Production of an exotic resonance in $\gamma\gamma \to \rho\rho$

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A case is made for the hypothesis that an exotic meson with $I = 2$, $J^P = 2^+$, and $m_E \approx 1.4$ GeV has been discovered in $\gamma\gamma \to \rho^0\rho^0$ and $\gamma\gamma \to \rho^+\rho^-$ reactions.

A significant increase in the cross section for the reaction $\gamma\gamma \to \rho^0\rho^0$ near its threshold has recently been observed and studied in some detail (see Refs. 1 and 2 and the review by Kolanoski[3]). The JADE group has recently observed[3] that there is no corresponding increase in the reaction $\gamma\gamma \to \rho^+\rho^-$. This phenomenon was predicted in our earlier papers.[4] Using the vector-dominance model and the predictions of the MIT bag model for the wave functions of four-quark states,[5] we showed[4] that the increase in the cross section for the reaction $\gamma\gamma \to \rho^0\rho^0$ can be attributed to the production of tensor $q^2\bar{q}^2$ states, but there should be no corresponding increase in the reaction $\gamma\gamma \to \rho^+\rho^-$. The reason for these conclusions is that the reaction $\gamma\gamma \to \rho\rho$ gives rise to several $q^2\bar{q}^2$ tensor states, one of which, which is clearly exotic with an isospin $I = 2$, interferes in different ways with the isoscalar resonances in the $\gamma\gamma \to \rho^0\rho^0$ and $\gamma\gamma \to \rho^+\rho^-$ channels.

In this letter we wish to discuss some phenomena observed in $\gamma\gamma \to \rho\rho$ reactions, avoiding to the extent possible any overly specific model-based assumptions, e.g., those associated with the MIT bag model. Instead we will use only the most general theoretical considerations and models. As a result, we conclude that an exotic resonance with an isospin $I = 2$, $J^P = 2^+$, and $m \approx 1.4$ GeV has been detected in the reaction $\gamma\gamma \to \rho^0\rho^0$.

Figure 1 shows data on the $\gamma\gamma \to \rho\rho$ reactions. The TASSO and CELLO data on the reaction $\gamma\gamma \to \rho^0\rho^0$ are slightly different, but both sets of data "unanimously" demonstrate qualitatively an increase with a peak at ~ 1.5 GeV near the reaction threshold.

A question of fundamental importance for a resonance interpretation of the increase in the $\gamma\gamma \to \rho^0\rho^0$ cross section is whether it has definite quantum numbers.

We will show that the CELLO results[2] justify the assumption that the increase in the $\gamma\gamma \to \rho^0\rho^0$ cross section has the quantum numbers of a tensor meson, $J^P = 2^+$. In the first place, the CELLO group found[2] that for $\gamma\gamma \to \rho^0\rho^0 \to 4\pi$ events selected in the intervals 1.3 GeV $< W_{\gamma\gamma} < 2.3$ and 0.66 GeV $< m_{\pi^+\pi^-} < 0.86$ GeV there is no dependence on the emission angle of the ρ^0 meson in the $\gamma\gamma$ c.m. frame ($\cos\theta\rho$; see Fig. 2a). This means that an S wave is playing a leading role in the $\rho^0\rho^0$ system; i.e., we have $J^P = 0^+$ or $J^P = 2^+$ for the state of the $\rho^0\rho^0$ system. That P-wave states with $J^P = 0^-$ and 2^- are unimportant in the reaction $\gamma\gamma \to \rho^0\rho^0$ is confirmed by the results of the TASSO group.[1] Second, the CELLO group found that the element ρ^H_{00} ($\cos\theta_\rho$) of the spin density matrix of the ρ^0 meson in the "helicity" system vanishes at $|\cos\theta_\rho| = 1$

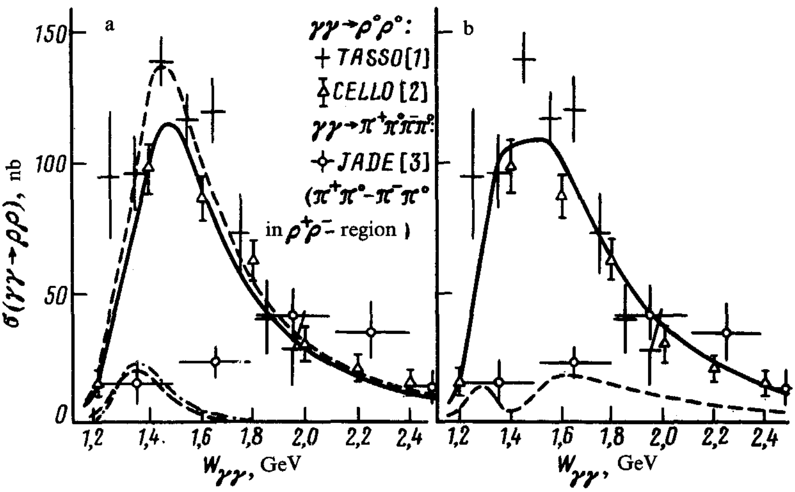

FIG. 1. a: $\sigma(\gamma\gamma\to\rho^0\rho^0)$. Solid curve—Best description of the CELLO data ($m_E = 1.4$ GeV, $\Gamma_E^1 = 2$ GeV, $\Gamma_E^0 = 0.3$ GeV) [$\Gamma_{E\gamma\gamma} \approx 6$ keV; see (3)]; dashed curve—best description of the TASSO data ($m_E = 1.4$ GeV, $\Gamma_E^1 = 2.3$ GeV, $\Gamma_E^0 = 0.29$ GeV) [$\Gamma_{E\gamma\gamma} \approx 6.9$ keV; see (3)]. $\sigma(\gamma\gamma\to\rho^+\rho^-)$: Dashed and dot-dashed curves—the same as the solid and dashed curves; respectively, for $\gamma\gamma\to\rho^0\rho^0$. b: Solid curve—$\sigma(\gamma\gamma\to\rho^0\rho^0)$; dashed curve—$\sigma(\gamma\gamma\to\rho^+\rho^-)$ ($m_E = 1.33$ GeV, $\Gamma_E^1 = 1.4$ GeV, $\Gamma_E^0 = 0.23$ GeV, $m_C = 1.6$ GeV, $\Gamma_C^1 = 1$ GeV, $\Gamma_C^0 = 0.6$ GeV) [$\Gamma_{E\gamma\gamma} \approx 4.2$ keV, $\Gamma_{C\gamma\gamma} \approx 3$ keV; see (3)].

(Fig. 2b); i.e., the increase in the $\gamma\gamma\to\rho^0\rho^0$ cross section is caused primarily by γ rays with helicities $|\lambda_\gamma - \lambda'_\gamma| = 2$. This means that the increase in the $\gamma\gamma\to\rho^0\rho^0$ cross section has the quantum numbers $J^P = 2^+$. For the $J^P = 0^+$ state in the $\rho^0\rho^0$ system the elements of the spin density matrix of the ρ^0 meson are completely independent of $\cos\theta_\rho$.

We thus have every basis to assume that the increase in the $\gamma\gamma\to\rho^0\rho^0$ cross section is of a resonance origin. If so, what does the absence of an analogous increase in the

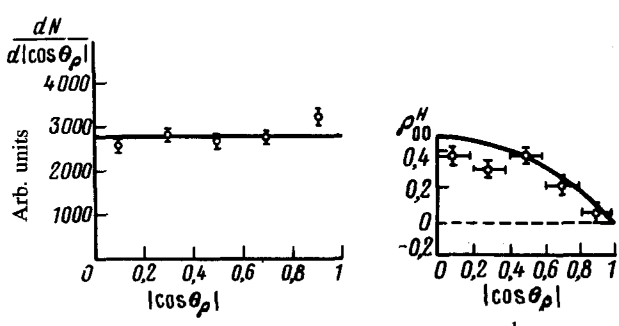

FIG. 2. a—Distribution in $|\cos\theta\rho|^2$ of events in the reaction $\gamma\gamma\to\rho^0\rho^0\to\pi^+\pi^-\pi^+\pi^-$; b—$\rho_{00}^H(\cos\theta_\rho)$ an element of the spin density matrix of the ρ^0 meson in the helicity system[2]; the curve is $(1/2)\sin^2$ (Refs. 4 and 6).

$\gamma\gamma\to\rho^+\rho^-$ cross section mean? The physically most plausible and at the same time the most elegant explanation is that the $\gamma\gamma\to\rho^0\rho^0$ reaction involves the production of at least one resonance with an isospin $I=0$ and one with $I=2$. These resonances have approximately equal masses and cancel out in the reaction $\gamma\gamma\to\rho^+\rho^-$.

It follows from general considerations based on isotopic invariance that

$$A(\gamma\gamma\to\rho^0\rho^0) = \frac{1}{3}A(0) + \frac{2}{3}A(2), \tag{1}$$

$$A(\gamma\gamma\to\rho^+\rho^-) = \frac{\sqrt{2}}{3}A(0) - \frac{\sqrt{2}}{3}A(2),$$

where $A(0)$ and $A(2)$ are the production amplitudes of the states with isospins 0 and 2, respectively. The identity of the ρ^0 mesons is incorporated in the normalization of the amplitude $A(\gamma\gamma\to\rho^0\rho^0)$. It can be seen from (1) that while the $I=0$ and 2 contributions add up in the reaction $\gamma\gamma\to\rho^0\rho^0$, it is their difference that figures in the reaction $\gamma\gamma\to\rho^+\rho^-$, since the contribution with $I=2$ changes sign.

Furthermore, the vector-dominance model $\gamma\gamma\to\rho^0\rho^0\to R+R'\ldots\to\rho^0\rho^0$ and $\gamma\gamma\to\rho^0\rho^0\to R+R'+\ldots\to\rho^+\rho^-$ logically leads to the conclusion that the resonances with approximately equal masses $(R, R'+,\ldots)$ add up in the reaction $\gamma\gamma\to\rho^0\rho^0$ because of a factorization of the coupling constants irrespective of their isotopic spin.

We restrict the discussion here to two tensor resonances. We call the resonance with $I=0$ "C" and that with $I=2$ "E". We also consider the well-known resonance $f(1273, 2^+)$, $I=0$. To calculate their contributions to the cross sections $\gamma\gamma\to\rho^0\rho^0$ and $\rho^+\rho^-$, we use the standard relativistic Breit-Wigner formulas. In the widths of the resonances, we single out the contributions from the decays $R\to\rho\rho$, which vary rapidly over the interval $s=W^2_{\gamma\gamma}$ of interest here:

$$\Gamma_R(s) = \Gamma_R^0 + \Gamma_{R\rho\rho}(s), \qquad \Gamma_{f\rho\rho}(s) = 3\Gamma_{f\rho^0\rho^0}(s),$$

$$\Gamma_{C\rho\rho}(s) = 3\Gamma_{C\rho^0\rho^0}(s),\ \Gamma_{E\rho\rho}(s) = 1{,}5\Gamma_{E\rho^0\rho^0}(s),\ \Gamma_{R\rho^0\rho^0}(s) = \Gamma_R^1 F_{\rho^0\rho^0}(s). \tag{2}$$

Here $F_{\rho^0\rho^0}<1$ is the phase volume of the system of unstable $\rho^0\rho^0$ mesons. In the spirit of the vector-dominance model, we assume that

$$\Gamma_{R\gamma\gamma} = \left(\frac{4\pi\alpha}{f_\rho^2}\right)^2 r_R\Gamma_R^1, \tag{3}$$

and we assume that the f, C, and E mesons are produced in the same spin amplitudes, since the f meson is also produced in $\gamma\gamma$ collisions, as we know, from $\gamma\gamma\to\pi\pi$ reactions,[6] for γ rays with $|\lambda_\gamma-\lambda'_\gamma|=2$. For simplicity, we assume that the parameter r_R in (3) is common to all three resonances ($r_R=r$), and we determine it from data on the f meson.[7]

Assuming that the entire decay $f\to\pi^+\pi^-\pi^+\pi^-$ occurs through the channel

$f \to \rho^0\rho^0$; using $BR(f \to \pi^+\pi^-\pi^+\pi^-) = 2.9\%$, $BR(f \to \gamma\gamma) = 0.0015\%$, and $F_{\rho^0\rho^0}(m_f^2) = 0.53 \times 10^{-2}$; and setting $(4\pi\alpha/f_\rho^2) = 10^{-5}$, we find $r \approx 0.3$.

The most surprising result of the fit of the data is that all the phenomena observed near the threshold for the reactions $\gamma\gamma \to \rho^0\rho^0$ and $\gamma\gamma \to \rho^+\rho^-$ can be explained in terms of simply two resonances: the well-known f meson and the exotic new E meson (Fig. 1a). In this case, the permissible values of m_E are restricted quite strongly to the interval 1.4–1.45 GeV.

The incorporation of the C resonance slightly expands the interval of allowed masses of the E meson ($1.3 < m_E < 1.5$ GeV), while the restrictions on m_C are very indistinct ($1.4 < m_C < 1.8$ GeV). The data are consistent with a significant contribution of the C resonance. Using it, we can even improve the agreement of the theoretical description of the reaction $\gamma\gamma \to \pi^+\pi^0\pi^-\pi^0$ with experimental data at $W_{\gamma\gamma} > 1.5$ GeV (Fig. 1b). However, the problem of fitting the theoretical curves to the data on the $\gamma\gamma \to \pi^+\pi^0\pi^-\pi^0$ reaction in this region cannot be assigned much weight, since no $\gamma\gamma \to \rho^+\rho^- \to \pi^+\pi^0\pi^-\pi^0$ events have been identified in the $\gamma\gamma \to \pi^+\pi^0\pi^-\pi^0$ reaction.[3]

Analysis of the data suggests that a strong coupling of the E meson is strongly coupled to with the $\rho\rho$ system: $\Gamma_E^1 \sim 1$ GeV (see also the Fig. 1 caption).

We are convinced that the data in the region $1.2 < W_{\gamma\gamma} < 1.8$ GeV cannot be described by a resonance with $I = 0$ and a background with $I = 2$.

We do not know of any well-grounded nonresonance explanations for the increase in the cross section for the reaction $\gamma\gamma \to \rho^0\rho^0$ that has been observed near the threshold. Furthermore, we see no other way to interpret this increase without a resonance. We are thus forced to conclude that an exotic meson with $I = 2$, $J^P = 2^+$, and $m_E \approx 1.4$ GeV, containing at least four quarks, $q^2\bar{q}^2$, has been discovered in the reaction $\gamma\gamma \to \rho^0\rho^0$.

This question is discussed in more detail in a preprint.[8]

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