CKM Angles

Jim Smith

CKM 2005
Workshop on the Unitarity Triangle
UCSD
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WG4 conveners:
Martin Beneke, Yuval Grossman, Andreas Höcker, Masashi Hazumi

WG5 conveners:
Amarjit Soni, Robert Fleischer, Tim Gershon, Luca Cavoto
Initial “Provocative” Outline

- How can we help find the WMD in Iraq?
- Strategies for dealing with growing budgets
- Sex and drugs in HEP recruiting
- Effects of steroids in HEP
  - Pumping up the publication list
- Does the B decay to octoquarks
- How to find inexpensive homes in La Jolla
Outline

• $\beta (\phi_1)$ from $c\bar{c}K^0$ decays
• Methods of measuring $\gamma$
  • $D_{CP}K^{(*)}$ (GLW)
  • $DK^{(*)}$ (ADS, GGSZ)
  • $2\beta+\gamma$ ($D^{(*)}K^0, D^*\pi/\rho$) [No time: session Thursday]
• Status of $\alpha (\phi_2)$
  • $B \rightarrow \pi\pi$
  • $B \rightarrow \rho\pi$
  • $B \rightarrow \rho\rho$
• Measurements of $\beta$ from $b \rightarrow s$ penguin decays
• Conclusion/Outlook
Perspective on angles status

- Direct and indirect measurements agree very well
- $\beta$ measurements now more restrictive than $V_{ub}$
- $\alpha$ meas. now squeezing more than $\varepsilon_K$ and mixing meas.
- Meas. of $\beta$ from $B \rightarrow \eta'K_S$ now as precise as from $c\bar{c}K^0$ 2001 observation

Thanks Andreas!
sin2\(\beta\) from c\(\bar{c}\)K\(^0\)

\[
\sin^2\beta = 0.722 \pm 0.040 \pm 0.023
\]

BABAR PUB-04/038
hep-ex/ 0408127

See talks by T. Browder and D. Lange tomorrow
Summary with $c\bar{c}d$ and $c\bar{c}s$ modes

| (cc-bar) s | BABAR         | 0.722 ± 0.040 ± 0.023 |
|           | Belle         | 0.728 ± 0.056 ± 0.023 |
|           | Average (incl. CDF and LEP) | 0.726 ± 0.037 |
| (cc-bar) d | $J/\psi \pi^0$ (BABAR) | $-0.05 ± 0.49 ± 0.16$ |
|           | $J/\psi \pi^0$ (Belle) | 0.72 ± 0.42 ± 0.09 |

| (dc-bar) c | $D^{*+} D^{-}$ (BABAR) | 0.65 ± 0.26 ± 0.08 |
|           | $D^{*+} D^{-}$ (Belle) | 0.75 ± 0.56 ± 0.12 |
|           | $D^{*+} D^{-}$ (BABAR) | 0.82 ± 0.75 ± 0.14 |
|           | $D^{*+} D^{-}$ (Belle) | 0.55 ± 0.39 ± 0.12 |
|           | $D^{*+} D^{-}$ (Belle) | 0.96 ± 0.43 ± 0.12 |

- $\eta_f \times S_f$

- Agreement looks fine
Prospects for $c\bar{c}K^0$

- Systematic errors are scaling with data
- Theory errors <0.01
  Boos, Mannel, Reuter, PRD 70, 036006 (2004)
- Bright prospects
  - $\sin2\beta = 0.725 \pm 0.037$ now
  M. Morandin, Moriond EW 2005
  - Expect precision of $\sim0.01$ with $2 \times 10^9 \frac{B\bar{B}}{}$ (2 ab$^{-1}$) for each experiment
Measuring $\gamma$

- **Gronau-London-Wyler method (GLW)**
  - $B^\pm \rightarrow D(*0)K^{(*)}\pm$ with $D(*0) \rightarrow CP$ eigenstates
    - $CP+: K^+K^-, \pi^+\pi^-$; $CP-: K_S \pi^0, K_S \phi, K_S \omega$

- **Atwood-Dunietz-Soni method (ADS)**
  - $B^+ \rightarrow D(*)0K^+$ with $D^0 \rightarrow K^-\pi^+$ (Cabibbo allowed)
  - $B^+ \rightarrow D(*)0K^+$ with $D^0 \rightarrow K^-\pi^+$ (DCSD)

- **Giri-Grossman-Soffer-Zupan method (GGSZ)**
  - $B^+ \rightarrow D(*)0K^+$ with $D^0 \rightarrow K_S \pi^+\pi^-$
  - $B^+ \rightarrow D(*)0K^+$ with $D^0 \rightarrow K_S \pi^+\pi^-$
  - Fit to interference between amplitudes in Dalitz plot

- All methods: measurable quantity $\propto r_B \sin \gamma$
  - $r_B \sim 0.1$ (ratio of $b \rightarrow u / b \rightarrow c$ amplitudes)
  - Measuring $\gamma$ is hard! New methods being invented to improve the efficiency.

Talks Thursday:
- K. Trabelsi, M. Rama

Talks Friday:
- K. Abe, M.H. Schune
Belle $B \to DK$ with $D \to K_S \pi^+\pi^-$

The two plots would be the same without CP violation – are they?

Similar BABAR analysis with 227M $B\bar{B}$
Dalitz analyses especially are providing quite useful determination of $\gamma$

$\gamma = 63^{+15}_{-13} \degree$

$\gamma = 64 \pm 18 \degree$

UTfit uses Bayesian approach
Measuring $\alpha$

- $B \to \pi\pi$ isospin analysis
  - Penguin pollution makes life difficult
  - Measure $2\alpha_{\text{eff}} = 2\alpha + \kappa_{\pi\pi}$
- $B \to \rho^+\pi^-$ time-dependent Dalitz plot analysis
  - $\rho\pi$ without DP analysis just doesn’t constrain $\alpha$
  - $B \to \rho^+\rho^-$ time-dependent plus isospin analysis is the same as $B \to \pi\pi$ – relabel the triangle sides $\pi \to \rho$

See session on alpha tomorrow
Progress in $B \rightarrow \pi^+\pi^-$

- Belle and BABAR now in better agreement (2.3σ)

See H. Ishino talk tomorrow
Status for $B \rightarrow \pi^0\pi^0$

- Now seen at $>5\sigma$ by both Belle and BABAR
  - $\text{BR} = (1.17 \pm 0.32 \pm 0.10) \times 10^{-6}$  
    - BABAR
  - $\text{BR} = (2.3 \,^{+0.4}_{-0.5} \,^{+0.2}_{-0.3}) \times 10^{-6}$  
    - Belle
  - $C(\pi^0\pi^0) = -0.12 \pm 0.56 \pm 0.06$  
    - BABAR
  - $C(\pi^0\pi^0) = -0.44 \pm 0.53 \pm 0.17$  
    - Belle
- Errors still very large but still constrains $C(\pi^0\pi^0)$ significantly (WA: $-0.28 \pm 0.40$)

See M. Cristinziani talk tomorrow
\( \alpha \) from \( B \to \pi\pi \)

- The core of the solution at CKM fit value is fairly precise 😊 – but 2\( \sigma \) doesn’t do so well. 😞
- Most of the information is now in the \( C(\pi^0\pi^0) \) meas.!
\[ \alpha \text{ from } B \rightarrow \rho^+ \pi^- \]

- \( A_{\rho \pi} \) measures direct CP violation. \( 3.4\sigma \) effect is not expected: \( \sim 0 \) for QCD factorization

\[ \alpha = \left( 113^{+27}_{-17} \pm 6 \right)^\circ \]

See M. Graham talk Thursday
\[ \alpha \text{ from } B \to \rho \rho \]

Penguin small:
BABAR
\[ B(\rho^0\rho^0) < 1.1 \times 10^{-6} \]

Penguin error is ±11°
Error small since isospin triangle doesn’t close. Would increase if \( B(\rho^+\rho^0) \) drops.

- Neglect
  - I=1 ampl. (due to \( \rho \) width) Falk, Ligeti, Nir, Quinn, PRD69 011502 (2004).
  - EW penguin shift \( (1.5 \pm 0.3^\circ) \) Gronau&Zupan hep-ph/0502139
  - \( \rho-\omega \) mixing (small and measurable) G&Z
  - Non-res \( \rho\pi\pi \) (included in systematic error)

\[ \alpha = 100 \pm 13^\circ \]

See A. Bevan talk tomorrow
\[ \alpha \text{ from } B \rightarrow \pi^+\pi^-, \rho^+\pi^-, \rho^+\rho^- \]

\[ \alpha = 101^{+16}_{-9} \degree \]

- Precision in \( \alpha \) impressive with all modes
\[ \sin 2\beta \text{ for } b \rightarrow s \text{ penguin modes} \]

- Typically have a dominant penguin amplitude and a Cabibbo- and color-suppressed tree
  - Penguin has no CKM phase \( \Rightarrow \) phase \( \beta \) from \( B \bar{B} \) mixing
  - Tree \( \propto V_{ub} \Rightarrow \) additional phase \( \gamma \)
- Tree large \( \Rightarrow \) deviations from \( \sin 2\beta \)
\[ \sin 2\beta \text{ from } \eta'K_S \]

Plot has cut on \( \frac{N_{\text{sig}}}{(N_{\text{sig}} + N_{\text{BG}})} \)

\[ N_{\text{sig}} = 819 \pm 38 \]

purity = 0.57

\[ N_{\text{sig}} = 512 \pm 27 \]

purity = 0.61

\[ S = +0.30 \pm 0.14 \pm 0.02 \]

\[ C = -0.21 \pm 0.10 \pm 0.02 \]

\[ S = +0.65 \pm 0.18 \pm 0.04 \]

\[ C = +0.19 \pm 0.11 \pm 0.05 \]
Status of $b \rightarrow s$ penguin modes

See talks by K. Hara, S. Wagner this afternoon

CP even ($\eta = +1$)

New
Can theory keep pace?

- SU(3) ("model-independent") approach currently has $\delta(\sin 2\beta) \sim 0.10$. Can’t do better than $\sim 0.05$ due to unknown relative strong phase for color-suppressed amplitude.

- Specific predictions for $\Delta S = S(\eta'K_S) - S(c\bar{c}K^0)$:
  - $0.011 \pm 0.018$ QCDFact [Beneke&Neubert, NPB675, 333 (2003).]
  - $0.01^{+0.00}_{-0.01}$ Fit [Chiang,Gronau,Rosner,Suprun, PRD70,034020 (2004).]
  - $0.006 \pm 0.018$ QCDFact+FSI [Cheng,Chua,Soni hep-ph/0502235]

See talks by Z. Ligeti, M. Beneke, M. Pierini this afternoon.
b → s penguin comparisons

- Cheng, Chua, Soni

\[
\begin{align*}
\text{Mode} & \quad \eta'K_S \quad \phi K_S \quad \pi^0K_S \quad \omega K_S \quad f_0K_S \\
\Delta S & \quad 0.006 \quad 0.029 \quad 0.048 \quad 0.008 \quad 0.021
\end{align*}
\]

- FSI effects substantially reduce \( \Delta S \) for \( \pi^0K_S \) and \( \omega K_S \)

- Rankings (3=Gold, 2=Silver, 1=Bronze):

\[
\begin{array}{cccc}
\text{Naïve theory} & \text{QCD Fact.} & \text{QCD Fact.+FSI} & \text{Experiment} \\
\eta'K_S & 2 & 3 & 3 & 3 \\
\phi K^0 & 3 & 3 & 2 & 1.5 \\
\pi^0K_S & 1 & 1 & 1 & 1 \\
\omega K_S & 1 & 1 & 1 & 1 \\
f_0K_S & 2? & 1 & 1 & 1 \\
K^+K^-K_S & 2 & - & - & 2.5 \\
K_SK_SK_S & 3 & - & - & 1
\end{array}
\]

- Million dollar question:

What can we believe when SM is at stake?
Summary

• We’re doing great
  • Direct and indirect measurements agree
  • $\sin^2 \beta(\bar{c}c) = 0.725 \pm 0.037 (23.2 \pm 1.5^\circ)$
  • $\gamma = 63^{+15}_{-13}^\circ$
  • $\alpha = 101^{+16}_{-9}^\circ$
  • Unconstrained sum of angles = 187° – not bad
  • CKMfitter (all): $\alpha = 98.8^{+4.9}_{-7.0}^\circ$, $\gamma = 58.0^{+7.1}_{-4.9}^\circ$
  • $\sin^2 \beta($penguins$) = 0.43 \pm 0.07$
    (3.7$\sigma$ from $\bar{c}c$ ignoring theory error)
How could we do with 2+2 ab^{-1}?

- Project current status to 4 ab^{-1} (2010-2011?) This is \sim 10\times what we have now so error/3

- $\alpha$ is hard to project due to $B \rightarrow \rho^0\rho^0$ unknown. Guess $\delta\alpha \sim 3^\circ$

- $\gamma$ is likely to improve more than with statistics. New methods will improve but GGSZ (DP) method hard to project $\delta\gamma \sim 5^\circ$

- $\delta(\sin 2\beta) \sim 0.01$ ($\delta\beta \sim 0.5^\circ$)
  - Penguin modes
    - $\eta'K^0 \delta(\sin 2\beta) \sim 0.03$
    - All penguin average $\delta(\sin 2\beta) \sim 0.02$
    - Will it agree with c\bar{c}K^0 value?