



# Why LHC?

Finding the hidden pieces at CERN



A night sky with the Milky Way galaxy and a desert landscape with sand dunes. The Milky Way is visible as a bright, cloudy band of stars across the upper half of the image. The desert landscape is in the foreground, with sand dunes and a dark horizon line. The overall scene is dark and starry.

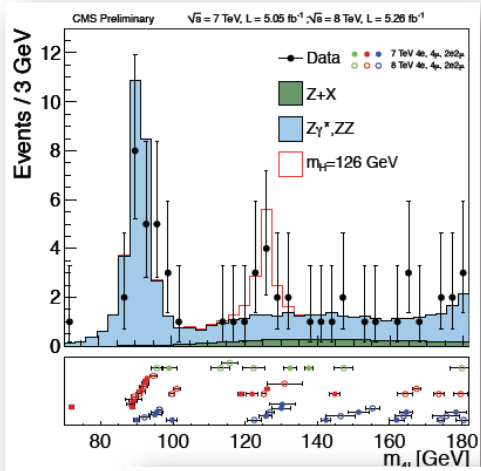
## **Warning:**

This talk contains actual facts. It might not be convenient for audiences who prefer “alternative facts” or outright lies. Follow at your own risk.

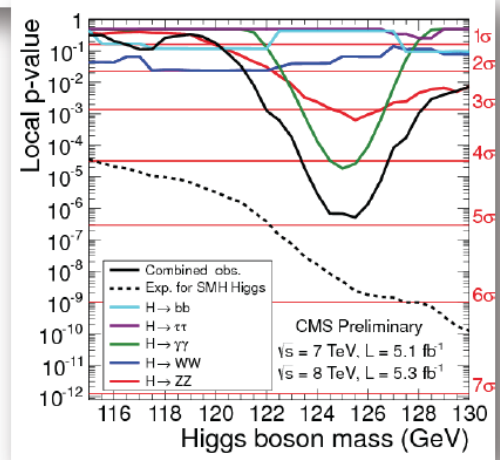
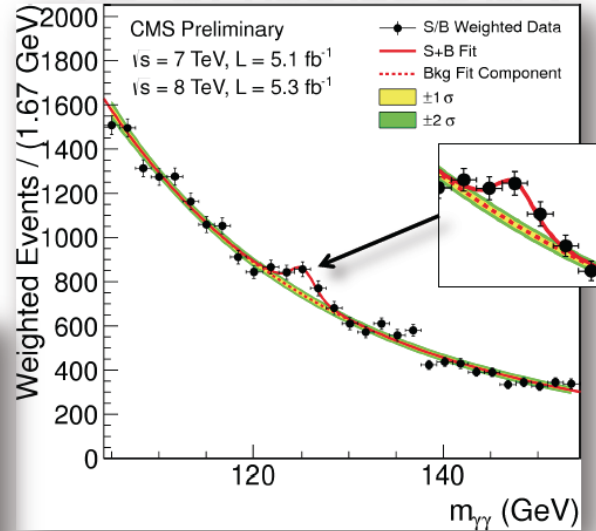




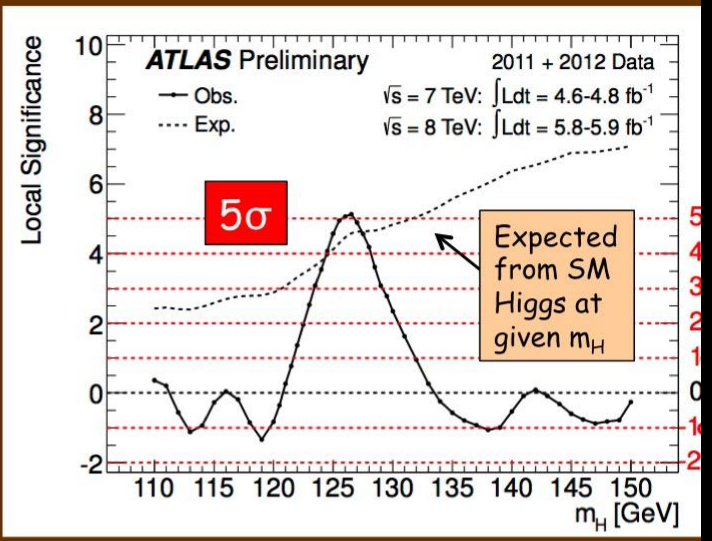
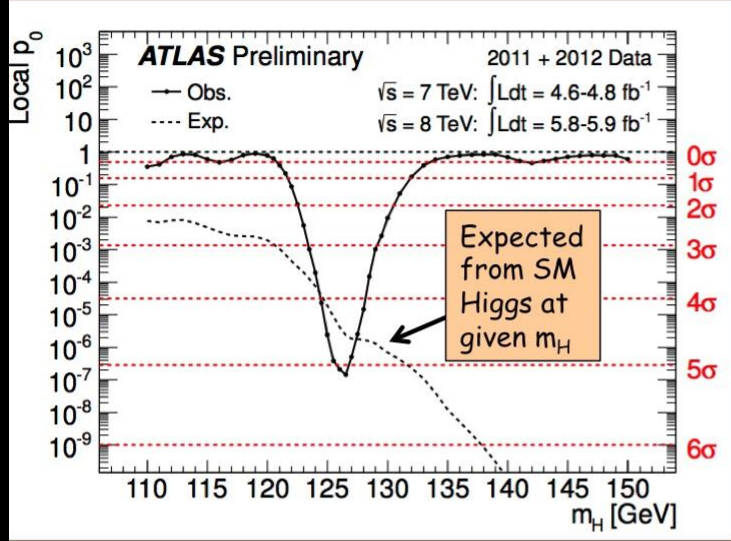
Physics Seminar – 4 July 2012



# In summary



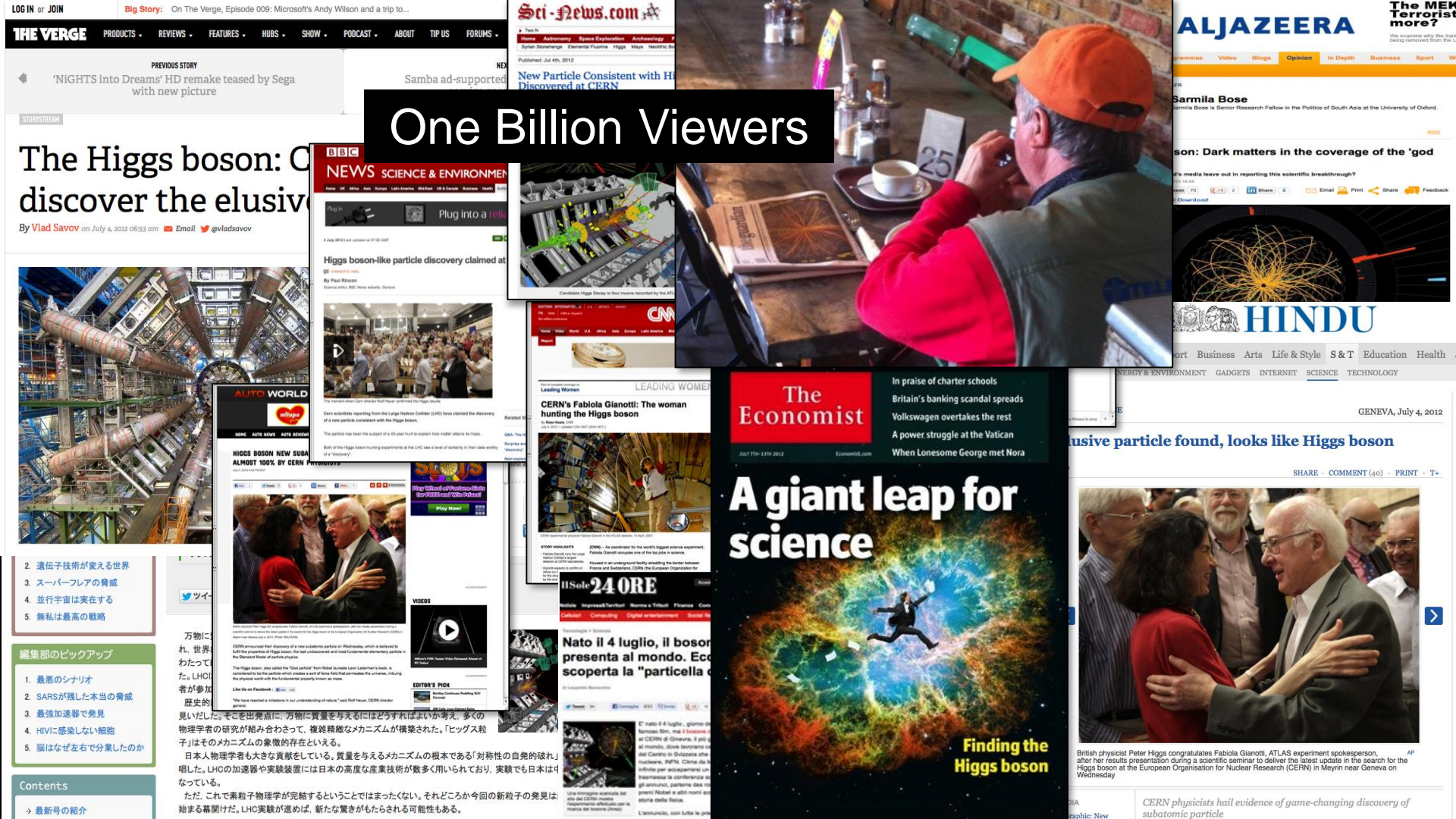
# Combined results: the excess



Maximum excess observed at	$m_H = 126.5 \text{ GeV}$
Local significance (including energy-scale systematics)	$5.0 \sigma$
Probability of background up-fluctuation	$3 \times 10^{-7}$
Expected from SM Higgs $m_H=126.5$	$4.6 \sigma$

Global significance: 4.1-4.3  $\sigma$  (for LEE over 110-600 or 110-150 GeV)





# One Billion Viewers

## The Higgs boson: CERN discover the elusive particle

By Vlad Savov on July 4, 2012 06:53 am



- 2. 遠伝子技術が変える世界
- 3. スーパーリアの育成
- 4. 並行宇宙は実在する
- 5. 無私は最高の戦略

- ### 編集部ピックアップ
- 1. 最悪のシナリオ
  - 2. SARSが残した本当の脅威
  - 3. 最強加速器で発見
  - 4. HIVに感染しない細胞
  - 5. 脳はなぜ左右で分業したのか

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### BBC NEWS SCIENCE & ENVIRONMENT

Plug into a robot

4 July 2012, Last updated at 07:38 GMT

#### Higgs boson-like particle discovery claimed at CERN

By Paul Rincon



CERN scientists reporting from the Large Hadron Collider (LHC) have claimed the discovery of a new particle consistent with the Higgs boson.

The particle has been the subject of a 48-year hunt to explain how matter gets its mass.

Most of the Higgs boson hunting experiments at the LHC use a beam of protons in their data search.



### HIGGS BOSON NEW SUBA ALMOST 100% BY CERN

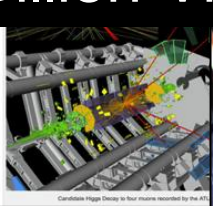
by anandkumar

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万物に力、世界を動かす。それが重力だ。重力は質量と関係している。LHCの発見が、歴史的な発見だ。それを出発点に、万物に質量を与えるにはどうすればよいか考え、多くの物理学者の研究が組み合わさって、複雑精緻なメカニズムが構築された。「ヒッグス粒子」はそのメカニズムの象徴的存在といえる。

日本人物理学者も大きな貢献をしている。質量を与えるメカニズムの根本である「対称性の自発的破れ」を唱じた。LHCの加速器や実験装置には日本の高度な産業技術が数多く用いられており、実験でも日本は欠かせない。

ただ、これで素粒子物理学が完結するということではまったくない。それどころか今回の新粒子の発見は、ただ幕開けだ。LHC実験が進めば、新たな驚きもたらされる可能性もある。



### Leading Women

#### CERN's Fabiola Gianotti: The woman hunting the Higgs boson

By Sarah Lyall



### Il Sole 24 ORE

#### Nato il 4 luglio, il bosone presenta al mondo. Ecco scoperta la "particella di Dio"



Il 4 luglio, giorno del Ferragosto, ma il bosone di Dio, il bosone di Higgs, è stato scoperto. Il bosone di Higgs è la particella che conferisce massa alle particelle elementari. È stato scoperto al CERN di Ginevra, il più grande acceleratore di particelle del mondo. Il bosone di Higgs è stato scoperto in un esperimento che ha coinvolto 30.000 scienziati di 40 paesi. Il bosone di Higgs è stato scoperto in un esperimento che ha coinvolto 30.000 scienziati di 40 paesi. Il bosone di Higgs è stato scoperto in un esperimento che ha coinvolto 30.000 scienziati di 40 paesi.



### The Economist

July 7th - 13th 2012

#### A giant leap for science



### Finding the Higgs boson



### The Economist

July 7th - 13th 2012

#### In praise of charter schools

#### Britain's banking scandal spreads

#### Volkswagen overtakes the rest

#### A power struggle at the Vatican

#### When Lonesome George met Nora



### The Economist

July 7th - 13th 2012

#### In praise of charter schools

#### Britain's banking scandal spreads

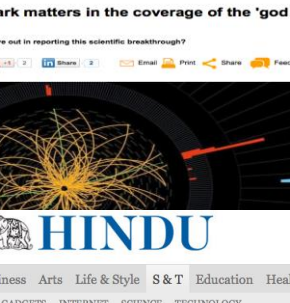
#### Volkswagen overtakes the rest

#### A power struggle at the Vatican

#### When Lonesome George met Nora



British physicist Peter Higgs congratulates Fabiola Gianotti, ATLAS experiment spokesperson, after her results presentation during a scientific seminar to deliver the latest update in the search for the Higgs boson at the European Organisation for Nuclear Research (CERN) in Meyrin near Geneva on Wednesday



### ALJAZEERA

son: Dark matters in the coverage of the 'god particle'



### HINDU


GENEVA, July 4, 2012

#### Disruptive particle found, looks like Higgs boson

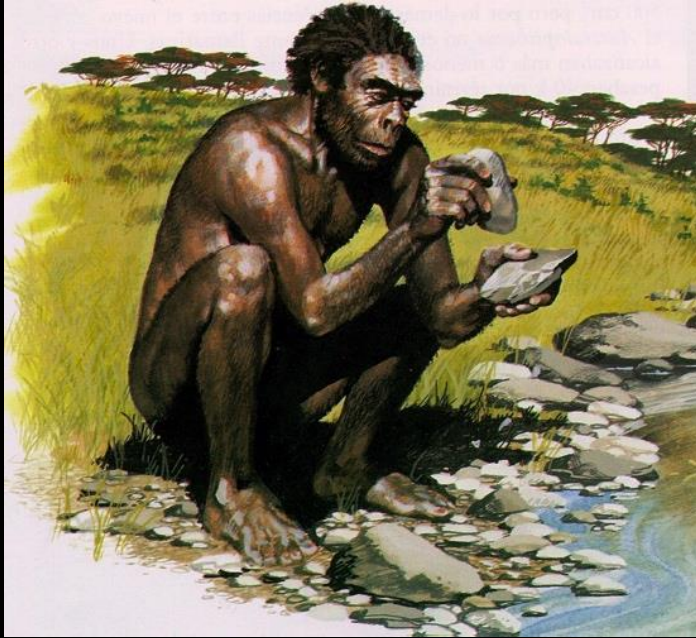
SHARE · COMMENT (40) · PRINT · T+

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



A wide-angle photograph of a night sky over a desert landscape. The Milky Way galaxy is visible as a bright, horizontal band of stars and dust stretching across the upper half of the frame. The sky is filled with numerous individual stars. In the foreground, the dark, undulating dunes of a desert are visible, with a small, dark structure or building on a ridge in the distance. The overall scene is dark and atmospheric.

Why?



Physics Seminar – 4 July 2000012 BCE



A night sky filled with stars, with the Milky Way galaxy visible as a bright, cloudy band of light stretching across the upper half of the frame. Below the sky, the dark, rolling dunes of a desert landscape are visible under the starlight.

The Big Questions:



A night sky filled with stars, with the Milky Way galaxy visible as a bright, cloudy band of light stretching across the upper half of the frame. Below the sky, the dark, rolling dunes of a desert landscape are visible under the starlight.

Where do we come from?



A night sky filled with stars, with the Milky Way galaxy visible as a bright, cloudy band of light stretching across the upper half of the frame. The foreground shows the dark, rolling dunes of a desert landscape under a starry sky.

What are we made of ?



A night sky with the Milky Way galaxy and a desert landscape. The Milky Way is visible as a bright, cloudy band of stars stretching across the upper half of the frame. The sky is filled with numerous individual stars. In the foreground, the dark, silhouetted ridges of sand dunes are visible against the starry background.

What is our destiny?



A wide-angle photograph of a night sky over a desert landscape. The Milky Way galaxy is prominently visible, stretching across the upper half of the frame. The stars are sharp and numerous, with some brighter stars standing out. The foreground shows the dark, undulating dunes of a desert, with a small, dark silhouette of a building or structure on a ridge in the distance. The overall scene is dark and serene, capturing the vastness of the universe.

What are the rules behind all this?



A night sky with the Milky Way galaxy visible over a desert landscape. The Milky Way is a dense band of stars and dust stretching across the upper half of the frame. The foreground shows dark, rolling sand dunes under a starry sky.

Is there anything else we don't see?



A wide-angle photograph of a night sky over a desert landscape. The Milky Way galaxy is prominently visible, stretching across the upper half of the frame. The stars are sharp and numerous, with some appearing as bright blue or white points. The foreground shows the dark, undulating silhouettes of sand dunes under a deep blue twilight sky. The overall scene is serene and awe-inspiring, capturing the vastness of the universe.

Our first scientific instrument





Photo: Eric Wiessner CC-BY-SA



Human Hair (15cm away)



Photo: Steven Goldfarb, CC-BY-SA

Andromeda (2.5 million light years away)



Photo: Thomas Bresson, CC-BY-SA



Good enough?



Never!

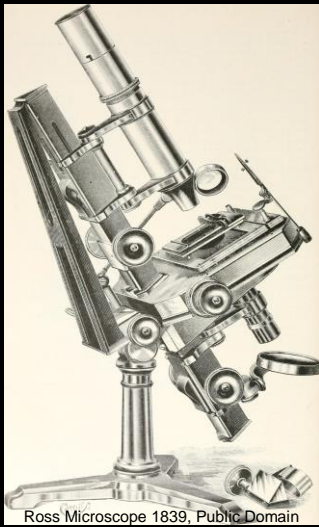




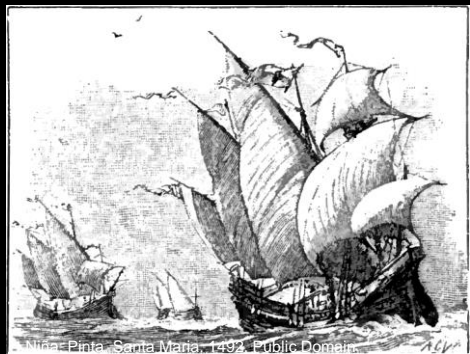
How do we measure what we can't see?



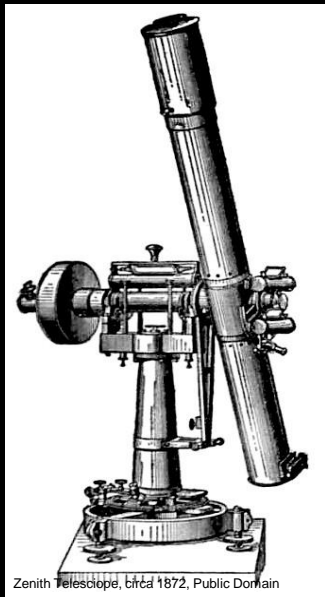
# Exploration



Ross Microscope 1839, Public Domain



Niña Pinta, Santa Maria, 1492, Public Domain



Zenith Telescopio, circa 1872, Public Domain

# Extrapolation



Plato in his academy, circa 400 BCE, Public Domain

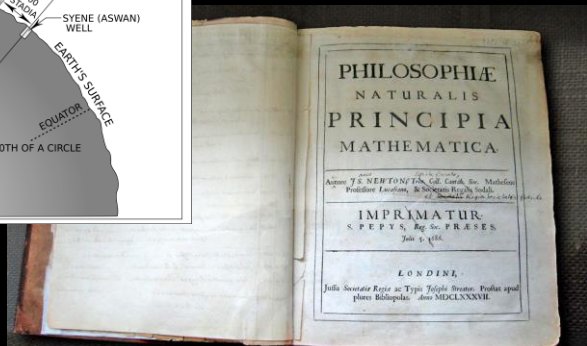
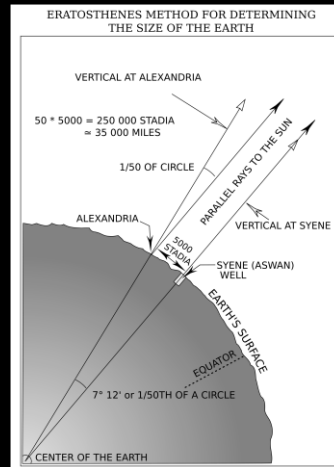
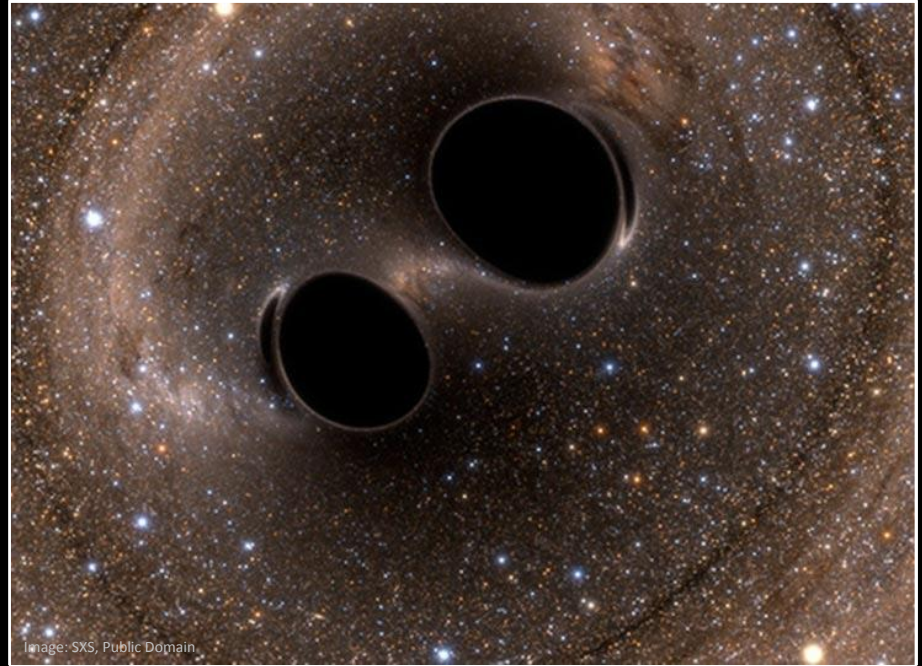
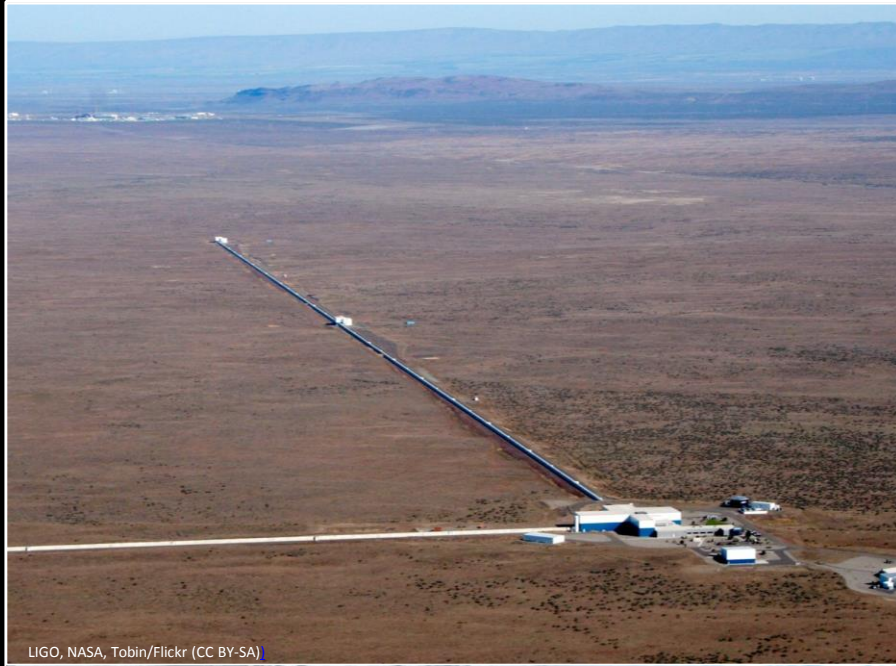


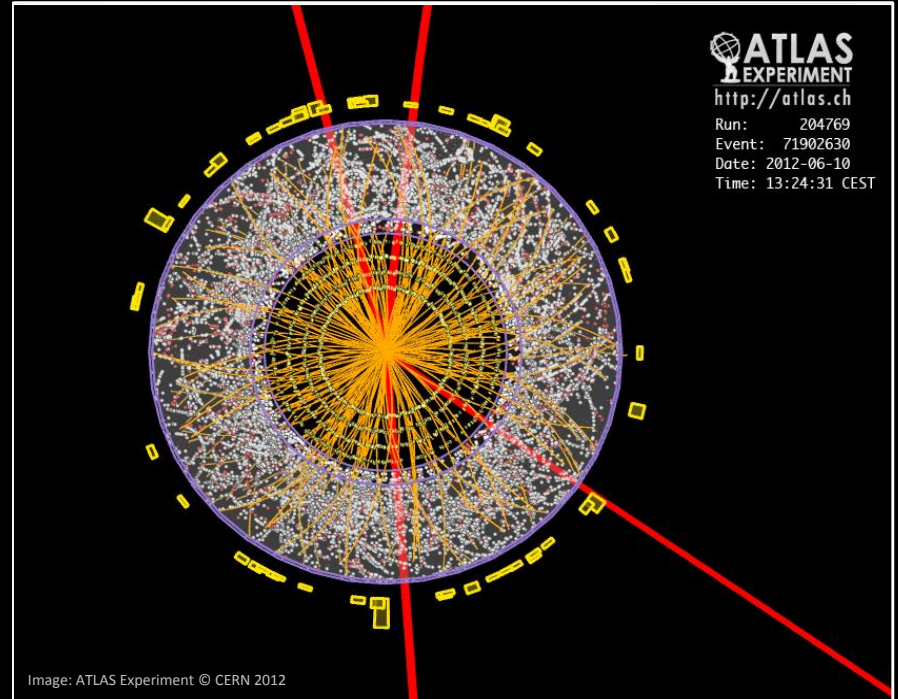
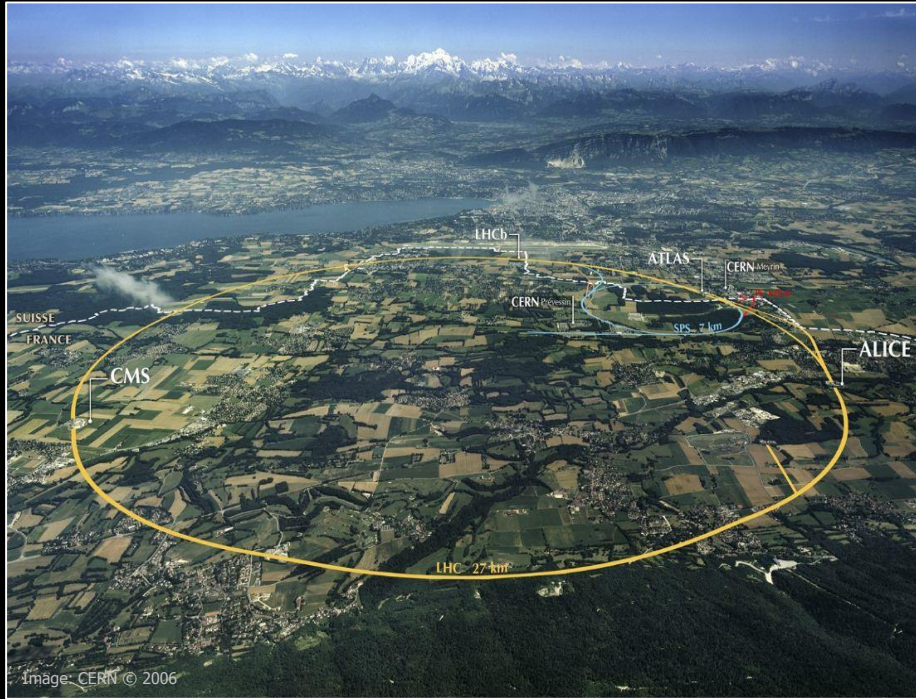
Photo © Andrew Dunn, CC-BY-SA

# Looking out





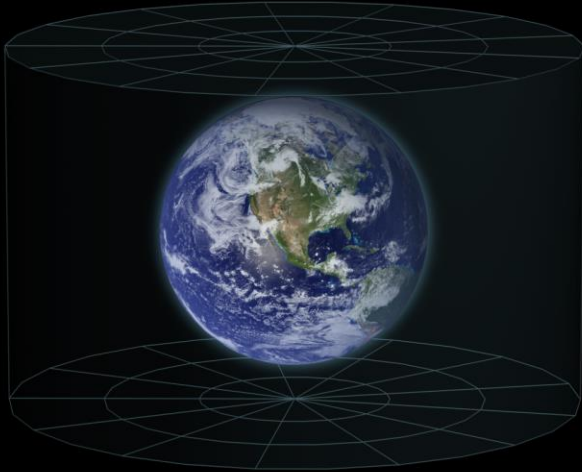
# Looking in



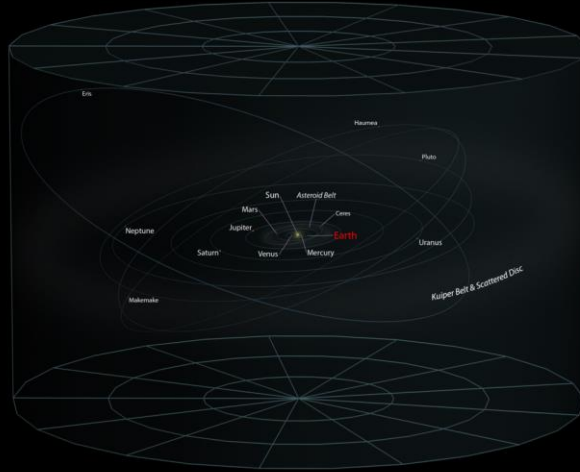
What have we learned?



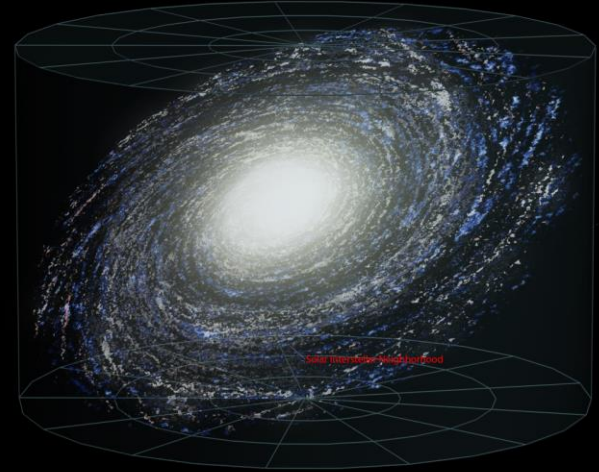
# EARTH



# SOLAR SYSTEM



# MILKY WAY GALAXY



Images: Andrew Z. Colvin, CC-BY-SA

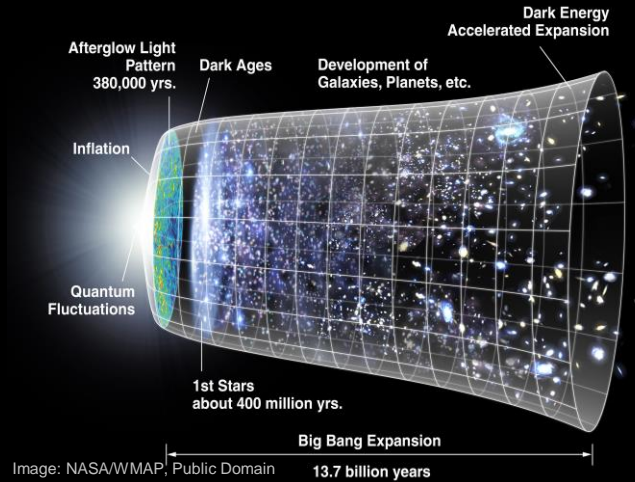


Image: NASA/WMAP, Public Domain

# CELL

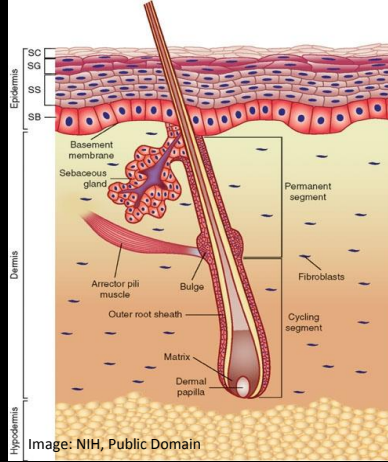


Image: NIH, Public Domain

# MOLECULE

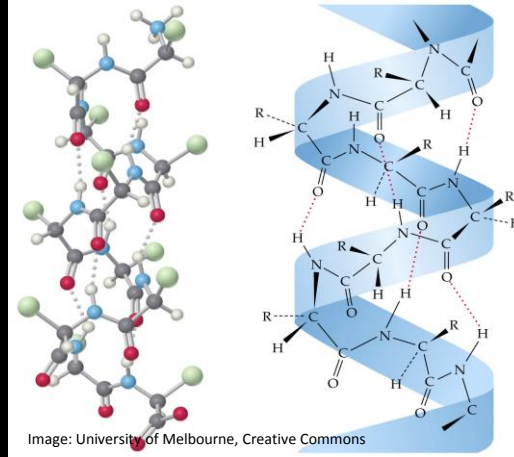


Image: University of Melbourne, Creative Commons

# ATOM

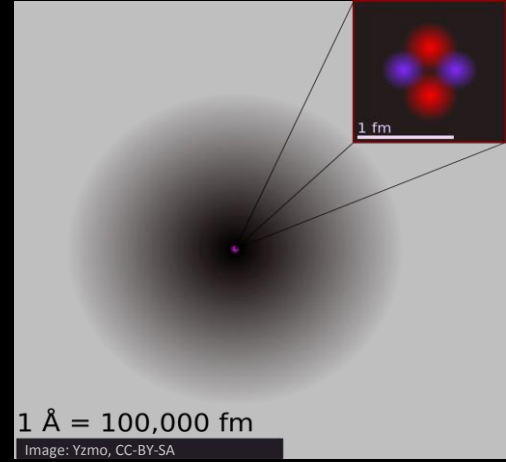


Image: Yzmo, CC-BY-SA

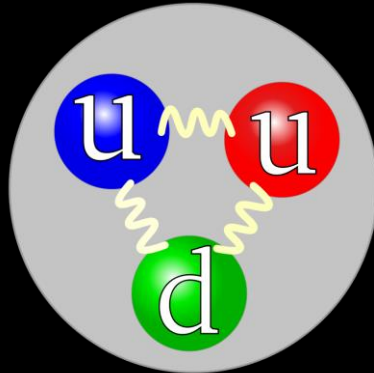



Image: Arpad Horvath, CC-BY-SA

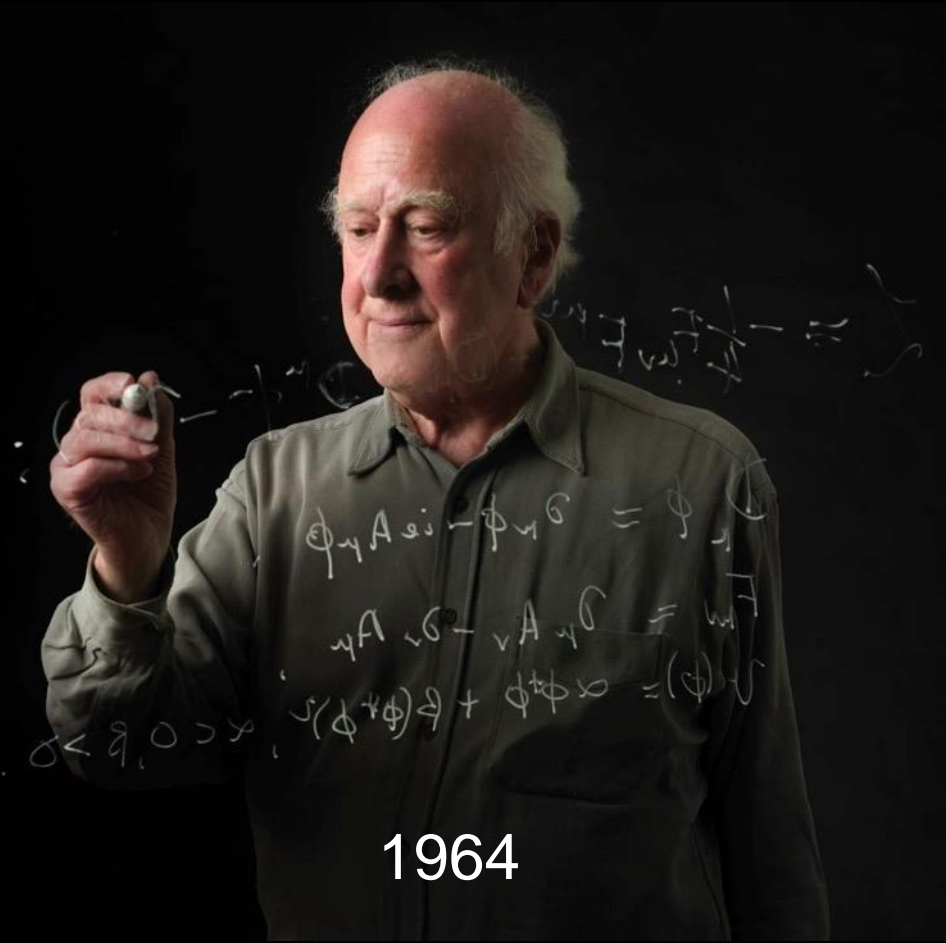
	mass	charge	spin	
QUARKS	~2.4 MeV/c <sup>2</sup>	2/3	1/2	<b>u</b> up
	~1.275 GeV/c <sup>2</sup>	2/3	1/2	<b>c</b> charm
	~172.44 GeV/c <sup>2</sup>	2/3	1/2	<b>t</b> top
	~4.8 MeV/c <sup>2</sup>	-1/3	1/2	<b>d</b> down
	~95 MeV/c <sup>2</sup>	-1/3	1/2	<b>s</b> strange
	~4.18 GeV/c <sup>2</sup>	-1/3	1/2	<b>b</b> bottom
LEPTONS	0	0	1	<b>g</b> gluon
	0	0	1	<b>γ</b> photon
	~0.511 MeV/c <sup>2</sup>	-1	1/2	<b>e</b> electron
	~105.67 MeV/c <sup>2</sup>	-1	1/2	<b>μ</b> muon
	~1.7768 GeV/c <sup>2</sup>	-1	1/2	<b>τ</b> tau
	~91.19 GeV/c <sup>2</sup>	0	1	<b>Z</b> Z boson
GAUGE BOSONS	0	0	1	<b>W</b> W boson
	<2.2 eV/c <sup>2</sup>	0	1/2	<b>ν<sub>e</sub></b> electron neutrino
	<1.7 MeV/c <sup>2</sup>	0	1/2	<b>ν<sub>μ</sub></b> muon neutrino
	<15.5 MeV/c <sup>2</sup>	0	1/2	<b>ν<sub>τ</sub></b> tau neutrino



A wide-angle photograph of a night sky over a desert landscape. The Milky Way galaxy is visible as a bright, horizontal band of stars and dust stretching across the upper half of the frame. The foreground shows dark, rolling sand dunes under a starry sky. The text "Why mass?" is centered in the middle of the image.

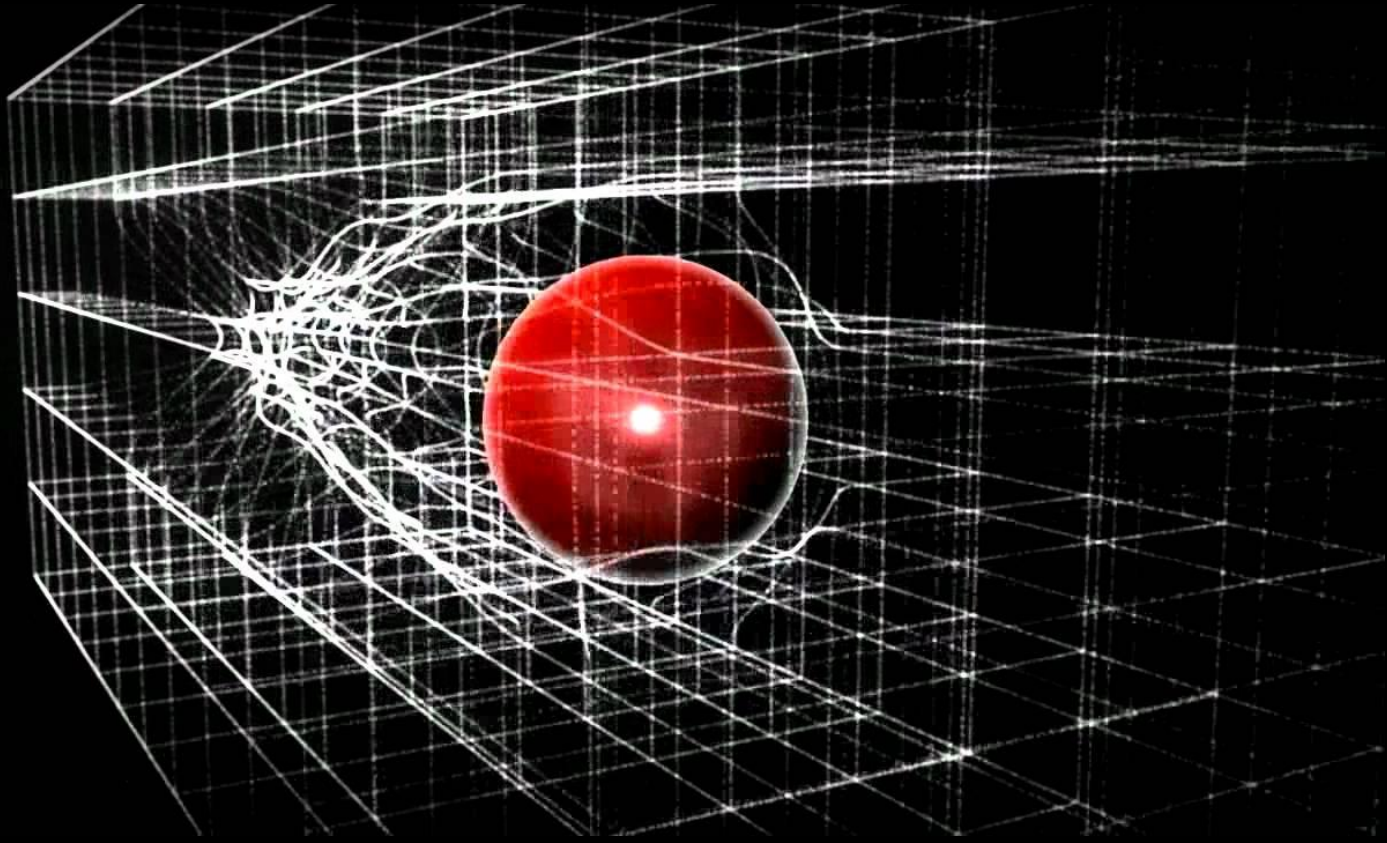
Why mass?

# How do fundamental particles attain mass?



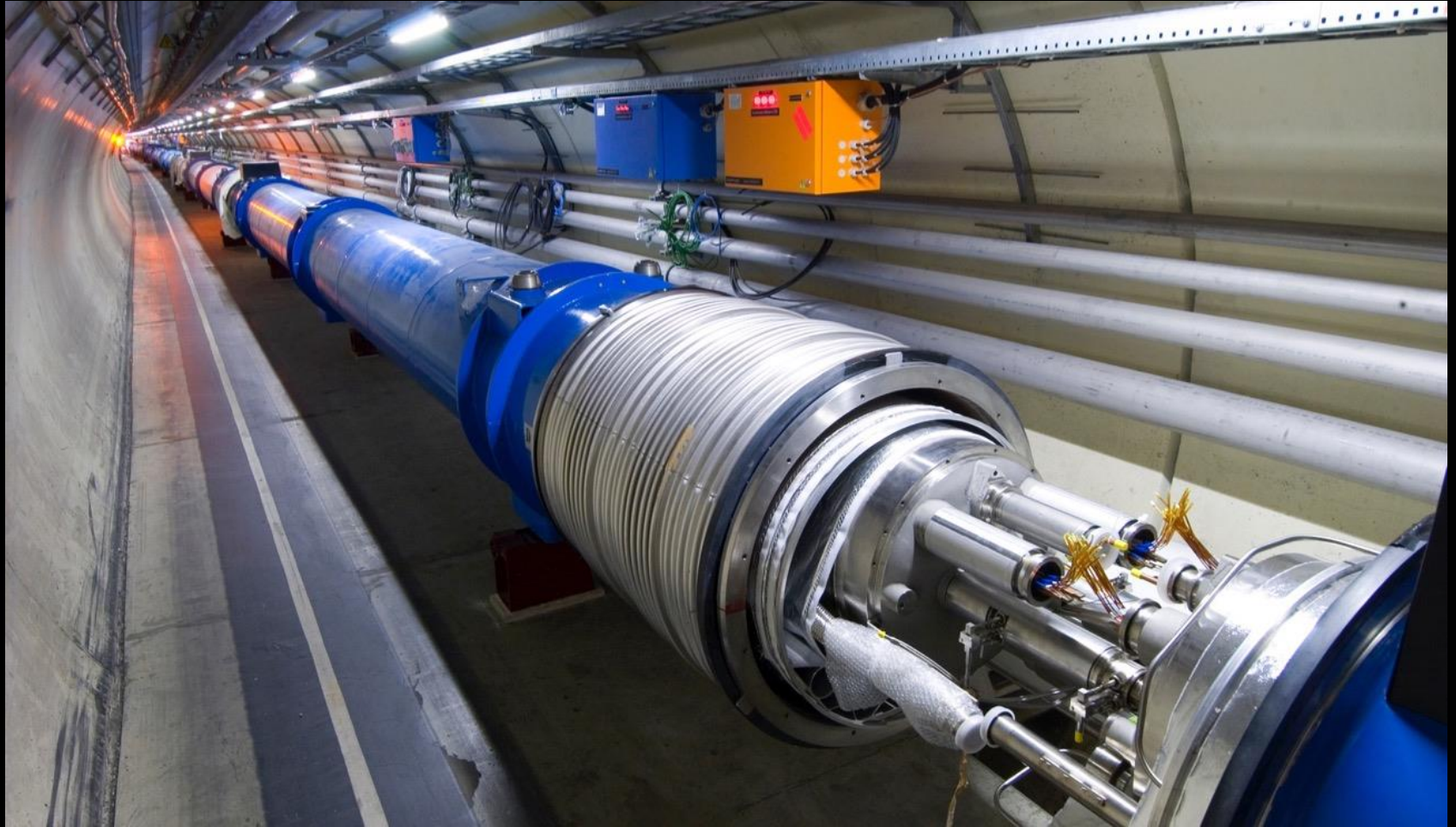
1964





The Brout-Englert-Higgs Mechanism

# The Large Hadron Collider at CERN





# The Large Hadron Collider at CERN



**CMS**

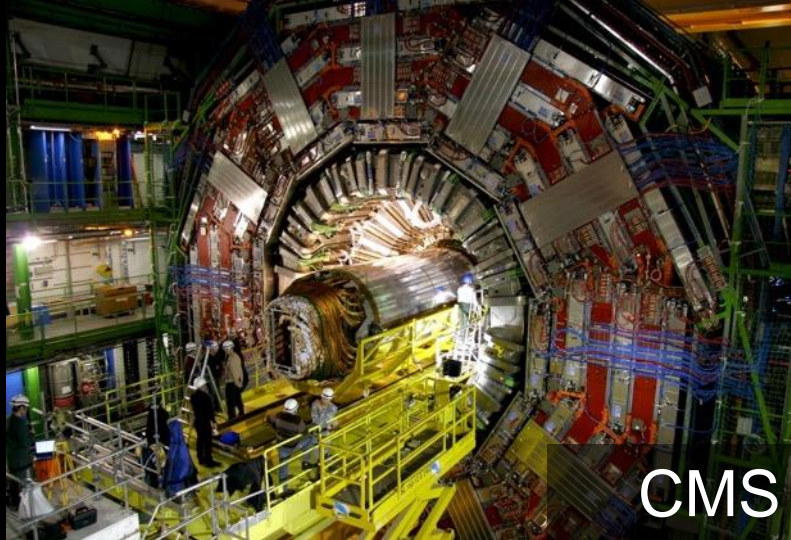
27 km

**ALICE**

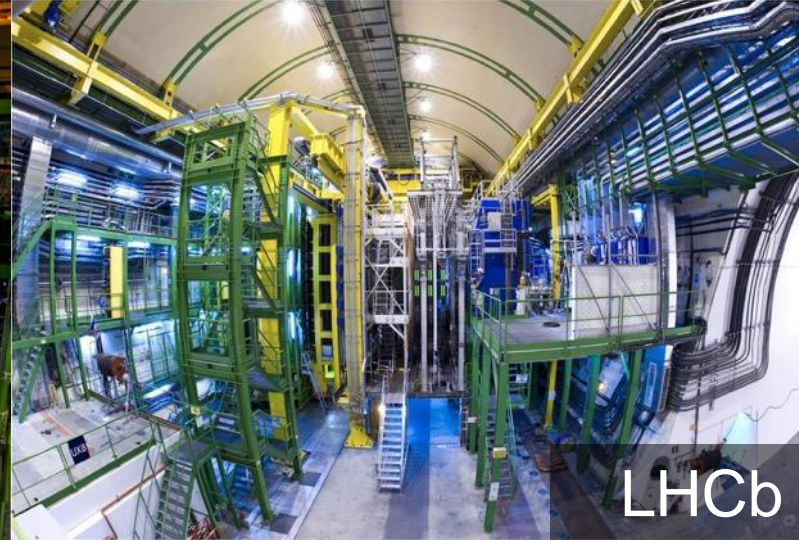
**ATLAS**

**LHCb**





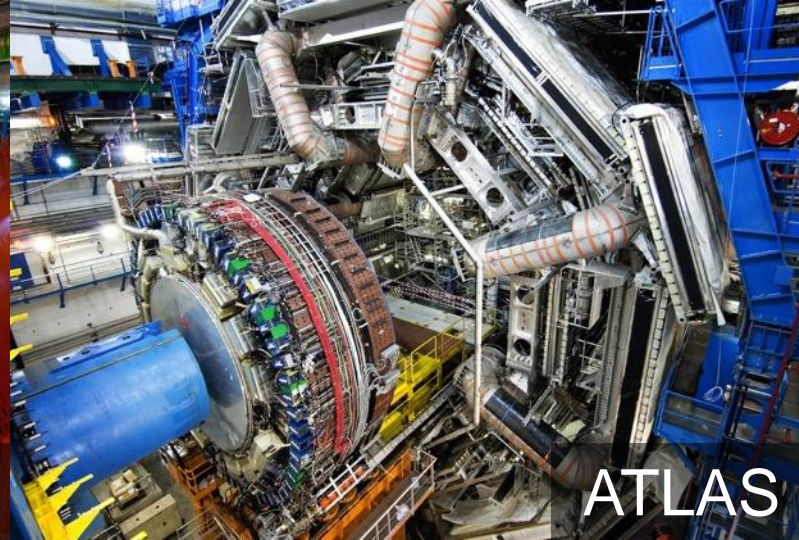
CMS



LHCb



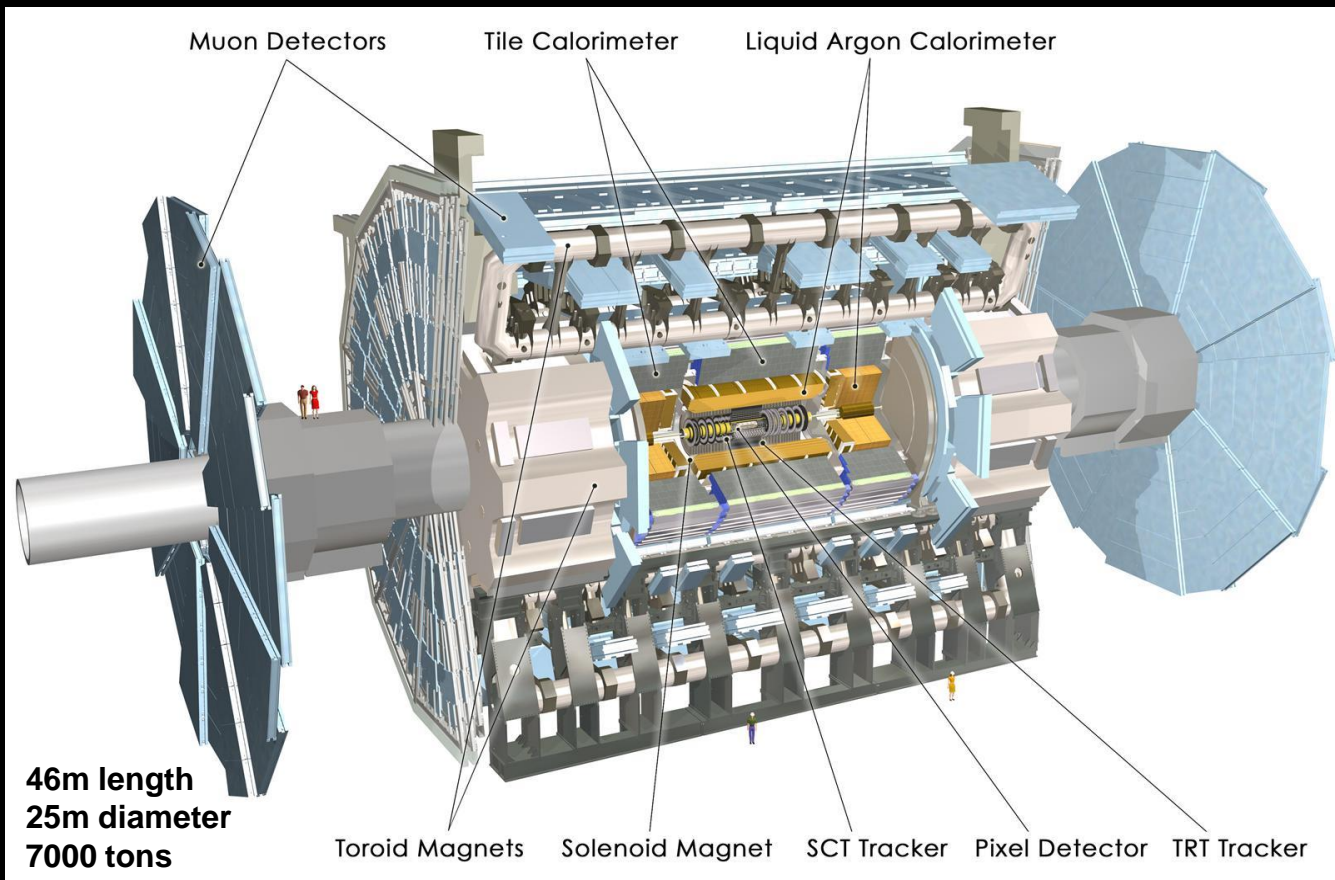
ALICE



ATLAS



# The ATLAS Detector



# The CMS Detector

## CMS DETECTOR

Total weight : 14,000 tonnes  
Overall diameter : 15.0 m  
Overall length : 28.7 m  
Magnetic field : 3.8 T

STEEL RETURN YOKE  
12,500 tonnes

SILICON TRACKERS  
Pixel ( $100 \times 150 \mu\text{m}$ )  $\sim 16\text{m}^2 \sim 66\text{M}$  channels  
Microstrips ( $80 \times 180 \mu\text{m}$ )  $\sim 200\text{m}^2 \sim 9.6\text{M}$  channels

SUPERCONDUCTING SOLENOID  
Niobium titanium coil carrying  $\sim 18,000\text{A}$

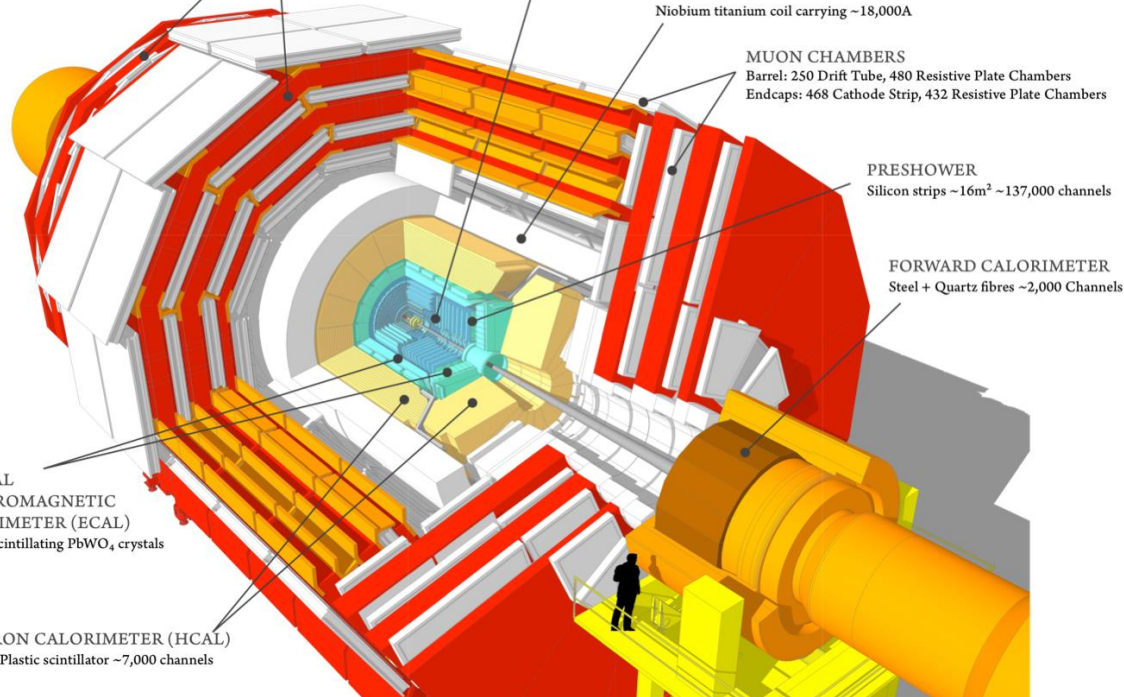
MUON CHAMBERS  
Barrel: 250 Drift Tube, 480 Resistive Plate Chambers  
Endcaps: 468 Cathode Strip, 432 Resistive Plate Chambers

PRESHOWER  
Silicon strips  $\sim 16\text{m}^2 \sim 137,000$  channels

FORWARD CALORIMETER  
Steel + Quartz fibres  $\sim 2,000$  Channels

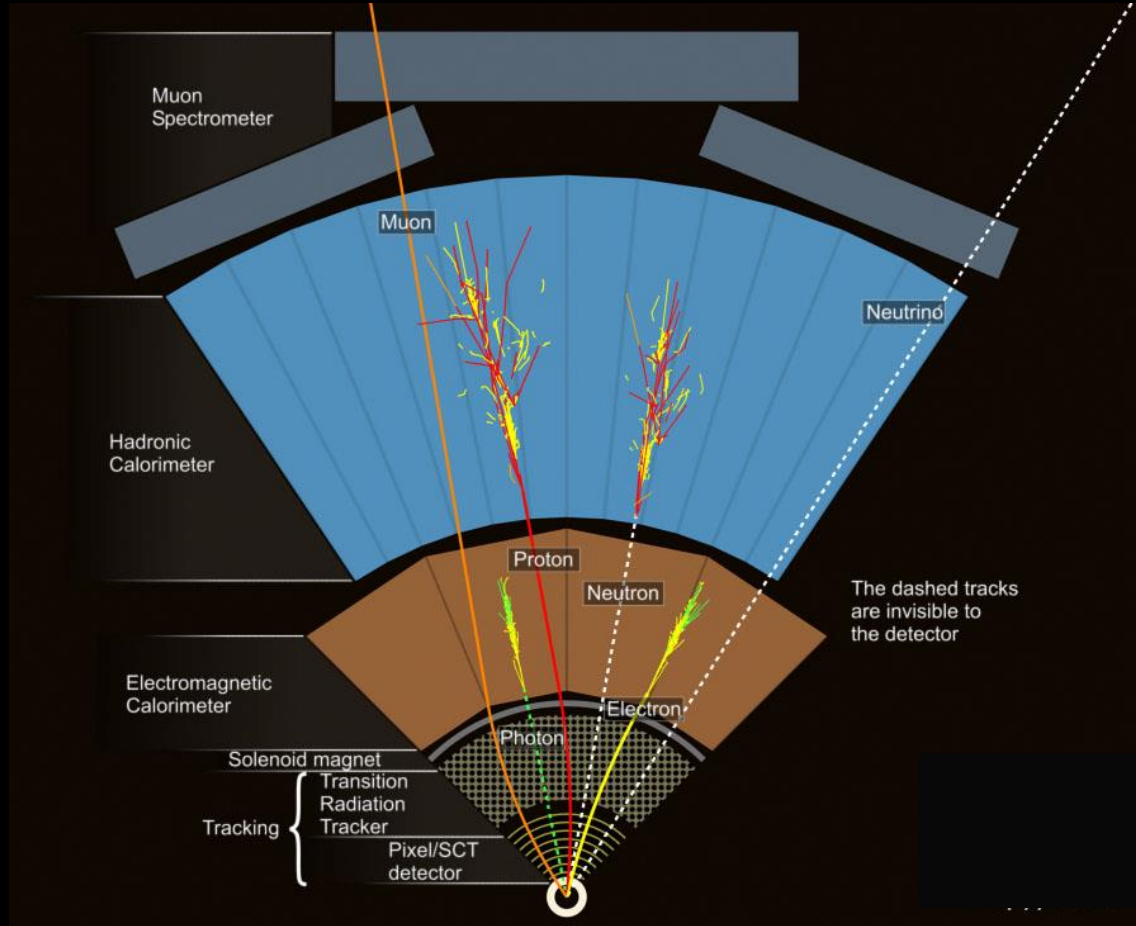
CRYSTAL  
ELECTROMAGNETIC  
CALORIMETER (ECAL)  
 $\sim 76,000$  scintillating  $\text{PbWO}_4$  crystals

HADRON CALORIMETER (HCAL)  
Brass + Plastic scintillator  $\sim 7,000$  channels





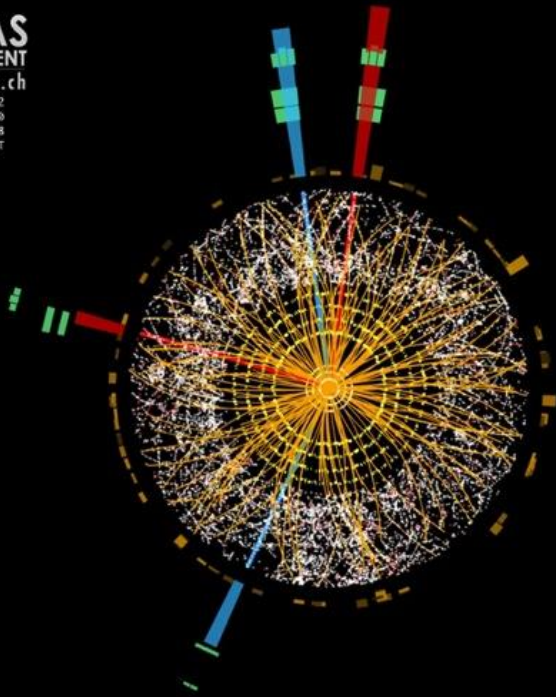
# Particle Detection in ATLAS



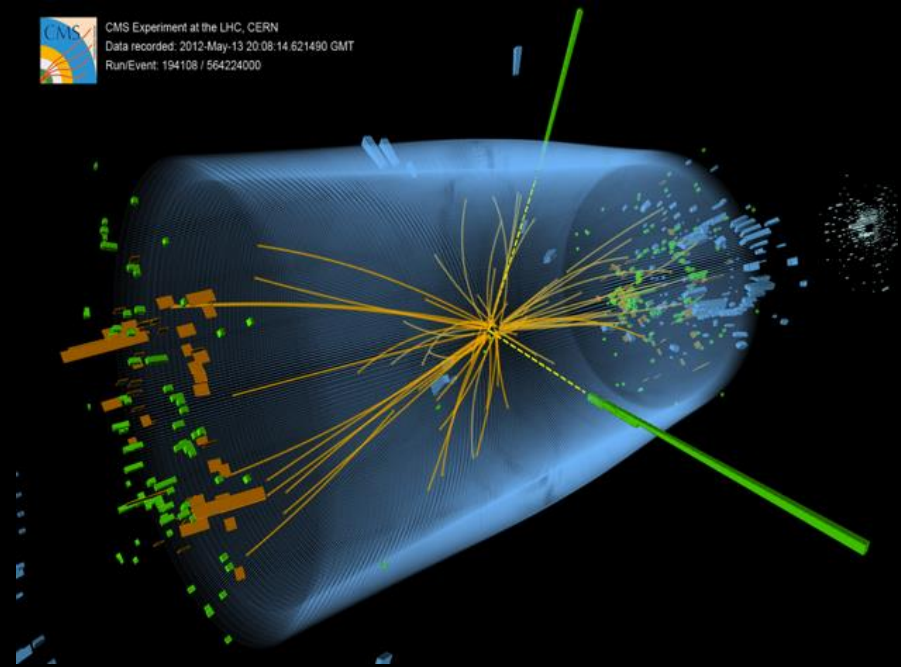
**ATLAS**  
EXPERIMENT

<http://atlas.ch>

Run: 203602  
Event: 82614360  
Date: 2012-05-18  
Time: 20:28:11 CEST

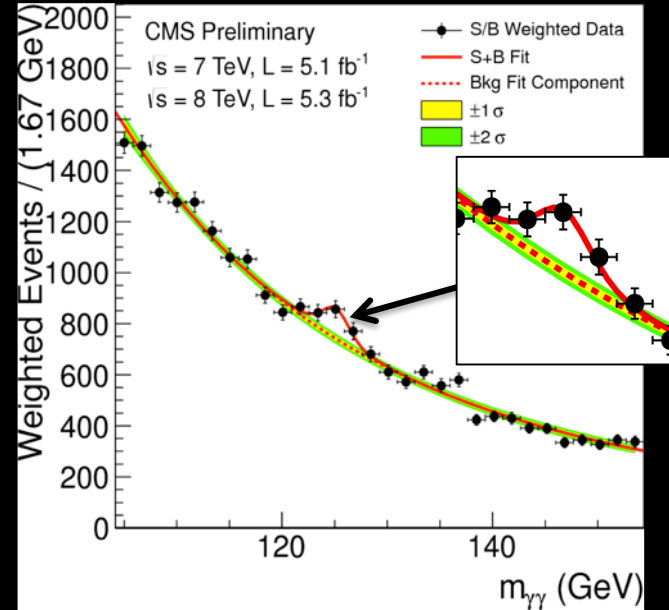
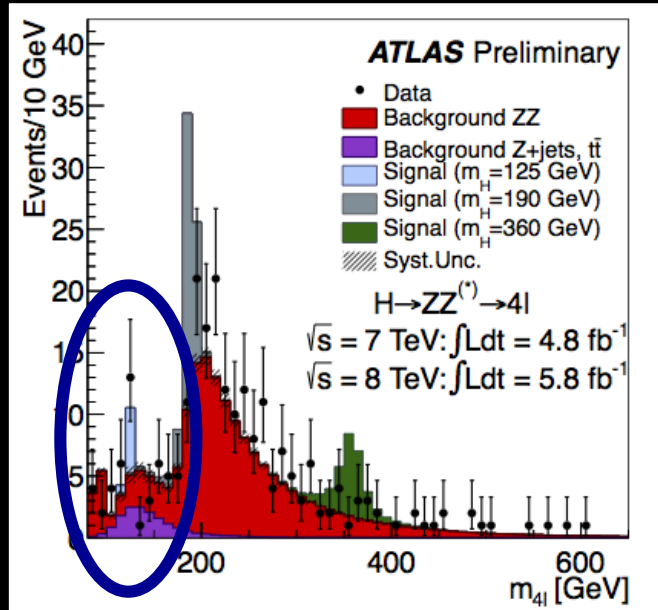


CMS Experiment at the LHC, CERN  
Data recorded: 2012-May-13 20:08:14.621490 GMT  
Run/Event: 194108 / 564224000

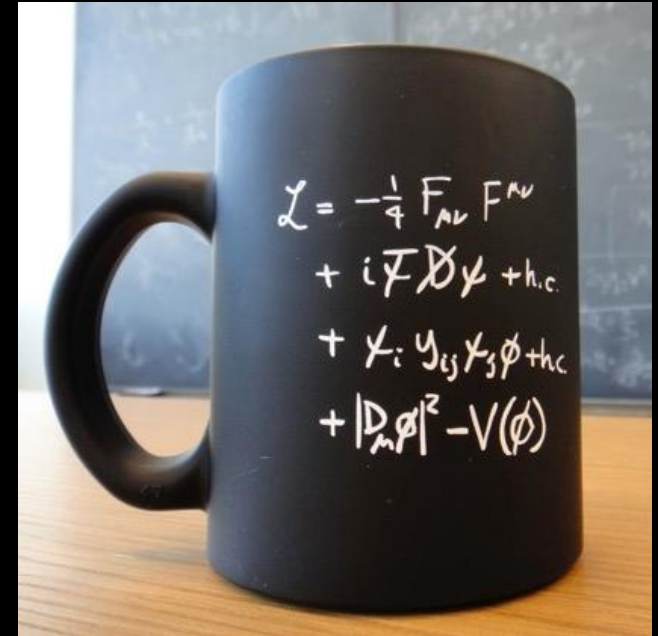


2012





	<p>mass <math>\approx 2.4 \text{ MeV}/c^2</math></p> <p>charge <math>2/3</math></p> <p>spin <math>1/2</math></p> <p><b>u</b></p> <p>up</p>	<p>mass <math>\approx 1.275 \text{ GeV}/c^2</math></p> <p>charge <math>2/3</math></p> <p>spin <math>1/2</math></p> <p><b>c</b></p> <p>charm</p>	<p>mass <math>\approx 172.44 \text{ GeV}/c^2</math></p> <p>charge <math>2/3</math></p> <p>spin <math>1/2</math></p> <p><b>t</b></p> <p>top</p>	<p>mass <math>0</math></p> <p>charge <math>0</math></p> <p>spin <math>1</math></p> <p><b>g</b></p> <p>gluon</p>	<p>mass <math>\approx 125.09 \text{ GeV}/c^2</math></p> <p>charge <math>0</math></p> <p>spin <math>0</math></p> <p><b>H</b></p> <p>Higgs</p>	
<b>QUARKS</b>	<p>mass <math>\approx 4.8 \text{ MeV}/c^2</math></p> <p>charge <math>-1/3</math></p> <p>spin <math>1/2</math></p> <p><b>d</b></p> <p>down</p>	<p>mass <math>\approx 95 \text{ MeV}/c^2</math></p> <p>charge <math>-1/3</math></p> <p>spin <math>1/2</math></p> <p><b>s</b></p> <p>strange</p>	<p>mass <math>\approx 4.18 \text{ GeV}/c^2</math></p> <p>charge <math>-1/3</math></p> <p>spin <math>1/2</math></p> <p><b>b</b></p> <p>bottom</p>	<p>mass <math>0</math></p> <p>charge <math>0</math></p> <p>spin <math>1</math></p> <p><b><math>\gamma</math></b></p> <p>photon</p>	<b>SCALAR BOSONS</b>	
	<p>mass <math>\approx 0.511 \text{ MeV}/c^2</math></p> <p>charge <math>-1</math></p> <p>spin <math>1/2</math></p> <p><b>e</b></p> <p>electron</p>	<p>mass <math>\approx 105.67 \text{ MeV}/c^2</math></p> <p>charge <math>-1</math></p> <p>spin <math>1/2</math></p> <p><b><math>\mu</math></b></p> <p>muon</p>	<p>mass <math>\approx 1.7768 \text{ GeV}/c^2</math></p> <p>charge <math>-1</math></p> <p>spin <math>1/2</math></p> <p><b><math>\tau</math></b></p> <p>tau</p>	<p>mass <math>\approx 91.19 \text{ GeV}/c^2</math></p> <p>charge <math>0</math></p> <p>spin <math>1</math></p> <p><b>Z</b></p> <p>Z boson</p>		<b>GAUGE BOSONS</b>
	<p>mass <math>&lt; 2.2 \text{ eV}/c^2</math></p> <p>charge <math>0</math></p> <p>spin <math>1/2</math></p> <p><b><math>\nu_e</math></b></p> <p>electron neutrino</p>	<p>mass <math>&lt; 1.7 \text{ MeV}/c^2</math></p> <p>charge <math>0</math></p> <p>spin <math>1/2</math></p> <p><b><math>\nu_\mu</math></b></p> <p>muon neutrino</p>	<p>mass <math>&lt; 15.5 \text{ MeV}/c^2</math></p> <p>charge <math>0</math></p> <p>spin <math>1/2</math></p> <p><b><math>\nu_\tau</math></b></p> <p>tau neutrino</p>	<p>mass <math>\approx 80.39 \text{ GeV}/c^2</math></p> <p>charge <math>\pm 1</math></p> <p>spin <math>1</math></p> <p><b>W</b></p> <p>W boson</p>		



The Standard Model of Particle Physics



A wide-angle photograph of a night sky over a desert landscape. The Milky Way galaxy is visible as a bright, horizontal band of stars and dust, stretching across the upper half of the frame. The sky is filled with numerous individual stars of varying brightness. In the foreground, the dark, undulating dunes of a desert are visible, with a small, dark silhouette of a structure or building on a ridge in the distance. The overall scene is dark and atmospheric, with the light from the stars illuminating the dust in the galaxy.

What we still don't know

# Where do we come from? Where are we going?

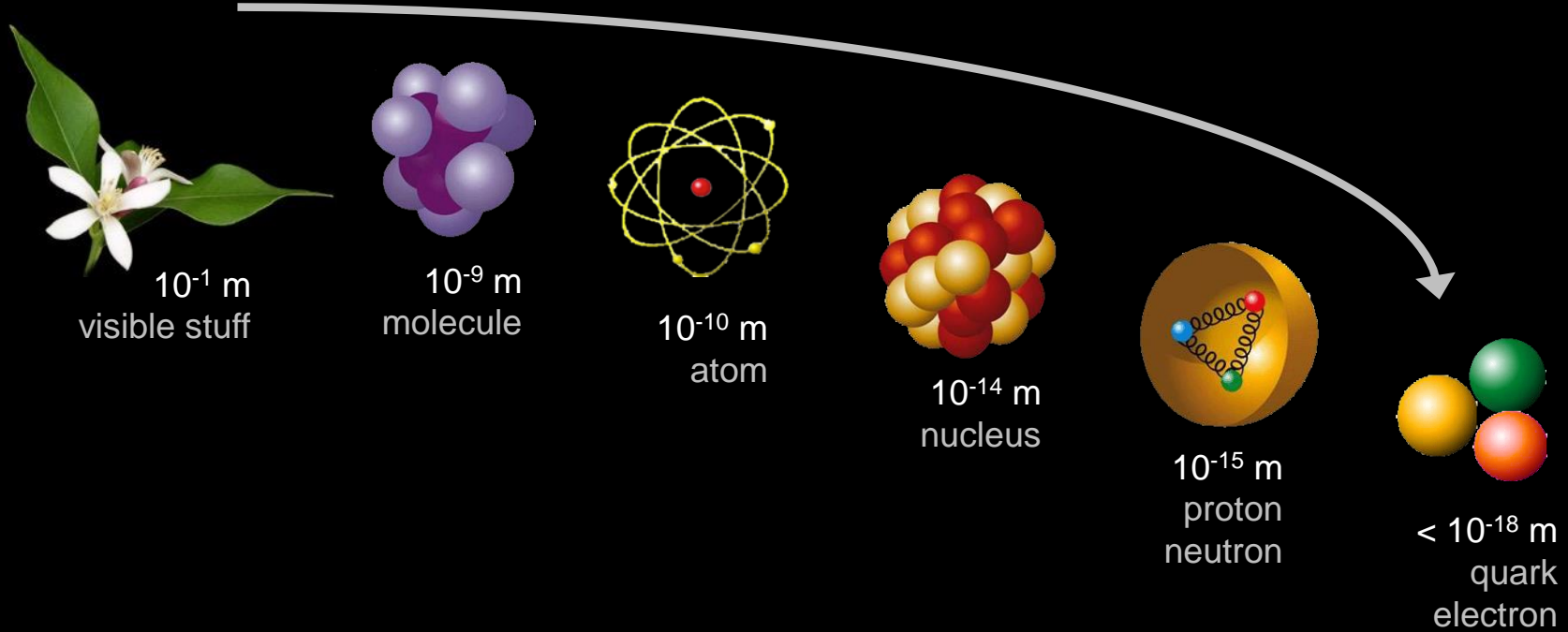




Why do we exist at all?

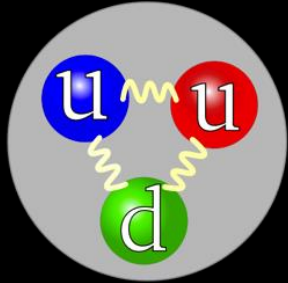


# What are we made of ?

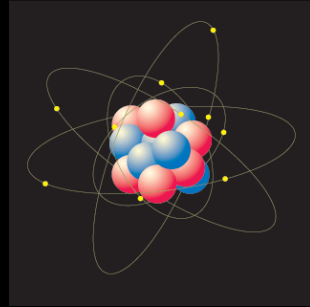




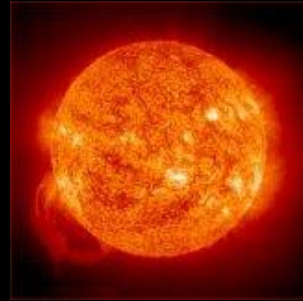
# Why is gravity so weak?



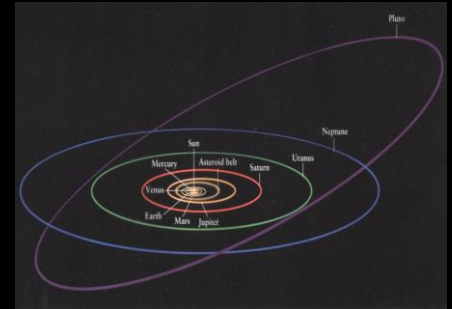
Strong Nuclear  
60



Electromagnetism  
1



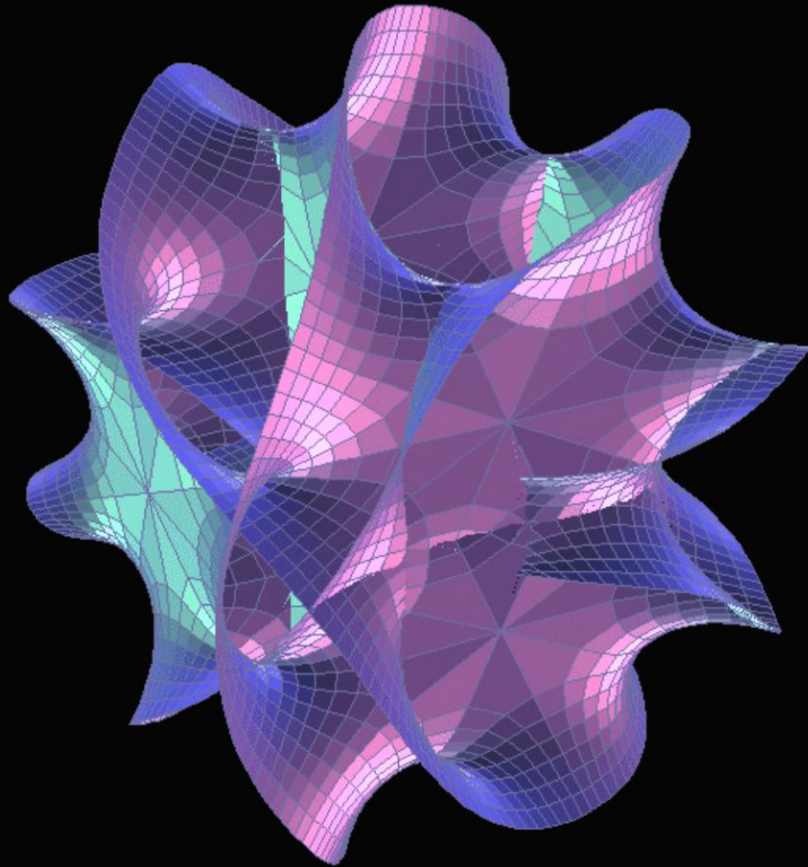
Weak Nuclear  
 $10^{-4}$



Gravity  
 $10^{-41}$

Relative force strengths specified at scale of quarks and gluons

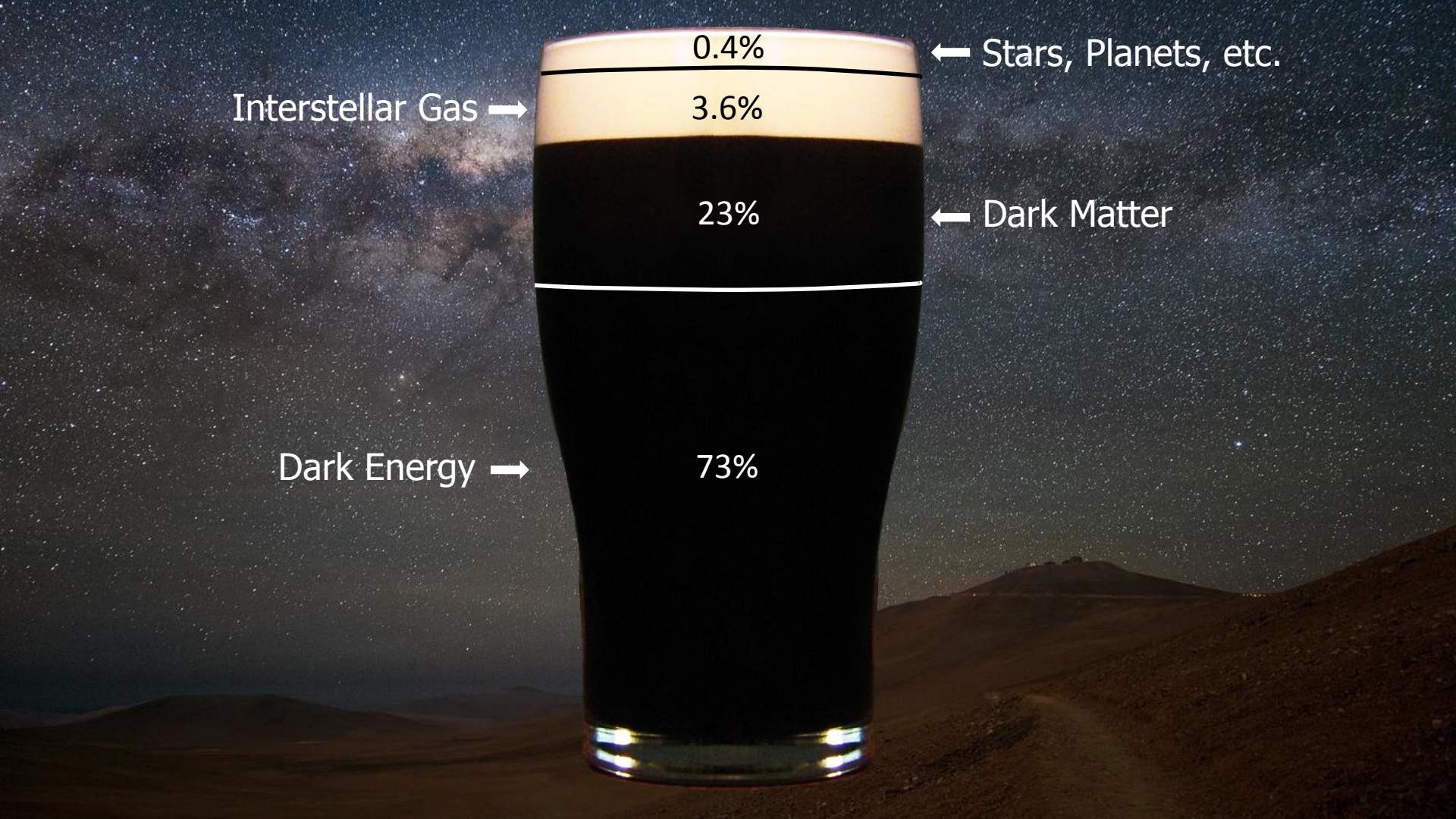
Could there be other dimensions?





What is holding this together?





0.4%

← Stars, Planets, etc.

Interstellar Gas →

3.6%

23%

← Dark Matter

Dark Energy →

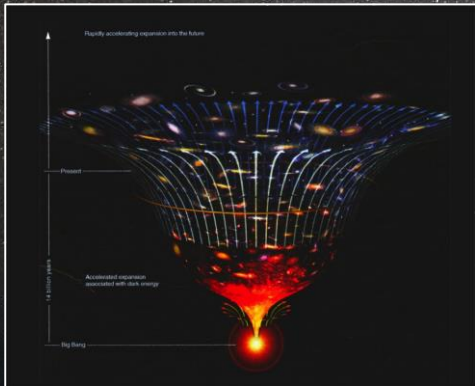
73%



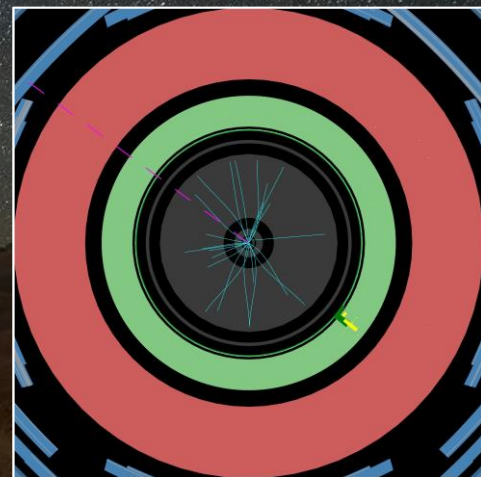
?



?



?





A night sky with the Milky Way galaxy and a desert landscape. The Milky Way is visible as a bright, cloudy band of stars stretching across the upper half of the frame. The sky is filled with numerous individual stars. In the foreground, the dark, silhouetted ridges of sand dunes are visible against the starry background.

Now, let's see how to discover particles...