PROCEEDINGS OF SCIENCE

Final state interactions and long-distance effects in $B \to \pi\pi K$ and $B \to K\bar{K}K$ decays [*]

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Charged and neutral B decays into the $\pi^+\pi^- K$, K^+K^-K and $K^0_S K^0_S K^0_S$ systems have been studied. The $\pi^+\pi^-$ and K^+K^- final state interactions in the S-wave isoscalar state are treated in an unitary way. The long-distance contributions called charming penguins are introduced in the model. Effective mass distributions, branching ratios and some asymmetries are succesfully compared with the recent BaBar and Belle data. A particularly large negative direct CP-violating asymmetry in the charged B decays into $f_0(980)K$ is evaluated for one set of the charming penguin amplitudes.

International Europhysics Conference on High Energy Physics
July 21st - 27th 2005
Lisboa, Portugal

PoS(HEP2005)249

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[*] This work has been performed in the framework of the IN2P3-Polish laboratories Convention (project No. 99-97).
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1. Introduction

A good description of final state interactions is crucial to obtain a precise determination of the Cabibbo-Kobayashi-Maskawa matrix elements. Recent experimental results on the B decays into three pseudoscalar mesons are a rich source of information about weak decay amplitudes and two body mesonic strong interactions. Direct CP-violation effects can appear in these reactions. Here we study the B decays into $\pi\pi K$ and $K\bar{K}K$ channels. An important part of these processes is a production of the $\pi\pi$ or $K\bar{K}$ pairs in the isospin zero S-wave. A very prominent maximum of the $f_0(980)$ resonance has been seen in the $\pi\pi$ spectra obtained by the BaBar and Belle collaborations (see, for example refs.[1-4]). One can expect that the other scalar resonance $f_0(600)$ plays some role at lower $\pi\pi$ effective masses. Both resonances are incorporated in a natural way in the unitary three-channel model of pion-pion, kaon-kaon and four-pion interactions [5]. We use this model to calculate the final state interactions in the different B-decay channels.

The penguin diagrams are essential in studies of B decays into $\pi\pi K$ and $K\bar{K}K$. However, different penguin amplitudes interfere destructively in the decay $B \to f_0(980)K$. This leads to much too small branching ratios calculated in the factorization approach. Thus we consider the long-distance contributions originating from enhanced charm quark loops. These so-called charming penguin terms correspond, for example, to weak decays of B to intermediate $D_s^{(*)}D^{(*)}$ states followed by transitions to the $f_0(980)K$ final states via $c\bar{c}$ annihilations. The charming penguins have been used in fits of experimental branching fractions for two-body charmless B decays [6-7]. Below we show that these long-distance contributions are also needed in analyses of B decays into three pseudoscalar mesons $\pi\pi K$ or $K\bar{K}K$.

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

We have constructed a model for the following charged and neutral B 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.

Below we outline only the main features of the amplitudes described in more detail in [8]. The decay amplitudes consist of two parts both related to weak transitions $b \to s\bar{n}n$ and $b \to s\bar{s}s$, where n denotes u or d quarks. The first part corresponds to the factorization approximation with some QCD corrections. The second one is the long-distance amplitude A_{LD} with c- or u-quark loops. Its form for the $B^- \to (\pi^+\pi^-)_S K^-$ decay reads:

$$A_{LD} = \frac{G_F}{\sqrt{3}}\chi\left[C(m_{\pi\pi})\Gamma_1^{n*}(m_{\pi\pi}) + C(m_K)\Gamma_1^{s*}(m_{\pi\pi})\right], \tag{2.1}$$

where G_F is the Fermi coupling constant, χ is a constant which value is close to 30 GeV^{-1}, m_K is the kaon mass, $\Gamma_1^n(m_{\pi\pi})$ and $\Gamma_1^s(m_{\pi\pi})$ are the non-strange and strange pion scalar form factors depending on the effective pion-pion mass $m_{\pi\pi}$. The charming penguin contribution is written similarly as in ref. [6]:

$$C(m) = -\left(M_B^2 - m^2\right) f_\pi F_\pi \left(V_{ub}V_{us}^* P_u + V_{tb}V_{ts}^* P_t\right), \tag{2.2}$$

where $f_\pi F_\pi = 0.042$ GeV, P_t and P_u are complex parameters multiplied by the products of the Cabibbo-Kobayashi-Maskawa matrix elements V. We have performed numerical calculations using two sets of parameters fitted to data on two-body charmless B-decays. We consider the model I in which [6] $P_t = (0.068 \pm 0.007)\exp[i(1.32 \pm 0.10)]$ and $P_u = (0.32 \pm 0.14)\exp[i(1.0 \pm 0.27)]$, and the model II [7] with $P_t = (0.08 \pm 0.02)\exp[-i(0.6 \pm 0.5)]$ and $P_u = 0$.

In our treatment of final state interactions we use not only the pion scalar form factors $\Gamma_1^{n}(m_{\pi\pi})$ and $\Gamma_1^{s}(m_{\pi\pi})$ but also the kaon scalar form factors $\Gamma_2^{n}(m_{K\bar{K}})$ and $\Gamma_2^{s}(m_{K\bar{K}})$. The first and the second form factors are responsible for the transitions from the $\bar{n}n$ quark pair and from the $\bar{s}s$ quark pair to the $\pi\pi$ pair, respectively. Similarly the third and the fourth form factors correspond to the $\bar{n}n \to K\bar{K}$ and to the $\bar{s}s \to K\bar{K}$ transitions. In the B-decay processes transitions from the $\pi\pi$ channel to the $K\bar{K}$ channel and vice versa are possible. They are incorporated in the two-body scattering matrix T. The interchannel couplings are included in the following formulae:

$$\Gamma_i^{n,s}(m) = R_i^{n,s}(m) + \sum_{j=1}^{2} \langle k_i | R_j^{n,s}(m) G_j(m) T_{ij}(m) | k_j \rangle, \tag{2.3}$$

where $|k_i\rangle$ and $|k_j\rangle$ represent the wave functions of the two mesons in the momentum space and the indices $i, j = 1, 2$ refer to the $\pi\pi$ and $K\bar{K}$ channels, respectively. The center of mass channel momenta are given by $k_1 = \sqrt{m^2/4 - m_\pi^2}$ and $k_2 = \sqrt{m^2/4 - m_K^2}$.

In the numerical calculations we use the solution A of the coupled channel model [5]. The functions $G_i(m)$ are the free particle Green's functions defined in [5] and $R_i^{n,s}(m)$ are the production functions responsible for the initial formation of the meson pairs prior to rescattering. The production functions have been derived by Meißner and Oller in the one-loop approximation of the chiral perturbation theory [9].

Let us remark that in this approach a sum of many Breit-Wigner terms typical for the so-called isobar model, usually used in phenomenological fits to Dalitz plots, is replaced by a set of the coupled meson-meson amplitudes T. These amplitudes can be expressed in terms of the phase shifts $\delta_{\pi\pi}$, δ_{KK} and the inelasticity η known from other experiments. Thus no arbitrary phases nor relative intensity free parameters for different resonances are needed. In addition, both the T- and the Γ-matrices satisfy unitarity constraints. A generalization of Watson's theorem to multi-channel B-decays is thus realized.

3. Results

Table 1 shows that the results of our calculations compare reasonably well with the results of the experimental analyses averaged by HFAG in spring 2005.

In Fig.1a we compare the model I with the BaBar data [1] for the $B^\pm \to \pi^+\pi^-K^\pm$ decays. One can see that the theoretical solid line describes well the shape of the $f_0(980)$ resonance. Fig. 1b shows the Belle data [4] in comparison with our model for the neutral B^0 decays to $\pi^+\pi^-K^0$ in a wide range of effective masses. The model provides us with an absolute prediction for the branching ratio of the B^0 decay into $f_0(980)K^0$ if the effective mass distributions in the range of the $f_0(980)$ resonance for the charged B decays are reproduced.

For the model I one obtains a particularly large negative direct CP-violation asymmetry.

Table 1: Branching ratios $\mathscr{B}$ in units of 10^{-6}, direct CP asymmetry $\mathscr{A}_{CP}$, time dependent asymmetry parameters $\mathscr{A}$ and $\mathscr{S}$ for the $B \to f_0(980)K$, $f_0(980) \to \pi^+\pi^-$ decay. The model errors come from uncertainties of the charming penguin amplitudes.

decay mode	observable	experiment	Model I	Model II
		HFAG	$\chi = 33.5$ GeV^{-1}	$\chi = 23.5$ GeV^{-1}
$B^{\pm}$	$\mathscr{B}$	$8.49^{+1.35}_{-1.26}$	8.49 (fit)	8.46 (fit)
	$\mathscr{A}_{CP}$	$-0.13^{+0.19}_{-0.12}$	-0.52 ± 0.12	0.20 ± 0.20
B^0	$\mathscr{B}$	6.0 ± 1.6	5.9 ± 1.6	5.8 ± 2.8
	$\mathscr{A}$	-0.14 ± 0.22	0.01 ± 0.10	0.0004 ± 0.0010
	$\mathscr{S}$	-0.39 ± 0.26	-0.63 ± 0.09	-0.77 ± 0.0004

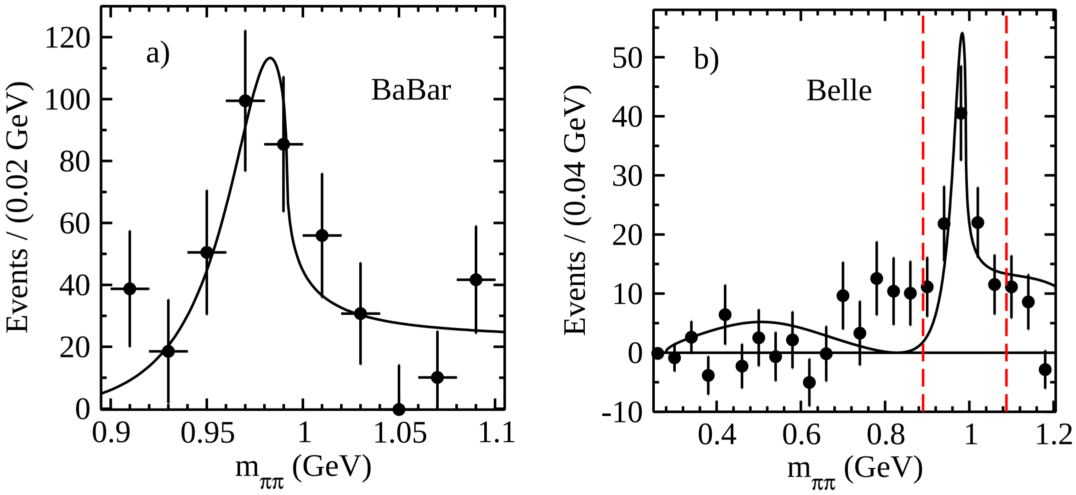

Figure 1: $\pi^+\pi^-$ mass distributions in the $B^{\pm} \to \pi^+\pi^-K^{\pm}$ (a) and in the $B^0 \to \pi^+\pi^-K^0$ decays (b). Vertical lines delimit a band of the $f_0(980)$ events.

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