Results on direct CP violation in PV and 3 body B decays in *BABAR* and Belle

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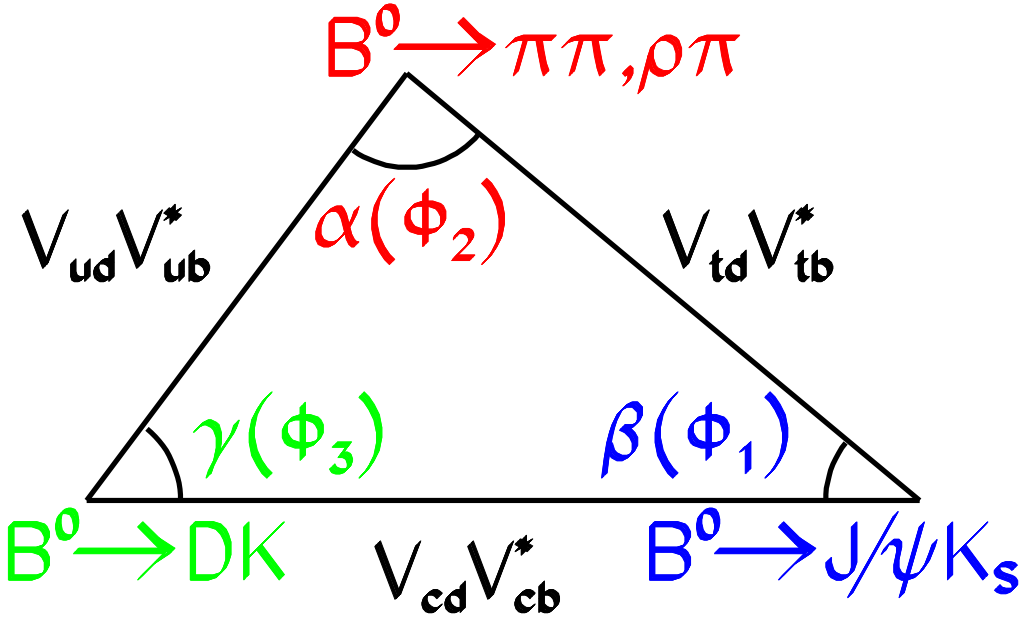
Outline

- Motivation
- Methodology
- Results
  - $B^+ \to h^+h^-h^+$ $(h = \pi, K)$
  - $B \to \omega\pi, \omega K$
  - $B \to \phi K$
  - $B \to \rho\pi, \rho K$
- Summary

CP violation in the Standard Model (SM)

Quark mixing matrix : *CKM*

- ☞ Complex, 3 quark families
- ☞ 1 irremovable phase
- ☞ Origin of $\not{CP}$ in SM



$$\mathbf{V} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

$\Downarrow$ *Unitarity*

$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$

$\rightarrow$ Triangle

$$\alpha, \beta, \gamma \neq 0, \pi \Leftrightarrow \not{CP}$$

BABAR / Belle look for CP-violating effects in B decays related to the three angles

Direct CP violation

Compare the decay probabilities of two CP-conjugate processes :

$$\text{Prob}(B \to f) \neq \text{Prob}(\overline{B} \to \bar{f}) \Longleftrightarrow \text{Direct } \not{CP}$$

Condition for observability

Several competing amplitudes :

$$\begin{cases} A_{B\to f} = \sum_i |A_i| e^{i\Phi_i} e^{i\delta_i} \\ A_{\overline{B}\to \bar{f}} = \sum_i |A_i| e^{-i\Phi_i} e^{i\delta_i} \end{cases}$$

Φ_i : Weak phases, CP-odd

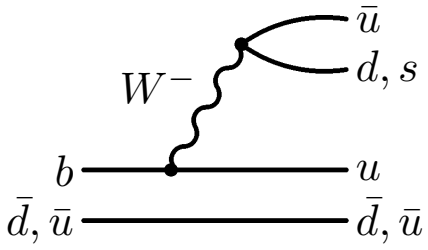
δ_i : Strong phases, CP-even

$$A_{CP} = \frac{|A_{\overline{B}\to\bar{f}}|^2 - |A_{B\to f}|^2}{|A_{\overline{B}\to\bar{f}}|^2 + |A_{B\to f}|^2} \propto \sum_{i,j} |A_i||A_j| \sin(\Phi_i - \Phi_j) \sin(\delta_i - \delta_j)$$

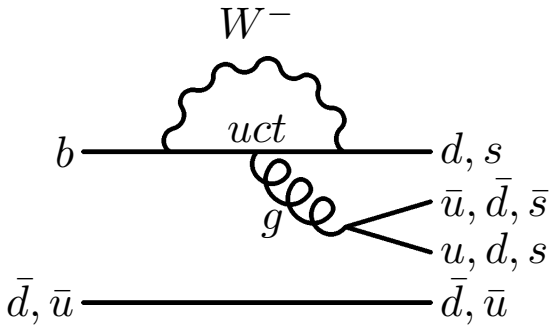
Direct $\not{CP}$ if
- ☞ At least two competing amplitudes
- ☞ Different weak phases
- ☞ Different strong phases

Charmless B decays

Tree



Penguin



Penguin amplitudes are disfavoured due to loop but may be CKM enhanced :

Non-strange channels : $T \propto \lambda^3$ and $P \propto \lambda^3$

Strange channels : $T \propto \lambda^4$ and $P \propto \lambda^2$

$(\lambda = \sin\theta_C = |V_{us}| \sim 0.22)$

Various weak phases : in some cases $|\Phi_i - \Phi_j| = \gamma$

$\Rightarrow$ one of the conditions for direct $\not{CP}$ is fulfilled

2 Motivations

$P \sim T$

- Direct $\not{CP}$ may be present (if strong phase difference)
- The measurement of A_{CP} may put constraints on γ
- Theoretical uncertainty : the long distance contributions to P and T need to be evaluated

$P \ll T$ **or** $P \gg T$

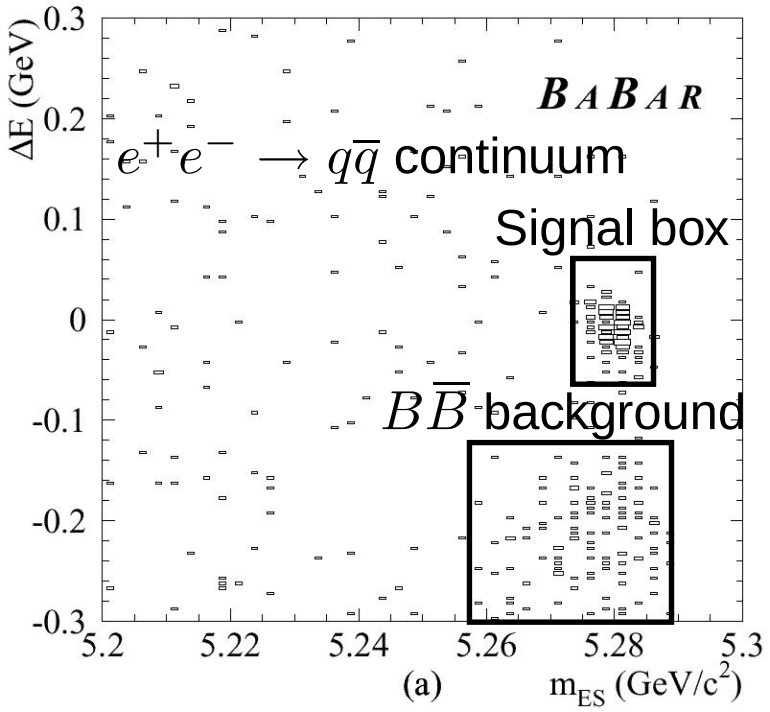
- No direct $\not{CP}$ is expected in the SM
- In case of a discovery : another competing amplitude is present with a different phase
- Signature of new physics

Methodology : continuum background rejection

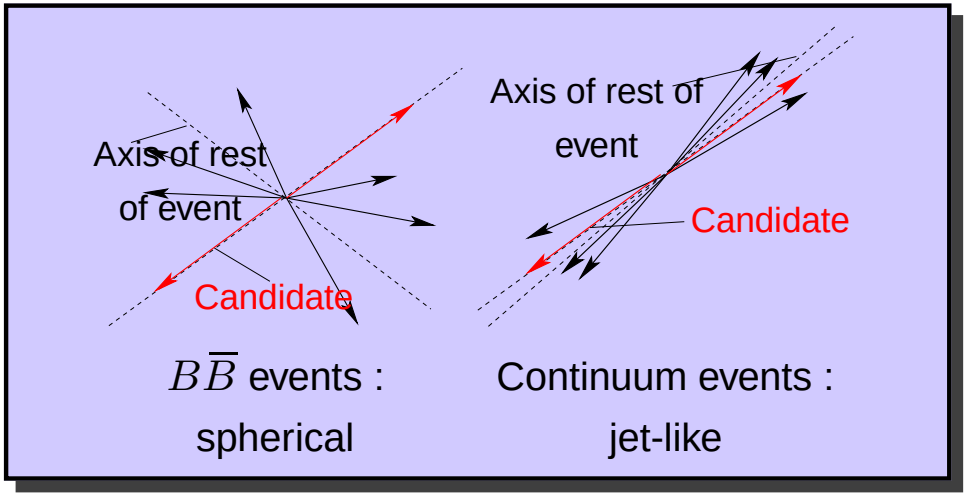
High contamination from $e^+e^- \rightarrow q\bar{q}(q = u, d, s, c)$

Kinematic variables

- $\Delta E = E_B^* - \frac{\sqrt{s}}{2}$ conservation of energy
  - ➠ $\sigma(\Delta E) \sim 15 - 80\,\mathrm{MeV}$ mode dependent
- $m_{\mathrm{ES}} = \sqrt{\frac{s}{4} - {p_B^*}^2}$ ➠ $\sigma(m_{\mathrm{ES}}) \sim 3\,\mathrm{MeV}/c^2$

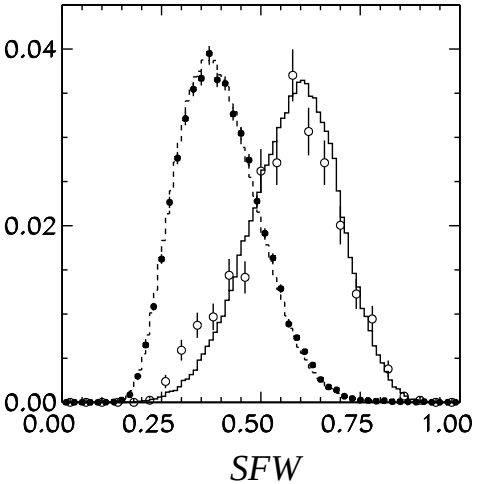


Event shape variables



Several variables combined

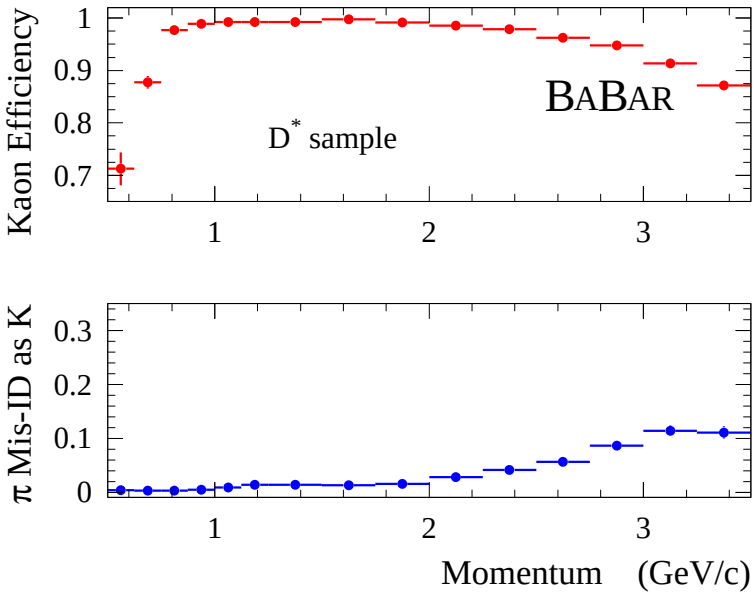
- Neural net-work
- Fisher



K/π separation

BABAR

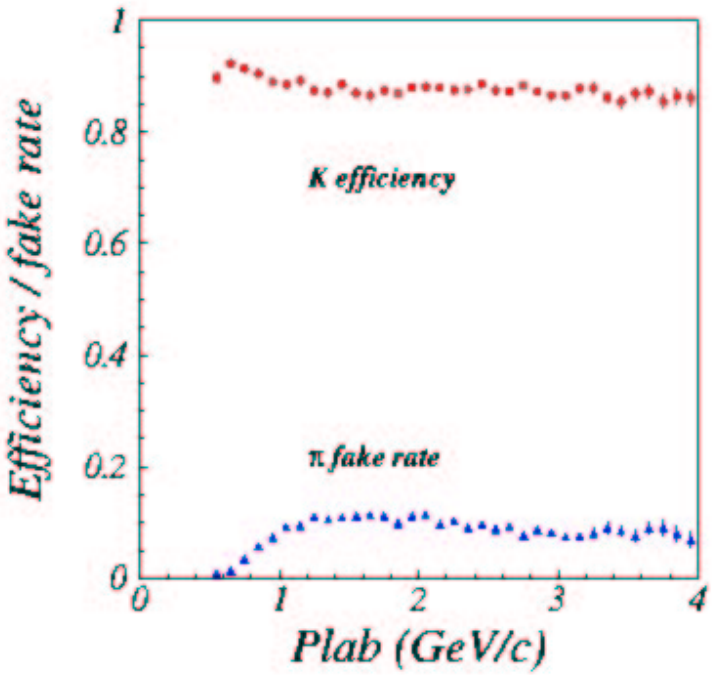
- Main device for PID : Dirc
- Measurement of the Cherenkov angle produced in quartz radiators



Belle

Likelihood ratio combining :

- Aerogel Cherenkov counter
- Time of flight
- dE/dx



BABAR $81.1\,\text{fb}^{-1}$

Inclusive $B^+ \to h^+h^-h^+$ ($h = \pi, K$)

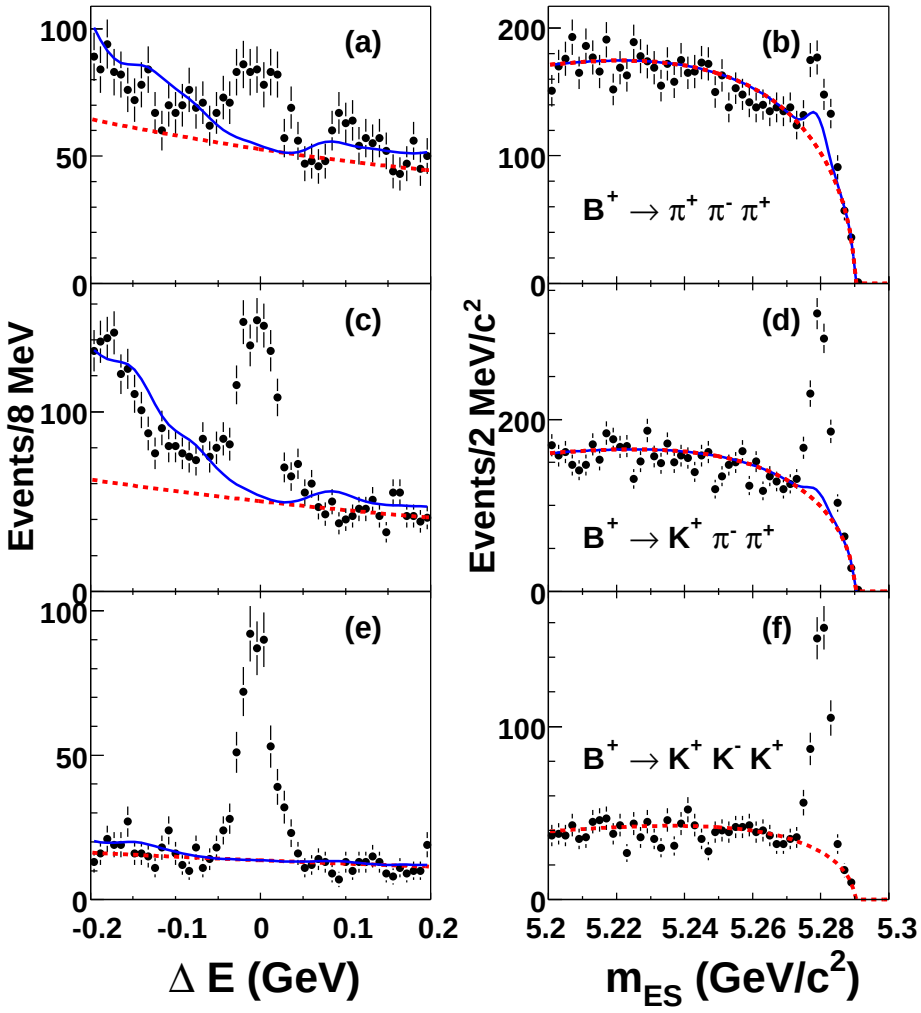
Motivations

- Feasibility of future Dalitz analyses
  - γ : e.g. interference between non-resonant amplitude with $B^+ \to \chi_{c0}\pi^+$
    [B. Bajc *et al.*, Phys. Lett. B **447**, 313 (1999)]
  - α : isospin analysis with $\pi^+\pi^-\pi^0$ and $\pi^+\pi^-\pi^+$
    [A.E. Snyder, H.R. Quinn, Phys. Rev. D **48**, 2139 (1993)]
- Look for standard model suppressed decays
  - $B^+ \to K^-\pi^+\pi^+$
  - $B^+ \to K^+K^+\pi^-$

Method

- Cut-based analysis
- Continuum background extrapolated from $m_{\rm ES}$ and ΔE sidebands
- Efficiency varied across Dalitz
- Crossfeed between modes mainly due to $K \to \pi$ mis-ID
- Corrections for $B \to D\pi, DK$ background

BABAR $81.1\,\text{fb}^{-1}$



Continuum
B-background

Results

$\mathcal{B}(10^{-6})$	*BABAR*	Belle ($79\,\text{fb}^{-1}$)
$B^+ \to \pi^+\pi^-\pi^+$	$10.9 \pm 3.3 \pm 1.6$	–
$B^+ \to K^+\pi^-\pi^+$	$59.1 \pm 3.8 \pm 3.2$	$53.9 \pm 3.1 \pm 5.7$
$B^+ \to K^+K^-\pi^+$	<6.3	$9.3 \pm 2.3 \pm 1.0$ (<13)
$B^+ \to K^+K^-K^+$	$29.6 \pm 2.1 \pm 1.6$	$33.0 \pm 1.8 \pm 1.3$
$B^+ \to K^-\pi^+\pi^+$	<1.8	<4.2
$B^+ \to K^+K^+\pi^-$	<1.3	<2.4

A_{CP}	*BABAR*
$B^+ \to \pi^+\pi^-\pi^+$	-0.39$\pm$ 0.33$\pm$ 0.12
$B^+ \to K^+\pi^-\pi^+$	0.01$\pm$ 0.07$\pm$ 0.03
$B^+ \to K^+K^-K^+$	0.02$\pm$ 0.07$\pm$ 0.03

hep-ex/0304006, Submitted to Phys. Rev. Lett.

BABAR $82\,\text{fb}^{-1}$, Belle $78\,\text{fb}^{-1}$

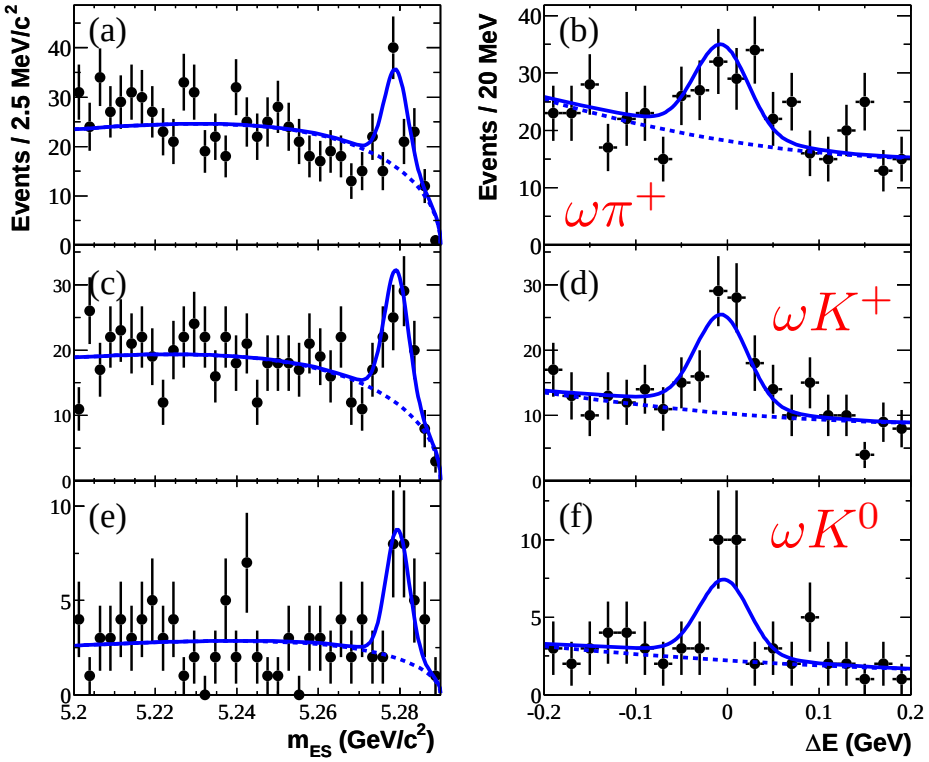
$B \to \omega K, \omega\pi$

- ωK^+, ωK^0 : dominated by penguin
- ωK^0, $\omega\pi^0$: tree is color suppressed
- $\omega\pi^+$: dominated by tree

Theory predicts $B \sim 5 \times 10^{-6}$ for all modes (except for $\omega\pi^0$) and small A_{CP}

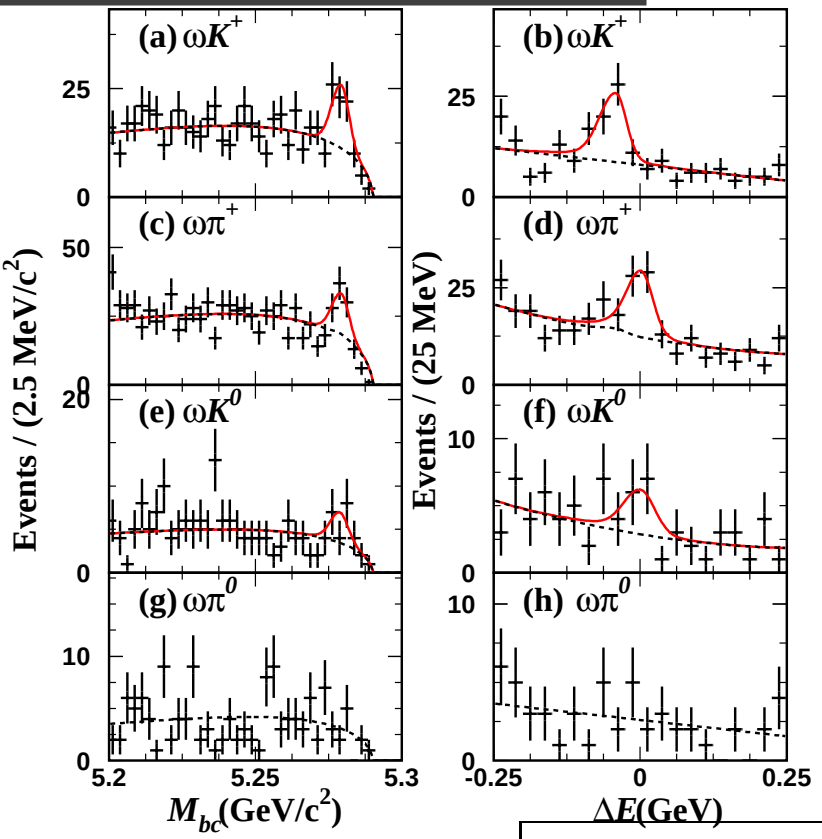
Likelihood method :

- continuum separation kinematic, event shape variables and helicity angle
- K/π separation with Dirc for *BABAR*, likelihood ratio for Belle
- B background is low



BABAR observes $\omega\pi^+$, ωK^+ and ωK^0

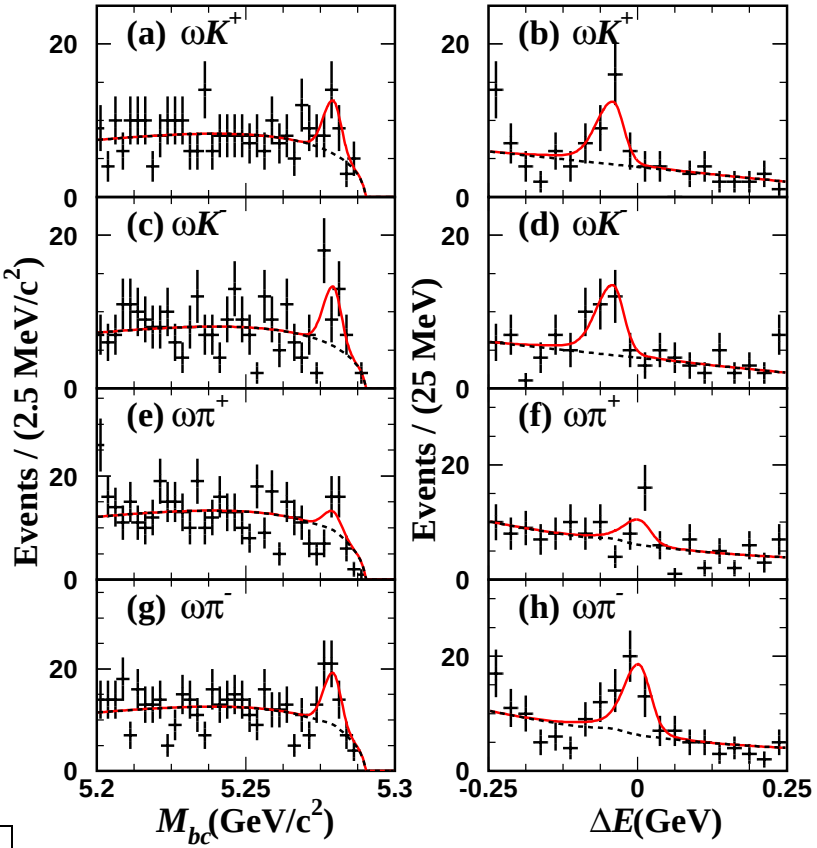
BABAR $82\,\text{fb}^{-1}$, Belle $78\,\text{fb}^{-1}$



Belle results

$\mathcal{B}$ ⬅

$\mathcal{CP}$ ➡



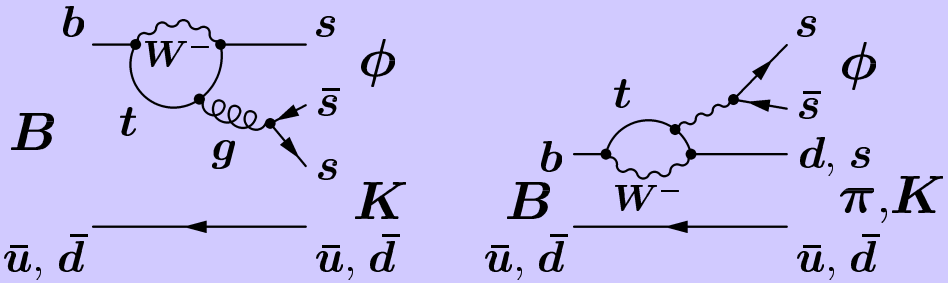
		BABAR	Belle
$\mathcal{B}$ (10^{-6})	$B^+ \to \omega K^+$	$5.0 \pm 1.0 \pm 0.4$	$6.7^{+1.3}_{-1.2} \pm 0.6$
	$B^+ \to \omega \pi^+$	$5.4 \pm 1.0 \pm 0.5$	$5.7^{+1.4}_{-1.3} \pm 0.6$
	$B^+ \to \omega K^0$	$5.3^{+1.4}_{-1.2} \pm 0.5$	$4.0^{+1.9}_{-1.6} \pm 0.5 (< 7.6)$
	$B^+ \to \omega \pi^0$	–	< 1.9
A_{CP}	$B^+ \to \omega \pi^+$	$0.04 \pm 0.17 \pm 0.01$	$0.48^{+0.23}_{-0.20} \pm 0.02$
	$B^+ \to \omega K^+$	$-0.05 \pm 0.16 \pm 0.01$	$0.06^{+0.20}_{-0.18} \pm 0.01$

hep-ex/0303040 (*BABAR*)

BELLE-CONF-0312

BABAR $82\,\text{fb}^{-1}$, Belle $78\,\text{fb}^{-1}$

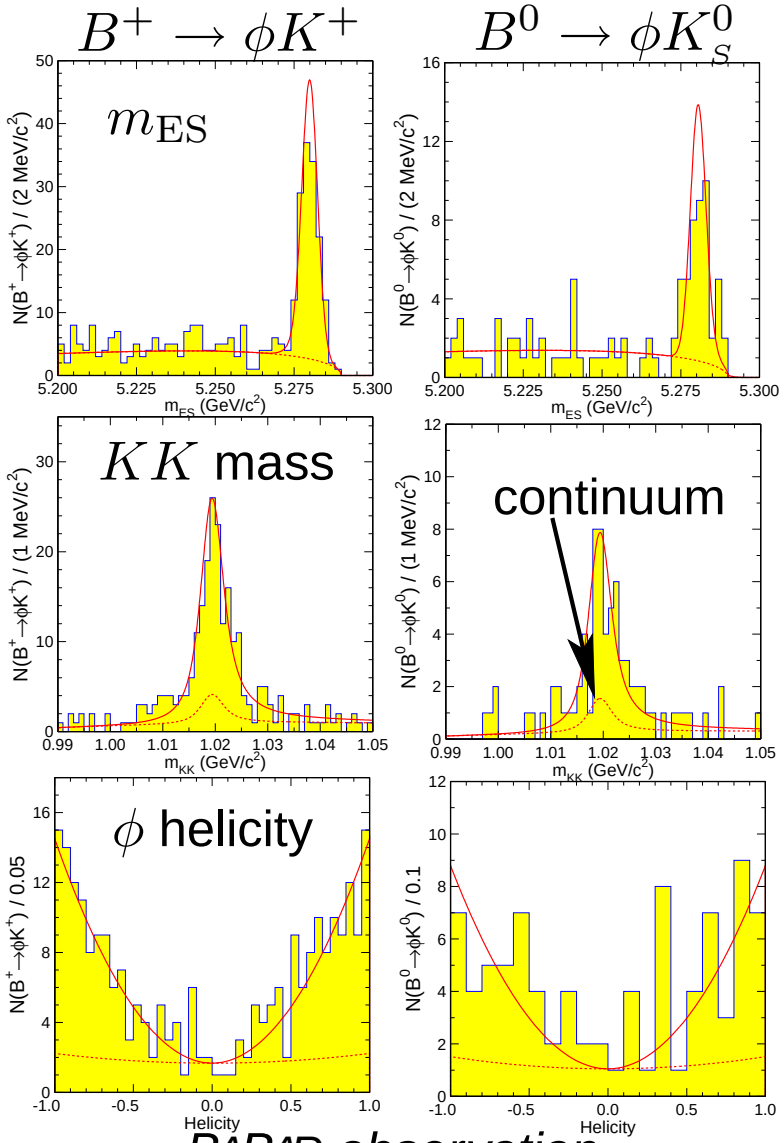
$B^+ \to \phi K, \phi\pi$



Penguin-only decay :

- No direct $\not{CP}$ expected
- Sensitive to new physics
- $\phi\pi$ could be enhanced in case of large FS rescattering

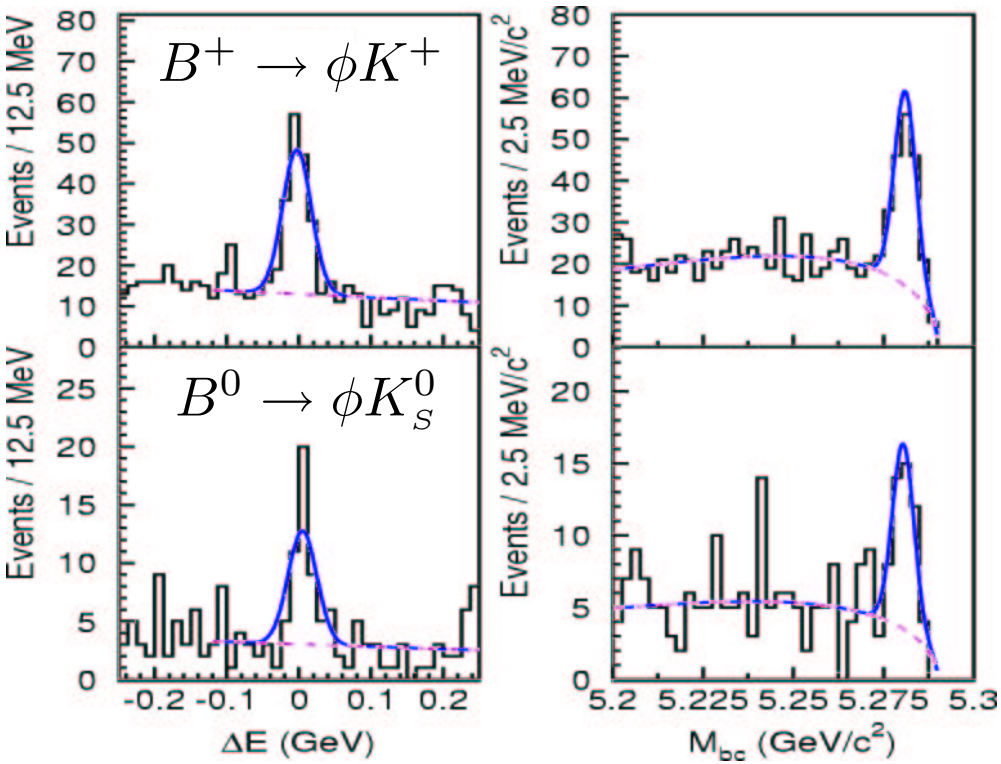
- Many kaons in final state : high purity
- Continuum discriminated with a maximum likelihood technique
- Time-dependent asymmetry for ϕK^0_S : see talk by J. MacNaughton



BABAR observation

BABAR $82\,\text{fb}^{-1}$, Belle $78\,\text{fb}^{-1}$

Belle observation for
$B^0 \to \phi K^0_S$ and
$B^+ \to \phi K^+$



	BABAR		Belle	
	$\mathcal{B}(10^{-6})$	direct $C\!P$	$\mathcal{B}(10^{-6})$	direct $C\!P$
$B^0 \to \phi K^0$	$7.6^{+1.3}_{-1.2} \pm 0.5$	$C = -0.80 \pm 0.51 \pm 0.07$	$9.0^{+2.2}_{-1.8} \pm 0.7$	$A = -C = -0.56 \pm 0.41 \pm 0.16$
$B^0 \to K^+K^-K^0$	–	–	$29.3 \pm 3.4 \pm 4.1$	$-0.40 \pm 0.33 \pm 0.10^{+0.00}_{-0.26}$
$B^+ \to \phi K^+$	$10.0^{+0.9}_{-0.8} \pm 0.5$	$A_{CP} = 0.039 \pm 0.086 \pm 0.011$	$9.4 \pm 1.1 \pm 0.7$	$A_{CP} = 0.01 \pm 0.12 \pm 0.05$
$B^+ \to \phi\pi^+$	< 0.41 (90% CL)	–	–	–

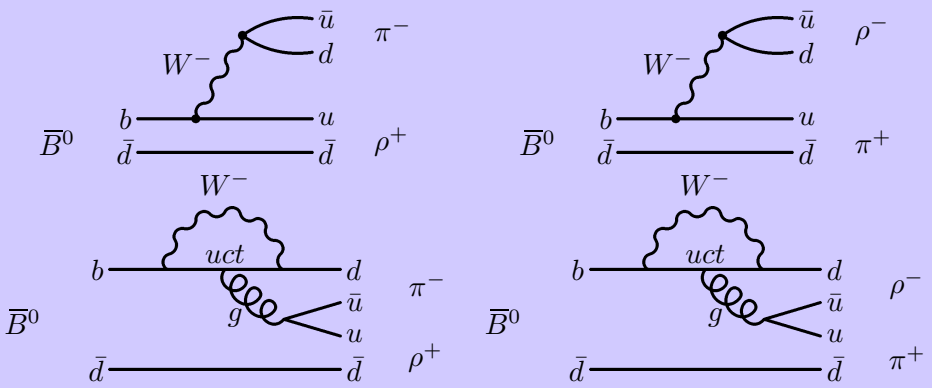
$$C = \frac{|A_{B^0 \to \phi K^0_S}|^2 - |A_{\overline{B}^0 \to \phi K^0_S}|^2}{|A_{B^0 \to \phi K^0_S}|^2 + |A_{\overline{B}^0 \to \phi K^0_S}|^2}$$

hep-ex/0303029 (*BABAR*)

hep-ex/0212062, *hep-ex/0307014* (Belle)

BABAR $82\,\text{fb}^{-1}$, Belle $78\,\text{fb}^{-1}$

$B \to \rho\pi$, $B \to \rho K$



- Large branching ratios expected (∼several 10^{-5})
- Interesting constraints on α
- Direct $\not{CP}$ possible if penguins large

- Neutral modes : time-dependent asymmetries : see talk by C. Yèche
- One or two π^0 in final state, large resonance : *signal characterization challenging*
  - Likelihood fit used to discriminate continuum
  - Detailed study of the B-background

hep-ex/0306030 submitted to Phys. Rev. Lett. (*BABAR*)

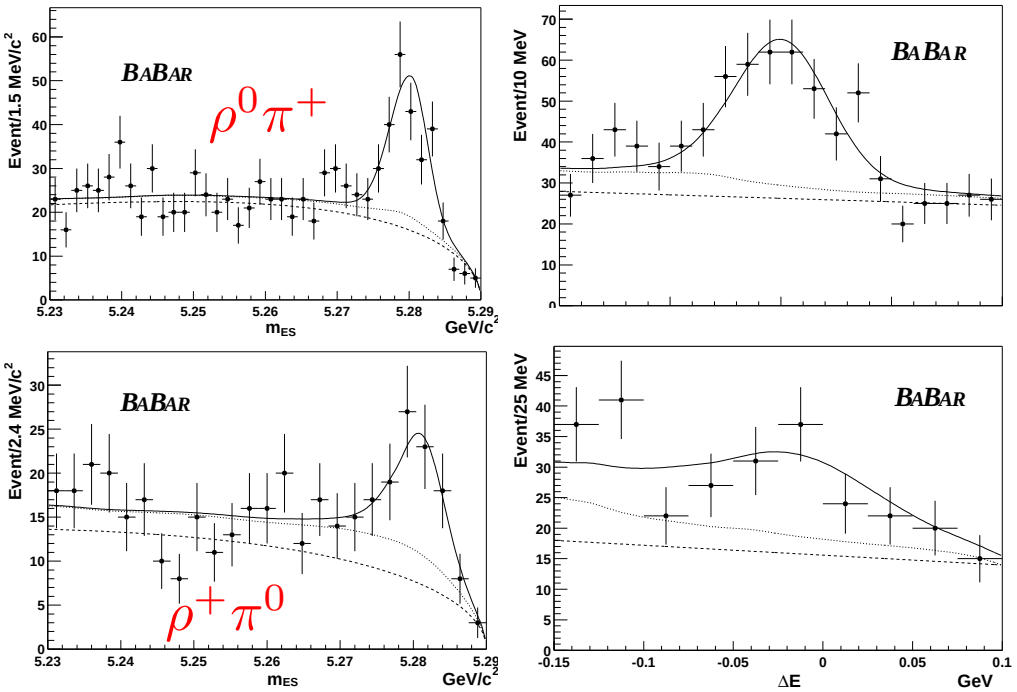
BABAR-CONF-03/014

BELLE-CONF-0317, BELLE-CONF-0318

BABAR $82\,\text{fb}^{-1}$, Belle $78\,\text{fb}^{-1}$

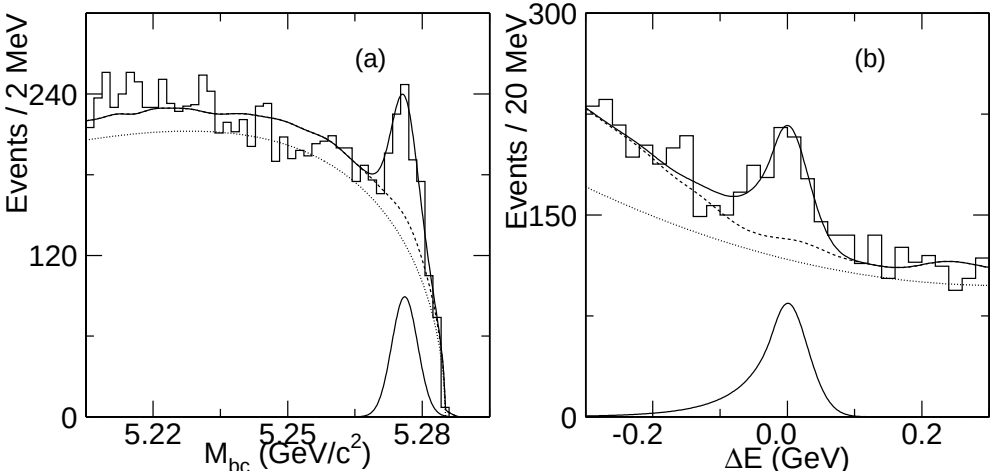
Results on branching ratios

$\mathcal{B}/10^{-6}$	*BABAR*	Belle
$B^0 \to \rho^\pm\pi^\mp$	$22.6 \pm 1.8 \pm 2.2$	$29.1^{+5.0}_{-4.9} \pm 4.0$
$B^+ \to \rho^0\pi^+$	$9.2 \pm 1.0 \pm 0.8$	$8.0^{+2.3}_{-2.0} \pm 0.7$
$B^+ \to \rho^+\pi^0$	$11.0 \pm 1.9 \pm 1.9$	–
$B^0 \to \rho^- K^+$	$7.3^{+1.3}_{-1.2} \pm 1.3$	$15.1^{+3.4+1.4+2.0}_{-3.3-1.5-2.1}$
$B^0 \to K^+\pi^-\pi^0$	–	$36.6^{+4.2}_{-4.3} \pm 3.0$



First observation of the mode

$B^+ \to \rho^+\pi^0$ by *BABAR*



Belle observation for

$B^0 \to K^+\pi^-\pi^0$

BABAR $82\,\text{fb}^{-1}$, Belle $78\,\text{fb}^{-1}$

$B^0 \to \rho^{\mp}\pi^{\pm}$: two parameterisations

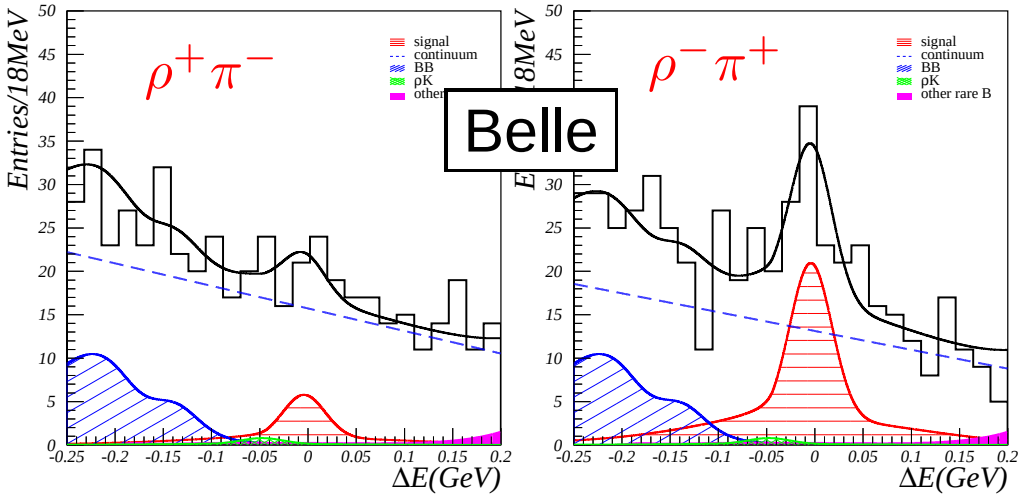
$$\mathcal{A} = \frac{N(B \to \rho^+\pi^-) - N(B \to \rho^-\pi^+)}{N(B \to \rho^+\pi^-) + N(B \to \rho^-\pi^+)}$$

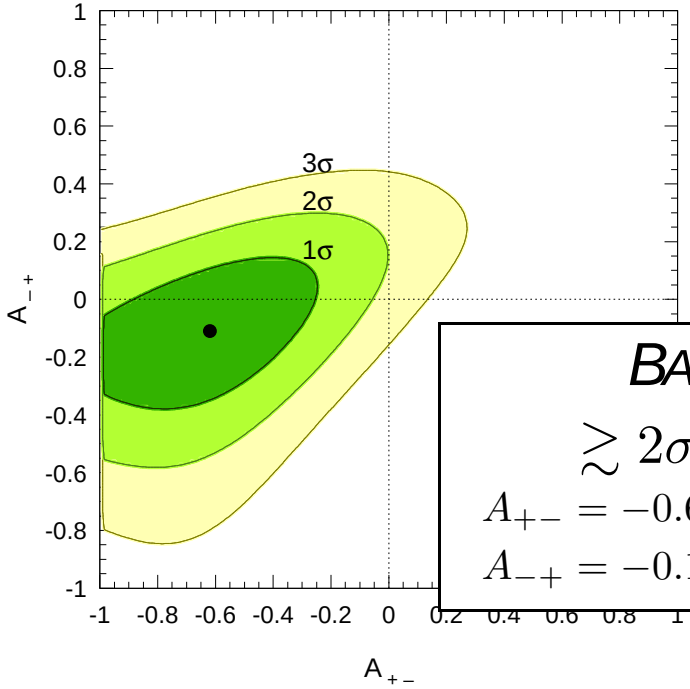
$$C \sim \frac{N(B^0 \to \rho\pi) - N(\overline{B}^0 \to \rho\pi)}{N(B^0 \to \rho\pi) + N(\overline{B}^0 \to \rho\pi)}$$

$$A_{+-} = \frac{\Gamma(\overline{B}^0 \to \rho^+\pi^-) - \Gamma(B^0 \to \rho^-\pi^+)}{\Gamma(\overline{B}^0 \to \rho^+\pi^-) + \Gamma(B^0 \to \rho^-\pi^+)}$$

$$A_{-+} = \frac{\Gamma(\overline{B}^0 \to \rho^-\pi^+) - \Gamma(B^0 \to \rho^+\pi^-)}{\Gamma(\overline{B}^0 \to \rho^-\pi^+) + \Gamma(B^0 \to \rho^+\pi^-)}$$

	BABAR	Belle
$\mathcal{A}$	$-0.18 \pm 0.08 \pm 0.03$	$-0.38^{+0.19+0.04}_{-0.21-0.05}$
C	$0.36 \pm 0.18 \pm 0.04$	–





BABAR

$\gtrsim 2\sigma$ effect

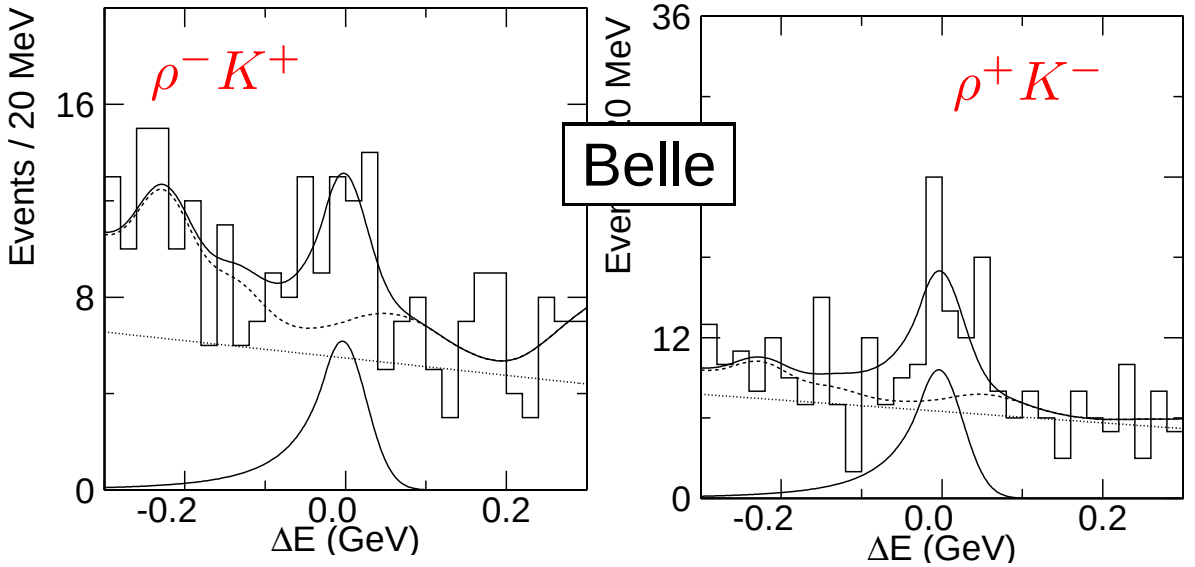
$A_{+-} = -0.62^{+0.24}_{-0.28} \pm 0.06$

$A_{-+} = -0.11^{+0.16}_{-0.17} \pm 0.04$

BABAR $82\,\text{fb}^{-1}$, Belle $78\,\text{fb}^{-1}$

Other $B \to \rho h$ modes

A_{CP}	*BABAR*	Belle
$B^+ \to \rho^0\pi^+$	$-0.17 \pm 0.11 \pm 0.02$	–
$B^+ \to \rho^+\pi^0$	$0.23 \pm 0.16 \pm 0.06$	–
$B^0 \to \rho^- K^+$	$0.28 \pm 0.17 \pm 0.08$	$0.22^{+0.22+0.06}_{-0.23-0.02}$
$B^0 \to K^+\pi^-\pi^0$	–	$0.07 \pm 0.11 \pm 0.01$



Summary

- The search for direct $\not{CP}$ at *BABAR* and Belle is starting to give numerous results
  - New results from *BABAR* of $B^+ \to \rho\pi$ and first observation of $B^+ \to \rho^+\pi^0$
  - New results from Belle for $B \to \phi K^+$, $B \to \omega\pi^+$, $B^0 \to \rho^+\pi^-$ and $B^0 \to K^+\pi^-\pi^0$
  - Updated results from Belle for $B^+ \to \omega K^+$
- The theoretical predictions for the asymmetries are in general model-dependent
- Few cases where 0 asymmetry is predicted with great precision
- No observation up to now