Feasibility study of Higgs pair creation in $\gamma\gamma$ collider

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We studied a feasibility of measuring Higgs boson pair production in a Photon Linear
Collider. The optimum energy of $\gamma\gamma$ collision was estimated with a realistic luminosity
distribution. We also discussed simulation study for detecting the signal against W
boson pair backgrounds.

1 Introduction

As a possible option of the International
Linear Collider, feasibility of physics oro-
tundities of high energy photon-photon in-
teraction has been considered. In the high
energy photon linear colliders(PLCs), high
energy photon beams are generated by in-
verse Compton scattering between the elec-
tron and the laser beams as illustrated in
figure 1. Feasibility of the PLC for both
physics and technical aspect, has been stud-
ied and summarized in [1]. In these study,
one assumed integrated luminosity of 3 4
years PLC operation which, for example,
may happens after initial operation of e^+e^-
mode of the ILC at $\sqrt{s} = 500$GeV.

In this study, we investigated a feasibil-
ity of self-coupling of the Higgs boson as an
example of a precise measurement with the
PLC by assuming an ultimate integrated lu-
minosity, i.e., 10years operation with a high
luminosity parameters.

The Higgs boson self-coupling constant
is reprensented by $\lambda = \lambda^{SM}(1 + \delta\kappa)$ which
contributes Higgs boson pair production via
a diagram shown in figure 2. Here, λ^{SM}
is Higgs boson self-coupling constant which
is included in the Standard Model. $\delta\kappa$
represent the deviation from the Standard
Model.

The self-coupling of the Higgs boson can
also be studied in e^+e^- collision via the di-
agram shown in figure 3. Comparing with the $e^+e^- \rightarrow ZHH$ channel, where Higgs boson
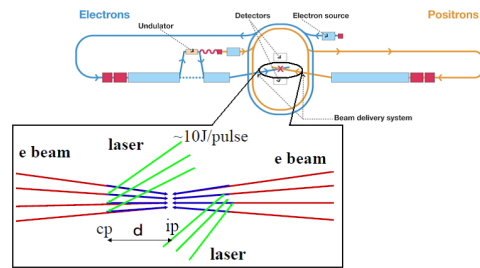

Figure 1: An outline of PLC. Positron beam of
ILC is replaced with electron beam. High en-
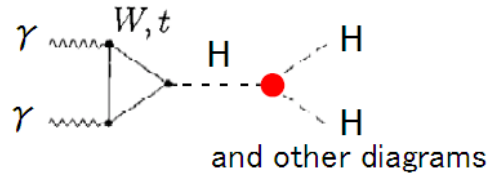ergy photon is generated by collision between
laser and electron beam.

Figure 2: An example of $\gamma\gamma \rightarrow HH$ diagram.
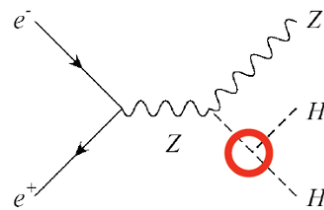Higgs self-coupling occurs at red point.

Figure 3: $e^+e^- \rightarrow ZHH$ diagram. Higgs self-
coupling occurs at red circle.

pairs are associated with the Z boson production, the Higgs bosons are produced by s channel via loop diagrams in $\gamma\gamma$ collision. Therefore, contribution of the $\delta\kappa$ to the production cross section is difference for the e^+e^- and for $\gamma\gamma$ and studies in these two modes will be complementary each other. Detail of the theoritical background in this analysis can be found in [2].

2 Sensitivity Sutdy

For optimization photon-photon collision energy, we defined the sensitivity for the $\delta\kappa$ as;

$$sensitivity = \frac{|N(\delta\kappa) - N_{SM}|}{\sqrt{N_{obs}}} = \frac{L|\eta\sigma(\delta\kappa) - \eta\sigma_{SM}|}{\sqrt{L(\eta\sigma(\delta\kappa) + \eta_B\sigma_B)}}$$

where, $N(\delta\kappa)$ is a expected number of events as a function of $\delta\kappa$ and N_{SM} is the number of events expected from the Standard Model. $L, \eta, \sigma(\delta\kappa), \sigma_{SM}, \eta_B$ and σ_B are integrated luminosity, detection efficiency of signal, cross section with $\delta\kappa$, cross section with the Standard model, detection efficiency for background events and the cross section for background processes, respectively. For $\eta = 1$, $\eta_B = 0$, sensitivity is written;

$$sensitivity = \sqrt{L}\frac{|\sigma(\delta\kappa) - \sigma_{SM}|}{\sqrt{\sigma(\delta\kappa)}}$$

The Higgs boson mass of 120GeV and the integrated luminosity of 1000fb^{-1} was assumed in the study. The cross section is calculated by the formula which is described in [3] with a theoretically calculated PLC luminosity spectrum. The sensitivity as a function of the center of mass energy of the $\gamma\gamma$ collision for $\delta\kappa = 1$ and -1 is plotted in figure 4.

From the figure, the optimum energy for the $\gamma\gamma$ collision for Higgs boson mass of 120GeV was found to be around 270GeV.

3 Background

Figure 5 shows cross section as a function of collision energy for photon-photon interactions. Figure 5 indicates that $\gamma\gamma \to WW$ is main background with the production cross section of about 90pb. On the other hand,

Figure 4: A graph showing sensitivity v.s. $W_{\gamma\gamma}$. $W_{\gamma\gamma}$ means photon-photon collision energy. Sensitivity has peak at near $W_{\gamma\gamma} \simeq 270$GeV, not depend on $\delta\kappa$.

Figure 5: cross section v.s. collision energy. $\gamma\gamma \to WW$ is main background against $\gamma\gamma \to HH$.

signal cross section is 0.044fb at optimized energy. Therefore, observation of signal requires background suppression of 10^{-7}. The other reaction that has large cross section such as $\gamma\gamma \to WWZ$ and $\gamma\gamma \to t\bar{t}$. However the optimum energy for $\gamma\gamma \to HH$ is below these threshold for these channel.

4 Simulation Framework

JLC Study Framework(JSF) is used as simulation framework in this study [4].

The helicity amplitude for the signal is calculated by theoritical calculation program [5]. The helicity amplitude for background processes were calculated by a helicity amplitude calculation package; HELAS [6].

The luminosity distribution used in the analysis were generated using the CAIN[7] program with the input parameters shown in table 1 [8]. The luminosity spectrum simulated with the CAIN is shown in figure 6.

From these helicity amplitude and luminosity spectrum, BASES/SPRING integrated and generated events. Pythia made parton shower and hadronized. Quick detector simulator read particle list that from pythia. Finaly, data from Quick Detector Simulator is analyzed.

With this spectrum, we expect signal of 16event/year, while 10^7event/year for background.

5 Analysis

The decay branching ratio of the Higgs boson of 120GeV is shown in table 2. Since main decay mode of the Higgs boson of 120GeV is b-quark pairs with the branching ratio of about 0.67, we tried the case that both Higgs boson decayed into b-quark pairs.

For each event, we applied forced four jets analysis in which a clustering algorithm is applied to an event by changing the clustering parameter until the event is catego-

Table 1: Input parameters to CAIN. This parameters set make luminosity peak at optimum energy.

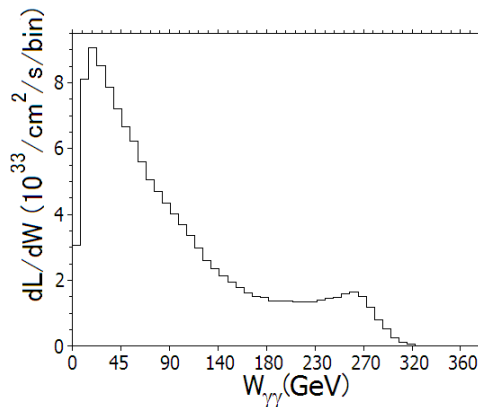|	
$E_e[GeV]$	190
$N/10^{10}$	2
$\sigma_z[mm]$	0.35
$\gamma\varepsilon_{x/y}/10^{-6}[mrad]$	2.5/0.03
$\beta_{x/y}[mm]@IP$	1.5/0.3
$\sigma_{x/y}[nm]$	96/4.7
$\lambda_L[nm]$	1054
Pulse energy$[J]$	10
$x = 4\omega E_e/m_e^2$	3.76

Figure 6: Luminosity spectrum generated by CAIN using table 1 parameters set.

Table 2: Branching ratio of Higgs particle.

particles	Branching ratio
$b\bar{b}$	0.6774
$\mu\mu$	0.00024
$c\bar{c}$	0.02982
$\tau\tau$	0.06916
$s\bar{s}$	0.00051
gg	0.0713
$\gamma\gamma$	0.002231
γZ	0.001084
WW	0.1331
ZZ	0.0152

rized as a four jets event. After the forced four jets analysis, invariant masses for jet pairs were calculated. For a four jets event, we must to choose a right jets pairs originating from parent Higgs (or W for the background) bosons out of three possible combinations. For this purpose, we defined χ^2s as;

$$\chi_H^2 = \frac{(M_1 - M_H)^2}{\sigma_{2j}^2} + \frac{(M_2 - M_H)^2}{\sigma_{2jH}^2}$$

$$\chi_W^2 = \frac{(M_1 - M_W)^2}{\sigma_{2j}^2} + \frac{(M_2 - M_W)^2}{\sigma_{2jW}^2}$$

where, M_1 and M_2 are reconstructed particle mass, M_H and M_W are Higgs boson and W boson mass respectively, with σ_{2jH} and σ_{2jW} being their resolutions. The jet of the least χ^2 was chosen to be the most probable combination for an event. Figure 7 shows correlation of χ_H^2 and χ_W^2 for the most probable combination. To enhance Higgs boson from the W boson events, we choosed an event satisfies $-140/20 \times \chi_H^2 + 140 \geq \chi_W^2$. The mass distributions for the Higgs and W boson events after χ^2 cut are shown in figure 8.

6 b-tagging

By the χ^2 analysis described in previous section, the W boson background was suppressed by 0.0541 while keeping the 46% efficiency for the Higgs boson events. In order further improve signal to background ratio, we applied b-quark tagging method for remaing events.

Figure 9 illustrates a b-quark tagging method we applied. For each track in a reconstucted jet, $N_{sig} = L/\sigma_L$ was calculated, where L is the least approach to the interaction point of the track in the plane perpendicular to the beam and σ_L being its resolution. Then, $N_{off}(a)$, number of track which has $N_{sig} > a$, is calculated for each jet as a function of a. In current analysis we requied all jets must satisfy $N_{off}(3.5) \geq 2$. Figure 10 is the χ^2 plot after b-tagging but before χ^2 cuts. We obtaned background suppression of $1.35 \pm 0.18 \times 10^{-6}$ and efficiency of signal of 0.1454 ± 0.0044, where the errors
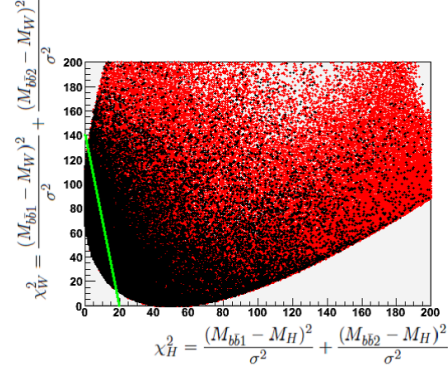

Figure 7: Reconstructed particles χ^2 distribution. Black indicates signal events, red indicates background events. Green line is represented by $-140/20 \times \chi_H^2 + 140 = \chi_W^2$. Here, to make signal clear, signal cross section is about 5×10^4 times as large as usual.
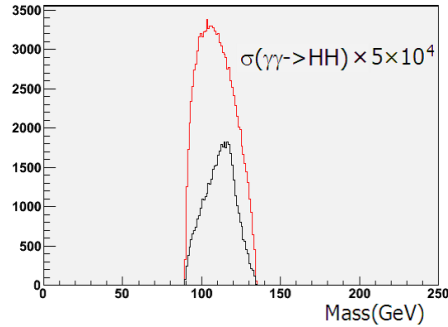

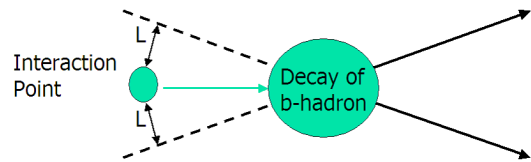Figure 8: Reconstructed particle mass spectrum that cutted. Background is suppressed, but not enough.

Figure 9: An outline of nsig method. B-hadron is generated at interaction point and decay at "Decay of b-hadron". Arrows mean particle tracks. Dotted line means extrapolate particle tracks.

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are from statistic of the Monte Carlo simulation. For remaining envents, χ^2 cut were applyied. As a results, no WW events survied out of 3.85×10^7 simulated events while keeping signal efficiency of 0.1096 ± 0.0014.

7   Summary and prospect

We studied feasibility of measurement of Higgs self-coupling constant at the PLC. For Higgs mass of 120GeV, optimum photon-photon collision energy for observe $\gamma\gamma \rightarrow HH$ was found to be about 270GeV. With a parameters of PLC(TESLA-optimistic), 16events/year is expected for Higgs boson events while main background of $\gamma\gamma \rightarrow WW$ is about 10^7events/year.
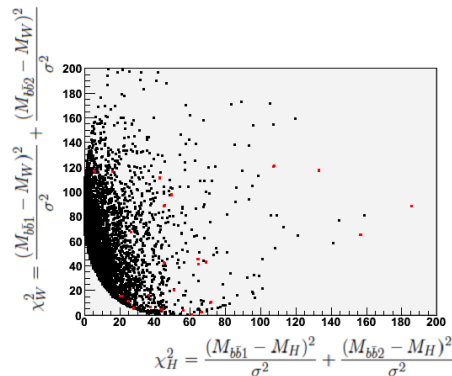

Figure 10: A result of b-tag selection. Number of b-tagged jets = 4 is required. Black indicates signal event. Red indicates background event. Number of remained background event is 52.

We tried an event selection with kinematical parameters and b-quark tagging by the simulation and found that backgound suppression of 10^{-7} with keeping signal efficiency of about 10% seemed to be possible.

For further analysis, we plan to improve signal efficicency by :

optimization of selection criteria for $HH \rightarrow b\bar{b}b\bar{b}$ mode.

study for $HH \rightarrow b\bar{b}WW^*$ decay.

For the backgound, it is necessary to estimate contribution from $\gamma\gamma \rightarrow ZZ$ events.

8   Acknowledgement

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