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Comparison Of Anomalous Higgs Couplings at the Large Hadron Collider and at Proton-Proton Collider with 100 TeV Energy

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Abstract γp and γγ ,called photon induced processes, have been examined in various colliders like Large Hadron Collider (LHC) and proton-proton collider with 100 TeV energy. One of the importance of these processes is that they allow for probing the anomalous Higgs couplings. The anomalous Higgs couplings constitute a testing ground for electroweak symmetry breaking (EWSB) mechanism and mass production system. For measuring anomalous Hγγ and HZγ couplings at the LHC and at the proton-proton collider with 100 TeV energy, the potential of the pp→pγp→pHqX has been examined. Sensitivity bounds on anomalous Higgs couplings have been obtained at %95 confidence level. The analyses have been done for various integrated luminosities and different scenarios Then the results of them have been compared. Model-independent effective Lagrangian technique has been used, and the Higgs boson couplings to gauge bosons have been examined by dimension-six operators.

1. Introduction

The Large Hadron Collider (LHC) which has a center of mass energy with 14 TeV and luminosity of 10^{34} cm^{-2} s^{-1} is one of the the most important accelarator of the world.

ATLAS and CMS Collaborations discovered the Higgs boson estimated by Standard Model (SM) of particle physics at the LHC [1,2]. The next stage is to examine the features of this significant particle and its couplings to other SM particles. These studies have a great importance for supporting SM and investigating new physics . On the other hand the future100 TeV proton-proton collider ensures an ideal venue to examine new physics. [3-5]. Such studies on anomalous Higgs couplings at LHC and at future 100 TeV proton-proton collider have been speedily increasing in the literature. (6-18) In this paper Higgs boson production via the main process pp→pγp→pHqX haven been examined at the LHC and at future 100 TeV collider. This process can be shown as follow diagram(40):

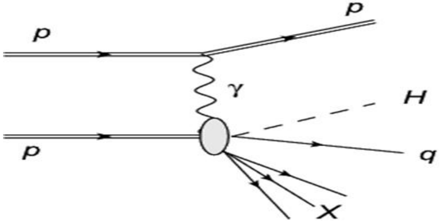

Figure 1. Representation of the process pp→pγp→pHqX.

Here, q and X constitute quarks and proton remnants respectively.

The top quark distribution has been ignored and 10 independent subprocess for q= u,d,s,c,b,$\bar{u}$, $\bar{d}$, $\bar{s}$, $\bar{c}$, $\bar{b}$ have been considered. In the existence of anomalous Hγγ and HZγ couplings the Feynmann diagrams of subprocess γq → Hq is drawn as follows(40):

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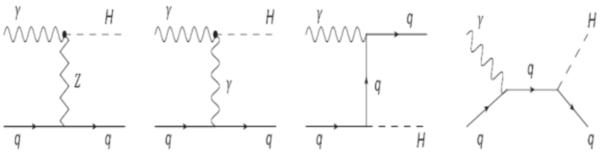


Figure 2. Feynman diagrams of γq→Hq at the tree-level.

At last studies, the presence of these photon-induced processes have been confirmed by CMS ATLAS Collaborations [19-23]. And also it is verified that these reactions have an important potential to examine new physics [21-23]. In such a process, photon-proton collision takes place when.quasirel photon has been emitted from one of the incoming protons. So that it can be thought that proton-photon collision is a subprocess of the proton-proton collision. In that paper equivalent photon approximation (EPA) [24-26] has been taken into account. According to this approximation, emitted photons are accepted to be real becouse of having a very low virtuality. The protons which emit quasireal photons do not divide into partons and they keep to be intact [27-28].

2. Material and Method

2.1. Anomalous Hγγ and HZγ Couplings And The Cross Section

For examining anomalous HZγ and Hγγ couplings one of the ways is to employ effective Lagrangian formalism. [7-9,29-33]
In this formalism total effective Lagrangian can be expressed as follows:

$$L_{eff} = \sum_n \frac{f_n}{\Lambda^2} O_n \qquad (1)$$

Here f_n indicates the anomalous couplings and the scale of new physics is described by Λ . Also O_n indicates five dimension- six operators which alter the Higgs boson couplings to Z and γ bosons [7-9,29-33] They can be explicitly expressed as follows:

$$O_{WW} = \phi^t W\mu\nu W^{\mu\nu} \phi$$
$$O_W = (D_\mu \phi)^+ W^{\mu\nu} (D_\nu\phi)$$
$$O_{BB} = \phi^t B_{\mu\nu} B^{\mu\nu}\phi$$
$$O_B = (D_\mu \phi)^+ B^{\mu\nu}(D_\nu\phi)$$
$$O_{BW} = \phi^t B_{\mu\nu}W^{\mu\nu} \phi \qquad (2)$$

Here, Φ indicates the scalar doublet and Dμ indicates the covariant derivative. Also the other fields can be expressed as follows:

$$W_{\mu\nu} = i\frac{g}{2}(\vec{\sigma}.\overrightarrow{W_{\mu\nu}})$$
$$B_{\mu\nu} = i\frac{g'}{2}\overrightarrow{B_{\mu\nu}} \qquad (3)$$

where g is the $SU(2)_L$ gauge coupling and g′ is the $U(1)_Y$ gauge coupling. Also σ is the pauli matrices. The effective Lagrangian in Eq-1 can be described as follows after the symmetry breaking. :

$$L_{eff} = g_{H\gamma\gamma} HA_{\mu\nu}A^{\mu\nu} + g^1_{Hz\gamma} A_{\mu\nu}Z^{\mu}\partial^{\gamma}H + g^2_{Hz\gamma}HA_{\mu\nu}Z^{\mu\nu} \qquad (4)$$

Here, $V_{\mu\nu} = \partial_\mu V_\nu$-$\partial_\nu V_\mu$ with V=A(photon) and Z field. Also $g_{H\gamma\gamma}, g^1_{Hz\gamma}$ ve $g^2_{Hz\gamma}$ are anomalous couplings which involve the couplings f_n as follows:

$$g_{H\gamma\gamma} = -\left(\frac{g m_W}{\Lambda^2}\right)\sin\theta_W^2\left(\frac{f_{BB+}\, f_{WW-} f_{BW}}{2}\right) \qquad (5.1)$$

$$g^1_{HZ\gamma} = \left(\frac{g m_W}{\Lambda^2}\right)\sin\theta_W\left(\frac{f_W - f_B}{2\cos\theta_W}\right) \qquad (5.2)$$

$$g^2_{HZ\gamma} = \left(\frac{g m_W}{\Lambda^2}\right)\frac{\sin\theta_W}{2\cos\theta_W}\left[2\sin\theta_W^2 f_{BB-}\, 2\cos\theta_W^2\, f_{WW} + (\cos\theta_W^2 - \sin\theta_W^2)f_{BW}\right] \qquad (5.3)$$

Here, θ_W and m_W indicates Weinberg angle and W boson’s mass respectively. Also in the calculations taken into account the energy scale of new physics as Λ=1 TeV. For the aim of the easiness six scenarios of new physics have been considered as follows:

Senaryo I ; $f_B = f_W$=0 , $f_{WW}= f_{BB}$
Senaryo II ; $f_{WW}= f_{BB}$ = 0 , $f_B = -f_W$
Senaryo III ; $f_B = f_W$= 0 , $f_{WW}= -f_{BB}$
Senaryo Iv ; $f_B = f_W$= 0 , $f_{WW}= tan^2\theta_W f_{BB}$
Senaryo V ; $f_{WW} = f_W$= 0
Senaryo VI ; $\boldsymbol{f_{BB} = f_B}$= 0

For ignoring the contributions of HZZ and HWW couplings in the calculations f_{BW} is taken to be zero (f_{BW} =0). Taking into account one-loop level contribution of SM for the anomalous Hγγ ve HZγ couplings, the effective Lagrangian can be written as follows [34,35] ;

$$\mathcal{L}_{eff}^{(SM)} = g_{H\gamma\gamma}^{(SM)} H A_{\mu\nu} A^{\mu\nu} + g_{HZ\gamma}^{(SM)} H A_{\mu\nu} Z^{\mu\nu} \qquad (6)$$

Here, $g_{HZ\gamma}^{(SM)} = \frac{\alpha}{4\pi v \sin\theta_W}(5.508 - 0.004i)$ and

$g_{H\gamma\gamma}^{SM} = \frac{2\alpha}{9\pi v}$.

The cross section of the main process is given as;

$$\sigma(pp \to p\gamma p \to pHqX) = \int_{x_{1min}}^{x_{1max}} dx_1 \int_0^1 dx_2 \int_{Q_{min}^2}^{Q_{max}^2} dQ^2 \left(\frac{dN_\gamma}{dx_1\, dQ^2}\right)\left(\frac{dN_q}{dx_2}\right) \times \hat{\sigma}(\gamma q \to Hq) \qquad (7)$$

where $\left(\frac{dN_q}{dx_2}\right)$ and $\left(\frac{dN_\gamma}{dx_1\, dQ^2}\right)$ are quark distribution and equivalent photon functions, respectively.

Detailed information and the integral bounds for equivalent photon distribution function can be found in the literature [36,37]. Also, using the MSTW2008 programme (38) , the quark distribution functions can be calculated numerically At the high energies (E>>m_p), x_1 can be taken as $x_1 = \frac{E - E'}{E} = \frac{E_\gamma}{E} \approx \xi$ ξ is called forward detector acceptance . Here, E is energy of the initial proton and E' is energy of final (scattered) proton. Also Eγ indicates the equivalent photon energy. ξ is called forward detector acceptance . Therefore during the calculations x_{1min} and x_{1max} are taken as $x_{1min} = \xi_{min} = 0.015$ ve $x_{1max} = \xi_{max} = 0.15$.

In the analysis χ^2 criterion has been used and bounds on anomalous Higgs couplings have been determined at 95% (C.L.) . χ^2 criterion is taken as follows:

$$\chi^2 = \left(\frac{N_{AN} - N_{SM}}{N_{SM}\,\delta_{err}}\right)^2 \qquad (8)$$

Here, N_{AN} is number of events which contains SM and new physics contributions, N_{SM} is number of events in the SM and δ_{err} is the statistical error. $N_{AN(SM)}$ is calculated from the formula:

$N_{(AN)SM=}$ E x S x L_{int}x Br x $\sigma_{(AN)SM}$, where S represents the survival probability factor (S=0.7), E represents the b-tagging efficiency ($E = 0.6$) ,L_{int} represents the integrated luminosity and BR is the branching ratio for H→$b\bar{b}$ (Br = 0.6.) Also, σ_{SM} and σ_{AN} are SM and anomalous cross sections respectively.

The background subprocesses $\gamma q \to k, b, b$ ($q = u, d, s, c, b, u, d, s, c, b$; $k = u, d, s, c, b, t, u, d, s, c, b, t$) which contribute to main process $pp \to p\gamma p \to pbbqX$, are calculated by using CalcHEP 3.6.20. [39]

At the background caculations, H→$b\bar{b}$ decay channel of Higgs boson has been considered and $b\bar{b}$ final state with invariant mass in the interval 120 GeV < M(b, $\bar{b}$) < 130 GeV is identified as the signal. When these cuts are applied to the signal, the cross section of the background decline dramatically.

For LHC, taking into account scenarios I-IV, the bounds on anomalous f_W , f_{WW} and f_{BB} couplings are obtained in the Table –I at 95% C.L.

Table I. For various scenarios and luminosities the anomalous bounds are given at 95% C.L for LHC($\sqrt{s}$=14 TeV)

Luminosite	$(Senaryo\text{-I})f_{ww}$	$(Senaryo\text{-II})f_w$	$(Senaryo\text{-III})f_{bb}$	$(Senaryo\text{-IV})f_{bb}$
$10fb^{-1}$	(-6.3,7.9)	(-19.8,15.4)	(-9.9,7.7)	(-13.2,15.6)
$30fb^{-1}$	(-4.6,6.2)	(-15.6,11.3)	(-7.8,5.6)	(-9.8,12.2)
$50fb^{-1}$	(-3.9,5.6)	(-14.1,9.7)	(-7.0,4.9)	(-8.5,10.8)
$100fb^{-1}$	(-3.2,4.8)	(-12.2,7.9)	(-6.1,3.9)	(-7.0,9.3)
$200fb^{-1}$	(-2.6,4.2)	(-10.7,6.4)	(-5.3,3.2)	(-5.7,8.1)
$500fb^{-1}$	(-1.9,3.6)	(-9.0,4.7)	(-4.5,2.4)	(-4.3,6.7)

For scenarios V and VI , at LHC, with 95% C.L. restricted regions in two-dimensional $f_B - f_{BB}$ and $f_W - f_{WW}$ parameter spaces are given in Figure 3-4 .

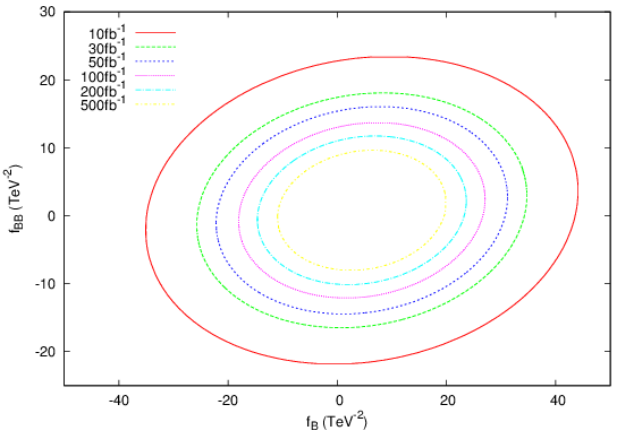


Figure 3. At 95% C.L. the restricted areas on $f_B - f_{BB}$ parameter spaces are shown for LHC. ($\sqrt{s}$=14 TeV)

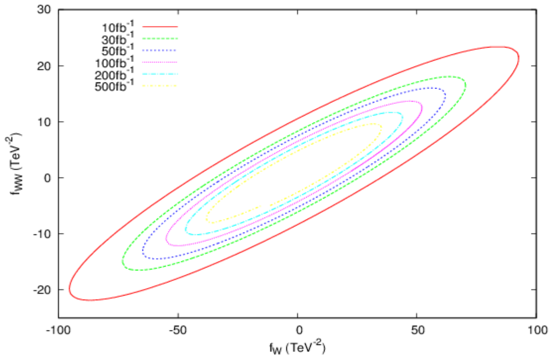
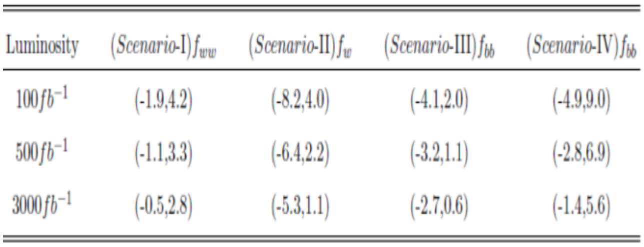


Figure 4. At 95% C.L. the restricted areas on $f_w - f_{ww}$ parameter spaces are shown for LHC. ($\sqrt{s}$=14 TeV)

Similarly, for 100 TeV proton-proton collider ,taking into account scenarios I-IV, the bounds on anomalous f_w , f_{ww} and f_{BB} couplings are obtained in the Table –II at 95% C.L.

Table II. For various scenarios and luminosities the anomalous bounds are given at 95% C.L for future 100 TeV proton-proton collider .



Luminosity	$(Scenario\text{-}I) f_{ww}$	$(Scenario\text{-}II) f_w$	$(Scenario\text{-}III) f_{bb}$	$(Scenario\text{-}IV) f_{bb}$
$100 fb^{-1}$	(-1.9,4.2)	(-8.2,4.0)	(-4.1,2.0)	(-4.9,9.0)
$500 fb^{-1}$	(-1.1,3.3)	(-6.4,2.2)	(-3.2,1.1)	(-2.8,6.9)
$3000 fb^{-1}$	(-0.5,2.8)	(-5.3,1.1)	(-2.7,0.6)	(-1.4,5.6)

For scenarios V and VI, at 100 TeV proton-proton collider, with 95% C.L. restricted regions in two-dimensional $f_B - f_{BB}$ and $f_w - f_{ww}$ parameter spaces are given in Figure 5-6.

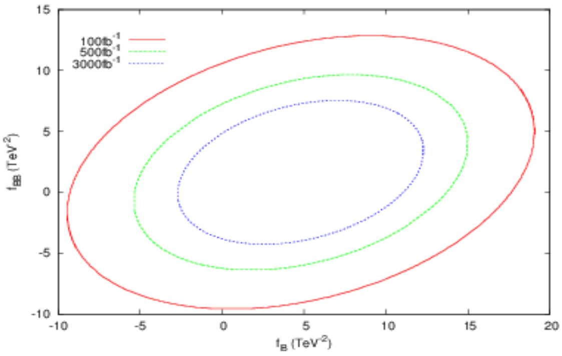


Figure 5. At 95% C.L. the restricted areas on $f_B - f_{BB}$ parameter spaces are shown for 100 TeV proton-proton collider.

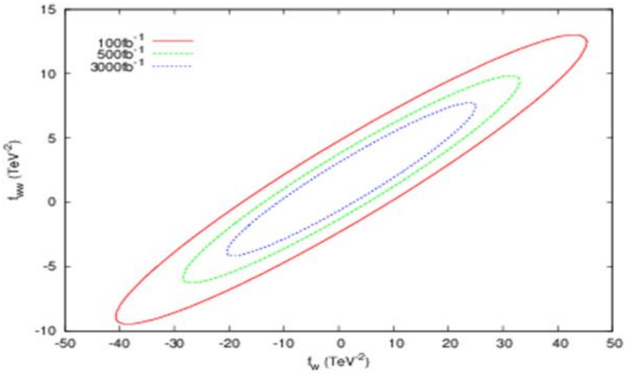


Figure 6. At 95% C.L. the restricted areas on $f_w - f_{ww}$ parameter spaces are shown for 100 TeV proton-proton collider.

3. Conclusion and Suggestions

As expected, γp collision at 100 TeV proton-proton collider with a higher energy and a higher luminosity relatively, probes the anomalous Hγγ and HZγ couplings with better sensitivity than γp collision at the LHC. Consequently, we can say that, the sensitivity bounds on anomalous Higgs couplings are refined by an improvement factor of 2.

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