CP Violation and Nonleptonic B-meson Decays

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We discuss the perturbative QCD approach for exclusive non-leptonic two body B-meson decays. We briefly review its ingredients and some important theoretical issues related to the factorization approach. We show numerical results. They are compatible with present experimental data for the charmless B-meson decays. Specially we predict the possibility of large direct CP violation effects in $B^0 \to \pi^+\pi^-$ $(23 \pm 7\%)$ and $B^0 \to K^+\pi^-$ $(-17 \pm 5\%)$. For charmed decay $B \to D^{(*)}\pi$, we get big non-factorizable contributions for Color-suppressed decays and obtain $|a_2/a_1| \sim 0.4 - 0.5$ and $Arg(a_2/a_1) \sim -42^o$. In the last section we investigate the method to extract the weak phases ϕ_2 from $B \to \pi\pi$ decay and ϕ_3 from $K\pi$ modes. From BaBar measurement of CP asymmetry for the $\pi^+\pi^-$ decay, the prefered CKM weak phases are: $\phi_1 = 24^o$, $\phi_2 = 78^o$ and $\phi_3 = 78^o$.

1 Introduction

Understanding nonleptonic B meson decays is crucial for testing the standard model, and also for uncovering the trace of new physics. The simplest case is two-body nonleptonic B meson decays, for which Bauer, Stech and Wirbel proposed the factorization assumption (FA) in their pioneering work [1]. Considerable progress, including the generalized FA [2–4] and QCD-improved FA (QCDF) [5], has been made since this proposal. On the other hand, techniques to analyze hard exclusive hadronic scattering has been developed by Brodsky and Lepage [6] based on collinear factorization theorem in perturbative QCD (PQCD). A modified framework based on k_T factorization theorem has been given in [7,8], and extended to exclusive B meson decays in [9–12]. The infrared finiteness and gauge invariance of k_T factorization theorem was shown explicitly in [13]. Using the PQCD approach, we have investigated the dynamics of nonleptonic B meson decays [14–16]. Our observations are summarized as follows:

1. FA is approximately correct, as our computation shows that nonfactorizable contributions in charmless B meson decays are negligible.

2. Penguin amplitudes are enhanced, as the PQCD formalism inludes dynamics from the energy region as low as $\sqrt{\bar{\Lambda} m_b}$. Here $\bar{\Lambda} \equiv m_B - m_b$, being the B meson and b quark mass difference. Note that $\sqrt{\bar{\Lambda} m_b}$ is much lower than m_b(or $m_b/2$) which is often used as the energy scale.

3. Annihilation diagrams give rise to large short-distance strong phases through $(S+P)(S-P)$ penguin operators.

4. The sign and magnitude of CP asymmetries in two-body nonleptonic B meson decays can be calculated, and we have predicted relatively large CP asymmetries in the $B \to K^{(*)}\pi$ [14] and $\pi\pi$ modes[15,16].

In this talk we summarize the PQCD method and important theoretical issues, and describe the analysis of branching ratios of B-meson decays including $B \to D^{(*)}\pi$ decays and discuss the origin of large direct CP-violation in $B \to \pi\pi$ process.

2 Ingredients of PQCD and Theoretical Issues

End Point Singularity and Form Factors: If we calculate the $B \to \pi$ transition form factor $F^{B\pi}$ at large recoil using the Brodsky-Lepage formalism [17,18], a difficulty immediately occurs. The lowest-order diagram for the hard amplitude is proportional to $1/(x_1 x_3^2)$, x_1 being the momentum fraction associated with the spectator quark on the B meson side. If the pion distribution amplitude vanishes like x_3 as $x_3 \to 0$ (in the leading-twist, *i.e.*, twist-2 case), $F^{B\pi}$ is logarithmically divergent. If the pion distribution amplitude is a constant as $x_3 \to 0$ (in the next-to-leading-twist, *i.e.*, twist-3 case), $F^{B\pi}$ even becomes linearly divergent. These end-point singularities have also appeared in the evaluation of the nonfactorizable and annihilation amplitudes in QCDF.

Note that in the above discussion parton transverse momenta $k_\perp$ has been neglected. More accurately, we have

$$\frac{1}{x_1\, x_3^2 M_B^4} \;\to\; \frac{1}{(x_3 M_B^2 + k_{3\perp}^2)\;[x_1 x_3 M_B^2 + (k_{1\perp} - k_{3\perp})^2]} \qquad (1)$$

and the end-point singularity is smeared out. More precise analysis including the Sudakov and threshold resummation effects has been given [14].

In PQCD, we can calculate the form factors for $B \to P,V$ transitions [19,20].

Dynamical Penguin Enhancement vs Chiral Enhancement: The typical hard scale is about 1.5 GeV as discussed in Ref.[14]. Since the RG evolution of the Wilson coefficients $C_{4,6}(t)$ increase drastically as $t < M_B/2$, while that of $C_{1,2}(t)$ remain almost constant, we can get a large enhancement effects from both Wilson coefficents and matrix elements in PQCD.

In general the amplitude can be expressed as

$$Amp \sim [a_{1,2} \pm a_4 \pm m_0^{P,V}(\mu) a_6] \cdot < K\pi|O|B > \qquad (2)$$

with the chiral factors $m_0^P(\mu) = m_P^2/[m_1(\mu)+m_2(\mu)]$ for pseudoscalar meson and $m_0^V = m_V$ for vector meson. To accommodate the $B \to K\pi$ data in FA and QCD-factorization approach, one relies on the chiral enhancement by increasing m_0 to as large as about 3 GeV at $\mu = m_b$ scale. So two methods accomodate large branching ratios of $B \to K\pi$. But, there is no such adjustable parameter for $B \to PV$ decay. For $B \to PV$ there is no chiral factor in LCDAs of the vector meson. Here $m_0 = m_V$. It is difficult to explain large penguin contribution in QCDF[22].

We can test whether a dynamical enhancement or a chiral enhancement is responsible for the large $B \to K\pi$ branching ratios by measuring the $B \to VP,VV$ modes. In these modes penguin contributions dominate, such that their branching ratios are insensitive to the variation of the unitarity angle ϕ_3. Our prediction for various modes are shown at Table 2. We point out that QCDF can not globally fit the experimental data for $B \to PP,VP$ and VV modes simultaneously with same sets of free parameters (ρ_H,ϕ_H) and (ρ_A,ϕ_A) [23].

Fat Imaginary Penguin in Annihilation: There is a folklore that annihilation contribution is negligible compared to the W-emission. For this reason, annihilation contribution was not included in the general factorization approach and the first paper on QCD-factorization by Beneke et al. [24]. In fact there is a suppression effect for the operators with structure $(V-A)(V-A)$ because of a mechanism similar to the helicity suppression for $\pi \to \mu\nu_\mu$. However annihilation from the operators $O_{5,6,7,8}$ with the structure $(S-P)(S+P)$ via Fiertz transformation survive under the helicity suppression. Moreover, they provide large imaginary part. The real part of the factorized annihilation contribution becomes small because there is a cancellation between left-handed gluon exchanged diagram and right-handed gluon exchanged one as shown in Table 1 of ref.[16]. This mostly pure imaginary value of annihilation is a main source of large CP asymmetry in $\pi^+\pi^-$ and $K^+\pi^-$ decays. In Table 3 we summarize the CP asymmetry in $B \to K(\pi)\pi$ decays with experimental measurements.

Small Strong Phase for FA and QCDF: We have seen that the dominant strong phase in PQCD comes from the factorizable annihilation diagram[14]. For FA and QCDF, stong phases come from the Bander-Silverman-Soni (BSS) mechanism[21] and from the final state interaction (FSI). In fact, the two sources of strong phases in the FA and QCDF are strongly suppressed by the charm mass threshold and by the end-point behavior of meson wave functions. So the strong phase in these approaches is almost zero without soft-annihilation contributions.

3 Numerical Results in Charmless B-decays

Branching ratios in $B \to PP,VP$ and VV: The PQCD approach allows us to calculate the amplitudes for charmless B-meson decays in terms of ligh-cone distribution amplitudes upto twist-3. We focus on decays whose branching ratios have already been measured. We take allowed ranges of shape parameter for the B-meson wave funtion as $\omega_B = 0.36-0.44$, which accommodate reasonable form factors: both $F^{B\pi}(0) = 0.27-0.33$ and $F^{BK}(0) = 0.31-0.40$. We use values of chiral factor with $m_0^\pi = 1.3GeV$ and $m_0^K = 1.7GeV$. Finally we obtain branching ratios for $B \to K(\pi)\pi$ [14,15], $K\phi$ [19,25] $K^*\phi$[26] and $K^*\pi$[14], which are in agreement with experimental data.

CP Asymmetry of $B \to \pi\pi, K\pi$: Because we have a large imaginary contribution from factorized annihilation diagrams, we predict large CP asymmetry ($\sim$ 25%) in $B^0 \to \pi^+\pi^-$ decays and about -15% CP violation effects in $B^0 \to K^+\pi^-$. The detail prediction is given in Table 3. The precise measurement of direct CP asymmetry (both magnitude and sign) is a crucial way to test factorization models which have different sources of strong phases.

Understanding of $Br(K^*\pi)$ and $Br(\omega K^+/\omega\pi^+)$: In PQCD, penguin contributions enhances both $Br(K\pi)$ and $Br(K^*\pi)$. Our results are shown in Table 2. As noted before, in FA and QCDF, the penguin enhancement can achieved by taking m_0 as large as 3 GeV, however, they fail to explain the large branching ratio for $K^*\pi$ decay.

Another hot issue is how can we understand $Br(\omega K/\omega\pi) \sim 1$. Since ωK^+ decay is penguin dominant process and $\omega\pi^+$ decay is tree dominant one: $(a_1 + x a_2)$, it is hard to get the same Barching ratio. PQCD mathod predicts $Br(\omega K^+) \sim 3.22 \times 10^{-6}$ and $Br(\omega\pi^+) \sim 6.20 \times 10^{-6}$, which still has about factor 2 differences between them. We need more precise measurements on ωK^+ decay.

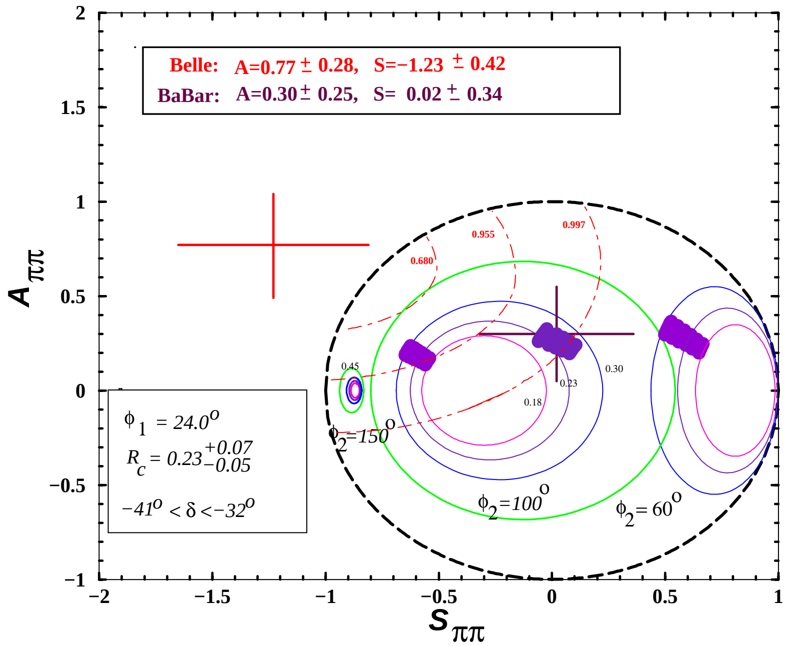

Figure 1. Plot of $A_{\pi\pi}$ versus $S_{\pi\pi}$ for various values of ϕ_2 with $\phi_1 = 24.3^o$, $0.18 < R_c < 0.30$ and $-41^o < \delta < -32^o$ in the pQCD method.

4 Extraction of ϕ_2 from $B \to \pi^+\pi^-$

Even though isospin analysis of $B \to \pi\pi$ can provide a clean way to determine ϕ_2, it might be difficult in practice because of the small branching ratio of $B^0 \to \pi^0\pi^0$. Here we describe the time-dependent analysis of $B^0(t) \to \pi^+\pi^-$. Since penguin contributions are sizable and are about 20-30 % of the total amplitude, we expect that direct CP violation can be large if strong phases are different in the tree and penguin diagrams.

The ratio between penguin and tree amplitudes is $R_c = |P_c/T_c|$ (here we use the c-convention notation) and the strong phase difference between penguin and tree amplitudes $\delta = \delta_P - \delta_T$. The time-dependent asymmetry measurement provides two equations for $C_{\pi\pi}$ and $S_{\pi\pi}$ in terms of three unknown variables R_c, δ and ϕ_2[27].

Since pQCD provides us $R_c = 0.23^{+0.07}_{-0.05}$ and $-41^o < \delta < -32^o$, the allowed range of ϕ_2 at present stage is determined as $55^o < \phi_2 < 100^o$ as shown in Figure 3.

According to the power counting rule in the pQCD approach, the factorizable annihilation contribution with large imaginary part becomes big and give a negative strong phase from $-i\pi\delta(k_\perp^2 - xM_B^2)$. Therefore we have a relatively large strong phase in contrast to QCD-factorization ($\delta \sim 0^o$) and predict large direct CP violation effect in $B^0 \to \pi^+\pi^-$ with $A_{cp}(B^0 \to \pi^+\pi^-) = (23 \pm 7)\%$, which will be tested by more precise experimental measurement within two years.

In the numerical analysis, since the data by Belle collaboration[28] is located ourside allowed physical regions, we considered the recent BaBar measurement[29] with 90% C.L. interval taking into account the systematic errors:

- $S_{\pi\pi} = 0.02 \pm 0.34 \pm 0.05$ [-0.54, +0.58]
- $A_{\pi\pi} = 0.30 \pm 0.25 \pm 0.04$ [-0.72, +0.12].

The central point of BaBar data corresponds to $\phi_1 = 24^o$, $\phi_2 = 78^o$, and $\phi_3 = 78^o$ when the Standard Model works.

Even though the data by Belle collaboration[28] is located outside allowed physical regions, we can have overlapped ranges within 2 σ bounds.

5 Extraction of ϕ_3 from $B \to K\pi$

By using tree-penguin interference in $B^0 \to K^+\pi^-(\sim T' + P')$ versus $B^+ \to K^0\pi^+(\sim P')$, CP-averaged $B \to K\pi$ branching fraction may lead to non-trivial constaints on the ϕ_3 angle[30]. In order to determine ϕ_3, we need one more useful information on CP-violating rate differences[31]. Let's introduce the following observables :

$$\begin{aligned} R_K &= \frac{\overline{Br}(B^0 \to K^+\pi^-)\,\tau_+}{\overline{Br}(B^+ \to K^0\pi^+)\,\tau_0} = 1 - 2\,r_K\,cos\delta\,cos\phi_3 + r_K^2 \\ A_0 &= \frac{\Gamma(\bar{B}^0 \to K^-\pi^+) - \Gamma(B^0 \to K^+\pi^-)}{\Gamma(B^- \to K^0\pi^-) + \Gamma(B^+ \to K^0\pi^+)} \\ &= A_{cp}(B^0 \to K^+\pi^-)\,R_K = -2r_K\,sin\phi_3\,sin\delta. \end{aligned} \quad (3)$$

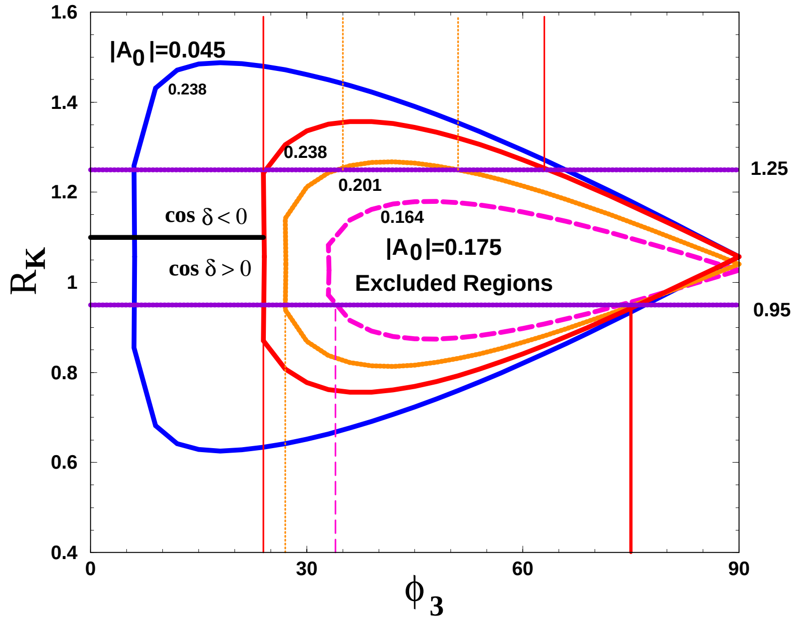

Figure 2. Plot of R_K versus ϕ_3 with $r_K = 0.164, 0.201$ and 0.238.

where $r_K = |T'/P'|$ is the ratio of tree to penguin amplitudes in $B \to K\pi$ and $\delta = \delta_{T'} - \delta_{P'}$ is the strong phase difference between tree and penguin amplitides. After eliminating $sin\delta$ in Eq.(8)-(9), we have

$$R_K = 1 + r_K^2 \pm \sqrt{(4r_K^2 cos^2\phi_3 - A_0^2 cot^2\phi_3)}. \quad (4)$$

Here we obtain $r_K = 0.201 \pm 0.037$ from the PQCD analysis and $A_0 = -0.11 \pm 0.065$ by combining recent BaBar measurement on CP asymmetry of $B^0 \to K^+\pi^-$: $A_{cp}(B^0 \to K^+\pi^-) = -10.2 \pm 5.0 \pm 1.6\%$ [29] with present world averaged value of $R_K = 1.10 \pm 0.15$[32].

PQCD method provides $\delta_{P'} = 157^o$, $\delta_{T'} = 1.4^o$ and the negative $cos\delta$: $cos\delta = -0.91$. As shown in Fig.2, we can constrain the allowed range of ϕ_3 within 1σ range of World Averaged R_K as follows:

- For $cos\delta < 0$, $r_K = 0.164$: we can exclude $0^o \le \phi_3 \le 6^0$.
- For $cos\delta < 0$, $r_K = 0.201$: we can exclude $0^o \le \phi_3 \le 6^0$ and $35^o \le \phi_3 \le 51^0$.
- For $cos\delta < 0$, $r_K = 0.238$: we can exclude $0^o \le \phi_3 \le 6^0$ and $24^o \le \phi_3 \le 62^0$.

When we take the central value of $r_K = 0.201$, ϕ_3 is allowed within the ranges of $51^o \le \phi_3 \le 90^o$, which is consistent with the results by the model-independent CKM-fit in the (ρ, η) plane.

6 Large Nonfactorizable contribution in Charmed B-decays

Large a_2/a_1 in $B \to D^{(*)}\pi$ Decays: Being free from the end-point singularities, all topologies of decay amplitudes of charmed decays can be computed in the PQCD approach, including the nonfactorizable color-suppressed one. This amplitude can not be calculated in the QCDF approach based on collinear factorization theorem because of the existence of the singularities. However, we found that this amplitude is crucial for explaining the observed $B \to D^{(*)}\pi$ branching ratios, since it is not suppressed by the Wilson coefficient (proportional to C_2/N_c), and provides a large strong phase required by the isospin relation. The tree annihilation amplitude, also contributing to the strong phase, is not important. As stated above, we have predicted large strong phases from the scalar-penguin annihilation amplitudes, which are required by the large CP asymmetries in two-body charmless decays. The success in predicting the storng phases from the nonfactorizable color-suppressed amplitudes for the two-body charmed decays further supports k_T factorization theorem. The conclusion is that the short-distance strong phase is sufficient to account for the $B \to D^{(*)}\pi$ data. A long-distance strong phase from final-state interaction may be small, though it should exist. Finally we obtained $a_2/a_1 \sim 0.4 - 0.5$ and $Arg(a_2/a_1) \sim -42^o$ by including annihilation contributions[33].

7 Summary and Outlook

In this talk we have discussed ingredients of PQCD approach and some important theoretical issues with numerical results. The PQCD factorization approach provides a useful theoretical framework for a systematic analysis on non-leptonic two-body B-meson decays. Specially pQCD predicted large direct CP asymmetries in $B^0 \to \pi^+\pi^-$,$K^+\pi^-$, $K^{*\pm}\pi^{\mp}$ and $K^{*\pm}\pi^0$ decays, which will be a crucial touch stone to distinguish PQCD approach from others in future precise measurement.

We discussed two methods to determine weak phases ϕ_2 and ϕ_3 within the pQCD approach through 1) Time-dependent asymmetries in $B^0 \to \pi^+\pi^-$, 2) $B \to K\pi$ processes via penguin-tree interference. We can get interesting bounds on ϕ_2 and ϕ_3 from present experimental measurements. From BaBar measurement of CP asymmetry in $\pi^+\pi^-$ decay the prefered CKM weak phases are: $\phi_1 = 24^o$, $\phi_2 = 78^o$ and $\phi_3 = 78^o$.

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References

1. M. Bauer, B. Stech, M. Wirbel, Z. Phys. C **29**, 637 (1985); *ibid.* **34**, 103 (1987).
2. H.Y. Cheng, Phys. Lett. B **335**, 428 (1994).
3. H.Y. Cheng, Z. Phys. C **69**, 647 (1996).
4. J. Soares, Phys. Rev D **51**, 3518 (1995); A.N. Kamal and A.B. Santra, Z. Phys. C **72**, 91 (1996); A.N. Kamal, A.B. Santra, and R.C. Verma, Phys. Rev. D **53**, 2506 (1996).
5. M. Beneke, G. Buchalla, M. Neubert, and C.T. Sachrajda, Phys. Rev. Lett. **83**, 1914 (1999); Nucl. Phys. **B591**, 313 (2000).
6. G.P. Lapage and S.J. Brodsky, Phys. Lett. B **87**, 359 (1979); Phys. Rev. D **22**, 2157 (1980).
7. J. Botts and G. Sterman, Nucl. Phys. **B225**, 62 (1989).
8. H-N. Li and G. Sterman, Nucl. Phys. **B381**, 129 (1992).
9. H-N. Li and H.L. Yu, Phys. Rev. Lett. **74**, 4388 (1995); Phys. Lett. B **353**, 301 (1995); Phys. Rev. D **53**, 2480 (1996).
10. C.H. Chang and H-N. Li, Phys. Rev. D **55**, 5577 (1997).
11. T.W. Yeh and H-N. Li, Phys. Rev. D **56**, 1615 (1997).
12. H.Y. Cheng, H-N. Li, and K.C. Yang, Phys. Rev. D **60**, 094005 (1999).
13. H-N. Li, Phys. Rev. D **64**, 014019 (2001); M. Nagashima and H-N. Li, hep-ph/0202127; Phys. Rev. D **67**, 034001 (2003).
14. Y.Y. Keum, H-N. Li, and A.I. Sanda, Phys. Lett. B **504**, 6 (2001); Phys. Rev. D **63**, 054008 (2001); Y.Y. Keum and H-N. Li, Phys. Rev. **D63**, 074006 (2001); Y.Y. Keum, hep-ph/0210127.
15. C. D. Lü, K. Ukai, and M. Z. Yang, Phys. Rev. D **63**, 074009 (2001).
16. Y.Y. Keum and A. I. Sanda, Phys. Rev. D **67**, 054009 (2003); Y.Y. Keum, hep-ph/0209208.
17. G.P. Lepage and S.J. Brodsky, Phys. Rev. **D22**, 2157 (1980).
18. A. Szczepaniak, E.M. Henley and S. Brodsky, *Phys. Lett.* **B 243**, 287 (1990).
19. C.-H. Chen, Y.-Y. Keum and H.-N. Li, *Phys. Rev.* **D 64**, 112002 (2001).
20. T. Kurimoto, H.-N. Li and A.I. Sanda, *Phys. Rev.* **D 65**, 014007 (2002).
21. M. Bander, D. Silverman and A. Soni, *Phys. Rev. Lett.* **43**, 242 (1979).
22. H.-Y. Cheng and K.-C. Yang, *Phys. Rev.* **D 64**, 074004 (2001). H.-Y. Cheng Y.-Y. Keum and K.-C. Yang, *Phys. Rev.* **D 65**, 094023 (2002).
23. D.S. Du, J.-F. Sun, D.-S. Yang and G.-H. Zhu, *Phys. Rev.* **D 67**, 014023 (2003); R. Aleksan, P.F. Giraud, V. Morenas, O. Pene and A.S. Safir, hep-ph/0301165.
24. M. Beneke, G. Buchalla, M. Neubert and C.T. Sachrajda, *Phys. Rev. Lett.* **83**, 1914 (1999).
25. S. Mishima, *Phys. Lett.* **B 521**, 252 (2001).
26. C.-H. Chen, Y.-Y. Keum and H.-N. Li, *Phys. Rev.* **D 66**, 054013 (2002).
27. R. Fleischer and J. Matias, Phys.Rev.**D66** (2002) 054009 ; M. Gronau and J.L. Rosner, Phys.Rev.**D65** (2002) 013004, Erratum-ibid.**D65** (2002) 079901; Phys. Rev. **D65** (2002) 093012; hep-ph/0205323.
28. Belle Collaboration (K. Abe et al.), Belle-preprint 2002-8 [hep-ex/0204002].
29. BaBar Collaboration (B. Aubert et al.), BaBar-Pub-02/09 [hep-ex/0207055].
30. R. Fleischer and T. Mannel, Phys. Rev. **D57**, (1998) 2752; M. Neubert and J.L. Rosner, Phys. Lett. **B441** (1998) 403; Phys. Rev. Lett. **81**, (1998) 5076.
31. M. Gronau and J.L. Rosner, Phys.Rev.**D65** (2002) 013004, Erratum-ibid.**D65** (2002) 079901.
32. R. Bartoldus, talk on Review of rare two-body B decays at FPCP workshop, May 17, 2002.
33. Y.-Y. Keum, T. Kurimoto, H.-N. Li, C.-D. Lu, and A.I. Sanda, hep-ph/0305335.

Table 1. Branching ratios of $B \to \pi\pi, K\pi$and KK decays with $\phi_3 = 80^0$, $R_b = \sqrt{\rho^2+\eta^2} = 0.38$. Here we adopted $m_0^\pi = 1.3$ GeV, $m_0^K = 1.7$ GeV and $0.36 < \omega_B < 0.44$. Unit is 10^{-6}.

Decay Channel	CLEO	BELLE	BABAR	World Av.	PQCD
$\pi^+\pi^-$	$4.5^{+1.4+0.5}_{-1.2-0.4}$	$4.4\pm0.6\pm0.3$	$4.7\pm0.6\pm0.2$	4.6 ± 0.4	$5.93-10.99$
$\pi^+\pi^0$	$4.6^{+1.8+0.6}_{-1.6-0.7}$	$5.3\pm1.3\pm0.5$	$5.5^{+1.0}_{-0.9}\pm0.6$	5.3 ± 0.8	$2.72-4.79$
$\pi^0\pi^0$	<4.4	<4.4	<3.6	<3.6	$0.33-0.65$
$K^\pm\pi^\mp$	$18.0^{+2.3+1.2}_{-2.1-0.9}$	$18.5\pm1.0\pm0.7$	$17.9\pm0.9\pm0.7$	18.2 ± 0.8	$12.67-19.30$
$K^0\pi^\mp$	$18.8^{+3.7+2.1}_{-3.3-1.8}$	$22.0\pm1.9\pm1.1$	$20.0\pm1.6\pm1.0$	20.6 ± 1.4	$14.43-26.26$
$K^\pm\pi^0$	$12.9^{+2.4+1.2}_{-2.2-1.1}$	$12.8\pm1.4^{+1.4}_{-1.0}$	$12.8^{+1.2}_{-1.0}\pm1.0$	12.8 ± 1.1	$7.87-14.21$
$K^0\pi^0$	$12.8^{+4.0+1.7}_{-3.3-1.4}$	$12.6\pm2.4\pm1.4$	$10.4\pm1.5\pm1.8$	11.5 ± 1.7	$7.92-14.27$
$K^\pm K^\mp$	<0.8	<0.7	<0.6	<0.6	0.06
$K^\pm\bar{K}^0$	<3.3	<3.4	<2.2	<2.2	1.4
$K^0\bar{K}^0$	<3.3	<3.2	<1.6	<1.6	1.4

Table 2. Branching ratios of $B \to \phi K^{(*)}$and $K^*\pi$ decays with $\phi_3 = 80^0$, $R_b = \sqrt{\rho^2+\eta^2} = 0.38$. Here we adopted $m_0^\pi = 1.3$ GeV and $m_0^K = 1.7$ GeV. Unit is 10^{-6}.

Decay Channel	CLEO	BELLE	BABAR	World Av.	PQCD
$\phi K^\pm$	$5.5^{+2.1}_{-1.8}\pm0.6$	$9.4\pm1.1\pm0.7$	$10.0^{+0.9}_{-0.8}\pm0.5$	9.3 ± 0.8	$8.1-14.1$
ϕK^0	$5.4^{+3.7}_{-2.7}\pm0.7$	$9.0\pm2.2\pm0.7$	$7.6^{+1.3}_{-1.2}\pm0.5$	7.7 ± 1.1	$7.6-13.3$
$\phi K^{*\pm}$	$10.6^{+6.4+1.8}_{-4.9-1.6}$	$6.7^{2.1+0.7}_{-1.9-1.0}$	$12.1^{+2.1}_{1.9}\pm1.1$	9.4 ± 1.6	$12.6-21.2$
ϕK^{*0}	$11.5^{+4.5+1.8}_{-3.7-1.7}$	$10.0^{+1.6+0.7}_{-1.5-0.8}$	$11.1^{+1.3}_{-1.2}\pm0.8$	10.7 ± 1.1	$11.5-19.8$
$K^{*0}\pi^\pm$	$7.6^{+3.5}_{-3.0}\pm1.6$	$19.4^{+4.2+4.1}_{-3.9-7.1}$	$15.5\pm3.4\pm1.8$	12.3 ± 2.6	$10.2-14.6$
$K^{*\pm}\pi^\mp$	$16^{+6}_{-5}\pm2$	<30	$-$	16 ± 6	$8.0-11.6$
$K^{*+}\pi^0$	<31	$-$	$-$	<31	$2.0-5.1$
$K^{*0}\pi^0$	<3.6	<7	$-$	<3.6	$1.8-4.4$

Table 3. Direct CP-asymmetry in $B \to K\pi, \pi\pi$ decays with $\phi_3 = 40^0 \sim 90^0$, $R_b = \sqrt{\rho^2+\eta^2} = 0.38$. Here we adopted $m_0^\pi = 1.3$ GeV and $m_0^K = 1.7$ GeV for the PQCD results.

Direct $A_{CP}(\%)$	BELLE	BABAR	PQCD	QCDF	Charming Penguin ($\lvert A_{cp}\rvert$)
$\pi^+\pi^-$	$77\pm27\pm8$	$30\pm25\pm4$	$16.0\sim30.0$	-6 ± 12	39 ± 20
$\pi^+\pi^0$	$-14\pm24^{+5}_{-4}$	$-3\pm18\pm2$	0.0	0.0	0.0
π^+K^-	$-7\pm6\pm1$	$-10.2\pm5.0\pm1.6$	$-12.9\sim-21.9$	5 ± 9	21 ± 12
π^0K^-	$23\pm11^{+1}_{-4}$	$-9.0\pm9.0\pm1.0$	$-10.0\sim-17.3$	7 ± 9	22 ± 13
π^-K^0	7^{+9+1}_{-8-3}	-4.7 ± 13.9	$-0.6\sim-1.5$	1 ± 1	0.0