Y(4260) as four-quark state

S. Dubnička, A. Z. Dubničková, A. Issadykov, M. A. Ivanov, and A. Liptaj

1Institute of Physics, Slovak Academy of Sciences, Bratislava, Slovak Republic
2Dept. of Theoretical Physics, Comenius University, Bratislava, Slovak Republic
3Bogoliubov Laboratory of Theoretical Physics, Joint Institute for Nuclear Research, 141980 Dubna, Russia

Abstract

We treat the Y(4260) resonance as a four-quark state in the framework of the covariant confining quark model. We study two choices of the interpolating current, either the molecular-type current which effectively corresponds to the product of D and D̄1 quark currents or tetraquark one. In both cases we calculate the widths of decays Y(4260) → Zc(3900) + π and Y(4260) → D(∗) + D̄(∗). It is found that in both approaches the mode Y → Zc+ + π− is enhanced compared with the open charm modes. However the absolute value of the Y → Zc+ + π− decay width obtained in molecular picture is arguably too large. On the other hand the value obtained in tetraquark picture is reasonable.

PACS numbers:

*Electronic address: stanislav.dubnicka@savba.sk
†Electronic address: anna.dubnickova@fmpha.uniba.sk
‡Electronic address: issadykov.a@gmail.com
§Electronic address: ivanovm@theor.jinr.ru
¶Electronic address: andrej.liptaj@savba.sk
I. INTRODUCTION

In 2005 BABAR Collaboration observed a broad resonance around 4.26 GeV in analyzing the mass spectrum of $\pi^+\pi^-J/\psi$ in initial-state-radiation (ISR) production $e^+e^- \rightarrow \gamma_{\text{ISR}} \pi^+\pi^-J/\psi$ [1]. Since this resonance was found in the $e^+e^-$ annihilation through ISR, its spin-parity is $J^{PC} = 1^{--}$. However, its mass does not fit any mass of charmonium states in the same mass region, such as the $\psi(4040)$, $\psi(4160)$, and $\psi(4415)$. Moreover, the $Y(4260)$ has strong coupling to the $\pi^+\pi^-J/\psi$ final state, but no evidence was found for coupling to any open charm decay modes as $D(\ast)\bar{D}(\ast)$, $D(\ast)s\bar{D}(\ast)s$ where $D(\ast)$ = $D$ or $D^*$ [2–6]. These properties perhaps indicate that the $Y(4260)$ state is not a conventional state of charmonium [7].

In addition to the $Y(4260)$, the the BESIII Collaboration reported on the observation of another exotic state named as $Z_c(3900)$ in the reaction $e^+e^- \rightarrow \pi^+\pi^-J/\psi$ [8]. It carries an electric charge and couples to charmonium. A fit to the $\pi^\pm J/\psi$ invariant mass spectrum results in a mass of $M_{Z_c} = 3899.0 \pm 3.6(\text{stat}) \pm 4.9(\text{syst})$ MeV and a width of $\Gamma_{Z_c} = 46 \pm 10(\text{stat}) \pm 20(\text{syst})$ MeV. This state was confirmed by Belle [9] and CLEO [10] Collaborations. Then the BESIII Collaboration observed a distinct charged structure in the $(DD^\ast)^\mp$ invariant mass distribution of the process $e^+e^- \rightarrow \pi^\mp(DD^\ast)^\pm$ [11]. Assuming this structure and the $Z_c(3900) \rightarrow \pi J/\psi$ signal are from the same source, the ratio of partial widths is $\Gamma(Z_c \rightarrow D\bar{D}^\ast)/\Gamma(Z_c \rightarrow \pi J/\psi) = 6.2 \pm 2.7$. That means that the $Z_c(3900)$ state has a much stronger coupling to $DD^\ast$ than to $\pi J/\psi$ [12].

Now we go back to the $Y(4260)$ and shortly review some theoretical efforts to understand the underlying structure of this state. We refer to Ref. [7] for more complete review of this subject. Probably, one of the first attempts to analyze the possible interpretations of the $Y(4260)$ was undertaken in Ref. [13]. The conclusion has been done that only the hybrid charmonium picture is not in conflict with available experimental data from BABAR measurement. The interpretation of the $Y(4260)$ as a charmonium hybrid has been also explored in Refs. [14, 15].

The three-body $J/\psi\pi\pi$ and $J/\psiKK$ systems have been treated as coupled channels in Ref. [16]. It was found by solving the Faddeev equations that the resonance $Y(4260)$ can be generated due to the interaction between these three mesons. The $Y(4260)$ has been identified as the low member of the pair $\psi(4S) - \psi(3D)$ charmonium by using simple quark model [17].
In the paper [18] it was suggested that the $Y(4260)$ is a $\chi_{c1} - \rho^0$ molecule. In that picture one can show that the width of decay $Y(4260) \to \pi^+\pi^-J/\psi$ is larger than $Y(4260) \to DD$ which has not been observed.

It was proposed in Ref. [19] to interpret the $Y(4260)$ as the first orbital excitation of a diquark-antidiquark state ($[cs][\bar{c}\bar{s}]$). In this case the $Y(4260)$ should decay predominantly to $D_s\bar{D}_s$.

Masses of heavy tetraquarks have been calculated in the relativistic quark model [20]. It was found the P-wave state of the tetraquark combination ($([cq]_{S=0}[\bar{c}\bar{q}]_{S=0})$ has a mass of 4244 MeV which is close to the $Y(4260)$ mass. At the same time the mass of charm-strange diquark-antidiquark was found to be more than 200 MeV heavier than the $Y(4260)$ mass. It was concluded that a more natural tetraquark interpretation of the $Y(4260)$ is charm-nonstrange diquark-antidiquark state. Then the dominant decay mode of the $Y(4260)$ would be in $DD$ pairs.

However, as mentioned above, no evidence was found for the decays $Y(4260) \to D^{(*)}\bar{D}^{(*)}, D_s^{(*)}\bar{D}_s^{(*)}$. In the Ref. [21] it was assumed that the $Y(4260)$ is $DD_1$ molecular state where $D = D(1870)$ is the pseudoscalar meson with the quantum numbers $I(J^P) = \frac{1}{2}(0^-)$ and $D_1 = D_1(2420)$ is the narrow axial meson $I(J^P) = \frac{1}{2}(1^+)$, $\Gamma = 27 \pm 3$ MeV. With this ansatz, the observation of $Z_c(3900)$ in the $\pi^+\pi^-J/\psi$ invariant mass distribution has as obvious explanation as well the absence of the $Y(4260)$ in the decays with open charm.

However, in Ref. [22] it was argued that the production of an S-wave $DD_1$ pair in $\ell^+\ell^-$-annihilation is forbidden by the heavy quark spin symmetry. This argument is certainly not in the favor of considering the $Y(4260)$ as S-wave $DD_1$ state. Despite of this, there are many studies of the $Y(4260)$ as $DD_1$ molecular state. We briefly mention some of them. By assuming that the $Y(4260)$ is a $DD_1$ molecular state, some hidden-charm and charmed pair decay channels of the $Y(4260)$ via intermediate $DD_1$ meson loops within an effective Lagrangian approach have been investigated in Ref. [23]. By treating the $Y(4260)$ as a $DD_1$ weakly bound state and also the $Z_c(3900)$ as a $DD^*$ molecule [24], the two-body decay $Y(4260) \to Z_c(3900) + \pi$ has been studied. Moreover the decay mode $Y(4260) \to J/\psi + \pi^+\pi^-$ was also computed.

The approach we propose is based on the covariant confining quark model (CCQM) [25–27] which represents an effective quantum field treatment of hadronic effects. The model is derived from Lorentz invariant non-local Lagrangian in which a hadron is coupled to
its constituent quarks. Hadrons are characterized by size parameters $\Lambda_H$ from which the strength of the quark-hadron coupling can derived. It is done by using so-called composite-ness condition $[28, 29]$, this condition requires the wavefunction renormalization constant of the hadron to be zero $Z_H = 0$. Besides reducing the number of free parameters (i.e. couplings), it also guarantees a correct description of bound states as dressed (with no overlap with bare states) and solves the double counting problem. The vertices are described by a Gaussian-type vertex functions which are supposed to effectively include contributions from gluons (which are not present). Thanks to the built-in confinement, based on a cutoff in the integration space of Schwinger parameters (stemming from representation of quark propagators), the model can be used for description of arbitrary heavy hadrons. The model should be understood as a practical tool for computing hadronic form factors from assumed quark currents, which is, in this text, applied to $Y(4260)$ and $Z_c(3900)$ states.

In our earlier papers devoted to description of the multi-quark states Refs. $[30, 31]$, first, we have explored the consequences of treating the $X(3872)$ meson as a tetraquark, i.e. diquark-antidiquark bound state. We have calculated the decay widths of the observed channels and concluded that for reasonable values of the size parameter of the $X(3872)$ one finds consistency with the available experimental data. Then we have critically checked in Ref. $[32]$ the tetraquark picture for the $Z_c(3900)$ state by analyzing its strong decays. We found that $Z_c(3900)$ has a much more stronger coupling to $DD^*$ than to $J/\psi \pi$ which is in discord with experiment. As an alternative we have employed a molecular-type four-quark current to describe the decays of the $Z_c(3900)$ state. We found that a molecular-type current gives the values of the above decays in accordance with the experimental observation. By using molecular-type four-quark currents for the recently observed resonances $Z_b(10610)$ and $Z_b(10650)$, we have calculated in Ref. $[33]$ their two-body decay rates into a bottomonium state plus a light meson as well as into B-meson pairs. A brief sketch of our findings may be found in Ref. $[34]$.

In the present paper we treat the $Y(4260)$ resonance as a four-quark state. We study two choices of the interpolating currents either the molecular-type current which effectively corresponds to the product of $D$ and $\bar{D}_1$ quark currents or tetraquark one. In both cases we calculate the widths of decays $Y(4260) \rightarrow Z_c(3900) + \pi$ and $Y(4260) \rightarrow D^{(*)} + \bar{D}^{(*)}$.

The paper is organized as follows: Two subsequent sections $[II]$ and $[III]$ are dedicated to the general formalism for describing $Y(4260)$ as four quark molecular state and tetraquark state
respectively, full expressions of studied quark currents and related amplitudes are provided. In the next, last section the decay width formulas are written down and used to reach our numerical results which are presented together with our conclusion.

II. Y(4260) AS FOUR-QUARK STATE WITH MOLECULAR-TYPE CURRENT

We start with an assumption that both the $Y(4260)$ and $Z^+_c(3900)$ resonances are four-quark states with the molecular-type currents given in Table I.

TABLE I: Quantum numbers and molecular-type currents.

| Title         | $I^G(J^{PC})$ | Interpolating current                                                                 | Mass (MeV) | Width (MeV) |
|---------------|---------------|---------------------------------------------------------------------------------------|------------|-------------|
| $Y(4260)$     | $0^-(1^{--})$ | $\frac{1}{\sqrt{2}} \left\{ (\bar{q} \gamma_5 c)(\bar{c} \gamma^\mu \gamma_5 q) - (\gamma_5 \leftrightarrow \gamma^\mu \gamma_5) \right\}$ | 4230±8     | 55±19       |
| $Z^+_c(3900)$ | $1^+(1^{+-})$ | $\frac{i}{\sqrt{2}} \left\{ (\bar{d} \gamma_5 c)(\bar{c} \gamma^\mu u)(x_4) + (\gamma_5 \leftrightarrow \gamma^\mu \gamma_5) \right\}$ | 3887.2±2.3 | 28.2±2.6    |

Their nonlocal generalizations are given by

\[
J_{Y_{\text{mol}}}^\mu(x) = \int dx_1 \ldots dx_4 \delta \left( x - \sum_{i=1}^{4} w_i x_i \right) \Phi_Y \left( \sum_{i<j} (x_i - x_j)^2 \right) J_{Y_{\text{mol};4q}}^\mu(x_1, \ldots, x_4),
\]  

(1)

\[
J_{Z_{\text{mol}}}^\mu(x) = \int dx_1 \ldots dx_4 \delta \left( x - \sum_{i=1}^{4} w_i x_i \right) \Phi_Z \left( \sum_{i<j} (x_i - x_j)^2 \right) J_{Z_{\text{mol};4q}}^\mu(x_1, \ldots, x_4),
\]  

(2)

\[
J_{Y_{\text{mol}}}^\mu(x) = \frac{1}{\sqrt{2}} \left\{ (\bar{q}(x_3)\gamma_5 c(x_1)) \cdot (\bar{c}(x_2)\gamma^\mu \gamma_5 q(x_4)) - (\gamma_5 \leftrightarrow \gamma^\mu \gamma_5) \right\}
\]  

(1)

\[
J_{Z_{\text{mol}}}^\mu(x) = \frac{i}{\sqrt{2}} \left\{ (\bar{d}(x_3)\gamma_5 c(x_1)) \cdot (\bar{c}(x_2)\gamma^\mu u(x_4)) + (\gamma_5 \leftrightarrow \gamma^\mu \gamma_5) \right\}.
\]  

The reduced quark masses are specified as

\[
w_1 = w_2 = \frac{m_c}{2(m_c + m_q)}, \quad w_3 = w_4 = \frac{m_q}{2(m_c + m_q)},
\]  

(3)

where we assume no isospin-violation in the $u - d$ sector, i.e. $m_u = m_d$. The Fourier-transform of the vertex function $\Phi$ may be written as

\[
\Phi \left( \sum_{i<j} (x_i - x_j)^2 \right) = \prod_{i=1}^{3} \int \frac{d^4q_i}{(2\pi)^4} e^{-iq_1(x_1-x_4)-iq_2(x_2-x_4)-iq_3(x_3-x_4)} \Phi \left( -\frac{1}{2} \sum_{i\leq j} q_i q_j \right).
\]  

(4)
We consider two kinds of the strong $Y$-decays: $Y \to D + \bar{D}$ where we imply the open-charm combinations as $D \bar{D}$, $D \bar{D}^*$, $D^* D$, $D^* \bar{D}^*$, and $Y \to Z_c + \pi$. The Feynman diagrams describing these decays are shown in Fig. 1. The matrix elements of the decays $Y_u \to D_1 + \bar{D}_2$

\[ M \left( Y_u(p, \epsilon^\mu) \to D_1^0(p_1) + \bar{D}_2^0(p_2) \right) = \frac{9}{\sqrt{2}} g_Y g_{D_1} g_{D_2} \]

\[ \times \int \frac{d^4k_1}{(2\pi)^4} \int \frac{d^4k_2}{(2\pi)^4} \tilde{\Phi}_Y (-\Omega^2_q) \tilde{\Phi}_{D_1} (-\ell^2_1) \tilde{\Phi}_{D_2} (-\ell^2_2) \]

\[ \times \left\{ \text{tr} [\gamma_5 S_c(k_1) \Gamma_2 S_u(k_3)] \cdot \text{tr} [\gamma^\mu \gamma_5 S_u(k_2) \Gamma_1 S_c(k_4)] - (\gamma_5 \leftrightarrow \gamma^\mu \gamma_5) \right\} . \quad (5) \]

Here, $\Gamma_1 \otimes \Gamma_2 = \gamma_5 \otimes \gamma_5$ for $D \bar{D}$ pair, $\epsilon^*_1 \gamma^\nu_1 \otimes \gamma_5$ for $D^* \bar{D}$ pair, and $\epsilon^*_1 \gamma^\nu_1 \otimes \epsilon^*_2 \gamma^\nu_2$ for $D^* \bar{D}^*$ pair. The momenta are defined as

\[ \Omega^2_q = \frac{1}{2} \sum_{i \leq j} q_i q_j, \quad q_1 = -k_1 - w^Y_1 p, \quad q_2 = k_4 - w^Y_2 p, \quad q_3 = k_3 - w^Y_3 p, \]

\[ \ell_1 = k_2 + w^D_1 p_1, \quad \ell_2 = -k_1 - w^D_2 p_2, \quad k_3 = k_1 + p_2, \quad k_4 = k_2 + p_1. \quad (6) \]

The calculation of the matrix element of the decay $Y \to Z_c + \pi$ is more involved because it is described by three-loop diagram as shown in Fig. 1b. One has

\[ M \left( Y_u(p, \epsilon^\nu) \to Z_c^+(p_1, \epsilon^\nu) + \pi^- \right) = \frac{9}{2} g_Y g_{Z_c} g_{\pi} \]

\[ \times \prod_{j=1}^3 \left[ \int \frac{d^4k_j}{(2\pi)^4} \right] \tilde{\Phi}_Y (-\Omega^2_q) \tilde{\Phi}_{Z_c} (-\Omega^2_\pi) \tilde{\Phi}_\pi (-\ell^2) \]

\[ \times \epsilon_\mu(p) \epsilon^*_\nu(p_1) \sum_{\Gamma} \text{tr} [\Gamma_1 S_c(k_1) \Gamma_2 S_u(k_2)] \cdot \text{tr} [\Gamma_3 S_u(k_3) \Gamma_4 S_d(k_4) \Gamma_5 S_c(k_5)] . \quad (7) \]
Here

\[ \sum_{\Gamma} [\Gamma_1 \otimes \Gamma_2] \cdot [\Gamma_3 \otimes \Gamma_4 \otimes \Gamma_5] = [\gamma_5 \otimes \gamma_5] \cdot [\gamma^\mu \gamma_5 \otimes \gamma_5 \otimes \gamma^\nu] \]

\[ - [\gamma^\mu \gamma_5 \otimes \gamma^\nu] \cdot [\gamma_5 \otimes \gamma_5 \otimes \gamma_5] - [\gamma^\mu \gamma_5 \otimes \gamma_5] \cdot [\gamma_5 \otimes \gamma_5 \otimes \gamma^\nu], \]  

(8)

The momenta are defined as

\[ \Omega_q^2 = \frac{1}{2} \sum_{i \leq j} q_i q_j, \quad q_1 = -k_1 - w_1^Y p, \quad q_2 = k_5 - w_2^Y p, \quad q_3 = k_2 - w_3^Y p, \]

\[ \Omega_r^2 = \frac{1}{2} \sum_{i \leq j} r_i r_j, \quad r_1 = -k_5 + w_1^Z p_1, \quad r_2 = k_1 + w_2^Z p_1, \quad r_3 = k_4 - w_3^Z p_1, \]

\[ \ell = k_3 + w_6^p p_2, \quad k_4 = k_3 + p_2, \quad k_5 = k_1 - k_2 + k_3 + p. \]

(9)

III. \( Y(4260) \) AS FOUR-QUARK STATE WITH TETRAQUARK CURRENT

Now we treat the \( Y(4260) \) as four-quark state with the tetraquark current:

\[ J_{Y_{\text{tet}}}^\mu = \frac{1}{\sqrt{2}} \epsilon_{abc} \epsilon_{dec} \left\{ (q_a C_\gamma \gamma_5 c_b)(\bar{q}_d \gamma^\mu \gamma_5 c_e) - (q_a C \gamma^\mu \gamma_5 c_b)(\bar{q}_d \gamma_5 c_e) \right\}. \]

(10)

where the charge conjugate matrix is chosen in the form \( C = \gamma^0 \gamma^2 \) so that \( C^T = -C, C^\dagger = C \) and \( C^2 = C \). Its nonlocal generalization is given by

\[ J_{Y_{\text{tet}},4q}^\mu (x) = \int dx_1 \ldots \int dx_4 \delta \left( x - \sum_{i=1}^{4} w_i^Y x_i \right) \Phi_Y \left( \sum_{i<j} (x_i - x_j)^2 \right) J_{Y_{\text{tet}},4q}^\mu (x_1, \ldots, x_4), \]

\[ J_{Y_{\text{tet}},4q}^\mu = \frac{1}{\sqrt{2}} \epsilon_{abc} \epsilon_{dec} \left\{ (q_a (x_4) C_\gamma \gamma_5 c_b (x_1)) (\bar{q}_d (x_3) \gamma^\mu \gamma_5 c_e (x_2)) - (\gamma_5 \leftrightarrow \gamma^\mu \gamma_5) \right\}. \]

(11)

The matrix elements of the decays \( Y_u \rightarrow D_1 + \bar{D}_2 \) read as

\[ M \left( Y_{\text{tet}} (p, e_p^\mu) \rightarrow D_1^0 (p_1) + \bar{D}_2^0 (p_2) \right) = \frac{6}{\sqrt{2}} g_Y g_{D_1} g_{D_2} \]

\[ \times \int \frac{d^4 k_1}{(2\pi)^4} \int \frac{d^4 k_2}{(2\pi)^4} \tilde{\Phi}_Y \left( - \Omega_q^2 \right) \tilde{\Phi}_{D_1} \left( - \ell_1^2 \right) \tilde{\Phi}_{D_2} \left( - \ell_2^2 \right) \]

\[ \times \left\{ Tr \left[ \gamma_5 S_c (k_1) \Gamma^D_S u (k_3) \gamma^\mu \gamma_5 S_c (k_2) \Gamma^D_S u (k_4) \right] - (\gamma_5 \leftrightarrow \gamma^\mu \gamma_5) \right\}. \]

(12)

The momenta are defined as

\[ \Omega_q^2 = \frac{1}{2} \sum_{i \leq j} q_i q_j, \quad q_1 = -k_1 - w_1^Y p, \quad q_2 = -k_2 - w_2^Y p, \quad q_3 = k_3 - w_3^Y p, \]

\[ \ell_1 = -k_2 - w_6^D p_1, \quad \ell_2 = -k_1 - w_2^D p_2, \quad k_3 = k_1 + p_2, \quad k_4 = k_2 + p_1. \]

(13)
The matrix element of the decay $Y \rightarrow Z_c + \pi$ is written down

$$
M \left( Y_{\text{tet}}(p, e^\mu) \rightarrow Z_c^+(p_1, e^\nu) + \pi^-(p_2) \right) = 3 g_Y g_Z g_\pi \\
\times \prod_{j=1}^3 \left[ \int \frac{d^4k_j}{(2\pi)^4 i} \right] \tilde{\Phi}_Y (-\Omega_q^2) \tilde{\Phi}_{Z_c} (-\Omega_r^2) \tilde{\Phi}_\pi (-\ell^2) \\
\times \epsilon_\mu(p) \epsilon_\nu^*(p_1) \sum_{\Gamma} \text{tr} \left[ \Gamma^1 S_c(k_1) \Gamma^2 S_u(k_2) \Gamma^Y S_c(k_3) \Gamma^Z S_d(k_4) \gamma_5 S_u(k_5) \right]
$$

(14)

where $\tilde{\Gamma} = C^{-1} \Gamma^T C$ and $\sum_{\Gamma} = [\gamma_5 \otimes \gamma^\mu \gamma_5 - \gamma^\mu \gamma_5 \otimes \gamma_5]_Y \otimes [\gamma_5 \otimes \gamma^\nu - \gamma^\nu \otimes \gamma_5]^Z$. The momenta are defined as

$$
\Omega_q^2 = \frac{1}{2} \sum_{i \leq j} q_i q_j, \quad q_1 = -k_1 - w_1^Y p, \quad q_2 = -k_3 - w_2^Y p, \quad q_3 = k_2 - w_3^Y p, \\
\Omega_r^2 = \frac{1}{2} \sum_{i \leq j} r_i r_j, \quad r_1 = k_3 + w_1^Z p_1, \quad r_2 = k_1 + w_2^Z p_1, \quad r_3 = -k_4 + w_3^Z p_1, \\
\ell = -k_4 - w_5^\pi p_2, \quad k_4 = k_1 - k_2 + k_3 + p_1, \quad k_5 = k_1 - k_2 + k_3 + p.
$$

(15)
IV. NUMERICAL RESULTS AND CONCLUSION

We remind the formulas for the two-body decay widths expressed via Lorentz form factors.

\[
M(V(p) \rightarrow P(p_1) + P(p_2)) = \epsilon_\nu^c q_\mu G_{VVPP}, \quad q = p_1 - p_2,
\]

\[
\Gamma(V \rightarrow PP) = \frac{|P_1|^3}{6\pi m^2} G_{VVPP}^2,
\]

\[
M(V(p) \rightarrow A(p_1) + P(p_2)) = \epsilon_\nu^c \epsilon_A^* (g_{\mu\nu}A + p_1 \mu p_\nu B),
\]

\[
\Gamma(V \rightarrow AP) = \frac{|P_1|}{24\pi m^2} \left\{ \left( 3 + \frac{|P_1|^2}{m_1^2} \right) A^2 + \frac{m^2}{m_1^2} |P_1|^4 B^2 + \frac{m^2 + m_1^2 - m_2^2}{m_1^2} |P_1|^2 AB \right\},
\]

\[
M(V(p) \rightarrow V(p_1) + P(p_2)) = \epsilon_\nu^c \epsilon_\nu^c \epsilon_{\nu_1}^* \epsilon_{\nu_2}^* \left\{ p_{1\mu} p_{2\nu} + g_{\mu\nu} p_1 p_2 B 
\right. 
\left. + g_{\mu\nu} p_2 C + g_{\nu_1 \nu_2} p_1 D \right\},
\]

\[
\Gamma(V \rightarrow V_1 V_2) = \frac{|P_1|^3}{24\pi m^2 m_1^2} \left\{ m^2 |P_1|^4 A^2 + |P_1|^2 - 3 m_1^2 |B|^2 + |P_1|^2 + 3 m_2^2 |C|^2 
\right. 
\left. + |P_1|^2 + 3 \frac{m_1^2 m_2^2}{m^2} D^2 + |P_1|^2 |m^2 + m_1^2 - m_2^2| AB 
\right. 
\left. + |P_1|^2 |m_2 + m_1^2 - m_2^2| AC + |P_1|^2 |m^2 - m_1^2 - m_2^2| AD 
\right. 
\left. + 2 |P_1|^2 |m_1^2 + m_2^2| BC + 2 |P_1|^2 + m_1^2 + \frac{m_2^2}{m^2} (m_2^2 - m_2^2) |BD 
\right. 
\left. + 2 |P_1|^2 |m_1^2 + m_2^2| CD \right\}.
\]

We calculate the decay widths and put their numerical values in Table III. We have taken the value of \( Z_c \) size parameter to be equal \( \Lambda_{Z_c} = 3.3 \text{ GeV} \) as was obtained in our paper [32]. We vary the value of \( Y \) size parameter in some vicinity of this average value \( \Lambda_Y = 3.3 \pm 0.1 \text{ GeV} \). One can see that in both approaches the mode \( Y \rightarrow Z_c^+ \pi^- \) is enhanced compared with the open charm modes. The two approaches differ in the decay width values \( \Gamma(Y \rightarrow Z_c^+ \pi^-) \). Comparison with the total decay width of the \( Y(4260) \) particle from experiment \( 55 \pm 19 \text{MeV} \) disqualifies the molecular picture. As a result, one can conclude that the CCQM model calculations favor the tetraquark picture of the \( Y(4260) \) state since it leads to reasonable number of the decay width into \( Z_c^+ \pi^- \).
TABLE II: Decay widths in MeV.

| Mode                        | Molecular-type current | Tetraquark current |
|-----------------------------|------------------------|--------------------|
| $Y \rightarrow Z_c^+ + \pi^-$ | $146 \pm 13$           | $5.77 \pm 0.39$    |
| $Y \rightarrow D^0 + \bar{D}^0$ | $11 \pm 2$             | $(0.42 \pm 0.16) \cdot 10^{-3}$ |
| $Y \rightarrow D^{*0} + \bar{D}^{*0}$ | $(0.39 \pm 0.14) \cdot 10^{-2}$ | $0.32 \pm 0.09$ |
| $Y \rightarrow D^{*0} + \bar{D}^{*0}$ | $0$                   | $(0.19 \pm 0.08) \cdot 10^{-3}$ |

Acknowledgments

The work was supported by the Joint Research Project of Institute of Physics, Slovak Academy of Sciences (SAS), and Bogoliubov Laboratory of Theoretical Physics, Joint Institute for Nuclear Research (JINR), Grant No. 01-3-1135-2019/2023. A. Z. Dubničková, S. Dubnička and A. Liptaj also acknowledge the support from Slovak Grant Agency for Sciences (VEGA), Grant No.2/0153/17.

[1] B. Aubert et al. [BaBar Collaboration], Phys. Rev. Lett. 95, 142001 (2005) [hep-ex/0506081].
[2] D. Cronin-Hennessy et al. [CLEO Collaboration], Phys. Rev. D 80, 072001 (2009) [arXiv:0801.3418 [hep-ex]].
[3] G. Pakhlova, K. Abe et al. [Belle Collaboration], Phys. Rev. Lett. 98, 092001 (2007) [hep-ex/0608018].
[4] B. Aubert et al. [BaBar Collaboration], Phys. Rev. D 76, 111105 (2007) [hep-ex/0607083].
[5] B. Aubert et al. [BaBar Collaboration], Phys. Rev. D 79, 092001 (2009) [arXiv:0903.1597 [hep-ex]].
[6] P. del Amo Sanchez et al. [BaBar Collaboration], Phys. Rev. D 82, 052004 (2010) [arXiv:1008.0338 [hep-ex]].
[7] N. Brambilla et al., Eur. Phys. J. C 71, 1534 (2011) [arXiv:1010.5827 [hep-ph]].
[8] M. Ablikim et al. [BESIII Collaboration], Phys. Rev. Lett. 110, 252001 (2013) doi:10.1103/PhysRevLett.110.252001 [arXiv:1303.5949 [hep-ex]].
[9] Z. Q. Liu et al. [Belle Collaboration], Phys. Rev. Lett. 110, 252002 (2013).

[10] T. Xiao, S. Dobbs, A. Tomaradze and K. K. Seth, Phys. Lett. B 727, 366 (2013).

[11] M. Ablikim et al. [BESIII Collaboration], Phys. Rev. Lett. 112, 022001 (2014).

[12] Z. Liu, [arXiv:1504.06102 [hep-ex]].

[13] T. Xiao, S. Dobbs, A. Tomaradze and K. K. Seth, Phys. Lett. B 727, 366 (2013).

[14] M. Ablikim et al. [BESIII Collaboration], Phys. Rev. Lett. 112, 022001 (2014).

[15] Z. Liu, arXiv:1504.06102 [hep-ex].

[16] T. Xiao, S. Dobbs, A. Tomaradze and K. K. Seth, Phys. Lett. B 727, 366 (2013).

[17] M. Ablikim et al. [BESIII Collaboration], Phys. Rev. Lett. 112, 022001 (2014).

[18] E. Kou and O. Pene, Phys. Lett. B 631, 164 (2005) [hep-ph/0507119].

[19] F. E. Close and P. R. Page, Phys. Lett. B 628, 215 (2005) [hep-ph/0507199].

[20] A. Martinez Torres, K. P. Khemchandani, D. Gamermann and E. Oset, Phys. Rev. D 80, 094012 (2009) [arXiv:0906.5333 [nucl-th]].

[21] F. J. Llanes-Estrada, Phys. Rev. D 72, 031503 (2005) [hep-ph/0507035].

[22] X. Liu, X. Q. Zeng and X. Q. Li, Phys. Rev. D 72, 054023 (2005) [hep-ph/0507177].

[23] L. Maiani, V. Riquer, F. Piccinini and A. D. Polosa, Phys. Rev. D 72, 031502 (2005) [hep-ph/0507062].

[24] D. Ebert, R. N. Faustov and V. O. Galkin, Phys. Lett. B 634, 214 (2006) [hep-ph/0512230].

[25] Q. Wang, C. Hanhart and Q. Zhao, Phys. Rev. Lett. 111, no. 13, 132003 (2013) [arXiv:1303.6355 [hep-ph]].

[26] G. E. Efimov and M. A. Ivanov, Int. J. Mod. Phys. A 4, 2031 (1989).

[27] G. E. Efimov and M. A. Ivanov, The Quark Confinement Model of Hadrons (CRC Press, Boca Raton, 1993).

[28] T. Branz, A. Faessler, T. Gutsche and V. E. Lyubovitskij, Phys. Rev. D 81, 034010 (2010) [arXiv:0912.3710].

[29] A. Salam, Nuovo Cimento 25, 224 (1962).

[30] S. Weinberg, Phys. Rev. 130, 776 (1963).

[31] S. Dubnička, A. Z. Dubničková, M. A. Ivanov and J. G. Körner, Phys. Rev. D 81, 114007 (2010) [arXiv:1004.1291 [hep-ph]].
[32] F. Goerke, T. Gutsche, M. A. Ivanov, J. G. Körner, V. E. Lyubovitskij and P. Santorelli, Phys. Rev. D 94, no. 9, 094017 (2016) [arXiv:1608.04656 [hep-ph]].

[33] F. Goerke, T. Gutsche, M. A. Ivanov, J. G. Körner and V. E. Lyubovitskij, Phys. Rev. D 96, no. 5, 054028 (2017) [arXiv:1707.00539 [hep-ph]].

[34] M. Ivanov, EPJ Web Conf. 192, 00042 (2018) [arXiv:1809.02973 [hep-ph]].

[35] M. Tanabashi et al. [Particle Data Group], Phys. Rev. D 98, no. 3, 030001 (2018). doi:10.1103/PhysRevD.98.030001