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Anomalous $WW\gamma$ couplings with beam polarization at the Compact Linear Collider

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Abstract

We study the anomalous $WW\gamma$ couplings at the Compact Linear Collider through the processes $e^+e^- \to W^+W^-$, $e^-e^+ \to e^-\gamma^*e^+ \to e^+\nu_e W^-$ and $e^-e^+ \to e^-\gamma^*\gamma^*e^+ \to e^-W^+W^-e^+$ (γ^* is the Weizsacker–Williams photon). We give the 95% confidence level limits for unpolarized and polarized electron (positron) beam on the anomalous couplings for various values of the integrated luminosities and center-of-mass energies. We show that the obtained limits on the anomalous couplings through these processes can highly improve the current experimental limits. In addition, our limits with beam polarization are approximately two times better than the unpolarized case.

1. Introduction

The Standard Model (SM) has been so far successful in describing the below the electroweak scale with high precision. Therefore, electroweak interactions are known very well in this model. Self-interactions of the gauge bosons are outcomes of the $SU_L(2) \times U_Y(1)$ gauge symmetry of the SM. Determination of these type of interactions plays an important role to test the non-

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Abelian gauge symmetries of the electroweak sector. Searching that kind of interactions can generate extra confirmation of the SM with a higher sensitivity or reveal some information for new physics beyond the SM. Any measurement which conflicts with the SM expectations would lead to the existence of new physics.

The traditional approach to investigate new physics effect to $WW\gamma$ interactions is introduced in a model independent way by means of the effective Lagrangian method. The theoretical motivations of such a method would be based on the guess that at higher energy regions beyond the SM, there is a main physics which reduces to the SM at lower energy regions. Such a procedure is quite general and independent of the details of the model. Hence, this method is generally known model independent analysis. The effective Lagrangian for $WW\gamma$ interaction which conserves charge and parity can be given as follows [1,2],

$$\frac{iL}{g_{WW\gamma}} = g_1^\gamma (W^\dagger_{\mu\nu} W^\mu A^\nu - W^{\mu\nu} W^\dagger_\mu A_\nu) + \kappa W^\dagger_\mu W_\nu A^{\mu\nu} + \frac{\lambda}{M_W^2} W^\dagger_{\rho\mu} W^\mu_\nu A^{\nu\rho}. \tag{1}$$

Here $g_{WW\gamma} = e$, $V_{\mu\nu} = \partial_\mu V_\nu - \partial_\nu V_\mu$ ($V_\mu = W_\mu, A_\mu$), g_1^γ, κ, λ are the dimensionless anomalous parameters. They are related to magnetic dipole and electric quadrupole moments of W boson. In the SM, the couplings are obtained $g_1^\gamma = 1$, $\kappa = 1$ and $\lambda = 0$ at the tree level. The $g_1^\gamma = 1$ value is fixed for on-shell photons at tree level by electromagnetic gauge invariance to its SM value. Then, the Feynman rule for the anomalous vertex can be found from Eq. (1),

$$\begin{aligned}\Gamma_{\mu\nu\rho} = {} & eg_{\mu\nu}\left(p_1 - p_2 - \frac{\lambda}{M_W^2}[(p_2.p_3)p_1 - (p_1.p_3)p_2]\right)_\rho \\ & + eg_{\mu\rho}\left(\kappa p_3 - p_1 + \frac{\lambda}{M_W^2}[(p_2.p_3)p_1 - (p_1.p_2)p_3]\right)_\nu \\ & + eg_{\nu\rho}\left(-\kappa p_3 + p_2 - \frac{\lambda}{M_W^2}[(p_1.p_3)p_2 - (p_1.p_2)p_3]\right)_\mu \\ & + \frac{e\lambda}{M_W^2}(p_{2\mu}p_{3\nu}p_{1\rho} - p_{3\mu}p_{1\nu}p_{2\rho})\end{aligned} \tag{2}$$

where all of momentums are incoming the vertex.

However, after the recent discovery of a new particle which is consistent with the SM Higgs boson, then new physics is described in terms of a direct extension of the ordinary SM formalism; i.e. using a linear realization of the symmetry. Considering CP-conserving interactions of dimension six, eleven independent operators can be constructed. Among them the three operators which do not affect the gauge boson propagators at tree-level, but give rise to deviations in the charge and parity conserving $WW\gamma$ gauge couplings. Denoting the corresponding couplings as $\alpha_{W\phi}$, $\alpha_{B\phi}$, and α_W, the $WW\gamma$ couplings inducing effective Lagrangian can be given by [3]

$$\begin{aligned}L = {} & ig'\frac{\alpha_{B\phi}}{m_W^2}(D_\mu\Phi)^\dagger B^{\mu\nu}(D_\nu\Phi) + ig\frac{\alpha_{W\phi}}{m_W^2}(D_\mu\Phi)^\dagger\vec{\tau}.\vec{W}^{\mu\nu}(D_\nu\Phi) \\ & + 9\frac{\alpha_W}{6m_W^2}\vec{W}^\mu_\nu.(\vec{W}^\nu_\rho \times \vec{W}^\mu_\rho)\end{aligned} \tag{3}$$

Replacing the Higgs doublet field by its vacuum expectation value in the above equation, nonvanishing anomalous $WW\gamma$ gauge couplings in Eq. (1) can be expressed as