# Distinctive Effects in a Model of Dynamical Electroweak Symmetry Breaking

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The problem of possible deviations from the Standard Model is considered in the framework of a variant of dynamical electroweak symmetry breaking. The parameters of the theory are obtained, which describe deviations from SM in $Z \to \bar{b}b$ decay, are also consistent with leptonic left-right asymertry (SLAC data) and with the existence of a nontrivial solution for vertex $\bar{t}(Z,\gamma)c$. The occurrence of this solution leads to a significant enhancement in neutral flavor changing transition $t \to c$. The intensity of this transition is connected with the $c$-quark mass, that leads to estimates of probabilities of exotic decays $t \to c(Z,\gamma)$ (few %) and of the cross-section of a single $t$-quark production in process $e^+e^- \to t\bar{c}$ at LEP2 ($\simeq 0.03\,pb$ at $\sqrt{s} = 190\,GeV$). The model is shown to be consistent with the totality of the existing data; the predictions allow its unambiguous check.

It is well-known, that the Standard Model (SM) of the electroweak interaction agrees excellently with the totality of experimental data with the only possible exceptions in decay $Z \to b\,\bar{b}$ and in leptonic left-right asymmetry [1]. However, variants of the theory are considered, in which the electroweak symmetry breaking is not due to the usual Higgs elementary scalars, but some dynamical mechanism leads to the symmetry breaking. In the present

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talk we consider the variant of the dynamical electroweak symmetry breaking being proposed in [2, 3], which is connected with a selfconsistent mechanism of an appearance in the theory of the additional gauge-invariant vertex of electroweak vector bosons' interaction. This vertex effectively acts in the region of "small" momenta, restricted by a cut-off $\Lambda$ being few $TeV$ by the order of magnitude, which automatically appears in the theory. The vertex of interaction of $W^+$, $W^-$, $W^0$ with momenta and indices respectfully $p$, $\mu$; $q$, $\nu$; $k$, $\rho$ has the form

$$\begin{aligned}
\Gamma(W^+,W^-,W^0)_{\mu\nu\rho}(p,q,k) \;&=\; \frac{i\lambda g}{M_W^2}\,F(p^2,q^2,k^2)\,\Gamma_{\mu\nu\rho}(p,q,k)\,;\\
\Gamma_{\mu\nu\rho}(p,q,k) \;&=\; g_{\mu\nu}(p_\rho(qk)-q_\rho(pk))+g_{\nu\rho}(q_\mu(pk)-k_\mu(pq))+\\
&\quad+g_{\rho\mu}(k_\nu(pq)-p_\nu(qk))+k_\mu p_\nu q_\rho-q_\mu k_\nu p_\rho\,.\\
F(p^2,q^2,k^2) \;&=\; \frac{\Lambda^6}{(\Lambda^2-p^2)(\Lambda^2-q^2)(\Lambda^2-k^2)}\,.
\end{aligned} \tag{1}$$

Here $g$ is the gauge electroweak coupling constant, $\lambda$ is the basic parameter of the model, nonzero value of which follows from the solution of a set of equations for parameters of the model [2]. This solution leads to masses of gauge bosons $W$ and $Z$. We mean, that $W^0 = \cos\theta_W\,Z + \sin\theta_W\,A$ is the neutral component of $W$ triplet. Note, that anomalous vertices of the form (1) are often considered in the framework of a phenomenological analysis of possible deviations from the SM [4, 5]. Equally with gauge bosons the $t$-quark has also a large mass. The origin of its mass in our approach is connected with anomalous vertex of its interaction with a photon

$$\Gamma^t_\mu(p,q,k) \;=\; \frac{ie\kappa}{2M_t}\,F(p^2,q^2,k^2)\,\sigma_{\mu\nu}\,k_\nu\,; \tag{2}$$

As a result we obtain the theory, in which the initial symmetry is broken, $W$, $Z$, $t$ acquire masses and all other quarks (and leptons) are massless, the elementary Higgs scalars are absent and the main distinction from SM consists in effective vertices (1), (2). These vertices lead, of course, to effects, which differ the variant from the SM, that at the moment means the existence of limitations for parameters. Namely, the direct experiments (search for $W$ pair production, $t$ pair production) give the following experimental limitations [6, 8]

$$-0.31 < \lambda < 0.29; \qquad |\kappa| < 1. \tag{3}$$

On the other hand, vertices (1), (2) have to lead to deviations from SM due to loop diagrams. Let us note, that the presence of formfactors $F(p^2, q^2, k^2)$, $F_m(p^2, k^2)$ in the new vertices results in the convergence of the loop integrals. The significant effects appear in parameters of decay $Z \to \bar{b}b$ : $R_b$, $A^b_{FB}$. Namely, the measurement of these parameters give $R_b = 0.2178 \pm 0.0011$ instead of SM value 0.2158 and for forward-backward asymmetry $A^b_{FB} = 0.0979 \pm 0.0023$ instead of calculated 0.1022 [1]. The relative deviations

$$\begin{aligned}\Delta_b \;&=\; \frac{R_b(exp) - R_b(th)}{R_b(th)} \;=\; 0.009 \pm 0.005\,;\\ \Delta_{FB} \;&=\; \frac{A^b_{FB}(exp) - A^b_{FB}(th)}{A^b_{FB}(th)} \;=\; -\,0.042 \pm 0.023\,.\end{aligned} \tag{4}$$

indicate a possibility for a contradiction with SM predictions. In the framework of our approach in studying of this problem the effective vertex $\bar{t}Wb$ is important. We have assumed [9], that here additional terms of a magnetic dipole type are also present

$$\Gamma^{tb}_\rho(p, q, k) \;=\; \frac{ig}{2M_t}\, F_m(p^2, k^2)\, \sigma_{\rho\omega}\, k_\omega \left(\xi_+(1+\gamma_5) + \xi_-(1-\gamma_5)\right); \tag{5}$$

where $p$, $q$ are respectfully momenta of $t$ and $b$ quarks, $k$ is the momentum of $W$ and the formfactor is like in (1) Using the main vertices (1), (2) we formulate the set of equations for parameters of vertex (5) in one-loop approximation. For $\xi_+$ (left-handed $b$) we have an inhomogenous equation, while for $\xi_-$ (right-handed $b$) we have a homogenous one

$$\begin{aligned}&\xi_+ \;=\; -\,\frac{\lambda C\kappa}{24\sqrt{2}\,F_1}\left(1 - \frac{\sqrt{2}\,\kappa K}{8}\,\beta\,\xi_+\right); \qquad \xi_- \;=\; \frac{\lambda C K\kappa^2}{192\,F_2}\,\beta\,\xi_-\,;\\ &F_1 \;=\; 1 - \lambda C\left(\frac{\kappa}{40} - \frac{7}{48\theta}\right); \qquad F_2 \;=\; 1 - \lambda C\left(\frac{\kappa}{40} - \frac{1}{8\theta}\right);\\ &\beta \;=\; \frac{1}{4} + \frac{\lambda}{5(1-\theta)}; \qquad C \;=\; \frac{\alpha\Lambda^2}{\pi M_W^2}\,; \qquad K \;=\; \frac{\alpha\Lambda^2}{\pi M_t^2}\,.\end{aligned} \tag{6}$$

Here and in what follows we use the abbreviated notation $\theta = \sin^2\theta_W = 0.23$ . It seems natural to decide, that the homogenuos equation for $\xi_-$ has trivial solution $\xi_- = 0$. However, with this solution it is impossible to describe deviations (4). It occurs, that the satisfactory description can be achieved only if the equation for $\xi_-$ has a nontrivial solution $\xi_- \not\equiv 0$. This impose the following conditions on the parameters of the problem

$$\frac{\lambda C K \kappa^2}{192\,F_2}\,\beta\;=\;1;\qquad \xi_+\;=\;-\,\sqrt{2}\,\kappa\,\theta. \tag{7}$$

Emphasize, that condition (7) by no means is the so called fine tuning condition, because the parameters, which enter into it, are just subjects for determination from the set (6). Now parameter $\xi_-$ is ambiguous and we fix it and also the parameter

$$R\;=\;\frac{\xi_-}{\xi_+}\,; \tag{8}$$

from the condition of correspondence with deviations (4). The simple calculations show [9], that deviations (4) correspond to the following values of the parameters

$$|R|\;=\;2.45^{+0.25}_{-0.35}\,;\qquad \xi_+\;=\;-\,0.043^{+0.013}_{-0.007}\,; \tag{9}$$

Note, that value $\Lambda = 4.5\,TeV$ of the effective cut-off was used in the analysis, which corresponds to all the selfconsistency conditionsof the model (see [2, 3, 6, 9]) and the fine structure constant $\alpha = 1/128$. With the existence of the nontrivial solution the main parameters of the model acquire also fixed values

$$\lambda\;=\;-\,0.23 \pm 0.01\,;\qquad \kappa\;=\;0.13^{+0.02}_{-0.04}\,; \tag{10}$$

which are in the correspondence with experimental limitations (3). Let us emphasize, that we can obtain the set of parameters (9), (10), which gives the description of data, including deviations (4), only for the nontrivial solution of set (6), which means an additional symmetry breaking and leads to an appearance of terms, which are absent in the initial theory in all orders of perturbation theory. For example, the appearance of right-handed components of the $b$-quark in vertex (5) is impossible in the initial, unbroken theory. Now we consider a possibility, that similar phenomena can occur also for other vertices involving the $t$-quark. Namely, we study vertex of interaction of neutral current $\bar{t}c$ and $W^0$ [10]. Such flavor changing current usually appears at the two-loop level and gives small effects. However, nontrivial solutions may lead here to an essential enhancement. Now, let us consider vertex $\bar{t}W^0c$

$$\Gamma^{tc}_\rho(p,k)\;=\;\frac{i\,g}{2M_t}\,F_m(p^2,k^2)\,\sigma_{\rho\omega}k_\omega\,\Big(y_+(1+\gamma_5)+y_-(1-\gamma_5)\Big)\,; \tag{11}$$

where formfactor $F_m(p^2,k^2)$ is the same as in (5), $p$, $k$ are respectfully momenta of $t$ and $W^0$. In the one-loop approximation vertex (11) leads to an appearance of new terms in vertex $\bar{b}Wc$ ($\Gamma^{bc}$), which we schematically represent in the following form

$$\Gamma^{bc} \,=\, \Bigl(\Gamma^{tb}\,\Gamma(W\,W\,W^0)\,\Gamma^{tc}\Bigr) \,+\, \Bigl(\Gamma^{tb}_0\,\Gamma(W\,W\,W^0)\,\Gamma^{tc}\Bigr) \,+ \\ +\Bigl(\Gamma^{tb}\,\Gamma_0(W\,W\,W^0)\,\Gamma^{tc}\Bigr)\,; \qquad (12)$$

where index "0" means the usual vertex of SM and we, of course, mean the corresponding propagators between vertices and the momentum integration $(d^4q/(2\pi)^4)$. In expression (12) there are terms with matrix structures $\gamma_\rho$ and $\sigma_{\rho\mu}\,k_\mu$, denoting them respectfully as $\Gamma^{bc}_1$ and $\Gamma^{bc}_2$, we write down, again schematically, the following expression for vertex (11)

$$\Gamma^{tc} \,=\, \Bigl(\Gamma^{tb}\,\Gamma(W\,W\,W^0)\,\Gamma^{bc}_0\Bigr) \,+\, \Bigl(\Gamma^{tb}_0\,\Gamma(W\,W\,W^0)\,\Gamma^{bc}_2\Bigr) \,+ \\ +\Bigl(\Gamma^{tb}\,\Gamma(W\,W\,W^0)\,\Gamma^{bc}_1\Bigr)\,; \qquad (13)$$

Performing the calculation of the loop integrals in expressions (12), (13), we obtain the following set of equations for $y_\pm$

$$y_+ \,=\, \Bigl(-\,\frac{H^2}{8\sqrt{2}}\,\Bigl(\frac{\xi_+}{20}-\frac{1}{12\sqrt{2}}\Bigr) \,-\, \frac{HS}{4}\,\xi_+^2R^2 \,+\, \frac{5H^2\Lambda^2}{3072M_t^2}\,\xi_+^2R^2\Bigr)\,y_+\,; \\ y_- \,=\, \Bigl(-\,\frac{HS}{4}+\frac{5H^2\Lambda^2}{3072M_t^2}\Bigr)\,\xi_+^2\,y_- + y_-^0\,;\; H=\frac{\lambda C}{\theta}\,;\; S=\frac{K}{16\theta}\,; \qquad (14)$$

where

$$y_-^0 \,=\, -\,\frac{\lambda C\xi_+U_{bc}}{8\sqrt{2}\theta}\,; \qquad |U_{bc}| \,=\, 0.039\pm 0.001\,;$$

is the initial term for one-loop expression for vertex (11) (where $y_\pm=0$), and all other parameters are defined above. Let us now look for a nontrivial solution of set (14). Provided $y_+\not\equiv 0$, the following condition is valid

$$\frac{5H^2\Lambda^2}{3072M_t^2}\,\xi_+^2R^2 \,-\, \frac{H^2}{8\sqrt{2}}\,\Bigl(\frac{\xi_+}{20}-\frac{1}{12\sqrt{2}}\Bigr) \,-\, \frac{HS}{4}\,\xi_+^2R^2 \,=\, 1\,. \qquad (15)$$

It comes out, that condition (15) is satisfied by the same values of the parameters as those obtained earlier. E.g., set of the parameters

$$\lambda = -0.237; \qquad \xi_+ = -0.039; \qquad R = 2.45\,; \tag{16}$$

satisfies equation (15) and evidently is situated in the range of accuracy of parameters (9), (10). We shall assume, that both conditions are fulfilled: (7) and (15). Their simultaneous fulfillment must not cause a surprise. Indeed, condition (7) is the equation for two parameters: $\lambda$, $\xi_+$, and condition (15) is the equation for $\lambda$, $\xi_+$, $R$. Therefore, for the fixed value of $R$ set of equations (7) and (15) gives two equations for two variables. Values (16) for parameters $\lambda$ and $\xi_+$ are just the solution of the set for $R = 2.45$. Note once more, that this solution describes data (4). For $y_-$ we obtain

$$y_- \;=\; y_-^0\,\Bigl(1-\frac{1}{R^2}+\frac{H^2}{8\sqrt{2}R^2}\Bigl(\frac{1}{12\sqrt{2}}-\frac{\xi_+}{20}\Bigr)\Bigr)^{-1}. \tag{17}$$

Substituting the parameters being obtained we get estimate $|y_-| = 0.0012$. We shall see below, that this estimate is, at least, two orders of magnitude smaller, than a possible value of $y_+$, and so in what follows we will not take into account contributions of $y_-$. Let us estimate a possible value $y_+$. To achieve this goal we use the contribution of vertex (11) to the $c$-quark mass. The initial $c$-quark mass in our approach is zero. Provided the vertex of the type (11) does not appear, the mass remains to be zero. However, if the nontrivial solution exists, there appear nonzero contributions to the mass. The simplest terms correspond to two-loop diagrams, which is described by the chains: $c \to b(W^+) \to t(W^-) \to c(W^0)$ and $c \to t(W^0) \to b(W^+) \to c(W^-)$. Here in the brackets after transitions the sort of $W$ is indicated and three gauge bosons are tied together by vertex (1). Transitions $c \leftrightarrow b$, $b \leftrightarrow t$ are described by SM expressions, whereas transitions $t \leftrightarrow c$ correspond to vertex (11). We obtain

$$M_c \;=\; \frac{\alpha^2\,\lambda\,y_+\,U_{cb}\,\Lambda^4}{32\pi^2\,\sin^4\theta_W\,M_W^2\,M_t}\cdot I\,; \tag{18}$$
$$I = \frac{1}{\pi^4}\int\!\!\int \frac{p^2\,(p^2q^2-(pq)^2)\,d^4p\,d^4q}{(p^2)^2(q^2)^2(p-q)^2((p-q)^2+1)(p^2+1)^3(q^2+1)} =$$
$$= 0.48\,.$$

where substitutions $p \to p\Lambda$, $q \to q\Lambda$ are made and the Wick rotation is performed, so that the two-loop integral is calculated in the Eucleadean space. Relation (18) connects $y_+$ with $M_c$, all other parameters here are either well-known or defined above. Taking into account uncertainties in $M_c$ (which is the largest one), in $M_t$ and in $U_{cb}$ and the above remark, we obtain from (18) the possible interval for value $y_+$

$$y_+ \;=\; 0.26 \pm 0.06\,. \tag{19}$$

Now we can use value (19) for estimations of the effects. Let us start with probabilities of exotic decays of the $t$-quark: $t \to c\,Z$, $t \to c\,\gamma$. Vertex (11) immediately leads to the following expressions for the decay widths

$$\begin{aligned}
\Gamma(t \to c\gamma) \;&=\; \frac{1}{4}\,\alpha\,M_t\,y_+^2\,;\\
\Gamma(t \to cZ) \;&=\; \frac{g^2(M_t^2 - M_Z^2)}{32\,\pi M_t^3\,(1-\theta)}\,y_+^2\left(2M_t^2 - M_Z^2 - \frac{M_Z^4}{M_t^2}\right).
\end{aligned} \tag{20}$$

For value (19) the ratios of these widths to the total one read

$$\begin{aligned}
B_\gamma &= BR\,(t \to c\gamma) = 0.0155 \pm 0.0055\,;\\
B_Z &= BR\,(t \to cZ) = 0.053 \pm 0.023\,.
\end{aligned} \tag{21}$$

Experimental limitations $B_\gamma \leq 3.2\%$; $B_Z \leq 33\%$ [11] do not contradict to estimates (21). The next important process, in which vertex (11) can manifest itself, is the single $t$ ($\bar{t}$)-quark production in $e^+e^-$ collisions above the threshold of $t\,\bar{c}$ production. Provided the energy exceeds the threshold by few $GeV$ one may neglect $c$-quark mass in the expression for the cross-section of process $e^+\,e^- \to t\,\bar{c}$, which reads as follows

$$\begin{aligned}
\sigma = {}& \frac{\pi\alpha^2 y_+^2 (s - M_t^2)^2 (s + 2M_t^2)}{2M_t^2 s^2} \times\\
&\times \left(\frac{1}{s} + \frac{1 - 4\,\theta}{4\,\theta(s - M_Z^2)} \;+\; \frac{s(2 - 8\,\theta \,+\, 16\,\theta^2)}{16\,\theta^2 (s - M_Z^2)^2}\right).
\end{aligned} \tag{22}$$

Process $e^+\,e^- \to \bar{t}\,c$ has the same cross-section, so to estimate the cross-section for single $t$ ($\bar{t}$) production we have to redouble expression (22). Using values $M_t = 176\,GeV$ and (19) we obtain e.g. the following estimate for the cross-section of the single production at energy $192\,GeV$ : $\sigma = \Big(0.037 \pm 0.016\Big)\,pb$. The study of a validity of the variant under consideration is quite achievable for forthcoming experiments at LEP2 (see also [12]). One more observable effect, which we can estimate, is decay $Z \to \bar c\,c$. One has to take into account four one-loop diagrams with vertices (11), (12). With their account vertex $\bar c Z c$ looks as follows

$$\begin{aligned}
&\Gamma_\rho = \frac{g}{2\cos\theta_W}\Big(a\gamma_\rho\,+\,b\gamma_\rho\gamma_5\Big);\; a\,=\frac{1}{2}-\frac{4}{3}\theta+b_1\,;\; b\,=\frac{1}{2}\,-\,b_1\,;\\
&b_1 = \frac{Ky_+^2}{4}\left(\frac{1}{4\theta}-\frac{1}{3}+D^2\Big(\frac{1}{2}-\frac{3}{4\theta}+\frac{3(1-\theta)}{2\theta}+\frac{25\lambda}{72\theta}\Big)\right); \qquad (23)\\
&D\,=\,-\,\frac{\lambda\,C}{12\sqrt{2}\theta}\,.
\end{aligned}$$

Vertex (23) leads to the decay probability, which differs from the SM prediction. We represent its ratio $R_c$ to the full hadron width in the form $R_c = R_c^{SM}(1+\Delta_c)$, $R_c^{SM} = 0.172$ and we have

$$\Delta_c\,=\,\frac{36\,b_1^2\,-\,48\theta\,b_1}{9\,-\,24\theta\,+\,32\theta^2}\,. \qquad (24)$$

Expression (24) gives us value $R_c\,=\,0.161\pm 0.005$, which is to be compared with experimental number $0.1715\pm 0.0056$. The obtained value agrees with the experimental one, however, it gives a marked difference with the SM. There is also deviation from SM in SLAC data on leptonic left-right asymmetry. In our approach the deviation from SM in this parameter is connected with a contribution of anomalous vertex (1) to vertax $\bar e e Z$ vertex:

$$\Delta\,\Gamma_\mu\,=\,\frac{ig^3\lambda}{3(2\pi)^4M_W^2}\,(k^2\gamma_\mu - k_\mu\,\hat k)(1+\gamma_5)\,\times\,I\,; \qquad (25)$$

$$I\,=\,\int\frac{\Lambda^4}{(\Lambda^2+p^2)^2}\,\frac{(p^2k^2-(pk)^2-(pk)(qk)+(pq)k^2)\,d^4p}{p^2\,((p+q)^2+M_W^2)((p+q+k)^2+M_W^2)}\,; \qquad (26)$$

where $k$ is $Z$ momentum and $q$, $-q-k$ are momenta of an electron and a positron. Integral $I$ is already defined in Euclidean space. We take the same value for effective cut-off $\Lambda\,=\,4.5\,TeV$ and obtain on the mass shell of $Z$ $I\,=\,4.71\,\pi^2$. Then the corrected vertex of $\bar e e Z$ interaction on the $Z$ mass shell is the following ($\theta \equiv \sin^2\theta_W$)

$$\Gamma_\mu \;=\; \frac{ig}{4\cos\theta_W}\,\gamma_\mu\left(\left(-1+2\theta+\;4.71\,\frac{\alpha\lambda}{3\pi\theta}\right)(1+\gamma_5)\;+\;2\theta(1-\gamma_5)\right). \qquad (27)$$

To compare with deviation from SM in electron left-right asymmetry $A_{LR}$ in SLD data we define

$$\theta_{eff}\;=\;\frac{\theta}{D}\,;\qquad D\;=\;1-4.71\frac{\alpha\lambda}{3\pi\theta}\,. \qquad (28)$$

Experimental data [1] $\theta_{eff} = 0.23055 \pm 0.0041$ lead to the following estimate

$$\lambda\;=\;-\,0.248 \pm 0.105\,; \qquad (29)$$

which quite agrees with our basic result (10) So, $R_b$ , $A^b_{FB}$ , $A^l_{LR}$ are simultaneously described in the model. To conclude we mark few important points. We have shown, that the model under consideration describes quite satisfactorily the totality of experimental data on the precise test of the electroweak theory, including possible deviations from the SM in $Z$-decays. The model also gives definite predictions, which can be looked for; we draw attention to the following items. 1. Prediction for the constant of the anomalous triple vector boson interaction $\lambda \simeq -0.23$ can be tested at LEP2 [13]. 2. Prediction for the cross-section of the single $t$-quark production $\sigma \simeq 0.03\,pb$ at the energy of $e^+e^-$ collisions around $190\,GeV$ also can be studied in the forthcoming experiments at LEP2. Exotic $t$-quark decays at the level of accuracy $\simeq$ 1% are also very important. 3. An improvement of the accuracy of data on decays $Z \to \bar{b}b$, $Z \to \bar{c}c$ are also of a great interest. Maybe the second decay is the most crucial for the test of the scheme.

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