CERN experiments observe particle consistent with long-sought Higgs boson

Geneva, 4 July 2012.

At a seminar held at CERN[1] today as a curtain raiser to the year's major particle physics conference, ICHEP2012 in Melbourne, the ATLAS and CMS experiments presented their latest preliminary results in the search for the long sought Higgs particle. Both experiments observe a new particle in the mass region around 125-126 GeV.

"We observe in our data clear signs of a new particle, at the level of 5 sigma, in the mass region around 126 GeV. The outstanding performance of the LHC and ATLAS and the huge efforts of many people have brought us to this exciting stage," said ATLAS experiment spokesperson Fabiola Gianotti, *"but a little more time is needed to prepare these results for publication."*

"The results are preliminary but the 5 sigma signal at around 125 GeV we're seeing is dramatic. This is indeed a new particle. We know it must be a boson and it's the heaviest boson ever found," said CMS experiment spokesperson Joe Incandela. *"The implications are very significant and it is precisely for this reason that we must be extremely diligent in all of our studies and cross-checks."*

"It's hard not to get excited by these results," said CERN Research Director Sergio Bertolucci. *" We stated last year that in 2012 we would either find a new Higgs-like particle or exclude the existence of the Standard Model Higgs. With all the necessary caution, it looks to me that we are at a branching point: the observation of this new particle indicates the path for the future towards a more detailed understanding of what we're seeing in the data."*

The results presented today are labelled preliminary. They are based on data collected in 2011 and 2012, with the 2012 data still under analysis. Publication of the analyses shown today is expected around the end of July. A more complete picture of today's observations will emerge later this year after the LHC provides the experiments with more data.

The next step will be to determine the precise nature of the particle and its significance for our understanding of the universe. Are its properties as expected for the long-sought Higgs boson, the final missing ingredient in the Standard Model of particle physics? Or is it something more exotic? The Standard Model describes the fundamental particles from which we, and every visible thing in the universe, are made, and the forces acting between them. All the matter that we can see, however, appears to be no more than about 4% of the total. A more exotic version of the Higgs particle could be a bridge to understanding the 96% of the universe that remains obscure.

"We have reached a milestone in our understanding of nature," said CERN Director General Rolf Heuer. "*The discovery of a particle consistent with the Higgs boson opens the way to more detailed studies, requiring larger statistics, which will pin down the new particle's properties, and is likely to shed light on other mysteries of our universe."*

Positive identification of the new particle's characteristics will take considerable time and data. But whatever form the Higgs particle takes, our knowledge of the fundamental structure of matter is about to take a major step forward.

CERN press office

Further information:

- Statement from ATLAS
- Statement from CMS

1. CERN, the European Organization for Nuclear Research, is the world's leading laboratory for particle physics. It has its headquarters in Geneva. At present, its Member States are Austria, Belgium, Bulgaria, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Italy, the Netherlands, Norway, Poland, Portugal, Slovakia, Spain, Sweden, Switzerland and the United Kingdom. Romania is a candidate for accession. Israel and Serbia are Associate Members in the pre-stage to Membership. India, Japan, the Russian Federation, the United States of America, Turkey, the European Commission and UNESCO have Observer status.

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Latest Results from ATLAS Higgs Search
4 July 2012

On 4 July, 2012, the ATLAS experiment presented a preview of its updated results on the search for the Higgs Boson. The results were shown at a seminar held jointly at CERN and via video link at ICHEP, the International Conference for High Energy Physics in Melbourne, Australia, where detailed analyses will be presented later this week. At CERN, preliminary results were presented to scientists on site and via webcast to their colleagues located in hundreds of institutions around the world.

"The search is more advanced today than we imagined possible," said ATLAS spokesperson Fabiola Gianotti. *"We observe in our data clear signs of a new particle, at the level of 5 sigma, in the mass region around 126 GeV. The outstanding performance of the LHC and ATLAS and the huge efforts of many people have brought us to this exciting stage. A little more time is needed to finalize these results, and more data and more study will be needed to determine the new particle's properties."*

The Higgs Boson is an unstable particle, living for only the tiniest fraction of a second before decaying into other particles, so experiments can observe it only by measuring the products of its decay. In the Standard Model, a highly successful physics theory that provides a very accurate description of matter, the Higgs Boson is expected to decay to several distinct combinations of particles, or channels, with the distribution among the channels depending on its mass.

ATLAS concentrated its efforts on two complementary channels: Higgs decays to either two photons or to four leptons. Both of these channels have excellent mass resolution; however, the two-photon channel has a modest signal over a large but measured background, and the four-lepton channel has a smaller signal but a very low background. Both channels show a statistically significant excess at about the same place: a mass of around 126 GeV. A statistical combination of these channels and others puts the significance of the signal at 5 sigma, meaning that only one experiment in three million would see an apparent signal this strong in a universe without a Higgs.

The current results are an update on previous analyses shown at a CERN seminar last December and published at the beginning of this year. The December results, based on 7 TeV proton collision data collected in 2011, limited the mass of the Higgs Boson to two narrow windows in the range between about 117 GeV and 129 GeV. A small excess of events above the expected background was seen by both ATLAS and CMS at around 126 GeV, about the mass of an iodine atom.

The next steps for ATLAS, the LHC and the high-energy physics community are to measure the properties of this particle and compare these measurements with the predicted properties of the Higgs Boson. Already some of these properties match the predictions: the fact that it is seen in the predicted channels and at a mass favoured by other, indirect measurements. In the weeks and months ahead, ATLAS will better measure these properties, enabling a clearer picture to emerge about whether this particle is the Higgs Boson, or the first of a larger family of such particles, or something else entirely.

The 2012 data set comes from proton collisions with an increased centre of mass energy of 8 TeV and includes more data (collected in only three months) than was collected in all of 2011. This rapid accumulation of data was possible thanks to the outstanding efforts of the LHC accelerator group. The data set presented at the seminar comes from approximately one quadrillion (million billion) proton collisions.

The ATLAS detector has performed remarkably well, even under the more difficult beam conditions of 2012, and has, with nearly full efficiency, collected high quality data for this search. Powerful computing provided by the worldwide LHC Computing Grid was essential for the reconstruction and analysis of the data.

The LHC is expected to provide ATLAS with double the data again by the end of the 2012, before the beginning of a long shutdown to upgrade the accelerator. When the machine starts up again toward the end of 2014, it will operate at nearly twice its current energy. The new 2012 data and the data generated by the improved accelerator will allow scientists to address the questions about the Higgs prompted by today's announcement as well as other questions fundamental to our knowledge of nature.

About ATLAS
Information about ATLAS can be found on the public web site [http://atlas.ch].

ATLAS is a particle physics experiment at the Large Hadron Collider (LHC) at CERN. The ATLAS detector is searching for new phenomena in the head-on collisions of hadrons of extraordinarily high energy. ATLAS is studying the basic forces that have shaped our Universe since the beginning of time and that will determine its fate. Among the possible unknowns are the origin of mass, extra dimensions of space, the unification of fundamental forces, and evidence for dark matter candidates in the Universe.

At the time of writing, the ATLAS Collaboration comprises 3000 physicists from 176 institutions located in 38 different countries around the world. More than 1000 PhD students are involved in the operation of ATLAS and in the analysis of its data.

EPP notes (QMUL) - Higgs Challenge
In 1993, the then UK Science Minister, William Waldegrave, issued a challence to physicists to answer the questions 'What is the Higgs boson, and why do we want to find it?' on one side of a single sheet of paper.

Bottles of champagne were awarded to the five winning entries at the annual meeting of the British Association for the Advancement of Science. The winning entries taken from
Physics World Volume 6 Number 9, are given below.

How Particles Acquire Mass
By Mary and Ian Butterworth, Imperial College London, and Doris and Vigdor Teplitz, Southern Methodist University, Dallas, Texas, USA.

The Higgs boson is a hypothesised particle which, if it exists, would give the mechanism by which particles acquire mass.

Matter is made of molecules; molecules of atoms; atoms of a cloud of electrons about one-hundred-millionth of a centimetre and a nucleus about one-hundred-thousandth the size of the electron cloud. The nucleus is made of protons and neutrons. Each proton (or neutron) has about two thousand times the mass of an electron. We know a good deal about why the nucleus is so small. We do not know, however, how the particles get their masses. Why are the masses what they are? Why are the ratios of masses what they are? We can't be said to understand the constituents of matter if we don't have a satisfactory answer to this question.

Peter Higgs has a model in which particle masses arise in a beautiful, but complex, progression. He starts with a particle that has only mass, and no other characteristics, such as charge, that distinguish particles from empty space. We can call his particle H. H interacts with other particles; for example if H is near an electron, there is a force between the two. H is of a class of particles called "bosons". We first attempt a more precise, but non-mathematical statement of the point of the model; then we give explanatory pictures.

In the mathematics of quantum mechanics describing creation and annihilation of elementary particles, as observed at accelerators, particles at particular points arise from "fields" spread over space and time. Higgs found that parameters in the equations for the field associated with the particle H can be chosen in such a way that the lowest energy state of that field (empty space) is one with the field not zero. It is surprising that the field is not zero in empty space, but the result, not an obvious one, is: all particles that can interact with H gain mass from the interaction.

Thus mathematics links the existence of H to a contribution to the mass of all particles with which H interacts. A picture that corresponds to the mathematics is of the lowest energy state, "empty" space, having a crown of H particles with no energy of their own. Other particles get their masses by interacting with this collection of zero-energy H particles. The mass (or inertia or resistance to change in motion) of a particle comes from its being "grabbed at" by Higgs particles when we try and move it.

If particles do get their masses from interacting with the empty space Higgs field, then the Higgs particle must exist; but we can't be certain without finding the Higgs. We have other hints about the Higgs; for example, if it exists, it plays a role in "unifying" different forces. However, we believe that nature could contrive to get the results that would flow from the Higgs in other ways. In fact, proving the Higgs particle does not exist would be scientifically every bit as valuable as proving it does.

These questions, the mechanisms by which particles get their masses, and the relationship amongs different forces of nature, are major ones and so basic to having an understanding of the constituents of matter and the forces among them, that it is hard to see how we can make significant progress in our understanding of the stuff of which the earth is made without answering them.

The Need to Understand Mass

By Roger Cashmore, Department of Physics, University of Oxford, UK.

What determines the size of objects that we see around us or indeed even the size of ourselves? The answer is the size of the molecules and in turn the atoms that compose these molecules. But what determines the size of the atoms themselves? Quantum theory and atomic physics provide an answer. The size of the atom is determined by the paths of the electrons orbiting the nucleus. The size of those orbits, however, is determined by the mass of the electron. Were the electron's mass smaller, the orbits (and hence all atoms) would be smaller, and consequently everything we see would be smaller.* So understanding the mass of the electron is essential to understanding the size and dimensions of everything around us.

It might be hard to understand the origin of one quantity, that quantity being the mass of the electron. Fortunately nature has given us more than one elementary particle and they come with a wide variety of masses. The lightest particle is the electron and the heaviest particle is believed to be the particle called the top quark, which weighs at least 200,000 times as much as an electron. With this variety of particles and masses we should have a clue to the individual masses of the particles.

Unfortunately if you try and write down a theory of particles and their interactions then the simplist version requires all the masses of the particles to be zero. So on one hand we have a whole variety of masses and on the other a theory in which all masses should be zero. Such conundrums provide the excitement and the challenges of science.

There is, however, one very clever and very elegant solution to this problem, a solution first proposed by Peter Higgs. He proposed that the whole of space is permeated by a field, similar in some ways to the electromagnetic field. As particles move through space they travel through this field, and if they interact with it they acquire what appears to be mass. This is similar to the action of viscous forces felt by particles moving through any thick liquid. the larger the interaction of the particles with the field, the more mass they appear to have. Thus the existence of this field is essential in Higgs' hypothesis for the production of the mass of particles.

We know from quantum theory that fields have particles associated with them, the particle for the electromagnetic field being the photon. So there must be a particle associated with the Higgs field, and this is the Higgs boson. Finding the Higgs boson is thus the key to discovering whether the Higgs field does exist and whether our best hypothesis for the origin of mass is indeed correct.

*Note: This argument is the wrong way round - if the electron's mass were smaller, the orbits would be larger, and everything would be larger.

Politics, Solid State and the Higgs
By David Miller, Department of Physics and Astronomy, University College, London, UK.

1. The Higgs Mechanism

Imagine a cocktail party of political party workers who are uniformly distributed across the floor, all talking to their nearest neighbours. The ex-Prime Minister enters and crosses the room. All of the workers in her neighbourhood are strongly attracted to her and cluster round her. As she moves she attracts the people she comes close to, while the ones she has left return to their even spacing. Because of the knot of people always clustered around her she acquires a greater mass than normal, that is she has more momentum for the same speed of movement across the room. Once moving she is hard to stop, and once stopped she is harder to get moving again because the clustering process has to be restarted.

In three dimensions, and with the complications of relativity, this is the Higgs mechanism. In order to give particles mass, a background field is invented which becomes locally distorted whenever a particle moves through it. The distortion - the clustering of the field around the particle - generates the particle's mass. The idea comes directly from the physics of solids. instead of a field spread throughout all space a solid contains a lattice of positively charged crystal atoms. When an electron moves through the lattice the atoms are attracted to it, causing the electron's effective mass to be as much as 40 times bigger than the mass of a free electron.

The postulated Higgs field in the vacuum is a sort of hypothetical lattice which fills our Universe. We need it because otherwise we cannot explain why the Z and W particles which carry the weak interactions are so heavy while the photon which carries electromagnetic forces is massless.

2. The Higgs Boson

Now consider a rumour passing through our room full of uniformly spread political workers. Those near the door hear of it first and cluster together to get the details, then they turn and move closer to their next neighbours who want to know about it too. A wave of clustering passes through the room. It may spread to all the corners or it may form a compact bunch which carries the news along a line of workers from the door to some dignitary at the other side of the room. Since the information is carried by clusters of people, and since it was clustering that gave extra mass to the ex-Prime Minister, then the rumour-carrying clusters also have mass.

The Higgs boson is predicted to be just such a clustering in the Higgs field. We will find it much easier to believe that the field exists, and that the mechanism for giving other particles is true, if we actually see the Higgs particle itself. Again, there are analogies in the physics of solids. A crystal lattice can carry waves of clustering without needing an electron to move and attract the atoms. These waves can behave as if they are particles. They are called phonons and they too are bosons.

There could be a Higgs mechanism, and a Higgs field throughout our Universe, without there being a Higgs boson. The next generation of colliders will sort this out.

Of Particles, Pencils and Unification

By Tom Kibble, Department of Physics, Imperial College, London, UK.

Theoretical physicists always aim for unification. Newton recognised that the fall of an apple, the tides and the orbits of the planets as aspects of a single phenomenon, gravity. Maxwell unified electricity, magnetism and light. Each synthesis extends our understanding and leads eventually to new applications.

In the 1960s the time was ripe for a further step. We had a marvellously accurate theory of electromagnetic forces, quantum electrodynamics, or QED, a quantum version of Maxwell's theory. In it, electromagnetic forces are seen as due to the exchange between electrically charged particles of photons, packets (or quanta) of electromagnetic waves. (The distinction between particle and wave has disappeared in quantum theory.) The "weak" forces, involved in radioactivity and in the Sun's power generation, are in many ways very similar, save for being much weaker and restricted in range. A beautiful unified theory of weak and electromagnetic forces was proposed in 1967 by Steven Weinberg and Abdus Salam (independently). The weak forces are due to the exchange of W and Z particles. Their short range, and apparent weakness at ordinary ranges, is because, unlike the photon, the W and Z are, by our standards, very massive particles, 100 times heavier than a hydrogen atom.

The "electro-weak" theory has been convincingly verified, in particular by the discovery of the W and Z at CERN in 1983, and by many tests of the properties. However, the origin of their masses remains mysterious. Our best guess is the "Higgs mechanism" - but that aspect of the theory remains untested.

The fundamental theory exhibits a beautiful symmetry between W, Z and photon. But this is a spontaneously broken symmetry. Spontaneous symmetry breaking is a ubiquitous phenomenon. For example, a pencil balanced on its tip shows complete rotational symmetry - it looks the same from every side. - but when it falls it must do in some particular direction, breaking the symmetry. We think the masses of the W and Z (and of the electron) arise through a similar mechanism. It is thought there are "pencils" throughout space, even in vacuum. (of course, these are not real physical pencils - they represent the "Higgs field" - nor is their direction a direction in real physical space, but the analogy is fairly close.) The pencils are all coupled together, so that they all tend to fall in the same direction. Their presence in the vacuum influences waves travelling through it. The waves have of course a direction in space, but they also have a "direction" in this conceptual space. In some "directions", waves have to move the pencils too, so they are more sluggish; those waves are the W and Z quanta.

The theory can be tested, because it suggests that there should be another kind of wave, a wave in the pencils alone, where they are bouncing up and down. That wave is the Higgs particle. Finding it would confirm that we really do understand the origin of mass, and allow us to put the capstone on the electro-weak theory, filling in the few remaining gaps.

Once the theory is complete, we can hope to build further on it: a longer-term goal is a unified theory involving also the "strong" interactions that bind protons and neutrons together in atomic nuclei - and if we are really optimistic, even gravity, seemingly the hardest force to bring into the unified scheme.

There are strong hints that a "grand unified" synthesis is possible, but the details are still very vague. Finding the Higgs would give us very significant clues to the nature of that greater synthesis.

Ripples at the Heart of Physics

By Simon Hands, Theory Division, CERN, Geneva, Switzerland.

The Higgs boson is an undiscovered elementary particle, thought to be a vital piece of the closely fitting jigsaw of particle physics. Like all particles, it has wave properties akin to those ripples on the surface of a pond which has been disturbed; indeed, only when the ripples travel as a well defined group is it sensible to speak of a particle at all. In quantum language the analogue of the water surface which carries the waves is called a field. Each type of particle has its own corresponding field.

The Higgs field is a particularly simple one - it has the same properties viewed from every direction, and in important respects is indistinguishable from empty space. Thus physicists conceive of the Higgs field being "switched on", pervading all of space and endowing it with "grain" like that of a plank of wood. The direction of the grain in undetectable, and only becomes important once the Higgs' interactions with other particles are taken into account. for instance, particles called vector bosons can travel with the grain, in which case they move easily for large distances and may be observed as photons - that is, particles of light that we can see or record using a camera; or against, in which case their effective range is much shorter, and we call them W or Z particles. These play a central role in the physics of nuclear reactions, such as those occurring in the core of the sun.

The Higgs field enables us to view these apparently unrelated phenomenon as two sides of the same coin; both may be described in terms of the properties of the same vector bosons. When particles of matter such as electrons or quarks (elementary constituents of protons and neutrons, which in turn constitute the atomic nucleus) travel through the grain, they are constantly flipped "head-over-heels". this forces them to move more slowly than their natural speed, that of light, by making them heavy. We believe the Higgs field responsible for endowing virtually all the matter we know about with mass.

Like most analogies, the wood-grain one is persuasive but flawed: we should think of the grain as not defining a direction in everyday three-dimensional space, but rather in some abstract internal space populated by various kinds of vector boson, electron and quark.

The Higgs' ability to fill space with its mysterious presence makes it a vital component in more ambitious theories of how the Universe burst into existence out of some initial quantum fluctuation, and why the Universe prefers to be filled with matter rather than anti-matter; that is, why there is something rather than nothing. To constrain these ideas more rigorously, and indeed flesh out the whole picture, it is important to find evidence for the Higgs field at first hand - in other words, find the boson. There are unanswered questions: the Higgs' very simplicity and versatility, beloved of theorists, makes it hard to pin down. How many Higgs particles are there? Might it/they be made from still more elementary components? Most crucial, how heavy is it? Our current knowledge can only put its mass roughly between that of an iron atom and three times that of a uranium atom. This is a completely new form of matter about whose nature we still have only vague hints and speculations and its discovery is the most exciting prospect in contemporary particle physics.