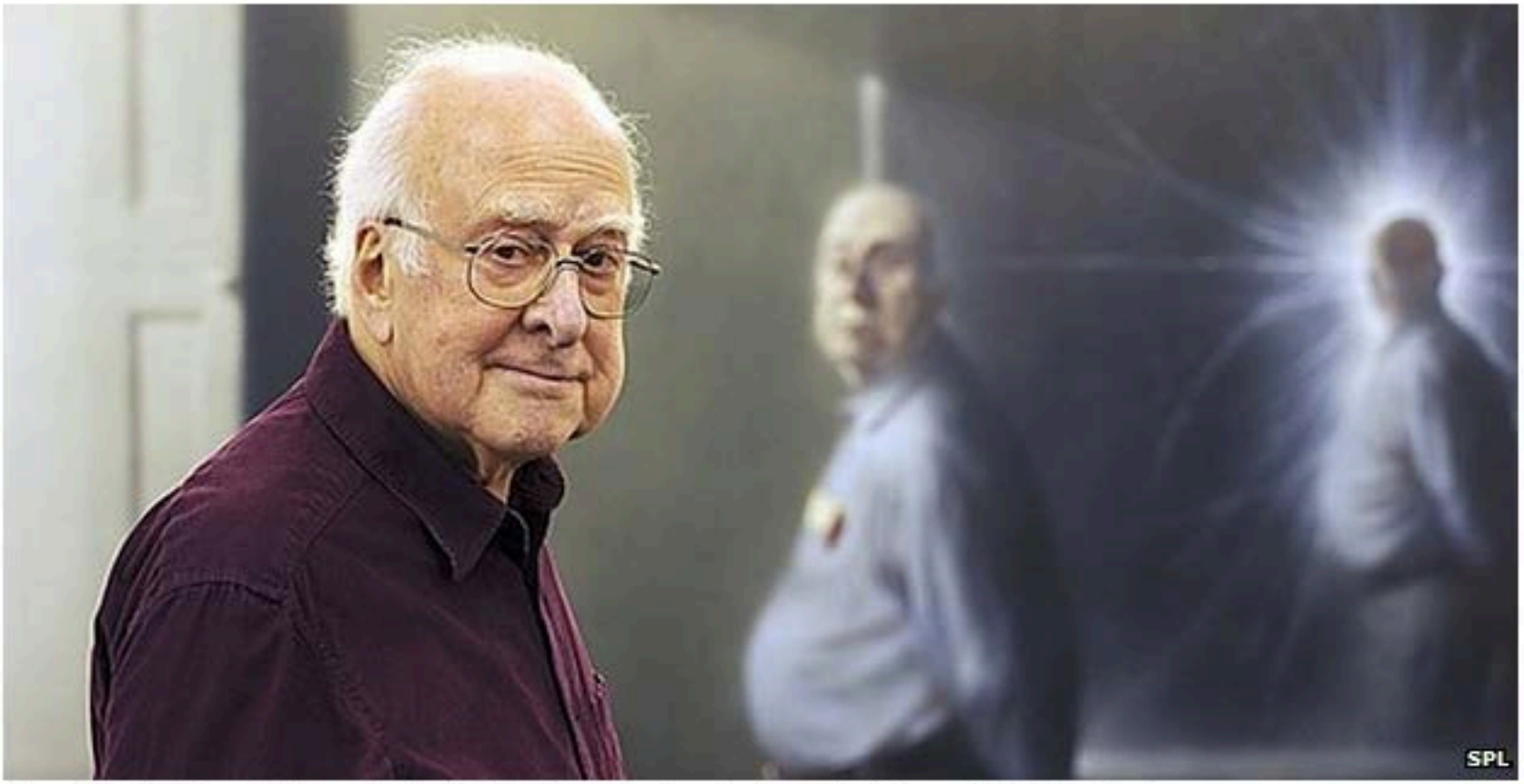
The Vacuum, The EBHGHK+ Field and Mr Higgs' Boson

The vacuum is not nothing

When we understand the vacuum,
we will understand all of fundamental physics

Mike Albrow
Fermilab



Here, the Edinburgh-based physicist stands in front of a portrait by artist Ken Currie

The theory of a new field was a joint effort of 6 ++ physicists (~ 1964)
Peter Higgs said there should be a new particle going with the field

The vacuum:

Much ado about nothing

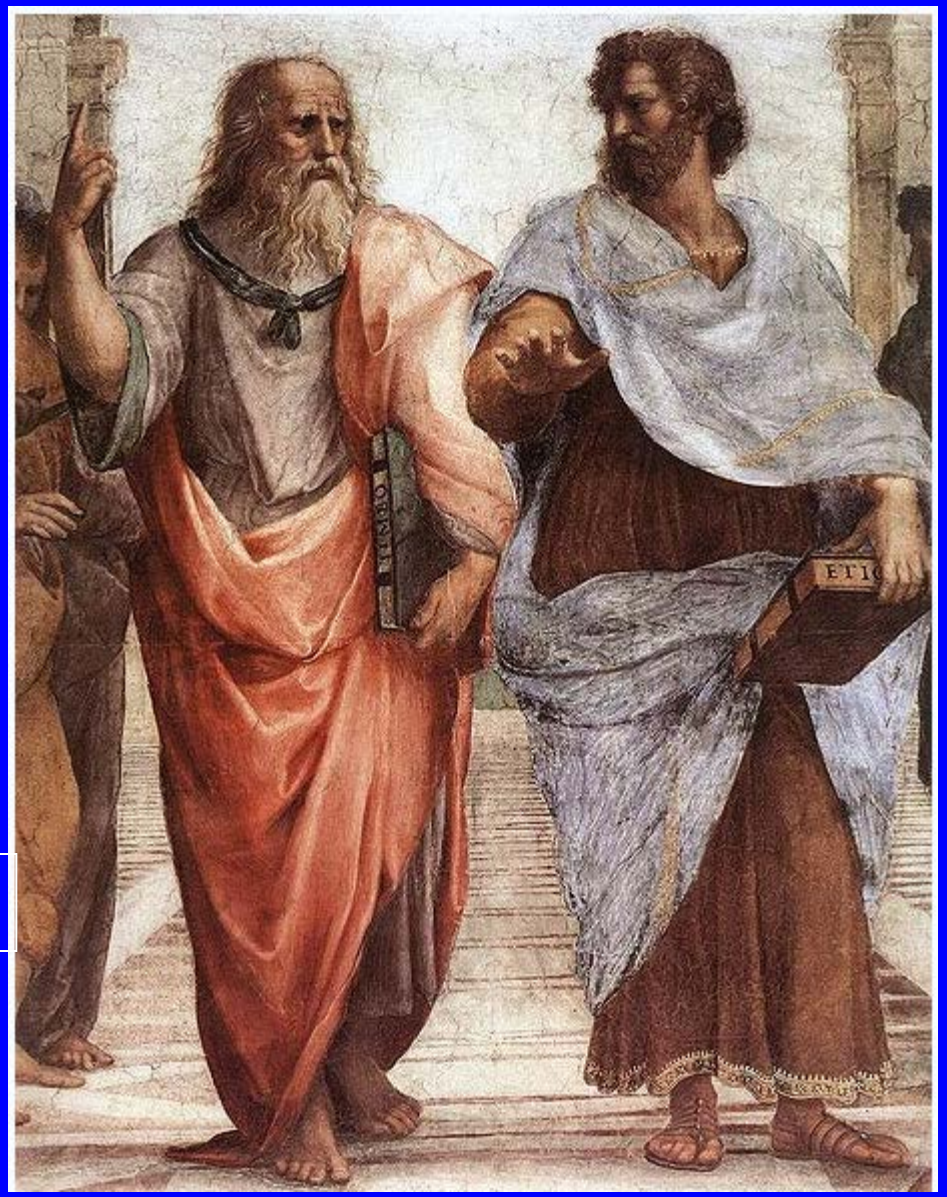
..... Shakespeare

“Nature abhors a vacuum”

... Aristotle

Oh, really?

The vacuum contains all of physics



Plato & Aristotle

An early experiment on the vacuum: (Otto von Guericke, 1650)

demo

"The vacuum sucks!"

Common notion, but it's those tiny atoms pushing in from the outside,
and even teams of horses could not beat those tiny atoms!
16 horses against lots of atoms! There's strength in numbers.

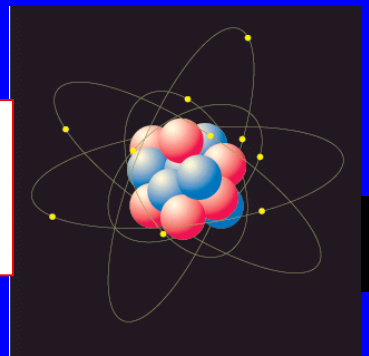
Atoms are nearly all just electromagnetic fields

ATOM is to NUCLEUS as 10 meters is to 1 mm

Magnify an atom to the size of a house:

The nucleus is the size of a pinhead in that house!

Size of electron orbits

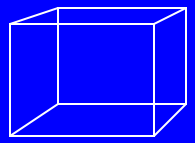


NASA-ESIP project for schools !!!

NO !!

In pursuit of the perfect vacuum (recipe) :

Box of vacuum:



Matter (nuclei and electrons) take 10^{-18} of volume! (in air)
1/1,000,000,000,000,000,000th

Even in heavy metal, 15 zeros! But it is FULL of electromagnetic fields.

Imagine: Take out all the atoms (electrons and nuclei)
Put in a thick metal box to keep electric and magnetic fields, X-rays etc. out.
Still have a gravitational field: let if fall freely, no more gravity

Is there anything left in the box?

We got rid of everything we possibly could.

BUT: We can create particles of matter out of energy:

Photon + photon → electron + positron $\gamma + \gamma \rightarrow e^- + e^+$

or $\mu^+\mu^-$ (muon pair) or

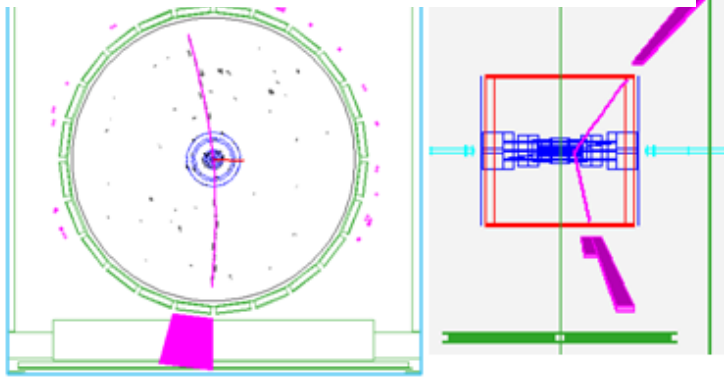
photon + photon → quark + antiquark, etc.

$E = m c^2$

How do the particles created, where there was no matter before,

"know" what mass to have?

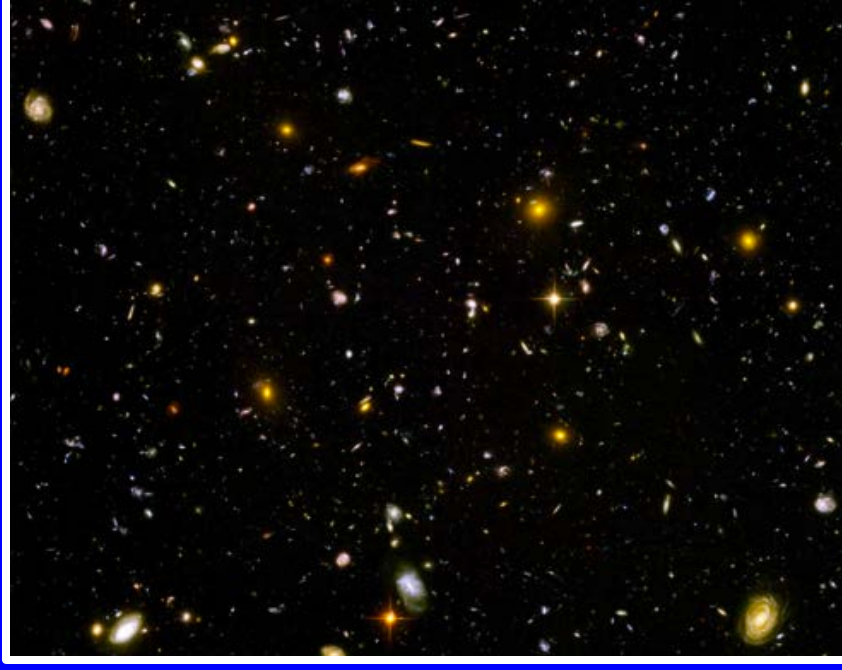
$\gamma + \gamma \rightarrow e^+e^-$ event at Tevatron



Anything left in the box?

1964 six+ theorists : A “scalar field” could be everywhere.
Scalar means **no direction, only a value**. So ***that’s*** why an electron (or muon or quark) here and in far away galaxies have the same mass.
They “know” what mass to have even when created by photons colliding.
If there’s really “nothing”, how could they possibly know?

How do we define the vacuum anyway, if not the absence of any stuff?
Let’s say: the lowest possible energy state
“The Higgs field IS ~ the vacuum”



Let's just call it: The Higgs Field

Unlike Gravity and Electromagnetism:

It has **no direction, just a value**
The **same everywhere in space and time** (as far as we can see!)

All the most "elementary" particles ... W & Z, quarks and leptons (not you) get their masses from interacting with this Higgs field.

Without it electrons – for example – NO MASS, Speed of LIGHT!
No atoms or matter as we know it!

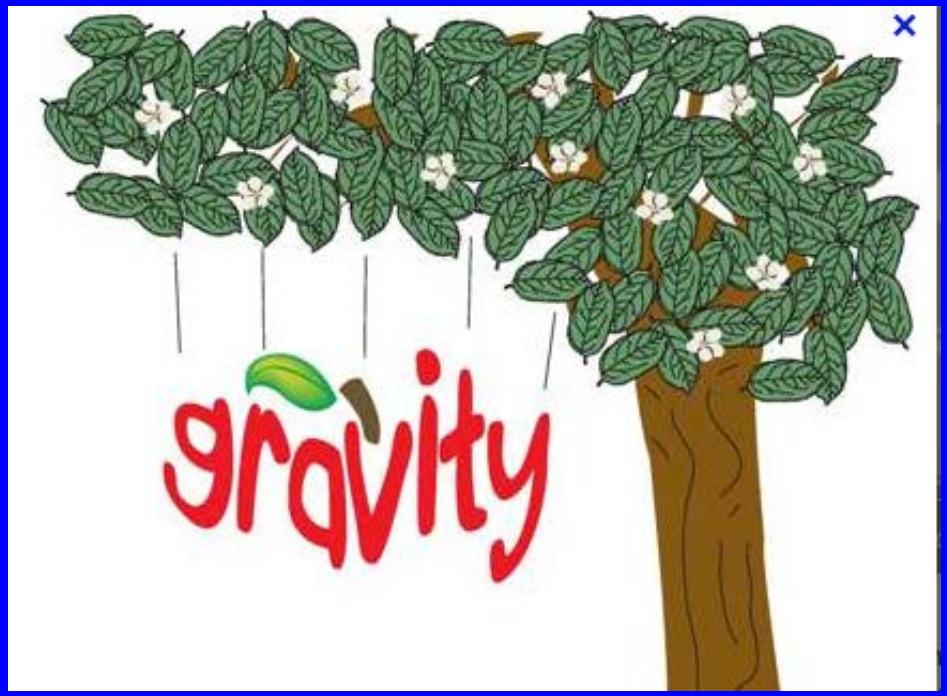
Fields you know:

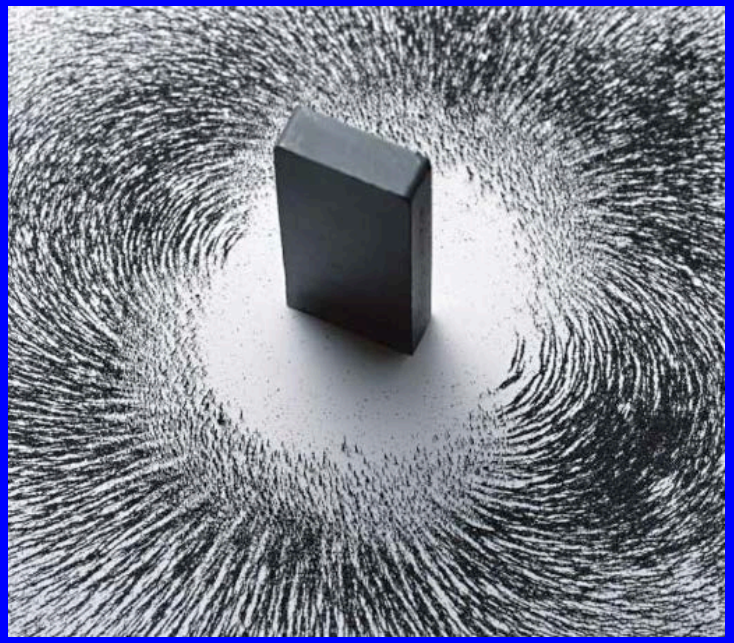
Electricity and Magnetism

Gravity ...

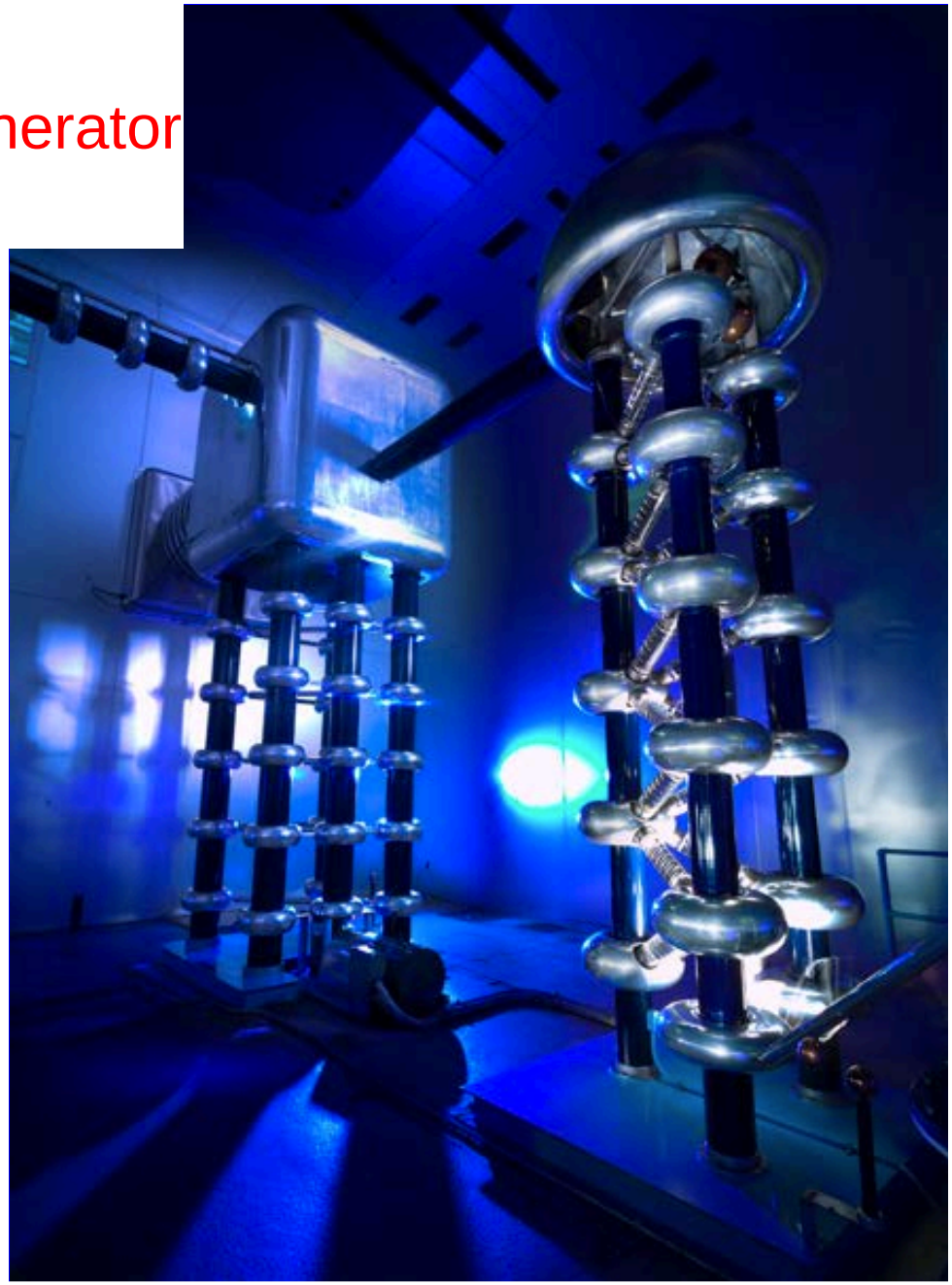
These fields vary from place to place and from time to time.

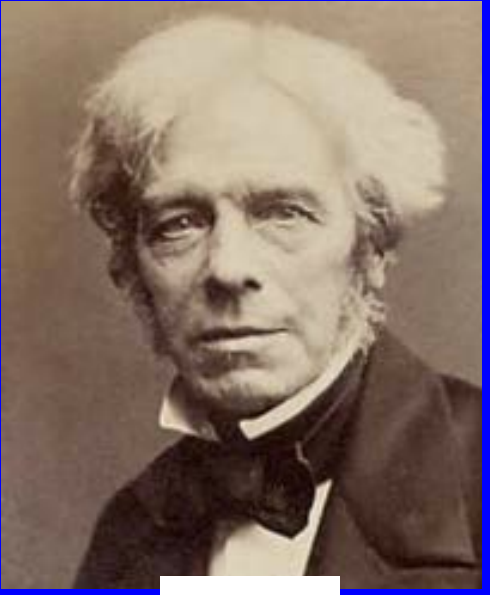
Also they have a direction.



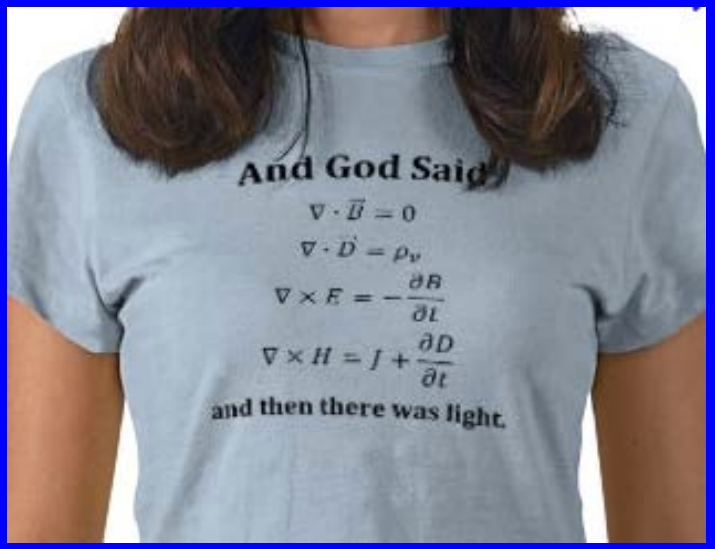


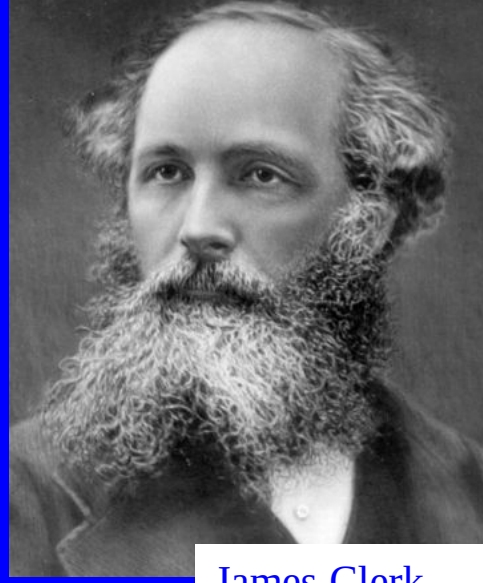
Cockroft-Walton High Voltage generator at Fermilab





Michael Faraday





James Clerk Maxwelll

ELECTRICITY

Maxwell combined the equations and out popped a speed. He put in the numbers and out came 186,000 m/sec! Light!

One theory, electromagnetic waves:

Radio, microwaves, heat, light, X-rays, gamma rays

MAGNETISM

UNIFY!

Light!
Photons!

Symmetries: the basis of physics

Sphere: rotate it any way ... the same

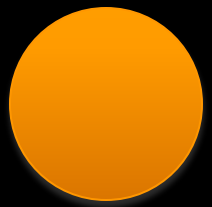
Emmy Noether:

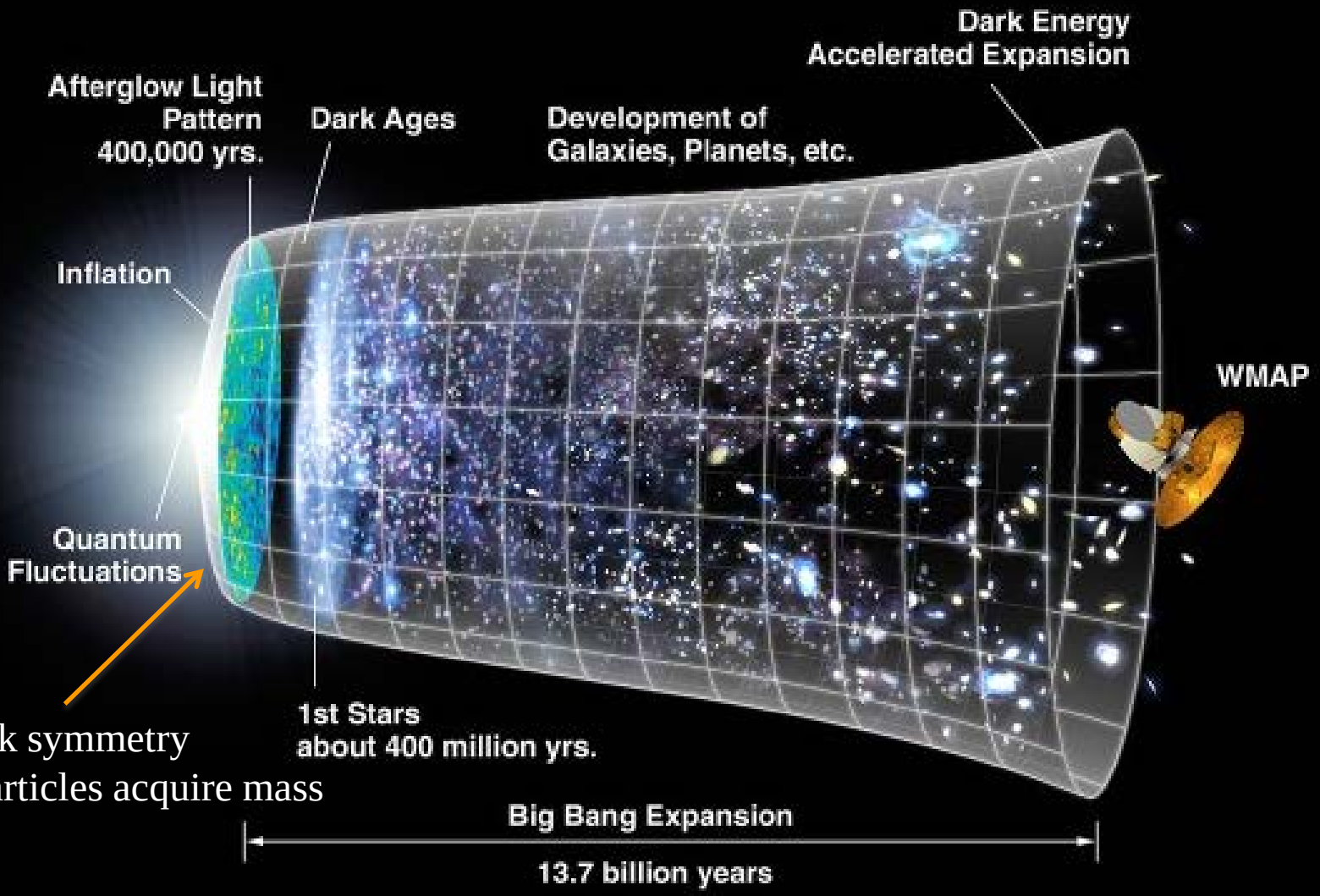
Most brilliant mathematician
Could not get a university post
Had to lecture under professor's name

Orientation of experiment does not matter (if no external fields)
Physics the same in any place → momentum conservation
Physics the same at any time → Energy conservation

But matter –antimatter symmetry is broken! We are all matter.

(Pencil falls)

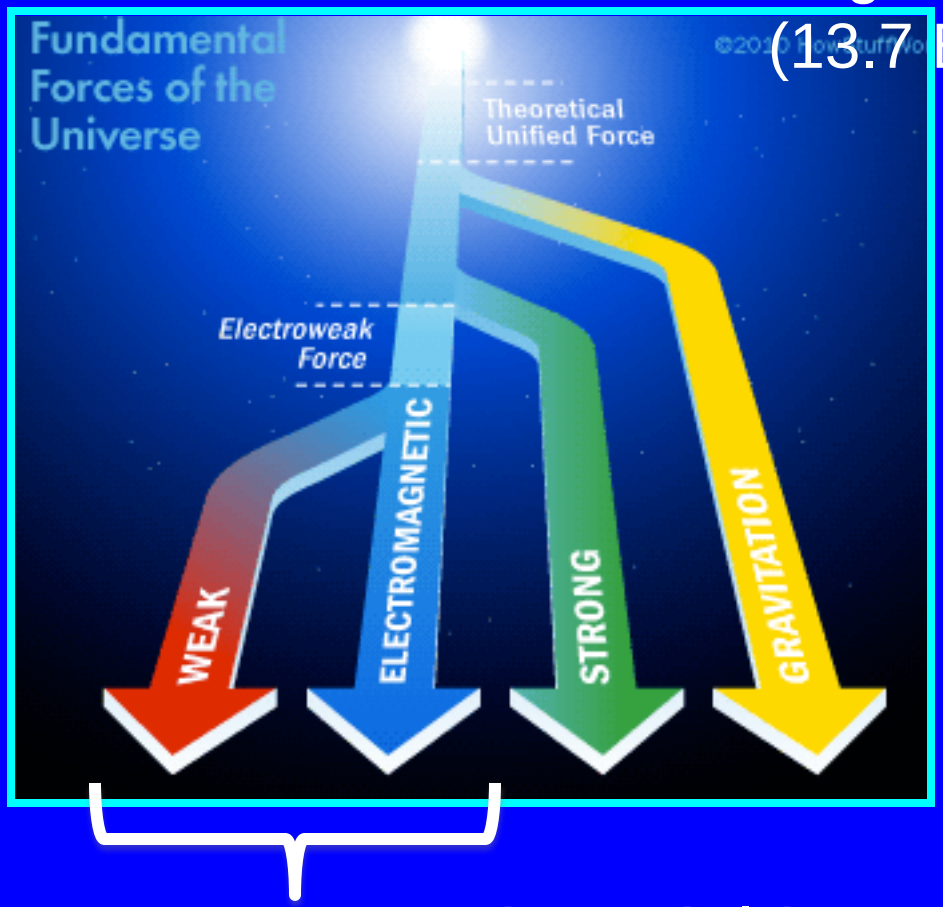




Electro-weak symmetry breaking. Particles acquire mass

In the beginning, big bang, one unified force (symmetry)
As universe expanded and cooled, symmetry was broken, forces became different.

Beginning
(13.7 Billion years ago)



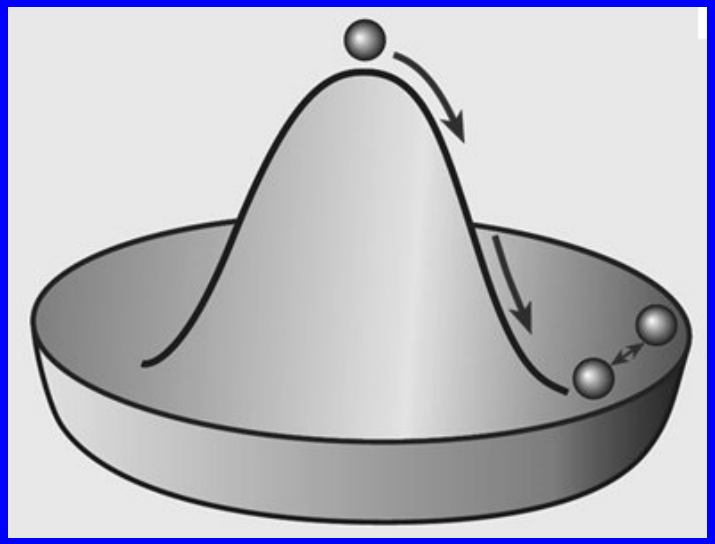
Today

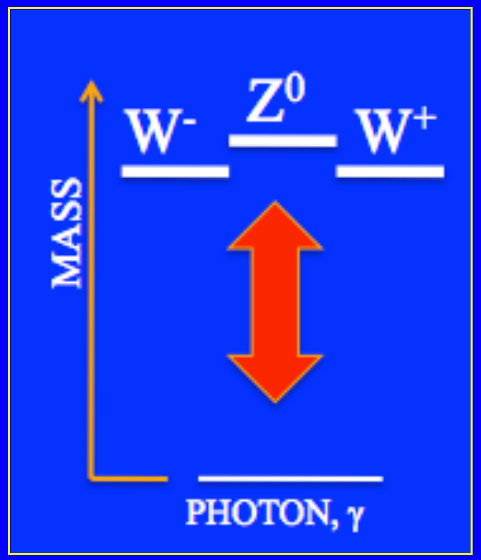
Unify → W & Z → Higgs field → Higgs Boson

HUGE GREAT BIG QUESTION:
How do these particles get their masses?
Naturally they should be massless!
Electrons would zip off at the speed of light : 186,000 miles/sec
→ No atoms, no us.

Quanta (carriers) of the weak force

Spontaneous symmetry breaking





γ

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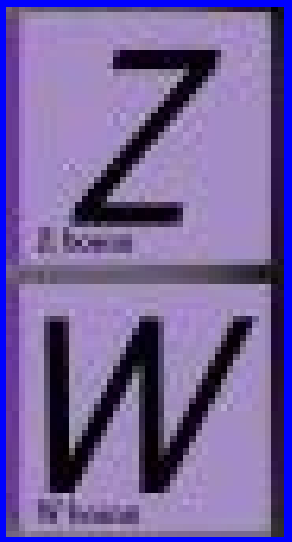
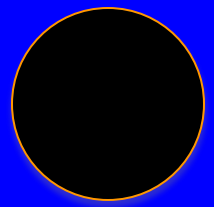


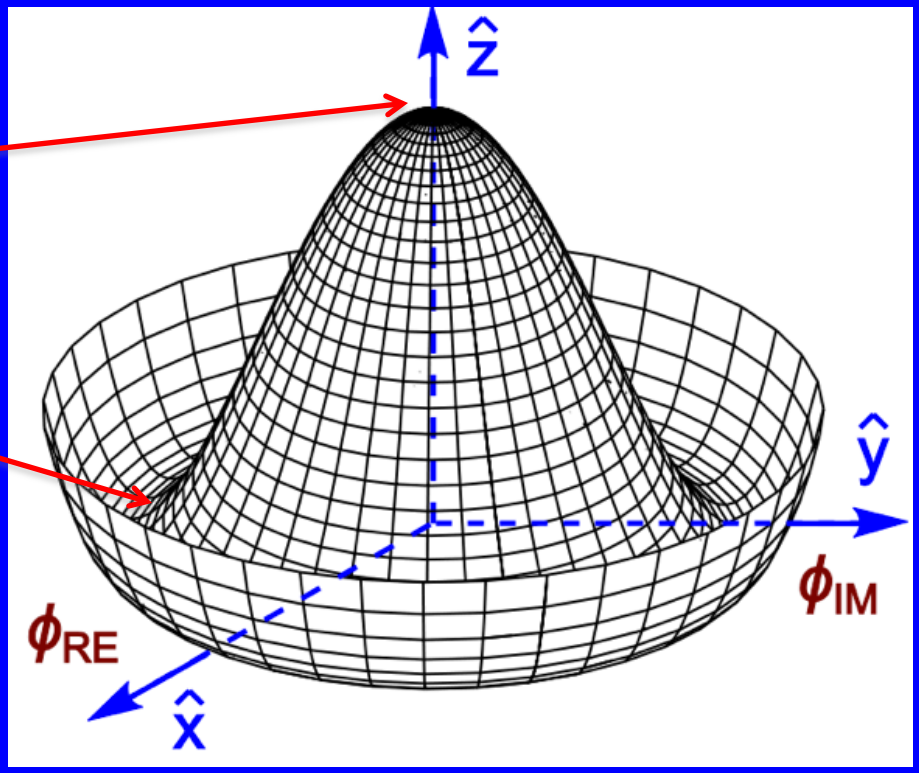


The Mexican Hat & Symmetry Breaking

Look down: symmetric

If field had this value **masses** would be zero

Field “rolls down into rim”: masses not zero. Was this at the end of BB inflation?

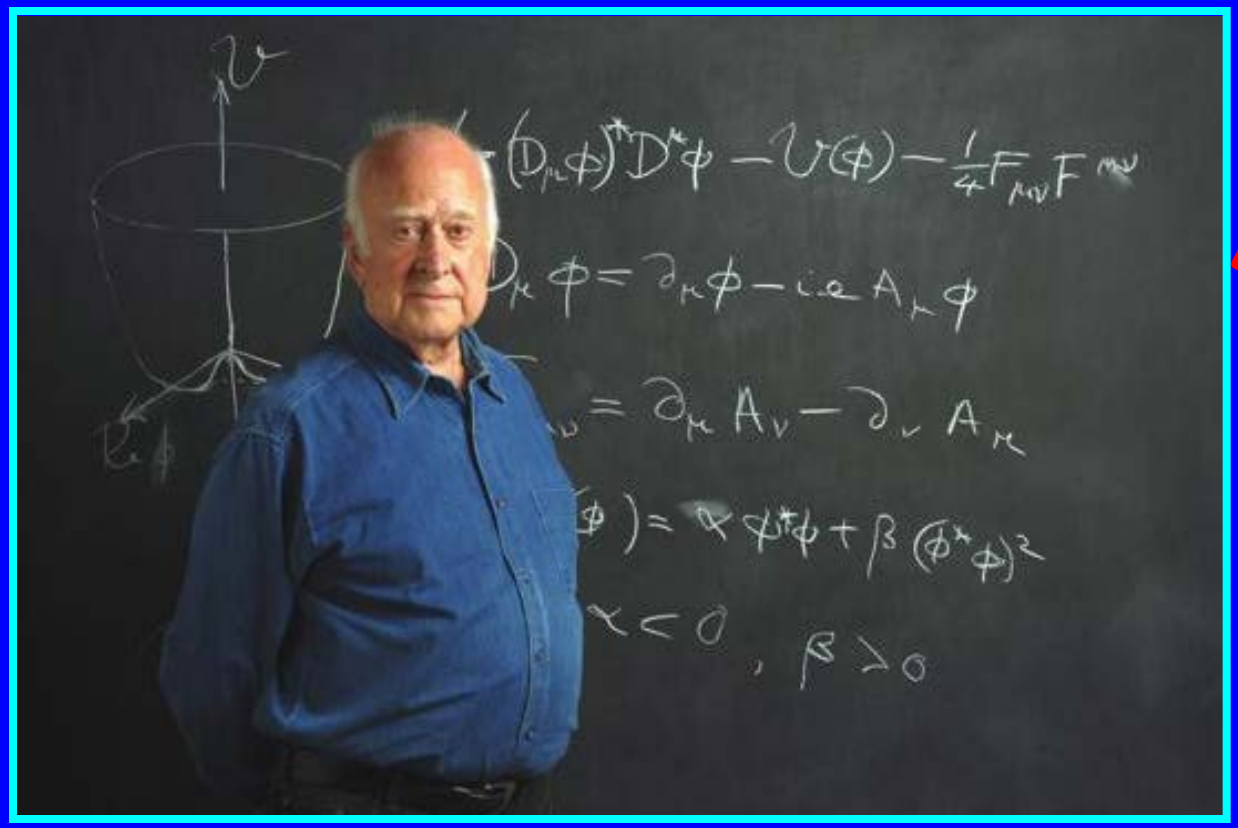


Broken Symmetry (Robert Wilson, Physicist, Director and Sculptor

Brout – Englert – Higgs – Guralnik – Hagen – Kibble

Electro-weak Symmetry-breaking field EBHGHK

Professor Higgs said there should be a particle with the field



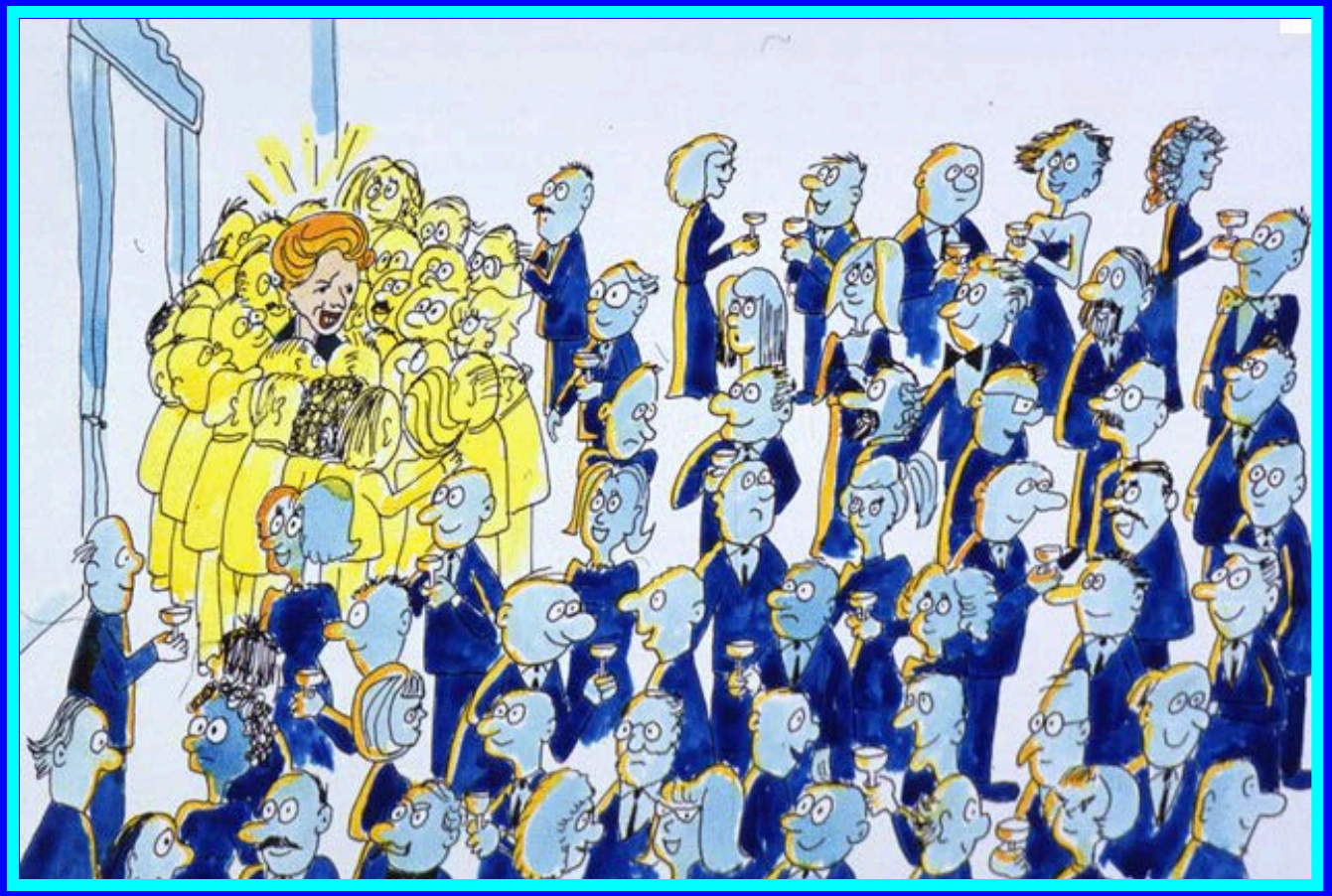
Bose higgson?

Bose: Indian theorist

Boson: force carrying particle

Fermion: particle of matter

Conservative party (UK) cocktail party

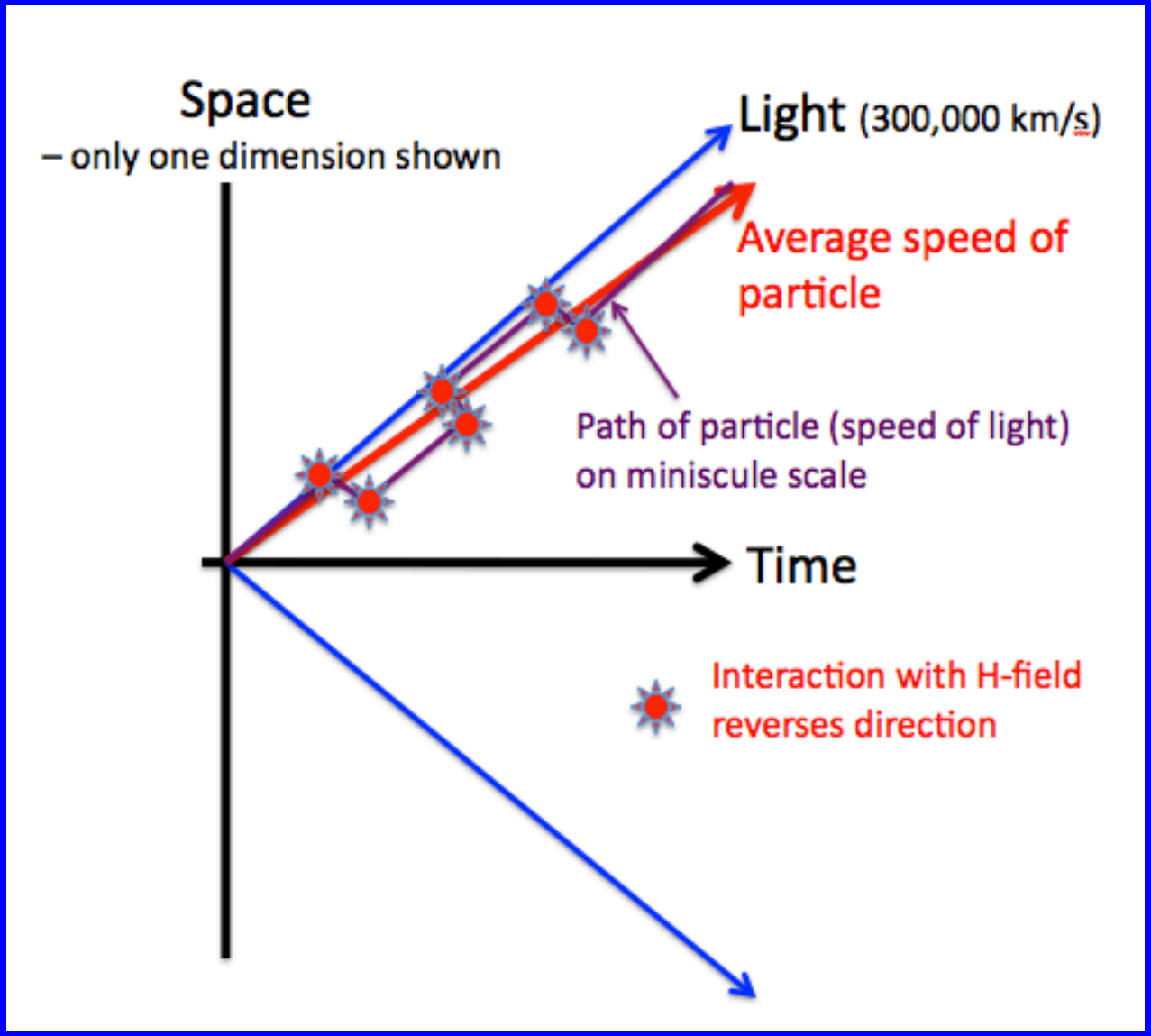


The Iron Lady analogy (helped UK funding for LHC!)

Or Angelina Jolie and me (!) ...

Sean Carroll : “The Particle at the End of the Universe”

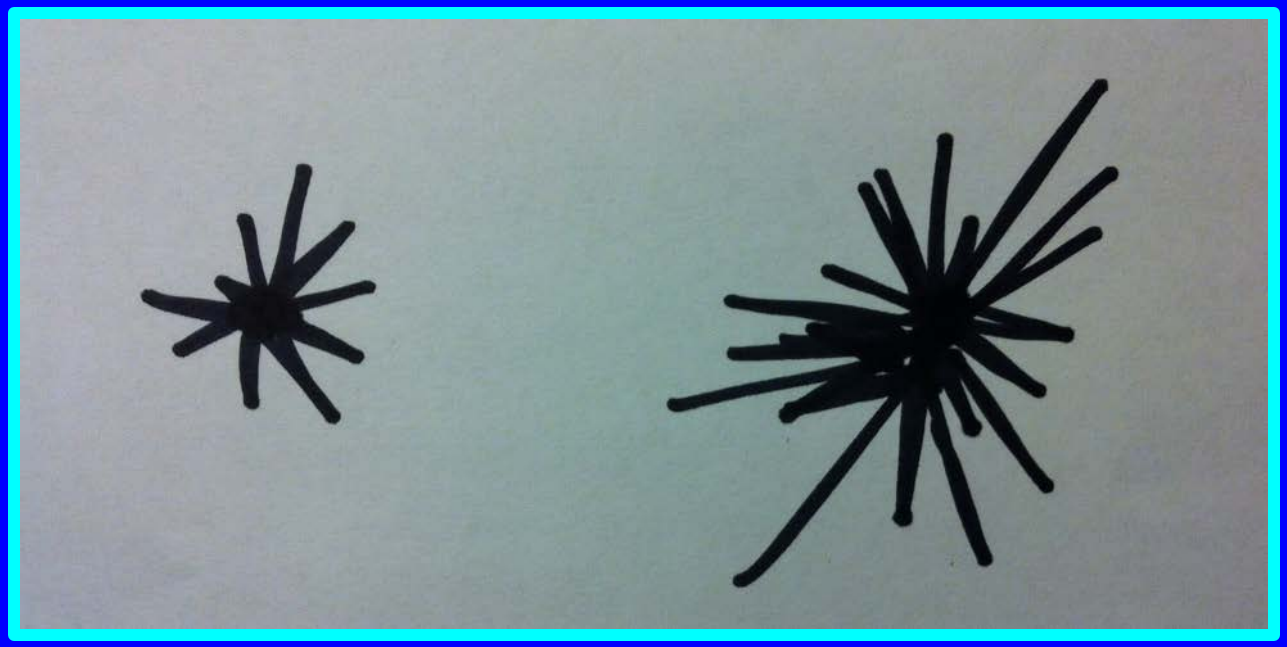
Another analogy: particles zig-zag at light speed



Axes scale really ~ a trillion trillion trillion times smaller

What about a particle “at rest” ?

With no Higgs field it zips off at the speed of light, but the H-field keeps kicking it back. A heavier particle (muon) interacts more strongly and it stays “small”. A light particle (electron) interacts more weakly:



Muon (μ) Electron (e)

Note: these diagrams are magnified gzillions of times!

The Search for the Higgs Boson

1967 Electro-Weak symmetry breaking predicts W,Z force carriers
Nobel prize to Glashow, Weinberg and Salam for theory based on field

1982 W and Z discovered at CERN, Nobel prize to Rubbia, Van der Meer

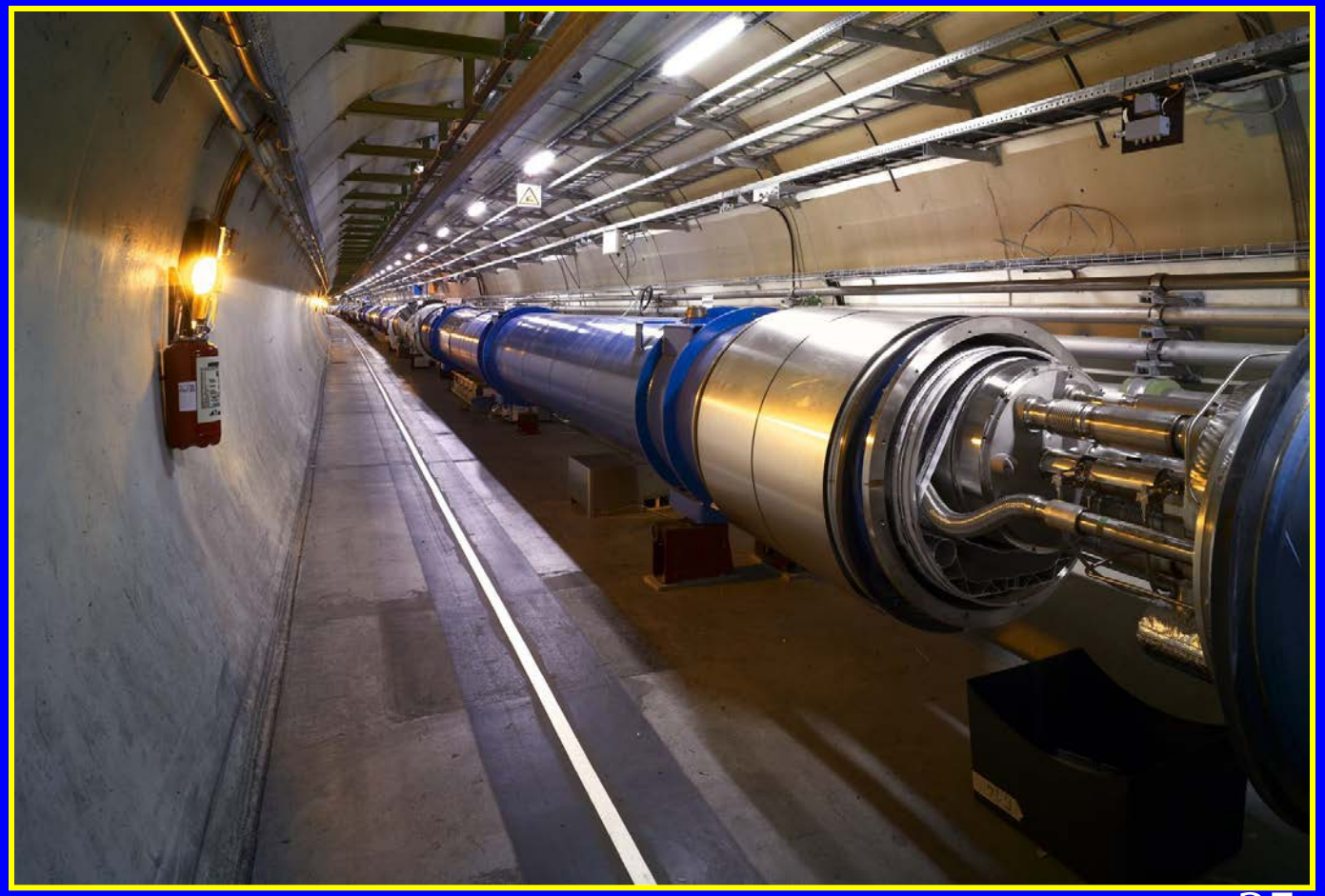
About 1986 Serious search begins:
Superconducting Super Collider in Texas (cancelled 1993)
Large Hadron Collider (LHC) at CERN in existing (e+e-) 16-mile tunnel.

2009 Nov. First pp collisions

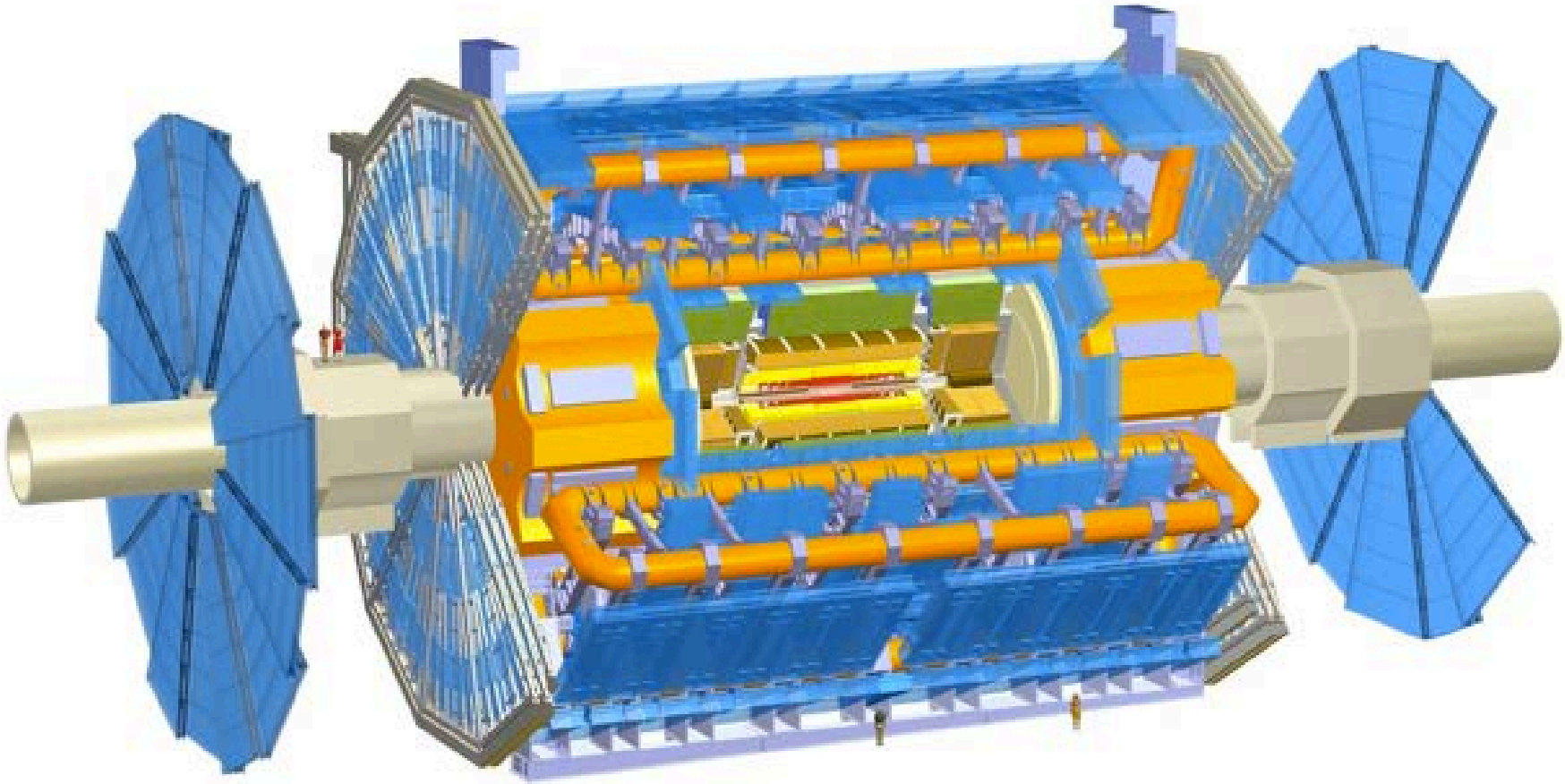
July 4th 2012 Observation of new "Higgs-like" particle announced
ATLAS and CMS : each 5 standard deviations. (1/2,000,000 chance statistical fluctuation)

The Large Hadron Collider, LHC: 27km of 2K superconducting magnets

CERN Geneva Switzerland & France : All European countries, since 1950s

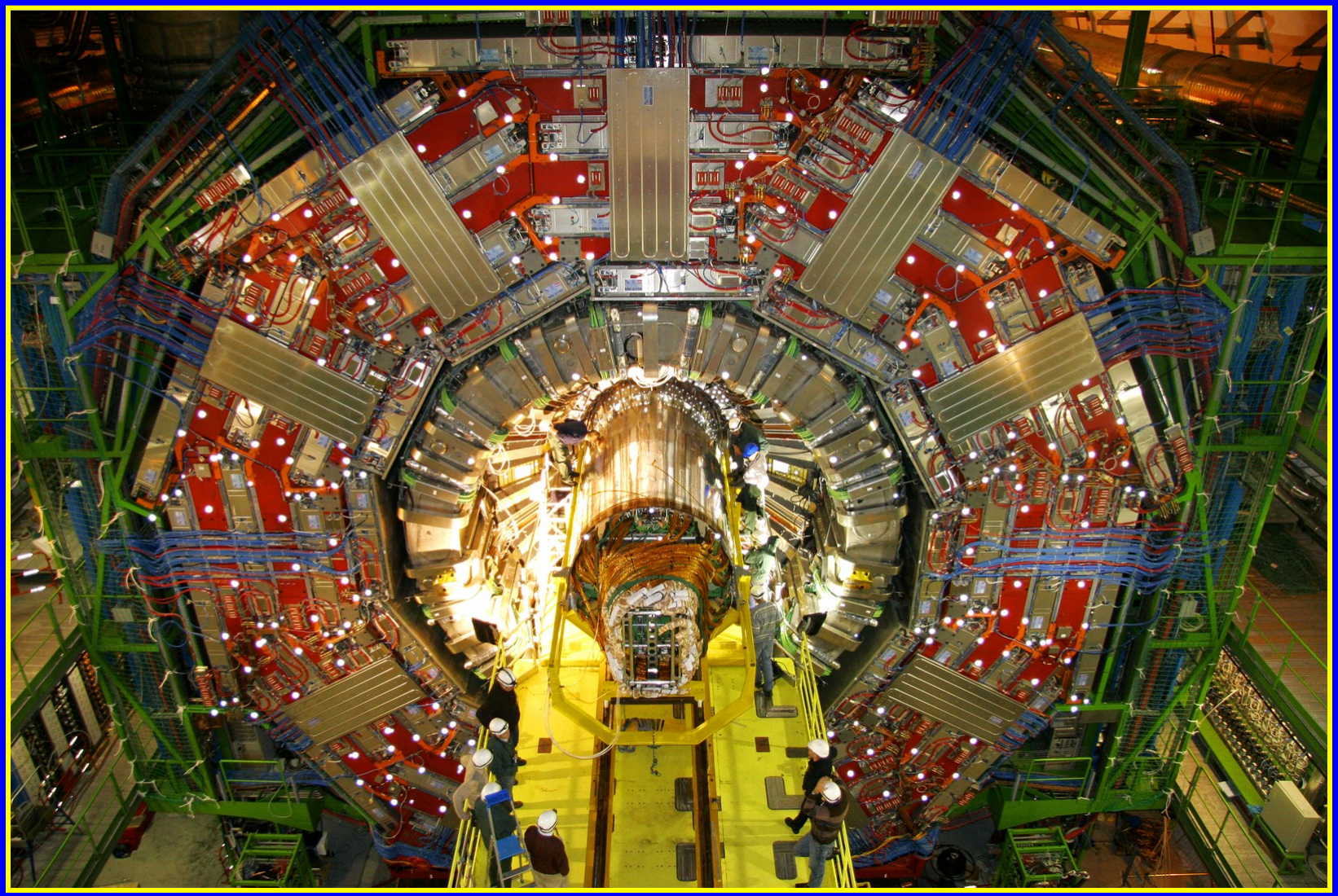


ATLAS: A 7000 Ton detector underground

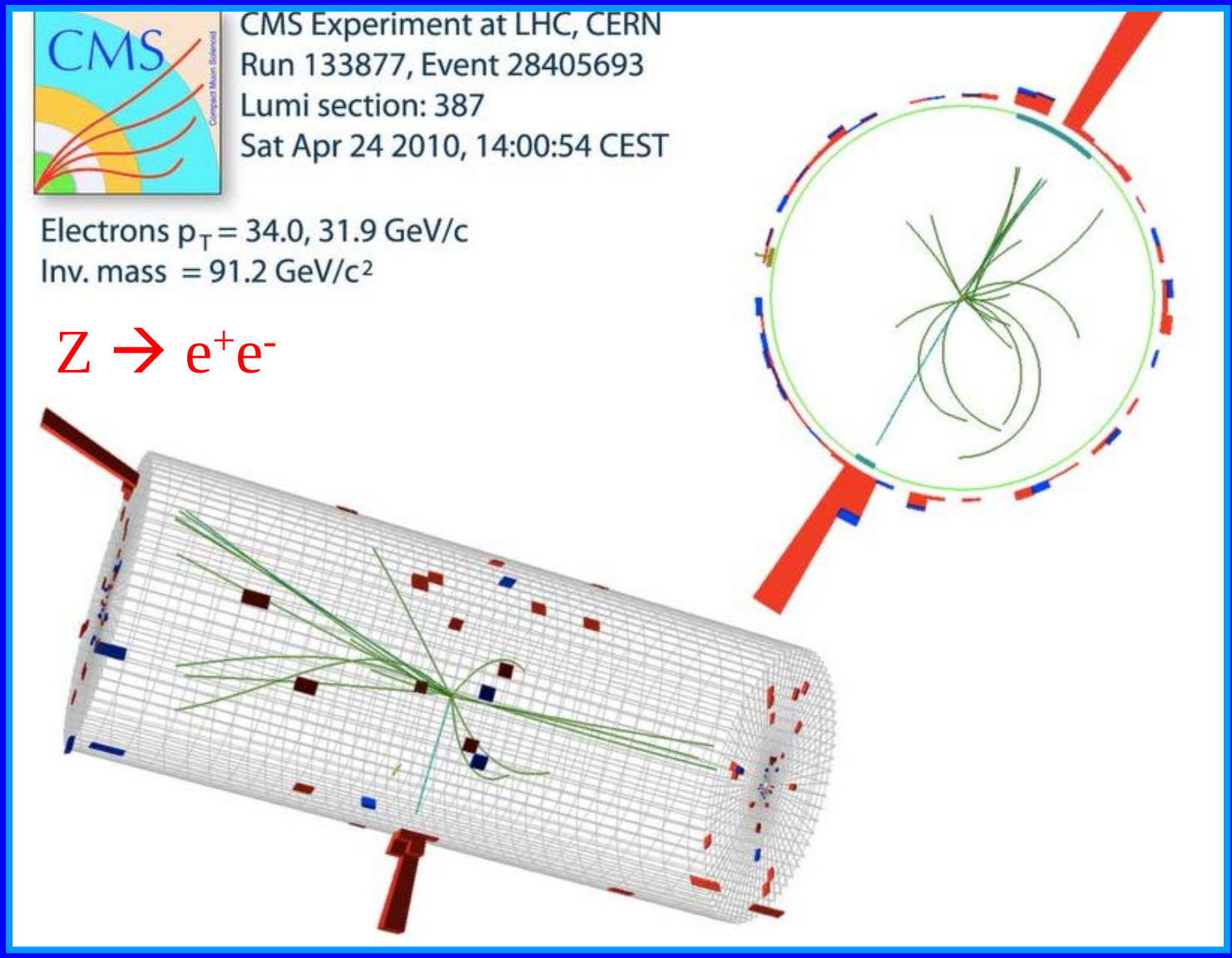


Look at the tiny people!

The “Compact” Muon Spectrometer. “My (+2500) experiment”



12,500 tons, 80,000 crystals of lead-tungstate (98% metal yet transparent!)
700,000 electronic channels! In 1 sec writes “10,000 Encyclopaedia Brittanicas”

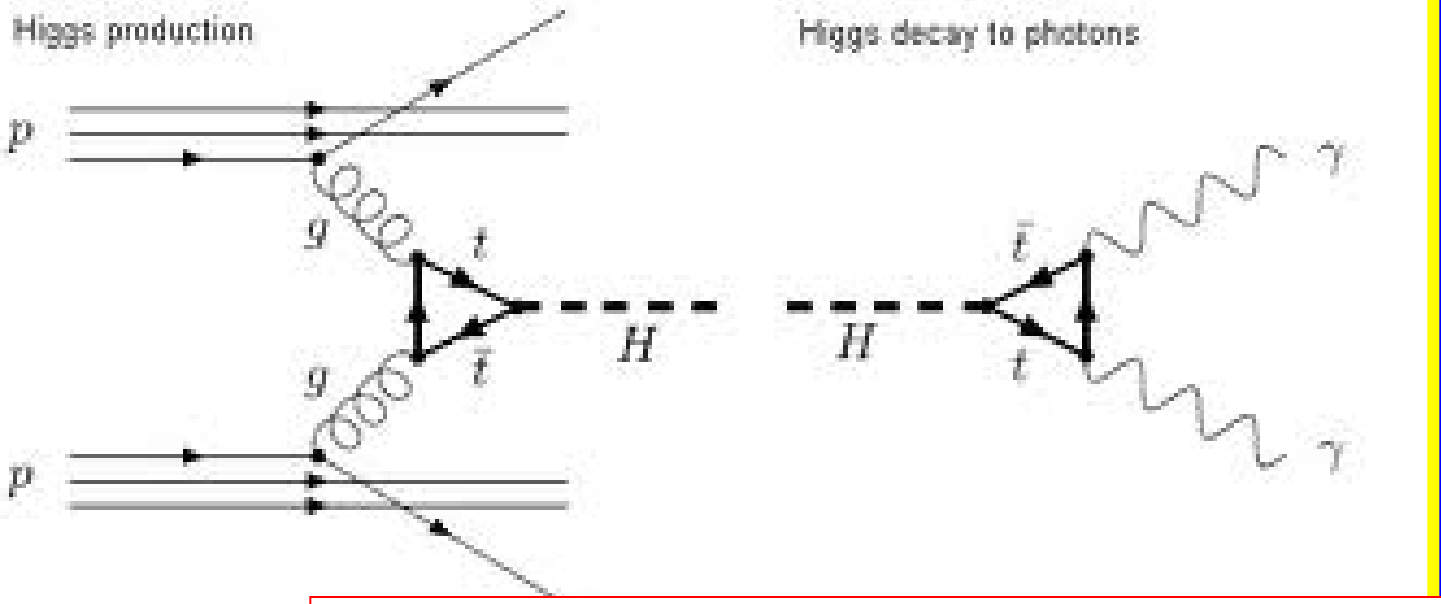


Tracks of particles reconstructed from signals in tiny strips of silicon, curving in a magnetic field.

$$g + g \longrightarrow \gamma + \gamma$$

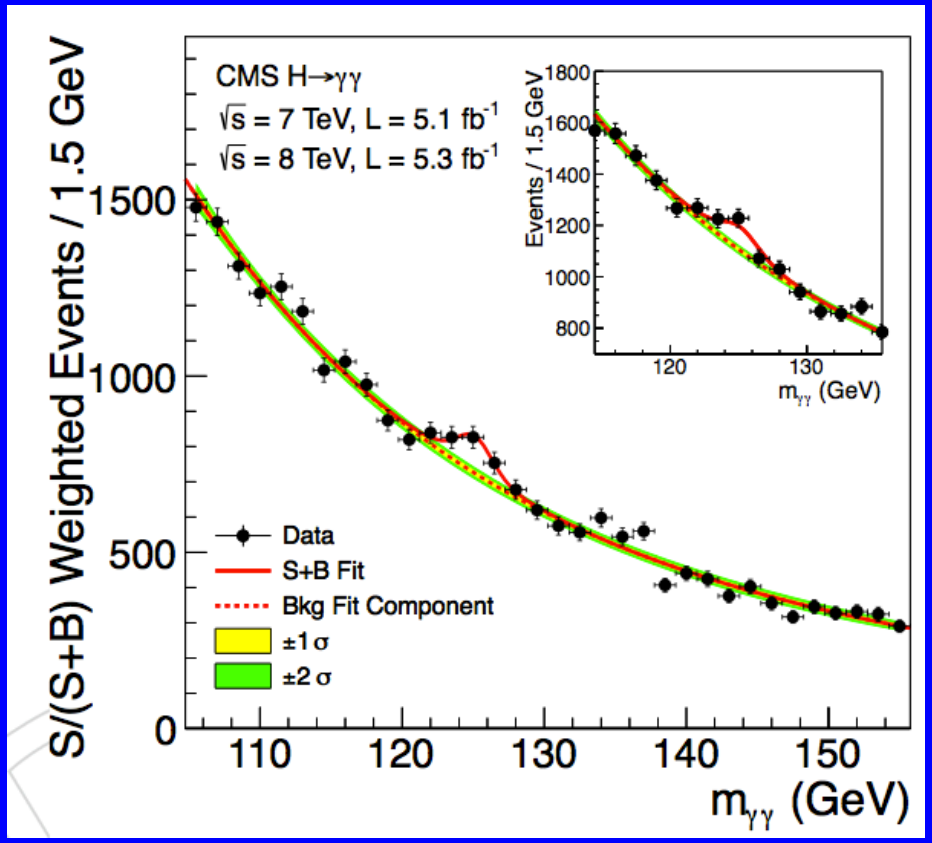
gluon + gluon → HIGGS → photon + photon

Higgs does not connect to gluons because they are massless.
Higgs does not connect to photons because they are massless.

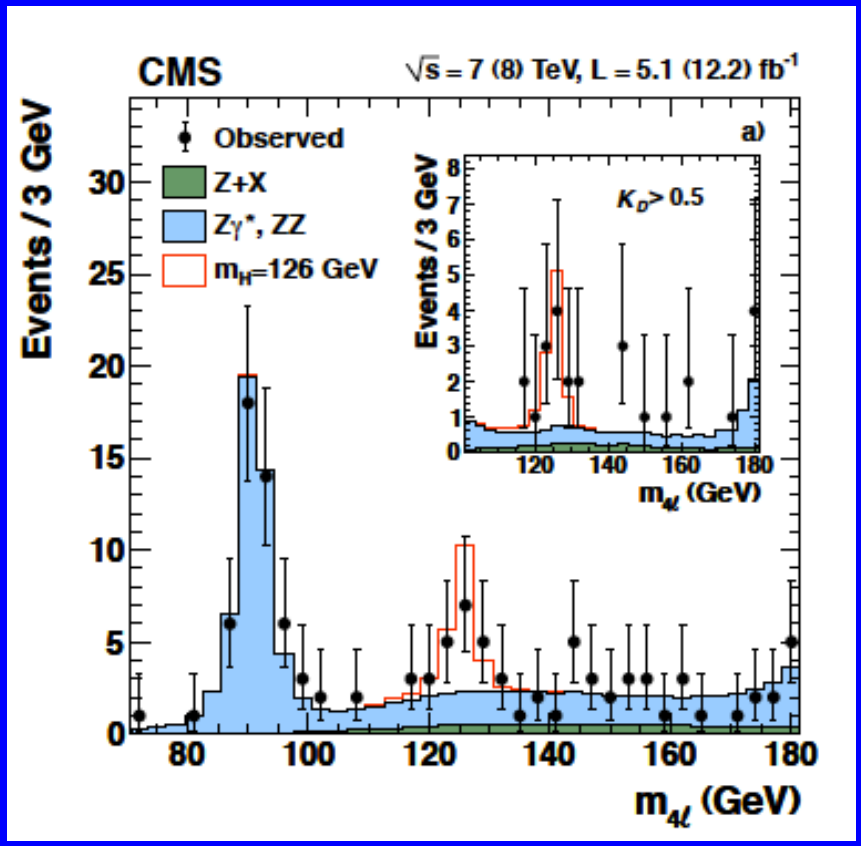


It has to connect through "virtual" top quark loops

The key evidence (CMS, ATLAS has similar)



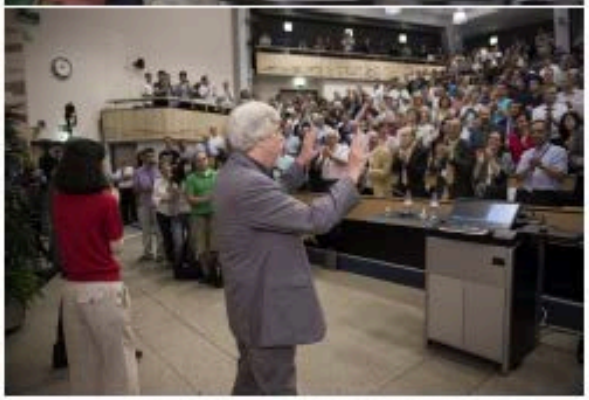
H → γγ

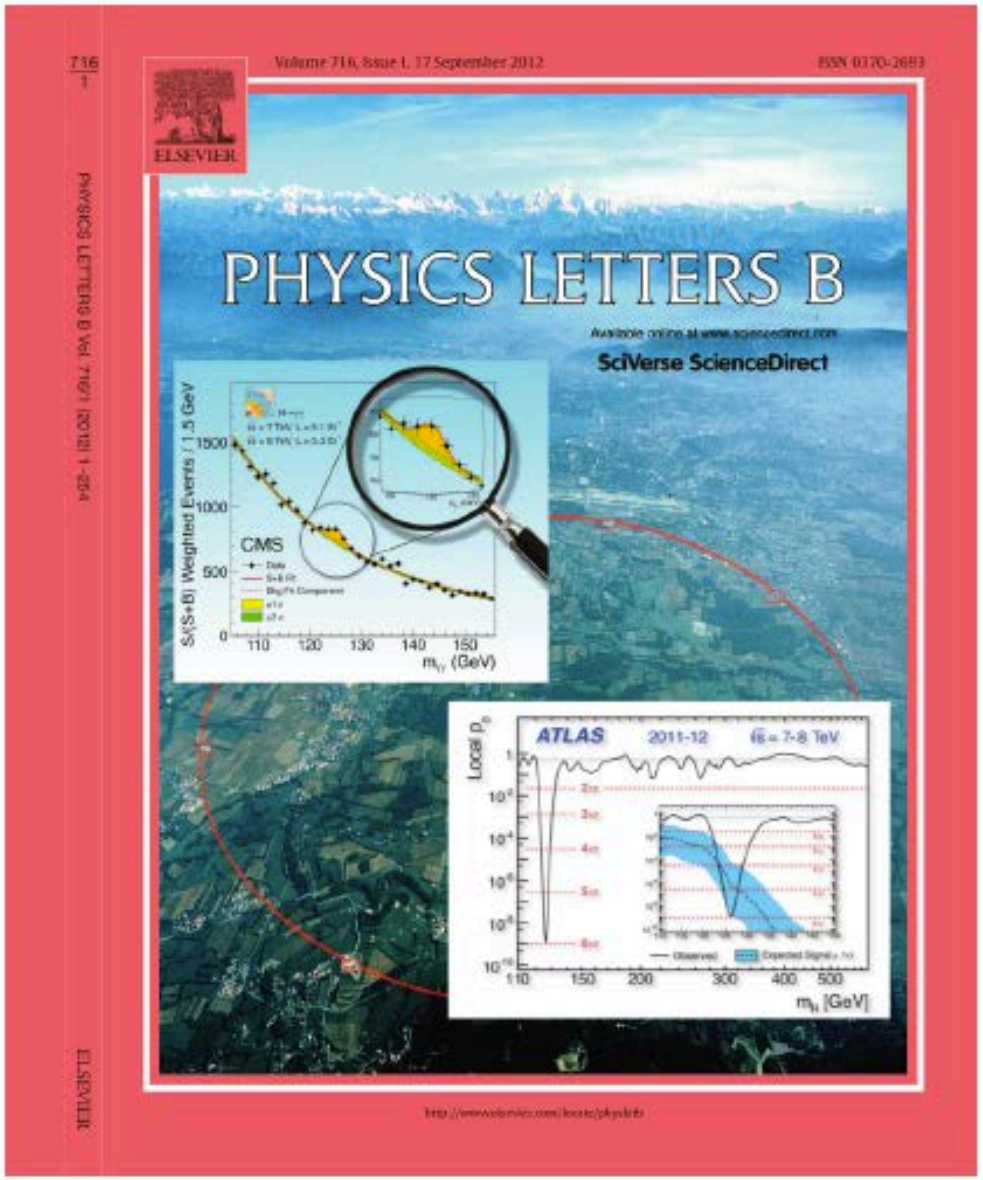


H → ZZ → 4 leptons

July 4th 2012 at CERN and around the world

The discovery of a new mass resonance at LHC: $m \approx 125 - 126\ GeV$





The achievement is awesome!

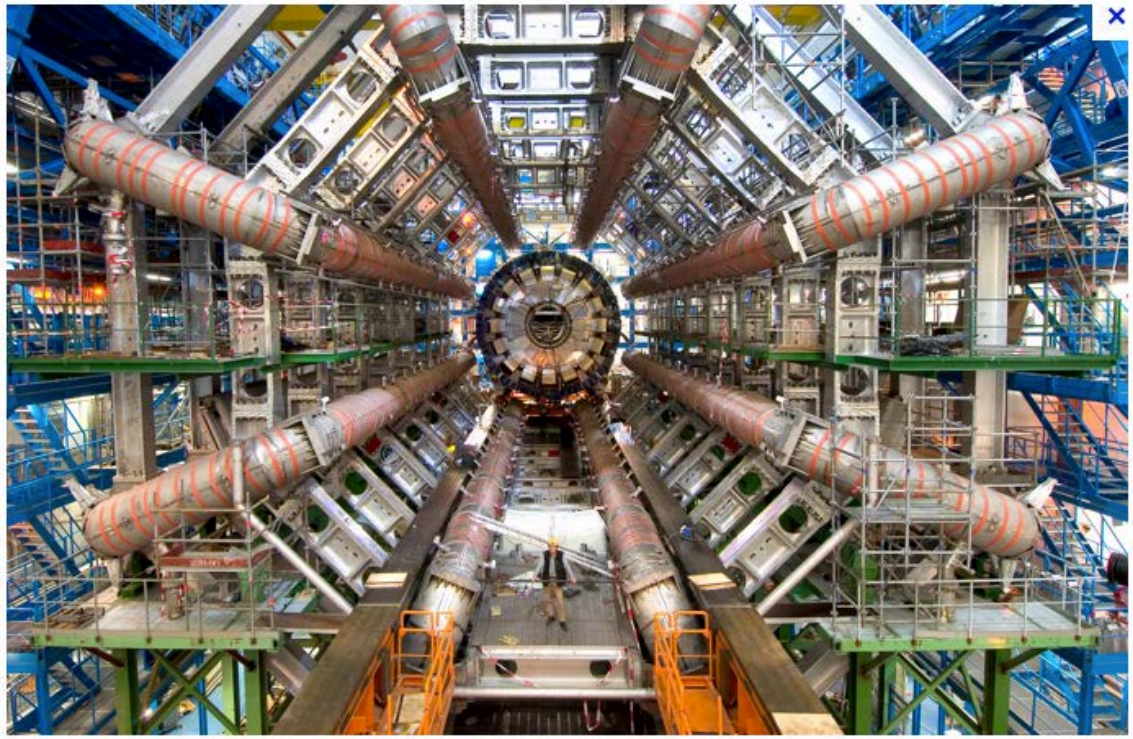
16 miles of accelerator:
sub-millimetre precision

Two 5-storey high particle detectors with about 3000 physicists each.

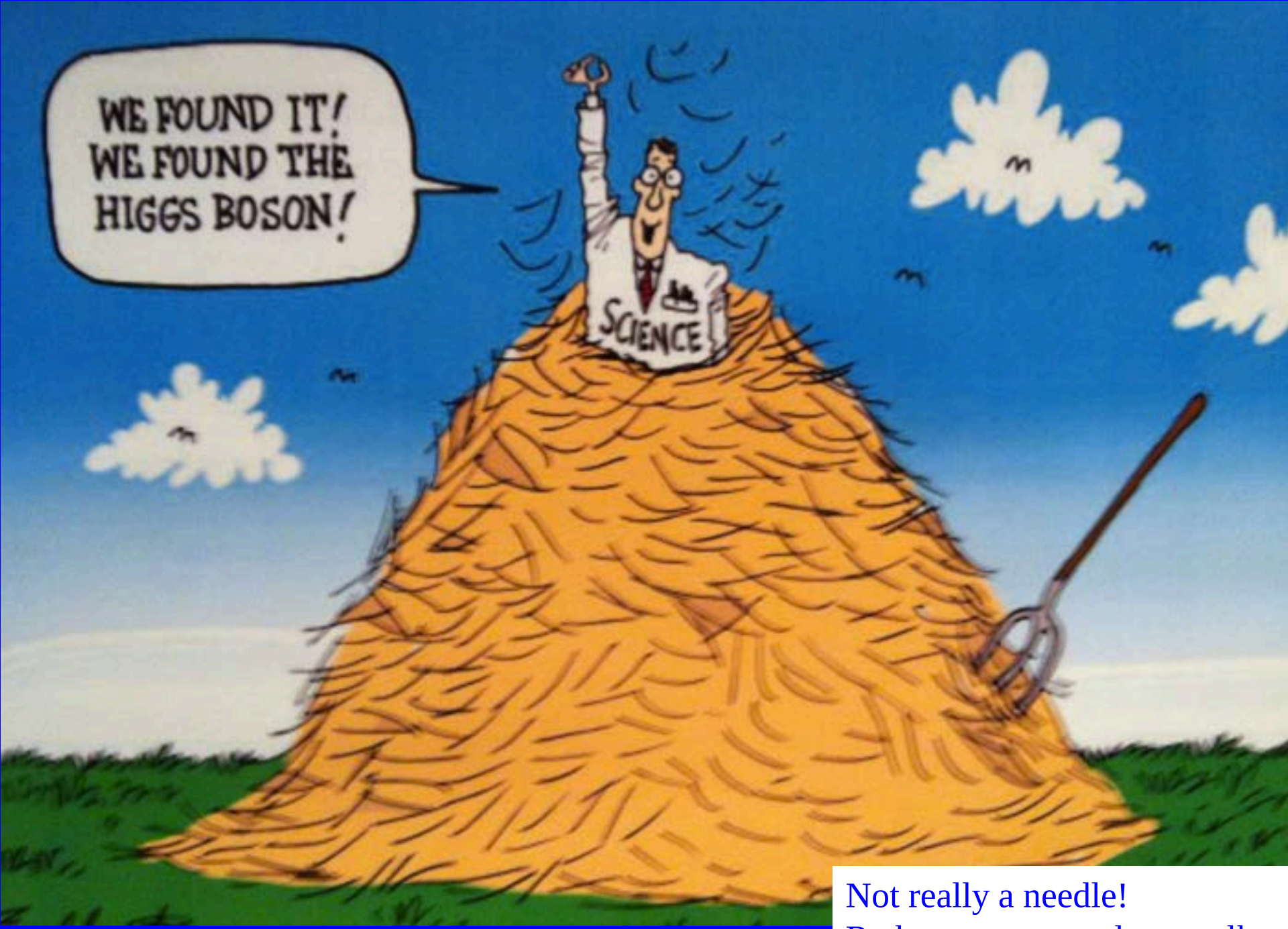
100 tons of superfluid He @ 2K

Tens of Petabytes data stored and shared around the world.

Unprecedented data handling:
100 Tb/sec out of the detectors



ATLAS



Not really a needle!
Rather some extra long stalks


WOOHOO!
PEOPLE ARE STILL SCIENCING!
quickmeme.com

The New York Times

Late Edition

NEW YORK, THURSDAY, JULY 5, 2012

$2.50

ROMNEY NOW SAYS HEALTH MANDATE BY OBAMA IS A TAX

SHIFT RENEWS CRITICISM

Move Aligns Him With Conservative Voices Within His Party

Physicists Find Elusive Particle Seen as Key to Universe

Scientists in Geneva on Wednesday applauded the discovery of a subatomic particle that looks like the Higgs boson.

Date Night at the Zoo, if Rare Species Play Along

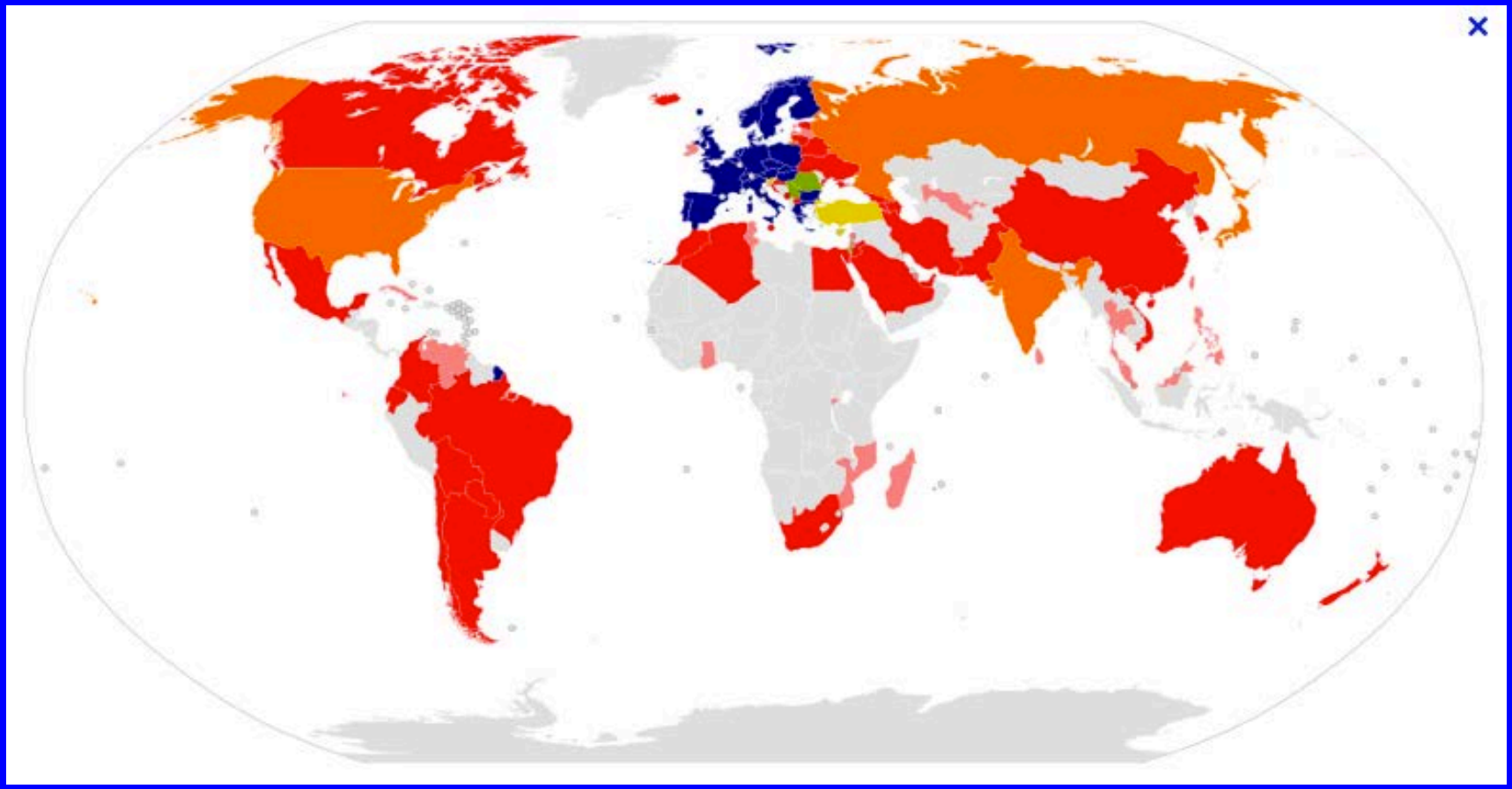
THE ANIMAL LIFEBOAT

'I Think We Have It' Is Cheer of Day at Home of Search

A truly global scientific enterprise:

CERN member states : black

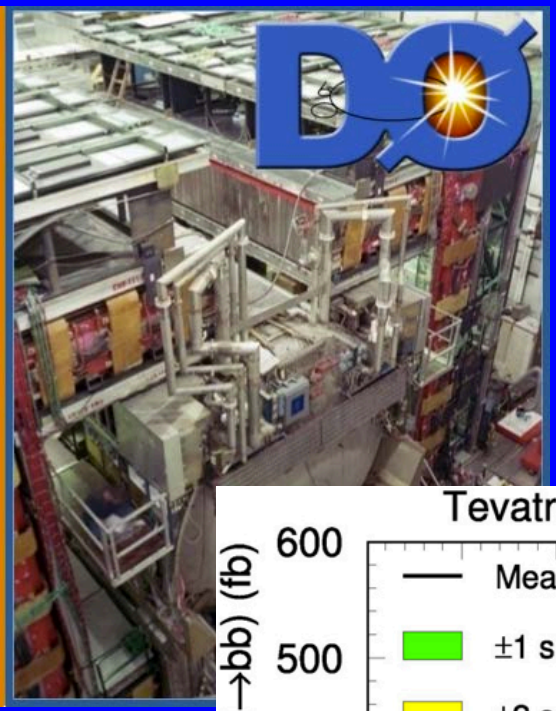
Scientists from all countries in collaborate



In 1982 (Cold war) my team had Russians, Chinese, Israel, USA, EUR

.... a small contribution towards world peace

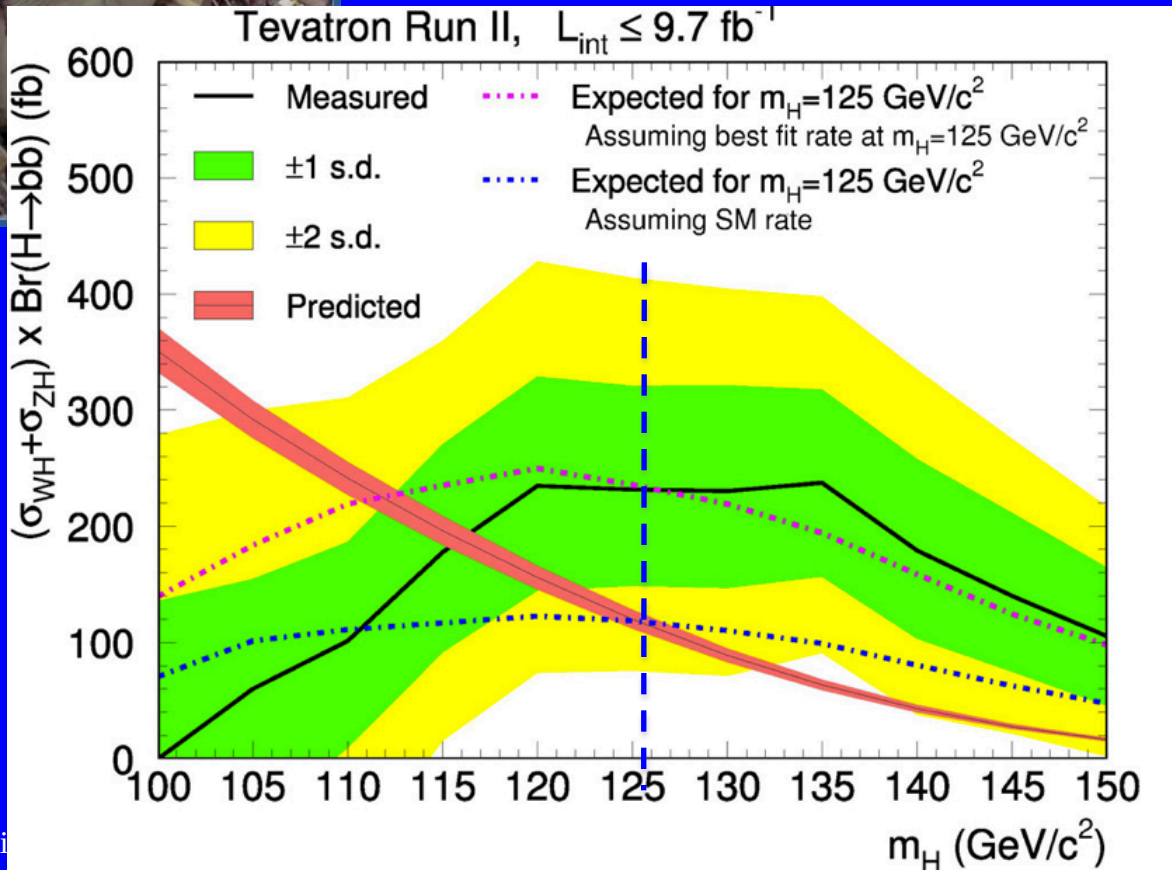
Back home at the Fermilab Tevatron (proton-antiproton collider):



After about a decade searching

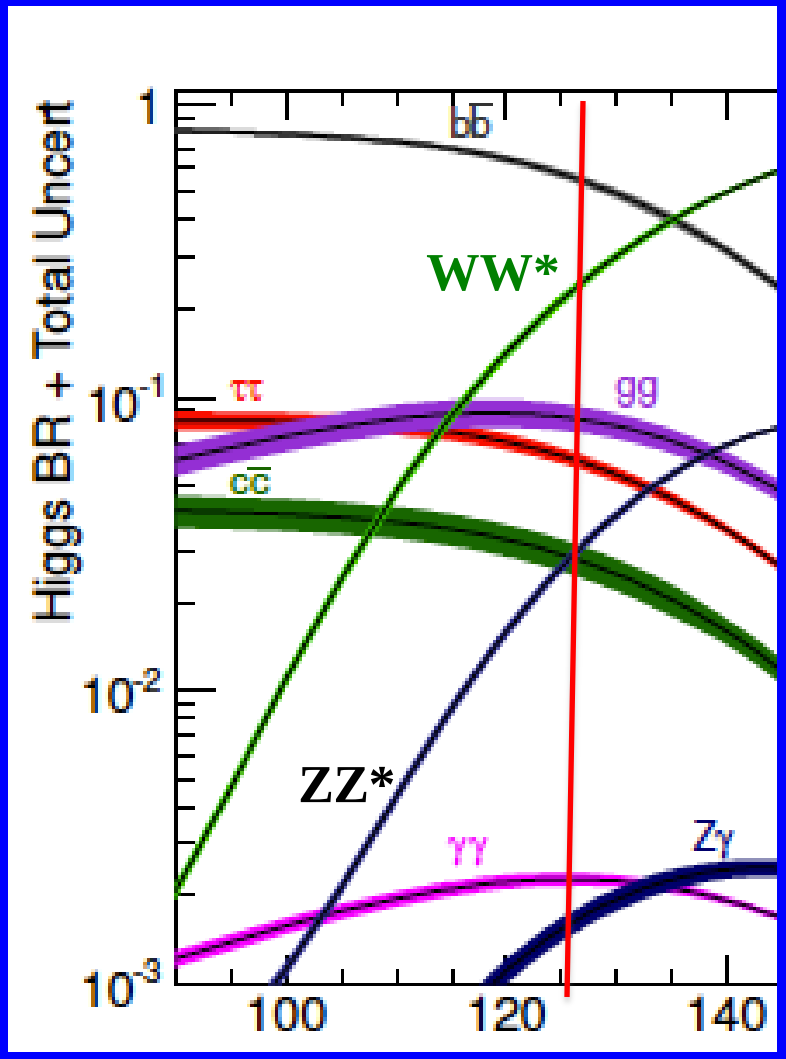
Both experiments combined:
July 2012 (not quite last word)

There seem to be some Higgs there, but not enough to be sure.



Standard Model decays well calculated. Is it so?

Old predictions
before mass known:



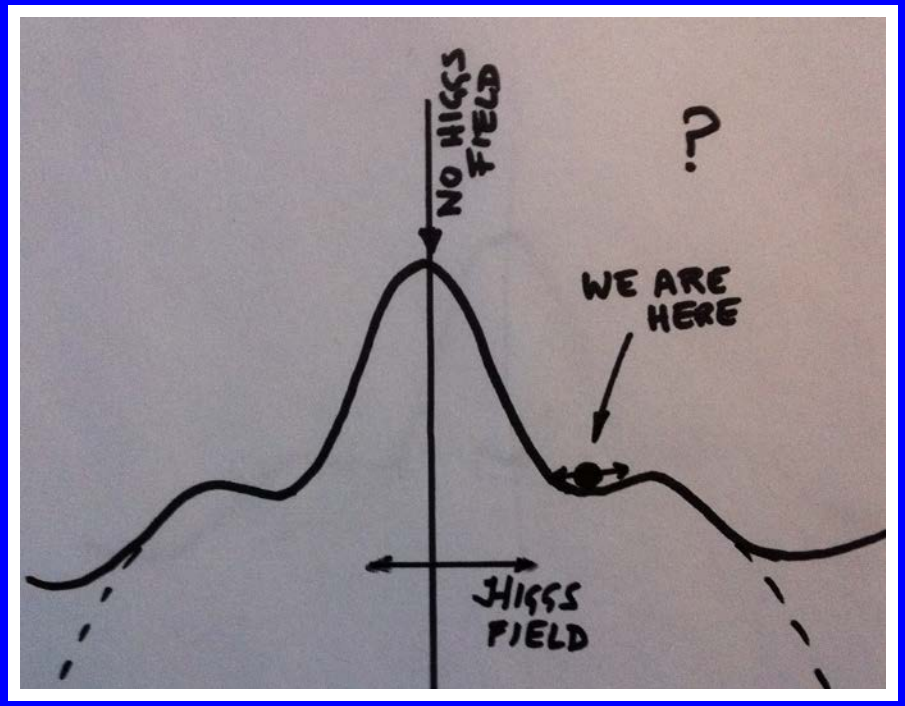
We hope not ... that would be a break-out of from the SM
We need a surprise to move forward!

Some theorists say:
If the Higgs boson were much lighter than about 125 GeV

The vacuum would be unstable!

Like clean pure water below freezing, drop in an ice crystal and

WHOOSH! .... all ice



Unless new physics is there at higher energies.

But then maybe not. It didn't happen yet in the whole Universe!

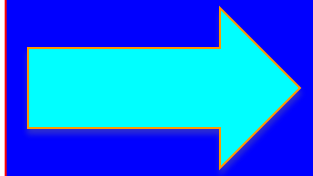
There’s something else very strange about the vacuum:
DARK ENERGY

Astronomers say something is making the Universe expand faster and faster!

The End of Fundamental Physics?

Absolutely not!
The completion of one chapter & the turning of a page,
& the rejection of many wrong theoretical blind alleys.

My personal belief / faith / hope :
There will be questions to answer
as long as we are here to ask them



Why **3** matter families?

Why **3** space dimensions?
Are there more? 10,11?

Does **H(125)** decay as predicted?
Hopefully not!

What is **DARK MATTER**?
Other particles? SuperSymmetry?

Is our UNIVERSE just one among trillions?

12 matter parti… different mas…s? Calculate?

What happened to all the **ANTIMATTER?**

What is **DARK ENERGY**?
Why is the Universe accelerating?

Do the **strong** and **electro-weak forces** unify?

What will happen in DEEP TIME?
10^{20} years? 10^{100} years?

Thank you

and thank you Higgs* field for letting us stand still

* EHBHGK

The fundamental particles of matter and forces known since 1995

The "Standard Model" All of them except H = Higgs boson

FERMIONS

Quarks

u c t

d s b

Leptons

e μ τ

ν_e ν_μ ν_τ

BOSONS

H
Higgs boson

Forces

Z γ

W g

High mass

No mass

All 12 matter particles have different masses, and we do not understand that "spectrum"