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The role of $D^{\star\star}$ in $B^- \to D_s^+ K^- \pi^-$

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Abstract

The BaBar Collaboration has recently reported the observation of the decay mode $B^- \to D_s^+ K^- \pi^-$. We investigate the role played by the $D^{\star\star}$ resonances in this decay mode using HQET. Although these resonances cannot appear as physical intermediate states in this reaction, their mass is very close to the $D_s^+ K^-$ production threshold and may, therefore, play a prominent role. We pursue this possibility to extract information on the properties of the strong $D^{\star\star} DM$ couplings. As a byproduct of this analysis we point out that future super-B factories may be able to measure the $D_0^0 D^\star \gamma$ radiative coupling through the reaction $B^- \to D^\star \gamma \pi^-$.

1. Introduction

The BaBar Collaboration has recently reported the observation of the decay mode $B^- \to D_s^+ K^- \pi^-$ with a branching ratio $\mathcal{B}(B^- \to D_s^+ K^- \pi^-) = (1.88 \pm 0.13 \pm 0.41) \times 10^{-4}$ [1]. This decay mode is different from the mode $B^- \to D^{\star\star}\pi^- \to D^+\pi^-\pi^-$ observed by Belle Collaboration [2] in that the $D^{\star\star}$ resonances are too light to decay into $D_s^+ K^-$. Nevertheless their masses [2],

$$
\begin{aligned}
m_{D_0^{\star\star}} &= (2308 \pm 17 \pm 15 \pm 28)\ \text{MeV}, \\
m_{D_2^{\star\star}} &= (2461.6 \pm 2.1 \pm 0.5 \pm 3.3)\ \text{MeV},
\end{aligned} \tag{1}
$$

are sufficiently close to the threshold for production of $D_s^+ K^-$ that we can entertain the possibility of them playing a significant role in $B^- \to D_s^+ K^- \pi^-$ as "quasi-resonant" intermediate states.

In this Letter we use heavy quark effective theory (HQET) to investigate this possibility. This study will serve as a probe of the properties of the $D^{\star\star} DM$ interactions, where M a member of the light pseudoscalar meson octet. In particular, we can check the $SU(3)$ relations in strong $D^{\star\star}$ decay. In addition, an analysis of a distribution with respect to the angle between the pion and kaon momenta can further constrain the D_2^0 tensor couplings.

Schematically, our procedure consists of splitting the decay $B^- \to D_s^+ K^- \pi^-$ into "quasi-resonant" and non-resonant contributions as depicted in Fig. 1. If the $D^{\star\star}$ resonances were heavy enough to decay into $D_s^+ K^-$ we would expect the "quasi-resonant" contribution to dominate. Furthermore, in the narrow width approximation the production and decay processes would factorize, and we could study the properties of the strong decay vertex. We investigate the extent to which the "quasi-resonant" process dominates by first computing the amplitudes with the aid of heavy quark effective theory (HQET). We then normalize the resulting rates to the two-body $B^- \to D_{0,2}^0 \pi^-$ weak decay rates and use this as a constraint on the weak transition. Finally we study the behavior of the normalized rates for different parametrizations of the weak vertex, treating the residual dependence on the weak vertex as an indication of the extent to which the "quasi-resonant" contribution dominates.

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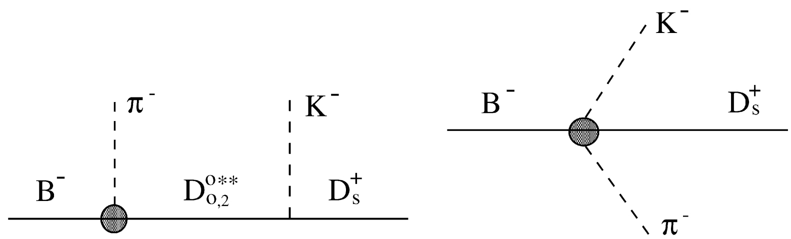

Fig. 1. Decomposition of the decay mode $B^- \to D_s^+ K^- \pi^-$ into contributions that are mediated by a $D^{\star\star}$ that is near its mass shell and those that are not. (a) Quasi-resonance; (b) Nonresonant.

2. Formalism

We use the HQET formalism to describe the interactions involving the heavy meson $(0^-, 1^-)$ doublet, its excited positive parity partners $(0^+, 1^+)$ and $(1^+, 2^+)$, and light pseudo-scalar mesons [3–8]. We follow standard notation to incorporate the light pseudo-scalars as the Goldstone bosons of spontaneously broken chiral symmetry through the matrix $\xi = \exp(\frac{iM}{f_\pi})$ with a normalization in which the pion decay constant is $f_\pi = 132$ MeV. The matrix M is explicitly given by,

$$M = \begin{pmatrix} \sqrt{\frac{1}{2}}\pi^0 + \sqrt{\frac{1}{6}}\eta & \pi^+ & K^+ \\ \pi^- & -\sqrt{\frac{1}{2}}\pi^0 + \sqrt{\frac{1}{6}}\eta & K^0 \\ K^- & \bar{K}^0 & -\sqrt{\frac{2}{3}}\eta \end{pmatrix}. \tag{2}$$

Similarly, the heavy meson doublets are described by the following fields and their conjugates,

$$\begin{aligned} &(0^-, 1^-) \to H = \frac{1+\not{v}}{2}(\not{P}^* - P\gamma_5), \qquad \bar{H} = \gamma_0 H^\dagger \gamma_0, \\ &(0^+, 1^+) \to S = \frac{1+\not{v}}{2}(\not{P}_1\gamma_5 - P_0), \qquad \bar{S} = \gamma_0 S^\dagger \gamma_0, \\ &(1^+, 2^+) \to T^\mu = \frac{1}{2}(1+\not{v})\left[P_2^{\mu\nu}\gamma_\nu - \sqrt{3/2}\tilde{P}_{1\nu}\gamma_5\left(g^{\mu\nu} - \frac{1}{3}\gamma^\nu\left(\gamma^\mu - v^\mu\right)\right)\right], \qquad \bar{T}^\mu = \gamma_0 T^{\dagger\mu}\gamma_0. \end{aligned} \tag{3}$$

At leading order in the heavy quark and chiral expansions, the strong interaction mediated decays of the form $H, S, T \to HM$ are described by the Lagrangians [3–5,9]

$$\begin{aligned} &\mathcal{L}_H = g\,\mathrm{Tr}\left[H\gamma_\mu\gamma_5 A^\mu \bar{H}\right], \\ &\mathcal{L}_S = h\,\mathrm{Tr}\left[S\gamma_\mu\gamma_5 A^\mu \bar{H}\right] + \text{h.c.}, \\ &\mathcal{L}_T = \frac{h_1}{\Lambda_\chi}\mathrm{Tr}\left[H\gamma_\lambda\gamma_5\left(D_\mu A^\lambda\right)\bar{T}^\mu\right] + \frac{h_2}{\Lambda_\chi}\mathrm{Tr}\left[H\gamma_\lambda\gamma_5\left(D^\lambda A_\mu\right)\bar{T}^\mu\right] + \text{h.c.}, \end{aligned} \tag{4}$$

where the axial current is given by,

$$A_\mu \equiv \frac{i}{2}\left(\xi^\dagger\partial_\mu\xi - \xi\partial_\mu\xi^\dagger\right), \tag{5}$$

and the traces are over Dirac and flavor indices. For our numerical estimates we will use the values $|h'| = |(h_1 + h_2)/\Lambda_\chi| \approx 0.5\ \text{GeV}^{-1}$, $h = -0.52$ and $g = 0.4$ [8,10]. We will also replace $f_\pi \to f_K \sim 1.3 f_\pi$ where appropriate.

It is a simple exercise to write the corresponding weak vertices describing the transitions from a b-quark meson to a c-quark meson. In this case, however, we do not expect a reliable description of the weak transition as the $m_b - m_c$ mass difference is larger than Λ_χ. We will use the HQET framework to parametrize the weak transitions in a manner similar to that of Ref. [11]. We then treat the result as a phenomenological description of the weak transition in terms of three free parameters that are constrained by the two body decays $B^- \to D^0_{0,2}\pi^-$.

The dominant short distance operator responsible for the decays $B^- \to D_s^+ K^- \pi^-$, $B^- \to D^+\pi^-\pi^-$ is an $SU(3)$ octet of the form $\bar{c}\gamma_\mu(1-\gamma_5)b\bar{d}\gamma^\mu(1-\gamma_5)u$. We use standard techniques [12] to introduce this operator into the HQET formalism. We first construct the matrix λ_{12} with ${\lambda_{12}}^i_j = \delta^i_1\delta^2_j$ to represent the $SU(3)$ properties of the operator. We then pretend that λ_{12} transforms as $\lambda_{12} \to L\lambda_{12}L^\dagger$ under chiral symmetry and construct chiral symmetric operators that include λ_{12}. The transformation properties under chiral symmetry of the other relevant objects are $H_Q \to H_Q U^\dagger$, $\bar{H}_Q \to U\bar{H}_Q$, $\xi \to L\xi U^\dagger$ and $\xi^\dagger \to U\xi^\dagger L^\dagger$. With these ingredients we construct the effective weak Lagrangian beginning with the $H_b \to H_c$ transitions. There is only one term without