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New Higgs couplings at e^+e^- and hadronic colliders

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We examine the potentiality of both CERN LEP and Fermilab Tevatron colliders to establish bounds on new couplings involving the bosonic sector of the standard model. We pay particular attention to the anomalous Higgs interactions with γ, $W^{\pm}$, and Z^0. A combined exclusion plot for the coefficients of different anomalous operators is presented. The sensitivity that can be achieved at the Next Linear Collider and at the upgraded Tevatron is briefly discussed. [S0556-2821(99)01607-0]

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I. INTRODUCTION: EFFECTIVE LAGRANGIANS FOR HIGGS INTERACTIONS

We certainly expect the standard model (SM), despite its astonishing success in describing all the precision high energy experimental data [1], to be an incomplete picture of nature at high energy scales. In particular, the Higgs sector of the model, responsible for the spontaneous electroweak symmetry breaking and for the mass generation, is introduced in an *ad hoc* way and has not yet been directly probed.

Although we do not know the specific theory which will eventually supersede the SM, we can always parametrize its effects by means of an effective Lagrangian [2] that contains operators with dimension higher than four and involves the fields and symmetries of the low energy theory. The effective Lagrangian approach is a model-independent way to describe new physics that is expected to manifest itself directly at an energy scale Λ, larger than the scale where the experiments are performed.

The effective Lagrangian depends on the particle content at low energies. We consider here the possibility of having a light Higgs boson that should be present in the higher dimensional operators. Hence, we use a linearly realized $SU_L(2)\times U_Y(1)$ invariant effective Lagrangian [3,4] to describe the bosonic sector of the SM, keeping the fermionic sector unchanged.

A general set of dimension-6 operators that involve gauge bosons and the Higgs scalar field, respecting local $SU_L(2)\times U_Y(1)$ symmetry, and C and P conserving, contains eleven operators [3]. Some of these operators either affect only the Higgs self-interactions or contribute to the gauge boson two-point functions at tree level and is strongly constrained from low energy physics below the present sensitivity of high energy experiments [4]. The remaining five ''blind'' operators can be written as [3,4]

$$\mathcal{L}_{\rm eff}=\sum_i \frac{f_i}{\Lambda^2}\mathcal{O}_i=\frac{1}{\Lambda^2}[f_{WWW}\ \ {\rm Tr}[\hat{W}_{\mu\nu}\hat{W}^{\nu\rho}\hat{W}^{\mu}_{\rho}] + f_W(D_\mu\Phi)^\dagger\hat{W}^{\mu\nu}(D_\nu\Phi)+f_B(D_\mu\Phi)^\dagger\hat{B}^{\mu\nu}(D_\nu\Phi) + f_{WW}\Phi^\dagger\hat{W}_{\mu\nu}\hat{W}^{\mu\nu}\Phi+f_{BB}\Phi^\dagger\hat{B}_{\mu\nu}\hat{B}^{\mu\nu}\Phi] \tag{1}$$

where Φ is the Higgs field doublet, $\hat{B}_{\mu\nu}=i(g'/2)B_{\mu\nu}$, and $\hat{W}_{\mu\nu}=i(g/2)\sigma^a W^a_{\mu\nu}$ with $B_{\mu\nu}$ and $W^a_{\mu\nu}$ being the field strength tensors of the $U(1)$ and $SU(2)$ gauge fields respectively. It is also possible to construct dimension-6 operators that modify the Higgs coupling to fermions, such as $(\Phi^\dagger\Phi)(\bar{F}f\Phi)$, where $F(f)$ is the left (right) -handed fermion doublet (singlet). These operators do not alter the fermionic interaction of the vector boson which is quite well measured. However, one expects that operators containing fermions are suppressed by powers of m_f/Λ, making their contribution negligible, with the exception of those involving the top quark which do not contribute to the processes studied here.

Anomalous $H\gamma\gamma$, $HZ\gamma$, and HZZ and HWW and couplings are generated by Eq. (1), which modify the Higgs boson production and decay [5]. In the unitary gauge they are given by

$$\mathcal{L}^{\rm H}_{\rm eff}=g_{H\gamma\gamma}HA_{\mu\nu}A^{\mu\nu}+g^{(1)}_{HZ\gamma}A_{\mu\nu}Z^{\mu}\partial^{\nu}H+g^{(2)}_{HZ\gamma}HA_{\mu\nu}Z^{\mu\nu} + g^{(1)}_{HZZ}Z_{\mu\nu}Z^{\mu}\partial^{\nu}H+g^{(2)}_{HZZ}HZ_{\mu\nu}Z^{\mu\nu}+g^{(2)}_{HWW}HW^{+}_{\mu\nu}W^{\mu\nu}_{-} + g^{(1)}_{HWW}(W^{+}_{\mu\nu}W^{\mu}_{-}\partial^{\nu}H+{\rm H.c.}) \tag{2}$$

where $A(Z)_{\mu\nu}=\partial_\mu A(Z)_\nu-\partial_\nu A(Z)_\mu$. The effective couplings $g_{H\gamma\gamma}$, $g^{(1,2)}_{HZ\gamma}$, and $g^{(1,2)}_{HZZ}$ and $g^{(1,2)}_{HWW}$ are related to the coefficients of the operators appearing in Eq. (1) and can be found elsewhere [5]. In particular the Higgs couplings to two photons is given by

$$g_{H\gamma\gamma}=-\left(\frac{gM_W}{\Lambda^2}\right)\frac{s^2(f_{BB}+f_{WW})}{2} \tag{3}$$

with g being the electroweak coupling constant, and $s(c)\equiv\sin(\cos)\theta_W$.

Equation (1) also generates new contributions to the triple gauge boson vertex [3,4]. The operators $\mathcal{O}_W$ and $\mathcal{O}_B$ give rise to both anomalous Higgs-gauge boson couplings and to new triple and quartic self-couplings amongst the gauge bosons, while the operator $\mathcal{O}_{WWW}$ solely modifies the gauge boson self-interactions. On the other hand $\mathcal{O}_{WW}$ and $\mathcal{O}_{BB}$ only affect HVV couplings, since their contribution to the $WW\gamma$ and WWZ tree-point couplings can be completely absorbed in the redefinition of the SM fields and gauge couplings [4,5]. Therefore, one cannot obtain any constraint on these couplings from the study of anomalous trilinear gauge boson couplings.

Anomalous Higgs boson couplings have been studied in Higgs and Z^0 boson decays [5], and in e^+e^- [6–10], $p\bar{p}$ [11–13] and $\gamma\gamma$ colliders [14]. In this work, we make a combined analysis, based on several experimental searches at the CERN e^+e^- collider LEP collider and at the Fermilab Tevatron collider, in order to establish the attainable bounds on the coefficient of the effective operators describing the anomalous bosonic sector. Our results are presented in Sec. II. In Sec. III we discuss the sensitivity that can be achieved at the Fermilab Tevatron upgrade and at the Next Linear Collider (NLC). Finally, in Sec. IV, we compare our results with existing limits on the coefficients of dimension-six operators based on searches for anomalous triple gauge boson couplings.

II. BOUNDS FROM THE RECENT LEP AND TEVATRON SEARCHES

In this section, we derive combined bounds on anomalous Higgs boson interactions taking into account both LEP [15] and Tevatron [16–18] data on the following signatures:

$$\begin{aligned} &e^+e^- \to \gamma\gamma\gamma \\ &p\bar{p} \to jj\gamma\gamma \\ &p\bar{p} \to \gamma\gamma + \not{E}_T \\ &p\bar{p} \to \gamma\gamma\gamma. \end{aligned} \tag{4}$$

Events containing two photons plus missing energy, additional photons or charged fermions represent a signature for several theories involving physics beyond the SM, such as some classes of supersymmetric models [19] and they have been extensively searched for [15–18]. In the framework of anomalous Higgs couplings presented before, they can also arise from the production of a Higgs boson which subsequently decays in two photons. In the SM, the decay width $H\to\gamma\gamma$ is very small since it occurs just at one-loop level [20]. However, the existence of the new interactions (2) can enhance this width in a significant way. Recent analyses of these signatures presented a good agreement with the expectations from the SM. Thus we can employ these negative experimental results to constrain new anomalous couplings in the bosonic sector of the SM.

We have included in our calculations all SM (QCD plus electroweak), and anomalous contributions that lead to these final states. The SM one-loop contributions to the $H\gamma\gamma$ and $HZ\gamma$ vertices were introduced through the use of the effective operators with the corresponding form factors in the coupling. Neither the narrow-width approximation for the Higgs boson contributions, nor the effective W boson approximation were employed. We consistently included the effect of all interferences between the anomalous signature and the SM background. The SM Feynman diagrams corresponding to the background subprocess were generated by MADGRAPH [21] in the framework of Helas [22]. The anomalous couplings arising from the Lagrangian (1) were implemented in FORTRAN routines and were included accordingly. For the $p\bar{p}$ processes, we have used the Martin-Roberts-Stirling set G [MRS (G)] [23] set of proton structure functions with the scale $Q^2=\hat{s}$.

All processes listed in Eq. (4) have been the object of direct experimental searches. In our analysis we have closely followed theses searches in order to make our study as realistic as possible. In order to establish bounds on the values of the anomalous coefficients $f_i, i=WW,BB,W,B,$ we have imposed an upper limit on the number of signal (anomalous) events based on Poisson statistics. In the absence of background this implies $N_{\text{signal}}<1(3)$ at 64% (95%) C.L. In the presence of background events, we employed the modified Poisson analysis [24].

For events containing three photons in the final state at electron-positron collisions [8],

$$e^+e^- \to \gamma + H(\to\gamma\gamma), \tag{5}$$

we have used the recent OPAL data [15] where data taken at several energy points in the range $\sqrt{s}=130$–172 GeV, were combined. They have established an upper limit at 95% C.L. for $\sigma(e^+e^-\to\gamma+X)\times BR(X\to\gamma\gamma)$ where X is a scalar particle. These results were used to derive our limits.

The process

$$p\bar{p} \to W(Z)(\to jj) + H(\to\gamma\gamma) \tag{6}$$

can also be employed to further constrain the anomalous Higgs boson couplings described in Eq. (2) [11]. DØ Collaboration reported the results for the search of high invariant-mass photon pairs in $p\bar{p}\to\gamma\gamma jj$ events [16] at $\sqrt{s}=1.8$ TeV and 100 pb^{-1} of integrated luminosity. In our analysis, we applied the same cuts of Ref. [16] and included the particle identification and trigger efficiencies. We have searched for Higgs boson with mass in the range $100<M_H\lesssim 220$, since after the $WW(ZZ)$ threshold is reached the diphoton branching ratio of Higgs boson is quite reduced. Since no event with two-photon invariant mass in the range $100<M_{\gamma\gamma}\lesssim 220$ were observed, a 95% C.L. in the determination of the anomalous coefficient f_i is attained requiring 3 events coming only from the anomalous contributions.

For events containing two photons plus large missing transverse energy ($\gamma\gamma\not{E}_T$) [12] we have used the results from DØ Collaborations [17]. Anomalous Higgs couplings can give rise to this final state via

$$\begin{aligned} &p\bar{p} \to Z^0(\to\nu\bar{\nu}) + H(\to\gamma\gamma) + X \\ &p\bar{p} \to W(\to l\nu) + H(\to\gamma\gamma) + X \end{aligned} \tag{7}$$

where in the latter case the charged lepton ($l=e,\mu$) escapes undetected.

TABLE I. 95% C.L. allowed range for f/Λ^2, from $\gamma\gamma\gamma$ production at LEP OPAL data and Tevatron CDF data analysis, from $\gamma\gamma+\not\!\!E_T$ Tevatron DØ data analysis, and from $\gamma\gamma jj$ Tevatron DØ data analysis assuming all f_i to be equal. We denote by ''—'' limits worse than $|f|=200$ TeV^{-2}.

M_H(GeV)	f/Λ^2(TeV^{-2})			
	$e^+e^-\to\gamma\gamma\gamma$ at LEP	$p\bar{p}\to\gamma\gamma\gamma$ at CDF	$p\bar{p}\to\gamma\gamma+\not\!\!E_T$ at DØ	$p\bar{p}\to\gamma\gamma jj$ at DØ
100	(−64 , 57)	(−62 , 65)	(−28 , 57)	(−16 , 42)
120	(−82 , 70)	(−76 , 77)	(−37 , 62)	(−19 , 46)
140	(−192 , 175)	(−92 , 93)	(−48 , 72)	(−26 , 49)
160	—	(−113 , 115)	(−62 , 84)	(−33 , 56)
180	—	—	(−103 , 123)	(−63 , 81)
200	—	—	(−160 , 164)	(−96 , 99)
220	—	—	—	(−126 , 120)

In order to compare our predictions with the results of DØ Collaboration, we have applied the same cuts of last article in Ref. [17]. After these cuts we find that 80% to 90% of the signal comes from associated Higgs-Z^0 production while 10% to 20% arises from Higgs-W. We also include in our analysis the particle identification and trigger efficiencies which vary from 40% to 70% per photon [25]. Since no event with two-photon invariant mass in the range $100<M_{\gamma\gamma}\lesssim 2M_W$ were observed, a 95% C.L. in the determination of the anomalous coefficient $f_i, i=WW,BB,W,B$ is attained requiring 3 events coming only from the anomalous contributions. Table I shows the 95% C.L. allowed region of the anomalous couplings in the above scenario. We exhibit in Fig. 1 the 95% C.L. exclusion region in the plane $f_{BB}\times f_{WW}$ obtained from the DØ data on $\gamma\gamma+\not\!\!E_T$ [17].

Finally we have also analyzed events with three photons in the final state [13]

$$p\bar{p}\to\gamma+H(\to\gamma\gamma), \tag{8}$$

and compare our results with the recent search reported by CDF Collaboration [18] for this signature. They looked for $\gamma\gamma\gamma$ events requiring two photons in the central region of the detector, with a minimum transverse energy of 12 GeV, plus an additional photon with $E_T>25$ GeV. The photons were required to be separated by more than 15°. In these conditions they were able to establish that the signal should have less than 3 events, in the 85 pb^{-1} collected data, at 95% C.L.

We have used the results described above to constrain the value of the coefficients f_i of Eq. (1). The coupling $H\gamma\gamma$ (3) involves f_{WW} and f_{BB} [5], and in consequence, the anomalous signature $f\bar{f}\gamma\gamma$ is only possible when those couplings are not vanishing. The couplings f_B and f_W, on the other hand, affect the production mechanisms for the Higgs boson. In Fig. 1(a) we present our results for the excluded region in the f_{WW}, f_{BB} plane from the different channels studied for $M_H=100$ GeV assuming that these are the only nonvanishing couplings. Since the anomalous contribution to $H\gamma\gamma$ is zero for $f_{BB}=-f_{WW}$, the bounds become very weak close to this line, as is clearly shown in Fig. 1.

In order to reduce the number of free parameters one can make the assumption that all blind operators affecting the Higgs interactions have a common coupling f, i.e., $f=f_W=f_B=f_{WW}=f_{BB}$ [4,5,26]. We present in Table I the 95% C.L. allowed regions of the anomalous couplings in this scenario, for different Higgs boson mass.

These results obtained from the analysis of the four reactions (4) can be statistically combined in order to obtain a better bound on the coefficient of the effective operators (1). We exhibit in Fig. 1(b) the 95% C.L. exclusion region in the plane $f_{BB}\times f_{WW}$ obtained from combined results. In Fig. 2, we present the combined limits for the coupling constant $f=f_{BB}=f_{WW}=f_B=f_W$ (upper scale) for Higgs boson masses in the range of $100\leq M_H\leq 220$ GeV.

III. FUTURE PERSPECTIVES

The effect of the anomalous operators becomes more evident with the increase of energy, and higher sensitivity to smaller values of the anomalous coefficients can be achieved by studying their contribution to different processes at the upgraded Tevatron collider or at new machines, like the Next Linear Collider.

We first extend our analysis of the $p\bar{p}\to\gamma\gamma\not\!\!E_T$ and $p\bar{p}\to\gamma\gamma jj$ reactions for the upgraded Tevatron collider. We have considered the run II upgrade with a luminosity of 1 fb^{-1}, and for the TeV33 upgrade we assumed 10 fb^{-1} [27]. In our estimates we have taken the same cuts and detection efficiencies given in our previous analysis.

For the $\gamma\gamma\gamma$ final state we have studied the improvement on the sensitivity to the anomalous coefficients by implementing additional kinematical cuts [13]. Best results are obtained for the following set of cuts: $E_{T_1}>40$ GeV, with $E_{T_{2,3}}>12$ GeV where we have ordered the three photons according to their transverse energy, i.e., $E_{T_1}>E_{T_2}>E_{T_3}$. We always require the photons to be in the central region of the detector ($|\eta_i|<1$) where there is sensitivity for electromagnetic showering. In our estimates we assume the same detection efficiency for photons as considered by Collider Detector at Fermilab (CDF) Collaboration [18].

In Table II we present the 95% C.L. limit on the anomalous couplings for Tevatron run II and for TeV33 for each individual process. All couplings are assumed equal ($f=f_{BB}=f_{WW}=f_B=f_W$) and the Higgs boson mass is varied

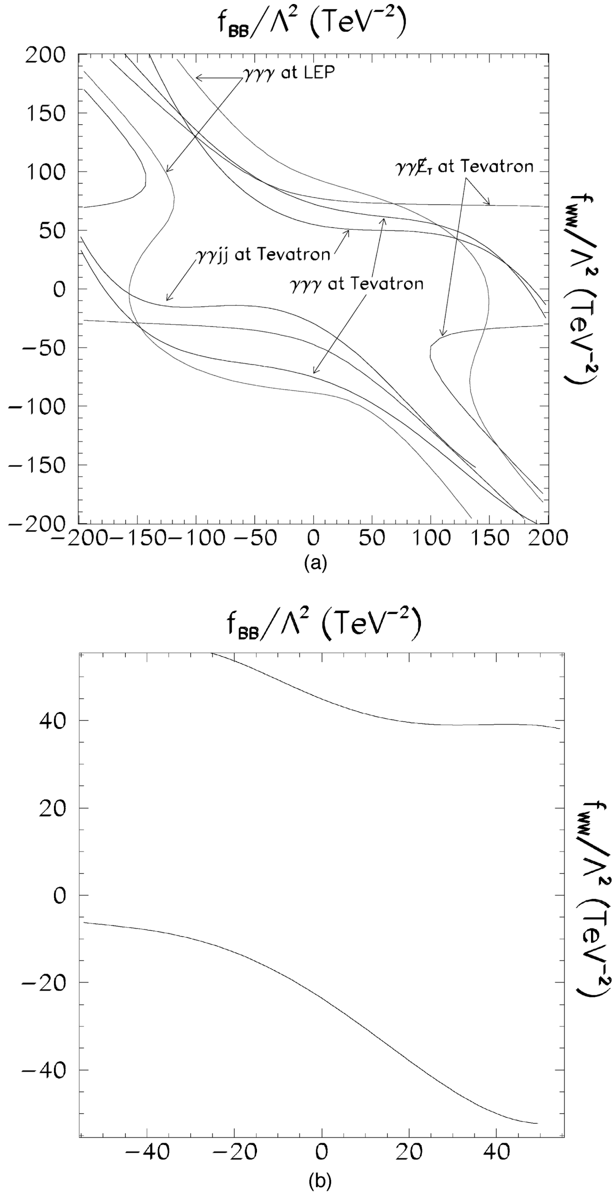

FIG. 1. **(a)** Exclusion region outside the curves in the $f_{BB} \times f_{WW}$ plane, in TeV^{-2}, based on the CDF analysis [18] of $\gamma\gamma\gamma$ production, on the DØ analysis [16] of $\gamma\gamma jj$ production, on the DØ analysis [17] of $\gamma\gamma\not{E}_T$, and on the OPAL analysis [15] of $\gamma\gamma\gamma$ production, always assuming $M_H=100$ GeV. The curves show the 95% C.L. deviations from the SM total cross section. **(b)** Same as (a) for the combined analysis.

in the range $100 \leqslant M_H \leqslant 220$ GeV. Combination of the results obtained from the analysis of the three reactions (6), (7), (8) leads to the improved bounds given in the last column of Table II. Comparing these results with those in Table I (or with the upper scale of Fig. 2) we observe an improvement of about a factor $\sim 2-3$ [$\sim 4-6$] for the combined limits at run II [TeV33].

The Next Linear electron-positron Collider will open an important opportunity to further improve the search for new physics. In particular, the anomalous Higgs boson couplings can be investigated in the processes [9,10]:

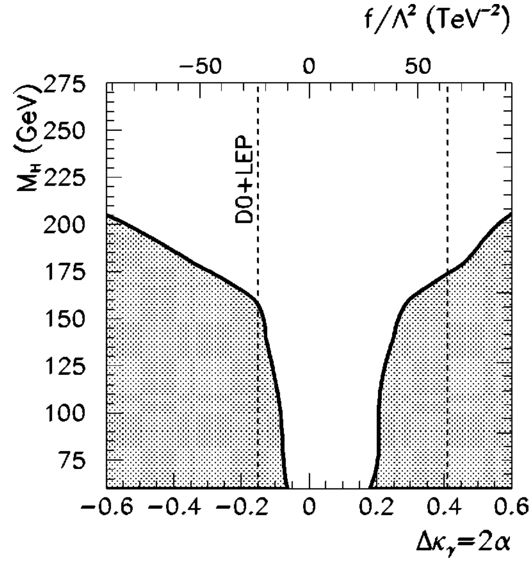

FIG. 2. Excluded region in the $f \times M_H$ plane from the combined analysis of the $\gamma\gamma\gamma$ production at LEP, $\gamma\gamma\gamma, \gamma\gamma+\not{E}_T$, and $\gamma\gamma jj$ production at Tevatron, assuming that all f_i are equal (see text for details).

$$e^+e^- \to W^+W^-\gamma \tag{9}$$

$$e^+e^- \to Z^0Z^0\gamma. \tag{10}$$

We studied the sensitivity of NLC to these processes assuming a energy in the center-of-mass of $\sqrt{s}=500$ GeV and an integrated luminosity $\mathcal{L}=50$ fb^{-1}. We adopted a cut in the photon energy of $E_\gamma > 20$ GeV and required the angle between any two particles to be larger than 15°. We have analyzed these processes for different values of the Higgs boson mass.

TABLE II. 95% C.L. allowed range for f/Λ^2, from $\gamma\gamma\gamma, \gamma\gamma+\not{E}_T, \gamma\gamma jj$ production at Tevatron run II [TeV33] assuming all f_i to be equal. We denote by "—" limits worse than $|f|=100$ TeV^{-2}.

M_H(GeV)	f/Λ^2(TeV^{-2})			
	$p\bar{p}\to\gamma\gamma\gamma$	$p\bar{p}\to\gamma\gamma+\not{E}_T$	$p\bar{p}\to\gamma\gamma jj$	Combined
100	(−24 , 24)	(−16 , 36)	(−9.2 , 22)	(−7.6 , 19)
	[−13 , 15]	[−9.4 , 26]	[−3.3 , 5.6]	[−3 , 5.6]
120	(−26 , 26)	(−20 , 39)	(−8.6 , 21)	(−7.4 , 18)
	[−14 , 14]	[−15 , 27]	[−3.4 , 5.9]	[−3.3 , 5.9]
140	(−30 , 31)	(−25 , 44)	(−10 , 23)	(−9.1 , 20)
	[−15 , 16]	[−14 , 30]	[−4.5 , 8.9]	[−4.0 , 8.7]
160	(−36 , 38)	(−29 , 50)	(−11 , 24)	(−9.9 ,22)
	[−17 , 19]	[−14 , 33]	[−6.0 , 14]	[−5.1 , 13]
180	—	(−63 , 72)	(−26 , 34)	(−24 , 33)
	—	[−46 , 53]	[−16 , 24]	[−16 , 24]
200	—	(−87 , 90)	(−33 , 40)	(−32 , 39)
	—	[−50 , 53]	[−17 , 23]	[−17 , 23]
220	—	—	(−42 , 45)	(−42, 45)
	—	—	[−19, 26]	[−19, 26]

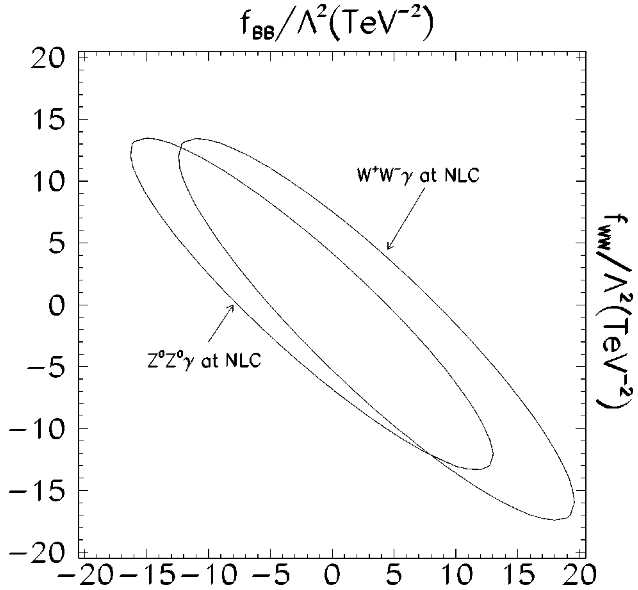

FIG. 3. Contour plot of $f_{BB}\times f_{WW}$, from $e^+e^-\to W^+W^-\gamma$ and $e^+e^-\to Z^0Z^0\gamma$ at NLC, for $M_H=200$ GeV with a cut of $p_{T_\gamma}>100$ GeV. The curves show the 95% C.L. deviations from the SM total cross section.

We have investigated different distributions of the final state particles in order to search for kinematical cuts that could improve the NLC sensitivity. The most promising variable is the photon transverse momentum. We observe that the contribution of the anomalous couplings is larger in the high p_{T_γ} region. Since the anomalous signal is dominated by on-mass-shell Higgsγ production with the subsequent $H\to W^+W^-$ or Z^0Z^0 decay, the photon transverse momentum is distributed around the monochromatic peak $E_\gamma^{\mathrm{mono}}=(s-M_H^2)/(2\sqrt{s})$. In consequence for Higgs boson masses in the range $2M_{W,Z}\leqslant M_H\leqslant(\sqrt{s}-E_\gamma^{\mathrm{min}})$ GeV, where on-shell production is allowed, a cut of $p_{T_\gamma}\gtrsim 100$ drastically reduces the background. For lighter Higgs bosons, e.g., $M_H<2M_{W,Z}$, the p_{T_γ} cut is ineffective since the Higgs boson is off-mass-shell and the peak in the photon transverse momentum distribution disappears. This makes the bounds on the anomalous coefficients obtained from the $W^+W^-(Z^0Z^0)\gamma$ production to be very loose.

In Fig. 3 we show the 95% C.L. exclusion region in the plane $f_{BB}\times f_{WW}$ for $M_H=200$ GeV from the study of reactions (9) and (10). Notice that for these two reactions the exclusion region closes the gap at $f_{BB}=-f_{WW}$ since the anomalous decay widths $H\to W^+W^-(Z^0Z^0)$ do not vanish along this axis [5].

We present in Table III the limits on the coefficient f/Λ^2 based on a 95% C.L. deviation in the total cross section for a Higgs mass in the range $170\leqslant M_H\leqslant 350$ GeV. The results coming from the $Z^0Z^0\gamma$ production are a little better than the ones obtained from $W^+W^-\gamma$ production, and they are one order of magnitude better than the actual limits derived from LEP and Tevatron data analyses.

TABLE III. 95% C.L. allowed range for f/Λ^2, from $W^+W^-\gamma$ and $Z^0Z^0\gamma$ production at NLC, assuming all f_i to be equal.

M_H(GeV)	$f/\Lambda^2(\mathrm{TeV}^{-2})$	
	$e^+e^-\to W^+W^-\gamma$ at NLC	$e^+e^-\to Z^0Z^0\gamma$ at NLC
170	(−2.3 , 3.7)	—
200	(−3.2 , 4.0)	(−2.6, 3.9)
250	(−4.3 , 4.8)	(−3.2 , 4.3)
300	(−6.3 , 6.3)	(−4.7 , 5.2)
350	(−12 , 9.5)	(−7.1 , 8.3)

IV. DISCUSSION

So far we have estimated the limits on anomalous dimension-six Higgs boson interactions that can be derived from the study of several signatures at LEP and Tevatron colliders. Combined results from the different reactions were established. We compare now these results with existing limits on the coefficients of other dimension-six operators.

As discussed in Sec. I, for linearly realized effective Lagrangians, the modifications introduced in the Higgs and in the vector boson sector are related to each other. In consequence, the bounds on the new Higgs couplings should also restrict the anomalous gauge-boson self interactions. Under the assumption of equal coefficients for all anomalous Higgs operators, we can relate the common Higgs boson anomalous coupling f with the conventional parametrization of the vertex WWV $(V=Z^0,\gamma)$ [28],

$$\Delta\kappa_\gamma=\frac{M_W^2}{\Lambda^2}f,$$

$$\Delta\kappa_Z=\frac{M_Z^2}{2\Lambda^2}(1-2s_W^2)f, \quad (11)$$

$$\Delta g_1^Z=\frac{M_Z^2}{2\Lambda^2}f.$$

A different set of three independent couplings has been also used by the LEP Collaborations [29]: $\alpha_{B\Phi},\alpha_{W\Phi}$, and α_W. These parameters are related to the parametrization of Ref. [28] through $\alpha_{B\Phi}\equiv\Delta\kappa_\gamma-\Delta g_1^Z c_W^2, \alpha_{W\Phi}\equiv\Delta g_1^Z c_W^2, \alpha_W\equiv\lambda_\gamma$, or in terms of the anomalous Higgs boson coupling f by

$$\alpha=\alpha_{B\Phi}=\alpha_{W\Phi}=\frac{M_W^2}{2\Lambda^2}f=\frac{\Delta\kappa_\gamma}{2}. \quad (12)$$

The current experimental limit on these couplings from combined results on double gauge boson production at Tevatron and LEP II [30] is

$$-0.15<\Delta\kappa_\gamma=2\alpha<0.41 \quad (13)$$

at 95 % C.L. This limit is derived under the relations given in Eq. (11) [4].

TABLE IV. 95% C.L. allowed range for the anomalous triple gauge boson couplings derived from the limits obtained for the anomalous Higgs boson coupling f.

Process	M_H (GeV)	$\Delta\kappa_\gamma = 2\alpha = 2\alpha_{B\Phi} = 2,\alpha_{W\Phi}$
Combined Tevatron runI + LEPII	100	$(-0.084$, $0.204)$
Combined Tevatron runII	100	$(-0.048$, $0.122)$
Combined Tevatron TeV33	100	$(-0.020$, $0.036)$
$e^+e^- \to W^+W^-\gamma$ at NLC	200	$(-0.020$, $0.026)$
$e^+e^- \to Z^0Z^0\gamma$ at NLC	200	$(-0.016$, $0.024)$

In Table IV, we present the 95% C.L. limit of the anomalous coupling $\Delta\kappa_\gamma$ using the limits on f/Λ^2 obtained through the analysis of the processes considered in Sec. II. We also present the expected bounds that will be reachable at the upgraded Tevatron and at the NLC. Our results show that the present combined limit from the Higgs production analysis obtained in this paper is comparable with the existing bound from gauge boson production (13) for $M_H \leq 170$ GeV, as can be seen in Fig. 2 (lower scale).

Summarizing, we have estimated the limits on anomalous dimension-six Higgs boson interactions that can be derived from the investigation of three photon events at LEP2 and Tevatron and diphoton plus missing transverse energy events or dijets at Tevatron. Under the assumption that the coefficients of the four ''blind'' effective operators contributing to Higgs-vector boson couplings are of the same magnitude, the study can give rise to a significant indirect limit on anomalous WWV couplings. We have also studied the expected improvement on the sensitivity to Higgs anomalous couplings at the Fermilab Tevatron upgrades and at the Next Linear Collider.

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