Higgs Boson : The Ultimate Particle of the Universe

Kul Prasad Dahal
Department of Physics, Prithvi Narayan Campus, Tribhuvan University, Nepal
Correspondence: dahalkp@yahoo.com

Abstract

The concept of basic constituent particles of matter have been changing from ancient time to present. Scientists have been looking for the Higgs since the long with experiments at CERN and Fermilab. Confirming the existence of the Higgs would only be the start of a new era of particle physics. To find the particle and characterize it, scientists are smashing beams of proton together inside LHC at close to the speed of light. The recent discovery declared that the finding is very close to the ultimate particle called Higgs particle. This is believed to be the basic building block of the universe.

Keywords*:* *fundamental particle, antiparticle, standard model, Higgs particles, grand unified theories.*

Introduction

The ideas about constitution of the universe have begun from the time before Lord Buddha and Christ. In the ancient time water, fire, air and earth were assumed as basic elements of the universe. Similarly Hindu Philosophy considered water, fire, air, sky and earth as basic constituents of the universe. Aristotle and Democritus were the follower of this type of idea. However the idea about the indivisibly of constituent part of matter began from the time of Democritus. John Dalton pointed about the molecular state of matter. Different scientists like Thomson, Rutherford, Bohr, de Broglie, Somerfield, Chadwick and so on had proposed different models of smallest structure of matter called "atom". The discovery of elementary particles like proton, neutron and electron were subsequent and located properly within an atom. This was a successful model of that time and has still been accepted. Proton and neutron are made by much smaller particles called quarks. Quarks are much smaller than the wavelength of visible light(10^{-7} m). The particles are elementary in the sense that they are structureless i.e. they cannot be explained as a system of other elementary particles. The elementary particles discovered so far are around 200 in number. They are of different kinds on the basis of their properties. They are baryons, mesons and leptons. They still have subclasses depending on their behavior and properties. On the other hand theory in physics revealed that every particle has an anti-structure called antiparticle. Antiparticles are same as the particle in regards its mass and spin but opposite in nature of charge. For example, antiproton is an antiparticle of a proton, they both annihilate with emission of energy when come in contact. This phenomenon is true for all particles and antiparticles.

The different groups of particles have different forces of interaction which bind them together. They are gravitational, electromagnetic, weak and strong forces. The standard model of an atom which was proposed in 1960s is to explain new atomic model on the basis of interaction of the four forces. The physicists hope to find a unified theory that will explain all the forces as different aspects of a single force. The success of the unification of the electromagnetic and weak nuclear force led to a number of attempts to combine these two forces with the strong nuclear force into Grand Unified Theories (GUTs).The value of grand unification energy will be tremendously large to thousand million million gigaelectron volts(GeV) :{GeV or giga electron volt, is a unit of mass used by particle physicists: one GeV is about the mass of a proton}. However gravity is excluded from the GUTs for being very very weak interaction relatively.

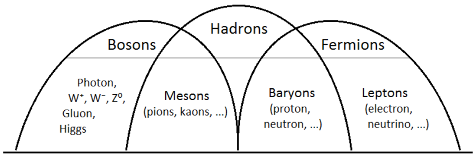


Fig. 1 Different classes of particles

The Standard Model of particle physics is a simple and comprehensive theory that explains all the hundreds of particles and their complex interactions, with only six quarks, six leptons, such as the electron, and a handful of force carrying bosons, such as the photon. Though it's not a theory of everything – it leaves gravity out of the mix, for example – the Standard Model is a well tested, highly successful theory, one of the great triumphs of modern physics.

However, the Standard Model cannot yet explain why particles have mass. In the 1960s, a deep look at the mathematics behind the Standard Model led physicists to propose the existence of the "Higgs field," which interacts with all particles, through a process called the "Higgs mechanism," to give them mass. The stronger a particle's interaction with the Higgs field, the larger it's mass. The Higgs field is required by the Standard Model: the model absolutely will not work without it, or something like it. Without the Higgs mechanism, all particles would be massless, like the photon. We ourselves would not exist. Fields give rise to particles. The Higgs boson is the smallest possible ripple in a Higgs field, the way the photon is the smallest possible ripple in an electromagnetic field. The simplest case, the one predicted in the Standard Model is that there would be one Higgs boson, though it's possible that there could be several. The Large Hadron Collider (LHC) at CERN has two general purpose experiments, ATLAS and CMS, which were designed (among other things) to find the Higgs boson. Specifically, ATLAS and CMS have been looking for a Higgs between 115 and 141 GeV. Another way of saying all this is that the Standard Model, contains 18 particles, and found so far 17 of them. The Higgs is the last. If it is found, then there will be good evidence that the Higgs mechanism is right. This will led to a step closer to developing a theory to underpin both the Higgs mechanism that gives particles mass and the Standard Model itself. If no Standard Model Higgs is found to exist, to learn something entirely new.

Large Hadron Collider

Experiments to try to show whether the Higgs boson did or did not exist began in the 1980s, but until the 2000s it could only be said that certain areas were plausible, or ruled out. In 2008 the Large Hadron Collider (LHC) was inaugurated, being the most powerful particle accelerator ever built. It was designed especially for this experiment, and other very-high-energy tests of the Standard Model. Experiments to confirm and determine the nature of Higgs boson using the Large Hadrons Collider at European Organization for Nuclear Research (CERN) began in early 2010. It was built at a cost of about $ 9 billion precisely for the purpose of smashing together protons with enough energy to produce a Higgs boson. The large Hadron Collider was built answer the question of whether the Higgs boson actually exists. The LHC is about 27 Kilometers in circumference tunnel built 175 meter beneath the boarder of Switzerland and France near Geneva. Accelerating two streams of protons in opposite directions at more than 99.9999 percent the speed of light and smashing them together in spectacular collisions billions of times each second, producing hundreds of particles in each collision. There is a bank of more than 3,000 computers analyzing the events in real time in order to search for something interesting by about 5000 researchers. The Higgs particle itself never directly appears.

Fig. 2 Large Hadron Collider at CERN

It can generate high energy 7-8 TeV - teraelectronvolt proton beam to head on collision. The temperature maintained in it is about 1.9 Kelvin with the help of liquid helium, whereas ordinary environmental temperature is taken 300 Kelvin. A similar work was performed at Fermilab's Tevatron in late 2011. On 4th July 2012 two main experiments and the LHC reported that they found a new particle with a mass of about 125 GeV/c^2 which is consistent with Higgs boson. This newly observed particle has several properties similar to the predicted simplest Higgs. Further work would be needed to conclude that it is indeed the Higgs boson.

Standard Model of an atom

The Standard Model was established in the mid 1970s. The model is sometimes driven forward by new experimental discoveries and sometimes by theoretical advances. The discoveries of the bottom quark, the top quark and the tau neutrino have given further credence to the standard model. More recently the apparent detection of the Higgs boson completes the set of predicted particles. Because of its

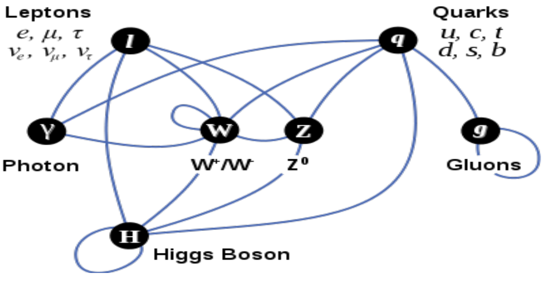
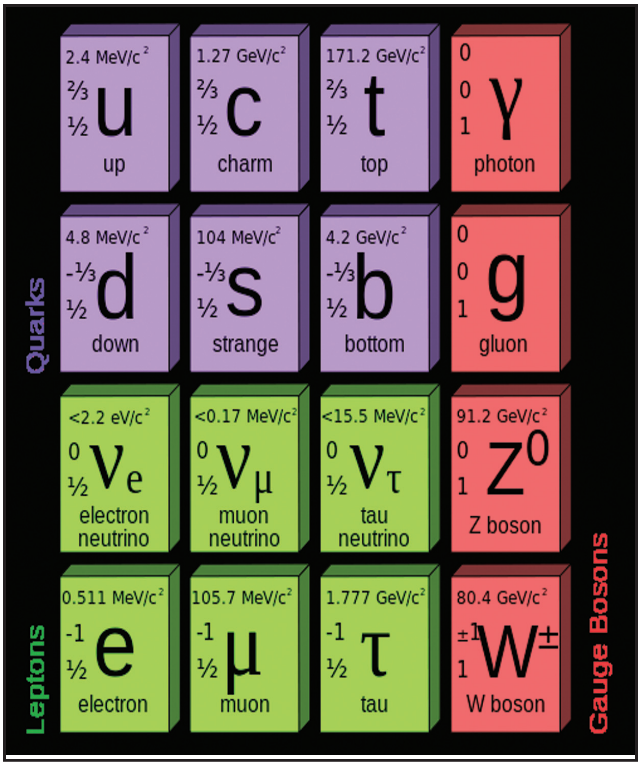


Fig. 3 Interation among different particles

success in explaining a wide variety of experimental results, the standard model is sometimes regarded as a "Theory of almost everything."



Quarks	2.4 MeV/c^2 ⅔ ½ u up	1.27 GeV/c^2 ⅔ ½ c charm	171.2 GeV/c^2 ⅔ ½ t top	0 0 1 γ photon
Quarks	4.8 MeV/c^2 -⅓ ½ d down	104 MeV/c^2 -⅓ ½ s strange	4.2 GeV/c^2 -⅓ ½ b bottom	0 0 1 g gluon
Leptons	<2.2 eV/c^2 0 ½ ν_e electron neutrino	<0.17 MeV/c^2 0 ½ ν_μ muon neutrino	<15.5 MeV/c^2 0 ½ ν_τ tau neutrino	91.2 GeV/c^2 0 1 Z^0 Z boson
Leptons	0.511 MeV/c^2 -1 ½ e electron	105.7 MeV/c^2 -1 ½ μ muon	1.777 GeV/c^2 -1 ½ τ tau	80.4 GeV/c^2 ±1 1 $W^\pm$ W boson

Fig 4 An illustration of the standard model and the three generations, these are approximate masses

The standard model is the name given to the present model consisting of elementary particles and their interactions. In this model, the theory of the strong interaction has been joined to that of the electroweak interaction to make a single picture. In this model the strong, weak and electromagnetic forces appear as different manifestations of one basic phenomenon, with leptons and quarks finding natural places within the scheme. The first category of particles of standard model are three generation leptons {(e^-, ν_e), (μ^-, ν_μ) and (τ^-, ν_τ)} and three generation quarks {(d, u), (s, c), (b, t)} and their antiparticle. These are the group of particles with spin ½ fermions and antifermions. Similarly another category is one massless electroweak boson (photon-γ) and three massive electroweak bosons (W^+, W^- & Z^o). In addition, there are eight colored gluons. These are all spin 1 gause bosons. The third category of the standard model is Higgs boson with zero spin.

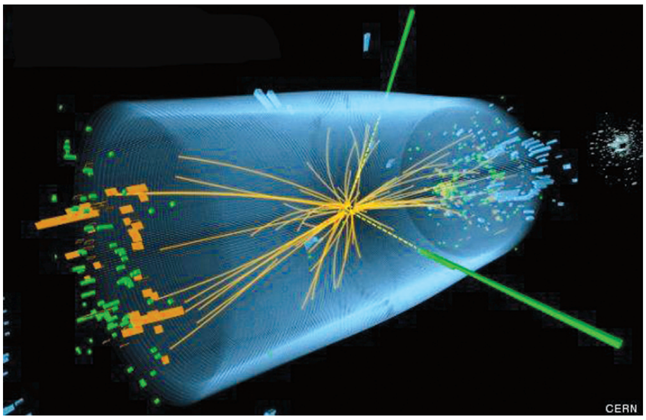


Fig 5 Higgs Boson: event recorded with the CMS detector

Thus Higgs boson, a part of "The Standard Model" of particle physics is a quantized scalar particle. It has no its intrinsic spin and for that reason is classified as a boson. This is a set of rules that lays out our understanding of the fundamental building blocks of the universe. In addition, it helps us understand what happens in the universe by having a precise picture of the smallest building blocks of matter and their interactions. If the Higgs boson did not exist the Standard Model would be proved incorrect. The importance of Higgs particle is also addressed as "A major milestone for the standard model". The worth importance is further emphasized as "picture the Standard Model as a car, then Higgs boson to be the wheels of that car". Recently, about the discovery of Higgs particles CERN's own announcement says positive identification. 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 step forward.

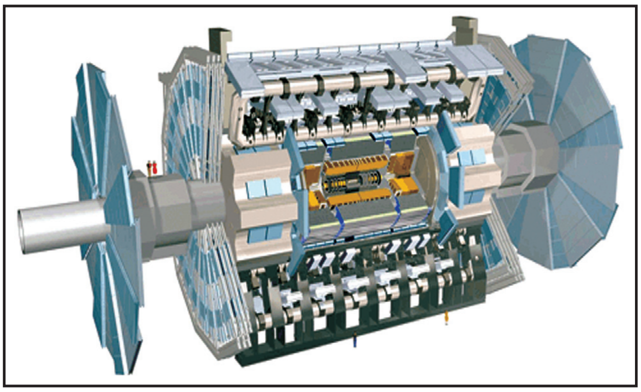


Fig 6 The ATLAS detector

Nevertheless, the standard model is important to theoretical and experimental particle physicists. For theorists, the standard model is a paradigm of a quantum field theory which exhibits a wide range of physics including spontaneous symmetry breaking anomalies non-perturbative behavior, etc. It is used as a basis of building more exotic models that incorporates hypothetical particles, extra dimensions and elaborate symmetries in an attempt to explain experimental results at variance with the standard model, such as existence of dark matter and neutrino oscillations. Recently the standard model has found applications in fields besides particle physics such as astrophysics, cosmology and nuclear physics.

Role of Higgs boson

Higgs boson plays a unique role in the standard model by explaining why the other elementary particles, except the photon and gluon are massive. Higgs bosons will explain why the photon has no mass, while the W and Z bosons are very heavy. The particle which was theorized 50 years ago is a necessary part of the Standard Model, the best description of the forces that shape the subatomic world. Higgs particle is a massive particle and also decays almost immediately. Only a very high energy particle accelerator can observe and record it.

Detection of Higgs boson

The Higgs mechanism is a process by which vector bosons can get rest mass without explicitly breaking gauge invariance. The proposal for such a spontaneous symmetry breaking mechanism originally was suggested in 1962 by Philip Warren Anderson and developed into a full relativistic model, independently and almost simultaneously, by three groups of physicists: by François Englert and Robert Brout in August 1964; by Peter Higgs in October 1964; and by Gerald Guralnik, C. R. Hagen, and Tom Kibble (GHK) in November 1964. Properties of the model were further considered by Guralnik in 1965 and by Higgs in 1966. The Higgs boson is often referred to as the "God particle" by individuals outside the scientific community, after the title of Nobel Physics prize winner Leon Lederman’s popular science book on particle physics, The God Particle: If the Universe Is the Answer, What Is the Question? While use of this term may have contributed to increased media interest, many scientists dislike it, since it is sensational and overstates the particle’s importance.

On 4 July 2012, the two main experiments at the LHC (ATLAS and CMS) both reported independently that they found a new particle with a mass of about 125 GeV/c^2 (about 133 proton masses, on the order of 10^{-25} kg), which is “consistent with the Higgs boson.” Although it has several properties similar to the predicted “simplest” Higgs, they acknowledged that further work would be needed to conclude that it is indeed the Higgs boson, and exactly which version of the Standard Model Higgs it best supported if confirmed.

Conclusion

The tentative discovery of the Higgs particle might be a step of ice break. It represents historic turning point — a triumph for those who proposed the Higgs mechanism, and for those who operate the LHC and the ATLAS and CMS detectors. Yet it does not represent the end to the puzzles about the masses of the known particles. It is only the beginning of hope of solving them. As the energy and collision rate at the LHC increase, ATLAS and CMS will be pursuing exhaustive and systematic studies of the Higgs particle. Hopefully, the Standard Model be able to describe a set of particles from which we can attempt to build the universe. The convincing evidence of Higgs Particle could success to find background field known as a Higgs field, and it must be associated with Higgs Particle. The secrets of the particles with mass and without mass could come to the reality. The Higggs experiment would open the door to something new offering insights into questions the Standard Model can not yet answer. The Higgs, that could lead support to big theories that try to push physics beyond the Standard Model. The outcome will allow to resolve the mysteries of this mass-giving ocean in which we swim, and will propel us forward on our epic journey begun over a century ago, whose end may yet lie decades, perhaps centuries, beyond our current horizon.

References

1. Hawking S W (1998). *A brief history of time*. Berkshire: Cox & Wyman Ltd.
2. Hawking S W (1993). *Black holes and baby universe*. Berkshire: Cox & Wyman Ltd.
3. Murugesan R & Sivaprasath K (1984).*Modern Physics*. New Delhi: S Chanda & Company Ltd.
4. Lee J V (Ed). (2006). *Search for Higgs boson*. New York: Nova Science Publishers, Inc.
5. www.elsevier.com/locate/physletb {Physics letter B 710(2012)49-66}
6. http://www.perimeterinstitute.ca/images/outreach/what_s_the_higgs_boson.pdf (obtained: 2012.07)
7. http://profmattstrassler.com/articles-and-posts/the-higgs-particle/why-the-higgs-particle-matters/ (obtained: 2012.07).
8. Jennifer A., (2012). *The Higgs Boson* (Project No. SA104X) Royal Institute of Technology Stockholm, Swedon