ASKING THE BIG QUESTIONS:
A JOURNEY INTO PARTICLE PHYSICS

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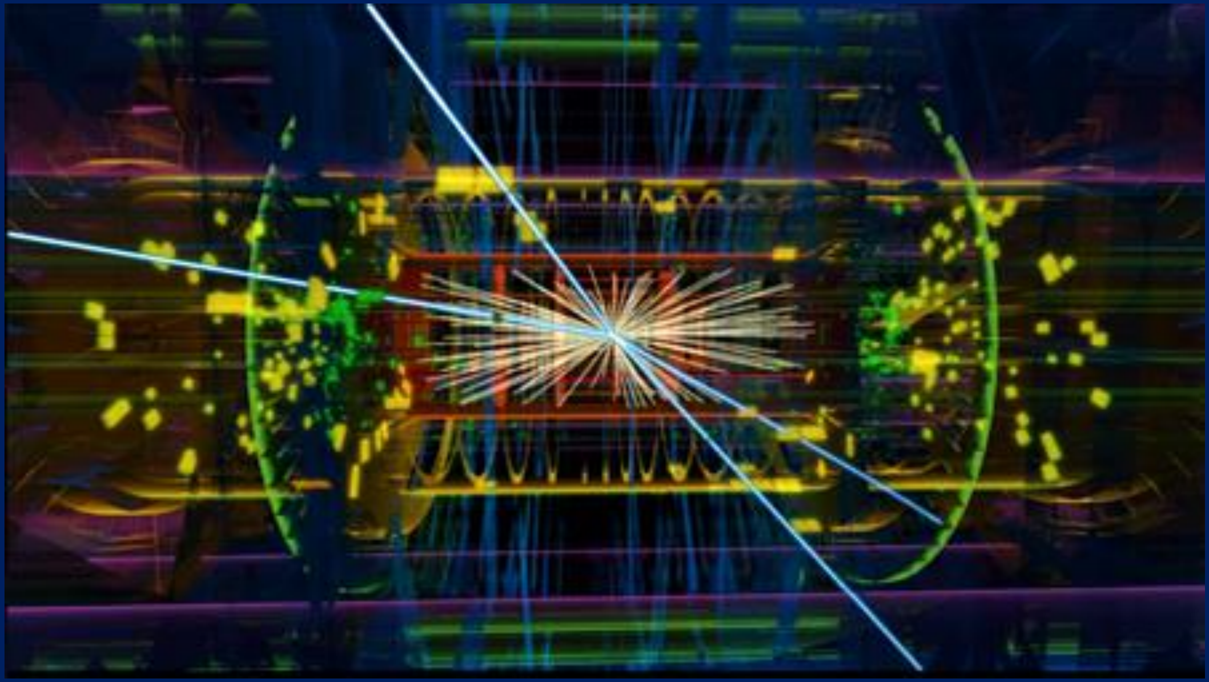
The Abdus Salam International Centre for Theoretical Physics
ATLAS Collaboration

7th August 2017

RN International Teacher Weeks Programme 2017

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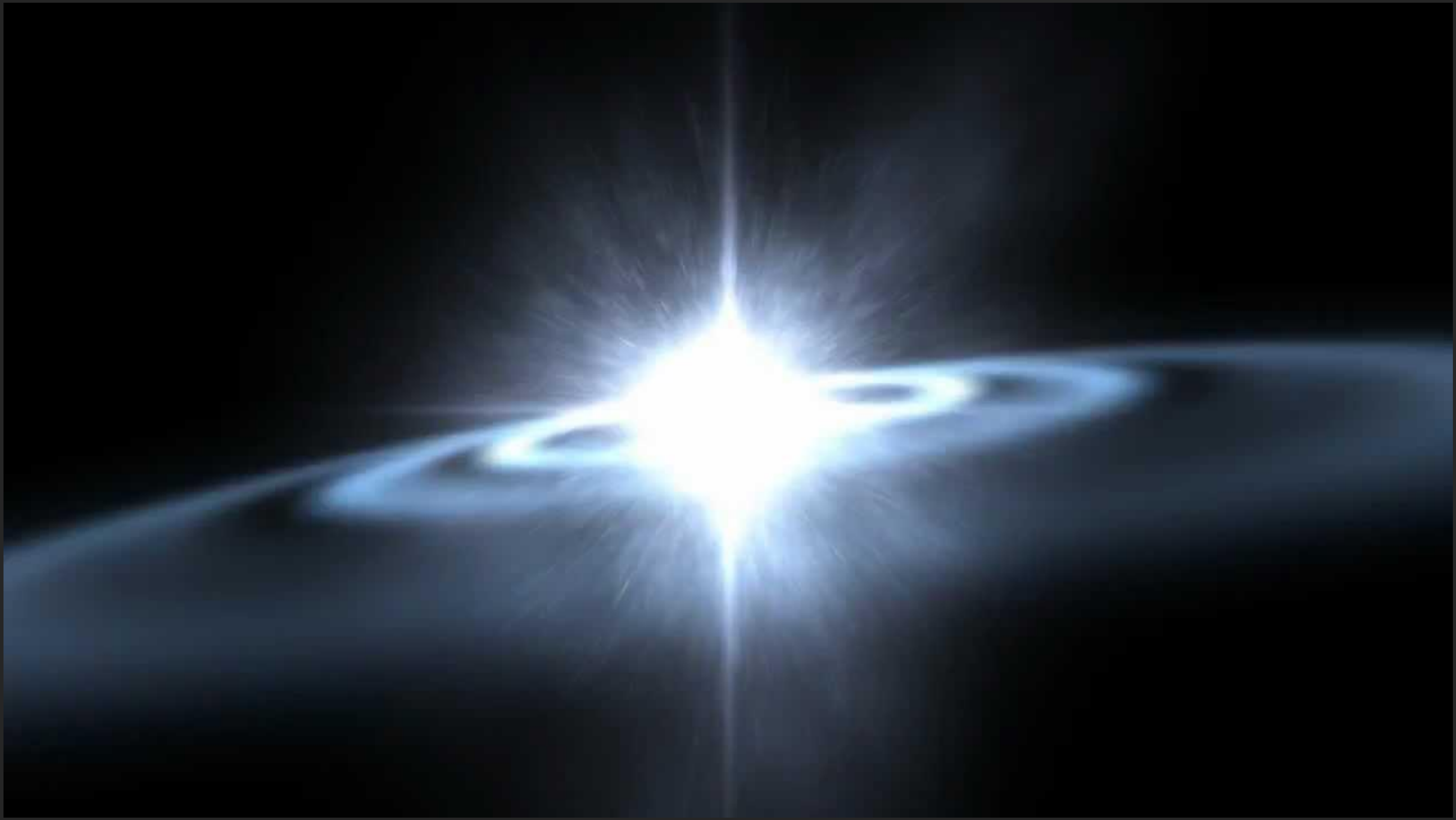
The observable Universe has around **350 billion large galaxies**

It is **90 billion light years across**

Particle Physicists aim to understand what the universe is made out of, how everything interacts
and where everything came from!

Physicists are ambitious!

WHERE DID EVERYTHING COME FROM ?

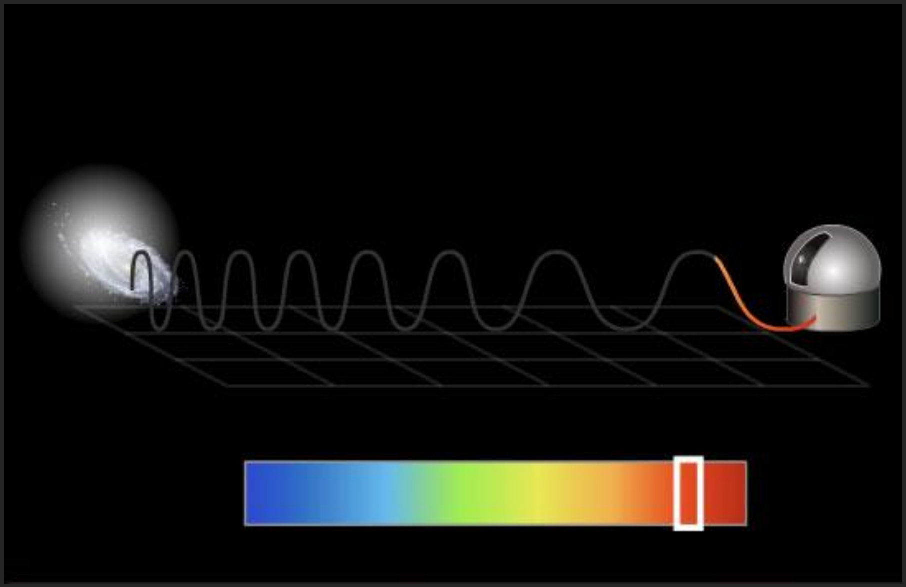


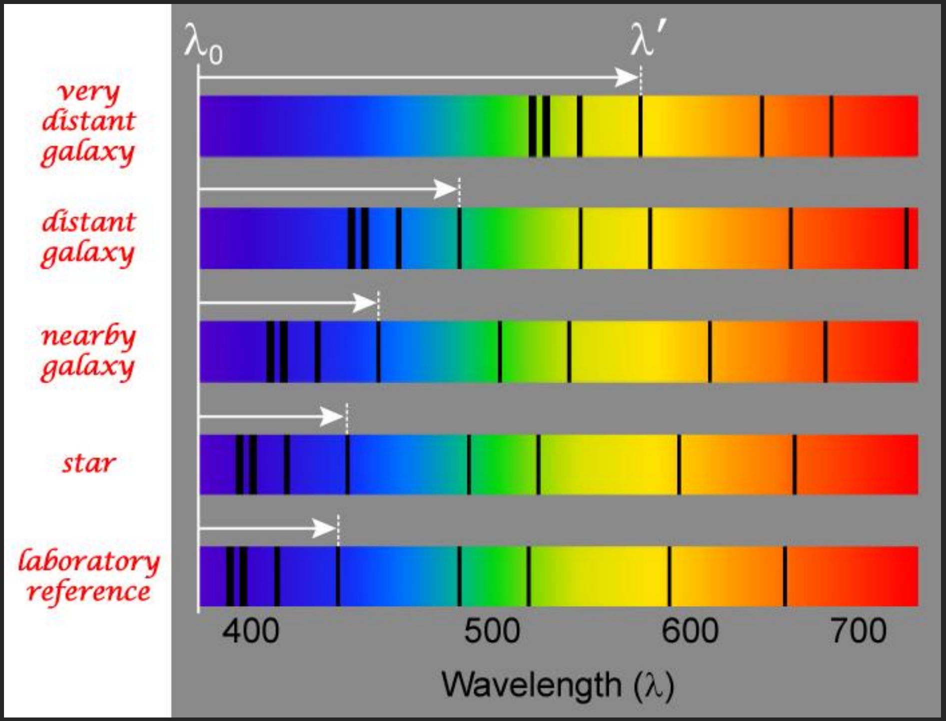
BIG BANG 13.8 Billion years ago

WHERE DID EVERYTHING COME FROM ?

Edwin Hubble, American Astronomer, first to prove there are galaxies outside of the Milky Way (1924)

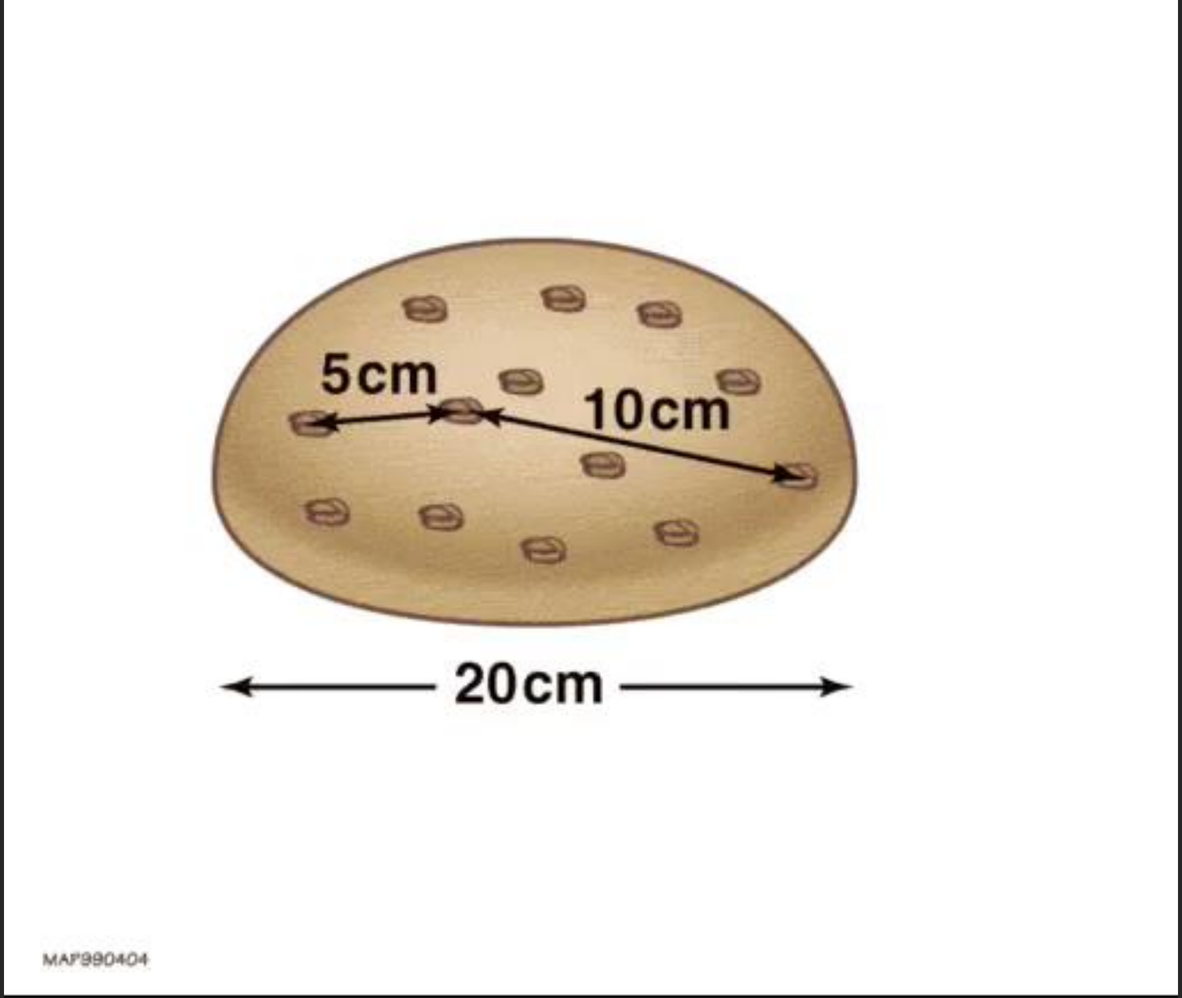
WHERE DID EVERYTHING COME FROM ?





Hubble showed that the further away a galaxy is from us (or any point in space), the **faster it appears to move** (1929)

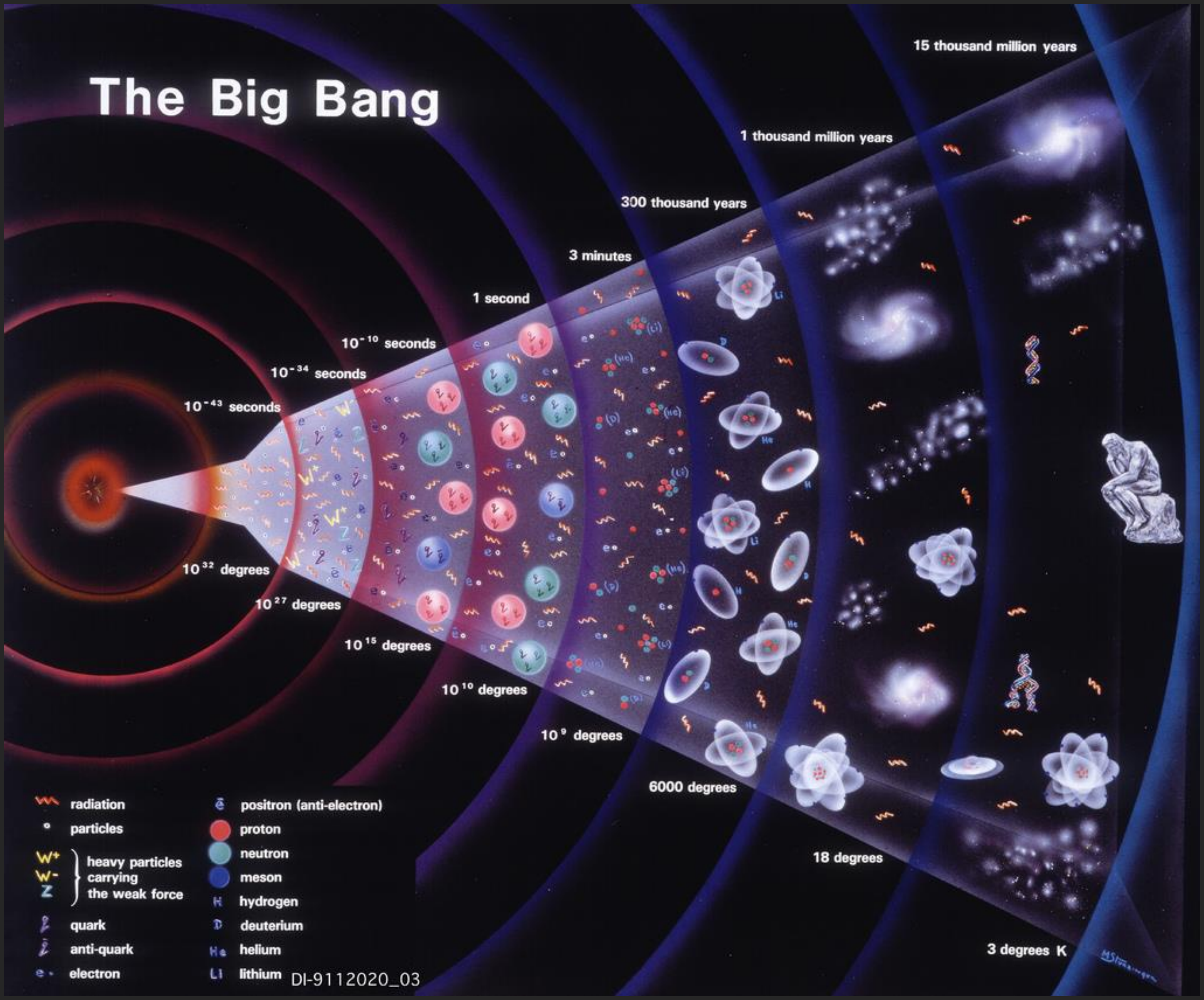
WHERE DID EVERYTHING COME FROM ?



Space is stretching at a constant rate!

Hubble constant: 42 miles/second/3 million light year steps

WHERE DID EVERYTHING COME FROM ?



BIG BANG 13.8 Billion years ago

WHAT IS EVERYTHING MADE OF?

Democritus , Ancient Greek philosopher, ~5 BC

Leucippus , Ancient Greek philosopher, ~5 BC

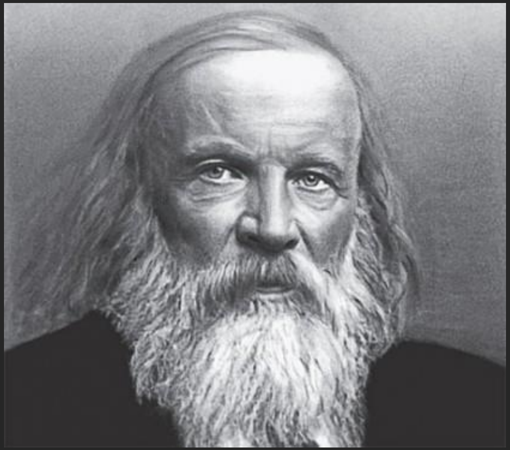
"The universe is composed of two elements: the atoms and the void in which they exist and move."

'All matter consists of invisible particles called 'atoms'

The word *atom* comes from *atomos*, an ancient Greek word meaning *indivisible*

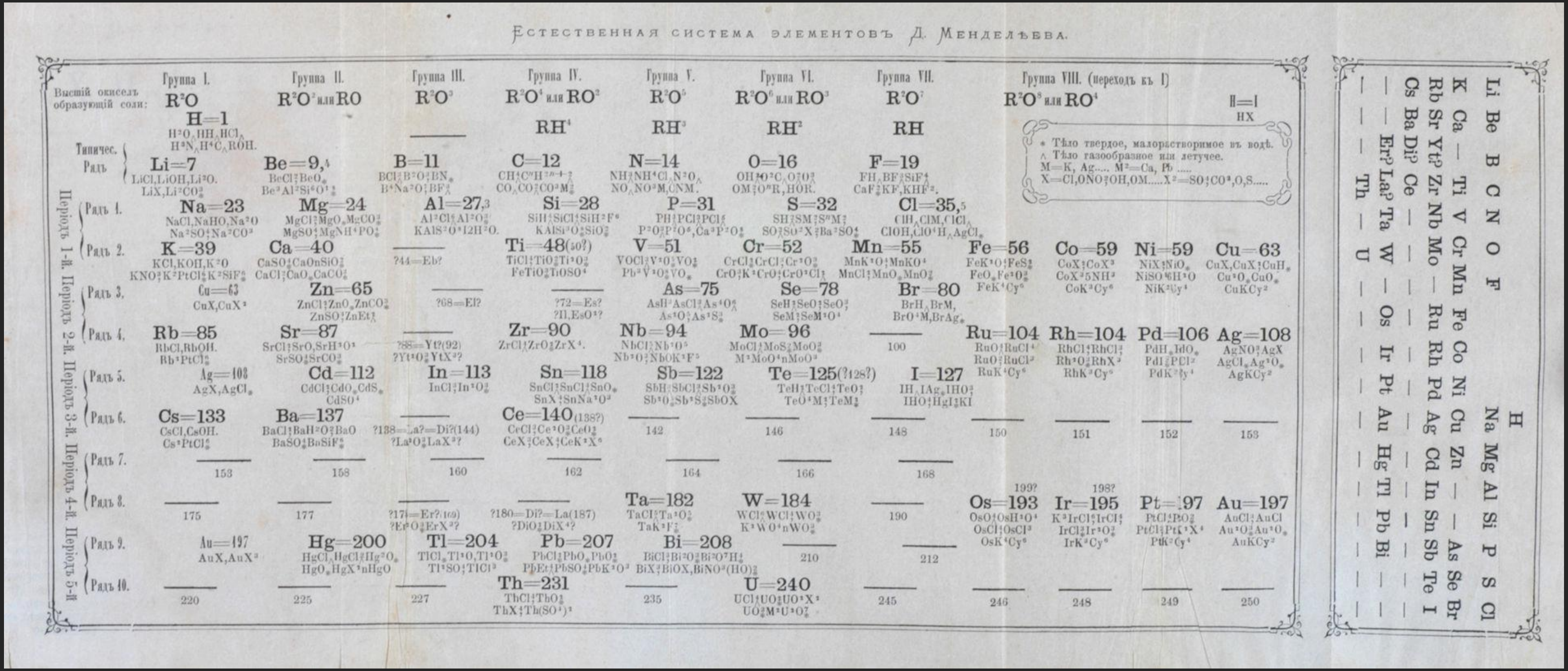
'Atoms are indestructible, solid but invisible, homogenous, and differ in size, shape, mass, position and arrangement'

WHAT IS EVERYTHING MADE OF?



In 1869 Russian chemist Dimitri Mendeleev published the **periodic table**, arranging chemical elements by atomic mass.

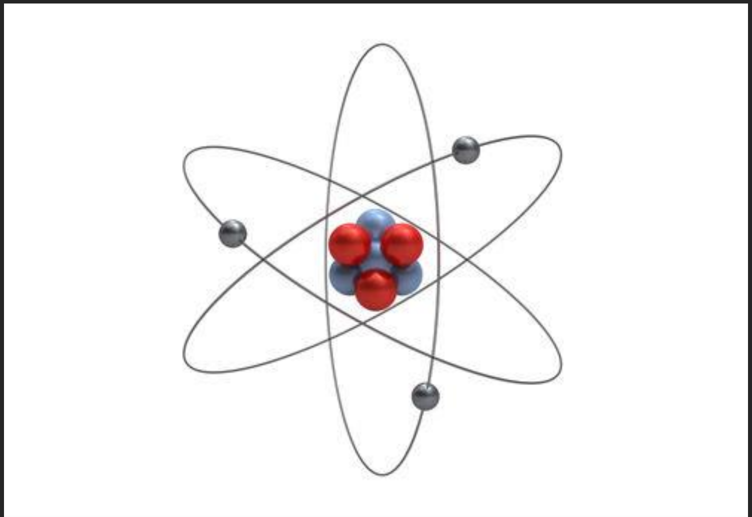
~ **80 elements** – WHY SO MANY?
Is there a simpler structure?



WHAT IS EVERYTHING MADE OF?

Particle Physics seeks to understand fundamental particle and forces

The atom



- 1897 electron discovered by J.J. Thompson
- 1911 nucleus of the atom discovered by Ernest Rutherford, and nucleus of hydrogen a proton
- 1932 neutron discovered by James Chadwick

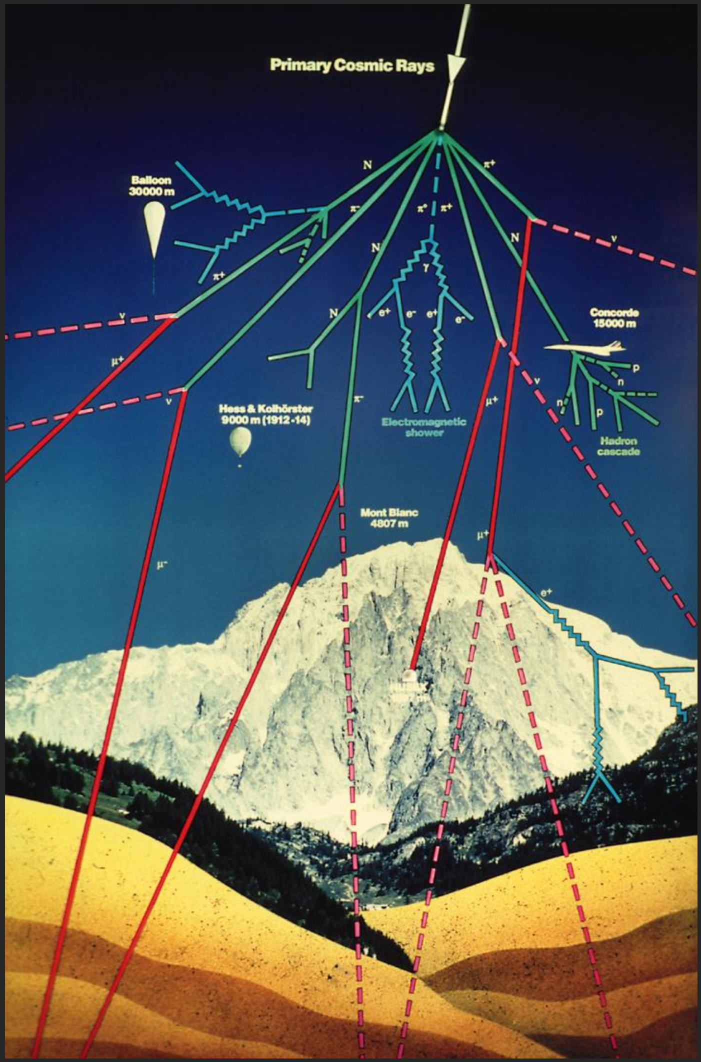
- Photon – particle of the electromagnetic force suggested by Einstein in 1905

However other particles not part of the atom seemed to appear!

- 1932 positron detected (predicted by Dirac in 1928)
- 1934 neutrinos established in theory – detected in 1956

WHAT IS EVERYTHING MADE OF?

Cosmic rays



- 1937 muons were discovered in cosmic rays

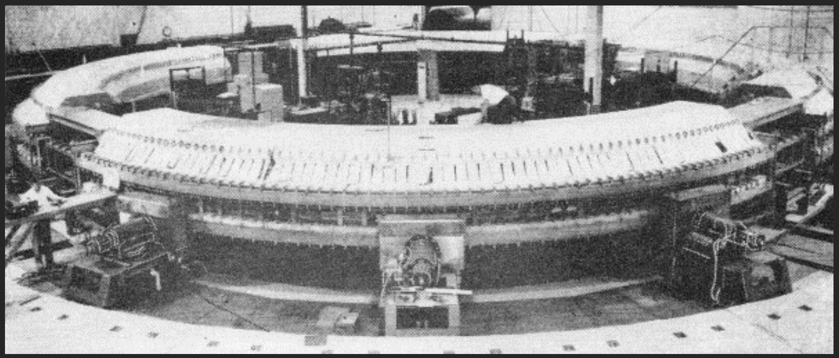
  Who ordered that?

- 1947 pions (a type of meson) were also discovered!!

Things were getting out of hand! What were all these particles?

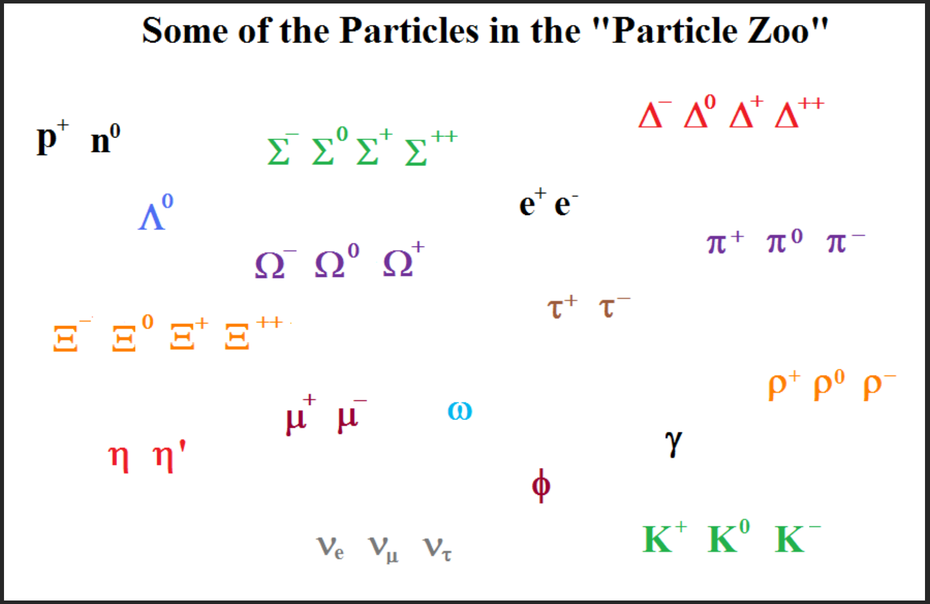
WHAT IS EVERYTHING MADE OF?

Atom smashers (1950s)



The Brookhaven Cosmotron, at 1.3 – 3.3 GeV accelerator

Plethora of NEW particles started coming out of these atom smashes!
Sigma particles, rho particles, Delta particles, kaons, Lambda…



WHAT IS EVERYTHING MADE OF?

Particle Zoo

HADRONS

Particle Zoo (1950s, 1960s)

BARYONS		MESONS		LEPTONS		PHOTON	
Symbol	Charge	Symbol	Charge	Symbol	Charge	Symbol	Charge
p	+1	π^+	+1	e^-	−1	γ	0
$\bar{p}$	−1	π^-	−1	e^+	+1		
n	0	π^0	0	ν_e	0		
Δ	0	K^+	+1	$\bar{\nu}_e$	0		
		K^-	−1				
		K^0	0				

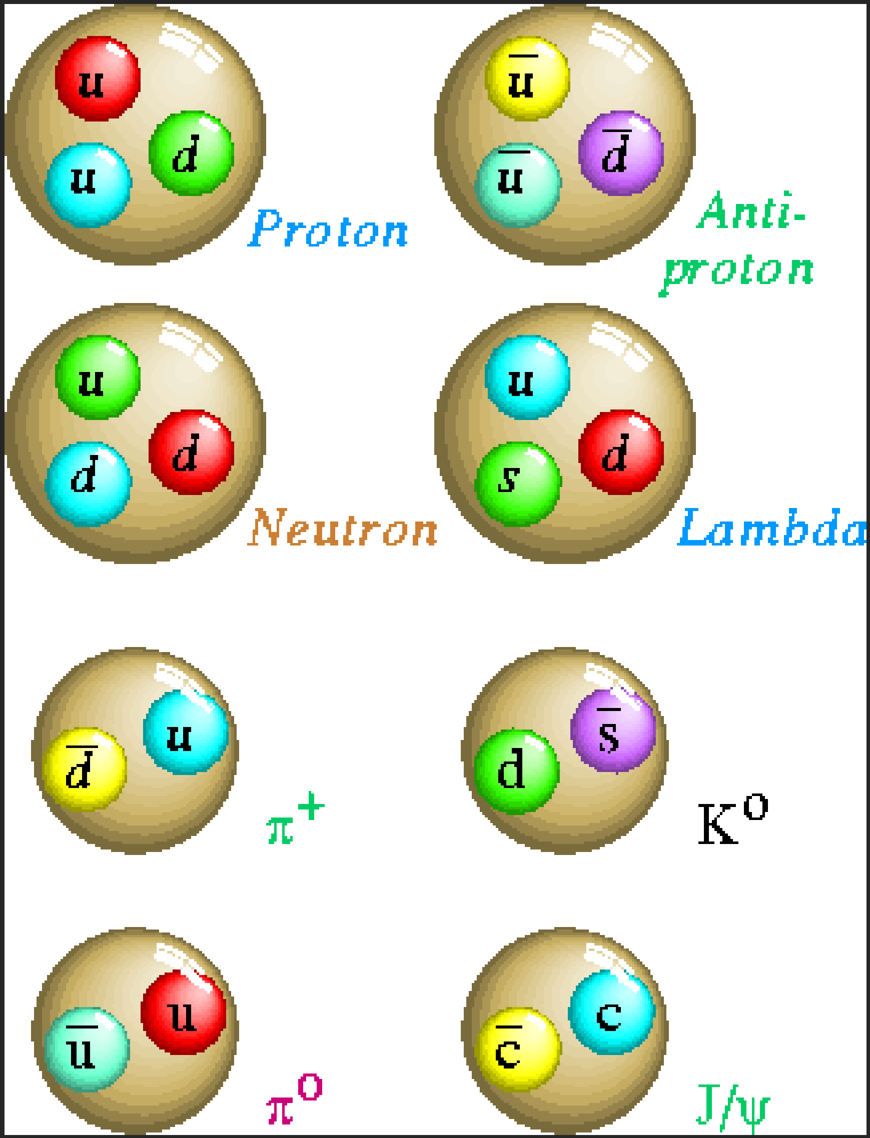
Over 100 'elementary' particles

WHAT IS EVERYTHING MADE OF?

BREAK THROUGH

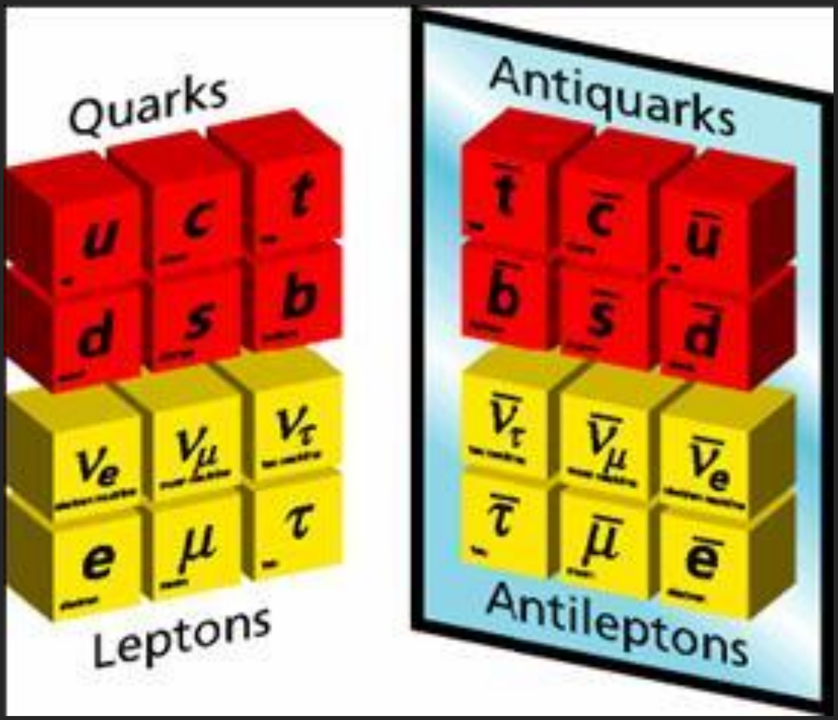
1960s Murray Gell-Mann of Caltech said hadrons are composed of more fundamental particles which he called quarks.

The word comes from a line in Finnegans Wake, a book written by James Joyce.

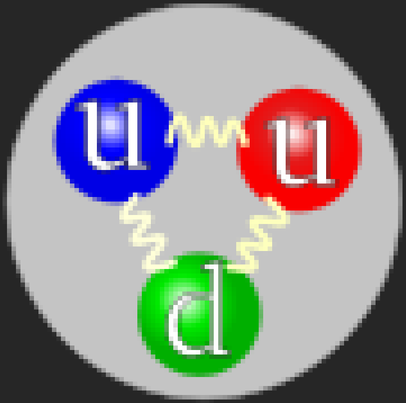


WHAT IS EVERYTHING MADE OF?

Fundamental matter particles



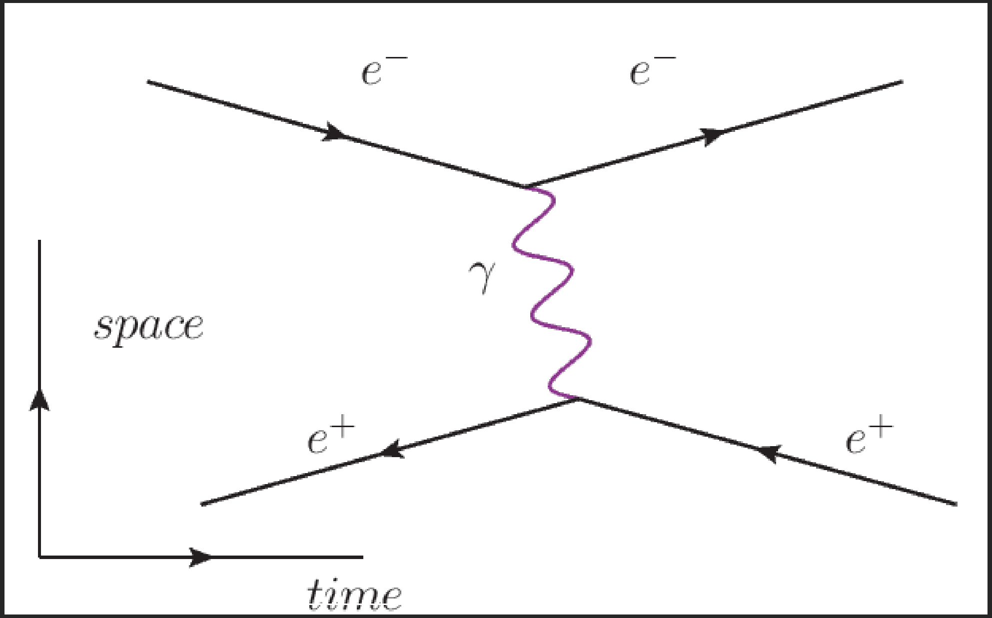
Quarks lived together in twos or threes, making up hadrons like the proton



WHAT IS EVERYTHING MADE OF?

Fundamental forces described using relativistic quantum field theories

Electromagnetism: Quantum electrodynamics describes how light and matter interact



Extremely successful theory!

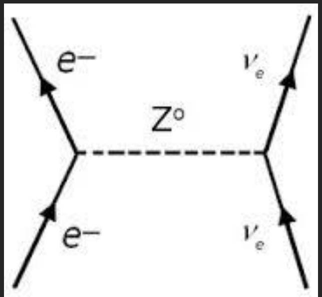
e.g. measurements of the fine structure constant show agreement to within ten parts in a billion (10^{-8})

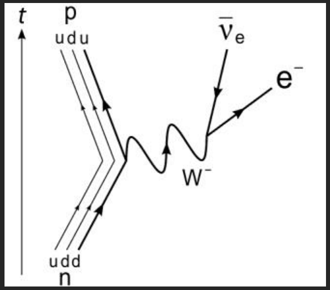
When electrically charged particles interact they exchange a photon

WHAT IS EVERYTHING MADE OF?

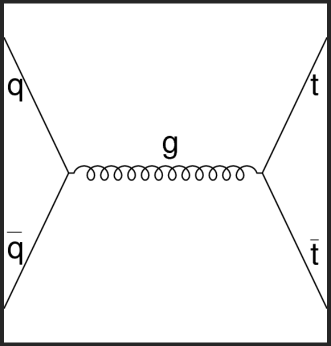
Fundamental forces described using relativistic quantum field theories

A unified theory with electromagnetism was obtained in 1968 – the electroweak theory
W and Z predicted and discovered at CERN 1983



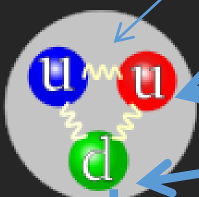


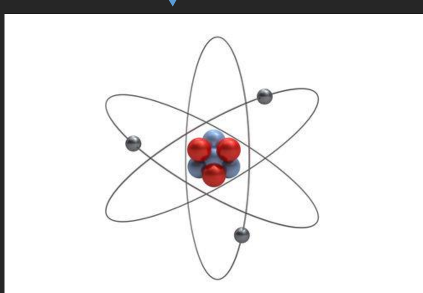
Finally the Strong Force – a very much more complicated force – was described in Quantum Chromodynamics

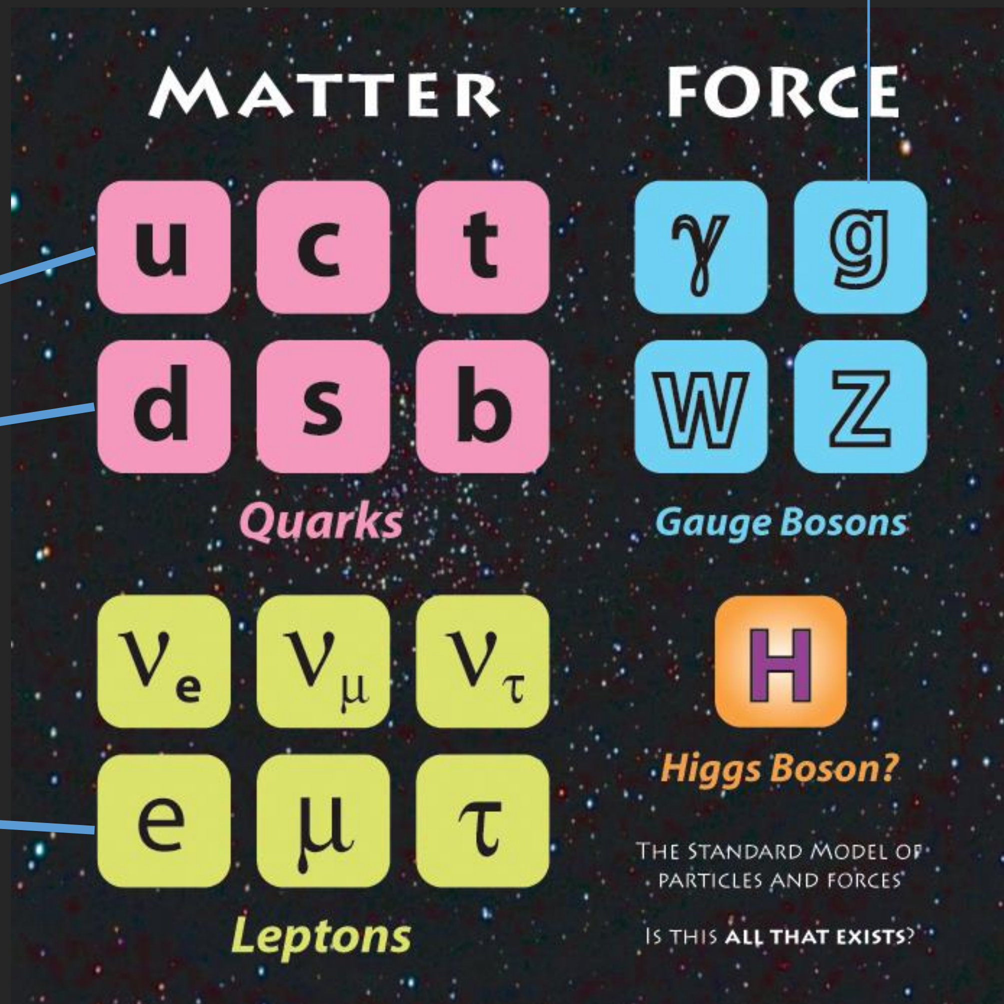


WHAT IS EVERYTHING MADE OF?

The Standard Model

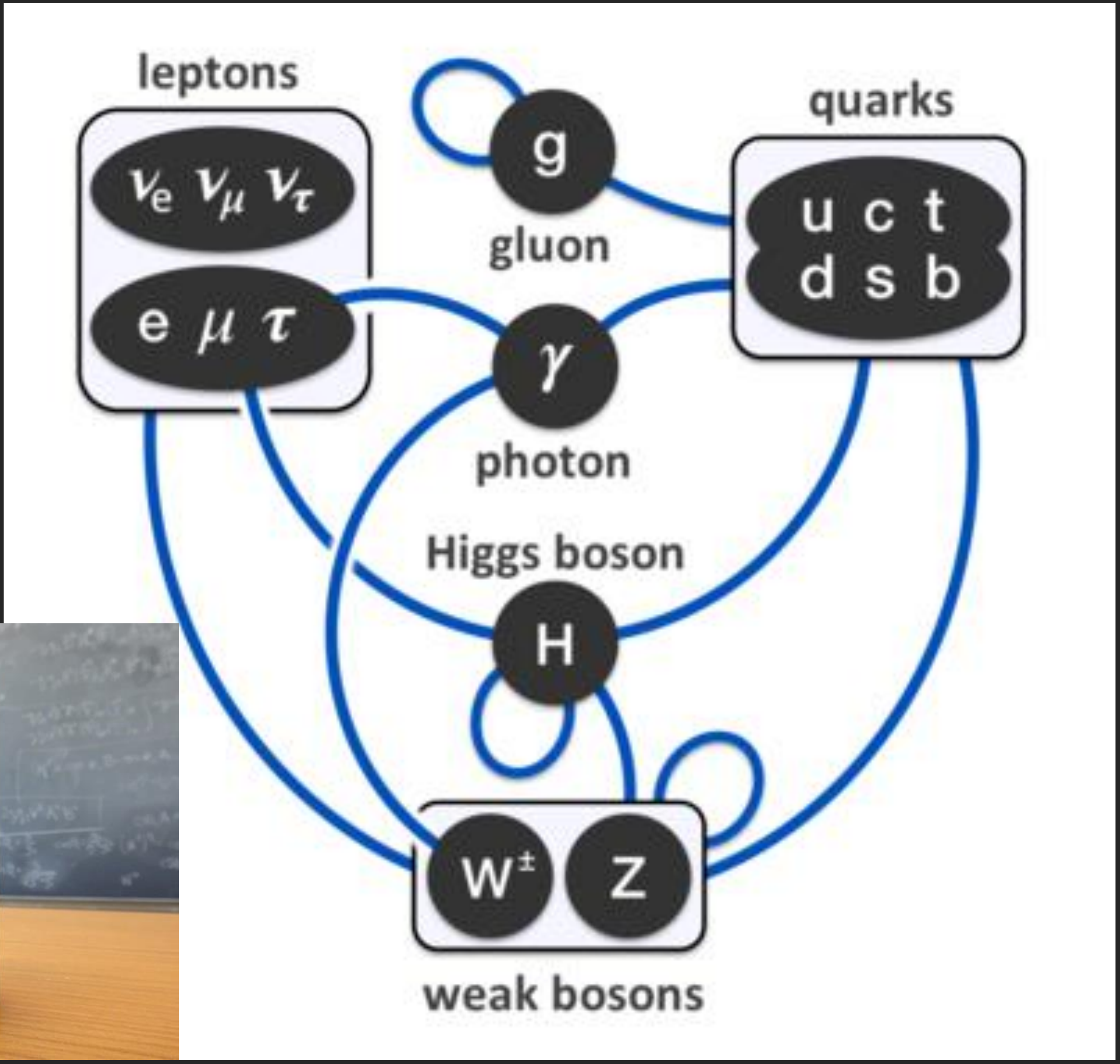


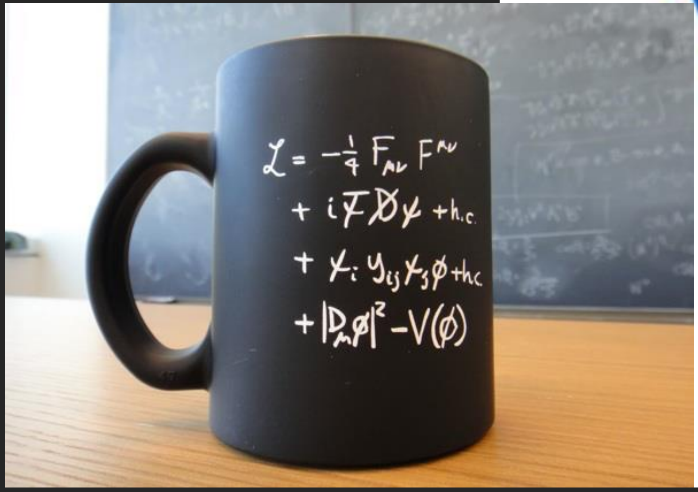




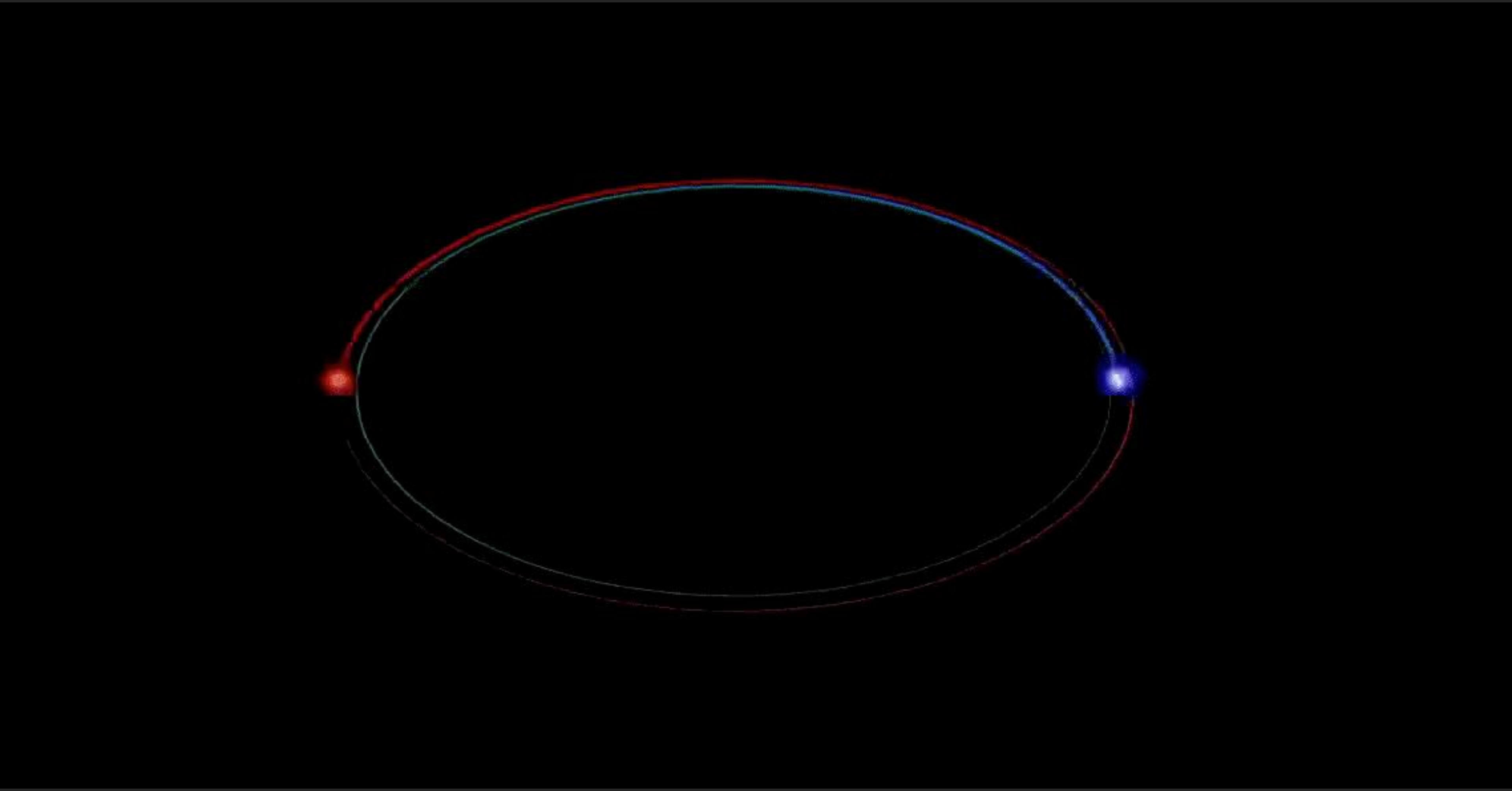
WHAT IS EVERYTHING MADE OF?

The Standard Model





HOW DO WE STUDY PARTICLE PHYSICS?



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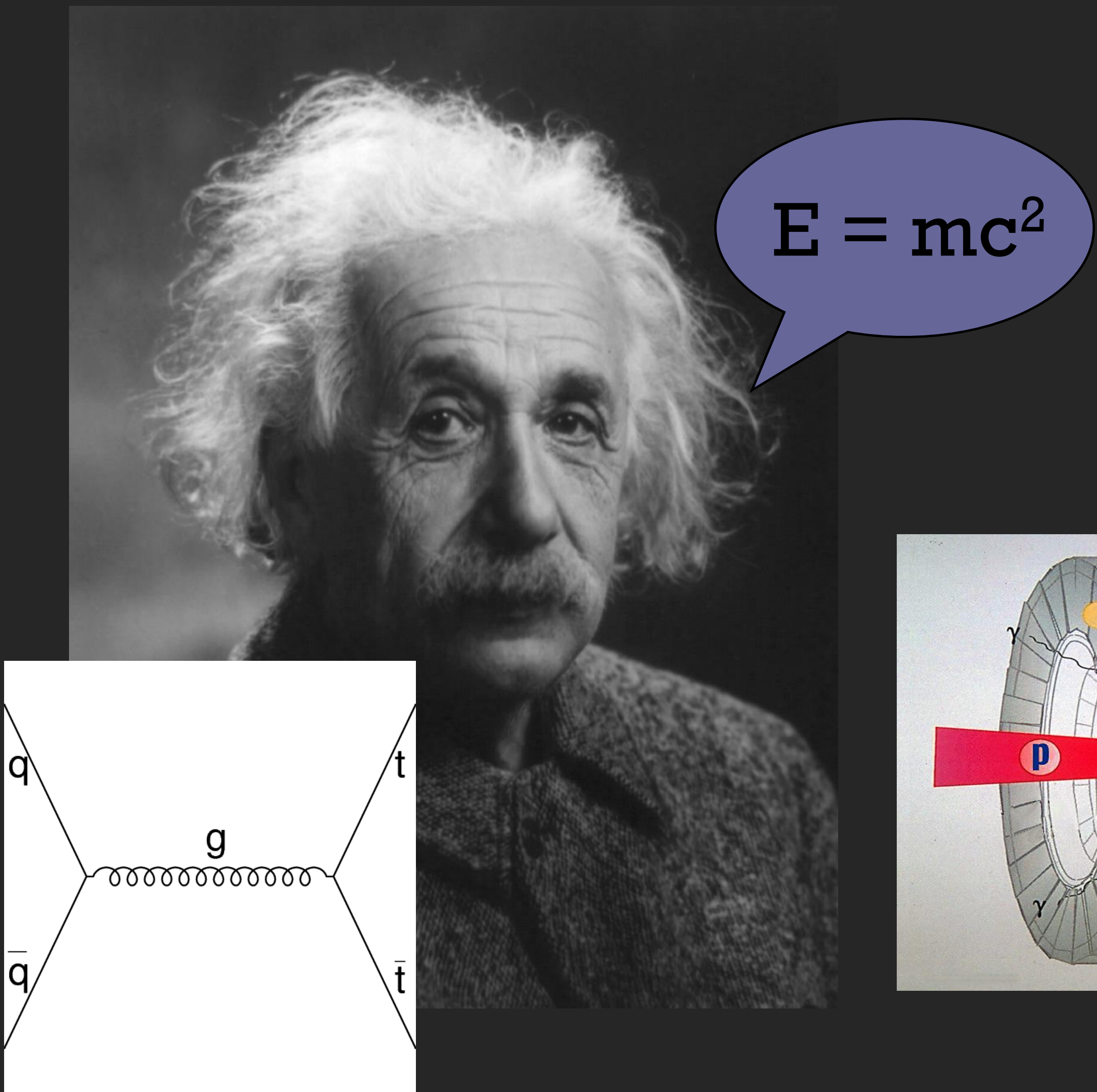

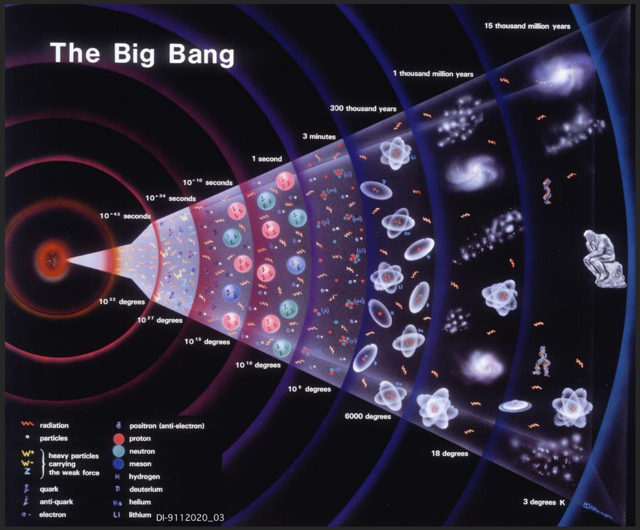

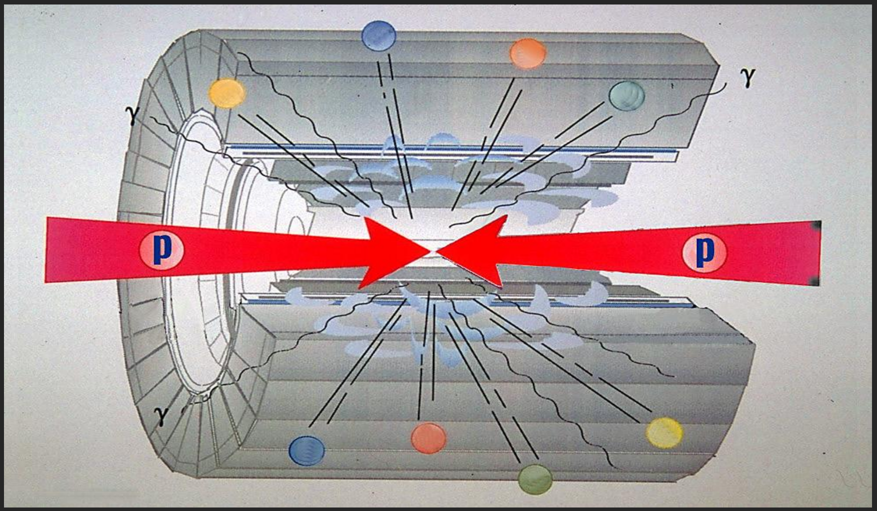

THE LARGE HADRON COLLIDER

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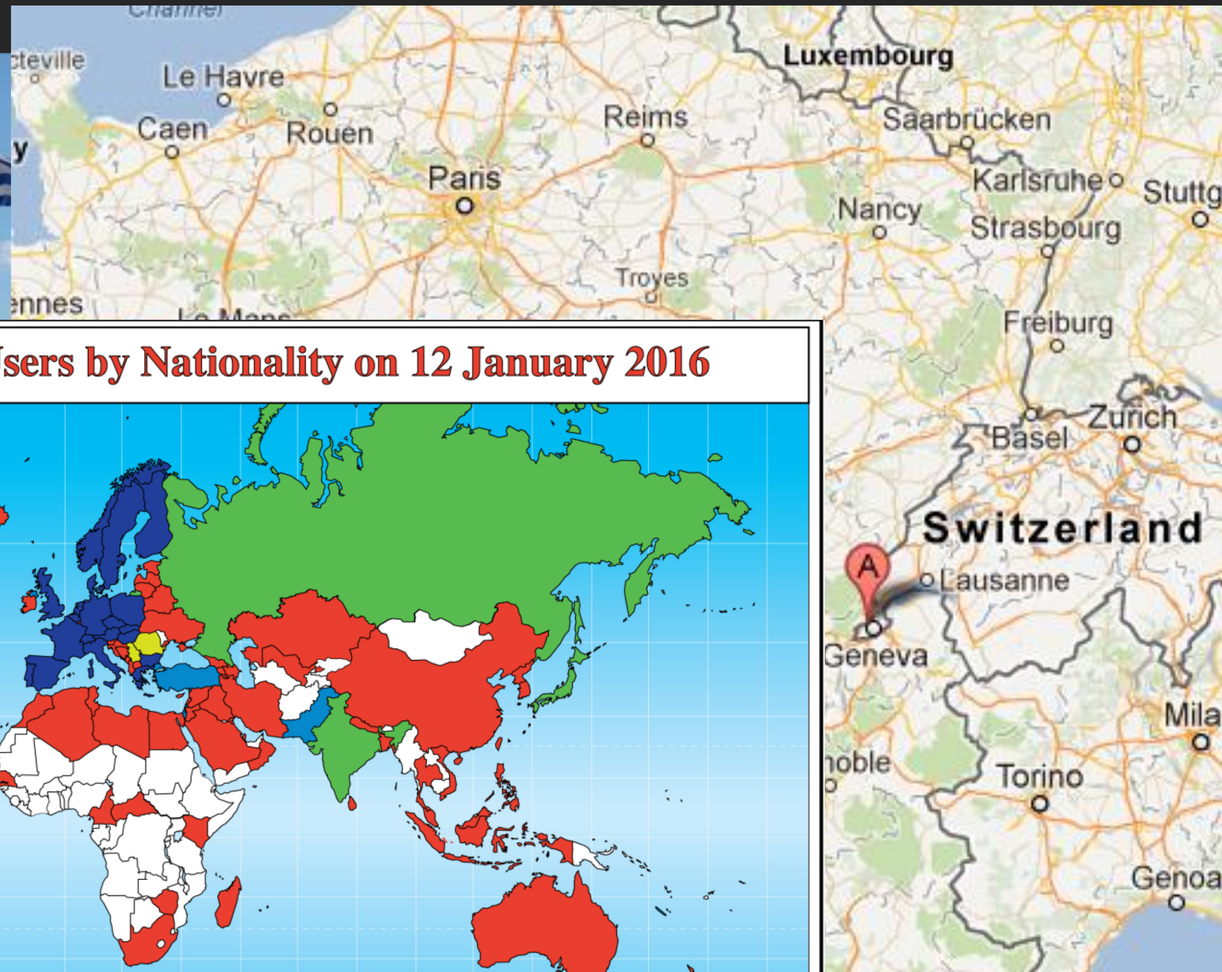

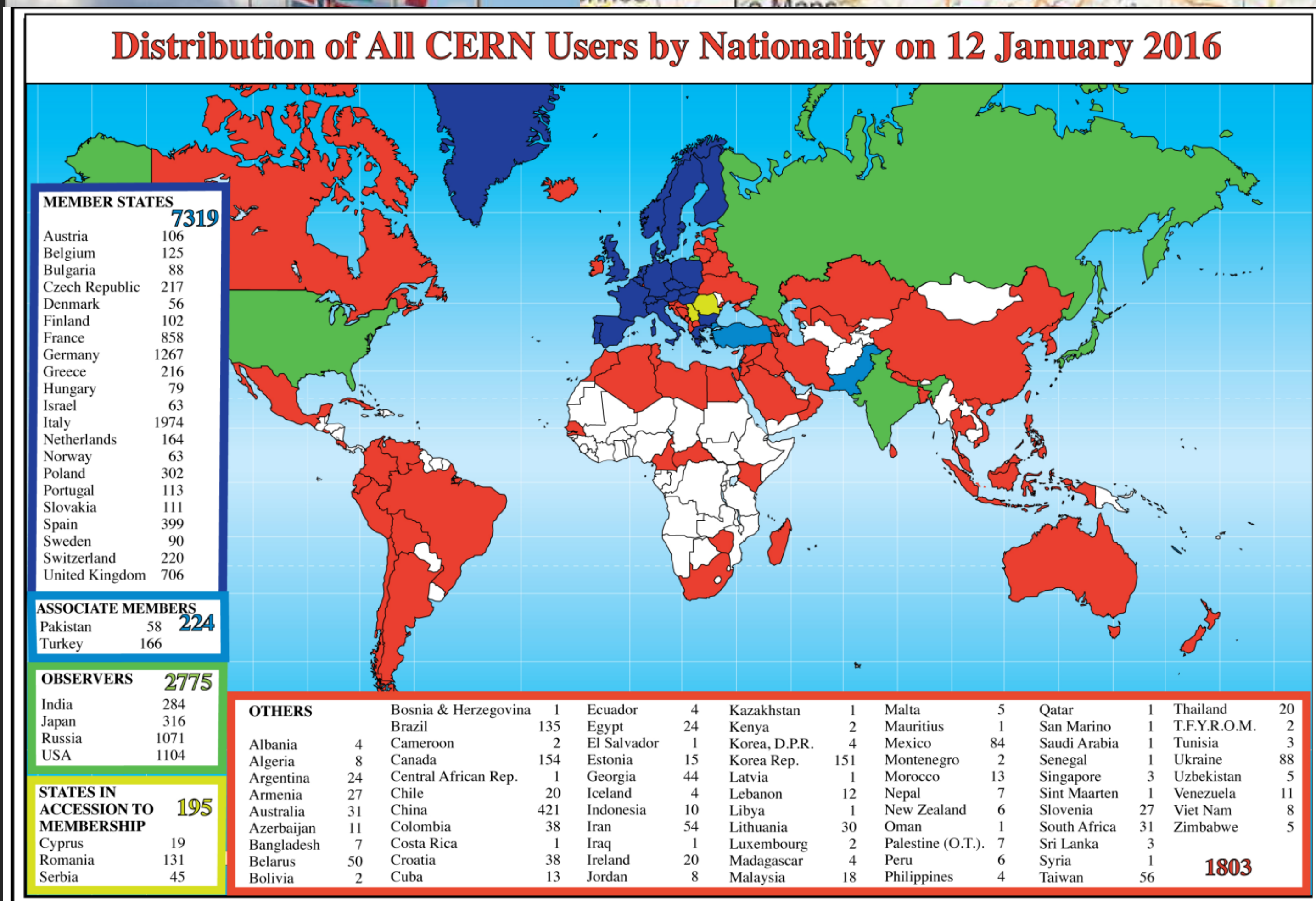

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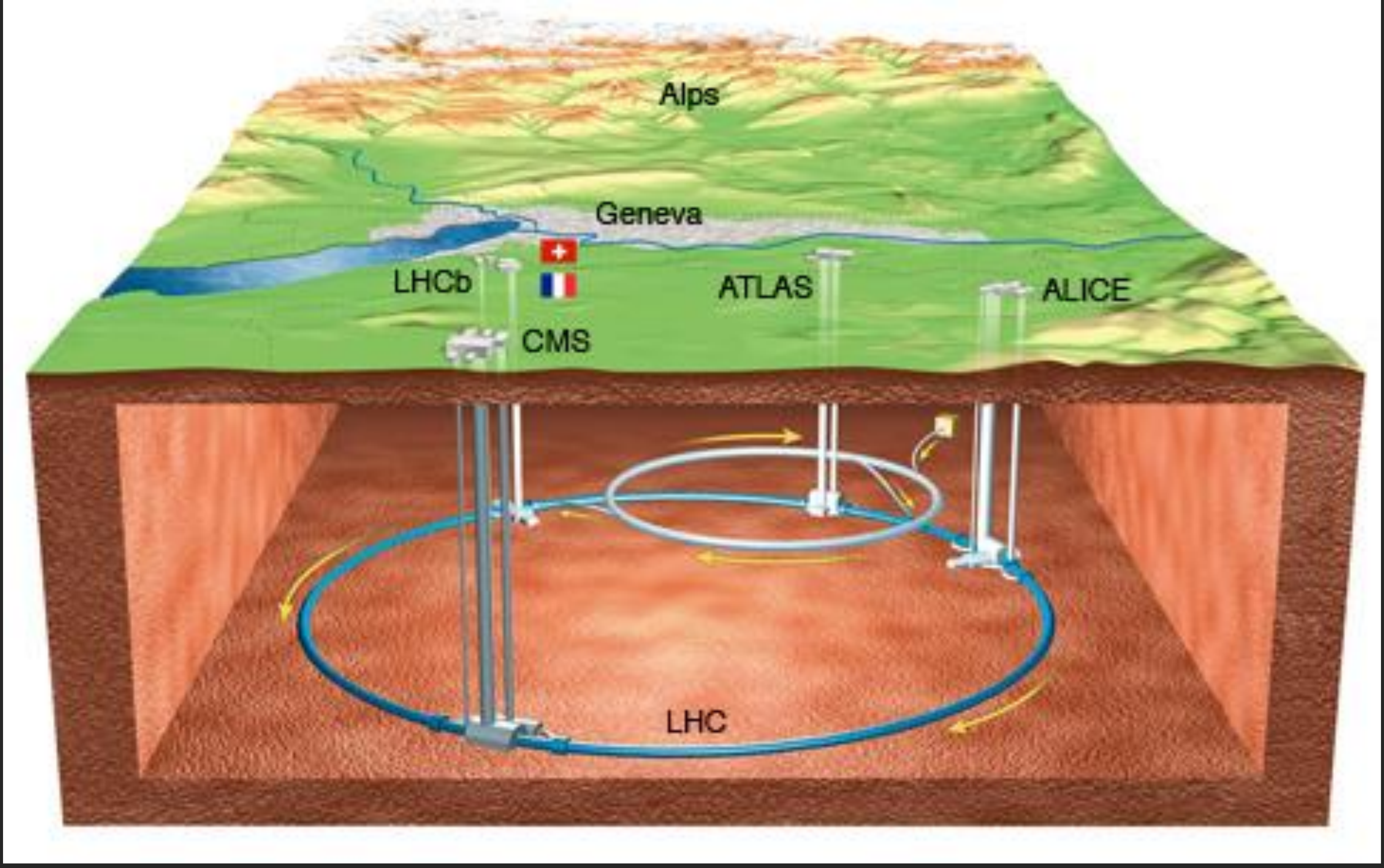
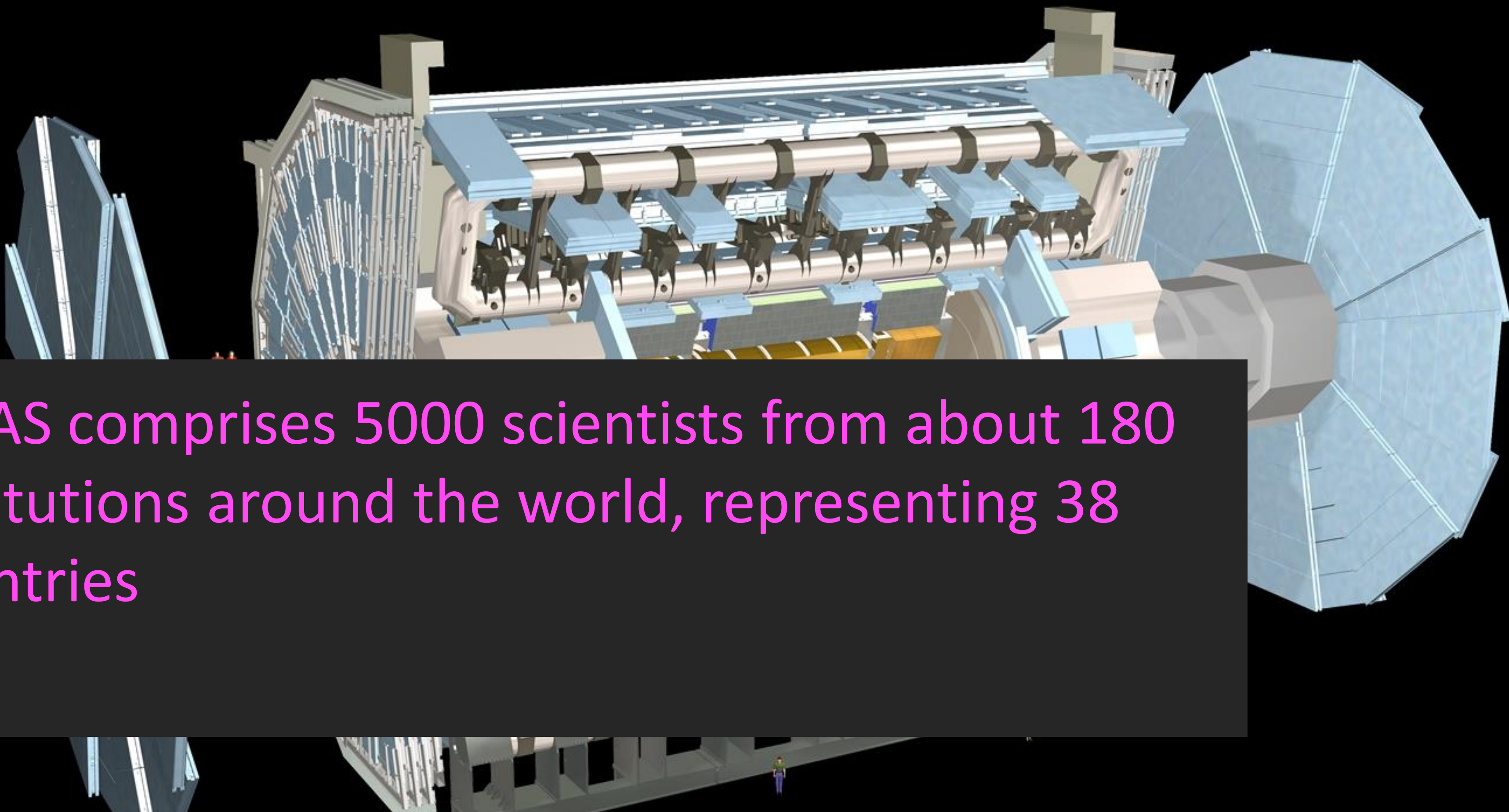
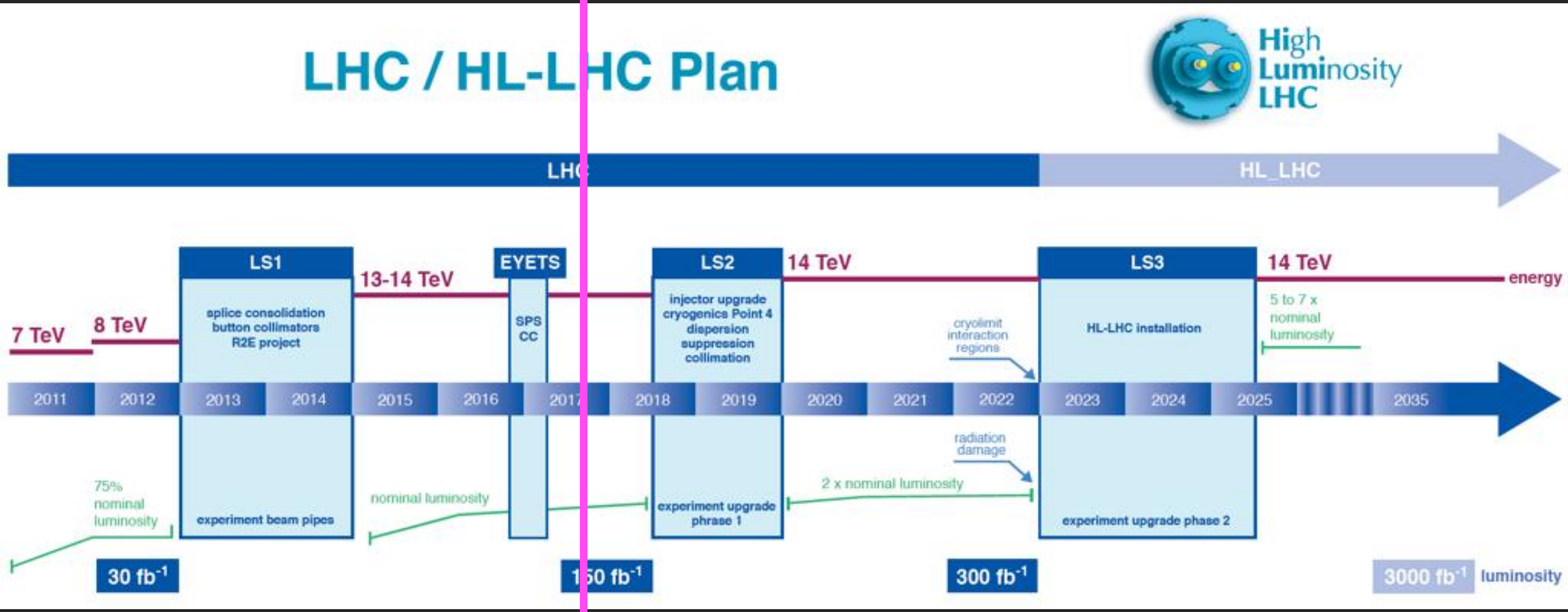


THE ATLAS EXPERIMENT



ATLAS comprises 5000 scientists from about 180 institutions around the world, representing 38 countries

THE LARGE HADRON COLLIDER



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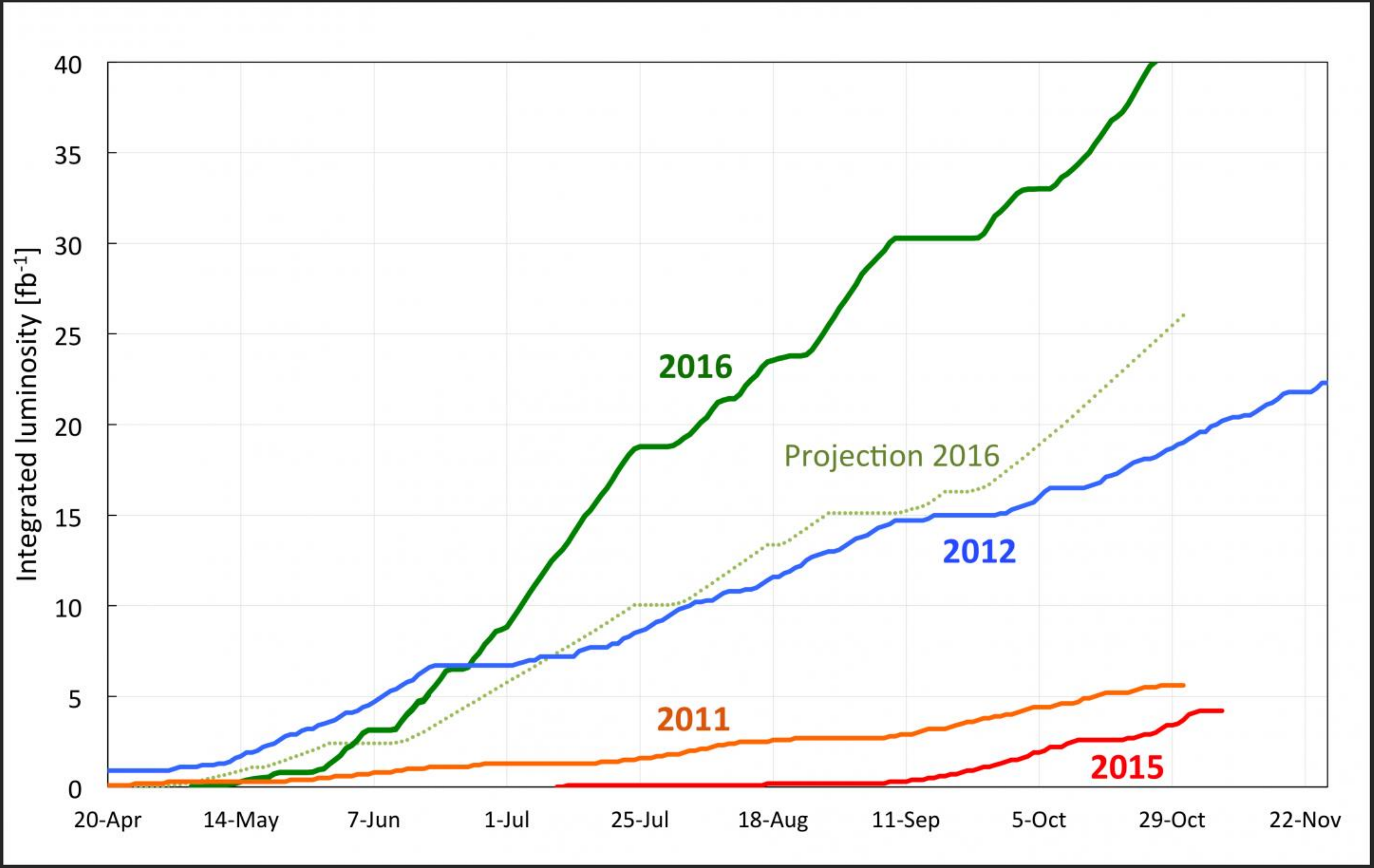
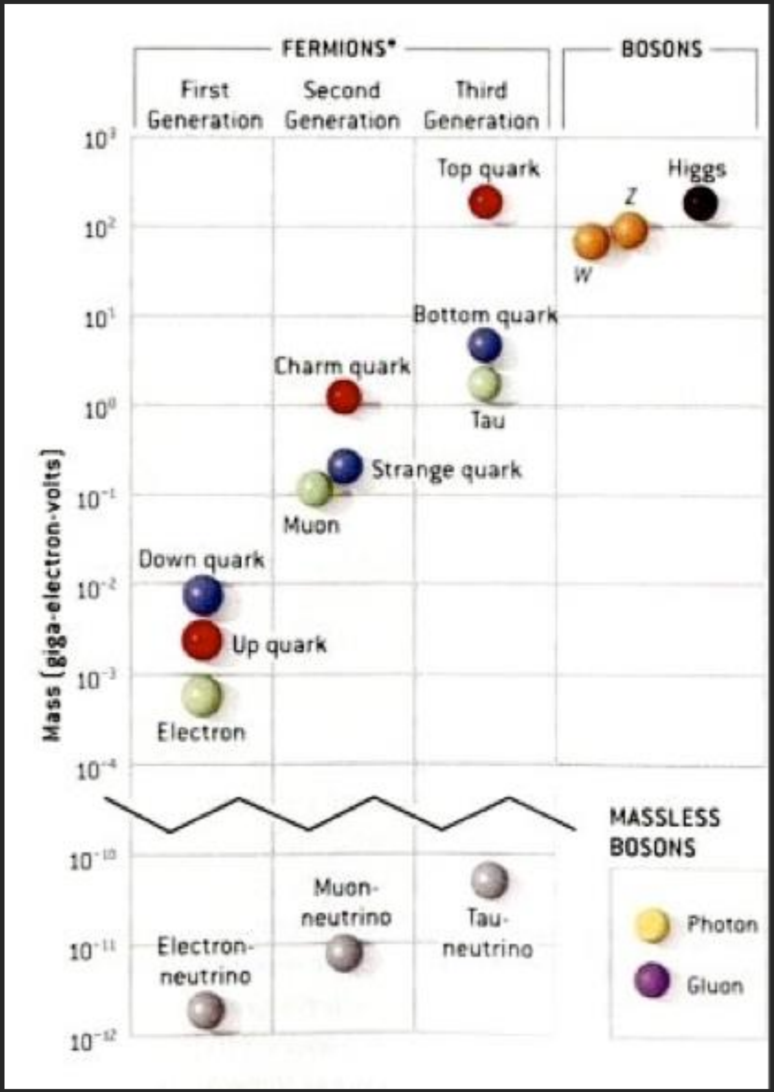


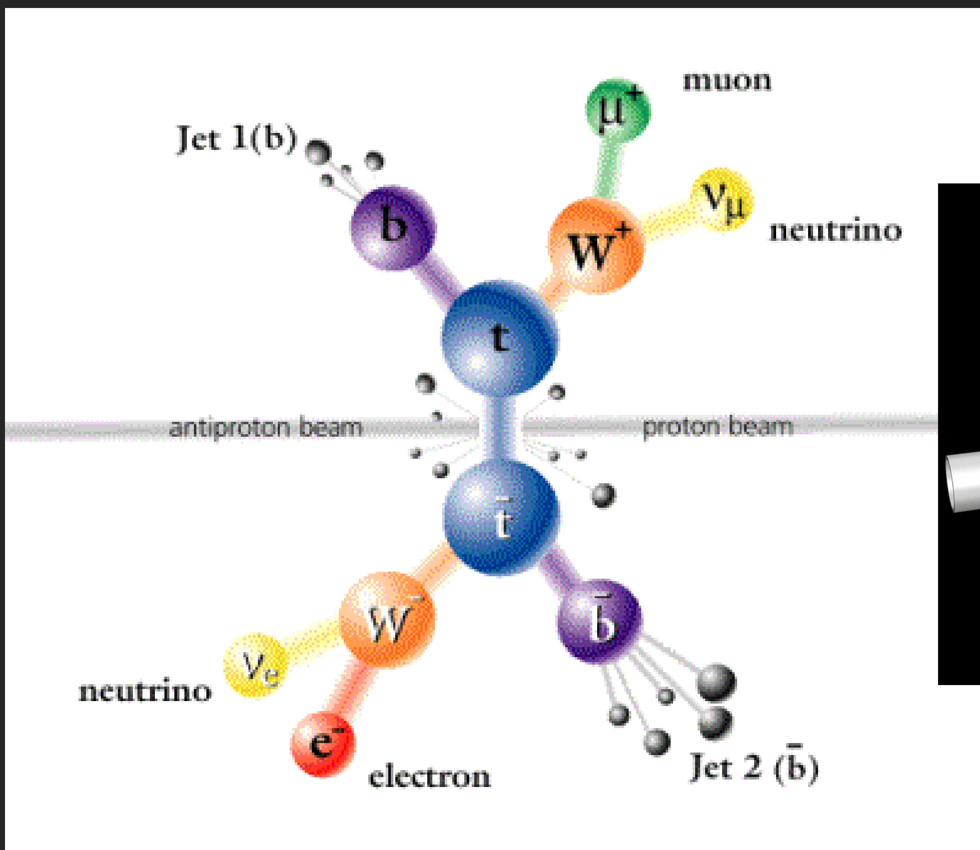
THE ATLAS EXPERIMENT

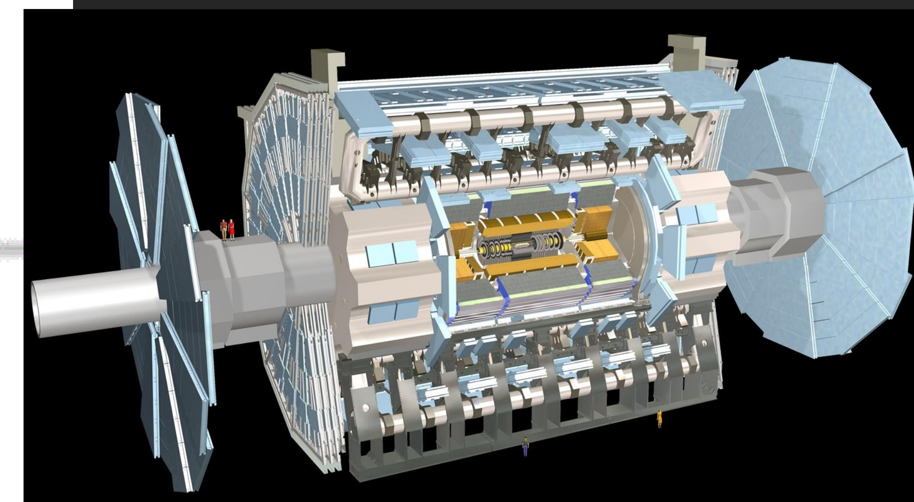
How do we find new particles?



THE ATLAS EXPERIMENT

How do we find particles?





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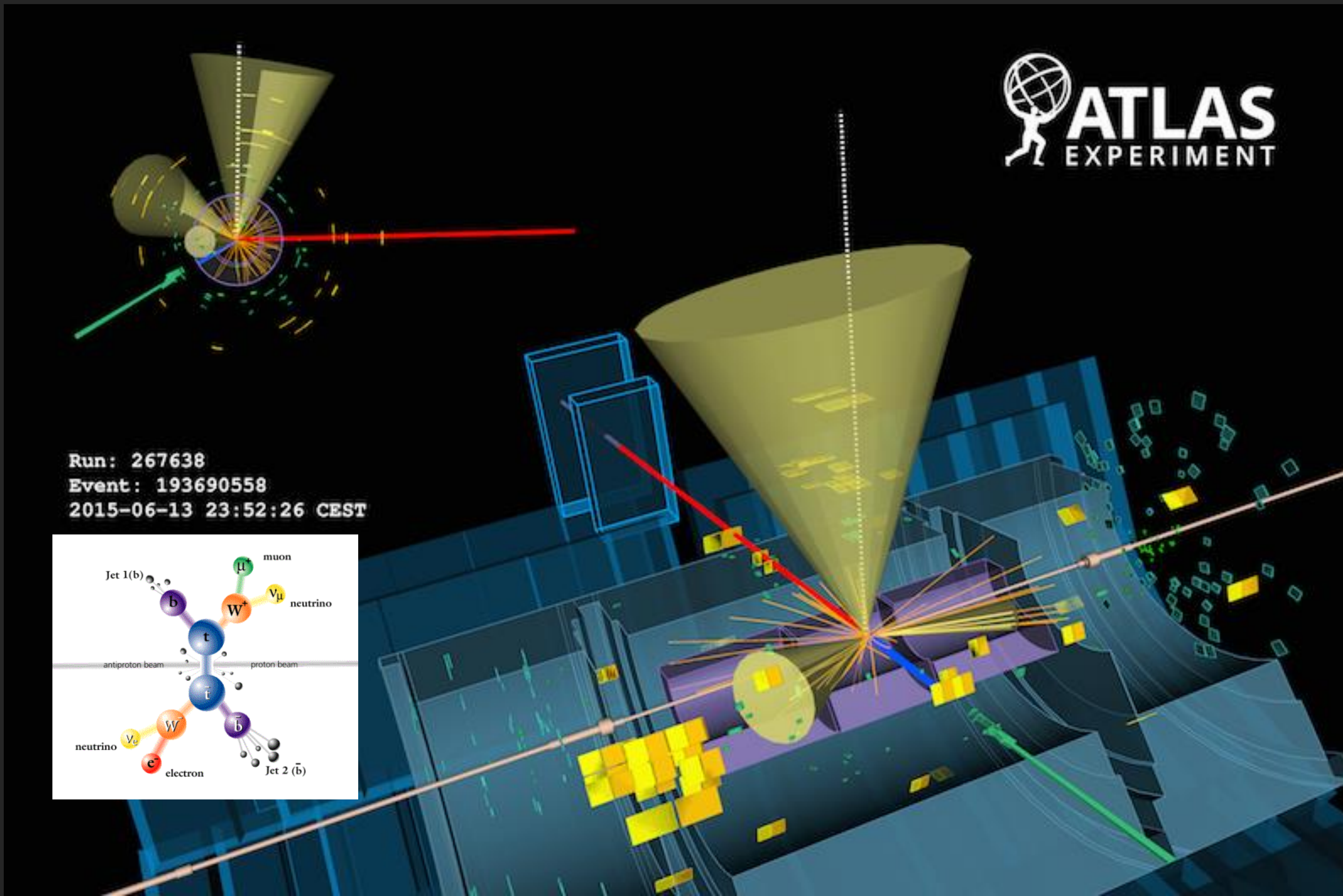
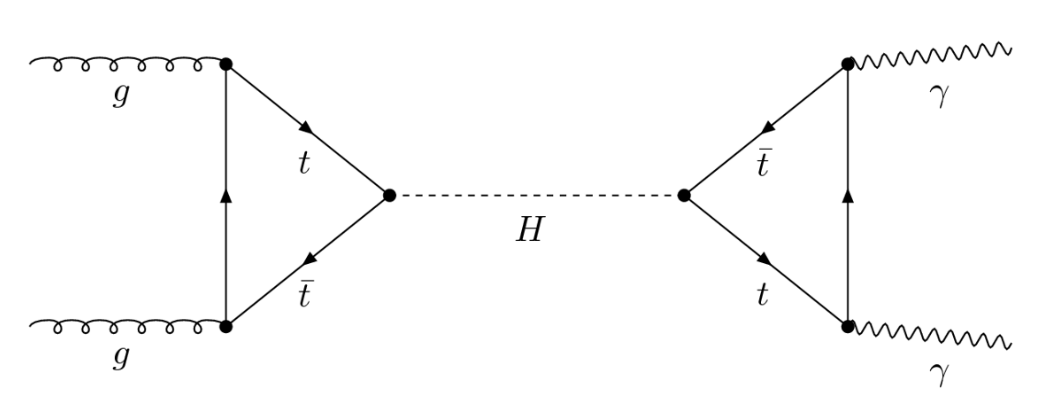
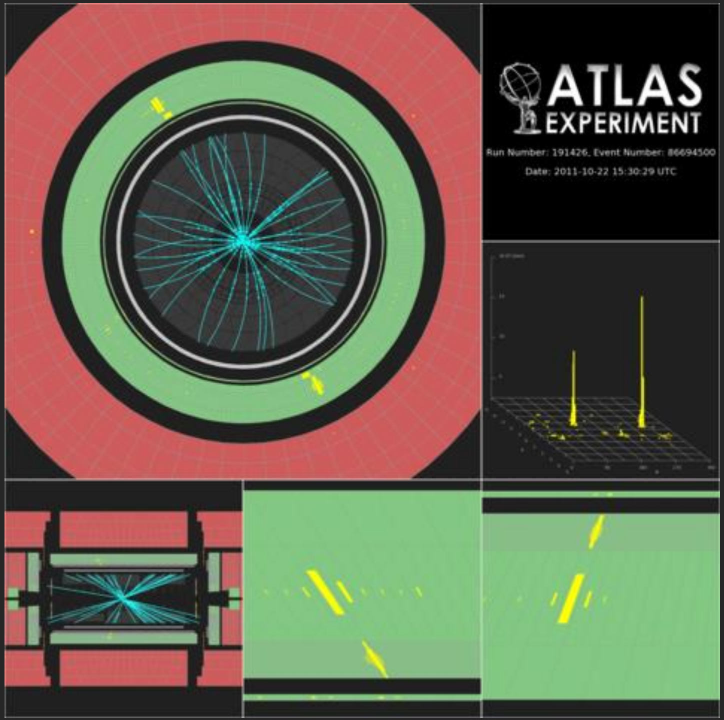


THE ATLAS EXPERIMENT

How did we find the Higgs?

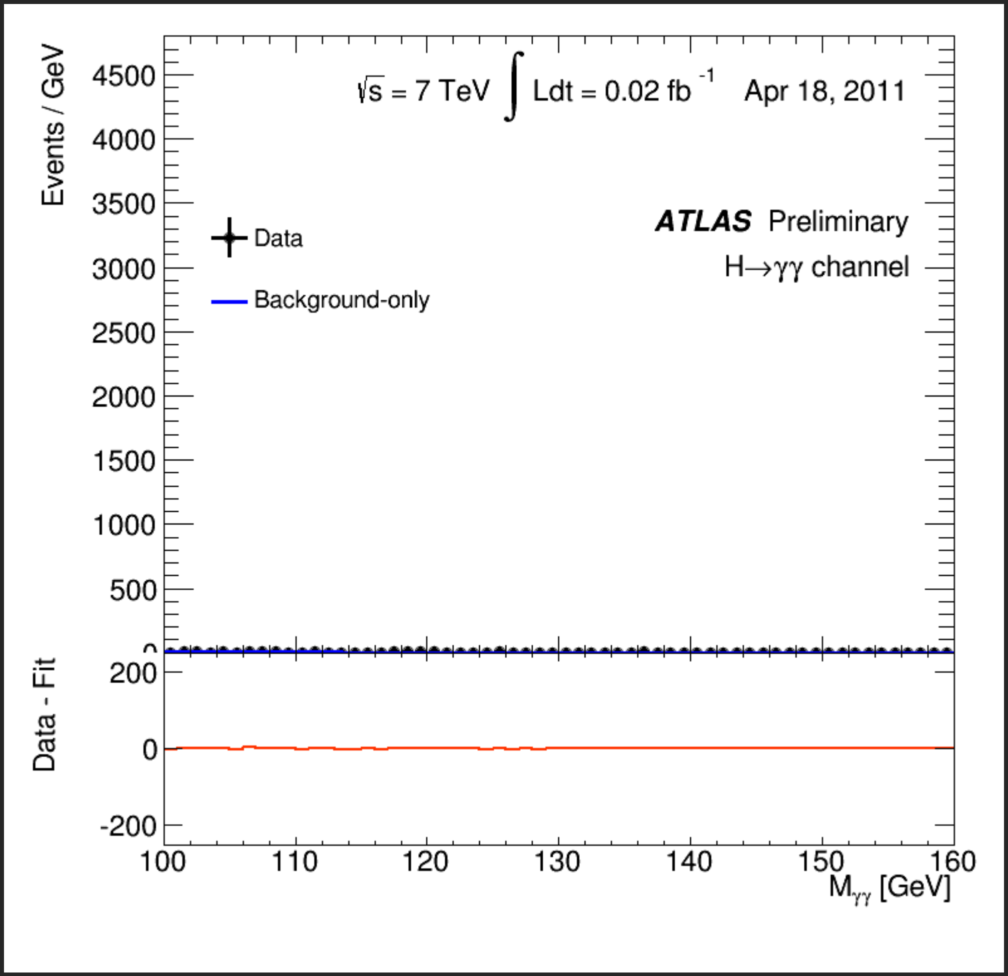


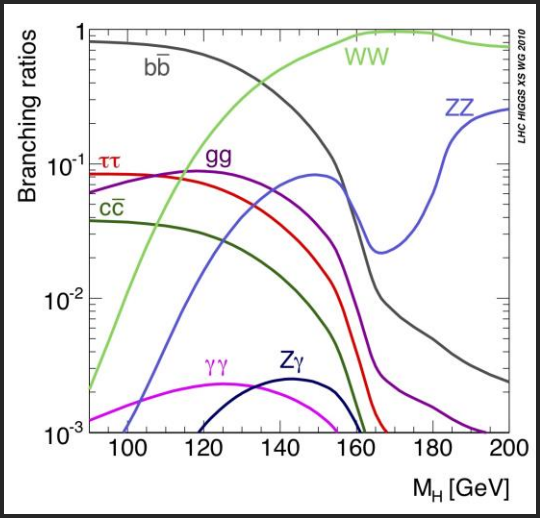


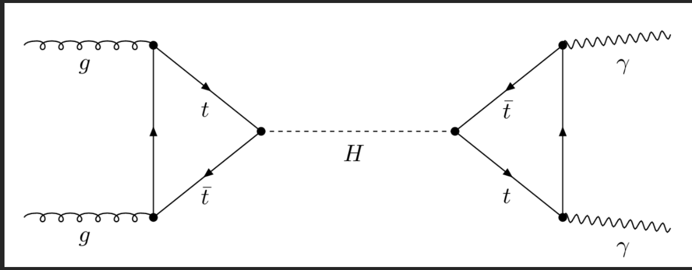
Example: Higgs decays into two photos

THE ATLAS EXPERIMENT

How did we find the Higgs?







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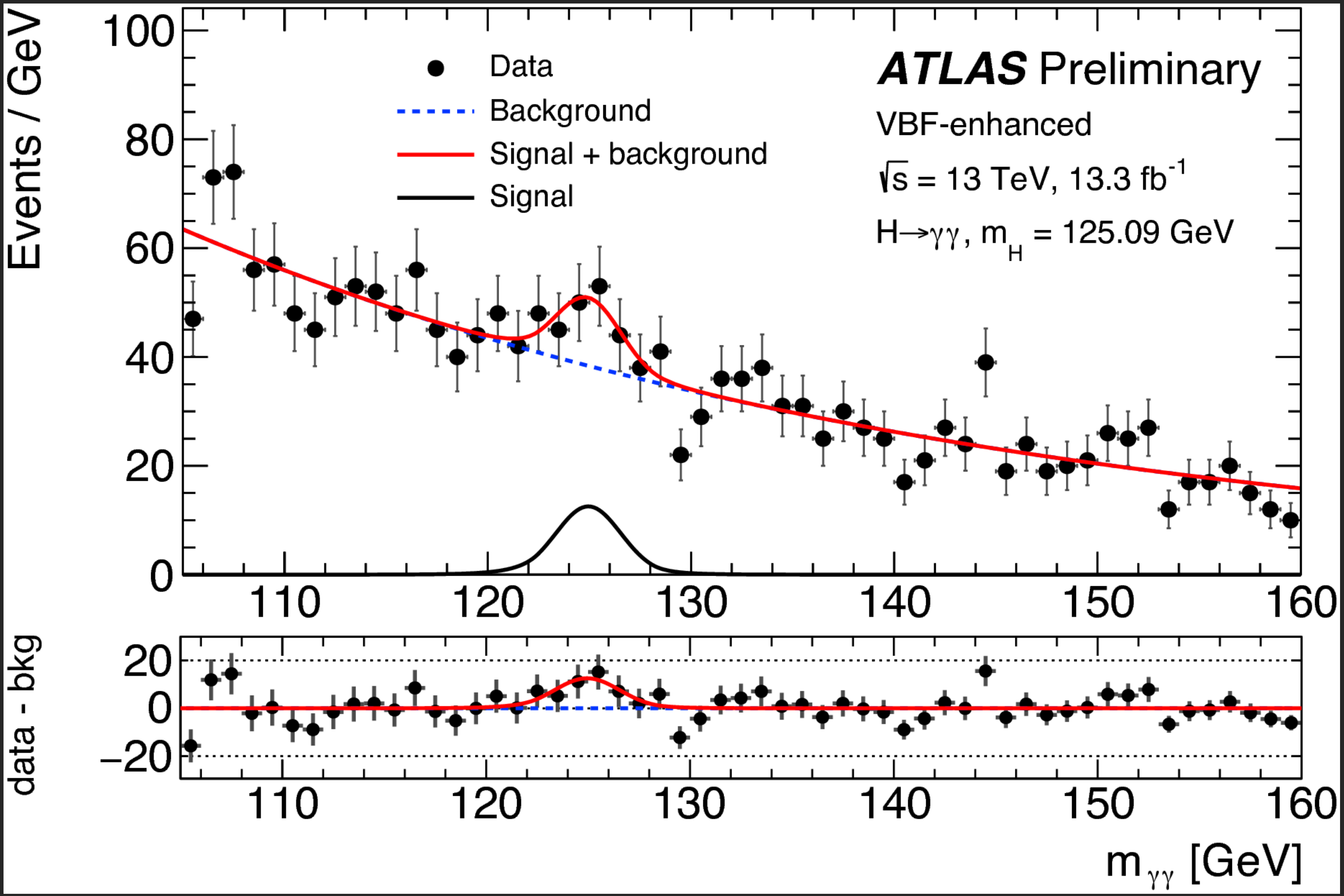

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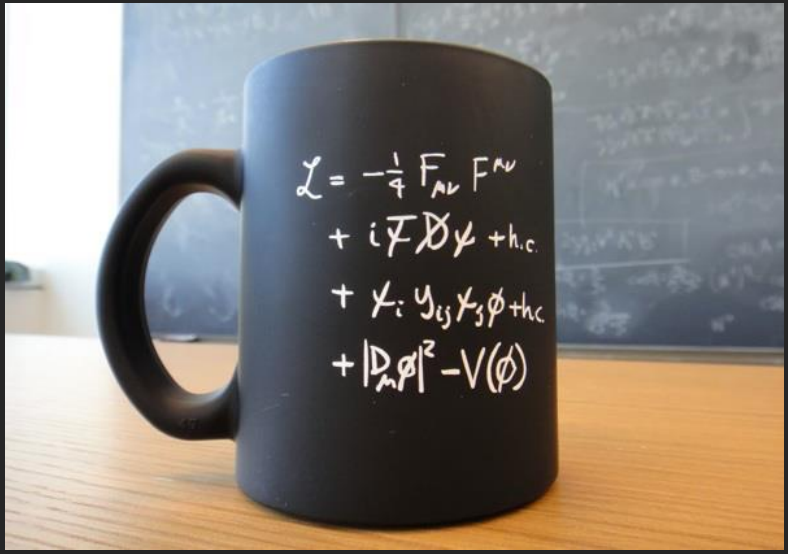
PARTICLE PHSYICS

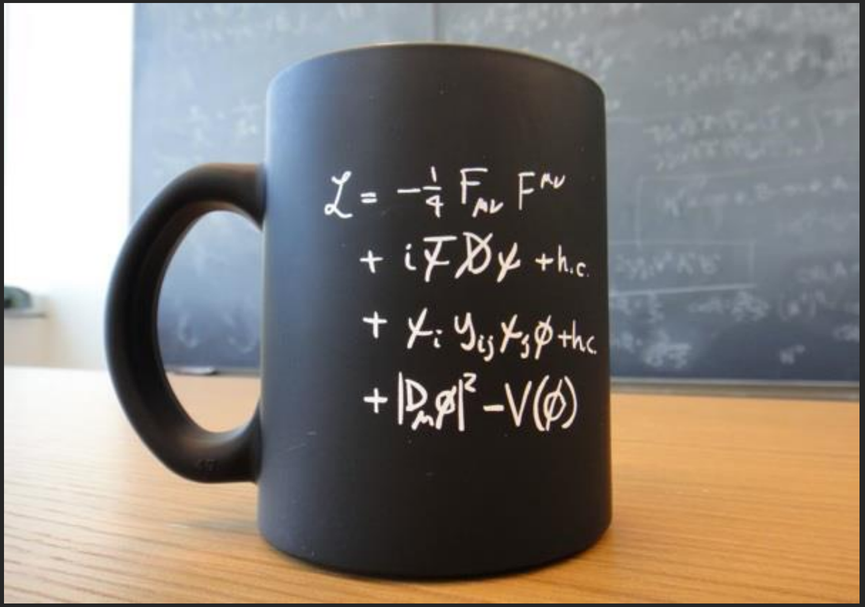
GREAT JOB PARTICLE PHYSICIS!!!!



PARTICLE PHSYICS

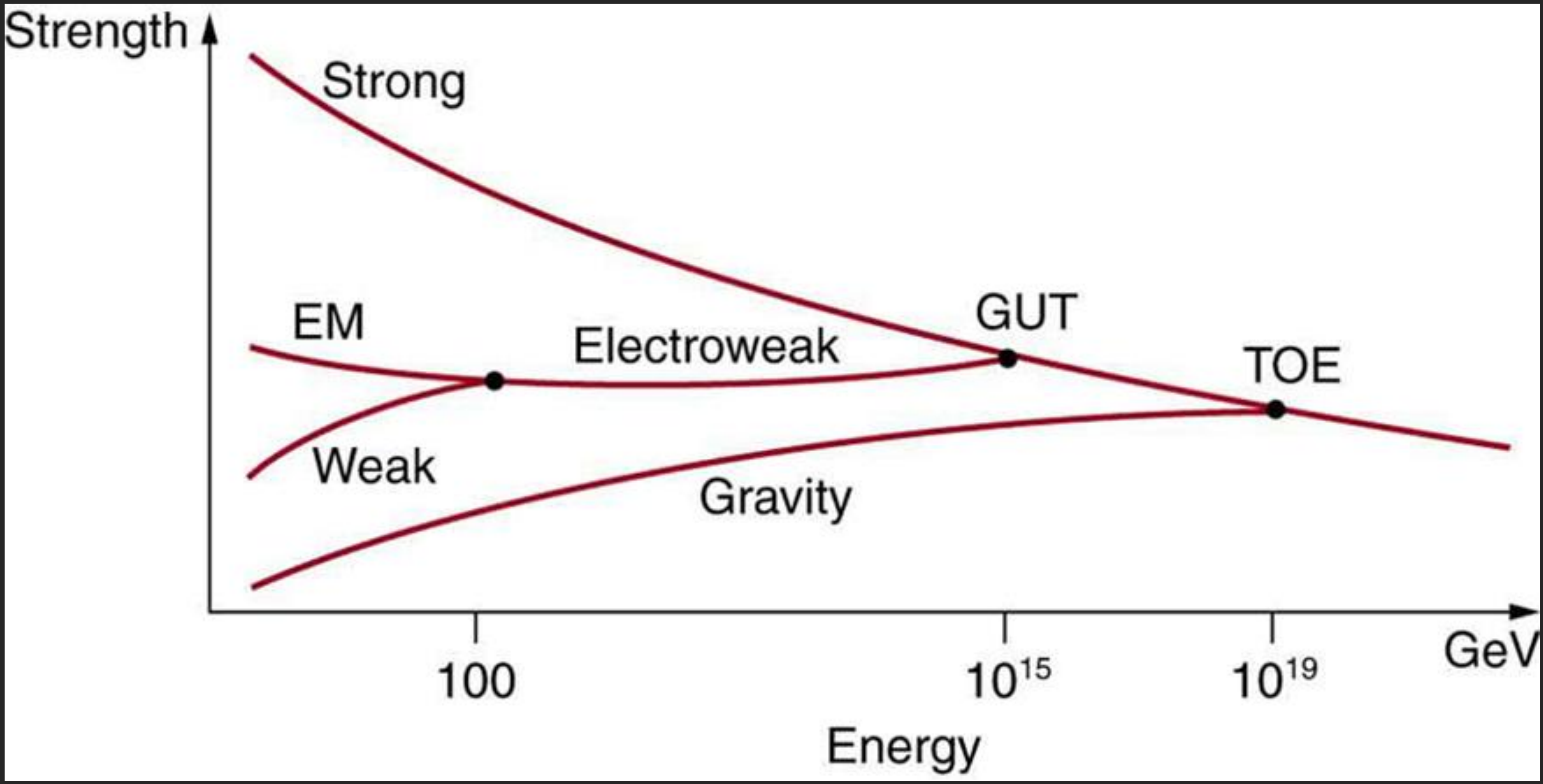
Issues:

- Gravity
- Dark Energy, Dark Matter
- Neutrino masses
- Matter-antimatter asymmetry
- Hierarchy problem



PARTICLE PHYSICS

Fundamental forces described using relativistic quantum field theories

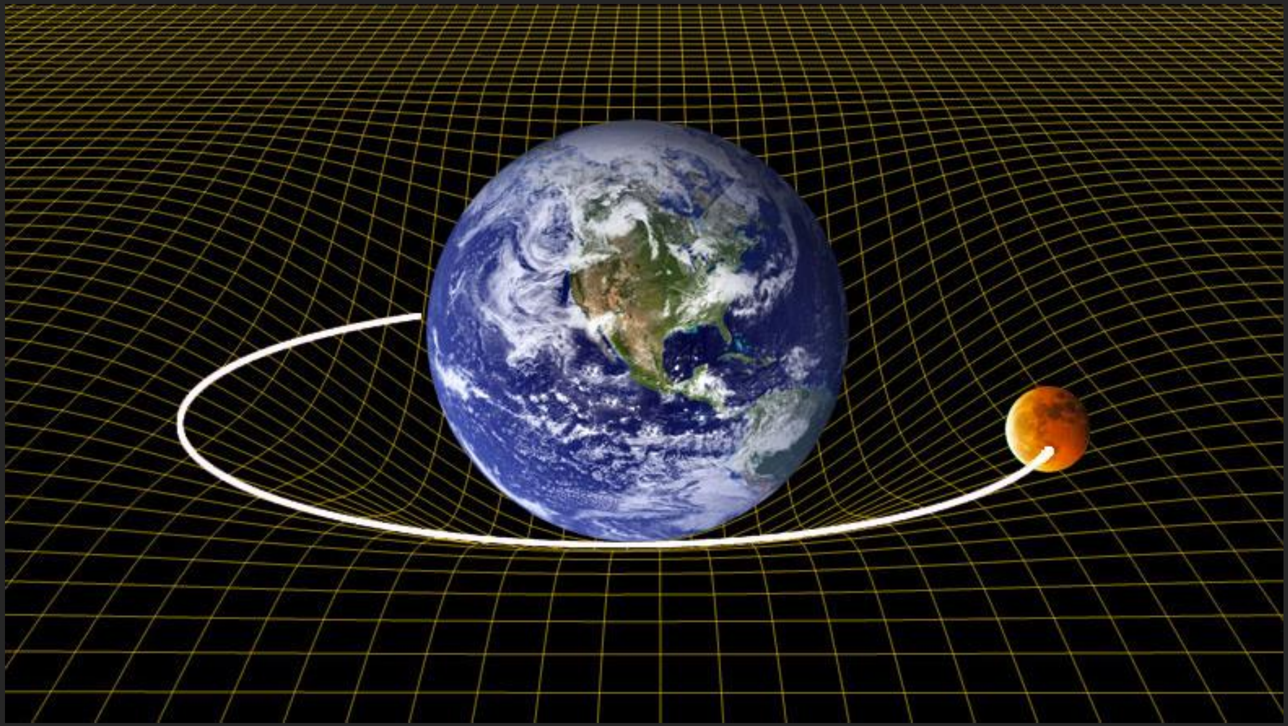


Today

Time

THE PROBLEM WITH GRAVITY

Gravity is described by General Relativity!
We currently don't have a quantum theory of gravity!



Problem in making a quantum theory of gravity due to something called renormalisation – infinities occur!

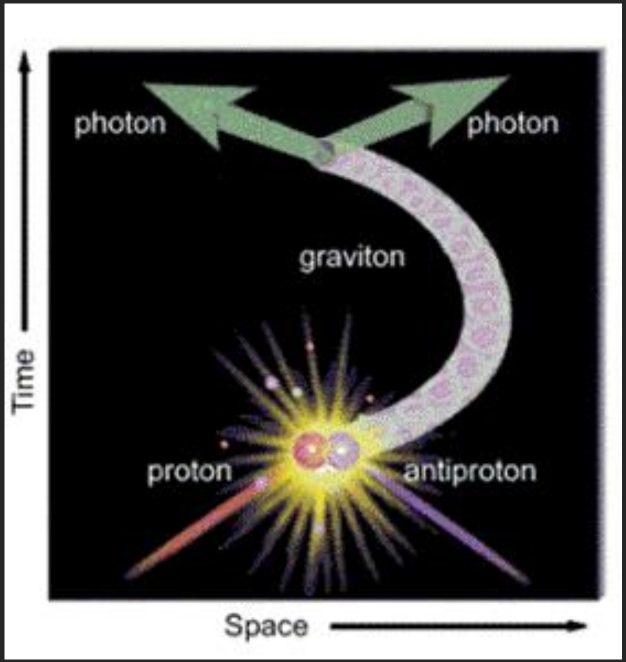
Other approaches include string theory and loop quantum gravity

THE PROBLEM WITH GRAVITY

Hypothetical force carrier for Gravity: **The Graviton**

- Graviton: spin 2 massless (tensor) boson
- Cross-section would be very low!

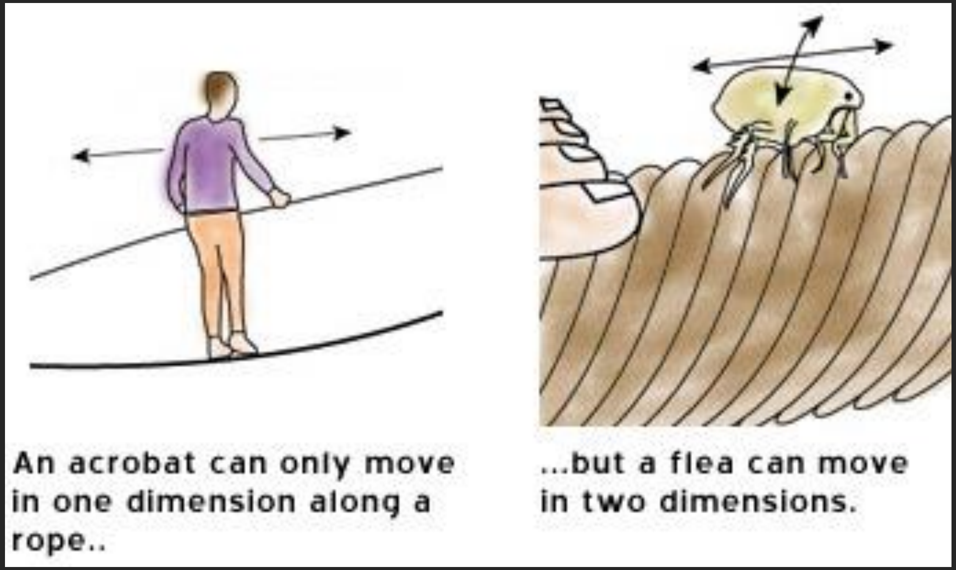
- ATLAS and CMS are still searching for it!

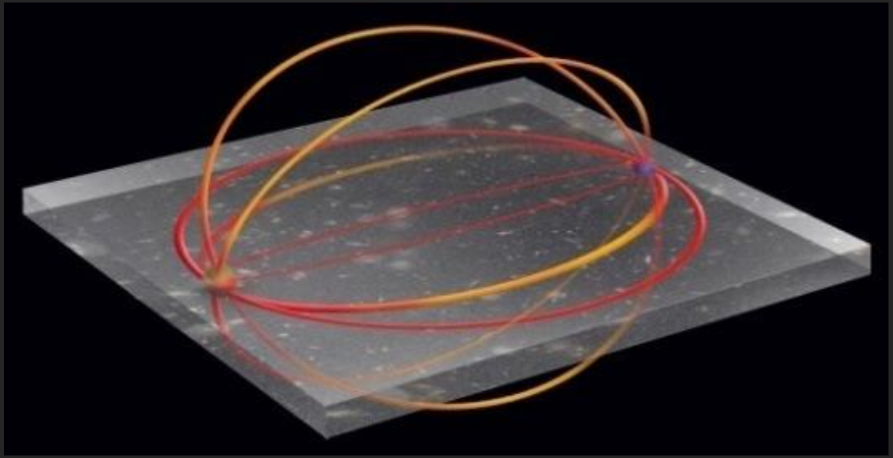


EXTRA DIMENSIONS?

Einstein's general theory of relativity tells us that space can expand, contract, and bend.

If one dimension were to contract to a size smaller than an atom, it would be hidden from our view.



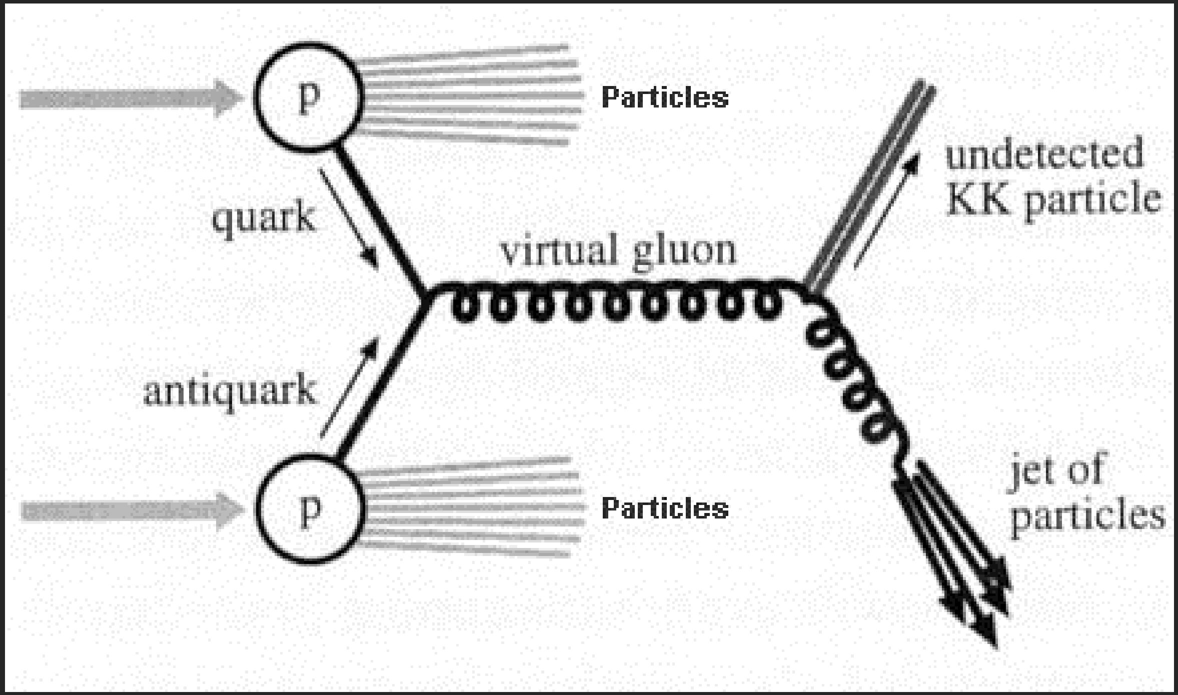


One possibility for gravity being so weak is because part of it spreads to extra dimensions

THE GRAVITON & EXTRA DIMENSIONS?

If gravitons exist, it should be possible to create them at the LHC, but they would rapidly disappear into extra dimensions.

Example – Graviton produced in association with a jet



The Graviton propagates in the extra dimensions

Only one jet of hadrons would be observed in our four-dimensional world.

We would see of monojet events at colliders.

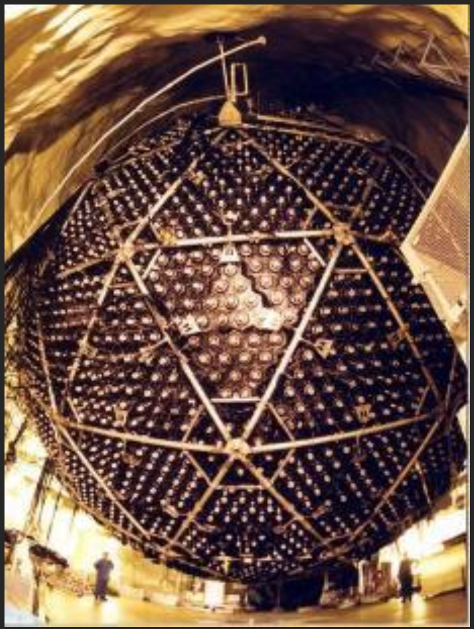
NEUTRINO MASSES

Neutrinos are the least understood particles in the standard model. They come in 3 flavours, were found to oscillate between these flavours in the 90's and 00's, indicating they have a **non-zero mass!**

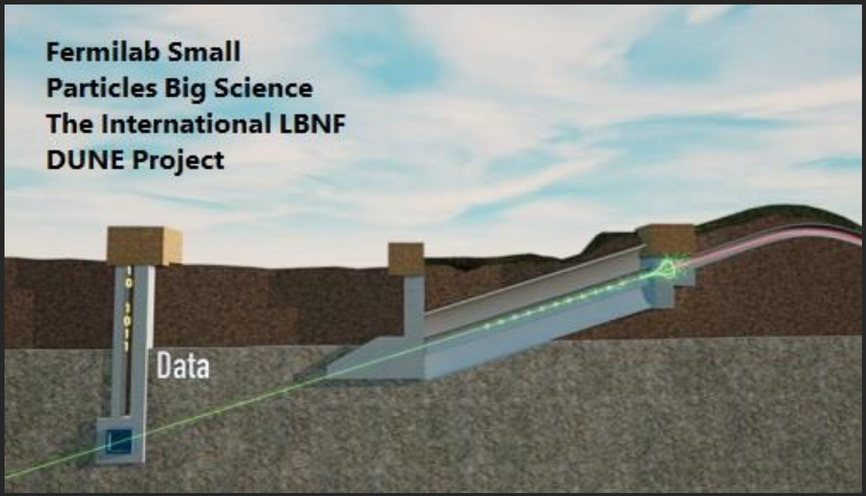
This is not predicted by the Standard Model.

Scientists are studying these elusive particles in numerous experiments.

T2K, Japan

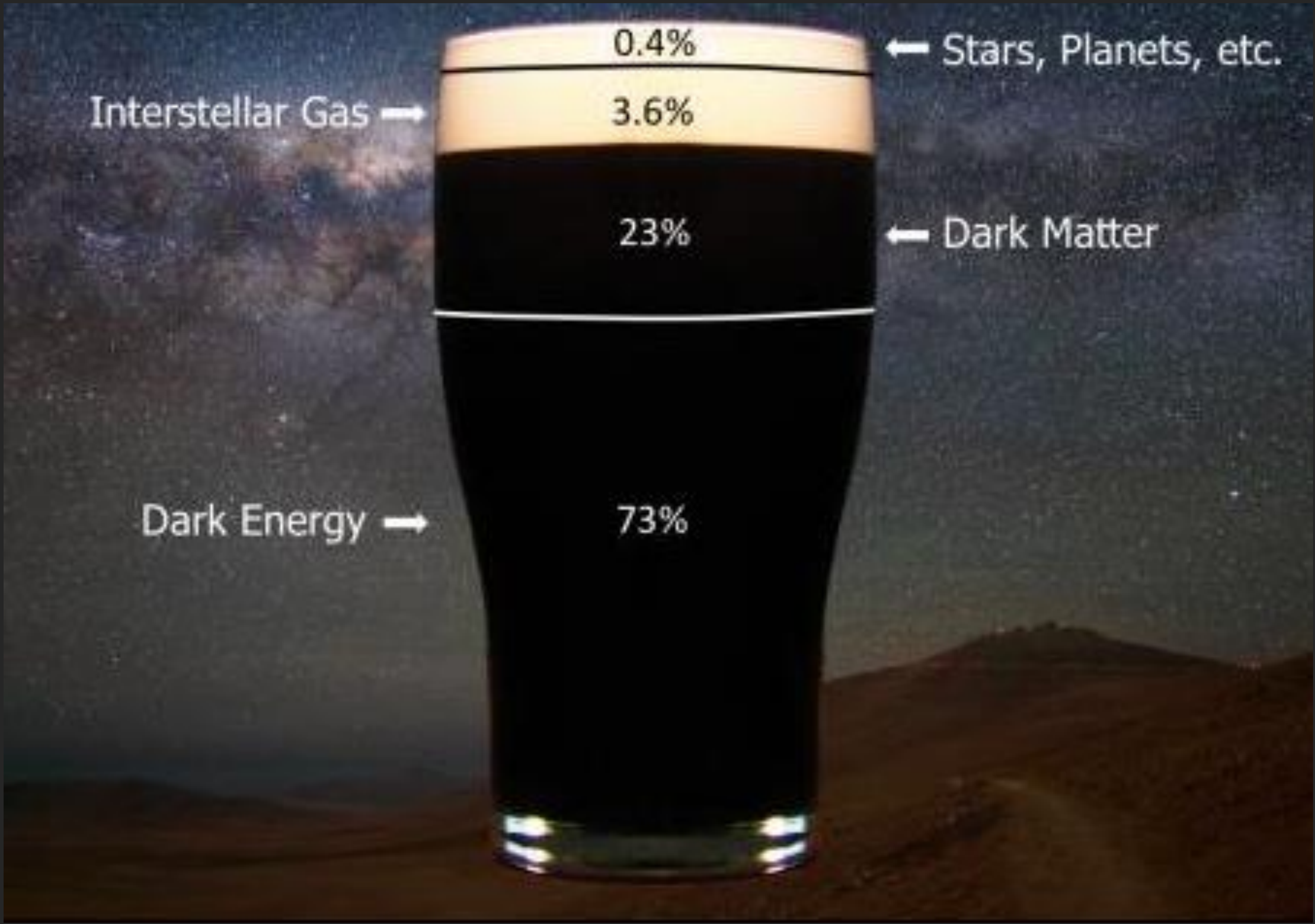


SNO+, Canada

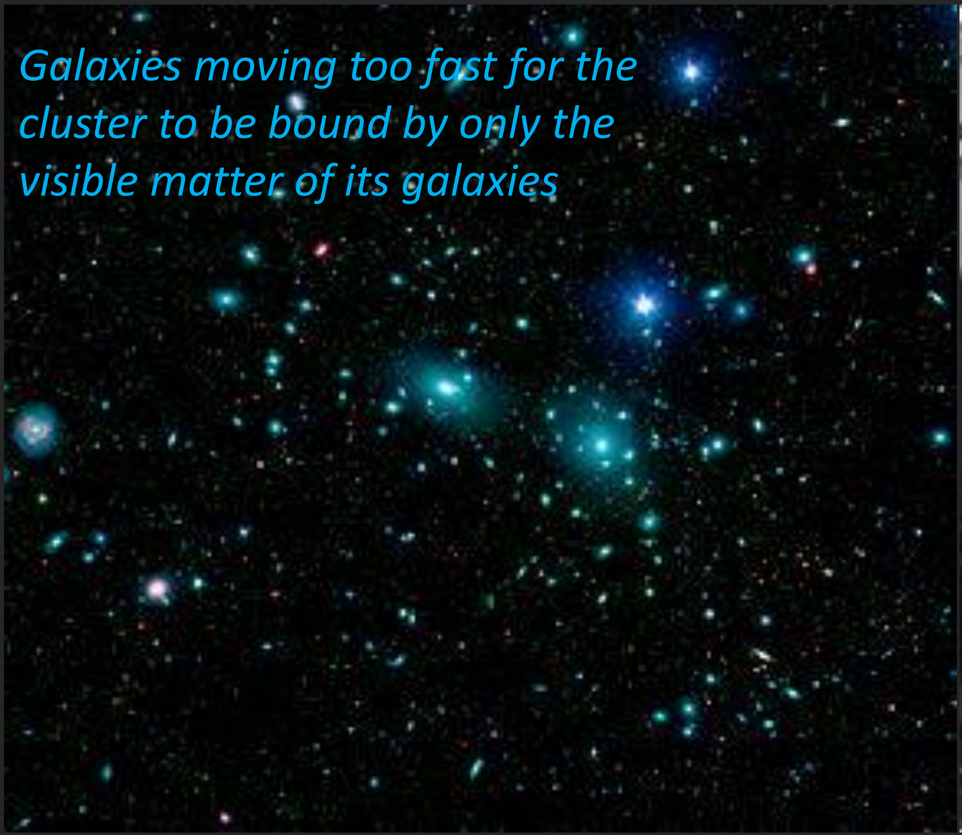


Dune, US

DARK ENERGY & DARK MATTER



DARK MATTER

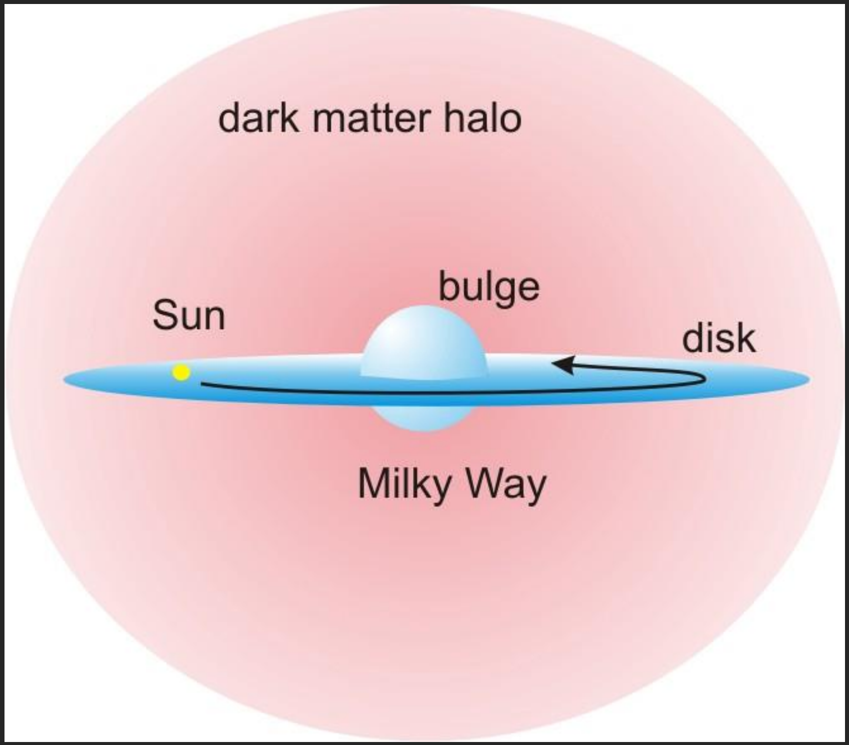


Coma Cluster, contains over 1000 identified galaxies, 321 million light years away from Earth, ~ 90 % dark matter

Fritz Zwicky, Swiss Astronomer
In 1933 inferred existence of *dunkle Materie*

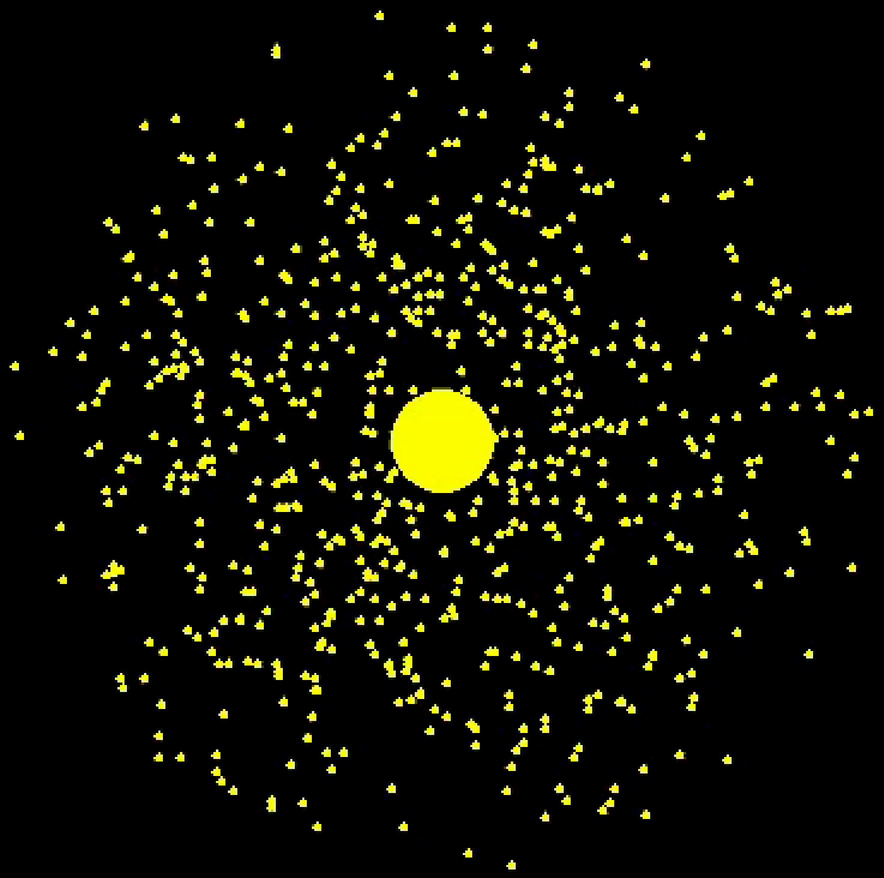
Galaxies must be held together by some dunkle Materie

DARK MATTER



1970s Vera Rubin: Investigated rotational curves of spiral galaxies

DARK MATTER



Galaxies must be held together by some dunkle Materie

DARK MATTER

By 1980 Dark Matter was widely recognised as an unsolved problem in astronomy

What do we know about dark matter?

- Its dark, it does not absorb, reflect or emit light! This means it does not interact with the electromagnetic force
- It interacts with Gravity

We know what it is *not*:

- clouds of normal matter without stars
- antimatter – which produces unique gamma rays when it interacts with normal matter
- made of black holes - as these are confined objects, dark matter is scattered

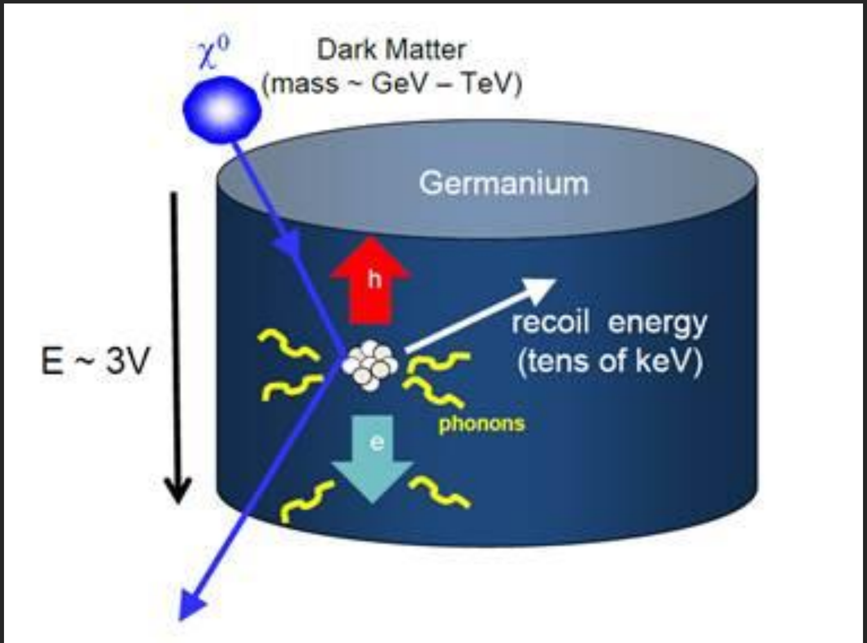
DARK MATTER

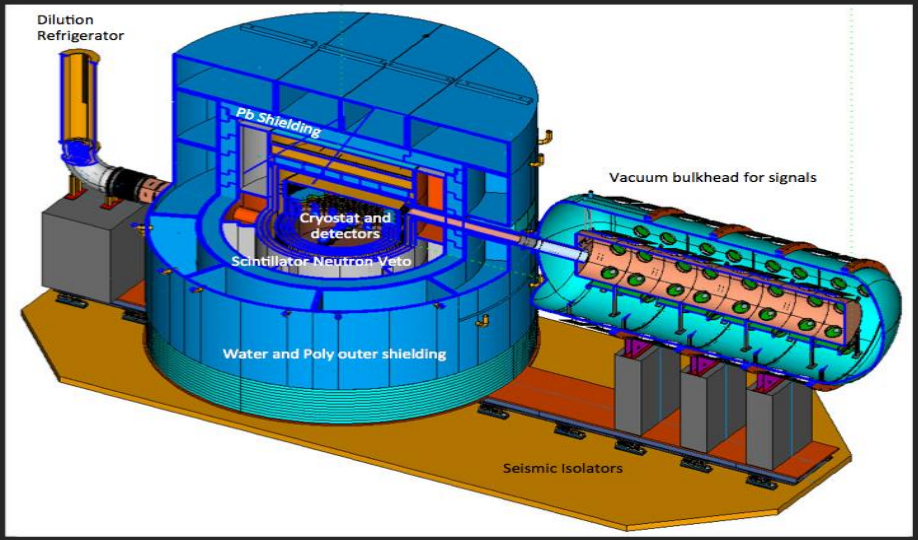
A heavy candidate is the WIMP: Weakly Interacting Massive Particles

- If not too massive these should be detectable at the LHC
- A theory named SUPERSYMMETRY which solves the hierarchy problem provides a neutral, heavy, weakly interacting particle, which is an ideal candidate for the WIMP!

Light candidates: Axion, Gravitino, light moduli, dilatons

BUT – nothing has been seen in direct searches!





Cryogenic Dark Matter Search (CDMS)

DARK MATTER

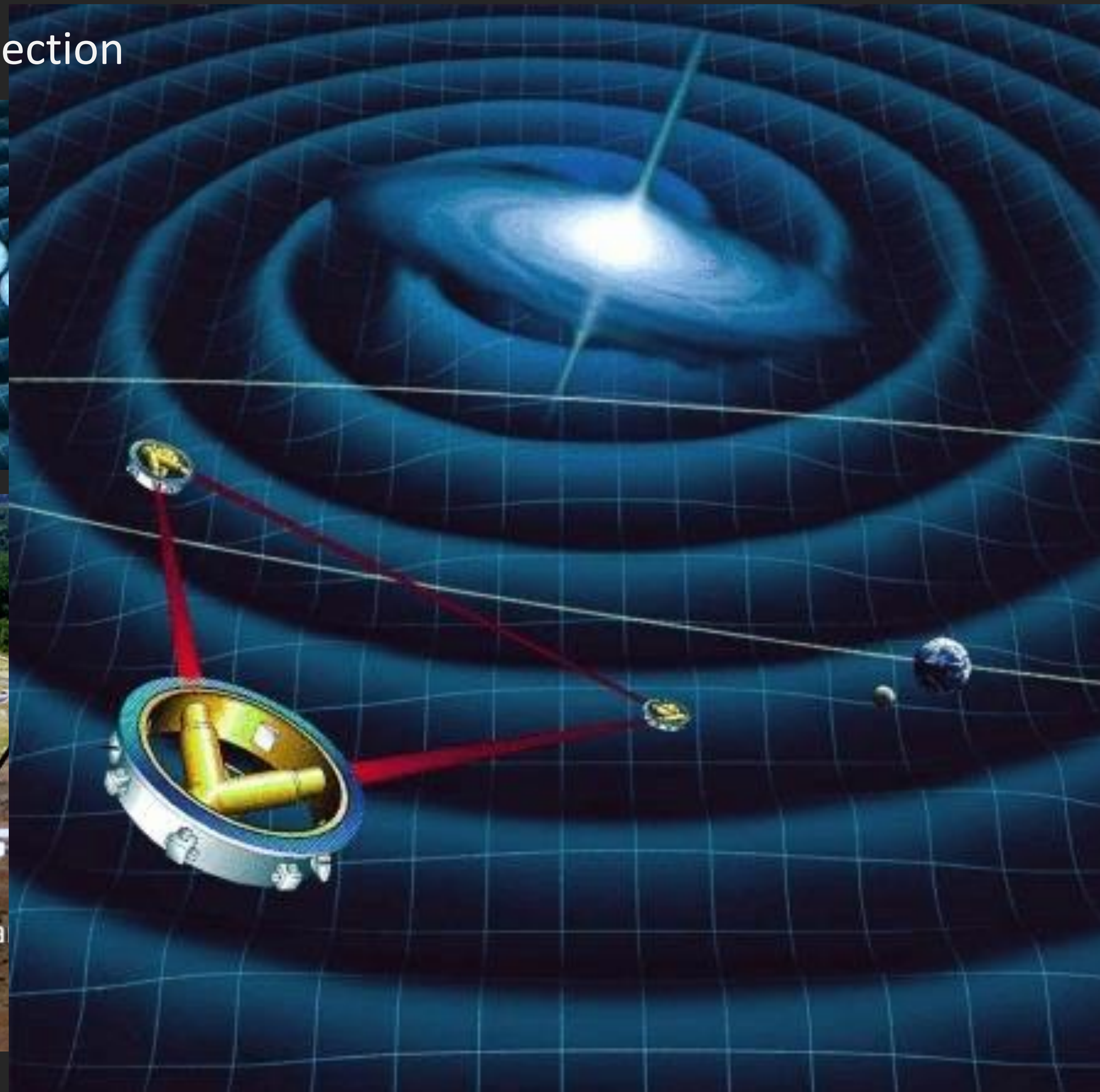
Asimina Arvanitaki, Stavros Niarchos Foundation Aristarchus Chair in Theoretical Physics at Perimeter Institute, Canada

- Suggests novel method to search for ultra light Dark Matter
- Using a type of gravitational wave detector (that use differential measurement of two atom interferometer)

arXiv:1606.04541

DARK MATTER

Gravitational wave detection

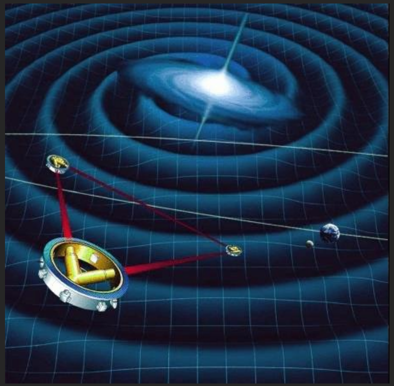


DARK MATTER

arXiv:1606.04541

Asimina Arvanitaki, Stavros Niarchos Foundation Aristarchus Chair in Theoretical Physics at Perimeter Institute, Canada

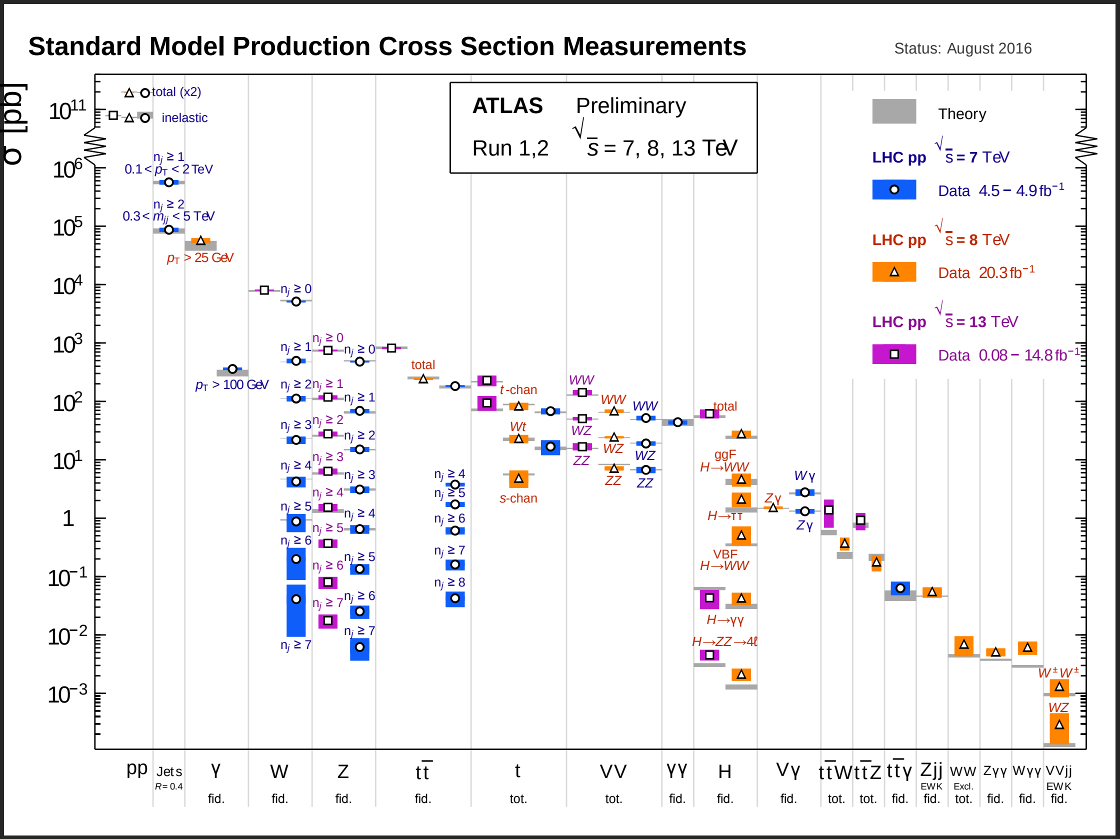
- Packed particles, specifically bosons, in a given space will overlap and begin to behave like a wave
- Ultra light dark matter can cause temporal oscillations in fundamental constants
- Frequency set by DM mass, amplitude set by local DM density



Looking for cracks in the SM

Testing Standard Model predictions at the LHC

Using the Higgs, the Top and others and a probe for New Physics!



Looking for cracks in the SM

Dirac famously predicted that, for electrons and muons, the factor relating the magnetic moment to spin would have a value of 2.

A recent measurement for the muon differs with a significance of 3.5σ

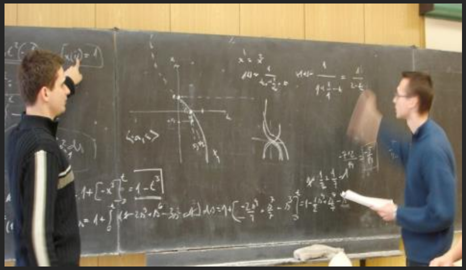
The muon g-2 experiment at Fermilab, US, aims to measure the anomalous magnetic moment of the muon to unprecedented accuracy

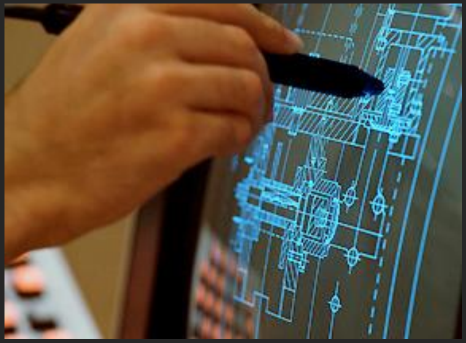
UK institutes include Liverpool, UCL, Lancaster, Oxford

Particle Physics for Society

Because particle physics asked BIG questions we need new unique and innovative ideas and equipment which has had a huge impact in society!

WORLD OF PARTICLE PHYSICS



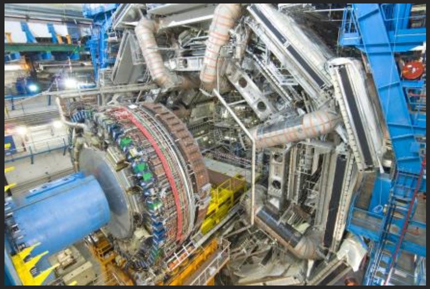


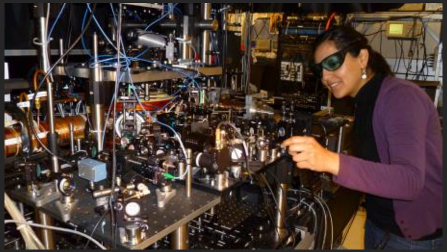
Fundamental Science

Applied Science

Technology, Engineering and Innovation

Sustainable Development

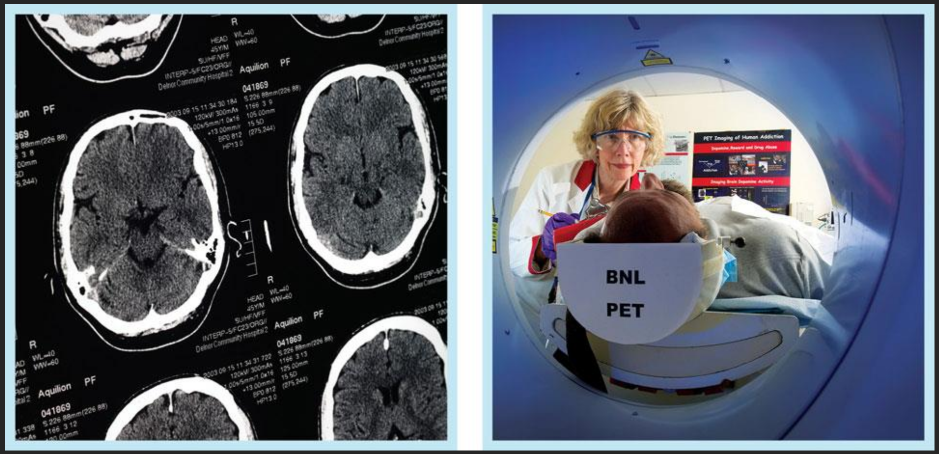




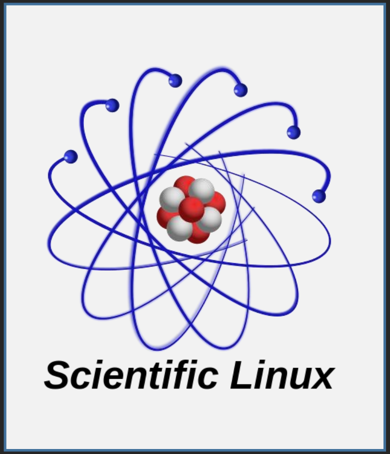
WORLD OF PARTICLE PHYSICS

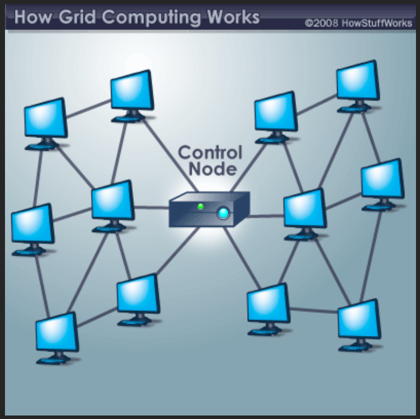
Technology

World Wide Web developed at CERN



MRI and PET





GRID Computing

WORLD OF PARTICLE PHYSICS

Education – physics/science undergraduates / PhDs

The need to solve environmental and developmental problems requires scientists

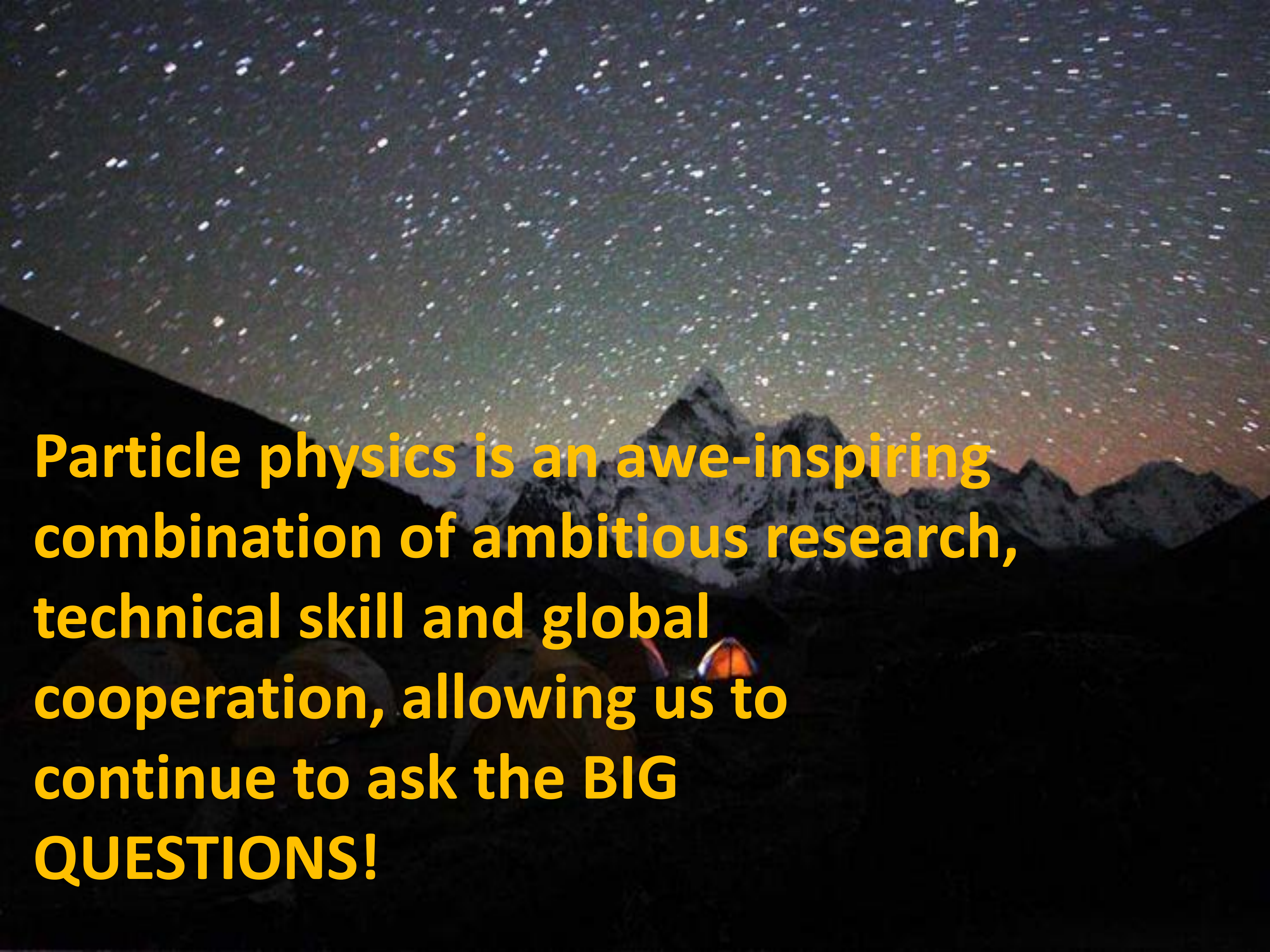
Education and investment into educational, technological and cultural institutions play a key role in growing a knowledge-based economy

Higher education, research and innovation fuel national development

WORLD OF PARTICLE PHYSICS

Education – Particle Physics can inspire young people!

Science teaches young people to think for themselves, ask questions, query assumptions!


Particle physics is an awe-inspiring combination of ambitious research, technical skill and global cooperation, allowing us to continue to ask the BIG QUESTIONS!

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THANK YOU