ИНСТИТУТ ЯДЕРНОЙ ФИЗИКИ СО АН СССР

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REACTION $e^+e^- \to \omega\pi$ IN THE C.M. ENERGY RANGE FROM 1.0 TO 1.4 GeV

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Abstract

The reaction $e^+e^-\to\omega\pi^0\to\pi^0\pi^0\gamma$ has been studied with the Neutral Detector at the VEPP-2M collider. The cross section values differ from the predictions of the vector dominance model with one $\varrho(770)$ meson and are consistent with the contributions of $\varrho(770)$ and $\varrho(1600)$, $\varrho(1250)$ has not been observed.

INTRODUCTION

Investigation of the reaction $e^+e^-\to\omega\pi^0$ is of interest by several reasons. First, it is relevant to the problem of $\varrho(1250)$ [1',2]. If such an isovector resonance with $J^{PC}=1^{--}$ exists, then one of its main decay modes is $\varrho(1250)\to\omega\pi^0$ and one should observe a resonance structure in the cross secton of this reaction at 1.25 GeV. Second, the reaction is determined by the same vertex as decay modes $\omega\to3\pi$, $\omega\to\pi^0\gamma$, $\omega\to\pi^0\mu^+\mu^-$ (cf. the review [3]) and provides additional opportunities for its phenomenological study. The measured value of the coupling constant arising in this vertex can be compared to its recent calculations using QCD sum rules [4, 5]. Finally, this reaction gives an important contribution to the total cross section of e^+e^- annihilation into hadrons in the c.m. energy range under study.

Earlier the following processes have been observed in this energy range: $e^+e^-\to\pi^+\pi^-\pi^0\pi^0$ [6, 7] and $\gamma N\to\pi^+\pi^-\pi^0\pi^0 N$ [8]. It was shown that these reactions were due to the intermediate states $\omega\pi^0$, $A_1\pi$ and $\varrho\pi\pi$. The separation of contributions of different mechanisms was, however, rather complicated and did not clarify the problem of $\varrho(1250)$.

In this work we study for the first time the process:

$$e^+e^-\to\omega\pi^0\to\pi^0\pi^0\gamma, \quad (1)$$

using the decay mode $\omega\to\pi^0\gamma$. Such a final state allows unambiguous selection of the $\omega\pi^0$ mechanism.

The experiment has been performed at the electron-positron collider VEPP-2M [9] with the Neutral Detector (ND) [10]. The main part of ND is an electromagnetic calorimeter consisting of 168 NaI(Tl) counters. Angles of charged particles and photons were measured using proportional chambers. For this analysis we have used the data collected in 1982—1985 in the c.m. energy ($2E$) range between 1.0 and 1.4 GeV corresponding to the integrated luminosity of 11 pb^{-1} and the total number of triggerings about $4 \cdot 10^7$. About 3 pb^{-1} were collected in the energy range above 1.04 GeV in which the reaction (1) dominated other neutral modes of e^+e^- annihilation. More detail on the experiment as well as its preliminary results can be found in previous papers [11].

EVENT SELECTION

Preliminary selection of events due to the process under study was done by using the following criteria:

— 4 or 5 photons are detected;
— the total energy deposition in ND is higher than $1.3E$;
— the total momentum of photons in the plane perpendicular to the beam axis is less than 150 MeV;
— the angle between any two photons is higher than 25°.

These selection criteria suppress completely the background of cosmic particles and that due to the particles lost from the beam. Considerably reduced is also the background due to neutral decays of the Φ-meson. 174 events with 5 and 455 events with 4 photons were selected outside the Φ-meson ($2E > 1.04$ GeV). The spectrum of the photon pair masses is shown in Fig.1. π^0-mesons observed in these events were used to separate events of the reaction (1). The main background comes from the following non-resonance processes:

$$e^+e^- \to \gamma\gamma\gamma\gamma \quad \text{(QED)}, \tag{2}$$
$$e^+e^- \to \omega\gamma \to \pi^0\gamma\gamma, \tag{3}$$
$$e^+e^- \to \pi^0\pi^0\gamma \to 5\gamma \quad (\text{besides } \omega\pi^0) \tag{4}$$

The reaction (4) can be due to the polarizability of the neutral pion [12], or intermediate states $\varrho^0\pi^0$ and $f\gamma$, decaying through the modes $\varrho^0 \to \pi^0\ \gamma$ и $f \to 2\pi^0$ respectively.

The five-photon events were fit using energy-momentum balance

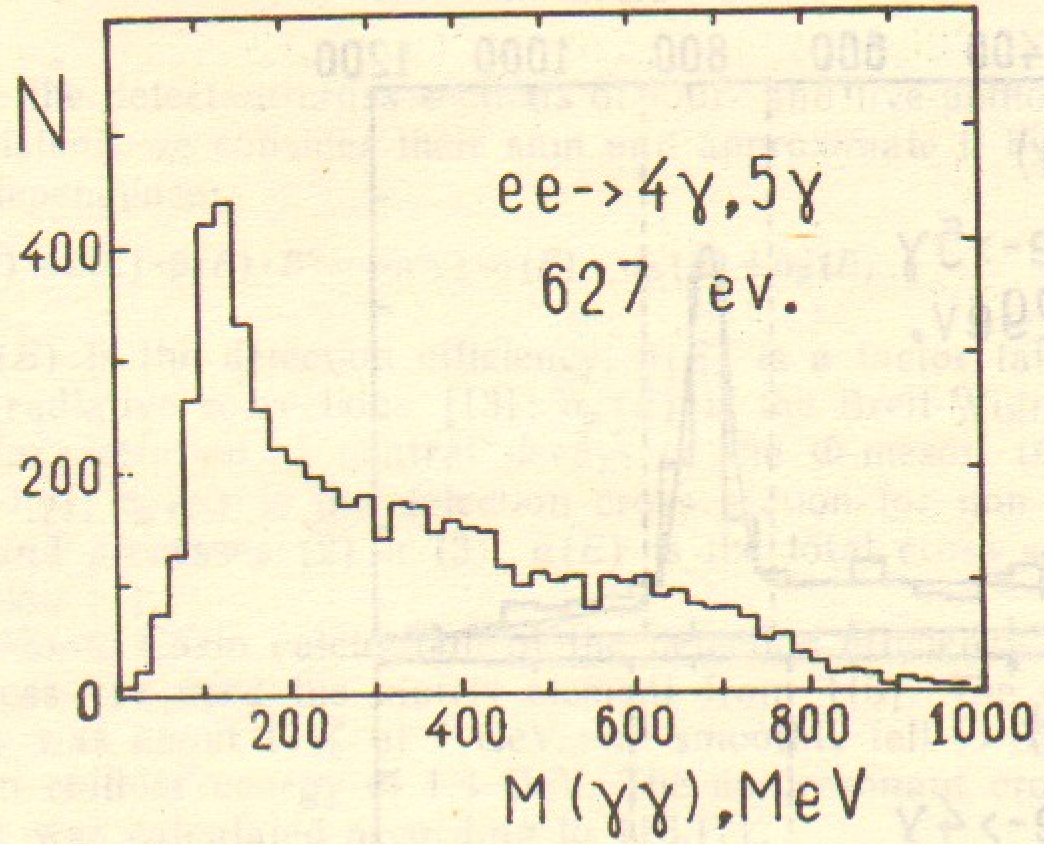

Fig. 1. Invariant mass of photon pairs for events above the Φ-meson ($2E > 1{,}04$ GeV).

with a requirement of two π^0-mesons in the event [10]. A spectrum of invariant masses of a π^0-meson and photon in selected events is shown in Fig. 2*a*. In most events one of the two combinations is close to the ω-meson mass and can be ascribed to the process (1). The process (4) has not been observed. From a sample of five-photon events the following upper limit for the total cross section of this process was placed in the energy range 1.0—1.4 GeV:

$$\sigma_{tot}(e^+e^- \to \pi^0\pi^0\gamma) < 0.2 \text{ nb} \quad (90\% \text{ c.l.}) \tag{5}$$

When two close photons merge or one photon escapes detection through the detector edges, the events due to (1) are detected as four-photon events. In this case for selection of the process (1) events were considered in which at least one π^0-meson was found. For these events we plotted the recoil masses of π^0-mesons (Fig. 2*b*) as well as invariant masses of a π^0-meson and a photon (Fig. 2*c*). A clear peak at the ω-meson mass seen in the figures allows separation of the reaction under study. The detection efficiency for four-photon events is by a factor of 2 higher than that for five-photon events.

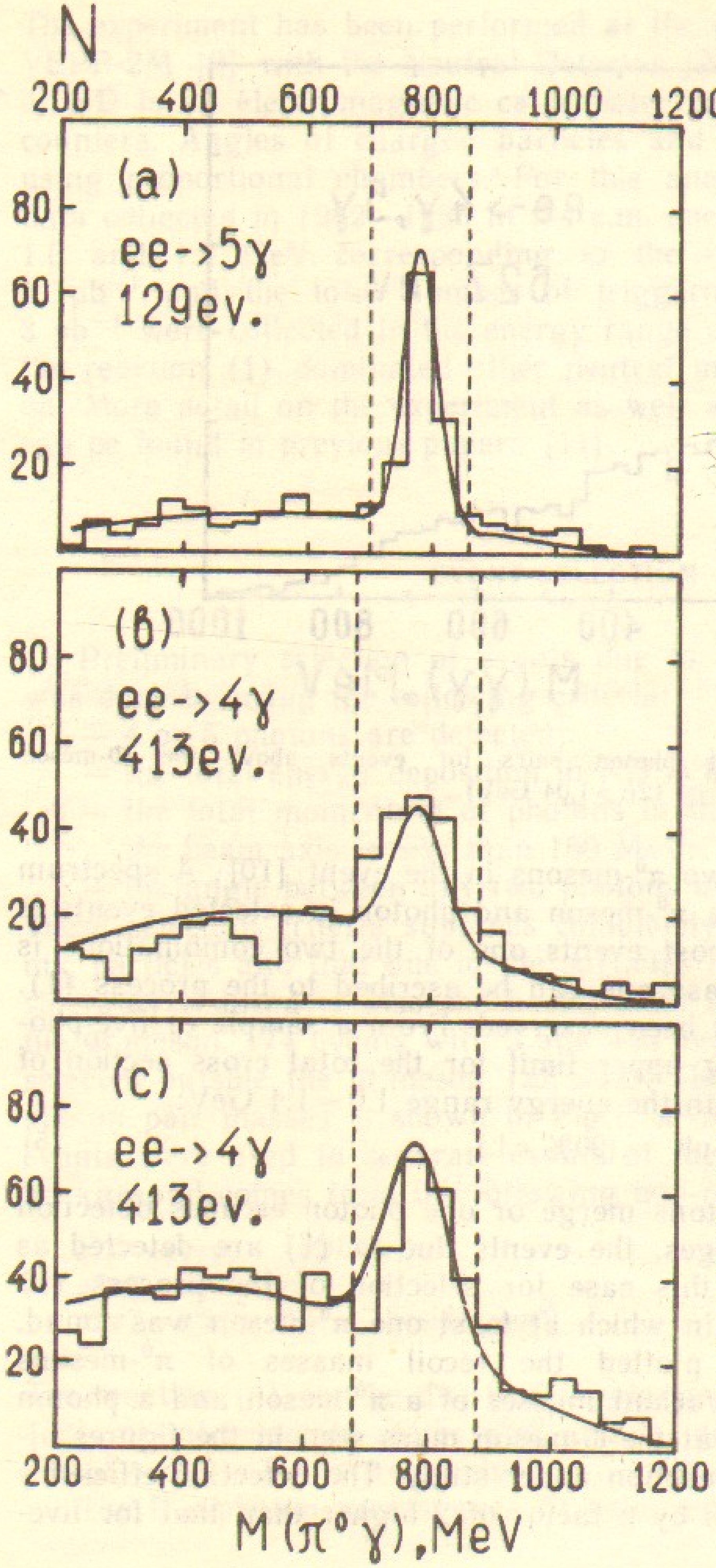

Fig. 2. Separation of events with the ω-meson from spectra of invariant masses: *a*—masses of π^0-mesons and a photon in five-photon events; *b*—recoil masses of π^0-mesons in four-photon events; *c*—masses of π^0-meson and photons in four-photon events. Dashed lines show the boundaries of the cuts, solid lines show the Monte Carlo for $e^+e^-\to\omega\pi^0$. Events are taken at the energy above the Φ-meson ($2E>1.04$ GeV).

DATA ANALYSIS

Since the detection cross sections of four- and five-photon events are consistent, we consider their sum and approximate it by the following dependence:

$$\sigma_{vis}(E)=\varepsilon(E)\cdot\beta(E)\cdot B(\omega\to\pi^0\gamma)\cdot\sigma(E)+\sigma_\Phi(E)+\sigma_B(E) \quad (6)$$

where $\varepsilon(E)$ is the detection efficiency; $\beta(E)$ is a factor taking into account radiative corrections [13]; $\sigma_\Phi(E)$ is the Breit-Wigner cross section for detection of neutral decays of the Φ-meson ($\Phi\to K_S K_L$ and $\Phi\to\eta\gamma$); $\sigma_B(E)$ is the detection cross section for non-resonant background processes (2) и (3), $\sigma(E)$ is the total cross section of the reaction (1).

The Monte Carlo calculation of the detection efficiency [14] for the process (1) used the matrix element from [15]. The detection efficiency was about 11% at 1 GeV and smoothly fell to 8% at the maximum collider energy of 1.4 GeV. The non-resonant cross section $\sigma_B(E)$ was calculated according to [16,17].

From the fit of the detection cross sections in the energy range 1.00—1.04 GeV the resonant cross section $\sigma_\Phi(E)$ as well as the cross section of the reaction (1) were obtained. Using the table value $B(\omega\to\pi^0\gamma)=(8.7\pm0.5)\%$ [1] and the obtained values of $\sigma_\Phi(E)$ and $\sigma_B(E)$, one can derive from (6) the total cross section of (1) (Table 1). Only statistical errors are given in the table. A systematic uncertainty of the cross section arises from the systematic errors in the detection efficiencies and the integrated luminosity, also contributes the error of the table value of $B(\omega\to\pi^0\gamma)$. The total systematic error of 8% was taken into account in further fits.

The obtained cross section of the proccess (1) (Fig. 3) was approximated in the vector dominance model (VDM) taking into account the contributions of the $\varrho(770)$, $\varrho(1250)$ and $\varrho(1600)$ mesons [15, 18]:

$$\sigma(E)=\frac{4\pi\alpha^2P_\omega^3(s)}{3s^{3/2}}\left|\frac{g_{\varrho\omega\pi}}{g_\varrho}F_\varrho(s)+\frac{g_{\varrho_1\omega\pi}}{g_{\varrho_1}}F_{\varrho_1}(s)+\frac{g_{\varrho_2\omega\pi}}{g_{\varrho_2}}F_{\varrho_2}(s)\right|^2$$

$$F_{\varrho_i(s)}=\frac{m_{\varrho_i}^2(s)}{s-m_{\varrho_i}^2+i\sqrt{s}\,\Gamma_{\varrho_i}(s)},\qquad s=4E^2 \quad (7)$$

Table 1

Cross sections of the reaction $e^+e^-\to\omega\pi^0$. Only statistical errors are given. A systematic uncertainty is 8%.

2E, GeV	L (nb^{-1})	N(4γ+5γ)	N(back-ground)	$\sigma_{tot}(e^+e^-\to\omega\pi^0)$, (nb)
1.02	8000	—	—	8.7±1.0
1.05	399	52	17.8	9.1±2.1
1.07	276	41	8.0	12.6±2.6
1.09	270	39	6.1	12.8±2.6
1.11	78	17	1.5	20.9±6.2
1.13	76	9	1.2	10.8±4.9
1.15	80	12	1.1	14.4±5.0
1.17	70	7	0.9	9.4±4.3
1.19	81	7	1.0	8.1±4.0
1.21	178	31	1.9	18.1±3.7
1.23	97	14	1.0	15.0±4.9
1.25	76	14	0.6	20.3±6.4
1.27	87	12	0.6	15.5±5.4
1.29	239	31	1.7	14.8±3.0
1.31	221	28	1.5	15.0±3.3
1.33	166	20	1.1	14.7±3.8
1.35	216	25	1.4	14.6±3.4
1.37	239	39	1.5	21.9±3.9
1.39	219	30	1.3	19.1±4.0

where indices ϱ, ϱ_1 and ϱ_2 refer to the parameters of the ϱ(770), ϱ(1250) and ϱ(1600) mesons respectively, $P_\omega(s)$ is a momentum of the ω-meson, constants g_{ϱ_i} are related to the lepton widths of the mesons through $\Gamma(\varrho_i\to e^+e^-)=4\pi\alpha^2 m_{\varrho_i}/(3g_{\varrho_i}^2)$. The fit of the data was performed using the table values of ϱ(770) and ϱ(1600) parameters [1]. As free parameters we have chosen the coupling con-

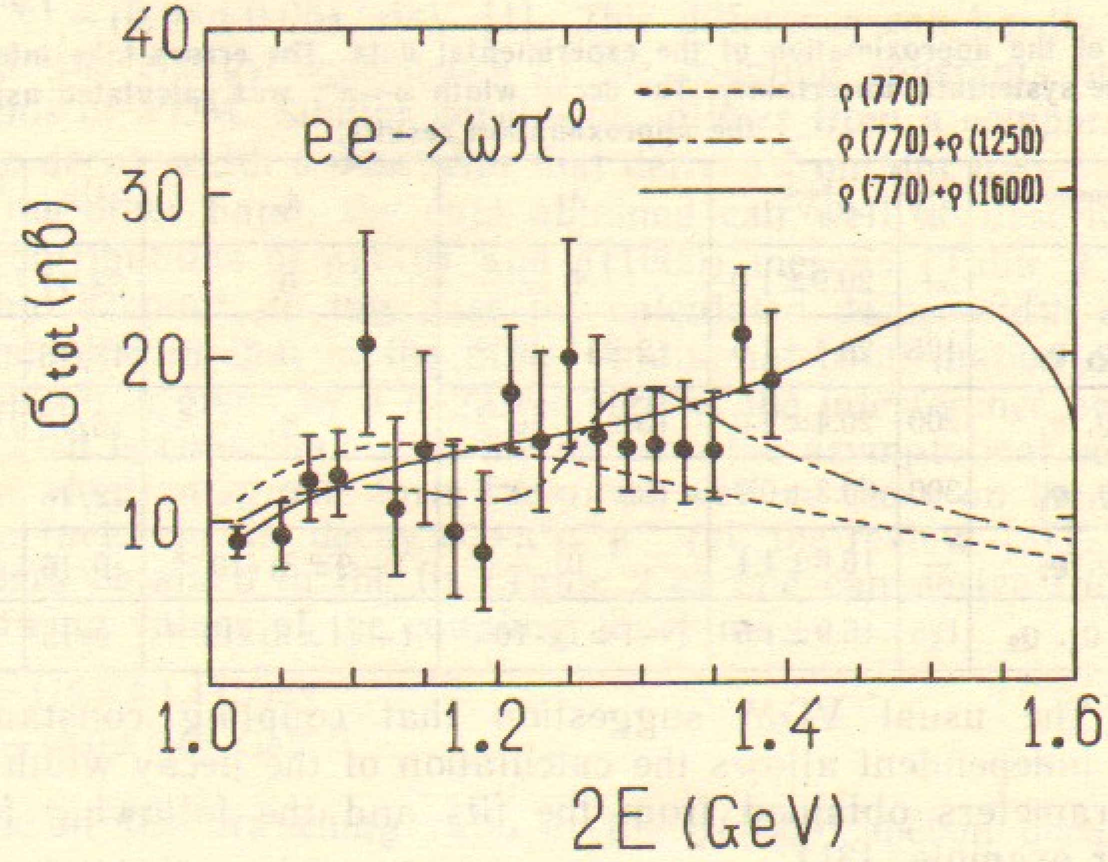

Fig. 3. Total cross section of the process $e^+e^-\to\omega\pi^0$. Curves are obtained from different fits of experimental data (cf. Tables 2 *a, b, e*).

stant $g_{\varrho\omega\pi}$ and the interference amplitudes A_1, A_2 which can be expressed through coupling constants in the following manner:

$$A_i=\frac{g_{\varrho_i\omega\pi}}{g_{\varrho\omega\pi}}\cdot\frac{g_\varrho}{g_{\varrho_i}},\qquad i=1,2 \tag{8}$$

The interference amplitude was assumed to be purely real. Additional check showed that an imaginary part of the interference amplitudes did not influence the fit.

No evident resonance structure is observed in the energy dependence of the total cross section (Fig.3). Therefore in contrast to the previous works devoted to a search for ϱ(1250) (cf. [1]), We have used in the fits the table value of its mass $M=1264$ MeV and several fixed values of its width suggested earlier. Results of the fits are presented in Table 2 and Fig. 3.

The cross section of the reaction (1) is determined by the same vertex as the decay $\omega\to\pi^0\gamma$, therefore in VDM they depend on the same coupling constant. The difference is that in the decay of the ω-meson is on the mass shell, i.e. $q^2=0$, whereas in the reaction (1)

Table 2.

Results of the approximation of the experimental data. The errors take into account the systematic uncertainty. The decay width $\omega\to\pi^0\gamma$ was calculated using the approximation results.

N	Resonances	Γ_{ϱ_1}, MeV	$g_{\varrho\omega\pi}$, (GeV^{-1})	A_1	A_2	χ^2/N_D	$\Gamma(\omega\to\pi^0\gamma)$, MeV
a	ϱ	—	20.9 ± 1.0	0	0	33/17	2.3 ± 0.2
b	ϱ, ϱ_1	125	20.4 ± 1.0	$(2\pm1)\cdot10^{-2}$	0	18/16	2.3 ± 0.2
c	ϱ, ϱ_1	200	20.4 ± 1.0	$(3\pm1)\cdot10^{-2}$	0	15/16	2.4 ± 0.2
d	ϱ, ϱ_1	300	20.3 ± 0.9	$(5\pm1)\cdot10^{-2}$	0	12/16	2.4 ± 0.2
e	ϱ, ϱ_2	—	16.6 ± 1.1	0	$(-9\pm3)\cdot10^{-2}$	9/16	1.2 ± 0.2
f	ϱ, ϱ_1, ϱ_2	125	15.9 ± 1.5	$(-1\pm1)\cdot10^{-2}$	$(-11\pm3)\cdot10^{-2}$	9/15	1.1 ± 0.3

$q^2=s$. The usual VDM suggestion that coupling constants are energy independent allows the calculation of the decay width taking the parameters obtained from the fits and the following formula (cf., for example, [3]):

$$\Gamma(\omega\to\pi^0\gamma)=\frac{1}{3}\alpha P_\gamma^3\left|\frac{g_{\varrho\omega\pi}}{g_\varrho}+\frac{g_{\varrho_1\omega\pi}}{g_{\varrho_1}}+\frac{g_{\varrho_2\omega\pi}}{g_{\varrho_2}}\right|^2, \qquad (9)$$

where P_γ is a photon momentum in the decay $\omega\to\pi^0\gamma$. Results of the calculation are shown in Table 2.

DISCUSSION

In this work we have obtained for the first time the cross section of the process $e^+e^-\to\omega\pi^0$ using the neutral decay mode of the ω-meson. Our results are consistent with the previous studies of the reactions $e^+e^-\to\pi^+\pi^-\pi^0\pi^0$ [6,7] and $\gamma N\to\pi^+\pi^-\pi^0\pi^0 N$ [8].

The observed energy dependence of the cross section of the reaction (1) can not be satisfactorily accounted for by the contribution of the $\varrho(770)$ meson only (Table 2 a), the significance level of such an assumption being about 1%.

Data are well described by the dependence (7), if one additionally takes into account the contribution of the $\varrho(1250)$ meson (Table 2 b—d). In this case, however, the calculated values of the decay width of the ω-meson differ dramatically from the table value $\Gamma(\omega\to\pi^0\gamma)=(0.86\pm0.05)$ MeV [1]. This difference can hardly be ascribed to the energy dependence of the coupling constants or other corrections of VDM. Similar conclusion follows from a comparison of the table decay width $\omega\to3\pi$ with that derived from our data.

On the other hand, the data obtained can well be described by (7) if contributions of $\varrho(770)$ and $\varrho(1600)$ mesons (Table 2 e) are taken into account. In this case the calculated decay width $\omega\to\pi^0\gamma$ is consistent with that in the table. Additional confirmation of such a description is given by a negative sign of the interference amplitude A_2 which is consistent with the data on the asymptotical behaviour of the electromagnetic form factor as well as those on the transient form factor in the decay $\omega\to\pi^0\mu^+\mu^-$ (cf. the review [3]). Using parameters obtained in the fit (Table 2 e) one can derive from (7) the following values of the coupling constants:

$$g_{\varrho\omega\pi}=(16.6\pm1.1)\ \text{GeV}^{-1},\qquad g_{\varrho_2\omega\pi}=(2.0\pm0.6)\ \text{GeV}^{-1}. \qquad (10)$$

the value of the branching ratio of the $\varrho(1600)$ meson decay into $\omega\pi^0$ can also be found:

$$B(\varrho_2\to\omega\pi^0)=\frac{g^2_{\varrho_2\omega\pi}\cdot P^3_\omega(m^2_{\varrho_2})}{12\pi\Gamma_{\varrho_2}}=(8\pm4)\% \qquad (11)$$

The table value of the branching ratio $B(\varrho_2\to4\pi)$ is $(60\pm7)\%$ [1] and apparently includes the value obtained in this paper.

To estimate quantitatively the probability of $\varrho(1250)$ production we have performed the fit of the data taking into account $\varrho(770)$, $\varrho(1250)$ and $\varrho(1600)$ simultaneously (Table 2 f). Results of the fit were used to place an upper limit for the product of the leptonic width of the $\varrho(1250)$ meson with $\Gamma_{\varrho_1}=125$ MeV and the probability of the decay $\varrho_1\to\omega\pi^0$:

$$\Gamma(\varrho_1\to e^+e^-)\cdot B(\varrho_1\to\omega\pi^0)<13\ \text{eV}\ (90\%\ \text{c.l.}). \qquad (12)$$

The value of the obtained upper limit is by a factor of 500 lower than the leptonic widths of the $\varrho(770)$ and $\varrho(1600)$ mesons which are about 7 keV. Since the decay $\varrho_1\to\omega\pi^0$ is believed to be dominant for the $\varrho(1250)$ meson [2], it means that our results rule out the existence of the $\varrho(1250)$ meson.

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ПРОЦЕСС $e^+e^- \to \omega\pi$
В ОБЛАСТИ ЭНЕРГИЙ $2E = 1.0-1.4$ GeV

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