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

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(for the Belle Collaboration)

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Outline

- Introduction
- Experiment / Analysis overview

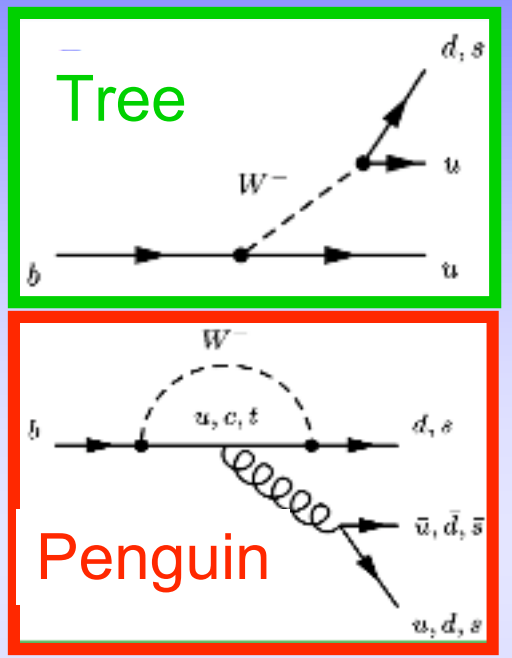
- Results
  - ηK^+ , ηK^0 **update with 500 fb^{-1}**
  - $\eta \pi^+$ **update with 500 fb^{-1}**
  - ηK^{*+}, ηK^{*0} **update with 414 fb^{-1}**
  - $\eta \rho^+$, $\eta \rho^0$ **414 fb^{-1}**
  - η' h* with h*= ρ+, ρ0, ϕ, η, η' or ω **500 fb^{-1}**

- Summary

Introduction

- Charmless two-body B decays
  ⇒ B decay dynamics, CP violation

- Decay amplitudes dominated by
  - b → u Tree (T) CKM suppressed (|Vub|<<|Vcb|)
  - b → d,s Penguin (P) loop suppressed



- Interference b/w two decay amplitudes T and P
  ⇒ Direct CPV:

$$A_{CP} \equiv \frac{\Gamma(\bar{B} \to \bar{f}) - \Gamma(B \to f)}{\Gamma(\bar{B} \to \bar{f}) + \Gamma(B \to f)} = \frac{2r \sin\phi \sin\delta}{1 + r^2 + 2r \cos\phi \cos\delta}, \; r = \frac{|P|}{|T|}$$

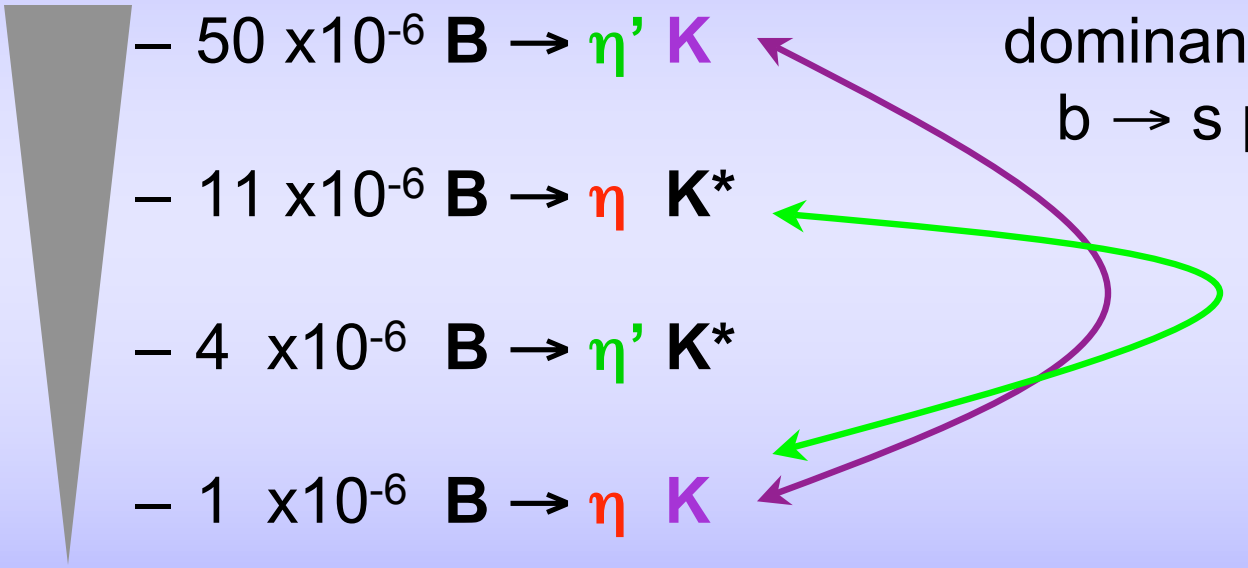
- Large CPV:
  - expected in SM for decays with similar T and P contributions
  - possible through New Physics

Introduction

- Flavour singlet penguin
- Ratio charged / neutral
  ⇒ additonal SU(3) singet contribution ?
- Close to theory expectations for unobserved decays
- New physics effects possible

Introduction

- Theory expectation: Nucl.Phys. B675:333-415 (2003)



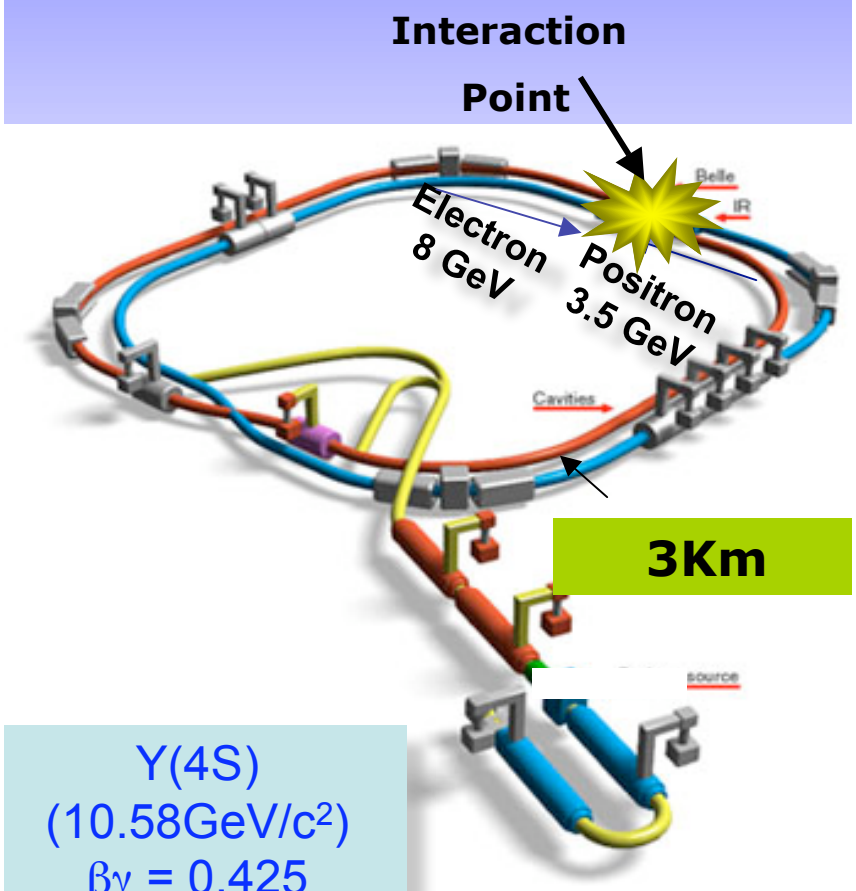
dominant, mixing enhanced
b → s penguin dominant

Charm/non-charm
Interference η

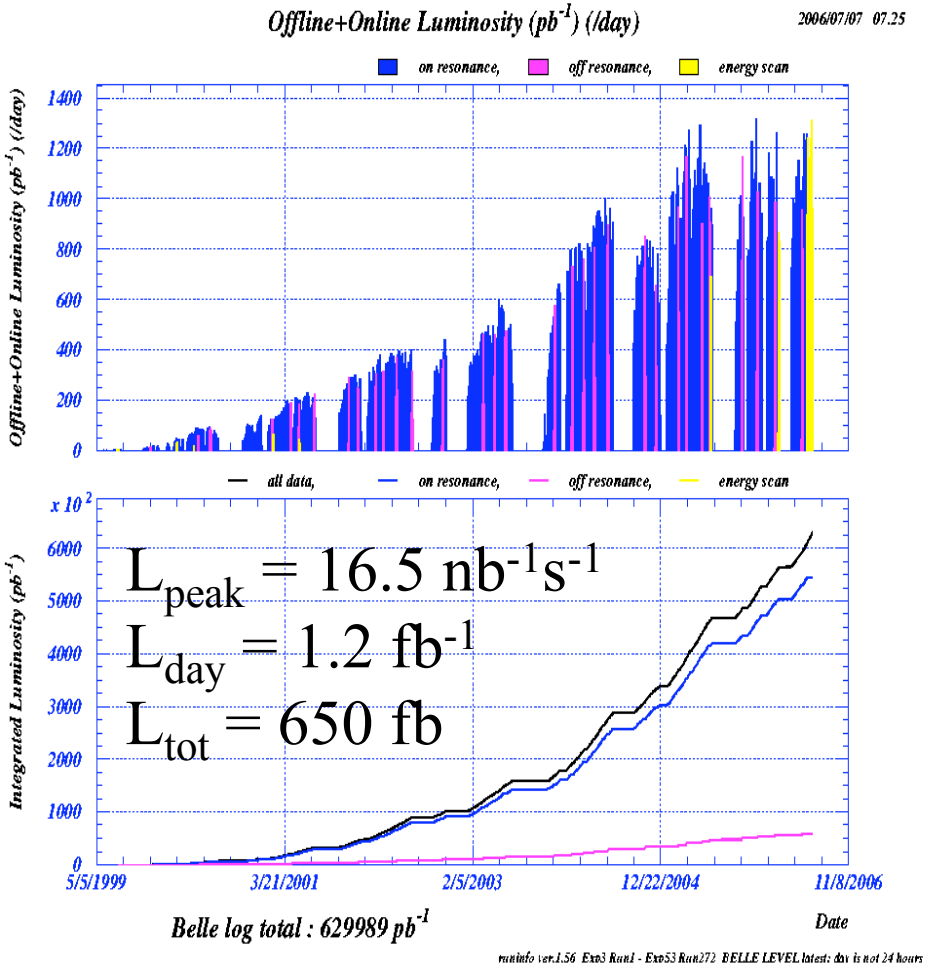
9x10^{-6} B→η ρ^+
6x10^{-6} B→η'ρ^+
5x10^{-6} B→η π^+
3x10^{-6} B→η'π^+

charged > neutral → additional SU(3)
singlet contrib. ?

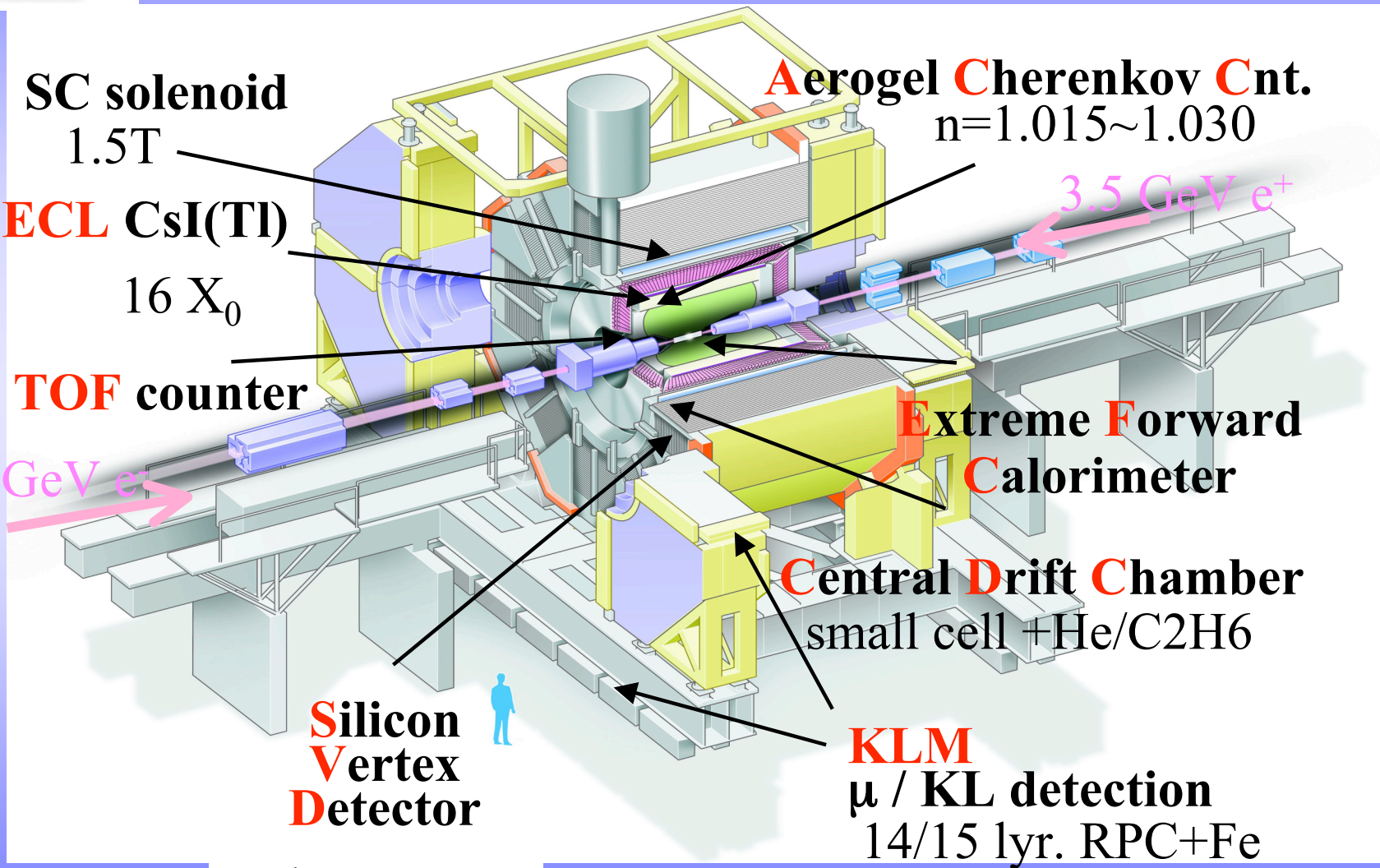
KEKB



Y(4S)
(10.58GeV/c²)
βγ = 0.425



Belle Detector



B reconstruction

$B \to \eta \pi^+$

Two kinematic variables:

$$M_{bc} = \sqrt{(E^*_{beam})^2 - p^2_B}$$

or

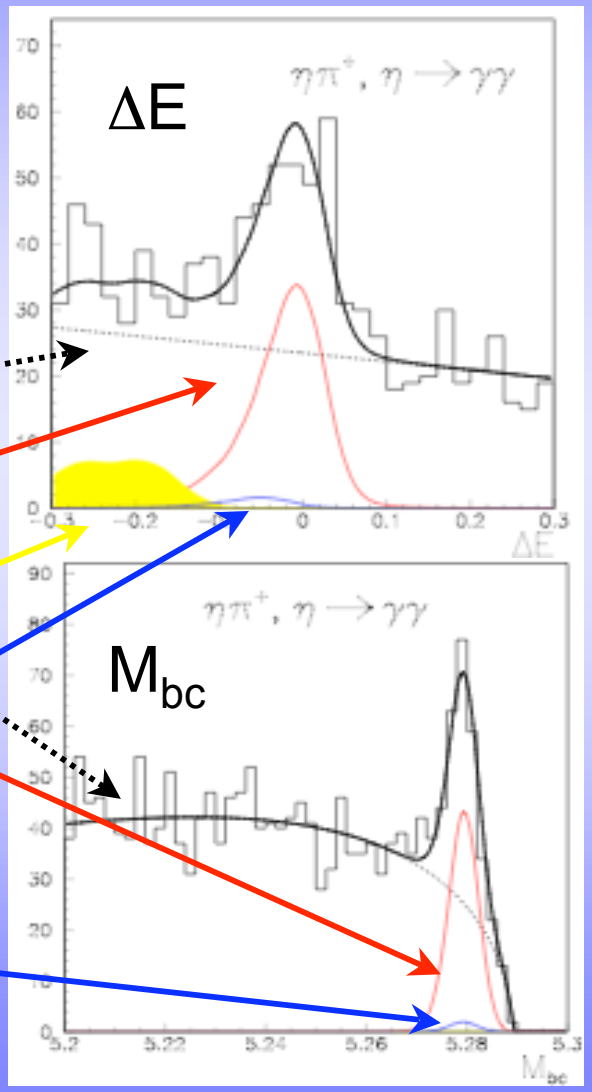
$$\Delta E = E_B - E^*_{beam}$$

Continuum background (dominant)

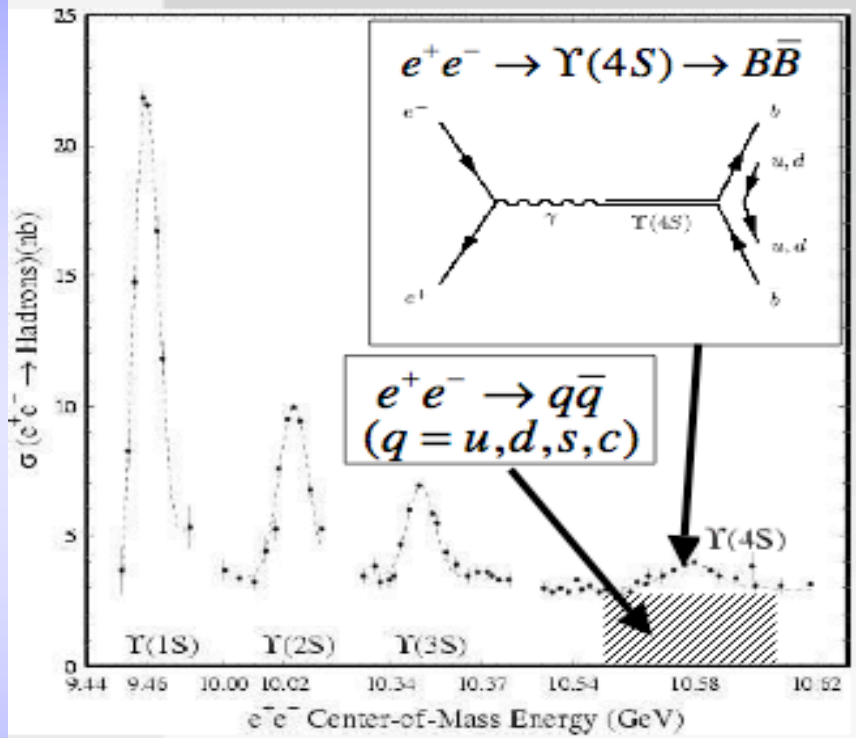
Signal events

Rare B decays (well understood)

K/π reflection (PID)

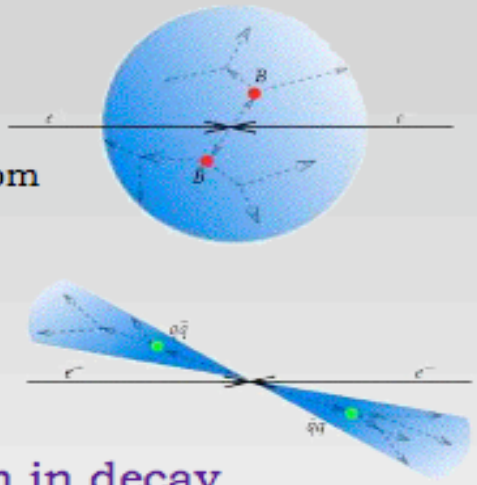


Background suppression



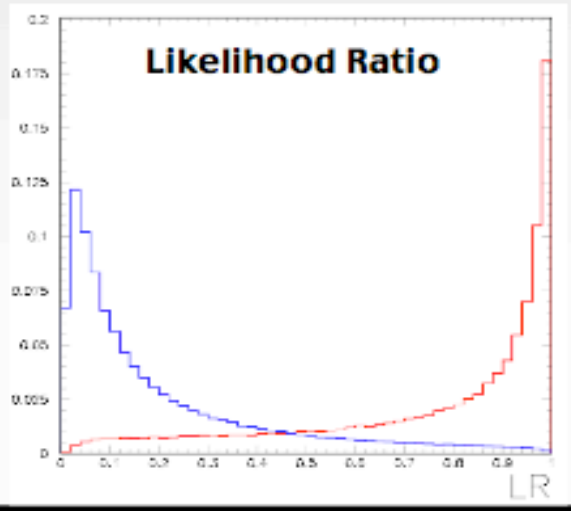
➔ **Event topology**

Fisher discriminant from modified Fox-Wolfram moments.



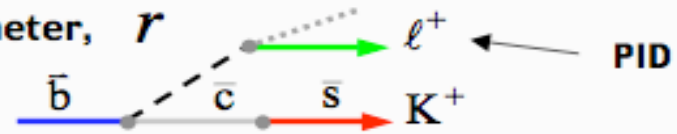
➔ **J^P conservation in decay**

B flight direction variable, $\cos\theta_B$



➔ **B-flavour tagging information**

Tag quality parameter, r



Results

$B \to \eta\, h$

ηK: $b \to s$ penguin, $b \to u$ tree

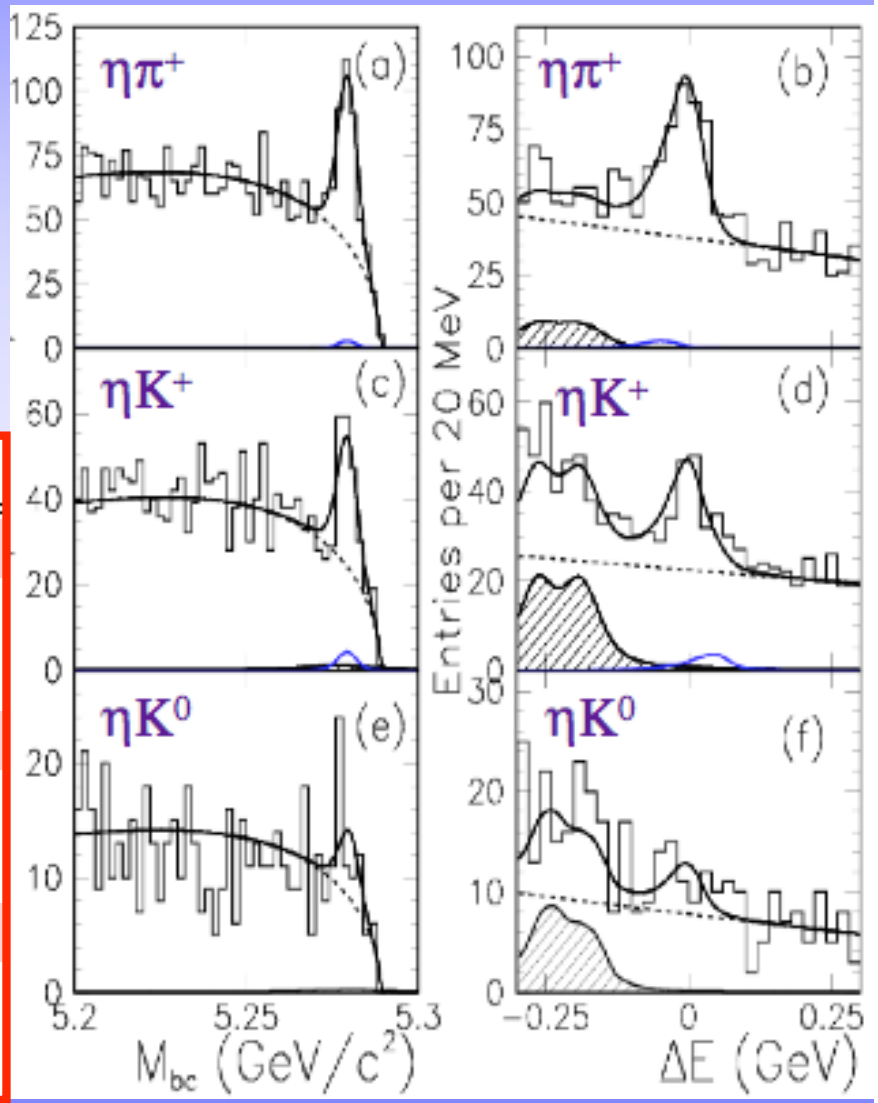
$\eta\pi$: $b \to u$ tree, ($b \to d$ penguin)

$B \to \eta h$

535 Mio $B\bar{B}$

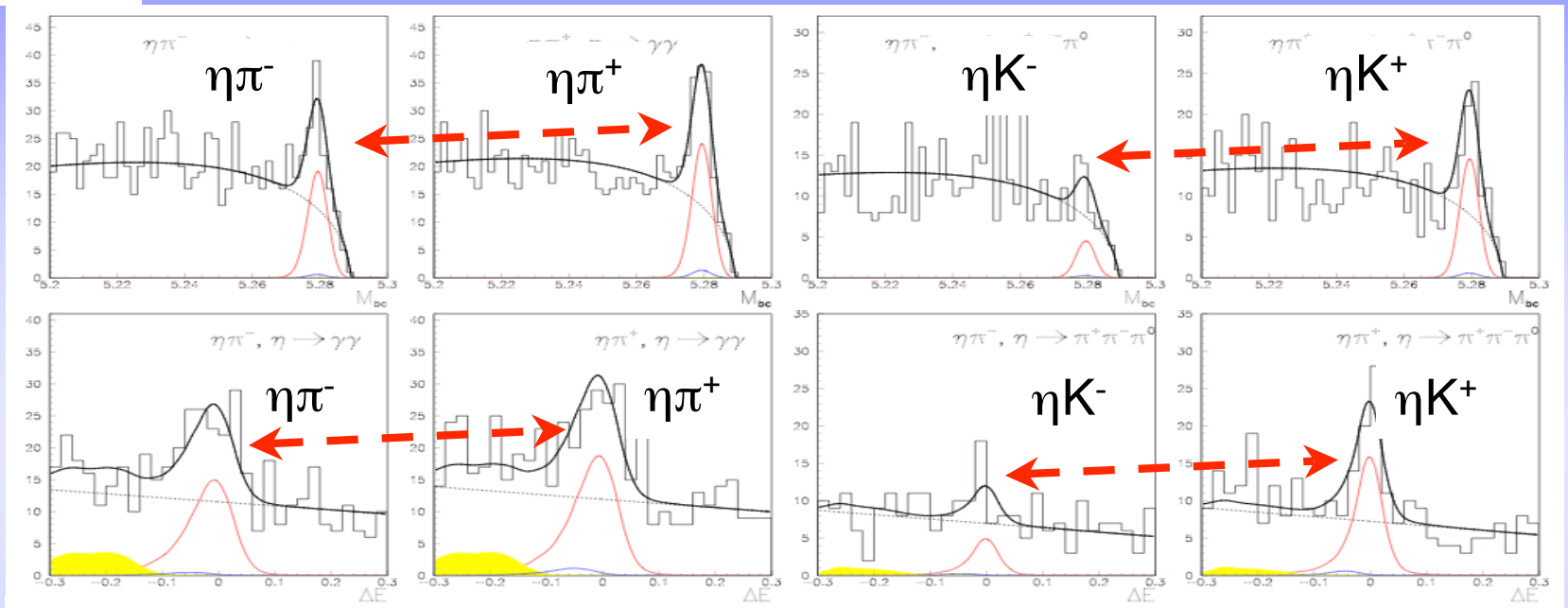
- Unbined max. likelihood fit to (ΔE,M_b)
- $\eta \to \gamma\gamma$ / $\eta \to \pi^+\pi^-\pi^0$ decays

Mode	$\epsilon(\%)$	Yield	Sig.	$\mathcal{B}(10^{-6})$	UL(10^{-6})
$B^\pm \to \eta\pi^\pm$			15.0	$4.2 \pm 0.4 \pm 0.2$	
$\eta_{\gamma\gamma}\pi^\pm$	8.32	$182.7^{+20.2+4.8}_{-19.5-5.4}$	12.1	$4.1^{+0.5}_{-0.4} \pm 0.2$	
$\eta_{3\pi}\pi^\pm$	3.11	$73.1^{+12.6+2.2}_{-11.8-2.6}$	8.8	$4.4^{+0.8}_{-0.7} \pm 0.3$	
$B^\pm \to \eta K^\pm$			8.1	$1.9 \pm 0.3^{+0.2}_{-0.1}$	
$\eta_{\gamma\gamma}K^\pm$	7.29	$71.7^{+14.3+4.4}_{-13.4-3.1}$	6.5	$1.9^{+0.4}_{-0.3} \pm 0.1$	
$\eta_{3\pi}K^\pm$	2.66	$28.8^{+8.4}_{-7.6} \pm 1.8$	4.9	$2.0^{+0.6}_{-0.4} \pm 0.2$	
$B^0 \to \eta K^0$			2.9	$1.1 \pm 0.4 \pm 0.1$	< 1.9
$\eta_{\gamma\gamma}K^0$	2.68	$16.4^{+8.4}_{-7.7} \pm 1.0$	2.6	$1.1^{+0.6}_{-0.5} \pm 0.1$	< 2.2
$\eta_{3\pi}K^0$	1.01	$4.6^{+4.6}_{-3.7} \pm 0.3$	1.2	$0.9^{+0.9}_{-0.7} \pm 0.1$	< 2.4



$B \to \eta h$ A_{CP}

535 Mio $B\bar{B}$



Mode	A_{CP}
$B^\pm \to \eta\pi^\pm$	$-0.23 \pm 0.09 \pm 0.02$
$\eta_{\gamma\gamma}\pi^\pm$	$-0.11 \pm 0.11 \pm 0.01$
$\eta_{3\pi}\pi^\pm$	$-0.52 \pm 0.16 \pm 0.02$
$B^\pm \to \eta K^\pm$	$-0.39 \pm 0.16 \pm 0.03$
$\eta_{\gamma\gamma}K^\pm$	$-0.30 \pm 0.19 \pm 0.02$
$\eta_{3\pi}K^\pm$	$-0.55^{+0.27+0.05}_{-0.28-0.04}$

2.5 σ from zero

2.4 σ from zero

Need more statistics

$B \to \eta\, h^*$

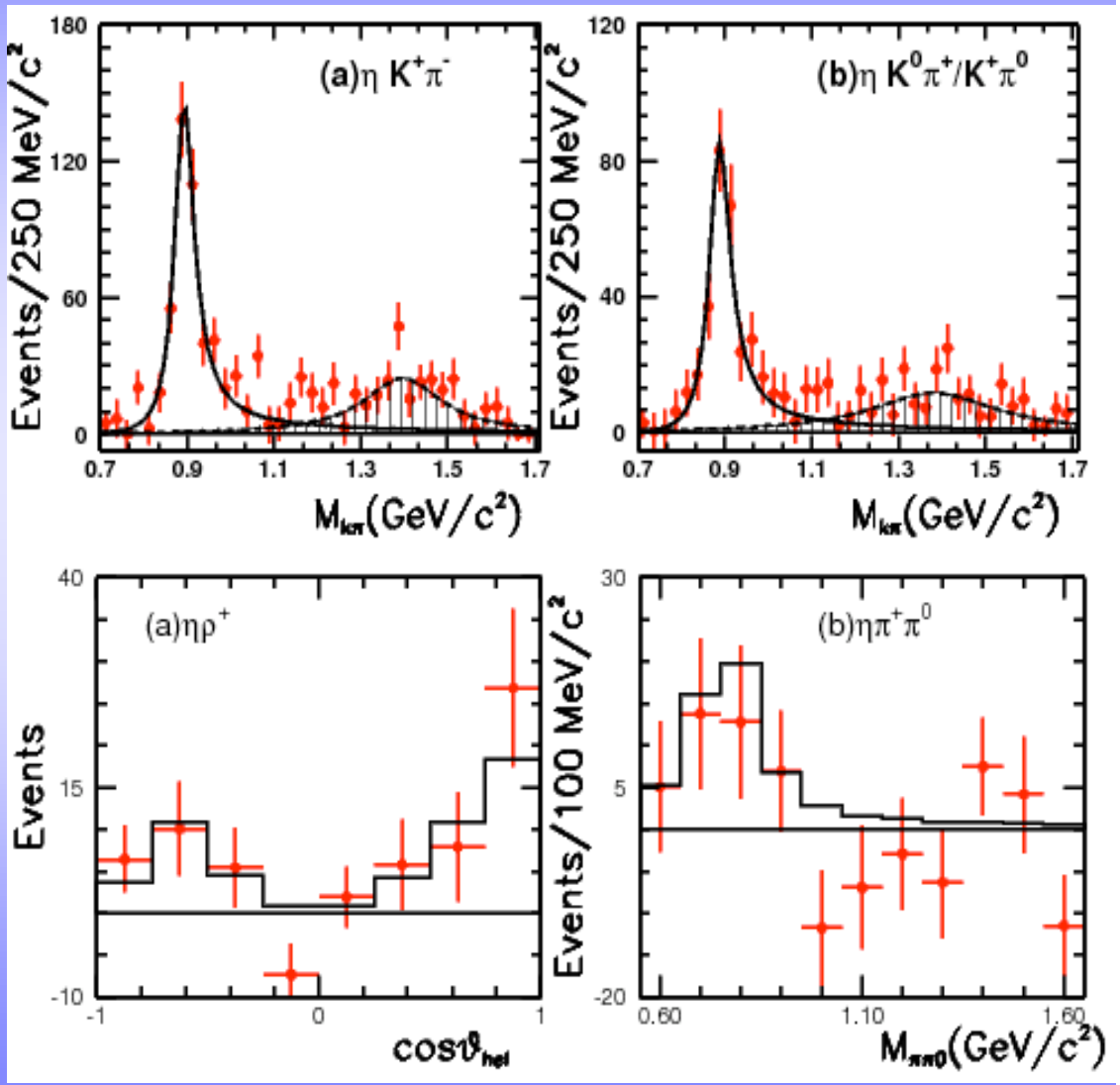
ηK^*: b→s penguin

$\eta\rho$: b→u tree

K* purity / ρ consistent

- Study non K* resonant behaviour
- Scan wide mass range
- Correct branching fraction

- Clear ρ helicity sturcture
- Consitent with expectation
- No significant non-resonant contribution

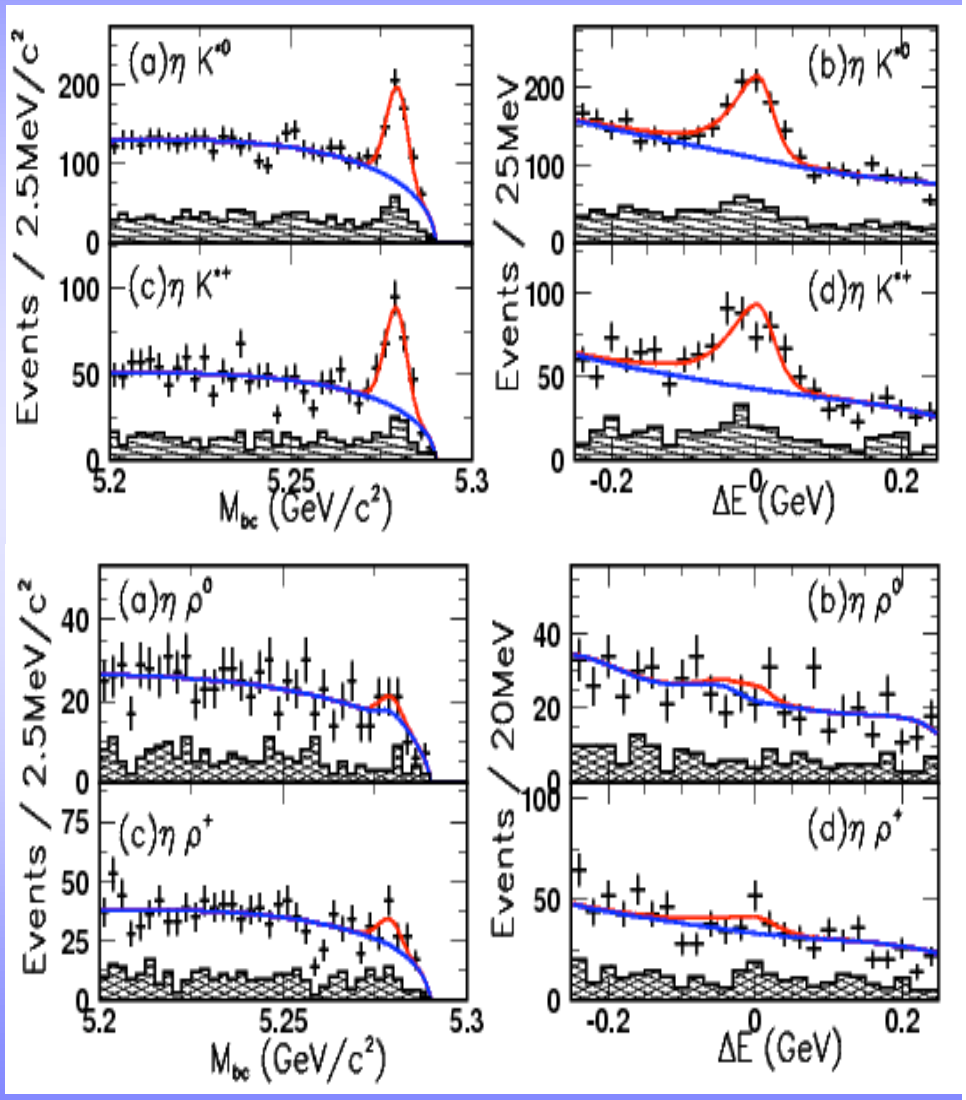


$B \to \eta h^*$

449 Mio $B\bar{B}$

- Unbined max. likelihood fit to (ΔE,M_b)
- $\eta \to \gamma\gamma$ / $\eta \to \pi^+\pi^-\pi^0$ decays
- $K^{*0} \to K^0\pi^0$ / $K^{*0} \to K^+\pi^-$

Mode	N_S	$\epsilon(\%)$	Σ	$\mathcal{B}(10^{-6})$
$\eta_{\gamma\gamma}K^{*0}_{K^+\pi^-}$	$336.2^{+30.1}_{-29.2}$	16.9	14.2	$16.9^{+1.5}_{-0.9}$
$\eta_{\pi\pi\pi^0}K^{*0}_{K^+\pi^-}$	$93.4^{+14.6}_{-13.8}$	9.8	8.7	$14.1^{+2.2}_{-2.1}$
$\eta_{\gamma\gamma}K^{*0}_{K^0\pi^0}$	$20.1^{+7.5}_{-6.7}$	2.1	3.6	$16.7^{+6.3}_{-5.6}$
$\eta_{\pi\pi\pi^0}K^{*0}_{K^0\pi^0}$	$9.5^{+5.0}_{-4.2}$	1.3	2.6	$21.6^{+11.5}_{-9.7}$
ηK^{*0}	-	-	17.1	16.1 ± 1.2
$\eta_{\gamma\gamma}K^{*+}_{K^+\pi^0}$	$79.8^{+16.1}_{-15.3}$	6.7	6.1	$20.1^{+4.1}_{-3.9}$
$\eta_{\pi\pi\pi^0}K^{*+}_{K^+\pi^0}$	$24.1^{+8.7}_{-7.9}$	4.2	3.5	$17.0^{+6.1}_{-5.6}$
$\eta_{\gamma\gamma}K^{*+}_{K^0\pi^+}$	$120.3^{+16.2}_{-15.4}$	4.5	10.1	$22.6^{+3.1}_{-2.9}$
$\eta_{\pi\pi\pi^0}K^{*+}_{K^0\pi^+}$	$29.2^{+7.3}_{-6.6}$	2.6	6.2	$17.0^{+4.8}_{-3.8}$
ηK^{*+}	-	-	13.8	$20.3^{+2.0}_{-1.9}$
$\eta_{\gamma\gamma}\rho^0$	$19.5^{+11.3}_{-10.4}$	8.9	2.1	$1.25^{+0.73}_{-0.67}$
$\eta_{\pi\pi\pi^0}\rho^0$	$0.9^{+4.6}_{-3.9}$	5.5	0.2	$0.17^{+0.84}_{-0.66}$
$\eta\rho^0$	-	-	1.6	$0.84^{+0.56}_{-0.51}$ (< 1.5)
$\eta_{\gamma\gamma}\rho^+$	$38.1^{+16.1}_{-15.2}$	5.5	2.6	$3.9^{+1.7}_{-1.6}$
$\eta_{\pi\pi\pi^0}\rho^+$	$15.8^{+8.9}_{-8.0}$	3.50	2.1	$4.4^{+2.5}_{-2.2}$
$\eta\rho^+$	-	-	3.4	$4.1^{+1.4}_{-1.3}$



$B \to \eta h^*$ A_{CP}

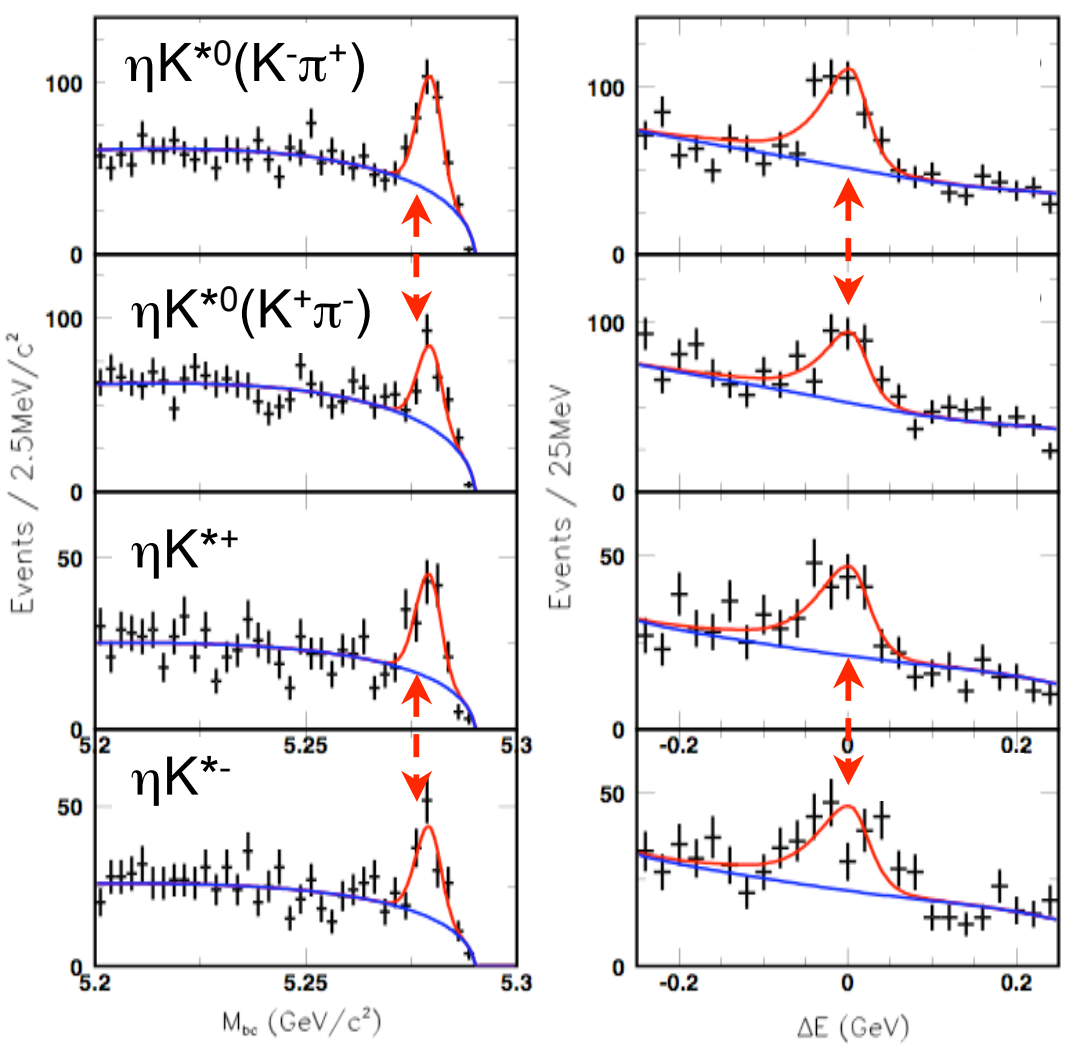
- Consistent with no A_{CP} asymmetry
- Consistent with SM

ηK^{*0}	$\mathcal{A}_{cp}$	$\mathcal{A}_{cp,qq}$
$\eta_{2\gamma}$	0.21 ± 0.09	-0.023 ± 0.089
$\eta_{3\pi}$	-0.06 ± 0.15	-0.025 ± 0.015
$\eta K^{*+}_{K^+\pi^0}$	$\mathcal{A}_{cp}$	$\mathcal{A}_{cp,qq}$
$\eta_{2\gamma}$	-0.04 ± 0.19	-0.019 ± 0.020
$\eta_{3\pi}$	0.37 ± 0.33	-0.043 ± 0.031
$\eta K^{*+}_{K^-\pi^+}$	$\mathcal{A}_{cp}$	$\mathcal{A}_{cp,qq}$
$\eta_{2\gamma}$	-0.08 ± 0.13	-0.012 ± 0.020
$\eta_{3\pi}$	0.28 ± 0.23	0.035 ± 0.036
$\eta\rho^+$	$\mathcal{A}_{cp}$	$\mathcal{A}_{cp,qq}$
$\eta_{2\gamma}$	$-0.36^{+0.41}_{-0.48}$	-0.030 ± 0.017
$\eta_{3\pi}$	$0.55^{+0.78}_{-0.53}$	-0.023 ± 0.027

$$\mathcal{A}_{cp}(\eta K^{*0}) = 0.174 \pm 0.076 \pm 0.01,$$

$$\mathcal{A}_{cp}(\eta K^{*+}) = 0.032 \pm 0.095 \pm 0.01,$$

$$\mathcal{A}_{cp}(\eta \rho^+) = -0.040^{+0.34}_{-0.32} \pm 0.01.$$



$B \rightarrow \eta' h$

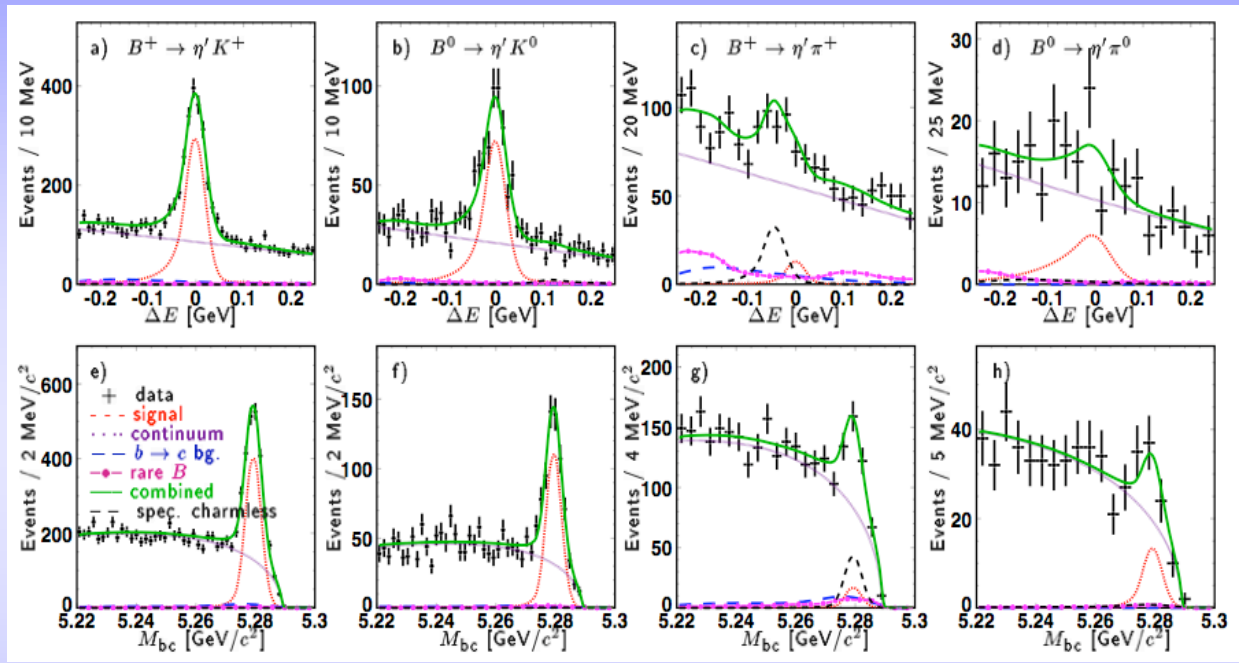
(published, PRL 97,061802)

$\eta'K$: b→s penguin

$\eta'\pi$: b→u tree

$B \to \eta' h$

- $\eta' \to \eta\pi^+\pi^-$ / $\eta' \to \rho\gamma$ decays
- Extended unbinned likelihood fit
- **First evidence of $B \to \eta' \pi^0$**
- A_{CP} included in fit



	$B^+ \to \eta' K^+$	$B^0 \to \eta' K^0$	$B^+ \to \eta' \pi^+$	$B^0 \to \eta' \pi^0$
N_S	1895.7 ± 59.5	515.3 ± 31.7	39.0 ± 13.2	35.8 ± 12.7
N_{tot}	25281	6044	8411	1345
$\mathcal{B}[10^{-6}]$	$69.2 \pm 2.2 \pm 3.7$	$58.9^{+3.6}_{-3.5} \pm 4.3$	$1.76^{+0.67+0.15}_{-0.62-0.14}$	$2.79^{+1.02+0.25}_{-0.96-0.34}$
A_{CP}	$0.028 \pm 0.028 \pm 0.021$	—	$0.20^{+0.37}_{-0.36} \pm 0.04$	—
σ	> 10	> 10	3.2	3.1

$B \rightarrow \eta' h^*$

$\eta'K^*$: b→s penguin

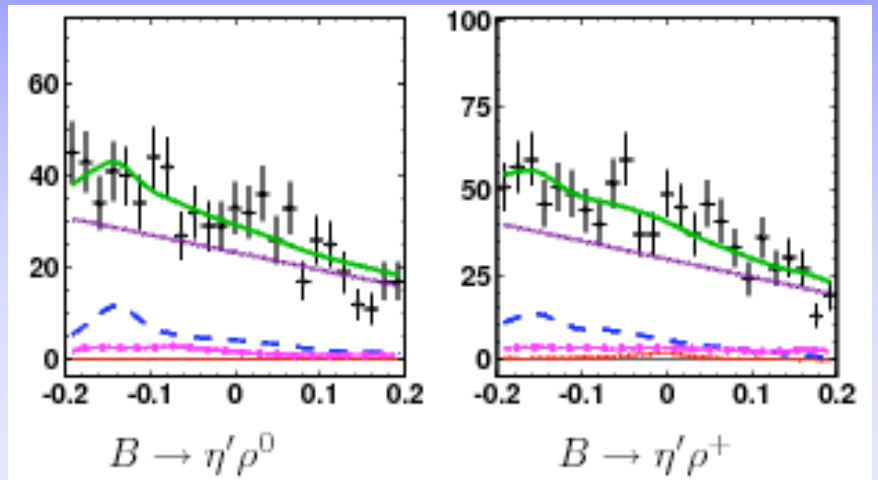
$\eta'\rho$: b→u tree

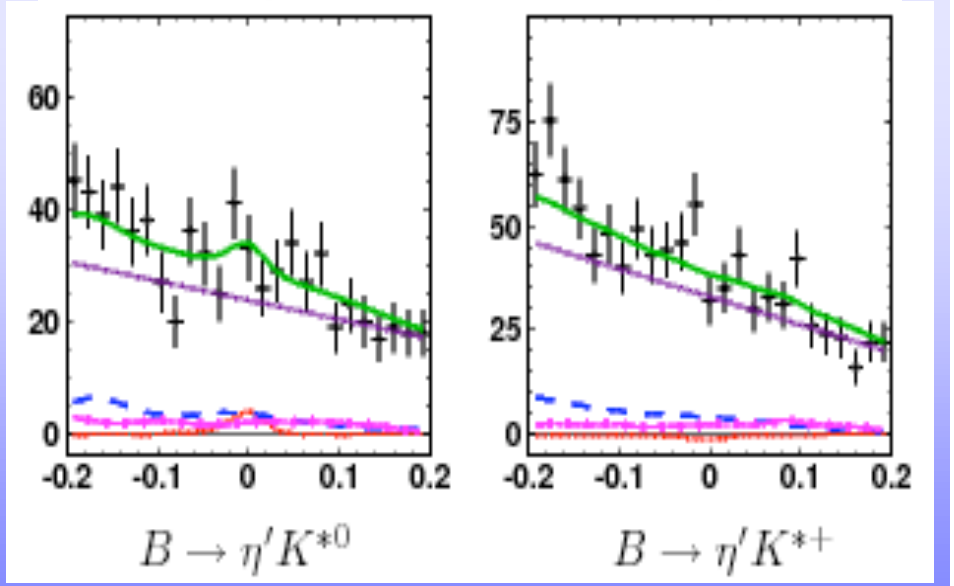
$B \to \eta' h^*$

535 Mio $B\bar{B}$

- $\eta' \to \eta\pi^+\pi^-$ / $\eta' \to \rho\gamma$ decays
- No significant signal
- Extended unbinned likelihood fit
- 90% conf. level UL

	N_S	Upper limit ($\times 10^{-6}$)
$B \to \eta' \rho^0$	$0.1^{+8.2}_{-7.0}$	1.26
$B \to \eta' \rho^+$	$18.5^{+23.3}_{-21.7}$	4.7
$B \to \eta' K^{*0}$	$14.2^{+9.1}_{-8.0}$	2.6
$B \to \eta' K^{*+}$	$-6.4^{+10.9}_{-7.9}$	2.8





$B \to \eta' h^*$

$\eta\phi$: A tree, penguin A

$\eta'\eta$: b→d penguin, C b→u tree

$\eta'\eta'$: b→d penguin, C b→u tree

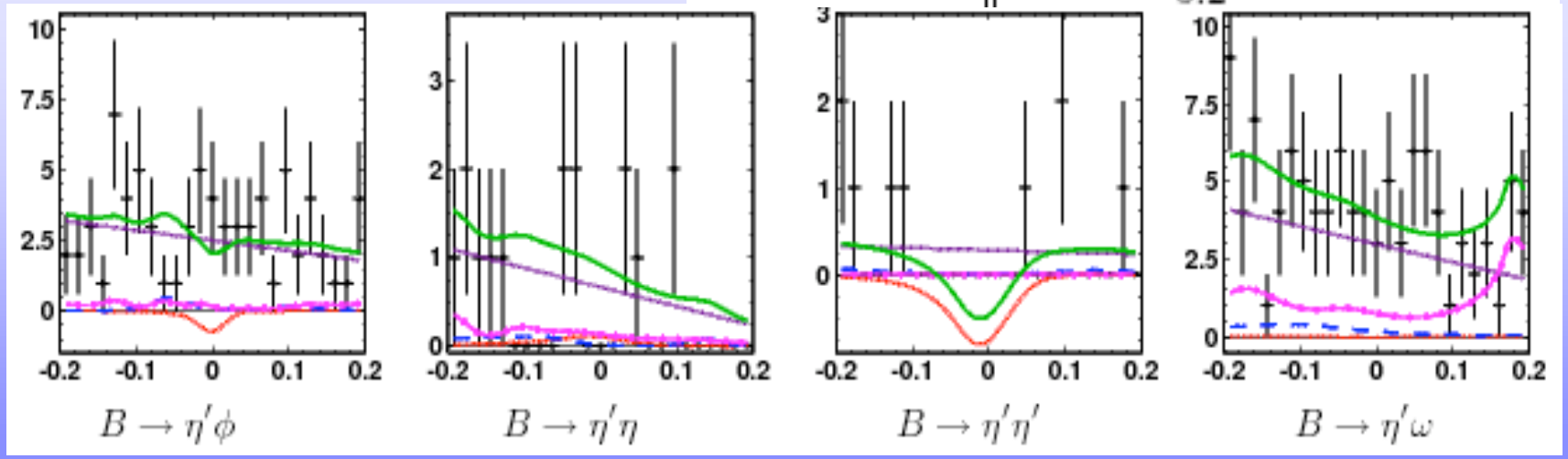
$\eta'\omega$: C b→u tree

$B \to \eta' h^*$

535 Mio $B\bar{B}$

- $\eta' \to \eta\pi^+\pi^-$ / $\eta' \to \rho\gamma$ decays
- No significant signal
- Extended unbinned likelihood fit
- 90% conf. level UL

	N_S	Upper limit $(\times 10^{-6})$
$B \to \eta'\phi$	$-2.4^{+2.5}_{-3.5}$	0.5
$B \to \eta'\eta$	$1.0^{+4.6}_{-3.6}$	4.0
$B \to \eta'\eta'$	$-6.3^{+2.2}_{-2.1}$	7.7
$B \to \eta'\omega$	$0.9^{+6.3}_{-5.2}$	2.2



Hirachy of η/η' h(*)

	Exp. (Belle) [10^{-6}]	Theory (Nucl.Phys. B675:333-415)
• B → η' K^+/K^0	69 / 59	49 / 47
• B → η K^{*+}/K^{*0}	20 / 16	11 / 11
• B → η π^+/π^0	4 / --	5 / 0.3
• B → η' π^+/π^0	2 / 3	3 / 0.2
• B → η K^+/K^0	2 / 1	2 / 1
• B → η' K^{*+}/ K^{*0}	<3 / <3	5 / 4
• B → η ρ^+/ρ^0	4 / <1.5	9 / 0.03
• B → η' ρ^+/ρ^0	<4 / <1	6 / 0.01
• B → η' other	< 4	< 0.4

Conclusion

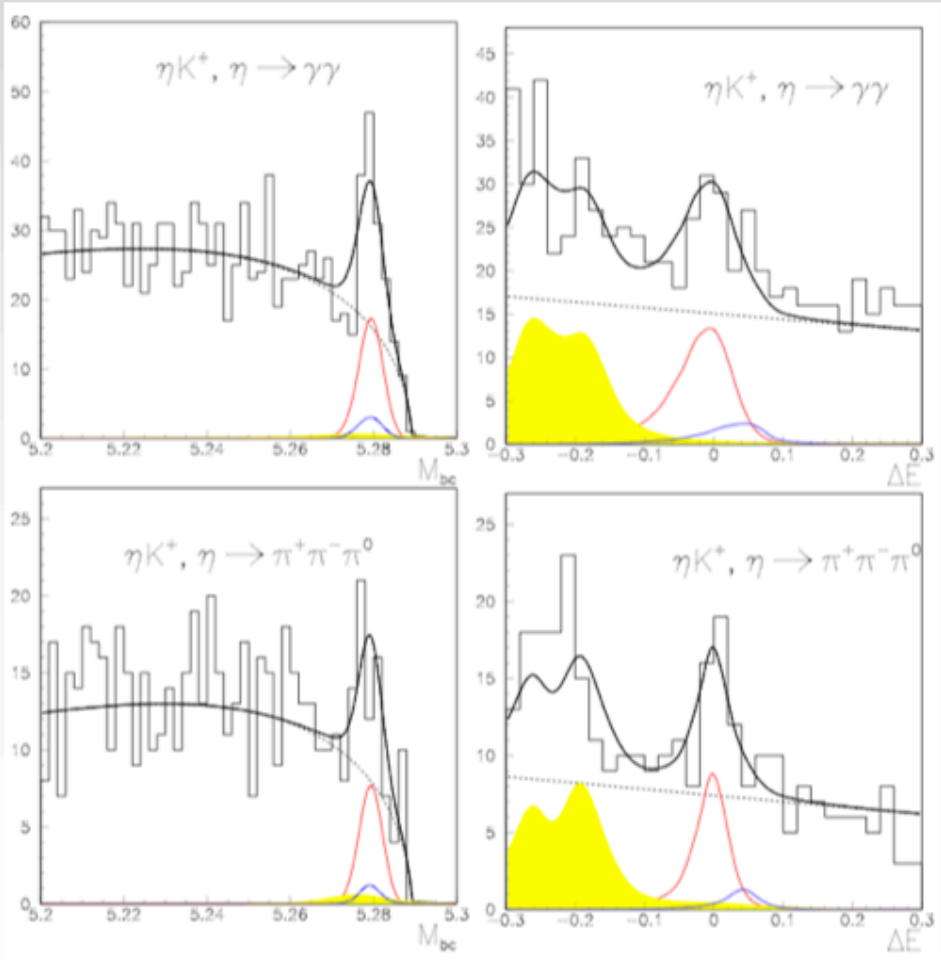
- Updated results for $B \to \eta K$ and $B \to \eta \pi$
- Updated result for $B \to \eta K^*$
- First evidence of $B \to \eta \rho$
- New upper limits for $B \to \eta' h^*$
- Now (nearly complete) $B \to \eta^{(')} h^{(*)}$ information available from Belle with $> 414\ fb^{-1}$
- Good situation to study penguin and singlet contributions

Backup

B → η' K⁺ breakdown

TABLE VII: Results of likelihood fit for $B^{\pm} \to \eta K^{\pm}$

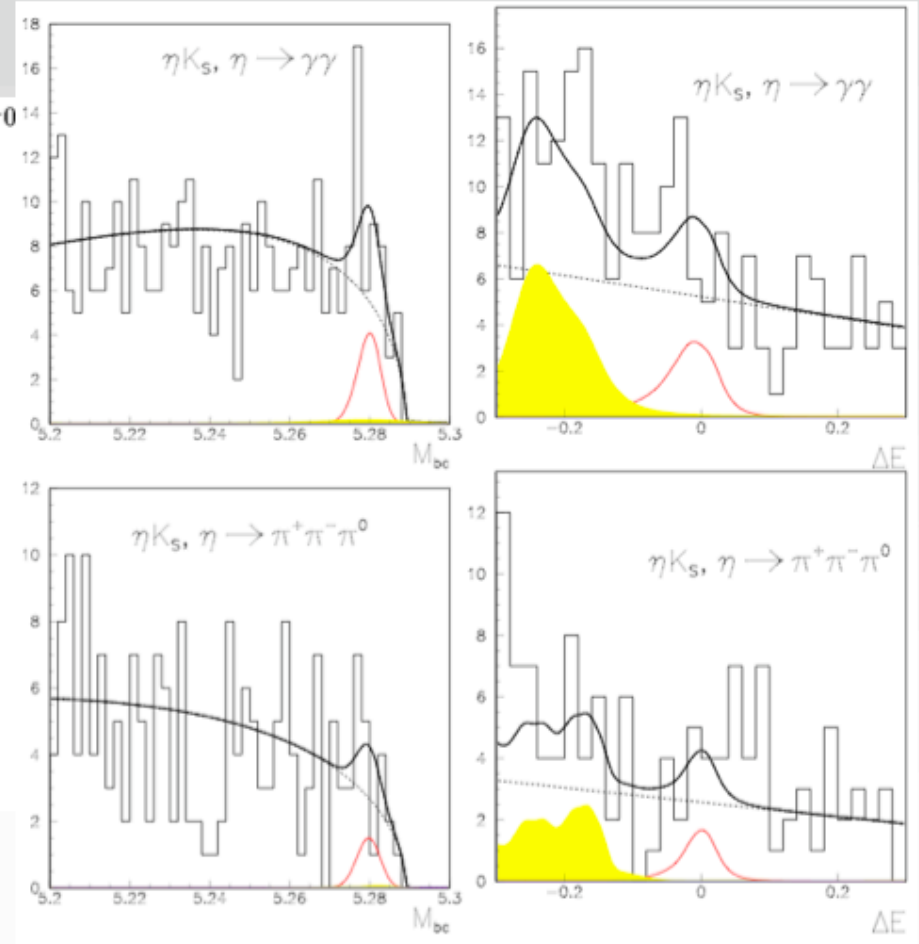
Mode	Yield	Eff.	Sig.	$\mathcal{B}$ (10^{-6})	A_{CP}
$\gamma\gamma$	$71.7^{+14.3}_{-13.4}$	-	6.9	$1.85^{+0.37}_{-0.34}$	$-0.298^{+0.188}_{-0.191}$
SVDI	$26.6^{+7.6}_{-6.8}$	7.17%	–	–	–
SVDII	$45.1^{+12.1}_{-11.6}$	7.34%	–	–	–
$\pi^+\pi^-\pi^0$	$28.8^{+8.4}_{-7.6}$	-	5.1	$2.02^{+0.59}_{-0.54}$	$-0.549^{+0.273}_{-0.276}$
SVDI	$9.3^{+4.6}_{-3.8}$	2.72%	–	–	–
SVDII	$19.5^{+7.1}_{-6.6}$	2.64%	–	–	–



B → η' K^0 breakdown

TABLE IX: Results of likelihood fit for $B^0 \to \eta K^0$

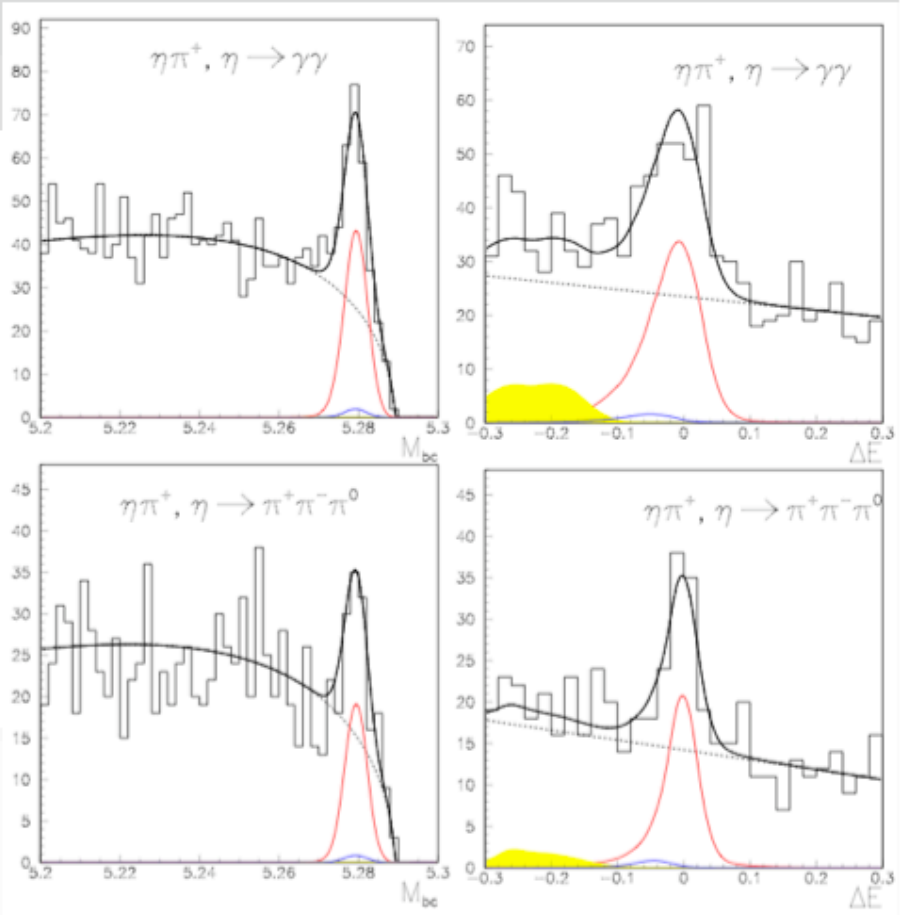
Mode	Yield	Eff.	Sig.	$\mathcal{B}$ (10^{-6})
$\gamma\gamma$	$16.4^{+8.4}_{-7.5}$	–	2.7	$1.1^{+0.6}_{-0.5}$
SVDI	$0.4^{+4.3}_{-3.3}$	2.60%	-	–
SVDII	$16.0^{+7.3}_{-6.8}$	2.71%	–	–
$\pi^+\pi^-\pi^0$	$4.6^{+4.6}_{-3.7}$	-	1.3	$0.9^{+0.9}_{-0.7}$
SVDI	$1.2^{+2.6}_{-1.7}$	1.05%	–	–
SVDII	$3.4^{+3.8}_{-3.3}$	0.99%	–	–
Combined	-	-	2.1	0.9 ± 0.6



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

TABLE IV: Results of likelihood fit for $B^\pm \to \eta\pi^\pm$

Mode	Yield	Eff.	Sig.	$\mathcal{B}$ (10^{-6})	A_{CP}
$\gamma\gamma$	$182.7^{+20.2}_{-19.5}$	–	12.1	$4.12^{+0.46}_{-0.44}$	-0.114 ± 0.106
SVDI	$55.7^{+10.6}_{-9.9}$	8.23%	–	–	–
SVDII	$127.0^{+17.2}_{-16.8}$	8.36%	–	–	–
$\pi^+\pi^-\pi^0$	$73.1^{+12.6}_{-11.8}$	–	8.8	$4.42^{+0.76}_{-0.69}$	-0.527 ± 0.162
SVDI	$16.3^{+6.1}_{-5.2}$	3.17%	–	–	–
SVDII	$56.9^{+11.0}_{-10.5}$	3.08%	–	–	–



ηh* Systematics

Table 14: Systematics for ηK^{*0}.

mode	$\eta_{2\gamma}K^{*0}_{K^+\pi^-}$ (%)	$\eta_{3\pi}K^{*0}_{K^+\pi^-}$ (%)	$\eta_{2\gamma}K^{*0}_{K^0\pi^0}$ (%)	$\eta_{3\pi}K^{*0}_{K^0\pi^0}$ (%)	$<\eta K^{*0}>$ (%)
TK, K_s	2	4	4.5	4.9	2.8
$\gamma\gamma, \pi^0$	2	4	4.5	5.7	2.8
η mass cut	2	2	2	2	2
PID	1.4	1.6	-	1.1	1.4
LR	1.0	1.0	1.0	1.0	1.0
K^* mass cut	2	2	2	2	2
B_s	0.66	1.77	0.66	1.77	1.0
non-resonance $K\pi$	0.5	0.5	0.5	0.5	0.5
$N_{B\bar{B}}$	1.0	1.0	1.0	1.0	1.0
Σ	4.5	6.9	7.1	8.4	4.3
Fitting PDF	±2.3	2.5	2.6	4.6	2.1
Total	5.1	7.4	7.6	9.6	5.8

Table 15: Systematics for ηK^{*+}.

mode	$\eta_{2\gamma}K^{*+}_{K^-\pi^0}$ (%)	$\eta_{3\pi}K^{*+}_{K^+\pi^0}$ (%)	$\eta_{2\gamma}K^{*+}_{K^0\pi^+}$ (%)	$\eta_{3\pi}K^{*+}_{K^0\pi^+}$ (%)	$<\eta K^{*+}>$ (%)
Tk,K_s	1	3	5.5	5.85	4.4
$\gamma\gamma, \pi^0$	4.5	5.7	2	4	3.5
η mass cut	2	2	2	2	2
PID	1.1	1.3	0.8	1.3	1.0
B_s	0.66	1.77	0.66	1.77	1.0
K^* mass cut	2	2	2	2	2
LR cut	1	1	1	1	1
non-resonance K^*	2	2	2	2	2
$N_{B\bar{B}}$	1	1	1	1	1
Σ	6.1	7.7	7.0	8.3	6.9
PDF	2.3	2.8	2.4	2.3	2.2
Total	6.5	8.2	7.4	8.6	7.2

Table 16: Systematics for $\eta\rho$.

mode	$\eta_{2\gamma}\rho^0$ (%)	$\eta_{3\pi}\rho^0$ (%)	$<\eta\rho^0>$ (%)	$\eta_{2\gamma}\rho^+$ (%)	$\eta_{3\pi}\rho^+$ (%)	$<\eta\rho^+>$ (%)
Tracking	2	4	3.3	1	3	1.8
$\gamma\gamma, \pi^0$	2.0	4	3.2	4.5	5.7	4.8
η mass cut	2.0	2	2	2.0	2.0	2
PID	1.3	1.8	1.6	0.8	1.3	0.8
B_s	0.66	1.77	1.4	0.66	1.77	0.8
ρ mass cut	2	2	2	2	2	2
LR cut	2	2	2	2	2	2
non-resonance ρ	4	4	4	4	4	4
$N_{B\bar{B}}$	1	1	1	1	1	1
Σ	6.0	8.0	7.2	6.9	8.5	7.2
PDF	15.9	64.6	20.4	4.8	4.5	4.3
Total	17.0	65.0	21.6	8.5	9.6	8.0