Elementary Particle Physics

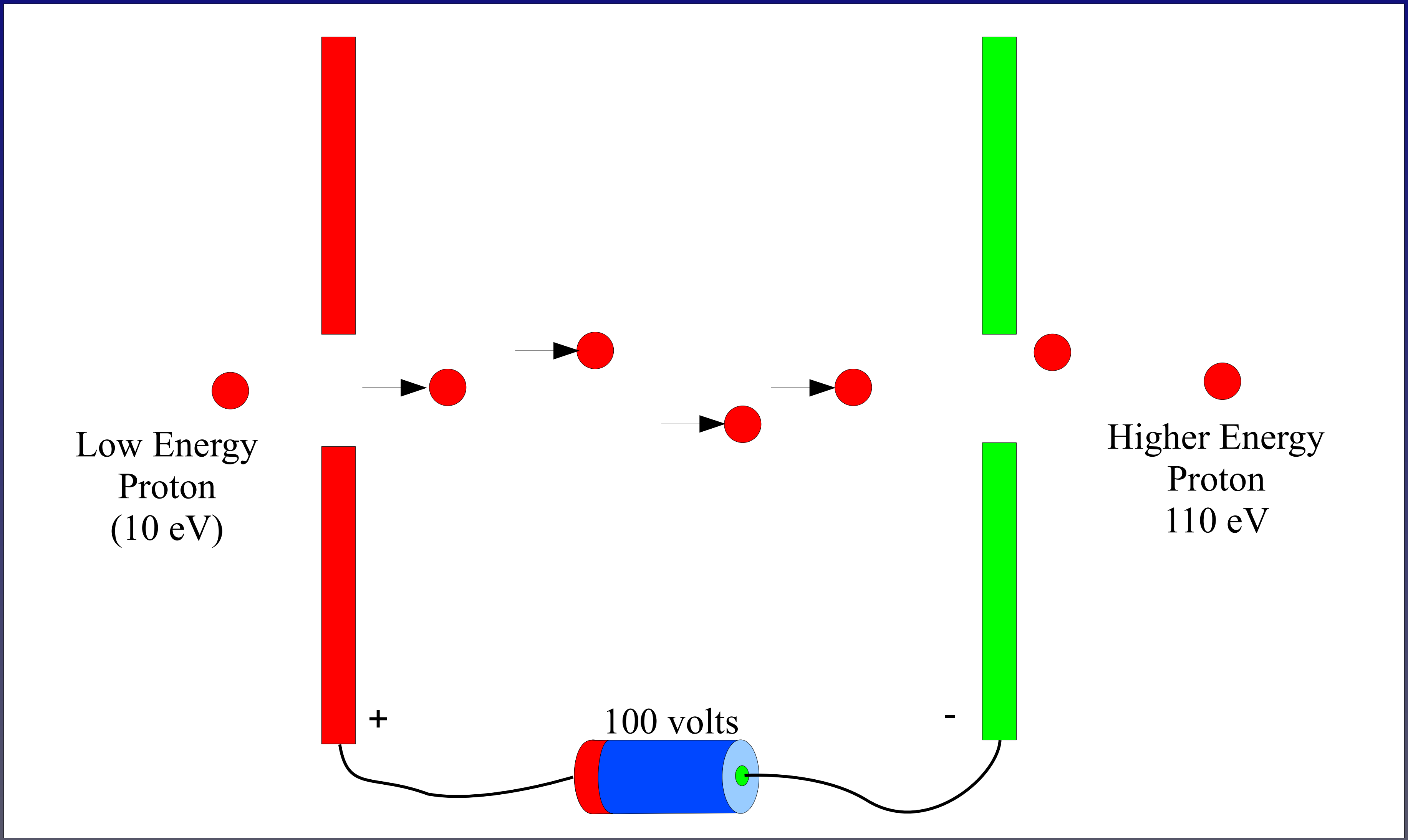
Accelerators

The next step in particle physics will probably come via

The Large Hadron Collider

The Large Hadron Collider

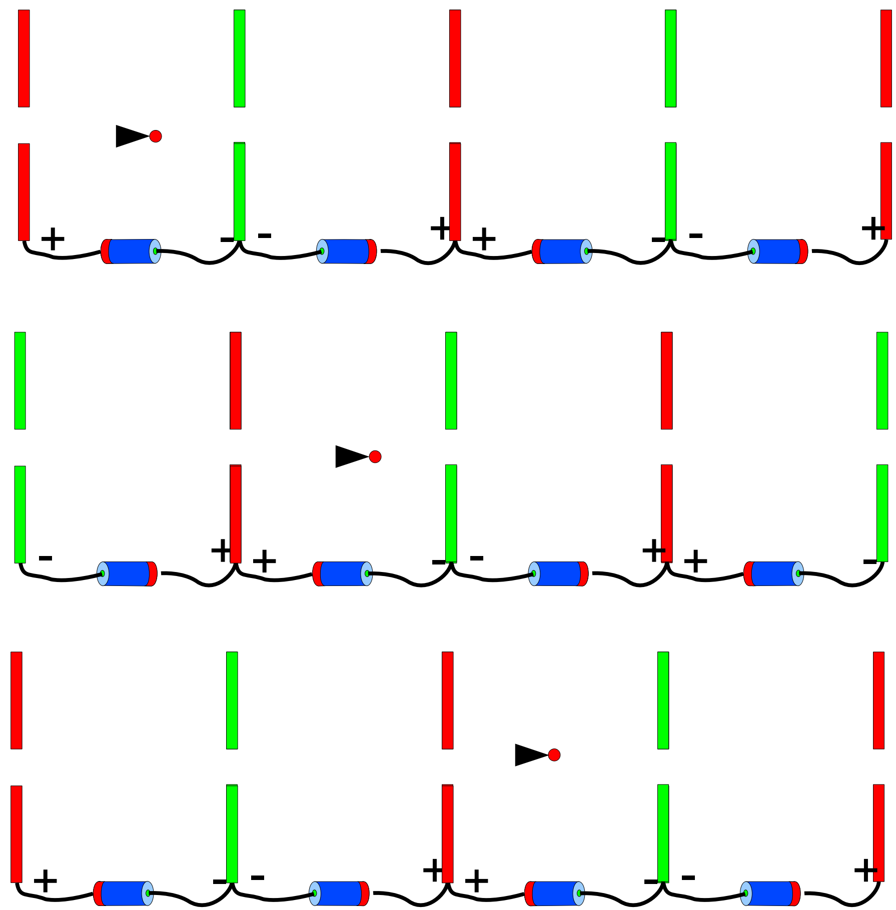
Accelerating a proton beam



The Large Hadron Collider

Accelerating a proton beam

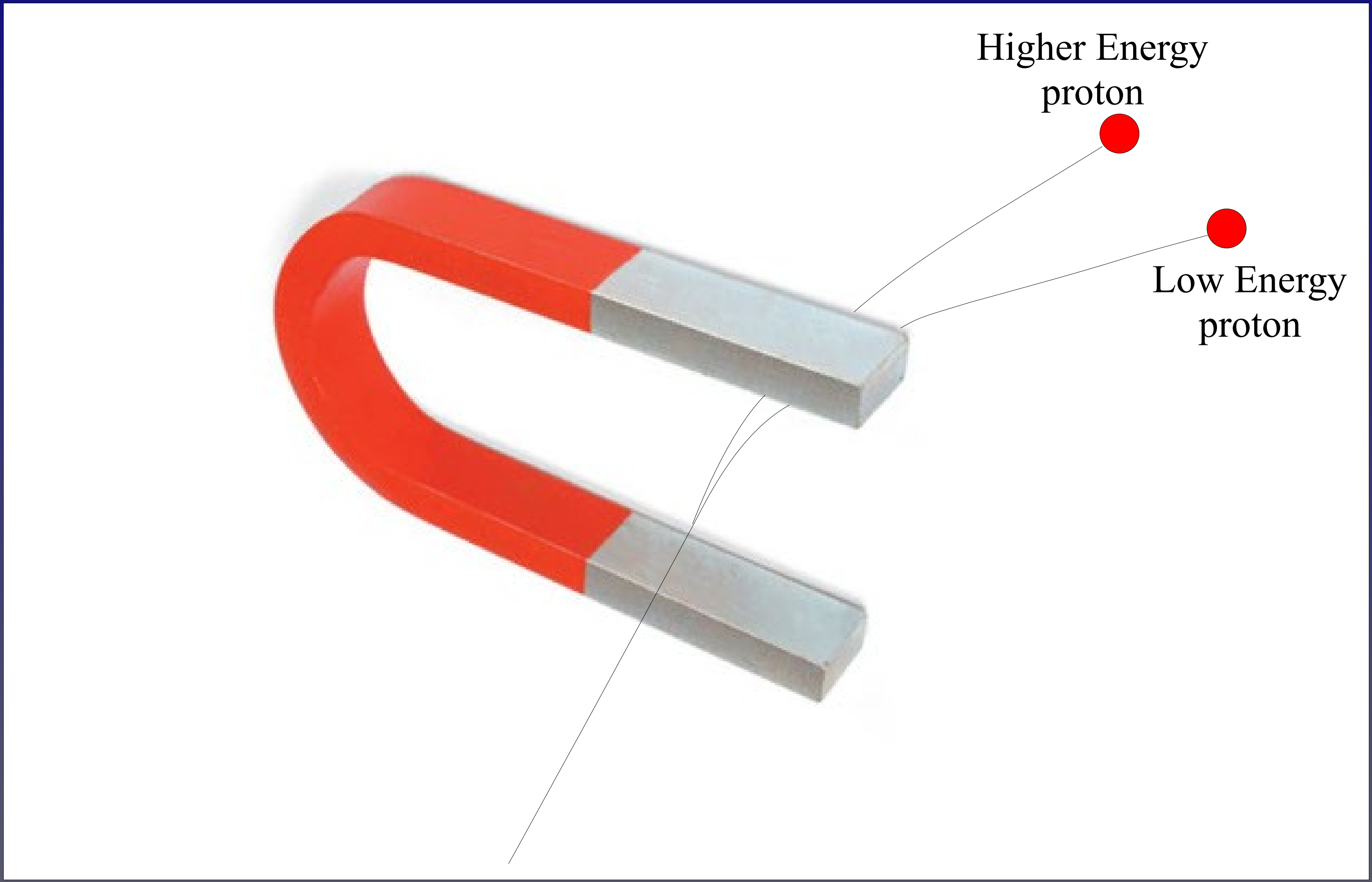
Low Energy protons



Higher Energy Protons 410 eV

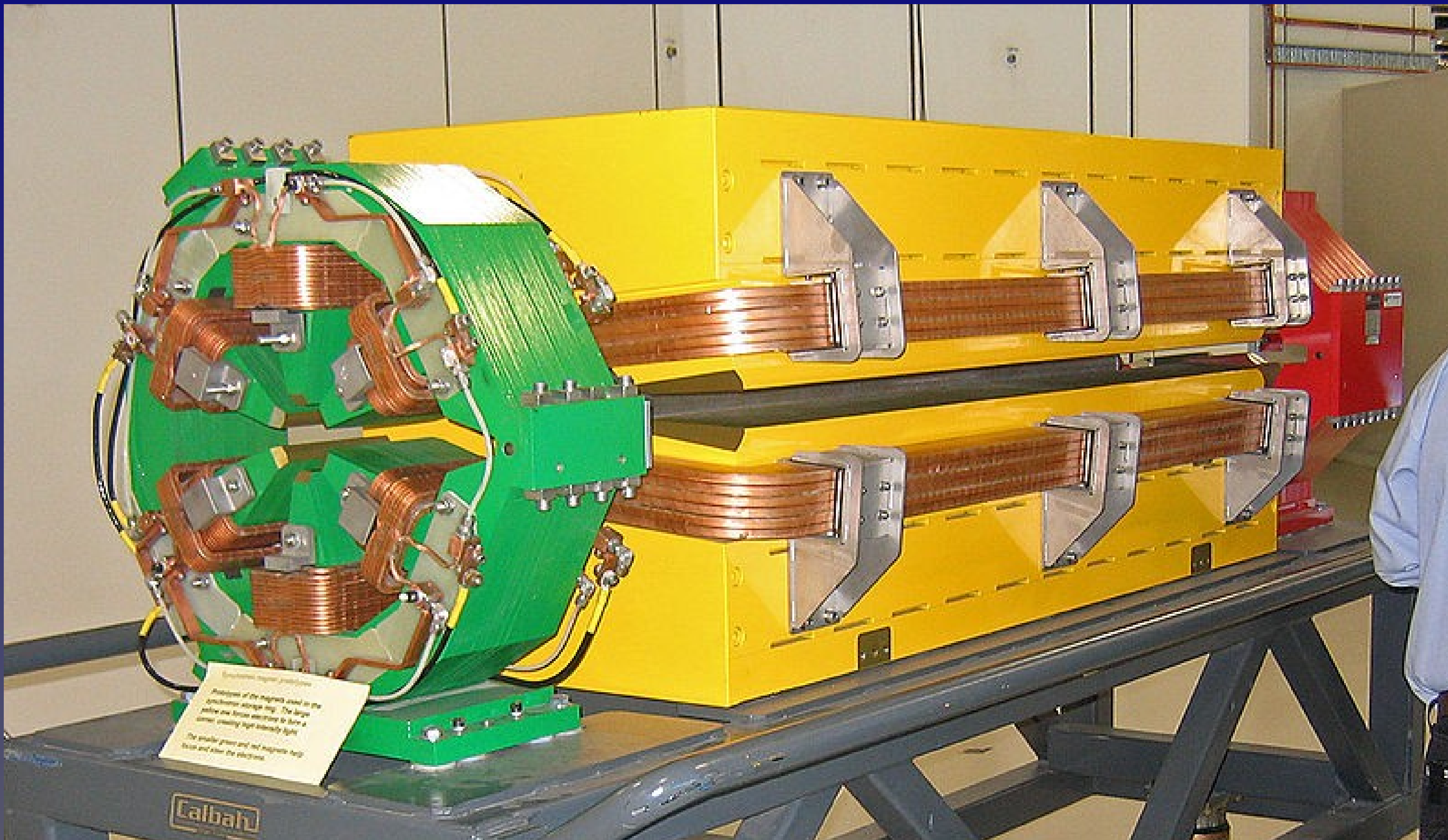
The Large Hadron Collider

Bending the beam



The Large Hadron Collider

Bending the beam

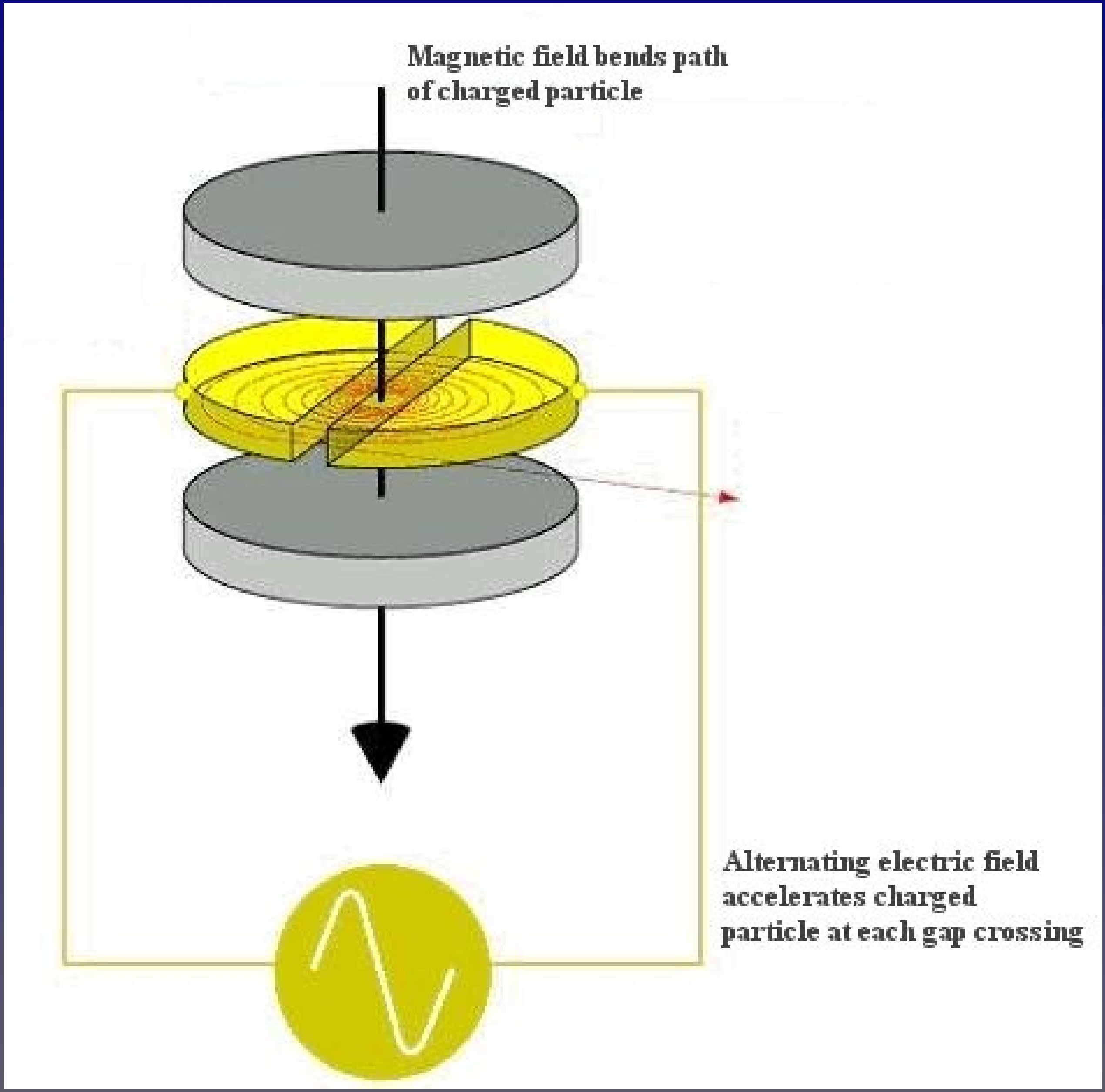


The Large Hadron Collider

A Cyclotron

One of the earliest accelerators that used both repeated acceleration and a circular beam path is the Cyclotron

Earnest Lawrence, 1932



The Large Hadron Collider

Straddling the border between France and Switzerland near Geneva is the newest, largest particle accelerator, the LHC

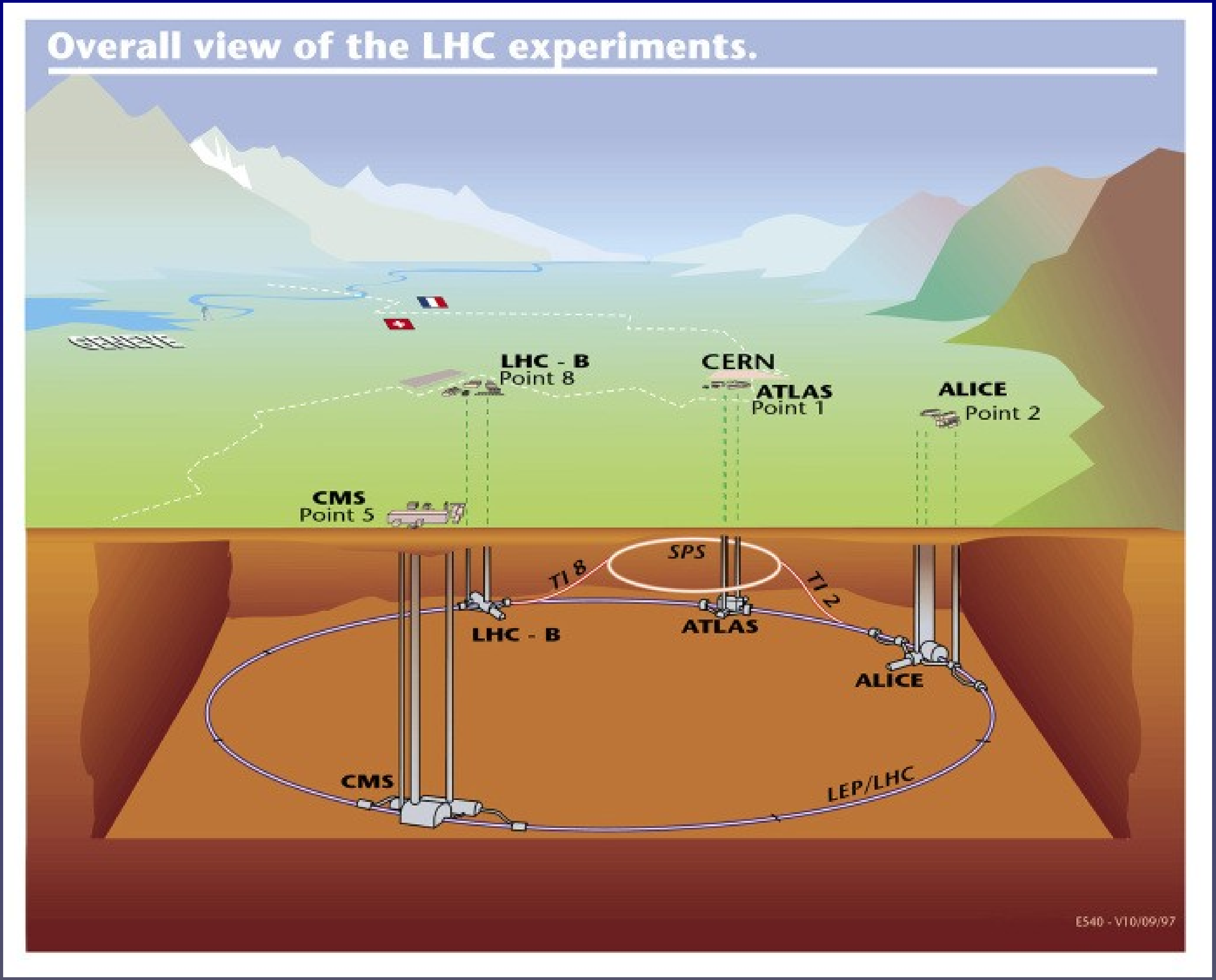
The LHC accelerates protons inside a vacuum pipe that is 17 miles in circumference

The Large Hadron Collider

The LHC is in a tunnel about one hundred feet below ground for stability and to block radiation

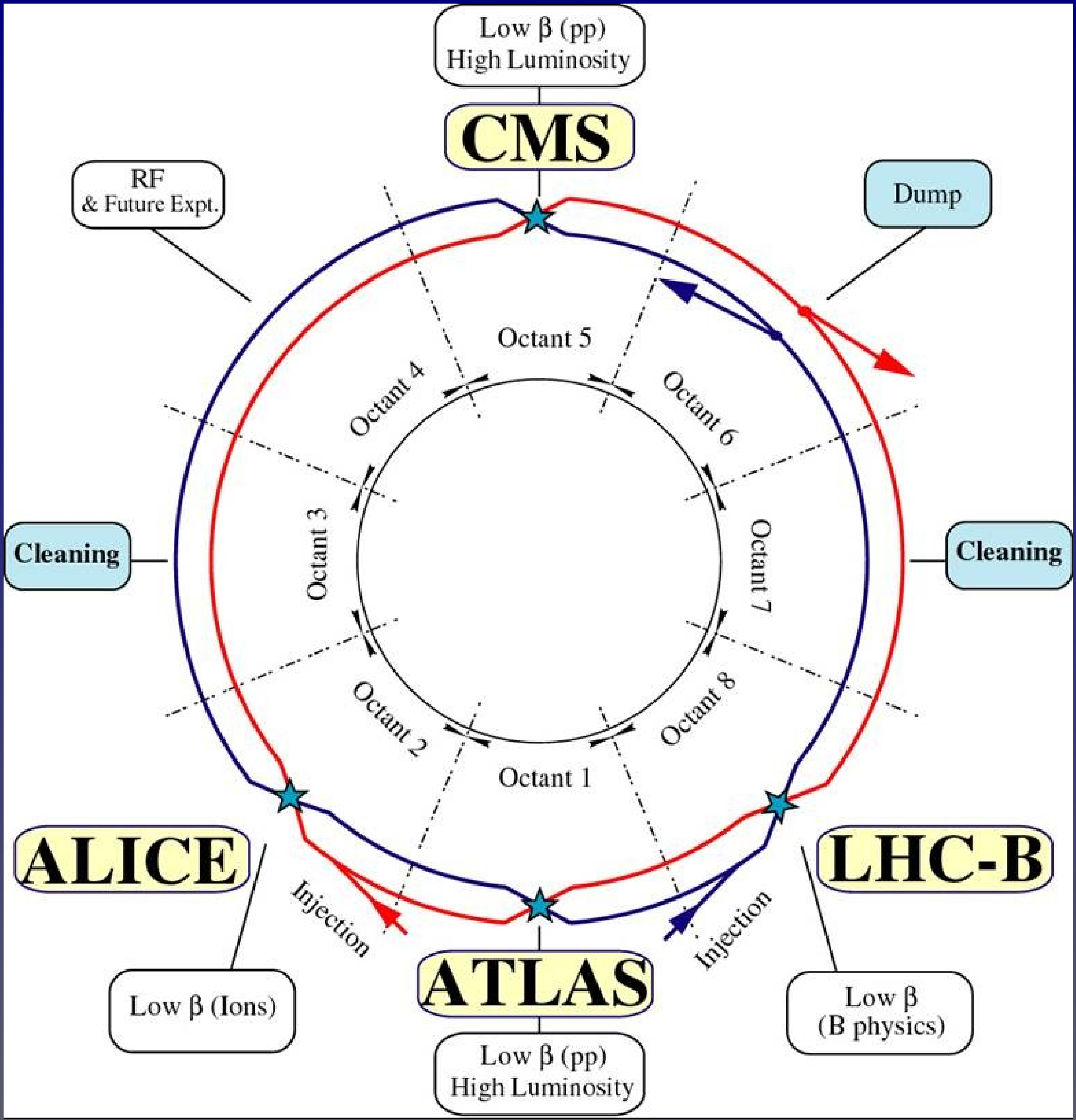
Access shafts from the surface are placed at the sites of the beam source and the experiments

The tunnel is reused from an earlier accelerator



Beam Animation

The Large Hadron Collider



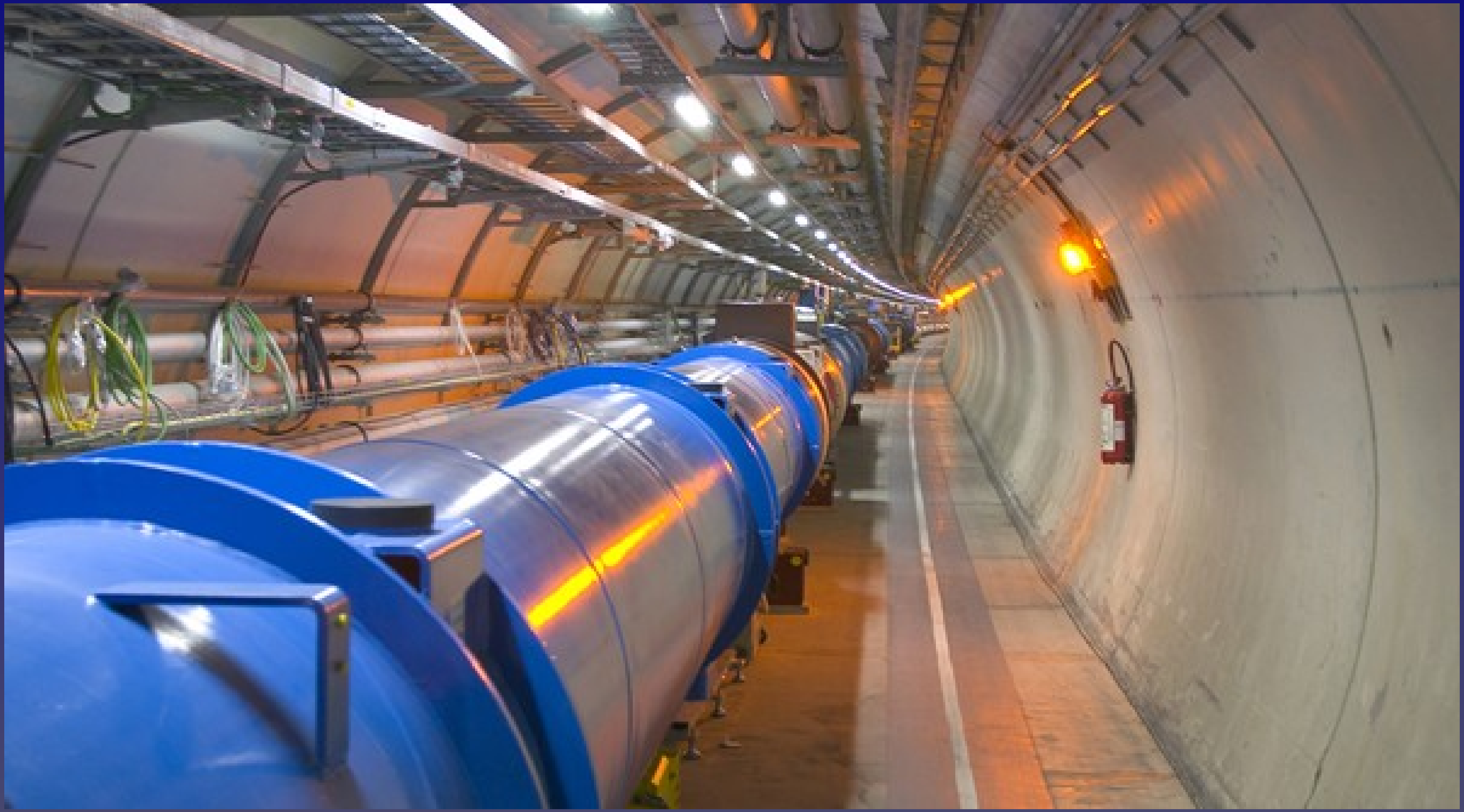
The Large Hadron Collider

Most of the length of the tunnel is filled with superconducting magnets

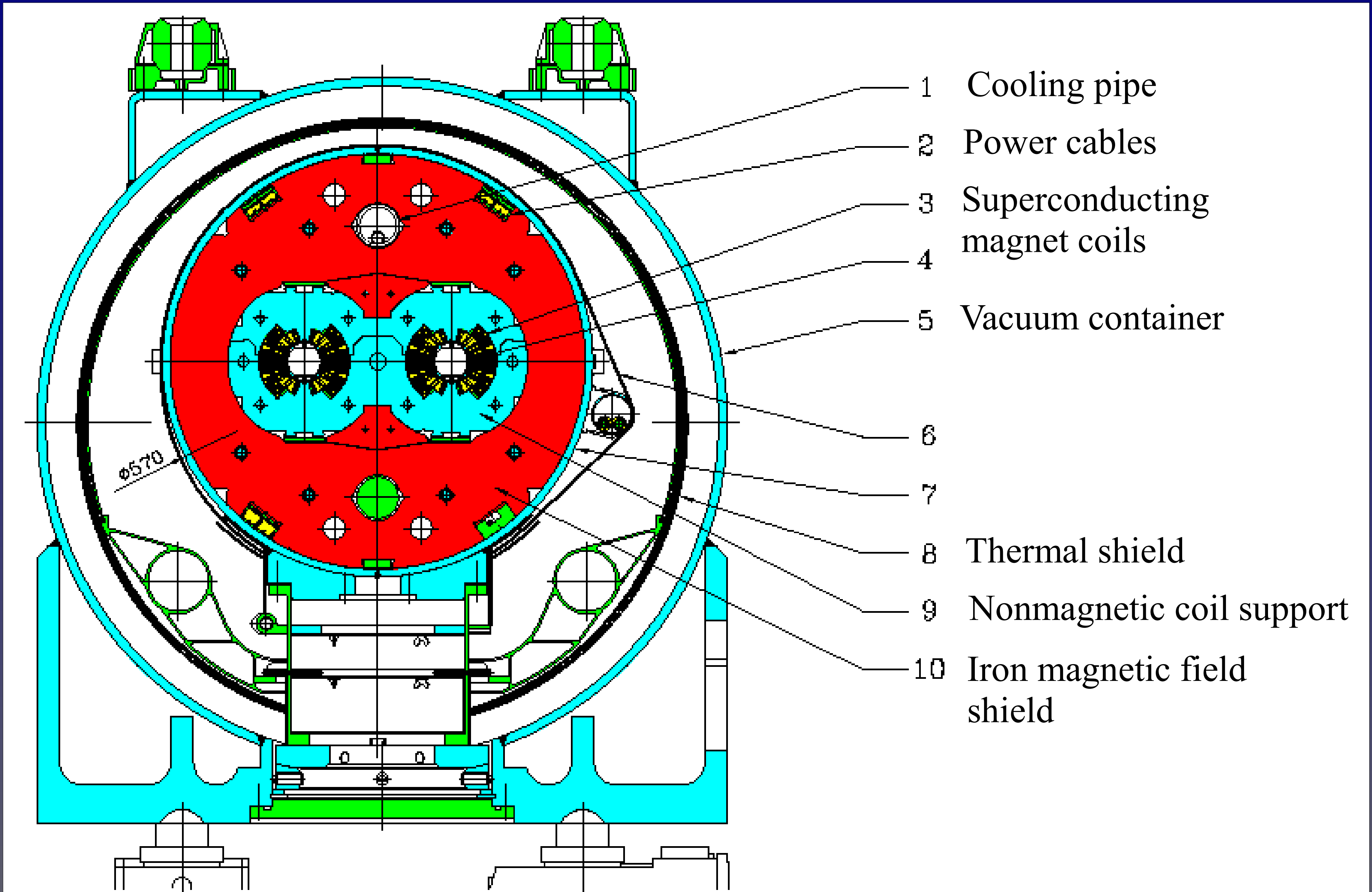
Each magnet uses superconducting wire (zero electrical resistance)

To remain superconducting, the wire must be kept at −456.25 degrees Fahrenheit

Absolute zero is -459.67



The Large Hadron Collider



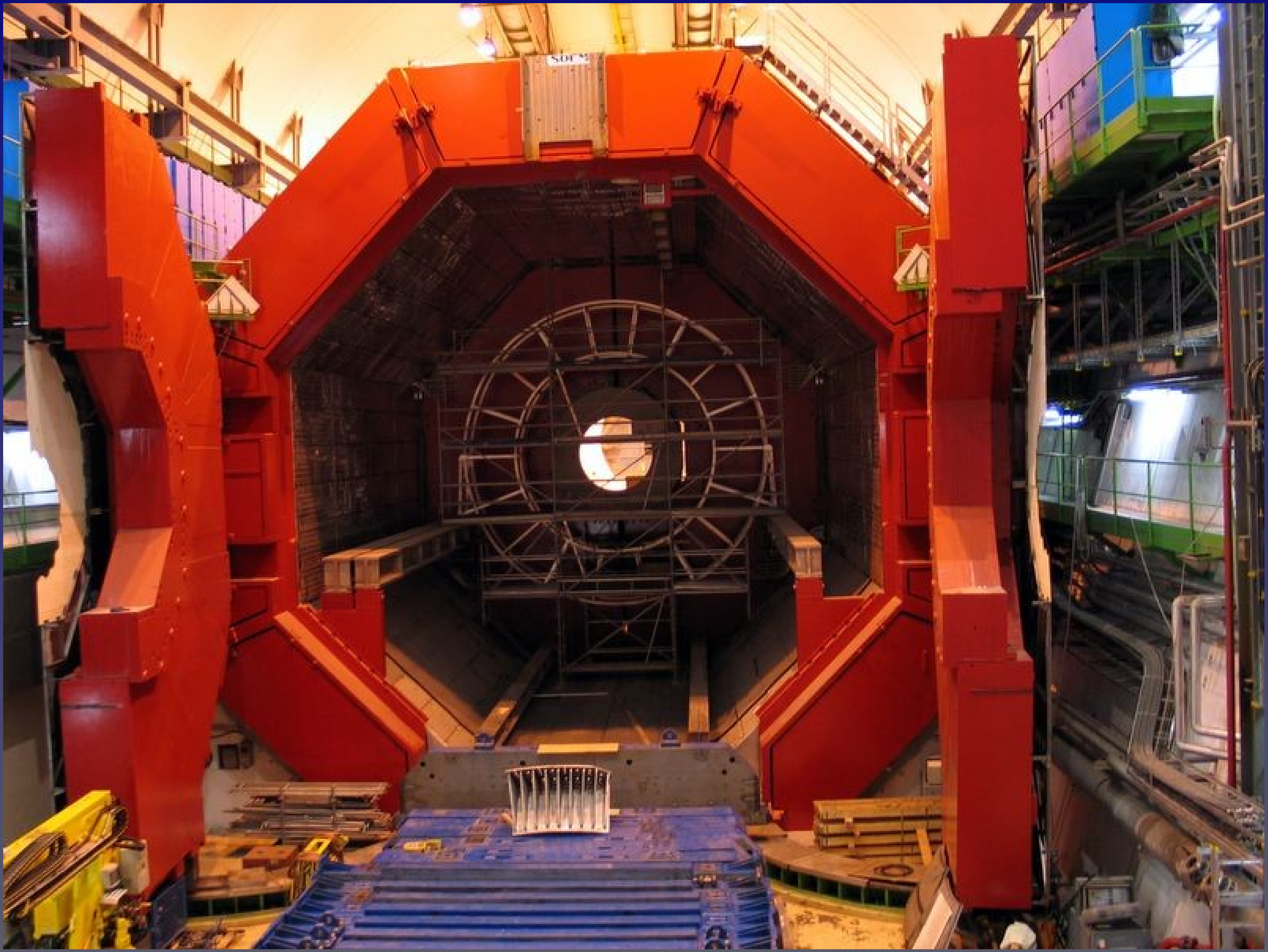
The Large Hadron Collider

At intervals around the accelerator ring, these sections use microwave electric fields to push the protons to higher energies

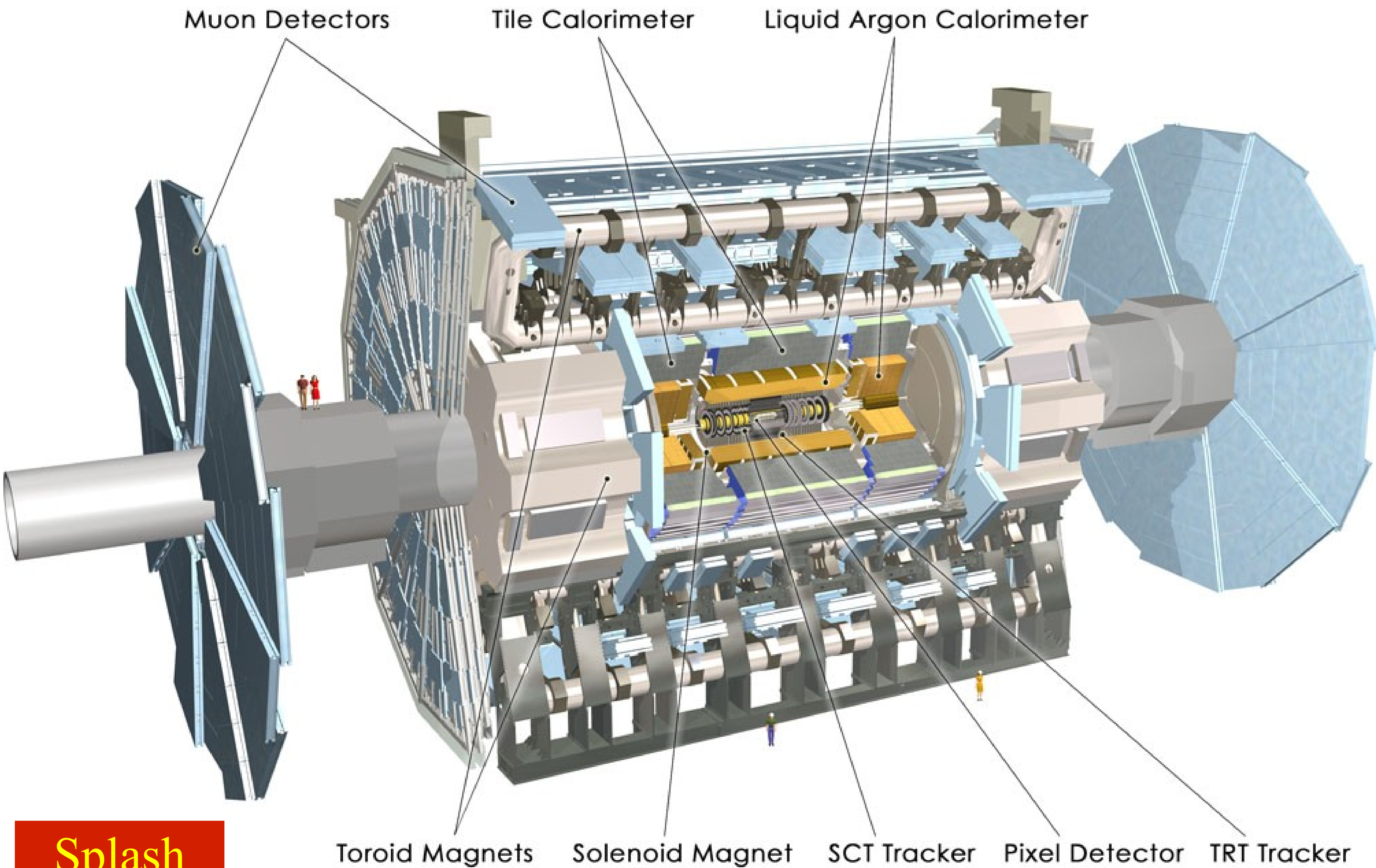
The Large Hadron Collider
CMS detector

The Large Hadron Collider
Alice detector

dual

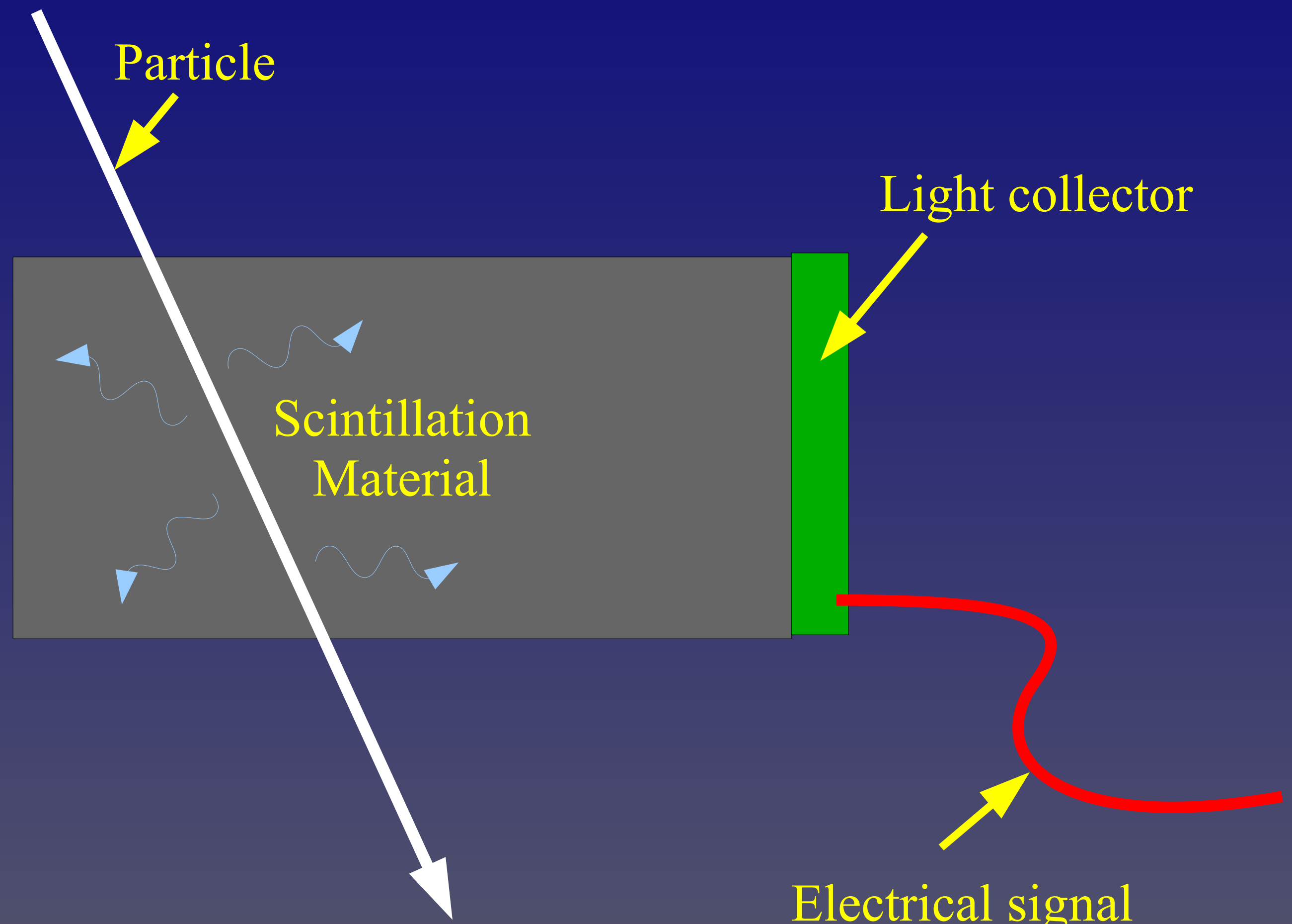


LHC Atlas Detector

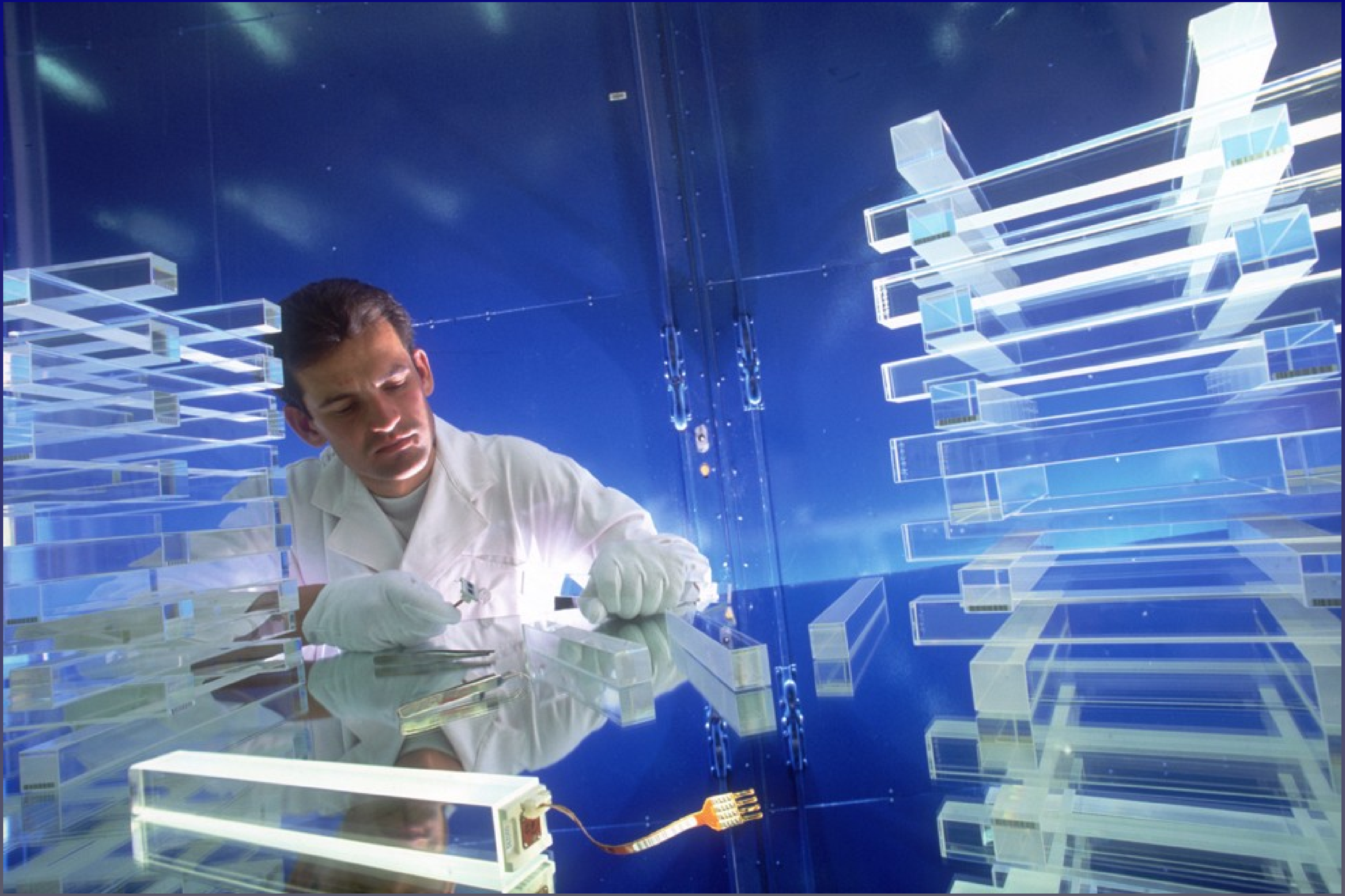


Splash Event

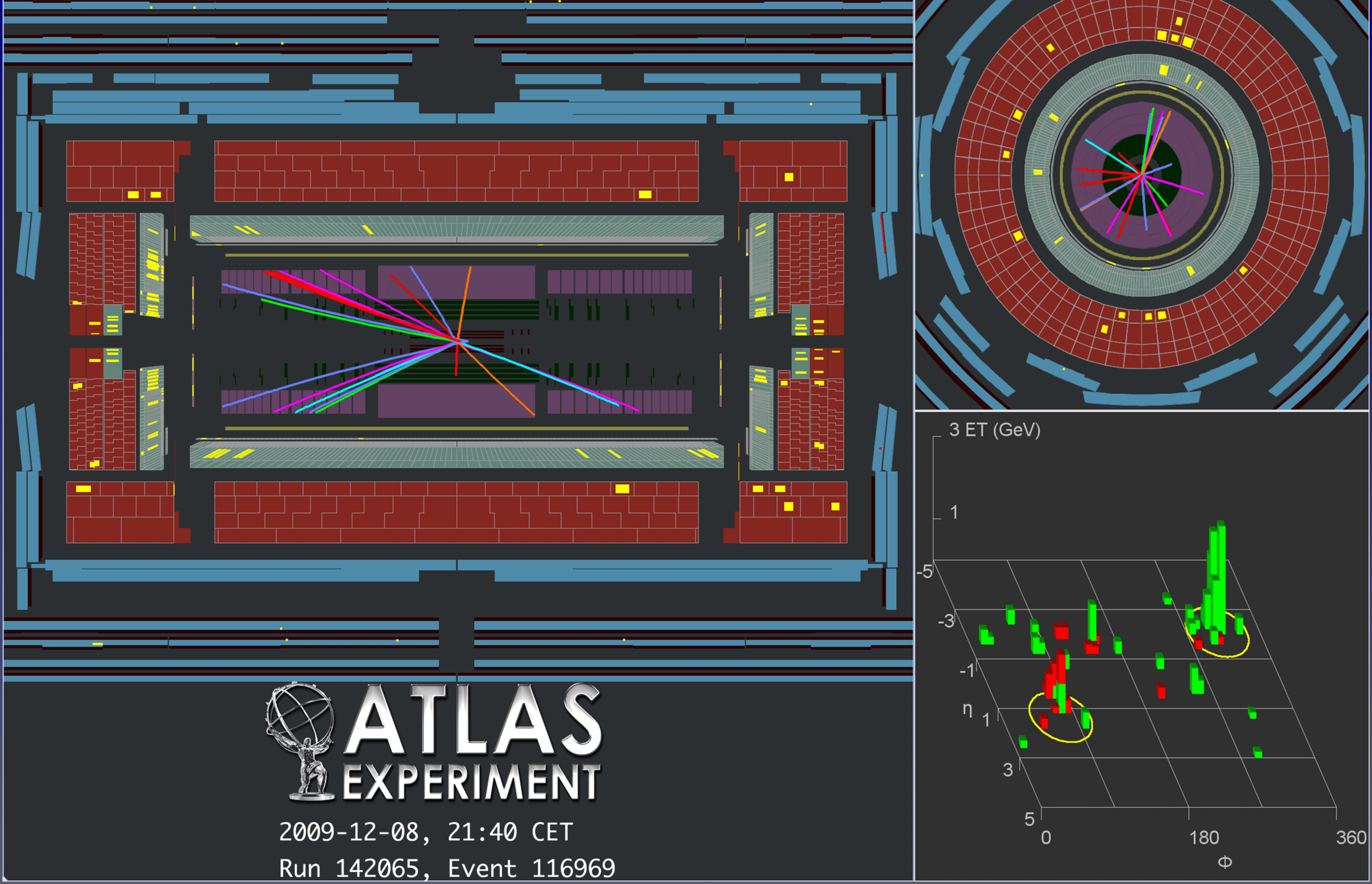
Particle Detectors



Particle Detectors



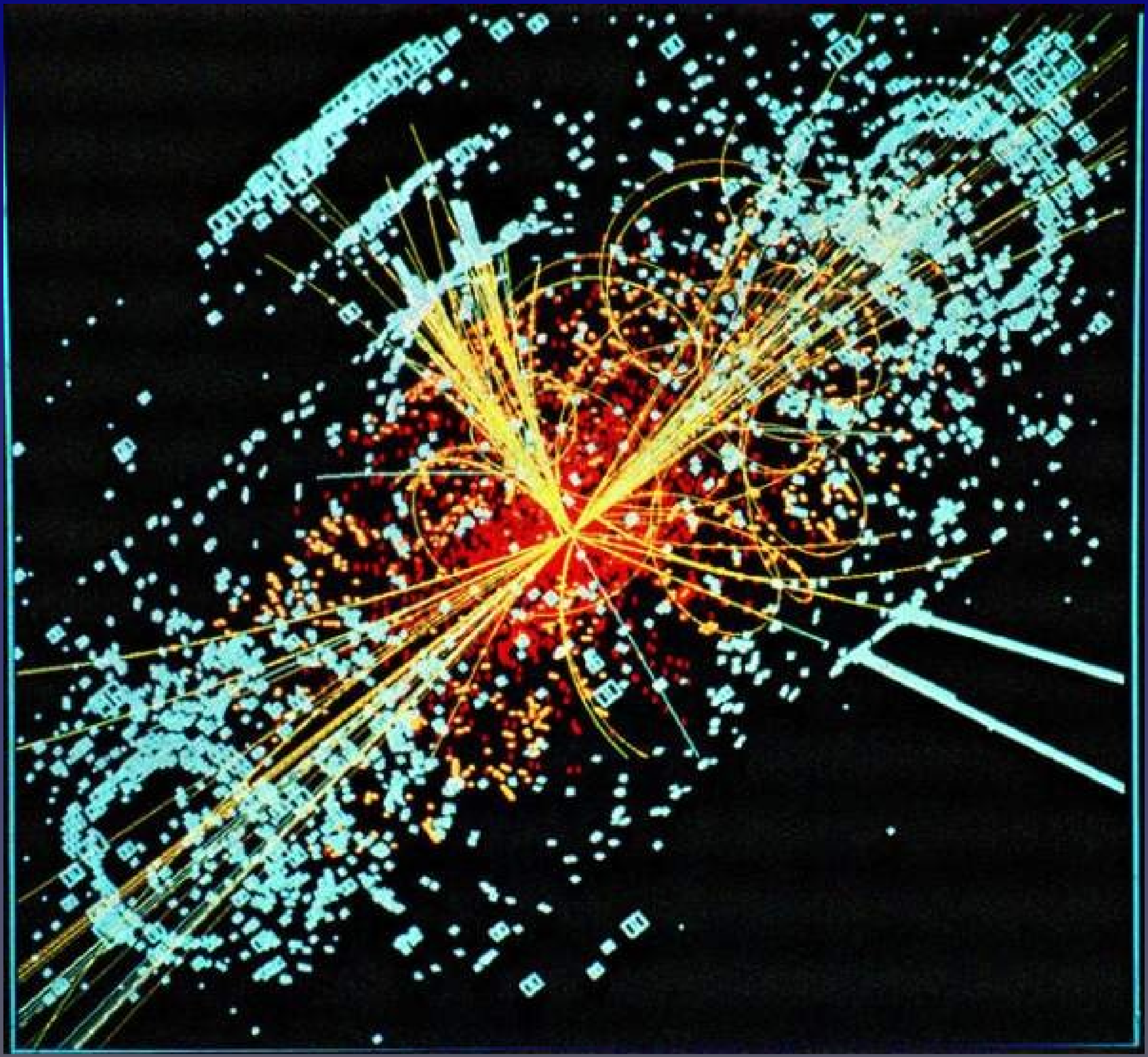
2-Jet Event at 2.36 TeV



The Large Hadron Collider

CMS detector simulation

A simulation of what the creation of a Higgs boson would look like in the CMS detector



Elementary Particle Physics

Beyond the Standard Model: String Theory

Since a beginning by Gabriele Veneziano in 1968, the idea that particles are like tiny strings has gone through several different forms

The strings are very, very small: about the Planck Length

$$L_p = \sqrt{\frac{\hbar G}{c^3}}$$

where

$\hbar$ *is Planck's constant*

G *is the universal gravitational constant*, and

c *is the speed of light.*

$$L_p = 1.6 \times 10^{-35}\ meters$$

$$= \frac{1.6\ meters}{100{,}000{,}000{,}000{,}000{,}000{,}000{,}000{,}000{,}000{,}000{,}000}$$

Elementary Particle Physics

Beyond the Standard Model: String Theory

The strings are known only as a mathematical concept

Originally, each particle of the Standard Model was supposed to be a string vibrating a certain way

Using Einstein's discovery that mass and energy are equivalent, the energy of the vibrating sting became the particle's mass

The main attraction of the theory was that it could potentially describe gravity. No other quantum theory did that.

The theory didn't give a realistic description of the particle zoo

So the small intrepid band of researchers kept working

Elementary Particle Physics

Beyond the Standard Model: String Theory

In 1984, the First Superstring Revolution occurred

So far, every calculation of anything had produced only infinity

Schwarz and Green showed that in a ten-dimensional space, some calculations might give a finite number

Then, they found not only one finite string theory, but another, and another

So far, nobody could actually calculate any real physical quantity, so which string theory was the right one?

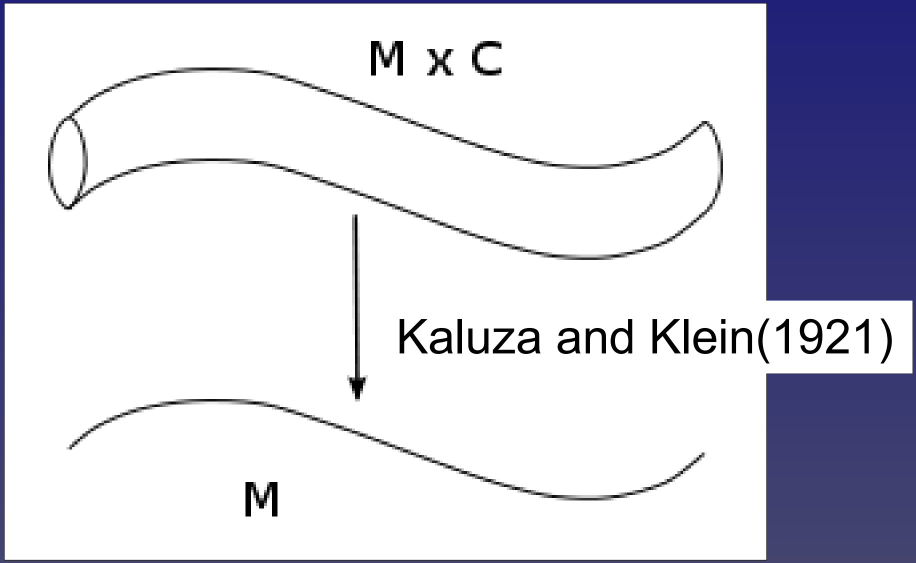
Keep working. Even Newton went though a phase where he thought he was on the right trail, but had no final result.

Elementary Particle Physics

Beyond the Standard Model: String Theory

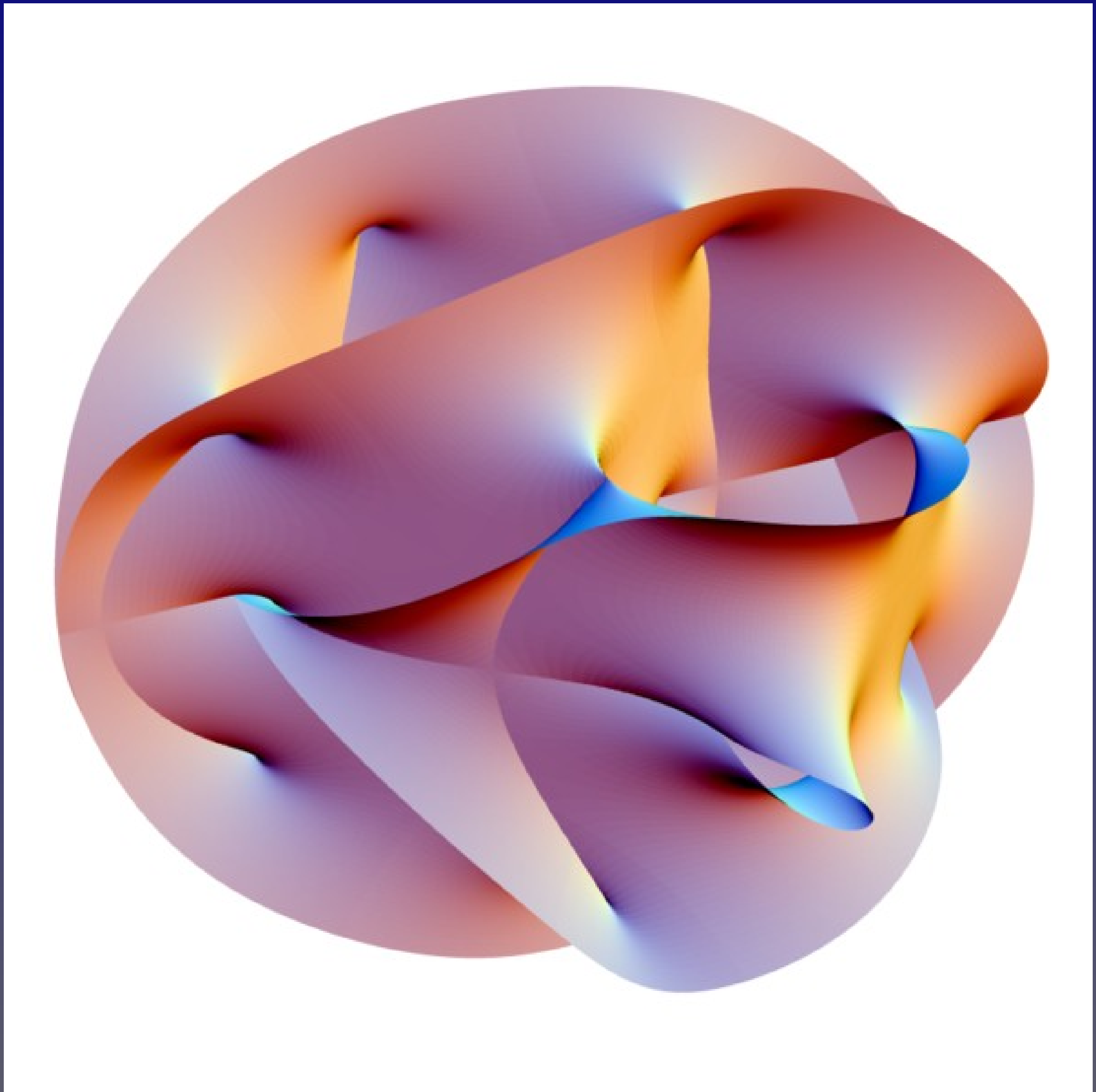
What does it mean to have a universe of ten dimensions?

Six of the dimensions might be curled up so tightly we can't see them



Elementary Particle Physics

Chalabi-Yau Space of six dimensions



A two dimensional sheet (piece of paper) in the Chalabi-Yau space

Elementary Particle Physics

Beyond the Standard Model: String Theory

In 1995 The Second Superstring Revolution happened

By now there were five superstring theories

Edward Witten showed evidence that all five theories were actually the same, just written using different but related mathematical methods

Witten suggested that the “real” string theory had eleven dimensions, and the five ten-dimensional theories were each a special case of the general theory

The special cases were due to different ways of curling up the extra dimensions

Okay, let's find the general theory. Keep working.

Elementary Particle Physics

Beyond the Standard Model: String Theory

As work progressed, Joseph Polchinski discovered that there were not only strings (one-dimensional objects) in the theory, but also objects with more dimensions

There were two-dimensional objects—membranes

There were three-dimensional objects—three-branes

An object with p dimensions was called a p-brane (pea-brain)

An object with zero dimensions was a no-brane.

Maybe our three-spatial-dimensional universe is a three-brane in the eleven overall dimensions

No time to rest guys, keep working!

Elementary Particle Physics

Beyond the Standard Model: String Theory

Still, no one could calculate any physical quantity

String theory makes no predictions that can be used to prove or disprove it in experiments

Finally, the concept of branes allows an experimental test using Newton's law of gravity

$$F = \frac{G \times M_1 \times M_2}{R^2}$$

The gravitational force drops off as $1/r^2$ because the gravitational field spreads in three dimensions

Once gravity is measured on a scale smaller than the curled-up dimensions, its radial behavior will not be $1/r^2$

Elementary Particle Physics

Beyond the Standard Model: String Theory

Again, as work progressed more and more slightly different string theories emerged

Eventually it appeared that there are an infinite number of string theories

Each theory describes a different universe

The universe of universes was named the *Multiverse*

So several theorists proposed *The Anthropic Solution*

There actually are an infinite number of universes. We just happen to live in one of them

Choose any theory that describes what we see

The "end of physics," but very different than expected?

Shall we keep working???

Elementary Particle Physics

The politics of string theory

They kept on working........

String theory has been under development for 42 years

At each moment, the workers thought themselves on the verge of "the theory of everything"

No time to waste. No resources to spare. Ignore the nonbelievers

There are other theories: loop quantum gravity, causal set theory, spin foam, others

Anyone who works on another theory is a nonbeliever

Elementary Particle Physics

The politics of string theory

Statements that are simply not true began to appear in the literature. For example:

The finiteness of the theories had not been proven, but it was said to be so in many cases.

Some of the younger researchers didn't know it was not proven

String theory had developed many of the characteristics of a hierarchical religion

Elementary Particle Physics

The politics of string theory

Universities wouldn't hire or promote anyone who wasn't working in string theory

Funding agencies wouldn't fund any other kind of work

Hiring drives funding and funding drives hiring

"...no assistant professors working on an approach to quantum gravity not based on string theory or higher dimensions have been hired by a US research university since around 1990."

Lee Smolin in The *Trouble With Physics*

Elementary Particle Physics

The politics of string theory

The String Theory Problem won't be resolved until experiment weeds out fact from passionate wishfulness

String theory has highlighted, once again, the importance of experiment in discovering scientific fact

The LHC may be the device that breaks the impasse

- Does the Higgs particle exist?
- Do other particles not predicted by the Standard Model exist?
- Will we see interactions that support the ideas of greater than three dimensions?
- Will we be surprised?

Elementary Particle Physics

Cosmology

While the Standard Model is not complete (no gravity, no particle mass) and probably has an underlying theory, it will survive just as Newton's Gravity survived General Relativity

What can the Standard Model plus General Relativity tell us about the history and structure of the Universe?

If the stuff of the Standard Model emerged from a Big Bang, what would happen?

Elementary Particle Physics

Cosmology

At first, everything would be so hot and so dense, none of the particles and forces could exist

It would be a pure, homogeneous soup of energy

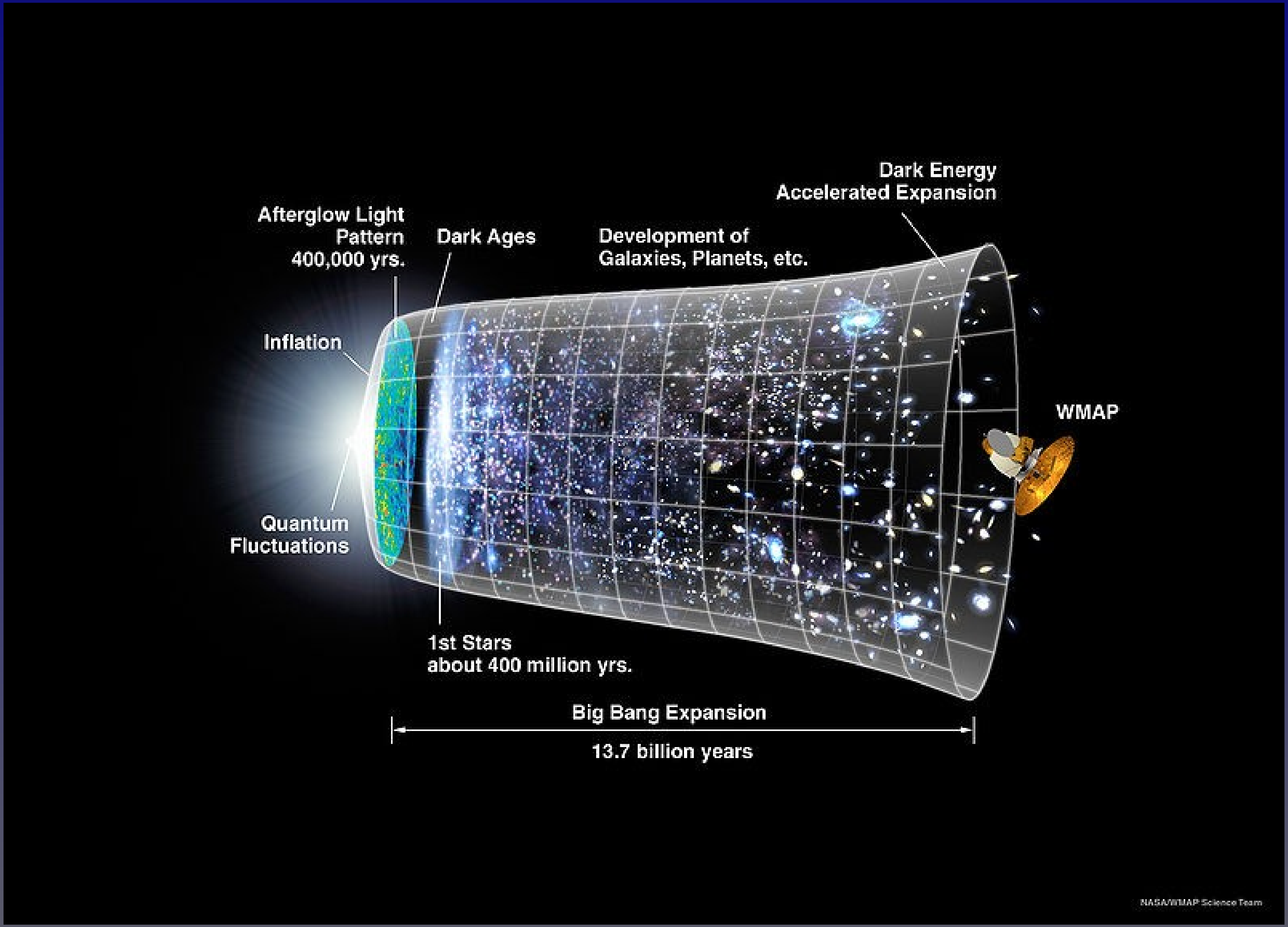
We don't yet understand what form the energy would have

The big bang produced not only all matter, but space and time

Was the Big Bang the formation of a black hole with our universe inside?

Elementary Particle Physics

Cosmology



Elementary Particle Physics

Cosmology

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It would be a pure, homgeneous soup of energy

The big bang produced not only all matter, but space and time

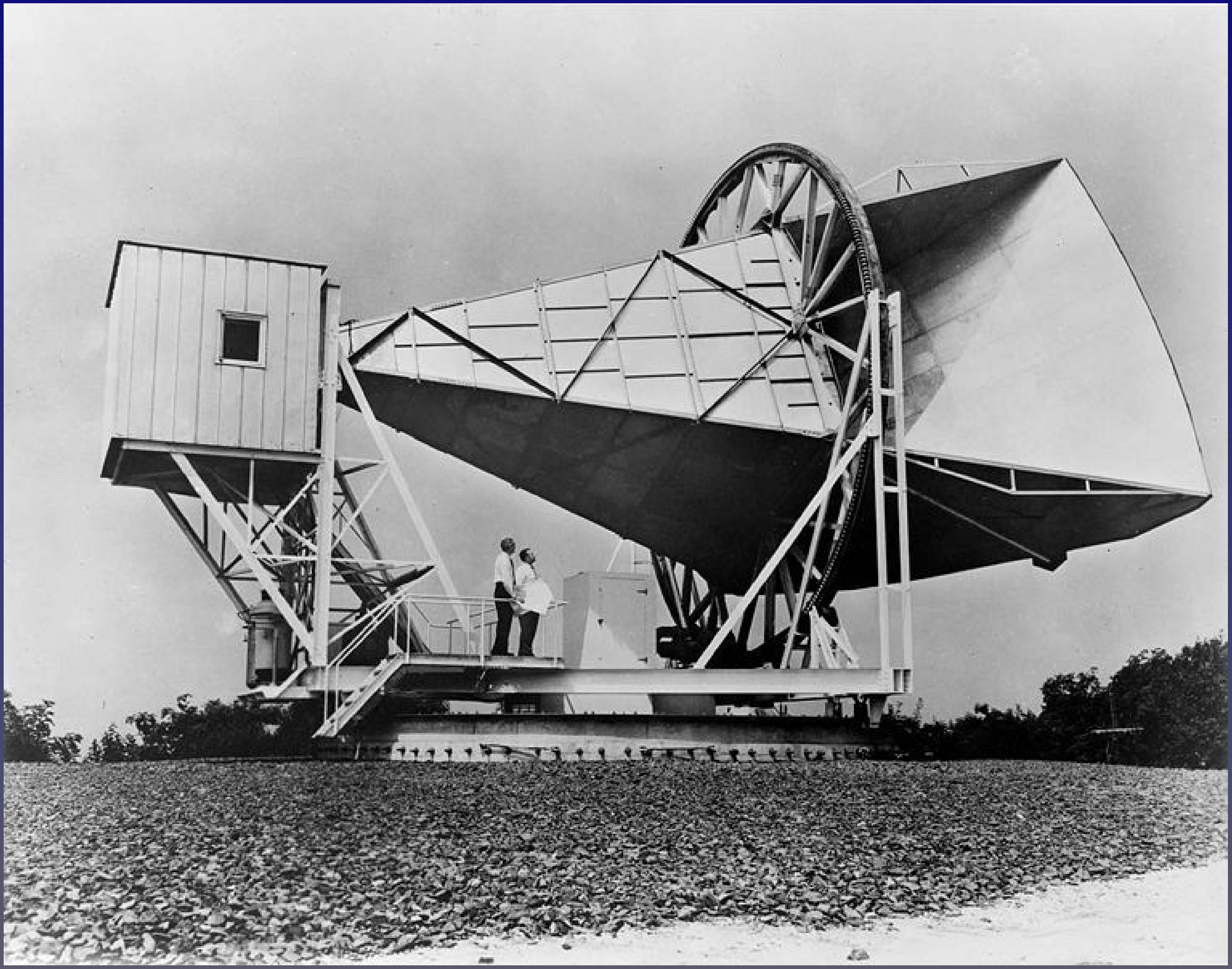
As the universe expanded, the situation changed rapidly (to say the least)

Big Bang Timeline

Elementary Particle Physics

The cosmic microwave background

In 1965, Arno Penzias and Robert W Wilson at the Crawford Hill location of Bell Telephone Laboratories in Holmdel Township, New Jersey could not explain a constant noise in a microwave antenna



Elementary Particle Physics

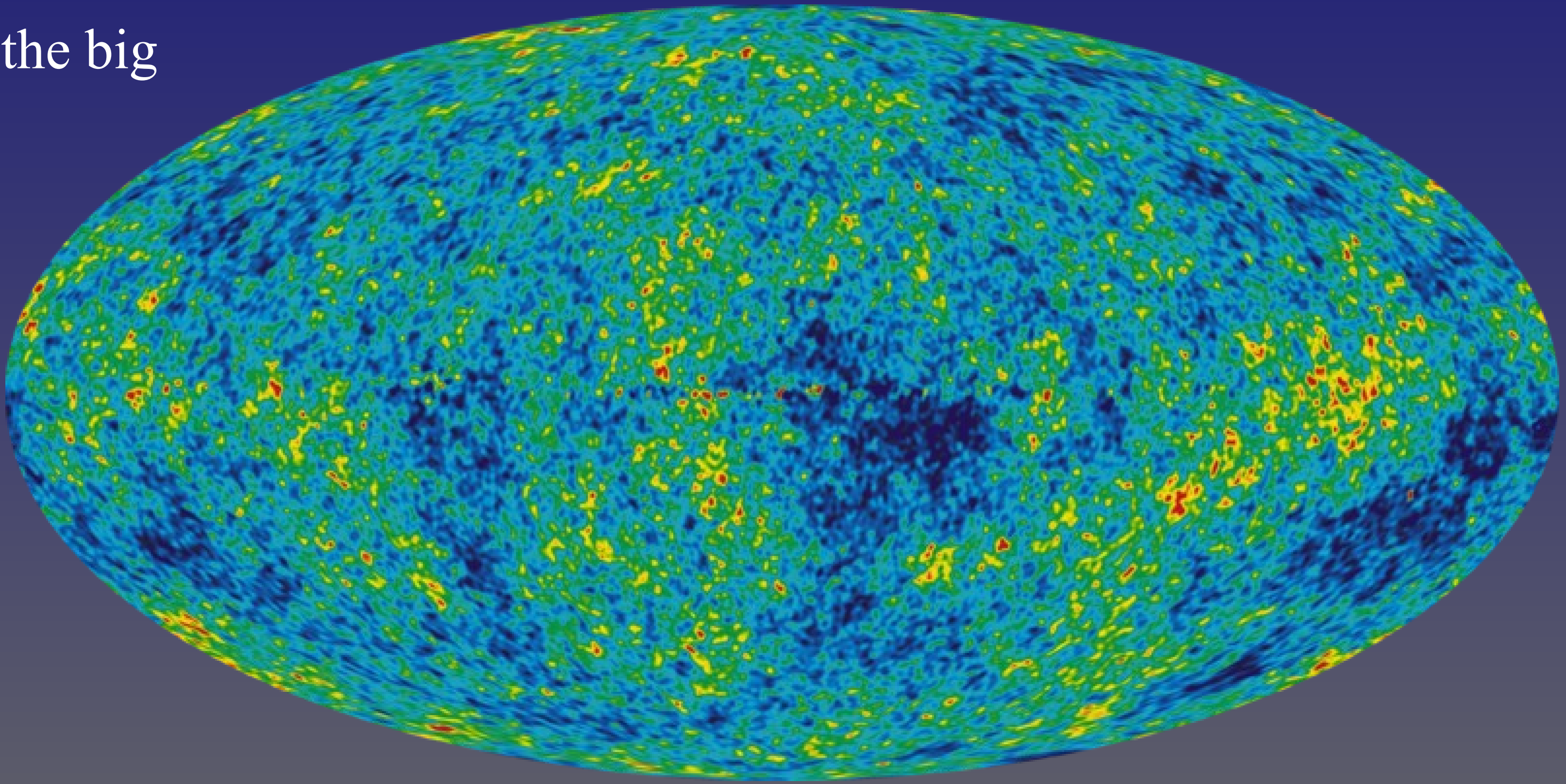
The cosmic microwave background

The noise turned out to be the heat left over from the big bang

The background temperature of the universe is 2.725 degrees Kelvin (-454.495 F)

It is almost uniform throughout the universe (varies by ±0.0002 deg. K)

Agrees with the big bang theory very well



Elementary Particle Physics

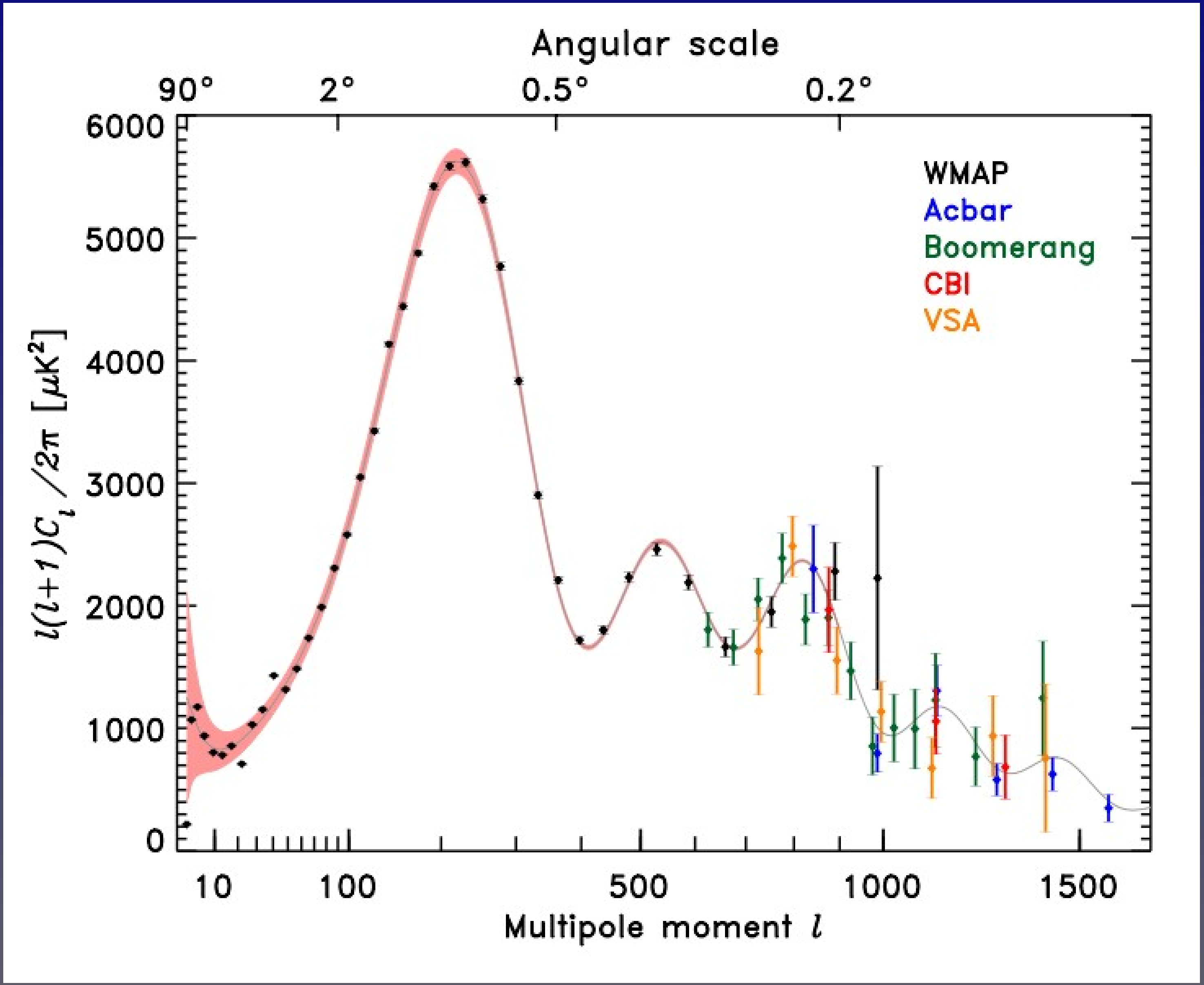
The cosmic microwave background

The radiation is polarized

The polarization varies across the sky

The distribution is predicted by photon-baryon interaction about 380,000 years ABB

Amazing evidence for our understanding of particle physics



The Physics of Everything

Summary

In the last century, mankind has extended our understanding of the Universe to particles vastly smaller than the atom and to the entire visible universe

No one expected what we found

At the atomic and subatomic scale, Quantum Mechanics explains how the world works, and the picture is strange and completely nonintuitive

Matter is neither made of solid particles or insubstantial waves. It has some characteristics of both

Our understanding of quantum mechanics has made possible electronics, medical imaging, modern chemistry, modern biology, new man-made materials, nuclear energy, and more

Quantum Mechanics is scientific fact

The Physics of Everything

Summary

Albert Einstein's development of Special Relativity based on the constant speed of light indicates that the length of an object, the mass of an object, and how fast time ticks away all depend on how fast we see it traveling

All these strange features have been verified experimentally

Einstein's General Relativity was derived from the equivalence of acceleration and gravity.   It tells us that gravity bends space and also affects the pace of time

It is also experimentally verified

Like quantum mechanics, Relativity predicts many strange occurrences like Black Holes. They are indirectly verified

The Physics of Everything

Summary

The combination of Quantum Mechanics and Relativity explain the history of the Universe from a Big Bang to the present day

Many experimental observations make this view of cosmic history very unlikely to change radically in the future

The Big Bang is a scientific fact. The details are still up for discussion

The Physics of Everything

Summary

All this progress in understanding the Universe has not been free of conflict and controversy

At present, string theory has many problems, incompletenesses, contradictions, and lacks any experimental support

Politics and human weaknesses have hampered progress in fundamental physics for a few decades now

We may never know what lies beyond the Standard Model, or

We may yet find a whole new level of physical detail and understanding

The results from the Large Hadron Collider and Cosmology will provide the next clues to The Theory of Everything