E2-2009-102

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HIGGS MECHANISM IN THE STANDARD MODEL AND POSSIBILITY OF ITS RIGHT PHYSICAL REALIZATION

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Бештоев Х. М. E2-2009-102

Хиггсовский механизм в стандартной модели и возможность
его прямой физической реализации

Целью работы является получение ответа на вопрос: возможна ли прямая физическая реализация хиггсовского механизма? Показано, что этот механизм не может иметь прямой физической реализации, так как условия для этого не выполняются. Это означает, что если на Большом адронном коллайдере в ЦЕРН будет обнаружена скалярная частица, то она не будет являться хиггсовской частицей.

Работа выполнена в Лаборатории физики высоких энергий им. В. И. Векслера и А. М. Балдина ОИЯИ.

Сообщение Объединенного института ядерных исследований. Дубна, 2009

Beshtoev Kh. M. E2-2009-102

Higgs Mechanism in the Standard Model and Possibility
of Its Right Physical Realization

The aim of this work is to answer the question: Is the direct physical realization of Higgs mechanism in the Standard Model possible? It is shown that this mechanism cannot have a direct physical realization since the condition for this realization is not fulfilled. It means that if at the Large Hadron Collider (LHC) at CERN a scalar particle is detected, it does not mean that it is a Higgs particle.

The investigation has been performed at the Veksler and Baldin Laboratory of High Energy Physics, JINR.

Communication of the Joint Institute for Nuclear Research. Dubna, 2009

1. INTRODUCTION

At present the generally accepted point of view is that the standard electroweak model [1] has full confirmation and now remains only to detect a Higgs scalar particle.

The Lagrangian of the standard electroweak model [1] besides the quark and lepton interactions via W, Z bosons, also includes Higgs sector which is used to generate lepton, quark and W-, Z- boson masses. This mechanism provides the renormalizability of this model [2]. At present three families of quarks and leptons as well as W, Z bosons have been detected and their masses (with the exception of neutrinos) have been measured [3]. It is necessary to remark that the attempt to register the scalar Higgs boson was not successful. In connection with the commission of the new collider at CERN, where this scalar particle can be registered, the problem of origin of elementary particle masses becomes important. The strong and electromagnetic interactions can generate the masses of elementary particles since they are left-right symmetrical. In contrast to these interactions the weak interactions are left-side interactions (i. e., chiral invariant ones) but not the left-right symmetrical ones. As a result of this, the Higgs mechanism is used to generate masses in the standard electroweak model.

In principle masses of elementary particles can be generated in an interaction in analogy with the chromodynamics. This approach was applied in the Technicolor model [4, 5].

At present it is a very important question whether the scalar particle (if discovered) is a Higgs particle or it has another origin.

This work is devoted to the discussion of a possible direct physical realization of the Higgs mechanism where the Higgs scalar particle appears.

2. HIGGS MECHANISM IN THE STANDARD MODEL AND A POSSIBILITY OF ITS DIRECT PHYSICAL REALIZATION

2.1. Higgs Mechanism in the Standard Model. A doublet of scalar Higgs fields

$$\Phi = \begin{pmatrix} \Phi^{(+)} \\ \Phi^{(0)} \end{pmatrix}, \tag{1}$$

with hypercharge equal to the unity, is introduced. It is assumed that this doublet interacts with the vector and fermion fields in such a way that local gauge invariance is not broken. To the Lagrangian of the electroweak interactions we add the Higgs potential $V(\Phi^+,\,\Phi)$

$$V(\Phi^+,\Phi) = k(\Phi^+,\Phi)^2 - \mu^2(\Phi^+,\Phi) \tag{2}$$

(k, μ^2 are positive constants), which leads to vacuum degeneracy and to a non-vanishing vacuum expectation value $\langle\Phi^0\rangle$ of the field Φ^0:

$$\langle\Phi^0\rangle = \sqrt{\frac{\mu^2}{2k}} = \frac{\nu}{\sqrt{2}}, \quad \nu = \sqrt{\frac{\mu^2}{k}}. \tag{3}$$

This means that (fixing the vacuum state) we can generate a mass term of the fields of the intermediate bosons, fermions, and Higgs boson.

In the unitary gauge by using (3) we can rewrite $V(\Phi)$ in the following form ($\nu^2 = \frac{\mu^2}{k}$):

$$\begin{aligned} V(\Phi) = -\frac{\mu^4}{2}(\nu+\Phi^o)^2 + \frac{k}{4}(\nu+\Phi^0)^4 = \\ = -\frac{\mu^4}{4k} + \mu^2(\Phi^0)^2 + \ldots = -\frac{\mu^4}{4k} + \frac{m^2_\Phi}{2}(\Phi^0)^2 + \ldots, \end{aligned} \tag{4}$$

hence, we see that Higgs boson Φ^0 has mass $m^2_{\Phi^0} = 2\mu^2$.

The covariant derivative for Higgs fields is

$$D_\alpha\Phi = (\partial_\alpha - ig\frac{\tau^i A^i_\alpha}{2} - i\frac{g'}{2}B_\alpha)\Phi. \tag{5}$$

The kinetic energy term of Higgs bosons (in the unitary gauge) has the following form:

$$(D^\alpha\Phi)^+ D_\alpha\Phi = M^2_W W^{\alpha+}W^-_\alpha + \frac{M^2_Z}{2}Z^\alpha Z_\alpha + \ldots, \tag{6}$$

where $W^\pm_\alpha = (A^1_\alpha \pm A^2_\alpha)/\sqrt{2}$, and their masses are as follows:

$$M^2_W = g^2\frac{\nu^2}{4}, \quad M^2_Z = (g^2 + g'^2)\frac{\nu^2}{4}.$$

The quark masses are obtained by using a Lagrangian of the Yukawa type which is $SU(2)_L \times U(1)$ invariant:

$$\mathcal{L}_1 = -\sum_{i;q=d,s,b}^{3} \bar{\Psi}_{iL} M^1_{iq} q_R \bar{\Phi} + H.C., \tag{7}$$

$$\mathcal{L}_2 = -\sum_{i;q=u,c,t}^{3} \bar{\Psi}_{iL} M^2_{iq} q_R \bar{\Phi} + H.C.,$$

where M^1, M^2 — complex 3×3 matrix, and

$$\bar{\Phi} = i\tau_2 \Phi^* = \begin{pmatrix} \Phi^{o*} \\ -\Phi^{+*} \end{pmatrix} \tag{8}$$

is a doublet of Higgs fields with hypercharge $Y = -1$.

Taking into account (3) and using the gauge invariance of the Lagrangian (4), (8), we can choose (in the unitary gauge)

$$\Phi(x) = \begin{pmatrix} 0 \\ \dfrac{\nu + \Phi^0(x)}{\sqrt{2}} \end{pmatrix}, \quad \bar{\Phi}(x) = \begin{pmatrix} \dfrac{\nu + \Phi^0(x)}{\sqrt{2}} \\ 0 \end{pmatrix}, \tag{9}$$

where $\Phi^0(x)$ is the neutral scalar Higgs field.

Substituting (9) in (7) for the quark masses we obtain the expressions

$$\begin{aligned} \mathcal{L}_1 &= -\bar{p}_L M'_1 p_R + H.C., \\ \mathcal{L}_2 &= -\bar{n}_L M'_2 n_R + H.C., \end{aligned} \tag{10}$$

where

$$p_{L,R} = \begin{pmatrix} u_{L,R} \\ c_{L,R} \\ t_{L,R} \end{pmatrix}, \quad n_{L,R} = \begin{pmatrix} d_{L,R} \\ s_{L,R} \\ b_{L,R} \end{pmatrix}.$$

Thus, the elements M'_1, M'_2 of the quark mass matrix are equal to the constants of the quark–Higgs-boson Yukawa coupling up to the factor ν.

2.2. Remarks to the Higgs Mechanism in the Electroweak Model and a Possibility of Its Direct Physical Realization. We know that quarks, leptons and vector bosons have the same masses in every point of the Universe. Then Higgs fields must fill the Universe and since the masses are real masses, then the Higgs fields must also be real (here we have the analogy with the superconductivity). If the Higgs field is real, then the energy density of this field is $\rho_{\text{Higgs}} \sim 2 \times 10^{49}$ GeV/cm^3 [6, 7] (see also references in [7]). It is a huge value. The measured energy density in the Universe is $\rho_{\text{Univ}} \sim 10^{-4}$ GeV/cm^3. Then the relation of the energy density of the Higgs fields to the measured energy value is

$$\rho_{\text{Higgs}} / \rho_{\text{Univ}} \sim 10^{53}. \tag{11}$$

It is interesting to remark that at this density of the energy the condition to create a black hole is fulfilled for the volume with radius

$$R \geqslant \sqrt{\frac{3}{4\pi \rho_{\text{Higgs}} G_N}} \approx 9.5 \text{ cm}, \tag{12}$$

where G_N is a gravitational constant (i.e., the Universe will be filled with the black holes). It is clear that the Higgs mechanism has big problems for its realization.

The other problem: Is there a possibility of its direct physical realization? The Higgs potential which is added to the Lagrangian of electroweak interactions is given by expression (2). The Lagrangian of the Higgs field is

$$L(\Phi) = \frac{1}{2}\partial_\mu \Phi^+ \partial^\mu \Phi + V(\Phi^+, \Phi). \tag{13}$$

Before going on our discussion let us consider mechanisms of generation of particle effective masses.

1. Usually it is supposed that, when we ascribe a charge to a particle, its mass changes. We cannot compute this changing but by using the renormalization group we can compute the changing of this mass dependence of the momentum transfer.

2. When the confined (bound) states of particles are formed then the particle effective masses are changed. This changing of the particle effective masses has a local character.

3. There are other mechanisms of the effective masses changing, for example: the change of the effective mass of electrons in metal [8], or correlation of electrons in the superconductive state [9] (see also Wikipedia: Superconductivity). In these cases the changing of the electron effective mass (or correlation of electrons) has a nonlocal character and it changes in all this medium.

The main problem is: Which type of the mass generation does the Higgs mechanism belong to?

It is clear that quarks, leptons and gauge bosons must have the same masses in every point of the Universe. If their masses are generated as a result of their interactions with Higgs field, then in order to get masses, the sources of the Higgs field must be distributed in all the Universe uniformly. And in every point of the Universe without the Higgs field the particle masses will be equal to zero (i.e., they will have zero masses).

The problem is: How and in what way does the Higgs field fill the Universe? This problem is just a physical problem. Then the sources of the Higgs field must be distributed continuously or in the form of lattices. Without further discussion it is obvious that these distributions of the Higgs field in the Universe are not realistic. Especially if to take into account what enormous vacuum energy density appears in this mechanism, we have to come to a conclusion that this mechanism is physically inadmissible in spite of the fact that this mechanism provides the electroweak model to be renormalized.

As we have seen above, the Higgs mechanism cannot be realized physically and then the nature of this scalar particle will remain unclear. It is necessary to remark that if at the new collider at CERN the scalar particle is detected it will not mean that it is just a Higgs particle. Besides, as it is stressed in [10], the Higgs mechanism contains a contradiction. There are some arguments that mass sources can be a mechanism which is analogous to the strong interactions [11], i.e., masses are generated via interactions between the quark and lepton subparticles, then the problem of singularity of the theory does not arise (i.e., it will be solved in analogy with chromodynamics).

3. CONCLUSION

It is well known that the Higgs mechanism in the electroweak model is perfect from the mathematical point of view and it leads to renormalizability of this model. It allows one to make computations of higher orders of the perturbation theory.

Is the direct physical realization of this mechanism possible? It is shown that this mechanism cannot have direct physical realization since the condition for this realization is not fulfilled. It means that if at the new collider at CERN a scalar particle is detected it does not mean that it is just a Higgs particle.

The central problem of the weak interactions is

- Why are these interactions left-right nonsymmetric (i.e., why at interactions via W bosons the right components of fermions do not participate). The electroweak model is only a model to compute weak and electromagnetic processes but it does not give an answer to the question above.

The next question is

- What is a dynamical source of the particle (i.e., quarks and leptons) masses? No doubt, that finding (discovering) schemes to compute weak processes was a very important problem. But also a very important problem is to understand the basis of the weak interactions.

It is necessary to stress that there is another problem. It is well known that in the theories with left-right symmetric interactions we can use renormalization groups for computation of the couple constants in dependence on square momenta transfer.

- Is it correct using the renormalization group in the case when the theory is not left-right symmetrical as it takes place in the weak interactions [12]?

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Received on July 3, 2009.

Корректор *Т. Е. Попеко*

Подписано в печать 3.08.2009.
Формат 60 × 90/16. Бумага офсетная. Печать офсетная.
Усл. печ. л. 0,68. Уч.-изд. л. 0,94. Тираж 415 экз. Заказ № 56675.

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