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Finite Renormalization Effects in induced $\bar{s}dH$ Vertex

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ABSTRACT

The finite renormalization contributins to $\bar{s}dH$ vertex are examined in the standard model. They are explicitly shown to cancel each other among diagrams, so that the lower bound on Higgs mass M_H > 325 MeV is not affected by such effects.

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Although Higgs boson plays an essential role in the spontaneous breakdown of SU(2) x U(1) symmetry, it has not been observed yet and we know very little about the mass M_H. The most stringent lower bound quoted in the literature stems from $K^+ \to \pi^+ H$:[1] $M_H > 325$ MeV, while the theoretical lower bound can be avoided in several ways.[2]

There exists a criticism[3] about the only phenomenological lower bound mentioned above, based upon the following observations:

i) The result of the calculation for relevant one-loop induced $\bar{s}dH$ vertex in the standard model differs from the earlier result in the literature.[1,4]

ii) There is a competing non-perturbative contribution to $K^+ \to \pi^+ H$ transition.[5]

iii) The t quark contribution to $\bar{s}dH$ vertex is negligible.

From these points they found a very small branching ratio, $B(K^+ \to \pi^+ H) \simeq 2 \times 10^{-8}$, so that the lower bound of 325 MeV is invalidated. What makes the branching ratio so small in their analysis is a huge cancellation between the perturbative c quark contribution (in $\bar{s}dH$ vertex) and the non-perturbative effect. Accepting the points ii) and iii), such cancellation extremely relies on the disagreement of results for $\bar{s}dH$ vertex, by factor 3 for c quark contribution, stated in i). It is claimed in Ref. 3 that the difference seems to have its origin in the finite renormalization effects, i.e., the effects due to counterterms in $\bar{s}dH$ vertex.

Our purpose in this brief report is to discuss such counterterm effects in detail, in order to clarify the controversial point.

Radiative corrections can be calculated taking account of all relevant terms in the interaction lagrangian. To get the induced $\bar{s}dH$ vertex at order

g^3 we should, therefore, calculate the contributions of counterterms (Fig. 1), as well as ten one-loop diagrams with W and charged unphysical scalar exchange (see, for example, diagrams in Ref. 4). We have calculated the one-loop diagrams for off-shell Higgs, in general.[6] Being imposed the on-shell condition for Higgs boson, our result is confirmed to reduce to the one of Ref. 4. So in this paper we will concentrate on the contributions of counterterms.

We essentially follow the procedure by Marciano and Sirlin,[7] to construct the flavor changing counterterms. The relevant part of lagrangian is, from $M_{W_o} = g_o v_o/2$,

$$\mathscr{L} = \bar{\psi}_o(i\partial\!\!\!/ - M_o)\psi_o - \frac{g_o}{2M_{W_o}} \bar{\psi}_o M_o \psi_o H_o, \tag{1}$$

where ψ_o and M_o (including γ_5 in general) should be understood as a column vector and a matrix in the generation space of down-type quarks, d_o, s_o, ---, and the symbol o denotes bare quantities. At the one-loop level (order g^2), only wave-function renormalizations and mass renormalizations of down-type quarks are responsible for the flavor changing counterterms:

$$\psi_o = (Z_L L + Z_R R)\,\psi, \; M_o = M + \delta M L + \delta M^{\dagger} R\ , \tag{2}$$

where $L, R = (1 \mp \gamma_5)/2$, $Z_{L,R}$ and δM are non-diagonal matrices in general, to be fixed by the renormalization prescription, and the renormalized mass matrix M is flavor-diagonal. The counterterms can be obtained straightforwardly from eqs. (1) and (2),

$$\begin{aligned}\mathscr{L}_c &= \bar{\psi}\left\{ i\partial\!\!\!/(AL + BR) + (CL + DR)\right\}\psi \\ &+ \frac{g}{2M_W}\bar{\psi}\,(CL + DR)\,\psi\, H\ ,\end{aligned} \tag{3}$$

where new matrices are defined by $A = Z_L^{\dagger} Z_L - 1$, $B = Z_R^{\dagger} Z_R - 1$, $C = -(\delta M + Z_R^{\dagger} M Z_L - M)$ and $D = C^{\dagger}$. Let us note that the mass counterterms and the counterterms for Yukawa couplings are not independent, each another. This is simply because we are considering only flavor changing pieces; equation (3) is valid only for the off-diagonal counterterms we are interested in.

The contributions of these counterterms to the effective $\bar{s}dH$ vertex through each diagram of Fig. 1, which we indicate by $\Gamma^{(a)}$ etc., can be calculated easily (putting external quarks on-shell):

$$\Gamma^{(a)} = \frac{g}{2M_W(m_s^2 - m_d^2)} \{ m_s m_d \left(m_s(\alpha R + \beta L) + m_d(\alpha L + \beta R) \right)$$

$$+ m_d \left(m_s(\gamma R + \delta L) + m_d(\gamma L + \delta R) \right) \} ,$$

$$\Gamma^{(b)} = \frac{-g}{2M_W(m_s^2 - m_d^2)} \{ m_s m_d \left(m_s(\alpha R + \beta L) + m_d(\alpha L + \beta R) \right)$$

$$+ m_s \left(m_d(\gamma R + \delta L) + m_s(\gamma L + \delta R) \right) \} ,$$

$$\Gamma^{(c)} = \frac{g}{2M_W} (\gamma L + \delta R) , \qquad (4)$$

where m_s and m_d are quark masses and α etc. are defined as $d \to s$ transition parts of A etc., e.g., $\alpha = A_{sd}$. From eq. (4) we find that the effects of kinetic counterterms, α and β, cancel between diagrams (a) and (b), while the effects of mass counterterms, γ and δ, disappear when all diagrams are summed up. It should be noticed that this argument is valid for arbitrary constants α etc., and therefore is independent of the renormalization scheme. Thus we have shown that there is no finite renormalization effect in $\bar{s}dH$ vertex.

For completeness, we have also checked using this method that there is no finite renormalization effect for on-shell external quarks in the induced $\bar{s}dZ$, $\bar{s}d\gamma$ and $\bar{s}d\gamma\gamma$ couplings. Instead of repeating similar discussions, here we will just give counterterms, necessary for the arguments, in addition to eq. (3)

$$\mathscr{L}_c = (g/\cos\theta_w)\, \bar{\psi}\gamma_\mu[(-1/2)\, AL + (1/3)\sin^2\theta_w(AL+BR)]\psi\cdot Z^\mu$$
$$-(e/3)\, \bar{\psi}\gamma_\mu(AL+BR)\psi\cdot A^\mu \quad . \tag{5}$$

As a summary, we have shown by explicit calculation that there is no finite renormalization effect in $\bar{s}dH$ vertex. The calculation of $\bar{s}dH$ vertex in Ref. 4 is thus confirmed and, therefore, the obtained lower bound on the Higgs mass $M_H > 325$ MeV[1] does not seem to be ruled out. We would also like to comment on the calculation of $\bar{s}dH$ for off-shell Higgs in Ref. 8. The result differs from the one in Ref. 4 by a term proportional to M_H^2. However, these two results become the same for on-shell Higgs, in which we should put $M_H = 0$ for consistency. Although for off-shell case the term proportional to M_H^2 is important for large M_H, it has been shown[6] to be gauge dependent and we have to take into account the corresponding box diagram contribution to get a meaningful result.

Finally, we will emphasize that it is very important to get correct results for the flavor changing Yukawa couplings. These vertices appear in many interesting processes, such as $b \to sH$ decay[4] and the muon polarization in $K_L \to \mu\bar{\mu}$ through the Higgs exchange in $d\bar{s} \to \mu\bar{\mu}$,[6] besides $K^+ \to \pi^+ H$ discussed above.

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FIGURE CAPTIONS

Fig. 1 The contributions of the flavor changing counterterms, indicated by x, to the $\bar{s}dH$ vertex.

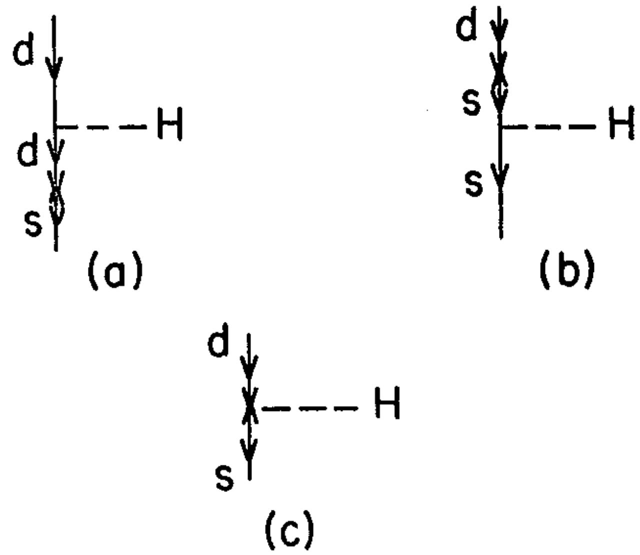

Fig. 1