

Study of charmless B -decays $B^\pm \longrightarrow K_S^0 K_S^0 h^\pm$ at Belle

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Outline

- ◆ Motivation for the study
- ◆ KEKB and belle detector
- ◆ Analysis strategy
- ◆ Signal and background studies
- ◆ Signal extraction
- ◆ Results and summary

Motivation for the study

- Sensitive to possible non-SM contributions.
- Interesting to study the quasi-two-body resonances and search for CP asymmetry localized in phase space.

Table 1: $B^\pm \rightarrow K_S^0 K_S^0 K^\pm$

Exp.	Data	Signal yield	B.F. ($\times 10^{-6}$)	\mathcal{A}_{CP}
<i>Belle</i> ^[1]	78 fb^{-1}	66.5 ± 9.3	$13.4 \pm 1.9 \pm 1.5$	-
<i>BaBar</i> ^[2]	426 fb^{-1}	636 ± 28	$10.6 \pm 0.5 \pm 0.3$	$(4_{-5}^{+4} \pm 2) \%$

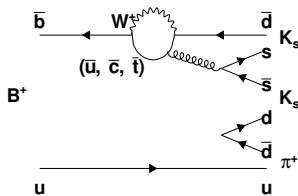
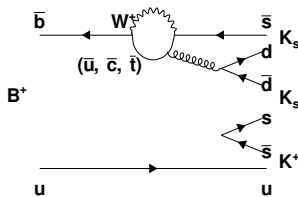
Table 2: $B^\pm \rightarrow K_S^0 K_S^0 \pi^\pm$

Exp.	Data	Signal yield	B.F.
<i>Belle</i> ^[1]	78 fb^{-1}	-1.8 ± 7.7	$< 3.2 \times 10^{-6}$
<i>BaBar</i> ^[3]	423.7 fb^{-1}	15 ± 15	$< 5.1 \times 10^{-7}$

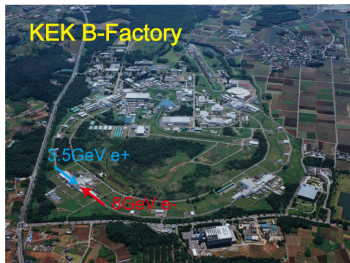
^[1]Phys. Rev. D **69**, 012001 (2004).

^[2]Phys. Rev. D **85**, 112010 (2012).

^[3]Phys. Rev. D **79**, 051101 (R) (2009).

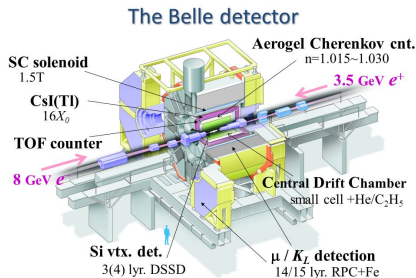


KEKB and belle detector



- Asymmetric e^+e^- collider at the High Energy Accelerator Research Organization(KEK), Japan.
- 8 GeV e^- collides to 3.5 GeV e^+ at $\Upsilon(4S)$ resonance.

- Collected about 772 million $B\bar{B}$ till 2010.
- The main goal was to search for CP violation in B meson decays.



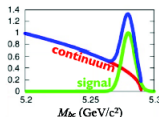
Analysis strategy

- Signal and background studies using Monte Carlo (MC) samples.
- Candidate selection using various kinematic variables.
- Use $B^+ \rightarrow \bar{D}^0(K_S^0 \pi^- \pi^+) \pi^+$ as a control mode.
- 2D simultaneous unbinned extended maximum likelihood fit to extract the signal yield, branching fraction (\mathcal{B}) and direct CP asymmetry (\mathcal{A}_{CP}).
- Obtain \mathcal{B} and \mathcal{A}_{CP} as a function of $M_{K_S^0 K_S^0}$ for $B^\pm \rightarrow K_S^0 K_S^0 K^\pm$.

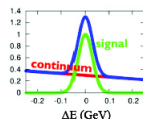
Signal MC study

- Use kinematic informations (ΔE and M_{bc}) from beam and B -vertices for the signal candidate selection.
- Primary selection cuts;

$$M_{bc} = \sqrt{E_{\text{BEAM}}^{*2} - \vec{p}_B^{*2}}$$



$$\Delta E = E_B^* - E_{\text{BEAM}}^*$$

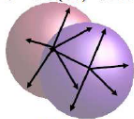


Sl.no.	Variable	Cut
1	$|dr|$	< 0.2 cm
2	$|dz|$	< 5.0 cm
3	$L(K/\pi)$	> 0.6 (Kaon) & < 0.4 (Pion)
4	K_S^0 mass	$\pm 3\sigma$ from the PDG value
5	ΔE	-0.30 GeV $< \Delta E < 0.50$ GeV
6	M_{bc}	> 5.2 GeV/ c^2

Background studies

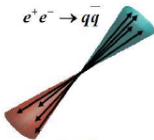
- The dominant background for this decay is from $e^+e^- \rightarrow q\bar{q}$ ($q = u, d, s, c$) continuum processes.
- Combine event topology variables in a Neural Network.
- 91% signal efficiency with 84% background rejection.

$e^+e^- \rightarrow Y(4S) \rightarrow B\bar{B}$

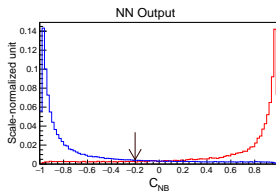


Spherical

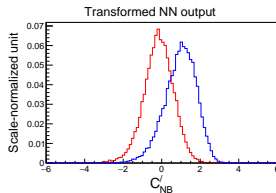
$e^+e^- \rightarrow q\bar{q}$



Jet-like



$$C'_{NB} = \ln\left(\frac{C_{NB} - C_{NB,min}}{C_{NB,max} - C_{NB}}\right)$$



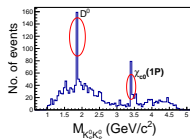
Background studies

- Charmed B decays, mediated via the $b \rightarrow c$ transitions.
- Vetoes: $B \rightarrow D^0 K$, $B \rightarrow \chi_{c0}(1P) K$, $B \rightarrow D^0 \pi$.
- Combinatorial B : Other B decays dominated by $b \rightarrow u, d, s$ transitions.
- Feed-across: $K_S^0 K_S^0 \pi$ in $K_S^0 K_S^0 K$, $K_S^0 K_S^0 K$ in $K_S^0 K_S^0 \pi$.
- Detection efficiency after all selection cuts:

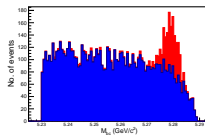
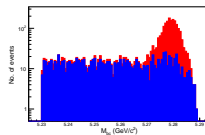
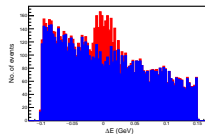
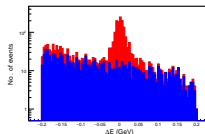
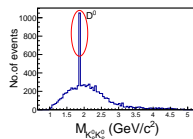
$$\epsilon_{K_S^0 K_S^0 K} \simeq 24\%$$

$$\epsilon_{K_S^0 K_S^0 \pi} \simeq 26\%$$

$B^\pm \rightarrow K_S^0 K_S^0 K^\pm$ (MC)



$B^\pm \rightarrow K_S^0 K_S^0 \pi^\pm$ (MC)



Fit preparation

- We define the branching fraction & inclusive charge asymmetry as:

$$\mathcal{B} = \frac{N_{\text{sig}}}{\epsilon \times N_{B\bar{B}} \times [\mathcal{B}(K_S^0 \rightarrow \pi^+\pi^-)]^2} \quad (1)$$

$$\mathcal{A}_{CP} = \frac{N_{B^-} - N_{B^+}}{N_{B^+} + N_{B^-}} \quad (2)$$

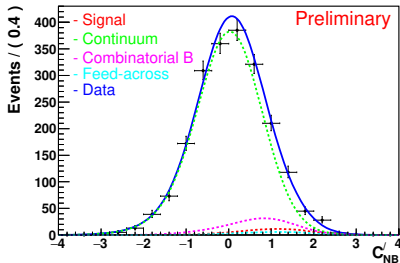
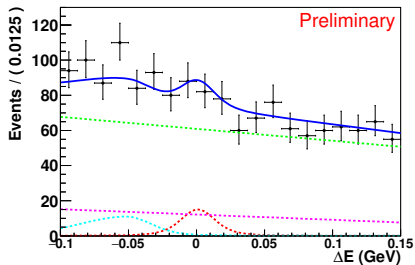
- We perform a 2D ($\Delta E - C'_{NB}$) simultaneous unbinned extended maximum likelihood fit to extract the signal yield for B^+ and B^- .
- To account for crossfeed between the two channels, they are simultaneously fitted, with the $B^+ \rightarrow K_S^0 K_S^0 K^+$ branching fraction determining the normalization of the crossfeed in the $B^+ \rightarrow K_S^0 K_S^0 \pi^+$ fit region, and vice versa.

Table 3: PDFs for $B^\pm \rightarrow K_S^0 K_S^0 K^\pm$. G

and Poly1 denote a Gaussian and a first-order polynomial

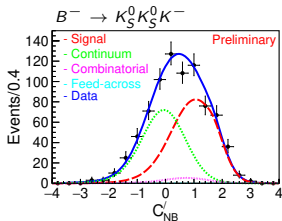
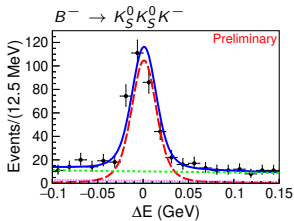
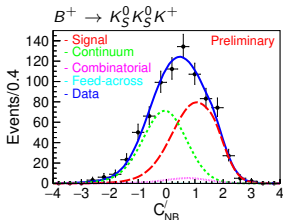
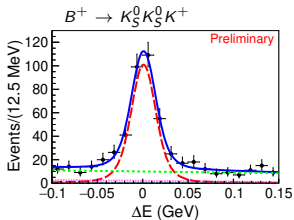
Event category	ΔE	C'_{NB}
Signal	3 G	G+AG
Continuum	Poly1	2 G
Combinatorial B	Poly1	2 G
Feed-across	G+Poly1	G

Fit results: $B^\pm \rightarrow K_S^0 K_S^0 \pi^\pm$



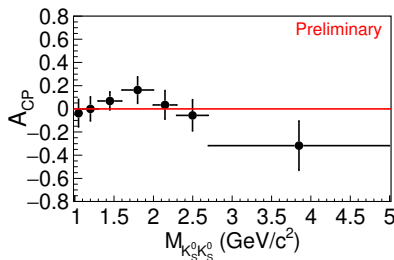
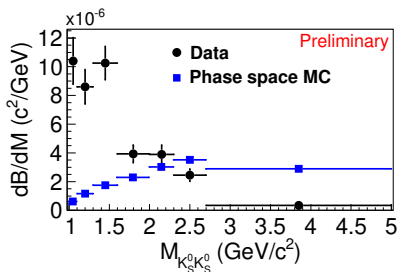
- Signal yield = 64 ± 26 ; corresponds 2.5σ significance.
- In the absence of a significant signal yield, we set a 90% confidence-level upper limit on the B.F. at 8.7×10^{-7}

Fit results: $B^\pm \rightarrow K_S^0 K_S^0 K^\pm$



\mathcal{B} and \mathcal{A}_{CP} as a function of $M_{K_S^0 K_S^0}$ for $B^\pm \rightarrow K_S^0 K_S^0 K^\pm$

- Observed an excess of events at $M_{K_S^0 K_S^0} < 1.5 \text{ GeV}/c^2$.
- The results agree with BaBar, who reported an \mathcal{A}_{CP} consistent with zero as well as the presence of quasi-two-body resonances $f_0(980)$, $f_0(1500)$, and $f_2'(1525)$ in the low $M_{K_S^0 K_S^0}$ region.



\mathcal{B} and \mathcal{A}_{CP} as a function of $M_{K_S^0 K_S^0}$ for $B^\pm \rightarrow K_S^0 K_S^0 K^\pm$

- Overall \mathcal{B} and \mathcal{A}_{CP} :

Preliminary results

$$\mathcal{B}(K_S^0 K_S^0 K^\pm) = (10.42 \pm 0.43 \pm 0.22) \times 10^{-6}$$

$$\mathcal{A}_{CP} = (1.6 \pm 3.9 \pm 1.1)\%$$

Table 4: Efficiency, differential branching fraction, and \mathcal{A}_{CP} in $M_{K_S^0 K_S^0}$ bins.

$M_{K_S^0 K_S^0}$ (GeV/ c^2)	Efficiency (%)	$d\mathcal{B}/dM \times 10^{-6}$ (c^2/GeV)	\mathcal{A}_{CP} (%)
1.0 – 1.1	24.0 ± 0.4	$10.40 \pm 1.24 \pm 0.41$	$-3.9 \pm 10.9 \pm 1.0$
1.1 – 1.3	23.4 ± 0.2	$8.60 \pm 0.85 \pm 0.37$	$-0.1 \pm 9.3 \pm 1.1$
1.3 – 1.6	22.9 ± 0.1	$10.23 \pm 0.73 \pm 0.42$	$+6.6 \pm 6.9 \pm 1.1$
1.6 – 2.0	21.8 ± 0.1	$3.93 \pm 0.43 \pm 0.17$	$+16.1 \pm 10.3 \pm 1.1$
2.0 – 2.3	24.1 ± 0.1	$3.90 \pm 0.47 \pm 0.17$	$-3.3 \pm 11.3 \pm 1.1$
2.3 – 2.7	25.2 ± 0.1	$2.45 \pm 0.33 \pm 0.11$	$-5.7 \pm 12.2 \pm 1.2$
2.7 – 5.0	26.3 ± 0.0	$0.35 \pm 0.07 \pm 0.02$	$-31.9 \pm 19.7 \pm 1.6$

Results and summary

- In the absence of a significant signal yield, we obtain a 90% confidence-level upper limit on the branching fraction of $B^\pm \rightarrow K_S^0 K_S^0 \pi^\pm$ as: 8.7×10^{-7} Preliminary

- Overall $\mathcal{B.F.}$ and \mathcal{A}_{CP} for $B^\pm \rightarrow K_S^0 K_S^0 K^\pm$ is obtained as:

$$\mathcal{B}(K_S^0 K_S^0 K^\pm) = (10.42 \pm 0.43 \pm 0.22) \times 10^{-6}$$

$$\mathcal{A}_{CP} = (1.6 \pm 3.9 \pm 1.1)\%$$

Preliminary

- Observed an excess of events similar to BaBar at $M_{K_S^0 K_S^0} < 1.5 \text{ GeV}/c^2$ of $B^\pm \rightarrow K_S^0 K_S^0 K^\pm$.
- These supersede Belle's earlier measurements and constitute the most precise results to date.

THANK YOU!



Back up: Systematic uncertainties

Table 5: Systematic uncertainties in the branching fraction of $B^+ \rightarrow K_S^0 K_S^0 \pi^+$.

Source	Relative uncertainty in \mathcal{B} (%)
Tracking	0.35
Particle identification	0.80
Number of $B\bar{B}$ pairs	1.37
Continuum suppression	0.34
Requirement on M_{bc}	0.03
K_S^0 reconstruction efficiency	3.22
Fit bias	1.86
Signal PDF	1.30
Combinatorial $B\bar{B}$ PDF	+1.31, -1.98
Feed-across PDF	+3.57, -4.10
Fixed background yield	0.00
Fixed background \mathcal{A}_{CP}	0.50
Total	+5.74, -6.27

Back up: Systematic uncertainties for $B^+ \rightarrow K_S^0 K_S^0 K^+$

$M_{K_S^0 K_S^0}$ (GeV/ c^2)	1.0 – 1.1	1.1 – 1.3	1.3 – 1.6	1.6 – 2.0	2.0 – 2.3	2.3 – 2.7	2.7 – 5.0
Source	Relative uncertainty in $d\mathcal{B}/dM$ (%)						
Tracking [†]				0.35			
Particle identification [†]				0.80			
Number of $B\bar{B}$ pairs [†]				1.37			
Continuum suppression [†]				0.34			
Requirement on M_{bc}^\dagger				0.03			
K_S^0 reconstruction efficiency [†]				3.22			
Fit bias [†]				0.53			
Signal PDF	+0.33	+0.63	+0.46	+0.22	+0.52	0.67	1.10
Combinatorial $B\bar{B}$ PDF	-0.27	-0.48	-0.44	-0.63	-0.38		
Feed-across PDF	0.09	+0.08	0.12	+0.17	+0.26	0.40	0.40
Fixed background yield	...	-0.13	...	-0.21	-0.34	...	...
Fixed background \mathcal{A}_{CP}	...	...	...	...	...	...	...
Total	±4.00	±4.33	±4.15	±4.40	±4.25	±4.45	±4.84

$M_{K_S^0 K_S^0}$ (GeV/ c^2)	1.0 – 1.1	1.1 – 1.3	1.3 – 1.6	1.6 – 2.0	2.0 – 2.3	2.3 – 2.7	2.7 – 5.0
Source	Absolute uncertainty in \mathcal{A}_{CP}						
Signal PDF	0.001	0.002	0.001	0.002	0.001	0.001	0.004
Combinatorial $B\bar{B}$ PDF	0.001	0.001	0.001	...	0.001	0.002	0.001
Feed-across PDF	...	...	...	...	...	...	...
Fixed background yield	...	...	0.001	0.001	0.001	0.001	0.001
Fixed background \mathcal{A}_{CP}	...	...	0.001	0.001	0.001	0.002	0.006
Detector bias [†]				0.009			

