Reducing Model Dependence in $\gamma$ from $B \rightarrow D_{CP} K$ with CLEO-c Data

David Asner, University of Pittsburgh
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Introduction
Technique
Sensitivity
Summary
Introduction: Methods for Determining $\gamma$

1. Gronau-London-Wyler Method - yesterday’s WG-5 session
   - $B^- \to D_{CP}K^-$ Statistics Limited
   - BaBar: hep-ex/0408069 & Belle: hep-ex/0307074
   - Proper treatment of multibody $D_-$ modes ($K_S\phi$) equivalent to method 3.
   - CLEO-c will provide constraints on charm mixing

2. Atwood-Dunietz-Soni Method - yesterday’s WG-5 session
   - $B^- \to D K^-$ No signal
   - BaBar: hep-ex/0408028 & Belle: hep-ex/0406067
   - CLEO-c will measure $r_D$ & $\cos \delta_D \sim \pm 10\%$
   - Precise measurement of $r_D$ from B-factories will proportionally improve
     CLEO-c measurement of $\cos \delta_D$.

3. Dalitz plot Method - this talk
   - $B^- \to D_{CP}K^-$, $D_{CP} \to K_s\pi^+\pi^-$, $\pi^+\pi^-\pi^0$, $K_SK^+K^-$
   - Will be limited by uncertainty due to Dalitz plot model
   - CLEO-c: Exploit correlated D’s to reduce Dalitz plot model dependence
CLEO-c & D Tagging

- Pure DD final state, no additional particles \((E_D = E_{\text{beam}})\).
- Low particle multiplicity \(\sim 5-6\) charged particles/event.
- Good coverage to reconstruct \(\nu\) in semileptonic decays.
- Pure \(J^{PC} = 1-\) initial state.

\[e^+e^- \rightarrow \psi(3770) \rightarrow DD\]

Tag one D meson in a selected tag mode.
- Flavor tags \(K^-\pi^+, K^-\pi^+\pi^0, K^-\pi^+\pi^-\pi^+\)
- \(CP^+ K^+K^-, \pi^+\pi^-, K_S\pi^0\pi^0\)
- \(CP^- K_S\pi^0, K_S\omega, K_S\phi\)

Study decays of other D, \((\text{signal D})\)
- \(K_s\pi^+\pi^-\)
- \(\pi^+\pi^-\pi^0\)
- \(K_sK^+K^-\)

Analysis Preview

- Phase difference between \(D^0\) & \(\bar{D}^0\) varies across Dalitz plot – model dependent.
- Simultaneously analyze Dalitz plot vs flavor tag and Dalitz plot vs CP tag.
- Direct measurement of phase difference \(\Rightarrow\) less model dependence on \(\gamma\).
Typically model of D decay described as a function of $m_{\pm} = K_S^0 \pi^\pm$ by a sum over Breit-Wigner Amplitudes

$$|f(m_+^2, m_-^2)|^2 = \left| \sum_j a_j e^{i\phi_j} A(m_+^2, m_-^2) \right|^2$$

Problem for extracting $\gamma$ is due to model dependent phase difference between $f(m_+^2, m_-^2)$ and $f(m_-^2, m_+^2)$
Belle and BaBar have studied the dependence of $\gamma$ on the D decay model

  \[ \phi_3 = \left( 77^{+17}_{-19} \pm 13 \pm 11 \right)^\circ \]

- **BaBar** - ICHEP04 paper hep-ex/0408088
  \[ \gamma = \left( 70 \pm 26 \pm 10 \pm 10 \right)^\circ \]

- Monte Carlo studies with D decay models containing only known resonances lead to assigned modeling systematic error

- Models with arbitrary Breit-Wigners provide a better fit to data and smaller systematic uncertainty $\pm 1^\circ$
CLEO Model: BaBar Data

- CLEO II.V MODEL
    - $\rho, \omega, f_0(980), f_0(1370)$
    - $K^*(892), K_0(1430), K_2(1430), K^*(1680)$
    - DCS $K^*(892)$
    - Small non-resonant
- Clearly not a good representation of Babar data - hep-ex/0406067
  - 15x statistics of CLEO sample

BaBar Data: CLEO Model

- Poor representation of $\pi\pi$ S-wave
- DCS $K^*(892)$
- DCS $K_{0,2}(1430)$
BaBar Data Best Fit to D⁰ → K_s π⁺π⁻

- Model Describes data well
  - CLEO Model “PLUS”
  - σ₁, σ₂, ρ(1450)
  - K₁(1410)
  - DCS K₀(1430) K₂(1430)

- What is “wrong” with this fit?
  - Arbitrary ππ S-wave Breit-Wigner resonances σ₁, σ₂ account for 10% of fit fraction
  - σ₁, σ₂ only from D⁺

- How can CLEO-c data help?
  - K-matrix ππ S-wave model
  - Measure phase difference between f(m_+², m_⁻²) & f(m_⁻², m_+²)
CP Tagged Dalitz Plots

- **Double Tags have very low backgrounds**
  - $\sim 10^{-4}$ for all tracks modes such as $K^+K^-$ vs $K_S\pi^+\pi^-$
  - $\sim 10^{-3}$ for modes with a $\pi^0$ such as $K_S\pi^0$ vs $K_S\pi^+\pi^-$

![Diagrams showing Dalitz plots for different particle interactions](image)

CLEO-c
- Data
- D$^0$ Double Tags

**CLEO-c Data**

- $K^+K^-$ vs $K_S\pi^+\pi^-$
- $K_S\pi^0$ vs $K_S\pi^+\pi^-$

**MC**

- $C=-1$
- $C=+1$

- $f_0(980)$
- $\rho(770)$
- $K^*(892)$
CLEO-c Data: Single Tag $D^0 \rightarrow K_S \pi^+ \pi^-$

- Single Tag Dalitz plot of $D^0 \rightarrow K_S \pi^+ \pi^-$ (pilot run 57 pb$^{-1}$)
- Construct Double Tags with
  - $CP^+ K^+K^-, \pi^+\pi^-, K_S\pi^0\pi^0$
  - $CP^- K_S\pi^0, K_S\omega, K_S\eta, K_S\phi$
- Double Dalitz plot $(D \rightarrow K_S \pi^+ \pi^-)^2$
- Dalitz plot has CP content
  - $1/3$ CP+ $K_S f_0$
  - $1/3$ CP- $K_S \rho, K_S \omega$
  - Significantly augments statistics of 2-body & pseudo-2-body CP modes
Belle Monte Carlo Study

- Belle studied relationship between systematic error on $\gamma$ and # of CP± vs $K_S\pi^+\pi^-$ events at CLEO-c
- CLEO Model - minus $f_2(1270)$, $K_2(1430)$, $K^*(1680)$

<table>
<thead>
<tr>
<th>#D°</th>
<th>#D_{CP+}</th>
<th>#D_{CP-}</th>
<th>$\Delta\phi_3$ (max)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>100</td>
<td>100</td>
<td>15.2 ± 5.4</td>
</tr>
<tr>
<td>5000</td>
<td>500</td>
<td>500</td>
<td>7.0 ± 2.5</td>
</tr>
<tr>
<td>20000</td>
<td>2000</td>
<td>2000</td>
<td>1.6 ± 0.6</td>
</tr>
</tbody>
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- Recall that measured phase in $B^\pm$ decay is $\theta_\pm = \delta \pm \phi_3$

$$\Delta\phi_3(\delta, \theta) = \frac{\Delta \theta(\delta + \phi_3) - \Delta \theta(\delta - \phi_3)}{2}$$

- Scan $(\delta, \phi_3)$, Determine RMS $\Delta\phi_3(\delta, \phi_3)$
- Worst case taken as $\Delta\phi_3$(max)
### Sensitivity Estimate from CLEO-c

**Projected number of reconstructed events**

<table>
<thead>
<tr>
<th></th>
<th>( #D^0 \rightarrow K_S \pi^+ \pi^- )</th>
<th>( #D_{CP+} )</th>
<th>( #D_{CP-} )</th>
<th>((K_S \pi^+ \pi^-)^2)</th>
</tr>
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<tbody>
<tr>
<td>285 pb(^{-1})</td>
<td>~25000</td>
<td>~115</td>
<td>~135</td>
<td>~240</td>
</tr>
<tr>
<td>1 fb(^{-1})</td>
<td>~87500</td>
<td>~400</td>
<td>~470</td>
<td>~840</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>( #D^0 \rightarrow \pi^+ \pi^- \pi^0 )</th>
<th>( #D_{CP+} )</th>
<th>( #D_{CP-} )</th>
<th>((\pi^+ \pi^- \pi^0)^2)</th>
</tr>
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<tbody>
<tr>
<td>285 pb(^{-1})</td>
<td>~9200</td>
<td>~40</td>
<td>~50</td>
<td>~35</td>
</tr>
<tr>
<td>1 fb(^{-1})</td>
<td>~32200</td>
<td>~150</td>
<td>~175</td>
<td>~115</td>
</tr>
</tbody>
</table>

**CLEO-c goal:** 6 fb\(^{-1}\) @ \(E_{cm}>3770\) MeV \(\Rightarrow \Delta \phi_3(\text{max}) \sim 1^o\)
**Summary**

- Best method to determine $\gamma$: $B^{-}\rightarrow D_{CP}K^{-}$, $D_{CP}\rightarrow K_{S}\pi^{+}\pi^{-}$
- Eventually Dalitz plot model will be limiting systematic uncertainty ($\approx \pm 10^\circ$)
- CLEO-c: first results based on 285 pb$^{-1}$ this summer
  - Belle study indicates CP tagged Dalitz plots at CLEO-c will limit systematic uncertainty to $\approx 7^\circ$ with 285 pb$^{-1}$
  - CLEO-c: full data set may reduce Dalitz plot model uncertainty to $\approx 1^\circ$
- **K-matrix** $\pi\pi$ S-wave model may improve fit to large samples from Belle and Babar of $D^{0}\rightarrow K_{S}\pi^{+}\pi^{-}$
    - Implemented model of Anisovich & Sarantsev
  - CLEO: to be submitted to PRL - $D^{0}\rightarrow \pi^{+}\pi^{-}\pi^{0}$
    - Implemented model of Au, Morgan & Pennington