Research at CERN
CMS and the LHC

Stephen Wimpenny

Our perspective has changed with time………..

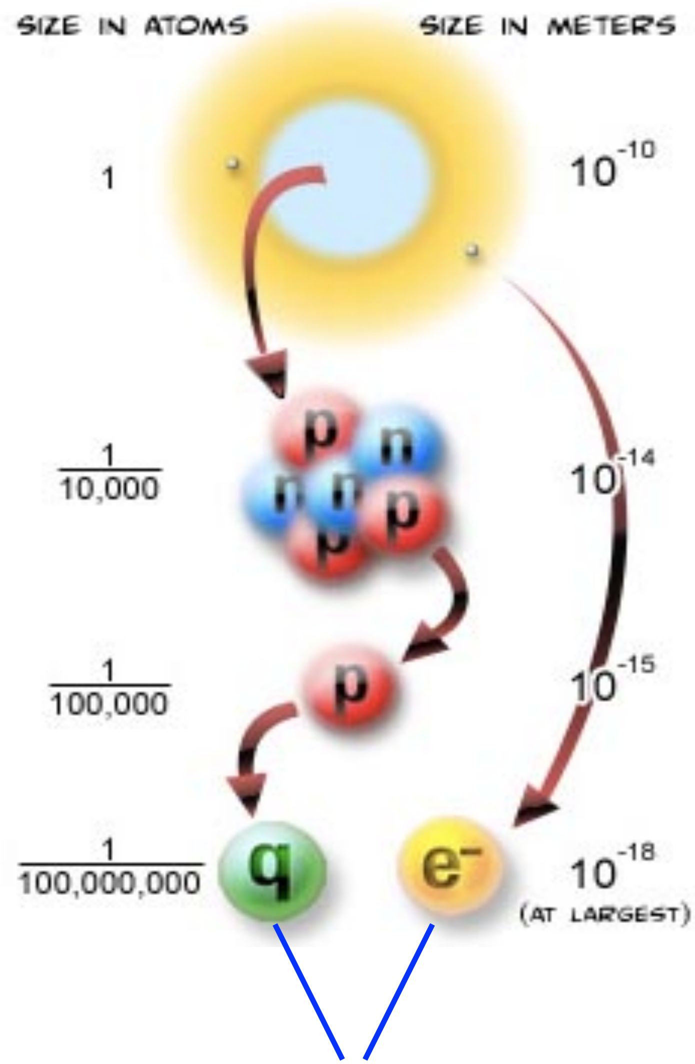
according to our ability to probe to shorter and shorter distance scales

Atom:

Nucleus:

Nucleon:

Quarks & Leptons:



Fundamental Particles (2012)

Elementary Particles ?

Our perspective has changed with time………..

according to our ability to probe to shorter and shorter distance scales

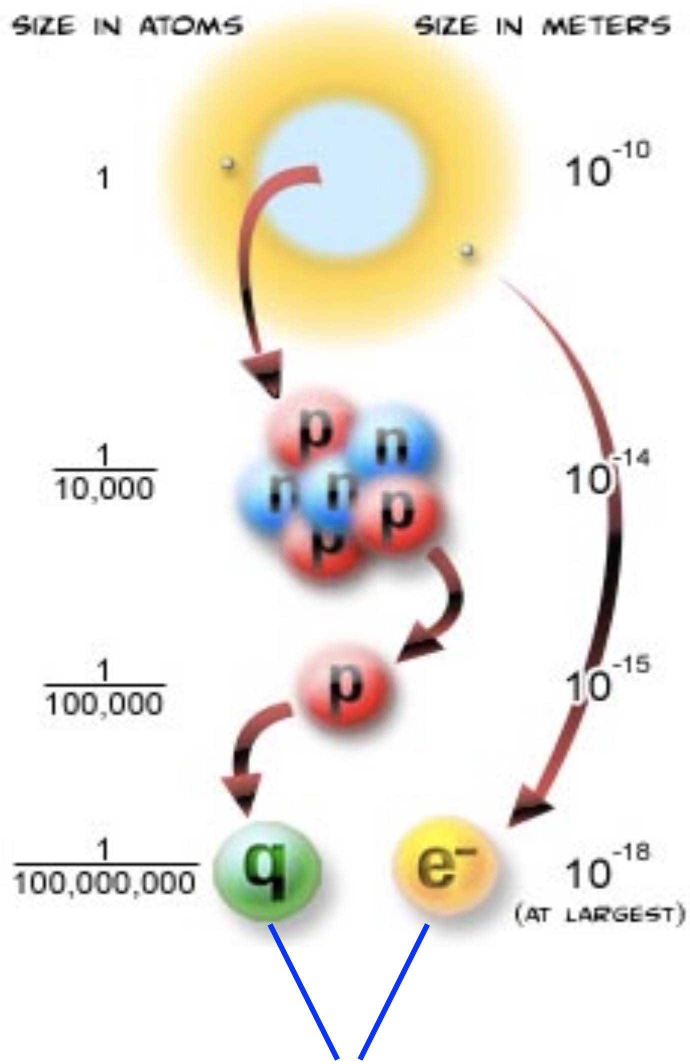
Today's High Energy Accelerators can probe to ~ 10^{-19} m

Atom:

Nucleus:

Nucleon:

Quarks & Leptons:



Fundamental Particles (2012)

➔ The Standard Model ➔

Fundamental Particles

6 Quarks: *up (u), down (d), charm (c), strange (s)*
top (t) and bottom (b)

with fractional electric charges

➔ The Standard Model ←

Fundamental Particles

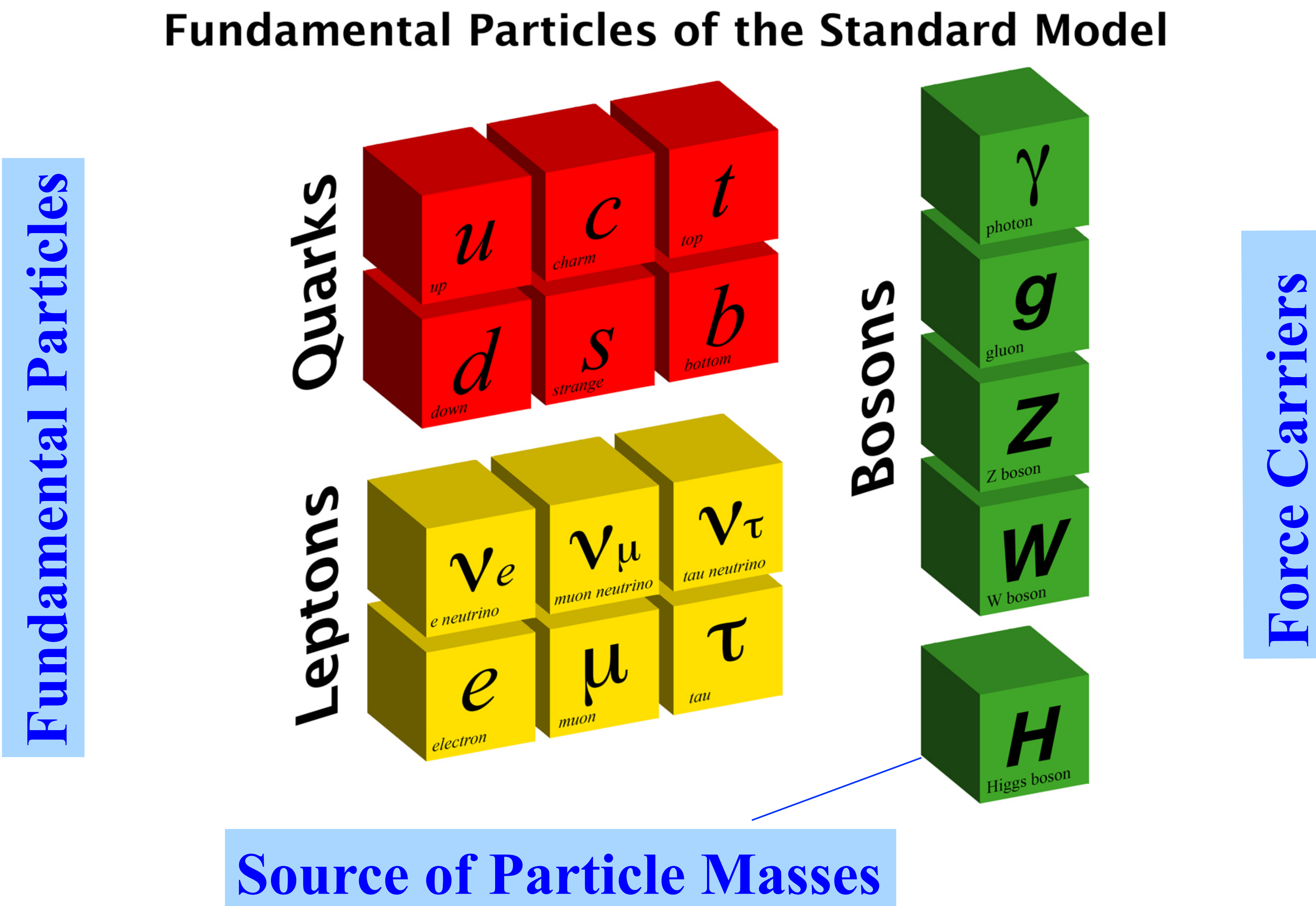
6 Quarks: *up (u), down (d), charm (c), strange (s)*
top (t) and bottom (b)

with fractional electric charges

6 Leptons: *electron (e), muon (μ), tau (τ)*
electron neutrino (ν_e), muon neutrino (ν_μ) and tau neutrino (ν_τ)

with unit or no electric charge

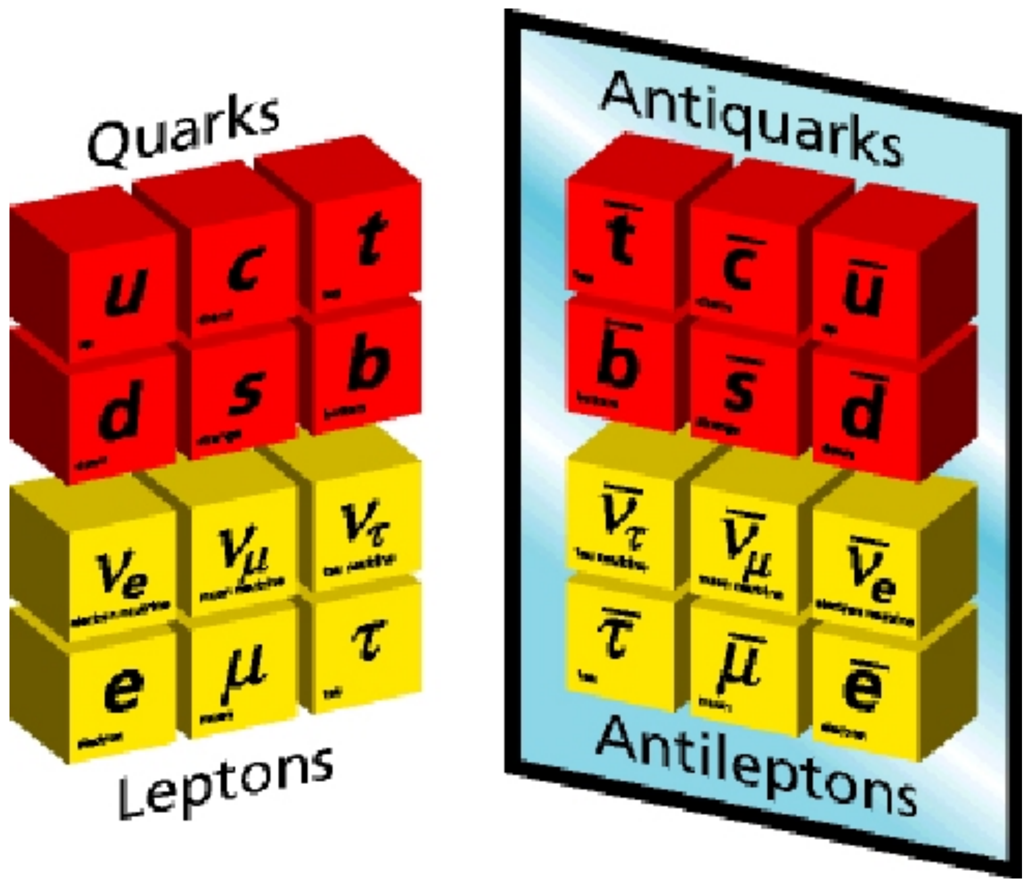
The Standard Model



The non-dark part of the matter
in our Universe
is made up of the
'1st generation' particles
(u, d, e, ν_e)

Matter and Anti-matter

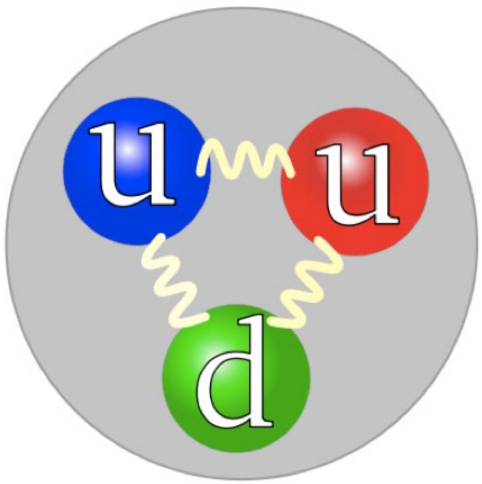
To this picture we add three generations of anti-particles



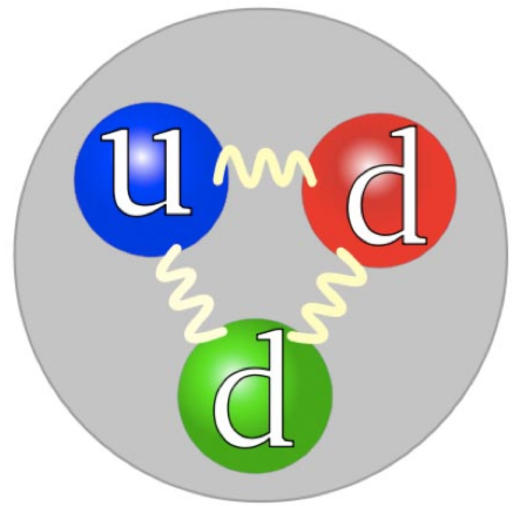
All 24 particles have been observed

Let's go back to the proton and neutron…..

Proton:
(*uud*)

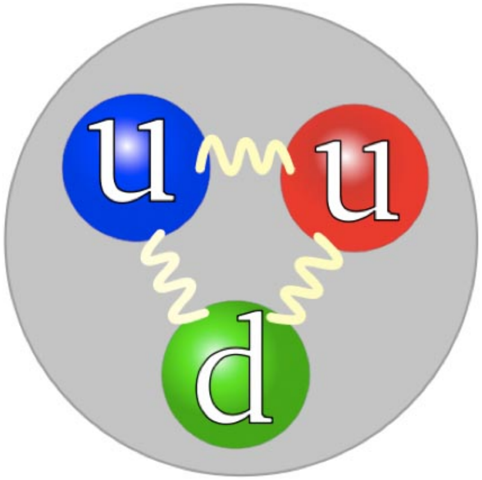


Neutron:
(*udd*)

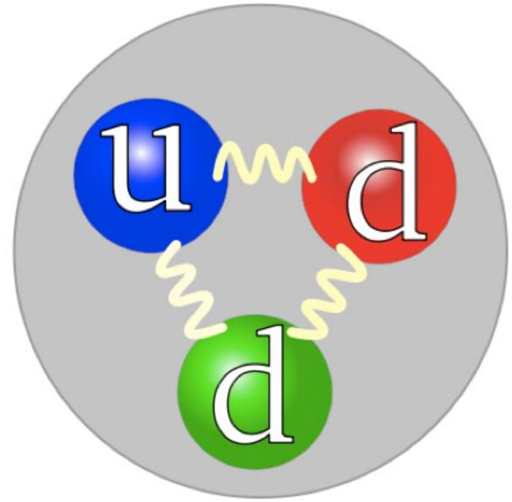


The quarks are bound together by the exchange of gluons

Proton:
(*uud*)



Neutron:
(*udd*)



To see the structure of an object ➔ need a probe with a deBrolgie wavelength shorter than the size of the object.
e.g. nucleus ➔ nuclear size (~10^{-14} m)

The higher the collision (probe) energy ➔ the shorter distance probed

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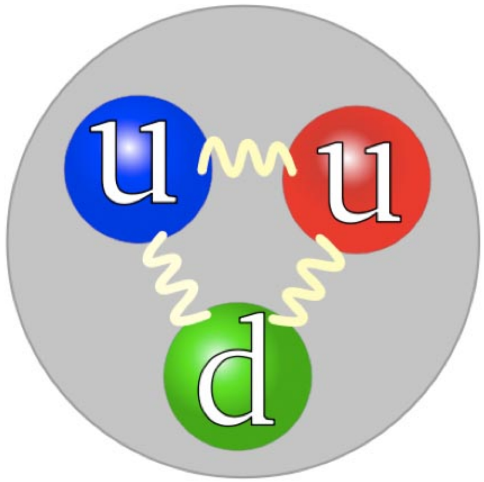
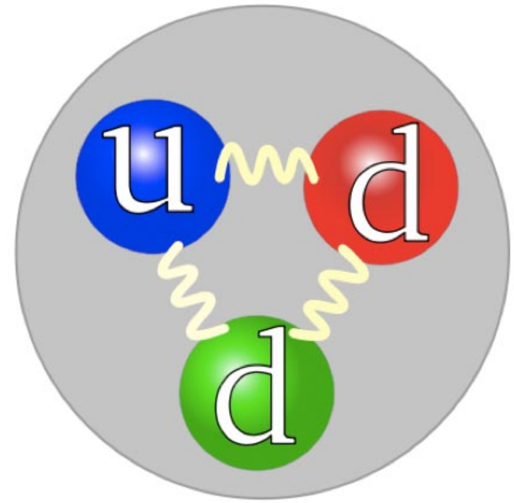
(uud)



Neutron:
(udd)



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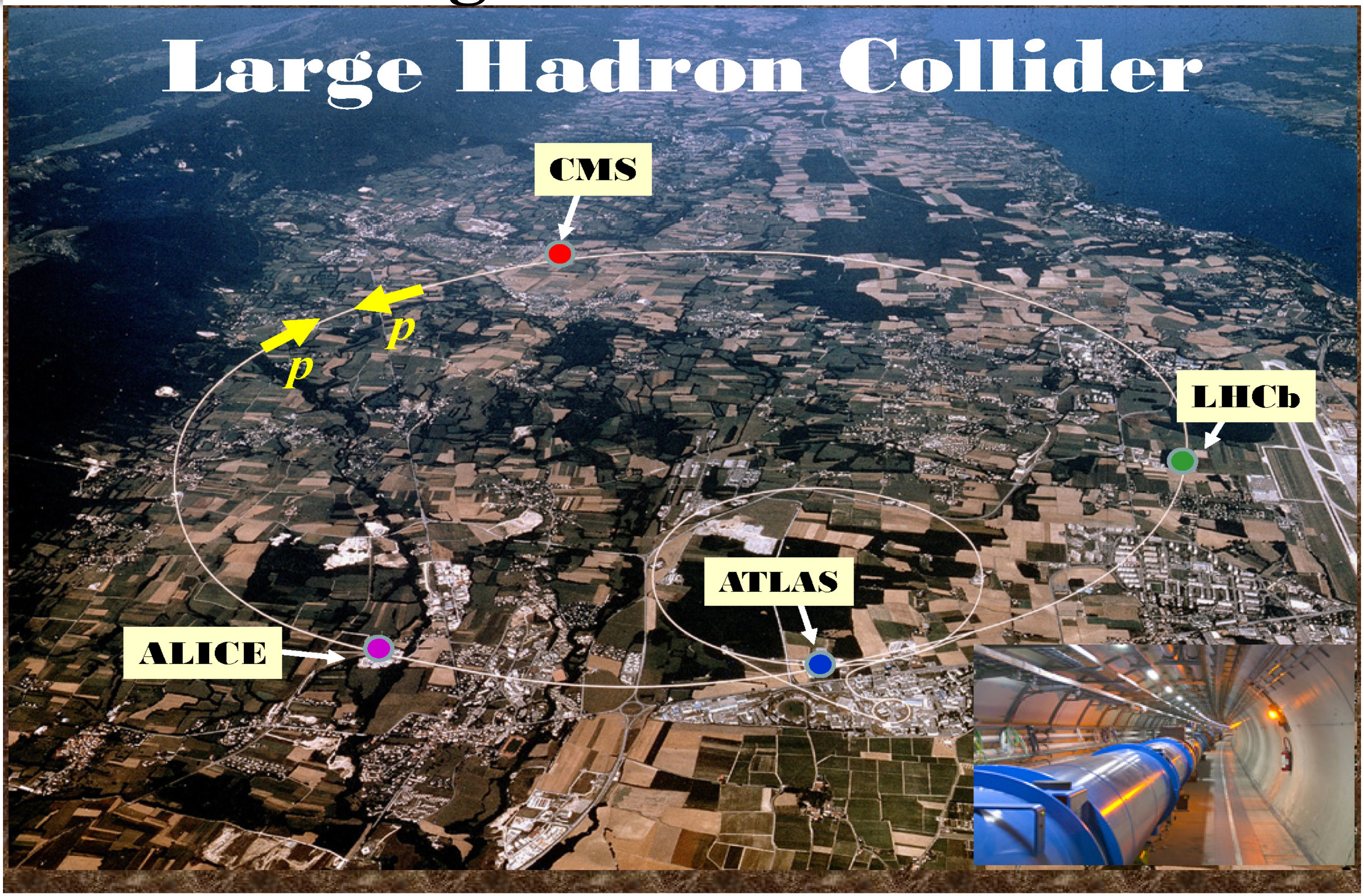
The LHC ➔ Highest Collision Energy in the World

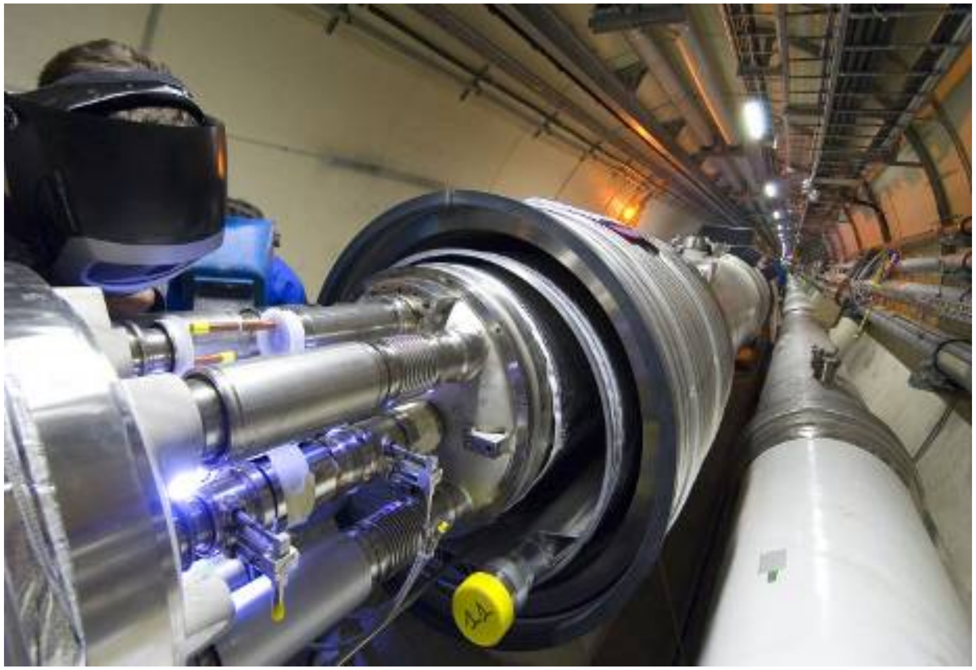
The Large Hadron Collider



One of the **fastest** racetracks on the planet

Several thousand billion protons travelling at 99.9999991 % of the speed of light travel round the 27 km LHC ring over 11000 times a second!

The **emptiest** space in the solar system



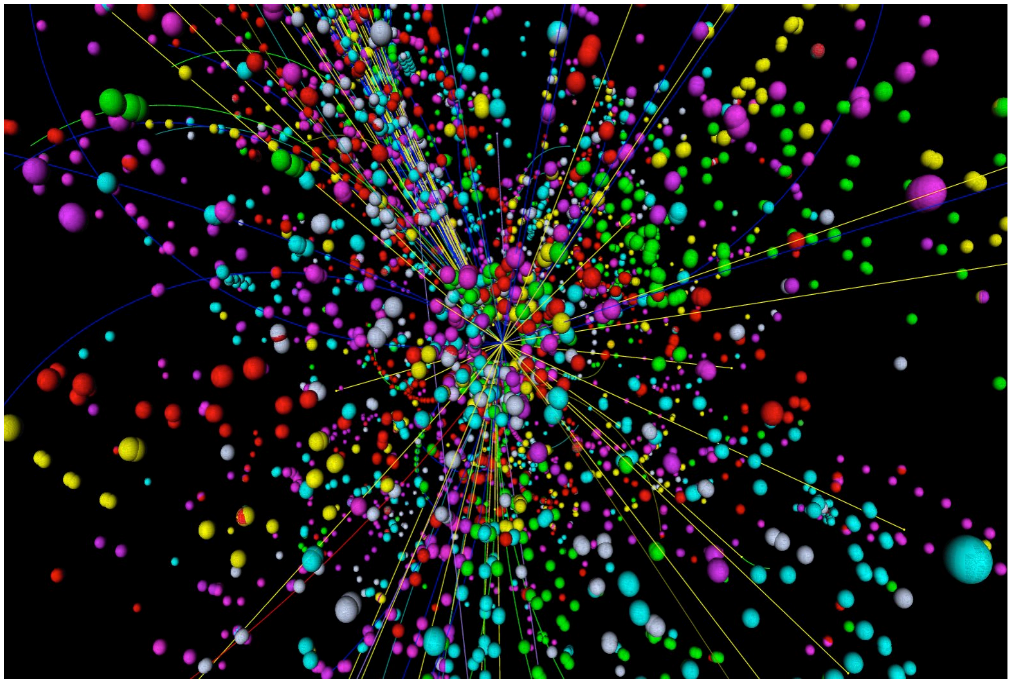
To accelerate protons to almost the speed of light ➔need a vacuum similar to outer space.

The pressure in the beam-pipes of the LHC is about ten times lower than on the moon.

One of the **coolest** places in the Universe

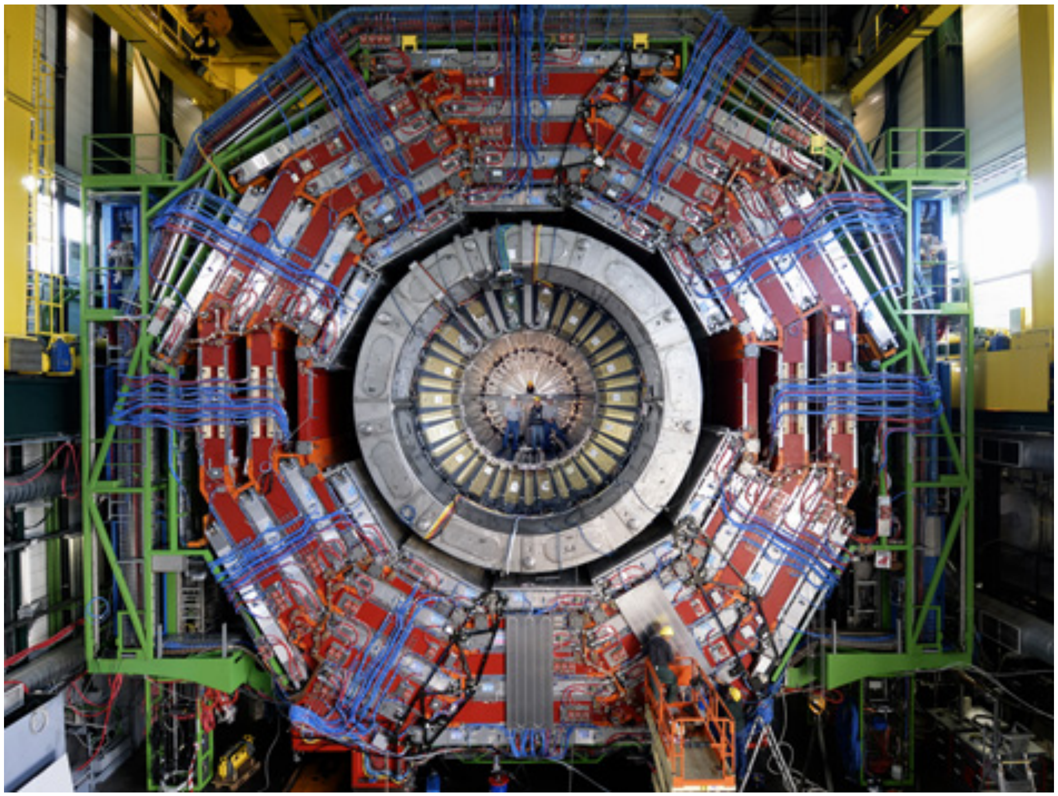
With a temperature of around -271 degrees Celsius, or 1.9 degrees above absolute zero, the LHC is colder than outer space.

One of the **hottest** places in the Galaxy



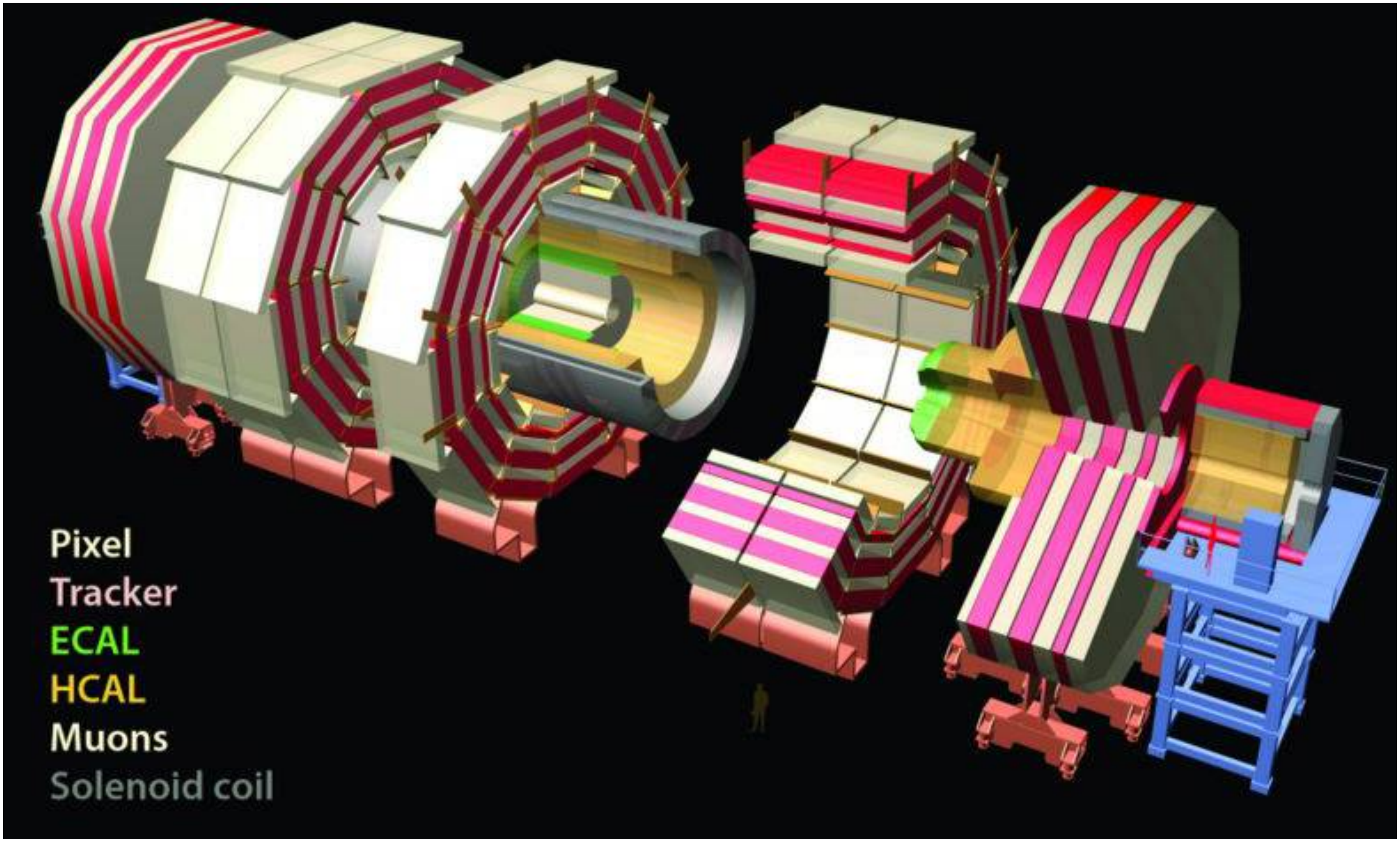
When two beams of protons collide they generate, within a tiny volume and for a tiny fraction of a second, temperatures more than a billion times those in the very heart of the Sun.

Large teams of Scientists study the collisions using the **largest and most complex detectors** ever built



To select and record the signals from the 600 million proton collisions every second, scientists have built huge detectors to measure the tiny particles to an extraordinary precision.

The CMS Detector



CMS is a **huge** detector…..

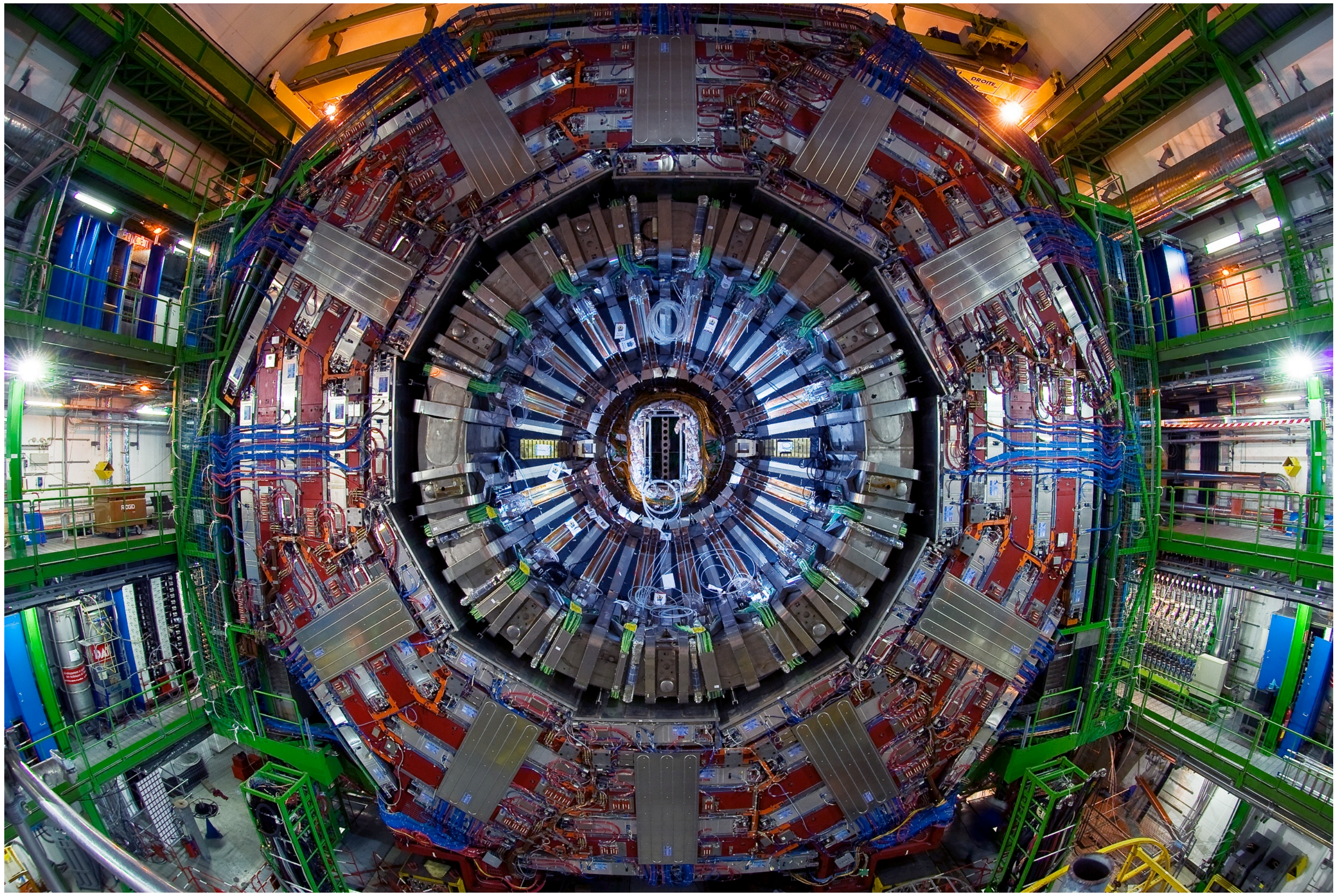
Situated 100 m underground

The detector is 15 m wide and 21.5 m long

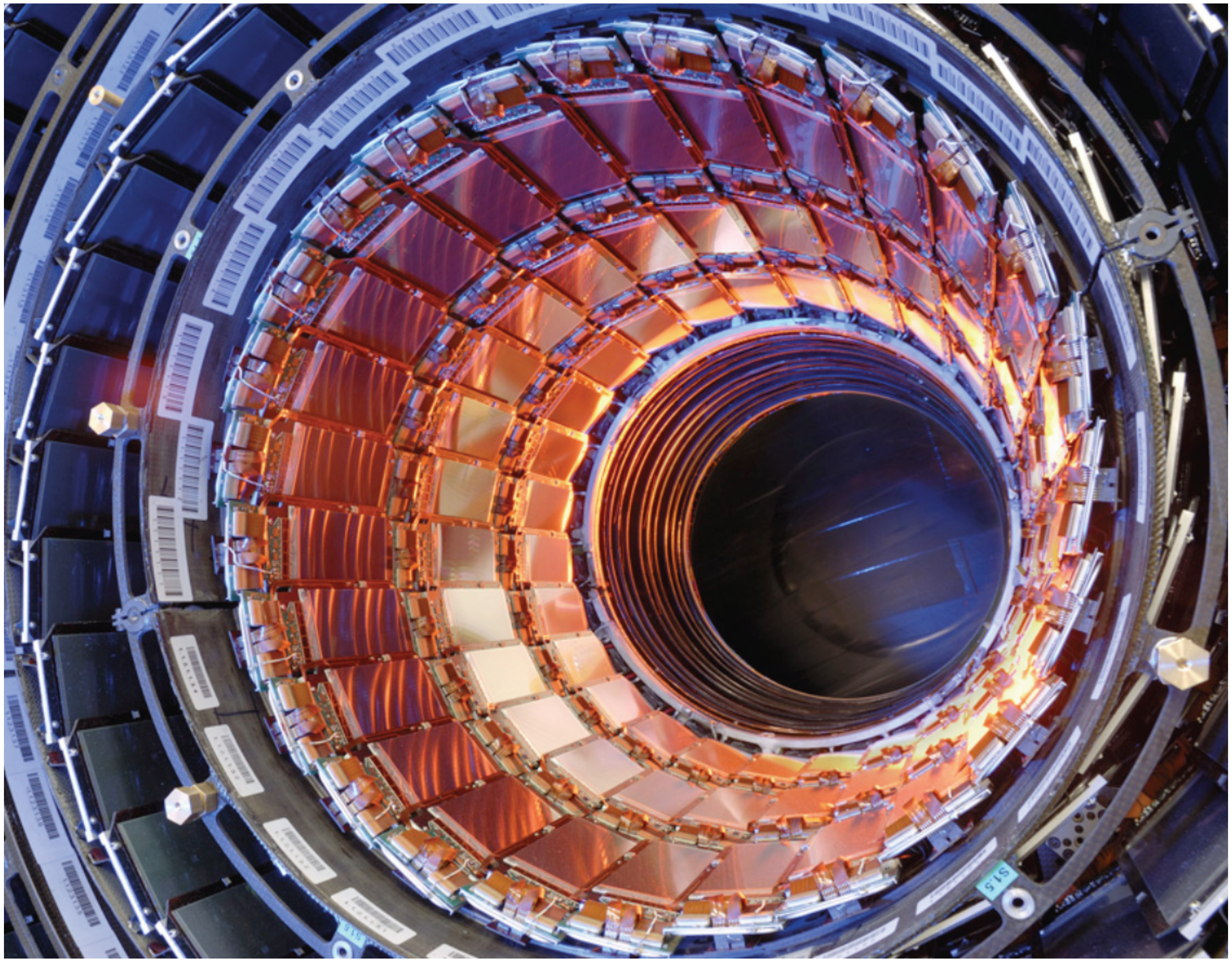
It weighs twice as much as the Eiffel Tower

(12,500 T)

Uses the largest, most powerful magnet of its kind ever made



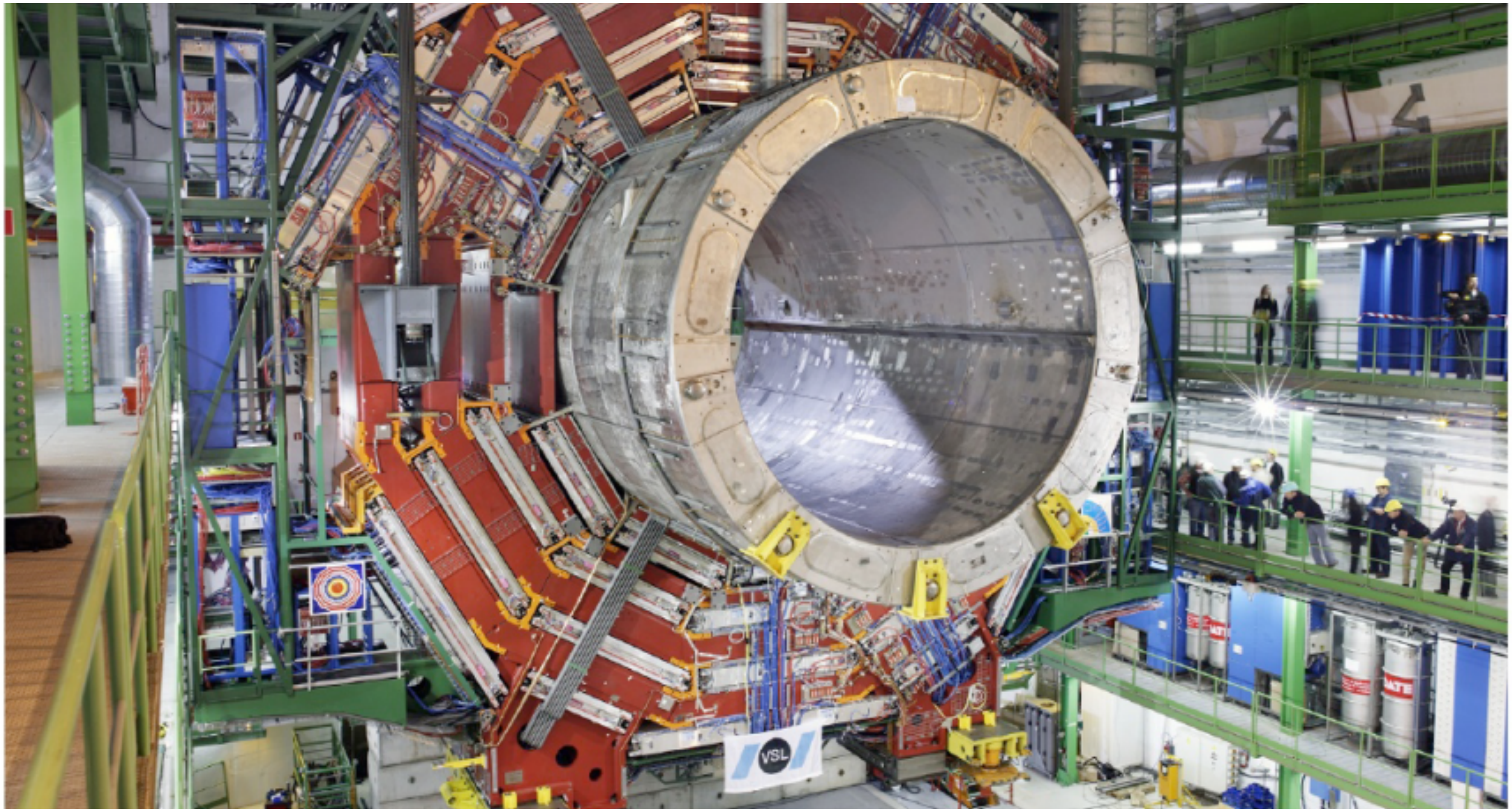
…built with incredible **precision…**



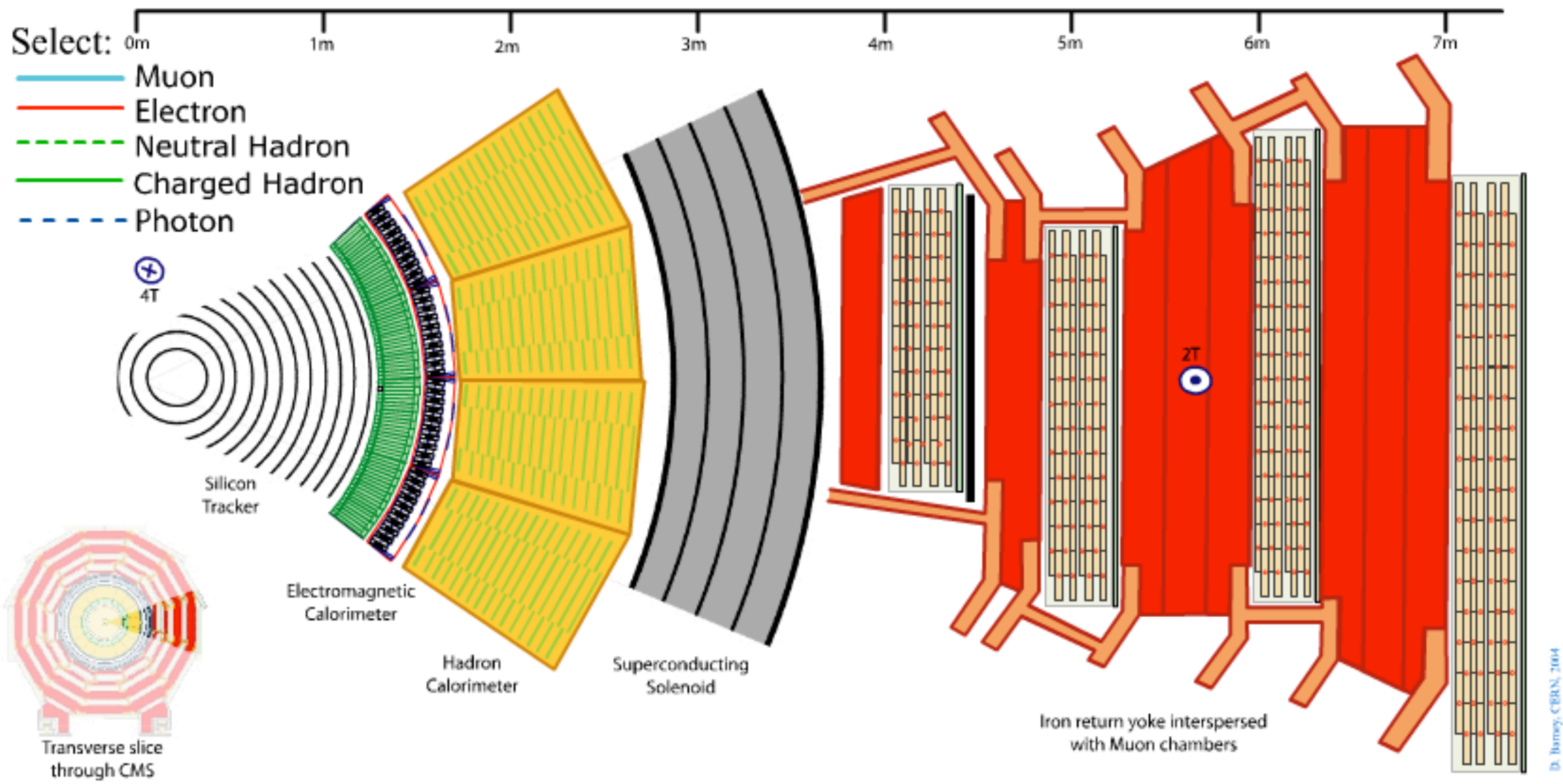
Took almost 20 years to design and build

Like a 75 million pixel 3D camera which takes 40 million photos per second

…on the surface and lowered 100m underground!



with several different **layers**



But why are we doing all this?
Don't we already know everything?

But why are we doing all this?
Don't we already know everything?

In fact we know very little!

The Mystery of Anti-matter

14 billion years ago the Big Bang created equal amounts of matter and antimatter

We exist because there is no antimatter around

So where did it all go?

Why does Nature prefer matter?

What Happened to the Anti-matter?

After more than 50 years of research we know that some particles behave differently from their anti-particles.

But…..

The difference is not sufficient to explain why the Universe is the way it is.

What Happened to the Anti-matter?

➔ There must be something else going on ➔

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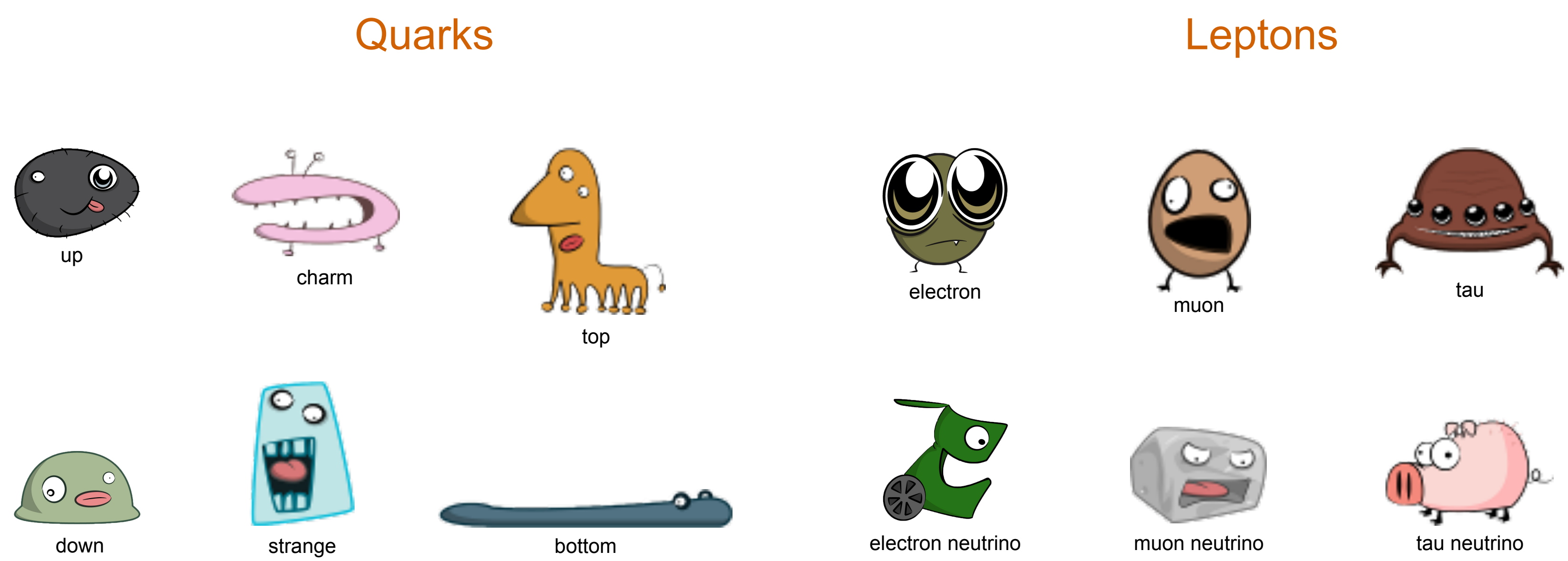
The LHC produces equal amounts of matter and anti-matter.

Studying both in detail may provide us with new insights.

The Mystery of Mass



Why do the masses of the fundamental particles vary by almost 9 orders of magnitude?

The reason *could* be the existence of a new particle, called the "Higgs boson"

What is Really Out There? (and In Here!)

Astronomy tells us that the matter we know

(i.e. protons, neutrons and electrons)

accounts for just 5% of the universe

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The rest is dark matter

and dark energy

Dark Matter

"Dark" because we can't detect it directly

Can tell it's there from effects on galaxies

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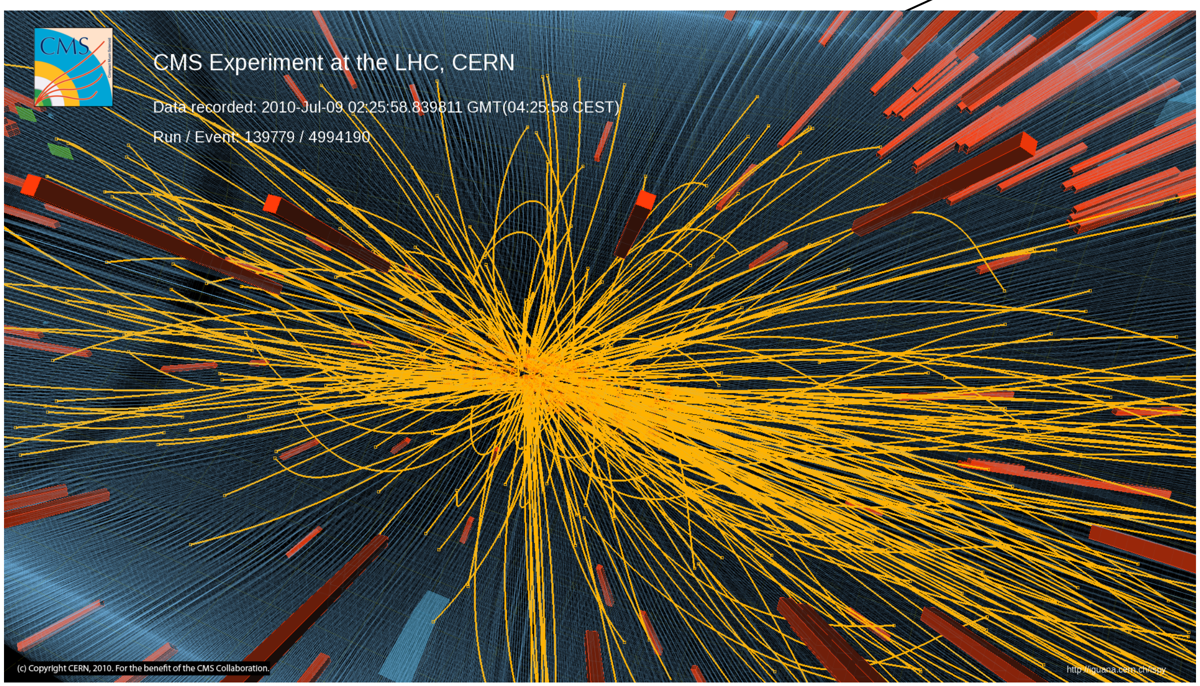
Could be made of undiscovered particles
→ SUPERSYMMETRY

LHC could create these particles and CMS could (indirectly) detect them

LHC Experiments are Taking Data

The LHC is running and we are busy studying collision like this one.



Data-taking

Key to all of these studies is the total number of collisions recorded (aka "luminosity") and the collision energy

2010: 7 TeV

- *March-November 36 pb^{-1}*

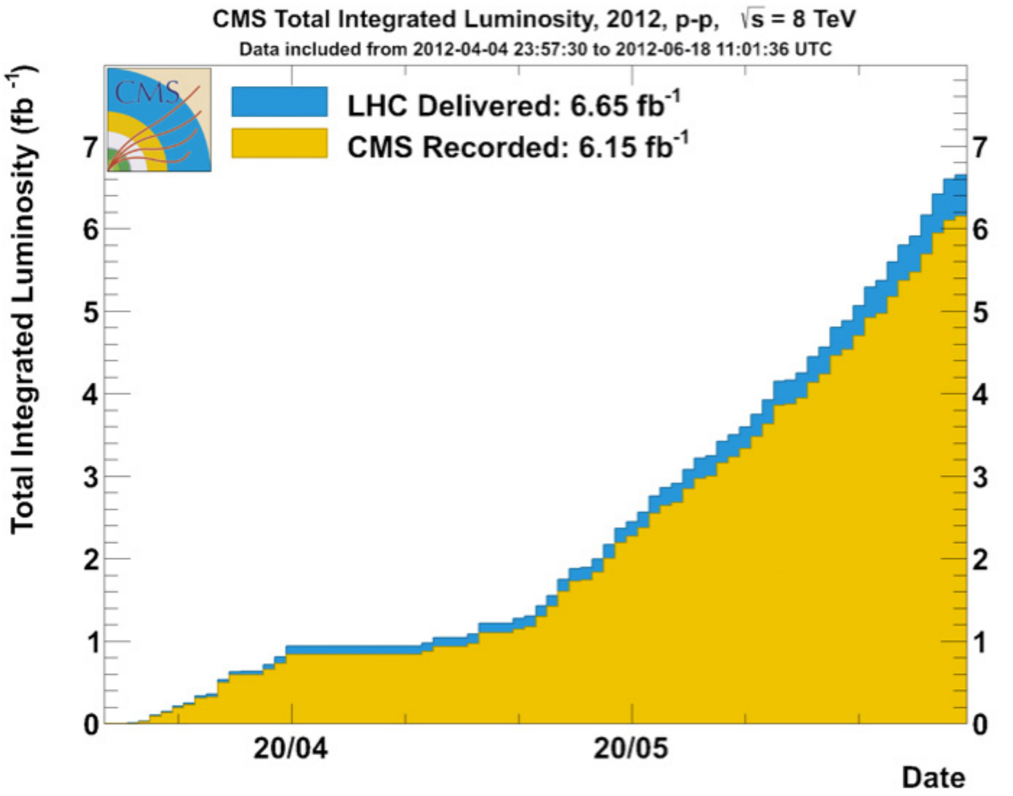
2011: 7 TeV

- *March-November 5 fb^{-1} (factor of 140 more)*

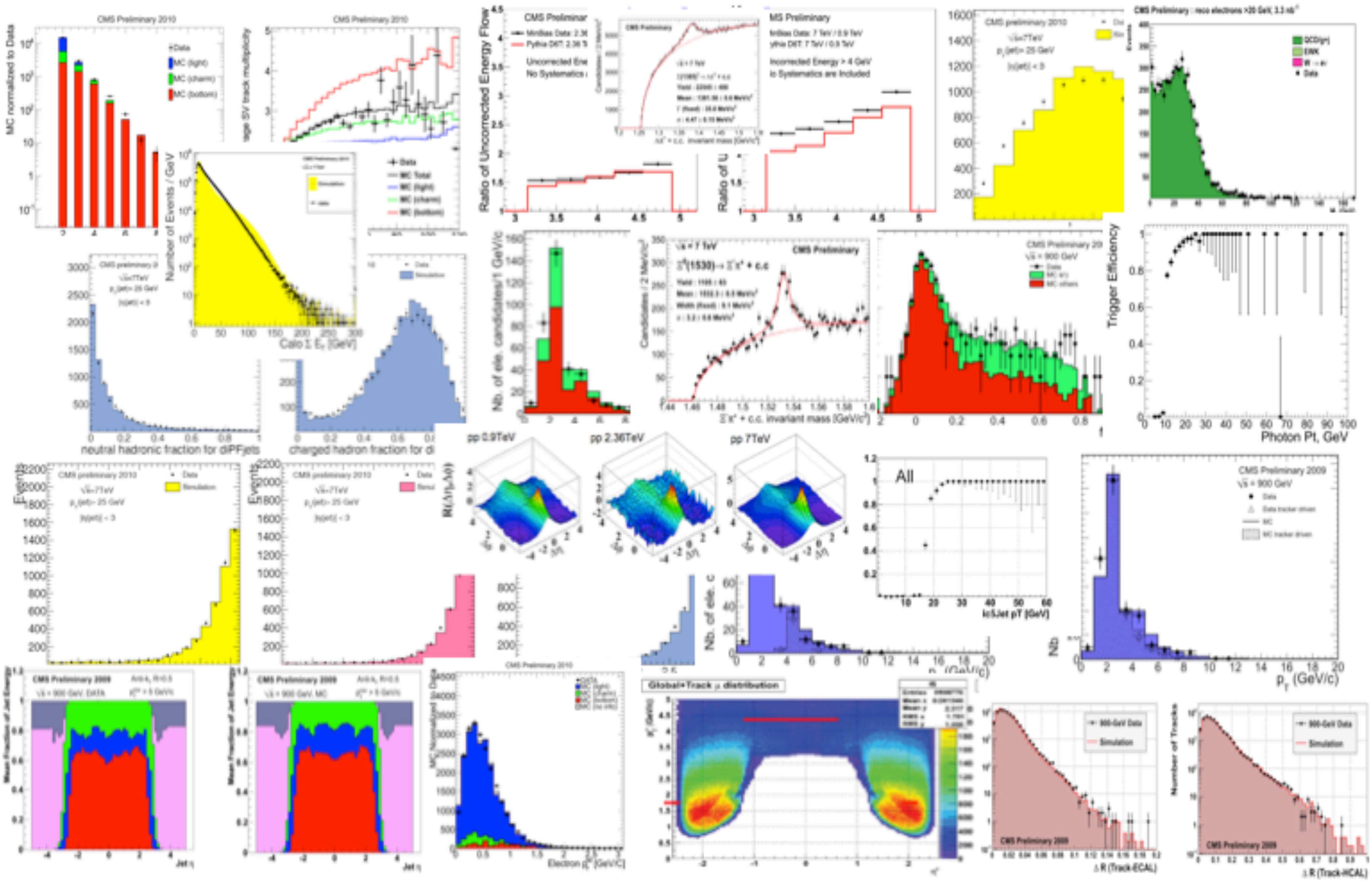
2012: 8 TeV

- *March-June 6 fb^{-1}*

  (run in progress)

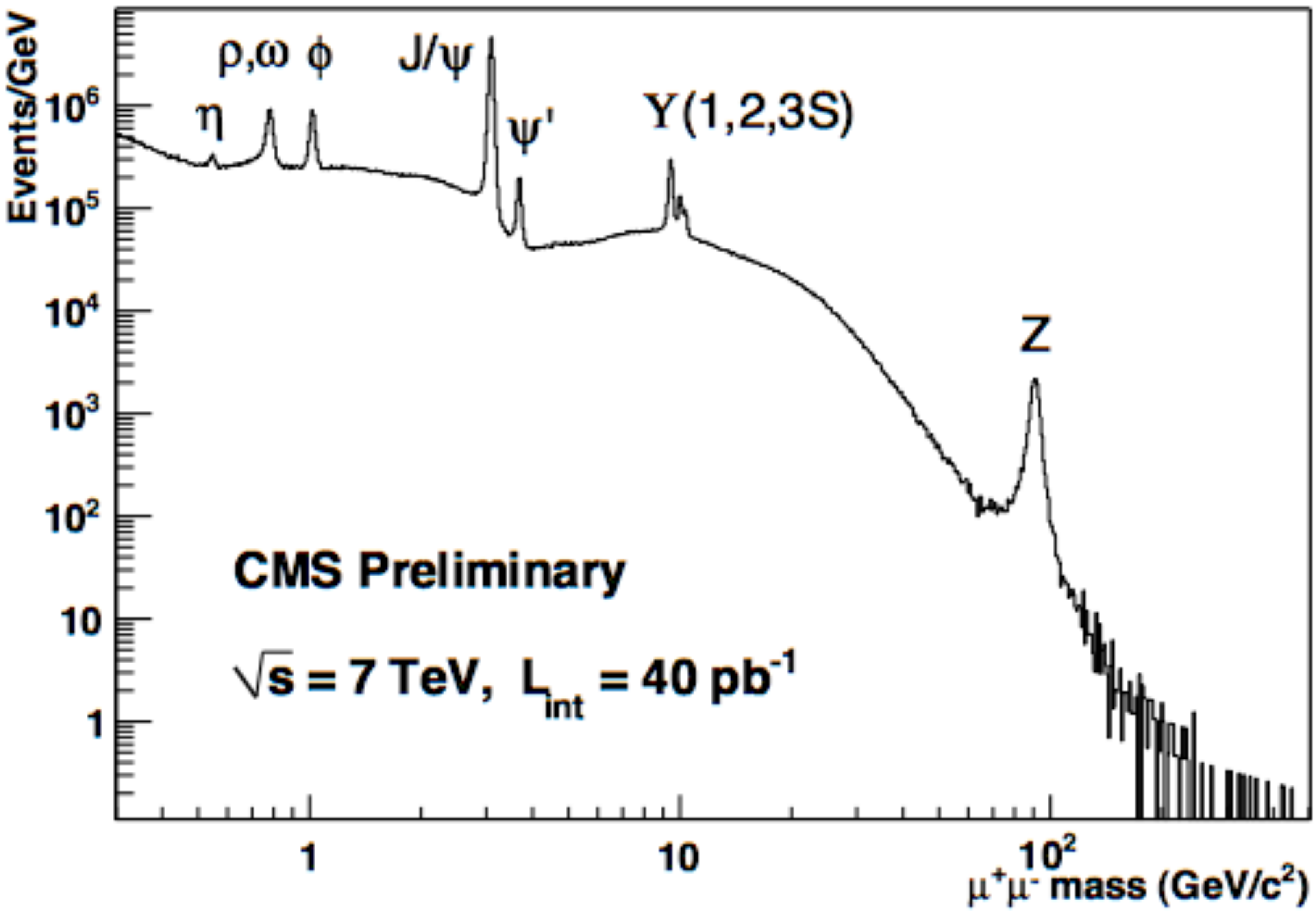


Lots of Results Heading for Publication



Example - $\mu^+\mu^-$ Mass Spectrum

"Muon" is our middle name!



Example – Precision Measurements

One way to search for new physics is to do precision measurements…..

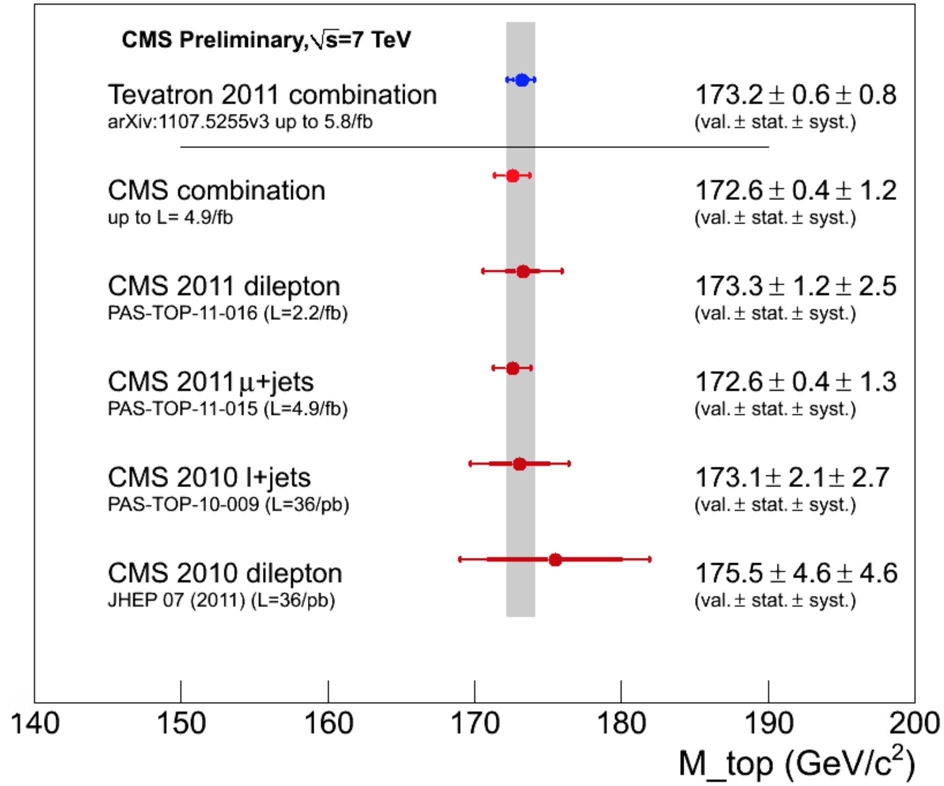
Most massive known particle

is top quark

Discovered 1995 at Fermilab

10 years of study by

two experiments (D0

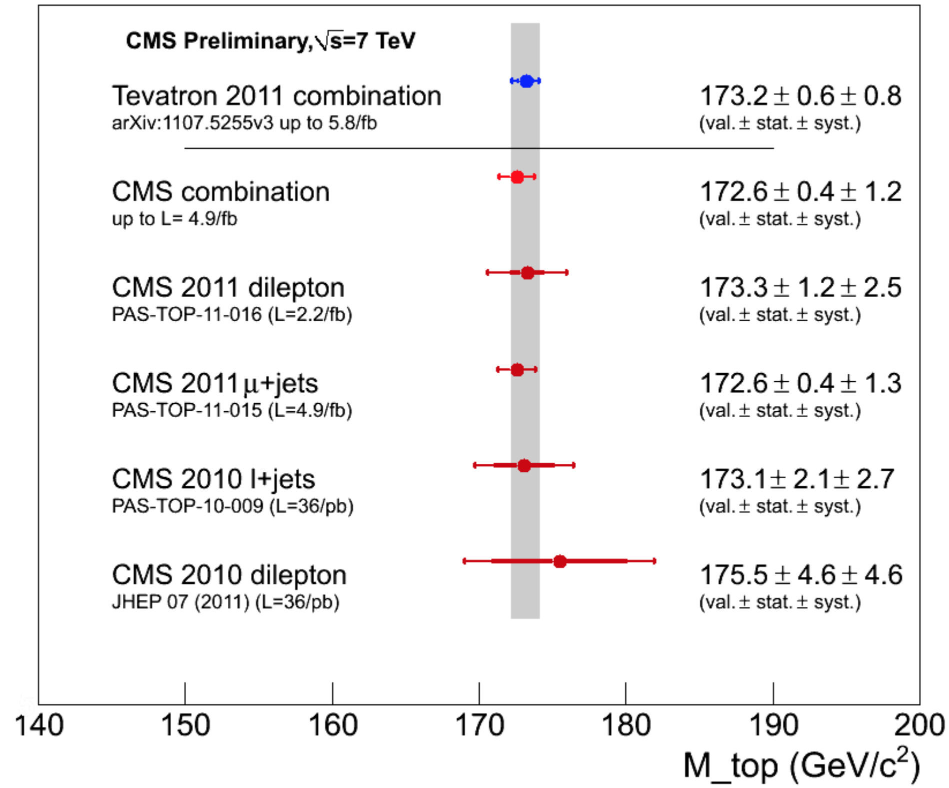


Example – Precision Measurements

Most massive known particle

is top quark

➡ Mass =173.2 ± 0.6 ± 0.8 GeV



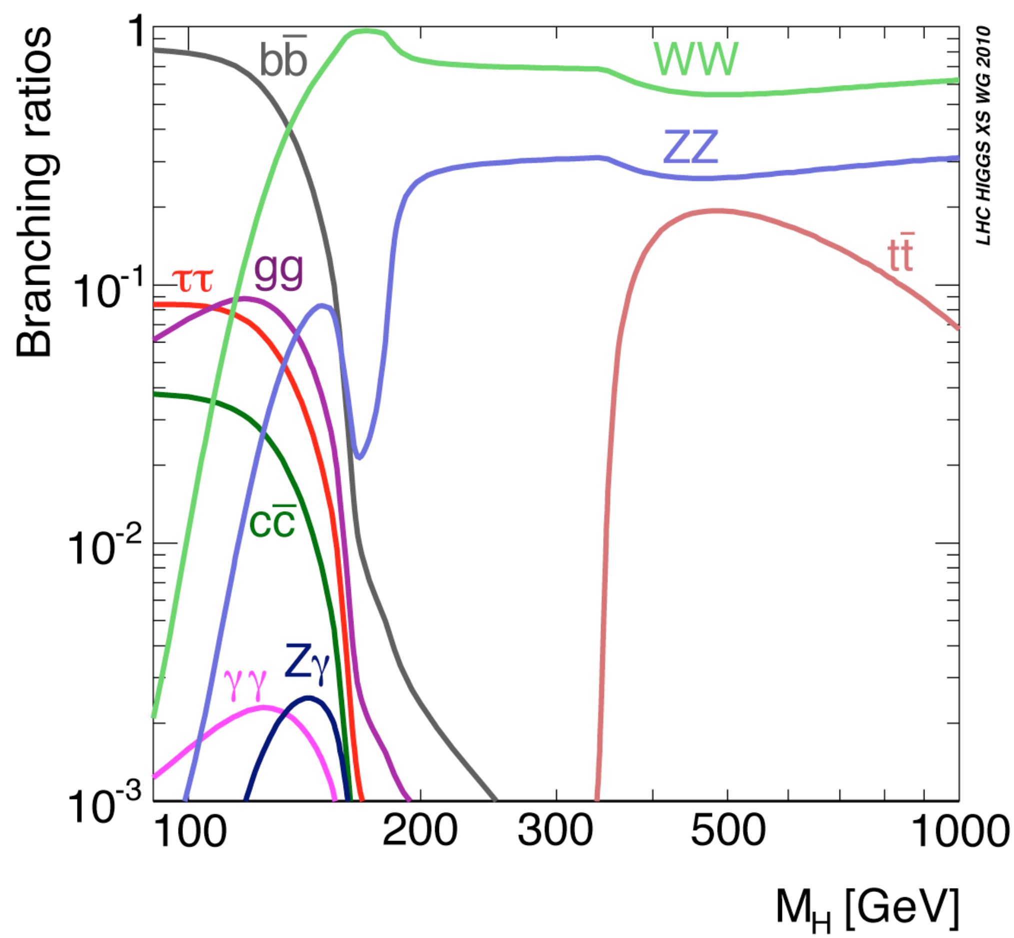
CMS Experiment (Preliminary):

Example – Search for Higgs Boson

Very difficult
to do

➔ Higgs particle decays differently depending on its mass is

➔ Many parallel analyses are needed

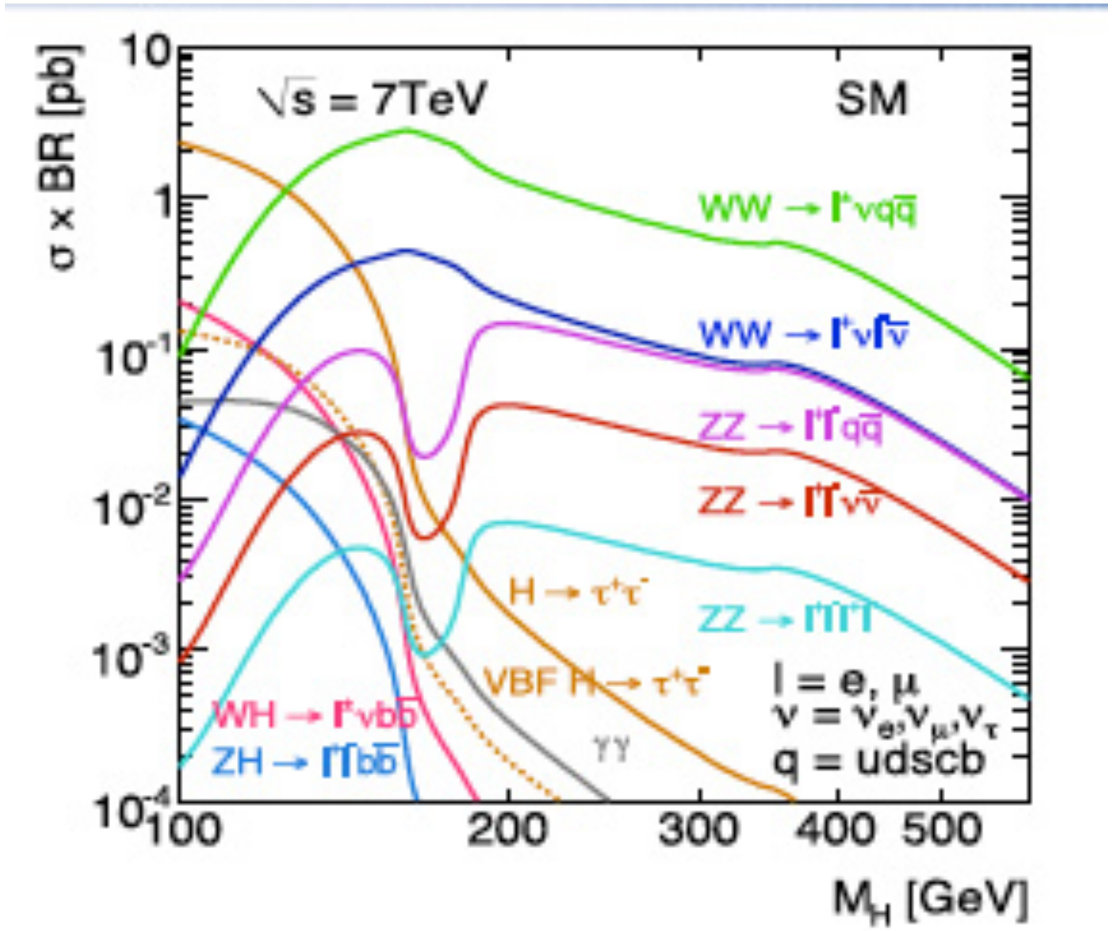


Example – Search for Higgs Boson

Production rate for
Higgs particles
is very small

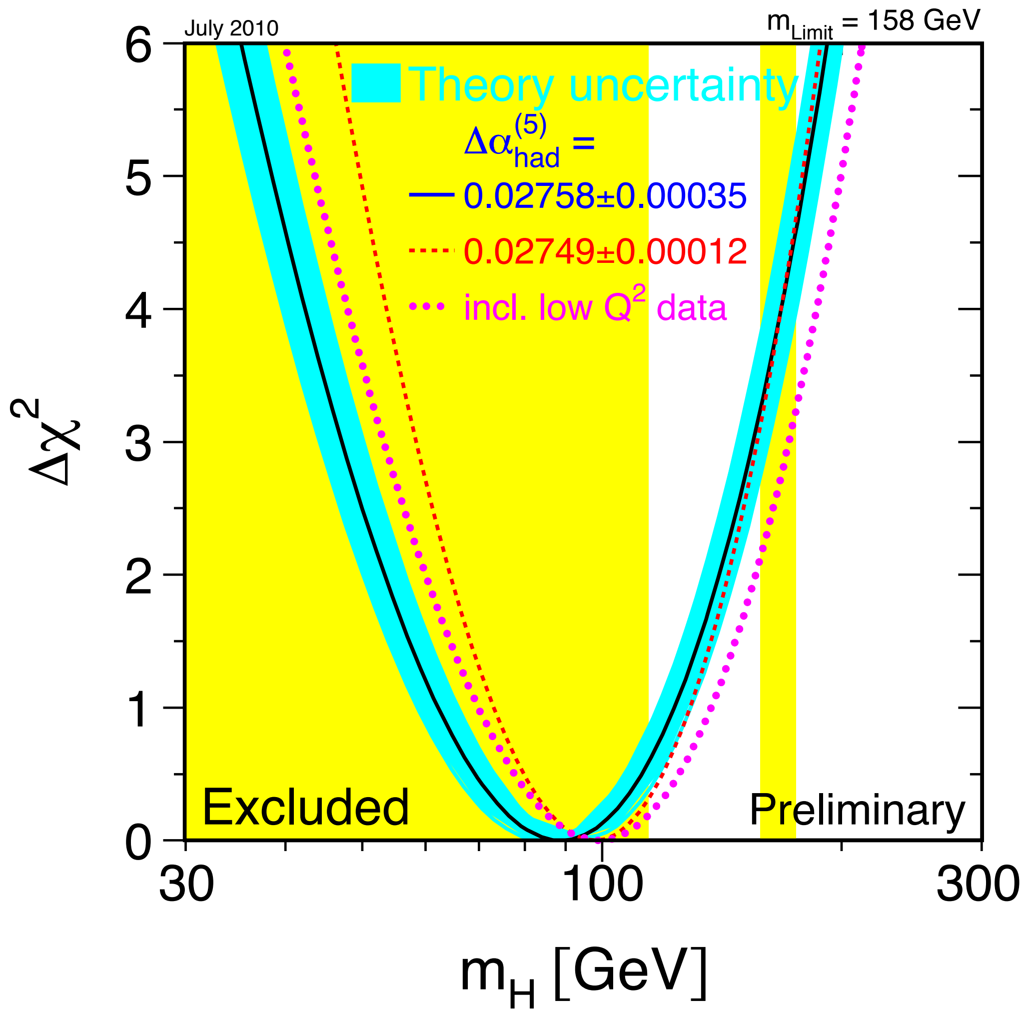
and

the backgrounds
can be very large



Summer 2010

Combined results from experiments at CERN and Fermilab

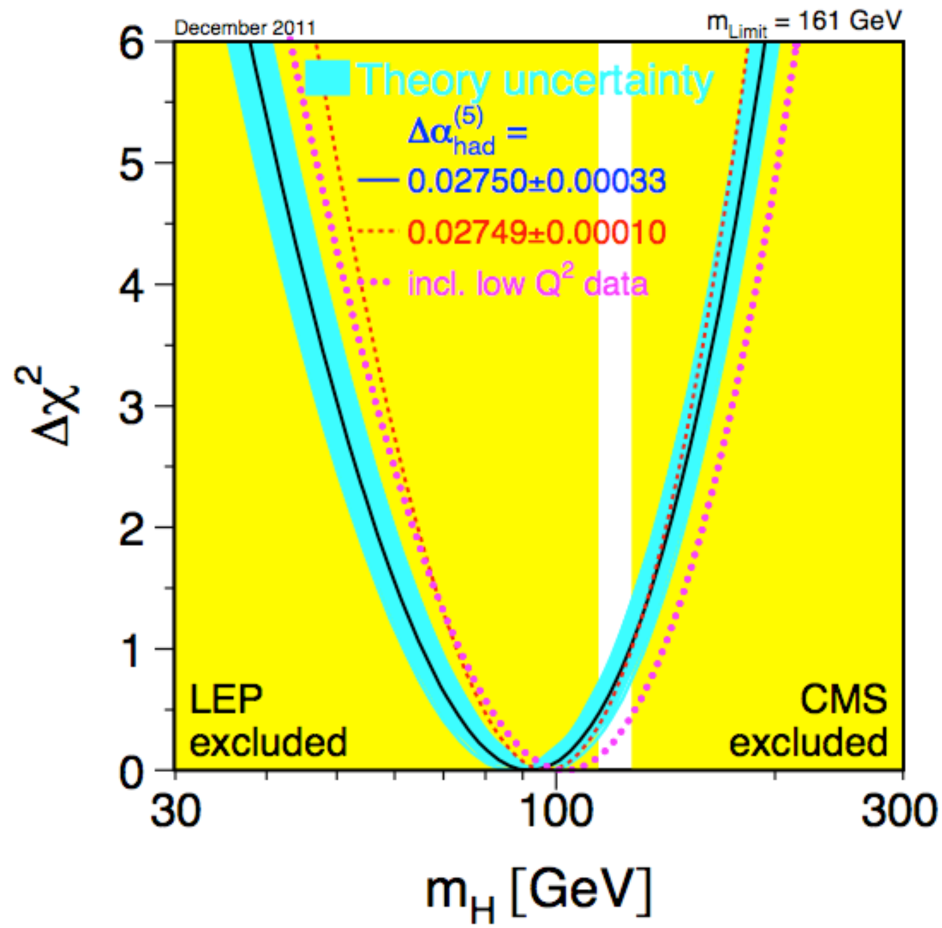


Higgs – after 2011 LHC Run

Winter 2011-12

Combined results from
CERN and Fermilab
and the
LHC experiments

Small allowed mass range
Some indications of
small number of events
between 115 and 127 GeV



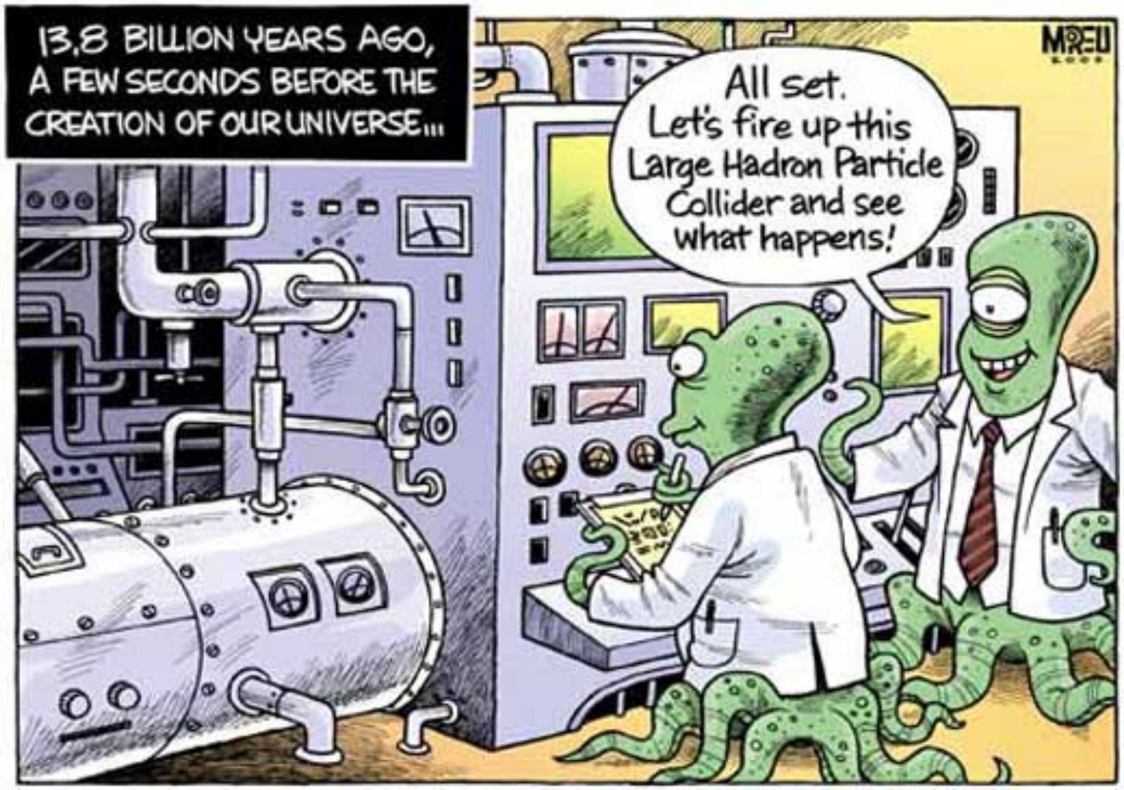
Higgs – 2011+2012 Data

Higgs – 2011+2012 Data

If there is a signal around 115-127 GeV we should be able to either see or exclude it by the end of the 2012 run.

Update of latest results from the two big LHC experiments (CMS and ATLAS) will be presented at a Press Conference at CERN on July 4th

A Closing Thought…….



Both the LHC and Experiments are running exceptionally well
We are probing for new physics in a completely new energy regime…………..stay tuned!