THE SIMPLE LO-DOWN ON THE GOD PARTICLE

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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 ?

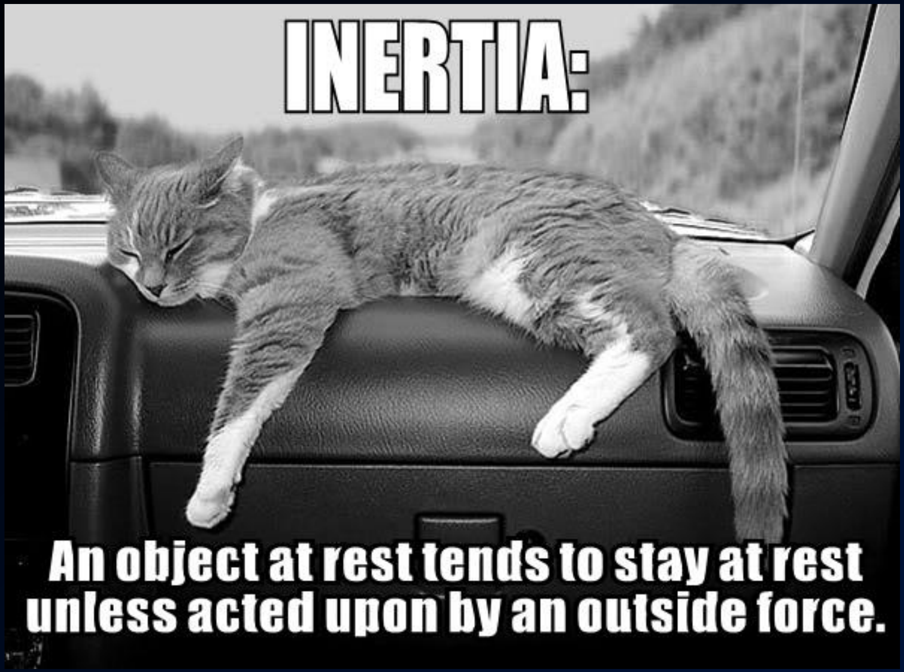
- **Mass**: **mass** refers to the quantity of matter in an object….

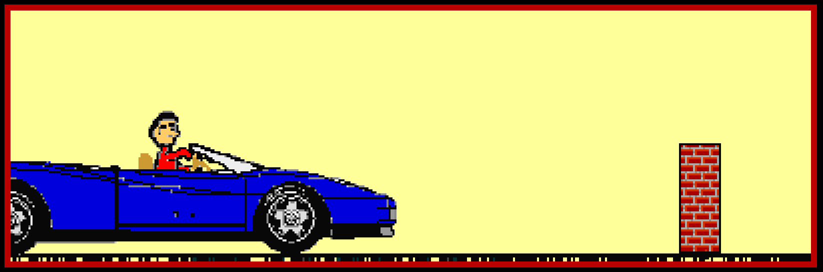
Small mass ..

Dung beetle, pushing, well, you know what …

Large mass ..

Definition 2: Measure of Inertia





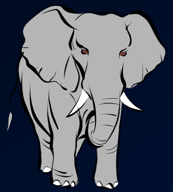
Object in motion stay in motion unless acted on by a force

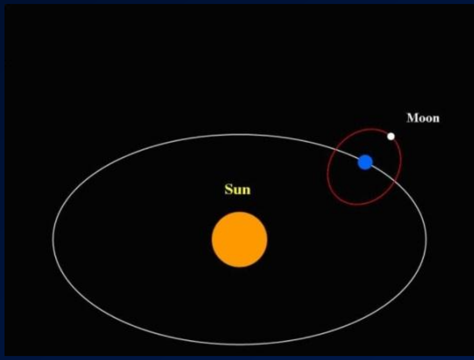
Inertial mass

Measure of how hard it is to <u>change the state of motion</u> of an object

Definition 3: Gravitational mass

- To explain why
  - All objects in free-fall experience the same acceleration ($g = 9.8\ m/s^2$) 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:

$$F_g = mg$$

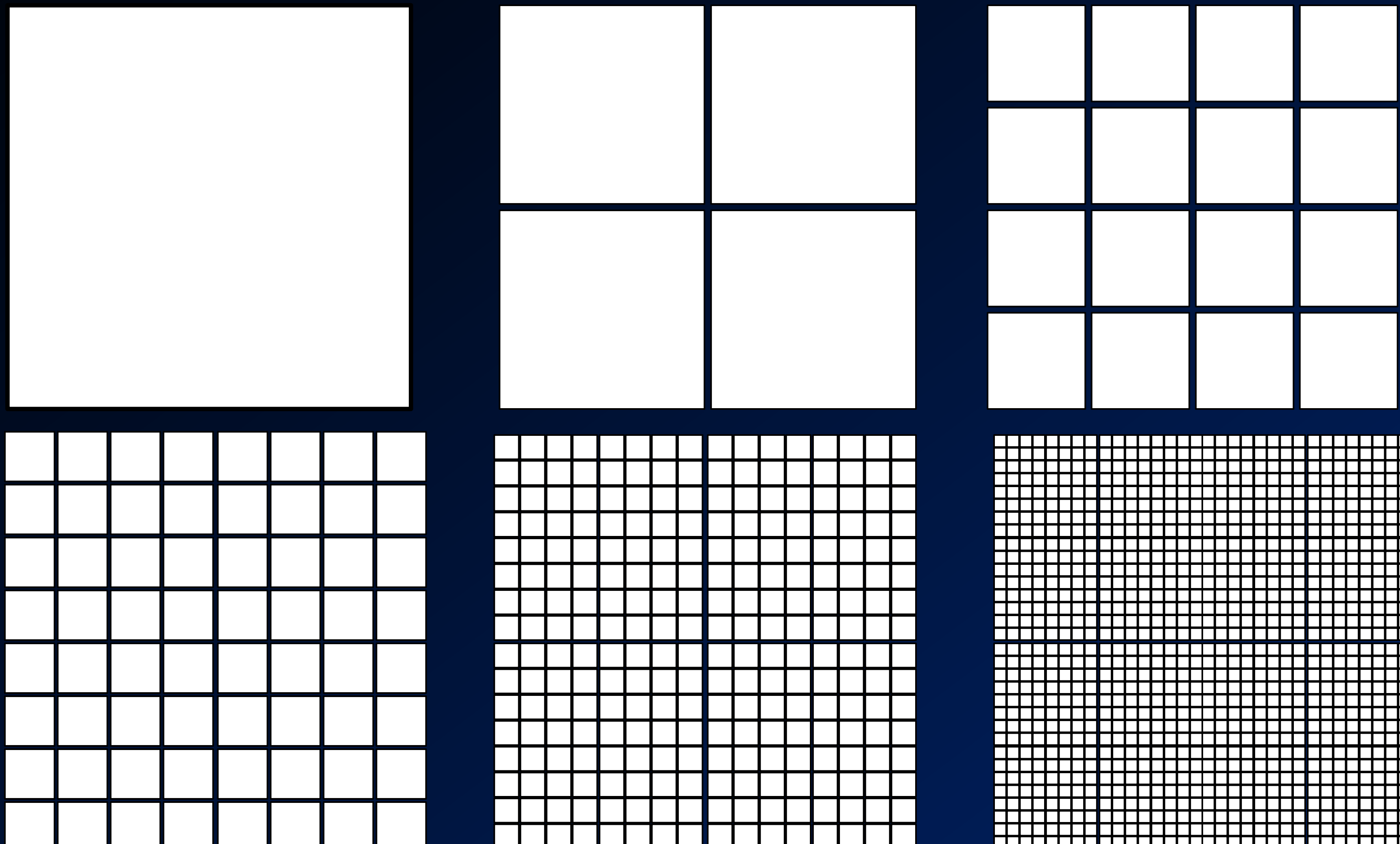
- **Gravitational mass**:
  the quantity that connects the gravitational force (F_g) and g

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.

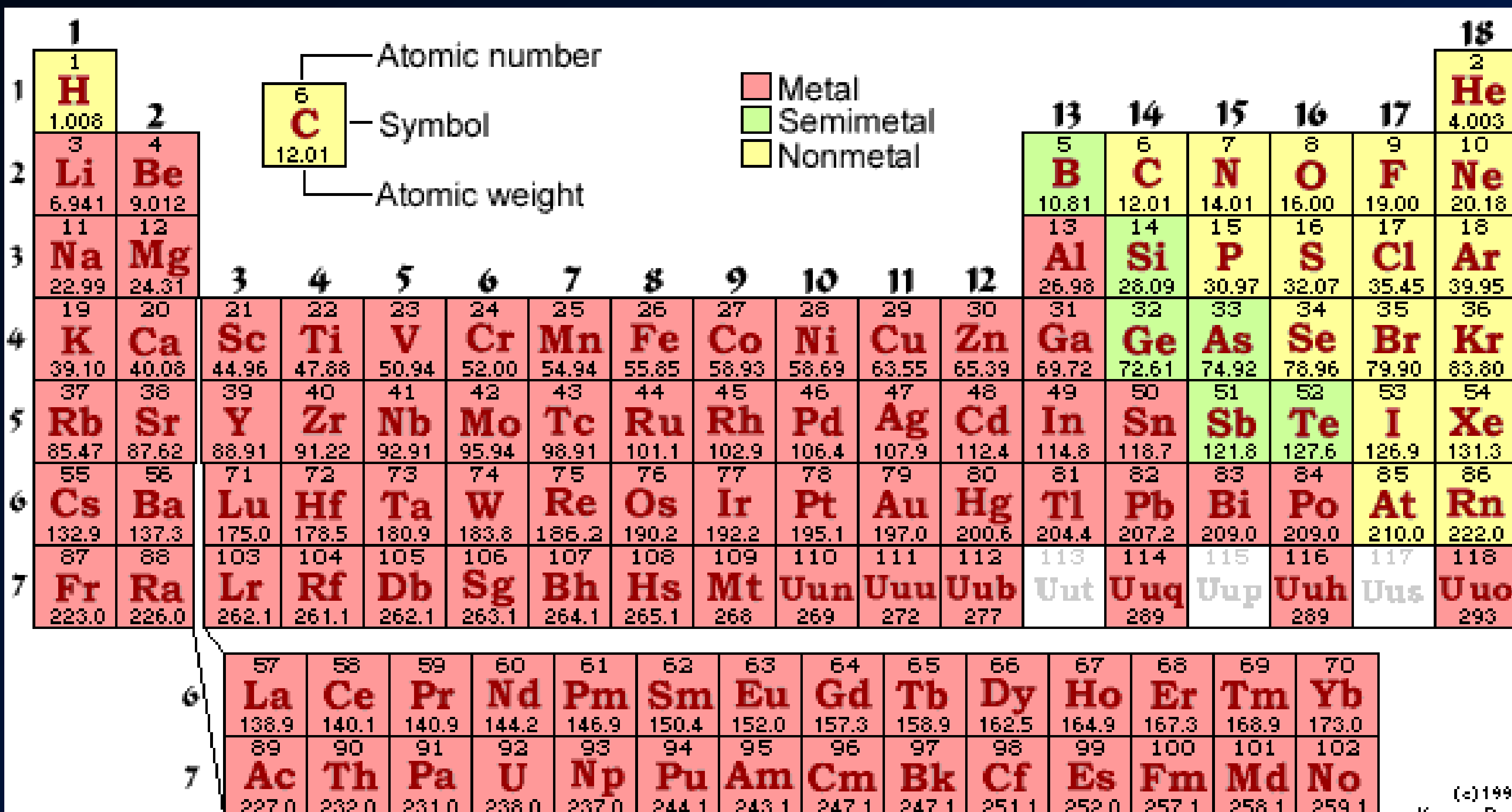
- But why do things have the mass that they do?
  - Why does an electron have a mass of 9.11×10^{-31} kg?
  - Why does a proton have a mass of 1.67×10^{-27} kg?
  - How do these particles acquire mass, and why do they have the values that they do?

Fundamental constituents of matter

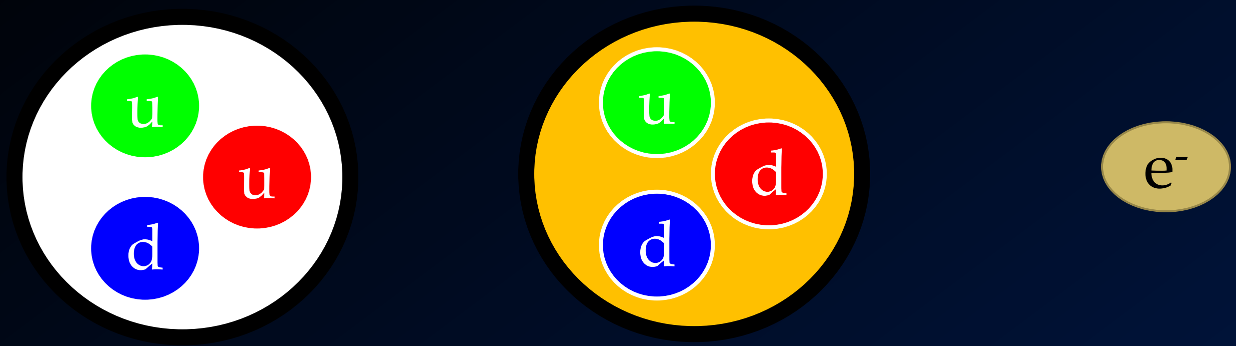


Keep ripping…

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



And life was sooo good …



proton　　neutron

Charges:

up = +2/3

down = -1/3

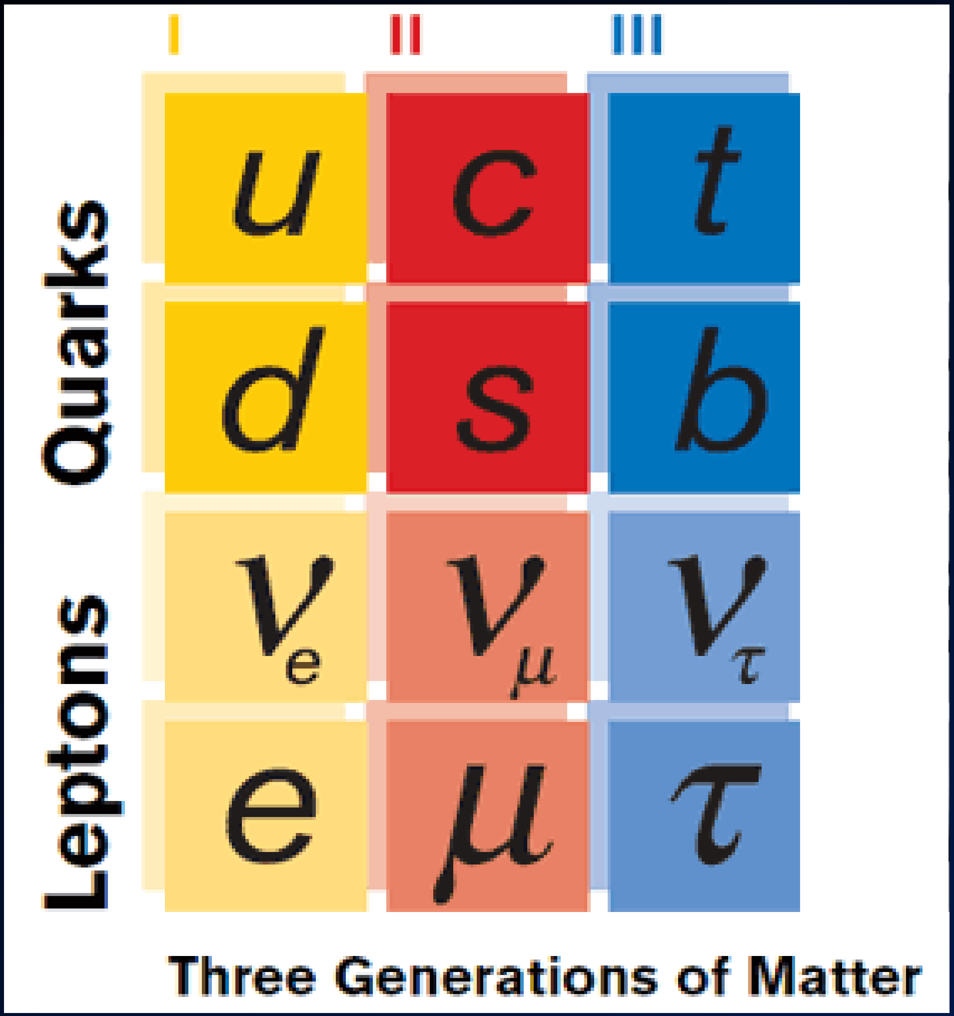
electron = -1

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 (μ^-) and tau (τ^-)
  - 3 (almost massless) neutral particles: neutrinos (ν_e, ν_μ, ν_τ)

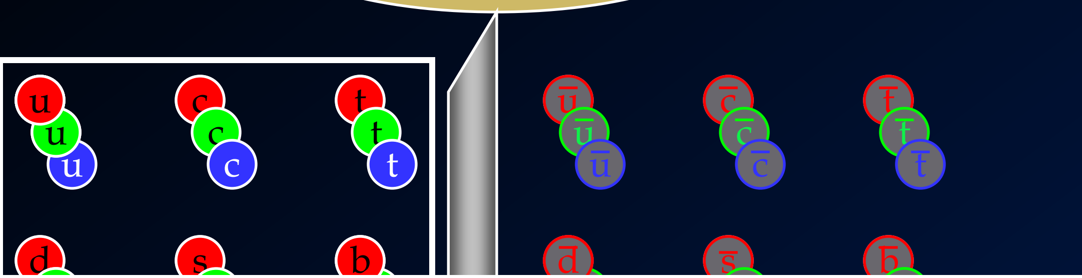
The "new" periodic table



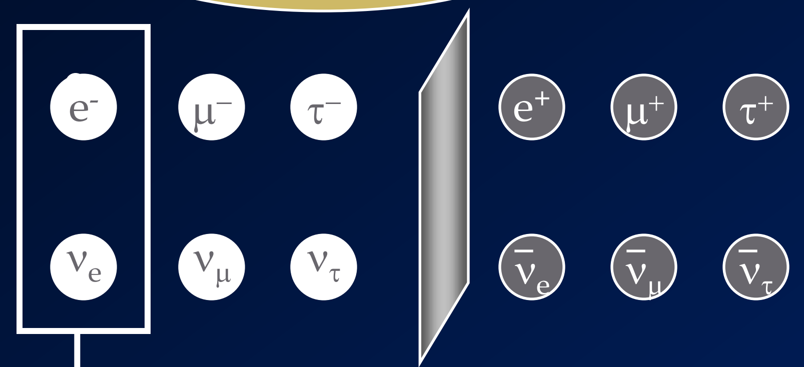
- Rather than 100+ seemingly different forms of matter, we have a **much simpler** structure !
- 3 "families"
- We have also discovered that all of these particles have a corresponding **antiparticles** !

Matter in the Standard Model

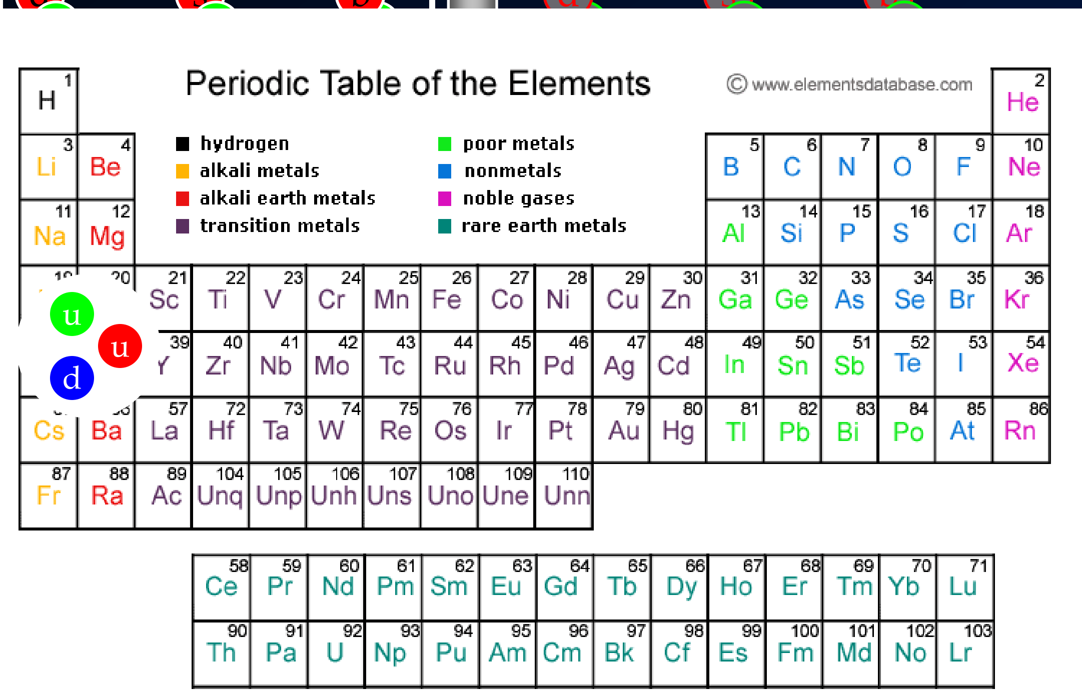
Quarks



Leptons



Observed “free”in atoms, nuclear reactions



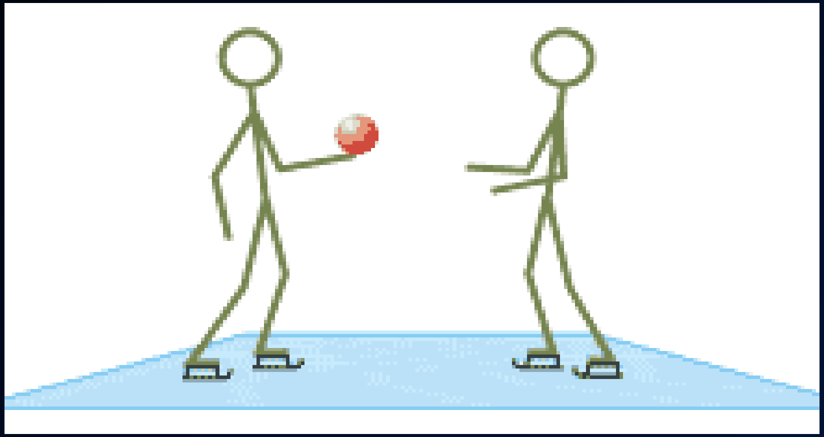
Hydrogen

Fundamental Forces

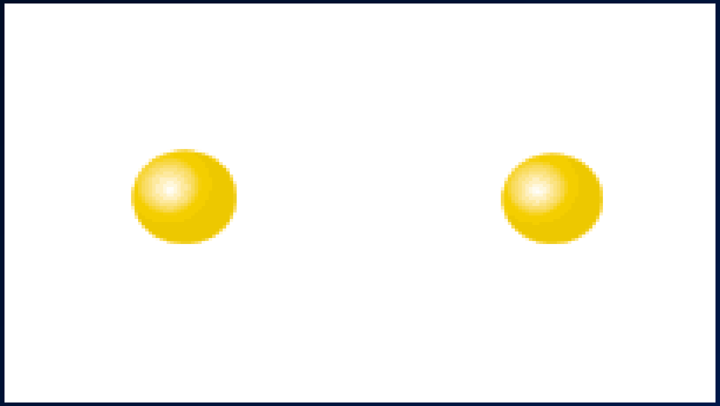
How do the fundamental particles interact with each other?

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



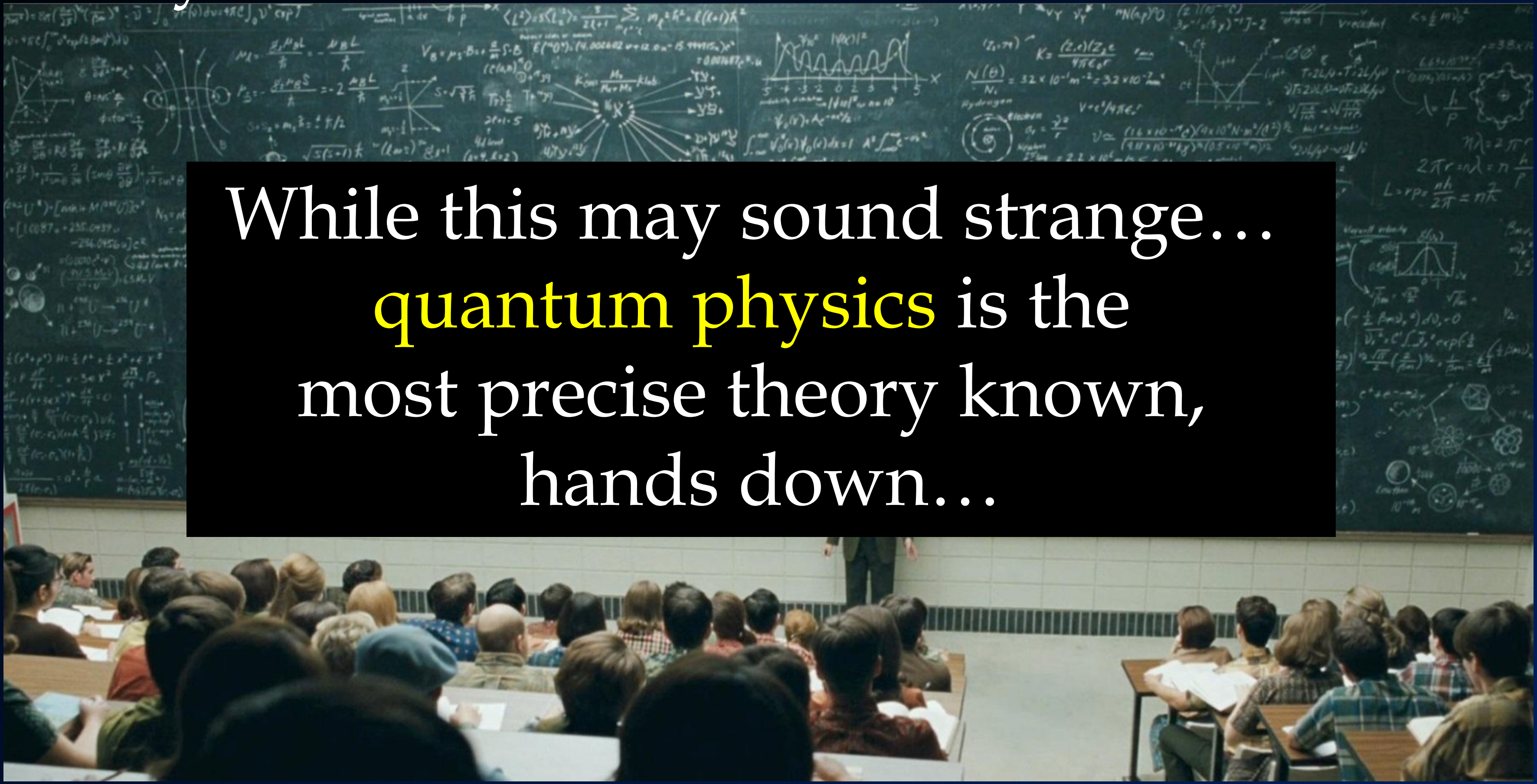
Interactions == Particle Exchange

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…

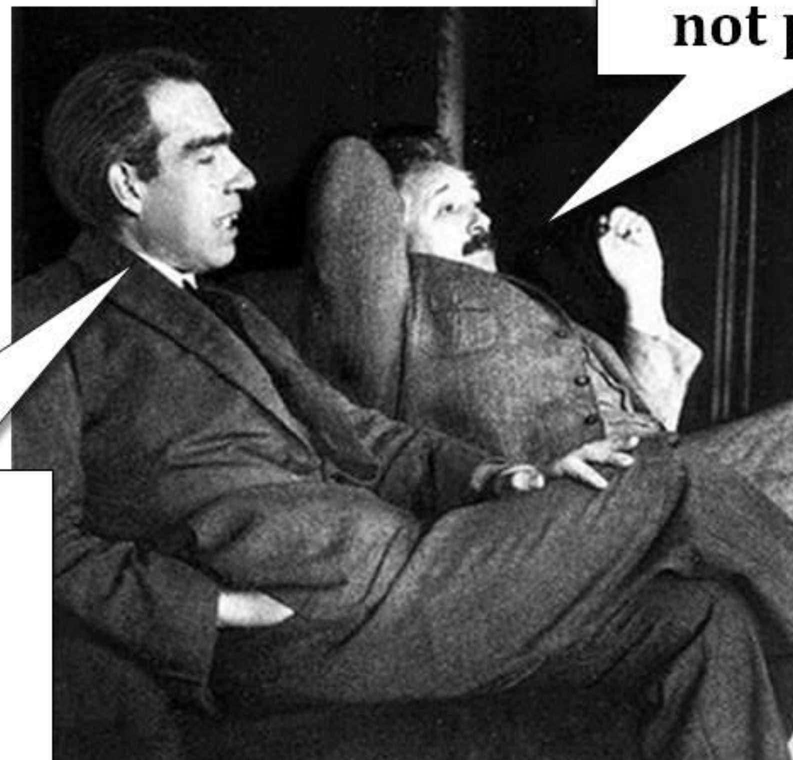
Quantum physics in brief:

1) Unless strictly forbidden, anything is possible with some probability.

2) Laws of physics governed by probabilities!

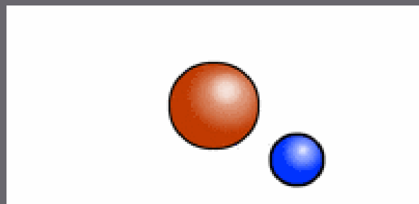
3) The probability that you could walk through a wall is **not zero** !

It drove Einstein crazy !



A Einstein and N. Bohr

Standard Model forces and force carriers

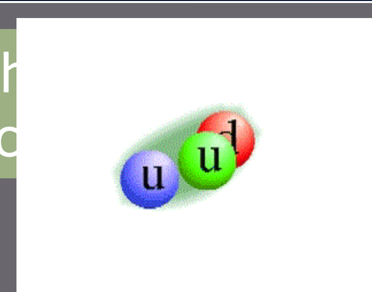


γ

EM Force (photon)

Photons interact with **electric** charge

Wh the nuc er?



g

Strong Force (gluon)

Gluons interact with **color** charge

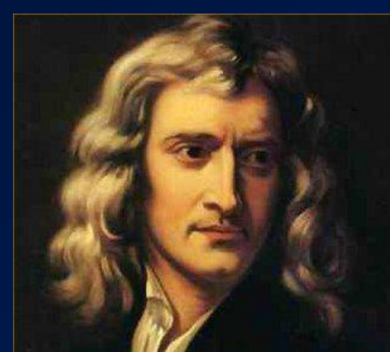
Massive Force Carriers

$W^{\pm}$

Z^0

Weak Force

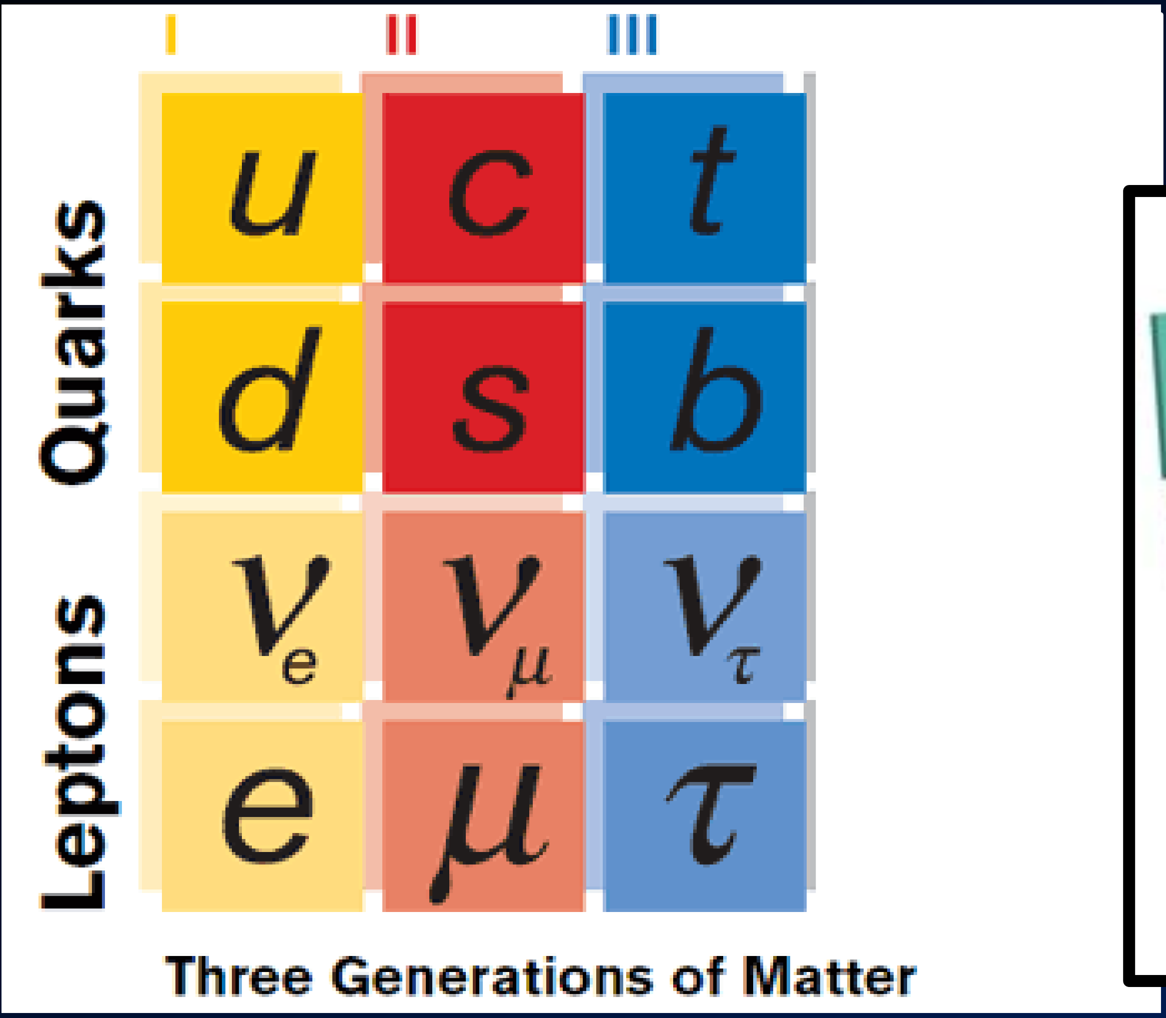
But, what about gravity????



No quantum theory for gravity (yet)

VERY HARD PROBLEM

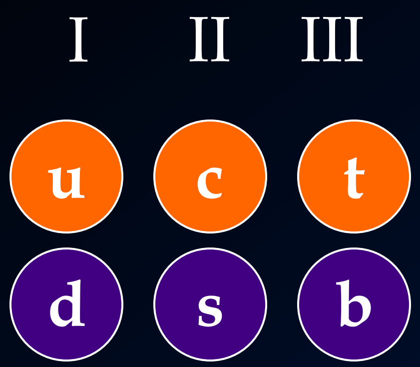
The "almost complete" Standard Model



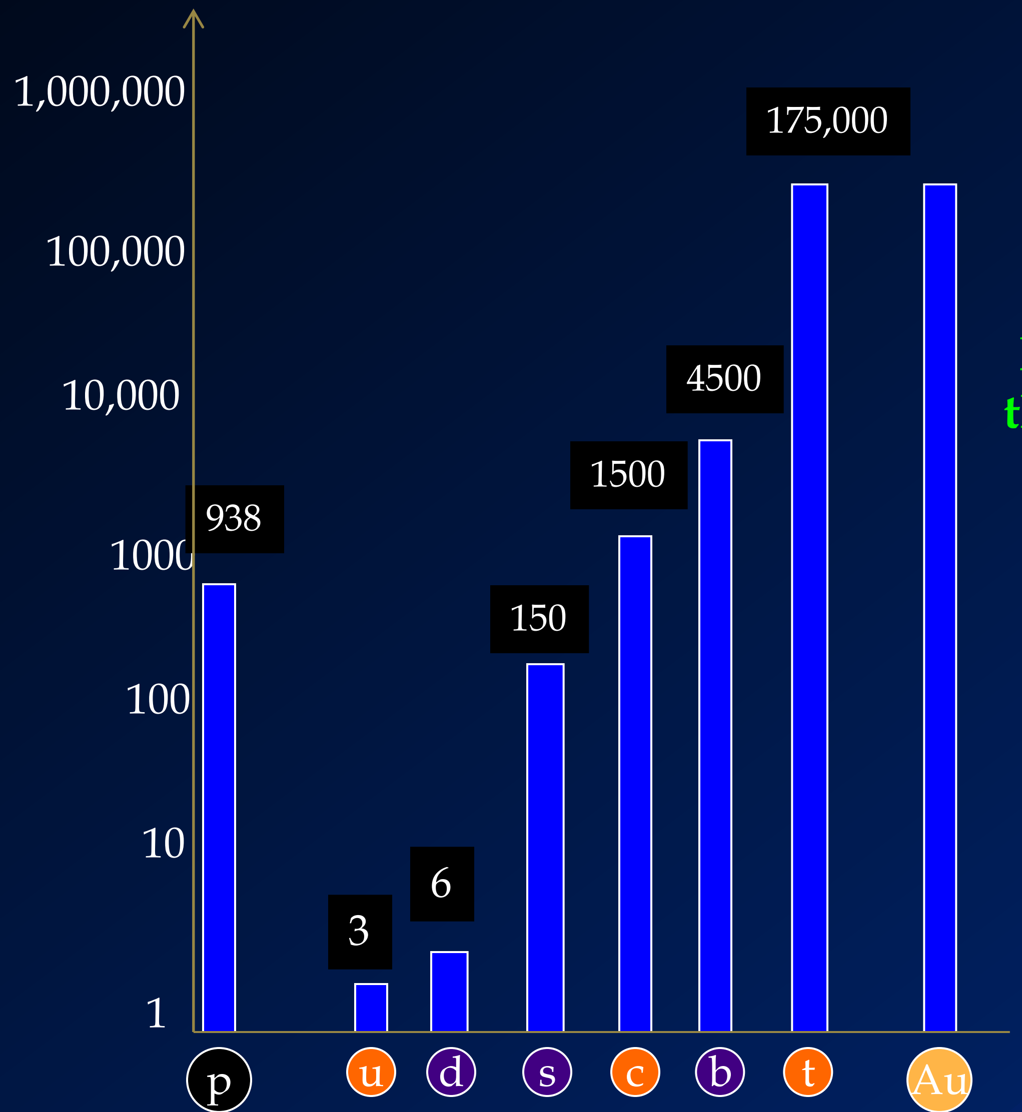
But still, there is one missing piece…

The question of mass

- How do particles get their mass?
- Why do quarks have the masses that they do?



- Mass?
  - Let's weight them



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

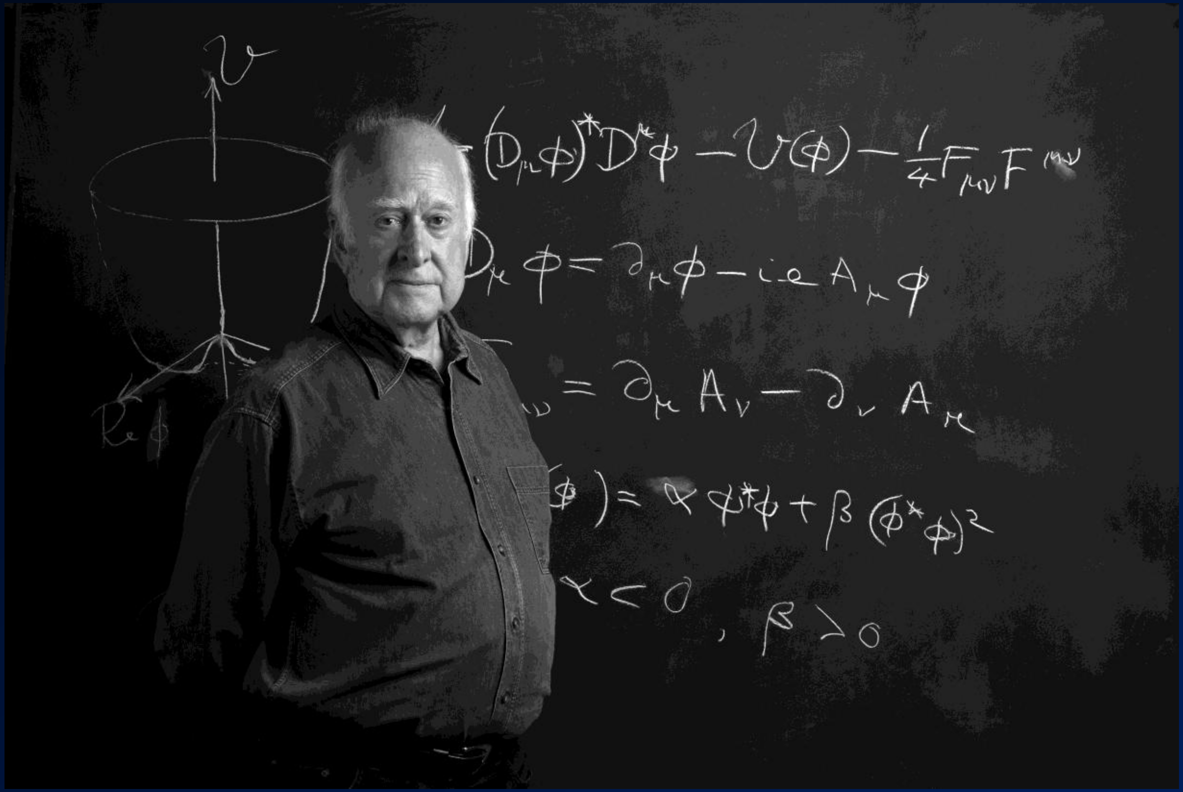
Why?

What was nature thinking?

The long-standing puzzle

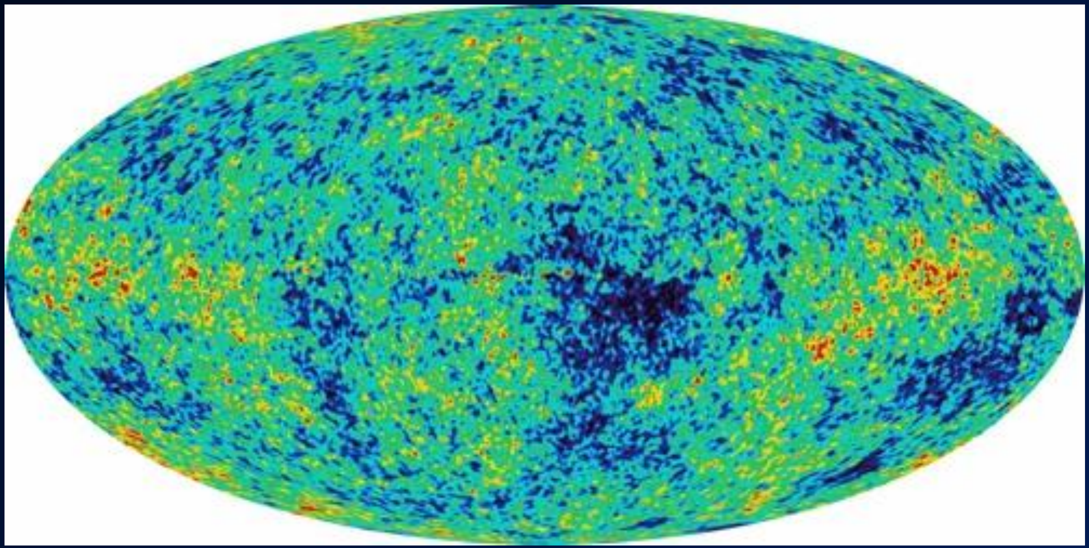
How do particles get their mass?

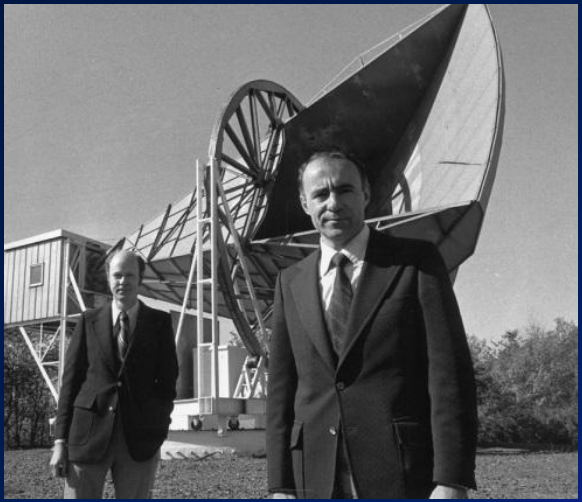
An explanation was put forth by **Peter Higgs**, and several others in 1964..



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

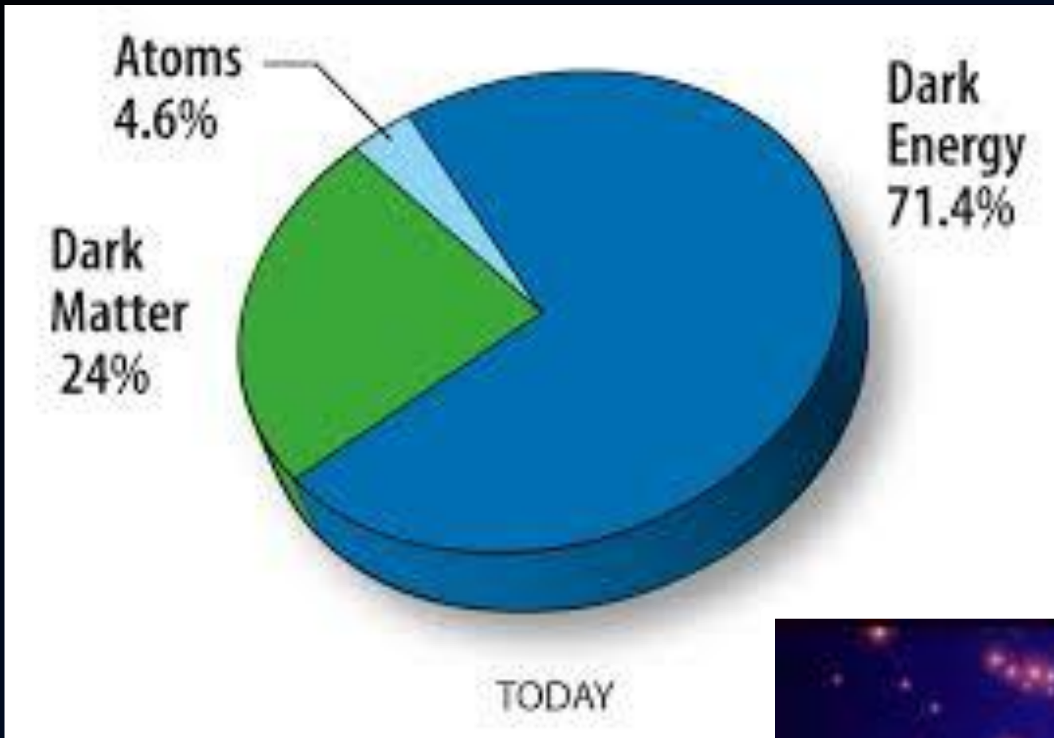
- Data support that the Universe was created in a cataclysmic event, called the **Big Bang**.
- All the matter we see today, such as stars, planets (and us) are a result of this event.
- **But were there things created that are not so easily seen?**
  - **1964:** Discovery that the Universe is completely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





Penzias & Wilson

Other mysterious things lurking …



What does this have to do with the Higgs particle?

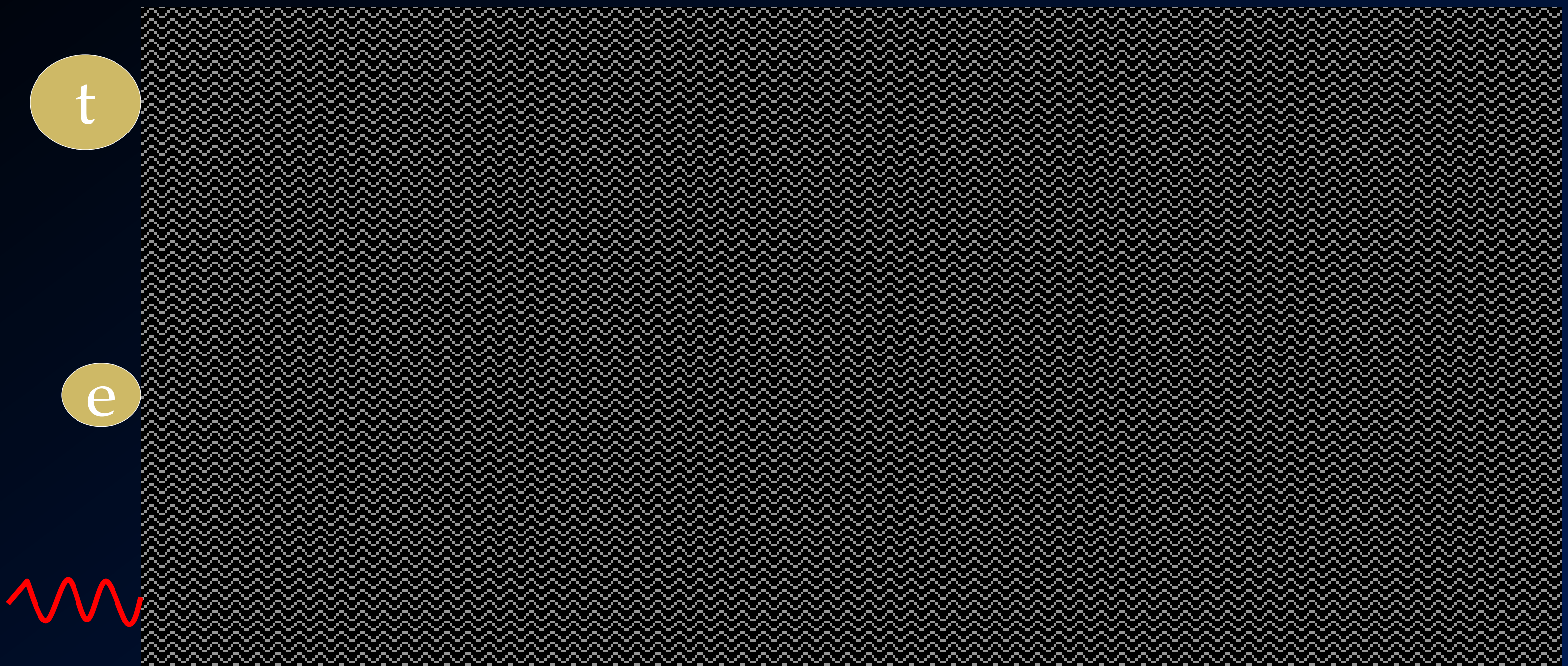
- Suppose the Universe is also filled with an invisible "field", called the **Higgs field**….
  - Yup, also **a remnant of the Big Bang**!

- **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…

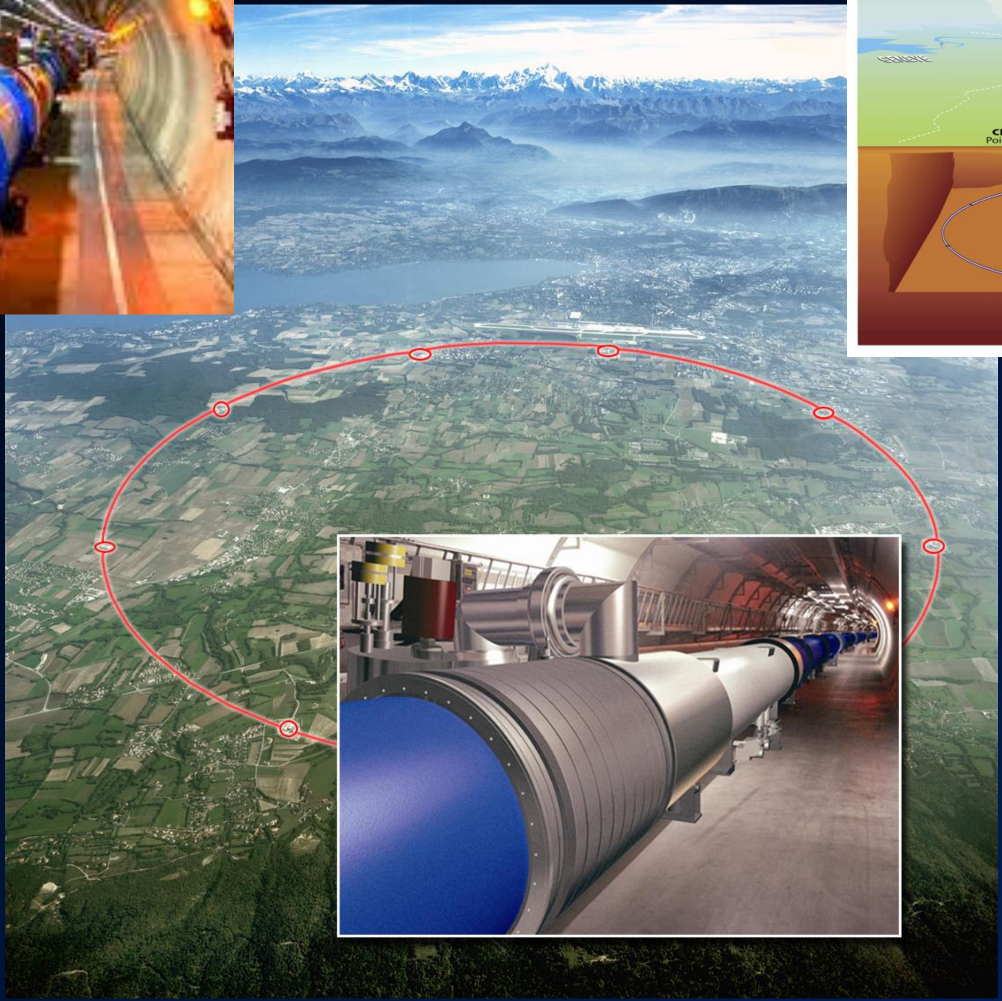


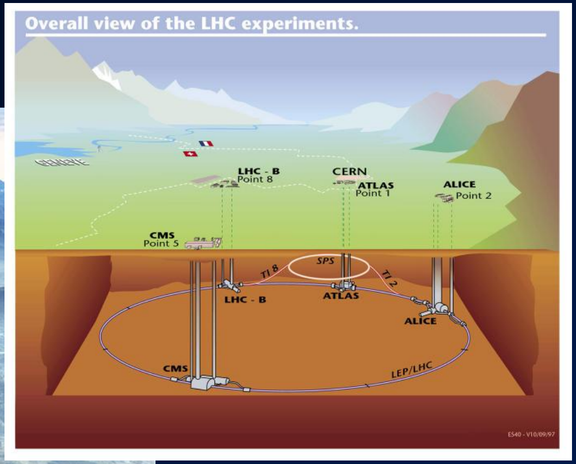
Since the top quark interacts most strongly with the Higgs field, it is harder for it to move through the Higgs field

→ Larger inertia → interpreted as larger mass

→ Photon is interpreted as having zero mass

Making it happen – the accelerator



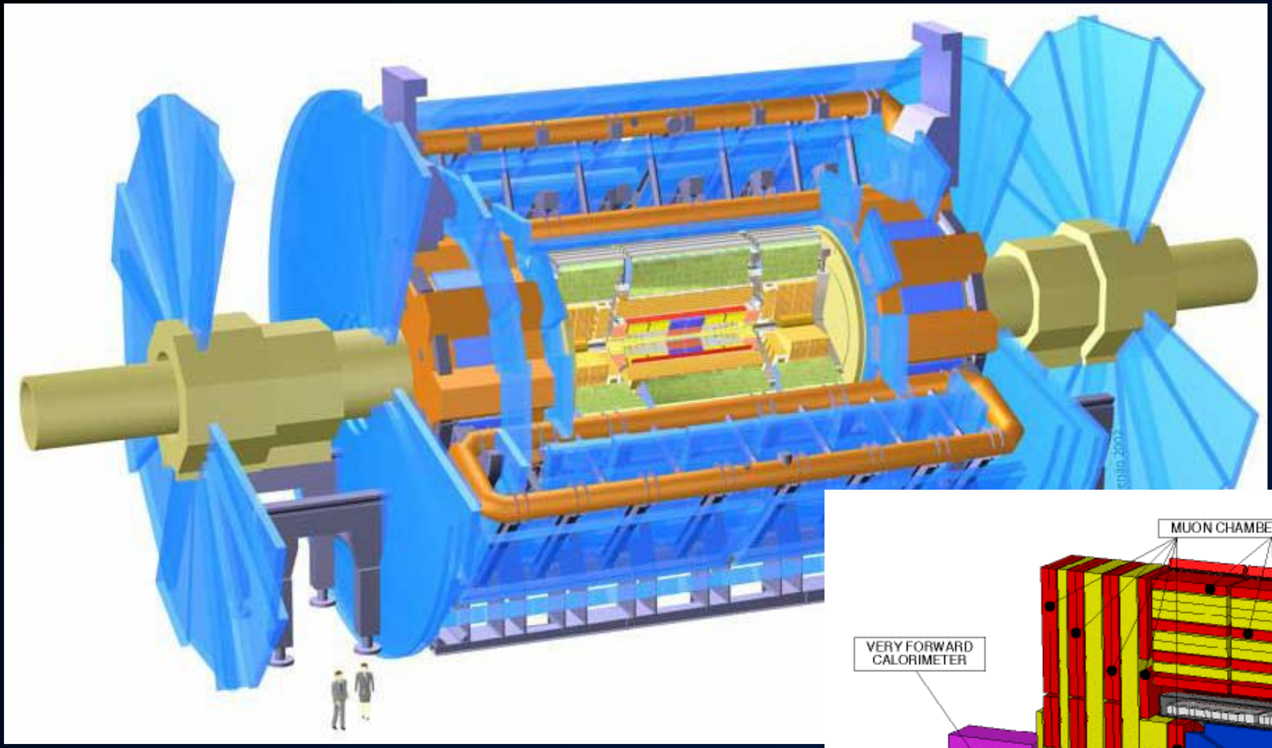


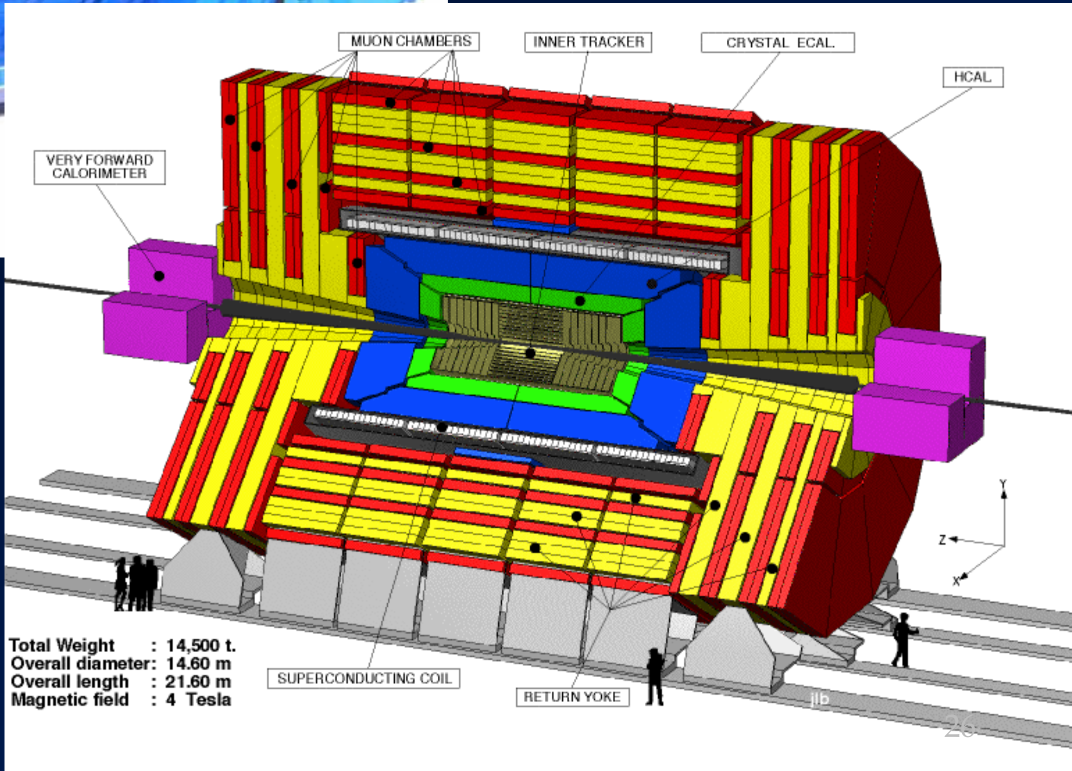
Movie

Large Hadron Collider:

Smash high energy protons into one another

Making it happen - the detectors





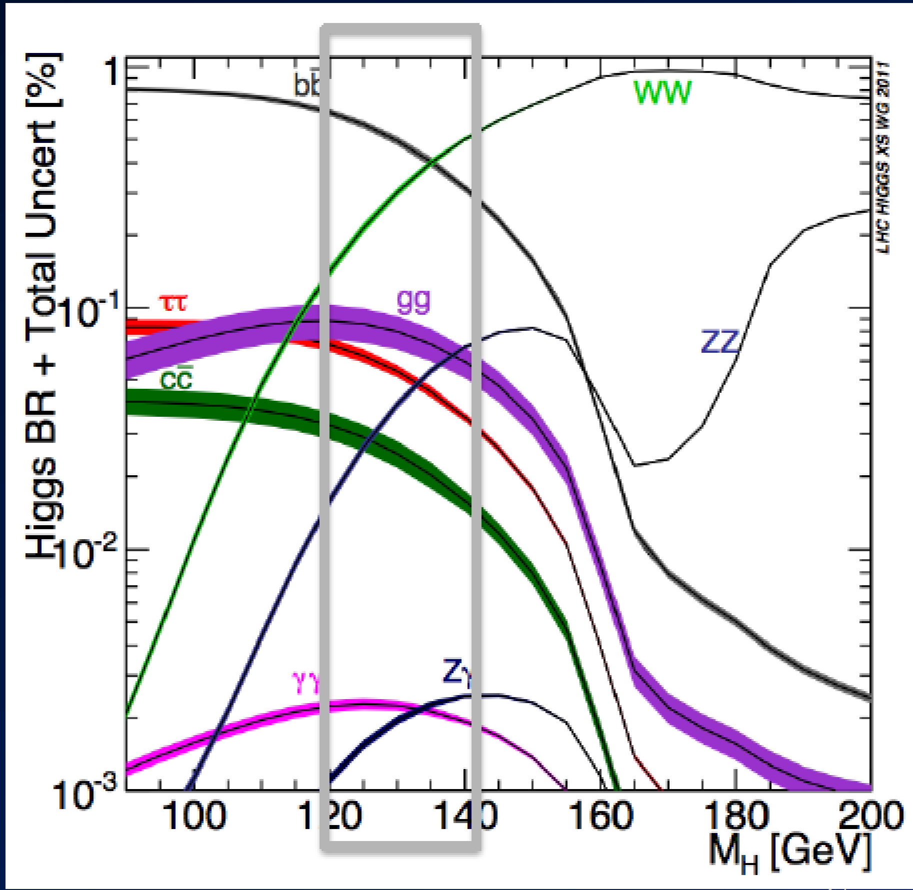
[Atlas from space]

How to detect the Higgs

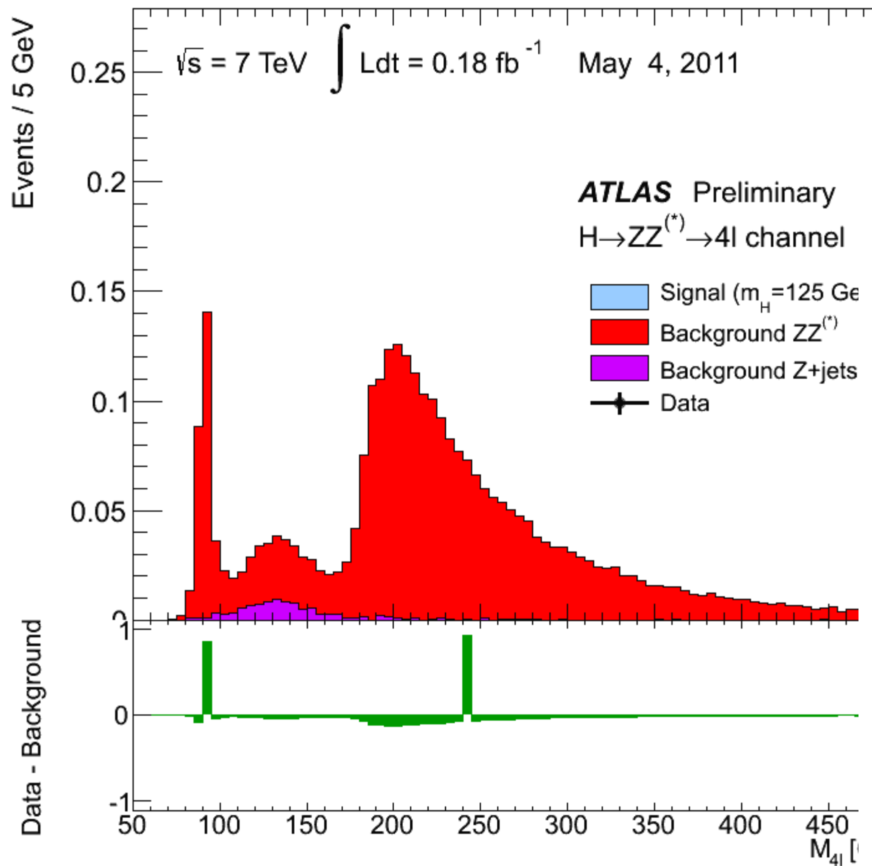
- First you have to produce the Higgs..
  - **Only produced in about 1 / 100,000,000,000 collisions**
- Like most particles, the physical Higgs particle decays.
- In the SM, the Higgs is expected to decay as follows:

- $H \rightarrow bb$ (~ 60%)
- $H \rightarrow W^+W^-$ (~ 19%)
- $H \rightarrow gg$ (~ 9%)
- $H \rightarrow \tau^+\tau^-$ (~ 7%)
- $H \rightarrow cc$ (~ 3%)
- $\mathbf{H \rightarrow Z^0Z^0}$ **(~ 2%)**
- $\mathbf{H \rightarrow \gamma\gamma}$ **(~ 0.2%)**

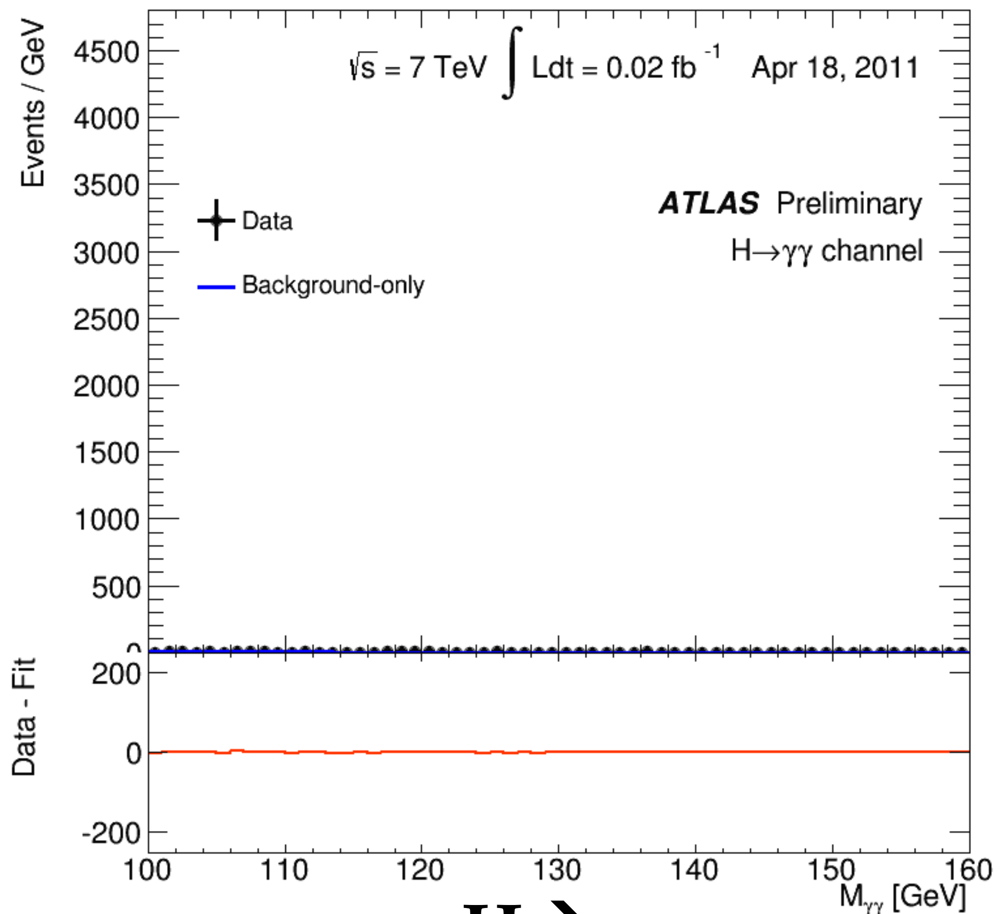
Smallest fraction of total, but experimentally cleanest way to detect the Higgs



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

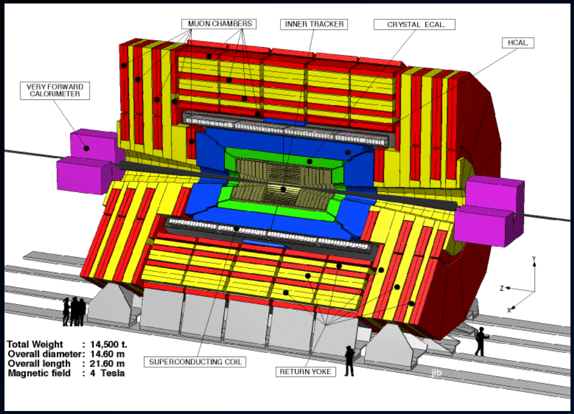


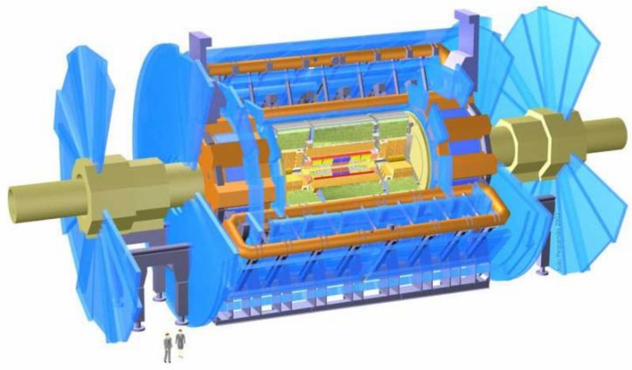
H→Z⁰Z⁰

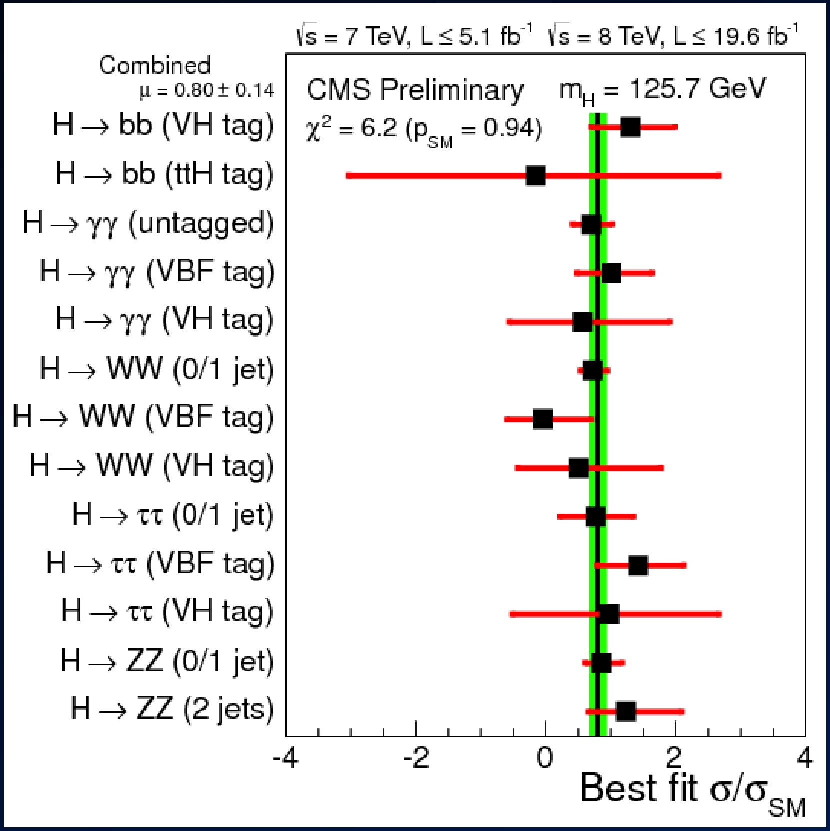


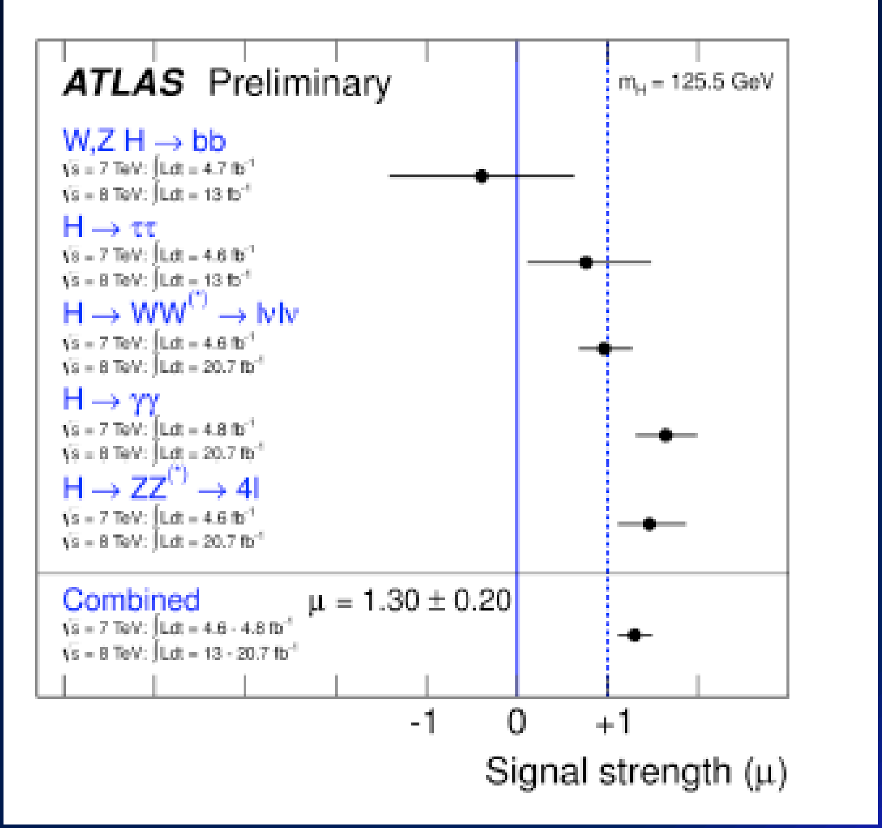
H→γγ

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

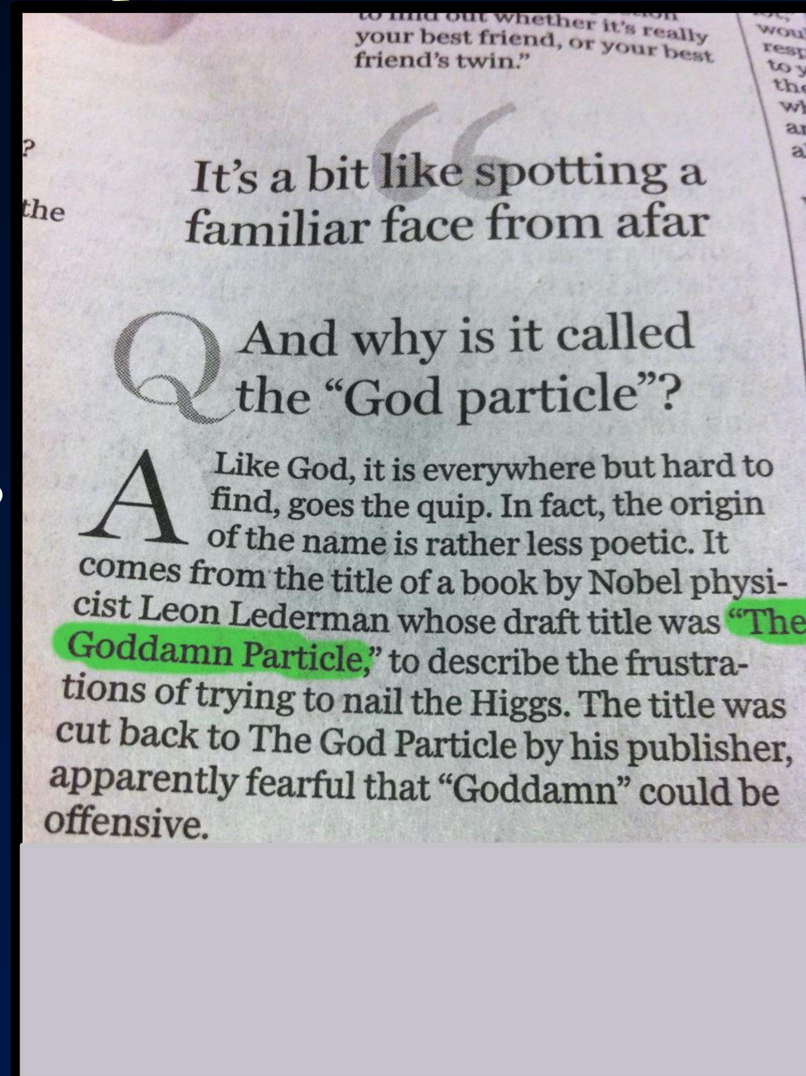
- The LHC will restart in 2015.
- Will start amassing much larger date samples
- Proton beams energy increase from 4 TeV to 6.5 – 7.0 TeV
- ~2X larger beam intensity

→ **~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!



your best friend, or your best friend's twin."

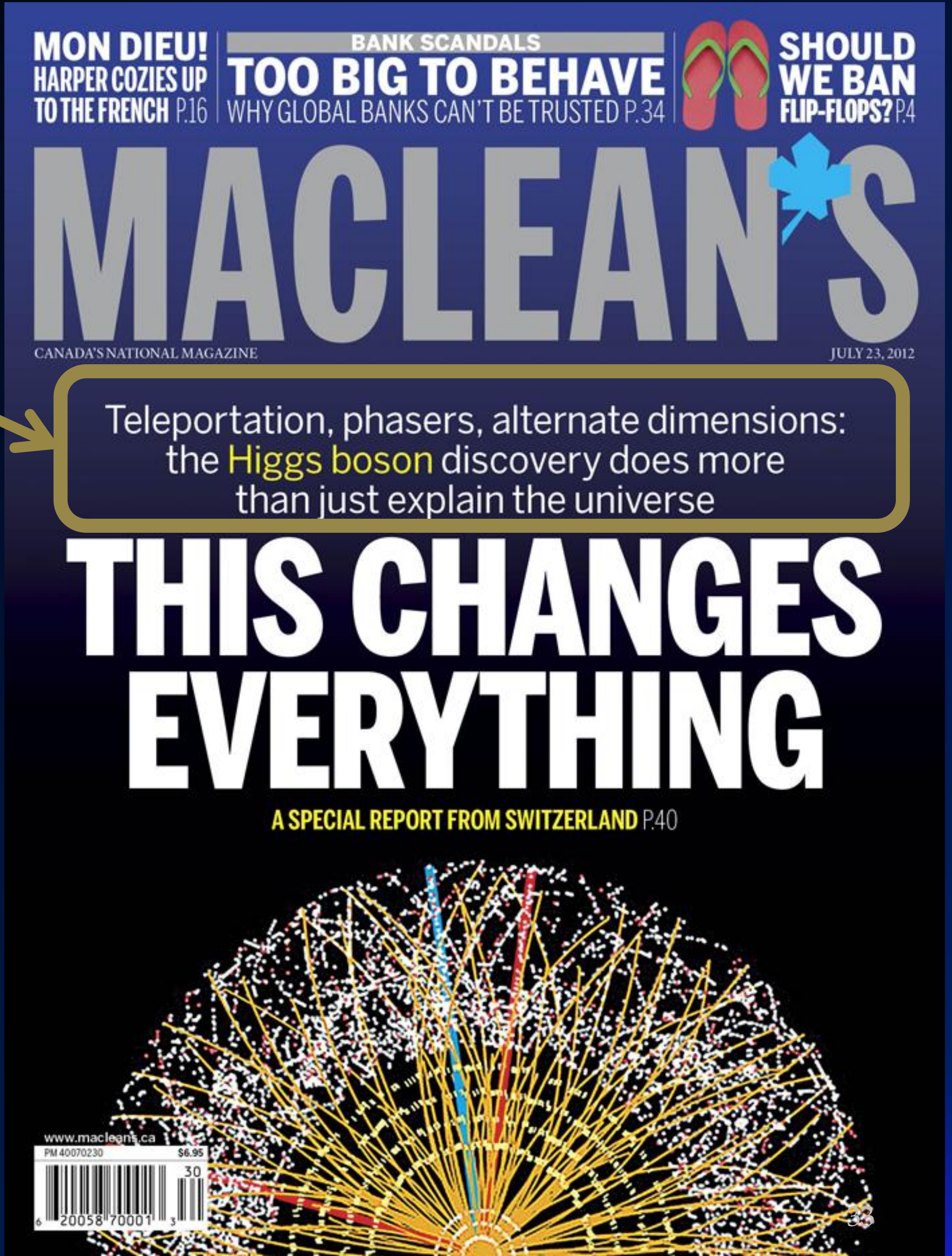
It's a bit like spotting a familiar face from afar

Q And why is it called the "God particle"?

A Like God, it is everywhere but hard to find, goes the quip. In fact, the origin of the name is rather less poetic. It comes from the title of a book by Nobel physicist Leon Lederman whose draft title was "The Goddamn Particle," to describe the frustrations of trying to nail the Higgs. The title was cut back to The God Particle by his publisher, apparently fearful that "Goddamn" could be offensive.

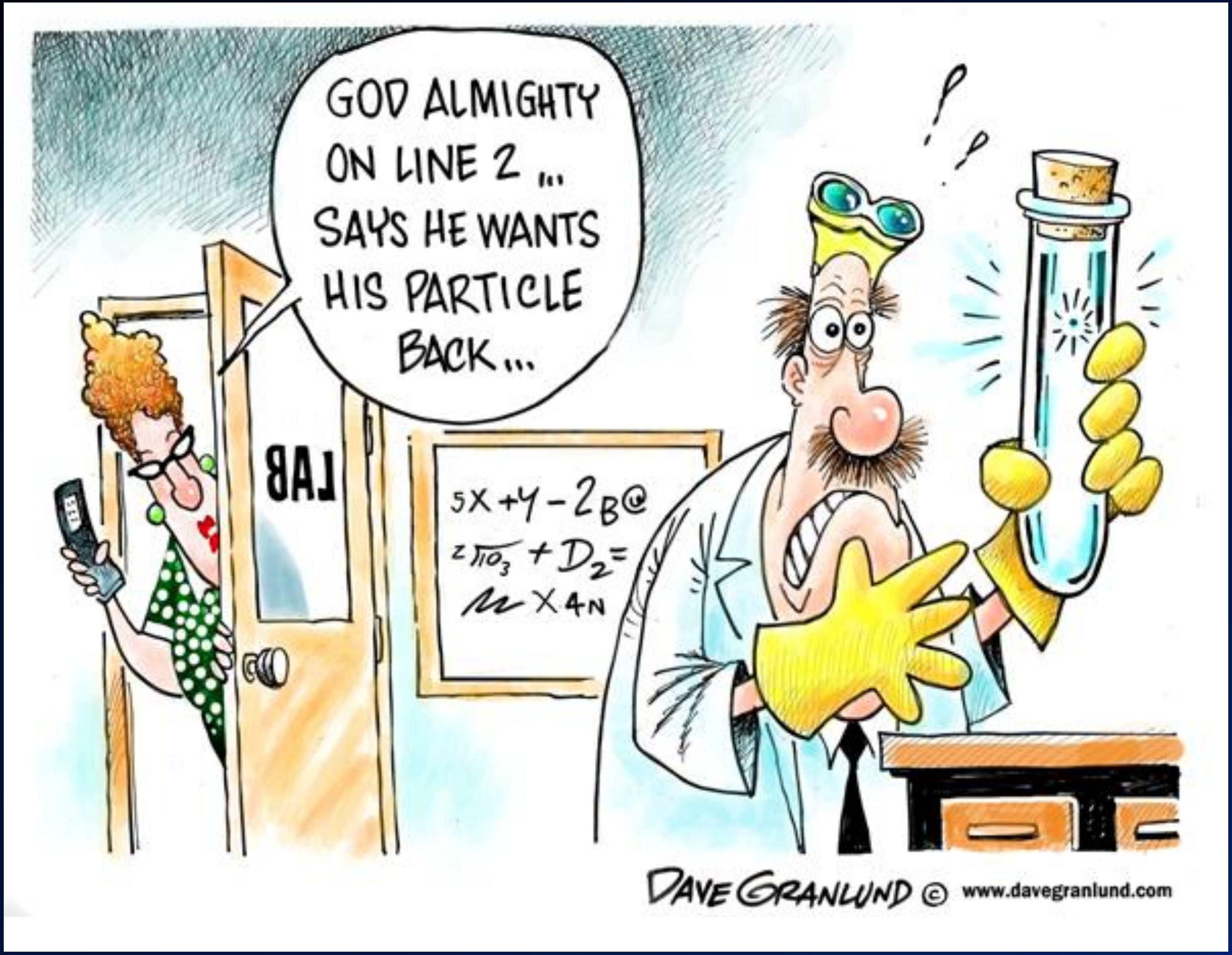
IT VERY WELL MIGHT !

But, don't believe me…



Thank You

FINI…


GOD ALMIGHTY ON LINE 2 … SAYS HE WANTS HIS PARTICLE BACK…
LAB
5X+Y-2B@
2√10₃ + D₂=
XN X 4N
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