Two-body Charmed B Meson Decays In Factorization Assisted Topological Amplitude Approach (Postprint)

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Abstract

We analyze the two-body charmed B meson decays Bu,d,s→D(∗)P(V) in the factorization assisted topological amplitude approach, where P(V) denoting a light pseudoscalar (vector) meson. Different from the conventional topological diagram approach, flavor SU(3) symmetry breaking effects are taken into account. Therefore only four universal nonperturbative parameters are introduced to describe the contribution from non-factorization diagrams for all the decay channels. The number of free parameters and the 2 per degree of freedom are both significantly reduced comparing with the conventional topological diagram approach. With the 4 fitted parameters, we predict the branching fractions of 120 decay modes induced by both b→c and b→u transitions, which are well consistent with the measured data or to be tested on the future experiments. We also investigated the relative size of different topological diagrams, isospin violation, flavor SU(3) symmetry breaking effects, compared with previous approaches.

Full Text

Preamble

Two-Body Charmed B Meson Decays in Factorization Assisted Topological Amplitude Approach

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We analyze the two-body charmed B meson decays $B_{u,d,s} \to D^{(*)}P(V)$ in the factorization assisted topological amplitude approach, where $P(V)$ denotes a light pseudoscalar (vector) meson. Unlike the conventional topological diagram

approach, flavor SU(3) symmetry breaking effects are taken into account. Therefore, only four universal nonperturbative parameters are introduced to describe the contributions from non-factorization diagrams for all decay channels. The number of free parameters and the χ^2 per degree of freedom are both significantly reduced compared with the conventional topological diagram approach. With the four fitted parameters, we predict the branching fractions of 120 decay modes induced by both $b \to c$ and $b \to u$ transitions, which are well consistent with the measured data and can be tested in future experiments. We also investigate the relative size of different topological diagrams, isospin violation, and flavor SU(3) symmetry breaking effects, compared with previous approaches.

1 Introduction

The charmed hadronic B meson decays $B \to D^{(*)}P(V)$ are of great interest due to their theoretical application of heavy quark symmetry. These processes serve as a good testing ground for various theoretical issues in hadronic B decays, such as the factorization hypothesis, flavor SU(3) symmetry breaking, and isospin violation, which are essential for the study of CP asymmetry in other channels. Experimentally, numerous two-body charmed hadronic B decays have been observed in heavy flavor experiments [?]. On the theoretical side, the factorization of color-favored decays has been proven within the QCD factorization approach [?] and the soft-collinear effective theory [?]. However, the color-suppressed modes were found to have very large branching ratios experimentally, which provides evidence for the failure of naive factorization and for sizable relative strong-interaction phases between different isospin amplitudes [?]. This was confirmed in the perturbative QCD (PQCD) approach based on k_T factorization [?, ?, ?]. The $D^{(*)}P(V)$ modes have also been studied within some models [?]. Under the assumption of flavor SU(3) symmetry, global fits were performed in the topological quark diagram approach [?], where the magnitudes and strong phases of the topologically distinct amplitudes were studied, but the information of SU(3) asymmetry was lost. Due to the large difference between pseudoscalar and vector mesons, the χ^2 fit had to be performed for each category of decays, resulting in three sets of parameters.

Recently, the factorization assisted topological amplitude (FAT) approach was proposed to study the two-body hadronic decays of D mesons [?, ?]. By incorporating non-factorizable contributions and SU(3) symmetry breaking effects, most theoretical predictions for D decays were in much better agreement with experimental data. The prediction of direct CP asymmetry in D meson decays by this approach achieves the best precision to date [?]. In this framework, the two-body hadronic weak decay amplitudes are first decomposed in terms of some distinct quark diagrams similar to the conventional topological diagrammatic approach. Then, in order to retain the flavor SU(3) breaking effects in the decay amplitudes, we factorize out the decay constants and form factors formally from each topological amplitude. The topological amplitude then becomes universal for all decay channels after factorization of those hadronic parameters, which can be treated as nonperturbative parameters for non-factorization topological diagrams or as effective Wilson coefficients for factorization contributions.

In the present work, we generalize the FAT approach to study the two-body charmed non-leptonic B meson decays. Only four theoretical parameters need to be fitted from the available experimental data for 31 decay channels.

2 The Amplitudes of $B \to D^{(*)}P(V)$ Decays in the FAT Approach

The topological diagrams in the $b \to c$ transitions include the color-favored tree emission diagram T, the color-suppressed tree emission diagram C, and the W-exchange diagram E, as shown in Fig.~1. Note that the W-annihilation diagram A does not occur in the $b \to c$ transition processes, but only appears in the $b \to u$ transitions. In terms of the factorization hypothesis, the three diagrams of the DP modes can be written as

$$T_{DP} = \sqrt{2}G_F V_{cb} V_{uq}^* a_1(\mu) f_P(m_D^2) F_0^{B\to D}(m_P^2),$$

$$C_{DP} = \sqrt{2}G_F V_{cb} V_{uq}^* f_D(m_P^2) F_0^{B\to P}(m_D^2) \chi_C^c e^{i\phi_C^c},$$

$$E_{DP} = \sqrt{2}G_F V_{cb} V_{uq}^* f_B(m_D^2) f_D(s) f_P(s) \chi_E^c e^{i\phi_E^c},$$

where the subscript c stands for processes induced by $b \to c$ transition. a_1 is the effective Wilson coefficient for the factorization diagram T. f_P and f_D are the decay constants of the light pseudoscalar meson and D meson, respectively. $F_0^{B\to D}$ and $F_0^{B\to P}$ are the scalar form factors of the $B \to P$ and $B \to D$ transitions. The contributions from the non-factorization dominated diagram C are parameterized as χ_C^c, while the contributions from the W-exchange diagram E are χ_E^c, with relative strong phases ϕ_C^c and ϕ_E^c.

[Figure 1: see original paper] –Topological diagrams in the $b \to c$ transitions: (a) the color-favored tree diagram, T; (b) the color-suppressed tree diagram, C; and (c) the W-exchange annihilation-type diagram, E. Note that the E diagram occurs only in the B_s decays.

Similarly to the amplitudes of $B \to DP$ decays, the topological amplitudes of T, C, and E for the $B \to D^*P$ and $B \to DV$ decays can be given respectively by

$$T_{D^*P} = \sqrt{2}G_F V_{cb} V_{uq}^* a_1(\mu) f_P m_{D^*} A_0^{B\to D^*}(m_P^2)(\varepsilon^* \cdot p_B),$$

$$C_{D^*P} = \sqrt{2}G_F V_{cb} V_{uq}^* f_{D^*} m_{D^*} F_0^{B\to P}(m_{D^*}^2) \chi_C^c e^{i\phi_C^c}(\varepsilon^* \cdot p_B),$$

$$E_{D^*P} = \sqrt{2}G_F V_{cb} V_{uq}^* m_{D^*} f_B \chi_E^c e^{i\phi_E^c} (\varepsilon^* \cdot p_B),$$

and

$$T_{DV} = \sqrt{2}G_F V_{cb} V_{uq}^* a_1(\mu) f_V m_V F_1^{B\to D}(m_V^2)(\varepsilon^* \cdot p_B),$$

$$C_{DV} = \sqrt{2}G_F V_{cb} V_{uq}^* f_D m_V A_0^{B\to V}(m_D^2) \chi_C^c e^{i\phi_C^c} (\varepsilon^* \cdot p_B),$$

$$E_{DV} = \sqrt{2}G_F V_{cb} V_{uq}^* m_V f_B \chi_E^c e^{i\phi_E^c} (\varepsilon^* \cdot p_B),$$

where ε^* represents the polarization vectors of the D^* and V mesons. f_{D^*} and f_V are the decay constants of the corresponding vector mesons. $A_0^{B\to D^*}$ and $F_1^{B\to D}$ are the vector form factors of $B \to D^*$ and $B \to P$ transitions, respectively. Note that after factorizing out the corresponding form factors and decay constants, we can use the same nonperturbative universal parameters for all three categories of $B \to DP$, $B \to D^*P$, and $B \to DV$ decays. The total number of free parameters to be fitted from experimental data is four. This is in contrast to the conventional topological diagram approach [**?**], where 15 parameters were needed for the three categories of processes.

3 Numerical Results and Discussion

With the 31 experimental data induced by $b \to c$ transition [**?**] and using χ^2 fit, we extract the four parameters with the best-fitted values as

$$\chi_C^c = 0.48 \pm 0.01, \quad \phi_C^c = (56.6^{+3.2}_{-3.8})^\circ,$$

$$\chi_E^c = 0.024^{+0.002}_{-0.001}, \quad \phi_E^c = (123.9^{+3.3}_{-2.2})^\circ,$$

with χ^2/d.o.f. = 1.4. Even though they have many more parameters than us, the χ^2 per degree of freedom is larger than ours in ref.~[**?**]. With so many parameters, they lost the predictive power for the branching fractions of $B \to D^{(*)}P(V)$ decays, because there are not enough data. By contrast, with only four fitted parameters, we can predict 120 branching fractions of $b \to u$ and $b \to c$ processes [**?**], where we employ an approximation that the four non-factorizable parameters in the $b \to u$ processes are the same as those in the $b \to c$ processes. The factorizable contribution from the W-annihilation diagram A is calculated in the pole model [**?**].

Our results are consistent with experimental data and can be tested in future LHCb and Belle-II experiments. The hierarchies of topological amplitudes are obtained as follows:

$$|T_{DP}| : |C_{DP}| : |E_{DP}| \sim 1 : 0.45 : 0.1,$$

$$|T_{D^*P}| : |C_{D^*P}| : |E_{D^*P}| \sim 1 : 0.36 : 0.1,$$

$$|T_{DV}| : |C_{DV}| : |E_{DV}| \sim 1 : 0.31 : 0.1.$$

It is obvious that the amplitudes of non-factorizable dominated color-suppressed C diagrams are relatively larger in the FAT approach compared with QCD-inspired methods [**?**, **?**, **?**, **?**]. For example, the relation $|C/T| \sim 0.1$ was found in the PQCD approach. The relatively larger C diagrams have significant impacts on processes without T diagrams. For instance, the topological amplitudes of $B \to D^0\rho^0$ and $B \to D^0\omega$ decays are $(E - C)/\sqrt{2}$ and $(E + C)/\sqrt{2}$, respectively. The branching fraction of the $D^0\rho^0$ mode is predicted to be almost one half of that of the $D^0\omega$ mode in the PQCD approach [**?**], since C and E diagrams contribute destructively for the former mode but constructively for the latter one, which does not agree with experiment.

However, this issue can be easily explained in the FAT approach, in which both channels are dominated by the C diagram. It is easy to see that there is a non-negligible difference for the C contributions between different categories of decays $B \to DP$, $B \to D^*P$, and $B \to DV$. This is the major reason why the conventional topological diagram approach cannot fit the three categories of decays together. On the other hand, the strong phase of the C diagram in eq.~(10) is universal for all three kinds of decays, which agrees with the soft-collinear effective theory [**?**].

The isospin-amplitude ratio in the $B \to D\pi$ system shows significant deviation from the heavy-quark limit, which can be traced back to the large color-suppressed C topologies due to ignored contributions from E diagrams. The flavor SU(3) symmetry breaking effect in $B \to D^0K^-$ and $B^- \to D^0K^-$ is about 20% at the amplitude level. By testing the SU(3) symmetry breaking effect in the $B_s \to D^0\pi^\pm$ decay, we conclude that the source of SU(3) symmetry breaking is mainly from the decay constants of light mesons in T-diagram dominated decay modes, as expected from factorization hypothesis. The SU(3) symmetry breaking effect in $B_s \to D_s^\pm K^\pm$ is a little smaller than measurements imply, suggesting they might be more sizable than we expected.

4 Conclusions

Under the framework of the factorization assisted topological amplitude approach, we analyzed $B \to D^{(*)}P(V)$ decays. By using the factorization results for the T diagram, only four universal nonperturbative parameters for the non-factorization dominated C and W-exchange diagram E were introduced and fitted from 31 well-measured branching fractions. With the fitted results, we then predicted the branching fractions of all 120 $B_{u,d,s} \to D^{(*)}P(V)$ decay modes. For modes induced by $b \to c$ transition, most results agree well with experimental data.

Comparing with previous topological diagram analyses, the number of free parameters and the χ^2 per degree of freedom are both significantly reduced. The SU(3) symmetry breaking is more than 10%, and even reaches 31% at the amplitude level. The unmeasured branching fractions, especially those processes dominated by $b \to u$ transition, and possible larger SU(3) symmetry breaking effects will be measured or tested in the ongoing LHCb experiment and the forthcoming Belle-II experiment.

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Note: Figure translations are in progress. See original paper for figures.