Rare B decays

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

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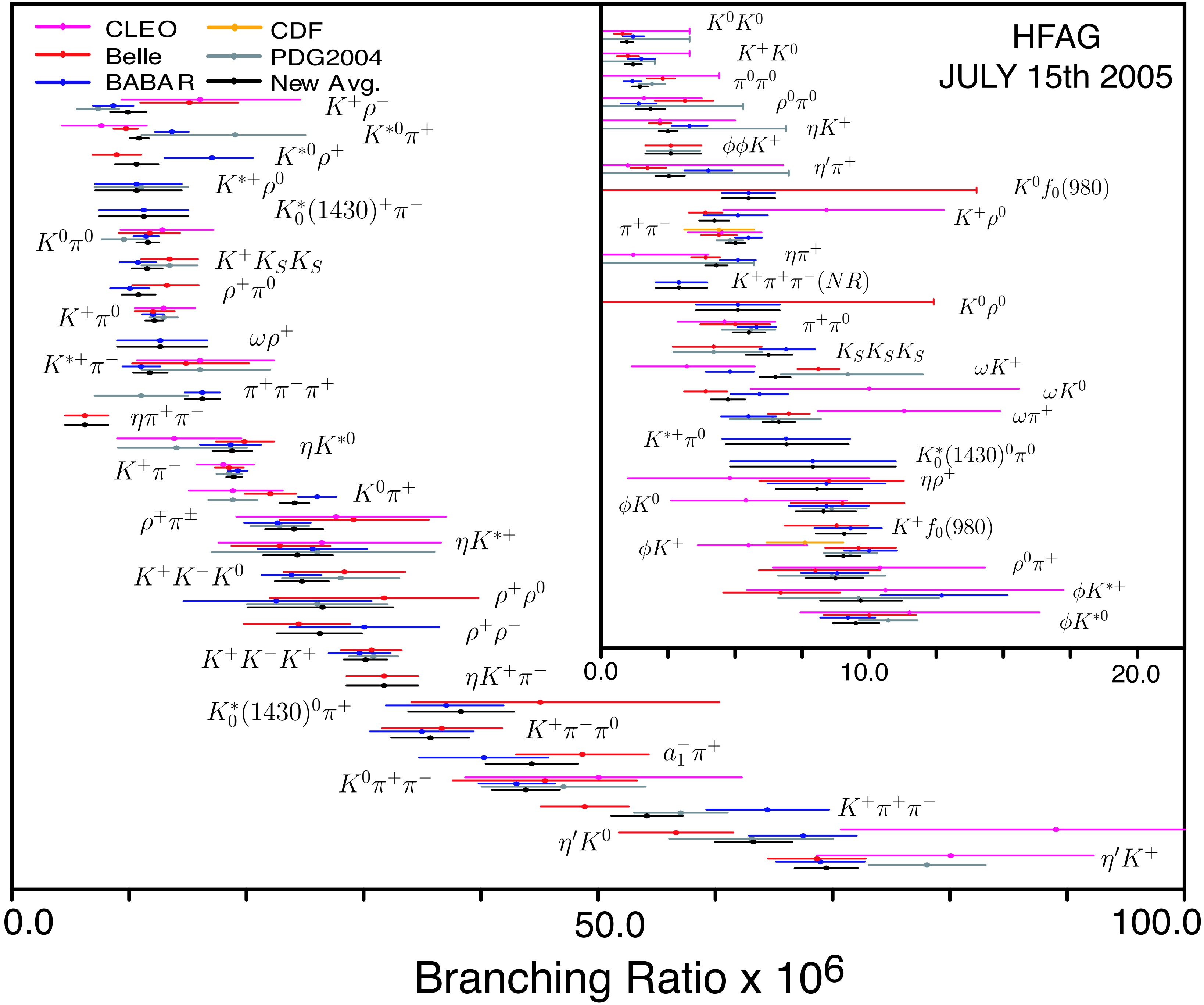
Overview

- Contents of talk
  - Introduction to charmless two body decays
  - Theoretical predictions and previous results
  - Status of BaBar and PEPII
  - Analysis details (selection, fit, backgrounds)
  - Results and systematics
  - Conclusion
- Chosen to focus on one particular analysis
- The search for four modes (charged and neutral) $B \to \eta' K^*$ and $B \to \eta' \rho$
- Territory of “rare” B decays being explored rapidly. . .

Charmless B Branching Fractions



Quasi Two Body Decays

J^{PC} classification of light meson decays

L	S	J^{PC}	mesons	nickname
0	0	0^{-+}	$\pi^0, \pi^\pm, \eta, K^\pm, K_S^0, K_L^0, \eta'$, etc.	pseudoscalars
0	1	1^{--}	$\rho^0, \rho^\pm, \omega, \phi, K^{*\pm}, K^{*0}, \overline{K^{*0}}$, etc.	vectors
1	0	1^{+-}	$h_1^0(1170), b_1^{0\pm}(1235)$, etc.	axial vectors
1	1	0^{++}	$f_0^0(980), a_0^{0\pm}(980)$, etc.	scalars
1	1	2^{++}	$f_2^0(1270), a_2^{0\pm}(1320)$, etc.	tensors

PP $B \to \eta K, \pi\pi, \eta'\pi...$ VV $B \to \rho\rho, \phi K^*, \phi\omega...$

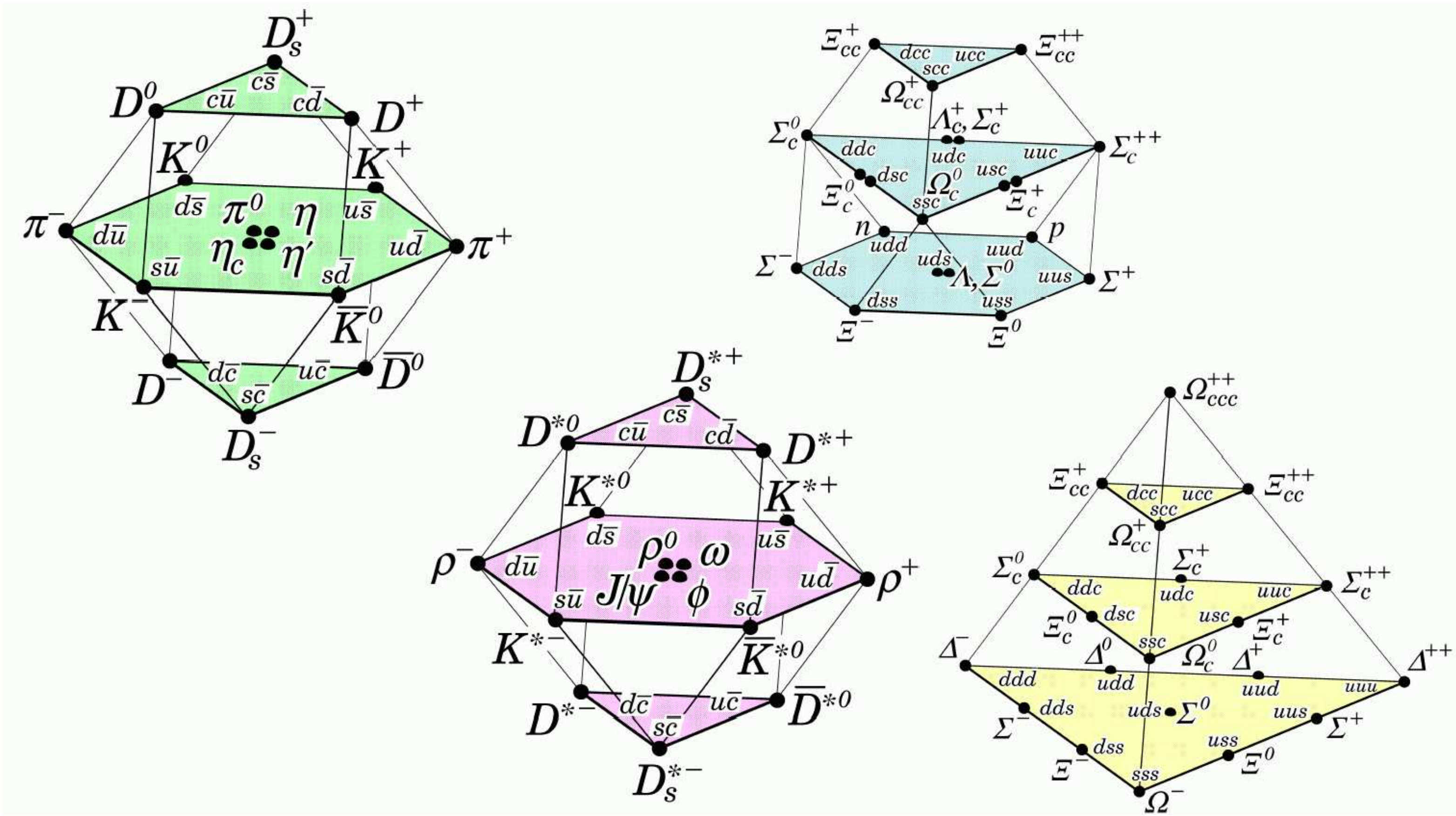
PV $B \to \eta' K^*, \eta'\rho, \pi\phi, ...$ SP $B \to a_0\pi, f_0\pi...$

- $B \to \eta' K^*$ and $B \to \eta'\rho$ are PV decays

SU(4) multiplets

Meson pseudoscalar and vector 16-plets

based on central su(3) *nonets* (excluding η_c and J/ψ)



shown also are the baryon 20-plets (su(3) octet and decuplet based)

The η & η' quark content

SU(3) nonet consists of singlet and octet states ($3 \otimes \bar{3} = 8 \oplus 1$)

$$\eta_1 = \frac{1}{\sqrt{3}}(u\bar{u} + d\bar{d} + s\bar{s})$$
$$\eta_8 = \frac{1}{\sqrt{6}}(u\bar{u} + d\bar{d} - 2s\bar{s})$$

Physical η and η' states are octet-singlet mixed states:

$$\eta = \eta_1 \sin\theta - \eta_8 \cos\theta$$
$$\eta' = \eta_1 \cos\theta + \eta_8 \sin\theta$$

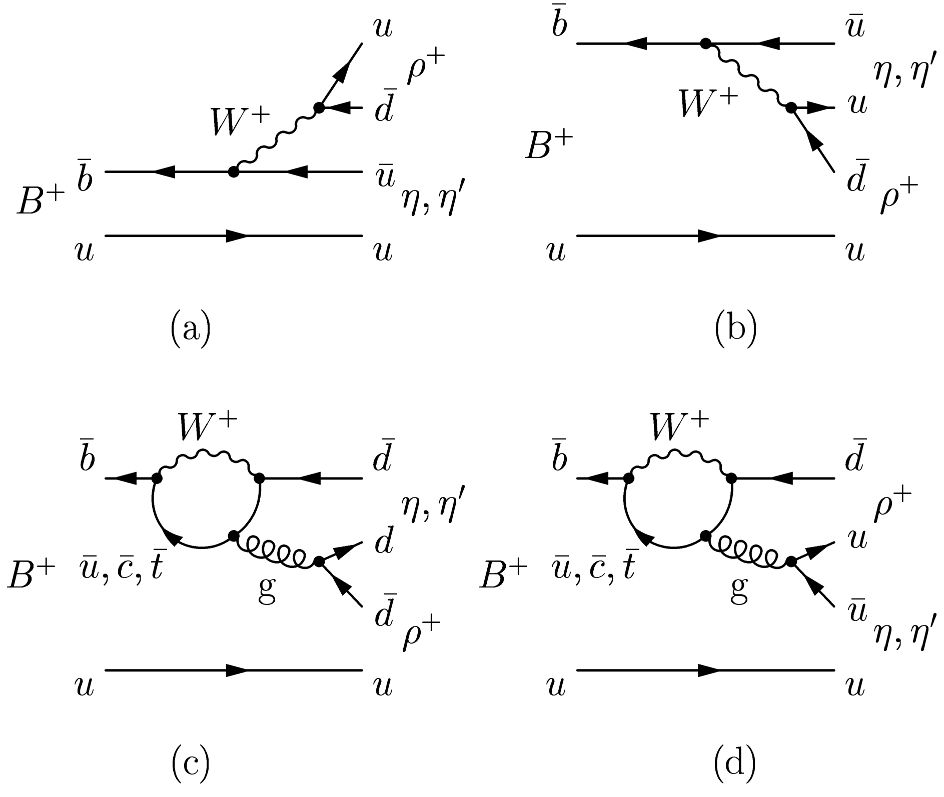
Assuming a mixing angle $\theta = 20^\circ$ (vector mesons $\theta = 35^\circ$)

$$\eta = \frac{1}{\sqrt{3}}(u\bar{u} + d\bar{d} - s\bar{s})$$
$$\eta' = \frac{1}{\sqrt{6}}(u\bar{u} + d\bar{d} + 2s\bar{s})$$

Theoretical Approaches (1)

Diagrammatic methods

- Methodology
  - Isospin & SU(3)
- Advantages
  - very intuitive
  - powerful relations
- Disadvantages
  - SU(3) breaking
  - *a priori* information
  - non exact results



(a) T_p (b) C_v (c) P_v (d) P_p

Theoretical Approaches (2)

Effective Hamiltonian

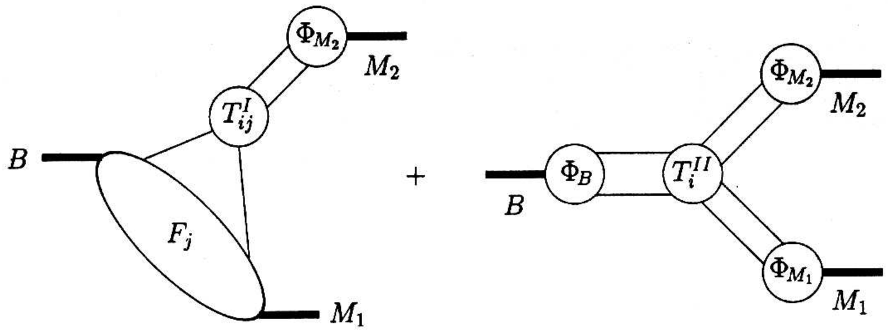
- Methodology
  - QCD operator product expansion
  - Wilson coeffs $\times$ operators
- Advantages
  - Better handling of QCD corrections
- Disadvantages
  - Huge uncertainties in operator matrix elements
  - One approach is QCD factorisation

- **Current-current operators:**

$$Q_1^{\alpha\beta k} \equiv (\bar{b}_x \alpha_y)_{V-A} (\bar{\beta}_y k_x)_{V-A},$$
$$Q_2^{\alpha\beta k} \equiv (\bar{b} \alpha)_{V-A} (\bar{\beta} k)_{V-A};$$

- **Gluonic-penguin operators:**

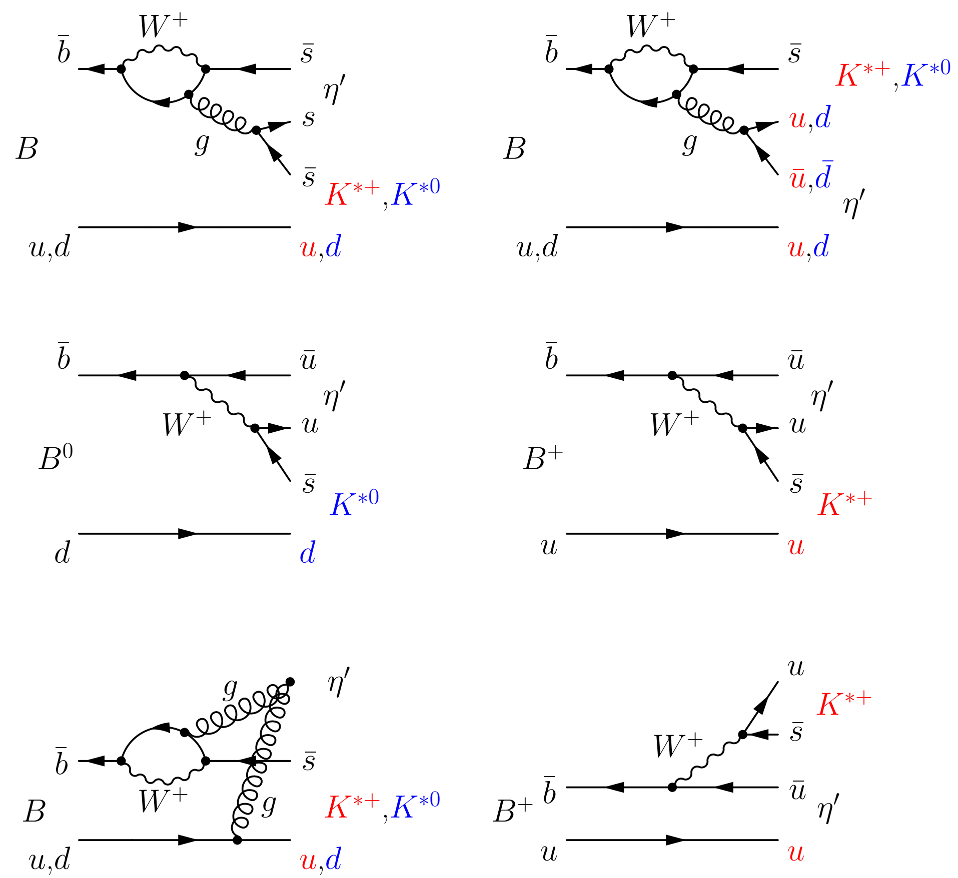
$$Q_3^k \equiv (\bar{b} k)_{V-A} \sum_q (\bar{q} q)_{V-A},$$
$$Q_4^k \equiv (\bar{b}_x k_y)_{V-A} \sum_q (\bar{q}_y q_x)_{V-A},$$
$$Q_5^k \equiv (\bar{b} k)_{V-A} \sum_q (\bar{q} q)_{V+A},$$
$$Q_6^k \equiv (\bar{b}_x k_y)_{V-A} \sum_q (\bar{q}_y q_x)_{V+A};$$



Other approaches: Soft Collinear Effective Theory & perturbative QCD factorization

$B \to \eta' K^*$ diagrams

- One loop $b \to s$ penguins expected to dominate
- CKM and colour suppressed internal trees
- CKM suppressed external tree for $B^+ \to \eta' K^{*+}$
- $B^0 \to \eta' K^{*0}$ diagrams identical to $\eta' K^0$
- Variety of possible singlet and rescattering diagrams



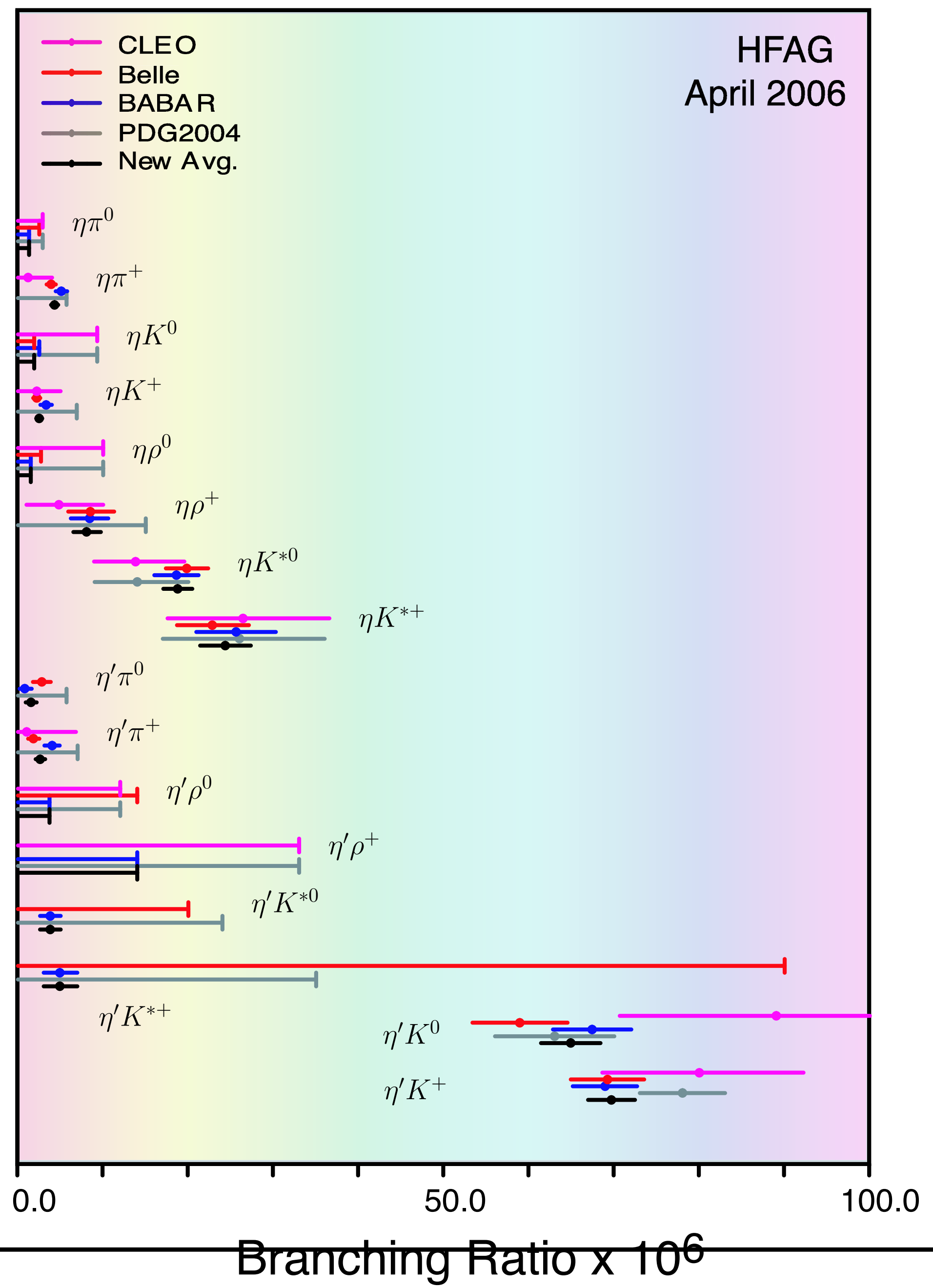
$\eta - \eta'$ puzzle

- The decays $\eta' K$ and $B \to \eta K^*$ are large
  - $\mathcal{B}(B^0 \to \eta' K^0) = 63.2 \pm 3.3$
  - $\mathcal{B}(B^+ \to \eta' K^+) = 69.4 \pm 2.7$
  - $\mathcal{B}(B^0 \to \eta K^{*0}) = 18.7 \pm 1.7$
  - $\mathcal{B}(B^+ \to \eta K^{*+}) = 24.3^{+3.0}_{-2.9}$

HFAG July 2005

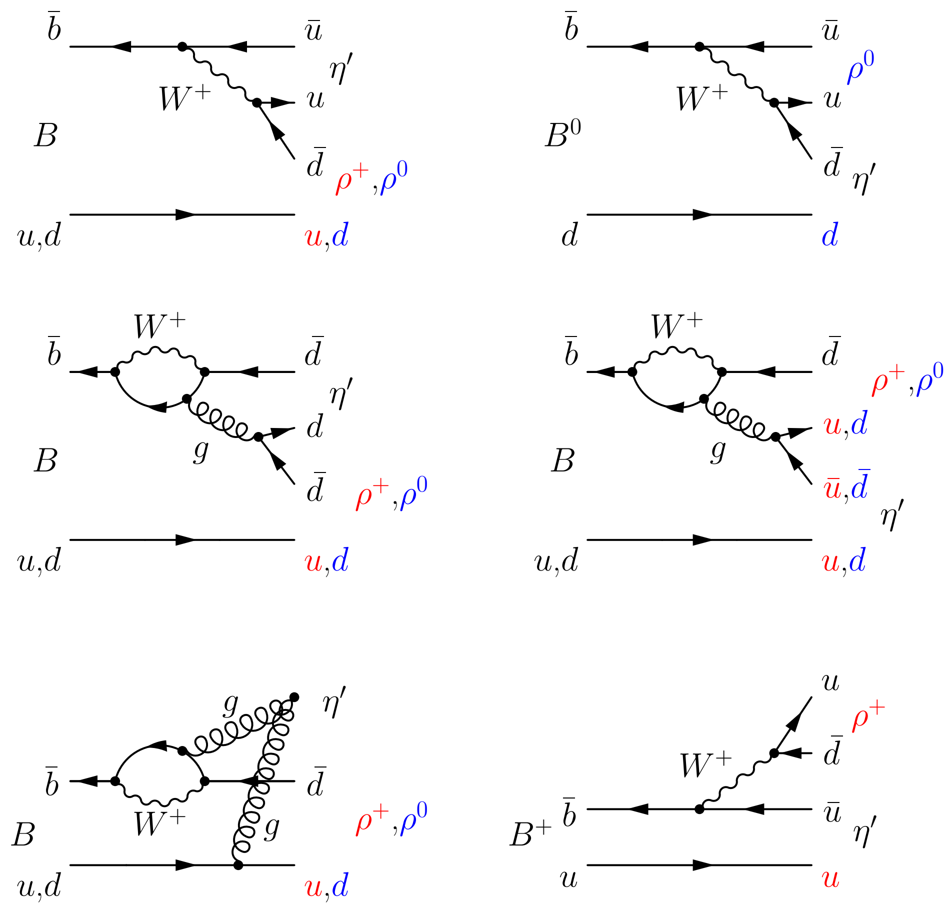
- but why are $B \to \eta K$ and $\eta' K^*$ small?
  - $\mathcal{B}(B^0 \to \eta K^0) < 1.9$
  - $\mathcal{B}(B^+ \to \eta K^+) = 2.5 \pm 0.3$
  - $\mathcal{B}(B^0 \to \eta' K^{*0}) < 7.6$
  - $\mathcal{B}(B^+ \to \eta' K^{*+}) < 14$
- Various theory explanations
  - sum rule put forward by Lipkin
  - η' charm content

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



$B \to \eta' \rho$ diagrams

- CKM and colour suppressed internal trees
- One loop $b \to d$ penguins
- CKM suppressed external tree for $\eta' \rho^+$
- $\eta' \rho^0$ expected to be small
  - Internal trees cancel
    - $\eta' \simeq \frac{1}{\sqrt{6}}(u\bar{u} + d\bar{d} + 2s\bar{s})$
    - $\rho^0 \simeq \frac{1}{\sqrt{2}}(u\bar{u} - d\bar{d})$



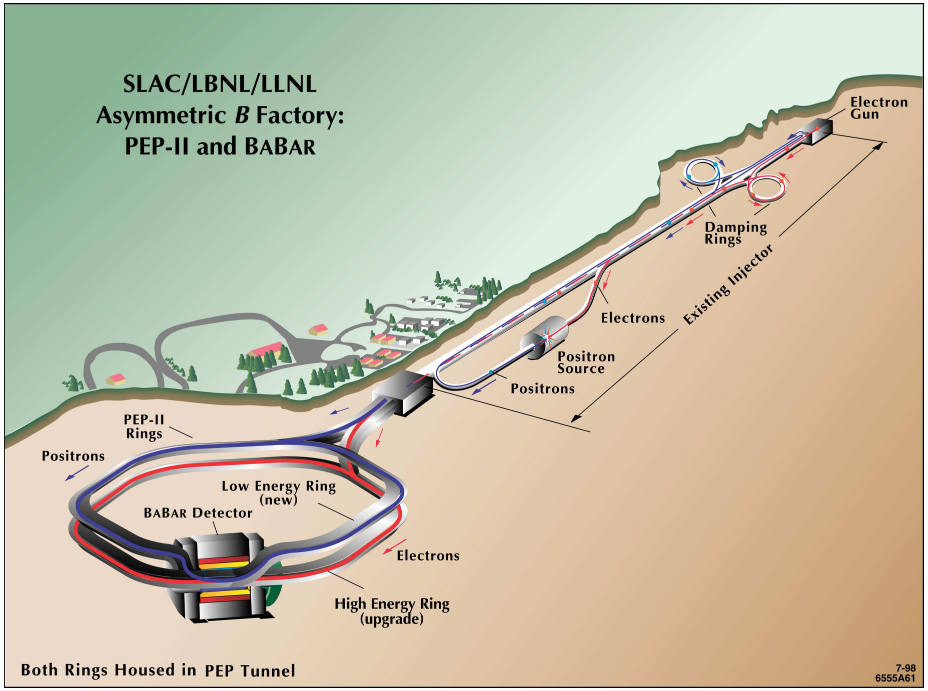
Motivation

Decay mode	Theoretical predictions		Experimental status		
	SU(3) flavor	QCD fact.	HFAG(7/05)	BaBar	Belle
$B^0 \to \eta' K^{*0}$	$3.0^{+1.2}_{-0.3}$	$3.9^{+9.24}_{-5.07}$	< 7.6	< 7.6	< 20
$B^+ \to \eta' K^{*+}$	$2.8^{+1.2}_{-0.3}$	$5.1^{+10.31}_{-\ 5.94}$	< 14	< 14	< 90
$B^0 \to \eta' \rho^0$	$0.07^{+0.10}_{-0.05}$	$0.01^{+0.12}_{-0.06}$	< 4.3	< 4.3	< 14
$B^+ \to \eta' \rho^+$	$4.9^{+0.7}_{-0.7}$	$6.3^{+4.0}_{-3.3}$	< 22	< 22	$--$

- Use increased dataset (run1-4) to tighten upper limits
- Try to constrain theory predictions
- Might get lucky (*c.f. run1-2 yields*)

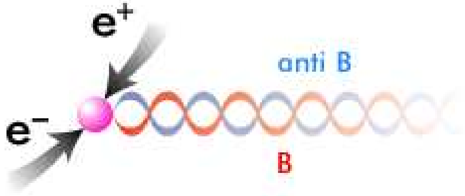
  $\mathcal{S}(\eta' K^{*0}) = 2.1\sigma$ $\quad$ $\mathcal{S}(\eta' K^{*+}) = 1.9\sigma$ $\quad$ $\mathcal{S}(\eta' \rho^{+}) = 2.6\sigma$
- Magnitude of $\eta' K^*$ suppression vs. $\eta' K$ enhancement

PEPII at SLAC

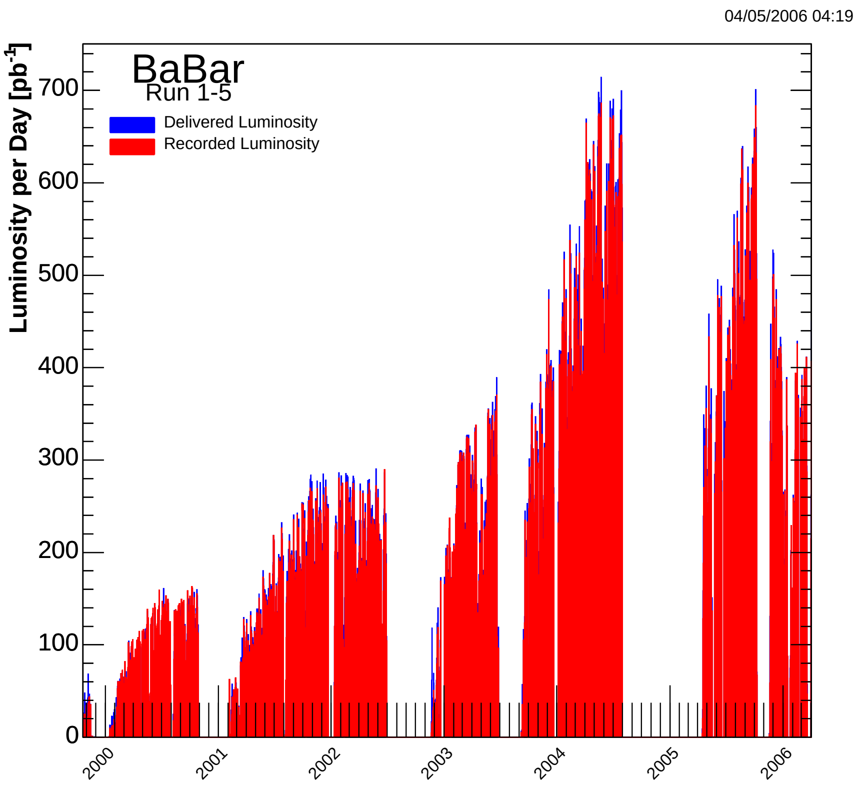


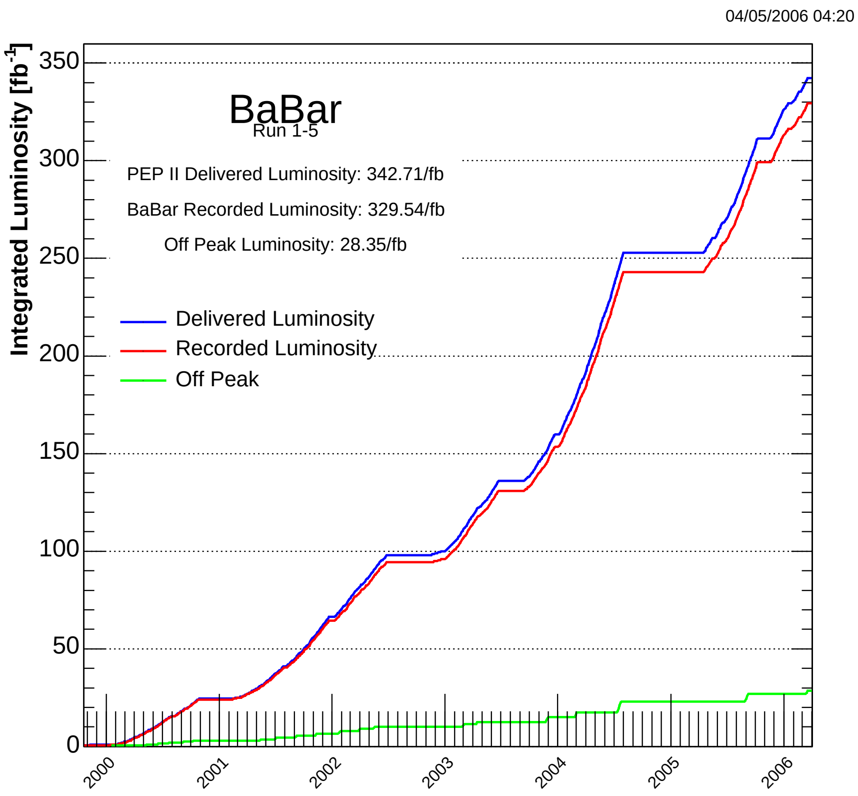
- Asymmetric collisions:
  $9.1\,\mathrm{GeV}\ e^-$ / $3.1\,\mathrm{GeV}\ e^+$
- Construction
  - started in 1994
  - completed in 1999
- Design luminosity in 2000

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



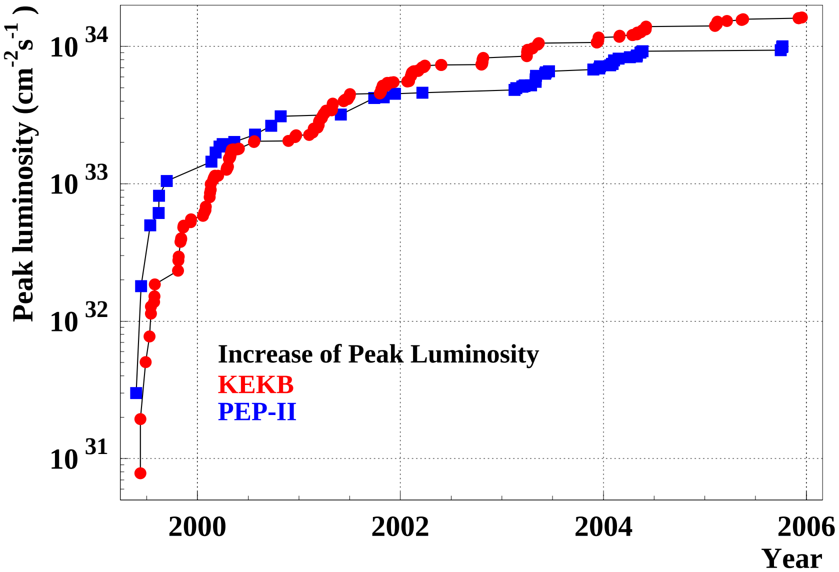
Integrated luminosity

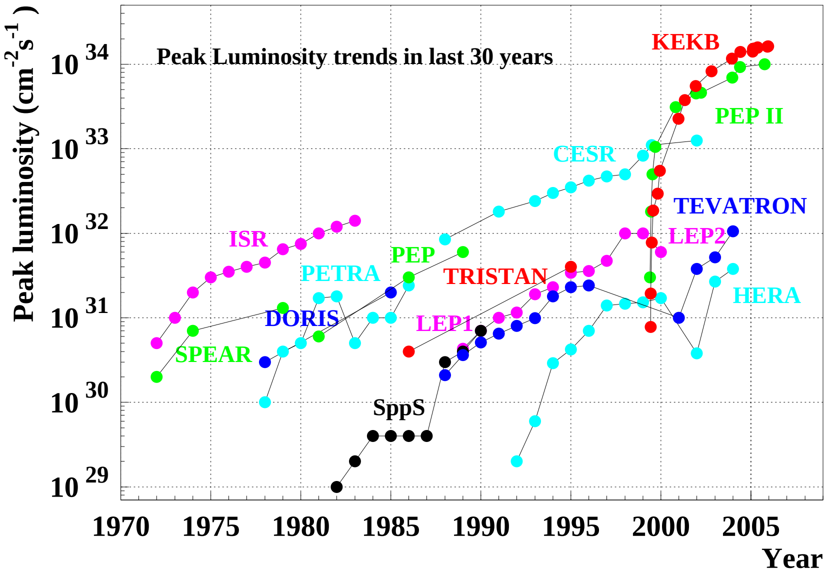




- Long downtime (electrical accident) 2004
- Luminosity problems so far in 2006

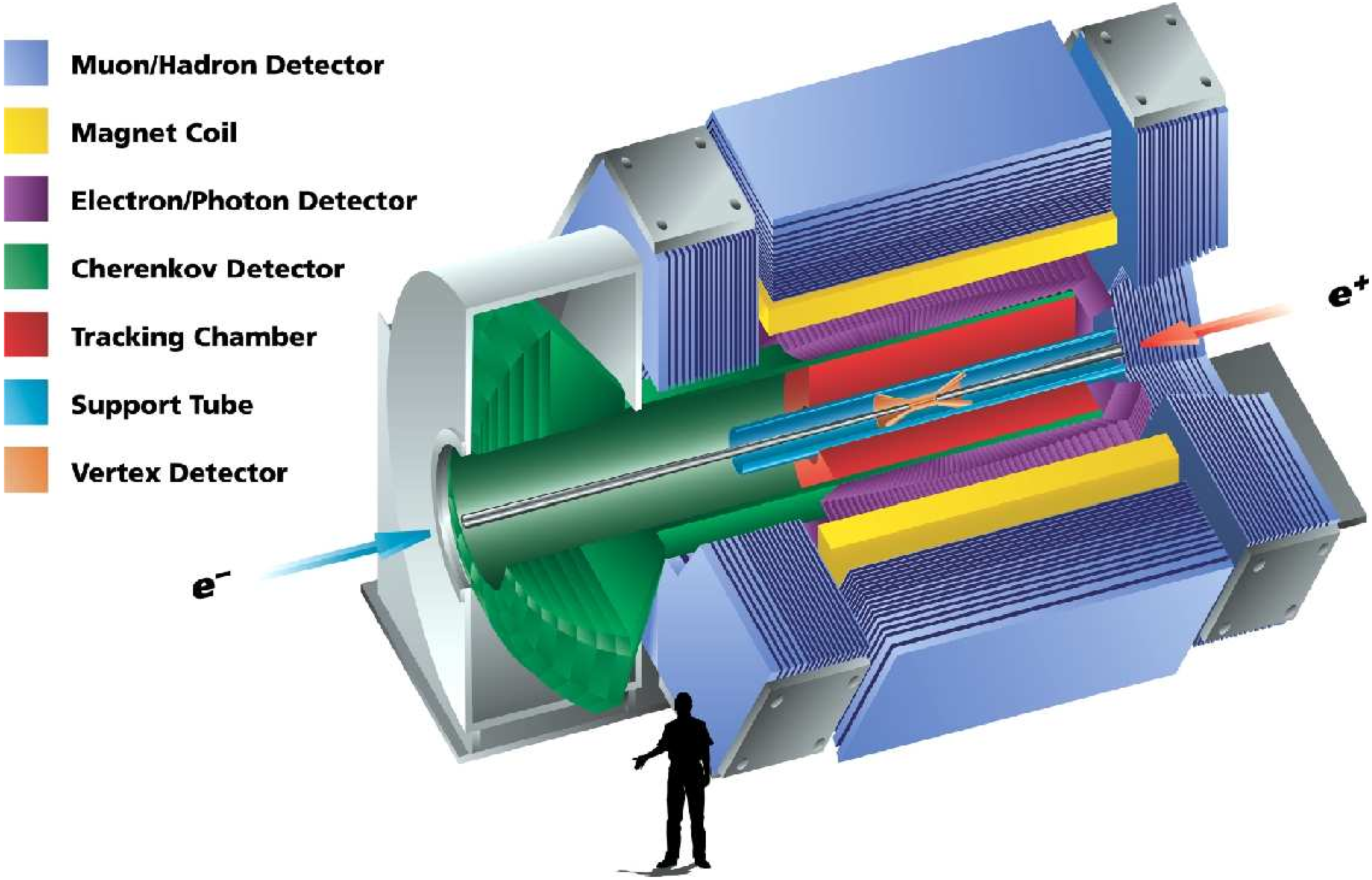
Luminosity trends





- Excellent performance of the B factories
- Design luminosity
  - KEKB $1 \times 10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$
  - PEPII $3 \times 10^{33}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$
- Instantaneous luminosity frontier

The BaBar detector

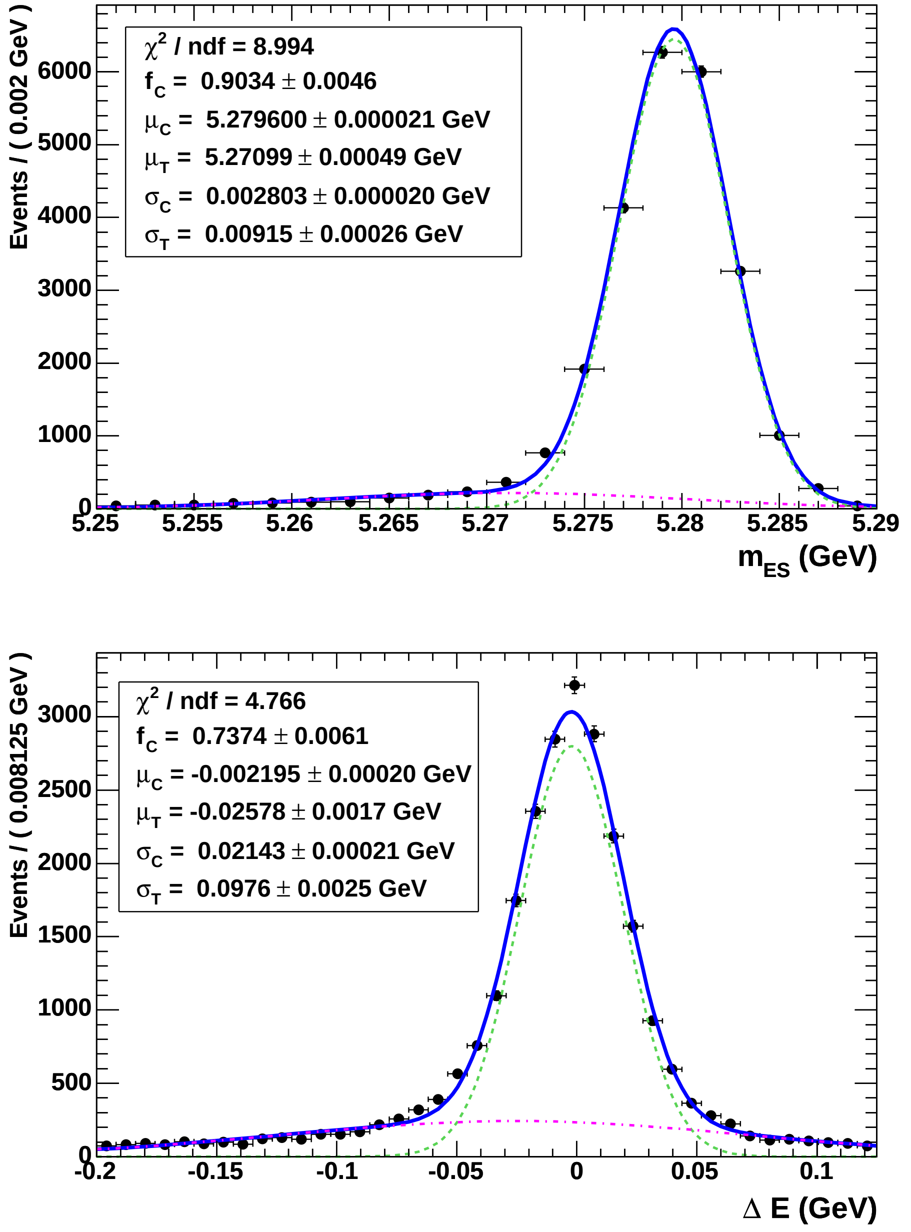


Datasets

- The data sample for this analysis is 210 fb^{-1} at $\Upsilon(4S)$
  - corresponding to (231.8 ± 2.6) million $B\overline{B}$ pairs.
- Monte Carlo samples typically 120k events per mode
- For B background studies we use 670 million generic $B\overline{B}$ events.
- Previous analysis data sample was 82 fb^{-1}
  - Published: Phys. Rev. D70, 032006 (2004)
  - Contains good description of analysis techniques

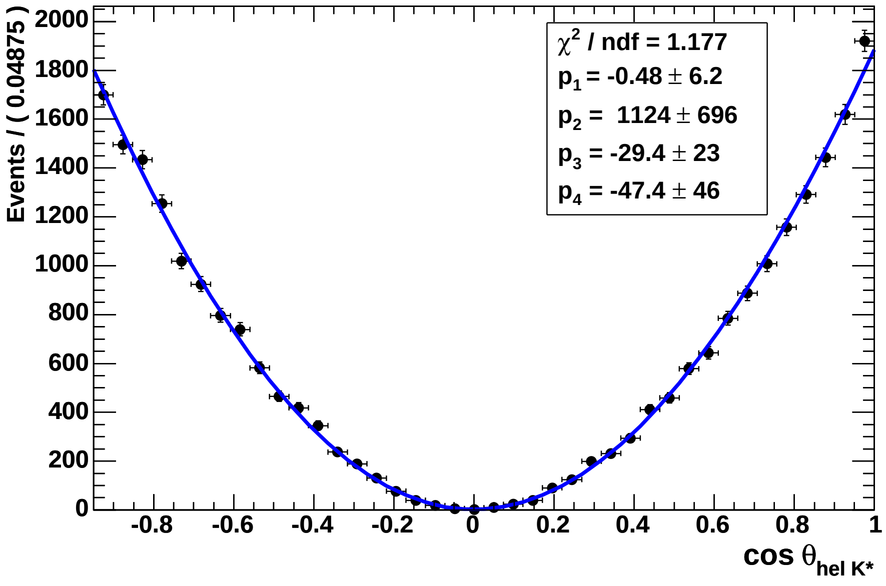
BaBar kinematics

- Energy substituted mass:
  $$m_{\mathrm{ES}} = \sqrt{(s/2 + \mathbf{p}_0 \cdot \mathbf{p}_B)^2 / E_0^2}$$
- Energy difference:
  $$\Delta E = E_B^* - \sqrt{s}/2$$
- GTL = “Good Tracks Loose” doesn’t include short tracks
- GTVL = “Good Tracks Very Loose” includes short tracks

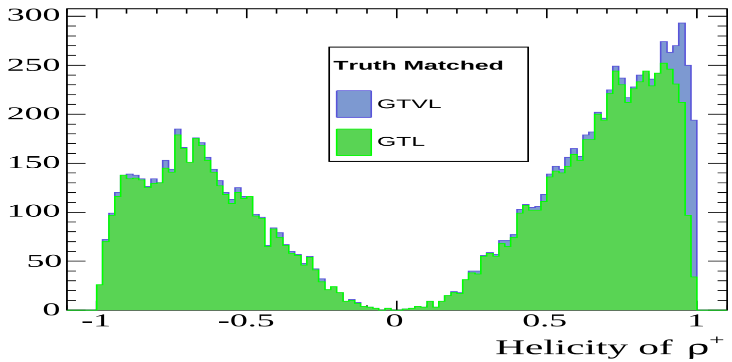


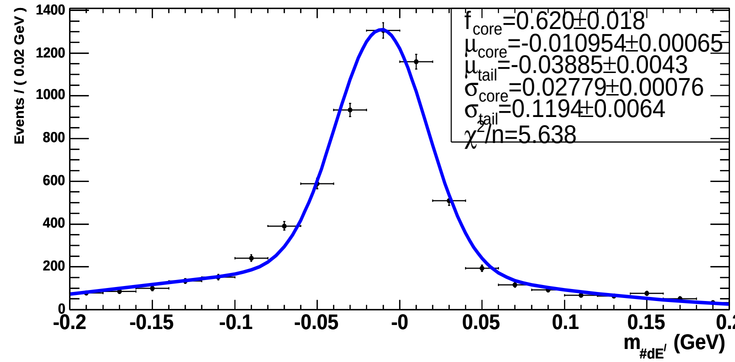
Helicity of the vector meson (ρ or K^*)

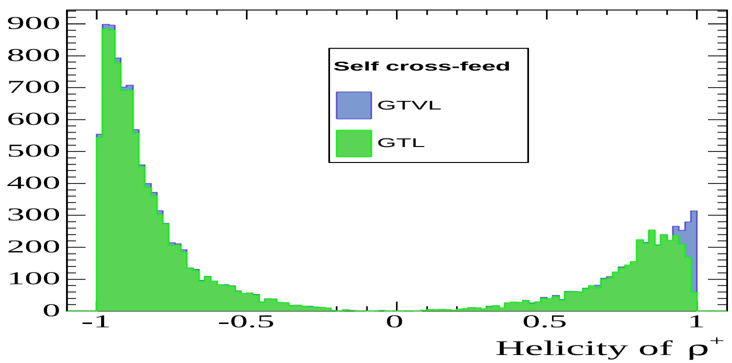
- $B \to PV$
  - B^0 spin 0 decaying to spin 0 + spin 1 final state
  - Vector meson can only take on one spin polarisation
- Define helicity
  - $\cos\theta_H$ (cosine of angle between daughter π and negative B direction in vector meson frame)
  - signal has $\cos^2\theta$ shape

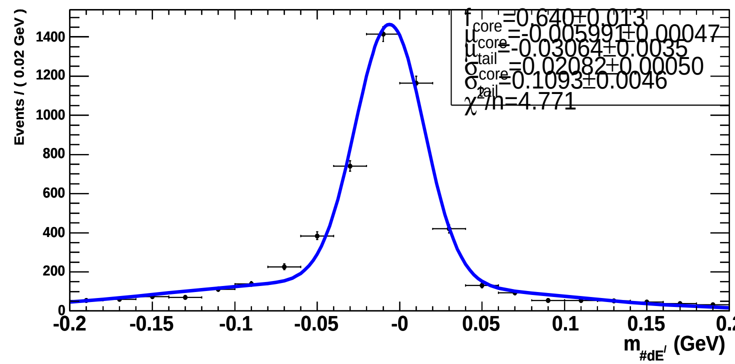


Some analysis Improvements









- GTL$\rightarrow$ GTVL for ρ and K^* meson daughter pions
- Mass constrain η and η' for B candidates
- (5.2$\rightarrow$ 5.25) $< m_{\mathrm{ES}} <$ 5.29

Skim selection

- Inclusive skim (for case $\eta' \to \eta\pi\pi$)
  - $1.9\,\mathrm{GeV}/c < p^* < 3.1\,\mathrm{GeV}/c$
- Exclusive skim (for case $\eta' \to \rho\gamma$)
  - Necessary due to larger backgrounds
  - Look for 16 $B \to \eta' X$ decays
    - $1.9\,\mathrm{GeV}/c < p^* < 3.1\,\mathrm{GeV}/c$
    - $m_B > 5.15\,\mathrm{GeV}/c^2$
    - $|\Delta E| < 0.3\,\mathrm{GeV}$
    - $E_\gamma > 0.050\,\mathrm{GeV}$

Final state	Signal efficiency ($\%$)	$q\bar{q}$ efficiency ($\%$)
$\eta' K^*$	40	3.8
$\eta'\rho^0/\rho^+$	$58/36$	< 4.5

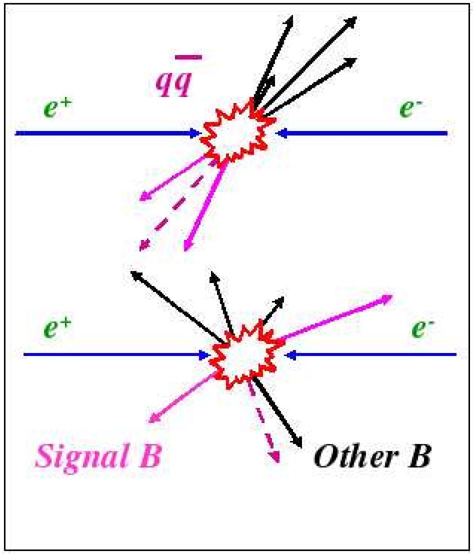
Event selection

- ten decay modes
  - $\eta'_{\eta\pi\pi} K^{*0}_{K^+\pi^-}$, $\eta'_{\rho\gamma} K^{*0}_{K^+\pi^-}$
  - $\eta'_{\eta\pi\pi} K^{*+}_{K^+\pi^0}$, $\eta'_{\rho\gamma} K^{*+}_{K^+\pi^0}$
  - $\eta'_{\eta\pi\pi} K^{*+}_{K^0\pi^+}$, $\eta'_{\rho\gamma} K^{*+}_{K^+\pi^0}$
  - $\eta'_{\eta\pi\pi}\rho^0$, $\eta'_{\rho\gamma}\rho^0$
  - $\eta'_{\eta\pi\pi}\rho^+$, $\eta'_{\rho\gamma}\rho^+$
- K^0_S candidate lifetime $\tau/\sigma_t > 3$
- Particle identifi cation
  - $e/p/K$ veto for pions
  - tight ID for kaons

Criterion	Requirement
$\eta_{\gamma\gamma}$	$490 < m(\gamma\gamma) < 600$
$\eta'_{\eta\pi\pi}$	$910 < m(\eta\pi\pi) < 1000$
$\eta'_{\rho\gamma}$	$910 < m(\rho\gamma) < 1000$
$K^*_{K\pi}$	$755 < m(K\pi) < 1035$
ρ^+	$470 < m(\pi\pi) < 1070$
ρ^0	$510 < m(\pi\pi) < 1060$
π^0	$120 < m(\gamma\gamma) < 150$
K^0_S	$486 < m(\pi\pi) < 510$
γ (from η)	$E_\gamma < 100$
γ (from π^0)	$E_\gamma < 30$
γ (from η')	$E_\gamma < 200$
$N_{\rm trks}$	$\geq \max[3, N_{\rm trks\ \ in\ decay\ mode} + 1]$
Fisher, $\mathcal{F}$	$-4 < \mathcal{F} < 5$
$m_{\rm ES}$	$5.25 \leq m_{\rm ES} < 5.29\ {\rm GeV}/c^2$

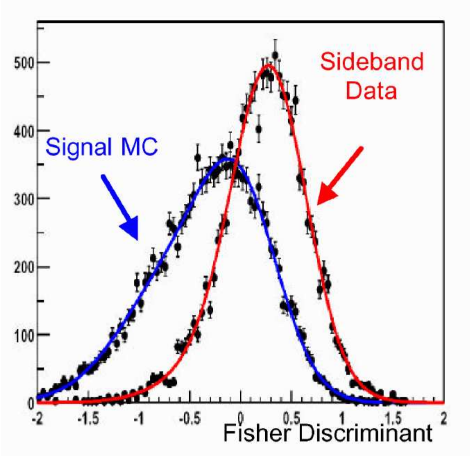
$q\overline{q}$ background rejection (1)

- Rare charmless decays
  - small signal / large background
  - two body kinematics help remove background
- Dominant remaining background is $q\overline{q}$ continuum
- Reject jet-like topologies
- Define "thrust" axis and cut on angle
  - $|\cos\theta_{\rm T}| < 0.9$ $\eta'_{\eta\pi\pi}$ modes
  - $|\cos\theta_{\rm T}| < 0.75$ $\eta'_{\rho\gamma}$ modes



$q\overline{q}$ background rejection (2)

- Many other “event shape” variables, all highly correlated
- Distinguish signal from $q\overline{q}$ with Fisher ($\mathcal{F}$) discriminant
  - $|\cos\theta_B|$, θ_B angle between $\vec{p_B}$ and beam axis
  - $|\cos\theta_C|$, θ_C angle between candidate thrust axis and beam
  - Legendre Polynomials P_0 and P_2, angular distribution of “rest of event” momentum flow wrt. B thrust axis
- Linear weights are applied to each variable to maximise S to B separation.



$B\overline{B}$ backgrounds

- Mainly backgrounds picking up extra particle (eg. $B \to \eta' K$)
- ΔE and helicity cuts help
  - $-0.200 < \Delta E < 0.125$ ($-0.200 < \Delta E < 0.150$ modes with π^0)
  - $\cos\theta_H > -0.95$ removes slow π^+ combs
  - For π^0 modes we remove slow π^+ or slow π^0 combs
    - $-0.8 < \cos\theta_H < 0.95$ $\eta'_{\eta\pi\pi}$ modes
    - $-0.7 < \cos\theta_H < 0.95$ $\eta'_{\rho\gamma}$ modes
- Identify remaining $B\overline{B}$ using generic MC then dedicated signal MC (added $a_1\rho/K^*$)
- $\eta'_{\eta\pi\pi}$modes have less $B\overline{B}$ background than $\eta'_{\rho\gamma}$ (have not unblinded $\eta'_{\rho\gamma}\rho$)

Signal mode ($B^0 \to \eta' K^{*0}$) Bkg. channel	Mode #	MC ϵ (%)	Est. $\mathcal{B}$ (10^{-6})	$\prod \mathcal{B}_i$	Norm. # $B\overline{B}$ B kg.	# in PDF Bkg. fi le
$B^+ \to \eta'_{\eta_{\gamma\gamma}\pi\pi} K^+$	1506	0.46	69	0.174	12.8	658
$B^0 \to \eta_{3\pi} K^{*0}_{K^+\pi^-}$	1540	0.7	19	0.151	4.7	240
$B^0 \to \eta'_{\eta_{\gamma\gamma}\pi\pi} K_S$	1510	0.32	63	0.060	2.8	146
$B^0 \to a_1^0 K^{*0}(L, f_L = 0.7)$	5329	0.03	21	0.467	0.7	38
$B^0 \to \omega\, K^{*0}_{K^+\pi^-}(L, f_L = 1)$	2507	0.11	4	0.594	0.6	31
$B^+ \to a_1^+(\rho^+\pi^0) K^{*0}(L, f_L = 0.7)$	5331	0.02	42	0.233	0.4	21

Some modes have large $B\overline{B}$ backgrounds

- $\eta'_{\rho\gamma}$ modes have 20-30 $B\overline{B}$ bkgs
- All modes: ~ 300 bkgs
- Dropped $\eta'_{\rho\gamma}\rho^+$ and $\eta'_{\rho\gamma}\rho^0$
  - Statistical power small
  - Systematics huge

Signal mode Bkg. channel	Mode #	MC ϵ (%)	Est. $\mathcal{B}$ (10^{-6})	$\prod \mathcal{B}_i$	Norm. # $B\overline{B}$ Bkg.	# in PDF Bkg. file
$\eta'_{\rho\gamma}\rho^+$						
$B^+ \to a_1^0\rho^+(L, f_L = 1)$	3999	0.94	48	1.000	105	1509
$B^0 \to a_1^+(\rho^0\pi^+)\rho^-(L, f_L = 1)$	4002	0.7	84	0.500	68.5	984
$B^0 \to \rho^+\rho^-(L, f_L = 1)$	2498	0.9	26	1.000	54.2	778
$B^+ \to \rho^+\rho^0(L, f_L = 1)$	2390	0.75	26	1.000	45.1	648
$B^+ \to a_1^+(\rho^+\pi^0)\rho^0(L, f_L = 1)$	4107	0.69	48	0.500	38.3	550
$B^+ \to a_1^+\pi^0$	3584	0.27	15	1.000	9.4	135
$B^+ \to a_1^+(\rho^0\pi^+)\pi^0$	4799	0.42	15	0.500	7.2	103
$B^+ \to \omega\rho^+(L, f_L = 0.88)$	2768	0.25	12	0.891	6.1	88
$B^0 \to \pi^-a_1^+$	4157	0.07	33	1.000	5.5	79
$B^0 \to \rho^-\pi^+\pi^0$	2491	0.22	10	1.000	5	72
$B^+ \to a_1^+(\rho^+\pi^0)\pi^0$	4957	0.26	15	0.500	4.5	64
$B^+ \to \rho^0\pi^+\pi^0$	2484	0.18	10	1.000	4.2	60
$B^+ \to a_1^+(\rho^0\pi^+)a_1^0(L, f_L = 1)$	6650	0.14	49	0.250	4.1	58
$B^+ \to a_1^+(\rho^0\pi^+)\rho^0(L, f_L = 1)$	4105	0.07	48	0.500	4	57
$B^+ \to a_1^0\pi^+$	4156	0.13	12	1.000	3.7	52
$B^0 \to a_0^-(\eta_{\gamma\gamma}\pi^-)\rho^+$	2458	0.4	10	0.394	3.6	52
$B^+ \to \rho^+\pi^0$	1940	0.13	12	1.000	3.6	51
$B^0 \to \eta'_{\rho\gamma}K_s$	1511	0.23	63	0.101	3.3	47
$B^0 \to a_1^0\rho^0(L, f_L = 1)$	4518	0.66	2	1.000	3	43
$B^+ \to \rho^+\pi^+\pi^-$	2489	0.12	10	1.000	2.8	40
$B^0 \to a_1^0K^{*0}(L, f_L = 0.7)$	5329	0.12	21	0.467	2.6	37
$B^+ \to \rho^+ K^{*0}_{K^+\pi^-}(L, f_L = 0.7)$	2244	0.23	7	0.667	2.5	36
$B^+ \to a_1^+(\rho^+\pi^0)K^{*0}(L, f_L = 0.7)$	5331	0.11	42	0.233	2.5	35
$B^0 \to \rho^-K^{*+}_{K^+\pi^0}(T, f_L = 0.25)$	2500	0.36	9	0.333	2.5	35
$B^0 \to \rho^-K^{*+}_{K_S\pi^+}(T, f_L = 0.25)$	2502	0.43	9	0.229	2.1	29
$B^+ \to a_1^0K^{*+}(K^+\pi^0)(L, f_L = 1)$	5327	0.11	21	0.333	1.7	24
$B^0 \to a_1^+(\rho^0\pi^+)a_1^-(\rho^0\pi^-)(L, f_L = 1)$	6639	0.04	64	0.250	1.4	20
$B^+ \to \pi^+\pi^0\pi^0$	1938	0.06	10	1.000	1.3	19
$B^+ \to \rho^+ K^{*0}_{K^+\pi^-}(T, f_L = 0.7)$	2243	0.29	3	0.667	1.3	19
$B^+ \to \omega\rho^+(T, f_L = 0.88)$	2766	0.6	1	0.891	1.2	17
$B^0 \to a_1^-(\rho^-\pi^0)K^{*+}(K^+\pi^0)(L, f_L = 1)$	5323	0.07	42	0.167	1.2	17
$B^+ \to a_1^+(\rho^+\pi^0)K^{*0}(T, f_L = 0.7)$	5332	0.12	42	0.100	1.1	16
$B^0 \to a_1^-(\rho^0\pi^-)K^{*+}(K^+\pi^0)((L, f_L = 1)$	5325	0.06	42	0.167	1.1	15
$B^+ \to \rho^-\pi^+\pi^+$	4151	0.08	5	1.000	0.9	13
$B^0 \to a_1^0K^{*0}(T, f_L = 0.7)$	5330	0.08	21	0.200	0.8	11
$B^+ \to \pi^0\pi^-\pi^+\pi^+$	4153	0.06	5	1.000	0.7	10
$B^0 \to \rho^-K^{*+}_{K_S\pi^+}(L, f_L = 0.25)$	2501	0.35	3	0.229	0.6	8
					406.6	5831

Maximum likelihood fit details

$$\mathcal{L} = \frac{e^{-(\sum n_j)}}{N!} \prod_{i=1}^{N} \mathcal{L}_i \text{ , where } \mathcal{L}_i = \sum_{j=1}^{m} n_j \mathcal{P}_j(\mathbf{x}_i)$$

- Fit components, n_j, for signal, $q\bar{q}$ and $B\bar{B}$
- For $\eta'\rho^0$ we include an extra component $\eta' f_0$

Variable (x_i)	Signal ($\mathcal{P}$)	Continuum ($\mathcal{P}$)	$B\bar{B}$ background ($\mathcal{P}$)
ΔE	$G+G$	$P1$	$G+P1$
$m_{\rm ES}$	$G+G$	$ARGUS$	$ARGUS+G+G$
$\mathcal{F}$	$BG+G$	$BG+G$	$BG+G$
$m_{\eta'}$	$G+G$	$P1+(G+G)_{\rm sig}$	$P1+(G+G)_{\rm sig}$
m_{K^*}	BW	$P2+(BW)_{\rm sig}$	$P2+(BW)_{\rm sig}$
m_ρ	BW	$P2+(BW)_{\rm sig}$	$P2+(BW)_{\rm sig}$
$\cos\theta_H$	$P4$	$P4$	$EXP+P2$

pdfs – $\eta'_{\eta\pi\pi}K^{*0}$

sig | $q\bar{q}$ | $B\bar{B}$

ΔE

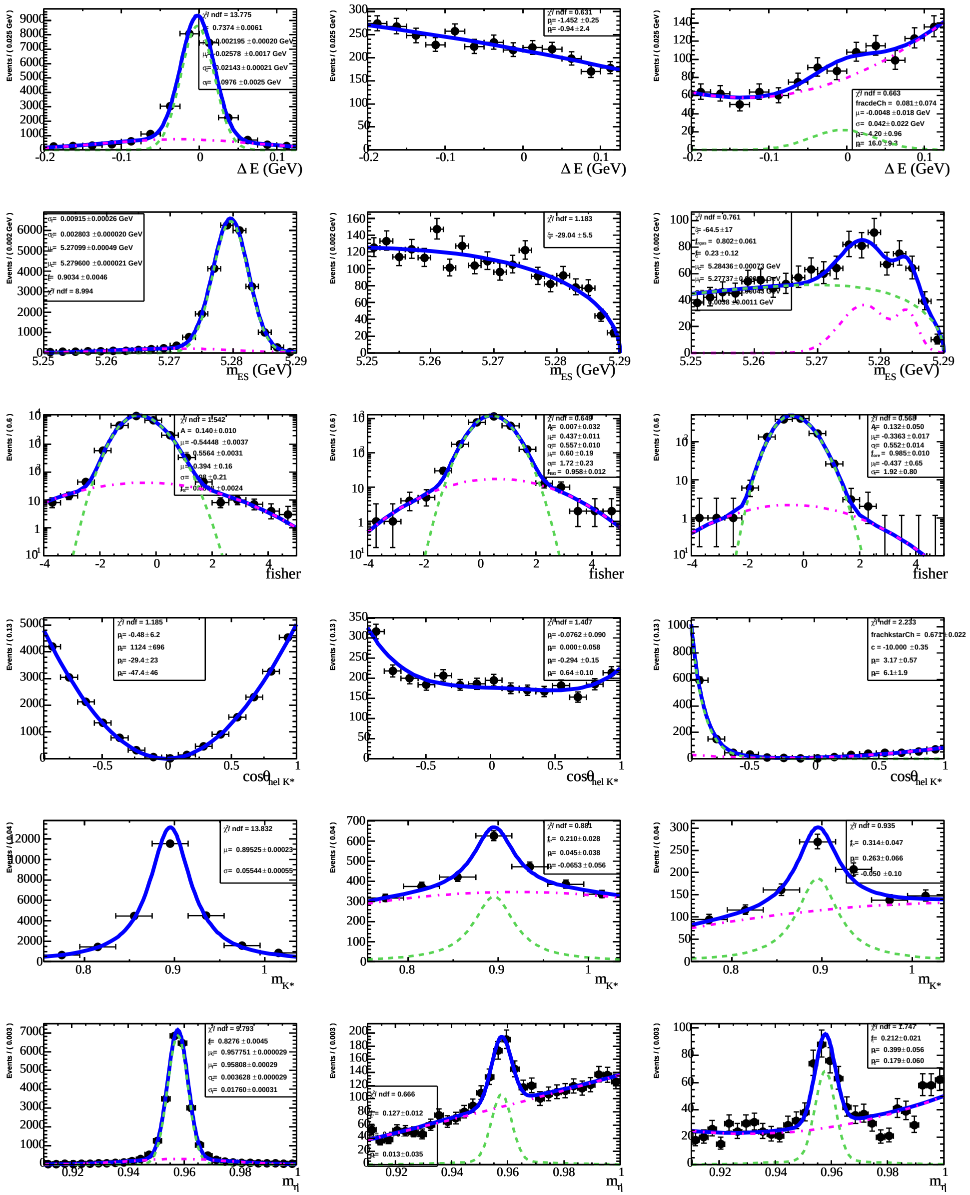
m_{ES}

$\mathcal{F}$

$\cos\theta_H$

m_{K^*}

$m_{\eta'}$



pdfs – $\eta'_{\rho\gamma} K^{*0}$

sig | $q\bar{q}$ | $B\bar{B}$

ΔE

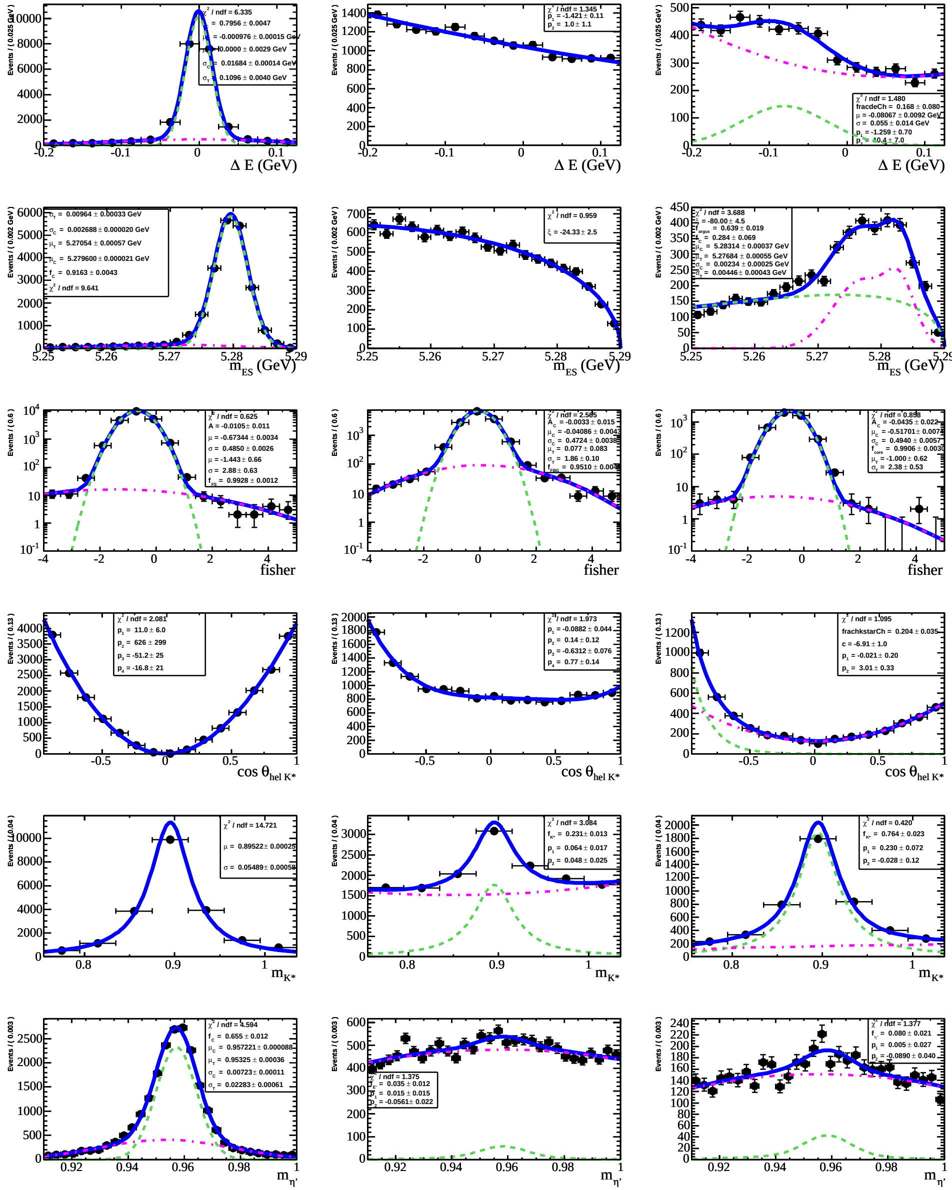
m_{ES}

$\mathcal{F}$

$\cos\theta_H$

m_{K^*}

$m_{\eta'}$



Toy Monte Carlo Studies

- Determine ML fit yield bias
- Signal and $B\overline{B}$ events embedded from SP5/6 MC
- Continuum $q\overline{q}$ events generated from PDFs

Mode	N_{total}	N_{sig} (in)	$N_{B\overline{B}}$ (in)	N_{sig} (fit)	$N_{B\overline{B}}$ (fit)	$\sigma(N_{sig})$ (fit)	$\sigma(N_{B\overline{B}})$ (fi	bias [evts]
$\eta'_{\eta\pi\pi}K^{*0}$	4837	21	46	22.0 ± 0.3	42.9 ± 0.9	7.2	22.4	$+1.0 \pm 0.3$
$\eta'_{\rho\gamma}K^{*0}$	23790	25	409	34.5 ± 0.6	400.2 ± 5.2	14.2	122.7	$+9.5 \pm 0.6$
$\eta'_{\eta\pi\pi}K^{*+}_{K^0\pi^+}$	2114	10.8	16	11.6 ± 0.2	16.2 ± 0.5	3.8	10.7	$+0.8 \pm 0.2$
$\eta'_{\rho\gamma}K^{*+}_{K^0\pi^+}$	9962	12	231	14.9 ± 0.4	228.4 ± 2.8	9.7	70.2	$+2.9 \pm 0.4$
$\eta'_{\eta\pi\pi}K^{*+}_{K^+\pi^0}$	3020	4.5	46	5.5 ± 0.2	47 ± 0.8	4.9	17.2	$+1.0 \pm 0.2$
$\eta'_{\rho\gamma}K^{*+}_{K^+\pi^0}$	12996	5.5	337	3.2 ± 0.6	388.3 ± 3.0	11.7	66.5	-2.3 ± 0.6
$\eta'_{\eta\pi\pi}\rho^+$	17287	38	266	51.5 ± 0.7	270.8 ± 2.7	15.7	60	$+13.5 \pm 0.7$
$\eta'_{\eta\pi\pi}\rho^0$	13329	3.5	289	14.3 ± 0.7	294 ± 2	11.0	41.8	$+10.8 \pm 0.7$

Neutral Modes – $B^0 \to \eta' K^* / \rho$

ML fit quantity	$\eta'_{\eta\pi\pi} K^{*0}$	$\eta'_{\rho\gamma} K^{*0}$	$\eta'_{\eta\pi\pi}\rho^0/\eta'_{\eta\pi\pi} f_0$	$\eta'_{\rho\gamma}\rho^0/\eta'_{\rho\gamma} f_0$
Events to fit	4837	23790	13329	40538
signal yield	$22.6^{+7.7}_{-6.7}$	$35.1^{+14.2}_{-12.7}$	$14.9^{+10.6}_{-8.4}$/$-2.6^{+6.0}_{-4.0}$	blind
Fit $B\overline{B}$ yield	$45.8^{+24.3}_{-22.3}$	396^{+115}_{-115}	289^{+44}_{-43}	blind
ML-fit bias (events)	+1.7	+9.5	+11.2/-3.8	blind
MC ϵ (%)	20.1	17.2	24.1/26.8	18.2/7.8
Tracking corr. (%)	97.4	98.0	97.4	98.0
Neutral corr. (%)	97.3	100.0	97.3	100.0
Corr. ϵ (%)	19.0	16.9	22.8/25.4	17.8/7.6
$\prod \mathcal{B}_i$ (%)	11.6	19.7	17.5/17.5	29.5/66.7
Corr. $\epsilon \times \prod \mathcal{B}_i$ (%)	2.2	3.3	4.0/4.4	5.3/5.1
Stat. sign. (σ)	4.1	2.2	0.4/0.2	blind
$\mathcal{B}(10^{-6})$	$4.1^{+1.5}_{-1.3}$	$3.3^{+1.9}_{-1.6}$	$0.4^{+1.2}_{-0.9}/0.1^{+0.6}_{-0.4}$	blind
UL $\mathcal{B}$ (10^{-6})	–	6.3	3.7/2.0	blind

Combined results	K^{*0}	ρ^0/f_0
$\mathcal{B}(10^{-6})$	$3.8^{+1.1+0.5}_{-1.0-0.4}$	$0.4^{+1.2+1.6}_{-0.9-0.6}$/$0.1^{+0.6+0.9}_{-0.4-0.4}$
Signif.	4.5	0.3/0.2
UL $\mathcal{B}(10^{-6})$	–	3.7/2.0

Charged Modes – $B^+ \to \eta' K^* / \rho$

ML fit quantity	$\eta'_{\eta\pi\pi} K^{*+}_{K^0\pi^+}$	$\eta'_{\rho\gamma} K^{*+}_{K^0\pi^+}$	$\eta'_{\eta\pi\pi} K^{*+}_{K^+\pi^0}$	$\eta'_{\rho\gamma} K^{*+}_{K^+\pi^0}$	$\eta'_{\eta\pi\pi} \rho^+$	$\eta'_{\rho\gamma} \rho^+$
Events to fit	2114	9962	3020	10467	17287	44094
Signal yield	$11.2^{+5.7}_{-4.5}$	$14.8^{+11.2}_{-9.7}$	$5.2^{+5.4}_{-3.6}$	$3.1^{+12.1}_{-9.6}$	$51.1^{+17.5}_{-16.0}$	blind
BB yield	$16.5^{+11.1}_{-9.4}$	228^{+72}_{-71}	46^{+22}_{-21}	337^{+74}_{-72}	265 ± 62	blind
ML-fit bias (events)	$+0.8$	$+2.9$	$+1.0$	-2.3	$+13.5$	blind
MC ϵ (%)	19.2	16.4	11.6	8.4	14.7	9.21
Tracking corr. (%)	97.9	98.5	97.9	98.5	97.9	98.5
K^0_S corr. (%)	98.2	98.1	–	–	–	–
Neutrals corr. (%)	97.3	100.0	94.3	97.0	94.7	97.5
Corr. ϵ (%)	18.0	15.8	10.7	8.0	13.6	8.61
$\prod \mathcal{B}_i$ (%)	4.0	6.8	5.8	9.8	17.5	29.5
Corr. $\epsilon \times \prod \mathcal{B}_i$ (%)	0.7	1.1	0.6	0.8	2.4	2.5
Stat. sign. (σ)	3.3	1.3	1.2	0.5	2.6	blind
$\mathcal{B}(10^{-6})$	$6.2^{+3.4}_{-2.7}$	$4.7^{+4.5}_{-3.9}$	$2.9^{+3.7}_{-2.6}$	$2.9^{+6.7}_{-5.4}$	$6.8^{+3.2}_{-2.9}$	blind
UL $\mathcal{B}$ (10^{-6})	11.6	11.8	9.4	22.2	14.2	blind

	$\eta' K^{*+}$ (combined)	$\eta' \rho^+$ (combined)
$\mathcal{B}(10^{-6})$	$4.9^{+1.9+0.8}_{-1.7-0.7}$	$6.8^{+3.2+3.9}_{-2.9-1.3}$
Signif. w syst. (σ)	3.6	2.3
UL $\mathcal{B}(10^{-6})$	7.9	14

sPlots $\eta'_{\eta\pi\pi}K^{*0}$

sig | $q\bar{q}$ | $B\bar{B}$

ΔE

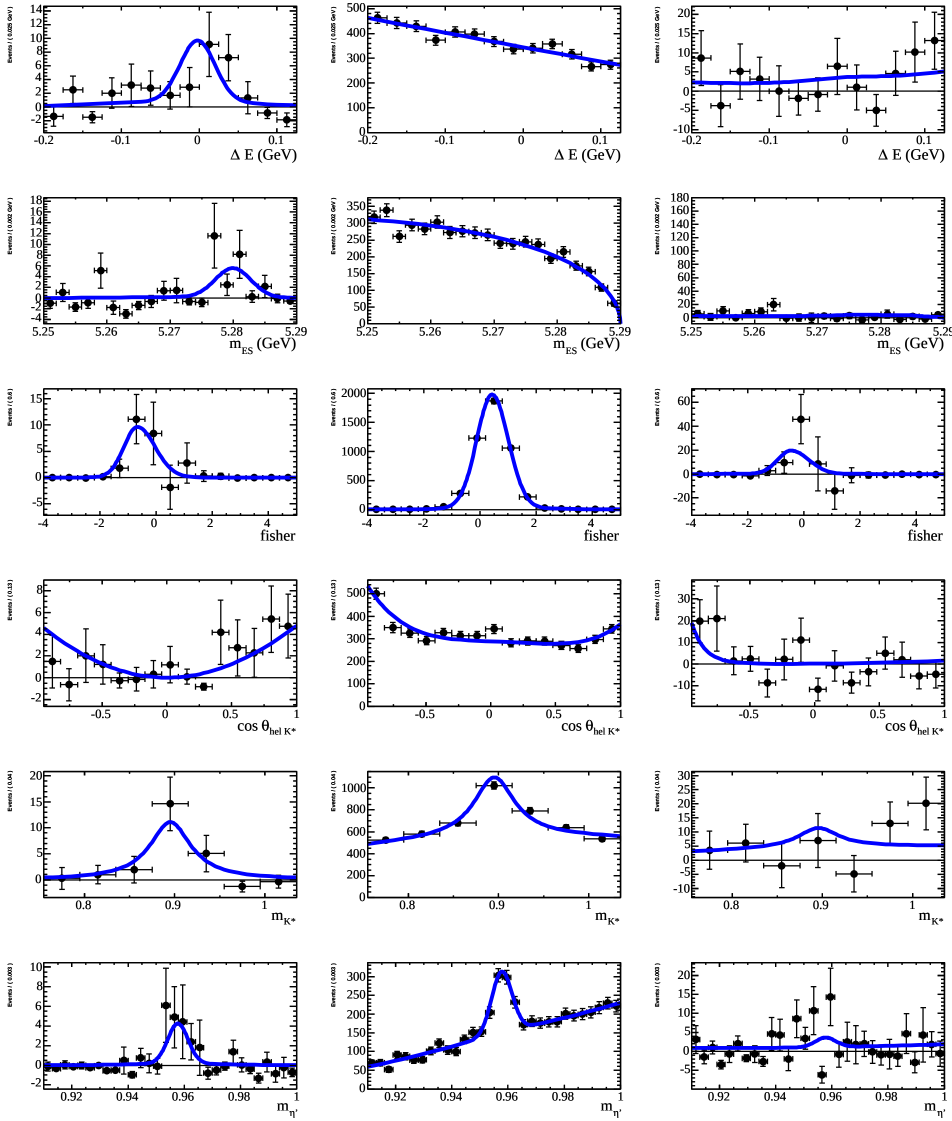
m_{ES}

$\mathcal{F}$

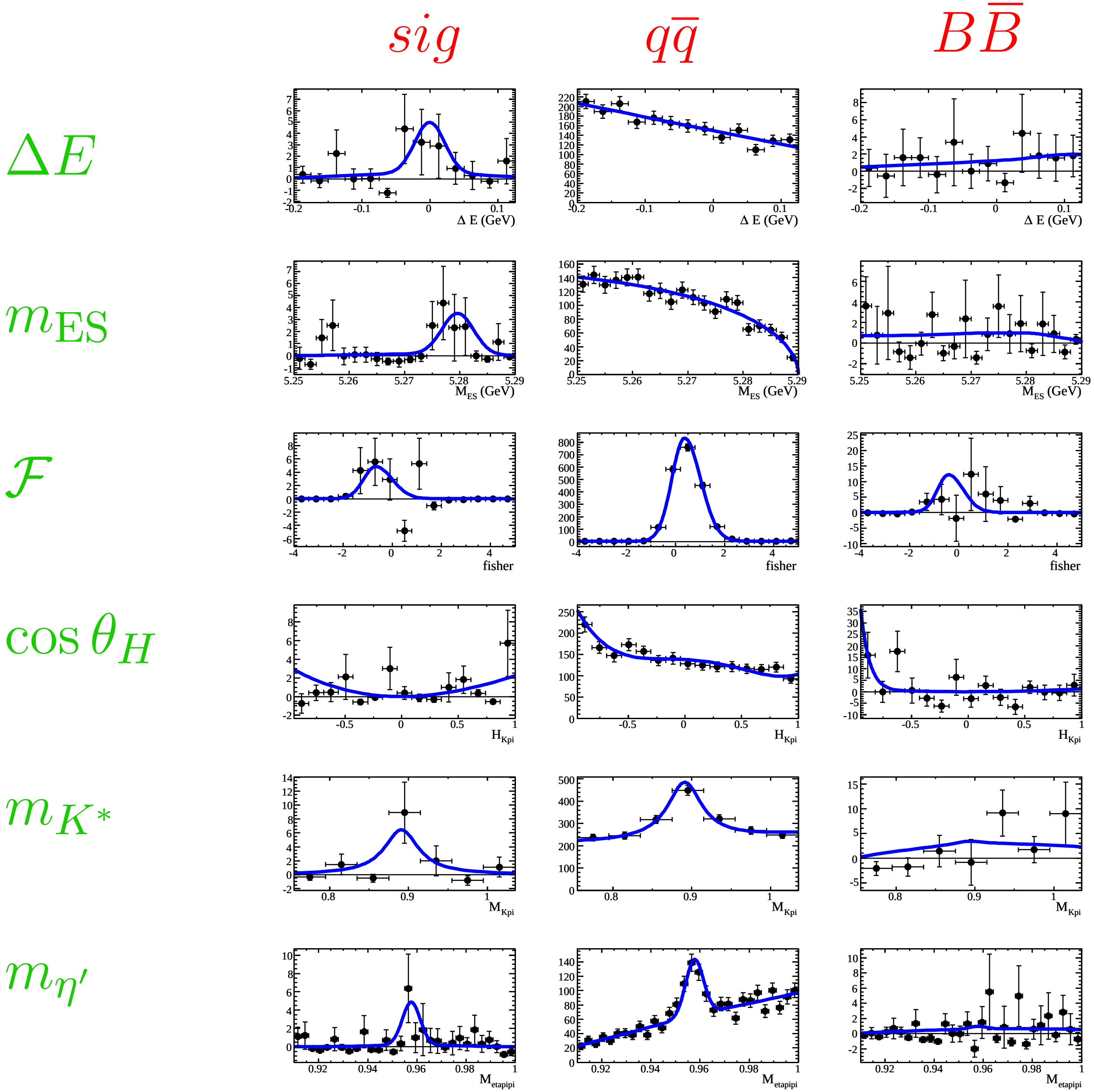
$\cos\theta_H$

m_{K^*}

$m_{\eta'}$

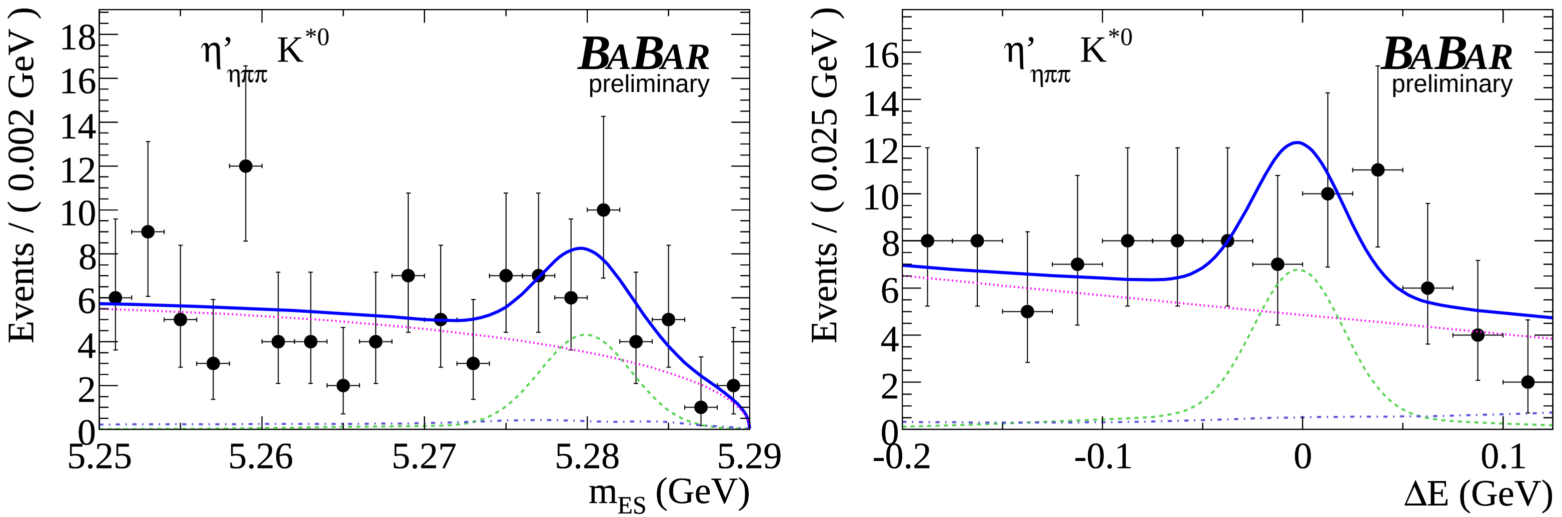


sPlots $\eta'_{\eta\pi\pi} K^{*+}_{K^0\pi^+}$

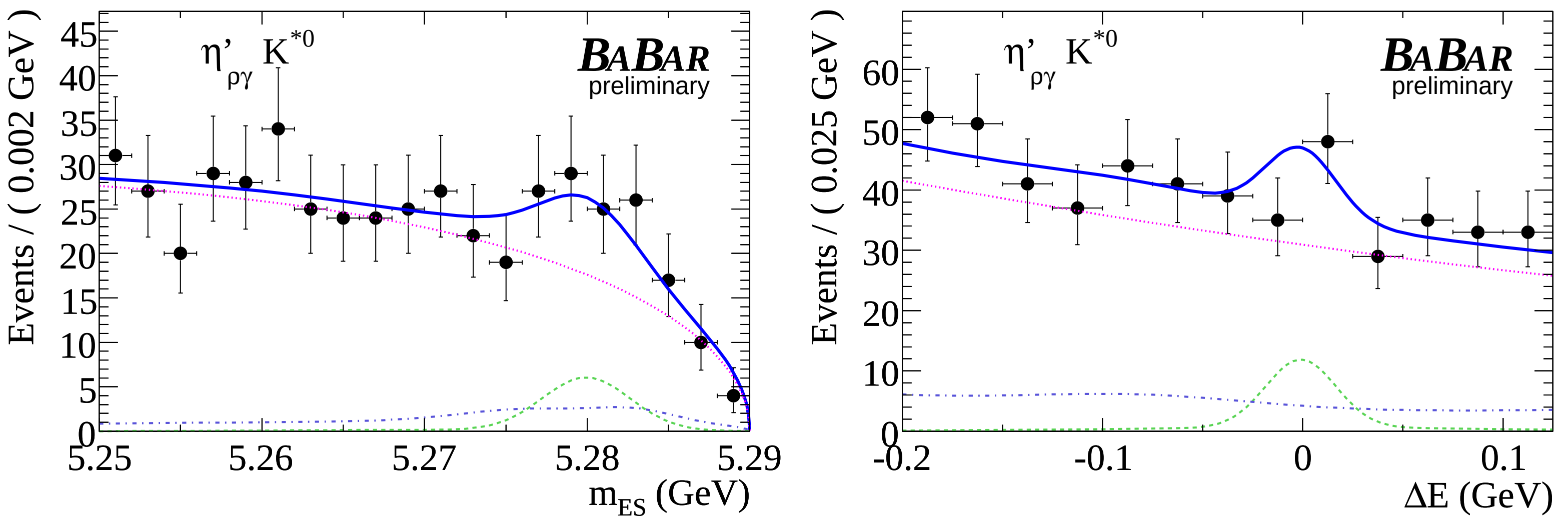


Projection plots

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

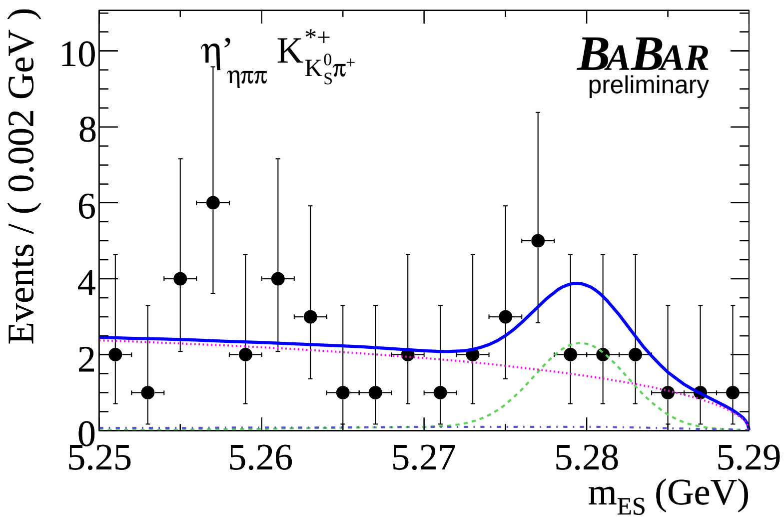


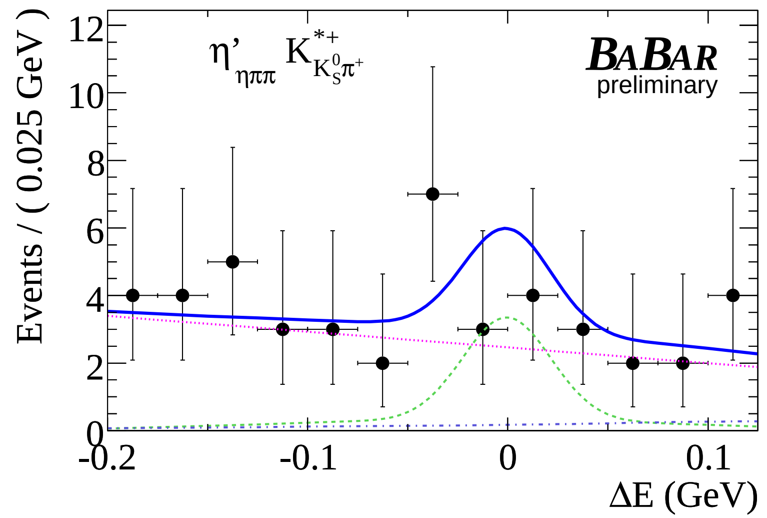
$B^0 \to \eta'_{\rho\gamma} K^{*0}$



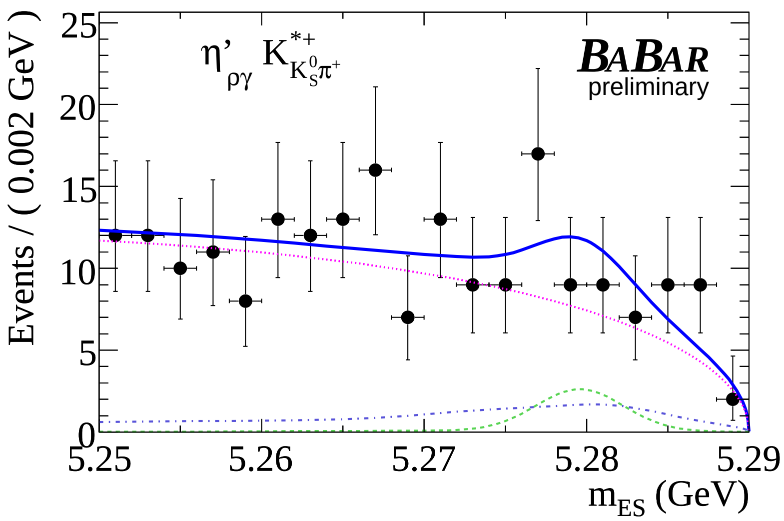
Projection plots

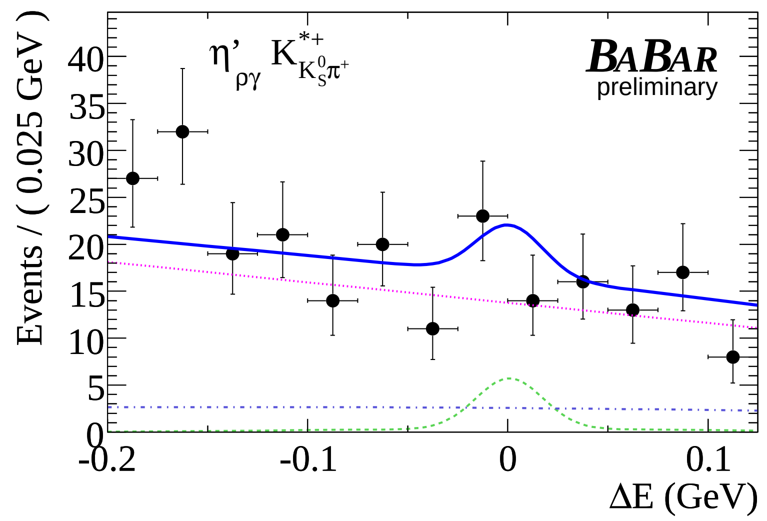
$B^+ \to \eta'_{\eta\pi\pi} K^{*+}_{K^0\pi^+}$





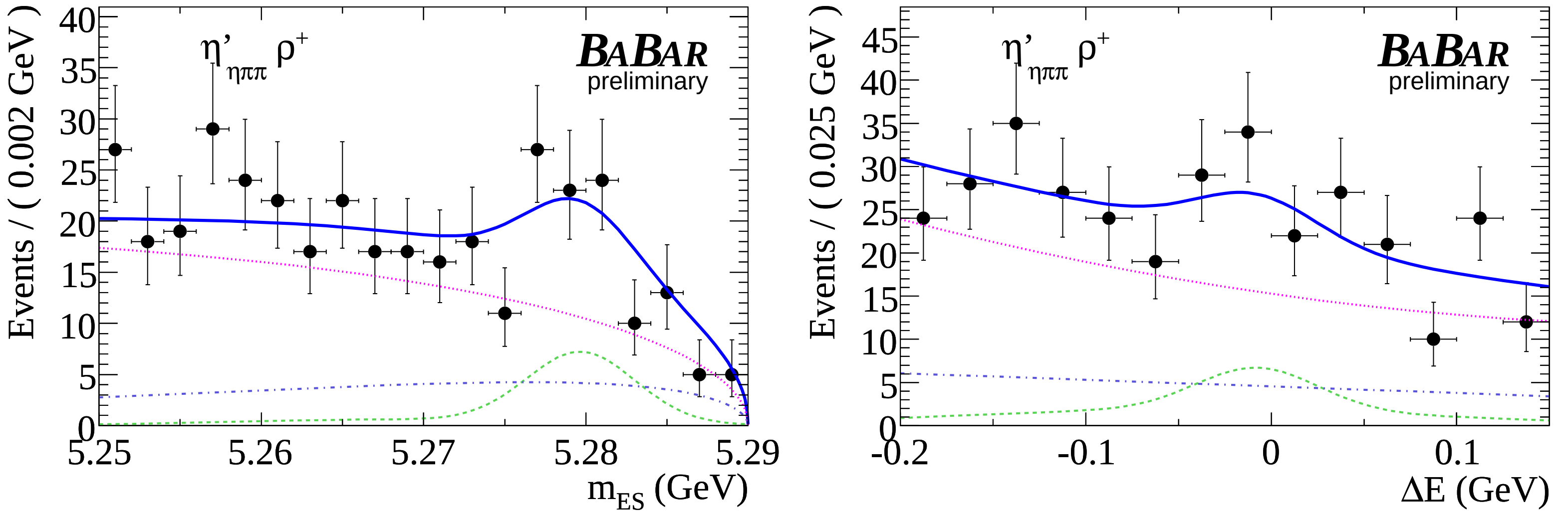
$B^+ \to \eta'_{\rho\gamma} K^{*+}_{K^0\pi^+}$



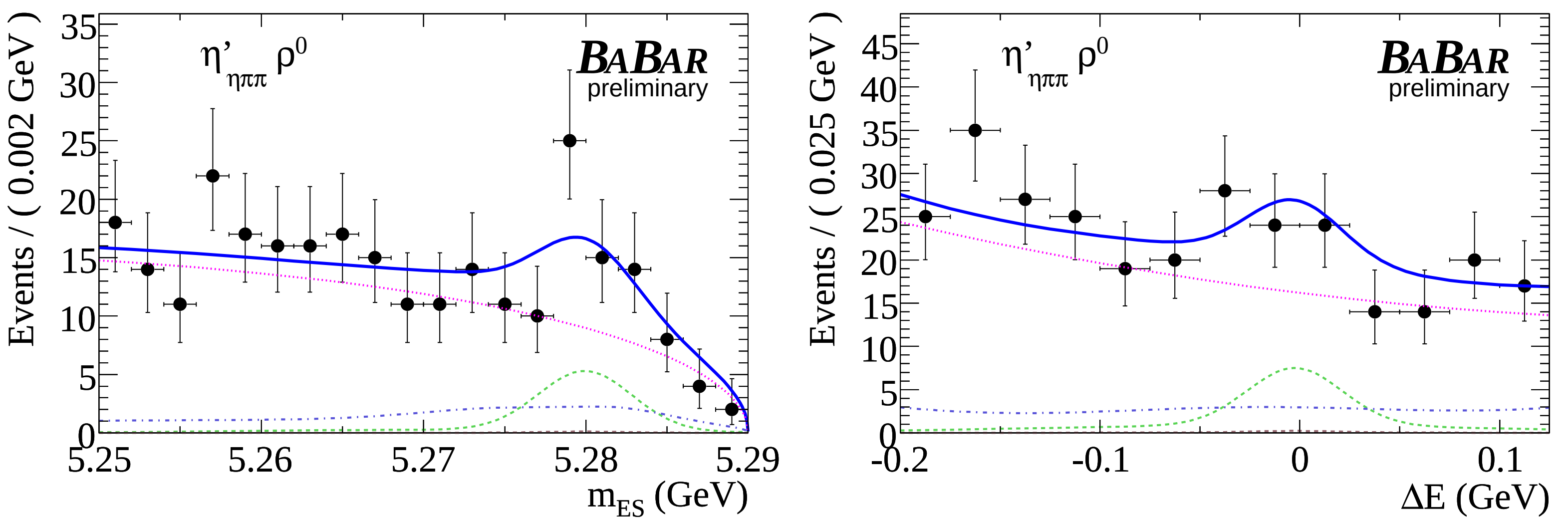


Projection plots

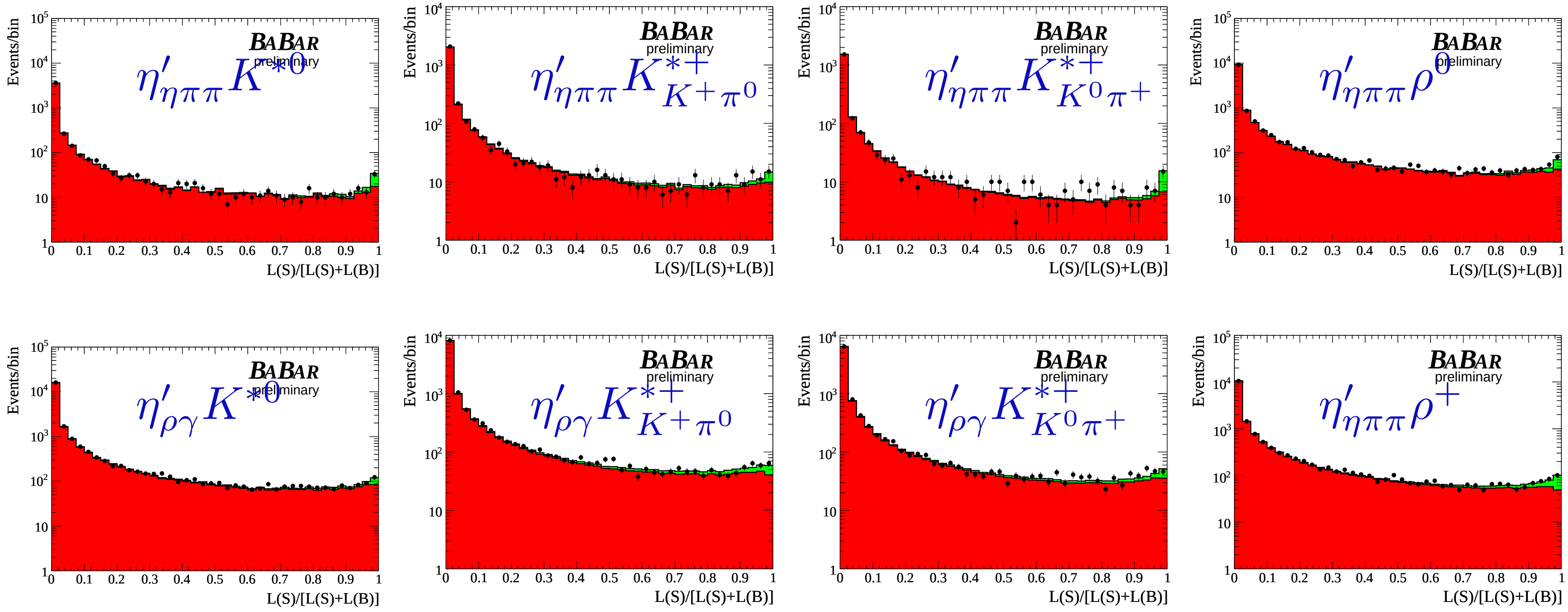
$B^+ \to \eta'_{\eta\pi\pi}\rho^+$



$B^0 \to \eta'_{\eta\pi\pi}\rho^0$



Likelihood ratio plots



- $\mathcal{L}_{sig}/[\mathcal{L}_{sig} + \sum \mathcal{L}_{bkg}]$ for all modes.
- Points are on-peak data,
- background $q\bar{q}$ & $B\overline{B}$ expectation (pure toy)
- signal (pure toy) + background

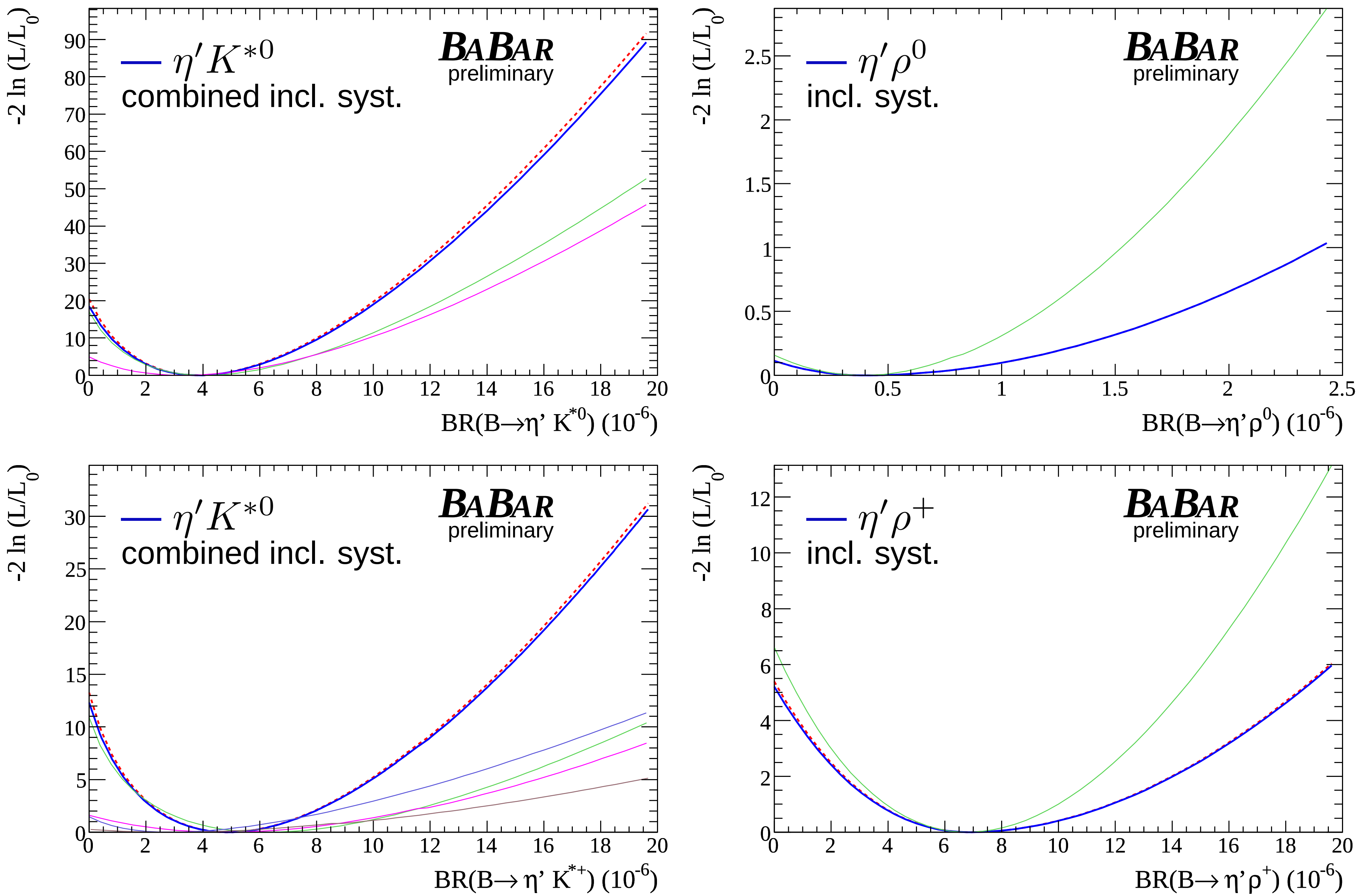
Systematics – $B^0 \rightarrow \eta' K^* / \rho$

Quantity	$\eta'_{\eta\pi\pi} K^{*0}$	$\eta'_{\rho\gamma} K^{*0}$	$\eta'_{\eta\pi\pi}\rho^0$/$\eta'_{\eta\pi\pi} f_0$
Multiplicative errors (%)			
Track multiplicity (C)	1.0	1.0	1.0
Tracking effi ciency [C]	5.4	5.6	5.4
π^0/$\eta_{\gamma\gamma}$/γ eff [C]	3.0	1.8	3.0
Number $B\overline{B}$ [C]	1.1	1.1	1.1
$\cos\theta_T$ [C]	0.5	3.0	0.5
Branching fractions [U]	3.4	3.4	3.4/3.4
MC statistics [U]	0.6	0.6	0.5
Total multiplicative	7.3	7.6	7.2/7.2
Additive errors (events)			
Signal Model [U]	± 0.55	± 0.83	$\pm 1.2/0.48$
Fit bias [U]	± 0.90	± 4.8	$\pm 5.7/2.0$
$B\overline{B}$ background [U]	$+0.82$	$+5.2$	$+14/3.6$
Total additive (events)	${}^{+1.3}_{-1.1}$	${}^{+7.2}_{-4.9}$	${}^{+15}_{-5.8}/{}^{+4.1}_{-2.0}$
Total errors [$\mathcal{B}(10^{-6})$]			
Total Additive	${}^{+0.26}_{-0.21}$	${}^{+0.93}_{-0.64}$	${}^{+1.6}_{-0.62}/{}^{+0.40}_{-0.20}$
Uncorrelated	${}^{+0.30}_{-0.25}$	${}^{+0.94}_{-0.65}$	${}^{+1.6}_{-0.62}/{}^{+0.40}_{-0.20}$
Correlated	± 0.26	± 0.22	$\pm 0.03/0.01$

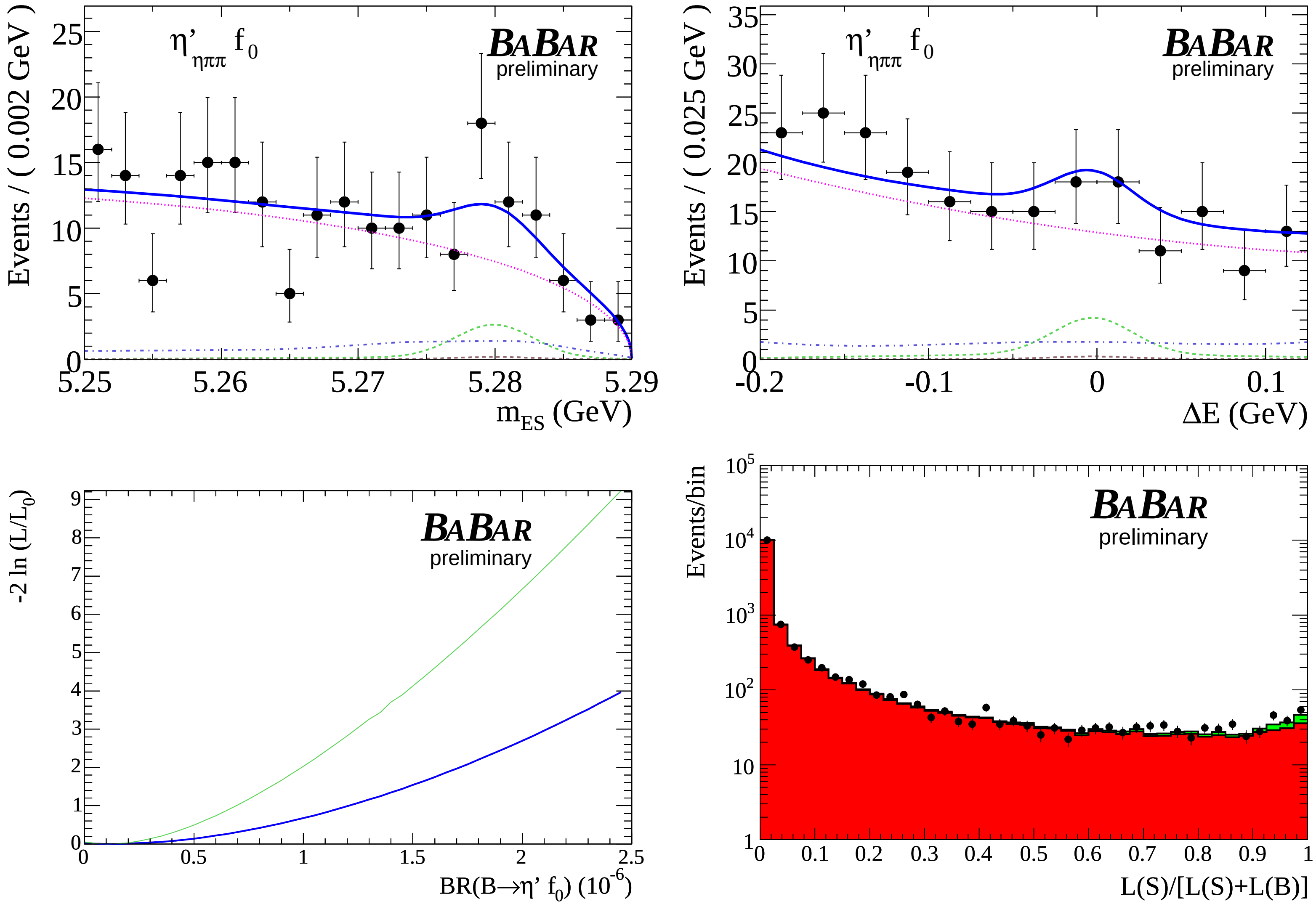
Systematics – $B^+ \to \eta' K^* / \rho$

Quantity	$\eta'_{\eta\pi\pi} K^{*+}_{K^0\pi^+}$	$\eta'_{\rho\gamma} K^{*+}_{K^0\pi^+}$	$\eta'_{\eta\pi\pi} K^{*+}_{K^+\pi^0}$	$\eta'_{\rho\gamma} K^{*+}_{K^+\pi^0}$	$\eta'_{\eta\pi\pi} \rho^+$
Multiplicative errors (%)					
Track multiplicity [C]	1.0	1.0	1.0	1.0	1.0
Tracking effi ciency [C]	5.9*	6.1 *	3.9	4.1	4.0
π^0/$\eta_{\gamma\gamma}$/γ eff [C]	3.0	1.8	6.0	4.8	6.0
Number $B\overline{B}$ [C]	1.1	1.1	1.1	1.1	1.1
$\cos\theta_T$ [C]	0.5	1.3	0.5	1.3	0.5
Branching fractions [U]	3.4	3.4	3.4	3.4	3.4
MC statistics [U]	0.6	0.6	0.8	0.9	0.7
Total multiplicative (%)	7.6	7.5	8.1	7.5	8.2
Additive errors (events)					
Signal model [U]	± 0.35	± 1.1	± 0.13	± 1.6	± 1.6
Fit bias [U]	± 0.45	± 1.5	± 0.54	± 1.3	± 6.8
$B\overline{B}$ background [U]	$+0.2$	$+1.9$	$+0.3$	$+17$	$+20$
Total additive (events)	${}^{+0.60}_{-0.57}$	${}^{+2.7}_{-1.9}$	${}^{+0.63}_{-0.55}$	${}^{+17}_{-1.6}$	${}^{+21}_{-7.0}$
Total errors [$\mathcal{B}(10^{-6})$]					
Total Additive	${}^{+0.36}_{-0.34}$	${}^{+1.1}_{-0.74}$	${}^{+0.45}_{-0.40}$	${}^{+9.4}_{-0.88}$	${}^{+3.8}_{-1.3}$
Uncorrelated	${}^{+0.42}_{-0.40}$	${}^{+1.1}_{-0.76}$	${}^{+0.46}_{-0.41}$	${}^{+9.4}_{-0.88}$	${}^{+3.8}_{-1.3}$
Correlated	± 0.42	± 0.31	± 0.27	± 0.19	± 0.5

Log likelihood scan plots



$B^0 \to \eta' f_0(\to \pi^+\pi^-)$

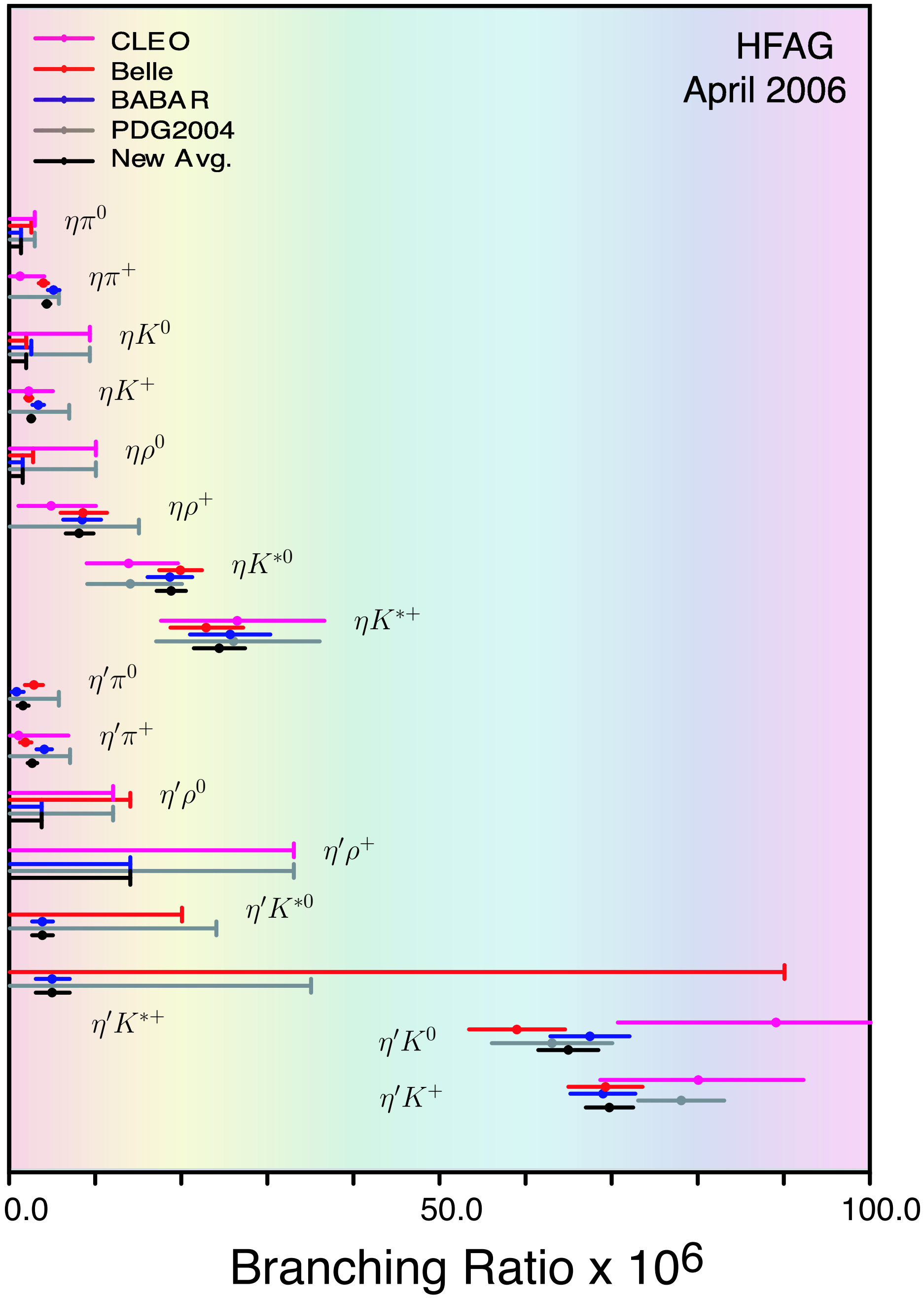


Comparison to predictions

- Central values agree well with QCD factorisation predictions
- Also agree with SU(3) numbers
- As expected $B^0 \to \eta' \rho^0$ is probably very small
- New upper limit for $B^0 \to \eta' f_0(\to \pi^+\pi^-)$

Decay mode	Theoretical predictions		Experimental results					
	SU(3) flavour	QCD fact.	HFAG	BaBar	Belle	**New results**		
$B^0 \to \eta' K^{*0}$	$3.0^{+1.2}_{-0.3}$	$3.9^{+9.2}_{-5.1}$	< 7.6	< 7.6	< 20	$3.8^{+1.1}_{-1.0}{}^{+0.5}_{-0.4}$	$(4.5\,\sigma)$	
$B^+ \to \eta' K^{*+}$	$2.8^{+1.2}_{-0.3}$	$5.1^{+10.3}_{-\ 5.9}$	< 14	< 14	< 90	$4.9^{+1.9}_{-1.7}{}^{+0.8}_{-0.7}$	$(3.6\,\sigma)$	< 7.9
$B^0 \to \eta' \rho^0$	$0.07^{+0.10}_{-0.05}$	$0.01^{+0.12}_{-0.06}$	< 4.3	< 4.3	< 14	$0.4^{+1.2}_{-0.9}{}^{+1.6}_{-0.6}$	$(0.3\,\sigma)$	< 3.7
$B^+ \to \eta' \rho^+$	$4.9^{+0.7}_{-0.7}$	$6.3^{+4.0}_{-3.3}$	< 22	< 22	–	$6.8^{+3.2}_{-2.9}{}^{+3.9}_{-1.3}$	$(2.3\,\sigma)$	< 14
$B^0 \to \eta' f_0(\to \pi^+\pi^-)$			–	–	–	$0.1^{+0.6}_{-0.4}{}^{+0.9}_{-0.4}$	$(0.2\,\sigma)$	< 2.0

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



Conclusions

- Measurement of $\eta' K^{*0}$ and evidence for $\eta' K^{*+}$
- New upper limits for $B^0 \to \eta' \rho^0$ and $B^+ \to \eta' \rho^+$
- Level of $B \to \eta' K$ enhancement wrt. $B \to \eta' K^*$

	Decay mode $\mathcal{B}(10^{-6})$			
	η'		η	
K^*	$B^0 \to \eta' K^{*0}$	$3.8^{+1.1+0.5}_{-1.0-0.4}$ $(4.5\,\sigma)$	$B^0 \to \eta K^{*0}$	18.7 ± 1.7
	$B^+ \to \eta' K^{*+}$	$4.9^{+1.9+0.8}_{-1.7-0.7}$ $(3.6\,\sigma)$	$B^+ \to \eta K^{*+}$	$24.3^{+3.0}_{-2.9}$
K	$B^0 \to \eta' K^0$	63.2 ± 3.3	$B^0 \to \eta K^0$	< 1.9
	$B^+ \to \eta' K^+$	69.4 ± 2.7	$B^+ \to \eta K^+$	2.5 ± 0.3