BABAR

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Measurements of branching fractions and CP asymmetries in charmless quasi-two-body B decays at BaBar

- $B \to \eta K^*$
- $B \to \eta' K^*, \eta' \rho$
- $B \to \eta_X K$
- $B \to \phi\phi K$
- $B \to a_0 \pi$

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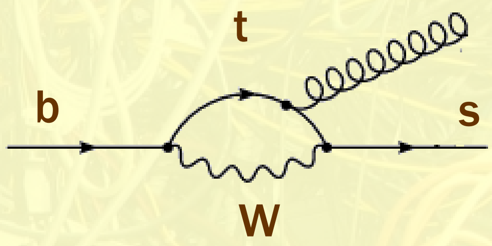
Flavor-changing neutral current

BaBar

- doesn't exist in SM at tree level (GIM mechanism)
- sensitive to new physics
- early predictions didn't explain the data (the η' puzzle)



<u>Implications for the (η-η')$K^{(*)}$ system:</u>

- Mixing of η and η' enhances some rates and suppresses others
- Flavor SU(3) and measurements of branching fractions can constrain theoretical models
- $B \rightarrow \eta' K^*$ is the last one of four that was not measured. Now it is.
- There are more similar decays with higher K^*s and ηs, they may be helpful.

See also

H. J. Lipkin, Phys. Lett. B ***254****, 247 (1991)*

M. Beneke and M. Neubert, Nucl. Phys. B ***651****, 225 (2003)*

BaBar

The BaBar detector

From the inside out:

Silicon Vertex Tracker
5 layers, double sided strips

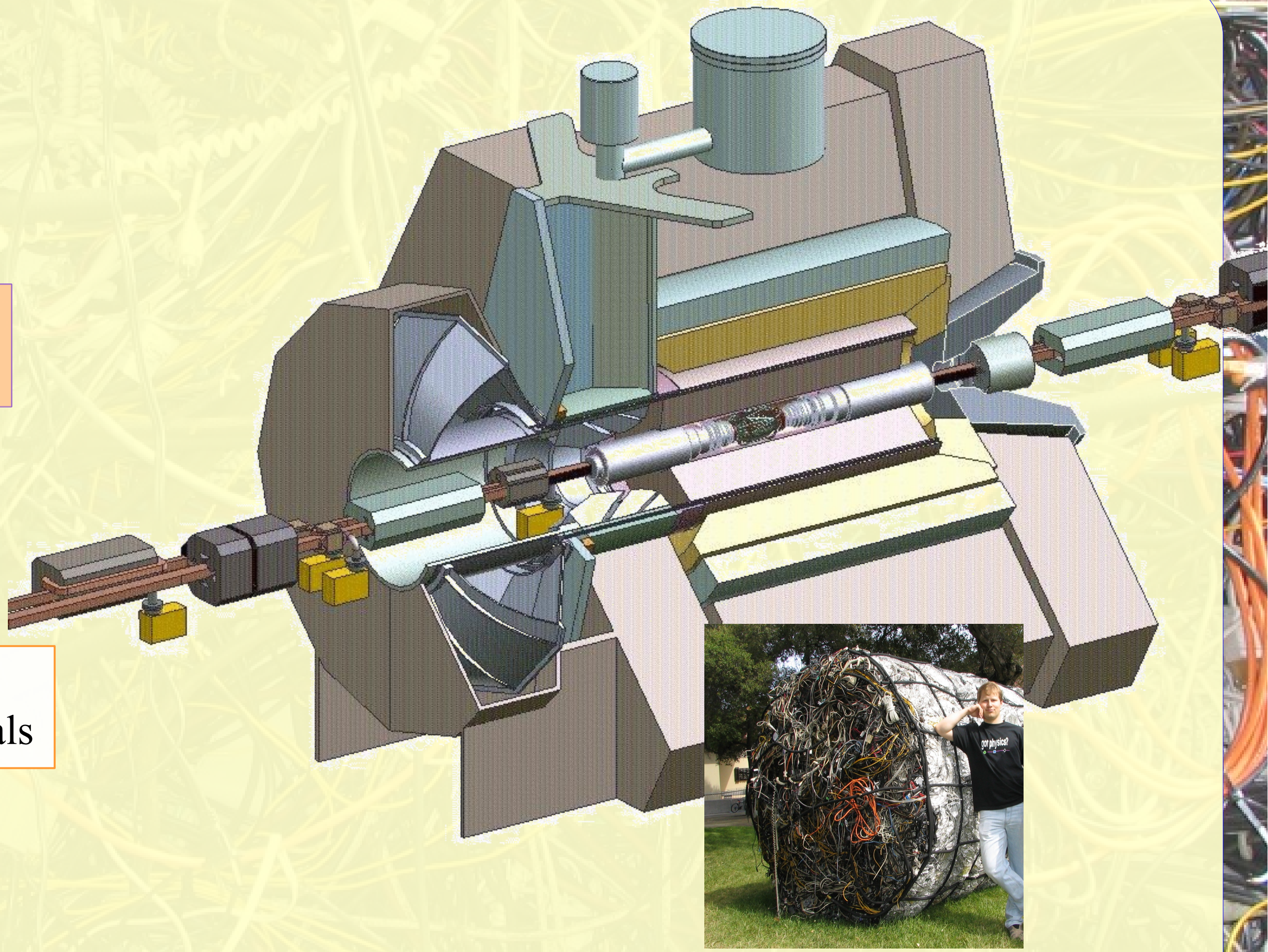
Drift Chamber
40 layers

DIRC (PID)
144 quartz bars
11000 PMs

EMC
6580 CsI(Tl) crystals

1.5T solenoid

Instrumented Flux Return
iron/RPCs/LSTs (muon / neutral hadrons)

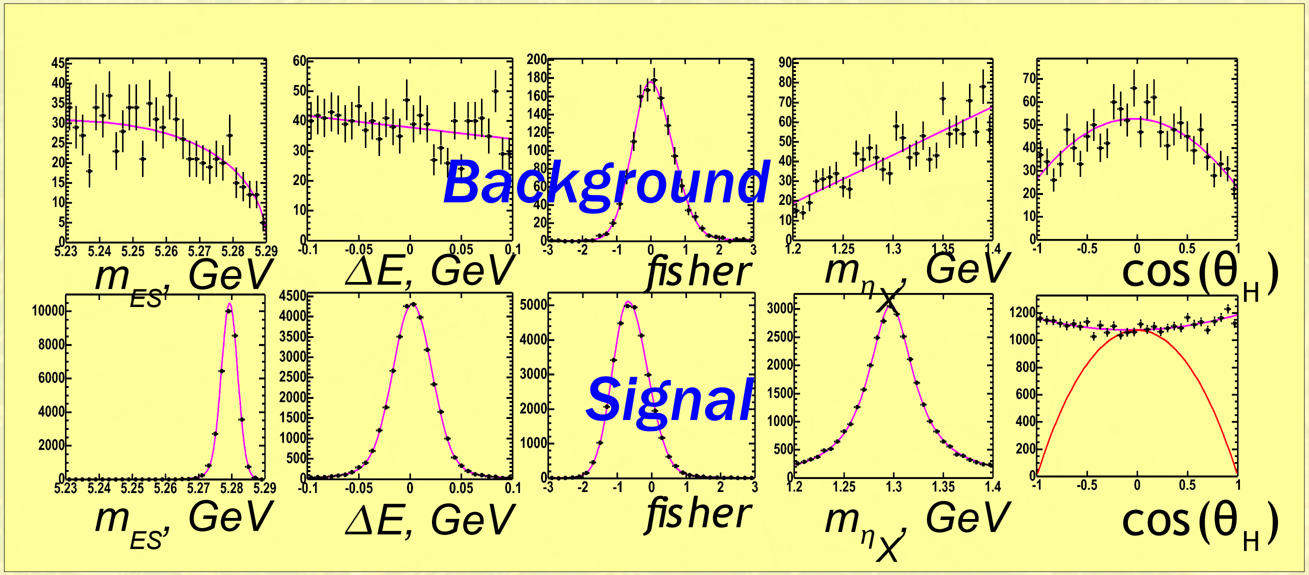


ML fit

$P_j(\vec{x}_i;\vec{\beta})$ - probability density functions

$\vec{x}_i = \{m_{ES}, \Delta E, ...\}$ - observables (must be uncorrelated, we check that)

$\vec{\beta}$ - PDF parameters



Likelihood function:

$$L = \exp(-\sum n_j) \prod_{i=1}^{N_{cand}} L_i$$

$$L_i = \sum_j n_j P_j(\vec{x}_i;\vec{\beta})$$

$$P_j(\vec{x}_i;\vec{\beta}) = P(m_{ES}) \times P(\Delta E) \times ...$$

We minimize $-2 \log L$

Kinematic Constraints

$\Upsilon(4S) \rightarrow B\bar{B}$

Lorenz-invariant

$$\Delta E = \hat{E}_{B\,meson} - \hat{E}_{beam} \equiv \frac{2 q_{\Upsilon} q_B - s}{2\sqrt{s}}$$

Center of mass frame

$$m_B = \sqrt{\hat{E}_B^2 - \hat{\vec{p}}_B^{\,2}} \xrightarrow{\hat{E}_B \rightarrow E_{beam}} m_{ES} = \sqrt{\frac{\left(\frac{s}{2} + \vec{p}_{\Upsilon} \cdot \vec{p}_B\right)^2}{E_{\Upsilon}^2 - p_B^2}}$$

$$s = (q_B + q_{\bar{B}})^2 \equiv E^2_{center\ of\ mass}$$

Laboratory frame

BaBar

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

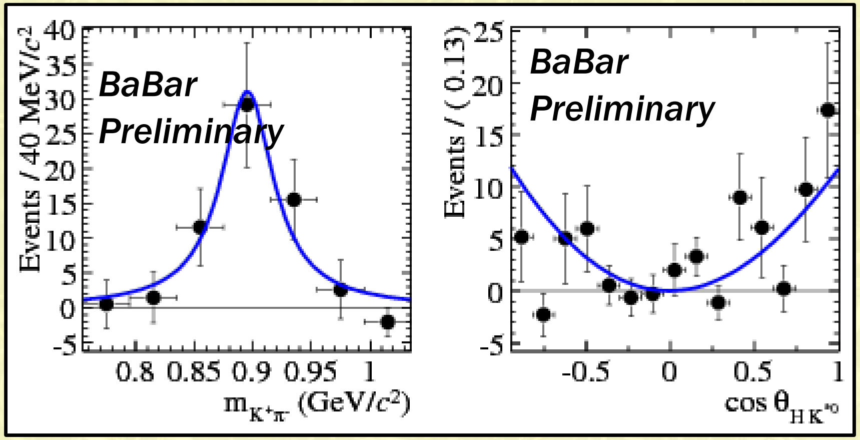
hep-ex/0607109
submitted to PRL

$B \to \eta K$ and $B \to \eta' K^*$ are suppressed, $B \to \eta' K$ and $B \to \eta K^*$ are enhanced

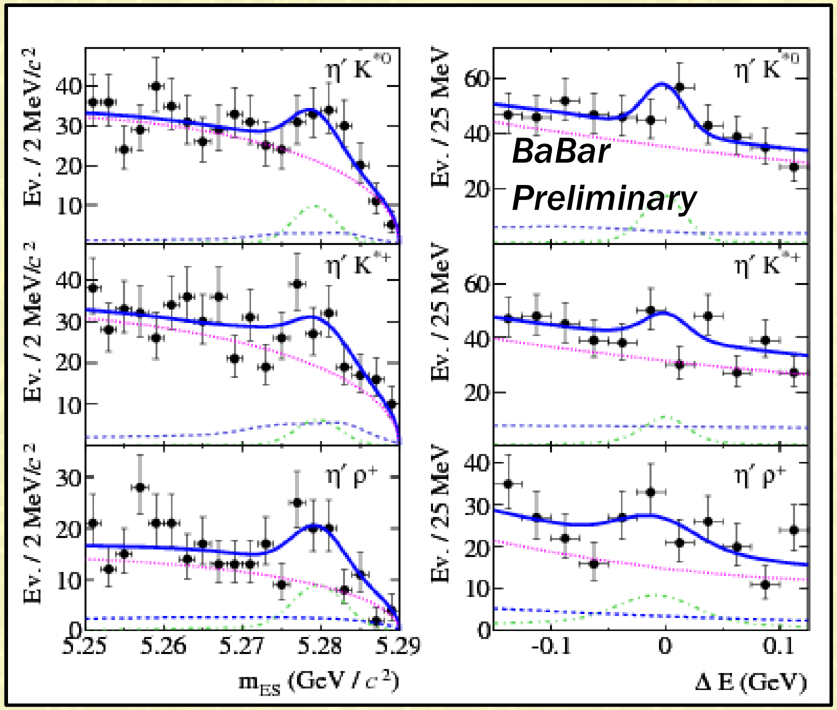
Two significantly different explanations:
Lipkin (1991), Neubert (2003)
Now there is a **first** measurement

Decay modes:
$\eta' \to \eta\pi\pi$, $\rho^0\gamma$, $K^{*0} \to K^+\pi^-$, $K^{*+} \to K_s^0\pi^+$, $K^+\pi^0$,
ρ^0 and $f_0 \to \pi^+\pi^-$, $\rho^+ \to \pi^+\pi^0$, $\eta \to \gamma\gamma$, $K_s^0 \to \pi^+\pi^-$, $\pi^0 \to \gamma\gamma$

- Now all $B \to \eta^{(\prime)} K^{(*)}$ are measured
- Sensitive to flavor singlet



$B^0 \to \eta' K^{*0}$



BaBar

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

hep-ex/0607109
submitted to PRL

232 million BBbar pairs

Mode	$S(\sigma)$	$\mathcal{B}(10^{-6})$	$\mathcal{A}_{ch}$
$B \to \eta' K^*$	**5.6**	$4.1^{+1.0}_{-0.9} \pm 0.5$	
$B^0 \to \eta' K^{*0}$	**4.3**	$3.8 \pm 1.1 \pm 0.5$	$-0.08 \pm 0.25 \pm 0.02$
$\eta'_{\eta\pi\pi} K^{*0}$	3.9	$4.1^{+1.5}_{-1.3}$	
$\eta'_{\rho\gamma} K^{*0}$	2.0	$3.3^{+1.9}_{-1.6}$	
$B^+ \to \eta' K^{*+}$	**3.6**	$4.9^{+1.9}_{-1.7} \pm 0.8 (< 7.9)$	$0.30^{+0.33}_{-0.37} \pm 0.02$
$\eta'_{\eta\pi\pi} K^{*+}_{K^0\pi^+}$	3.2	$6.2^{+3.4}_{-2.7}$	
$\eta'_{\rho\gamma} K^{*+}_{K^0\pi^+}$	1.2	$4.7^{+4.5}_{-3.9}$	
$\eta'_{\eta\pi\pi} K^{*+}_{K^+\pi^0}$	1.2	$2.9^{+3.7}_{-2.6}$	
$\eta'_{\rho\gamma} K^{*+}_{K^+\pi^0}$	0.5	$2.9^{+6.7}_{-5.4}$	
$B^0 \to \eta' \rho^0$	**0.3**	$0.4^{+1.2+1.6}_{-0.9-0.6} (< 3.7)$	
$B^0 \to \eta' f_0(980)(f_0 \to \pi^+\pi^-)$	**0.2**	$0.1^{+0.6+0.9}_{-0.4-0.4} (< 1.5)$	
$B^+ \to \eta' \rho^+$	**3.2**	$8.7^{+3.1+2.3}_{-2.8-1.3} (< 14)$	$-0.04 \pm 0.28 \pm 0.02$

BELLE

$\eta' K^{*0} < 20 \cdot 10^{-6}$

$\eta' K^{*+} < 90 \cdot 10^{-6}$

(*H. Aihara, talk at FPCP 2003*)

Main systematic uncertainties:

- PDF modeling (control samples, taking B background out of the fit)
- fit bias (“toy MC” experiments)
- track and neutral efficiencies (dedicated studies of the control samples)
- charge asymmetry (due to asymmetry in charged kaon ID and slow pions reconstruction)

$B \to \eta K^*$

hep-ex/0608005
accepted by PRL

344 million BBbar pairs

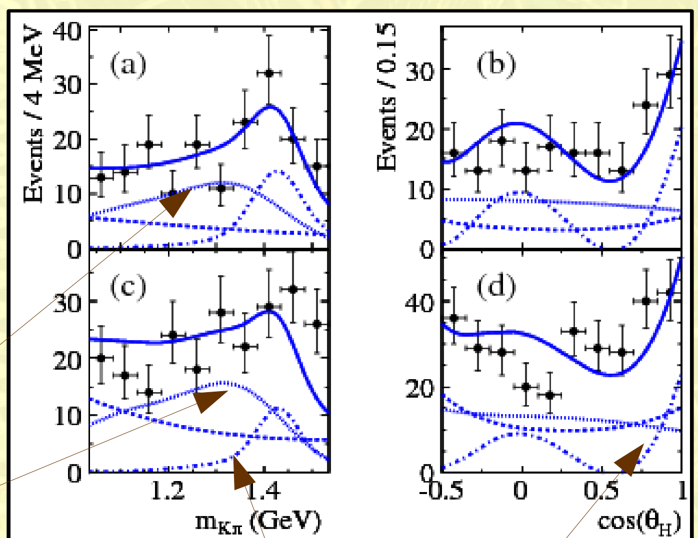
Consider K*(892), $K^*_2(1430)$ and $(K\pi)^*_0$ – s-wave component

hasn't been measured previously, no prediction

Main systematic uncertainties:

- PDFs, fit bias and reconstruction (see η'K*)
- interference between signal components (treated as systematics)

ηK*(892) ηK*(1430)

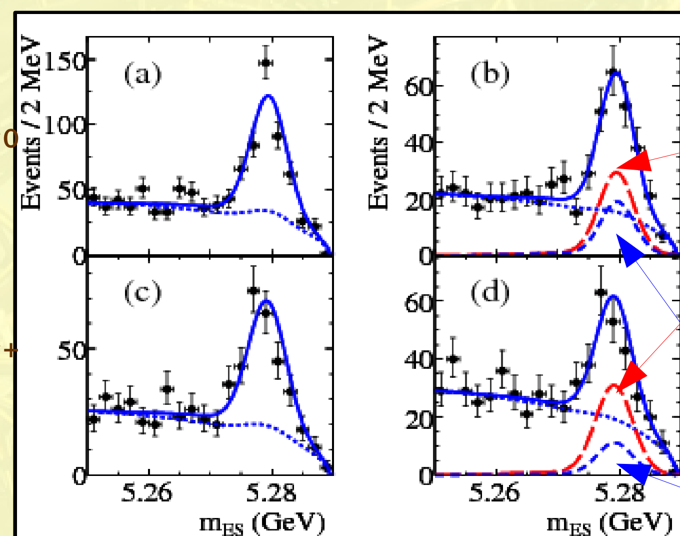


$K^*_0(1430)$

$K^*_2(1430)$

K^{*0}

K^{*+}



$(K\pi)^*_0$

$K^*_2(1430)$

BaBar

$B \to \eta K^*$

hep-ex/0608005
accepted to PRL

Consider $K^*(892)$, $K^*_2(1430)$ and $(K\pi)^*_0$ – s-wave component

Mode	Y_S (ev.)	Bias (ev.)	ϵ (%)	$\prod \mathcal{B}_i$ (%)	$\mathcal{S}$ (σ)	$\mathcal{B}$ (10^{-6})	$\mathcal{A}_{ch}$
$\eta_{\gamma\gamma} K^{*0}_{K^+\pi^-}(892)$	407 ± 29	$+15$	24	26	17.6	18.2 ± 1.4	0.24 ± 0.07
$\eta_{3\pi} K^{*0}_{K^+\pi^-}(892)$	111 ± 16	$+13$	16	15	6.3	10.9 ± 2.0	0.12 ± 0.14
$\mathbf{B^0 \to \eta K^{*0}(892)}$					**18.8**	$\mathbf{16.5 \pm 1.1 \pm 0.8}$	$\mathbf{0.21 \pm 0.06 \pm 0.02}$
$\eta_{\gamma\gamma} K^{*+}_{K^+\pi^0}(892)$	99 ± 16	$+7$	11	13	6.9	18.0 ± 3.2	0.19 ± 0.16
$\eta_{3\pi} K^{*+}_{K^+\pi^0}(892)$	56 ± 11	$+4$	8	8	6.1	25.4 ± 5.5	-0.05 ± 0.20
$\eta_{\gamma\gamma} K^{*+}_{K^0\pi^+}(892)$	149 ± 19	$+12$	22	9	8.6	20.5 ± 2.9	-0.03 ± 0.13
$\eta_{3\pi} K^{*+}_{K^0\pi^+}(892)$	36 ± 10	$+5$	15	5	3.8	11.9 ± 3.9	-0.23 ± 0.28
$\mathbf{B^+ \to \eta K^{*+}(892)}$					**13.0**	$\mathbf{18.9 \pm 1.8 \pm 1.3}$	$\mathbf{0.01 \pm 0.08 \pm 0.02}$
$\eta_{\gamma\gamma} K_0^{*0}(K^+\pi^-)$	163 ± 25	$+17$	15	26	5.3	10.8 ± 1.9	0.14 ± 0.15
$\eta_{3\pi} K_0^{*0}(K^+\pi^-)$	69 ± 17	$+9$	10	15	3.6	11.4 ± 3.2	-0.18 ± 0.25
$\mathbf{B^0 \to \eta(K\pi)_0^{*0}}$					**5.7**	$\mathbf{11.0 \pm 1.6 \pm 1.5}$	$\mathbf{0.06 \pm 0.13 \pm 0.02}$
$\eta_{\gamma\gamma} K_0^{*+}(K^+\pi^0)$	93 ± 20	$+9$	10	13	4.3	19.2 ± 4.5	-0.05 ± 0.21
$\eta_{3\pi} K_0^{*+}(K^+\pi^0)$	39 ± 12	$+6$	7	8	3.4	18.0 ± 6.3	0.03 ± 0.29
$\eta_{\gamma\gamma} K_0^{*+}(K^0\pi^+)$	55 ± 16	$+5$	12	9	3.0	13.3 ± 4.2	0.13 ± 0.25
$\eta_{3\pi} K_0^{*+}(K^0\pi^+)$	49 ± 11	$+3$	9	5	4.4	28.1 ± 6.7	0.18 ± 0.22
$\mathbf{B^+ \to \eta(K\pi)_0^{*+}}$					**5.9**	$\mathbf{18.2 \pm 2.6 \pm 2.6}$	$\mathbf{0.05 \pm 0.13 \pm 0.02}$
$\eta_{\gamma\gamma} K_2^{*0}(K^+\pi^-)$	72 ± 17	-1	18	14	4.7	8.4 ± 1.9	-0.20 ± 0.23
$\eta_{3\pi} K_2^{*0}(K^+\pi^-)$	40 ± 13	-1	12	8	3.4	12.5 ± 4.1	0.23 ± 0.31
$\mathbf{B^0 \to \eta K_2^{*0}(1430)}$					**5.3**	$\mathbf{9.6 \pm 1.8 \pm 1.1}$	$\mathbf{-0.07 \pm 0.19 \pm 0.02}$
$\eta_{\gamma\gamma} K_2^{*+}(K^+\pi^0)$	26 ± 12	-1	13	7	2.3	9.1 ± 4.0	-0.16 ± 0.41
$\eta_{3\pi} K_2^{*+}(K^+\pi^0)$	20 ± 8	-1	9	4	2.6	17.8 ± 7.2	-0.82 ± 0.47
$\eta_{\gamma\gamma} K_2^{*+}(K^0\pi^+)$	12 ± 10	-1	13	5	1.8	6.4 ± 4.7	0.05 ± 0.58
$\eta_{3\pi} K_2^{*+}(K^0\pi^+)$	2 ± 5	$+1$	10	3	0.2	0.9 ± 5.1	-1.00 ± 1.56
$\mathbf{B^+ \to \eta K_2^{*+}(1430)}$					**3.5**	$\mathbf{9.1 \pm 2.7 \pm 1.4}$	$\mathbf{-0.45 \pm 0.30 \pm 0.02}$

$m(K_sK^+\pi^-)$, GeV

$15.9 \pm 1.2 \pm 0.9$

BELLE

(*hep-ex/0608034*)

$19.7^{+2.0}_{-1.9} \pm 1.4$

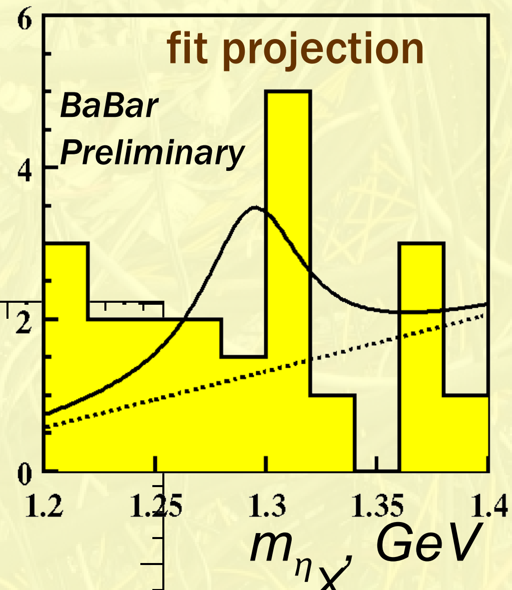
Treatment of $K^*(1430)$ and $(K\pi)^*_0$ with *BELLE* is not clear

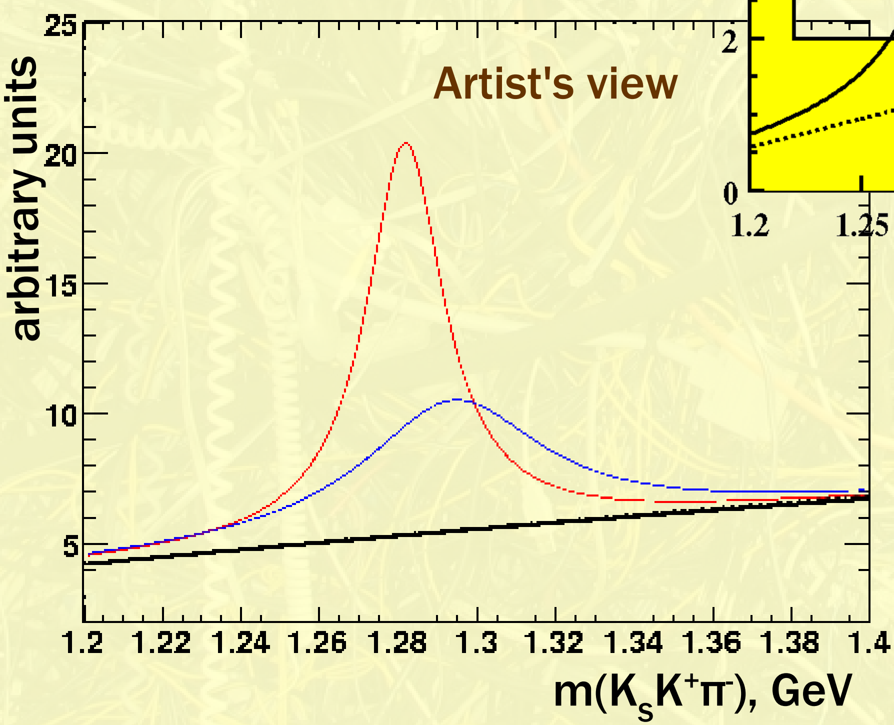
$B^+ \to \eta_X K^+$

BaBar

$\eta_x \to K_s K^+ \pi^-$

We are looking for the charmless η_x candidates





No significant signal has been found in a portion of the η_x spectrum between 1.2 and 1.4 GeV in the $\eta_x \to K_s K^+ \pi^-$ channel.

$BR(B^+ \to \eta(1295)K^+) \times BR(\eta(1295) \to K^0 K^- \pi^+)$
$< 2.1 \times 10^{-6}$, 90% C.L.

$BR(B^+ \to f_1(1285)K^+) < 2.0 \times 10^{-5}$, 90% C.L.

BaBar

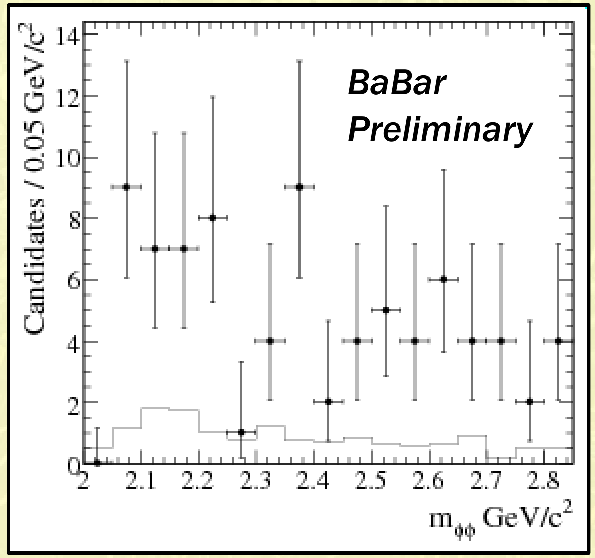
$B \to \phi\phi K$

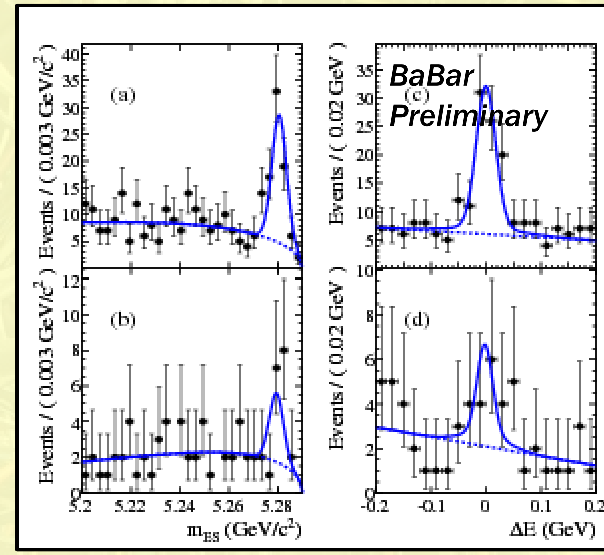
hep-ex/0609027
submitted to PRL

$B^+ \to \phi\phi K^+$ and $B^0 \to \phi\phi K^0$ are expected to be equal in SM ($\Delta I=1$ suppressed)

Proceeds through $b \to s s^{bar} s$

There is an indication that the $\phi\phi$ spectrum extends beyond 2.85 GeV. That is a possibility to look for direct CP violation in interference with $b \to c c^{bar} s$ ($B \to \eta_c K$)





Mode	Signal Yield	$\epsilon(\%)$	$\prod \mathcal{B}_i$ (%)	$S(\sigma)$	$\mathcal{B}(10^{-6})$
$B^+ \to \phi\phi K^+$	64 ± 9	15.3	24.2	12.9	$7.5 \pm 1.0 \pm 0.7$
$B^0 \to \phi\phi K^0$	$10^{+4.1}_{-3.4}$	12.6	8.3	4.2	$4.1^{+1.7}_{-1.4} \pm 0.4$

BELLE reported $B \to \phi\phi K$ to be lower:
$B^+ \to \phi\phi K^+$: $3.18^{+0.60}_{-052}$(stat)± 0.27(syst) $\cdot 10^{-6}$ (*ICHEP 2006*)
$B^0 \to \phi\phi K^0$: $2.31^{+1.00}_{-074}$(stat)± 0.24(syst) $\cdot 10^{-6}$ (*ICHEP 2006*)

BaBar

$B \to a_0\pi$

Existing upper limits on branching fractions for $B \to a_0^- \pi^+$ and $B \to a_0^0\pi+$

*PRD RC **70**, 111102 (2004)*

Now we present search for $B^\pm \to a_0^\pm\pi^0$, $a_0^\pm \to \eta\pi^+$

$B \rightarrow a_0^{\pm}\pi^0$

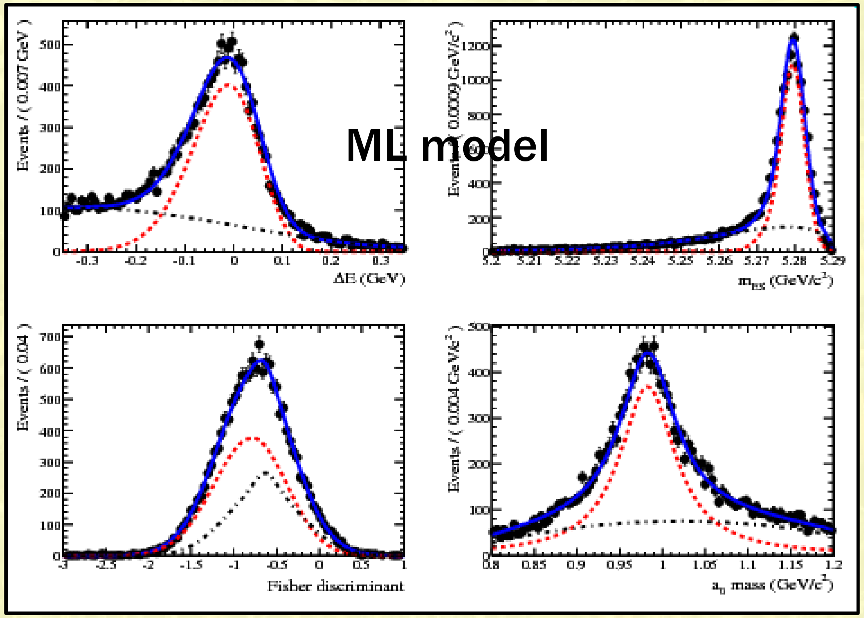
hep-ex/0607064

252 million BBbar pairs

$a_0^{\pm} \rightarrow \eta\pi^{+}$

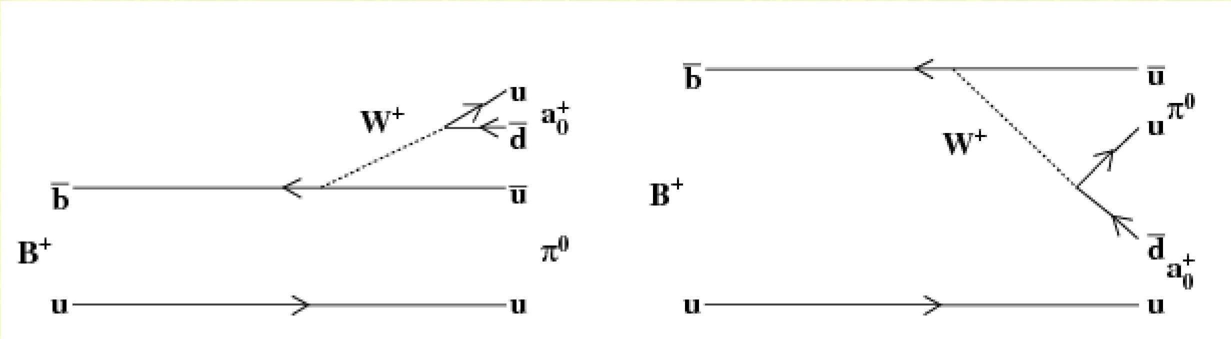
The structure of the a_0 meson is a debate:

- two quark or four quark
- glueball
- KKbar



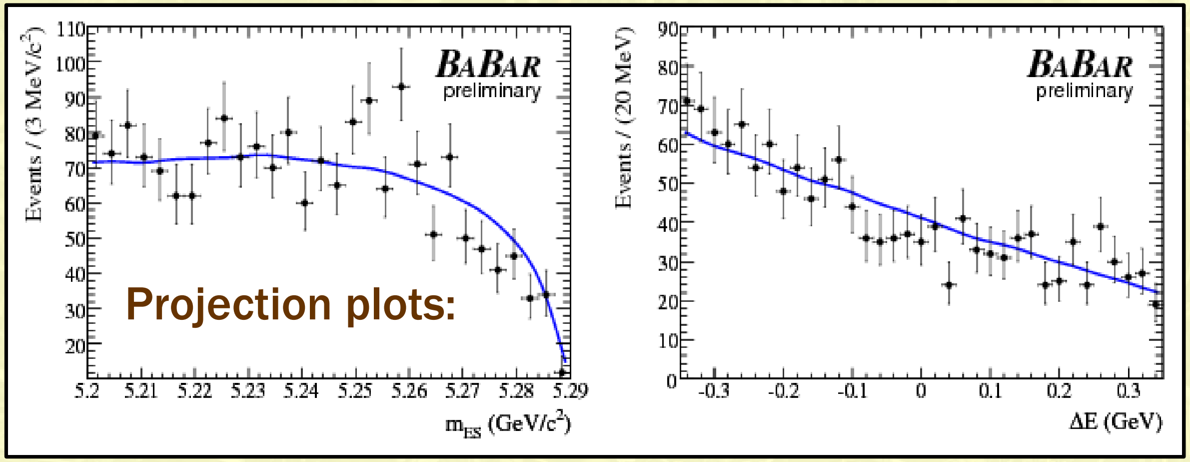
Predicted BF = $2 \cdot 10^{-7}$ for two-quark, ten times smaller for four-quark

Suppressed by G-parity, vector current conservation



Color suppressed

$B \to a_0^{\pm}\pi^0,\ a_0^{\pm} \to \eta\pi^+$ hep-ex/0607064



Required quantity/result	
Candidates to fit	36098
Signal Yield (events)	-18±11
Continuum Yield (candidates)	35324±190
ML Fit bias (events)	2.55
Accepted eff. and BFs	
ϵ (%)	16.18
$\mathcal{B}(\eta \to \gamma\gamma)$ (%)	39.43
$\mathcal{B}(a_0^+ \to \eta\pi^+)$ (%)	84.5
Results	
Branching Fraction ($\times 10^{-6}$)	$-1.5^{+0.9}_{-0.7}(stat)^{+0.6}_{-0.4}(syst)$
Upper Limit 90% C.L. ($\times 10^{-6}$)	$<$ 1.06 (statistical error only)
Upper Limit 90% C.L. ($\times 10^{-6}$)	$<$ 1.32 (total error)

Source of Uncertainty	$\eta \to \gamma\gamma$
Additive (Events)	
Fit Parameters	$^{+7.7}_{-4.4}$
Charmless Yields	$^{+2.3}_{-1.5}$
Charm Yields	$^{+0.2}_{-0.0}$
Fit Bias	± 1.6
Total Additive (Events)	$^{+8.2}_{-4.9}$
Multiplicative (%)	
Neutral efficiency	± 6.0
Tracking efficiency	± 0.5
$\lvert\cos(\theta_{TB})\rvert$ Selection	± 5.0
MC Statistics	± 0.9
Number of $B\overline{B}$ Events	± 1.1
Daughter a_0 Decay BF	± 2.0
Daughter η Decay BF	± 0.7
Total Multiplicative (%)	± 8.2

Cannot tell between two and four quark a_0 structure

BaBar

Summary and outlook

- Updated measurements of $B^0 \to \eta K^{*0}$ and $B^+ \to \eta K^{*+}$ agree with earlier results and theoretical predictions.
- First observation of $B \to \eta' K^*$ (5.6σ with all submodes combined) completes the set of $B \to \eta^{(\prime)} K^{(*)}$ decays. In excellent agreement with the flavor SU(3) and QCD factorization predictions.
- First measurements of $B^0 \to \eta(K\pi)^{*0}_0$, $B^+ \to \eta(K\pi)^{*+}_0$, $B0 \to \eta K^{*0}_2(1430)$ and $B^+ \to \eta K^{*+}_2(1430)$.
- Branching fractions for $B^0 \to \eta K^{*0}_0(1430)$ and $B^+ \to \eta K^{*+}_0(1430)$.
- Continue search for decays involving other higher resonances.
- Measurement of $B^+ \to \eta' \rho^+$. Improved upper limit for $B^0 \to \eta' \rho^0$ and studied for the first time $B^0 \to \eta' f_0(980)$.
- Upper limit on branching fraction for $B^+ \to a_0^+ \pi^0$.
- Observation of $B^+ \to \phi\phi K^+$ and evidence for $B^0 \to \phi\phi K^0$ below η_c threshold. Mass spectrum for φφ seems to extend beyond 2.85 GeV which may allow for future search for direct CP violation in mixing with η_c.
- Charge asymmetry for $B^0 \to \eta K^{*0}(892)$ shows evidence for direct CP violation. All other values are consistent with zero.