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

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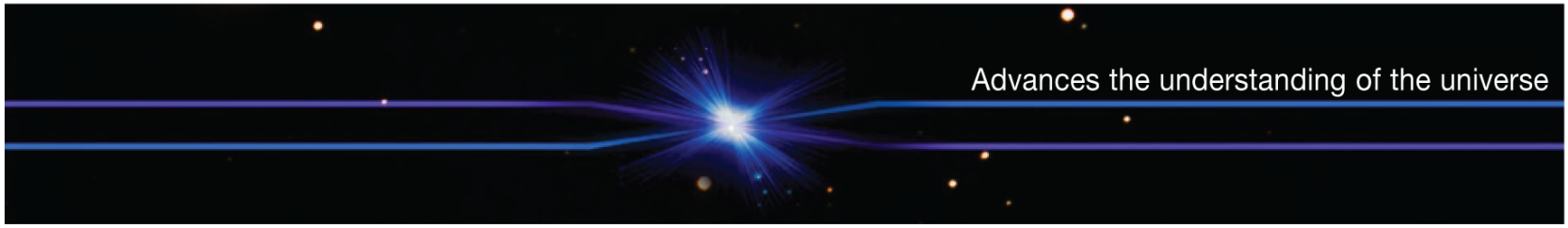


Overview

Introduction

Event Selection and Analysis

Current Results

1. $B \to \phi\pi$

   arXiv:1206.4760v1 (Accepted in PRD)

   New upper limit

2. $B \to \mathrm{hh}$

   $B \to K^+\pi^-, K^+\pi^0, K^0\pi^+, \pi^+\pi^-, K^+K^0, K^0K^0$

   ; (new) branching fraction using final Belle dataset

   $B \to K^+K^-$

   ; (new) upper limit

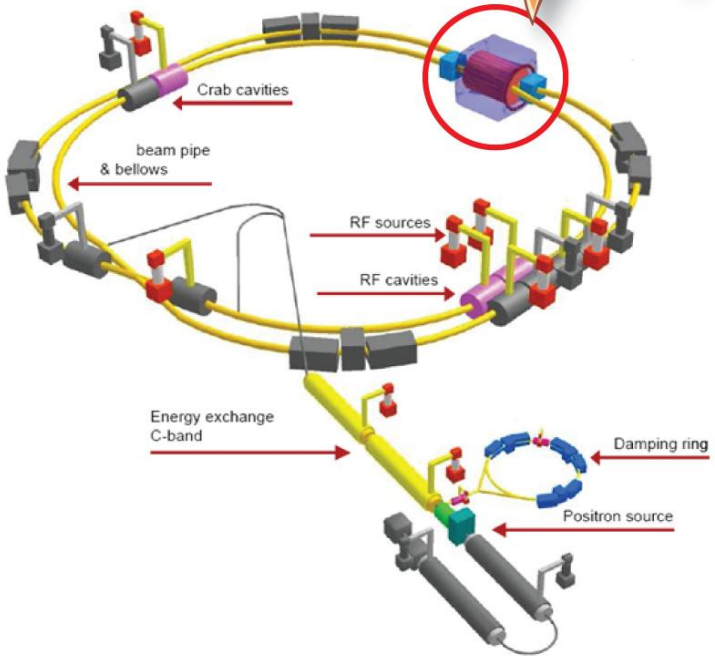
Summary

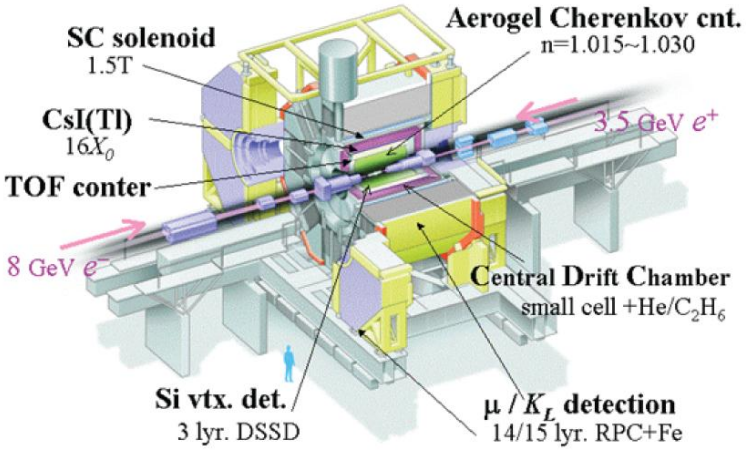
Introduction

Hadronic B Decays

- Charmless B decays provide an excellent probe in to the accuracy of the Standard Model.
- Measurement of branching fractions and $\mathcal{A}_{CP}$ can be to measure CKM parameters.
- Measurements can confirm theoretical predictions, or indicate the presence of New Physics.

Experimental Apparatus





Circulation
~3.0 Km

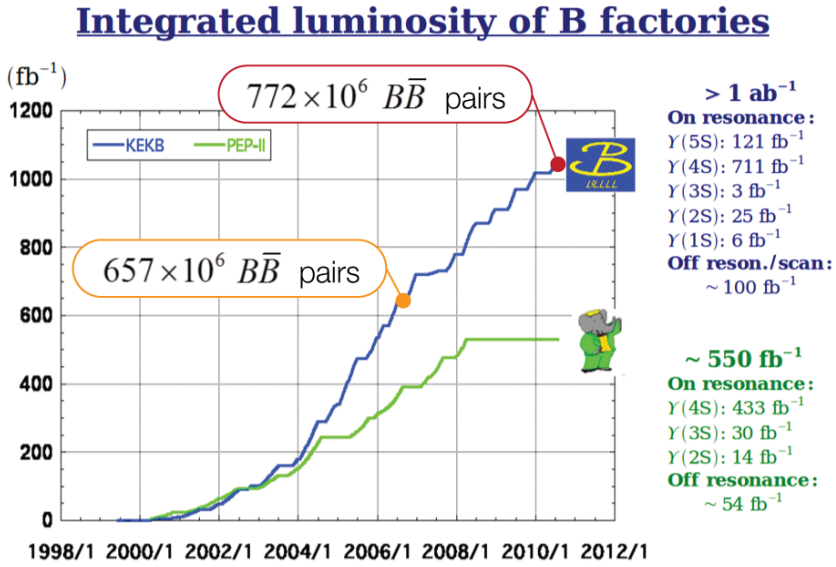
Beam
Asysmmeric 8.0 GeV (e^-) 3.5 GeV (e^+) CM 10.58 GeV

Luminosity
1 ab^{-1} with the Belle detecter

Goal
Measurement of CP violation

Data Sample

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

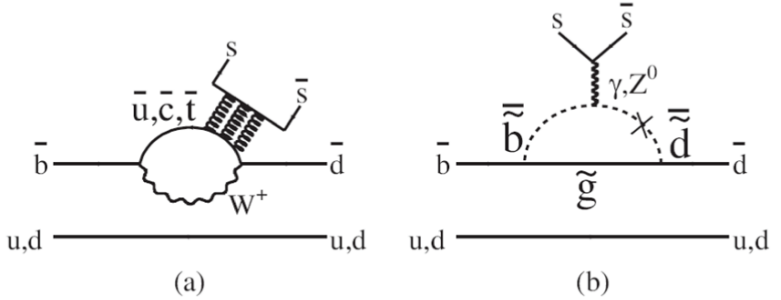


- $B \to \phi\pi$
  are measured using 657×10^6 $B\bar{B}$ pairs
- $B \to hh$
  All other analyses are performed on the full Belle $\Upsilon(4S)$ dataset of 772×10^6 $B\bar{B}$ pairs

Introduction

$B \to \phi\pi$

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



Penguin processes of $B \to \phi\pi$ in both SM and CMSSM

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.

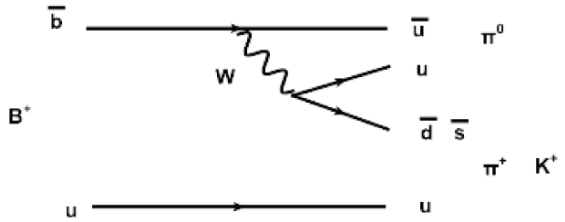
The branching fractions of the theories and experiment

Model	$\mathcal{B}(B \to \phi\pi)$	Reference
SM	$\sim (3.2 \times 10^{-8}, 6.8 \times 10^{-9})$	Y. Li *et al.* Phys. Rev. D **80**, 014024 (2009)
Four quark generation	$\sim 10^{-8}$	B. Mawlong *et al.* Phys. Lett. B **668**, 116 (2008)
Z' model	$\sim 10^{-7}$	J.-F. Cheng *et al.*, Phys. Lett. B **647**, 413 (2007)
Supersysmetry	$\gtrsim 10^{-7}$	J.-F. Cheng *et al.*, Phys. Lett. B **554**, 155 (2003)
experiment(BABAR(06))	$(2.8, 2.4) \times 10^{-7}$	BaBar Collaboration, Phys. Rev. D **74**, 011102(R) (2006)

Introduction

$$B \to \mathrm{hh}$$

- The branching fraction between theoretical calculations and exprimental measurements have large uncertainties.
- The $\mathcal{A}_{CP}$ measurements will help observe SM quantities.
- Improved experimental uncertainties can help our understanding of the standard model and help indentify New Physics.



$$\Delta\mathcal{A}_{K\pi} = \mathcal{A}_{CP}(K\pi^0) - \mathcal{A}_{CP}(K\pi)$$

- As $B^+ \to K^+\pi^0$ and $B^0 \to K^+\pi^-$ have very similar leading order feynman diagrams, we would expect them to have similar $\mathcal{A}_{CP}$.
- 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 indentified using two kinematic variables;

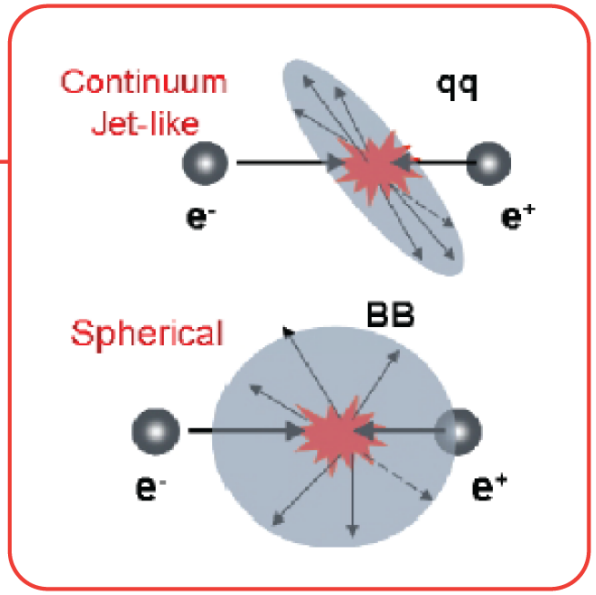
$$\text{beam-energy-constrained mass} \quad M_{\rm bc} = \sqrt{E^2_{\rm beam} - |\sum_i \vec{p}_i|^2}$$

$$\text{energy difference} \quad \Delta E = \sum_i E_i - E_{\rm beam}$$

where $E_{\rm beam}$ 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.

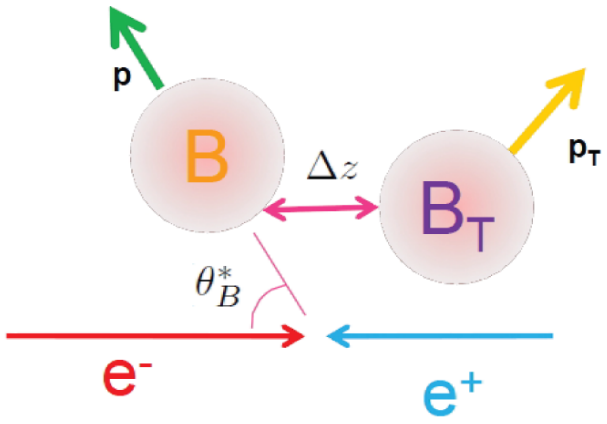
- Particle identification (PID) for charged kaons and pions is based on the likelihood ratios derived from ACC and TOF information and dE/dx measurements in the CDC.
- These analysis all make use of a continuum suppression variable made up of a combination of event properties combined in to a likelihood ratio (LR).
- Background contributions from $\Upsilon(4S) \to B\overline{B}$ events are investigated with a large MC sample that includes events from both charm and charmless B decays.

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 (Δz)

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

- The B flight direction with respect to the beam axis (θ_B^*)

$$L^{\cos\theta_{B^*}} = P_0 - P1\cos^2\theta_{B^*}$$

Current Results

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

Previous upper limit: (BaBar 2006)

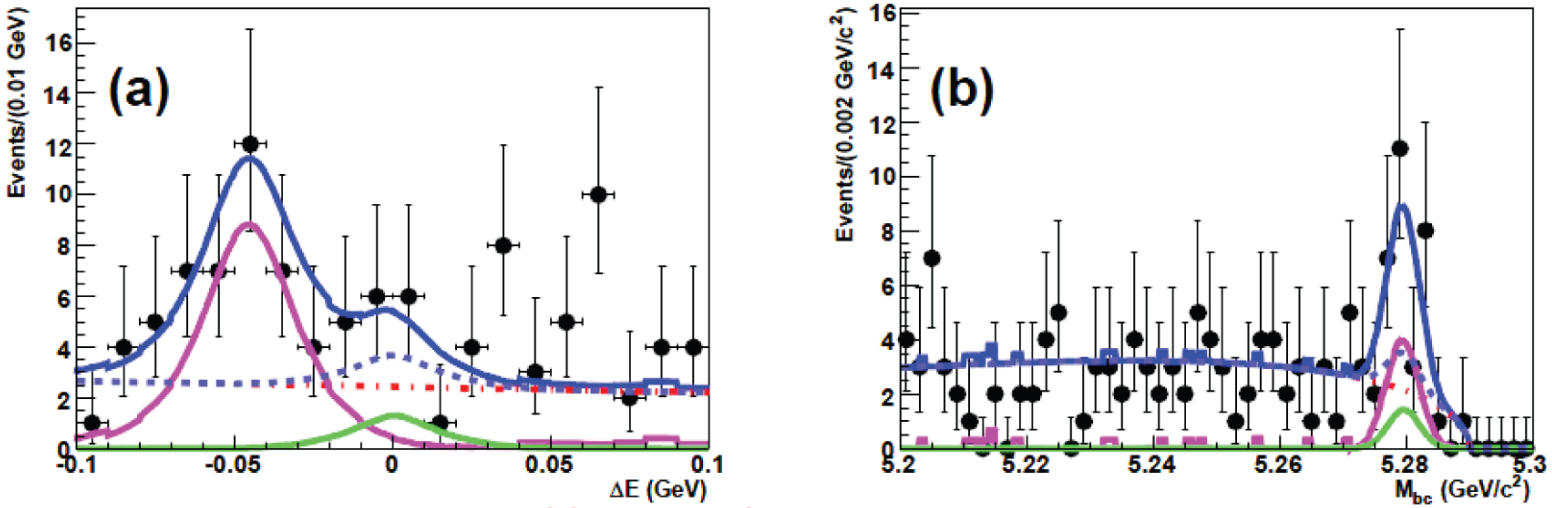
$$\mathcal{B}_{UL}(B^+ \to \phi\pi^+) < 2.4\times10^{-7}$$

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

	$B^+ \to \phi\pi^+$
Yield	$4.5^{+5.1\,+3.1}_{-4.3\,-6.9}$
$\epsilon_{\rm data}$	8.4%
$\mathcal{B}(10^{-7})$	$0.8^{+0.9\,+0.6}_{-0.8\,-1.3}$
$\mathcal{B}_{UL}(10^{-7})$	3.3

(657×10^6 $B\bar{B}$ pairs)

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



Projection of fits in the fit region with ΔE and $M_{\rm bc}$

Current Results

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

New upper limit !

Previous upper limit: (BaBar 2006)

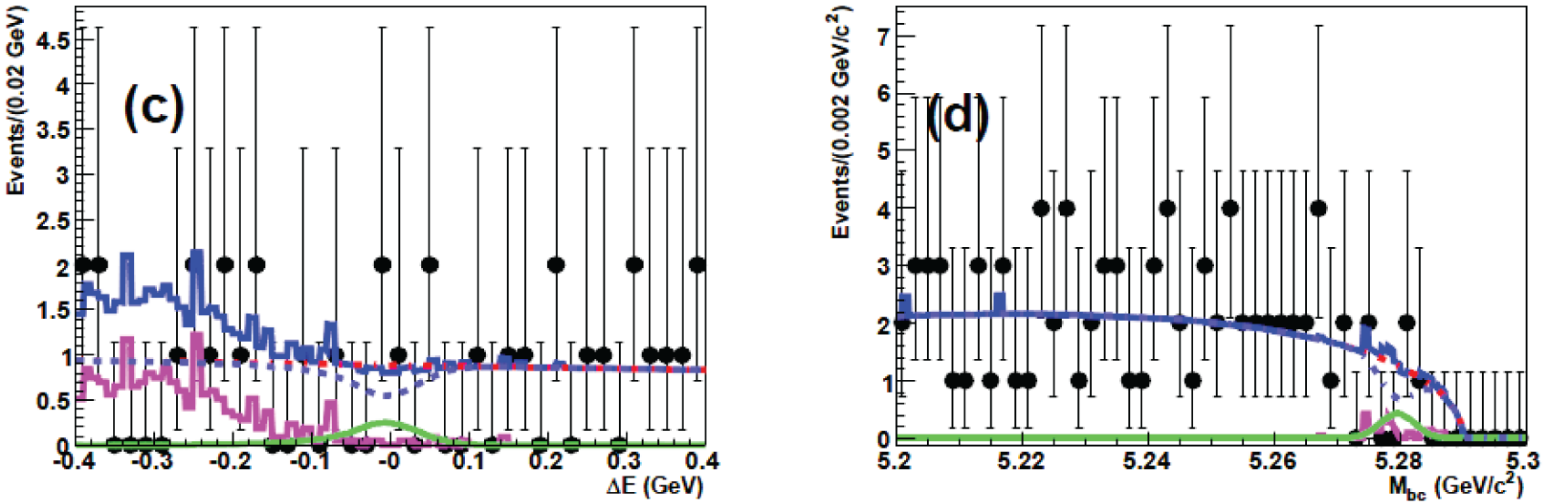
$$\mathcal{B}_{UL}(B^0 \to \phi\pi^0) < 2.8\times10^{-7}$$

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

	$B^0 \to \phi\pi^0$
Yield	$-2.2^{+2.1+1.3}_{-1.2-2.4}$
$\epsilon_{\rm data}$	4.9%
$\mathcal{B}(10^{-7})$	$-0.7^{+0.6+0.4}_{-0.4-0.8}$
$\mathcal{B}_{UL}(10^{-7})$	1.5

(657×10^6 $B\bar{B}$ 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 ΔE and $M_{\rm bc}$

Current Results

(Belle preliminary)

$B^0 \to K^+\pi^-$ and $B^0 \to \pi^+\pi^-$

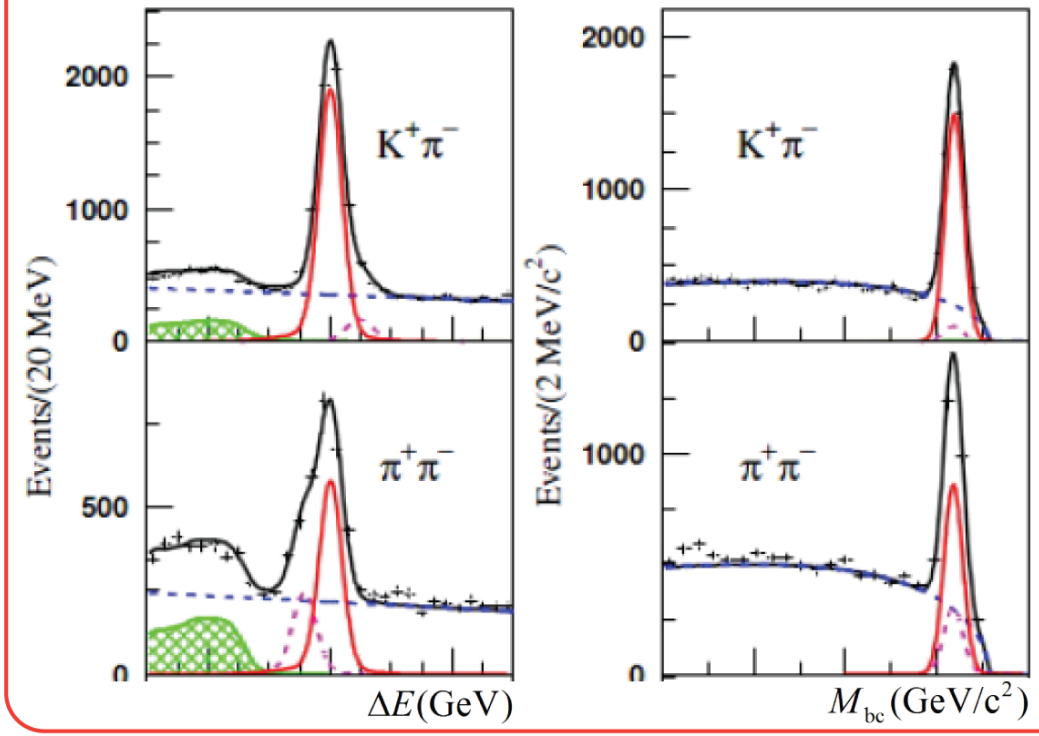
Signal yield, measured branching fraction and $\mathcal{A}_{CP}$ for both $B^0 \to K^+\pi^-$ and $B^0 \to \pi^+\pi^-$

Decay	Yield	$\mathcal{B}(10^{-6})$	$\mathcal{A}_{CP}$
$B^0 \to K^+\pi^-$	7525 ± 127	$20.00 \pm 0.34 \pm 0.63$	$-0.069 \pm 0.014 \pm 0.007$
$B^0 \to \pi^+\pi^-$	2111 ± 89	$5.04 \pm 0.21 \pm 0.19$	Update coming soon

(772×10^6 $B\bar{B}$ pairs)

Background from charmless B decays (hatched)

Background from mis-identification (dashed)



- Previous Belle Result $\mathcal{A}_{CP}(B \to K\pi)$:

  -0.094 ± 0.018 ± 0.008

  Using 535 x 10^6 $B\overline{B}$ pairs

  Nature **452**, 332 (2008)

- 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

(Belle preliminary)

$B^+ \to K^+\pi^0$ and $B^+ \to \pi^+\pi^0$

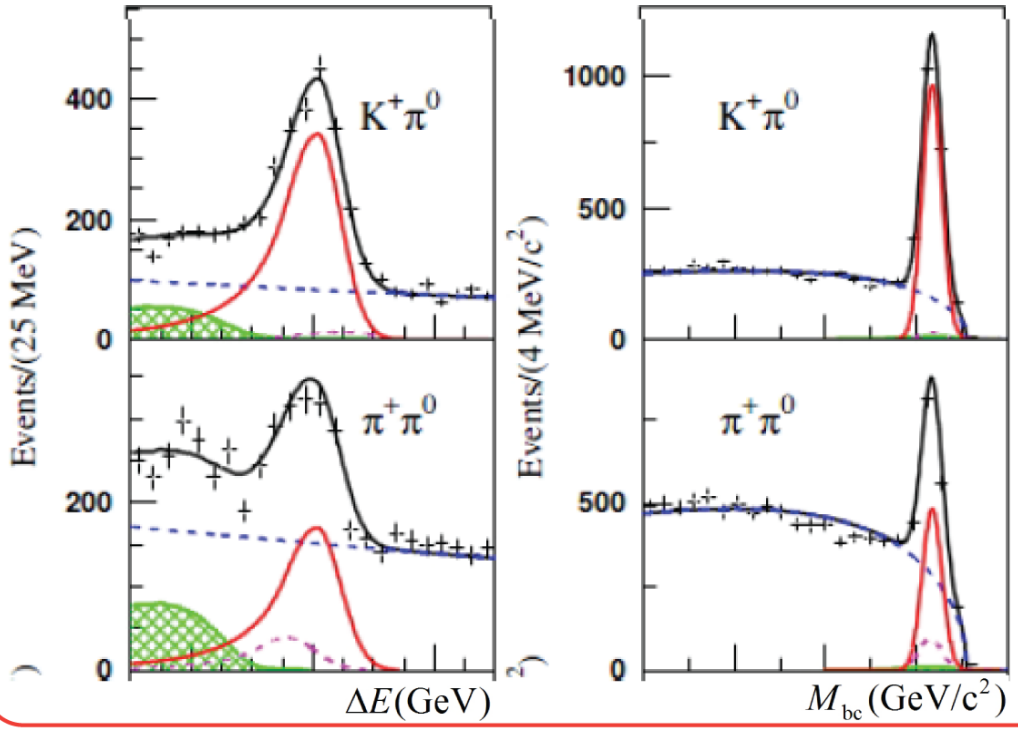
Signal yield, measured branching fraction and $\mathcal{A}_{CP}$ for both $B^+ \to K^+\pi^0$ and $B^+ \to \pi^+\pi^0$

Decay	Yield	$\mathcal{B}(10^{-6})$	$\mathcal{A}_{CP}$
$B^+ \to K^+\pi^0$	3731 ± 92	$12.62 \pm 0.31 \pm 0.56$	$+0.043 \pm 0.024 \pm 0.002$
$B^+ \to \pi^+\pi^0$	1846 ± 82	$5.86 \pm 0.26 \pm 0.38$	$-0.025 \pm 0.043 \pm 0.007$

(772×10^6 $B\bar{B}$ pairs)

Background from charmless B decays (hatched)

Background from mis-identification (dashed)



- Previous Belle Result

$\mathcal{A}_{CP}(B^+ \to K^+\pi^0)$:

$0.07 \pm 0.03 \pm 0.01$

Using 535 x 10^6 $B\bar{B}$ pairs

Nature **452**, 332 (2008)

$\mathcal{A}_{CP}(B^+ \to \pi^+\pi^0)$

$0.07 \pm 0.06 \pm 0.01$

Using 535 x 10^6 $B\bar{B}$ pairs

Nature **452**, 332 (2008)

Current Results

(Belle preliminary)

$$\Delta\mathcal{A}_{K\pi} = \mathcal{A}_{CP}(K\pi^0) - \mathcal{A}_{CP}(K\pi)$$

Previous Belle Result :

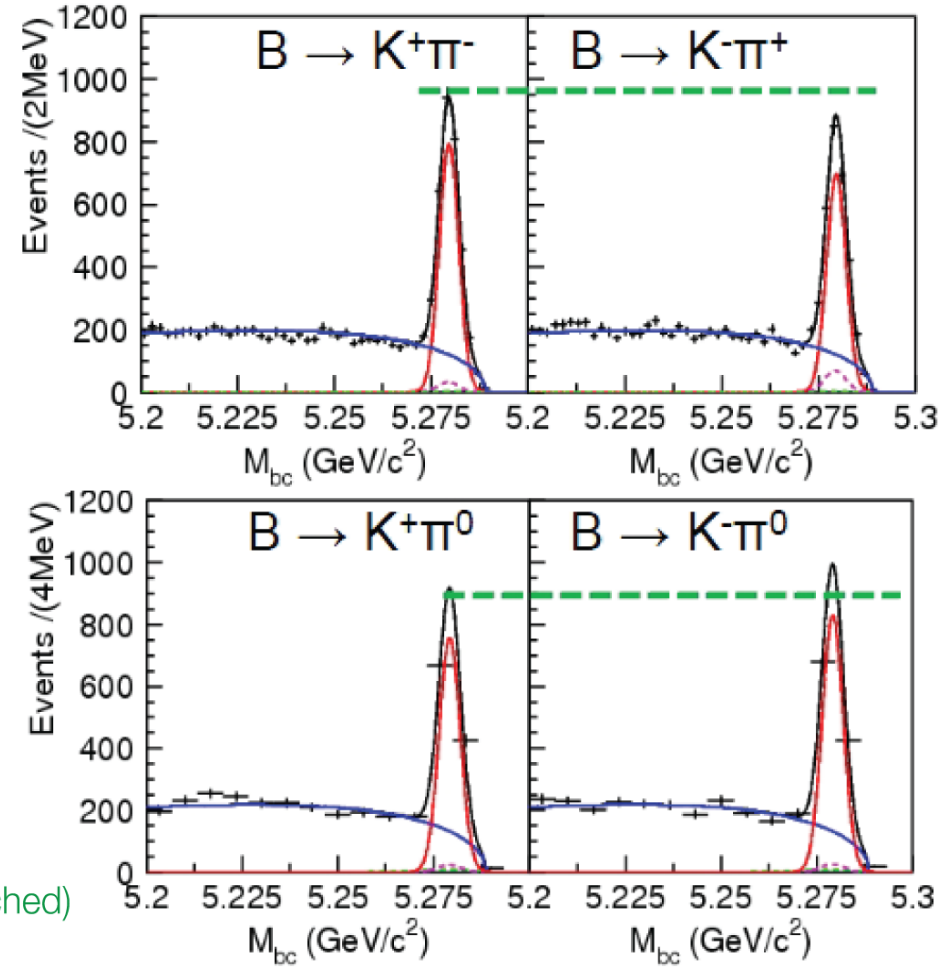
$\Delta\mathcal{A}_{K\pi} = +0.164 \pm 0.037\ 4.4\sigma$

(535 x 10^6 $B\bar{B}$ pairs)

New Result :

$\Delta\mathcal{A}_{K\pi} = +0.112 \pm 0.027\ 4\sigma$

(772×10^6 $B\bar{B}$ pairs)



Background from charmless B decays (hatched)

Background from mis-identification (dashed)

Current Results

(Belle preliminary)

$B \to K^0\pi$ and $B \to K^0K$

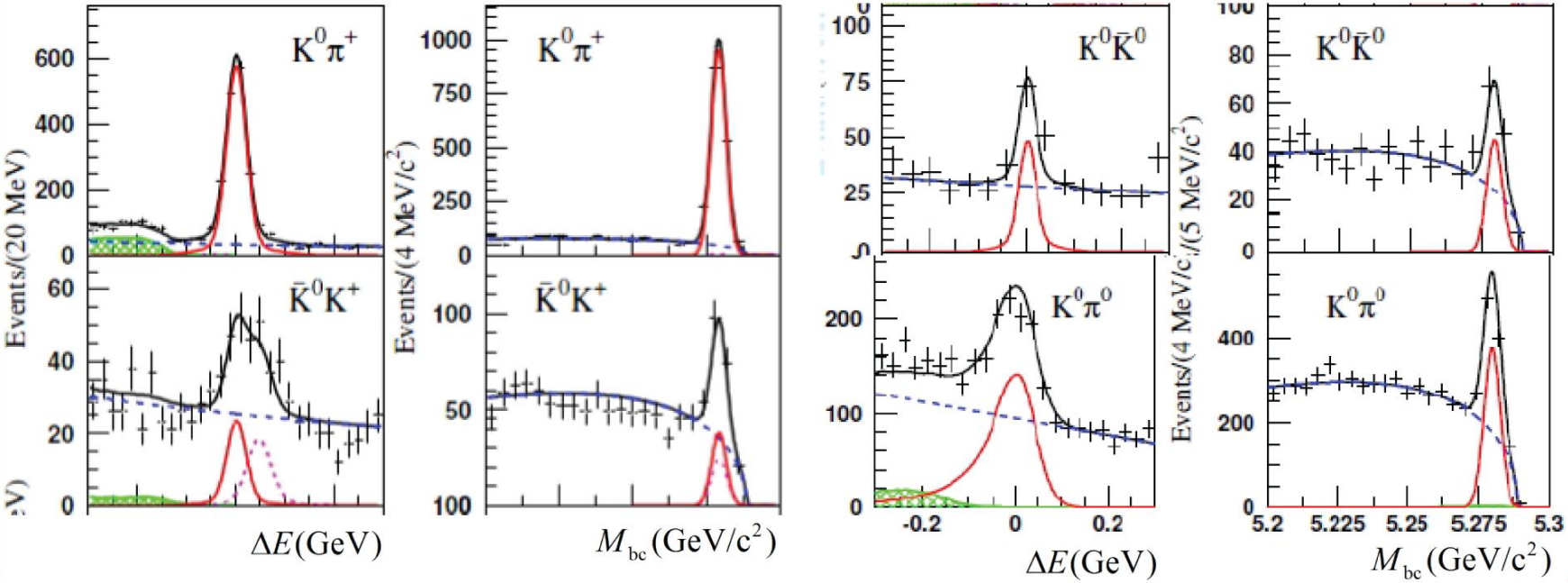
Signal yield, measured branching fraction and $\mathcal{A}_{CP}$ for $B^+ \to K^0\pi^+$, $B^+ \to K^0K^+$, $B^0 \to K^0K^0$ and $B \to K^0\pi^0$

Decay	Yield	$\mathcal{B}(10^{-6})$	$\mathcal{A}_{CP}$
$B^+ \to K^0\pi^+$	3229 ± 71	$23.97 \pm 0.53 \pm 0.69$	$-0.014 \pm 0.021 \pm 0.006$
$B^+ \to K^0K^+$	134 ± 23	$1.11 \pm 0.19 \pm 0.05$	$+0.017 \pm 0.168 \pm 0.002$
$B^0 \to K^0K^0$	103 ± 15	$1.26 \pm 0.19 \pm 0.06$	-
$B^0 \to K^0\pi^0$	961 ± 45	$19.68 \pm 0.46 \pm 0.50$	-

$\mathcal{A}_{CP}$ (PDG)
0.009 ± 0.029 (2012)
0.12 ± 0.18 (2012)

(772×10^6 $B\bar{B}$ pairs)

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



Current Results

(Belle preliminary)

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

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

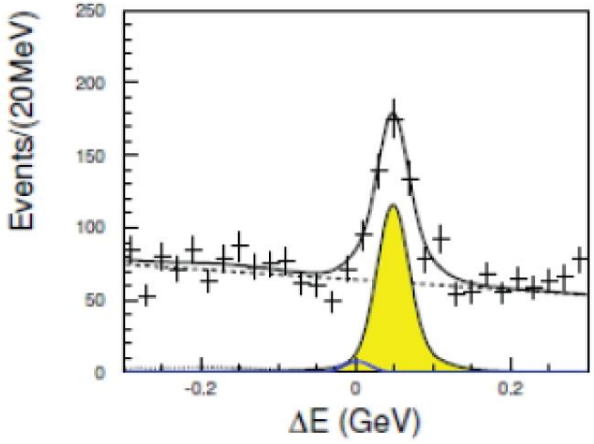
Decay	Yield	$\mathcal{B}(10^{-6})$	$\mathcal{A}_{CP}$
$B^+ \to K^0\pi^+$	35 ± 29	$0.1 \pm 0.08 \pm 0.06 (< 0.2)$	-

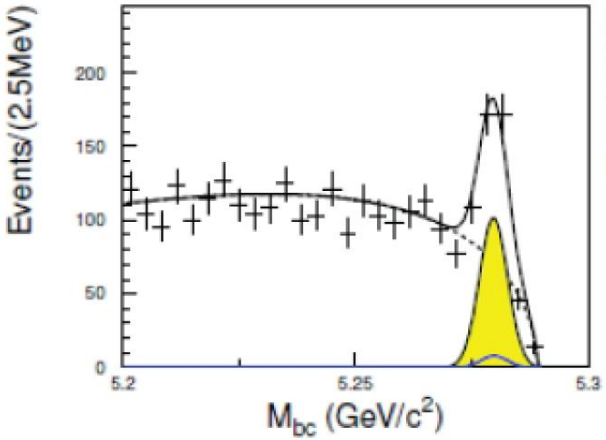
(772×10^6 $B\bar{B}$ pairs)

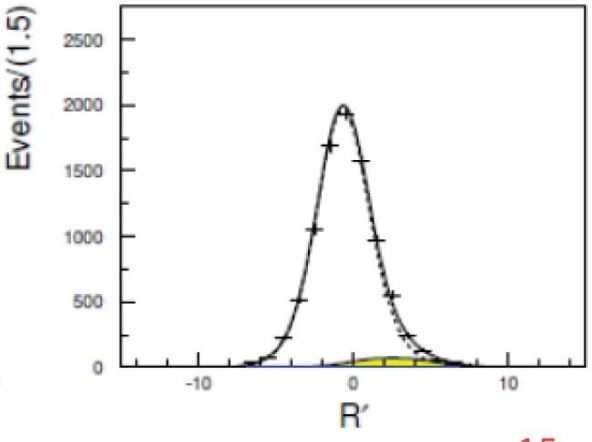
Previous and other experiments results

Experiment	$\mathcal{B}(10^{-6})$
Belle (2007)	$0.09^{+0.18}_{-0.13}$ (< 0.41)
BaBar (2007)	$0.04 \pm 0.15 \pm 0.08$ (< 0.5)
PDG (2010)	$0.15^{+0.11}_{-0.10}$ (< 0.41)
LHCb (2012) (Preliminary)	$0.11^{+0.05}_{-0.04} \pm 0.06$ (< 0.18)

Background from mis-identification (yellow)







Summary

- New branching fractions and direct $\mathcal{A}_{CP}$ are available for $B \to hh$ the final Belle dataset with improved (new tracking, large data) analyses.
  (To be submitted to PRL)

- A new, improved upper limit is available for $B \to \phi\pi$ 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 $\mathcal{A}_{CP}$ confirmes as evidence.

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

- New upper limits in $B^0 \to K^+K^-$ and updated branching fractions are also consistent with previous results.

Backup

Event Selection and Analysis

$B \to \phi\pi$ Analysis

- ϕ candidates are created from a pair of charged kaons with an invariant mass within $1.008\ \mathrm{GeV}/c^2 < M_{K^+K^-} < 1.031\ \mathrm{GeV}/c^2$ (2.5 times of the ϕ full width).
- Candidate π^0's are reconstructed from γ pairs that have invariant mass between $115.3\ \mathrm{MeV}/c^2$ and $152.8\ \mathrm{MeV}/c^2$ ($\pm 2.5\sigma$ standard deviations (σ)).
- The K^+K^- pair is combined with either a π^+ or a π^0 candidate.
- $M_{\mathrm{bc}} > 5.20\ \mathrm{GeV}$, and $|\Delta E| < 0.1\ \mathrm{GeV}$ for $B^+ \to \phi\pi^+$
  and $|\Delta E| < 0.4\ \mathrm{GeV}$ for $B^0 \to \phi\pi^0$
- 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 ϕ rest frame (θ_H).

Event Selection and Analysis

$B \to \phi\pi$ Analysis

Summary of the PDF's used in the measurement of $B \to \phi\pi$ decays

Mode	$B^+ \to \phi\pi^+$			$B^0 \to \phi\pi^0$		
	ΔE	$M_{\rm bc}$	Method (Yield)	ΔE	$M_{\rm bc}$	Method (Yield)
Signal	Sum of two Gaussians	Gaussian	Float($4.5^{+5.1}_{-4.3}$)	CB	Gaussian	Float($-2.2^{+2.1}_{-1.2}$)
$e^+e^- \to q\bar{q}$ process	1^{st} order poly.	ARGUS	Float($330.0^{+19.1}_{-18.4}$)	1^{st} order poly.	ARGUS	Float($265.6^{+16.9}_{-16.2}$)
$b \to c$	2D HistoPDF		Fixed(7.1)	2D HistoPDF		Fixed(4.8)
$b \to u, d, s$	2D HistoPDF		Fixed(4.1)	2D HistoPDF		Fixed(13.5)
$B^+ \to \phi K^+$	Sum of two Gaussians	Gaussian	Fixed(33.8)	-	-	-
Nonresonant $B \to K^+K^-\pi$	Sum of two Gaussians	Gaussian	Fixed(4.7)	CB	Gaussian	Fixed(1.6)

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

Systematic errors of the efficiency

Type		$B^0 \to \phi\pi^0$		$B^\pm \to \phi\pi^\pm$	
		$+\sigma$	$-\sigma$	$+\sigma$	$-\sigma$
MC acceptance	σ_M	0.8%	-0.8%	0.6%	-0.6%
PID	σ_M	1.3%	-1.3%	2.0%	-2.0%
Tracking	σ_M	2.0%	-2.0%	3.1%	-3.1%
π^0 detection efficiency	σ_M	3.0%	-3.0%	-	-
MDLR efficiency	σ_M	4.1%	-4.1%	2.4%	-2.4%
$N_{B\bar{B}}$	σ_M	1.4%	-1.4%	1.4%	-1.4%
Sum:σ_M		5.8%	-5.8%	4.7%	-4.7%

Event Selection and Analysis

$B \to hh$ Analysis

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

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

- $M_{\mathrm{bc}} > 5.20\ \mathrm{GeV}/c^2$ and $|\Delta E| < 0.3\ \mathrm{GeV}$

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

$$M_{\mathrm{bc}} \equiv \sqrt{E^{*2}_{\mathrm{beam}}/c^4 - |\vec{p}^{\,*}_B/c|^2}\ , \qquad \vec{p}^{\,*}_B = \vec{p}^{\,*}_h + \frac{\vec{p}^{\,*}_{\pi^0}}{|\vec{p}^{\,*}_{\pi^0}|}\sqrt{(E^*_{\mathrm{beam}} - E^*_{\mathrm{h}})^2 - m^{*2}_{\pi^0}}$$

Event Selection and Analysis

$B \to hh$ Analysis

- Data was fitted in 3 dimensions M_{bc}, ΔE and the continuum suppression variable.

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

- Other modes were fitted separately.

A background to the $\phi \to K^+K^-$ decays

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

- **Belle**

  $B \to K^+K^-\pi$ ($a_0(980) \to K^+K^-$, $f_0(980) \to K^+K^-$ and a nonresonant contribution)
  We obtain the expected yields for each mode, $B \to a_0(980)\pi$, $B \to f_0(980)\pi$ and nonresonant $B \to K^+K^-\pi$, from side-band data

  We assigned the PDF as signal of $B \to \phi\pi$

  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 $(K^+K^-)_{\text{S-wave}}$ system

  Further discrimination is provided by the K^+K^- invariant mass distribution, $M_{K^+K^-}$, which peaks at the ϕ 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 2σ

$$A_{CP}(K^+\pi^-) + A_{CP}(K^0\pi^+)\frac{B(K^0\pi^+)}{B(K^+\pi^-)}\frac{\tau_0}{\tau_+} = A_{CP}(K^+\pi^0)\frac{2B(K^+\pi^0)}{B(K^+\pi^-)}\frac{\tau_0}{\tau_+} + A_{CP}(K^0\pi^0)\frac{2B(K^0\pi^0)}{B(K^+\pi^-)}$$

$$A_{CP}(K^+\pi^-) + A_{CP}(K^0\pi^+)\frac{\Gamma(K^0\pi^+)}{\Gamma(K^+\pi^-)} = A_{CP}(K^+\pi^0)\frac{2\Gamma(K^+\pi^0)}{\Gamma(K^+\pi^-)} + A_{CP}(K^0\pi^0)\frac{2\Gamma(K^0\pi^0)}{\Gamma(K^+\pi^-)}$$

$$Lside - Rside = -0.270 \pm 0.145$$