IMPLICATIONS OF RECENT MEASUREMENTS OF NONLEPTONIC 
CHARMLESS B DECAYS

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Implications of recent measurements of hadronic charmless B decays are discussed.

1 $B \to \pi \pi, \pi K$ Decays

Both $B$ factories BELLE and BABAR have reported at this conference the preliminary results of $B \to K \pi$ and $B \to \pi^+ \pi^-$ (see Table I). For the unitary angle $\gamma \sim 60^\circ$, the ratio $R = B(B \to K^\pm \pi^\mp)/B(B \to \pi^+ \pi^-)$ is conventionally predicted to lie in the region 1.3–2.0, to be compared with the experimental values of $4.0 \pm 1.6, 2.8 \pm 2.0$ and $1.3 \pm 0.5$ obtained by CLEO, BELLE and BABAR, respectively. Hence, the expected ratio $R$ is smaller than the CLEO and BELLE results and in agreement with BABAR. Of course, more data are needed to clarify the issue.

If the CLEO or BELLE data are taken seriously, we may ask the question of how to accommodate the data of $K \pi$ and $\pi \pi$ simultaneously. A fit to $\pi^+ \pi^-$ yields $F_\pi^\pi(0) < 0.25$ for $|V_{ub}/V_{cb}| = 0.09$ and $\gamma = 60^\circ$. The $K \pi$ rates will then become too small compared to the data. By contrast, a fit to $K \pi$ modes usually implies a too large $\pi^+ \pi^-$ rate. There are several possibilities that the CLEO or BELLE data of $K^\pm \pi^\mp$ and $\pi^+ \pi^-$ can be accommodated: (1) $\gamma \sim 60^\circ$ and $F_\pi^\pi(0) < 0.25$ with a smaller strange quark mass, say $m_s(m_b) = 60$ MeV. The idea is that the $K \pi$ mode will receive a sizable $(S - P)(S + P)$ penguin contributions, while the $\pi \pi$ decay is not much affected. However, a rather smaller $m_s$ is not consistent with recent lattice calculations. (2) $\gamma \sim 60^\circ$ and $F_\pi^\pi(0) = 0.30$ with the following cases: (i) a smaller $V_{ub}$, say $|V_{ub}/V_{cb}| \approx 0.06$, so that the $\pi^+ \pi^-$ rate is suppressed. However, this small $V_{ub}$ is not favored by data. (ii) a large nonzero isospin $\pi \pi$ phase shift difference of order, say $70^\circ$, can yield a substantial suppression of the $\pi^+ \pi^-$ mode. However, $\pi^0 \pi^0$ will be substantially enhanced by the same strong phase. The CLEO new measurement $B(B \to \pi^0 \pi^0) < 5.7 \times 10^{-6}$ indicates that the strong phase cannot be too large. (iii) a large inelasticity for $\pi^+ \pi^-$ and $D^+ D^-$ modes so that the former is suppressed whereas the latter is enhanced. (3) a large $\gamma$, say $\gamma \sim (110 - 130)^\circ$, and $F_\pi^\pi(0) = 0.30$. Several calculations based on generalized or QCD improved factorization imply $\gamma > 100^\circ$. This scenario is interesting and popular, but it encounters two problems: (i) It is in conflict with the unitary angle $\gamma = (58.5 \pm 7.1)^\circ$ extracted from the global CKM fit. (ii) The CLEO data other than $K \pi$ and $\pi \pi$ do not strongly support a large $\gamma$ (see below). (4) $\gamma \sim 90^\circ$ and $F_\pi^\pi(0) = 0.25$ as assumed in a recent PQCD analysis. In this work, the $\pi^+ \pi^-$ rate is small because of the small form factor $F_\pi^\pi(0)$, and $K \pi$ rates are enhanced by large penguin effects owing to steep $\mu$ dependence of the leading-order penguin coefficients $c_4(\mu)$ and $c_6(\mu)$ at the hard scale $t < m_b/2$.

As shown in $\phi_5$, the nonfactorized term is dominated by hard gluon exchange in the heavy quark limit as soft gluon contributions to $\chi_i$ are suppressed by orders of $\Lambda_{QCD}/m_b$. However, there is an additional chirally enhanced corrections to the spectator-interaction diagram, which are logarithmically divergent. For example, an additional $(V - A)(V - A)$ spectator interaction proportional to the twist-3 wave function $\phi_5^\pi$ will contribute to $B \to \pi \pi, \pi K$. 
Consequently, the nonfactorized contribution to the coefficient $a_2(\pi\pi)$, for example, can be large [11] and its real part lies in the range 0.17–0.25. This will affect the prediction of $B \rightarrow \pi^+\pi^0$ and in particular $B \rightarrow \pi^0\pi^0$. We find that even in the leading-twist approximation, the same logarithmically divergent integral also appears in the charm quark mass corrections to the spectator-interaction diagram in $B \rightarrow J/\psi K(K^*)$ decays [11]. As a result, Re $a_2(J/\psi K)$ is in the vicinity of 0.22.

### 2 $B \rightarrow \rho\pi, \omega\pi$ Decays

The class-III decays $B^\pm \rightarrow \rho^0\pi^\pm, \omega\pi^\pm$ are tree-dominated and sensitive to $(N_c^{\text{eff}})_{2}$ appearing in $a_{2}$: their branching ratios decrease with $(N_c^{\text{eff}})_{2}$. The present data [12] imply $(N_c^{\text{eff}})_{2} < 3$ as in $B \rightarrow D\pi$ decays.

The decay rate of $\rho^0\pi^\pm$ is sensitive to $\gamma$, while $\omega\pi^\pm$ is not. For example, $B(B^\pm \rightarrow \rho^0\pi^\pm)/B(B^\pm \rightarrow \omega\pi^\pm) \sim 1$ for $\gamma \sim 60^\circ$, and $B(B^\pm \rightarrow \rho^0\pi^\pm)/B(B^\pm \rightarrow \omega\pi^\pm) > 1$ for $\gamma > 90^\circ$ if $A_{B}(0) = A_{B}(0')$. Therefore, a large $\gamma$ preferred by the previous measurement [11] $B(B^\pm \rightarrow \rho^0\pi^\pm) = (15 \pm 5 \pm 4) \times 10^{-6}$, is no longer favored by the new measurement of $\rho^0\pi^\pm$.

### 3 $B \rightarrow \phi K$ Decays

The previous limit [3] for the branching ratio of $B^\pm \rightarrow \phi K^\pm$ is $0.59 \times 10^{-5}$ at 90\% C.L. However, CLEO has also seen a $3\sigma$ evidence for the decay $B \rightarrow \phi K^*$. Its branching ratio, the average of $\phi K^+$ and $\phi K^{*0}$ modes, is reported to be $B(B \rightarrow \phi K^*) = (1.1^{+0.6}_{-0.5} \pm 0.2) \times 10^{-5}$. Theoretical calculations based on factorization indicate that the branching ratio of $\phi K$ is similar to that of $\phi K^*$. Therefore, it is difficult to understand the non-observation of $\phi K$.

An observation of the $\phi K$ signal was reported at this conference to be $(6.4^{+2.5+0.5}_{-2.1-2.0}) \times 10^{-6}$ by CLEO [11] and $(17.2^{+6.7}_{-5.4} \pm 1.8) \times 10^{-6}$ by BELLE [11]. The decay amplitude of the penguin-dominated mode $B \rightarrow K\phi$ is governed by $[a_3 + a_4 + a_5 - \frac{1}{2}(a_{7} + a_{9}) + a_{10}]$, where $a_3$ and $a_5$ are sensitive to nonfactorized contributions. In the absence of nonfactorized effects, we find $B(B^\pm \rightarrow \phi K^\pm) = (6.3-7.3) \times 10^{-6}$, which is in good agreement with the CLEO result, but smaller than the BELLE measurement.

### 4 $B \rightarrow K\eta', K^*\eta$ Decays

The decays $B \rightarrow K^{(*)}\eta(\eta')$ involve interference between the penguin amplitudes arising from $(\bar{u}u + \bar{d}d)$ and $s\bar{s}$ components of the $\eta$ or $\eta'$. The branching ratios of $K\eta'$
\( (K^*\eta) \) are anticipated to be much greater than \( K\eta \) \((K^*\eta')\) modes owing to the presence of constructive interference between two comparable penguin amplitudes arising from non-strange and strange quarks of the \( \eta'(\eta) \).

The measured branching ratios of the decays \( B \rightarrow \eta'K \) are

\[
\begin{align*}
B(B^\pm \rightarrow \eta'K^\pm) &= (80^{+10}_{-9} \pm 7) \times 10^{-6}, \\
B(B^0 \rightarrow \eta'K^0) &= (89^{+18}_{-16} \pm 9) \times 10^{-6}.
\end{align*}
\]

by CLEO \cite{1} and \((62 \pm 18 \pm 8) \times 10^{-6}, < 1.12 \times 10^{-4} \), respectively by BABAR \cite{2}. The earlier theoretical predictions in the range \((1 - 2) \times 10^{-5} \) are too small compared to experiment. It was realized later (for a review, see e.g. \cite{3}) that \( \eta'K \) gets enhanced because of (i) the small running strange quark mass at the scale \( m_b \), (ii) the sizable \( SU(3) \) breaking in the decay constants \( f_8 \) and \( f_9 \), (iii) an enhancement of the form factor \( F_0^{B_{q'}}(0) \) due to the smaller mixing \( \eta - \eta' \) mixing angle \(-15.4^\circ \) rather than \( \approx -20^\circ \), (iv) contribution from the \( \eta' \) charm content, and (v) constructive interference in tree amplitudes. It was also realized not long ago that \cite{4} the above-mentioned enhancement is partially washed out by the anomaly effect in the matrix element of pseudoscalar densities, an effect overlooked before. As a consequence, the net enhancement is not very large; we find \cite{4} \( B(B^\pm \rightarrow K^\pm\eta') = (40 - 50) \times 10^{-6} \), which is still smaller than the CLEO result but consistent with the BELLE measurement. This implies that we probably need an additional (but not dominant !) \( SU(3) \)-singlet contribution to explain the \( B \rightarrow K\eta' \) puzzle.

Finally, it is worth remarking that if \( \gamma > 90^\circ \), the charged mode \( \eta'K^\pm \) will get enhanced, while the neutral mode \( \eta'K^0 \) remains stable\cite{5}. The present data of \( K\eta' \) cannot differentiate between \( \cos \gamma > 0 \) and \( \cos \gamma < 0 \).

\section{5 \( B \rightarrow \omega K \) and \( \rho K \) Decays}

The published CLEO result \cite{6} of a large branching ratio \((15^{+4}_{-3} \pm 2) \times 10^{-6} \) for \( B^\pm \rightarrow \omega K^\pm \) imposes a serious problem to the generalized factorization approach: The observed rate is enormously large compared to naive expectation. The destructive interference between \( a_4 \) and \( a_6 \) terms renders the penguin contribution small. It is thus difficult to understand the large rate of \( \omega K \).

Theoretically, it is expected that \( B(B^- \rightarrow \omega K^-) \geq 2B(B^- \rightarrow \rho^0 K^-) \sim 2 \times 10^{-6} \), which now agrees with the new measurement \cite{7} of \( B(B^- \rightarrow \omega K^-) < 7.9 \times 10^{-6} \).

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