$\eta(1475)$ and $f_1(1420)$ resonances in $J/\psi \to \gamma(\rho\rho,\ \gamma\rho^0,\ \gamma\phi)$ decays and $\gamma\gamma^*$ collisions

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ABSTRACT

- We resolve the contradiction between the suppression of the $\eta(1475) \to \gamma\gamma$ decay and the strong couplings of the $\eta(1475)$ to the $\rho\rho$, $\omega\omega$, and $\gamma\rho^0$ channels by taking into account the effect of the heavy vector mesons $\rho'^{\,0}$, ω', ϕ'.
- This lead us to the explanation of the resonancelike Q^2 dependence on the $\gamma\gamma^*(Q^2) \to K\bar{K}\pi$ reaction cross section by $\eta(1475)$ production, which is an alternative to the conventional explanation of dependence by $f_1(1420)$ production.
- To check our scenario and resolve the difficulties accumulated in understanding properties of the $\eta(1475)$, the definition of the spin-parity of resonance contributions, R, in $\gamma\gamma^*(Q^2)\to R\to K\bar{K}\pi$ and $J/\psi\to\gamma R\to\gamma(\gamma\rho^0,\gamma\phi)$ are required.

OUTLINE

1. **Introduction**, some general remarks
2. **Paradox** of the $\eta(1475) \to \rho^0\rho^0$, $\gamma\rho^0$, and $\gamma\gamma$ decays
3. **Solution** of the $\eta(1475) \to \gamma\gamma$ decay problem
4. **Explanation** of the $\gamma\gamma^*(Q^2) \to K\bar{K}\pi$ data
5. **Conclusion and outlook** for further measurements

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INTRODUCTION, SOME GENERAL REMARKS

1. Recall that in 2004 the long-known state E$/\iota(1440)/\eta(1440)$ was officially split into two components $\eta(1405)$ and $\eta(1475)$, decaying mainly into $a_0(980)\pi$ and $K^*(892)\bar{K}$, respectively. The splitting of the $\eta(1440)$ significantly complicates the classification of the pseudoscalar mesons $\pi(1300), \eta(1295), \eta(1405), \eta(1475), K(1460)$.
2. Note that in $J/\psi \to \gamma\eta(1440) \to \gamma(\gamma\rho^0, \rho^0\rho^0)$ decays, the $\eta(1440)$ (or $\eta(1405/1475)$) state remains unresolved.
3. To clarify the existing uncertain situation, we attribute the data on $J/\psi \to \gamma\eta(1440) \to \gamma(\gamma\rho^0, \rho^0\rho^0)$ decays to the $\eta(1475)$ state. If we were to attribute these decays to $\eta(1405)$, then our scenario would not change.

Discuss now

PARADOX OF THE $\eta(1475) \to \rho^0\rho^0, \gamma\rho^0$, AND $\gamma\gamma$ DECAYS

In 1985, we showed [Phys. Lett. B 156 (1985) 434] that $J^P = 0^-$ structures discovered by MARK III in the $\rho\rho$ and $\omega\omega$ mass spectra near their thresholds in the $J/\psi \to \gamma\rho\rho$ and $J/\psi \to \gamma\omega\omega$ decays can be explained by decays $\eta(1440) \to \rho\rho$ and $\eta(1440) \to \omega\omega$ at the resonance tail.

We also showed that the strong coupling of $\eta(1440)$ to $\rho^0\rho^0$ leads within the usual vector dominance model (VDM) to the large decay widths $\eta(1440) \to \gamma\gamma$ and $\eta(1440) \to \gamma\rho^0$:

$$\Gamma(\eta(1440) \to \rho^0\rho^0 \to \gamma\gamma) \approx \text{6.6 keV},$$

$$\Gamma(\eta(1440) \to \gamma\rho^0) \approx \text{1.3 MeV}.$$

These values should be doubled at present because $B(J/\psi \to \gamma\eta(1405/1475) \to \gamma\rho^0\rho^0) = (1.7 \pm 0.4) \times 10^{-3}$ has since increased approximately 2 times.

PARADOX OF THE $\eta(1475) \to \rho^0\rho^0, \gamma\rho^0$, AND $\gamma\gamma$ DECAYS

Such an estimate for the width $\Gamma(\eta(1440) \to \gamma\gamma)$ is in apparent contradiction with the results of its direct measurements.

Experimentally $\Gamma(\eta(1475) \to \gamma\gamma)$ is small.

Experiment	$\Gamma(\eta(1475) \to \gamma\gamma)$ $\times B(\eta(1475) \to K\bar{K}\pi)$ (keV)
MARK II (1983)	< 8
TASSO (1985)	< 2.2
TPC/2γ (1986)	< 1.6
CELLO (1989)	< 1.2
L3 (2001)	$0.212 \pm 0.050 \pm 0.023$
CLEO II (2005)	< 0.089 (90% C.L.), or < 0.140
L3 (2007)	$0.23 \pm 0.05 \pm 0.05$

The recent measurements performed by L3 and CLEO II essentially sharpened this contradiction when compared to its first manifestations in the eighties.

We now estimate $\Gamma(\eta(1475)\to\gamma\gamma)$ using the data on the $\eta(1475)\to\gamma\rho^0,\ \gamma\phi$ decays.

First we consider the data on the $J/\psi\to\gamma\gamma\rho^0$ decay, revealing the coupling of the $\eta(1475)$ to the $\gamma\rho^0$ decay channel[a] and apply the relation

$$\Gamma(\eta(1475)\to\gamma\rho^0)=\Gamma^{tot}_{\eta(1475)}B(\eta(1475)\to K\bar{K}\pi)$$
$$\times\frac{B(J/\psi\to\gamma\eta(1475)\to\gamma\gamma\rho^0)}{B(J/\psi\to\gamma\eta(1475)\to\gamma K\bar{K}\pi)},$$

together with the available information from BES and PDG.

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[a] The first Crystal Ball and MARK III measurements (1984-1990) did not clarify the question about the spin-parity of the resonance observable in the $\gamma\rho^0$ system. In 2004 the BES Collaboration obtained some indirect indication in favor of the $\eta(1440)$ meson production in the $\gamma\rho^0$ mass spectrum in the $J/\psi\to\gamma R\to\gamma\gamma\rho^0$ decay and against of the $f_1(1420)$ meson production.

Information about $\eta(1475) \to K\bar{K}\pi$, $\gamma\rho^0$, and $\gamma\phi$ decays

Experiment	Data
BES (2000)	$B(J/\psi \to \gamma\eta(1440) \to \gamma K\bar{K}\pi) =$ $= (1.66 \pm 0.10 \pm 0.58) \times 10^{-3}$
BES (2004)	$B(J/\psi \to \gamma\eta(1440) \to \gamma\gamma\rho^0) =$ $= (1.07 \pm 0.17 \pm 0.11) \times 10^{-4}$
BES (2004)	$B(J/\psi \to \gamma\eta(1440) \to \gamma\gamma\phi) =$ $= (0.31 \pm 0.30) \times 10^{-4}$, or $< 0.82 \times 10^{-4}$ (95% C.L.)
PDG (2010)	$B(J/\psi \to \gamma\eta(1475) \to \gamma K\bar{K}\pi)$ $= (2.8 \pm 0.6) \times 10^{-3}$
PDG (2010)	$B(J/\psi \to \gamma\eta(1475) \to \gamma\gamma\rho^0) =$ $= (0.78 \pm 0.2) \times 10^{-4}$

$\Gamma(\eta(1475)\to\gamma\gamma)$ from the $\eta(1475)\to\gamma\rho^0,\gamma\phi$ decays

Using the last BES data for $B(J/\psi\to\gamma\eta(1475)\to\gamma\gamma\rho^0)$ and $B(J/\psi\to\gamma\eta(1475)\to\gamma K\bar{K}\pi)$, we find

$$\Gamma(\eta(1475)\to\gamma\rho^0)\approx 3.3\ \text{MeV}.$$

If we use the PDG averages, then we have

$$\Gamma(\eta(1475)\to\gamma\rho^0)\approx 1.4\ \text{MeV}.$$

We accept as a conservative estimate

$$\Gamma(\eta(1475)\to\gamma\rho^0)=1\ \text{MeV}.$$

Then, applying VDM and SU(3) symmetry, together with the nonet symmetry assumption for $V(=\rho^0,\omega,\phi)$ meson interactions, and the ideal $\omega-\phi$ mixing, one can write the following relation for the coupling constants of $\eta(1475)$ to $\gamma\gamma$ and $\gamma\rho$:

$\Gamma(\eta(1475)\to\gamma\gamma)$ from the $\eta(1475)\to\gamma\rho^0,\gamma\phi$ data

$$g_{\eta(1475)\gamma\gamma}=\frac{e}{f_\rho}g_{\eta(1475)\gamma\rho}\left(1_{(\gamma\rho)}+\frac{1}{9}_{(\gamma\omega)}+\frac{2}{9}h_{(\gamma\phi)}\right).$$

$\Gamma(\eta(1475)\to\gamma\rho^0\to\gamma\gamma)\approx$ **5.9 keV,**

$\Gamma(\eta(1475)\to(\gamma\rho^0+\gamma\omega)\to\gamma\gamma)\approx$ **7.3 keV,**

If the $\eta(1475)$ is an $SU(3)$ singlet, then h = 1, and

$\Gamma(\eta(1475)\to(\gamma\rho^0+\gamma\omega+\gamma\phi)\to\gamma\gamma)\approx$ **10.5 keV.**

Using the BES data on the $J/\psi\to\gamma\eta(1475)\to\gamma(\gamma\rho^0,\gamma\phi)$ decays, we obtain the restriction $|h|<2.77$ and estimate

$\Gamma(\eta(1475)\to\gamma\gamma)>$ **1.45 keV ,**

which is in conflict with the L3 ($(0.23\pm0.05\pm0.05)$ keV) and CLEO II (<0.089 keV) results for the $\eta(1475)\to\gamma\gamma$ decay.

SOLUTION OF THE $\eta(1475) \to \gamma\gamma$ DECAY PROBLEM

In Yad. Fiz. 51 (1990) 854 [Sov. J. Nucl. Phys. 51 (1990) 543], we showed that taking into account the heavy vector mesons V' (V' = $\rho'^{\,0}$, ω', ϕ') in the VDM framework, along with the usual ρ^0, ω, and ϕ mesons, permits one to easily resolve the problem with $\Gamma(\eta(1475) \to \gamma\gamma)$ owing to the strong destructive interference between the V and V' contributions in the $\eta(1475) \to (\gamma V + \gamma V') \to \gamma\gamma$ transition amplitude. Here we discuss this solution in more detail.

It is important that the proposed explanation results in the nontrivial prediction:

There must arise the resonance peak caused by the $\eta(1475)$ meson production in the $\gamma\gamma^*(Q^2) \to K\bar{K}\pi$ reaction cross section for $Q^2 \neq 0$.

SOLUTION OF THE $\eta(1475) \to \gamma\gamma$ DECAY PROBLEM

Indeed, if the almost total compensation between the V and V' contributions takes place at $Q^2 = 0$ in $\Gamma(\eta(1475) \to \gamma\gamma)$ $\equiv \Gamma(\eta(1475) \to \gamma\gamma^*(Q^2 = 0))$, then it is broken with increasing Q^2 because of the considerable V-V' mass difference, and $\Gamma(\eta(1475) \to \gamma\gamma^*(Q^2))$ sharply increases.

It is very likely that only the above phenomenon has been observed in single-tagged $\gamma\gamma^*$ interactions, $\gamma\gamma^*(Q^2) \to K^0_S K^\pm \pi^\mp$, by the TPC/2$\gamma$, MARK II, JADE, CELLO, CLEO II, and L3 Collaborations.

SOLUTION OF THE $\eta(1475) \to \gamma\gamma$ DECAY PROBLEM

The absence of the resonance signal in $\sigma(\gamma\gamma \to K^0_S K^\pm \pi^\mp)$ and its appearance in $\sigma(\gamma\gamma^*(Q^2) \to K^0_S K^\pm \pi^\mp)$ has led naturally to the hypothesis of the $f_1(1420)$ resonance production, which is forbidden in two real photon collisions, according to the selection rule for $J^{PC} = 1^{++}$ states. For small Q^2, the $\gamma\gamma^*(Q^2) \to f_1(1420)$ transition amplitude is proportional to $\sqrt{Q^2}$.

However, this can in no way eliminate the contradiction connected with the $\eta(1475) \to \gamma\gamma,\ \gamma\rho^0,\ \rho^0\rho^0$ decays.

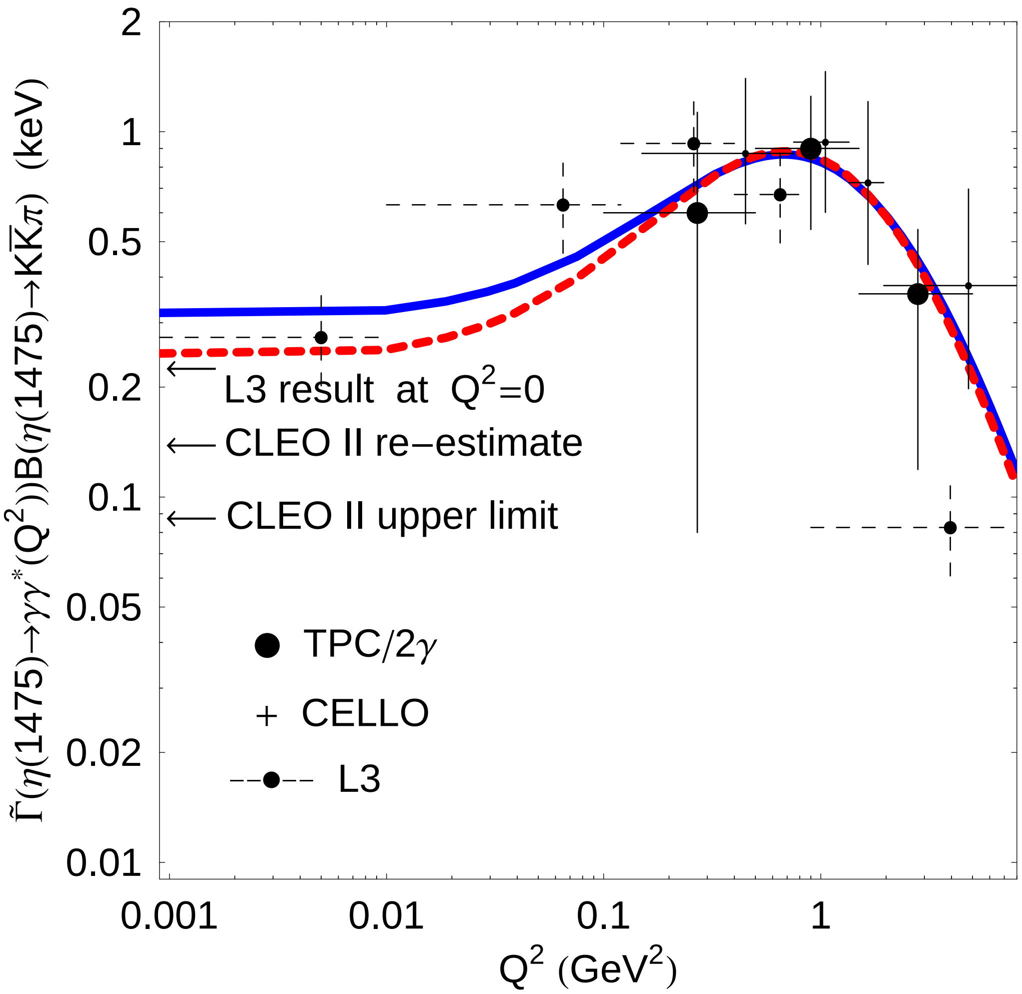
Notice that conclusions about the quantum numbers of the enhancement discovered in $\sigma(\gamma\gamma^*(Q^2) \to K^0_S K^\pm \pi^\mp)$ in the region 1.35–1.55 GeV by TPC/2γ (12 events), MARK II (13 events), JADE (16 events), CELLO (17 events), and L3 (193 ± 20 events) are based only on the data for the Q^2 dependence of the cross

SOLUTION OF THE $\eta(1475) \to \gamma\gamma$ DECAY PROBLEM

section, but not on the spin-parity determination of the resonance structure directly with the angular distributions. As already noted above, the resonance signal at $Q^2 \approx 0$ has not been observed in the CLEO II experiment, and, therefore, the enhancement discovered for intermediate Q^2 (0.04 GeV$^2 < Q^2 <$ 0.36 GeV^2 and $Q^2 \gtrsim 1$ GeV^2) was attributed without any provisos to the $f_1(1420)$ production.

The possibility that we outlined permits one to explain the available data on the reaction $\gamma\gamma^*(Q^2) \to K\bar{K}\pi$ in the $f_1(1420)/\eta(1475)$ region by the $\eta(1475)$ resonance production only, as shown in the following figures.

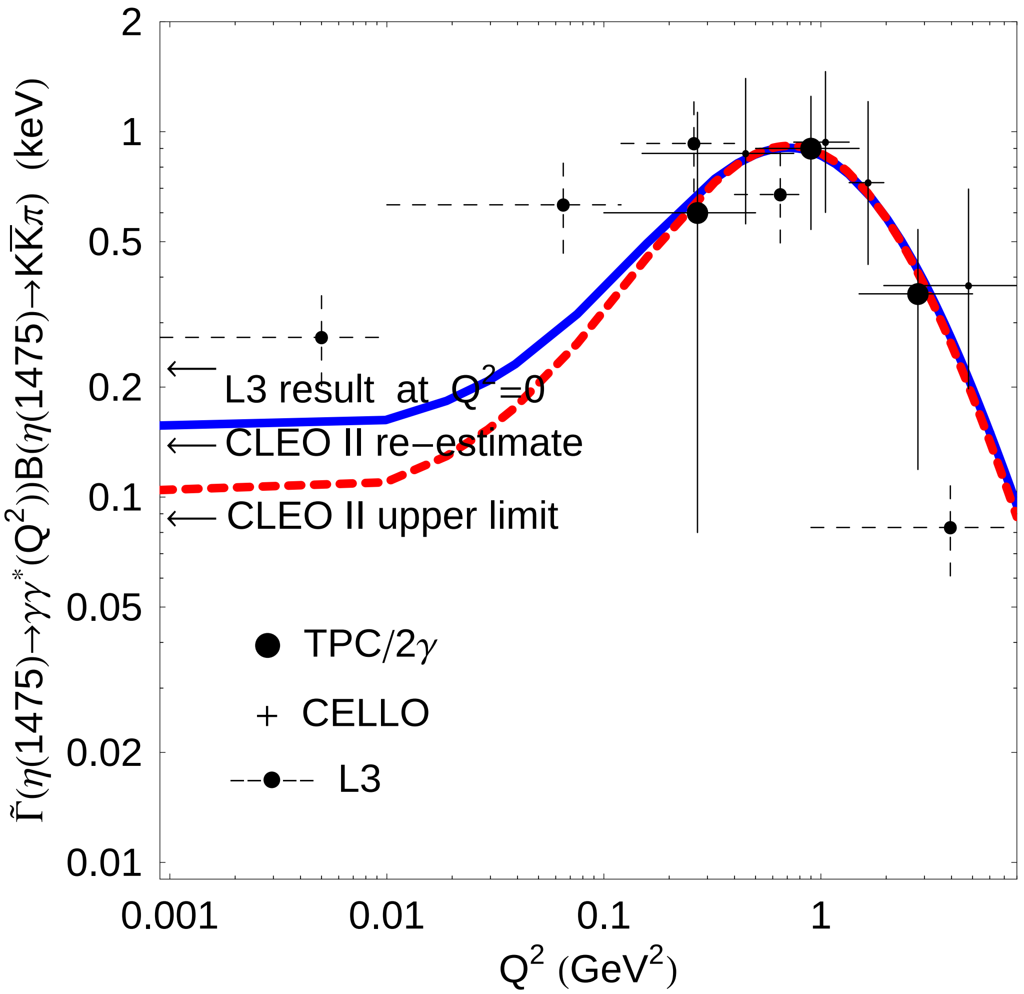
EXPLANATION OF THE $\gamma\gamma^*(Q^2) \to K\bar{K}\pi$ DATA



The Q^2 dependence of $\widetilde{\Gamma}(\eta(1475) \to \gamma\gamma^*(Q^2))B(\eta(1475) \to K\bar{K}\pi)$.

The points with the error bars were recalculated from data from TPC/2γ, CELLO, and L3. The curves are results of the fits.

EXPLANATION OF THE $\gamma\gamma^*(Q^2) \to K\bar{K}\pi$ DATA



The Q^2 dependence of $\widetilde{\Gamma}(\eta(1475) \to \gamma\gamma^*(Q^2))B(\eta(1475) \to K\bar{K}\pi)$.

Two more fitting variants different in normalization at $Q^2 = 0$.

EXPLANATION OF THE $\gamma\gamma^*(Q^2) \to K\bar{K}\pi$ DATA

To describe $\widetilde{\Gamma}(\eta(1475) \to \gamma\gamma^*(Q^2))B(\eta(1475) \to K\bar{K}\pi)$, we use the following parametrization:

$$\widetilde{\Gamma}(\eta(1475) \to \gamma\gamma^*(Q^2))B(\eta(1475) \to K\bar{K}\pi)$$
$$= \left| A\left(\frac{10}{9}\frac{1}{1+Q^2/m_\rho^2} + \frac{2}{9}\frac{h}{1+Q^2/m_\phi^2}\right) + A'\left(\frac{10}{9}\frac{1}{1+Q^2/m_{\rho'}^2} + \frac{2}{9}\frac{h}{1+Q^2/m_{\phi'}^2}\right)\right|^2, \qquad (1)$$

where A, A', and h are the fitting parameters; if we fix the value of $\Gamma(\eta(1475) \to \gamma\gamma)B(\eta(1475) \to K\bar{K}\pi)$, then Eq. (1) will contain only two free parameters A and h. ($m_{\rho'}$ = 1.45 GeV and $m_{\phi'}$ = 1.68 GeV.) In so doing,

EXPLANATION OF THE $\gamma\gamma^*(Q^2) \to K\bar{K}\pi$ DATA

$$A^2 = \Gamma(\eta(1475) \to \gamma\rho^0 \to \gamma\gamma)B(\eta(1475) \to K\bar{K}\pi),$$

$$A' = -A - 9\frac{\sqrt{\Gamma(\eta(1475) \to \gamma\gamma)B(\eta(1475) \to K\bar{K}\pi)}}{(10+2h)},$$

$$\Gamma(\eta(1475) \to \gamma\gamma) = \widetilde{\Gamma}(\eta(1475) \to \gamma\gamma^*(Q^2=0)).$$

The fit variants are:

1. $\Gamma(\gamma\gamma)B(K\bar{K}\pi) = 0.3$ keV (free): A = 1.88 keV$^{1/2}$, A' = 2.48 keV$^{1/2}$, and $h = -0.9$ (χ^2/n.d.f. = 3.9/8; $\Gamma(\gamma\rho^0) \approx 1$ keV for $B(K\bar{K}\pi) \approx 0.6$); —— .
2. $\Gamma(\gamma\gamma)B(K\bar{K}\pi) = 0.23$ keV (fixed by L3): A = 2.44 keV$^{1/2}$ and $h = -1.7$ (χ^2/n.d.f. = 5/9; $\Gamma(\gamma\rho^0) \approx 1$ keV for $B(K\bar{K}\pi) \approx 1$); - - - - - .
3. $\Gamma(\gamma\gamma)B(K\bar{K}\pi) = 0.14$ keV (fixed by CLEO II re-estimate up.lim.): A = 3.22 keV$^{1/2}$ and $h = -2.36$; —— .
4. $\Gamma(\gamma\gamma)B(K\bar{K}\pi) = 0.089$ keV (fixed by CLEO II up.lim.): A = 3.75 keV$^{1/2}$ and $h = -2.66$; - - - - - .

EXPLANATION OF THE $\gamma\gamma^*(Q^2) \to K\bar{K}\pi$ DATA

Thus, with the help of the $\eta(1475)$, one can explain simultaneously the peak in the $\gamma\rho^0$ mass spectrum in the $J/\psi \to \gamma\gamma\rho^0$ decay, the pseudoscalar structures near thresholds in the $\rho\rho$ and $\omega\omega$ mass spectra in $J/\psi \to \gamma(\rho\rho, \omega\omega)$ decays, and the suppression of the $\eta(1475)$ signal in the reaction $\gamma\gamma \to K\bar{K}\pi$ and its appearance in $\gamma\gamma^*(Q^2) \to K\bar{K}\pi$ for $Q^2 \neq 0$.

Our explanation might be rejected unambiguously by measuring the spin-parity of the resonance signal in the reaction $\gamma\gamma^*(Q^2) \to K\bar{K}\pi$ in the region of 1475 MeV, together with the disavowal of the pseudoscalar structures observed in the $\rho\rho$ and $\gamma\rho^0$ mass spectra in the $J/\psi \to \gamma\rho\rho$ and $J/\psi \to \gamma\gamma\rho^0$ decays.

CONCLUSION AND OUTLOOK

- There exists seeming contradiction between the data indicative of the suppression of the $\eta(1475)$ meson production in $\gamma\gamma$ collisions and the data on the $J/\psi \to \gamma\gamma\rho^0$ and $J/\psi \to \gamma\rho\rho$ decays indicative of the strong couplings of the $\eta(1475)$ to the $\gamma\rho^0$ and $\rho\rho$ decay channels.
- In order to resolve the difficulties accumulated in understanding properties of the $\eta(1475)$, further experimental investigations are required:

FURTHER MEASUREMENTS

- Measurements of spin-parities of the intermediate states in the reaction $\gamma\gamma^*(Q^2) \to K\bar{K}\pi$ in the $\eta(1475)$ region for $0 \lesssim Q^2 \lesssim 3$ GeV^2 (which implies the separation of pseudoscalar and pseudovector contributions by using the angular distributions).
- Further high-statistics measurements of the pseudoscalar structures in the $\rho\rho$ and $\omega\omega$ mass spectra near their thresholds in the $J/\psi \to \gamma\rho\rho$ and $J/\psi \to \gamma\omega\omega$ decays.
- A reliable determination of the spin of the $\gamma\rho^0$ system in the $J/\psi \to \gamma R \to \gamma\gamma\rho^0$ decay in the region of 1.475 GeV.
- Acquisition of accurate data on the $\eta(1475)/f_1(1420)$ $\to \gamma\phi$ decays.

High-statistics experiments necessary to solve these problems seem feasible at B and C/τ factories with the Belle, *BABAR*, CLEO II, and BES III detectors.

Thank you !

Once again
in more detail

OUTLINE

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2. **Paradox** of the $\eta(1475) \to \rho^0\rho^0$, $\gamma\rho^0$, and $\gamma\gamma$ decays
3. **Solution** of the $\eta(1475) \to \gamma\gamma$ decay problem.
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4. **Comment** on the $f_1(1420) \to \gamma\rho^0$, $\gamma\phi$, and $\gamma\gamma^*$ decays
5. **Conclusion and outlook** (further measurements)

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INTRODUCTION (SOME GENERAL REMARKS)

1) The family (decuplet) of the pseudoscalar mesons

$\pi(1300), \eta(1295), \eta(1405), \eta(1475), K(1460)$

has very mysterious properties [PDG (2010)]. The $\eta(1475)$ can be also confused with the $f_1(1420)$ in the $K\bar{K}\pi$ decay channel, without carrying out a partial wave analysis.

2) Recall that in 2004 the long-known state E$/\iota(1440)/\eta(1440)$ was officially split into two components $\eta(1405)$ and $\eta(1475)$, decaying mainly into $a_0(980)\pi$ and $K^*(892)\bar{K}$, respectively. The splitting of the $\eta(1440)$ significantly complicates the classification of the above-mentioned pseudoscalar states.

3) Note that in $J/\psi \to \gamma\eta(1440) \to \gamma(\gamma\rho^0$, $\rho^0\rho^0$) decays, the $\eta(1440)$ (or $\eta(1405/1475)$) state remains unresolved.

INTRODUCTION (SOME GENERAL REMARKS)

4) To clarify the existing uncertain situation, we attribute the data on $J/\psi \to \gamma\eta(1440) \to \gamma(\gamma\rho^0, \rho^0\rho^0)$ decays to the $\eta(1475)$ state.

(If we were to attribute these decays to $\eta(1405)$, then our scenario would not change.)

Experimental verification of our scenario will automatically resolve the question of the role of the $\eta(1405)$ in the problem under discussion. Note that, if the L3 Collaboration is right when they assert that the $\eta(1405)$ signal is absent in $\gamma\gamma$ and $\gamma\gamma^*$ collisions, then most likely the data on the $\gamma\rho^0$ decay cannot be attributed to the $\eta(1405)$.

Discuss now

PARADOX OF THE $\eta(1475) \to \rho^0\rho^0, \gamma\rho^0$, AND $\gamma\gamma$ DECAYS

In 1985, we showed [Phys. Lett. B 156 (1985) 434] that pseudoscalar ($J^P = 0^-$) structures discovered by MARK III in the $\rho\rho$ and $\omega\omega$ mass spectra near their thresholds in the $J/\psi \to \gamma\rho\rho$ and $J/\psi \to \gamma\omega\omega$ decays can be explained by decays $\eta(1440) \to \rho\rho$ and $\eta(1440) \to \omega\omega$ at the resonance tail.

(This explanation was supported by the subsequent results from MARK III, DM2, and BES on the $J/\psi \to \gamma(\rho\rho, \omega\omega)$ decays.)

We also showed that the strong coupling of $\eta(1440)$ to $\rho^0\rho^0$ leads within the usual vector dominance model (VDM) to the large decay widths $\eta(1440) \to \gamma\gamma$ and $\eta(1440) \to \gamma\rho^0$:

$$\Gamma(\eta(1440) \to \rho^0\rho^0 \to \gamma\gamma) \approx \text{6.6 keV},$$
$$\Gamma(\eta(1440) \to \gamma\rho^0) \approx \text{1.3 MeV}.$$

Note that these values should be doubled at present because the branching ratio $B(J/\psi \to \gamma\eta(1405/1475) \to \gamma\rho^0\rho^0) = (1.7 \pm 0.4) \times 10^{-3}$ has since increased approximately 2 times.

PARADOX OF THE $\eta(1475) \to \rho^0\rho^0, \gamma\rho^0$, AND $\gamma\gamma$ DECAYS

Such an estimate for the width $\Gamma(\eta(1440) \to \gamma\gamma)$ is in apparent contradiction with the results of its direct measurements.

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The recent measurements performed by L3 and CLEO II essentially sharpened this contradiction when compared to its first manifestations in the eighties.

$\Gamma(\eta(1475) \to \gamma\gamma)$ from the $\eta(1475) \to \gamma\rho^0, \gamma\phi$ decays

Consider the data on the $J/\psi \longrightarrow \gamma\gamma\rho^0$ decay, revealing the coupling of the $\eta(1475)$ to the $\gamma\rho^0$ decay channel.

First Crystal Ball and MARK III measurements (1984-1990) did not clarify the question about the spin-parity of the resonance observable in the $\gamma\rho^0$ system near 1.44 GeV.

In 2004 the BES Collaboration obtained some indirect indication in favor of the $\eta(1440)$ meson production in the $\gamma\rho^0$ mass spectrum in the $J/\psi \longrightarrow \gamma R \longrightarrow \gamma\gamma\rho^0$ decay and against of the $f_1(1420)$ meson production.

$$\Gamma(\eta(1475) \to \gamma\rho^0) = \Gamma^{tot}_{\eta(1475)} B(\eta(1475) \to K\bar{K}\pi)$$
$$\times \frac{B(J/\psi \to \gamma\eta(1475) \to \gamma\gamma\rho^0)}{B(J/\psi \to \gamma\eta(1475) \to \gamma K\bar{K}\pi)}\,.$$

Information about $\eta(1475) \to K\bar{K}\pi$, $\gamma\rho^0$, and $\gamma\phi$ decays

Experiment	Data
BES (2000)	$B(J/\psi \to \gamma\eta(1440) \to \gamma K\bar{K}\pi) =$ $= (1.66 \pm 0.10 \pm 0.58) \times 10^{-3}$
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BES (2004)	$B(J/\psi \to \gamma\eta(1440) \to \gamma\gamma\phi) =$ $= (0.31 \pm 0.30) \times 10^{-4}$, or $< 0.82 \times 10^{-4}$ (95% C.L.)
PDG (2010)	$B(J/\psi \to \gamma\eta(1475) \to \gamma K\bar{K}\pi)$ $= (2.8 \pm 0.6) \times 10^{-3}$
PDG (2010)	$B(J/\psi \to \gamma\eta(1475) \to \gamma\gamma\rho^0) =$ $= (0.78 \pm 0.2) \times 10^{-4}$

$\Gamma(\eta(1475)\to\gamma\gamma)$ from the $\eta(1475)\to\gamma\rho^0,\gamma\phi$ decays

Using the last BES data for $B(J/\psi\to\gamma\eta(1475)\to\gamma\gamma\rho^0)$ and $B(J/\psi\to\gamma\eta(1475)\to\gamma K\bar{K}\pi)$, we find

$$\Gamma(\eta(1475)\to\gamma\rho^0)\approx 3.3\ \text{MeV}.$$

If we use the PDG averages, then we have

$$\Gamma(\eta(1475)\to\gamma\rho^0)\approx 1.4\ \text{MeV}.$$

We accept as a conservative estimate

$$\Gamma(\eta(1475)\to\gamma\rho^0)=1\ \text{MeV}.$$

Then, applying VDM and SU(3) symmetry, together with the nonet symmetry assumption for $V(=\rho^0,\omega,\phi)$ meson interactions, and the ideal $\omega-\phi$ mixing, one can write the following relation for the coupling constants of $\eta(1475)$ to $\gamma\gamma$ and $\gamma\rho$:

$\Gamma(\eta(1475) \to \gamma\gamma)$ from the $\eta(1475) \to \gamma\rho^0, \gamma\phi$ data

$$g_{\eta(1475)\gamma\gamma} = \frac{e}{f_\rho} g_{\eta(1475)\gamma\rho} \left(1_{(\gamma\rho)} + \frac{1}{9}_{(\gamma\omega)} + \frac{2}{9} h_{(\gamma\phi)} \right) .$$

$\Gamma(\eta(1475) \to \gamma\rho^0 \to \gamma\gamma) \approx$ **5.9 keV,**

$\Gamma(\eta(1475) \to (\gamma\rho^0 + \gamma\omega) \to \gamma\gamma) \approx$ **7.3 keV,**

If the $\eta(1475)$ is an $SU(3)$ singlet, then h = 1, and

$\Gamma(\eta(1475) \to (\gamma\rho^0 + \gamma\omega + \gamma\phi) \to \gamma\gamma) \approx$ **10.5 keV.**

Using the BES data on the $J/\psi \to \gamma\eta(1475) \to \gamma(\gamma\rho^0, \gamma\phi)$ decays, we obtain the restriction $|h| < 2.77$ and estimate

$\Gamma(\eta(1475) \to \gamma\gamma) >$ **1.45 keV ,**

which is in conflict with the L3 ($(0.23 \pm 0.05 \pm 0.05)$ keV) and CLEO II (< 0.089 keV) results for the $\eta(1475) \to \gamma\gamma$ decay.

SOLUTION OF THE $\eta(1475) \to \gamma\gamma$ DECAY PROBLEM

In Yad. Fiz. 51 (1990) 854 [Sov. J. Nucl. Phys. 51 (1990) 543], we showed that taking into account the heavy vector mesons V' ($V' = \rho'^0, \omega', \phi'$) in the VDM framework, along with the usual ρ^0, ω, and ϕ mesons, permits one to easily resolve the problem with $\Gamma(\eta(1475) \to \gamma\gamma)$ owing to the strong destructive interference between the V and V' contributions in the $\eta(1475) \to (\gamma V + \gamma V') \to \gamma\gamma$ transition amplitude. Here we discuss this solution in more detail.

It is important that the proposed explanation results in the nontrivial prediction:

There must arise the resonance peak caused by the $\eta(1475)$ meson production in the $\gamma\gamma^*(Q^2) \to K\bar{K}\pi$ reaction cross section for $Q^2 \neq 0$.

SOLUTION OF THE $\eta(1475) \to \gamma\gamma$ DECAY PROBLEM

Indeed, if the almost total compensation between the V and V' contributions takes place at Q^2 = 0 in $\Gamma(\eta(1475) \to \gamma\gamma)$ $\equiv \Gamma(\eta(1475) \to \gamma\gamma^*(Q^2 = 0))$, then it is broken with increasing Q^2 because of the considerable V-V' mass difference, and $\Gamma(\eta(1475) \to \gamma\gamma^*(Q^2))$ sharply increases.

It is very likely that only the above phenomenon has been observed in single-tagged $\gamma\gamma^*$ interactions, $\gamma\gamma^*(Q^2) \to K^0_S K^\pm \pi^\mp$, by the TPC/2$\gamma$, MARK II, JADE, CELLO, CLEO II, and L3 Collaborations.

SOLUTION OF THE $\eta(1475) \to \gamma\gamma$ DECAY PROBLEM

The absence of the resonance signal in $\sigma(\gamma\gamma \to K^0_S K^\pm \pi^\mp)$ and its appearance in $\sigma(\gamma\gamma^*(Q^2) \to K^0_S K^\pm \pi^\mp)$ has led naturally to the hypothesis of the $f_1(1420)$ resonance production, which is forbidden in two real photon collisions, according to the selection rule for $J^{PC} = 1^{++}$ states. For small Q^2, the $\gamma\gamma^*(Q^2) \to f_1(1420)$ transition amplitude is proportional to $\sqrt{Q^2}$.

However, this can in no way eliminate the contradiction connected with the $\eta(1475) \to \gamma\gamma,\ \gamma\rho^0,\ \rho^0\rho^0$ decays.

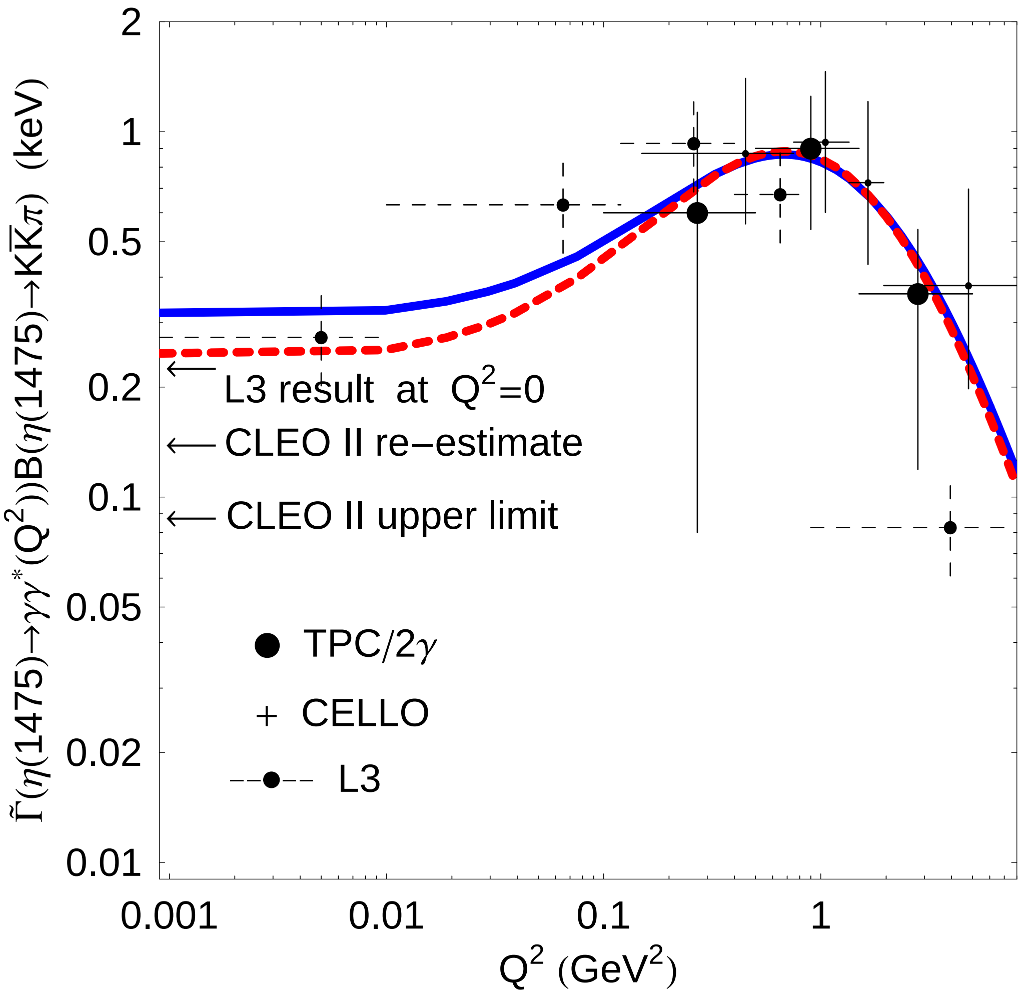
Notice that conclusions about the quantum numbers of the enhancement discovered in $\sigma(\gamma\gamma^*(Q^2) \to K^0_S K^\pm \pi^\mp)$ in the region 1.35–1.55 GeV by TPC/2γ (12 events), MARK II (13 events), JADE (16 events), CELLO (17 events), and L3 (193 ± 20 events) are based only on the data for the Q^2 dependence of the cross

SOLUTION OF THE $\eta(1475) \to \gamma\gamma$ DECAY PROBLEM

section, but not on the spin-parity determination of the resonance structure directly with the angular distributions. As already noted above, the resonance signal at $Q^2 \approx 0$ has not been observed in the CLEO II experiment, and, therefore, the enhancement discovered for intermediate Q^2 (0.04 GeV$^2 < Q^2 <$ 0.36 GeV^2 and $Q^2 \gtrsim 1$ GeV^2) was attributed without any provisos to the $f_1(1420)$ production.

The possibility that we outlined permits one to explain the available data on the reaction $\gamma\gamma^*(Q^2) \to K\bar{K}\pi$ in the $f_1(1420)/\eta(1475)$ region by the $\eta(1475)$ resonance production only, as shown in the following figures.

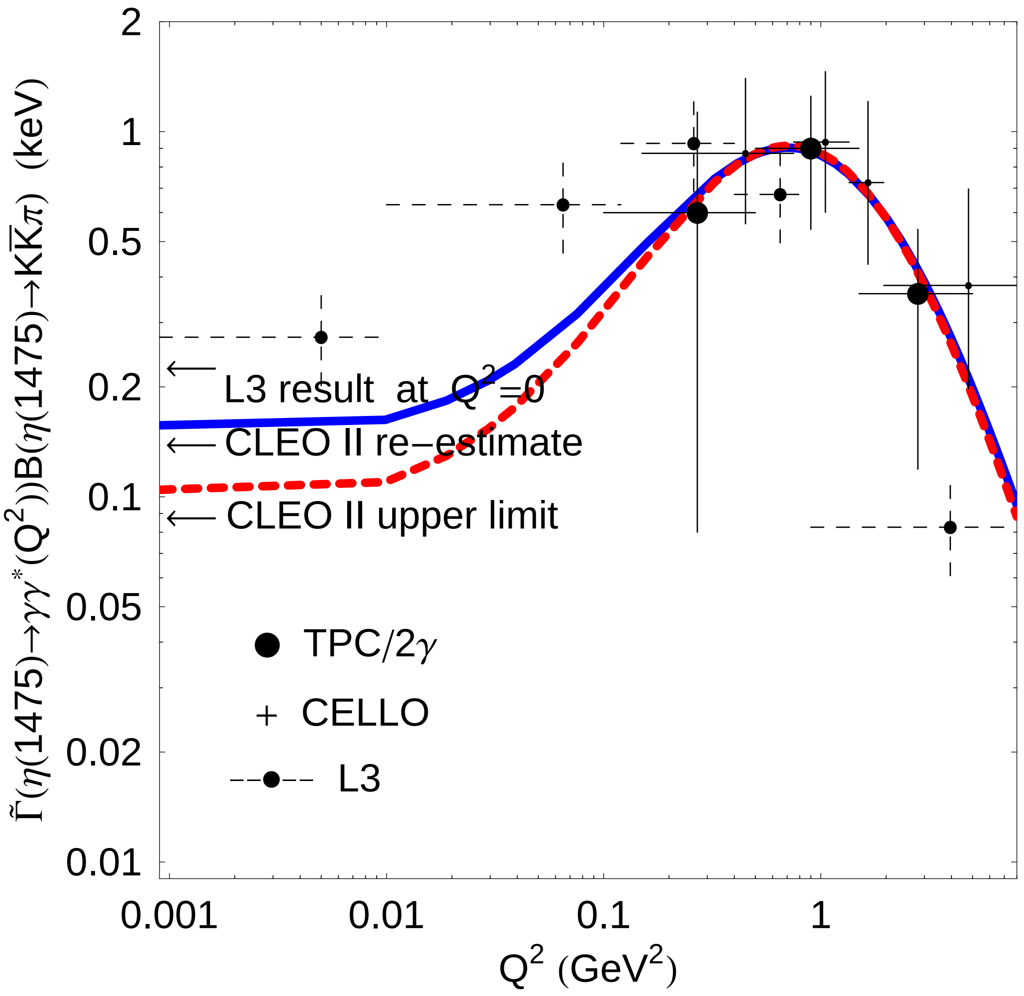
EXPLANATION OF THE $\gamma\gamma^*(Q^2) \to K\bar{K}\pi$ DATA



The Q^2 dependence of $\widetilde{\Gamma}(\eta(1475) \to \gamma\gamma^*(Q^2))B(\eta(1475) \to K\bar{K}\pi)$.

The points with the error bars were obtained from data from TPC/2γ, CELLO, and L3. The curves are results of the fits.

EXPLANATION OF THE $\gamma\gamma^*(Q^2) \to K\bar{K}\pi$ DATA



The Q^2 dependence of $\widetilde{\Gamma}(\eta(1475) \to \gamma\gamma^*(Q^2))B(\eta(1475) \to K\bar{K}\pi)$.

Two more fitting variants different in normalization at $Q^2 = 0$. (Notice that the log-scale for Q2 is used to emphasize the small and moderate Q2 regions.)

EXPLANATION OF THE $\gamma\gamma^*(Q^2) \to K\bar{K}\pi$ DATA

To describe $\widetilde{\Gamma}(\eta(1475) \to \gamma\gamma^*(Q^2))B(\eta(1475) \to K\bar{K}\pi)$, we use the following parametrization:

$$\widetilde{\Gamma}(\eta(1475) \to \gamma\gamma^*(Q^2))B(\eta(1475) \to K\bar{K}\pi)$$
$$= \left| A\left(\frac{10}{9}\,\frac{1}{1+Q^2/m_\rho^2} + \frac{2}{9}\,\frac{h}{1+Q^2/m_\phi^2}\right) + A'\left(\frac{10}{9}\,\frac{1}{1+Q^2/m_{\rho'}^2} + \frac{2}{9}\,\frac{h}{1+Q^2/m_{\phi'}^2}\right)\right|^2, \qquad (2)$$

where A, A', and h are the fitting parameters; if we fix the value of $\Gamma(\eta(1475)\to\gamma\gamma)B(\eta(1475)\to K\bar{K}\pi)$, then Eq. (1) will contain only two free parameters A and h. ($m_{\rho'}$ = 1.45 GeV and $m_{\phi'}$ = 1.68 GeV.) In so doing,

EXPLANATION OF THE $\gamma\gamma^*(Q^2) \to K\bar{K}\pi$ DATA

$$A^2 = \Gamma(\eta(1475) \to \gamma\rho^0 \to \gamma\gamma) B(\eta(1475) \to K\bar{K}\pi),$$

$$A' = -A - 9\frac{\sqrt{\Gamma(\eta(1475) \to \gamma\gamma) B(\eta(1475) \to K\bar{K}\pi)}}{(10+2h)},$$

$\Gamma(\eta(1475) \to \gamma\gamma) = \widetilde{\Gamma}(\eta(1475) \to \gamma\gamma^*(Q^2=0))$. The fit variants are:

1. $\Gamma(\gamma\gamma)B(K\bar{K}\pi) = 0.3$ keV (free): A = 1.88 keV$^{1/2}$, A' = 2.48 keV$^{1/2}$, and $h = -0.9$ (χ^2/n.d.f. = 3.9/8; $\Gamma(\gamma\rho^0) \approx 1$ keV for $B(K\bar{K}\pi) \approx 0.6$); —— .
2. $\Gamma(\gamma\gamma)B(K\bar{K}\pi) = 0.23$ keV (fixed, L3): A = 2.44 keV$^{1/2}$ and $h = -1.7$ (χ^2/n.d.f. = 5/9; $\Gamma(\gamma\rho^0) \approx 1$ keV for $B(K\bar{K}\pi) \approx 1$); - - - - - .
3. $\Gamma(\gamma\gamma)B(K\bar{K}\pi) = 0.14$ keV (fixed, CLEO II re-estimate up.lim.): A = 3.22 keV$^{1/2}$ and $h = -2.36$; —— .
4. $\Gamma(\gamma\gamma)B(K\bar{K}\pi) = 0.089$ keV (fixed, CLEO II up.lim.): A = 3.75 keV$^{1/2}$ and $h = -2.66$; - - - - - .

EXPLANATION OF THE $\gamma\gamma^*(Q^2) \to K\bar{K}\pi$ DATA

Thus, with the help of the $\eta(1475)$, one can explain simultaneously the peak in the $\gamma\rho^0$ mass spectrum in the $J/\psi \to \gamma\gamma\rho^0$ decay, the pseudoscalar structures near thresholds in the $\rho\rho$ and $\omega\omega$ mass spectra in $J/\psi \to \gamma(\rho\rho, \omega\omega)$ decays, and the suppression of the $\eta(1475)$ signal in the reaction $\gamma\gamma \to K\bar{K}\pi$ and its appearance in $\gamma\gamma^*(Q^2) \to K\bar{K}\pi$ for $Q^2 \neq 0$.

Our explanation might be rejected unambiguously by measuring the spin-parity of the resonance signal in the reaction $\gamma\gamma^*(Q^2) \to K\bar{K}\pi$ in the region of 1475 MeV, together with the disavowal of the pseudoscalar structures observed in the $\rho\rho$ and $\gamma\rho^0$ mass spectra in the $J/\psi \to \gamma\rho\rho$ and $J/\psi \to \gamma\gamma\rho^0$ decays.

COMMENT ON THE $f_1(1420) \to \gamma\rho^0, \gamma\phi$, AND $\gamma\gamma^*$ DECAYS

We analyzed the data on the $f_1(1420)$ production in the reaction $\gamma\gamma^*(Q^2) \to f_1(1420) \to K\bar{K}\pi$, using the information about $f_1(1420) \to \gamma(\rho^0, \phi)$ decays as a guide. The result is in the following. A comparison of our tentative estimate

$$\widetilde{\Gamma}(f_1' \to \gamma\gamma) = \lim_{Q^2 \to 0} \frac{m^2_{f_1'}}{Q^2} \Gamma^{\mathrm{LT}}(f_1' \to \gamma\gamma^*(Q^2))$$

$$\approx (1 - 0.3)\,\text{keV} \times B(f_1' \to K\bar{K}\pi)$$

$[f_1' = f_1(1420)]$ with the highly model-dependent data on $\widetilde{\Gamma}(f_1' \to \gamma\gamma)B(f_1' \to K\bar{K}\pi)$ does not allow conclusions about the $f_1(1420)$ dominance in the reaction $\gamma\gamma^*(Q^2) \to K\bar{K}\pi$. It is impossible to exclude that there are two resonance contributions in this reaction, from the pseudoscalar $\eta(1475)$ and the axial-vector $f_1(1420)$.

The data on $\widetilde{\Gamma}(f_1' \to \gamma\gamma)B(f_1' \to K\bar{K}\pi)$

$F(Q^2)$: $F_\rho = 1/(1+Q^2/m_\rho^2)$, $F_\phi = 1/(1+Q^2/m_\phi^2)$,
$F_{L3} = 1/[(1+Q^2/(0.926\,\text{GeV})^2)^2(1+Q^2/m_{f_1'}^2)^{1/2}]$

Experiment	$\widetilde{\Gamma}(f_1' \to \gamma\gamma)$ $\times B(f_1' \to K\bar{K}\pi)$ (keV)	$F(Q^2)$
MARK II (1987)	$1.6 \pm 0.7 \pm 0.3$	F_ρ
	$1.1 \pm 0.5 \pm 0.2$	F_ϕ
TPC/2γ (1988)	$1.3 \pm 0.5 \pm 0.3$	F_ρ
	$0.63 \pm 0.24 \pm 0.15$	F_ϕ
JADE (1989)	$2.3 \pm^{1.0}_{0.9} \pm 0.8$	F_ρ
	$1.5 \pm^{0.6}_{0.5} \pm 0.5$	F_ϕ
CELLO (1989)	$1.5 \pm 0.5 \pm 0.4$	F_ρ
	$0.7 \pm 0.2 \pm 0.2$	F_ϕ
L3 (2007)	$3.2 \pm 0.6 \pm 0.7$	F_{L3}

CONCLUSION AND OUTLOOK

- There exists seeming contradiction between the data indicative of the suppression of the $\eta(1475)$ meson production in $\gamma\gamma$ collisions and the data on the $J/\psi \to \gamma\gamma\rho^0$ and $J/\psi \to \gamma\rho\rho$ decays indicative of the strong couplings of the $\eta(1475)$ to the $\gamma\rho^0$ and $\rho\rho$ decay channels.
- In order to resolve the difficulties accumulated in understanding properties of the $\eta(1475)$, further experimental investigations are required:

FURTHER MEASUREMENTS

- **Measurements of spin-parities of the intermediate states in the reaction $\gamma\gamma^*(Q^2) \to K\bar{K}\pi$ in the $\eta(1475)$ region for $0 \lesssim Q^2 \lesssim 3$ GeV^2 (which implies the separation of pseudoscalar and pseudovector contributions by using the angular distributions).**
- **Further high-statistics measurements of the pseudoscalar structures in the $\rho\rho$ and $\omega\omega$ mass spectra near their thresholds in the $J/\psi \to \gamma\rho\rho$ and $J/\psi \to \gamma\omega\omega$ decays.**
- **A reliable determination of the spin of the $\gamma\rho^0$ system in the $J/\psi \to \gamma R \to \gamma\gamma\rho^0$ decay in the region of 1.475 GeV.**
- **Acquisition of accurate data on the $\eta(1475)/f_1(1420) \to \gamma\phi$ decays.**

High-statistics experiments necessary to solve these problems seem feasible at B and C/τ factories with the Belle, *BABAR*, CLEO II, and BES III detectors.

The history of the search for the $\eta(1475) \to \gamma\gamma$ decay

Experiment	$\Gamma(\eta(1475) \to \gamma\gamma)$ $\times B(\eta(1475) \to K\bar{K}\pi)$ (keV)
MARK II (1983)	< 8
TASSO (1985)	< 2.2
TPC/2γ (1986)	< 1.6
CELLO (1989)	< 1.2
L3 (2001)	$0.212 \pm 0.050 \pm 0.023$
CLEO II (2005)	< 0.089 (90% C.L.)
L3 (2007)	$0.23 \pm 0.05 \pm 0.05$

According to experiment, $\Gamma(\eta(1475) \to \gamma\gamma)$ is small.

(If the world average width of $\eta(1475)$ is used, the CLEO II upper limit increases from 0.089 keV to 0.140 keV that is consistent with the L3 result within two errors.)