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Production of $P_{cs}(4459)$ from Ξ_b Decay

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Inspired by the $P_{cs}(4459)$ reported by the LHCb collaboration recently, we investigate the $P_{cs}(4459)$ production from Ξ_b decay in a molecular scenario using an effective Lagrangian approach. With different J^P assignments to $P_{cs}(4459)$, the magnitude of branching fractions of $\Xi_b \to P_{cs}(4459)K$ is estimated, which is of the order of 10^{-4}. Together with the decay properties of $P_{cs}(4459)$, the present estimations could be further testified by precise measurements and contribute to a better understanding of the molecular interpretations and the exploration of J^P quantum numbers of $P_{cs}(4459)$.

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The notion of pentaquark can date back to the birth of the quark model. The searches of pentaquark states become one of the most crucial inspections on the quark model. A lot of efforts have been made from both experimental and theoretical aspects and progresses have been achieved in recent decades (see recent reviews[1−3] for more details). Among these achievements, the observations of P_c states are undoubtedly one of the most important experimental breakthroughs, which was initially reported by the LHCb collaboration in 2015. The two pentaquark candidates, $P_c(4380)$ and $P_c(4450)$, were observed in the $J/\psi p$ invariant mass distribution of $\Lambda_b \to KJ/\psi p$ process.[4] And later in 2019, with more data samples, the LHCb collaboration updated their analysis of the $J/\psi p$ invariant mass distribution of $\Lambda_b \to KJ/\psi p$ and discovered the split of structures $P_c(4380)$ and $P_c(4450)$ into three structures, namely $P_c(4312)$, $P_c(4440)$ and $P_c(4457)$.[5]

Since these P_c states were observed in the $J/\psi p$ invariant mass distribution, the most possible quark components are $c\bar{c}uud$, which indicates that these P_c states can be good candidates of pentaquark states. In the pentaquark scenario, the spectroscopy and decay properties have been investigated using the QCD sum rule[6−8] and the constituent quark model.[9−12] In the vicinity of P_c states, there are abundant thresholds of a baryon and a meson, such as $\Sigma_c^{(*)}\bar{D}^{(*)}$, $\Lambda_c\bar{D}^*$, $\chi_{c1}p$, $\psi(2S)p$. In particular, the mass of $P_c(4312)$ is very close to the threshold of $\Sigma_c\bar{D}$, while $P_c(4440)$ and $P_c(4457)$ are close to the threshold of $\Sigma_c\bar{D}^*$. Considering the S wave interaction, the possible J^P quantum numbers of $\Sigma_c\bar{D}$ are $1/2^-$, while for the $\Sigma_c\bar{D}^*$ system, the possible J^P quantum numbers are $1/2^-$ and $3/2^-$, which illustrates that $P_c(4440)$ and $P_c(4457)$ could be assigned as a $\Sigma_c\bar{D}^*$ molecular state with different J^P quantum numbers. Along this way, the mass spectrum,[13−22] decay properties[23−32] and production behaviors[33−35] of these P_c states have been investigated in various methods, such as the QCD sum rule,[20−22,30,31] the potential model[13−19] and the effective Lagrangian approach.[24−26,33−35]

Inspired by the P_c states, the authors in Refs. [36–50] investigated the existence of the hidden-charm pentaquark states with strangeness, named as P_{cs} states. Based on the $SU(3)$ flavor symmetry, the authors in Ref. [40] advised to search the P_{cs} states in $\Xi_b \to P_\Sigma K$ and $\Omega_b \to P_\Xi K$ which may consist rates comparable to $\Lambda_b \to P_p K$. In Refs. [41,42], hidden-charm pentaquark states with strangeness were studied in the diquark-diquark-antiquark picture. The $J/\psi\Lambda$ invariant mass distribution was studied in reactions of $\Lambda_b \to J/\psi\eta\Lambda$,[43] $\Lambda_b \to J/\psi K^0\Lambda$[44] and $\Xi_b^- \to K^- J/\psi\Lambda$[45,46] to examine the existence of the hidden-charm pentaquark states with strangeness. In the molecular scenario, the prediction of hidden-charm pentaquark states with strangeness was provided in Refs. [47–49].

Experimentally, one predicted P_{cs} state was reported very recently by the LHCb collaboration in the $J/\psi\Lambda$ invariant mass spectrum of the $\Xi_b^- \to J/\psi\Lambda K^-$ decays for the first time.[51] The measured mass and width are, respectively,

$$m_{P_{cs}} = 4458.8 \pm 2.9^{+4.7}_{-1.1}\text{MeV}, \quad (1)$$

$$\Gamma_{P_{cs}} = 17.3 \pm 6.5^{+8.0}_{-.57}\text{MeV}. \quad (2)$$

However, the J^P quantum numbers of $P_{cs}(4459)^0$ were not determined.

It should be noticed that the mass of $P_{cs}(4459)^0$ is about 19 MeV below the threshold of $\Xi_c\bar{D}^*$, which

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naturally assigns $P_{cs}(4459)^0$ to a hadronic molecule state composed of $\Xi_c\bar{D}^*$ with possible J^P quantum numbers $1/2^-$ or $3/2^-$. As a strange partner of P_c, the properties of $P_{cs}(4459)$ were investigated in molecular[52–56] and pentaquark[57] scenarios after the observation. Along the way of $\Xi_c\bar{D}^*$ molecular scenario, we investigate the production mechanism of $\Xi_b^- \to P_{cs}(4459)^0K^-$ using an effective Lagrangian approach. In such an estimation, we regard $P_{cs}(4459)^0$ as a $\Xi_c\bar{D}^*$ molecule state, while the probable conditions $J^P = 1/2^-$ and $3/2^-$ are both considered. Similar to the case of P_c state,[25,34] the present estimation helps to test the molecular interpretations and verify the quantum number of the P_{cs} state in the molecule ansatz.

The present work is organized as follows. After the introduction, the formulae of the productions of $\Xi_b \to P_{cs}(4459)K$ are shown, including the relevant effective Lagrangians and production amplitudes. Also, we exhibit our numerical estimation and some discussions on our results. Finally, we give a short summary.

The Productions of $\Xi_b \to P_{cs}K$. The quark components of Ξ_b are bsd, while the quarks in the final states are $s\bar{u}(K)csd(\Xi_c)\bar{c}u(\bar{D}^*)$. At the quark level, the process $\Xi_b \to P_{cs}K$ [hereafter, P_{cs} refers to $P_{cs}(4459)$] occurs via the following subprocess from the phenomenological point of view: (1) the bottom quark transits to charm quark by emitting a W^- boson which couples to $\bar{c}s$; (2) the $\bar{c}s$ and the $u\bar{u}$ pair created from vacuum transits to K^- and $\bar{D}^*$, then $\bar{D}^*$ and Ξ_c form a bound state, i.e., P_{cs}. For simplicity, H_W and H_T are used to denote the first and the second subprocess respectively. The production of P_{cs} can be written as $\langle KP_{cs}|H|\Xi_b\rangle = \langle KP_{cs}|H_WH_T|\Xi_b\rangle$. The direct estimations of this production process at quark level are much more difficult. In the present work, we qualitatively estimate this process at hadron level by inserting a complete basis formed by a meson and a baryon between H_W and H_T, then the production process of P_{cs} becomes

$$\langle KP_{cs}|H|\Xi_b\rangle = \sum_{B,M}\langle KP_{cs}|H_T|BM\rangle\langle BM|H_W|\Xi_b\rangle. \quad (3)$$

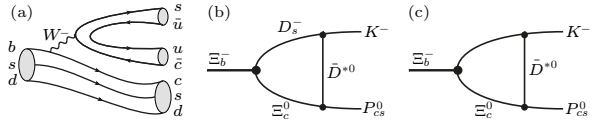

Fig. 1. Diagrams contributing to $\Xi_b \to P_{cs}K$ at the quark level [diagram (a)] and hadron level [diagrams (b) and (c)].

In principle, all the possible basis that can connect the initial Ξ_b and KP_{cs} should be considered. In the molecular scenario, the molecule should couple to its constituent hadrons more strongly than to other hadrons. Moreover, the loops composed by the ground states of the baryons and mesons are regarded as the major contributions as indicated in Refs. [58–63]. With such an assumption, the dominant diagrams contributing to $\Xi_b \to P_{cs}K$ at hadron level are presented in diagrams (b) and (c) in Fig. 1.

Effective Lagrangian. In the present work, the diagrams at the hadron level are estimated by an effective Lagrangian approach. In the molecular scenario, the P_{cs} is considered to be molecular state composed of $\bar{D}^*\Xi_c$ with $J^P = 1/2^-$ or $3/2^-$ and the simplest coupling of P_{cs} with its components are[64]

$$\begin{aligned}\mathcal{L}^{1/2^-}_{p_{cs}\Xi_c\bar{D}^*} &= g^{1/2^-}_{p_{cs}}\,\bar{\Xi}_c\gamma_5\Big(g_{\mu\nu} - \frac{p_\mu p_\nu}{m^2}\Big)\gamma^\nu P_{cs}\bar{D}^{*\mu},\\ \mathcal{L}^{3/2^-}_{p_{cs}\Xi_c\bar{D}^*} &= g^{3/2^-}_{p_{cs}}\,\bar{\Xi}_c P_{cs\mu}\bar{D}^{*\mu},\end{aligned} \quad (4)$$

where $\mathcal{L}^{1/2^-}_{p_{cs}\Xi_c\bar{D}^*}$ and $\mathcal{L}^{3/2^-}_{p_{cs}\Xi_c\bar{D}^*}$ denote the Lagrangians for $J^P = 1/2^-$ and $3/2^-$, respectively; p and m are the momentum and mass of P_{cs}, respectively.

The effective Lagrangians relevant to $\Xi_b \to \Xi_cD_s^{(*)}$ are[65]

$$\begin{aligned}\mathcal{L}_{\Xi_b\Xi_cD_s} &= i\bar{\Xi}_c(A + B\gamma_5)\Xi_bD_s,\\ \mathcal{L}_{\Xi_b\Xi_cD_s^*} &= D_s^{*\mu}\bar{\Xi}_c(A_1\gamma_\mu\gamma_5 + A_2p_{2\mu}\gamma_5\\ &\quad + B_1\gamma_\mu + B_2p_{2\mu})\Xi_b,\end{aligned} \quad (5)$$

where p_2 is the momentum of Ξ_c.A, B, A_1, A_2, B_1 and B_2 are the combinations of the form factors f_1, f_2, g_1 and g_2, which are[65]

$$\begin{aligned}A &= \lambda a_1 f_{D_s}(m - m_2)f_1,\\ B &= \lambda a_1 f_{D_s}(m + m_2)g_1,\\ A_1 &= -\lambda a_1 f_{D_s^*}m_1[g_1 + g_2(m - m_2)],\\ A_2 &= -2\lambda a_1 f_{D_s^*}m_1g_2,\\ B_1 &= \lambda a_1 f_{D_s^*}m_1[f_1 - f_2(m + m_2)],\\ B_2 &= 2\lambda a_1 f_{D_s^*}m_1f_2,\end{aligned} \quad (6)$$

with $\lambda = \frac{G_F}{\sqrt{2}}V_{cb}V_{cs}^*$, and $a_1 = 1.07$.[66] Here m, m_1 and m_2 are the masses of Ξ_b, $D_s^{(*)}$ and Ξ_c, respectively; $f_{D_s}^{(*)}$ is the decay constant of a charmed strange meson, which is estimated by a twisted-mass lattice QCD.[67] The form factors f_i and g_i $(i = 1,2)$ will be discussed in the following.

Following Refs. [68,69] and starting with $SU(4)$ Lagrangian for pseudoscalar and vector meson, we can construct the effective Lagrangian relevant for $D_s^{(*)}D^*K$,

$$\begin{aligned}\mathcal{L}_{KD_sD^*} &= ig_{KD_sD^*}D^{*\mu}[\bar{D}_s\partial_\mu K - (\partial_\mu\bar{D}_s)K] + \text{H.c.},\\ \mathcal{L}_{KD_s^*D^*} &= -g_{KD_s^*D^*}\varepsilon^{\mu\nu\alpha\beta}(\partial_\mu\bar{D}^*_\nu\partial_\alpha D^*_{s\beta}\bar{K}\\ &\quad + \partial_\mu D^*_\nu\partial_\alpha\bar{D}^*_{s\beta}K),\end{aligned} \quad (7)$$

where the coupling constants are $g_{KD_sD^*} = 5.0$ and $g_{KD_s^*D^*} = 7.0\,\text{GeV}^{-1}$.[68,69]

Decay Amplitude. With the above effective Lagrangians, we can obtain the amplitudes corresponding to the diagrams b and c in Fig. 1. With the assumption that the J^P quantum numbers of $P_{cs}(4459)$ are $\frac{1}{2}^-$, the decay amplitudes could be derived as follows:

$$\begin{aligned}\mathcal{M}_b^{1/2} =& i^3\int\frac{d^4q}{(2\pi)^4}\left[g_{p_{cs}}^{1/2^-}\bar{u}(p_4)\gamma^\nu\gamma_5\left(g_{\mu\nu}-\frac{p_{4\mu}p_{4\nu}}{m_4^2}\right)\right]\\&\times(\not{p}_2+m_2)[i(A+B\gamma_5)u(p)]\\&\times[ig_{KD^*D_s}(ip_{3\alpha}+ip_{1\alpha})]\\&\times\frac{1}{p_1^2-m_1^2}\frac{1}{p_2^2-m_2^2}\frac{-g^{\mu\alpha}+q^\mu q^\alpha/m_E^2}{q^2-m_E^2}\mathcal{F}\\&\times(q^2,m_E^2).\\\mathcal{M}_c^{1/2} =& i^3\int\frac{d^4q}{(2\pi)^4}\left[g_{p_{cs}}^{1/2^-}\bar{u}(p_4)\gamma^\nu\gamma_5\left(g_{\mu\nu}-\frac{p_{4\mu}p_{4\nu}}{m_4^2}\right)\right]\\&\times(\not{p}_2+m_2)[(A_1\gamma_\alpha\gamma_5+A_2p_{2\alpha}\gamma_5\\&+B_1\gamma_\alpha+B_2p_{2\alpha})u(p)]\\&\times[-g_{KD^*D_s^*}\varepsilon_{\rho\sigma\tau\lambda}iq^\rho(-i)p_1^\tau]\\&\times\frac{-g^{\alpha\lambda}+p_1^\alpha p_1^\lambda/m_1^2}{p_1^2-m_1^2}\\&\times\frac{1}{p_2^2-m_2^2}\frac{-g^{\mu\sigma}+q^\mu q^\sigma/m_E^2}{q^2-m_E^2}\mathcal{F}(q^2,m_E^2).\end{aligned}\tag{8}$$

In the same way, with the assumption that the J^P quantum numbers of P_{cs} are $3/2^-$, the amplitudes corresponding to diagrams b and c in Fig. 1 could be derived as follows:

$$\begin{aligned}\mathcal{M}_b^{3/2} =& i^3\int\frac{d^4q}{(2\pi)^4}[g_{p_{cs}}^{3/2^-}\bar{u}_\mu(p_4)]\\&\times(\not{p}_2+m_2)[i(A+B\gamma_5)u(p)]\\&\times[ig_{KD^*D_s}(ip_{3\nu}+ip_{1\nu})]\frac{1}{p_1^2-m_1^2}\frac{1}{p_2^2-m_2^2}\\&\times\frac{-g^{\mu\nu}+q^\mu q^\nu/m_E^2}{q^2-m_E^2}\mathcal{F}(q^2,m_E^2).\\\mathcal{M}_c^{3/2} =& i^3\int\frac{d^4q}{(2\pi)^4}[g_{p_{cs}}^{3/2^-}\bar{u}_\mu(p_4)](\not{p}_2+m_2)\\&\times[(A_1\gamma_\nu\gamma_5+A_2p_{2\nu}\gamma_5+B_1\gamma_\nu+B_2p_{2\nu})u(p)]\\&\times[-g_{KD^*D_s^*}\varepsilon_{\rho\sigma\tau\lambda}iq^\rho(-i)p_1^\tau\\&\times\frac{-g^{\nu\lambda}+p_1^\nu p_1^\lambda/m_1^2}{p_1^2-m_1^2}\\&\times\frac{1}{p_2^2-m_2^2}\frac{-g^{\mu\sigma}+q^\mu q^\sigma/m_E^2}{q^2-m_E^2}\mathcal{F}(q^2,m_E^2).\end{aligned}\tag{9}$$

In order to depict the structure and off-shell effects, a form factor in monopole form is introduced,[70–74]

$$\mathcal{F}(q^2,m^2)=\frac{m^2-\Lambda_E^2}{q^2-\Lambda_E^2},\tag{10}$$

where the parameter Λ_E is reparameterized as $\Lambda_E = m_{D^*}+\alpha\Lambda_{\rm QCD}$ with $\Lambda_{\rm QCD}=220\,{\rm MeV}$; and m_{D^*} is the mass of the exchanged D^* meson. The model parameter α should be of the order of unity.[71–74] However, its precise value cannot be estimated by the first principle. In practice, the value of α is usually determined by comparing theoretical estimations with the corresponding experimental measurements.

With the above amplitudes, the partial width of $\Xi_b\to P_{cs}K$ could be estimated by

$$\Gamma_{\Xi_b}=\frac{1}{2}\frac{1}{8\pi}\frac{|\boldsymbol{p}|}{m^2}\overline{|\mathcal{M}|^2},\tag{11}$$

where the factor 1/2 results from the average of Ξ_b spin and $\boldsymbol{p}$ is the momentum of P_{cs} or K in the rest frame of Ξ_b. The overline indicates the sum over the spins of final states.

Numerical Results and Discussion—Coupling Constants and Transition Form Factors. The coupling constants relevant to the molecular states can be estimated by the compositeness condition with the assumption that the observed P_{cs} is in a molecule state which gives[75]

$$g_{P_{cs}}^{1/2^-}=1.61^{+0.13}_{-0.08},\quad g_{P_{cs}}^{3/2^-}=2.82^{+0.20}_{-0.14},\tag{12}$$

where the center values are estimated with the model parameter $\Lambda=1.0\,{\rm GeV}$, while the uncertainties of the coupling constants are obtained by varying the parameter Λ from 0.8 GeV to 1.2 GeV. The parameter Λ in Ref. [75] comes from an exponent form of form factor, i.e., $\exp(p^2/\Lambda^2)$. It depicts the componential distribution in the molecular states, and it also plays the role of removing the ultraviolet divergences.[25,61]

As an s-wave shallow bound state, the coupling constants of P_{cs} and its components $\Xi_c\bar{D}^*$ could be estimated under non-relativistic conditions[76,77]

$$g^2=\frac{4\pi}{4m_0m_2}\frac{(m_1+m_2)^{5/2}}{(m_1m_2)^{1/2}}\sqrt{32E_b},\tag{13}$$

where m_0, m_1 and m_2 are the masses of P_{cs}, D^* and Ξ_c, respectively, and $E_b=m_1+m_2-m_0$ is the binding energy of the s-wave shallow bound state. With the measured mass of P_{cs}, the coupling constant is estimated to be $g=2.00$, which is very close to the estimation under compositeness conditions. Moreover, the coupling constants are also similar to those of $g_{P_c(4440)\bar{D}^*\Sigma_c}$ and $g_{P_c(4457)\bar{D}^*\Sigma_c}$,[25,34] which is consistent with the expectation of SU(3) symmetry.

The transition form factors of $\Xi_b\to\Xi_c$ could be parameterized in the form of[65]

$$f(Q^2)=\frac{f(0)}{(1-Q^2/m_{\rm V}^2)^2},\ g(Q^2)=\frac{g(0)}{(1-Q^2/m_{\rm A}^2)^2},\tag{14}$$

where $m_{\rm V}$ ($m_{\rm A}$) is the pole mass of the vector (axial-vector) meson. For the $b\to c$ transition, the pole mass are $m_{\rm V}=6.34\,{\rm GeV}$ and $m_{\rm A}=6.73\,{\rm GeV}$.[65] In Table 1, the parameters related to the transition form

factors of $\Xi_b \to \Xi_c$[65] are collected. It should be noticed that considering the form factor in Eq. (9) and the transition form factors, the loop integrals contain no ultraviolet divergences.

Table 1. The values of the parameters $f_i(0)$ and $g_i(0)$ in the form factors of $\Xi_b \to \Xi_c$ transition.[65]

Parameter	Value	Parameter	Value
$f_1(0)$	$f_2(0)m_{\Xi_b}$	$g_1(0)$	$g_2(0)m_{\Xi_b}$
0.533	−0.124	0.580	−0.019

Partial Width of $\Xi_b \to P_{cs}K$. To date, the J^P quantum numbers of P_{cs} have not been determined by LHCb collaboration. In the s-wave $\bar{D}^*\Xi_c$ molecular scenario, the possible assignments can be $J^P = 1/2^-$ and $3/2^-$. In the present work, the branching ratios of $\Xi_b \to P_{cs}K$ with two different J^P assignments are estimated. The model parameter α varies from 0.8 to 1.2, which is the same as the one of P_c production.[34] In this α range, the branching ratio is estimated to be $(0.84 \sim 1.31) \times 10^{-4}$ for $J^P = 1/2^-$ and $(8.85 \sim 14.1) \times 10^{-4}$ for $J^P = 3/2^-$. It indicates that the branching ratio of $\Xi_b \to P_{cs}K$ should be of the order of 10^{-4}. Moreover, the α dependences for two different assignments are found to be very similar, the ratio of the branching fractions with different J^P assignments is presented in the right panel of Fig. 2. The branching ratio with $J^P = 3/2^-$ is about one order of magnitude larger than that with $J^P = 1/2^-$. Our estimation indicates that the ratio is around 10.6, and its dependence on the model parameter is weak. Thus, a molecular state of $\bar{D}^*\Xi_c$ with $J^P = 3/2^-$ is more simply produced from Ξ_b decay.

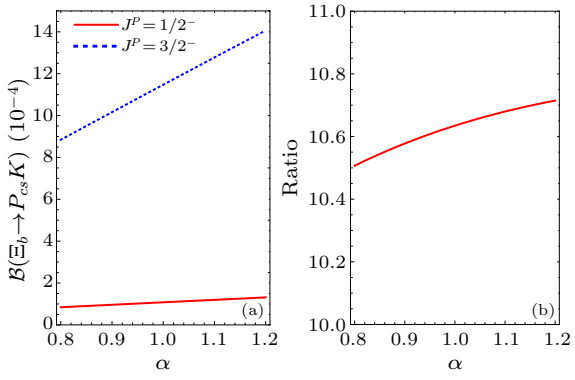

Fig. 2. The branching fractions of $\Xi_b \to P_{cs}K$ with different J^P assignments (a) and the ratio of the branching fractions (b) depending on the parameter α.

In Ref. [34], the authors argued that the production of P_c states occurs via $\Lambda_b \to \Sigma_c D_s^{(*)} \to P_c K$. However, the weak transition of $\Lambda_b \to \Sigma_c$ should be suppressed with a suppression factor $R = 0.09$ due to isospin violation and spin flip of the light di-quark. In Refs. [78,79], the authors indicated that there can be important contribution from other color suppressed diagrams. The present estimation indicate that the branching fraction of $\Xi_b \to P_{cs}K$ occur via a very similar process but without isospin violation and spin flip of the light di-quark. The branching ratio is of the order of 10^{-4}, which is about two orders larger than that of $\Lambda_b \to P_c K$.

Moreover, the experimental analysis of LHCb collaboration indicated that the fit fraction of P_{cs} is $(2.7^{+1.9+0.7}_{-0.6-1.3})\%$, which indicates[51]

$$\frac{\mathcal{B}(\Xi_b \to P_{cs}K \to J/\psi\Lambda K)}{\mathcal{B}(\Xi_b \to J/\psi\Lambda K)} = (2.7^{+1.9+0.7}_{-0.6-1.3})\%, \quad (15)$$

while the branching fraction of $\Xi_b \to J/\psi\Lambda K$ is measured to be[80]

$$\frac{f_{\Xi_b}}{f_{\Lambda_b}} \frac{\mathcal{B}(\Xi_b \to J/\psi\Lambda K)}{\mathcal{B}(\Lambda_b \to J/\psi\Lambda)} = (4.19 \pm 0.29 \pm 0.15) \times 10^{-2}, \quad (16)$$

with f_{Ξ_b} and f_{Λ_b} being the fragmentation fractions of $b \to \Xi_b$ and $b \to \Lambda_b$ transitions, respectively. The branching fraction of $\Lambda_b \to J/\psi\Lambda$ has been measured by CDF collaboration, which is[81]

$$\mathcal{B}(\Lambda_b \to J/\psi\Lambda) = (3.7 \pm 1.7 \pm 0.7) \times 10^{-4}. \quad (17)$$

This measured branching fraction is consistent with the theoretical estimation in Ref. [82], which is 2.1×10^{-4}. As for the fragmentation fractions, the theoretical estimations are model-dependent.[83–87] Using the data sample at $\sqrt{s} = 7,\ 8$ TeV, the recent experimental analysis from the LHCb collaboration shows that the ratio of the fragmentation fractions is[88]

$$\frac{f_{\Xi_b}}{f_{\Lambda_b}} = (6.7 \pm 0.5 \pm 0.5 \pm 2.0) \times 10^{-2}, \quad (18)$$

which is very consistent with the estimations in Refs. [86,87]. With the above experimental results, the branching ratio of $\Xi_b \to P_{cs}K \to J/\psi\Lambda K$ could be obtained as follows:

$$\mathcal{B}(\Xi_b \to P_{cs}K \to J/\psi\Lambda K) = (6.25^{+5.98}_{-4.98}) \times 10^{-6}. \quad (19)$$

Considering the small width of P_{cs}, an approximation of $\mathcal{B}(\Xi_b \to P_{cs}K) \times \mathcal{B}(P_{cs} \to J/\psi\Lambda) \simeq \mathcal{B}(\Xi_b \to P_{cs}K \to J/\psi\Lambda K)$ could be obtained. The present estimations indicate the branching ratio of $\Xi_b \to P_{cs}K$ is of the order of 10^{-4}, thus the expected branching ratio of $P_{cs} \to J/\psi\Lambda$ should be of the order of 10^{-2}–10^{-1}. In Ref. [89], bound states of $\bar{D}^*\Xi_c$ are found and the branching fraction of $J/\psi\Lambda$ mode is estimated to be of the order of 10^{-2} for $J^P = 1/2^-$ and 10^{-1} for $J^P = 3/2^-$, which is consistent with the above analysis. In addition, in the estimations of Ref. [89], the dominant decay modes of P_{cs} state are $\rho\Sigma$ and $K^*\Xi$.

Before the end of this work, it is worth mentioning that the two resonances have been fitted by the LHCb collaboration.[51] However, the analysis indicate that the two-peak hypothesis cannot be confirmed due to limit of the current data. In addition, in the two-resonance fit scheme, the masses of the resonances are

fitted to be 4454.9 ± 2.7 MeV and 4467.8 ± 3.7 MeV, respectively, which are consistent with that of $P_{cs}(4459)$ within uncertainty even when the systematical uncertainties are excluded in the two-resonance scenario. Experimentally, more precise data is expected in future, which would provide more information on the charmed-strange pentaquark states.

In summary, we have presented an investigation on the production of the newly observed P_{cs} state from Ξ_b decay in a $\bar{D}^*\Xi_c$ molecular scenario. By analyzing the P_{cs} production at quark level, the dominant contributions to P_{cs} productions are found to be the charmed-strange hadron loops, where the initial Ξ_b couples to $\Xi_c\bar{D}_s^{(*)}$ by weak interaction, and then the $\bar{D}_s^{(*)}$ transits into $\bar{D}^*$ via kaon emission, and the recoil $\bar{D}^*$ and Ξ_c form the molecular state, i.e., P_{cs}.

The production process of $\Xi_b \to P_{cs}K$ is estimated at hadron level with an effective Lagrangian approach. Our estimation indicates that the branching fraction of $\Xi_b \to P_{cs}K$ is of the order of 10^{-4} for both $J^P = 1/2^-$ and $3/2^-$. Moreover, we find the ratio of the branching fractions with $J^P = 3/2^-$ and $1/2^-$ is about 10.6 and almost independent of the model parameter. Our analysis indicates that the estimated productions fraction in the present work are consistent with the experimental measurements and the theoretical estimations in the literature available.

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