Implications of Recent Measurements of Hadronic Charmless *B* Decays

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Taipei, Taiwan, R.O.C.

July 29, 2000

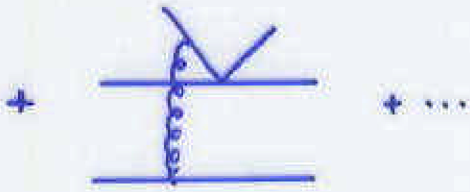
ICHEP2000, Osaka

Outline

1. Theoretical background
2. $B \to \pi\pi$, $K\pi$ decays and γ
3. $B \to \rho\pi$, $\omega\pi$ decays
4. $B \to K\eta'$, $K^*\eta$
5. $B \to \omega K$, ρK
6. Conclusions

In effective Hamiltonian approach:

$$\langle Q(\mu)\rangle = \langle Q\rangle_{\rm VIA} +$$



$$\sum c_i(\mu)\langle Q_i(\mu)\rangle = \sum a_i \langle Q_i\rangle_{\rm VIA}$$

For B decays

$$a_1 = \underbrace{c_1(\mu) + c_2(\mu)(\frac{1}{N_c} + \chi_1)}_{\text{naive factorization}} + \frac{\alpha_s}{4\pi}(\underbrace{\gamma_V \ln\frac{m_b^2}{\mu^2}}_{\text{scale}} + \underbrace{r_V}_{\gamma_5\ \text{scheme}})c$$

Vertex corrections to 4-quark operators ensure that the effective parameter a_1 be scheme and scale independent. The gauge and infrared problems with vertex corrections are resolved when external quarks are on shell. (Cheng, Li, Yang)

In general

$$a_{2i} = c_{2i}(\mu) + c_{2i-1}(\mu)(\frac{1}{N_c} + \chi_{2i})$$
$$+ \ \phi - \text{indep. vertex and penguin corrections},$$
$$a_{2i-1} = c_{2i-1}(\mu) + c_{2i}(\mu)(\frac{1}{N_c} + \chi_{2i-1})$$
$$+ \ \phi - \text{indep. vertex and penguin corrections}$$

Nonfactorized terms $\chi_i = \chi_i(\alpha_s, \Lambda_{\rm QCD}/m_b)$ are complex. In $m_b \to \infty$ limit, χ_i are short-distance dominated and hence calculable. (Beneke et al.)

Sometimes effective number of colors is defined as

$$\left(\frac{1}{N_c^{\rm eff}}\right)_i \equiv \frac{1}{N_c} + \chi_i$$

If χ_i are process independent $\Rightarrow$ generalized factorization. In reality, nonfactorized terms are process dependent.

$B \to \pi\pi$, πK decays and γ

- CLEO data of $K\pi$ alone do not discern $\gamma < 90°$ from $\gamma > 90°$, recalling that global CKM fit yields $\gamma < 90°$. $\gamma = (58.5 \pm 7.1)°$ Stocchi et al.

- UKQCD lattice and light-cone sum rule calculations imply $F_0^{B\pi}(0) \approx 0.30$ (BSW model yields 0.33) $\Rightarrow$ CLEO data of $B \to K\pi$ can be accommodated with $\gamma \sim 65°$. However, the predicted $\pi^+\pi^-$ rate is too large if $|V_{ub}/V_{cb}| = 0.09$; a fit of $\pi^+\pi^-$ data demands $F_0^{B\pi}(0) < 0.25$.

How to accommodate πK and $\pi\pi$ data simultaneously ?

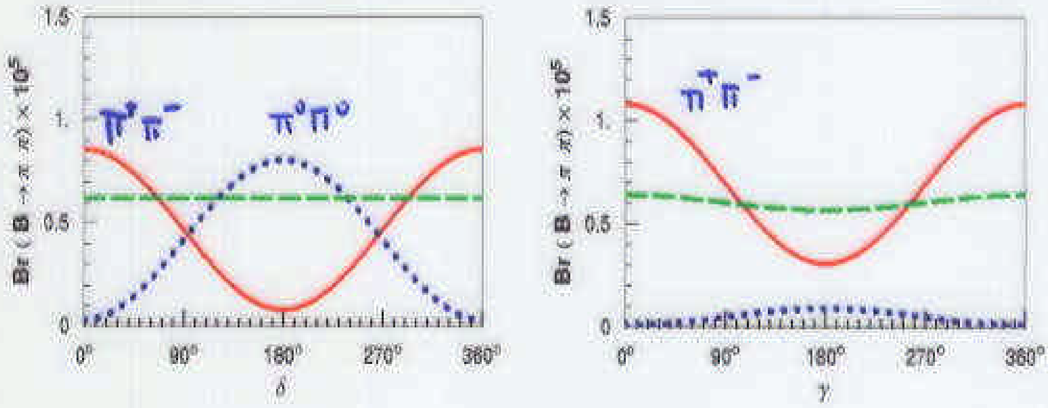
Several possibilities:

- $\gamma \sim 65°$ and $F_0^{B\pi}(0) < 0.25 \Rightarrow$ too small $K\pi$ and $K\eta'$ rates.

- $\gamma \sim 65^\circ$ and $F_0^{B\pi}(0) = 0.30$

1. $|V_{ub}/V_{cb}| = 0.06$, not favored by data

2. large strong phase difference, e.g. $\delta_{\pi\pi} > 70^\circ$. Should $\delta_{\pi\pi}$ vanish in heavy quark limit ? Will $\pi^0\pi^0$ be enhanced too much ? (recall that $\pi^0\pi^0/\pi^+\pi^-$ is observed to be small in charm decay)



3. very small m_s so that Q_6 penguin operator contributes more to $K\pi$ modes than $\pi\pi$, but not preferred by lattice and SR results on m_s.

4. large inelasticity for $\pi^+\pi^-$ and K^+K^- (D^+D^-) modes so that the former is suppressed whereas the

latter is enhanced

- $\gamma \sim (110-130)^\circ$ and $F_0^{B\pi}(0)=0.30$: Generalized or QCD improved factorization $\Rightarrow \gamma > 100^\circ$ from the measured ratio $K^-\pi^+/\pi^-\pi^+ \sim 4$ (Hou, Smith, Würthwein; Muta et al., Du et al., [redacted]): interesting but with two problems:

  1. in conflict with γ extracted from global CKM fit
  2. large γ not strongly supported by $K\eta'$, $\rho\pi$ and $\omega\pi$ data (see below)

- $\gamma \sim 90^\circ$ and $F_0^{B\pi}(0)=0.25$ in pQCD analysis (Keum, Li, Sanda)

  1. $\pi^+\pi^-$ mode is OK (see also Lü, Ukai, Yang)
  2. $K\pi$ is enhanced by large penguin effects owing to steep μ dependence of $c_4(\mu)$ and $c_6(\mu)$ at

hard scale $t < m_b/2$. [However, only leading $c_i(\mu)$ are considered; vertex corrections are not included.]

3. large imaginary annihilation penguins $\Rightarrow$ large CP violation

4. $\mathcal{B}(B \to \pi^-\pi^0) \sim 3.0 \times 10^{-6} < \mathcal{B}(B \to \pi^+\pi^-)$

If $\pi^-\pi^0 \gtrsim \pi^+\pi^-$ is observed in the future, it will imply

- large γ
- and/or large $\delta_{\pi\pi}$
- and/or large inelasticity for $\pi^+\pi^-$

It is important to measure $\pi^+\pi^0$ and $\pi^0\pi^0$ to test various schemes.

Tree-dominated $B \to \rho\pi,\ \omega\pi$ decays

Class-III decays $B^{\pm} \to \rho^0\pi^{\pm}$, $\omega\pi^{\pm}$ are tree-dominated and sensitive to $(N_c^{\rm eff})_2$ appearing in a_2; their BRs decrease with $(N_c^{\rm eff})_2$.

$$\mathcal{B}(B^{\pm} \to \rho^0\pi^{\pm}) = (10.4^{+3.3}_{-3.4} \pm 2.1) \times 10^{-6}$$

$$\mathcal{B}(B^{\pm} \to \omega\pi^{\pm}) = (11.3^{+3.3}_{-2.9} \pm 1.5) \times 10^{-6}$$

Data $\Rightarrow \left|(N_c^{\rm eff})_2\right| < 3$ as in $B \to D\pi$ decays.

The branching ratio of $\rho^0\pi^{\pm}$ is sensitive to γ, while $\omega\pi^{\pm}$ is not:

$$\mathcal{B}(B^{\pm} \to \rho^0\pi^{\pm})/\mathcal{B}(B^{\pm} \to \omega\pi^{\pm}) \sim 1 \text{ for } \gamma \sim 65^\circ$$

$$\mathcal{B}(B^{\pm} \to \rho^0\pi^{\pm})/\mathcal{B}(B^{\pm} \to \omega\pi^{\pm}) > 1 \text{ for } \gamma > 90^\circ$$

for $A_0^{B\omega}(0) = A_0^{B\rho}(0)$.

$\gamma > 90^\circ$ preferred by the previous measurement $\mathcal{B}(B^{\pm} \to \rho^0\pi^{\pm}) = (15 \pm 5 \pm 4) \times 10^{-6}$, is no longer strongly favored by the new data of $\rho^0\pi^{\pm}$.

$B \to K\eta'$, $K^*\eta$ decays

$B \to K\eta(\eta')$, $K^*\eta(\eta')$ involve interference between penguin diagrams arising from $(\bar{u}u + \bar{d}d)$ and $\bar{s}s$ components of $\eta(\eta')$.

constructive: $K\eta', K^*\eta$, destructive: $K\eta, K^*\eta'$.

We predict $K\eta' > K^*\eta \gg K\eta \gtrsim K^*\eta'$, and

$\mathcal{B}(B^- \to K^-\eta') = (53-68) \times 10^{-6}$, $(80^{+10}_{-9} \pm 8) \times 10^{-6}$ $62 \pm 18 \pm 8$

$\mathcal{B}(B^0 \to K^0\eta') = (48-62) \times 10^{-6}$, $(88^{+18}_{-16} \pm 9) \times 10^{-6}$

$\mathcal{B}(B^- \to K^{*-}\eta) = (13-15) \times 10^{-6}$, $(26.4^{+9.6}_{-8.2} \pm 3.3) \times 10^{-6}$

$\mathcal{B}(B^0 \to K^{*0}\eta) = (10-12) \times 10^{-6}$, $(13.8^{+5.5}_{-4.6} \pm 1.6) \times 10^{-6}$

Earlier predictions, BR=$(1-2) \times 10^{-5}$ for $K\eta'$, are too small compared to data.

Enhancement: 1. small running strange quark mass at m_b:

$m_s(m_b) = 85$ MeV,

2. sizeable SU(3) breaking in decay constants f_8 and f_0,

3. $\eta - \eta'$ mixing angle $-15.4° \Rightarrow F_0^{B\eta'}(0)$ is increased,

4. contribution from η' charm content ($f^c_{\eta'} = -6.3$ MeV),

5. constructive interference in tree amplitudes.

Suppression: QCD anomaly effects in $\langle \eta' | \bar{s}\gamma_5 s | 0 \rangle$ (Kagan, Petrov; Ali, Greub)

The predicted branching ratios of $K\eta'$ are still small compared to experiment.

Several enhancement mechanisms specific to η' have been proposed:

- large η' charm content with $|f^c_{\eta'}| \sim |f^{u,s}_{\eta'}|$ (Halperin, Zhitnisky)
- two-gluon fusion via η' anomalous coupling (Ahmady et al; Du et al.)
- SUSY without R-parity (Choudhury et al.)

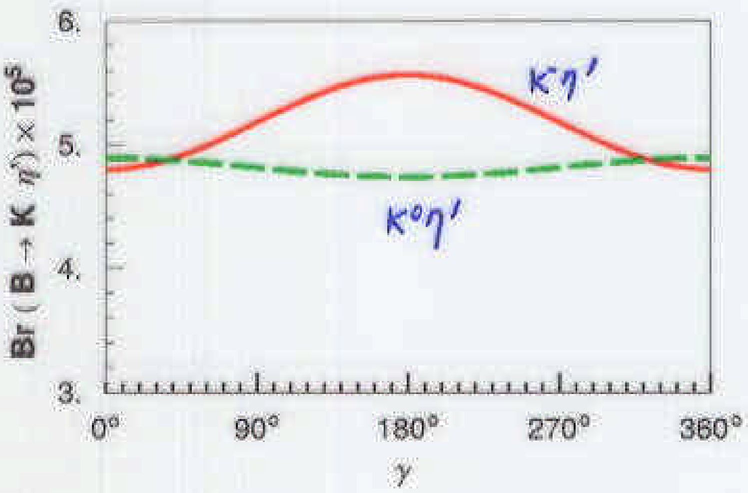
Phenomenological and theoretical studies

$$\Rightarrow -2.0 \text{ MeV} \le f^c_{\eta'} \le -18.4 \text{ MeV} \Rightarrow |f^c_{\eta'}| \ll |f^{u,s}_{\eta'}|$$

We conclude that

1. we probably need additional (but not dominant !) SU(3)-singlet contribution to explain $B \to K\eta'$ puzzle.
2. it is expected that $K^{*-}\eta/K^{*0}\eta \sim 1.3$, while this ratio at central values is measured to be $\sim 2 \Rightarrow$ improved measurement is urged.

If $\gamma > 90°$, $\eta' K^-$ gets enhanced, while $\eta' K^0$ remains stable. The present data of $K\eta'$ cannot differentiate between $\cos\gamma > 0$ and $\cos\gamma < 0$.



$B \to \omega K$, ρK decays

The previous CLEO observation of a large branching ratio for $\omega K^\pm$

$$\mathcal{B}(B^\pm \to \omega K^\pm) = \left(15^{+7}_{-6} \pm 2\right) \times 10^{-6}$$

imposes a serious problem to the factorization approach. Destructive interference between a_4 and a_6 terms renders the penguin contribution small $\Rightarrow$ It is difficult to understand the large rate of ωK.

The expectation

$$\mathcal{B}(B^- \to \omega K^-) \gtrsim 2\mathcal{B}(B^- \to \rho^0 K^-) \sim 2 \times 10^{-6}$$

now agrees with the new measurement: $\mathcal{B}(B^- \to \omega K^-) < 8.0 \times 10^{-6}$.

Conclusions

- Tree-dominated modes $B \to \rho\pi^{\pm}$, $\omega\pi^{\pm}$ imply $|(N_c^{\rm eff})_2| < 3$.
- Three known possibilities for accommodating $K\pi$ and $\pi^+\pi^-$ data:
  - $\gamma \sim 65^\circ$, $F_0^{B\pi}(0) \approx 0.30$
  - $\gamma \sim (110-130)^\circ$, $F_0^{B\pi}(0) \approx 0.30$
  - $\gamma \sim 90^\circ$, $F_0^{B\pi}(0) \approx 0.25$

  It is important to measure $\pi^+\pi^0$ and $\pi^0\pi^0$ to test various schemes.
- Present data of $\rho^0\pi^{\pm}$, $\omega\pi^{\pm}$ and $K^{\pm}\eta'$, $K^0\eta'$ do not strongly favor $\cos\gamma < 0$.
- Constructive interference of two comparable penguin amplitudes accounts for the bulk of

$K\eta'$ and $K^*\eta$ data, but it is still not adequate. We probably need an additional SU(3)-singlet (but not dominant) contribution to explain $B \to K\eta'$ puzzle.

- Need improved measurements of $K^{*-}\pi^+, \bar{K}^0\pi^0$ to resolve discrepancy between theory and experiment.