Production of the $D_{s0}(2317)$ and $D_{s1}(2460)$ by kaon-induced reactions on a proton target

HongQiang Zhu\textsuperscript{1} and Yin Huang *2,\textsuperscript{†}

\textsuperscript{1}College of Physics and Electronic Engineering, Chongqing Normal University, Chongqing 401331, China
\textsuperscript{2}School of Physics and Nuclear Energy Engineering, Beihang University, Beijing 100191, China

(Dated: March 11, 2022)

We investigate the possibility to study the charmed-strange mesons $D_{s0}(2317)$ and $D_{s1}(2460)$ by kaon-induced reactions on a proton target in an effective Lagrangian approach. The production process is described by the $t$-channel $D^*$ and $D'$ exchanges, respectively. Our theoretical approach is based on the chiral unitary theory where the $D_{s0}(2317)$ and $D_{s1}(2460)$ resonances are dynamically generated. Within the coupling constants of the $D_{s0}(2317)$ to $KD$ and $D_{s1}(2460)$ to $KD'$ channels obtained from the chiral unitary theory, the total and differential cross sections of the $K^* p \rightarrow \Lambda, D_{s0}(2317)$ and $K^* p \rightarrow \Lambda, D_{s1}(2460)$ are evaluated. The $Kp$ initial state interaction mediated by Pomeron and Reggeon exchanges is also included, which reduces the production cross sections of the $D_{s0}(2317)$ and $D_{s1}(2460)$. If measured in future experiments, the predicted total cross sections and specific features of the angular distributions can be used to test the (molecular) nature of the $D_{s0}(2317)$ and $D_{s1}(2460)$.

PACS numbers: 13.60.Le, 12.39.Mk, 13.25.Jx

I. INTRODUCTION

In recent years, many charmed-strange mesons have been observed [1]. Among them, the $D_{s0}(2317)$ and $D_{s1}(2460)$ are two peculiar states (we abbreviate it as $D_{s0}^*$ and $D_{s1}^*$ hereafter), since their masses are about 160 MeV and 70 MeV, respectively, below the quark model predicted values [2]. The charmed-strange meson $D_{s0}^*$ was first observed by the BaBar collaboration as a narrow peak in the $D_s^* \pi$ invariant mass distribution [3]. The state was shortly confirmed by CLEO [4] and Belle [5, 6] collaborations. Nowadays it is well established in the PDG [1] with quantum numbers $I(J^P) = 0(0^+)$.

The $D_{s1}^*$ was also observed in the CLEO experiment [4] in the $D_{s1}^* \pi$ channel and BaBar [7–9] also found a signal in that region. Nowadays it is also well established in the PDG [1] with quantum numbers $I(J^P) = 0(1^+)$.

The mass and width of the $D_{s0}^*$ and $D_{s1}^*$ states reported by the above collaborations [3–9] are consistent with each other, i.e.,

$$D_{s0}(2317)^*: \quad M = 2317.7 \pm 1.3 \text{ MeV},$$

$$\Gamma < 3.8 \text{ MeV};$$

$$D_{s1}(2460)^*: \quad M = 2459.5 \pm 0.6 \text{ MeV},$$

$$\Gamma < 3.5 \text{ MeV}.$$

The large disagreement between the quark model expectations [2] and the experimental measurements [3–9] made it difficult to assign these two states as conventional charmed-strange mesons. Since the masses of the $D_{s0}^*$ and $D_{s1}^*$ are about 40 MeV below the $DK$ and $D^*K$ thresholds, respectively, many studies proposed that the $D_{s0}^*$ and $D_{s1}^*$ are S-wave $DK$ and $D^*K$ molecular states. The studies in the Bethe-Salpeter approach [10] and potential model [11] showed indeed that the $D_{s0}^*$ could be a $DK$ hadronic molecule. In Ref. [12], the $D_{s0}^*$ and $D_{s1}^*$ were considered as kaonic molecules bound by short range strong force. Assuming that the $D_{s0}^*$ and $D_{s1}^*$ are $DK$ and $D^*K$ molecular states, the strong and radiative decays of the $D_{s0}^*$ and $D_{s1}^*$ were studied by several groups [13–16]. The production of the $D_{s0}^*$ and $D_{s1}^*$ from the nonleptonic $B$ decay were calculated in Ref. [17], in which the $D_{s0}^*$ and $D_{s1}^*$ were also considered as hadronic molecules of $DK$ and $D^*K$, respectively. In the chiral unitary approach [18–23], the $D_{s0}^*$ and $D_{s1}^*$ can be dynamically generated from the $DK/D^*K$ and coupled channel interactions.

In addition to the interpretation of the $D_{s0}^*$ and $D_{s1}^*$ as $DK$ and $D^*K$ molecules, the possibility to assign them as a conventional open charm meson was also discussed in many different approaches, such as the relativistic quark model [24], the chiral perturbation theory [25], the quark pair-creation model [26, 27], and the QCD sum rules [28–32]. On the other hand, the large-$N_c$ expansion indicated that the $D_{s0}^*$ could be a tetraquark meson [33]. The tetraquark interpretation was also proposed to understand the mass and decay behavior of the $D_{s0}^*$ [34]. We note that the QCD sum rules also supported the idea that the $D_{s0}^*$ does not seem to be a standard quark-antiquark meson [35].

The present knowledge about the $D_{s0}^*$ and $D_{s1}^*$ was obtained from the $e^+e^-$ collision [3–9]. Thus, it will be helpful to understand the nature of the $D_{s0}^*$ and $D_{s1}^*$ if we can observe them in other production processes. High-energy kaon beams are available at OKA@U-70 [36] and SPS@CERN [37], which provide another alternative to study $D_{s0}^*$ and $D_{s1}^*$. The kaon beam at J-PARC can also be upgraded to the energy region required in charmed-strange meson productions [38]. Therefore, it is interesting to study the $D_{s0}^*$ and $D_{s1}^*$ productions in the $K^* p \rightarrow \Lambda, D_{s0}^*$ and $K^* p \rightarrow \Lambda, D_{s1}^*$ reactions. Since there exist plenty of experimental information about the $Kp$ elastic interaction in the energy region relevant to the $D_{s0}^*$ and $D_{s1}^*$ production [3–9], the effect from the $Kp$ initial state interaction (ISI) can be taken into account in order to make a more reliable prediction.

This paper is organized as follows. In Sec. II, we will present the theoretical formalism. In Sec. III, the numerical...
result of the kaon-induced $D_s^*$ and $D_s^*$ production on a proton target will be given, followed by discussions and conclusions in the last section.

II. THEORETICAL FORMALISM

The tree level Feynman diagrams for the $K^- p \rightarrow \Lambda_c D_{s}^0$ and $K^- p \rightarrow \Lambda_c D_{s}^*$ reactions are depicted in Fig. 1, where the $t$-channel $D$ and $D^*$ exchange are considered. In this work, the contributions from $s$– and $u$– channels are ignored, because the $s$- and $u$-channels, which involves the creation of an additional $s$ quark pair creation in the kaon-induced production, are usually strongly suppressed, Hence, the $K^- p \rightarrow \Lambda_c D_{s}^0$ and $K^- p \rightarrow \Lambda_c D_{s}^*$ reactions should be dominated by the Born terms through the $t$-channel $D$ and $D^*$ exchanges, which makes the background very small.

\[
\begin{align*}
K^- & \rightarrow p_1 - D_{s}^+ K^- - p_2 \quad (a) \\
D & \rightarrow p_3 - D_1^- \quad (b) \\
p & \rightarrow p_4, \Lambda_c^+ \quad \Lambda_c^+ \quad \Lambda_c^+
\end{align*}
\]

FIG. 1: Feynman diagram for the mechanism of the $D_{s}^0$ and $D_{s}^*$ production in the $K^- p \rightarrow D_{s}^0 \Lambda_c$ and $K^- p \rightarrow D_{s}^* \Lambda_c$ reaction. We also show the definition of the kinematics ($p_1$, $p_2$, $p_3$, and $p_4$) used in the calculation.

A. Lagrangians

To compute the diagrams shown in Fig. 1, we need the effective Lagrangian densities for the relevant interaction vertices. For the $\Lambda_c p D$ and $\Lambda_c p D^*$ vertices, we adopt the commonly employed Lagrangian densities as follows [39],

\[
\begin{align*}
\mathcal{L}_{\Lambda_c p D} &= ig_{\Lambda_c p D} \bar{\Lambda_c} \gamma_5 \gamma_\mu p D^0 + \text{H.c.}, \quad (1) \\
\mathcal{L}_{\Lambda_c p D^*} &= g_{\Lambda_c p D^*} \bar{\Lambda_c} \gamma_\mu p D_\mu^0 + \text{H.c.}. \quad (2)
\end{align*}
\]

The coupling constants $g_{\Lambda_c p D} = -13.98$ and $g_{\Lambda_c p D^*} = -5.20$ are determined from the SU(4) invariant Lagrangians [40] in terms of $g_{\pi NN} = 13.45$ and $g_{\rho NN} = 6.0$.

In addition to the $\Lambda_c p D$ and $\Lambda_c p D^*$ vertices, we also need the information on the $KDD_s^*$ and $KDD_s^*$ vertices. As mentioned in the chiral unitary approach of Refs. [18–23], the $D_s^*$ and $D_{s}^*$ resonance are identified as $s$-wave meson-meson molecule that include big $K$ and $K^*$ component, respectively. We can write down the $KDD_s^*$ and $KDD_{s*}^*$ vertices of Fig. 1 as

\[
\begin{align*}
\mathcal{L}_{KDD_s^*} &= g_{KDD_s^*} \bar{K} D_s^* D_0^0, \quad (3) \\
\mathcal{L}_{KDD_{s*}^*} &= g_{KDD_{s*}^*} \bar{K} D_{s*}^* D_{s*}^*.
\end{align*}
\]

where the coupling of the $D_{s0}^0$ to $D_s^0 K^*$, $g_{KDD_s^*}$, is obtained from the coupling constant of the $D_{s0}^0$ to the $DK$ channel in isospin $I = 0$, found to be $g_{KDD_s^*} = 10.21$ in Ref. [18], multiplied by the appropriate Clebsch-Gordan (CG) coefficient, namely $g_{KDD_s^*} = g_{KDD_s^*}/\sqrt{2}$. Similarly to Ref. [18], we rely on the chiral unitary approach [19] to obtain the coupling constant $g_{KDD_{s*}^*} = 9.82/\sqrt{2}$.

When evaluating the scattering amplitudes of the $K^- p \rightarrow \Lambda_c D_{s}^0$ and $K^- p \rightarrow \Lambda_c D_{s}^*$ reactions, we need to include form factors because hadrons are not point-like particles. We adopt here a common scheme used in many previous works [41, 42],

\[
F_{D_s^*}(q_{D_s^*}^2, M_{ex}) = \frac{\Lambda_{D_s^*}^2 - M_{ex}^2}{\Lambda_{D_s^*}^2 - q_{D_s^*}^2},
\]

for the $t$-channel $D_s^*$ meson exchange. Here the $q_{D_s^*}^2$ and $M_{D_s^*}$ are the four momentum and the mass of the exchanged $D_s^*$ meson, respectively. In this model, the $\Lambda_{D_s^*}$ is the hard cutoff and it can be directly related to the hadron size. Empirically, the cutoff parameter $\Lambda_{D_s^*}$ should be at least a few hundred MeV larger than the $D_s^*$ mass. Hence, we chose $\Lambda_{D_s^*} = M_{D_s^*} + \alpha_{QCD}$ with $\alpha_{QCD} = 0.22$ GeV as used in previous works [43–45] for other reactions. The parameter $\alpha$ is usually close to unitary, and in this work a variation of the cutoff will be made to show the sensitivity of the results on the cutoff.

B. Initial state interaction(ISI)

Following Ref. [46], the initial state interaction for the $K^- p \rightarrow K^- p$ reaction at high energies will be taken into account and the relevant Feynman diagram for the Initial state interaction(ISI) is shown in Fig. 2. The amplitude $T_{K^- p \rightarrow K^- p}$ is written in terms of the Pomeron and Reggeon exchanges [46]

\[
T_{K^- p \rightarrow K^- p} = A_{P} + A_{f_{2}} + A_{a_{2}} + A_{\omega} + A_{\rho}.
\]

When the center-of-mass energy $\sqrt{s}$ is large, the elastic $K^- p$ scattering amplitude is a sum of the following terms,

\[
A_{i}(s, t) = \eta_{i} s C_{i}^{KN} \frac{S}{s_0} \eta_{i} (t) \exp i B_{i}^{KN} \frac{t}{2}
\]

where $i = P$ for Pomeron and $f_2$, $a_2$, $\omega$, and $\rho$ Reggeons. The energy scale $s_0 = 1$ GeV$^2$. The coupling constants $C_{i}^{KN}$, the parameters of the Regge linear trajectories$[\alpha_{i}(t) = \alpha_{i}(0) + \alpha_{i}^{'}, t]$, the signature factors$\eta_{i}$, and the $B_{i}^{KN}$ used in Ref. [46] provide a rather good description of the experimental data. The parameters determined in Ref. [46] are listed in Table. I.
TABLE I: Parameters of Pomeron and Reggeon exchanges determined from elastic and total cross sections in Ref. [46].

| $i$ | $a_i(t)$ | $C_i^{K\Lambda}(mb)$ | $B_i^{K\Lambda}(GeV^{-2})$ |
|-----|----------|----------------------|---------------------|
| $P$ | $i$      | 1.081 + 0.25 GeV^{-2} | 11.82               |
| $f_2$ | $-0.861 + i$ | 0.548 + 0.93 GeV^{-2} | 15.67               |
| $\rho$ | $-1.162 - i$ | 0.548 + 0.93 GeV^{-2} | 2.05                |
| $\omega$ | $-1.162 - i$ | 0.548 + 0.93 GeV^{-2} | 7.055               |
| $a_2$ | $-0.861 + i$ | 0.548 + 0.93 GeV^{-2} | 1.585               |

III. KAON-INDUCED $D_s^\pm$ AND $D_{s1}^0$ PRODUCTION ON PROTON TARGET

First, we calculate the total cross section of the $K^- p \rightarrow \Lambda_c^+ D_s^-$ and $K^- p \rightarrow \Lambda_c^+ D_{s1}^-$ reactions. The corresponding unpolarized differential cross section reads

$$
\frac{d\sigma}{d \cos \theta} = \frac{m_p m_{\Lambda_c}}{8 \pi s} |\vec{p}_{\text{cm}}| \left( \frac{1}{2} \sum_{i=1}^{2} |M_i^{1/2}|^2 \right),
$$

where $s = (p_1 + p_2)^2$, $\theta$ is the scattering angle of the outgoing meson relative to the beam direction, $\vec{p}_{\text{cm}}$ are the $K^-$ and $D_{s1}^- (D_{s1}^-)$ momenta in the center of mass frame,

$$
|\vec{p}_1| = \frac{\lambda^{1/2}(s, m_K^2, m_{D_s}^2)}{2 \sqrt{s}},
$$

$$
|\vec{p}_2| = \frac{\lambda^{1/2}(s, m_{D_{s1}^0}^2, m_{\Lambda_c}^2)}{2 \sqrt{s}}.
$$

where $\lambda(x, y, z) = (x - y - z)^2 - 4yz$. The $m_K$, $m_{D_s}$, and $m_{\Lambda_c}$ are the masses of the $K^-$ meson, proton, and $\Lambda_c$, respectively. Here, we take $m_K = 493.68$ MeV, $m_p = 938.27$ MeV, and $m_{\Lambda_c} = 2286.46$ MeV.

Taking the ISI of the $K^- p$ system into account, the full amplitude for the process $K^- p \rightarrow \Lambda_c^+ D_{s1}^-$ is a sum of the Born and ISI amplitudes. With the Lagrangians given in the previous section, the Born amplitude of the $K^- (p_1)p(p_2) \rightarrow \Lambda_c^+ (p_3) D_{s1}^-$ reaction can be obtained as,

$$
M_B^{D_s} = -g_{\Lambda_c D_{s1}^-} \bar{u}(p_4, \gamma_3) u(p_2, s_2) \frac{1}{(p_3 - p_1)^2 - m_{D_s}^2} \times g_{K D_s} F_{D_s}^2((p_3 - p_1)^2, m_D),
$$

$$
M_B^{D_{s1}^-} = i g_{\Lambda_c D_{s1}^-} \bar{u}(p_4, \gamma_3) u(p_2, s_2) \frac{1}{(p_3 - p_1)^2 - m_{D_{s1}}^2} \times (-g_{K D_{s1}^-} \times \frac{(p_3 - p_1)^2 - m_{D_{s1}}^2}{m_{D_{s1}}^2} \times g_{K D_{s1}^-} D_{s1}^-(p_3),
$$

where $\bar{u}(p_4, s_4)$ and $u(p_2, s_2)$ are the Dirac spinors with $s_4 (p_4)$ and $s_2 (p_2)$ being the spins (the four-momenta) of the outgoing $\Lambda_c$ and the initial proton, respectively. The $\epsilon_i^\Lambda (p_3)$ is the polarization vector of the $D_{s1}^-$. Following the strategy of Ref. [46], the ISI amplitude can be written as

$$
M_{ISI}^{D_s} = \frac{i}{16\pi^2} \int d^2 k \mathcal{J}_{K^- p \rightarrow K^- p}(s, k^2) \times M_{ISI}^{D_{s1}^-}(-p_2 - k_1 + p_3), \tag{13}
$$

where $k_i$ is the momentum transfer in the $K^- p \rightarrow K^- p$ reaction.

With the formalism and ingredients given above, the total cross section versus the beam momentum of the $K^- p$ system for the $K^- p \rightarrow \Lambda_c^+ D_{s1}^-$ and $K^- p \rightarrow \Lambda_c^+ D_{s1}^-$ reactions are evaluated. The results for beam momentum $p_K$ from the reaction threshold to 20.0 GeV are shown in Fig. 3. Because the cut-off cannot be well determined, the results obtained with several cutoffs are also presented. It is worth mentioning that the value of the cross section is very sensitive to the model parameter $\alpha$ when varying the cutoff parameter $\alpha$ from 1.0 to 2.0. This is because the model parameters we selected are very close to the masses of the exchanged particles. To make a reliable prediction for the cross section of the $K^- p \rightarrow \Lambda_c^+ D_{s1}^-$ and $K^- p \rightarrow \Lambda_c^+ D_{s1}^-$ reactions thus requires a good knowledge on the form factors. More and accurate experimental data can also be used to constrain the value of the cutoff parameter.

The results in Fig. 3 also show that the total cross section increases sharply near the $D_{s1}^- \Lambda_c$ threshold. At higher energies, the cross section increases continuously but relatively slowly compared with that near threshold. However, the total cross section decreases but very slowly for the $D_{s1}^-$ production in the $K^- p \rightarrow \Lambda_c^+ D_{s1}^-$ reaction when we change the beam energy $p_K$ from 14.6 GeV to 20.0 GeV. With the increase of the cutoff, the total cross section increases. Comparing the cross section of the $K^- p \rightarrow \Lambda_c^+ D_{s1}^-$ reaction with that of the $K^- p \rightarrow \Lambda_c^+ D_{s1}^-$ reaction, we found that the line shapes of the cross section are very different. A possible explanation for this may be that $K D$ interaction to form the $D_{s1}^-$ is stronger than that $K D^*$ interaction to form $D_{s1}^-$ due to the $D^*$ meson decays completely to the final state containing the $D$ meson [1].

The results show that the total cross section for $D_{s1}^-$ production is bigger than that for $D_{s1}^-$ production. At a beam mo-
mentum about 14.6 GeV and the parameter \( \alpha = 1 \) the cross section is of the order of 10 nb, which is quite large for an experimentally observation of the \( D_{s0}^- \) at current and future facilities. Our results suggest that it will takes high energy, at least above 14.6 GeV, to observe the production of \( D_{sl}^+ \) in the \( K^- p \to \Lambda_c^+ D_{sl}^- \) reaction.

To show the effect from the \( K^- p \) ISI, we compare the cross sections obtained with and without ISI for the cutoff of \( \alpha = 2.0 \) in Fig. 4, for he \( K^- p \to \Lambda_c^+ D_{s0}^- \) (panel A) and \( K^- p \to \Lambda_c^+ D_{sl}^- \) (panel B) reactions, respectively. In Fig. 4, the dashed red lines are the pure Born amplitude contribution, while the solid black lines are the full results. It shows that the role of the ISI is to reduce the cross section by approximately 20%, in agreement with the conclusions drawn from Refs. [39, 47, 48] that the ISI for \( pp \) or \( p\bar{p} \) reactions reduces the cross section.

In addition to the total cross section, we also compute the differential cross section for the \( K^- p \to \Lambda_c^+ D_{s0}^- \) and \( K^- p \to \Lambda_c^+ D_{sl}^- \) reactions as a function of the scattering angle of the outgoing meson relative to the beam direction at different beam energies, i.e., \( K^- p = 12.0, 14.0, 16.0, \) and 18.0 GeV. The theoretical results are shown in Fig. 5. We note that the differential cross section is the largest at the extreme forward angle and decreases with the increase of the scattering angle. This is because we have only considered the contributions from the \( t \)-channel mesons and \( D \) and \( D^* \) exchanges. It should be pointed out that, if there are contributions from the \( s \)- and \( u \)-channels, there will be a clear bump (or peak) in the total cross section which can be distinguished easily.

**IV. SUMMARY**

In this work, the production of the \( D_{s0}^- \) and \( D_{sl}^- \) resonances in the \( K^- p \to \Lambda_c^+ D_{s0}^- \) and \( K^- p \to \Lambda_c^+ D_{sl}^- \) reactions was studied in an effective Lagrangian approach. The production process is described by the \( t \)-channel \( D^0 \) and \( D^{*0} \) meson exchanges, respectively. The coupling constants of the \( D_{s0}^- \) to \( K D \) and \( D_{sl}^- \) to \( K D^* \) are obtained from the chiral unitary theory [18, 19], where the \( D_{s0}^- \) and \( D_{sl}^- \) resonance are dynamically generated. The \( K^- p \) initial state interaction(ISI) was included by Pomeron and Reggeon exchanges [46], which was shown to reduce the cross section by about 20%. The total and differential cross sections computed can be used to test the molecular picture of the \( D_{s0}^- \) and \( D_{sl}^- \) mesons in facilities such as OKA@U-70, SPS@CERN, and future J-PARC.

Finally, we would like to stress that, thanks to the absence of the \( s \)-channel, \( u \)-channel, and background contribution in the \( K^- p \to \Lambda_c^+ D_{s0}^- \) and \( K^- p \to \Lambda_c^+ D_{sl}^- \) reactions, future experimental data for these two reactions can be used to improve our knowledge of \( D_{s0}^- \) and \( D_{sl}^- \) properties, which are at present poorly known.

**Acknowledgments**

Y.H. thank Li-Sheng Geng for valuable discussions. This work was supported by the Science and Technology Research Program of Chongqing Municipal Education Commission (Grant No. KJQN201800510), the Opened Fund of the State Key Laboratory on Integrated Optoelectronics (GrantNo. IOSKL2017KF19), and China Postdoctoral Science Foundation (No. 2018M641143). This work also was supported in part by the National Natural Science Foundation of China under Grants No. 11522539 and No. 11735003.
[1] M. Tanabashi et al. [Particle Data Group], Review of Particle Physics, Phys. Rev. D 98, 030001 (2018).
[2] S. Godfrey and N. Isgur, Mesons in a Relativized Quark Model with Chordodynamics, Phys. Rev. D 32, 189 (1985).
[3] B. Aubert et al. [BaBar Collaboration], Observation of a narrow meson decaying to $D^*_{s0} \pi^0$ at a mass of 2.32-GeV/c^2, Phys. Rev. Lett. 90, 242001 (2003).
[4] D. Besson et al. [CLEO Collaboration], Observation of a narrow resonance decaying to $D^*_s \pi^0$ and confirmation of the $D^*_s(2317)$ state, Phys. Rev. D 68, 032002 (2003) [Erratum: Phys. Rev. D 75, 119908 (2007)].
[5] Y. Mikami et al. [Belle Collaboration], Measurements of the $D_{sJ}$ resonance properties, Phys. Rev. Lett. 92, 012002 (2004).
[6] F. K. Guo, P. N. Shen, H. C. Chiang, R. G. Ping and B. S. Zou, Dynamically generated 0^+ heavy mesons in a heavy chiral unitary approach, Phys. Lett. B 641, 278 (2006).
[7] F. K. Guo, P. N. Shen and H. C. Chiang, Dynamically generated 1^+ heavy mesons, Phys. Lett. B 647, 133 (2007).
[8] J. B. Liu and M. Z. Yang, Spectrum of the charmed and b-flavored mesons in the relativistic potential model, J. High Energy. Phys 07, (2014) 106.
[9] S. Najjari and A. Prapnotik Brdinik, Chiral loops in the isospin violating decays of $D^*_s$ and $D^{*+0}$, Phys. Rev. D 92, 074047 (2015).
[10] X. Liu, Y. M. Yu, S. M. Zhao and X. Q. Li, Study on decays of $D^*_s(2317)$ and $D^*_s(2460)$ in terms of the CQM model, Eur. Phys. J. C 47, 445 (2006).
[11] J. Lu, X. L. Chen, W. Z. Deng and S. L. Zhu, Pionic decays of $D^*_s(2317)$, $D^*_s(2460)$ and $B_{sJ}(5718)$, $B_{sJ}(5750)$, Phys. Rev. D 73, 054012 (2006).
[12] Z. G. Wang, Radiative decays of the $D_{sJ}$, $D^*$ and the related strong coupling constants, Phys. Rev. D 75, 034013 (2007).
[13] Y. B. Dai, C. S. Huang, C. Liu and S. L. Zhu, Understanding the $D^*_s(2317)$ and $D^*_s(2460)$ with sum rules in HQET, Phys. Rev. D 68, 114011 (2003).
[14] P. Colangelo and F. De Fazio, Understanding $D_{sJ}(2317)$, Phys. Lett. B 570, 180 (2003).
[15] P. Colangelo, F. De Fazio and A. Ozpineci, Radiative transitions of $D^*_s(2317)$ and $D^*_s(2460)$, Phys. Rev. D 72, 074004 (2005).
[16] P. Colangelo, F. De Fazio, F. Gianuzzi and S. Nicotri, New meson spectroscopy with open charm and beauty, Phys. Rev. D 86, 054024 (2012).
[17] Z. H. Guo, U. G. Meißen and D. L. Yao, New insights into the $D^*_s(2317)$ and other charm scalar mesons, Phys. Rev. D 92, no. 9, 094008 (2015).
[18] M. Nielsen, $D^*_s(2317) \rightarrow D^*_s\pi^0$ decay width, Phys. Lett. B 634, 35 (2006).
[19] Z. G. Wang and S. L. Wan, $D^*_s$ as a tetraquark state with QCD sum rules in heavy quark limit, Nucl. Phys. A 778, 22 (2006).
[20] V. Obraztsov [OKA Collaboration], High statistics measurement of the $K^+ \rightarrow \pi^+ e^+ e^- (\gamma\gamma) \bar{K}(3370)$ decay formfactors, Nucl. Part. Phys. Proc. Phys. Proc. 273-257, 1330 (2016).
[21] B. Velghe [NA62-RK and NA48/2 Collaborations], $K^+ \rightarrow \pi^+ \gamma \gamma$ Studies at NA48/2 and NA62-RK Experiments at CERN, Nucl. Part. Phys. Proc. Phys. Proc. 273-275, 2720 (2016).
[22] T. Nagae, The J-PARC project, Nucl. Phys. A 805, 486 (2008).
[23] Y. Dong, A. Faessler, T. Gutsche and V. E. Lyubovitskij, Role of the hadron molecule $\Lambda(2940)$ in the $p\bar{p} \rightarrow pD^0\bar{\Lambda}$ reaction using mild QCD potential, Phys. Rev. D 90, 094001 (2014).
[24] Y. Dong, A. Faessler, T. Gutsche, S. Kumano and V. E. Lyubovitskij, Radiative decay of $\Lambda(2940)^+$ in a hadronic molecule picture, Phys. Rev. D 82, 034035 (2010).
[25] J. He, Z. Ouyang, X. Liu and X. Q. Li, Production of charmed baryon $\Lambda(2940)^+$ at PANDA, Phys. Rev. D 84, 114010 (2011).
[26] J. J. Xie, Y. B. Dong and X. Cao, Role of the $\Lambda(2940)^+$ in the $\pi^+ p \rightarrow D^0 D^0 p$ reaction close to threshold, Phys. Rev. D 92, 034029 (2015).
[27] Y. Huang, J. He, H. F. Zhang and X. R. Chen, Discovery potential of hidden charm baryon resonances via photoproduction, J. Phys. G 41, 115004 (2014).
[28] C. J. Xiao and D. Y. Chen, Analysis of the hidden bottom quark contributions to the $D^*_s(2460)$ and $Z_b(10650)$ via final state interaction, Phys. Rev. D 96,014035 (2017).
[29] H. Xu, J. J. Xie and X. Liu, Implication of the observed $e^+ e^- \rightarrow p\bar{p} \bar{e}^0$ for studying the $p\bar{p} \rightarrow \psi(3770)\bar{e}^0$ process, Eur. Phys. J. C
[46] P. Lebiedowicz and A. Szczurek, \( pp \to ppK^+K^- \) reaction at high energies, Phys. Rev. D 85, 014026 (2012).

[47] C. Hanhart, Meson production in nucleon-nucleon collisions close to the threshold, Phys. Rept. 397, 155 (2004).

[48] V. Baru, A. M. Gasparyan, J. Haidenbauer, C. Hanhart, A. E. Kudryavtsev and J. Speth, Production of eta mesons in nucleon-nucleon collisions, Phys. Rev. C 67, 024002 (2003).