Testing for observability of Higgs effective couplings in triphoton production at FCC-hh

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Abstract

We investigate the potential of the $pp \to \gamma\gamma\gamma + X$ process to probe CP-conserving and CP-violating dimension-six operators of Higgs-gauge boson interactions in a model-independent Standard Model effective field theory framework at the center of mass energy of 100 TeV which is designed for Future Circular hadron-hadron Collider. Signal events in the existence of anomalous Higgs boson couplings at $H\gamma\gamma$ and $HZ\gamma$ vertices and the relevant SM background events are generated in MadGraph, then passed through Pythia 8 for parton showering and Delphes to include detector effects. After detailed examination of kinematic variables, we use invariant mass distribution of two leading photons with optimized kinematic cuts to obtain constraints on the Wilson coefficients of dimension-six operators. We report that limits at 95\% confidence level on $\tilde{c}_\gamma$ and $\tilde{\bar{c}}_\gamma$ couplings with an integrated luminosity of 10 ab$^{-1}$ are [-0.0041; 0.0019] and [-0.0027; 0.0027], respectively.

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I. INTRODUCTION

The investigation of the Higgs sector of Standard Model (SM) responsible to the mechanism of the electroweak symmetry breaking has became an attraction point in particle physics after the ATLAS and CMS collaboration’s discovery of a scalar particle with 125 GeV which is compatible with predicted Standard Model (SM) Higgs boson [1, 2]. Thus, the precision measurements of the Higgs couplings have a great potential to shed light on the new physics beyond the SM involving massive particles that are decoupled at energy scales much larger than the Higgs sector energies. One of the well-known investigation method looking for a deviation from SM is the Effective Field Theory (EFT) approach which is based on new physics effects described by a systematic expansion in a series of high dimensional operators beyond the SM fields as well as SM operators [4, 5]. Since the dimension-6 operators match to ultraviolet (UV) models which are simplified by the universal one-loop effective action, they play an important role in the EFT framework. There have been many studies on EFT operators between Higgs and SM gauge boson via different production mechanism at hadron colliders [6–21]. Among the production mechanisms in the hadron colliders, having triphoton in the final state provides an ideal platform to search for deviations from SM since it is rare in the SM and involves only pure electroweak interaction contributions at tree level [22–24]. The triphoton can be produced in hadron-hadron collisions either in the hard interaction via annihilation of an initial state quark-antiquark pair which is called direct production or from the fragmentation of high $p_T$ parton which is called fragmentation process. Since photons produced via direct production are typically isolated, requiring isolated photons will reduce the background contributions from the decays of unstable particles such as $\pi^0 \rightarrow \gamma\gamma$ and suppress the signal process with one or more fragmentation photons.

One of the future project currently under consideration by CERN is the Future Circular Collider (FCC) facility which would be built in a 100 km tunnel and designed to deliver $pp$, $e^+e^-$ and $ep$ collisions [25]. The FCC facility which has the potential to search for a wide parameter range of new physics is the energy frontier collider project following the completion of the LHC and High-luminosity LHC physics programmes. FCC-hh, one of the unique option of FCC, is designed to provide proton-proton collisions at the proposed 100 TeV centre-of-mass energy with peak luminosity $5 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$ [26].

In this study, we investigate the potential of the process $pp \rightarrow \gamma\gamma\gamma + X$ at FCC-hh in the existence of anomalous Higgs boson couplings at $H\gamma\gamma$ and $HZ\gamma$ vertices. Description of the SM EFT Lagrangian is given in the next section. Details of the analysis including event generation, detector
effects and event selection as well as statistical method used to obtain the limits on the anomalous Higgs-neutral gauge boson couplings are illustrated in section III. Our results for integrated luminosity of 10 ab⁻¹ is presented and discussed in the last section.

II. EFFECTIVE OPERATORS

The most general form of effective Lagrangian including dimension-6 operators of the Strongly Interacting Light Higgs (SILH) as well as SM is given as follows;

\[ \mathcal{L}_{eff} = \mathcal{L}_{SM} + \sum_i \bar{c}_i O_i + \sum_i \bar{c}_i O_i \]  

where \( \bar{c}_i \) and \( \bar{c}_i \) are normalized Wilson coefficients of the CP-conserving and CP-violating interactions, respectively. In this work, we focused on the CP-conserving and CP-violating interactions of the Higgs boson and electroweak gauge boson in SILH basis as described in Ref. [27]. The CP-conserving part of the effective Lagrangian is

\[ \mathcal{L}_{CPC} = \frac{\bar{c}_H}{2v^2} \partial^\mu \left[ \Phi^\dagger \Phi \right] \partial_\mu \left[ \Phi^\dagger \Phi \right] + \frac{\bar{c}_T}{2v^2} \left[ \Phi^\dagger \hat{D}^\mu \Phi \right] \left[ \Phi^\dagger \hat{D}_\mu \Phi \right] - \frac{\bar{c}_6}{v^2} \left[ \Phi^\dagger \Phi \right]^3 

- \left[ \frac{\bar{c}_u}{v^2} y_u \Phi^\dagger \Phi \hat{D}_\mu \hat{Q}_{L} u_R + \frac{\bar{c}_d}{v^2} y_d \Phi^\dagger \Phi \hat{Q}_{L} d_R + \frac{\bar{c}_l}{v^2} y_l \Phi^\dagger \Phi \Phi \hat{L}_L \epsilon_R + \text{h.c.} \right] 

+ \frac{ig}{m_W^2} \left[ \Phi^\dagger T_{2k} \hat{D}^\mu \Phi \right] D^{\nu} W_{\mu \nu}^k + \frac{ig'}{2m_W^2} \left[ \Phi^\dagger \hat{D}^\mu \Phi \right] \hat{D}^{\nu} B_{\mu \nu} 

+ \frac{g'^2}{2m_W^2} \Phi^\dagger \Phi B_{\mu \nu} B^{\mu \nu} + \frac{g_s^2}{2m_W^2} \Phi^\dagger \Phi G_{\mu \nu}^a G^a_{\mu \nu} \]  

where \( \Phi \) is Higgs sector contains a single \( SU(2)_L \) doublet of fields; \( \lambda \) is the Higgs quartic coupling; \( g', g \) and \( g_s \) are coupling constant of \( U(1)_Y, SU(2)_L \) and \( SU(3)_C \) gauge fields, respectively; \( y_u, y_d \) and \( y_l \) are the \( 3 \times 3 \) Yukawa coupling matrices in flavor space; the generators of \( SU(2)_L \) in the fundamental representation are given by \( T_{2k} = \sigma_k/2 \) (here \( \sigma_k \) are the Pauli matrices); \( \hat{D}_\mu \) is the Hermitian derivative operators; \( B^{\mu \nu} \), \( W^{\mu \nu} \) and \( G^{\mu \nu} \) are the electroweak and the strong field strength tensors, respectively.

The effective Lagrangian in SILH basis can be expanded to involve the extra \( CP \)-violating operators defined as,

\[ \mathcal{L}_{CPV} = \frac{ig}{m_W^2} \left[ \Phi^\dagger T_{2k} D^{\nu} \Phi \hat{D}^\mu W_{\mu \nu}^k \right] + \frac{ig'}{2m_W^2} \left[ \Phi^\dagger \hat{D}^\mu \Phi \hat{D}^{\nu} B_{\mu \nu} \right] + \frac{g'^2}{2m_W^2} \Phi^\dagger \Phi B_{\mu \nu} \hat{B}^{\mu \nu} 

+ \frac{g_s^2}{2m_W^2} \Phi^\dagger \Phi G_{\mu \nu}^a G^a_{\mu \nu} + \frac{g_s^3}{m_W^2} \epsilon_{ijk} W_{\mu \nu}^i W^{\nu j} \hat{W}^{\rho \delta} W_{\rho \delta}^k + \frac{g_s^3}{m_W^2} f_{abc} G_{\mu \nu}^a G^{\mu \nu} \hat{G}^{\rho \mu \nu} \]
where
\[ \tilde{B}_{\mu\nu} = \frac{1}{2} \tilde{\epsilon}_{\mu
u\alpha\beta} B^{\alpha\beta}, \quad \tilde{W}_{\mu\nu}^k = \frac{1}{2} \tilde{\epsilon}_{\mu\nu\rho\sigma} W^{\rho\sigma k}, \quad \tilde{G}_{\mu\nu}^a = \frac{1}{2} \tilde{\epsilon}_{\mu\nu\rho\sigma} G^{\rho\sigma a} \]
are the dual field strength tensors.

The SILH bases of CP-conserving and CP-violating dimension-6 operators given in Eq.(2) and Eq.(3) can be defined in terms of the mass eigenstates after electroweak symmetry breaking. The Lagrangian with the relevant subset of anomalous Higgs and neutral Gauge boson couplings in the mass basis for triphoton production as follows
\[
\mathcal{L} = -\frac{1}{4} g_{h\gamma\gamma} F_{\mu\nu} F^{\mu\nu} h - \frac{1}{4} \tilde{g}_{h\gamma\gamma} \tilde{F}_{\mu\nu} h
- \frac{1}{4} g_{hzz} Z_{\mu\nu} Z^{\mu\nu} h - g_{hzz} Z_{\mu} \partial_{\mu} Z^{\mu} h + \frac{1}{2} g_{hzz} Z_{\mu} Z^{\mu} h
- \frac{1}{4} g_{hzz} Z_{\mu} \tilde{Z}^{\mu} h
- \frac{1}{2} g_{hzz} Z_{\mu} F^{\mu\nu} h - g_{hzz} Z_{\mu} \partial_{\mu} F^{\mu\nu} h
\]
where \(Z_{\mu\nu}\) and \(F_{\mu\nu}\) are the field strength tensors of \(Z\)-boson and photon, respectively. The effective couplings in gauge basis defined as dimension-6 operators are given in Table I in which \(a_H\) coupling is the SM contribution to the \(H\gamma\gamma\) vertex at loop level.

**TABLE I:** The relations between Lagrangian parameters in the mass basis (Eq.(4) and the Lagrangian in gauge basis (Eqs. 2 and 3). \((c_W \equiv \cos \theta_W, s_W \equiv \sin \theta_W)\)

| Parameter | Mass Basis | Gauge Basis |
|-----------|------------|-------------|
| \(g_{h\gamma\gamma}\) | \(a_H - \frac{8 g c_s^2 c_W^2}{m_W}\) | \(\tilde{g}_{h\gamma\gamma} = -\frac{8 g c_s^2 c_W^2}{m_W}\) |
| \(g_{hzz}^{(1)}\) | \(-\frac{2 g c_W}{c_W s_W}\) | \(g_{hzz}^{(2)} = \frac{g}{c_W s_W}\) |
| \(g_{hzz}^{(3)}\) | \(-\frac{g}{c_W s_W}\) | \(g_{hzz}^{(4)} = \frac{g}{c_W s_W}\) |
| \(g_{h\gamma\gamma}^{(1)}\) | \(-\frac{g}{c_W s_W}\) | \(g_{h\gamma\gamma}^{(2)} = \frac{g}{c_W s_W}\) |
| \(g_{h\gamma\gamma}^{(2)}\) | \(-\frac{8 g c_s^2 c_W^2}{m_W}\) | \(\tilde{g}_{h\gamma\gamma} = -\frac{8 g c_s^2 c_W^2}{m_W}\) |

This parametrization [27] based on the formulation [28] is not complete [29, 30] since it chooses to remove two fermionic invariants while retaining all the bosonic operators. However, this choice assumes completely unbroken U(3) flavor symmetry of the UV theory and flavor diagonal dimension-six effects. At the end, we only claim a sensitivity study for \(\tilde{c}_{HW}, \tilde{c}_{HB}, \tilde{c}_{\gamma}, \tilde{c}_{HW}, \tilde{c}_{HB}\) and \(\tilde{c}_{\gamma}\) couplings and do not consider higher order electroweak effects.

Our study is based on the Monte Carlo simulations with leading order in MadGraph5_aMC@NLO v2.6.3.2 [31] involving effect of the dimension-6 operators on triphoton production mechanism in \(pp\) collisions. The effective Lagrangian of the SM EFT in Eq.(4) is implemented into the MadGraph5_aMC@NLO using FeynRules [32] and UFO [33] framework. The
triphoton process is sensitive to Higgs-gauge boson couplings; \( g_{h\gamma\gamma} \) and \( g_{h\gamma\gamma} \), and the couplings of a quark pair to single Higgs field; \( \tilde{y}_u, \tilde{y}_d \) in the mass basis. On the other hand, this process is sensitive to the eight Wilson coefficients in the gauge basis: \( \tilde{c}_W, \tilde{c}_B, \tilde{c}_{HW}, \tilde{c}_{HB}, \tilde{c}_\gamma, \tilde{c}_{HW}, \tilde{c}_{HB} \) and \( \tilde{c}_\gamma \) related to Higgs-gauge boson couplings and also effective fermionic couplings. Due to the small Yukawa couplings of the first and second generation fermions, we neglect the effective fermionic couplings. We set \( \tilde{c}_W + \tilde{c}_B \) to zero in all our calculations since the linear combination of \( \tilde{c}_W + \tilde{c}_B \) strongly constrained from the electroweak precision test of the oblique parameters \( S \) and \( T \). Fig 1 shows the cross sections of \( pp \rightarrow \gamma\gamma\gamma + X \) process as a function of CP-conserving \( \tilde{c}_{HW}, \tilde{c}_{HB}, \tilde{c}_\gamma \) couplings on the left panel and CP-violating \( \tilde{c}_{HW}, \tilde{c}_{HB} \) and \( \tilde{c}_\gamma \) couplings on the right panel. The photon transverse momentum greater than 15 GeV is required to calculate cross sections. In this figure, one of the effective couplings is non-zero at a time, while the other couplings are fixed to zero. One can easily see the deviation from SM for \( \tilde{c}_\gamma \) and \( \tilde{c}_\gamma \) couplings even in a small value region for \( pp \rightarrow \gamma\gamma\gamma + X \) process. Therefore, we will only consider these couplings in the detailed analysis including detector effects through \( pp \rightarrow \gamma\gamma\gamma + X \) process at FCC-hh with 100 TeV center of mass energy in the next section.

### III. SIGNAL AND BACKGROUND ANALYSIS

We perform the detailed analysis of \( \tilde{c}_\gamma \) and \( \tilde{c}_\gamma \) effective couplings via \( pp \rightarrow \gamma\gamma\gamma + X \) process for signal including SM contribution as well as interference between effective couplings and SM contributions \( (S + B_{SM}) \). We consider the relevant background has the same final state of the considered signal process including only SM contribution \( (B_{SM}) \). The generated signal and SM background events at parton level in MadGraph5_aMC@NLO v2.6.3.2 are passed through the Pythia 8 \[34\] for parton showering and hadronization. The detector responses are taken into account with FCC detector card in Delphes 3.4.1 \[35\] package. Then, all events are analysed by using the ExRootAnalysis utility \[36\] with ROOT \[37\].

Requiring at least 3 photons with their transverse momenta \( (p_{T}^{\gamma}) \) greater than 0.5 GeV is the pre-selection of the event for detailed analysis. First of all, photons are ordered according to their transverse momentum, i.e., \( p_{T}^{\gamma_1} > p_{T}^{\gamma_2} > p_{T}^{\gamma_3} \). In order to obtain best kinematic cuts to select the signal and background events, transverse momentum \( (p_{T}^{\gamma}) \) and pseudo-rapidity \( (\eta^{\gamma}) \) of the first (the second) leading photon versus invariant mass of two leading photons for signal \( \tilde{c}_\gamma=0.05 \) and \( \tilde{c}_\gamma=0.05 \) and relevant SM Background are plotted in Fig 2 (Fig. 3), respectively. Comparing signal and SM background distributions indicates that \( p_{T}^{\gamma_1} > 40 \text{ GeV}, p_{T}^{\gamma_2} > 25 \text{ GeV} \) and \( |\eta^{\gamma_1,2}| < 2.5 \) at the region

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TABLE II: Event selection and kinematic cuts used for the analysis of signal and background events.

| Cuts                                                                 | Pre-selection | Kinematics          |
|----------------------------------------------------------------------|---------------|---------------------|
|                                                                      | $N_{\gamma} \geq 3$ |                      |
|                                                                      | $p_{T}^{\gamma_{1} \gamma_{2}}/m_{\gamma_{1} \gamma_{2}} > 1/3(1/4)$ |                      |
|                                                                      | $|\eta_{\gamma_{1}, \gamma_{2}}| < 2.5$ |                      |
|                                                                      | $m_{\gamma_{1} \gamma_{2} \gamma_{3}} > 120$ GeV |                      |
|                                                                      | $\Delta R(\gamma_{i}, \gamma_{j}) > 0.7$ |                      |

|                                                                      | Higgs-reconstruction | 120 GeV $< m_{\gamma \gamma} < 128$ GeV |

of Higgs mass as seen in Fig. 2 and Fig. 3. In order to prevent distortion of the low end of the invariant mass spectrum of two photon, we use the thresholds in $p_{T}/m_{\gamma_{1} \gamma_{2}}$ rather than fixed cut in $p_{T}$. Therefore, we apply $p_{T}^{\gamma_{1} \gamma_{2}}/m_{\gamma_{1} \gamma_{2}}$ to be greater than 1/3 (1/4) in addition to fixed cut on the transverse momentum of the third leading photon $p_{T}^{\gamma_{3}} > 12$ GeV. The minimum distance between each photon is required to satisfy $\Delta R(\gamma_{i}, \gamma_{j}) = [(\Delta \phi_{\gamma_{i}, \gamma_{j}})^{2} + (\Delta \eta_{\gamma_{i}, \gamma_{j}})^{2}]^{1/2} > 0.7$ where $\Delta \phi_{\gamma_{i}, \gamma_{j}}$ and $\Delta \eta_{\gamma_{i}, \gamma_{j}}$ are azimuthal angle and the pseudo rapidity difference between any two photons. The invariant mass of three-photons versus invariant mass of two photons for signal $c_{\gamma}=0.05$ and $\tilde{c}_{\gamma}=0.05$ and relevant SM Background are shown in Fig. 4. We also apply $m_{\gamma_{1} \gamma_{2} \gamma_{3}} > 120$ GeV to exclude distortion of the low end of the invariant mass spectrum of two photon. After all mention kinematic cuts, the reconstructed invariant mass of two leading photons is presented for signal $c_{\gamma}=0.05$ and $\tilde{c}_{\gamma}=0.05$ and relevant SM Background in Fig. 5. Finally, events in which reconstructed invariant mass from two leading photons is in the range of 120 GeV $< m_{\gamma \gamma} < 128$ GeV are used to obtain limits on the anomalous Higgs effective couplings. Summary of the cuts used in the analysis is given in Tab. II.

The sensitivity of the dimension-6 Higgs-gauge boson couplings in $pp \rightarrow \gamma \gamma \gamma + X$ process by applying $\chi^{2}$ criterion. The $\chi^{2}$ function is defined as follows

$$\chi^{2}(\bar{c}_{i}) = \sum_{i}^{n_{bins}} \left( \frac{N_{i}^{NP}(\bar{c}_{i}) - N_{i}^{B}}{\sqrt{N_{i}^{B}}} \right)^{2}$$

where $N_{i}^{NP}$ is the total number of events in the existence of effective couplings ($S$), $N_{i}^{B}$ is number of events of relevant SM backgrounds in $i$th bin of the invariant mass distributions of reconstructed Higgs boson from two leading photon. In this analysis, we focused on $\bar{c}_{\gamma}$ and $\tilde{c}_{\gamma}$ couplings which are the main coefficients contributing to $pp \rightarrow \gamma \gamma \gamma + X$ signal process.

Fig. 6 shows the obtained $\chi^{2}$ value as a functions of $\bar{c}_{\gamma}$ and $\tilde{c}_{\gamma}$ couplings for 100 TeV center of mass energy with an integrated luminosity of 10 ab$^{-1}$. The 95% Confidence Level (C.L.) limits
on dimension-6 Higgs-gauge boson couplings $\bar{c}_\gamma$ and $\tilde{c}_\gamma$ are $[-0.0041; 0.0019]$ and $[-0.0027; 0.0027]$, respectively. Here, only statistical uncertainties are considered and the effects of systematic and theoretical sources are neglected. The current experimental limits on these couplings probed using a fit to five differential cross sections measured by ATLAS experiment in $H \to \gamma\gamma$ decay channel with an integrated luminosity of 20.3 fb$^{-1}$ at $\sqrt{s} = 8$ TeV are $[-0.00074; 0.0057]$ and $[-0.0018; 0.0018]$ in Ref. [13]. However, a similar analysis carried out by ATLAS Collaboration using 36.1 fb$^{-1}$ of proton-proton collision at $\sqrt{s} = 13$ TeV did not consider $\bar{c}_\gamma$ and $\tilde{c}_\gamma$ couplings due to the lack of sensitivity of the $H \to \gamma\gamma$ decay channel [21]. The high luminosity LHC constraint on CP-conserving coupling $\bar{c}_\gamma$ extrapolated from LHC Run1 data with $pp \to H + j$, $pp \to H + 2j$, $pp \to H$, $pp \to W + H$, $pp \to Z + H$ and $pp \to t\bar{t} + H$ production modes using a shape analysis on the Higgs transverse momentum is obtained $[-0.00016; 0.00013]$ at 95 % CL at the center-of-mass energy of 14 TeV with 300 fb$^{-1}$ [13]. Using Run-1 data with variety of Higgs and electroweak boson production channels, constraint on CP-violating $\tilde{c}_\gamma$ coupling is $[-0.0012; 0.0012]$ and expected to be a factor of 2 improvement with the high-luminosity LHC prospects [12]. Phenomenological study on CP-conserving the dimension-six operators via $pp \to H + \gamma$ process have been performed considering a fast detector simulation with Delphes at $\sqrt{s} = 14$ TeV [16]. It is found that the limits on coupling $\tilde{c}_\gamma$ is expected to be $[-0.013; 0.023]$ and $[-0.0042; 0.0075]$ with the integrated luminosities of 300 fb$^{-1}$ and 3000 fb$^{-1}$, respectively.

IV. CONCLUSIONS

We have investigated the CP-conserving and CP-violating dimension-6 operators of Higgs boson with other SM gauge boson via $pp \to \gamma\gamma\gamma + X$ process using an effective Lagrangian approach at FCC-hh ($\sqrt{s} = 100$ TeV, $L_{int} = 10$ ab$^{-1}$). We have used leading-order strongly interacting light Higgs basis assuming vanishing tree-level electroweak oblique parameterize and flavor universality of the new physics sector considering realistic detector effect in the analysis. We have shown the 2D plots of kinematic variables, transverse momentum and pseudo-rapidity of each photon and invariant mass distributions of three photon as function of reconstructed invariant mass of two leading photons to determine a cut-based analysis. The reconstructed invariant mass of Higgs-boson from two leading photons is used to obtain limits on the anomalous Higgs effective couplings. We have obtained 95 % C.L. limits on dimension-six operators analysing invariant mass distributions of two leading photon in $pp \to \gamma\gamma\gamma + X$ signal process and the relevant SM background. The $pp \to \gamma\gamma\gamma + X$ process is more sensitive to $\bar{c}_\gamma$ and $\tilde{c}_\gamma$ couplings than the other dimension-six couplings. Our results show
that FCC-hh with $\sqrt{s} = 100$ TeV, $L_{int}=10$ ab$^{-1}$ will be able to probe the dimension-six couplings of Higgs-gauge boson interactions in $pp \rightarrow \gamma\gamma\gamma + X$ process especially for $\bar{c}_\gamma$ and $\tilde{c}_\gamma$ couplings as $[-0.0041; 0.0019]$ and $[-0.0027; 0.0027]$, respectively. Finally, including all production modes as well as triphoton production in a global fit to the experimental data would affect the exclusion ranges and may improve the sensitivities.

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FIG. 1: The total cross section as a function of CP-conserving $\bar{c}_{HW}$, $\bar{c}_{HB}$ and $\bar{c}_\gamma$ couplings (on the left) and CP-violating $\tilde{c}_{HW}$, $\tilde{c}_{HB}$ and $\tilde{c}_\gamma$ couplings (on the right) for $pp \to \gamma\gamma\gamma$ process at the FCC-hh with $\sqrt{s}=100$ TeV.

FIG. 2: Distributions of transverse momentum (in the first row) and the pseudo-rapidity (in the second row) of the first leading photon versus invariant mass of two photons for signal $\bar{c}_\gamma$=0.05 and $\tilde{c}_\gamma$=0.05 and relevant SM Background.
FIG. 3: Distributions of transverse momentum (in the first row) and the pseudo-rapidity (in the second row) of the second leading photon versus invariant mass of two photons for signal $\bar{c}_\gamma=0.05$ and $\tilde{c}_\gamma=0.05$ and relevant SM Background.

FIG. 4: Distribution of invariant mass of three-photons versus invariant mass of two photons for signal $\bar{c}_\gamma=0.05$ and $\tilde{c}_\gamma=0.05$ and relevant SM Background.
FIG. 5: Invariant mass distribution of two photons after all kinematical cuts for signal $\tilde{c}_{\gamma}=0.05$ (red), $\bar{c}_{\gamma}=0.05$ (green) and relevant SM Background (blue).

FIG. 6: Obtained $\chi^2$ as a functions of $\tilde{c}_{\gamma}$ and $\bar{c}_{\gamma}$ couplings for 100 TeV center of mass energy for the integrated luminosity of 10 ab$^{-1}$ (the blue line corresponds to 95% C.L.). The limits are each derived with all other coefficients set to zero.