Pair-production of Higgs boson in association with top quarks pairs at $e^+e^-$ colliders

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Abstract. We study the Higgs pair-production in the Standard Model of the strong and electroweak interactions at future $e^+e^-$ collider energies, with the reaction $e^+e^- \rightarrow t\bar{t}HH$. We evaluated the total cross section of $t\bar{t}HH$ and calculate the number total of events considering the complete set of Feynman diagrams at tree-level. The numerical computation is done for the energy which is expected to be available at a possible Next Linear $e^+e^-$ Collider: with center-of-mass energy 800, 1600 GeV and luminosity 1000 $fb^{-1}$.

1. Introduction

The search for Higgs boson is one of the main missions of present and future high-energy colliders. The observation of this particle is of major importance for the present understanding of the interactions of the fundamental particles.

The trilinear Higgs self-coupling can be measured directly in pair-production of Higgs particles at hadron and high-energy $e^+e^-$ linear colliders. Higgs pairs can be produced through double Higgs-strahlung of $W$ or $Z$ bosons [1-4], $WW$ or $ZZ$ fusion [2,5-8]; moreover through gluon-gluon fusion in $pp$ collisions [9-11] and high-energy $\gamma\gamma$ fusion [2,5,12] at photon colliders. The two main processes at $e^+e^-$ colliders are double Higgs-strahlung and $WW$ fusion:

\[
\text{double Higgs-strahlung} \quad : \quad e^+e^- \rightarrow ZHH \\
\text{WW double-Higgs fusion} \quad : \quad e^+e^- \rightarrow \bar{\nu}_e\nu_eHH. \quad (1)
\]

The $ZZ$ fusion process of Higgs pairs is suppressed by an order of magnitude since the electron-Z coupling is small. However, the process $e^+e^- \rightarrow t\bar{t}H$, has been extensively studied. This three-body process is important because it is sensitive to Yukawa couplings. The inclusion of four-body processes with heavy fermions $f$, $e^+e^- \rightarrow f\bar{f}HH$ [5] in which the SM Higgs boson is radiated by a $t(\bar{t})$ quark, at future $e^+e^-$ colliders [13-15] with a c.m. energy in the range of 500 to 1600 GeV, such as the TESLA machine [16] is necessary in order to know its impact on the three-body mode processes and also to search for new relations that could have a clear signature of the Higgs boson production.
Table 1. Total production of Higgs pairs in the SM for $\mathcal{L} = 1000$ fb$^{-1}$ and $m_t = 175$ GeV.

| $M_H$ (GeV) | $\sqrt{s} = 800$ GeV | $\sqrt{s} = 1600$ GeV |
|-----------|----------------|----------------|
| 110       | 14             | 19             |
| 130       | 6              | 15             |
| 150       | 2              | 11             |
| 170       | 1              | 9              |
| 190       |                | 7              |

Moreover, this process depends on the Higgs boson triple self-coupling, which could lead us to obtain the first non-trivial information on the Higgs potential. We are interested in finding regions that could allow the observation of the process $t\bar{t}HH$ at the next generation of high energy $e^+e^-$ linear colliders. We consider the complete set of Feynman diagrams at tree-level and used the CalcHep [17] packages for the evaluation of the amplitudes and of the cross section.

2. Cross Section of the Higgs Pairs Production in the SM

In this work, we evaluate the total cross section of the Higgs pair-production in the SM at next generation linear $e^+e^-$ colliders.

For the SM parameters, we have adopted the following: the angle of Weinber $\sin^2 \theta_W = 0.232$, the mass ($m_t = 175$ GeV) of the top, the mass ($m_{Z^0} = 91.2$ GeV) of the $Z^0$, with the mass $M_H$ of the Higgs boson having been taken as inputs [18].

We have considered the high energy stage of a possible Next Linear $e^+e^-$ Collider with $\sqrt{s} = 800, 1600$ GeV and design luminosity 1000 fb$^{-1}$. In the evaluation of the amplitudes and of the cross section, we used the CalcHep [17] packages.

In order to illustrate our results of the production of Higgs pairs in the SM, we present in Table 1 the total production of Higgs pair in the MS $\mathcal{L} = 1000$ fb$^{-1}$ and $m_t = 175$ GeV.

For center-of-mass energies of 800-1600 GeV and high luminosity, the possibility of observing the process $t\bar{t}HH$ is promising as shown in Table 1.

3. Conclusions

In conclusion, the double Higgs production in association with $t(\bar{t})$ quarks ($e^+e^- \rightarrow t\bar{t}HH$) will be observable at the Next Generation Linear $e^+e^-$ Colliders. The study of this process is important in order to know their impact on the 3-body process and it could be useful to probe anomalous $HHH$ coupling given the following conditions: very high luminosity, center-of-mass large energy and intermediate range Higgs mass.

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