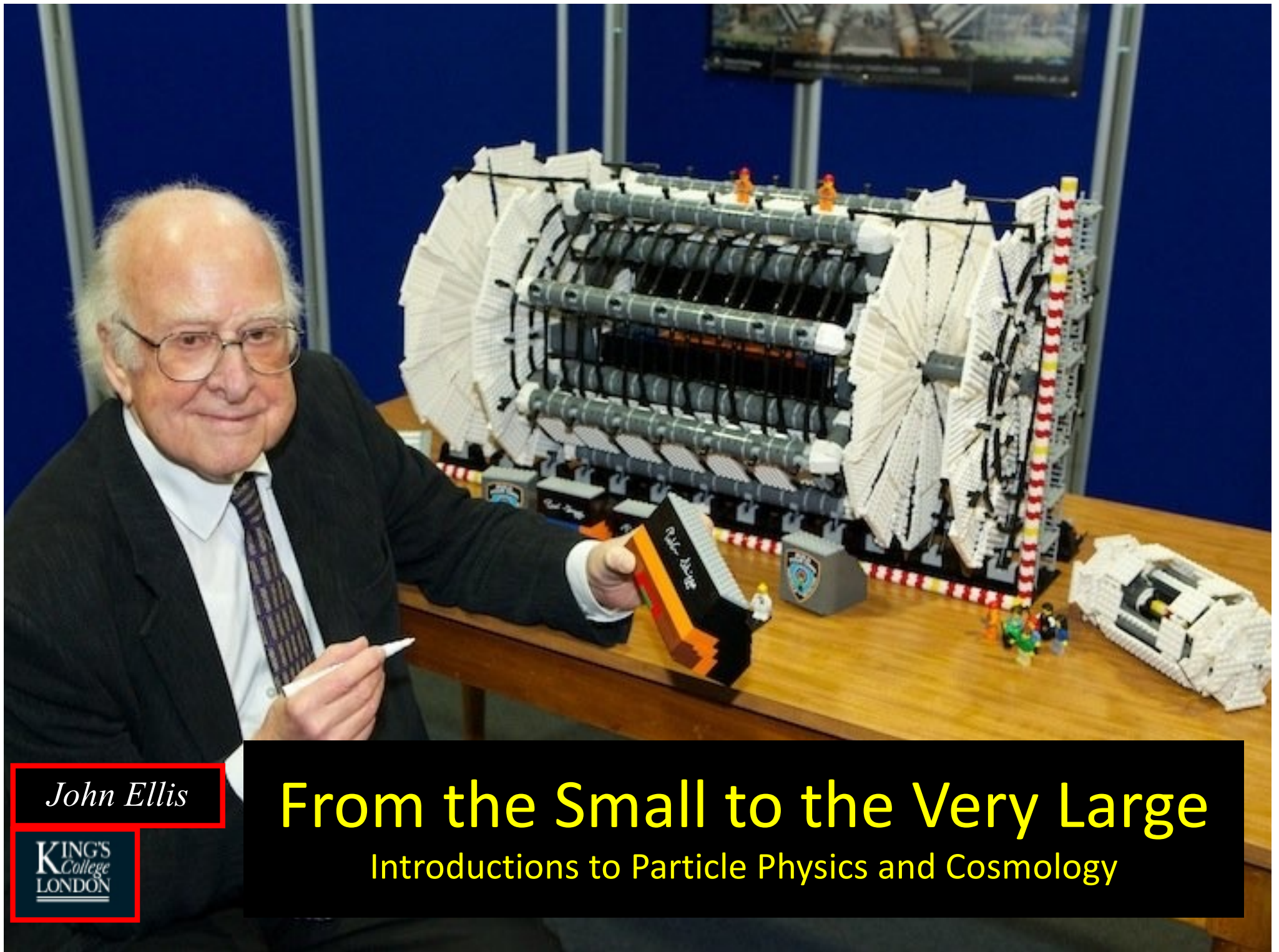




John Ellis

KING'S
College
LONDON

From the Small to the Very Large

Introductions to Particle Physics and Cosmology

Evolution of the Universe

What will
happen in
the
future?

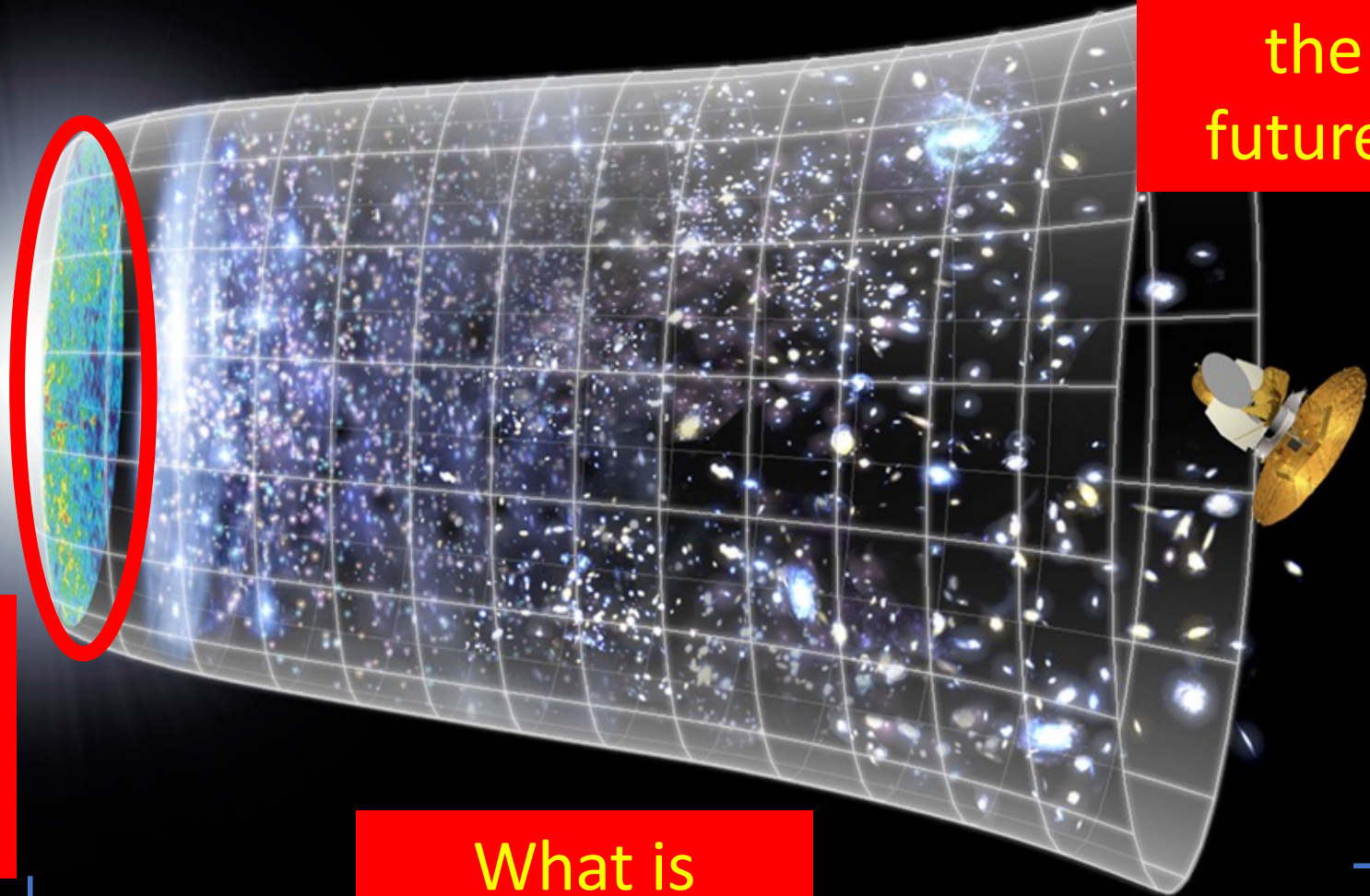
Big Bang

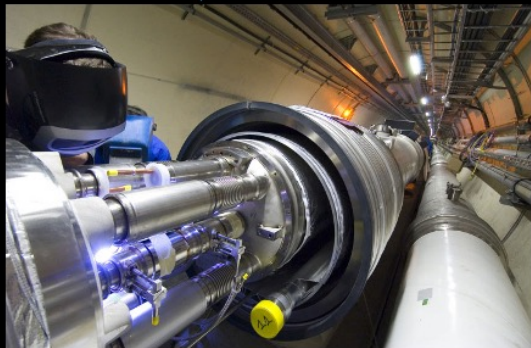
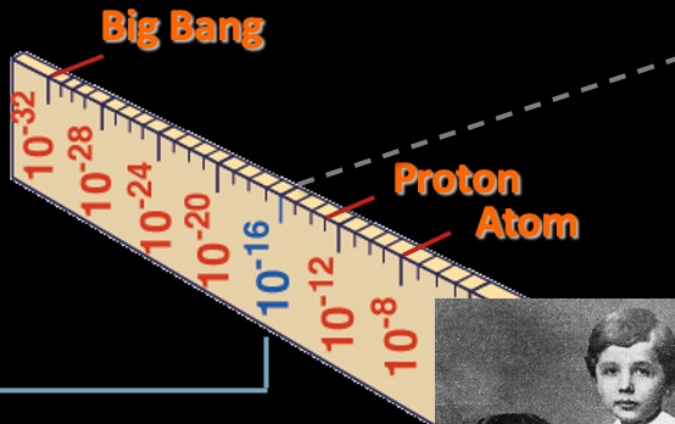
What
happened
then?

What is
the universe
made of?

Today

10^{28} cm



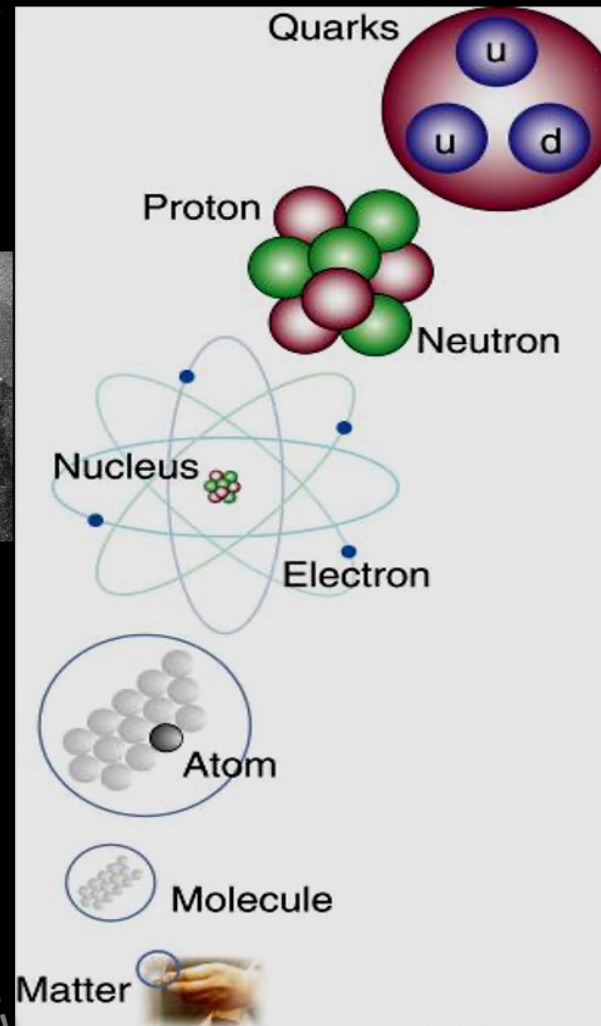
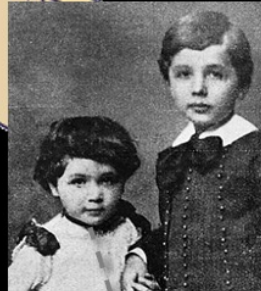


LHC

Super-Microscope



**Study physics laws of first moments after Big Bang
increasing Symbiosis between Particle Physics,
Astrophysics and Cosmology**

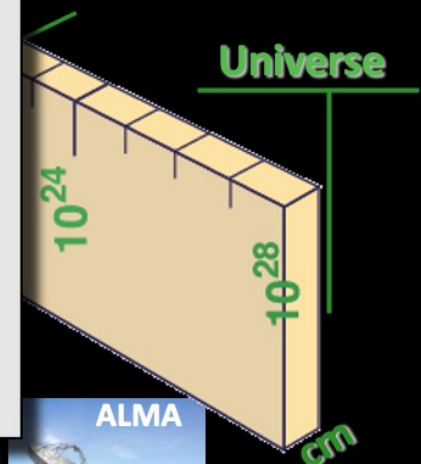


Dark matter!



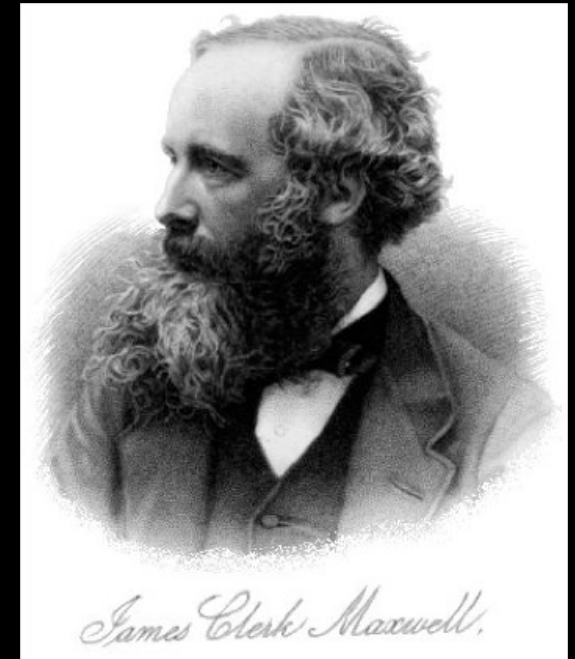
Radius of Galaxies

Universe



Electromagnetic Interactions

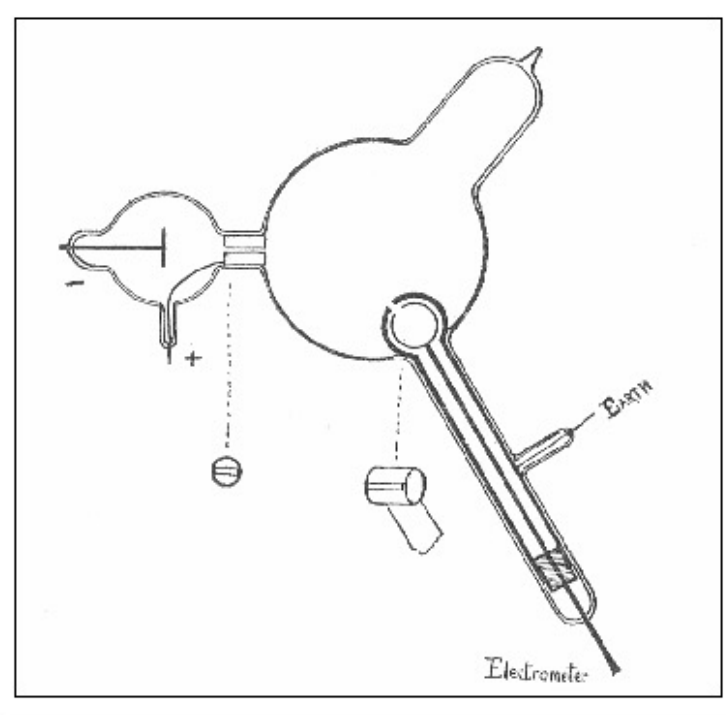
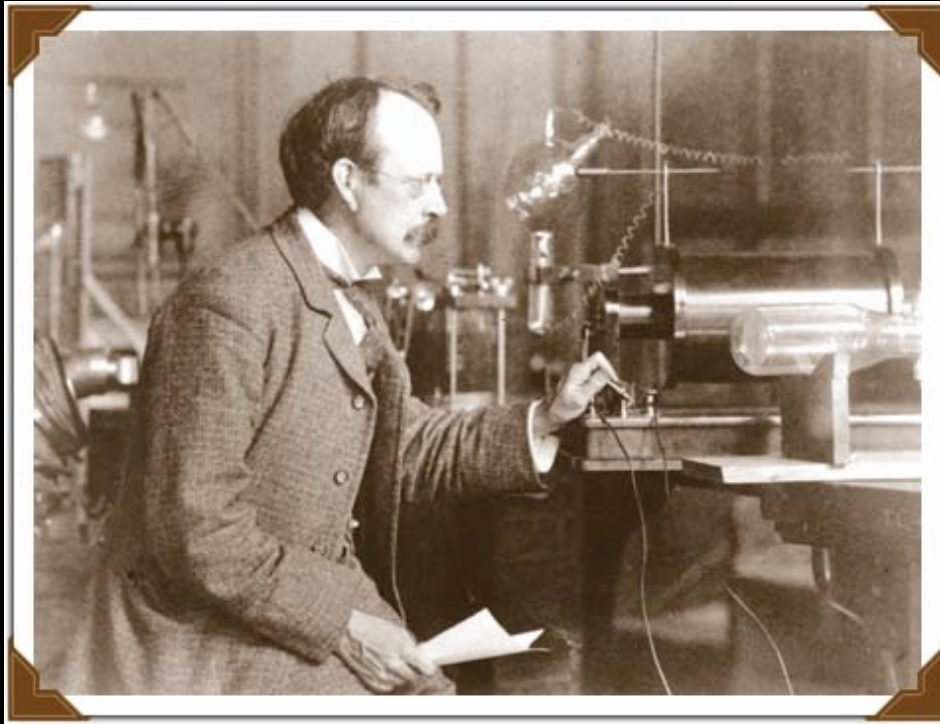
- James Clerk Maxwell
- Professor at King's 1860 – 1865
- **Unified theory of electricity and magnetism**
- Predicted electromagnetic waves
- Identified light as due to these waves
- Calculated the velocity of light
- ...



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

The First Elementary Particle

- Discovered by J.J. Thomson in 1897



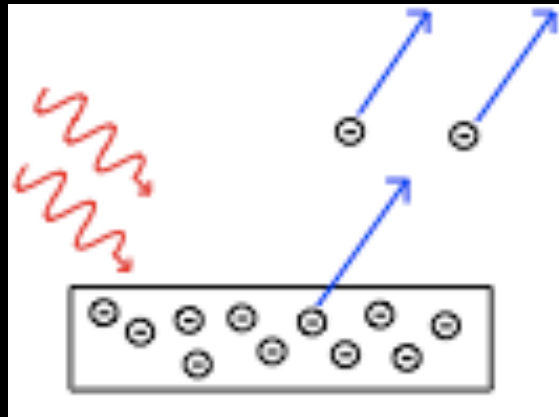
- **The electron** – the basis of the electronic industry
- An accelerator in your home: old-style TV sets used beams of electrons

Photon: the Electromagnetic Quantum

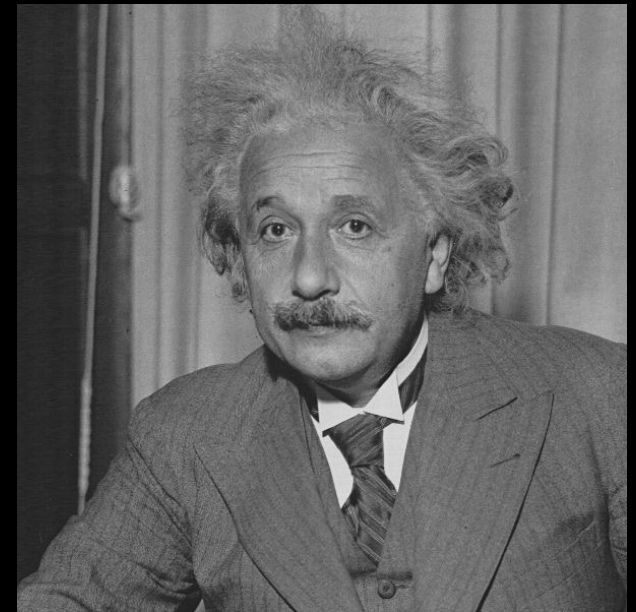
- Quantum hypothesis introduced by Planck:

$$E = hf$$

- 1905: Physical reality postulated by Einstein to explain photoelectric effect



- **First force particle discovered**

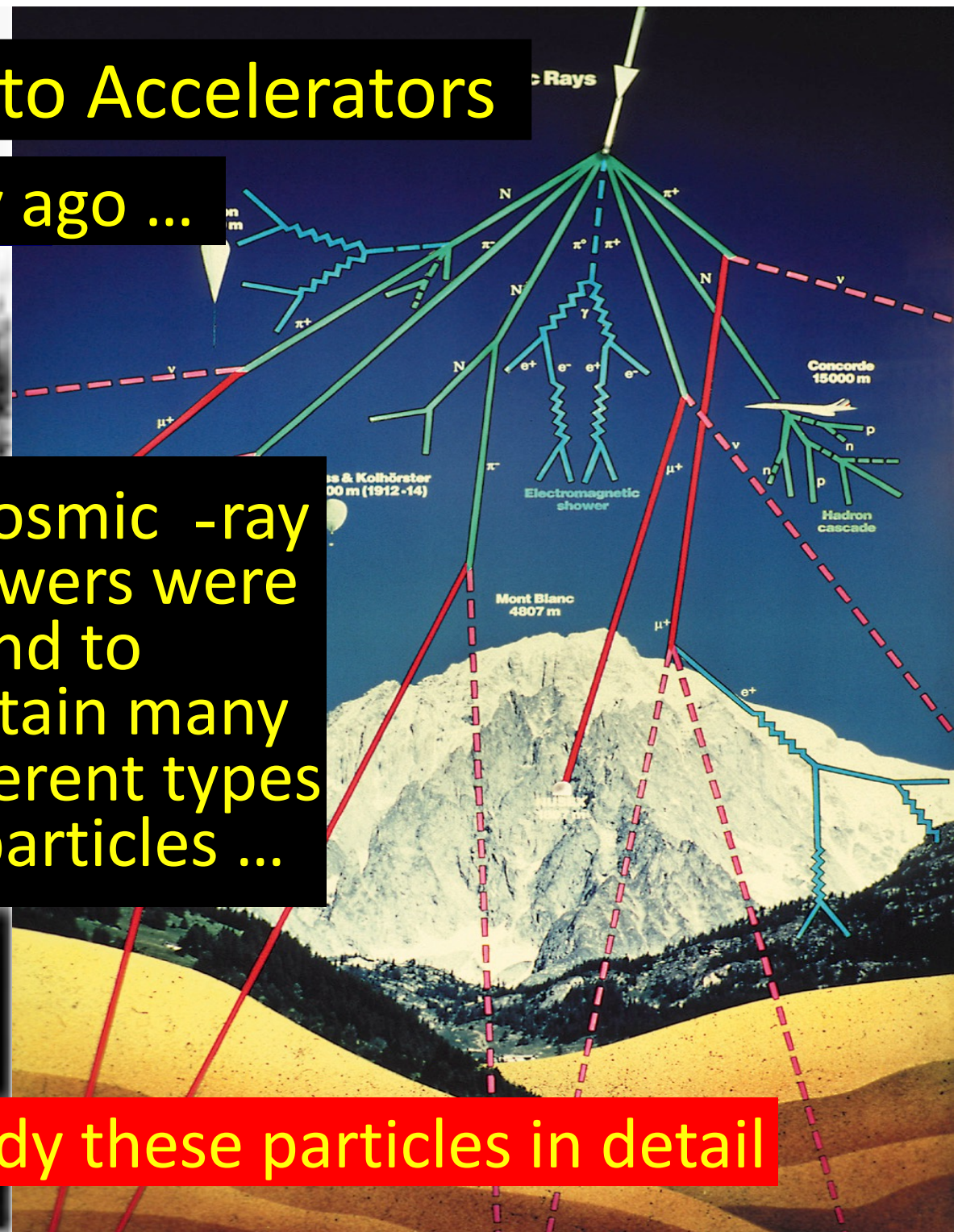


From Cosmic Rays to Accelerators

Discovered a century ago ...

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

Accelerators study these particles in detail



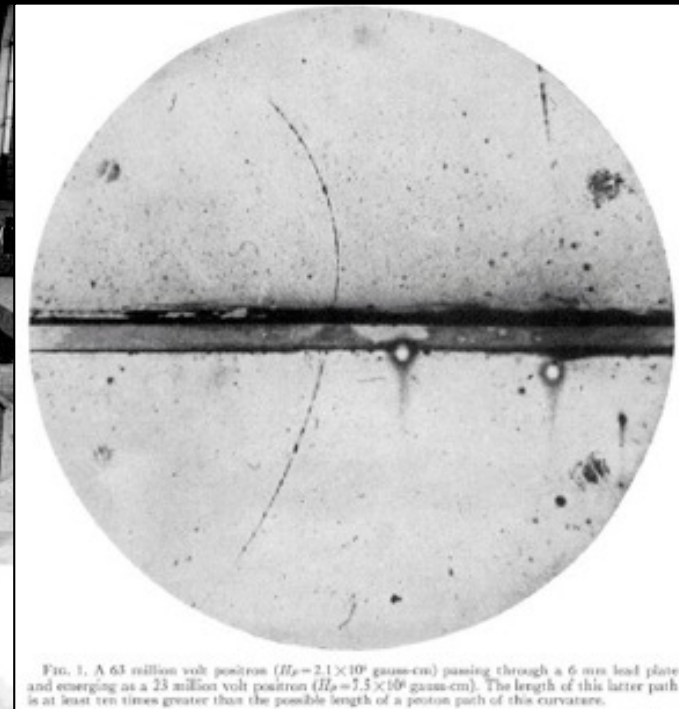


The Discovery of Antimatter



Existence predicted by Dirac

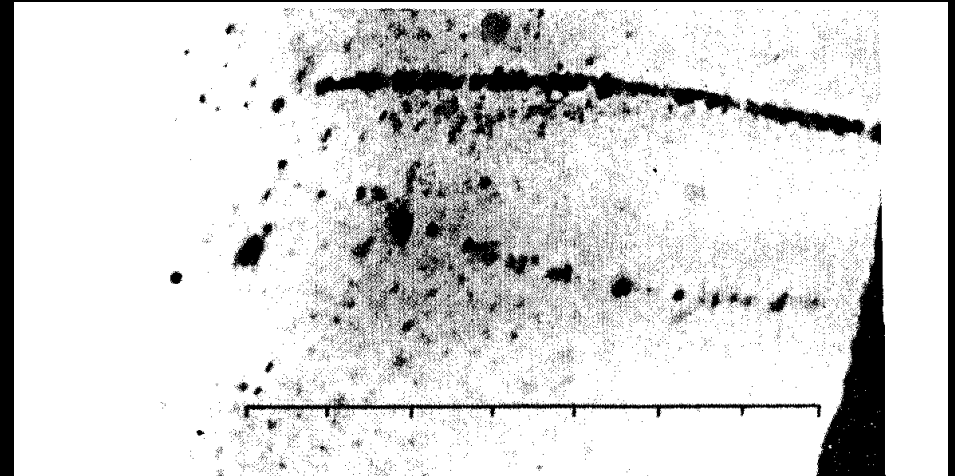
- The antiparticle of the electron (the positron) was discovered in cosmic rays by Anderson



- 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
- A “heavy electron”
- Passing through us all the time
- “*Who ordered that*” – I.I. Rabi



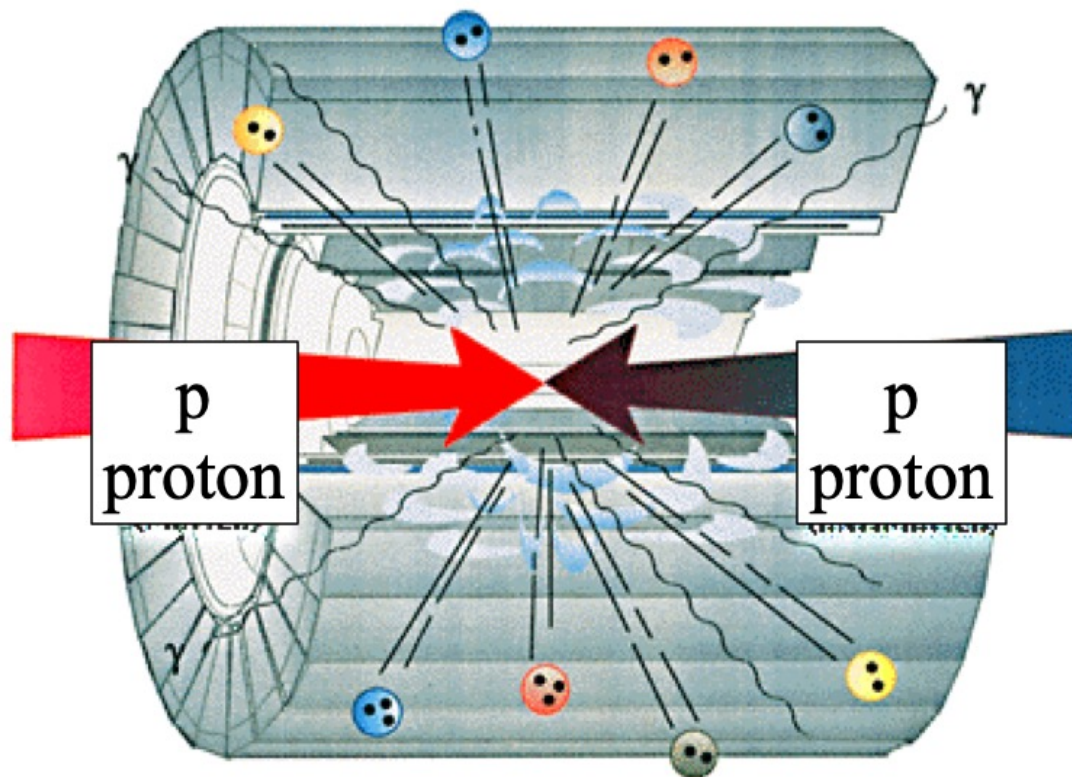
"The other double trace of the same type (figure 5) shows closely together the thin trace of an electron of 37 MeV, and a much more strongly ionizing positive particle with a much larger bending radius. The nature of this particle is unknown; for a proton it does not ionize enough and for a positive 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

Experiments with Accelerators

In order to study particles, we need super-microscopes using high energies to probe small distances:

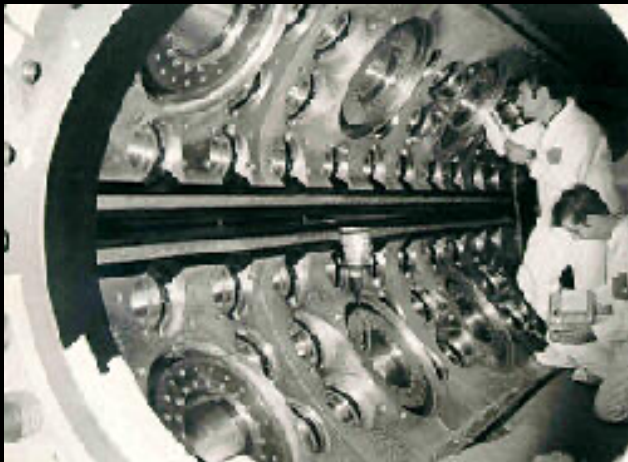
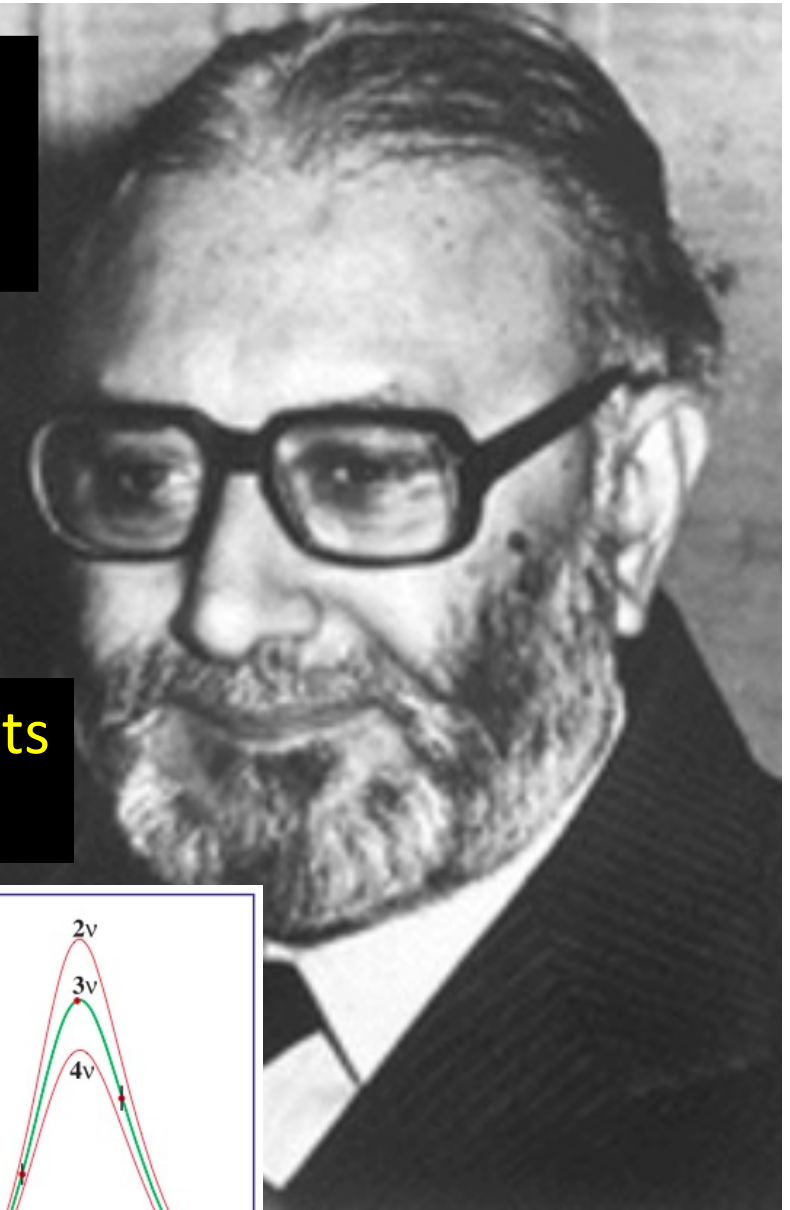
Particle Colliders



Collisions reproduce the conditions at beginning of Big Bang

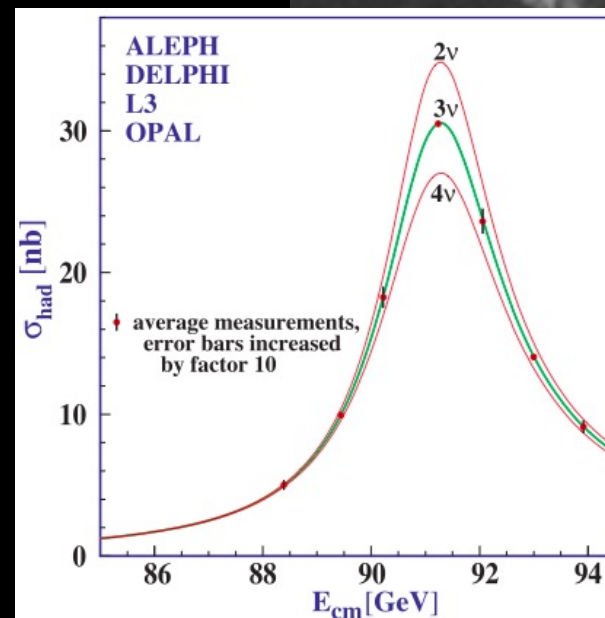
The 'Standard Model' of Particle Physics

Proposed by Abdus Salam,
Glashow and Weinberg



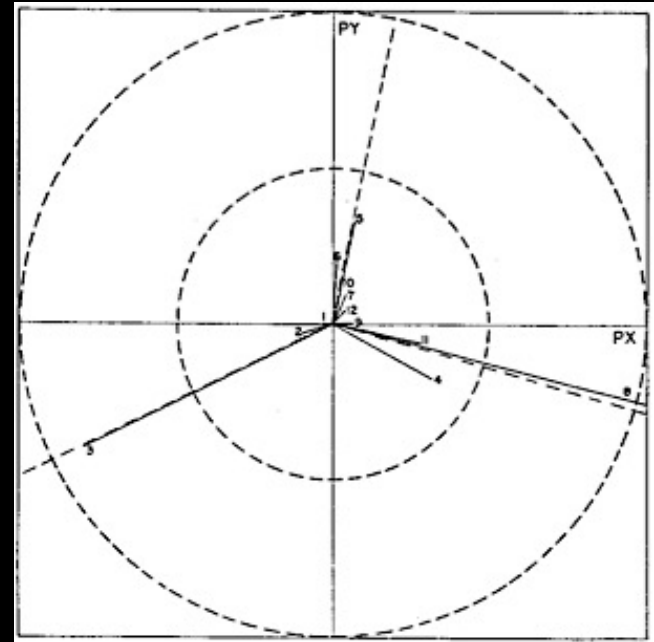
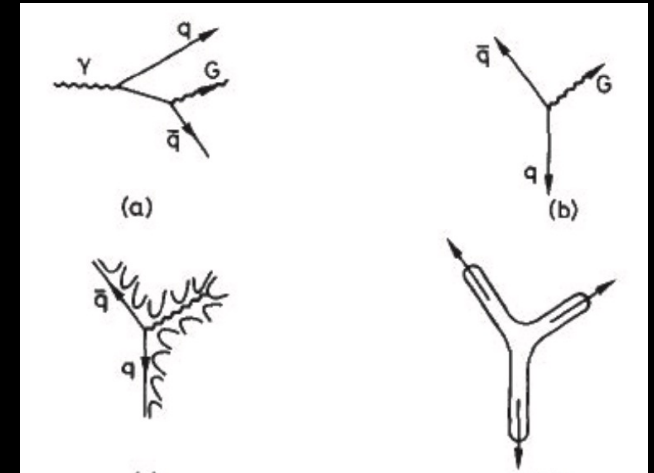
Tested by experiments
at CERN

Perfect agreement between
theory and experiments
in all laboratories



Strong Nuclear Interactions

- Theory modelled after Maxwell
- Force between quarks due to massless 'gluons', analogues of photon
- In 1976 JE, Mary Gaillard, Graham Ross suggested discovery method in 3-jet events
- Radiation of gluon by quark
- Discovered at DESY laboratory in Hamburg in 1979
- **Second force particle discovered**



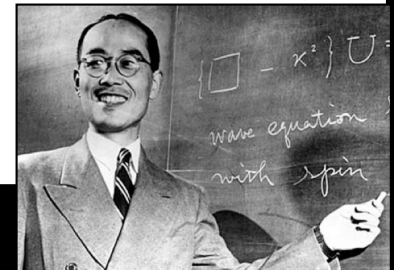
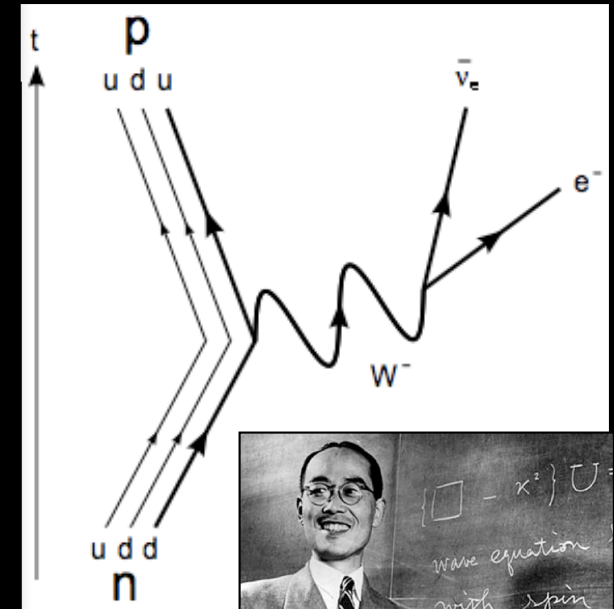
Why are we not all Radioactive?

Radioactivity due to weak interactions
(β decay)

W boson - carrier of weak interaction
must be massive

postulated by Yukawa

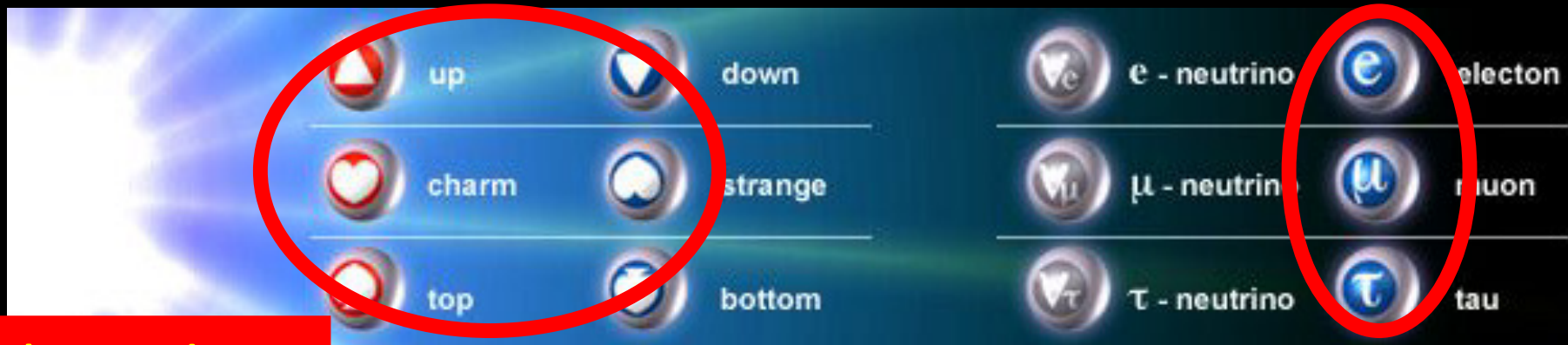
Discovered at CERN in
1983 by Carlo Rubbia et al



Why is it as heavy as a nucleus?

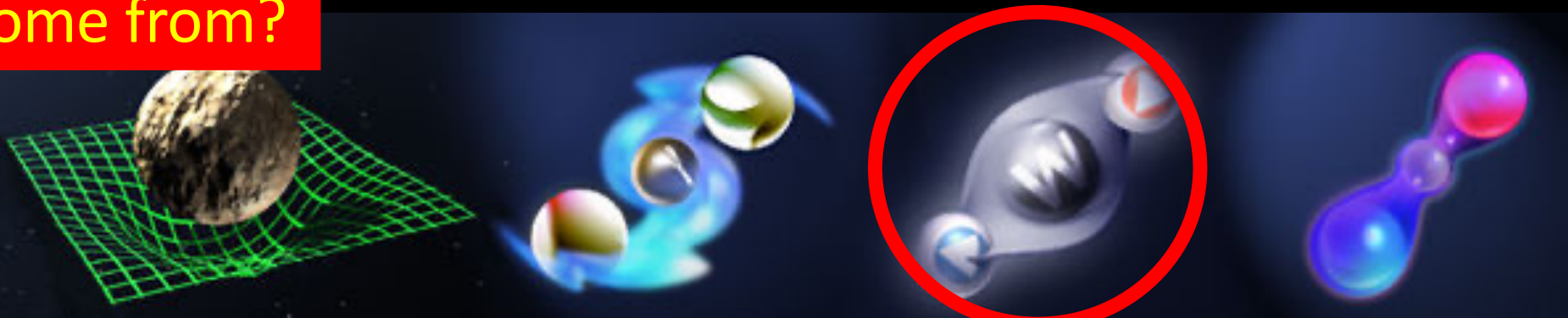
The 'Standard Model'

The matter particles



Where does
mass
come from?

The fundamental interactions



Gravitation electromagnetism weak nuclear force strong nuclear force

Why do Things Weigh?

Newton:

Weight proportional to Mass

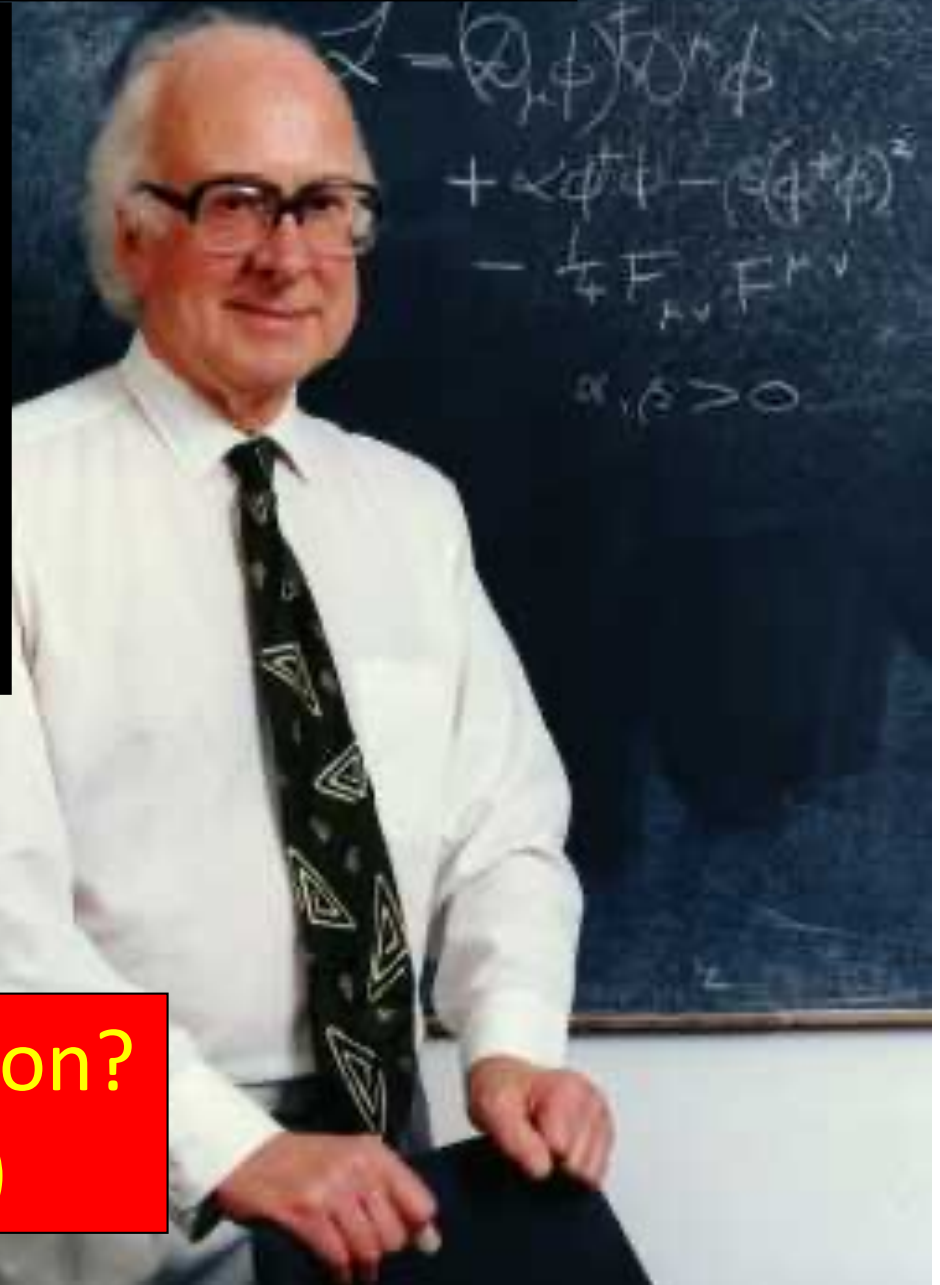
Einstein:

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 discovered
the snowflake:
The Higgs Boson

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



Snowshoer sinks into snow,
moves slower:

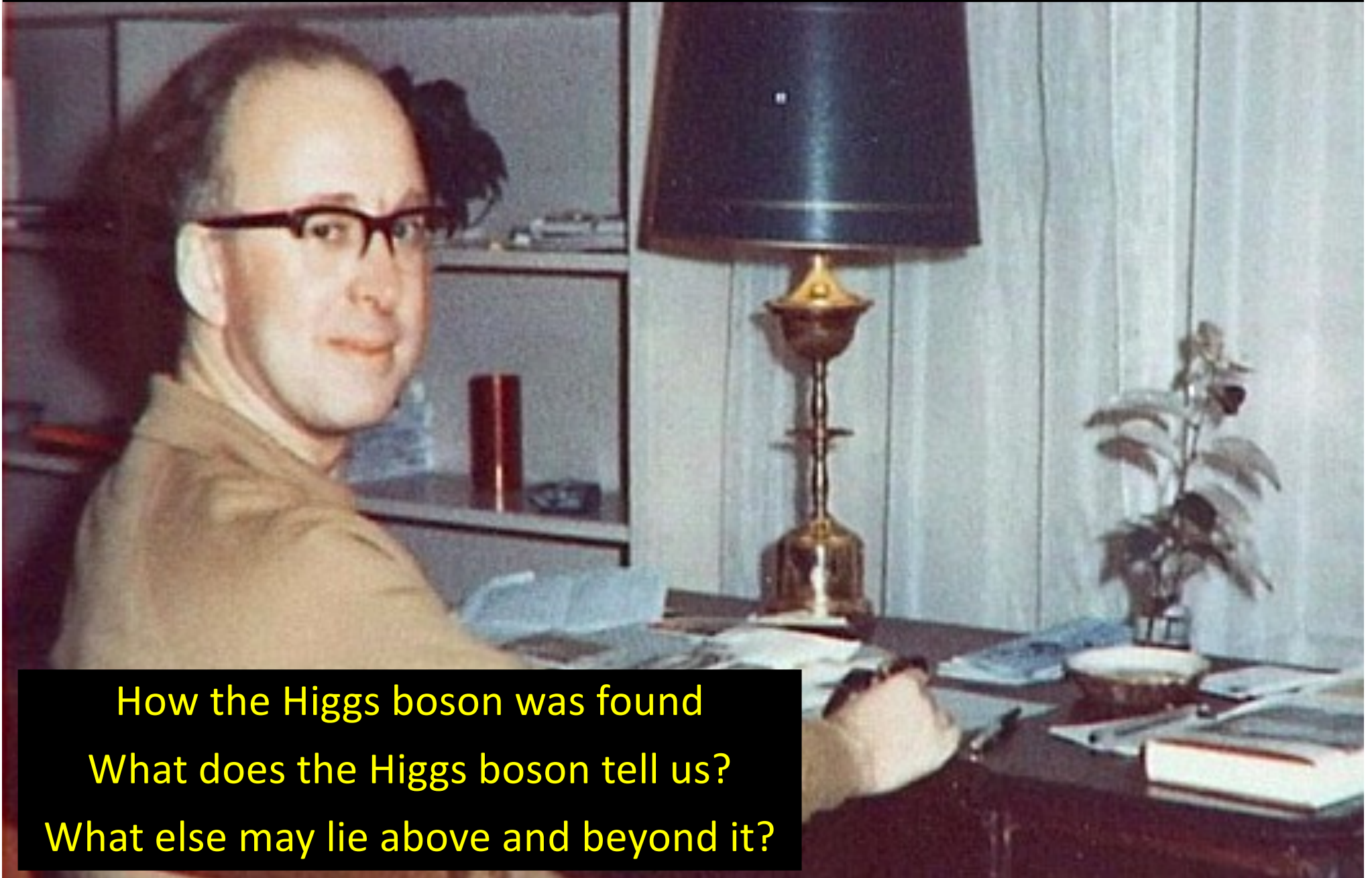


Like particle with mass
e.g., electron

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



The Higgs Boson & Beyond



How the Higgs boson was found

What does the Higgs boson tell us?

What else may lie above and beyond it?

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.



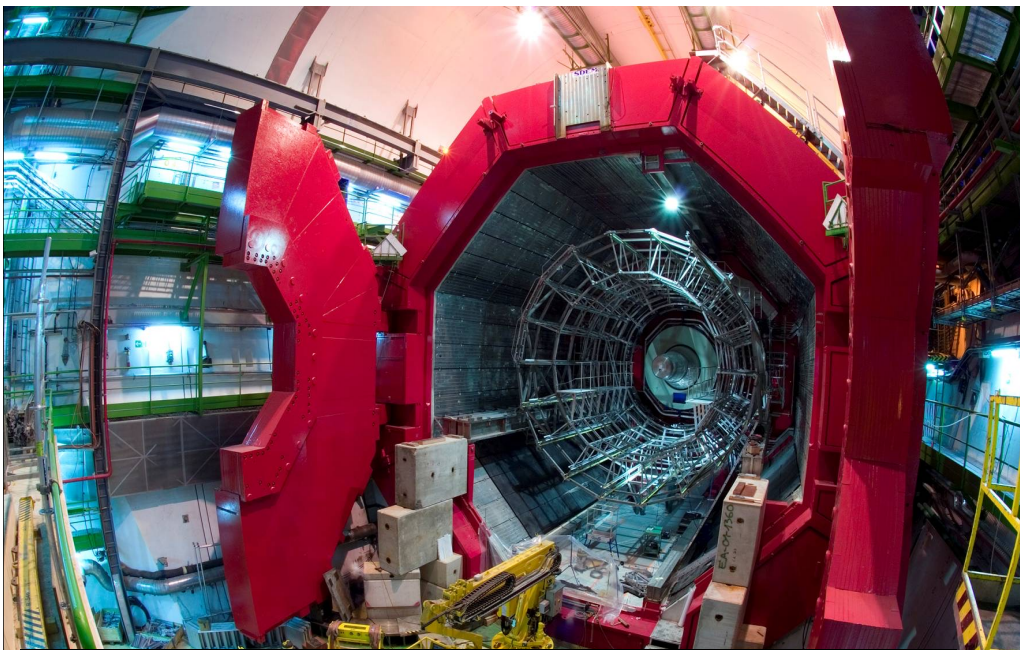
The Large Hadron Collider at CERN

The Large Hadron Collider (LHC)

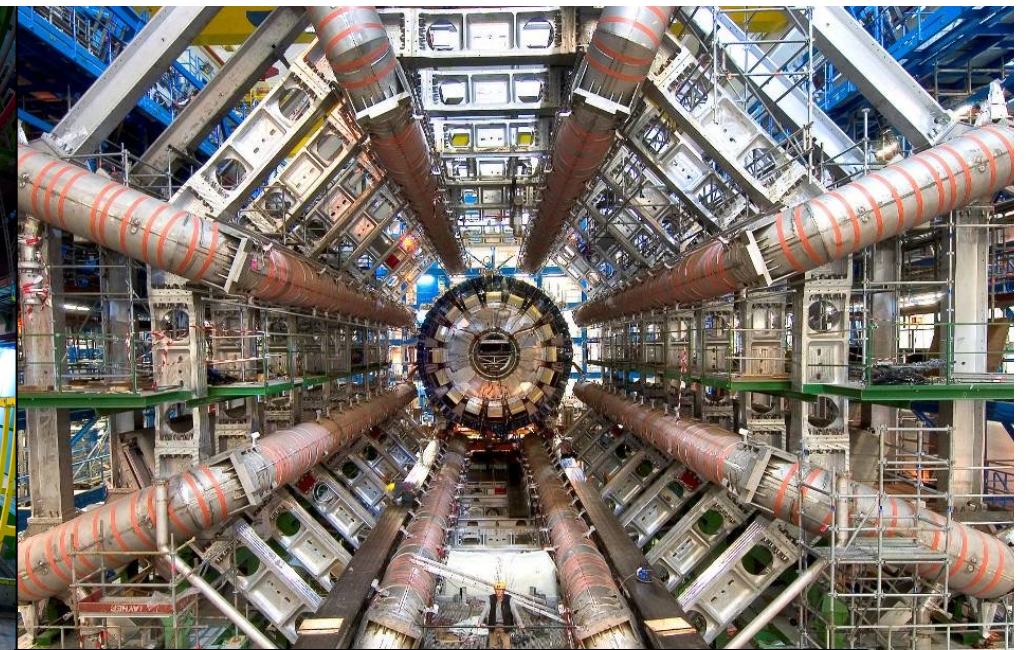
Several thousand billion protons
Each with the energy of a fly
99.9999991% of light speed
Orbit 27km ring 11 000 times/second
A billion collisions a second

Primary targets:

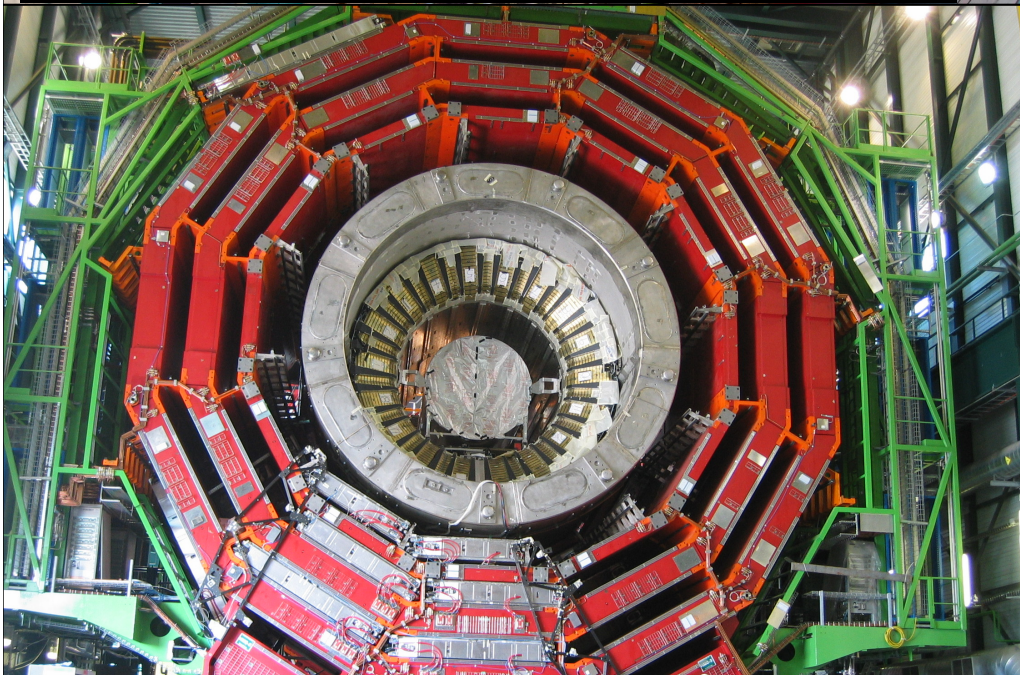
- Origin of mass
- Nature of Dark Matter
- Primordial Plasma
- Matter vs Antimatter



ALICE: Primordial cosmic plasma



ATLAS: Higgs and dark matter



CMS: Higgs and dark matter



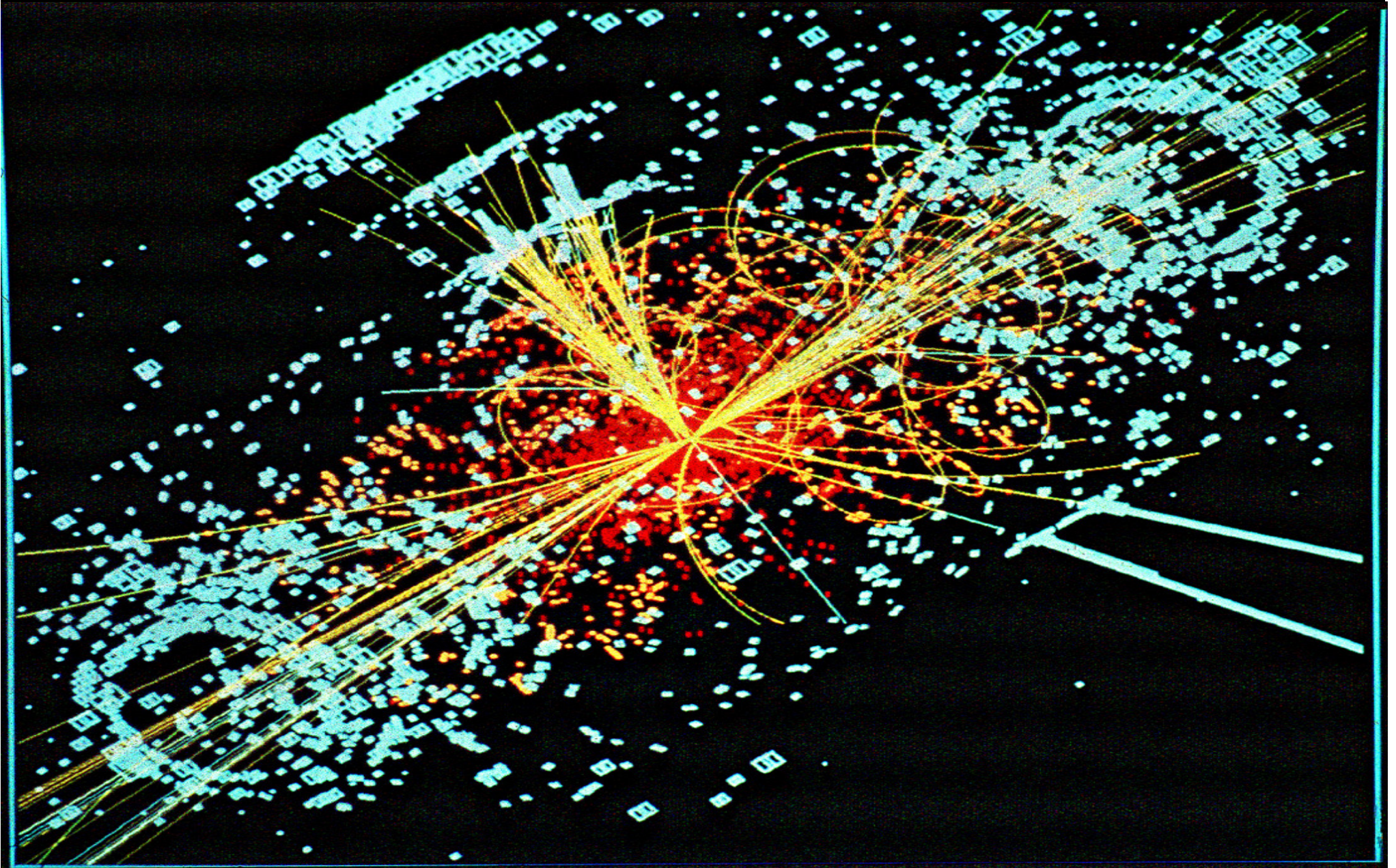
LHCb: Matter-antimatter difference

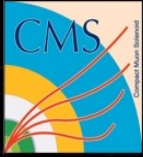
2012: The discovery of the Higgs Boson



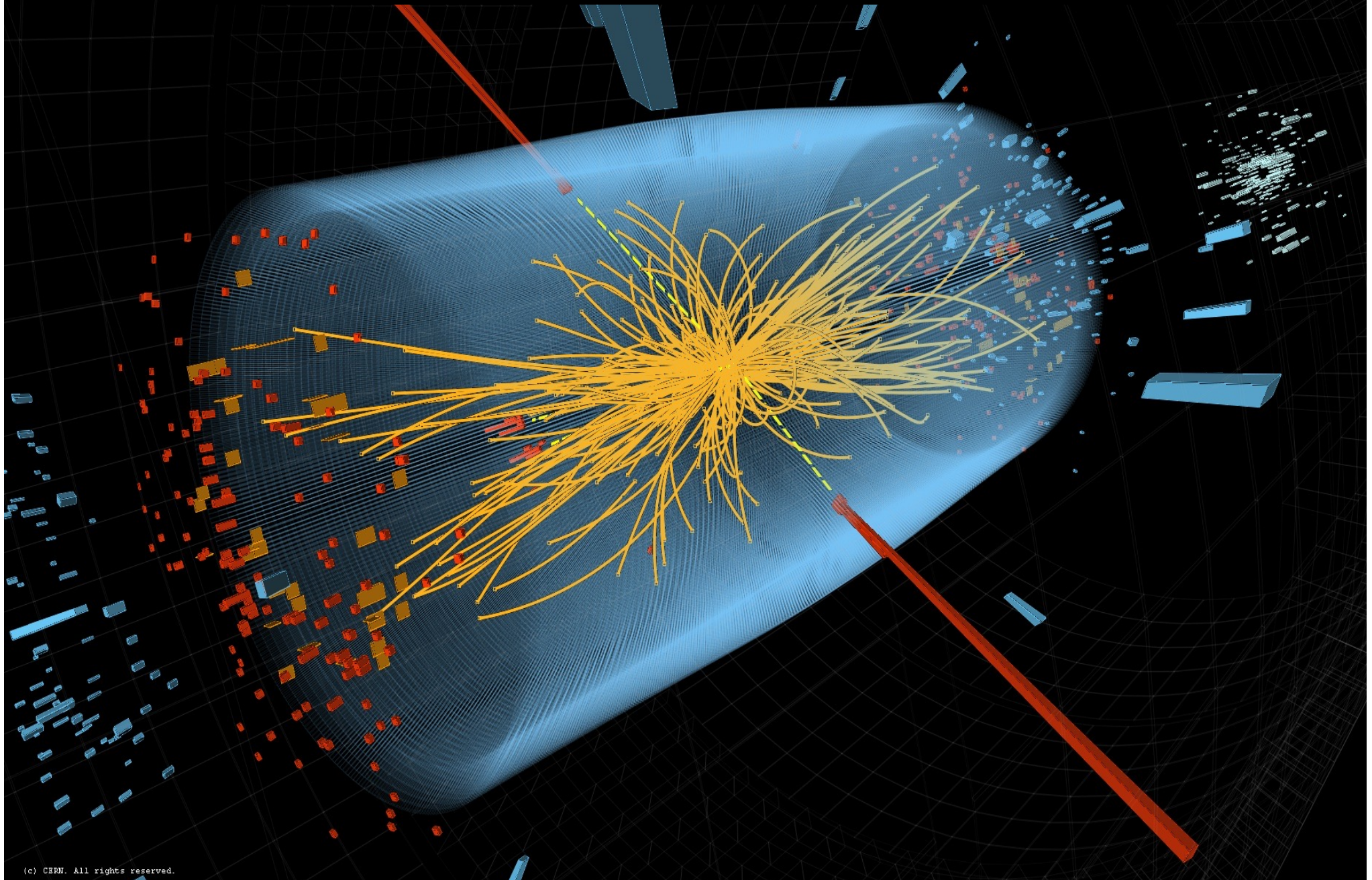
Mass Higgsteria

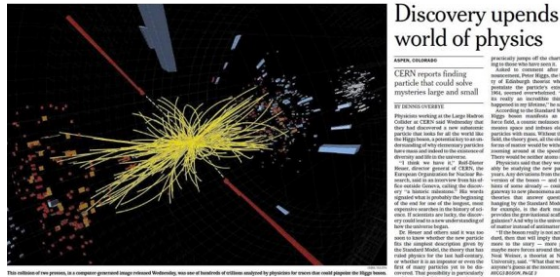
A Simulated Higgs Event @ LHC





An Interesting Event ...





Discovery upends world of physics

CERN reports finding particle that could solve mystery of mass and might be Higgs boson

Physicists working at the Large Hadron Collider (LHC) have announced the discovery of a new particle, which they believe is the Higgs boson, the last missing piece of the Standard Model of particle physics. The discovery, announced on Thursday, July 4, marks a historic moment in physics, as it confirms the existence of the particle that gives other particles their mass.



Finding the Higgs boson

В ТЕАТРАХ БУДУТ ПУСКАТЬ ПО МОБИЛЬНЫМ ТЕЛЕФОНАМ

ДЮНА РЕУНИ
СЕРВИС ГИПЕР
НА СЕРВЕР

НАША ПОЛИЦИЯ ОТКАЗАЛАСЬ

ПОСЛЕДНИЙ КИРПИЧ В СТЕНУ МИРОЗДАНИЯ

«КРЕМЛЕВСКИЕ» САМОЛЕТЫ ПРИШЛОСЬ МЕНЯТЬ НА ПЕРЕПРАВЕ

СРЭЧУ В ТРИ СТОПОВЫХ ОБЪЕДИНИЛИ НАПРАВЛЕНИЯ

МЕТРО СПУСКАЕТ НА ВОДУ

ВВБАШКА

THE HINDU
INDIA'S NATIONAL NEWSPAPER SINCE 1878

RARE CHOLA INSCRIPTIONS

MAY HAVE BEEN POISONED

SUBBARAO ON MFIS

RAHANE RETURNS

Elusive particle found, looks like Higgs boson

CERN physicists hail evidence of game-changing discovery of subatomic particle

PHYSICISTS HAVE FOUND THE HIGGS BOSON, THE LAST MISSING PIECE OF THE STANDARD MODEL OF PARTICLE PHYSICS. THE DISCOVERY, ANNOUNCED ON THURSDAY, JULY 4, MARKS A HISTORIC MOMENT IN PHYSICS, AS IT CONFIRMS THE EXISTENCE OF THE PARTICLE THAT GIVES OTHER PARTICLES THEIR MASS.

July 4th 2012 The discovery of a new particle

ヒッグス粒子発見か
新素粒子検出 年内に結論
日米欧2チーム

EDICAO LISBOA QUL 5 JUL 2012

Por dia, Dece recebe 87 casos por causa de sobrelotamento p14

HUGO HERÓIS MARVEL
Oscarização: o ator português da série de filmes em português
1º livro, Homem Aranha, Integral Frank Miller, por apenas +4.906

Milhares de moradores de bairros sociais em risco de perderem RSI

A mudança está a passar despercebida, mas deve afectar milhares de beneficiários do RSI que vivem em habitação social agora, morar numa casa camarária é uma forma de rendimento Portugal 12

ALGEMEEN DAGBLAD

Zieke Kai en zijn moeder toch samen in de VS

EINDELIJK GELIJK NA 48 JAAR

SPORTWERELD VAN PERSI

CORRIERE DELLA SERA

La particella che può svelare i segreti dell'universo

Ukraincy hnia sie o jez. Rosyjski

Chastke Higgsa fizycy najpierw wymyślił, potem szukali 40 lat

BOSKA MASA

Pełen odkrycia świat był nigdy nie byłoby taki sam. Najbardziej imponujący we wszystkich składowych materiałach został wyprodukowany - potężnym i wyjątkowo precyzyjnym zrodkiem CERN

The New York Times

Oil Backed Up, Iranians Put It On Idled Ships

ROMNEY NOW SAYS HEALTH MANDATE BY OBAMA IS A TAX

Physicists Find Elusive Particle Seen as Key to Universe

God particle discovery has scientists giddy

The Gazette

EL PAIS

fallada la partícula clave para a comprensión del universo

La Audiencia Nacional imputa a toda la cúpula de Bankia

CHINADAILY

THE TIMES OF INDIA

Big bang moment: Scientists may have found 'God particle'

Adarsh scam: Finally, CBI charges sheets 13

গাজেতা

বিজ্ঞানের 'ঈশ্বর' দর্শন

সত্যেন্দ্রনাথকে বিনয় প্রণাম

পেয়েছি, যা খুঁজছিলাম

The Discovery of the Higgs Boson



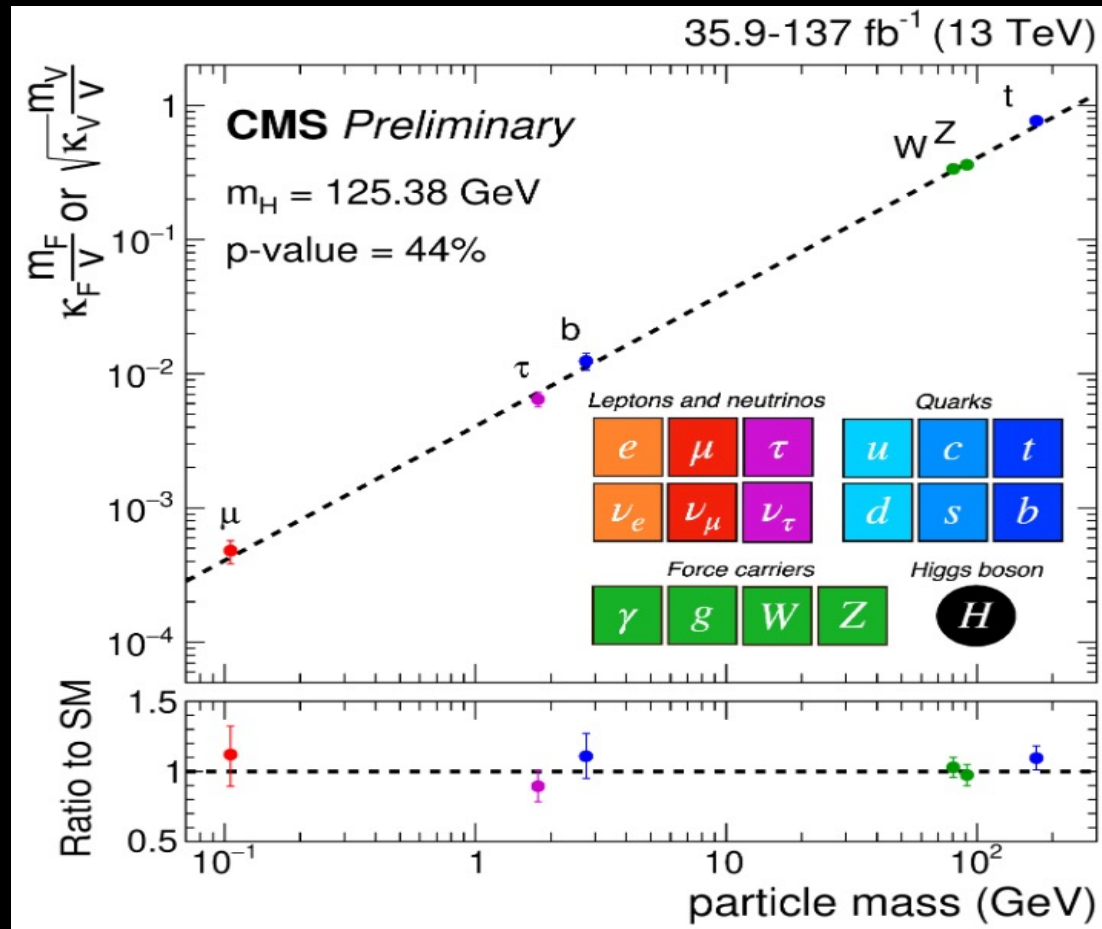
The Particle Higgsaw Puzzle



Did the LHC find the missing piece?
Is it the right shape?
Is it the right size?

The Mysterious Higgs Boson

- No spin, couplings scale $\sim$ mass, unlike any other particle



- One of a kind, or the tip of an iceberg?

Scientists from around the World

Member States 7446

Austria 97 – Belgium 102 – Bulgaria 83 – Czech Republic 207 Denmark 50 – Estonia 20 – Finland 76 – France 801
Germany 1131 – Greece 220 – Hungary 84 – Israel 56 – Italy 2013
Netherlands 154 – Norway 60 – Poland 370 – Portugal 125 Romania 141 – Serbia 50 – Slovakia 122 – Spain 497
Sweden 76 – Switzerland 196 – United Kingdom 715

Associate Member States in the pre-stage to Membership 55

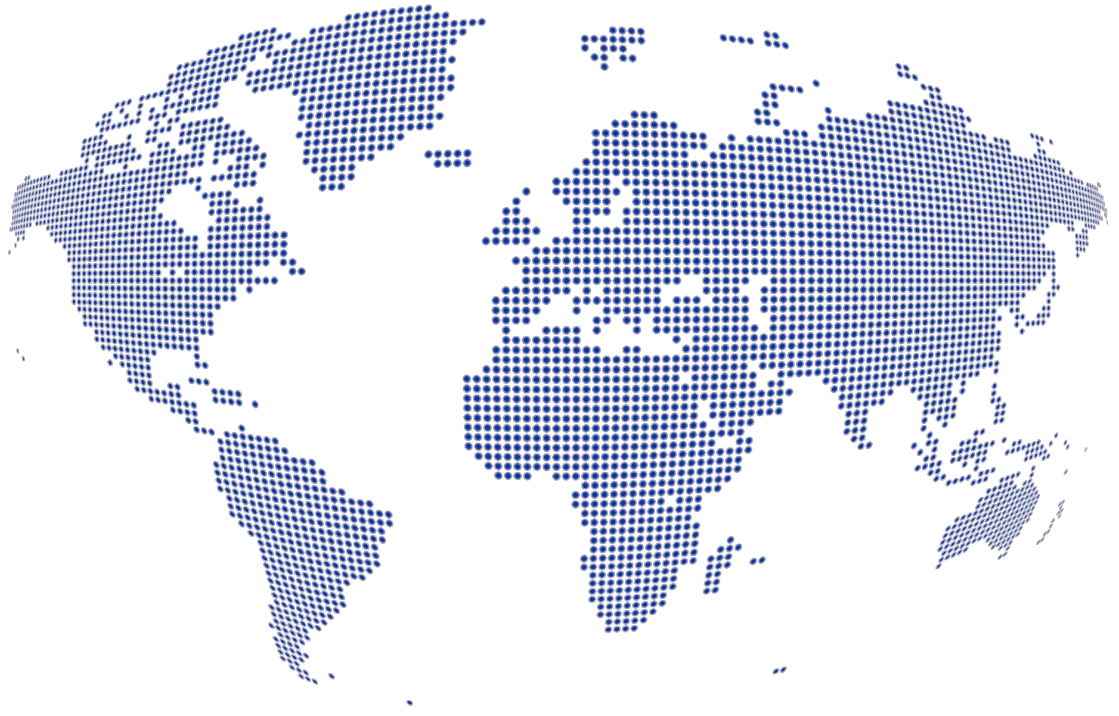
Cyprus 18 – Slovenia 37

Associate Member States 1064

Brazil 157 – Croatia 51 – India 463 – Latvia 18 – Lithuania 27 – Pakistan 70
Türkiye 187 – Ukraine 91

Observers 2200

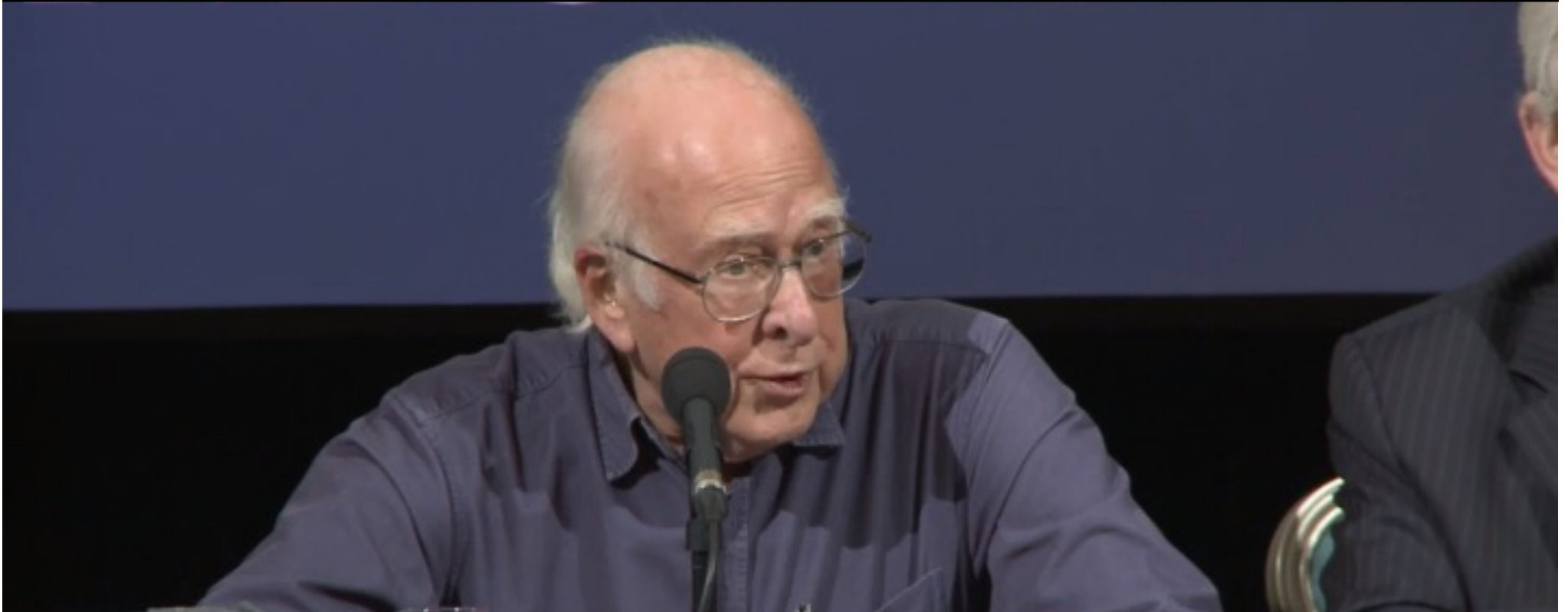
Japan 230 – Russia (suspended) 824 – United States of America 1146



Non-Member States and Territories 1975

Afghanistan 3 – Albania 6 – Algeria 15 – Argentina 22 – Armenia 17 – Australia 35 – Azerbaijan 5 – Bahrain 11 Bangladesh 11 – Belarus 26
– Bolivia 2 – Bosnia and Herzegovina 1 – Botswana 1 – Burundi 1 – Canada 149
Chile 43 – Colombia 57 – Congo 1 – Costa Rica 4 – Cuba 16 – Democratic Republic of the Congo 1 – Ecuador 13
Egypt 38 – El Salvador 1 – Georgia 58 – Guatemala 2 – Honduras 3 – Hong Kong 5 – Iceland 3 – Indonesia 11 – Iran 45
Ireland 33 – Jamaica 1 – Jordan 5 – Kazakhstan 15 – Kenya 2 – Kuwait 1 – Kyrgyzstan 2 – Lebanon 23 – Lesotho 1 Luxembourg 2 –
Madagascar 4 – Macao 2 – Malaysia 11 – Malta 3 – Mauritius 1 – Mexico 97 – Mongolia 3 – Montenegro 7 Morocco 31 – Myanmar 1 –
Nepal 13 – New Zealand 2 – Nigeria 6 – North Macedonia 4 – Palestine 5 – People's Republic of China 701 – Paraguay 2 – Peru 11 –
Philippines 2 – Republic of Korea 197 – Saint Kitts and Nevis 1 – Saudi Arabia 4 Senegal 2 – South Africa 49 – Sri Lanka 9 – Syrian Arab
Republic 4 – Taiwan 57 – Thailand 20 – Trinidad and Tobago 1 Tunisia 6 – Uganda 1 – Uruguay 1 – Uzbekistan 2 – Venezuela 7 – Viet Nam 12
– Yemen 1 – Zambia 1 – Zimbabwe 3

Dixit Swedish Academy



Today we believe that “Beyond any reasonable doubt, it is a Higgs boson.” [1]

http://www.nobelprize.org/nobel_prizes/physics/laureates/2013/advanced-physicsprize2013.pdf

[1] = JE & Tevong You, arXiv:1303.3879

Without Higgs ...

... there would be no atoms

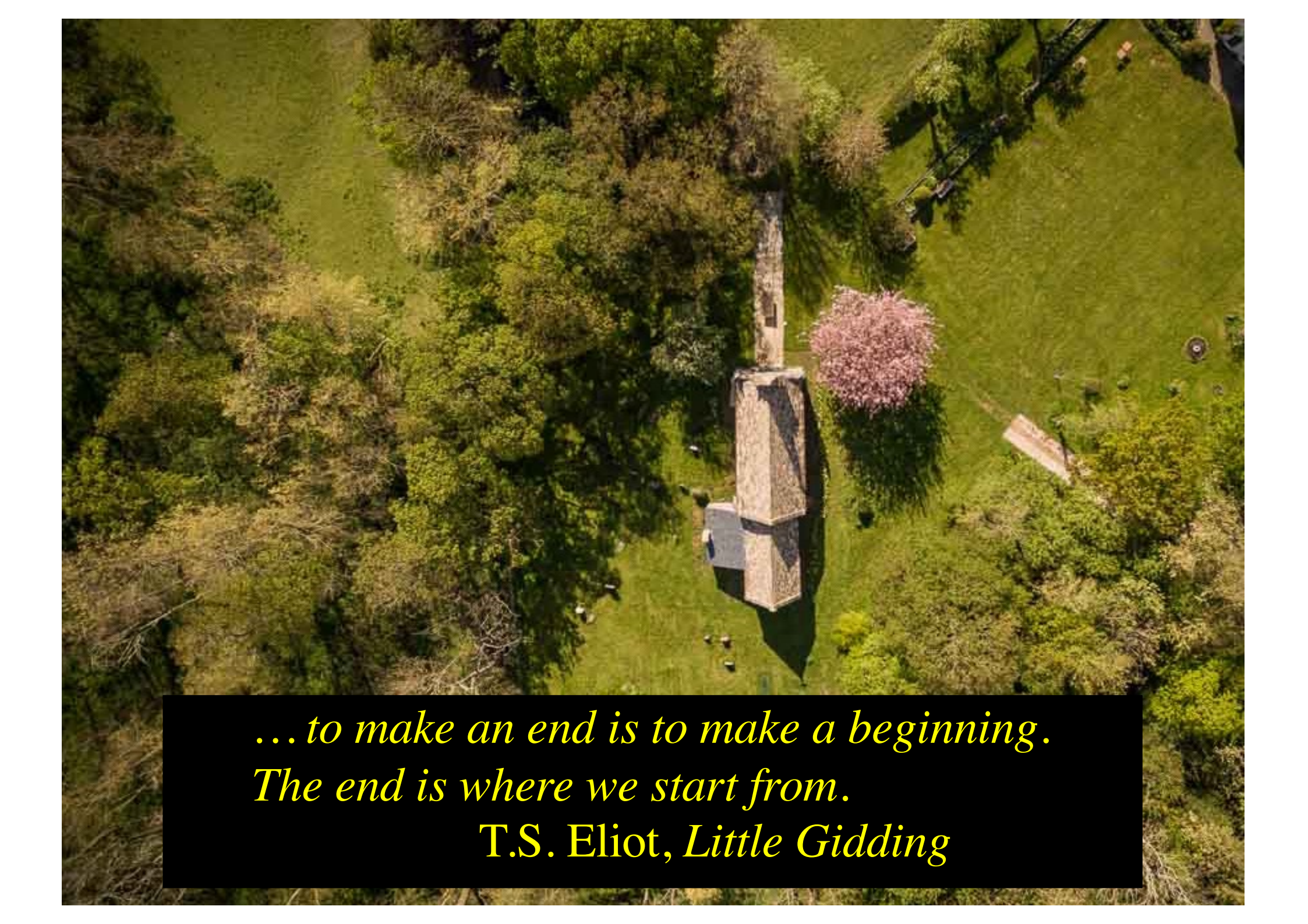
- massless electrons would escape at the speed of light

... there would be no heavy nuclei

... weak interactions would not be weak

- Life would be impossible: everything would be radioactive

Its existence is a big deal!



*...to make an end is to make a beginning.
The end is where we start from.*

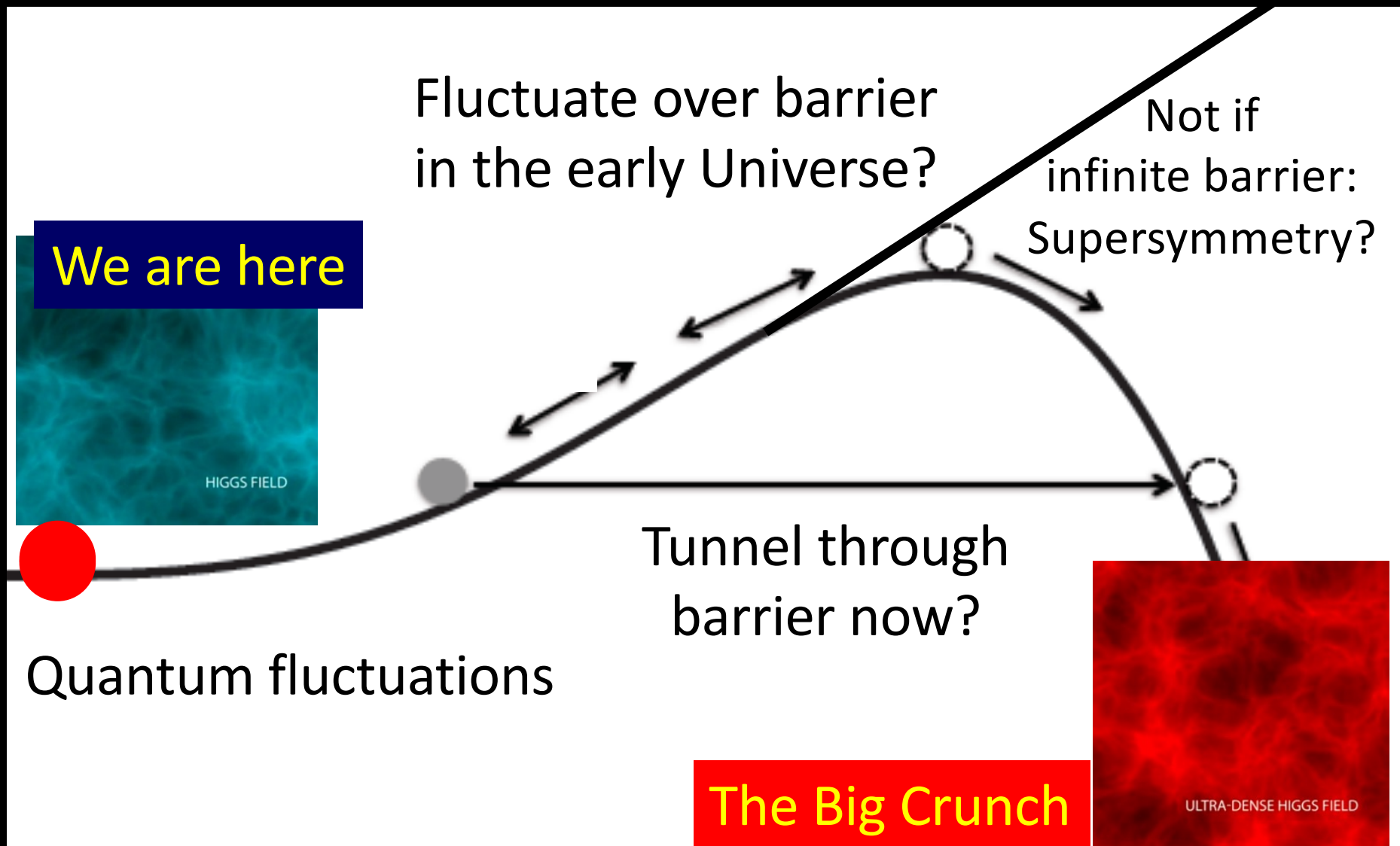
T.S. Eliot, Little Gidding

- LHC

007 12

Will the Universe Collapse?

Should it have Collapsed already?



The Dark Matter Hypothesis

- Proposed by Fritz Zwicky, based on observations of the Coma galaxy cluster
- The galaxies move too quickly
- The observations require a stronger gravitational field than provided by the visible matter
- **Dark matter?**



The Rotation Curves of Galaxies

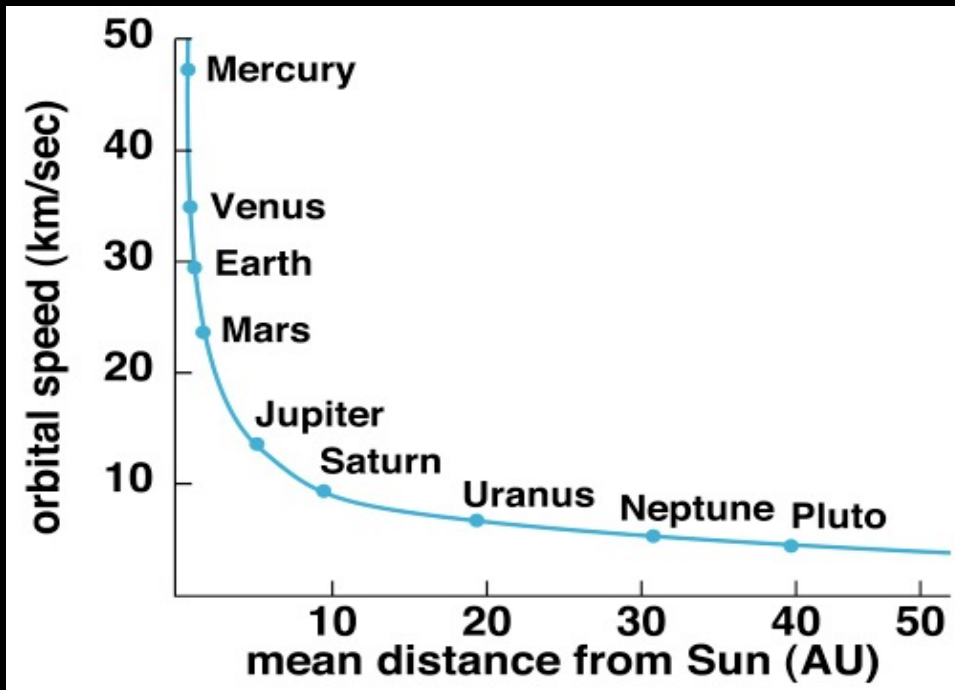
- Measured by Vera Rubin
- The stars also orbit 'too quickly'
- Her observations also required a stronger gravitational field than provided by the visible matter
- **Further strong evidence for dark matter**



Scanned at the American
Institute of Physics

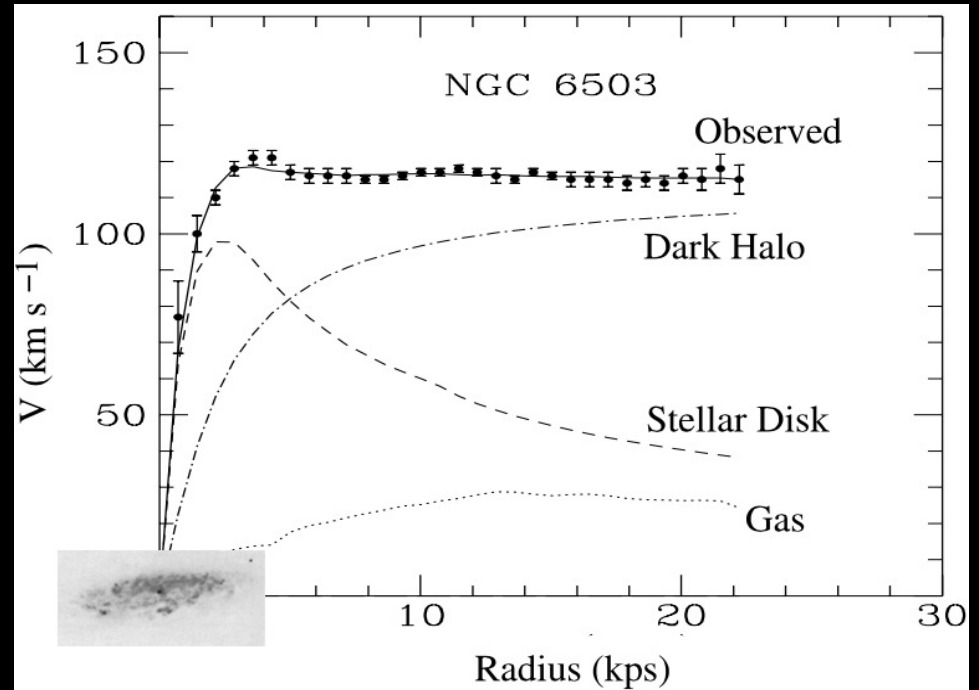
Rotation Curves

- In the Solar System



- The velocities decrease with distance from Sun
- Mass lumped at centre

- In galaxies



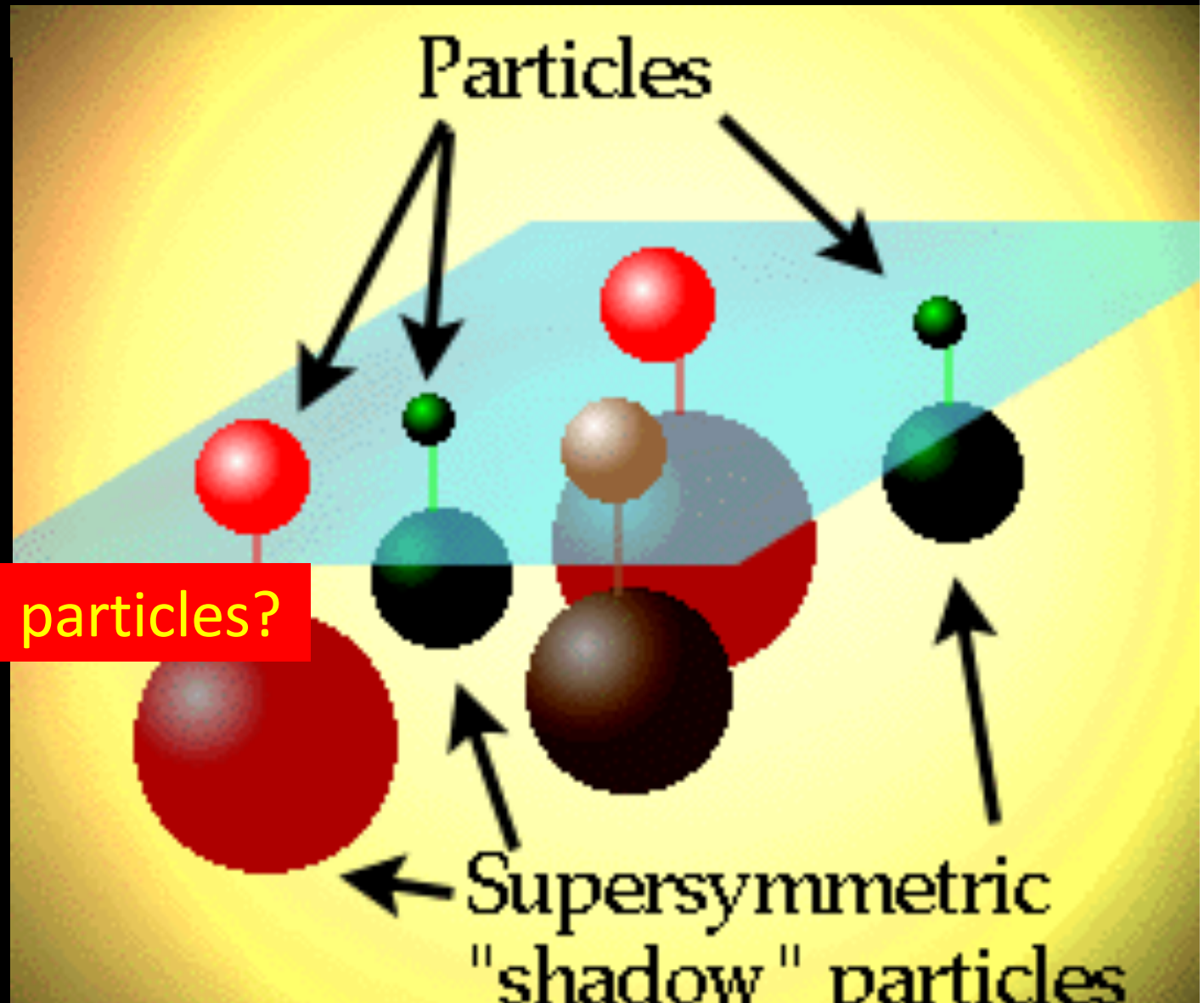
- The velocities do not decrease with distance
- Dark matter spread out

What is the Dark Matter in the Universe?

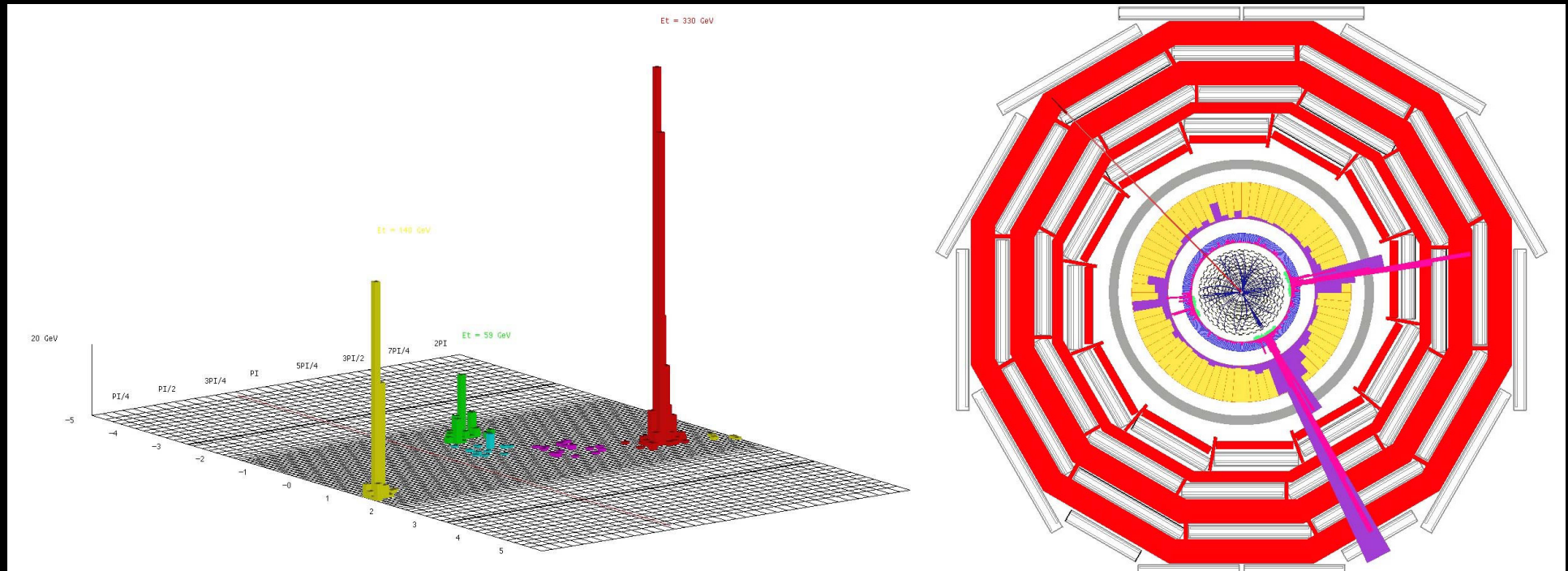
Astronomers say
that most of the
matter in the
Universe is
invisible
Dark Matter

Made of unknown particles?

We are
searching for
them at the
LHC



Classic Dark Matter Signature



Missing transverse energy
carried away by dark matter particles

General Interest in Antimatter Physics



Physicists cannot make enough for
Star Trek or Dan Brown!

How do Matter and Antimatter Differ?

Dirac predicted the existence of antimatter:

- same mass

- opposite internal properties:

 - electric charge, ...

Discovered in cosmic rays

Studied using accelerators

Used in PET scanners



Matter and antimatter not quite equal and opposite: WHY?

Why does the Universe mainly contain matter, not antimatter?

Experiments at LHC and elsewhere looking for answers

How to Create the Matter in the Universe?

Sakharov

- Need a difference between matter and antimatter
observed in the laboratory
- Need interactions able to create matter
predicted by theories
not yet seen by experiment
- Need the expansion of the Universe
a role for the Higgs boson?

Will we be able to calculate
using laboratory data?



The LHC is the world's most
powerful microscope ...



... and also a telescope
addressing
cosmological questions