Measurement of sin2ϕ_1 from $B \rightarrow \eta' K^0$, ωK_S and $\pi^0 K^0$

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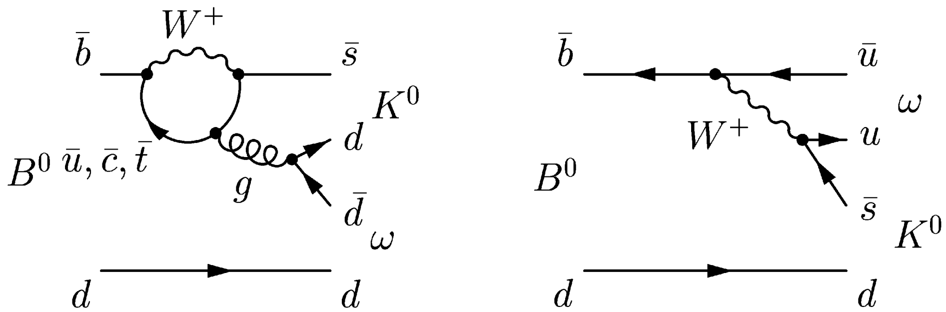
on behalf of the Belle Collaboration

Introduction

- b→s penguin dominated decays B→η'K^0, ω K_S, π^0 K^0 are sensitive to sin2ϕ_1:

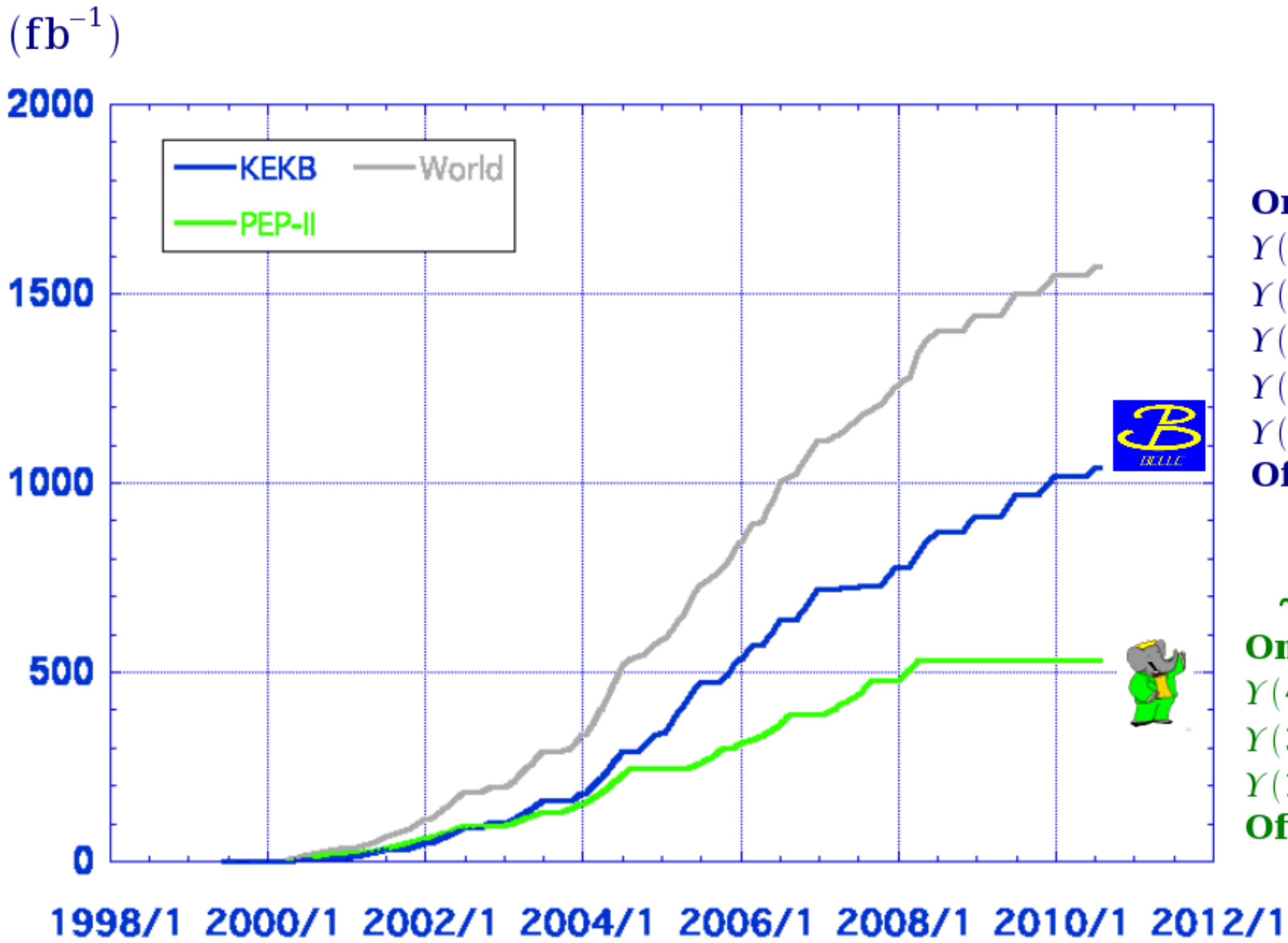
$$A_f(\Delta t) = \frac{\Gamma(\overline{B}^0(\Delta t) \to f) - \Gamma(B^0(\Delta t) \to f)}{\Gamma(\overline{B}^0(\Delta t) \to f) + \Gamma(B^0(\Delta t) \to f)} = -C_f \cos(\Delta m_B \Delta t) + S_f \sin(\Delta m_B \Delta t)$$

  - in case of pure penguin amplitude $S_f \approx \sin 2\phi_1$
- Presence of color-suppressed tree amplitudes shifts S_f from sin2ϕ_1 for a value of 0.01~0.1 depending on decay mode



- Examining for a larger deviations of S_f from sin2ϕ_1 is an important test of the Standard Model

Luminosity at B factories



> 1 ab^{-1}

On resonance:

$\Upsilon(5S)$: 121 fb^{-1}

$\Upsilon(4S)$: 711 fb^{-1}

$\Upsilon(3S)$: 3 fb^{-1}

$\Upsilon(2S)$: 24 fb^{-1}

$\Upsilon(1S)$: 6 fb^{-1}

Off reson./scan:

$\sim$100 fb^{-1}

~ 550 fb^{-1}

On resonance:

$\Upsilon(4S)$: 433 fb^{-1}

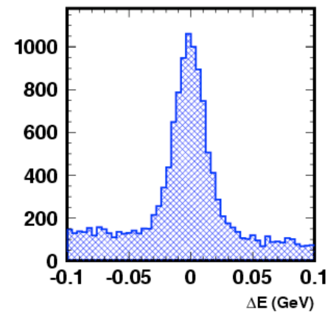
$\Upsilon(3S)$: 30 fb^{-1}

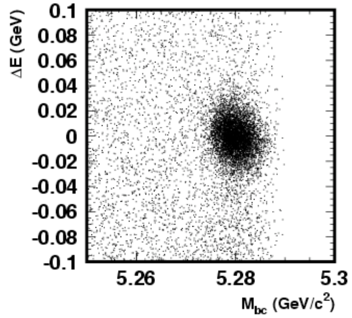
$\Upsilon(2S)$: 14 fb^{-1}

Off resonance:

$\sim$54 fb^{-1}

B meson reconstruction

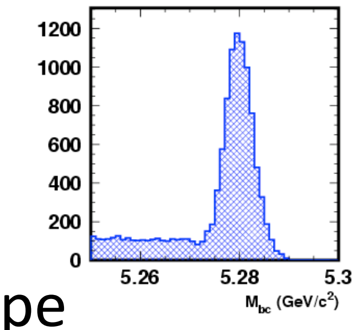




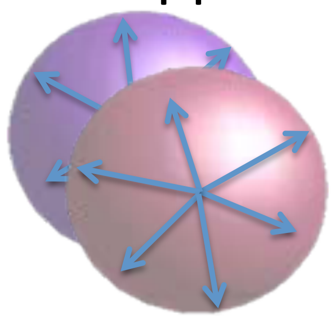
- *B* candidates selected by:

$$\Delta E = \sum E_i - (E_{CM}/2)$$

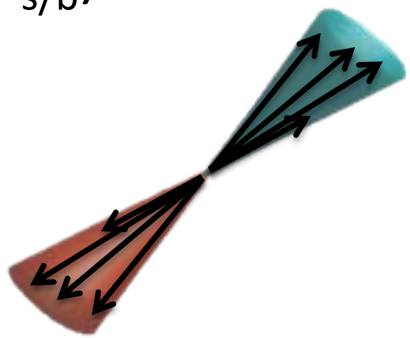
$$M_{bc} = m_{ES} = \sqrt{(E_{CM}/2)^2 - (\sum p_i)^2}$$



- Main background is continuum [$e^+e^- \rightarrow qq$ (q=u,d,s,c)]
  - suppressed by Likelihood ratio ($L_{s/b}$) from event shape



$e^+e^- \rightarrow$ Y(4S) $\rightarrow$ BB
(spherical)



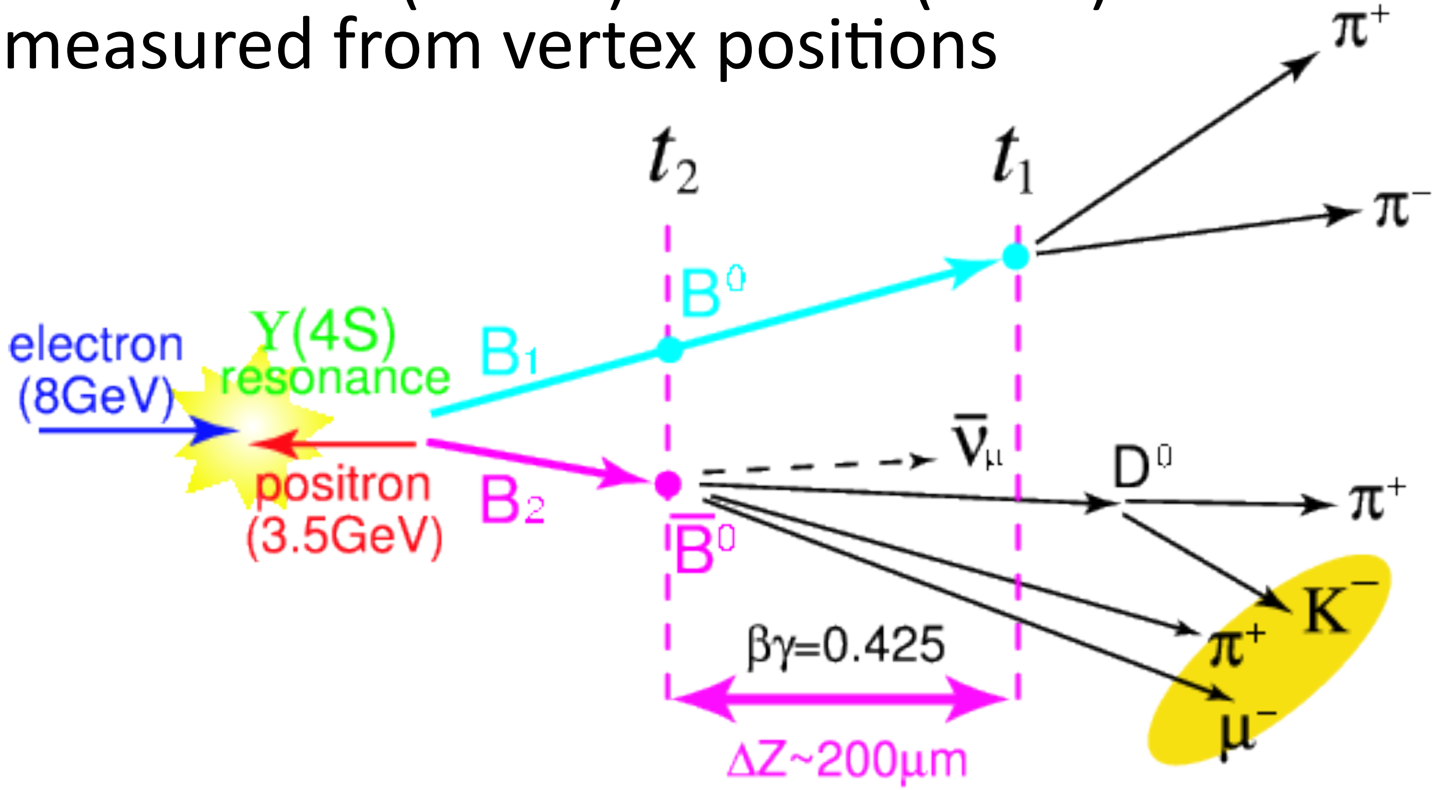
$e^+e^- \rightarrow qq$
(jet-like)

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

tCPV measurements on B-factories

B mesons are produced in a boosted frame

- boost factor 0.56 (BaBar) & 0.425 (Belle)
- Δt is measured from vertex positions



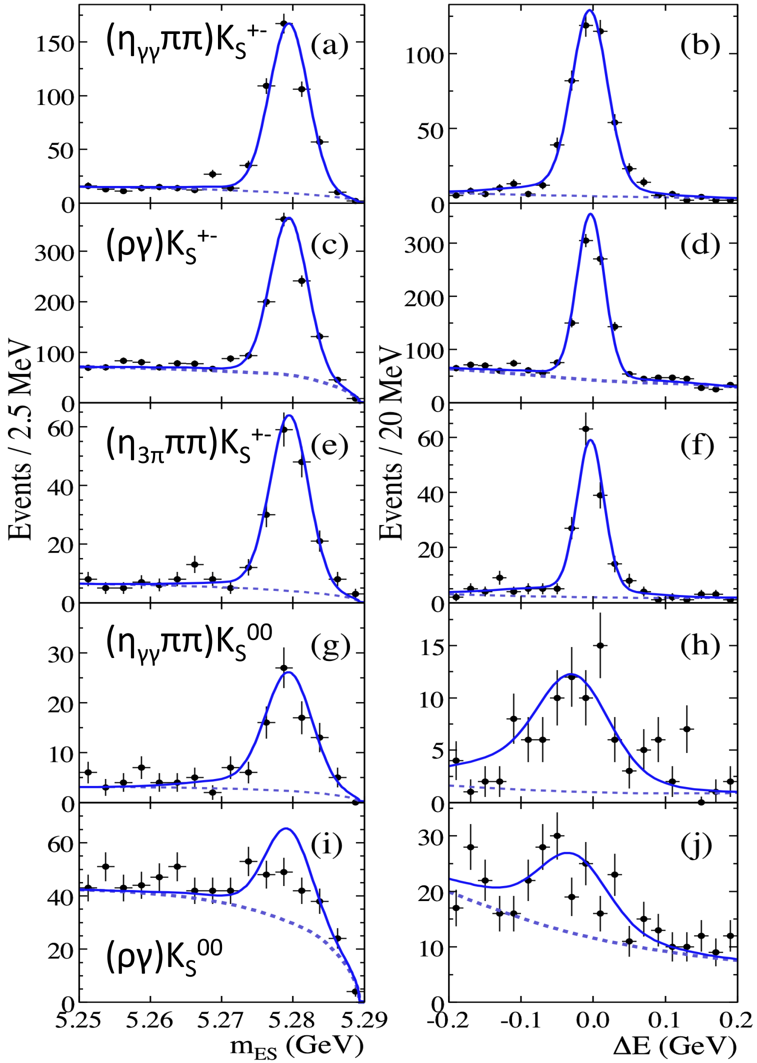
B mesons are entangled
→ flavor of B_1 at time t_2 is determined by B_2 decay

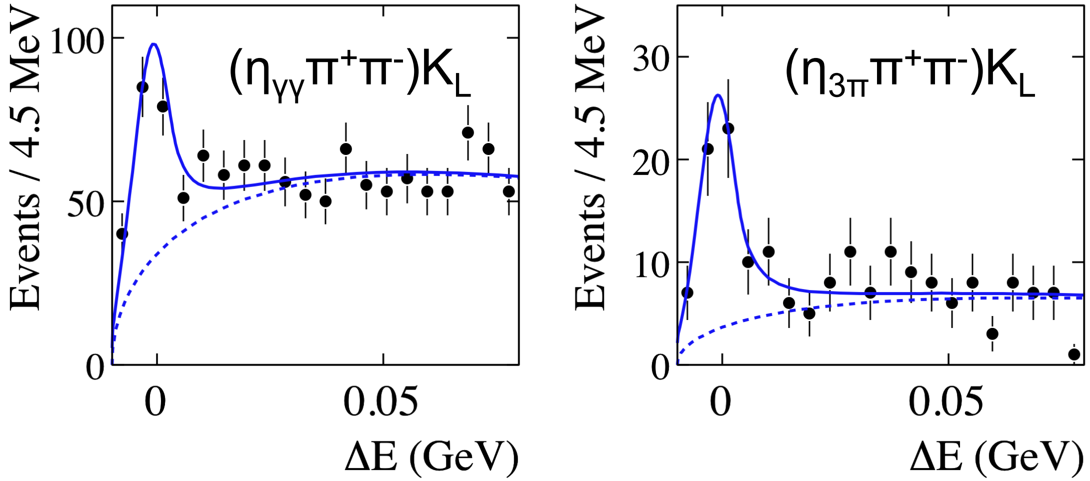
TM & © Nelvana

$B^0 \rightarrow \eta' K^0$

BaBar: 467M, PRD 79, 052003 (2009)

$$\eta'(\rho\gamma,\ \eta_{\gamma\gamma}\,\pi^+\pi^-,\ \eta_{3\pi}\,\pi^+\pi^-)K^0_S\,(\pi^+\pi^-)$$
$$\eta'(\rho\gamma,\ \eta_{\gamma\gamma}\,\pi^+\pi^-)K^0_S\,(\pi^0\pi^0)$$
$$\eta'(\eta_{\gamma\gamma}\,\pi^+\pi^-,\ \eta_{3\pi}\,\pi^+\pi^-)K^0_L$$





B mass was used in case of $\eta' K_L$ to re-calculate unknown K_L momentum

Signal yields:

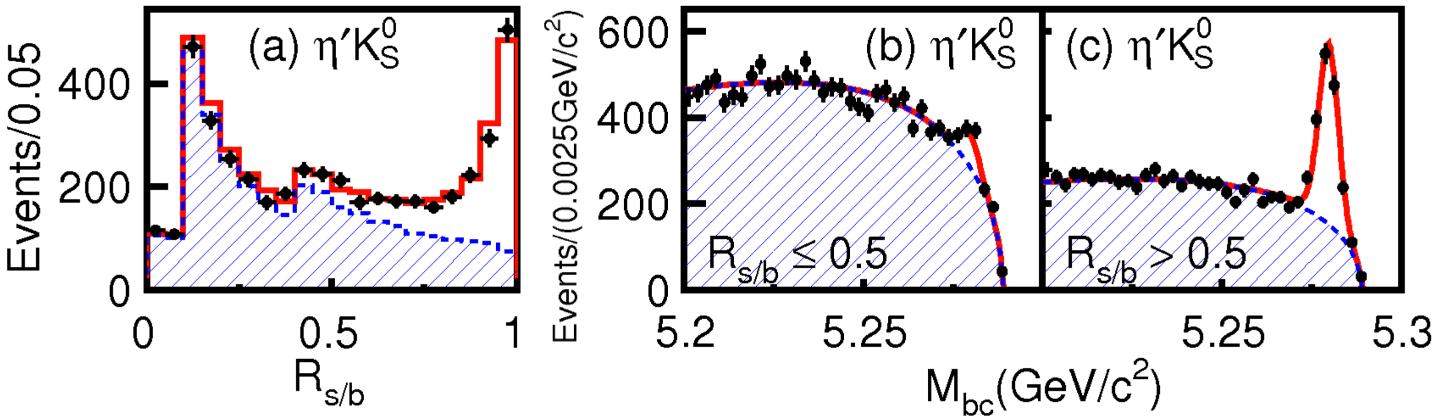
$B^0 \rightarrow \eta' K_S$: 1457 ± 43

$B^0 \rightarrow \eta' K_L$: 341 ± 23

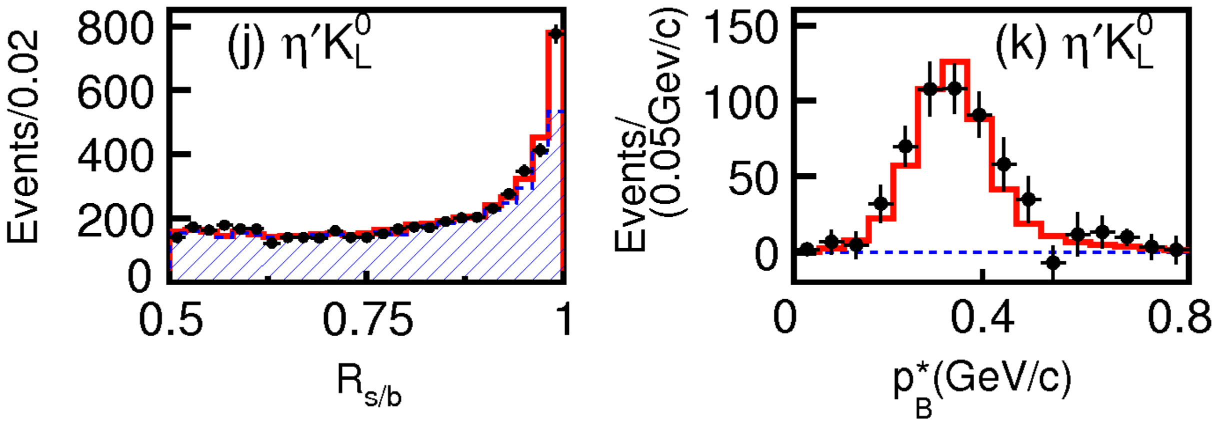
$B^0 \rightarrow \eta' K^0$

Belle: 535M, PRL 98, 031802 (2007)

Same decay modes are used as shown before



All variables which describes event shape are combined into a single variable $R_{s/b}$ used in the fit

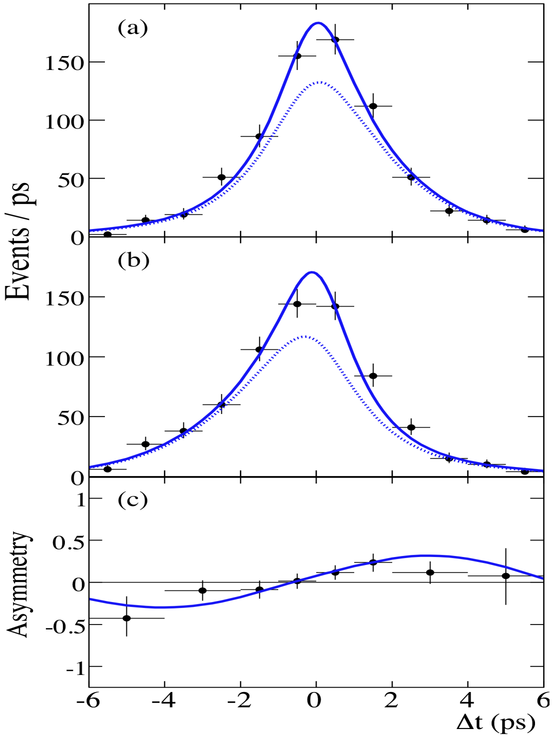


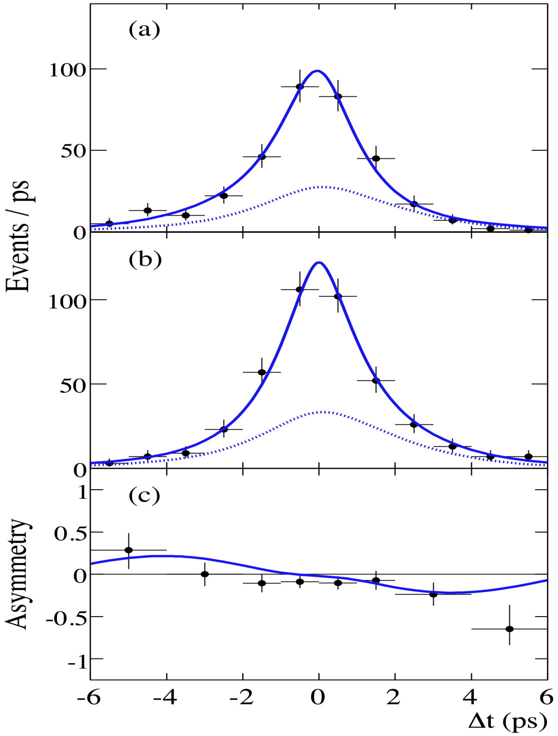
Signal yields:

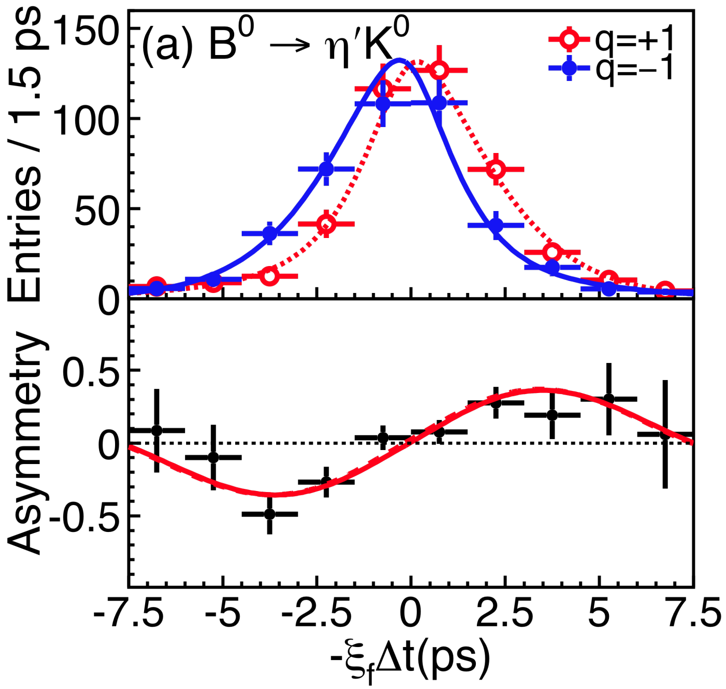
$\eta' K_S$: 1421 ± 46

$\eta' K_L$: 454 ± 39

CPV in $B^0 \rightarrow \eta' K^0$







$S_f = + 057 \pm 0.08 \pm 0.02$

$C_f = - 0.08 \pm 0.06 \pm 0.02$

$S_f = + 0.64 \pm 0.10 \pm 0.04$

$A = -C_f = \ - 0.01 \pm 0.07 \pm 0.05$

K_S: $S_f = + 0.53 \pm 0.08 \pm 0.02$

$C_f = - 0.11 \pm 0.06 \pm 0.02$

K_L: $S_f = + 0.82 \pm 0.19 \pm 0.02$

$C_f = + 0.09 \pm 0.14 \pm 0.02$

K_S: $S_f = + 0.67 \pm 0.11$

$A = - 0.03 \pm 0.07$

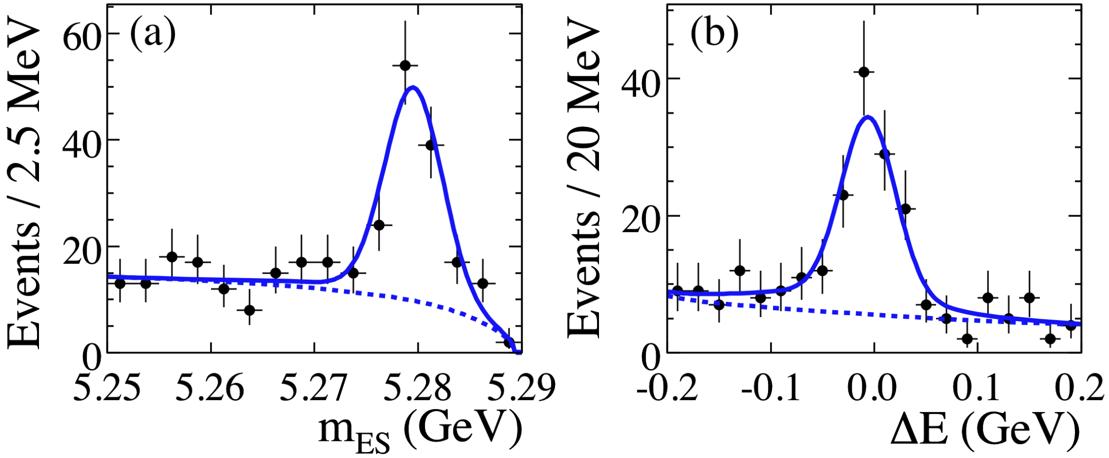
K_L: $S_f = + 0.46 \pm 0.24$

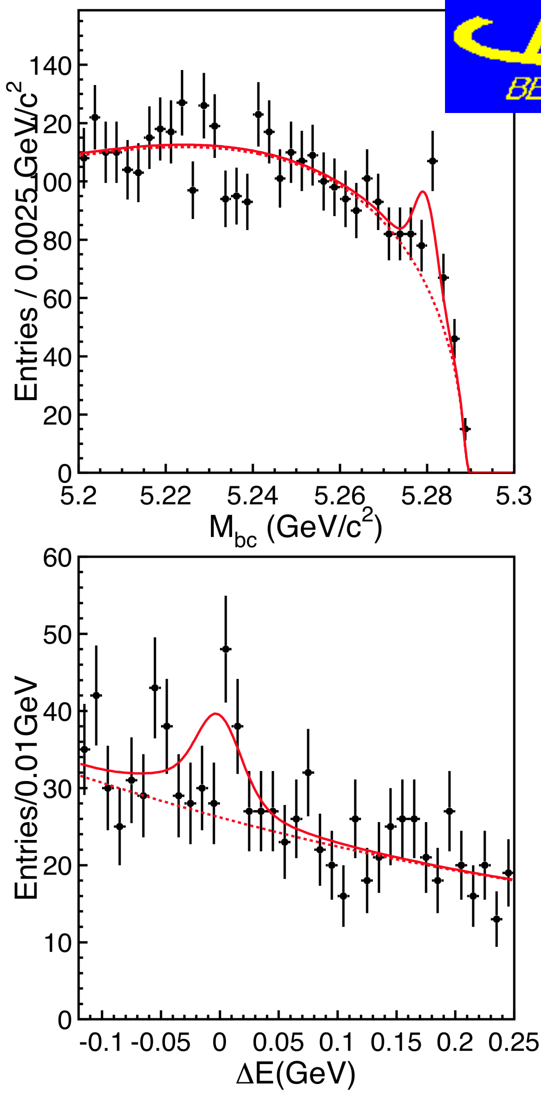
$A = + 0.09 \pm 0.16$ (stat errors only)

The only b→s mode where significant CPV is measured

$B^0 \to \omega K_S$

BaBar: 467M, PRD 79, 052003 (2009)
Belle: 535M, PRD 76, 091103(R) (2007)





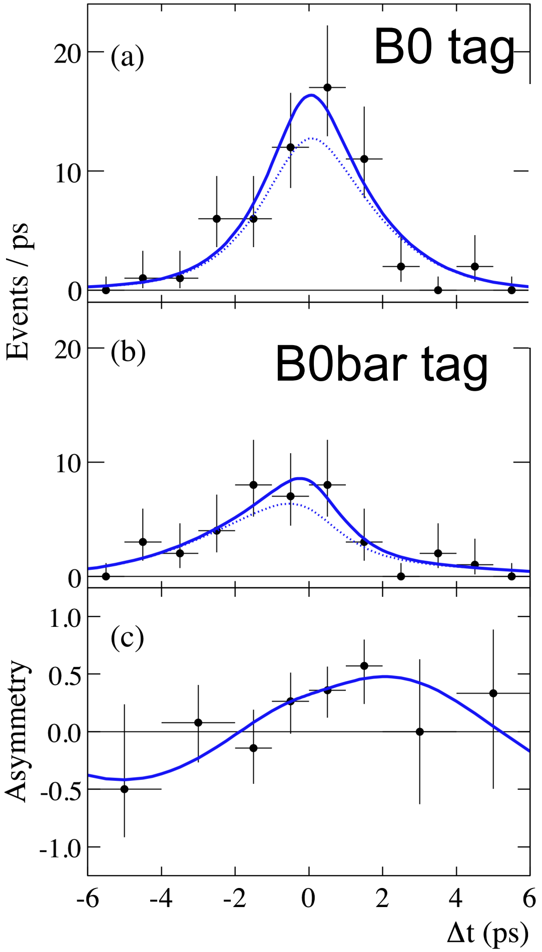
Signal yields:

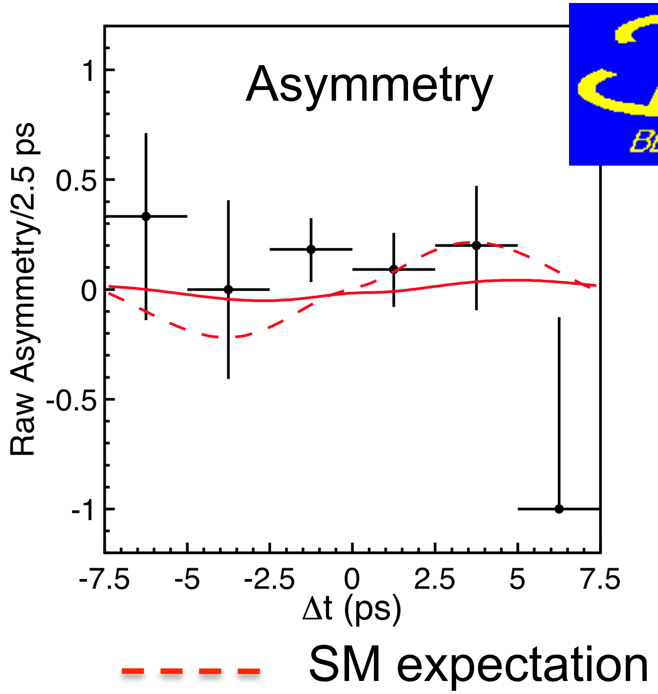
BaBar: 121 ± 13

Belle: 118 ± 18

CPV in $B^0 \to \omega K_S$

BaBar: 467M, PRD 79, 052003 (2009)
Belle: 535M, PRD 76, 091103(R) (2007)





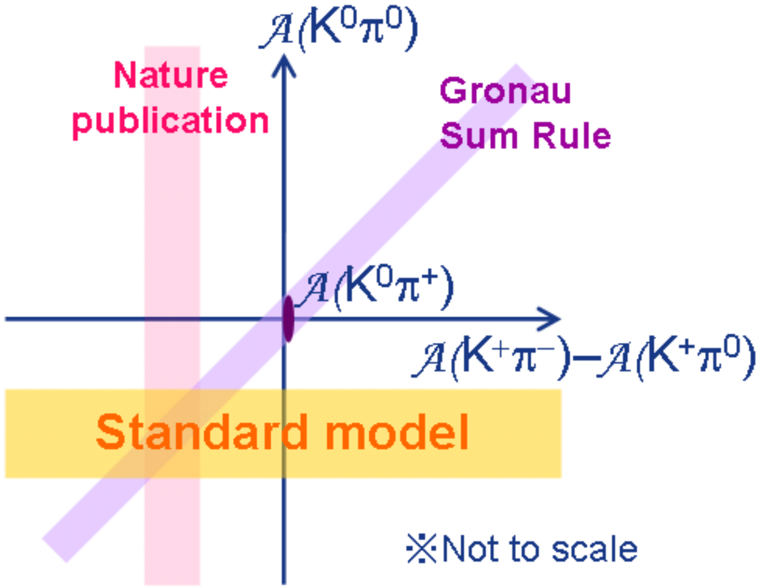
BaBar: $S_f = +0.55\ ^{+0.26}_{-0.29} \pm 0.02$
$C_f = -0.52\ ^{+0.22}_{-0.20} \pm 0.03$

Belle: $S_f = +0.11 \pm 0.46 \pm 0.07$
$A = -C_f = -0.09 \pm 0.29 \pm 0.06$

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

- $A_{CP}(B^0 \to K^+\pi^-) \neq A_{CP}(B^+ \to K^+\pi^0)$ (Nature, 452, 332-335, 2008)
- Isospin sum rule (M.Gronau, PLB 672, 82-88, 2005):

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



Breaking sum rule indicates new physics

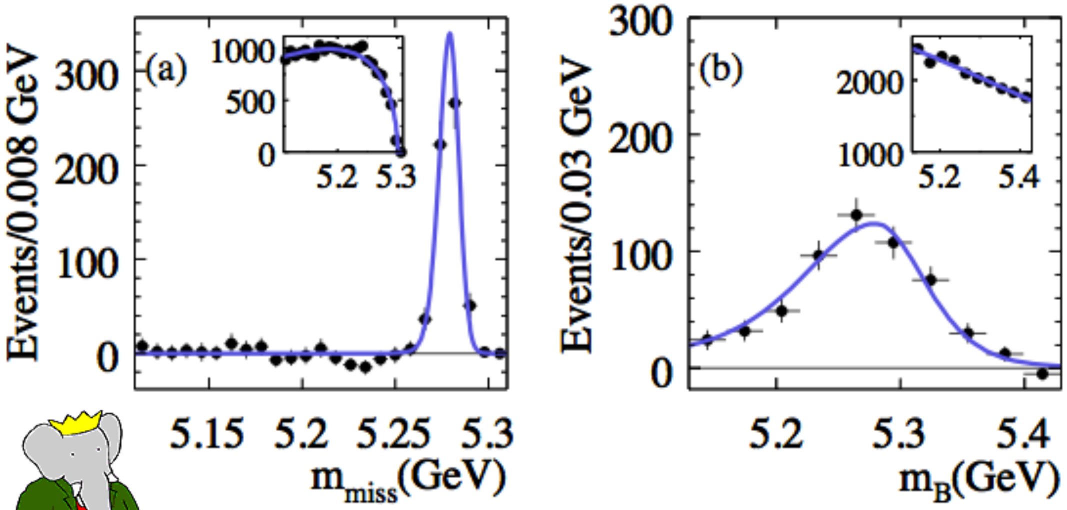
$A_{CP}(K^0\pi^0)$ is the most poor measured value

Both S and A measurements are important

Complimentary information in Y.Unno's talk

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

BaBar: 467M, PRD 79, 052003 (2009)
Belle: 657M, PRD 81, 011101 (2010)



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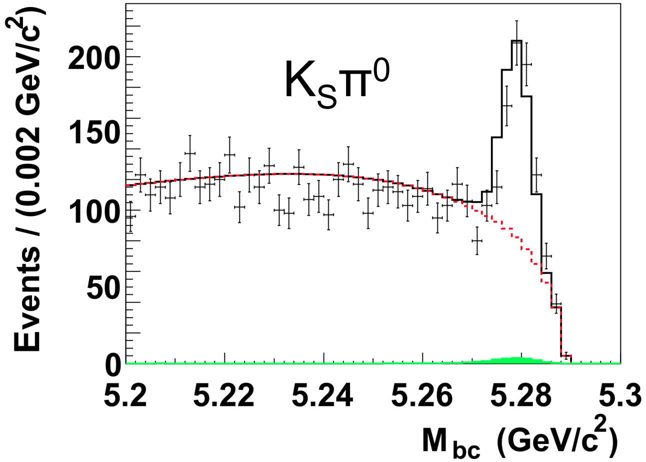
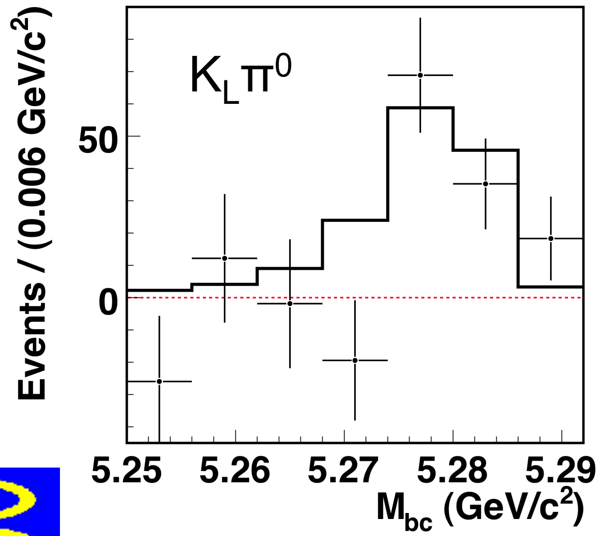




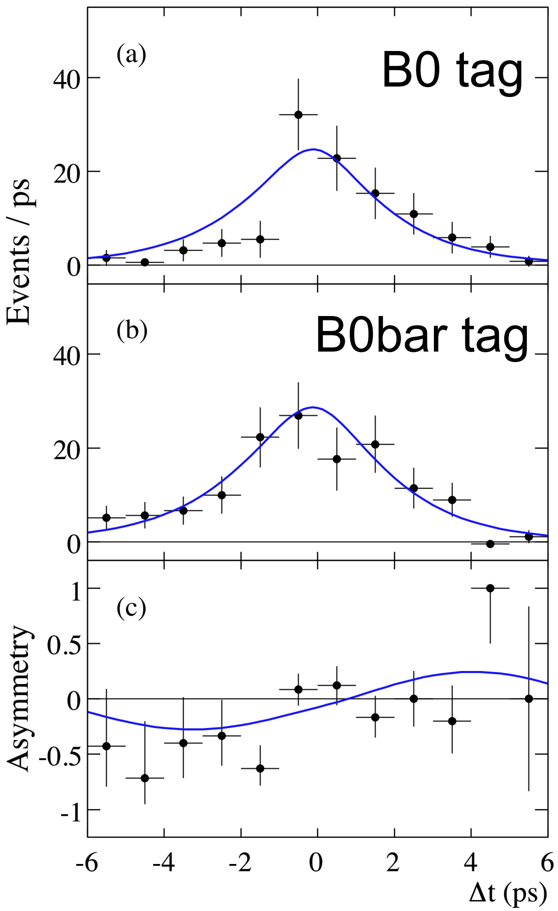
Signal yields:

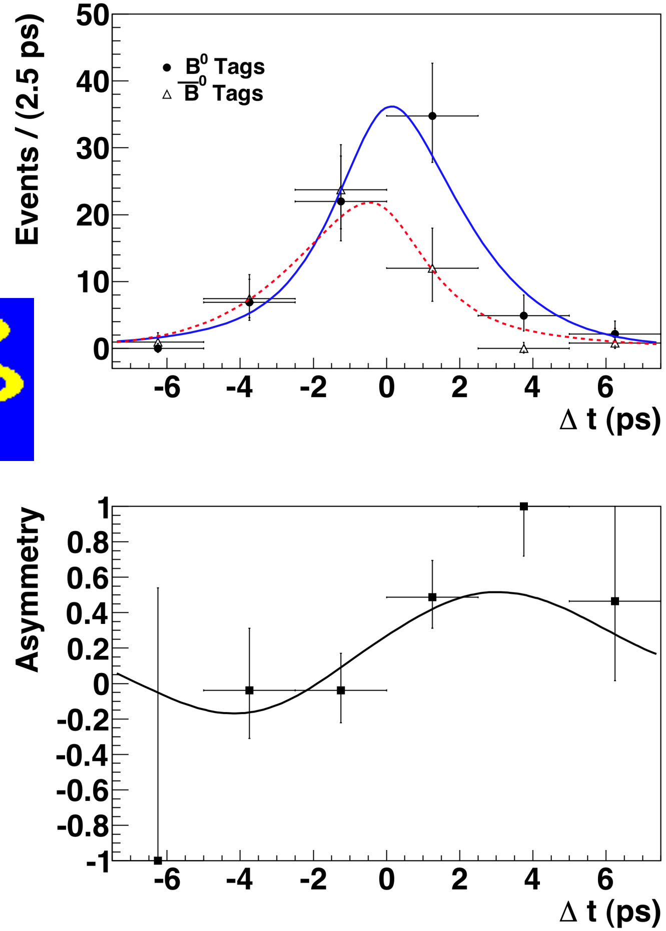
- BaBar:
  - $K_s\pi^0$: 411 ± 24
- Belle:
  - $K_s\pi^0$: 634 ± 34
  - $K_L\pi^0$: 285 ± 52 (3.7σ)

Belle used both K_S and K_L to reconstruct signal: for K_L reconstruction known B energy and K_L direction are used

CPV in $B^0 \rightarrow \pi^0 K^0$

BaBar: 467M, PRD 79, 052003 (2009)
Belle: 657M, PRD 81, 011101 (2010)





BaBar:

$S = + 0.55 \pm 0.20 \pm 0.03$

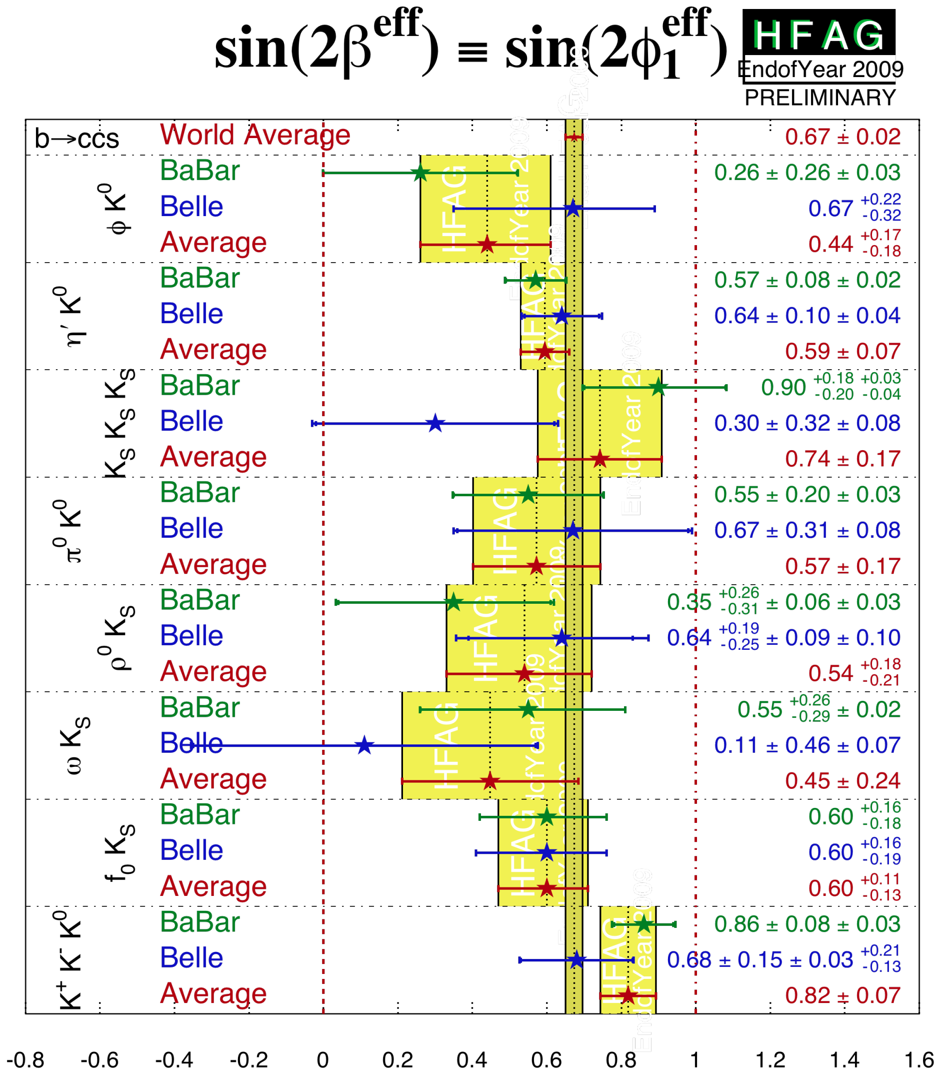
$C = + 0.13 \pm 0.13 \pm 0.03$

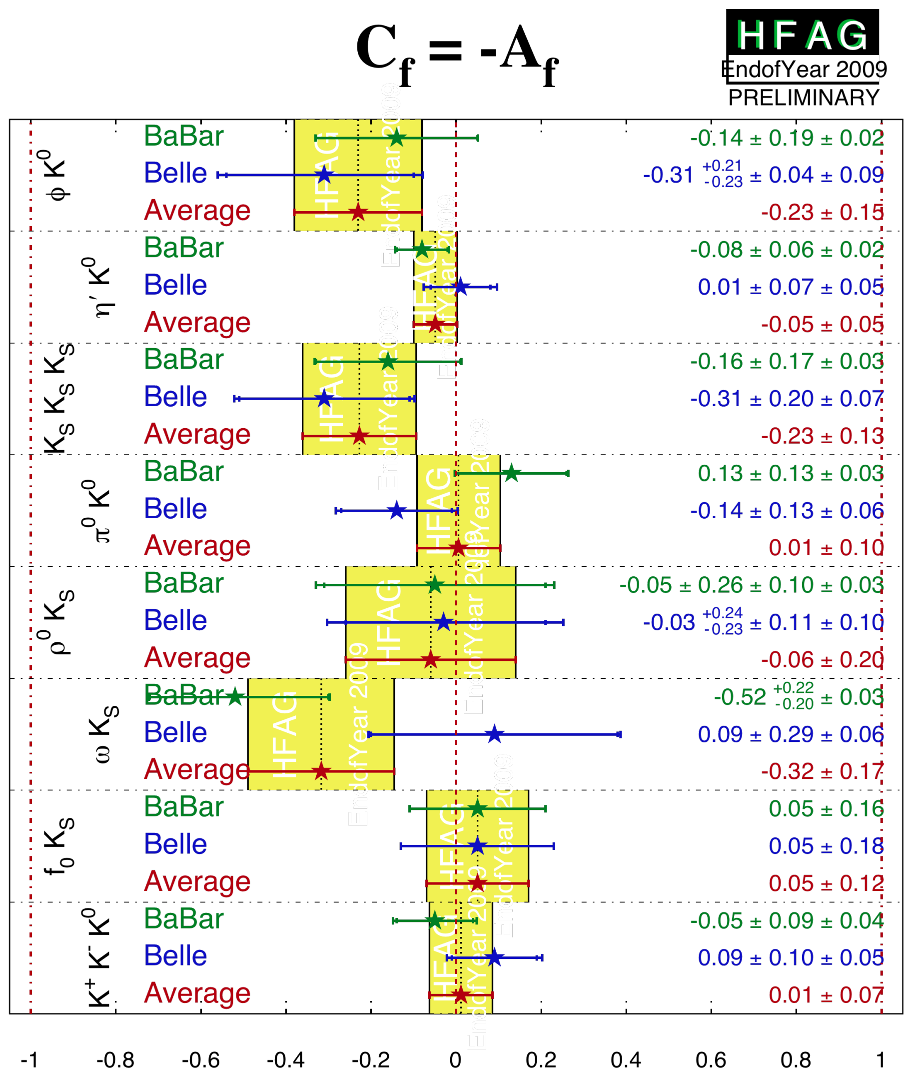
Belle:

$S = + 0.67 \pm 0.31 \pm 0.08$

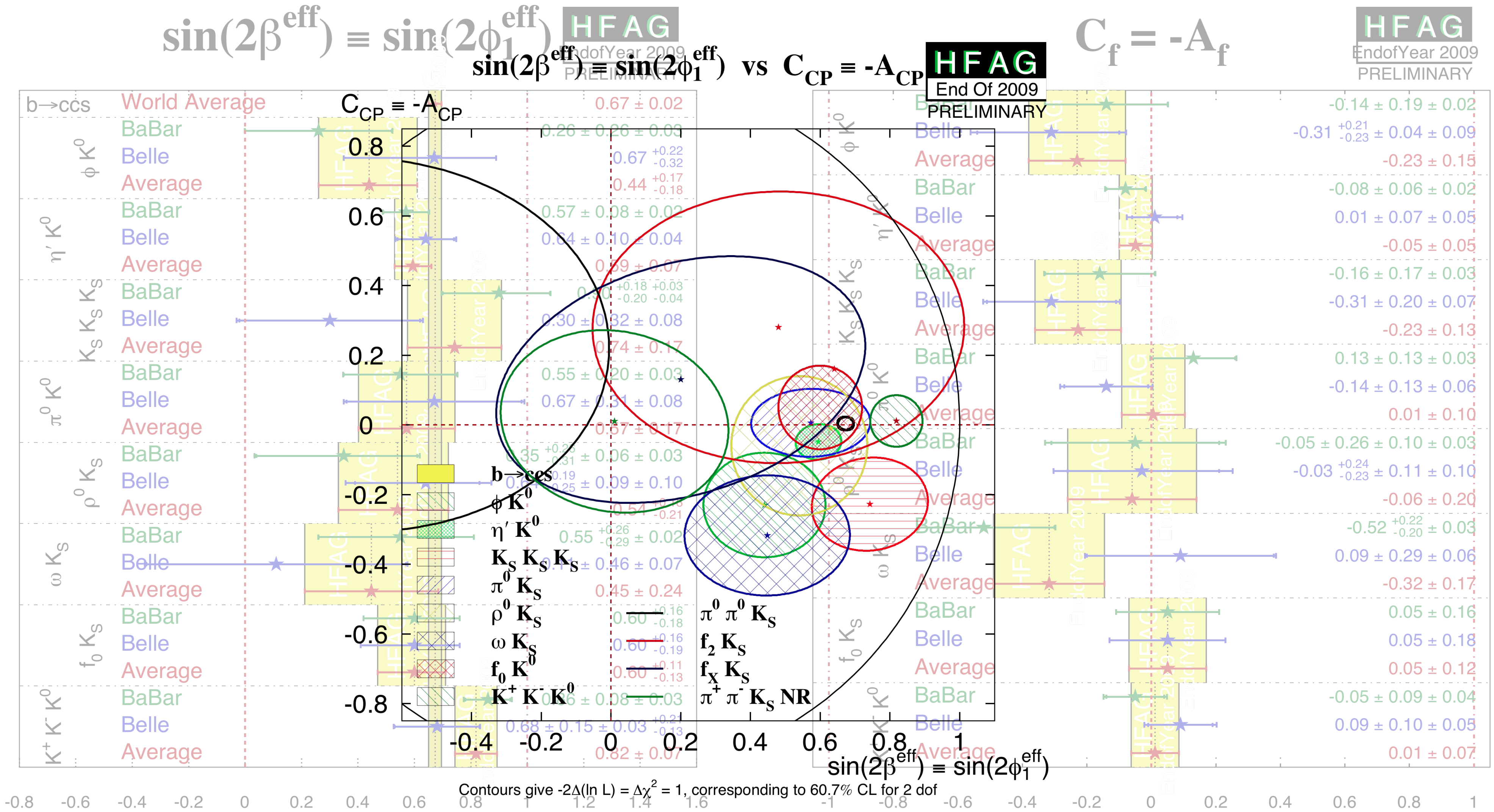
$A = -C = + 0.14 \pm 0.13 \pm 0.06$

Summary


sin(2β^eff) ≡ sin(2φ1^eff)
HFAG
EndofYear 2009
PRELIMINARY
b→ccs
World Average 0.67 ± 0.02
φ K0
BaBar 0.26 ± 0.26 ± 0.03
Belle 0.67 +0.22 -0.32
Average 0.44 +0.17 -0.18
η′ K0
BaBar 0.57 ± 0.08 ± 0.02
Belle 0.64 ± 0.10 ± 0.04
Average 0.59 ± 0.07
KS KS KS
BaBar 0.90 +0.18 -0.20 +0.03 -0.04
Belle 0.30 ± 0.32 ± 0.08
Average 0.74 ± 0.17
π0 K0
BaBar 0.55 ± 0.20 ± 0.03
Belle 0.67 ± 0.31 ± 0.08
Average 0.57 ± 0.17
ρ0 KS
BaBar 0.35 +0.26 -0.31 ± 0.06 ± 0.03
Belle 0.64 +0.19 -0.25 ± 0.09 ± 0.10
Average 0.54 +0.18 -0.21
ω KS
BaBar 0.55 +0.26 -0.29 ± 0.02
Belle 0.11 ± 0.46 ± 0.07
Average 0.45 ± 0.24
f0 KS
BaBar 0.60 +0.16 -0.18
Belle 0.60 +0.16 -0.19
Average 0.60 +0.11 -0.13
K+ K- K0
BaBar 0.86 ± 0.08 ± 0.03
Belle 0.68 ± 0.15 ± 0.03 +0.21 -0.13
Average 0.82 ± 0.07
-0.8 -0.6 -0.4 -0.2 0 0.2 0.4 0.6 0.8 1 1.2 1.4 1.6


Cf = -Af
HFAG
EndofYear 2009
PRELIMINARY
φ K0
BaBar -0.14 ± 0.19 ± 0.02
Belle -0.31 +0.21 -0.23 ± 0.04 ± 0.09
Average -0.23 ± 0.15
η′ K0
BaBar -0.08 ± 0.06 ± 0.02
Belle 0.01 ± 0.07 ± 0.05
Average -0.05 ± 0.05
KS KS KS
BaBar -0.16 ± 0.17 ± 0.03
Belle -0.31 ± 0.20 ± 0.07
Average -0.23 ± 0.13
π0 K0
BaBar 0.13 ± 0.13 ± 0.03
Belle -0.14 ± 0.13 ± 0.06
Average 0.01 ± 0.10
ρ0 KS
BaBar -0.05 ± 0.26 ± 0.10 ± 0.03
Belle -0.03 +0.24 -0.23 ± 0.11 ± 0.10
Average -0.06 ± 0.20
ω KS
BaBar -0.52 +0.22 -0.20 ± 0.03
Belle 0.09 ± 0.29 ± 0.06
Average -0.32 ± 0.17
f0 KS
BaBar 0.05 ± 0.16
Belle 0.05 ± 0.18
Average 0.05 ± 0.12
K+ K- K0
BaBar -0.05 ± 0.09 ± 0.04
Belle 0.09 ± 0.10 ± 0.05
Average 0.01 ± 0.07
-1 -0.8 -0.6 -0.4 -0.2 0 0.2 0.4 0.6 0.8 1

Summary



$\sin(2\beta^{eff}) \equiv \sin(2\phi_1^{eff})$ vs $C_{CP} \equiv -A_{CP}$
HFAG
End Of 2009
PRELIMINARY
$C_{CP} \equiv -A_{CP}$
$\sin(2\beta^{eff}) \equiv \sin(2\phi_1^{eff})$
b→ccs
ϕK^0
$\eta' K^0$
$K_S K_S K_S$
$\pi^0 K_S$
$\rho^0 K_S$
ωK_S
$f_0 K^0$
$K^+ K^- K^0$
$\pi^0 \pi^0 K_S$
$f_2 K_S$
$f_X K_S$
$\pi^+ \pi^- K_S$ NR
Contours give $-2\Delta(\ln L) = \Delta\chi^2 = 1$, corresponding to 60.7% CL for 2 dof
$C_f = -A_f$

Conclusion

- Current measurements are consistent with SM
- Further improvements are expected from Belle:
  - currently not the whole statistics is used
  - Belle data are re-processed with new reconstruction, which gives 10-30% improvement in the efficiency depending on the decay mode
- For the modes which require much more data Belle II will help