Testing the $Z\gamma H$ vertex at future linear colliders for intermediate Higgs masses*

E. Gabrielli[a], V.A. Ilyin[b] and B. Mele[c]

[a] *University of Notre Dame, IN, USA*
[b] *Institute of Nuclear Physics, Moscow State University, Russia*
[c] *INFN, Sezione di Roma 1 and Rome University "La Sapienza", Italy*

Abstract

Higgs production in $e\gamma$ collisions, through the one-loop reaction $e\gamma \to eH$ at large p_T, can provide a precise determination of the $Z\gamma H$ vertex.

Among other couplings, the interactions of the Higgs scalar with γ and Z are particularly interesting, since they depend on the relation between the spontaneous symmetry breaking mechanism and the electroweak mixing of the two gauge groups $SU(2)$ and $U(1)$. In this respect, three vertices can be studied: ZZH, $\gamma\gamma H$ and $Z\gamma H$. While in the SM the ZZH vertex stands at the tree level, the other two contribute only at one-loop. This means that the $\gamma\gamma H$ and $Z\gamma H$ couplings can be sensitive to the contributions of new particles circulating in the loop. For the Higgs masses discussed here, $m_H \lesssim 140$ GeV, a measurement of the $\gamma\gamma H$ coupling should be possible by the determination of the BR for the decay $H \to \gamma\gamma$, e.g. in the LHC Higgs discovery channel, $gg \to H \to \gamma\gamma$, or in $\gamma\gamma \to H$ at future $\gamma\gamma$ linear colliders. A chance of measuring the $Z\gamma H$ vertex is given by collision processes, e.g. in $e^+e^- \to \gamma H\,, ZH$. However, in the ZH channel the $Z\gamma H$ vertex contributes to the one-loop corrections, thus implying a large tree-level background. The reaction $e^+e^- \to \gamma H$ has been extensively studied [1]. Unfortunately, it suffers from small rates, $\approx 0.05 \div 0.001$ fb at $\sqrt{s} \sim 500 \div 1500$ GeV, and (as we estimated) the main background $e^+e^- \to \gamma b\bar{b}$ process has large cross sections: $\approx 4 \div 0.8$ fb for $m_{b\bar{b}} = 100 \div 140$ GeV, at $\sqrt{s} \sim 500 \div 1500$GeV, assuming reasonable kinematical cuts. Recently, the one-loop process $e\gamma \to eH$ was analysed in details [2]. The total rate for this reaction is rather high, > 1 fb for $m_H < 400$ GeV. The main strategy to enhance the $Z\gamma H$ vertex effects consists in requiring a final electron tagged at large angle. E.g., for $p_T^e > 100$GeV, $Z\gamma H$ is about 60% of the generally dominant $\gamma\gamma H$ contribution. The main irreducible background comes from $e\gamma \to eb\bar{b}$. A further background is the charm production through $e\gamma \to ec\bar{c}$, when the c quarks are misidentified into b's. At $\sqrt{s} = 500$ GeV the cut $\theta_{b(c)} > 18^\circ$ (between each $b(c)$ quark and the beams) makes the background comparable to the signal [2]. Resolved $e\gamma(g) \to eb\bar{b}(ec\bar{c})$ production, where the photon interacts via its gluonic content, could also contribute but, as we found, it is quite small.

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We studied polarization effects and found they are rather strong. E.g., for right handed electrons there is a strong destructive interference between the terms $\gamma\gamma H$ and $Z\gamma H$.

Now we discuss the prospects of the $e\gamma \to eH$ reaction in setting experimental bounds on a possible anomalous $Z\gamma H$ coupling. We assume, that the anomalous $\gamma\gamma H$ contributions have been well tested in some other experiment (e.g., through $\gamma\gamma \to H$). Then, one would like to get limitations just on the anomalous $Z\gamma H$ contributions. Anomalous CP-even and CP-odd operators contributing to $e\gamma \to eH$ [3] are:

$$\mathcal{O}_{UW;UB} = \left(\frac{|\Phi|^2}{v^2} - \frac{1}{2}\right)\{WW;BB\} , \qquad \bar{\mathcal{O}}_{UW;UB} = \frac{|\Phi|^2}{v^2}\left\{W\tilde{W};B\tilde{B}\right\} ,$$

where $\mathcal{L}^{eff} = d\cdot\mathcal{O}_{UW} + d_B\cdot\mathcal{O}_{UB} + \bar{d}\cdot\bar{\mathcal{O}}_{UW} + \bar{d}_B\cdot\bar{\mathcal{O}}_{UB}$. The corresponding $Z\gamma H$ anomalous terms in the helicity amplitudes of $e\gamma \to eH$ are

$$\frac{4\pi\alpha}{M_Z(M_Z^2 - t)}\sqrt{-\frac{t}{2}}\left\{d_{\gamma Z}[(u-s) - \sigma\lambda(u+s)] - i\bar{d}_{\gamma Z}[\lambda(u-s) + \sigma(u+s)]\right\},$$

where s, t and u are the Mandelstam kinematical variables, $\sigma/2$ and λ are the electron and photon helicities, and $d_{\gamma Z} = d - d_B$, $\bar{d}_{\gamma Z} = \bar{d} - \bar{d}_B$.

At $\sqrt{s} = 500$ GeV, for $m_H = 120$ GeV, one can then constrain the CP-even coupling in the following way: $-0.0025 < d_{\gamma Z} < 0.004$ in the unpolarized case, $|d_{\gamma Z}| < 0.0015$ for left-handed and $-0.007 < d_{\gamma Z} < 0.004$ for right-handed electrons. The corresponding bounds on the CP-odd coupling depends only slightly on the electron polarization, and are $|\bar{d}_{\gamma Z}| \lesssim 0.006$. Here we have taken into account the contributions for background from $e\gamma \to eb\bar{b}(ec\bar{c})$, assuming 10% of the c/b misidentifying, and from the resolved photons. The cuts $\theta_{b(c)} > 18°$, $p_T^e > 100$ GeV and $|m_{b\bar{b}(c\bar{c})} - m_H| < 3$ GeV are applied. The bounds presented have been computed by using the requirement that no deviation from the SM cross section is observed at the 95% CL, with an integrated luminosity 100 fb^{-1}. If the anomalous terms appear as contributions of new particles in the $Z\gamma H$ loop with the mass M_{new}, then one gets $d_{\gamma Z}, \bar{d}_{\gamma Z} \sim (v/M_{new})^2$. By using this relation, one obtains the bounds $M_{new} \gtrsim 6.2$ TeV in the CP-even case and $M_{new} \gtrsim 3.5$ TeV in the CP-odd case. All the results presented here were obtained with the help of the CompHEP package [4].

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