**B^{±} \rightarrow \omega K^{±}/\pi^{±} and**

**Time-dependent CPV in B \rightarrow \eta'Ks at Belle**

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Flavor Physics & CP Violation(FPCP)  
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**Outline**

- Introduction
- $B^{±} \rightarrow \omega K^{±}$
- CP in $B \rightarrow \eta'Ks$
- Summary
Rare B decays are useful to determine the unitary triangle.
Test of current understanding of B physics.
Search for CP violation and probe new physics.
**B\(^{\pm}\)\(\rightarrow\omega h^{\pm}\)**

**Introduction**

- \(B^{\pm}\rightarrow\omega h^{\pm}\) can test B decay models.
- Useful to search for direct CP violation.
- **Brief History:**
  - CLEO first reported the \(B^{\pm}\rightarrow\omega K^{\pm}\) decay branching fractions in 1998.  
    [PRL 81, 272(1998)]
  - \(B^{\pm}\rightarrow\omega\pi^{\pm}\) is found to be larger than \(\omega K^{\pm}\) with new data set.  
    [PRL 85, 2881(2000)]
  - BaBar confirms \(B^{\pm}\rightarrow\omega\pi^{\pm}\rightarrow\omega K^{\pm}\).  
    [PRL 87, 221802(2001)]

<table>
<thead>
<tr>
<th>(B(B\rightarrow\omega\pi)\times10^{-6})</th>
<th>(B(B\rightarrow\omega K)\times10^{-6})</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLEO(1998) (&lt;2.3)</td>
<td>(15^{+7}_{-6} \pm 2)</td>
</tr>
<tr>
<td>CLEO(2000) (11.3^{+3.3}_{-2.9} \pm 1.5)</td>
<td>(&lt;8 \ [3.2^{+2.4}_{-1.9} \pm 0.8])</td>
</tr>
<tr>
<td>BaBar(2001) (6.6^{+2.1}_{-1.8} \pm 0.7)</td>
<td>(&lt;4 \ [1.4^{+1.3}_{-1.0} \pm 0.3])</td>
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B$^\pm \rightarrow \omega h^\pm$ Results

- Results from 31.9M BB pairs.
- Yields are extracted by a 2-dimensional unbinned likelihood method.

Yields are extracted by a 2-dimensional unbinned likelihood method.

<table>
<thead>
<tr>
<th></th>
<th>Yield $\pm$</th>
<th>$\Sigma$</th>
<th>$\epsilon$ (%)</th>
<th>$B(\times 10^{-6})$ $\pm$</th>
<th>U.L</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B \rightarrow \omega \pi$</td>
<td>$10.6^{+4.8}_{-4.5} \pm 0.4$</td>
<td>3.3$\sigma$</td>
<td>7.7$%$</td>
<td>$4.3^{+2.9}_{-2.0} \pm 0.5$</td>
<td>&lt;8.2</td>
</tr>
<tr>
<td>$B \rightarrow \omega K$</td>
<td>$19.7^{+5.4}_{-4.8} \pm 0.7$</td>
<td>6.4$\sigma$</td>
<td>6.3$%$</td>
<td>$9.9^{+2.7}_{-2.4} \pm 1.0$</td>
<td>-</td>
</tr>
</tbody>
</table>

FPCP @ PHILADELPHIA
Consistency Checks

(a) A clear $\omega$ peak shown in $\pi^+\pi^-\pi^0$ spectrum with B candidate.
(b) The $\omega$ helicity angle distribution matches $P \rightarrow VP$ decay.
(c),(d) By removing the KID requirement, the $\Delta E$ distribution is consistent with $\omega K$ and $\omega \pi$ yields.
Direct CPV in $B^\pm \rightarrow \omega K^\pm$

- Search for $A_{cp}$ in $B^\pm \rightarrow \omega K^\pm$ mode.

- $A_{cp}(= \frac{\omega K^- - \omega K^+}{\omega K^- + \omega K^+}) = -0.22 \pm 0.27 \pm 0.04$

(-0.70 $< A_{cp} < 0.26$ @ 90% C.L.)

$B \rightarrow \omega K^-$
7.4 $\pm$ 3.5 events

$B \rightarrow \omega K^+$
11.6 $\pm$ 3.7 events
Summary of $B^\pm \rightarrow \omega h^\pm$

- We have observed $B^\pm \rightarrow \omega K^\pm$, and evidence for $B^\pm \rightarrow \omega \pi^\pm$.

\[ B(\omega K^\pm) = (9.9^{+2.7}_{-2.4} \pm 1.0) \times 10^{-6} \ (6.4\sigma) \]

\[ B(\omega \pi^\pm) = (4.3^{+2.0}_{-1.8} \pm 0.5) \times 10^{-6} \ (3.3\sigma) < 8.2 \times 10^{-6} \]

- Compare results with other experiments:

<table>
<thead>
<tr>
<th>Experiment</th>
<th>$B(B \rightarrow \omega \pi) \times 10^{-6}$</th>
<th>$B(B \rightarrow \omega K) \times 10^{-6}$</th>
</tr>
</thead>
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<tr>
<td>Belle(2002)</td>
<td>$&lt; 8.2 \ [4.3^{+2.0}_{-1.8} \pm 0.5]$</td>
<td>$9.9^{+2.7}_{-2.4} \pm 1.0$</td>
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- $A_{cp}(\omega K^\pm) = -0.22 \pm 0.27 \pm 0.04$
  
  (-0.70 < $A_{cp}$ < 0.26 @ 90% C.L.)
CPV in $B \rightarrow \eta'K$

- Within the SM, $B \rightarrow \eta'K$ consists of penguin process and contribution from tree diagrams.

The time-dependent CP asymmetry can be expressed as:

$$A_{CP}(\Delta t) = \frac{\Gamma(B^0(t) \rightarrow \eta' K_S) - \Gamma(B^0(t) \rightarrow \eta' K_S)}{\Gamma(B^0(t) \rightarrow \eta' K_S) + \Gamma(B^0(t) \rightarrow \eta' K_S)} = A_{\eta'K_s} \cos \Delta m \Delta t + S_{\eta'K_s} \sin \Delta m \Delta t$$

$$\approx S_{\eta'K_s} \sin \Delta m \Delta t = \sin 2(\phi_1 + \phi_{NP}) \sin \Delta m \Delta t \quad (\text{if } A_{\eta'K_s} = 0)$$
Time-dependent Measurement

- Fully reconstruct \( B \rightarrow \eta' K_s \) as cp-side. (\( \eta' K^\pm \) as control sample)
- The \( b \)-flavor is determined by the accompanying \( B \) meson (Btag) by a multi-dimensional likelihood method (MDLH).
- Determine the CP parameters from the \( \Delta t \) distribution by an unbinned likelihood fit.
B\rightarrow \eta' K$ Reconstruction

- Data set for this analysis is 42$fb^{-1}$.
- Two sub decay modes of $\eta'$ are reconstructed: $\eta' \rightarrow \eta \pi \pi$ \textbf{and} $\eta' \rightarrow \rho \gamma$.
- A unbinned 2-dimensional likelihood fit is performed.

\begin{itemize}
  \item $\eta' \rightarrow \eta \pi \pi$ \textbf{and} $\eta' \rightarrow \rho \gamma$.
  \item A unbinned 2-dimensional likelihood fit is performed.
\end{itemize}

\begin{figure}[h]
  \centering
  \includegraphics[width=\textwidth]{diagram.png}
  \caption{Plot showing $\eta' K$ and $\eta' K_s$ distributions.
  \textbf{Expected $BB$ background}}
\end{figure}

- Preliminary

$N(\eta \pi \pi K^+) = 78.5^{+9.6}_{-9.1}$
$N(\rho \gamma K^+) = 150 \pm 14$
$N(\eta \pi \pi K_s) = 27.4^{+6.2}_{-5.6}$
$N(\rho \gamma K_s) = 45.7^{+8.6}_{-7.9}$

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Consistency Checks

- Checks by B-lifetime fit with 229 $\eta'K^\pm$ and 73 $\eta'Ks$ events:
  \[ \tau(B^\pm) = 1.54^{+0.14}_{-0.13} \text{ ps} \]
  (PDG: 1.653$\pm$0.028 ps)
  \[ \tau(B^0) = 1.58^{+0.31}_{-0.26} \text{ ps} \]
  (PDG: 1.548$\pm$0.032 ps)

- CP-fit with non-asymmetric sample: $\eta'K^\pm$
  \[ \sin2(\phi_1 + \phi_{NP}) = 0.11^{+0.29}_{-0.30} \]
  \[ S(\eta'K^\pm) = 0.11 \pm 0.29 \]
  \[ A(\eta'K^\pm) = -0.27 \pm 0.17 \]
Time-dependent Acp

- CP-fit is performed with 73 $\eta'$Ks signal candidates.

$$S(\eta'Ks) = 0.27^{+0.54}_{-0.55}$$

$$A(\eta'Ks) = 0.12 \pm 0.32$$

If $A(\eta'Ks)$ is set to be zero:

$$\sin^2(\phi_1 + \phi_{NP}) = 0.29^{+0.53}_{-0.54}$$

- First measurement of time-dependent CPV in $B \rightarrow \eta'Ks$ decay.

- Probe phases from New Physics.
Systematic Uncertainties

- Systematic uncertainties are determined by repeating fit on data with ±1σ to each parameters.

- Systematic uncertainties include

<table>
<thead>
<tr>
<th>Vertical/track selection</th>
<th>S(η'Ks)</th>
<th>A(η'Ks)</th>
<th>sin2(φ1+φNP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wtag fractions</td>
<td>+0.02/-0.03</td>
<td>+0.03/-0.03</td>
<td>+0.02/-0.02</td>
</tr>
<tr>
<td>Resolution function</td>
<td>+0.04/-0.03</td>
<td>+0.01/-0.01</td>
<td>+0.04/-0.03</td>
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<tr>
<td>PDF functions</td>
<td>+0.03/-0.03</td>
<td>+0.01/-0.01</td>
<td>+0.04/-0.04</td>
</tr>
<tr>
<td>Event fractions</td>
<td>+0.02/-0.02</td>
<td>+0.01/-0.01</td>
<td>+0.02/-0.02</td>
</tr>
<tr>
<td>BB background</td>
<td>+0.02/-0.02</td>
<td>+0.00/-0.01</td>
<td>+0.02/-0.01</td>
</tr>
<tr>
<td>Sum</td>
<td>+0.07/-0.07</td>
<td>+0.07/-0.07</td>
<td>+0.07/-0.07</td>
</tr>
</tbody>
</table>
Summary of CPV in $\eta'K$

- First measurement of time-dependent CPV parameters in $B \to \eta'Ks$ decay
- Probe for phases from New Physics.

$$S(\eta'Ks) = 0.27^{+0.54}_{-0.55} \text{(stat.)} \pm 0.07 \text{(syst.)}$$

$$A(\eta'Ks) = 0.12 \pm 0.32 \text{(stat.)} \pm 0.07 \text{(syst.)}$$

If $A(\eta'Ks)$ set to be zero:

$$\sin^2(\phi_1 + \phi_{\text{NP}}) = 0.29^{+0.53}_{-0.54} \text{(stat.)} \pm 0.07 \text{(syst.)}$$

$$\sin^2(\phi_1) = 0.82 \pm 0.12 \text{(stat.)} \pm 0.05 \text{(syst.)}$$
Conclusion

$B^\pm \rightarrow \omega h^\pm$

- We have observed $B \rightarrow \omega K^\pm$
- Evidence for $B \rightarrow \omega \pi^\pm$.
- First look at direct CPV in $B \rightarrow \omega K^\pm$.

CP in $B \rightarrow \eta'K$

- First measurement of time-dependent CPV in $B \rightarrow \eta'Ks$ decay.

Perspectives

- More data are coming soon
  - 8 fb$^{-1}$ per month.
  - 90 fb$^{-1}$ for summer.