CP violation in $B \to \pi\pi$ and $B \to KK$

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This was motivated by R.Fleischer, PLB 459 (1999) 306.

- Measure $A_{dir\ CP}$ in $B_d \to \pi^+\pi^-$
- Measure $A_{mix\ CP}$ in $B_s \to K^+K^-$
- Measure $A_{dir\ CP}$ in $B_s \to K^+K^-$
- Use U-spin argument to relate these measurements

$\Rightarrow$ determine γ without hadronic uncertainties???

Expected Yields for 2fb^{-1} in Run II

CLEO Measurements

$$
\begin{aligned}
\mathcal{B}(B_d \to \pi^+\pi^-) &= (4.3 \pm 1.6) \times 10^{-6} \\
\mathcal{B}(B_d \to K^+\pi^-) &= (17.2 \pm 2.8) \times 10^{-6}
\end{aligned}
$$

Assume SU(3) and $B_d/B_s \sim 2.5$

$B_d \to \pi^+\pi^-$	$B_d \to K^+\pi^-$	$B_s \to \pi^+K^-$	$B_s \to K^+K^-$
1	4	0.5	2
4-7k	16-28k	2-4k	8-14k

Time Evolution of various A_{cp}

$$unmixed:$$

$$\frac{B_d\to K^+\pi^- - \bar{B}_d\to\pi^+K^-}{B_d\to K^+\pi^- + \bar{B}_d\to\pi^+K^-} = \frac{|A|^2-|\bar{A}|^2}{|A|^2+|\bar{A}|^2}$$

$$mixed:$$

$$\frac{B_d\to K^-\pi^+ - \bar{B}_d\to\pi^-K^+}{B_d\to K^-\pi^+ + \bar{B}_d\to\pi^-K^+} = -\frac{|A|^2-|\frac{q}{p}|^4|\bar{A}|^2}{|A|^2+|\frac{q}{p}|^4|\bar{A}|^2}$$

$$\frac{B_d\to\pi^+\pi^- - \bar{B}_d\to\pi^+\pi^-}{B_d\to\pi^+\pi^- + \bar{B}_d\to\pi^+\pi^-} = A\times\sin(\Delta m_d t+\phi_d)$$

$$\frac{B_s\to K^+K^- - \bar{B}_s\to K^+K^-}{B_s\to K^+K^- + \bar{B}_s\to K^+K^-} = \frac{2e^{-\langle\Gamma\rangle t}}{e^{-\Gamma_H t}+e^{-\Gamma_L t}+A_{\Delta\Gamma}(e^{-\Gamma_H t}-e^{-\Gamma_L t})}\times A\times\sin(\Delta m_s t+\phi_s)$$

All A_{cp} have different time dependence

$$|A| = \sqrt{(A_{cp}^{dir})^2+(A_{cp}^{mix})^2}$$

$$\tan\phi = -A_{cp}^{dir}/A_{cp}^{mix}$$

$$1 = (A_{cp}^{dir})^2+(A_{cp}^{mix})^2+(A_{\Delta\Gamma})^2$$

from untagged lifetime fit :

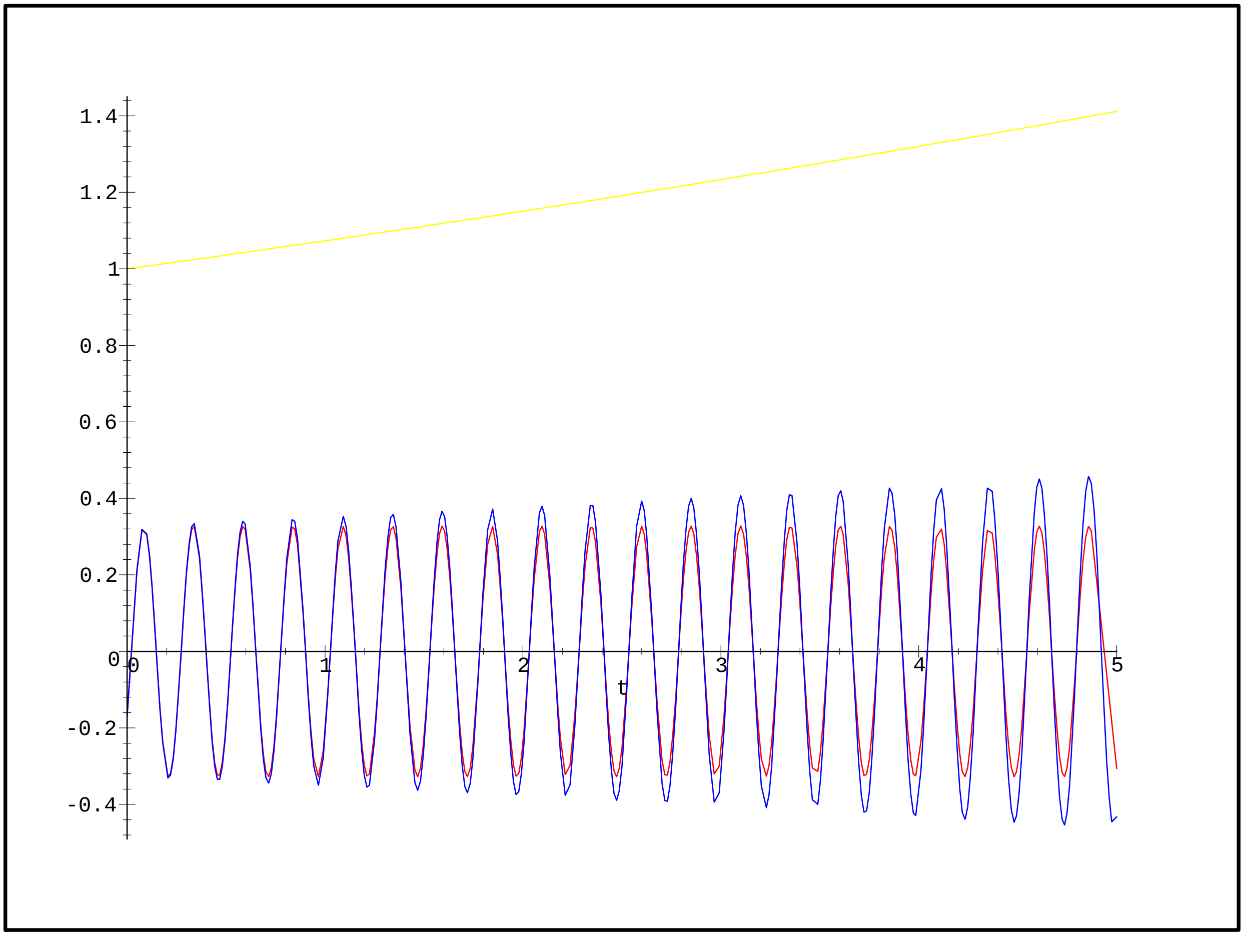
$$A_{\Delta\Gamma} = (R_H-R_L)/(R_H+R_L)$$

List of Observables

- Relative BR of $B_d \to \pi^+\pi^-, K^\pm\pi^\mp$
- Relative BR of $B_s \to K^+K^-, K^\pm\pi^\mp$
- Direct CP violation in $B_d \to K^+\pi^-$
- Direct CP violation in $B_s \to K^-\pi^+$
- A_{cp}^{mix},A_{cp}^{dir},$A_{\Delta\Gamma}$ in tagged $B_d \to \pi^+\pi^-$
- A_{cp}^{mix},A_{cp}^{dir}, $A_{\Delta\Gamma}$ in tagged $B_s \to K^+K^-$
- $A_{\Delta\Gamma}$ in untagged $B_s \to K^+K^-$ decays
- $A_{\Delta\Gamma}$ in untagged $B_d \to \pi^+\pi^-$ decays
- mean lifetime of $B_d \to \pi^+\pi^-$
- mean lifetime of $B_s \to K^+K^-$

All but three of these are interesting within SM

A_{cp} for $B_s \to K^+K^-$



Experimental Requirements

- 2 track Trigger (see last workshop, or Tanaka WG3)
- distinguish $K\pi/\pi\pi/KK$ for B_s and B_d
  - fit untagged sample in m_B and dE/dx

  $\rightarrow$ results from Toy MC
- tagging (see last workshop, or Jones WG3)
- Measure CP violating oscillations

  $\rightarrow$ Toy MC fits (Craig Blocker)

  $\rightarrow$ analytic error calculation

The untagged sample

```
                Conservative    Nominal
mass res. = 30MeV,              20MeV
dEdx sep. = 0.7sigma            1.3sigma
Bd:
Nkpi = 20k +- 260(190)          +-190(160)
Npipi=  5k +- 270(190)          +-140(110)
Bs:
Nkk   = 10k +- 280(220)         +-160(140)
Npik = 2.5k+- 200( 95)          +-120( 64)

    Numbers in () are without bkg.
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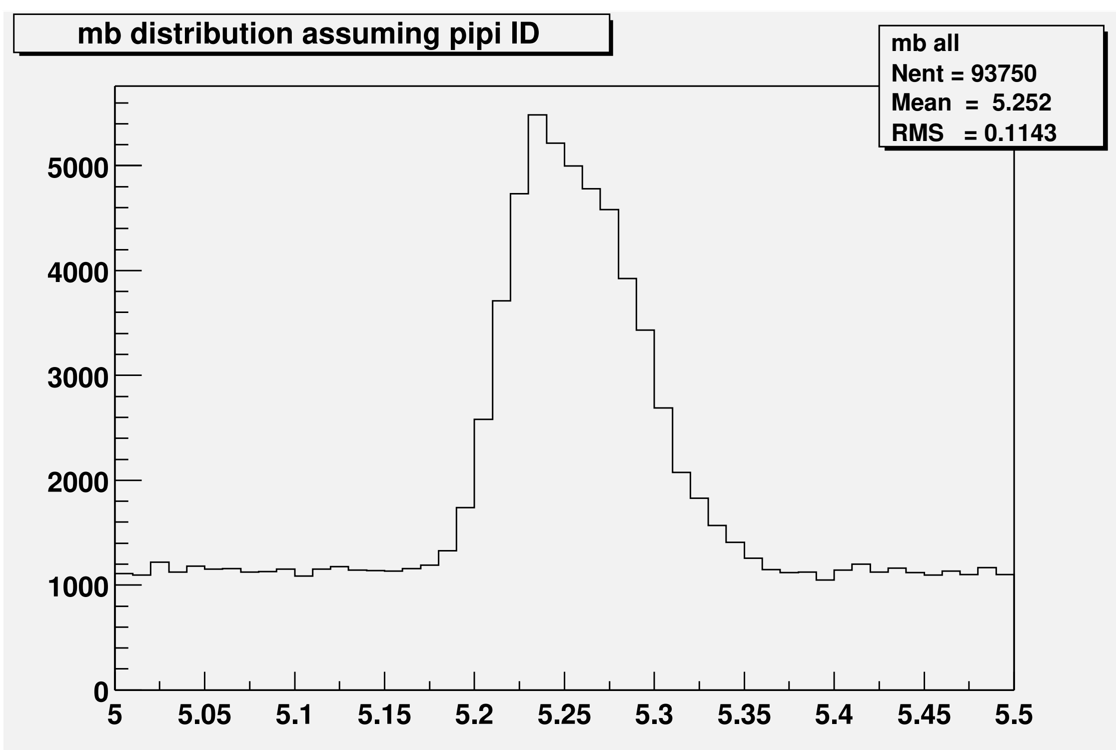


Sensitivity for A_{cp} — analytical expressions

$$A_{cp} = A \times \cos xt + B \times \sin xt$$

Ignore $\Delta\Gamma$ for now, G = inverse of cov. matrix

i.e. $\sigma_A^2 = G_{AA}^{-1} \times (1-\rho^2)^{-1}$

$\sigma_{Acp} \sim 0.08$ for $B_s \to K^+K^-$ and $x_s \sim 25$

$$\begin{aligned}
G_{AA} &= N/2 \times \epsilon D^2 \times \frac{S}{S+1} \times e^{-(x_s\sigma_t/\tau)^2} \\
&\sim 283 \times (0.70 - 0.24) \text{ for } \mathrm{x_s} = 20 - 40 \\
G_{BB} &= G_{AA} \\
G_{AB} &\sim 3 (\text{i.e. negligible})
\end{aligned}$$

Sensitivity for A_{cp} — analytical expressions

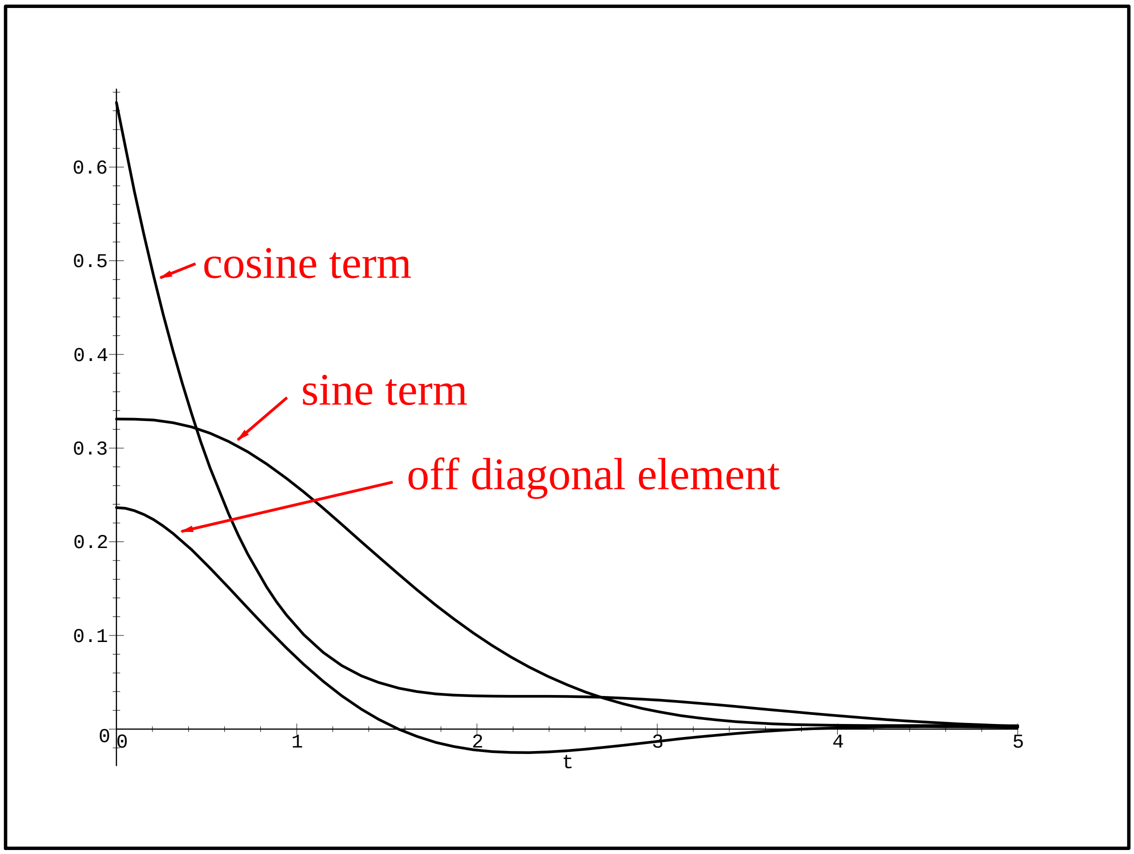
$$A_{cp} = A \times \cos xt + B \times \sin xt$$

$$\sigma_{Acp} \sim 0.14 \text{ for } B_d \to \pi^+\pi^-$$

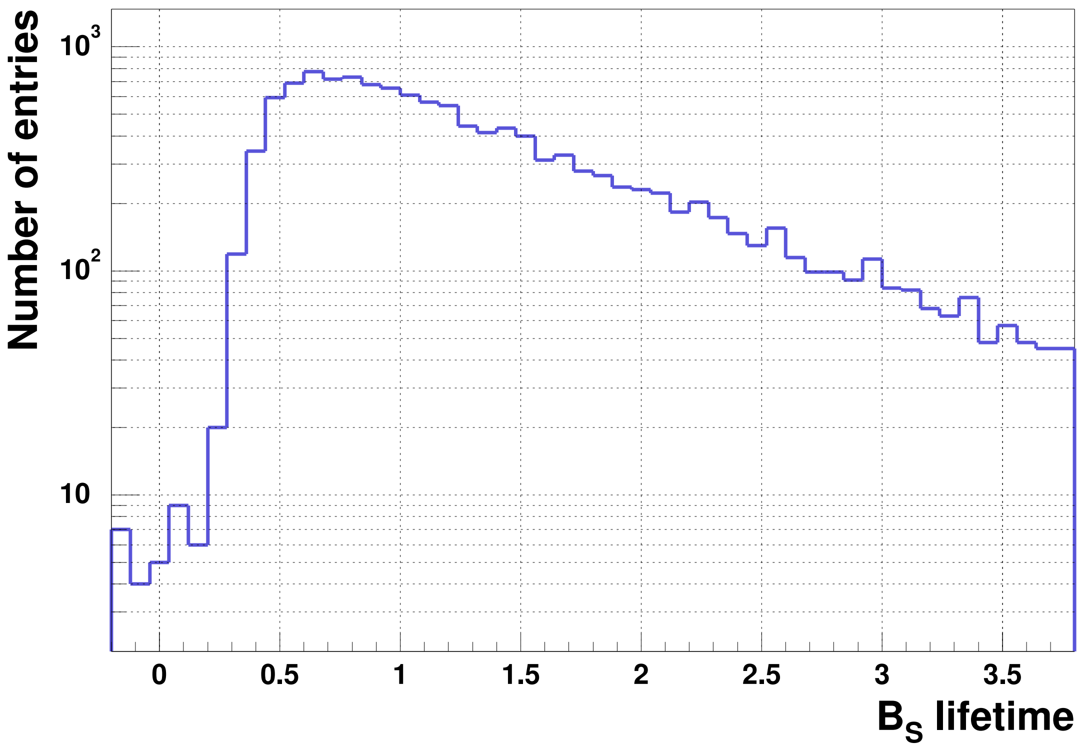
$$\begin{aligned}
G_{AA} &= N_{0.5} \times e^{-(T-0.5)}(1 + f(T)) \\
&\sim 72(\text{ for T} = 0.5) \\
G_{BB} &= N_{0.5} \times e^{-(T-0.5)}(1 - f(T)) \\
&\sim 79(\text{ for T} = 0.5) \\
G_{AB} &\sim 44(\text{ for T} = 0.5)
\end{aligned}$$

$$\begin{aligned}
N_{0.5} &= N/2 \times \epsilon D^2 \times \tfrac{S}{S+1} \times e^{-0.5} \sim 76 \\
f(T) &= (\cos 2x_d T - 2x_d \sin 2x_d T)/(1 + 4x_d^2) \\
f(0.5) &= -0.046(\text{ i.e. negligible}) \\
f(1) &= -0.41(\text{ i.e. sizable})
\end{aligned}$$

Dependence of G on lifetime cut



GEANT simulation incl. 2 track trigger



(Thanks to K. Anikeev MIT)

Inputs for previous pages:

$$B_s \to K^+ K^-$$

- $\epsilon D^2 = 11.3\%$ (Blocker: 10%)
- reconstructed yield = 10,000 events
- signal/bkg = 1
- $\sigma_{ct}/\tau = 3\%$ (Blocker: 3.33%)
- $x_s = 25 \to \sigma_A = 8\%$, $x_s = 40 \to \sigma_A = 12\%$

$$B_d \to \pi^+ \pi^-$$

- $x_d = 0.7$
- $\epsilon D^2 = 9.1\%$ (Blocker: 10%)
- reconstructed yield = 5,000 events
- signal/bkg = 1/2
- T = 0.5 (Blocker: ??)

Note: Blocker does simultaneous fit to $\pi\pi$ and KK

Blocker: $\sigma^{\pi\pi}_{Adir/mix} = 0.10/0.14$, $\sigma^{KK}_{Adir/mix} = 0.10/0.10$

fkw: $\sigma^{\pi\pi}_{Adir/mix} = 0.14/0.14$, $\sigma^{KK}_{Adir/mix} = 0.08/0.08$

Theoretical Interpretation

(R.Fleischer PLB459 (1999) 306)

χ^2 fit to 5 experimental results

Four unknowns:

- $d =$ ratio of hadronic matrix elements
- $\theta =$ phase of ratio of hadronic matrix elements
- $\gamma, \beta =$ weak phases

Five observables:

$$A_{cp}^{dir}(\pi^+\pi^-) = -\frac{2d\sin\theta\sin\gamma}{1-2d\cos\theta\cos\gamma+d^2}$$

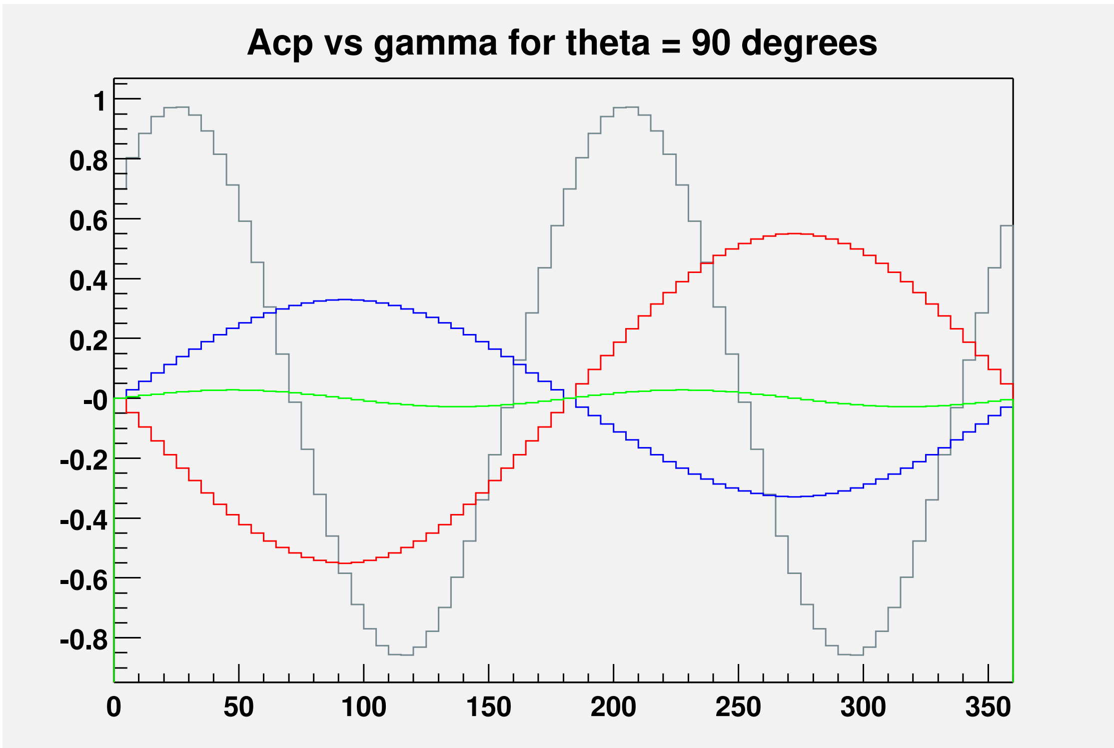
$$A_{cp}^{dir}(K^+K^-) = \frac{2d\frac{1-\lambda^2}{\lambda^2}\sin\theta\sin\gamma}{1+2d\frac{1-\lambda^2}{\lambda^2}\cos\theta\cos\gamma+(\frac{1-\lambda^2}{\lambda^2})^2d^2} \sim \frac{2\lambda^2}{d}\sin\theta\sin\gamma$$

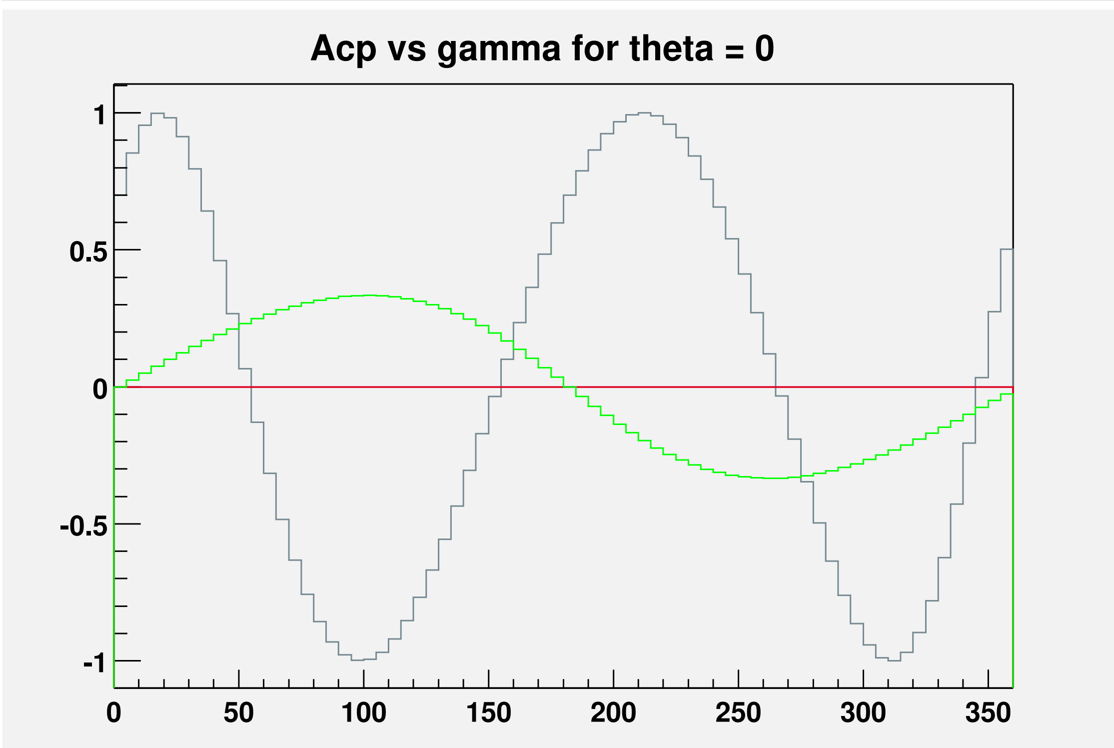
$$A_{cp}^{mix}(K^+K^-) = \frac{\sin 2\gamma+2d\frac{1-\lambda^2}{\lambda^2}\cos\theta\sin\gamma}{1+2d\frac{1-\lambda^2}{\lambda^2}\cos\theta\cos\gamma+d^2(\frac{1-\lambda^2}{\lambda^2})^2} \sim \frac{2\lambda^2}{d}\cos\theta\sin\gamma$$

$$A_{cp}^{mix}(\pi^+\pi^-) = \frac{\sin 2(\beta+\gamma)-2d\cos\theta\sin(2\beta+\gamma)+d^2\sin 2\beta}{1-2d\cos\theta\cos\gamma+d^2}$$

$$\sin 2\beta = 0.70 \pm 0.05$$

What to expect $(d = 0.3, \gamma = 70°, \beta = 22.2°)$





Simplified Example:

Take $\sin 2\beta = 0.7$, $\gamma = 70^\circ$, $d = 0.3$, $\theta = 0$.

$$\begin{aligned} \rightarrow \quad \sin(2\beta+\gamma) &\sim \sin\gamma \\ \rightarrow \quad \sin(2\beta+2\gamma) &\sim 0 \end{aligned}$$

Equations simplify:

$$\begin{aligned} A_{cp}^{dir}(\pi^+\pi^-) &= -\tfrac{2d\sin\theta\sin\gamma}{1-2d\cos\gamma+d^2} &\sim& \quad 0 \\ A_{cp}^{dir}(K^+K^-) &\sim \tfrac{2\lambda^2}{d}\sin\theta\sin\gamma &\sim& \quad 0 \\ A_{cp}^{mix}(K^+K^-) &\sim \tfrac{2\lambda^2}{d}\cos\theta\sin\gamma &\sim& \quad 0.3 \\ A_{cp}^{mix}(\pi^+\pi^-) &\sim \tfrac{-2d\cos\theta\sin(\gamma)}{1-2d\cos\gamma+d^2} &\sim& \quad -0.6 \end{aligned}$$

$A_{\pi\pi} \propto \sin\gamma \times d$, $A_{KK} \propto \sin\gamma / d$

$\Rightarrow$ sensitivity to both d and $\sin\gamma$

$A_{\pi\pi}^{dir} \propto -\sin\theta\sin\gamma$, $A_{KK}^{dir} \propto +\sin\theta\sin\gamma$

$\Rightarrow$ sensitivity to $\sin\theta$ including it's sign.

Conclusion

- Expect CDF to measure A^{dir} and A^{mix} for $B_d \to \pi^+\pi^-$ as well as $B_s \to K^+K^-$.
- χ^2 fit to 4 A's and $\sin 2\beta$ to determine $\sin\gamma$.
- VERY PRELIMINARY assessment of sensitivity looks promising.
- VERY PRELIMINARY assessment of theoretical uncertainties look promising.
- MORE WORK required to make firm conclusions.