PASCOS' 03

INFN Istituto Nazionale di Fisica Nucleare

CP-Violating Asymmetries in $h¢K$ and Direct CP Violation Searches with BaBar In Charmless Hadronic B decays

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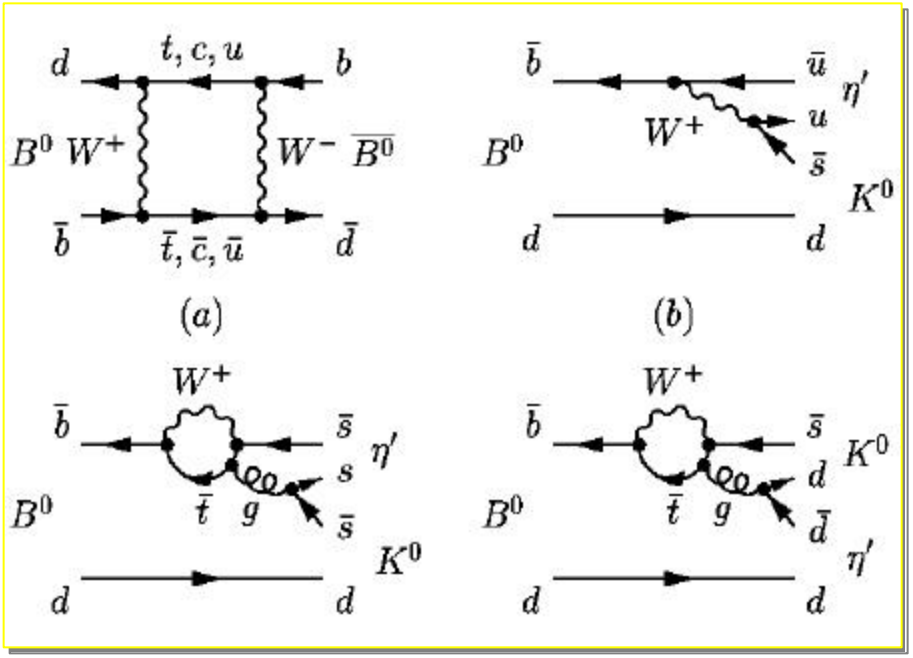
on behalf of the BaBar Collaboration

Overview

- Physics Motivation
- Data Analysis: Samples, Event Selection, ML fits
- Results on Branching Fractions, Charge asymmetry and time dependent S and C parameters in $B \to h^{0} K^{0}$
- Direct CPV in $B \to f K^{*}$ Modes
- Other BaBar Results on Direct CPV
- Conclusion

h¢K Physics Motivation

- Branching Fractions higher than expected. Several different conjectures: Flavor singlet, charm enhanced, QCD anomaly (glue coupling to η′), constructive interference of penguin amplitudes, etc



Need more precise measurements

h¢K Physics Motivation

• Time-dependent CP-asymmetry: Decay dominated by penguins, expected to give a good alternative measurement of sin (2β)

• Deviation from value found in charmonium channels: phases from new physics ?

Direct CP Violation

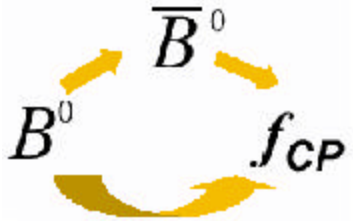
- In rare B decays interference of different decay amplitudes (Penguin-Tree) could enhance direct CP-violation when amplitudes have comparable magnitudes and different weak (φ) and strong (δ) phases:

  Time-independent asymmetry: $$\mathcal{A}_{CP} \equiv \frac{\Gamma(\overline{B} \to \bar{f}) - \Gamma(B \to f)}{\Gamma(\overline{B} \to \bar{f}) + \Gamma(B \to f)}$$

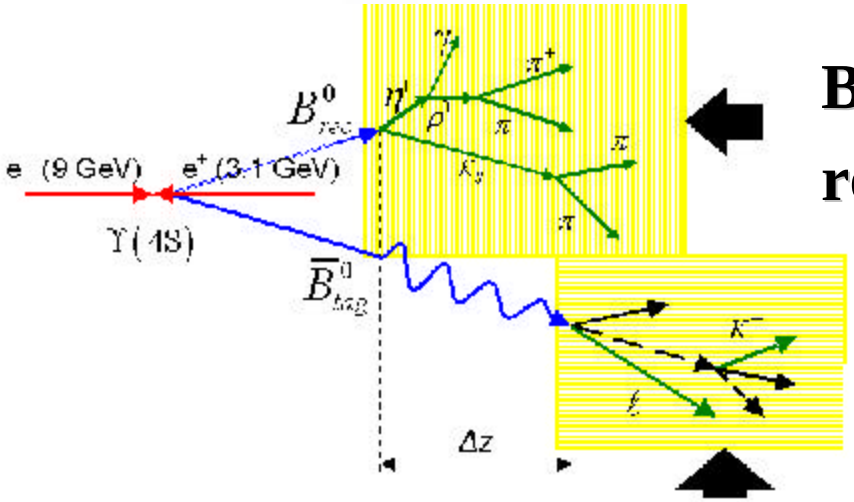
$$\mathcal{A}_{CP} = \frac{2\,|P|\,|T|\,\sin\Delta\phi\,\sin\Delta\delta}{|P|^2 + |T|^2 + 2\,|P|\,|T|\,\cos\Delta\phi\,\cos\Delta\delta}$$

- It *can occur* in charged and neutral modes
- Model dependent predictions
- No simple connection with weak phase angle (large theoretical uncertainties in $\Delta\delta$ calculation)
- Sensitive to new physics (expecially in pure penguin modes)

Time Dependent CPV



$$f_- = \Gamma(B^0 \to f_{CP})$$
$$f_+ = \Gamma(B^0 \to f_{CP})$$



B_{CP} fully reconstructed

$$\Delta t \approx \frac{\Delta z}{\langle \beta\gamma \rangle} \frac{1}{c}$$

Other B used for flavor tagging

Decay rate distribution different for B^0 and $\overline{B}^0$

Time Dependent CPV

$$f_{\pm}(\Delta t) = \frac{e^{-|\Delta t|/\tau}}{4\tau}\left[1 \pm S_f \sin(\Delta m_d \Delta t) \mp C_f \cos(\Delta m_d \Delta t)\right]$$

$$S_f = \frac{2\,\mathrm{Im}\,\lambda_{f_{CP}}}{1 + |\lambda_{f_{CP}}|^2}$$

Indirect CP violation $\rightarrow S \neq 0$

$$C_f = \frac{1 - |\lambda_{f_{CP}}|^2}{1 + |\lambda_{f_{CP}}|^2}$$

Direct CP violation $\rightarrow C \neq 0$

$$\begin{aligned} f_{B^0\,\mathrm{tag}} &= (1 - w_{B^0}) f_+ + w_{\overline{B^0}} f_- \\ f_{\overline{B}^0\,\mathrm{tag}} &= (1 - w_{\overline{B^0}}) f_- + w_{B^0} f_+ \end{aligned}$$

Tagging

$$\begin{aligned} F_{B^0\,\mathrm{tag}} &= f_{B^0\,\mathrm{tag}} \otimes \mathcal{R}_{\mathrm{sig}} \\ F_{\overline{B}^0\,\mathrm{tag}} &= f_{\overline{B}^0\,\mathrm{tag}} \otimes \mathcal{R}_{\mathrm{sig}} \end{aligned}$$

Resolution function

h¢ K^0 Decay Channels

We have considered four decays:

$B^0 \to \eta' K^0_S$ $\quad K^0_S \to \pi^+\pi^-$

$B^+ \to \eta' K^+$

with

$\eta' \to \eta\pi^+\pi^-$ $\quad \eta \to \gamma\gamma$

$\eta' \to \rho^0\gamma$

data:

on-resonance: 81.9 fb^{-1}
(88.9 million *BB* pairs)

off resonance: 9.6 fb^{-1}

Event Selection

- Beam energy to constraint B mass and energy :

$$\Delta E = E_B^* - \frac{1}{2}\sqrt{s} \qquad m_{ES} = \sqrt{\left(\frac{1}{2}\sqrt{s}\right)^2 - p_B^{*2}}$$

- Event shapes to distinguish B events from continuum udsc: Fisher discriminants,Thrust,Sphericity, Fox-Wolfram

- With loose cuts based on shapes variables, PID and kinematical quantities of secondary daughters we prepare input to Maximum Likelihood Fit

Observables

- Two types of background:
  - $q\bar{q}$ (continuum) dominant
  - $b\bar{b}$ (non continuum) ~ 3 – 4%

- Observables: ΔE, M_{ES} , Fisher, h' mass and Δt (for *time dependent analyses*)

- Fisher done with four variables: energy flow of rest of event wrt B thrust axis (L_0, L_2), direction of B thrust axis wrt beams and direction of B momentum wrt beams

BF Results

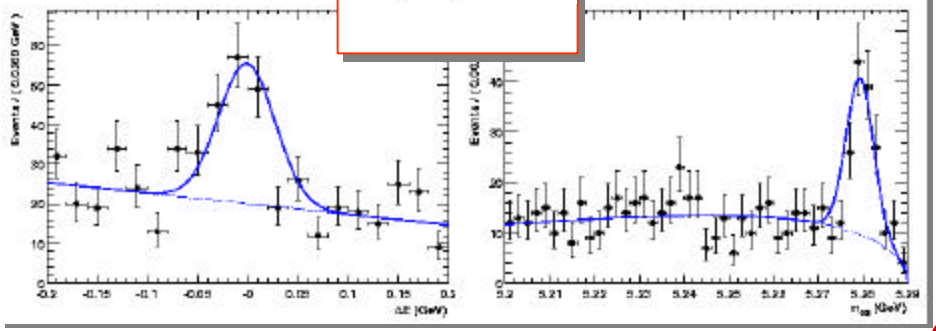
ML fit quantity	$\eta'_{\eta\pi\pi}K^+$	$\eta'_{\rho\gamma}K^+$	$\eta'_{\eta\pi\pi}K^0_S$	$\eta'_{\rho\gamma}K^0_S$
Signal yield	269^{+19}_{-18}	514^{+31}_{-30}	48^{+8}_{-8}	155^{+17}_{-16}
MC ϵ (%)	24.5	24.0	23.9	24.7
$\prod \mathcal{B}_i$ (%)	17.4	29.5	5.99	10.1
$\mathcal{B}(\times 10^{-6})$	$71.1^{+4.9}_{-4.7}$	$81.5^{+5.0}_{-4.8}$	$37.9^{+6.6}_{-6.1}$	$69.7^{+7.5}_{-7.2}$
Combined $\mathcal{B}(\times 10^{-6})$	$76.9 \pm 3.5 \pm 4.4$		$55.4 \pm 5.2 \pm 4.0$	

$R\ (B^+ B^- / B^0 \overline{B}^0) = 1$ assumed

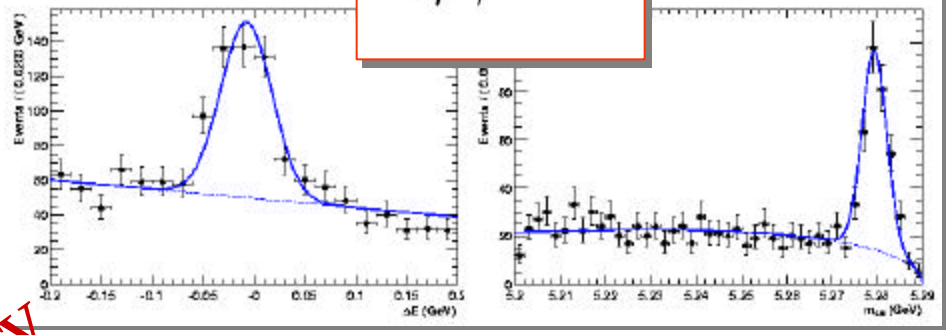
Preliminary

M_{ES} and DE Projections

$\eta'_{\rho\gamma} K^0$



$\eta'_{\rho\gamma} K^+$



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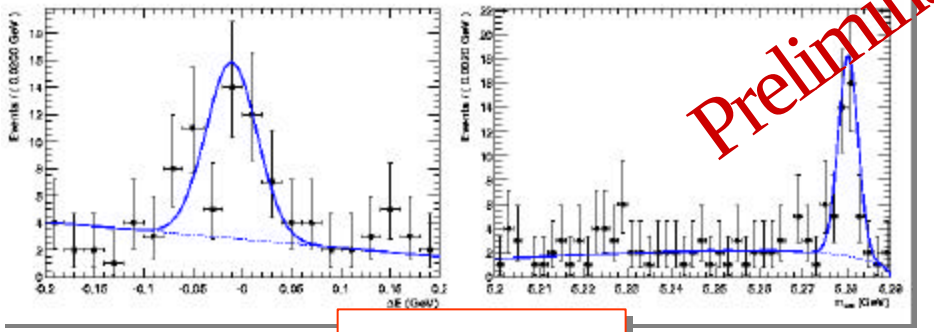
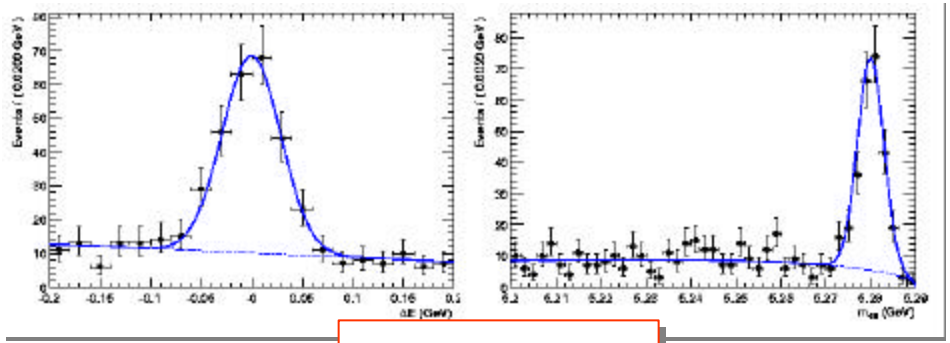


$\eta'_{\eta\pi\pi} K^0$



$\eta'_{\eta\pi\pi} K^+$

Charge Asymmetry

Final state	$N_{\rm sig}$	$\mathcal{A}_{\rm ch}$ (%)
$\eta'_{\eta\pi\pi}K^+$	$267\,^{+18}_{-18}$	-0.1 ± 6.8
$\eta'_{\rho\gamma}K^+$	$514\,^{+31}_{-30}$	6.3 ± 5.9

Preliminary

Charge Asymmetry on combined sample:

$A_{ch} = 0.037 \pm 0.045 \pm 0.011$

90 % C.L. Interval: [–0.04, +0.11]

Belle [–0.13, +0.10]

CP Fit Result

Quantity	$\eta'_{\rho\gamma}K^0$	$\eta'_{\eta\pi\pi}K^0$	$\eta'_{\rho\gamma}K^+$	$\eta'_{\eta\pi\pi}K^+$
S	-0.41 ± 0.41	0.75 ± 0.51	-0.07 ± 0.16	0.08 ± 0.20
C	0.24 ± 0.25	-0.22 ± 0.35	-0.14 ± 0.11	-0.16 ± 0.15

Combined Fit

$$\begin{cases} S_{\eta' K^0} = 0.02 \pm 0.34 \pm 0.03 \\ C_{\eta' K^0} = 0.10 \pm 0.22 \pm 0.03 \end{cases}$$

$$\begin{cases} S_{\eta' K^+} = -0.01 \pm 0.13 \\ C_{\eta' K^+} = -0.15 \pm 0.09 \end{cases}$$

Preliminary

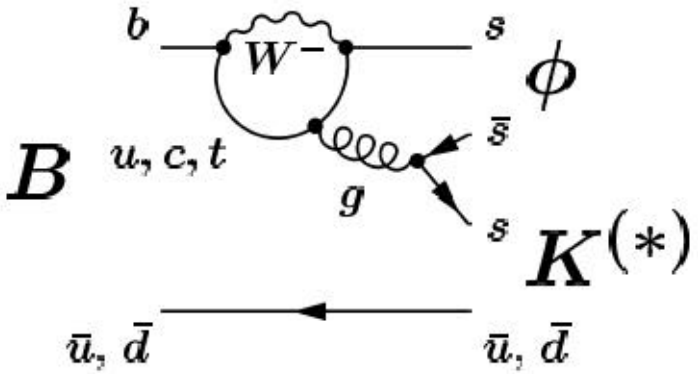
Belle:

at 78 fb^{-1}

$$\begin{cases} S_{\eta' K^0_S} = +0.71 \pm 0.37 \ (\text{stat})^{+0.05}_{-0.06} \ (\text{syst}) \\ C_{\eta' K^0_S} = -0.26 \pm 0.22 \ (\text{stat}) \pm 0.03 \ (\text{syst}) \\ S_{\eta' K^+} = -0.03 \pm 0.20 \ (\text{stat}) \\ C_{\eta' K^+} = -0.05 \pm 0.13 \ (\text{stat}) \end{cases}$$

Direct CPV in B to fK^*

•Pure Gluonic Penguins Modes : sensitive to new physics



Charge asymmetry prediction in SM ~1%

Up to 30 % or more with new particles in loop

• Three self-tagging K* decay modes

• 89 million B $\bar{B}$ pairs

Direct CPV in B to fK^*

Mode	$\mathcal{B}_i \times \epsilon$ (%)	$\mathcal{B}$ ($\times 10^{-6}$)	$\mathcal{A}_{CP}$	90% C.L. limits for $\mathcal{A}_{CP}$
$\phi K^{*0}_{K^+\pi^-}$	9.7	$11.7 \pm 1.4 \pm 1.1$	$+0.04 \pm 0.12 \pm 0.02$	
$\phi K^{*0}_{K^0\pi^0}$	0.6	$3.5\ ^{+6.1}_{-2.3} \pm 1.1$	–	
$\phi K^{*0}_{\text{comb.}}$	10.2	$11.1\ ^{+1.3}_{-1.2} \pm 1.1$	$+0.04 \pm 0.12 \pm 0.02$	$[-0.16, +0.23]$
$\phi K^{*+}_{K^0\pi^+}$	2.9	$12.7\ ^{+2.8}_{-2.5} \pm 1.2$	$-0.02 \pm 0.20 \pm 0.03$	
$\phi K^{*+}_{K^+\pi^0}$	2.3	$10.7\ ^{+3.6}_{-3.1} \pm 1.9$	$+0.63\ ^{+0.25}_{-0.31} \pm 0.05$	
$\phi K^{*+}_{\text{comb.}}$	5.3	$12.1\ ^{+2.1}_{-1.9} \pm 1.5$	$+0.16 \pm 0.17 \pm 0.04$	$[-0.13, +0.43]$
$\phi K^{*}_{\text{comb.}}$	–	$11.4 \pm 1.1 \pm 1.2$	$+0.07 \pm 0.10 \pm 0.03$	$[-0.08, +0.23]$

Preliminary

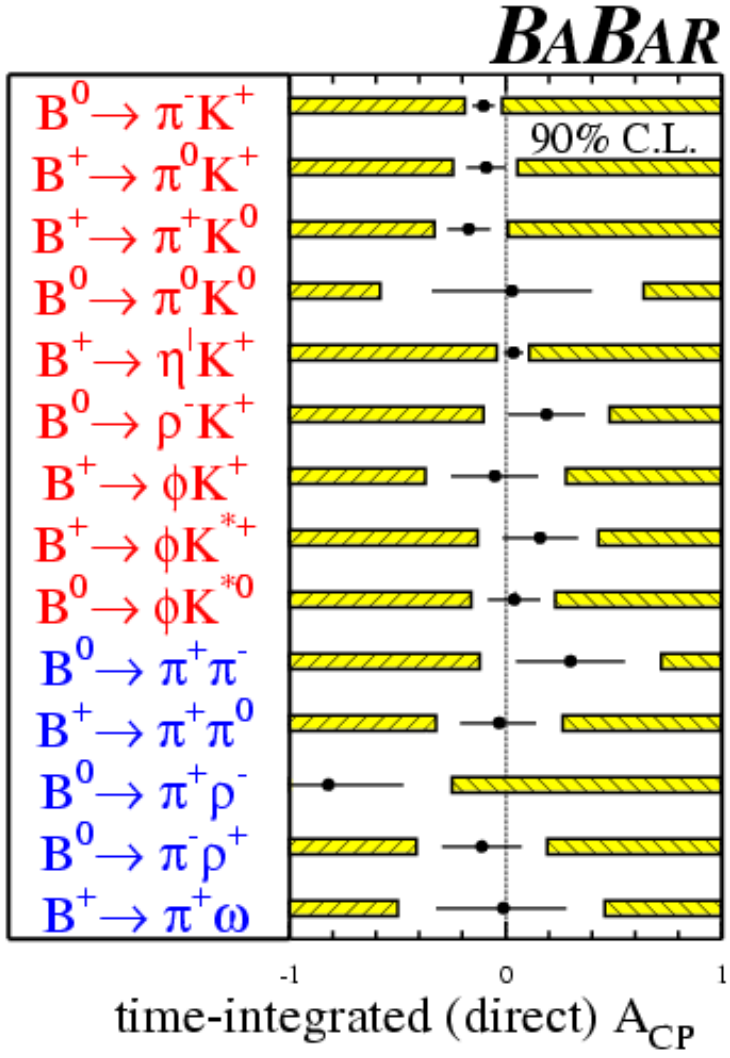
Other BaBar Results On Direct CPV

Final state	Signal Yield	$\mathcal{B}$ (10^{-6})	$\mathcal{A}$	90% CL interval
$\pi^+\pi^0$	$125^{+23}_{-21} \pm 10$	$5.5^{+1.0}_{-0.9} \pm 0.6$	$-0.03^{+0.18}_{-0.17} \pm 0.02$	[-0.32, 0.27]
$K^+\pi^0$	$239^{+21}_{-22} \pm 6$	$12.8^{+1.2}_{-1.1} \pm 1.0$	$-0.09 \pm 0.09 \pm 0.01$	[-0.24, 0.06]
$K^0\pi^0$	$86 \pm 13 \pm 3$	$10.4 \pm 1.5 \pm 0.8$	$0.03 \pm 0.36 \pm 0.09$	[-0.58, 0.64]
$K^+\pi^-$	589 ± 30	$17.9 \pm 0.9 \pm 0.6$	$-0.102 \pm 0.050 \pm 0.016$	[-0.188, -0.016]
$K^0\pi^+$	$172 \pm 17 \pm 9$	$17.5 \pm 1.8 \pm 1.3$	$-0.17 \pm 0.10 \pm 0.02$	
$K^+\phi$			$-0.05 \pm 0.20 \pm 0.03$	
ρK			$0.19 \pm 0.14 \pm 0.11$	
$\rho\pi$			$-0.22 \pm 0.08 \pm 0.07$	
$\pi^+\pi^-$			$C_{\pi\pi} = -0.30 \pm 0.25 \pm 0.04$	

Preliminary

Summary on Direct CPV

- *Several measurements done*
- *No evidence for direct CPV*



Conclusion

We have presented the following preliminary results

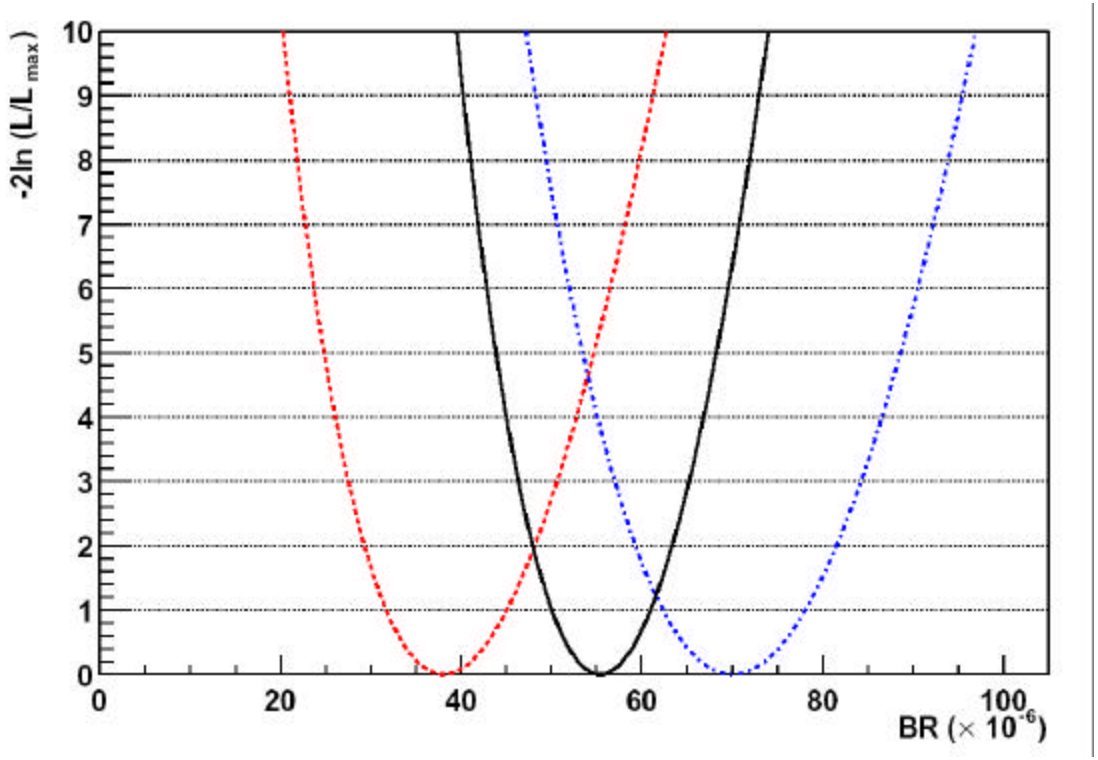
for $B \to \eta' K$:

$$\mathcal{B}(B^+ \to \eta' K^+) = (76.9 \pm 3.5 \pm 4.4) \times 10^{-6}$$
$$\mathcal{B}(B^0 \to \eta' K^0) = (55.4 \pm 5.2 \pm 4.0) \times 10^{-6}$$
$$\mathcal{A}_{ch} = 0.037 \pm 0.045 \pm 0.011$$
$$S_{\eta' K^0} = 0.02 \pm 0.34 \pm 0.03$$
$$C_{\eta' K^0} = 0.10 \pm 0.22 \pm 0.03$$

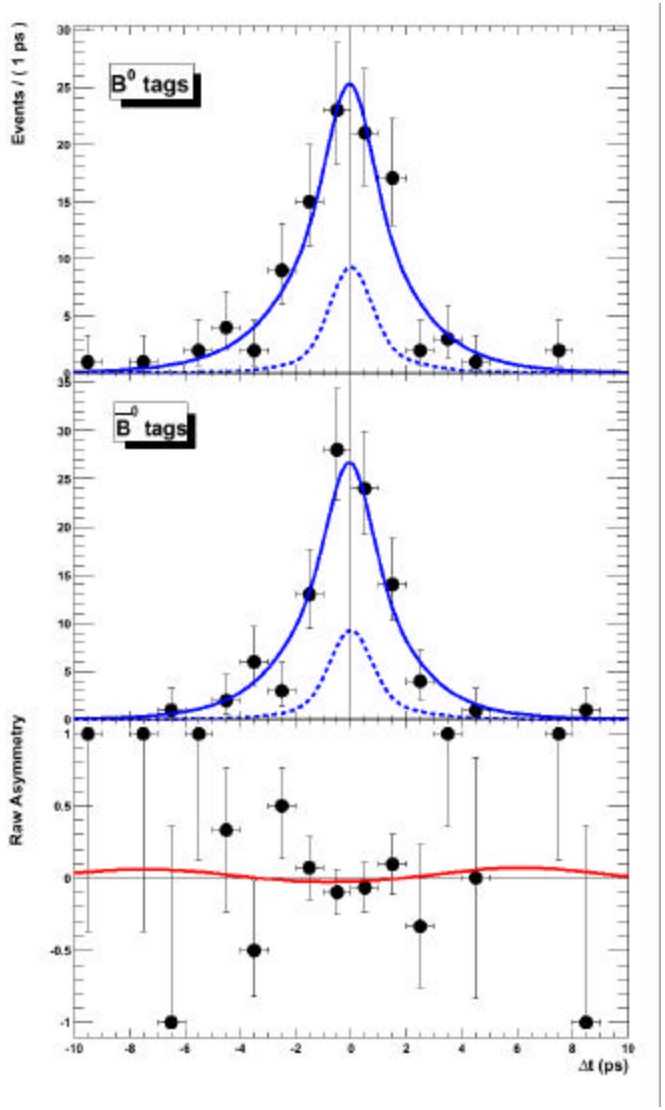
for $B^0 \to \phi K^*(892)^0$ and $B^+ \to \phi K^*(892)^+$:

$$\mathcal{B}(\phi K^{*0}) = (11.1^{+1.3}_{-1.2} \pm 1.1) \times 10^{-6} \qquad \mathcal{B}(\phi K^{*+}) = (12.1^{+2.1}_{-1.9} \pm 1.5) \times 10^{-6}$$
$$\mathcal{A}_{CP}(\phi K^{*0}) = +0.04 \pm 0.12 \pm 0.02 \qquad \mathcal{A}_{CP}(\phi K^{*+}) = +0.16 \pm 0.17 \pm 0.04$$

Negative logLikelihood



Dt Projection and Raw Asymmetry



BF in Cleo,Belle and BaBar

Belle				
Quantity	$\eta'_{\rho\gamma}K^0$	$\eta'_{\eta\pi\pi}K^0$	$\eta'_{\rho\gamma}K^+$	$\eta'_{\eta\pi\pi}K^+$
Fit $\mathcal{B}\times10^{-6}$	79^{+34}_{-28}	46^{+25}_{-20}	92^{+18}_{-20}	69^{+15}_{-14}
Significance (σ)	4	3.5	7.5	9.4
Signal events	$10.1^{+4.4}_{-3.6}$	$6.4^{+3.4}_{-2.7}$	$42.5^{9.1}_{-8.3}$	$28.9^{+6.5}_{-5.7}$
$\epsilon\times\prod\mathcal{B}_i(\%)$	1.16	1.25	4.18	3.78
Integ. Lumin. (fb^{-1})	10.4			
Combined BR	55^{+19}_{-16}		79^{+12}_{-11}	

BABAR				
Quantity	$\eta'_{\rho\gamma}K^0$	$\eta'_{\eta\pi\pi}K^0$	$\eta'_{\rho\gamma}K^+$	$\eta'_{\eta\pi\pi}K^+$
Fit $\mathcal{B}\times10^{-6}$	67 ± 9	32 ± 7	71 ± 6	65 ± 6
Significance (σ)	15	10	20	26
Signal events	106^{+14}_{-13}	29^{+7}_{-6}	293^{+23}_{-22}	152^{+14}_{-13}
$\epsilon\times\prod\mathcal{B}_i(\%)$	2.46	1.43	6.42	3.82
Integ. Lumin. (fb^{-1})	55.6			
Combined BR	46 ± 6		67 ± 5	

CLEO				
Quantity	$\eta'_{\rho\gamma}K^0$	$\eta'_{\eta\pi\pi}K^0$	$\eta'_{\rho\gamma}K^+$	$\eta'_{\eta\pi\pi}K^+$
Fit $\mathcal{B}\times10^{-6}$	105^{+25}_{-22}	67^{+26}_{-21}	72^{+13}_{-12}	88^{+16}_{-14}
Significance (σ)	9	8	10	14
Signal events	$29.6^{+7.0}_{-6.2}$	$9.2^{+3.6}_{-2.9}$	$60.8^{+11.0}_{-10.1}$	$39.6^{+7.0}_{-6.4}$
$\epsilon\times\prod\mathcal{B}_i(\%)$	2.9	1.4	8.7	4.7
Integ. Lumin. (fb^{-1})	9.13			
Combined BR	89^{+18}_{-16}		80^{+10}_{-9}	