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The Higgs mechanism and the first experiments at the Large Hadron Collider

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Abstract: The role of the Higgs mechanism in the Standard Model of elementary particles is discussed. The first experiments provided by means of the Large Hadron Collider are discussed as well.

Keywords: Standard Model, Higgs Mechanism, Large Hadron Collider, Higgs Boson

1. The Higgs Mechanism

In the Standard Model (SM) the masses of the W and Z gauge bosons and fermions are generated through the Higgs mechanism [1,2], implemented by the Higgs doublet

$$\Phi(x) = \begin{pmatrix} \varphi^+(x) \\ \varphi^0(x) \end{pmatrix} \quad (1)$$

Here $\phi^+(x)$ is a charged scalar field and $\phi^0(x)$ is a neutral complex scalar field. The transformation of the Higgs doublet under an element

$$g\left(\vec{\theta}(x), \eta(x)\right)$$

of the gauge group is given by $SU(2)_L \times U(1)_Y$

$$\Phi \to \Phi' = U\left(\vec{\theta}(x), \eta(x)\right)\Phi = e^{\frac{i}{2}\vec{\theta}(x)\cdot\vec{\tau} + \frac{i}{2}\eta(x)}\Phi. \quad (2)$$

The symmetry group $SU(2)_L$ is called weak isospin. This group has three generators $I_a\ (a = 1,2,3)$. They satisfy the angular momentum communication relations

$$[I_a, I_b] = i \in_{abc} I_c \quad (3)$$

The symmetry group $U(1)_Y$ is called hypercharge. It is generated by the hypercharge operator Y, which is connected to I_3 and the charge operator Q by the Gell-Mann-Nishijima relation

$$Q = I_3 + \frac{Y}{2}. \quad (4)$$

The covariant derivative must transform as

$$D_\mu \to D'_\mu = U\left(\vec{\theta}(x), \eta(x)\right) D_\mu U^{-1}\left(\vec{\theta}(x), \eta(x)\right). \quad (5)$$

The Higgs part of the SM Lagrangian,

$$L_{Higgs} = \left(D_\mu\Phi\right)^+ \left(D^\mu\Phi\right) - \mu^2\Phi^+\Phi - \lambda\left(\Phi^+\varphi\right)^2, \quad (6)$$

$g\left(\vec{\theta}(x), \eta(x)\right)$. is invariant under a gauge transformation The coefficient λ must be positive, $\lambda > 0$, in order to have a potential

$$V(\Phi) = \mu^2\Phi^+\Phi + \lambda\left(\Phi^+\Phi\right)^2, \quad (7)$$

which is bounded below. The squared mass-like coefficient $\mu^2 < 0$, in order to realize the spontaneous breaking of the symmetry

$$SU(2)_L \times U(1)_Y \to U(1)_Q, \quad (8)$$

where $U(1)_Q$ is the gauge symmetry group of electromagnetic interactions, associated with the conservation of electric charge. Defining

$$v = \sqrt{-\frac{\mu^2}{\lambda}}, \quad (9)$$

the Higgs potential can be written as

$$V(\Phi) = \lambda\left(\Phi^+\Phi - \frac{v^2}{2}\right)^2. \quad (10)$$

It is clear that the potential is minimum for

$$\Phi^+\Phi = \frac{v^2}{2}. \quad (11)$$

In the unitary gauge, the Higgs doublet reads

$$\Phi(x) = \frac{1}{\sqrt{2}}\begin{pmatrix} 0 \\ v+H \end{pmatrix}, \quad (12)$$

and

$$D_\mu(x)\Phi(x) = \left[d_\mu + \frac{i}{2}g\vec{A}_\mu(x)\cdot\vec{\tau} + \frac{i}{2}g'B_\mu(x)\right]\Phi(x). \quad (13)$$

In the unitary gauge, the Higgs Lagrangian in (6) is given by

$$L_{Higgs} = \frac{1}{2}(dH)^2 + \frac{g^2}{4}(v+H)^2 W_\mu^+ W^\mu + \frac{g^2}{8\cos^2\theta_W}(v+H)^2 Z_\mu Z^\mu - \frac{\lambda}{4}\left(H^2 + 2vH\right)^2. \quad (14)$$

Expanding the above, we obtain

$$\begin{aligned} L_{Higgs} = &\frac{1}{2}(dH)^2 - \lambda v^2 H^2 - \lambda v H^3 - \frac{\lambda}{4}H^4 \\ &+ \frac{g^2v^2}{4}W_\mu^+ W^\mu + \frac{g^2v^2}{8\cos^2\theta_W}Z_\mu Z^\mu \\ &+ \frac{g^2v}{2}W_\mu^2 W^\mu H + \frac{g^2 v}{4\cos^2\theta_W}Z_\mu Z^\mu H \\ &+ \frac{g^2}{4}W_\mu^+ W^\mu H^2 + \frac{g^2}{8\cos^2\theta_W}Z_\mu Z^\mu H^2. \end{aligned} \quad (15)$$

The first term on the right-hand is the kinetic term for the Higgs boson. The second term is the mass term for the Higgs boson, from which the mass of the Higgs boson is given by

$$m_H = \sqrt{2\lambda v^2} = \sqrt{-2\mu^2}. \quad (16)$$

Since μ^2 is a negative parameter specifically introduced in the SM, its value is not connected to other quantities already measured. Hence, the SM does not give a prediction for the value of the Higgs mass, which must be determined experimentally. The third and fourth terms on the right-hand side of (15) generate, respectively, trilinear and quadrilinear self-couplings of the Higgs field. The fifth and sixth terms on the right-hand side of (15) are of fundamental importance, because they are mass terms for W and Z gauge bosons. From them, we see that the masses of the W and Z gauge bosons by

$$m_W = \frac{gv}{2} \qquad m_Z = \frac{gv}{2\cos\theta_W}. \quad (17)$$

The widely used parameter ρ, defined by

$$\rho = \frac{m_W^2}{m_W^2\cos^2\theta_W}, \quad (18)$$

has the value

$$\rho = 1, \quad (19)$$

in the SM. Finally, the Higgs lepton Yukawa Lagrangian can be written as

$$L_{H,L} = -\sum_{\alpha=e,\mu,\tau}\frac{y_\alpha^l v}{\sqrt{2}}\bar{l}_\alpha l_\alpha - \sum_{\alpha=e,\mu,\tau}\frac{y_\alpha^l}{\sqrt{2}}\bar{l}_\alpha l_\alpha, \quad (20)$$

where

$$l_\alpha \equiv l_{\alpha L} + l_{\alpha R} \quad (\alpha = e,\mu,\tau). \quad (21)$$

The first term on the right-hand side of (21) is the mass term for the charged leptons, whose masses are given by

$$m_\alpha = \frac{y_\alpha^l v}{\sqrt{2}} \quad (\alpha = e,\mu,\tau). \quad (22)$$

Since the coefficients y_e^l, y_μ^l, y_τ^l are unknown parameters of the SM, the masses of the charged leptons cannot be predicted and must be obtained from experimental measurements. An interesting property following from the second term on the right-hand sides of (20) and (22) is that the trilinear couplings between the charged leptons and the Higgs boson are proportional to the charged lepton masses. Indeed, that term can be written as

$$-\sum_{\alpha=e,\mu,\tau}\frac{m_\alpha}{v}\bar{l}_\alpha l_\alpha H. \quad (23)$$

On the other hand, neutrinos, being massless, do not couple to the Higgs boson.

2. Higgs Boson in the Universe

From the formula (23) is visible that in Higgs boson disintegration on leptons

$$H \to l_\alpha^+ + l_\alpha^- \quad (24)$$

a birth of photons of leptons of various generations to proportionally square of masses of these leptons. At the same time, disintegration of standard neutral leptons occurs in absolutely excellent image, for example, [3]

$$\begin{array}{lll} \rho(770)^0\ m = 775MeV & e^+e^- & 4.72\cdot 10^{-5} \\ & \mu^+\mu & 4.55\cdot 10^{-5} \\ \omega(782)\, m = 782MeV & e^+e^- & 7.28\cdot 10^{-5} \\ & \mu^+\mu^- & 9.00\cdot 10^{-5} \\ \Phi(1020)\, m = 1019MeV & e^+e^- & 2.95\cdot 10^{-4} \\ & \mu^+\mu^- & 2.87\cdot 10^{-4} \\ J/\Psi(1S)\, m = 3096MeV & e^+e^- & 5.94\cdot 10^{-2} \\ & \mu^+\mu^- & 5.93\cdot 10^{-2} \\ \Psi(2S)\, m = 3686MeV & e^+e^- & 7.72\cdot 10^{-3} \\ & \mu^+\mu^- & 7.70\cdot 10^{-3} \\ & \tau^+\tau^- & 3.00\cdot 10^{-3} \\ (2S)\, m = 9460MeV & e^+e^- & 2.48\cdot 10^{-2} \\ & \mu^+\mu^- & 2.48\cdot 10^{-2} \\ & \tau^+\tau^- & 2.60\cdot 10^{-2}. \\ \Upsilon & & \end{array} \tag{25}$$

Apparently, the Higgs boson structure differs from the structure of neutral leptons.

The Higgs mechanism of occurrence of masses and indemnification of divergences is a necessary element of Standard Model. Experimental searches of Higgs bosons represent especial interest. The Higgs boson is not a stable particle and in a combination to the big own mass does not play an essential role in the Universe. On cubic meter in the modern Universe < 0.04 Higgs bosons are necessary. Apparently, be observed it can only on colliders.

3. The First Experiments at the Large Hadron Collider (LHC)

The Atlas and CMS Collaborations at the LHC announced the observation of a narrow resonance with mass near 125 GeV [4,5] with properties consistent with that of the Higgs boson predicted in SM of particle physics. In [6] have been summarized the results from searches for the SM Higgs boson in pp collisions at $\sqrt{s} = 7$ and 8 TeV in the CMS experiment at the LHC and the measurements of mass, cross section, and properties of the narrow resonance recently observed. The five most sensitive decay modes were investigated. These are the following:

$$H \to \gamma\gamma;\ H \to ZZ \to 4l;\ H \to WW \to 2l2v;\ H \to bb.$$

The combined best-fit mass of a new particle is

$$m_X = 125.3 \pm 0.4(stat) \pm 0.5(syst)\ GeV.$$

The CMS collaboration is strongly active in searches for beyond SM Higgs boson. In an simple extension of the SM two models have been tested. The first one is the SM including a fourth generation of fermions (the SM4 model) [7]. The second one includes a fermiophobic (FP) Higgs boson [7,8]. Analyses have been performed in the contest both of the Minimal Supersymmetric Standard Model (MSSM) with two Higgs doublets [9,10,11,12] and of the Next-to-Minimal Supersymmetric Standard Model (nMSSM) with additional scalar field [13].

The searches beyond SM Higgs boson are highlighted and at moment there is no evidence for any excess above backgrounds but a strong constraints are imposed.

SM assumes that the part of parameters is defined not from model, and from experiment. It concerns first of all masses of elementary particles. So measurement on experiment of mass of Higgs boson has made doubtful variety of variants of models out of SM. As to a neutrino problem, we have no advancements to true. In SM Higgs boson does not co-operate with neutrino because of its small mass equal to zero. So in this sense SM correctly defines mass of neutrino with sufficient accuracy. As to oscillations that this process is the result of impossibility of existence of different generations without any difference, in this case on unique parameter - mass of neutrino.

References

[1] S.F. Novaes, “Standard Model: An Introduction”, hep-ph/0001283, 2000.

[2] C. Giunti, C.W. Kim, “Fundamentals of neutrino physics and astrophysics”, Oxford University Press, 2011.

[3] Journal of Physics G Vol. 37m N7A, Particle Data Group, 2010.

[4] G. Aad et al., ATLAS Collaboration, Phys. Lett. B 718 1, 2012.

[5] S. Chatrchyan et al. CMS Collaboration Phys. Lett. B 716 30, 2012.

[6] R. Salerno, CMS Collaboration, hep-ex/1301.3405 v1, 2013.

[7] S. Chatrchyan et al. CMS Collaboration, CMS-PAS-HIG-12-008.

[8] S. Chatrchyan et al. CMS Collaboration, CMS-PAS-HIG-12-022.

[9] S. Chatrchyan et al. CMS Collaboration, JHEP 1203 081, 2012.

[10] S. Chatrchyan et al. CMS Collaboration, CMS-PAS-HIG-12-026.

[11] S. Chatrchyan et al. CMS Collaboration, CMS-PAS-HIG-12-027.

[12] S. Chatrchyan et al. CMS Collaboration, CMS-PAS-HIG-12-033.

[13] S. Chatrchyan et al. CMS Collaboration, CMS-PAS-HIG-12-004.