Final State Interaction Effects in the $B^+ \rightarrow D^+ K^0$ Decay

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The exclusive decay of $B^+ \rightarrow D^+ K^0$ is calculated by the QCD factorization method (QCDF) and final state interaction (FSI). First, the $B^+ \rightarrow D^+ K^0$ decay is calculated via QCDF method. The result that is found by using the QCDF method is less than the experimental result. So FSI is considered to solve the $B^+ \rightarrow D^+ K^0$ decay. For this decay, the $D_s^+ \pi^0$, $D_s^+ \rho^0$, $D_s^+ \phi$ via the exchange of $K^0_s$, $K^{*0}$, $D^*$, and $D^{*-}$ mesons are chosen for the intermediate states. The above intermediate states are calculated by using the QCDF method. In the FSI effects, the results of our calculations depend on $\eta$ as the phenomenological parameter. The range of this parameter is selected from 2 to 2.4. It is found that if $\eta = 2.4$ is selected, the numbers of the branching ratio are placed in the experimental range. The experimental branching ratio of this decay is less than $2.9 \times 10^{-6}$ and our results calculated by QCDF and FSI are $(0.16 \pm 0.04) \times 10^{-6}$ and $(2.8 \pm 0.09) \times 10^{-6}$, respectively.

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1. INTRODUCTION

Non-leptonic decays of the $B$ mesons are significant for testing theoretical frameworks and searching new physics beyond the standard model. The next-to-leading order low-energy effective Hamiltonian is used for the weak interaction matrix elements and final state interaction (FSI). The importance of the FSI in hadronic processes has been identified for a long time. Recently, its applications in $D$ and $B$ decays have attracted extensive interests and attentions of theorists. Since the hadronic matrix elements are fully controlled by non-perturbative QCD, the most important problem is how to evaluate them properly. The factorization method enables one to separate the non-perturbative QCD effects from the perturbative parts and to calculate the latter in terms of the field theory order by order. Several factorization approaches have been proposed to analyze $B$ meson decays, such as the naive factorization approach, QCDF approach, the perturbative QCD approach and soft-collinear-effective theory, but none provided an estimate of the FSI at the hadronic level. These approaches successfully explain many phenomena; however, there are still some problems which are not easy to describe within this framework. These may be some hints for the need of FSI in $B$ decays. FSI effects are non-perturbative in nature [1]. In many decay modes, FSI may play a crucial role [2]. In this way, the CKM matrix elements and the color factor are suppressed and the CKM’s most favored two-body intermediate states are the only ones that have been taken into consideration [3]. The FSI can be considered as a soft re-scattering style for certain intermediate two-body hadronic channel $B^+ \rightarrow D_s^+ \pi^0$ decay [4]. Therefore, FSI are estimated via the one particle exchange processes at the hadron loop level (HLL) as explained in Section 4. We calculated the $B^+ \rightarrow D^+ K^0$ decay according to QCDF method. This process only occurs via annihilation between $b$ and $\bar{u}$. We selected the leading order Wilson coefficients at the scale $m_b$ [5, 6] and obtained the BR $(B^+ \rightarrow D^+ K^0) = (0.16 \pm 0.04) \times 10^{-6}$. The decay is a pure annihilation decay channel. It is therefore, expected to be very small in factorization approach. The FSI can give sizable corrections. Rescattering amplitude can be derived by calculating the absorptive part of triangle diagrams. In this decay, intermediate state are the $D_s^+ \pi^0$, $D_s^+ \rho^0$, $D_s^+ \phi$. Then we calculated the $B^+ \rightarrow D^+ K^0$ decay according to HLL method. By FSI method we obtain the branching ratio of $B^+ \rightarrow D^+ K^0$ decay, $(2.8 \pm 0.09) \times 10^{-6}$ and the experimental result of this decay is less than $2.9 \times 10^{-6}$. We present the calculation of QCDF for $B^+ \rightarrow D^+ K^0$ decay in Section 2. In Section 3, we calculate the amplitudes of the intermediate states. Then we present the calculation of HLL for $B^+ \rightarrow D^+ K^0$ decay in Section 4. In Section 5, we give the numerical results, and in Section 6, we have conclusion.

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2. QCD FACTORIZATION OF $B^+ \rightarrow D^+ K^0$ DECAY

To compare QCDF with FSI, we explore QCDF analysis. In this case, we only have current-current, penguin and electroweak penguin annihilation effects. These contributions are small, but it is interesting and necessary to discuss them. For annihilation amplitude when all the basic building blocks equations are solved it is found that weak annihilation kernels exhibit endpoint divergence. Divergence terms are determined by

$$X_A = 1 + \rho e^{i\phi} \ln \frac{m_B}{\Lambda_h}, \quad \rho \leq 1, \quad \Lambda_h = 0.5 \text{ GeV.}$$

And for the pseudoscalar mesons of $D^+$ and $K^0$, the relation $r_X^p$ and $r_X^p$ are defined as

$$r_X^p = \frac{2m_D^2}{(m_b - m_c)(m_d + m_c)},$$

$$r_X^p = \frac{2m_K^2}{(m_b - m_c)(m_d + m_c)}.$$

3. AMPLENTIES OF INTERMEDIATE STATES

In this section, before analyzing FSI in the $B^+ \rightarrow D^+ K^0$ decay, we introduce the factorization approach in detail. The effective weak Hamiltonian for $B$ decays consists of a sum of local operators $Q_i$ multiplied by QCDF coefficients $C_i$ and products of elements of the quark mixing matrix [7]. The factorization approach of the heavy-meson decays can be expressed in terms of different topologies of various decay mechanisms such as tree, penguin and annihilation.

3.1. $B^+ \rightarrow D_s^+ \pi^0$ Decay

According to quark level diagrams in the next section, $D_s^+ \pi^0$ and $D_s^+ \rho^0$ are produced for intermediate states via exchange meson of $K^0$, $\bar{K}^0$, $D^-$, and $D^-$. 