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The Mass of Higgs Boson

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ABSTRACT

Higgs boson is the recently discovered new particle at the LHC. It is considered as the final particle of the standard model (SM) of particle physics. It is an important particle because it is responsible for the Higgs mechanism by which all particles acquire mass. But unfortunately its mass is not determined in the SM. In this paper, we study the mass of Higgs boson.

Keywords: *spontaneous breaking of gauge symmetries; string; gauge bosons; standard model Higgs boson*

1. INTRODUCTION

The standard model (SM) of particle physics is a phenomenally successful theory which describes electromagnetic, weak and strong interactions of fundamental matter fields: quarks and leptons [1]. In this model, Brout-Englert-Higgs (BEH) mechanism (popularly known as Higgs mechanism) is the source of electroweak symmetry breaking (EWSB) and predicts appearance of Higgs boson [2,3]. Recently ATLAS and CMS experiments at the LHC have announced the discovery of a new particle like the SM Higgs boson with mass $m_H = 125\text{–}126$ GeV [4,5]. This mass causes the problem of the electroweak vacuum stability [6,7]. This renders the electroweak vacuum is not perfectly stable. It is metastable with a long lifetime. The metastability of the vacuum depends sensitively on the mass of the top quark m_t and on the mass of Higgs boson m_H. For the central values of Higgs mass and top mass from the LHC data, it is found that the lifetime of the electroweak vacuum is longer than the present age of the universe [8,9]. Recently Frampton and Hung [7] have discussed a possible reason for $m_H \approx 126$ GeV. It [10] is claimed that graphene, the 2010 Nobel Prize winning two-dimensional nanomaterial, would help physicists to probe the Higgs boson's secrets. When we compress graphene it ripples and displays a sort of symmetry breaking. Again we know that the Higgs mechanism explains the symmetry breaking. That is why, it is expected that the ripple effect of graphene would give hints about the Higgs field and the Higgs boson, which gets its mass from vibrations in the Higgs field. Furthermore, it is expected that graphene might help us to understand the mechanisms behind the formation of the universe. Thirty three years ago, Littlewoods and Varma realized that a precise analog of Higgs boson can be seen in the fluctuations of the amplitude of the Cooper pair density in niobium selenide superconductors [11]. Recently, it is claimed that the Higgs boson might interact with dark matter [12,13] and there exists relation between the Higgs boson and dark matter. Since (i) the Higgs field does not directly couple to the quanta of light (photons), and (ii) it generates mass. Dark matter is responsible for the discrepancy between the apparent observed mass of the universe and its actual mass. Again dark matter does not interact with the electromagnetic force, but whose presence can be inferred from gravitational effects on visible matter. Hertzberg [13] has predicted a correlation between the Higgs mass and the abundance of dark matter. His theoretical result is good agreement with current data. He has predicted the mass of Higgs boson as 125.7 ± 0.6 GeV. Thus, although the Higgs boson belongs to the SM of particle physics its study is a very challenging and fascinating topic which interplays between different branches of physics like particle physics, condensed matter physics and cosmology [14,15]. In this paper, we study the mass of Higgs boson in four different ways.

This paper is organized as follows: In Sec. 2, we discuss the Higgs boson in the standard model. In Sec. 3, we study the mass of Higgs boson in four different ways. Finally, we present our conclusions in Sec. 4.

2. HIGGS BOSON IN THE STANDARD MODEL

The gauge group of the standard model is $SU(3)_C \times SU(2)_L \times U(1)_Y$. The $SU(3)_C$ group describes strong interaction, $SU(2)_L$ is the weak symmetry group and $U(1)_Y$ is the electromagnetic symmetry group. The Lagrangian of the SM is electroweak symmetric but this symmetry is not clear in our world. Therefore it must be broken [1]. In the SM, it is postulated that the breaking of electroweak symmetry via the Higgs mechanism gives mass to all fundamental particles. The Higgs field ϕ is an SU(2) doublet and can be written as [16,17]:

$$\phi = \begin{pmatrix} \phi^+ \\ \phi_0 \end{pmatrix} \qquad (1)$$

with a vacuum expectation value

$$\langle 0|\phi|0\rangle = \begin{pmatrix} 0 \\ \mathrm{v}/\sqrt{2} \end{pmatrix} \quad (2)$$

In the standard model with a Higgs sector as described above, the scalar potential can be written as [18]:

$$V_{SM} = \mu^2\phi^\dagger\phi + \lambda\ (\phi^\dagger\phi)^2. \quad (3)$$

Spontaneous symmetry breaking in a gauge theory generates mass for gauge bosons and their masses are proportional to the Higgs vacuum expectation value $\langle\phi_0\rangle = \mathrm{v}/\sqrt{2}$ where

$$\mathrm{v} = \sqrt{-\mu^2/\lambda} = 246.218\ \mathrm{GeV}. \quad (4)$$

The self-coupling of Higgs field shows that the Higgs field itself has mass. Higgs boson is an uncharged scalar boson. The top quark, W boson and Higgs boson masses are given [17,18] in terms of v and their respective Yukawa couplings:

$$m_W = \frac{1}{2} g\,\mathrm{v}, \quad m_Z = \frac{1}{2}(g+g')^{1/2}\,\mathrm{v}, \quad m_t = g_t\frac{\mathrm{v}}{2}, \quad m_H^2 = 2\lambda \mathrm{v}^2. \quad (5)$$

Here, $g'/g = \tan\theta_W$, θ_W is the Weinberg angle and g_t is the top Yukawa coupling. In the SM, the Higgs self-coupling λ is not determined. That why Higgs mass is not determined in the SM and today scientists are trying to estimate it. Existence of this Higgs boson can be counted among the definitive predictions of the SM.

3. MASS OF HIGGS BOSON

In this section, we have studied the mass of Higgs boson in four different ways as follows:

a. Considering the recent results about Higgs boson from ATLAS and CMS experiments at the LHC, Torrente-Lujan [18] has presented a phenomenological relation between Higgs mass, top quark mass and mass of Z boson (m_Z) by defining the ratio

$$r_t = \frac{m_Z m_t}{m_H^2} \quad (6)$$

It is found that $r_t^{\exp} = 0.9956 \pm 0.0081$ which is close to 1. Hence, we use the relation

$$m_H^2 \approx m_Z m_t \quad (7)$$

to estimate the mass of Higgs boson. We have used the current values [19]: $m_Z = 91.1876 \pm 0.0021$ GeV and $m_t = 173.5 \pm 0.6 \pm 0.8$ GeV. We get the mass of Higgs boson:

$$m_H = 125.8 \pm 0.2\ \mathrm{GeV}. \quad (8)$$

b. Similarly, there is a phenomenological relation between Higgs mass, top quark mass and mass of W boson (m_W) by defining the ratio [18]

$$r_{Wt} = \frac{m_W + m_t}{2m_H} \quad (9)$$

It is found that $r_{Wt}^{\exp} = 1.0066 \pm 0.0035$ which is close to 1. Hence, we use the relation

$$m_H \approx \frac{m_W + m_t}{2} \quad (10)$$

to estimate the mass of Higgs boson. We have used the current values [19]: $m_W = 80.365 \pm 0.020$ GeV and $m_t = 173.5 \pm 0.6 \pm 0.8$ GeV. We get the mass of Higgs boson:

$$m_H = 126.9 \pm 0.3\ \mathrm{GeV}. \quad (11)$$

c. Civaram and Sinha [20–22] proposed a universal mass formula for elementary particles. Considering weak interactions, the mass of Higgs boson is given by [20]

$$m_H = \frac{1}{2}\left(\frac{\hbar^3}{G_F c}\right)^{1/2}, \quad (12)$$

where $\hbar = h/2\pi$, h is the Planck constant, c is the velocity of light and G_F is the universal Fermi constant and $G_F = 1.16638 \times 10^{-5}\ \mathrm{GeV}^{-2}$. Substituting these values in equation (12), it is found that the mass of Higgs boson is around 125 GeV.

d. Again the mass of Higgs boson can be predicted using another formula [20–22] m_P / α, where the mass of proton m_P = 938.27 MeV/c^2 and the electromagnetic fine structure constant α = 1/137. Using these values we get the mass of Higgs boson as 128.54 GeV.

4. CONCLUSIONS

Higgs boson is a central part of the standard model of electroweak interactions. Because it is responsible for the Higgs mechanism by which all particles acquire mass. But in the SM, the mass of Higgs boson is not specified. From the recent experimental results at the LHC, the mass of this particle is found to be 125.6 ± 0.4 (stat.) ± 0.2 (syst.) GeV (CMS) [23] and $125.5 \pm 0.2\,(\text{stat.})^{+0.5}_{-0.6}\,(\text{syst})$ GeV (ATLAS) [24]. At the Tevatron, the mass of Higgs boson is observed in the range 120–135 GeV [25,26]. In compactified string / M theories [27] it is predicted that there will be a single SM Higgs boson with a mass in the range 105 GeV $\leq m_H \leq$ 129 GeV depending on tan β (the ratio of the Higgs vacuum expectation values in the MSSM). For tan β > 7, the prediction is 122 GeV $\leq m_H \leq$ 129 GeV. The SUGRA grand unification predicts an upper limit on the Higgs boson mass ~ 130 GeV [28–30]. More interestingly, our estimated values of Higgs boson mass are consistent with the recent experimental results as well as with the results obtained in string theory and SUGRA unification. The study of Higgs boson mass is not only interesting but also opens an exciting window for new physics.

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