CP-Violation in Charmless Hadronic Decays of B Mesons

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for the

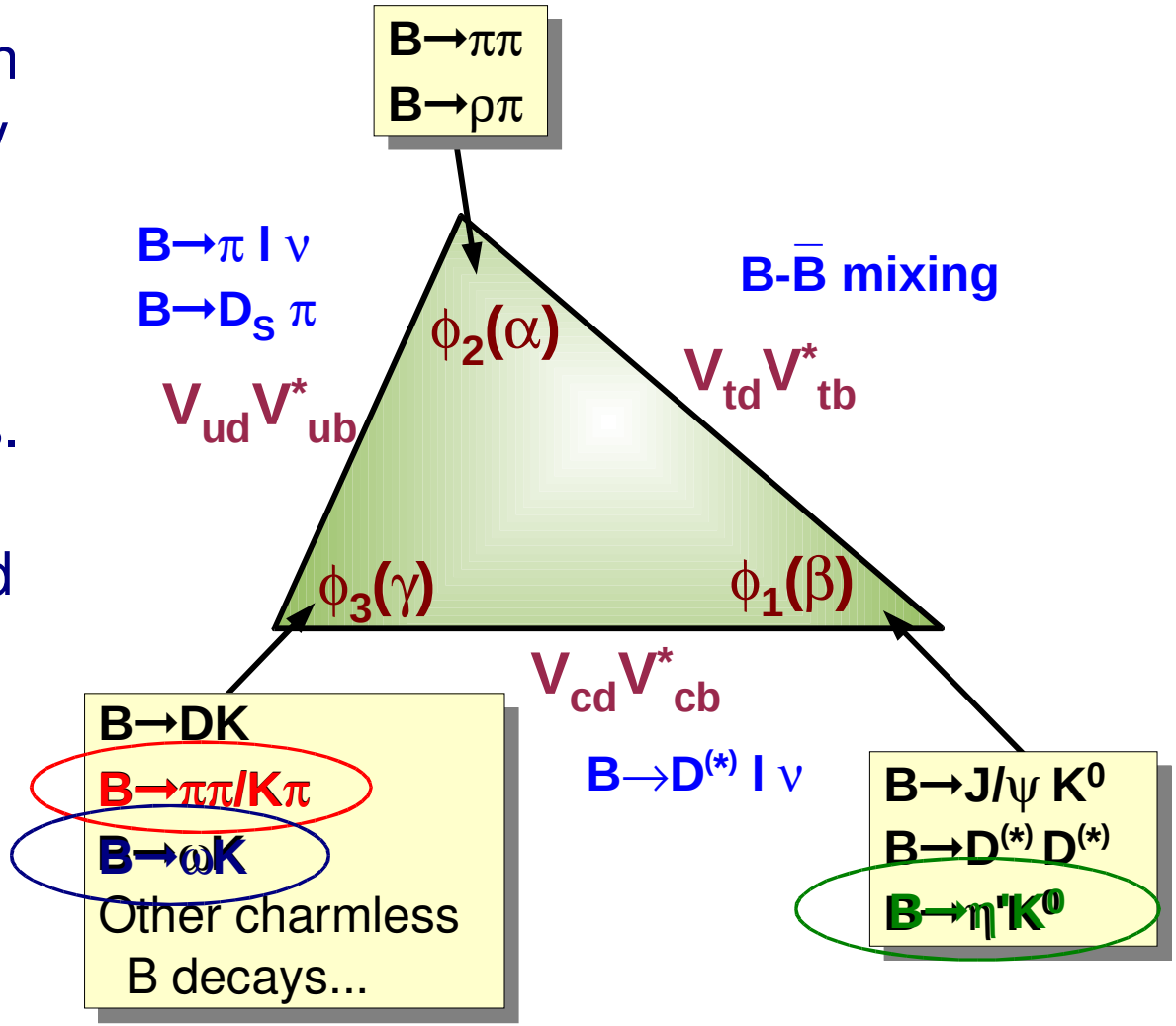
Belle Collaboration

XIVth Rencontres de Blois
Matter Anti-Matter Asymmetry
Château de Blois, France
16 – 22 June 2002

- *Introduction*
- *DCPV:* $\pi\pi/K\pi$, $\omega\pi/\omega K$, $\eta^{(\prime)}/\pi K^{(*)}$
- *Time-dependent CPV of* $\eta' K_S$
- *Summary and Outlook*

Introduction

- Rare B decays are useful in determination of the unitary triangle.
- Test of current understanding of B physics.
- Search for CP violation and probe new physics.



CP Asymmetry

- Sizable Penguin amplitudes for most modes
  - Penguin-Tree interference
    - ➪ Possible direct CP violation

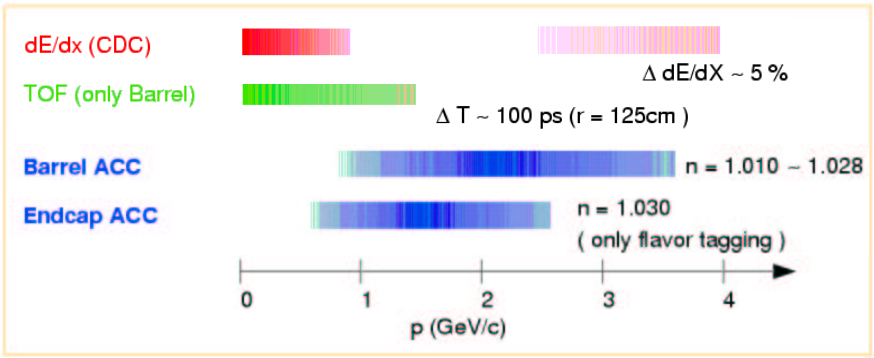
$$A_{CP} = \frac{\Gamma(\bar{B}\to\bar{f})-\Gamma(B\to f)}{\Gamma(\bar{B}\to\bar{f})+\Gamma(B\to f)} = \frac{2|P||T|\sin(\Delta\phi)\sin(\Delta\delta)}{|P|^2+|T|^2+2|P||T|\cos(\Delta\phi)\cos(\Delta\delta)}$$

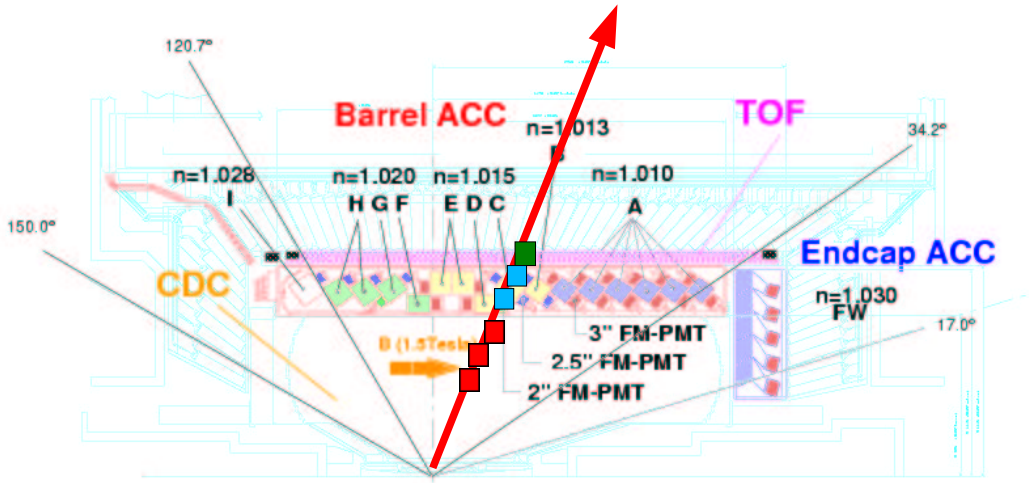
  - $\Delta\phi(\Delta\delta)$: weak(strong) penguin-tree phase difference
  - b-quark convension

- "pure" Penguin modes: $\phi K^{(*)}$, $K^0\pi$
  - Negligible direct CP violation in Standard Model
    - ➪ Probe new physics!

Particle Identification: K/π

- Clear K/p separation is essential in identifying final states of B meson decay
  - DK/Dπ, ωK/ωπ, ππ/Kπ/KK, ...etc
  - K*γ/ργ



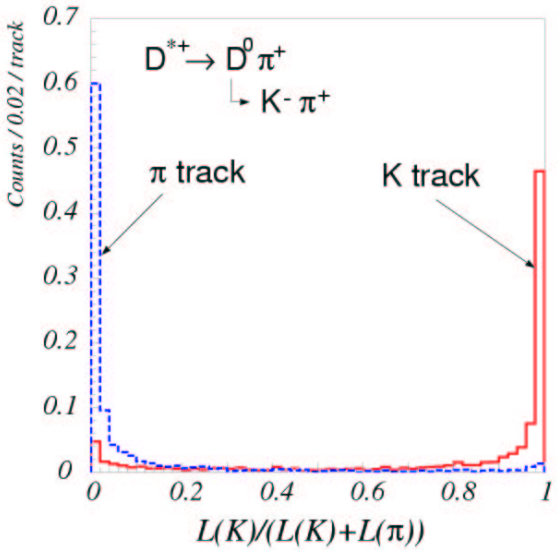


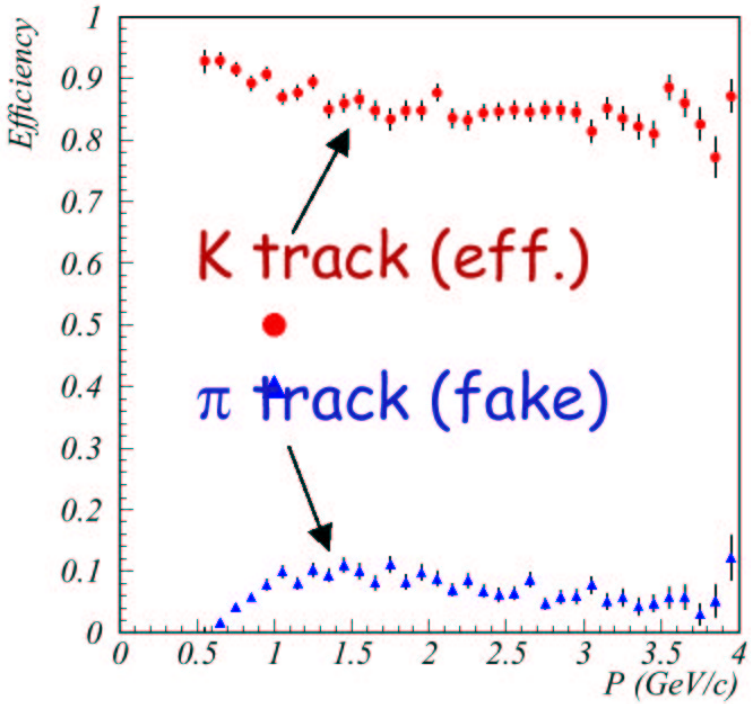
Particle Identification: K/π (cont.)

$$PID(K) = \frac{L(K)}{L(K)+L(\pi)} \quad \begin{array}{l} \sim 1 \Rightarrow \mathrm{K} \\ \sim 0 \Rightarrow \pi \end{array}$$

- Calibration:

  with $D^{*+} \rightarrow D^0\pi^+$, $D^0 \rightarrow K^-\pi^+$



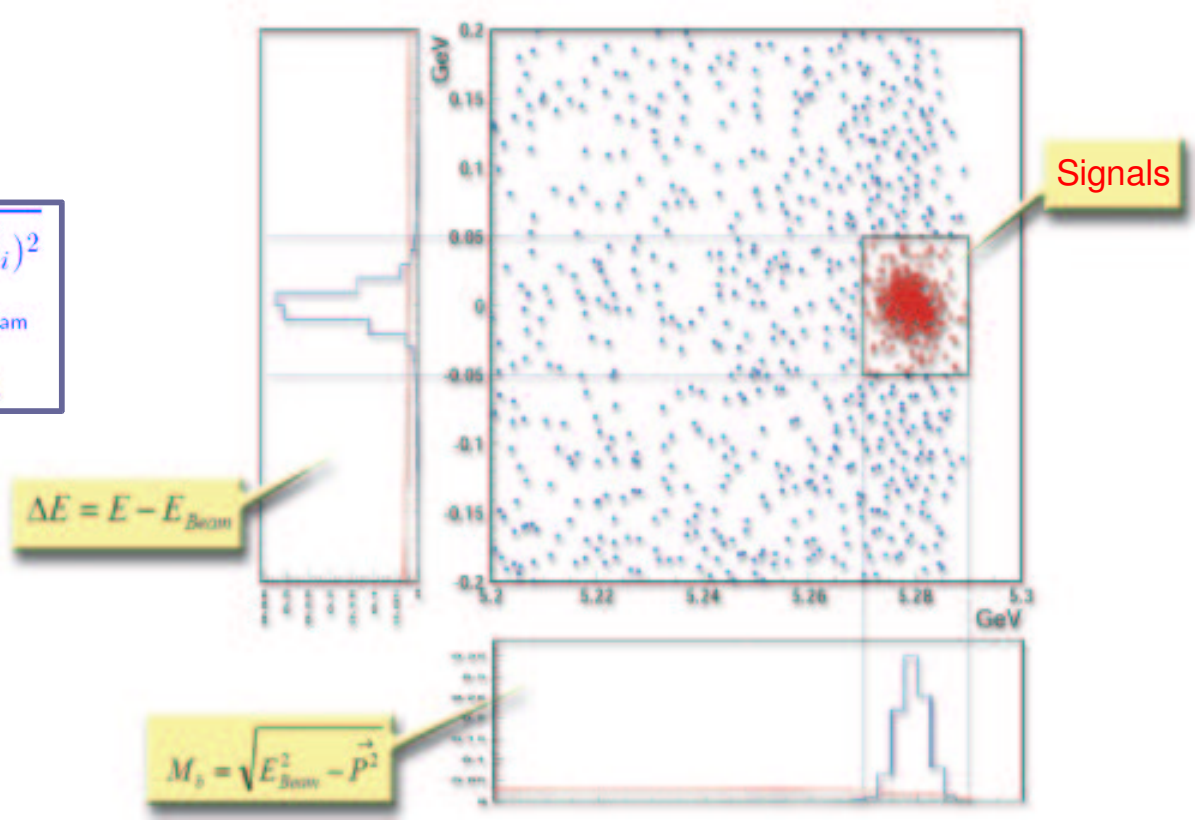


B Meson Reconstruction

- Signature: reconstructed B meson mass and energy

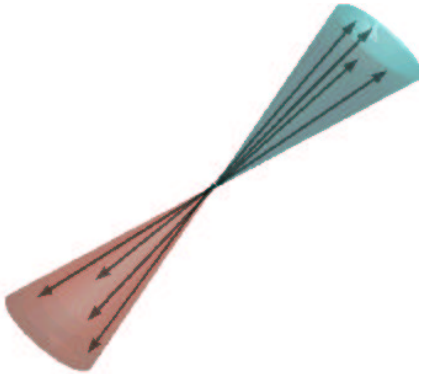
$$M_{bc} = \sqrt{E^2_{\text{beam}} - (\Sigma \vec{P}_i)^2}$$
$$\Delta E = \Sigma E_i^{\text{measured}} - E_{\text{beam}}$$

$E_{\text{beam}} \sim 5.29$ GeV at CM frame.

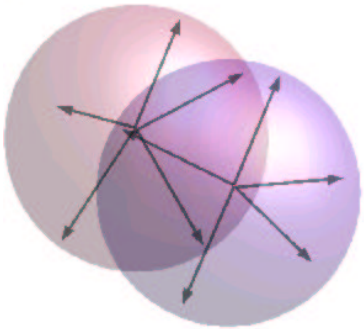


Continuum Suppression

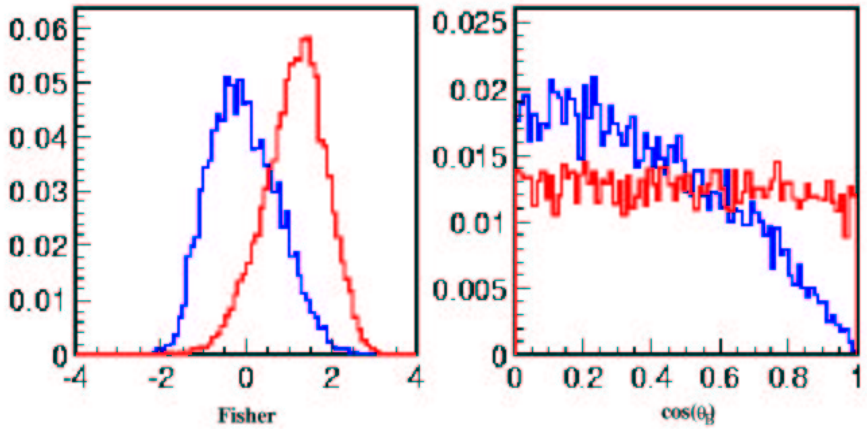
- Separate jet-like and B-like events.
- Event shape variables:
  - Sphericity
  - Super Fox-Wolfram moments
  - Reconstructed B flight direction
  - Angle between thrust axis and other particles



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

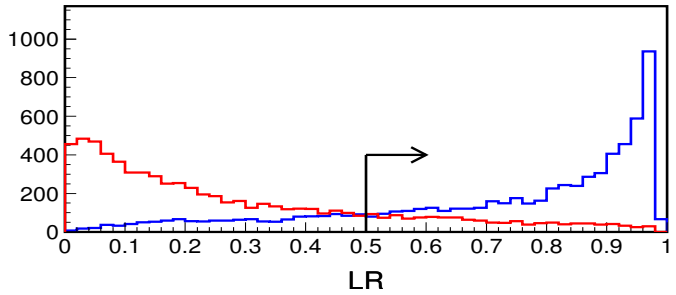


$e^+e^- \to \Upsilon(4S) \to B\bar{B}$



$$L = L(Fisher) \times L(|\cos\theta_B|)$$

$$LR = \frac{L_{sig}}{L_{sig} + L_{bg}}$$

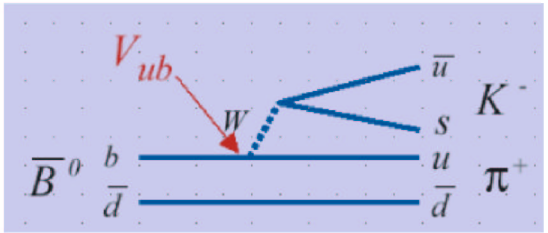


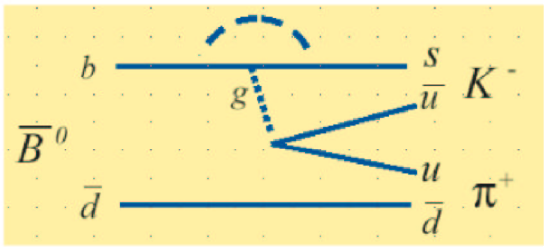
B → Kπ/ππ Branching Fractions

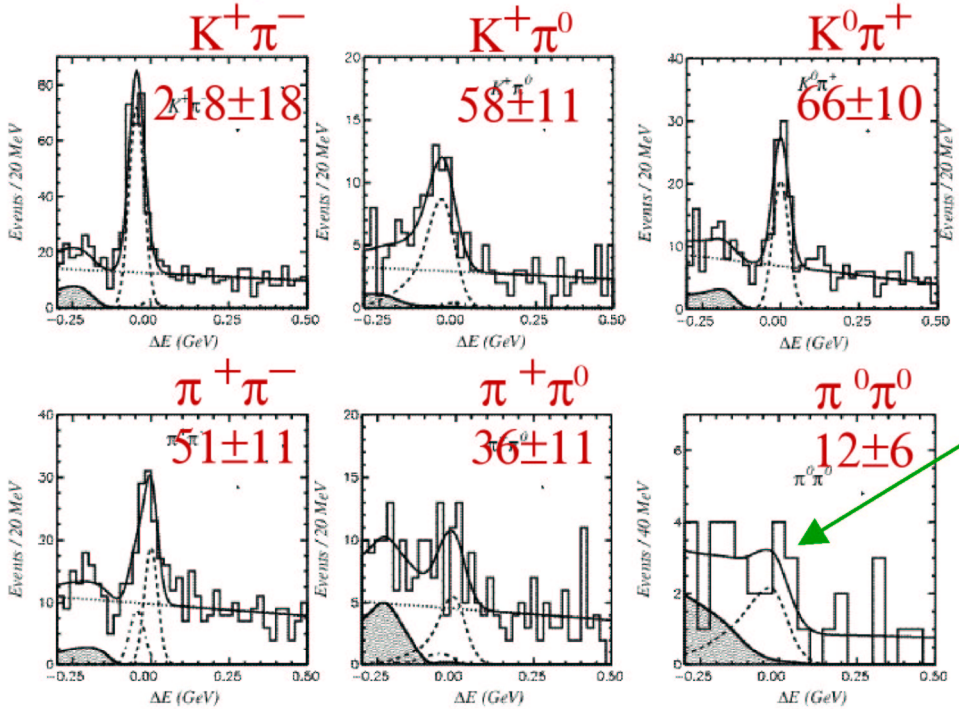
Updated measurements with 31.7M BB

- Continuum suppression optimized for each mode
- Feed-across background from charmless B decays studied carefully

  ⇒ fit systematics well controlled







$\pi^0\pi^0$ Hint

$(2.9 \pm 1.5 \pm 0.6) \times 10^{-6}$

Preliminary

B → Kπ/ππ for ϕ_3

Braching fractions ratios:

(A) $2BF(K^+\pi^0)/BF(K^0\pi^+) = 1.33\pm0.33\pm0.14$

(B) $BF(K^+\pi^-)/BF(K^0\pi^0) = 1.43\pm0.60\pm0.28$

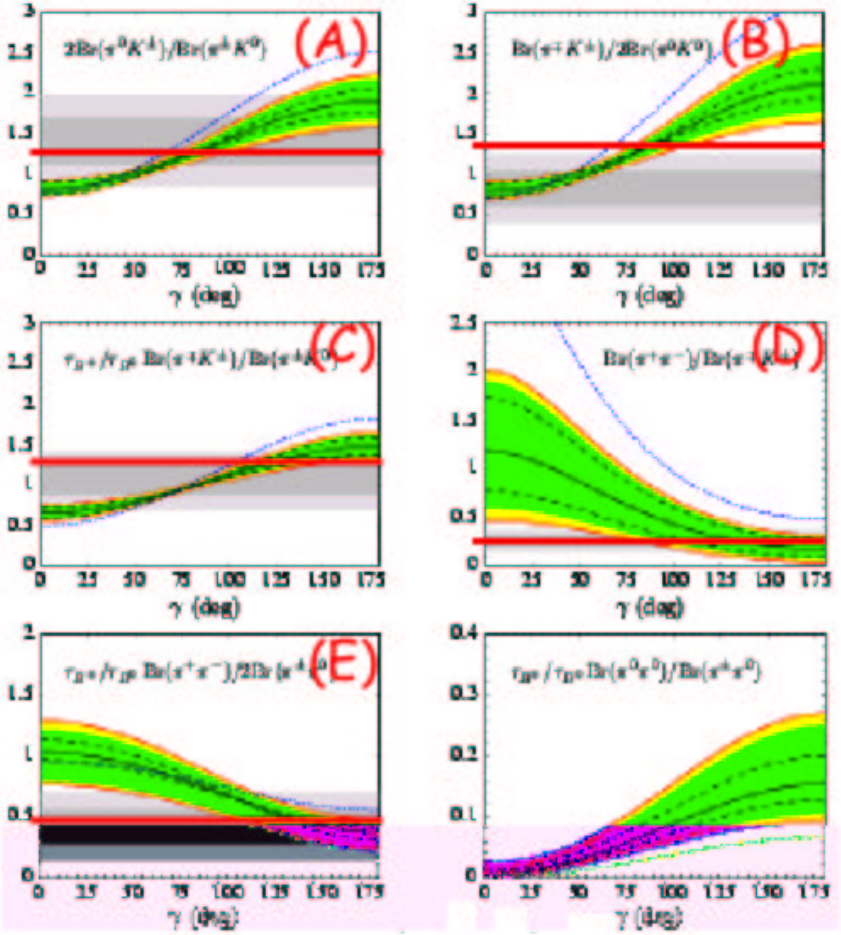
(C) $\tau_+/\tau_0\ BF(K^+\pi^-)/2BF(K^0\pi^+)$
$= 1.27\pm0.23\pm0.09\pm0.04$

(D) $BF(\pi^+\pi^-)/BF(K^+\pi^-) = 0.24\pm0.06\pm0.02$

(E) $\tau_+/\tau_0\ BF(\pi^+\pi^-)/2BF(\pi^+\pi^0)$
$= 0.40\pm0.15\pm0.05\pm0.01$
$\neq 1$ (~ 4σ effect)

Evidence for large interf. in ππ system

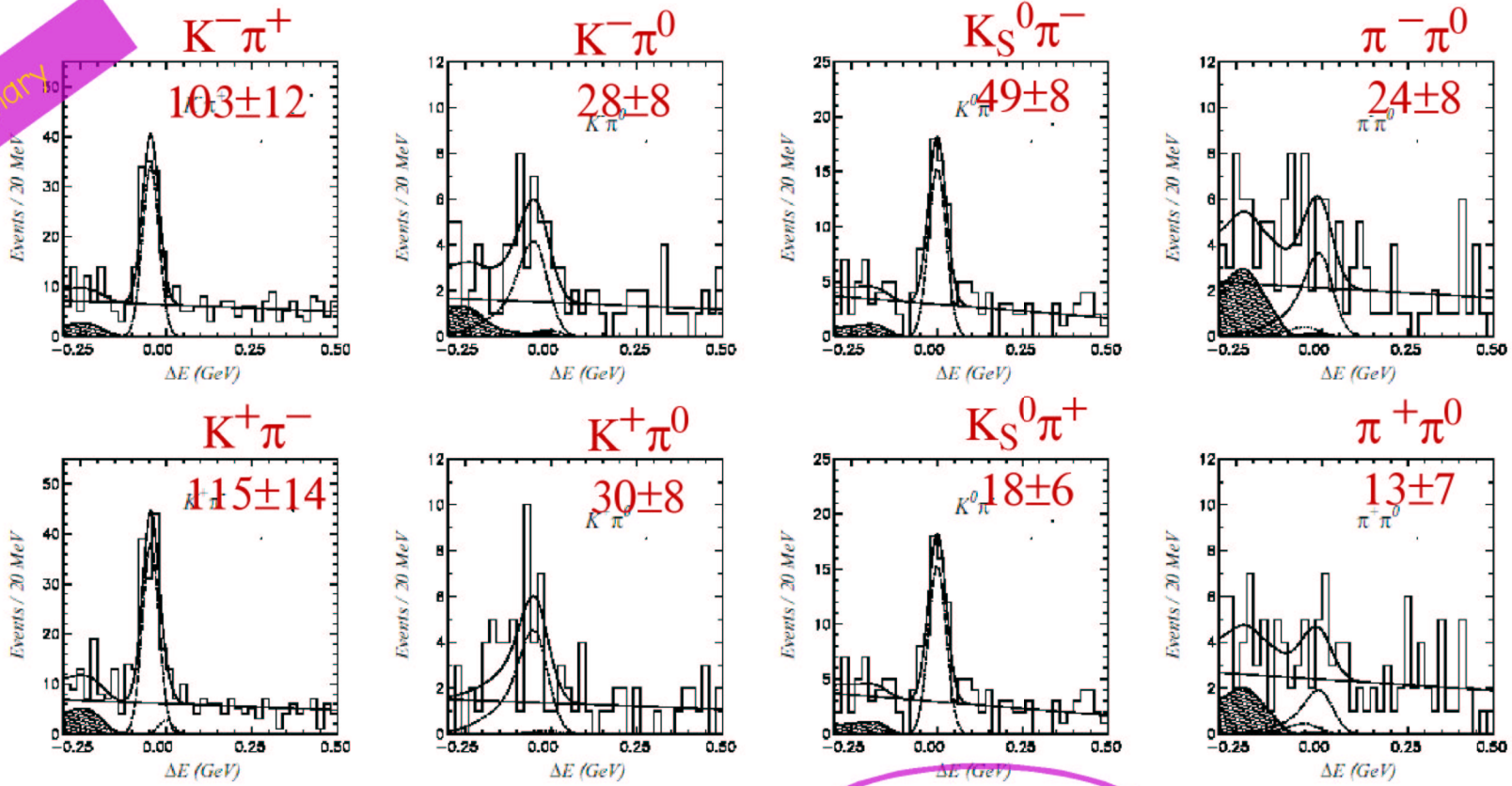
Favors large ϕ_3, but still consistent with indirect determinations



BF ratios vs ϕ_3 (QCD factorziation)
Beneke, Buchalla, Neubert, Sachrajda
hep-ph/0104110

B → Kπ/ππ Direct A_{CP}

Preliminary



	$K^-\pi^+$	$K^-\pi^0$	$K_S^0\pi^-$	$\pi^-\pi^0$
A_{CP}	$-0.06\pm0.08+0.01$	$-0.04\pm0.19+0.03$	$0.46\pm0.15+0.02$	$0.31\pm0.31+0.05$

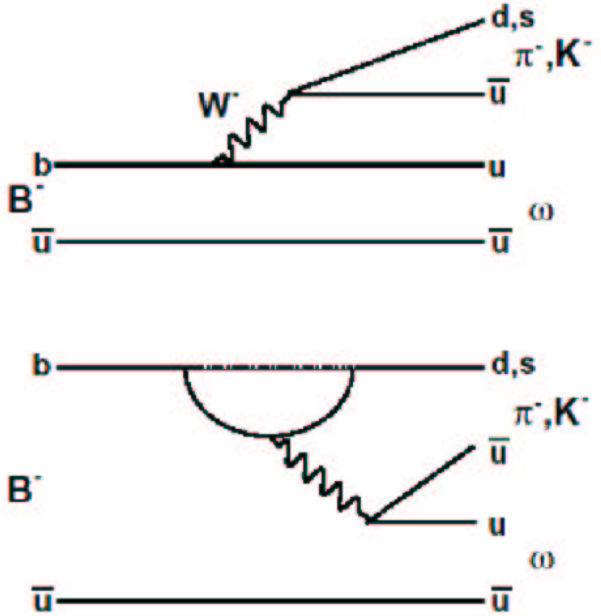
Fluctuation?

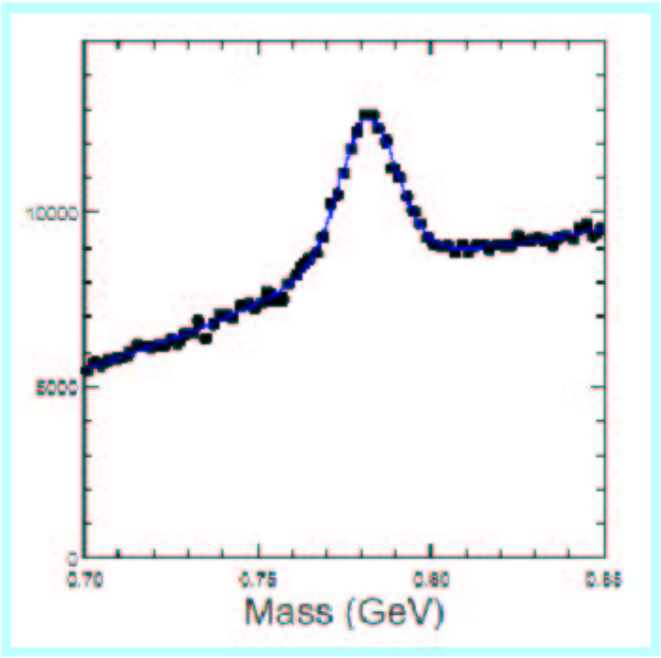
No clear evidence for partial rate asymmetries

BaBar 55.6 fb^{-1}: $-0.17\pm0.10\pm0.02$

$B \to \omega K / \omega \pi$

- Test current model of B decays
- Penguin-Tree interference $\Rightarrow$ DCPV?
- The $\omega(782)$ vector meson dominantly decays to $\pi^+\pi^-\pi^0$ (88.8%)

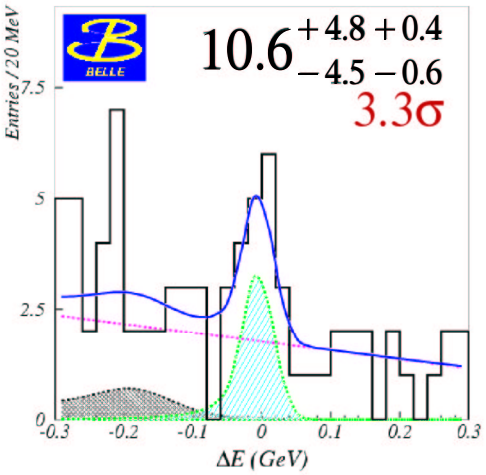




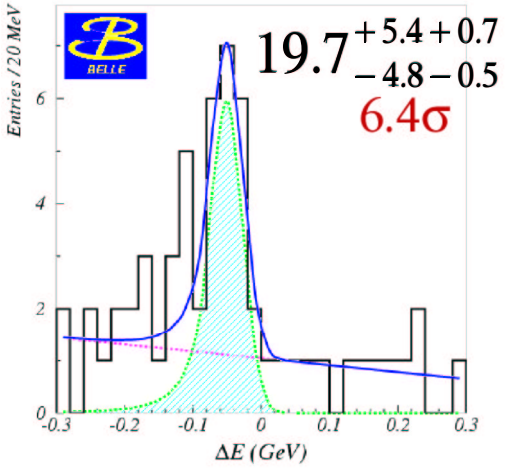
Intriguing history of measurements by CLEO and now Babar/Belle

B → ω K Branching Fraction and Direct A_{CP}

ωπ



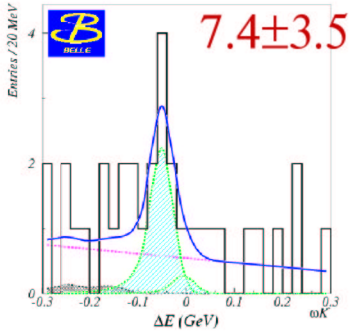
ωK



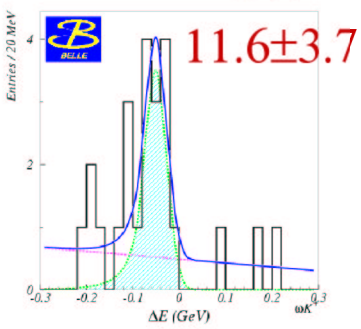
$BF < 8.2\times10^{-6}$

$BF = (9.9^{+2.7}_{-2.4} \pm 1.0)\times10^{-6}$

ωK^-



ωK^+



$A_{CP} = -0.22 \pm 0.27 \pm 0.04$

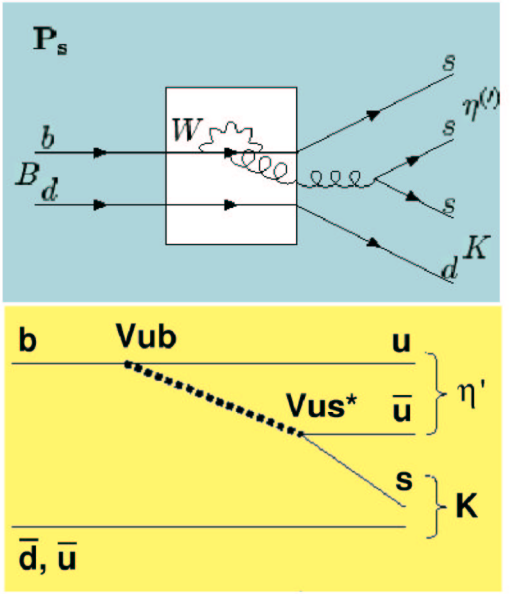
$-0.70 < A_{CP} < 0.26$

Preliminary

	BF(ωπ)	BF(ωK)	
CLEO'98	<2.3	$15\ ^{+7}_{-6} \pm 2$	PRL 81, 272 (1998)
CLEO'00	$11.3\ ^{+3.3}_{-2.9} \pm 1.4$	<7.9 $(3.2\ ^{+3.2}_{-2.4} \pm 0.8)$	PRL 85, 2881 (2000)
BaBar'01	$6.6\ ^{+2.1}_{-1.8} \pm 0.7$	<4 $(1.4^{+1.3}_{-1.0} \pm 0.3)$	PRL 87, 221802 (2001)
Belle'02	<8.2 (4.3±2.0±0.5)	$9.9\ ^{+2.7}_{-2.4} \pm 1.0$	H.C.Huang, Moriond 2002

$B \to \eta^{(\prime)} K/\pi$

- The BFs for $B \to \eta' K$ and $B \to \eta K^{(*)}$ are unexpectedly large: first discovered by CLEO then confirmed by Belle and BaBar.
  - New Physics?
  - Possible direct CP violation from Penguin-Tree interference
    ($P \propto V_{tb}V_{ts}^* \sim \lambda^2$, $T \propto V_{ub}V_{us}^* \sim \lambda^4$)

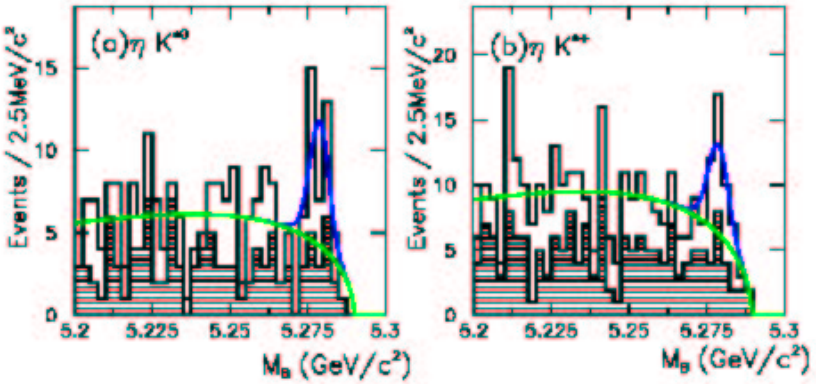


- $B \to \eta\pi^+$ may have large DCPV (Rosner *et. al.*)
- Studying both BF and A_{CP} enables determination of $\Delta\delta$ and ϕ_2. (Chiang & Rosner, hep-ph/0112285)

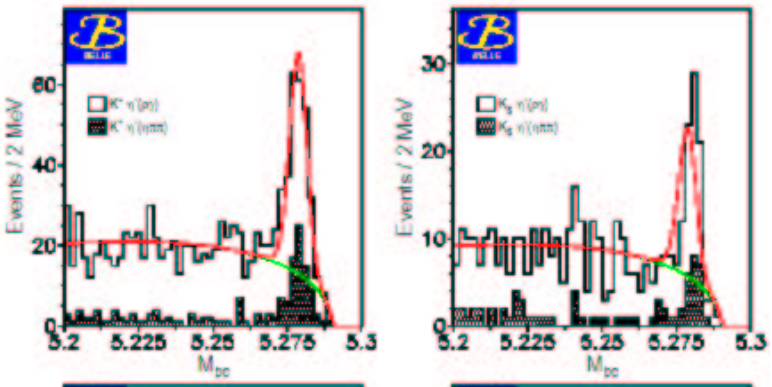
Results on B → η K* / η' K

29 fb^{-1}

$B^0 \to \eta K^{*0}$ $B^+ \to \eta K^{*+}$ $B^+ \to \eta' K^+$ $B^0 \to \eta' K^0_S$



Mode	CLEO	BaBar	Belle
ηK^{*+}	$26.4^{+9.6}_{-8.2} \pm 3.3$	$22.1^{+11.1}_{-9.2} \pm 3.3$	$26.5^{+7.8}_{-7.0} \pm 3.0$
ηK^{*0}	$13.8^{+5.5}_{-4.6} \pm 1.6$	$19.8^{+6.5}_{-5.6} \pm 1.7$	$16.5^{+4.6}_{-4.2} \pm 1.2$



Mode	CLEO	BaBar	Belle
$\eta' K^+$	$80^{+10}_{-9} \pm 7$	$70 \pm 8 \pm 5$	$77.9^{+6.2}_{-5.9} \pm 9$
$\eta' K^0$	$89^{+18}_{-16} \pm 9$	$42^{+13}_{-11} \pm 4$	$68.0^{+10.4}_{-9.6} \pm 8$

$B \to \eta^{(\prime)} K^{(*)}/\pi$ Results

- Belle found the first evidence of $B^+ \to \eta K^+$ and $B^+ \to \eta \pi^+$ with 31.7M B meson pairs.

$$BF(B^+ \to \eta K^+) = (5.3^{+1.8}_{-1.5} \pm 0.6) \times 10^{-6} \; (4.9\sigma)$$
$$BF(B^+ \to \eta \pi^+) = (5.4^{+2.0}_{-1.7} \pm 0.6) \times 10^{-6} \; (4.3\sigma)$$

- Summary of other results:

Mode	$BF\ (\times 10^{-6})$	A_{CP}
ηK^{*+}	$26.5^{+7.8}_{-7.0} \pm 3.0$	$-0.05^{+0.25}_{-0.30}$
ηK^{*0}	$16.5^{+4.6}_{-4.2} \pm 1.2$	$0.17^{+0.28}_{-0.25}$
$\eta' K^+$	$77.9^{+6.2}_{-5.9}$	$-0.12 \pm 0.08 \pm 0.01$
$\eta' K^0$	$68.0^{+10.4}_{-9.6}$	–

Preliminary

Time-Dependent Acp($B \to \eta' K_S$)

The possible "New Physics" that's responsible for large $B \to \eta' X_s$

BF likely introduces phases.

➪ CP violation

The time-dependent CP asymmetry can be expressed as:

$$A_{CP}(\Delta t) = \frac{\Gamma(\overline{B^0} \to \eta' K_S; t) - \Gamma(B^0 \to \eta' K_S; t)}{\Gamma(\overline{B^0} \to \eta' K_S; t) + \Gamma(B^0 \to \eta' K_S; t)} = A_{\eta' K_s} \cos(\Delta m \Delta t) + S_{\eta' K_s} \sin(\Delta m \Delta t)$$

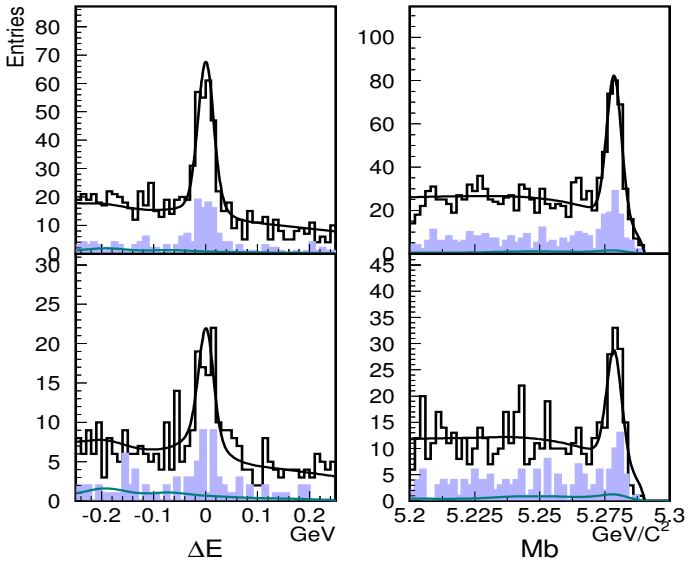
$$\approx S_{\eta' K_s} \sin(\Delta m \Delta t) = \sin 2(\phi_1 + \phi_{NP}) \sin(\Delta m \Delta t)$$

- $A_{\eta' K_S}$: direct CP violation term
- ϕ_{NP}: phase from "New Physics".

Belle measurement: with 42 fb^{-1} data.

Reconstruction of $B \to \eta' K_S$

- $\eta' \to \eta_{\gamma\gamma} \pi^+\pi^-$ and $\eta' \to \rho\gamma$
- Unbinned (M_{bc},ΔE) 2D likelihood fit for yield.



$N(\eta\pi\pi\, K^+) = 78.5\ ^{+9.6}_{-9.1}$

$N(\rho\gamma\, K^+) = 150 \pm 14$

$N(\eta\pi\pi\, Ks) = 27.4\ ^{+6.2}_{-5.6}$

$N(\rho\gamma\, Ks) = 45.7\ ^{+8.6}_{-7.9}$

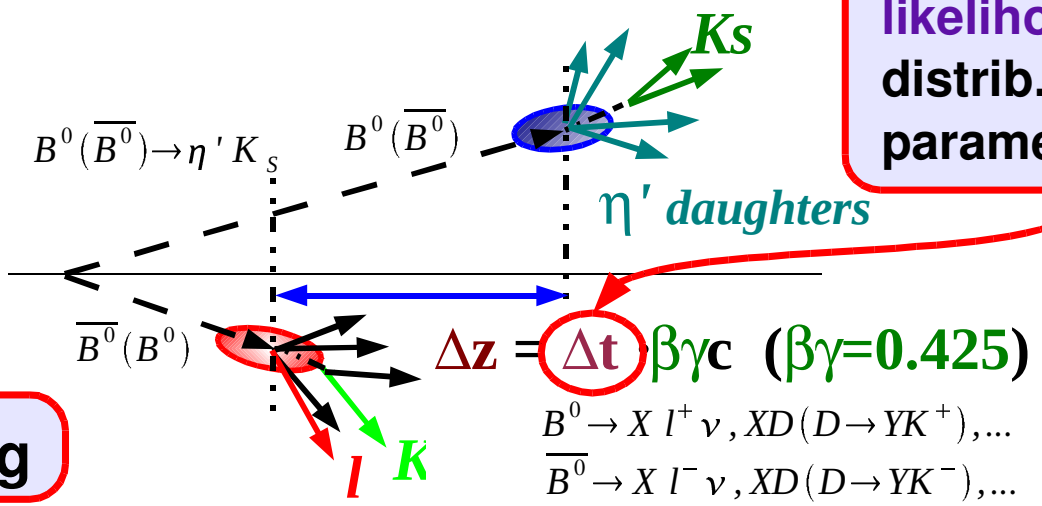
Fully reconstruct

CP Side

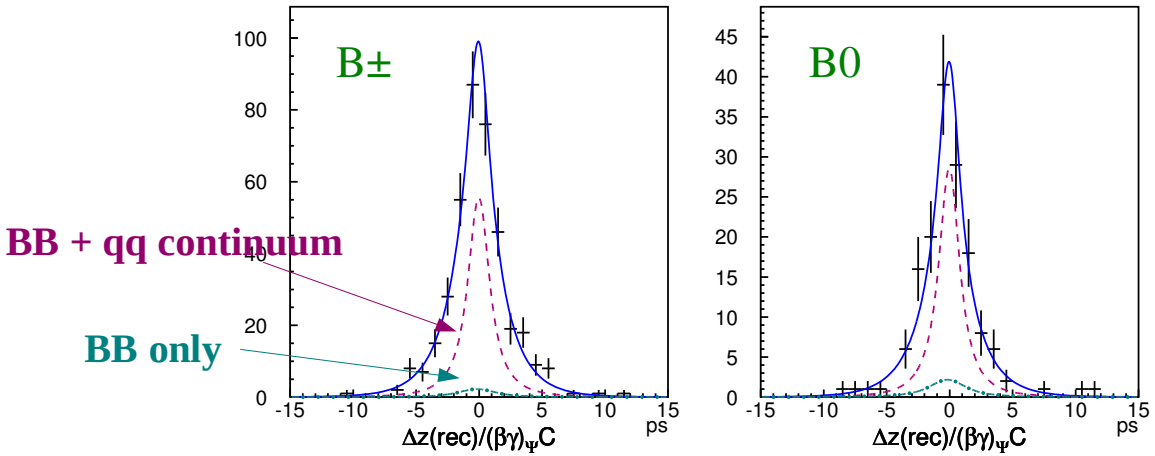
Tag Side

MDLH flavor tagging

Unbinned likelihood fit on Δt distrib. to get CP parameters



Δt reconstruction in B→η' K_S



$\tau(B^{\pm}) = 1.54^{+0.14}_{-0.13}$ ps

(PDG: 1.653±0.028 ps)

$\tau(B^{0}) = 1.58^{+0.31}_{-0.26}$ ps

(PDG: 1.548±0.032 ps)

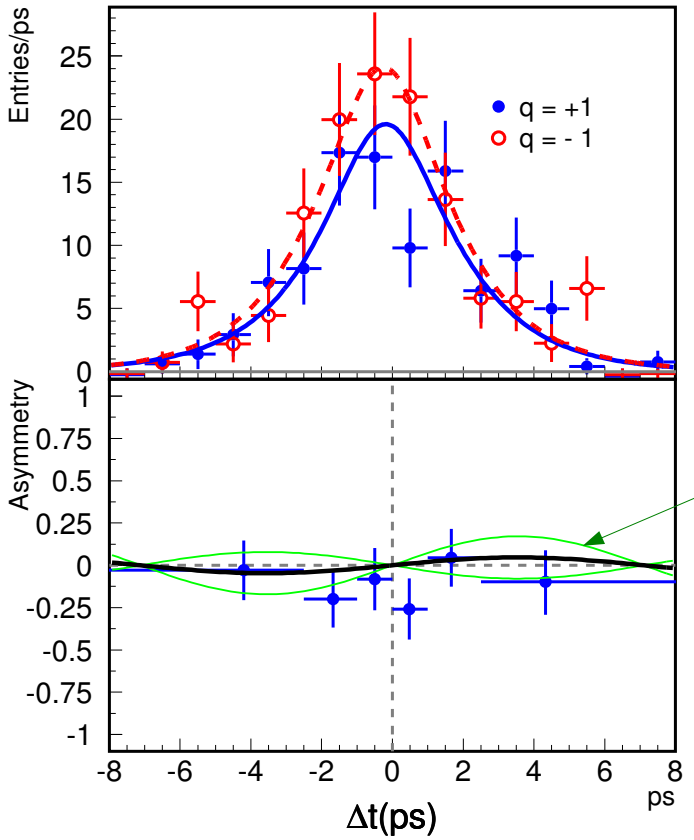
Acp(B→η' K_s) Checks

- **CP-fit with non-asymmetric sample: η'K±**

" sin2($\phi_1+\phi_{NP}$)" = $0.11^{+0.29}_{-0.30}$

" S(η'K±)" = 0.11±0.29

" A(η'K±)" = -0.27±0.17



Acp(B→η' K_s) Measurement

- **CP-fit is performed with 73 η'Ks candidates.**

  $S(\eta'Ks) = 0.27^{+0.54}_{-0.55} \pm 0.07$

  $A(\eta'Ks) = 0.12 \pm 0.32 \pm 0.07$

  If A(η'Ks) is set to be zero:

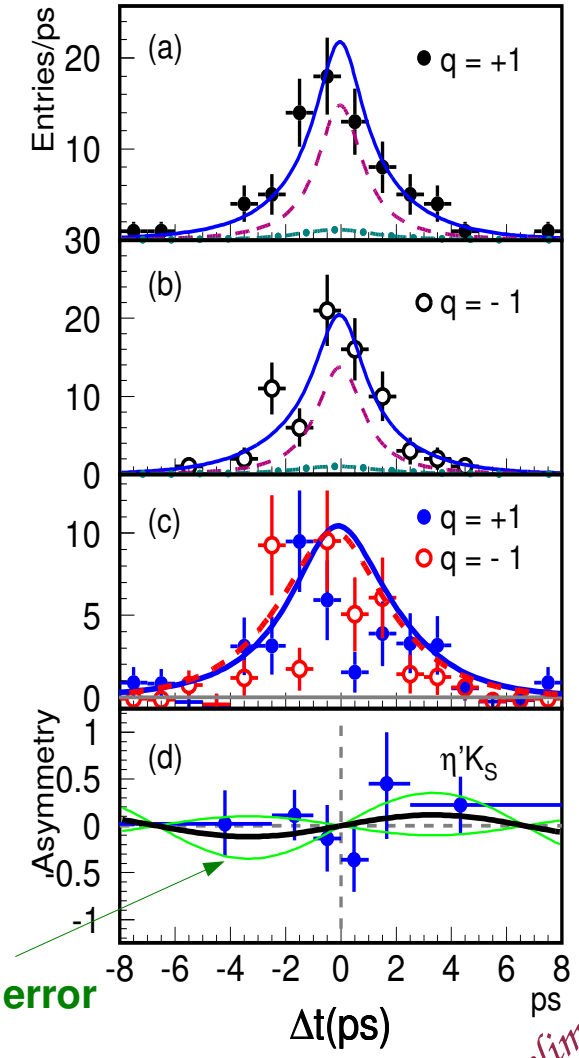
  $\sin2(\phi_1+\phi_{NP}) = 0.29^{+0.53}_{-0.54} \pm 0.07$

- **First measurement of time-dependent CPV in B→η'K_s decay.**

- **Probe phases from New Physics.**

Belle

$\sin2\phi_1 = 0.82 \pm 0.12(\text{stat.}) \pm 0.05(\text{syst.})$



Summary and Outlook

- Penguin-Tree interference brings possibility of direct CP violation.
- The firsts:
  - Observed ωK and performed the first measurement on direct $A_{CP}(\omega K)$.
  - Evidence of ηK and $\eta\pi$.
  - Time-dependent CP asymmetry of $\eta' K_S$.
- Of all modes, no significant CP asymmetry is found with the possible exception of $K_S\pi^-$ (fluctuation?). Need more data.
- Much more data is coming!