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Yu.G. SHAKHNAZARYAN

Θ - RESONANCE PHOTOPRODUCTION

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The two-photon collisions performed in colliding e^+e^- beams are as helpful for studying hadronic states with the positive charge parity (C=+1) and total moment $J \neq 1$ as one-photon channel of e^+e^- annihilation for studying vector mesons with quantum numbers $J^{PC} = 1^{--}$.

In the recent years, at PETRA and SPEAR storage rings they have been studying intensively the process [1-3]

$$e^+e^- \rightarrow e^+e^-\pi^+\pi^-\pi^+\pi^-. \qquad (1)$$

It was revealed that the process was due mainly to the reaction

$$\gamma\gamma \rightarrow \rho^\circ\rho^\circ \rightarrow \pi^+\pi^-\pi^+\pi^-. \qquad (2)$$

Both at PETRA [1] and SPEAR [2], a considerable increase of the cross section of this process not far from the threshold of $\rho^\circ\rho^\circ$-pair production was found. In a number of theoretical works [4-6] the mentioned increase is connected with the formation of resonance decaying into $\rho^\circ\rho^\circ$.

On the basis of the analysis of angular correlations in final state of the process (2) in the invariant mass region $1.2 < M_{4\pi} < 2.0$ GeV in Ref.[3] a noticeable contribution of states with $J^P = 0^-$ and 2^- into the reaction $\gamma\gamma \rightarrow \rho^\circ\rho^\circ$ is excluded. The data show that at $M_{4\pi} < 1.7$ GeV the $\rho^\circ\rho^\circ$ contribution has predominantly the quantum numbers $J^P = 0^+$, whereas the share of 2^+-state is small. At masses $M_{4\pi} > 1.7$ GeV the 2^+-state contribution becomes dominating.

On the assumption that the increase of the cross section of process (2) near the threshold of the $\rho^\circ\rho^\circ$-pair production is due to the recently discovered in the radiative decay $\psi \to \gamma\eta\eta$ θ (1640)-resonance [7], the following relation is given in Ref. [3] for the width $\Gamma(\theta \to \gamma\gamma)$ and $B(\theta \to \rho^\circ\rho^\circ)$:

$$\Gamma(\theta \to \gamma\gamma) \cdot B(\theta \to \rho^\circ\rho^\circ) < 1.2 \text{ keV}. \qquad (3)$$

While studying the decay $\psi \to \gamma\pi^+\pi^-\pi^+\pi^-$ at SPEAR [8], they found out an essential contribution of the channel $\psi \to \gamma\rho^\circ\rho^\circ$ into this decay in the invariant mass region $M_{\rho\rho} < 2.0$ GeV. For the parameters of the possible resonance in the $\rho^\circ\rho^\circ$ system they gave the following values:

$$M(\theta) = 1.65 \pm 0.05 \text{ GeV}, \qquad \Gamma(\theta) = 0.20 \pm 0.10 \text{ GeV}. \qquad (4)$$

The authors of [9] reported at the Paris conference on the observation by the TASSO group at PETRA of the narrow structure at 2.1 GeV in the reaction (2) on the background of a smoothly falling tail of the main peak near the threshold of the $\rho^\circ\rho^\circ$- pair production. Interpreting this structure as resonance and fitting the experimental points by the nonrelativistic formula of Breit-Wigner, the authors of the mentioned work obtained for the parameters of the resonance (call it θ' (2100)) the following values:

$$M(\theta') = 2.100 \pm 0.020 \text{ GeV}, \qquad \Gamma(\theta') = 0.030 \pm 0.034 \text{ GeV} \qquad (5)$$

The width of the decay of this resonance into two γ -quanta is determined by the value

$$\Gamma(\theta' \to \gamma\gamma) = [1.25 \pm 0.5 \text{ (stat)} \pm 0.5 \text{ (syst.)}] / (2J + 1) \text{ keV} \qquad (6)$$

where J is the spin of resonance.

It is of interest to examine the possibility of studying the discussed θ and θ' resonances in the other processes, too, particularly in the photoproduction

$$\gamma p \to \theta(\theta') p. \qquad (7)$$

As far as the available at present data on these resonances are rather poor, we shall restrict ourselves to the Born amplitude with the ρ° -meson exchange when studying the process (7) at low energies. We realize fully that such a consideration will allow us to have only a notion about the order of the expected cross sections and the character of angular distributions.

Suppose $\theta(\theta')$ resonance has the quantum numbers $J^{PC} = 0^{++}$. In the general case, the vertex of the transition $0^+ \to 1^- 1^-$, where parity is conserved, is described by two independent combinations

$$T = \epsilon_\mu(q_1)\epsilon_\nu(q_2)\left(g_1\delta_{\mu\nu} + \frac{1}{M^2} g_2 q_{2\mu} q_{1\nu}\right), \qquad (8)$$

where q_1 and q_2 are 4-momenta of vector mesons, g_1 and g_2 are dimensional coupling constants, M is θ -resonance mass (what is said is to be applied to θ' -resonance either). At such a choice of the vertex function the $\theta \to \rho^\circ\rho^\circ$ decay width is defined by the expression

$$\Gamma(\theta \to \rho^\circ\rho^\circ) = \frac{1}{32\pi M}\sqrt{1 - \frac{4m_\rho^2}{M^2}} \left\{ 2g_1^2 + \left[\left(\frac{M^2}{2m_\rho^2} - 1\right) g_1 - \left(\frac{M^2}{4m_\rho^2} - 1\right) g_2 \right]^2 \right\}. \qquad (9)$$

The additional requirement of the gradient invariance leads to that the radiative decay of θ -resonance is described by a single structure which we take as

$$T = \frac{1}{M} g_{\theta\rho\gamma}\, e_\mu(k)\epsilon_\nu(q)\left[(kq)\delta_{\mu\nu} - q_\mu k_\nu\right]. \qquad (10)$$

Here the decay width is

$$\Gamma(\theta \to \rho^\circ \gamma) = \frac{g^2_{\theta\rho\gamma}}{32\pi} M \left(1 - \frac{m^2_\rho}{M^2}\right)^3 . \tag{11}$$

Finally, the $\theta \to \gamma\gamma$ transition vertex has the form

$$T = \frac{1}{M} g_{\theta\gamma\gamma} e_\mu(k_1) e_\nu(k_2) \left[(k_1 k_2)\delta_{\mu\nu} - k_{2\mu}\, k_{1\nu} \right] ; \tag{12}$$

and the corresponding width is

$$\Gamma(\theta \to \gamma\gamma) = \frac{g^2_{\theta\gamma\gamma}}{64\pi} M . \tag{13}$$

The coupling constants $g_{\theta\rho\gamma}$ and $g_{\theta\gamma\gamma}$, as distinct from g_1 and g_2, are dimensionless.

In order to calculate the cross section of the process (7) on the basis of the Born diagram with ρ°-meson exchange, we need besides (10) also the vertex $p\rho^\circ p$ which we shall take in a standard form

$$\bar{u}(p_2) \left[\gamma_\alpha G_V - \frac{i}{4m} (\gamma_\alpha \hat{f} - \hat{f} \gamma_\alpha) G_T \right] u(p_1) \varepsilon_\alpha(f),$$

where p_1 and p_2 are 4-momenta of the proton in initial and final states, $f = p_1 - p_2$, m is the proton mass, the constants G_V and G_T are well known: $G_V = 2.858$, $G_T = 10.5746$.

Thus, for the differential cross section of the process (7) we arrive at the expression

$$\frac{d\sigma}{dt} = \frac{g^2_{\theta\rho\gamma}}{4\pi} \frac{1}{(m^2_\rho - t)^2} \left\{ -\frac{t}{M^2} \left(\frac{M^2 - t}{s - m^2} \right)^2 (G_V + G_T)^2 + \right.$$

$$\left. + 2\left[\left(1 - \frac{t}{M^2}\right)\left(1 + \frac{M^2}{s - m^2}\right) - \frac{s}{M^2} \left(\frac{M^2 - t}{s - m^2} \right)^2 - 1 \right] \left(G_V^2 - \frac{t}{4m^2} G_T^2 \right) \right\} , \tag{14}$$

where s is total energy square in c.m.s., $t = -f^2 < 0$ is transferred momentum square. Via this formula we can estimate the θ- and θ'-resonances photoproduction cross sections, if the coupling constant $g_{\theta\rho\gamma}$ is known for them.

We shall start with θ' (2100)-resonance. At the value $J = 0$ from (6) we have

$$\Gamma(\theta' \to \gamma\gamma) = 1.25 \text{ keV}. \tag{15}$$

On the basis of the vector dominance model we find out

$$\Gamma(\theta' \to \rho^\circ \gamma) = 2 \frac{(f^2_\rho / 4\pi)}{\alpha} \left(1 - \frac{m^2_\rho}{M^2}\right)^3 \Gamma(\theta' \to \gamma\gamma) \simeq 445 \text{ keV}, \tag{16}$$

which corresponds to the value $g^2_{\theta'\rho\gamma}/4\pi \simeq 2.6 \cdot 10^{-3}$.

Now we can estimate the cross section of the reaction (7) whose threshold for θ'-resonance is $K_{\text{thresh.}} = 4.45$ GeV ($s_{\text{thresh.}} = 9.23$ GeV^2). The differential cross section of this process as a function of the production angle ϑ in c.m.s. (ϑ is the angle between momenta of γ-quantum and θ-resonance) at some values of photon energy in the range 4.5 - 10 GeV in lab is given in Fig.1. The distribution over angle ϑ, being practically isotropic near the reaction threshold, becomes more and more unisotropic as the energy increases. Fig.2 shows the integrated over t cross section as a function of γ-quantum energy. The cross section increases from 0.34 μb at $K = 4.5$ GeV up to 4.6 μb at $K = 10$ GeV, however the cross section growth becomes slower as energy increases.

If we try to bind the vertices $\theta\rho^\circ\gamma$ and $\theta\rho^\circ\rho^\circ$ using the vector dominance model, we shall get the following relation between the widths

$$\Gamma(\theta \to \rho^\circ \rho^\circ) = \frac{1}{64\alpha} \left(\frac{f^2_\rho}{4\pi} \right) \left(1 - \frac{m^2_\rho}{M^2}\right)^{-3} \sqrt{1 - \frac{4m^2_\rho}{M^2}} \times$$

$$\times\left[8\left(1-\frac{m_\rho^2}{M^2}\right)^2+\left(1+\frac{2m_\rho^2}{M^2}\right)^2\right]\Gamma(\theta\to\rho^0\gamma). \qquad (17)$$

For θ' -resonance by this formula we obtain the estimate

$$\Gamma(\theta'\to\rho^0\rho^0)\simeq 15.2 \text{ MeV}. \qquad (18)$$

Let us turn now to θ (1650)-resonance. The absence of necessary data on this resonance (inequality (3) contains insufficient information) does not allow to find constant $g_{\theta\rho\gamma}$ and get analogous quantitative estimates for the photoproduction cross section. Using expression (14) one may predict the shape of angular distributions as well as the dependence of the total cross section on γ -quantum energy which are shown respectively in Figs.3 and 4 in the energy range 3.2 - 10 GeV (one may consider the values of $d\sigma/dt$ and σ along the ordinate axis being given in the relative units *). Note that the photoproduction threshold of θ (1650)-resonance is $K_{\text{thresh.}}$ = 3.1 GeV ($S_{\text{thresh.}}$ = 6.7 GeV^2).

Consider now the case when θ (θ')-resonance has quantum numbers $J^{PC}=2^{++}$. The vertex of $2^+\to 1^-1^-$ transition with parity preserved, is described in the general case by five independent combinations

* The values indicated on the ordinate axis (in units of μb/GeV^2 in Fig.3 and μb in Fig.4) correspond to the value of coupling constant $g_{\theta\rho\gamma}$ which is obtained on the basis of the vector dominance model (formula (17)) and the upper limit of inequality (3) at the values (4).

$$T=\epsilon_\mu(q_1)\epsilon_\nu(q_2)\epsilon_{\alpha\beta}(p)\Big[\frac{1}{M^2}\Big(g_1\delta_{\mu\nu}+\frac{1}{M^2}g_2q_{2\mu}q_{1\nu}\Big)q_{1\alpha}q_{1\beta}+g_3(\delta_{\mu\alpha}\delta_{\nu\beta}+\delta_{\mu\beta}\delta_{\nu\alpha})+\frac{1}{M^2}g_4(\delta_{\mu\alpha}q_{1\beta}+\delta_{\mu\beta}q_{1\alpha})q_{1\nu}+\frac{1}{M^2}g_5(\delta_{\nu\alpha}q_{1\beta}+\delta_{\nu\beta}q_{1\alpha})q_{2\mu}\Big], \qquad (19)$$

where $\epsilon_{\alpha\beta}(p)$ is polarization tensor describing the particle with spin J=2.

For the decay $\theta\to\rho^0\rho^0$, in virtue of particle identity in final state the number of independent combinations is four:

$$T=\epsilon_\mu(q_1)\epsilon_\nu(q_2)\epsilon_{\alpha\beta}(p)\Big\{\frac{1}{M^2}\Big(g_1\delta_{\mu\nu}+\frac{1}{M^2}g_2q_{2\mu}q_{1\nu}\Big)q_{1\alpha}q_{1\beta}+g_3(\delta_{\mu\alpha}\delta_{\nu\beta}+\delta_{\mu\beta}\delta_{\nu\alpha})+\frac{1}{M^2}g_4\big[(\delta_{\mu\alpha}q_{1\nu}-\delta_{\nu\alpha}q_{2\mu})q_{1\beta}+(\delta_{\mu\beta}q_{1\nu}-\delta_{\nu\beta}q_{2\mu})q_{1\alpha}\big]\Big\}. \qquad (20)$$

In order to get the vertex of $\theta\to\rho^0\gamma$ transition, it is necessary to impose on (19) the requirement of gradient invariance:

$$T=e_\mu(K)\epsilon_\nu(q)\epsilon_{\alpha\beta}(p)\Big\{\frac{1}{M^2}g_1\big[\delta_{\mu\nu}K_\alpha K_\beta-\tfrac{1}{2}(\delta_{\mu\alpha}K_\beta+\delta_{\mu\beta}K_\alpha)K_\nu\big]+\frac{1}{M^4}g_2\big[q_\mu K_\alpha K_\beta-\tfrac{1}{2}(Kq)(\delta_{\mu\alpha}K_\beta+\delta_{\mu\beta}K_\alpha)\big]K_\nu+\frac{1}{M^2}g_5\big[\delta_{\nu\alpha}(q_\mu K_\beta-(Kq)\delta_{\mu\beta})+\delta_{\nu\beta}(q_\mu K_\alpha-(Kq)\delta_{\mu\alpha})\big]\Big\}, \qquad (21)$$

i.e. the vertex we are interested in is described by three independent structures.

It is obvious that in the absence of sufficient experimental data the presence of three unknown coupling constants allows to obtain in this case neither quantitative nor qualitative predictions for the cross section of θ (θ')-resonance photoproduction.

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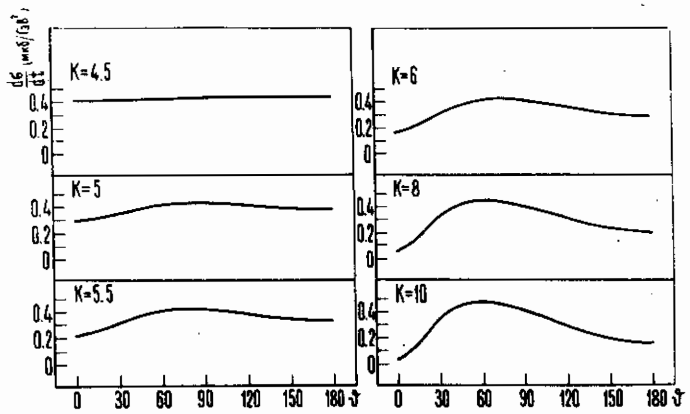

Fig.1

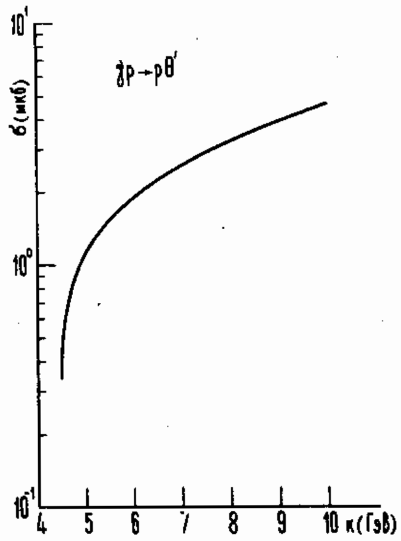

Fig.2

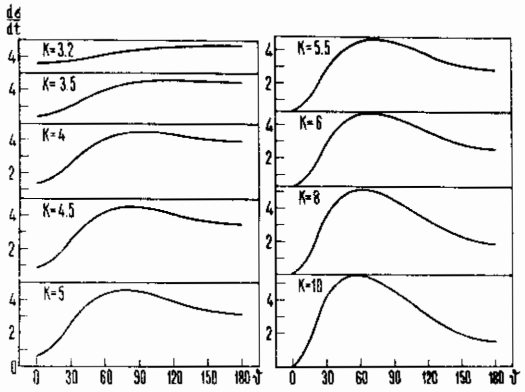

Fig.3

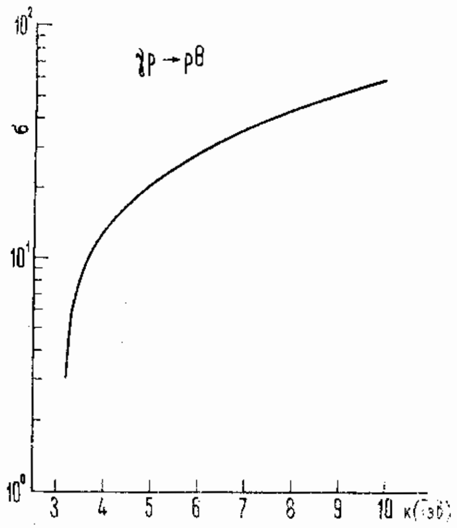

Fig.4

FIGURE CAPTIONS

Fig.1. Differential cross section of the process $\gamma p \to p\theta'(2100)$ as a function of the production angle ϑ in c.m.s. at some values K (in GeV) of γ-quantum energy in lab.

Fig.2. Integral cross section of the process $\gamma p \to p\theta'(2100)$ as a function of γ-quantum energy in lab.

Fig.3. The shape of the dependence of differential cross section of the process $\gamma p \to p\theta$ (1650) on the production angle ϑ in c.m.s. at some values K (in GeV) of γ-quantum energy in lab (the values on the ordinate axis are given in the relative units; see the text).

Fig.4. The shape of the dependence of integral cross section of the process $\gamma p \to p\theta$ (1650) on the γ-quantum energy in lab (the values on the ordinate axis are given in the relative units; see the text).

REFERENCES

1. TASSO Collab., Brandelik R., Braunschweig W., Gather K. et al. Rho-Rho Production by Two Photon Scattering.- Phys.Lett., 1980, vol.97B, p.448-452.
2. Burke D.L., Abrams G.S., Alam M.S. et al. A Measurement of the Cross Section for Four-Pion Production in $\gamma\gamma$ Collisions at SPEAR. - Phys. Lett., 1981, vol.103B, p.153-156.
3. TASSO Collab., Althoff M., Braunschweig W., Gather K. et al. Angular Correlations in $\gamma\gamma \to \rho^\circ\rho^\circ$ near Threshold. DESY Report 82-062, 1982.
4. Godbole R.M., Sarma K.V.L. Is the Threshold Enhancement in $\gamma\gamma \to \rho^\circ\rho^\circ$ Evidence for an Isoscalar, $J^{PC} = 0^{++}$ Exotic State? - Phys.Lett., 1982, vol.109B, p.504-508.
5. Li B.A., Liu K.F. In Search of $Q^2\bar{Q}^2$ Mesons in $\gamma\gamma$ Reactions. - SLAC-PUB-2783 (T/E), 1981.
6. Achasov N.N., Devyanin S.A., Shestakov G.N. Two Photon Production of Four-Quark States.- Phys.Lett., 1982, vol.108B, p.134-139.
7. Edwards C., Partridge R., Peck C. et al. Evidence for an $\eta\eta$ Resonance in J/ψ Radiative Decays. - Phys.Rev.Lett., 1982, vol.48, p.458-461.
8. Burke D.L., Trilling G.H., Abrams G.S. et al. Observation of the Decay $\psi \to \gamma\rho^\circ\rho^\circ$. - Phys.Rev.Lett., 1982, vol.49, p.632-635.
9. TASSO Collab., Luke D. Recent Results from TASSO at PETRA. - DESY Report 82-073, 1982.

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Редактор Л.П.Мукаян

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