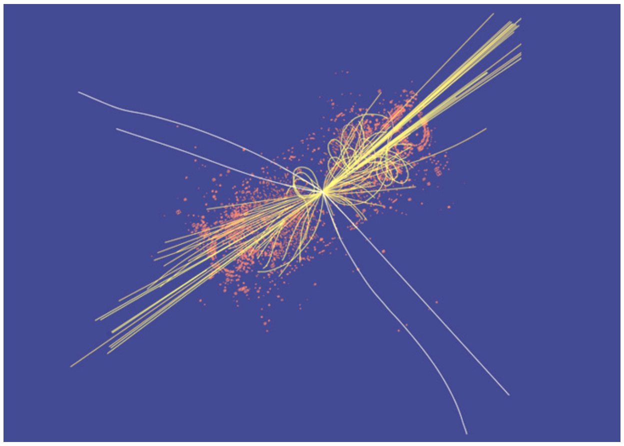
Particle prediction



Computer simulation of an event in which the decay of a Higgs boson produces four muons.
Photo credit: CERN/Photo Researchers, Inc.

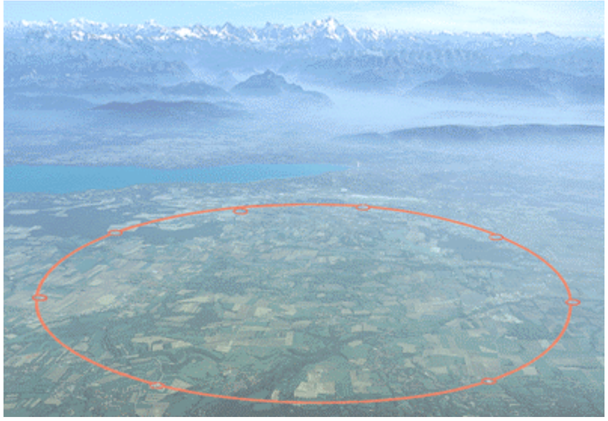
For years, physicists have been trying to see and measure subatomic particles and describe their actual energy, momentum, mass, charge, motion, life time, and spin. Recently, evidence of the existence of a long sought after subatomic particle, the Higgs boson, has been confirmed.

A way of seeing these tiny particles, or at least traces of where they have just been, is by moving tiny protons towards each other at high speeds and observing what particles are emitted when they collide.

Imagine for a moment two racecars (unmanned) heading towards each other at 150 mph. Their collision would have the force of both of their speeds combined, 300 mph, and the race cars would, no doubt, break into smaller pieces. The same idea is what is driving the present experiments in physics … to try to visualize and measure the tiny particles that are emitted after colliding protons at immense speed.

A gigantic machine has been built partially in France and partially in Switzerland to create these collisions. Near Geneva, buried beneath the earth, there is the largest and highest energy particle accelerator in the world. The European Laboratory for Particle Physics (CERN) has created with 111 nations and thousands of scientists, the Large Hadron Collider (LHC) to try to observe and measure subatomic particles.

The LHC lies in a tunnel 17 miles in circumference, as deep as 574 feet beneath the France/Swiss border near Geneva, Switzerland. Here's an aerial photo of the site. The underground location of the LHC has been drawn on to the image.



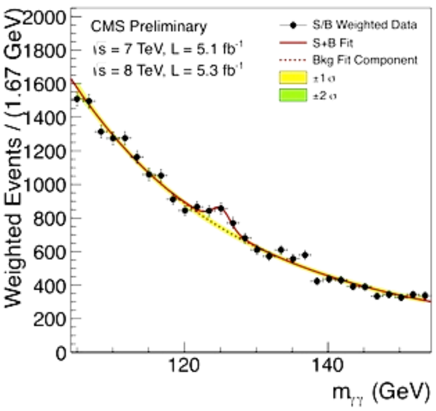
1. The LHC is a circular tunnel with a circumference of 17 miles, what is the approximate length and width of the square area that contains it?

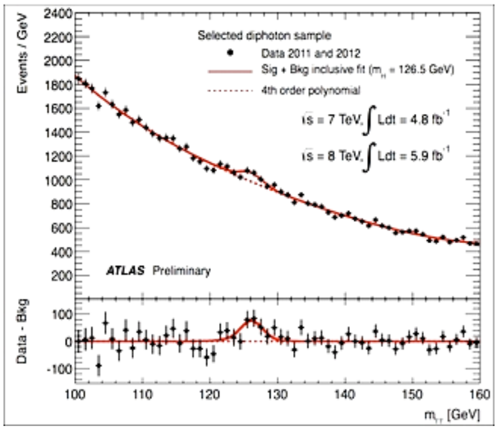
The Hadron Collider can accelerate particles to 99.99975 % of the speed of light. The speed of light is 299,792,458 meters per second or 186,282 miles per second.

2. What is the maximum speed that the protons can reach in the LHC?
    a. In miles per second
    b. In meters per second

The collisions of protons are being observed in several huge particle detectors. Two of these detectors, the ATLAS and the CMS detectors, are the two machines and teams that were involved in last week's discovery. The two separate teams, with different experiments, presented their findings in Australia after some 500 trillion collisions and found that they had both seen evidence of the same new particle. With two different ways of observing and testing for the particle, the findings of the two teams corroborate each other's conclusions and the existence of the particle.

In the image below you can see the twin peaks of the boson particle detection. Both the CMS (left) and the ATLAS (right) detectors see evidence of the Higgs boson decaying into a pair of photons in the form of a peak in a so-called mass plot. The agreement of the two peaks and other data clinch the discovery of the Higgs.





In 1964, Peter Higgs, a theorist from the University of Edinburgh in the United Kingdom, and Professors Francoise Englert and Robert Brout first predicted the existence of a field that gave mass to subatomic particles that pass through the field. This field was given the name of the Higgs field and it should be detectible as a particle in the LHC.

3. How long ago did Professors Higgs, Brout and Englert predict the existence of this particle?

    This is the amount of time that scientists have been looking for the existence of the Higgs field and its boson particle.

4. Professor Higgs was at CERN when scientists reported their findings. The newspapers said that he is now 85 years old. How old was he when he first predicted this particle?

Particle physics has an accepted definition for a discovery: a "five-sigma" (or five standard-deviation) level of certainty. The number of sigmas measures how unlikely it is to get a certain experimental result as a matter of chance rather than due to a real effect.

At CERN, each team might consider 500 trillion collisions. The mean data of those collisions is what helps

measure the standard deviations from the mean = σ (lower case Greek letter, Sigma).
Let's consider some simple data to decide what standard deviation means.

Suppose I have 5 pieces of data. I'm going to show you 3 sets of 5 pieces of data so that we can compare them.

Set A	Set B	Set C
{9,10,11,7,13}	10,10,10,10,10}	{1,1,10,19,19}

5. Find each set's average (mean) value = μ (Greek letter called mu).

Set A	Set B	Set C

6. Find the differences between each set's data and its mean value in the charts below.

Set A	abs (Difference from μ)	(Difference from mean)^2
9		
10		
11		
7		
13		

Set B	abs (Difference from μ)	(Difference from mean)^2
10		
10		
10		
10		
10		

Set C	abs (Difference from μ)	(Difference from mean)^2
1		
1		
10		
19		
19		

7. Then square those differences in the chart above.

8. The standard deviation of this data is the square root of the sum of those μ^2. Find the standard deviation of your data.

9. What do you think the standard deviations demonstrate about these sets of data?

In a normal distribution there is an approximately 68 percent chance that a new value will fall within the first standard deviation of the distribution … 1-sigma.
Here are the approximate percentages of data falling between other ranges of standard deviations.

2-sigma: 95.5 percent
3-sigma: 99.73 percent
4-sigma: 99.993 percent
5-sigma: 99.99994 percent

So that means that purely statistical fluctuations will give you a result way out in the 5-sigma range 0.00006 percent of the time.

10. If a fluke result might happen 0.00006 per cent of the time, figure out how often you would have to do the experiment to have a fluke occur. Do that by expressing 0.00006 percent as a fraction and then reducing that fraction to a unit fraction with one as it's numerator.

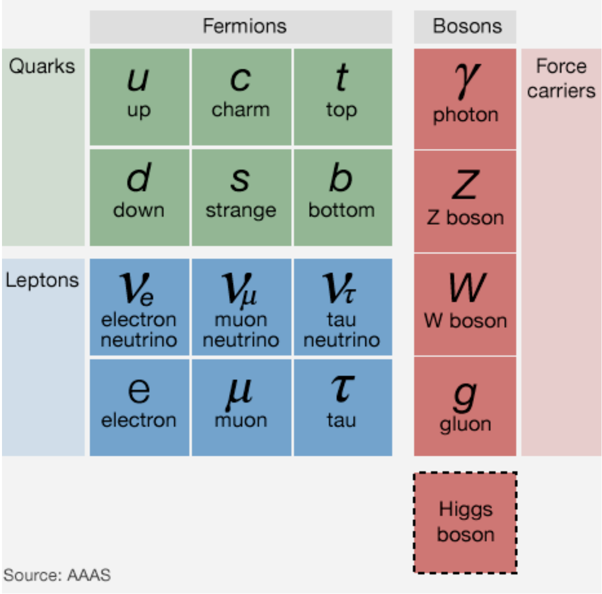
Particle physicists working on the CMS and ATLAS experiments are looking for "bumps" in their data that stand out from the background. When these bumps reach the 5-sigma level, they have very good reason to believe that they've discovered or observed a new particle.

There is a "bump" in both experiments (ATLAS and CMS) data at about 125 GeVs which is a tiny mass of about one barium atom. Since the statistical probability that this "bump" is a fluke is so small, physicists feel certain that they have discovered a new particle, a Higgs boson like particle.

More great resources about the Higgs-Boson search

- This is a great video that shows the LHC with the science explained by a young professor Brian Cox. http://www.planet-science.com/categories/over-11s/technology/2011/01/large-hadron-collider-explained.aspx
- This is a second video by professor Brian Cox of a presentation at TED (Ideas worth spreading). http://videosift.com/video/Brian-Cox-at-TEDtalks-on-the-Large-Hadron-Collider

The Standard Model and the Higgs boson



	Fermions			Bosons	
Quarks	u up	c charm	t top	γ photon	Force carriers
	d down	s strange	b bottom	Z Z boson	
Leptons	ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino	W W boson	
	e electron	μ muon	τ tau	g gluon	
				Higgs boson	

Source: AAAS

- **The Standard Model** is the simplest set of ingredients - elementary particles - needed to make up the world we see in the heavens and in the laboratory

- **Quarks** combine together to make, for example, the proton and neutron - which make up the nuclei of atoms today - though more exotic combinations were around in the Universe's early days

- **Leptons** come in charged and uncharged versions; electrons - the most familiar charged lepton - together with quarks make up all the matter we can see; the uncharged leptons are neutrinos, which rarely interact with matter

- **the "force carriers"** are particles whose movements are observed as familiar forces such as those behind electricity and light (electromagnetism) and radioactive decay (the weak nuclear force)

- **The Higgs boson** came about because although the Standard Model holds together neatly, nothing requires the particles to have mass; for a fuller theory, the Higgs - or something else - must fill in that gap

Sources:

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http://thelede.blogs.nytimes.com/2012/07/04/what-in-the-world-is-a-higgs-boson/
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