Measurement of the Higgs self-coupling at JLC

Y. Yasui$^{1*}$, S. Kanemura$^1$, S. Kiyoura$^{1,2*}$, K. Odagiri$^1$, Y. Okada$^1$, E. Senaha$^{1,3}$ and S. Yamashita$^4$

$^1$ KEK, Tsukuba, 1-1 Oho, Tsukuba, Ibaraki 305-0801, Japan
$^2$ Department of Radiological Sciences, Ibaraki Prefectural University of Health Sciences, Ami, Inashiki, Ibaraki 300-0394, Japan
$^3$ Department of Particle and Nuclear Physics, the Graduate University for Advanced Studies, Tsukuba, Ibaraki 305-0801, Japan
$^4$ ICEP, University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-0033, JAPAN

Abstract

We examine the double Higgs production process at JLC. We focus our attention on the measurement of the Higgs self-coupling. The sensitivity of the triple Higgs coupling measurement is discussed in the Higgs mass range 100-200 GeV and the center of mass energy to be 500 GeV-1.5 TeV.

After the discovery of the Higgs boson, detailed study of the Higgs potential will be one of the important issues at the linear collider (LC) experiment[1, 2]. From the standard model (SM) Higgs potential $V(\Phi) = -\mu^2\Phi^\dagger\Phi + \lambda(\Phi^\dagger\Phi)^2$, we obtain the simple relation between the Higgs boson mass $m_h$ and the self coupling $\lambda$ as $m_h^2 = 2\lambda v^2$, where $v$ is the vacuum expectation value of the Higgs boson. The precision test of this relation could give clear evidence for the new physics[3]. At the LC, multiple Higgs boson production processes will provide the direct information of the triple Higgs coupling. In this talk, we discuss the double Higgs production at JLC[4]. We examine the potential of the triple Higgs coupling measurement.

At JLC, we can use the two modes, $e^+e^- \rightarrow hhZ$ and $e^+e^- \rightarrow (WW)\nu\bar{\nu} \rightarrow hh\nu\bar{\nu}$. In the low center of mass energy region ($\sqrt{s} \lesssim 1$ TeV), the $hhZ$ mode is dominant. On the other hand, the $hh\nu\bar{\nu}$ mode will be important at the 1 TeV or higher energies. Here, we introduce the effective coupling which includes the anomalous contribution

*e-mail address:yoshiaki.yasui@kek.jp; This work was supported in part by Grand-in-Aid for Scientific Research $^1$(A)(1) (No. 13047101), $^2$(C) (No. 13640309), $^3$(A)(No.14046205).
as \( V(h^3) = (\lambda_3 + \delta \lambda_3)hhh \), where \( \lambda_3 (\equiv \lambda v) \) is the SM triple Higgs coupling and \( \delta \lambda_3 \) is the deviation from the SM prediction. In figure 1, we show the \( \delta \lambda_3 \) dependence of the total cross section for (a) \( e^+e^- \to hhZ \) and (b) \( e^+e^- \to hh\nu\bar{\nu} \). Here, the Higgs mass is 120 GeV with the CM energy of 500 GeV, 1 TeV and 1.5 TeV. To compute the cross section, we mainly employ the GRACE[5] system, and use the CompHEP[6] system for the cross-check. In the low values of the invariant mass \( M_{hh} \) for \( hh \), the \( hhZ \) mode is sensitive to \( \delta \lambda_3 \) (Fig. 2). We found that the cut for \( M_{hh} \) is powerful to improve the sensitivity. The polarized electron beam is also useful to reduce the background for the \( hh\nu\bar{\nu} \) mode, due to the \( V-A \) nature of the weak bosons.

We show the sensitivity of the triple Higgs coupling to \( \delta \lambda_3 \) in the mass range 100 – 200 GeV at the parton level (Fig. 3). Here, we assumed that the efficiency of the particle tagging is 100% with an integrated luminosity of 1 \( ab^{-1} \). Dashed (dotted, sold) lines are the results of the \( hhZ \) mode (\( hh\nu\bar{\nu} \) mode, combined both modes). At \( \sqrt{s} = 500 \) GeV, the \( hhZ \) mode is dominant. If the Higgs mass is relatively light (\( m_h \lesssim 150 \) GeV), we can measure the triple Higgs coupling in about 20% accuracy. For \( \sqrt{s} \) to be 1 TeV or higher, the \( hh\nu\bar{\nu} \) mode is dominant. Here, we used the invariant mass cut as \( m_{hh} < 600 \) GeV for \( hhZ \) mode. We also used the 100% polarized electron beam for the \( hh\nu\bar{\nu} \) mode. We can expect the high sensitivity in this case (\( \delta \lambda_3/\lambda_3 \lesssim 10\% \)).

**Acknowledgment** We would like to thank Y. Kurihara, T. Kaneko, T. Ishikawa, J. Fujimoto, Y. Shimizu and S. Kim for valuable discussions.

![Figure 1](image-url)

Figure 1: The \( \delta \lambda_3 \) dependence of the cross section; (a) \( e^+e^- \to hhZ \), (b)\( e^+e^- \to hh\nu\bar{\nu} \)
Figure 2: The $hh$ invariant mass dependence of the $hhZ$ mode for several values of $\delta \lambda$.  

Figure 3: The $\lambda_3$ measurement sensitivity; $hhZ$ (dashed line), $hh\nu\bar{\nu}$ (dotted line) and combined results (solid line).

References

[1] F. Boudjema and E. Chopin, Z.Phys. C73 (1996) 85; V.A.Ilyin, T.Kaneko, Y.Kurihara, A.E.Pukhov and Y.Shimizu, Phys.Rev. D54 (1996) 6717; Marco Battaglia and Klaus Desch, "Studying the Higgs Potential at the e+e- Linear Collider" Proceedings of the Linear Collider Workshop LCWS2000; arXiv:hep-ph/0111276.

[2] A. Djouadi, W. Kilian, M. Muhlleitnera and P.M. Zerwas, Eur.Phys.J. C10 (1999) 45.

[3] See for example, the SUSY model was discussed in [2], the 2HDM was discussed in S. Kanemura, S. Kiyoura, Y. Okada, E. Senaha and C.-P. Yuan, Proceedings of the Linear Collider Workshop LCWS2002; arXiv:hep-ph/0209326.

[4] ACFA Linear Collider Working Group report, KEK Report 2001-11; arXiv:hep-ph/0109166.

[5] J. Fujimoto, T. Ishikawa, M. Jimbo, T. Kaneko, K. Kato, S. Kawabata, K. Kon, M. Kuroda, Y.Kurihara, Y. Shimizu and H. Tanaka, KEK-CP-129; arXiv:hep-ph/0208036.

[6] A. Pukhov, E. Boos, M. Dubinin, V. Edneral, V. Ilyin, D. Kovalenko, A. Kryukov, V. Savrin, S. Shichanin, and A. Semenov, INP MSU 98-41/542; arXiv:hep-ph/9908288