Higgs Physics and possible extentions of the Standard Model

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Abstract: In this work we study the possibility that the recently discovered particle at the Large Hadron Collider (LHC) with similar properties to the ones of the Standard Model (SM) Higgs boson and a mass around $125\,GeV$ could be related to the dilaton, the Goldstone boson that appears when scale invariance is spontaneously broken. We will focus on the Coleman-Weinberg (CW) mechanism, in which the mass term from the Higgs potential is turned off, thus obtaining a theory classically invariant under dilatations. It is due to quantum effects that the spontaneous breaking of this symmetry occurs. We will study the viability of this scenario treating with the CW potential and doing numerical testing as well as proposing possible modifications of the SM.

I. INTRODUCTION

The Higgs boson is a fundamental piece in the SM, as it allows to give masses to both gauge bosons and fermions by means of the Higgs mechanism. Although in 2012 it was discovered a Higgs-like resonance at 125 GeV, we still do not have enough evidence to identify it as the predicted SM Higgs particle. Instead, it could correspond to the Goldstone boson associated to the spontaneous breaking of scale invariance, the dilaton.

We say that there is a spontaneous symmetry breaking when the lagrangian of a system presents some symmetries that we do not find in the state of minimal energy. This situation gives rise to the existence of different vacua, among which the vacuum of the theory is chosen arbitrarily. According to the Goldstone theorem, when this occurs there emerge as many Goldstone bosons as generators of the broken symmetry.

In the case of the Higgs field, the lagrangian without including the gauge fields is [4]

$$\mathcal{L} = (\partial_\mu \phi)^\dagger (\partial^\mu \phi) - V(\phi^\dagger, \phi), \tag{1}$$

with a potential

$$V(\phi^\dagger, \phi) = \frac{1}{2}\mu^2 \phi^\dagger \phi + \frac{1}{4}\lambda(\phi^\dagger \phi)^2 = \frac{1}{2}\mu^2 |\phi|^2 + \frac{1}{4}\lambda |\phi|^4, \tag{2}$$

being μ the mass of the particle and λ the dimensionless quartic coupling constant, which is positive to ensure an absolute minimum in the lagrangian. This potential is symmetric under rotations in the ϕ internal space. This corresponds to the SU(2) symmetry (unitary transformations with 2×2 complex matrices). Here ϕ is a complex doublet scalar field whose components are a charged field ϕ^+ and a neutral field ϕ^0:

$$\phi = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix} = \begin{pmatrix} \phi_1 + i\phi_2 \\ \sigma + i\chi \end{pmatrix}. \tag{3}$$

Contrary to the case $\mu^2 > 0$, in which the minimization condition of the potential leads to $|\phi|^2 = 0$, when $\mu^2 < 0$, ϕ acquires a non-zero vacuum expectation value (VEV), $v = \langle 0|\phi|0\rangle$, and the SU(2) symmetry is spontaneously broken. As a consequence, there emerge three massless Goldstone bosons and a massive particle, the Higgs boson, whose mass is given by $M_H = \sqrt{2\lambda v^2}$. To determine these masses we need to look at small perturbations around the minimum. To get acquainted with this procedure, it is useful to consider an even simpler case of the Higgs effective potential. If the complex doublet is replaced by a real scalar field, eq. (1) becomes

$$\mathcal{L} = \frac{1}{2}\partial_\mu \phi \partial^\mu \phi - \frac{1}{2}\mu^2 \phi^2 - \frac{1}{4}\lambda \phi^4. \tag{4}$$

The potential possesses a symmetry $\phi \to -\phi$. In this case, imposing $\frac{dV}{d\phi} = 0$ at $\phi = v$, we obtain $v^2 = \frac{-\mu^2}{\lambda}$. If we introduce a field $\xi = \phi - v$ centered at the vacuum and we replace $\phi = v + \xi$ and $\mu^2 = -\lambda v^2$ at eq. (4), we obtain

$$\mathcal{L} = \frac{1}{2}\partial_\mu \xi \partial^\mu \xi - \lambda v^2 \xi^2 - \lambda v \xi^3 - \frac{1}{4}\lambda \xi^4 + \frac{1}{4}\lambda v^4. \tag{5}$$

After perturbing around the true vacuum, it turns out that $V(\xi) \neq V(-\xi)$, and a massive ξ particle of mass $m_\xi^2 = \frac{d^2V}{d\xi^2} = 2\lambda v^2$ appears due to the broken symmetry.

So far this is the conventional treatment. In this work, however, we are interested in considering a different approach to induce the spontaneous symmetry breaking. We will consider that the Higgs mechanism is a quantum phenomenon. The main idea, proposed in 1973 by Coleman and Weinberg, is that, instead of having a negative mass term giving rise to spontaneous symmetry braking, the responsible for the latter are radiative corrections to the quartic term [1]. The CW mechanism consists in setting $\mu = 0$, thus obtaining a scale invariant model at the classical level. The modifications that the perturbation theory provides to a purely $\lambda|\phi|^4$ potential give place to the CW potential, which corresponds to the quantum corrections. This potential may present non trivial minima and in this case we do refer to the spontaneous breaking of scale invariance (i.e. dilatation symmetry). The Higgs boson would then correspond to the Goldstone boson of spontaneous breaking of scale invariance.

II. SCALE INVARIANCE

Within the CW approach the scale invariance is broken due to the introduction of a regulator at quantum level. For this reason a brief description of this invariance is required. This symmetry of spacetime appears when the coupling constant is dimensionless. A scale invariant theory remains the same when the energy or length scales are changed. We caracterize scale transformations (or dilatations) as

$$x^\mu \to x'^\mu = e^\alpha x^\mu, \tag{6}$$

being α a real number. In turn, if Δ is the scaling dimension of an operator $\mathcal{O}$, it transforms as

$$\mathcal{O}(x) \to \mathcal{O}'(x) = e^{\alpha\Delta}\mathcal{O}(e^\alpha x). \tag{7}$$

If the lagrangian is written in terms of a basis of operators and its respective coupling constants, $g_i(M)$, being M the renormalization scale, one haves

$$\mathcal{L} = \sum_i g_i(M)\mathcal{O}_i(x). \tag{8}$$

It can be shown [3] by application of the Noether theorem that in this case the conserved current D^μ (dilatation current) satisfies

$$\partial_\mu D^\mu = \sum_i g_i(M)(\Delta_i - 4)\mathcal{O}_i(x) + \sum_i \beta_i(g)\frac{\partial \mathcal{L}}{\partial g_i}. \tag{9}$$

Here we have introduced the so called beta function $\beta(g)$ of the coupling constant g, defined as

$$\beta(g) = \frac{\partial g(M)}{\partial \ln M}. \tag{10}$$

Therefore, in order to have scale invariance ($\partial_\mu D^\mu = 0$), it is necessary that $\Delta_i = 4$ and $\beta_i = 0$.

III. COLEMAN-WEINBERG POTENTIAL

He have seen that in the SM approach the Higgs potential (eq. (2)) has a mass term and is therefore not invariant under dilatations, as it has a characteristic scale. Following the steps of Coleman and Weinberg, we now start from a theory without a defined mass scale, $\lambda|\phi|^4$, that is classically scale invariant. At the quantum level the unique corrections one has are logarithms, and since their argument has to be dimensionless, a mass scale M^2 needs to appear, also breaking the scale invariance of the theory, but only logarithmically. We then obtain a dynamically generated potential, known as the CW potential, which in the one-loop approximation takes the form [1]

$$V(\phi) = \frac{\lambda}{4}|\phi|^4 + \frac{1}{8}\beta|\phi|^4\left[\ln\left(\frac{|\phi|^2}{M^2}\right) - a\right], \tag{11}$$

where β is the beta function of the Higgs quartic coupling, λ, calculated in the one-loop approximation, while a is a constant which can be absorbed in a scale shift of the M^2 scale, so it will not be of more relevance. M is the mass that has to be introduced for dimensional reasons when ultraviolet divergences are regulated.

Our first objective is to minimize this potential. In case there was a minimum different from $|\phi|^2 = 0$, the global invariance of the SM would be broken and three Goldstone bosons of mass zero would be produced. In the conventional Higgs mechanism we already have this scenario, but with any mechanism in which the field ϕ has a VEV different from zero we come across the same situation. Here the VEV would be obtained in an autogenerated way. Since our initial theory presents scale invariance, which is spontaneously broken, there must be a fourth Goldstone boson, different from the others, with a mass probably zero or very small. The Higgs boson could be then interpreted as the dilaton of the spontaneous breaking of this symmetry, but its mass is not zero because $\beta \neq 0$ and according to (9) the dilatation current is not exactly conserved.

To find the minimum we start calculating its derivative:

$$\frac{dV(\phi)}{d|\phi|^2} = \frac{\lambda}{2}|\phi|^2 + \frac{1}{8}\beta\left[2|\phi|^2\ln\left(\frac{|\phi|^2}{M^2}\right) + |\phi|^2(1-2a)\right].$$

Imposing $\left(\frac{dV(\phi)}{d|\phi|^2}\right)_{|\phi|^2=v^2} = 0$, we obtain, on the one hand, the trivial solution $|\phi|^2 = v^2 = 0$ which already existed at the classical level, although now it turns out to be a maximum instead of a minimum. However, the relevant solution is given by

$$\frac{\lambda}{2} + \frac{1}{8}\beta\left[2\ln\left(\frac{v^2}{M^2}\right) + (1-2a)\right] = 0, \tag{12}$$

from which

$$v^2 = M^2 e^{-\frac{2\lambda}{\beta} + a - \frac{1}{2}}. \tag{13}$$

Since $\phi = \begin{pmatrix}\phi_1 + i\phi_2 \\ \sigma + i\chi\end{pmatrix}$, we have that $|\phi|^2 = \phi^\dagger\phi = \begin{pmatrix}\phi_1 - i\phi_2 & \sigma - i\chi\end{pmatrix}\begin{pmatrix}\phi_1 + i\phi_2 \\ \sigma + i\chi\end{pmatrix} = \phi_1^2 + \phi_2^2 + \sigma^2 + \chi^2 = v^2$, which can be achieved for example setting $\sigma = v$ and $\phi_1 = \phi_2 = \chi = 0$. This will be our vacuum choice. Therefore, if we redefine the σ field as $v + \sigma$, we have that

$$\phi = \begin{pmatrix}\phi_1 + i\phi_2 \\ v + \sigma + i\chi\end{pmatrix}. \tag{14}$$

With this redefinition, small variations of σ are small variations around the real vacuum of the theory, instead of $|\phi|^2 = 0$, which is an unstable point.

The last step is to find the small oscillations around this minimum. In our original potential there was no quadratic term, but the correction we have made generates automatically quadratic terms. This will enable us to determine the masses of all four fields. Indeed,

$$|\phi|^2 = \phi_1^2+\phi_2^2+(v+\sigma)^2+\chi^2 = \phi_1^2+\phi_2^2+v^2+\sigma^2+2v\sigma+\chi^2.$$

Squaring it and just keeping second order terms (we do not need further contributions), we have

$$|\phi|^4 = 2v^2\phi_1^2 + 2v^2\phi_2^2 + v^4 + 6v^2\sigma^2 + 4v^3\sigma + 2v^2\chi^2 + \cdots .$$

On the other hand,

$$\ln\left(\frac{|\phi|^2}{M^2}\right) = \ln\left(\frac{v^2}{M^2}\right) + \ln\left(1+\frac{\phi_1^2+\phi_2^2+\sigma^2+2v\sigma+\chi^2}{v^2}\right).$$

Expanding the logarithm to second order in the fields, we have

$$\ln\left(\frac{|\phi|^2}{M^2}\right) = \ln\left(\frac{v^2}{M^2}\right) + \frac{\phi_1^2+\phi_2^2-\sigma^2+2v\sigma+\chi^2}{v^2}+\cdots .$$

The expansion of the CW potential to second order in the fields is therefore

$$V(\phi) = \left[\frac{\lambda}{4} - \frac{a\beta}{8} + \frac{1}{8}\beta\ln\left(\frac{v^2}{M^2}\right) + \right.$$
$$\left. +\frac{1}{8}\beta\left(\frac{\phi_1^2+\phi_2^2-\sigma^2+2v\sigma+\chi^2}{v^2}\right)\right]|\phi|^4+\cdots .$$

Notice that, from eq. (13), $\frac{\lambda}{4}-\frac{a\beta}{8}+\frac{1}{8}\beta\ln\left(\frac{v^2}{M^2}\right) = -\frac{\beta}{16}$. Combining this relation with the expressions derived above, one finally finds

$$V(\phi) = -\frac{\beta}{16}v^4 + \frac{1}{2}\beta v^2\sigma^2 + \cdots . \qquad (15)$$

The second derivative of the field at the minimum directly gives us the masses of the four fields: $m_{\phi_1}^2 = \frac{\partial^2 V(\phi)}{\partial\phi_1^2} = 0$, $m_{\phi_2}^2 = \frac{\partial^2 V(\phi)}{\partial\phi_2^2} = 0$, $m_\chi^2 = \frac{\partial^2 V(\phi)}{\partial\chi^2} = 0$ and $m_\sigma^2 = \frac{\partial^2 V(\phi)}{\partial\sigma^2} = \beta v^2$.

With the implemented shift the SU(2) symmetry is broken and we thus obtain three massless particles (Goldstone bosons), and a particle of mass $m_\sigma = \sqrt{\beta}v$. If the numerology worked in a way such that this was compatible with the experimentally measured physics, the Higgs could be interpreted as a dilaton, the particle responsible for the spontaneous breaking of the scale symmetry, and the proof is that its mass is proportional to the regulator mass, M, that breaks scale invariance, even if only logarithmically. Indeed, if $\beta = 0$, $m_\sigma = 0$, in fulfillment of the conclusions of section II.

Numerically, knowing that the observed Higgs mass is $M_H = 125\,GeV$ and the VEV of the Higgs field is $v = 246\,GeV$ (known as the electroweak scale), we can compute β:

$$\beta = \frac{M_H^2}{v^2} = \frac{(125\ GeV)^2}{(246\,GeV)^2} \approx 0.258. \qquad (16)$$

This is the value we want for β, but in the SM its value is $\beta = -0.0204$.

IV. QUARTIC COUPLING EQUATION

We will now focus on the corrections of the CW potential including the electroweak part. Up to now we have not taken into account the coupling of the gauge bosons of the SM nor the Yukawa coupling. The contribution of scalars, gauge bosons and fermions to the beta function of the λ coupling is given by the quartic coupling equation [2]:

$$\beta_\lambda^{(1)} = \frac{1}{16\pi^2}\left(24\lambda^2 - 6y^4 + \frac{3}{4}g_2^4 + \frac{3}{8}(g_2^2+g_1^2)^2 \right.$$
$$\left. + (-9g_2^2 - 3g_1^2 + 12y^2)\lambda\right), \qquad (17)$$

being y the top Yukawa coupling and g_1 and g_2 the U(1) and SU(2) gauge couplings, respectively. The only relevant fermion contribution is due to the top quark. Here what gives the mass scale is the fermi scale ($v = 246\,GeV$), and the mass of a fermion is the Yukawa coupling times this scale ($m = yv$), but since the top quark is much heavier than the other fermions, only the top Yukawa coupling is not negligible.

Although y, g_1 and g_2 depend on the scale, it is reasonable to take their values at the fermi scale: $g_1 = 0.359$, $g_2 = 0.648$ and $y = 0.938$ [2]. With the value of β found in the preceding section, eq. (17) becomes a second grade equation for λ:

$$24\lambda^2 + (-9g_2^2 - 3g_1^2 + 12y^2)\lambda +$$
$$+\left(-6y^4 + \frac{3}{4}g_2^4 + \frac{3}{8}(g_2^2+g_1^2)^2 - 16\pi^2\beta_\lambda^{(1)}\right) = 0. \quad (18)$$

Solving this equation, we obtain two values, $\lambda = 1.245$ and $\lambda = -1.511$. However, for negative values of λ, the potential would be an inverted quartic without an absolute minimum, which would led to an unstable universe. For this reason, we will discard the negative solution.

On the other hand, the positive solution is about ten times greater than the SM value, which is around 0.125, and this would question the validity of perturbation theory. Our objective now is to study possible modifications of the theory in order to obtain lower values of λ. A first possibility could be that there existed a fourth generation of heavy fermions so that its Yukawa coupling was much greater than the top quark one. In such case, the Yukawa coupling y from eq.(18) would be dominated by this generation. However, if we plot λ as a function of y (figure 1), without changing the gauge part, we see that although at first the curve goes down a little bit (and not significantly), it rises immediately, so we must discard this option.

We now propose a more general treatment to try to solve the problem, writing the beta function as

$$\beta = a\lambda^2 + b\lambda + c = \left(\frac{M_H}{v}\right)^2 \simeq 0.258. \qquad (19)$$

We want to find out which values a, b or c should be modified in order to obtain $\lambda < \epsilon$. To fix ideas we will

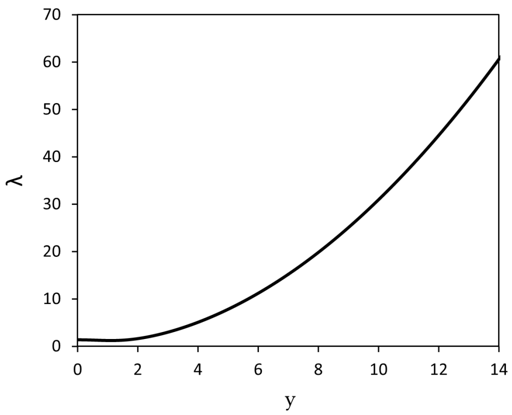

FIG. 1: Representation of λ as a function of y. We recover $\lambda = 1.245$ for $y = 0.938$.

choose $\epsilon = 0.3$. Solving for λ, we have

$$0 < \lambda = \frac{-b + \sqrt{b^2 + 4a(\beta - c)}}{2a} < \epsilon. \tag{20}$$

The values we used previously were

$$a = \frac{24}{16\pi^2} = 0.152, \tag{21}$$
$$b = \frac{-9g_2^2 - 3g_1^2 + 12y^2}{16\pi^2} = 0.040, \tag{22}$$
$$c = \frac{-6y^4 + \frac{3}{4}g_2^4 + \frac{3}{8}(g_2^2 + g_1^2)^2}{16\pi^2} = -0.028. \tag{23}$$

If we keep a positive and rearrange (20), we obtain the relation

$$\epsilon^2 a + \epsilon b + c > \beta. \tag{24}$$

To fulfill this equation we could increase the value of a or b. Recall from (20) that c has to be negative or positive but lower than β to have solution. Then, another option to reduce the value of λ could be to change the sign of c and approach its value to β.

If we want to modify the independent term, c, in a way such that $\beta - c$ is small, we can simplify eq. (20) using that $\sqrt{1+x} \simeq 1 + \frac{x}{2}$ for small x:

$$\lambda = \frac{b}{2a}\left(-1 + \sqrt{1 + \frac{4a(\beta - c)}{b^2}}\right) \simeq \frac{\beta - c}{b}. \tag{25}$$

Looking at eq. (23), the simplest modification we can think of is the addition of new fields U(1). This is not an irrational idea, there are actually indications that there might be new physics: in LHCb experiments some discrepancies in the relative intensity of certain reactions between electrons and muons are being found, when in theory there should not be any difference due to the universality of the weak interactions. One of the possible interpretations of this is the existence of a new neutral gauge boson, Z', very massive. We will assume that this new U(1) field is coupled in the same way that the U(1) of weak hypercharge does. Otherwise an explicit calculation of the beta function should be done, which is beyond the objectives of this work. With this modification, equations (22) and (23) become

$$b' = \frac{-9g_2^2 - 3g_1^2 + 12y^2 - 3g_1'^2}{16\pi^2}, \qquad c' = \frac{-6y^4 + \frac{3}{4}g_2^4 + \frac{3}{8}(g_2^2 + g_1^2)^2 + \frac{3}{8}g_1'^4}{16\pi^2}. \tag{26}$$

Apart from this, we will consider a different possibility: the duplication of the SU(2) part. This idea is justified by the existence of the so called left-right models, which suppose that the SM is highly asymmetric in the sense that the left-handed coupling of fermions interacts with the gauge sector while the right-handed component does not (it does not have weak interactions except for the small contribution of the electromagnetism). A natural extension of the SM would be a left-right model, where there is a left gauge sector and a right one. The reason why we do not see the right sector is that the gauge bosons of this part are very massive and have not already been produced with the energies we have. Despite this, they can contribute to the beta function in a certain range of energies. Within this proposal, equations (22) and (23) become

$$b' = \frac{-9g_2^2 - 3g_1^2 + 12y^2 - 9g_2'^2}{16\pi^2}, \qquad c' = \frac{-6y^4 + \frac{3}{4}g_2^4 + \frac{3}{8}(g_2^2 + g_1^2)^2 + \frac{3}{4}g_2'^4 + \frac{3}{8}g_2'^4}{16\pi^2}. \tag{27}$$

In order to find the necessary values of g_i' $(i = 1, 2)$ to be able to trust perturbation theory, we will plot λ against g_i':

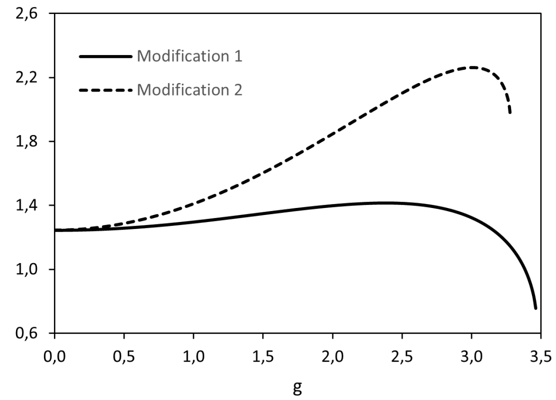

FIG. 2: Representation of λ as a function of g_1' (continuous line) and g_2' (dashed line). We recover $\lambda = 1.245$ for $g_i' = 0$.

With the second modification, the results are even worse, while with the first one the value of λ is almost halved for $g_1' = 3.469$. However, we should have at least a value of $\lambda = 0.3$ to trust our methodology. For this reason, we propose a combination of the two modifications:

$$b' = \frac{-9g_2^2 - 3g_1^2 + 12y^2 - 9g_2'^2 - 3g_1'^2}{16\pi^2}, \quad (28)$$

$$c' = \frac{-6y^4 + \frac{3}{4}g_2^4 + \frac{3}{8}(g_2^2 + g_1^2)^2 + \frac{3}{4}g_2'^4 + \frac{3}{8}(g_2'^2 + g_1'^2)^2}{16\pi^2}.$$

Since for $g_1' = 3.469$ we have improved our results, we will use this value to compute the hypothetical value of g_2'. Using eq. (25) and $\lambda = 0.3$, we find a value of $g_2' = 0.201$. We can check that $c' = 0.315$, so it is a positive value close to beta, as expected.

Therefore, a small enough value for lambda is achieved by introducing new gauge bosons, one of which holds a non perturbative coupling, g_1'. This also leads to phenomenological problems; once the spontaneous symmetry braking takes place, there appear three massless Goldstone bosons, as well as the Higgs particle, with a finite mass. Due to the gauge invariance of the SM, one can choose a gauge transformation such that the Goldstone bosons are incorporated as longitudinal degrees of freedom of the three gauge bosons of the SM. When one has a gauge theory such as electromagnetism, there are only two degrees of freedom that propagate, the two transverse degrees of freedom (the electric and magnetic field in the electromagnetism case), but we know that the particles responsible for the weak interactions (W^+, W^- and Z bosons) have mass, so we can find a reference frame where these particles are at rest. Thus, we have spin 1 particles with three degrees of freedom (one can choose three polarizations instead of two). In short, the Goldstone bosons do not appear in the spectrum, but become part of the longitudinal component of the gauge bosons.

We are now coupling new degrees of freedom with the Higgs, so we are giving masses to these new particles, which acquire an additional degree of freedom that can only be a consequence of the Goldstone bosons; however, we have already used them to give the additional polarization degree of freedom to the physical particles. What is actually happening is that, since we are coupling these new particles in a very specific way, what really acquires mass are lineal combinations of the new particles with the ones that already existed in the SM. For example, if we add a new particle with the U(1) group and B_μ is the associated gauge boson, with coupling g_1, then it will be the combination $g_1 B_\mu + g_1' B_\mu'$ that will acquire mass. In sum, with the modification we have proposed we are solving the problem related to the value of λ, but we are tampering with the gauge interaction part and the part that gives masses. A possibility that would give support to our ideas is that these particles already had mass before the coupling, either due to a Higgs mechanism with higher energies or a different mechanism.

To conclude this discussion we will examine one more possibility. It could be that the Higgs particle was not only coupled to fermions and gauge bosons, but also to a hypothetical scalar particle. Let χ be the scalar sector that couples to the SM doublet with a quartic coupling of the form $|\phi|^2|\chi|^2$ (χ is a copy of the SM doublet). Then eqs. (22) and (23) would be modified as $b' = b + \bar{b}\eta$ and $c' = c + \bar{c}\eta^2$, where η is the coupling constant and for similarity with the case $\lambda|\phi|^4$ we expect that $\bar{b}$ and $\bar{c}$ are of the order of $\frac{24}{16\pi^2}$ (10^{-1} order). Eq. (25) is still valid, since we want that the difference $\beta - c$ remains small. Imposing again $\lambda = 0.3$, we find

$$\eta = \frac{-\lambda\bar{b} + \sqrt{(\lambda\bar{b})^2 - 4\bar{c}(\lambda b - \beta + c)}}{2\bar{c}} \sim \mathcal{O}(1). \quad (29)$$

Therefore, with a relatively large coupling (not perturbative) we would achieve a small enough value for λ.

V. CONCLUSIONS

In this paper we have studied the situation in which spontaneous symmetry breaking appears due to radiative corrections and considered the possibility that the Higgs boson is related to a dilaton. Studying the beta function, we have seen that if we want $\beta = \frac{M_H^2}{v^2}$ with a perturbative value of λ, we can either add new fields U(1) and SU(2) or a scalar sector that couples with the SM doublet. For $\lambda = 0.3$ their corresponding coupling constants would be $g_1' = 3.469$, $g_2' = 0.201$ and $\eta \sim \mathcal{O}(1)$. From our analysis it seems that for the CW mechanism to work there must be some strong coupling, be it λ, a gauge constant of a new interaction or even adding more scalars. These modifications have consequences in some aspects of the SM that have not been studied in this work; additional modifications to the theory would be required to guarantee the viability of our proposal.

Acknowledgments

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