Sensitivity study of anomalous HZZ couplings at future Higgs factory

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Abstract

We study the sensitivity of constraining the model independent Higgs-Z-Z coupling under Effective Theory up to Dimension-6 operators at the future Higgs factory, angular distribution and CP violation involved with the coupling constants from effective theory are constrained from characteristics of Circular Electron Positron Collider(CEPC), which will be an appropriate window to test the Standard Model and look for New Physics.

Introduction and Structure

Since the discovery of Higgs particle, the generic Higgs coupling to vector bosons presents about $\sim 7\%$ deviation from SM prediction, and its experimental error is so big ($\pm 56\%$) that the good agreements with SM still stand tenable. Future lepton colliders such as CEPC, CLIC, ILC and FCC-ee (TLEP) will accumulate events with full kinematics and less backgrounds at high luminosity, which will support precision tests in the Higgs sector. In our work an Effective Field Theory (EFT) approach is adopted with so called Strongly Interacting Light Higgs (SILH) scenario on the HZZ couplings. This model-independent description however consists of 12 independent operators for a single HZZ vertex, it is not practical to extract so many Wilson coefficients in experiments or even on the above mentioned leptonic colliders with luminosity up to several thousands of femtobarn. So we further followed a compression where only four phenomena parameters are involved and demonstrated how to constrain these 4 parameters with the distributions of polarization angle and azimuthal angle.

Analytical: Analysis results of angular distribution and CP-violation terms for Z decays to 2 leptons affected by new HZZ coupling are presented.
Numerical: Numerical limits on the sensitivity of new physics parameters based on the design of CEPC, and several figures are attached.
Summary.

Process Illustration and Dimension-6 EFT

The Effective Lagrangian of HZZ sector is written as,

$$\mathcal{L}_{HZZ} = -\frac{1}{4} g^{(1)}_{hzz} Z_{\mu\nu} Z^{\mu\nu} h - g^{(2)}_{hzz} Z_{\nu} \partial_{\mu} Z^{\mu\nu} h + g^{(3)}_{hzz} Z_{\mu} Z^{\mu} h - \frac{1}{4} \widetilde{g}_{hzz} Z_{\mu\nu} \widetilde{Z}^{\mu\nu} h. \quad (1)$$

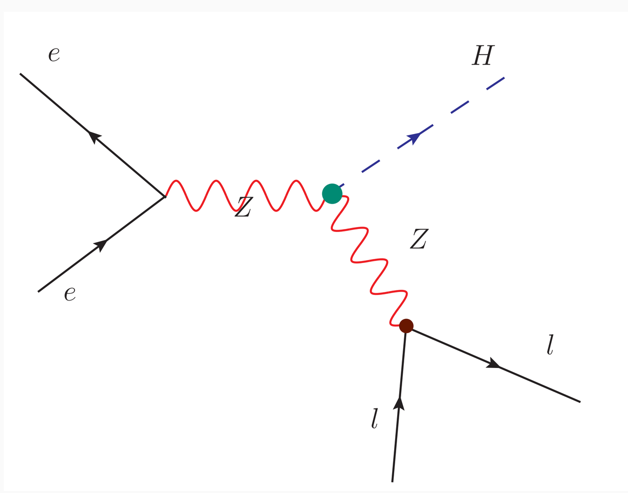

Fig. 1: Feynman diagram for process$e^+e^- \to HZ(l^+l^-)$,

the effective Feynman rule can be derived as,

$$V_{\mu\nu} = i g_{\mu\nu}[g_0 + g_3 + g_2(p_3^2 + p_2^2) + g_1(p_2 \cdot p_3)] - i[\frac{1}{2} g_1 (p_3^{\mu} p_2^{\nu} + p_2^{\mu} p_3^{\nu}) + g_2(p_2^{\mu} p_2^{\nu} + p_3^{\mu} p_3^{\nu}) - \widetilde{g} \epsilon_{\mu\nu\rho\sigma} p_3^{\rho} p_2^{\sigma}]. \quad (2)$$

The scatting angle $\hat{\vartheta}$, polarization angle ϑ and azimuthal angle φ is defined in Fig.2 such that above production amplitude and decay amplitude can be evaluated in each own frame and directly be connected.

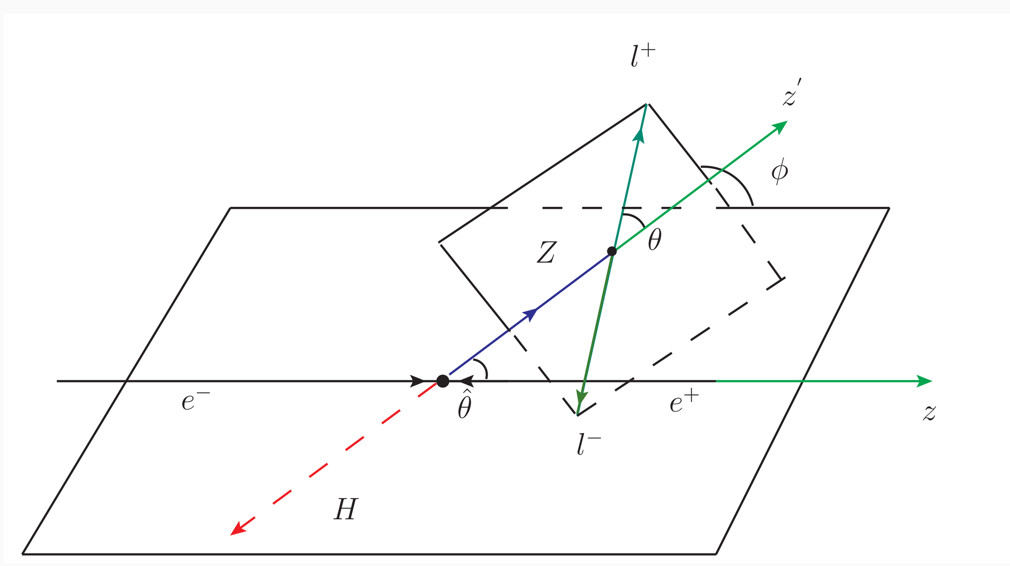

Fig. 2: $e^+e^- \to HZ(l^+l^-)$.

Angular distribution and CP-violation

After we apply narrow width approximation, differential cross section is expressed as,

$$\frac{d\sigma}{dcos\hat{\vartheta} dcos\vartheta d\varphi} = K \sum_{\tau} D^{*}_{\lambda',\tau} \rho^{\lambda'\lambda} D_{\lambda,\tau} = K \sum_{\tau} \sum_{\sigma_1,\sigma_2} D^{*}_{\lambda',\tau} \mathcal{M}^{\lambda'^{\dagger}} \mathcal{M}^{\lambda} D_{\lambda,\tau}. \quad (3)$$

. where K and β below are kinetic factors for specific process, $D_{\lambda,\tau}$ is the decay (helicity) amplitude of Z boson in its rest frame and $\mathcal{M}^{\lambda}$ refers to the the amplitude of HZ production.
Polarization in Z decay:

$$\frac{d\sigma}{\sigma dcos\vartheta} = \frac{3M_Z^2}{8(a_f^2 + v_f^2)\ Q} \{[g_0^2(1 + 2\frac{g_3'}{g_0}) \frac{E_Z^2}{M_Z^2} + g_1 g_0 \frac{Q_1}{M_Z^2}] \Gamma^0(\vartheta) + g_0^2(1 + 2\frac{g_3'}{g_0})[\Gamma^-(\vartheta) + \Gamma^+(\vartheta)]\}. \quad (4)$$

$g_3' = 2g_2(s + m_Z^2) + g_3 + g_1\sqrt{s}E_Z$. is a compact combination of coupling constants g_i in the Lagrangian.
Azimuthal angle distribution for CPV:

$$\frac{d\sigma}{\sigma d\varphi} = \frac{M_Z^2}{4\pi Q} \times \{\frac{2Q}{M_Z^2} - g_0^2(1 + 2\frac{g_3'}{g_0}) c_{2\varphi} + 0 \cdot c_{\varphi} - g_0 \tilde{g} s \beta s_{2\varphi} + 0 \cdot s_{\varphi}\}. \quad (5)$$

The $sin\varphi$ characteristic can be recovered by breaking the symmetry in decay angle with integrating only half over ϑ, at a price of $cos\varphi$ background:

$$\frac{d\sigma}{\sigma d\varphi}|_{\vartheta \gtrless \pi/2} = \frac{M_Z^2}{16\pi Q} \times \{\frac{8Q}{M_Z^2} - 4g_0^2(1 + 2\frac{g_3'}{g_0}) c_{2\varphi} - 4 g_0 \tilde{g} s \beta s_{2\varphi} \pm 3 g_0 \tilde{g} s \frac{\pi a_e v_e}{v_e^2 + a_e^2} \frac{E_Z}{M_Z} s_{\varphi} \pm 6 \frac{\pi a_e v_e}{(v_e^2 + a_e^2)} [g_0^2(1 - 2\frac{g_3'}{g_0}) \frac{E_Z}{M_Z} + g_0 g_3' \frac{Q_1}{E_Z M_Z}] c_{\varphi}\}. \quad (6)$$

Numerical analysis and estimations on NP coupling constants

Characteristics on CEPC, Luminosity : $5000fb^{-1}$ at $E = 240GeV$; Phase space cut: $p_l \geq 18GeV, |cos\theta_l| \leq 0.98, |M_{l^+l^-} - M_Z| < 15GeV$.

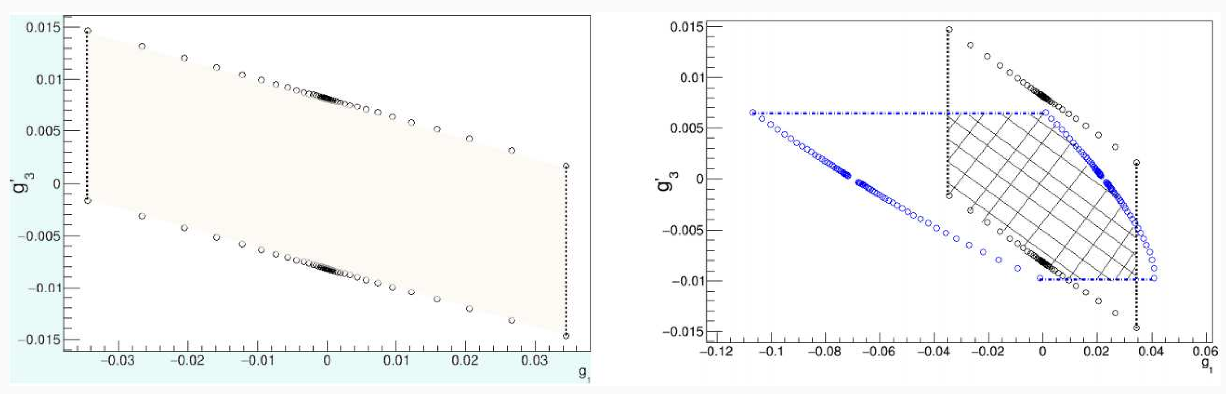

Fig. 3: Left: Limits from cross section, no sensitivity in the encompassed region in the belt.
Right: Limits from polarization angle and cross section, no sensitivity in the meshed belt closed by the blue lines. The black belt is from left figure.

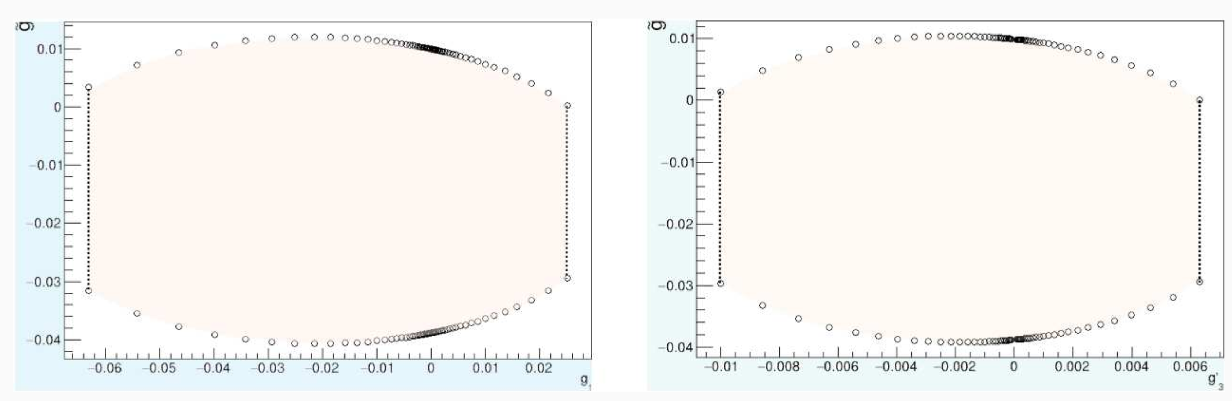

Fig. 4: Left: Limits from azimuthal angle distribution, with g_1 in correlation, no sensitivity in the belt ;
Right: Limits from azimuthal angle distribution, with g_3' in correlation, no sensitivity in the belt .

Coupling constants	Estimations of eliminating interval
g_1	-0.035 $\sim$ 0.035
g_3'	-0.01 $\sim$0.0053
$\tilde{g}$	-0.04 $\sim$ 0.01

Fig. 5: Numerical limits.

Summary We have studied the $e^+e^- \to HZ$ process under Dimension-6 EFT, where the effects deviate from SM are characterised on cross section, angular distribution and CP-violation, which are reflected from the parameters of effective coupling constants $g_1, g_3', \tilde{g}$. Based the most recently design characteristics on the future electron positron collider(CEPC), we estimate the limits on these parameters, which will offer an effective window for searching of New Physics beyond Standard Model.