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f-MESON CONTRIBUTION TO CHARGE ASYMMETRY OF π-MESONS IN THE REACTION $e^+e^- \to \pi^+\pi^-$

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The decay $f \to 2\pi^+ 2\pi^-$ proceeding via $\rho^\circ\rho^\circ$-intermediate state is considered. Using the value of the coupling constant $g_{f\rho\rho}$ thus obtained the charge asymmetry of π-mesons in the reaction $e^+e^- \to \pi^+\pi^-$ is estimated. At the total energy 2E=1.3 Gev the asymmetry may be as large as 8.1%.

The possibility of investigating with e^+e^- colliding beams the resonances with positive charge parity produced via two - photon intermediate state has been first noted in /1/. The problem of the π -meson charge asymmetry in the reaction $e^+e^- \to \pi^+\pi^-$ at the energy near the f-meson mass was considered in detail in /2/ (see also /3,4/). To estimate the value of the charge asymmetry the knowledge of the coupling constant of the f-meson with ρ -mesons $g_{f\rho\rho}$ is needed. Values of $g_{f\rho\rho}$ used in /2-4/ differ notably from each other. In this work for calculation of $g_{f\rho\rho}$ we use the assumption consistent with the experimental data /5,6/ that f-meson decays into $2\pi^+2\pi^-$ via $\rho^0\rho^0$-intermediate state. Comparing the experimental width $\Gamma_{f\to 2\pi^+2\pi^-}$ with the decay probability calculated according to the assumption above one can find $g_{f\rho\rho}$.

The vertex $f \to \rho^0\rho^0$ is written in the form

$$T_{f\to\rho\rho} = -\frac{g_{f\rho\rho}}{m_f} t_{\mu\nu} \left(F^{(1)}_{\mu\lambda} F^{(2)}_{\lambda\nu} + F^{(2)}_{\mu\lambda} F^{(1)}_{\lambda\nu} \right) \quad (1)$$

where $t_{\mu\nu}$ - symmetrical tensor describing polarisation of the f-meson with the momentum $k = k_1 + k_2$ $(k_\mu t_{\mu\nu} = 0 \ , \ t_{\mu\mu} = 0)$; $F^{(i)}_{\mu\nu} = k_{i\mu} e^{(i)}_\nu - k_{i\nu} e^{(i)}_\mu$ (i=1,2); k_1, k_2 - momenta of ρ -mesons; $e^{(1)}$, $e^{(2)}$ - polarisations of ρ -mesons; m_f - f-meson mass.

Two diagrams of Fig.1 corresponding to decays of ρ -mesons into $\pi_1^+\pi_2^-$, $\pi_3^+\pi_4^-$ and $\pi_1^+\pi_4^-$, $\pi_3^+\pi_2^-$ should be taken into account.

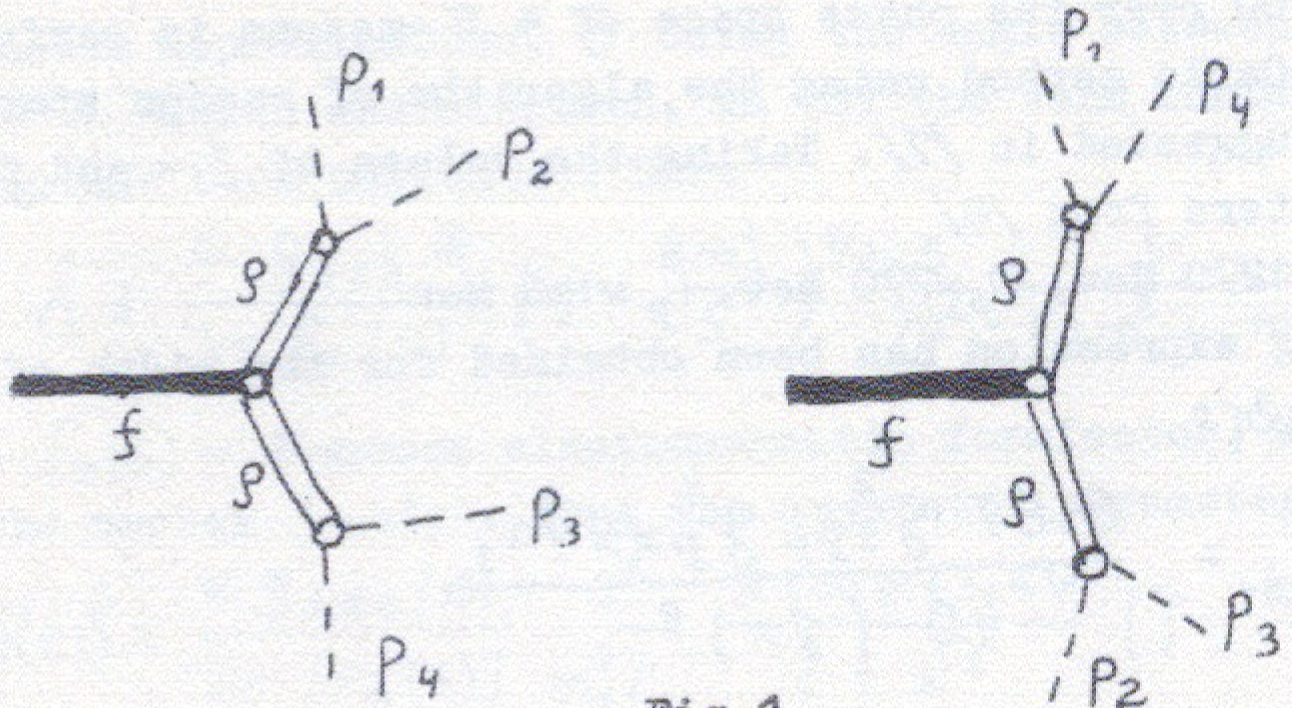

Fig.1.

After simple calculations the amplitude of the decay $f\to 2\pi^+2\pi^-$ takes the form

$$T_{f\to 4\pi} = -\frac{g_{f\rho\rho}\, g^2_{\rho\pi\pi}}{m_f}\, t_{\mu\nu}\left(R^{(1)}_{\mu\nu}+R^{(1)}_{\nu\mu}+R^{(2)}_{\mu\nu}+R^{(2)}_{\nu\mu}\right) \qquad (2)$$

where

$$R^{(1)}_{\mu\nu} = \frac{4\left[(P_2P_4)P_{1\mu}P_{3\nu}-(P_2P_3)P_{1\mu}P_{4\nu}+(P_1P_3)P_{2\mu}P_{4\nu}-(P_1P_4)P_{2\mu}P_{3\nu}\right]}{\left[m^2_\rho-(P_1+P_2)^2-im_\rho\Gamma_\rho\right]\left[m^2_\rho-(P_3+P_4)^2-im_\rho\Gamma_\rho\right]} \qquad (3)$$

Here P_i – momentum of the i-th π-meson, $R^{(2)}_{\mu\nu}$ is obtained from $R^{(1)}_{\mu\nu}$ substituting $P_2\leftrightarrow P_4$.

Averaging over f-meson polarisations the square of the amplitude is obtained:

$$\overline{|T_{f\to 4\pi}|^2} = \frac{g^2_{f\rho\rho}\, g^4_{\rho\pi\pi}}{5\, m^2_f}\left(S_{\alpha\beta}S^*_{\alpha\beta}-\frac{1}{3}S_{\alpha\alpha}S^*_{\beta\beta}\right) \qquad (4)$$

where

$$S_{\alpha\beta} = R^{(1)}_{\alpha\beta}+R^{(1)}_{\beta\alpha}+R^{(2)}_{\alpha\beta}+R^{(2)}_{\beta\alpha} \qquad (\alpha,\beta=1,2,3).$$

Integration over the phase space of 4 π-mesons is performed by the Monte-Carlo method using the algorithm of random stars generation suggested in /7/. Taking the values of f- and ρ-meson parameters from /8/

m_f =1270 Mev, m_ρ=770 Mev, Γ_ρ=146 Mev

the following expression has been obtained for the width of the decay $f\to 2\pi^+2\pi^-$:

$$\Gamma_{f\to 2\pi^+2\pi^-} = \frac{0.67\, g^2_{f\rho\rho}\, g^4_{\rho\pi\pi}\, m_f}{40\ (2\pi)^8} \qquad (5)$$

Averaging of $\Gamma_{f\to 2\pi^+2\pi^-}$ from /8/ and recent experimental data /6,9/ gives

$$\Gamma_{f\to 2\pi^+2\pi^-} = (5.5\pm 1.0)\ Mev \qquad (6)$$

From (5) and (6) $g_{f\rho\rho}$ is found:

$$g_{f\rho\rho} = 22.4 \pm 2.5 \qquad (7)$$

It is interesting to compare $g_{f\rho\rho}$ with the coupling constant of the f-meson with π-mesons $g_{f\pi\pi}$. Using the expression

$$\Gamma_{f\to 2\pi} = \frac{g^2_{f\pi\pi}\, m_f}{320\,\pi}\left(1-\frac{4m^2_\pi}{m^2_f}\right)^{5/2}$$

and the experimental value from /8/

$$\Gamma_{f\to 2\pi} = (134\pm 9)\ Mev$$

$g_{f\pi\pi}$ is calculated: $g_{f\pi\pi}$ = 10.9 ± 0.4 . Thus

$$g_{f\rho\rho}/g_{f\pi\pi} = 2.1 \pm 0.2$$

implying that f-meson coupling with ρ-mesons is notably stronger than that with π-mesons.

Proceed now to estimation of the π-meson charge asymmetry in the reaction $e^+e^-\to\pi^+\pi^-$. Using the results of /2/ the differential cross-section of this reaction can be written as

$$\frac{d\sigma}{d\Omega} = \frac{d\sigma_0}{d\Omega}\left(1+2\,Re\,\delta\,\cos\theta\right) \qquad (8)$$

where $d\sigma_0/d\Omega$ is the cross-section of the reaction in the one-photon approximation, θ being the angle between the momenta of π^--meson and electron. In (8) the term containing δ squared has been neglected. Here

$$\delta = \frac{\alpha\, g_{f\pi\pi}\, \varkappa}{4\pi\, F_\pi(s)}\left(1-\frac{4m^2_\pi}{s}\right)^{1/2}\frac{s}{m^2_f}\,\frac{s}{s-m^2_f+im_f\Gamma_f} \qquad (9)$$

where $F_\pi(s)$ – π-meson electromagnetic formfactor, $\varkappa$ determines the vertex $f\to e^+e^-$. Thus the asymmetry parameter

$$2\,Re\,\delta = \frac{\alpha\, g_{f\pi\pi}\,|\varkappa|}{2\pi\,|F_\pi(s)|}\,\frac{s^2}{m^3_f\Gamma_f}\,\frac{x\cos\varphi+\sin\varphi}{1+x^2}\left(1-\frac{4m^2_\pi}{s}\right)^{1/2} \qquad (10)$$

where

$$\varkappa = (s - m_f^2)/m_f\Gamma_f\ , \quad \varphi = \arg\varkappa - \arg F_\pi = \varphi_\varkappa - \varphi_\pi$$

To estimate $|\varkappa|$ its lower limit obtained from the unitarity condition in /2/ is taken:

$$|\varkappa| \geqslant \mathrm{Im}\,\varkappa = \frac{1}{6}\, g_{f\gamma\gamma} \qquad (11)$$

where $g_{f\gamma\gamma}$ - the coupling constant of the f-meson with γ-quanta. Vector dominance model gives

$$g_{f\gamma\gamma} = g_{f\rho\rho}\cdot 4\pi g_\rho^{-2} \qquad (12)$$

where the value of g_ρ determining the $\rho-\gamma$ transition is known from e^+e^- colliding beam experiments /10/. In (12) we have neglected the ω-meson contribution since $4\pi g_\omega^{-2}$ is small as well as $f-\phi$ interaction. Using the value of $g_{f\rho\rho}$ from (7)

$$g_{f\gamma\gamma} = 8.8 \pm 1.3 \qquad (13)$$

Then (11) gives

$$|\varkappa|_{min} = 1.5 \pm 0.2 \qquad (14)$$

e^+e^- colliding beam experiments indicate /11/ that in the energy region of interest the formfactor $|F_\pi(s)|$ is approximately constant:

$$|F_\pi(s)| \simeq 1.8 \pm 0.2$$

Using this value and $|\varkappa|$ from (14) 2Reδ can be calculated. The values of the asymmetry parameter 2Reδ thus obtained are shown in Fig.2 for $\varphi = 0$ and $\varphi = 1.31$. If φ were equal to 1.31 the asymmetry parameter should be maximal and equal to $(8.1 \pm 1.4)\%$ at 2E = 1.3 Gev. Note that it is a lower limit of the asymmetry parameter because of (11). For comparison the non-resonant contribution to the asymmetry parameter due to soft virtual photons is 7% at $\theta = 45^\circ$ and $\Delta E/E \sim 1\%$ /12/.

The value of $g_{f\gamma\gamma}$ found can be used to calculate the decay width of f-meson into 2γ:

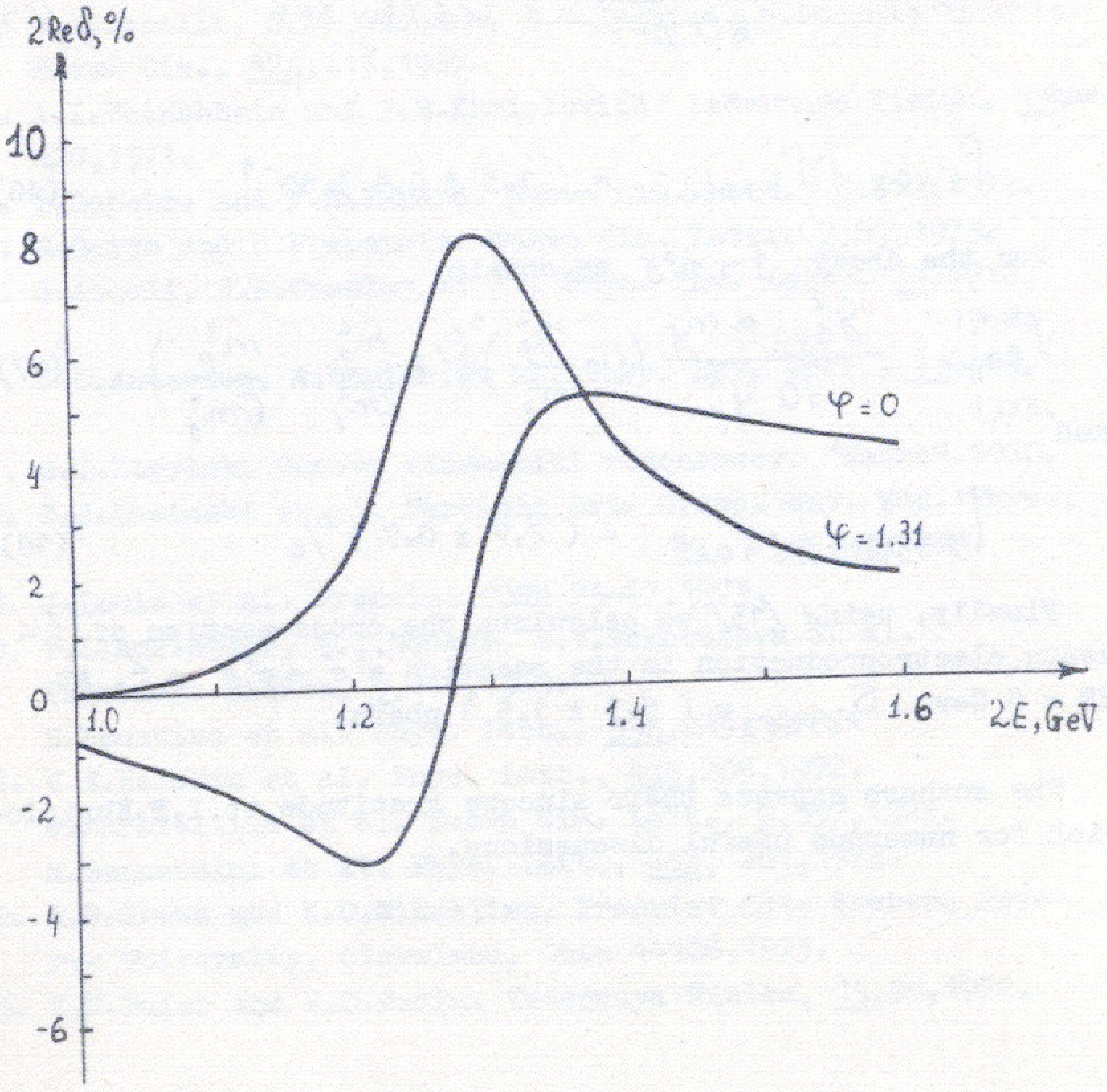

Fig.2. Energy dependence of the asymmetry parameter 2Reδ.

$$\Gamma_{f\to 2\gamma} = \frac{\alpha^2 g^2_{f\gamma\gamma}\, m_f}{80\,\pi} = (21 \pm 6)\ \mathrm{keV} \tag{15}$$

and

$$\Gamma_{f\to 2\gamma} / \Gamma_{f\to all} = (1.3 \pm 0.4) \times 10^{-4} \tag{16}$$

For the decay $f \to \rho^0 \gamma$ we obtain

$$\Gamma_{f\to\rho\gamma} = \frac{g^2_{f\rho\rho}\, \alpha\, m_f}{10\, g^2_\rho} \left(1 - \frac{m^2_\rho}{m^2_f}\right)^3 \left(1 + \frac{m^2_\rho}{2m^2_f} + \frac{m^4_\rho}{6m^4_f}\right) \tag{17}$$

and

$$\Gamma_{f\to\rho\gamma} / \Gamma_{f\to all} = (2.7 \pm 0.7)\,\% \tag{18}$$

Finally, using /13/ we calculate the cross-section of f-meson electroproduction in the reaction $e^+e^- \to e^+e^- + f$. At 2E = 6 Gev $\sigma_{e^+e^-\to e^+e^- f} = (5.3 \pm 1.5)$ nbarn.

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