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Probing Intermediate Mass Higgs Interactions at the CERN Large Hadron Collider

O. J. P. Éboli [1], M. C. Gonzalez–Garcia [2], S. M. Lietti [3], and S. F. Novaes [1]
[1] *Instituto de Física Teórica, Universidade Estadual Paulista, Rua Pamplona 145, 01405–900, São Paulo, Brazil*
[2] *Instituto de Física Corpuscular IFIC CSIC–Universidad de Valencia, Edificio Institutos de Paterna, Apartado 2085, 46071 Valencia*
[3] *Lawrence Berkeley National Laboratory Berkeley, CA 94720, USA*
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Abstract

We analyze the potentiality of the CERN Large Hadron Collider to probe the Higgs boson couplings to the electroweak gauge bosons. We parametrize the possible deviations of these couplings due to new physics in a model independent way, using the most general dimension–six effective lagrangian where the $SU(2)_L \otimes U(1)_Y$ is realized linearly. For intermediate Higgs masses, the decay channel into two photons is the most important one for Higgs searches at the LHC. We study the effects of these new interactions on the Higgs production mechanism and its subsequent decay into two photons. We show that the LHC will be sensitive to new physics scales beyond the present limits extracted from the LEP and Tevatron physics.

I. INTRODUCTION

The search for the Higgs boson and the study of the $SU(2)_L \otimes U(1)_Y$ symmetry breaking mechanism are the main goals of the present and future high energy experiments [1]. At present, the best available limit on the Higgs mass arises from searches at the CERN LEP collider. The ALEPH Collaboration analysis of the 1999 data with integrated luminosities of 29 pb^{-1} at $\sqrt{s} = 191.6$ GeV and 69.5 pb^{-1} at $\sqrt{s} = 195.6$ GeV [2] yields $M_H > 98.8$ GeV at 95% CL. A next step will be given by the CERN Large Hadron Collider (LHC) that will be able to detect the standard Higgs boson in the decay channel $H \to \gamma\gamma$ for masses in the range of 100–150 GeV [3,4].

If a Higgs boson is observed then it is imperative to verify whether its couplings are in agreement with the ones predicted by the Standard Model (SM) with a single scalar doublet. In the SM, the precise form of the Higgs couplings to the gauge bosons and its self–couplings are completely determined in terms of one free parameter which can be chosen to be the Higgs mass M_H. However, in this simple realization, the theory presents the problem that the quantum corrections to the Higgs mass are quadratically divergent with the cut–off. This implies the necessity of a large fine–tuning in order to keep the theory perturbative up to very high energies, or, conversely, the existence of new physics which manifest itself above a certain scale Λ. If the energy scale of new physics is large compared to the electroweak scale and there is no new light resonances, we can represent its impact on Higgs boson properties via the introduction of effective operators [5]. In this approach, we parametrize the Higgs anomalous interactions by the most general dimension–six effective lagrangian with the linear realization of the $SU(2)_L \otimes U(1)_Y$ symmetry.

In the linear realization of the SM there are eleven C and P conserving dimension–six operators with some of them contributing at tree level to well measured observables, and consequently being severely constrained [6,7]. In Ref. [6] it was argued that it is unnatural to expect a large hierarchy between the coefficients of the various dimension–six operators independently on whether they do or do not contribute at tree level to the low energy observables. As a consequence the existing limits coming from the LEP I physics would preclude the direct observation of new effects in the processes accessible at LEP II and Tevatron.

In this work, we study the potentiality of the CERN LHC to probe the interactions of an intermediate mass Higgs boson and consequently its sensitivity to new physics scales beyond the constraints stemming from the tree level contribution of the effective operators to low energy observables. For intermediate Higgs masses, the decay channel $H \to \gamma\gamma$ is the most important one for the Higgs search at the LHC. Moreover the effect of the additional Higgs interactions on the properties of an intermediate mass Higgs can be more easily seen in processes that are suppressed in the SM, such as the Higgs decay into two photons. In the SM, this decay occurs only at one–loop level, and it can be enhanced (or suppressed) by the anomalous interactions.

We analyze the Higgs production and subsequent decay into two photons through gluon–gluon fusion

$$pp \;\to\; gg \;\to\; H \;(\to\; \gamma\gamma) \;, \tag{1}$$

as well as through vector–boson fusion mechanism

$$pp \rightarrow qq'VV \rightarrow j + j + H(\rightarrow \gamma\gamma) \ . \tag{2}$$

with $V = W^{\pm}$ or Z^0. We show that the LHC will be able to expand considerably the present sensitivity on the dimension–six Higgs couplings, being able to probe new physics scales as large as 2.2 TeV, provided that the Higgs is observed. In this case, our results show that the LHC will be able to improve the limits arising from the tree level contribution to the LEP I observables, which are presently the most severe constraint. Furthermore, there is also a distinct possibility, *i.e.* the existence of anomalous Higgs interactions reduces its decay into two photons. In this case, no signal will be observed in the above reactions, and, consequently, if the Higgs is observed in other decay channel, the existence of non–vanishing anomalous couplings could also be established.

II. EFFECTIVE HIGGS INTERACTIONS AND PRESENT BOUNDS

In the linear representation of the $SU(2)_L \otimes U(1)_Y$ symmetry breaking mechanism, the SM model is the lowest order approximation while the first corrections, which are of dimension six, can be written as

$$\mathcal{L}_{\text{eff}} = \sum_n \frac{f_n}{\Lambda^2} \mathcal{O}_n \ , \tag{3}$$

where the operators $\mathcal{O}_n$ involve vector–boson and/or Higgs–boson fields with couplings f_n [8]. This effective Lagrangian describes the phenomenology of models that are somehow close to the SM since a light Higgs scalar doublet is still present at low energies. Of the eleven possible operators $\mathcal{O}_n$ that are P and C even, only seven of them modify the Higgs–boson couplings to vector bosons [7,9],

$$\begin{aligned}
\mathcal{O}_{BW} &= \Phi^{\dagger} \hat{B}_{\mu\nu} \hat{W}^{\mu\nu} \Phi \ , \\
\mathcal{O}_{WW} &= \Phi^{\dagger} \hat{W}_{\mu\nu} \hat{W}^{\mu\nu} \Phi \ , \\
\mathcal{O}_{BB} &= \Phi^{\dagger} \hat{B}_{\mu\nu} \hat{B}^{\mu\nu} \Phi \ , \\
\mathcal{O}_{W} &= (D_{\mu}\Phi)^{\dagger} \hat{W}^{\mu\nu} (D_{\nu}\Phi) \ , \\
\mathcal{O}_{B} &= (D_{\mu}\Phi)^{\dagger} \hat{B}^{\mu\nu} (D_{\nu}\Phi) \ , \\
\mathcal{O}_{\Phi,1} &= (D_{\mu}\Phi)^{\dagger} \, \Phi^{\dagger}\Phi \, (D^{\mu}\Phi) \ , \\
\mathcal{O}_{\Phi,2} &= \frac{1}{2} \partial^{\mu} \left(\Phi^{\dagger}\Phi\right) \partial_{\mu} \left(\Phi^{\dagger}\Phi\right) \ ,
\end{aligned} \tag{4}$$

where Φ is the Higgs doublet, D_μ the covariant derivative, $\hat{B}_{\mu\nu} = i(g'/2)B_{\mu\nu}$, and $\hat{W}_{\mu\nu} = i(g/2)\sigma^a W^a_{\mu\nu}$, with $B_{\mu\nu}$ and $W^a_{\mu\nu}$ being respectively the $U(1)_Y$ and $SU(2)_L$ field strength tensors. It is interesting to notice that the operators $\mathcal{O}_{\Phi,1}$ and $\mathcal{O}_{\Phi,2}$ contribute to the weak boson mass and Higgs wave function, which in turn leads to new Higgs couplings to the gauge bosons.

The effective operators in Eq. (4) give rise to anomalous $H\gamma\gamma$, $HZ\gamma$, HZZ, and HW^+W^- couplings, which, in the unitary gauge, are given by

$$
\begin{aligned}
\mathcal{L}_{\rm eff}^{\rm HVV} = & \, g_{H\gamma\gamma} \; H A_{\mu\nu} A^{\mu\nu} + g^{(1)}_{HZ\gamma} \; A_{\mu\nu} Z^{\mu} \partial^{\nu} H + g^{(2)}_{HZ\gamma} \; H A_{\mu\nu} Z^{\mu\nu} \\
& + g^{(1)}_{HZZ} \; Z_{\mu\nu} Z^{\mu} \partial^{\nu} H + g^{(2)}_{HZZ} \; H Z_{\mu\nu} Z^{\mu\nu} + h^{(3)}_{HZZ} \; H Z_{\mu} Z^{\mu} \\
& + g^{(1)}_{HWW} \; \left(W^{+}_{\mu\nu} W^{-\,\mu} \partial^{\nu} H + \text{h.c.} \right) + g^{(2)}_{HWW} \; H W^{+}_{\mu\nu} W^{-\,\mu\nu} + g^{(3)}_{HWW} \; H W^{+}_{\mu} W^{-\,\mu} \;\; ,
\end{aligned}
\tag{5}
$$

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 $g^{(1,2,3)}_{HZZ}$ are related to the coefficients of the operators appearing in (3) through,

$$
\begin{aligned}
g_{H\gamma\gamma} &= - \left(\frac{g M_W}{\Lambda^2} \right) \frac{s^2 (f_{BB} + f_{WW} - f_{BW})}{2} \;\; , \\
g^{(1)}_{HZ\gamma} &= \left(\frac{g M_W}{\Lambda^2} \right) \frac{s (f_W - f_B)}{2c} \;\; , \\
g^{(2)}_{HZ\gamma} &= \left(\frac{g M_W}{\Lambda^2} \right) \frac{s [2 s^2 f_{BB} - 2 c^2 f_{WW} + (c^2 - s^2) f_{BW}]}{2c} \;\; , \\
g^{(1)}_{HZZ} &= \left(\frac{g M_W}{\Lambda^2} \right) \frac{c^2 f_W + s^2 f_B}{2c^2} \;\; , \\
g^{(2)}_{HZZ} &= - \left(\frac{g M_W}{\Lambda^2} \right) \frac{s^4 f_{BB} + c^4 f_{WW} + c^2 s^2 f_{BW}}{2c^2} \;\; , \\
g^{(3)}_{HZZ} &= \left(\frac{g M_W v^2}{\Lambda^2} \right) \frac{f_{\Phi,1} - f_{\Phi,2}}{4c^2} \;\; , \\
g^{(1)}_{HWW} &= \left(\frac{g M_W}{\Lambda^2} \right) \frac{f_W}{2} \;\; , \\
g^{(2)}_{HWW} &= - \left(\frac{g M_W}{\Lambda^2} \right) f_{WW} \;\; , \\
g^{(3)}_{HWW} &= - \left(\frac{g M_W v^2}{\Lambda^2} \right) \frac{f_{\Phi,1} + 2 f_{\Phi,2}}{4} \;\; ,
\end{aligned}
\tag{6}
$$

with g being the electroweak coupling constant and $s(c) \equiv \sin(\cos)\theta_W$. In the couplings $g^{(3)}_{HZZ}$ and $g^{(3)}_{HWW}$ we have also included the effects arising from the contribution of the operators $\mathcal{O}_{\Phi,1}$ and $\mathcal{O}_{\Phi,2}$ to the renormalization of the weak boson masses and the Higgs field wave function.

The operators $\mathcal{O}_{\Phi,1}$ and $\mathcal{O}_{BW}$ contribute at tree level to the vector–boson two–point functions, and consequently are severely constrained by low–energy data [6,7]. The present 95% CL limits on these operators for 90 GeV $\leq M_H \leq$ 800 GeV and $m_{\rm top} = 175$ GeV read [10],

$$
-1.2 \leq \frac{f_{\Phi,1}}{\Lambda^2} \leq 0.56 \text{ TeV}^{-2} \;\; , \tag{7}
$$

$$
-1.0 \leq \frac{f_{BW}}{\Lambda^2} \leq 8.6 \text{ TeV}^{-2} \;\; . \tag{8}
$$

On the order hand, the remaining operators can be indirectly constrained via their one–loop contributions to low–energy observables, which are suppressed by factors $1/(16\pi^2)$. Using the "naturalness" assumption that large cancellations do not occur among their contributions, we can consider only the effect of one operator at a time. In this case, the following constraints at 95% CL (in units of TeV^{-2}) arise [10]

$$
\begin{aligned}
-12. \leq \frac{f_W}{\Lambda^2} \leq 2.5 \ , \\
-7.6 \leq \frac{f_B}{\Lambda^2} \leq 22 \ , \\
-24 \leq \frac{f_{WW}}{\Lambda^2} \leq 14 \ , \\
-79 \leq \frac{f_{BB}}{\Lambda^2} \leq 47 \ .
\end{aligned}
\tag{9}
$$

These limits depend in a complex way on the Higgs mass. The values quoted above for the sake of illustration were obtained for $M_H = 200$ GeV.

Some of the anomalous Higgs interaction can also be constrained by their effect on the triple gauge–boson vertices. Recently, the LEP and Tevatron Collaborations have studied the production of pairs of gauge bosons and derived bounds on the anomalous interactions that modify the $WW\gamma$ and WWZ vertices. Combining the published results from DØ and the four LEP experiments, the 95% CL bounds on the anomalous Higgs interactions are (in TeV^{-2}) [11]:

$$
-31 \leq \frac{(f_W + f_B)}{\Lambda^2} \leq 68 \ , \quad \text{for} \quad f_{WWW} = 0 \ . \tag{10}
$$

Notice that, since neither f_{WW} nor f_{BB} contribute to the triple gauge–boson vertices, no direct constraint on these couplings can be derived from this analysis. Notwithstanding, these couplings can be constrained by data on Higgs searches at LEP II [12] and Tevatron [13] colliders. The combined analysis [14] of these signatures yields the following 95% CL bounds on the anomalous Higgs interactions (in TeV^{-2}):

$$
-7.5 \leq \frac{f_{WW(BB)}}{\Lambda^2} \leq 18
$$

for $M_H \leq 150$ GeV. These limits can be improved by a factor 2–3 in the upgraded Tevatron runs.

III. INTERMEDIATE MASS HIGGS PRODUCTION AND NEW INTERACTIONS

A. Gluon–gluon fusion

At the LHC, light Higgs bosons are copiously produced through gluon-gluon fusion and it was established that the decay mode $H \to \gamma\gamma$ provides the best signature for Higgs masses in the range $90 < M_H < 150$ GeV [15]. However, this channel also possesses a very large background, requiring a good energy resolution from the detectors in order to be observed. In our analyses we computed the SM and anomalous Higgs production cross sections using the cuts and efficiencies that the ATLAS Collaboration applied in their studies. We imposed the acceptance cuts

$$
p_T^{\gamma_{1(2)}} > 25 \ (40) \ \text{GeV} \quad , \qquad |\eta_{\gamma_{(1,2)}}| < 2.5 \quad ,
$$

where $p_T^{\gamma_{1(2)}}$ stands for the largest (second largest) transverse momentum of the photons in the event and $\eta_{\gamma_{(1,2)}}$ are the rapidities of these photons. We also required that

$$\frac{p_T^{\gamma_1}}{(p_T^{\gamma_1} + p_T^{\gamma_2})} < 0.7$$

to reduce the quark bremsstrahlung background. The efficiency for reconstruction and identification of one photon was taken to be 80%. We collected the photon pair events whose invariant masses fall in bins of size $2\Delta M_H$ around the Higgs mass with

$$\left(\frac{\Delta M_H}{M_H}\right) = \frac{5\%}{\sqrt{M_H}} \oplus 0.5\% \quad .$$

In order to take advantage of the careful estimates of backgrounds and detector efficiencies made by the ATLAS collaboration, we normalized our predictions for the SM Higgs cross section to their value for each value of the Higgs mass and then we rescaled the anomalous production cross section by the same factor. This factor varies from 0.65 to 0.80, depending on the Higgs mass. We present in Table I the expected number of Higgs and background events in the SM for a center of mass energy $\sqrt{s} = 14$ TeV and an integrated luminosity of 100 fb^{-1} after cuts and efficiencies. The SM irreducible background is by far the most important one, however, there is still rather large jet–jet and γ–jet reducible backgrounds. It is worth mentioning that the SM Higgs can be observed in this channel with an statistical significance of more than 3.9 standard deviations.

For an intermediate mass Higgs, $\mathcal{O}_{BB}$, $\mathcal{O}_{WW}$, and $\mathcal{O}_{BW}$ are the only effective operators (4) that contribute significantly at tree level to the process $gg \to H \to \gamma\gamma$. For the sake of illustration, we exhibit in Fig. 1 the expected number of events after cuts for a Higgs boson with $M_H = 130$ GeV as a function of the anomalous coupling

$$f \equiv \frac{(f_{BB} + f_{WW} - f_{BW})}{\Lambda^2} \; . \tag{11}$$

Notice that the anomalous contribution to $H \to \gamma\gamma$ depends only on this combination of the effective interactions [see Eq. (6)].

Let us initially assume that the Higgs boson has indeed been observed in the $\gamma\gamma$ channel and that its production cross section is in agreement with the SM prediction. In this case we can extract the sensitivity of this process to the anomalous interactions using as background the processes listed in Table I together with the SM Higgs signal. We present in Table II the 95% CL allowed range of f for an integrated luminosity of 100 fb^{-1}. In Fig. 1, we also exhibit the 95% CL interval around the SM Higgs signal (upper shadowed region) for $M_H = 130$ GeV. The two allowed parameter ranges given in Table II correspond to the two intersections of the signal curve with the 95% CL region. One should notice that the existence of a sizable interference between the SM and anomalous contributions to the Higgs into two photons width allows the existence of a range of anomalous couplings not compatible with zero even if its production rate is in accordance with the SM predictions. This range would correspond to $2.5 < f/\Lambda^2 < 3.0$ TeV^{-2}, for $M_H = 130$ GeV (see Fig. 1).

The bounds in Table II, derived from the SM Higgs observation, are more restrictive than the ones emanating from the contribution of these operators to the low–energy and

LEP physics either at tree level (8) or at the one–loop level (9). As seen in this table for any Higgs mass, this process is sensitive to new physics which characteristic scale up to $\Lambda \simeq 2.2$ TeV for $f_{BB} = f_{WW} = f_{BW} = 1$.

Another possible scenario is the one where no SM Higgs signal is observed in the $\gamma\gamma$ channel. In this case, we obtain different constraints on the anomalous couplings for a given value of M_H. In order to extract the sensitivity region for the anomalous couplings we have to consider only the SM Higgs backgrounds listed in Table I without including in that the SM Higgs signal. In Table III we present sensitivity range for the anomalous coupling f at 95% CL, assuming that only the SM Higgs background is observed for an integrated luminosity of 100 fb^{-1}. The interpretation of these results depend on the observation of the Higgs in other channels. Should the Higgs be observed in another decay channel insensitive to these anomalous couplings, such as in $H \to \tau^+\tau^-$ [16], the non observation of the corresponding signal in $\gamma\gamma$ should be interpreted as the inevitable existence of new physics in the Higgs couplings to photons with characteristic strength as given in Table III. If, on the other hand, no signal is observed in any other decay channel, the existence of the Higgs of a given mass can be ruled out and no limit can be extracted from the non observation of the $\gamma\gamma$ signal, becoming meaningless the constraints in Table III.

B. Vector boson fusion

Higgs bosons can also be produced in pp collisions via the vector boson fusion (VBF) process (2). A nice feature of this production mechanism is that the jets in the VBF signal events tend to populate the forward direction and can be used to tag these events and reduce the background. Moreover, the background can be further suppressed by vetoing additional jet activity in the central region [17].

In our analysis of this process we followed closely the study of Ref. [18]. We considered all backgrounds from QCD and electroweak processes, as well as the corresponding interferences, which can lead to events with two photons and two jets. We generated the scattering amplitudes for both the SM Higgs signal and the background with the package Madgraph [19] which makes use of the helicity amplitudes contained in the package Helas [20]. In our calculations we have used the MRS(G) [21] proton structure function.

In order to reduce the background, we required the photons to satisfy the acceptance cuts

$$p_T^{\gamma_{1(2)}} > 25 \ (50) \ \text{GeV} \quad , \qquad |\eta_{\gamma_{(1,2)}}| < 2.5 \quad ,$$

and we tagged the jets in the forward region and vetoed their presence in the central detector

$$\begin{gathered} p_T^{j_{(1,2)}} > 20 \ (40) \ \text{GeV} \quad , \\ |\eta_{j_{(1,2)}}| < 5.0 \quad , \quad |\eta_{j_1} - \eta_{j_2}| > 4.4 \quad , \quad \eta_{j_1} . \eta_{j_2} < 0 \quad . \end{gathered}$$

We also imposed that the photons are isolated from the jets ($\Delta R_{\gamma j} > 0.7$) and, as before, used the photon detection efficiency of 80%.

We display in Table IV the expected number of SM Higgs signal and background events using the above cuts and efficiencies for an integrated luminosity of 100 fb^{-1}. Our results show good quantitative agreement with the analysis in Ref. [18], taking into account the different choice of structure functions and the inclusion of the photon detection efficiency. Notice that the SM irreducible background and the SM Higgs signal are of the same order of magnitude.

The dimension–six operators in Eq. (4) contribute to the $\gamma\gamma$ signal of Higgs production via vector boson fusion by modifying both the production cross section as well as the Higgs decay width. On one hand, the operators $\mathcal{O}_{BB}$, $\mathcal{O}_{WW}$, and $\mathcal{O}_{BW}$ contribute to the Higgs production and decay while $\mathcal{O}_W$, $\mathcal{O}_B$, $\mathcal{O}_{\Phi,1}$, and $\mathcal{O}_{\phi,2}$ change only the production vertices. In our calculation of the anomalous contribution we have included all amplitudes generated by these operators in the spirit of Refs. [12,13].

As in the gluon–gluon fusion analysis, we first assume that the Higgs boson has indeed been observed in the $\gamma\gamma jj$ channel and that its production cross section is in agreement with the SM prediction. In this case, the SM backgrounds for the anomalous interactions are the processes listed in Table IV together with the SM Higgs signal. We present in Table V the 95% CL sensitivity to anomalous coupling combination (11) assuming that the other anomalous couplings vanish, for an integrated luminosity of 100 fb^{-1}. This Table also contains the 95% CL allowed range for the "super–blind" operator $\mathcal{O}_{\Phi,2}$ alone as well as the limits attainable assuming all couplings to be equal ($f_{all} = f_{BB} = f_{WW} = f_{BW} = f_W = f_B = f_{\Phi_1} = f_{\Phi_2}$).

Here we also find two allowed ranges of anomalous parameters due to the sizeable interference between the SM and the anomalous contributions to the Higgs production and decay. Comparing the results in Tables II and V we see that for those operators contributing to the Higgs decay into two photons, the VBF process leads to slightly better sensitivity to new interactions. On the other hand, the LHC capability to probe the operators contributing only to the Higgs production in VBF is much smaller, being $f_{\Phi,2}$ the only coupling that can be meaningfully constrained. For f_B, f_W, and $f_{\Phi,1}$ we verified that the expected sensitivity from this analysis is much worse than present limits in Eqs. (7), (8), and (10).

Different sensitivity bounds are obtained if no Higgs boson signal is observed in the VBF channel for a given value of M_H. In this scenario, we assumed that only the SM background for the Higgs search were observed (see Table IV). In Table VI we show sensitivity range of anomalous couplings at the 95% CL for an integrated luminosity of 100 fb^{-1} assuming that no Higgs signal is observed in the corresponding mass bin.

As discussed above the interpretation of these results depend whether the Higgs has been observed in other channels. The effective interactions $\mathcal{O}_{BB}$, $\mathcal{O}_{WW}$, and $\mathcal{O}_{BW}$ can diminish the Higgs decay width into $\gamma\gamma$ and consequently this Higgs signature will not be observed neither in gluon–gluon fusion nor in VBF. In this case, the VBF Higgs production can be seen in the $\tau^+\tau^-$ channel. If the Higgs is really discovered in this channel, the analysis of the $\gamma\gamma$ channel is a strong sign of the existence of new Higgs interactions. Of course, the constraints on the anomalous couplings are meaningless if the Higgs is not seen in any channel. For the operators $\mathcal{O}_W$, $\mathcal{O}_B$, $\mathcal{O}_{\Phi,1}$, and $\mathcal{O}_{\phi,2}$ the main effect is to modify the production cross section, affecting equally the Higgs signal in all decay modes. Therefore, the bounds on these operators make sense only if the Higgs production via gluon–gluon fusion is observed.

IV. CONCLUSIONS

In this work we have studied the sensitivity of the LHC collider to new physics in the Higgs sector of the SM. In particular we have concentrated on new signals associated to the decay of an intermediate mass Higgs boson in two photons both in gluon–gluon fusion (1) as well as in gauge–boson fusion (2).

We have shown that the LHC will be able to expand considerably the present sensitivity on the dimension–six Higgs couplings that modify the $H\gamma\gamma$ vertex, being able to probe new physics scales as large as 2.2 TeV, provided that the Higgs is observed. In both channels our result show that of the LHC is sensitive to new physics scales beyond the present constraints originating from their contribution at tree level to the LEP I and low energy observables. For the effective operators that do not change the Higgs coupling to photons, the LHC possible bounds are weaker than the ones presently available, with the exception of the "super–blind" operator $\mathcal{O}_{\Phi,2}$.

We have also found that due to the presence of a sizeable interference between the anomalous and the SM contributions there is the distinct possibility that the anomalous Higgs interactions dilute its decay into two photons and the Higgs may be not observable in the above reactions. Thus the observation of the Higgs in other decay channel, namely $\tau^+\tau^-$, would imply the existence of new physics in the Higgs couplings to gauge bosons at a characteristic scale of 0.7–1.4 TeV.

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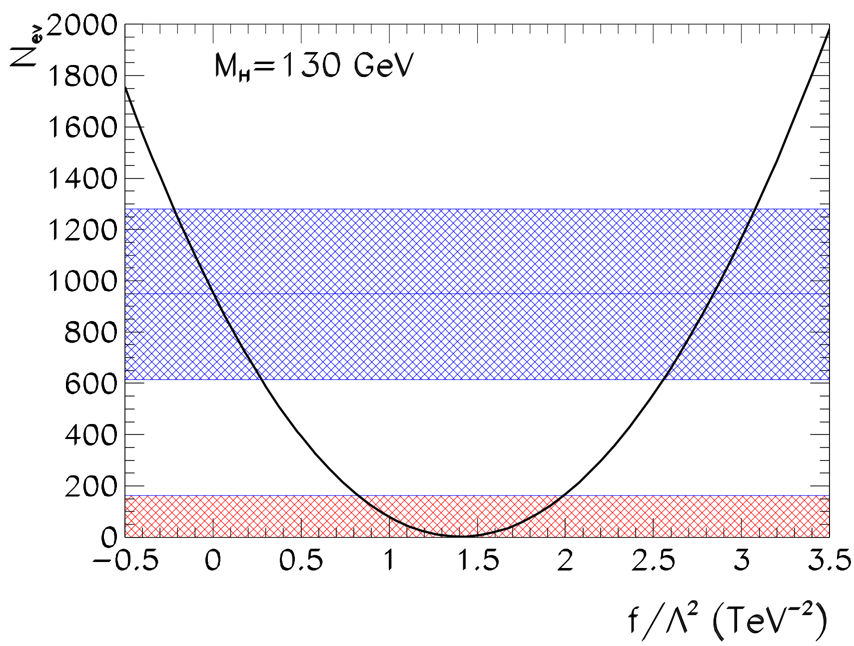


FIG. 1. Number of events $pp \to gg \to H \to \gamma\gamma$ as a function of the anomalous coupling f [Eq.(11)] for M_H=130 GeV and an integrated luminosity of 100 fb^{-1}. We show the 95% CL allowed region assuming that the SM Higgs is observed (upper shadowed area). The lower shadowed area represents the 95% CL allowed region for the scenario where only the SM background is observed, *i.e.* with no SM Higgs signal is seen.

TABLES

M_H (GeV)	100	110	120	130	140	150
SM ($pp \to H \to \gamma\gamma$)	840	950	1040	950	715	560
Background ($\gamma\gamma$)	40700	40700	29900	26300	22600	15300
Background (jet–jet)	1700	1300	1200	1200	1050	900
Background (γ–jet)	5000	3600	3200	2700	2250	1800
$\mathcal{S}/\sqrt{\mathcal{B}}$	3.9	5.1	5.9	5.8	4.4	4.2

TABLE I. Expected number of events for the Higgs production via gluon–gluon fusion after cuts and efficiencies as given by the ATLAS collaboration for an integrated luminosity of $\mathcal{L} = 100$ fb^{-1}. We also exhibit the SM irreducible and reducible backgrounds. We denoted by $\mathcal{S}/\sqrt{\mathcal{B}}$ the statistical significance of the SM Higgs signal.

M_H(GeV)	$(f_{BB} + f_{WW} - f_{BW})/\Lambda^2$ (TeV^{-2})
100	(-0.29, 0.38) or (2.1, 2.8)
110	(-0.23, 0.28) or (2.2, 2.8)
120	(-0.21, 0.25) or (2.3, 2.8)
130	(-0.22, 0.27) or (2.5, 3.0)
140	(-0.28, 0.34) or (2.6, 3.3)
150	(-0.35, 0.46) or (2.8, 3.6)

TABLE II. 95% CL allowed ranges in TeV^{-2} assuming that an intermediate mass Higgs has been observed in gluon–gluon fusion production with the SM rates for a luminosity of 100 fb^{-1}.

M_H(GeV)	$(f_{BB} + f_{WW} - f_{BW})/\Lambda^2$ (TeV^{-2})
100	(0.36, 2.1)
110	(0.49, 2.1)
120	(0.58, 2.1)
130	(0.59, 2.2)
140	(0.56, 2.4)
150	(0.52, 2.8)

TABLE III. 95% CL sensitivity ranges in TeV^{-2} coming from the non observation of SM Higgs produced via gluon–gluon fusion.

M_H (GeV)	100	110	120	130	140	150
SM ($pp \to VV \to H(\to \gamma\gamma)jj$)	61	79	93	93	78	52
SM background	69	71	67	64	58	53
$\mathcal{S}/\sqrt{\mathcal{B}}$	7.3	9.4	11.4	11.6	10.2	7.1

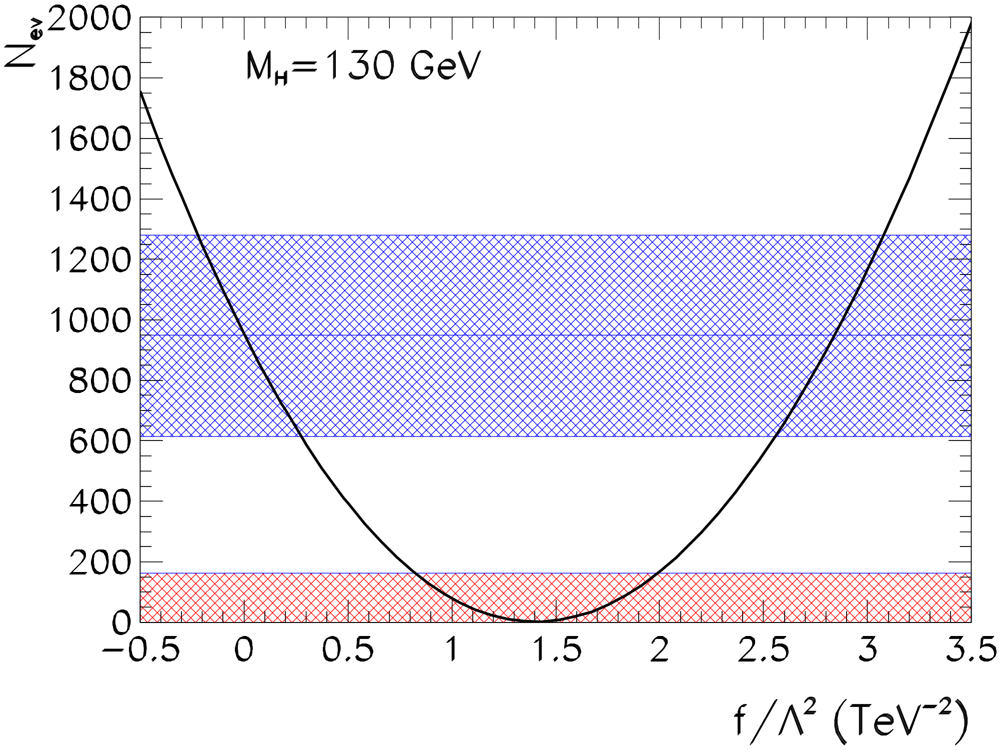
TABLE IV. Expected number of events for SM Higgs production via vector boson fusion after including cuts and efficiencies for an integrated luminosity of $\mathcal{L} = 100$ fb^{-1}. We also present the SM irreducible background and statistical significance of the signal.

M_H(GeV)	$(f_{BB} + f_{WW} - f_{BW})/\Lambda^2$ (TeV^{-2})	f_{Φ_2}/Λ^2 (TeV^{-2})	f_{all}/Λ^2 (TeV^{-2})
100	(−0.21, 0.26) or (2.2, 2.7)	(−2.2, 2.8) or (18, 23)	(−0.20, 0.23) or (2.6, 3.0)
110	(−0.18, 0.22) or (2.4, 2.8)	(−1.9, 2.2) or (24, 28)	(−0.17, 0.20) or (2.7, 3.1)
120	(−0.17, 0.19) or (2.5, 2.8)	(−1.7, 2.0) or (23, 27)	(−0.17, 0.19) or (3.0, 3.4)
130	(−0.17, 0.20) or (2.6, 3.0)	(−1.7, 2.0) or (24, 28)	(−0.17, 0.19) or (3.1, 3.5)
140	(−0.21, 0.24) or (2.8, 3.2)	(−2.1, 2.3) or (37, 41)	(−0.20, 0.23) or (3.3, 3.7)
150	(−0.29, 0.36) or(2.9, 3.6)	(−2.8, 3.3) or (32, 39)	(−0.29, 0.34) or (3.4, 4.0)

TABLE V. 95% CL allowed ranges in TeV^{-2} assuming that an intermediate mass Higgs has been observed in the process $pp \to qq'VV \to j + j + H(\to \gamma\gamma)$ with the SM production rate for an integrated luminosity of 100 fb^{-1}.

M_H(GeV)	$(f_{BB} + f_{WW} - f_{BW})/\Lambda^2$ (TeV^{-2})	f_{Φ_2}/Λ^2 (TeV^{-2})	f_{all}/Λ^2 (TeV^{-2})
100	(0.60, 1.9)	(7.2, 14.)	(0.67, 2.2)
110	(0.70, 1.9)	(7.4, 18.)	(0.74, 2.1)
120	(0.78, 1.9)	(8.5, 16.)	(1.0, 2.2)
130	(0.84, 2.0)	(8.7, 17.)	(1.0, 2.3)
140	(0.85, 2.1)	(7.6, 32.)	(0.99, 2.5)
150	(0.79, 2.5)	(7.0, 29.)	(0.89, 2.8)

TABLE VI. 95% CL sensitivity ranges in TeV^{-2} from vector boson fusion production when no Higgs signal is observed in the VBF channel.



N_{ev}
M_H=130 GeV
2000
1800
1600
1400
1200
1000
800
600
400
200
0
−0.5
0
0.5
1
1.5
2
2.5
3
3.5
f/Λ^2 (TeV^{-2})