We study the potential for using $e\gamma$ collisions produced by backscattered laser photons to investigate $WW\gamma$ couplings. We present results for Next Linear Collider energies of 500 GeV and 1 TeV. We find that where statistics allow, off $W$ mass shell results can be quite important, complementing on $W$ mass shell results from this and other studies. It is shown that $e\gamma$ colliders would prove quite valuable in the investigations of $W$-boson physics.

1. Introduction

The study of gauge boson interactions is still unexplored territory. To this point, our only glimpse of these interactions is via radiative loop corrections induced by these interactions at low energies. Although, high precision measurements give us some information on the gauge boson couplings, a direct test of them is still necessary. The first such direct test of triple gauge boson couplings will come at LEP200, where sufficient $\sqrt{s}$ energy exists for $W$ pair production. However, the limited available phase space means precision tests of the three vector coupling will undoubtedly await the arrival of a 500 GeV to 1 TeV $e^+e^-$ linear collider.

By limiting ourselves to $e^+e^-$ collisions, we limit the information that can be obtained. $W$ pair production can proceed through both $\gamma$ and $Z$ exchange, and one ends up probing both the $WWZ$ and $WW\gamma$ vertex simultaneously. A way to isolate one of these vertices is therefore needed. An $e\gamma$ collider provides such a method. There exists two possible means of creating an $e\gamma$ collider from a $e^+e^-$ collider. The first possibility uses a combination of beamstrahlung photons and classical bremsstrahlung\cite{1,2}. This possibility, however, suffers from its soft photon distribution. Hard photon distributions may be obtained through backscattering high intensity laser beams off the incoming electron beams\cite{3}. It is this possibility that we will concentrate on.

To parametrize the $WW\gamma$ vertex we use a common parametrization of the $WW\gamma$ vertex that imposes C and P symmetries separately\cite{4,5}:

$$\mathcal{L} = -ie \left\{ (W_{\mu\nu}^+ W^\mu A^\nu - W_{\mu\nu}^+ A_\mu W^{\mu\nu}) + \kappa_\gamma W_{\mu\nu}^+ W_\mu A_\nu + \frac{\lambda_\gamma}{M_W^2} W_{\lambda\mu}^+ W_\mu A^{\nu\lambda} \right\}. \quad (1)$$

In the standard model, $\kappa_\gamma = 1$ and $\lambda_\gamma = 0$.

One may obtain model independent estimates of these anomalous couplings in the context of a chiral lagrangian framework\cite{6}, where one expects $\delta_{\kappa\nu} \sim O(10^{-2})$,
Figure 1: Feynman diagrams for the process $e\gamma \rightarrow \nu_e q\bar{q}'$ and $\lambda_V \sim O(10^{-4})$. Model specific calculations bear these estimates out [7]. What this implies is that unless there is some radical new physics, one must be able to measure these anomalous couplings to the percent level if one would like to see new physics. This paper will show that this percent level could be achieved at a $\sqrt{s} = 500$ GeV or 1 TeV $e^+e^-$ collider; the Next Linear Collider, operating in $e\gamma$ mode.

2. Calculations and Results

In previous papers of this nature[8, 9], calculations were performed using the process $e\gamma \rightarrow \nu_e W$, with the appropriate decay widths to the observed final states. This is a decent approximation to the actual process, since the greatest percentage of the cross section proceeds through a real W. However, we feel by making this approximation, possible valuable physics is lost. Although the off resonance cross sections are small, the deviations of non-standard model gauge couplings in these cross sections can be significant. We have therefore considered the processes $e\gamma \rightarrow \nu_e q\bar{q}'$, $e\gamma \rightarrow \nu_e \mu \bar{\nu}_\mu$, and $e\gamma \rightarrow \nu_e \bar{\nu}_e$, which may proceed via the four diagrams of figure 1. The process, $e\gamma \rightarrow \nu_e \bar{\nu}_e$, also proceeds through a Z exchange diagram not shown here. In what follows we will concentrate on the $q\bar{q}'$ modes.

Amplitudes for these processes were calculated using the CALKUL helicity technique. In the case of the anomalous magnetic moment, $\kappa_\gamma$, plus standard model terms, these amplitudes can be found in an earlier paper by Couture et al [10]. Monte Carlo integration techniques were then used to perform the phase space integrations and calculate the cross sections. The photon distributions are treated as structure functions, which are then integrated with the $e\gamma$ cross section to obtain our results. The exact forms of these photon distributions, along with the required parameters will be given in a longer paper [11].

Figures 2 and 3 display some of the relevant distributions of the $q\bar{q}'$ cross section for a $\sqrt{s}$ of 500 GeV and 1 TeV in the case of a backscattered photon. Displayed are the differential cross sections as functions of the the $q\bar{q}'$ invariant mass, $M_{q\bar{q}'}$, the transverse momentum of the reconstructed W, $p_{TW}$, and the angular distribution of the reconstructed W, $\theta_W$. A beamline angular cut of $10^\circ$ was made on the quark directions, as well as a 5 GeV cut on $p_{TW}$. For the $p_T$ and angular distributions, we have also made a cut on $M_{q\bar{q}'}$ of $75 < M_{q\bar{q}'} < 85$.

From the invariant mass distribution we see that off W mass shell results can
be particularly useful. Although the cross sections here are small, small deviations in either $\lambda_\gamma$ and $\kappa_\gamma$ can produce order of magnitude differences in the cross section. The $p_T$ distribution also provides useful information. Here, especially in the high $p_T$ regions, the non-standard model couplings deviate significantly from the standard model values. We will use a combination of $p_T$ bins and angular distribution bins to provide our best constraints on the anomalous couplings.

To obtain constraints we consider the process $e\gamma \rightarrow \nu_e q q'$ and assumed a integrated luminosity of $10 \, fb^{-1}$. Our total cross sections at 500 GeV and 1 TeV are 16.7 pb and 18.9 pb respectively, so statistics should not be the limiting factor. We have assumed a systematic error of 5% on cross sections and a systematic error of 3% for ratios of cross sections. The total error is then taken to be the statistical and systematic error combined in quadrature. It should be emphasised that both the integrated luminosity and the systematic errors are conservative estimates. We expect that more realistic estimates of these variables will significantly improve our constraints.

Using the error in the standard model values as the error, we calculate the $\chi^2$ values. Figure 4 a) is the resulting 95% confidence limits on $\kappa_\gamma$ and $\lambda_\gamma$ for a 500 GeV collider based on a 4 bin $p_{TW}$ measurement and a 4 bin $\theta_W$ measurement. One sees that both $\kappa_\gamma$ and $\lambda_\gamma$ are constrained to 6%. Figure 4 b) repeats the above analysis for a 1 TeV collider. Figure 4 b) also includes the confidence level that is obtained through a measurement of the cross section with invariant mass, $M_{q q'} > 600$ GeV. This is not included in the combined limits. One sees that here $\kappa_\gamma$ is still constrained to 6% but $\lambda_\gamma$ to 2%.
Figure 4: a) Limits on $\kappa_\gamma$ and $\lambda_\gamma$ at the 95% confidence level for a 500 GeV $e\gamma$ collider: Dashed line is limit based upon 4 $\theta_W$ bins, dotted line is based upon 4 $p_T W$ bins, and solid line is the combined measurement. b) Same as a) except for 1 TeV $e\gamma$ collider: The additional vertical dash-dotted line is limit based upon cross-sectional measurement with $M_{q\bar{q}} > 600$ GeV.

4. Conclusions

We see that an $e\gamma$ collider operating at either 500 GeV or 1 TeV can constrain the non-standard model gauge couplings $\kappa_\gamma$ and $\lambda_\gamma$ to the percent level. These constraints represent an improvement on similar constraints from LEP and are comparable with those obtainable at SSC or LHC. We conclude that one would increase the knowledge of triple gauge boson couplings by running an $e^+e^-$ accelerator in a backscattered laser $e\gamma$ mode.

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6. References

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