INTERNATIONAL CENTRE for THEORETICAL SCIENCES

TATA INSTITUTE OF FUNDAMENTAL RESEARCH

Higgs Discovery and Particle Physics

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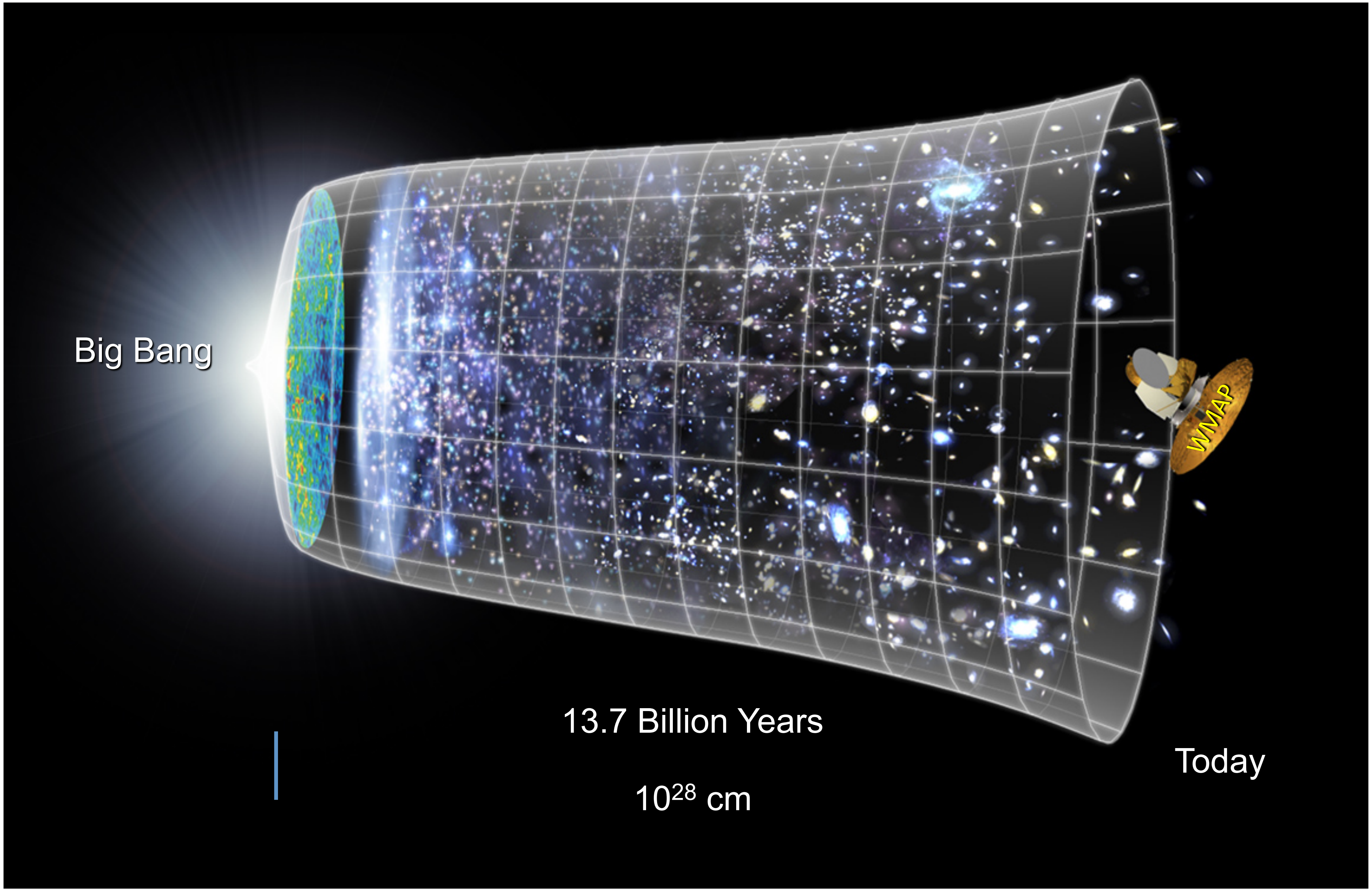
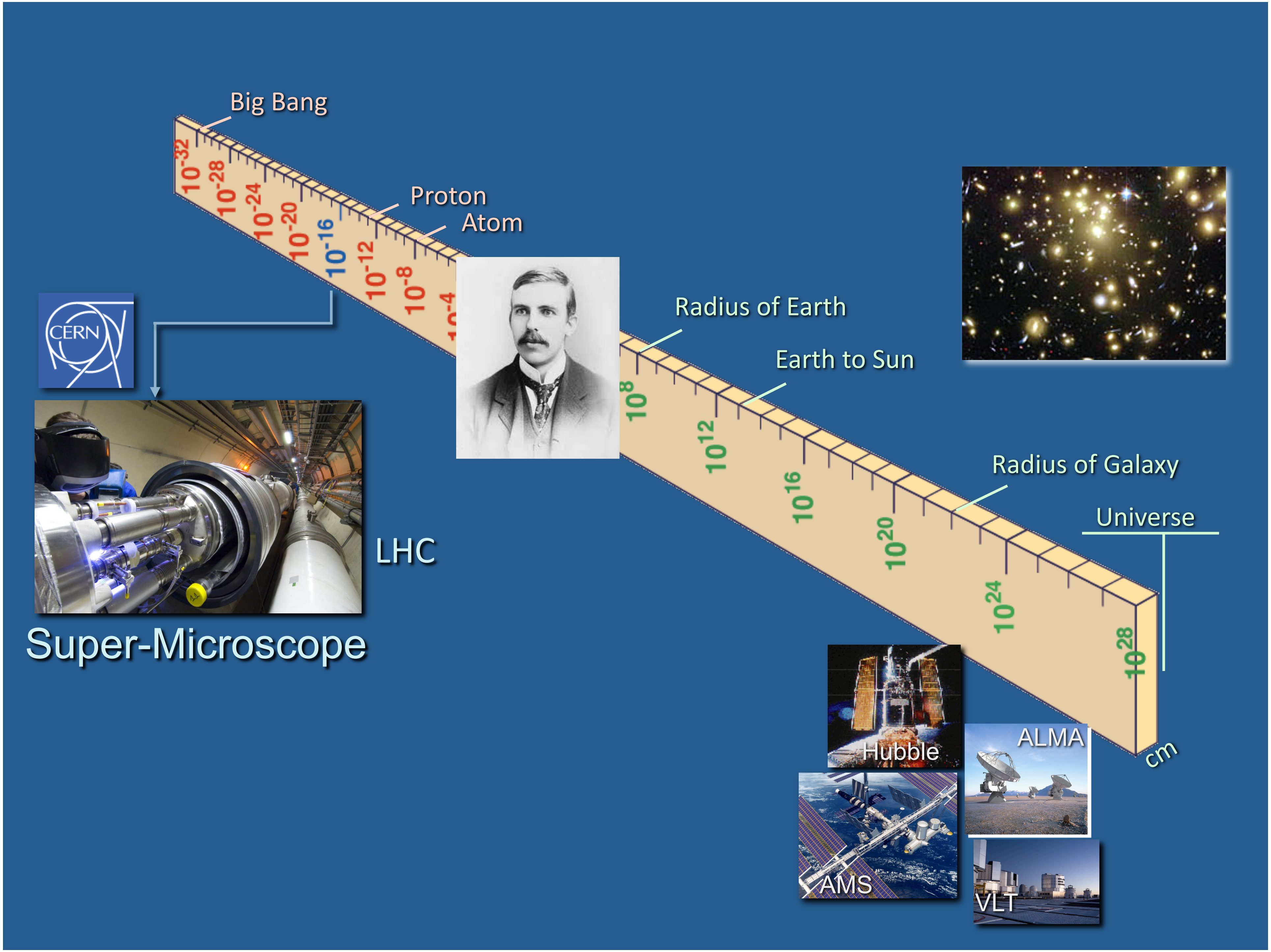
Tata Institute of Fundamental Research

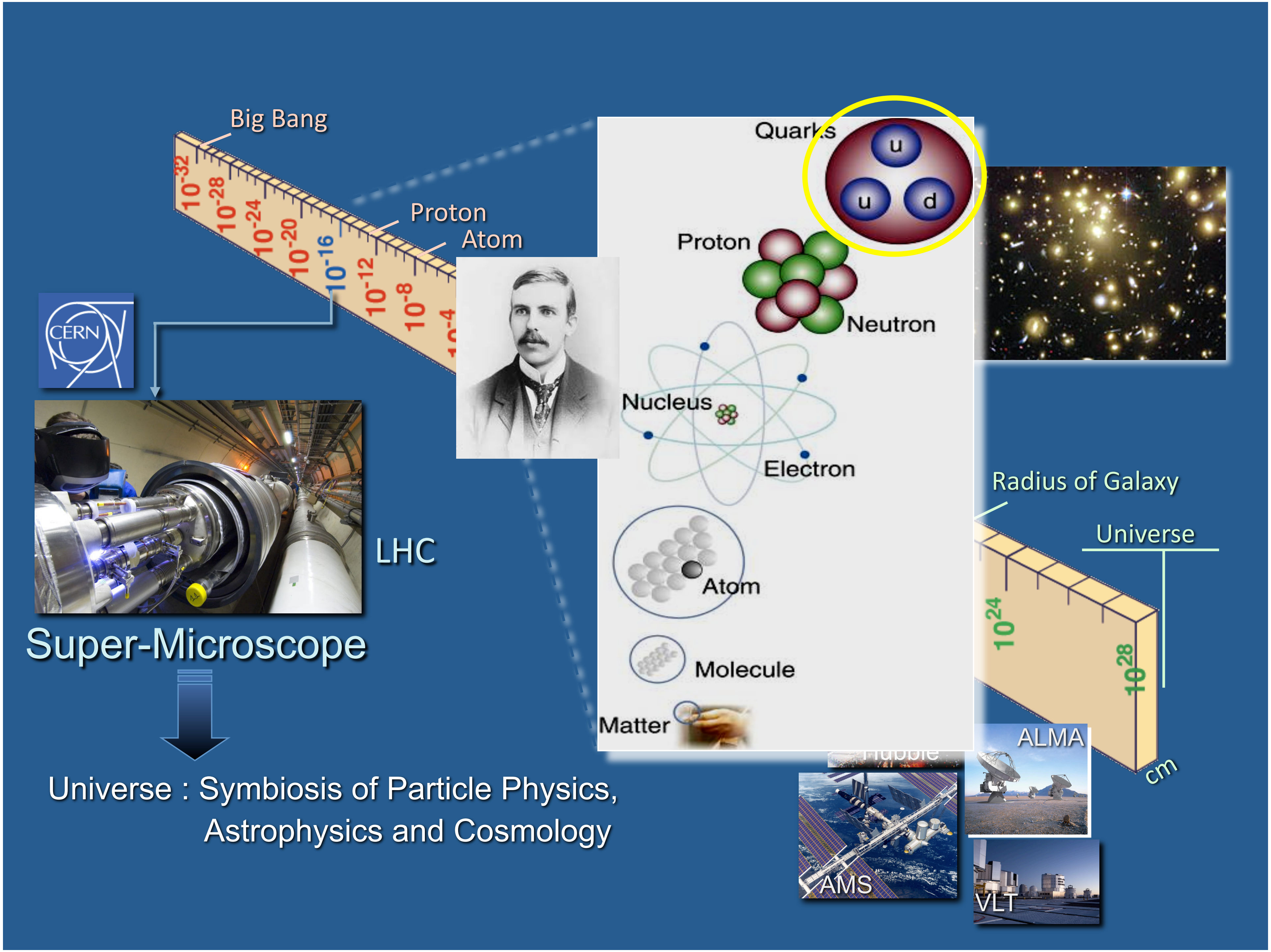
LVPEI Hyderabad, 31 August 2012

The Universe after the Big Bang





Big Bang
Proton
Atom
10^{-32}
10^{-28}
10^{-24}
10^{-20}
10^{-16}
10^{-12}
10^{-8}
10^{-4}
CERN
LHC
Super-Microscope
Radius of Earth
Earth to Sun
10^{8}
10^{12}
10^{16}
10^{20}
Radius of Galaxy
Universe
10^{24}
10^{28}
cm
Hubble
ALMA
AMS
VLT



Big Bang
Proton
Atom
10-32
10-28
10-24
10-20
10-16
10-12
10-8
CERN
LHC
Super-Microscope
Universe : Symbiosis of Particle Physics,
Astrophysics and Cosmology
Quarks
u
u
d
Proton
Neutron
Nucleus
Electron
Atom
Molecule
Matter
Radius of Galaxy
Universe
1024
1028
cm
ALMA
AMS
VLT

Matter and Forces

- Gravity
- Electricity and Magnetism understood in terms of the electrons the first elementary particle…J.J. Thompson 1897
- Atoms and Nuclei
- As you `see' or `probe' smaller distances you need higher energies…short wavelengths resolve shorter distances

The 'Standard Model'

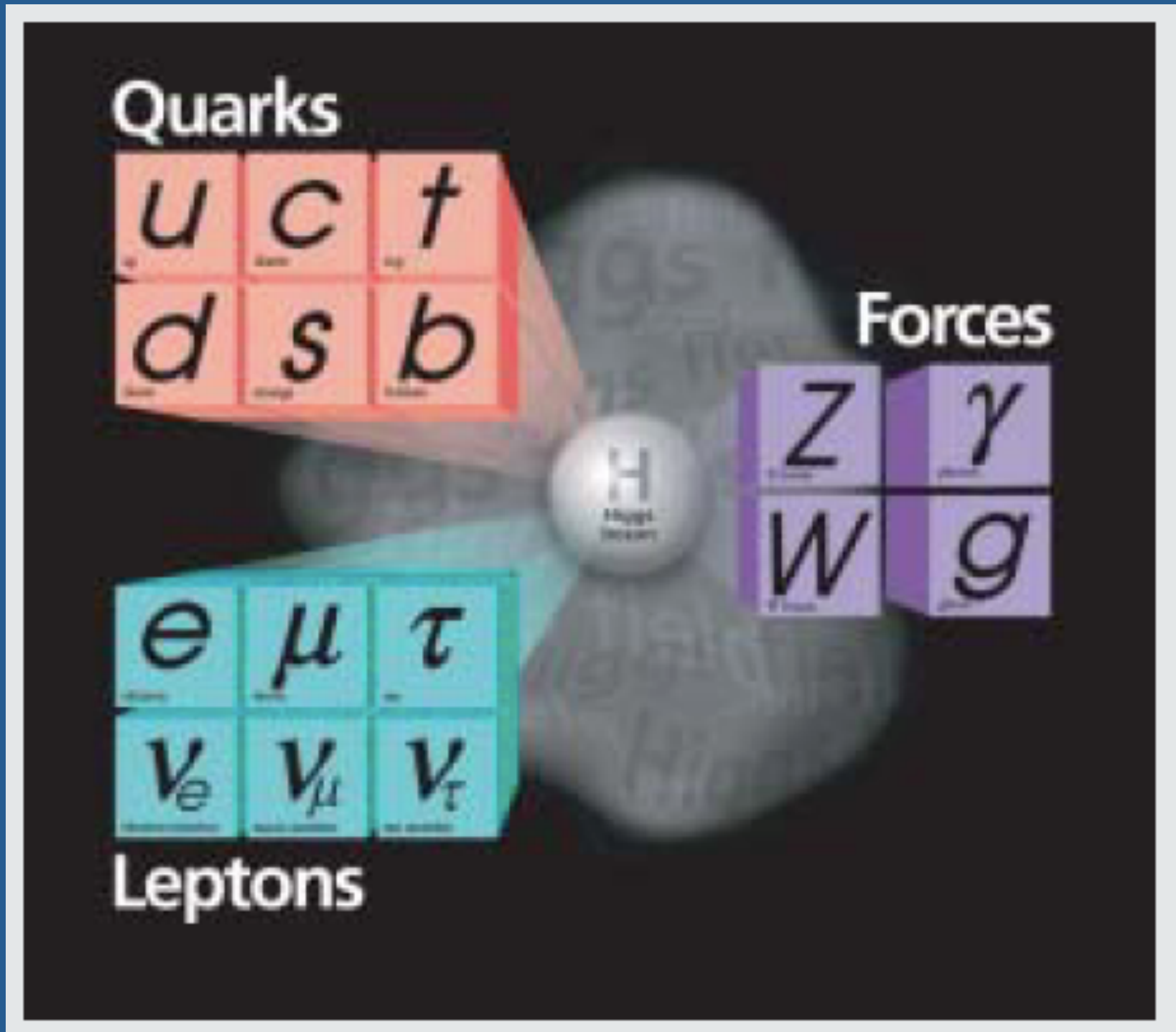
Glashow Salam Weinberg

The matter particles

The fundamental interactions

Gravitation electromagnetism weak nuclear force strong nuclear force

HIGGS PARTICLE



Mev, Gev, Tev?

The energy of the LHC is currently 4 TeV in each beam or 8 TeV in all.

Let us remember the characters:

1 eV typical energy of an electron coming out of an ordinary flashlight battery

1 MeV is mc^2 of an electron

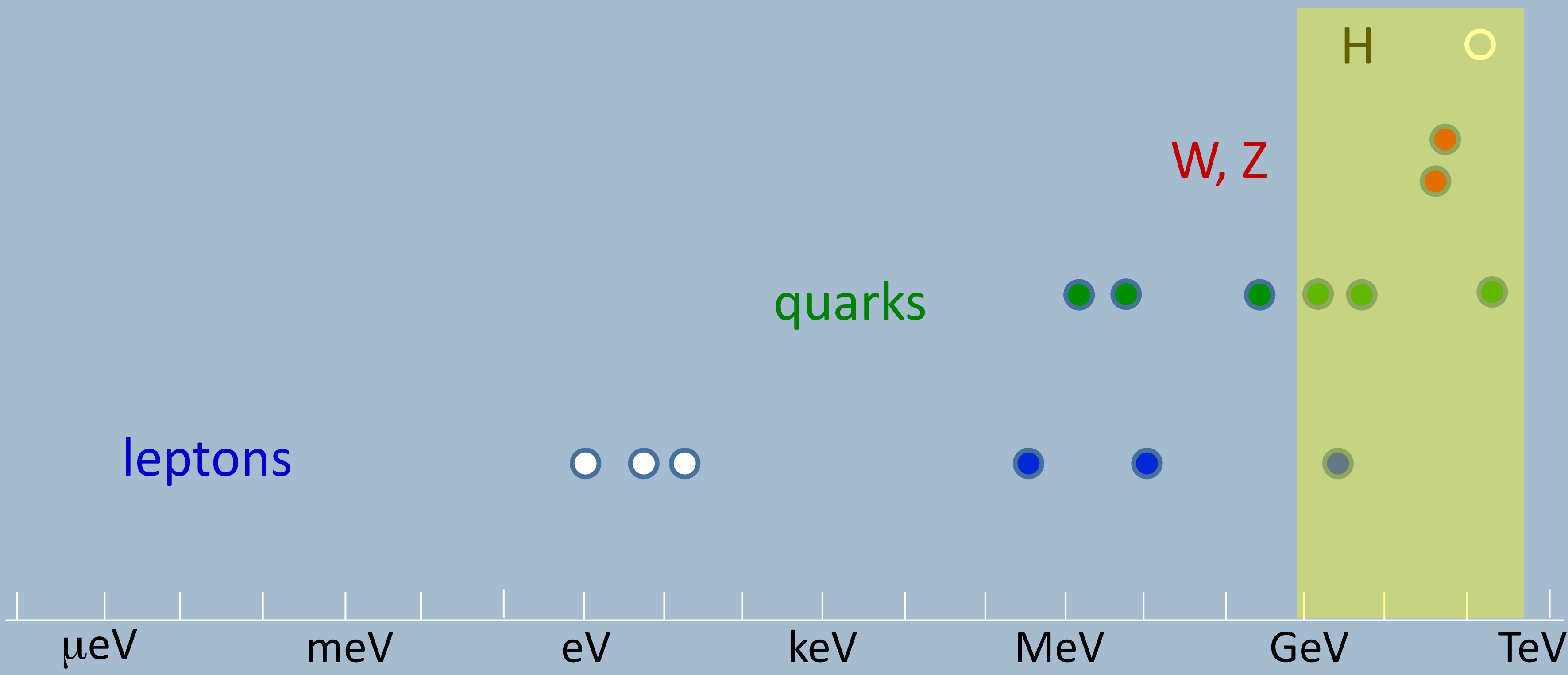
1 GeV is mc^2 of a proton

1 TeV is 1000 times bigger still, or 10^{12}eV

The (Higgs) boson has mass somewhere in

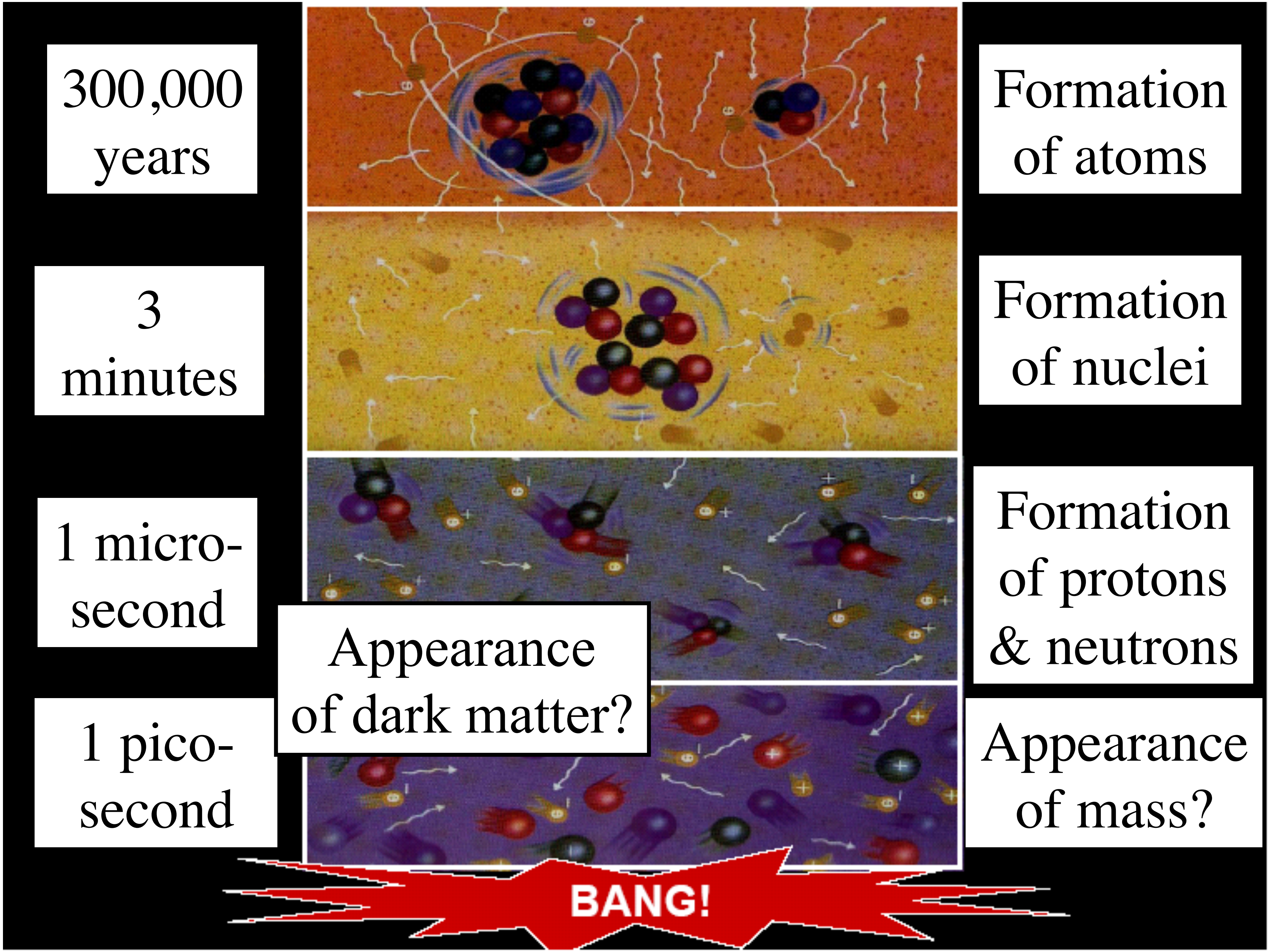
122 – 129 GeV

$$m_t > M_H > M_Z > M_W > m_b > m_\tau > m_c > \cdots$$



What is the Higgs mechanism and the boson?

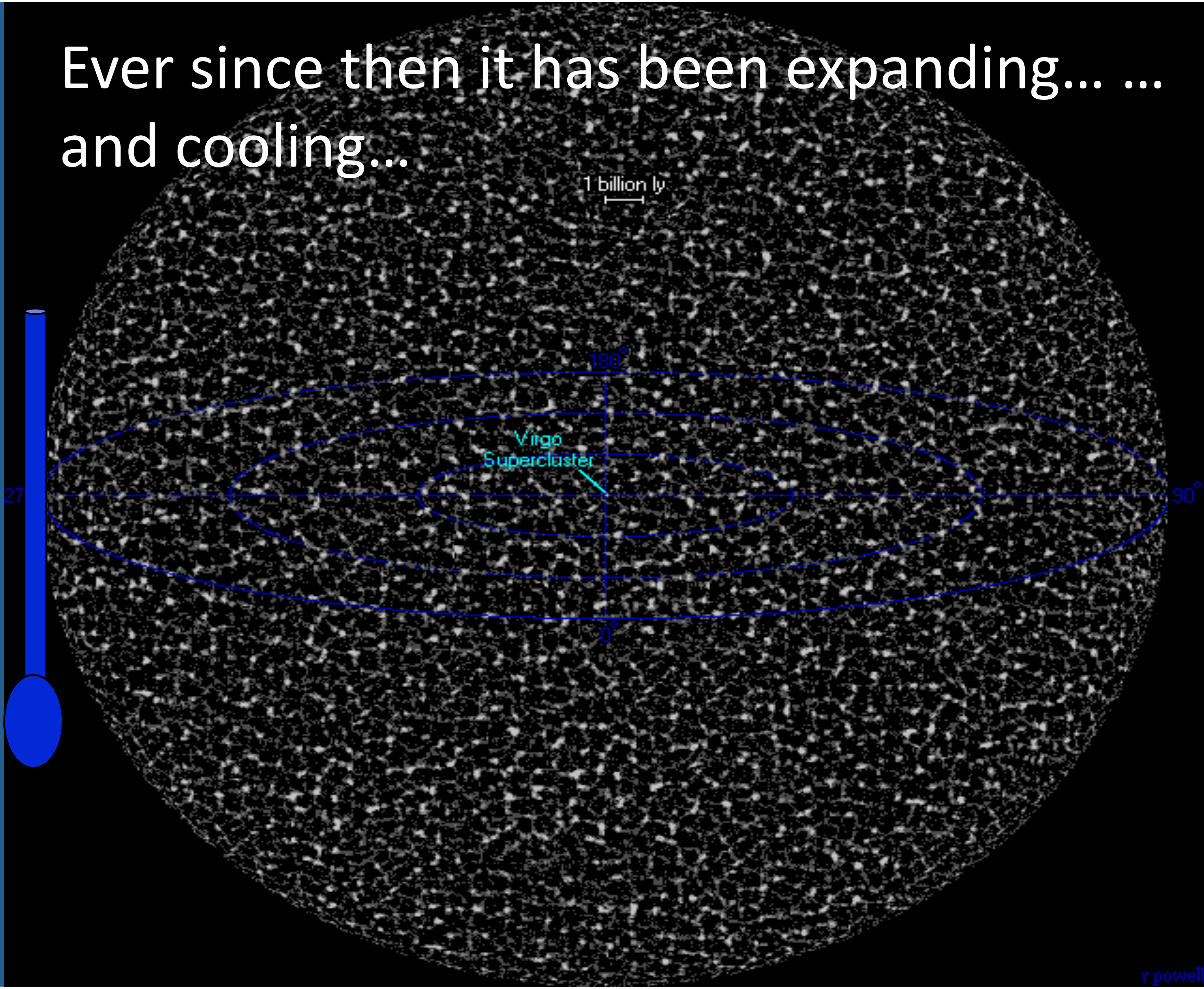
Begin at the beginning…


300,000 years
Formation of atoms
3 minutes
Formation of nuclei
1 micro-second
Formation of protons & neutrons
Appearance of dark matter?
1 pico-second
Appearance of mass?
BANG!

Some 13.8 billion years ago, the Universe was created from a single point in an explosion of stupendous power…

This primordial fireball expanded… and cooled…

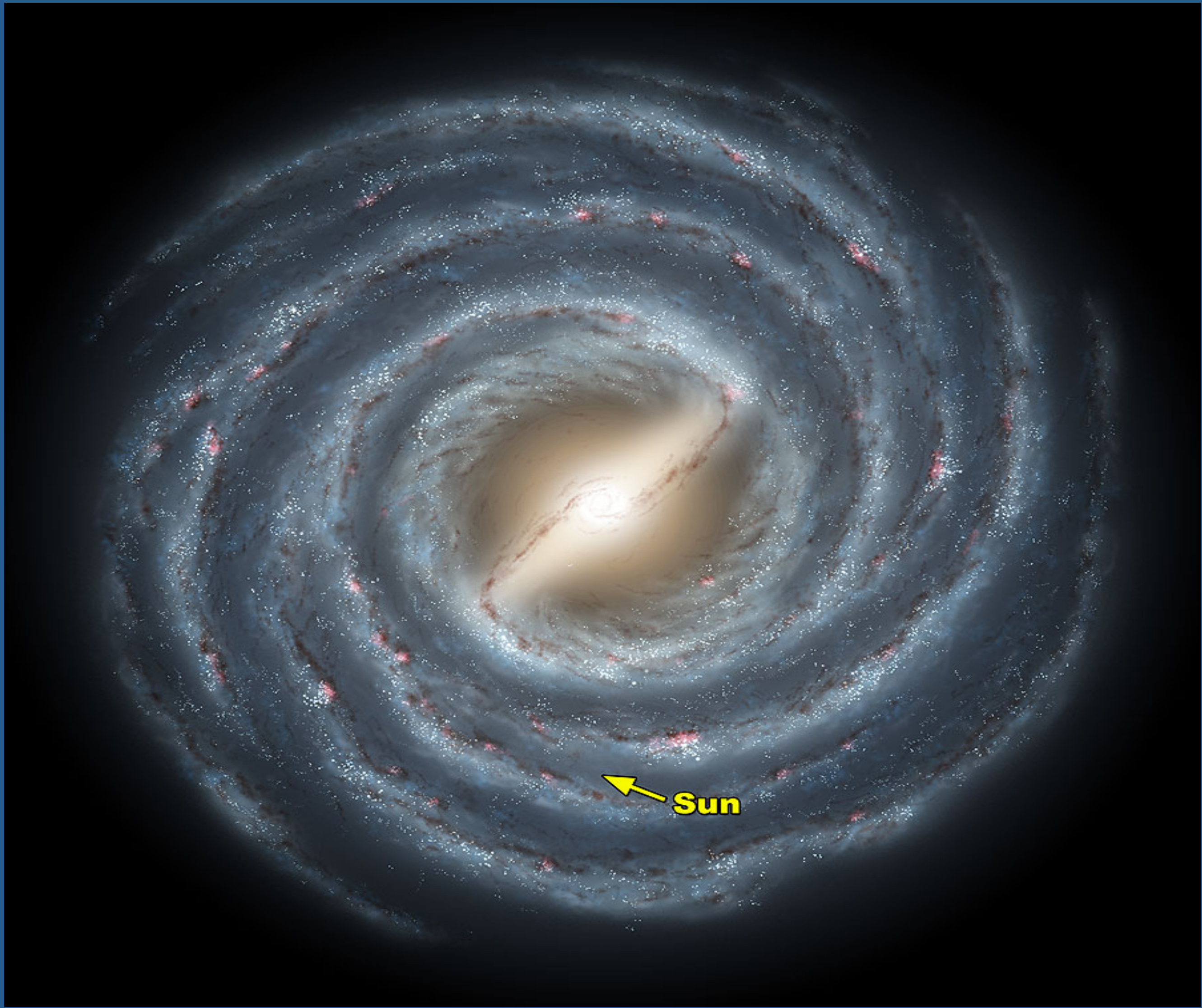
Ever since then it has been expanding… …and cooling…



… till now it looks like this…

T = - 270.27 C

This cooled-down, ancient Universe is full of the most weird and lovely structures…



The Theory
(begins more than 50 years ago)

Spontaneous Symmetry Breaking and the Higgs mechanism

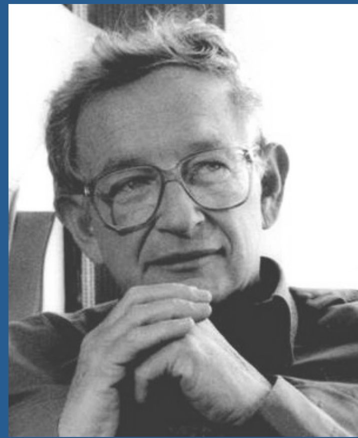
As the Universe cooled the Higgs `field' that is like a fluid that permeates all of space underwent a phase transition…

Phase transition: water boils into vapor is a phase transition

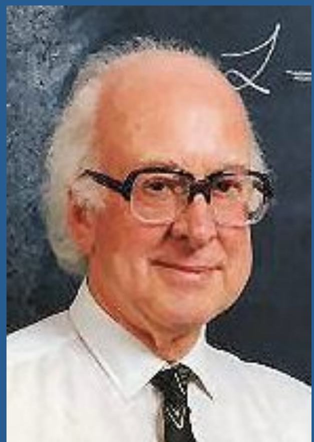
Ideas from the theory of superconductivity were brought over
In one of the most prescient intellectual leaps of the
20th century by Yoichiro Nambu of the University of Chicago
in the 1960s

Spontaneous Symmetry Breaking and Higgs mechanism pioneers

Y. Nambu



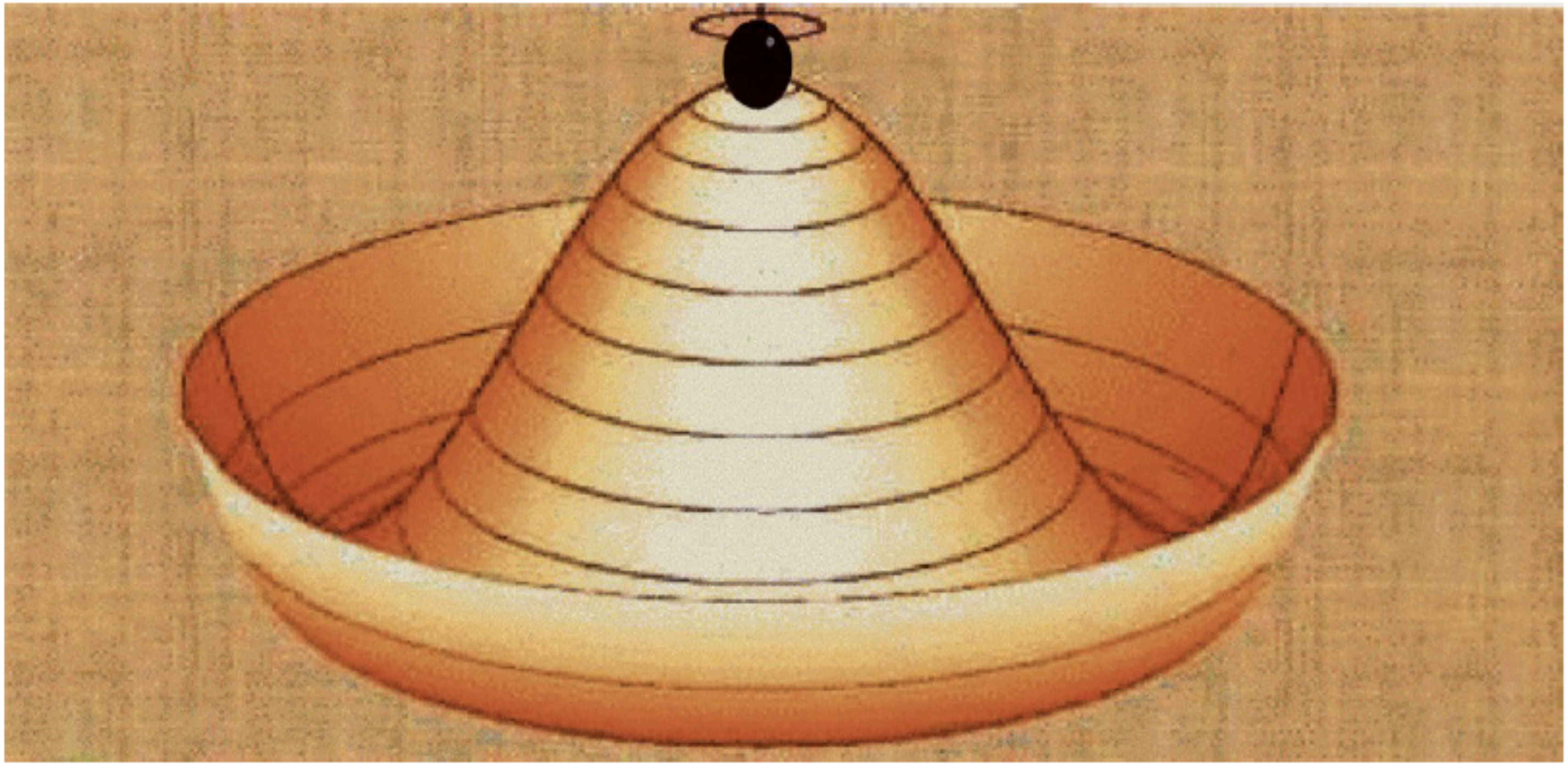
P. W. Anderson



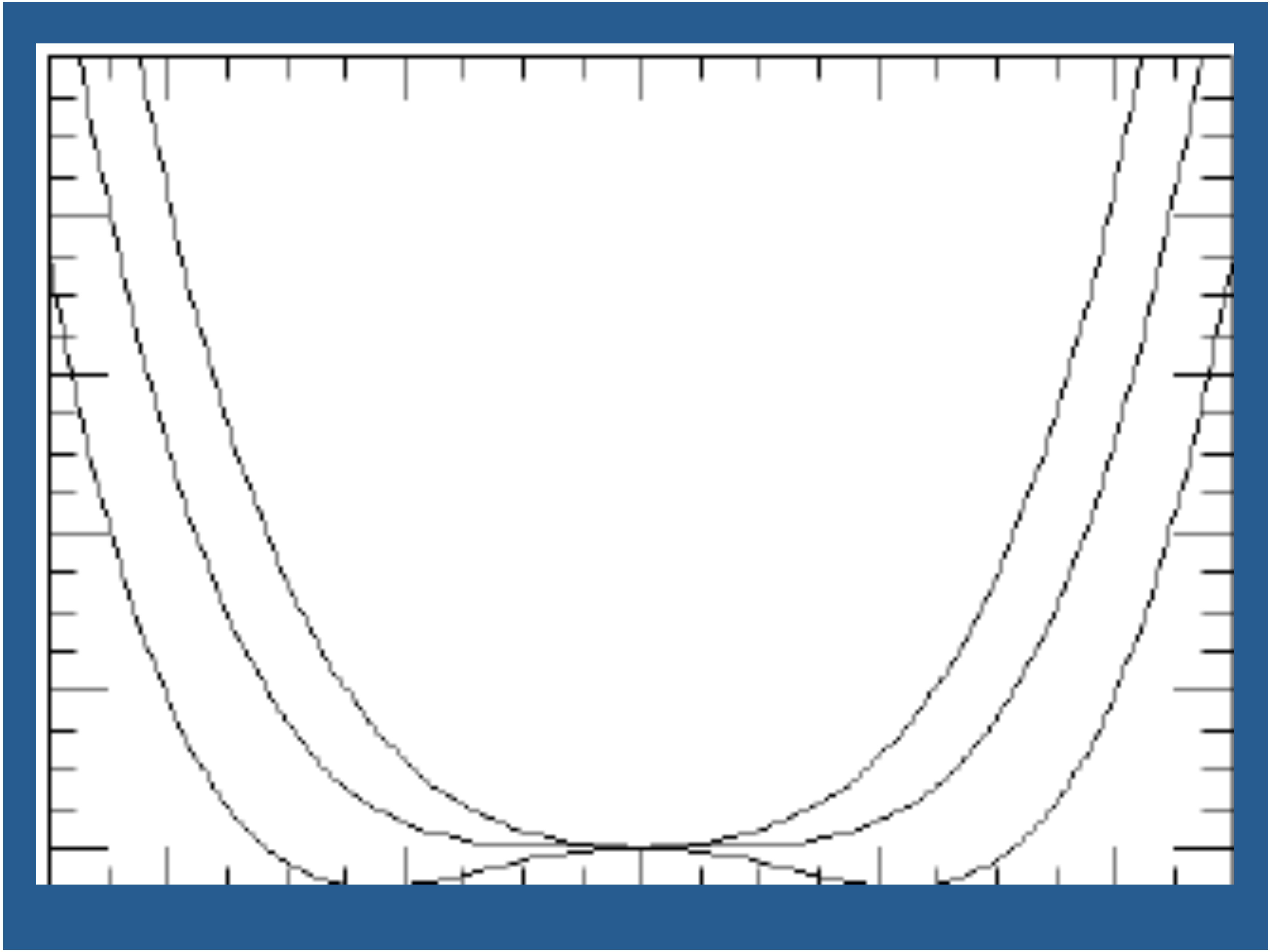
P. W. Higgs

R. Brout

F. Englert

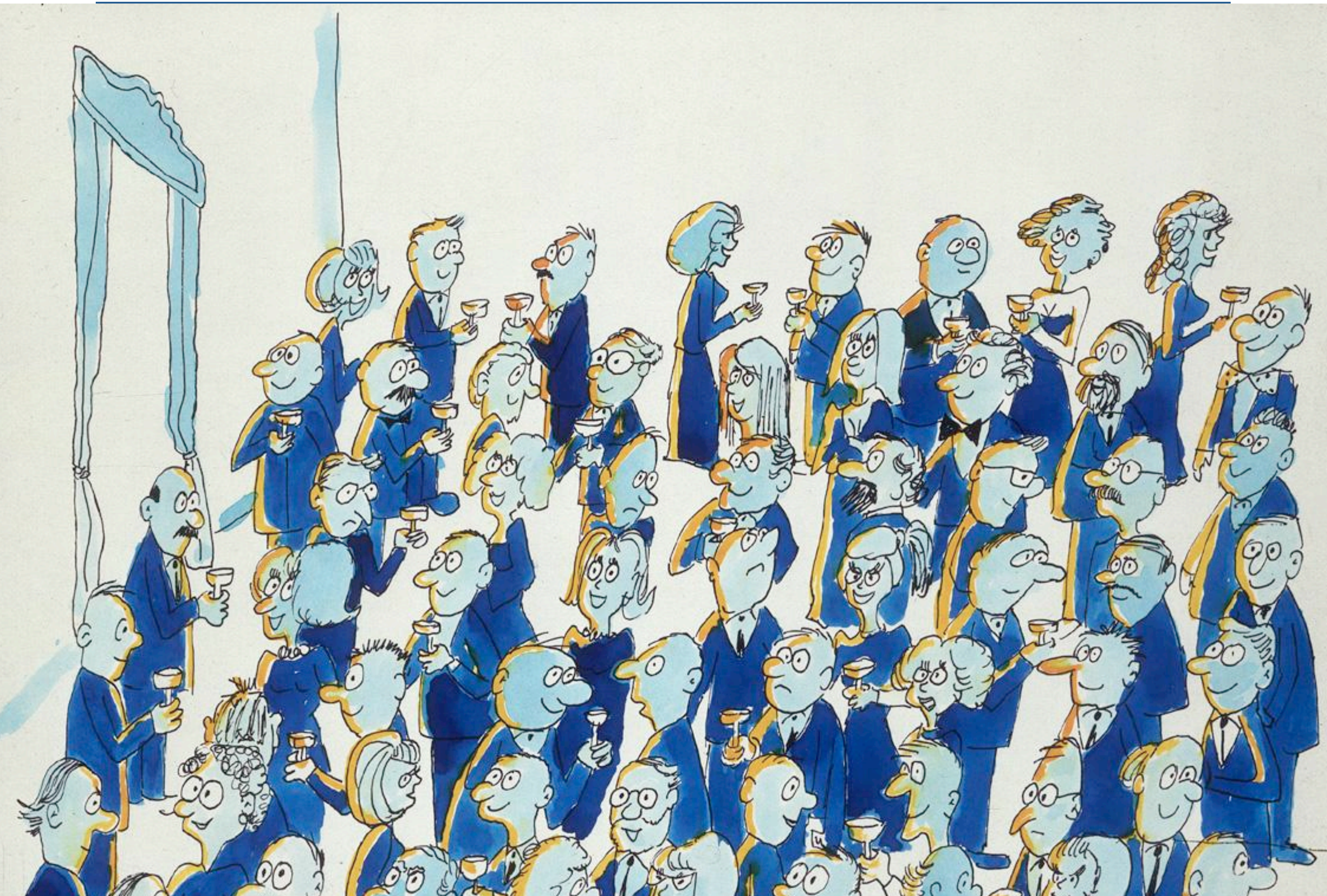


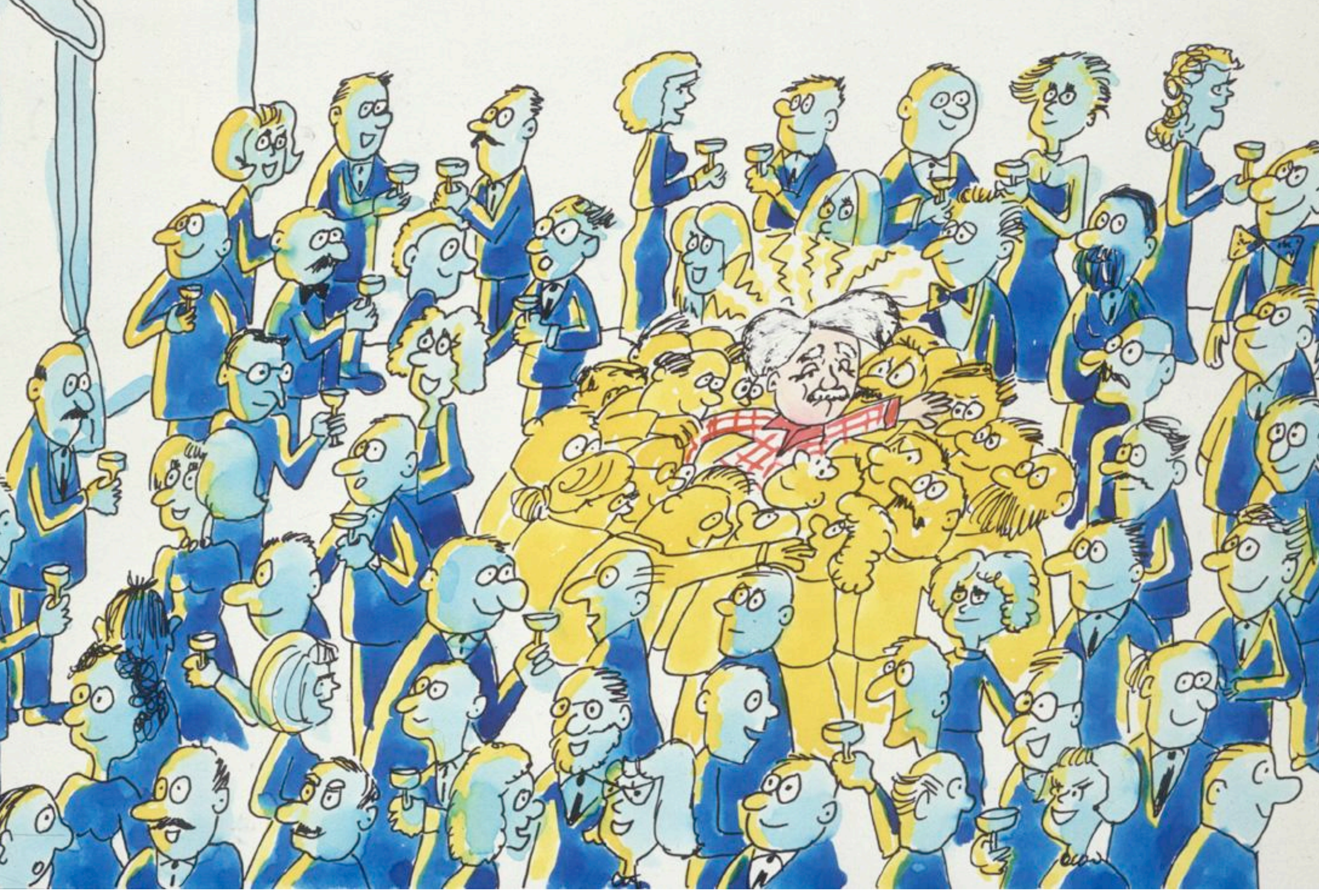
.01 nano-seconds after the big-bang the Higgs Field underwent a phase-transition and the Universe sitting on the top rolls down breaking the symmetry which existed between the various forces and particles…



The Higgs field sticks to all particles except the photon giving them a mass!

The Higgs particle is the oscillation at the bottom of the rim and its mass is around 125 Gev



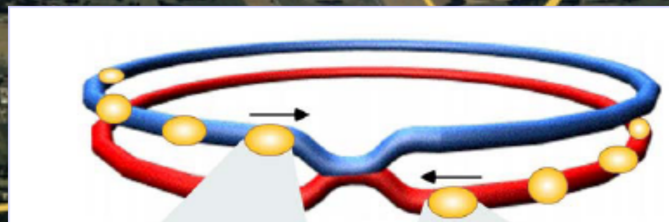


The Experiment

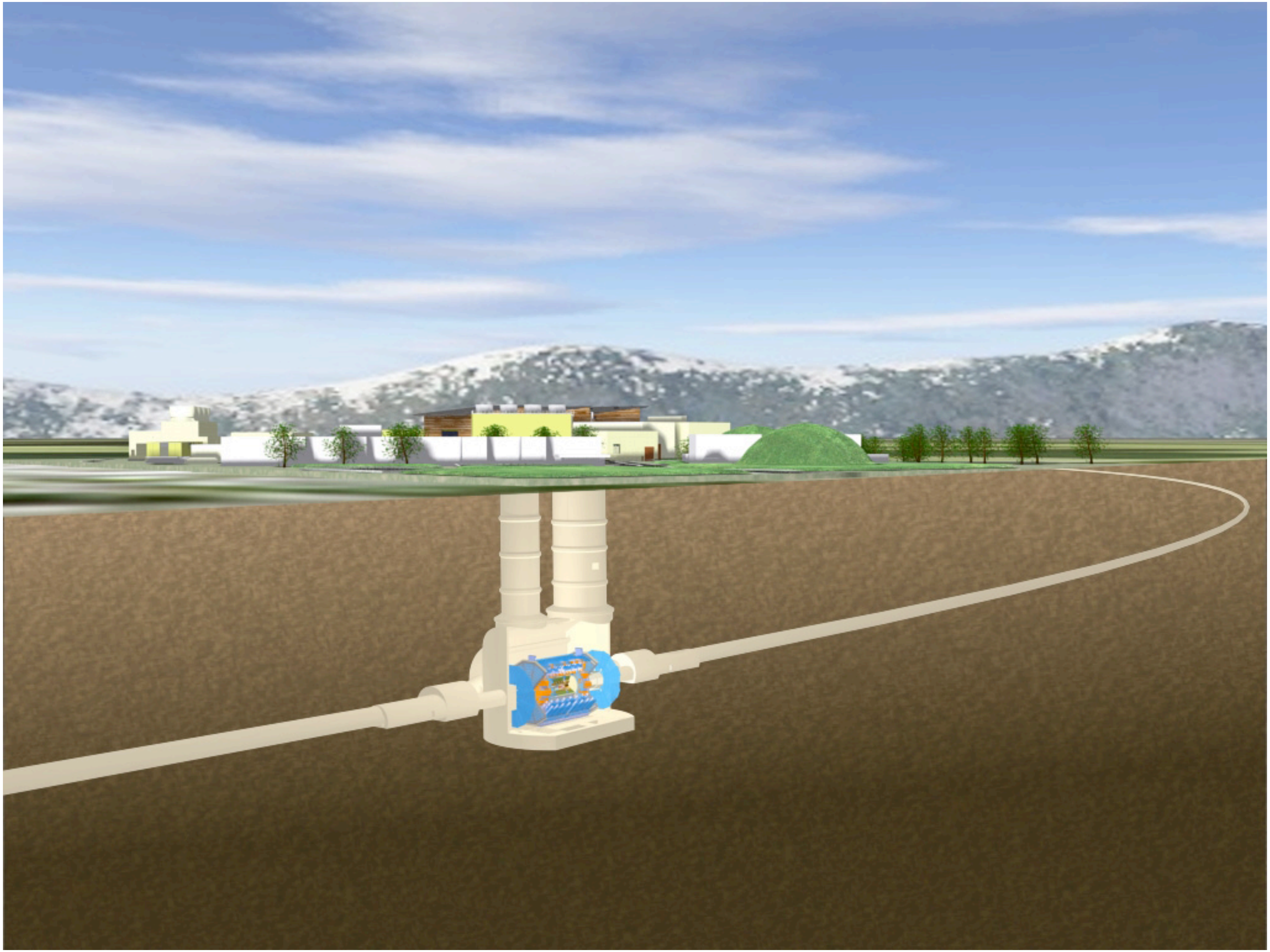
the Large Hadron Collider (LHC)

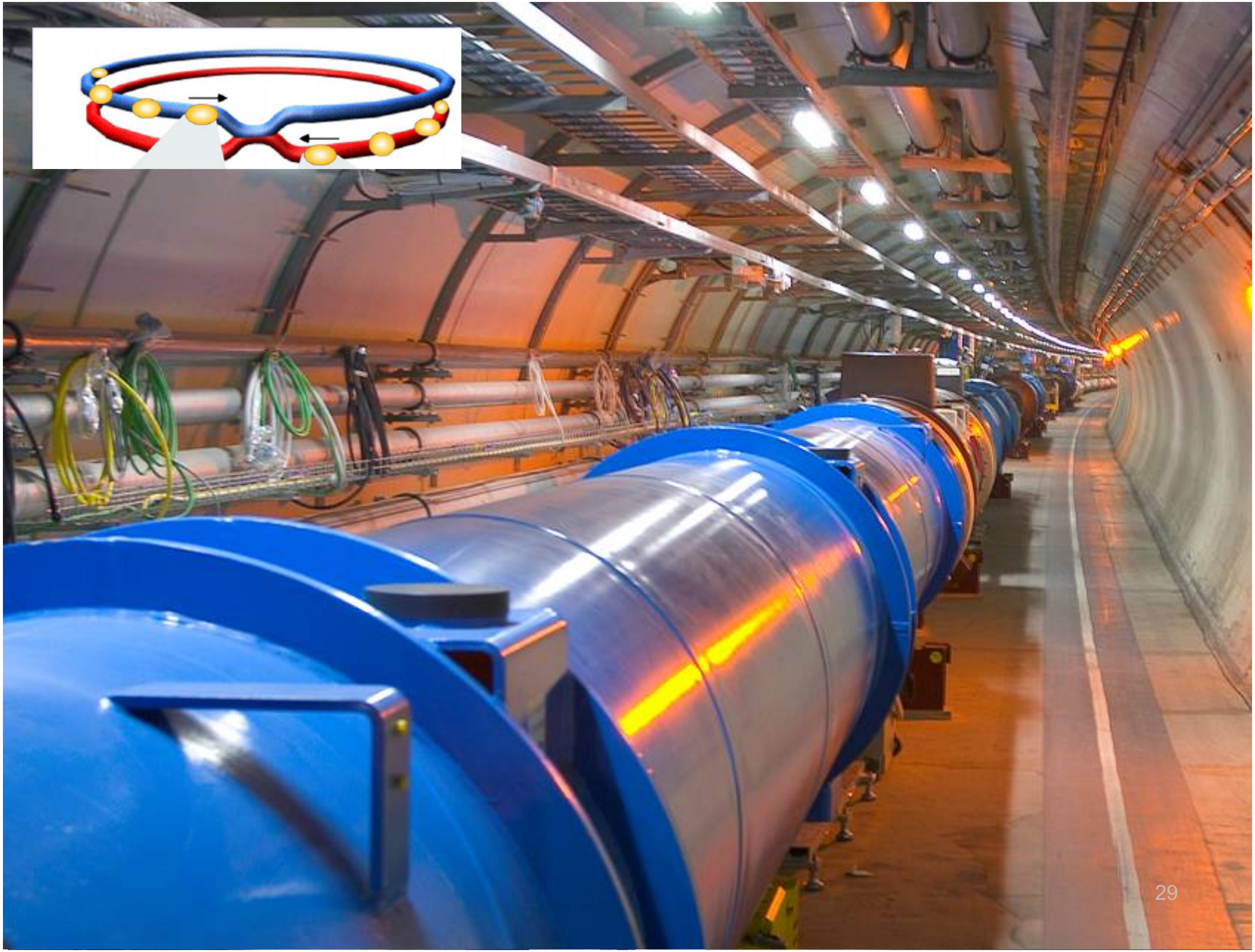
- Largest scientific instrument ever built, 27km of circumference
- >10 000 people involved in its design and construction
- Collides protons to reproduce conditions at the birth of the Universe...

...40 million times a second

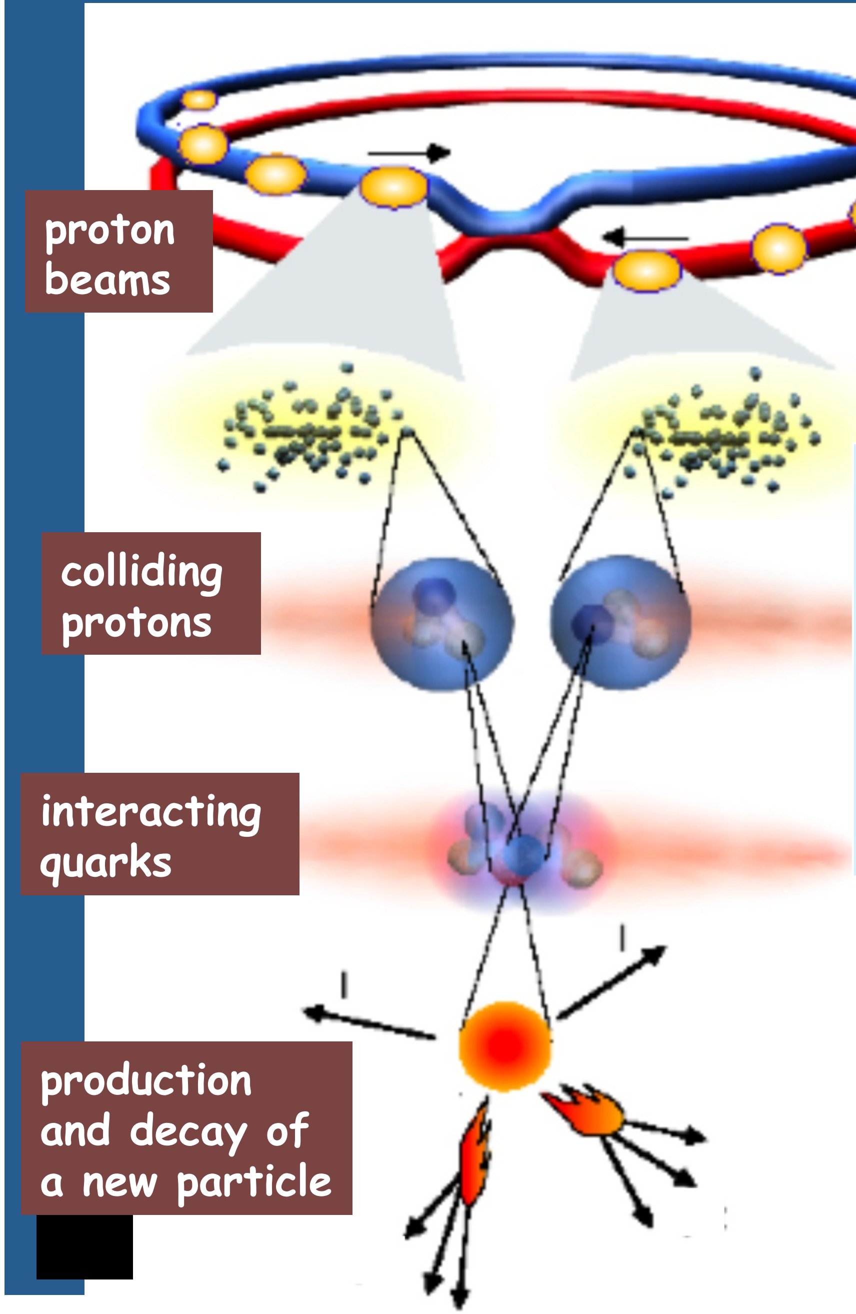


Announced on 6th July 2012 the discovery of a boson of mass 125 Gev





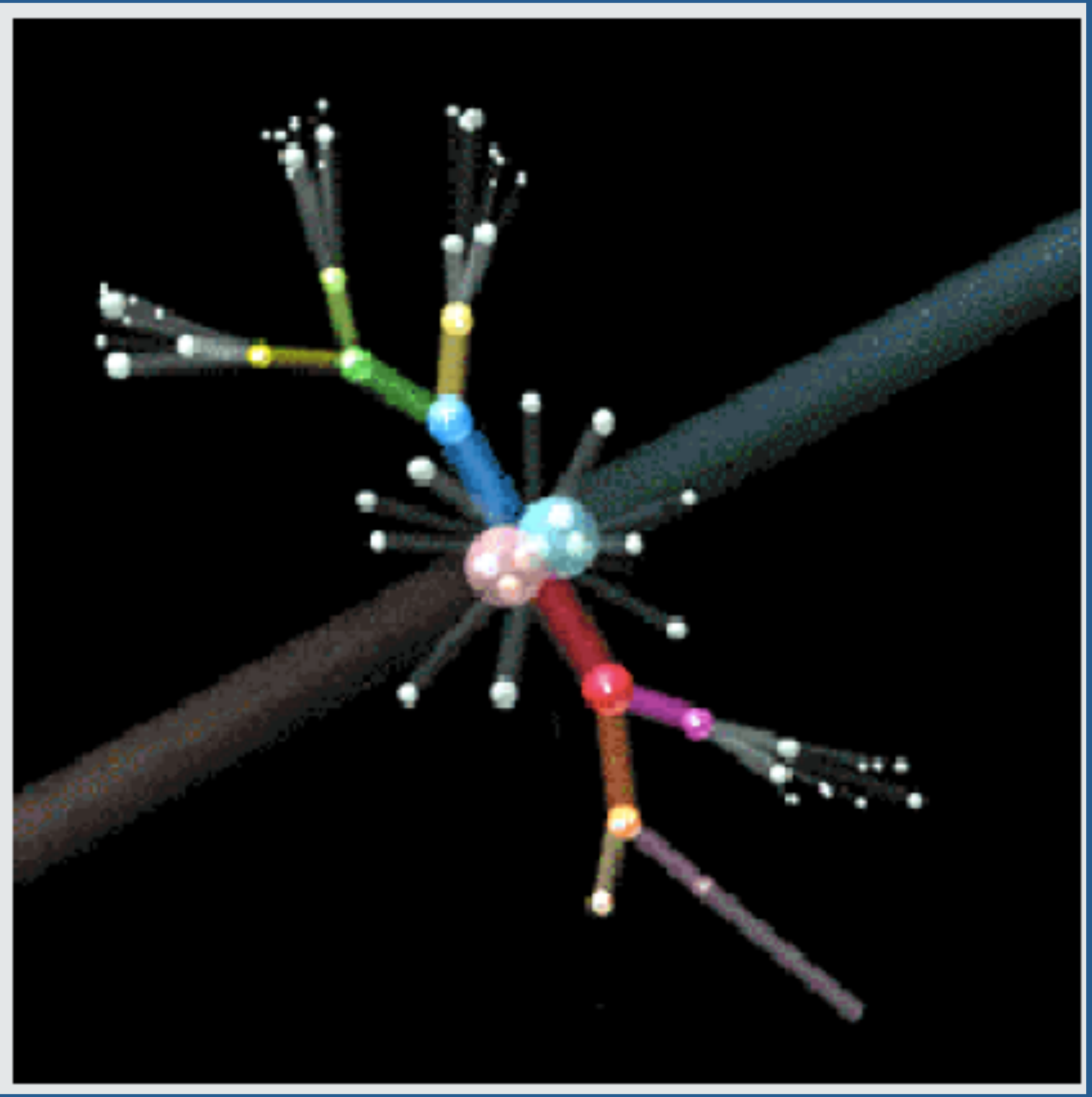
LHC: study the elementary particles and their interactions

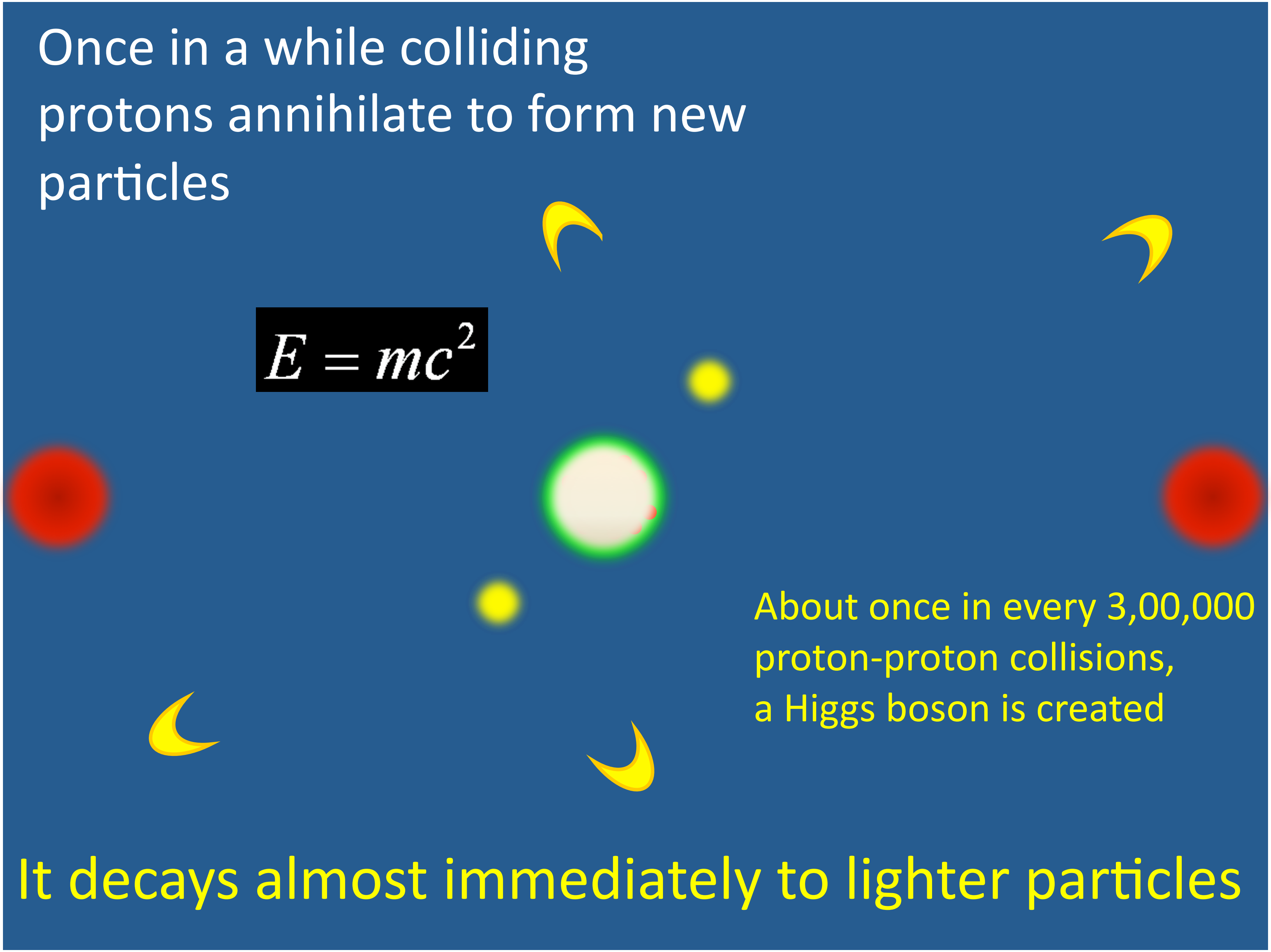


Acceleration of two beams of particles (e.g. protons) in ‘bunches’ close to the speed of light and collide these bunches

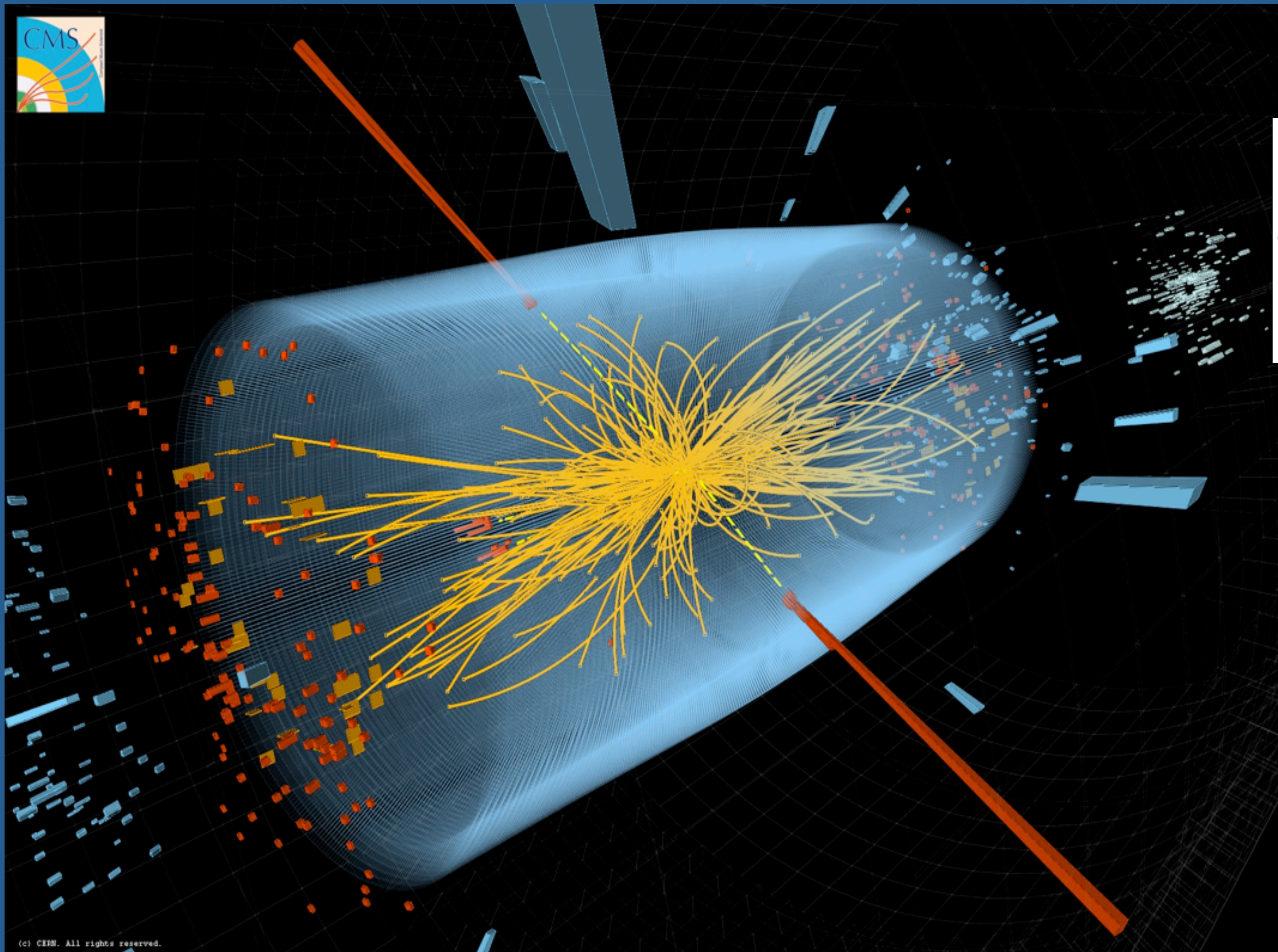
The colliding protons break into their fundamental constituents (e.g. quarks).
These constituents interact at high energy:
(new) heavy particles can be produced in the collision ($E=mc^2$). The higher the accelerator energy, the heavier the produced particles can be. These particles then decay into lighter (known) particles: electrons, photons, etc.

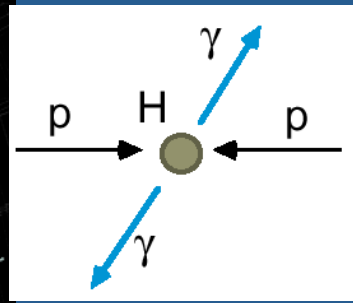
By placing high-tech powerful detectors around the collision point we can detect the collision products and reconstruct what happened in the collision (which phenomena, which particles and forces were involved, etc.)



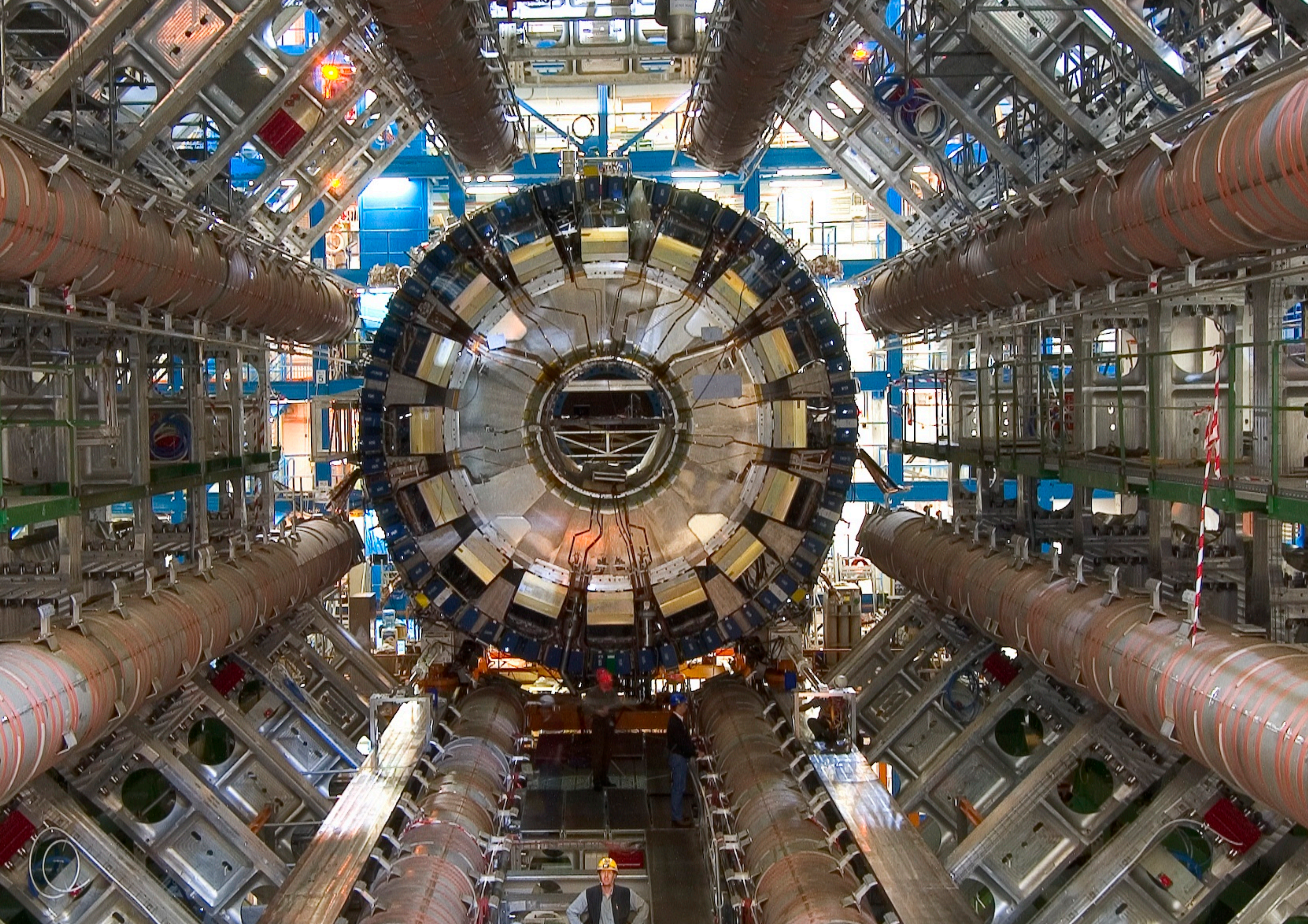

Once in a while colliding protons annihilate to form new particles
$E = mc^2$
About once in every 3,00,000 proton-proton collisions, a Higgs boson is created
It decays almost immediately to lighter particles

A Collision with two Photons





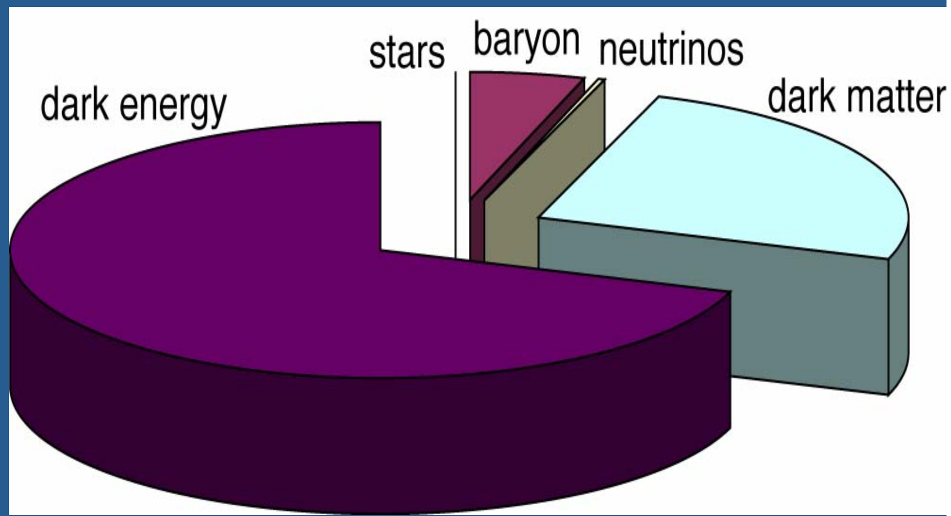
A Higgs or a ‘background’ process without a Higgs?



Where are we and What next?

Standard Model

THE ENERGY BUDGET OF THE UNIVERSE



Ω_B BARYONS

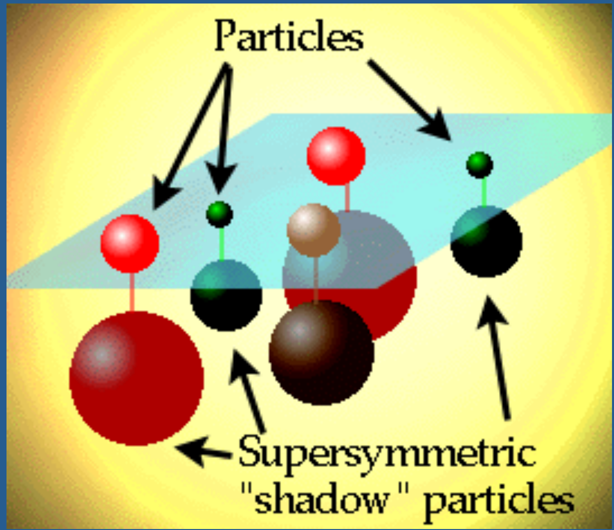
Ω_{CDM} DARK MATTER

Ω_ν NEUTRINOS

Ω_{DE} DARK ENERGY

$$\Omega_{TOT} = \Omega_B + \Omega_{CDM} + \Omega_\nu + \Omega_{DE}$$

Supersymmetry



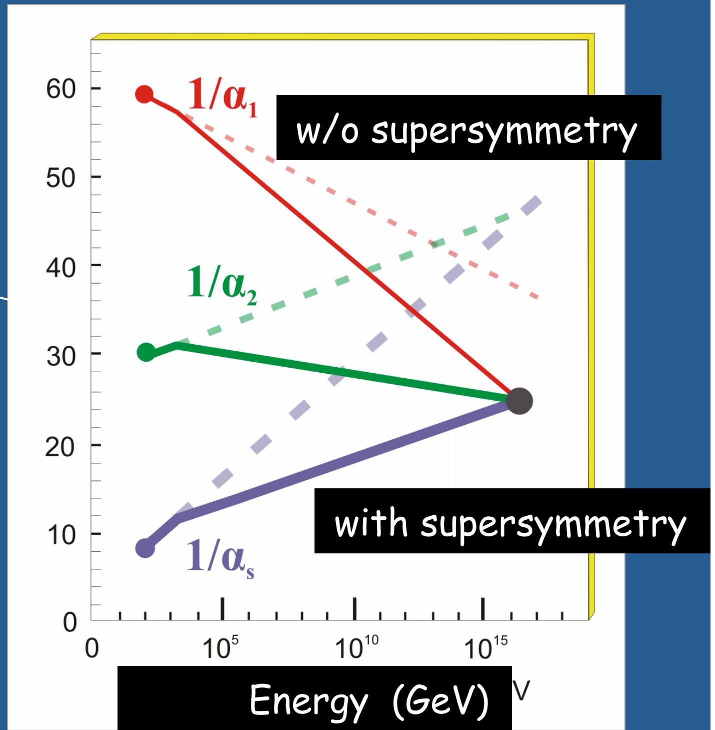
- unifies matter with forces

  for each particle a supersymmetric partner (*sparticle*) of opposite statistics is introduced

- allows to unify strong and electroweak forces

  $\sin^2\theta_W^{SUSY} = 0.2335(17)$

  $\sin^2\theta_W^{exp} = 0.2315(2)$



- provides link to string theories

- provides Dark Matter candidate

  (stable Lightest Supersymmetric Particle)

Steven Weinberg on larger implications of fundamental science:

So what? Even if the particle is the Higgs boson, it is not going to be used to cure diseases or improve technology. This discovery simply fills a gap in our understanding of the laws of nature that govern all matter, and throws light on what was going on in the early universe. It's wonderful that many people do care about this sort of science, and regard it as a credit to our civilization.

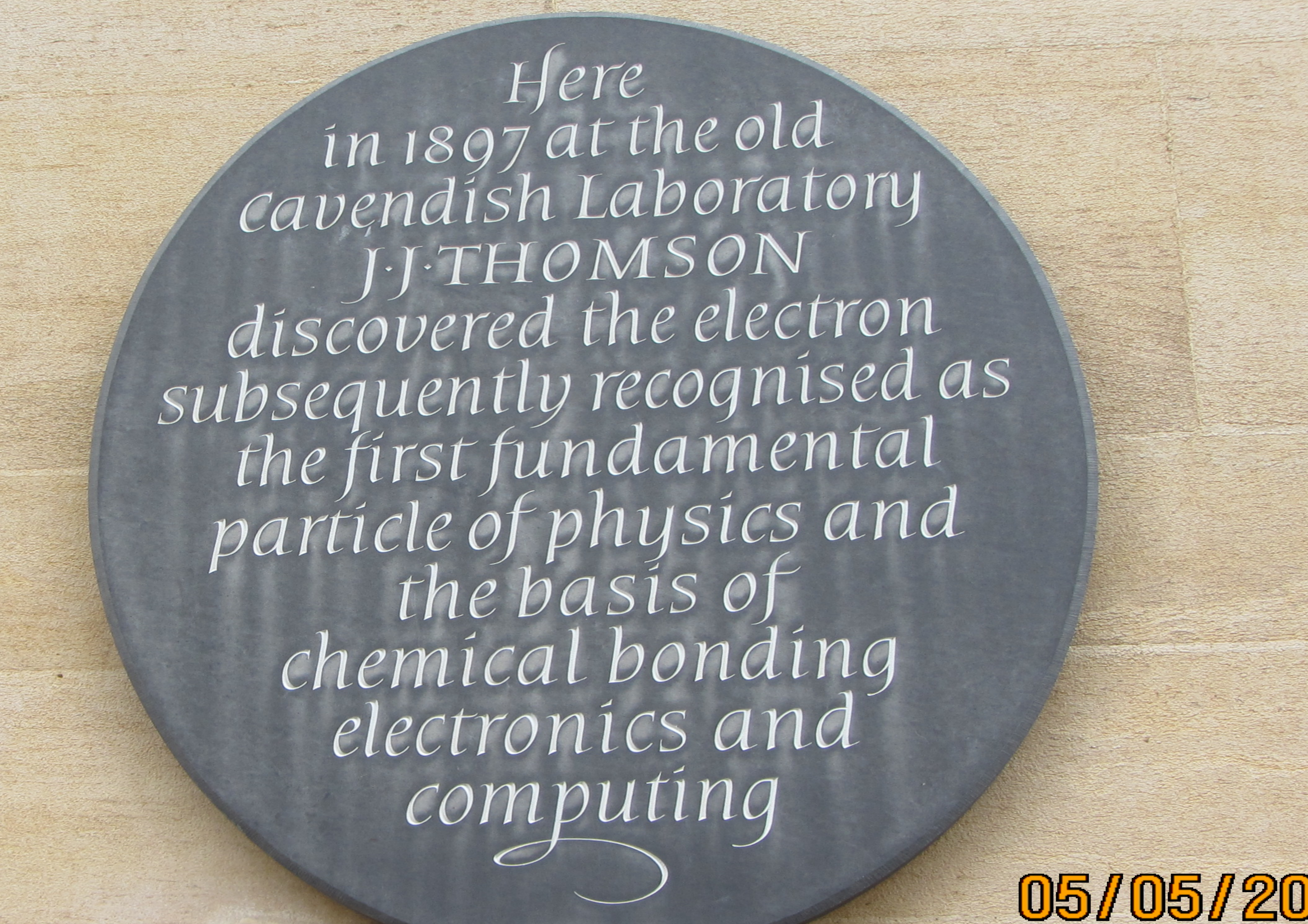
Of course not everyone feels this way, and even those who do have to ask whether learning the laws of nature is worth the billions of dollars it costs to build particle accelerators. This question is going to come up again, since our present Standard Model is certainly not the end of the story. It leaves out gravitation; it does not explain the particular values of the masses of quarks and electrons and other particles; and none of its particles can account for the "dark matter" that astronomers tell us makes up five-sixths of the mass of the universe. You can count on physicists to ask their governments for the facilities they need to grapple with these problems.

A case can be made for this sort of spending, even to those who don't care about learning the laws of nature. Exploring the outer frontier of our knowledge of nature is in one respect like war: It pushes modern technology to its limits, often yielding new technology of great practical importance.

For instance, the new particle was produced at CERN in collisions of protons that occur at a rate of over a hundred million collisions per second. To analyze the flood of data produced by all these collisions requires real time computing of unmatched power. Also, before the protons collide, they are accelerated to an energy over 3,000 times larger than the energy contained in their own masses while they go many times around a 27-kilometer circular tunnel. To keep them in their
tracks requires enormously strong superconducting magnets, cooled by the world's largest source of liquid helium.

In previous work at CERN, elementary particle physicists developed a method of sharing data that has become the World Wide Web.

On a longer time scale, the advance of technology will reflect the coherent picture of nature we are now assembling. At the end of the 19th century physicists in England were exploring the properties of electric currents passing through a near vacuum. Although this was pure science, it led to our knowledge of the electron, without which a large part of today's technology would be impossible. If these physicists had limited themselves to work of obvious practical importance, they would have been studying the behavior of steam boilers.


Here
in 1897 at the old
Cavendish Laboratory
J·J·THOMSON
discovered the electron
subsequently recognised as
the first fundamental
particle of physics and
the basis of
chemical bonding
electronics and
computing
05/05/20

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