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Nuclear Physics B 909 (2016) 186–196

www.elsevier.com/locate/nuclphysb

The $\Upsilon(1S) \to B_c \rho$ decay with perturbative QCD approach

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Received 10 March 2016; received in revised form 5 May 2016; accepted 12 May 2016

Available online 17 May 2016

Editor: Hong-Jian He

Abstract

With the potential prospects of the $\Upsilon(1S)$ data samples at the running LHC and upcoming SuperKEKB, the $\Upsilon(1S) \to B_c \rho$ weak decay is studied with the pQCD approach. It is found that (1) the lion's share of branching ratio comes from the longitudinal polarization helicity amplitudes; (2) branching ratio for the $\Upsilon(1S) \to B_c \rho$ decay can reach up to $\mathcal{O}(10^{-9})$, which might be hopefully measurable.

1. Introduction

The $\Upsilon(1S)$ meson consists of the bottom quark and antiquark pair $b\bar{b}$, carries the definitely established quantum numbers of $I^G J^{PC} = 0^- 1^{--}$ [1], and lies below the kinematic $B\bar{B}$ threshold. The $\Upsilon(1S)$ meson decay mainly through the strong interaction, the electromagnetic interaction and radiative transition. Besides, the $\Upsilon(1S)$ meson can also decay via the weak interactions within the standard model. More than 10^8 $\Upsilon(1S)$ data samples have been accumulated at Belle [2]. More and more upsilon data samples with high precision are promisingly expected at the running LHC and the forthcoming SuperKEKB. Although the branching ratio for the $\Upsilon(1S)$

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http://dx.doi.org/10.1016/j.nuclphysb.2016.05.012

weak decay is tiny, it seems to exist a realistic possibility to search for the signals of the $\Upsilon(1S)$ weak decay at future experiments. In this paper, we will study the $\Upsilon(1S) \to B_c\rho$ weak decay with the perturbative QCD (pQCD) approach [3–5].

Experimentally, there is no report on the $\Upsilon(1S) \to B_c\rho$ weak decay so far. The signals for the $\Upsilon(1S) \to B_c\rho$ weak decay should, in principle, be easily identified, due to the facts that the final states have different electric charges, have definite momentum and energy, and are back-to-back in the rest frame of the $\Upsilon(1S)$ meson. In addition, the identification of a single flavored B_c meson could be used to effectively enhance signal-to-background ratio. Another important and fashionable motivation is that evidences of an abnormally large branching ratio for the $\Upsilon(1S)$ weak decay might be a hint of new physics.

Theoretically, the $\Upsilon(1S) \to B_c\rho$ weak decay belongs to the external W emission topography, and is favored by the Cabibbo–Kabayashi–Maskawa (CKM) matrix elements $|V_{cb}V_{ud}^*|$. So it should have relatively large branching ratio among the $\Upsilon(1S)$ weak decays, which has been studied with the naive factorization (NF) approximation [6,7]. Recently, some attractive methods have been developed, such as the pQCD approach [3–5], the QCD factorization approach [8–10], soft and collinear effective theory [11–14], and applied widely to accommodate measurements on the B meson weak decays. The $\Upsilon(1S) \to B_c\rho$ decay permit one to cross check parameters obtained from the B meson decay, to test the practical applicability of various phenomenological models in the vector meson weak decays, and to further explore the underlying dynamical mechanism of the heavy quark weak decay. In addition, as it is well known, the B_c meson carries two explicit heavy flavors and has extremely abundant decay modes, but its hadronic production is suppressed compared with that for hidden-flavor quarkonia and heavy-light mesons, due to higher order in QCD coupling constants α_s and the presence of additional heavy quarks [15, 16]. The $\Upsilon(1S) \to B_c\rho$ decay offers another platform to study the B_c meson production at high energy colliders.

This paper is organized as follows. In section 2, we present the theoretical framework and the amplitudes for the $\Upsilon(1S) \to B_c\rho$ decay with the pQCD approach. Section 3 is devoted to numerical results and discussion. The last section is our summary.

2. Theoretical framework

2.1. The effective Hamiltonian

The effective Hamiltonian responsible for the $\Upsilon(1S) \to B_c\rho$ weak decay is [17]

$$\mathcal{H}_{\rm eff} = \frac{G_F}{\sqrt{2}} V_{cb}V_{ud}^* \Big\{ C_1(\mu)\, Q_1(\mu) + C_2(\mu)\, Q_2(\mu) \Big\} + \text{H.c.}, \tag{1}$$

where $G_F \simeq 1.166\times10^{-5}\ \text{GeV}^{-2}$ [1] is the Fermi coupling constant; the CKM factor is written as a power series in the Wolfenstein parameter $\lambda \simeq 0.2$ [1],

$$V_{cb}V_{ud}^* = A\lambda^2 - \frac{1}{2}A\lambda^4 - \frac{1}{8}A\lambda^6 + \mathcal{O}(\lambda^8). \tag{2}$$

The local operators are defined as follows:

$$Q_1 = [\bar{c}_\alpha \gamma_\mu (1-\gamma_5) b_\alpha][\bar{q}_\beta \gamma^\mu (1-\gamma_5) u_\beta], \tag{3}$$

$$Q_2 = [\bar{c}_\alpha \gamma_\mu (1-\gamma_5) b_\beta][\bar{q}_\beta \gamma^\mu (1-\gamma_5) u_\alpha], \tag{4}$$

where α and β are color indices.