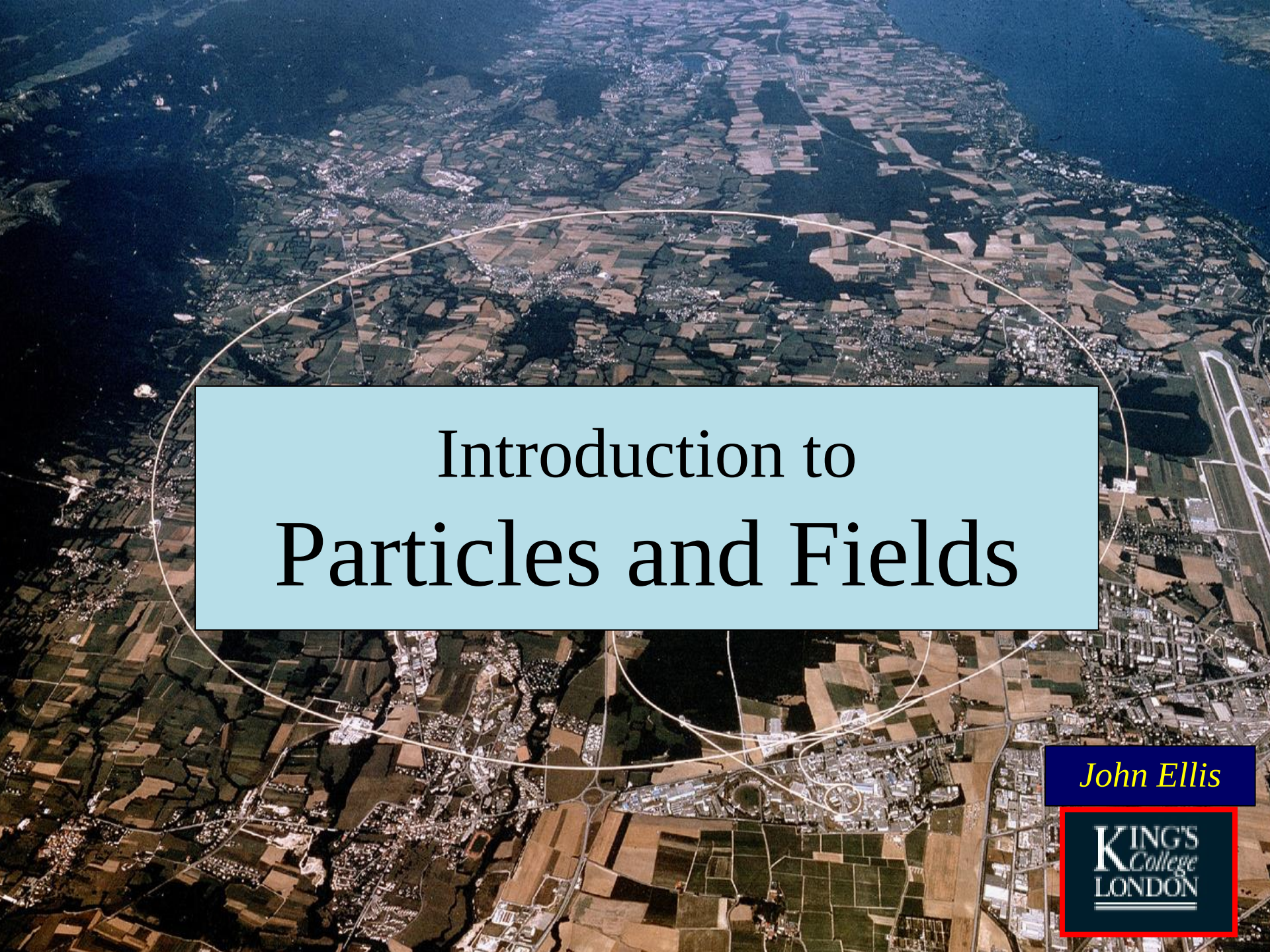


Introduction to Particles and Fields

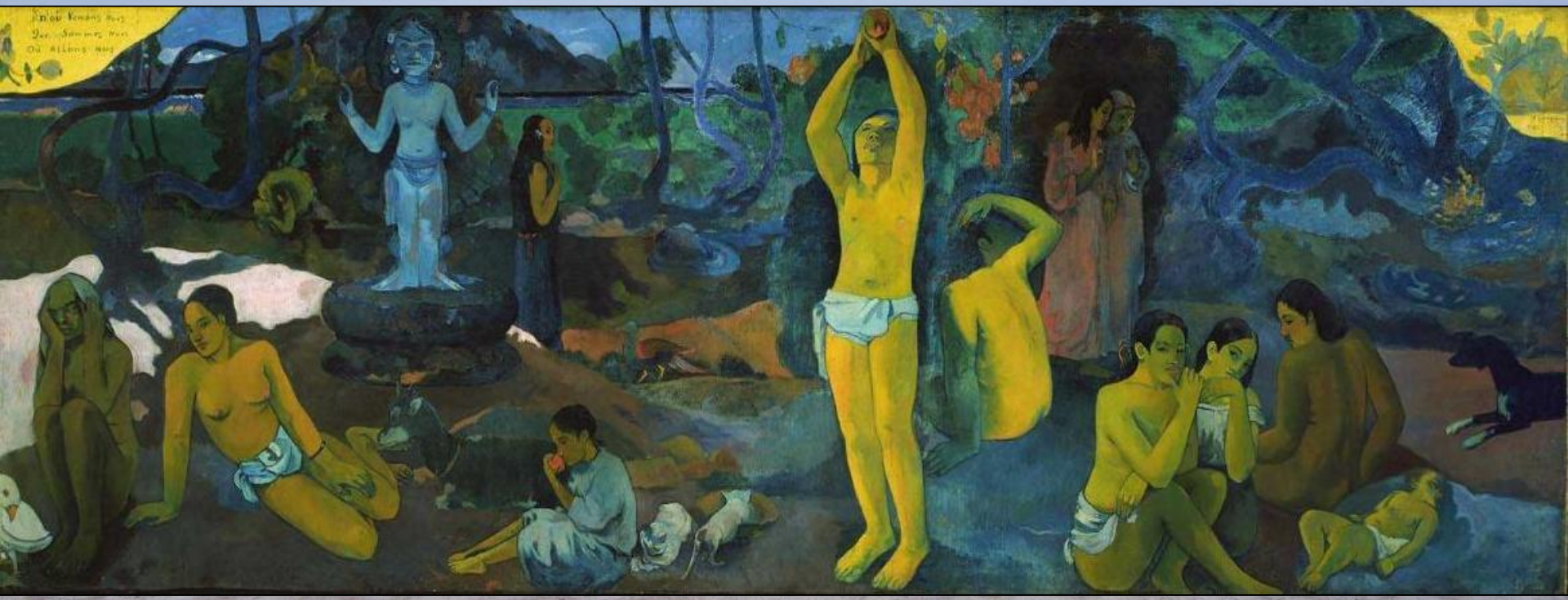
John Ellis

KING'S College LONDON

Where do we come from?

What are we?

Where are we going?



The aim of fundamental physics:
What is the Universe made of?

What is the Universe made of?

over 150 Years of Fundamental Physics

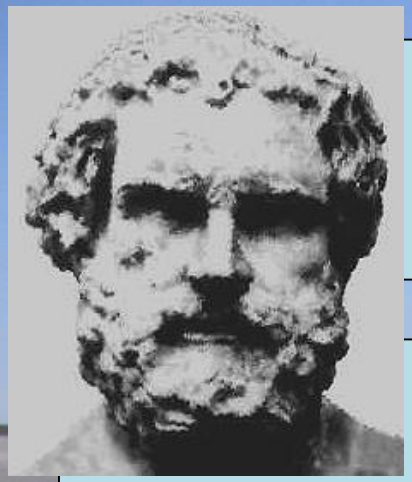
The trail towards a unified

'Theory of Everything'

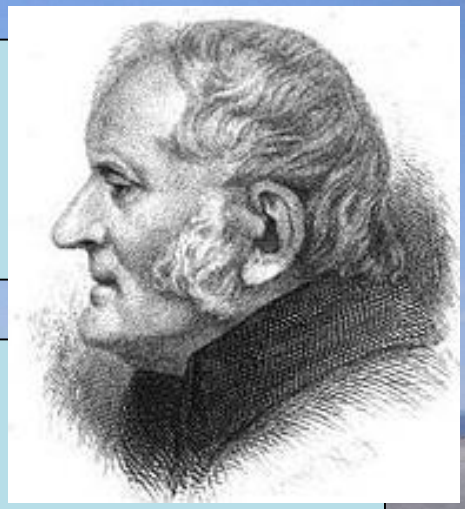
- from electricity and magnetism

towards the Higgs boson at the LHC

- and beyond?



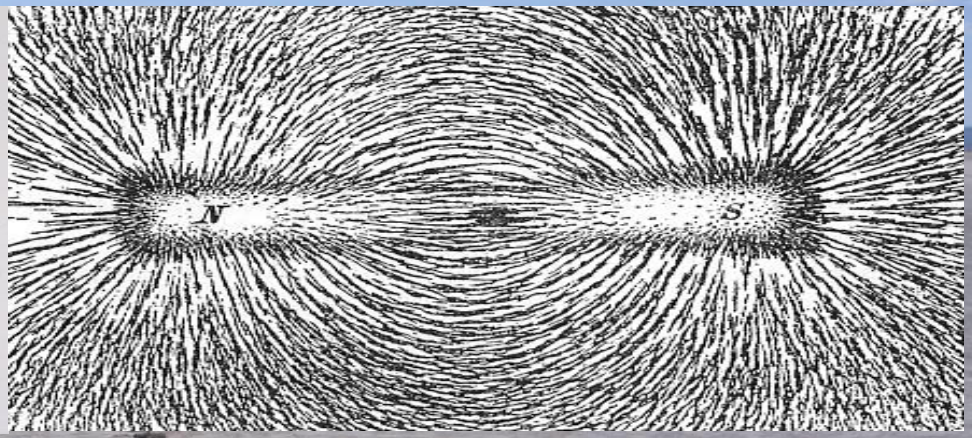
Atoms



Demokritos: ‘Cannot be cut’

- Atomic theory of Dalton (1805)
  - Elements are made of small particles called atoms
  - Atoms of a given element are identical in size, mass, and other properties
  - Atoms cannot be subdivided, created, or destroyed
  - Atoms of different elements combine in simple whole-number ratios to form chemical compounds
  - In chemical reactions, atoms are combined, rearranged
- **Physical existence questioned until ~ 1900**

Electricity and Magnetism



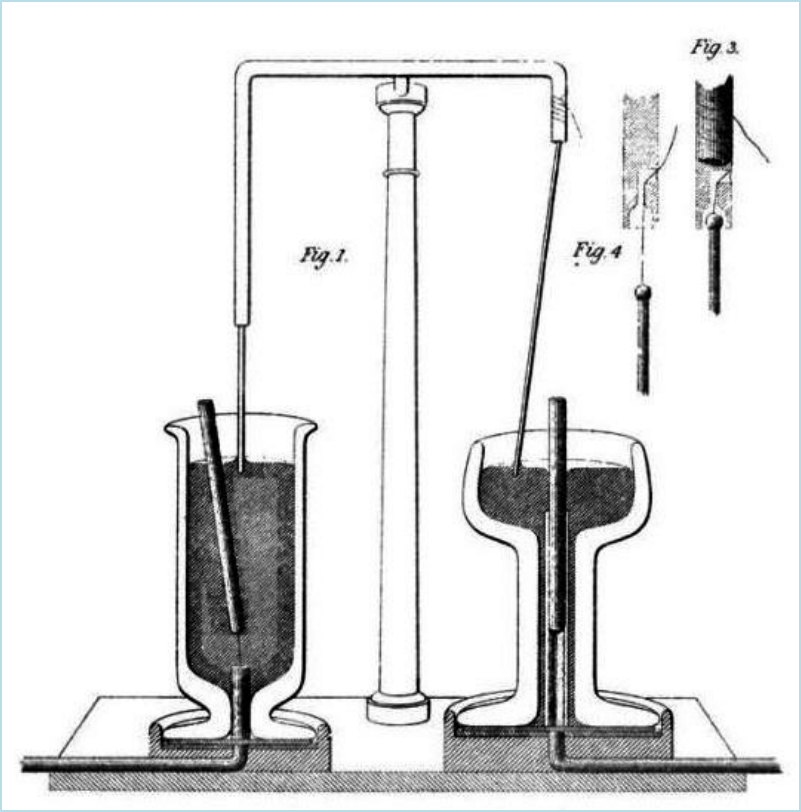
- Electricity:
  - Named using the Greek word for amber
  - Fish, lightning, …
  - Static electricity and electric currents

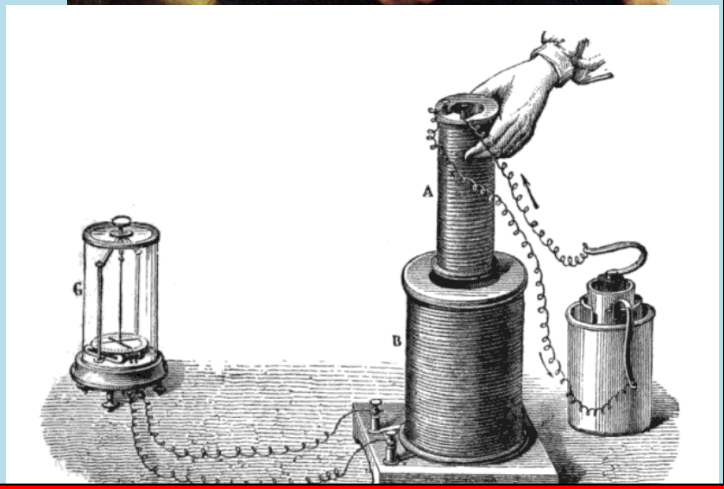
- Magnetism:
  - Named for the region of Greece where lodestones were found
  - Used for navigation from 12th century

Who could have foreseen their importance for development?

Michael Faraday

- Invented the electric motor

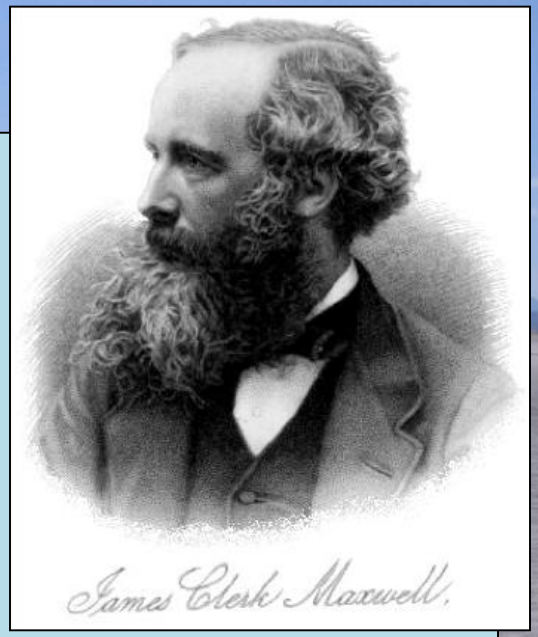




There is every probability that you will soon be able to tax it!

Faraday to politican, when asked about the practical worth of electricity

James Clerk Maxwell



- Professor at King's 1860 – 1865
- The first colour photograph
- Unified theory of electricity and magnetism
- Predicted electromagnetic waves
- Identified light as due to these waves
- Calculated the velocity of light
- …

KING'S College LONDON

One scientific epoch ended and another began with James Clerk Maxwell - *Albert Einstein*

Maxwell's Equations

- Prototype for describing particle interactions:

  unified

  electricity &

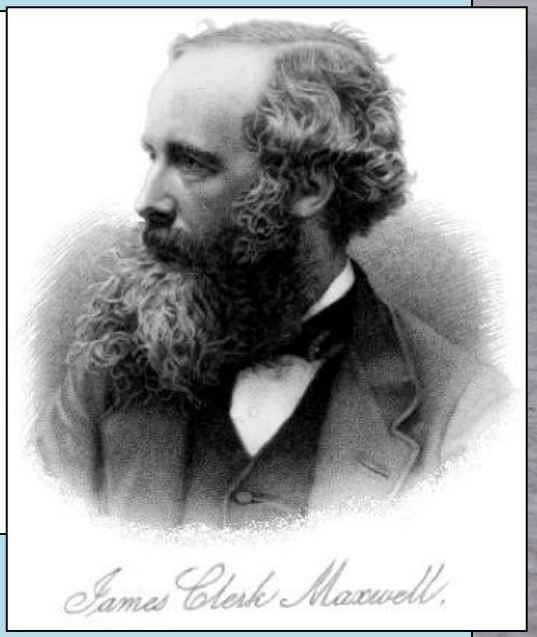
  magnetism

$$\nabla \cdot \mathbf{E} = 0$$

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

$$\nabla \cdot \mathbf{B} = 0$$

$$\nabla \times \mathbf{B} = \mu_0 \epsilon_0 \frac{\partial \mathbf{E}}{\partial t}$$

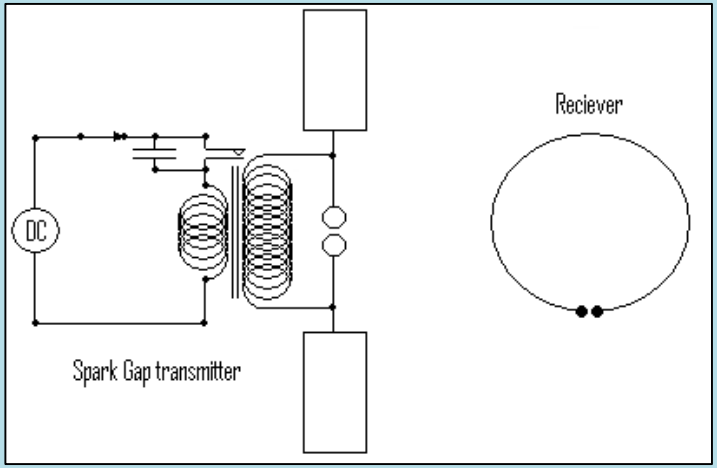


- Basis for Einstein's theories of relativity

Einstein's study had pictures of Newton, Faraday and Maxwell

Electromagnetic Waves

- Proposed by Maxwell
- Discovered by Hertz

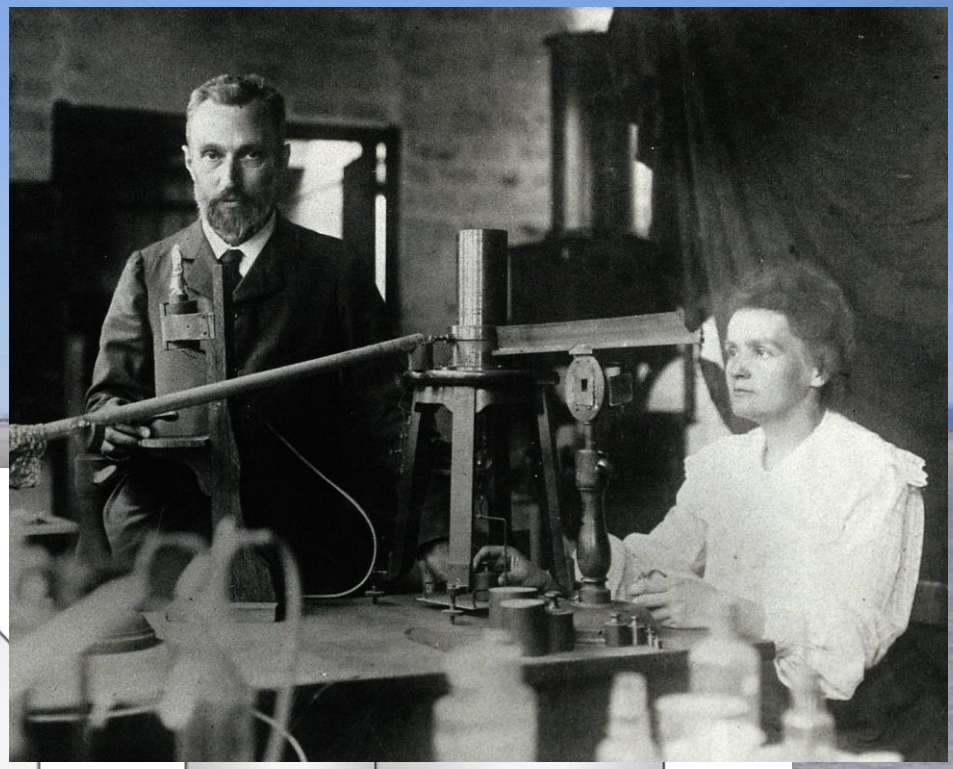


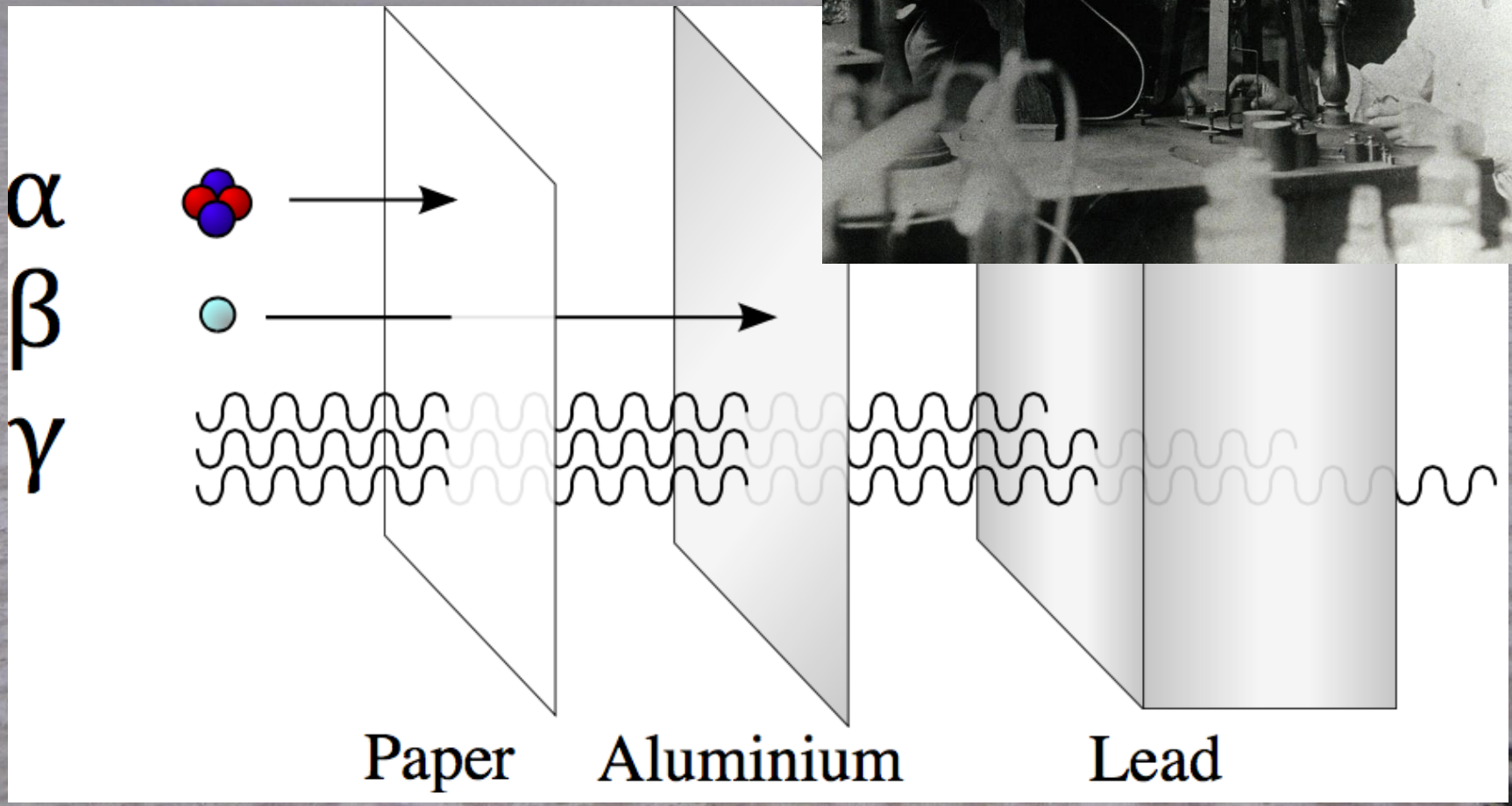
- A lot to answer for ….
- **Nobody knows where fundamental physics may lead**

Radioactivity

- Discovered by Becquerel
- Uranium emits penetrating radiations (not electromagnetic)
- Now distinguish 3 types:
  - α = Helium nuclei
  - β = electrons
  - γ = particles of light

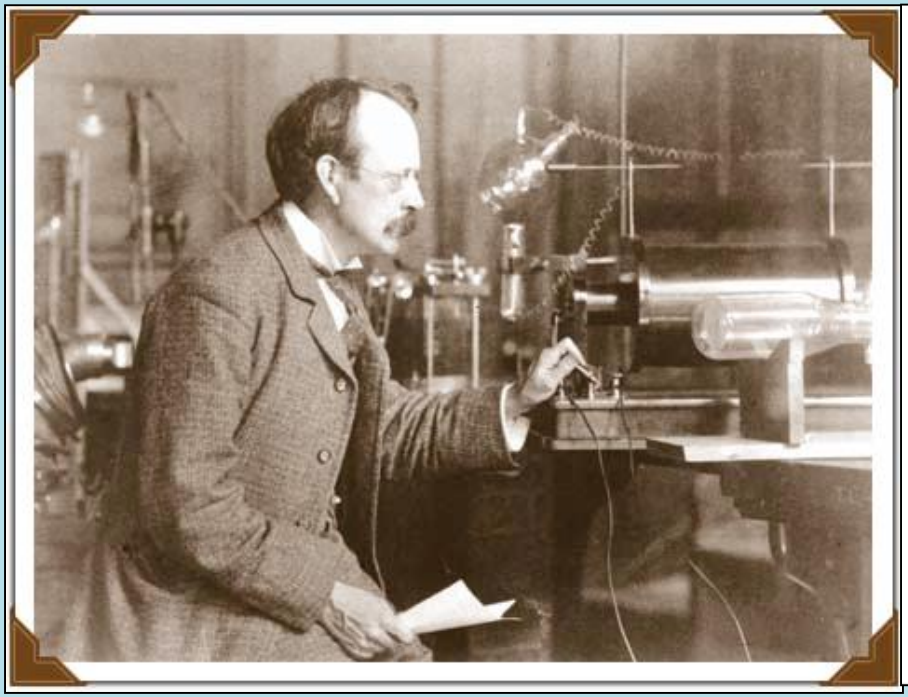
Different Types of Radioactivity

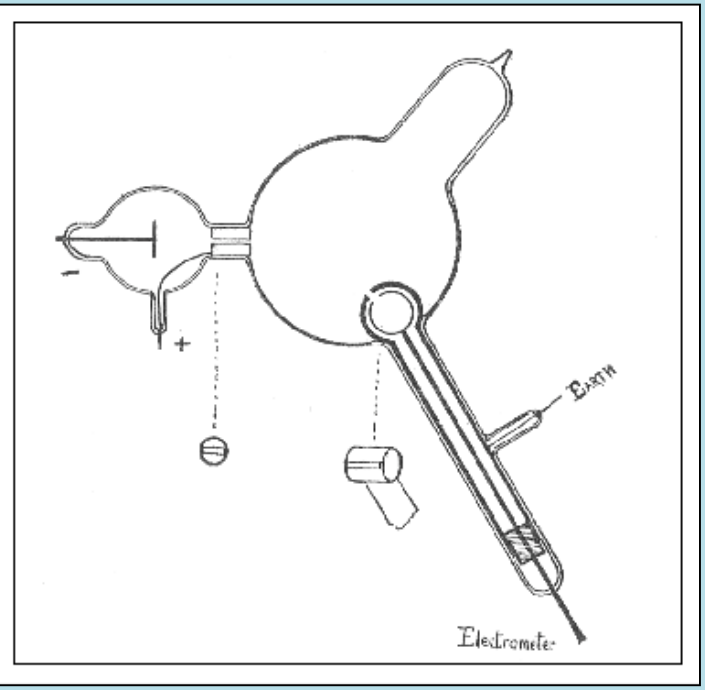




The First Elementary Particle

- Discovered by J.J. Thomson in 1897





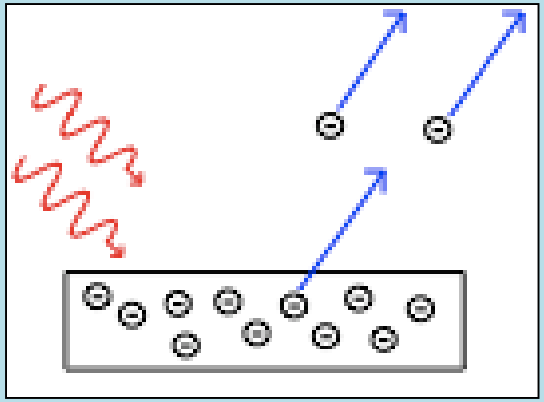
- **The electron** – the basis of the electronic industry
- Old-style TV sets used beams of electrons

Photon: the Particle of Light

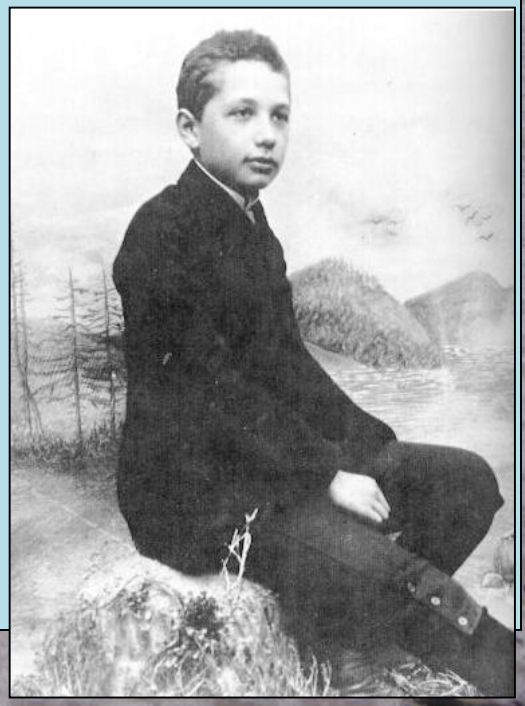
- Quantum hypothesis introduced by Planck:

$$E = hf$$

- Physical reality postulated by Einstein to explain photoelectric effect

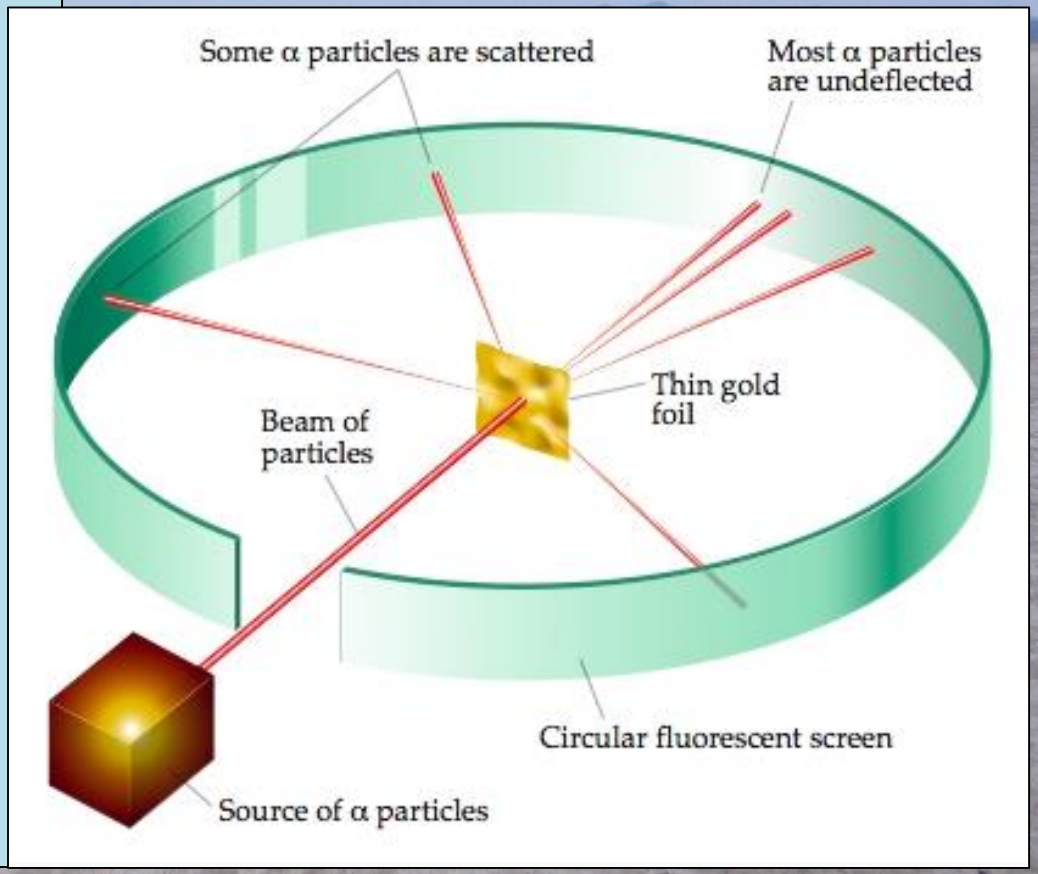


- **Motivation for his Nobel Prize**

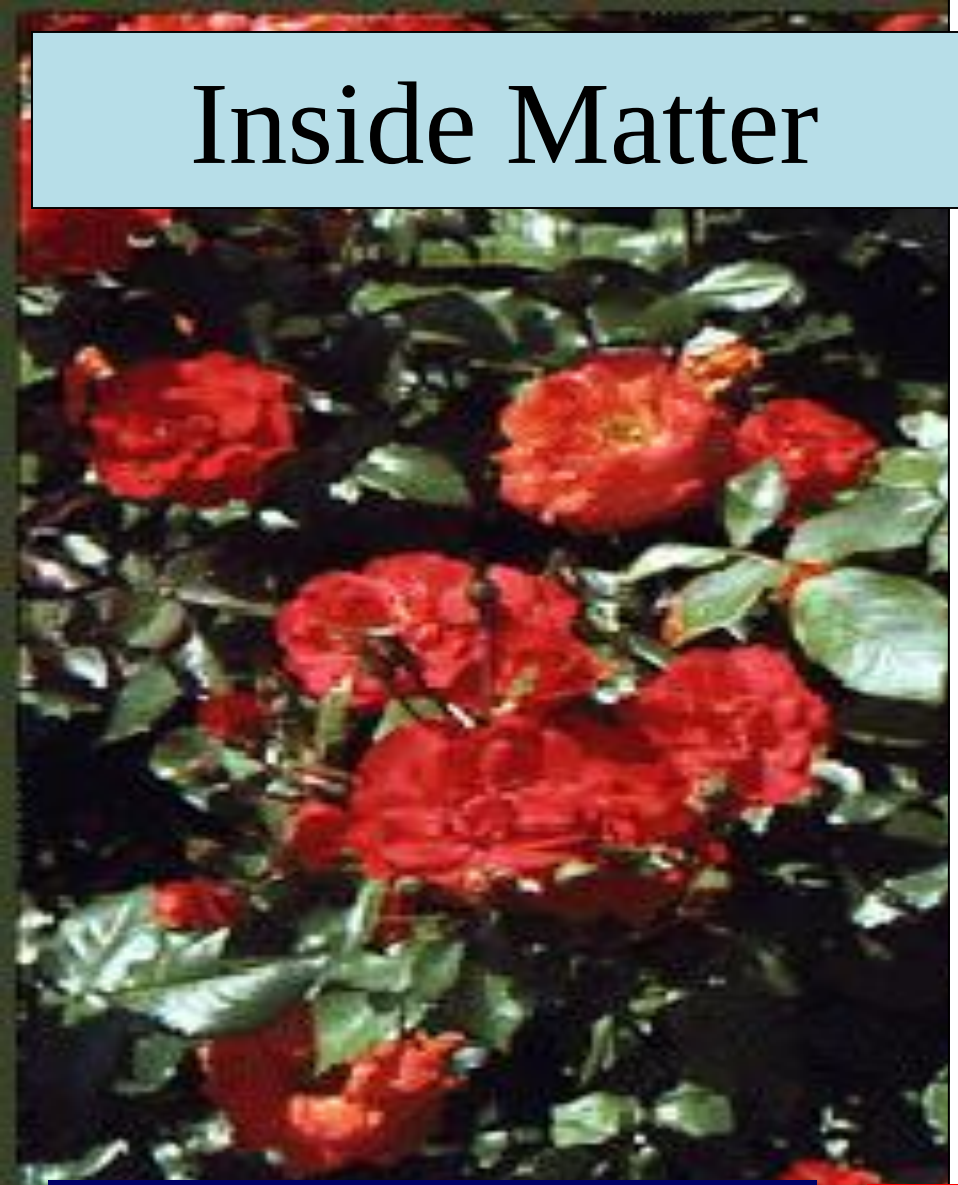


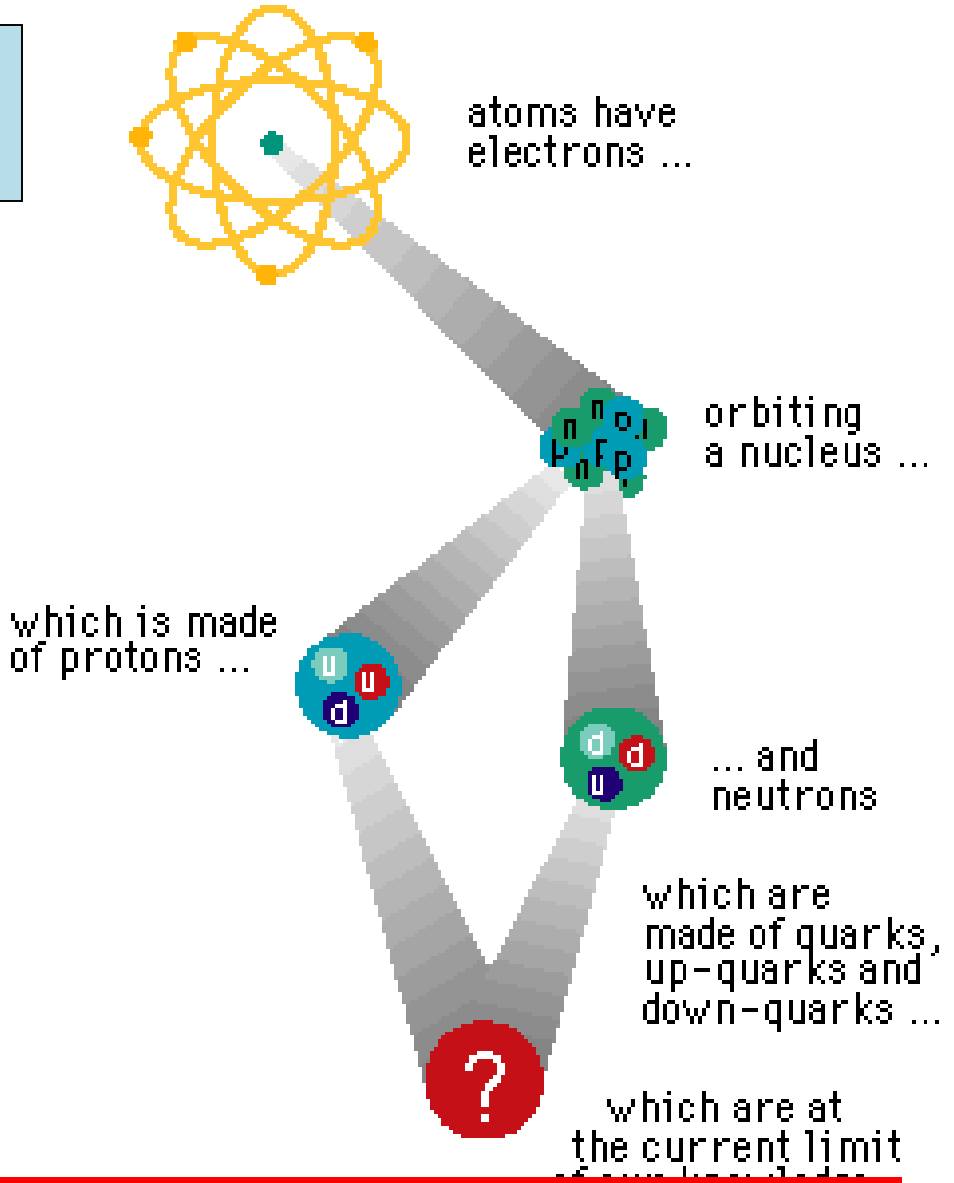
Discovery of the Atomic Nucleus

- Bombard gold foil with α particles (= Helium nuclei)
- Most go (almost) straight through
- Some scatter at large angles (even bounce back)
- Atom contains small, hard nucleus



Inside Matter





All matter is made of the same constituents

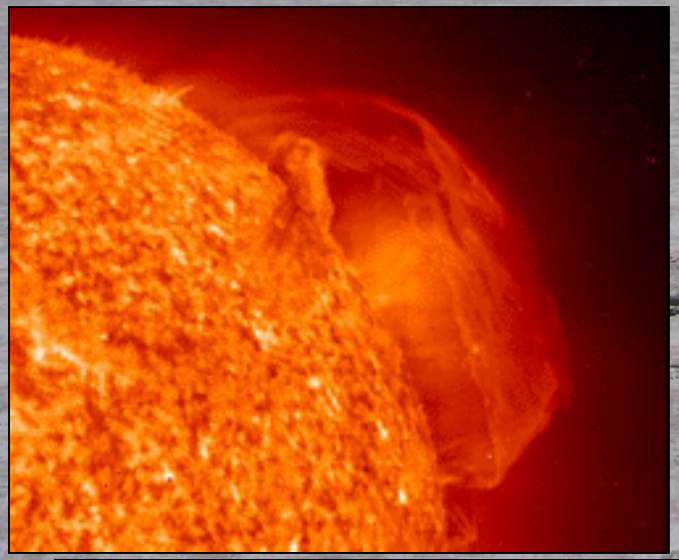
What are they?
What forces between them?

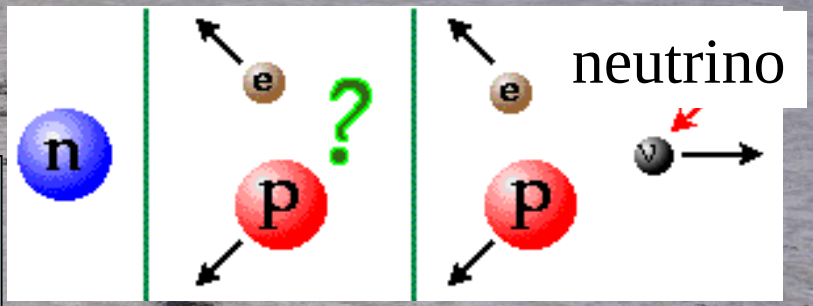
The Fundamental Forces of Nature

Electromagnetism:
the origin of light, radio, …, holds atoms together

Strong nuclear force:
holds nuclei together

Weak nuclear force:
the origin of radioactivity



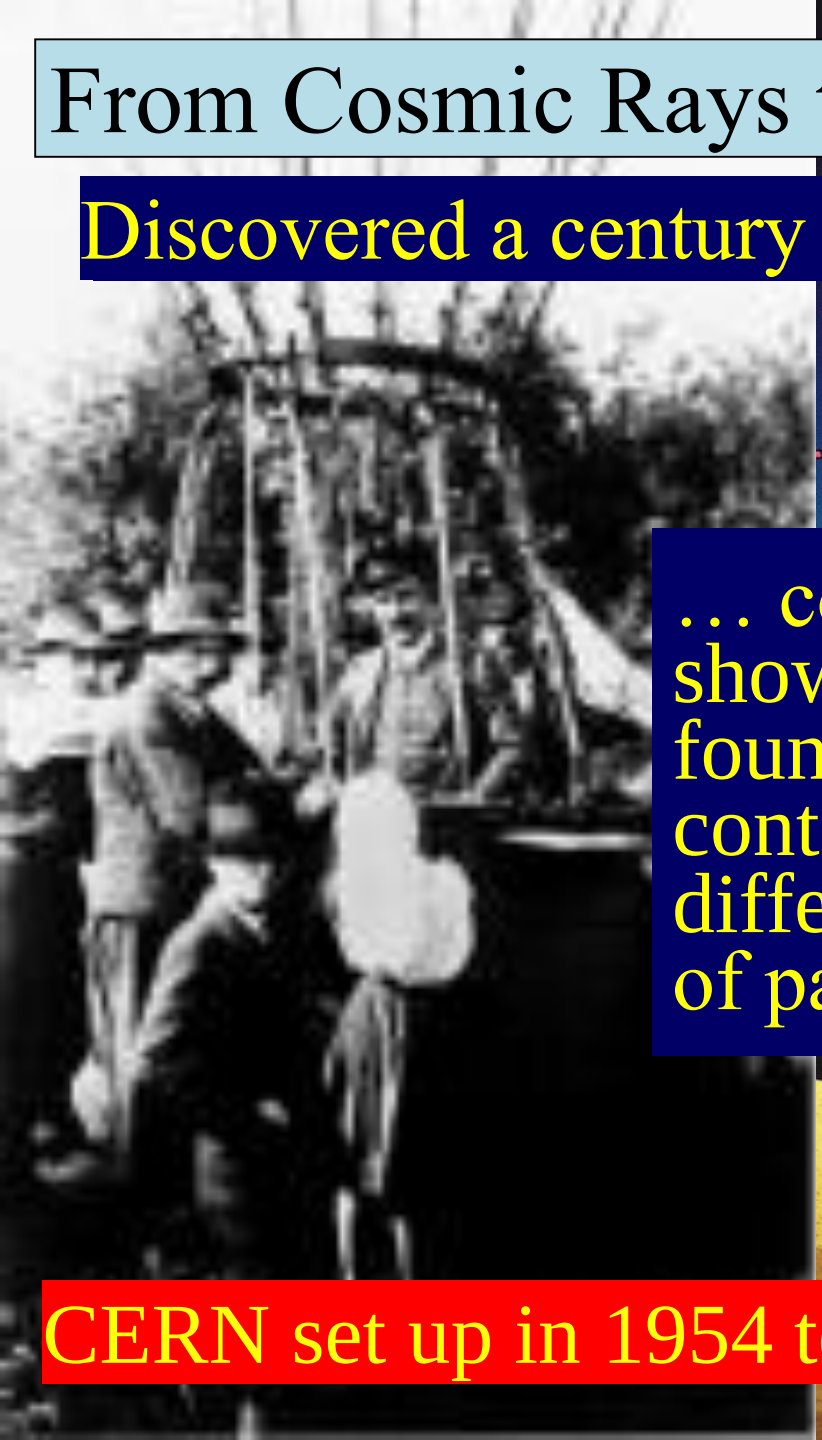


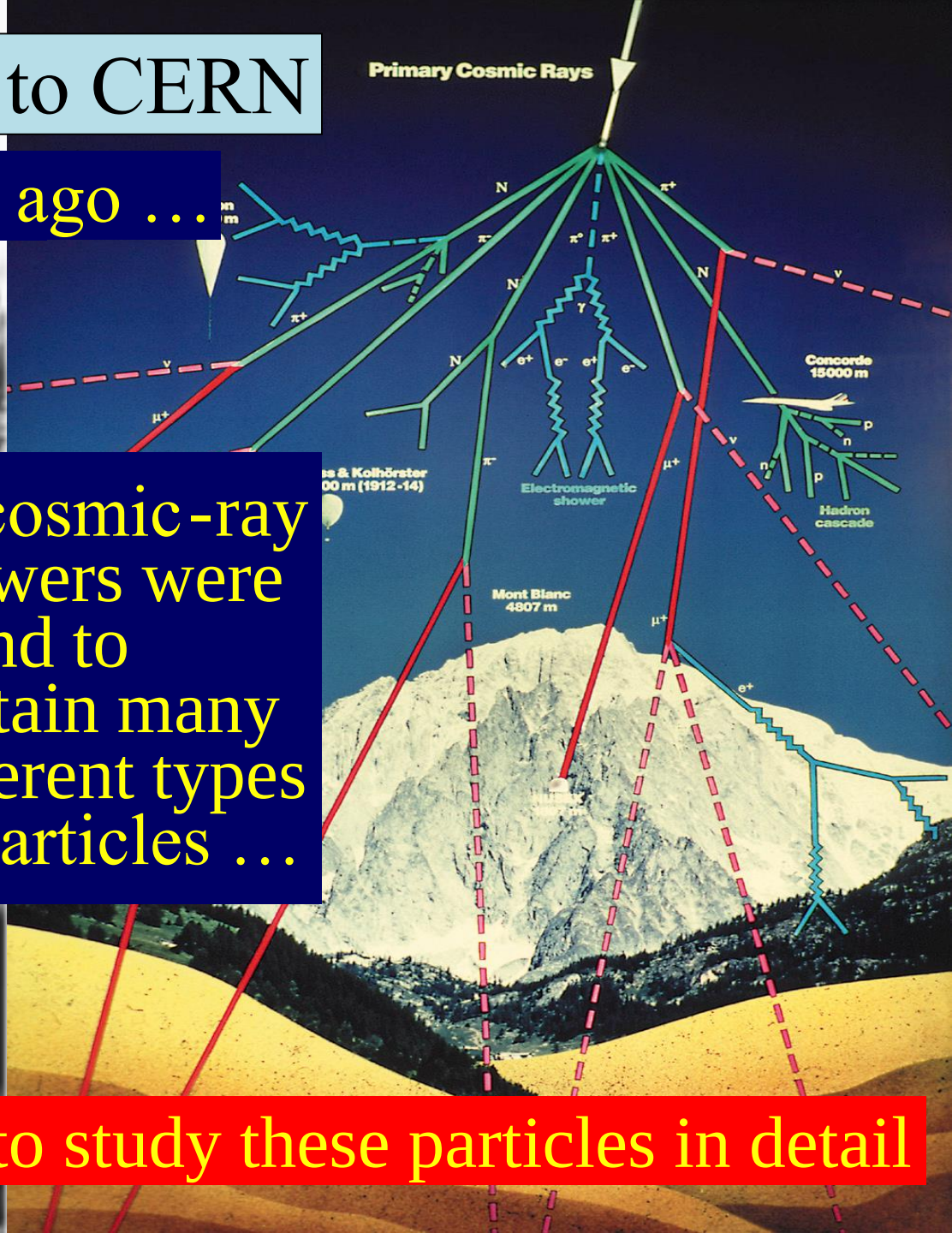
Combine
to provide
the heat
from the Sun

Gravity:
holds planets, stars, galaxies together

From Cosmic Rays to CERN

Discovered a century ago …



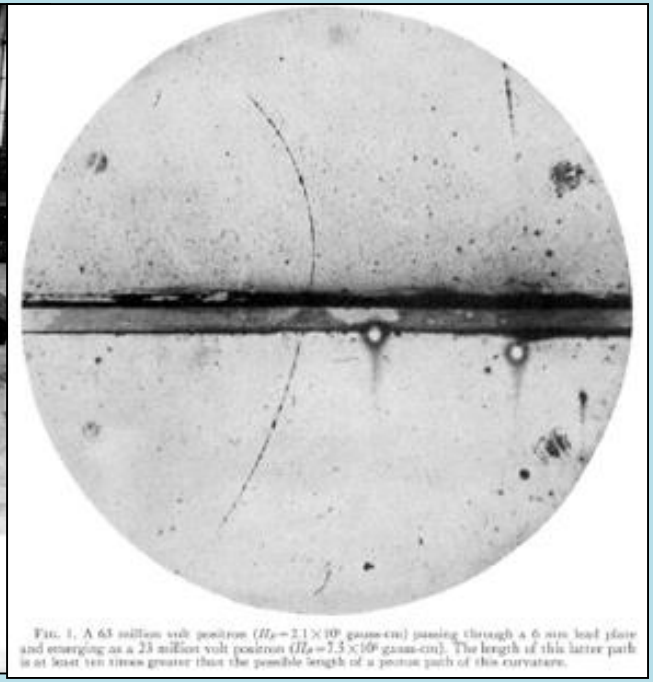


… cosmic-ray showers were found to contain many different types of particles …

CERN set up in 1954 to study these particles in detail

The Discovery of Antimatter

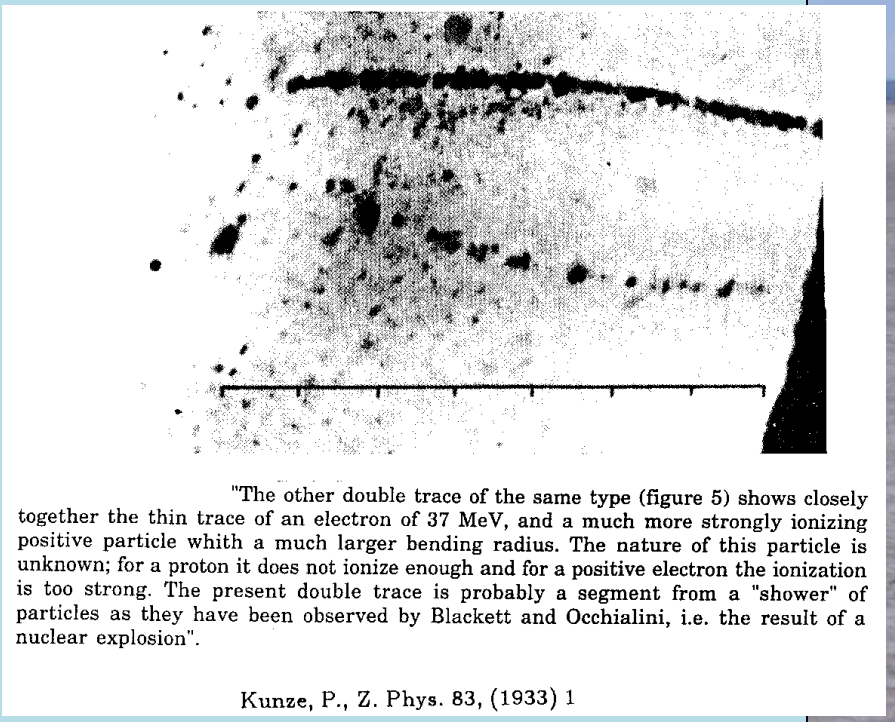
- Existence predicted by Dirac
- The antiparticle of the electron (the positron) was discovered in cosmic rays by Anderson



- The same mass as the electron, opposite electric charge
- Used in medical diagnosis (PET scanners)

The Discovery of the Muon

- **NOT predicted**
- Observed in cosmic rays by Kunze in 1932
- Larger bending radius than the positron
- Ionizes less than proton
- Passing though us all the time
- *"Who ordered that"* – I.I. Rabi



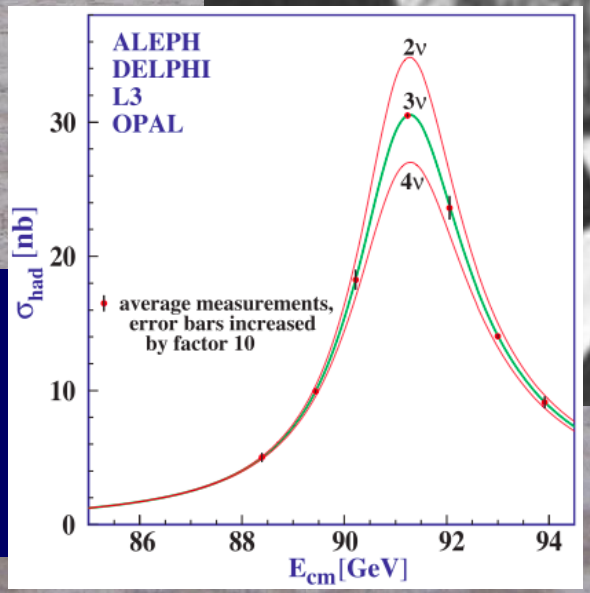
"The other double trace of the same type (figure 5) shows closely together the thin trace of an electron of 37 MeV, and a much more strongly ionizing positive particle whith a much larger bending radius. The nature of this particle is unknown; for a proton it does not ionize enough and for a positive electron the ionization is too strong. The present double trace is probably a segment from a "shower" of particles as they have been observed by Blackett and Occhialini, i.e. the result of a nuclear explosion".

Kunze, P., Z. Phys. 83, (1933) 1

The ‘Standard Model’ of Particle Physics

Proposed byAbdus Salam, Glashow and Weinberg

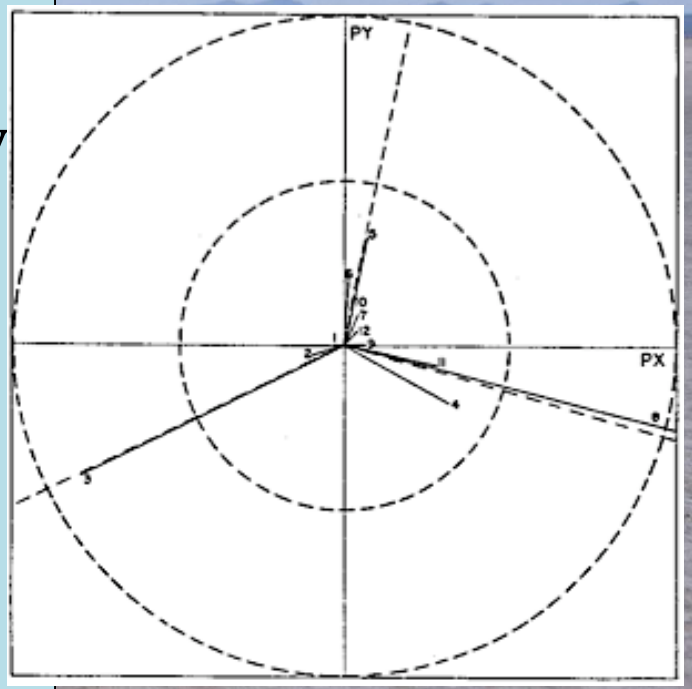
Tested by experiments at CERN



Perfect agreement between theory and experiments in all laboratories

Strong Nuclear Force

- Holds quarks together inside protons inside nuclei
- Modelled after Maxwell's theory
- Carried by 'gluon' particles
- First direct evidence in 1979
- Using method suggested by JE, Mary Gaillard, Graham Ross in 1976
- **Second force particle to have been discovered**



Weak Interactions

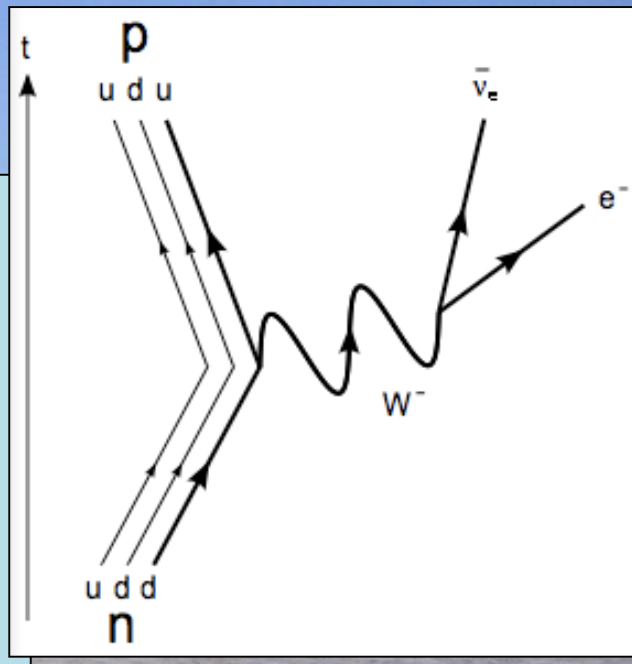
Responsible for radioactivity

Theory also modelled on Maxwell

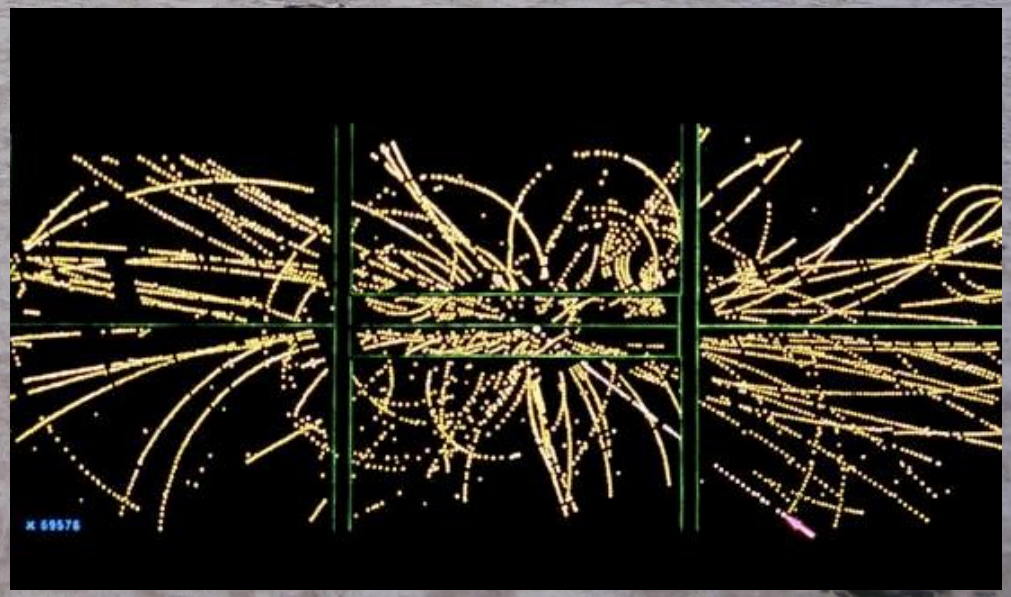
BUT

W boson - carrier of weak interactions

Predicted to weigh ~ 80 GeV



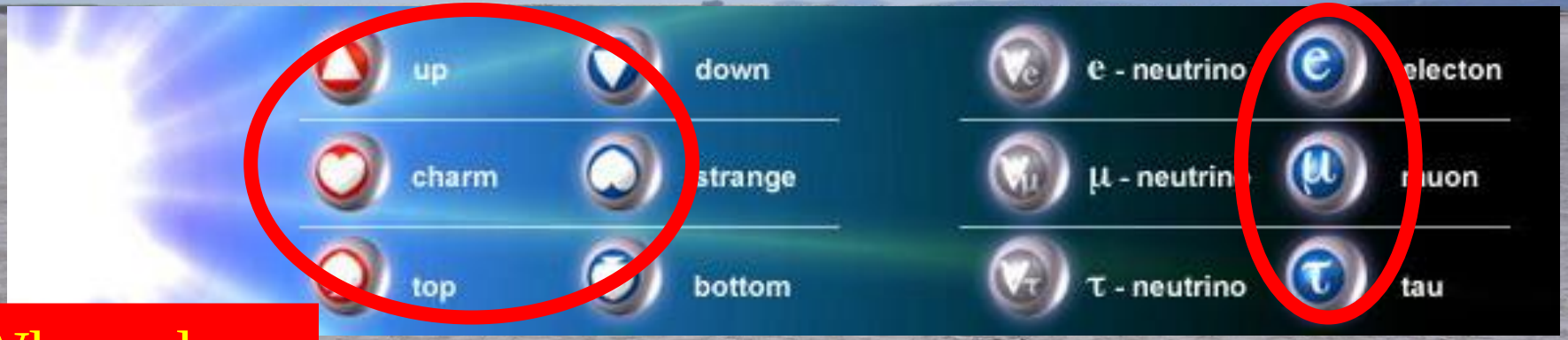
Discovered at CERN in 1983 by Carlo Rubbia et al



The ‘Standard Model’

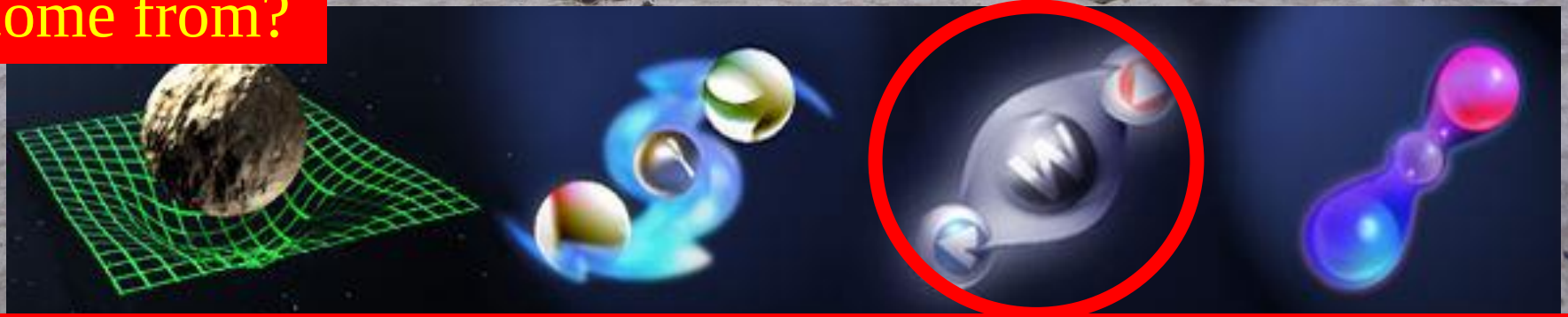
= Cosmic DNA

The matter particles



Where does mass come from?

The fundamental interactions



Gravitation electromagnetism weak nuclear force strong nuclear force

BUT

Why do Things Weigh?

Newton:

Weight proportional to Mass

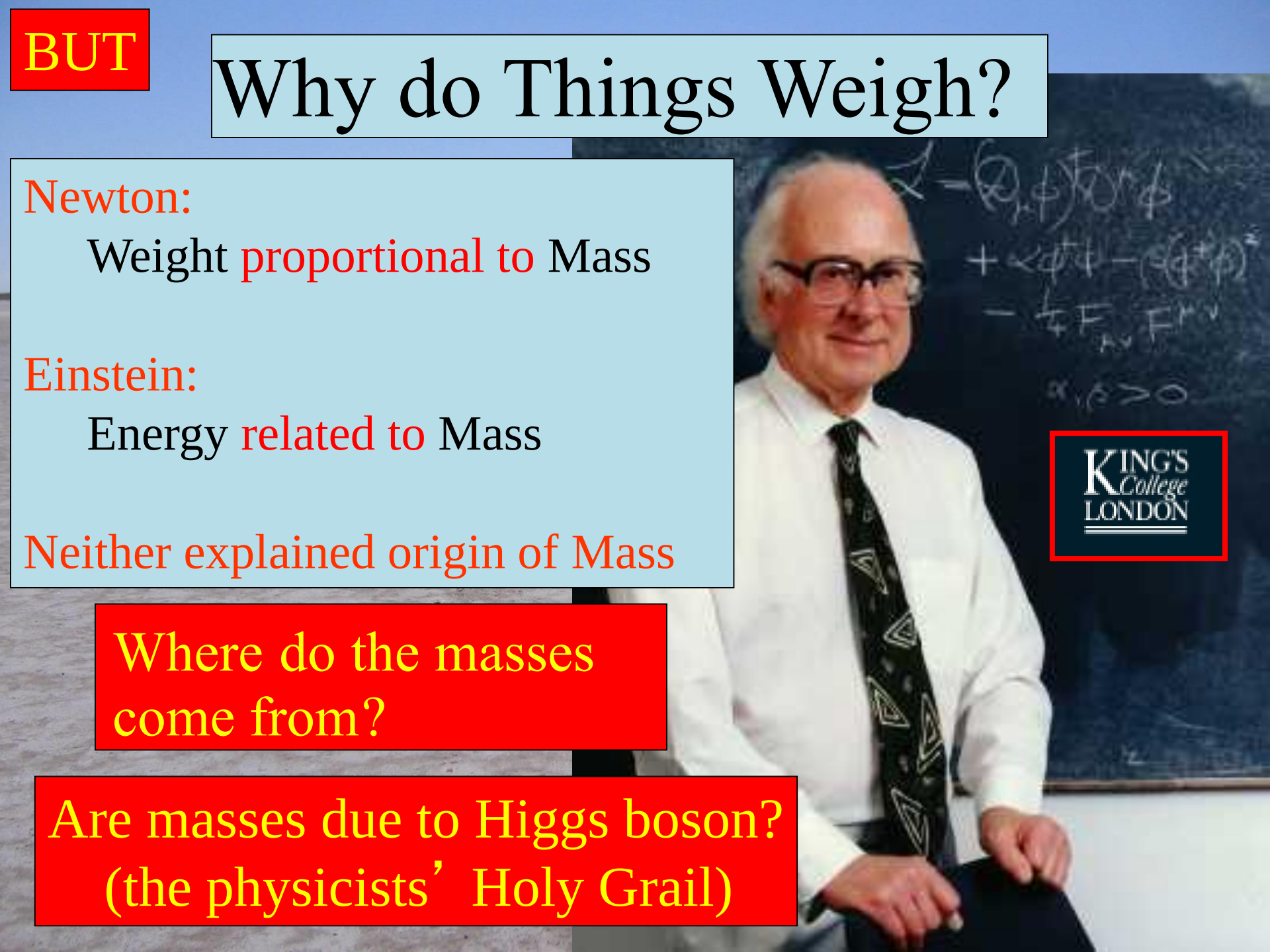
Einstein:

Energy related to Mass

Neither explained origin of Mass

Where do the masses come from?

Are masses due to Higgs boson? (the physicists' Holy Grail)



Think of a Snowfield

The LHC looked for the snowflake: The Higgs Boson

Skier moves fast:
Like particle without mass
e.g., photon = particle of light

Snowshoer sinks into snow, moves slower:
Like particle with mass
e.g., electron

Hiker sinks deep, moves very slowly:
Particle with large mass

A Phenomenological Profile of the Higgs Boson

- First attempt at systematic survey

A PHENOMENOLOGICAL PROFILE OF THE HIGGS BOSON

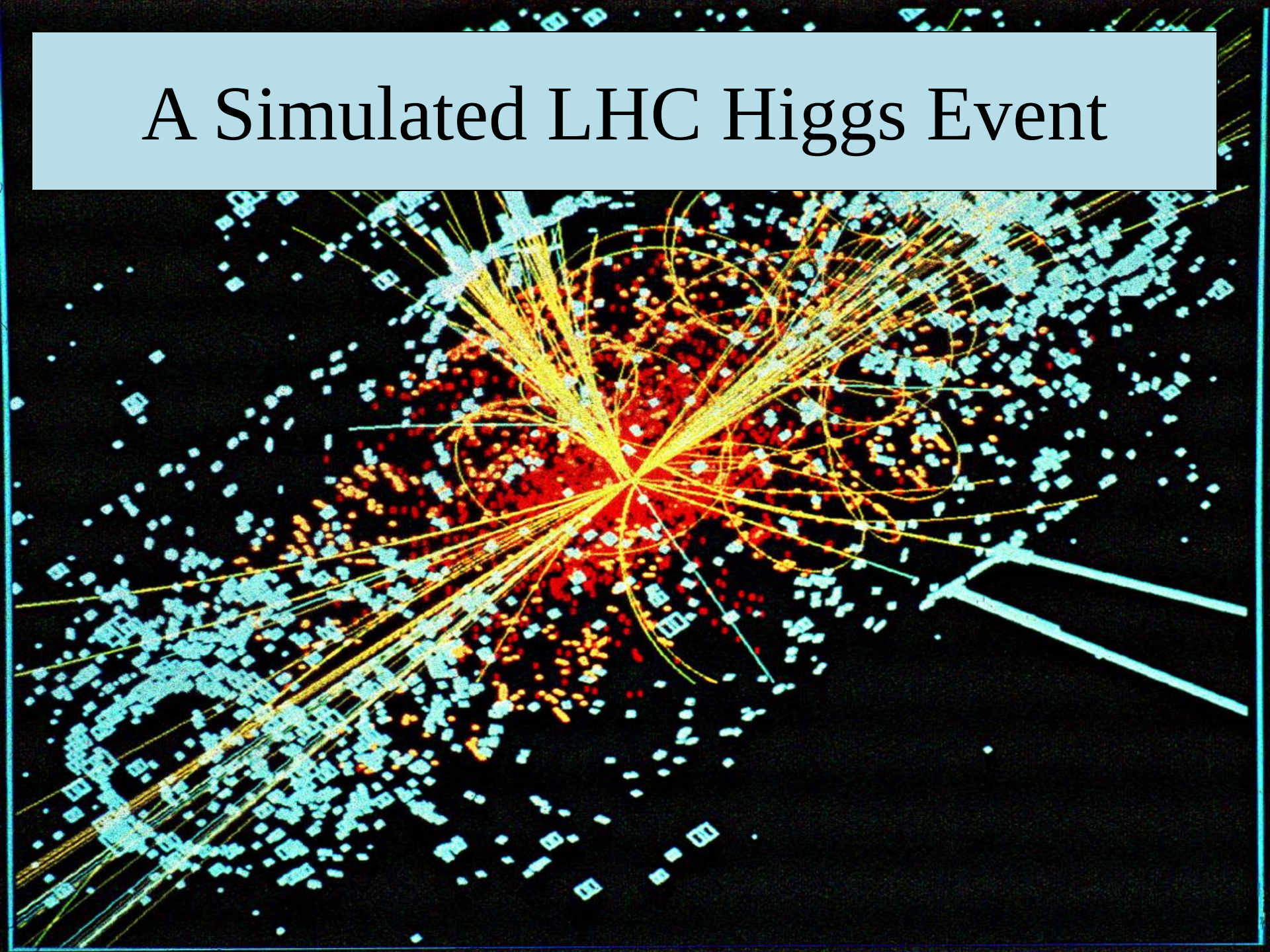
John ELLIS, Mary K. GAILLARD * and D.V. NANOPOULOS **
CERN, Geneva

Received 7 November 1975

A discussion is given of the production, decay and observability of the scalar Higgs boson H expected in gauge theories of the weak and electromagnetic interactions such as the Weinberg-Salam model. After reviewing previous experimental limits on the mass of

We should perhaps finish with an apology and a caution. We apologize to experimentalists for having no idea what is the mass of the Higgs boson, unlike the case with charm [3,4] and for not being sure of its couplings to other particles, except that they are probably all very small. For these reasons we do not want to encourage big experimental searches for the Higgs boson, but we do feel that people performing experiments vulnerable to the Higgs boson should know how it may turn up.

A Simulated LHC Higgs Event



Without Higgs …

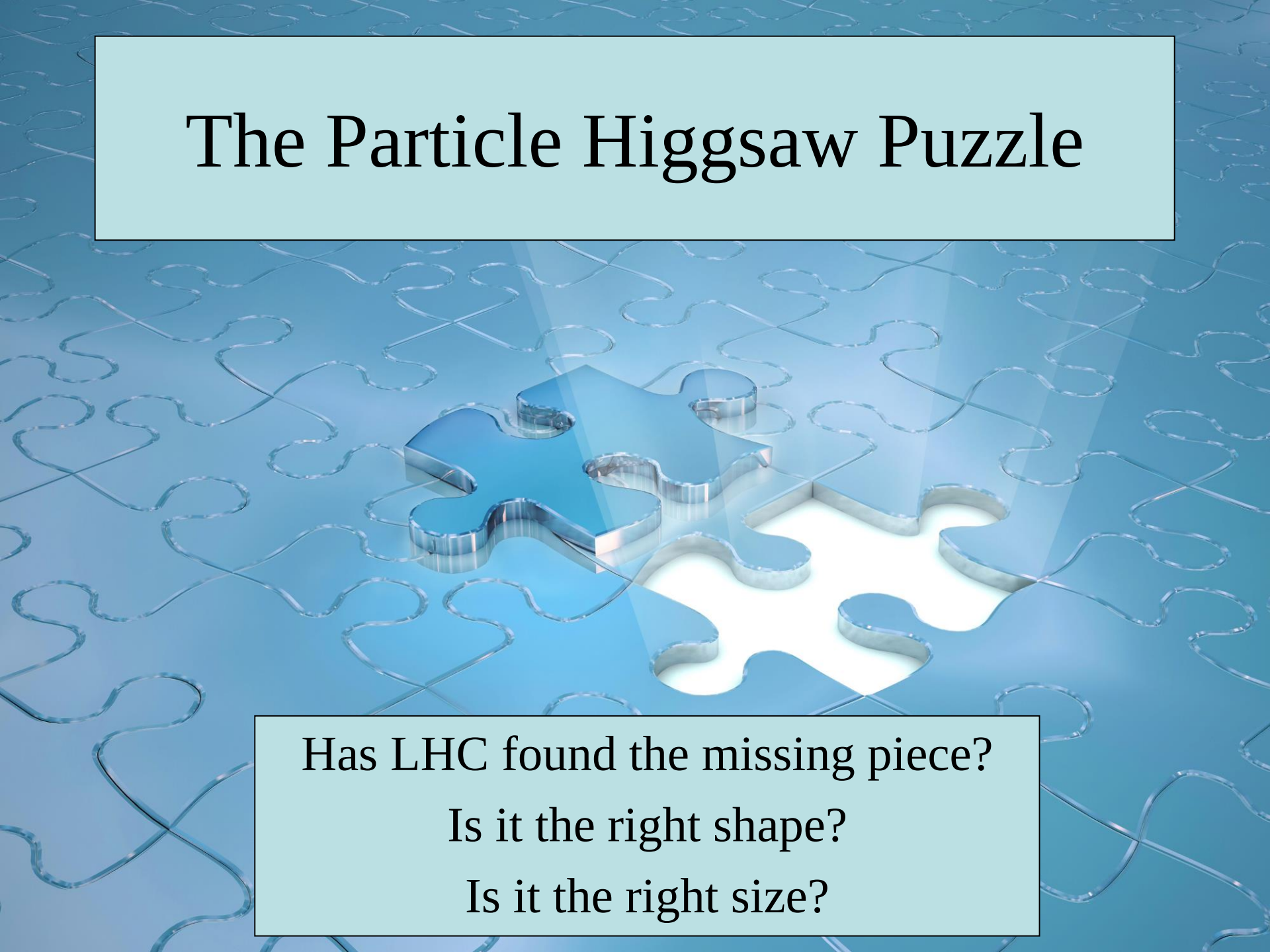
… there would be no atoms

- Electrons would escape at the speed of light

… weak interactions would not be weak

- Life would be impossible: there would be no nuclei, everything would be radioactive

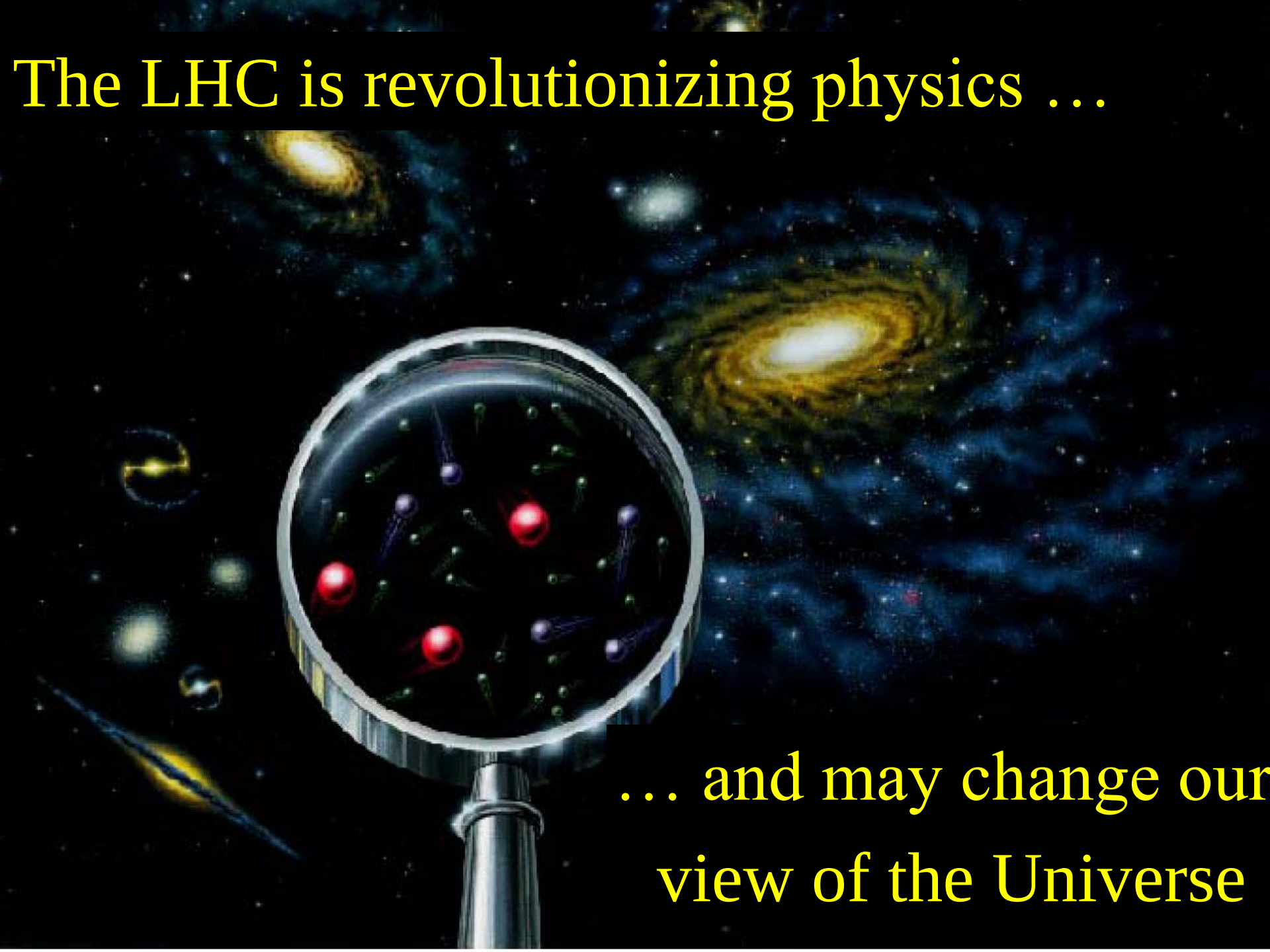
The Particle Higgsaw Puzzle



Has LHC found the missing piece?

Is it the right shape?

Is it the right size?


The LHC is revolutionizing physics …
… and may change our
view of the Universe