CP VIOLATION
&
B Physics

Interference and rho pi

Lecture #12

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$\rho\pi$ $\begin{cases} \text{Isospin} \\ \text{Interference effects} \end{cases}$

Review Isospin $\quad I_b = 0 \rightarrow I_{u\bar{u}d} = \tfrac{1}{2}$ or $\tfrac{3}{2}$

$I_f = I_{u\bar{u}d\bar{d}}$ (or $d\bar{d}d\bar{d}$)

$$
\begin{array}{lccccc}
\Delta I & & \tfrac{1}{2} & & \tfrac{3}{2} & \\
 & \swarrow & \boxed{\text{Tree + Penguin}} & \searrow \;\; \swarrow & \boxed{\text{Tree only}} & \searrow \\
I_f & 0 & & 1 & & 2
\end{array}
$$

$A_{\frac{1}{2}0} = T_{\frac{1}{2}0} + P_0 \qquad A_{\frac{1}{2}1} = T_{\frac{1}{2}1} + P_1 \qquad A_{\frac{3}{2}2} = T_{\frac{3}{2}2}$

$A_{\frac{3}{2}1} = T_{\frac{3}{2}1}$

Reminder

$T =$ "tree dominated" — includes penguin part with same ΔI and same weak phase $V_{ub}V_{ud}^* (p_u - p_c)$

$P = V_{tb}V_{td}^* (p_t - p_c)$

= penguin-only term with different weak phase from tree

Note that $\mathrm{Im}\left(\frac{q}{p}\frac{\bar{P}}{P}\right) = 0 \Leftarrow$ <u>known weak phase</u>, decay phase cancels mixing phase

12.1

Keeping track of Clebsch Gordan coefficients

$A_{ij} = \langle \rho^i \pi^j | \mathcal{H} | B^k \rangle =$

spectator I-spin

$$\sum_{\Delta I\, I_f} A_{\Delta I, I_f} (1\, i; 1\, j \,|\, I_f\; k+\tfrac{1}{2})(\Delta I\, \tfrac{1}{2}; I_b\, k \,|\, I_f\; k+\tfrac{1}{2})$$

Note $B^k \Rightarrow \begin{matrix} \bar{b}u \\ \bar{b}d \end{matrix}$ $I_B = \tfrac{1}{2}$ $\begin{matrix} k=+\tfrac{1}{2} \\ k=-\tfrac{1}{2} \end{matrix}$

ΔI ($b \to u\bar{u}\bar{d}$ or $d\bar{d}\bar{d}$)

$\Delta I = \tfrac{1}{2}, \tfrac{3}{2}$ $\quad \Delta I_2 = +\tfrac{1}{2}$

So we find

$A(+0)$ $\hookrightarrow \pi^+\pi^0\pi^0$ $\quad \frac{1}{\sqrt{2}}\left(1.A_{\frac{1}{2}1} - \frac{1}{2} A_{\frac{3}{2}1}\right) + \frac{1}{\sqrt{2}} \frac{\sqrt{3}}{2} A_{\frac{3}{2}2}$

A_{0+} $\hookrightarrow \pi^+\pi^-\pi^+$ $\quad \frac{-1}{\sqrt{2}}\left(1.A_{\frac{1}{2}1} - \frac{1}{2} A_{\frac{3}{2}1}\right) + \frac{1}{\sqrt{2}} \frac{\sqrt{3}}{2} A_{\frac{3}{2}2}$

A_{+-} $\pi^+\pi^0\pi^-$ $\quad \frac{1}{\sqrt{3}} \frac{1}{\sqrt{2}} A_{\frac{1}{2}0} + \frac{1}{\sqrt{2}}\left(\frac{1}{\sqrt{2}} A_{\frac{1}{2}1} + \frac{\sqrt{3}}{2} A_{\frac{3}{2}1}\right) + \frac{1}{\sqrt{6}} \frac{1}{2} A_{\frac{3}{2}2}$

A_{-+} $\hookrightarrow \pi^-\pi^0\pi^+$ $\quad \frac{1}{\sqrt{3}} \frac{1}{\sqrt{2}} A_{\frac{1}{2}0} - \frac{1}{\sqrt{2}}\left(\frac{1}{\sqrt{2}} A_{\frac{1}{2}1} + \frac{\sqrt{3}}{2} A_{\frac{3}{2}1}\right) + \frac{1}{\sqrt{6}} \frac{1}{2} A_{\frac{3}{2}2}$

A_{00} $\hookrightarrow \pi^+\pi^-\pi^0$ $\quad -\frac{1}{\sqrt{3}} \frac{1}{\sqrt{2}} A_{\frac{1}{2}0} + \sqrt{\frac{2}{3}}\, \frac{1}{2} A_{\frac{3}{2}2}$

5 channels
+ CP conjugate 5

6 (4T, 2P) amplitudes
(in ~~4~~ linear combinations) $A_{\Delta I, I}$

Things to notice

(1) A_{+-} and A_{-+} contain same linear combination of $A_{1/2,1}$ and $A_{3/2,1}$

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

(2)

$$A_{+0} - A_{0+} = \frac{2}{\sqrt{2}}\left(A_{1/2,1} - \tfrac{1}{2}A_{3/2,1}\right)$$ ← Not in neutrals

$$A_{+0} + A_{0+} = \frac{2}{\sqrt{2}}\,\frac{\sqrt{3}}{2}\,A_{3/2,2}$$

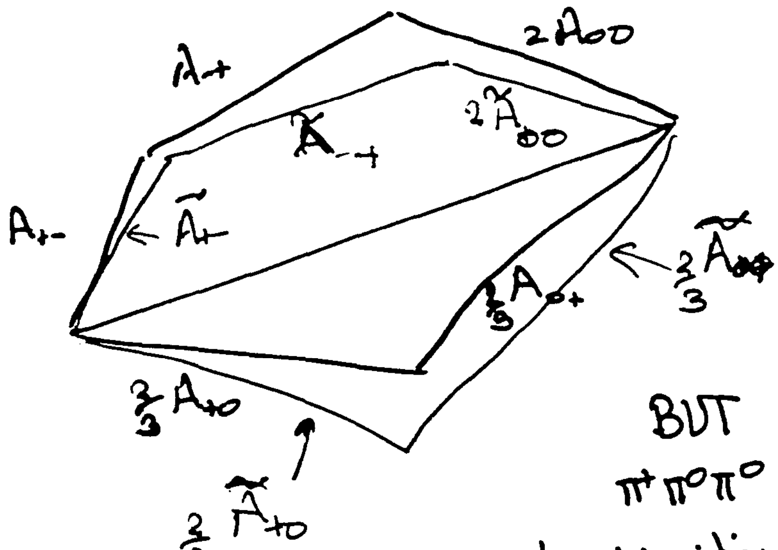
$$A_{+-} + A_{-+} + 2A_{00} = \sqrt{\tfrac{2}{3}}\,A_{3/2,2}$$

I=2 only

no penguin

⇒ geometrical construction – 5 sided figure

$\tilde{I} = q_p \bar{A}$



Not likely to be useful

BUT

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

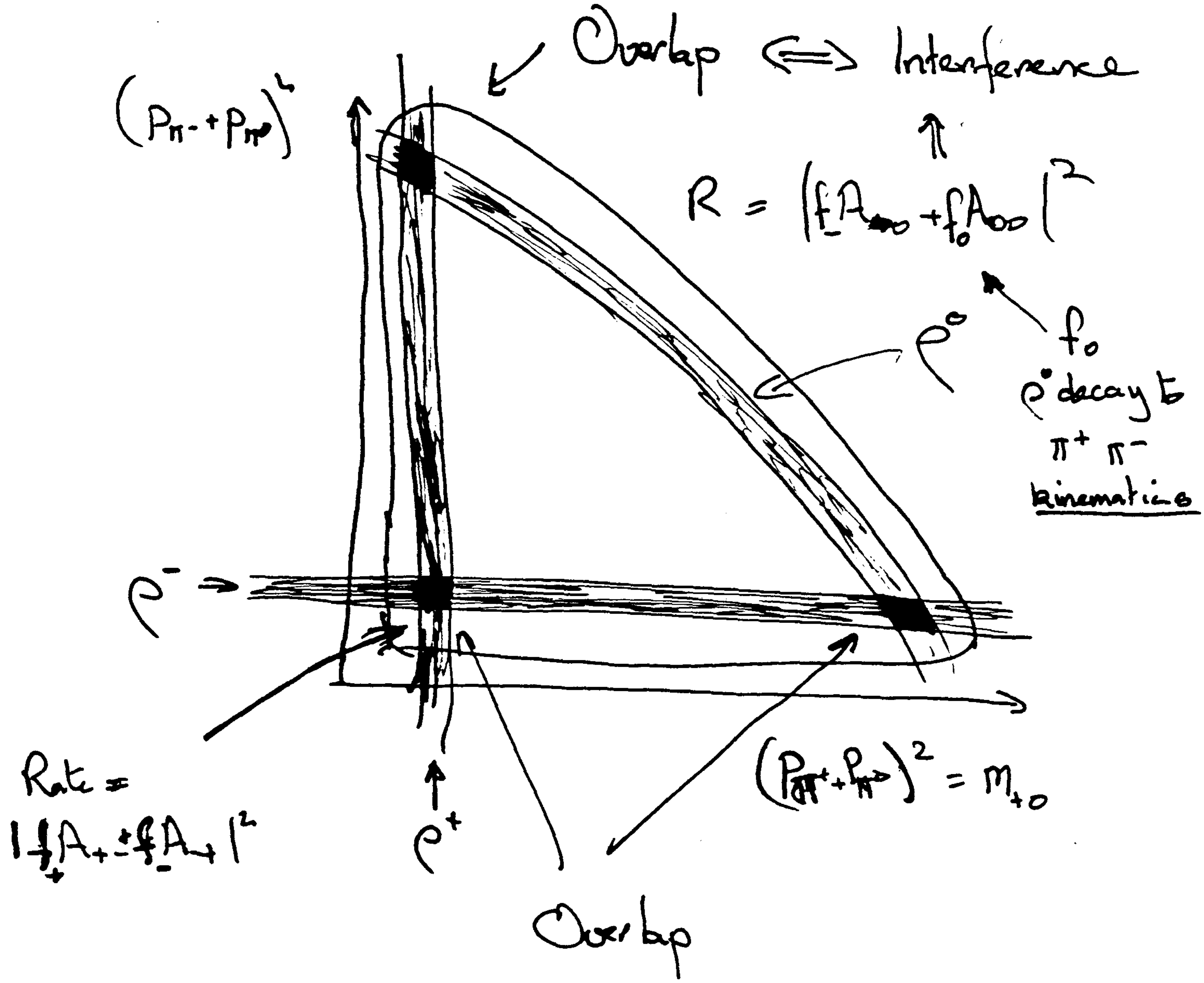
sensitive to errors / ambiguities in construction

↳ ambiguities in corrections

Neutral channels only

$B \rightarrow \pi^+ \pi^- \pi^0$

Dalitz plot (with exaggerated ρ bands)



Further ρ helicity $= 1 \Rightarrow \cos\theta$ distribution

12.34 $\Rightarrow$ more events toward corners of plot.

$$A_{\pi^+\pi^-\pi^0} = f_0 A_{00} + f_+ A_{+-} + f_- A_{-+}$$

f = ρ decay kinematic dependence

— $\cos\theta$ from helicity 1 ρ

— Breit Wigner

$$\frac{1}{\underbrace{(P_1+P_2)^2 - m_\rho^2}_{\text{Real Part}} + \underbrace{i m_\rho \Gamma_\rho}_{\text{Imaginary Part}}}$$

known strong phase behavior in $\pi\pi$ at ρ $\Longrightarrow$ kinematically varying strong phase

Assume this variation dominates strong phase variation across the Dalitz plot

i.e. each amplitude has fixed strong phase in addition to that from ρ Breit Wigner

12.IV

$\Rightarrow$ Multivariable fit to Dalitz plot (ρ bands)

		# parameters
3	independent tree amplitudes	5
2	~~fr~~penguin amplitudes	4
α	tree weak phase $\frac{q}{p}\frac{\bar{T}}{T} = e^{2i\alpha}$	1
	penguin ~~w~~eak phase $= 0$	0
		10

Note $\Rightarrow$ $\mathrm{Im}\,\frac{q}{p} f_i^* f_i A_i^* \bar{A}_i \Rightarrow \underline{\sin 2\alpha}$ terms

terms like $\Rightarrow$ $\mathrm{Im}\,\frac{q}{p} f_+^* f_0 A_+^* \bar{A}_0$

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

$\uparrow$

* Fixes $\sin 2\alpha$ and $\cos 2\alpha$ $\Longrightarrow$ Resolves $\alpha \Leftrightarrow \pi - \alpha$ ambiguity

Another similar case $K\pi\pi$

$B \to K^{*}\pi$ $\qquad$ $B \to K\rho$

$b \to u\bar{u}s$ and $d\bar{d}s$

Tree amplitude $\quad V_{ub}V_{us}^{*}$ $\quad$ – includes $(P_u - P_t)$

$\qquad \qquad \qquad \qquad O(\lambda^4)$

Penguin $\quad V_{cb}V_{cs}^{*}\ (P_c - P_t)$ $\Rightarrow$ Pure $\Delta I = 1/2$

$\qquad \qquad \qquad \qquad O(\lambda^2)$

	# parameters
∴ 1 amplitude for $K\pi$ decays	1
1 amplitude for $K\rho$ decays	2

Same weak phase for all (β)

$\rightarrow$ Dalitz plot fitting with fewer parameters to test method

Issues still being explored

* Background sensitivity $\Longleftrightarrow$ more parameters in fits !

  - Non-resonant $B \to \pi\pi\pi$

    $\Rightarrow$ populates non-ρ regions of plot

  - Other resonances

    eg $f_2\pi$ .... $\rho'\pi$ .....

    $\to \pi^+\pi^-\pi^0$

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

    BUT

    even more parameters

Adding back charge channels

$B^+ \to \pi^+\pi^+\pi^-$ — no new constraint

1 new amplitude and 2 new rates $\nearrow B^+$ $\searrow B^-$

← 2 more parameters

So we need $\underline{B^+ \to \pi^+\pi^0\pi^0}$ to gain new information on existing (neutral B) parameters

2 neutral pions 1 "hard" 1 "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 $\rho\pi$!

Boost (separated B vertices) may help supress backgrounds

Beyond Isospin $\Leftrightarrow$ SU(3) relationships

e.g. $K\pi$ penguin dominated

$\nwarrow\!\!\searrow$ SU(3)

penguin amplitude for $\pi\pi$

Local 4 quark operator

? SU(3) breaking effects

$$\langle 0 | \bar{q}\gamma_\mu\gamma_5 q | \begin{matrix}\pi \\ K\end{matrix} \rangle = \begin{matrix} f_\pi q_\mu \\ f_K q_\mu \end{matrix}$$

$$f_K / f_\pi \sim 1.2$$

$= 1$ in SU(3) limit

But operator making π or K is not always an axial current

What then?

As a way to estimate size of

$\pi\pi$ penguin terms

SU(3) $\Rightarrow$ $\pm 20\%$ error OK

As a way to construct geometrical

relationships to extract γ

$\Rightarrow$ large uncertainties in γ

(but still may be best available method.)

<u>Note also</u> Electroweak penguins can be

a large effect in $K\pi$

$\Rightarrow$ further source of error.

A few References

I-spin Gronau & London PRL 65 3381 (1990)

$\rho\pi$ Quinn & Snyder PRD 48 2139 (1993)
(beware of sign errors!)

SU(3) Gronau Hernández London & Rosner
PRD50 4529 (1994)

Electroweak penguin-review – Fleischer
hep-ph/9612446

A good review article

Buras hep-ph 9509329