Charmless *B* Decays

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Heavy Quark and Leptons 2006

Outline

Introduction

Charmless B decays
The B factories

Constraining $\Delta S_f = S_f - \sin 2\beta$

$\sin 2\beta$ in $b \to q\bar{q}s$ penguins
Constraining SM pollution

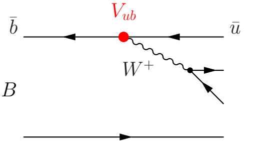
BF, CP And $\mathcal{A}_{ch}$

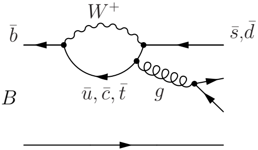
Measurements related to α/ϕ_2
$B \to \eta^{(\prime)} K^{(*)}$
$B \to VV$ decays
Other charmless B decays

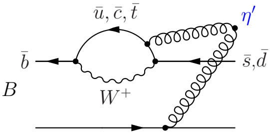
All results preliminary unless journal reference given

Charmless hadronic B decays

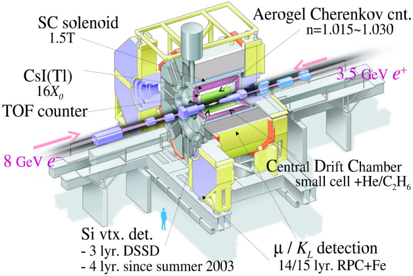
- Contributing amplitudes: CKM suppressed trees, penguins, …
- Can be used to study
  - Interfering SM amplitudes
  - CP violation
  - Effects of new particles in loops (New Physics?)
- Perturbative calculations possible (QCD factorisation, pQCD, SCET)
- Constrain models

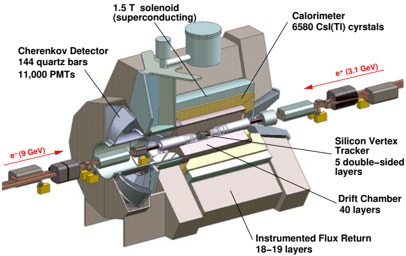






The B factories: BELLE and $B\!A\!B\!A\!R$





$$e^+e^- \rightarrow \Upsilon(4S) \rightarrow B\bar{B}$$

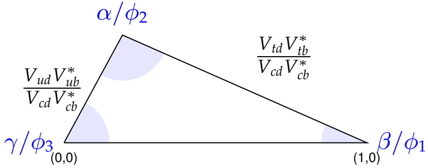
Asymmetric beam energies

- KEK-B: 8 GeV e^- × 3.5 GeV e^+
- $\mathcal{L}_{\text{int}} \approx 640\,\text{fb}^{-1}$ so far

- PEP-II: 9 GeV e^- × 3.1 GeV e^+
- $\mathcal{L}_{\text{int}} \approx 406\,\text{fb}^{-1}$ so far

Measuring time-dependent CP asymmetries

Unitarity triangle



Unitarity of the CKM matrix:
$V_{td}V_{tb}^* + V_{cd}V_{cb}^* + V_{ud}V_{ub}^* = 0$

Time-dependent CP asymmetry in B^0-$\bar{B}^0$ mixing

$$\mathcal{A}_{cp}(\Delta t) = \frac{\Gamma(\bar{B}^0 \to f) - \Gamma(B^0 \to f)}{\Gamma(\bar{B}^0 \to f) + \Gamma(B^0 \to f)}$$
$$= S_f \sin \Delta m_d \Delta t - C_f \cos \Delta m_d \Delta t$$

For example $B^0 \to J/\psi\, K_S^0$ ($b \to c\bar{c}s$): $S_{J/\psi\, K_S^0} = \sin 2\beta$, $C_{J/\psi\, K_S^0} = 0$

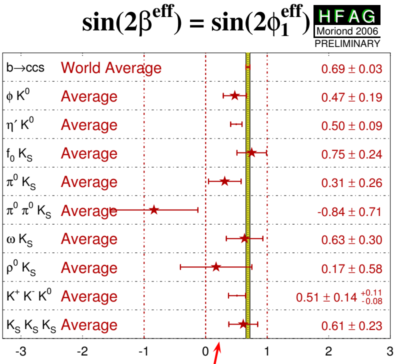
Constraining $\Delta S_f = S_f - \sin 2\beta$

$\sin 2\beta$ from $b \to q\bar{q}s$ penguins

- Measure CPV in $b \to s$ penguin dominated decays: S_f, C_f
- Standard model & penguin only:

  $S_f = \sin 2\beta$

- New Physics can show up in loops and modify S_f
- Sub-dominant standard model amplitudes introduce additional weak and strong phases
  $\Rightarrow S_f \neq \sin 2\beta$ even without NP
- So, what is SM expectation for $\Delta S_f \equiv S_f - \sin 2\beta$?
- Measuring related modes helps pin down expected deviations



$\sin 2\beta$ from $b \to c\bar{c}s$

Constraining SM pollution in $B^0 \to \phi K^0$

- Constrain sub-dominant (V_{ub}) contributions to $B^0 \to \phi K^0_S$ via SU(3) flavour relations Grossman *et al.*, Phys. Rev. D **68**:015004 (2003)

$$\Delta S_{\phi K^0_S} \propto \frac{1}{4}\mathcal{B}(\rho^0\pi^0) - \frac{1}{4}\mathcal{B}(\omega\pi^0) + \frac{1}{2}\sqrt{\frac{3}{2}}\left[c\mathcal{B}(\phi\eta) - s\mathcal{B}(\phi\eta')\right] + \frac{\sqrt{3}}{4}\left[c\mathcal{B}(\omega\eta) - s\mathcal{B}(\omega\eta')\right] - \frac{\sqrt{3}}{4}\left[c\mathcal{B}(\rho^0\eta) - s\mathcal{B}(\rho^0\eta')\right] + \frac{1}{2}\left[\mathcal{B}(\bar{K}^{*0}K^0) - \mathcal{B}(K^{*0}\bar{K}^0)\right] - \frac{1}{2\sqrt{2}}\mathcal{B}(\phi\pi^0)$$

Search for $B^0 \to K^{*0}K^0_S$

BABAR, hep-ex/0606050, 208 fb^{-1}

Upper limit at 90% C.L.:

$$\mathcal{B}(\bar{K}^{*0}K^0) + \mathcal{B}(K^{*0}\bar{K}^0) < 1.9 \times 10^{-6}$$

SU(3) upper bound $\Delta S_{\phi K^0} < 0.43$

Improved $\mathcal{B}(\phi\pi^0)$

BABAR, Phys. Rev. D **74**:011102, 211 fb^{-1}

Upper limits at 90% C.L.:

$$\mathcal{B}(B^0 \to \phi\pi^0) < 2.8 \times 10^{-7}$$
$$\mathcal{B}(B^+ \to \phi\pi^+) < 2.4 \times 10^{-7}$$

Constraining SM pollution in $B^0 \to \eta' K^0$

- Constrain $\Delta S_{\eta' K^0_S}$ using flavour SU(3) and $B^0 \to \eta^{(\prime)}\pi^0$, $\eta'\eta$.
  Gronau *et al.*, Phys. Lett. B **596**, 107
- Expected $\mathcal{B}$ in the ranges $0.2 - 1 \times 10^{-6}$ $(\eta^{(\prime)}\pi^0)$ and 0.3–2×10^{-6} $(\eta'\eta)$.

Upper limits at 90% CL:

$$
\begin{aligned}
\mathcal{B}(B^0 \to \eta\pi^0) &< 1.3 \times 10^{-6} \\
\mathcal{B}(B^0 \to \eta'\eta) &< 1.7 \times 10^{-6} \\
\mathcal{B}(B^0 \to \eta'\pi^0) &< 2.1 \times 10^{-6}
\end{aligned}
$$

BABAR, 211 fb^{-1}

Phys. Rev. D **73**:071102

$$\mathcal{B}(\eta'\pi^0) = (2.79^{+1.02+0.25}_{-0.96-0.34}) \times 10^{-6}$$

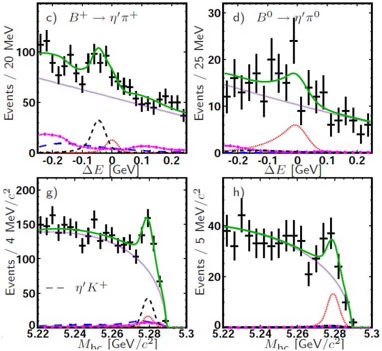
BELLE, Phys. Rev. Lett. **97**:061802

(next slide)

- With new upper limits, expect $-0.046 < S_{\eta' K^0_S} < 0.094$
  Gronau *et al.*, hep-ex/0608085
- Also improvement for $\sin 2\alpha$ measured in $B^0 \to \pi^+\pi^-$

$B \to \eta' \pi$

BELLE $386 \times 10^6 B\bar{B}$, Phys. Rev. Lett. **97**:061802



- $B^+ \to \eta' \pi^+$

  $\mathcal{B} = (1.76^{+0.67+0.15}_{-0.62-0.14}) \times 10^{-6}$

  $\mathcal{A}_{ch} = 0.20^{+0.37}_{-0.36} \pm 0.04$

  Previous *BABAR*:
  $\mathcal{B} = (4.0 \pm 0.8 \pm 0.4) \times 10^{-6}$
  Phys. Rev. Lett. **95**, 131803

- $B^0 \to \eta' \pi^0$

  $\mathcal{B} = (2.79^{+1.02+0.25}_{-0.96-0.34}) \times 10^{-6}$

  Significance 3.1 σ

  BABAR: $< 2.1 \times 10^{-6}$
  Phys. Rev. D **73**, 071102

- $\eta'\pi^+$ clearly seen
  $\eta'\pi^0$ not clear

Search for $B \to K_S^0 K_S^0 K_L^0$

- Pure $b \to s\bar{s}s$ penguin, analoguous to $B \to K_S^0 K_S^0 K_S^0$
- Avoids SM pollution
- CP eigenstate
- Resonant ϕK_S^0 contribution small, but non-resonant component may be large:

$$\mathcal{B} = (5.23^{+2.52+6.86+0.05}_{-1.96-2.53-0.06}) \times 10^{-6}$$

Cheng *et al.*, Phys. Rev. D **72**, 094003, using factorisation

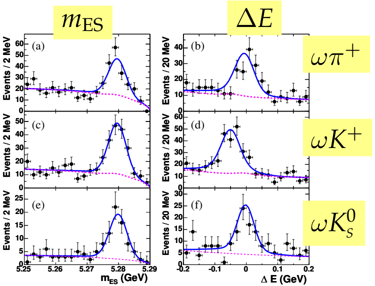
- Experimentally difficult: $\epsilon \times \prod \mathcal{B}_i$ small
- Assuming uniform 3-body phase space, and excluding ϕ: UL at 90% CL:

$$\mathcal{B}(B^0 \to K_S^0 K_S^0 K_L^0) < 7.4 \times 10^{-6}$$

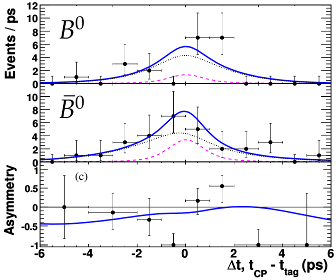
BABAR, 211 fb^{-1}, Phys. Rev. D **74**:032005

- Limited use for understanding CPV in $b \to q\bar{q}s$

CP asymmetries in $B \to \omega\,\pi/K$



BABAR



- $b \to q\bar{q}s$, dominated by single penguin
- Expect $\Delta S_{\omega K^0} \approx 0.1$ and $\mathcal{A}_{ch} \approx 0$
  [Phys. Lett. B **620**,143; Phys. Rev. D **72**, 014006]
- BABAR:

	$\mathcal{B}(10^{-6})$	$\mathcal{A}_{ch}$
$B^+ \to \omega\pi^+$	$6.1 \pm 0.7 \pm 0.4$	$-0.01 \pm 0.10 \pm 0.01$
$B^+ \to \omega K^+$	$6.1 \pm 0.6 \pm 0.4$	$0.05 \pm 0.09 \pm 0.01$
$B^0 \to \omega K_S^0$	$6.2 \pm 1.0 \pm 0.4$	–

ωK_S^0, fix $C = 0$: $S = 0.60^{+0.42}_{-0.38}$, $\Delta S = 0.12 \pm 0.40$

211 fb^{-1}, Phys. Rev. D **74**:01106

- BELLE:

	$\mathcal{B}(10^{-6})$	$\mathcal{A}_{ch}$
$B^+ \to \omega\pi^+$	$6.9 \pm 0.6 \pm 0.5$	$-0.02 \pm 0.09 \pm 0.01$
$B^+ \to \omega K^+$	$8.1 \pm 0.6 \pm 0.6$	$0.05^{+0.08}_{-0.07} \pm 0.01$
$B^0 \to \omega K_S^0$	$4.4^{+0.8}_{-0.7} \pm 0.4$	–
$B^0 \to \omega\pi^0$	< 2.0	–

388×10^6 $B\bar{B}$, hep-ex/0609022

Measurements related to α/ϕ_2

Updates on $B \to \rho\rho$

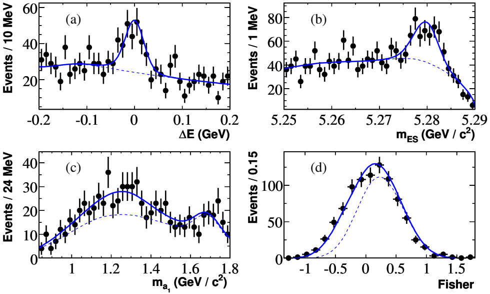
- Set of $B^0 \to \rho^0\rho^0$, $\rho^+\rho^-$ and $B^+ \to \rho^+\rho^0$ to extract angle α/ϕ_2
- Updates for all Branching Fractions, CP asymmetries from both *BABAR* and BELLE

➠ See talk by Christos Touramanis on Wednesday morning

$B^0 \to a_1^{\pm}(1260)\,\pi^{\mp}$

- Can be used to extract α/ϕ_2 up to 4-fold ambiguity [Aleksan *et al.*, Nucl. Phys. B **361**, 141]
- Sub-leading penguin amplitude with different weak phase dilutes α
- Can be overcome by exploiting symmetries:
  - Isospin [Gronau & London (1990)]
  - Approximate SU(3) flavour [Dighe, Gronau & Rosner (1998); Gronau & Zupan (2005)]

First step: measure branching fraction



Nice signal seen ($N_{\rm sig} = 421 \pm 48$)

Assume $BR(a_1^+ \to (3\pi)^+) = 100\%$

$$\mathcal{B}(B^0 \to a_1^{\pm}\pi^{\mp}) = (33.2 \pm 3.8 \pm 3.0) \times 10^{-6}$$

BABAR Phys. Rev. Lett. **97**:051802

Next step: time dependent analysis

Search for $B^0 \to a_1^+ \rho^-$

- $b \to u\bar{u}d$ transition:
  with sufficient statistics, could be used to measure α/ϕ_2
- $B \to 5\pi$ important background contribution for $B \to \rho\rho$ analyses
- Little known about this decay:

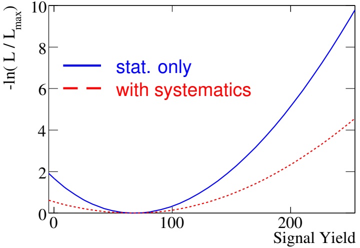
  Theory: $\mathcal{B}(B^0 \to a_1^\pm \rho^\mp)\mathcal{B}(a_1^+ \to (3\pi)^+) = 43 \times 10^{-6}$

  [Bauer *et al.*, Z. Phys. C **34**, 103 (1987)]

  using $|V_{ub}/V_{cb}| = 0.08$

  Experiment: $\mathcal{B}(B^0 \to a_1^\pm \rho^\mp) < 3.4 \times 10^{-3}$

  [ARGUS, Phys. Lett. B **241**, 278 (1990), 214 pb^{-1}]



Assume $f_L = 1$ to get most conservative upper limit (90% C.L.):

$$\mathcal{B}(B^0 \to a_1^\pm \rho^\mp)\mathcal{B}(a_1^+ \to (3\pi)^+) < 61 \times 10^{-6}$$

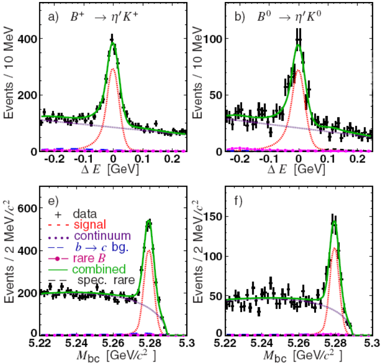
BABAR, 100 fb^{-1},
Phys. Rev. D **74**:031104

$B \to \eta^{(\prime)} K^{(*)}$

$B \to \eta^{(\prime)} K^{(*)}$

- $\mathcal{B}(B \to \eta' K)$ found unexpectedly large (CLEO, 1997)
- Understood? Interference between two dominant penguin amplitudes [Lipkin 1991] plus enhancements from m_s, form factors, higher-order in α_s [Beneke & Neubert 2003]
- Predicts ηK^* large,
  $\eta' K^*$ small unless flavour singlet diagram important
- Important in light of measuring $\sin 2\beta$ in $B^0 \to \eta' K^0$ [➠ G. Dubois-Felsmann]

$B \to \eta' K$



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

  $\mathcal{B} = (69.2 \pm 2.2 \pm 3.7) \times 10^{-6}$

  $\mathcal{A}_{ch} = 0.028 \pm 0.028 \pm 0.021$

- $B^0 \to \eta' K^0$

  $\mathcal{B} = (58.9^{+3.6}_{-3.5} \pm 4.3) \times 10^{-6}$

BELLE, $386 \times 10^6 B\bar{B}$, Phys. Rev. Lett. **97**, 061802

$B \to \eta K^* / \rho$

- $B \to \eta K^*(892), \eta\rho$

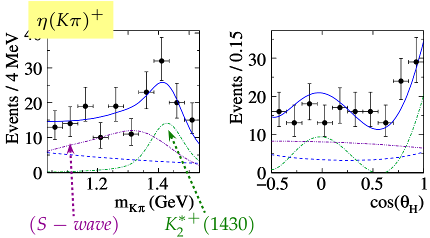
	$\mathcal{B}(10^{-6})$	
	BELLE hep-ex/0608034	BABAR hep-ex/0608005
$B^0 \to \eta K^{*0}$	$15.9 \pm 1.2 \pm 0.9$	$16.5 \pm 1.1 \pm 0.8$
$B^+ \to \eta K^{*+}$	$19.7^{+2.0}_{-1.9} \pm 1.4$	$18.9 \pm 1.8 \pm 1.3$
$B^+ \to \eta\rho^+$	$4.1^{+1.4}_{-1.3} \pm 0.34$	
$B^0 \to \eta\rho^0$	< 1.9	

- Confirm earliear measurements of ηK^*
- Agree with predictions
- Direct CP asymmetries consistent with 0
- New: ηK_2^* and $\eta(K\pi)_0^*$ (no predictions so far)

- $B \to \eta(K\pi)^*$

$K_2^*(1430)$ and $K\pi$ S-wave

	$\mathcal{B}(10^{-6})$
$B^0 \to \eta(K\pi)_0^{*0}$	$11.0 \pm 1.6 \pm 1.5$
$B^+ \to \eta(K\pi)_0^{*+}$	$18.2 \pm 2.6 \pm 2.6$
$B^0 \to \eta K_2^{*0}$	$9.6 \pm 1.8 \pm 1.1$
$B^+ \to \eta K_2^{*+}$	$9.1 \pm 2.7 \pm 1.4$

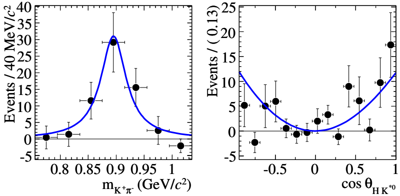


Signal-enhanced projection plots

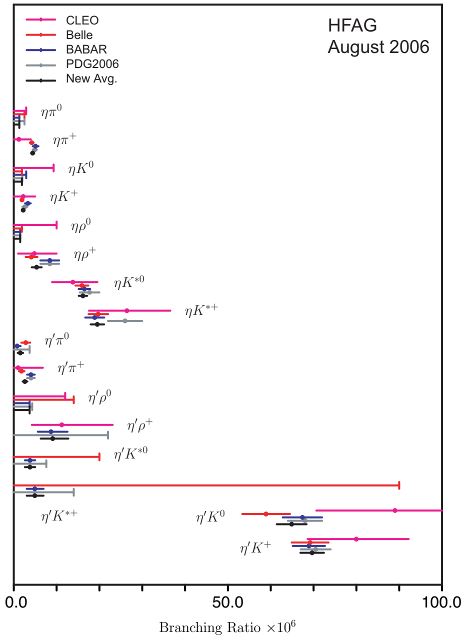
$B \to \eta' K^* / \rho$

Decay mode	Theoretical predictions: SU(3) flavour	Theoretical predictions: QCD fact.	BABAR 211 fb^{-1} (hep-ex/0607109)		
		Branching Fraction (10^{-6})			
$B^0 \to \eta' K^{*0}$	$3.0^{+1.2}_{-0.3}$	$3.9^{+9.2}_{-5.1}$	$3.8 \pm 1.1 \pm 0.5$	$(4.3\,\sigma)$	
$B^+ \to \eta' K^{*+}$	$2.8^{+1.2}_{-0.3}$	$5.1^{+10.3}_{-\ 5.9}$	$4.9^{+1.9}_{-1.7} \pm 0.8$	$(3.6\,\sigma)$	< 7.9
$B^0 \to \eta' \rho^0$	$0.07^{+0.10}_{-0.05}$	$0.01^{+0.12}_{-0.06}$	$0.4^{+1.2+1.6}_{-0.9-0.6}$	$(0.3\,\sigma)$	< 3.7
$B^+ \to \eta' \rho^+$	$4.9^{+0.7}_{-0.7}$	$6.3^{+4.0}_{-3.3}$	$8.7^{+3.1+2.3}_{-2.8-1.3}$	$(3.2\,\sigma)$	< 14
$B^0 \to \eta' f_0(980) \times \mathcal{B}(f_0 \to \pi^+\pi^-)$			$0.1^{+0.6+0.9}_{-0.4-0.4}$	$(0.2\,\sigma)$	< 1.5
	Phys. Rev. D **68**,074012	Nucl. Phys. B **675**, 333			

- Predictions have large error, both compatible with measurements
- $\eta^{(\prime)} \rho^0$ likely to be very small
- Predicted pattern in $\eta^{(\prime)} K^{(*)}$ seen

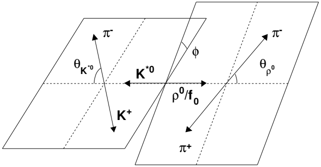


$\mathcal{B}(B \rightarrow (\eta,\ \eta')\ (K^{(*)},\ \pi,\ \rho))$



$B \to VV$ decays

Polarisation in $B \to VV$ decays



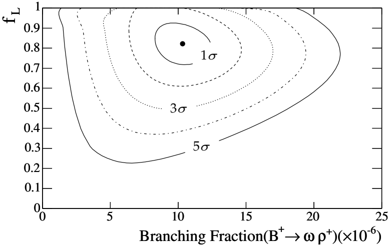
- Longitudinal polarisation fraction f_L in VV decays:

$$\frac{d^2\Gamma}{d\cos\theta_1 \, d\cos\theta_2} \propto \frac{1}{4}(1 - f_L)\sin^2\theta_1 \sin^2\theta_2 + f_L \cos^2\theta_1 \cos^2\theta_2$$

- Helicity conservation arguments $\Rightarrow f_L \approx 1 - \frac{m_v^2}{m_B^2}$
  - Valid for tree-dominated decays. Penguins? (factorisation?)
  - Experiment: ok for $\rho\rho$: $f_L \approx 0.95$

- $\rho\rho$, $\omega\rho$, $\omega\omega$ tree-dominated
- ϕK^*, ρK^*, ωK^* penguin-dominated
  - Surprise: $f_L \approx 0.50$ for ϕK^*
  - What about ρK^*, ωK^*?

Search for $B \to \omega V$ decays



$$
\begin{aligned}
\mathcal{B}(B^+ \to \omega\rho^+) &= (10.6 \pm 2.1^{+1.6}_{-1.0}) \times 10^{-6} \\
f_L(\omega\rho^+) &= 0.82 \pm 0.11 \pm 0.02 \\
\mathcal{A}_{ch}(\omega\rho^+) &= 0.04 \pm 0.18 \pm 0.02 \\
\mathcal{B}(B^0 \to \omega K^{*0}) &< 4.2 \times 10^{-6} \\
\mathcal{B}(B^+ \to \omega K^{*+}) &< 3.4 \times 10^{-6} \\
\mathcal{B}(B^0 \to \omega\rho^0) &< 1.5 \times 10^{-6} \\
\mathcal{B}(B^0 \to \omega\omega) &< 4.0 \times 10^{-6} \\
\mathcal{B}(B^0 \to \omega\phi) &< 1.2 \times 10^{-6} \\
\mathcal{B}(B^0 \to \omega f_0) &< 1.5 \times 10^{-6}
\end{aligned}
$$

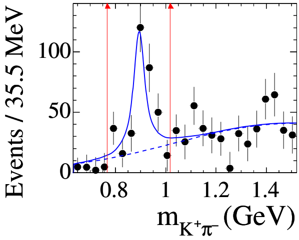
BABAR 211 fb^{-1}, Phys. Rev. D **74**:051102

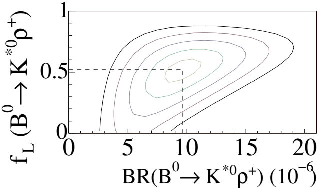
- Polarisation large, as expected for tree-dominated decay

Reasonable agreement with predictions
[e.g. Ali *et al.*, Phys. Rev. D **60**,014005; Cheng & Yang, Phys. Lett. B **511**, 40]

$B \to \rho K^*$

$B^+ \to \rho^+ K^{*0}$



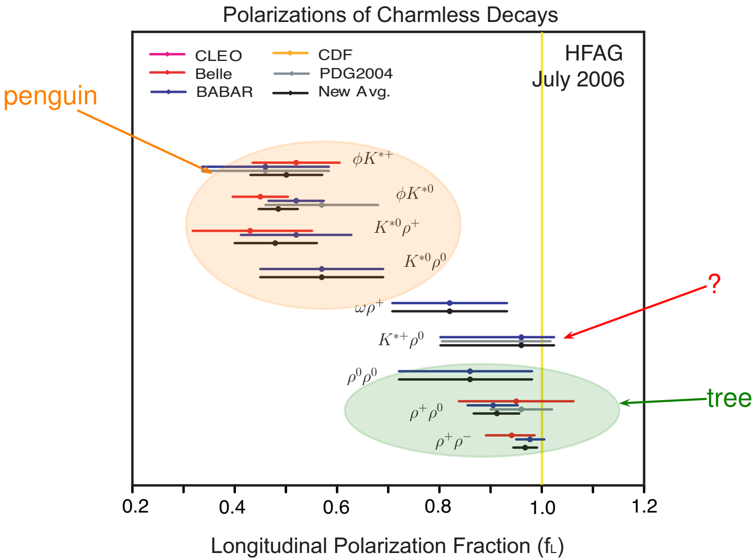


$$
\begin{aligned}
\mathcal{B}(\rho^+ K^{*0}) &= (9.6 \pm 1.7 \pm 1.5) \times 10^{-6} \\
f_L(\rho^+ K^{*0}) &= 0.52 \pm 0.10 \pm 0.04 \\
\mathcal{A}_{ch}(\rho^+ K^{*0}) &= -0.01 \pm 0.16 \pm 0.02 \\
\\
\mathcal{B}(\rho^0 K^{*0}) &= (5.6 \pm 0.9 \pm 1.3) \times 10^{-6} \\
f_L(\rho^0 K^{*0}) &= 0.57 \pm 0.09 \pm 0.08 \\
\mathcal{A}_{ch}(\rho^0 K^{*0}) &= 0.09 \pm 0.19 \pm 0.02
\end{aligned}
$$

BABAR, hep-ex/0607057

- Significant $K\pi$ S-wave component
- Better agreement with previous BELLE results (Phys. Rev. Lett. **95**:141801)
- Polarisation ≈ 0.5 as expected for penguin-dominated

$B \to VV$ Polarisation



Other charmless B decays

New results on $B \to \pi\pi, K\pi, KK$

- Updated branching fractions
- Improved statistics asks for radiative corrections
  BABAR extracts non-radiative BF $\mathcal{B}^0$:
  $\Gamma^{incl}_{P_1P_2}(E^{\max}) = \Gamma(B \to P_1P_2 + n\gamma)|_{\sum E_\gamma < E^{\max}} = \Gamma_{P_1P_2} + \Gamma_{P_1P_2\ n\gamma}(E^{\max})$
  $\Gamma^{incl}_{P_1P_2}(E^{\max}) = \Gamma^0_{P_1P_2} G_{P_1P_2}(E^{\max})$ Baracchini, Isidori, Phys. Lett. B **633**, 309

Mode	BELLE	*BABAR*	
	$\mathcal{B}(10^{-6})$	$\mathcal{B}(10^{-6})$	$\mathcal{B}^0(10^{-6})$
	hep-ex/0609015	hep-ex/0608003	
$\pi^+\ \pi^-$	$5.1 \pm 0.2 \pm 0.2$	$5.4 \pm 0.4 \pm 0.3$	$5.8 \pm 0.4 \pm 0.3$
$K^+\ \pi^-$	$20.0 \pm 0.4^{+0.9}_{-0.8}$	$18.6 \pm 0.6 \pm 0.6$	$19.7 \pm 0.6 \pm 0.6$
$K^+\ K^-$	—	< 0.40	< 0.40

New results on $B \to \pi\pi, K\pi, KK$

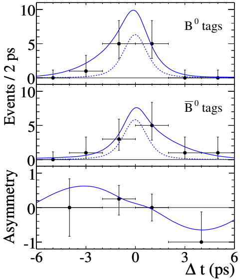
- Updated results for all BF
- $\bar{K}^0 K^0$ and $K^0 K^+$ have statistical significance $> 5\sigma$
  $b \to d$ hadronic penguins finally observed!

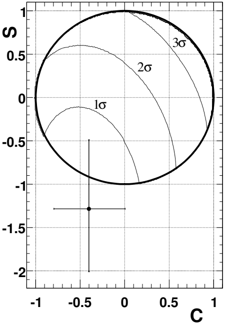
Mode	BABAR $\mathcal{B}(10^{-6})$	BELLE $\mathcal{B}(10^{-6})$
$B^0 \to \pi^0\pi^0$	$1.48 \pm 0.26 \pm 0.12$	$2.3^{+0.4+0.2}_{-0.5-0.3}$
$B^+ \to \pi^+\pi^0$	$5.12 \pm 0.47 \pm 0.29$	$6.6 \pm 0.4^{+0.4}_{-0.5}$
$B^\pm \to K^\pm\pi^0$	$13.3 \pm 0.56 \pm 0.64$	$12.4 \pm 0.5^{+0.7}_{-0.6}$
$B^+ \to K^0\pi^+$	$23.9 \pm 1.1 \pm 1.0$	$22.9^{+0.8}_{-0.7} \pm 1.3$
$B^+ \to \bar{K}^0 K^+$	$1.61 \pm 0.44 \pm 0.09$	$1.22^{+0.33+0.13}_{-0.28-0.16}$
$B^0 \to \bar{K}^0 K^0$	$1.08 \pm 0.28 \pm 0.11$	$0.86^{+0.24}_{-0.21} \pm 0.09$
$B^0 \to K^0_S\pi^0$	$10.5 \pm 0.7 \pm 0.5$	$9.2^{+0.7+0.6}_{-0.6-0.7}$
	hep-ex/0607106	Phys. Rev. Lett. **94**, 180803
	hep-ex/0608036	hep-ex/0608049
	hep-ex/0607096	hep-ex/0609015

Time-dependent CP violation in $B^0 \to K^0 \overline{K}^0$

- Pure $b \to d s \bar{s}$ penguin
  ➠ New window for CPV in penguin decays
- Allows estimate of penguin contribution in $B^0 \to \pi\pi$ via flavour SU(3)
- Direct CP asymmetry expected to be zero
- Measured as $B^0 \to K^0_S K^0_S$

$$S = -1.28^{+0.80+0.11}_{-0.73-0.16}$$
$$C = -0.40 \pm 0.41 \pm 0.06$$

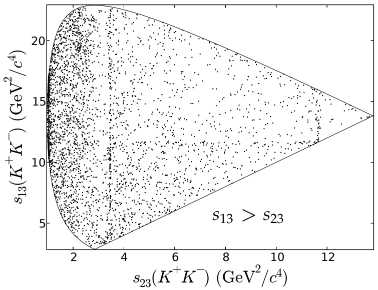


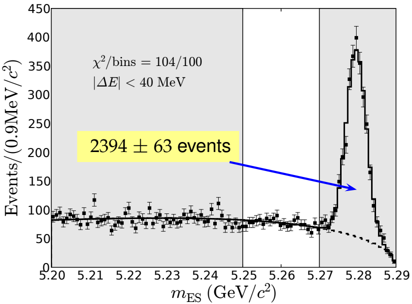


BABAR, hep-ex/0608036

Dalitz plot analysis of $B^+ \to K^+K^+K^-$

- Full Dalitz plot analysis, measure amplitudes and relative phases
- Fit B^+ and B^- separately for $\mathcal{A}_{ch}$





$$\mathcal{B}(B^+ \to K^+K^+K^-) = (35.2 \pm 0.9 \pm 1.6) \times 10^{-6}$$

Comp.	ρ	ϕ (rad)	F (%)	$F \times \mathcal{B}(B^\pm \to K^\pm K^\pm K^\mp)$	A	$(A_{\min}, A_{\max})_{90\%}$	$\delta\phi$ (rad)
$\phi(1020)$	1.66 ± 0.06	$2.99 \pm 0.20 \pm 0.06$	$11.8 \pm 0.9 \pm 0.8$	$(4.14 \pm 0.32 \pm 0.33)\times10^{-6}$	$0.00 \pm 0.08 \pm 0.02$	$(-0.14, 0.14)$	$-0.67 \pm 0.28 \pm 0.05$
$f_0(980)$	5.2 ± 1.0	$0.48 \pm 0.16 \pm 0.08$	$19 \pm 7 \pm 4$	$(6.5 \pm 2.5 \pm 1.6)\times10^{-6}$	$-0.31 \pm 0.25 \pm 0.08$	$(-0.72, 0.12)$	$-0.20 \pm 0.16 \pm 0.04$
$X_0(1550)$	8.2 ± 1.1	$1.29 \pm 0.10 \pm 0.04$	$121 \pm 19 \pm 6$	$(4.3 \pm 0.6 \pm 0.3)\times10^{-5}$	$-0.04 \pm 0.07 \pm 0.02$	$(-0.17, 0.09)$	$0.02 \pm 0.15 \pm 0.05$
$f_0(1710)$	1.22 ± 0.34	$-0.59 \pm 0.25 \pm 0.11$	$4.8 \pm 2.7 \pm 0.8$	$(1.7 \pm 1.0 \pm 0.3)\times10^{-6}$	$0.0 \pm 0.5 \pm 0.1$	$(-0.66, 0.74)$	$-0.07 \pm 0.38 \pm 0.08$
χ_{c0}^{I}	0.437 ± 0.039	$-1.02 \pm 0.23 \pm 0.10$	$3.1 \pm 0.6 \pm 0.2$	$(1.10 \pm 0.20 \pm 0.09)\times10^{-6}$	$0.19 \pm 0.18 \pm 0.05$	$(-0.09, 0.47)$	$0.7 \pm 0.5 \pm 0.2$
χ_{c0}^{II}	0.604 ± 0.034	0.29 ± 0.20	6.0 ± 0.7	$(2.10 \pm 0.24) \times 10^{-6}$	-0.03 ± 0.28	-	-0.4 ± 1.3
NR	13.2 ± 1.4	0	$141 \pm 16 \pm 9$	$(5.0 \pm 0.6 \pm 0.4)\times10^{-5}$	$0.02 \pm 0.08 \pm 0.04$	$(-0.14, 0.18)$	0

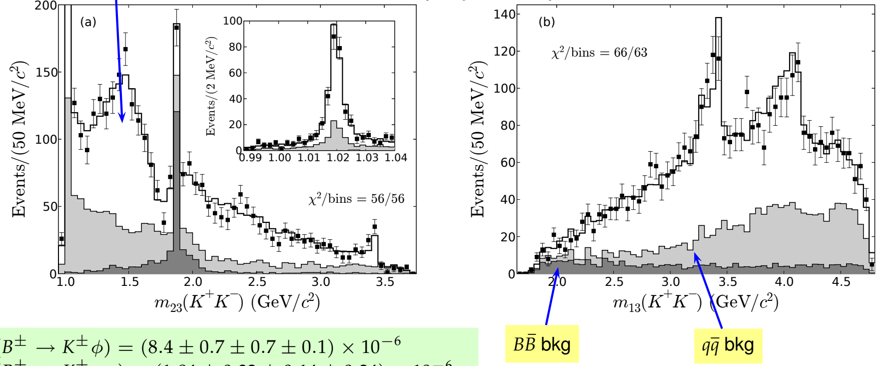
Non-resonant component not flat across DP

Dalitz plot analysis of $B^+ \to K^+K^+K^-$

BaBar
$m_0(X_0) = 1.539 \pm 0.020\,\mathrm{GeV}/c^2$
$\Gamma_0(X_0) = 0.257 \pm 0.033\,\mathrm{GeV}/c^2$
Phys. Rev. D **74**032003

BELLE: doublet of solutions
$m_0(X_0) = 1.524 \pm 0.014/1.491 \pm 0.01\,\mathrm{GeV}/c^2$
$\Gamma_0(X_0) = 0.136 \pm 0.023/0.145 \pm 0.029\,\mathrm{GeV}/c^2$
Phys. Rev. D **71**,092003 (2005)

Mass projection plots



$\mathcal{B}(B^\pm \to K^\pm\phi) = (8.4 \pm 0.7 \pm 0.7 \pm 0.1) \times 10^{-6}$
$\mathcal{B}(B^\pm \to K^\pm\chi_{c0}) = (1.84 \pm 0.32 \pm 0.14 \pm 0.24) \times 10^{-6}$

$$\mathcal{B}(B^+ \to K^+K^+K^-) = (35.2 \pm 0.9 \pm 1.6) \times 10^{-6}$$

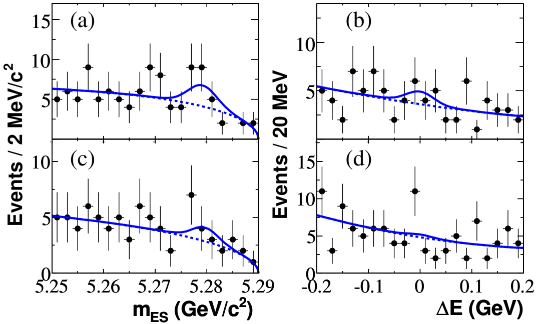
BaBar, 205 fb^{-1}

Search for $B \to \eta'\eta' K$

- Motivation:
  - Large $\mathcal{B}(B \to \eta' K)$
  - CP violation in $B \to P^0 P^0 Q^0$ [Gershon & Hazumi, 2004], e.g. observation of $B^0 \to K^0_S K^0_S K^0_S$
    [BELLE, Phys. Rev. D **69**, 012001 , BABAR, Phys. Rev. Lett. **95**, 011810]
- Results (@ 90% CL):

$$\mathcal{B}(B^+ \to \eta'\eta' K^+) < 25 \times 10^{-6}$$
$$\mathcal{B}(B^0 \to \eta'\eta' K^0) < 31 \times 10^{-6}$$

BABAR, 211 fb^{-1}, Phys. Rev. D **74**:031105



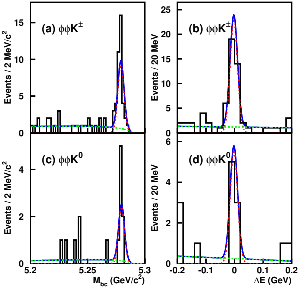
$\eta'\ \eta'\ K^+$

$\eta'\ \eta'\ K^0$

$B \to \phi\phi K$

$m_{\phi\phi} < 2.85\,\mathrm{GeV}/c^2$

- $b \to s\bar{s}s$ with additional $s\bar{s}$ pair
- Direct CPV could be enhanced in interference between non-SM decays and decays via η_c
- BELLE, hep-ex/0609016
  Search for charmless decays by reqiring $m_{\phi\phi}$ below charm threshold



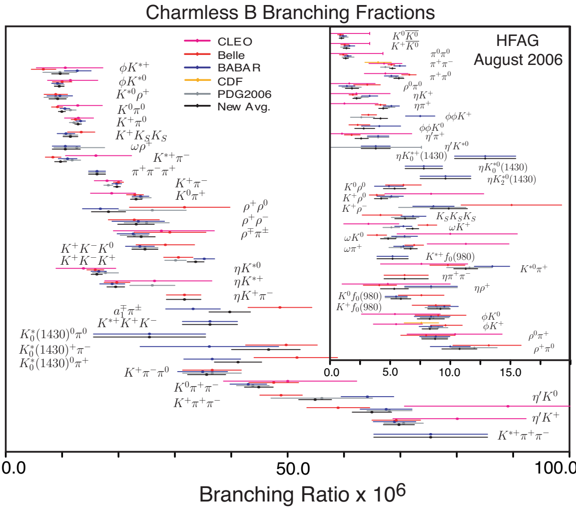
Charmless:
$\mathcal{A}_{ch} = 0.01^{+0.19}_{-0.16} \pm 0.02$

$\eta_c K^+$:
$\mathcal{A}_{ch} = 0.15^{+0.16}_{-0.17} \pm 0.02$

Mode	Yields	Σ	$\mathcal{B}(10^{-6})$
$B^\pm \to \phi\phi K^\pm$ ($M_{\phi\phi} < 2.85$ GeV$/c^2$)	$34.2^{+6.4}_{-5.8}$	9.5	$3.2^{+0.6}_{-0.5} \pm 0.3$
$B^0 \to \phi\phi K^0$ ($M_{\phi\phi} < 2.85$ GeV$/c^2$)	$7.3^{+3.0}_{-2.4}$	4.7	$2.3^{+1.0}_{-0.7} \pm 0.2$
$B^\pm \to \eta_c K^\pm$, $\eta_c \to \phi\phi$	$29.7^{+6.8}_{-5.5}$	7.2	$2.4^{+0.6}_{-0.5} \pm 0.2$
$B^\pm \to \eta_c K^\pm$, $\eta_c \to \phi K^+ K^-$	$76.8^{+13.6}_{-12.4}$	9.4	$3.5 \pm 0.6 \pm 0.3$
$B^\pm \to \eta_c K^\pm$, $\eta_c \to 2(K^+K^-)$	$104.6^{+20.2}_{-17.3}$	10.2	$2.4^{+0.5}_{-0.4} \pm 0.2$
$B^\pm \to J/\psi K^\pm$, $J/\psi \to \phi K^+ K^-$	$25.5^{+7.0}_{-6.0}$	8.5	$1.2 \pm 0.3 \pm 0.1$
$B^\pm \to J/\psi K^\pm$, $J/\psi \to 2(K^+K^-)$	$41.0^{+7.3}_{-6.6}$	9.7	$0.97^{+0.17}_{-0.16} \pm 0.1$

Summary

- Many new and updated results from both B factories
- Impressive agreement between BELLE and *BABAR*
- Rare charmless B decays help to improve understanding of Standard Model amplitudes
- More and more precise results to come with more data

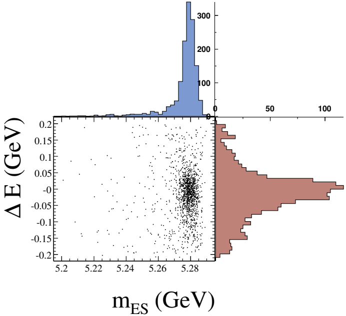


Backup Slides

Detecting a signal

- Largest backgrounds from $e^+e^- \to q\bar{q}$
- Kinematic variables:

$$\Delta E = E_B^* - E_{\text{beam}}^* \qquad m_{\text{ES}} = \sqrt{E_{\text{beam}}^{*} - p_B^{*2}}$$



- Event shape for background suppression: