Full Simulation Study of WW Scattering at the ILC

David Ward and Wenbiao Yan

University of Cambridge, Cavendish Laboratory, JJ Thomson Avenue,
Cambridge CB3 0HE, United Kingdom

We study full simulation of WW scattering with a linear collider detector model at $\sqrt{s} = 800$ GeV for the process $e^+e^- \to \nu_e\bar{\nu}_e\mathrm{WW} \to \nu_e\bar{\nu}_e q\bar{q}q\bar{q}$ and $e^+e^- \to \nu_e\bar{\nu}_e\mathrm{ZZ} \to \nu_e\bar{\nu}_e q\bar{q}q\bar{q}$, and obtain the limits on α_4 and α_5 in the electroweak chiral Lagrangian.

1 Introduction

The standard model introduces the Higgs boson to explain the breaking of electroweak symmetry, and hence we should not observe strong WW scattering. However, one can imagine that there is no Higgs boson, and that electroweak symmetry breaking is broken by a strong interaction. The W bosons become strongly interacting particles at TeV energies in this case [2]. WW scattering is a useful probe of breaking of electroweak symmetry. The WW scattering at low energies can be described by an effective Lagrangian approach, in which there are two anomalous couplings α_4 and α_5 in the theory [3]. α_4 and α_5 are model dependent, and are zero in the standard model. The sensitivity of α_4 and α_5 has already been studied for the CERN LHC case [4] and linear collider TESLA case with fast simulation at $\sqrt{s} = 800$ GeV [3, 5] and $\sqrt{s} = 1000$ GeV [6]. The motivation of this work is study the sensitivity α_4 and α_5 by full detector simulation (*not* fast simulation !) for the different linear collider detector models and different Particle Flow Algorithms (PFA) for the detector design studies. However, in this talk. we only show preliminary results on the linear collider detector model LDC00Sc, which is implemented in the Mokka [7] Monte Carlo, with Pandora PFA [7].

2 Analysis setup

The Monte Carlo samples are generated at $\sqrt{s} = 800$ GeV, beam polarisations of 80% for electrons and 40% for positrons are assumed. For the $t\bar{t}$ events, PYTHIA [8] is used without beam polarisations. For the other event samples , WHIZARD [9] is used. The hadronization is done by JETSET. Table 1 shows the summary of all Monte Carlo samples for the analysis. The single weak boson process is generated with an additional cut on $M(q\bar{q}) > 130$ GeV to reduce the number of generated events [6]. According to the results in [3, 5], the processes $e^+e^- \to \mathrm{WW/ZZ} \to q\bar{q}q\bar{q}$ and $e^+e^- \to q\bar{q} \to X$ can be neglected. Because WHIZARD calculates matrix elements for all diagrams for the process $\nu_e\bar{\nu}_e q\bar{q}q\bar{q}$, it is necessary to separate the signal events and background events. The suggestions in [3, 5] are followed to choose doubly resonant signals $\nu_e\bar{\nu}_e\mathrm{WW}$ and $\nu_e\bar{\nu}_e\mathrm{ZZ}$: (1) $147.0 < m^1_{qq} + m^2_{qq} < 171.0$ GeV for $\nu_e\bar{\nu}_e\mathrm{WW}$; $171.0 < m^1_{qq} + m^2_{qq} < 195.0$ GeV for $\nu_e\bar{\nu}_e\mathrm{ZZ}$. (2) $|m^1_{qq} - m^2_{qq}| \leq 20.0$ GeV. (3) $m_{\nu_e\bar{\nu}_e} \geq 100.0$ GeV, where m^1_{qq} and m^2_{qq} are the invariant masses of two pairs of quarks. The cut $m_{\nu_e\bar{\nu}_e} \geq 100.0$ GeV is used to reject WWZ and ZZZ events, where the Z decays into a neutrino pair. The rest of the events are considered as 6-fermion background events.

The Mokka 6.2 [7] program is used for the detector simulation, and Marlin 0.9.6 [7] is used for the event reconstruction. The output of Pandora PFA [7] is used in the analysis.

Channel	σ_{800GeV} (fb)	Generator
$\nu_e\bar{\nu}_e$WW $\rightarrow \nu_e\bar{\nu}_e q\bar{q}q\bar{q}$	8.55	Whizard 1.50
$\nu_e\bar{\nu}_e$ZZ $\rightarrow \nu_e\bar{\nu}_e q\bar{q}q\bar{q}$	3.97	Whizard 1.50
$\nu_e\bar{\nu}_e q\bar{q}q\bar{q}$ (background)	5.46	Whizard 1.50
$e\nu_e$WZ $\rightarrow e\nu_e q\bar{q}q\bar{q}$	38.75	Whizard 1.50
eeWW/ZZ $\rightarrow eeq\bar{q}q\bar{q}$	289.43	Whizard 1.50
$t\bar{t} \rightarrow$ X	299.63	PYTHIA 6.1
$\nu_e e$W $\rightarrow \nu_e eq\bar{q}$	108.59	Whizard 1.50
$\nu_{\mu,\tau}\bar{\nu}_{\mu,\tau}$WW/ZZ $\rightarrow \nu_{\mu,\tau}\bar{\nu}_{\mu,\tau}q\bar{q}q\bar{q}$	8.85	Whizard 1.50

Table 1: The Cross section of signal and background Monte Carlo samples in the analysis.

3 Event selection

The WW scattering events are selected with some cuts similar to paper [3, 5], and are unified for the WW/ZZ events. In order to suppress background events, the following cuts are used in the analysis. (1) The recoil mass $M_{recoil} \geq 200.0$ GeV. (2) Total transverse momentum $P_T \geq 40$ GeV. (3) Total transverse energy $E_T \geq 150$ GeV. (4) Total missing momentum and most energetic track have $|\cos\theta| < 0.99$. (5) Energy in a 10^o cone around the most energetic track $E_{cone} \geq 2.0$ GeV. (6) The PFA objects in the detector are forced into four jets with the Ktjet package [10]. The events with four good jets (i.e. $E_{jet} > 10.0$ GeV and $|\cos\theta_{jet}| < 0.99$) and $Y_{34} > 0.0001$ [a] are used in the analysis. The number of charged tracks in each jet ≥ 2.

The jet pairing is chosen by requiring the product $|m_{ij} - m_{\mathrm{W/Z}}||m_{kl} - m_{\mathrm{W/Z}}|$ to be minimum for three possible pairs [3]. For the $\nu_e\bar{\nu}_e$WW events, the reconstructed W mass is between 60 GeV and 88 GeV. For the $\nu_e\bar{\nu}_e$ZZ events, the reconstructed Z mass is above 85 GeV and below 100 GeV. The separation power of W and Z is an important issue in the WW scattering. In the Figure 1 shows the hadronic mass separation for $\nu_e\bar{\nu}_e$WW (blue) and $\nu_e\bar{\nu}_e$ZZ (red) at $\sqrt{s} = 800$ GeV at primary parton level (left) and detector level (right). There is no W/Z selection at detector level in the right-hand part of Figure 1, which suggests the W and Z could be separated by reconstructed mass via jets.

4 Fitting method and results

The distribution $d^2\sigma/(dM_{VV}d|\cos\theta^\star_V|)$ (V= W, Z) in 10×10 bins at detector level is used to extract α_4 & α_5 with a binned likelihood fit, where M_{VV} is the event mass, and $\cos\theta^\star_V$ is the polar angle of V in the VV rest frame. The SM Monte Carlo sample with ($\alpha_4 =$ 0.0, $\alpha_5 = 0.0$) is the "data" sample in the fitting, and the integrated luminosity of the "data" sample is 1000 fb^{-1}. The Poisson distribution $p(n) = e^{-\lambda}\lambda^n/n!$ is used for each bin, where n is the observed number in the "data" sample and background event samples, and $\lambda = m^{signal}(\alpha_4, \alpha_5) + m^{bcg1}(\alpha_4, \alpha_5) + m^{bcg2}$ is the expected number. $m^{signal}(\alpha_4, \alpha_5)$ is the contribution from doubly resonant signal events, $m^{bcg1}(\alpha_4, \alpha_5)$ is for background events with α_4 & α_5 dependence, e.g. $e\nu_e$WZ events. m^{bcg2} is due to background events without α_4 & α_5 dependence, e.g. $t\bar{t}$ events. Finally, the likelihood function $-\ln\mathcal{L}$ is defined as

[a] Y_{34} is the jet resolution parameter in the Ktjet package [10] at which an event is reclassified from four to three jets.

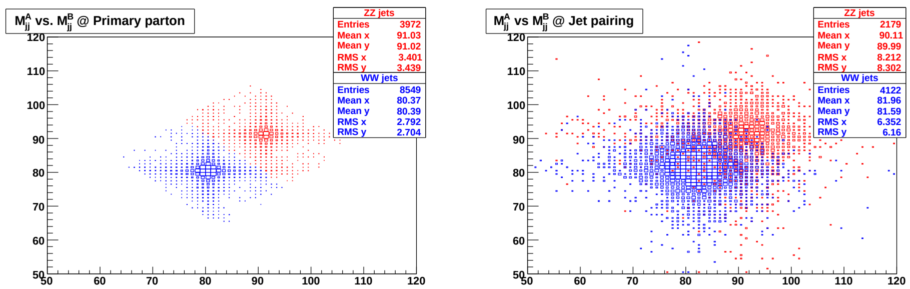

Figure 1: Hadronic mass separation for $\nu_e\bar{\nu}_e$WW (blue) and $\nu_e\bar{\nu}_e$ZZ (red) at $\sqrt{s} = 800GeV$ at primary parton level (left) and detector level. There is no W/Z selection at detector level.

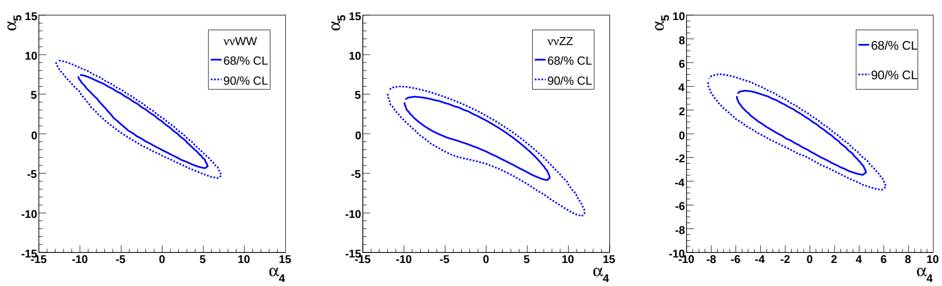

Figure 2: The left (middle) plot shows the 68% (continuous line) and 90% (dashed line) C.L. contours obtained by $\nu_e\bar{\nu}_e$WW ($\nu_e\bar{\nu}_e$ZZ), the right plot shows the C.L. contours obtained by combination of $\nu_e\bar{\nu}_e$WW and $\nu_e\bar{\nu}_e$ZZ events.

$-\sum \ln p(n_i) = -\sum n_i \ln \lambda_i + \sum \lambda_i + \sum \ln(n_i!)$, here $\sum \ln(n_i!)$ is a constant and is ignored in the fitting.

Each Monte Carlo SM event (ith event) of the signal is weighted by $R_i(\alpha_4, \alpha_5) = 1.0 + A_i\alpha_4 + B_i\alpha_4^2 + C_i\alpha_5 + D_i\alpha_5^2 + E_i\alpha_4\alpha_5$, where $R_i(\alpha_4, \alpha_5)$ is obtained in the following way: using the generated SM events, we recalculate matrix elements for each event with 20 sets of (α_4, α_5) values, and decide $(A_i, B_i, C_i, D_i, E_i)$ by TMinuit fitting to 20 R for ith event. $m^{signal}(\alpha_4, \alpha_5)$ is obtained by counting selected events with weight $R_i(\alpha_4, \alpha_5)$. $m^{bcg1}(\alpha_4, \alpha_5)$ is obtained a similar way.

The fitted α_4 & α_5 are shown in Figure 2. The left (middle) plot shows the 68% (continuous line) and 90% (dashed line) C.L. contours obtained by $\nu_e\bar{\nu}_e$WW ($\nu_e\bar{\nu}_e$ZZ), the right plot shows the C.L. contours obtained by combination of $\nu_e\bar{\nu}_e$WW and $\nu_e\bar{\nu}_e$ZZ events. The results are also comparable with TESLA results based on fast simulation [3, 6], and are shown in the slides [1].

5 Acknowledgments

We would like to thank Wolfgang Kilian on the WHIZARD generator, Predrag Krstonosic and Andres F. Osorio on the WW scattering, Mark Thomson on the Pandora PFA.

References

[1] Slides:
`http://ilcagenda.linearcollider.org/contributionDisplay.py?contribId=236&sessionId=76&confId=1296`

[2] E. Boos *et al.*, Phys. Rev. **D57** 1553 (1998);
Michael E. Peskin and James D. Wells, Phys. Rev. **D64** 093003 (2001);
Michael S. Chanowitz, arXiv:hep-ph/0412203 (2004).

[3] R. Chierici, S. Rosati and Michael Kobel, " Strong electroweak symmetry breaking signals in WW scattering at tesla", LC-PHSM-2001-038.

[4] A. S. Belyaev *et al.*, Phys. Rev. **D59** 015022 (1998).

[5] Andres F. Osorio, University of Manchester. PhD thesis, 2006.

[6] M. Beyer *et al.*, arXiv:hep-ph/0604048 (2006);
P. Krstonosic *et al.*, arXiv:hep-ph/0508179 (2005).

[7] ILC software packages, http://ilcsoft.desy.de/portal.

[8] PYTHIA 6.1, http://www.thep.lu.se/ torbjorn/Pythia.html.

[9] WHIZARD 1.50, http://www-ttp.physik.uni-karlsruhe.de/whizard.

[10] J. M. Butterworth *et al.*, Comp. Phys. Comm. **153** 85 (2003).