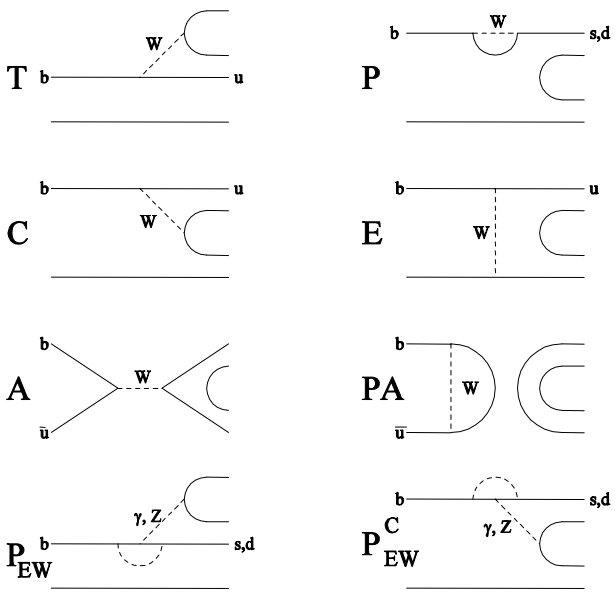
Branching ratios and DCPV results for Quasi two-body B decays

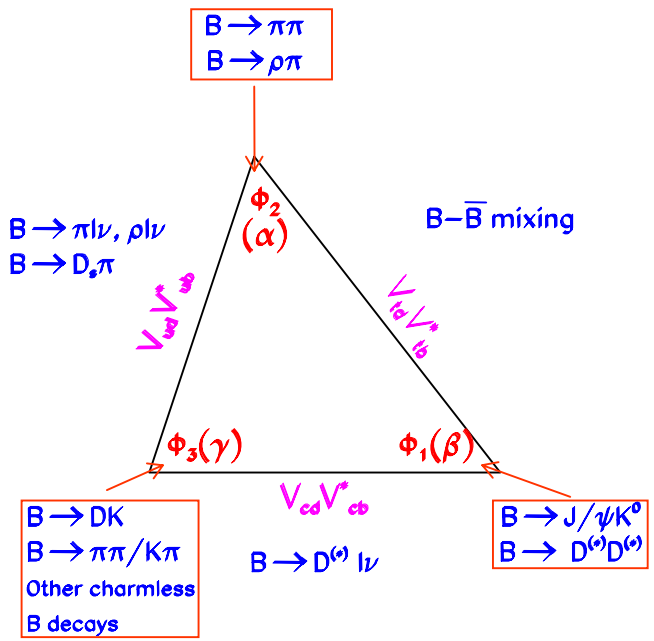
Alex Bondar, BINP, Novosibirsk

- Introduction
- Results on branching fractions measurements
- Search for direct CP violation
- Conclusion

Introduction

- Rare B decays can be described by various tree and penguin diagrams
- They are useful to determine the CKM unitarity triangle
- Search for CP violation and probe new physics





B Reconstruction

- Exclusive B decays are kinematically reconstructed by using two (almost) independent variables, Mb and ΔE.
- Mb: beam energy constrained B mass.

$$Mb = \sqrt{(E^*_{beam})^2 - (\Sigma_i \vec{p}_i)^2}$$

$E^*_{beam} \sim 5.29 GeV$: accuracy ~0.5%

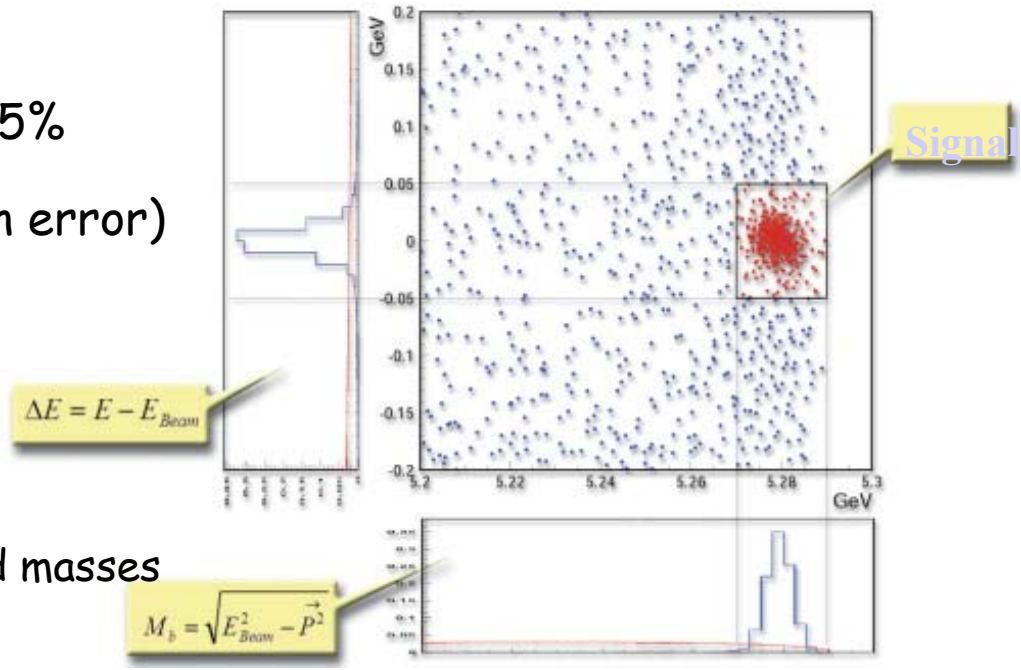
$\Sigma_i \vec{p}_i$: small (-> small effect on error)

σ ~3MeV

- ΔE: energy imbalance

$$\Delta E = (\Sigma_i E_i^{measured}) - E^*_{beam}$$

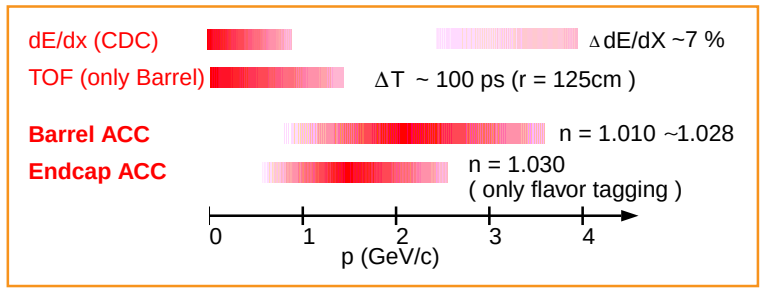
$E_i^{measured}$: Calculated with assumed masses



σ ~16–40MeV depending on #tracks,#π^0,#γ etc.

Belle Particle Identification

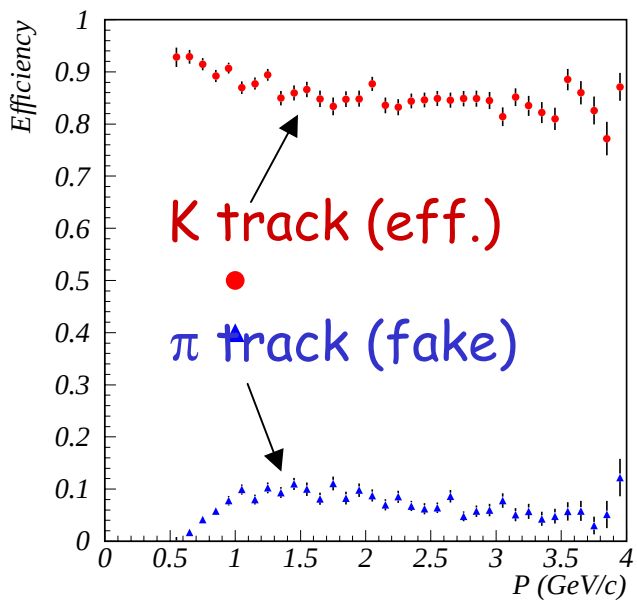
- Clear K/π separation is essential to distinguish decays.
  - DK/Dπ
  - Kπ/ππ/KK etc.
  - K*γ/ργ



- Belle use dE/dx + ToF + ACC
  - Wide momentum coverage
  - ACC: Aerogel Cherenkov
  - Combined into likelihood;

$$PID(K) = \frac{L(K)}{L(K) + L(\pi)}$$

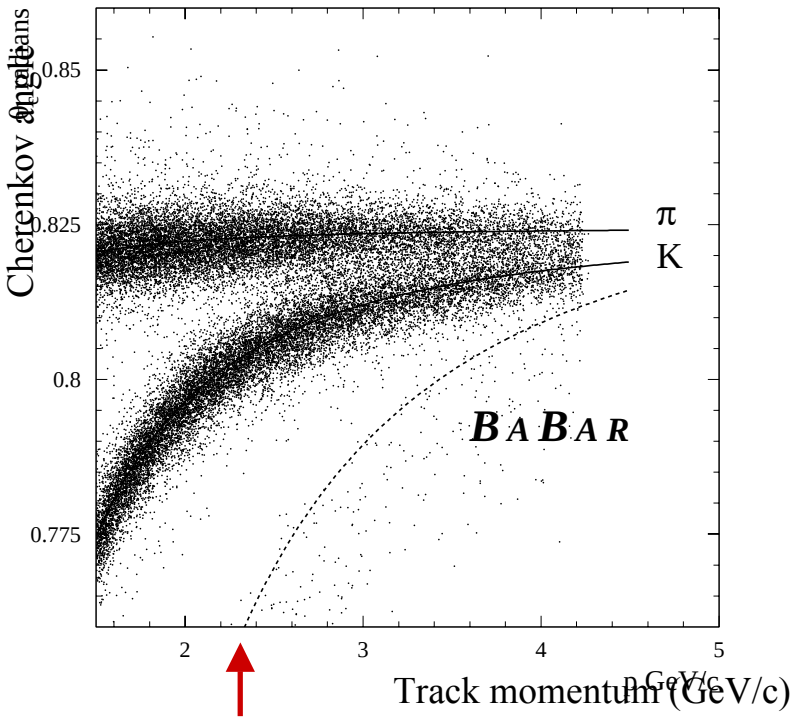
~1 for K
~0 for π



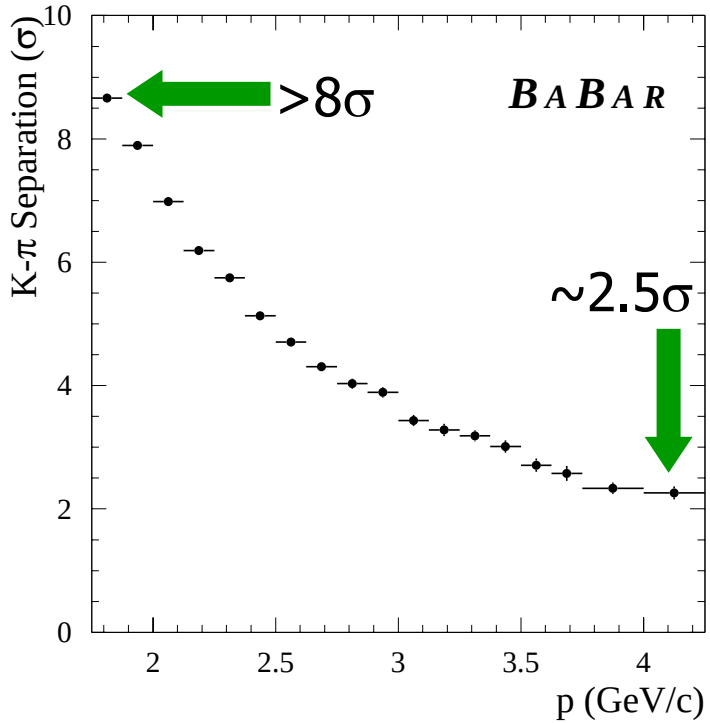
- Calibration with $D^{*+} \to D^0\pi^+$, $D^0 \to K^-\pi^+$

BaBar Particle Identification

- DIRC θ_c resolution and K-π separation measured in data $\Rightarrow$ $D^{*+} \rightarrow D^0\pi^+ \rightarrow (K^-\pi^+)\pi^+$ decays



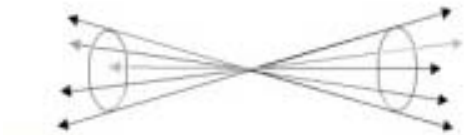
Proton rejection cut



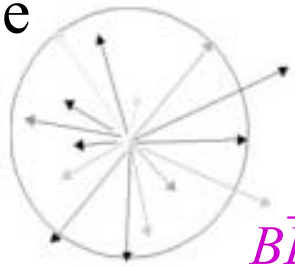
Continuum suppression

- Separate jet and spherical shape

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



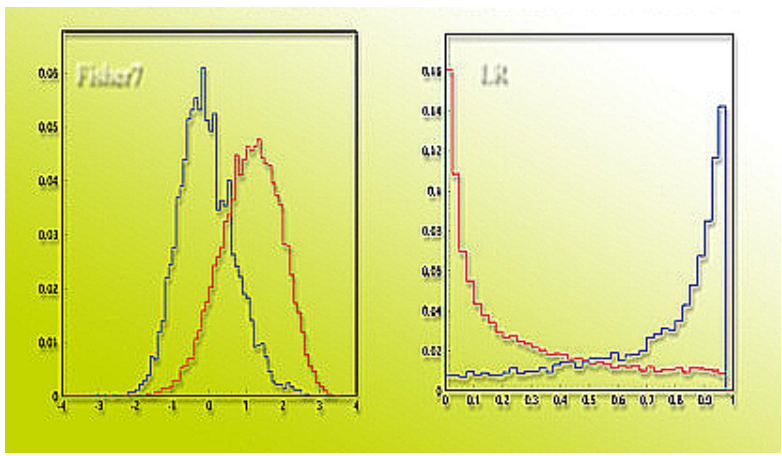
Continuum

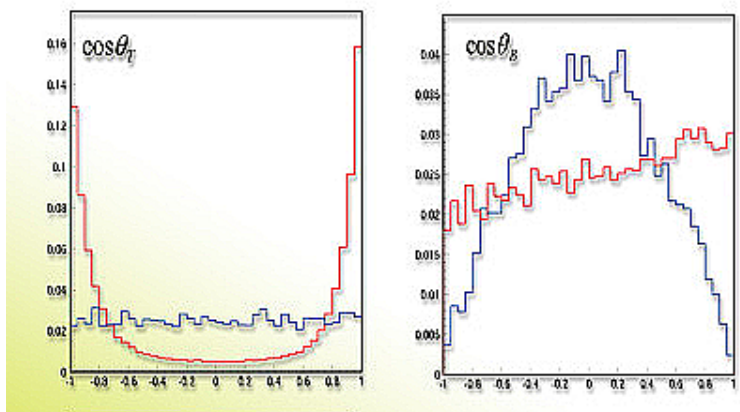


$B\bar{B}$

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

- Shape variables:
  - Thrust angle:
    - The angle between thrust axes of B and other particles
  - Super Fox-Wolfram moment or Fisher discriminant





$B \to \eta^{(\prime)}h$: Introduction

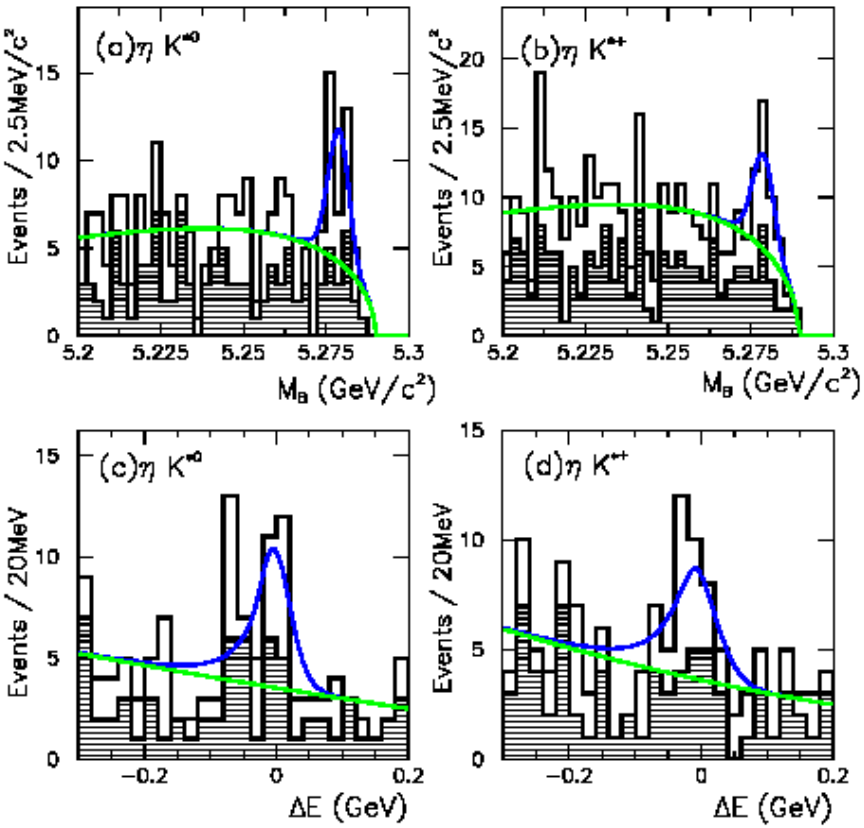
- The BFs for $B \to \eta' K$ and $B \to \eta K^*$ were first found to be unexpectedly large by CLEO and then confirmed by Belle and BaBar.
- Study of $B^+ \to \eta K^+$ and $\eta\pi^+$ can help understand the penguin interfernce between $\eta h - \eta' h$ decays.
- The decay $B^+ \to \eta\pi^+$ is predicted to have large direct CP violation. (Rosner *et al.*)
- By studying both rates and CP asymmetries, one can determine both the relative strong phases of penguin and tree amplitudes and ϕ_2. (Chiang & Rosner, hep-ph/0112285)
- Results from CLEO's search: [PRL **85**, 520 (2000)]

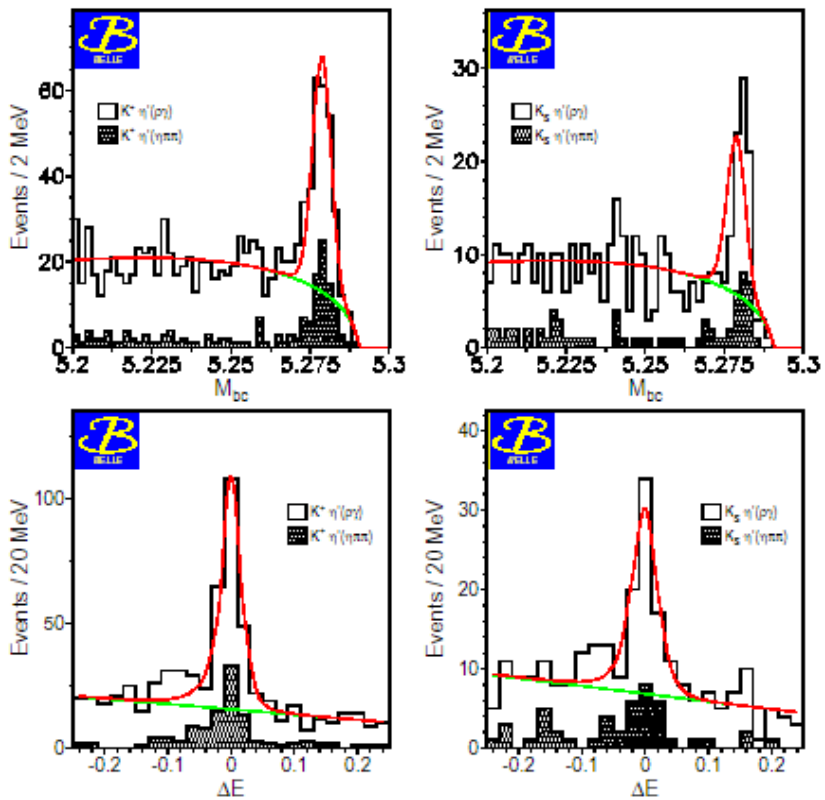
$$\mathcal{B}(B \to \eta K^+) \quad < 6.9 \times 10^{-6} \quad (2.2^{+2.8}_{-2.2})$$
$$\mathcal{B}(B \to \eta\pi^+) \quad < 5.7 \times 10^{-6} \quad (1.2^{+2.8}_{-1.2})$$

- Theory predictions for the BFs are around few $\times 10^{-6}$.

Belle results on B → ηK* / η'K

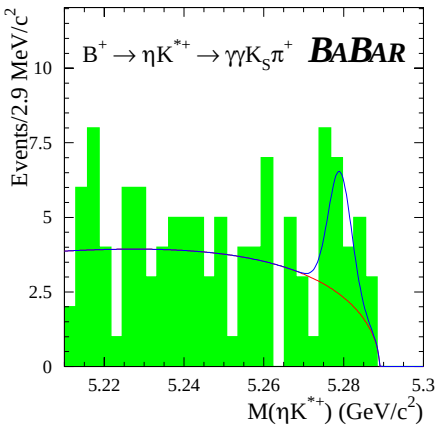
$B^0 \to \eta K^{*0}$ $B^+ \to \eta K^{*+}$ $B^+ \to \eta' K^+$ $B^0 \to \eta' K^0_S$

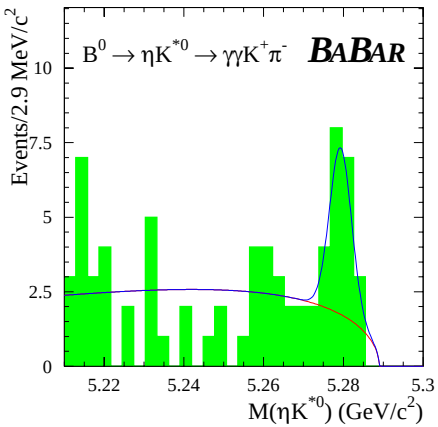




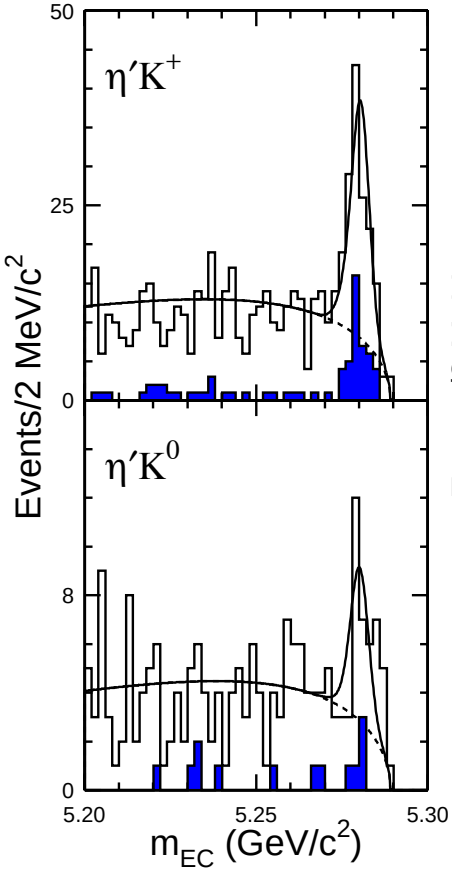
BaBar results on $\eta^{(')}K^{(*)}$

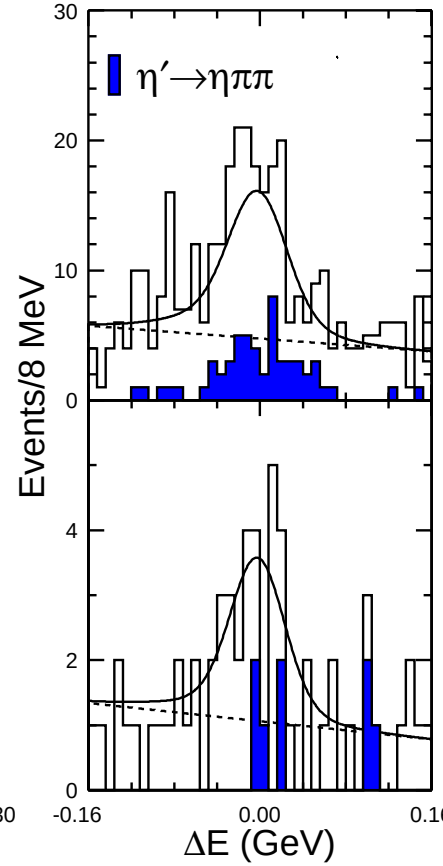
- Tree is CKM suppressed $\Rightarrow$ $b \to s$ Penguin





Mode	Signal yield	$S(\sigma)$	$/10^{-6}$	(90% CL)
ηK^{*0}	20.5 ± 6.0	5.4	$19.8^{+6.5}_{-5.6} \pm 1.7$	
ηK^{*+}	14.3 ± 6.6	3.2	$22.1^{+11.1}_{-9.2} \pm 3.3$	(< 33.9)
$\eta'_{\eta\pi\pi} K^+$	$49.5^{+8.1}_{-7.3}$	15	63^{+10}_{-9}	
$\eta'_{\rho\gamma} K^+$	$87.6^{+13.4}_{-12.5}$	11	80^{+12}_{-11}	
$\eta' K^+$		17	$70 \pm 8 \pm 5$	
$\eta'_{\eta\pi\pi} K^0$	$6.3^{+3.3}_{-2.5}$	4.7	28^{+15}_{-11}	
$\eta'_{\rho\gamma} K^0$	$20.8^{+7.4}_{-6.5}$	4.2	61^{+22}_{-19}	
$\eta' K^0$		5.9	$42^{+13}_{-11} \pm 4$	
$\eta'_{\eta\pi\pi} \pi^+$	$5.7^{+3.8}_{-2.8}$	3.2	$7.1^{+4.8}_{-3.5}$	
$\eta'_{\rho\gamma} \pi^+$	$-0.9^{+7.8}_{-6.2}$	0.1	$-0.7^{+6.7}_{-5.3}$	
$\eta' \pi^+$		2.8	$5.4^{+3.5}_{-2.6} \pm 0.8$	(< 12)

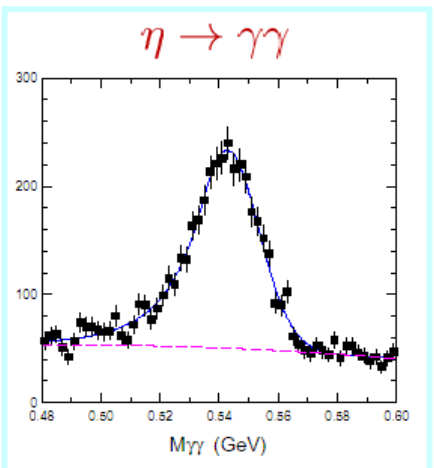


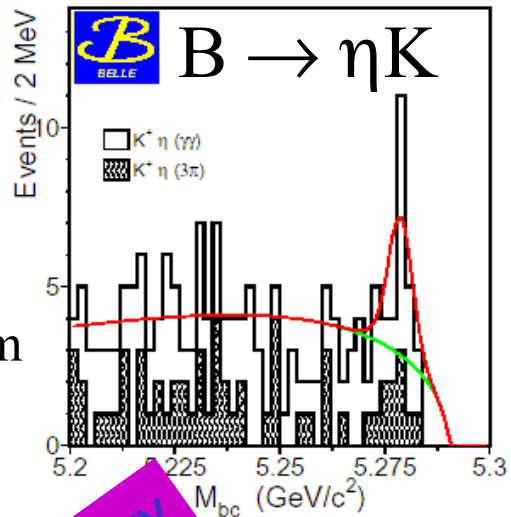


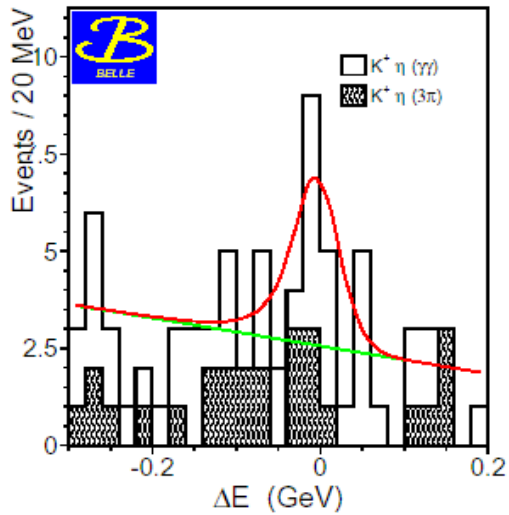
Belle results on $B \to \eta K$ / $\eta\pi$

$\eta_{\gamma\gamma}$ Open histogram

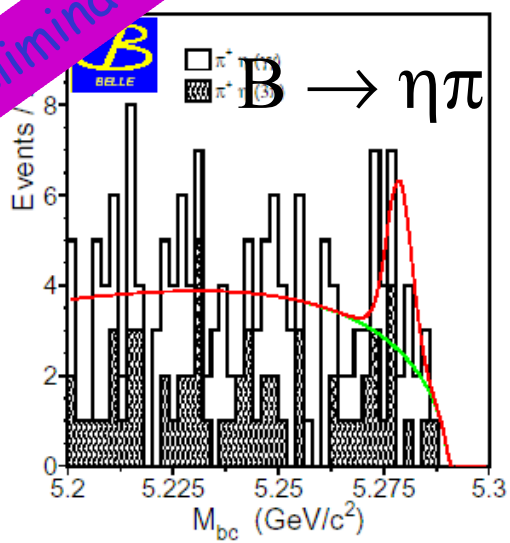
$\eta_{\pi^+\pi^-\pi^0}$ Hatched histogram

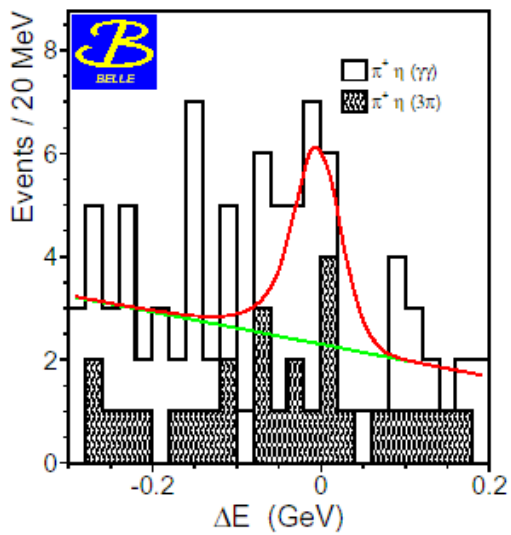






Preliminary

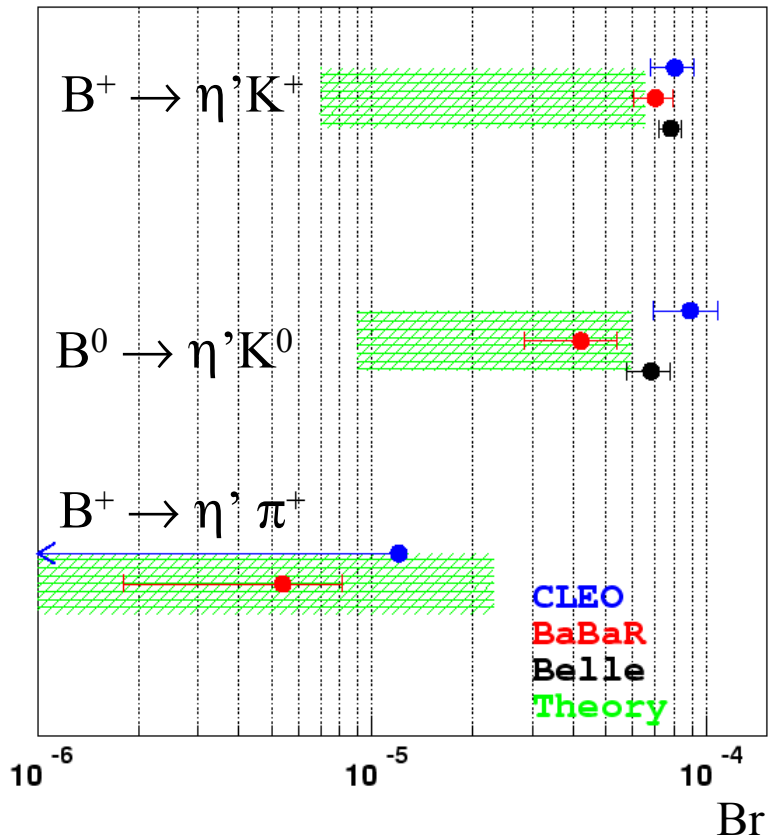




$B \to \eta' h$ summary

Mode	CLEO	BaBar	Belle
$\eta' K^+$	$80^{+10}_{-9} \pm 7$	$70 \pm 8 \pm 5$	$77.9^{+6.2}_{-5.9} \pm$
$\eta' K^0$	$89^{+18}_{-16} \pm 9$	$42^{+13}_{-11} \pm 4$	$68.0^{+10.4}_{-9.6} \pm$
$\eta' \pi^+$	< 12	$5.4^{+3.5}_{-2.6} \pm 0.8$	—

Branching ratios are given in units of 10^{-6}



CLEO: PRL 85, 520 (2000)

BaBar: C.Dallapiccola, 9th Heavy Flavor, Sep. 2001

PRL 87, 221802 (2001)

Belle: H.C.Huang, XXXVII Recontres de Moriond, March 2002.

$B \to \eta h$ summary

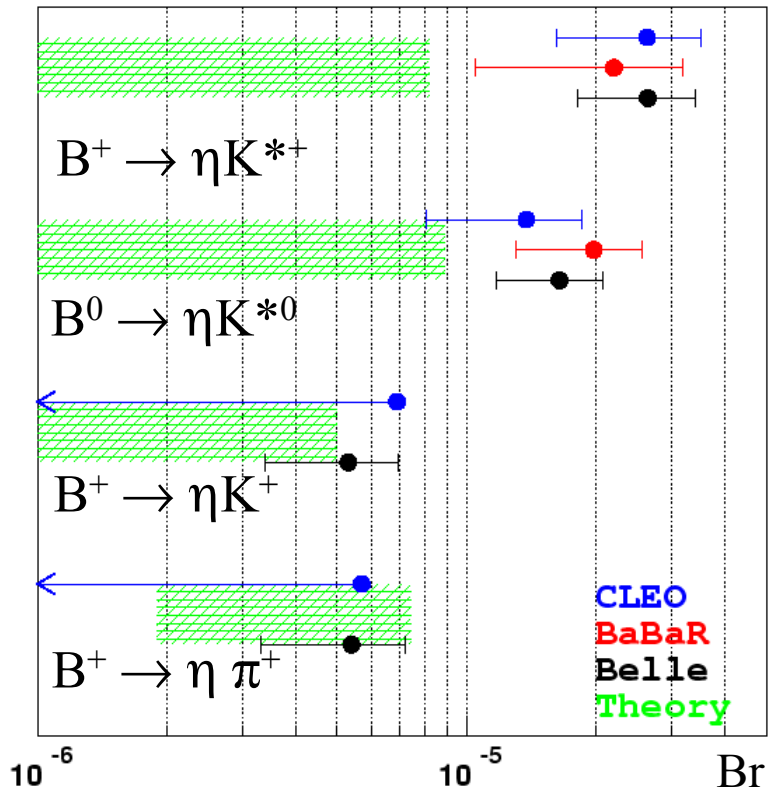
Mode	CLEO	BaBar	Belle
ηK^{*+}	$26.4^{+9.6}_{-8.2} \pm 3.3$	$22.1^{+11.1}_{-9.2} \pm 3.3$	$26.5^{+7.8}_{-7.0} \pm 3.0$
ηK^{*0}	$13.8^{+5.5}_{-4.6} \pm 1.6$	$19.8^{+6.5}_{-5.6} \pm 1.7$	$16.5^{+4.6}_{-4.2} \pm 1.2$
ηK^{+}	< 6.9	—	$5.3^{+1.8}_{-1.5} \pm 0.6$
$\eta \pi^{+}$	< 5.7	—	$5.4^{+2.0}_{-1.7} \pm 0.6$

Branching ratios are given in units of 10^{-6}

CLEO: PRL 85, 520 (2000)

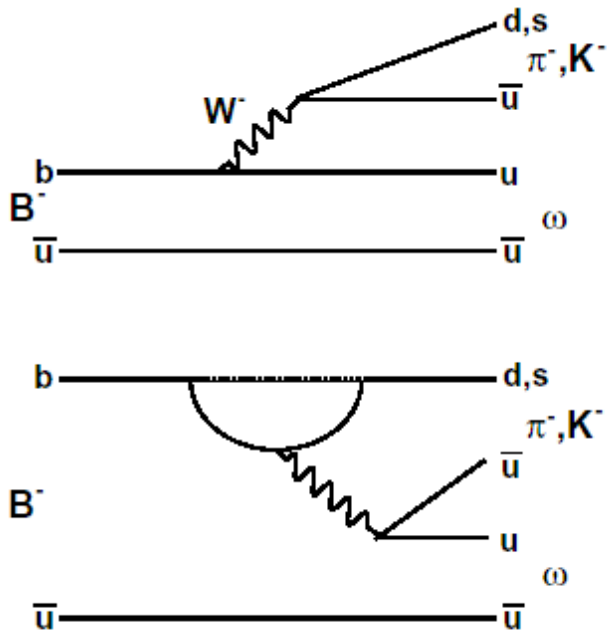
BaBar: C.Dallapiccola, 9th Heavy Flavor, Sep. 2001

Belle: H.C.Huang, XXXVII Recontres de Moriond, March 2002.

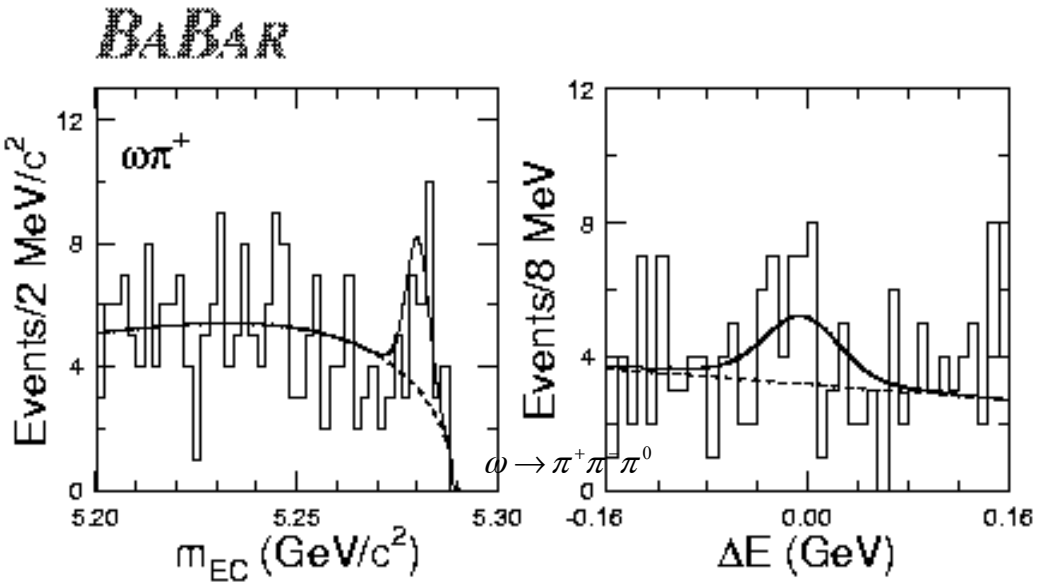


B → ωh: Introduction

- Study of rare decay $B^- \to \omega h^-$ will test current models of B decays and could be used to search for direct CP violation
- In 1998, CLEO reported the observation of $B^- \to \omega K^-$ decays [PRL **81**, 272 (1998)]
- But with new and larger data set, CLEO found $\omega\pi^-$ is larger than ωK^- [PRL **85**, 2881 (2000)]
- BaBar confirms $\omega\pi^- > \omega K^-$ but with smaller $\omega\pi^-$ branching ratio [PRL **87**, 221802 (2001)]



BaBar result on $B^+ \to \omega\pi^+$

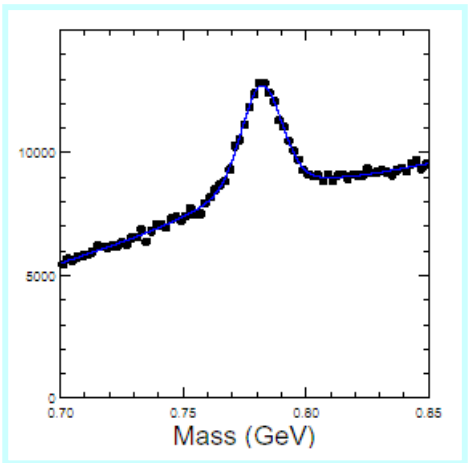


Mode	Signal yield	$S(\sigma)$	B/10^{-6}	(90% CL)
ωK^+	$6.4^{+5.6}_{-4.4}$	1.3	$1.4^{+1.3}_{-1.0} \pm 0.3$	(< 4)
ωK^0	$8.1^{+4.6}_{-3.6}$	3.2	$6.4^{+3.6}_{-2.8} \pm 0.8$	(< 13)
$\omega\pi^+$	$27.6^{+8.8}_{-7.7}$	4.9	$6.6^{+2.1}_{-1.8} \pm 0.7$	
$\omega\pi^0$	$-0.9^{+5.0}_{-3.2}$	–	$-0.3 \pm 1.1 \pm 0.3$	(< 3)

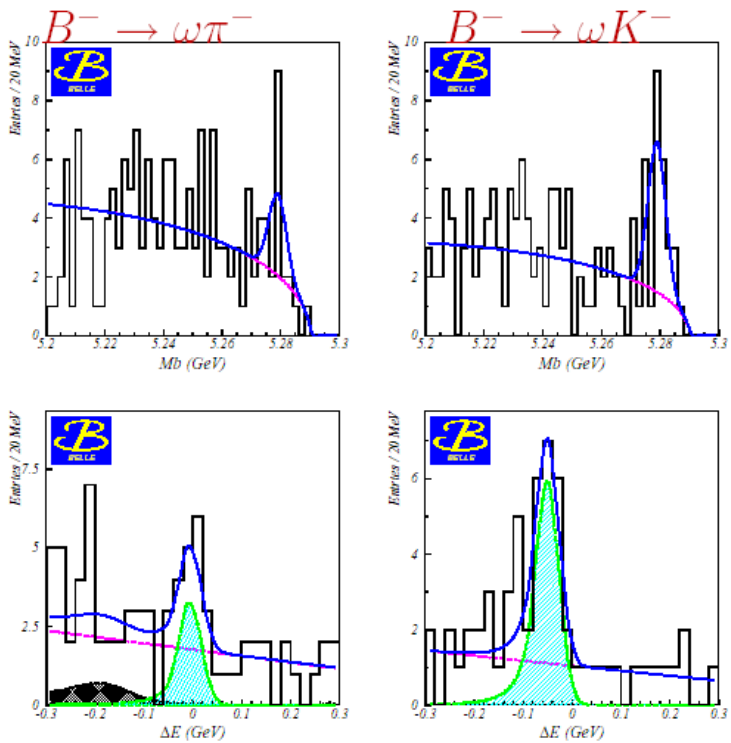
Belle results on B → ωh

- Simultaneous unbinned 2D fit to M_{bc} and ΔE.

$\omega \to \pi^+\pi^-\pi^0$



$M_{\pi^+\pi^-\pi^0}$



Preliminary

	yield	Σ	ϵ	Br $(\times 10^{-6})^\dagger$	UL
$\omega\pi^-$	$10.6^{+4.8+0.4}_{-4.5-0.6}$	3.3σ	7.7%	$4.3^{+2.0}_{-1.8} \pm 0.5$	8.2
ωK^-	$19.7^{+5.4+0.7}_{-4.8-0.5}$	6.4σ	6.3%	$9.9^{+2.7}_{-2.4} \pm 1.0$	-

$B \to \omega h$ summary

Mode	CLEO	BaBar	Belle
ωK^+	< 7.9	< 4	$9.9^{+2.7}_{-2.4} \pm 1.0$
ωK^0	< 21	< 13	—
$\omega \pi^+$	$11.3^{+3.3}_{-2.9} \pm 1.4$	$6.6^{+2.1}_{-1.9} \pm 0.7$	< 8.2
$\omega \pi^0$	< 5.5	< 3	—

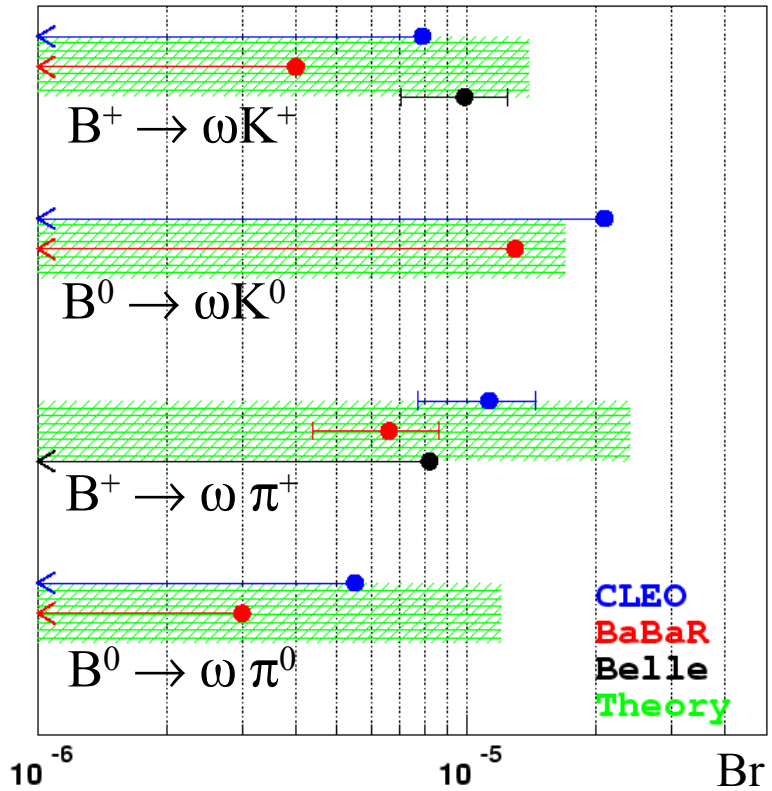
Branching ratios are given in units of 10^{-6}

CLEO: PRL 85, 2881 (2000)

BaBar: C.Dallapiccola, 9th Heavy Flavor, Sep. 2001

PRL 87, 221802 (2001)

Belle: H.C.Huang, XXXVII Recontres de Moriond, March 2002.



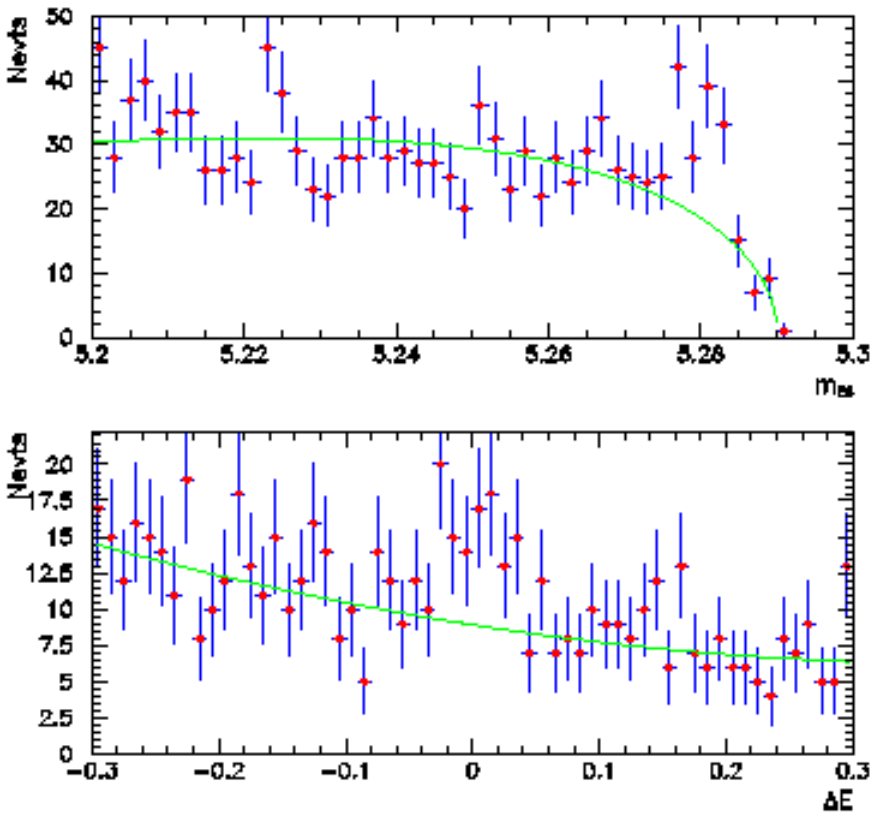
BaBar results on $B \to \rho\pi$

$$\mathcal{BR}(B^0 \to \rho^{\pm}(770)\pi^{\mp}) = 28.9 \pm 5.4 \pm 4.3 \cdot 10^{-6}$$

5σ significance

$$\mathcal{BR}(B^0 \to \rho^0(770)\pi^0) < 10.6 \cdot 10^{-6}$$

$$\mathcal{BR}(B^0 \to \pi^+\pi^-\pi^0(NR)) < 7.3 \cdot 10^{-6}$$



- Asymmetry also measured:

$$A_{\rho\pi} = \frac{\Gamma(\rho^+\pi^-) - \Gamma(\rho^-\pi^+)}{\Gamma(\rho^+\pi^-) + \Gamma(\rho^-\pi^+)}$$

$$= -0.04 \pm 0.18 \pm 0.02$$

$B \to \rho\pi$ summary

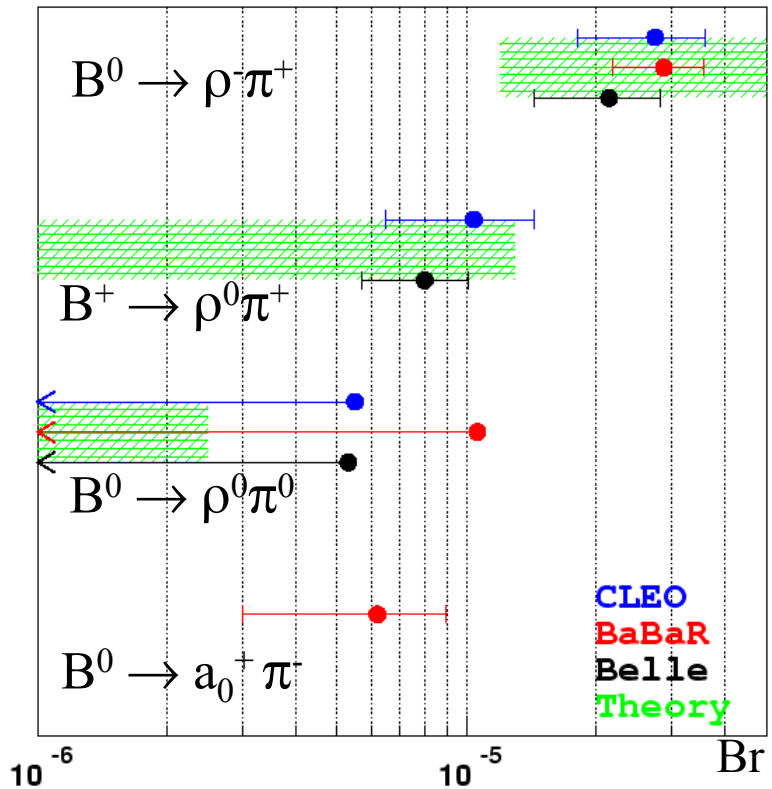
Mode	CLEO	BaBar	Belle
$\rho^{\pm}\pi^{\mp}$	$27.6^{+8.4}_{-7.4} \pm 4.2$	$28.9 \pm 5.4 \pm 4.3$	$21.5^{+6.3}_{-6.0} \pm 3.3$
$\rho^0\pi^+$	$10.4^{+3.3}_{-3.4} \pm 2.1$	—	$8.0^{+2.2}_{-2.0} \pm 0.7$
$\rho^0\pi^0$	< 5.5	< 10.6	< 5.3
$a_0^{\pm}\pi^{\mp}$	—	$6.2^{+3.0}_{-2.5} \pm 1.1$	—

Branching ratios are given in units of 10^{-6}

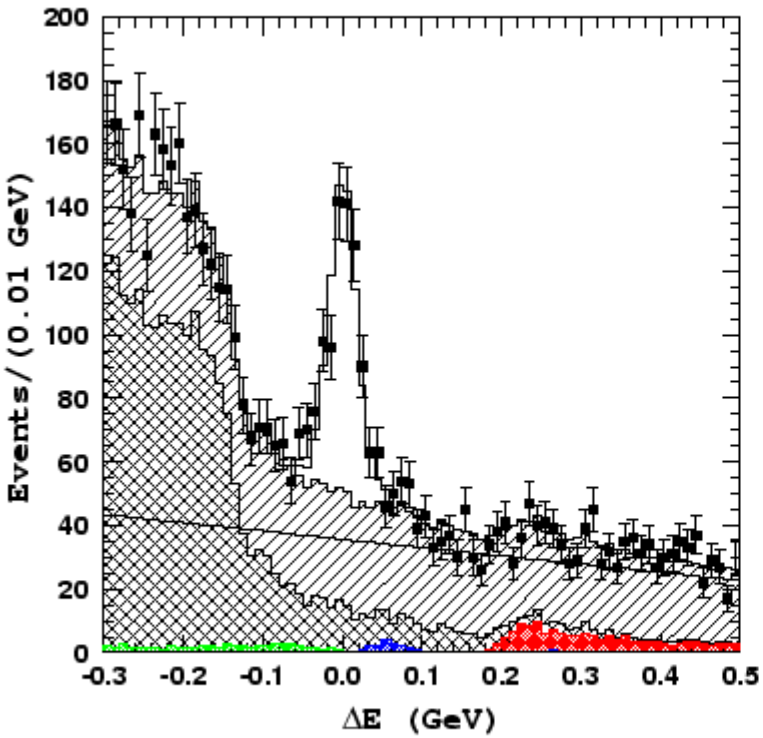
CLEO: PRL 85, 2881 (2000)

BaBar: C.Dallapiccola, 9th Heavy Flavor, Sep. 2001

Belle: Preliminary



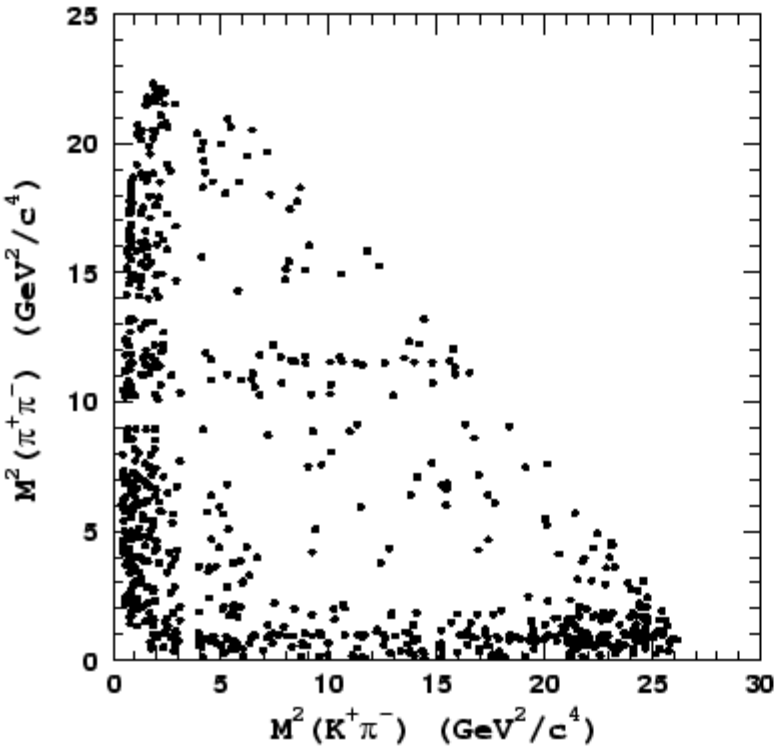
Belle results on $B^+ \to K^+\pi^+\pi^-$



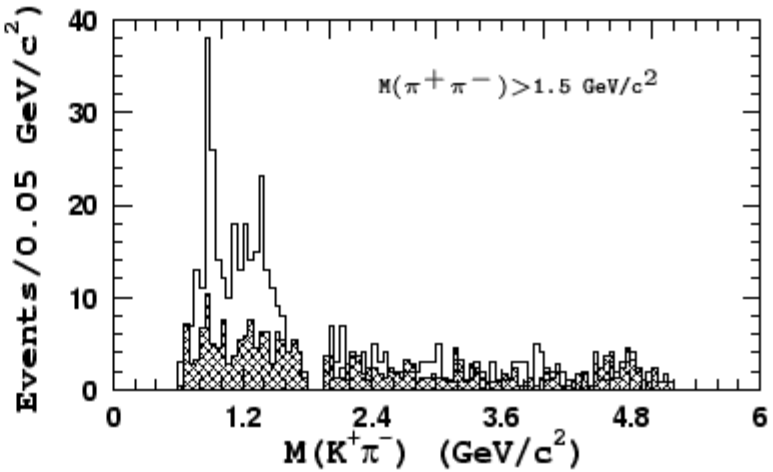
Fit components:

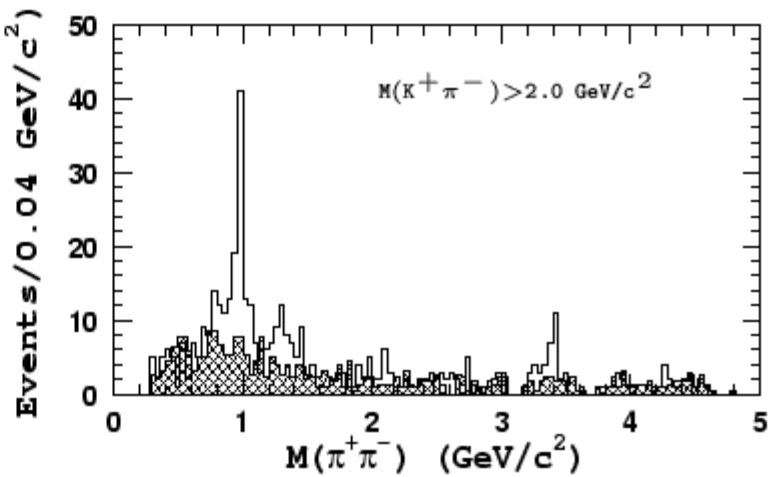
- Signal 463 ± 32
- Continuum 2645 ± 110
- $B\bar{B}$ grneric 2097 ± 95
- Rare Background:
  - $B^+ \to \eta' K^+ \to (\gamma\pi^+\pi^-)K^+$: 60 events (fixed) green histogram
  - $B^+ \to \rho^0\pi^+ \to (\pi^+\pi^-)\pi^+$: 30 events (fixed) blue histogram
  - $B \to hh$: 140 events (fixed) red histogram

Belle results on $B^+ \to K^+\pi^+\pi^-$

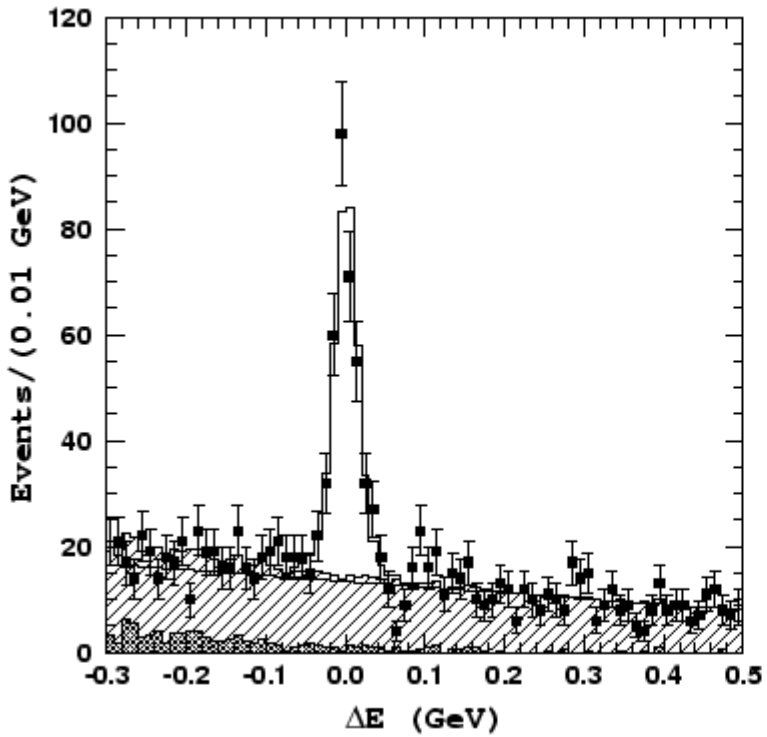


- open histograms - B signal region;
- hatched histograms - background estimation from the ΔE sidebands.





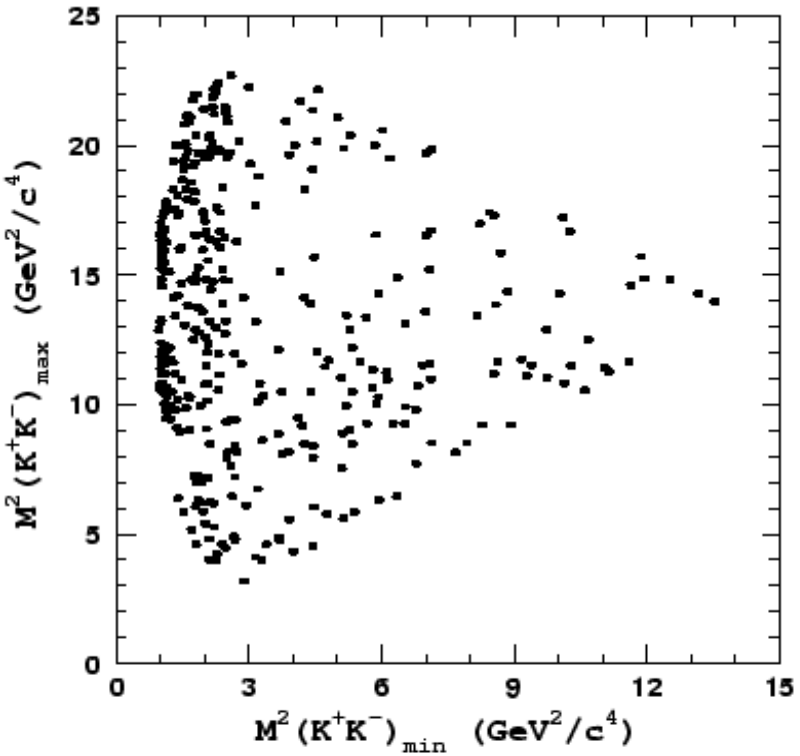
Belle results on $B^+ \to K^+K^+K^-$

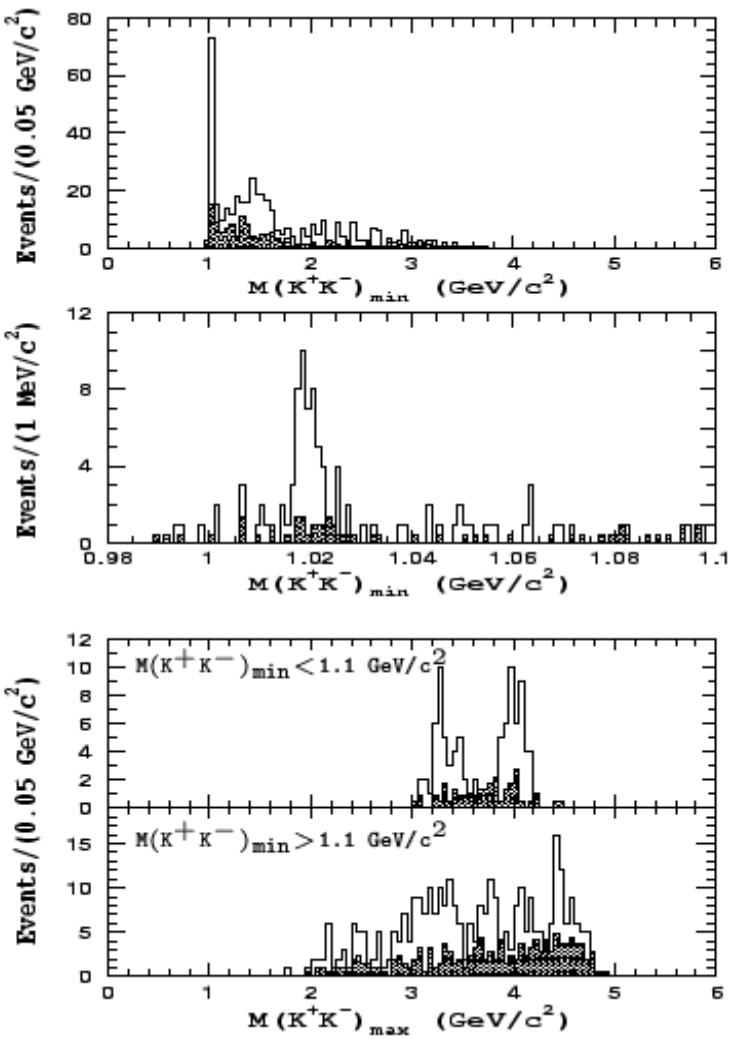


Fit components:

- Signal 289 ± 20
- Continuum 987 ± 35
- $B\bar{B}$ grneric 67 ± 20
- Rare Background:
  - none

Belle results on $B^+ \to K^+K^+K^-$





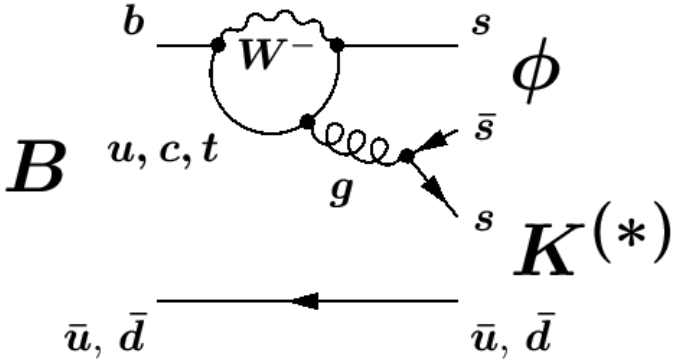
- open histograms - B signal region;
- hatched histograms - background estimation from the ΔE sidebands.

Belle results on quasi two-body decays

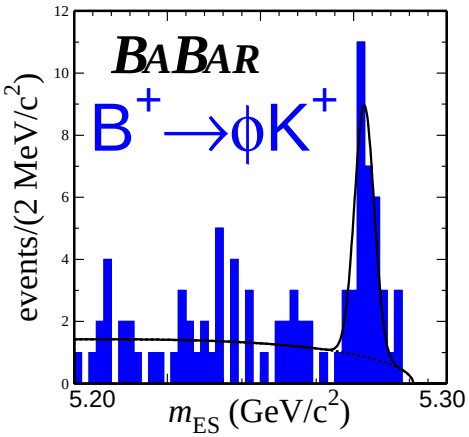
Two body mode	Efficiency, %	Yield, events	Significance, σ	$\mathcal{B}_{B^+\to Rh^+} \times \mathcal{B}_{R\to h^+h^-}$, 10^{-6}
$K^{*o}(892)\pi^+$	18.9	60^{+13}_{-12}	6.2	$12.9^{+2.8+1.4+2.3}_{-2.6-1.4-4.5}$
$K_X(1400)\pi^+$	16.2	58^{+14}_{-13}	4.9	$14.5^{+3.5+1.8+3.3}_{-3.3-1.8-6.5}$
$\rho^o(770)K^+$	15.1	9.0^{+13}_{-12}	0.8	< 12
$f_o(980)K^+$	17.8	42^{+11}_{-10}	5.0	$9.6^{+2.5+1.5+3.4}_{-2.3-1.5-0.8}$
$f_X(1300)K^+$	16.9	46^{+14}_{-13}	3.9	$11.1^{+3.4+1.4+7.2}_{-3.1-1.4-2.9}$
$\phi(1020)K^+$	23.6	$42^{+8.7}_{-7.9}$	7.2	$7.2^{+1.5+0.9+0.4}_{-1.4-0.9-0.4}$
$f_X(1500)K^+$	21.3	146^{+17}_{-17}	12	$27.6^{+3.2+3.5+1.4}_{-3.2-3.5-1.4}$

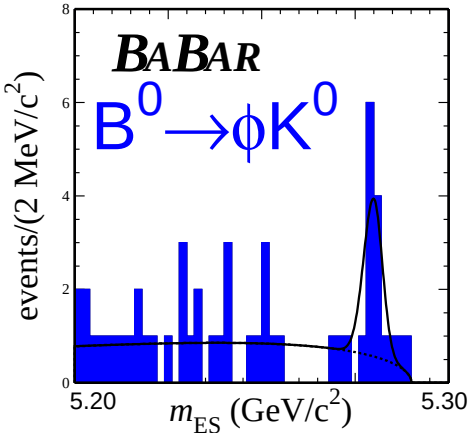
BaBar results on $B \to \phi K^{(*)}$

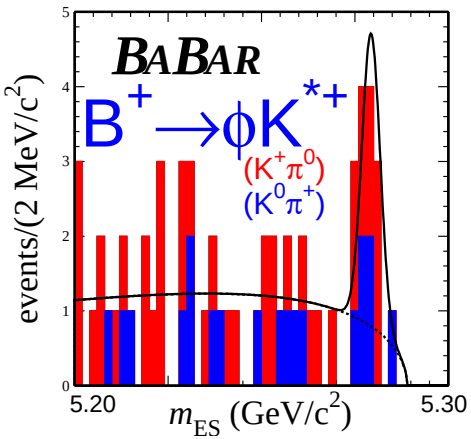
- ~Pure Penguin $\phi K^0 \Rightarrow$ CP eigenstate (sin2β)

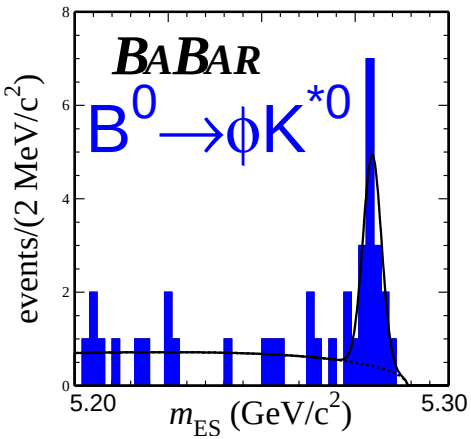


Mode	n_{sig}	S	$\mathcal{B}(10^{-6})$
ϕK^+	$31.4^{+6.7}_{-5.9}$	10.5	$7.7^{+1.6}_{-1.4} \pm 0.8$
ϕK^0	$10.8^{+4.1}_{-3.3}$	6.4	$8.1^{+3.1}_{-2.5} \pm 0.8$
ϕK^{*+}	–	4.5	$9.7^{+4.2}_{-3.4} \pm 1.7$
$\phi K^{*+}_{K^+}$	$7.1^{+4.3}_{-3.4}$	2.7	$12.8^{+7.7}_{-6.1} \pm 3.2$
$\phi K^{*+}_{K^0}$	$4.4^{+2.7}_{-2.0}$	3.6	$8.0^{+5.0}_{-3.7} \pm 1.3$
ϕK^{*0}	$20.8^{+5.9}_{-5.1}$	7.5	$8.7^{+2.5}_{-2.1} \pm 1.1$
$\phi\pi^+$	$0.9^{+2.1}_{-0.9}$	0.6	< 1.4 (90% CL)





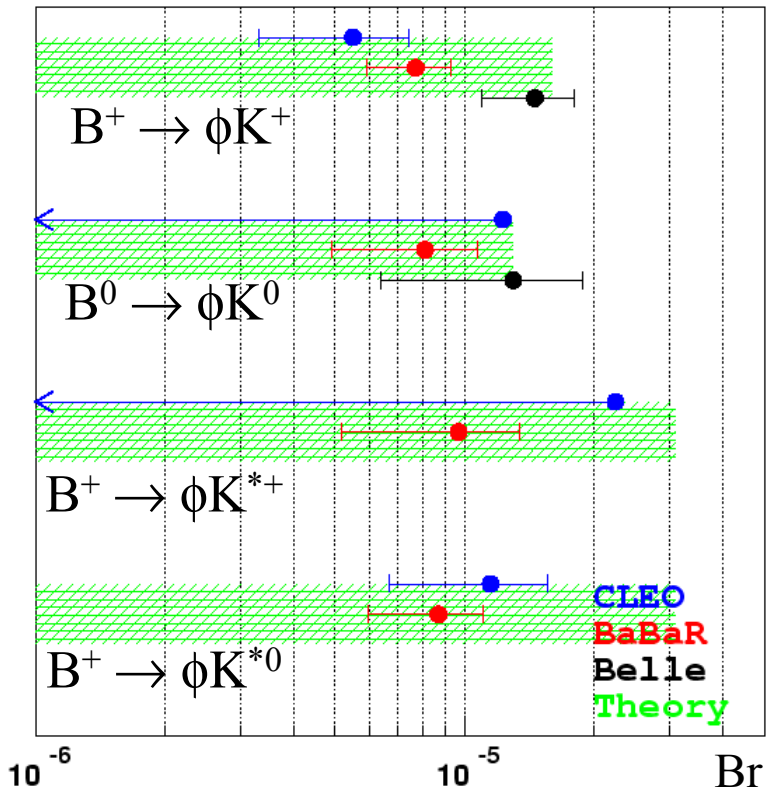




$B \to \phi K^{(*)}$ summary

Mode	CLEO	BaBar	Belle
ϕK^+	$5.5^{+2.1}_{-1.8} \pm 0.6$	$7.7^{+1.6}_{-1.4} \pm 0.8$	$14.6^{+3.0}_{-2.8} \pm 2.0$
ϕK^0	< 12.3	$8.1^{+3.1}_{-2.5} \pm 0.8$	$13.0^{+6.1}_{-5.2} \pm 2.6$
ϕK^{*+}	< 22.5	$9.7^{+4.2}_{-3.4} \pm 1.7$	—
ϕK^{*0}	$11.5^{+4.5+1.8}_{-3.7-1.7}$	$8.7^{+2.5}_{-2.1} \pm 1.1$	—

Branching ratios are given in units of 10^{-6}



CLEO: PRL 86, 3718 (2001)

BaBar: C.Dallapiccola, 9th Heavy Flavor, Sep. 2001

PRL 87, 151801 (2001)

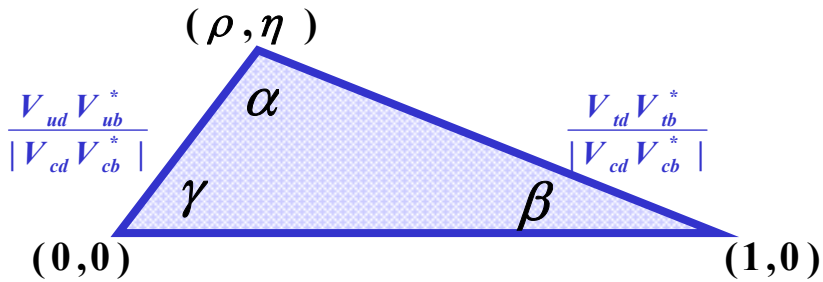
Belle: H.C.Huang, XXXVII Recontres de Moriond, March 2002.

Motivation: CP violation

- Significant amplitudes for Penguins for most modes
  - P↔T interference ⇒ possible direct CP violation

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

- $\Delta\varphi(\Delta\delta)$=weak(strong) P-T phase diff.
- $P_{b\to s} \to \Delta\varphi=\gamma$
- $P_{b\to s} \to \Delta\varphi=\gamma+\beta$



  - "Pure" Penguin → $\phi K^{(*)}$, $K^0\pi$

    Negligible direct CP violation in SM ⇒ probe new physics!

Search for direct CP violation

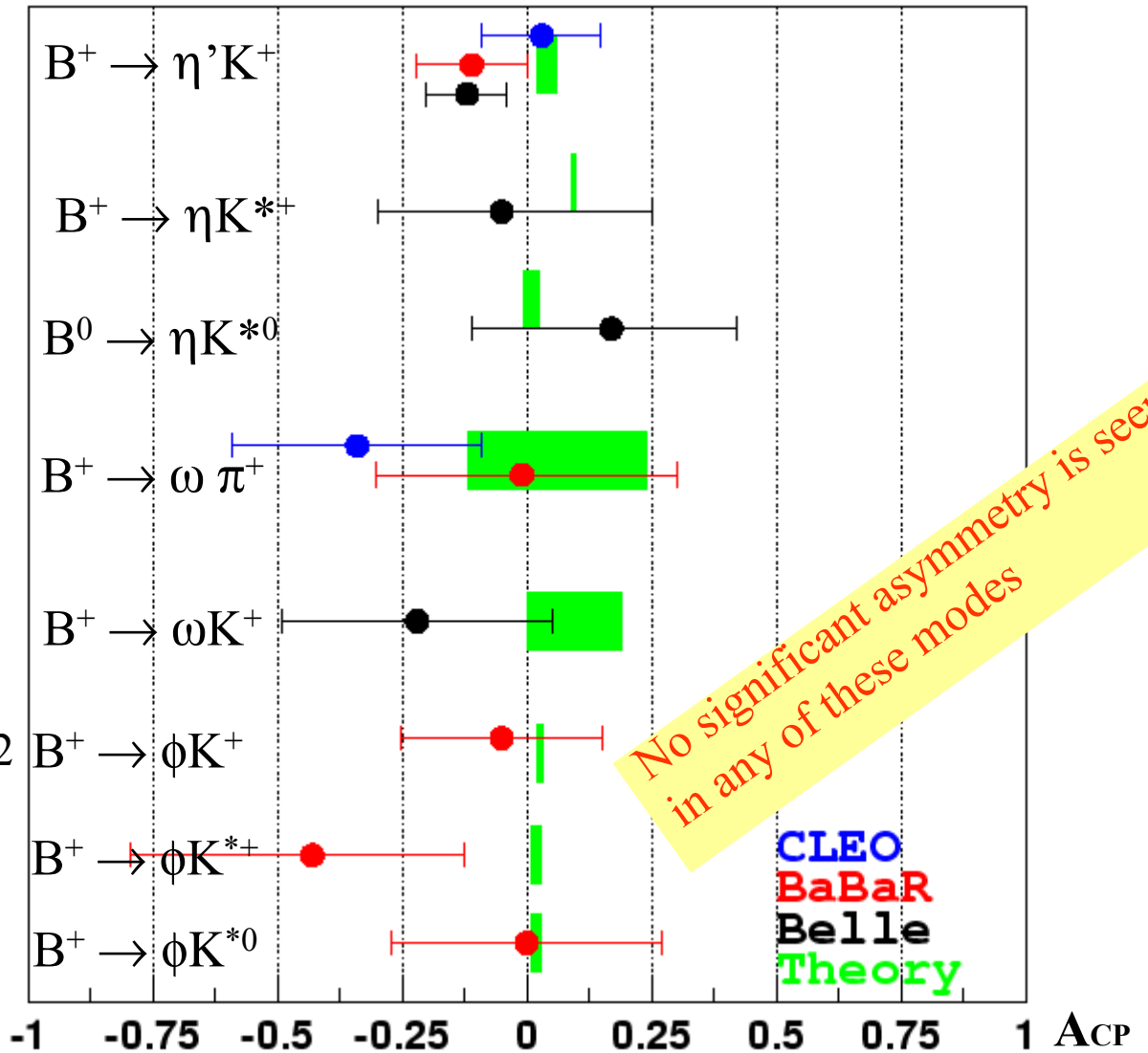
$$A_{CP} = \frac{\Gamma(B^- \to f^-) - \Gamma(B^+ \to f^+)}{\Gamma(B^- \to f^-) + \Gamma(B^+ \to f^+)}$$

CLEO: PRL 85, 525 (2000)

BaBar: PRD 65, 051101 (2002)

Belle: H.C.Huang, XXXVII Recontres de Moriond March 2002

Theory: A.Ali, *et al.* , PRD 59, 014005



Conclusion

- The many of new results were provided during last three years successful operation of B-factories.
- The level of accessible branching fractions is order $(3-5)\times 10^{-6}$
- First attempts of the search for direct CP violation have been done. No statistically significant asymmetries in charged B-meson decays were observed yet.
- New measurements with lager statistics $(100\ \ fb^{-1})$ are coming.