Charmless Hadonic Two-body B Meson Decays with Belle (and BABAR)

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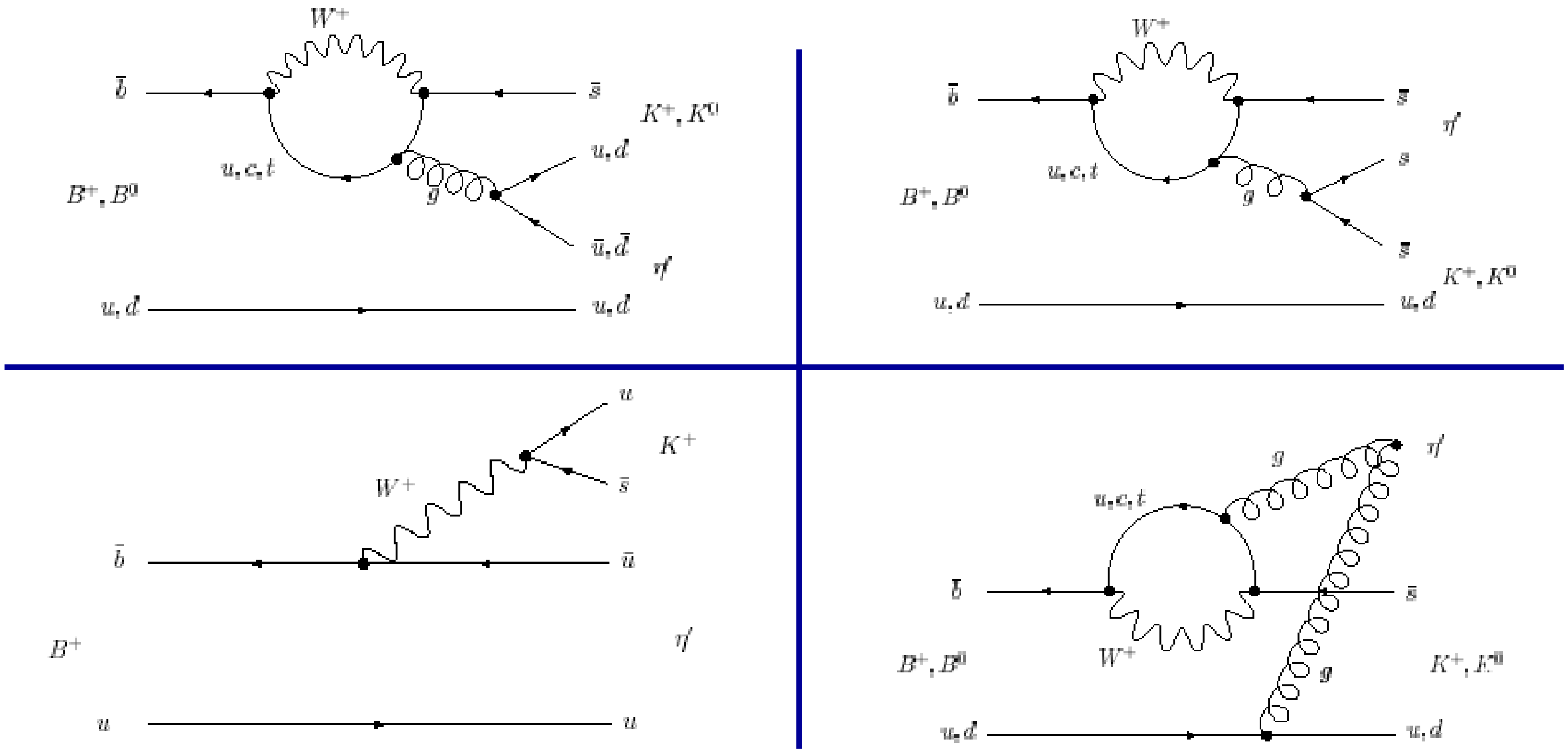
Introduction

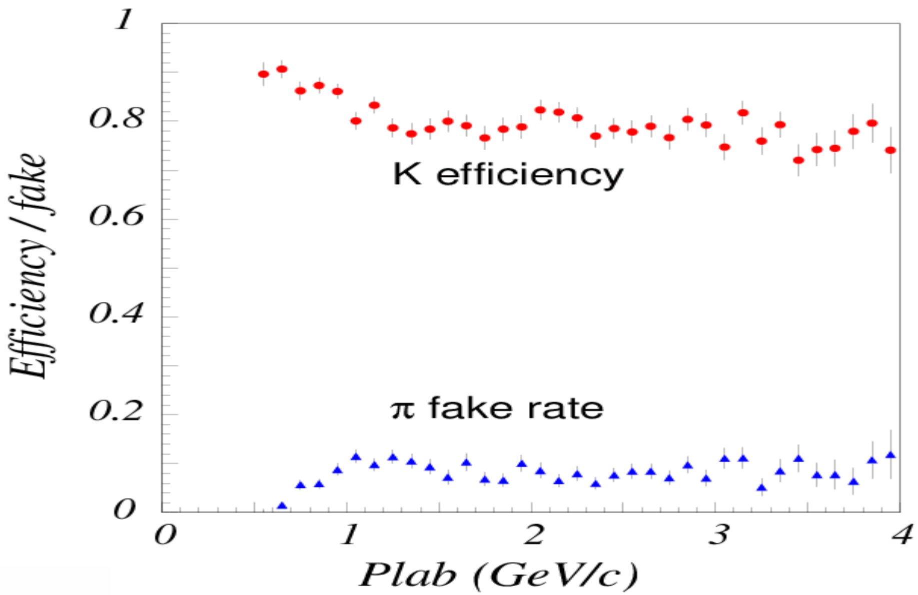
- Charmless Hadronic Two Body B decays provide rich information about DCPV and CKM.
- Interference between "Tree" and "Penguin" diagrams.

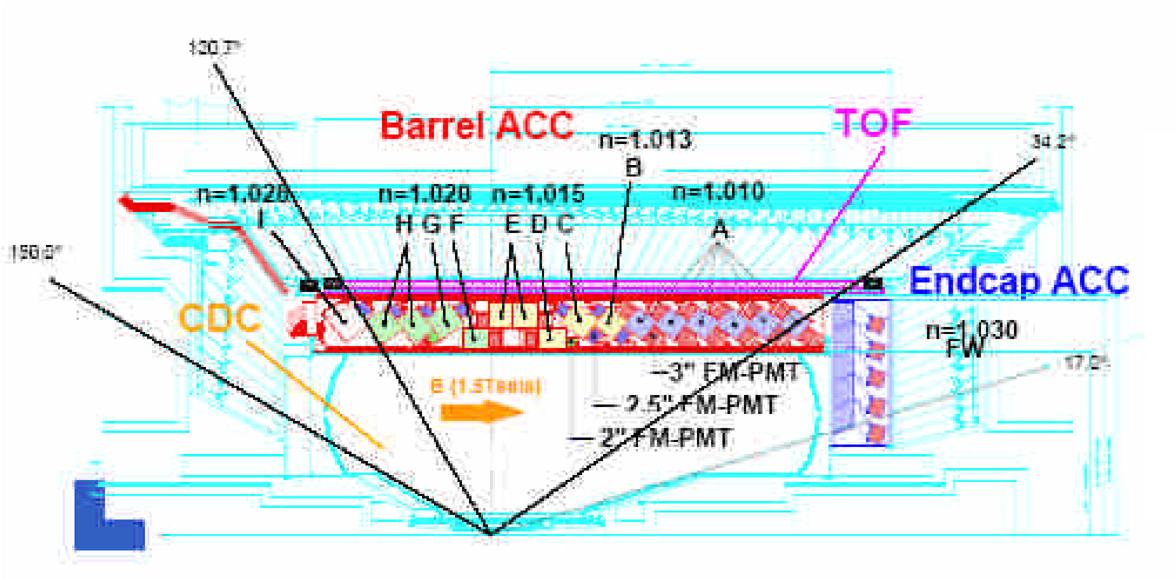


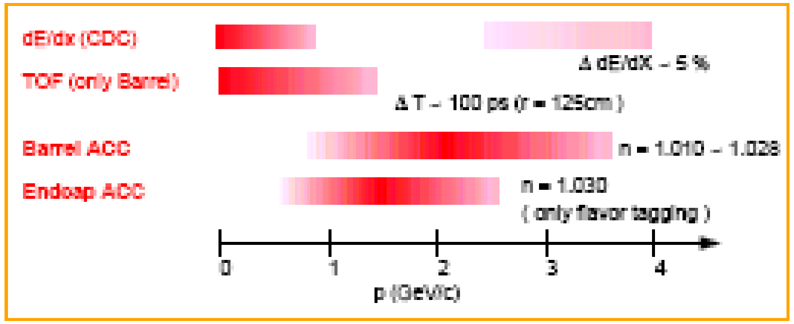
Belle Detector

Belle uses Aerogel+ToF+dE/dx information for particle ID

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







General Information

- Data Set: 357 fb^{-1} @ $\Upsilon(4S)$

  386×10^6 BBar Pairs

- Particle Reconstruction:

  Ks $\rightarrow \pi^+\pi^-$ with vertex displaced and mass cuts.

  π^0 identified by combining two γ**'s** with energy cut and constrained to nominal mass.

  $\eta \rightarrow \gamma\gamma$, $\eta \rightarrow \pi^+\pi^-\pi^0$

  $\eta' \rightarrow \eta\pi^+\pi^-$, $\eta' \rightarrow \rho^0\gamma$

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

- DCPV: Acp

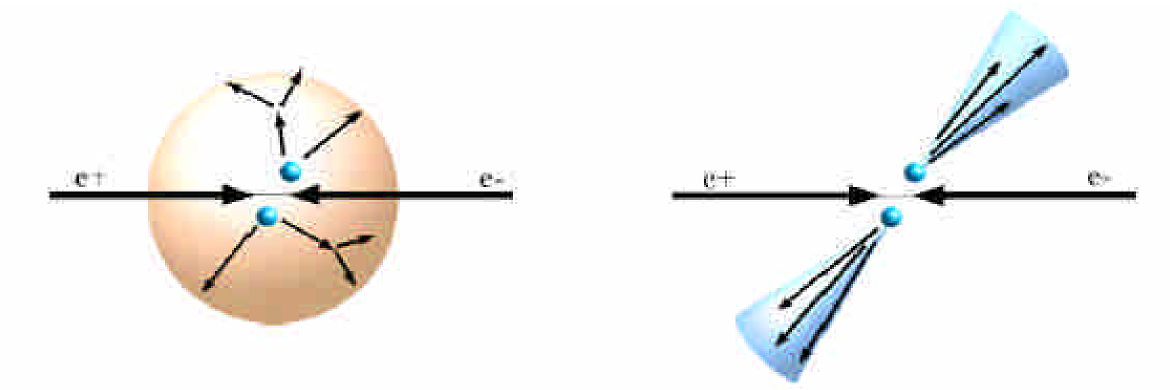
$$A_{CP} = \frac{N(\overline{B} \rightarrow \overline{f}) - N(B \rightarrow f)}{N(\overline{B} \rightarrow \overline{f}) + N(B \rightarrow f)}$$

Analysis Method/Background Suppression(I)

Main background for hadronic rare B is continuum events

$$e^+e^- \rightarrow \gamma^* \rightarrow q\bar{q} \qquad (q=u,d,s,c)$$

Topology of continuum events and B decays are different.



Event shape variables are used:

Modified Fox-Wolfram moment

$$R_l^{so} = \frac{\sum_{i,k} |\vec{p}_i||\vec{p}_k| P_l(\cos\theta_{ik})}{\sum_{i,k} |\vec{p}_i||\vec{p}_k|} \qquad R_l^{oo} = \frac{\sum_{i,j} |\vec{p}_i||\vec{p}_j| P_l(\cos\theta_{ij})}{\sum_{i,j} |\vec{p}_i||\vec{p}_j|}$$

Analysis Method/Background Suppression(II)

θ_{Thrust} : angle between thrust axis of B candidate daughter particles and that of the rest of the particles in an event

$S_{\perp}$: scalar sum of the transverse momentum of all particles outside a 45° cone around the trust axis of the B candidates divided by the scalar sum of their momenta

Choose $|\cos\theta_{Thrust}|$ $S_{\perp}$ R_2^{so} R_4^{so} R_2^{oo} R_3^{oo} R_4^{oo} as inputs to form a Fisher function. Use Fisher discriminant to optimize the coefficients.

$$F = \sum_{i=2,3,4} \alpha_i R_i^{oo} + \sum_{i=2,4} \beta_i R_i^{so} + \gamma \, |\cos\theta_{Thrust}| + \delta S_{\perp}$$

Combine F with $\cos\theta_B$ to form the likelihood and calculate the Likelihood Ratio.

$$\mathcal{LR} = \frac{\mathcal{L}_s}{\mathcal{L}_s + \mathcal{L}_b}$$

θ_B: angle between the flight direction of the B candidate and the beam direction

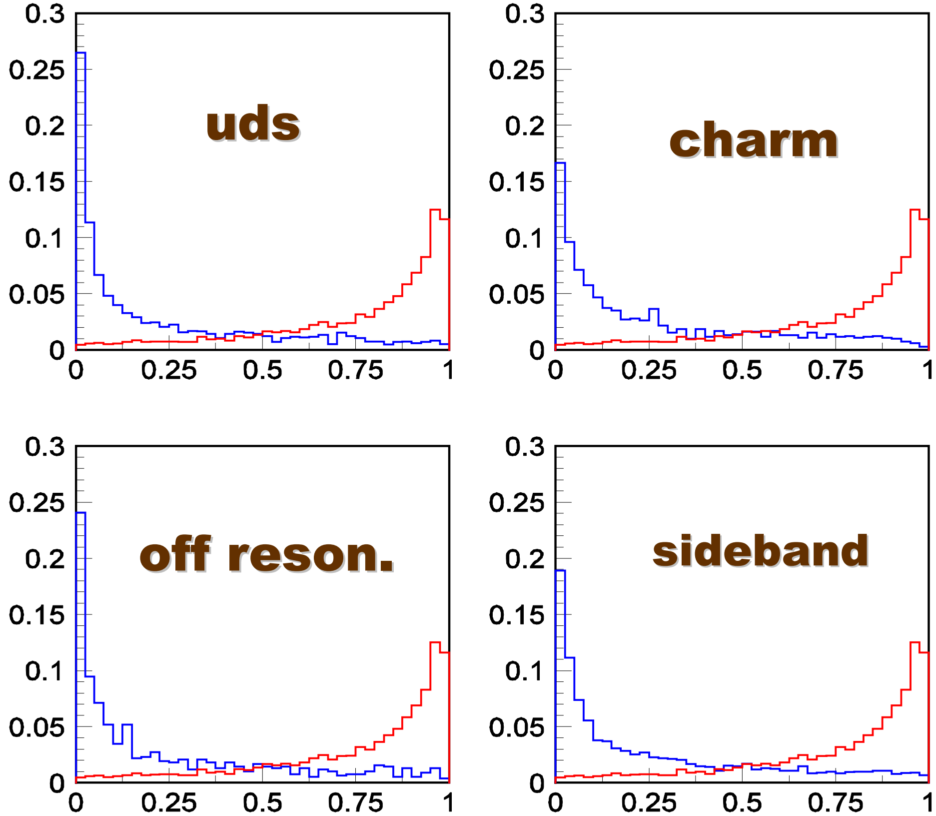
Analysis Method/Likelihood Ratio ($\mathcal{LR}$)

$$\mathcal{LR} = \frac{\mathcal{L}_s}{\mathcal{L}_s + \mathcal{L}_b}$$

~ 75% efficiency

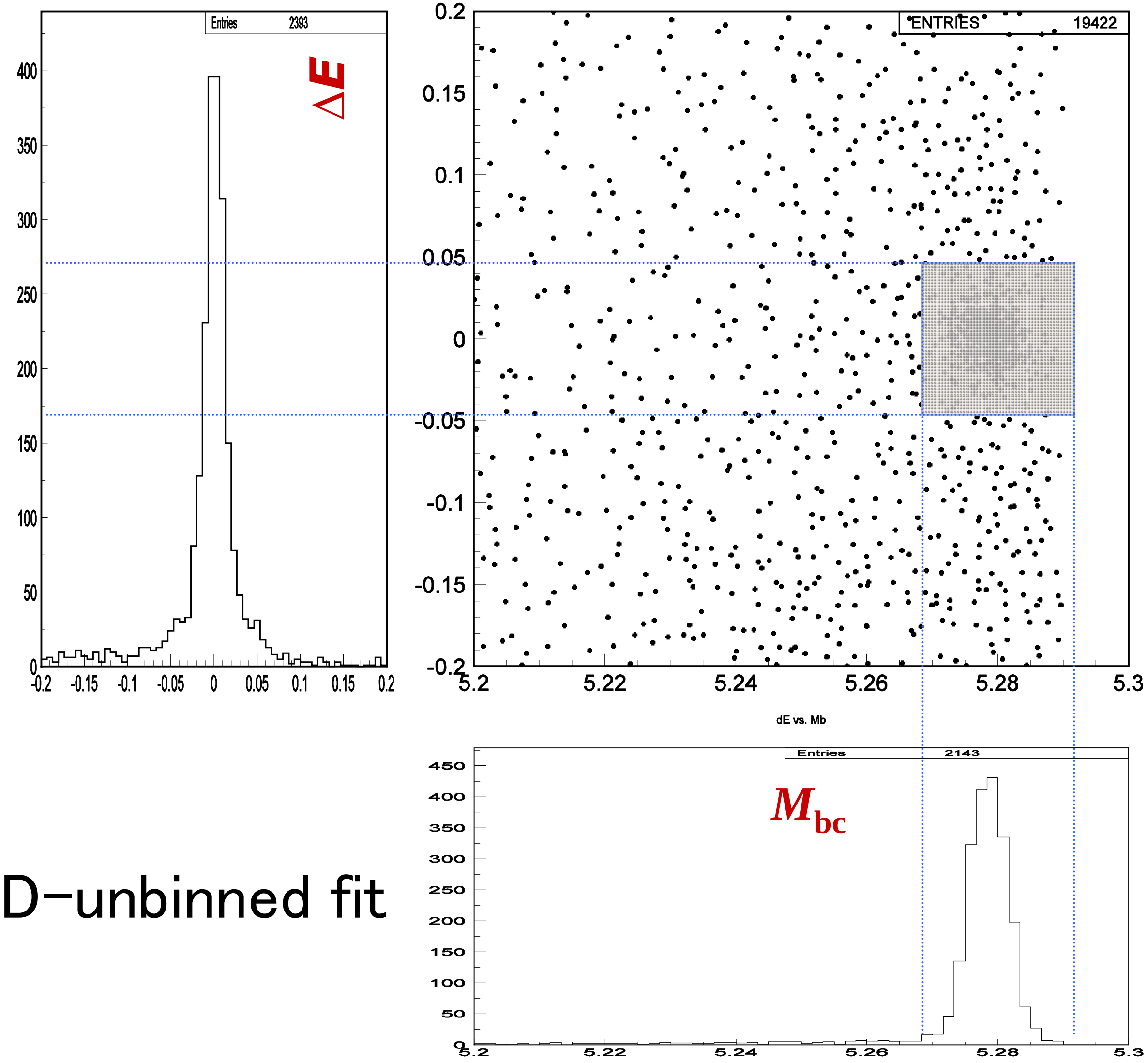
~ 80% bg rejection

with LR > 0.5



Cont. supp. *LR* s are optimized with sig. MC and data sideband

Analysis Method / B Signal Reconstruction

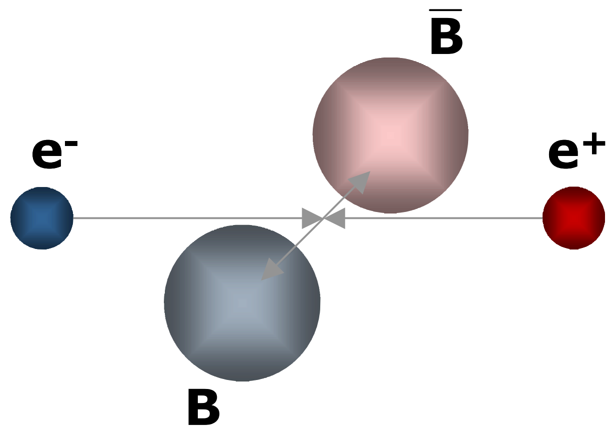


2D-unbinned fit

In $\Upsilon(4S)$ rest frame:

$$M_{\rm bc} = \sqrt{E_{\rm beam}^2 - p_B^2}$$

$$\Delta E = E_B - E_{\rm beam}$$



Analysis Method / B Yields Extraction

B signal yields and partial asymmetries (Acp) are obtained simultaneously from an extended unbinned maximum-likelihood fit with input variables M_{bc} and $\triangle E$ after LR cut.

$$\mathcal{L} = \exp^{-\sum_j N_j} \times \prod_i (\sum_j N_j \mathcal{P}_j)$$

$$\mathcal{P}_j = \frac{1}{2}[1 - q_i \cdot \mathcal{A}_{CPj}] P_j(M_{bci}, \Delta E_i)$$ **for flavor specific B decay mode.**

q indicates the B meson flavor. ***q*** = +1 (-1) for B^+ (B^-)

For the neutral B modes, $\mathcal{P}_j = P_j(M_{bci}, \Delta E_i)$

For BABR, they use *F* as well as particles ($\eta^{(\prime)}$,ω) mass as input variables for likelihood fit.

$$\mathcal{P}^{\,i}_{jk} = \mathcal{P}_j({m_{\rm ES}}^i)\mathcal{P}_j(\Delta E^i_k[, S^i_k])\mathcal{P}_j(\mathcal{F}^i)\mathcal{P}_j(m^i_{\rm res}[, \mathcal{H}^i])$$

Analysis Method / Systematics

Systematic uncertainties mainly come from

- Charged tracking, neutral cluster reconstructing
- LR cuts and fitting function PDFs
- K^+ and π^+ feed across
- Particle secondary decay branching fractions (Bs)

$B \to \eta' K/\pi$ (I)

- Unexpectedly large BF first observed (CLEO1997/98):

Present Status:	BABAR(2005)	CLEO(2000)
BF($B \to \eta' K^+$) ($\times 10^{-6}$):	$68.9 \pm 2.0 \pm 3.2$	$80^{+10}_{-9} \pm 7$
BF($B \to \eta' K^0$) ($\times 10^{-6}$):	$67.4 \pm 3.3 \pm 3.2$	$89^{+18}_{-16} \pm 9$
BF($B \to \eta' \pi^+$) ($\times 10^{-6}$):	$4.0 \pm 0.8 \pm 0.4$	$1.0^{+5.8}_{-1.0}$

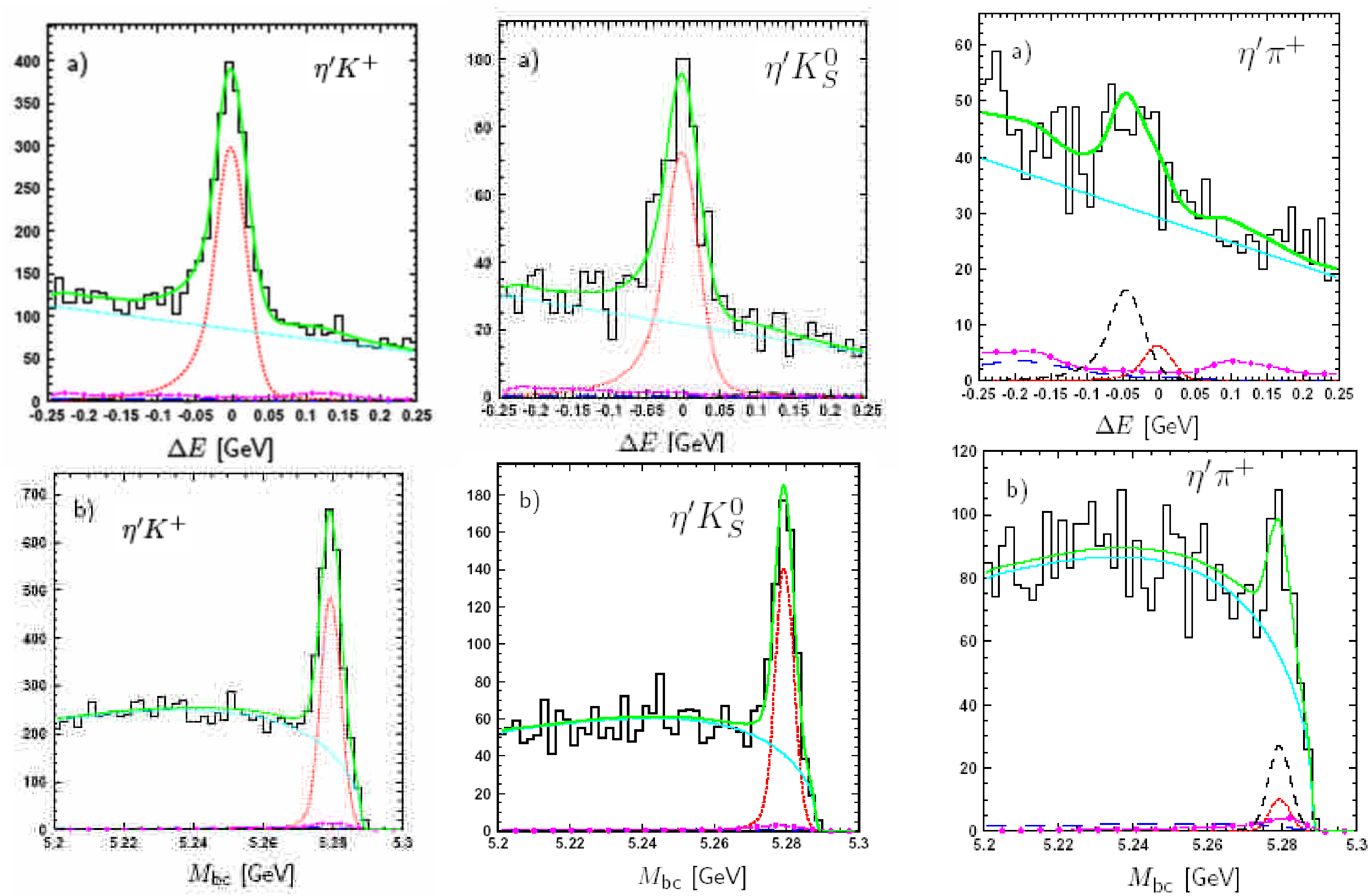
- Belle update η' results with 35 times more data than the previous one in summer 2005 (hep-ex/0509016)
- BF($B \to \eta' K^+$) ($\times 10^{-6}$): $68.6 \pm 2.1 \pm 3.6$ / $N_S = 1952 \pm 61$ / $\chi^2/N = 1.14$ (gof)
- BF($B \to \eta' K^0$) ($\times 10^{-6}$): $56.6 \pm 3.6 \pm 3.3$ / $N_S = 520 \pm 33$ / $\chi^2/N = 1.51$ (gof)
- BF($B \to \eta' \pi^+$) ($\times 10^{-6}$): $1.73\,^{+0.69}_{-0.63} \pm 0.10$ / $N_S = 37.7 \pm 14.4$ / $\chi^2/N = 1.16$ (gof) / $\sigma = 3.0$
- $A_{cp}(\eta' K^+) = 0.029 \pm 0.028 \pm 0.021$; $A_{cp}(\eta' \pi^+) = 0.029 \pm 0.028 \pm 0.021$

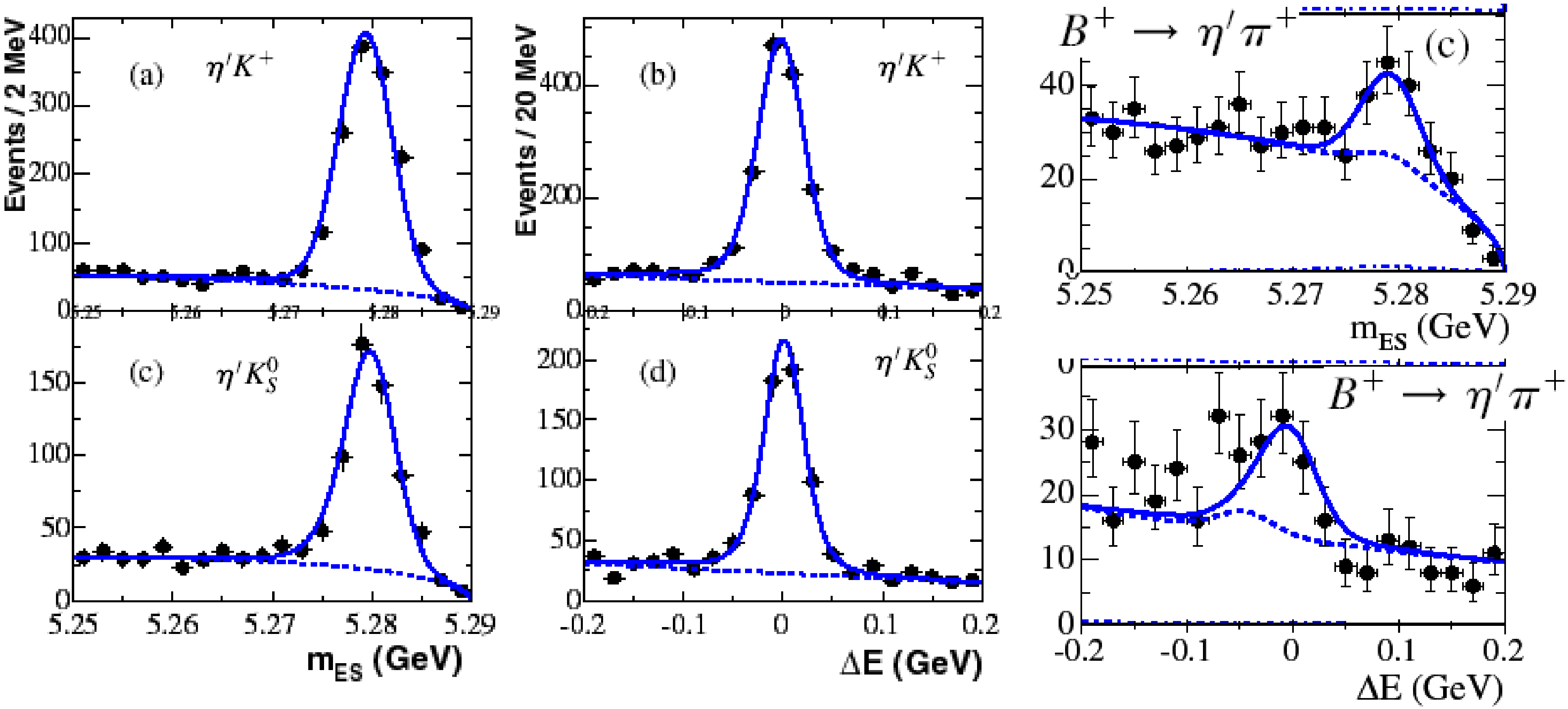
$B \to \eta' K/\pi$ (II)

History of the branching fractions measurements for $\eta' K/\pi$

EXP (Bbar pairs)	BF($B \to \eta' K^+$)	BF($B \to \eta' K^0$)	($\times 10^{-6}$)
CLEO(3.3M)	$65 \pm 15 \pm 8$	$47^{+27}_{-20} \pm 9$	
CLEO(9.7M)	$80 \pm 10 \pm 7$	$89^{+18}_{-16} \pm 9$	
BABAR(22.7M)	$70 \pm 8 \pm 5$	$42^{+13}_{-11} \pm 4$	
BABAR(89M)	$76.9 \pm 3.5 \pm 4.4$	$60.6 \pm 5.6 \pm 4.6$	
BABAR(232M)	$68.9 \pm 2.0 \pm 3.2$	$67.4 \pm 3.3 \pm 3.2$	
Belle(11M)	$79 \pm 12 \pm 9$	$55^{+19}_{-16} \pm 8$	
Belle(386M)	$68.6 \pm 2.1 \pm 3.6$	$56.6 \pm 3.6 \pm 3.3$	

$B \to \eta' K/\pi$ (III)





Figures from BABAR

$B \to \omega K/\pi$(I)

- ωK^+ & $\omega\pi^+$ BF varies since first observed (CLEO1998):

Present Status:	Belle(2004)	BABAR	CLEO
$BF(B \to \omega K^+)$ ($\times 10^{-6}$):	$6.5^{+1.3}_{-1.2} \pm 0.6$	$4.8 \pm 0.8 \pm 0.4$	$3.2^{+2.4}_{-1.9} \pm 0.8$
$BF(B \to \omega \pi^+)$ ($\times 10^{-6}$):	$5.7^{+1.4}_{-1.3} \pm 0.6$	$5.5 \pm 0.5 \pm 0.9$	$11.3^{+3.3}_{-2.9} \pm 1.4$
$BF(B \to \omega K^0)$ ($\times 10^{-6}$):	$4.0^{+1.9}_{-1.6} \pm 0.5$	$5.9 \pm 1.0 \pm 0.4$	$10.0^{+5.4}_{-4.2}$

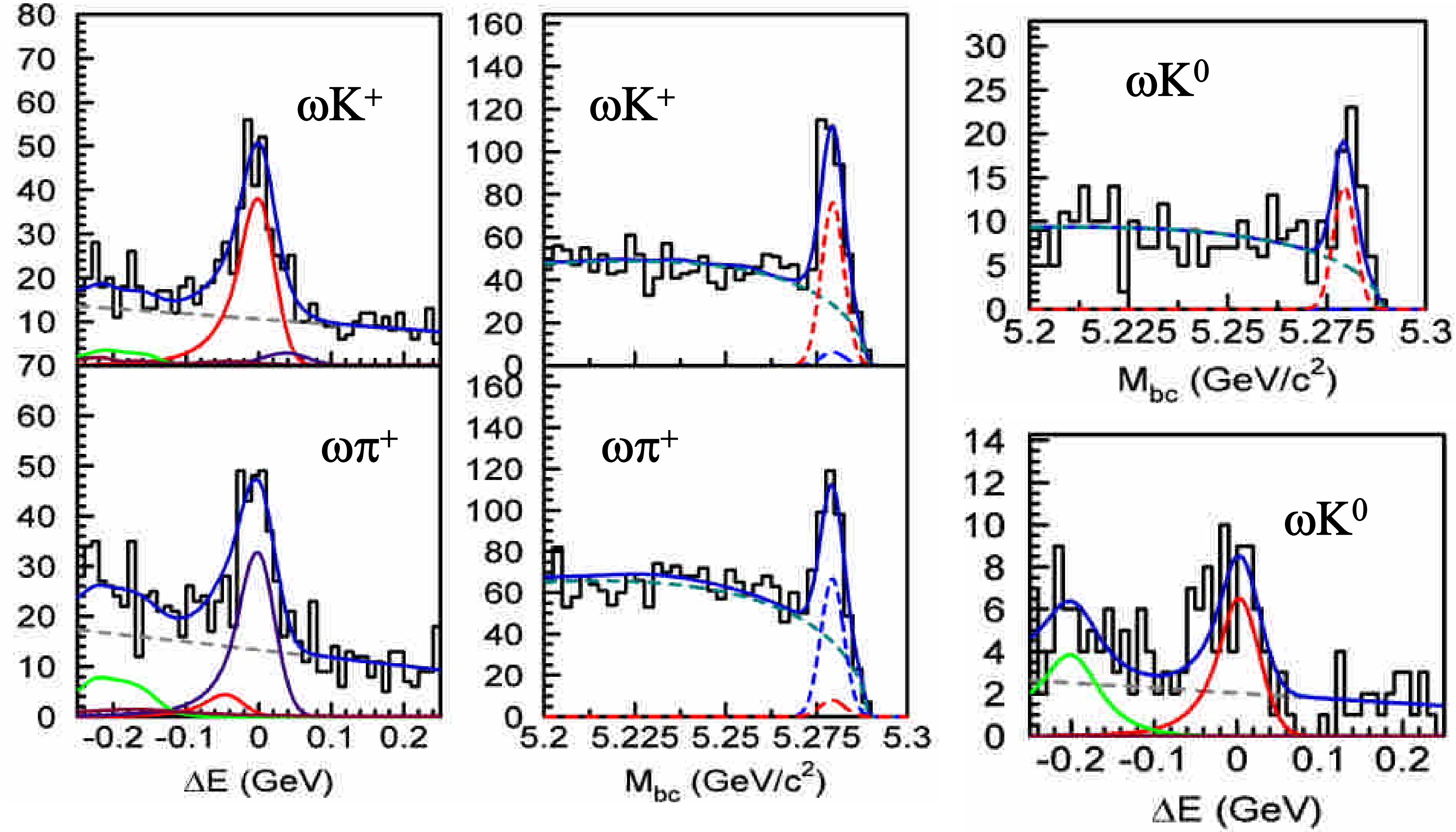
- Belle update ω results in summer 2005 (hep-ex/0508052)
- $BF(B \to \omega K^+)$ ($\times 10^{-6}$): $8.1 \pm 0.6 \pm 0.5$ / $N_S = 260 \pm 20$
- $BF(B \to \omega \pi^+)$ ($\times 10^{-6}$): $7.0 \pm 0.6 \pm 0.5$ / $N_S = 229 \pm 20$
- $BF(B \to \omega K^0)$ ($\times 10^{-6}$): $3.9 \pm 0.7 \pm 0.4$ / $N_S = 30 \pm 7$
- $BF(B \to \omega \pi^0)$ ($\times 10^{-6}$): < 1.5 / $NS = 2.8 \pm 4.7$

$B \to \omega K/\pi$(II)

History of the branching fractions measurements for $\omega K/\pi$

EXP (Bbar pairs)	BF($B \to \omega K^+$)	BF($B \to \omega \pi^+$)	($\times 10^{-6}$)
CLEO(3.3M)	$15 \pm 7 \pm 2$	< 23	
CLEO(9.7M)	$3.2^{+2.4}_{-1.9} \pm 0.8$	$11.3^{+3.3}_{-2.9} \pm 1.4$	
BABAR(22.7M)	$1.4^{+1.3}_{-1.0} \pm 0.3$	$6.6^{+2.1}_{-1.8} \pm 0.7$	
BABAR(89M)	$4.8 \pm 0.8 \pm 0.4$	$5.5 \pm 0.9 \pm 0.5$	
Belle(32M)	$9.2^{+2.6}_{-2.3} \pm 1.0$	$4.2^{+2.0}_{-1.8} \pm 0.5$	
Belle(85M)	$6.5^{+1.3}_{-1.2} \pm 0.6$	$5.7^{+1.4}_{-1.3} \pm 0.6$	
Belle(386M)	$8.1 \pm 0.6 \pm 0.5$	$7.0 \pm 0.6 \pm 0.5$	

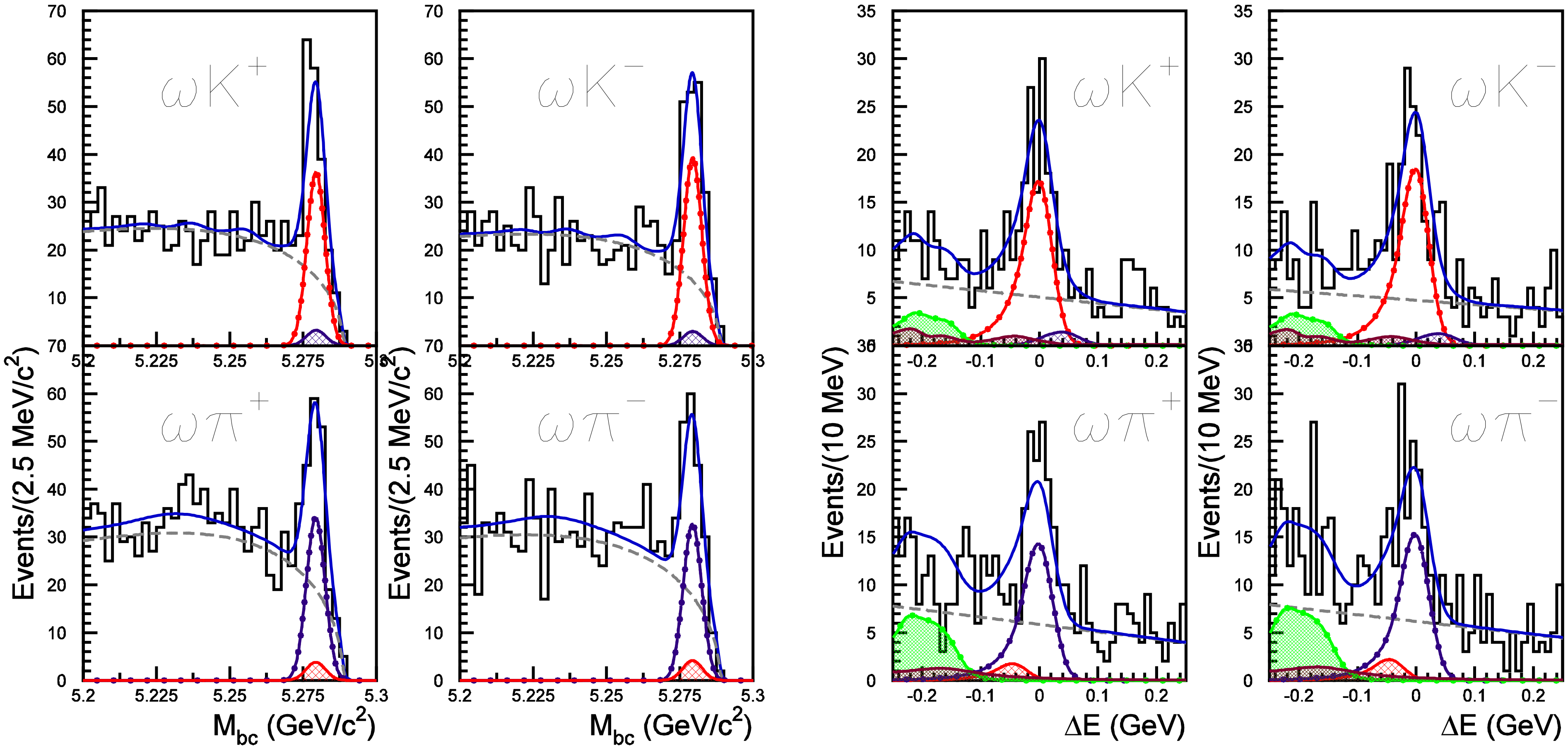
$B \to \omega K/\pi$(III)



$A_{cp}(\omega K/\pi)$

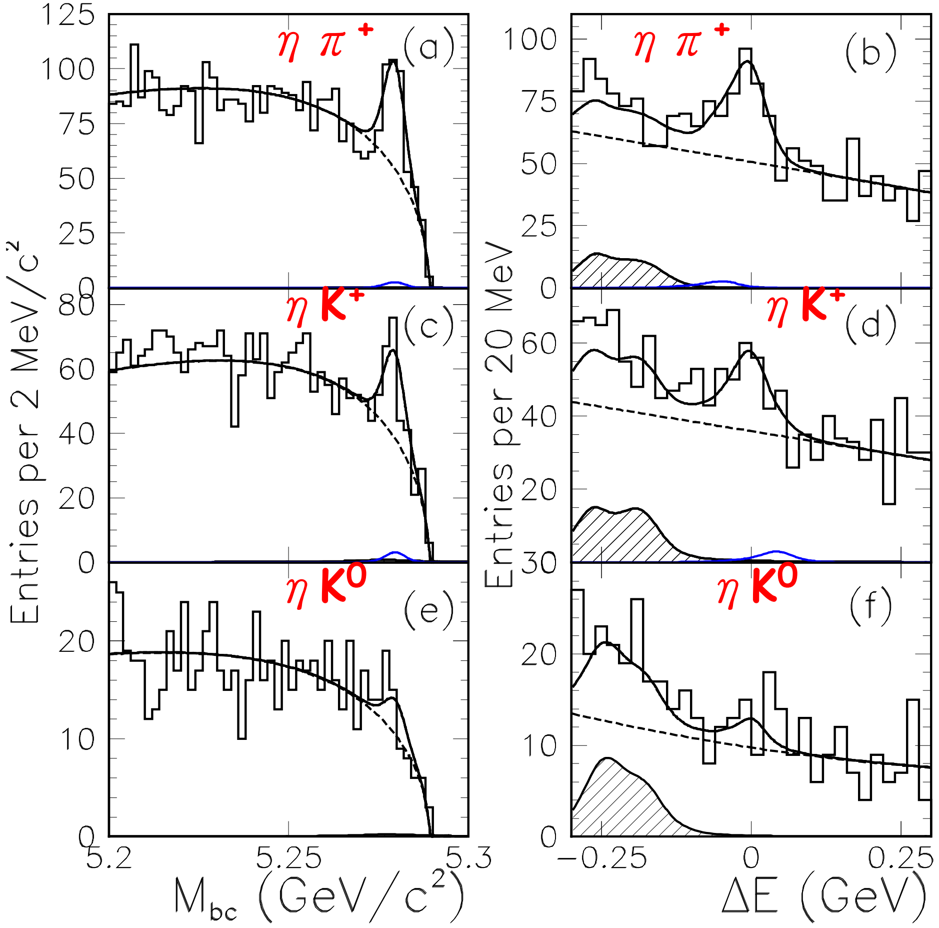
- **Status:** Belle(2003) BABAR(2003) Belle(2005)

	Belle(2003)	BABAR(2003)	Belle(2005)
$A_{cp}(\omega K^{\pm})$	0.06±0.21±0.01	-0.09±0.17±0.01	0.05±0.08±0.01
$A_{cp}(\omega \pi^{\pm})$	0.50±0.23±0.02	0.03±0.16±0.01	-0.03±0.09±0.02



$B \to \eta\, K/\pi$

Present Status:	Belle(2004)	BABAR(2005)	CLEO(2000)
BF($B \to \eta K^+$) ($\times 10^{-6}$):	2.1±0.6 ±0.2	3.3±0.6±0.3	2.2 +2.8/-2.2
BF($B \to \eta \pi^+$) ($\times 10^{-6}$):	4.8±0.8 ±0.3	5.1±0.6±0.3	1.2 +2.8/-1.2



Belle update in summer 2005 (hep-ex/0508030)

BF($B \to \eta K^+$)
$(2.2 \pm 0.4 \pm 0.1) \times 10^{-6}$

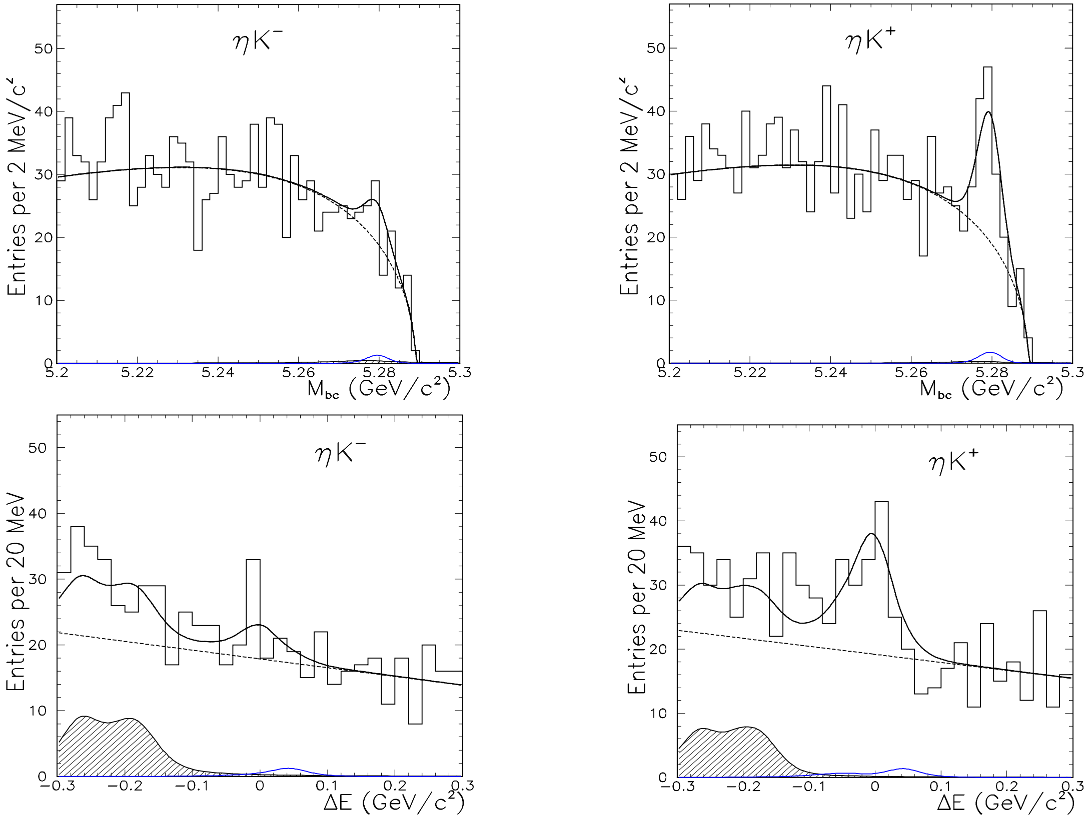
BF($B \to \eta \pi^+$)
$(3.9 \pm 0.5 \pm 0.2) \times 10^{-6}$

BF($B \to \eta K^0$)
$(0.9 \pm 0.6 \pm 0.1) \times 10^{-6} < 1.9 \times 10^{-6}$

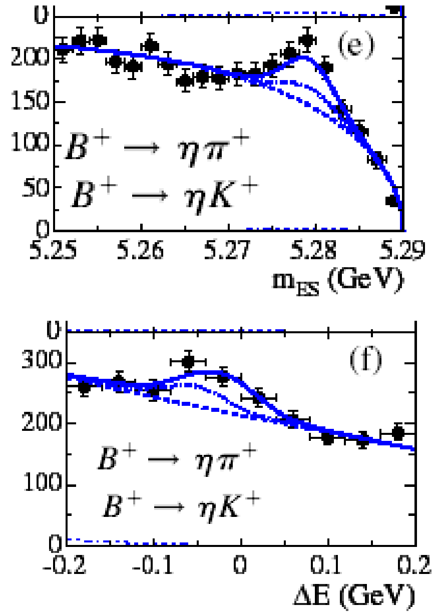
Acp(η K/π)

- **Status:**

	Belle(2004)	BABAR(2005)	Belle(2005)
Acp(η $K^{\pm}$)	-0.49±0.31±0.07	-0.20±0.15±0.01	-0.55±0.19±0.04
Acp(η $\pi^{\pm}$)	0.07±0.15±0.03	-0.13±0.12±0.01	-0.10±0.11±0.02



Result of Acp(η $K^{\pm}$) is 2.9 σ from zero.



BABAR's results for $\eta h^{\pm}$

Summary and Outlook

- Updated results of **B** $\rightarrow$ η' **h** , η **h** , ω**h** with 386×10^{6} BBar Pairs from Belle.

- Hints of direct CP violation for **B** $\rightarrow \eta$ **K**$^{\pm}$ with 2.9 σ significance from Belle. No direct CP violation found for other modes.

- Continue search for more rare decay modes and look for more DCPV.