ρ'(1250) meson in the e^+e^- annihilation

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New data for the $e^+e^-\to 4\pi$, which were obtained at the Institute of Nuclear Physics of the USSR Academy of Sciences, Siberian Branch, are evaluated. The mass and the total lepton widths of the first excitation of a ρ meson, the so-called ρ'(1250) meson, are determined.

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New data for the $e^+e^-\to 4\pi$ reaction in the region $\sqrt{s} = 0.8$–1.4 GeV, which were obtained at the Institute of Nuclear Physics of the USSR Academy of Sciences, Siberian Branch, were recently published.[1,2]

According to Refs. 1–4, we can assume that 4π are produced in the e^+e^- annihilation via quasi-two-particle $\pi\omega$ and $\rho\epsilon$ states.

The cross section $\sigma(e^+e^-\to\pi^0\omega)$ can be calculated by using the equation

$$\sigma(e^+e^-\to\pi^0\omega) = \frac{\Gamma_\omega}{\Gamma_{\omega\to 3\pi}}\left[\sigma(e^+e^-\to\pi^+\pi^-2\pi^0) - R\,\sigma(e^+e^-\to 2\pi^+2\pi^-)\right]. \tag{1}$$

The second term in this equation takes into account the contribution of the $\rho\epsilon$ state to the cross section $\sigma(e^+e^-\to\pi^+\pi^-2\pi^0)$. The coefficient $R = \sigma(e^+e^-\to\rho\epsilon\to\pi^+\pi^-\pi^0\pi^0)/\sigma(e^+e^-\to\rho\delta\to 2\pi^+2\pi^-)$, which was calculated in Ref. 5 with allowance for the interference effects, varies within the limits $R = 0.27 - 0.35$ in the investigated region.

The radiated quantity is the form factor of the transition $\gamma\to\pi^0\omega F_\omega$, which is connected with $\sigma(e^+e^-\to\pi^0\omega)$ in the following way:

$$\sigma(e^+e^-\to\pi^0\omega) = \frac{4\pi\alpha^2}{3s^2}\rho_\omega|F_\omega|^2, \tag{2}$$

where

$$\rho_\omega = 4\sqrt{s}\,[(s-(m_\omega-m_\pi)^2)(s-(m_\omega+m_\pi)^2)/4s]^{3/2}.$$

The simplest model for the form factor F_ω is a "unified" vector-dominance model in which

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TABLE I.

Mode	Ref. Data	$\frac{g_{\rho\omega\pi}}{2g_{\rho\gamma}}$	$\frac{g_{\rho'\omega\pi}}{2g_{\rho'\gamma}}$	$\frac{g_{\rho''\omega\pi}}{2g_{\rho''\gamma}}$	$m_{\rho'}$ MeV	$\Gamma_{\rho'}$ MeV	$\Gamma_{\omega\to\pi\gamma}$ MeV	Number of degrees of freedom	χ^2	$p(\chi^2)$
ρ	1; 3	2.9	–	–	–	–	4.4	20	45	10^{-3}
ρ	2; 3	2.7	–	–	–	–	3.8	18	90	10^{-26}
$\rho+\rho''$	1; 3	2.4	–	−0.3	–	–	2.3	19	20	0.4
$\rho+\rho''$	2;3	1.4	–	−0.4	–	–	0.5	17	22	0.2
$\rho+\rho'+\rho''$	1;3	0.55	0.75	−0.3	1185	380	0.5	16	11	0.85
$\rho+\rho'+\rho''$	2;3	0.65	0.63	−0.3	1185	390	0.5	14	7.5	0.85

$$F_\omega(s) = \sum_i \frac{g_{\rho i\omega\pi}}{2g_{\rho i\gamma}} \frac{m^2}{m^2_{\rho i} - s - i\Gamma_{\rho i} m_{\rho i}}, \quad (3)$$

where $i=0$ corresponds to the $\rho(770)$ meson, $i=1$ corresponds to the predicted $\rho'(1250)$ meson, and $i=2$ corresponds to the $\rho''(1600)$ meson.

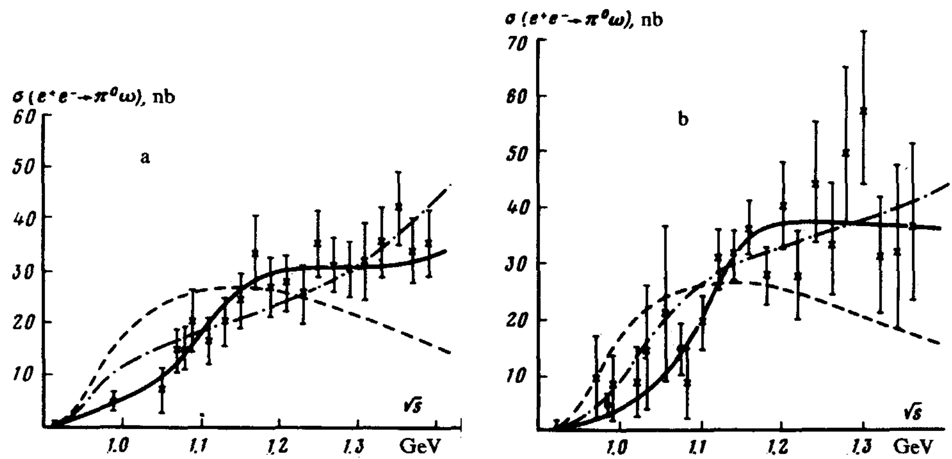

FIG. 1. The cross section $\sigma(e^+e^-\to\pi^0\omega)$. , ρ-dominance model for the transition $\gamma\to\pi^0\omega$;-----, an approximation with ρ and $\rho''(1600)$----, a model with ρ, $\rho'(1250)$, and $\rho''(1600)$. Data (a) ×, Novosibirsk (Ref. 1); Orsay (Ref. 3). (b) ×, Novosibirsk (Ref. 2); Orsay (Ref. 3).

Budnev *et al.*[6] obtained a model-free expression for F_ω in terms of the experimental characteristics of hadronic processes; however, a more graphic equation (3) is adequate for our purpose.

The results of fitting the data [1,2] using the κ^2 method in a number of models are given in Table I and in Fig. 1. The data of Refs. 1 and 2 were fitted separately, since the authors of these papers allowed a systematic disagreement between the results of the experiments. The data of Ref. 3 were also included in the fitting.

1. The ρ-dominance model in which F_ω is completely determined by the $\gamma^* \to \rho \to \pi^0\omega$ amplitude. As we can see in Table I and in Figs. 1 and 2, the predictions of this model contradict the data for $\sigma(e^+e^- \to \pi^0\omega)$.

In selecting the model for the $F_\omega(s)$ form factor, we must also consider the $F_\pi(s)$ pion form factor, since the inelastic effects appreciably affect F_π for $\sqrt{s} \gtrsim 1$ GeV. Using the unitarity and analyticity properties, we can determine the contribution to F_π from the lower inelastic $\pi\omega$ state in the following way:

$$F_\pi(s) = F_\pi^\rho(s)\left(1 \pm \frac{s}{\pi}\int \frac{ds'}{s'(s'-s)}\left\{\left|\frac{F_\pi^{exp}(s')}{F_\pi^\rho(s')}\right|\sqrt{\frac{1-\eta^2}{4\eta}}\right.\right.$$
$$\left.\left.\times\left(\frac{\sigma(e^+e^- \to \pi^0\omega)}{\sigma(e^+e^- \to \pi^+\pi^-)}\cdot\frac{1-\eta}{1+\eta}\right)^{1/2}\right\}\right). \qquad (4)$$

Here $F_\pi^\rho = m_\rho^2/(m_\rho^2 - s - i\Gamma_\rho m_\rho)$, η is the inelastic $\pi\pi$ scattering, and the sign in front of the integral depends[6] on the phase of the transition form factor $\gamma \to \pi^0\omega$. The $\rho\epsilon$ channel can be determined analogously. If $\pi\omega$ and $\rho\epsilon$ channels are dominated by the ρ meson, then Eq. (4) should have a minus sign and the inelastic effects will decrease F_π, inconsistent with the data.

Finally, the $F_\omega(s)$ form factor was normalized for $s = 0$ to the width of the decay $\omega \to \pi^0\gamma \Gamma^{exp}_{\omega\to\pi^0\gamma} = (0.88 \pm 0.05)$ MeV.[7] In the analyzed model $\Gamma_{\omega\to\pi^0\gamma}$ amounts to ~ 4 MeV, which is almost five times greater than the experimental width of the $\omega \to \pi^0\gamma$ decay.

2. We shall determine in Eq. (3) the contributions from the ρ meson and $\rho''(1600)$ meson with $m_{\rho''} = 1600$ MeV and $\Gamma_{\rho''} = 300$ MeV, which was included in Table I (Ref. 7). As is evident in Table I and in Figs. 1 and 2, a description of the data for $\sigma(e^+e^- \to \pi^0\omega)$ in the region $\sqrt{s} \lesssim 1.4$ GeV is improved considerably. However, for $\sqrt{s} \sim 1600$ MeV the cross section $\sigma(e^+e^- \to \pi^0\omega)$ in this case reaches a value of ~ 100 nb, which is several factors greater than the experimental data.[8,9] (Since the data of Ref. 8 contradict those of Ref. 9, we did not take them into account in the fitting, but they give a cross section of the same order of magnitude, $\sim$20–30 nb.)

As in the previous case, the contribution of inelastic channels to the pion form factor in the investigated model with ρ and ρ'' mesons and with coupling constants

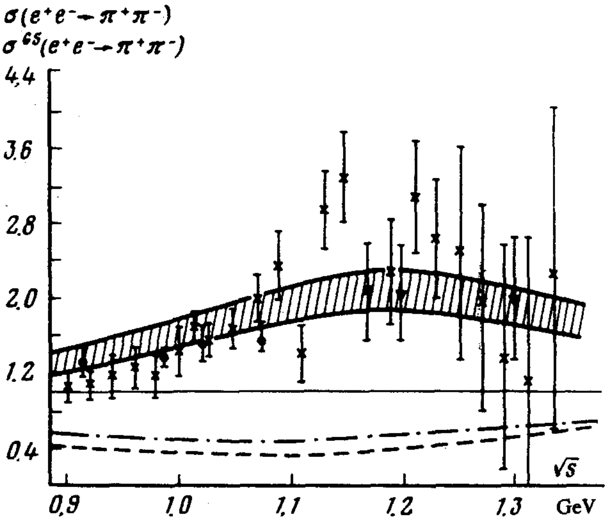

FIG. 2. The ratio $\sigma(e^+e^-\to\pi^+\pi^-)/\sigma^{G.S.}(e^+e^-\to\pi^+\pi^-)$.-----, Gunaris-Sakurai prediction;- - - -, ρ-dominance approximation for $e^+e^-\to\pi\omega$ and $e^+e^-\to\rho\epsilon$; -----, a calculation with allowance for the ρ meson and $\rho''(1600)$ with parameters taken from Table I; the shaded area represents a calculation taking into account ρ, $\rho'(1250)$, and $\rho''(1600)$, the experimental uncertainty in the phase, and the inelastic $\pi\pi$ scattering. Data: Novosibirsk; Orsay; Frascati.

from Table I is negative, and there is a discrepancy between the data.

3. We shall assume that a $\rho'(1250)$ meson exists in addition to ρ and ρ'' mesons. The F_ω form factor in this case has an interference minimum for $\sqrt{s}\sim 1$ GeV and the imaginary part of the form factor must be correctly determined[6] in this region

$$\mathrm{Im}\,F_\omega(s) = \sqrt{\frac{1-\eta(s)}{1+\eta(s)}}\left(\frac{p_\pi(s)}{p_\omega(s)}\right)^{3/2}\frac{F_\pi(s)}{2s}\,. \tag{5}$$

The data for $\sigma(e^+e^-\to\pi^0\omega)$ can be fitted with a certainty of $p(\chi^2)\sim 0.85$, if all three resonances are taken into account. The pion form factor is such model for $F_\omega(s)$ is also in good agreement with the data.

Thus, we can assert that to interpret the data for $\sigma(e^+e^-\to\pi^0\omega)$ in the region $0.9\leqslant\sqrt{s}\leqslant 1.4$ GeV, with allowance for this cross section to within an order of magnitude for $\sqrt{s}\sim 1600$ MeV and also the data for $F_\pi(s)$, we must take into account the $\rho'(1250)$ meson in addition to the ρ and $\rho''(1600)$ mesons. As a result of fitting the data for it, we obtained the following parameters: $m_{\rho'} = 1185\pm 20$ MeV, $\Gamma_{\rho'} = 380\pm 15$ MeV, and $\Gamma_{\rho'\to e^+e^-} = 0.85\pm 0.08$ keV.

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