PRAMANA
— journal of
physics

© Indian Academy of Sciences

Vol. 79, No. 5
November 2012
pp. 1247–1250

Single W production in $e^-\gamma$ collisions through the decay lepton spectrum to probe γWW couplings

SATENDRA KUMAR* and P POULOSE

Department of Physics, Indian Institute of Technology-Guwahati, Guwahati 781 039, India
*Corresponding author. E-mail: satendra@iitg.ac.in

Abstract. The effect of an anomalous γWW coupling in the $e^-\gamma \to \nu_e W^-$ process through the angular and energy spectrum of the secondary leptons is investigated. Within the narrow-width-approximation (NWA), a semianalytical study of the secondary lepton energy angle double distribution is considered. Different observables constructed using this distribution are expected to be very effective to probe the anomalous coupling at a typical International Linear Collider machine. Further, suitable combinations of these observables could be used to disentangle the effect of contributions from different terms in the effective Lagrangian.

Keywords. Electron–photon collision; γWW coupling; W-boson.

PACS Nos **12.15.−y; 14.70.−e; 14.70.Fm**

1. Introduction

One of the focus points of present day particle physics is the issue of electroweak symmetry breaking (EWSB). Search for Higgs particle of the Standard Model (SM) at LHC has ruled out such a particle with mass 141–475 GeV [1], while the LEP has provided a lower bound of about 114 GeV for the Higgs mass. Within the gauge field theory, EWSB and gauge boson couplings are strongly interrelated. While the LHC is expected to explore the gauge boson couplings to certain extent, the clean environment of the proposed International Linear Collider (ILC) has many advantages to offer [2]. Our main aim in this work is to study the possibility of exploiting the secondary lepton spectrum including the energy and angular distributions, of the gauge bosons produced at the ILC, to probe relevant new physics signals related to guage bosons, and thus to the EWSB. To illustrate the idea, we consider the case of anomalous γWW coupling in the $e^-\gamma \to \nu_e W^-$ process. The effective γWW vertex is commonly parametrized in terms of $\delta\kappa_\gamma$ and $\lambda\gamma$, in the absence of CP-violating anomalous couplings, given by the effective Lagrangian [3]

$$\mathcal{L}_{\gamma \mathrm{WW}} = -ie\left\{ W^\dagger_{\mu\nu} W^\mu A^\nu - W^\dagger_\mu A_\nu W^{\mu\nu} + (1+\delta\kappa_\gamma) W^\dagger_\mu W_\nu F^{\mu\nu} + \frac{\lambda_\gamma}{m^2_{\mathrm{W}}} W^\dagger_{\lambda\mu} W^\mu_\nu F^{\lambda\nu} \right\}. \tag{1}$$

DOI: 10.1007/s12043-012-0433-z; ***e*Publication: 7 November 2012**

In the SM, the gauge structure $SU(2)_\mathrm{L} \times U(1)_\mathrm{Y}$ dictates the γWW couplings, with vanishing $\delta\kappa_\gamma$ and λ_γ at tree-level. LEP constraints in single-parameter analysis gives bounds of $-0.105 < \delta\kappa_\gamma < +0.069$ and $-0.059 < \lambda_\gamma < +0.026$, and two-parameter analysis limits their values to $-0.072 < \delta\kappa_\gamma < +0.0127$ and $-0.068 < \lambda_\gamma < +0.023$ at 95% CL [4]. Phenomenology of anomalous γWW coupling in the context of LHC as well as ILC has been carried out in a number of recent publications [5–8].

2. Analysis and numerical results

We perform our calculation in the narrow-width-approximation (NWA) of the W boson, kinematics are fixed according to figure 1, with z-axis along $\vec{k}_l$, the momentum of the outgoing lepton, and y-axis defined as $\vec{k}_l \times \vec{k}_e$, where $\vec{k}_e$ is the momentum of the colliding electron. The W comes out at a polar angle θ_W and azimuthal angle ϕ_W. With this, we get the DCS in the CM frame,

$$\frac{\mathrm{d}\sigma(\hat{s})}{\mathrm{d}E_\mu\ \mathrm{d}\cos\theta\ \mathrm{d}\phi_\mathrm{W}} = \frac{1}{(2\pi)^3}\frac{m_\mathrm{W}}{16\Gamma_\mathrm{W}}\frac{|M_\mathrm{r}|^2}{E_\mu(\hat{s}+m_\mathrm{W}^2-2\sqrt{\hat{s}}E_\mu)^2}, \tag{2}$$

where $\sqrt{\hat{s}}$ is the centre-of-mass energy, E_μ is the energy of the muon and $\cos\theta = (\vec{k}_l\cdot\vec{k}_e)/|\vec{k}_l\cdot\vec{k}_e|$. Here M_r is the reduced amplitude given in terms of the invariant amplitude M as, $M = 1/\left(k_\mathrm{W}^2 - m_\mathrm{W}^2\right)M_\mathrm{r}$. The cross-section in the lab-frame is obtained by folding the above cross-section with the appropriate photon distribution function, $f_{\gamma/e}(x)$ [9,10],

$$\sigma = \int f_{\gamma/e}(x)\sigma(\hat{s})\mathrm{d}x, \tag{3}$$

where $x = \hat{s}/4E_e^2$, with E_e the electron beam energy. Our numerical results are obtained by numerical intergration of the differential cross-section using eqs (2) and (3) with the package CUBA [11], while we have used FORM [12] to compute the invariant amplitude square. For our numerical analysis, we consider the boundary points of the anomalous coupling from the LEP results, $\delta\kappa_\gamma = -0.072, +0.069$. Figure 2a shows the effect of

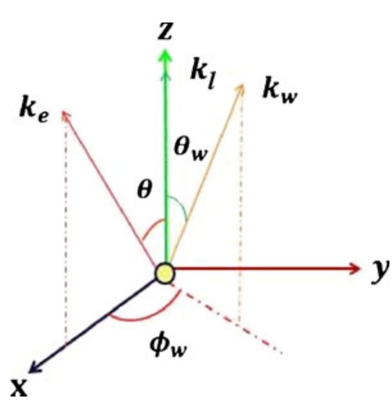

Figure 1. Reference frame defining different angles used in eq. (2).

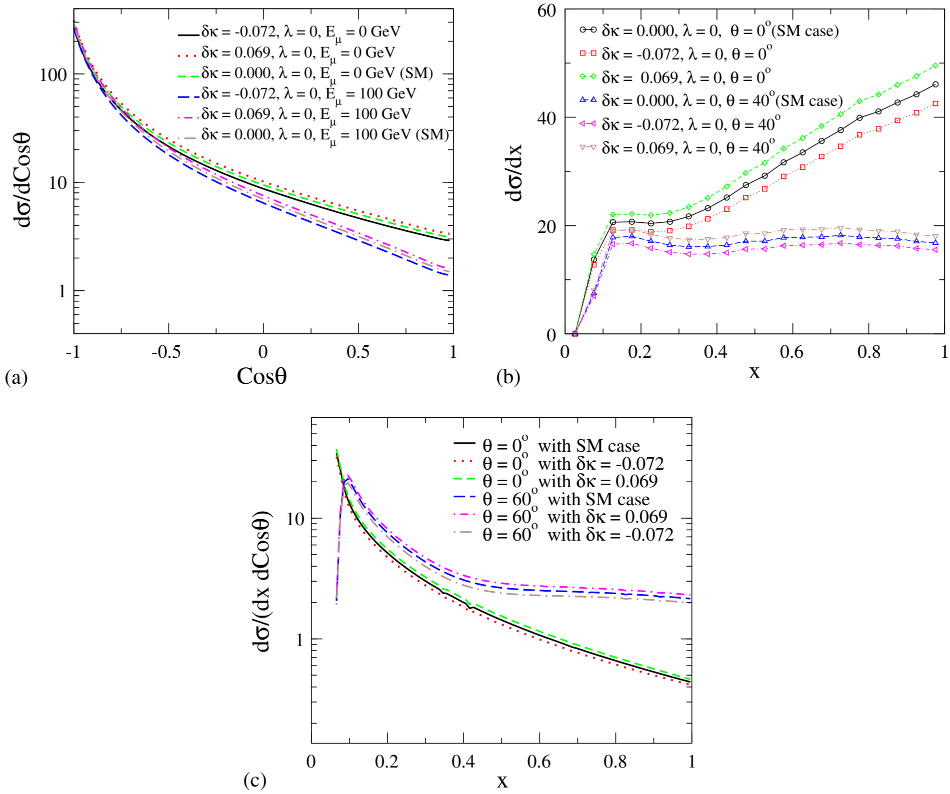

Figure 2. Angle and energy distributions of the secondary muons at $\sqrt{s} = 500$ GeV.

the cut on E_μ on the angular distribution of the secondary muons at $\sqrt{s} = 500$ GeV, with and without the anomalous couplings. The effect is more pronounced at larger $\cos\theta$ values, while most of the events are gathered in the backward direction. Figure 2b shows the effect of angular cut on the energy distribution of the secondary muons. In this case, a nominal improvement in the sensitivity to the anomalous couplings with angular cut is

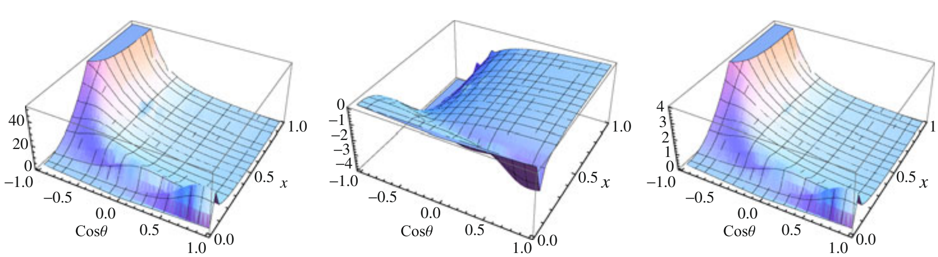

Figure 3. 3D plots showing energy–angle distribution of secondary muons at $\sqrt{s} =$ 500 GeV: (**a**) shows the SM case, (**b**) and (**c**) show deviation from the SM for $\delta\kappa_\gamma = -0.072$ and $+0.069$ respectively.

observed. Figure 2c shows the energy distribution of secondary muons at $\sqrt{s} = 500$ GeV, and at two values of θ, namely 0° and 60°. Here the peak of the distribution moves from lower values of E_μ to higher values as we go from smaller θ values to larger ones. Figure 3 presents the energy–angle distribution of secondary muon, $\mathrm{d}\sigma/(\mathrm{d}x\, \mathrm{d}\cos\theta^{\mathrm{lab}})$, at $\sqrt{s} =$ 500 GeV. Although naively believed to be useful, in order to establish the usefulness of these observables in disentangling different couplings involved, we need to study the process in the presence of those couplings.

3. Summary and conclusions

We have presented a semianalytical way to explore the secondary lepton energy–angle distribution in $e\gamma \to \nu_e W$ with $W \to \bar{\nu}\, l$. Variables, being defined in the lab frame, can be directly used to apply experimental cuts. The advantage of such an observable in analysing the SM case and probing possible new physics effects may easily be demonstrated with the inclusion of other anomalous couplings in the study.

Acknowledgement

PP’s work is partly supported by a BRNS, DAE project.

References

[1] The ATLAS and CMS Collaboration, ATLAS-CONF-2011-157, CMS PAS HIG-11-023
[2] ILC Collaboration: J Brau *et al*, arXiv:0712.1950 [physics.acc-ph]
ILC Collaboration: G Aarons *et al*, arXiv:0709.1893 [hep-ph]
[3] K Hagiwara, R D Peccei, D Zeppenfeld and K Hikasa, *Nucl. Phys.* **B282**, 253 (1987)
[4] LEP Electroweak Working Group: J Alcaraz *et al*, arXiv:hep-ex/0612034
[5] S J Brodsky, T G Rizzo and I Schmidt, *Phys. Rev*. **D52**, 4929 (1995)
[6] M A Doncheski, S Godfrey and K A Peterson, *Phys. Rev*. **D59**, 117301 (1999)
[7] I Sahin and A A Billue, *Phys. Rev*. **D83**, 035011 (2011)
[8] E Yehudai, *Phys. Rev*. **D41**, 33 (1990)
[9] I F Ginzburg *et al*, *Nucl. Instrum. Methods* **205**, 47 (1993); **219**, 5 (1984)
[10] V I Tenlov, arXiv:0908.3136 [physics, acc-ph]
[11] T Hahn, *Comput. Phys. Commun.* **168**, 78 (2005)
[12] J A M Vermaseren, arXiv:math-ph/0010025