Measurement of sin $2\beta_{\text{eff}}$ in $B^0 \rightarrow K_S^0 K_S^0 K_S^0$, $K^+ K^- K_S^0$, $\pi^0 K_S^0$, and $\omega K_S^0$

CKM 2005 Workshop, UCSD

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- Belle and BaBar results on the “harder” $b \rightarrow s$ penguin modes:
- Low branching fraction (BF)
- or not CP-eigenstate
- or no charged tracks from $B^0_{CP}$ decay
- or combination of above
- Plus short summary of all $b \rightarrow s$ penguin modes
Measurement of $\sin 2\beta_{\text{eff}}$ in $B^0 \to K_S^0 K_S^0, K^+ K^- K_S^0, \pi^0 K_S^0$, and $\omega K_S^0$

**Generalities**

- All Belle results $253 \text{ fb}^{-1}$ ($275 \times 10^6 \, \overline{B}B$ pairs) - Belle has about $\sim 340 \text{ fb}^{-1}$ on-res now, $\sim 200 \text{ fb}^{-1}$ with new SVD-II
- All BaBar results $205 \text{ fb}^{-1}$ ($227 \times 10^6 \, \overline{B}B$ pairs) *except* $\omega K_S^0$ ($211 \text{ fb}^{-1}/232 \times 10^6$)
- *All* results preliminary (though BaBar $K_S^0 K_S^0 K_S^0, K^+ K^- K_S^0, \pi^0 K_S^0$ submitted for publication)
- Direct CP-violation from fit $C_{\text{BaBar}} = -A_{\text{Belle}}$
- More details of analysis techniques (fitting) in tomorrow morning’s WG5 session
Measurement of $\sin 2\beta_{\text{eff}}$ in $B^0 \rightarrow K^0_S K^0_S, K^+ K^- K^0_S, \pi^0 K^0_S$, and $\omega K^0_S$

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**$B^0 \rightarrow K^+ K^- K^0_S$**

### Belle

- **BABAR Preliminary**

- **BaBar** $N_{\text{SIG}} = 452 \pm 28$

- **Belle** $N_{\text{SIG}} = 399 \pm 28$

- Same final state particles as $B^0 \rightarrow \phi K^0_S, \phi \rightarrow K^+ K^-$ but significantly higher product BF

- Two tracks at the $B^0_{\text{CP}}$ vertex

- Lose some background rejection without the $\phi$ mass cut, but both Belle and BaBar have good $K^\pm$ particle ID, and mis-ID = $\Delta E$ shift
Measurement of $\sin 2\beta_{\text{eff}}$ in $B^0 \to K^0_SK^0_SK^0_S, K^+K^-K^0_S, \pi^0K^0_S$, and $\omega K^0_S$

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\[ f_{\text{even}}^{SU(2)} \] for $B^0 \to K^+K^-K^0_S$

- Cut out $\chi_{c0}, \chi_{c2}, D^0, D^\pm$ two-kaon decays ($b \to c\bar{c}s$ and $b \to c\bar{u}s$ pollution easily removed) in addition to removing $\phi \to K^+K^-$

- Leave $f_0(980)$, etc two-kaon decays in. Dominantly $b \to s\bar{q}q$, and some are broad and not very prominent

- But $B^0 \to K^+K^-K^0_S$ not CP-eigenstate by symmetry

- Belle first suggested isospin symmetry to determine CP-even fraction in $B^0 \to K^+K^-K^0_S$

\[ f_{\text{even}}^{SU(2)} = 2\Gamma(B^+ \to K^0_SK^0_S)/\Gamma(B^0 \to K^+K^-K^0_S) \]

- Argument refined by Grossman/Ligeti/Nir/Quinn and Gronau/Rosner. Belle still uses to convert fit $S_{KKK}$ to $\sin 2\beta_{\text{eff}} / \sin 2\phi_{1}^{\text{eff}}$

- $f_{\text{even}}^{\text{Belle}} = 1.03 \pm 0.15 \pm 0.05$ from 140 $fb^{-1}$ of data.

- BaBar now uses above method only as a cross-check; $f_{\text{even}}^{\text{BaBar}} = 0.75 \pm 0.11$ (stat error only/preliminary/205 $fb^{-1}$)
Measurement of $\sin 2\beta_{\text{eff}}$ in $B^0 \rightarrow K_S^0 K_S^0 K_S^0$, $K^+ K^- K_S^0$, $\pi^0 K_S^0$, and $\omega K_S^0$

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**$B^0 \rightarrow K^+ K^- K_S^0$ Angular Moments Analysis**

- BaBar now takes the $f_{\text{even}}$ it uses from an angular moments analysis
- Use $S$ and $P$ waves to describe $K^+ K^- \cos \theta_H$ at $m_{K^+ K^-}$
- $A_S^2 = \sqrt{2} \langle P_0 \rangle - \sqrt{5/2} \langle P_2 \rangle$
- $A_P^2 = \sqrt{5/2} \langle P_2 \rangle$
- $f_{\text{even}} = A_S^2 / (A_S^2 + A_P^2)$
  
  $f_{\text{even}} = 0.89 \pm 0.08 \pm 0.06$

- Other moments fit ($\ell \leq 6$), mostly consistent with 0
- $|A(m)|^2 = \sum_{\ell} \langle P_\ell \rangle P_\ell (\cos \theta_H)$,
  
  $\langle P_\ell \rangle = \sum_j P_\ell (\cos \theta_{H,j}) \mathcal{W}_j / \varepsilon_j$
- $\mathcal{W}_j$ is the j-th evt s-Weight (Pivk/Le Diberder) and $\varepsilon_j$ is eff from MC
- Syst errors from possible $D$ wave and $S - D$ interference in the $f_2(1270) - f_2'(1525)$ region and possible MC eff modeling bias
Measurement of $\sin 2\beta_{\text{eff}}$ in $B^0 \rightarrow K^0_S K^0_S K^0_S$, $K^+ K^- K^0_S$, $\pi^0 K^0_S$, and $\omega K^0_S$

**$B^0 \rightarrow K^+ K^- K^0_S$ Asymmetries**

**Belle**

- **Belle** $S_{KKK} = -0.49 \pm 0.18 \pm 0.04 \quad C_{KKK} = 0.08 \pm 0.12 \pm 0.07$
- **BaBar** $S_{KKK} = -0.42 \pm 0.17 \pm 0.03 \quad C_{KKK} = 0.10 \pm 0.14 \pm 0.03$
- **Belle** shows “raw” (including background) asymmetry for 2 different regions of tag “quality”
- **This BaBar** asym plot uses S/B likelihood ratio cut
- **Remember asymmetry not** just fit to data and errors shown on these plots - plots are projections, and fits include more information
Measurement of $\sin 2\beta_{\text{eff}}$ in $B^0 \rightarrow K^0_S K^0_S K^0_S$, $K^+ K^- K^0_S$, $\pi^0 K^0_S$, and $\omega K^0_S$

**$B^0 \rightarrow K^+ K^- K^0_S$ Systematics**

- Dominant systematic error from $f_{\text{even}}$
- BaBar $\sin 2\beta_{\text{eff}} = S_{KKK}/(1 - 2f_{\text{even}}) = 0.55 \pm 0.22 \pm 0.04 \pm 0.11$
- Belle $\sin 2\beta_{\text{eff}} = S_{KKK}/(1 - 2f_{\text{even}}) = 0.49 \pm 0.18 \pm 0.04^{+0.16}_{-0.00}$
- Belle fits 2 parameters ($S$ and $A = -C$) to $\Delta t$ distribution; BaBar has 34 free parameters it fits to 4 distributions
- But typical of the $b \rightarrow c\bar{c}s$ analyses, and those produce consistent results
- Systematic errors are small but a little larger than those for $b \rightarrow c\bar{c}s$ asymmetries (not as much data to constrain)
Measurement of $\sin 2\beta_{\text{eff}}$ in $B^0 \rightarrow K_S^0 K_S^0 K_S^0$, $K^+ K^- K_S^0$, $\pi^0 K_S^0$, and $\omega K_S^0$

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- CP-odd eigenstate with “large-ish” BF = $(11.9 \pm 1.5) \times 10^{-6}$ (HFAG)

- But no charged tracks at $B^0_{CP}$ vertex

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

- Belle

- BaBar $N_{SIG} = 300 \pm 23$

- Belle $N_{SIG} = (168 \pm 16) + (83 \pm 18)$ (not shown, low $R_{s/b}$)
Measurement of $\sin 2\beta_{eff}$ in $B^0 \to K^0_SK^0_S, K^+K^-K^0_S, \pi^0K^0_S,$ and $\omega K^0_S$

$B^0 \to \pi^0K^0_S$ Vertexing

- If $K^0_S \to \pi^+\pi^-$ decays close enough in to pick up enough Si detector hits, can use $K^0_S$ vertex, and position and size of “luminous region” to fit for $B^0_{CP}$ vertex
- $\Delta z$ measurement still dominated by resolution of tag vertex (like for $B^0 \to J/\psi K^0_S$ decays)

- Study resolutions, biases with MC samples
- Test using $B^0 \to J/\psi K^0_S$ ignoring $J/\psi$ tracks (Belle: $S_{J/\psi^0K^0} = 0.68 \pm 0.10, C = -0.02 \pm 0.04$)
\[ B^0 \rightarrow \pi^0 K^0_S \text{ Asymmetries} \]

- **Belle**
  \[ S_{\pi^0 K^0} = 0.30 \pm 0.59 \pm 0.11 \quad C_{\pi^0 K^0} = 0.12 \pm 0.20 \pm 0.07 \]

- **BaBar**
  \[ S_{\pi^0 K^0} = 0.35^{+0.30}_{-0.33} \pm 0.04 \quad C_{\pi^0 K^0} = 0.06 \pm 0.18 \pm 0.03 \]

- **BaBar plot** is s-Plots - weighted evts, essentially background sub signal
B\(^0\) → \(\pi^0K_S^0\) Systematics

- Belle loses larger fraction to vertexing fiducial cuts (SVD-I)
- Use \(B^+ \rightarrow K_S^0\pi^+\) in addition to \(B^0 \rightarrow J/\psi K_S^0\) to validate vertexing
- BaBar changed vertex algorithm for new result → constrain \(B_{CP}\) production pt to IP, rather than \(B_{CP}\) decay pt (to inflated IP) → removes (known) small bias in \(\Delta t\) scale
- BaBar’s dominant syst errors on \(S\) are resolution fcn (0.023), SVT misalignment (0.020), and crossfeed from other \(B\)’s (0.019) → sum is 0.04 (previous result was 0.06)
- Belle’s dominant errors on \(S\) are resolution fcn (0.05) and background fraction (0.07) → sum is 0.11
Measurement of $\sin 2\beta_{\text{eff}}$ in $B^0 \rightarrow K_S^0 K_S^0 K_S^0$, $K^+ K^- K_S^0$, $\pi^0 K_S^0$, and $\omega K_S^0$

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$B^0 \rightarrow K_S^0 K_S^0 K_S^0$ (I)

- Smaller BF and product BF than $\pi^0 K_S^0$ (though Belle allows one $K_S^0 \rightarrow \pi^0 \pi^0$ in addition to $K_S^0 \rightarrow \pi^+ \pi^-$)

- And similar vertexing problem $\rightarrow$ no charged tracks at $B_{CP}$ vertex

• Belle $N_{SIG} = 88 \pm 13$

• BaBar $N_{SIG} = 88 \pm 10$

• BaBar $\mathcal{B}(B^0 \rightarrow K_S^0 K_S^0 K_S^0) = (6.9^{+0.9}_{-0.8} \pm 0.6) \times 10^{-6}$
Measurement of $\sin 2\beta_{\text{eff}}$ in $B^0 \rightarrow K^0_S K^0_S K^0_S$, $K^+ K^- K^0_S$, $\pi^0 K^0_S$, and $\omega K^0_S$

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$B^0 \rightarrow K^0_S K^0_S K^0_S$ (II)

- A little easier than $\pi^0 K^0_S \rightarrow$ 3-body decay vs 2-body decay makes the $K^0_S$ spectra a little softer
- If one $K^0_S$ decays outside the “good-ver texing” fiducial region, mostly likely 1 or 2 of the other $K^0_S$ decay within ($\varepsilon_{VTX} \sim 100\%$)
- Unlike $K^+ K^- K^0_S$, $B^0 \rightarrow K^0_S K^0_S K^0_S$ is a CP (even) eigenstate
- And unlike $K^+ K^- K^0_S$, no valence $u$-quarks in the final state
**B^0 \rightarrow K_S^0 K_S^0 K_S^0** Asymmetries

- **Belle** \( S_{3K_S^0} = +1.26 \pm 0.68 \pm 0.18 \) \( C_{3K_S^0} = -0.54 \pm 0.34 \pm 0.08 \)
- **BaBar** \( S_{3K_S^0} = -0.71^{+0.38}_{-0.32} \pm 0.04 \) \( C_{3K_S^0} = -0.34^{+0.28}_{-0.25} \pm 0.05 \)
- **BaBar plots are again s-Plots**
- **2.5\sigma** difference between Belle and BaBar \( S \rightarrow \) need more data to resolve
Measurement of $\sin 2\beta_{\text{eff}}$ in $B^0 \to K_S^0 K_S^0 K_S^0$, $K^+ K^- K_S^0$, $\pi^0 K_S^0$, and $\omega K_S^0$

**$B^0 \to K_S^0 K_S^0 K_S^0$ Systematics**

- BaBar result uses new vertex algorithm (discussed for $\pi^0 K_S^0$) → better pulls
- BaBar $S$ systematics look like those for $\pi^0 K_S^0$ but a little smaller (more info from additional $K_S^0$) except for error (0.025) assigned to PDFs (less signal → less well constrained) → sum is 0.044
- Belle’s are dominated by large resolution fcn error (0.12) and background fraction again (0.10) → sum is 0.18
Measurement of $\sin 2\beta_{\text{eff}}$ in $B^0 \rightarrow K_S^0 K_S^0 K_S^0$, $K^+ K^- K_S^0$, $\pi^0 K_S^0$, and $\omega K_S^0$

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$B^0 \rightarrow \omega K_S^0$ (I)

- Naively expect $\pi^0 K_S^0$ and $\omega K_S^0$ to have largest potential SM $\Delta S = \sin 2\beta_{\text{eff}} - \sin 2\beta_{c\bar{c}s}$ from $u - quark$ content of $\pi^0$, $\omega$ (tree still CKM and color suppressed)
- CP-odd eigenstate with smaller $\text{BF} = (5.5^{+1.2}_{-1.1}) \times 10^{-6}$ (HFAG)
- Two charged tracks at $B^0_{CP}$ vertex
- Belle $N_{SIG} = 31 \pm 7$
Measurement of $\sin 2\beta_{\text{eff}}$ in $B^0 \rightarrow K_S^0 K_S^0$, $K^+ K^- K_S^0$, $\pi^0 K_S^0$, and $\omega K_S^0$

$B^0 \rightarrow \omega K_S^0$ (II)

- BaBar uses $m_{ES}$, $\Delta E$, $m_{\pi^+ \pi^- \pi^0}$, $F$, and $\cos \theta_H$ in yield fit (and $\Delta t$ for CP asymmetries)
- New preliminary BaBar $\mathcal{B}(B^0 \rightarrow \omega K_S^0) = (5.9 \pm 1.0 \pm 0.4) \times 10^{-6}$
- BaBar $N_{SIG} = 96 \pm 14$. More than $\times 3$ Belle yield with less data → mostly due to tighter Belle cuts (different analysis strategy)
- Plots below and BaBar asymmetry plots (on next page) were made with likelihood ratio cuts

![Graphs showing event distribution](image)
Measurement of $\sin 2\beta_{\text{eff}}$ in $B^0 \rightarrow K^0_S K^0_S, K^+ K^- K^0_S, \pi^0 K^0_S$, and $\omega K^0_S$

**$B^0 \rightarrow \omega K^0_S$ Asymmetries**

- **Belle** $S_{\omega K^0_S} = 0.75 \pm 0.64^{+0.13}_{-0.16}$
- **Belle** $C_{\omega K^0_S} = -0.26 \pm 0.48 \pm 0.15$
- **BaBar** $S_{\omega K^0_S} = 0.50^{+0.34}_{-0.38} \pm 0.02$
- **BaBar** $C_{\omega K^0_S} = -0.56^{+0.29}_{-0.27} \pm 0.03$
Measurement of $\sin 2\beta_{\text{eff}}$ in $B^0 \rightarrow K_S^0 K_S^0 K_S^0$, $K^+ K^- K_S^0$, $\pi^0 K_S^0$, and $\omega K_S^0$

$B^0 \rightarrow \omega K_S^0$ Systematics

- Belle quotes a much larger syst error on $S$, $C$ than BaBar (as with $\pi^0 K_S^0$ and $K_S^0 K_S^0 K_S^0$).

- But except for level of background, and additional parameters (in BaBar fit), syst errors should not be that much different from $b \rightarrow c\bar{c} s$ measurement ($\pm 0.023$, both experiments).

- Belle $S$ error dominated by background fraction (0.10), possible fit bias, and resolution fcn (0.07).

- BaBar error dominated by resolution fcn (0.02), effect of ignoring $B$ background (0.01). Use of additional parameters in ML fit controls background fraction uncertainties (stat error $\leftrightarrow$ syst error).

- Matter of taste and all measurements still statistics dominated.
Measurement of $\sin 2\beta_{\text{eff}}$ in $B^0 \to K_S^0 K_S^0 K_S^0$, $K^+ K^- K_S^0$, $\pi^0 K_S^0$, and $\omega K_S^0$

**Summary of All $b \to s$ Penguin Modes**

- 7 modes!
- “Blind” analysis techniques give us more faith we’re not just getting the result we want (whatever that is)
- Dangerous to average modes which may have different SM, NP $\Delta S$
- But why not? Common effect(s) and mode-dependent corrections?

### 3.7σ deviation from $\Delta S = 0$

- s-penguin average $\Delta S_{\text{Belle}} = -0.34 \pm 0.12$ vs $\Delta S_{\text{BaBar}} = -0.28 \pm 0.10$
• If NP and new phases, don’t expect $C = 0$
• But measurements looks pretty much like 7 measurements drawn from $C_{TRUE} = 0$
• Cheng/Chua/Soni investigating correlation of $\Delta S$ from SM final state rescattering and $C \neq 0$
• Predict sizable $C$ for $\omega K_S^0$ from FSI (but with opposite sign from measurements)
• Continue to grind away to get the most out of the data
• Pick up some decays where one \( K^0_S \rightarrow \pi^0 \pi^0 \)
• Pick up some modes with a \( K^0_L \) in place of a \( K^0_S \)
• Pick up some 2-body modes with another \( \pi^0 \), etc thrown in
• But probably no killer app left - except for luminosity
• The results so far look very suggestive
• But in order to convince anyone, even with more data, we’ll need the continued help of theorists in better constraining \( \Delta S_f \) from SM sources