More Charmless B Decays VP/VV Results

FPCP 2003

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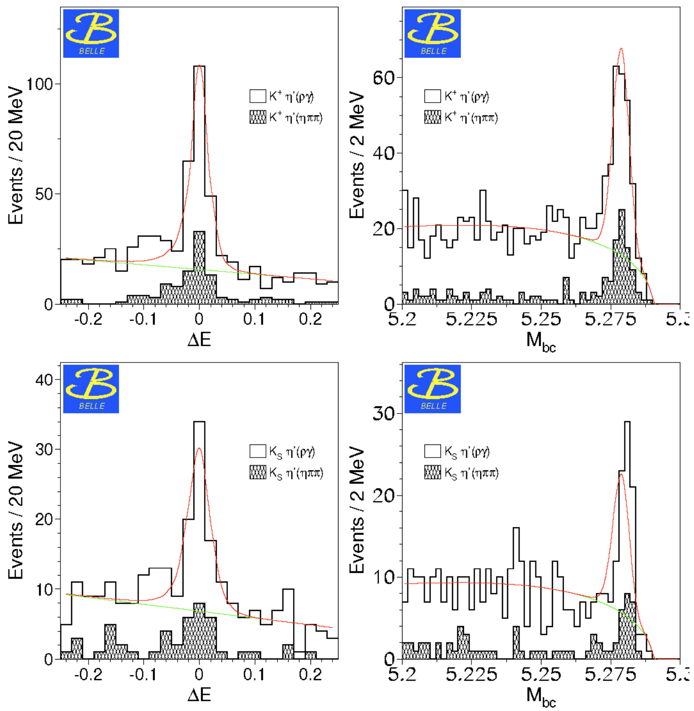
Outline

- B to ηX and $\eta' X$
- ωh
- $\phi K^{(*)}$
- $VV(\rho^+\rho^0, K^*\rho^0)$
- $\phi\phi K$

$B \to \eta' h$

- Still lack of a convincing theory to explain the large $\eta' K$ branching fractions.
- $\mathcal{B}(B^0 \to \eta' K^0) < \mathcal{B}(B^+ \to \eta' K^+) \Rightarrow$ isospin break?
- No $\eta' \pi$ yet.

Belle
32M

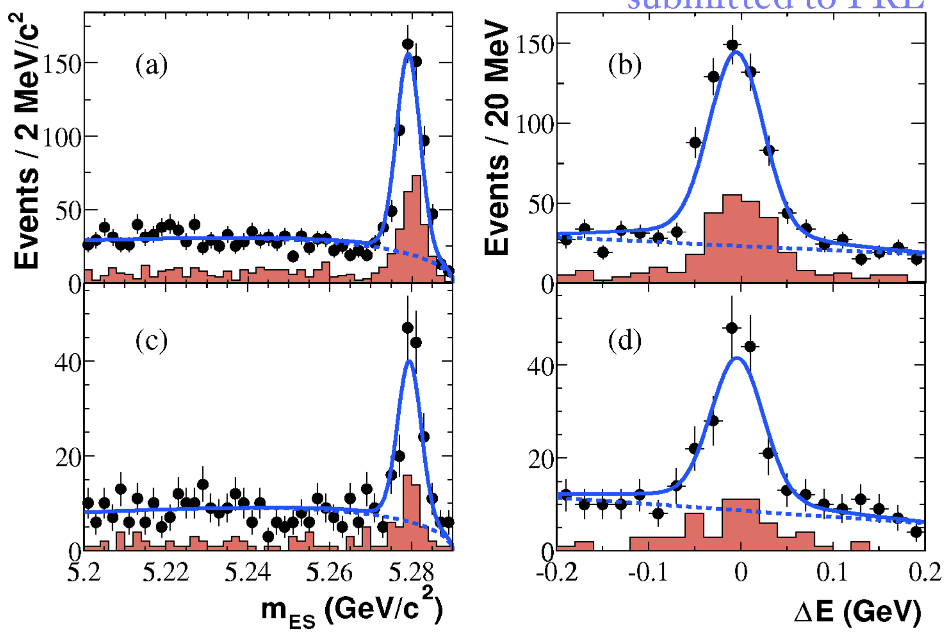


$\eta' K^{\pm}$

$\eta' K^0$

BaBar 89M

hep-ex/0303046,
submitted to PRL



$B \to \eta' K^*, \eta' \rho$

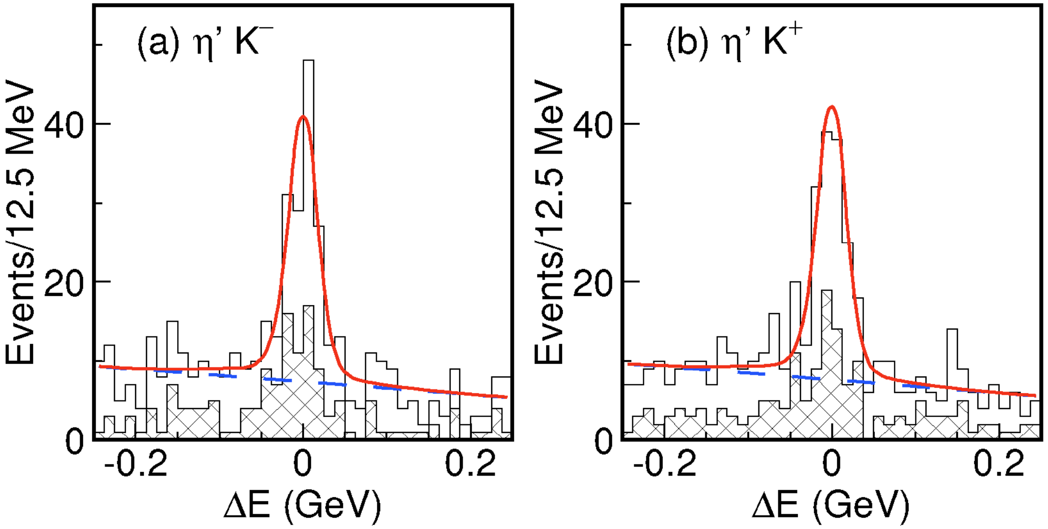
- Small branching fractions of $\eta' K^*$ and $\eta' \rho$

$(\times 10^{-6})$

Mode	Belle 32 M	CLEO 10 M	BABAR 89 M	Avg.
$B^+ \to \eta' K^+$	$78 \pm 6 \pm 9$	$80^{+10}_{-9} \pm 7$	$76.9 \pm 3.5 \pm 4.4$	78 ± 5
$B^0 \to \eta' K^0$	$68 \pm 10^{+9}_{-8} \pm 8$	$89^{+18}_{-16} \pm 9$	$55.2 \pm 5.4 \pm 4.0$	60.8 ± 5.6
$B^+ \to \eta' K^{*+}$	< 90	< 35		< 35
$B^0 \to \eta' K^{*0}$	< 20	< 24	< 13	< 13
$B^+ \to \eta' \pi^+$	< 7	< 12	< 12	< 7
$B^0 \to \eta' \pi^0$		< 5.7		< 5.7
$B^+ \to \eta' \rho^+$		< 33		< 33
$B^0 \to \eta' \rho^0$	< 14	< 12		< 12

$\mathcal{A}_{CP}(B^\pm \to \eta' K^\pm)$

- No direct CPV is found



Belle 46M
PLB 546, 196 (2002)

BaBar: $0.04 \pm 0.05 \pm 0.01$ (88 M $B\bar{B}$)

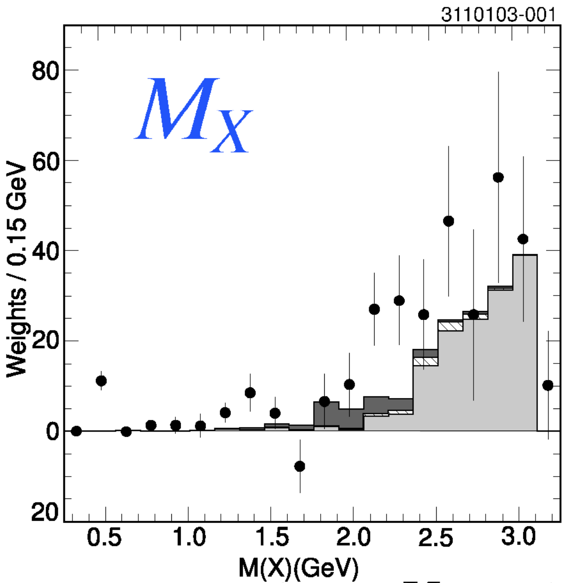
Belle: $-0.01 \pm 0.07 \pm 0.01$ (46 M $B\bar{B}$)

CLEO: $0.03 \pm 0.12 \pm 0.02$ (9.7 M $B\bar{B}$)

Inclusive $B \to \eta'$

CLEO

hep-ex/0303009,
submitted to PRD

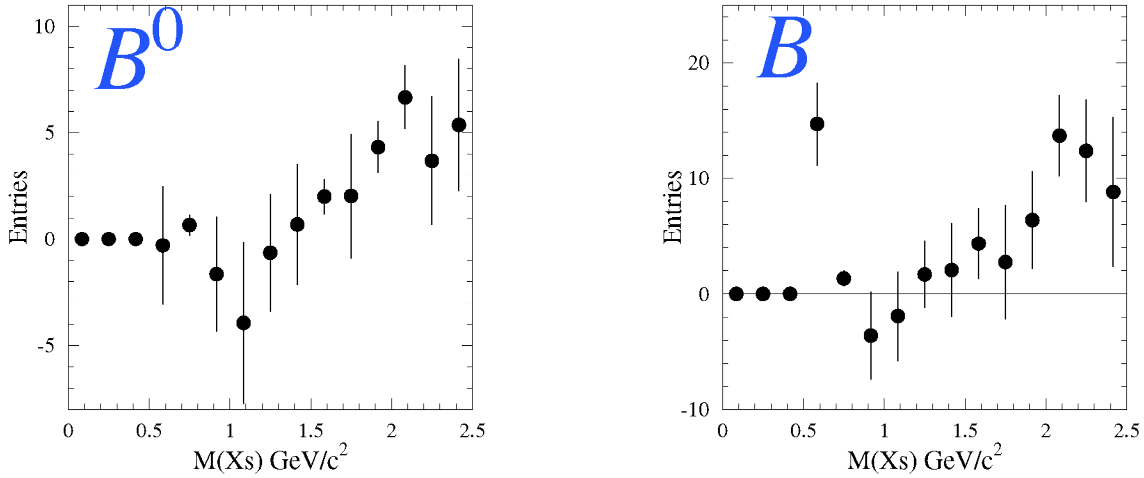


- Semi-inclusive reconstruction: $X_s = 1K + (1 \sim 4)\pi$
- Subtract continuum fraction using off-resonant data.
- $\mathcal{B} = (6.2 \pm 1.6 \pm 1.3^{+0.0}_{-1.5}) \times 10^{-4}$ PRL **81**, 1786 (1998)

  $8 \sim 9\times$ larger than $\mathcal{B}(\eta' K)$
- $\mathcal{B} = (4.6 \pm 1.1 \pm 0.4 \pm 0.5) \times 10^{-4}$ New!
- Rising spectrum on recoiled mass.

Inclusive $B \to \eta'$

BaBar
22M
hep-ex/0109034



- Confirm large BF: $\mathcal{B} = (6.8 \pm 0.7 \pm 1.0^{+0.0}_{-0.5}) \times 10^{-4}$
- Also observe the rising $M(X_s)$ distributions.
  Large yiled at $M(X_s) > 2.0$ GeV$/c^2$
- So far experimental information is still limited.
- Thorough study on the $M(X_s)$ spectrum is needed to help understand $B \to \eta'$ decay.

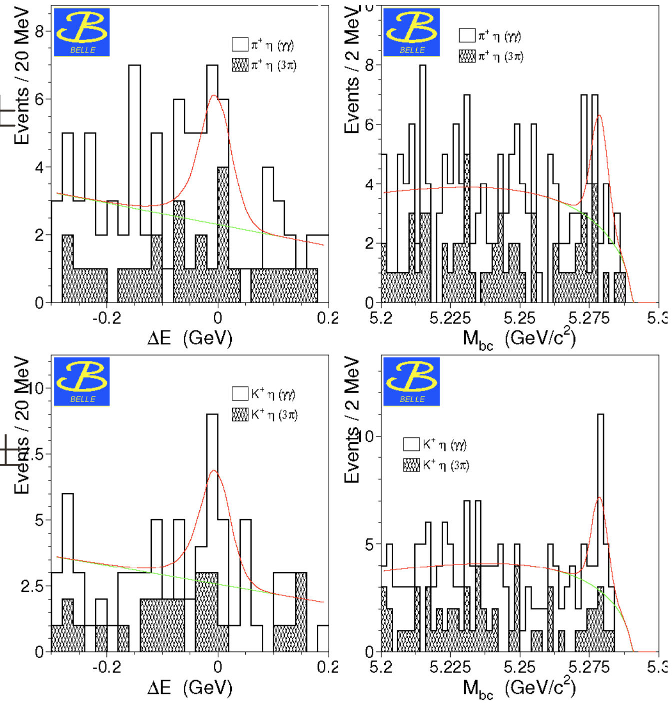
$B \to \eta h$

Belle 32M

hep-ex/0205062

$\eta\pi^{\pm}$

$\eta K^{\pm}$



BaBar 89M

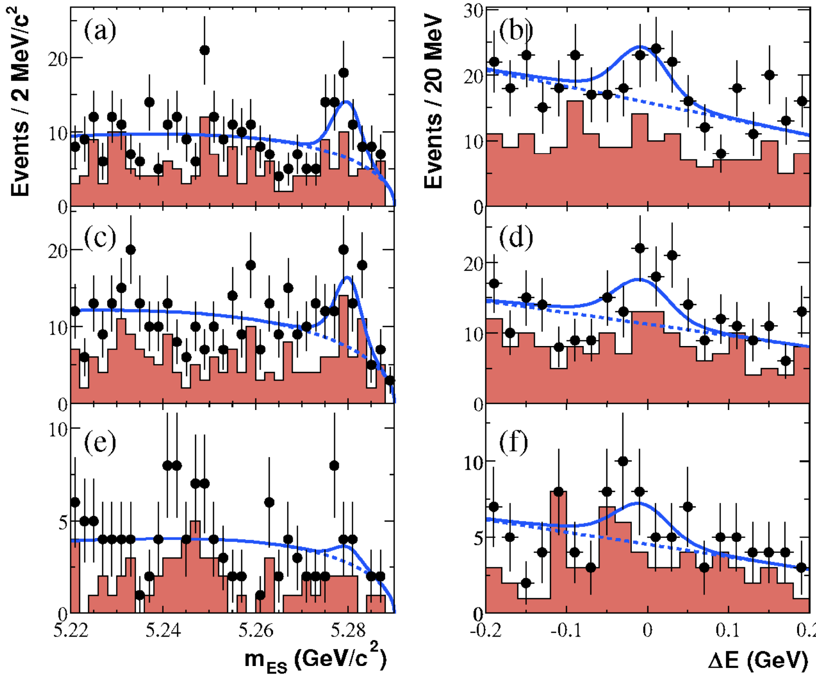
hep-ex/0303039

m_{ES} ΔE

$\eta\pi^{\pm}$

$\eta K^{\pm}$

ηK^{0}



- Clear $B^{+} \to \eta K^{+}/\pi^{+}$ signals observed by both Belle and BaBar.
- Similar $B^{+} \to \eta K^{+}$ and $B^{+} \to \eta\pi^{+}$ decay rates.

$B \to \eta h$

Expt.	# $B\overline{B}$ ($\times 10^6$)	Fit B($\times 10^{-6}$)	UL B($\times 10^{-6}$)	Signif. (σ)	Signal yield	ϵ (%)
$B^\pm \to \eta\pi^\pm$						
CLEO	10	$1.2^{+2.8}_{-1.2}$	5.7	0.6	5.7	25.0
BABAR	23	$2.2^{+1.8}_{-1.6} \pm 0.1$	5.2	1.5	8.0	15.8
Belle	32	$5.4^{+2.0}_{-1.7} \pm 0.6$	—	4.3	15.4	9.5
BABAR	89	$4.2^{+1.0}_{-0.9} \pm 0.3$	—	7.0	67.6	16.5
$B^\pm \to \eta K^\pm$						
CLEO	10	$2.2^{+2.8}_{-2.2}$	6.9	0.8	5.9	24.1
BABAR '02	23	$3.8^{+1.8}_{-1.5} \pm 0.2$	6.4	3.7	12.9	15.6
Belle	32	$5.3^{+1.8}_{-1.5} \pm 0.6$	—	4.9	16.9	10.6
BABAR	89	$4.2^{+1.0}_{-0.9} \pm 0.3$	—	6.2	48.7	17.2
$B^0 \to \eta K^0$						
CLEO	10	$0.0^{+3.2}_{-0.0}$	9.3	0.0	0.0	7.0
BABAR '02	23	$6.0^{+3.8}_{-2.9} \pm 0.4$	12.2	3.2	5.7	4.2
BABAR	89	$2.6^{+0.9}_{-0.8} \pm 0.2$	4.6	3.3	11.2	5.1

$$\mathcal{A}_{CP}(B^\pm \to \eta\pi^\pm) = -0.51^{+0.20}_{-0.18} \pm 0.01$$

$$\mathcal{A}_{CP}(B^\pm \to \eta K^\pm) = -0.32^{+0.22}_{-0.18} \pm 0.01$$ BaBar

$B \to \eta K^*$

Mode	BaBar 23 M	Belle 32 M	CLEO 10 M
$B^+ \to \eta K^{*+}$	$22.1^{+11.1}_{-9.2} \pm 3.3$	$26.5^{+7.8}_{-7.0} \pm 3.0$	$26.4^{+9.6}_{-8.2} \pm 3.3$
$B^0 \to \eta K^{*0}$	$19.8^{+6.5}_{-5.6} \pm 1.7$	$16.5^{+4.6}_{-4.2} \pm 1.2$	$13.8^{+5.5}_{-4.6} \pm 1.6$
$B^+ \to \eta \rho^+$	< 6.8	< 6.2	< 15
$B^0 \to \eta \rho^0$		< 5.5	< 10

- $\frac{\mathcal{B}(B \to \eta' K)}{\mathcal{B}(B \to \eta K^*)} \sim 4\,,$
- $\mathcal{B}(B \to \eta' K) > \mathcal{B}(B \to \eta' K^*)$
- No $\eta\rho$ signal yet!

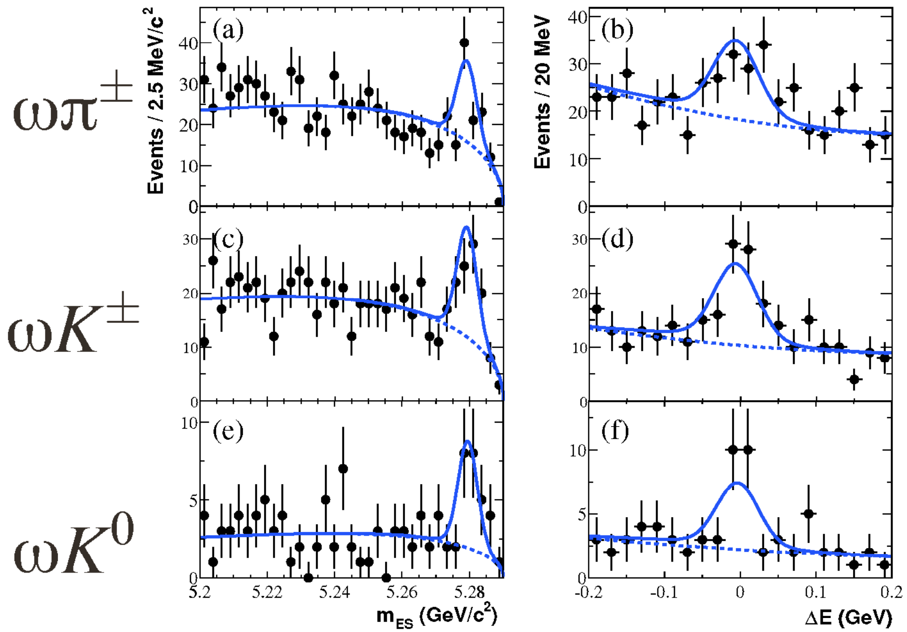
$B \to \omega h$

Expt.	# $B\overline{B}$ ($\times 10^6$)	$\mathcal{B}$ ($\times 10^{-6}$)	UL ($\times 10^{-6}$)	Signif. (σ)
$B^{\pm} \to \omega K^{\pm}$				
CLEO	10	$3.2^{+2.4}_{-1.9} \pm 0.8$	7.9	2.1
BABAR PRL	23	$1.4^{+1.3}_{-1.0} \pm 0.3$	3.3	1.6
Belle PRL	32	$9.2^{+2.6}_{-2.3} \pm 1.0$	-	6.0
$B^{\pm} \to \omega \pi^{\pm}$				
CLEO	10	$11.3^{+3.3}_{-2.9} \pm 0.8$	-	6.2
BABAR PRL	23	$6.6^{+2.1}_{-1.8} \pm 0.7$	-	5.1
Belle PRL	32	$4.2^{+2.0}_{-1.8} \pm 0.5$	8.1	3.3
$B^0 \to \omega K^0$				
CLEO	10	$10.0^{+5.4}_{-4.2} \pm 1.4$	21	3.9
BABAR ICHEP02	62	$5.9^{+1.7}_{-1.5} \pm 0.9$	-	6.6

Interesting History

- CLEO and BaBar observed $B^+ \to \omega\pi^+$ but no ωK^+
- Early CLEO saw $B^+ \to \omega K^+$ but no $\omega\pi^+$
- Belle observed $B^+ \to \omega K^+$ and hints of $\omega\pi^+$
  $\mathcal{A}_{CP}(B^+ \to \omega K^+) = -0.21 \pm 0.28 \pm 0.03$
- BaBar observed $B \to \omega K^0$!!!

BABAR Update on ωh



BaBar 89M

hep-ex/0303040

	N_S	$\mathcal{B}\,(\times 10^{-6})$	Σ
$\omega K^{\pm}$	87 ± 15	$5.0 \pm 1.0 \pm 0.4$	8.9
$\omega\pi^{\pm}$	101 ± 18	$5.4 \pm 1.0 \pm 0.5$	8.4
ωK^{0}	33^{+9}_{-8}	$5.3^{+1.4}_{-1.2} \pm 0.5$	7.5

- With 89 M $B\bar{B}$, BaBar observed both ωK and $\omega\pi$
- Central value of ωK^{+} larger than the upper limits given with 23 M $B\bar{B}$ $\Rightarrow$ statistical fluctuation!!!

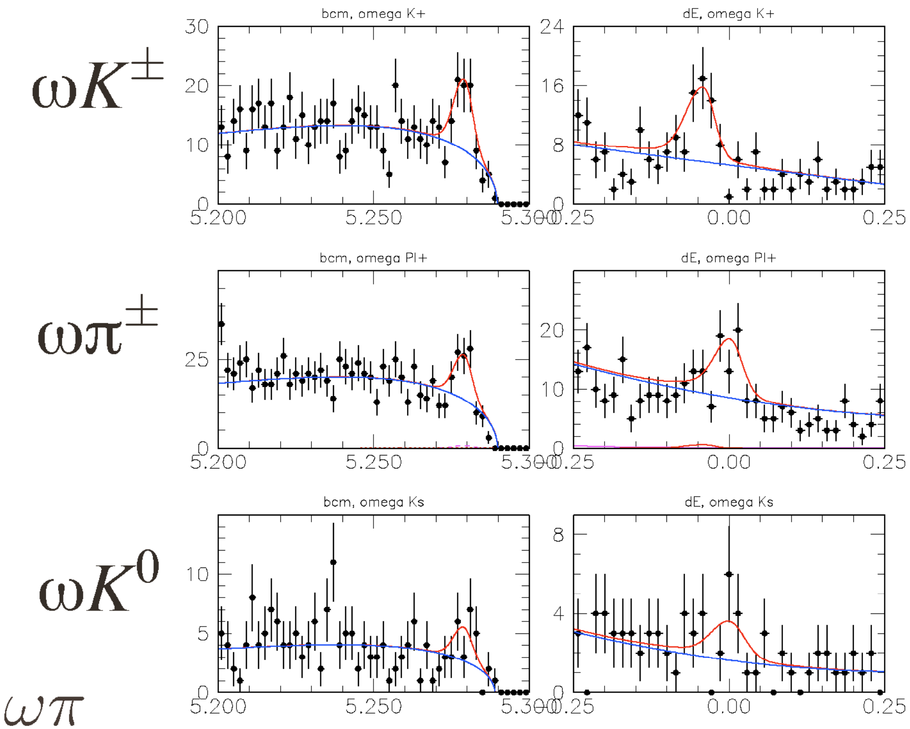
  $\mathcal{B}(B^{+} \to \omega K^{+}) = (5.0 \pm 1.0 \pm 0.4) \times 10^{-6}$ (New)

  $\mathcal{B}(B^{+} \to \omega K^{+}) < 3.3 \times 10^{-6}$ (Old)

Belle Update on ωh

Belle 85M

	N_S	$\mathcal{B}\,(\times 10^{-6})$	Σ
$\omega K^{\pm}$	$46.1^{+9.1}_{-8.4}$	$6.7^{+1.3}_{-1.2} \pm 0.6$	7.8
$\omega \pi^{\pm}$	$43.1^{+10.1}_{-9.3}$	$5.9^{+1.4}_{-1.3} \pm 0.6$	6.0
ωK^{0}	$11.1^{+5.2}_{-4.4}$	< 7.6	3.2



- 85 M $B\bar{B}$
- Observe both ωK and $\omega\pi$
- Now measurements from both experiments consistent to each other.
- Theoretical challenge to explain $\frac{\mathcal{B}(\omega K)}{\mathcal{B}(\omega\pi)} \sim 1$

$B \to \phi h$

BaBar 89M

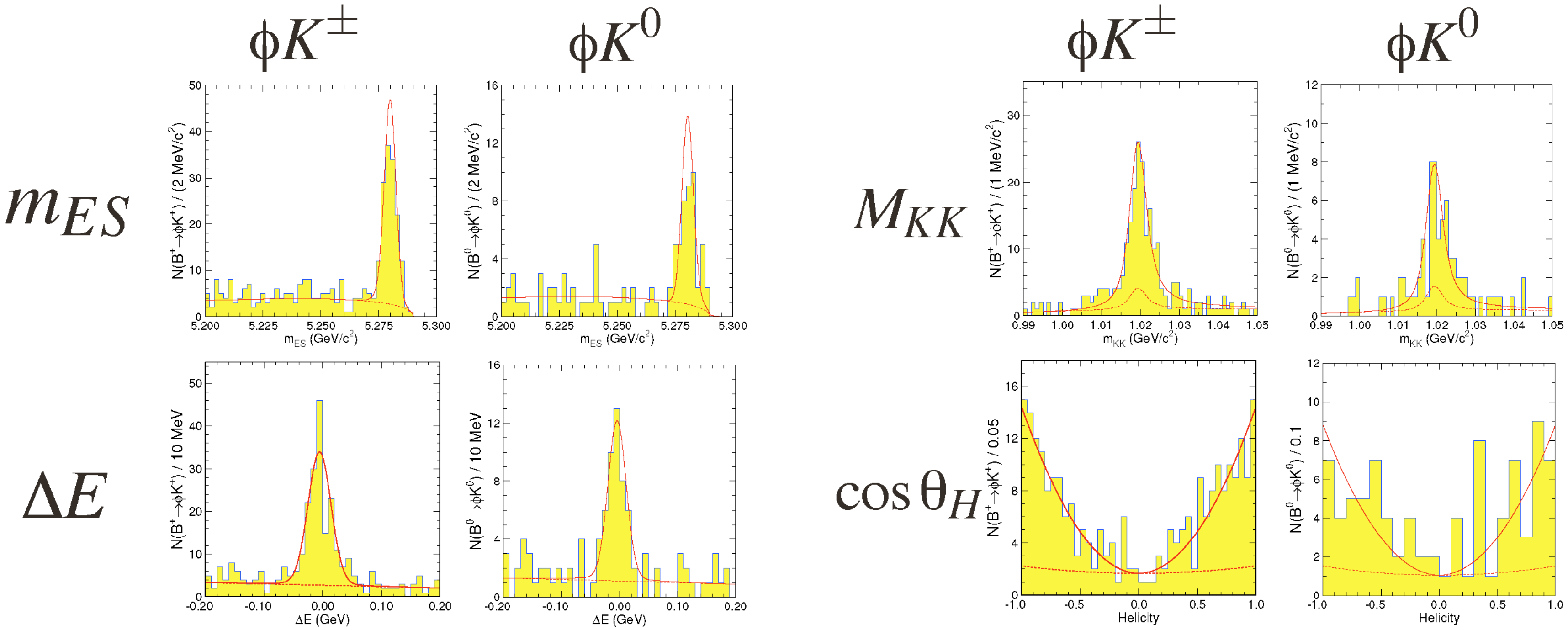
hep-ex/0303029

$$\mathcal{B}(B^{\pm} \to \phi K^{\pm}) = (10.0^{+0.9}_{-0.8}(\text{stat.}) \pm 0.5(\text{syst.})) \times 10^{-6}$$

$$\mathcal{B}(B^{0} \to \phi K^{0}) = (7.6^{+1.3}_{-1.2}(\text{stat.}) \pm 0.5(\text{syst.})) \times 10^{-6}$$

$$\mathcal{A}_{CP}(B^{\pm} \to \phi K^{\pm}) = 0.039 \pm 0.086(\text{stat.}) \pm 0.011(\text{syst.})$$

CKM– and color-suppressed $\mathcal{B}(B^{\pm} \to \phi\pi^{\pm}) < 0.41 \times 10^{-6}$ (90% CL)



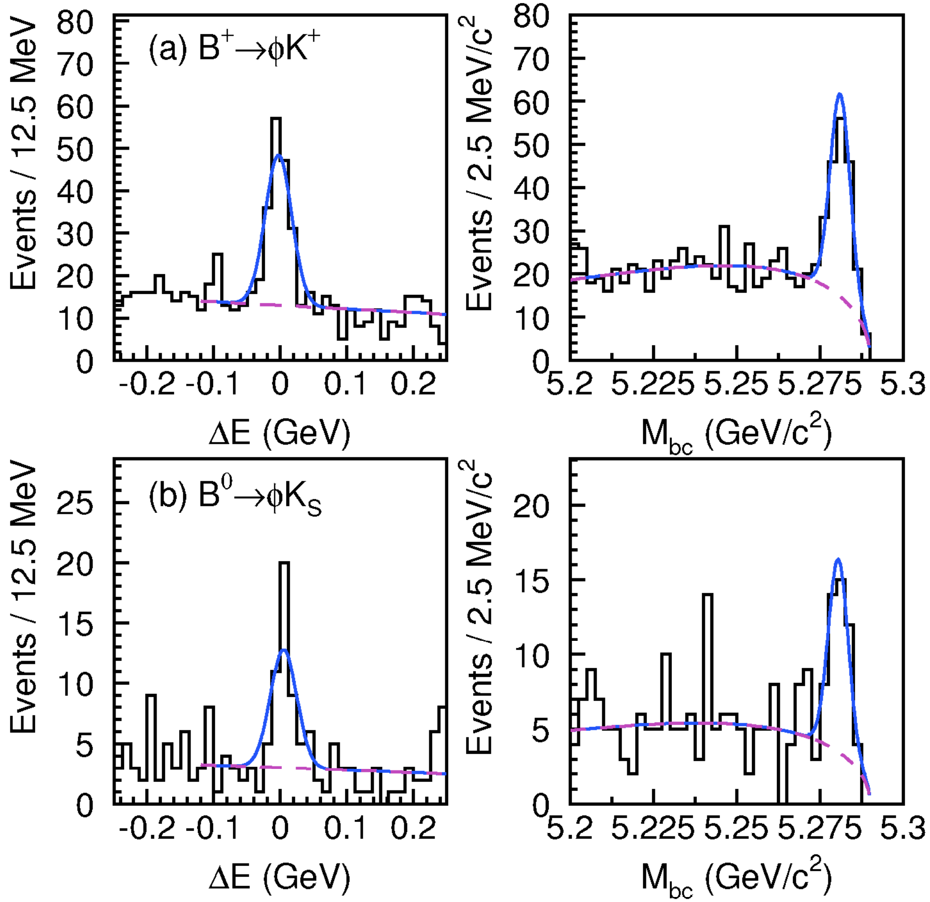
$B \to \phi h$

Belle 85M

$$\mathcal{B}(B^\pm \to \phi K^\pm) = (9.4 \pm 1.1(stat.) \pm 0.7(syst.)) \times 10^{-6}$$
$$\mathcal{B}(B^0 \to \phi K^0) = (9.0^{+2.2}_{-1.8}(stat.) \pm 0.7(syst.)) \times 10^{-6}$$
$$\mathcal{A}_{\mathcal{CP}}(B^\pm \to \phi K^\pm) = 0.01 \pm 0.12(stat.) \pm 0.05(syst.)$$

$\phi K^\pm$

ϕK^0



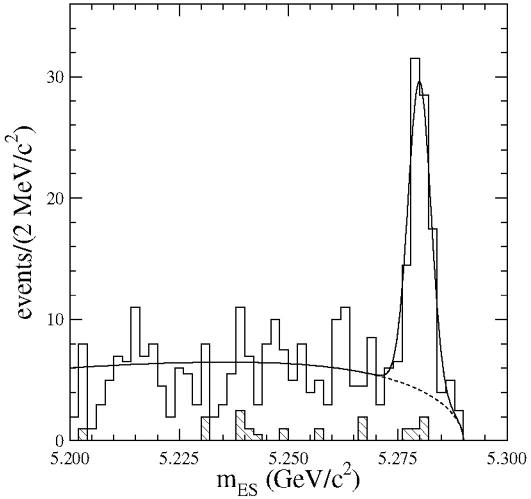
$B \to \phi K^*$

BaBar 89M

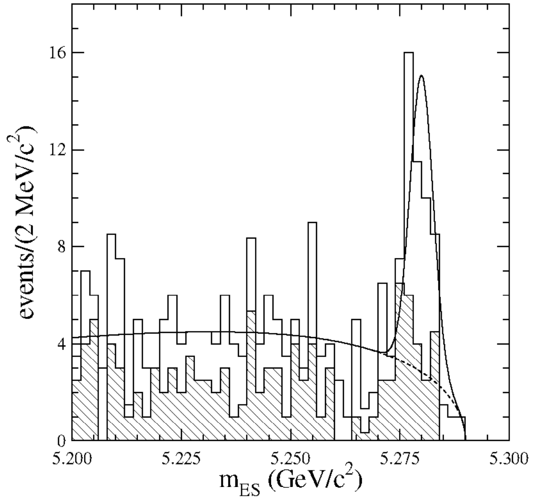
hep-ex/0303020

m_{ES}

ϕK^{*0}



$\phi K^{*\pm}$



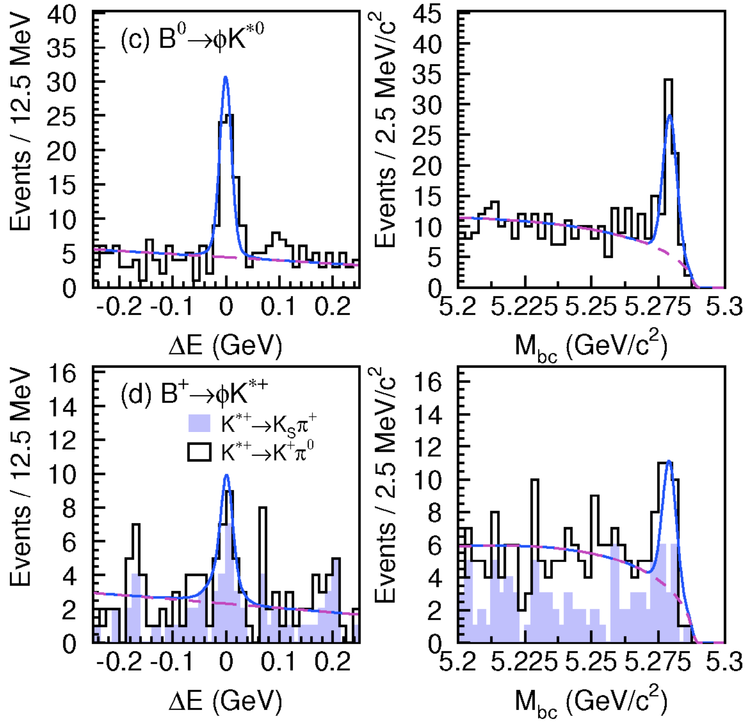
Mode	$\mathcal{B}$ $(\times 10^{-6})$	$\mathcal{A}_{CP}$	f_L
ϕK^{*+}	$12.1\ ^{+2.1}_{-1.9} \pm 1.5$	$+0.16 \pm 0.17 \pm 0.04$	$0.46 \pm 0.12 \pm 0.05$
ϕK^{*0}	$11.1\ ^{+1.3}_{-1.2} \pm 1.1$	$+0.04 \pm 0.12 \pm 0.02$	$0.65 \pm 0.07 \pm 0.04$

$B \to \phi K^*$

Belle 85M

ϕK^{*0}

$\phi K^{*\pm}$



$$\mathcal{B}(B^0 \to \phi K^{*0}) = (10.0^{+1.6}_{-1.5}) \times 10^{-6}$$

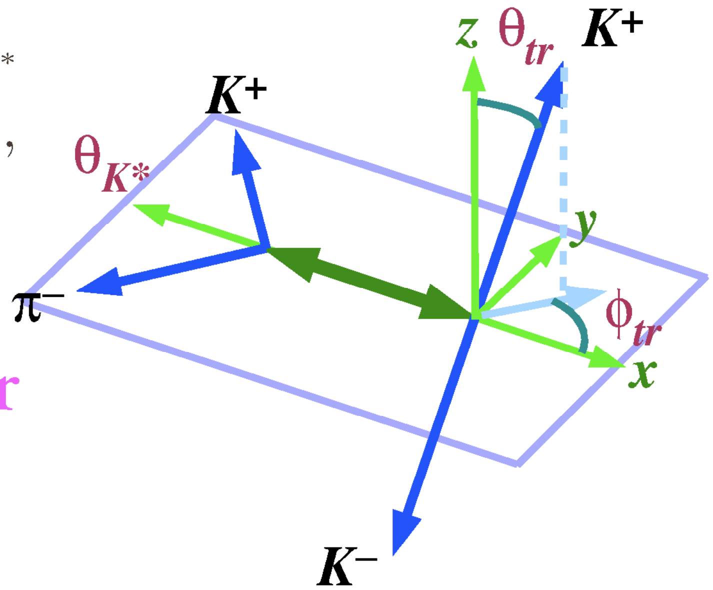
$$\mathcal{B}(B^+ \to \phi K^{*+}) = (6.7^{+2.1+0.7}_{-1.9-1.0} \times 10^{-6}$$

$$A_{CP}(B^0 \to \phi K^{*0}) = 0.07 \pm 0.15^{+0.05}_{-0.03}$$

$$A_{CP}(B^+ \to \phi K^{*+}) = -0.13 \pm 0.29^{+0.08}_{-0.11}$$

Angular analysis on ϕK^*

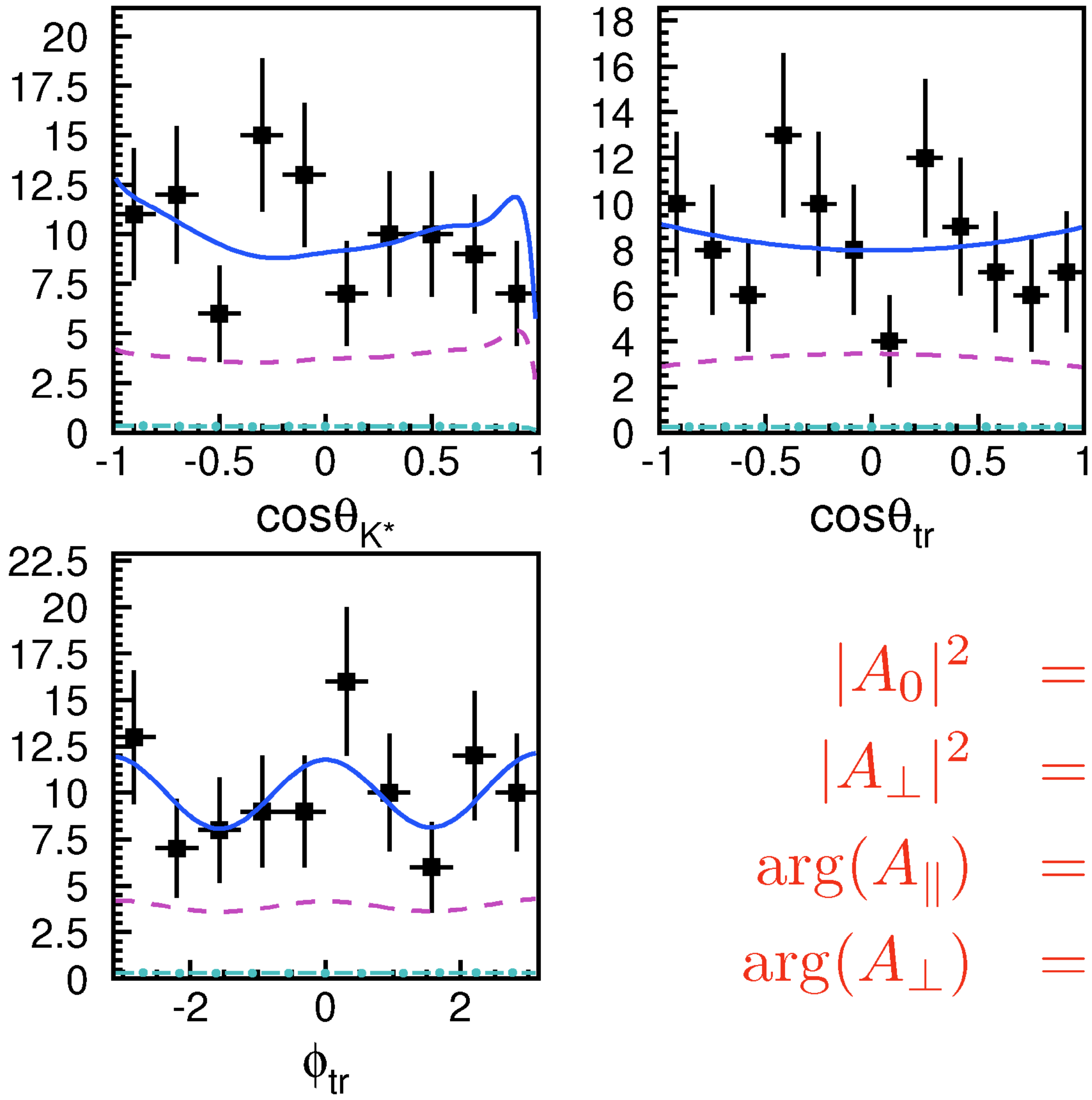
$$\frac{d^3\Gamma(\phi_{\rm tr},\cos\theta_{\rm tr},\cos\theta_{K^*})}{d\phi_{\rm tr}d\cos\theta_{\rm tr}d\cos\theta_{K^*}} = \frac{9}{32\pi}[|A_\perp|^2 2\cos^2\theta_{\rm tr}\sin^2\theta_{K^*}$$
$$+ |A_\parallel|^2 2\sin^2\theta_{\rm tr}\sin^2\phi_{\rm tr}\sin^2\theta_{K^*}$$
$$+ |A_0|^2 4\sin^2\theta_{\rm tr}\cos^2\phi_{\rm tr}\cos^2\theta_{K^*}$$
$$+ \sqrt{2}{\rm Re}(A_\parallel^* A_0)\sin^2\theta_{\rm tr}\sin 2\phi_{\rm tr}\sin 2\theta_{K^*}$$
$$- \eta\sqrt{2}{\rm Im}(A_0^* A_\perp)\sin 2\theta_{\rm tr}\cos\phi_{\rm tr}\sin 2\theta_{K^*}$$
$$- 2\eta{\rm Im}(A_\parallel^* A_\perp)\sin 2\theta_{\rm tr}\sin\phi_{\rm tr}\sin^2\theta_{K^*}]\ ,$$



- Belle perform an angular analysis to study the helicity states

Angular analysis on ϕK^*

Belle 85M



$$|A_0|^2 = 0.43 \pm 0.09 \pm 0.04$$

$$|A_\perp|^2 = 0.41 \pm 0.10 \pm 0.04$$

$$\arg(A_\parallel) = -2.57 \pm 0.39 \pm 0.09$$

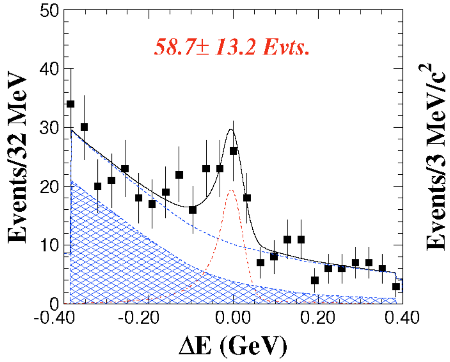
$$\arg(A_\perp) = 0.48 \pm 0.32 \pm 0.06$$

$B^{\pm} \to \rho^{\pm}\rho^{0}$

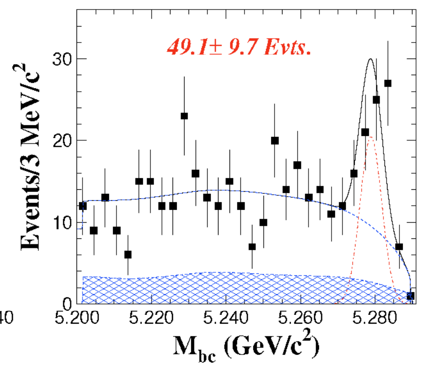
Belle 85M

First Observation

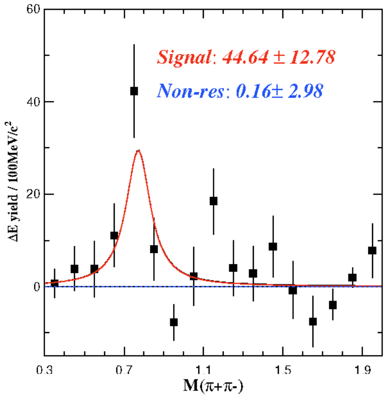
ΔE



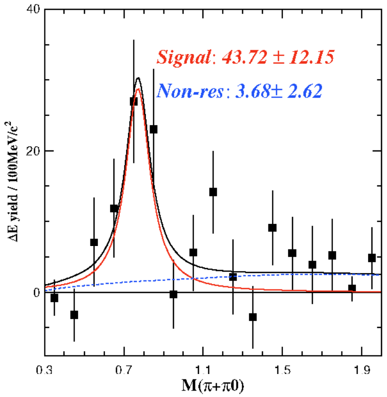
M_{bc}



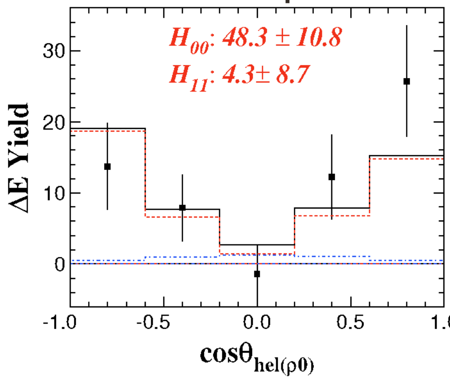
$M_{\pi^+\pi^-}$



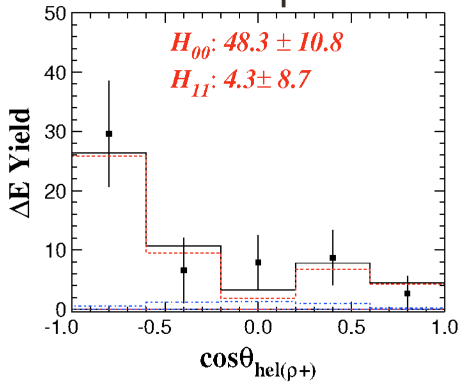
$M_{\pi^+\pi^0}$



$\cos\theta_{\rho^0}$



$\cos\theta_{\rho^+}$



$$\frac{\Gamma_L}{\Gamma} = (94.8 \pm 10.6 \pm 2.1)\%$$

$$\mathcal{B}(B^{\pm} \to \rho^0\rho^{\pm}) = (31.7 \pm 7.1^{+3.7}_{-6.4}{}^{+1.0}_{-2.1}\,(\mathrm{pol})) \times 10^{-6}$$

Significance 5.3σ

$$\mathcal{A}_{CP}(B^{\pm} \to \rho^0\rho^{\pm}) = (0.1 \pm 22.4^{+2.6}_{-2.8}\%$$

$B^{\pm} \rightarrow \rho^0 K^{*\pm}$

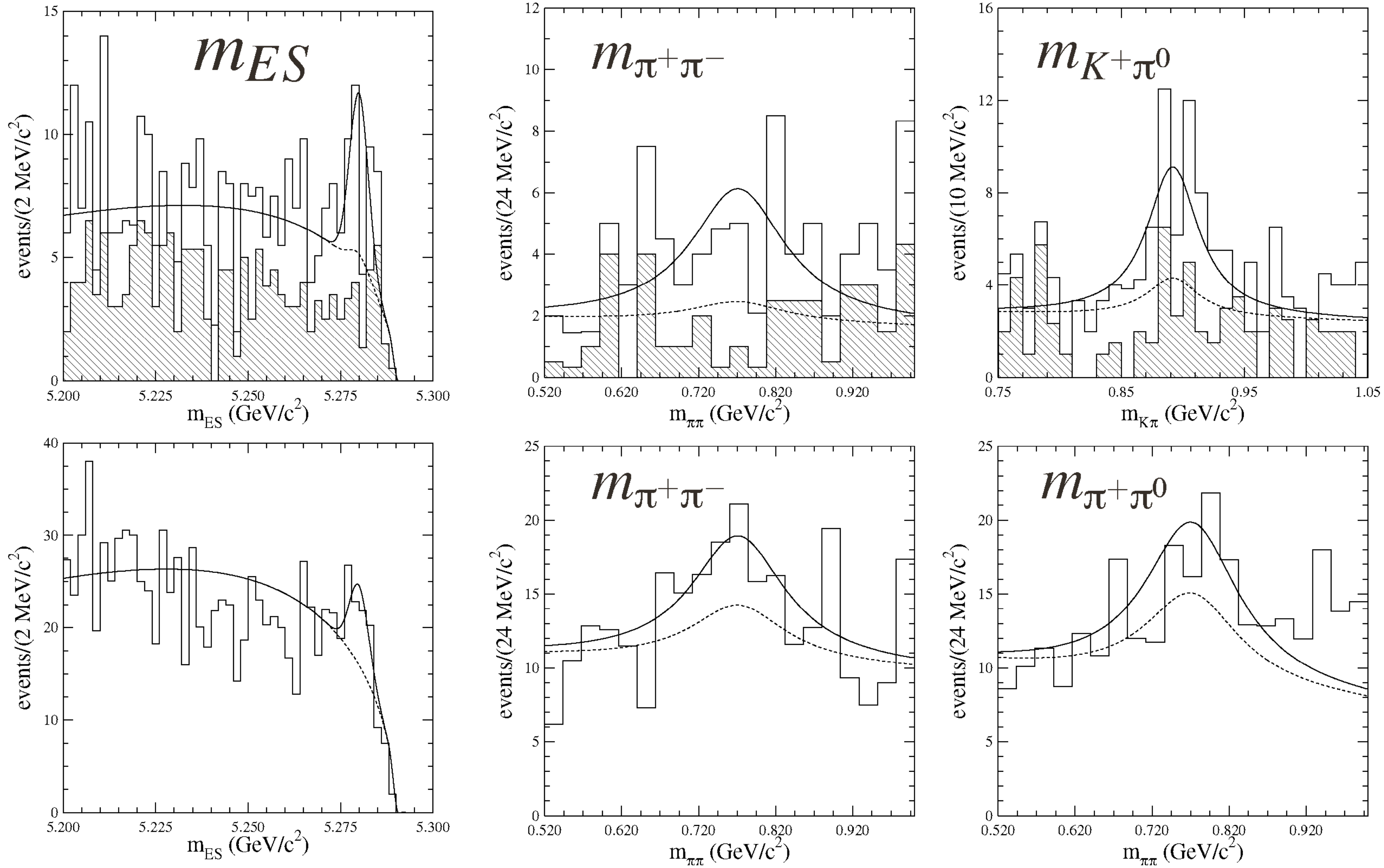
BaBar 89M

hep-ex/0303020

First Observation

$\rho^0 K^{*\pm}$

$\rho^0 \rho^{\pm}$



$B^{\pm} \to \rho^0 K^{*\pm}, \rho^0 \rho^{*\pm}$

BaBar 89M
hep-ex/0303020

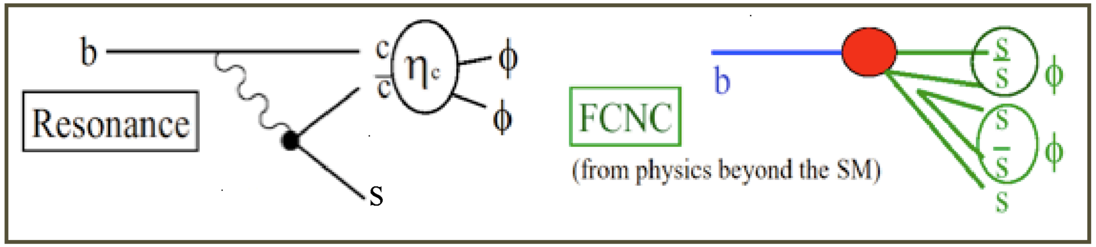
Mode	ε	$\varepsilon_{\rm tot}$	$n_{\rm sig}$	$\mathcal{B}$ $(\times 10^{-6})$
$\rho^0 K^{*+}$	–	8.4	–	$7.7^{+2.1}_{-2.0} \pm 1.4$
$\to K^0\pi^+$	21.0	4.8	$44.4^{+12.5}_{-11.4} \pm 3.4$	$10.4^{+2.9}_{-2.7} \pm 1.7$
$\to K^+\pi^0$	10.9	3.6	$9.1^{+11.1}_{-9.6} \pm 5.2$	$2.9^{+3.5}_{-3.0} \pm 1.8$
$\rho^0\rho^+$	11.3	11.1	$97.5^{+26.1}_{-24.3} \pm 12.1$	$9.9^{+2.6}_{-2.5} \pm 2.5$

- $\mathcal{B}(B^+ \to \rho^0 \rho^{*+})$ measurements between Belle and BaBar are not consistent to each other.

$B \to \phi\phi K$

- Brand new decay channel: First $b \to s\bar{s}s\bar{s}s$
- $b \to ss\bar{s}$ decays, $B \to KK\overline{K}$, ϕK, are sizable
  $\Rightarrow$ Understading $s\bar{s}$ popping
- Possible large DCPV from New Physics
  $\Rightarrow$ Interference with $\eta_c(\to \phi\phi)K$

M. Hazumi hep-ph/0303089



- Glueball search in B Physics:

Chua, Hou, Tsai, PLB'02

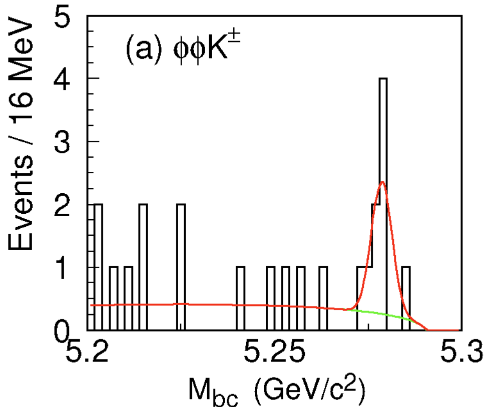
  – $B \to Glueball(\to \phi\phi) + K$

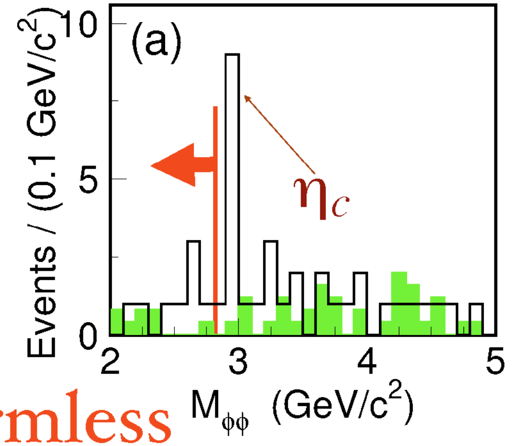
$B \to \phi\phi K$

Belle 85M

hep-ex/0305068, submitted to PRL

First Observation





Charmless

- Charmless region: $M_{\phi\phi} < 2.85$ GeV
- Yields: $7.3^{+3.2}_{-2.5}$ with significance of 5.1σ.

  $\Rightarrow \mathcal{B}(B^{\pm} \to \phi\phi K^{\pm}) = (2.6^{+1.1}_{-0.9} \pm 0.3) \times 10^{-6}$
- Combining K^0_S mode, yields: $8.7^{+3.6}_{-2.9}$ with significance of 5.3σ

  $\Rightarrow \mathcal{B}(B \to \phi\phi K) = (2.3\ ^{+0.9}_{-0.8} \pm 0.3) \times 10^{-6}$ (assumed isospin symmetry)

Summary

- With successful running of B factories, precise and new measurements on rare decays become available.

- B decays to η, η':
  - $\mathcal{B}(\eta' K) : \mathcal{B}(\eta K^*) : \mathcal{B}(\eta K) \sim 16 : 4 : 1$
  - No signals on $\eta^{(\prime)}\pi/\rho$ and $\eta' K^*$
  - Large enhancement on $M(X_S) > 2$ GeV in $B \to \eta' X_S$

Summary II

- B decays to ω, ϕ:
  - $\mathcal{B}(\omega K) \sim \mathcal{B}(\omega\pi) \sim (5-6) \times 10^{-6}$
    Experimantal results finally agree with each other
  - Precise measurements on $\mathcal{B}(B \to \phi K^{(*)})$
  - Both CP-even and CP-odd are sizeable in ϕK^*

Summary III

- B decays to VV:
  - First observation of $B \to \rho^+\rho^0$ by Belle

    $\mathcal{B} = (31.7 \pm 7.1^{3.7+1.0}_{-6.4-2.1}) \times 10^{-6}; \quad \Gamma_L/\Gamma \sim 1$

    BaBar $\mathcal{B} = (9.9^{+2.6}_{-2.5} \pm 2.5) \times 10^{-6}$
  - First observation of $B \to K^{*+}\rho^0$ by BaBar
- First observation of $b \to s\bar{s}s\bar{s}s$ transistion by Belle.
- No A_{CP}, except maybe for BaBar

  $A_{CP}(\eta\pi^\pm) = -0.51^{+0.20}_{-0.18} \pm 0.01$

Direct CP Violation

- Partial-rate asymmetry

$$A_{CP} \equiv \frac{\Gamma(\overline{B} \to \overline{f}) - \Gamma(B \to f)}{\Gamma(\overline{B} \to \overline{f}) + \Gamma(B \to f)}$$

$$= \frac{2|P||T| \sin \Delta\phi \sin \Delta\delta}{|P|^2 + |T|^2 + 2|P||T| \cos \Delta\phi \cos \Delta\delta}$$

  - Interference between Tree and Penguin diagrams
    - $T(P)$: Amplitude of Tree (Penguin) diagram
    - $\Delta\phi(\Delta\delta)$: differences in weak (strong) phases between Tree and Penguin
  - DCPV in B decays has not been observed yet.
  - Sensitive to new physics contribution in penguin loop.