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Long-distance effects and final state interactions in $B \to \pi\pi K$ and $B \to K\bar{K}K$ decays

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Abstract

B decays into $\pi\pi K$ and $K\bar{K}K$, where the $\pi\pi$ and $\bar{K}K$ pairs interact in isospin zero S-wave, are studied in the $\pi\pi$ effective mass range from threshold to 1.2 GeV. The interplay of strong and weak decay amplitudes is analyzed using an unitary $\pi\pi$ and $K\bar{K}$ coupled channel model. Final state interactions are described in terms of four scalar form factors constrained by unitarity and chiral perturbation theory. Branching ratios for the $B \to f_0(980)K$ decay, calculated in the factorization approximation with some QCD corrections, are too low as compared to recent data. In order to improve agreement with experiment, we introduce long-distance contributions called charming penguins. Effective mass distributions, branching ratios and asymmetries are compared with the existing data from BaBar and Belle Collaborations. A particularly large negative asymmetry in charged B decays is predicted for one set of the charming penguin amplitudes.

1. Introduction

Recent experimental results from B factories indicate that charmless hadronic three-body decays are more frequent than two-body ones [1]. Moreover one observes on Dalitz plots a definitive surplus of events at relatively small effective masses. This is a signal of especially strong interactions between hadrons at not too high relative energies. Many resonances are explicitly visible but in general the interference pattern is quite complicated. Knowledge of these final state interactions is important to obtain a precise determination of the Cabibbo–Kobayashi–Maskawa (CKM) matrix elements. Weak decay observables give information on hadron–hadron interactions and internal quark or hadronic structure of the produced particles.

Prominent maxima in the $\pi^+\pi^-$ spectra are observed in the $B \to \pi^+\pi^- K$ decays in the $f_0(980)$ region [2–9]. The $B^+ \to f_0(980)K^+$ and $B^0 \to f_0(980)K^0$ branching ratios are relatively large, and

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of the order of 10^{-5}. Direct and time-dependent CP-violating asymmetries are also measured. The first Belle result on the $B^+ \to f_0(980)K^+$ branching ratio [2] has motivated the study of Chen [10]. In the perturbative QCD approach Chen finds that the non-strange content of the $f_0(980)$ can be important. According to Cheng and Yang [11], subleading corrections due to intrinsic gluon effects inside B meson may enhance the decay rate of $B \to f_0(980)K$. B decays into scalar–pseudoscalar or scalar–vector particles have been studied by Minkowski and Ochs with a special emphasis on the presence of the lightest glueball [12]. The $\pi^+\pi^-$ mass spectrum in $B \to K\pi\pi$ decays, reported by Belle in 2003, is reproduced by a model amplitude of the coherent sum of $f_0(980)$, $f_0(1500)$ and a very broad glueball as a background.

In the present Letter we study the B decays into $\pi\pi K$ and $K\bar{K}K$. We restrict ourselves to the case where the produced $\pi\pi$ or $K\bar{K}$ pairs interact in isospin zero S-wave from the $\pi\pi$ threshold to about 1.2 GeV. One expects the $\pi\pi$ isospin two S-wave contribution to be small since the upper limit of the branching fraction for the $B^+ \to \pi^+\pi^+K^-$ decay is less than 1.8×10^{-6} [13]. Using the $K\bar{K}/\pi\eta$ branching ratio of $a_0(980)$ [1] and the upper limit of 2.5×10^{-6} [14] for the branching ratio of $B^+ \to a_0^0(980)K^+$, $a_0^0(980) \to \pi^0\eta$, one can estimate the branching fraction $\mathcal{B}(B^+ \to a_0^0(980)K^+, a_0^0(980) \to K^+K^-)$ to be smaller than 1×10^{-6}. This indicates that the $K\bar{K}$ isospin one S-wave amplitude is suppressed in the $B^\pm \to K^+K^-K^\pm$ decays.

Two-pion S-wave rescattering effects have been recently considered by Gardner and Meißner [15]. They study the effect of the $f_0(600)$ (or σ) resonance on the B^0 decay into $\pi^+\pi^-\pi^0$ in the range where the $\rho(770)\pi$ channel dominates. The $\sigma\pi$ channel can play a role in the determination of the CKM angle α from the $B^0 \to \rho\pi$ decays. Gardner and Meißner describe the broad $f_0(600)$ introducing a scalar form factor constrained by the chiral dynamics of low-energy meson–meson interactions [16]. This scalar form factor is used instead of the commonly applied Breit–Wigner form to improve the description of the broad σ and the understanding of the $B \to \rho\pi$ decays.

We extend the approach of Ref. [15] to the $f_0(980)$ resonance. The four strange and non-strange $\pi\pi$ and $K\bar{K}$ scalar form factors are constrained by chiral perturbation theory as developed by Meißner and Oller [16]. Our final state interaction is, however, different from that of [15] and [16]. Here we consider the unitary $\pi\pi$ and $K\bar{K}$ coupled channel model of [17].

First the $B \to (\pi\pi)_{S\text{-wave}}K$, $B \to (K\bar{K})_{S\text{-wave}}K$ decay amplitudes are calculated within the naive factorization approximation [18,19]. Penguin amplitudes interfere destructively which leads to much too small $B \to f_0(980)K$ branching ratios. Then we consider some QCD factorization corrections [20] calculated by de Groot, Cottingham and Whittingham [21]. These corrections are not sufficient to obtain agreement with experiment. Further contributions are needed. Here we include the long-distance contributions which have been considered in [21] to improve their fit to hadronic charmless strange and non-strange two-body B-decay data. These amplitudes, called charming penguin terms, originate from enhanced charm quark loops [22]. They could, for instance, correspond to weak decays of B to intermediate $D_s^{(*)}D^{(*)}$ states followed by transitions to $f_0(980)K$ final states via $c\bar{c}$ annihilations. Their addition allows us to obtain a good agreement with the measured $B \to f_0(980)K$ branching fractions.

In Section 2 we describe our weak decay amplitudes supplemented by the scalar form factors. Our model for the final state interactions is given in Section 3. Results of calculations and comparison with available data are presented in Section 4. In Section 5 we give some conclusions and final remarks.

2. Amplitudes for the $B \to \pi\pi K$ and $B \to K\bar{K}K$ decays

We shall write the model amplitudes for the following decays: $B^\pm \to (\pi\pi)_S K^\pm$, $B^\pm \to (K\bar{K})_S K^\pm$, $B^0 \to (\pi\pi)_S K^0$, $B^0 \to (K\bar{K})_S K^0$, $\bar{B}^0 \to (\pi\pi)_S \bar{K}^0$ and $\bar{B}^0 \to (K\bar{K})_S \bar{K}^0$. Here by $(\pi\pi)_S$ and $(K\bar{K})_S$ we mean $\pi^+\pi^-$ or $\pi^0\pi^0$ and K^+K^- or $K^0\bar{K}^0$ pairs in isospin zero S-wave.

The possible quark line diagrams for the B^- decay, together with the final state mesons, are shown in Fig. 1. For the B^0 decay there are only two types of penguin diagrams similar to those shown in Fig. 1(b) and (c). The tree diagram of Fig. 1(a) is absent. The $u\bar{u}$ or $s\bar{s}$ transitions into $\pi\pi$ or $K\bar{K}$ states, shown in Fig. 1, are described by four scalar form factors.