Vol. 36 (2005) ACTA PHYSICA POLONICA B No 3

INFLUENCE OF CHARMING PENGUINS ON THE EXTRACTION OF γ IN $B \to PP$ DECAYS

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(Received September 15, 2004)

Charmless $B \to PP$ decays are studied using flavour SU(3) symmetry. Amplitude with charming penguin topology is considered for two cases: with zero and with arbitrary strong phase. Two sets of data (an older and the most recent one) are used in the fits, so that the stability of the fits is tested. It is shown that within the present uncertainties in the data the parameters of the fit may be significantly modified, especially the γ angle. The fits indicate the strong phase of the charming penguin amplitude to be around $\pm 20^\circ$.

PACS numbers: 13.25.Hw, 12.15.Hh

1. Introduction

B-meson decays are an excellent source of information about the CKM mechanism and allow us to test our understanding of the CP violation. In nonleptonic B decays we must deal with final states interactions (FSI) as well, since they may modify the values of the extracted parameters. It is hard to take FSI into consideration properly since there are a lot of possible decay channels.

During the recent years several authors have investigated various possible corrections due to FSI. Most of the analyses take into account the elastic and inelastic effects arising from intermediate states containing light quarks (u, d, s) [1–6] and apply symmetries of strong interactions (isospin, SU(3)) to reduce the number of parameters. Some authors argued that intermediate states containing charmed quarks (c) may also play an important role [7–13].

In the present paper we analyse B decays into two light noncharmed pseudoscalar mesons. We consider FSI originating only from the intermediate states containing c quarks. In Sections 2 and 3 we introduce our parametrisation and relations between the amplitudes. Section 4 contains the description of the fit procedure and our results together with the CP asymmetry predictions. Finally, a short summary is given in Section 5.

2. Short-distance amplitudes

The decays of B meson into two noncharmed pseudoscalar mesons are characterised by 10 $\mathrm{SU}(3)_f$ invariant amplitudes corresponding to the specific quark-line diagrams. As in [6, 14] we use four dominant amplitudes: tree $T(T^{'})$, colour-suppressed $C(C^{'})$, penguin $P(P^{'})$ and singlet penguin $S^{'}$. Unprimed (primed) amplitudes denote strangeness conserving (violating) processes and are related to each other. Topological decompositions of decay amplitudes can be found in [6].

We use the Wolfenstein parameters: $\lambda = 0.222$, $A = 0.832$, $\bar{\rho} = 0.224$ and $\bar{\eta} = 0.317$ [15]. All relations bellow are calculated up to $O(\lambda^4)$ unless explicitly written otherwise. Terms proportional to λ^4 are kept on account of complex factor in $P^{'}$, which may interfere with FSI correction. We assume that all short-distance (SD) strong phases are negligible. For the tree amplitude we have

$$T^{'} = \frac{V_{us}}{V_{ud}}\frac{f_K}{f_\pi}T = 0.278T\,, \tag{1}$$

where $\frac{f_K}{f_\pi}$ is the SU(3) breaking factor. Both T and $T^{'}$ amplitudes have a weak phase equal γ. We assume that SD penguin amplitudes are dominated by t quark contribution. When terms of order λ^4 are included, the strangeness violating penguin amplitude $P^{'}$ acquires a small weak phase. Thus, $P^{'}$ can be represented as a sum of two terms, the second one due to the $O(\lambda^4)$ correction:

$$P^{'} = \frac{V_{ts}}{V_{td}}P = -(5.241 + 0.105e^{i\gamma})|P|\,. \tag{2}$$

Penguin amplitude P has weak phase $-\beta$. We used in our fits the value of $\beta = 24^\circ$ consistent with the world average. The singlet penguin has the same phase as penguin P':

$$S^{'} = e^{i\arg(P')}|S'|\,. \tag{3}$$

Finally, we accept relations between the tree and colour-suppressed amplitudes:

$$C = \xi T\,, \tag{4}$$

$$C^{'} = (\xi - (1+\xi)\delta_{\mathrm{EW}}e^{-i\gamma})T^{'}\,, \tag{5}$$

where $\xi = 0.17$ and $\delta_{\rm EW} = 0.65$. The last equation includes electroweak penguin $P^{'}_{\rm EW}$. The EW penguin contribution $\sim \delta_{\rm EW} e^{-i\gamma}$ was calculated (see *e.g.* [16, 17]) without λ^4 corrections. This fact should not affect the fits much since $P^{'}_{\rm EW} \sim S^{'}$ [18] and the small correction in $S^{'}$ is practically invisible in the fits (the only changes we observed were in the asymmetry for the $B^+ \to \eta^{'} K^+$ decay channel).

3. Long-distance charming penguins

It was argued [7–13] that the intermediate states composed of charmed mesons ($D\bar{D}$, *etc.*), generated from the $b \to c\bar{c}d(s)$ tree amplitudes $T_c^{(')}$, may lead via rescattering to amplitudes of penguin topology with an internal c quark (the "charming penguin"). Our calculations are similar as in the case of long-distance u-type penguins [14]. Assuming SU(3) symmetry, we can redefine penguins:

$$P^{(')} \to P^{(')} + i d_c T_c^{(')} \,, \tag{6}$$

where d_c is related to the size of the LD charming penguin and is a complex number in general. Because we do not have information about d_c (or $T_c^{(')}$), it is convenient to introduce the following parametrisation:

$$i d_c T_c^{(')} = P_{c\rm LD}^{(')} e^{i\delta_c} \,. \tag{7}$$

Strong phase δ_c and size $P_{c\rm LD}^{(')}$ of the charming penguin are additional free parameters in our fits. The weak phases are determined by the tree amplitudes $T_c^{(')}$ and are either π or 0. We can eliminate $P^{'}_{c\rm LD}$ using the relation

$$\frac{P^{'}_{c\rm LD}}{P_{c\rm LD}} = \frac{T^{'}_c}{T_c} = \frac{V_{cs}}{V_{cd}} = -4.388 \,. \tag{8}$$

Short-distance charming penguin $P^{'}_c$ has the same weak phase as $P^{'}_{c\rm LD}$. It can be included in a new redefined charming penguin

$$P_{cef}^{(')} e^{i\delta} = P_c^{(')} + P_{c\rm LD}^{(')} e^{i\delta_c} \tag{9}$$

with new effective size and strong phase.

4. Results of fits

We minimise function f defined as:

$$f = \sum_i \frac{(B_i^{\rm theor} - B_i^{\rm exp})^2}{(\Delta B_i^{\rm exp})^2} \,, \tag{10}$$

where $B_i^{\text{theor(exp)}}$ denote theoretical (experimental) CP-averaged branching fractions and ΔB_i^{exp} is an experimental error for i-th decay channel. The sum is over all 16 decay channels as in [14, 19]. Experimental branching ratios and their errors are listed in Tables I and II. The connection between the amplitudes and branching ratios was corrected in our calculations for the lifetime difference between B^+ and B^0:

$$\frac{\tau_{B^+}}{\tau_{B^0}} = 1.068\,. \tag{11}$$

We considered two sets of data. The first one was the same as in [14]. The second one was used in [19]. Data in Table II are more recent and differ from the previous ones in a couple of entries. We performed fits in three general cases:

1. Without long-distance charming penguin contributions and with $|T|$, $|P|$, $|S'|$, γ treated as free parameters;
2. with long-distance charming penguins described by real P_{cef} as an additional parameter and $\delta = 0$, which is consistent with calculations done in [19] but without any assumed connection between P_c and P_t;
3. with long-distance charming penguins described by two additional free parameters: δ, P_{cef}.

Results of the fits are contained in Tables I, II. The branching fractions were calculated for the best fits and for the fit with fixed $\gamma = 64.5°$. The minimums f_m obtained by minimising f of (10) are showed in the last rows of the tables. In general, the fitted values of γ are far from the standard model prediction. To find out what happens one should study the dependence of the fitted function on γ. Let us denote by $f_m(\gamma)$ the minimum values of f obtained when keeping γ fixed. The function $f_m(\gamma)$ is obtained either by setting P_{cef}=0, or by assuming $\delta = 0$ while letting P_{cef} free, or by letting both P_{cef} and δ free. Figure 1 shows $f_m(\gamma)$ for the first (left) and second (right) set of data. The worst fits are those without charming penguins (solid lines). The minimal values were achieved for $\gamma = 103°$ and $\gamma = 85°$, respectively. For both fits with charming penguin and the strong phase $\delta_c = 0$ (dashed lines), the best fit corresponds to γ shifted down by $9°(17°)$ and a slightly lower value of f_m. In the third case shown (dotted lines) δ was let free. For the first set of data, the $f_m(\gamma)$ is fairly small over the whole region shown ($\gamma \in (0, 120°)$). For the second, more recent set of data this region is restricted to about 10°–80°. Since the values of f_m differ a little in the above-mentioned region we should rather think of an allowed range of γ.

TABLE I

Fits to the first set of data (in units of 10^{-6})

Decay channel	Exp	SD amplitudes only (case 1)	Charming penguin (case 2) $\delta = 0°$	Charming penguin (case3) γ free	Charming penguin (case3) $\gamma = 64.5°$
$(B^+ \to \pi^+\pi^0)$	5.8 ± 1.0	5.01	5.65	5.73	5.85
$(B^+ \to K^+\bar{K}^0)$	0.0 ± 2.0	0.68	0.71	2.10	1.81
$(B^+ \to \pi^+\eta)$	2.9 ± 1.1	2.15	1.76	2.47	2.24
$(B^+ \to \pi^+\eta')$	0.0 ± 7.0	1.07	0.88	1.24	1.12
$(B_d^0 \to \pi^+\pi^-)$	4.7 ± 0.5	4.90	4.78	4.76	4.75
$(B_d^0 \to \pi^0\pi^0)$	1.9 ± 0.7	0.62	0.73	1.50	1.36
$(B_d^0 \to K^+K^-)$	0.0 ± 0.6	0.00	0	0.00	0.00
$(B_d^0 \to K^0\bar{K}^0)$	0.0 ± 4.1	0.62	0.66	1.94	1.67
$(B^+ \to \pi^+K^0)$	18.1 ± 1.7	18.40	19.21	18.67	20.41
$(B^+ \to \pi^0K^+)$	12.7 ± 1.2	13.11	13.10	11.61	10.63
$(B^+ \to \eta K^+)$	4.1 ± 1.1	2.46	2.30	4.30	3.96
$(B^+ \to \eta' K^+)$	75 ± 7.0	73.00	73.37	68.91	69.69
$(B_d^0 \to \pi^-K^+)$	18.5 ± 1.0	18.76	18.60	18.38	18.60
$(B_d^0 \to \pi^0K^0)$	10.2 ± 1.2	6.20	6.57	7.76	9.12
$(B_d^0 \to \eta K^0)$	0.0 ± 9.3	1.81	1.79	3.19	4.22
$(B_d^0 \to \eta' K^0)$	56 ± 9.0	66.28	67.36	62.35	66.12
$\|T\|$		2.60	2.76	2.78	2.81
$\|P\|$		0.79	1.45	2.59	1.92
$\|S'\|$		1.75	1.72	2.46	3.02
P_{cef}			-0.77	-2.81	-2.32
γ		103°	94°	110°	64.5°
δ			0°	$\pm 18°$	$\pm 26°$
f_m		15.36	14.79	6.37	9.39

The values of fitted parameters $|P|$,$|S^{'}|$,$|P_{cef}|$ vary for different values of γ. The most stable are the ratio $\frac{P_{cef}}{P}$ and the strong phase δ. $|\frac{P_{cef}}{P}|$ changes from 1.1 to 1.3(1.2) only. The function $f_m(\delta,\gamma)$ has a deep minimum around $\delta \approx \pm 20°$ (Fig. 2) for a wide range of fits with fixed γ. Both positive

TABLE II

Fits to the second set of data (in units of 10^{-6})

Decay channel	Exp	SD amplitudes only (case 1)	Charming penguin (case 2) $\delta = 0°$	(case3) γ free	$\gamma = 64.5°$
$(B^+ \to \pi^+\pi^0)$	5.3 ± 0.8	4.27	5.32	5.05	5.40
$(B^+ \to K^+\bar{K}^0)$	0.0 ± 2.4	0.69	0.96	2.55	1.58
$(B^+ \to \pi^+\eta)$	4.2 ± 0.9	2.66	2.04	3.04	2.29
$(B^+ \to \pi^+\eta')$	0.0 ± 4.5	1.33	1.02	1.52	1.14
$(B_d^0 \to \pi^+\pi^-)$	4.6 ± 0.4	5.09	4.76	4.75	4.70
$(B_d^0 \to \pi^0\pi^0)$	1.9 ± 0.5	0.51	0.83	1.65	1.18
$(B_d^0 \to K^+K^-)$	0.0 ± 0.6	0.00	0	0.00	0.00
$(B_d^0 \to K^0\bar{K}^0)$	0.0 ± 1.8	0.64	0.89	2.35	1.46
$(B^+ \to \pi^+K^0)$	21.8 ± 1.4	19.10	22.11	22.44	21.57
$(B^+ \to \pi^0K^+)$	12.8 ± 1.1	11.97	12.45	10.92	11.39
$(B^+ \to \eta K^+)$	3.2 ± 0.7	2.03	1.57	2.71	3.04
$(B^+ \to \eta' K^+)$	77.6 ± 4.6	74.02	76.18	75.27	74.64
$(B_d^0 \to \pi^-K^+)$	18.2 ± 0.8	17.57	18.20	19.33	19.01
$(B_d^0 \to \pi^0K^0)$	11.9 ± 1.5	6.86	8.03	9.86	9.14
$(B_d^0 \to \eta K^0)$	0.0 ± 4.6	1.76	1.63	3.85	3.26
$(B_d^0 \to \eta' K^0)$	65.2 ± 6.0	68.66	72.32	73.14	70.76
$\lvert T\rvert$		2.36	2.68	2.61	2.7
$\lvert P\rvert$		0.83	2.06	2.63	1.9
$\lvert S'\rvert$		1.77	1.69	2.96	2.61
P_{cef}			-1.45	-3.05	-2.07
γ		85°	68°	22°	64.5°
δ			0°	±19°	±26°
f_m		27.98	24.73	14.97	15.71

and negative signs of δ are allowed as the fitted function is symmetric under $\delta \leftrightarrow -\delta$. The fact that the ratio $|\frac{P_{cef}}{P}|$ is close to unity is in agreement with the calculation in [21]. On the other hand, for the best fits with $\delta = 0$ the ratio $|\frac{P_{cef}}{P}|$ is about 0.53(0.7). This value for the second set of data is higher than that assumed in [19].

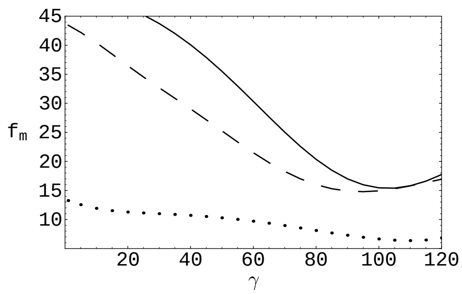

Fig. 1. Dependence of $f_m(\gamma)$ on γ for the first (left) and second (right) set of data. Solid lines denote case without charming penguin, dashed lines — case with charming penguin and $\delta = 0$, dotted lines — case with charming penguin and δ let free.

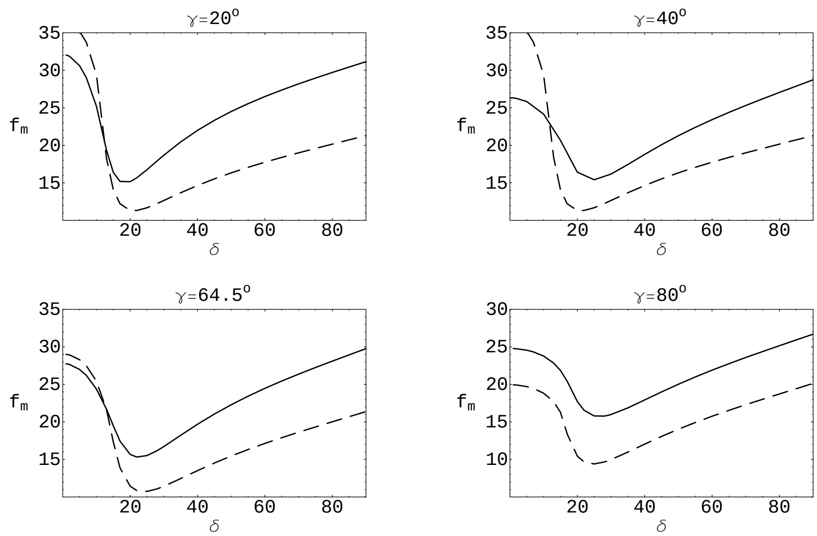

Fig. 2. Dependence of $f_m(\gamma, \delta)$ on δ for selected values of γ, dashed (solid) lines denote the first (second) set of data.

Charming penguins with a nonvanishing strong phase may be a source of direct CP asymmetries. The predicted values were calculated for the same points as in Tables I, II. The results are given in Table III together with the averages from Belle, BABAR and CLEO experiments [20]. The main features are large asymmetries in the $\Delta S = 0$ sector with relatively small asymmetries for the $\Delta S = 1$ decays channels. We are not able to predict the absolute signs of the asymmetries since we have two allowed signs of δ. The asymmetry for $(B^+ \to \pi^+ K^0)$ is a pure λ^4 effect and shows a potential influence of this correction.

TABLE III

Asymmetries generated by charming penguin for $\delta > 0$ (for $\delta < 0$ asymmetries are of opposite sign).

Decay channel	First set of data		Second set of data		Experiment
	γ fitted	$\gamma = 64.5°$	γ fitted	$\gamma = 64.5°$	
$(B^+ \to \pi^+\pi^0)$	0	0	0	0	-0.07 ± 0.14
$(B^+ \to K^+\bar{K}^0)$	-0.93	-0.90	-0.90	-0.98	—
$(B^+ \to \pi^+\eta)$	0.48	0.87	0.47	0.76	$-0.44 \pm 0.18 \pm 0.01$
$(B^+ \to \pi^+\eta')$	0.48	0.87	0.47	0.76	—
$(B^+ \to \pi^+K^0)$	0.11	0.08	0.04	0.07	0.02 ± 0.06
$(B^+ \to \pi^0K^+)$	-0.21	-0.28	-0.09	-0.23	0.00 ± 0.12
$(B^+ \to \eta K^+)$	0	0	0	0	$-0.52 \pm 0.24 \pm 0.01$
$(B^+ \to \eta' K^+)$	0.006	-0.004	0.005	-0.004	0.02 ± 0.042
$(B_d^0 \to \pi^-K^+)$	-0.19	-0.24	-0.075	-0.21	-0.09 ± 0.03

5. Conclusions

Our results permit to draw the following conclusions:

1. Even without the charming penguins the value of angle γ extracted from the fit depends on the details of data. More recent data prefer the value of γ more in accordance with the expectations of the standard model.

2. If we admit the non-zero value of the charming penguin (with strong phase equal zero), the fitted values of γ may move toward the SM value by 10°–15°.

3. Admitting strong phase of the charming penguin as a free parameter leads to a relatively flat function $f_m(\gamma)$ *i.e.* it allows a wide range of γ. This means that there is probably too much freedom in the fits. However, the fitted strong phase δ is relatively stable and close to ±20°.

I would like to thank P. Żenczykowski for helpful discussions and comments.

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