The Higgs boson and more from the LHC

Kevin Stenson

What is particle physics?

Particle physics is the ultimate *reductionist* science and seeks to answer just two questions:

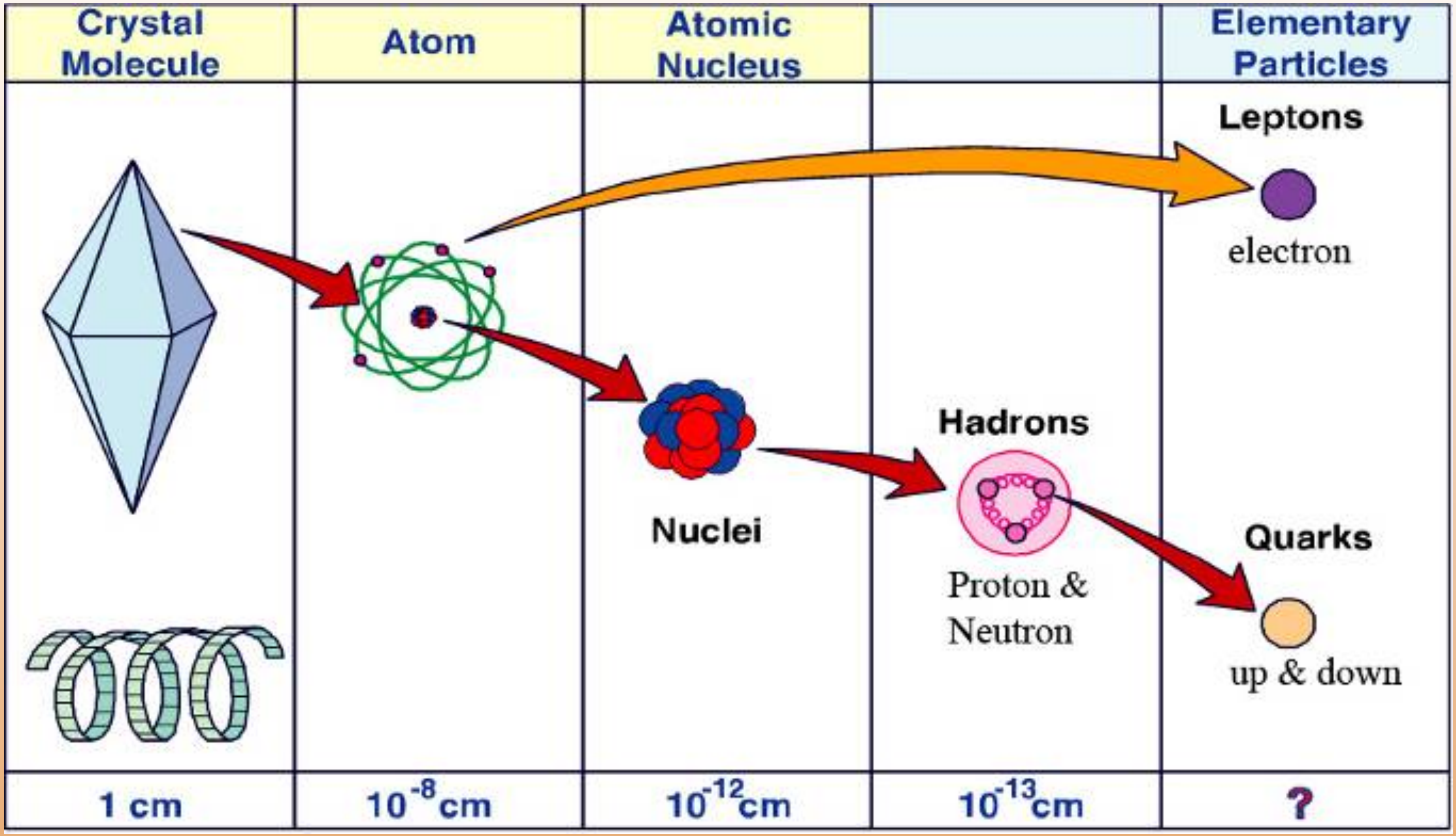
What are the fundamental building blocks (particles) in nature?

and

What is the nature of the forces acting between the particles?

First I will tell you what we know, starting with the fundamental particles…

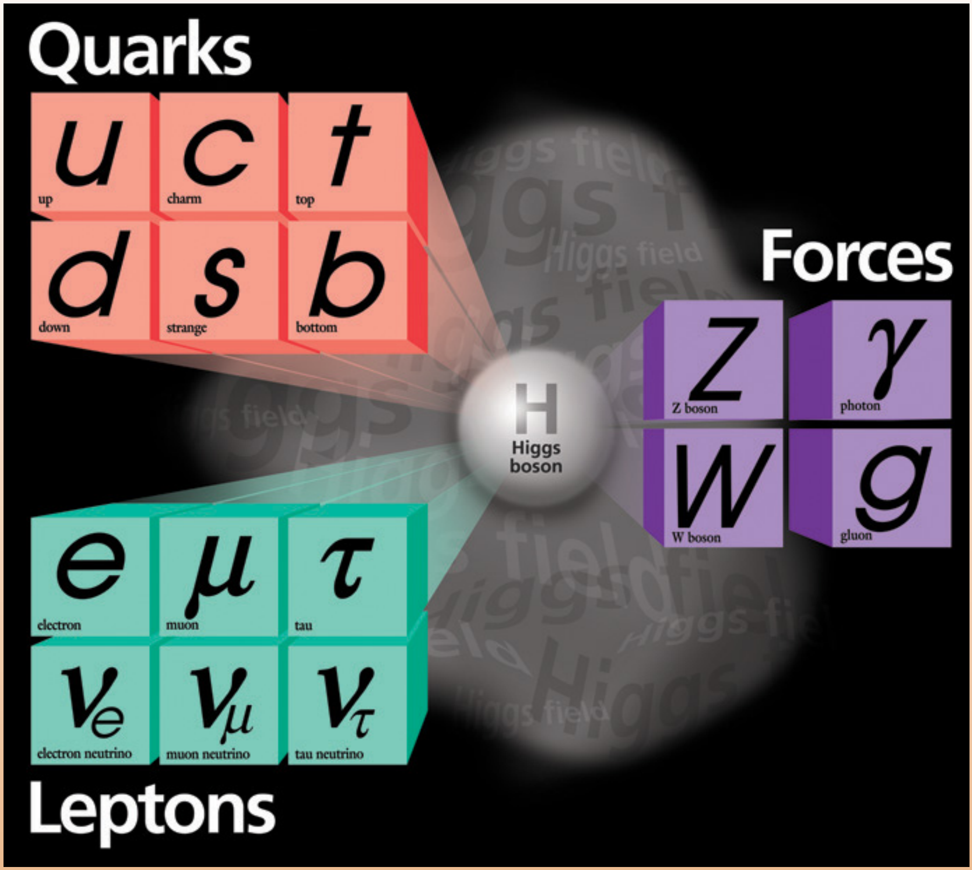
Looking at smaller and smaller distances



Probing smaller and smaller reveals more structure
until we reach the elementary (we think) particles.
Note that small distances is equivalent to high energy.

The standard model of particle physics

- 3 families of spin ½ quarks and leptons make up matter. The up and down quarks are in the protons and neutrons of the nucleus, which is surrounded by electrons in an atom.
- Spin 1 force carriers:
  - Photon mediates electromagnetic felt by charged particles
  - W and Z bosons mediate the weak force, felt by all particles
  - Gluons mediate strong force felt by quarks



The weak force behaves very differently than the electromagnetic force due to electroweak symmetry breaking. A way to explain this is with another field (Higgs field). This could also explain why the quarks and leptons have mass. Proof of this can be obtained by finding a particular particle, the spin 0 Higgs boson.

How does Higgs give mass to particles?

In the normal world, more mass corresponds to more protons and neutrons.

>

2 gallons of water is twice as massive as 1 gallon of water because there are twice as many water molecules so twice as many protons and neutrons.

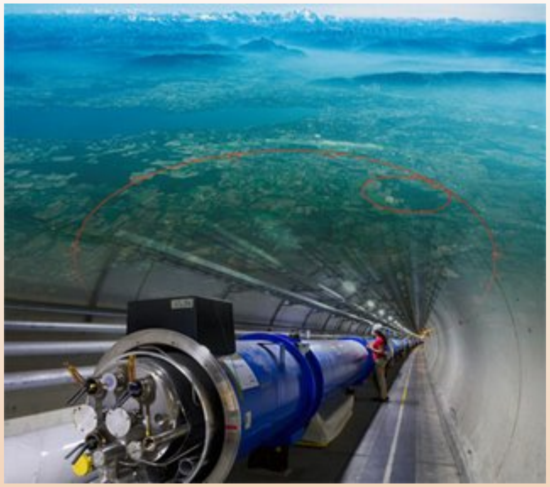
But quarks aren‘t made up of anything else. So where do they get their mass from?

Each quark is connected to the Higgs field, which permeates the universe. The stronger the connection to the Higgs field, the greater the mass. So really the mass is just the strength of the connection to the Higgs field.

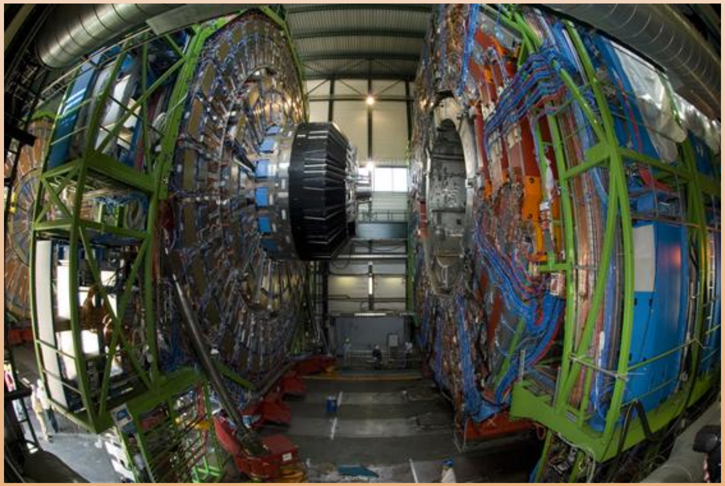
© 20th Century Fox

This mass behaves just like normal mass.

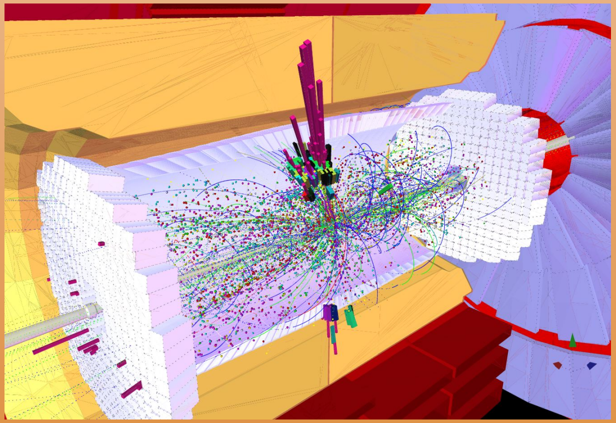
How do we find the Higgs boson?



Need a high energy particle collider to create Higgs particles



Need a detector to record the evidence of a Higgs particle



Need a way to separate the interesting events from the much more common boring events

The particle accelerator

The Higgs particle is unstable and so it decays into other particles immediately after being created. This means we need to make our own Higgs particles.

The most famous formula in physics gives us the prescription.

$E=mc^2$ tells us that mass and energy are equivalent.

An atomic bomb converts a small amount of mass into energy.

We do the opposite. With enough energy, you can create mass such as a Higgs particle.

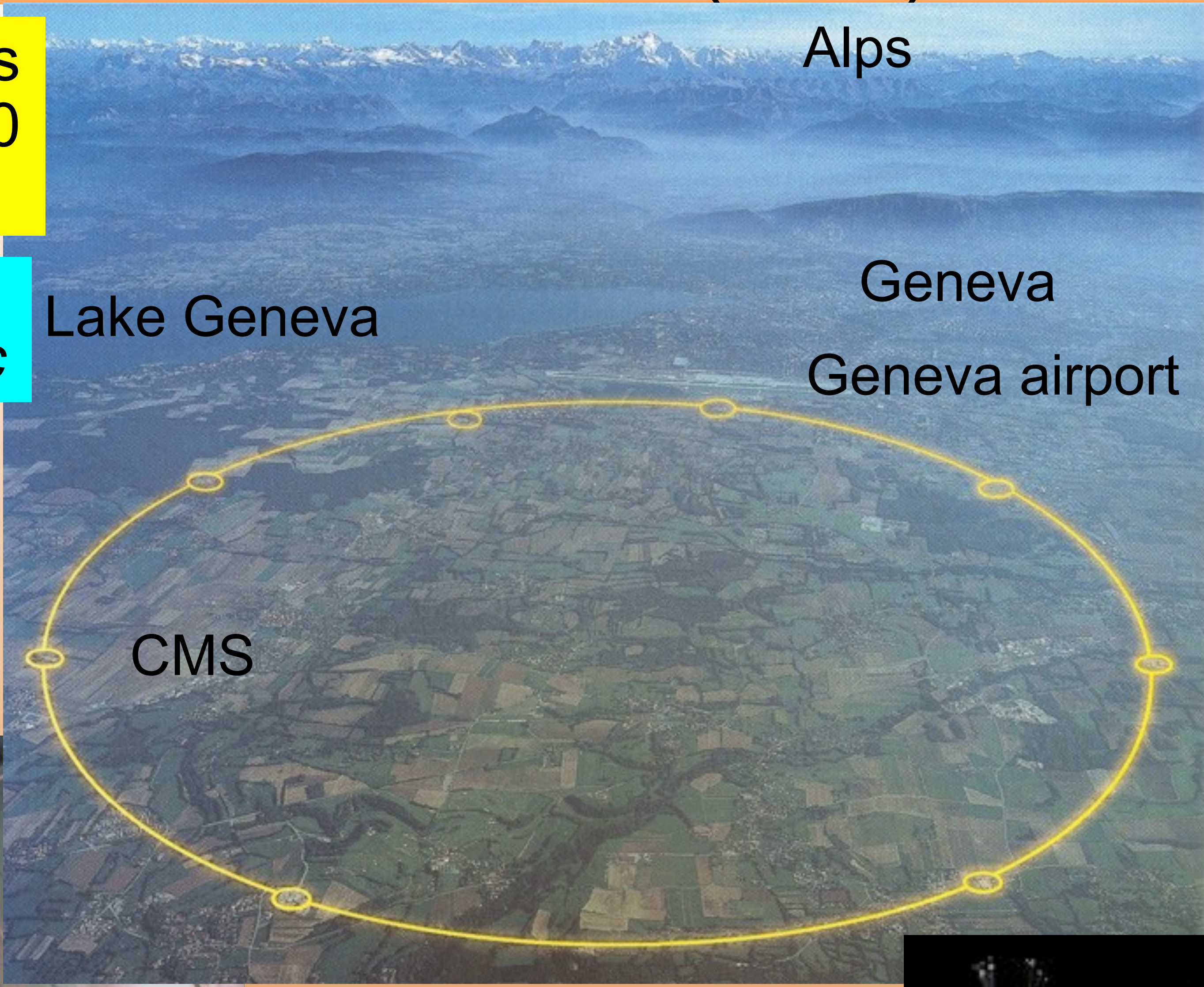
The name of the accelerator is the Large Hadron Collider (LHC) and is located at CERN (European Center for Nuclear Research).

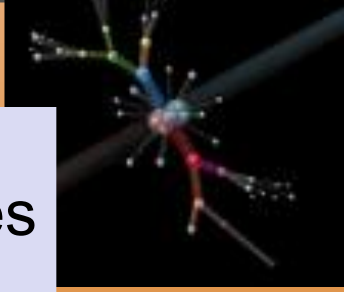
The Large Hadron Collider (LHC)

The LHC is 17 miles around and 100-500 feet underground

RF cavities accelerate protons to 0.99999999*c*

8.3 Tesla superconducting magnets at −456°F keep the protons going in circles

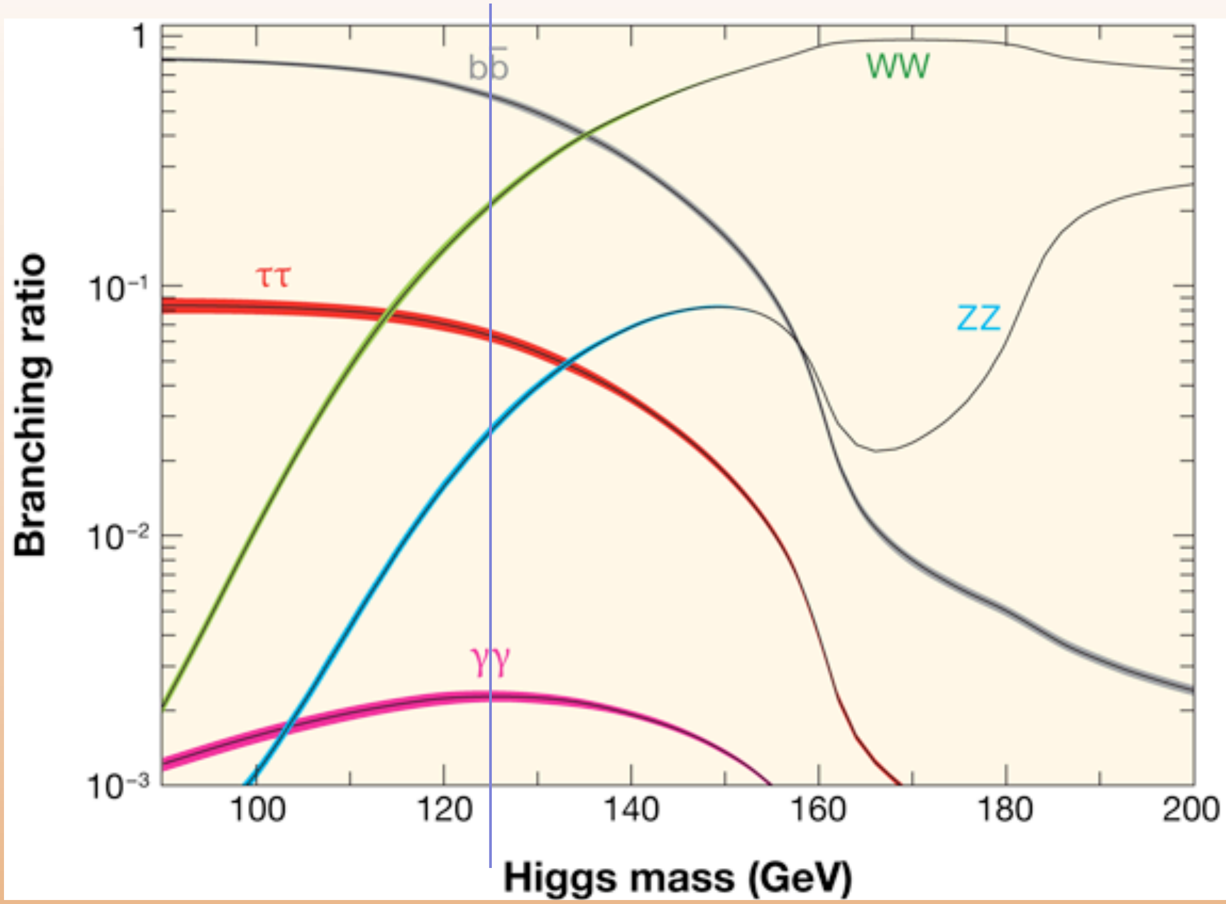


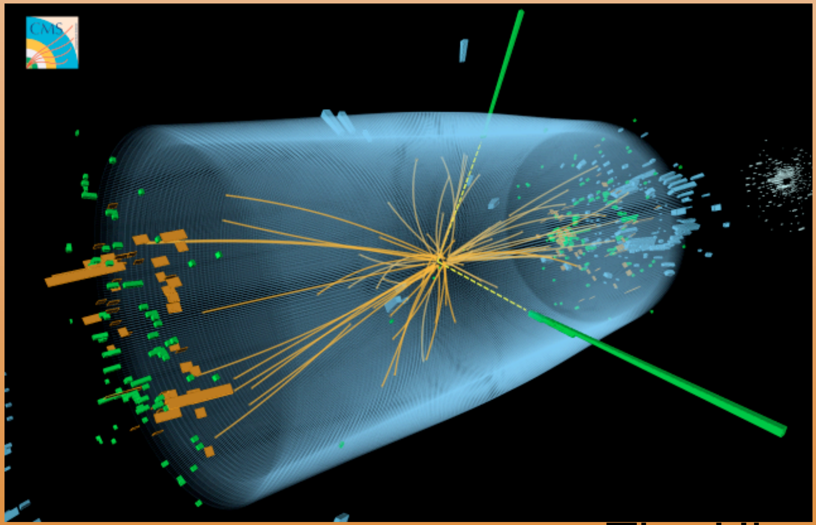


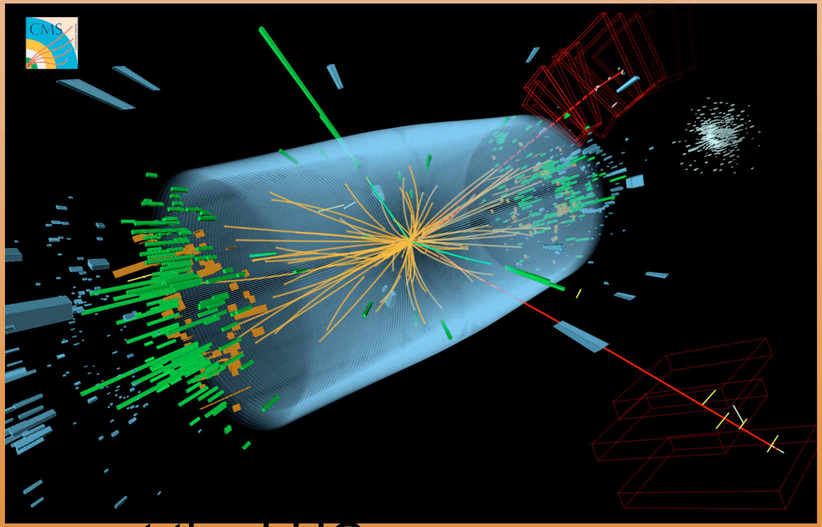
4 collision points at which Higgs particles are produced.

Higgs branching fractions

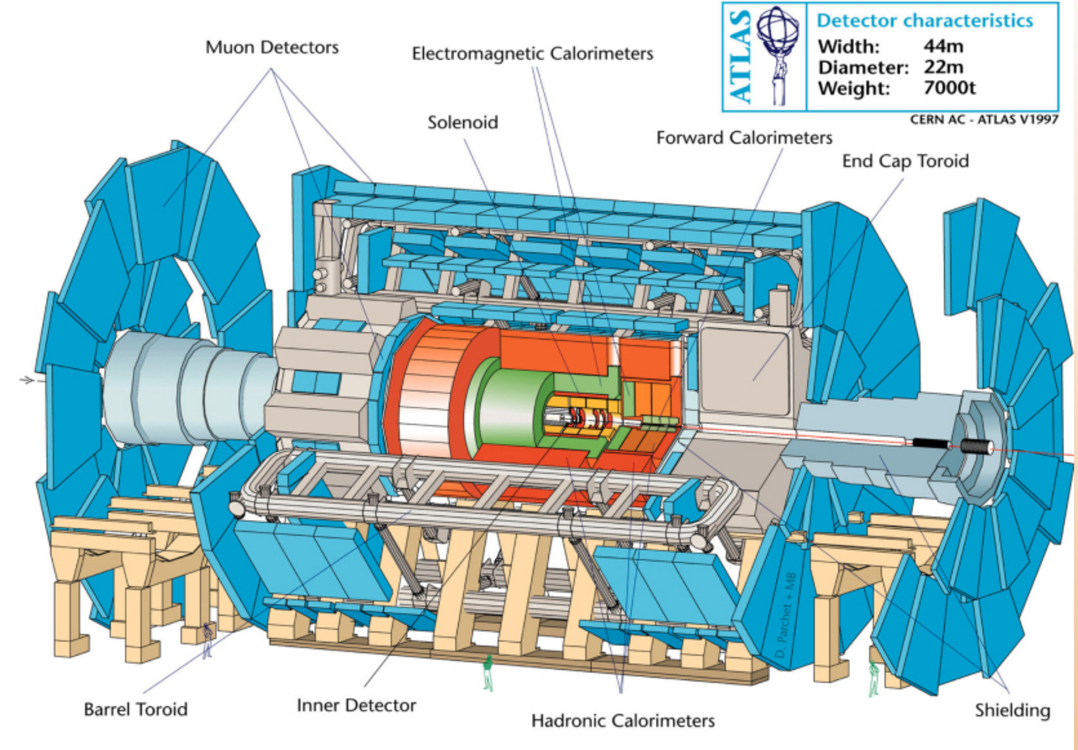
- A produced Higgs boson immediately decays into other particles.
- The Higgs can decay in a variety of ways; the relative proportions are given by *branching ratios*.
- Detectors identify and measure the decay products to infer that a Higgs boson was made.

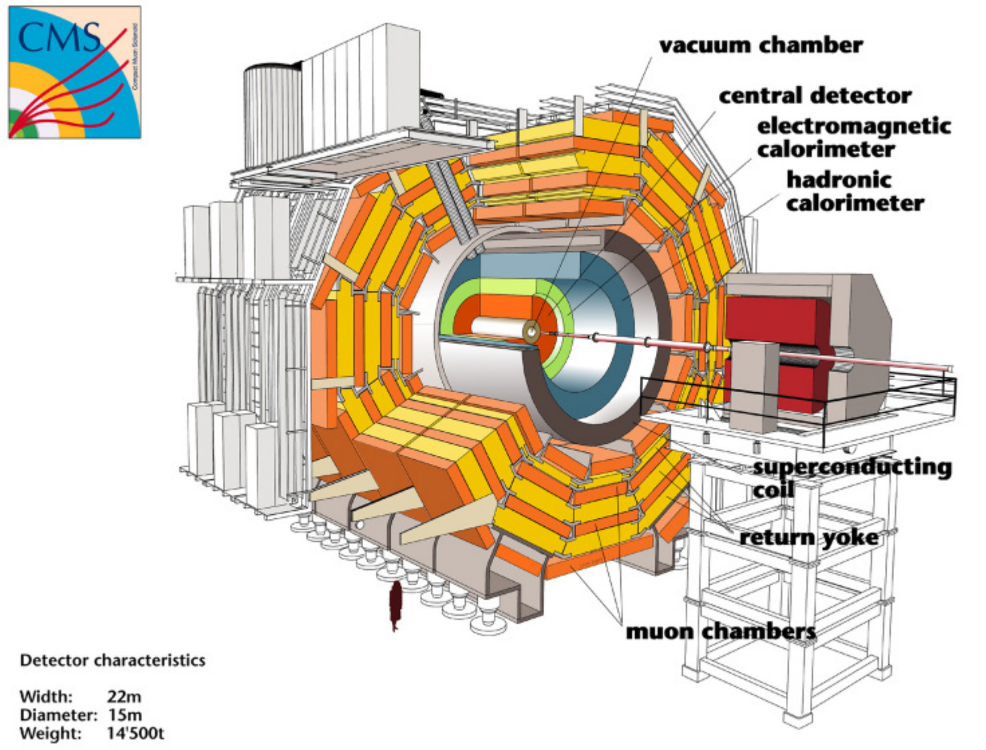


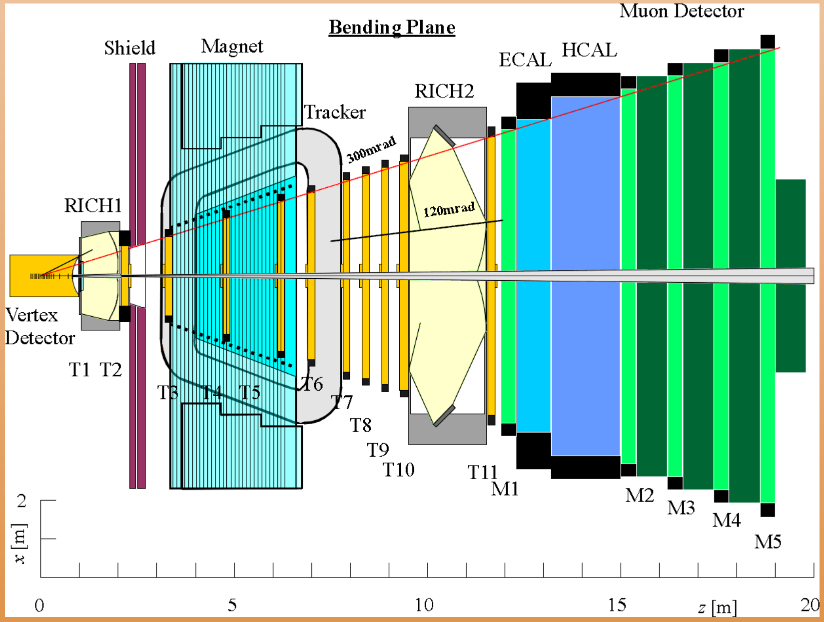


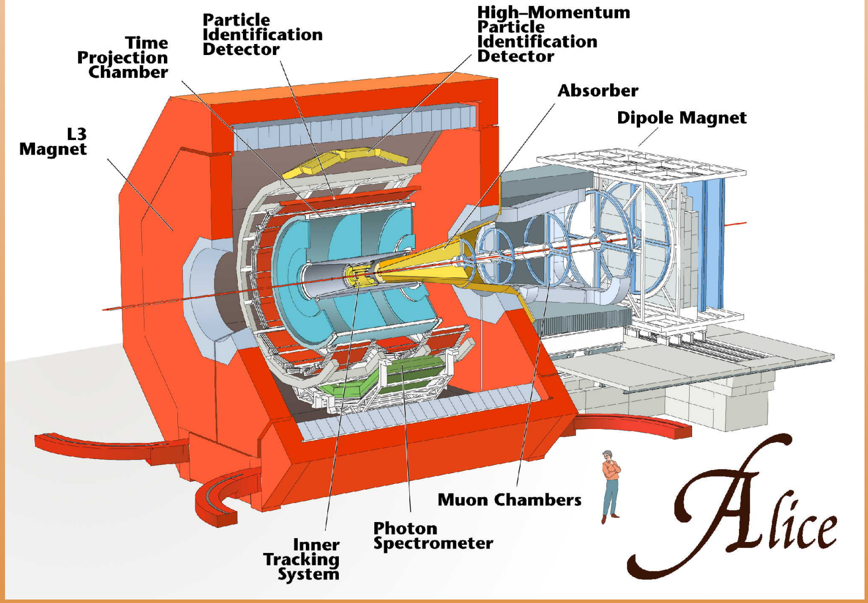


The four detectors at the LHC



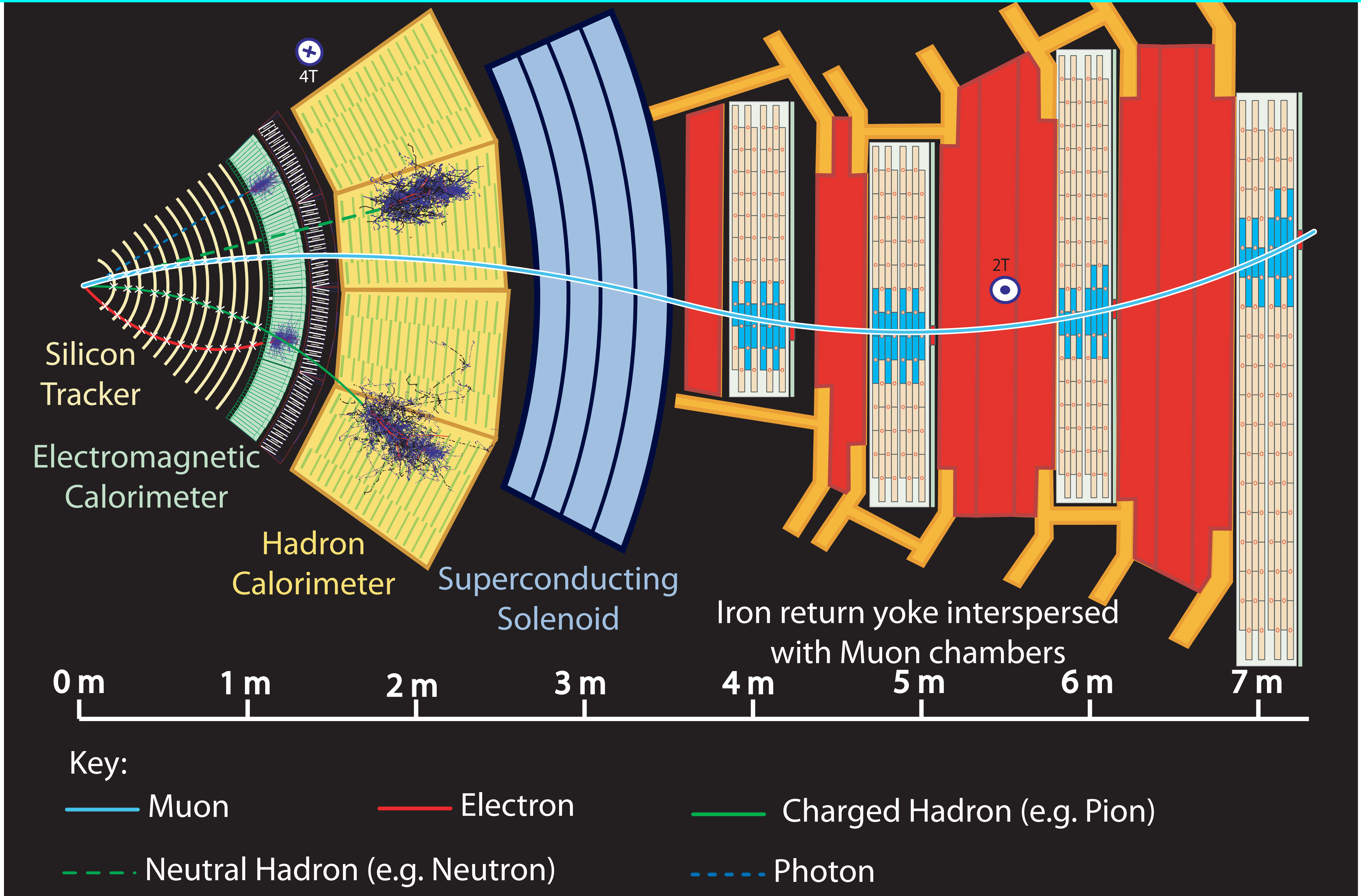




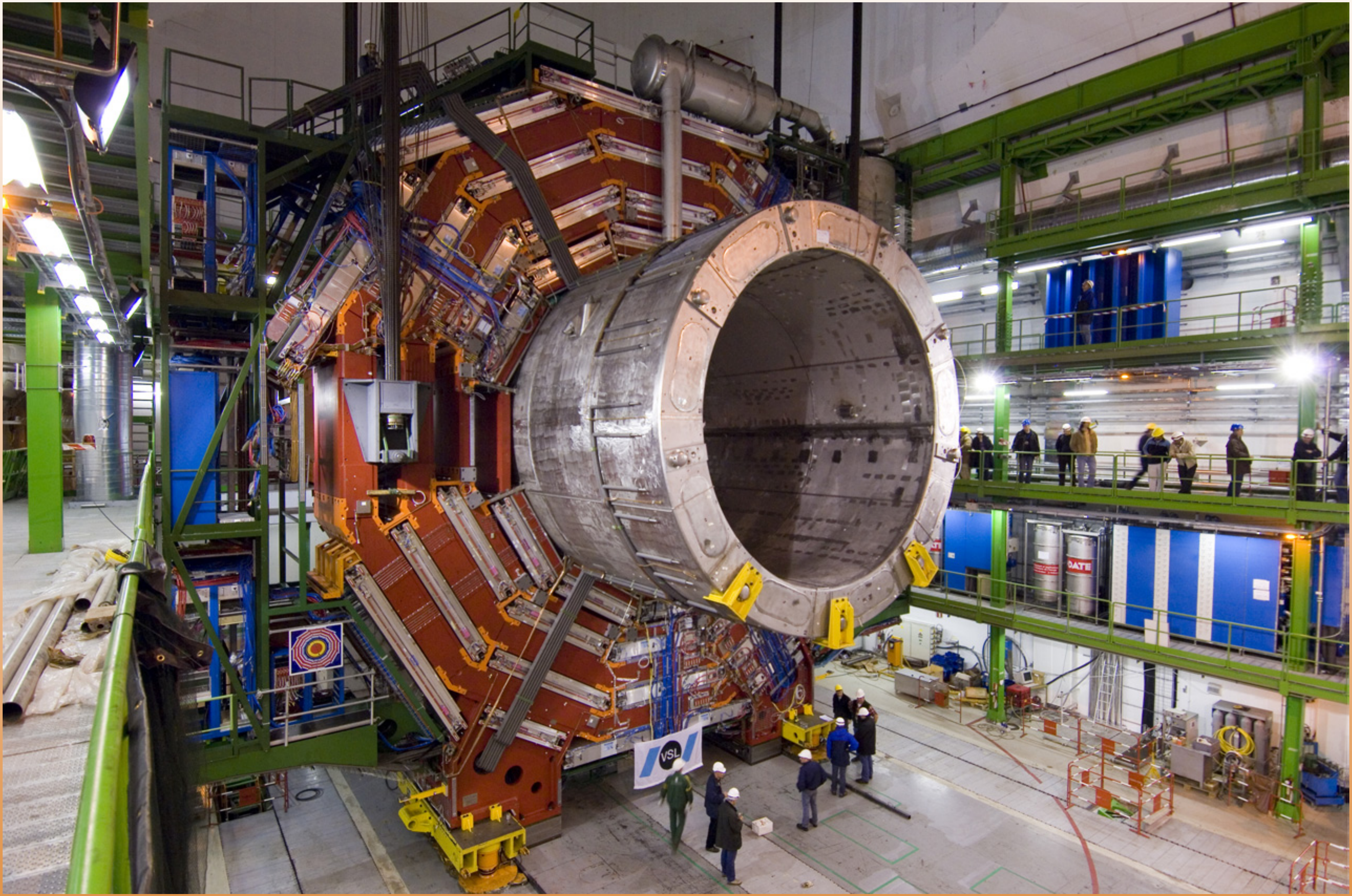


CMS slice

Different particles behave differently as they pass through the detector. This allows us to identify them and measure their energy.

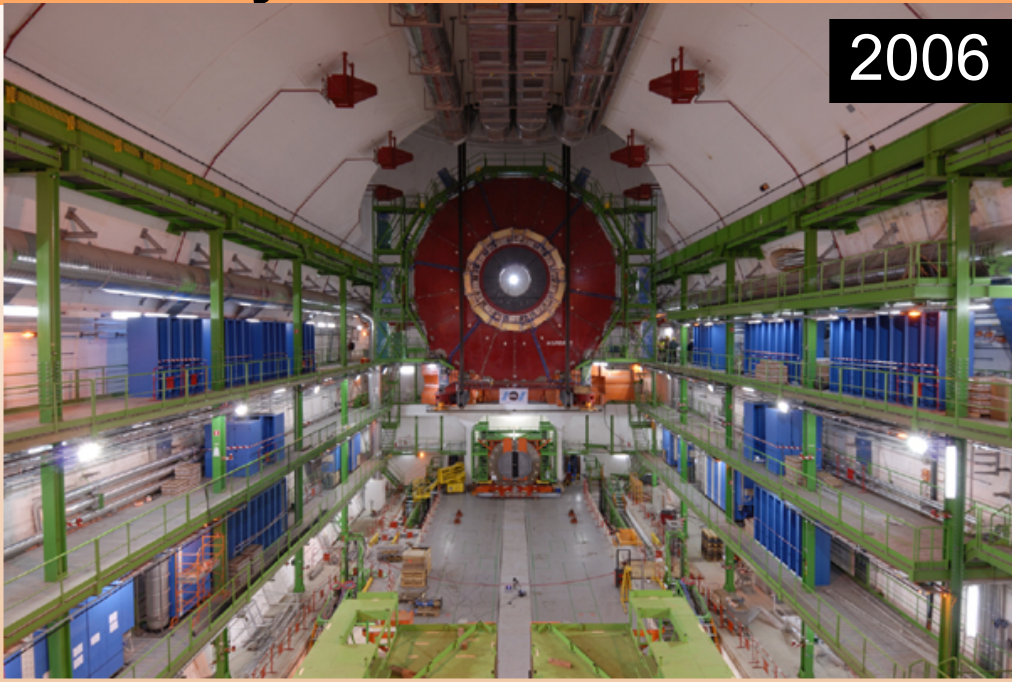


Lowering biggest piece of detector (2000 tons)

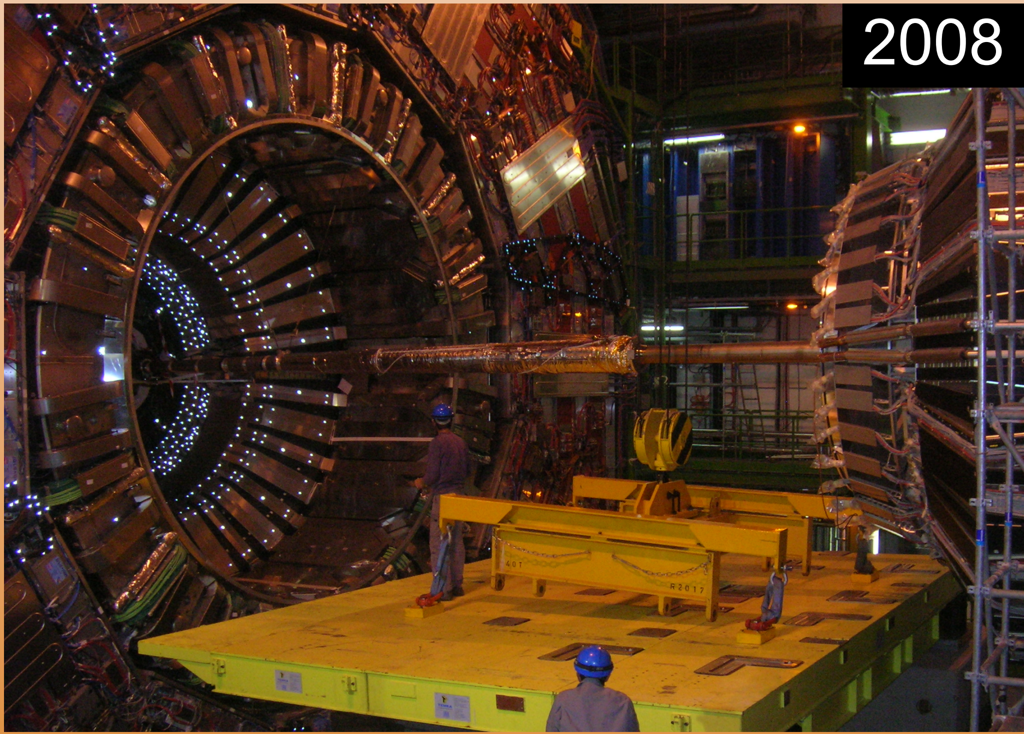


CMS assembly

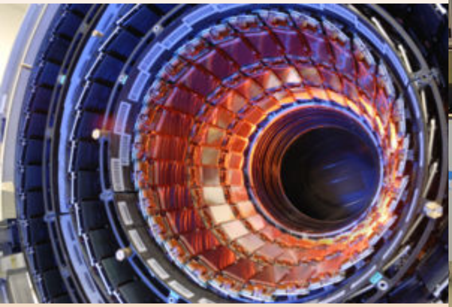

2005

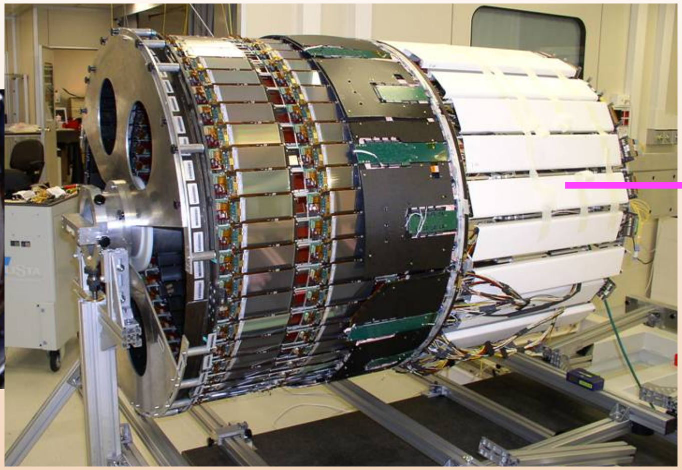

2006


2007

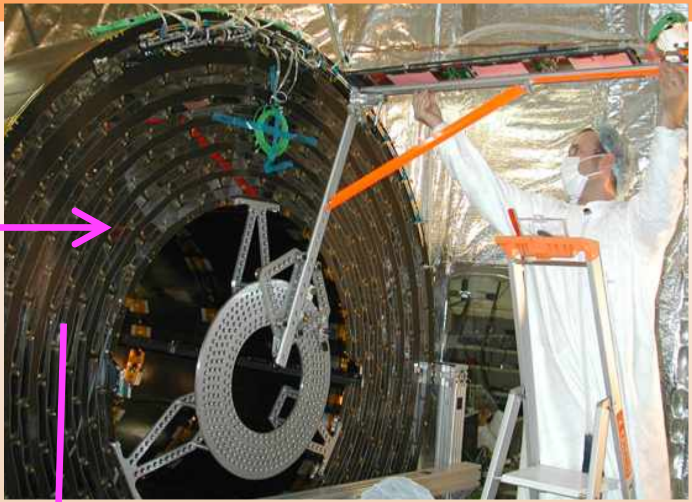

2008

CMS tracker

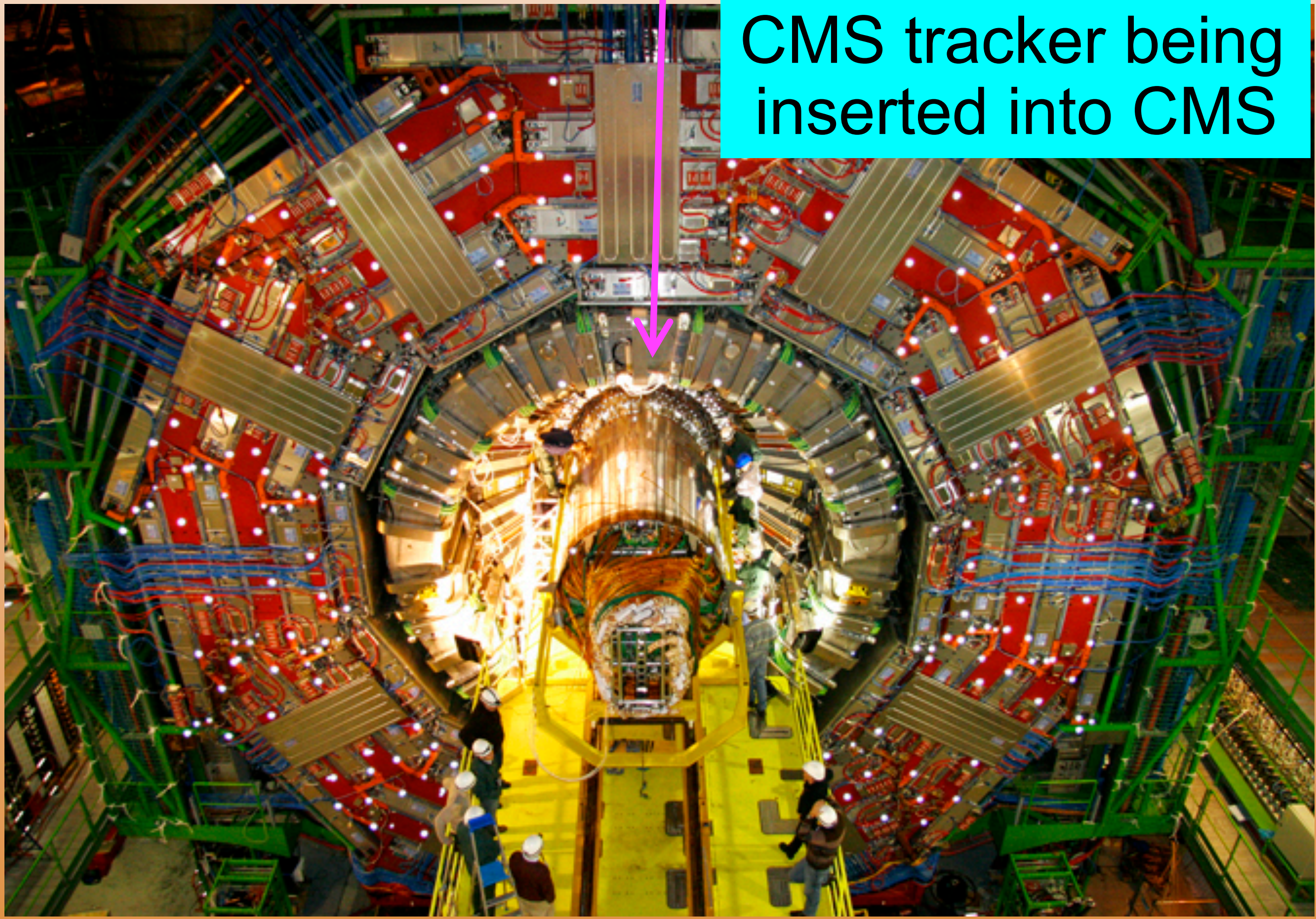




Goes inside



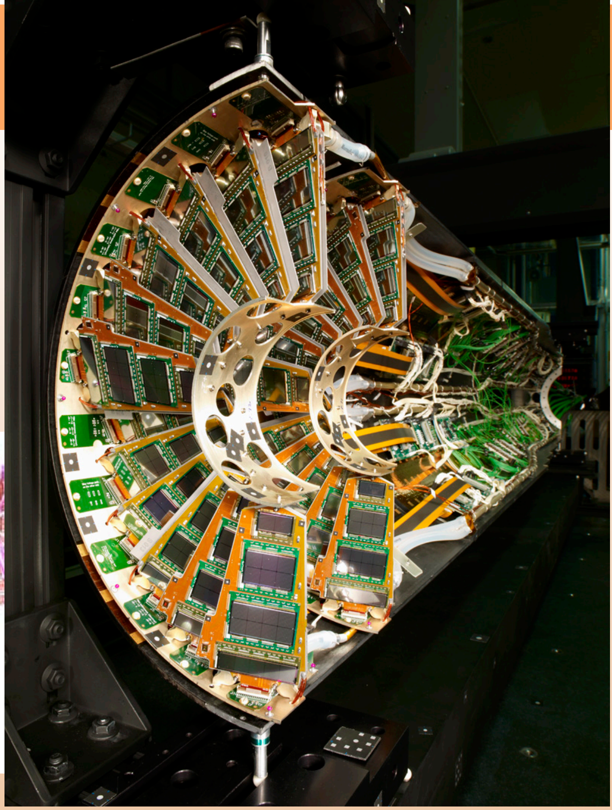
CMS tracker being inserted into CMS

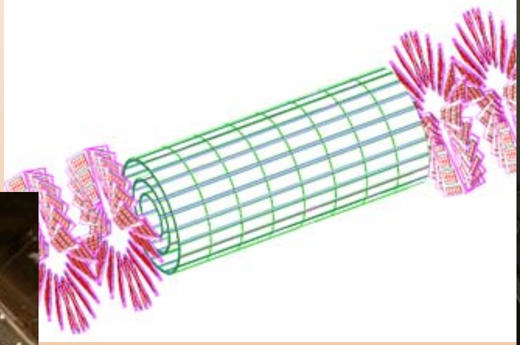


Featured on Megadeth album!

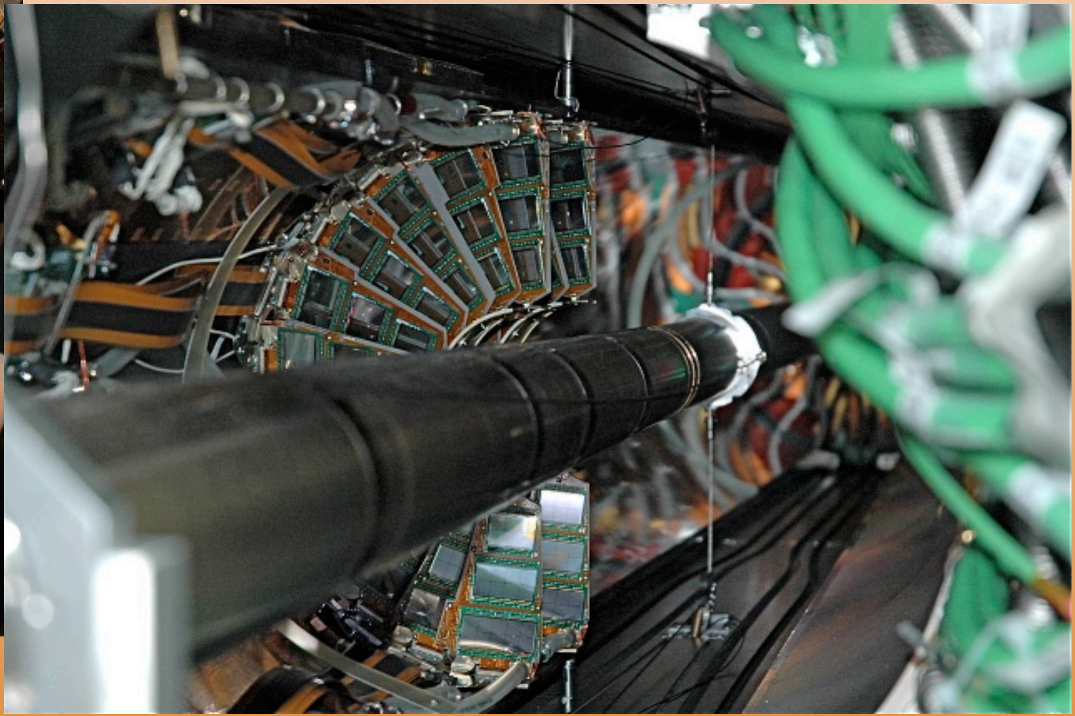
The pixel detector

Smallest detector but the most channels. There are 65 million pixels, each 4/1000 of an inch by 6/1000 of an inch.



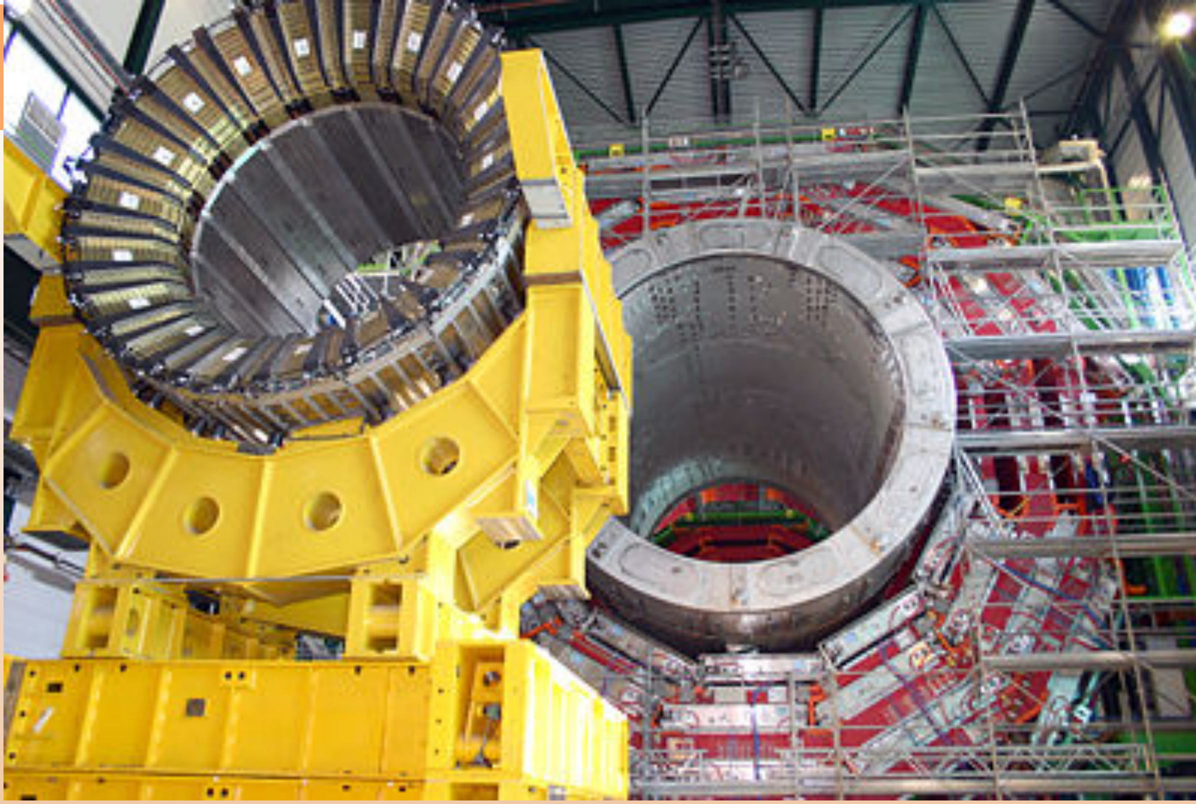


Inserting the detector

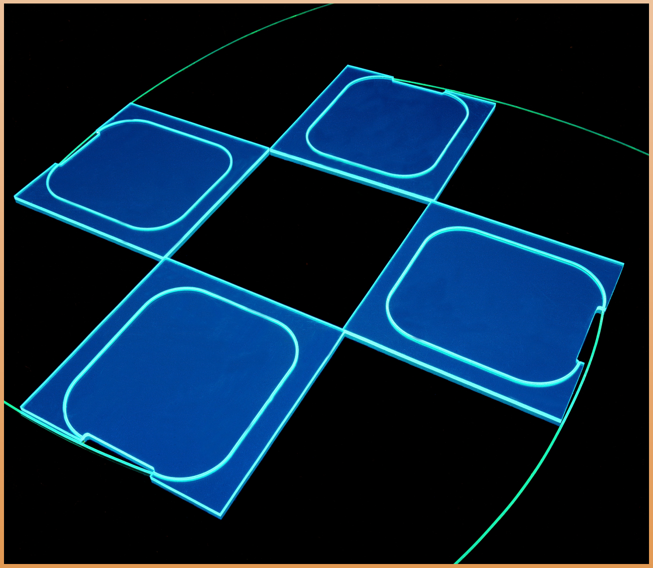


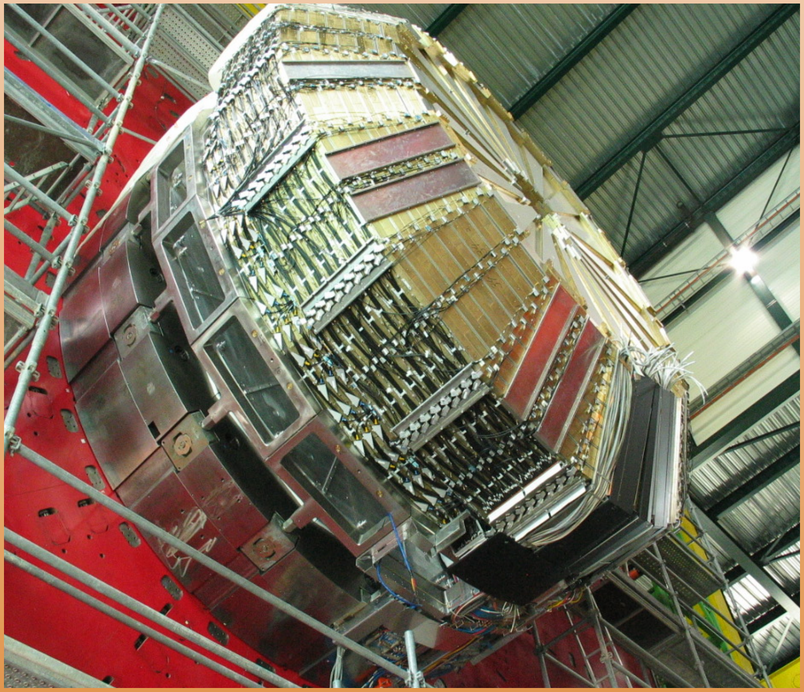
HCAL detector

- Shown here ready to be inserted.
- Measures energy of particles.
- Brass absorber from Russian artillery shells is what the particles hit.



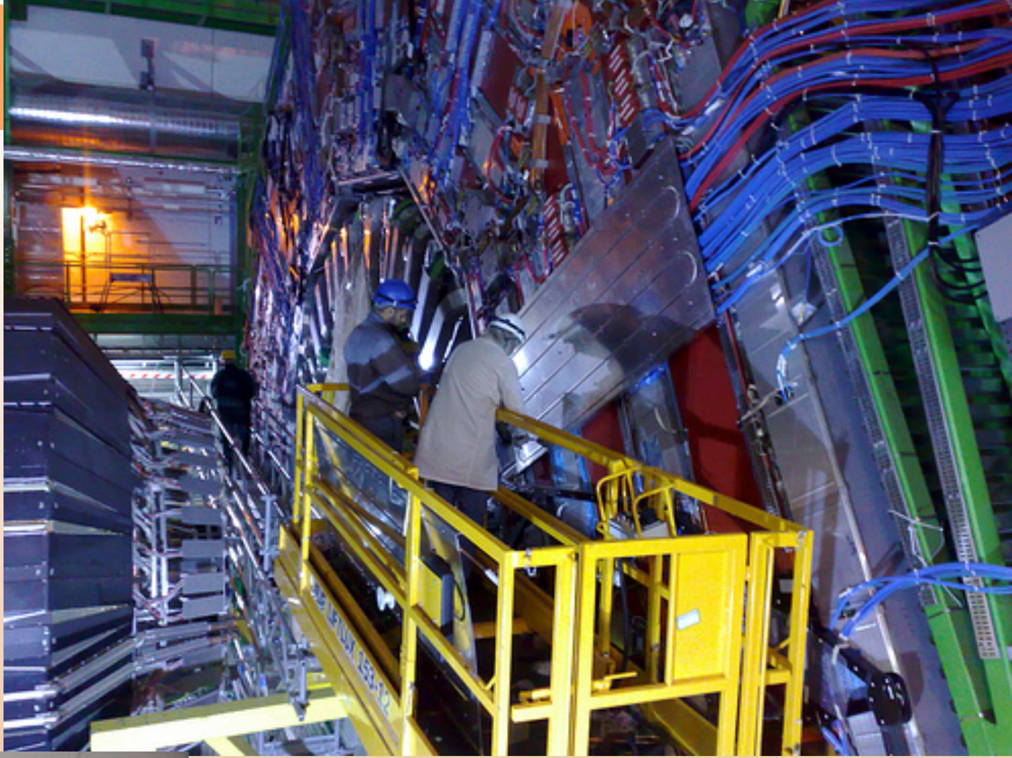
- Scintillating tiles with wavelength shifting fiber between the brass layers are used to measure the energy.

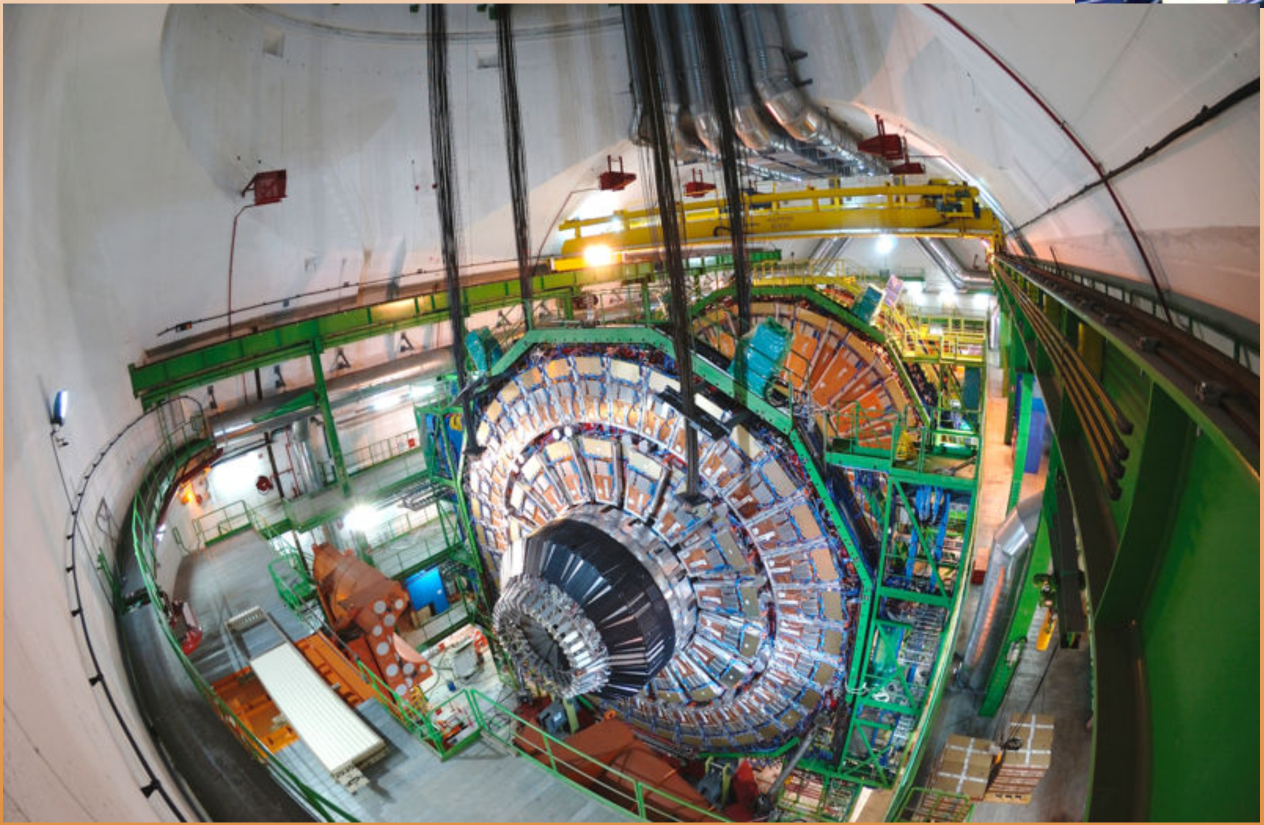




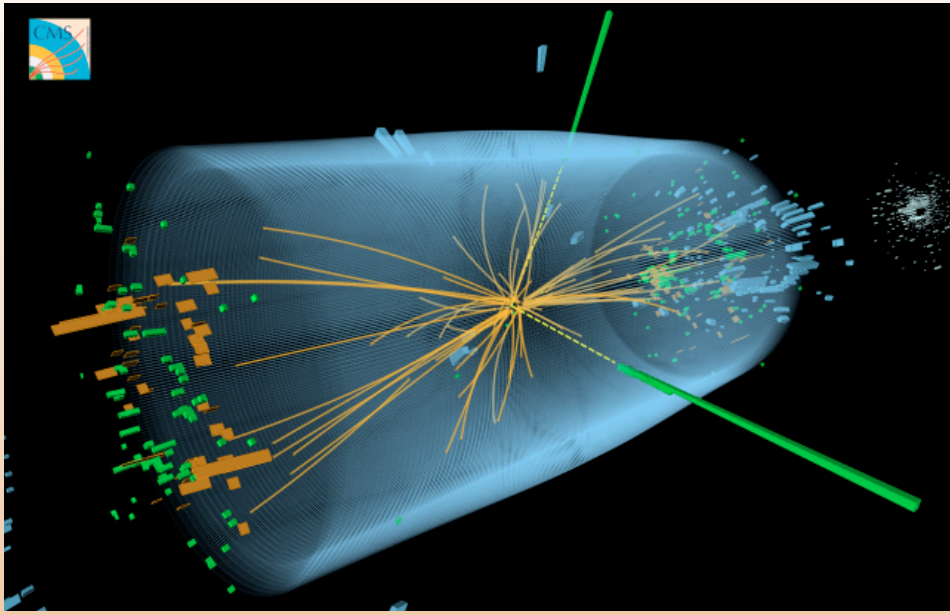
The muon detectors

- Muons interact less than other charged particles
- Place detectors after lots of steel and whatever comes through is a muon
- We use 12000 tons of steel.





Finding the Higgs boson

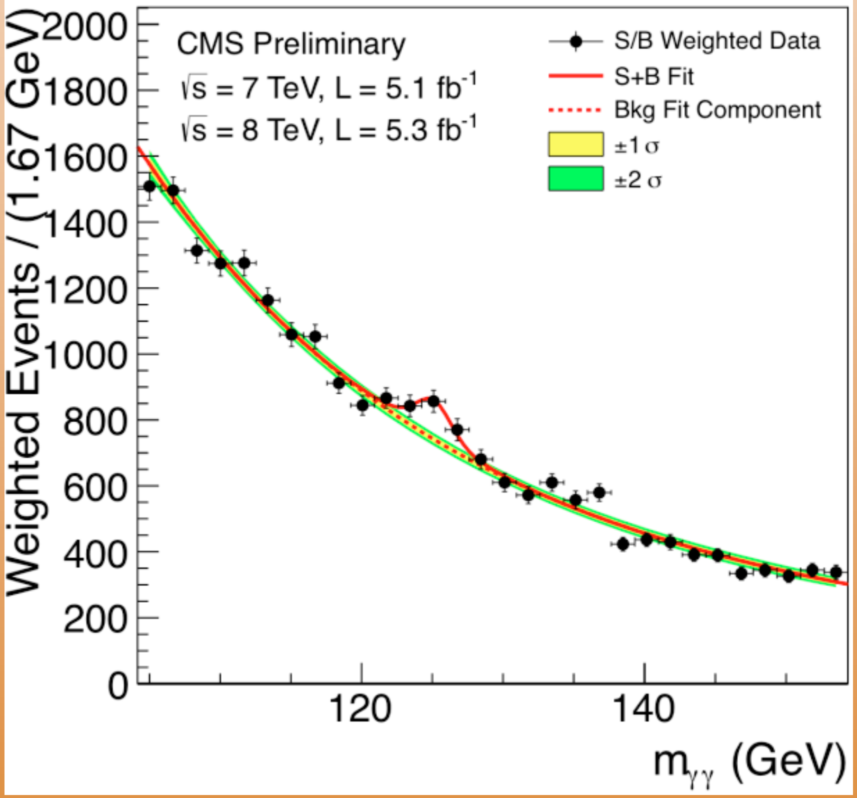


- 20 million times each second there are about 25 collisions of protons.
- This produces 40 Terabytes of data each second (way too much to keep).
- We keep about 500 of the most important 20 million events each second, throwing away the rest.
- Software takes the raw data from these events and reconstructs all the particles.
- Physicists then try to distinguish signal from background and estimate how many Higgs particles there were.
- We also measure the mass and spin of the Higgs boson.
- This is done for many different Higgs decay modes.

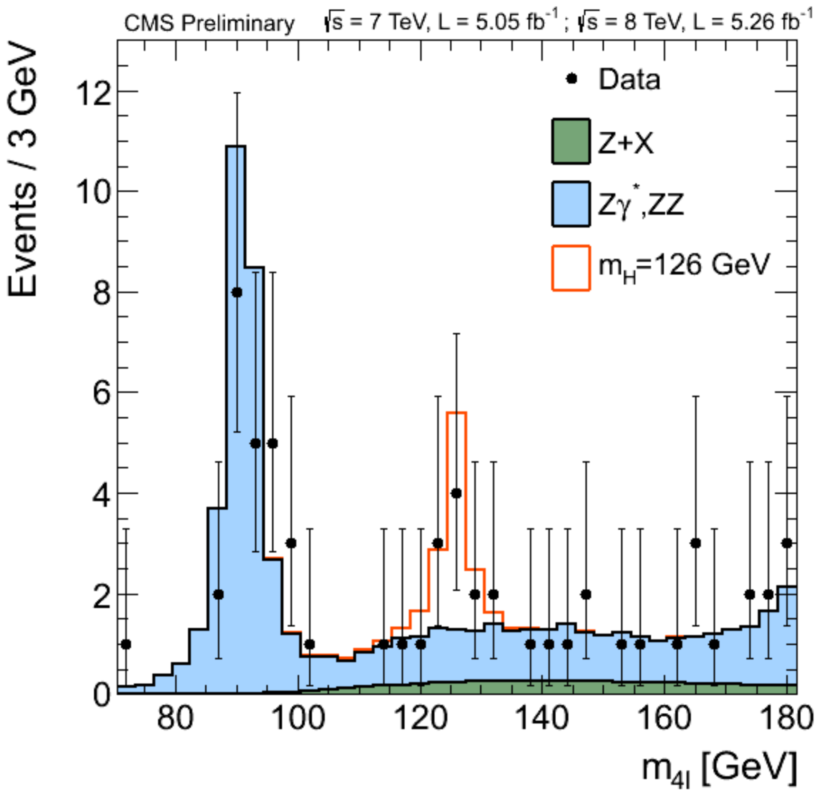
What was revealed on July 4, 2012?

From the data collected in 2011 we were able to rule out a Higgs over a wide mass range. With the additional data from April-June of 2012 we were able to definitively discover the Higgs.

The result of looking for Higgs decays to two photons. Small signal at a mass of 125 GeV over a large background.



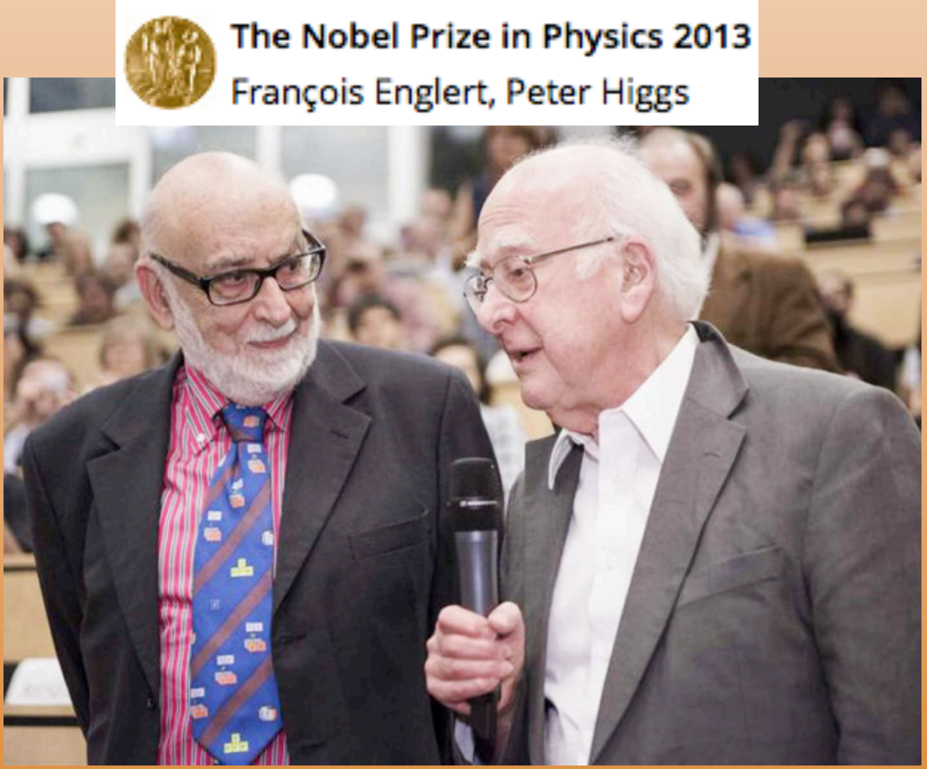
Result of looking for Higgs decays to four leptons (muons or electrons). A signal is seen at 125 GeV.



The 4th of July discovery!

- On July 4, 2012 the CMS and ATLAS experiments announced the discovery of the Higgs boson.
- The leaders of the experiments and of CERN are shown standing here in the auditorium.

- The 2013 Nobel prize in physics was awarded to Englert and Higgs for their theoretical work in 1964 (the photo is from July 4, 2012).



Lots of press


TEN MYTHS ABOUT RUSSIA | JAPAN: HOT GREEN CARS

Newsweek

The Biggest Experiment Ever

(And It's European)


Inflationary Woes | The Descent of Music | Cancer Viruses

ScienceNews

Higgs, Finally

High-energy collisions pop particle from its mass-giving field


THE AUSTRALIAN

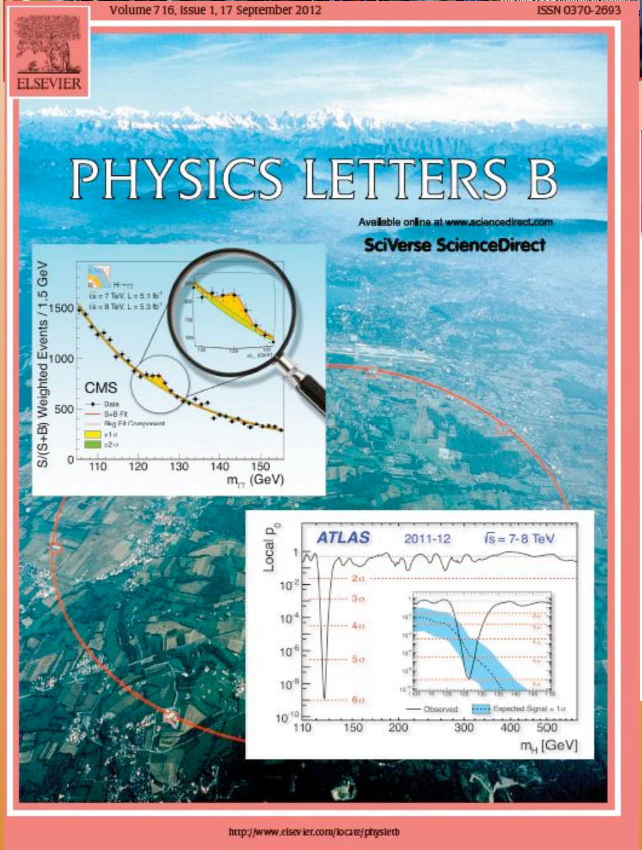
Carbon dealing not over for Labor

After 50 years – and billions of dollars – the God particle is no longer a theory


Science

BREAKTHROUGH of the YEAR

The HIGGS BOSON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Libération

Physique des particules

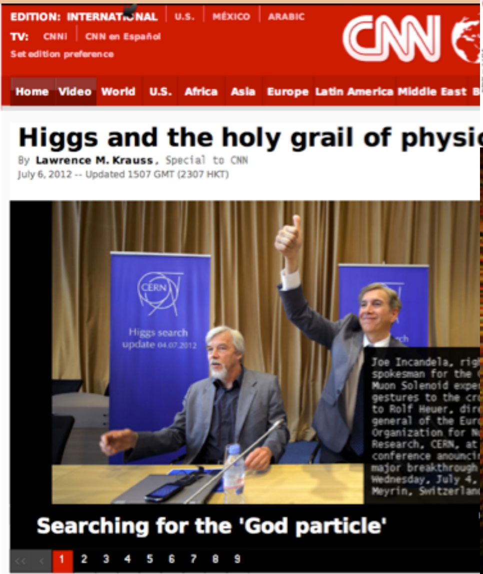
La masse est dite

Le Cern a réussi à mettre en évidence le boson de Higgs qui résout une énigme fondamentale et ouvre une nouvelle étape scientifique.

Les derniers feux des pharaons

Suicides chez France Télécom : l'ancien patron mis en examen

A nos lecteurs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Higgs and the holy grail of physics

By Lawrence M. Krauss, Special to CNN

July 6, 2012 -- Updated 1507 GMT (2307 HKT)

Searching for the 'God particle'


NewScientist

BEYOND THE HIGGS

SPECIAL REPORT

IT'S A JUNGLE IN THERE


The Economist

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

A giant leap for science

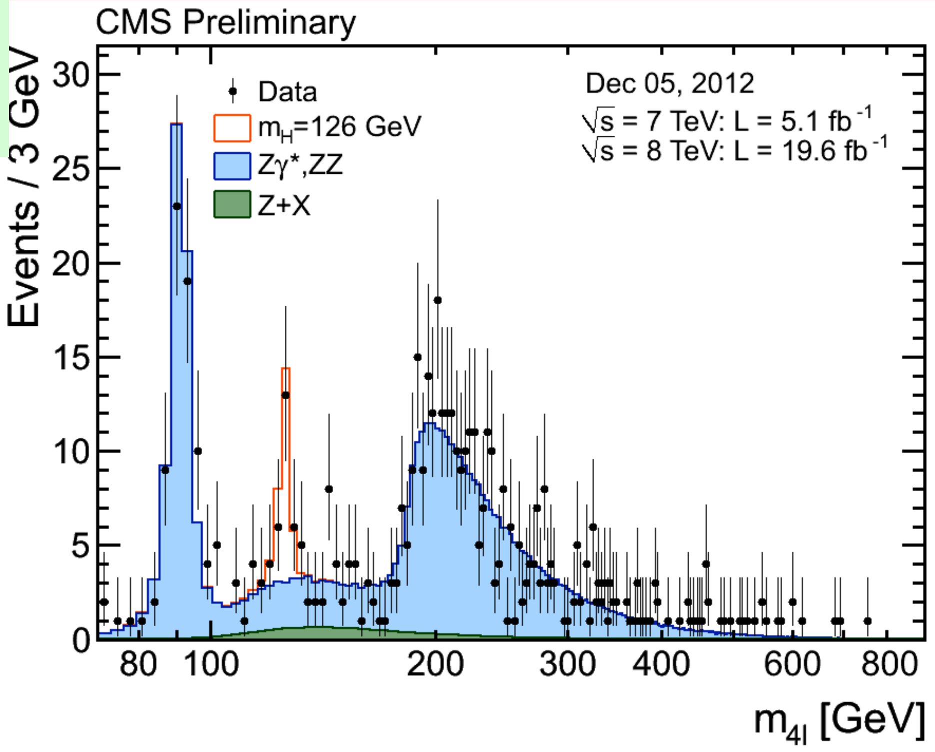
Finding the Higgs boson

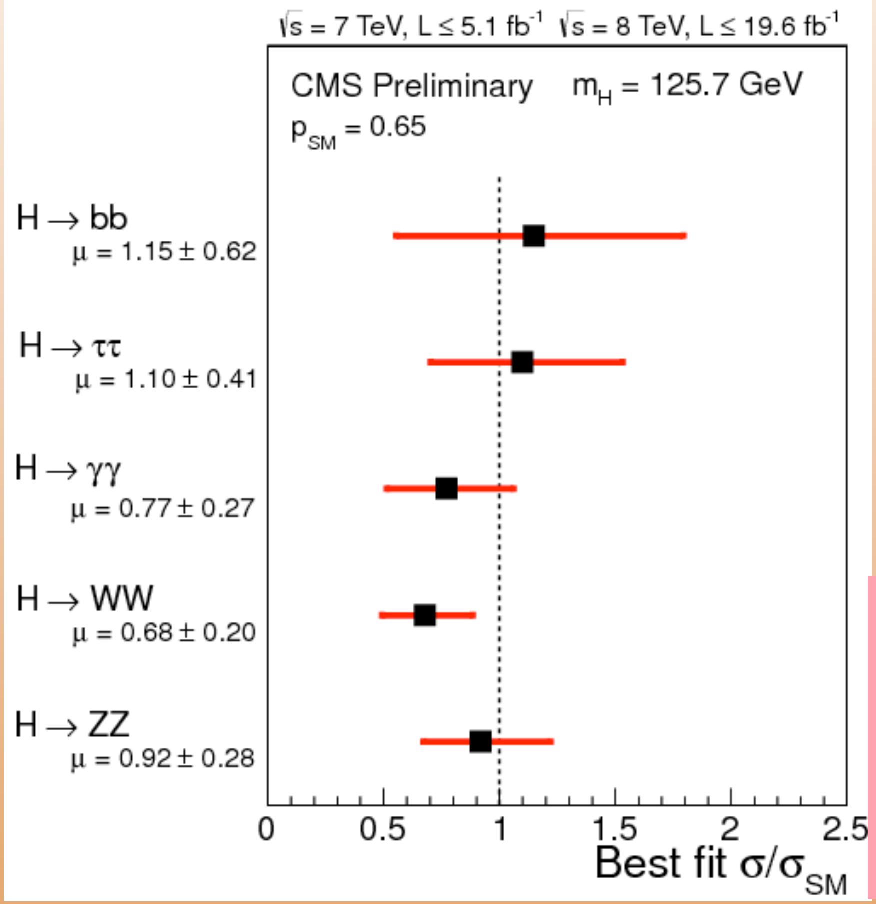
JULY 7TH - 13TH 2012

Worldwide excluding UK

Results since July 4, 2012

More events showing up, as expected.





The measured branching ratios are basically consistent with predictions (around 1 on this scale).

Also found that the spin is consistent with expectations. Therefore, we have transitioned from calling it a Higgs-like boson to just the Higgs boson.

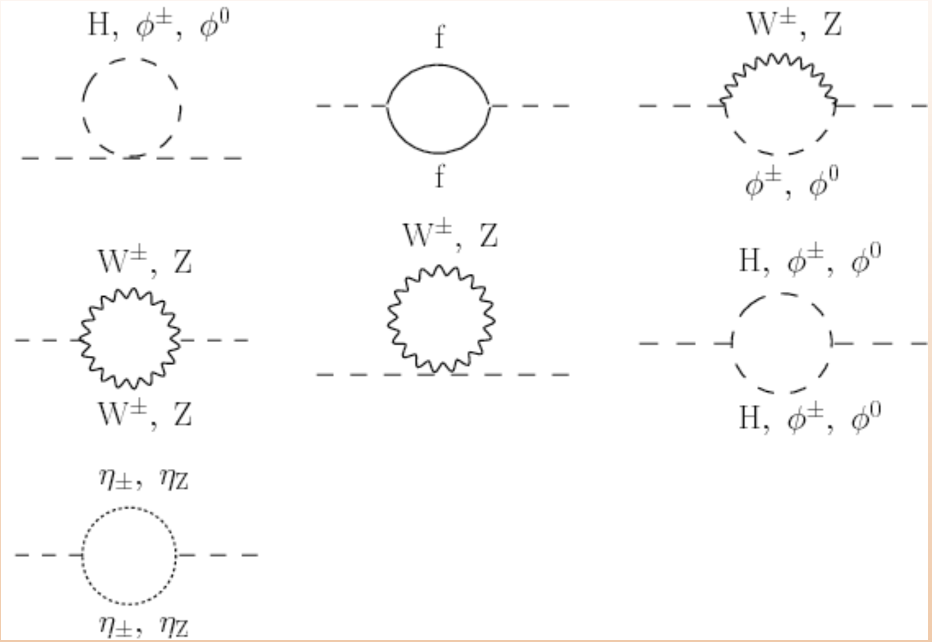
What’s next?

- Discovery of the Higgs completes the “standard model of particle physics”.
- BUT, we know the standard model is not a complete description of the universe. Lots of remaining mysteries:
  - Why is the Higgs mass so light?
  - Why didn’t all of the matter and antimatter annihilate in the early universe (leaving only photons and neutrinos)?
  - What is dark matter?
  - What is dark energy?
  - How do neutrinos get their mass and do neutrinos exhibit CP violation?
  - Why do the 19 free parameters of the standard model have the values they do?
- The LHC may be able to shed light on some of these questions.

Why is the Higgs so light?

The mass of the Higgs is made up of a “bare” mass plus corrections from virtual particles.

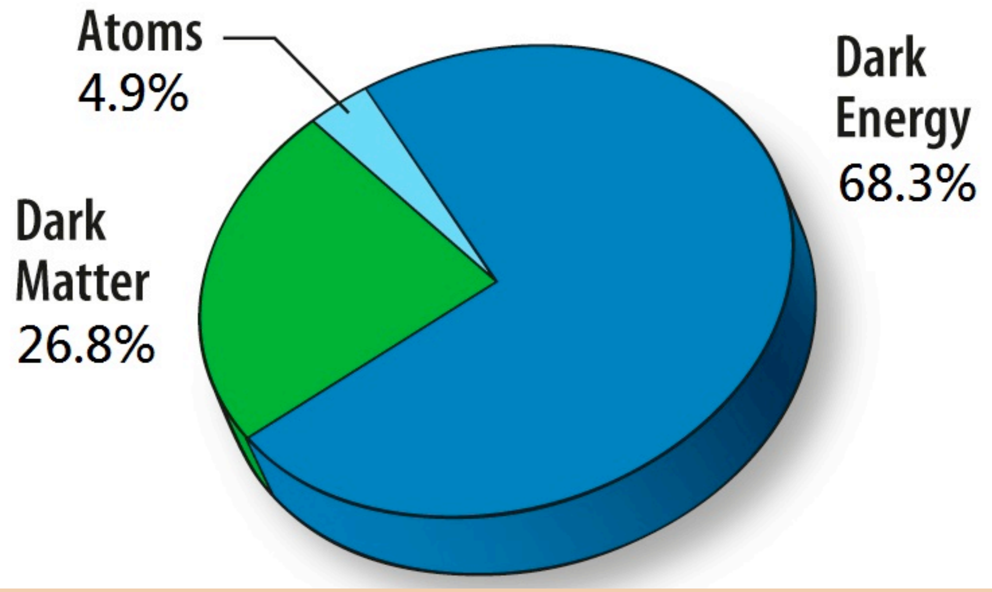
The corrections should make the Higgs mass much larger (like 10 trillion times larger) than we observe.



This is called the *hierarchy* problem. Without new physics, a Higgs mass of 125 GeV requires fine-tuning of fundamental constants to 1 part in 10 trillion; this seems unnatural.

What is the universe made of?

Galaxy rotation curves & cluster motion, cosmic microwave background, distant supernovae, big-bang nucleosynthesis, inflation, and simulations of structure formation give a consistent picture of the universe.



The source of dark energy and dark matter is still unknown even though their effects can be clearly seen.

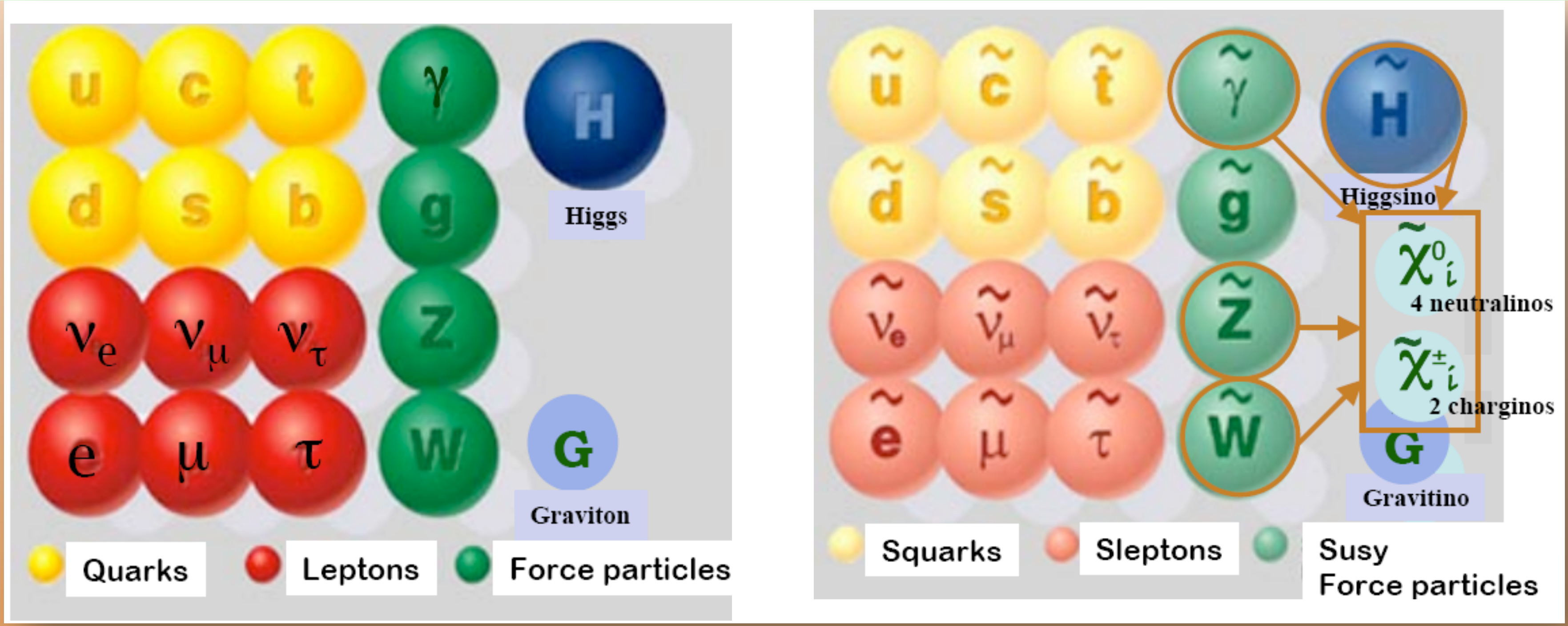
So far, no way to observe dark energy on earth.

However, dark matter particles may be produced at the LHC, allowing us to determine their nature.

Supersymmetry (SUSY)

An extension of the standard model called supersymmetry (SUSY) may solve the hierarchy problem and explain dark matter. This discovery would also make a grand unified theory more likely and may be interpreted as support for string theory.

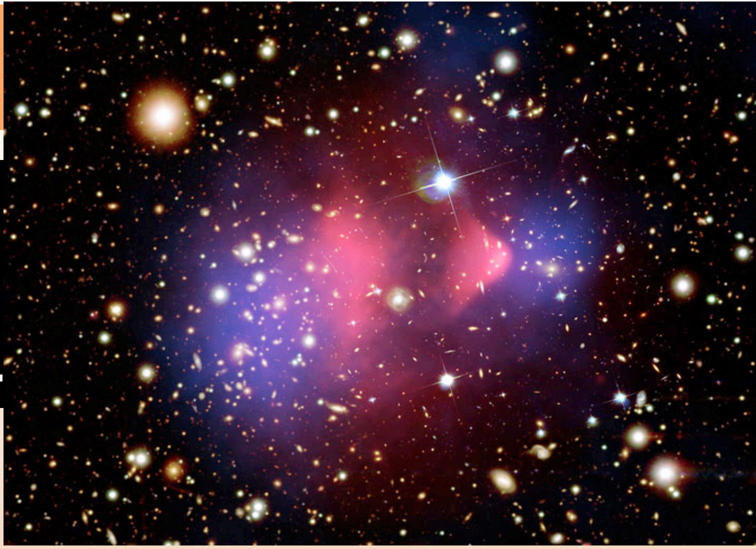
SUSY predicts that all elementary particles have a superpartner, with a different spin (but everything else the same).



These sparticles get cool names like squark, slepton, stau, wino, photino, and higgsino

SUSY solutions

The lightest SUSY particle may be the source of dark matter solving the dark matter mystery.

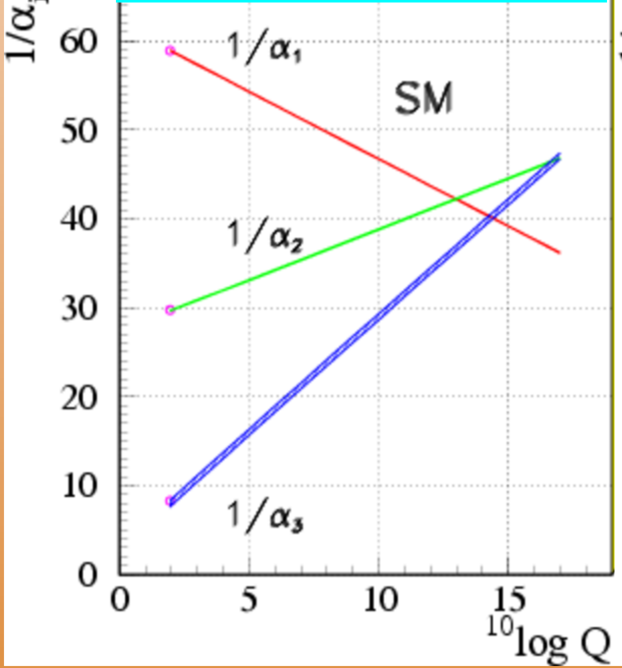


SUSY particles cancel the effects of the standard particles, making a Higgs mass of 125 GeV natural.

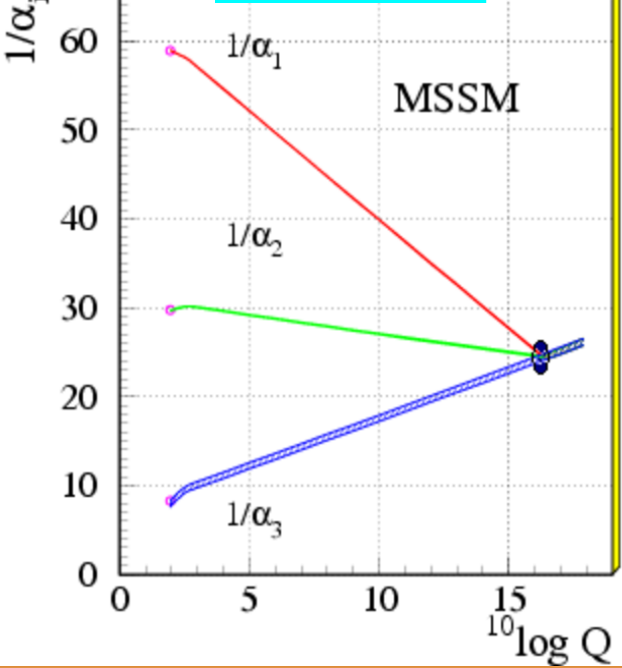
The strength of the strong, weak, and electromagnetic forces evolve in a known way.

When SUSY is included in the theory, the strengths merge at 10^{16} GeV, hinting at a grand unified theory.

Standard model

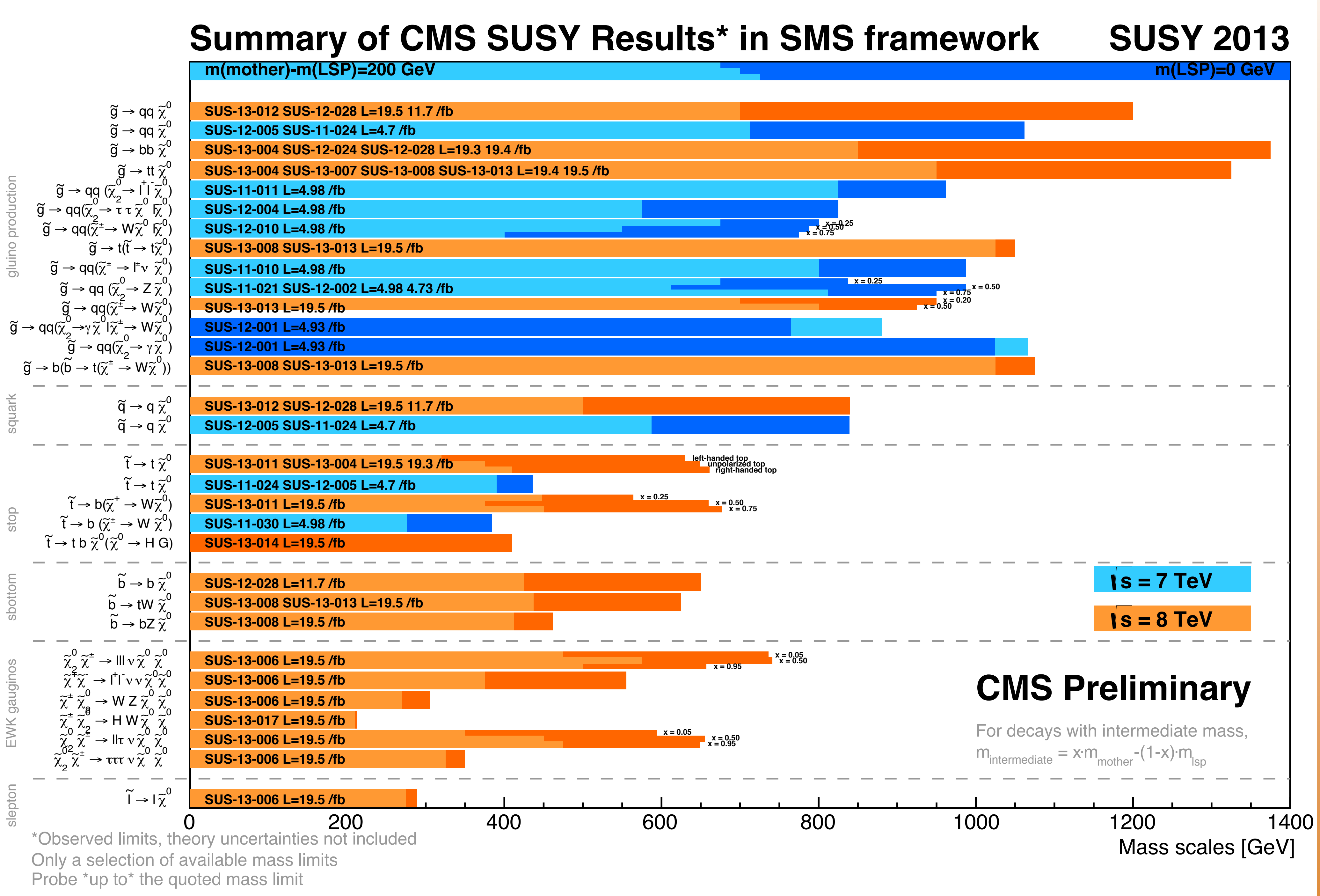


+ SUSY

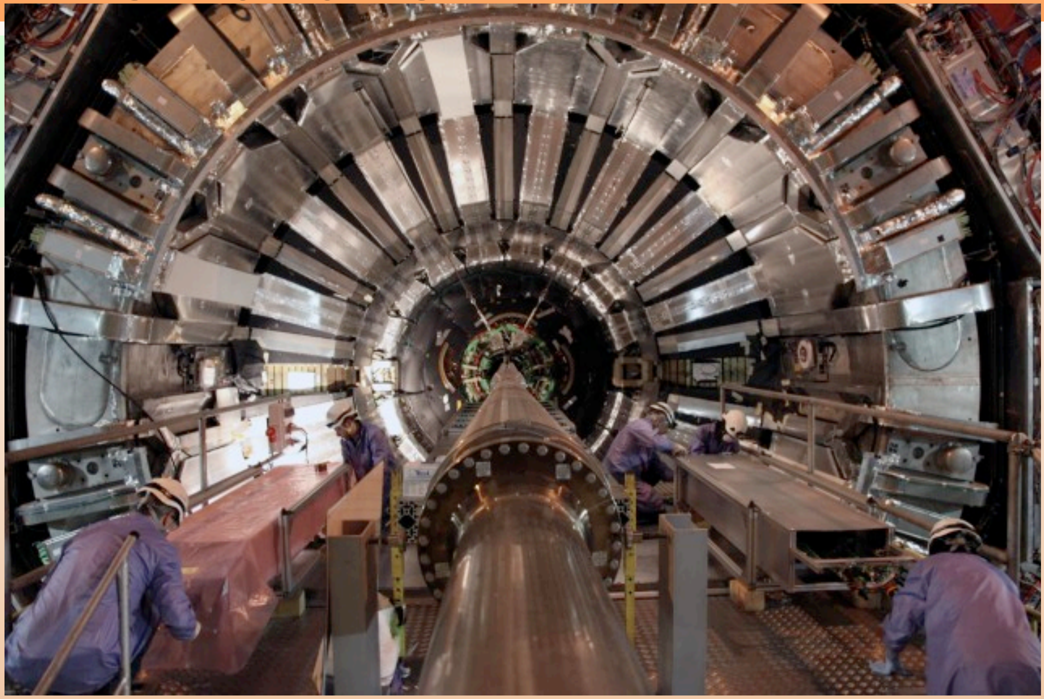


SUSY results

But no sign of SUSY after dozens of searches by ATLAS and CMS.



What about the future?



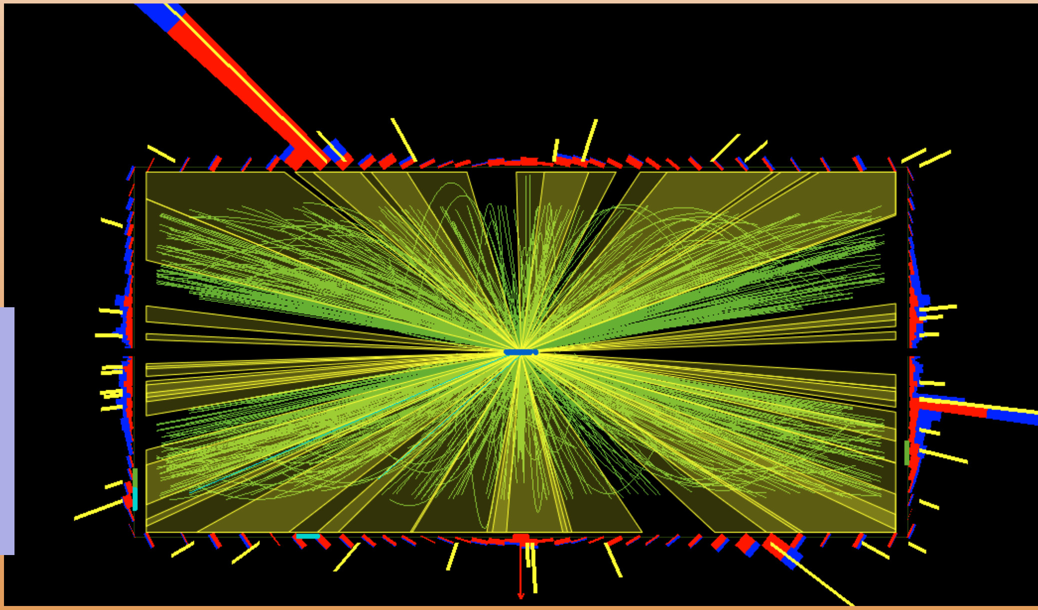
The accelerator and experiments are currently being improved.

In 2015 we will take data at higher energy (8→13 TeV).

In the years following, the data will increase ten fold.

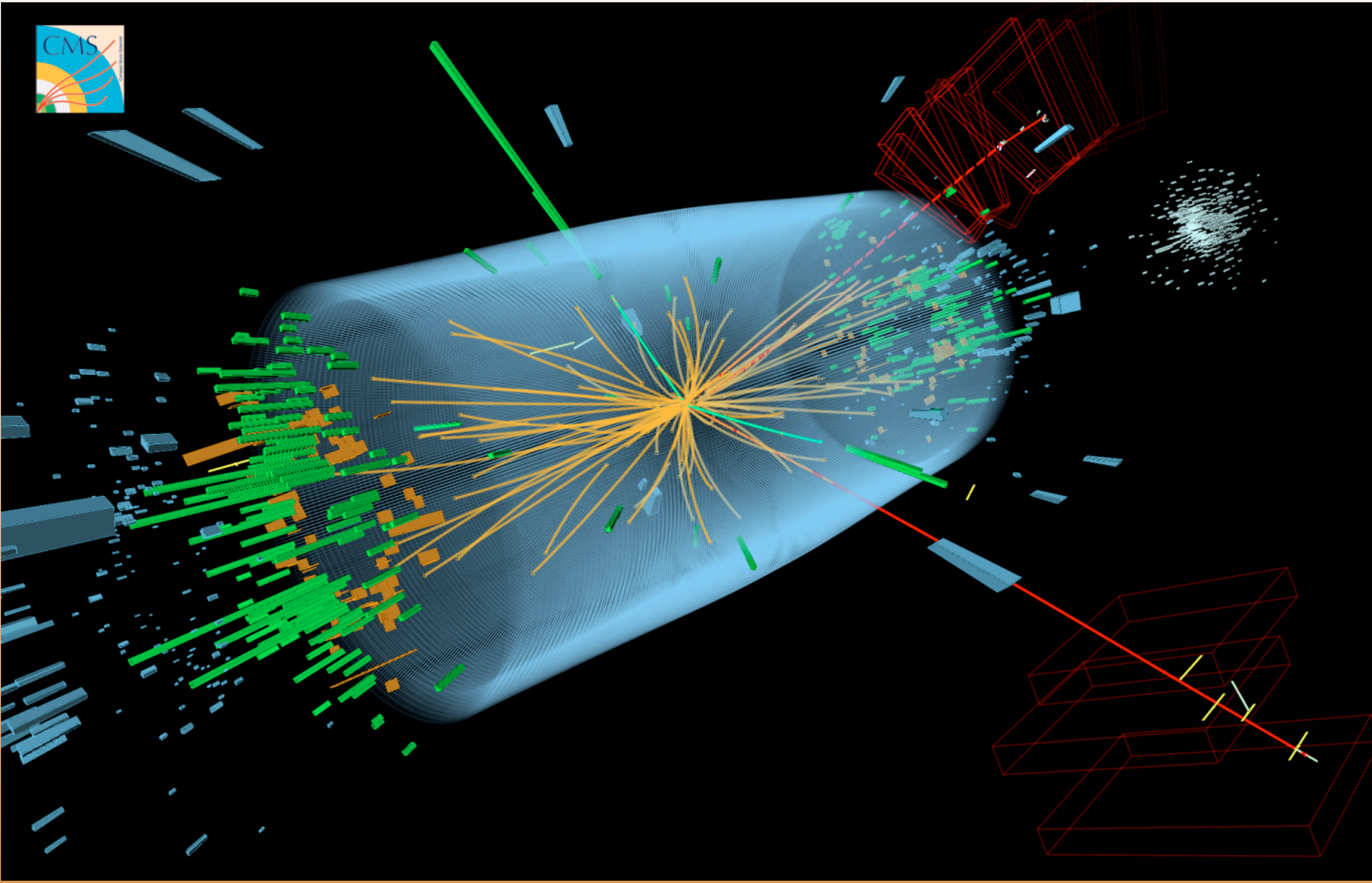
With higher energy and luminosity, we will discover much more about the universe.

Future upgrades to the detector and accelerator around 2023 will provide even more data.

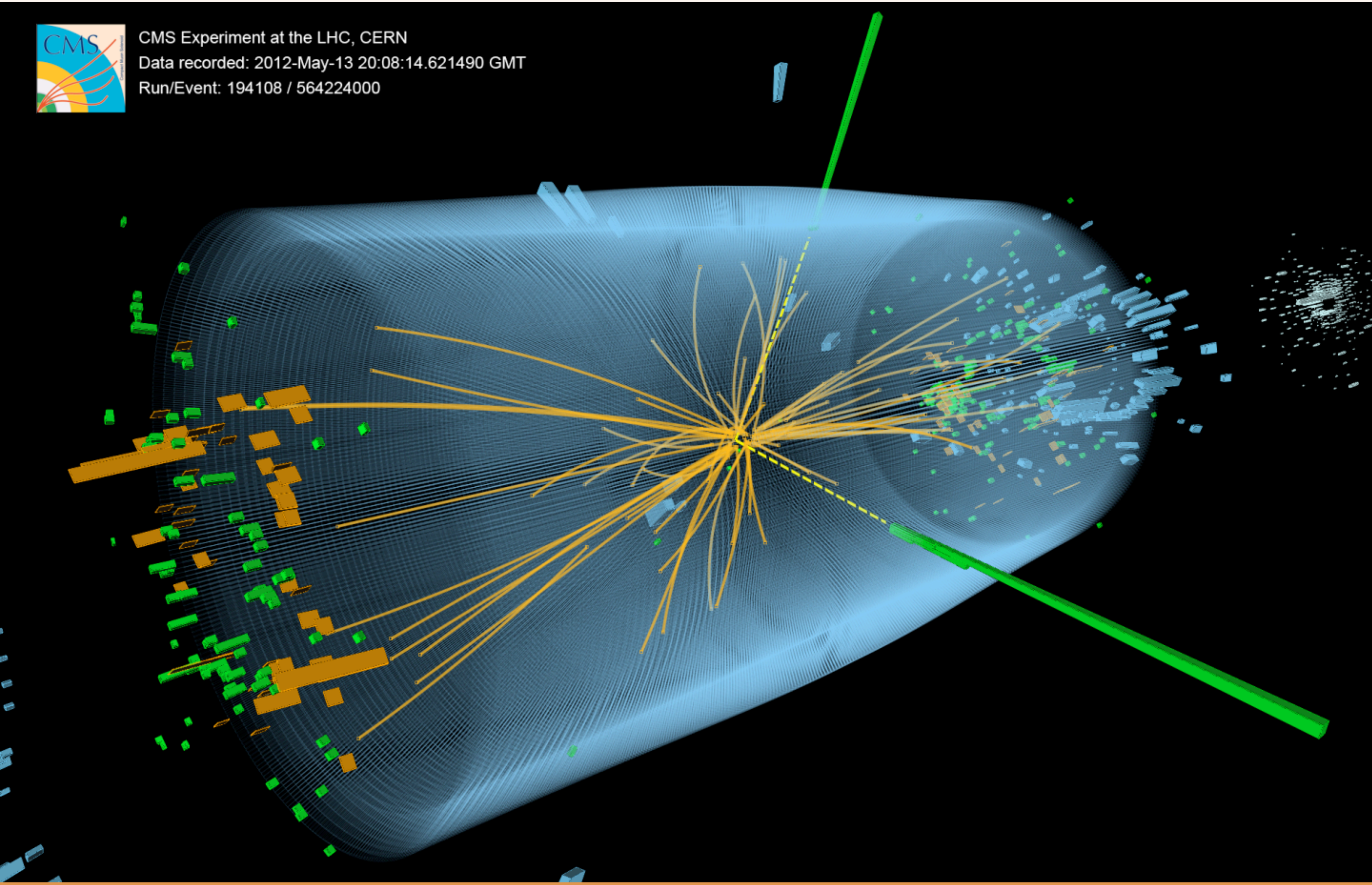


The best is yet to come…

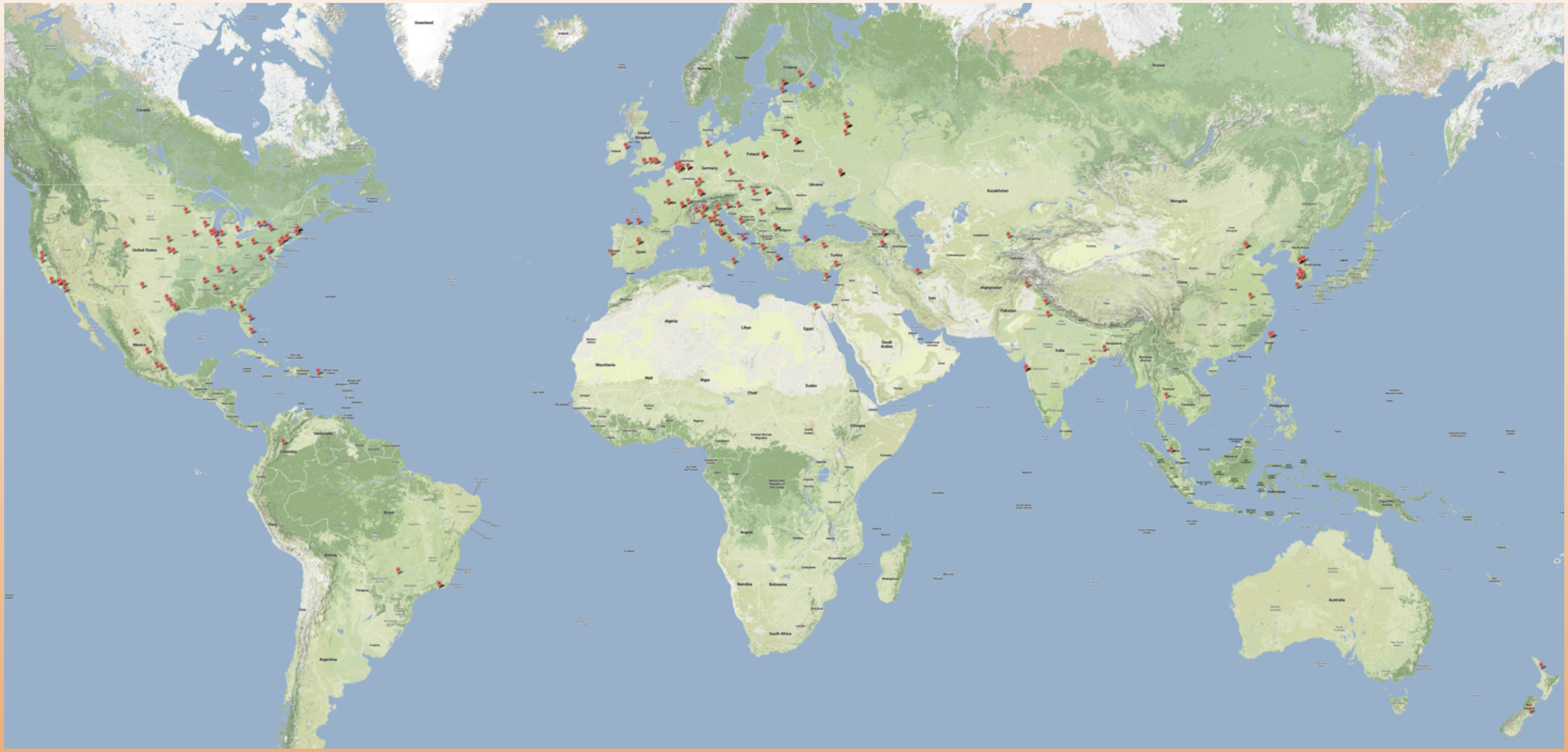
Event display: posible H→eeμμ



Event display: posible H→γγ



LHC experimental groups



CMS detector