CP VIOLATION
&
B Physics
Interference and rho pi

Lecture #12

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\[ \int \text{Isospin} \]
\[ \text{Interference effects} \]

Review \text{Isospin} \quad I_b = 0 \rightarrow I_{\text{ud}} = \frac{1}{2} \text{ or } \frac{3}{2} \]
\[ I_f = I_{\text{ud}} \quad \text{(and Jcd)} \]

\[ \begin{array}{c}
\frac{1}{2} \\
\text{Tree} + \\
\text{Penguin} \\
\end{array} \quad \rightarrow \quad \begin{array}{c}
\frac{3}{2} \\
\text{Tree only} \\
\end{array} \]

\[ A_{\frac{3}{2}0} = T_{\frac{3}{2}0} + P_0 \]
\[ A_{\frac{3}{2}1} = T_{\frac{3}{2}1} + P_1 \]
\[ A_{\frac{3}{2}2} = \frac{T_{\frac{3}{2}2}}{2} \]

\text{Reminder:}

\[ T = \text{"tree dominated" - includes penguin part} \]

with same AI and same weak phase $V_{ub}V_{ud}^\ast (P_e - P_c)$

\[ P = V_{ub}V_{td}^\ast (P_e - P_c) \]

= penguin-only term with different weak phase from tree

Note that \[ \text{Im} \left( \frac{g}{f} \frac{\bar{P}}{P} \right) = 0 \quad \textbf{known weak phase, decay phase cancels mixing phase} \]
Keeping track of Clebsch-Gordan coefficients

\[ A_{ij} = \langle \rho^i \pi^j | H | \pi^k \rangle = \]

\[ \sum_{\Delta I \Gamma_f} \frac{A_{\pi^i \pi^j} (1, i, j | \Gamma_f k \Gamma_f \sum (\Delta I \frac{3}{2}, \Gamma_f b \Gamma_f k \Gamma_f \Delta I (b \rightarrow u \bar{u}d \text{ or } d \bar{d}) \Delta I = \frac{1}{2}, \frac{3}{2}, \Delta I_2 = + \frac{1}{2})}{\Gamma_f} \]

Note \( B_k \Rightarrow \frac{B_{k+2}}{B_{k-2}} \)

So we find

\[ A_{\pi^0} \]
\[ G_{\pi^0 \pi^0} \]
\[ A_{\pi^+} \]
\[ G_{\pi^+ \pi^0} \]
\[ A_{\pi^+ \pi^0} \]
\[ G_{\pi^+ \pi^0} \]
\[ A_{\pi^0} \]
\[ G_{\pi^0 \pi^0} \]

5 channels
+ CP conjugates

\[ \begin{align*}
  & G (4T, 2P) \text{ amplitudes} \\
  & (\text{in } \sigma \text{ linear combinations}) \ \ A_{\sigma i, j}
\end{align*} \]
Things to notice

(1) $A_{+}^{-}$ and $A_{+}^{+}$ contain same linear combination of $A_{21}^{+}$ and $A_{-21}^{-}$

$A_{+0}$ and $A_{-0}$ have a different combination

(2)

$$A_{+0} = \frac{3}{5} \left( A_{+1}^{+} - \frac{1}{2} A_{-21}^{-} \right)$$

Not in neutals

$$A_{+0} + A_{0+} = \frac{3}{5} \frac{S_{2}}{2} A_{3/2}^{0}$$

$I=2$ only

$$A_{+}^{-} + A_{-}^{+} + 2A_{00} = \frac{\sqrt{2}}{3} A_{3/2,2}$$

No penguin

$\Rightarrow$ geometrical construction - 5-sided figure

$$\mathbf{q} = q_{0} \mathbf{A}$$

Not likely to be useful

12.3

BUT

$\pi^{+}\pi^{0}\pi^{0}$ difficult?

$\frac{2}{3} A_{+0}$ sensitive to errors/ambiguities in construction

Le ambassadors in corrections
Further χ helicity = 1 = χD distribution

\[ R_{\chi} = \frac{1}{2} A_+ + A_- \]

Neutral channels only

\[ B \rightarrow T \pi^+ \pi^- \]

Dalitz plot (with exaggerated \( \rho \) bands)

\[ R = \frac{1}{2} A_+ + A_- \]
\[ A_{\pi^+\pi^-\eta^0} = f_0 A_{00} + f_+ A_{+-} + f_- A_{-+} \]

\[ f = \rho \text{ decay kinematic dependence} \]

\[ \cos \theta \text{ from helicity} 1 \]

\[ \text{Breit Wigner} \quad \frac{1}{(P_1+P_2)^2 - m_\rho^2 + i m_\rho \Gamma_\rho} \]

\[ \text{Real Part} \quad \uparrow \quad \text{Imaginary Part} \]

\[ \text{known strong phase behaviour in NN at } \rho \]

\[ \Rightarrow \text{kinematically varying strong phase} \]

\[ \text{Assume this variation dominates} \]

\[ \text{strong phase variation across the Dalitz plot} \]

\[ \text{i.e. each amplitude has fixed strong phase in addition to that from } \rho \text{ Breit Wigner} \]
Multivariable fit to Dalitz plot

(P bands)

3 independent tree amplitudes

2 penguin amplitudes

$\alpha$ tree weak phase $q_0^+ \frac{T}{T} = e^{\pi i \alpha}$

Penguin weak phase $= 0$

Note $\Rightarrow \text{Im } \frac{q f_i^* f_i A_i A_i^*}{p} \Rightarrow \sin 2\alpha$ terms

Terms like $\Rightarrow \text{Im } \frac{q f_i^* f_i A_i A_i^*}{p}$

$= \sin (\text{arg } f^* f) \cos 2\alpha$

Fixes $\sin 2\alpha$

and $\cos 2\alpha$

Resolves $\alpha \leftrightarrow \pi - \alpha$ ambiguity
Another similar case: $K\pi\pi$

$B \rightarrow K^*\pi$ \hspace{1cm} $B \rightarrow K\rho$

$b$-quarks and $d\bar{d}$'s

Tree amplitude: $V_{ub}^*V_{us}$ \hspace{1cm} $O(\lambda^4)$

Penguin: $V_{cb}V_{cs}^* (P_e-P_T)$ \hspace{1cm} Pure $\Delta I = \frac{1}{2}$

$O(\lambda^2)$

$\beta$ parameters

1: Amplitude for $K\pi\pi$ decays
2: Amplitude for $K\rho$ decays

Same weak phase for all $\beta$'s

$\Rightarrow$ Dalitz plot fitting with fewer parameters to test method.
Issues still being explored

- Background sensitivity $\Leftrightarrow$ more parameters in fits!

- Non-resonant $B \rightarrow \pi\pi\pi$
  $\Rightarrow$ populates non-p regions of plot

- Other resonances

  $q \rightarrow \pi^+ \pi^- \rho^0$

  $\Rightarrow$ If any are significant
  then new information from new overlap regions

  BUT

  even more parameters
Adding back charge channels

\[ B^+ \rightarrow \pi^+ \pi^+ \pi^- \]  \quad - no new constraint

1 new amplitude and 2 new rates \[ B^+ \rightarrow \pi^+ \pi^0 \pi^0 \]

2 more parameters

So we need \[ B^+ \rightarrow \pi^+ \pi^0 \pi^0 \] to gain new information on existing (neutral B) parameters

2 neutral pions + "hard" + "soft" (in B rest frame)

? How hard is this to do experimentally?

- so far not studied as far as I know

Note: CLEO has yet to see \( \pi \pi \)!

Boost (separated B vertices) may help suppress backgrounds
Beyond Isospin \( \Rightarrow \) SU(3) relationships

e.g. \( K \pi \) penguin dominated

\[ \rightarrow \text{SU(3)} \]

local quark operators

\begin{align*}
&b \quad s \quad o \quad d \\
&u \bar{u} + d \bar{d}
\end{align*}

penguin amplitude for \( \pi \pi \)

\[ \langle 0 \mid \bar{q}_8 \gamma_5 q \mid \pi \pi \rangle = f_\pi q_\pi \\
f_K q_K
\]

\[ \frac{f_K}{f_\pi} \sim 1.2 \]

\[ = 1 \text{ in SU(3) limit} \]

But operator making \( \pi \) or \( K \) is not always an axial current

What then?
As a way to estimate size of TTH penguin terms

$$SV(3) \Rightarrow \pm 20\% \text{ error or c}$$

As a way to construct geometrical relationships to extract \( n \)

\( \Rightarrow \) large uncertainties in \( n \)

(but still may be best available method.)

Note also Electroweak penguins can be

a large effect in \( K\bar{K} \)

\( \Rightarrow \) further source of error.
A few References

I. spin
Gronau & London
PRL 65 2381 (1990)

II. Quinn & Snyder
PRD 48 2189 (1993)

(beware of sign errors!)

SU(3)
Gronau, Hernandez, London & Rosner
PRD 50 4529 (1994)

Electroweak penguin - review
- Fleischer
    hep-ph/9612446

A good review article

Buras
    hep-ph/9509329