

## Probing the $ZWW$ and $\gamma WW$ Couplings at $M_Z \leq \sqrt{s} < 2M_W$

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The reaction  $\gamma e \rightarrow W\nu$  is the most accessible test of the self-coupling of the electroweak bosons at  $\sqrt{s} < 2M_W$ , particularly if polarized electron and photon beams are used. The angular distribution of the  $W$  is quite sensitive to the anomalous magnetic moment of the  $W$ , which is predicted to be 1 in the standard model.

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Experimental studies of the  $ZWW$  and  $\gamma WW$  couplings can provide direct evidence for the nonabelian aspect of the gauge bosons of the electroweak fields. The considerable effort foreseen at LEP II to investigate the reaction  $e^+e^- \rightarrow W^+W^-$  is a measure of the importance attached to such studies.<sup>1</sup> Here we review the possibilities to probe these couplings at lower energies. While the rates are low, some scenarios of accelerator performance in the coming years may permit these studies prior to LEP II.

We consider 3 reactions, in order of increasing rate, and increasing perturbation on a program emphasizing  $Z^0$  production:

$$e^+e^- \rightarrow Z^0 \rightarrow Wl\nu \quad \text{or} \quad W + \text{hadrons} \quad (1)$$

$$e^+e^- \rightarrow We\nu \quad (2)$$

$$\gamma e \rightarrow W\nu \quad (3)$$

Of special interest in reactions (2) and (3) is the angular distribution of the  $W$ , which is very sensitive to the size of the anomalous magnetic moment of the  $W$ . On writing the magnetic moment as

$$\mu_W = \frac{e\hbar}{2M_W c}(1 + \kappa),$$

the anomalous moment  $\kappa$  is predicted to be 1 in the standard model.<sup>2,3</sup> Thus even a probe of the  $\gamma WW$  vertex yields a critical test of the standard model.

The decays  $Z^0 \rightarrow Wl\nu$  and  $W + \text{hadrons}$  could be studied in principle during ordinary  $e^+e^-$  running at the  $Z^0$  peak. But the branching ratio is only about  $10^{-7}$  into  $W + \text{hadrons}$ , and  $10^{-8}$  into  $W + \text{leptons}$ .<sup>4,5</sup> Furthermore, only about 40% of the decays are due to the  $ZWW$  coupling, so at least 100 events would be required to provide a clear test of this coupling strength.

Reaction (2) is suited for a run committed to a search for novel physics at  $\sqrt{s}$  slightly above the  $Z$  mass. However, the cross section has a threshold factor of  $(1 - M_W^2/s)^2$ , and is rather small as shown in Fig. 1.<sup>6,7</sup> The more prominent diagrams contributing to this reaction are shown in Fig. 2. The diagrams not involving the  $\gamma WW$  vertex can be suppressed if both the initial electron and positron have the *same* helicity.

FIG. 1. Cross sections as a function of center-of-mass energy,  $\sqrt{s}$ .

FIG. 2. The leading diagrams contributing to reaction (2).

Greater sensitivity to the size of the magnetic moment is obtained if the sign of the  $W$  is known. This can be inferred by observation of the spectator electron or positron, but perhaps only 1/3 of these will emerge from the beam pipe.<sup>7</sup> If the beams are polarized the sign of the  $W$  is fixed, *i.e.*, left-handed beams produce  $W^-$ .

The reaction  $e^+e^- \rightarrow W + \text{hadrons}$  has a cross section about 10 times that of  $e^+e^- \rightarrow We\nu$ , but there is almost no contribution from the  $\gamma WW$  vertex.

Reaction (3),  $\gamma e \rightarrow W\nu$ , could only be studied in a dedicated run at the Stanford Linear Collider (SLC), where the photon beam would be produced by Compton backscatter of a 4-5 eV laser beam. Lasers are now available of sufficient intensity to scatter 100% of, say, the positron beam, and could yield a luminosity for reaction (3) that is 20% of the  $e^+e^-$  luminosity. Dumping of the scattered positron beam requires some care as the energy spread is now 100%. The implementation of a photon beam at the SLC has been considered by Akerlof,<sup>8</sup> and by Ginzburg *et al.*<sup>8</sup>

The cross section for reaction (3) is also shown on Fig. 1 as a function of the center-of-mass energy of the  $\gamma e$  system.<sup>10,11</sup> The cross section is at least 100 times greater than that for  $e^+e^- \rightarrow We\nu$  at the same  $\sqrt{s}$ , which more than compensates for the lower luminosity. Of the two diagrams contributing to reaction (3) (Fig. 3) the one not involving a  $\gamma WW$  vertex can be suppressed by the use of right-handed photons, whether or not the charged beams are polarized. Of course only left-handed electrons produce  $W$ 's, so the rate is doubled if the electron beam is so polarized. Furthermore, the yield of high-energy photons via Compton backscattering is greater when they are prepared with circular polarization,<sup>9</sup> leading to an additional factor of 1.5 in the rate.

FIG. 3. The diagrams contributing to reaction (3). Diagram (a) is absent for beams polarized as  $\gamma_R e_L$ .

It is useful to present an effective cross section for reaction (3) at a given value of  $\sqrt{s}$  of the  $e^+e^-$  colliding beams (curve nn of Fig. 1), by averaging the cross section shown by curve mm over the spectrum of  $s_{\gamma e}$  obtained by backscattering a laser beam off the positron beam. For this we suppose the wavelength of the laser beam is  $0.266 \mu\text{m}$  (a frequency-quadrupled Nd:YAG laser), and that all of the positrons are scattered. For

$\sqrt{s_{ee}} > 94 \text{ GeV}$  reaction (3) is favored over reaction (2).

Fig. 4 shows how the angular distribution of the  $W$  in reaction (3) depends on the size of its anomalous magnetic moment.<sup>10,12</sup> A small number of events will distinguish the favored  $\kappa = 1$  from  $\kappa = 0$  (no anomalous moment) or  $-1$  (no magnetic moment). The  $W$ 's are predominantly produced in the direction of the photon beam.

FIG. 4. The angular distribution of the  $W$  with respect to the photon beam direction in reaction (3).

An important background to reaction (3) is

$$\gamma e \rightarrow Z^0 e. \quad (4)$$

The diagrams for this are those for Compton scattering but with the final-state photon replaced by the  $Z^0$ . In the energy range of interest the cross section for reaction (4) is about 100 pb for unpolarized beams,<sup>11,13</sup> leading to the effective cross section shown by curve aa in Fig. 1. Although the  $Z^0$  is produced predominantly along the electron direction, the relatively large rate for reaction (4) would compromise a measurement of the angular distribution of reaction (3). However, the use of polarized beams,  $\gamma_R e_L$ , as favored for reaction (3), greatly suppressed reaction (4)...by how much???? Thus by manipulation of the beam polarization reaction (4) could first provide a calibration and then be turned off during the study of reaction (3).

If the SLC could run with 60-GeV beams and an  $e^+e^-$  luminosity of  $10^{31} \text{ cm}^{-2}\text{s}^{-1}$  about 30 events could be collected in 10 days. The event rate with 55-GeV beams is about 1/2 this, and about 1/10 in the case of 50-GeV beams. Thus if the SLC exceeds its design parameters somewhat a dramatic test of the gauge boson couplings would be possible. The  $\gamma e$  initial state also offers distinctive signatures in new particles searches, many of which have been reviewed by Renard.<sup>13</sup>

<sup>1</sup>For recent considerations of the reaction  $e^+e^- \rightarrow WW$  see M. Kuroda *et al.*, Phys. Lett. **190B**, 217 (1987), and references therein.

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