Measurements 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.

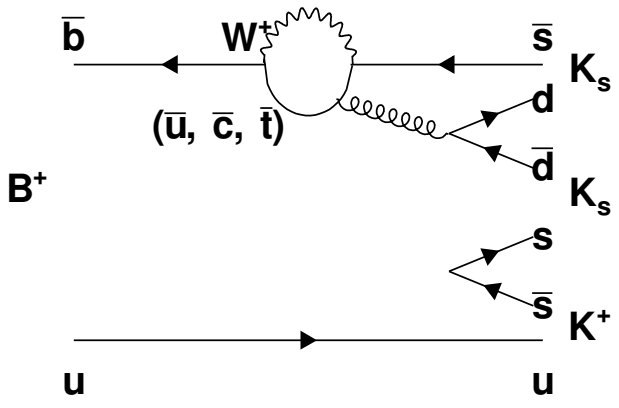
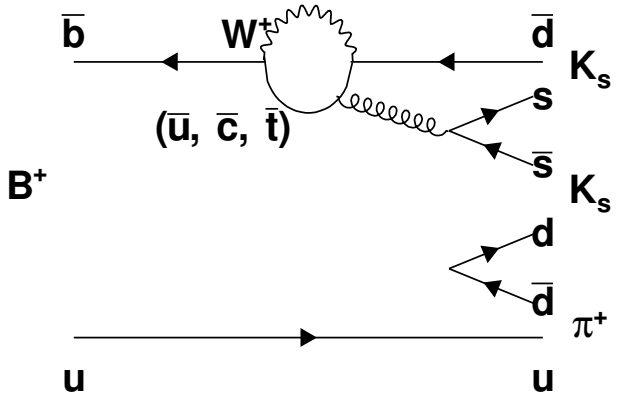


Table 1: $B^{\pm} \to K_S^0 K_S^0 K^{\pm}$

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

Table 2: $B^{\pm} \to K_S^0 K_S^0 \pi^{\pm}$

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

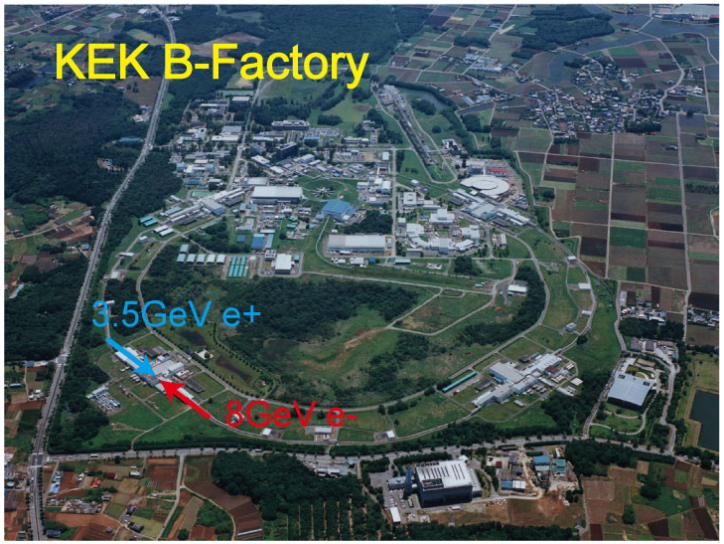


[1] Phys. Rev. D **69**, 012001 (2004).

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

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

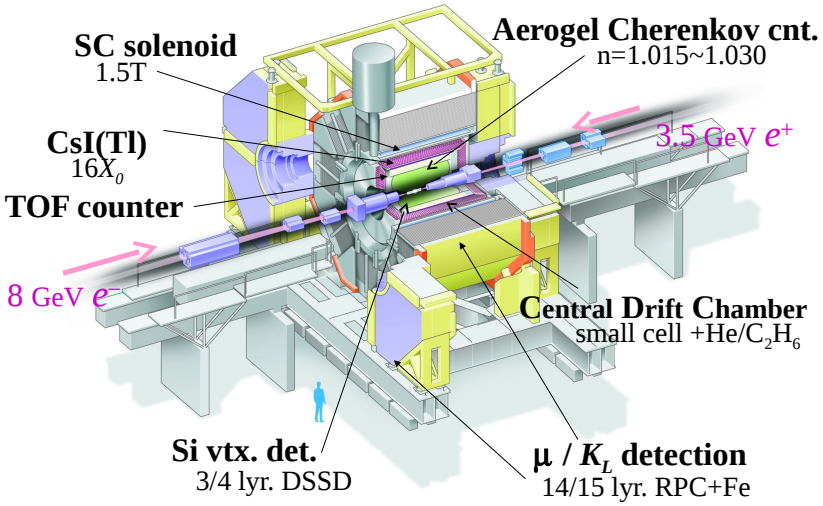
KEKB and belle detector



- 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.

Belle Detector



Analysis strategy

- Reconstruct the $B^{\pm}$ candidates from $K_S^0 K_S^0 K^{\pm}$ and $K_S^0 K_S^0 \pi^{\pm}$
- Candidate selection using various kinematic variables.
- Background studies using Monte Carlo (MC) samples.
- Use $B^+ \to \bar{D}^0(K_S^0\pi^-\pi^+)\pi^+$ 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 $B^{\pm} \to K_S^0 K_S^0 K^{\pm}$.

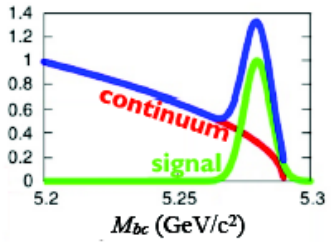
Signal MC study

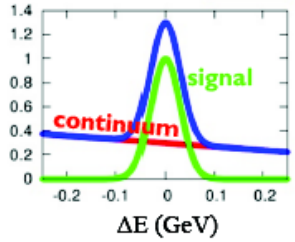
- Use kinematic informations (**ΔE** and $\mathbf{M_{bc}}$) for the signal candidate selection.

- Primary selection cuts;

$$M_{bc} = \sqrt{E^{*2}_{BEAM} - \vec{p}^{*2}_{B}}$$

$$\Delta E = E^{*}_{B} - E^{*}_{BEAM}$$

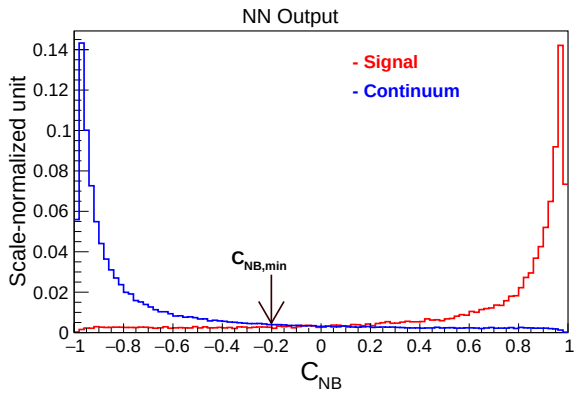




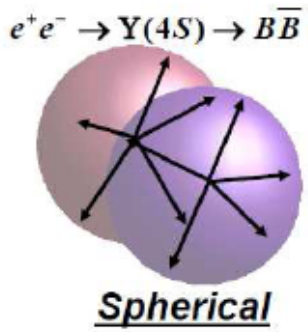
Sl.no.	Variable	Cut
1	$\lvert dr \rvert$	< 0.2 cm
2	$\lvert dz \rvert$	< 5.0 cm
3	$L(K/\pi)$	> 0.6 (Kaon) & < 0.4 (Pion)
4	K^0_S mass	$\pm 3\sigma$ from the PDG value
5	ΔE	$-0.30\ GeV < \Delta E < 0.50\ GeV$
6	$M_{\rm bc}$	$> 5.2\ GeV/c^2$

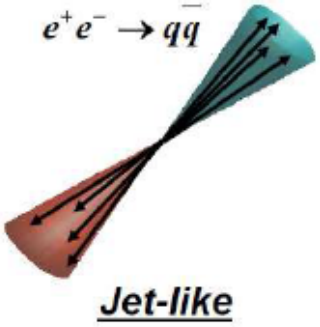
Background studies

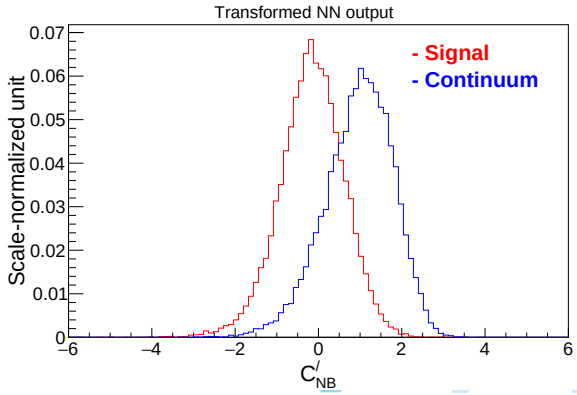
- The dominant background for this decay is from $e^+e^- \longrightarrow q\bar{q}$ (q = u, d, s, c) continuum processes.
- Combine event topology variables in a Neural Network.
- 91% signal efficiency with 84% background rejection.



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



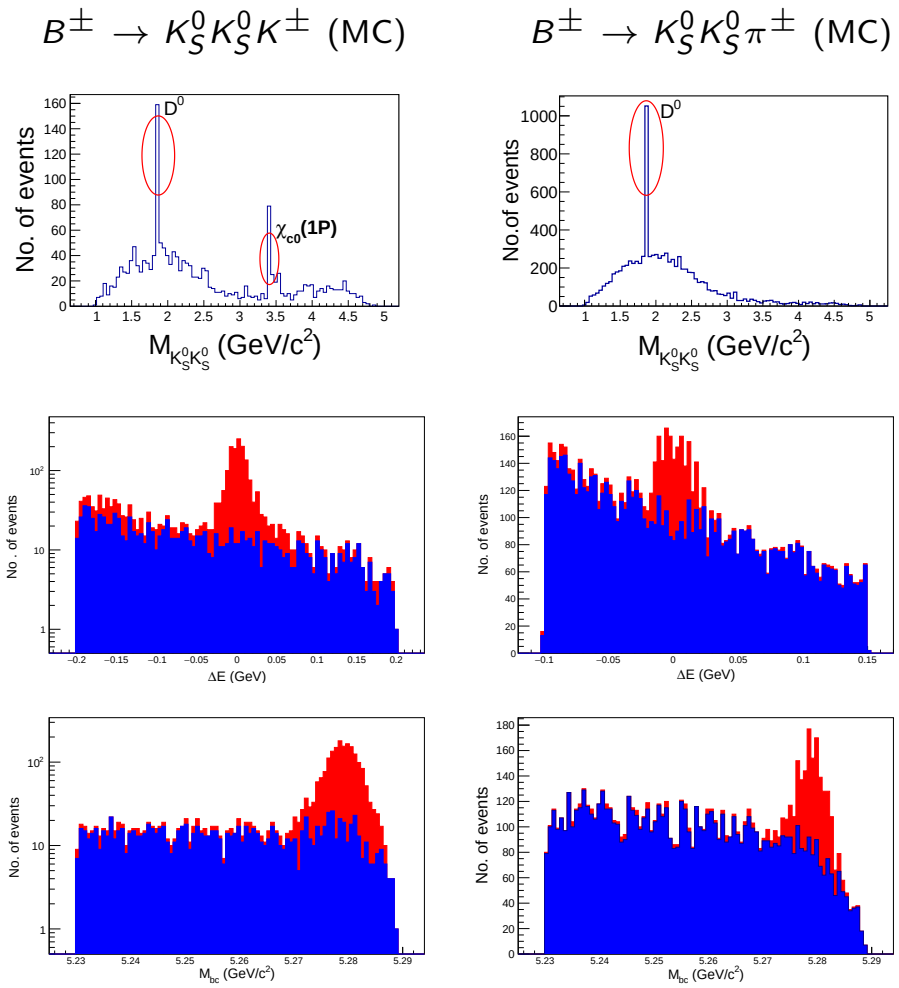




Background studies

- Charmed B decays, mediated via the $b \to c$ transitions.
- Vetoes: $B \to D^0 K$, $B \to \chi_{c0}(1P)K$, $B \to D^0\pi$.
- Combinatorial B : Other B decays dominated by $b \to u, d, s$ 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:

$$\epsilon_{K_S^0 K_S^0 K} \simeq 24\%$$
$$\epsilon_{K_S^0 K_S^0 \pi} \simeq 26\%$$



Fit preparation

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

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

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

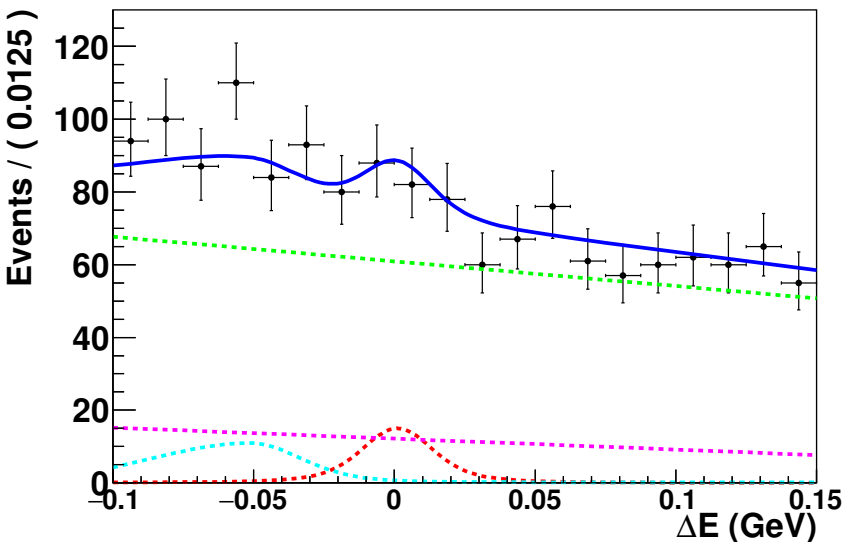
Table 3: PDFs for $B^\pm \longrightarrow K_S^0 K_S^0 K^\pm$. G and Poly1 denote a Gaussian and a first-order polynomial

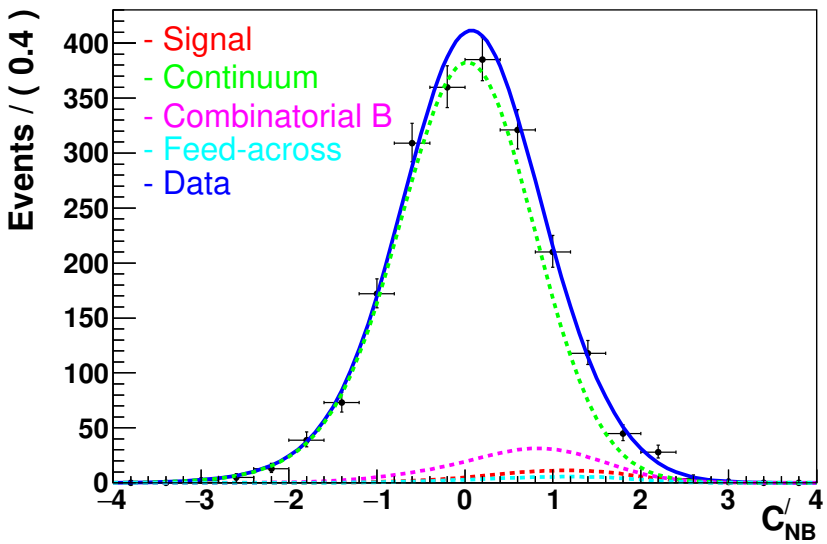
Event category	ΔE	C'_{NB}
Signal	3 G	G+AG
Continuum	Poly1	2 G
Combinatorial B	Poly1	2 G
Feed-across	G+Poly1	G

- We perform a 2D (ΔE-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 $B^+ \to K_S^0 K_S^0 K^+$ branching fraction determining the normalization of the crossfeed in the $B^+ \to K_S^0 K_S^0 \pi^+$ fit region, and vice versa.

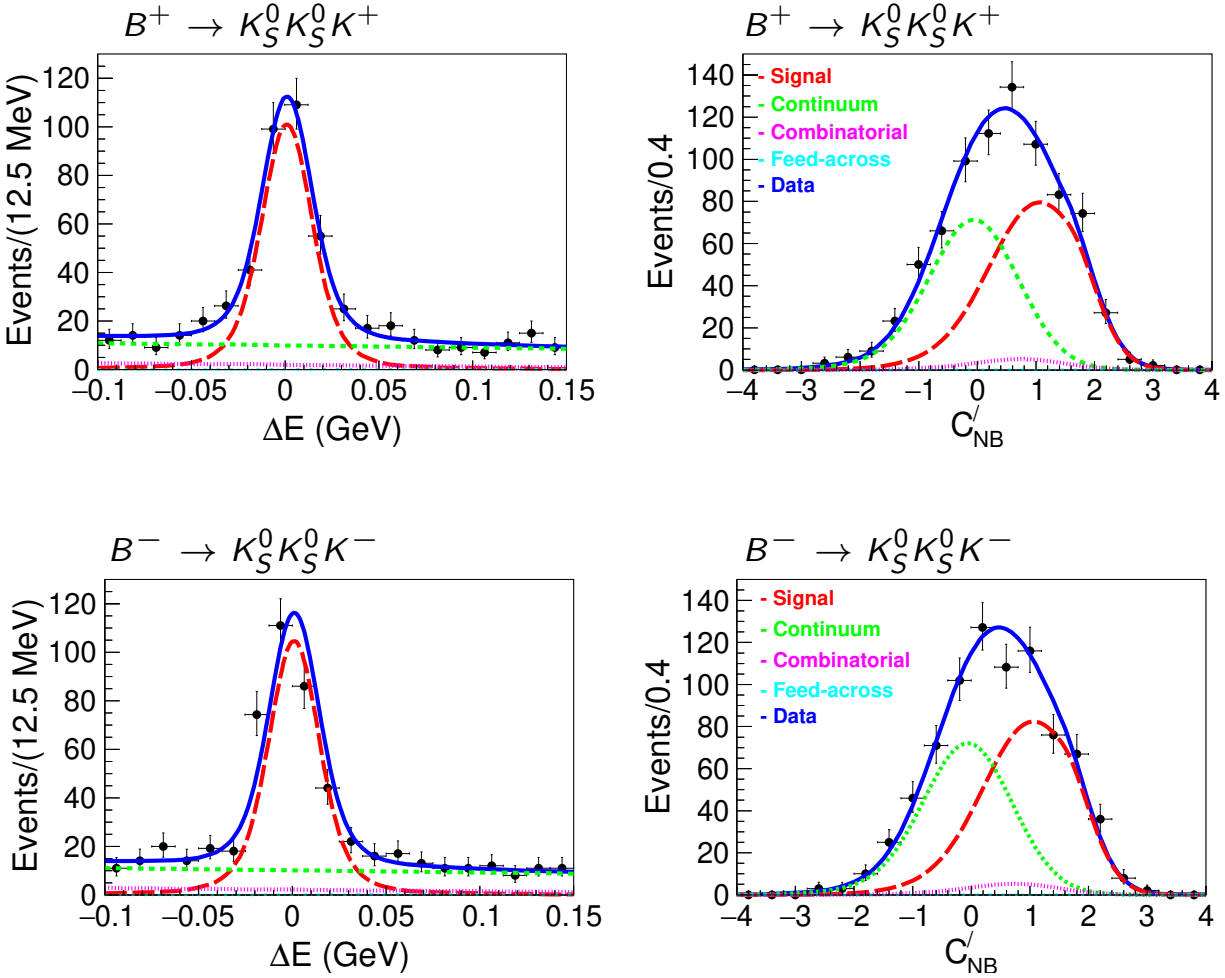
Fit results: $B^{\pm} \to K_s^0 K_s^0 \pi^{\pm}$





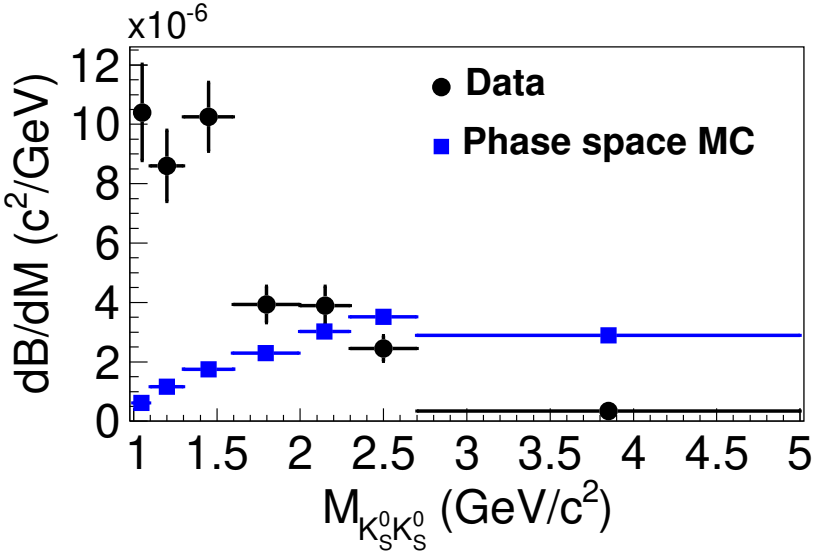
- Signal yield $= 64 \pm 26$; corresponds 2.5 σ significance.
- In the absence of a significant signal yield, we set a 90% confidence-level upper limit on the B.F. at $\boxed{8.7 \times 10^{-7}}$

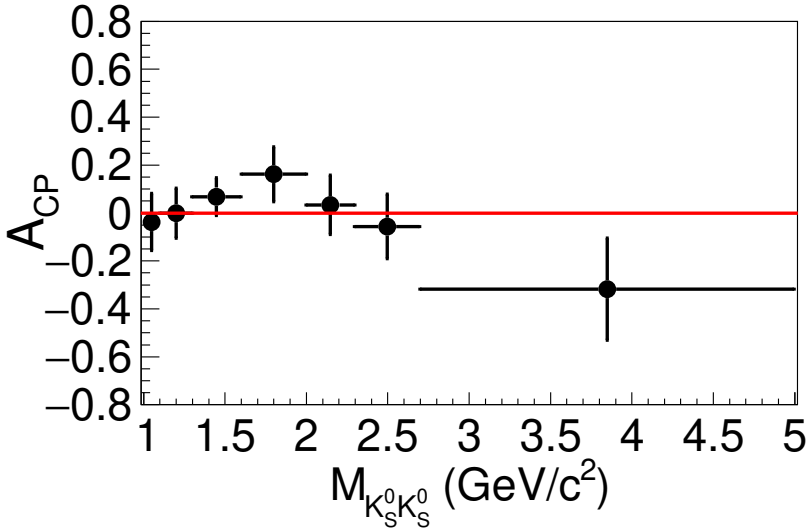
Fit results: $B^{\pm} \to K_s^0 K_s^0 K^{\pm}$



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

- Observed an excess of events at $M_{K_S^0 K_S^0} < 1.5\,\mathrm{GeV}/c^2$.
- 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 $B^\pm \to K_S^0 K_S^0 K^\pm$

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

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

$$\mathcal{A}_{CP} = (1.6 \pm 3.9 \pm 0.9)\%$$

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	$10.40 \pm 1.24 \pm 0.38$	$-3.9 \pm 10.9 \pm 0.9$
$1.1 - 1.3$	23.4 ± 0.2	$8.60 \pm 0.85 \pm 0.32$	$-0.1 \pm 9.3 \pm 0.9$
$1.3 - 1.6$	22.9 ± 0.1	$10.23 \pm 0.73 \pm 0.38$	$+6.6 \pm 6.9 \pm 0.9$
$1.6 - 2.0$	21.8 ± 0.1	$3.93 \pm 0.43 \pm 0.15$	$+16.1 \pm 10.3 \pm 0.9$
$2.0 - 2.3$	24.1 ± 0.1	$3.90 \pm 0.47 \pm 0.15$	$-3.3 \pm 11.3 \pm 0.9$
$2.3 - 2.7$	25.2 ± 0.1	$2.45 \pm 0.33 \pm 0.09$	$-5.7 \pm 12.2 \pm 1.0$
$2.7 - 5.0$	26.3 ± 0.0	$0.35 \pm 0.07 \pm 0.01$	$-31.9 \pm 19.7 \pm 1.2$

Major sources of systematic uncertainties

B.F. $(B^{\pm} \to K_S^0 K_S^0 K^{\pm})$

- Tracking
- Particle identification
- Number of $B\bar{B}$ pairs (1.37%)
- Continuum suppression
- K_S^0 reconstruction efficiency (3.22%)
- Fit bias
- PDF modelling (bin dependent)
- Fixed background yield (bin dependent)
- Fixed background $\mathcal{A}_{CP}$ (bin dependent)

B.F. $(B^{\pm} \to K_S^0 K_S^0 \pi^{\pm})$

- Tracking
- Particle identification
- Number of $B\bar{B}$ pairs. (1.37%)
- Continuum suppression
- K_S^0 reconstruction efficiency(3.22%)
- Fit bias (1.86%)
- PDF modelling(4%)
- Fixed background yield ((2.6%)
- Fixed background $\mathcal{A}_{CP}$

$\mathcal{A}_{CP}$ $(B^{\pm} \to K_S^0 K_S^0 K^{\pm})$

- Detector bias
- PDF modelling (bin dependent)
- Fixed background yield (bin dependent)
- Fixed background $\mathcal{A}_{CP}$ (bin dependent)

Results and summary

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

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

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

$$\boxed{\mathcal{A}_{CP} = (1.6 \pm 3.9 \pm 0.9)\%}$$

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1812.10221 [hep-ex]

- Observed an excess of events similar to BaBar at $M_{K_S^0 K_S^0} < 1.5\,\mathrm{GeV}/c^2$ of $B^{\pm} \to K_s^0 K_s^0 K^{\pm}$.

- 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 $B^+ \to K_s^0 K_s^0 \pi^+$.

Source	Relative uncertainty in $\mathcal{B}$ (%)
Tracking	0.35
Particle identification	0.80
Number of $B\overline{B}$ pairs	1.37
Continuum suppression	0.34
Requirement on $M_{\rm bc}$	0.03
K_S^0 reconstruction efficiency	3.22
Fit bias	1.86
Signal PDF	1.30
Combinatorial $B\overline{B}$ PDF	$+1.31, -1.98$
Feed-across PDF	$+3.57, -4.10$
Fixed background yield	$+2.63, -2.27$
Fixed background $\mathcal{A}_{CP}$	0.50
Total	$+6.30, -6.67$

Back up: Systematic uncertainties for $B^+ \to K_s^0 K_s^0 K^+$

$M_{K_S^0 K_S^0}$ (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 $B\overline{B}$ pairs†				1.37			
Continuum suppression†				0.34			
Requirement on $M_{\rm bc}^\dagger$				0.03			
K_S^0 reconstruction†				3.22			
Fit bias†				0.53			
Signal PDF	$^{+0.33}_{-0.27}$	$^{+0.63}_{-0.48}$	$^{+0.46}_{-0.44}$	$^{+0.22}_{-0.63}$	$^{+0.52}_{-0.38}$	0.67	1.10
Combinatorial $B\overline{B}$ PDF	0.09	$^{+0.08}_{-0.13}$	0.12	$^{+0.17}_{-0.21}$	$^{+0.26}_{-0.34}$	0.40	0.40
Feed-across PDF	...	...	...	...	...	...	...
Fixed background yield	...	0.10	0.10	0.23	...	0.11	0.60
Fixed background $\mathcal{A}_{CP}$	...	...	...	0.20	0.10	...	0.13
Total	±3.68	±3.72	±3.69	±3.73	±3.72	±3.75	±3.89

$M_{K_S^0 K_S^0}$ (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 $B\overline{B}$ 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	0.004
Fixed background $\mathcal{A}_{CP}$	...	...	0.001	0.001	0.001	0.002	0.006
Detector bias†				0.009			
Total	±0.009	±0.009	±0.009	±0.009	±0.009	±0.010	±0.012