PHYSICAL REVIEW D VOLUME 14, NUMBER 7 1 OCTOBER 1976

Weak neutral currents in electron-positron annihilation into three pions*

E. Calva-Tellez and A. Zepeda
Centro de Investigación del I.P.N., Apartado Postal 14–740, México 14, D.F.
(Received 12 January 1976)

We discuss how weak neutral currents of popular gauge models manifest themselves in the process $e^+e^- \to \pi^+\pi^-\pi^0$ for an unpolarized initial state. We define three asymmetry parameters A_{c1}, A_{c2}, and A_p which provide information about the presence of the neutral current. The former two give account of charge asymmetries in the $\pi^+\pi^-$ final state while A_p is nonzero when parity-violating effects occur. Using a phenomenological model for the hadronic vertices we obtain that the maximum value of these parameters is ~ 3 to 4%, and that this value is reached at a beam energy ≈ 20 GeV.

It has been pointed out by several authors[1,2] that the weak neutral currents could be detected in electron-positron colliding-beam experiments. The aim of these analyses has been not only to propose the confirmation of the existence of such currents but also to extricate their quantum numbers. With this question in mind we discuss in this paper how weak neutral currents of popular gauge models[3-5] manifest themselves in the e^+e^- annihilation into $\pi^+\pi^-\pi^0$ for an unpolarized initial state. We are interested in angular and/or charge asymmetries produced by the interference of the amplitude for annihilation via a neutral particle Z and the amplitude for annihilation via one photon.

We will assume that the neutral current is of the $V-A$ form, and that its hadronic part carries quantum numbers $I^G(J^P)C = 1^+(1^-)-$, $0^-(1^-)-$, and $1^-(1^+)+$. Then in the process $e^+e^- \to \pi^+\pi^-\pi^0$ only the axial and the vector isoscalar parts of the hadronic neutral current contribute. Because of the different charge-conjugation properties and different parities of the photon and the hadronic axial-vector neutral current, the interference of the amplitude for

$$e^+e^- \to \gamma \to \pi^+\pi^-\pi^0 \quad (1)$$

with the amplitude for

$$e^+e^- \to Z \to \pi^+\pi^-\pi^0 \quad (2)$$

gives rise to charge asymmetries[6] as well as to parity-violating angular asymmetries. In the second order of the weak coupling, that is, in the square of the amplitude for (2), the same asymmetries arise from the interference of vector and axial-vector couplings. If the hadronic neutral current does not contain an axial-vector part (of the form indicated above), as in the Bég-Zee model,[5] then there are no asymmetries at all since the quantum numbers of its vector isoscalar part are the same as those of the photon mediating (1).

Let q_-, q_+, p_-, p_+, and p_0 be the four-momenta of the electron, positron, and pions, respectively, in the center-of-mass frame of e^+e^-.

The sum of the amplitudes for (1) and (2) is

$$M = \frac{l^\mu}{s} L_\mu + (v_\mu + a_\mu)\frac{g^{\mu\nu} - P_f^\mu P_f^\nu/M_Z^2}{s - M_Z^2}(V_\nu + A_\nu), \quad (3)$$

where

$$P_f = p_+ + p_- + p_0, \quad s = P_f^{\,2},$$

$$l^\mu = ei\bar{v}\gamma^\mu u, \quad (4)$$

$$v_\mu = g_v i\bar{v}\gamma_\mu u, \quad (5)$$

$$a_\mu = g_a i\bar{v}\gamma_\mu\gamma_5 u. \quad (6)$$

e is the electron charge and g_v (g_a) is the coupling constant of the vector (axial-vector) neutral current to leptons. L_μ describes the $\gamma - \pi^+\pi^-\pi^0$ vertex and V_ν and A_ν describe the $Z - \pi^+\pi^-\pi^0$ one with vector and axial-vector coupling, respectively.

L_μ and V_μ are axial vectors antisymmetric in their dependence upon p_+, p_-, and p_0. That is,

$$L_\mu = ie\epsilon_{\mu\nu\rho\sigma}p_+^\nu p_-^\rho p_0^\sigma F_1, \quad (7)$$

$$V_\mu = ig_V\epsilon_{\mu\nu\rho\sigma}p_+^\nu p_-^\rho p_0^\sigma F_2, \quad (8)$$

where F_1 and F_2 are Lorentz scalars symmetric in their dependence on p_+, p_-, and p_0. On the

TABLE I. Transformation properties of the three terms in the differential cross section.

	Charge inversion	Space inversion	Both inversions combined
	$\theta_+ \leftrightarrow \theta_-$	$\theta_+ \leftrightarrow \pi - \theta_-$	$\theta_\pm \to \pi - \theta_\pm$
$d\sigma^s/d\theta_+ d\theta_-$	+	+	+
$d\sigma^{ca}/d\theta_+ d\theta_-$	−	+	−
$d\tilde{\sigma}^{pv}/d\theta_+ d\theta_-$	+	−	−

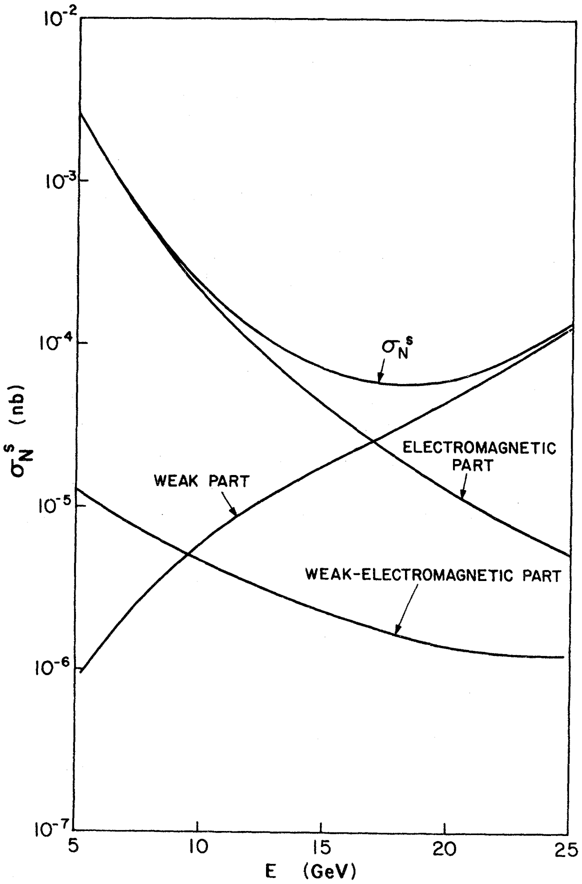

FIG. 1. σ_N^S and its three contributions.

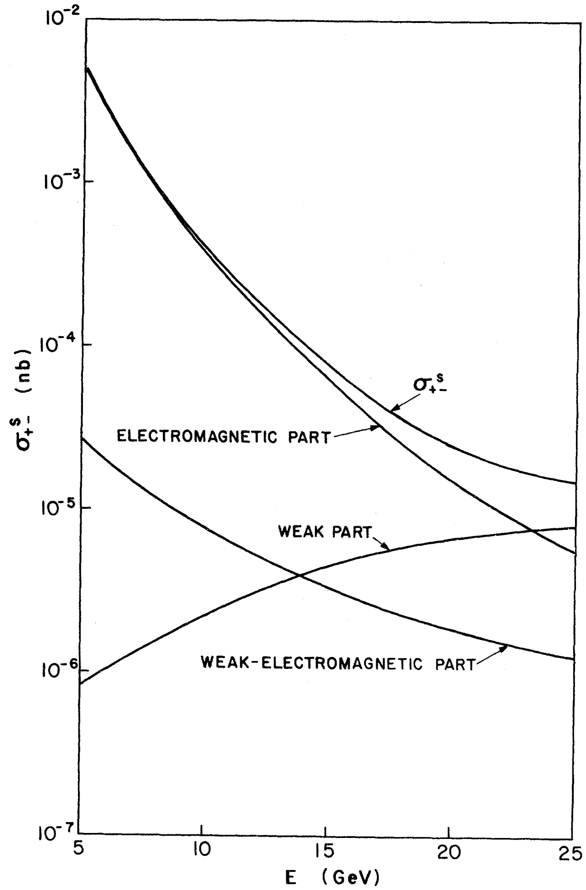

FIG. 2. σ_{+-}^S and its three contributions.

other hand, A_μ is a vector symmetric in p_+ and p_-:

$$A_\mu = g_A[(p_+ + p_-)_\mu F_3 + (p_+ - p_-)_\mu F_4 + P_{f\mu} F_5], \tag{9}$$

where F_3 and F_5 are symmetric in their dependence on p_+ and p_- and F_4 is antisymmetric. g_V and g_A are the coupling constants of the vector and axial-vector neutral current to hadrons.

Neglecting the lepton mass we obtain for unpolarized initial particles the parity-conserving differential cross section

$$\frac{d\sigma}{d\theta_+ d\theta_-} = \frac{1}{8(2\pi)^4 s} \int_M^{\overline{E}} dE_+ \int_M^{\overline{E}} dE_- R\{C_s^{(1)}[1+\cos(\theta_+ + \theta_-)\cos(\theta_+ - \theta_-) - 2\cos\theta_+ \cos\theta_- \cos\theta_{+-}]$$
$$+ C_s^{(2)}(\sin^2\theta_+ + \sin^2\theta_-) + C_s^{(3)}(\cos\theta_{+-} - \cos\theta_+ \cos\theta_-) + C_{ca}(\cos\theta_+ - \cos\theta_-)\}, \tag{10}$$

where R is a phase-space factor

$$R = (\sin\theta_+ \sin\theta_-)\theta(1-\cos^2\theta_{+-})\theta(\cos\theta_{+-} - \cos(\theta_+ + \theta_-))$$
$$\times\theta(\cos(\theta_+ - \theta_-) - \cos\theta_{+-})[\cos\theta_{+-} - \cos(\theta_+ + \theta_-)]^{-1/2}[\cos(\theta_+ - \theta_-) - \cos\theta_{+-}]^{-1/2},$$

$$C_s^{(1)} = \vec{p}_+^{\,2}\vec{p}_-^{\,2}\left[8\pi^2\alpha^2|F_1|^2 + \frac{s}{s-M_Z^2} 4\pi\alpha g_v g_V \mathrm{Re}\, F_1^* F_2 + \frac{s^2}{2(s-M_Z^2)^2}(g_v^2 + g_a^2) g_V^2 |F_2|^2\right],$$

$$C_s^{(2)} = \frac{s}{4(s-M_Z^2)^2}(g_v^2 + g_a^2) g_A^2 (|F_3 + F_4|^2 \vec{p}_+^{\,2} + |F_3 - F_4|^2 \vec{p}_-^{\,2}),$$

$$C_s^{(3)} = \frac{s}{(s-M_Z^2)^2}(g_v^2+g_a^2)g_A^2|\vec{p}_+||\vec{p}_-|(|F_3|^2-|F_4|^2),$$

$$C_{ca} = \frac{g_a g_A \sqrt{s}}{s-M_Z^2}(1+\cos\theta_{+-})|\vec{p}_+||\vec{p}_-|\,\mathrm{Re}\left\{\left(2\pi\alpha F_1^* + \frac{s g_v g_V}{s-M_Z^2}F_2^*\right)[F_3(|\vec{p}_+|+|\vec{p}_-|)+F_4(|\vec{p}_+|-|\vec{p}_-|)]\right\},$$

where $E_+=p_+^0$, $E_-=p_-^0$, θ_+ and θ_- are the angles of $\vec{p}_+$ and $\vec{p}_-$, respectively, with the direction of the beam ($\vec{q}_-$ for instance), θ_{+-} is the angle between $\vec{p}_+$ and $\vec{p}_-$ and is given by

$$\cos\theta_{+-} = \frac{s+M^2+2E_+E_- - 2\sqrt{s}(E_+ + E_-)}{2|\vec{p}_+||\vec{p}_-|}, \quad (11)$$

$\bar{E}=(s-3M^2)/2\sqrt{s}$, and M is the pion mass. Since we are interested in beam energies less than 30 GeV and since the width of the Z boson has been estimated[7] to be of the order of 0.6 GeV, we have neglected it in Eq. (10), assuming that $M_Z \sim 75$ GeV.

We can separate $d\sigma$ into two different parts according to its dependence on the coupling constants: $d\sigma^s$, the part of $d\sigma$ that contains α^2, $\alpha g_v g_V$, $(g_v^2+g_a^2)g_V^2$, and $(g_v^2+g_a^2)g_A^2$, and $d\sigma^{ca}$, the part of $d\sigma$ with terms proportional to $g_a g_A \alpha$ and $g_a g_A g_v g_V$. $d\sigma^s$ is charge symmetric while $d\sigma^{ca}$ is charge antisymmetric.

In Eq. (10) there are no parity-violating terms because we have integrated over the azimuthal angles of the π^+ and the π^-. To understand this point we first notice that in the problem there are only three independent vectors, e.g. $\vec{q}_-$, $\vec{p}_+$, and $\vec{p}_-$. Thus there is only one independent pseudoscalar, e.g. $b=\vec{q}_-\cdot(\vec{p}_-\times\vec{p}_+)$. If we choose the x axis to lie in the $(\vec{q}_-,\vec{p}_-)$ plane then $b=|\vec{q}_-||\vec{p}_-||\vec{p}_+|\sin\theta_+\sin\theta_-\sin\phi_+$. The variable ϕ_+ is not independent since from the law of conservation of four-momenta it is constrained by a δ function of the form $\delta(c+d\cos\phi_+)$ where $c=\cos\theta_{+-} - \cos\theta_+\cos\theta_-$ and $d=-\sin\theta_+\sin\theta_-$. The argument is completed by noticing that

$$\int_0^{2\pi} d\phi \sin\phi\,\delta(a+b\cos\phi)=0.$$

If we integrate one of the two azimuthal variables, ϕ_+ or ϕ_-, only from 0 to π or from π to 2π then the parity-violating term does not go away and we obtain a partial differential cross section given by

$$d\tilde{\sigma}_{E,W} = d\tilde{\sigma}^s + d\tilde{\sigma}^{ca} + d\tilde{\sigma}_{E,W}^{\text{pv}}, \quad (12)$$

where

$$d\tilde{\sigma}^s = \tfrac{1}{2}d\sigma^s, \quad d\tilde{\sigma}^{ca}=\tfrac{1}{2}d\sigma^{ca}, \quad (13)$$

$$\begin{aligned} d\tilde{\sigma}_{E,W}^{\text{pv}} = \pm \frac{d\theta_+ d\theta_-}{16(2\pi)^4 s}\sin\theta_+\sin\theta_- \int_M^{\bar{E}} dE_+ \int_M^{\bar{E}} dE_-\,&\theta(1-\cos^2\theta_{+-})\theta(\cos\theta_{+-}-\cos(\theta_+ + \theta_-)) \\ &\times\theta(\cos(\theta_+ - \theta_-)-\cos\theta_{+-})\frac{\sqrt{s}}{s-M_Z^2}(\cos\theta_+ + \cos\theta_-)|\vec{p}_+||\vec{p}_-| \\ &\times \mathrm{Im}\left\{\left[2\pi\alpha g_v g_A F_1^* + \frac{s(g_v^2+g_a^2)g_V g_A}{2(s-M_Z^2)}F_2^*\right]\right. \\ &\left.\times[F_3(|\vec{p}_+|+|\vec{p}_-|)+F_4(|\vec{p}_+|-|\vec{p}_-|)]\right\}. \end{aligned} \quad (14)$$

The subscript E (W) and the + (−) sign refer to the integration of ϕ_+ from 0 to π (π to 2π). In both cases ϕ_- is integrated from 0 to 2π. In Eq. (14) there are no parity-violating terms proportional to $\alpha g_a g_V$, $g_V^2 g_a g_v$, or $g_a g_v g_A^2$; the first two are identically zero while the third does not contribute owing to the symmetry of the (E_+, E_-) domain of integration.

$d\sigma^s$, $d\sigma^{ca}$, and $d\tilde{\sigma}^{\text{pv}}$ can also be recognized by their dependence on $\cos\theta_+$ and $\cos\theta_-$.[8] This structure implies that $d\sigma^s$, $d\sigma^{ca}$, and $d\tilde{\sigma}^{\text{pv}}$ have different "parities" under the angular inversions listed in Table I. From this Table we can see that the information on the presence of the neutral currents is obtained by measuring the asymmetry parameters

$$A_{c1} = \frac{\sigma_{+-}-\sigma_{-+}}{\sigma_{+-}+\sigma_{-+}}, \quad A_{c2} = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-}, \quad (15)$$

$$A_p = \frac{\Delta\sigma_N - \Delta\sigma_S}{\sigma_N + \sigma_S}, \quad (16)$$

where

$$\sigma_{\pm\mp} = \int_{\theta_0}^{\pi/2} d\theta_\pm \int_{\pi/2}^{\pi-\theta_0} d\theta_\mp \frac{d\sigma}{d\theta_+ d\theta_-} , \tag{17}$$

$$\sigma_+ = \int_{\theta_0}^{\pi/2} d\theta_+ \int_{\theta_0}^{\pi-\theta_0} d\theta_- \frac{d\sigma}{d\theta_+ d\theta_-} , \tag{18}$$

$$\sigma_- = \int_{\pi/2}^{\pi-\theta_0} d\theta_+ \int_{\theta_0}^{\pi-\theta_0} d\theta_- \frac{d\sigma}{d\theta_+ d\theta_-} , \tag{19}$$

$$\sigma_N = \int_{\theta_0}^{\pi/2} d\theta_+ \int_{\theta_0}^{\pi/2} d\theta_- \frac{d\sigma}{d\theta_+ d\theta_-} , \tag{20}$$

$$\sigma_S = \int_{\pi/2}^{\pi-\theta_0} d\theta_+ \int_{\pi/2}^{\pi-\theta_0} d\theta_- \frac{d\sigma}{d\theta_+ d\theta_-} ; \tag{21}$$

$\Delta\sigma_N$ ($\Delta\sigma_S$) is defined by an integration, analogous to that in Eq. (20) (21), of $\Delta d\sigma \equiv d\sigma_E - d\sigma_W$. θ_0 is some given angular cutoff determined by the measuring apparatus.

As we have already indicated above, A_{c1}, A_{c2}, and A_p are identically zero if the neutral current does not couple axially to hadrons. If it does couple then the following takes place: A_{c1} and A_{c2} are nonzero if and only if the neutral current couples axially to the e^+e^- state. A_p is zero if and only if the neutral current does not couple vectorially to both leptons and hadrons. However, for low energies, such that

$$s(g_v{}^2 + g_a{}^2)\,|g_V g_A| \ll 4\pi\alpha |g_v g_A|\,|s - M_Z{}^2| ,$$

the last premise reduces to the neutral current being coupled vectorially to leptons. The above statements follow from the following relations obtained from Table I:

$$\sigma_{-+}^s = \sigma_{+-}^s , \quad \sigma_{-+}^{ca} = -\sigma_{+-}^{ca} ,$$

$$\sigma_+^s = \sigma_-^s , \quad \sigma_+^{ca} = -\sigma_-^{ca} ,$$

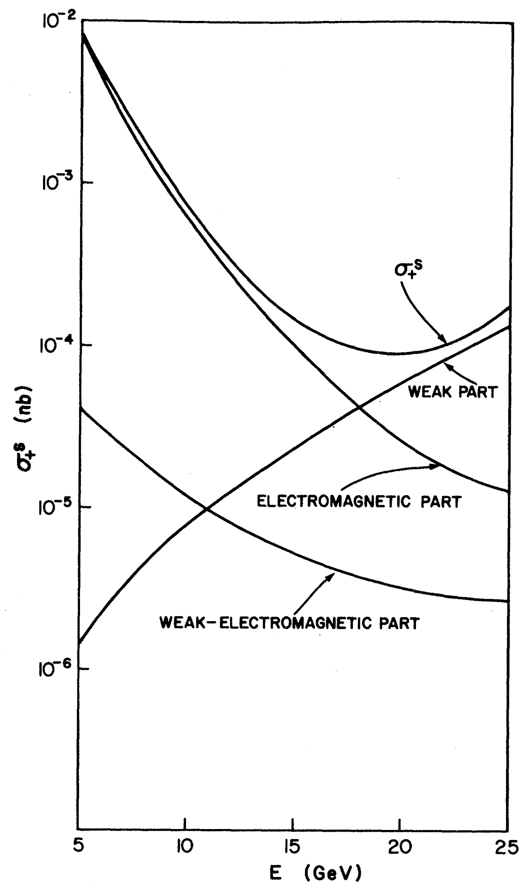

FIG. 3. σ_+^s and its three contributions.

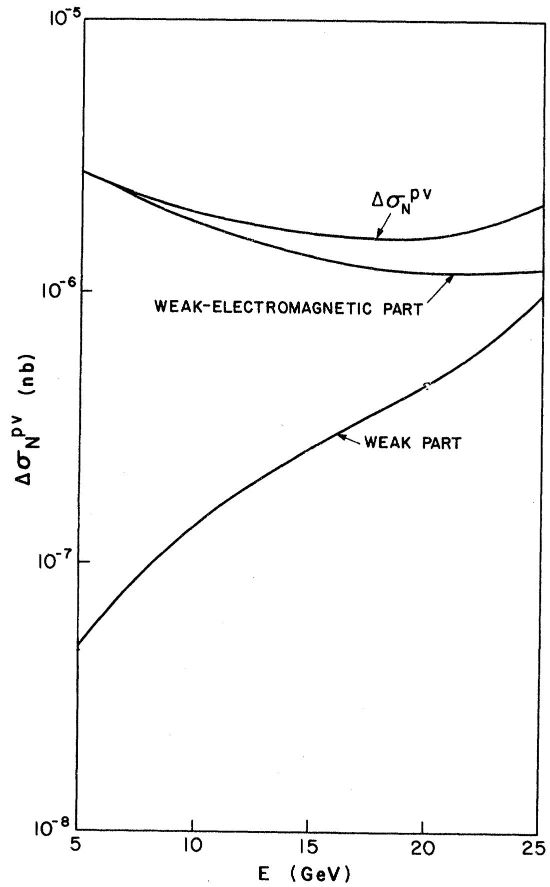

FIG. 4. $\Delta\sigma_N^{pv}$ and its two contributions.

$$\sigma_S^s = \sigma_N^s, \quad \sigma_S^{ca} = \sigma_N^{ca} = 0, \quad \Delta\sigma_S^{pv} = -\Delta\sigma_N^{pv} .$$

Thus

$$A_{c1} = \frac{\sigma_{+-}^{ca}}{\sigma_{+-}^s}, \quad A_{c2} = \frac{\sigma_+^{ca}}{\sigma_+^s}, \quad A_p = \frac{\Delta\sigma_N^{pv}}{\sigma_N^s} . \tag{22}$$

In order to obtain a numerical estimate we will use[4]

$$g_v = -(G/2\sqrt{2})^{1/2} M_Z (1 - 4\sin^2\theta_W),$$

$$g_a = -(G/2\sqrt{2})^{1/2} M_Z ,$$

$$g_V = -(8G/\sqrt{2})^{1/2} M_Z \sin^2\theta_W ,$$

$$g_A = -(\sqrt{2}G)^{1/2} M_Z ,$$

$\sin^2\theta_W = 0.35$, $M_Z = 75$ GeV, as well as simplified models for the form factors F_{1-4}. Saturating L_μ and V_μ with the ω resonance coupled to one pion and a ρ meson in all possible ways we get

$$F_1 = F_2 = \frac{2m_\omega^2 g_{\rho\omega\pi}}{s - m_\omega^2 - i\Gamma_\omega m_\omega} \{[(p_+ + p_-)^2 - m_\rho^2 - i\Gamma_\rho m_\rho]^{-1} + [(p_+ + p_0)^2 - m_\rho^2 - i\Gamma_\rho m_\rho]^{-1} + [(p_0 + p_-)^2 - m_\rho^2 - i\Gamma_\rho m_\rho]^{-1}\} , \tag{23}$$

where $g_{\rho\omega\pi} = 29$ GeV^{-1}, as obtained from a fit to the ω width. Assuming that the axial current couples to the three-pion state through the f resonance ($Z \to \pi^0 + f$, $f \to \pi^+\pi^-$) we get the expressions for F_3 and F_4

$$F_3 = \frac{g_{f\pi\pi}(p_+ - p_-)^2 p_0(p_+ + p_-)}{3m_f^3[(p_+ + p_-)^2 - m_f^2 - i\Gamma_f m_f]} , \tag{24}$$

$$F_4 = \frac{g_{f\pi\pi} p_0(p_+ - p_-)}{m_f[(p_+ + p_-)^2 - m_f^2 - i\Gamma_f m_f]} , \tag{25}$$

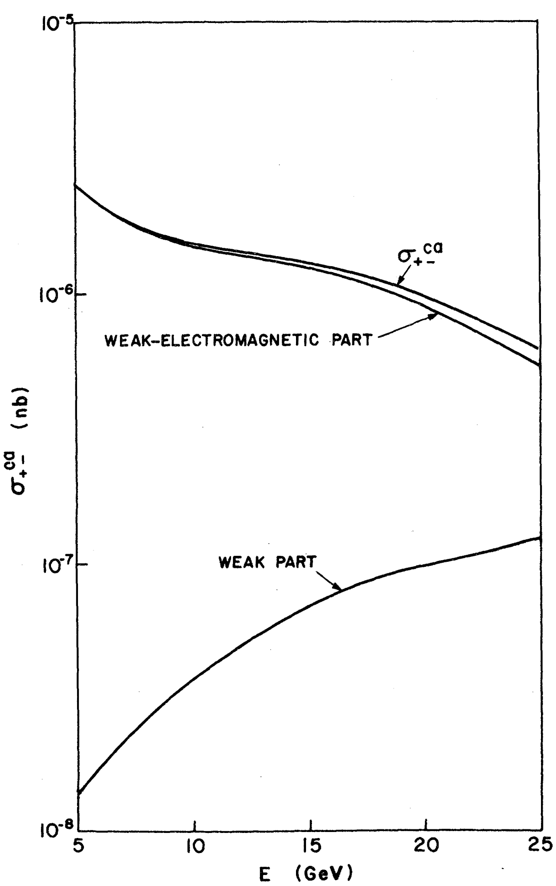

FIG. 5. σ_{+-}^{ca} and its two contributions.

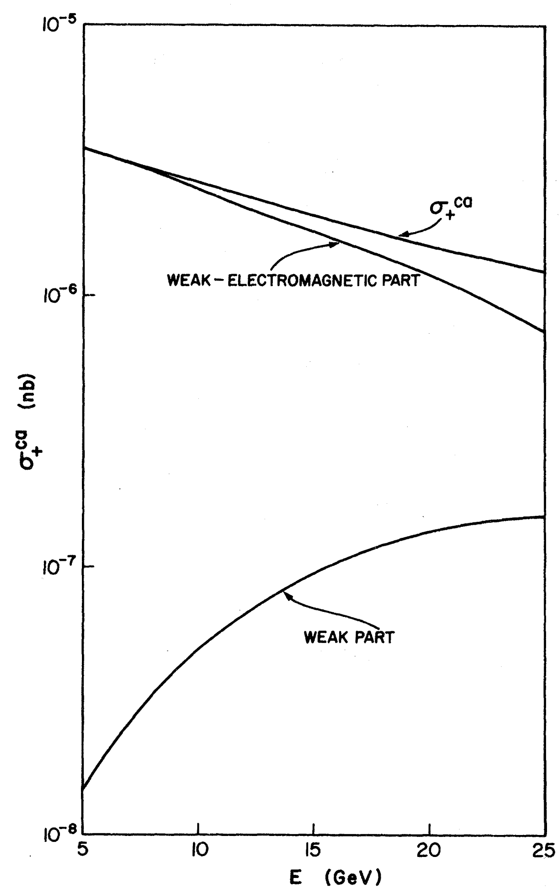

FIG. 6. σ_+^{ca} and its two contributions.

where $g_{f\pi\pi}=6.9$ fits the f width. To obtain expressions (24) and (25) we have used for the f propagator

$$\frac{\frac{1}{2}(\hat{P}_{\mu\rho}\hat{P}_{\nu\sigma}+\hat{P}_{\mu\sigma}\hat{P}_{\nu\rho})-\frac{1}{3}\hat{P}_{\mu\nu}\hat{P}_{\rho\sigma}}{(p_+ + p_-)^2 - m_f^2 - i\Gamma_f m_f} \tag{26}$$

with $\hat{P}_{\mu\nu}=-g_{\mu\nu}$ instead of

$$\hat{P}_{\mu\nu}=-g_{\mu\nu}+(p_+ + p_-)_\mu (p_+ + p_-)_\nu / m_f^2 . \tag{27}$$

This step has been taken in order to attenuate the quick rise with the energy which F_3 and F_4 show if we use the full spin-2 propagator. Since after this improvement F_3 and F_4 still rise too quickly, we have made a second modification to these form factors which consists in multiplying expressions (24) and (25) by a factor m_f^2/s. Without these changes the weak amplitudes rise too quickly.

A numerical integration with the Monte Carlo method produces the results shown in Figs. 1 to 7. We have used, for concreteness, $\cos\theta_0 = 0.65$ and restricted the energy variables in such a way that the minimum momentum of each charged pion is 0.2 GeV/c. These cutoffs correspond to present SPEAR experimental conditions. As we can see from Fig. 7 A_p, A_{c1}, and A_{c2} reach their maximum, 3–4%, at beam energies around 20 GeV, that is, at energies available with next-generation machines.

The question now arises whether the detection of the asymmetry parameters $A_{c1,2}$ is an unambiguous signal of the axial coupling of the neutral current to both leptons and hadrons. To be sure, the interference of the annihilation via one and two photons gives rise also to $A_{c1,2}$ due to the opposite charge-conjugation properties of the one- and two-photon states.[9] The two-photon state contains certainly a piece with the quantum numbers $I^G(J^P)C = 1^-(1^+)+$ which characterize the hadronic axial neutral current. In the leptonic process $e^+e^- \to \mu^+\mu^-$ the electromagnetic asymmetry can be computed accurately and has been done so[1] for beam energies < 5 GeV with the result that it is of the same order of magnitude as the weak charge asymmetry. Brown and Mikaelian[10] have computed in a model-independent way the infrared contributions to the electromagnetic asymmetry for the process $e^+e^- \to \pi^+\pi^-$. It is plausible that their method can be applied also to the case $e^+e^- \to \pi^+\pi^-\pi^0$. This problem is under study and the results will be published elsewhere. However, we expect the energy dependence of the two-photon process to

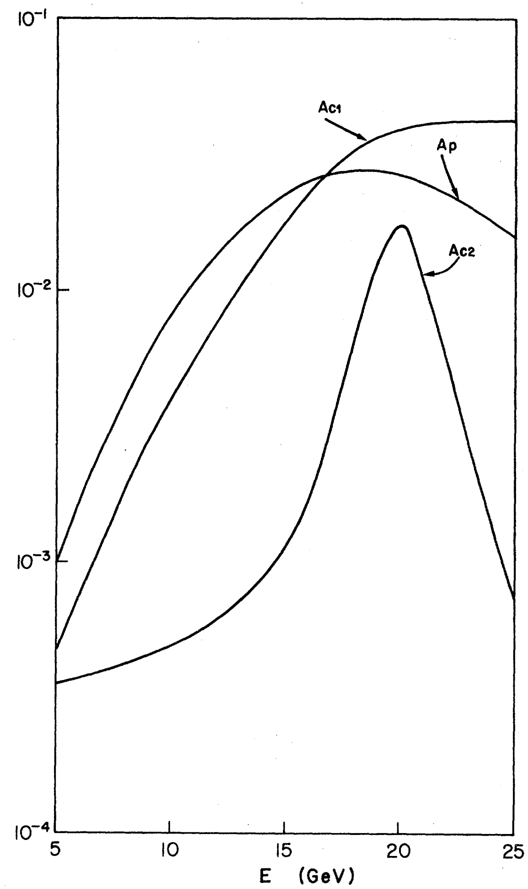

FIG. 7. The asymmetry parameters A_{c1}, A_{c2}, and A_p.

be quite different from that of the Z process.[11]

After this work was completed we became aware of a paper[12] which partially overlaps ours. The authors of Ref. 12 saturate the $Z - \pi^+\pi^-\pi^0$ vertex with the A_1 meson and study only one asymmetry parameter at energies around the A_1 mass.

This work was motivated by discussions with Professor M. A. B. Bég. We appreciate his continuous interest as well as the clarification of several points. We acknowledge an enlightening discussion with Professor J. Tran Thanh Van and with Professor S. Berman. One of us (E.C.T.) would like to thank the Rockefeller University for the hospitality extended to him. (A.Z.) would like to express his appreciation to the Aspen Center for Physics where a preliminary version of this work was finished.

*Work partially supported by the NSF United States-Latin American exchange program and by CONACyT (México) under Contract No. 540 (participating institutions: Centro de Investigación del IPN, México; Rockefeller University and Stevens Institute of Technology, U. S. A.).

[1]R. W. Brown, V. K. Cung, K. O. Mikaelian, and E. A. Paschos, Phys. Lett. 43B, 403 (1974) and references

therein; D. A. Dicus, Phys. Rev. D 8, 890 (1973); 10, 1699 (1974); E. M. Lipmanov and N. V. Mikheev, Yad. Fiz. 18, 386 (1973) [Sov. J. Nucl. Phys. 18, 199 (1974)].

[2]M.-S. Chen and Y.-P. Yao, Phys. Rev. Lett. 34, 628 (1975); E. Lendvai and G. Pocsik, Phys. Lett. 56B, 462 (1975); M. A. B. Bég and G. Feinberg, Phys. Rev. Lett. 33, 606 (1974); G. V. Dass and G. C. Ross, Phys. Lett. 57B, 173 (1975); R. Budny, *ibid.* 45B, 340 (1973); R. Budny and A. McDonald, *ibid.* 48B, 423 (1974); A. McDonald, Nucl. Phys. B75, 343 (1974); J. Godine and A. Hankey, Phys. Rev. D 6, 3301 (1972); R. Budny, Phys. Lett. 55B, 227 (1975); K. O. Mikaelian, *ibid.* 55B, 219 (1975).

[3]For a recent review see M. A. B. Bég and A. Sirlin, Annu. Rev. Nucl. Sci. 24, 379 (1974).

[4]S. Weinberg, Phys. Rev. D 5, 1412 (1972); J. Iliopoulos and Ph. Meyer, Phys. Lett. 38B, 519 (1972).

[5]M. A. B. Bég and A. Zee, Phys. Rev. Lett. 30, 675 (1973).

[6]A. Pais and S. B. Treiman, Phys. Lett. 29B, 308 (1969); G. Putzolu, Nuovo Cimento 20, 542 (1961).

[7]O. P. Sushkov, V. V. Flambaum, and I. B. Khriplovich, Yad. Fiz. 20, 1016 (1974) [Sov. J. Nucl. Phys. 20, 537 (1975)]

[8]A. Pais and S. B. Treiman, Phys. Rev. D 9, 1459 (1974).

[9]R. Gatto, in *Proceedings of the International Symposium on Electron and Photon Interactions at High Energies, Hamburg* 1965 (Springer, Berlin, 1965).

[10]R. W. Brown and K. O. Mikaelian, Lett. Nuovo Cimento 7, 305 (1974).

[11]G. T. Bodwin and C. D. Stockham, Phys. Rev. D 11, 3324 (1975).

[12]R. S. Patil, S. H. Patil, and S. D. Rindani, Phys. Rev. D 10, 3070 (1973). We thank Dr. M. A. Pérez for calling our attention to this paper.