

# THE SIMPLE LO-DOWN ON THE GOD PARTICLE

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FreakingNews.com



# The \$64,000 Question

**WHAT IS  
MASS ?**

# You'll see that...

- ▣ There's more than one definition, and our understanding of it has been evolving over time.
- ▣ **Less ambitious goal:** quantify it.
- ▣ **More ambitious goal:**  
Address: **Why do things have mass ?**

# Definition 1: What is mass ?

- ▣ **Mass:** mass refers to the quantity of matter in an object....

Small mass ..



Dung beetle, pushing, well,  
you know what ...

Large mass ..



# Definition 2: Measure of Inertia

**INERTIA:**



**An object at rest tends to stay at rest unless acted upon by an outside force.**



**Object in motion stay in motion unless acted on by a force**

**Inertial mass**

Measure of how hard it is to change the state of motion of an object

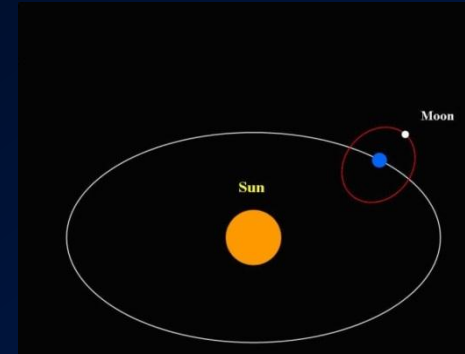
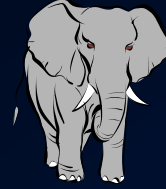
**Buckle Up!**



# Definition 3: Gravitational mass

□ To explain why

- All objects in free-fall experience the same acceleration ( $g = 9.8 \text{ m/s}^2$ ) near the surface of the Earth.
- the moon goes in a circle around the earth



□ Newton came up with the Universal Law of Gravitation from which he was able to show that near the surface of the earth, the gravitational force is given by:

$$F_g = mg$$

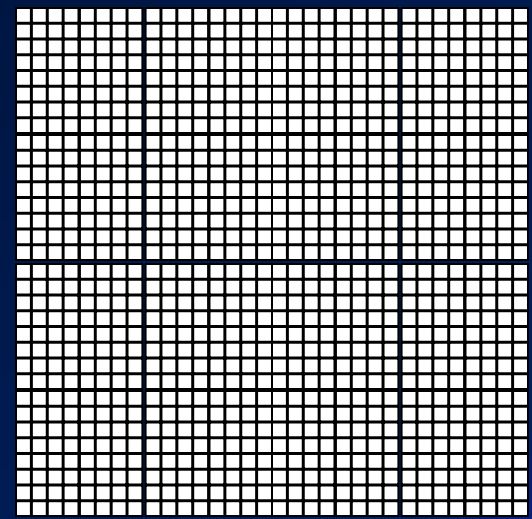
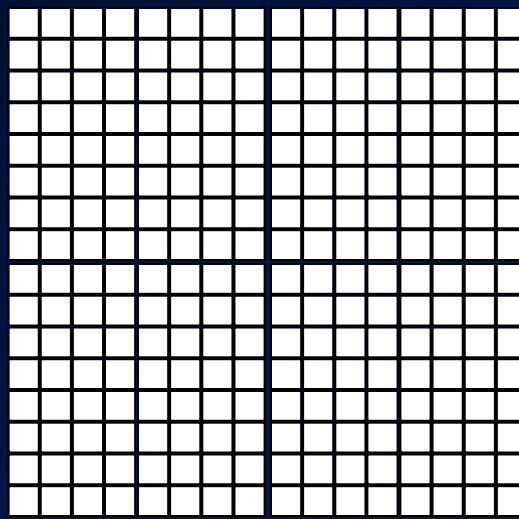
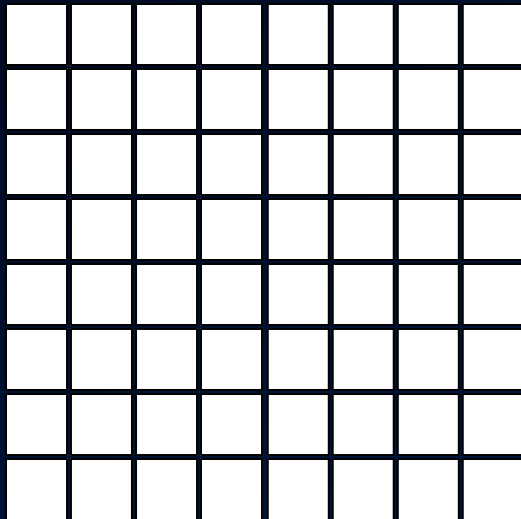
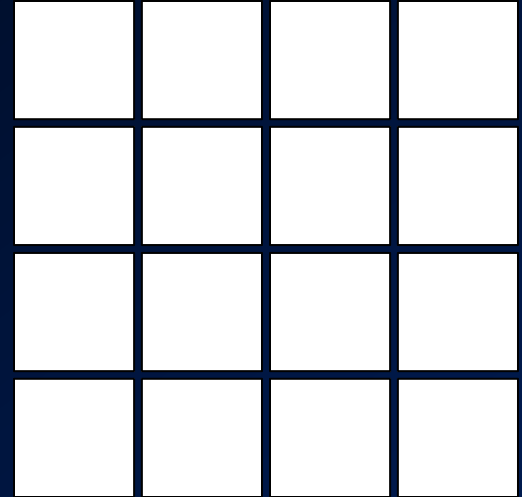
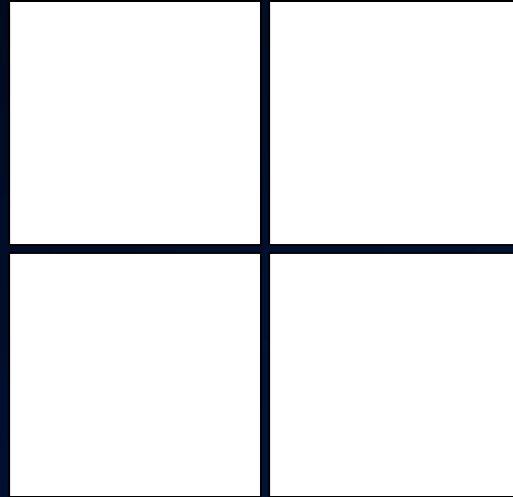
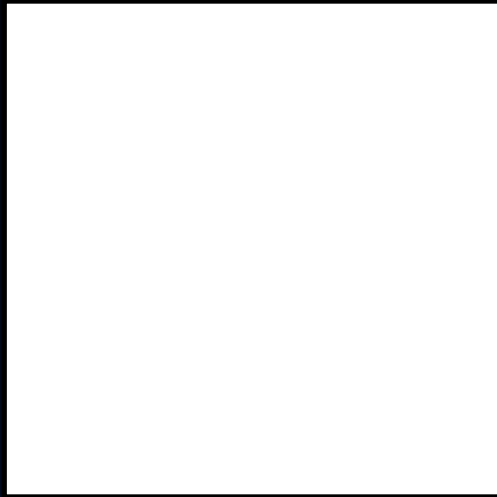
□ Gravitational mass:

the quantity that connects the gravitational force ( $F_g$ ) and  $g$

# But, why IS mass ?

- ▣ So far, viewed as:
  - Amount of material in an object
  - Measure of inertia: The “thing” in Newton’s Law:  $F = ma$
  - The link between gravitational force and gravitational acceleration.
  
- ▣ But why do things have the mass that they do?
  - Why does an electron have a mass of  $9.11 \times 10^{-31}$  kg?
  - Why does a proton have a mass of  $1.67 \times 10^{-27}$  kg?
  - How do these particles acquire mass, and why do they have the values that they do?

# Fundamental constituents of matter





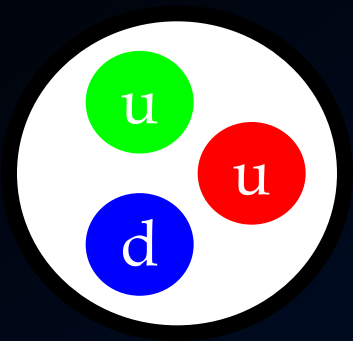
# Keep ripping...

- Eventually, you find you reach something that can no longer be ripped in half..
- About 125 years ago, we were pretty certain we had uncovered the most fundamental forms of matter...

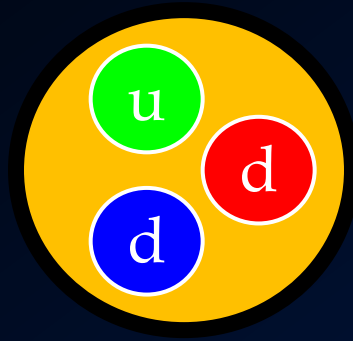
		Atomic number																18							
		6												13		14		15		16		17		18	
		C												B		C		N		O		F		He	
		12.01												10.81		12.01		14.01		16.00		19.00		20.18	
														Al		Si		P		S		Cl		Ar	
														26.98		28.09		30.97		32.07		35.45		39.95	
1		3		3										5		6		7		8		9		10	
2		4		4										13		14		15		16		17		18	
3		11		11										19		20		21		22		23		24	
4		19		19										27		28		29		30		31		32	
5		37		37										45		46		47		48		49		50	
6		55		55										63		64		65		66		67		68	
7		87		87										95		96		97		98		99		100	
1	<b>H</b> 1.008											<b>B</b> 10.81		<b>C</b> 12.01		<b>N</b> 14.01		<b>O</b> 16.00		<b>F</b> 19.00		<b>He</b> 4.003			
2	<b>Li</b> 6.941	<b>Be</b> 9.012											<b>Al</b> 26.98		<b>Si</b> 28.09		<b>P</b> 30.97		<b>S</b> 32.07		<b>Cl</b> 35.45		<b>Ar</b> 39.95		
3	<b>Na</b> 22.99	<b>Mg</b> 24.31	<b>Sc</b>	<b>Ti</b>	<b>V</b>	<b>Cr</b>	<b>Mn</b>	<b>Fe</b>	<b>Co</b>	<b>Ni</b>	<b>Cu</b>	<b>Zn</b>	<b>Ga</b>	<b>Ge</b>	<b>As</b>	<b>Se</b>	<b>Br</b>	<b>Kr</b>							
4	<b>K</b> 39.10	<b>Ca</b> 40.08	44.96	47.88	50.94	52.00	54.94	55.85	58.93	58.69	63.55	65.39	69.72	72.61	74.92	78.96	79.90	<b>Br</b>		<b>Kr</b> 83.80					
5	<b>Rb</b> 85.47	<b>Sr</b> 87.62	88.91	91.22	92.91	95.94	98.91	101.1	102.9	106.4	107.9	112.4	114.8	118.7	121.8	127.6	126.9	<b>I</b>		<b>Xe</b> 131.3					
6	<b>Cs</b> 132.9	<b>Ba</b> 137.3	175.0	178.5	180.9	183.8	186.2	190.2	192.2	195.1	197.0	200.6	204.4	207.2	209.0	209.0	210.0	<b>At</b>		<b>Rn</b> 222.0					
7	<b>Fr</b> 223.0	<b>Ra</b> 226.0	262.1	261.1	262.1	263.1	264.1	265.1	268	269	272	277	Uut	Uuq	Uup	Uuh	Uus	<b>Uuo</b>		293					
6			57	58	59	60	61	62	63	64	65	66	67	68	69	70									
			<b>La</b>	<b>Ce</b>	<b>Pr</b>	<b>Nd</b>	<b>Pm</b>	<b>Sm</b>	<b>Eu</b>	<b>Gd</b>	<b>Tb</b>	<b>Dy</b>	<b>Ho</b>	<b>Er</b>	<b>Tm</b>	<b>Yb</b>									
			138.9	140.1	140.9	144.2	146.9	150.4	152.0	157.3	158.9	162.5	164.9	167.3	168.9	173.0									
7			89	90	91	92	93	94	95	96	97	98	99	100	101	102									
			<b>Ac</b>	<b>Th</b>	<b>Pa</b>	<b>U</b>	<b>Np</b>	<b>Pu</b>	<b>Am</b>	<b>Cm</b>	<b>Bk</b>	<b>Cf</b>	<b>Es</b>	<b>Fm</b>	<b>Md</b>	<b>No</b>									
			227.0	232.0	231.0	238.0	237.0	244.1	243.1	247.1	247.1	251.1	252.0	257.1	258.1	259.1									

(c)1998  
Kremer Paul

# And life was sooo good ...



proton



neutron



Charges:

up =  $+2/3$

down =  $-1/3$

electron =  $-1$

**But, we couldn't leave well enough alone ☹️**

From 1950s – 1990s,

4 more **quarks** were discovered:

Named: “strange (s)”, “charm (c)”, “beauty (b)” and “top (t)”

+ 5 more **leptons**

2 electron-like, but with more mass: muon ( $\mu^-$ ) and tau ( $\tau^-$ )

3 (almost massless) neutral particles: neutrinos ( $\nu_e, \nu_\mu, \nu_\tau$ )

# The “new” periodic table

	I	II	III
Quarks	$u$	$c$	$t$
	$d$	$s$	$b$
Leptons	$\nu_e$	$\nu_\mu$	$\nu_\tau$
	$e$	$\mu$	$\tau$

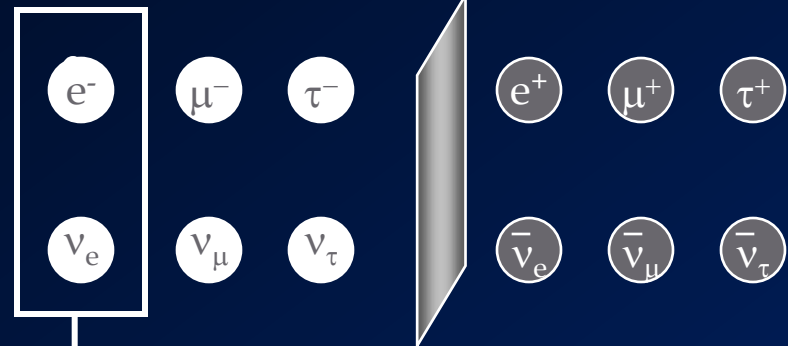
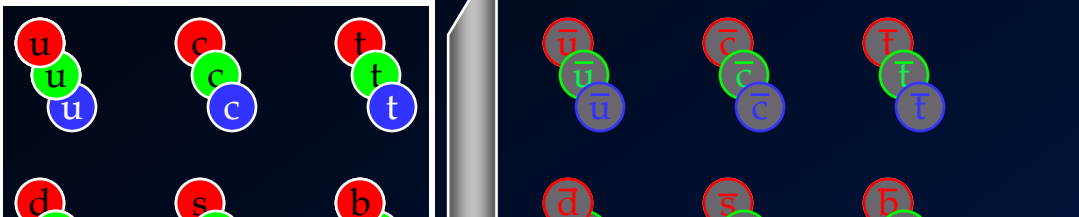
Three Generations of Matter

- Rather than 100+ seemingly different forms of matter, we have a **much simpler structure** !
- 3 “families”
- We have also discovered that all of these particles have a corresponding **antiparticles** !

# Matter in the Standard Model

## Quarks

## Leptons



Observed “free” in atoms, nuclear reactions

Periodic Table of the Elements © www.elementsdatabase.com

1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	57 La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	89 Ac	104 Unq	105 Unp	106 Unh	107 Uns	108 Uno	109 Une	110 Unn								

Legend:

- hydrogen (black)
- alkali metals (yellow)
- alkali earth metals (red)
- transition metals (purple)
- poor metals (green)
- nonmetals (blue)
- noble gases (pink)
- rare earth metals (teal)

58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

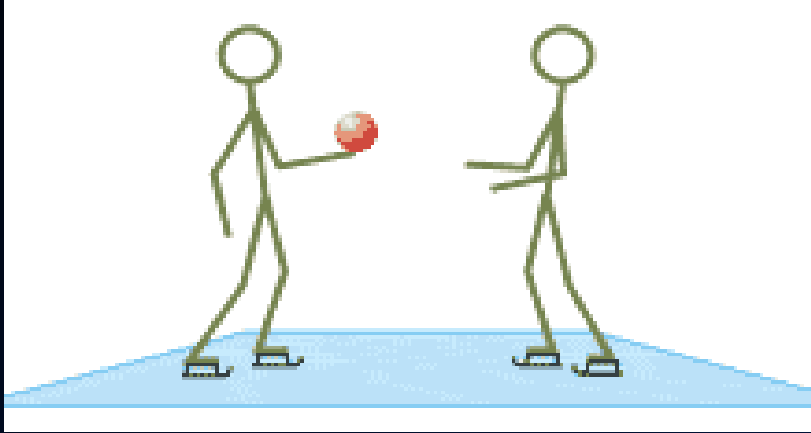
# Fundamental Forces



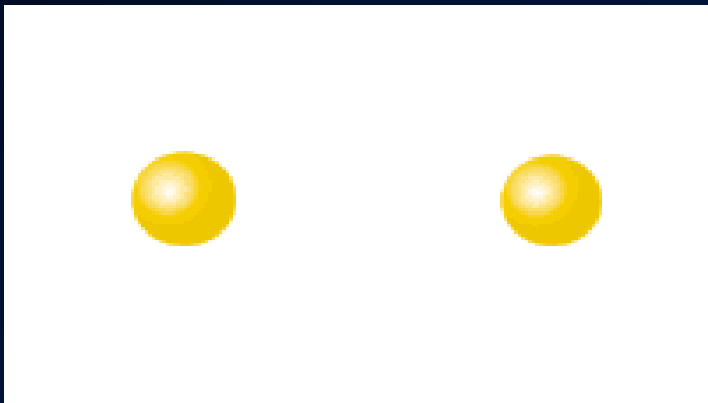
How do the fundamental particles interact with each other?

# Modern concept of forces

Besides a “push” or “pull”, FORCE can be viewed as something that **changes the state of motion** of an object



Exchanging a ball



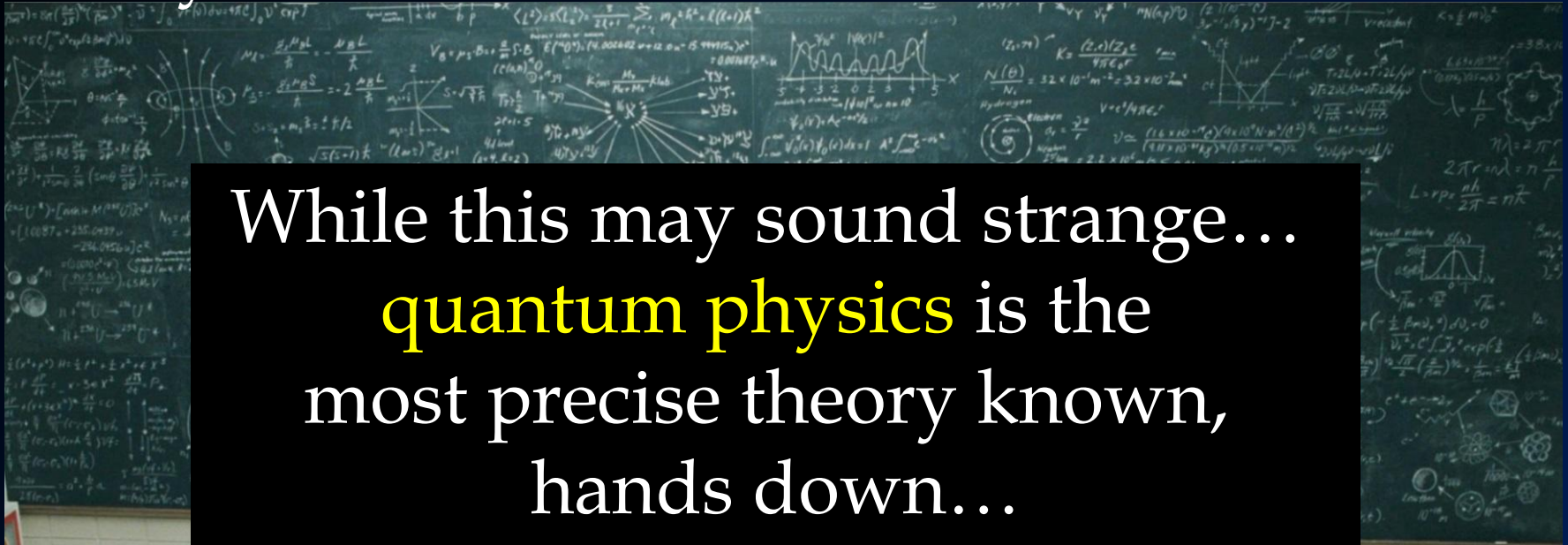
Interactions == Particle Exchange

This is our **best** understanding of how to describe (fundamental) forces.

**Particle exchange**

# This is all described by quantum physics

Briefly....



While this may sound strange...  
**quantum physics** is the  
most precise theory known,  
hands down...

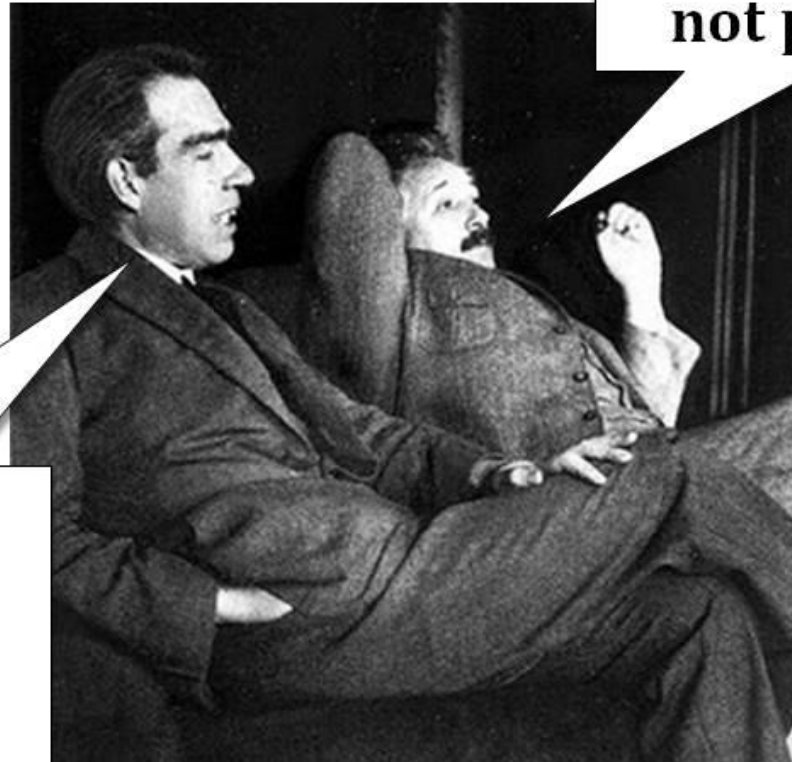


## Quantum physics in brief:

- 1) Unless **strictly forbidden**, anything is possible with some probability.
- 2) Laws of physics governed by **probabilities!**
- 3) The probability that you could walk through a wall is **not zero!**

# It drove Einstein crazy !

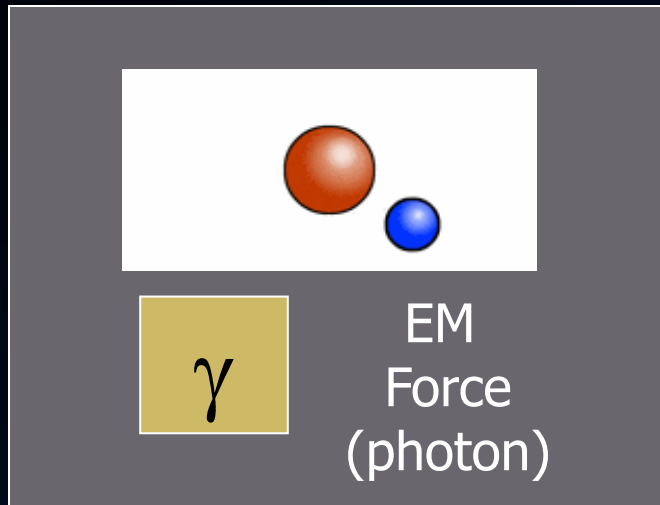
I am convinced  
that God does  
not play dice.



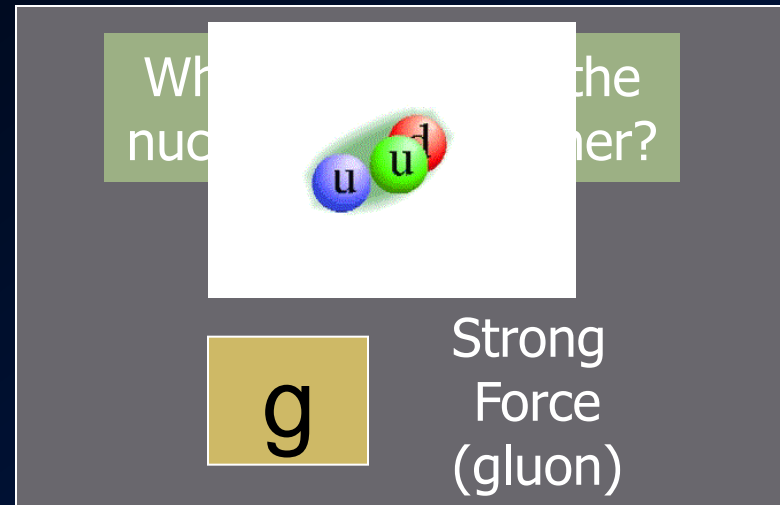
**A Einstein and N. Bohr**



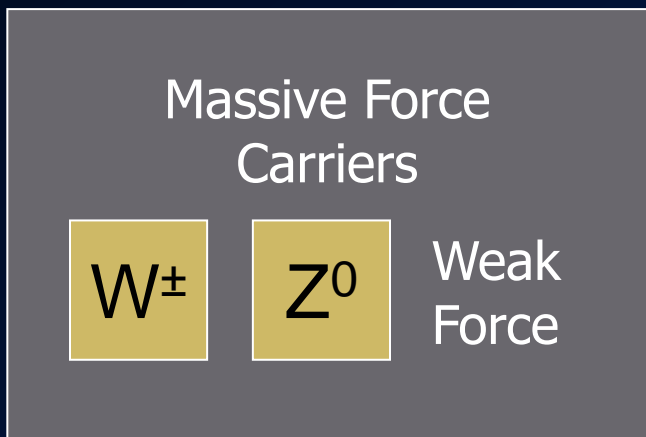
# Standard Model forces and force carriers



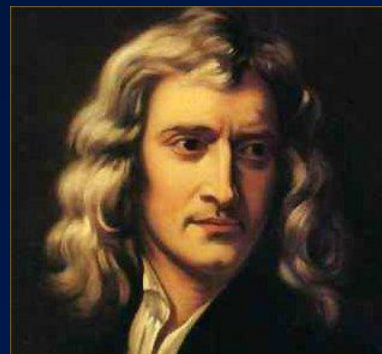
Photons interact with **electric** charge



Gluons interact with **color** charge



But, what about gravity????



No quantum theory for gravity (yet)  
**VERY HARD PROBLEM**

# The “almost complete” Standard Model

	I	II	III
Quarks	$u$	$c$	$t$
	$d$	$s$	$b$
Leptons	$\nu_e$	$\nu_\mu$	$\nu_\tau$
	$e$	$\mu$	$\tau$

Three Generations of Matter

But still, there is one  
missing piece...



# The question of mass

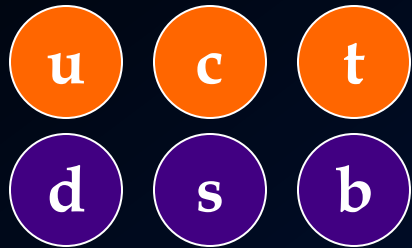


How do particles get their mass?



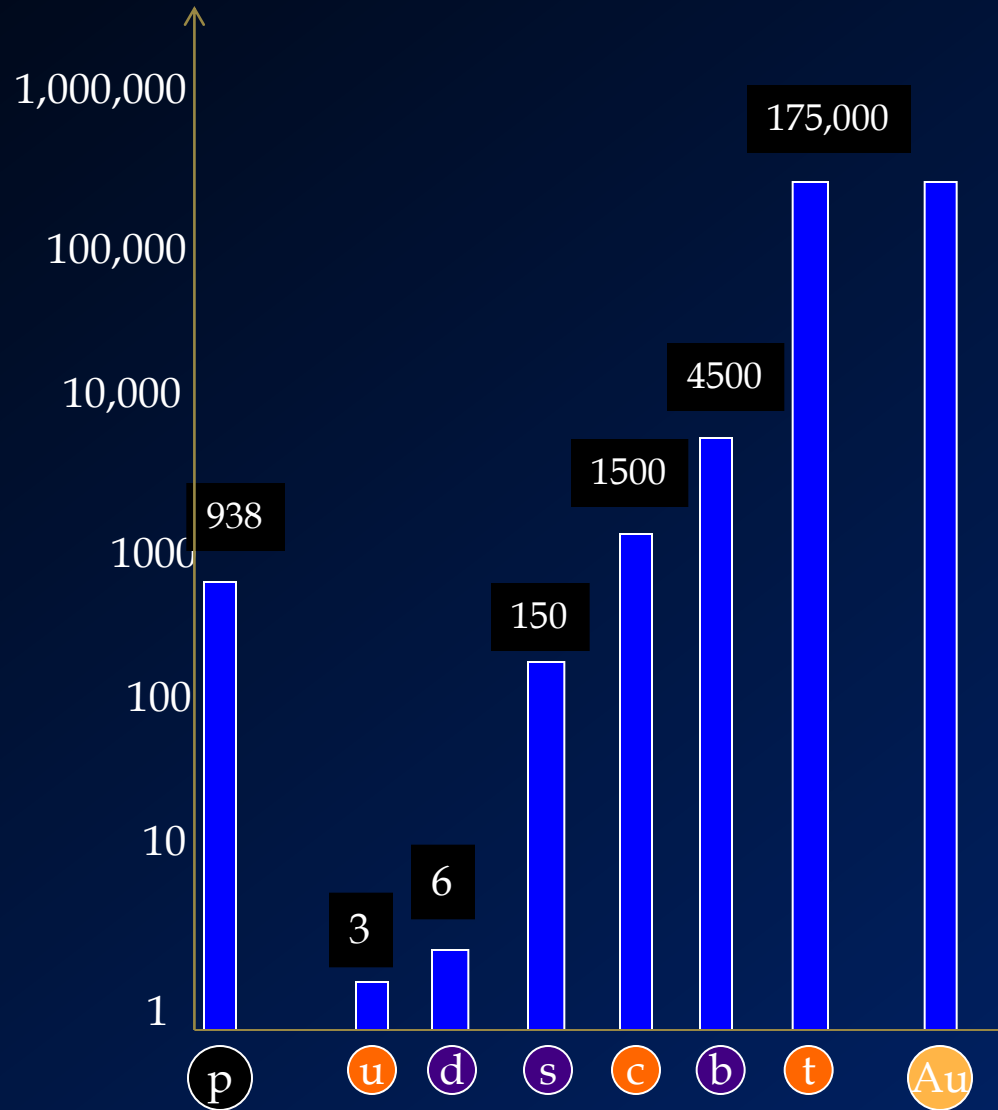
Why do quarks have the masses that they do?

I II III



Mass?

Let's weight them



Top quark is 60,000 X heavier than the up quark?

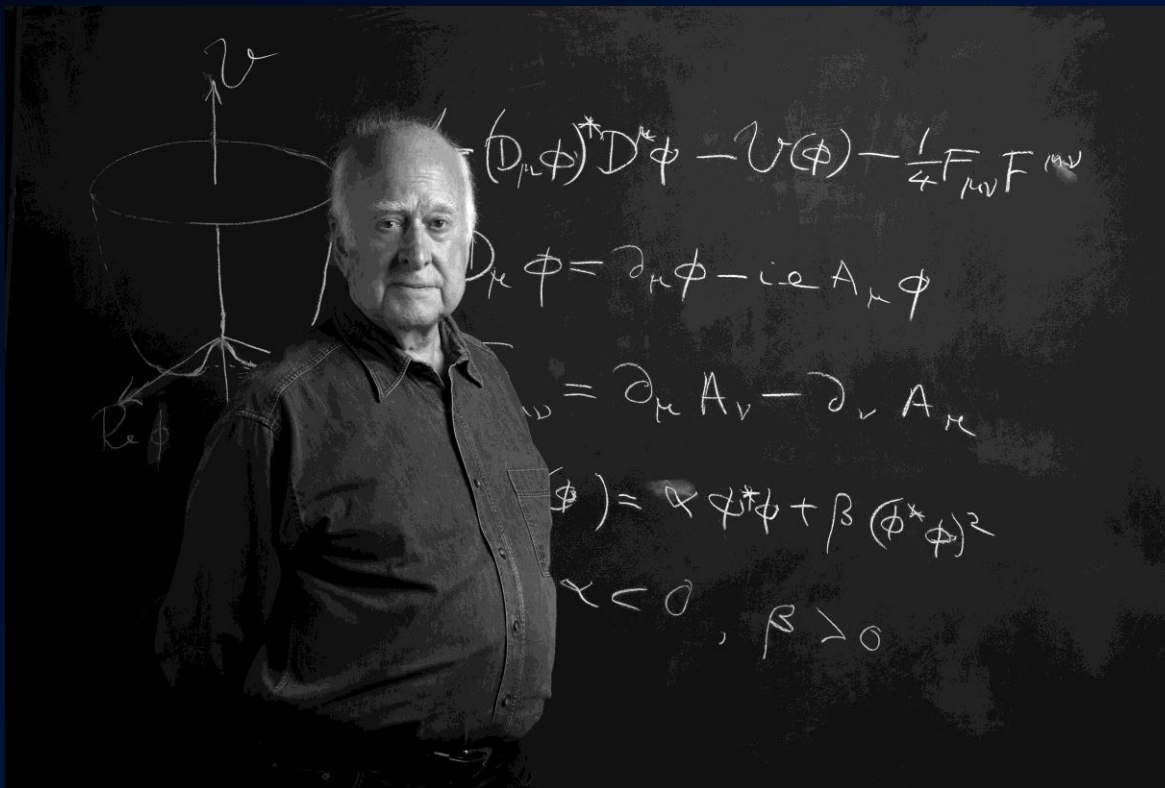
Why?

What was nature thinking?

# The long-standing puzzle

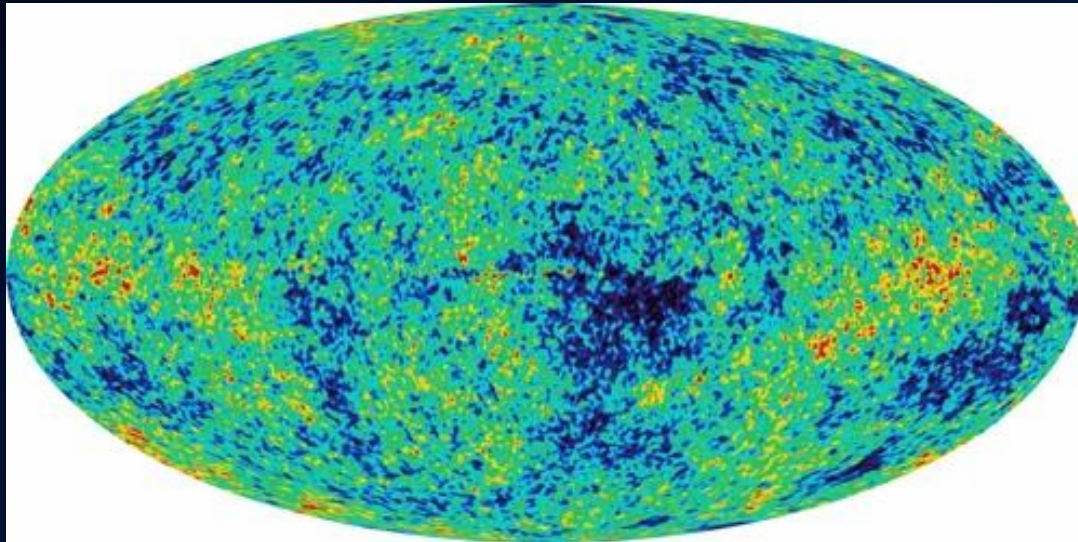
How do particles get their mass?

An explanation was put forth by **Peter Higgs**, and several others in 1964..



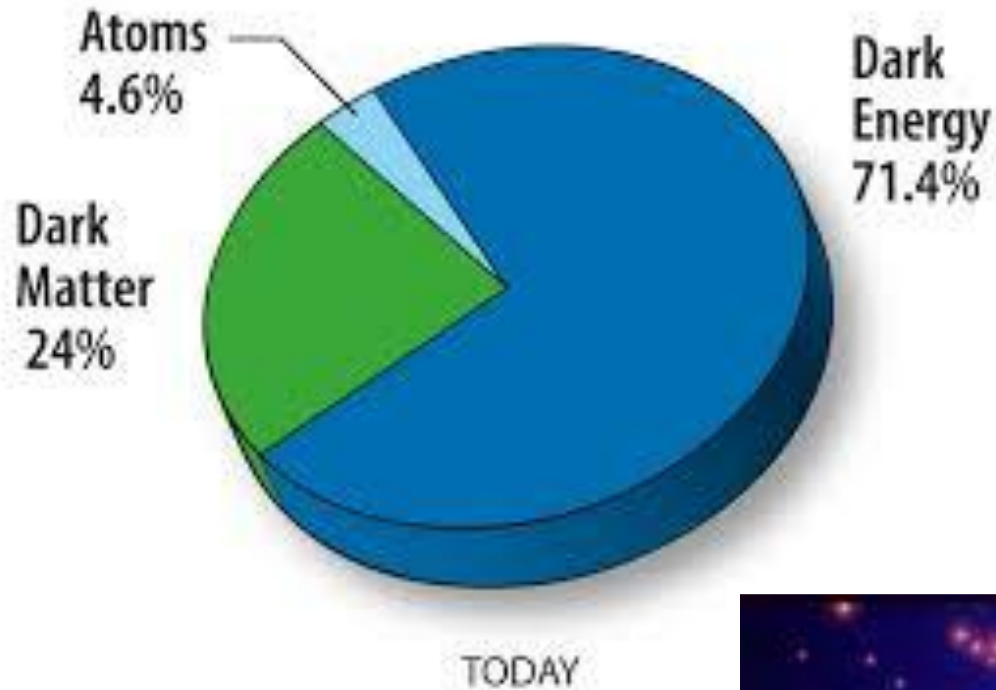
# The birth of fields in the **Big Bang**

- Data support that the Universe was created in a cataclysmic event, called the **Big Bang**.
- All the matter we see today, such as stars, planets (and us) are a result of this event.
- **But were there things created that are not so easily seen?**
  - **1964:** Discovery that the Universe is completely filled with microwaves (**EM fields**).
  - Big Bang theory predicts this (age Universe  $\gg \gg$  7000 years!)



Penzias & Wilson 21

# Other mysterious things lurking ...



# What does this have to do with the Higgs particle?

Suppose the Universe is also filled with an invisible “field”, called the **Higgs field**....

Yup, also **a remnant of the Big Bang!**



## Recall:

**Photon** (EM field) interacts with **electric charge**

**Gluon** (Strong force) interacts with **color charge**

Now, suppose the Higgs field interacts with ... mass !

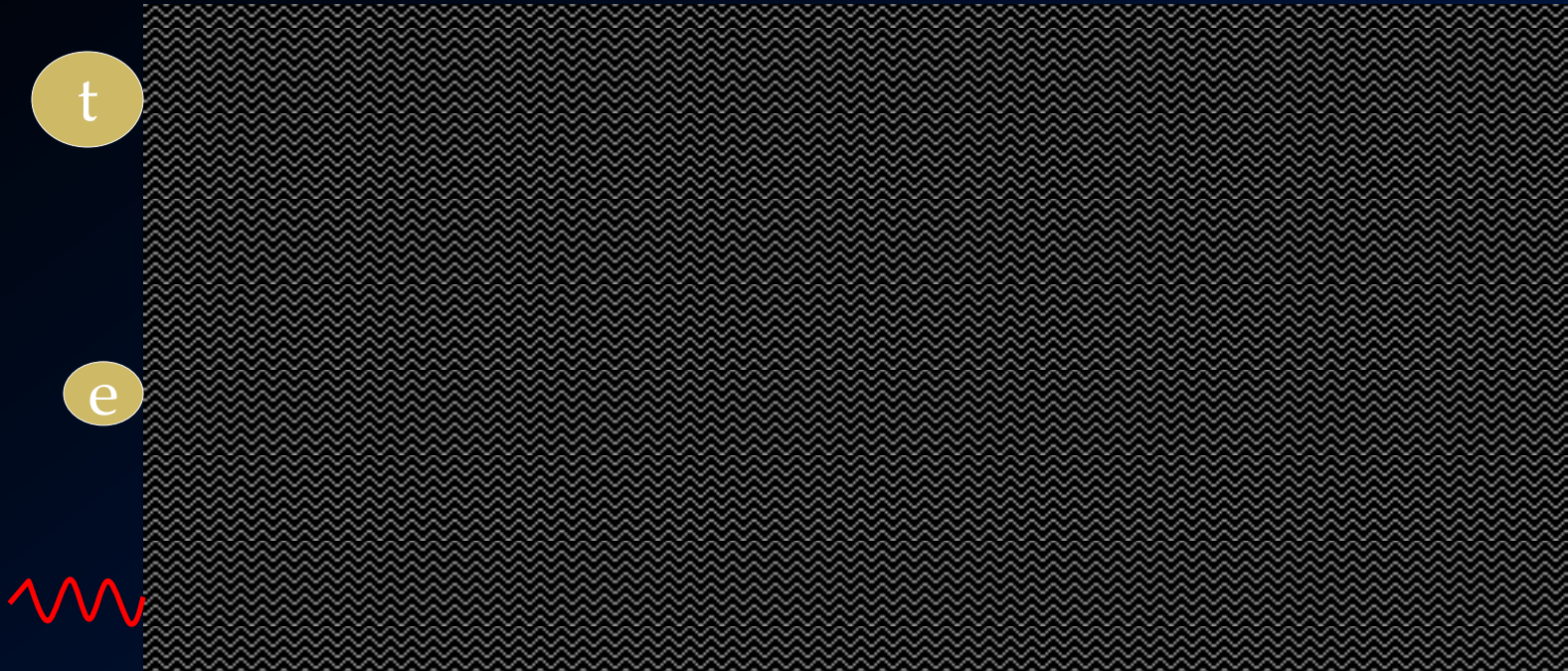
Particles that interact **strongly** with the Higgs field will be interpreted as having **large mass**.

“ “ “ **weakly** “ “ “ “ **small** mass.

Particles that **DO NOT interact** with the Higgs field will be interpreted as having **zero mass**. (like the photon!)

# A cartoon...

The top quark is 350,000 times heavier than the electron.



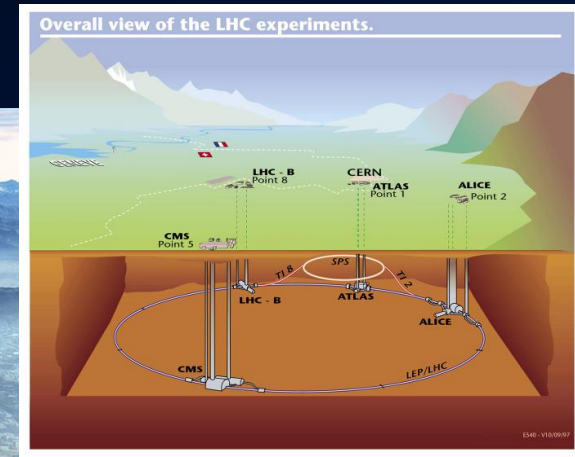
Since the top quark interacts most strongly with the Higgs field, it is harder for it to move through the Higgs field

→ Larger inertia → interpreted as larger mass

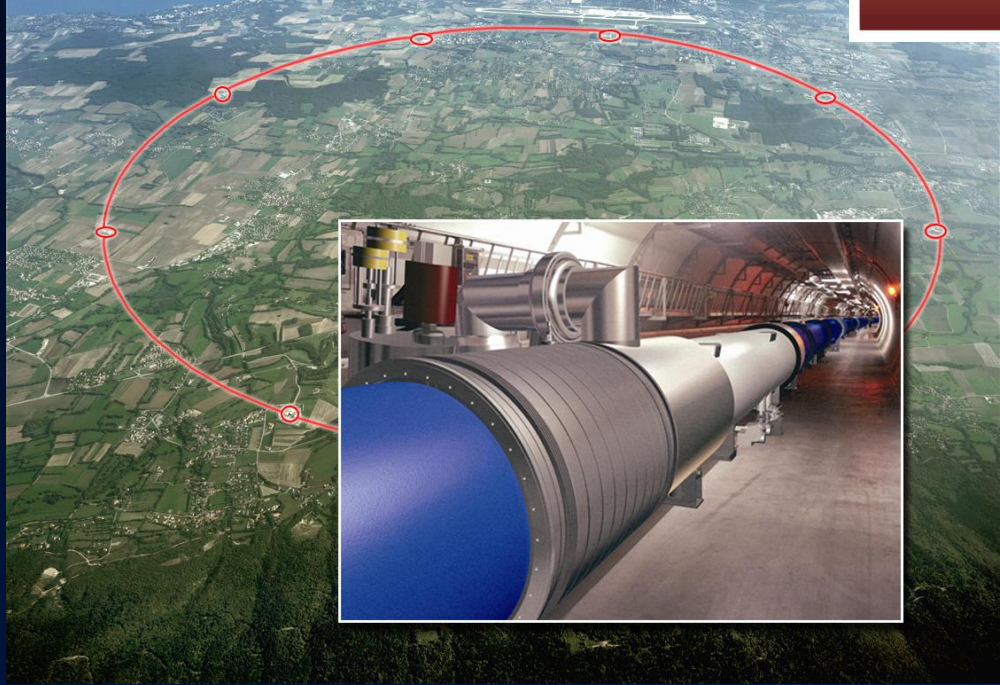
→ Photon is interpreted as having zero mass



# Making it happen – the accelerator

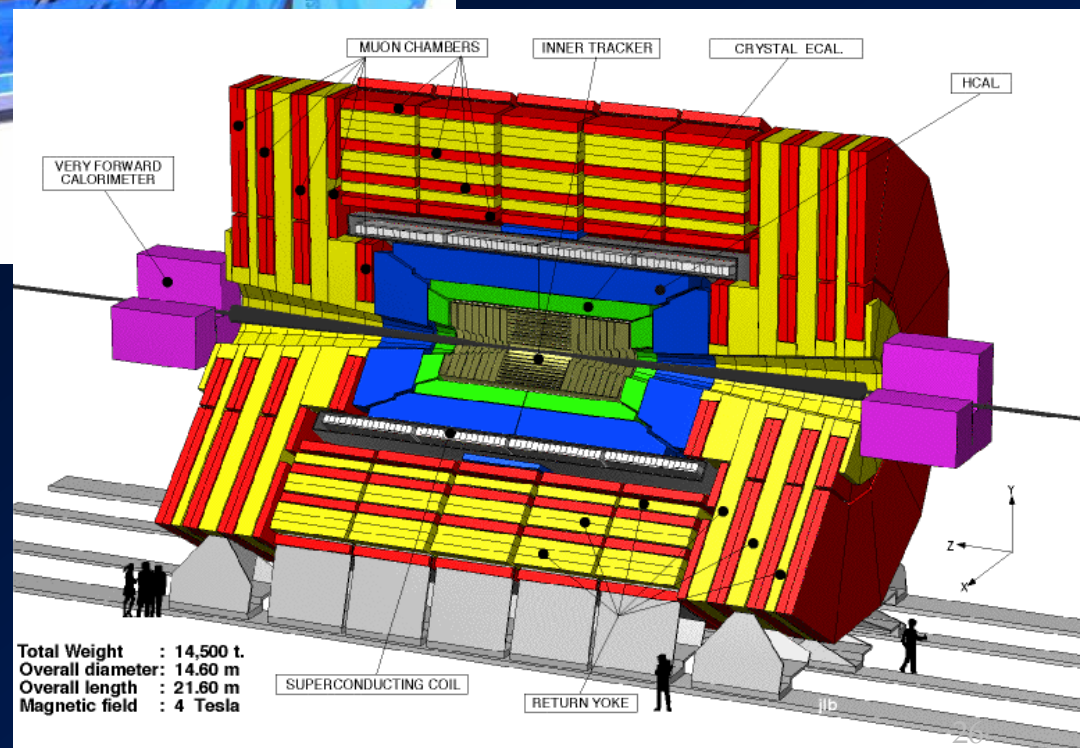
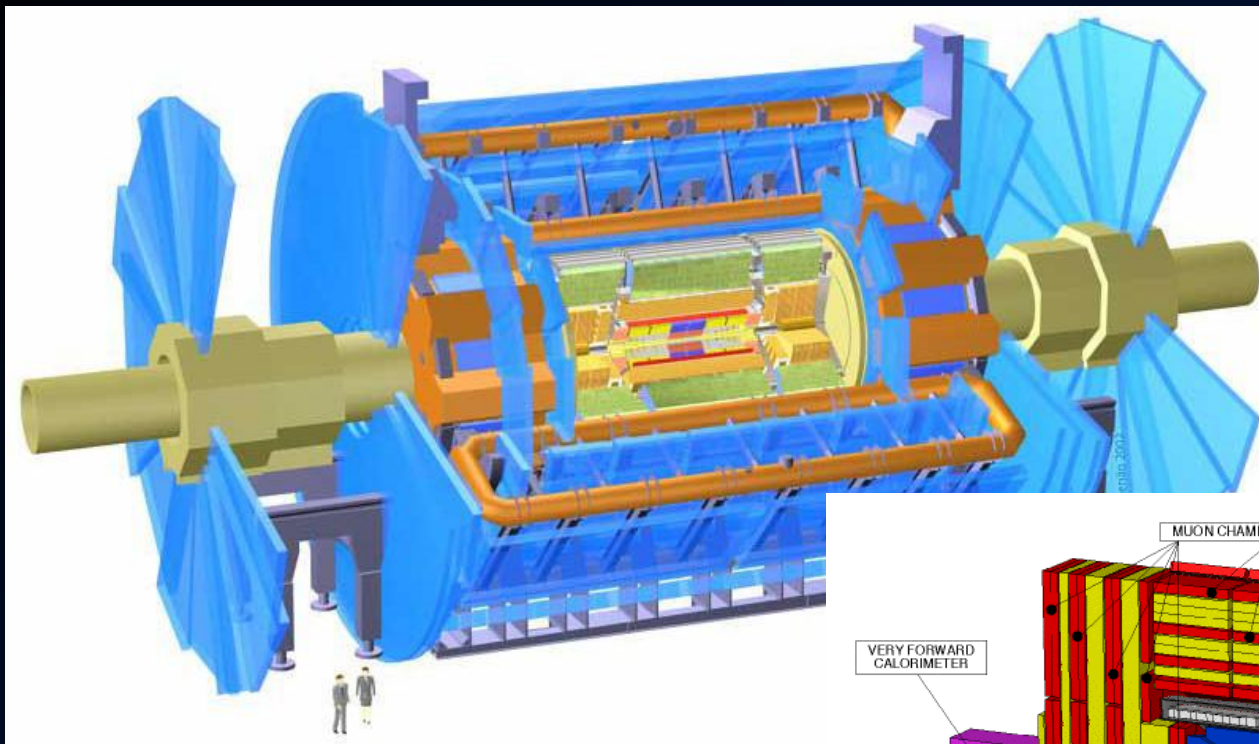


Movie



Large Hadron Collider:  
Smash high energy protons into one another

# Making it happen - the detectors



Total Weight : 14,500 t.  
Overall diameter: 14.60 m  
Overall length : 21.60 m  
Magnetic field : 4 Tesla

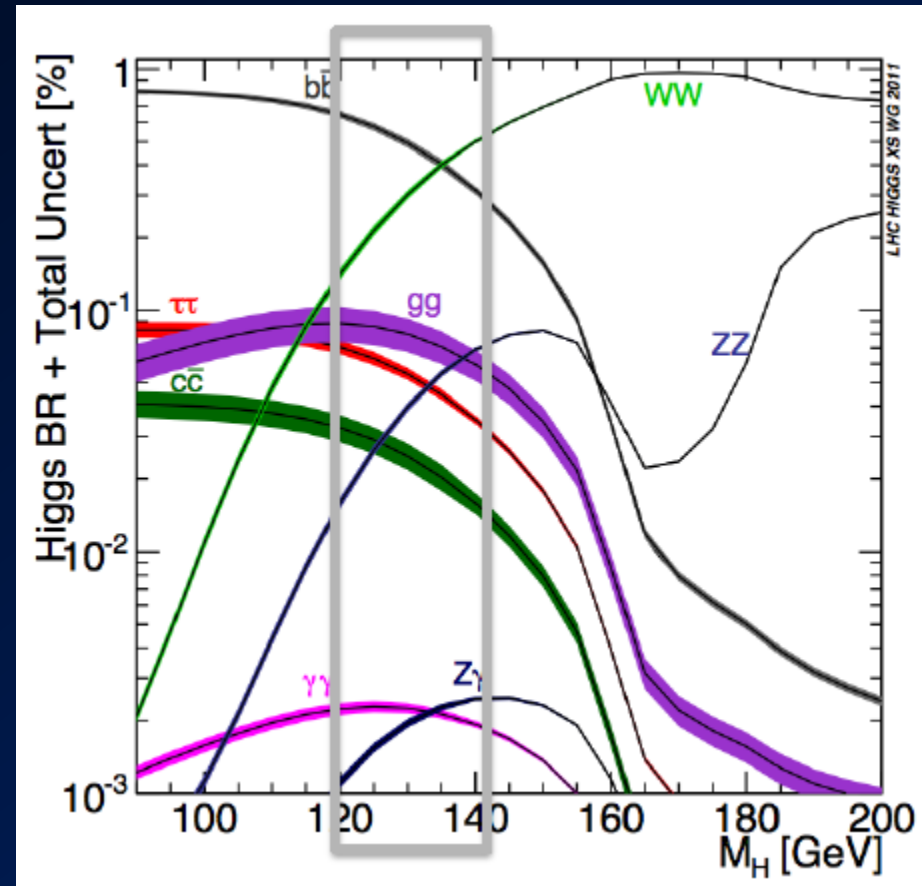
Atlas from space

# How to detect the Higgs

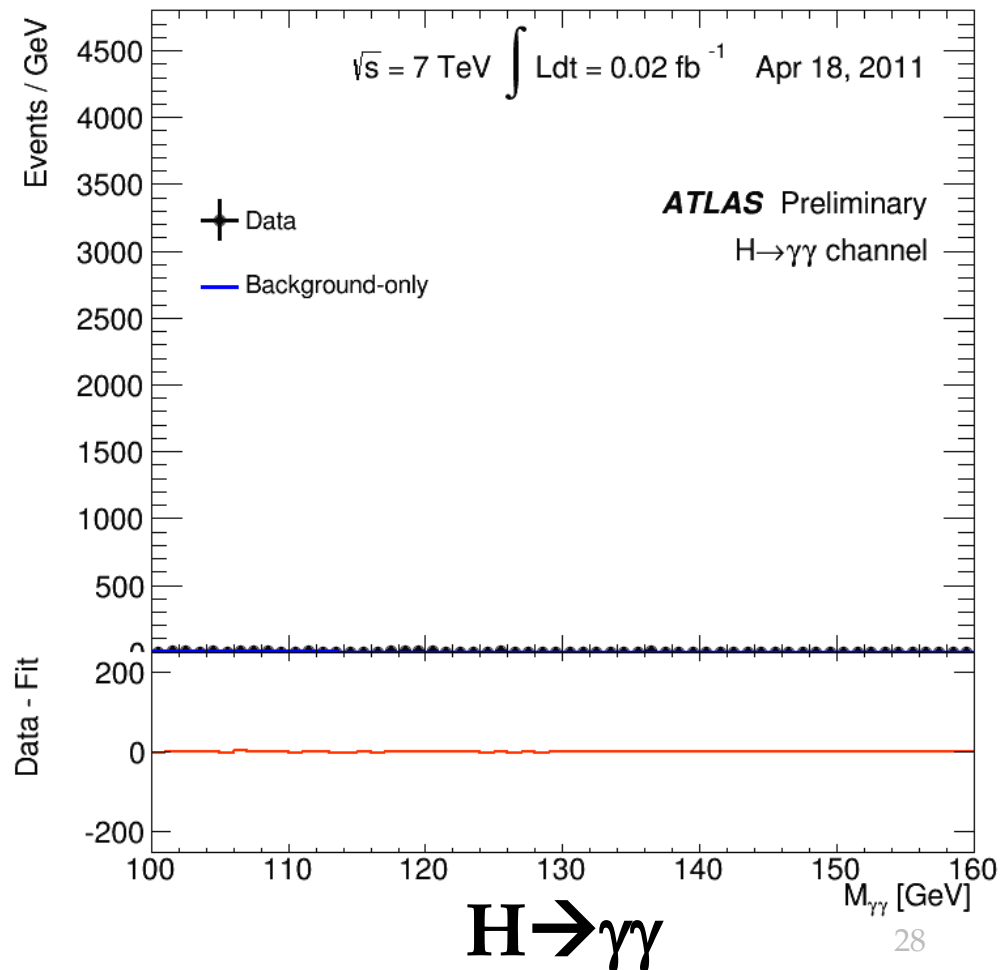
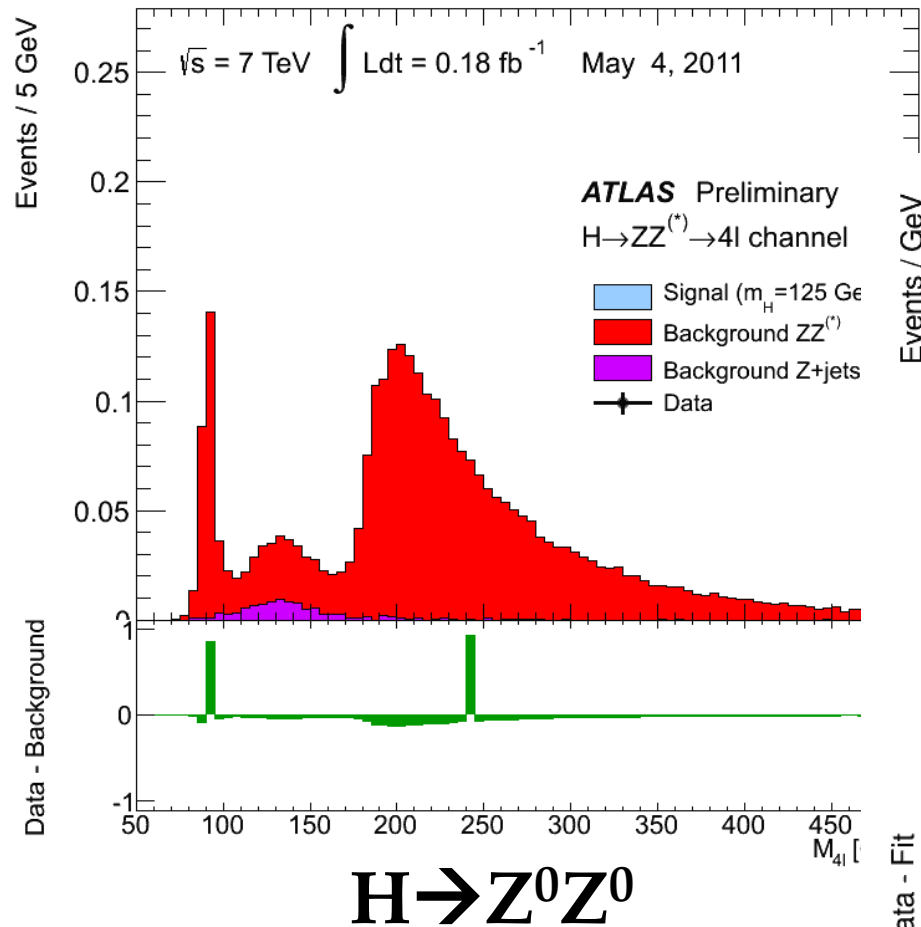
- First you have to produce the Higgs..
  - Only produced in about 1 / 100,000,000,000 collisions**
- Like most particles, the physical Higgs particle decays.
- In the SM, the Higgs is expected to decay as follows:

$H \rightarrow b\bar{b}$	( ~ 60% )
$H \rightarrow W^+W^-$	( ~ 19% )
$H \rightarrow gg$	( ~ 9% )
$H \rightarrow \tau^+\tau^-$	( ~ 7% )
$H \rightarrow c\bar{c}$	( ~ 3% )
$H \rightarrow Z^0Z^0$	( ~ 2% )
$H \rightarrow \gamma\gamma$	( ~ 0.2% )

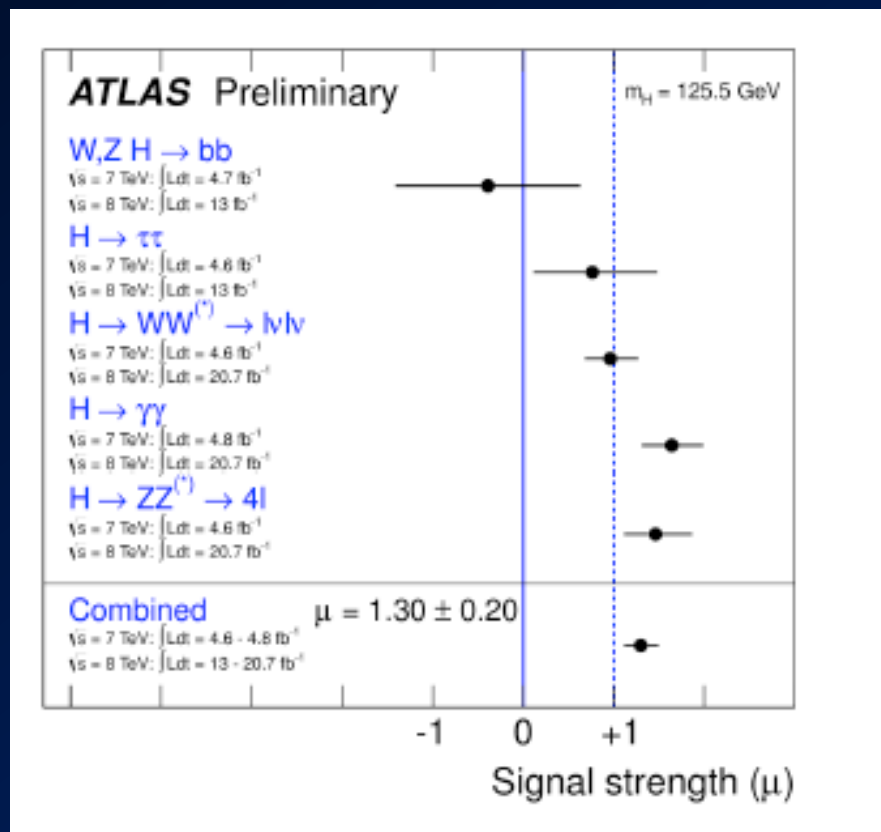
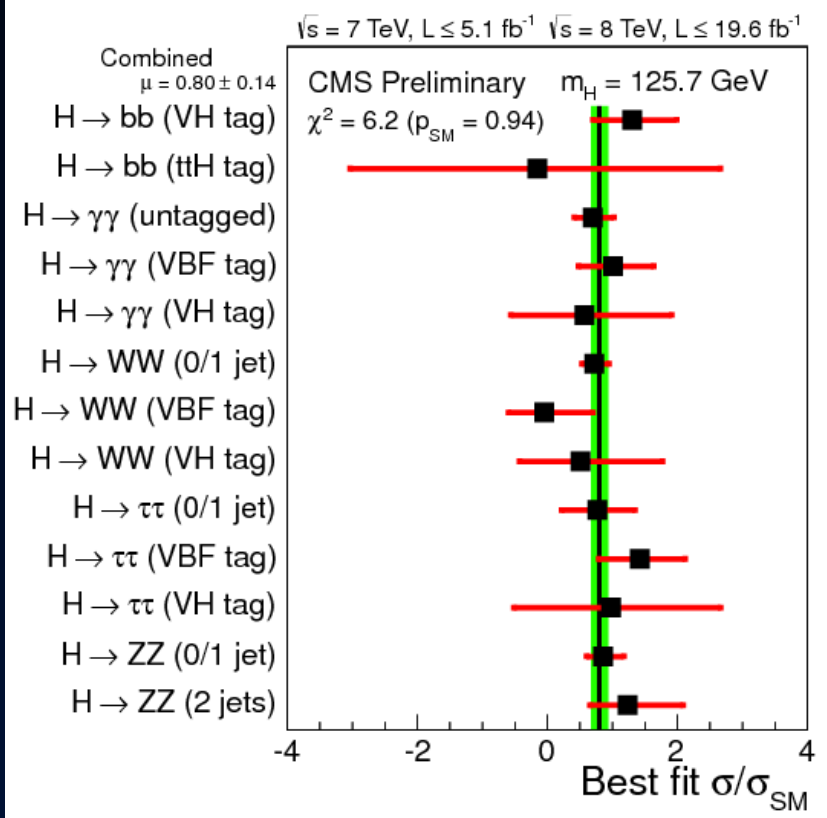
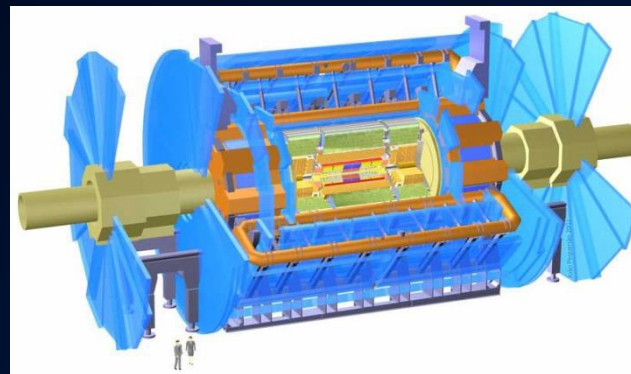
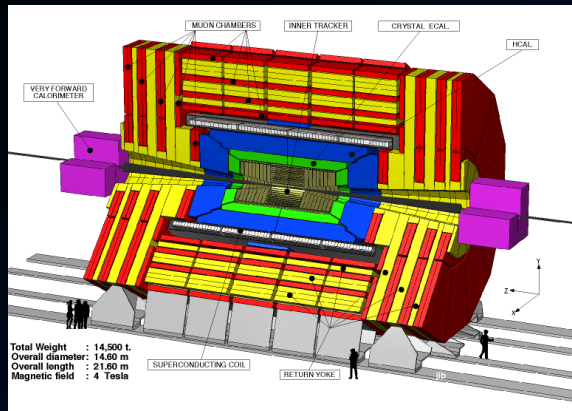
Smallest fraction of total, but  
experimentally cleanest  
way to detect the Higgs



# 2 years of data, 100's of person years in 30 seconds!



# Does it decay as you'd expect?



# So, what's next?

## More questions to answer about the Higgs

- 1) Is this really the Standard Model Higgs particle?
- 2) Why is the Higgs mass 125 GeV ?
- 3) Is the Higgs fundamental?

## And other deeper questions remain...

As elegant as the Standard Model is, it cannot be the final word..

- 1) What is the dark matter in the Universe?
  - Fundamental particle is the most likely explanation
- 2) Why are there (only) 6 quarks and 6 leptons ?
- 3) Do all the forces unify?
- 4) What is the Dark Energy in the Universe?
- 5) How does gravity fit in?

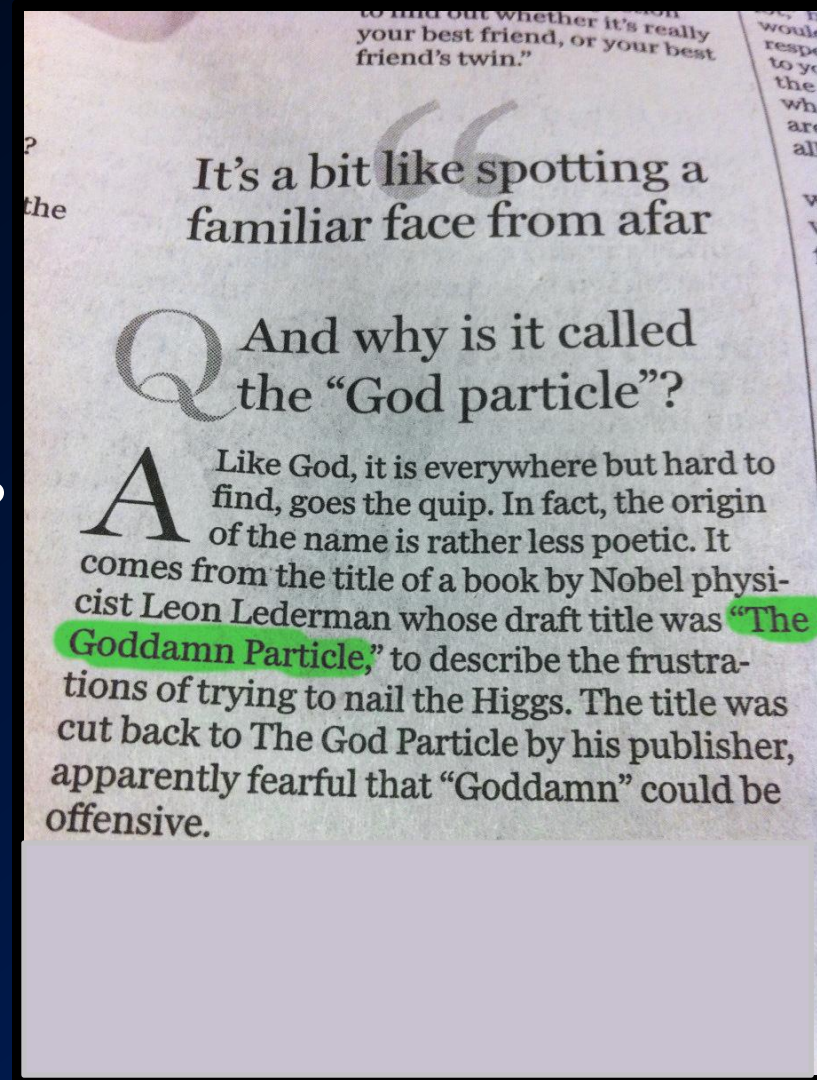
# LHC on tap

- ❑ The LHC will restart in 2015.
- ❑ Will start amassing much larger data samples
- ❑ Proton beams energy increase from 4 TeV to 6.5 – 7.0 TeV
- ❑ ~2X larger beam intensity
- ~4X larger Higgs' produced / time..
- Precision tests in the Higgs sector ... SM only, other Higgs's lurking? ...



# Summary

- After 50 years, the long-sought question on the **origin of mass** appears to have been answered.
  - It does appear to be 'the Higgs' ?
  - But....
- But more, deeper questions remain.
- More data from **the LHC, neutrinos space-based experiments** will provide clues!



IT VERY WELL MIGHT !



But, don't believe me...

Thank You

MON DIEU!  
HARPER COZIES UP  
TO THE FRENCH P.16

BANK SCANDALS

TOO BIG TO BEHAVE

WHY GLOBAL BANKS CAN'T BE TRUSTED P.34



SHOULD  
WE BAN  
FLIP-FLOPS? P.4

# MACLEAN'S

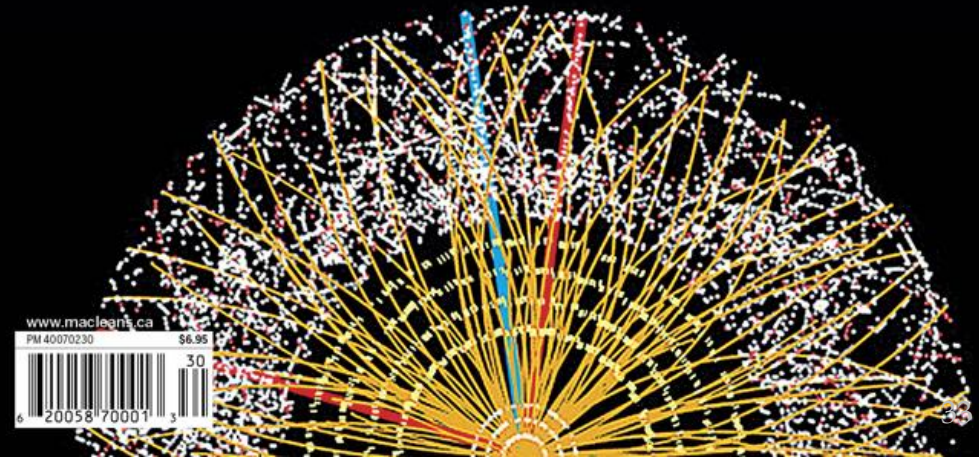
CANADA'S NATIONAL MAGAZINE

JULY 23, 2012

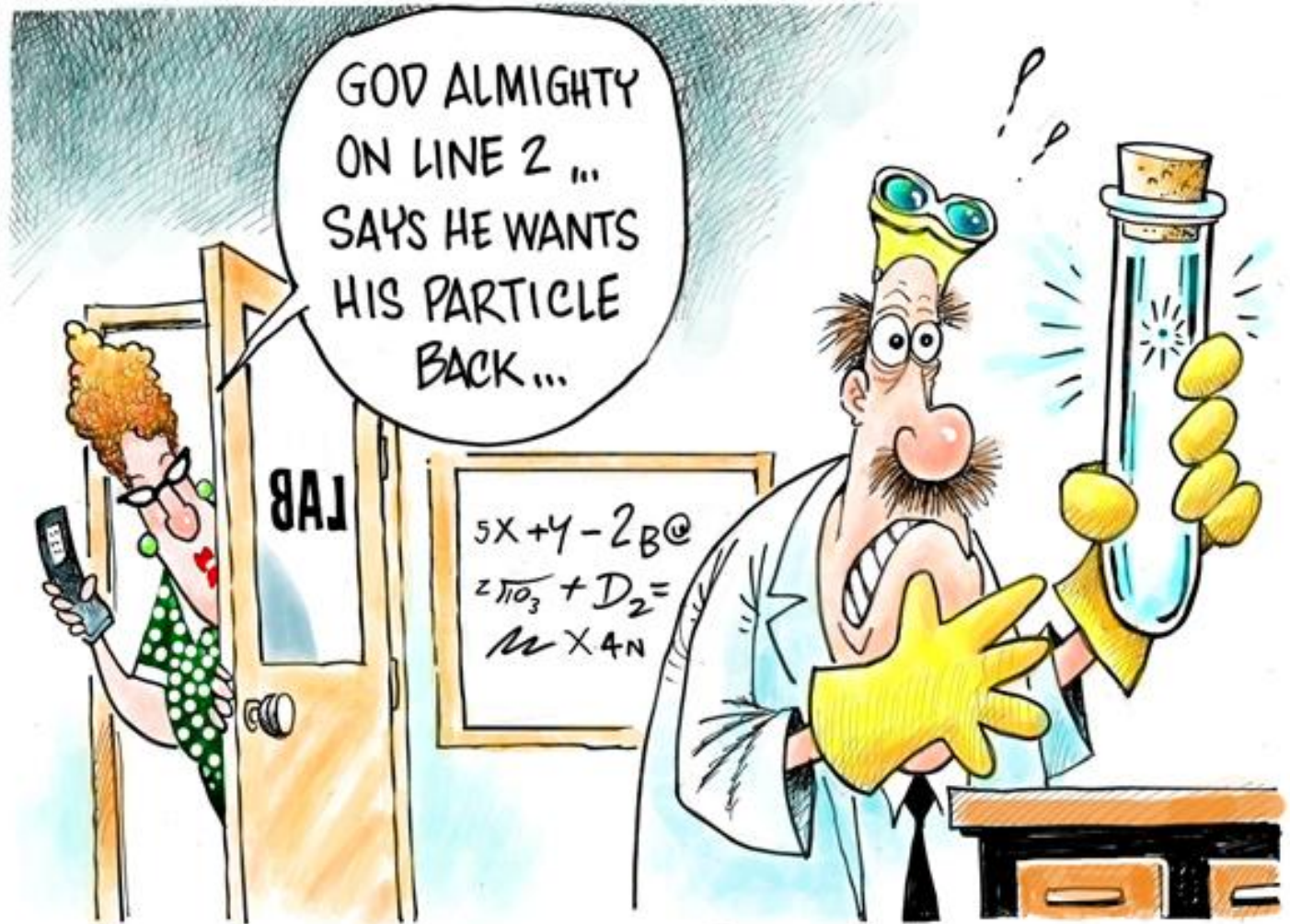
Teleportation, phasers, alternate dimensions:  
the **Higgs boson** discovery does more  
than just explain the universe

## THIS CHANGES EVERYTHING

A SPECIAL REPORT FROM SWITZERLAND P.40



# FINI...



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