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# « DARK MATTER CANDIDATES IN STANDARD MODEL EXTENSIONS»

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## Introduction

Practically all modern elementary particles physics is currently described by the Standard Model (SM) [1]. It's a theoretical construction that includes all known interactions at the present moment, except for the gravitational one. Though it's a mathematical representation of the physical processes of the microworld, however, it leaves unsolved a large number of questions (such as mass hierarchies problem, the mass availability of neutrinos, etc.). There are many indications that SM can be a low-energy limit of some more general theory, just as Galileo's principle of relativity is a special case of Einstein's relativity principle inside bounds of Newtonian mechanics. That's why the issue of the Standard Model extending to a theory that is capable to describe microworld processes more fully and in detail as well as resolve the contradictions existing within the SM theory is extremely acute at the moment.

For the "new physics" searching outside the boundaries of the SM, there are basically two possible ways. One of them is studying of processes with the probable creation of hypothetical new particles, the other is or searching for manifestations of the alleged "new physics" in already known interactions [2]. It should, however, be borne in mind that the experimental confirmation of the theories using the first approach may not be possible at the present time due to the probable presence of the particles of the "new physics" only at higher energies not yet achieved with accelerators.

This abstract is devoted to one of many hypothetical extensions of the Standard Model, the "Small Higgs" theory, in which the Higgs boson is not a fundamental, but a constituent particle, which leads to the elimination of some theoretical problems of the Standard Model.

This abstract is devoted to some of the many hypothetical extensions of the Standard Model, which leads to the elimination of some theoretical problems of the Standard Model, and also provides opportunities for solving one of the most pressing problems of cosmology - the problem of dark matter searching.

## 1. Standard Model contradictions

The Standard Model is a theory of strong and electroweak interactions based on the SU(3) xSU(2) xU(1) gauge group. The described interactions are gauge so they are carried out by exchange of calibration particles: photons in the case of electromagnetic interactions, gluons in strong interactions and W and Z in the case of weak interactions.

In contrast to massless photons and gluons, W and Z are massive particles (with a mass of the order of 100 GeV). The presence of a mass in these particles is a consequence of the symmetry breaking with respect to the SU(2) xU(1) group. Such a violation in the SM formalism can be a consequence of the existence of some scalar field. The vacuum value of this field leads to the presence of a certain direction in the space of generators of the group SU(2) xU(1). Then the fact of the presence of a mass for elementary particles (leptons, gauge ozone, etc.) is a consequence of the interaction of the particles themselves with the given scalar field. The quantum of this field is Higgs boson.

However, the Higgs boson explains only the fact of electroweak symmetry breaking, but not it's mechanism. This theory does not explain why the potential of the Higgs field is unstable at zero. Therefore, the electroweak sector is apparently an interesting area for the search for "New Physics" that goes beyond the SM.

## 2.“Little Higgs” model

### 2.1 Main idea

An analysis of the experimental data makes possible to do an unambiguous conclusion about the fact of electroweak symmetry violation but an understanding of the mechanism of this violation has not yet been formed.

If one assumes that there are no new particles with masses smaller than the masses of the electroweak sector then the "new physics" in the electroweak sector is realised by multidimensional operators suppressed by the energy scales of the "new physics" ($\Lambda$~TeV). These operators can be classified according to the symmetries that they violate. For example, it can be violation of CP - symmetry and symmetry of aromas. Thus, these operators impose strict restrictions on the preservation of symmetries on the investigated scale ~ 1 TeV and SM extensions should not violate this boundary.

For understanding of the Higgs-boson mass stabilising possibility without violating these limitations, it is necessary to consider the instability of the Higgs mass reasons.

Let's consider the main radiative corrections to the mass of the Higgs boson: one-loop diagrams with t-quarks (Fig. 1a), SU(2) gauge bosons (Fig. 1b) and Higgs loops (Fig. 1c)

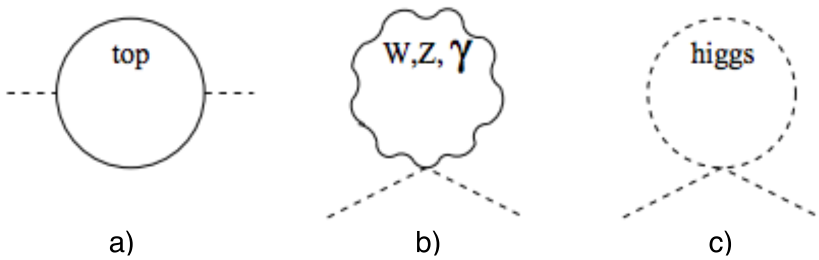


Fig. 1. Basic radiative corrections to the mass of the Higgs boson: a) single-loop diagrams with t-quarks b) single-loop diagrams with virtual Z and W bosons c) single-loop diagrams with Higgs bosons.

The contribution of the one-loop diagram is proportional to the square of the coupling constant [3], and this in turn is proportional to the mass of the virtual particle being formed. Since the mass of the t-quark significantly exceeds the masses of the remaining quarks (170 GeV is significantly higher than the next b-quark mass of the order of 4 GeV), all other contributions can be neglected. The remaining possible diagrams will give significantly lower contributions due to the smallness of their coupling constants in comparison with those considered.

If we assume that the SM remains true at energy scales of $\Lambda \sim 10$ TeV then the considered diagrams give a definite contribution to the mass of the Higgs boson (Table 1).

| Diagram | Operator | contribution to $(m_H)^2$ |
|---|---|---|
| t-quark loop | $-\frac{3}{8\pi^2}\lambda_t^2\Lambda^2$ | ~(2 ТэВ)$^2$ |
| SU(2) - bosons loop | $\frac{9}{64\pi^2}g^2\Lambda^2$ | ~(700 ТэВ)$^2$ |
| Higgs-bosons loop | $\frac{1}{16\pi^2}\lambda_t^2\Lambda^2$ | ~(500 ТэВ)$^2$ |

Table. 1. The contribution of the diagrams to the squared mass of the Higgs boson.

For the Higgs boson's mass remaining at the electroweak scale, the energy scale of cutting should be:

1) for a loop diagram with a top quark: $\Lambda \leq 2$ TeV;

2) for the loop diagram with gauge bosons: $\Lambda \leq 5$ TeV;

3) for the loop diagram with the Higgs-loop: $\Lambda \leq 10$ TeV.

Consequently, at the scale of energies of the order of 2 TeV one can expect the manifestation of a "new physics" associated with truncation of the divergent t-quark loop. It means that there have to exist new particles generating new loop diagrams that reduce the contribution from loops with the t-quark with the mass is equal to ~ 2 TeV and related by some symmetry to the t-quark.

Similarly at a scale of energies of the order of 5 TeV there must be new particles which are existing with a similar type of symmetry with gauge bosons of the Standard Model, and at energies of the order of 10 TeV there must be new particles that cut the divergent loop with the Higgs boson.

One of the SM extensions solving this problem is the Little Higgs model,where the Higgs boson is a pseudo-Nambu-Goldstone boson. In this case global symmetries lead to a shift of the Higgs fields and as a result the Higgs mass does not contain single-loop divergences.

## 2.2 Nambu-Goldstone bosons

Nambu-Goldstone bosons are particles that arise during spontaneous global symmetry breaking [4]. The simplest example is the consideration of the U(1) group.

Suppose that we have a scalar field φ with a potential V (φ*φ). The U(1) group includes the invariance of the potential with respect to the transformations:

$$\varphi \rightarrow \varphi \cdot e^{i\alpha}. \tag{1}$$

Нахождение минимума потенциала находится не в нуле, а в некоторой точке f>0 (рис. 2) приводит к спонтанному нарушению U(1) симметрии.
Because of the minimum of the potential is not equal to zero but some point f>0 (Fig. 2) U(1) symmetry spontaneous breaks.

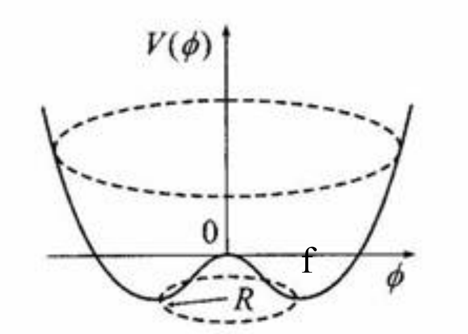


Fig. 2. Potential of spontaneous symmetry breaking of the U(1) group.

Будем считать, что отклонения поля от минимума малы. В таком случае, поле вблизи вакуумного значения можно разложить в ряд:
Let's assume that the deviations of the field from the minimum are small. In this case, the field near the vacuum value can be expanded in a series:

$$\phi(x) = \frac{1}{\sqrt{2}}(f + r(x)) \cdot \exp\left[\frac{i\theta(x)}{f}\right], \tag{2}$$

where r(x) is a massive radial mode, and θ (x) is a Nambu-Goldstone boson (NGB).

Because of the radial field r(x) must be invariant with respect to U(1) transformations, it can be shown that θ undergoes a shift to satisfy this condition: (3)

θ→θ+α, α<<θ.

It is important to note that the resulting effective Lagrangian must not contain the mass term of the field θ (x). The general form of the NGB Lagrangian is:

$$L = const + f^2 \left|\partial_\mu \phi\right|^2 + O\left(\partial^4\right). \tag{4}$$

### 2.3. Nambu-Goldstone bosons in non-abelian case

In the case of a spontaneous violation of a non-abelian symmetry group each disturbed generator leads to the formation of one Nambu-Goldstone boson.

For example one can consider the case of violation of SU(N) -> SU (N-1) due to the vacuum mean field φ. The number of generators of the group decreases from $(N)^2-1$ to $(N-1)^2-1$ so the number of disturbed generators is:

$$(N)^2-1-((N-1)^2-1) = 2N-1. \tag{5}$$

It is convenient to use the following form of record:

$$\phi = \exp\left[\frac{i}{f}\left(\begin{array}{ccc|c} \ddots & & \iddots & \pi_1 \\ & 0 & & \vdots \\ \iddots & & \ddots & \pi_{N-1} \\ \hline \pi_1^+ & \cdots & \pi_{N-1}^+ & \pi_0/\sqrt{2} \end{array}\right)\right]\begin{pmatrix} 0 \\ \vdots \\ f \end{pmatrix} = e^{\frac{i\pi}{f}}\phi_0, \tag{6}$$

The $\pi_0$ field is real and the remaining ones are complex.

$$\phi = \exp\left[\frac{i}{f}\begin{pmatrix} 0 & h \\ h^+ & 0 \end{pmatrix}\right]\begin{pmatrix} 0 \\ f \end{pmatrix} = \begin{pmatrix} 0 \\ f \end{pmatrix} + i\begin{pmatrix} 0 \\ h \end{pmatrix} - \frac{1}{2f}\begin{pmatrix} 0 \\ h^+h \end{pmatrix} \tag{8}$$