Zeros in $\gamma+e \rightarrow W+\nu$

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We point out a misprint in the differential cross section for $\gamma e \rightarrow W\nu$ reported recently by Ginzburg, Kotkin, Panfil, and Serbo. The corrected expression has a zero in accordance with the general formula derived earlier by Mikaelian. We plot the angular distributions for different values of κ, the anomalous-magnetic-moment parameter of the W. We suggest that the reaction $\gamma e \rightarrow W\nu$ is an attractive way to measure κ because the distributions are sensitive to it and the zero exists only if $\kappa=+1$ as in the standard electroweak theory.

In this Brief Report we present the differential cross section for $\gamma e \rightarrow W\nu$ and show that it is highly sensitive to κ, the anomalous-magnetic-moment parameter of the W. Correcting a misprint in the expression derived recently[1] by Ginzburg, Kotkin, Panfil, and Serbo, we show their result to be a special case $(Q=1)$ of the general formula derived earlier[2] for the photoproduction of W bosons off a fermion of charge Q. We point out that if $\kappa=+1$, as in the standard electroweak theory, then the differential cross section vanishes in the backward direction where the W is emitted antiparallel to the γ.

The differential cross section is calculated using the two Feynman diagrams shown in Fig. 1. The result, for $\kappa=+1$, is

$$\frac{d\sigma}{dt}=\frac{\tilde{\sigma}}{x^2}\left[\frac{(x^2+1)M^2}{(M^2-t)^2}-\frac{2x^2+x+1}{x(M^2-t)}+\frac{3}{2M^2}+\frac{t+M^2}{2xM^4}\right] , \tag{1}$$

where we have used the notation of Ref. 1:

$$\tilde{\sigma}=\frac{\pi\alpha^2}{M^2\sin^2\theta_W},\quad x=s/M^2,\quad \text{and}\quad t=(P_\gamma-P_W)^2 .$$

Equation (1) is for unpolarized beams and it agrees with Eq. (11a) of Ref. 1 except for the term $3/2M^2$ which appears as $3/M^2$ in Ref. 1.

Equation (1) vanishes at the kinematic point $M^2-t=xM^2$, i.e.,

$$\frac{d\sigma}{dt}[t=(1-x)M^2]=0 . \tag{2}$$

This zero is more clearly seen if we use the expression reported in Ref. 2 for $\gamma q \rightarrow Wq$. Setting $Q=1$ we get

$$\frac{d\sigma}{dt}=-\tilde{\sigma}\frac{M^2}{2s^3}\frac{u}{(s+u)^2}(s^2+u^2+2tM^2) , \tag{3}$$

where s, t, and u are the usual Mandelstam variables satisfying $s+t+u=M^2$. Clearly, Eq. (3) vanishes for $u=0$. More generally,[2] $d\sigma/dt$ contains the factor

$$Q-\frac{1}{1+u/s}$$

which vanishes at the kinematic point $1+u/s=1/Q$.

These zeros were reported in the crossed channels $q\bar{q} \rightarrow W\gamma$ (Ref. 3) and $W \rightarrow q\bar{q}\gamma$ (Ref. 4). Generalizations to an arbitrary gauge theory and to any number of particles were reported in Refs. 5 and 6, respectively.

The differential cross section (1) or (3), which are equivalent, was not discussed in detail in Ref. 1. Hence we present in Fig. 2 the angular distribution

$$\frac{d\sigma}{d\cos\theta}=\tfrac{1}{2}(s-M^2)\frac{d\sigma}{dt} ,$$

where θ is the angle between the γ and the W in the γe center-of-mass frame. Since

$$u=-\tfrac{1}{2}(s-M^2)(1+\cos\theta) ,$$

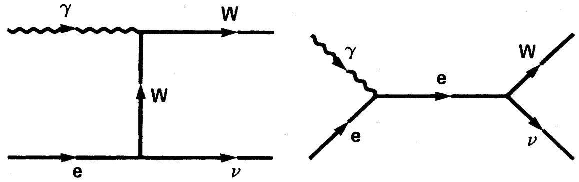

FIG. 1. Feynman diagrams for the process $\gamma+e \rightarrow W+\nu$.

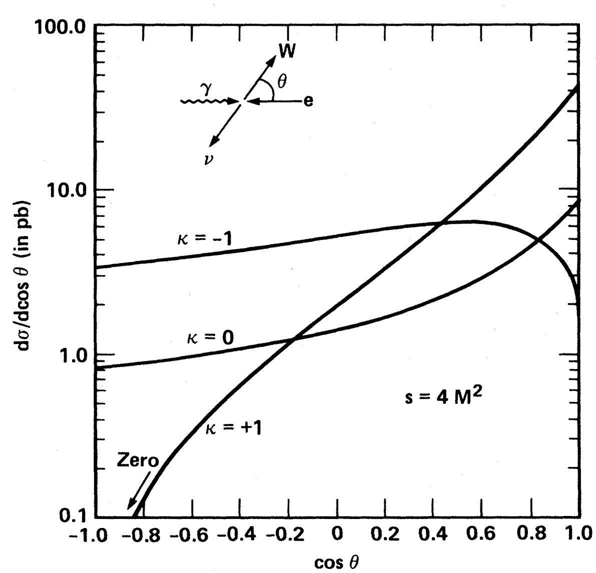

FIG. 2. The angular distribution $d\sigma/d\cos\theta$ (in pb) of the process $\gamma+e \rightarrow W+\nu$ for three different values of κ, the anomalous-magnetic-moment parameter of the W. In the standard electroweak theory $\kappa=+1$, in which case there is a zero at $\theta=180°$. The ratio $s/M^2=4$.

the zero occurs in the backward direction, $\theta = 180°$, where the W is produced antiparallel to the γ.

Equations (1) and (3) assume that κ, the anomalous-magnetic-moment parameter for the W boson, has the value $+1$ as predicted by the standard electroweak theory. The zero exists only for this value of κ. In Fig. 2 we also include the angular distributions for $\kappa = 0$ and $\kappa = -1$. The appropriate expressions are given in Ref. 2, where the angular distribution is derived for arbitrary κ and Q, and where we pointed out that if $\kappa = +1$ then the differential cross section can be written in an exceptionally simple form for arbitrary Q. The three curves in Fig. 2 are obtained by setting $Q = 1$ and $\kappa = -1$, 0, and $+1$ in $T(\kappa, Q, s, t)$ (see Ref. 2).

The overall scale of our cross sections is set by $\tilde{\sigma} = \sqrt{2}\alpha G_f \simeq 46$ pb. We need not specify the mass M of the W boson but only the ratio s/M^2. In Fig. 2 we set $s/M^2 = 4$. The same distributions are shown in Fig. 3 for $s/M^2 = 10$. We see that the overall shape of the curves does not change much as we go to higher energies. The zero occurs, of course, at all values of s/M^2 if $\kappa = +1$. In the limit $s >> M^2$ and for $\kappa = +1$ we get

$$\frac{d\sigma}{d\cos\theta} \underset{s>>M^2}{\longrightarrow} \tilde{\sigma}\left(\frac{M^2}{2s}\right)\frac{1+\cos\theta}{(1-\cos\theta)^2}\left[1+\tfrac{1}{4}(1+\cos\theta)^2\right] \quad . \quad (4)$$

It is clear from Figs. 2 and 3 that the angular distribution of the W bosons in $\gamma e \rightarrow W\nu$ is highly sensitive to the value of κ, and can be used to measure the magnetic moment of the W. The advantage of this reaction over $pp(\bar{p}) \rightarrow W\gamma X$ (Ref. 3) and $W \rightarrow 2\ \text{jets} + \gamma$ (Ref. 4) is that only leptonic reactions are involved which are presumably simpler than hadronic processes. Acquiring the necessary high-energy γ and e beams, however, is no simple matter, as discussed in Ref. 1. Furthermore, background from $\gamma e \rightarrow Z^0 e$ (see Ref. 1) may be a serious problem around $\theta = 180°$, and hence the forward direction, $\theta = 0°$, may be more convenient for measurements. Though there are no zeros in the forward direction, Figs. 2 and 3 show that $d\sigma/d\cos\theta$ in that region of phase space is still quite sensitive to the value of κ.

We should point out that the zero persists with polarized γ or e beams: since the unpolarized cross sections are obtained by summing over the absolute squares of the helicity amplitudes,

$$d\sigma \sim \sum_\lambda |M_\lambda|^2 \ ,$$

clearly $d\sigma = 0$ implies $M_\lambda = 0$ for all λ. As shown in Ref. 5, the factor $Q - 1/(1 + u/s)$ occurs in each helicity amplitude and hence the zero is independent of any initial or final polarizations.

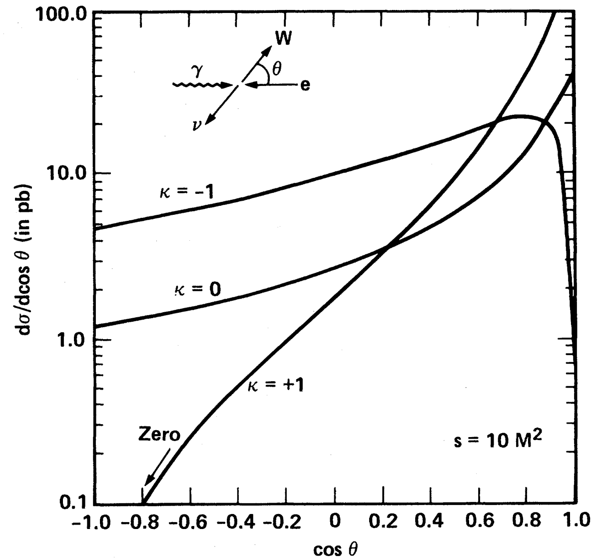

FIG. 3. Same as Fig. 2 for $s/M^2 = 10$.

We would also like to mention that the *total* cross section for $\gamma e \rightarrow W\nu$ with $\kappa = +1$ as reported in Ref. 1 is correct. The κ dependence of the total cross section was given in Ref. 7. It is a curious fact (see Ref. 2) that the total cross section in the high-energy limit is independent of Q for any value of κ. Finally, the difference in the total cross sections for $\kappa = -1$, 0, and $+1$ is not as striking as the difference in their angular distributions. These distributions, particularly the zero at $\theta = 180°$ if $\kappa = +1$, are a good measure of the magnetic moment of the charged intermediate vector boson which has recently been found.[8,9]

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