Further evidence for the lower-lying vector meson $\rho(1250)$ in the $e^+e^- \to \omega\pi^0$ process

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Summary. — Recently, a strong evidence for the existence of the isovector vector meson with a mass around 1.26 GeV, or $\rho(1250)$ was presented from a unitary multichannel reanalysis of elastic $\pi\pi$-scattering data by Hammoud *et al.* In this work, we examine whether the $\rho(1250)$ observed in the $\pi\pi$ scattering process is also seen in the production process $e^+e^- \to \omega\pi^0$.

1. – Introduction

In the early 1970s, several evidences/signals for the $\rho(1250)$ were reported in the analyses of the $\omega\pi$ and $\pi\pi$ systems (see the mini-review of vector mesons in ref. [1, 2]). After that, this state was reported in the analyses of the $\bar{p}p$ annihilation, photoproduction, hadroproduction, and e^+e^- annihilation processes [3]. On the other hand, its existence was not confirmed in the analysis of the $\omega\pi$ system from the e^+e^- annihilation or τ decay [4, 5, 6, 7, 8, 9]. Now, several results for evidences/signals around 1.25 GeV are listed under the $\rho(1450)$ in the Particle Data Group (PDG) tables [3] for their convenience, and are not recognized as a resonance state in the review "Spectroscopy of Light Meson Resonances" by the PDG [3]. Although the existence of the $\rho(1250)$ is still controversial, it has an attractive interest [8, 10], since this state cannot be accommodated as a $q\bar{q}$ state in the conventional quark models.

Recently, the existence of the $\rho(1250)$ was reinforced with a multichannel and fully unitary S-matrix analysis of elastic $\pi\pi$ scattering data with crossing-symmetry constraints by Hammound *et al.* [11]. In this work, we examine whether this state is seen in the $e^+e^- \to \omega\pi^0$ process by using the vector meson dominance (VMD) model.

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2. – Analysis data and method

The combined data of the cross sections for the $e^+e^- \to \omega\pi^0 \to \pi^0\pi^0\gamma$ process measured by SND [12, 13] and CMD-2 [14] and those for the $e^+e^- \to \omega\pi^0 \to \pi^+\pi^-\pi^0\pi^0$ process measured by BABAR [15] are used to study isovector vector resonances in the energy region from threshold to 2 GeV.

The VMD model and intermediate $\omega(782)\pi^0$ state are assumed for the processes $e^+e^- \to \gamma^* \to$ 'V' $\to \omega\pi^0 \to \pi^+\pi^-\pi^0\pi^0$ or $\pi^0\pi^0\gamma$, where the symbol 'V' denotes five intermediate states of the $\rho(770)$, $\rho(1250)$, $\rho(1450)$, $\rho(1600)$, and $\rho(1800)$. The $\omega(782)$ decays into either $\pi^+\pi^-\pi^0$ or $\pi^0\gamma$. The process is shown schematically in fig. 1a). The direct process of γ^* into the $\omega\pi^0$ is also taken into account, as shown in fig. 1b).

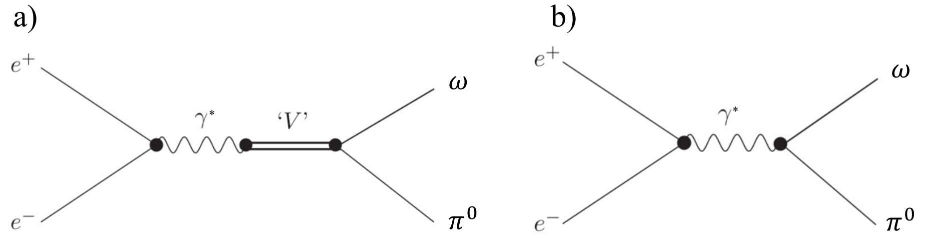

Fig. 1. – Feynman diagrams for the $e^+e^- \to \omega\pi^0$ process. a) The contribution from the $e^+e^- \to$ 'V' $\to \omega\pi^0$ process in the VMD model. b) The contribution from the direct process of γ^* into $\omega\pi^0$.

The formula of the cross section for the relevant processes is given by

$$\sigma_0(s) = \frac{4\pi\alpha^2}{s^{\frac{3}{2}}}\left(\frac{g_{\rho\omega\pi}}{f_\rho}\right)^2 \left| \frac{m_\rho^2\sqrt{F_\rho(s)}}{m_\rho^2 - s - i\sqrt{s}\Gamma_\rho(s)} + \sum_{i=1}^{4} \frac{A_i e^{i\theta_{\rho^{(i)}}} m_{\rho^{(i)}}^2 \sqrt{F_{\rho^{(i)}}(s)}}{m_{\rho^{(i)}}^2 - s - i m_{\rho^{(i)}}\Gamma_{\rho^{(i)}}} \right.$$

$$\left. + \frac{A_{\mathrm{dir}} e^{i\theta_{\mathrm{dir}}}}{s} \right|^2 P_f(s), \tag{1}$$

where $g_{\rho\omega\pi}$ and f_ρ are the coupling constants for the transitions $\rho \to \omega\pi$ and $\rho \to \gamma^*$, respectively and the resonances ρ, $\rho^{(1)}$, $\rho^{(2)}$, $\rho^{(3)}$, $\rho^{(4)}$ are assigned to the $\rho(770)$, $\rho(1250)$, $\rho(1450)$, $\rho(1600)$, $\rho(1800)$, based on the results of ref. [11]. The form factors are introduced as

$$F_R(s) = \frac{2m_R^2}{m_R^2 + s} \quad \text{for } R = \rho,\ \rho^{(i)} \tag{2}$$

and assuming the ω resonance to be infinitely narrow

$$P_f(s) = \frac{1}{3} p_\omega^3(s) B_\omega, \tag{3}$$

where $p_\omega(s)$ is the three momentum of $\omega(782)$ in the $\rho(770)$ at rest and B_ω is the branching ratios of $\omega \to \pi^0\gamma$ and $\omega \to \pi^+\pi^-\pi^0$, respectively, to be taken as 0.0835 and 0.892

[3]. The energy dependent width of $\rho(770)$ is given by

$$\Gamma_\rho(s) = \left(\Gamma_\rho(m_\rho^2)\frac{m_\rho^2}{s}\frac{p_\pi^3(s)}{p_\pi^3(m_\rho^2)} + \frac{g_{\rho\omega\pi}^2}{12\pi}p_\omega^3(s)\right)\frac{2m_\rho^2}{m_\rho^2+s}, \tag{4}$$

where $p_\pi(s)$ is the three momentum of each pion in $\rho(770) \to \pi^+\pi^-$. For the $\rho^{(i)}$ resonances constant widths are used.

The mass and width of $\rho(770)$ are fixed to their PDG values [3]. The $m_{\rho^{(i)}}$ and $\Gamma_{\rho^{(i)}}$ are treated as fitting parameters within the range of 3σ of the values of the analysis results of ref. [11]. The $r = g_{\rho\omega\pi}/f_\rho$, $A_{\rho^{(i)}}$, $A_{\rm dir}$ and $\theta_{\rm dir}$ are the fitting parameters. Each relative phase of $\theta_{\rho^{(i)}}$ is fixed to 0° or 180° in the present analysis.

3. – Results of the Analysis

As preliminary results of our analysis, four solutions were found. Obtained values of the parameters are shown in Table I. The relative phases of the $\rho(1250)$ referred to the $\rho(770)$ were obtained to be 180° for all solutions.

The solutions can be classified into two categories: (1) Solutions I and II, which have indications of $\rho(1600)$. (2) Solutions III and IV, where the contribution of $\rho(1600)$ can be considered negligible. The fit results of Solution I and Solution III are shown in fig. 2. The statistical significances of each amplitudes in the best solution, Solution I, are listed in Table II. The existence of $\rho(1250)$ is confirmed with a significance of 4.9σ. The existence of $\rho(1450)$ is indispensable with a significance greater than 10σ. The $\rho(1600)$ and the direct process are each indicated with a significance of about 2σ. The $\rho(1800)$ is less significant with a significance of 0.7σ.

TABLE I. – *Obtained values of the parameters.*

	Solution I	Solution II	Solution III	Solution IV
χ^2/ndf	212.6/117=1.82	215.2/117=1.84	219.3/117=1.87	233.6/117=2.00
$m_{\rho(1250)}$ (MeV)	1,330	1,344	1,312	1,343
$\Gamma_{\rho(1250)}$ (MeV)	333	325	333	333
$A_{\rho(1250)}$	6.50×10^{-2}	5.95×10^{-2}	7.79×10^{-2}	7.37×10^{-2}
$\theta_{\rho(1250)}$ (deg)	180	180	180	180
$m_{\rho(1450)}$ (MeV)	1,486	1,494	1,470	1,495
$\Gamma_{\rho(1450)}$ (MeV)	276	271	283	283
$A_{\rho(1450)}$	1.10×10^{-1}	1.28×10^{-1}	8.91×10^{-2}	1.02×10^{-1}
$\theta_{\rho(1450)}$ (deg)	180	180	180	180
$m_{\rho(1600)}$ (MeV)	1,609	1,609	1,604	1,596
$\Gamma_{\rho(1600)}$ (MeV)	151	151	146	127
$A_{\rho(1600)}$	7.46×10^{-3}	9.38×10^{-3}	$\simeq 0$	$\simeq 0$
$\theta_{\rho(1600)}$ (deg)	180	180	0	0
$m_{\rho(1800)}$ (MeV)	1,819	1,806	1,731	1,819
$\Gamma_{\rho(1800)}$ (MeV)	196	284	196	196
$A_{\rho(1800)}$	2.13×10^{-3}	$\simeq 0$	3.67×10^{-3}	3.37×10^{-4}
$\theta_{\rho(1800)}$ (deg)	180	0	0	180
r (GeV $^{-1}$)	3.18	2.92	3.67	3.34
$A_{\rm direct}$ (MeV^2)	7.71×10^{-2}	2.67×10^{-1}	1.85×10^{-1}	2.49×10^{-2}
$\theta_{\rm direct}$ (deg)	318	294	106	30.0

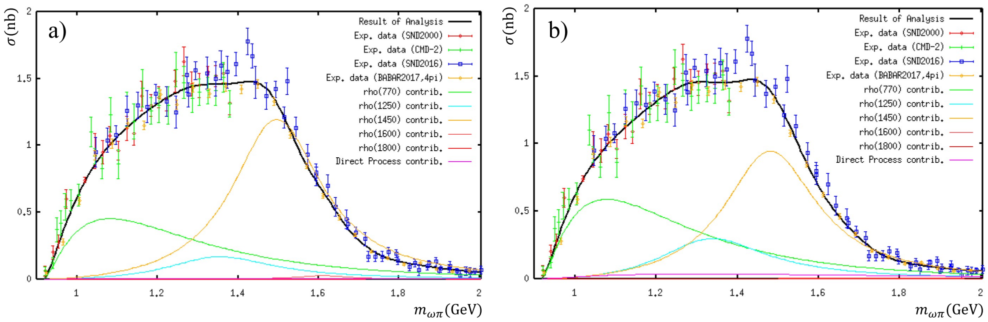

Fig. 2. – a) and b) show the results of analyses for Solution I and II. The green, light blue, brown, pink curves represent the contributions from the $\rho(770)$, $\rho(1250)$, $\rho(1450)$ and $\rho(1600)$, respectively. The black curves represent the fit results. The data measured in the process $e^+e^- \to \omega\pi^0 \to \pi^+\pi^-\pi^0\pi^0$ obtained by BABAR are scaled by the appropriate branching ratio.

TABLE II. – *Statistical significance of each amplitude.*

Amplitude	Significance
$\rho(1250)$	4.9σ
$\rho(1450)$	$> 10\sigma$
$\rho(1600)$	1.7σ
$\rho(1800)$	0.74σ
Direct process	1.9σ

4. – Summary

We examined whether an isovector vector meson with a mass around 1.26 GeV, identified as the $\rho(1250)$, is seen in the $e^+e^- \to \omega\pi^0$ process. It was found with the method of least squares that the cross section line shape is described well by the coherent sum of five resonant amplitudes of the $\rho(770)$ and four higher-mass ρ-like vector mesons, $\rho^{(1)}$, $\rho^{(2)}$, $\rho^{(3)}$, and $\rho^{(4)}$, around 1.3 GeV, 1.5 GeV, 1.6 GeV, and 1.8 GeV, respectively, together with a nonresonant amplitude for the direct production process. These four resonances correspond to $\rho(1250)$, $\rho(1450)$, $\rho(1600)$, and $\rho(1800)$ which were found between 1 and 2 GeV by Hammound *et al.* [11]. Then, since the fitted mass and width of the $\rho^{(1)}$ resonance were similar to their obtained values, it would be associated with the $\rho(1250)$, which seems to offer further evidence about its existence.

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