PRODUCTION OF THREE PHOTONS AT HIGH ENERGY E+ E- COLLIDERS IN RANDALL- SUNDRUM MODEL

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Abstract: *A search for the triple-photon production in the e^-e^+ scattering is indicated in CLIC energy scale. We have analyzed the contribution of γZh anomalous coupling with polarized initial beams. The dependence of the forward – backward asymmetry on the center of mass energy $\sqrt{s}$ is shown. The cross-section depends strongly on the polarization of e^-, e^+ initial beams, the center of mass energy $\sqrt{s}$. The results indicate that with new γZh coupling included mixed - Higgs boson, the total cross-section is enhanced.*

Keywords*: Randall-Sundrum model, triple-photon production, anomalous couplings.*

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1. INTRODUCTION

The Standard model (SM) has been the successful theoretical framework in describing the experimentally observed phenomena of the fundamental particles and their interactions. In spite of its successes, SM has existed some drawbacks. Therefore, some models beyond the SM have been motivated. The Randall-Sundrum (RS) model with two three-branes stabilized has been one of the most attractive attemplts. The RS model has allowed the existence of an additional scalar called the radion (ϕ) [3]. Radion and Higgs boson have the same quantum numbers. Thus, the radion field and the Higg field can be mixed.

The trilinear gauge boson couplings have been important in testing the electroweak interactions [5]. Diboson production, in particular ZZ and W^+W^-, are also extensively used in Higgs boson measurements [6]. Moreover, the anomalous vertices include ZZZ, ZZγ, $Z\gamma\gamma$ interactions, which are not present at tree level in SM, have been widely discussed in the different colliders: e^-e^+ collider, γe^- collider, hadron collider [5, 7 – 13]. In experiment, the cross-section for ZZ production in $p\overline{p}$ collisions has been measured by both the ATLAS and CMS collaboration [14 – 18]. Photon collider can be achieved the backscattered photon beams by Compton scattering of laser light off the high energy electrons at the International Linear Collider (ILC) which has been proposed to discover new physics beyond the SM. Because of clean electron and positron sources at ILC, Z boson produced at the high energy collisions could give possible measurement. Any possible new physics in the Z boson production collision is expected to change the cross-section and Z bosons produced at the high energy proton- proton collisions of LHC have a clean signature and give the possibility to perform precision measurements W and Z bosons produced at the high energy proton-proton collisions of LHC have a clean signature and give the possibility to perform precision measurements.

In our present work, we have studied $e^- e^+ \to \gamma h \to \gamma\gamma\gamma$ process included the vertices of spin-one boson as $\gamma Zh, \gamma\gamma h$. With new $\gamma Zh, \gamma\gamma h$ couplings included mixed - Higgs boson, the total cross-section has been expected to enhance. The layout of this paper is as follows. The influence of the new γZh coupling on the triple-photon production is calculated in Section II. Finally, we summarize our results and make conclusions in Section III.

2. CONTENT

The influence of the new γZh coupling on the triple-photon production

In this work, we evaluate the triple-photon production from electron-positron collision in the RS model. Triple-photon production provides a Higgs production in association with a photon, where the Higgs decays into a photon pair.

We consider the collision process in which the initial state contains electron and positron, the final state contains photon and Higgs boson:

$$e^-(p_1) + e^+(p_2) \to \gamma(k_1) + h(k_2)\,. \tag{1}$$

Here, p_i, k_i (i = 1, 2) stand for the momentums. There are three Feynman diagrams contributing to reaction (1), representing the s, u, t-channels exchange depicted in Fig.1.

The transition amplitudes representing the s, u, t -channels are respectively given by

$$\begin{aligned} M_s = & -i\frac{g_{eZ}C_{\gamma Zh}}{q_s^2 - m_Z^2} u(p_1)\gamma^\sigma(v_e - a_e\gamma^5)\overline{v}(p_2)\left(\eta_{\beta\sigma} - \frac{q_{s\beta}q_{s\sigma}}{m_Z^2}\right)(\eta^{\mu\beta}k_1 q_s - k_1^\beta q_s^\mu)\varepsilon_\mu^*(k_1) \\ & -i\frac{eC_{\gamma\gamma h}}{q_s^2} u(p_1)\gamma^\sigma\overline{v}(p_2)\eta_{\beta\sigma}(\eta^{\mu\beta}k_1 q_s - k_1^\beta q_s^\mu)\varepsilon_\mu^*(k_1) \end{aligned} \tag{2}$$

$$M_u = -i\frac{e\overline{g}_{eeh}}{q_u^2 - m_e^2}u(p_1)(\hat{q}_u + m_e)\varepsilon_\mu^*(k_1)\gamma^\mu\overline{v}(p_2), \quad (3)$$

$$M_t = -i\frac{e\overline{g}_{eeh}}{q_t^2 - m_e^2}\overline{v}(p_2)\gamma^\mu\varepsilon_\mu^*(k_1)(\hat{q}_t + m_e)u(p_1), \quad (4)$$

where

$$C_{\gamma\gamma h} = \frac{\alpha}{2\pi v_0}\left[g_h^r\left(b_2 + b_Y + \frac{4\pi}{\alpha k b_0}\right) - g_h\left(\sum_i e_i^2 N_c^i F_{1/2} + F_1\right)\right], \quad (5)$$

$$C_{\gamma Zh} = \frac{\alpha}{2\pi v_0}\left[2g_h^r\left(\frac{b_2}{\tan\theta_W} - b_Y\tan\theta_W\right) - g_h\left(A_F + A_W\right)\right]. \quad (6)$$

The total cross-section for the whole process $e^-e^+ \to \gamma h \to \gamma\gamma\gamma$ can be calculated as follows

$$\sigma = \sigma(e^-e^+ \to \gamma h) \times Br(h \to \gamma\gamma). \quad (7)$$

where

$$\frac{d\sigma(e^-e^+ \to \gamma h)}{d(cos\psi)} = \frac{1}{32\pi s}\frac{|\vec{k}_1|}{|\vec{p}_1|}|M_{fi}|^2 \quad (8)$$

is the expressions of the differential cross-section [24]. $\psi = (\vec{p}_1, \vec{k}_1)$ is the scattering angle.

For numerical calculations, we choose ILC running at a center-of-mass energy of 1000 GeV. We give estimates for the cross-sections as follows:

i) The differential cross-sections as the function of cosψ can be seen in Fig. 2. With the case of $P_{e^-} = 0.8, P_{e^+} = -0.3$, in our numerical estimation for $e^-e^+ \to \gamma h \to \gamma\gamma\gamma$, the differential cross-section starts to decrease when $-1 \le \cos\psi \le 0$, then increase when $0 \le \cos\psi \le 1$. Moreover, the forward-backward asymmetry decreases when the energy collision increases in Fig. 3. This result shows the energy collision region and direction to collect the final state from experiment.

ii) In Fig.4, the total cross-section is plotted as the function of P_{e^-}, P_{e^+}, which are the polarization coefficients of e^-, e^+ beams, respectively. The parameters are chosen as $\sqrt{s} = 1000$ GeV, $m_\phi = 110$ GeV, $\Lambda_\phi = 5000$ GeV, $\xi = 1/6$. The figure indicates that the total cross-section achieves the maximum value when $P_{e^-} = P_{e^+} = \pm 1$ and the minimum value when $P_{e^-} = 1, P_{e^+} = -1$ or $P_{e^-} = -1, P_{e^+} = 1.$

iii) The polarization coefficients of e^-, e^+ beams are same as in Fig. 4. The total cross-sections are measured in case of the different collision energy $\sqrt{s}$ in Fig. 5. This result shows that the total cross-section increases gradually when the collision energy increases. With the photon and Z boson contribution in s-channel propagators, the total cross-section is much larger than that only with Z boson contribution in s-channel.

3. CONCLUSION

In this work, we have studied the contribution of spin-1 boson Z, γ propagators in the three-photon production. In $e^-e^+ \to \gamma h \to \gamma\gamma\gamma$ collision, the result shows that s – channels give the main contribution. The results indicate that with new γZh, $\gamma\gamma h$ couplings included mixed - Higgs boson, the cross-section for the γh production is enhanced than that in the SM under the same conditions showed in Ref. 25.

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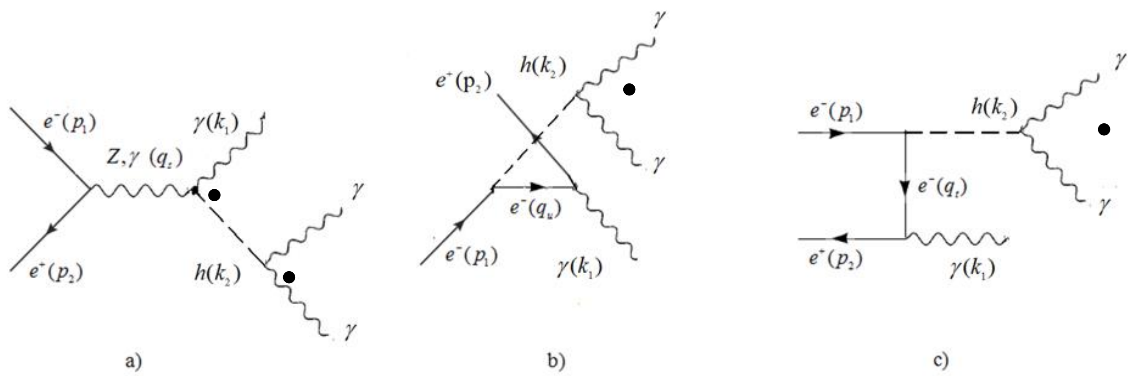

Fig.1. Feynman diagrams of $e^-e^+ \to \gamma h \to \gamma\gamma\gamma$ in the s, u, t-channels.

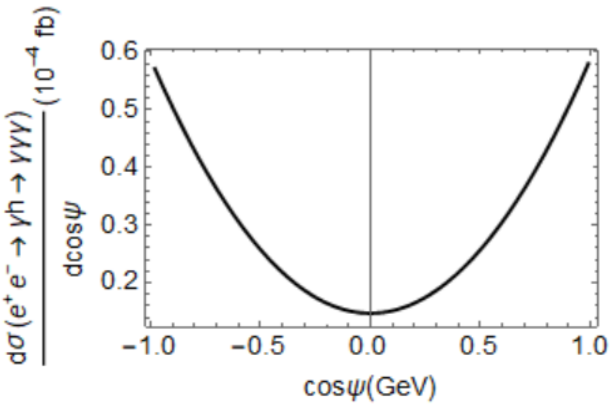

Fig. 2. The differential cross-section for the whole process $e^-e^+ \to \gamma h \to \gamma\gamma\gamma$ as a function of the cosψ. The polarization coefficients are chosen as $P_{e^-} = 0.8, P_{e^+} = -0.3$.

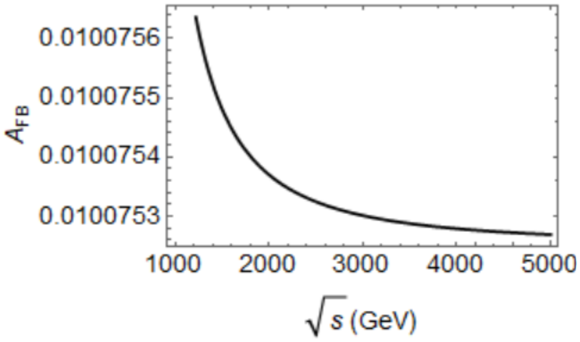

Fig. 3. The forward – backward asymmetry for the whole process $e^-e^+ \to \gamma h \to \gamma\gamma\gamma$ as a function of the collision energy.

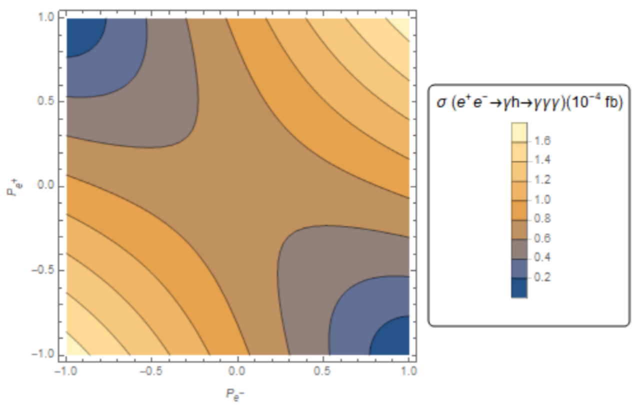

Fig. 4. The total cross-section as a function of the polarization coefficients (P_{e^-}, P_{e^+}) in $e^-e^+ \to \gamma h \to \gamma\gamma\gamma$ collision.

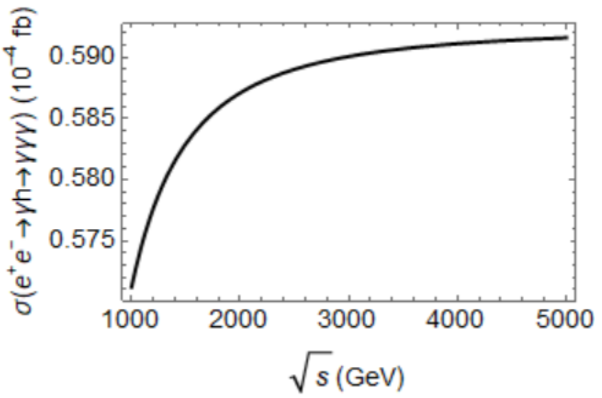

Fig. 5. **The total cross-section** for the whole process $e^-e^+ \to \gamma h \to \gamma\gamma\gamma$ **as a function of the collision energy** $\sqrt{s}$. The polarization coefficients are chosen as $P_{e^-} = 0.8, P_{e^+} = -0.3$.

REFERENCES

1. *G. Aad* et al., *ATLAS Collaboration,* Phys. Lett. B716 *(2012) 1, DOI:* https://doi.org/10.1016/j.physletb.2012.08.020
2. *S. Chatrchyan* et al., *CMS Collaboration,* Phys. Lett. B716 *(2012) 30, DOI:* https://doi.org/10.1016/j.physletb.2012.08.021
3. *L. Randall and R. Sundrum,* Phys. Rev. Lett. 83 *(1999) 3370, DOI:* https://doi.org/10.1103/PhysRevLett.83.3370.

A. *Ahmed, B. M. Dillon, B. Grzadkowski, J. F. Gunion and Y. Jiang* Phys. Rev. D95 *(2017) 095019, DOI:* https://doi.org/10.1103/PhysRevD.95.095019

4. *S. Atag and I. Sahin,* Phys. Rev. D68 *(2003) 093014, DOI:* https://doi.org/10.1103/PhysRevD.68.093014
5. *S. Kallweit, M. Wiesemann,* Phys. Lett. B786 *(2018) 382, DOI:* https://doi.org/10.1016/j.physletb.2018.10.016
6. *G. J. Gounaris, J. Layssac, and F. M. Renard,* Phys. Rev. D61 *(2000) 073013, DOI:* https://doi.org/10.1103/PhysRevD.61.073013
7. *U. Baur and D. L. Rainwater,* Phys. Rev. D62 *(2000) 113011, DOI:* https://doi.org/10.1103/PhysRevD.62.113011
8. *B. Ananthanarayan, S. D. Rindani, R. K. Singh and A. Bartl,* Phys. Lett. B593 *(2004) 95, DOI:* https://doi.org/10.1016/j.physletb.2004.04.067
9. *B. Ananthanarayan, S. K. Garg, M. Patra and S. D. Rindani,* Phys. Rev. D85 *(2012) 034006, DOI:* https://doi.org/10.1103/PhysRevD.85.034006
10. *B. Ananthanarayan, J. Lahiri, M. Patra, and S. D. Rindani,* JHEP 08 *(2014) 124, DOI:* https://doi.org/10.1007/JHEP08(2014)124
11. *R. Rahaman, R. K. Singh,* Eur.Phys.J. C76, *No.10 (2016) 539, DOI:* https://doi.org/10.1140/epjc/s10052-016-4374-4

12.*F. Cascioli* et al., Phys. Lett. B735 *9 (2014) 311, DOI:* https://doi.org/10.1016/j.physletb.2014.06.056
13.*J. Abdallah* et al., JHEP 01 *(2017) 099, DOI:* https://doi.org/10.1007/JHEP01(2017)099.
14.*ATLAS collaboration,* JHEP 03 *(2013) 128, DOI:* https://doi.org/10.1007/JHEP03(2013)128
15.*CMS collaboration,* JHEP 01 *(2013) 063, DOI:* https://doi.org/10.1007/JHEP01(2013)063
16.*ATLAS collaboration,* Phys. Rev. Lett. 116 *(2016) 101801, DOI:* https://doi.org/10.1103/PhysRevLett.116.101801
17.*ATLAS collaboration,* Phys. Lett. B753 *(2016) 552, DOI:* https://doi.org/10.1016/j.physletb.2015.12.048
18.*T. Melia, P. Nason, R. Rontsch, G. Zanderighi,* JHEP 1111 *(2011) 078, DOI:* https://doi.org/10.1007/JHEP11(2011)078
19.*D. V. Soa and B. T. H. Giang,* Mod. Phys. Lett. A35 *(2020) No. 25, 2050217, DOI:* https://doi.org/10.1142/S021773232050217X
20.*T. Kikuchi, N. Okada, M. Takeuchi,* Phys.Rev. D77 *(2008), 094012, DOI:* https://doi.org/10.1103/PhysRevD.77.094012
21.*D. Dominici, B. Grzadkowski, J. F. Gunion, and M. Toharia,* Nucl. Phys. B671 *(2003) 243, DOI:* https://doi.org/10.1016/j.nuclphysb.2003.08.020
22.*B. Grzadkowski, J. F. Gunion, and M. Toharia,* Phys. Lett. B712 *(2012) 70, DOI:* https://doi.org/10.1016/j.physletb.2012.04.037
23.*M. E. Peskin and D. V. Schroeder,* An Introduction to Quantum Field Theory, *Addision-Wesley Publishing (1995).*
24.*S. Kanemura, K. Mawatari, K. Sakurai, Phys. Rev. D.* 90 *(2019) 035023, DOI:* https://doi.org/10.1103/PhysRevD.99.035023

SỰ TẠO BA PHOTON TẠI VA CHẠM e^-e^+ NĂNG LƯỢNG CAO TRONG MẪU RANDALL-SUNDRUM

Tóm tắt: *Nghiên cứu sự tạo ba photon trong tán xạ e+e- được chỉ ra trong thang năng lượng CLIC. Chúng tôi đã phân tích đóng góp của các đỉnh tương tác dị thường với chùm phân cực hạt tới. Sự phụ thuộc đối xứng trước - sau vào năng lượng khối tâm cũng được chỉ ra. Tiết diện phụ thuộc mạnh vào phân cực của chùm hạt tới và năng lượng khối tâm. Kết quả cũng chỉ ra rằng với đóng góp của đỉnh dị thường mới, tiết diện toàn phần được tăng cường.*

Từ khoá: *Mẫu Randall-Sundrum, sự tạo ba photon, đỉnh tương tác dị thường*