Measurements of ϕ_1^{eff} from $K_S K_S K_S$, $K_S \pi^0 \pi^0$ and $K^0 \pi^0$

M. Fujikawa
The Belle Collaboration

Introduction

Δt : proper time difference

Δm: mass difference

η_{CP} : CP eigenvalue

$$\lambda = \frac{q}{p}\frac{A(\bar{B}^0 \to f\ )}{A(B^0 \to f\ )} \approx \eta_{CP}\ e^{-i2\phi_1}$$

- CP Asymmetry

$$A(\Delta t) = \frac{\Gamma(\bar{B}^0(\Delta t) \to f_{CP}) - \Gamma(B^0(\Delta t) \to f_{CP})}{\Gamma(\bar{B}^0(\Delta t) \to f_{CP}) + \Gamma(B^0(\Delta t) \to f_{CP})}$$

$$= \frac{|\lambda|^2 - 1}{1+|\lambda|^2}\cos(\Delta m \cdot \Delta t) + \frac{2\Im\lambda}{1+|\lambda|^2}\sin(\Delta m \cdot \Delta t)$$

$\mathcal{A}$ (= - $\mathcal{C}$) ~ 0

Belle BaBar

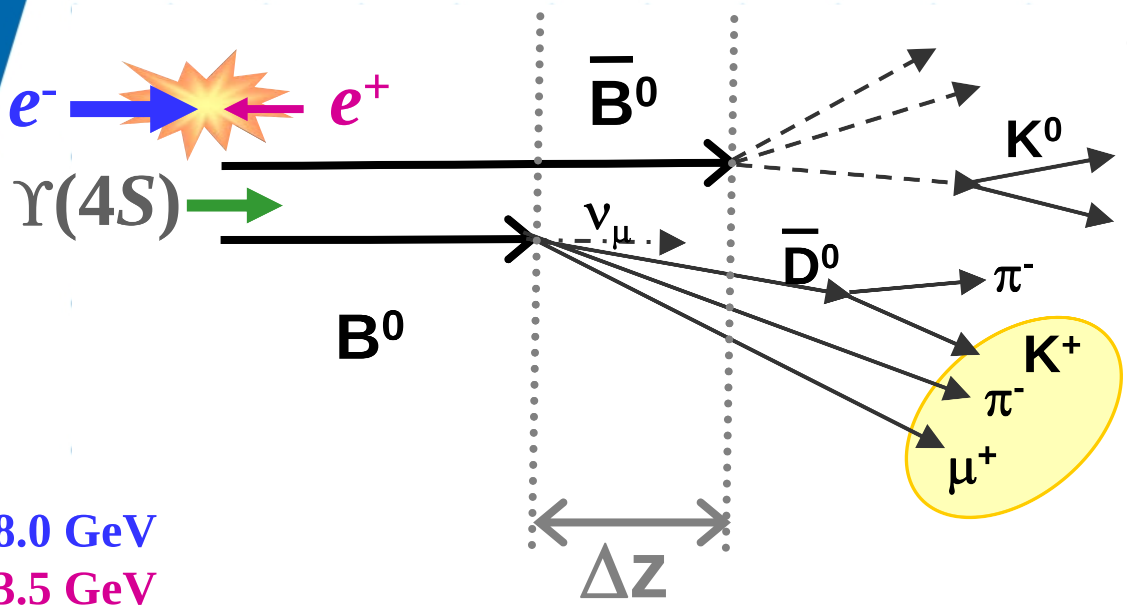
Direct CPV

SM expectation

$\mathcal{S}$: $-\eta_{CP}\sin 2\varphi_1$

Mixing-induced CPV

Basic Analysis Procedure



e^-: 8.0 GeV
e^+: 3.5 GeV

$\Delta z = \Delta t\ \beta\gamma c \sim 200 \mu m$

$\beta\gamma = 0.43 / 0.56$

Belle / BaBar

CP eigenstate

Reconstruction

↓

Flavour specific final state

Flavour tag

↓

Measure vertex distance (ΔZ)

↓

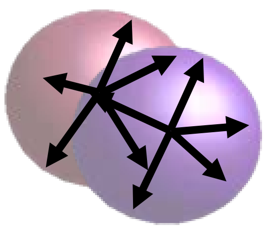
Fit proper time (Δt) distribution

Basic Analysis Procedure

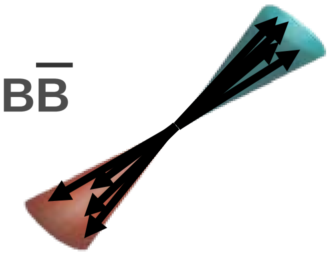
- B extracted with M_{bc} , ΔE

$$M_{bc} \equiv m_{ES} \equiv \sqrt{E^{*\,2}_{beam} - p^{*\,2}_{B}} \;,\quad \Delta E \equiv E^{*}_{B} - E^{*}_{beam}$$

- Main Background
  – Continuum event [$e^+e^- \rightarrow q\bar{q}$ (q=u,d,s,c)]
  – Separate with Likelihood ratio ($L_{s/b}$) from event shape



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

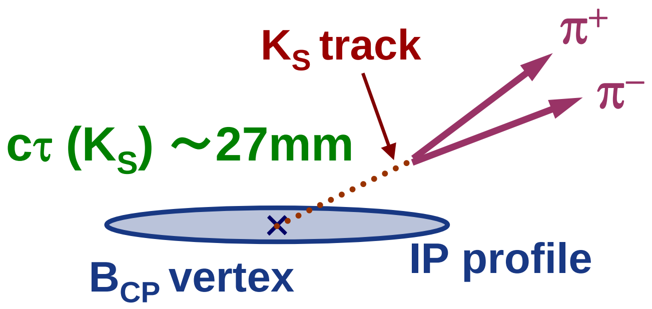


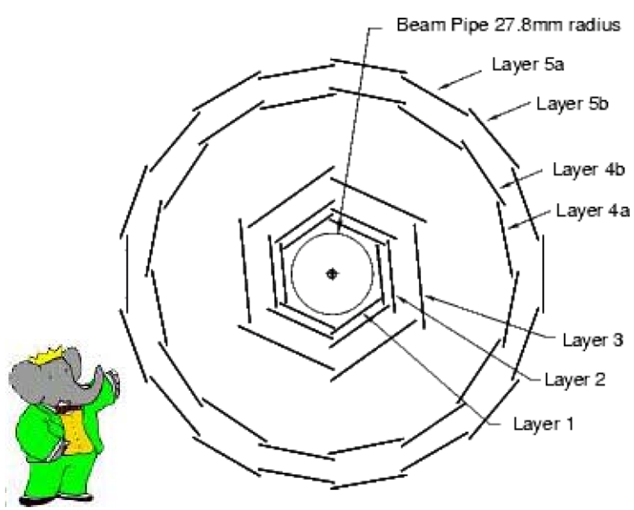
$e^+e^- \rightarrow q\bar{q}$
(Jet-like)

- Signal extraction
  – Multi-dimensions (M_{bc}, ΔE, $L_{s/b}$, …)
  – Extended unbinned maximum likelihood fit

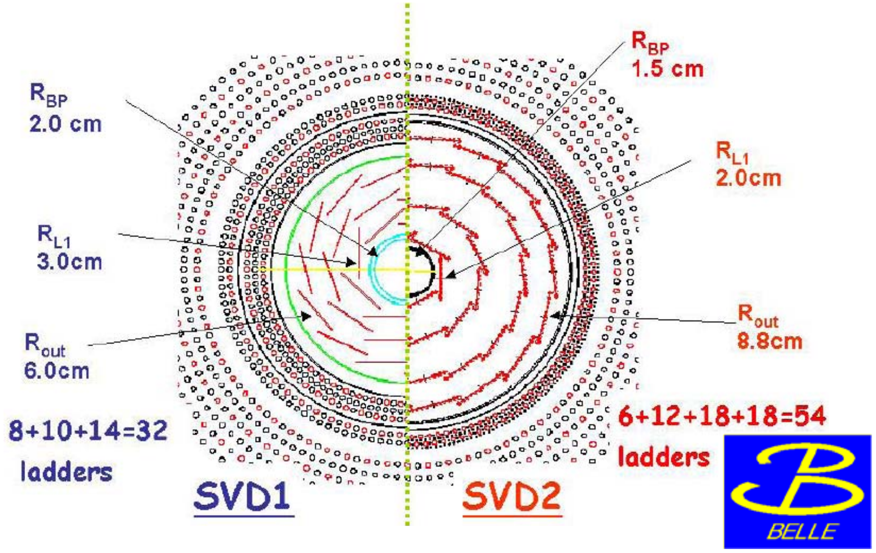
Vertex Reconstruction with K_S

- No primary tracks from B vertex
- Extrapolate K_S track to the Interaction Point
- Events are required to have enough SVD hits for vertexing



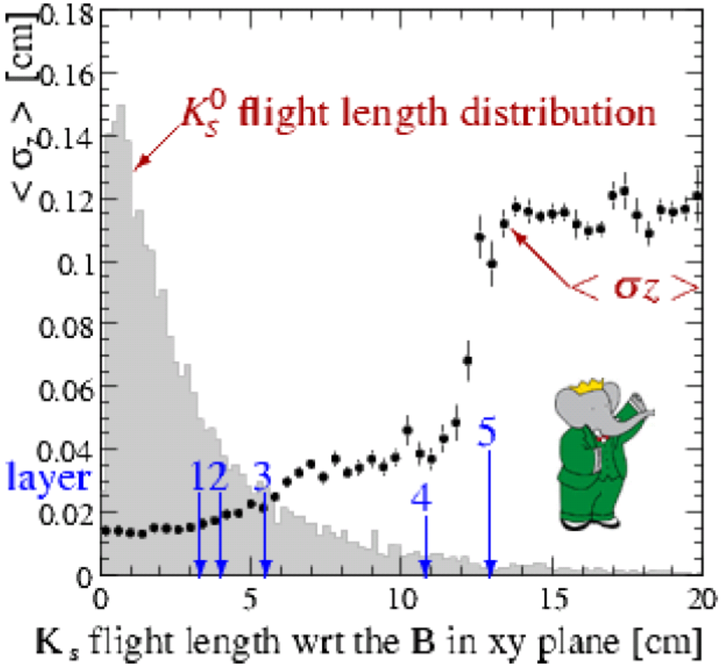


SVT structure



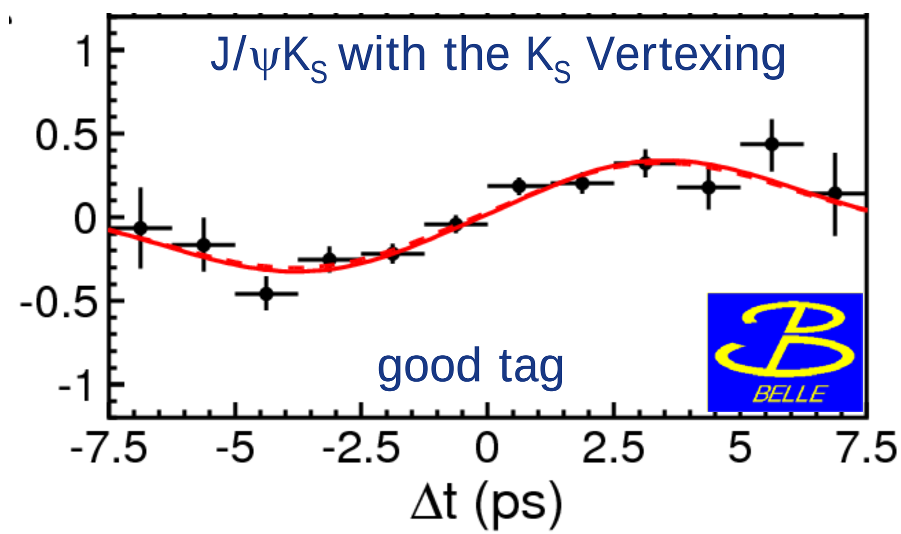
SVD structure

Vertex Reconstruction with K_S



The validity is confirmed using the J/ψ K_S control sample.

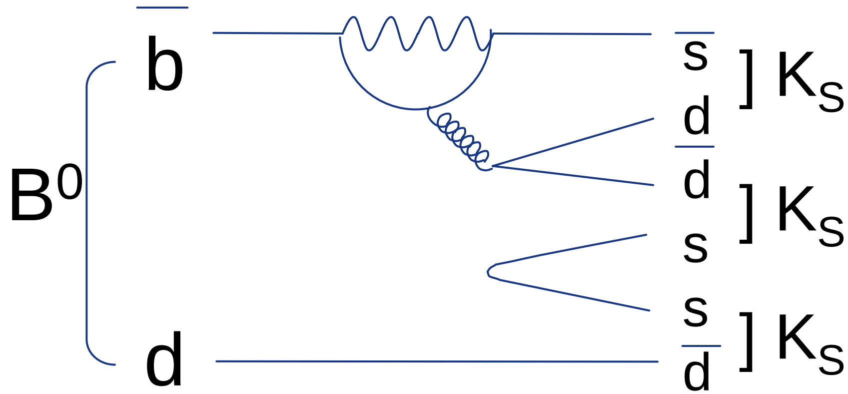
- B^0 Lifetime1.503±0.036 ps
- $\sin 2\phi_1 = +0.68 \pm 0.06$



- <σz> resolution similar to normal modes
- Events without the vertex can still be used to measure $\mathcal{A}$ (- $\mathcal{C}$)

$B^0 \to K_S K_S K_S$

- Dominated by $b \to s\bar{q}q$ penguin decay
  - Theoretically clean (no u quarks in the final state)



- CP even, regardless of any resonant structure

  [T. Gershon and M. Hazumi, PLB 596 163 (2004)]

SM expectation → $\mathcal{S} = -\sin 2\phi_1$

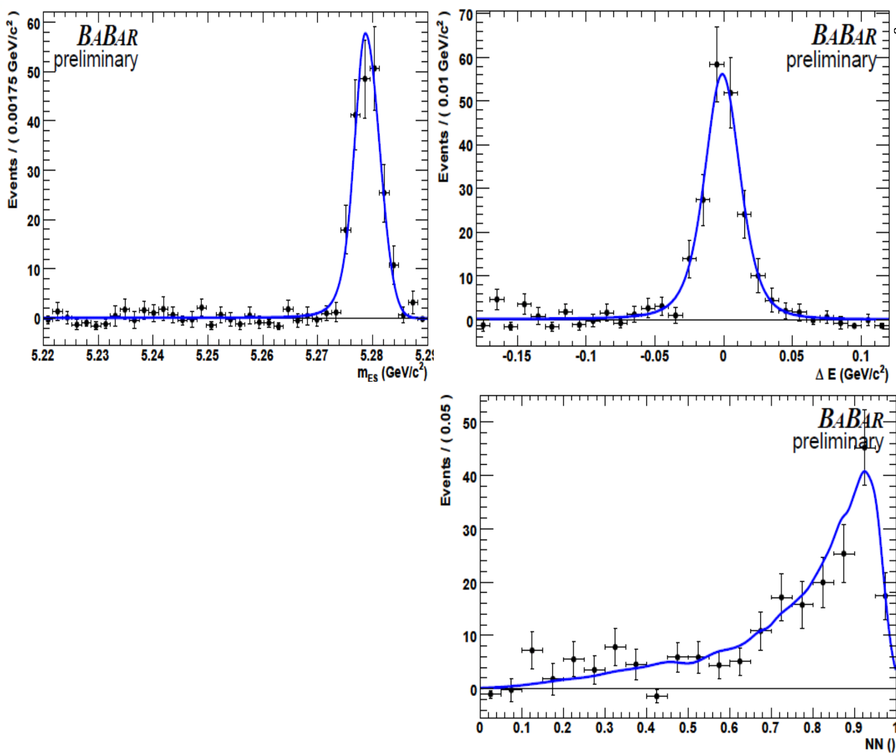
$\mathcal{A} = 0$

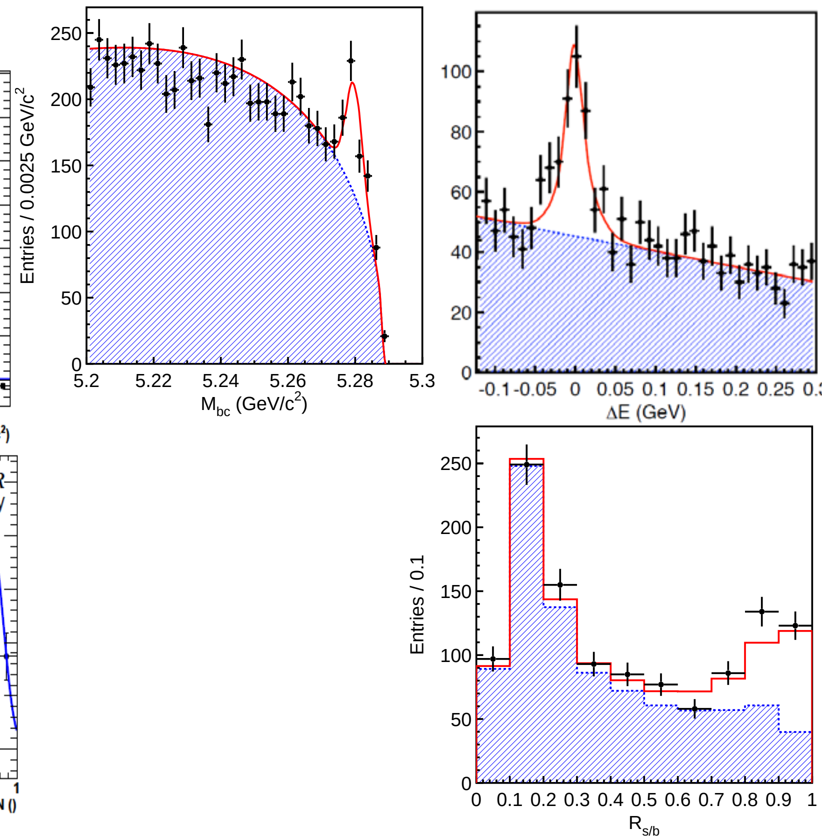
$B^0 \to K_S K_S K_S$ Signal Yield

465 M$B\bar{B}$

PRL 98 (2007) 031802

535 M$B\bar{B}$



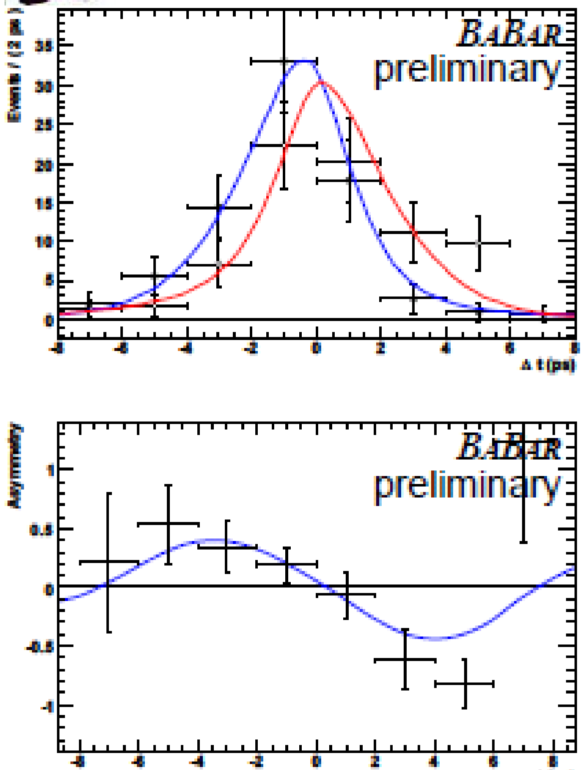


274 ± 20 $K_S K_S K_S$ signal

185 ± 17 $K_S K_S K_S$ signal

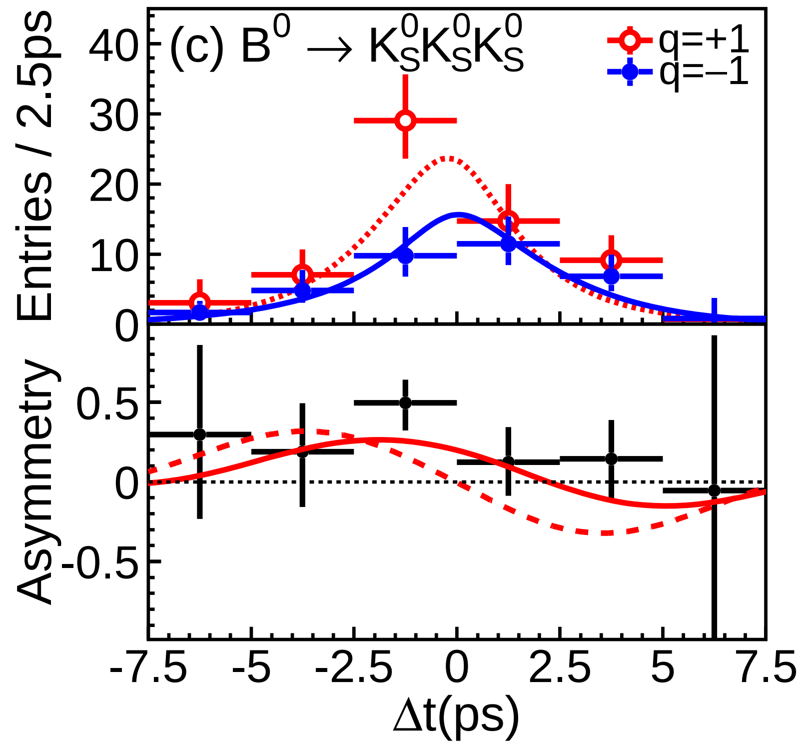
$B^0 \to K_S K_S K_S$ tCPV result

465 MB$\bar{B}$



PRL 98 (2007) 031802

535 MB$\bar{B}$



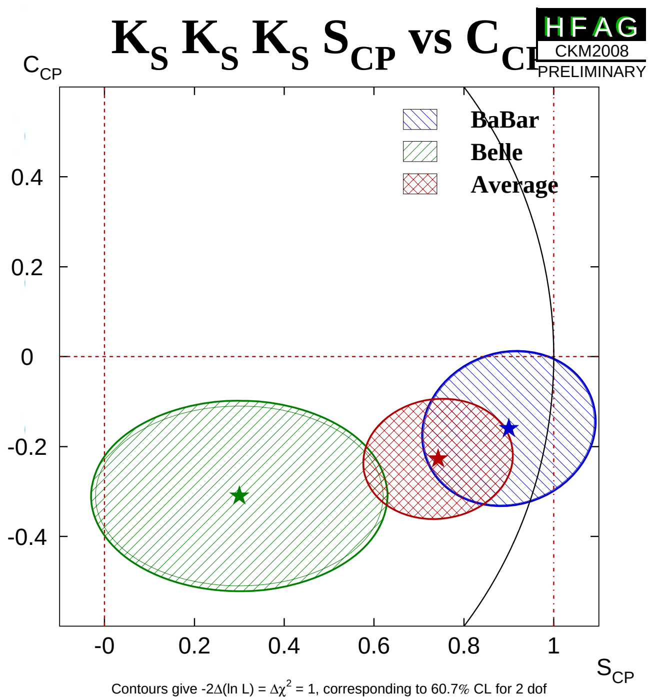
$\mathcal{A} = -\mathcal{C} = +0.16 \pm 0.17 \pm 0.03$

$\mathcal{S} = -0.90 \pm^{0.20}_{0.18} \pm^{0.04}_{0.03}$

$\mathcal{A} = +0.31 \pm 0.20 \pm 0.07$

$\mathcal{S} = -0.30 \pm 0.32 \pm 0.08$

$B^0 \rightarrow K_S K_S K_S$ Comparison



$C_{CP} = -\mathcal{A}$

BaBar $-0.16 \pm 0.17 \pm 0.03$

Belle $-0.31 \pm 0.20 \pm 0.07$

Average -0.23 ± 0.13

$\sin 2\phi_1^{eff} = -\mathcal{S}$

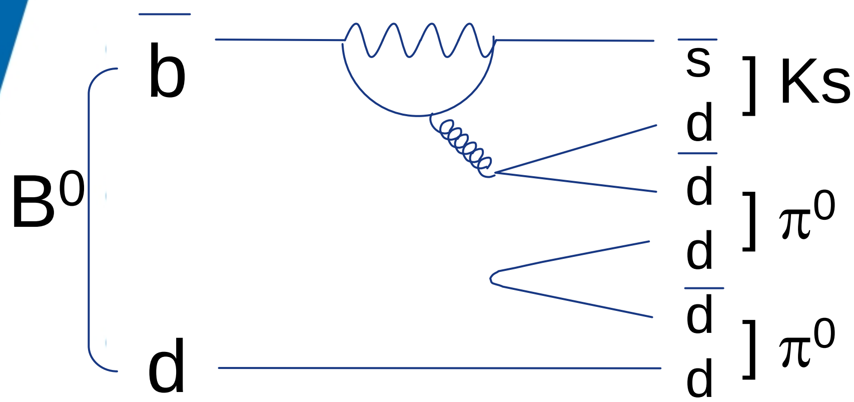
BaBar $0.90 \pm^{0.20}_{0.18} \pm^{0.04}_{0.03}$

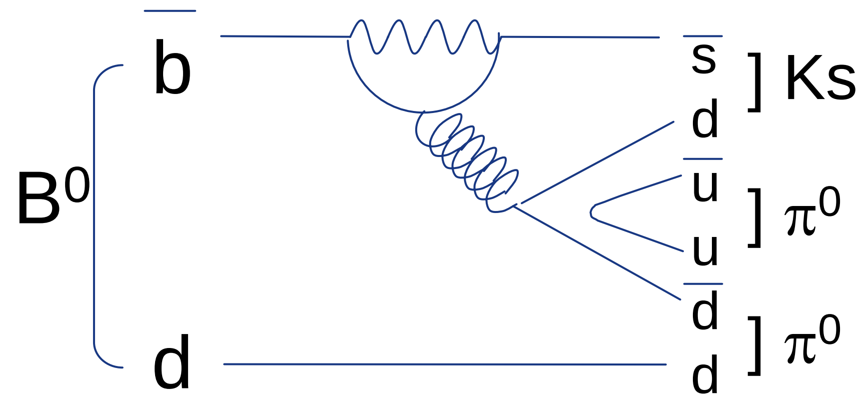
Belle $0.30 \pm 0.32 \pm 0.08$

Average 0.74 ± 0.17

$B^0 \to K_S \pi^0 \pi^0$

- Dominated by $b \to s\bar{q}q$ penguin decay





- CP even, regardless of any resonant structure

[T. Gershon and M. Hazumi, PLB 596 163 (2004)]

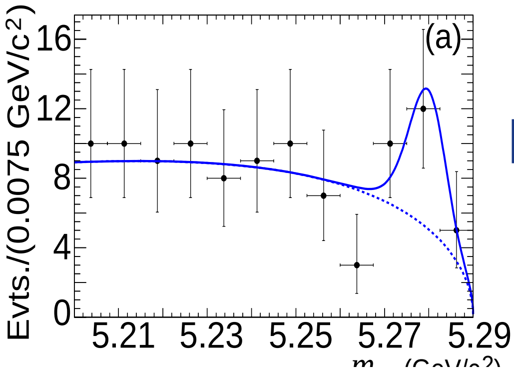
SM expectation → $\mathcal{S} = -\sin 2\phi_1$

$\mathcal{A} = 0$

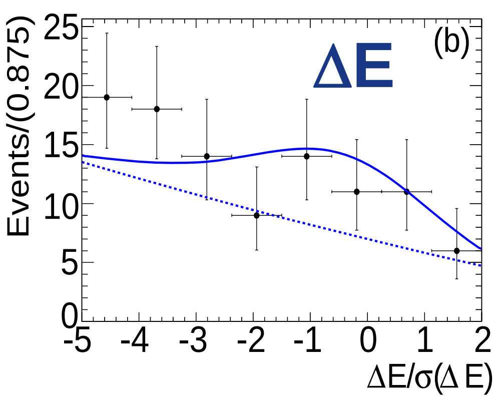
$B^0 \rightarrow K_S\pi^0\pi^0$ Signal Yield

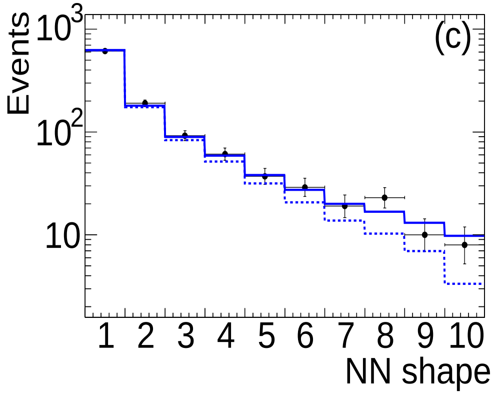
PRD 76 (2007) 071101

227 MB$\overline{B}$



M_{bc}

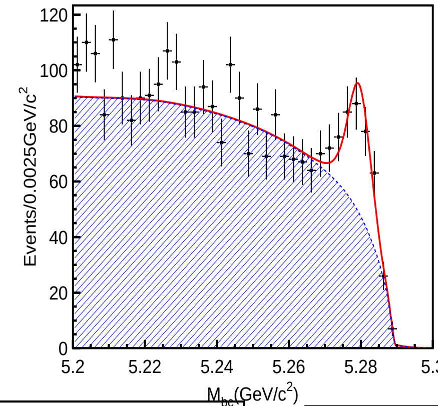




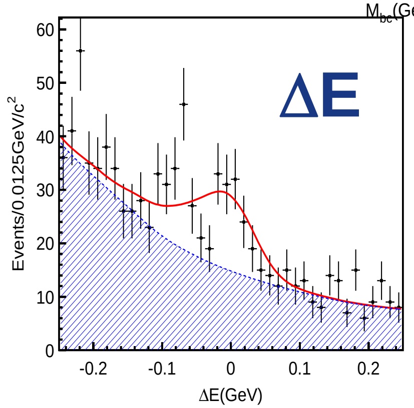
117 ± 27 $K_S\pi^0\pi^0$ signal

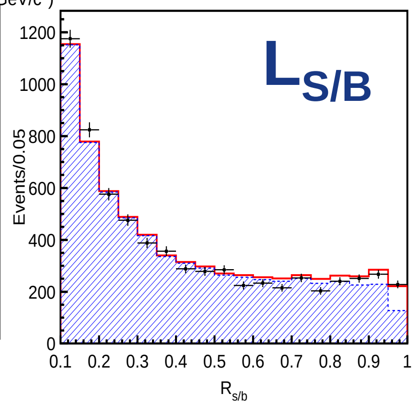
arXiv.0708.1845

657 MB$\overline{B}$



M_{bc}

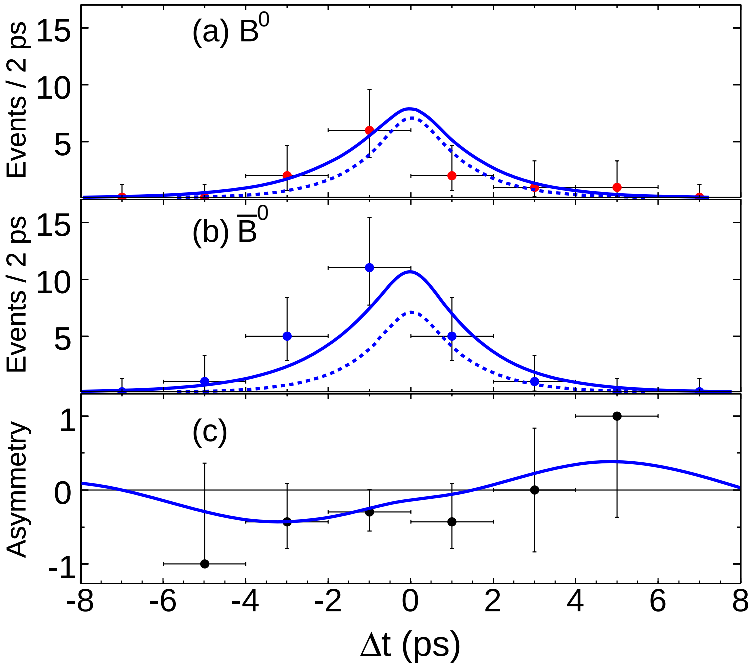




307 ± 32 $K_S\pi^0\pi^0$ signal

$B^0 \to K_S\pi^0\pi^0$ tCPV Result

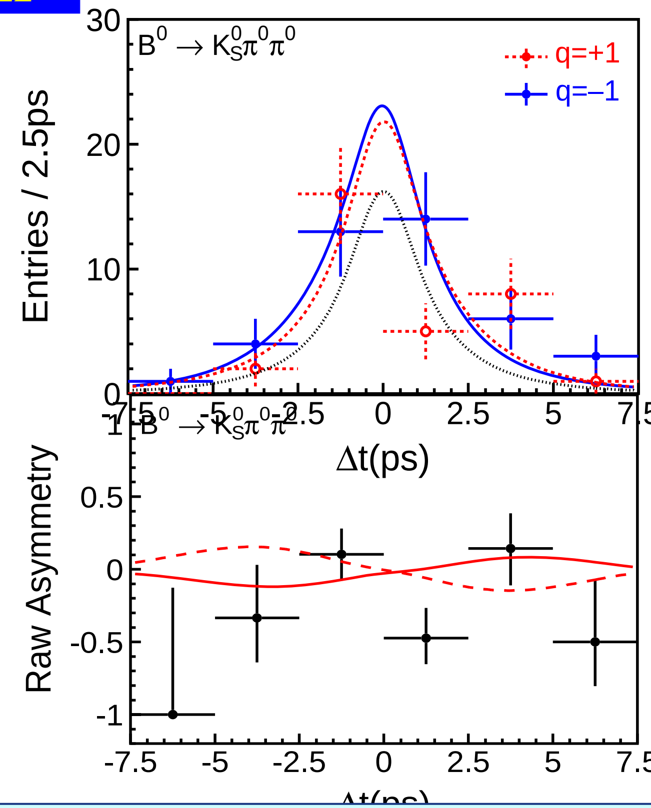
PRD 76 (2007) 071101
227 $MB\overline{B}$



$\mathcal{A} = -\mathcal{C} = -0.23 \pm 0.52 \pm 0.13$

$\mathcal{S} = +0.72 \pm 0.71 \pm 0.08$

arXiv.0708.1845
657 $MB\overline{B}$

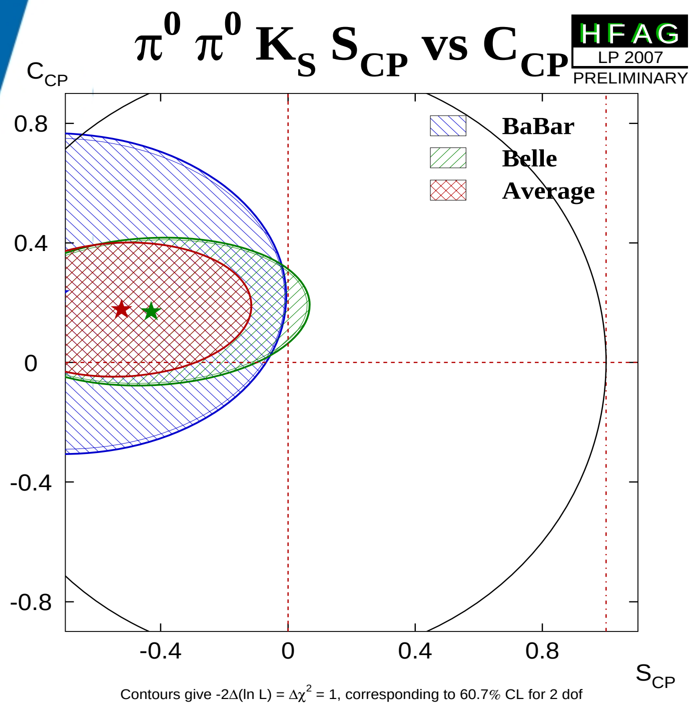


LR>0.9, good tag

$\mathcal{A} = -0.17 \pm 0.24 \pm 0.06$

$\mathcal{S} = +0.43 \pm 0.49 \pm 0.09$

$K_S\pi^0\pi^0$ tCPV Comparison



$\sin 2\phi_1^{\text{eff}} = -\mathcal{S}$

BaBar	$-0.72 \pm 0.71 \pm 0.08$
Belle	$-0.43 \pm 0.49 \pm 0.09$
Average	-0.52 ± 0.41

$\mathcal{C}_{CP} = -\mathcal{A}$

BaBar	$0.23 \pm 0.52 \pm 0.13$
Belle	$0.17 \pm 0.24 \pm 0.06$
Average	0.18 ± 0.22

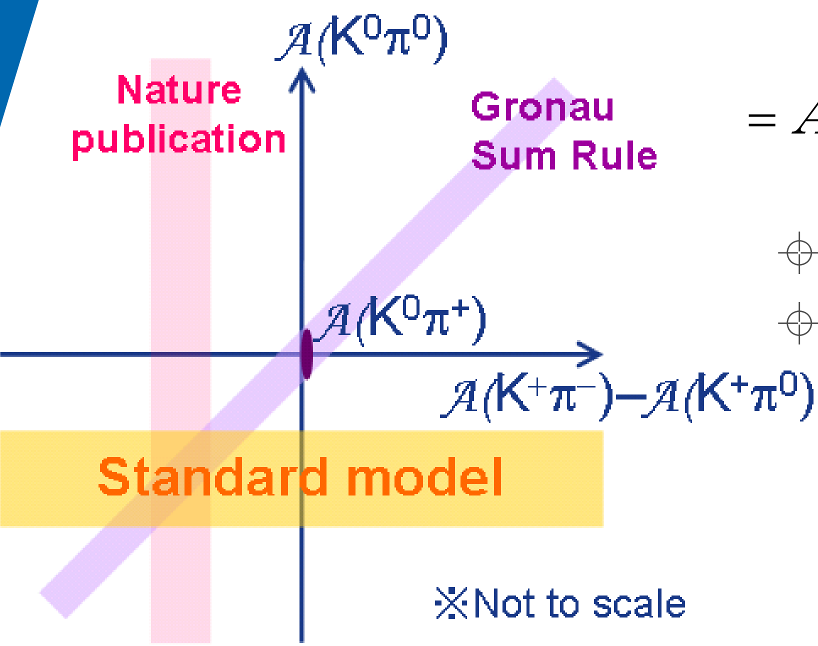
$B^0 \to K^0\pi^0$

- $A_{CP}(B^0 \to K^+\pi^-) \neq A_{CP}(B^+ \to K^+\pi^0)$
  - ΔA_{CP} puzzle   Nature 452, 332-335(2008)
- Isospin sum rule among $B \to K\pi$ CP asymmetries

M. Gronau, PLB 672(2005)82-88)

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

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

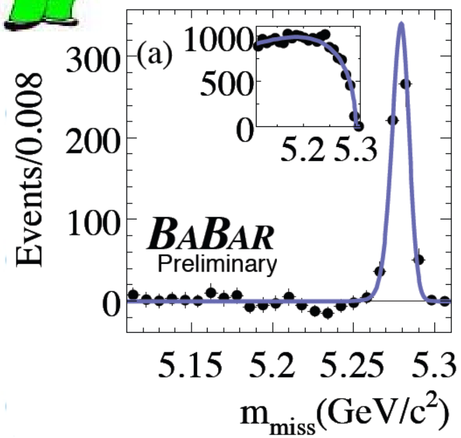


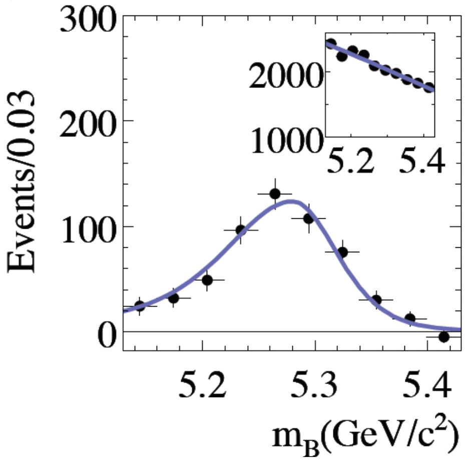
- Breaking sum rule indicates new physics
- Theoretical uncertainty ～SU(2) breaking

- Both S and A are important

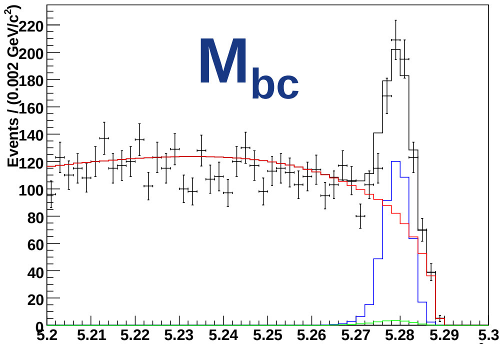
$B^0 \to K_S\pi^0$ Signal Yield

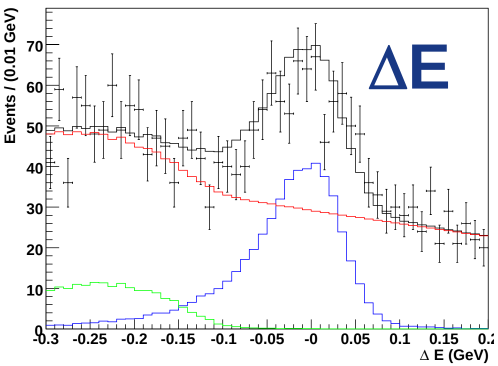
465 $MB\bar{B}$

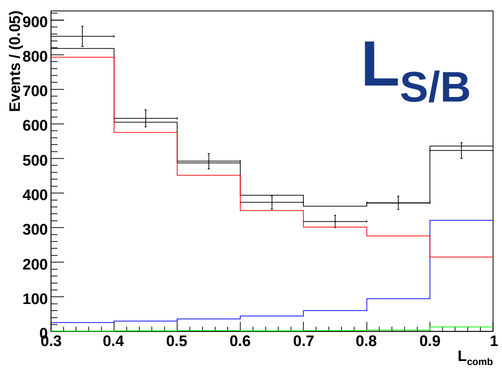




657 $MB\bar{B}$



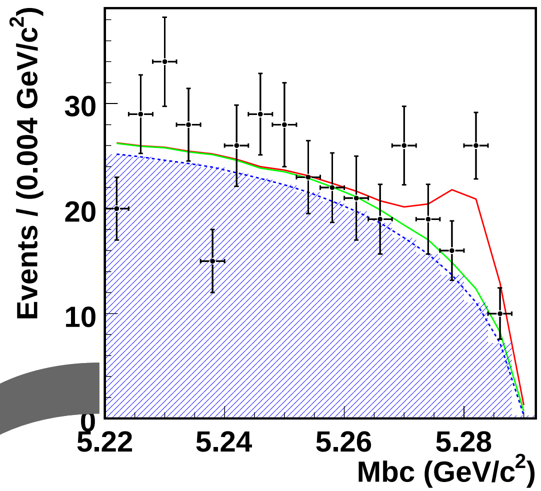


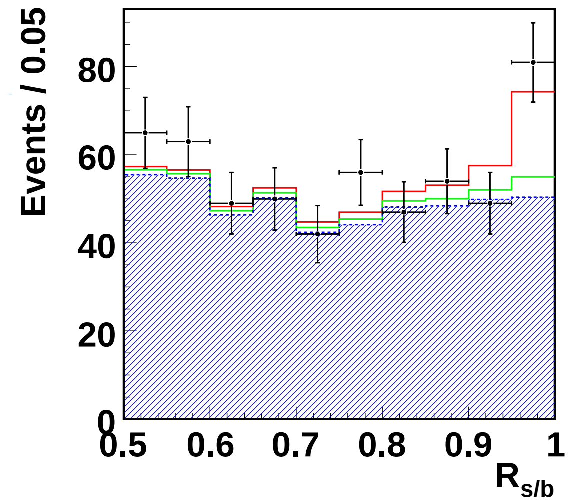


556 ± 32 $K_S\pi^0$ signal

657 ± 37 $K_S\pi^0$ signal

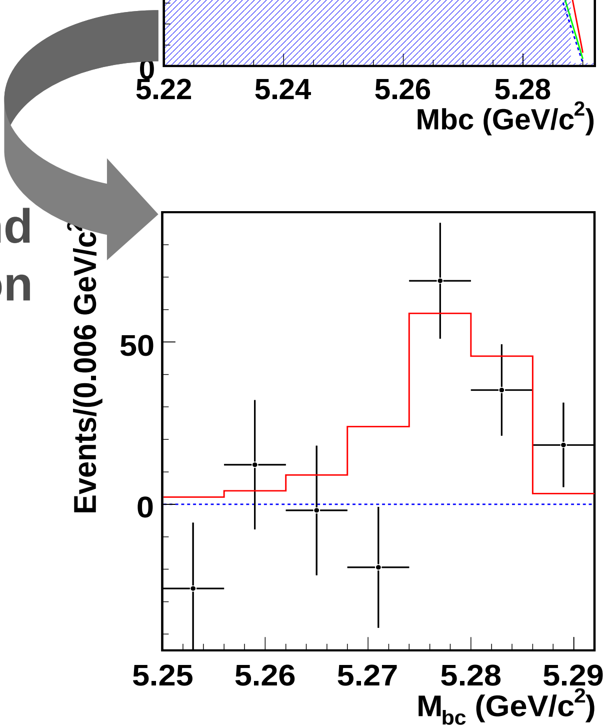
$B^0 \to K_L \pi^0$ Signal Yield





657 $MB\bar{B}$

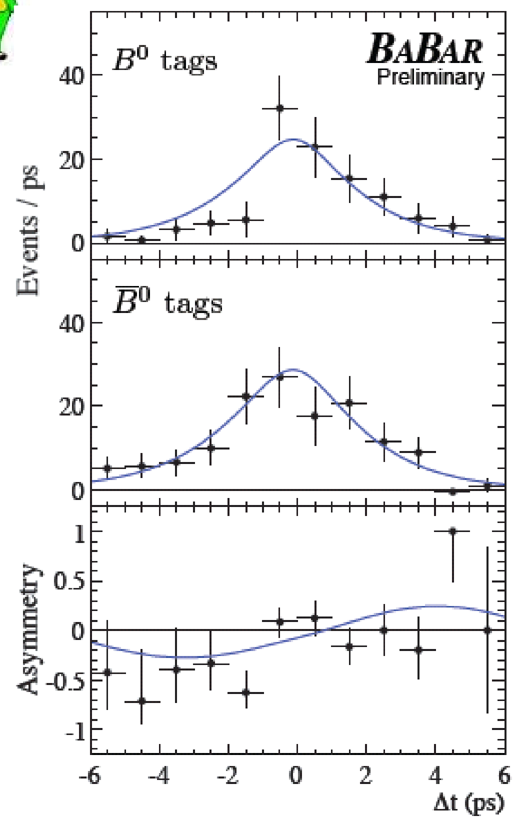
Background subtraction



- First measurement
- M_{bc} calculated from direction of K_L cluster
- $K_L \pi^0$ signal
  285 ± 52 (stat) ± 57 (syst)
  3.7σ (including systematics)

$B^0 \rightarrow K^0\pi^0$ tCPV result

465 $MB\overline{B}$

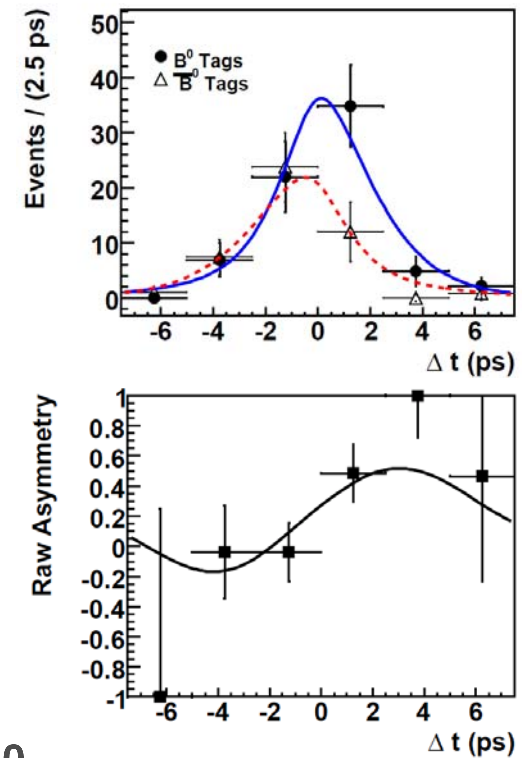


$K_S\pi^0$

$\mathcal{A} = -\mathcal{C} = -0.13 \pm 0.13 \pm 0.03$

$\mathcal{S} = +0.55 \pm 0.20 \pm 0.03$

657 $MB\overline{B}$

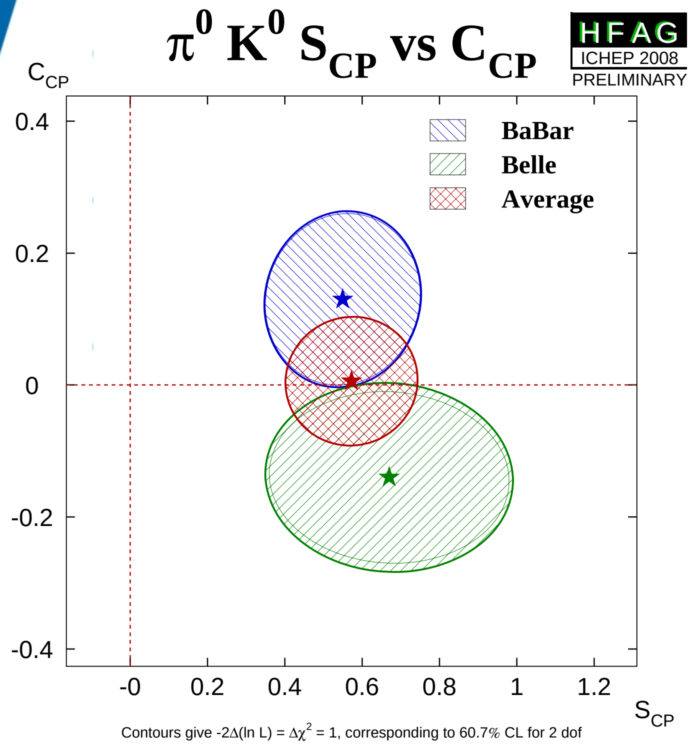


$K_S\pi^0 + K_L\pi^0$

$\mathcal{A} = +0.14 \pm 0.13 \pm 0.06$

$\mathcal{S} = +0.67 \pm 0.31 \pm 0.08$

$B^0 \rightarrow K^0\pi^0$ Comparison



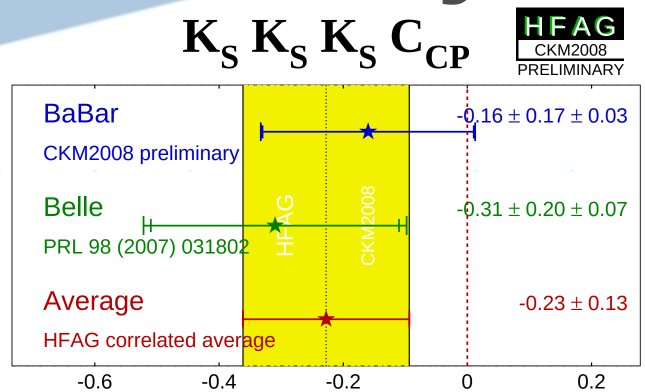
$\sin 2\phi_1^{eff} = \mathcal{S}$

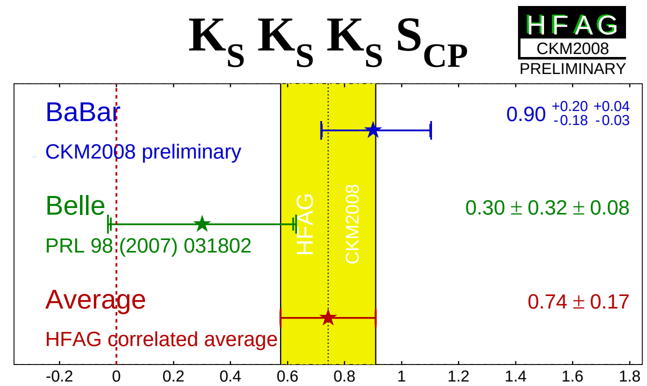
BaBar	$0.55 \pm 0.20 \pm 0.03$
Belle	$0.67 \pm 0.31 \pm 0.06$
Average	0.57 ± 0.17

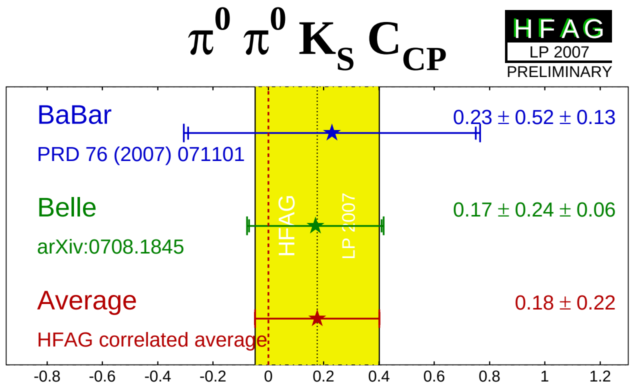
$C_{CP} = -\mathcal{A}$

BaBar	$0.13 \pm 0.13 \pm 0.03$
Belle	$-0.14 \pm 0.13 \pm 0.06$
Average	0.01 ± 0.10

Summary


$K_S K_S K_S C_{CP}$
HFAG
CKM2008
PRELIMINARY
BaBar
CKM2008 preliminary
-0.16 ± 0.17 ± 0.03
Belle
PRL 98 (2007) 031802
-0.31 ± 0.20 ± 0.07
Average
HFAG correlated average
-0.23 ± 0.13
HFAG
CKM2008
-0.6
-0.4
-0.2
0
0.2


$K_S K_S K_S S_{CP}$
HFAG
CKM2008
PRELIMINARY
BaBar
CKM2008 preliminary
$0.90\ ^{+0.20}_{-0.18}\ ^{+0.04}_{-0.03}$
Belle
PRL 98 (2007) 031802
0.30 ± 0.32 ± 0.08
Average
HFAG correlated average
0.74 ± 0.17
HFAG
CKM2008
-0.2
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8


$\pi^0 \pi^0 K_S C_{CP}$
HFAG
LP 2007
PRELIMINARY
BaBar
PRD 76 (2007) 071101
0.23 ± 0.52 ± 0.13
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arXiv:0708.1845
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Average
HFAG correlated average
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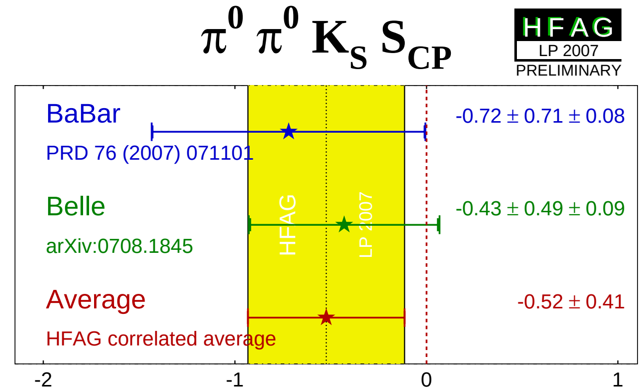
HFAG
LP 2007
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
1.2


$\pi^0 \pi^0 K_S S_{CP}$
HFAG
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PRD 76 (2007) 071101
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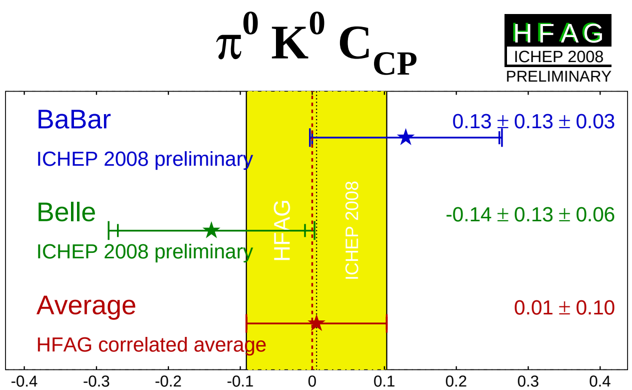
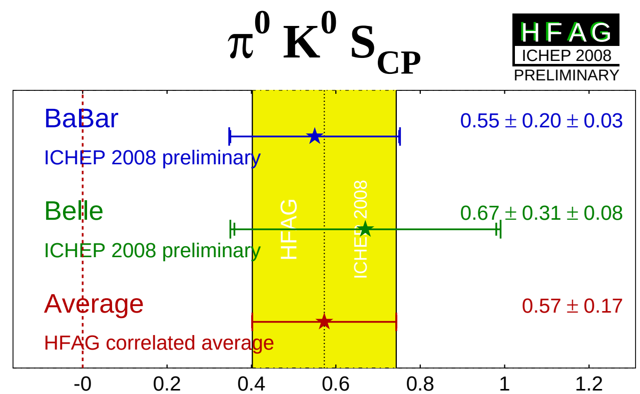
Belle
arXiv:0708.1845
-0.43 ± 0.49 ± 0.09
Average
HFAG correlated average
-0.52 ± 0.41
HFAG
LP 2007
-2
-1
0
1


$\pi^0 K^0 C_{CP}$
HFAG
ICHEP 2008
PRELIMINARY
BaBar
ICHEP 2008 preliminary
0.13 ± 0.13 ± 0.03
Belle
ICHEP 2008 preliminary
-0.14 ± 0.13 ± 0.06
Average
HFAG correlated average
0.01 ± 0.10
HFAG
ICHEP 2008
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4


$\pi^0 K^0 S_{CP}$
HFAG
ICHEP 2008
PRELIMINARY
BaBar
ICHEP 2008 preliminary
0.55 ± 0.20 ± 0.03
Belle
ICHEP 2008 preliminary
0.67 ± 0.31 ± 0.08
Average
HFAG correlated average
0.57 ± 0.17
HFAG
-0
0.2
0.4
0.6
0.8
1
1.2

Summary

- Results from Babar and Belle
  - HFAG average shows no significant deviation from SM

	$C_{CP} = -\mathcal{A}$	$\sin 2\phi_1^{\text{eff}}$	
$K_S K_S K_S$	-0.23 ± 0.13	0.74 ± 0.17	← Theoretically clean
$K_S \pi^0 \pi^0$	0.18 ± 0.22	-0.52 ± 0.41	← Anomaly?
$K^0 \pi^0$	0.01 ± 0.10	0.57 ± 0.17	← Sum rule predicts sizable direct CPV

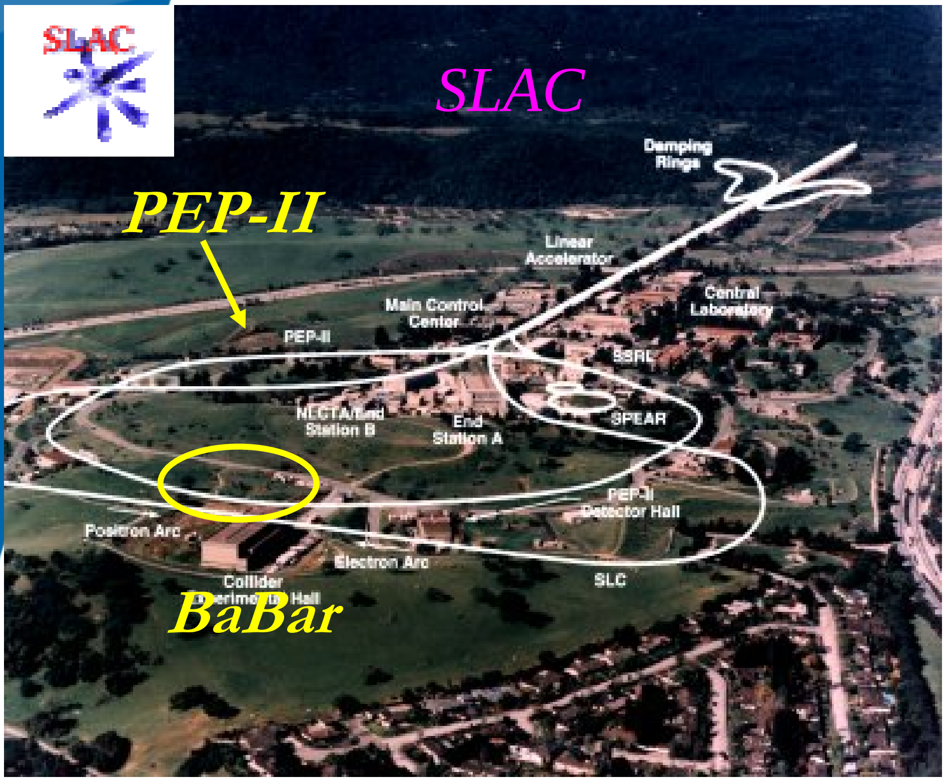
- Super B factory is necessary for these modes
- We need more statistics

Backup

Systematic Errors

	$K_SK_SK_S$		$K_S\pi^0\pi^0$		$K^0\pi^0$	
	δS	δA	δS	δA	δS	δA
Vertexing	0.010	0.020	0.011	0.020	0.013	0.022
Flavor tagging	0.012	0.006	0.008	0.005	0.007	0.005
Resolution	0.049	0.016	0.066	0.010	0.063	0.007
Physics	0.001	0.001	0.007	0.001	0.007	0.001
Fit bias	0.024	0.013	0.009	0.004	0.010	0.020
BG fraction	0.057	0.049	0.009	0.001	0.029	0.022
BG dt shape	0.007	0.010	0.046	0.019	0.015	0.006
TSI	0.001	0.042	0.001	0.043	0.014	0.054
Total	0.081	0.071	0.082	0.053	0.06	0.08

KEKB & PEP-II



9 GeV e^- x 3.1 GeV e^+

Head-on collision

PEP-II (USA) **$\beta\gamma$=0.56**

8 GeV e^- x 3.5 GeV e^+

±11mrad crossing

KEKB (Japan) **$\beta\gamma$=0.425**

Belle and BaBar Detectors