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Neutral Vector Meson Production From Electron Positron Colliding-Beam as A Test of C-noninvariance in Electromagnetic Interaction*

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Abstract

The production of a pair of identical neutral vector mesons from a colliding electron-positron beam is studied. Both processes from C-non-invariant and C-noninvariant interactions (i.e. 1γ and 2γ intermediate states) are considered and differential and total cross-sections are calculated. The correlation of the decay products from the vector mesons is also calculated for the C-noninvariant process.

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I. Introduction

The question of whether C-parity is conserved in electromagnetic interactions has been considered by Bernstein, Feinberg, Lee and Christ[1] in conjunction with the CP-noninvariant decay of the K_2^0 and the G- non-invariant decay of the η-meson. Berestetsky[2] proposed the production of a pair of identical neutral vector mesons from an electron-positron collision as a test of C-noninvariance in electromagnetic interactions. He calculated the angular distribution as well as the total cross-section to the lowest order in $\alpha = 1/137$.

All neutral vector particles which have been found are extremely shortlived and decay into other particles. The mesons which can be comparatively easily detected and analyzed by experiments are the ρ^0 which decays into a π^+, π^- with a branching ratio of nearly 1 and the ϕ^0 which decays into a K^+, K^- with a branching ratio of about 38%[3]. In the present article, the decay correlations of the charged pions and kaons corresponding to Fig. 1 are calculated. These will be discussed in Section II. The vector mesons can also be produced from C-invariant two-photons exchange diagrams as shown in Fig. 2. The angular distributions of the ρ^0 and ϕ^0 and the total cross-section corresponding to this diagram are calculated. They will be presented in Section III.

II. The C-noninvariant Neutral Vector Meson Production

The neutral vector mesons may interact with photons indirectly through other fields or they may directly couple to the photon. The Lagrangian density for direct coupling may be written

$$L = g\, A_\mu\, J_\mu$$
$$J_\mu = \partial_\lambda\, \partial_\lambda\, (\phi_\nu\, \partial_\nu\, \phi_\mu) - 2\, \partial_\lambda\, \partial_\nu\, (\phi_\nu\, \partial_\mu\, \phi_\lambda) \tag{1}$$

The neutral vector field ϕ_λ satisfies the subsidiary condition $\partial_\lambda\, \phi_\lambda = 0$. It can be easily verified that the current J_μ is conserved, $\partial_\mu\, J_\mu = 0$, and therefore, the interaction is gauge invariant. A_μ is odd under charge conjugation transformation C, while J_μ is always even under C regardless of the C-parity of ϕ. Hence L is odd under C, i.e. C-noninvariant. One notes that the interaction (1) is not of the form of a "minimal" electromagnetic interaction.

Consider the matrix element $\langle k_1, \varepsilon_1, k_2, \varepsilon_2\, |J_\mu|\, 0\rangle$ of the Heisenberg operator J_μ between the vacuum and two identical real neutral vector mesons of four momenta k_1, k_2 and four polarization vectors ε_1, ε_2. From invariance argument the most general parity-conserved vector current constructed from k_1, k_2, ε_1, ε_2 which is conserved and symmetrical with respect to the interchange of the two meson variables can be shown to be.

$$\langle k_1, \varepsilon_1, k_2, \varepsilon_2\, |J_\mu|\, 0\rangle =$$
$$= f(q^2)\, (\varepsilon_1 \cdot q\, \varepsilon_{2\mu} + \varepsilon_2 \cdot q\, \varepsilon_{1\mu}) - 2\, f(q^2)\, \varepsilon_1 \cdot q\, \varepsilon_2 \cdot q\, q_\mu \tag{2}$$

where $f(q^2)$ is a scalar form factor of the invariant $q^2 \equiv (k_1 + k_2)_\mu (k_1 + k_2)_\mu$, which is just the square of the total energy of the colliding electron-positron pair in the C. M. system. It is to be noted that the current J_μ in Eq. (1) produces the same expression of the matrix element (2) in the lowest order perturbation theory except the form factor $f(q^2)$. The production amplitude corresponding to Figure 1 is

$$M^{s_-s_+}(\varepsilon_1,\varepsilon_2)(2\pi)^4\delta^4(p_-+p_+-k_1-k_2),$$

$$M^{s_-s_+}(\varepsilon_1,\varepsilon_2) = -ef\bar{v}^{s_+}(p_+)(\varepsilon_1\cdot q\not\varepsilon_2+\varepsilon_2\cdot q\not\varepsilon_1)u^{s_-}(p_-) \tag{3}$$

Note that the second term in (2) does not contribute because of the conserved electron current.

The decay correlation is treated in the way of Gottfried and Jackson[4], and the helicity states of Jacob and Wick[5] are used. The helicity states are constructed as follows: For the 1st meson, take a set of right-handed local axes so that the 3rd axis is parallel to the space momentum vector k_1 of the meson, and the 1st axis parallel to $p_1 \times k_1$. Let $\varepsilon_1^{(0)}$, $\varepsilon_1^{(1)}$, $\varepsilon_1^{(2)}$, $\varepsilon_1^{(3)}$ be the four unit vectors along the time axis and along this local space coordinate system. The meson with helicities $\lambda_1 = \pm1,0$ are described by the polarization vectors

$$\varepsilon_{\lambda_1} = (1/\sqrt{2})\left(\varepsilon_1^{(1)}\pm i\varepsilon_1^{(2)}\right), \text{ for } \lambda_1 = \pm1$$

$$\varepsilon_{\lambda_1} = \frac{k_1}{m_\rho}\varepsilon_1^{(0)}+\frac{\omega_1}{m_\rho}\varepsilon_1^{(3)}, \text{ for } \lambda_1 = 0 \tag{4}$$

where m_ρ is the mass of the vector meson. Helicity states of the 2nd meson are constructed similarly. The production amplitude $M^{s_-s_+}$ with helicity λ_1 for the first meson and helicity λ_2 for the second meson is then obtained by putting $\varepsilon_1 = \varepsilon_{\lambda_1}$, $\varepsilon_2 = \varepsilon_{\lambda_2}$ into (3):

$$M^{s_-s_+}_{\lambda_1\lambda_2} = M^{s_-s_+}(\varepsilon_{\lambda_1}, \varepsilon_{\lambda_2}) \tag{5}$$

For definiteness, we first discuss ρ^0 pair production. The amplitude for decay of the two ρ^0's with helicities λ_1 and λ_2 into charged pions has the form

$$A_{\lambda_1}(\tilde{\Omega}_{1+})A_{\lambda_2}(\tilde{\Omega}_{2+}) = \frac{3}{4\pi} d^1_{\lambda_1 0}(\tilde{\theta}_{1+})e^{i\lambda_1\tilde{\phi}_{1+}} d^1_{\lambda_2 0}(\tilde{\theta}_{2+})e^{i\lambda_2\tilde{\phi}_{2+}}$$

where $d^1_{\lambda 0}$ is defined in Ref. 5, and $\tilde{\theta}_{1+}$, $\tilde{\phi}_{1+}$, $\tilde{\theta}_{2+}$, $\tilde{\phi}_{2+}$ are polar angles of the π^+'s which are defined in the appendix. The overall production amplitude of the pions from definite initial spins s_-, s_+ is

$$T^{s_-s_+} = \sum_{\lambda_1 = 0,\pm 1}\ \sum_{\lambda_2 = 0,\pm 1} M^{s_-s_+}_{\lambda_1\lambda_2} A_{\lambda_1}(\tilde{\Omega}_{1+})A_{\lambda_2}(\tilde{\Omega}_{2+}) \cdot (2\pi)^4\delta^4(p_+ + p_- - k_1 - k_2) \qquad (6)$$

and the production probability per unit space-time, after averaging the initial spins, is

$$W = \frac{1}{4}\sum_{s_-,s_+} |T^{s_-s_+}|^2 / \int d^4x$$

$$= \sum_{\lambda_1,\lambda_2} \rho_{\lambda_1\lambda_2\lambda_1'\lambda_2'} A_{\lambda_1}(\tilde{\Omega}_{1+})A_{\lambda_2}(\tilde{\Omega}_{2+})A_{\lambda_1'}(\tilde{\Omega}_{1+})A_{\lambda_2'}(\tilde{\Omega}_{2+}) \cdot (2\pi)^4\delta^4(p_- + p_+ - k_1 - k_2) \qquad (7)$$

where ρ is the density matrix

$$\rho_{\lambda_1\lambda_2\lambda_1'\lambda_2'} = \frac{1}{4}\sum_{s_-s_+} M^{s_-s_+}_{\lambda_1\lambda_2}(M^{s_-s_+}_{\lambda_1'\lambda_2'})^*$$

$$= \frac{e^2f^2}{4} \mathrm{Tr}\Big[\frac{\not{p}_+ - m}{2m}(\varepsilon_{\lambda_1}\cdot q\not{\varepsilon}_{\lambda_2} + \varepsilon_{\lambda_2}\cdot q\not{\varepsilon}_{\lambda_1}) \cdot$$

$$\cdot \frac{\not{p}_- + m}{2m}(\varepsilon^*_{\lambda_1'}\cdot q\not{\varepsilon}^*_{\lambda_2'} + \varepsilon^*_{\lambda_2'}\cdot q\not{\varepsilon}^*_{\lambda_1'})\Big], \quad \not{\varepsilon} = \varepsilon_\mu\gamma_\mu, \quad \not{\varepsilon}^* = \varepsilon^*_\mu\gamma_\mu$$

and obeys the symmetry relations

$$\rho_{abcd} = (\rho_{cdab})^* = (-1)^{a+b-c-d}\rho_{-a,-b,-c,-d},$$

$$\rho_{abcd}(\theta_1,\theta_2) = \rho_{badc}(\theta_2,\theta_1) \tag{9}$$

The differential cross-section for observing the 1st ρ^0 within $d\Omega_1$, the π_1^+ within $d\tilde{\Omega}_{1+}$ and the π_2^+ within $d\tilde{\Omega}_{2+}$ is, in the C. M. frame,

$$d\sigma = d\tilde{\Omega}_{1+}d\tilde{\Omega}_{2+}\frac{1}{|\underset{\sim}{v}_+-\underset{\sim}{v}_-|}\ \frac{m^2}{E_+E_-}\int W\frac{d^3k_1}{2\omega_1(2\pi)^3}\ \frac{d^3k_2}{2\omega_2(2\pi)^3}\cdot S$$

$$= \frac{m^2k}{128\pi^2E^3}\sum_{\lambda_1\lambda_2\lambda_1'\lambda_2'}\rho_{\lambda_1\lambda_2\lambda_1'\lambda_2'}A_{\lambda_1}(\tilde{\Omega}_{1+})A_{\lambda_2}(\tilde{\Omega}_{2+})\cdot \tag{10}$$

$$\cdot A_{\lambda_1'}(\tilde{\Omega}_{1+})A_{\lambda_2'}(\tilde{\Omega}_{2+})d\Omega_1 d\tilde{\Omega}_{1+}d\tilde{\Omega}_{2+}$$

with $S = \frac{1}{2!}$ being the statistics factor due to the presence of two identical final bosons.

Putting (4) into (9), it is found by directly evaluating the traces and neglecting m in the numerators that

$$\rho_{0101} = \frac{e^2f^2}{4m^2}\frac{k^2q_0^2E^2}{m_\rho^2}(1+\cos^2\theta_1)$$

$$\rho_{010-1} = \rho_{100-1} = -\rho_{1001} = -\frac{e^2f^2}{4m^2}\frac{k^2q_0^2E^2}{m_\rho^2}\sin^2\theta_1 \tag{11}$$

All other terms not given by the symmetry relations (9) are zero. The differential cross-section (10) becomes by means of (11),

$$d\sigma = (9/8)(4\pi)^{-2}\alpha f^2 \underset{\sim}{k}^3 E m_\rho^{-6} G d\Omega_1 d\tilde{\Omega}_{1+} d\tilde{\Omega}_{2+},$$

$$G = 2(\sin^2\tilde{\theta}_{1+}\cos^2\tilde{\theta}_{2+} + \sin\tilde{\theta}_{2+}\cos^2\tilde{\theta}_{1+})\cos^2\theta_1 \qquad (12)$$

$$+2\sin^2\theta_1(\sin\tilde{\theta}_{1+}\cos\tilde{\theta}_{2+}\sin\tilde{\phi}_{1+} + \cos\tilde{\theta}_{1+}\sin\tilde{\theta}_{2+}\sin\tilde{\phi}_{2+})^2; \quad \alpha = 1/137$$

Integration of (12) gives the differential and total cross-section of ρ^0 pair production

$$d\sigma = e^2 f^2 \underset{\sim}{k}^3 E(32\pi^2 m_\rho^2)^{-1}(1+\cos^2\theta_1)d\Omega_1,$$

$$\sigma = (2/3)\alpha f^2 m_\rho^{-2} \underset{\sim}{k}^3 E \qquad (13)$$

The differential and total cross-sections in (13) have been checked separately by invariant summation of the polarization states of the ρ^0-mesons without evaluating the density matrix in the way to be described in the following section.

If ϕ^0 pair production and the K^+K^- decay mode is observed, $\underset{\sim}{k}$ and m_ρ in (12) and (13) shall be the corresponding value for the ϕ^0-meson, $f(q^2)$ shall be the form factor of the ϕ^0-meson, and the branching ratio $(\phi^0 \to K^+ + K^-)/(\phi^0 \to \text{all})$ should be multiplied to the right side of (12) and (13).

IV. The C-invariant Process

The neutral vector meson production can occur through the C-invariant process such as shown in Fig. 2. The matrix element corresponding to Fig. 2 and its exchange diagram is

$$M_{\nu\mu} = e^2 \bar{v}(p_+)\gamma_\mu \frac{\not{p}_- - \not{k}_1 + m}{(p_- - k_1)^2 - m^2}\gamma_\nu u(p_-)\frac{\gamma_{\rho\gamma}^2}{k_1^2 k_2^2} + (k_1 \leftrightarrow k_2) \qquad (14)$$

In the above expression, $\nu, \mu (= 0,1,2,3)$ are the invariant polarization indices of the mesons with momenta k_1, k_2 respectively, and $\gamma_{\rho\gamma}$ the two-particle coupling constant between ρ^0-meson and photon which has been shown by Gell-Mann and Zachariasen[6] and Dashen and Sharp[7] to be related to the $\rho\pi\pi$ coupling constant γ_ρ by

$$\gamma_{\rho\gamma} = em_\rho^2(2\gamma_\rho)^{-1} \tag{15}$$

In calculating the cross-section, the summation over the meson polarization states is given by the invariant summation:

$$\sum_{\text{pol.}} |M_{\nu\mu}|^2 = M_{\nu\mu} M^*_{\nu'\mu'} \left(\frac{k_{1\nu}k_{1\nu'}}{m_\rho^2} - g_{\nu\nu'}\right) \cdot \left(\frac{k_{2\mu}k_{2\mu'}}{m_\rho^2} - g_{\mu\mu'}\right) \tag{16}$$

Averaging over the initial electron positron spins gives,

$$\frac{1}{4} \sum_{\text{spin}} \sum_{\text{pol.}} |M_{\nu\mu}|^2 =$$

$$= \frac{1}{16m}\left(\frac{e\gamma_{\rho\gamma}}{m_\rho^2}\right)^2 \mathrm{Tr}\left[\not{p}_+\left(\gamma_\mu \frac{\not{p}_- - \not{k}_1}{x_1}\gamma_\nu + \gamma_\nu \frac{\not{p}_- - \not{k}_2}{x_2}\gamma_\mu\right) \cdot \right.$$

$$\left. \cdot \not{p}_-\left(\gamma_{\nu'} \frac{\not{p}_- - \not{k}_1}{x_1}\gamma_{\mu'} + \gamma_{\mu'} \frac{\not{p}_- - \not{k}_2}{x_2}\gamma_{\nu'}\right)\right] \cdot \tag{17}$$

$$\cdot \left(\frac{k_{1\nu}k_{1\nu'}}{m_\rho^2} - g_{\nu\nu'}\right)\left(\frac{k_{2\mu}k_{2\mu'}}{m_\rho^2} - g_{\mu\mu'}\right)$$

$$\equiv \frac{1}{4m^2}\left(\frac{e\gamma_{\rho\gamma}}{m_\rho^2}\right)^4 \left(\frac{A_1}{x_1^2} + \frac{A_{12}}{x_1 x_2} + \frac{A_2}{x_2^2}\right)$$

where $x_1 = (p_- - k_1)^2$, $x_2 = (p_- - k_2)^2$ and the electron mass m has been neglected, except the factor $1/4m^2$.

The traces in (17) are evaluated directly, and for the convenience of doing angular integrations, they are expressed in terms of x_1, x_2:

$$A_i = 2m_\rho^2+4(E^2+\underset{\sim}{k}^2)x_i+(5/2-8E^2m_\rho^{-2})x_i^2$$

$$+(E^2+\underset{\sim}{k}^2)m_\rho^{-2}x_i^3+(2m_\rho^4)^{-1}x_i^4, \quad i = 1,2, \tag{18}$$

$$A_{12} = 48m_\rho^2E^2+64m_\rho^{-2}E^4\underset{\sim}{k}^2-4E^2\underset{\sim}{k}^2m_\rho^{-4}\sin^2\theta_1 x_1 x_2$$

The total cross section is

$$\sigma = \frac{1}{|\underset{\sim}{v}_+-\underset{\sim}{v}_-|}\frac{m^2}{E_+E_-}(2\pi)^4 S\cdot$$

$$\cdot\int\frac{1}{4}\sum_{\text{spin}}\sum_{\text{pol.}}|M_{\nu\mu}|^2\delta^4(p_++p_--k_1-k_2)\frac{d^3\underset{\sim}{k}_1}{2\omega_1(2\pi)^3}\frac{d^3\underset{\sim}{k}_2}{2\omega_2(2\pi)^3} \tag{19}$$

$$= (1/288)\pi\alpha^4\mu^4(1-4\mu^2)(1-\mu^2)^2\cdot$$

$$\cdot[2\beta+2\beta^3+(4-\beta^2+2\beta^4-\beta^6)(1+\beta^2)^{-1}\cdot\ln\{(1+\beta)(1-\beta)^{-1}\}]\Gamma^{-2}$$

where $\mu = m_\pi/m_\rho$, $\beta = k/E$, Γ = decay width of $\rho\to\pi^++\pi^-$. In the above expression, we have related γ_ρ to the decay width Γ by

$$\Gamma = (12\pi)^{-1}\gamma_\rho^2\mu^2(1-4\mu^2)^{\frac{1}{2}}(1-\mu^2)m_\rho \tag{20}$$

The angular distribution of ρ^0's is given by (17) and is energy-dependent and more complicated than in (13). Near the threshold the ρ^0's are isotropic, while in the very high energy region, they tend to peak in both forward and backward directions.

For the production of ϕ^0-meson pairs, and the observation of the K^+K^- decay mode, in Eq. (19), $\mu = m_K/m_\phi$, k = magnitude of ϕ^0-meson space momentum, and Γ = decay width of $\phi^0 \to K^+ + K^-$.

IV. Discussion

Except for the unknown form factor $f(q^2)$, the C-noninvariant total cross-section (13) increases rapidly with the energy, while the C-invariant total cross-section (19) increases very slowly with respect to energy. Thus, it seems that high energy beams favor the detection of C-noninvariant process. If only one of the diagrams Fig. 1 and Fig. 2 dominates, they can be distinguished by looking at the angular distribution of ρ^0(orϕ^0)-mesons. The interference term between Fig. 1 and Fig. 2 does not contribute, because the electron positron states in Fig. 1 always have charge parity -1, while those in Fig. 2 have charge parity +1, therefore, the products of these two amplitudes are always zero.

Some numerical values of the total cross-section for different total energies are given in Table I. For the C-noninvariant processes, we write $[f(q^2)]^2 (4\pi)^{-1} = \alpha\epsilon_\rho(q^2)\, m_\rho^{-4}$ for the $\rho\rho\gamma$-vertex and $\alpha\epsilon_\phi(q^2) m_\phi^{-4}$ for the $\phi\phi\gamma$-vertex, where α is the fine struction constant, $\epsilon(q^2)$ is dimensionless, and may be arbitrarily defined as the degree of C-violation. In Table I, the ratio $\sigma_{1\gamma}/\sigma_{2\gamma}$ are calculated for $\epsilon = 10^{-4}$. For other values of ϵ, the numerical numbers should be multiplied by $10^4\epsilon$. The following experimental numbers have been used in this calculation: m_ρ = 765 mev, m_ϕ = 1020 mev, $\Gamma(\rho^0 \to \pi^+ + \pi^-)$ = 124 mev, $\Gamma(\phi^0 \to K^+ + K^-)$ = 3.3 x 30% = 1 mev[3]. The smallness of the ratio $\sigma_{2\gamma}(e^{+}+e^{-}\rightarrow 2\rho^{0})/\sigma_{2\gamma}(e^{+}+e^{-}\rightarrow 2\phi^{0})$ is due to the big difference in the experimental values of $\Gamma(\rho^{0}\rightarrow\pi^{+}\pi^{-})$ and $\Gamma(\phi^{0}\rightarrow K^{+}+K^{-})$.

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Appendix, Glossary of Symbols

p_+, p_-, k_1, k_2,	four momenta of the positron, electron, 1st and 2nd vector mesons respectively.
$q = k_1 + k_2$, $q_0 = \omega_1 + \omega_2$	
ω_1, ω_2, $\mathbf{k}_1$, $\mathbf{k}_2$	energies and space momenta of these mesons
$k_1 = \lvert\mathbf{k}_1\rvert$, $k_2 = \lvert\mathbf{k}_2\rvert$	
E_+, E_-, $\mathbf{p}_+$, $\mathbf{p}_-$, $\mathbf{v}_+$, $\mathbf{v}_-$	energies, momenta and velocities of the positron and electron.
$E_+ = E_- = \omega_1 = \omega_2 = E$, $k_1 = k_2 = k$ in C. M. frame	
Ω_1	solid angle of first meson
θ_i	angle between $\mathbf{k}_i$ and $\mathbf{p}_-$, $i = 1, 2$
π_1^+, π_2^+	the positive pions decay products from the 1st and 2nd mesons respectively.
s_+, s_-	spin of the positron and electron respectively.
ε_1, ε_2	four polarization vectors of the 1st and 2nd mesons, $\varepsilon_{1\mu}\,\varepsilon_{1\mu} = \varepsilon_{2\mu}\,\varepsilon_{2\mu} = -1$
λ_1, λ_2 $(=0, \pm 1)$	helicities of the 1st and 2nd mesons.

$m, m_\pi, m_k, m_\rho, m_\phi$	masses of electron, pion, kaon, ρ^0--meson and ϕ^0-meson.
$\varepsilon_i^{(0)}, \varepsilon_i^{(1)}, \varepsilon_i^{(2)}, \varepsilon_i^{(3)}$	four mutually orthogonal unit vectors along the time and space ases with $\underset{\sim}{\varepsilon}_i^{(3)} \| \underset{\sim}{k}_i$, $\underset{\sim}{\varepsilon}_i^{(1)} \| \underset{\sim}{p}_- \times \underset{\sim}{k}_i$, and $\underset{\sim}{\varepsilon}_i^{(1)}$, $\underset{\sim}{\varepsilon}_i^{(2)}$, $\underset{\sim}{\varepsilon}_i^{(3)}$ form a right handed system, $i = 1, 2$.
$\tilde{\Omega}_{i+} = (\tilde{\theta}_{i+}, \tilde{\phi}_{i+})$	the polar angles of the π_i^+ in the rest frame of the ith-mesons with the polar axis parallel to $\underset{\sim}{\varepsilon}_i^{(3)}$ and the first axis parallel to $\underset{\sim}{\varepsilon}_i^{(1)}$.

2E(total C. M. energy) (Bev)	3	6	10	15	20
$10^{38} \times \sigma_{2\gamma}(e^+ + e^- \to 2\rho^0)$ (cm^2)	.65	.87	1.03	1.14	1.22
$10^{35} \times \sigma_{2\gamma}(e^+ + e^- \to 2\phi^0 \to 2K^+ + 2K^-)$ (cm^2)	3	4.1	5.2	5.6	6.1
$\dfrac{10^{-5}\sigma_{1\gamma}(e^+ + e^- \to 2\rho^0)}{\sigma_{2\gamma}(e^+ + e^- \to 2\rho^0)}$	.48	7.3	50	234	710
$\dfrac{\sigma_{1\gamma}(e^+ + e^- \to 2\phi^0 \to 2K^+ + 2K^-)}{\sigma_{2\gamma}(e^+ + e^- \to 2\phi^0 \to 2K^+ + 2K^-)}$	1	25	180	830	2500

Table I. Total cross-sections for different beam energies. The ratios $\sigma_{1\gamma}/\sigma_{2\gamma}$ are evaluated for $\varepsilon = 10^{-4}$. For other values of ε, a factor $10^4\varepsilon$ should be multiplied to the numbers.

CAPTION

Fig. 1. C-noninvariant neutral vector meson pair production.

Fig. 2 C-invariant neutral vector meson pair production.

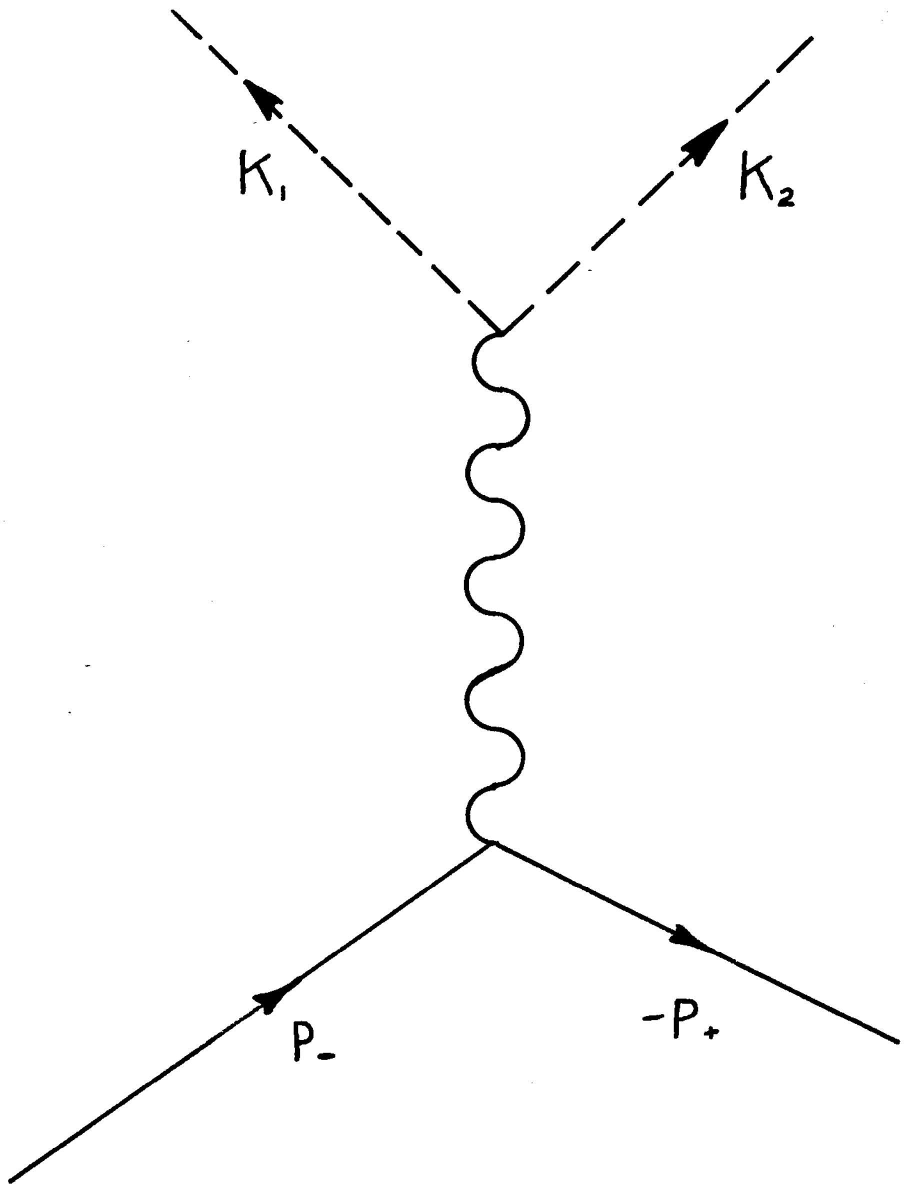

Fig. 1

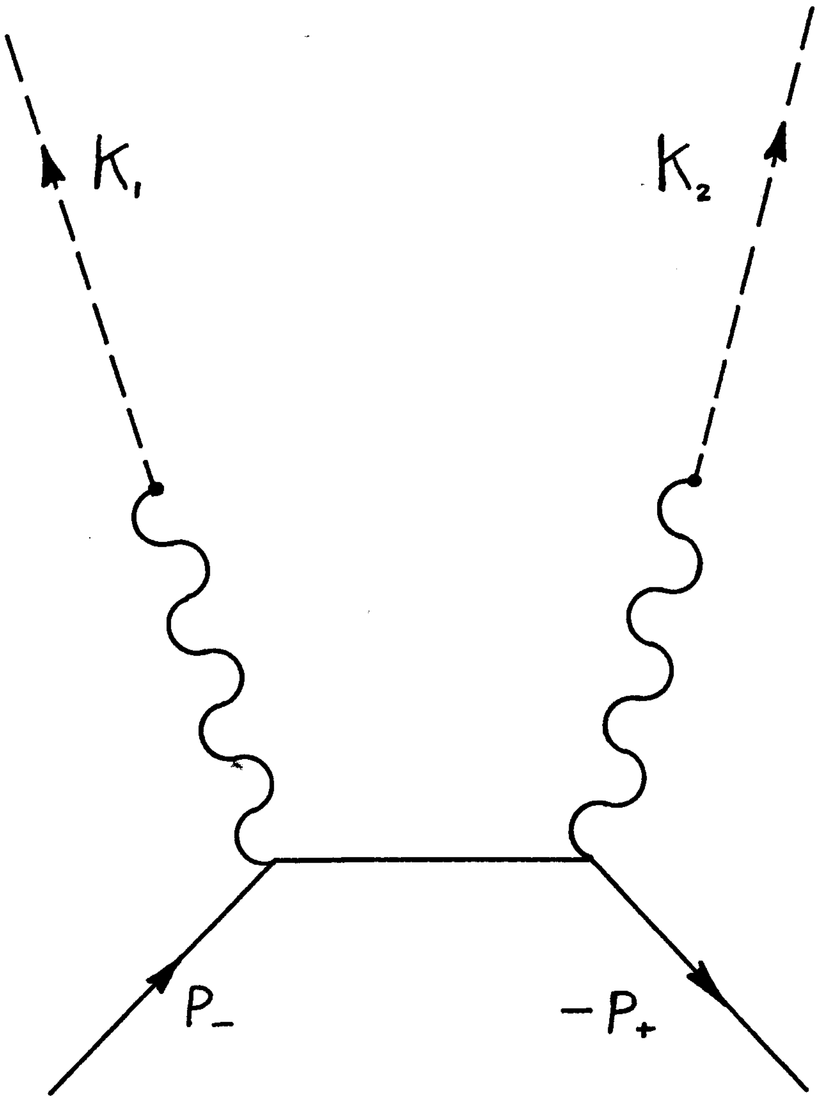

Fig. 2