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Short note

Partial widths for the decays $\eta(1295) \to \gamma\gamma$ and $\eta(1440) \to \gamma\gamma$

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Abstract. We discuss $\gamma\gamma$ partial widths of pseudoscalar/isoscalar mesons $\eta(M)$ in the mass region $M \sim 1000 - 1500$ MeV. The transition amplitudes $\eta(1295) \to \gamma\gamma$ and $\eta(1440) \to \gamma\gamma$ are studied within an assumption that the decaying mesons are the members of the first radial excitation nonet $2^1S_0q\bar{q}$. The calculations show that partial widths being of the order of 0.1 keV are dominantly due to the $n\bar{n}$ meson component while the contribution of the $s\bar{s}$ component is small.

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The two–photon decays of the pseudoscalar mesons served a great deal of information on the structure of the basic $1^1S_0q\bar{q}$ nonet. The value of the partial width $\pi^0 \to \gamma\gamma$ gave one of the first experimental evidence for colour structure of quarks. The decays $\eta \to \gamma\gamma$ and $\eta' \to \gamma\gamma$ provide an information on the quark/gluon content of these mesons.

The partial $\gamma\gamma$-widths of pseudoscalar mesons belonging to the basic nonet $1^1S_0q\bar{q}$ are relatively large: $\Gamma_{\pi^0\to\gamma\gamma} = 7.2 \pm 0.5$ eV, $\Gamma_{\eta\to\gamma\gamma} = 0.46 \pm 0.04$ keV, $\Gamma_{\eta'\to\gamma\gamma} = 4.27 \pm 0.19$ keV [1] thus giving a possibility to mesure not only partial widths but transition form factors $\pi^0 \to \gamma^*(Q^2)\gamma$, $\eta \to \gamma^*(Q^2)\gamma$, $\eta' \to \gamma^*(Q^2)\gamma$ over a broad range of photon virtualities, $Q^2 \le 20$ GeV^2 [2]. These data made it possible [3]:
(i) to restore the wave functions of η and η' (for both $n\bar{n}$ and $s\bar{s}$ components),
(ii) to estimate the gluonium admixture in η and η',
(iii) to restore the vertex function for the transition $\gamma \to q\bar{q}$ (or photon wave function) as a function of the $q\bar{q}$ invariant mass.

The same method as used in [3] for the analysis of the basic pseudoscalar mesons can be applied for a study of $\gamma\gamma$ decays of the first radial excitation mesons: in the present paper we discuss these processes.

The search for exotics in the pseudoscalar/isoscalar sector ultimately requires the investigation of η-mesons of the $2^1S_0q\bar{q}$ nonet: in the framework of this investigation program, here we calculate partial widths $\eta(1295) \to \gamma\gamma$ and $\eta(1440) \to \gamma\gamma$ under the assumption that the mesons $\eta(1295)$ and $\eta(1440)$ are members of the $2^1S_0q\bar{q}$ nonet. The state $\eta(1440)$ (old name is $E(1407)$ [4]) attracts our special attention: it is considered during long time as a state with possible rich gluonic component.

Transition form factors and partial widths

A partial width for the decay $\eta(M) \to \gamma\gamma$ is determined as $\Gamma_{\eta(M)\to\gamma\gamma} = \pi\alpha^2M^3F^2_{\eta(M)\to\gamma\gamma}(0)/4$, where $M(M)$ is the mass of the η-meson, $\alpha = 1/137$, and $F_{\eta(M)\to\gamma\gamma}(0)$ is the form factor of the considered decay.

In [3], the form factor $F_{\eta\to\gamma^*\gamma}(Q^2)$ was calculated for the virtual photon $\gamma^*(Q^2)$; the decay form factor is given by the limit $Q^2 \to 0$. The decay form factor $F_{\eta(M)\to\gamma\gamma}(0)$ reads [3]:

$$F_{\eta(M)\to\gamma\gamma}(0) = \frac{1}{6\sqrt{3}\pi^3}\int\frac{dxd^2k_\perp}{x(1-x)^2} \times\left[\frac{5m}{\sqrt{2}}\cos\phi\,\Psi_{n\bar{n}}(s)\Psi_{\gamma\to n\bar{n}}(s)+m_s\sin\phi\,\Psi_{s\bar{s}}(s)\Psi_{\gamma\to s\bar{s}}(s)\right]. \quad (1)$$

Two terms in the square brackets refer to $n\bar{n}$ and $s\bar{s}$ components of the $\eta(M)$-meson. The flavour wave function is determined as $\psi_\eta(M) = \cos\phi\; n\bar{n}+\sin\phi\; s\bar{s}$ where ϕ is mixing angle and $n\bar{n} = (u\bar{u} + d\bar{d})/\sqrt{2}$; m and m_s are masses of the non-strange and strange constituent quarks.

The wave functions for $n\bar{n}$ and $s\bar{s}$ components are written as $\Psi_{n\bar{n}}(s)$ and $\Psi_{s\bar{s}}(s)$ where s is $q\bar{q}$ invariant mass squared. In terms of the light cone variables $(x, \boldsymbol{k}_\perp)$, the $q\bar{q}$ invariant mass reads $s = (m^2 + k^2_\perp)/x(1-x)$. The photon wave function $\Psi_{\gamma\to q\bar{q}}(s)$ was found in [3]: it is shown in Fig. 1a.

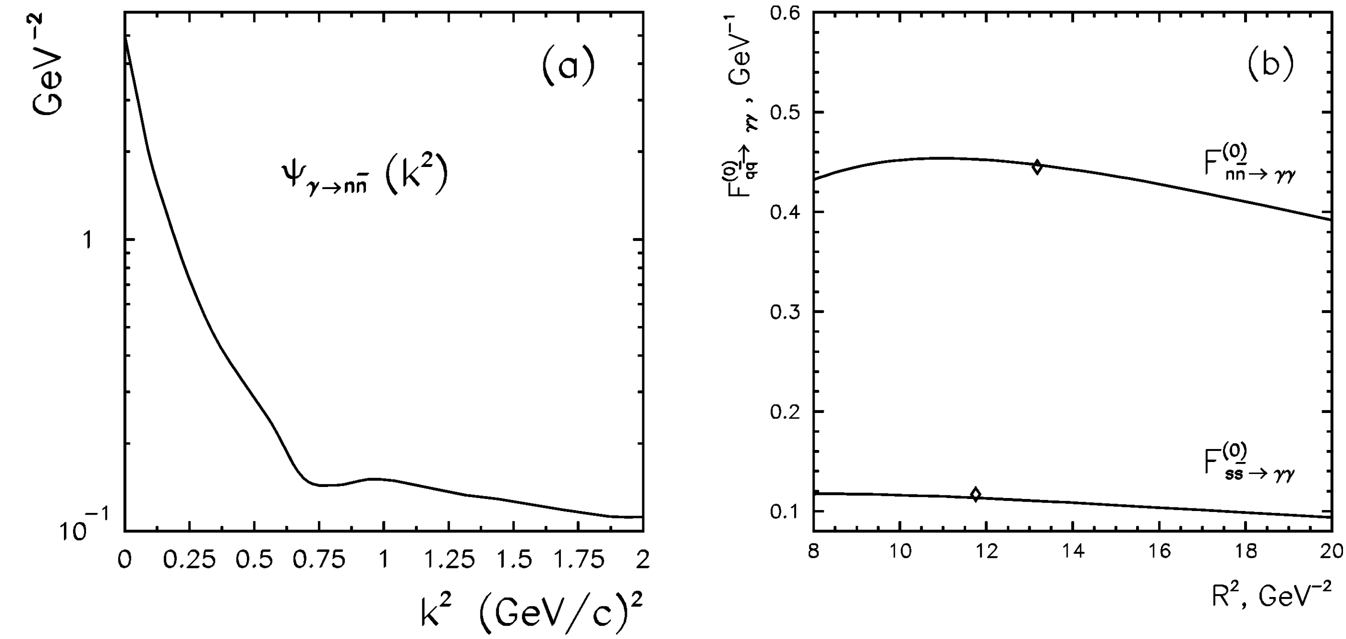

Fig. 1. (**a**) Photon wave function $\Psi_{\gamma\to n\bar{n}}(k^2) = g_\gamma(k^2)/(k^2+m^2)$, where $k^2 = s/4 - m^2$; the wave function for $s\bar{s}$ component is obtained by replacement $m \to m_s$. (**b**) Form factors $F^{(0)}_{n\bar{n}\to\gamma\gamma}(0)$ and $F^{(0)}_{s\bar{s}\to\gamma\gamma}(0)$ as functions of mean radius squared of η-meson. Solid curves present calculations with use parametrization (5); the rhombuses give values calculated with use the wave functions found in [3]

Wave functions of $\eta(M)$-mesons

We approximate wave functions of the $\eta(M)$-mesons in the one–parameter exponential form. For the basic multiplet and first radial excitation nonet, the wave functions are determined as follows:

$$\Psi^{(0)}_\eta(s) = Ce^{-bs}, \quad \Psi^{(1)}_\eta(s) = C_1(D_1 s - 1)e^{-b_1 s}. \qquad (2)$$

The parameters b and b_1 are related to the radii squared of corresponding $\eta(M)$-meson. Then the other constants (C, C_1, D_1) are fixed by the normalization and orthogonality conditions:

$$\Psi^{(0)}_\eta \otimes \Psi^{(0)}_\eta = 1, \quad \Psi^{(1)}_\eta \otimes \Psi^{(1)}_\eta = 1, \quad \Psi^{(0)}_\eta \otimes \Psi^{(1)}_\eta = 0. \quad (3)$$

The convolution of the η-meson wave function at $q_\perp \neq 0$ determines form factor of the η-meson, $f^{(n)}_\eta(q^2_\perp) = \left[\Psi^{(n)}_\eta \otimes \Psi^{(n)}_\eta\right]_{q_\perp\neq 0}$ thus allowing us to relate the parameter b (or b_1) at small $q^2_\perp$ to η-meson radius squared: $f_\eta(q^2_\perp) \simeq 1 - \frac{1}{6}R^2_\eta q^2_\perp$. The η-meson form factor reads [3]:

$$f_\eta(q^2_\perp) = \frac{1}{16\pi^3}\int \frac{dx d^2k_\perp}{x(1-x)^2}\Psi^{(n)}_\eta(s)\Psi^{(n)}_\eta(s') \times \left[\alpha(s+s'-q^2)+q^2\right],$$

$$\alpha = \frac{s+s'-q^2}{2(s+s') - \frac{(s'-s)^2}{q^2} - q^2} \qquad (4)$$

where $s' = (m^2 + (\boldsymbol{k}_\perp - x\boldsymbol{q}_\perp)^2)/x(1-x)$. When working with a simple one-parameter wave function representation of Eqs. (2) and (3), it is instructive to compare the results with those obtained using more precise wave function patametrization; such a comparison can be done for basic $2^1S_0 q\bar{q}$ nonet. The η and η' wave functions (or those for its $n\bar{n}$ and $s\bar{s}$ components) were found in [3] basing on the data for the transitions $\eta \to \gamma\gamma^*(Q^2)$, $\eta \to \gamma\gamma^*(Q^2)$ at $Q^2 \le 20$ GeV^2. The calculated decay form factors $F^{(0)}_{n\bar{n}\to\gamma\gamma}(k^2)$ and $F^{(0)}_{s\bar{s}\to\gamma\gamma}(k^2)$ for these wave functions are marked in Fig. 1b by rhombuses. The wave functions of [3] give the following mean radii squared for $n\bar{n}$ and $s\bar{s}$ components: $R^2_{n\bar{n}} = 13.1$ GeV^{-2} and $R^2_{s\bar{s}} = 11.7$ GeV^{-2}; in Fig. 1b we have drawn rhombuses for these values of radii. Solid curves in Fig. 1b represent $F^{(0)}_{n\bar{n}\to\gamma\gamma}(0)$ and $F^{(0)}_{s\bar{s}\to\gamma\gamma}(0)$ calculated by using the simple exponential parametrization (2): we see that both calculations coincide with each other within reasonable accuracy. The coincidence of the results justifies the exponential approximation for the calculation of transition form facrors at $q^2_\perp \sim 0$.

Results

The Fig. 2a demonstrates calculation results for the transition form factors $n\bar{n} \to \gamma\gamma$ and $s\bar{s} \to \gamma\gamma$ when these components refer to η-mesons of the first radial excitation multiplet. The form factor for the $n\bar{n}$ component, $F^{(1)}_{n\bar{n}\to\gamma\gamma}(0)$, depends strongly on the mean radius squared, increasing rapidly in the region $R^2_{n\bar{n}} \sim 14-24$ GeV^{-2} (0.7-1.2 fm^2). As for $s\bar{s}$ component, the form factor $F^{(1)}_{s\bar{s}\to\gamma\gamma}(0)$ is small; it changes sign at $R^2_{s\bar{s}} \simeq 15$ GeV^{-2}. Therefore, one can neglect the contribution of the $s\bar{s}$ component into

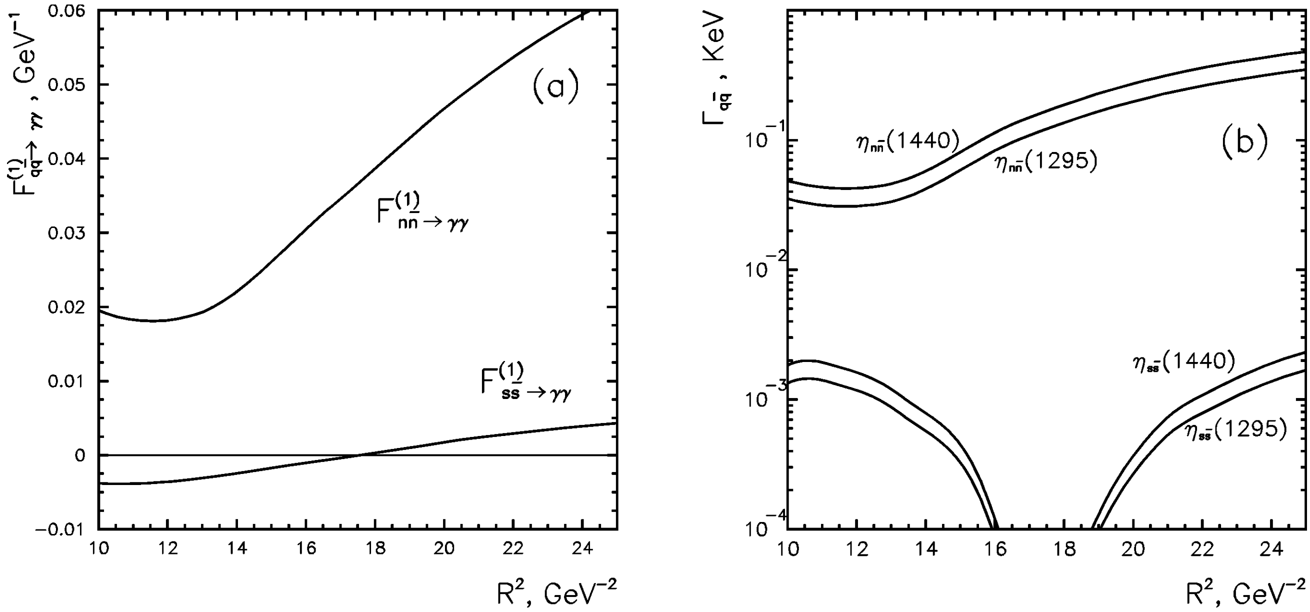

Fig. 2. (**a**) The transition form factors $F^{(1)}_{n\bar{n}\to\gamma\gamma}$ and $F^{(1)}_{s\bar{s}\to\gamma\gamma}$ as functions of the meson radius squared, R^2. (**b**) The partial widths $\Gamma^{(1)}_{n\bar{n}\to\gamma\gamma}$ and $\Gamma^{(1)}_{s\bar{s}\to\gamma\gamma}$ for $\eta(1295)$ and $\eta(1440)$ as functions of R^2

$\gamma\gamma$ decay. Then

$$\Gamma_{\eta(M)\to\gamma\gamma} \simeq \frac{\pi}{4}\alpha^2 M^3 \cos^2\phi F^{(1)\,2}_{n\bar{n}\to\gamma\gamma} = \cos^2\phi\,\Gamma^{(1)}_{n\bar{n}\to\gamma\gamma}(0), \tag{5}$$

where $\cos^2\phi$ is a probability for $n\bar{n}$ component in the $\eta(M)$ meson. The calculated values $\Gamma^{(1)}_{n\bar{n}\to\gamma\gamma}$ for $\eta(1295)$ and $\eta(1440)$ are shown in Fig. 2b as functions of $R^2_{n\bar{n}}$. A significant difference of widths $\Gamma^{(1)}_{n\bar{n}\to\gamma\gamma}$ for $\eta(1295)$ and $\eta(1440)$ is due to a strong dependence of partial width on the η-meson mass, $\Gamma_{\eta(M)\to\gamma\gamma} \sim M^3$.

Conclusion

We calculate the $\gamma\gamma$ partial width for $\eta(1295)$ and $\eta(1440)$ supposing these mesons to be members of the first radial excitation nonet $2^1S_0 q\bar{q}$. The calculation technique is based on that developed in [3] for the transition of mesons from basic nonet $1^1S_0 q\bar{q}$ into $\gamma^*(Q^2)\gamma$. The $\gamma\gamma$ partial widths of $\eta(1295)$ and $\eta(1440)$ are mainly determined by the flavour component $n\bar{n} = (u\bar{u} + d\bar{d})/\sqrt{2}$ so $\Gamma_{\eta(1295)\to\gamma\gamma} + \Gamma_{\eta(1440)\to\gamma\gamma} \simeq \Gamma^{(1)}_{n\bar{n}}$. Partial widths strongly depend on the meson radii squared: $\Gamma_{\eta(1295)\to\gamma\gamma} + \Gamma_{\eta(1440)\to\gamma\gamma} \simeq 0.04$ keV at $R^2_{\eta(X)}/R^2_\pi \le 1.5$ and $\Gamma_{\eta(1295)\to\gamma\gamma} + \Gamma_{\eta(1440)\to\gamma\gamma} \simeq 0.2$ keV at $R^2_{\eta(X)}/R^2_\pi \simeq 2$.

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References

1. C. Caso, et al. (PDG), Eur. Phys. J. C **3**, 1 (1998)
2. H.J.Behrend, et al. (CELLO), Z. Phys. C **49**, 401 (1991); H.Aihara, et al. (TCP/2γ), Phys. Rev. Lett. **64**, 172 (1990)
3. V. V. Anisovich, D. I. Melikhov, V. A. Nikonov, Phys. Rev. D **55**, 2918 (1997)
4. P. Baillon, et al. (CERN-CdF), Nuovo. Cim. A **50**, 393 (1967)