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PHYSICS OF ELEMENTARY PARTICLES AND ATOMIC NUCLEI. THEORY

Estimating of CP-Violation in $B^0 \to \psi(2S)\pi^0$ Decay[1]

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Abstract—I present estimates of CP-violating asymmetries in the non-leptonic charmonium two-body $B^0 \to \psi(2S)\pi^0$ decay and the same decays of $B^+ \to \psi(2S)\pi^+$, $B^0 \to \psi(2S)K^0$ and $B^+ \to \psi(2S)K^+$. These estimates are based on QCD and improved QCD factorization approach making use of next-to-leading order (NLO) contributions. The CP-violating asymmetry for $B^0 \to \psi(2S)\pi^0$ decay is not available, according to the same calculations, it is expected if it can be measured in the future its value will be $S_{\psi(2S)\pi^0}(B^0 \to \psi(2S)\pi^0) = 0.662 \pm 0.197$ and $C_{\psi(2S)\pi^0}(B^0 \to \psi(2S)\pi^0) = 0.024 \pm 0.007$.

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1. INTRODUCTION

B meson decays to two-body final states containing a charmonium resonance such as a $\psi(2S)$ offer a powerful way of studying electroweak transitions. Such decays probe charmonium properties and play a role in the study of CP violation and mixing in the neutral B system. Recently the Belle collaboration have reported a measurement of the $B^0 \to \psi(2S)\pi^0$ branching fraction based on the full $\gamma(4S)$ data set of $772\times10^6 B\bar{B}$ pairs collected by the Belle detector at the KEKB asymmetric-energy e^+e^- collider [1]. From the fit to the data containing 1090 $B^0 \to \psi(2S)\pi^0$ candidates, they have obtained the bias-corrected branching fraction

$$Br(B^0 \to \psi(2S)\pi^0) = (1.17 \pm 0.17(\text{stat}) \pm 0.08(\text{syst}))\times10^{-5}. \quad (1)$$

The branching fraction corresponds to 85 signal events, of which 38 are leptonic and 47 are hadronic, 628 events originate from other $b \to (c\bar{c})q$ decays and 377 events belong to the combinatorial background. Within the factorization approach, I calculate the amplitudes for the $B^0 \to \psi(2S)\pi^0$ decay and the same decays of $B^+ \to \psi(2S)\pi^+$, $B^0 \to \psi(2S)K^0$ and $B^+ \to \psi(2S)K^+$ by using a color-suppressed internal W-emission and a penguin diagrams as [2]

$$A(B \to \psi(2S)M) = \frac{G_F}{\sqrt{2}}\lambda_p a_i \langle \psi(2S)M|Q_i|B\rangle_F, \quad (2)$$

where $M = \pi, K$; $\lambda_p = V_{cb}V_{cd}^*$ ($b \to d$ transition); $\lambda_p = V_{cb}V_{cs}^*$ ($b \to s$ transition); $\lambda_p = V_{tb}V_{td(ts)}^*$ (penguin diagrams) and $\langle \psi(2S)M|Q_i|B\rangle_F$ is the factorized hadronic matrix element, which has the same definition as that in the "nonfactorizable" approach. All the "nonfactorizable" effects (coming from the vertex-correction and hard spectator-scattering diagrams) are encoded in the coefficients a_i, which are process dependent and can be calculated perturbatively. The general form of the coefficients a_i at next-to-leading order in α_s, can be written as

$$a_i(\psi(2S)M) = \left(c_i + \frac{c_{i\pm1}}{N_c}\right)N_i(\psi(2S)) + \frac{\alpha_s}{4\pi}\frac{C_F}{N_c}c_{i\pm1}\left(V_i(\psi(2S)) + \frac{4\pi^2}{N_c}H_i(\psi(2S)M)\right), \quad (3)$$

where the upper (lower) signs apply when i is odd (even), $N_i(\psi(2S))$ is the leading-order coefficient which will be considered $N_i(\psi(2S)) = 1$. The quantities $V_i(\psi(2S))$ account for one-loop vertex corrections and $H_i(\psi(2S)M)$ for hard-spectator interactions. Since the CP-violating asymmetry for $B^0 \to \psi(2S)\pi^0$ decay is not available, the values of the $B^+ \to \psi(2S)\pi^+$, $B^0 \to \psi(2S)K^0$ and $B^+ \to \psi(2S)K^+$ are considered for comparison with the main decay. The time-dependent CP asymmetry of neutral B decay under the improved QCD factorization are calculated at NLO scheme and different scales, they become

$$S_{\psi(2S)\pi^0}(B^0 \to \psi(2S)\pi^0) = 0.662 \pm 0.197,$$
$$C_{\psi(2S)\pi^0}(B^0 \to \psi(2S)\pi^0) = 0.024 \pm 0.007. \quad (4)$$

[1] The article is published in the original.

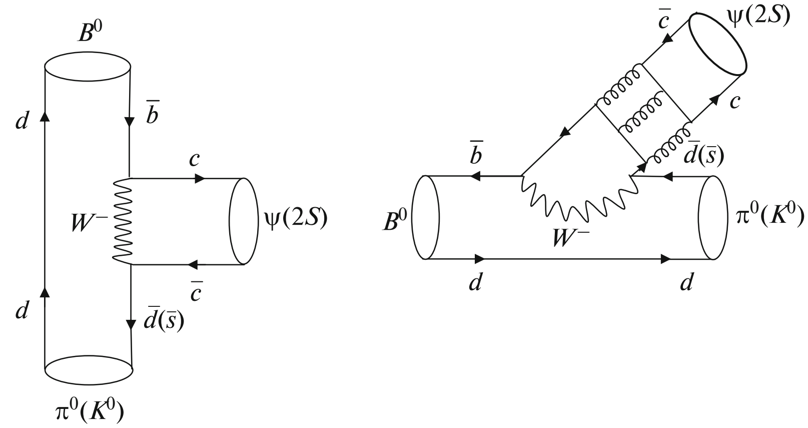

Fig. 1. Quark diagram illustration the process $B^0 \to \psi(2S)\pi^0$ and $B^0 \to \psi(2S)K^0$ decays. If the spectator quarks of d to be changed with u, the decays of $B^+ \to \psi(2S)\pi^+$ and $B^+ \to \psi(2S)K^+$ can be obtained.

It should be noted that my calculations depend on many input parameters, among the experimental data with error bars and the theoretical values including large uncertainties. I consider the main theoretical uncertainties arising from the uncertainties of the input parameters CKM elements, the form factors and the first inverse moment of the B-meson distribution amplitude λ_B.

2. AMPLITUDE OF THE $B^0 \to \psi(2S)\pi^0$ AND $B^0 \to \psi(2S)K^0$ DECAYS

In the factorization approach, Feynman diagrams for $B^0 \to \psi(2S)\pi^0$ and $B^0 \to \psi(2S)K^0$ decays are shown in Fig. 1, there are a current-current and a QCD penguin amplitudes for these decay modes, it has been advocated that the new internal W-emission contribution coming from the Cabibbo allowed process $B \to c\bar{c}d(s)$ followed by a conversion of the $c\bar{c}$ pair into the $\psi(2S)$ via two gluon exchanges is potentially important since its mixing angle $V_{cb}V^*_{cd(s)}$ is as large as that of the penguin amplitude and yet its Wilson coefficient a_2 is larger than that of penguin operators. In the color-suppressed internal W-emission tree (a_2), penguin (a_3) and electro-weak penguin (a_5, a_7 and a_9) diagrams both π^0 and K^0 mesons are placed in the form factor, the meson of $\psi(2S)$ is produced from the vacuum state, therefore the amplitudes of these decays consist of $\langle B^0 \to \pi^0\rangle$ and $\langle B^0 \to K^0\rangle$ multiplied by $\langle 0 \to \psi(2S)\rangle$ which are factorizable terms. The form factor $\langle P(p')|V_\mu|B(p)\rangle$ is parametrized as [3]

$$\langle M(p_M)|V_\mu|B(p_B)\rangle = \left[(p_B + p_M)_\mu - \frac{m_B^2 - m_M^2}{q^2}q_\mu\right] \times F_1(q^2) + \frac{m_B^2 - m_M^2}{q^2}q_\mu F_0(q^2), \tag{5}$$

where $M = \pi, K$ and $q = p_B - p_M$. The decay constant is defined as [4]

$$\langle 0|V_\mu|\psi(2S)(\epsilon_{\psi(2S)}, p_{\psi(2S)})\rangle = f_{\psi(2S)}m_{\psi(2S)}\epsilon_{\psi(2S)\mu}. \tag{6}$$

Because of $q_\mu = p_{\psi(2S)\mu}$ and $\epsilon_{\psi(2S)\mu} \cdot p^\mu_{\psi(2S)} = 0$, the matrix elements of the $B^0 \to \psi(2S)M$ is given by [5]

$$\begin{aligned}\langle\psi(2S)M^0|H_{\rm eff}|B^0\rangle &\propto [a_2V_{cb}V^*_{cq'} \\ &- (a_3 + a_9 + r_\chi^{\psi(2S)}(a_5 + a_7))V_{tb}V^*_{tq'}] \\ &\times f_{\psi(2S)}m_{\psi(2S)}F_1^{BM}(m^2_{\psi(2S)})(\epsilon_{\psi(2S)} \cdot (p_B + p_M)),\end{aligned} \tag{7}$$

where $q' = d$ for π, $q' = s$ for K mesons and

$$r_\chi^{\psi(2S)} = \frac{2m_{\psi(2S)}}{m_b}\frac{f^\perp_{\psi(2S)}}{f_{\psi(2S)}}, \quad \epsilon_{\psi(2S)} \cdot (p_B + p_M) = 2\epsilon_{\psi(2S)} \cdot p_B = \frac{2m_B}{m_{\psi(2S)}}|\vec{p}|, \tag{8}$$

where $|\vec{p}|$ is the absolute value of the 3-momentum of the π (or the K) in the B rest frame, and [6]

$$F_1^{BM}(q^2) = \frac{F(0)}{1 - a_F(q^2/m_B^2) + b_F(q^2/m_B^2)^2}, \quad (M = K, \pi), \tag{9}$$