New Results in Charmless B Meson Decays from BaBar

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August 16, 2013
Overview: 2 (of Many) New BaBar Results

1) Evidence for $B^0 \rightarrow \omega\omega$, and improved limit for $B^0 \rightarrow \omega\phi$.

Brand new! To be submitted to PRL

2) Measurement of CP violation in $B$ decays to three charged kaons.

PRD 85:112010 (2012); Also arXiv:1305.4218
1) Evidence for $B^0 \rightarrow \omega \omega$, and improved limit for $B^0 \rightarrow \omega \phi$

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$B^0 \rightarrow \omega\omega$ and $B^0 \rightarrow \omega\phi$: Motivation

- Anomalies in charmless decays with loops:
  \[ \sin(2\beta^{\text{eff}}) \equiv \sin(2\phi_1^{\text{eff}}) \]

- Quite low measured value of longitudinally-polarized fraction in $B^0 \rightarrow \phi K^*$ (HFAG avg. = $0.48 \pm 0.03$).

- Potential signs of new physics in loops…?

- (Somewhat) low values of CP asymmetries.

New Results in Charmless B Decays from BaBar

16 Aug. 13  J. Albert
$B^0 \rightarrow \omega \omega$ and $B^0 \rightarrow \omega \phi$:

Previous Measurement at $\textbf{BaBar}$ (2006)

- $B(\phi \omega) < 1.2 \times 10^{-6}$ (90% CL), $B(\omega \omega) = (1.8_{-0.9}^{+1.3} \pm 0.4) \times 10^{-6}$ ($< 4.0 \times 10^{-6}$ @ 90% CL)

- At leading order, $\phi \omega$ is pure penguin and $\omega \omega$ is a penguin-tree combination.

- Limits on BF$s$ can provide a constraint on amplitudes of $\phi K^*$. Neither helicity amplitude measurements, nor even significant signal peaks, are required.
$B^0 \rightarrow \omega \omega$ and $B^0 \rightarrow \omega \phi$: Reconstruction

- Full reconstruction of $B^0$ candidates, with $\omega \rightarrow \pi^+\pi^-\pi^0$ and $\phi \rightarrow K^+K^-$.  

<table>
<thead>
<tr>
<th>State</th>
<th>Inv. mass (MeV)</th>
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<tbody>
<tr>
<td>$\omega$</td>
<td>$740 &lt; m_{\pi\pi\pi} &lt; 820$</td>
</tr>
<tr>
<td>$\phi$</td>
<td>$1009 &lt; m_{KK} &lt; 1029$</td>
</tr>
<tr>
<td>$\pi^0$</td>
<td>$120 &lt; m_{\gamma\gamma} &lt; 150$</td>
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- Resulting $B^0$ signal candidates are characterized by the standard variables:

\[
\Delta E = E^*_B - \frac{1}{2}\sqrt{s} \\
m_{ES} = \sqrt{\left(\frac{1}{2}s + p_0 \cdot p_B\right)^2 / E^*_B^2 - p_B^2}
\]

- For a candidate to be selected, it must satisfy $|\Delta E| < 200$ MeV and $5.24 < m_{ES} < 5.29$ GeV, and have a vertex probability $> 0$.

- Event shape variables are additionally used to help reject continuum background.
$B^0 \rightarrow \omega\omega$ and $B^0 \rightarrow \omega\phi$:

Maximum Likelihood Fit

- We use an unbinned maximum likelihood in the 8 ($\omega\phi$) or 9 ($\omega\omega$) variables:
  - $m_{ES}$
  - $\Delta E$
  - the resonance masses (2)
  - the resonance helicities (2)
  - an event shape Fisher discriminant

- The likelihood is defined as:

$$L = \frac{e^{-(\sum Y_j)}}{N!} \prod_{i=1}^{N} \sum_{j} Y_j P_j^i$$

where $Y_j$ are the free parameters of the fit, i.e. the number of events for each hypothesis $j$ (signal, combinatoric background, and peaking background), and $P_j(x_i)$ are the probabilities for each hypothesis $j$ evaluated from the vector of 7 observables $x_{ij}$ for each of the $N$ total events.

Di-pion ($\pi+\pi-$) rest frame:

471 x $10^6$ $B\bar{B}$ decays
$B^0 \rightarrow \omega\omega$ and $B^0 \rightarrow \omega\phi$: Fit Result

- $\mathcal{B}(\omega\omega) = (1.2 \pm 0.3^{+0.3}_{-0.2}) \times 10^{-6}$ (4.4$\sigma$ significance)
- $\mathcal{B}(\phi\omega) < 0.7 \times 10^{-6}$ (90% CL)

Largest systematic contributions from fit yield bias estimation (O(5 events) ≈ 10% for $\omega\omega$) and marginalizing over longitudinal vs transverse fraction ($f_L = 0.88$ is used as the nominal central value).

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$B^0 \rightarrow \omega\omega$ and $B^0 \rightarrow \omega\phi$: Projection Plots

471 x $10^6 B\bar{B}$ decays

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2) Measurement of CP violation in $B$ decays to three charged kaons

**B → 3K CPV**

- Tree amplitudes subdominant in SM
- New Physics can appear in loops – altering CP violation from SM expectation!

- $B^0 \rightarrow K^+K^-K_S$:
  
  Measure time-dependent CP asymmetry
  
  $$A_{CP}(\Delta t) \sim \eta_{CP} \sin(2\beta_{eff}) \sin(\Delta m_d \Delta t)$$

  Complication — $K^+K^-K_S$ not CP eigenstate
  
  CP content depends on Dalitz plot/spin structure of intermediate state

- $B^+ \rightarrow K^+K^-K^+$ and $B^+ \rightarrow K_S K_S K^+$
  
  Study Dalitz structure – help understand CP content in $K^+K^-K_S$
  
  $f_X(1500)$ – poorly understood resonance, seen in $B \rightarrow KKK$, taken to be a scalar
  
  Large “nonresonant” contribution needs further study
  
  Search for direct CP violation
\[ \mathcal{B} \rightarrow 3K \text{ CPV: Dalitz} \]

\[ A \equiv A(B \rightarrow KKK; m_{12}, m_{23}) = \sum_j a_j F_j(m_{12}, m_{23}) \]

\[ a_j = c_j(1 + b_j)e^{i(\phi_j + \delta_j)} \]

\[ \bar{a}_j = c_j(1 - b_j)e^{i(\phi_j - \delta_j)} \]

\( F_j \) are resonant or nonresonant lineshapes: relativistic Breit-Wigner, with spin factors.

We measure the isobar coefficients \( c_j \) and \( b_j \).

From isobar coefficients can derive: partial branching fractions, \( A_{\text{CP}} = -2b/(1+b^2) \), \( \beta_{\text{eff}} = \beta + \delta \), etc.
$B \rightarrow 3K$ CPV: $\mathcal{B}$ vs. LHCb

- A BaBar followup to the amplitude analysis of $B^{\pm} \rightarrow K^{\pm}K^{+}K^{-}$.
- Invariant mass dependence of CP asymmetries, comparison with LHCb results:

PR D85, 112010 (2012)

LHCb-CONF-2012-018

- BaBar $A_{CP}$ from sPlots.
- LHCb $A_{raw}$ from fits in bins (no acceptance corrections; no corrections for detection and production asymmetry $\sim$ 1.4%).

$\Delta_{BaBar-LHCb} = 0.045 \pm 0.021$

$\Delta_{BaBar-LHCb} = 0.053 \pm 0.021$

- Similar patterns in the asymmetries.
- Apparent tension between BaBar and LHCb (less than 2$\sigma$) is consistent with the difference in the overall asymmetry, & reduced by acceptance etc. corrections.
- BaBar measures a 2.8$\sigma$ positive asymmetry in $\phi(1020)$, not seen by LHCb.
- Further investigation to pin down sources of CPV needed.
$B \rightarrow 3K$ CPV: Summary

- Indication of direct CP violation in $B^+ \rightarrow \phi K^+$ at 2.8σ.
  - $A_{CP} = (12.8 \pm 4.4 \pm 1.3)\%$
  - SM: $(0 - 4.7)\%$

  $A_{CP}(\phi K^+)$ larger than SM expectation:
  - (PQCD) Li, Mishima, PRD 74, 094020

- World’s most precise measurement of $\beta_{eff}(\phi K_S)$:
  - $\beta_{eff} = (21 \pm 6 \pm 2)$ degrees

  PRD 85:112010 (2012) ;
  Also arXiv:1305.4218 (2013)
  471 x $10^6$ BB decays

- $f_\chi(1500)$ not a single resonance – well described by $f_0(1500) + f_2'(1525) + f_0(1710)$

- Small tension in $A_{CP}$ measurements between Babar and LHCb; further studies needed.
Summary

1) Evidence (at 4.4σ level) for $B^0 \rightarrow \omega\omega$, and improved limit for $B^0 \rightarrow \omega\phi$.

$\mathcal{B}(\omega\omega) = (1.2 \pm 0.3^{+0.3}_{-0.2}) \times 10^{-6}$

$\mathcal{B}(\phi\omega) < 0.7 \times 10^{-6}$ (90% CL)

2) Measurement of CP violation in $B$ decays to three charged kaons.

World’s most precise measurement of $\beta_{\text{eff}}(\phi K_S)$:

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Backup Slide
\[ \Delta E = E^*_B - \frac{1}{2} \sqrt{s} \]

\[ m_{ES} = \sqrt{(\frac{1}{2} s + p_0 \cdot p_B)^2 / E_{0^*}^2 - p_B^2} \]

Energy substituted mass

\[ m_{ES} = \sqrt{E_{\text{beam}}^2 - p_B^2} \]

Beam-energy difference

Typical experimental resolution

~2.6 MeV/c^2

Typical experimental resolution

[15-20] MeV