Possible P-wave $D_s\bar{D}_{s0}(2317)$ molecular state $Y'(4274)$

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Stimulated by the measurement of the $J\psi\phi$ decay model of $Y(4274)$ by the LHCb Collaboration, we consider a possible interpretation of this state as a hadron molecular-a bound state of D_s and $\bar{D}_{s0}(2317)$ mesons. Using effective Lagrangian approach, we calculate the two-body strong decay channels $Y(4274) \to J/\psi\phi, \chi_{c0}\eta, \chi_{c0}\eta, D_s^*\bar{D}_s$, $D\bar{D}^*$, $K\bar{K}^*$, and $\phi\phi$ through hadronic loops and three-body decays into $\pi^0 D_s\bar{D}_s$. In comparison with the LHCb data, our results show that $Y(4274)$ cannot be assigned to be a $D_s\bar{D}_{s0}(2317)$ molecular state. The calculated partial decay widths with the $J^P = 1^+$ $D_s\bar{D}_{s0}$ molecular state picture indicate that allowed decay modes $\chi_{c0}\eta$ and $\chi_{c1}\eta$ may have the smallest branching ratio and are of the order of 0.0 MeV. Future experimental measurements of such two processes can be quite useful to test the different interpretations of the $Y(4274)$. If P-wave $D_s\bar{D}_{s0}$ molecular exists [marked as $Y'(4274)$], the total decay is at the order of 1.06–1.84 MeV, which seems to be within the reach of the current experiments such as Belle II. In addition, the calculated partial decay widths indicate that allowed decay mode $D\bar{D}^*$ may have the biggest branching ratio. The experimental measurements for this strong decay process could be a crucial to observe such a new state $Y'(4274)$.

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I. INTRODUCTION

Thanks to the great progress of the experiment in the past several decades, many hadrons that cannot be ascribed into the simple $\bar{q}q$ configuration for mesons or qqq configuration for baryons have been reported [1]. For example, various hidden-charm pentaquarks were observed in the $J/\psi p(\Lambda)$ invariant mass from the heavy baryon decay $\Lambda_b^+ \to K^- J/\psi p$ ($\Xi_b^- \to K^- J/\psi\Lambda$) by the LHCb Collaboration, $P_c(4312, 4440, 4450)$ and $P_{cs}(4459)$ [2,3]. Their confirmation, and determination of their quantum numbers, would allow new insights into the binding mechanisms present in multiquark systems and help improve understanding of QCD in the nonperturbative regime.

In 2017, a charmoniumlike meson named $Y(4274)$ was observed again by the LHCb Collaboration in the analysis of the $B^+ \to J/\psi\phi K^+$ reaction [4,5]. The observed resonance masses, widths, and favorable quantum numbers are

$$M = 4273.3 \pm 8.3^{+17.2}_{-3.6}\ \mathrm{MeV},$$
$$\Gamma = 56 \pm 11^{+8.0}_{-11}\ \mathrm{MeV}, \qquad J^{PC} = 1^{++}, \tag{1}$$

respectively, which are consistent with the early CDF Collaboration [6] report

$$M = 4274.4^{+8.4}_{-6.7}(\mathrm{stat})\ \mathrm{MeV},$$
$$\Gamma = 32.3^{+21.9}_{-15.3}(\mathrm{stat})\ \mathrm{MeV}. \tag{2}$$

Since the statistic is not enough, its spin-parity quantum number was not confirmed by the CDF Collaboration. However, the isospin of this state is zero, and it contains at least four valence quarks from the observed $J/\psi\phi$ decay mode.

Following the discovery of the $Y(4274)$, several theoretical studies have been performed. In the QCD sum rules approach, based on the analysis of the mass spectrum, the $Y(4274)$ can be interpreted as the S-wave $cs\bar{c}\bar{s}$ state with spin-parity $J^P = 1^+$ [7,8]. The compact tetraquark model, implemented by Stancu, can also describe the $Y(4274)$ [9], while only one $J^P = 1^+$ state exists. In Ref. [10], the mass of the $Y(4274)$ was studied in the relativized quark model, and it was shown that the $Y(4274)$ cannot be explained as a tetraquark state; however, it can be a good candidate of the

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conventional $\chi_{c1}(3^3P_1)$ state. And the $\chi_{c1}(3^3P_1)$ explanation for $Y(4274)$ was also proposed in Ref. [11]. In the context of the QCD two-point sum rule method by taking into account the quark, gluon, and mixed vacuum condensates, Ref. [12] assigned the $Y(4274)$ as a sextet $[cs][\bar{c}\bar{s}]$ diquark-antidiquark state with spin-parity $J^P = 1^+$. Based on the spin-spin interaction, Maiani, Polosa, and Riquer suggest that the $Y(4274)$ may have quantum number 0^{++} or 2^{++} [13], which contradicts the experimental observation [4,5]. Moreover, a detailed calculation is performed by Zhu [14], where the $Y(4274)$ may be described simultaneously by adding the up and down quark components.

Although the studies of Refs. [7–14] seem to indicate that this state is a compact tetraquark state or diquark-antidiquark state, $Y(4274)$ might still be a $D_s\bar{D}_{s0}(2317)$ hadronic molecule state. Since the mass of $Y(4274)$ is about 12 MeV below the threshold of $D_s\bar{D}_{s0}$ ($m_{D_{s0}} = 2317.8 \pm 0.6$ MeV and $m_{D_s} = 1968.34 \pm 0.07$ MeV [1]), it is reasonable to regard it as a bound state of $D_s\bar{D}_{s0}$. The idea comes from molecular state interpretation of deuteron due to deuteron mass being a little below the corresponding threshold and exhibiting sizable spatial extension. And because the quantum numbers of $\bar{D}_{s0}$ and D_s are $J^P = 0^+$ and $J^P = 0^-$, respectively, to form a bound state with quantum number $J^P = 1^+$, the coupling between $Y(4274)$ and its constituents should be a P wave. Indeed, it is shown in Ref. [15] that the interaction between a D_s meson and a $\bar{D}_{s0}$ meson is strong enough to form a bound state with a mass of about 4274 MeV.

From Ref. [15], $Y(4274)$ may be a molecular state. However, currently, we cannot fully exclude other possible explanations such as a compact pentaquark state [7–14]. Further research is required to distinguish whether it is a molecular or compact multiquark state. One way to distinguish the two scenarios is to study that allowing strong decay widths of the $Y(4274)$ baryon due to the strong decay almost saturates the total strong decay width. In the present paper, we consider possible strong decay modes using an effective Lagrangian approach by assuming that $Y(4274)$ is a hadronic molecule state of D_s and $\bar{D}_{s0}$.

This work is organized as follows. The theoretical formalism is explained in Sec. II. The predicted partial decay widths are presented in Sec. III, followed by a short summary in the last section.

II. FORMALISM AND INGREDIENTS

Besides the $J/\psi\phi$ decay model, which other decay is allowed? We first find that the transition from $Y(4274)$ to final states composed of purely neutral state $A\bar{A}$ are strictly forbidden by the conservation of the c parity. Thus, the decay of $Y(4274)$ into $\eta_c\eta$, $\chi_{c0}\eta$, $\chi_{c1}\eta$, $\phi\phi$, $\eta\eta$, $D_s^*\bar{D}_s$, $D\bar{D}^*$, $K\bar{K}^*$, and $\pi^0\bar{D}_sD_s$ is allowed by considering appropriate phase space [1]. However, the transitions $Y(4274) \to \eta_c\eta$ and $\eta\eta$ are also strictly forbidden by the conservation of angular momentum. In this work, we will calculate $J/\psi\phi$, $\chi_{c0}\eta$, $\chi_{c1}\eta$, $D_s^*\bar{D}_s$, $D\bar{D}^*$, $K\bar{K}^*$, and $\phi\phi$ strong decay patterns of the p-wave $D_s\bar{D}_{s0}$ molecular state within the effective Lagrangian approach and find the relation between the $D_s\bar{D}_{s0}$ molecular state and $Y(4274)$ by comparing with the experiment observation.

Before introducing the theoretical framework, we need to construct the flavor functions for the $D_s\bar{D}_{s0}$ system with definite $I(J^{PC})$. Since the $Y(4274)$ carry quantum numbers $I(J^{PC}) = 0(1^{++})$, the flavor function for a definite charge parity $\mathcal{C} = 1$ can be easy obtained [16]:

$$|D_s\bar{D}_{s0}\rangle = \frac{1}{\sqrt{2}}[D_s^+D_{s0}^- - D_s^-D_{s0}^+]. \tag{3}$$

Considering the quantum number $J^P = 1^+$ and the flavor function, $Y(4274)$ should couple to its components dominantly via the P wave, and the corresponding effective Lagrangian is in the form [17]

$$\begin{aligned}\mathcal{L}_{Y(4274)}(x) = {}& g_{YD_s\bar{D}_{s0}}Y^\mu(x)\int d^4y\Phi(y^2)\\ &\times\frac{1}{\sqrt{2}}[D_s^+(x+\omega_{D_{s0}^-}y)\overleftrightarrow{\partial}_\mu D_{s0}^-(x-\omega_{D_s^+}y)\\ &- D_s^-(x+\omega_{D_{s0}^+}y)\overleftrightarrow{\partial}_\mu D_{s0}^+(x-\omega_{D_s^-}y)],\end{aligned} \tag{4}$$

where $\omega_{D_s} = m_{D_s}/(m_{D_s}+m_{D_{s0}})$ and $\omega_{D_{s0}} = m_{D_{s0}}/(m_{D_s}+m_{D_{s0}})$. In the Lagrangian, an effective correlation function $\Phi(y^2)$ is introduced to describe the distribution of the two constituents, the D_s and the $\bar{D}_{s0}$, in the hadronic molecular $Y(4274)$ state. The introduced correlation function also makes the Feynman diagrams ultraviolet finite. Here, we choose the Fourier transformation of the correlation to be a Gaussian form in the Euclidean space [18–36]:

$$\Phi(p^2) \doteq \exp(-p_E^2/\Lambda^2) \tag{5}$$

with Λ being the size parameter which characterizes the distribution of the components inside the molecule. The value of Λ could not be determined from first principles; therefore, it should better be determined by experimental data. It is usually chosen to be about 1 GeV, which depends on experimental total widths [18–36]. In this work, we vary Λ in a range of $0.9\ \mathrm{GeV} \leq \Lambda \leq 1.10$ GeV to study whether the $Y(4274)$ can be interpreted as a P-wave molecule composed of $D_s\bar{D}_{s0}$.

The coupling constant $g_{YD_s\bar{D}_{s0}}$ in Eq. (4) can be computed by the compositeness condition [37,38], which indicates that the renormalization constants of a composite particle wave function should be zero, i.e.,

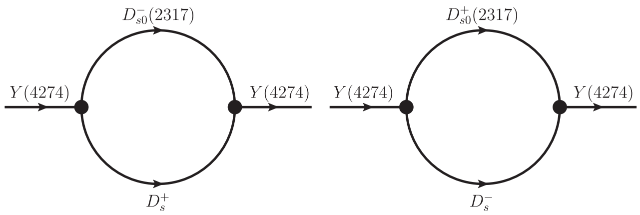

FIG. 1. Self-energy of the $Y(4274)$ state.

$$Z_Y = 1 - \frac{d\Sigma_Y^T}{dk_0}\bigg|_{k_0=m_Y} = 0, \tag{6}$$

where the Σ_Y^T is the transverse part of the mass operator and relates to its mass operator via the relation

$$\Sigma_Y^{\mu\nu}(p) = (g_{\mu\nu} - p^\mu p^\nu/p^2)\Sigma_Y^T + \cdots. \tag{7}$$

The concrete form of the mass operators of the $Y(4274)$ corresponding to the diagrams in Fig. 1 is

$$\Sigma_Y^{\mu\nu}(k_0) = \frac{g^2_{YD_s\bar{D}_{s0}}}{2}\int\frac{d^4k_1}{(2\pi)^4}\bigg\{\Phi^2[(k_1-k_0\omega_{D_s^+})^2]\frac{i}{k_1^2-m^2_{D_s^+}} \times\frac{i}{(k_1-k_0)^2-m^2_{D_{s0}^-}} + \Phi^2[(k_1-k_0\omega_{D_s^-})^2]\frac{i}{k_1^2-m^2_{D_s^-}} \times\frac{i}{(k_1-k_0)^2-m^2_{D_{s0}^+}}\bigg\}(k_0-2k_1)_\mu(k_0-2k_1)_\nu, \tag{8}$$

where $k_0^2 = m_Y^2$ with k_0 and m_Y denoting the four momenta and mass of the $Y(4274)$, respectively, and k_1, m_{D_s}, and $m_{D_{s0}}$ are the four-momenta, the mass of the D_s meson, and the mass of the $\bar{D}_{s0}$ meson, respectively. With the above preparations, we can obtain the coupling constant of the $D_s\bar{D}_{s0}$ molecule to its components

$$\frac{1}{g^2_{YD_s\bar{D}_{s0}}} = \frac{m_Y}{8\pi^2\mathcal{S}}\int_0^\infty d\alpha\int_0^\infty d\beta\sum_{i=1}^2 \times\exp\left[-\frac{1}{\Lambda^2}\left(-\mathcal{F}_i m_Y^2 + \mathcal{H}_i + \frac{\mathcal{C}_i^2 m_Y^2}{z}\right)\right]\left(\frac{\mathcal{F}_i}{z^3} - \frac{\mathcal{C}_i^2}{z^4}\right), \tag{9}$$

where $\mathcal{F}_1 = (2\omega^2_{D_s^+}+\beta)$, $\mathcal{F}_2 = (2\omega^2_{D_s^-}+\beta)$, $\mathcal{H}_1 = \alpha m^2_{D_s^+} + \beta m^2_{D_{s0}^-}$, $\mathcal{H}_2 = \alpha m^2_{D_s^-} + \beta m^2_{D_{s0}^+}$, $\mathcal{C}_1 = (2\omega_{D_s^+}+\beta)$, $\mathcal{C}_2 = (2\omega_{D_s^-}+\beta)$, $z = 2+\alpha+\beta$, and $\mathcal{S} = 1.0$ GeV.

A. The decay $Y(4274) \to J/\psi\phi$

Since the $Y(4274)$ was observed in the $J/\psi\phi$ invariant mass, we first calculate the $J/\psi\phi$ two-body decay width of the $Y(4274)$ via the triangle diagrams shown in Fig. 2. The hadronic decay of the $D_s\bar{D}_{s0}$ molecular state into $J/\psi\phi$ is mediated by the exchange of the D_s^* meson. To evaluate the diagrams, in addition to the Lagrangian in Eq. (4), the following effective Lagrangians, responsible for vector meson $V(= J/\psi, \phi)$ coupling to $D_s^*\bar{D}_{s0}$ are needed as well [17]:

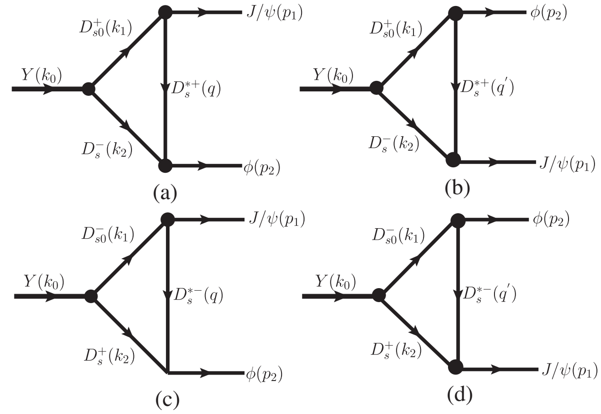

FIG. 2. Feynman diagrams for the $Y(4274) \to J/\psi\,\phi$ by the exchange D_s^* meson. The definitions of kinematics are also given.

$$\mathcal{L}_{D_s^*\bar{D}_{s0}V} = g_{V\bar{D}_{s0}D_s^*}[D_{s0}^- D^{*+}_{s;\mu\nu} - D_{s0}^+ D^{*-}_{s;\mu\nu}]V^{\mu\nu}, \tag{10}$$

where $V^{\mu\nu} = \partial^\mu V^\nu - \partial^\nu V^\mu$. The coupling constants $g_{J/\psi\bar{D}_{s0}D_s^*} = 0.225\ \text{GeV}^{-1}$ and $g_{\phi\bar{D}_{s0}D_s^*} = 0.135\ \text{GeV}^{-1}$ are from Ref. [17].

To compute the $D_sD_s^*V$ vertices, we also need the following effective Lagrangian [39,40]:

$$\mathcal{L}_{VVP} = \frac{G}{\sqrt{2}}\epsilon^{\mu\nu\alpha\beta}\langle\partial_\mu V_\nu\partial_\alpha V_\beta P\rangle, \tag{11}$$

where $G = 3h^2/(4\pi^2 f)$ with $h = -G_V m_\rho/(\sqrt{2}f^2)$, $f = 0.093$ GeV, $G_V = 0.069$ GeV [39,40], and $m_\rho = 0.775$ GeV. V_μ and P are standard $SU(4)$ matrices constructed with the 16-plet of the vector meson containing ρ and the 16-plet of pseudoscalar mesons containing π, respectively:

$$V_\mu = \begin{pmatrix} \frac{1}{\sqrt{2}}(\rho^0+\omega) & \rho^+ & K^{*+} & \bar{D}^{*0} \\ \rho^- & \frac{1}{\sqrt{2}}(-\rho^0+\omega) & K^{*0} & -D^{*-} \\ K^{*-} & \bar{K}^{*0} & \phi & D_s^{*-} \\ D^{*0} & -D^{*+} & D_s^{*+} & J/\psi \end{pmatrix}_\mu, \tag{12}$$

$$P=\sqrt{2}\begin{pmatrix} \frac{\pi^0}{\sqrt{2}}+\frac{\eta}{\sqrt{6}}+\frac{\eta'}{\sqrt{3}} & \pi^+ & K^+ & \bar{D}^0 \\ \pi^- & -\frac{\pi^0}{\sqrt{2}}+\frac{\eta}{\sqrt{6}}+\frac{\eta'}{\sqrt{3}} & K^0 & -D^- \\ K^- & \bar{K}^0 & -\sqrt{\frac{2}{3}}\eta+\frac{1}{\sqrt{3}}\eta' & D_s^- \\ D^0 & -D^+ & D_s^+ & \eta_c \end{pmatrix}. \tag{13}$$

With the above effective Lagrangians, we can get the decay amplitudes corresponding to the diagrams in Fig. 2:

$$\mathcal{M}_a=\frac{G}{\sqrt{2}}g_{J/\psi\bar{D}_{s0}D_s^*}g_{YD_s\bar{D}_{s0}}\int\frac{d^4q}{(2\pi)^4}\Phi[(k_1\omega_{D_s^-}-k_2\omega_{D_{s0}^+})^2](p_{1\mu}g_{\nu\sigma}-p_{1\nu}g_{\mu\sigma})(q_\mu g_{\nu\eta}-q_\nu g_{\mu\eta})\left(g_{\eta\lambda}-\frac{q_\eta q_\lambda}{m^2_{D_s^{*+}}}\right)$$
$$\times\epsilon^{\tau\lambda\alpha\beta}q_\tau p_{2\alpha}(k_1^\varphi-k_2^\varphi)\epsilon_\varphi^Y(k_0)\epsilon^{*\sigma}_{J/\psi}(p_1)\epsilon_\beta^{*\phi}(p_2)\frac{1}{q^2-m^2_{D_s^{*+}}}\frac{1}{k_2^2-m^2_{D_s^-}}\frac{1}{k_1^2-m^2_{D_{s0}^-}}, \tag{14}$$

$$\mathcal{M}_b=\frac{G}{\sqrt{2}}g_{\phi\bar{D}_{s0}D_s^*}g_{YD_s\bar{D}_{s0}}\int\frac{d^4q'}{(2\pi)^4}\Phi[(k_1\omega_{D_s^-}-k_2\omega_{D_{s0}^+})^2](p_{2\lambda}g_{\sigma\tau}-p_{2\sigma}g_{\lambda\tau})(q'_\lambda g_{\sigma\eta}-q'_\sigma g_{\lambda\eta})\left(g_{\nu\eta}-\frac{q'_\nu q'_\eta}{m^2_{D_s^{*+}}}\right)$$
$$\times\epsilon^{\mu\nu\alpha\beta}q'_\mu p_{1\alpha}(k_1^\varphi-k_2^\varphi)\epsilon_\varphi^Y(k_0)\epsilon_\tau^{*\phi}(p_2)\epsilon_\beta^{*J/\psi}(p_1)\frac{1}{q'^2-m^2_{D_s^{*+}}}\frac{1}{k_2^2-m^2_{D_s^-}}\frac{1}{k_1^2-m^2_{D_{s0}^-}}, \tag{15}$$

$$\mathcal{M}_c=\mathcal{M}_a(D_{s0}^+\to D_{s0}^-, D_s^-\to D_s^+, D_s^{*+}\to D_s^{*-}), \tag{16}$$

$$\mathcal{M}_d=\mathcal{M}_b(D_{s0}^+\to D_{s0}^-, D_s^-\to D_s^+, D_s^{*+}\to D_s^{*-}). \tag{17}$$

B. The decay $Y(4274)\to\chi_{c0}\eta$ and $\chi_{c1}\eta$

In this section, we compute the other possible decays of $Y(4274)$ with $D_s\bar{D}_{s0}$ molecular. Figure 3 shows the hadronic decay of the $D_s\bar{D}_{s0}$ molecular state into $\chi_{c0}\eta$ and $\chi_{c1}\eta$ mediated by the exchange of D_s meson. The ingredients need are the $\chi_{c0}D_s^+D_s^-$ and $\chi_{c1}D_s^+D_s^-$ Lagrangians [41,42]

$$\mathcal{L}_{\chi_{c1}D_s^+D_s^-}=-ig_{\chi_{c1}D_s^+D_s^-}(D_s^+\partial_\mu D_s^- - \partial_\mu D_s^+D_s^-)\chi_{c1}^\mu, \tag{18}$$

$$\mathcal{L}_{\chi_{c0}D_s^+D_s^-}=-g_{\chi_{c0}D_s^+D_s^-}\chi_{c0}D_s^+D_s^-. \tag{19}$$

The coupling constants $g_{\chi_{c1}D_s^+D_s^-}$ and $g_{\chi_{c0}D_s^+D_s^-}$ can be fixed from the heavy quark field theory [42].

Moreover, the effective Lagrangian, responsible for the coupling of D_{s0} to ηD_s, is needed as well [43]:

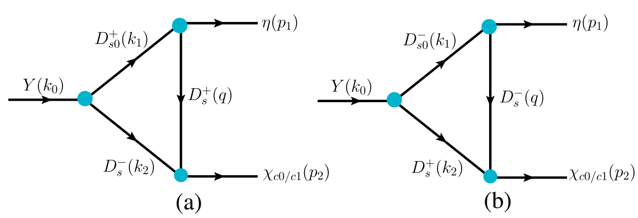

FIG. 3. Feynman diagrams for the process $Y(4274)\to\eta X_{c0/c1}$. The contributions include the t-channel D_s^+ (a) and D_s^- (b) exchanges.

$$\mathcal{L}_{D_{s0}D_s\eta}=g_{D_{s0}D_s\eta}D_{s0}D_s\eta, \tag{20}$$

where the coupling constant is found to be $g_{D_{s0}D_s\eta}=6.40$ [44].

Thus, we can obtain the following amplitudes for the decays $Y(4274)\to\chi_{c0}\eta$:

$$\mathcal{M}_a=\frac{g_{\eta\bar{D}_{s0}D_s}g_{YD_s\bar{D}_{s0}}g_{D_s^-D_s^+\chi_{c0}}}{\sqrt{2}}\int\frac{d^4q}{(2\pi)^4}\Phi[(k_1\omega_{D_s^-}-k_2\omega_{D_{s0}^+})^2]$$
$$\times(k_1^\varphi-k_2^\varphi)\epsilon_\varphi^Y(k_0)\frac{1}{q^2-m^2_{D_s^+}}\frac{1}{k_2^2-m^2_{D_s^-}}\frac{1}{k_1^2-m^2_{D_{s0}^+}}, \tag{21}$$

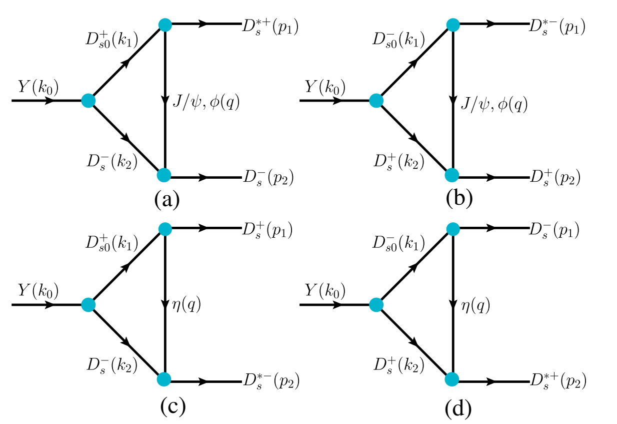

FIG. 4. Diagrams for $Y(4274)$ decay processes: (a),(d) $Y(4274)\to D_s^{*+}D_s^-$ and (b),(c) $Y(4274)\to D_s^{*-}D_s^+$.

$$\mathcal{M}_b = -\frac{g_{\eta\bar{D}_{s0}D_s} g_{YD_s\bar{D}_{s0}} g_{D_s^- D_s^+ \chi_{c0}}}{\sqrt{2}} \times \int \frac{d^4q}{(2\pi)^4} \Phi[(k_1\omega_{D_s^+} - k_2\omega_{D_{s0}^-})^2](k_1^\varphi - k_2^\varphi)\epsilon_\varphi^Y(k_0) \times \frac{1}{q^2 - m_{D_s^-}^2} \frac{1}{k_2^2 - m_{D_s^+}^2} \frac{1}{k_1^2 - m_{D_{s0}^-}^2}, \quad (22)$$

and $Y(4274) \to \chi_{c1}\eta$:

$$\mathcal{M}_a = \frac{g_{\eta\bar{D}_{s0}D_s} g_{YD_s\bar{D}_{s0}} g_{D_s^- D_s^+ \chi_{c1}}}{\sqrt{2}} \int \frac{d^4q}{(2\pi)^4} \Phi[(k_1\omega_{D_s^-} - k_2\omega_{D_{s0}^+})^2] \times (k_1^\varphi - k_2^\varphi)\epsilon_\varphi^Y(k_0)(k_2^\mu - q^\mu)\epsilon_\mu^{\chi_{c1}}(p_2) \times \frac{1}{q^2 - m_{D_s^+}^2} \frac{1}{k_2^2 - m_{D_s^-}^2} \frac{1}{k_1^2 - m_{D_{s0}^+}^2}, \quad (23)$$

$$\mathcal{M}_b = -\frac{g_{\eta\bar{D}_{s0}D_s} g_{YD_s\bar{D}_{s0}} g_{D_s^- D_s^+ \chi_{c1}}}{\sqrt{2}} \times \int \frac{d^4q}{(2\pi)^4} \Phi[(k_1\omega_{D_s^+} - k_2\omega_{D_{s0}^-})^2] \times (k_1^\varphi - k_2^\varphi)\epsilon_\varphi^Y(k_0)(k_2^\mu - q^\mu)\epsilon_\mu^{\chi_{c1}}(p_2) \times \frac{1}{q^2 - m_{D_s^-}^2} \frac{1}{k_2^2 - m_{D_s^+}^2} \frac{1}{k_1^2 - m_{D_{s0}^-}^2}. \quad (24)$$

The minus sign in Eqs. (27) and (24) come from the flavor function that is shown in Eq. (3). Then, we find $\mathcal{M}[Y(4274) \to \chi_{c0/c1}\eta]_{\mathrm{Total}} = \mathcal{M}_a + \mathcal{M}_b = 0$.

C. The decay $Y(4274) \to D_s^* \bar{D}_s$

Figure 4 shows the hadronic decay of the $D_s\bar{D}_{s0}$ molecular state into $D_s^*\bar{D}_s$ mediated by the exchange of the η meson. The ingredients needed are the vector(V)-pseudoscalar(P)-pseudoscalar(P) Lagrangian

$$\mathcal{L}_{\mathrm{VPP}} = -ig\langle[P, \partial_\mu P]V^\mu\rangle. \quad (25)$$

The coupling g is fixed from the strong decay width of $K^* \to K\pi$. With the help of Eq. (25), the two-body decay width $\Gamma(K^{*+} \to K^0\pi^+)$ is related to g as

$$\Gamma(K^{*+} \to K^0\pi^+) = \frac{g^2}{6\pi m_{K^{*+}}^2}\mathcal{P}_{\pi K^*}^3 = \frac{2}{3}\Gamma_{K^{*+}}, \quad (26)$$

where $\mathcal{P}_{\pi K^*}$ is the three-momentum of the π in the rest frame of the K^*. Using the experimental strong decay width ($\Gamma_{K^{*+}} = 50.3 \pm 0.8$ MeV) and the masses of the particles needed in the present work [1], we obtain $g = 4.61$.

Thus, we can obtain the following amplitudes for the decay $Y(4274) \to D_s^*\bar{D}_s$:

$$\mathcal{M}_a = \frac{-g g_{V\bar{D}_{s0}D_s^*} g_{YD_s\bar{D}_{s0}}}{\sqrt{2}} \int \frac{d^4q}{(2\pi)^4} \Phi[(k_1\omega_{D_s^-} - k_2\omega_{D_{s0}^+})^2] \times (p_{1\mu}g_{\nu\eta} - p_{1\nu}g_{\mu\eta})(q_\mu g_{\nu\lambda} - q_\nu g_{\mu\lambda})\left(g_{\lambda\alpha} - \frac{q_\lambda q_\alpha}{m_V^2}\right) \times (k_{2\alpha} + p_{2\alpha})(k_{1\omega} - k_{2\omega})\epsilon_{D_s^{*+}}^{*\eta}(p_1)\epsilon_Y^\omega(k_0) \times \frac{1}{q^2 - m_V^2} \frac{1}{k_2^2 - m_{D_s^-}^2} \frac{1}{k_1^2 - m_{D_{s0}^+}^2}, \quad (27)$$

$$\mathcal{M}_b = \mathcal{M}_b(D_{s0}^+ \to D_{s0}^-, D_s^- \to D_s^+, D_s^{*+} \to D_s^{*-}), \quad (28)$$

$$\mathcal{M}_c = \mathcal{M}_f(D_{s0}^- \to D_{s0}^+, D_s^+(k_2) \to D_s^-(k_2), D_s^{*+} \to D_s^{*-}), \quad (29)$$

$$\mathcal{M}_d = -\frac{g g_{YD_s\bar{D}_{s0}} g_{D_{s0}D_s\eta}}{\sqrt{6}} \int \frac{d^4q}{(2\pi)^4} \Phi[(k_1\omega_{D_s^+} - k_2\omega_{D_{s0}^-})^2] \times (q_\mu - k_{2\mu})(k_{1\nu} - k_{2\nu})\epsilon_\nu^Y(k_0)\epsilon_{D_s^{*+}}^{*\mu}(p_1) \times \frac{1}{q^2 - m_\eta^2} \frac{1}{k_2^2 - m_{D_s^+}^2} \frac{1}{k_1^2 - m_{D_{s0}^-}^2}. \quad (30)$$

D. The decay $Y(4274) \to D_s\bar{D}_s\pi^0$

Now we turn to the $D_s\bar{D}_s\pi^0$ three-body decay channel of $Y(4274)$. Under the $D_s\bar{D}_{s0}$ molecular state assignment, $Y(4274)$ first dissociates into $D_s^+D_{s0}^-$ or $D_s^-D_{s0}^+$. Then, the decay $Y(4274) \to D_s^+D_s^-\pi^0$ occurs via the transitions $D_{s0}^\pm \to D_s^\pm\pi^0$, where $D_{s0}^\pm$ decay into $D_s^\pm\pi^0$ by considering the $\eta - \pi^0$ mixing mechanism [45,46]. The relevant Feynman diagrams are shown in Fig. 5.

The Lagrangian including $\eta - \pi^0$ mixing for $\pi^0 D_{s0}D_s$ have been constructed in Ref. [47] and in the form

$$\mathcal{L}_{\pi^0 D_{s0}D_s} = g_{\pi^0 D_{s0}D_s}\pi^0 D_{s0}D_s, \quad (31)$$

where the coupling constant $g_{\pi^0 D_{s0}D_s}$ can be extracted by the relation

$$\Gamma(D_{s0}^\pm \to D_s^\pm\pi^0) = g_{\pi^0 D_{s0}D_s}^2 \frac{|\vec{\mathcal{P}}_{\pi^0}|}{8\pi m_{D_{s0}^\pm}^2}. \quad (32)$$

In the above, $\mathcal{P}_{\pi^0}$ is the three-momentum of π in the rest frame of D_{s0}.

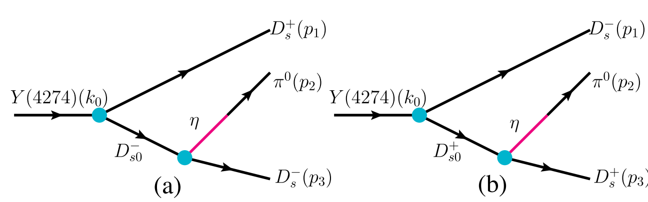

FIG. 5. Feynman diagrams for the $D_s^+D_s^-\pi^0$ three-body decay channel of $Y(4274)$.

At present, the experimental partial decay width on $D_{s0}^{\pm} \to D_s^{\pm}\pi^0$ is absent. We find only the absolute branching fraction $B(D_{s0}^{\pm} \to D_s^{\pm}\pi^0)$ is measured as $1.00^{+0.00}_{-0.14}(\text{stat})^{+0.00}_{-0.14}(\text{syst})$ [48] and the upper limit on the D_{s0} width is 3.8 MeV at the 95% confidence level (CL) [49]. In this work, we focus on whether $Y(4274)$ can be a P-wave $D_s\bar{D}_{s0}$ molecular state and hope that the theoretical maximum decay width cannot be compared with the experimental data. Thus, we use upper limit $\Gamma(D_{s0}) =$ 3.8 MeV to determine the coupling constant $g_{\pi^0 D_{s0} D_s} =$ 1.3124 GeV and in further calculations.

The general expression of the decay amplitude $Y(4274) \to D_s\bar{D}_s\pi^0$ is

$$\mathcal{M}_{a/b} = \frac{g_{\pi^0 D_{s0} D_s} g_{Y D_s \bar{D}_{s0}}}{\sqrt{2}}(q_\mu - p_{1\mu})\epsilon^\mu_Y(k_0) \times \Phi[(p_1\omega_{\bar{D}_{s0}} - q\omega_{D_s})^2]\frac{1}{q^2 - m^2_{D_{s0}} + im_{D_{s0}}\Gamma_{D_{s0}}}, \quad (33)$$

where $q = p_2 + p_3$.

E. The decay $Y(4274) \to D\bar{D}^*$, $K\bar{K}^*$, and $\phi\phi$

In this section, we calculate the two-body Okubo-Zweig-Iizuka (OZI) allowed strong decays $Y(4274) \to D\bar{D}^*$, $K\bar{K}^*$, and $\phi\phi$. The processes is described as a quark-antiquark pair $c\bar{c}$ or $s\bar{s}$ annihilation in the initial state. Meanwhile, a light quark-antiquark pair is created and then regroups into two outgoing hadrons by a quark rearrangement process. The decay of $Y(4274)$ into other channels, such as $Y(4274) \to \pi\bar{\pi}$, are ignored, because these processes, which involve the creation or annihilation of two $\bar{q}q$ ($q = u$, d, s, c) quark pairs, are usually strongly suppressed. The quark-level diagrams are depicted in Fig. 6 and corresponding hadron-level diagrams are in Fig. 7.

Besides the Lagrangians above, the effective Lagrangian of the KDD_{s0} vertex is also needed [43]:

$$\mathcal{L}_{KDD_{s0}} = g_{KDD_{s0}} KDD_{s0}, \quad (34)$$

where the coupling constant $g_{KDD_{s0}} = \sqrt{2}g_{K^- D^0 D^-_{s0}} =$ 10.21 is obtained from the coupling of the D_{s0} to the DK channel in isospin $I = 0$ [44]. Putting all the pieces together, we obtain the amplitudes for $Y(4274) \to D\bar{D}^*$,

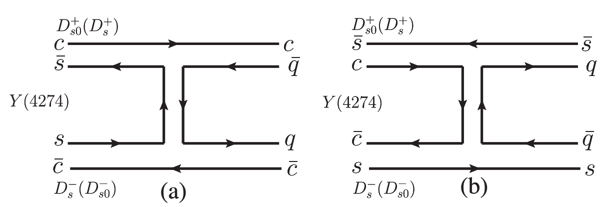

FIG. 6. The $Y(4274)$ decay process via the OZI mechanism. $q = u$, d quarks for diagram (a) and $q = u$, d, s quarks for diagram (b).

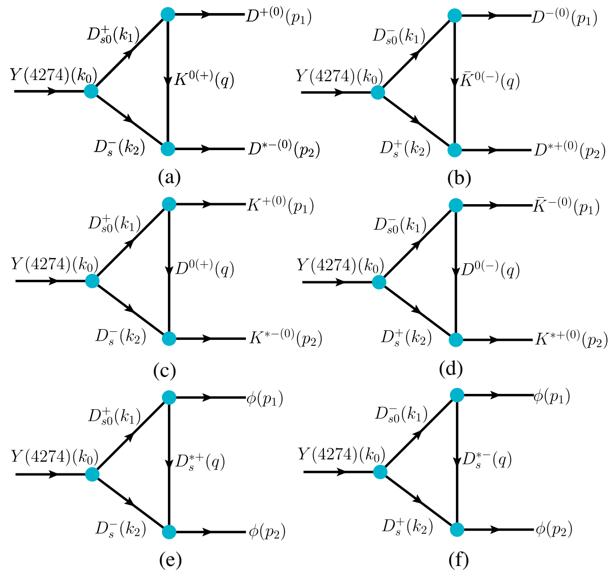

FIG. 7. Diagrams for $Y(4274)$ decay processes: (a),(b) $Y(4274) \to D\bar{D}^*$, (c),(d) $Y(4274) \to K\bar{K}^*$, and (e),(f) $Y(4274) \to \phi\phi$.

$K\bar{K}^*$, and $\phi\phi$ which correspond to the diagrams in Fig. 7:

$$\mathcal{M}_a = \frac{g_{KDD_{s0}} g g_Y}{\sqrt{2}} \int \frac{d^4q}{(2\pi)^4}\Phi[(k_1\omega_{D_s^-} - k_2\omega_{D^+_{s0}})^2] \times (q_\mu - k_{2\mu})(k_{1\nu} - k_{2\nu})\epsilon^\nu_Y(k_0)\epsilon^{*\mu}_{D^{*-(0)}}(p_2) \times \frac{1}{q^2 - m^2_{K^{0(+)}}}\frac{1}{k_2^2 - m^2_{D_s^-}}\frac{1}{k_1^2 - m^2_{D^+_{s0}}}, \quad (35)$$

$$\mathcal{M}_b = -\frac{g_{KDD_{s0}} g g_Y}{\sqrt{2}} \int \frac{d^4q}{(2\pi)^4}\Phi[(k_1\omega_{D_s^+} - k_2\omega_{D^-_{s0}})^2] \times (q_\mu - k_{2\mu})(k_{1\nu} - k_{2\nu})\epsilon^\nu_Y(k_0)\epsilon^{*\mu}_{D^{*+(0)}}(p_2) \times \frac{1}{q^2 - m^2_{\bar{K}^{0(-)}}}\frac{1}{k_2^2 - m^2_{D_s^+}}\frac{1}{k_1^2 - m^2_{D^-_{s0}}}, \quad (36)$$

$$\mathcal{M}_c = \mathcal{J}\frac{g_{KDD_{s0}} g g_Y}{\sqrt{2}} \int \frac{d^4q}{(2\pi)^4}\Phi[(k_1\omega_{D_s^-} - k_2\omega_{D^+_{s0}})^2] \times (q_\mu - k_{2\mu})(k_{1\nu} - k_{2\nu})\epsilon^\nu_Y(k_0)\epsilon^{*\mu}_{K^{*-(0)}}(p_2) \times \frac{1}{q^2 - m^2_{D^{0(+)}}}\frac{1}{k_2^2 - m^2_{D_s^-}}\frac{1}{k_1^2 - m^2_{D^+_{s0}}}, \quad (37)$$

$$\mathcal{M}_d = \mathcal{J}\frac{g_{KDD_{s0}} g g_Y}{\sqrt{2}} \int \frac{d^4q}{(2\pi)^4}\Phi[(k_1\omega_{D_s^+} - k_2\omega_{D^-_{s0}})^2] \times (q_\mu - k_{2\mu})(k_{1\nu} - k_{2\nu})\epsilon^\nu_Y(k_0)\epsilon^{*\mu}_{K^{*+(0)}}(p_2) \times \frac{1}{q^2 - m^2_{D^{0(-)}}}\frac{1}{k_2^2 - m^2_{D_s^+}}\frac{1}{k_1^2 - m^2_{D^-_{s0}}}, \quad (38)$$

$$\mathcal{M}_e = -\frac{G g_Y g_{\phi \bar{D}_{s0} D_s^*}}{2} \int \frac{d^4 q}{(2\pi)^4} \Phi[(k_1 \omega_{D_s^+} - k_2 \omega_{D_{s0}^-})^2] \times (q^\mu g^{\nu\eta} - q^\nu g^{\mu\eta})(p_{1\mu} g_{\nu\rho} - p_{1\nu} g_{\mu\rho})(-g^{\eta\lambda} + q^\eta q^\lambda / m_{D_s^{*+}}^2) \times \epsilon^{\tau\lambda\alpha\beta} q_\tau p_{2\alpha} (k_{1\sigma} - k_{2\sigma}) \epsilon_\phi^{*\rho}(p_1) \epsilon_\phi^{*\beta}(p_2) \epsilon_Y^\sigma(k_0) \times \frac{1}{q^2 - m_{D_s^{*+}}^2} \frac{1}{k_2^2 - m_{D_s^-}^2} \frac{1}{k_1^2 - m_{D_{s0}^+}^2}, \tag{39}$$

$$\mathcal{M}_f = \mathcal{M}_e(D_{s0}^+ \to D_{s0}^-, D_s^- \to D_s^+, D_s^{*+} \to D_s^{*-}), \tag{40}$$

where $\mathcal{J} = 1$ and -1 are for $D^0(D^0)$ and $D^+(D^-)$ exchange, respectively.

Once the amplitudes are determined, the corresponding partial decay widths can be obtained, which read

$$\Gamma(Y(4274) \to MB) = \frac{1}{24\pi} \frac{|\vec{p}_1|}{m_Y^2} \overline{|\mathcal{M}|^2}, \tag{41}$$

$$\Gamma(Y(4274) \to D_s \bar{D}_s \pi^0) = \frac{1}{3(2\pi)^5} \frac{1}{16 m_Y^2} \overline{|\mathcal{M}|^2} |\vec{p}_3^*| |\vec{p}_1| \times dm_{\pi^0 D_s^\pm} d\Omega_{p_3}^* d\Omega_{p_1}, \tag{42}$$

where J is the total angular momentum of the $Y(4274)$ state, the $|\vec{p}_1|$ is the three-momenta of the decay products in the center of mass frame, the overline indicates the sum over the polarization vectors of the final hadrons, and MB denotes the decay channel of MB, i.e., $J/\psi\phi$, $\chi_{c0}\eta$, $\chi_{c1}\eta$, $D_s^*\bar{D}_s$, $D\bar{D}^*$, $K\bar{K}^*$, and $\phi\phi$. In Eq. (42), the $\vec{p}_3^*$ and $\Omega_{p_3}^*$ are the momentum and angle of the particle $D_s^\pm$ in the rest frame of $D_s^\pm$ and π^0, respectively, and Ω_{p_1} is the angle of $D_s^\pm$ in the rest frame of the decaying particle $Y(4274)$. $m_{\pi^0 D_s^\pm}$ is the invariant mass for $D_s^\pm$ and π^0 and must meet $m_{D_{s0}^\pm} + m_{\pi^0} \le m_{\pi^0 D_s^\pm} \le m_Y - m_{D_s^\pm}$.

III. RESULTS AND DISCUSSIONS

In this work, we study the strong decays of the $Y(4274)$ to the two-body final states $J/\psi\phi, \chi_{c0}\eta, \chi_{c1}\eta, D_s^*\bar{D}_s$, $D\bar{D}^*$, $K\bar{K}^*$, and $\phi\phi$ and three-body decay into $\pi^0 D_s \bar{D}_s$ assuming that $Y(4274)$ is a $D_s\bar{D}_{s0}(2317)$ molecular state. In order to obtain the decay width shown in Figs. 2, 4, and 5, the coupling constant $g_{YD_s\bar{D}_{s0}}$ should be computed first.

According to the compositeness condition that we introduced in Eq. (6), Λ dependence of the coupling constant $g_{YD_s\bar{D}_{s0}}$ is computed. With a value of cutoff $\Lambda = 0.9$–1.1 GeV, the corresponding coupling constants are shown in Fig 8. We note that they decrease slowly with the increase of cutoff, and the coupling constant is almost independent of Λ, where $Y(4274)$ is a P-wave $D_s\bar{D}_{s0}$ molecular state. According to the studies in Refs. [18–36], a typical value of $\Lambda = 1.0$ GeV is often employed. Thus, in this work, we take $\Lambda = 1.0$ GeV, and the corresponding

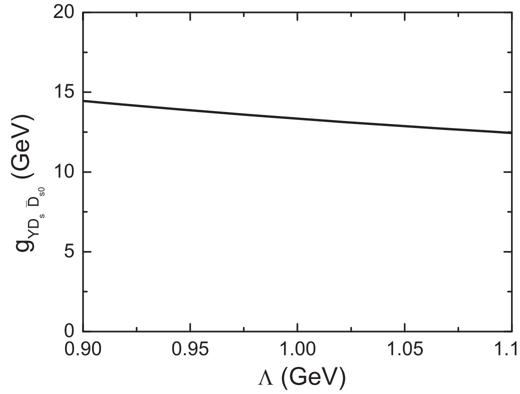

FIG. 8. The Λ dependence of the coupling $g_{YD_s\bar{D}_{s0}}$ estimated from the compositeness condition.

coupling constants are $g_{YD_s\bar{D}_{s0}} = 13.34^{+1.11}_{-0.89}$ GeV, in which the error reflects variation in Λ from 0.9 to 1.1 GeV.

Once the coupling constant $g_{YD_s\bar{D}_{s0}} = 13.34^{+1.11}_{-0.89}$ GeV is determined, the decay widths of $Y(4274)$ can be calculated straightforwardly. In Fig. 9, we show the partial decay widths of $Y(4274) \to J/\psi\phi, \chi_{c0}\eta, \chi_{c1}\eta, D_s^*\bar{D}_s$, $\pi^0 D_s\bar{D}_s$, $D\bar{D}^*$, $K\bar{K}^*$, and $\phi\phi$ as a function of cutoff parameter Λ. We find that the estimated two-body decay width increases with increase of cutoff and are all insensitive to cutoff parameter Λ, while the $Y(4274) \to \pi^0 D_s\bar{D}_s$ three-body decay decreases, but very slowly. We also find that the partial decay width is the largest for transition $Y(4274) \to D\bar{D}^*$. Thanks to the flavor symmetry of the wave function shown in Eq. (3), the $Y(4274) \to \chi_{c0}\eta$ and $\chi_{c1}\eta$ two-body decay widths are of the order of about 0.0 MeV. We also note that the three-body transition strength is quite small, and the decay width is of the order

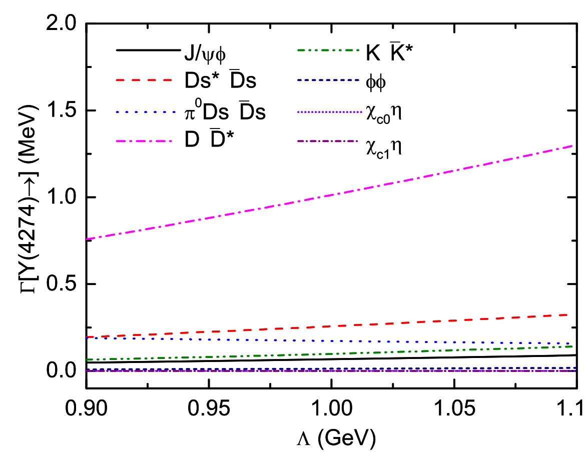

FIG. 9. Partial decay widths of the $Y(4274) \to J/\psi\phi$ (black solid line), $Y(4274) \to \pi^0 D_s\bar{D}_s$ (blue dotted line), $Y(4274) \to D_s^*\bar{D}_s$ (red dashed line), $Y(4274) \to \chi_{c0}\eta$ (violet short-dotted line), $Y(4274) \to D\bar{D}^*$ (magenta dash-dotted line), $Y(4274) \to K\bar{K}^*$ (olive dash-dot-dotted line), $Y(4274) \to \chi_{c1}\eta$ (purple short-dash-dotted line), and $Y(4274) \to \phi\phi$ (navy short-dashed line).

of 0.158–0.190 MeV. The small three-body decay width can be easy understood due to the decay $Y(4274) \to D_s\bar{D}_s\pi^0$ being an isospin violation process.

Two reasons can help us to understand why transition $Y(4274) \to D\bar{D}^*$ provides the dominant contribution. First is that transition $Y(4274) \to D\bar{D}^*$ is s-wave decay, and the lowest angular momentum gives the dominant contribution. Larger $Y(4274) \to D\bar{D}^*$ decay can also be understood due to the main component of D_{s0} being DK, and the coupling constant related to this vertex is larger than the others. The same $D_{s0}DK$ coupling also exists in the $Y(4274) \to K\bar{K}^*$ reaction. However, its partial decay width is small. A possible explanation is that a light quark-antiquark pair creation or annihilation in Fig. 6 is easier than that of a heavy quark-antiquark pair.

We also show the dependence of the total decay width on cutoff Λ in Fig. 10. In the present calculation, we vary Λ from 0.9 to 1.1 GeV. In this Λ range, the total decay width increases, and predicted decay width $\Gamma_Y = 1.25$–2.0 MeV is much smaller than the experimental width, which disfavors $Y(4274)$ in a $D_s\bar{D}_{s0}$ molecular picture. If we increase Λ to higher values, the total widths of $Y(4274)$ cannot be reproduced until a much larger Λ value of about 9.6 is adopted. Unfortunately, there are no such studies on taking $\Lambda = 9.6$ or higher, which is reasonable. Hence, the assignment as a P-wave $D_s\bar{D}_{s0}$ molecular state is impossible for $Y(4274)$ based on the total decay width experimentally measured. This is quite different from the conclusion in Ref. [15] that the interaction between a D_s meson and a $\bar{D}_{s0}$ meson is strong enough to form a bound state with a mass of about 4274 MeV, which can be associated to $Y(4274)$. Comparing our results with those in Ref. [15], it seems that a study of the spectroscopy alone does not give a complete picture of its nature.

Combining our results in Fig. 10 with the conclusion in Ref. [15], we predict a P-wave $D_s\bar{D}_{s0}$ molecular that we marked as $Y'(4274)$ may exist. Taking a typical value

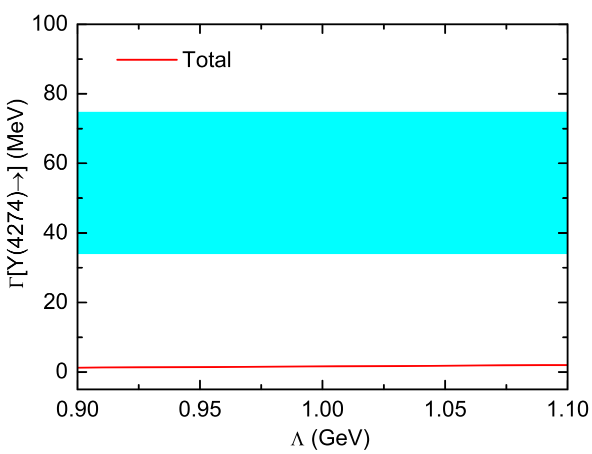

FIG. 10. The total decay width of the $Y(4274)$. The cyan bands denote the experimental total width [4,5].

$\Gamma(D_{s0}^{\pm} \to \pi D_s^{\pm}) = 79.3$ keV [19], where D_{s0} is assumed to be a DK bound state, the corresponding partial decay widths are $\Gamma[Y'(4274) \to D_s^*\bar{D}_s] = 0.20$–$0.33$ MeV, $\Gamma[Y'(4274) \to J/\psi\phi] = 0.048$–$0.090$, $\Gamma[Y'(4274) \to \pi^0 D_s\bar{D}_s] = 0.0066$–$0.0080$ MeV, $\Gamma[Y'(4274) \to D\bar{D}^*] = 0.76$–$1.30$ MeV, $\Gamma[Y'(4274) \to K\bar{K}^*] = 0.065$–$0.14$ MeV, $\Gamma[Y'(4274) \to \chi_{c0}\eta] = 0.0$ MeV, $\Gamma[Y'(4274) \to \chi_{c1}\eta] = 0.0$ MeV, and $\Gamma[Y'(4274) \to \phi\phi] = 0.0089$–$0.018$ MeV, which yields a total decay width of 1.06–1.84 MeV. And we find that the transition $Y'(4274) \to D\bar{D}^*$ is the main decay channel, almost saturating the total width. The experimental measurements for this strong decay process could be crucial to observe such a state.

IV. SUMMARY

In this work, inspired by the studies in Ref. [15] that showed the likely existence of a $D_s\bar{D}_{s0}$ bound state, we have studied its partial decay widths into $Y(4274) \to J/\psi\phi$, $\chi_{c0}\eta$, $\chi_{c1}\eta$, $\phi\phi$, $\eta\eta$, $D_s^*\bar{D}_s$, $D\bar{D}^*$, $K\bar{K}^*$, and $\pi^0\bar{D}_sD_s$. These decays involve the treatment of the $Y(4274)$ state as a quasibound state of $D_s\bar{D}_{s0}$ and utilizing the Weinberg compositeness condition to determine the corresponding coupling. Our studies find the P-wave $D_s\bar{D}_{s0}$ assignment for $Y(4274)$ is not allowed; it may be a compact tetraquark state or diquark-antidiquark state [7–14]. If $Y(4274)$ is a compact tetraquark state or diquark-antidiquark state [7–14], we suggest experimentally to search for $Y(4274)$ in the $Y(4274) \to \chi_{c0}\eta$ and $Y(4274) \to \chi_{c1}\eta$ reactions that the partial decay widths are of the order of 0.0 MeV by assuming $Y(4274)$ is a $D_s\bar{D}_{s0}$ molecular state. Theoretical investigations on decay modes and further experimental information on partial decay widths will be helpful to distinguish which inner structure of the $Y(4274)$ state is possible.

However, a P-wave $D_s\bar{D}_{s0}$ molecular with the total decay width at the order of 1.06–1.84 MeV [marked as $Y'(4274)$] is found. The predicted decay width seems to suggest that it is possible to observe such a state at Belle or Belle II, e.g., via the inclusive invariant mass distribution $D\bar{D}^*$, which is the largest transition. On the other hand, its production yields at these experimental setups remain to be studied.

If the $Y(4274)$ could be a P-wave $D_s\bar{D}_{s0}$ molecular, it naturally leads us to think about whether there are contributions from the light pseudoscalar meson exchanges (π, K, η, η') and the vector meson exchanges (ρ, ω, K^*)… or there exist other decay mechanisms for the few-body systems. However, only J/ψ, ϕ, η, K, D, D_s, and D_s^* exchange are included, because there is no information on studies about other meson exchange in the vertices of the charm-strange meson. Moreover, we always think the two-body decay modes of the multiquark states are usually the dominant ones. Hence, the current calculation is enough to explain that $Y(4274)$ cannot be a P-wave $D_s\bar{D}_{s0}$ molecular.

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