Recent Results on Hadronic B decays from Belle

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On behalf of Belle Collaboration

10th International Conference on Hyperons, Charm and Beauty Hadrons
2012.07.23~28

Advances the understanding of the universe
Overview

Introduction

Event Selection and Analysis

Current Results

1. $B \rightarrow \phi \pi$
   
   arXiv:1206.4760v1 (Accepted in PRD)
   New upper limit

2. $B \rightarrow hh$

   $B \rightarrow K^+\pi^-, K^+\pi^0, K^0\pi^+, \pi^+\pi^-, K^+K^0, K^0K^0$
   ; (new) branching fraction using final Belle dataset

   $B \rightarrow K^+K^-$
   ; (new) upper limit

Summary
Introduction

Hadronic $B$ Decays

- Charmless $B$ decays provide an excellent probe into the accuracy of the Standard Model.

- Measurement of branching fractions and $A_{CP}$ can be to measure CKM parameters.

- Measurements can confirm theoretical predictions, or indicate the presence of New Physics.
Experimental Apparatus

Belle Detector

Circulation
~3.0 Km

Beam
Asymmetric 8.0 GeV (e⁻) 3.5 GeV (e⁺) CM 10.58 GeV

Luminosity
1 ab⁻¹ with the Belle detector

Goal
Measurement of CP violation
Data Sample

Collected at the $\Upsilon(4S')$ resonance with the Belle detector at the KEKB asymmetric-energy $e^+e^-$ collider

**Integrated luminosity of B factories**

- $772 \times 10^6$ $B\bar{B}$ pairs
- $657 \times 10^6$ $B\bar{B}$ pairs

- $B \to \phi\pi$
  are measured using $657 \times 10^6$ $B\bar{B}$ pairs

- $B \to hh$
  All other analyses are performed on the full Belle $\Upsilon(4S)$ dataset of $772 \times 10^6$ $B\bar{B}$ pairs
Introduction

$B \rightarrow \phi \pi$

$B \rightarrow \phi \pi$ is forbidden at tree level and can only proceed through $b \rightarrow d$ penguin processes.

A precise measurement provides a means to study SM from suppressed diagrams in other modes including non-perturbative effects.

An enhanced branching fraction could indicate CMSSM, or the presence of a $Z'$ boson.

<table>
<thead>
<tr>
<th>Model</th>
<th>$B(B \rightarrow \phi \pi)$</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>SM</td>
<td>$\sim (3.2 \times 10^{-8}, 6.8 \times 10^{-9})$</td>
<td>Y. Li et al. Phys. Rev. D 80, 014024 (2009)</td>
</tr>
<tr>
<td>experiment(BABAR(06))</td>
<td>$(2.8, 2.4) \times 10^{-7}$</td>
<td>BaBar Collaboration, Phys. Rev. D 74, 011102(R) (2006)</td>
</tr>
</tbody>
</table>
Introduction

\[ B \rightarrow hh \]

- The branching fraction between theoretical calculations and experimental measurements have large uncertainties.
- The \( A_{\text{CP}} \) measurements will help observe SM quantities.
- Improved experimental uncertainties can help our understanding of the standard model and help identify New Physics.

\[
\Delta A_{K\pi} = A_{\text{CP}}(K\pi^0) - A_{\text{CP}}(K\pi)
\]

- As \( B^+ \rightarrow K^+\pi^0 \) and \( B^0 \rightarrow K^+\pi^- \) have very similar leading order feynman diagrams, we would expect them to have similar \( A_{\text{CP}} \).
- A difference could indicate the enhancement of the color suppressed tree diagram.
- However, the previous Belle result found the sign and magnitude of these asymmetries to be different.
- The difference in these could indicate New Physics, such as a difference between direct CP in neutral and charged B decays.
Event Selection and Analysis

- B meson candidates are identified using two kinematic variables:

\[
M_{bc} = \sqrt{E_{\text{beam}}^2 - |\sum_i \vec{p}_i|^2}
\]

\[
\Delta E = \sum_i E_i - E_{\text{beam}}
\]

where \( E_{\text{beam}} \) is the beam energy, and \( \vec{p}_i \) and \( E_i \) are the momenta and energies, respectively, of the daughters of the reconstructed \( B \) meson candidate in the center-of-mass (CM) frame.

- Particle identification (PID) for charged kaons and pions is based on the likelihood ratios derived from ACC and TOF information and \( dE/dx \) measurements in the CDC.

- These analysis all make use of a continuum suppression variable made up of a combination of event properties combined in to a likelihood ratio (LR).

- Background contributions from \( Y(4S) \rightarrow B\bar{B} \) events are investigated with a large MC sample that includes events from both charm and charmless \( B \) decays.
Event Selection and Analysis

Continuum Suppression

Typical continuum suppression variables include:

- A Fisher discriminant formed out of 16 modified Super Fox-Wolfram moments calculated in the CM frame

- The distance between the vertices of the reconstructed $B$ and the tag-side $B\,(\Delta z)$

$$L^\Delta z_s = \int_{-\infty}^{-\infty} \exp(-|\Delta z - \Delta z'|/c\gamma\beta\tau) \ast \exp[-\frac{1}{2} \ast (\frac{\Delta z - \Delta z'}{\sigma})^2] d\Delta z'$$

- The $B$ flight direction with respect to the beam axis ($\theta^*_B$)

$$L^{\cos \theta_B^*} = P_0 - P_1 \cos^2 \theta_B^*$$
Current Results

Result $B^+ \rightarrow \phi \pi^+$

Previous upper limit: (BaBar 2006)

$\mathcal{B}_{UL}(B^+ \rightarrow \phi \pi^+) < 2.4 \times 10^{-7}$

Signal yield, branching fraction and upper limit at the 90% CL

<table>
<thead>
<tr>
<th>$B^+ \rightarrow \phi \pi^+$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Yield</strong></td>
</tr>
<tr>
<td>$4.5^{+5.1}_{-4.3} \pm 3.1$</td>
</tr>
<tr>
<td><strong>$\epsilon_{data}$</strong></td>
</tr>
<tr>
<td>8.4%</td>
</tr>
<tr>
<td><strong>$\mathcal{B}(10^{-7})$</strong></td>
</tr>
<tr>
<td>$0.8^{+0.9}_{-0.8} \pm 0.6$</td>
</tr>
<tr>
<td><strong>$\mathcal{B}_{UL}(10^{-7})$</strong></td>
</tr>
<tr>
<td>3.3</td>
</tr>
</tbody>
</table>

(657 $\times 10^6$ $B\bar{B}$ pairs)

Signal + Continuum (dotted)
Continuum (dashed)
Non-resonant $B^+ \rightarrow K^+ K^- \pi^+$ (solid)
Other $B$ background (solid)
Total (solid)

Projection of fits in the fit region with $\Delta E$ and $M_{bc}$
Current Results

Result $B^0 \to \phi \pi^0$

Previous upper limit: (BaBar 2006)

$B_{UL}(B^0 \to \phi \pi^0) < 2.8 \times 10^{-7}$

New upper limit!

Signal yield, branching fraction and upper limit at the 90% CL

<table>
<thead>
<tr>
<th>$B^0 \to \phi \pi^0$</th>
<th>Yield</th>
<th>$\epsilon_{\text{data}}$</th>
<th>$B(10^{-7})$</th>
<th>$B_{UL}(10^{-7})$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$-2.2^{+2.1}<em>{-1.2}^{+1.3}</em>{-2.4}$</td>
<td>4.9%</td>
<td>$-0.7^{+0.6}<em>{-0.4}^{+0.4}</em>{-0.8}$</td>
<td>1.5</td>
</tr>
</tbody>
</table>

$(657 \times 10^6 \ BB \ \text{pairs})$

Signal + Continuum (dotted)
Continuum (dashed)
Non-resonant $B^0 \to K^+ K^- \pi^0$ (solid)
Other B background (solid)
Total (solid)

Projection of fits in the fit region with $\Delta E$ and $M_{bc}$
Current Results

\[ B^0 \rightarrow K^+\pi^- \quad \text{and} \quad B^0 \rightarrow \pi^+\pi^- \]

Signal yield, measured branching fraction and \( A_{CP} \) for both \( B^0 \rightarrow K^+\pi^- \) and \( B^0 \rightarrow \pi^+\pi^- \)

<table>
<thead>
<tr>
<th>Decay</th>
<th>Yield</th>
<th>( B(10^{-6}) )</th>
<th>( A_{CP} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( B^0 \rightarrow K^+\pi^- )</td>
<td>7525 ± 127</td>
<td>20.00 ± 0.34 ± 0.63</td>
<td>-0.069 ± 0.014 ± 0.007</td>
</tr>
<tr>
<td>( B^0 \rightarrow \pi^+\pi^- )</td>
<td>2111 ± 89</td>
<td>5.04 ± 0.21 ± 0.19</td>
<td>Update coming soon</td>
</tr>
</tbody>
</table>

(772 \times 10^6 \overline{B\overline{B}} \text{ pairs})

Background from charmless \( B \) decays (hatched)
Background from mis-identification (dashed)

- Previous Belle Result \( A_{CP}(B \rightarrow K\pi) \):
  
  \[-0.094 \pm 0.018 \pm 0.008\]

  Using 535 \times 10^6 \overline{B\overline{B}} \text{ pairs}


- Current Results:

  *BaBar*: -0.107 ± 0.016
  *arXiv*: 0807.42226

  *CDF*: -0.086 ± 0.023 ± 0.009
  *PRL* 106, 181802 (2011)

  *LHCb*: -0.074 ± 0.033 ± 0.008
  *arXiv*: 1106.1197
Current Results

\[ B^+ \rightarrow K^+ \pi^0 \quad \text{and} \quad B^+ \rightarrow \pi^+ \pi^0 \]

Signal yield, measured branching fraction and \( A_{CP} \) for both \( B^+ \rightarrow K^+ \pi^0 \) and \( B^+ \rightarrow \pi^+ \pi^0 \)

<table>
<thead>
<tr>
<th>Decay</th>
<th>Yield</th>
<th>( B(10^{-6}) )</th>
<th>( A_{CP} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( B^+ \rightarrow K^+ \pi^0 )</td>
<td>3731 ± 92</td>
<td>12.62 ± 0.31 ± 0.56</td>
<td>+0.043 ± 0.024 ± 0.002</td>
</tr>
<tr>
<td>( B^+ \rightarrow \pi^+ \pi^0 )</td>
<td>1846 ± 82</td>
<td>5.86 ± 0.26 ± 0.38</td>
<td>-0.025 ± 0.043 ± 0.007</td>
</tr>
</tbody>
</table>

\((772 \times 10^6\ B\bar{B} \ \text{pairs})\)

- Previous Belle Result

\( A_{CP}(B^+ \rightarrow K^+ \pi^0) \):

\[ 0.07 \pm 0.03 \pm 0.01 \]

Using \( 535 \times 10^6\ B\bar{B} \ \text{pairs} \)


\( A_{CP}(B^+ \rightarrow \pi^+ \pi^0) \):

\[ 0.07 \pm 0.06 \pm 0.01 \]

Using \( 535 \times 10^6\ B\bar{B} \ \text{pairs} \)


Background from charmless \( B \) decays (hatched)
Background from mis-identification (dashed)
Current Results

\[ \Delta A_{K\pi} = A_{CP}(K\pi^0) - A_{CP}(K\pi) \]

Previous Belle Result:
\[ \Delta A_{K\pi} = +0.164 \pm 0.037 \quad 4.4\sigma \]
(535 \times 10^6 \ B \bar{B} \text{ pairs})

New Result:
\[ \Delta A_{K\pi} = +0.112 \pm 0.027 \quad 4\sigma \]
(772 \times 10^6 \ B \bar{B} \text{ pairs})

Background from charmless \( B \) decays (hatched)
Background from mis-identification (dashed)
Current Results

\[ B \rightarrow K^0\pi \quad \text{and} \quad B \rightarrow K^0K \]

Signal yield, measured branching fraction and \( A_{CP} \) for \( B^+ \rightarrow K^0\pi^+ \), \( B^+ \rightarrow K^0K^+ \), \( B^0 \rightarrow K^0K^0 \) and \( B \rightarrow K^0\pi^0 \)

<table>
<thead>
<tr>
<th>Decay</th>
<th>Yield</th>
<th>( B(10^{-6}) )</th>
<th>( A_{CP} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( B^+ \rightarrow K^0\pi^+ )</td>
<td>3229 ± 71</td>
<td>23.97 ± 0.53 ± 0.69</td>
<td>-0.014 ± 0.021 ± 0.006</td>
</tr>
<tr>
<td>( B^+ \rightarrow K^0K^+ )</td>
<td>134 ± 23</td>
<td>1.11 ± 0.19 ± 0.05</td>
<td>+0.017 ± 0.168 ± 0.002</td>
</tr>
<tr>
<td>( B^0 \rightarrow K^0K^0 )</td>
<td>103 ± 15</td>
<td>1.26 ± 0.19 ± 0.06</td>
<td>-</td>
</tr>
<tr>
<td>( B^0 \rightarrow K^0\pi^0 )</td>
<td>961 ± 45</td>
<td>19.68 ± 0.46 ± 0.50</td>
<td>-</td>
</tr>
</tbody>
</table>

\( A_{CP} \) (PDG)

0.009 ± 0.029 (2012)
0.12 ± 0.18 (2012)

Background from charmless \( B \) decays (hatched)
Background from mis-identification (dashed)

(772 \times 10^6 \bar{B}B \text{ pairs})
Current Results

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

Signal yield and measured branching fraction for $B^0 \rightarrow K^+ K^-$

<table>
<thead>
<tr>
<th>Decay</th>
<th>Yield</th>
<th>$B(10^{-6})$</th>
<th>$A_{CP}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B^+ \rightarrow K^0 \pi^+$</td>
<td>35 ± 29</td>
<td>0.1 ± 0.08 ± 0.06 ($&lt; 0.2$)</td>
<td>-</td>
</tr>
</tbody>
</table>

(772 × 10^6 $B\bar{B}$ pairs)

Previous and other experiments results

<table>
<thead>
<tr>
<th>Experiment</th>
<th>$B(10^{-6})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belle (2007)</td>
<td>$0.09^{+0.18}_{-0.13}$ ($&lt; 0.41$)</td>
</tr>
<tr>
<td>BaBar (2007)</td>
<td>$0.04 \pm 0.15 \pm 0.08$ ($&lt; 0.5$)</td>
</tr>
<tr>
<td>PDG (2010)</td>
<td>$0.15^{+0.11}_{-0.10}$ ($&lt; 0.41$)</td>
</tr>
<tr>
<td>LHCb (2012) (Preliminary)</td>
<td>$0.11^{+0.05}_{-0.04} \pm 0.06$ ($&lt; 0.18$)</td>
</tr>
</tbody>
</table>

Background from mis-identification (yellow)
Summary

— New branching fractions and direct $A_{CP}$ are available for $B \rightarrow hh$ the final Belle dataset with improved (new tracking, large data) analyses. 

(To be submitted to PRL)

— A new, improved upper limit is available for $B \rightarrow \phi \pi$ from Belle. 

(To be published in PRD)

— CP asymmetries were not observed for $K^0 h^\pm$ as expected in the SM.

— The updated difference of $A_{CP}$ confirms as evidence.

— The presented branching fractions in $B \rightarrow hh$ are consistent with the expected theoretical values.

— New upper limits in $B^0 \rightarrow K^+K^-$ and updated branching fractions are also consistent with previous results.
Event Selection and Analysis

$B \rightarrow \phi \pi$ Analysis

$\phi$ candidates are created from a pair of charged kaons with an invariant mass within $1.008 \text{ GeV}/c^2 < M_{K^+K^-} < 1.031 \text{ GeV}/c^2$ (2.5 times of the $\phi$ full width).

Candidate $\pi^0$'s are reconstructed from $\gamma$ pairs that have invariant mass between $115.3 \text{ MeV}/c^2$ and $152.8 \text{ MeV}/c^2$ ($\pm 2.5\sigma$ standard deviations ($\sigma$)).

The $K^+K^-$ pair is combined with either a $\pi^+$ or a $\pi^0$ candidate.

$M_{bc} > 5.20 \text{ GeV}$, and $|\Delta E| < 0.1 \text{ GeV}$ for $B^+ \rightarrow \phi \pi^+$

and $|\Delta E| < 0.4 \text{ GeV}$ for $B^0 \rightarrow \phi \pi^0$

In this analysis, we use an additional Continuum Suppression variable, the angle between the final state $K^+$ direction and the $B$ meson direction in the $\phi$ rest frame ($\theta_H$).
### Summary of the PDF’s used in the measurement of $B \rightarrow \phi \pi$ decays

<table>
<thead>
<tr>
<th>Mode</th>
<th>$B^+ \rightarrow \phi \pi^+$</th>
<th>Method (Yield)</th>
<th>$B^0 \rightarrow \phi \pi^0$</th>
<th>Method (Yield)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal</td>
<td>$\Delta E$</td>
<td>$M_{bc}$</td>
<td>$\Delta E$</td>
<td>$M_{bc}$</td>
</tr>
<tr>
<td>$e^+e^- \rightarrow q\bar{q}$</td>
<td>Sum of two Gaussians</td>
<td>Gaussian</td>
<td>CB</td>
<td>Gaussian</td>
</tr>
<tr>
<td>$b \rightarrow c$</td>
<td>$1^{st}$ order poly.</td>
<td>ARGUS</td>
<td>Float($4.5^{+5.1}_{-4.3}$)</td>
<td>Float($-2.2^{+2.1}_{-1.2}$)</td>
</tr>
<tr>
<td>$b \rightarrow u,d,s$</td>
<td>2D HistoPDF</td>
<td></td>
<td>Float($330.0^{+19.1}_{-18.4}$)</td>
<td>Float($265.6^{+16.9}_{-16.2}$)</td>
</tr>
<tr>
<td>$B^+ \rightarrow \phi K^+$</td>
<td>Sum of two Gaussians</td>
<td>Gaussian</td>
<td>CB</td>
<td>Fixed(4.8)</td>
</tr>
<tr>
<td>Nonresonant $B \rightarrow K^+K^-\pi$</td>
<td>Sum of two Gaussians</td>
<td>Gaussian</td>
<td>CB</td>
<td>Fixed(13.5)</td>
</tr>
<tr>
<td></td>
<td>Fixed(4.7)</td>
<td></td>
<td></td>
<td>Fixed(1.6)</td>
</tr>
</tbody>
</table>

### Systematic errors of the efficiency

<table>
<thead>
<tr>
<th>Type</th>
<th>$B^0 \rightarrow \phi \pi^0$</th>
<th>$B^\pm \rightarrow \phi \pi^\pm$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$+\sigma$</td>
<td>$-\sigma$</td>
</tr>
<tr>
<td></td>
<td>$+\sigma$</td>
<td>$-\sigma$</td>
</tr>
<tr>
<td>MC acceptance</td>
<td>$\sigma_M$</td>
<td>0.8%</td>
</tr>
<tr>
<td>PID</td>
<td>$\sigma_M$</td>
<td>1.3%</td>
</tr>
<tr>
<td>Tracking</td>
<td>$\sigma_M$</td>
<td>2.0%</td>
</tr>
<tr>
<td>$\pi^0$ detection efficiency</td>
<td>$\sigma_M$</td>
<td>3.0%</td>
</tr>
<tr>
<td>MDLR efficiency</td>
<td>$\sigma_M$</td>
<td>4.1%</td>
</tr>
<tr>
<td>$N_{BB}$</td>
<td>$\sigma_M$</td>
<td>1.4%</td>
</tr>
<tr>
<td>Sum: $\sigma_M$</td>
<td></td>
<td>5.8%</td>
</tr>
</tbody>
</table>

Signal yields for $B \rightarrow \phi \pi$ decays are obtained by performing a two-dimensional extended unbinned maximum likelihood (ML) fit to the observables $M_{bc}$ and $\Delta E$. 
Event Selection and Analysis

\( B \rightarrow \text{hh} \quad \text{Analysis} \)

- Candidates of \( K^0 \) meson are reconstructed in \( K^0_S \rightarrow \pi^+ \pi^- \) by requiring the invariant mass of the pion-pair to be \( 480 \text{ MeV}/c^2 < M_{\pi\pi} < 516 \text{ MeV}/c^2 \) (\( \pm 5.0 \sigma \) above).

- Pairs of photons with invariant masses lying in the range of \( 115 \text{ MeV}/c^2 < M_{\gamma\gamma} < 152 \text{ MeV}/c^2 \) (\( \pm 2.0 \sigma \) above) are considered as \( \pi^0 \) candidates.

- \( M_{bc} > 5.20 \text{ GeV}/c^2 \) and \( |\Delta E| < 0.3 \text{ GeV} \)

- Decays with a \( \pi^0 \) in the final state use a modified \( M_{bc} \) that explain the shower leakage in the calorimeter.

\[
M_{bc} \equiv \sqrt{E_{\text{beam}}^2/c^4 - |\vec{p}_B|^2/c^2}, \quad \vec{p}_B^* = \vec{p}_h^* + \frac{\vec{p}_{\pi^0}^*}{|\vec{p}_{\pi^0}^*|} \sqrt{(E_{\text{beam}}^* - E_h^*)^2 - m_{\pi^0}^*}
\]
$B \rightarrow hh$ Analysis

Data was fitted in 3 dimensions $M_{bc}, \Delta E$ and the continuum suppression variable.

In the case of modes similar to each other
($B^0 \rightarrow K^+ \pi^-, B^0 \rightarrow \pi^+ \pi^-, B^+ \rightarrow K^+ \pi^0$ and $B^+ \rightarrow \pi^+ \pi^0$, and $B^+ \rightarrow K^0 \pi^+$ and $B^+ \rightarrow K^0 K^+$) a simultaneous fit was performed on both modes at once.

Other modes were fitted separately.
A background to the $\phi \rightarrow K^+K^-$ decays

The two dimensional fit to $M_{bc}$ and $\Delta E$ alone cannot distinguish the signal from other $B \rightarrow K^+K^-\pi$ events

- **Belle**
  
  $B \rightarrow K^+K^-\pi$ ($a_0(980) \rightarrow K^+K^-$, $f_0(980) \rightarrow K^+K^-$, and a nonresonant contribution)
  
  We obtain the expected yields for each mode, $B \rightarrow a_0(980)\pi$, $B \rightarrow f_0(980)\pi$ and nonresonant $B \rightarrow K^+K^-\pi$, from side-band data
  
  We assigned the PDF as signal of $B \rightarrow \phi\pi$

  We take a mode of the largest yield as a central value

- **BaBar**
  
  To discriminate against this background in the maximum likelihood fit, we use the helicity of the $(K^+K^-)_{S\text{-wave}}$ system

  Further discrimination is provided by the $K^+K^-$ invariant mass distribution, $M_{K^+K^-}$, which peaks at the $\phi$ mass for the signal, while it peaks at lower values for the $S$-wave background.
Current Results

The $\mathcal{A}_{CP}$ Sum rule

While $\mathcal{A}_{K\pi}$ asymmetry can be explained by colour suppressed tree diagrams, the $\mathcal{A}_{CP}$ sum rule is a model independent, and should hold

(Gronau et al. hep-ph/0608040)

The $\mathcal{A}_{CP}$ sum rule is found to be non zero to $2\sigma$

\[
\begin{align*}
A_{CP}(K^+\pi^-) + A_{CP}(K^0\pi^+) \frac{B(K^0\pi^+)}{B(K^+\pi^-)} \frac{\tau_{0}}{\tau_{+}} &= A_{CP}(K^+\pi^-) \frac{2B(K^+\pi^0)}{B(K^+\pi^-)} \frac{\tau_{0}}{\tau_{+}} + A_{CP}(K^0\pi^0) \frac{2B(K^0\pi^0)}{B(K^+\pi^-)} \\
A_{CP}(K^+\pi^-) + A_{CP}(K^0\pi^+) \frac{\Gamma(K^0\pi^+)}{\Gamma(K^+\pi^-)} &= A_{CP}(K^+\pi^-) \frac{2\Gamma(K^+\pi^0)}{\Gamma(K^+\pi^-)} + A_{CP}(K^0\pi^0) \frac{2\Gamma(K^0\pi^0)}{\Gamma(K^+\pi^-)}
\end{align*}
\]

$L_{side} - R_{side} = -0.270 \pm 0.145$