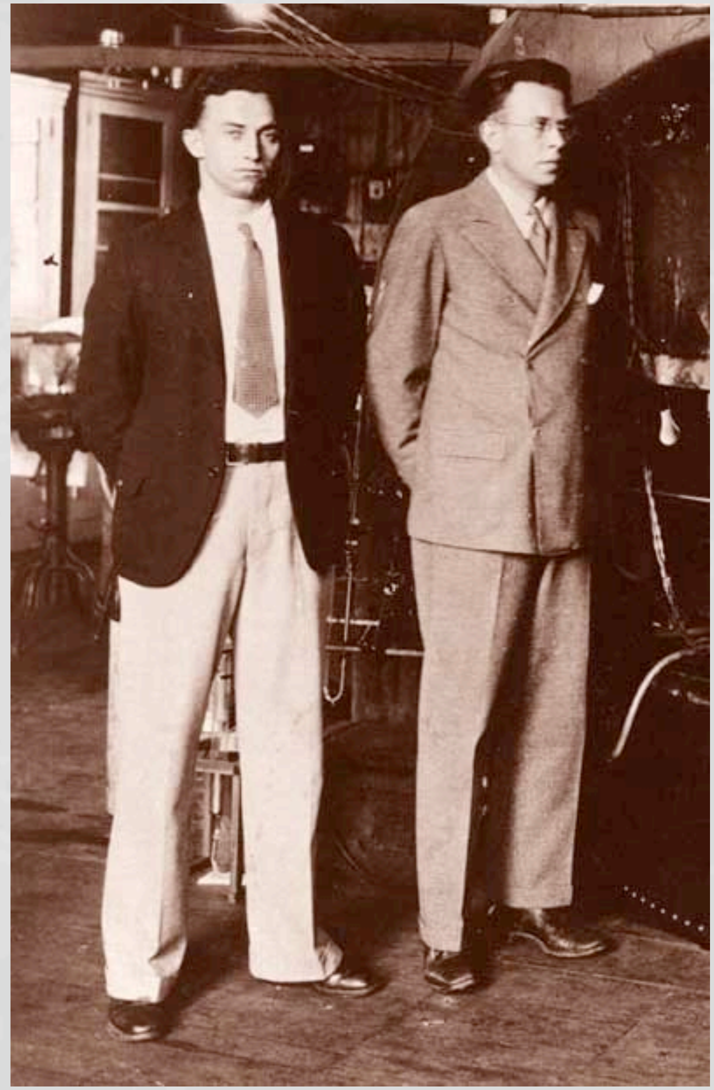


Particle accelerators are used to explore small objects. Electric fields are used to propel electrically charged particles to very high speeds.

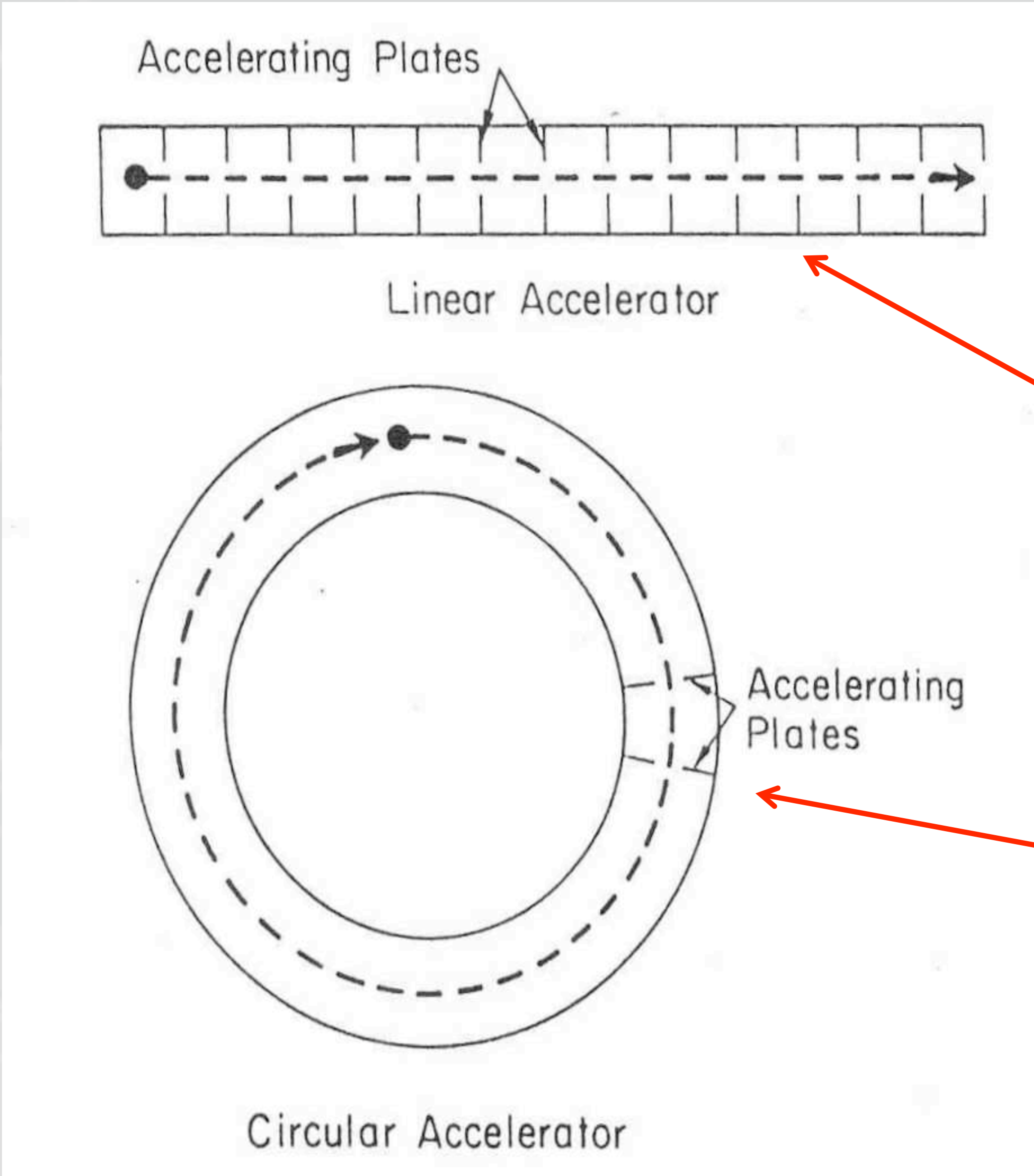
http://www.aip.org




One of the first accelerators was a small, 4.5 inch cyclotron, built by Lawrence and Livingston in 1931. The half-cylinders (dees) were the electrodes. While steered by a magnetic field, charged particles were given higher and higher energies by an oscillating electric field.



http://www.aip.org/history/lawrence/epa.htm




Two other types of accelerators are linear accelerators and synchrotron accelerators.

In order to probe further, higher and higher energies are needed. When particles in an accelerator collide, some of the energy can create new particles ($E=mc^2$). The more energy available, the more massive the potential new particles.

http://www.particle.kth.se

# The LHC

The Large Hadron Collider is 27 kilometers (16.7 miles) long. After 25 years of planning, 14 years of building, input from more than 60 countries and over $8 billion dollars, it is the highest energy accelerator ever built.

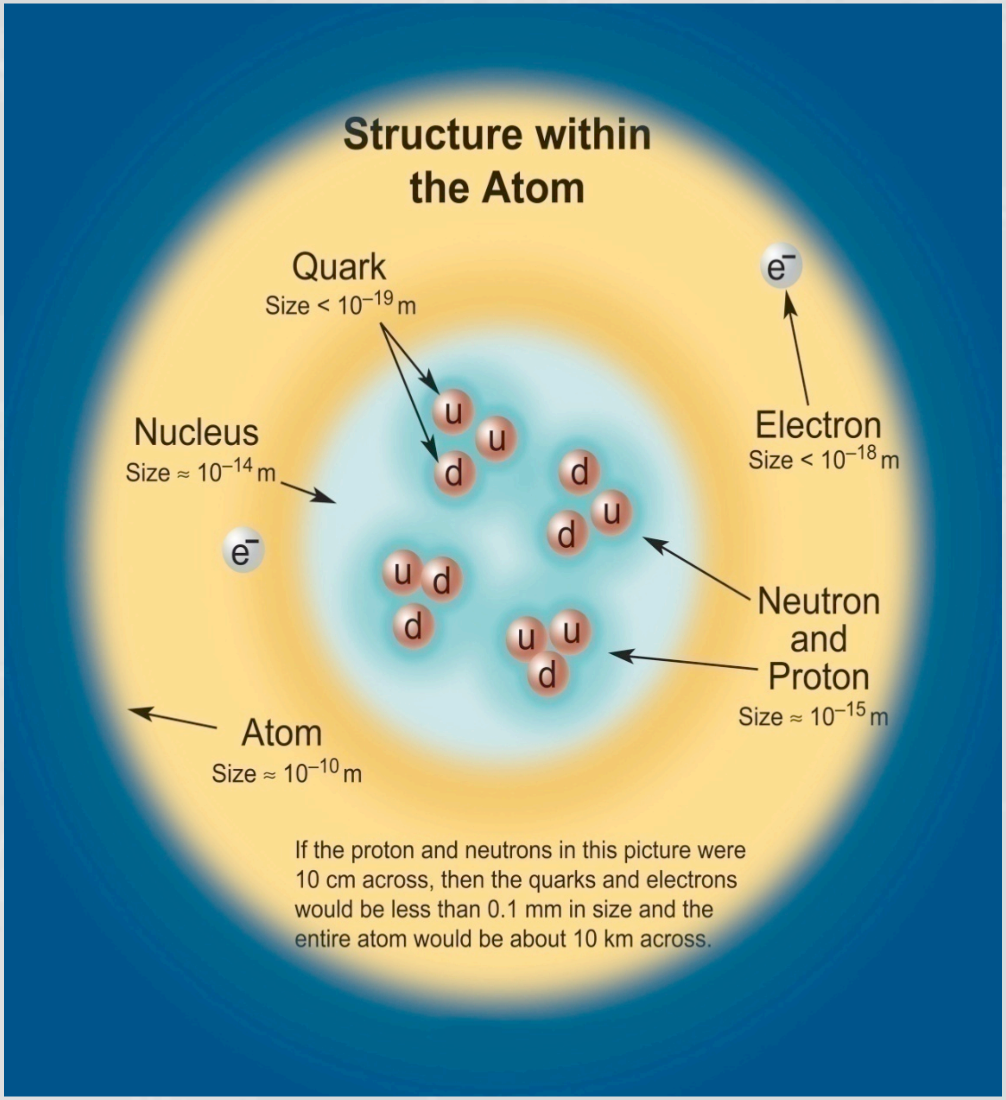
# Where is it located?

The LHC is at CERN which is located 100 meters (328 feet) below the countryside on border of France and Switzerland near Geneva, Switzerland.


The European Organization for Nuclear Research (Conseil Européen pour la Recherche Nucléaire)

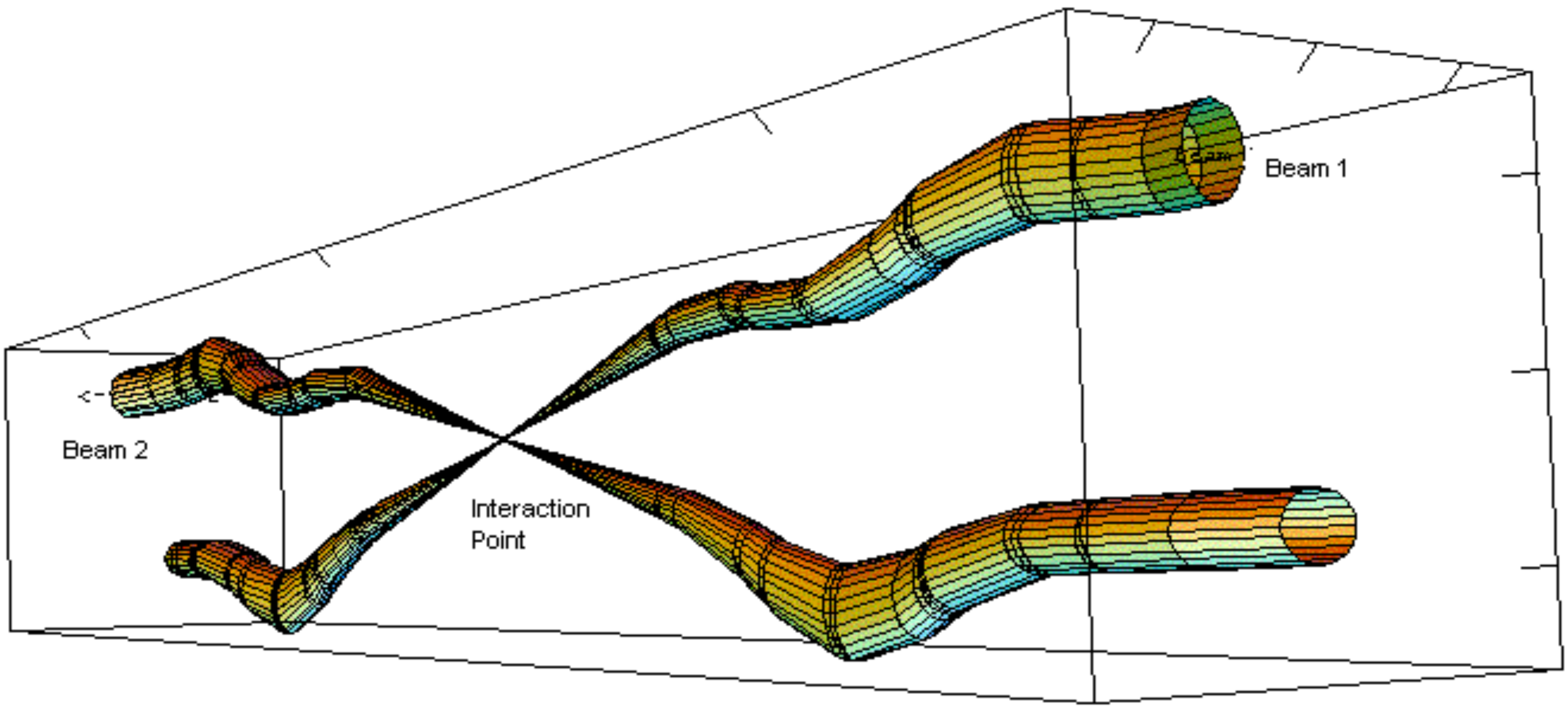
At the Large Hadron Collider, scientists hope to recreate the conditions just after the Big Bang by sending two beams of subatomic particles, called 'hadrons,' in opposite directions around the synchrotron ring.

The protons that the LHC will collide are made up of quarks and gluons. The collisions that will be the most interesting to the physicists at LHC are quark-quark, quark-gluon, or gluon-gluon collisions.




www.cpepweb.org

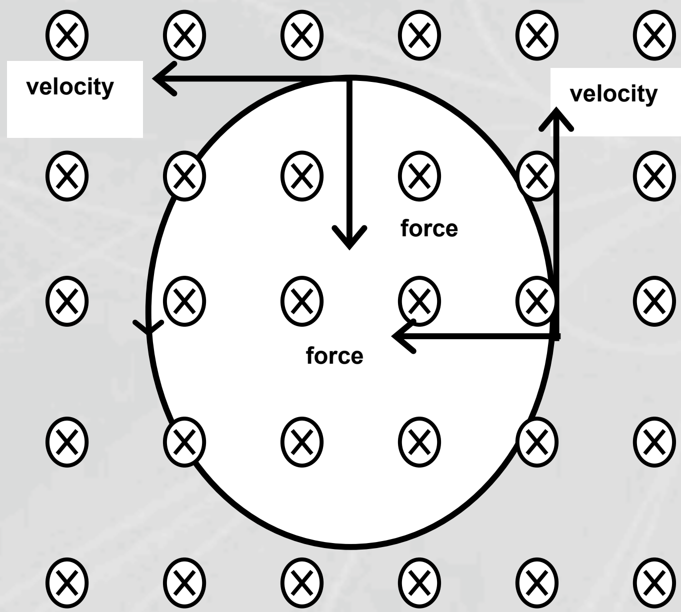
The two counter-rotating beams of protons will get faster, gaining energy every time they go around until they reach 7 TeV per proton and are going 0.999999991% the speed of light. They are steered with magnets and eventually collide head-on.



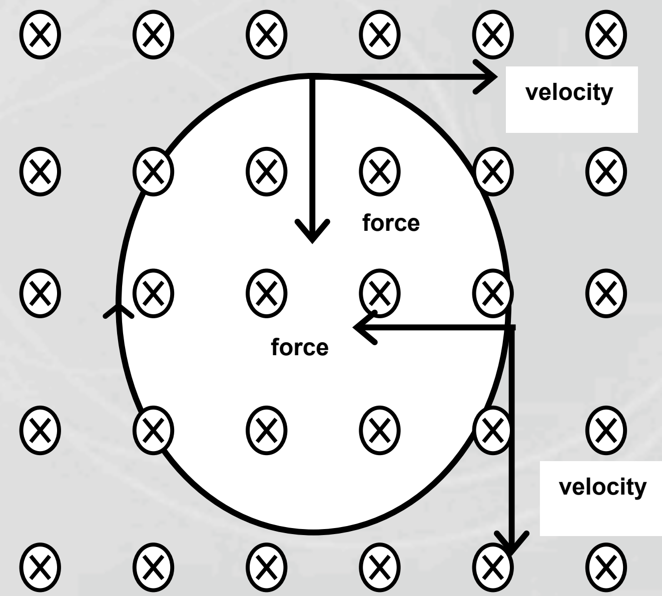

Relative beam sizes around IP1 (Atlas) in collision

CERN

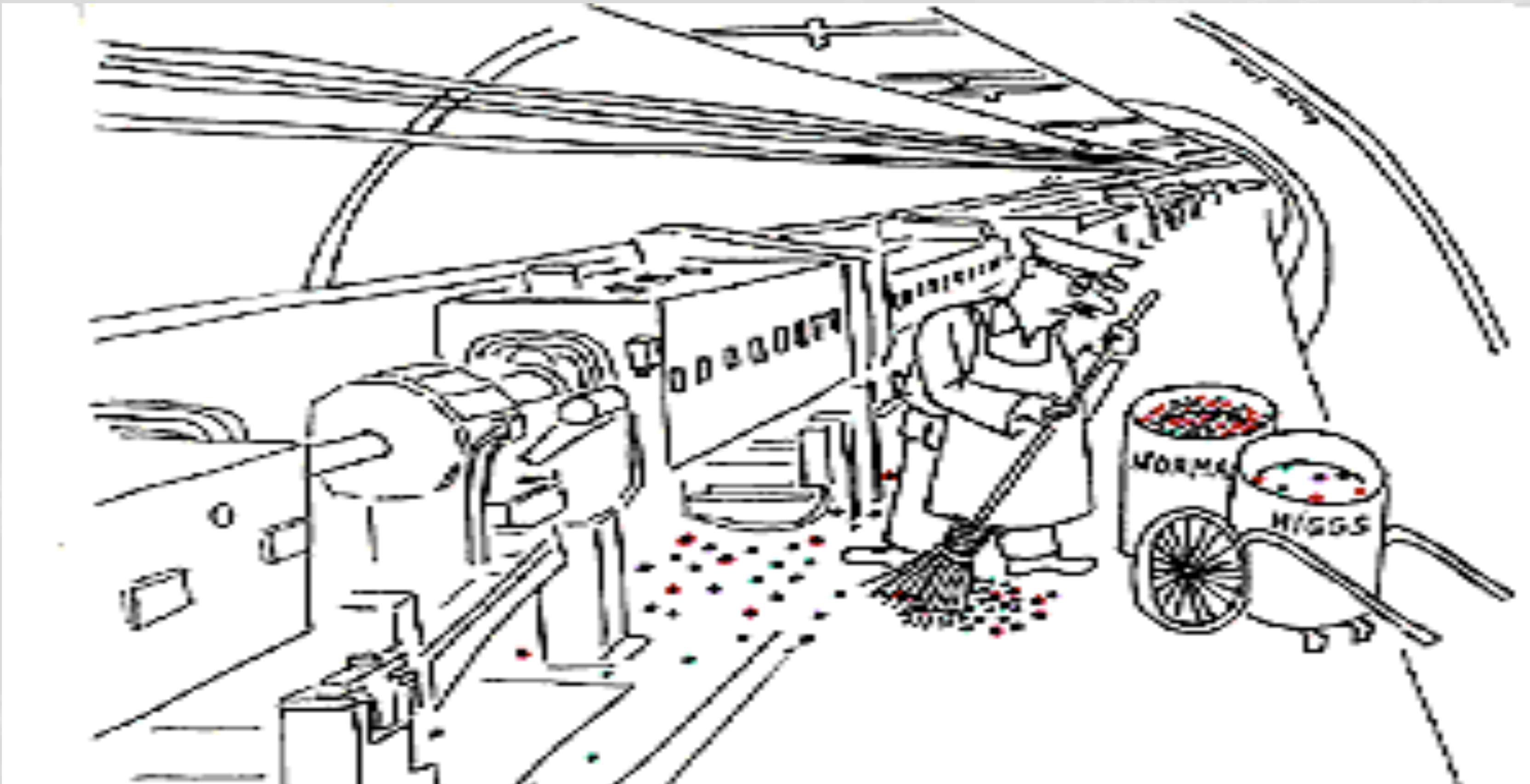
# Magnets are used to steer and focus beam, but don't add energy.




Positive particle




Negative particle



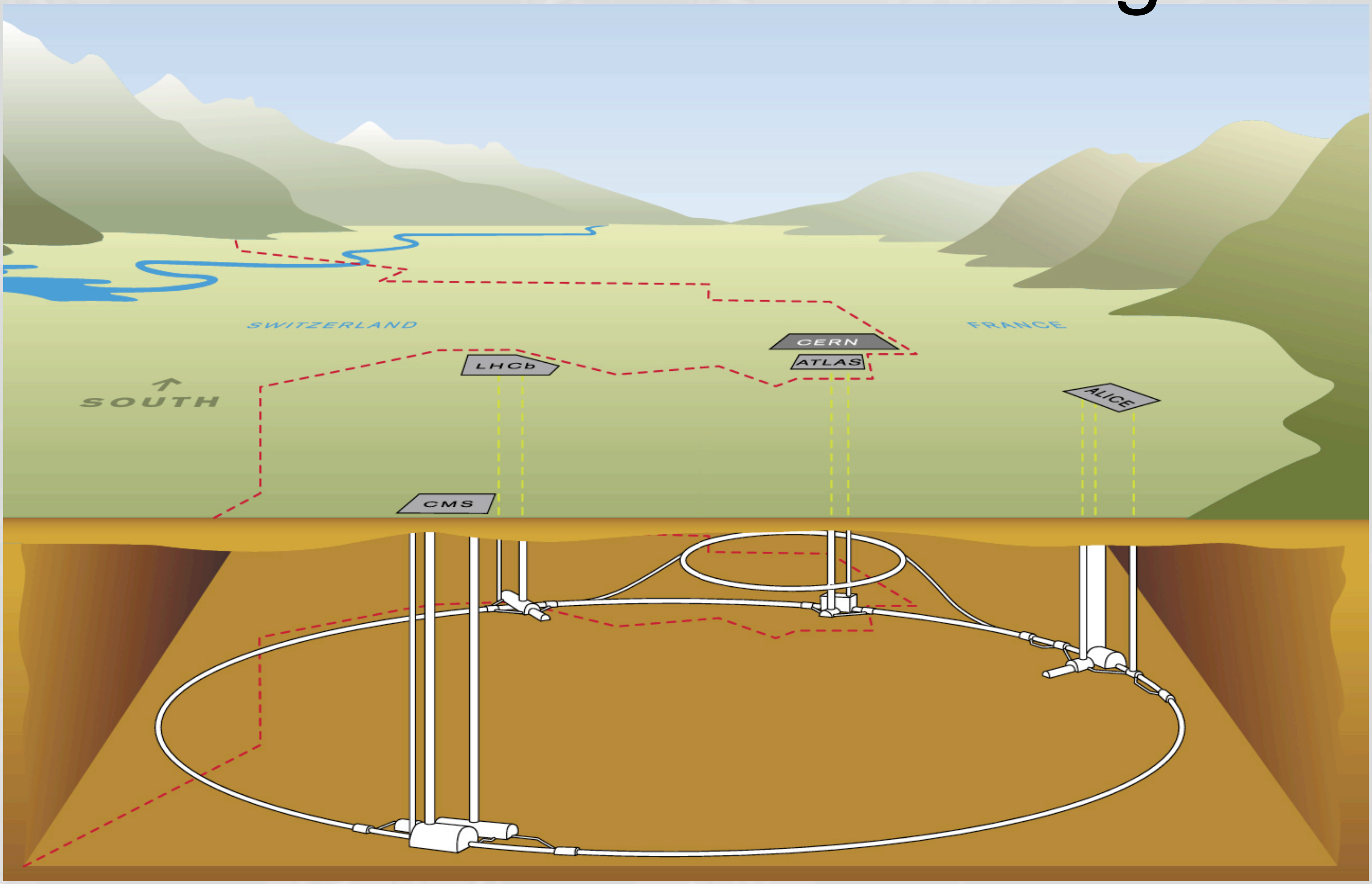

artwork: CERN

These collisions may be in the 0.1 to 1 TeV range – the region that physicists expect to find new, interesting particles such as the Higgs boson.

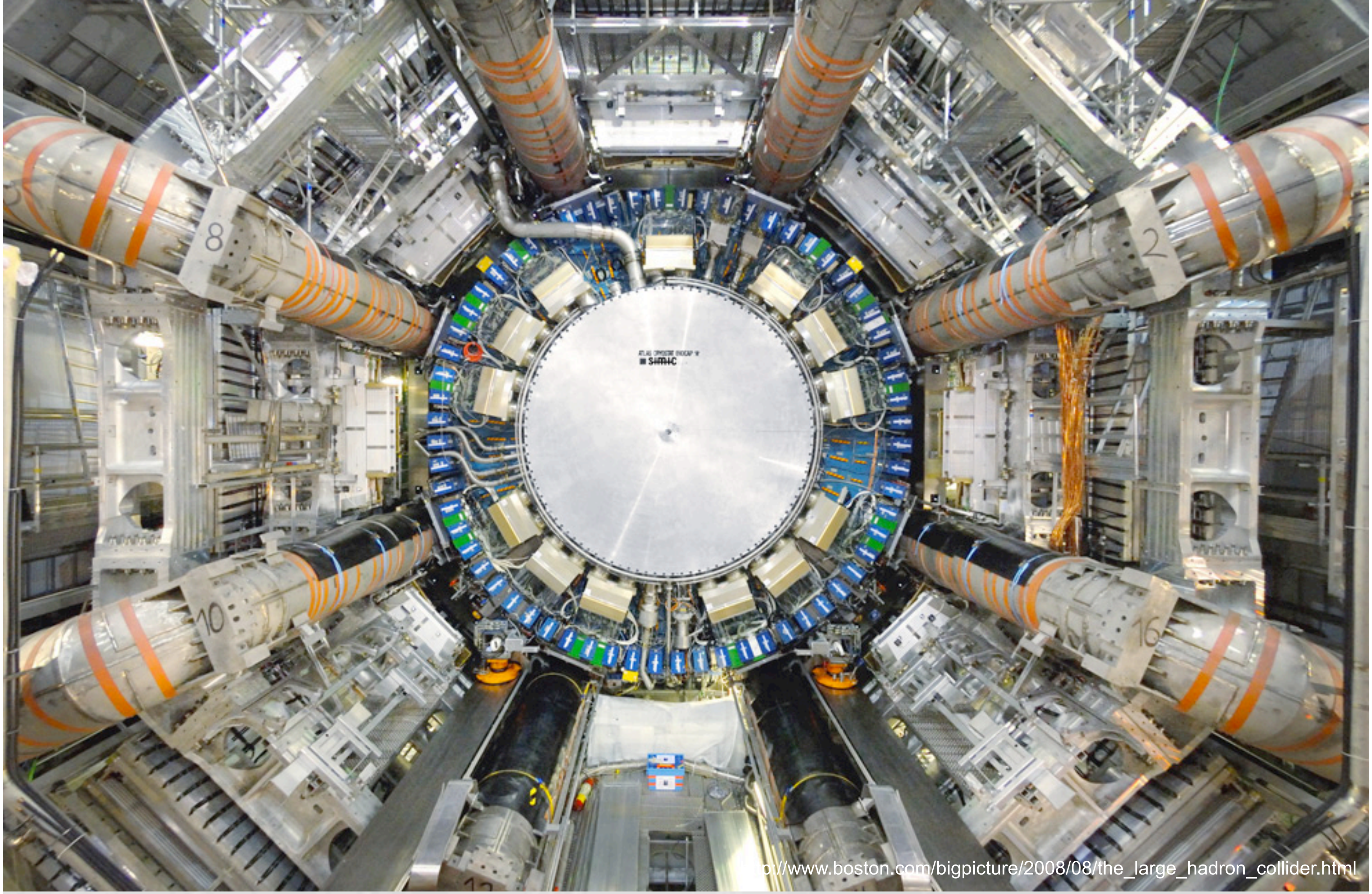
# What about the detectors?

- Multi-layered detectors surround the collision points. Each layer of a detector serves a purpose in tracking and identifying the many particles produced in a the collisions. There are four LHC experiments
  - **ATLAS**
  - **ALICE**
  - **CMS**
  - **LHCb**

# CERN and the LHC ring



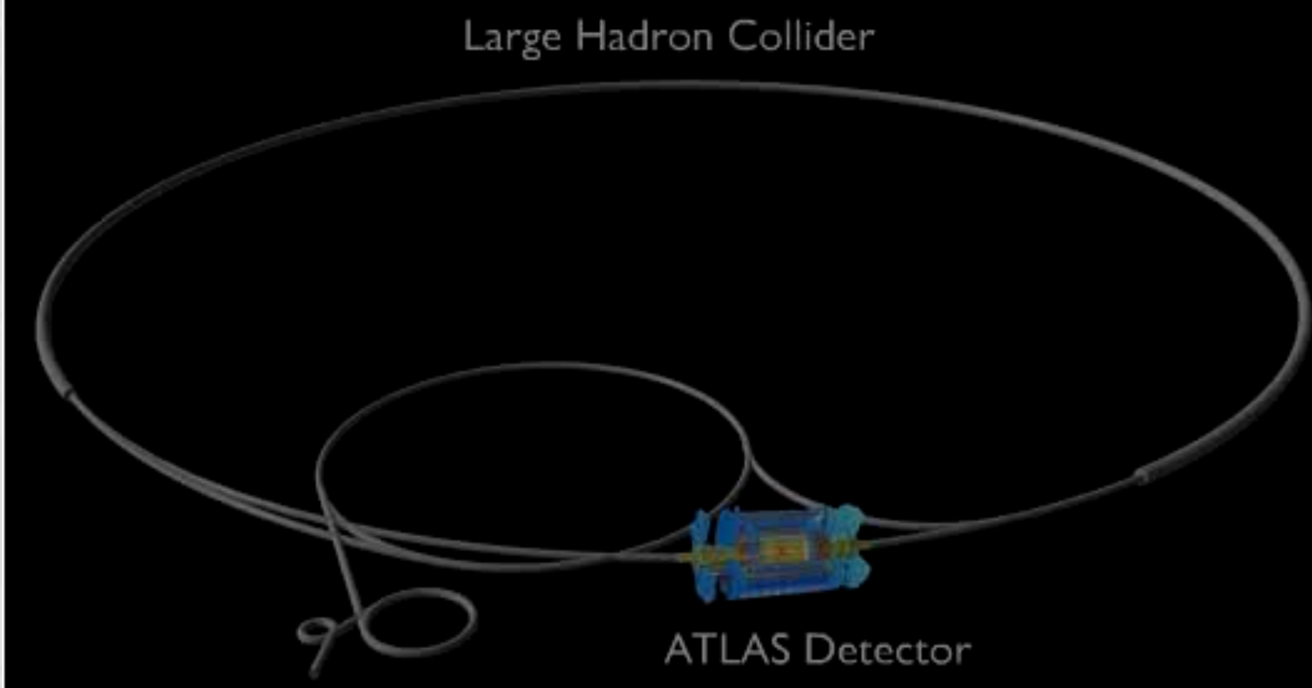

http://www.symmetrymagazine.org/cms/?pid=1000364

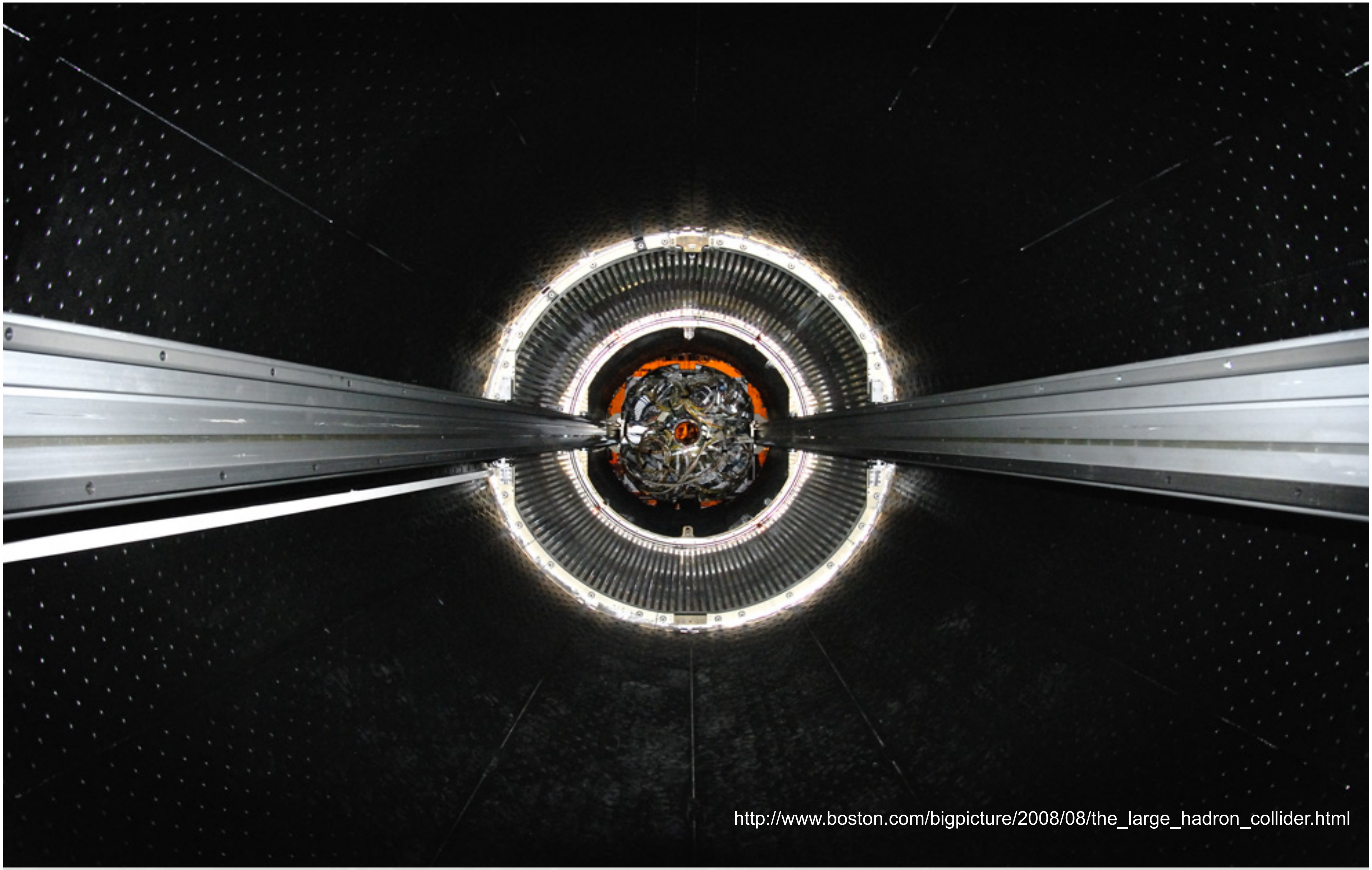



The ATLAS detector is 150 ft (46 m) long, 82 ft (25 m) high and weighs 7,000 tons. Its cables and wiring could wrap around the earth almost seven times!

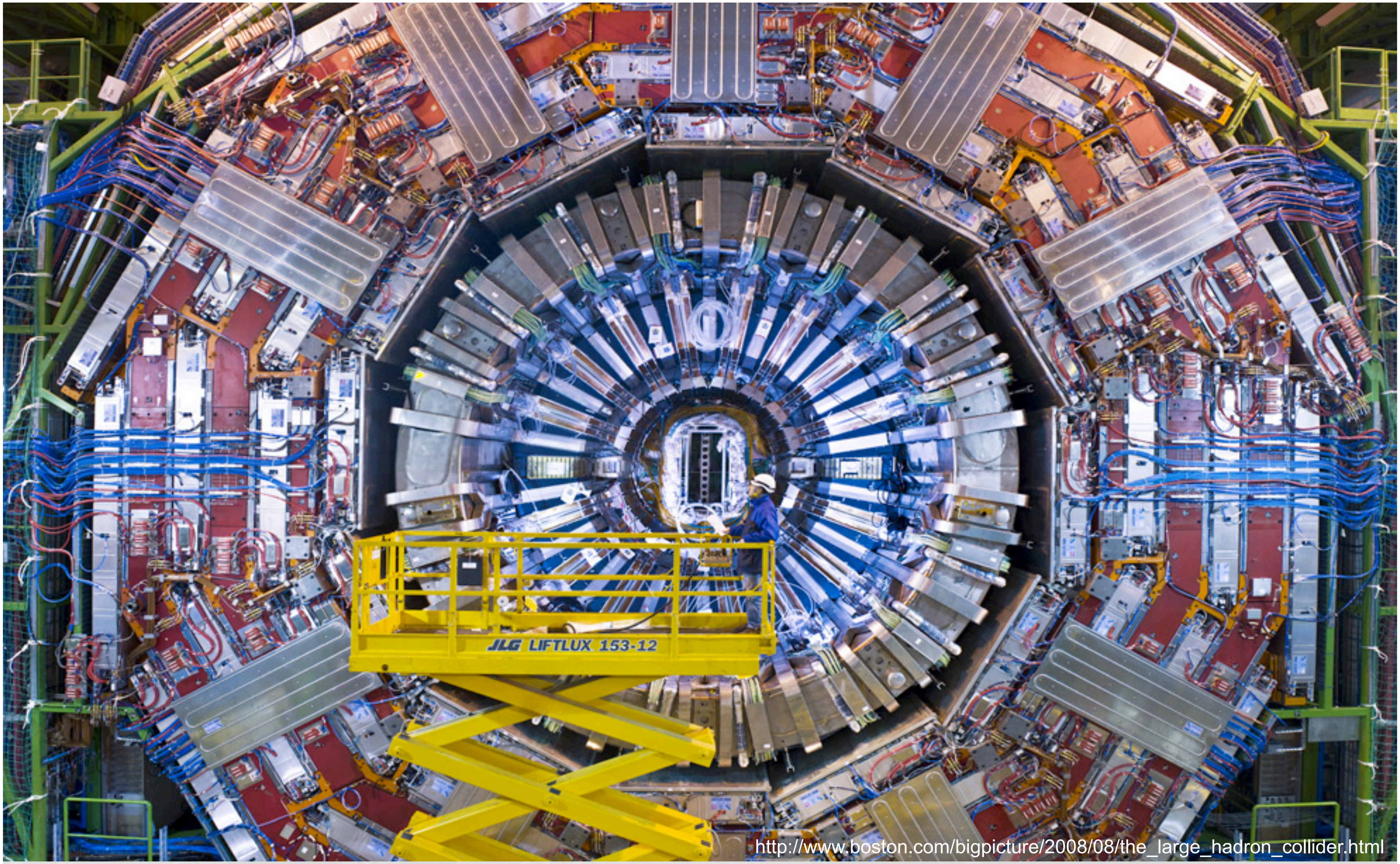

http://atlas.ch/etours_intro/etours_intro01.html

PLAY▶ http://www.youtube.com/watch?v=AHT9RTICqjQ

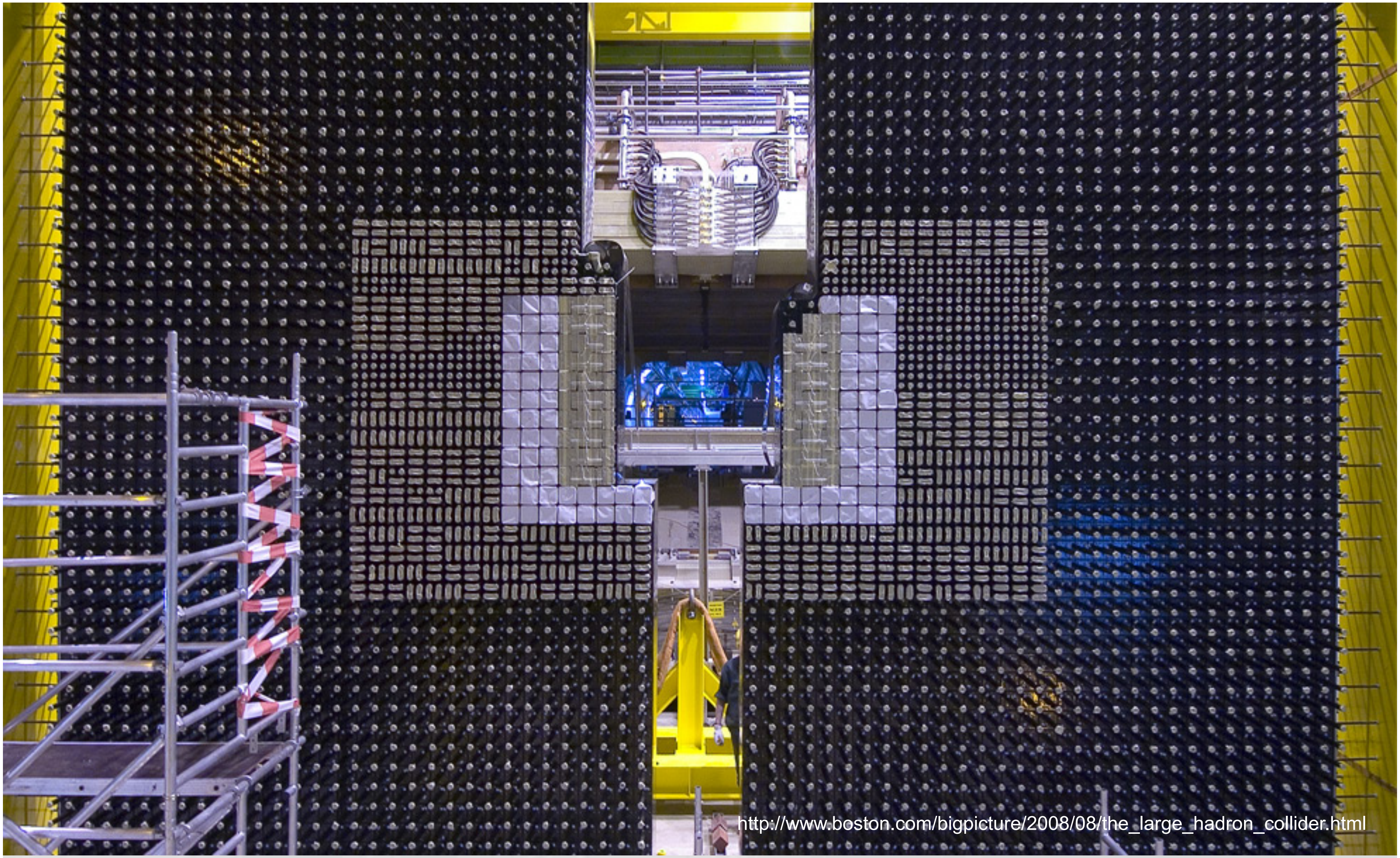





The inner tracking system of Alice (A Large Ion Collider Experiment)




The CMS (Compact Muon Solenoid) is one of two general purpose detectors. It weighs over 12,500 tons!




The LHCb electromagnetic calorimeter

# What do scientists hope to find?

- explanations and updates to the current Standard Model
- the Higgs boson
- information about dark matter & energy
- extra dimensions
- and answers to many other questions

# According to the Standard Model there are six types of quarks, six leptons, and four fundamental interactions.

- But why does this pattern of quarks, leptons, and forces exist? Are there more?
- Do quarks and leptons have a substructure?
- What particles form the dark matter in the universe?
- How does gravity fit with the other fundamental interactions?

| Quarks | spin =1/2 | |
|---|---|---|
| Flavor | Approx. Mass $GeV/c^2$ | Electric charge |
| u up | 0.002 | 2/3 |
| d down | 0.005 | –1/3 |
| c charm | 1.3 | 2/3 |
| s strange | 0.1 | –1/3 |
| t top | 173 | 2/3 |
| b bottom | 4.2 | –1/3 |

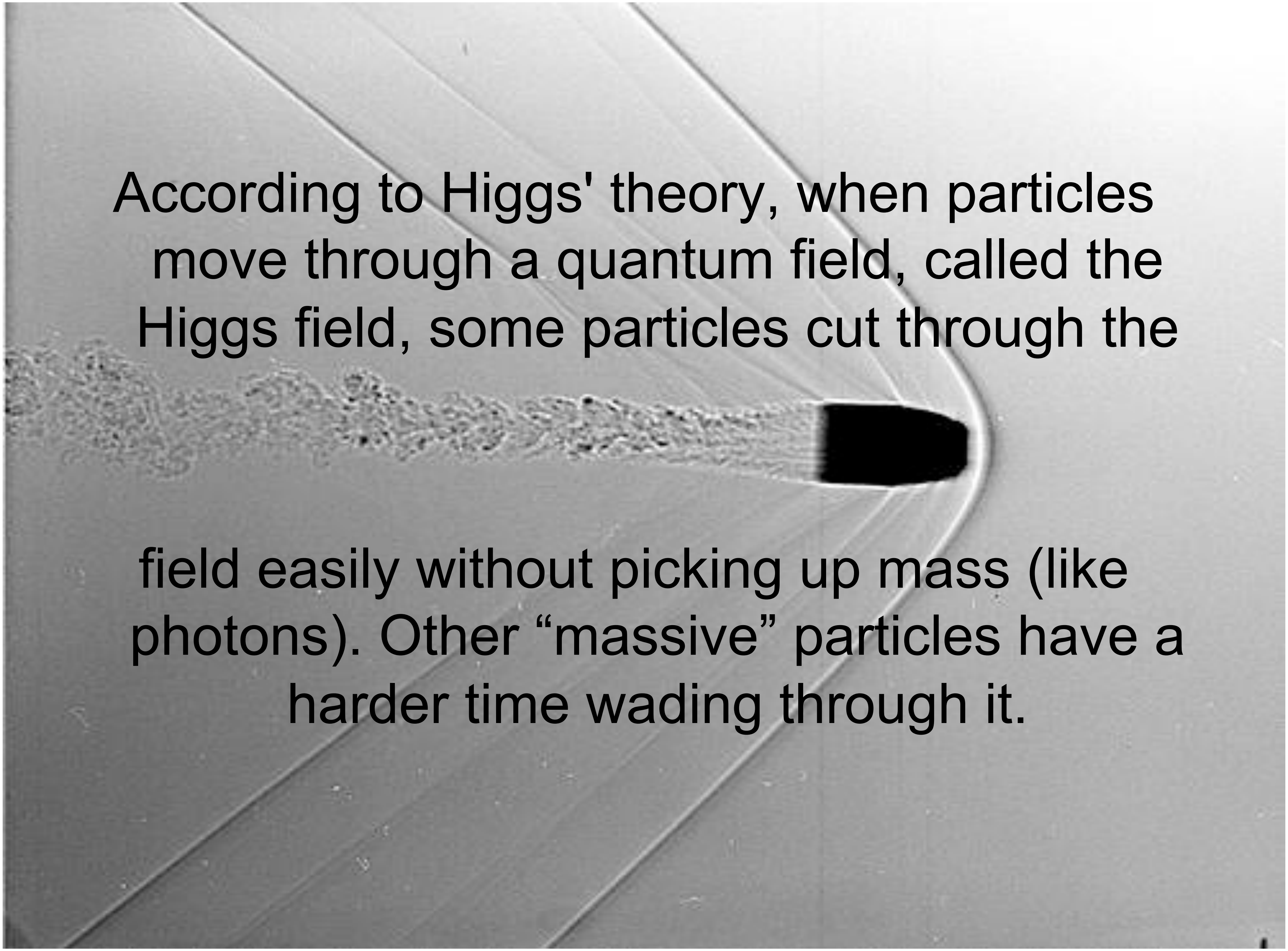
www.cpepweb.org

# The Higgs Boson

In 1964, Peter Higgs came up with a theory that there exists a single particle, now called the Higgs boson, which imparts mass to objects.

Physicist are hoping to find proof of the Higgs boson with experiments conducted at the the LHC.

http://www.time.com/time/health/article/0,8599,1729139,00.html



According to Higgs' theory, when particles move through a quantum field, called the Higgs field, some particles cut through the

field easily without picking up mass (like photons). Other “massive” particles have a harder time wading through it.

What is Dark Matter??

What is Dark Energy??

and why should we be concerned??

The density of energy and matter in our universe plays a crucial role in determining the geometry of space.  The amount of dark energy and matter is a large percentage of the total composition of our universe.

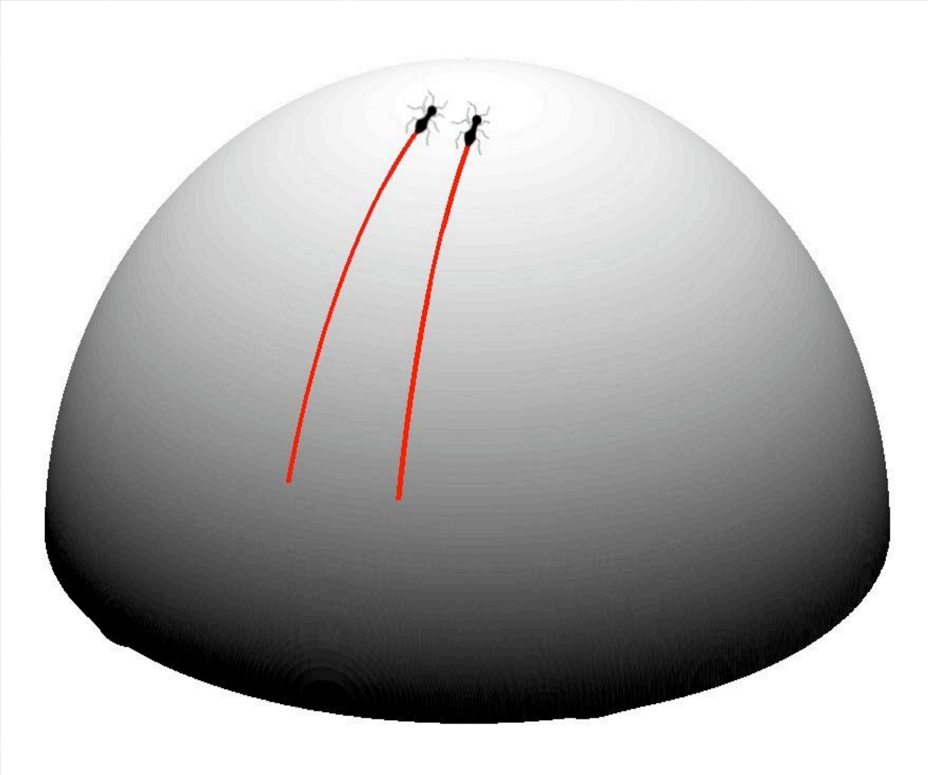
## Composition of the Universe

# A Flat Universe?

http://astronomy.nmsu.edu

Space in a universe at exactly the critical density is flat like a sheet of paper (Euclidean).

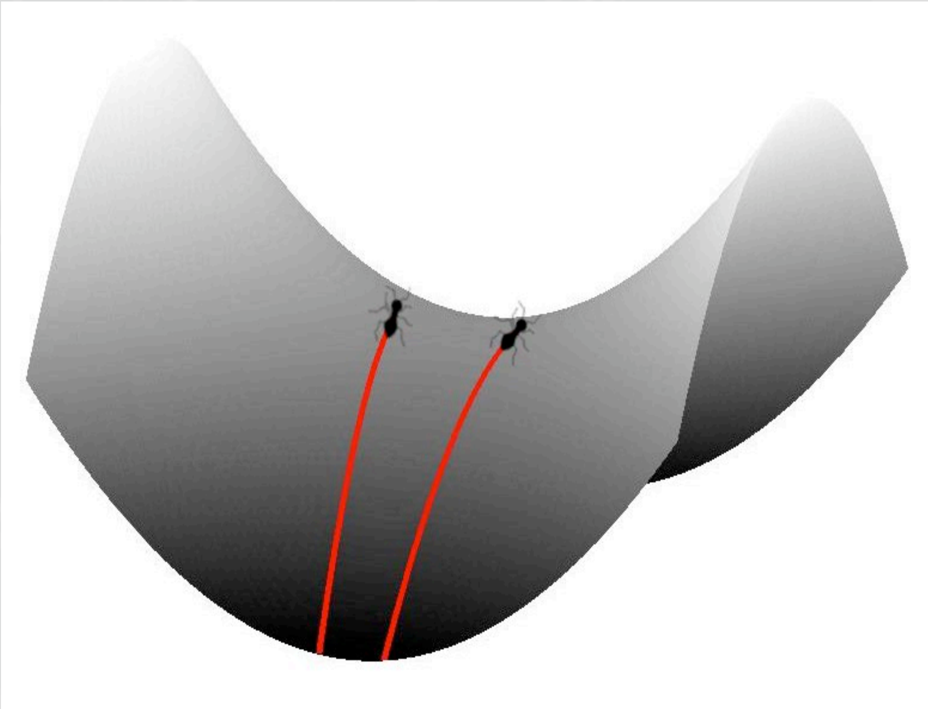
# Positive Curvature?



http://astronomy.nmsu.edu

If the density is greater than the critical density, space is closed & positively curved like the surface of a sphere.

# Negative Curvature?

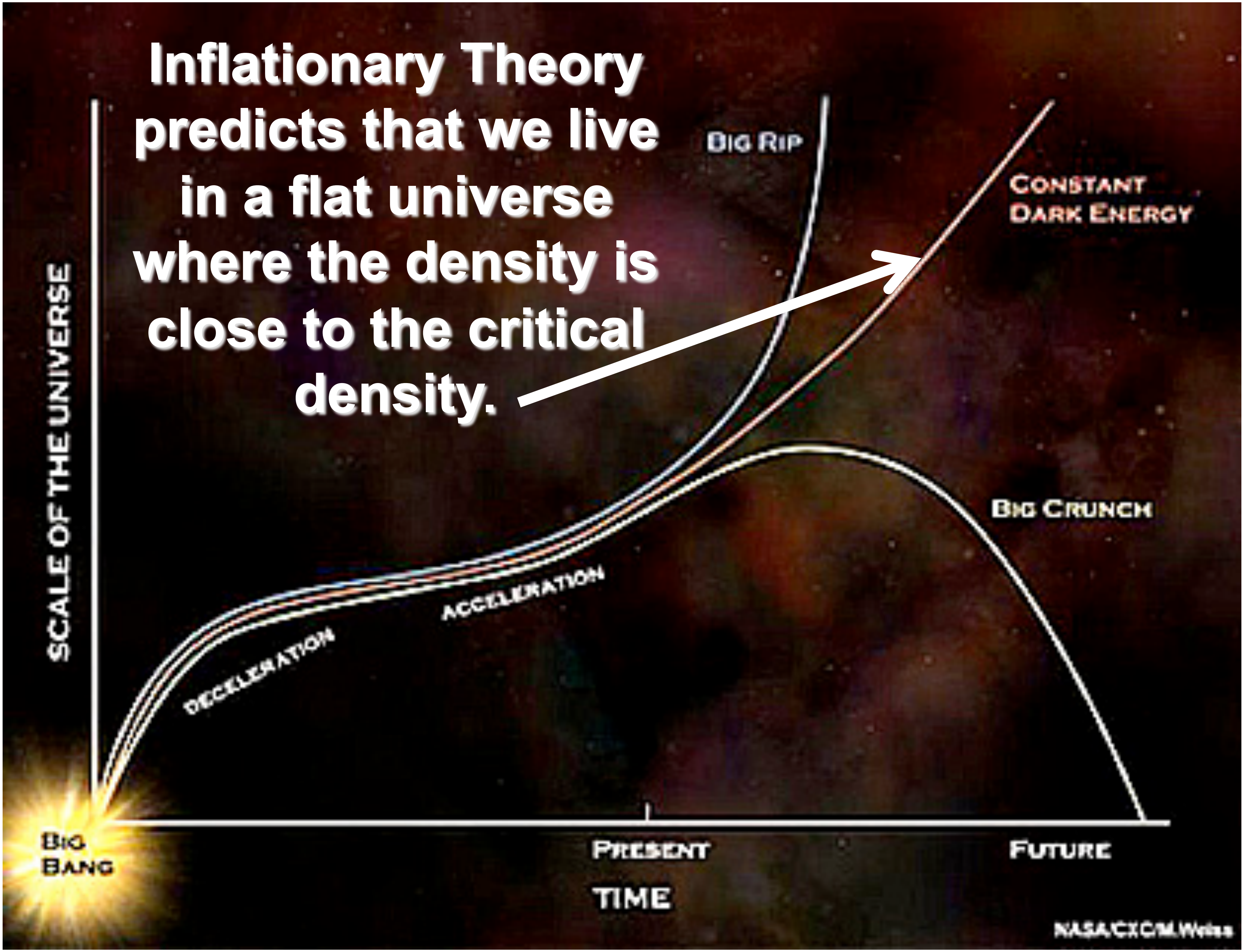


http://astronomy.nmsu.edu

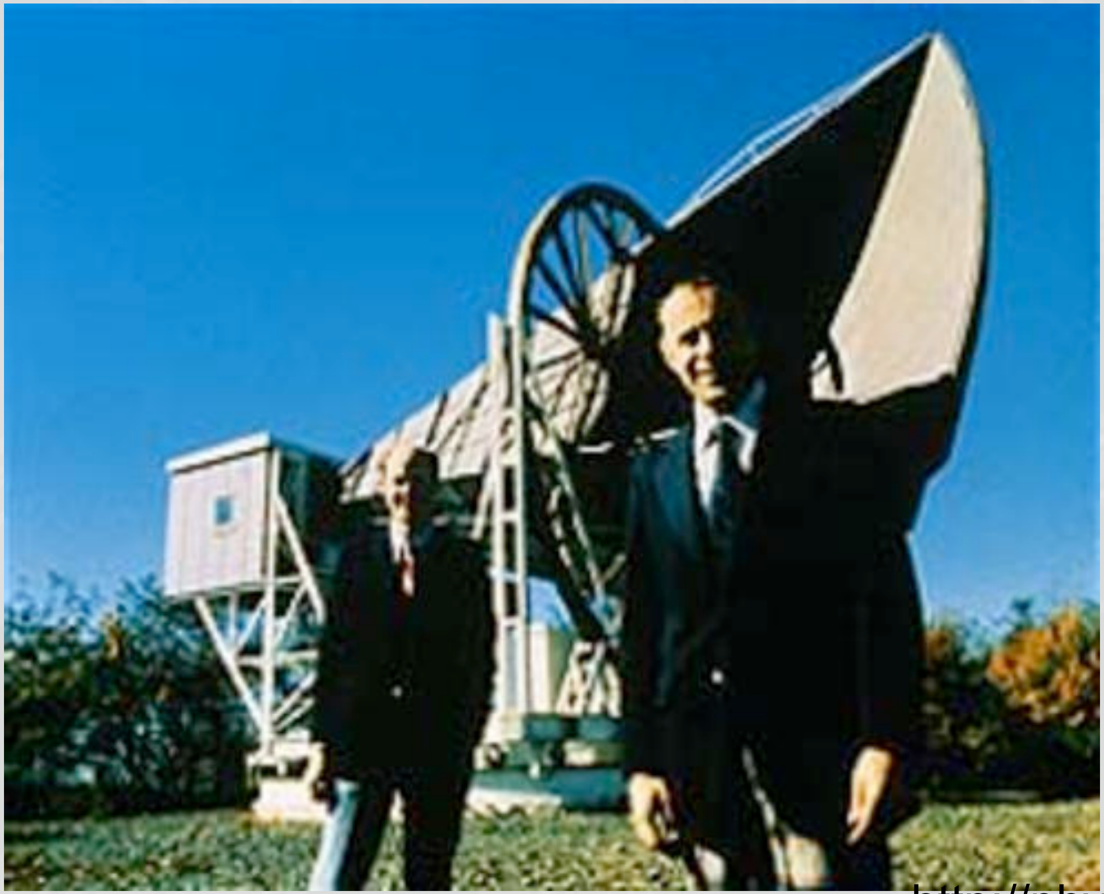
If the density is less than the critical density, the universe is open and space is negatively curved like a saddle.

| Geometry of Space | Curvature of Space | Type of Universe | Average Mass Density | Density Parameter ($\Omega_{mass}$) |
|---|---|---|---|---|
| Spherical | Positive | Closed | $\rho_0 > \rho_c$ | $\Omega_{mass} > 1$ |
| Flat | Zero | Flat | $\rho_0 = \rho_c$ | $\Omega_{mass} = 1$ |
| Hyperbolic (saddle) | Negative | Open | $\rho_0 < \rho_c$ | $\Omega_{mass} < 1$ |

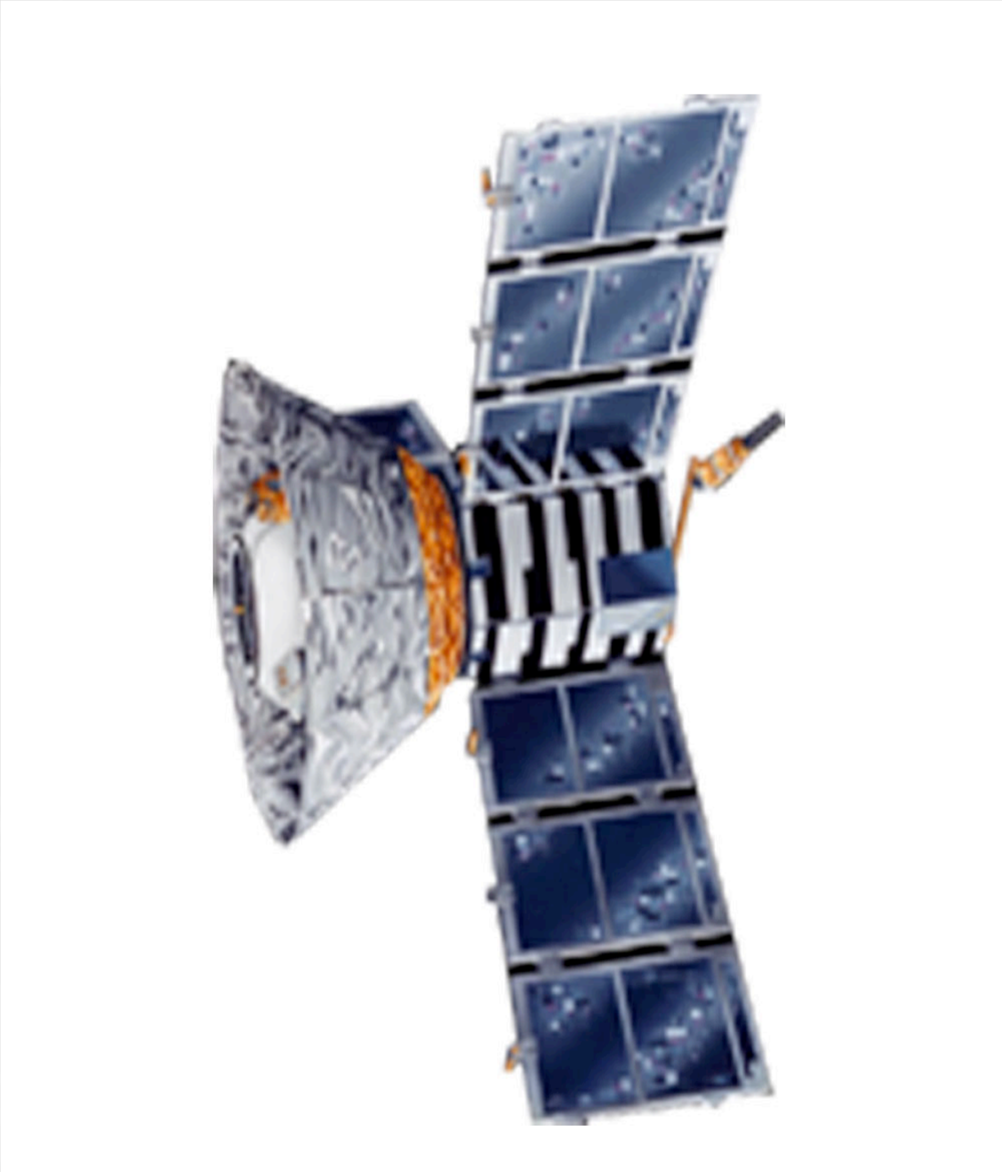
$\rho_c = 10^{-29}$ g/cm$^3$ = $10^{-26}$ kg/m$^3$ (about 6 protons/m$^3$)


Inflationary Theory predicts that we live in a flat universe where the density is close to the critical density.
Big Rip
Constant Dark Energy
Big Crunch
Acceleration
Deceleration
Scale of the Universe
Big Bang
Present
Future
Time
NASA/CXC/M.Weiss

The composition of the universe has been studied for years. In 1965, Penzias and Wilson discovered microwave background radiation with a 6 meter horn antenna.

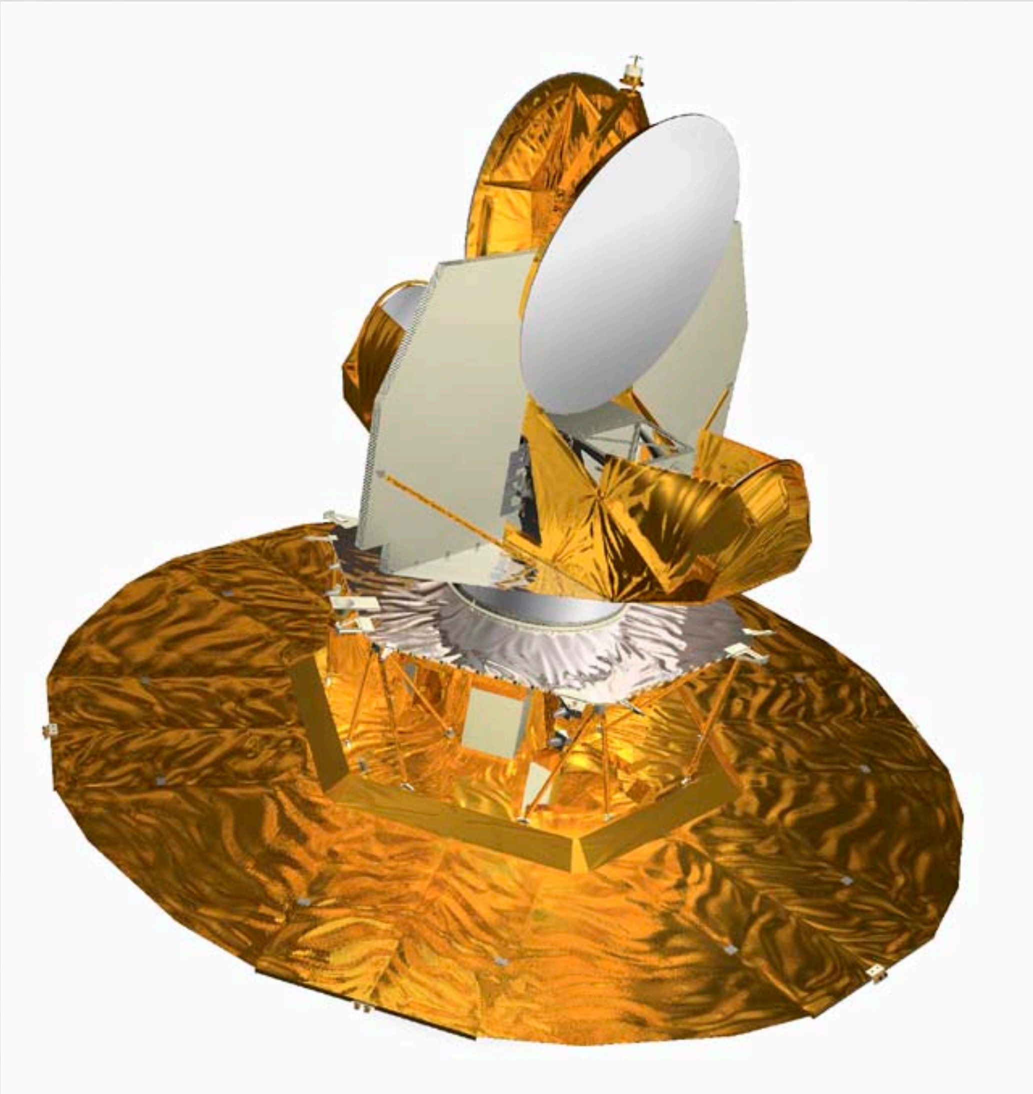


http://physics.uoregon.edu

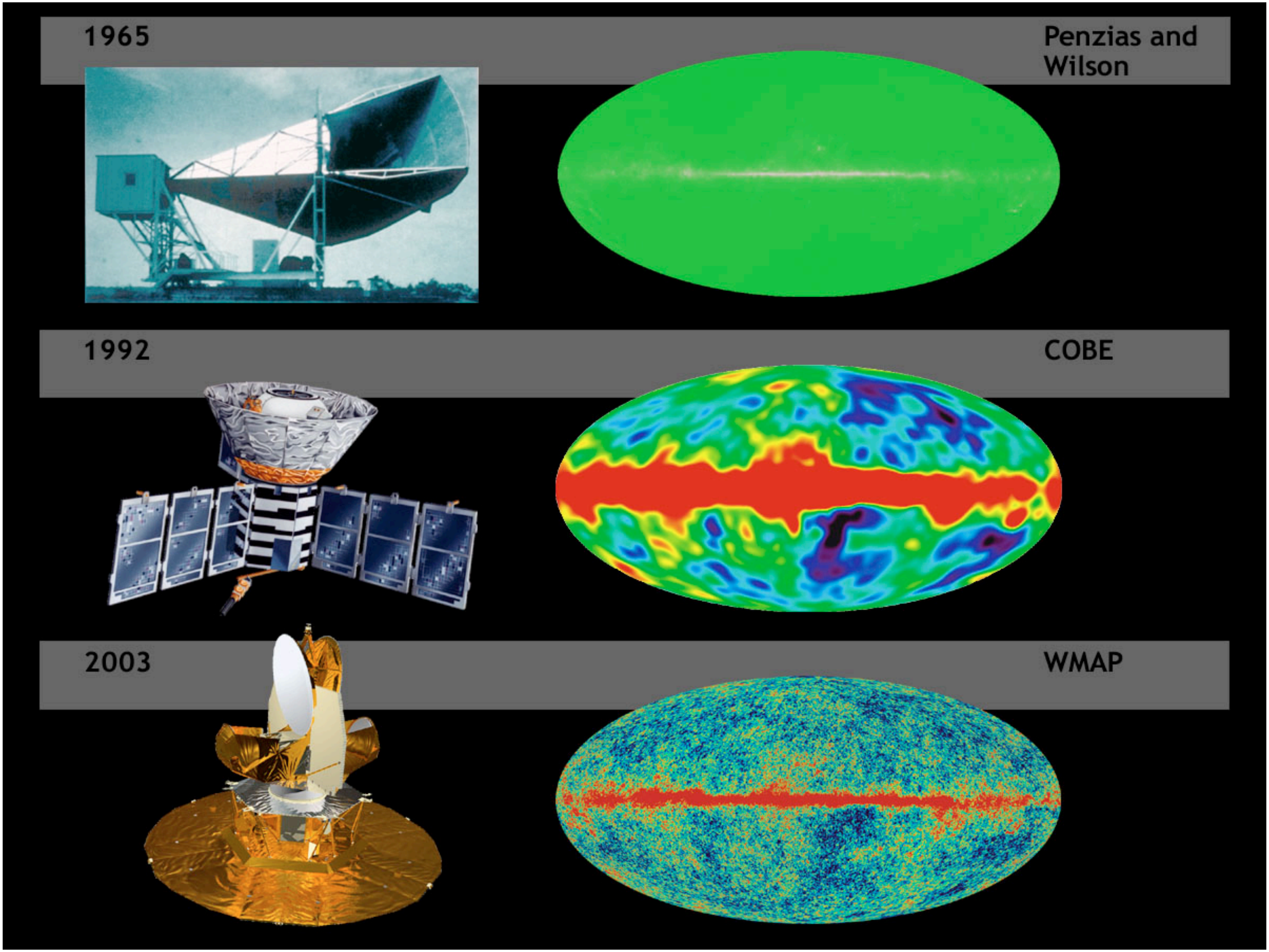


www.lbl.gov

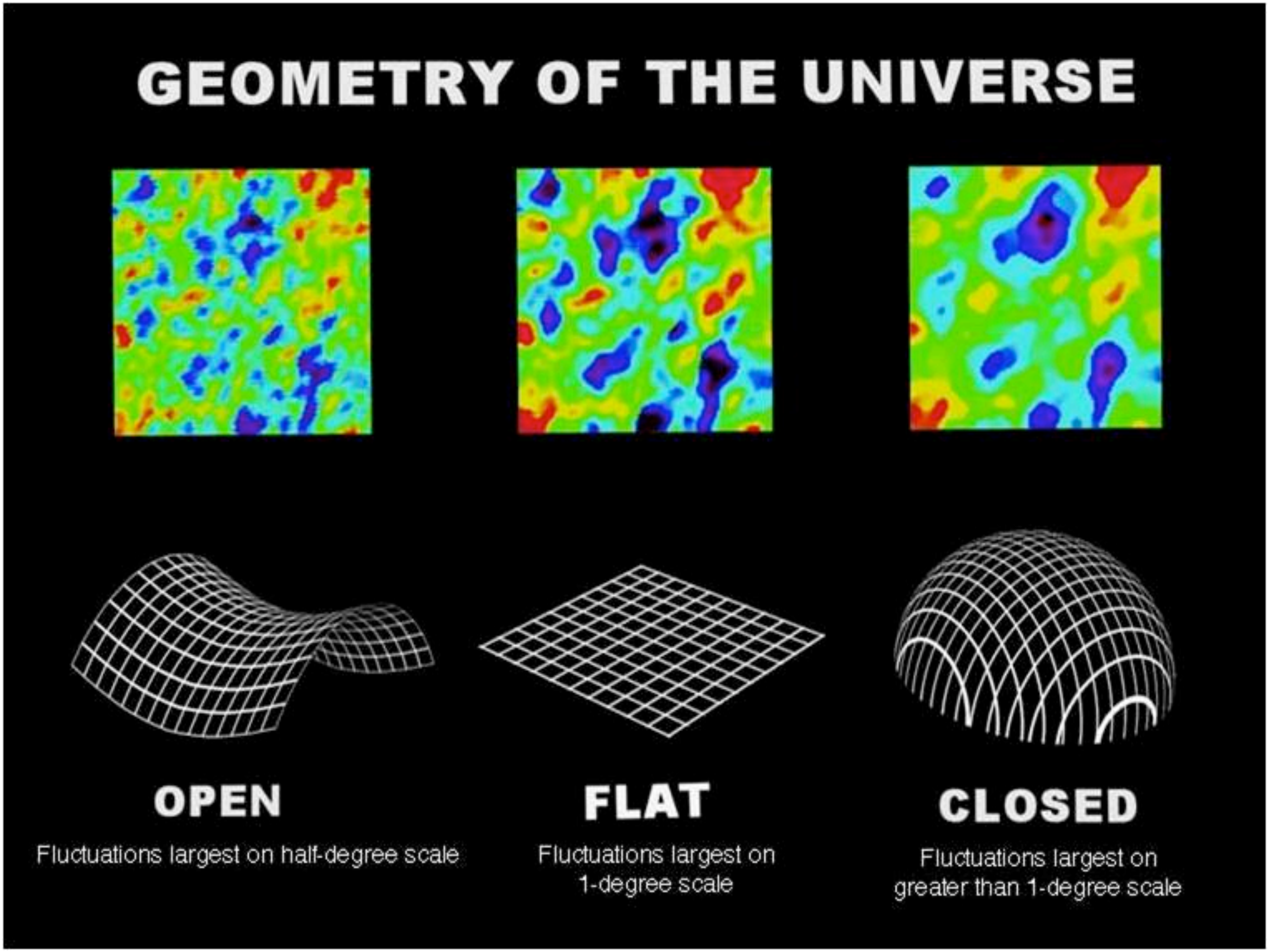
In 1992, NASA's Cosmic Background Explorer measured and mapped the microwave and infrared radiation in the universe.



WMAP was launched in 2001, and in 2003 mapped the Cosmic Microwave Background radiation more accurately than had ever been done before.


1965
Penzias and Wilson
1992
COBE
2003
WMAP

NASA’s Wilkinson Microwave Anisotropy Probe (WMAP) produced the first full-sky map of the microwave sky at a resolution of under a degree. The patterns confirmed a flat universe and the necessity of dark matter and energy. WMAP sees 1 degree fluctuations which implies a flat universe.


GEOMETRY OF THE UNIVERSE
OPEN
Fluctuations largest on half-degree scale
FLAT
Fluctuations largest on 1-degree scale
CLOSED
Fluctuations largest on greater than 1-degree scale

# Click to play this WMAP video…

http://map.gsfc.nasa.gov/media/030639/index.html

The findings of the LHC experiments will certainly broaden our understanding of our universe in ways we cannot yet even imagine. The results may change our future just as past experiments have brought us the knowledge and technology that we have today.

Many thanks to David Gross, Daniel Hone, Jocelyn Quick, the speakers (Ayana Holloway Arce, Kevin McFarland, Raman Sundrum, and James Wells) and everyone at the Kavli Institute for Theoretical Physics for enriching us with this information.