CP VIOLATION
&
B Physics

"Going after gamma"

Lecture #14

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Dr. Helen Quinn
Going after gamma
No clear path has yet emerged

Three ideas

1. $B_s \rightarrow \rho K_s$

2. $B_d \rightarrow D^* K^*$ or $B^+ \rightarrow D^0 K^+$

3. Methods based on SU(3) symmetry

* Experimental feasibility unclear
† Control over theoretical uncertainties unclear
$B_s \rightarrow 8Ks \quad b \rightarrow u \bar{u} d \quad ( + d \bar{d} d )$

Like $B_d \rightarrow \pi \pi \pi \pi \; (on \; \pi \pi \pi )$

but mixing phase for $B_s$ differs from mixing phase for $B_d$

$\phi_d - \phi_m = \gamma$ here.

Experimental Problems

$B$ factory running at $\sqrt{s}$

- luminosity

- branching fraction to $B_s$

- backgrounds to $4\pi$ hadrons

- triggering

- time integration

Hadrronic facility

Both environments

- rapid $B_s$ oscillation

Theory

Penguin effects (as in $B \rightarrow \pi \pi \pi \pi$)

Isospin? for $B_s$  \( \Delta T = I_f = \frac{1}{2} \) or \( \frac{3}{2} \)

\( \nu_p \rightarrow \text{pion} \)

3 amplitudes 2 times 1 penguin

$B_s \rightarrow 8Ks, \pi^+ \pi^- \pi^0 \pi^0$

3 magnitudes 2 relative strong phases

Not enough independent measurements!

2 weak phases \( \gamma \) for true, \( \beta \) for

\( \rho \) unbroken.
$B \rightarrow DK^*$

Basic idea: Use $B \rightarrow DK^*$ to measure amplitude magnitudes to constrain general relationships (such as in Ferguson analyses).

Construct geometrical relationships (much as in Ferguson analyses).

$L$-flavor tagging made interference if $D\rightarrow f$ well known.

Direct CP violation in these modes.

Example Charged $K$.

$b \rightarrow c \pi s$

$B^+ \rightarrow D^0 K^+$

$B^- \rightarrow D^0 K^-$

$\mathcal{B} \leftarrow A_1$

$\mathcal{V}_{cb} \mathcal{V}_{cd}^* = \mathcal{A}_2^2$

$\sum A (B^- \rightarrow D_{cp} K^-) = A (B^- \rightarrow D^0 K^-)$

$\sum A (B^+ \rightarrow D_{cp} K^+) = \sum A (B^+ \rightarrow D^0 K^+)$

$D_{cp} = D^0 \text{ or } \bar{D}^0 \rightarrow C P \text{ eigenstate}$

$A (B^+ \rightarrow D_{cp} K^+) = |A_1 + A_2|^2 = |A_1|^2 + |A_2|^2 + 2 \text{Re} A_1 A_2^*$

$A (B^- \rightarrow D_{cp} K^-) = |A_1 - A_2|^2 = |A_1|^2 + |A_2|^2 - 2 \text{Re} A_1 A_2^*$

$\text{Re} (A_1 A_2) \propto \cos (\delta + \gamma)$

$\text{Re} (A_1 A_2^*) \propto \cos (\delta - \gamma)$
Later additions

. Higher K* modes $\Rightarrow$ enhanced strong phases

. Do not need $D_{CP}$ eigenstate, can choose a final state such that $B^+ \rightarrow D \rightarrow f$ and $B^+ \rightarrow \bar{D} \rightarrow f$

we comparable in size

$B^+ \rightarrow \bar{D}$ allowed

$\bar{D} \rightarrow f$ doubly Cabibbo suppressed.

$B^+ \rightarrow D$

color suppressed

$D \rightarrow f$ allowed

$\Rightarrow$ larger interference effects (but smaller rates)

$\Rightarrow$ similar story for $D_{II}$

Problem for all $DK$ modes (i) RATE

(ii) $D$ Branching ratios must be well measured - errors compound
Theoretical problems?

- Analysis is clean up to ambiguities of ∆ orientation ⇒ 4 values
  - each orientation ⇒ (δ, θ)

δ + θ = φ + φ
δ - θ = ± θ

⇒
δ = ± \frac{φ + θ}{2}
θ = ± \frac{(φ - θ)}{2}

May be able to rule out some choices by arguing that |S| cannot be very big

( factorization; relationship of B→DK and B→Dy )

↑ Cabibbo allowed
\( SU(3) \) methods

\[ \pi^+, \pi^- K \quad \text{Gorodn, Rosner, London} \quad \text{PRL 73 21 (199}\]

\[ \pi^+, \pi^- K \quad \text{and KK} \quad \text{Hernandez, London, Gorodn, Rosner} \quad \text{Phys. Lett. B 333 (19}\]

\[ + \text{later work by same authors} \]

Idea \( SU(3) \) \( \pi^+ \leftrightarrow K \).

\( \Rightarrow \) form factors for hadron formation from similar operators are similar.

Note same argument says \( f_K/f_{\pi^+} > 1 \)

\[ \langle 0 | J_{\pi^+} | K \rangle = q f_K/f_{\pi^+} \quad \text{measured value} \approx 1.2 \]

\( \Rightarrow \) \( SU(3) \) breaking effects are "of order" 20%.

Only some of them are corrected by \( f_K/f_{\pi^+} \) factors.
Method

1. Categorize diagrams

   Topology

   Tree
   Color suppressed tree
   Penguin

   Exchange
   Annihilation
   Penguin annihilation

\[ f_{3/1} \] suppressed

\[ f_{3/1} \] suppressed

\[ \Rightarrow 13 \text{ decays, } 3 \text{ independent amplitudes } T, C, P \]

\[ B^+ \to \pi^+ \pi^0 \]
\[ -(T+C) \]
\[ B^+ \to K^+ \pi^0 \]
\[ -(T+C^1+p') \]

\[ B^0 \to \pi^0 \pi^0 \]

\[ B_0 \to \pi^0 \kappa^0 \]
\[ -(C-P') \]

\[ B_0 \to \pi^0 K^0 \]
\[ -(C'-P') \]

\[ B^0 \to \pi^+ \pi^- \]

\[ B^+ \to K^+ \]

\[ B^0 \to \pi^+ K^- \]
\[ -(T+p) \]

\[ B_0 \to \pi^- K^+ \]
\[ -(T+p') \]

\[ B_0 \to K^+ K^- \]
\[ B_0 \to \pi^+ \rho^- \]
\[ -(T+p') \]

\[ B_0 \to K^+ K^- \]
\[ B_0 \to \pi^+ \rho^- \]
\[ -(T+p') \]
\( \Rightarrow SU(3) \) relationships

\[
T + C = (T + p')/\gamma + (c' - p')/\rho
\]

\[
T + C = (T' + c' + p')/\rho - \frac{p'}{r}
\]

\[
(T' + p' - p') = r \int (T + p') - p' \phi
\]

Weak phases

\( \phi_T = \phi_c = \gamma \quad \phi_p = \beta \)

CP conjugate amplitudes \( \phi \leftrightarrow -\phi \)

Geometrical constructions:

\[ (T' + c' + p')/\rho \]

\[ \frac{p'}{r} \]

\[ T + C \]
Problems: ± 20% connection to sides $T + C + P'$ and $P'$ from $SU(3)$

For $T \Rightarrow$ axial operator $\frac{f_T}{f_K}$

For $C, P \Rightarrow$ no reason that $\frac{f_C}{f_K}$ is correct

$SU(3)$ connection

More sophisticated — using all 13 rates allow arbitrary $SU(3)$ connection $|P| \leftrightarrow |P'|$

but assume $SU(3)$ symmetric strong phase

? what error does that give?