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Nonfactorizable Contribution to B-Meson Decays to s-Wave Mesons

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ABSTRACT

Two-body weak decays of bottom mesons into two pseudoscalar and pseudoscalar and vector mesons, are examined under isospin analysis to study nonfactorizable contribution.

1. Introduction

There has been a growing interest in studying the nonfactorizable terms [1-4] of weak hadronic decays of charm and bottom mesons. We study the nonfactorizable contributions to various Cabibbo–Kobayashi–Maskawa (CKM) favored decays of B-mesons. Unfortunately, it has not been possible to calculate such contributions from the first principle, as these are non-perturbative in nature. Earlier attempts involved to find how much nonfactorizable contributions are required from the empirical details for weak charm hadronic decays [5-7]. We determine these contributions in the respective isospin $I = 1/2$ and $3/2$ amplitudes for $\bar{B} \to \pi D / \bar{B} \to \rho D$ and $\bar{B} \to \pi D^*$ decay modes by taking $N_C = 3$ to calculate the factorizable terms. The ratio of the nonfactorizable amplitude in these channels also seems to follow a universal value for all the above decay modes.

2. Methodology

The effective weak Hamiltonian for Cabibbo enhanced *B*-mesons decays is given by

$$H_w = \frac{G_F}{\sqrt{2}} V_{cb} V_{ud}^* \left[c_1 \left(\bar{c}b\right)\left(\bar{d}u\right) + c_2 \left(\bar{d}b\right)\left(\bar{c}u\right)\right], \qquad (1)$$

where $\bar{q}_1 q_2 = \bar{q}_1 \gamma_\mu \left(1-\gamma_5\right) q_2$ denotes color singlet *V–A* Dirac current and the QCD coefficients at bottom mass scale [4] are

$$c_1(\mu) = 1.12, \qquad c_2(\mu) = -0.26. \qquad (2)$$

where $\mu = m_B^2$, the values of c_1 and c_2 are taken from [5], and Fierz transforming the product of two Dirac currents of (1) in N_c color- space, we get

$$(\bar{d}u)(\bar{c}b) = \frac{1}{N_c}(\bar{c}u)(\bar{d}b) + \frac{1}{2}\left(\bar{c}\lambda^a u\right)\left(\bar{d}\lambda^a b\right) \qquad (3)$$

And similar term for $(\bar{c}u)(\bar{d}b)$, where λ^a are the Gell-Mann matrices. By using (3) and its analogue we reduced the effective Hamiltonian to describe color-favored (CF) and color-suppressed (CS) decays, respectively.

3. Results and Discussion

We applied the isospin formalism, and express decay amplitudes in terms of isospin reduced amplitudes $\left(A_{1/2}^{\pi D}, A_{3/2}^{\pi D}\right)$ and as final-state interaction phase difference $\delta = \left(\delta_{1/2} - \delta_{3/2}\right)$.

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$$A(\bar{B}^0 \to \pi^- D^+) = \frac{1}{\sqrt{3}} e^{i\delta_{3/2}} \left[A_{3/2}^{\pi D} + \sqrt{2} A_{1/2}^{\pi D} e^{i\delta} \right].$$
$$A(\bar{B}^0 \to \pi^0 D^0) = \frac{1}{\sqrt{3}} e^{i\delta_{3/2}} \left[\sqrt{2} A_{3/2}^{\pi D} - A_{1/2}^{\pi D} e^{i\delta} \right]. \quad (4)$$
$$A(B^- \to \pi^- D^0) = \sqrt{3} A_{3/2}^{\pi D} e^{i\delta_{3/2}}.$$

Branching ratio for two body *B*-meson decays to pseudoscaler mesons is related to decay amplitude

$$B\left(\bar{B} \to P_1 P_2\right) = \tau_B \left| \frac{G_F}{\sqrt{2}} V_{cb} V_{ud}^* \right|^2 \frac{p}{8\pi m_B^2} \left| A\left(\bar{B} \to P_1 P_2\right) \right|^2 \quad (5)$$

where τ_B is the life time of *B*-meson, $V_{ud}V_{cb}$ is the product of the CKM matrix elements [1], *p* is the magnitude of the 3-momentum of the final state particles in the rest frame of *B-meson* and $A\left(\bar{B} \to P_1 P_2\right)$ is the decay amplitude. We have calculated isospin reduced amplitudes, $A_{1/2}^{\pi D}$ and $A_{3/2}^{\pi D}$

$$\left| A_{1/2}^{\pi D} \right|_{\exp} = (1.272 \pm 0.065)\, GeV^3,$$
$$\left| A_{3/2}^{\pi D} \right|_{\exp} = (1.323 \pm 0.018)\, GeV^3, \quad (6)$$

using the experimental value [1], where the factorizable parts are calculated by using BSW model [3], expressed as

$$A^f(\bar{B}^0 \to \pi^- D^+) = a_1 f_\pi \left(m_B^2 - m_D^2 \right) F_0^{\bar{B}D}\left(m_\pi^2 \right) = (2.178 \pm 0.099)\, GeV^3$$
$$A^f(\bar{B}^0 \to \pi^0 D^0) = -\frac{1}{\sqrt{2}} a_2 f_D \left(m_B^2 - m_\pi^2 \right) F_0^{\bar{B}\pi}\left(m_D^2 \right) = -(0.139 \pm 0.025)\, GeV^3 \quad (7)$$
$$A^f(B^- \to \pi^- D^0) = a_1 f_\pi \left(m_B^2 - m_D^2 \right) F_0^{\bar{B}D}\left(m_\pi^2 \right) + a_2 f_D \left(m_B^2 - m_\pi^2 \right) F_0^{\bar{B}\pi}\left(m_D^2 \right) = (2.377 \pm 0.099)\, GeV^3$$

There are many calculations for form factors and decay constants, such as light-cone sum rules [8], perturbative QCD approach, and lattice QCD [9-13] etc. We write nonfactorizable part in terms of isospin C. G. coefficients as scattering amplitudes for spurion + $\bar{B} \to \pi D$ process:

$$A^{nf}(\bar{B}^0 \to \pi^- D^+) = \frac{1}{3} c_2 \left(\left\langle \pi D \left\| H_w^8 \right\| \bar{B} \right\rangle_{3/2} + 2 \left\langle \pi D \left\| H_w^8 \right\| \bar{B} \right\rangle_{1/2} \right),$$
$$A^{nf}(\bar{B}^0 \to \pi^0 D^0) = \frac{\sqrt{2}}{3} c_1 \left(\left\langle \pi D \left\| \tilde{H}_w^8 \right\| \bar{B} \right\rangle_{3/2} - \left\langle \pi D \left\| \tilde{H}_w^8 \right\| \bar{B} \right\rangle_{1/2} \right), \quad (8)$$
$$A^{nf}(B^- \to \pi^- D^0) = c_2 \left\langle \pi D \left\| H_w^8 \right\| \bar{B} \right\rangle_{3/2} + c_1 \left\langle \pi D \left\| \tilde{H}_w^8 \right\| \bar{B} \right\rangle_{3/2}.$$

So the reduced amplitudes from the isospin formalism are given by

$$A_{1/2}^{nf}(\bar{B} \to \pi D) = \frac{1}{\sqrt{3}} \left\{ \sqrt{2} A^{nf}(\bar{B}^0 \to \pi^- D^+) - A^{nf}(\bar{B}^0 \to \pi^0 D^0) \right\},$$
$$A_{3/2}^{nf}(\bar{B} \to \pi D) = \frac{1}{\sqrt{3}} \left\{ A^{nf}(\bar{B}^0 \to \pi^- D^+) + \sqrt{2} A^{nf}(\bar{B}^0 \to \pi^0 D^0) \right\}, \quad (9)$$
$$= \frac{1}{\sqrt{3}} \left\{ A^{nf}(B^- \to \pi^- D^0) \right\},$$

which yield

$$A_{1/2}^{nf} = -(0.587 \pm 0.105)\, GeV^3,$$
$$A_{3/2}^{nf} = -(2.468 \pm 0.064)\, GeV^3, \quad (10)$$

Repeating the same procedure used above for $\bar{B} \to \rho D$ and $\bar{B} \to \pi D^*$ decays the nonfactorizable amplitudes ratio can be obtained. For the sake of comparison we have summarized all the results in Table 1 given below.

Table 1: Comparison of final results for all the decay modes.

Decay modes	$\bar{B} \to \pi D$	$\bar{B} \to \rho D$	$\bar{B} \to \pi D^*$
$A_{1/2}^{nf}$	−0.730 ± 0.065	−0.081 ± 0.024	−0.064 ± 0.011
$A_{3/2}^{nf}$	−2.492 ± 0.018	−0.317 ± 0.009	−0.272 ± 0.004
$\alpha = A_{1/2}^{nf} / A_{3/2}^{nf}$	0.293 ± 0.026	0.256 ± 0.078	0.237 ± 0.043

Summary and Conclusions

The motivation for the exploration of nonfactorizable term has been the failure of the large-N_c limit, which was supposed to be supported by the D-meson phenomenology, especially when extended to the B-meson sector. For instance, D-decays demand a negative value for a_2, indicating $N_c \to \infty$ limit, whereas B-meson decays clearly favor positive value for a_2. Therefore, it has been suggested to investigate the effect of nonfactorizable terms in the heavy quark decays keeping the real value of color $N_c = 3$.

We determine $A_{1/2}^{nf}$ and $A_{3/2}^{nf}$ (as shown in table), for all the decay modes, $\bar{B} \to \pi D / \bar{B} \to \rho D$ and $\bar{B} \to \pi D^*$. We notices that the non-factorizable amplitudes shows as increasing pattern with decreasing momenta available to the final state particles, i.e.,

$$\left|A^{nf}(\bar{B} \to \pi D^*)\right| > \left|A^{nf}(\bar{B} \to \rho D)\right| > \left|A^{nf}(\bar{B} \to \pi D)\right| \quad (11)$$

This behavior is understandable, since low momentum states are likely to be affected more through the exchange of soft gluons and can acquire larger non-factorizable contributions [8]. We observe that in all the decay modes, the non-factorizable isospin amplitude $A_{1/2}^{nf}$ bears the same ratio, with in the experimental errors, as well as same sign, $A_{3/2}^{nf}$ amplitude.

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