Measurements of Exclusive Charmless B Decays Related to $\Delta S_{\phi K^0}$ and $\Delta S_{\eta' K^0}$ at BaBar

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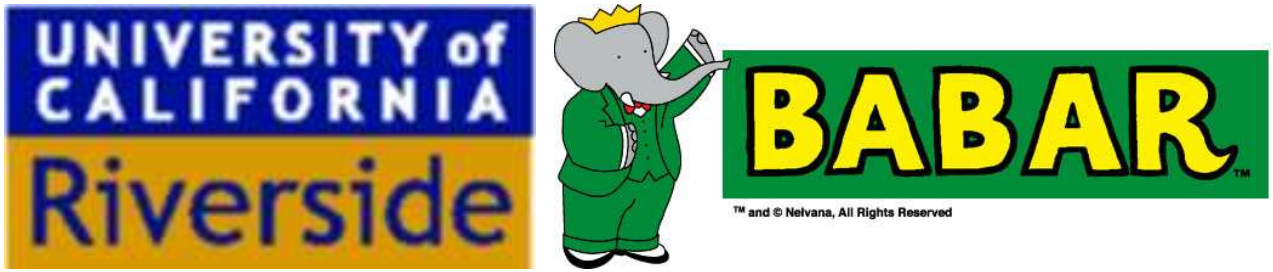


Modes Covered

- Modes covered and data sample used

Modes	Data ($B\bar{B}$)	Reference
$B^0 \to \eta K^0$, $\eta\eta$, $\eta'\eta'$, $\eta\phi$, $\eta'\phi$	324 M	PRD **74**, 051106(R) (2006)
$B^0 \to \eta\eta'$, $\eta'\pi^0$, $\eta\pi^0$	232 M	PRD **73**, 071102(R) (2006)
$B \to \phi\pi$	232 M	PRD **74**, 011102(R) (2006)
$B^0 \to \overline{K}^{*0} K^0$ †	232 M	PRD **74**, 072008 (2006)

† First search, others updates

- Submodes included:

$$
\begin{array}{lll}
K^0 \to K^0_S(\pi^+\pi^-) & \pi^0 \to \gamma\gamma & \phi \to K^+K^- \\
\eta_{3\pi} \to \pi^+\pi^-\pi^0 & \eta_{\gamma\gamma} \to \gamma\gamma & \overline{K}^{*0} \to K^-\pi^+ \\
\eta'_{\eta\pi\pi} \to \eta_{\gamma\gamma}\pi^+\pi^- & \eta'_{\gamma\rho} \to \gamma\rho^0 & \rho^0 \to \pi^+\pi^-
\end{array}
$$

- All submodes are combined to obtain final results:

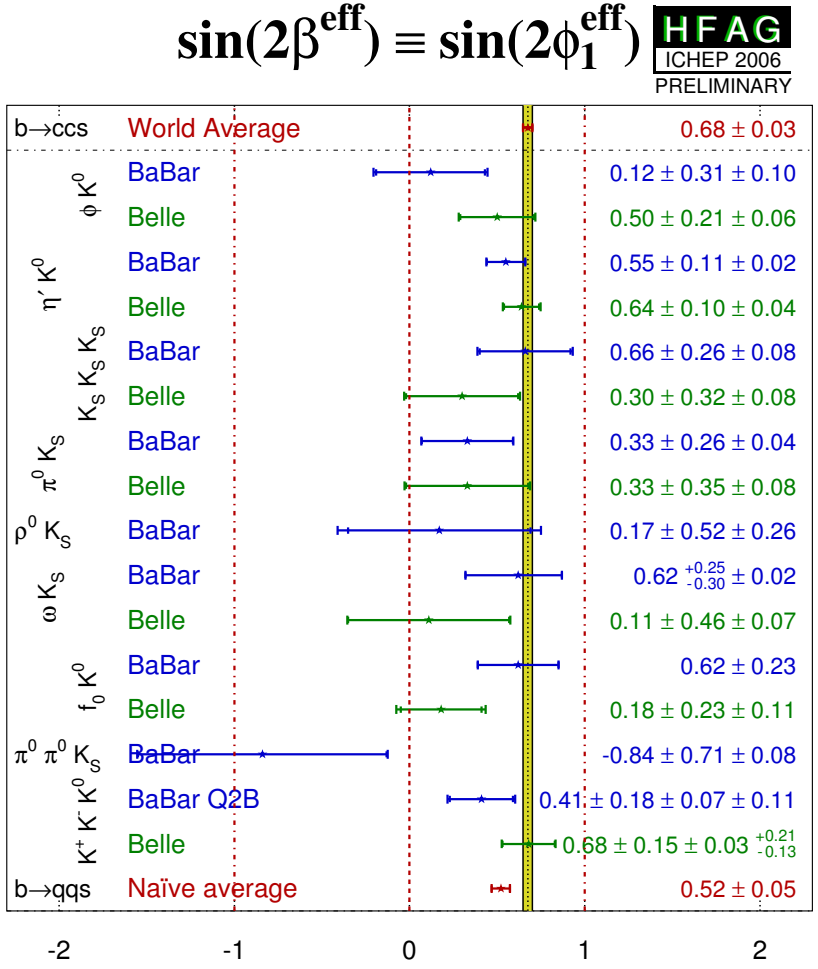
Motivations

- Motivation: difference of $\mathcal{A}_{\mathcal{CP}}$ for $b \to s\bar{s}s$ penguin processes and $b \to c\bar{c}s$ ($\Delta S = S_f - \sin 2\beta \sim 3\sigma$ difference)

  - ◇ Sensitive to

    a) New Physics
    b) SM polution ($b \to u$);

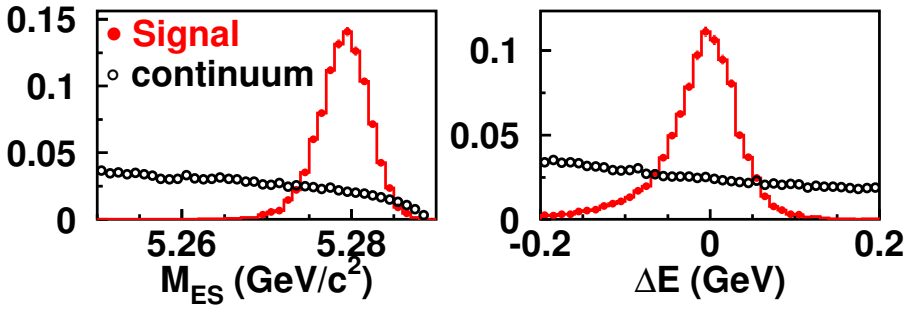
  - ◇ $B^0 \to \eta^{(\prime)} X$, ϕX and $K^* K$ help understand the SM polution for $S_{\phi K^0}$ and $S_{\eta' K^0}$.



- Theoretical interest: SU(3)$_f$, QCDF, soft collinear eff. theory:

Analysis Strategy

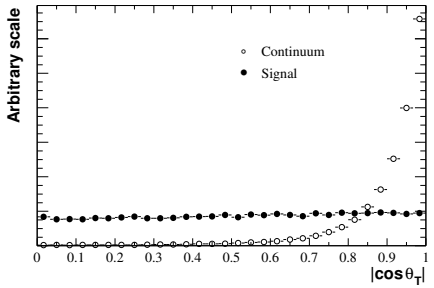
- Reconstructed B (PID applicable) (ΔE, M_{ES}/M_B)
- Event shape: continuum $\sim$ jetlike, $B\bar{B} \sim$ isotropic



$q\bar{q}$: $|\cos\theta_T|$ peak near 1, $B\bar{B}$: flat in CMS

- Build standard unbinned maximum likelihood:

$$\mathcal{L} = \frac{1}{N!}\exp\left(-\sum_j n_j\right)\prod_{i=1}^{N}\left[\sum_j n_j \mathcal{P}_j(\vec{\mathbf{x}}_i, \vec{\alpha}_j)\right],$$



$N = \sum_j n_j$: total events#, n_j: events# of the j^{th} component ($j \geq 3$),

$\vec{\mathbf{x}}$: variables (M_{ES}/M_B, ΔE, event shape ($\mathcal{F}$), M_R, $\cos\theta_V$...),

$\vec{\alpha}_j$: parameters for probability density functions (PDFs),

$\mathcal{P}_j(\vec{\mathbf{x}}_i)$: probability of event i to be component j.

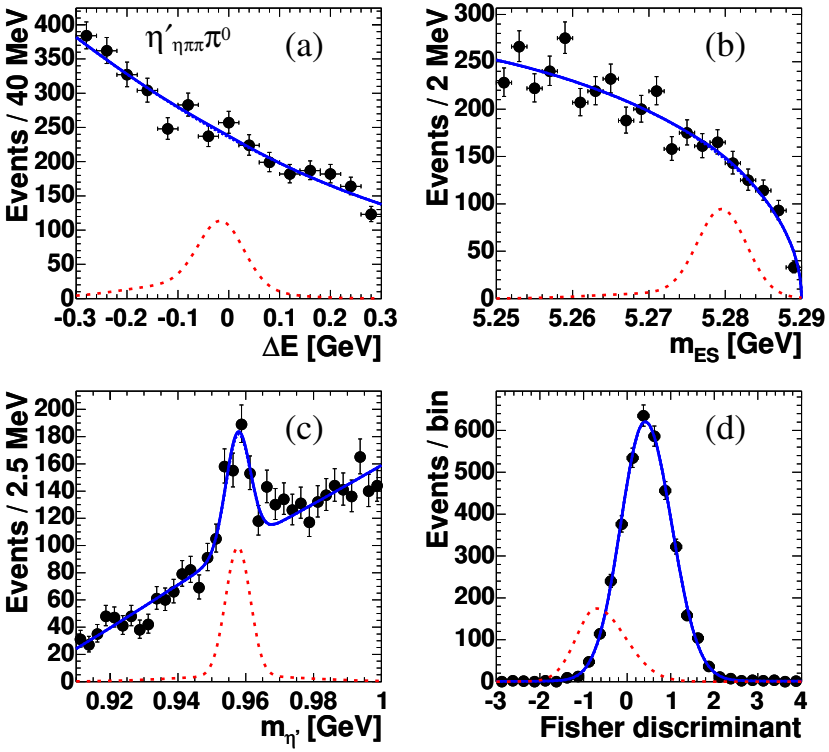
- Corrected bias if applicable due to correlations between variables neglected in ML (for detail, see references).

$B^0 \to \eta\pi^0$, $\eta'\pi^0$ and $\eta\eta'$

Mode	$\mathcal{B}$ $(\times 10^{-6})$	$\mathcal{S}(\sigma)$	UL(CL=90%)
$\eta\pi^0$	$0.6^{+0.5}_{-0.4} \pm 0.1$	1.3	< 1.3
$\eta'\pi^0$	$0.8^{+0.8}_{-0.6} \pm 0.1$	1.4	< 2.1
$\eta\eta'$	$0.2^{+0.7}_{-0.5} \pm 0.4$	1.3	< 1.7

- PRD **73**, 071102(R) (2006)
- constrain $\Delta S_{\eta' K^0}$
- e.g. $B^0 \to \eta'_{\eta\pi\pi}\pi^0 \Rightarrow$
  - $\mathcal{B} = (0.8^{+0.8}_{-0.6} \pm 0.1) \times 10^{-6}$ measured
  - assumed $\mathcal{B} = 50 \times 10^{-6}$ (red lines X62.5)
- consistent with BELLE

Mode	$\mathcal{B}$ $(\times 10^{-6})$	$\mathcal{S}(\sigma)$	UL(CL=90%)
$\eta\pi^0$	$1.2 \pm 0.7 \pm 0.1$	1.8	< 2.5
$\eta'\pi^0$	$2.79^{+1.02+0.25}_{-0.96-0.34}$	3.1	



BELLE: PRL **97**, 061802 (2006), PRD **71**, 091106(R) (2005)

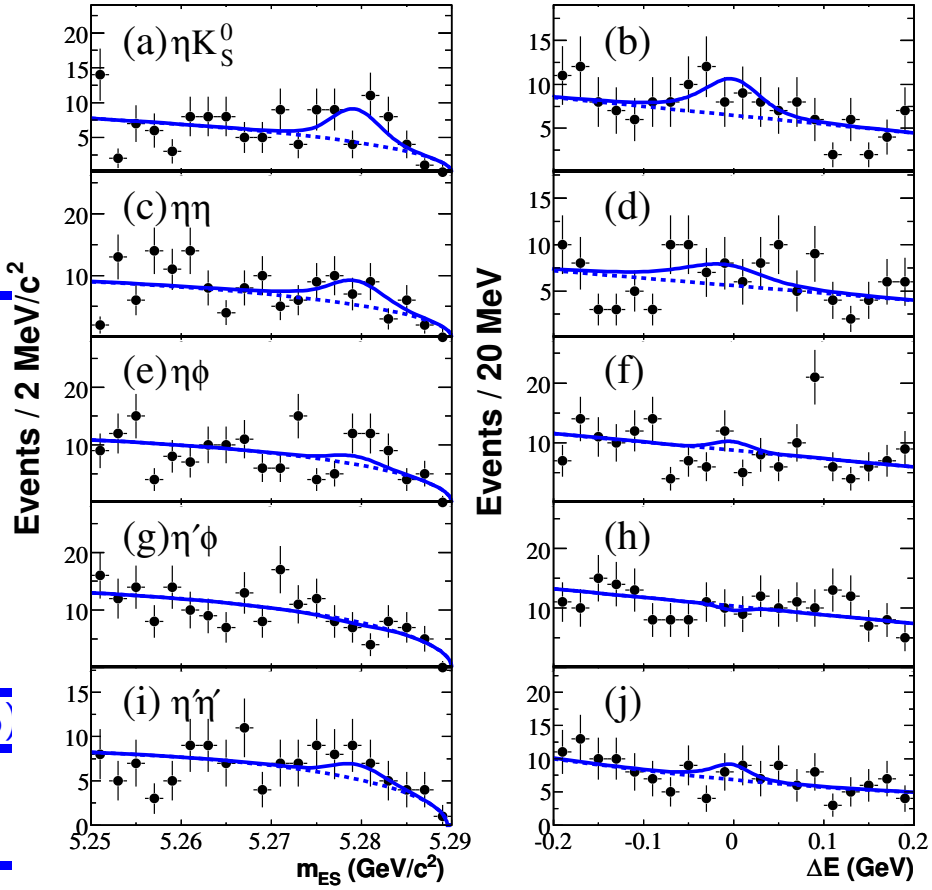
$B^0 \to \eta K^0$, $\eta\eta$, $\eta\phi$, $\eta'\phi$, and $\eta'\eta'$

Mode	$\mathcal{B}(10^{-6})$	$\mathcal{S}(\sigma)$	UL(CL=90%)
ηK^0	$1.8^{+0.7}_{-0.6} \pm 0.1$	3.6	< 2.9
$\eta\eta$	$1.1^{+0.5}_{-0.4} \pm 0.1$	3.1	< 1.8
$\eta\phi$	$0.1 \pm 0.2 \pm 0.1$	–	< 0.6
$\eta'\phi$	$0.2^{+0.4}_{-0.3} \pm 0.1$	0.5	< 1.0
$\eta'\eta'$	$1.0^{+0.8}_{-0.6} \pm 0.1$	1.8	< 2.4

- PRD **74**, 051106(R) (2006)
- constrain $\Delta S_{\eta' K^0}$ and $\Delta S_{\phi K^0}$
- good agreement with BELLE (hep-ex/0608033, PRD, **71** 091106 (2005))

Mode	$\mathcal{B}$ $(\times 10^{-6})$	$\mathcal{S}(\sigma)$	UL(CL=90%)
ηK^0	$1.1 \pm 0.4 \pm 0.1$	2.9	< 1.9
$\eta\eta$	$0.7^{+0.7}_{-0.6} \pm 0.1$	1.1	< 2.0

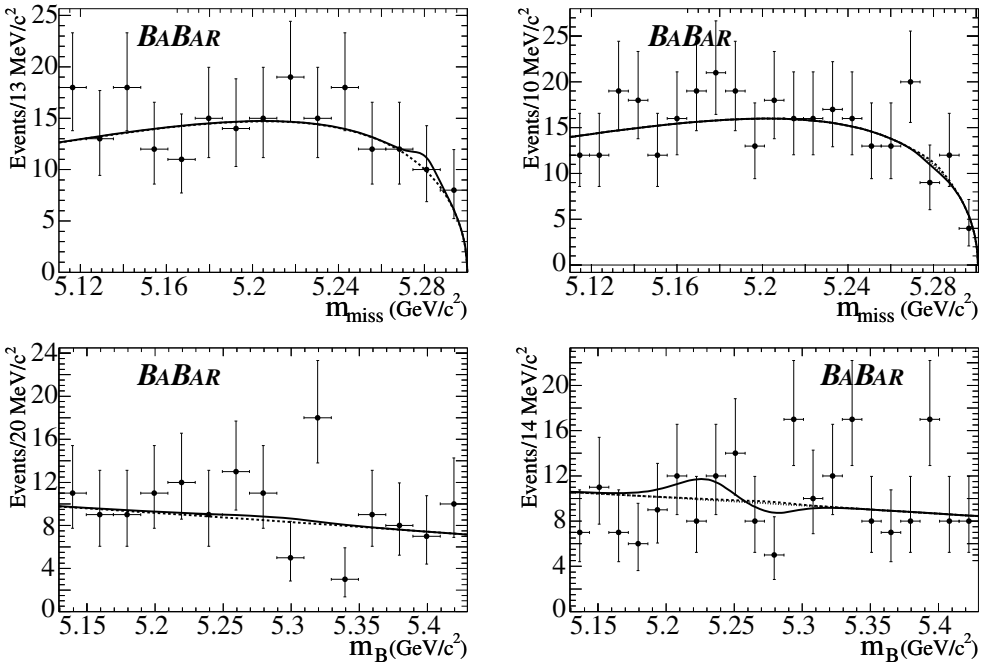
- Projections w/ a cut on $L_S/(L_S + \sum L_{bg})$



$B \to \phi\pi$

- $B^0 \to \phi\pi^0$ (left), $B^+ \to \phi\pi^+$ (right)

Mode	$\mathcal{B}(\times 10^{-6})$	UL
$B^+ \to \phi\pi^+$	$-0.04 \pm 0.17^{+0.04}_{-0.04}$	0.28
$B^0 \to \phi\pi^0$	$0.12 \pm 0.13^{+0.03}_{-0.04}$	0.24



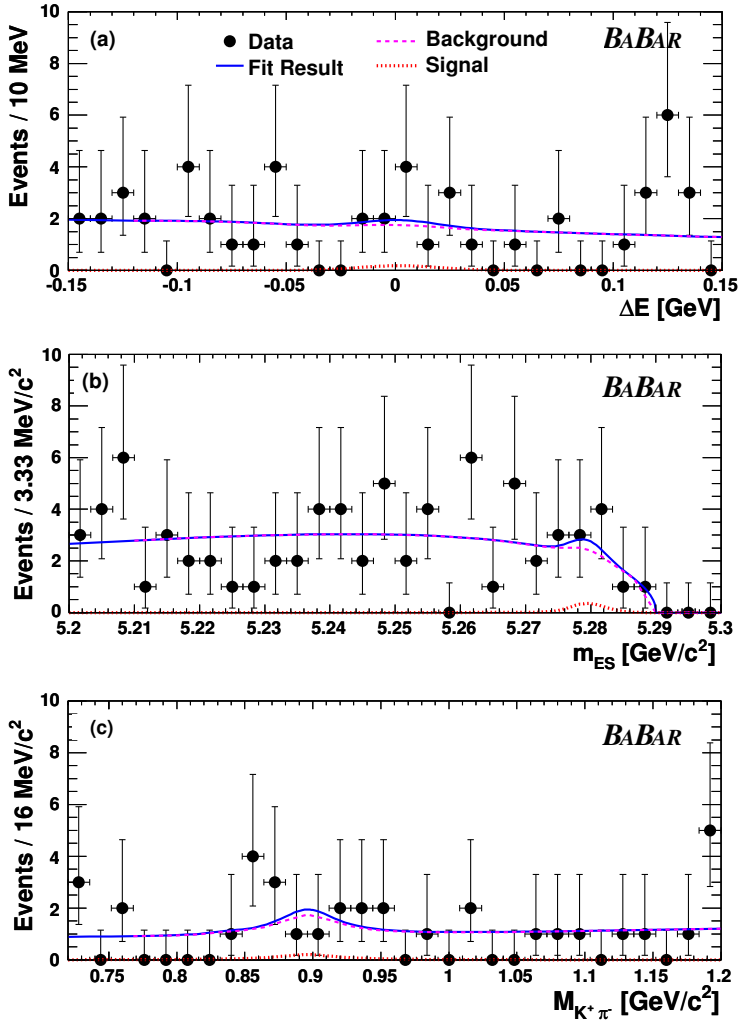
- PRD **74**, 011102(R) (2006)
- constrain $\Delta S_{\phi K^0}$

$B \to \overline{K}^{*0} K^0$

- First search for $B \to \overline{K}^{*0} K^0$

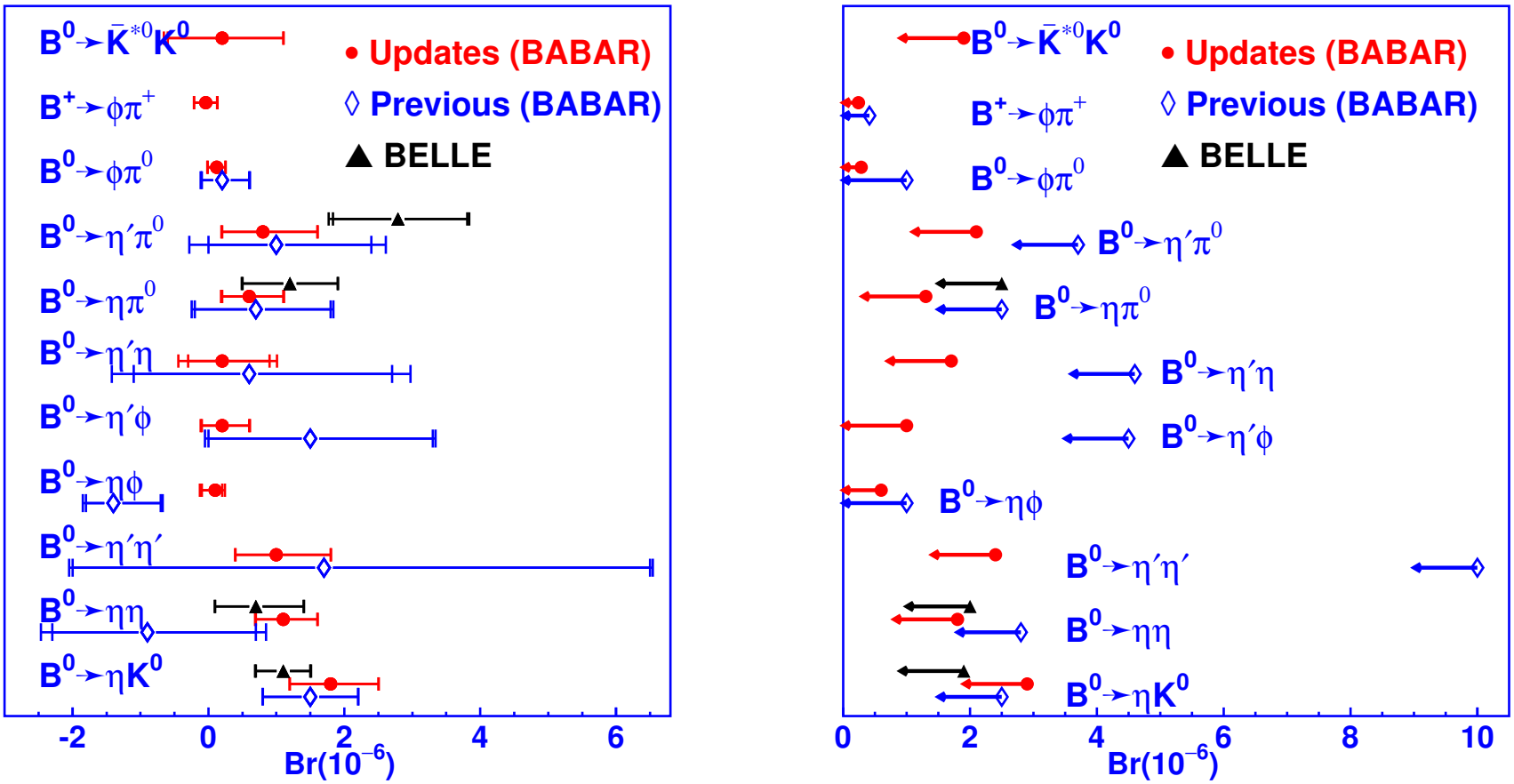
$\mathcal{B}(\times 10^{-6})$	$\mathcal{S}(\sigma)$	UL(CL=90%)
$\mathbf{0.2^{+0.9+0.1}_{-0.8-0.3}}$	0.3	$\mathbf{< 1.9}$

- PRD **74**, 072008 (2006)
- constrain $\Delta S_{\phi K^0}$



Summary of Results

- Comparison with the previous BABAR and BELLE results



- Much tighter ULs

Constraints on ΔS

- Grossman *et al.*: $|\Delta S| \equiv |S - \sin 2\beta| = 2\cos 2\beta \sin\gamma \cos\delta |\xi|$
  where $\xi \equiv \frac{V_{ub}^* V_{us}}{V_{cb}^* V_{cs}} \frac{a^u}{a^c}$ (PRD 68,015005 (2003))
  SU(3) relates $a_f^{c,u}$ of $A_f \equiv A(B^0 \to f) = V_{cb}^* V_{cs} a_f^c + V_{ub}^* V_{us} a_f^u$
  to sum of $b_{f'}^{c,u}$ of non-s. amp. $A_{f'} \equiv A(B^0 \to f') = V_{cb}^* V_{cd} b_{f'}^c + V_{ub}^* V_{ud} b_{f'}^u$
  to obtain bound on $\hat{\xi} \equiv \left| \frac{V_{us}}{V_{ud}} \times \frac{V_{cb}^* V_{cd} a^c + V_{ub}^* V_{ud} a^u}{V_{cb}^* V_{cs} a^c + V_{ub}^* V_{us} a^u} \right| = \left| \frac{\xi_f + (V_{us} V_{cd})/(V_{ud} V_{cs})}{1 + \xi_f} \right|$
  in terms of Br's or UL's as

$$|\hat{\xi}_{\eta' K^0}| \leq \left| \frac{V_{us}}{V_{ud}} \right| \left\{ 0.59 \sqrt{\frac{\mathcal{B}(\eta'\pi^0)}{\mathcal{B}(\eta' K^0)}} + 0.33 \sqrt{\frac{\mathcal{B}(\eta\pi^0)}{\mathcal{B}(\eta' K^0)}} + 0.14 \sqrt{\frac{\mathcal{B}(\pi^0\pi^0)}{\mathcal{B}(\eta' K^0)}} \right.$$
$$\left. + 0.53 \sqrt{\frac{\mathcal{B}(\eta'\eta')}{\mathcal{B}(\eta' K^0)}} + 0.38 \sqrt{\frac{\mathcal{B}(\eta\eta)}{\mathcal{B}(\eta' K^0)}} + 0.96 \sqrt{\frac{\mathcal{B}(\eta\eta')}{\mathcal{B}(\eta' K^0)}} \right\}.$$

  $\beta, \gamma(\delta)$weak (strong) phase

- We find $|\Delta S_{\eta' K^0}| < 0.15$ (0.22 formerly) for $S_{\eta' K^0}$ @CL=90%
- Gronau et. al., $C_{\eta' K^0}$ and $S_{\eta' K^0}$ $-0.133 < \Delta S_{\eta' K^0} < 0.152$ (6 modes) and $-0.046 < \Delta S_{\eta' K^0} < 0.094$ ($\eta\pi^0$,$\eta'\pi^0$ and $\eta\eta'$, see hep-ph/0608085)

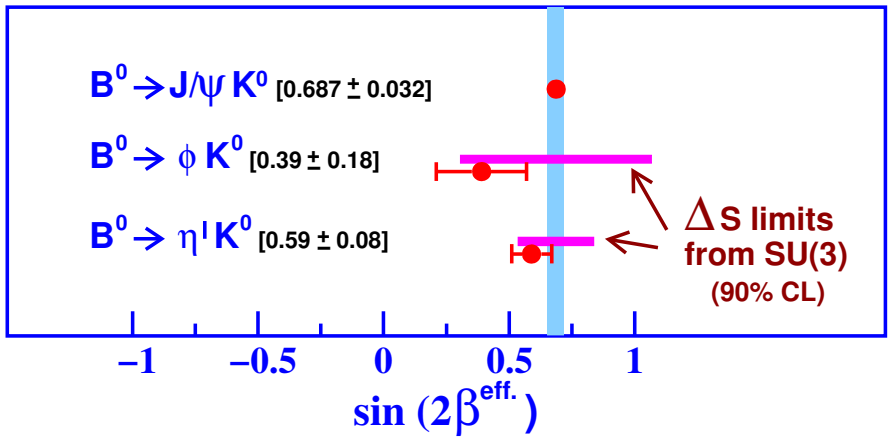
ΔS for ϕK^0

- $\Delta S_{\phi K^0}$

$$\hat{\xi}_{\phi K^0} \leq \left|\frac{V_{us}}{V_{ud}}\right| \left\{ \frac{1}{2}\left[\frac{\mathcal{B}(\overline{K}^{*0}K^0)+\mathcal{B}(K^{*0}\overline{K}^0)}{\mathcal{B}(\phi K^0)}\right] + \frac{\sqrt{6}}{4}\left[\frac{t\mathcal{B}(\phi\eta)+s\mathcal{B}(\phi\eta')}{\mathcal{B}(\phi K^0)}\right] \right.$$
$$\frac{\sqrt{3}}{4}\left[\frac{t\mathcal{B}(\omega\eta)+s\mathcal{B}(\omega\eta')}{\mathcal{B}(\phi K^0)}\right] + \frac{\sqrt{3}}{4}\left[\frac{t\mathcal{B}(\rho^0\eta)+s\mathcal{B}(\rho^0\eta')}{\mathcal{B}(\phi K^0)}\right]$$
$$\left. \frac{1}{4}\left[\frac{\mathcal{B}(\rho^0\pi^0)+\mathcal{B}(\omega\pi^0)}{\mathcal{B}(\phi K^0)}\right] + \frac{1}{2\sqrt{2}}\frac{\mathcal{B}(\phi\pi^0)}{\mathcal{B}(\phi K^0)} \right\}$$

$$t \equiv \cos\theta_{\eta\eta'} = 0.94, s = \sin\theta_{\eta\eta'} = 0.34 \text{ with } \theta_{\eta\eta'} = 20^0$$

- We find the first constraint (SU(3)$_f$) $|\Delta S_{\phi K^0}| < 0.38$ for $S_{\phi K^0}$ @ CL=90%



- consistent with the constraints
- Both charmless S and constraints on ΔS need further improvement $S_{J/\psi K^0} \sim 5\%$, $S_{\eta' K^0} \sim 14\%$ $S_{\phi K^0} \sim 50\%$

Summary

- Improved ULs for $B \to VP/PP$ ($\Delta S = S_f - \sin 2\beta$ for $\mathcal{A}_{\mathcal{CP}}^{\eta' K^0}$ and $\mathcal{A}_{\mathcal{CP}}^{\phi K^0}$)

Modes	Reference
$B^0 \to \eta K^0$, $\eta\eta$, $\eta'\eta'$, $\eta\phi$, $\eta'\phi$	PRD **74**, 051106(R) (2006)
$B^0 \to \eta\eta'$, $\eta'\pi^0$, $\eta\pi^0$	PRD **73**, 071102(R) (2006)
$B \to \phi\pi$	PRD **74**, 011102(R) (2006)
$B^0 \to \overline{K}^{*0} K^0$	PRD **74**, 072008 (2006)

- Much tighter constraint on $|\Delta S_{\eta' K^0}| < 0.15$ (0.22 formerly) for $S_{\eta' K^0}$ @CL=90%
- We find the first constraint $|\Delta S_{\phi K^0}| < 0.38$ for $S_{\phi K^0}$ @ CL=90%
- $S_{\eta' K^0}$ and $S_{\phi K^0}$ consistent with current constraints.

Summary of the Results

- BABAR results (blue), BELLE (black)

Mode	$\mathcal{S}(\sigma)$	$\mathcal{B}(10^{-6})$	UL $((10^{-6})$	previous	Reference
$\boldsymbol{B^0 \to \eta K^0}$	**3.6**	$\boldsymbol{1.8^{+0.7}_{-0.6} \pm 0.1}$	$\boldsymbol{< 2.9}$	$\boldsymbol{< 2.5}$	PRD 74, 051106 (2006)
	2.9	$1.1 \pm 0.4 \pm 0.1$	$\boldsymbol{< 1.9}$		hep-ex/0608033
$\boldsymbol{B^0 \to \eta\eta}$	**3.1**	$\boldsymbol{1.1^{+0.5}_{-0.4} \pm 0.1}$	$\boldsymbol{< 1.8}$	$\boldsymbol{< 2.8}$	
	1.1	$0.7^{+0.7}_{-0.6} \pm 0.1$	$\boldsymbol{< 1.9}$		PRD **71**, 091106 (2005)
$\boldsymbol{B^0 \to \eta'\eta'}$	**1.8**	$\boldsymbol{1.0^{+0.8}_{-0.6} \pm 0.1}$	$\boldsymbol{< 2.4}$	$\boldsymbol{< 10}$	
$\boldsymbol{B^0 \to \eta\phi}$	**0.0**	$\boldsymbol{0.1 \pm 0.2 \pm 0.1}$	$\boldsymbol{< 0.6}$	$\boldsymbol{< 1.0}$	
$\boldsymbol{B^0 \to \eta'\phi}$	**0.5**	$\boldsymbol{0.2^{+0.4}_{-0.3} \pm 0.1}$	$\boldsymbol{< 1.0}$	$\boldsymbol{< 4.5}$	
$\boldsymbol{B^0 \to \eta\eta'}$	**0.4**	$\boldsymbol{0.2^{+0.7}_{-0.5} \pm 0.4}$	$\boldsymbol{< 1.7}$	$\boldsymbol{< 4.6}$	PRD 73, 071102 (2006)
$\boldsymbol{B^0 \to \eta\pi^0}$	**1.3**	$\boldsymbol{0.6^{+0.5}_{-0.4} \pm 0.1}$	$\boldsymbol{< 1.3}$	$\boldsymbol{< 2.5}$	
	1.8	$1.2 \pm 0.7 \pm 0.1$	$\boldsymbol{< 2.5}$		PRD **71**, 091106 (2005)
$\boldsymbol{B^0 \to \eta'\pi^0}$	**1.4**	$\boldsymbol{0.8^{+0.8}_{-0.6} \pm 0.1}$	$\boldsymbol{< 2.1}$	$\boldsymbol{< 3.7}$	
	3.1	$2.79^{+1.02+0.25}_{-0.96-0.34}$			PRL **97**, 061802 (2006)
$\boldsymbol{B^0 \to \phi\pi^0}$	–	$\boldsymbol{0.12 \pm 0.13^{+0.03}_{-0.04}}$	$\boldsymbol{< 0.28}$	$\boldsymbol{< 0.41}$	PRD 74, 011102 (2006)
$\boldsymbol{B^+ \to \phi\pi^+}$	–	$\boldsymbol{-0.04 \pm 0.17^{+0.04}_{-0.04}}$	$\boldsymbol{< 0.24}$	$\boldsymbol{< 1.0}$	
$\boldsymbol{B^0 \to \overline{K}^{*0} K^0}$	**0.3**	$\boldsymbol{0.2^{+0.9+0.1}_{-0.8-0.3}}$	$\boldsymbol{< 1.9}$		PRD **74**, 072008 (2006)