Z. Phys. C – Particles and Fields 16, 65–67 (1982)

Zeitschrift für Physik C Particles and Fields

Electroweak Interference Effects in the High Energy $e^+ + e^- \to e^+ + e^- +$ Hadrons Process

H.C. Lee

Atomic Energy of Canada, Chalk River Nuclear Laboratories, Chalk River, Ontario, Canada

Li Bing-An, Shen Qi-Xing, Zhang Mei-Man

Institute of High Energy Physics, Academia Sinica, Beijing, China

Yu Hong[1]

International Centre for Theoretical Physics, and Scuola Internazionale Superiore di Studi Avanzati, I-34100 Trieste, Italy

Received 13 April 1982; in revised form 29 June 1982

Abstract. We examine interference effects of the electroweak interaction in the high energy $e^+ + e^- \to e^+ + e^- +$hadrons process. The effect provides a further test of the G-W-S model [1] and may lead to a better understanding of the photon structure functions.

Recently, electroweak interference effects in the lepton production in e^+e^- [2] and hadron-hadron [3] collision have been discussed. In the lowest order these effects arise from the interference between Feynman diagrams with a virtual photon γ and those with a neutral weak vector boson Z^0. Observations of the effect in $e^+ + e^- \to \mu^+ + \mu^-$ have been reported [4] from PETRA in the form of forward-backward asymmetry in the angular distribution of the produced μ^-.

In this paper we investigate the electroweak interference effects in the process

$$e^+ + e^- \to e^+ + e^- + \gamma\gamma \\ \hookrightarrow X \text{ (hadrons)}$$

In the parton model which we shall use in this study, the quark and antiquark have identical distribution functions in the photon. This implies that in the lowest order of the electroweak interaction interference effects are not observable unless at least either the initial electron or the initial positron is polarized.

The lowest order Feynman diagrams for the process of interest are given in Fig. 1. The corresponding element of the S-matrix is

$$\langle e^+ e^- X | S - 1 | e^+ e^- \rangle = \frac{(-i)^4}{4!} \int d^4\chi_1\, d^4\chi_2\, d^4\chi_3\, d^4\chi_4 \cdot \langle e^+ e^- X | T\{\mathcal{H}_i(x_1)\, \mathcal{H}_i(\chi_2)\, \mathcal{H}_i(\chi_3)\, \mathcal{H}_i(\chi_4)\} | e^+ e^- \rangle, \quad (1)$$

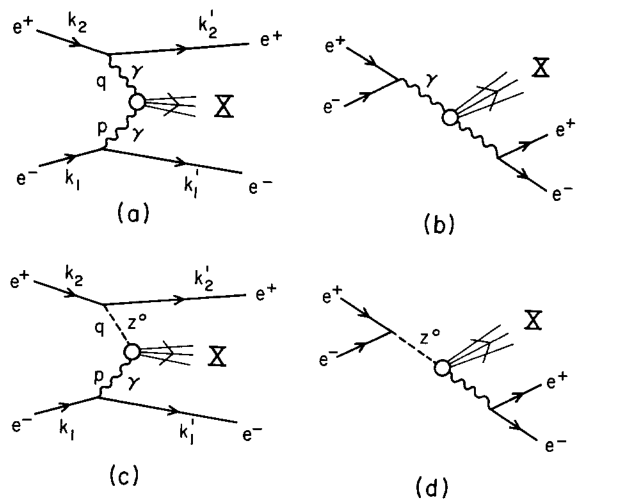

Fig. 1. Lowest order Feynman diagrams for the electroweak interference effects in the $e^+ + e^- \to e^+ + e^- + X$ (hadrons) process. At high energies, especially when $p^2 \approx 0$, the two annihilation, time-like diagrams can be neglected

1 Permanent address: Institute of High Energy Physics, Academia Sinica, Beijing, China

0170-9739/82/0016/0065/$01.00

where $\mathscr{H}_i$ is the interaction Hamiltonian. For simplicity we shall concentrate on the case when one of the photons is nearly on the mass shell, say, $p^2 \approx 0$. In this case the two time-like diagrams, Figs. 1b and 1d can be neglected, and

$$\begin{aligned}\langle e^+ e^- X | S-1 | e^+ e^-\rangle &= -e^4 \int d^4\chi_1\, d^4\chi_2\, d^4\chi_3\, d^4\chi_4 \\ &\cdot D(\chi_1-\chi_3)\, D(\chi_2-\chi_4)\, \bar{u}(\chi_1)\gamma^\mu u(\chi_1)\, \bar{v}(\chi_2)\gamma^\nu(\chi_2) \\ &\cdot \langle X | T\{\sum_i j_{\mu i}(\chi_3) j_{\nu i}(\chi_4)\} |0\rangle - ie^2 \frac{G_F}{\sqrt{2}} \int d^4\chi_1\, d^4\chi_2\, d^4\chi_3 \\ &\cdot D(\chi_1-\chi_3)\, \bar{u}(\chi_1)\gamma^\mu u(\chi_1)\, \bar{v}(\chi_2) O_W^\mu v(\chi_2) \\ &\cdot \langle X | T\{\sum_i j_{\nu i}^W(\chi_2) j_{\mu i}(\chi_3)\} |0\rangle,\end{aligned} \tag{2}$$

where G_F is the Fermi weak coupling constant, $D(x)$ is the photon propagator, $O_W^\mu = g^L\gamma^\mu(1+\gamma_5)+g^R\gamma^\mu(1-\gamma_5)$ and $j_{\mu i}^W(x)$ is the neutral weak quark current

$$j_{\mu i}^W(\chi) = \bar{\psi}_i(\chi)\{g_i^L\gamma_\mu(1+\gamma_5)+g_i^R\gamma_\mu(1-\gamma_5)\}\psi_i(\chi), \tag{3}$$

where the subscript i labels the quark flavour. In the G-W-S model [1]

$$\begin{aligned} g^L &= \frac{1}{\sqrt{2}}(-1+2\sin^2\theta_W), \\ g^R &= \frac{1}{\sqrt{2}}(2\sin^2\theta_W), \\ g_i^L &= \sqrt{2}(2I_{3i}-2Q_i\sin^2\theta_W), \\ g_i^R &= \sqrt{2}(-2Q_i\sin^2\theta_W), \end{aligned} \tag{4}$$

where I_3 is the Z-component of the isospin and Q_i is the electric charge in units of e. The differential cross-section due to $\gamma - Z^0$ interference is

$$\begin{aligned} d\sigma^{EW} &= \frac{-1}{(2\pi)^6} d^3k_1'\, d^3k_2' \frac{e^6 G_F}{\sqrt{2}p^4 q^2} \cdot \frac{1}{16E_1'E_2'(k_1\cdot k_2)} \\ &\cdot \mathscr{T}^{\rho\sigma}(1)\, \mathscr{T}_{EW}^{\nu\mu}(2)\, W_{\rho\sigma\nu\mu}, \end{aligned} \tag{5}$$

$$\begin{aligned} W_{\rho\sigma\nu\mu} &= \varepsilon_\rho^{\lambda *}(p)\, \varepsilon_\sigma^{\lambda'}(p) \int d^4\chi\, e^{iq\chi}\, 2p_0 \\ &\cdot \langle \gamma_{\lambda'} | \sum_i \{j_{\mu i}^W(\chi) j_{\nu i}(0) + j_{\mu i}(\chi) j_{\nu i}^W(0)\} | \gamma_\lambda\rangle, \\ \mathscr{T}^{\rho\sigma}(1) &= \bar{u}(k_1')\gamma^\rho u(k_1)\, \bar{u}(k_1)\gamma^\sigma u(k_1') \cdot 4E_1E_1', \\ \mathscr{T}_{EW}^{\nu\mu}(2) &= \bar{v}(k_2)\, O_W^\nu v(k_2')\, \bar{v}(k_2')\gamma^\mu v(k_2) \cdot 4E_2E_2'. \end{aligned} \tag{6}$$

For simplicity we consider the case when the initial positron is polarized and the electron unpolarized. Then

$$\begin{aligned} \mathscr{T}^{\rho\sigma}(1) &= p^2 g^{\rho\sigma} - p^\rho p^\sigma + (2k_1-p)^\rho (2k_1-p)^\sigma, \\ \mathscr{T}_{EW}^{\nu\mu}(2) &= 2\{(g^L+g^R)+s(g^L-g^R)\} \\ &\cdot (\tfrac{1}{2}q^2 g^{\nu\mu} + k_2^\nu k_2'^\mu + k_2^\mu k_2'^\nu - is\varepsilon^{\rho\sigma\nu\mu} k_{2\rho} k_{2\sigma}') \end{aligned} \tag{7}$$

where $s = \pm 1$ is the helicity of the positron. To evaluate the one-photon expectation value of the product of quark currents in the expression for $W_{\rho\sigma\nu\mu}$, we use the parton model and assume the quark and antiquark distribution functions in the photon are identical. The differential cross-section then becomes

$$\begin{aligned} d\sigma^{EW} &= \frac{-1}{(2\pi)^6} d^3k_1'\, d^3k_2' \frac{e^6 G_F}{\sqrt{2}p^2} \frac{1}{16E_1'E_2'(k_1\cdot k_2)} \\ &\cdot 8\pi\left[1+\frac{2}{(p\cdot q)^2}(k_1\cdot q)(k_1'\cdot q)\right][(g^L+g^R)+s(g^L-g^R)] \\ &\cdot \sum_i 4Q_i q_i(\chi, t)(g_i^L+g_i^R)\left[1+\frac{2(k_2\cdot p)(k_2'\cdot p)}{(p\cdot q)^2}\right]. \end{aligned} \tag{8}$$

where $q_i(\chi, t)$ are the quark distribution functions [5] in the photon ($\chi = Q^2/2\nu$ is the Bjorken scaling variable, $t = \ln(Q^2/\Lambda^2)$, $Q^2 = -q^2$, $\nu = p\cdot q$ and Λ is the QCD scale parameter).

For deep inelastic electron photon scattering ($p^2 \approx 0$) the momentum transfers Q^2 is not big. Even for the future electron-positron storage rings facility LEP, in order to get certain rates Q^2 is limited to be smaller than $25\,\mathrm{GeV}^2$. So the pure weak effect can be neglected. In addition the differential cross-section due to the electromagnetic interaction alone is independent of the polarization of the positron, we have

$$d\sigma^\uparrow - d\sigma^\downarrow = d\sigma^{EW}(s=+1) - d\sigma^{EW}(s=-1), \tag{9}$$

whereas

$$\begin{aligned} d\sigma^\uparrow + d\sigma^\downarrow &= 2\, d\sigma^{EM} = \frac{d^3k_1'\, d^3k_2'}{(2\pi)^6} \frac{e^8}{p^2 q^2} \frac{1}{16E_1'E_2'(k_1\cdot k_2)} \\ &\cdot 8\pi\left[1+\frac{2(k_1\cdot q)(k_1'\cdot q)}{(p\cdot q)^2}\right]\left[1+\frac{2(k_2\cdot p)(k_2'\cdot p)}{(p\cdot q)^2}\right] \\ &\cdot \sum_i 4Q_i^2 \cdot q_i(\chi, t). \end{aligned} \tag{10}$$

The arrows denote the longitudinal polarization of the initial positron.

For simplicity, we neglect the dependence on the azimuthal angle in (8) and (10) above.

Defining the asymmetry

$$R = \frac{d\sigma^\uparrow - d\sigma^\downarrow}{d\sigma^\uparrow + d\sigma^\downarrow} \tag{11}$$

then from (8) and (10)

$$R = \frac{\sqrt{2}G_F}{4\pi\alpha} Q^2 (g^L - g^R) \frac{\sum_i Q_i q_i(\chi, t)(g_i^L + g_i^R)}{\sum_i Q_i^2 q_i(\chi, t)} \tag{12}$$