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Study on the $\Upsilon(1S) \to B_c D_s$ decay

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Abstract

The branching ratio and direct *CP* asymmetry of the $\Upsilon(1S) \to B_c D_s$ weak decay are estimated with the perturbative QCD approach firstly. It is found that (1) the direct *CP*-violating asymmetry is close to zero, (2) the branching ratio $\mathcal{B}r(\Upsilon(1S) \to B_c D_s) \gtrsim 10^{-10}$ might be measurable at the future experiments.

1. Introduction

The $\Upsilon(1S)$ meson is the ground S-wave spin-triplet bottomonium (bound state of $b\bar{b}$) with the well-established quantum number of $I^G J^{PC} = 0^- 1^{--}$ [1]. Its mass, $m_{\Upsilon(1S)} = 9460.30 \pm 0.26$ MeV [1], is less than the kinematic open-bottom threshold. Phenomenologically, the dominated $\Upsilon(1S)$ hadronic decay through the $b\bar{b}$ pairs annihilation into three gluons, with branching

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ratio $\mathcal{B}r(\Upsilon(1S) \to ggg) = (81.7 \pm 0.7)\%$ [1], is suppressed by the Okubo–Zweig–Iizuka rule [2–4]. The partial width of the $\Upsilon(1S)$ electromagnetic decay through the $b\bar{b}$ pairs annihilation into a virtual photon, $(3 + R)\Gamma_{\ell^+\ell^-}$, is proportional to Q_b^2, where $Q_b = -1/3$ is the electric charge of the bottom quark in the unit of $|e|$, R is the ratio of the inclusive production cross section of hadrons to the $\mu^+\mu^-$ pair production cross section, and $\Gamma_{\ell^+\ell^-}$ is the partial width of the pure leptonic $\Upsilon(1S) \to \ell^+\ell^-$ decay. Besides,[1] the $\Upsilon(1S)$ meson can also decay via the weak interactions within the standard model, although the branching ratio is very small, about $2/\tau_B\Gamma_{\Upsilon(1S)} \sim \mathcal{O}(10^{-8})$ [1], where τ_B and $\Gamma_{\Upsilon(1S)}$ are the lifetime of the $B_{u,d,s}$ meson and the total width of the $\Upsilon(1S)$ meson, respectively. In this paper, we will study the $\Upsilon(1S) \to B_c D_s$ weak decays with the perturbative QCD (pQCD) approach [6–8]. The motivation is listed as follows.

From the experimental point of view, (1) over 10^8 $\Upsilon(1S)$ data samples were accumulated by the Belle detector at the KEKB e^+e^- asymmetric energy collider [9]. It is hopefully expected that more and more upsilon data samples will be collected with great precision at the forthcoming SuperKEKB and the running upgraded LHC. A large amount of $\Upsilon(1S)$ data samples offer a realistic possibility to search for the $\Upsilon(1S)$ weak decays which in some cases might be detectable. Theoretical studies on the $\Upsilon(1S)$ weak decays are necessary to give a ready reference. (2) For the $\Upsilon(1S) \to B_c D_s$ weak decay, the back-to-back final states with opposite electric charges have definite momentums and energies in the center-of-mass frame of the $\Upsilon(1S)$ meson. In addition, identification of either a single flavored D_s or B_c meson is free from the low double-tagging efficiency [10], and can provide an unambiguous evidence of the $\Upsilon(1S)$ weak decay. Of course, it should be noticed that small branching ratios for the $\Upsilon(1S)$ weak decays make the observation extremely challenging, and any evidences of an abnormally large production rate of either a single D_s or B_c meson might be a hint of new physics [10].

From the theoretical point of view, the $\Upsilon(1S)$ weak decays permit one to crosscheck parameters obtained from the b-flavored hadron decays, to further explore the underlying dynamical mechanism of the heavy quark weak decay, and to test various phenomenological approaches. In recent several years, many attractive methods have been developed to evaluate hadronic matrix elements (HME) where the local quark-level operators are sandwiched between the initial and final hadron states, such as pQCD [6–8], the QCD factorization [11] and the soft and collinear effective theory [12–15], which could give reasonable explanation for many measurements on the nonleptonic $B_{u,d}$ decays. The $\Upsilon(1S) \to B_c D_s$ weak decay is favored by the color factor due to the external W emission topological structure, and by the Cabibbo–Kobayashi–Maskawa (CKM) factors $|V_{cb}V_{cs}^*|$, so it should have a large branching ratio. However, as far as we know, there is no theoretical investigation on the $\Upsilon(1S) \to B_c D_s$ weak decay at the moment. In this paper, we will predict the branching ratio and direct CP-violating asymmetry of the $\Upsilon(1S) \to B_c D_s$ weak decay with the pQCD approach to confirm whether it is possible to search for this process at the future experiments.

This paper is organized as follows. In section 2, we present the theoretical framework and the amplitude for the $\Upsilon(1S) \to B_c D_s$ decay. Section 3 is devoted to numerical results and discussion. Finally, we conclude with a summary in the last section.

[1] In addition, there are the radiative decay $\Upsilon(1S) \to \gamma gg$ and the magnetic dipole transition decay $\Upsilon(1S) \to \gamma\eta_b$ [5]. The branching ratio for the radiative decay is $\mathcal{B}r(\Upsilon(1S) \to \gamma gg) = (2.2 \pm 0.6)\%$ [1]. No signals of the magnetic dipole transition decay $\Upsilon(1S) \to \gamma\eta_b$ have been seen experimentally until now.