Recently, BESIII Collaboration updated the data of exotic state, \( D_{s0}^{*}(2317) \), with mass at 2318.3 ± 1.2 ± 1.2 MeV in the positronium annihilation process. Inspired by experiment, We study the two hot exotic states, \( D_{s0}^{*}(2317) \) and \( D_{s1}(2460) \), in the more reasonable unquenched quark model with two modified factor: the one is distance convergence, while the other is energy suppression. Different from the other works, we first give all of possible the mass shift and component of \( D_{s0}^{*}(2317) \) and \( D_{s1}(2460) \) at the same time. All the calculation are done with the help of Gaussian expansion method, which is very accurate few body system calculation method. In addition, not only \( DK(D^*K) \) but also the other OZI allowed mesonium including \( D_s \eta \) are all taken into consideration. We propose an unquenched quark model to give a unitive description for \( D_s \) spectrum including four particles: \( D_s \), \( D_s^* \), \( D_{s0}^{*}(2317) \) and \( D_{s1}(2460) \), and the results show that \( D_{s0}^{*}(2317) \) and \( D_{s1}(2460) \) are a \( c\bar{s} \) state plus an extra important component due to continuum while \( D_s \) and \( D_s^* \) are almost pure quark-antiquark state.

I. INTRODUCTION

Since \( X(3872) \), which can’t be accommodated into traditional quark model and near \( DD^* \) threshold, was reported by Belle Collaboration in 2003 [1], theorists and experimentalists had been showing great interest in exotic states. At beginning, Barnes et al. assigned \( X(3872) \) into traditional charmonium [2], while Törnqvist put forward that one pion exchange potential can make contribution to bind state of \( X(3872) \) [3], analogous to deuteron. Now, people tend to believe \( X(3872) \) may be mixture of charmonium and mesonium [4, 5, 6]. Similarly, In 2003, BaBar Collaboration announced the other exotic state, \( D_{s0}^{*}(2317) \), of which energy is less than prediction from traditional quark model and near \( DK \) threshold [7]. Subsequently, CLEO Collaboration confirmed the state and supplemented the other state \( D_{s1}(2460) \) near the \( D^*K \) threshold. Different from \( X(3872) \) which mass is very close to \( DD^* \) threshold, there are several dozen MeVs of energy difference between \( D_{s0}^{*}(2317) \) and both traditional \( P \)-wave \( c\bar{s} \) meson and \( DK \) threshold [8].

There are a lot of work [10-14] for answering the question what’s the nature structure of \( D_{s0}^{*}(2317) \) and \( D_{s1}(2460) \)? Although the energy of ordinary meson \( c\bar{s} \) has 100 MeV bigger than \( D_{s0}^{*}(2317) \) from Godfrey-Isgur model prediction [15, 16], ordinary quark-antiquark picture was still invoked to explain the two exotic states [10-15]. Hadron mass is merely one property of particle, the mass difference between theoretical and experimental value can be remedied by fine-tuning the model parameters. The transition probabilities which related to the internal structure of the state put more stringent test of the model. For example, Godfrey assigned \( ^3P_0 \) and \( ^3P_1 \) quantum numbers to \( D_{s0}^{*}(2317) \) and \( D_{s1}(2460) \), and predicted the radiative decay width of \( D_{s0}^{*} \rightarrow D_s^\pm \gamma \), \( D_{s1} \rightarrow D_s \gamma \). Because the mass of \( D_{s0}^{*}(2317) \) is below strong decay threshold \( DK \), the radiative decay plays important role for understanding state \( D_{s0}^{*}(2317) \). Due to two decay modes: \( D_s^\pm \gamma \) and \( D_s \pi \) are all discovered experimentally, isospin violation in the transition is expected. Wang et al. studied the decay width of \( D_{s0}^{*}(2317) \) and \( D_{s1}(2460) \) in the chiral quark model with \( \pi - \eta \) mixing, the electromagnetic decay widths, but not pionic decay width, agreed with experimental data. In addition, the \( D_{s0}^{*}(2317) \) also can be ordinary \( c\bar{s} \) in the frame work of thermal QCD sum rule [12, 13].

However, BESIII Collaboration obtained the absolute branching fraction \( B(D_{s0}^{*}(2317) \rightarrow \pi^0D_s) = 1.00^{+0.00}_{-0.14} \pm 0.14 \) [17], which differs from the expectation of the ordinary \( c\bar{s} \) picture of \( D_{s0}^{*}(2317) \) [10]. Also the total decay width in the quark-antiquark picture is too small to agree with experimental data. Then the assumption: \( D_{s0}^{*}(2317) \) (\( D_{s1}(2460) \) may be \( DK(D^*K) \) molecular state, is aroused [17, 18, 20, 21, 23-25]. Guo et al. constructed an effective chiral Lagrangian including both electron-magnetic decay width and isospin violation decay width, and they got total width about \( 180 \pm 110 \) keV [21], then updated the data to \( 133 \pm 22 \) keV [23]. Faessler et al. got the result \( \Gamma(D_{s0}^{*}(2317) \rightarrow D_s^\pm \gamma) = 46.7 \) keV by effective Lagrangian approach. Recently, Wu et al. found that the attractive interaction between \( D \) and \( K \) is strong enough to make a bound molecular state [28]. The tetraquark system was also invoked to explain \( D_{s0}^{*}(2317) \) (\( D_{s1}(2460) \)) [30, 34]. Cheng et al. treated \( D_{s0}^{*}(2317) \) as \( cq\bar{q}q \) state, the mass and decay width were obtained as \( M = 2320 \) MeV and \( \Gamma = 11.3 \) keV. By employing QCD sum rule, Zhang et al. marked \( D_{s0}^{*}(2317) \) as \( 0^+ \) tetraquark to explain BESIII’s results. Lattice QCD was also applied to investigate the corresponding four-quark state by calculating the four-quark correlator, and they did not see a tetraquark mesonium in the \( D_{s0}^{*}(2317) \) meson region [32]. The realistic quark model calculation also did not support the molecular picture of \( D_{s0}^{*} \) and \( D_{s1} \) [34]. Our previous work showed that the interaction between \( D \) and \( K \) is repulsive while \( DK \)
could be a possible partner of $D_{s0}^*(2317)$ due to "good di-quark" \[51].

Actually, more and more people are drawing their attention to mixture of $c\bar{s}$ and $DK$ \[39 41\]. In other words, the state $D_{s0}^*(2317)$ may be a $c\bar{s}$ state affected severely by $DK$ mesonium. Lattice QCD had a try to take $S$-wave $DK$ threshold into consideration when studying $c\bar{s}$ system \[39–43, 45, 46\], some of them claimed $c\bar{s}$ occupies 70% component in $D_{s0}^*(2317)$ state \[43\]. What’s more, Ortega et al. utilized Isgur model with help of $3P_0$ operator to study the state $D_{s0}^*(2317)$ as a mixture of $c\bar{s}$ and $DK$ states, and got 66% of $c\bar{s}$ component and $D_{s1}(2460)$ with 54% $c\bar{s}$ component \[44\]. Other decay channels also have contributions, Torres et al. obtained accurate $DK$ phase shifts and the position of the $D_{s0}^*(2317)$ in the framework of an $SU(4)$ extrapolation of the chiral unitary theory with couple of $DK$ and $D_s\eta$ \[41\]. Hence, in this work, we study states $D_{s0}^*(2317)$ and $D_{s1}(2460)$ in the unquenched quark model by considering all of possible channels including $P$-wave and $D$-wave mesonia. In addition, the modified transition operator \[57\] which mixes the 2-quark and 4-quark states is employed. The numeric results are obtained with the help of the high precision few-body method, Gaussian expansion method (GEM) \[52\].

The paper is organized as follows. In section II, the chiral quark model and GEM for solving the $q\bar{q}$ and $q\bar{q}$-$q\bar{q}$ systems are presented. In Sec. III, we briefly introduce the unquenched quark model. The numerical results are given in Sec. IV. The last section is devoted to the summary.

II. CHIRAL QUARK MODEL AND GEM

The chiral quark model has been applied successfully in describing the hadron spectra and hadron-hadron interactions. The details of the model can be found in Refs. \[53, 57\]. Here only the Hamiltonian for the four-quark system is shown. Because we are interested in the low-lying states, only the central part of the quark-quark interactions are considered for four-quark system.

$$
H = \sum_{i=1}^{4} m_i + \frac{\mu_{12}^2}{2\mu_{12}} + \frac{\mu_{34}}{2\mu_{34}} + \frac{\mu_{1234}}{2\mu_{1234}} + \sum_{i<j=1}^{4} V^C_{\chi}(ij) 
$$

$$
+ \sum_{i<j=1}^{4} \left( V^C_{con}(ij) + V^C_{oge}(ij) + \sum_{\chi=\pi,K,\eta} V^C_{\chi}(ij) \right)
$$

where $m_i$ is the constituent masse of $i$-th quark (anti-quark), and $\mu$ is the reduced masse of two interacting quarks or quark-clusters,

$$
\mu_{ij} = \frac{m_im_j}{m_i + m_j},
$$

$$
\mu_{1234} = \frac{(m_i + m_j)(m_3 + m_4)}{m_1 + m_2 + m_3 + m_4},
$$

$$
p_{ij} = \frac{m_i - m_j}{m_i + m_j},
$$

$$
p_{1234} = \frac{(m_1 + m_4)p_{12} - (m_1 + m_2)p_{34}}{m_1 + m_2 + m_3 + m_4}.
$$

$V^C_{con}$ is the confining potential, mimics the “confinement” property of QCD,

$$
V^C_{con}(ij) = (-a_{\chi}r^2_{ij} - \Delta)\lambda^{\chi}_i \cdot \lambda^{\chi}_j
$$

The second potential $V^C_{oge}$ is one-gluon exchange interaction reflecting the “asymptotic freedom” property of QCD,

$$
\delta(r_{ij}) = \frac{e^{-r_{ij}/r_0(\mu_{ij})}}{4\pi r_{ij} r^2_{ij}(\mu_{ij})},
$$

$\sigma$ are the $SU(2)$ Pauli matrices; $\Lambda_c$ are $SU(3)$ color Gell-Mann matrices, $r_0(\mu_{ij}) = r_0/\mu_{ij}$ and $\alpha_s$ is an effective scale-dependent running coupling,

$$
\alpha_s(\mu_{ij}) = \frac{\alpha_0}{\ln((\mu_{ij}^2 + \mu_{ij}^2)/\Lambda_0^2)}.
$$

The third potential $V_{\chi}$ is Goldstone boson exchange, coming from “chiral symmetry spontaneous breaking” of QCD in the low-energy region,

$$
V^C_{\pi}(ij) = \frac{g_{ch}^2}{4\pi} \frac{m^2_\pi}{12m_i m_j} \Lambda^2_\pi - m^2_\pi v^3_{ij} \sum_{a=1}^{3} \lambda^{a}_i \lambda^{a}_j, \notag
$$

$$
V^C_{K}(ij) = \frac{g_{ch}^2}{4\pi} \frac{m^2_K}{12m_i m_j} \Lambda^2_K - m^2_K v^7_{ij} \sum_{a=4}^{7} \lambda^{a}_i \lambda^{a}_j, \notag
$$

$$
V^C_{\eta}(ij) = \frac{g_{ch}^2}{4\pi} \frac{m^2_\eta}{12m_i m_j} \Lambda^2_\eta - m^2_\eta v^9_{ij} \left[ \lambda^8 \lambda^8 \cos \theta_P - \lambda^8 \lambda^8 \sin \theta_P \right], \notag
$$

$$
V^C_{\sigma}(ij) = \frac{g_{ch}^2}{4\pi} \frac{\Lambda^2_\sigma}{\Lambda^2_\sigma - m_\sigma^2} m_\sigma \left[ Y(m_\sigma r_{ij}) - \Lambda_\sigma Y(\Lambda_\sigma r_{ij}) \right], \notag
$$

$$
v^{\chi}_{ij} = Y(m_\chi r_{ij}) - \frac{\Lambda^3_\chi}{m^3_\chi} Y(\Lambda_\chi r_{ij}) \sigma_i \cdot \sigma_j, \quad \chi = \pi, K, \eta, \notag
$$

$\lambda$ are $SU(3)$ flavor Gell-Mann matrices, $m_\chi$ are the masses of Goldstone bosons, $\Lambda_\chi$ are the cut-offs, $g_{ch}^2/4\pi$ is the Goldstone-quark coupling constant.

The orbital wave function of the four-quark system consists of two sub-cluster orbital wave functions and the
relative motion wave function between two subclusters (1,3 denote quarks and 2,4 denote antiquarks),

$$|R\rangle = |\Psi_{l_1}(r_{12}) \Psi_{l_3}(r_{34}) \rangle |_{l_2} \Psi_{l, r_{1234}} \rangle |_{L}^{M_L}$$, (7)

where the bracket "[ ]" indicates angular momentum coupling, and $L$ is the total orbital angular momentum which comes from the coupling of $L_e$, orbital angular momentum of relative motion, and $l_{12}$, which coupled by $l_1$ and $l_2$, sub-cluster orbital angular momenta. In GEM, the radial part of the orbital wave function is expanded by a set of Gaussians:

$$\Psi(r) = \sum_{n=1}^{n_{max}} c_n \psi_{nlm}^{G}(r), \quad (8a)$$

$$\psi_{nlm}^{G}(r) = N_{nl} r^l e^{-\nu_n r^2} Y_{lm}(\hat{r})$$, \quad (8b)

where $N_{nl}$ are normalization constants,

$$N_{nl} = \left[ \frac{2^{l+2}(2\nu_n)^{l+\frac{3}{2}}}{\sqrt{\pi}(2l+1)} \right]^\frac{1}{2}. \quad (9)$$

c$_n$ are the variational parameters, which are determined dynamically. The Gaussian size parameters are chosen according to the following geometric progression

$$\nu_n = \frac{1}{r_n^2}, \quad r_n = r_1 a^{n-1}, \quad a = \left( \frac{r_{n_{max}}}{r_1} \right)^{\frac{1}{n_{max}-1}}. \quad (10)$$

This procedure enables optimization of the using of Gaussians, as small as possible Gaussians are used.

All the parameters are determined by fitting the meson spectrum, from light to heavy, taking into account only a quark-antiquark component. They are shown in Table I. The calculated masses of the mesons involved in the present work are shown in Table II. For the quark-antiquark calculation, the spin-orientations and tensor interactions are also taken into account. In the following, we study these two states in the unquenched quark model.

### III. UNQUENCHED QUARK MODEL

In unquenched quark model, the high Fock components are taken into account. It is expected that the naive quark model is a good zeroth order approximation for hadron states, so we consider only four-quark components for mesons,

$$\Psi = c_2 \Psi_{2q} + \sum_{i=1}^{N} c_{4i} \Psi_{4qi}^i$$, \quad (11)

| Quark masses | $m_q = m_d$ (MeV) | 313 |
|---------------|------------------|-----|
|               | $m_s$ (MeV)      | 536 |
|               | $m_c$ (MeV)      | 1728|
|               | $m_b$ (MeV)      | 5112|

| Goldstone bosons | $\Lambda_\pi = \Lambda_\rho (\text{fm}^{-1})$ | 4.2 |
|------------------|---------------------------------------------|-----|
|                  | $g_{ch}^2/(4\pi)\mu$ | 0.54 |
|                  | $\theta_\rho(\mu)$ | -15 |

| Confined | $a_c$ (MeV/fm$^2$) | 101 |
|----------|-------------------|-----|
|          | $\Delta$ (MeV)   | -78.3|

| TABLE II. Meson spectrum (unit: MeV). |
|----------------|-----------------|-----|
| $D$             | $D^*$           | $K$ |
| Theo.           | 1862.6          | 1980.5|
| exp             | 1867.7          | 2008.9|
| $K^*$           | 949.3           | 913.6|
| $\eta'$         | 892.0           | 957.8|
| $\phi$          |                |     |
| Theo.           | 1015.8          | 1953.3|
| exp             | 1019.0          | 1968.0|
| $D_s$           | 2080.2          | 2433.1|
| $D_s^*$         | 2336.2          |     |
| $D_{s1}$        | 2460.0          | 2317.0|
| $D_{s0}$        | 2460.0          | 2317.0|

where $\Psi_{2q}$ and $\Psi_{4q}^i$ are the wave functions of the two- and four-quark components, respectively, and $N$ is the total number of four-quark channels. The expansion coefficients are determined by solving the Schrödinger equation,

$$H \Psi = E \Psi. \quad (12)$$

In the nonrelativistic quark model, the number of particles is conserved. So to write down the Hamiltonian of the nonrelativistic unquenched quark model in a usual way is not possible. Generally the prescription is given to the following Hamiltonian,

$$H = H_{2q} + H_{4q} + T_{24}. \quad (13)$$

$H_{2q}$ acts only on the wave function, $\Psi_{2q}$; $H_{4q}$ acts only on the wave functions $\Psi_{4q}^i$; and $T_{24}$ couples the two- and four-quark components.

The $^3P_0$ model (quark pair creation model) was originally introduced by Micu and further developed by Le Yaouanc, Ackleh and Roberts et al. It can be applied to the OZI rule allowed two-body strong decays.
of a hadron. The transition operator in the model is

\[ T_1 = -3 \gamma \sum_m (1 + m - m|00) \int dp_3 dp_4 \delta^3(p_3 + p_4) \times \gamma_1^m \left( \frac{p_3 - p_4}{2} \right) \chi_{1-m}^{34} \phi_0^{34} \omega_0^{34} b_j^1(p_3) d_j^0(p_4), \tag{14} \]

where \( \gamma \) represents the probability of the quark-antiquark pair with momentum \( p_3 \) and \( p_4 \) created from the vacuum. Because the intrinsic parity of the quark is negative, the created quark-antiquark pair must be in the state \( |3u + 1 \rangle \). The singlet states, respectively (the quark and the antiquark in the original meson are indexed by 1 and 2). The S-matrix element for the process \( A \rightarrow B + C \) is written as

\[ \langle BC|T|A \rangle = \delta^3(p_A - p_B - p_C) \mathcal{M}^{M_A M_B M_C}, \tag{15} \]

where \( p_B \) and \( p_C \) are the momenta of B and C mesons in the final state, and satisfy \( p_A = p_B + p_C = 0 \) in the center-of-mass frame of meson A. \( \mathcal{M}^{M_A M_B M_C} \) is the helicity amplitude of the process \( A \rightarrow B + C \).

Using the above transition operator in the unquenched quark model to calculate the mass shifts of light mesons due to the coupling of four-quark components, one obtained too large values. To deal with this issue, a modified transition operator was proposed. It reads,

\[ T_2 = -3\gamma \sum_m (1 + m - m|00) \int dr_3 dr_4 \left( \frac{1}{2\pi} \right)^{\frac{3}{2}} i r_2^{-\frac{5}{2}} f^{-5} Y_{1m}(\hat{r}) e^{-\frac{r^2}{4\sigma^2}} e^{-\frac{\hat{r}^2}{4\hat{r}^2}} \chi_{1-m}^{34} \phi_0^{34} \omega_0^{34} b_j^1(r_3) d_j^0(r_4). \tag{16} \]

Here, “A” stands for the bare meson and “V” denotes the quark-antiquark pair created in the vacuum, hence, \( R_{AV} \) is the relative distance between the source particle A and quark-antiquark pair V in the vacuum.

\[ R_{AV} = R_A - R_V; \]

\[ R_A = \frac{m_1 r_1 + m_2 r_2}{m_1 + m_2}; \]

\[ R_V = \frac{m_3 r_3 + m_4 r_4}{m_3 + m_4} = \frac{r_3 + r_4}{2} (m_3 = m_4). \]

The damping factors in the modified transition operator mainly consider the effect of quark-antiquark created in the vacuum. The first damping factor \( e^{-r^2/(4\sigma^2)} \) (the corresponding expression in the momentum space is \( e^{-f^2/4f^2} \)) suppresses the creation of quark-antiquark pair with high energy, and the second damping factor \( e^{-R_{AV}/R_0^2} \) takes account of the fact that the created quark-antiquark pair should not be far away from the original meson.

The parameter \( \gamma \) is generally determined by an overall fitting of the strong decay width of hadrons. The relation between the strength \( \gamma_{u,d} \) for \( uu, dd \) creation and the strength \( \gamma_s \) for \( ss \) creation is \( \gamma_s = \gamma_u / \sqrt{3} \). In this work, the parameters in the modified transition operator are taken from Ref. [57],

\[ \gamma_{u,d} = 32.2, \quad f = 0.5 \text{ fm}^2, \quad R_0 = 1.0 \text{ fm}^2. \]

## IV. RESULTS

In this section, we re-calculate the masses of S- and P-wave \( D_s \) mesons in the unquenched quark model. All the possible meson-meson channels are taken into account. From the quantum numbers of \( D_s \) mesons, one can see that the S-wave states, \( D_s(1968) \) and \( D_s^*(2112) \), will couple with the P-wave meson-meson states and the P-wave states \( D_{20}^*(2317) \) and \( D_{s1}(2460) \) (the P-wave excited states of \( D_s^*(2112) \) and \( D_s(1968) \)) will couple with the S- and/or D-wave meson-meson states.

Because the introducing of four-quark components to quark-antiquark components, the model parameters have to be adjusted, the adjusted parameters are listed in Table III. The calculated results are shown in Table IV. From the table, one can see that the S- and P-wave \( D_s \) mesons can be described well in the unquenched quark model. The dominant component for the ground states \( D_s \) and \( D_s^* \) is \( c\bar{s} \), \( \sim 97\% \), which supports the validity of the quenched quark model in describing the ground state of hadrons. For the P-wave mesons, the contribution from meson-meson channels play an important role, the percentage of \( c\bar{s} \) component in \( D_{20}^*(2317) \) and \( D_{s1}(2460) \) is \( \sim 43\% \) and \( \sim 36\% \), respectively. The main component of P-wave meson is S-wave \( D_s^* K^* \), other meson-meson channels have rather small contributions to \( D_s \) meson properties. Our results agree qualitatively with that of other work. In the following, a detailed analyses for two P-wave states are presented.

### A. \( D_{s1}(2460) \)

The \( D_{s1} \) in quenched quark model is \( c\bar{s} \) state with \( IJ^P = 01^+ \), because its energy is higher than \( D_{20}^* \), the spin of the state is expected to be 0, there is no contribution from spin-orbit interaction. So we can estimate the P-wave excitation energy from kinetic energy, \( 2460 - 1968 = 492 \text{ MeV} \). As shown in the Table II, the mass of \( D_{s1} \) in quenched quark model is close to

| \( m_c \) (MeV) | \( m_s \) (MeV) | \( a_c \) (MeV/fm²) | \( \Delta \) (MeV) | \( \alpha_{uu} \) | \( \alpha_{uc} \) | \( \alpha_{sc} \) | \( \alpha_{cc} \) |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| 1933            | 575             | 117.7           | -113.2          | 0.55            | 0.49            | 0.47            | 0.44            | 0.32            |

\[ \gamma_{u,d} = 32.2, \quad f = 0.5 \text{ fm}^2, \quad R_0 = 1.0 \text{ fm}^2. \]
and the experimental value of $D_{s1}(2460)$, and the quark content is $c\bar{s}$ with quantum numbers $IJ^{P} = 01^{+}$, the unquenched masses is almost the same as that of quenched mass. In unquenched quark model, the percentage of $c\bar{s}$ of $D_{s1}(2460)$ is about 36%, and the main components of meson-meson channels are S-wave $D^{(*)}K^{(*)}$. The contribution from $D_{s}\phi, D_{s}^{*}\phi$ and $D_{s}^{*}\eta$ is very small due to the OZI rule violation.

### B. $D_{s0}^{*}(2317)$

The $D_{s0}^{*}$ in quenched quark model is $c\bar{s}$ state with $IJ^{P} = 00^{+}$, and the spin of the $c\bar{s}$ system must be 1, the spin-orbit interaction plays a role. From the energy difference between $D_{s0}^{*}$ and $D_{s0}$, 2317 – 2112 = 205 MeV and the P-wave excitation energy from kinetic energy, one can estimate the spin-orbit splitting in the $c\bar{s}$ state is around $205 - 492 = -287$ MeV. In unquenched quark model, the components of meson-meson states are $c\bar{q}\bar{q}\bar{s}$ or $c\bar{s}s\bar{s}$ will enter the state $D_{s0}^{*}$. The physical contents of $c\bar{q}\bar{q}\bar{s}$ system can be $DK$ and $D^{*}K^{*}$, while $c\bar{s}s\bar{s}$ system can be $D_{s}\eta$ and $D_{s}^{*}\phi$. In the Table IV, one can see that the S-wave $DK$, S- and D-wave $D^{*}K^{*}$ components occupies about 56% of $D_{s0}^{*}(2317)$ contents, which is in agreement with that of the other work [37, 40, 12, 44]. The percentage of $DK$ are around 40%~60%. The contribution from the other channels, such as $D_{s}^{*}\phi$, is very small due to the OZI rule violation. It is worth to mention that the D-wave $D^{*}K^{*}$ make a rather large mass shift to the $c\bar{s}$ state although its percentage is not large.

### V. SUMMARY

We investigate the exotic states $D_{s0}^{*}(2317)$ and $D_{s1}(2460)$ in the unquenched quark model with modified transition operator, which works well in light meson spectrum [57] and charmonium spectrum [4]. All of calculation are done with help of Gaussian expansion method.
Although our quenched quark model can describe $D_{00}^{*}(2317)$ and $D_{41}(2460)$ well in mass, the bare $c\bar{s}$ picture is difficult to explain the large iso-violating decay, $D_{00}^{*}(2317) \rightarrow D_s \pi$. The molecular $DK$ structure is involved to explain the structure of $D_{00}^{*}(2317)$. So it is natural to study $D_{00}^{*}(2317)$ in unquenched quark model. Our calculation shows that the main component of $D_{00}^{*}(2317)$ is $DK$ (53%), so $D_{00}^{*}(2317)$ is a complete mixture structure. On the other hand, with the composition of the state, we roughly estimate the iso-violating decay width of $D_{00}^{*}(2317)$ about 60 keV. For $D_{41}(2460)$, we have similar results.

In conclusion, $D_{00}^{*}(2317)$ and $D_{41}(2460)$ may be complete mixture structure of $c\bar{s}$ and molecular states $(DK$ and $D^*K$) in our modified unquenched quark model, while S-wave partners, $D_s$ and $D_s^*$ may be almost pure $c\bar{s}$ structure.

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