$\phi_1(\beta)$ from $B^0 \to K^+K^-K_S$, $\pi^+\pi^-K_S$ and $K_SK_SK_S$

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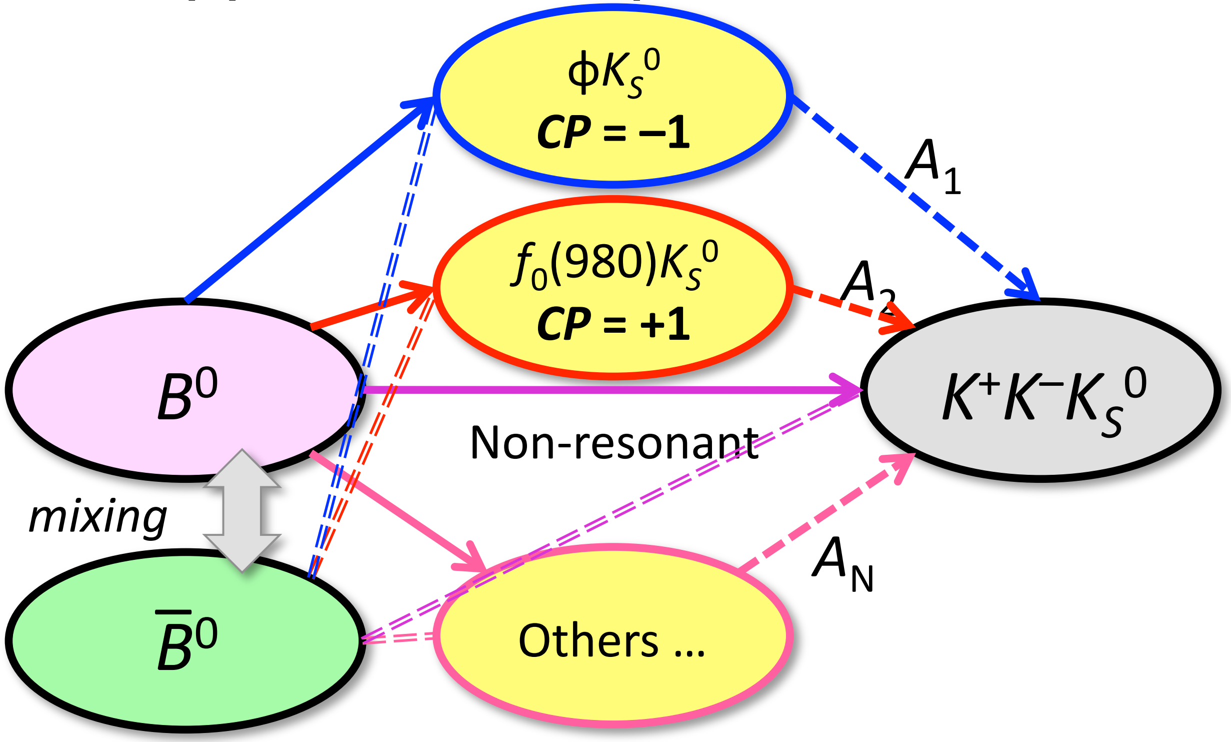
CKM2010

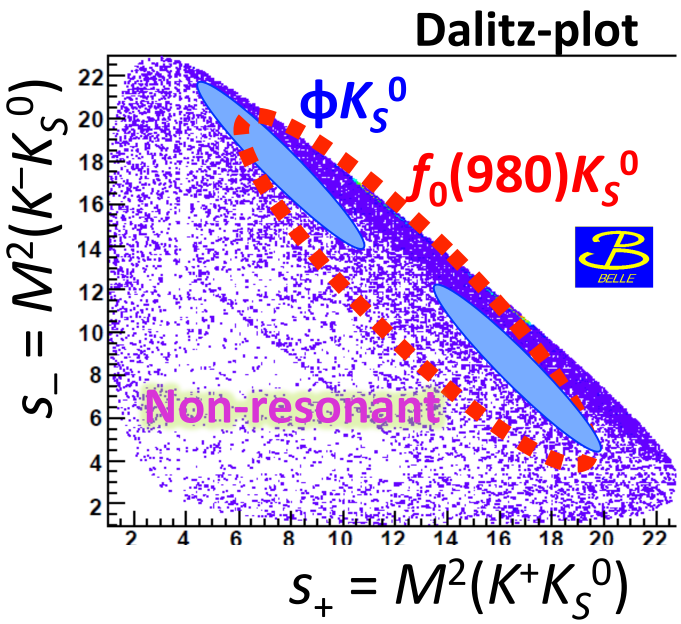
Introduction

- Time-dependent CP violation measurements started with tree-mediated two-body B decays.
  - i.e. $B^0 \rightarrow J/\psi\ K^0$
- Penguin-mediated B decays are good place to seek possible deviation(=new physics) from tree-mediated process. The first round measurements used a quasi-two-body approach.
  - i.e. $\phi\ K^0$, $\eta'\ K^0$, etc.
- However as you know,

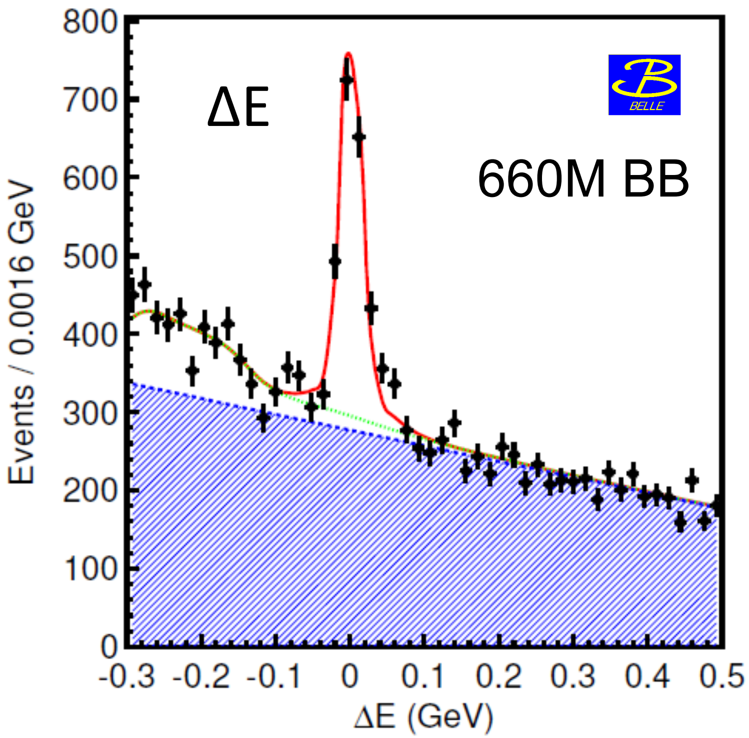
Several contributions are overlapping

- For example, $B^0 \rightarrow K^+K^-K_S$ final state has several different paths.
- Resolve them by fitting the Dalitz distribution. Same approach is required for $B^0 \rightarrow \pi^+\pi^-K_S$.

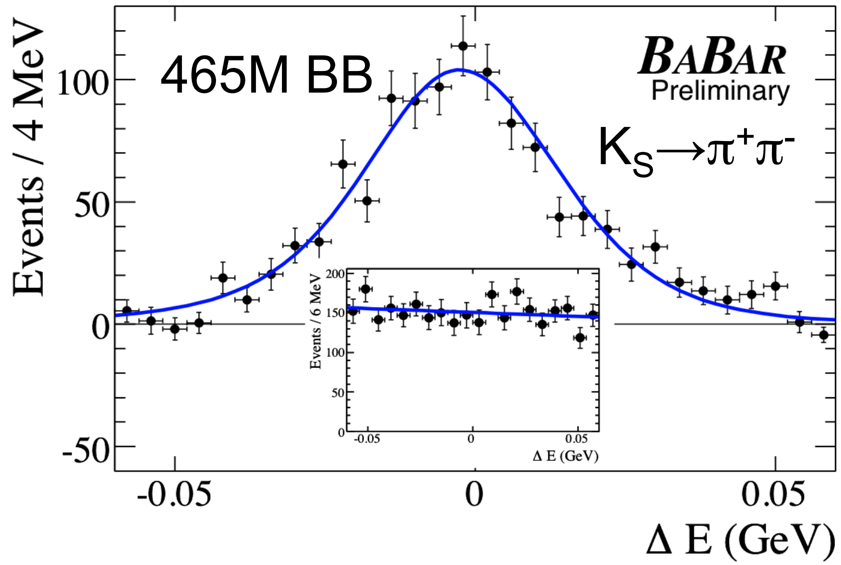




Reconstructed $B^0 \rightarrow K^+K^-K_S$ candidates

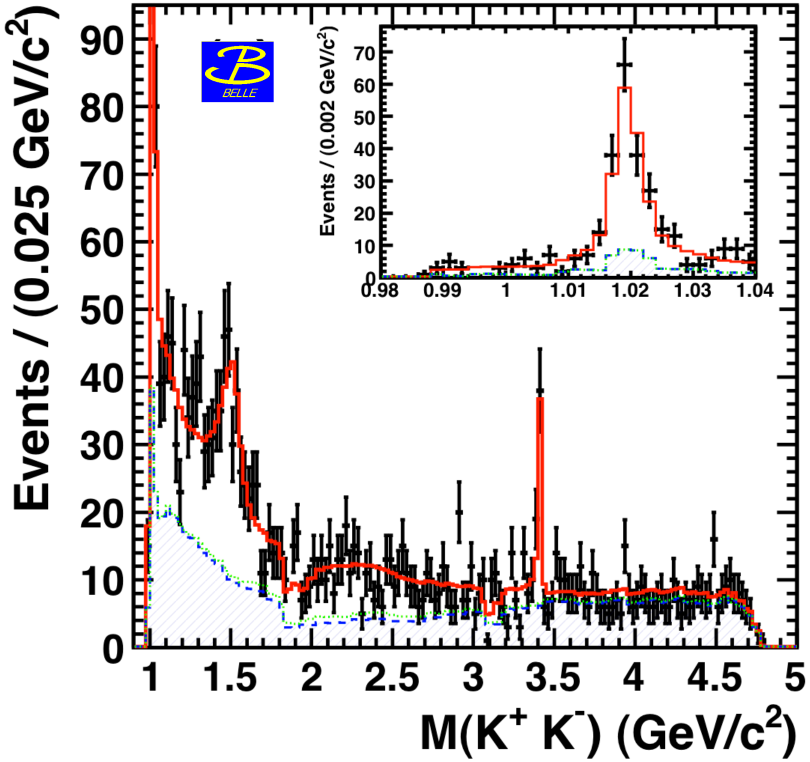


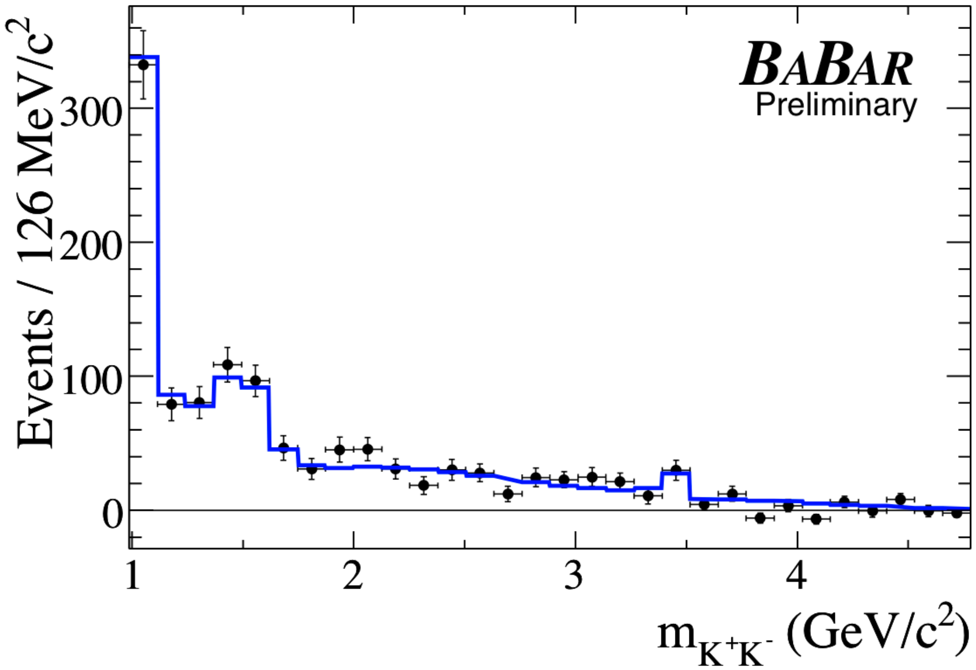
Belle : 1176±51 signal events. (arXiv:1007.3848, submitted to PRD)



BaBar : 1268±43($K_S \rightarrow \pi^+\pi^-$) and 160±19($K_S \rightarrow \pi^0\pi^0$) signal events, in whole Dalitz fit region. High-mass and low-mass fits are also attempted.(arXiv:0808.0700)

Projections of Dalitz distribution (M_{K+K-})





Peak around 1GeV/c^2 : ϕ(1020) and f_0(980)

Around 1.5GeV/c^2 : f_X

At 3.4GeV/c^2 : χ_{c0}

Multiple solutions

Belle found 4 solutions

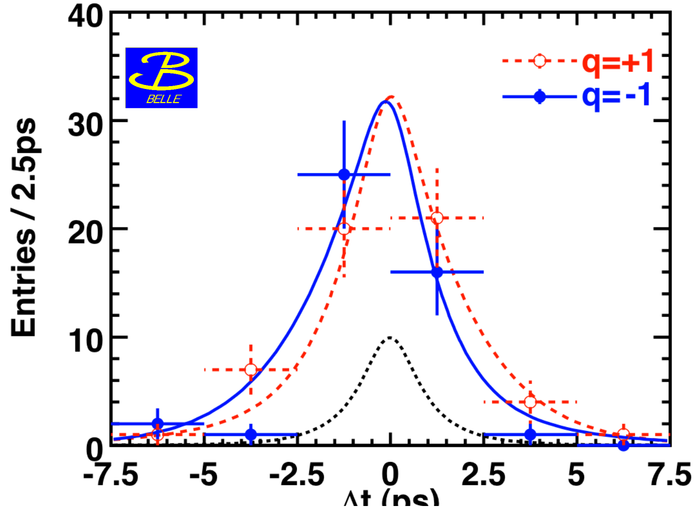
	Solution 1	Solution 2	Solution 3	Solution 4
$\mathcal{A}_{CP}(f_0(980)K_S^0)$	$-0.30 \pm 0.29 \pm 0.11 \pm 0.09$	$-0.20 \pm 0.15 \pm 0.08 \pm 0.05$	$+0.02 \pm 0.21 \pm 0.09 \pm 0.09$	$-0.18 \pm 0.14 \pm 0.08 \pm 0.06$
$\phi_1^{\rm eff}(f_0(980)K_S^0)$	$(31.3 \pm 9.0 \pm 3.4 \pm 4.0)^\circ$	$(26.1 \pm 7.0 \pm 2.4 \pm 2.5)^\circ$	$(25.6 \pm 7.6 \pm 2.9 \pm 0.8)^\circ$	$(26.3 \pm 5.7 \pm 2.4 \pm 5.8)^\circ$
$\mathcal{A}_{CP}(\phi(1020)K_S^0)$	$+0.04 \pm 0.20 \pm 0.10 \pm 0.02$	$+0.08 \pm 0.18 \pm 0.10 \pm 0.03$	$-0.01 \pm 0.20 \pm 0.11 \pm 0.02$	$+0.21 \pm 0.18 \pm 0.11 \pm 0.05$
$\phi_1^{\rm eff}(\phi(1020)K_S^0)$	$(32.2 \pm 9.0 \pm 2.6 \pm 1.4)^\circ$	$(26.2 \pm 8.8 \pm 2.7 \pm 1.2)^\circ$	$(27.3 \pm 8.6 \pm 2.8 \pm 1.3)^\circ$	$(24.3 \pm 8.0 \pm 2.9 \pm 5.2)^\circ$
$\mathcal{A}_{CP}$(others)	$-0.14 \pm 0.11 \pm 0.08 \pm 0.03$	$-0.06 \pm 0.15 \pm 0.08 \pm 0.04$	$-0.03 \pm 0.09 \pm 0.08 \pm 0.03$	$+0.04 \pm 0.11 \pm 0.08 \pm 0.02$
$\phi_1^{\rm eff}$(others)	$(24.9 \pm 6.4 \pm 2.1 \pm 2.5)^\circ$	$(29.8 \pm 6.6 \pm 2.1 \pm 1.1)^\circ$	$(26.2 \pm 5.9 \pm 2.3 \pm 1.5)^\circ$	$(23.8 \pm 5.5 \pm 1.9 \pm 6.4)^\circ$

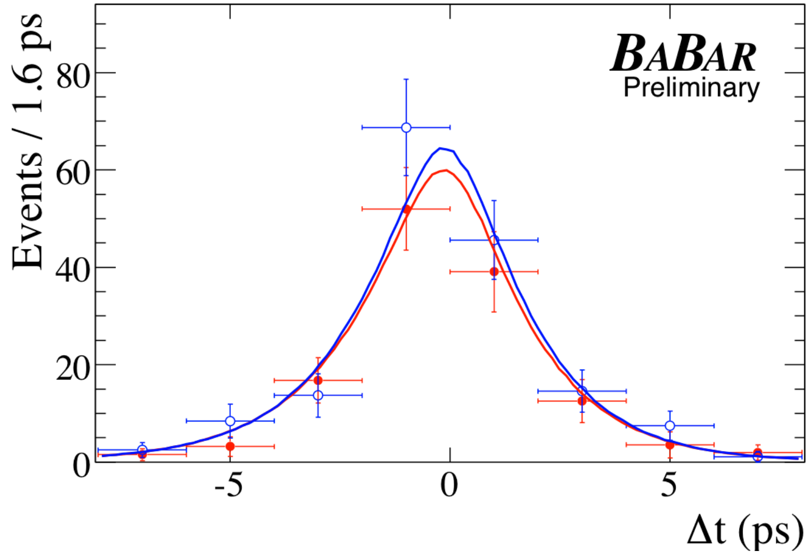
The preferred solution can not be selected by the fit likelihood value alone. With external information, solution 1 is preferred.

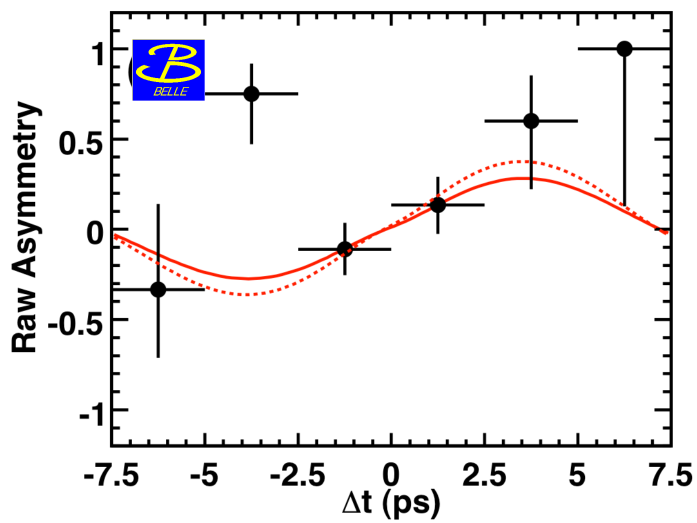
BaBar found 2 solutions in low-mass fit, (1) is chosen as nominal.

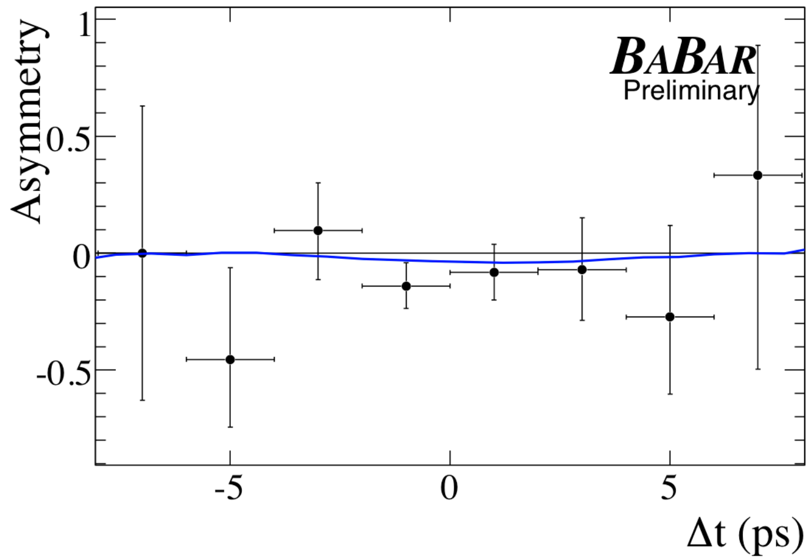
Name	Solution (1)	Solution (2)	Correlation			
			1	2	3	4
1 $A_{CP}(\phi K_S^0)$	$0.14 \pm 0.19 \pm 0.02$	0.13 ± 0.18	1.0	-0.09	-0.28	0.09
2 $\beta_{eff}(\phi K_S^0)$	$0.13 \pm 0.13 \pm 0.02$	0.14 ± 0.14		1.0	0.54	0.65
3 $A_{CP}(f_0 K_S^0)$	$0.01 \pm 0.26 \pm 0.07$	-0.49 ± 0.25			1.0	0.25
4 $\beta_{eff}(f_0 K_S^0)$	$0.15 \pm 0.13 \pm 0.03$	3.44 ± 0.19				1.0

Δt distribution in φ mass region

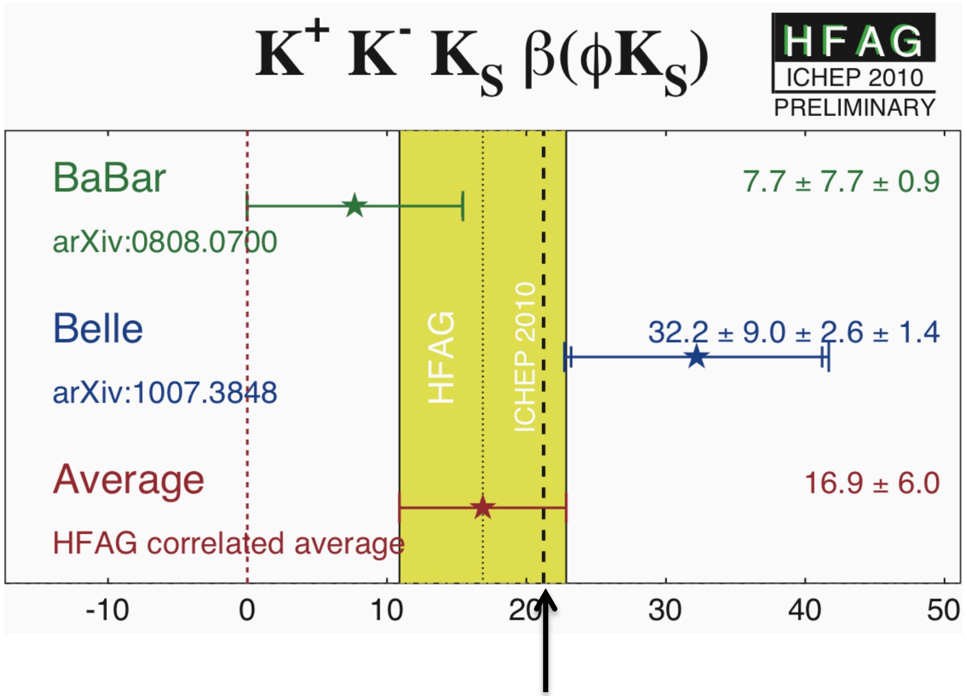


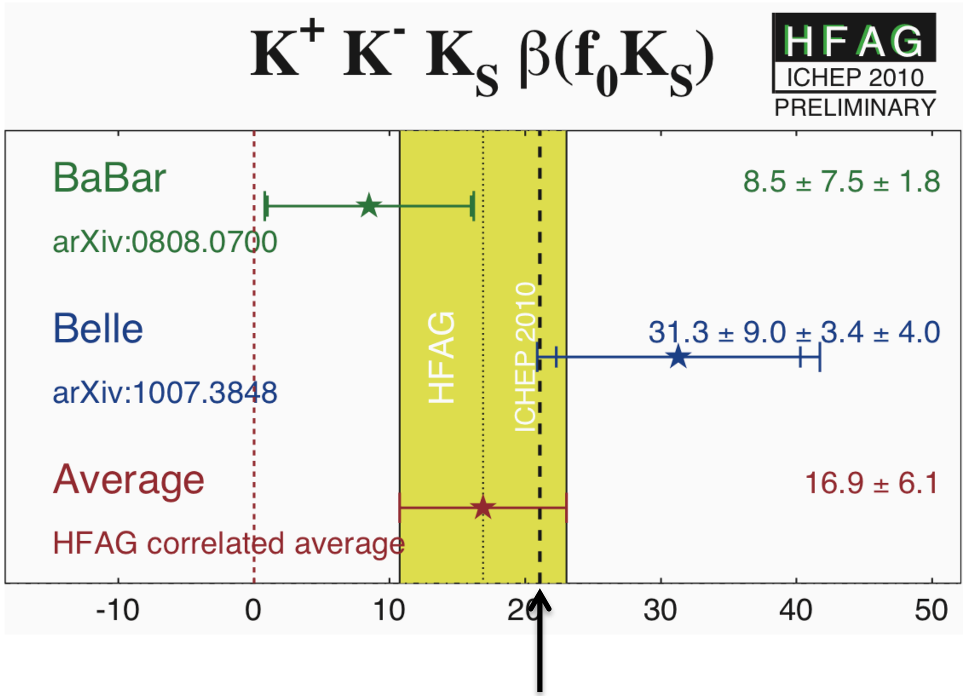






effective ϕ_1 of "solution 1"

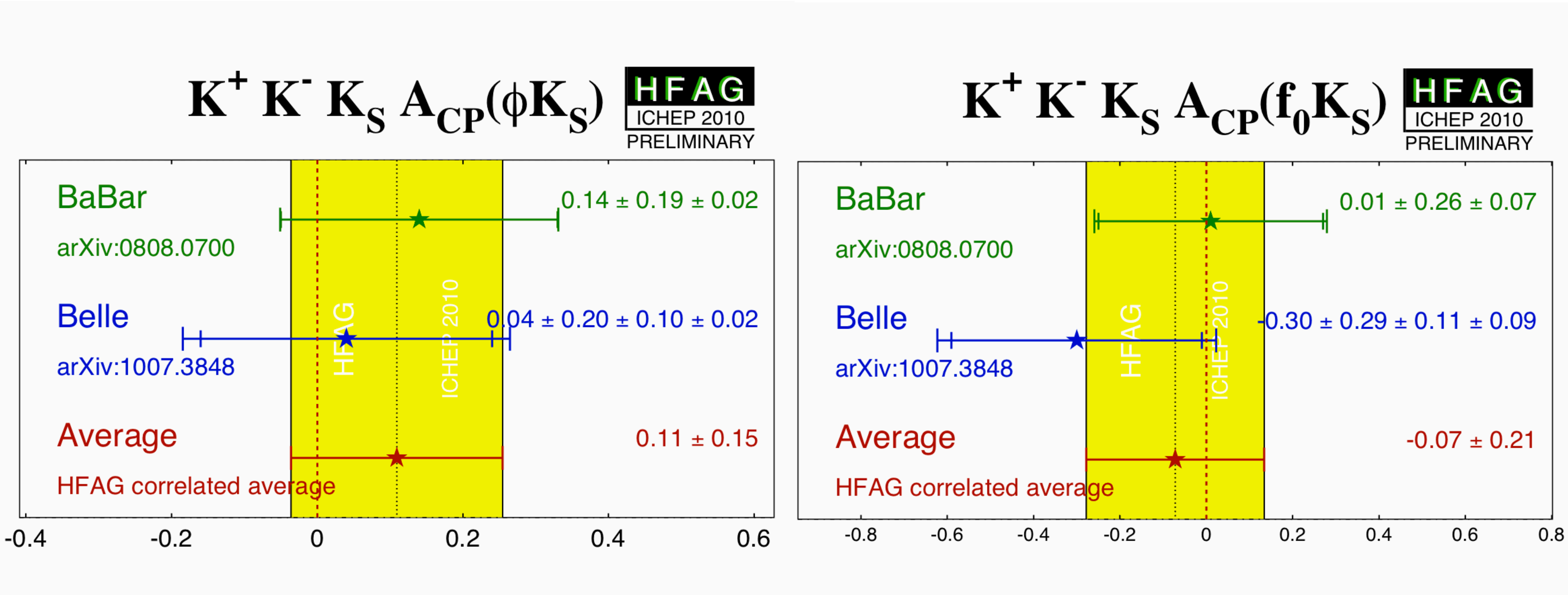




ϕ_1 by $(c\bar{c})K^0$ ϕ_1 by $(c\bar{c})K^0$

No significant deviation from measurements with $B^0 \to (c\bar{c})\ K^0 = \sin 2\phi_1$.

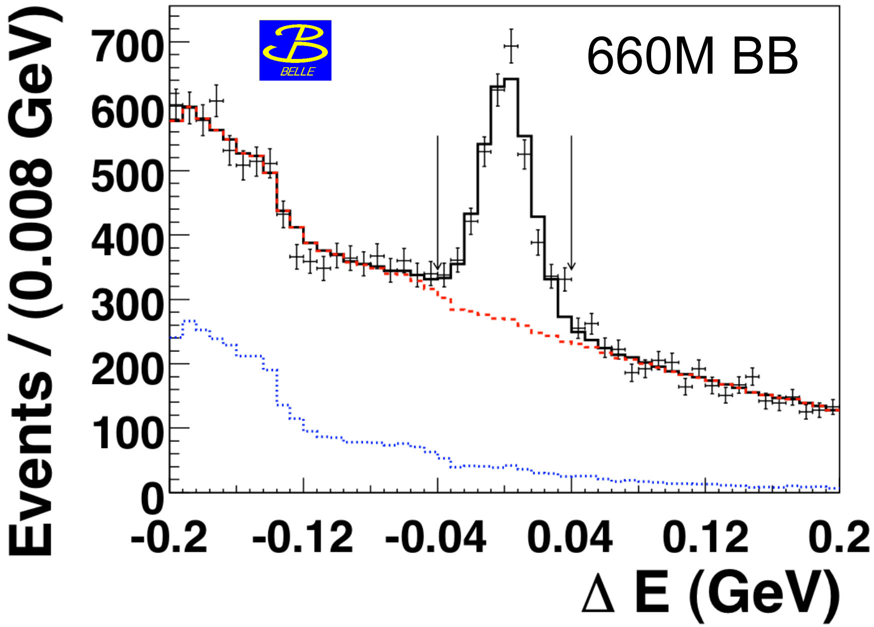
As for direct CP violation

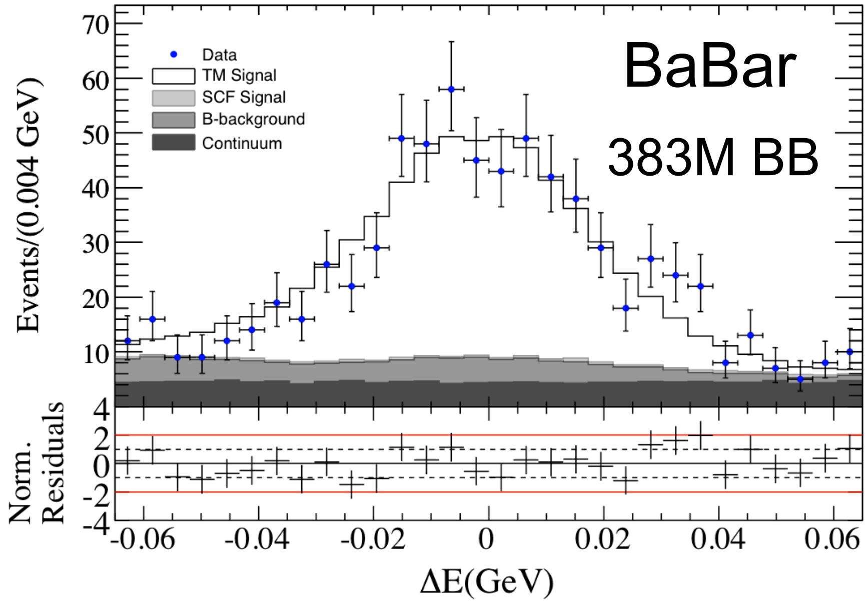


No significant direct CP violation has been observed.

$B^0 \rightarrow \pi^+\pi^- K_S$

Reconstructed candidates

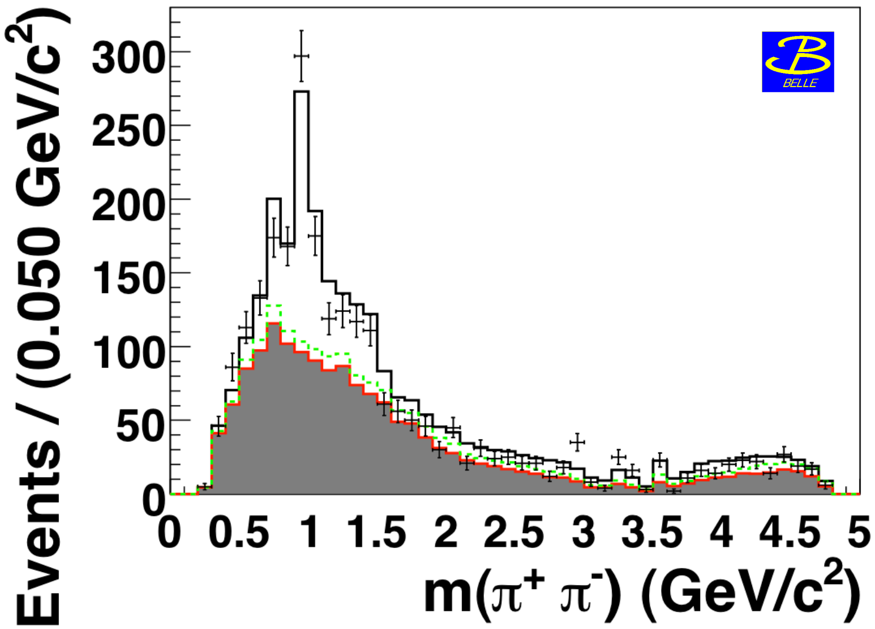


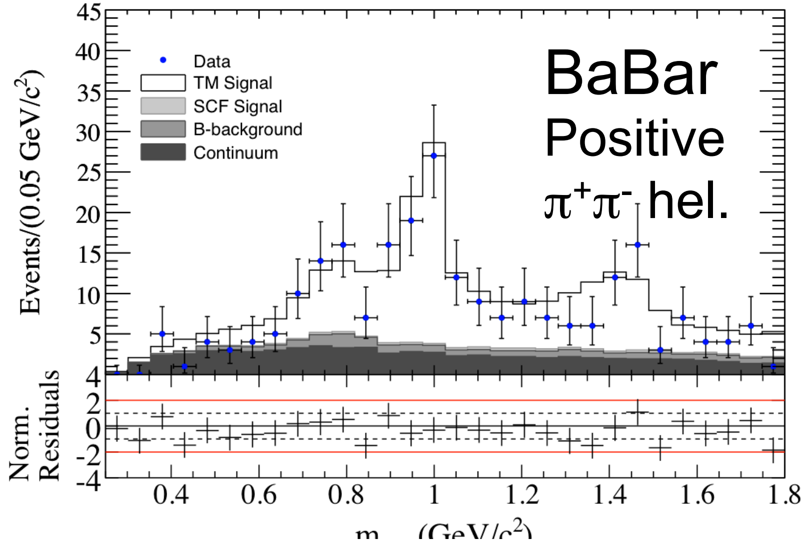


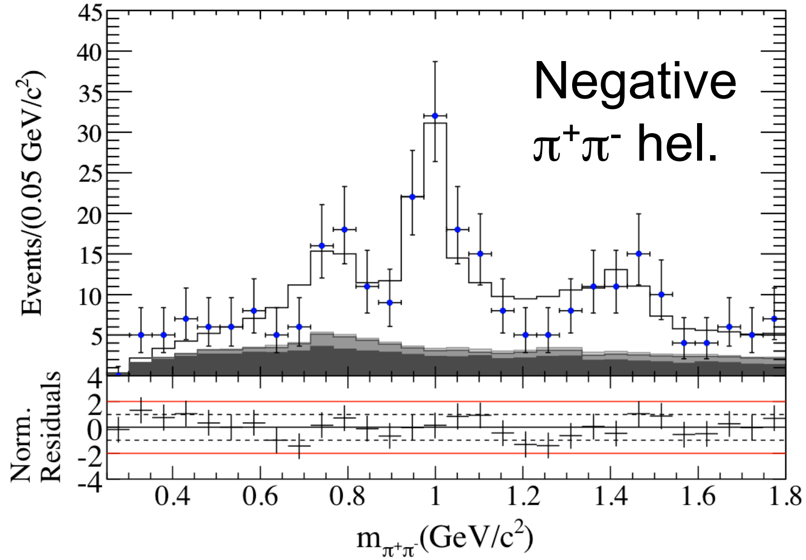
Belle : 1944±98 signal events.
(PRD79,072004(2009))

BaBar : 2182±64 signal events.
(PRD80,112001(2009))

Projections of Dalitz distribution ($M_{\pi\pi}$)



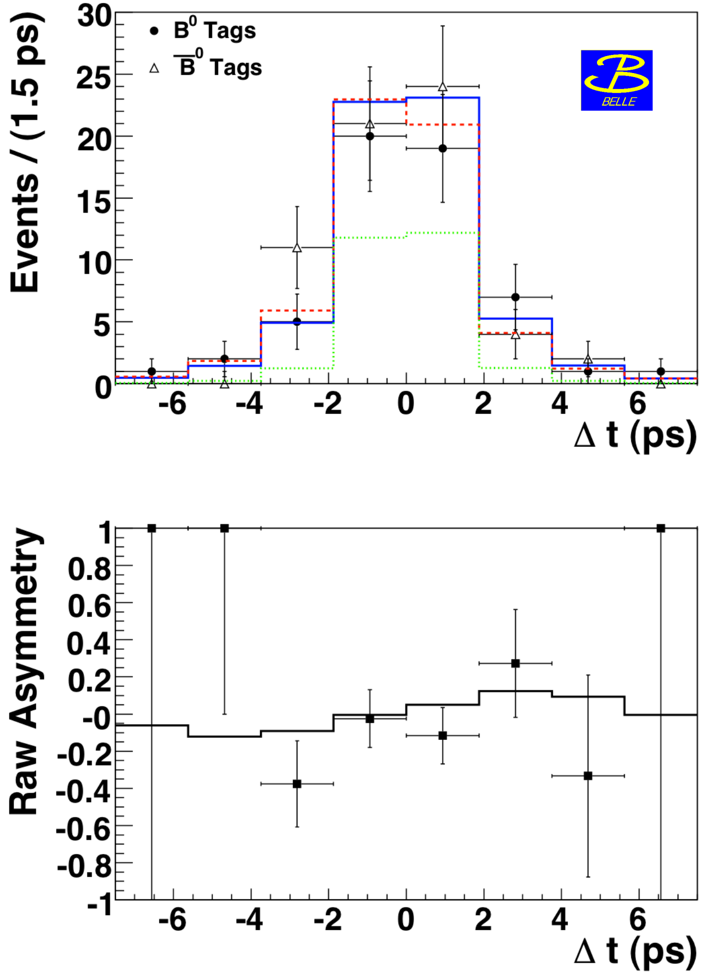




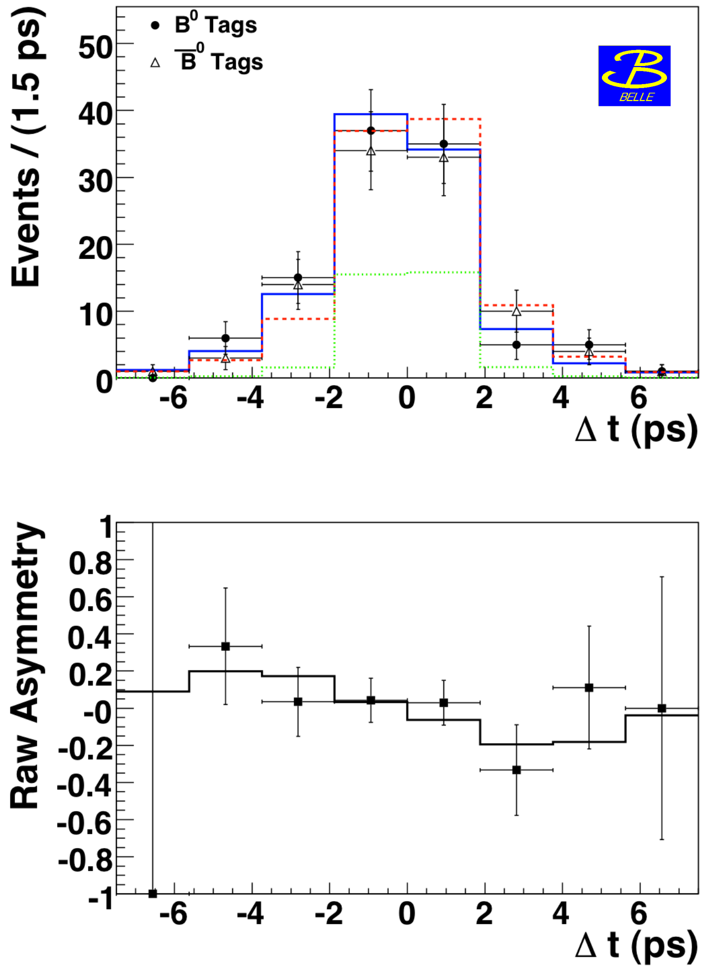
$\rho^0(770)$ and $f_0(980)$ contributions are clearly seen.

Δt distributions in $\rho^0 K_S$ and $f_0 K_S$ regions

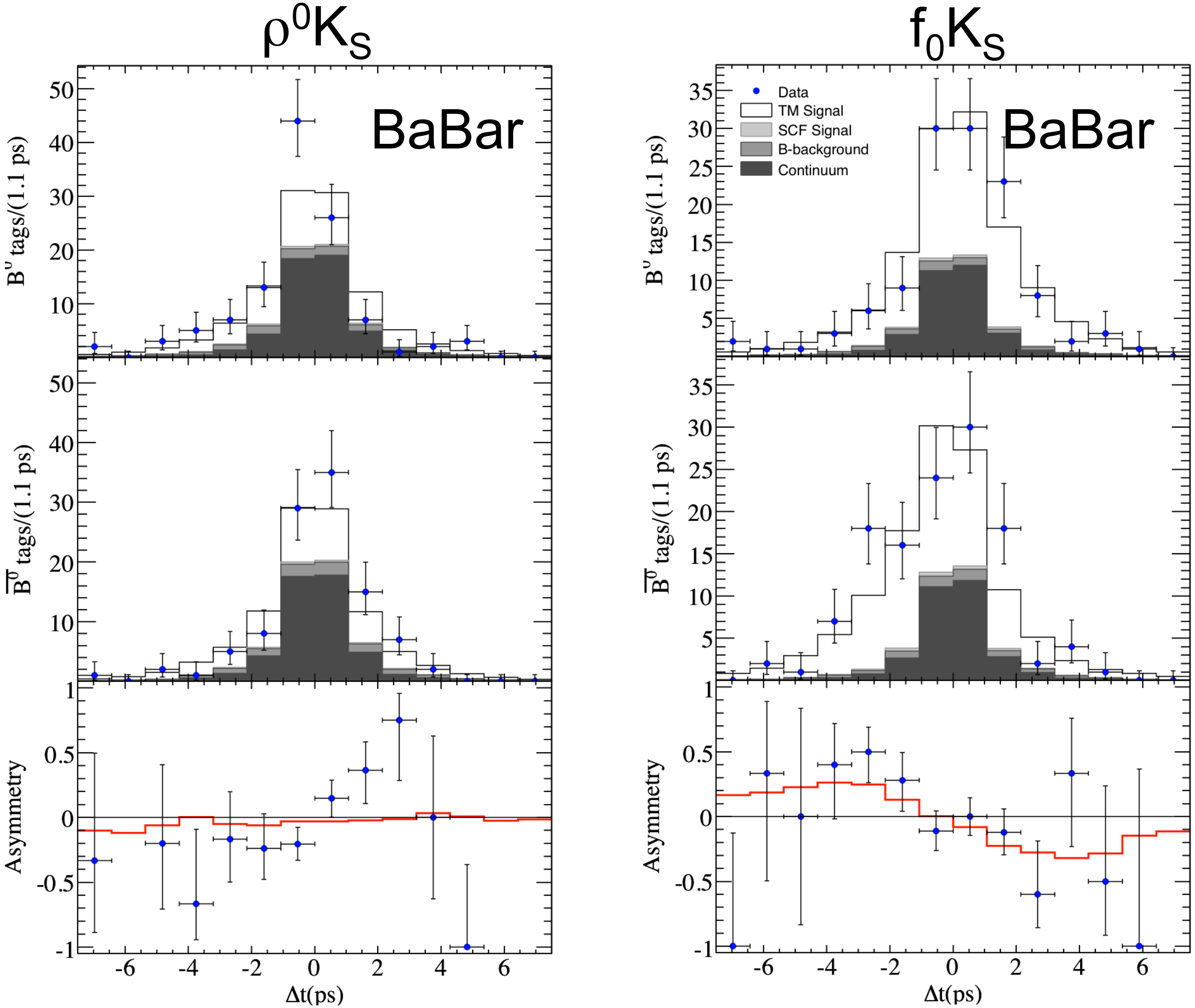
$\rho^0 K_S$



$f_0 K_S$



Δt distributions in $\rho^0 K_S$ and $f_0 K_S$ regions



Again multiple solutions

Belle found 4 solutions. After ensemble test checks and by using external information, two of them are chosen as possible physical solutions. Solution 1 is preferred ($K^{*+}_0(1430)\pi$ fraction and $K_S\pi$ mass spectrum). (PRD79,072004(2009))

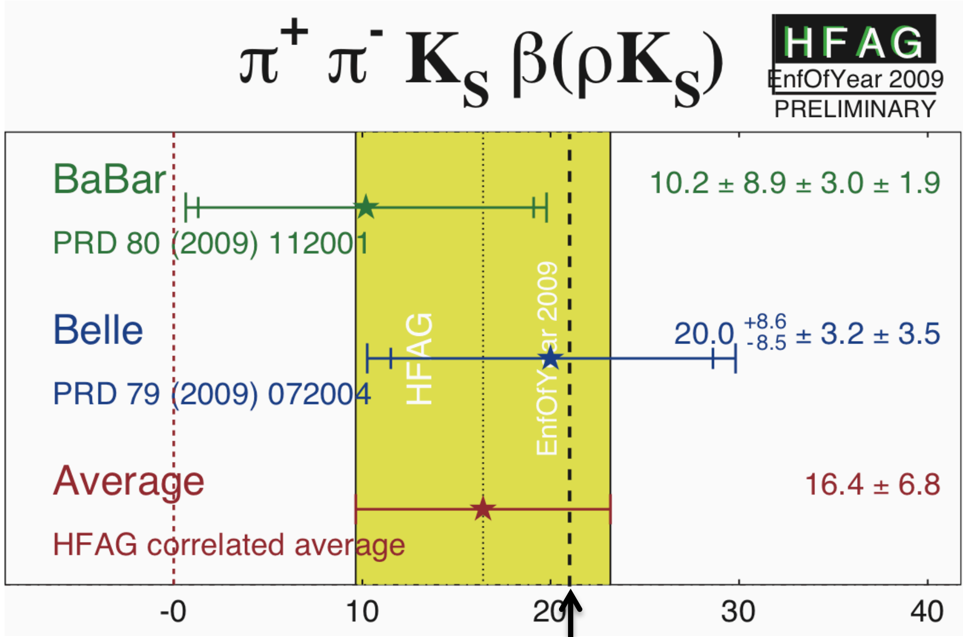
Parameter	Solution 1 (-2ln$L$=18472.5)	Solution 2 (-2ln$L$=18465.5)
$A(f_0K_S)$	0.08±0.19±0.03±0.04	0.23±0.19±0.03±0.04
$\beta(f_0K_S)=\phi_1(f_0K_S)$	(36.0±9.8±2.1±2.1)°	(56.2±10.4±2.1±2.1)°
$A(\rho^0K_S)$	-0.05±0.26±0.10±0.03	-0.14±0.26±0.10±0.03
$\beta(\rho^0K_S)=\phi_1(\rho^0K_S)$	(10.2±8.9±3.0±1.9)°	(33.4±10.4±3.0±1.9)°

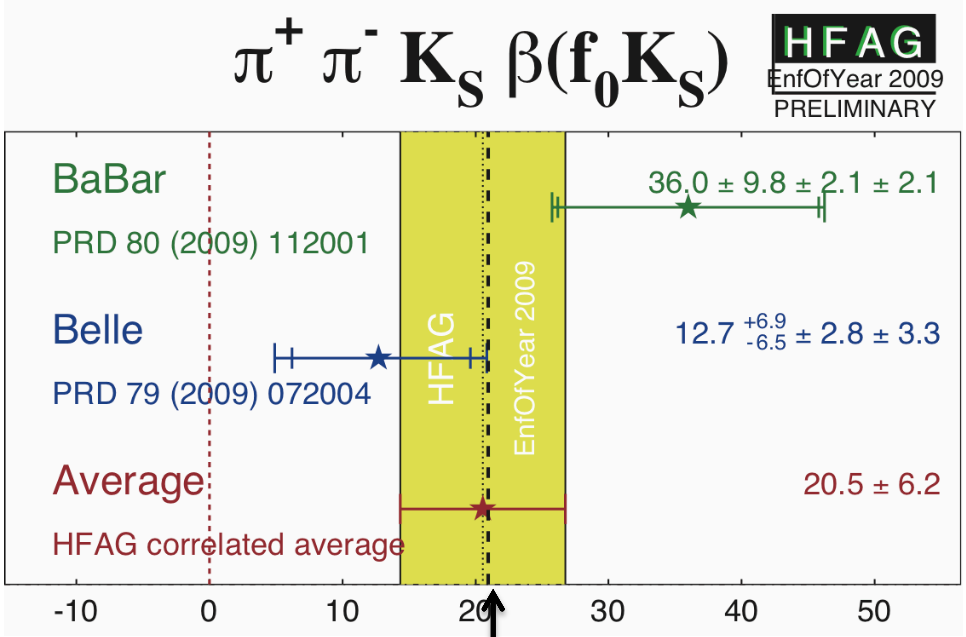
Again multiple solutions

Parameter	Solution 1	Solution 2
$C(f_0K_S)=-A(f_0K_S)$	0.08±0.19±0.03±0.04	0.23±0.19±0.03±0.04
$\beta(f_0K_S)=\phi_1(f_0K_S)$	(36.0±9.8±2.1±2.1)°	(56.2±10.4±2.1±2.1)°
$C(\rho^0K_S)=-A(\rho^0K_S)$	-0.05±0.26±0.10±0.03	-0.14±0.26±0.10±0.03
$\beta(\rho^0K_S)=\phi_1(\rho^0K_S)$	(10.2±8.9±3.0±1.9)°	(33.4±10.4±3.0±1.9)°

BaBar found 2 solutions.
(PRD80,112001(2009))

effective ϕ_1 of "solution 1"

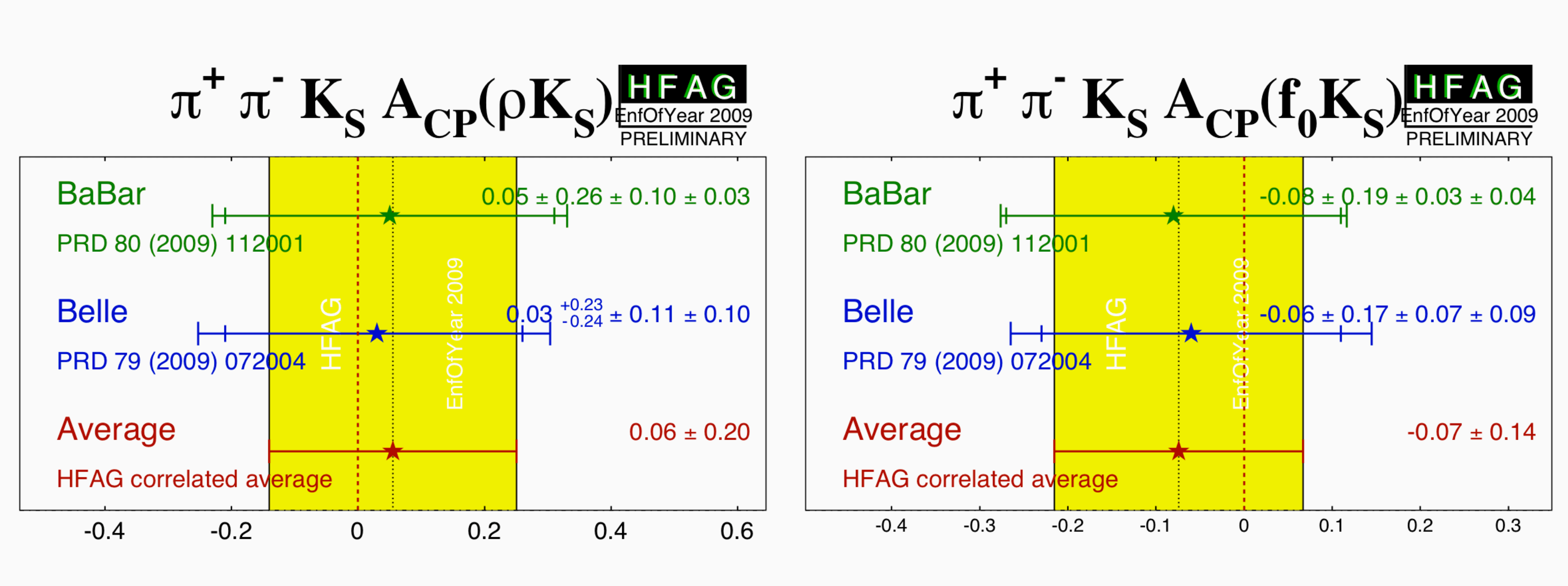




ϕ_1 by $(c\overline{c})K^0$ ϕ_1 by $(c\overline{c})K^0$

No significant deviation from measurements with $B^0 \to (c\overline{c})\ K^0 = \sin 2\phi_1$.

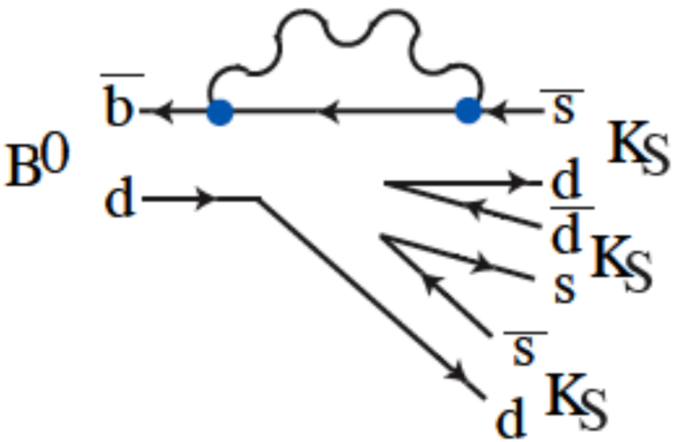
As for direct CP violation



No significant direct CP violation has been observed.

$B^0 \to K_S K_S K_S$

B^0 is a spin-0 meson, decays into three neutral spin-0 meson are CP eigenstate.
(T.Gershon and M.Hazumi, PLB596(2004)163)



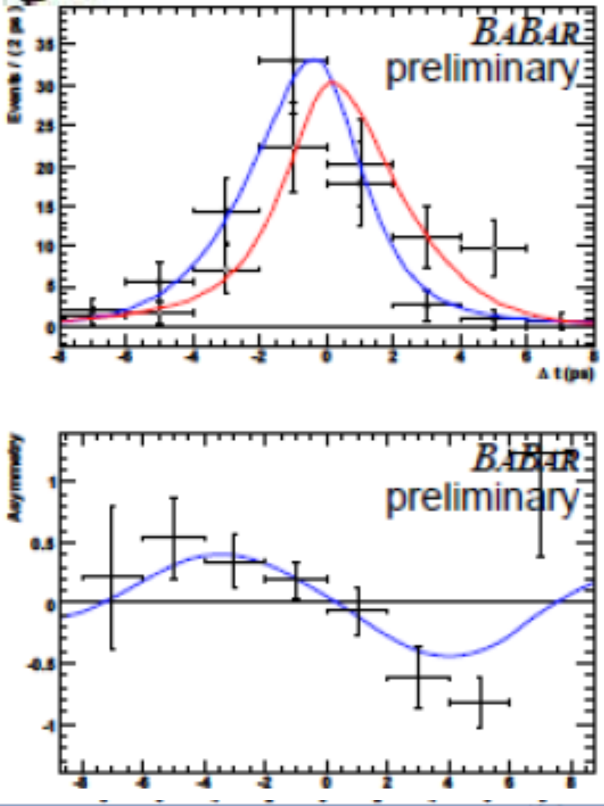
$B^0 \to K_S K_S K_S$ is CP-even final state caused purely by $b \to s$ penguin.
Measurements of Time-dep. CPV have been performed.

$$A_{CP}(\Delta t) = \frac{\Gamma(\overline{B}^0(\Delta t) \to f_{CP}) - \Gamma(B^0(\Delta t) \to f_{CP})}{\Gamma(\overline{B}^0(\Delta t) \to f_{CP}) + \Gamma(B^0(\Delta t) \to f_{CP})} = S_{f_{CP}} \sin(\Delta m \Delta t) + A_{f_{CP}} \cos(\Delta m \Delta t)$$

SM expectation is; $S_{KsKsKs} = -\sin 2\phi_1$ and $A_{KsKsKs} = 0$

Time-dep. CPV in $B^0 \to K_S K_S K_S$

465 MB$\bar{B}$

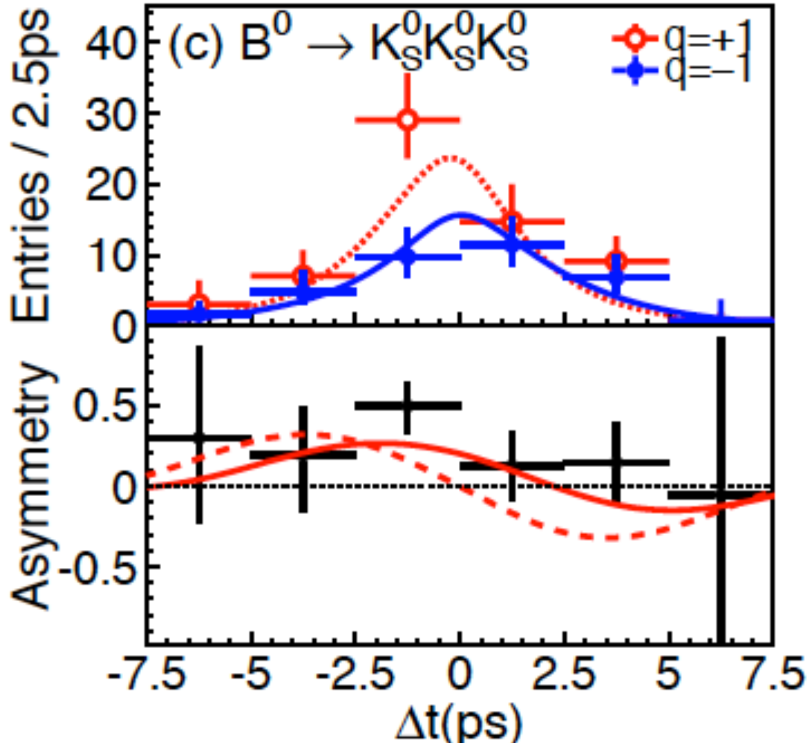


$\mathcal{A} = -\mathcal{C} = +0.16 \pm 0.17 \pm 0.03$

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

PRL 98 (2007) 031802

535 MB$\bar{B}$



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

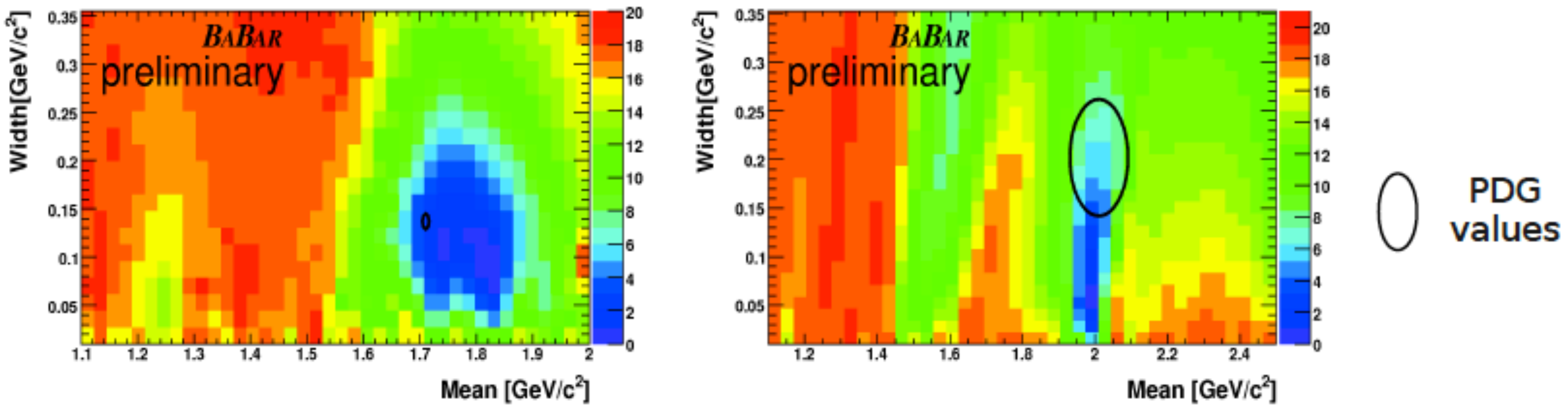
$\mathcal{S} = -0.30 \pm 0.32 \pm 0.08$

Recent BaBar's Dalitz approach

465M $B\bar{B}$, cuts slightly changed from Time-dependent CPV.

- 200 ± 15 signal events (305 ± 18 $q\bar{q}$);
- We start with a baseline model with f_0(980), χ_{c0}, and non-resonant. We add a resonance and scan the likelihood varying its mass and width;

Scan for a scalar resonance　　　Scan for a tensor resonance



- We only find significant contributions from f_0(1710) and f_2(2010), no evidence of the f_X(1500);
- We measure the inclusive branching fraction:

$BF(B^0 \rightarrow K_S K_S K_S) = (6.5 \pm 0.5 \pm 0.4) \times 10^{-6}$

Shown by A.Gaz at ICHEP2010

Summary and prospects

- Both BaBar and Belle collaborations have carried out time-dependent Dalitz analysis on $B^0 \to K^+K^-K_S$ and $B^0 \to \pi^+\pi^-K_S$.
- In principle, overlapping contributions and interference between resonances can be solved by fitting the Dalitz plot.
- However, we encounter multiple solutions with the currently available statistics.
- No significant deviation of effective ϕ_1 with respect to ϕ_1 determined by charmonium modes, so far.
- No significant direct CP violation has been observed so far.
- With Super B-factory level statistics, the best of the multiple solutions can be identified from likelihood alone.
- BaBar performed a Dalitz analysis of $B^0 \to K_SK_SK_S$.
  - $f_0(1710)$ and $f_2(2010)$ are evident.
  - It may be possible to measure the CP violation parameters of these new modes with higher statistics.

Backup slides

CP Violation Measurement in $B^0 \to K_S^0 K^+ K^-$

- **Solution #1 is most preferred from an external information.**

Intermediate state-by-state fraction

Parameter	Solution 1	Solution 2	Solution 3	Solution 4
$f_{f_0 K_S^0}$	26.0 ± 7.4	54.0 ± 9.6	26.4 ± 7.8	68.1 ± 12.3
$f_{\phi K_S^0}$	14.2 ± 1.2	14.5 ± 1.2	14.2 ± 1.2	14.4 ± 1.2
$f_{f_X K_S^0}$	5.10 ± 1.39	5.89 ± 1.86	39.6 ± 2.6	59.0 ± 3.0
$f_{\chi_{c0} K_S^0}$	3.73 ± 0.74	3.71 ± 0.73	3.68 ± 0.73	4.15 ± 0.79
$f_{(K^+K^-)_{\rm NR} K_S^0}$	138.4 ± 44.8	175.0 ± 52.6	157.4 ± 29.5	48.1 ± 11.7
$f_{(K_S^0 K^+)_{\rm NR} K^-}$	1.65 ± 4.17	21.0 ± 17.3	4.63 ± 6.76	7.87 ± 4.78
$f_{(K_S^0 K^-)_{\rm NR} K^+}$	26.0 ± 12.9	78.0 ± 36.2	38.6 ± 18.1	6.27 ± 3.81
$F_{\rm tot}$	215.2 ± 47.5	352.0 ± 66.8	284.5 ± 36.3	207.9 ± 18.4

- The $Br(f_0(980)\to\pi^+\pi^-)/Br(f_0(980)\to K^+K^-)$ favors solutions with low $f_0(980)K_S^0$ fraction, when compared to the PDG.
- The $Br(f_0(1500)\to\pi^+\pi^-)/Br(f_0(1500)\to K^+K^-)$ favors solutions with low $f_0(1500)K_S^0$ fraction, when compared to the PDG.
  - Here, we assume f_X as $f_0(1500)$.