Abstract

We study the associated production of Higgs and Z bosons in high energy CERN

production at photon linear colliders

Production of Z-Higgs boson pairs

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where $N_c = 3$ is the number of colors, and $Q_f$ is the charge of the fermion running in the loop. $\lambda_1$ and $\lambda_2$ are the helicities of the photons while $\lambda_3$ is the helicity of the $Z$ boson. In our calculations we used the expression given in Ref. [12] for the amplitude $T_{\gamma\gamma}$.

In the helicity basis, there are twelve possible helicity configurations, however, due to $CP$ invariance and Bose symmetry only five of them give rise to independent contributions. Denoting by $\sigma_{\lambda_1\lambda_2\lambda_3}$ the contribution to the elementary cross section from the helicity configuration $\{\lambda_1, \lambda_2, \lambda_3\}$, we have

\begin{align}
\hat{\sigma}_{+++} &= \hat{\sigma}_{---} , \\
\hat{\sigma}_{+++} &= \hat{\sigma}_{---} , \\
\hat{\sigma}_{++-} &= \hat{\sigma}_{-+-} , \\
\hat{\sigma}_{+-+} &= \hat{\sigma}_{-++} = \hat{\sigma}_{+-+} , \\
\hat{\sigma}_{+-0} &= \hat{\sigma}_{-+-} .
\end{align}

(2)

In Fig. 1, we plot the five independent contributions as a function of the center-of-mass energy of the $\gamma\gamma$ system. The triangle loops contribute only to the $J_z = 0$ amplitudes ($++0$ and $--0$), while the box diagrams contribute to all of them. In spite of the interference between the triangle and the box contributions being destructive [12], the largest polarized cross section comes from the $++0$ helicity configuration.

Figure 2 shows the behavior of the unpolarized elementary cross section

\[ \hat{\sigma} = \frac{1}{4} \sum_{\lambda_1\lambda_2\lambda_3} \hat{\sigma}_{\lambda_1\lambda_2\lambda_3} \]

for the subprocess $\gamma\gamma \rightarrow ZH$ as a function of the center-of-mass energy of the $\gamma\gamma$ system for two different values of the top quark mass. Since the $Z$ boson couples axially with the fermions in the loop, the contribution of a degenerated family to this process vanishes. In fact, the invariant amplitude in this limit is proportional to

\[ I_{f}Q_{f}^{2} + N_{t}I_{t}Q_{t}^{2} + N_{s}I_{s}Q_{s}^{2} = 0 , \]

where $I_f$ is the weak isospin of the fermion $f$. Therefore the cross section increases as the mass splitting inside a generation increases. In consequence, as we could expect, for a fixed values of the Higgs mass, the cross section at high energies is larger for a heavier top quark. Moreover, the elementary cross section exhibits peaks around the threshold for the production of the fermions - that is, for center-of-mass energies around twice the fermion masses.

In order to evaluate the total cross section for the $ZH$ production in a $\gamma\gamma$ collider, we must fold the photon luminosity with the subprocess elementary cross section, i.e.

\[ \sigma(s) = \int_{\text{max}}^{\text{min}} \frac{dL_{\gamma\gamma}}{dz} \hat{\sigma} (\sqrt{s} = z^2s) , \]

(5)

where $\sqrt{s} (\sqrt{s})$ is the center-of-mass energy of the $e^+e^-$ ($\gamma\gamma$) system, and

\[ \frac{dL_{\gamma\gamma}}{dz} = 2z \int_{1/y_{\text{max}}}^{y_{\text{min}}} \frac{dy}{y} F_{1}(x,y)F_{1}(x,z^{2}/y) . \]

(6)

We assumed that the backscattered photon beam is not polarized and employed the spectrum of backscattered photons $F_{1}(x,y)$ given in Ref. [5] with $x = 4.8$ in order to maximize the available energy of the photons and to avoid unwanted $e^+e^-$ pair production, which leads to a reduction of the $\gamma\gamma$ luminosity.

In Fig. 3 we plot the results for the total cross section for $\gamma\gamma \rightarrow ZH$ as a function of the Higgs boson mass ($M_{H}$) at $\sqrt{s} = 500$ and 1000 GeV. From this figure it is clear that the cross section grows as the value of $m_{top}$ and/or $\sqrt{s}$ increases. This behavior can be easily related to the subprocess elementary cross section given in Fig. 2 and to the available phase space for $ZH$ production. Therefore, within the framework of the standard model, this process will give rise only to very few events for an yearly integrated luminosity of 10 $fb^{-1}$, even at very high energies. Due to the low event rate of this process, it is not possible to look for invisibly decaying Higgs bosons because the signal will be immersed in a large $\gamma\gamma \rightarrow ZZ$ background.

In order to access the effect of new charged particles that might exist, we also analyzed the process taking into account a forth sequential generation of fermions. For most values of the allowed parameter space, this modification lead to a slight increase in the total cross section that is of the order of 10%. This is due to the fact that the elementary cross


FIGURES

FIG. 1. Contributions to the elementary cross section $\delta(\gamma\gamma \to ZH)$ from each helicity amplitude as a function of the center-of-mass energy $E_{\gamma\gamma}$ assuming $M_H = 80$ and 140 GeV.

FIG. 2. Unpolarized elementary cross section $\delta(\gamma\gamma \to ZH)$ as a function of the center-of-mass energy $E_{\gamma\gamma}$ assuming $M_H = 80$ GeV. The solid (dashed) line corresponds to $m_{top} = 140$ (200) GeV.

FIG. 3. Total cross section $\sigma(\gamma\gamma \to ZH)$ as a function of the Higgs-boson mass ($M_H$) for $\sqrt{s} = 500$ and 1000 GeV and $m_{top} = 140$ and 200 GeV.
Fig. 1

Fig. 2