The possibility of observing the $\omega'(1250)$ meson in the reaction $e^+e^-\to 3\pi$

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We discuss the possibility of experimentally observing isoscalar excitation in a system of nonstrange quarks, the $\omega'(1250, 1^{--})$ meson. It is shown that the picture of the $\rho-\omega$ interference in the mass spectrum of the $\pi^+\pi^-$ mesons in the reaction $e^+e^-\to\pi^+\pi^-\pi^0$ is quite critical to the existence of this excitation.

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Theoretical arguments that a quark-antiquark system should have higher excited states with a given angular momentum have been advanced long ago. There are also experimental indications of the existence of heavy $\rho'(1250,1^{--})$ and $\rho''(1600,1^{--})$ resonances.[1,2] The latest experiments at Stanford aimed at observing the new particles ψ, ψ', ψ'', ... are undoubtedly the strongest indications of the existence of such excitations.

The main difficulty in observing excitations in a system of uncharmed quarks in their large width. A possible exception is the lowest excitation in the system of strange quarks, the $\phi'(1450,1^{--})$ meson, for which one should expect a width $\Gamma_{\phi'}\sim 40$ MeV.[3]

If $\rho'(1250)$ does indeed exist, then according to the quark model $\omega'(1250,1^{--})$ should also exist. Experimental observation of this resonance is a very difficult task. The point is that the ρ' meson, as indicated by experiment,[1] decays in the main into $\omega\pi$ with width $\Gamma_{\rho'}\approx 150$ MeV. Then, according to the quark model, the width of ω' is

$$\Gamma_{\omega'} \approx 3\Gamma_{\rho'} \approx 450\,\text{MeV}, \tag{1}$$

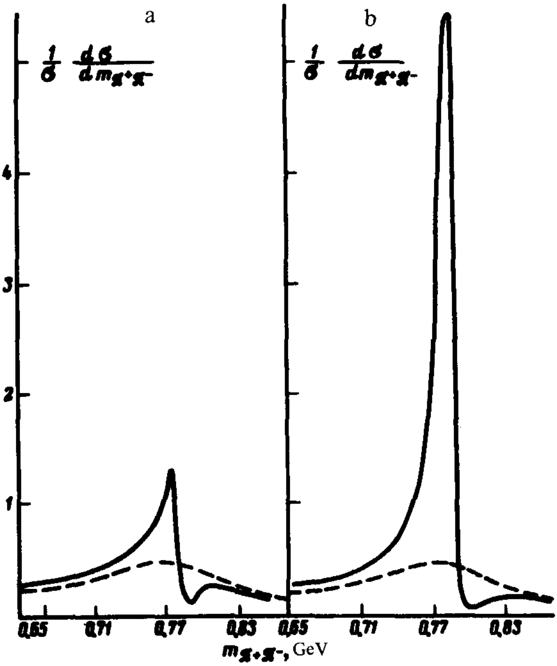
since the ω' should decay in three channels $\omega'\to\rho^0\pi^0+\rho^+\pi^-+\rho^-\pi^+$. At such a width, the observation of the resonance by means of the energy dependence of the cross section is quite difficult. It is therefore very important to have additional information favoring its existence.

We shall show below that a phenomenon due to electromagnetic ρ-ω mixing exists, and is clearly manifest in the region of the ω' and ρ' resonances.

It was shown in[4] that in the reaction $e^+e^-\to 3\pi$ at $\sqrt{s}\gtrsim 1$ GeV ($\sqrt{s}$ is the invariant mass of the e^+e^- pair), 10% of the events should be due to the effects of electromagnetic ρ-ω mixing and to the process $e^+e^-\to\omega\pi\to\rho^0\pi^0\to 3\pi$. For the reactions $e^+e^-\to\gamma_{\text{virt}}\to\omega\pi$ and $e^+e^-\to\gamma_{\text{virt}}\to\rho^0\pi^0$, $SU(3)$ predicts that

$$A_\rho/A_\omega = 1/3, \tag{2}$$

where A_ρ and A_ω are the amplitudes of the processes $e^+e^-\to\gamma_{\text{virt}}\to\rho^0\pi^0$ and $e^+e^-\to\gamma_{\text{virt}}\to\omega\pi$, respectively. The total amplitude of the processes $e^+e^-\to\rho\pi\to 3\pi$ and $e^+e^-\to\omega\pi\to\rho^0\pi^0\to 3\pi$ is



$$F \sim A_\rho \left(\frac{1}{D_{\rho^+}} + \frac{1}{D_{\rho^-}} + \frac{1}{D_{\rho^0}} \left(1 + \frac{A_\omega}{A_\rho} \frac{2m_\omega \delta}{D_\omega} \right) \right), \tag{3}$$

where $D_V = m_V^2 - K_V^2 - im_V\Gamma_V$; $V = \rho^+, \rho^-, \rho^0, \omega$, $K_{\rho 0}^2 = K_\omega^2$; δ is the constant of the electromagnetic $\rho \leftrightarrow \omega$ transition. Generally speaking, relation (2) is valid outside the resonance region, and may be violated inside the resonance region. In the considered case of ω' and ρ' resonances at $\sqrt{s} \approx m_{\rho'} \approx m_{\omega'}$ the violation of relation (2) is determined by the formula

$$\frac{A_\rho}{A_\omega} = \frac{f_{\rho'}}{f_{\omega'}} \left(\frac{s - m_{\rho'}^2 + im_{\rho'}\Gamma_{\rho'}}{s - m_{\omega'}^2 + im_{\omega'}\Gamma_{\omega'}} \right) \approx \frac{1}{3} \frac{\Gamma_{\rho'}}{\Gamma_{\omega'}} \approx \frac{1}{9} . \tag{4}$$

Here $f_{\rho'}$ and $f_{\omega'}$ are constants of the $\gamma_{\text{virt}} \leftrightarrow V'$ transitions, for which $SU(3)$ predicts $f_{\rho'}/f_{\omega'} \approx 1/3$.

Relation (4), as seen from formula (3), greatly enhances the influence of the ρ-ω mixing. Thus, approximately half the number of the events in the reaction $e^+e^- \to 3\pi$ at $\sqrt{s} \approx m_{\omega'}$ should be due to the process $e^+e^- \to \rho' \to \omega\pi \to \rho^0\pi^0 \to 3\pi$. This is seen from the following estimate:

$$\sigma(e^+e^- \to 3\pi) \approx \sigma(e^+e^- \to \omega' \to \rho\pi \to 3\pi) + \sigma(c^+e^- \to \rho' \to \omega\pi \to \rho\pi \to 3\pi)$$

$$= \sigma(e^+e^- \to \omega' \to \rho\pi \to 3\pi) \left(1 + \frac{\Gamma_{\omega\pi\pi}}{\Gamma_\omega} \frac{\Gamma_{\omega'}}{\Gamma_{\rho'}} \left(\frac{f_{\omega'}}{f_{\rho'}} \right)^2 \right) \approx 2\sigma(e^+e^- \to \omega' \to 3\pi) .$$

We have used here formula (3), and took for the ratio $\Gamma_{\omega\pi\pi}/\Gamma_{\omega}$ the value ($\approx 3.7\%$) obtained in the investigation of the ρ-ω interference in the reaction $e^+e^- \to \pi^+\pi^-$.[5] We note that there is practically no interference between the channels.

It is obvious that the contribution of $e^+e^- \to \rho' \to 3\pi$ should lead to a steeper behavior of the cross section in the region of the ω' meson—to an effective decrease of the ω'-resonance width by a factor 1.5—2.

The considered effect can be directly verified by measuring the mass spectra of the $\pi^+\pi^-$ mesons at $m_{\pi^+\pi^-} \approx m_\rho \approx m_\omega$ for beam energies in the region of the ω' resonance and outside this region. Figure a shows the mass spectrum of the $\pi^+\pi^-$ mesons outside the region of the ω' resonance, where the relation (2) predicted by $SU(3)$ symmetry is valid. Figure b illustrates the enhancement of the effect in the region of the ω' resonance as a result of violation of (2), due to the difference between the widths of the ω' and ρ' mesons. The dashed lines in the figure show the mass spectrum of the $\pi^+\pi^-$ mesons without allowance for the electromagnetic ρ-ω mixing. The relative change of the effect at different energies can be traced (independently of the normalizations of the cross section) by comparing the $\pi^+\pi^-$ and $\pi^\pm\pi^0$ mass spectra, since the influence of the electromagnetic ρ-ω mixing on the latter is obviously small.

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