Electric dipole and magnetic quadrupole moments of the W boson via a CP-violating HWW vertex in effective Lagrangians

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The possibility of nonnegligible W electric dipole ($\tilde{\mu}_W$) and magnetic quadrupole ($\tilde{Q}_W$) moments induced by the most general HWW vertex is examined via the effective Lagrangian technique. It is assumed that new heavy fermions induce an anomalous CP-odd component of the HWW vertex, which can be parametrized by an $SU_L(2) \times U_Y(1)$-invariant dimension-six operator. This anomalous contribution, when combined with the standard model CP-even contribution, leads to CP-odd electromagnetic properties of the W boson, which are characterized by the form factors $\Delta\tilde{\kappa}$ and $\Delta\tilde{Q}$. It is found that $\Delta\tilde{\kappa}$ is divergent, whereas $\Delta\tilde{Q}$ is finite, which reflects the fact that the latter cannot be generated at the one-loop level in any renormalizable theory. Assuming reasonable values for the unknown parameters, we found that $\tilde{\mu}_W \sim 3 - 6 \times 10^{-21}\ e \cdot \mathrm{cm}$, which is 8 orders of magnitude larger than the SM prediction and close to the upper bound derived from the neutron electric dipole moment. The estimated size of the somewhat less-studied $\tilde{Q}_W$ moment is of the order of $-10^{-36}\ e \cdot \mathrm{cm}^2$, which is 15 orders of magnitude above the SM contribution.

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I. INTRODUCTION

It is well known that a spin-s particle associated with a no self-conjugate field has $2s$ CP-odd permanent electromagnetic moments. In particular, a charged [1] or neutral vector particle [2,3] has two electromagnetic moments, namely, the electric dipole moment (EDM) and the magnetic quadrupole moment (MQM). The scrutiny of these properties may provide relevant information for our knowledge of CP violation, which still remains a mysterious phenomenon whose experimental validity has been well established via some flavor-changing processes such as the mixing of the K [4] and B [5] hadrons. There is no yet conclusive evidence that the origin of CP violation in $K^0 - \bar{K}^0$ mixing is the Cabibbo-Kobayashi-Maskawa (CKM) phase [6], which is the only source of CP violation in the electroweak sector of the standard model (SM), but recent results from B factories at SLAC and KEK strongly suggest [5,7] that the dominant contribution to $B^0 - \bar{B}^0$ mixing arises from such a phase indeed. This means that, as far as B hadron physics is concerned, there is not much room left to detect new sources of CP violation. On the other hand, diverse studies [8] show that the CKM phase has a rather marginal impact on flavor-diagonal processes such as the electric dipole moments of elementary particles, which means that they could be highly sensitive to new sources of CP violation. In fact, neither the fermions nor the W gauge boson can have EDMs at the one-loop level because a CP-violating phase cannot arise at this order since the corresponding amplitudes depend only on the absolute value of the CKM matrix elements. It has been shown [9] that the EDM of both quarks and W boson vanishes also at the two-loop level and appears first at the three-loop level [9,10]. In the case of charged leptons, without the presence of right-handed neutrinos the EDM is still more suppressed and it can only be generated at the four-loop level or higher orders [11]. However, the existence of new sources of CP violation in this sector is expected due to the possible discovery of neutrino masses and lepton mixing [12]. In contrast, as far as the W MQM is concerned, it has been shown [13] that it receives a tiny contribution at the two-loop level in the SM.

Apart from the mere theoretical interest, the study of the EDM and MQM of the W boson is important from the experimental point of view because they can induce large contributions to the EDM of the fermions [14], such as the electron or the neutron, which may be at the reach of low-energy experiments. It is thus worth investigating new sources of CP violation beyond the SM. Although these properties of the W boson can only be generated through loop effects within renormalizable theories, they may receive large contributions in many SM extensions [15]. The only class of models which can generate these quantities at the one-loop level are those involving both left- and right-handed currents with complex phases [3]. In principle, this one-loop generated effect would contribute dominantly to these W properties, but it could be strongly suppressed due to the presence of a tiny complex phase, as occurs in left-right symmetric models (LRSM) [16] due to experimental constraints on the $W_L - W_R$ mixing. Although the presence of at least one fermionic loop involving a Dirac trace is required to generate a term proportional to the Levi-Civita tensor in the $WW\gamma$ vertex, the combination of fermion and scalar fields may supply a potential source of CP violation in flavor-diagonal processes, provided that their interactions involve both scalar and pseudoscalar couplings. The simultaneous presence of these types of Higgs-fermion couplings violate CP invariance, which in turn can induce a trilinear Higgs-W vertex with similar CP property at the one-loop level. A ϕWW vertex including a linear combination of CP-even and CP-odd couplings is enough to generate a CP-odd component in the on-shell vertex $WW\gamma$, which would correspond to a two-loop effect in a renormalizable theory. Although this source of CP violation is generated at the two-loop level, it could give a contribution to the CP-odd electromagnetic moments of the W boson larger than those induced by other alternative sources. This mechanism does not depend crucially on the existence of a complex phase since it is a direct consequence of the presence of Higgs-fermion couplings that violate CP invariance in the fundamental Lagrangian, which contrasts with the case of the CKM phase or that arising from left- and right-handed charged currents. Indeed, it is not necessary to go beyond the Fermi scale to introduce the most general renormalizable CP-violating $\phi\bar{f}f$ vertex. It arises for instance in the Yukawa sector of the type-III two-Higgs doublet model (THDM) [17], where the ϕWW vertex is induced at the one-loop level as a linear combination of CP-even and CP-odd couplings, which in turn generate the most general on-shell $WW\gamma$ vertex including both CP-even and CP-odd dynamical structures at the two-loop level. Although there are many types of Feynman diagrams contributing to the W CP-odd properties in this model [18], the contribution from the one-loop ϕWW vertex generated by the Yukawa coupling $\mathcal{L}_Y = -\sum_i \phi\bar{\psi}_i(e + io\gamma_5)\psi_i$ differs from any other source as it leads to a finite and gauge invariant result by itself [19]. The same type of effect can arise from heavy fermions that may be present in several SM extensions, and we will focus on this possibility. Although SM extensions composed by very complex Higgs sectors are common, it is worth emphasizing that most of them contain at least one SM-like Higgs boson H. Such a Higgs boson is SM-like in the sense that it is expected to be relatively light, with a mass of order of the Fermi scale, and with tree level couplings presenting small deviations from the SM that vanish in some appropriate limit. In this work, we are interested in studying this class of deviations, which may lead to the appearance of CP-odd electromagnetic properties of the W boson. More specifically, we will concentrate on the most general HWW vertex including both CP-even and CP-odd components. Instead of focusing on a specific model, it is convenient to parametrize this class of effects in a model-independent manner via the effective Lagrangian technique [20]. It is assumed that these effects are induced by particles that are much heavier than the Fermi scale and can thus be integrated out in the generating functional. This framework is quite appropriate to describe any physics phenomenon that is absent or very suppressed in the SM. Apart from the advantages of working in a model-independent fashion, this approach has some additional advantages from the technical point of view. In particular, a two-loop calculation, as the one we are interested in, can be treated as a one-loop effect. Below, we will discuss the structure of the effective HWW vertex and its implications on the EDM and MQM of the W boson.

The rest of the paper is organized as follows. In Sec. II, the $SU_L(2) \times U_Y(1)$-invariant effective Lagrangian description of the HWW vertex is presented and used to determine its impact on the on-shell $WW\gamma$ vertex at the one-loop level within the effective theory, whereas Secs. III and IV are devoted to discuss our results and present our conclusions, respectively.

II. THE EFFECTIVE HWW COUPLING AND ITS CONTRIBUTION TO $WW\gamma$

A scheme that is well suited to analyze new physics effects lying beyond the Fermi scale consists in introducing $SU_L(2) \times U_Y(1)$-invariant operators of dimension higher than four that modify the SM dynamics. In particular, the structure of the tree level HWW vertex can be modified by introducing a dimension-six effective Lagrangian given by

$$\mathcal{L}_{\text{eff}} = gm_W HW^-_\mu W^{+\mu} + \frac{\alpha_{HWW}}{\Lambda^2}(\Phi^\dagger\Phi)W^i_{\mu\nu}W^{i\mu\nu} + \frac{\tilde{\alpha}_{HWW}}{\tilde{\Lambda}^2}(\Phi^\dagger\Phi)W^i_{\mu\nu}\tilde{W}^{i\mu\nu}, \tag{1}$$

where $W^i_{\mu\nu}$ is the $SU(2)$ field strength, $\tilde{W}^i_{\mu\nu} = \frac{1}{2}\epsilon_{\mu\nu\alpha\beta}W^{i\alpha\beta}$, and Φ is the standard model Higgs doublet. The parameters α_{HWW} and $\tilde{\alpha}_{HWW}$ parametrize the details of the underlying physics, and they could be determined once the fundamental theory is known. On the other hand, Λ and $\tilde{\Lambda}$ are new different physics scales, the latter being associated with CP-violating effects. Such anomalous Higgs-W interactions have already been considered in the literature [21,22]. For instance, they were introduced to analyze the CP structure of the HWW coupling at the CERN large hadron collider (LHC) [21], and more recently at next linear colliders (NLC) [22]. Also, it is worth mentioning that this vertex already arises at the one-loop level within the context of the SM provided that at least one W boson is off-shell [23]. For the purpose of this work, it is enough to concentrate on the first and last terms of the Lagrangian (1). Our main goal is to study the impact of this anomalous HWW vertex on the CP-odd electromagnetic properties of the W boson, which are generated at the one-loop level in the context of effective Lagrangians.

The most general on-shell $WW\gamma$ vertex can be written as a linear combination of CP-even and CP-odd electromagnetic gauge structures [24]:

$$\Gamma_{\alpha\beta\mu} = ie(\Gamma^{e}_{\alpha\beta\mu} + \Gamma^{o}_{\alpha\beta\mu}), \tag{2}$$

where $\Gamma^{e}_{\alpha\beta\mu}$ ($\Gamma^{o}_{\alpha\beta\mu}$) is the CP-even (CP-odd) component:

$$\Gamma^{e}_{\alpha\beta\mu} = A[2p_\mu g_{\alpha\beta} + 4(q_\beta g_{\alpha\mu} - q_\alpha g_{\beta\mu})] + 2\Delta\kappa(q_\beta g_{\alpha\mu} - q_\alpha g_{\beta\mu}) + \frac{4\Delta Q}{m_W^2} p_\mu q_\alpha q_\beta, \tag{3}$$

$$\Gamma^{o}_{\alpha\beta\mu} = 2\Delta\tilde{\kappa}\epsilon_{\alpha\beta\mu\lambda}q^\lambda + \frac{4\Delta\tilde{Q}}{m_W^2} q_\beta \epsilon_{\alpha\mu\lambda\rho} p^\lambda q^\rho. \tag{4}$$

The notation and conventions used in these expressions are shown in Fig. 1. The $\Delta\kappa$ and ΔQ form factors define the CP-conserving electromagnetic moments of the W boson, the magnetic dipole moment μ_W and the electric quadrupole moment Q_W, through the following relations:

$$\mu_W = \frac{e}{2m_W}(2 + \Delta\kappa), \tag{5}$$

$$Q_W = -\frac{e}{m_W^2}(1 + \Delta\kappa + \Delta Q). \tag{6}$$

On the other hand, $\Delta\tilde{\kappa}$ and $\Delta\tilde{Q}$ determine the CP-violating EDM and MQM:

$$\tilde{\mu}_W = \frac{e}{2m_W}\Delta\tilde{\kappa}, \tag{7}$$

$$\tilde{Q}_W = -\frac{e}{m_W^2}(\Delta\tilde{\kappa} + \Delta\tilde{Q}). \tag{8}$$

We now turn to show that a HWW vertex involving a linear combination of both CP-even and CP-odd couplings induces the $\Delta\tilde{\kappa}$ and $\Delta\tilde{Q}$ form factors at the one-loop level. As

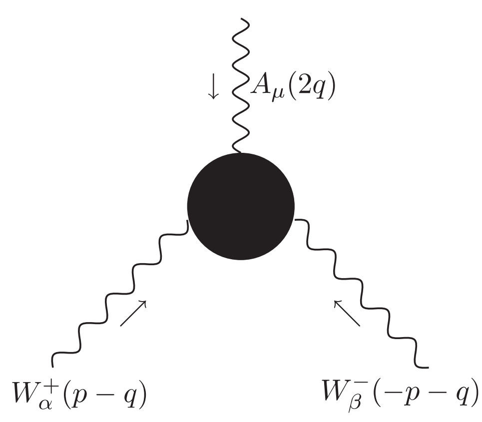

FIG. 1. The trilinear $WW\gamma$ vertex. The black circle denotes anomalous contributions.

already mentioned, this is a two-loop or higher order effect since the effective operator $(\Phi^\dagger\Phi)W^i_{\mu\nu}\tilde{W}^{i\mu\nu}$ can only be generated at one-loop or higher orders by the underlying theory [25]. Ignoring the term associated with the coefficient α_{WW}, the Higgs-W interaction can be written, in the unitary gauge, as

$$\mathcal{L}_{HW} = gm_W HW^-_\mu W^{+\mu} + \frac{g\tilde{\epsilon}_{HWW}}{4m_W}H[W^-_{\mu\nu}\tilde{W}^{+\mu\nu} + 2ie(\tilde{W}^+_{\mu\nu}A^\mu W^{-\nu} - \tilde{W}^-_{\mu\nu}A^\mu W^{+\nu})], \tag{9}$$

where $W^\pm_{\mu\nu} = \partial_\mu W^\pm_\nu - \partial_\nu W^\pm_\mu$. We have introduced the definition $\tilde{\epsilon}_{HWW} = (v/\tilde{\Lambda})^2\tilde{\alpha}_{HWW}$, being $v = 246$ GeV the Fermi scale. Notice that, due to $SU_L(2) \times U_Y(1)$ invariance, the $WW\gamma$ vertex receives contributions from both the trilinear HWW and quartic $HWW\gamma$ couplings. The Feynman rules needed to calculate the EDM and MQM are shown in Fig. 2, with the $\Gamma_{\mu\nu\lambda}$ tensor given by

$$\Gamma_{\mu\nu\lambda} = -(k_1 - k_2)_\mu g_{\nu\lambda} - (k_1 + 2k_2)_\nu g_{\mu\lambda} + (2k_1 + k_2)_\lambda g_{\mu\nu}. \tag{10}$$

In the unitary gauge, the CP-violating HWW vertex contributes to the $\Delta\tilde{\kappa}$ and $\Delta\tilde{Q}$ form factors through the Feynman diagrams shown in Fig. 3. It is worth noting that the effective Lagrangian given in Eq. (1) generates nonrenormalizable dimension-five HWW and γHWW vertices, which yield a divergent contribution to $\Delta\tilde{\kappa}$. After evaluating the Feynman diagrams of Fig. 3, we arrive at an ultraviolet divergent amplitude, which is due to the presence of a nonrenormalizable interaction, thereby requiring a renormalization scheme. We have used the $\overline{\text{MS}}$ scheme with the renormalization scale $\mu = \tilde{\Lambda}$, which leads to a logarithmic dependence of the form $\log(\tilde{\Lambda}^2/m_W^2)$. After some algebra, the CP-odd form factors can be written in terms of two-point Passarino-Veltman scalar functions:

$$\begin{aligned}\Delta\tilde{\kappa} = -\frac{\tilde{\epsilon}_{HWW}\alpha}{4\pi s_W^2}\frac{1}{48(x_H - 4)}\Big[&16(7 + 6(B_W - B_{WH})) \\ &- 8(23 + 21B_H + 15B_W - 36B_{WH})x_H \\ &+ 3(25 + 26B_H + 4B_W - 30B_{WH})x_H^2 \\ &- 3(1 + B_H - B_{WH})x_H^3 + 9(x_H - 4)x_H\log\Big(\frac{\tilde{\Lambda}^2}{m_W^2}\Big)\Big],\end{aligned} \tag{11}$$

$$\Delta\tilde{Q} = -\frac{\tilde{\epsilon}_{HWW}\alpha}{4\pi s_W^2}\frac{1}{(x_H - 4)}[-4 + (5 + 2(2B_H + B_W - 3B_{WH}))x_H - 2(1 + B_H - B_{WH})x_H^2], \tag{12}$$

where $x_H = (m_H/m_W)^2$, $B_H = B_0(0, m_H^2, m_H^2)$, $B_W = B_0(0, m_W^2, m_W^2)$, and $B_{WH} = B_0(m_W^2, m_H^2, m_W^2)$. Notice that

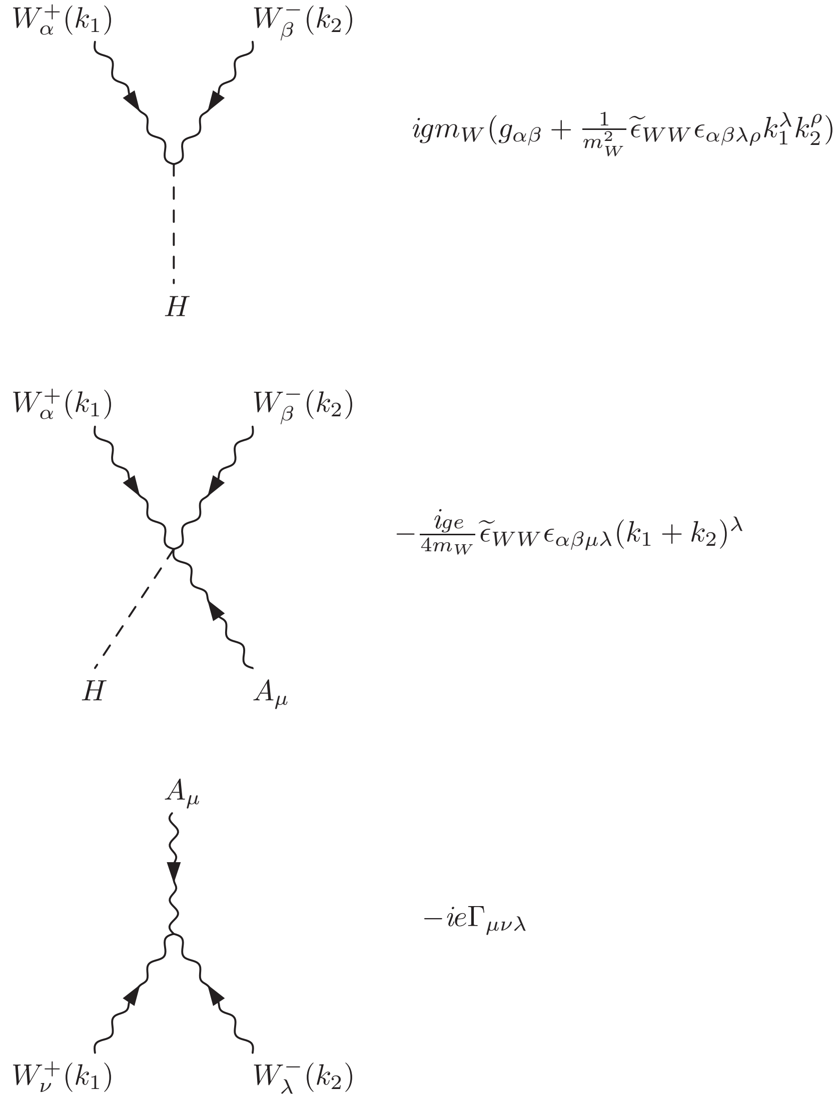

FIG. 2. Feynman rules for the vertices HWW, γHWW, and $WW\gamma$ in the unitary gauge.

the $\Delta\tilde{Q}$ form factor is ultraviolet finite, which is consistent with the fact that $\tilde{\mu}_W$ and $\tilde{Q}_W$ satisfy the relation $2\tilde{\mu}_W + m_W\tilde{Q}_W = 0$ in any renormalizable theory as $\Delta\tilde{Q}$ cannot arise at the one-loop level [3,16], but at higher orders. Since our calculation represents a two-loop or higher order effect in the fundamental theory, the contribution to $\Delta\tilde{Q}$ must be necessarily finite, in accordance with renormalization theory.

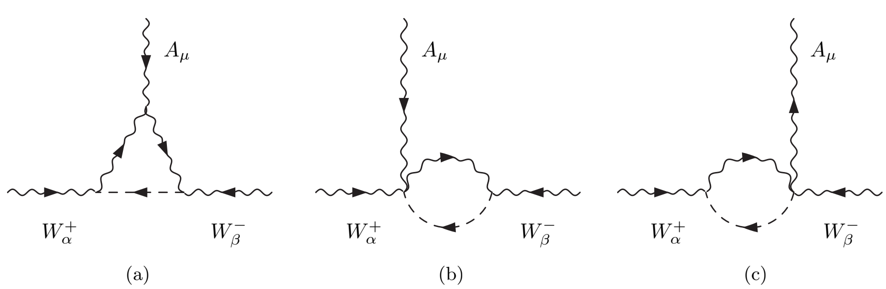

FIG. 3. Feynman diagrams contributing to the $WW\gamma$ vertex in the unitary gauge.

III. RESULTS AND DISCUSSION.

We turn now to our numerical results. The EDM and MQM of the W boson depend on three free parameters: the coupling constant $\tilde{\alpha}_{HWW}$, the new physics scale $\tilde{\Lambda}$, and the Higgs boson mass m_H. As already mentioned, the effective operator $(\Phi^\dagger\Phi)W^i_{\mu\nu}\tilde{W}^{i\mu\nu}$ can only be generated at one-loop or higher orders by the fundamental theory [25]. Assuming that it is induced at the one-loop level, the $\tilde{\alpha}_{HWW}$ parameter must contain a factor of $1/16\pi^2$ along with a g coupling for each gauge field. From these considerations, it is reasonable to assume that $\tilde{\alpha}_{HWW} \sim g^2/(16\pi^2)f$, where $f = f(v, \tilde{\Lambda})$ is a dimensionless loop function, whose specific structure depends on the details of the underlying physics. Since the CP-violating effects are expected to be of decoupling nature, f is expected to be of the order $O(1)$ at most. In order to make predictions, we will adopt a somewhat optimistic scenario, which consists in assuming that $f \sim 1$. We will thus make predictions under the assumption that $\tilde{\epsilon}_{HWW}$ has the following form:

$$\tilde{\epsilon}_{HWW} = \left(\frac{v}{\tilde{\Lambda}}\right)^2 \frac{\alpha}{4\pi s_W^2}. \tag{13}$$

We now would like to analyze the behavior of $\tilde{\mu}_W$ and $\tilde{Q}_W$ as a function of m_H and $\tilde{\Lambda}$. The dependence of $\tilde{\mu}_W$ ($\tilde{Q}_W$) on the Higgs boson mass is shown in Fig. 4 (Fig. 5) for m_H ranging between 120 and 200 GeV and for $\tilde{\Lambda} = 1$, 3, and 5 TeV. From these figures we can observe that $\tilde{\mu}_W$ and $\tilde{Q}_W$ are not very sensitive to the Higgs boson mass. In fact, for $\tilde{\Lambda} = 1$ TeV, $\tilde{\mu}_W$ ranges between 0.25×10^{-20} and 0.55×10^{-20} $e \cdot$ cm, whereas $\tilde{Q}_W$ goes from 1×10^{-36} to 2.5×10^{-36} $e \cdot \text{cm}^2$. As compared to the values obtained for $\tilde{\Lambda} = 1$ TeV, $\tilde{\mu}_W$ and $\tilde{Q}_W$ are decreased by a factor of 10^{-1} when $\tilde{\Lambda} = 3$ TeV and 5×10^{-1} when $\tilde{\Lambda} = 5$ TeV. Finally, the behavior of the W moments is shown in Fig. 6 as a function of $\tilde{\Lambda}$ and for $m_H = 160$ GeV.

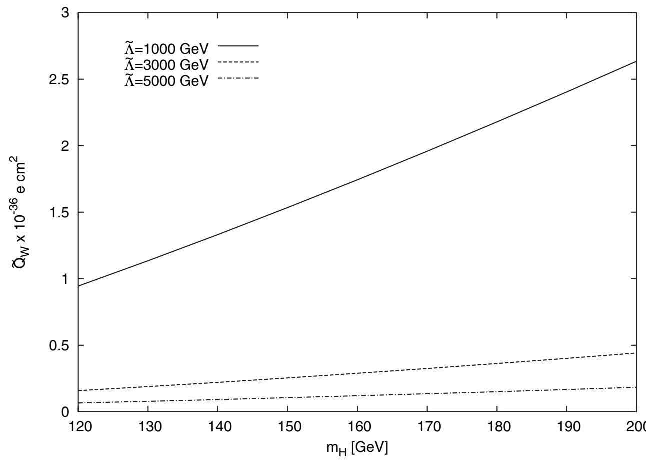

FIG. 5. The same as in Fig. 4 but now for the magnetic quadrupole moment $\tilde{Q}_W$.

It is worth comparing our results with those obtained in other scenarios. To begin with, we would like to discuss the SM predictions for $\tilde{\mu}_W$ and $\tilde{Q}_W$. As already noted, the lowest order nonzero contribution to $\tilde{\mu}_W$ arises at the three-loop level, whereas $\tilde{Q}_W$ appears up to the two-loop order. At the lowest order, $\tilde{\mu}_W$ has been estimated to be smaller than about 10^{-29} $e \cdot$ cm [10,26]. As far as $\tilde{Q}_W$ is concerned, it has been estimated to be about -10^{-51} $e \cdot \text{cm}^2$ [13]. In contrast, some SM extensions predict values for $\tilde{\mu}_W$ that are several orders of magnitude larger than the SM one. It must be emphasized here that all these studies have focused only on $\tilde{\mu}_W$. For instance, a value of 10^{-22} $e \cdot$ cm was estimated for $\tilde{\mu}_W$ in LRSM [10,16], and similar results were found in supersymmetric models, which induce this moment via one-loop diagrams mediated by charginos and neutralinos [10,27]. Also, a nonzero $\tilde{\mu}_W$ can arise through two-loop graphs in multi-Higgs models

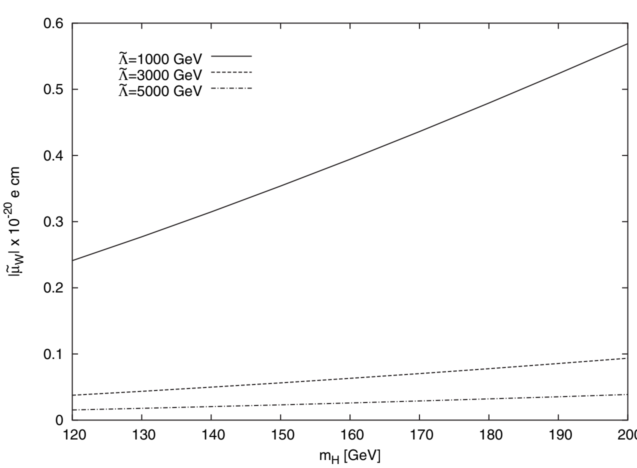

FIG. 4. The electric dipole moment $\tilde{\mu}_W$ as a function of m_H for $\tilde{\Lambda} = 1000$, 3000, and 5000 GeV.

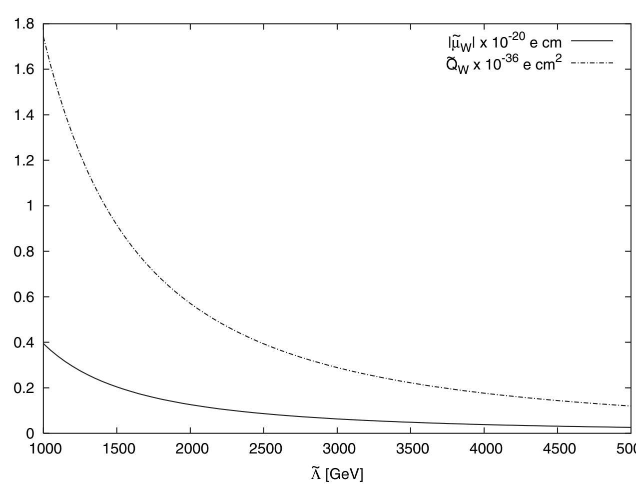

FIG. 6. The $\tilde{\mu}_W$ and $\tilde{Q}_W$ dependence on $\tilde{\Lambda}$ for $m_H = 160$ GeV.

[28]. Explicit calculations carried out within the context of THDMs show that $\tilde{\mu}_W \sim 10^{-20} - 10^{-21}\ e \cdot \mathrm{cm}$ [18]. A similar value was found in the context of the so-called 331 models, which induce a nonzero $\tilde{\mu}_W$ via two-loop graphs similar to the ones of THDM [29]. From these results, we can conclude that our model-independent estimation for $\tilde{\mu}_W$ lies within the range of the predictions obtained from some popular renormalizable theories.

It is well known that the W EDM and MQM can induce significant contributions to the EDM of light fermions. This fact was exploited by the authors of Ref. [14], who used the experimental upper bound on the neutron EDM, $d_n < 10^{-25}\ e \cdot \mathrm{cm}$, to obtain the upper bound $\tilde{\mu}_W < 10^{-20}\ e \cdot \mathrm{cm}$. Our prediction for $\tilde{\mu}_W$, which is 8 orders of magnitude larger than that of the SM, is consistent with this upper bound. As far as $\tilde{Q}_W$ is concerned, currently there is no indirect experimental upper bound, but we would like to emphasize that our result is quite remarkable as predicts that new physics effects are capable of enhancing $\tilde{Q}_W$ up to 15 orders of magnitude above the SM contribution.

As far as the direct observation of the CP-odd structure of the $WW\gamma$ vertex is concerned, the prospect of the NLC and CLIC [30] have triggered the interest in the $e^+e^- \rightarrow W^-W^+$ reaction as an efficient tool to produce large quantities of W boson pairs, which would allow one to study new physics effects on the WWV ($V = \gamma, Z$) vertex. The possibility of extracting CP-odd asymmetries from these colliders has been examined by several authors, mainly in a model-independent approach via effective Lagrangians [31]. These studies suggest that an effect in $\tilde{\mu}_W$ at the level of $10^{-20}\ e \cdot \mathrm{cm}$ may be at the experimental reach. Also, it is expected that careful studies on the polar and azimuthal distributions of lepton-antilepton pairs produced in W decays may further enhance the constraints on the size of $\tilde{\mu}_W$ [32].

IV. CONCLUSIONS

The origin of CP violation is a fascinating open problem worthwhile of both theoretical and experimental attention. Although flavor-diagonal CP-violating processes, such as the electric dipole and magnetic quadrupole moments of the W boson, are not induced by the CKM mechanism, their presence cannot be dismissed since they may represent a genuine effect of physics lying beyond the Fermi scale. This is suggested by many SM extensions predicting the existence of new sources of CP violation that may give sizeable contributions to the static quantities of the W boson. As far as renormalizable theories are concerned, the Yukawa sector of several SM extensions seems to be a potential source of CP violation since it may involve the presence of Higgs bosons with both scalar and pseudoscalar couplings to the fermions. In this work, we examined such a possibility via the model-independent approach of effective Lagrangians. We assumed the existence of new heavy fermions that generate the most general HWW vertex at the one-loop level. Such a CP-violating nonrenormalizable interaction was parametrized through an $SU_L(2) \times U_Y(1)$-invariant operator and combined with the usual CP-even SM coupling to calculate the one-loop contribution to the CP-odd structure of the on-shell $WW\gamma$ vertex. The fact that the dimension-six operator can only be generated at the one-loop level means that the CP-odd property of the $WW\gamma$ vertex is a two-loop effect in the fundamental theory. Explicit expressions for the form factors $\Delta\tilde{\kappa}$ and $\Delta\tilde{Q}$, which define the EDM and MQM of the W boson, were derived. An appropriate renormalization scheme was adopted in order to renormalize the divergent form factor $\Delta\tilde{\kappa}$. As for the form factor $\Delta\tilde{Q}$, its nondivergent nature reflects the fact that it cannot arise at the one-loop level in any renormalizable theory. Assuming reasonable values for the unknown parameters of the effective theory, the estimated values of the CP-odd electromagnetic moments are $\tilde{\mu}_W \sim 3 - 6 \times 10^{-20}\ e \cdot \mathrm{cm}$ and $\tilde{Q}_W \sim -10^{-36}\ e \cdot \mathrm{cm}^2$. These values are 8 and 15 orders of magnitude above the respective SM contributions. To our knowledge, this model-independent estimation for the size of the $\tilde{Q}_W$ is the first one obtained in theories beyond the SM. On the other hand, the value predicted for $\tilde{\mu}_W$ is of the same order of magnitude or larger than those predicted by some SM extensions, and it is consistent with the existing indirect upper bound derived from the neutron electric dipole moment.

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