Global analysis of $B \to PP, PV$ charmless decays with QCD factorization

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Abstract

The global analysis of $B \to PP, PV$ charmless decays with QCD factorization (QCDF) is presented. The predictions of QCDF are in good agreement with experiments. The best fitted CKM angle $\gamma$ is around 79°. The predicted branching ratios of $B \to \pi^0\pi^0, \omega K^+, \omega\pi^+, \pi^+K^{*0}$ etc. are also in good agreement with new data of BaBAR and BELLE.

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I. INTRODUCTION

The charmless two-body $B$ decays are very important for extracting CKM angles $\alpha$, $\gamma$ and for testing QCD. Up to now, BaBar and Belle have accumulated large set of data. It is highly interesting to analysis these data by using different theories and compare the data with theoretical predictions. QCD factorization [1] has been used to analysis $B \rightarrow PP$, $PV$ charmless decay data [2,3] (here $P$ denotes pseudoscalar meson, $V$ vector meson). With the data at that time, the theoretical results prefer a larger CKM angle $\gamma$. The QCD factorization (QCDF) predictions for some $B \rightarrow PV$ channels are only marginally consistent with the experimental data. Notice that the QCDF predictions contain large numerical uncertainties due to the CKM matrix elements, form factors, and annihilation parameters. Furthermore, the uncertainties of various decay channels are strongly correlated to each other. So we are stimulated to do a global analysis to check the consistency between the QCDF predictions and the experimental data. Beneke et al. [4] have done a gloabl analysis for $B \rightarrow PP$, including $\pi\pi$, $\pi K$ modes with QCDF approach. The results show a satisfactory agreement between QCDF predictions and data for $B \rightarrow PP$ branching fractions. But their fitted CKM angle $\gamma \sim 90^\circ$ which is not consistent with the standard CKM fit [5]: $37^\circ \leq \gamma \leq 80^\circ$. Now BaBar and Belle have a lot of data on $B \rightarrow PV$. It is necessary to do the global fit to $B \rightarrow PP$ and $PV$ at the same time. We have done it and found that QCDF can fit all data on $B \rightarrow PP$, $PV$. The fitted angle $\gamma \sim 79^\circ$ which is consistent with the standard CKM global fit. We also have new predictions on $B \rightarrow \pi^0 \pi^0$, $K^+ K^-$, $\pi^+ K^{*0}$, $\omega \pi^+$, $\omega K^+$. 

My talk is organized as follows: in Section II I give general remarks on QCD factorization. Section III is devoted to the global analysis on $B \rightarrow PP$, $PV$ decays. In Section IV I give the summary and conclusion.

II. GENERAL REMARKS ON QCD FACTORIZATION

The low energy effective Hamiltonian for $|B| = 1$ is

$$\mathcal{H}_{\text{eff}} = \frac{G_F}{\sqrt{2}} \sum_{q=u,c} v_q \left\{ C_1(\mu) Q^1_q(\mu) + C_2(\mu) Q^2_q(\mu) \right\} + \sum_{k=3}^{10} C_k(\mu) Q_k(\mu) \right\} + \text{H.c.},$$

(1)
The decay amplitude for $B \rightarrow M_1 M_2$ is

$$A(B \rightarrow M_1 M_2) = \frac{G_F}{\sqrt{2}} \sum_i \sum_q C_i(\mu) \langle M_1 M_2|Q_i(\mu)|B\rangle,$$

(2)

The Wilson coefficients $C_i(\mu)$ include short distance effects above the scale $O(m_b)$ and are perturbatively calculable. The long distance effects (contributions from the scale below $O(m_b)$) are included in the hadronic matrix elements $\langle M_1 M_2|Q_i(\mu)|B\rangle$.

For naive factorization (BSW),

$$\langle M_1 M_2|Q_i(\mu)|B\rangle \sim \langle M_1|J_1|0\rangle\langle M_2|J_2|B\rangle$$

decay constant form factor

There are no renormalization scheme and scale dependences. So the corresponding dependences of $C_i(\mu)$ cannot be canceled and the "non-factorizable" contributions cannot be accounted for.

In 1999, Beneke et al. [1] proposed a new factorization scheme based on QCD. That is so-called QCD factorization (QCDF). In this scheme, in the heavy quark limit,

$$\langle M_1 M_2|O_i|B\rangle = F_{j \rightarrow M_2}(q^2) \int_0^1 dx T_i^I(x) \Phi_{M_1}(x) + (M_1 \leftrightarrow M_2)$$

$$+ \sum_j \int_0^1 dx \int_0^1 dy T_{ij}^{II}(\xi, x, y) \Phi_{B}(\xi) \Phi_{M_1}(x) \Phi_{M_2}(y) + O(\Lambda_{QCD}/m_b)$$

(4)

where $T_i^{I,IH}$ denote hard scattering kernels which are calculable order by order in perturbation theory and include short distance effects. The long distance effects are included in decay constants, form factors and ling-cone distribution amplitudes. $M_1$ is a light meson or a charmonium state. $M_2$ contains the spectator quark in $B$ meson) is any light or heavy meson. If $M_2$ is heavy (for example, $D$ meson), the second line in the Eq.(4) is $1/m_b$ suppressed.

General observation:

- At the zeroth order of $\alpha_s$, it reduces to naive factorization
- At the higher order, the corrections can be computed systematically
- The renormalization scheme and scale dependence of $\langle Q_i \rangle$ is restored. In the heavy quark limit, the "non-factorization" contributions is calculable perturbatively. It does not need to introduce $N_c^{\text{eff}}$
In heavy quark limit, strong phases arise solely from vertex and penguin corrections, so are at $\mathcal{O}(\alpha_s)$. That means that strong phases are $\alpha_s$-suppressed.

Numerically, $\Lambda_{QCD}/m_b \sim \mathcal{O}(\alpha_s)$, so power corrections contribution to strong phases are also important. We do not have a systematic way to estimate power $(\Lambda_{QCD}/m_b)$ corrections. Thus the calculation of strong phase is not reliable. So CP asymmetry calculation is unreliable.

- $W$-exchange & $W$-annihilation diagrams are $1/m_b$ suppressed
- No long distance interactions between $M_1$ and $(BM_2)$

$T^I$ includes:
- $\alpha_s^0$: tree diagram
- $\alpha_s$: non-factorizable gluon exchange
  - vertex corrections (Fig. 1(a)-(d))
  - penguin corrections (Fig. 1(e)-(f))

\[\]
• \( T^{II} \) includes:
  \( \alpha_s \): hard spectator scattering (Fig.\( \text{I}(g)-(h) \))

Superficially, \( \Lambda_{QCD}/m_b \sim 1/15 \) is a small number, but in some cases, such power suppression fails numerically. For example

\[
\langle Q_6 \rangle_F = -2 \sum_{q'} \langle P_1 | (\bar{q} q')_{S-P} | 0 \rangle \langle P_2 | (\bar{q}' b)_{S+P} | B \rangle
\]

(5)
is always multiplied by a formally power suppressed but chirally enhanced factor \( r_\chi = 2\mu_P/m_b (\mu_P = m_1^2/(m_1 + m_2), m_i \text{ are current quark masses}) \). In the heavy quark limit, \( m_b \to \infty, r_\chi \to 0 \). But for \( m_b \sim 5 \text{GeV} \), \( r_\chi \sim \mathcal{O}(1) \), no \( 1/m_b \) suppression. So we should consider the chirally enhanced power corrections. For example, in \( B \to \pi K \), penguin is important. Dominant contribution to the amplitude \( \sim a_4 + a_6 r_\chi \), \( (a_4 \sim a_6 r_\chi) \). So chirally enhanced power correction term \( a_6 r_\chi \) cannot be neglected.

Possible sources of power corrections:

• high twist wave functions;
• quark transverse momentum \( k_\perp \);
• annihilation topology diagrams.

When we include chirally enhanced power corrections, the infrared (including soft and collinear) divergences for vertex corrections cancel only if \( \Phi_\sigma(x) \) is symmetric, i.e. \( \Phi_\sigma(x) = \Phi_\sigma(1 - x) \) (\( \Phi_\sigma, \Phi_P \) are twist-3 wave functions). But even \( \Phi_\sigma(x) = \Phi_\sigma(1 - x) \), there is still logarithmic divergence for hard spectator scattering and annihilation topology. It violates factorization.

\[
X_{H,A} = \int_0^1 \frac{dx}{x} = \ln \frac{m_B}{\Lambda_h} (1 + \rho_{H,A} e^{i\phi_{H,A}})
\]

\( \Lambda_h \sim 0.5 \text{GeV}, \ 0 < \rho_{H,A} < 1, \ 0^\circ \leq \phi_{H,A} < 360^\circ \)

(6)

Other power corrections maybe unimportant based on Renormalon Calculus estimation [6].

III. GLOBAL ANALYSIS OF \( B \to PP, PV \)

The decay amplitudes of \( B \to PP, PV \) can be written as
\[ \mathcal{A}(B \to M_1 M_2) = \frac{G_F}{\sqrt{2}} \sum_i v_q a_i^p \langle M_1 | J_1 | 0 \rangle \langle M_2 | J_2 | B \rangle + \frac{G_F}{\sqrt{2}} f_B f_{M_1} f_{M_2} \sum_i v_q b_i \]  

(7)

where \( b_i = b_i(X_A, \alpha_s) = \alpha_s f(X_A) \) is related to the contributions of annihilation topology.

We use CKMFITTER package \[7\] developed for global analysis of \( B \to PP \) and enlarged it to include \( B \to PV \). The RFit scheme is implemented for statistical treatment, assuming the experimental errors to be purely Gaussian, while quantities that cannot be computed precisely are bound to remain within their predefined allowed ranges.

The input parameters are as follows:

1. two-parton light-cone distribution amplitudes.

- for pseudoscalar meson

\[ \langle P(k) | \bar{q}_\alpha(z_2) q_\beta(z_1) | 0 \rangle = \frac{if_P}{4} \int_0^1 dx e^{i(k \cdot z_2 + \bar{k} \cdot z_1)} \left\{ \bar{k} \gamma_5 \Phi_P(x) - \mu_P \gamma_5 \left[ \Phi_P^p(x) - \sigma_{\mu \nu} k_\mu z_\nu \Phi_P^V(x) \right] \right\} \beta \alpha \]  

(8)

where \( z = z_1 - z_2 \).

- for longitudinally polarized vector meson

\[ \langle V(k, \lambda) | \bar{q}_\alpha(z_2) q_\beta(z_1) | 0 \rangle = -\frac{if_V}{4} m_V \int_0^1 dx e^{i(k \cdot z_2 + \bar{k} \cdot z_1)} \left\{ \bar{k} \Phi_V(x) \right\} \beta \alpha, \]  

for vector meson, the contributions of the twist-3 LCDAs are doubly suppressed, so can be safely disregarded.

- In order to reduce the number of input parameters, we use the asymptotic light-cone distribution amplitudes for final light mesons instead of Gegenbauer polynomials.

\[ \Phi_P(x) = 6x \bar{x}, \quad \Phi_P^p(x) = 6x \bar{x}, \quad \Phi_P^V(x) = 1, \quad \Phi_V(x) = 6x \bar{x}, \]  

(10)

- for \( B \) meson, its wave function appears only in the contributions of hard spectator scattering \[4\]

\[ \int_0^1 \frac{d\xi}{\xi} \Phi_B(\xi) = \frac{m_B}{\lambda_B}, \quad \lambda_B = (350 \pm 150) \text{ MeV}, \]  

(11)
2. chirally enhanced factor & annihilation-related parameters

\[ r_\chi^{\pi} \simeq r_\chi^{\eta} \simeq r_\chi^K = \frac{2m_b^2}{m_s m_b}, \quad m_b(m_b) = 4.2 \text{ GeV}, \quad m_s(2 \text{ GeV}) = (110 \pm 25) \text{ MeV}, \]

\[ X_{H,A}^{PP} = \ln \frac{m_B}{\Lambda_h} (1 + \rho_{H,A}^{PP} e^{i\phi_{H,A}}), \quad X_{H,A}^{PV} = \ln \frac{m_B}{\Lambda_h} (1 + \rho_{H,A}^{PV} e^{i\phi_{H,A}}) \] (12)

(note: \( X_H, X_A \) for \( B \to PP \) are different for \( B \to PV \))

3. Decay constants and form factors

\[ f_\pi = 131 \text{ MeV}, \quad f_K = 160 \text{ MeV}, \quad f_{K^*} = 214 \text{ MeV}, \quad f_\rho = 210 \text{ MeV}, \]

\[ f_\omega = 195 \text{ MeV}, \quad f_\phi = 233 \text{ MeV}, \quad f_B = 180 \text{ MeV}, \quad \phi = 39.3^\circ, \]

\[ f_q = 1.07 f_\pi, \quad f_s = (1.34 \pm 0.06) f_\pi, \quad f_q^0 = f_q \cos \phi, \quad f_q^3 = -f_q \sin \phi, \]

\[ F_{0,1}^{B \rightarrow \pi}(0) = 0.28 \pm 0.05, \quad A_0^{B \rightarrow \rho}(0) = 0.30 \pm 0.05, \quad R_{\pi K}^{f_{X}F_{K}\rightarrow K_{F}} = 0.9 \pm 0.1, \] (13)

\[ A_0^{B \rightarrow \omega}(0) = A_0^{B \rightarrow \rho}(0), \quad F_{0,1}^{B \rightarrow \eta} = F_{0,1}^{B \rightarrow \pi} \left( \frac{\cos \theta_s}{\sqrt{6}} - \frac{\sin \theta_s}{\sqrt{3}} \right), \]

\[ f_q \rightarrow |\eta_0\rangle = \frac{|u \bar{d} + |d \bar{d}|}{\sqrt{2}}, \quad \langle 0 | s \gamma_5 \bar{s} | \eta \rangle = -i \frac{m_\pi^2}{2m_s} \left( f_{\eta}^u - f_{\eta}^s \right) \theta_s = \phi - \arctan(\sqrt{2} f_q / f_s), \]

\[ f_s \rightarrow |\eta_s\rangle = |s \bar{s}\rangle, \quad \frac{\langle 0 | u \gamma_5 \bar{u}(0) \rangle}{\langle 0 | s \gamma_5 \bar{s}(0) \rangle} = \frac{\eta^u}{\eta^s}, \quad \theta_0 = \phi - \arctan(\sqrt{2} f_s / f_q), \]

4. CKM parameters

We use Wolfenstein parameterization for the CKM matrix and take

\[ A = 0.835, \quad \lambda = 0.22, \quad |V_{ub}| = 3.49 \pm 0.24_{\text{exp}} \pm 0.55_{\text{theo}}, \] (14)

and use the measured branching fractions listed in Table II as input. We did not use the branching ratios in Table II as input. The reason is that the errors of the data are large and the glue content of \( \eta(\rho)\)-meson cannot be treated neatly. Detailed discussion can be found in our published paper [8]. For experimental constraints of \( CP \) asymmetries, the corresponding QCDF predictions are not reliable. Thus we do not use measured \( CP \) asymmetries as input in our global fit.

For \( B \to \pi \pi, \pi K \), the fit is sensitive to \( |V_{ub}|, \gamma(\rho, \eta), F_{\pi \rightarrow \pi}, F_{\pi \rightarrow K}, X_A, f_B / \lambda_B, m_s \).

Including seven \( B \rightarrow PV \) decay channels, only \( A_0^{B \rightarrow \rho}, X_A^{PV} \) are newly involved sensitive parameters. So including \( B \rightarrow PV \) we shall have more stringent test of QCDF. Our best fit of \( \gamma \sim 79^\circ \) (see Figure 3) which is consistent with recent fit results \( 37^\circ < \gamma < 80^\circ \) [7]. The best fitted results are listed in Table III.

The confidence levels of the fitted branching ratios are presented in Figure 4. From Figure 4 we can see that
• For $B \to \pi^0\pi^0$, the best fit is around $1 \times 10^{-6}$ while the BABAR and BELLE averaged measurement is $(1.90 \pm 0.49) \times 10^{-6}$.

• For $B^+ \to \omega K^+$, the best fit is $6.25 \times 10^{-6}$ while the BELLE measurement is $(9.2^{+2.6}_{-2.3} \pm 1.0) \times 10^{-6}$, and the CLEO measurement is $< 8 \times 10^{-6}$.

• For $B^+ \to \omega\pi^+$, the best fit is $6.66 \times 10^{-6}$ while the BABAR measurement is $(6.6^{+2.1}_{-1.8} \pm 0.7) \times 10^{-6}$, and the BELLE measurement is $< 8.2 \times 10^{-6}$.

• For $B^+ \to \pi^+K^*$, the best fit $\sim 10 \times 10^{-6}$ while the BABAR preliminary measurement reported at LP03 is $(10.3 \pm 1.2^{+1.0}_{-2.7}) \times 10^{-6}$.

On the whole, our global fit is successful.

IV. SUMMARY & CONCLUSION

• QCD factorization is a promising method for charmless two-body $B$ decays, which are crucial for the determination of the unitarity triangle.

• We enlarged the CKMFitter package to include $B \to PV$ charmless decay channels and did a global analysis. It is shown that the QCDF predictions are basically in good agreement with the experiments.

• We obtain $\gamma \sim 79^\circ$, consistent with the CKM global fit.
• For $B \to \pi^0\pi^0$, the best fit is around $1 \times 10^{-6}$ while the BABAR and BELLE averaged measurement is $(1.90 \pm 0.49) \times 10^{-6}$.

• For $B^+ \to \omega K^+$, the best fit is $6.25 \times 10^{-6}$ while the BELLE measurement is $(9.2^{+2.6}_{-2.3} \pm 1.0) \times 10^{-6}$, and the CLEO measurement is $< 8 \times 10^{-6}$.

• For $B^+ \to \omega\pi^+$, the best fit is $6.66 \times 10^{-6}$ while the BABAR measurement is $(6.6^{+2.1}_{-1.8} \pm 0.7) \times 10^{-6}$, and the BELLE measurement is $< 8.2 \times 10^{-6}$.
• For $B^+ \to \pi^+ K^{*0}$, the best fit $\sim 10 \times 10^{-6}$ while the BABAR preliminary measurement reported at LP03 is $(10.3 \pm 1.2^{+1.0}_{-2.2}) \times 10^{-6}$.

The results are already published in [8]. I thank Drs. Junfeng Sun, Deshan Yang and Guohuai Zhu for their collaboration.

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### TABLE I: Experimental data used in the global fit

| $B_r \times 10^6$ | CLEO      | BaBar     | Belle     | weighted average |
|-------------------|------------|-----------|-----------|------------------|
| $B^0 \to \pi^+\pi^-$ | $4.3^{+1.6}_{-1.4} \pm 0.5$ | $4.7 \pm 0.6 \pm 0.2$ | $5.4 \pm 1.2 \pm 0.5$ | $4.77 \pm 0.54$ |
| $B^+ \to \pi^+\pi^0$ | $5.4^{+2.1}_{-2.0} \pm 1.5$ | $5.5^{+1.0}_{-0.9} \pm 0.6$ | $7.4^{+2.3}_{-2.2} \pm 0.9$ | $5.78 \pm 0.95$ |
| $B^0 \to K^+\pi^-$ | $17.2^{+2.5}_{-2.4} \pm 1.2$ | $17.9 \pm 0.9 \pm 0.7$ | $22.5 \pm 1.9 \pm 1.8$ | $18.5 \pm 1.0$ |
| $B^+ \to K^+\pi^0$ | $11.6^{+3.0+1.4}_{-2.7-1.3}$ | $12.8^{+1.2}_{-1.1} \pm 1.0$ | $13.0^{+2.5}_{-2.4} \pm 1.3$ | $12.7 \pm 1.2$ |
| $B^+ \to K^0\pi^+$ | $18.2^{+4.6}_{-4.0} \pm 1.6$ | $17.5^{+1.8}_{-1.7} \pm 1.3$ | $19.4^{+3.1}_{-3.6} \pm 1.6$ | $18.1 \pm 1.7$ |
| $B^0 \to K^0\pi^0$ | $14.6^{+5.9+2.4}_{-5.1-3.3}$ | $10.4 \pm 1.5 \pm 0.8$ | $8.0^{+3.3}_{-3.1} \pm 1.6$ | $10.2 \pm 1.5$ |
| $B^+ \to \eta\pi^+$ | $< 5.7$ | $< 5.2$ | $5.3^{+2.0}_{-1.7} (< 8.2)$ | $< 5.2$ |
| $B^0 \to \pi^0\rho^+$ | $27.6^{+8.4}_{-8.4} \pm 4.2$ | $28.9 \pm 5.4 \pm 4.3$ | $20.8^{+6.0+2.8}_{-6.3-3.1}$ | $25.4 \pm 4.3$ |
| $B^+ \to \pi^0\rho^0$ | $10.4^{+3.3}_{-3.4} \pm 2.1$ | $< 39$ | $8.0^{+2.3}_{-2.0} \pm 0.7$ | $8.6 \pm 2.0$ |
| $B^0 \to K^0\rho^-$ | $16.0^{+7.6}_{-6.4} \pm 2.8$ | $11.2^{+5.9+1.9}_{-5.6-1.8}$ | $13.1 \pm 4.7$ |
| $B^+ \to \phi K^+$ | $5.5^{+2.1}_{-1.8} \pm 0.6$ | $9.2 \pm 1.0 \pm 0.8$ | $10.7 \pm 1.0+0.9_{-1.6}$ | $8.9 \pm 1.0$ |
| $B^0 \to \phi K^0$ | $5.4^{+3.7}_{-2.7} \pm 0.7$ | $8.7^{+1.7}_{-1.5} \pm 0.9$ | $10.0^{+1.9+0.9}_{-1.7-1.3}$ | $8.6 \pm 1.3$ |
| $B^+ \to \eta\rho^+$ | $< 10$ | $< 6.2$ | $< 6.2$ |
| $B^0 \to \omega K^0$ | $< 21$ | $5.9^{+1.7}_{-1.5} \pm 0.9$ | $5.9 \pm 1.9$ |

### TABLE II: data not used in the global fit

| $B_r \times 10^6$ | CLEO      | BaBar     | Belle     | weighted average |
|-------------------|------------|-----------|-----------|------------------|
| $B^+ \to \eta K^+$ | $< 6.9$ | $< 6.4$ | $5.2^{+1.7}_{-1.5} (< 7.7)$ | $< 6.4$ |
| $B^+ \to \pi^+ K^{*0}$ | $< 16$ | $15.5 \pm 3.4 \pm 1.8$ | $16.2^{+1.1}_{-3.8} \pm 2.4$ | $15.8 \pm 3.0$ |
| $B^0 \to \pi^- K^{**}$ | $16^{+6}_{-5} \pm 2$ | $26.0 \pm 8.3 \pm 3.5$ | $19.0 \pm 4.9$ |
| $B^+ \to \eta K^{**}$ | $26.4^{+9.6}_{-8.2} \pm 3.3$ | $22.1^{+11.1}_{-9.2} \pm 3.3$ | $26.5^{+7.8}_{-7.0} \pm 3.0$ | $25.4 \pm 5.3$ |
| $B^0 \to \eta K^{*0}$ | $13.8^{+5.5}_{-4.6} \pm 1.6$ | $19.8^{+6.5}_{-5.6} \pm 1.7$ | $16.5^{+4.6}_{-4.2} \pm 1.2$ | $16.4 \pm 3.0$ |
| $B^+ \to \omega K^+$ | $< 8$ | $< 4$ | $9.2^{+2.0}_{-2.3} \pm 1.0$ |
| $B^+ \to \omega \pi^+$ | $11.3^{+3.3}_{-2.9} \pm 1.5$ | $6.6^{+2.1}_{-1.8} \pm 0.7$ | $< 8.2$ |
TABLE III: Fit1 and Fit2 mean the best fit value with and without the contribution of the chirally enhanced hard spectator and annihilation topology, respectively.

| modes         | Exp.   | Fit1  | Fit2  |
|---------------|--------|-------|-------|
| $B^0 \rightarrow \pi^+ \pi^-$ | 4.77±0.54 | 4.82  | 5.68  |
| $B^+ \rightarrow \pi^+ \pi^0$    | 5.78±0.95 | 5.35  | 3.25  |
| $B^0 \rightarrow K^+ \pi^-$      | 18.5±1.0  | 19.0   | 18.8  |
| $B^+ \rightarrow K^+ \pi^0$      | 12.7±1.2  | 11.4   | 12.6  |
| $B^+ \rightarrow K^0 \pi^+$      | 18.1±1.7  | 20.1   | 20.2  |
| $B^0 \rightarrow K^0 \pi^0$      | 10.2±1.5  | 8.2    | 7.3   |
| $B^+ \rightarrow \eta \pi^+$     | < 5.2    | 2.8    | 1.8   |
| $B^0 \rightarrow \pi^\pm \rho^+$ | 25.4±4.3  | 26.7   | 29.5  |
| $B^+ \rightarrow \pi^+ \rho^0$   | 8.6±2.0   | 8.9    | 8.5   |
| $B^0 \rightarrow K^+ \rho^-$     | 13.1±4.7  | 12.1   | 5.1   |
| $B^+ \rightarrow \phi K^+$       | 8.9±1.0   | 8.9    | 7.1   |
| $B^0 \rightarrow \phi K^0$       | 8.6±1.3   | 8.4    | 6.7   |
| $B^+ \rightarrow \eta \rho^+$    | < 6.2    | 4.6    | 3.8   |
| $B^0 \rightarrow \omega K^0$     | 5.9±1.9   | 6.3    | 1.2   |