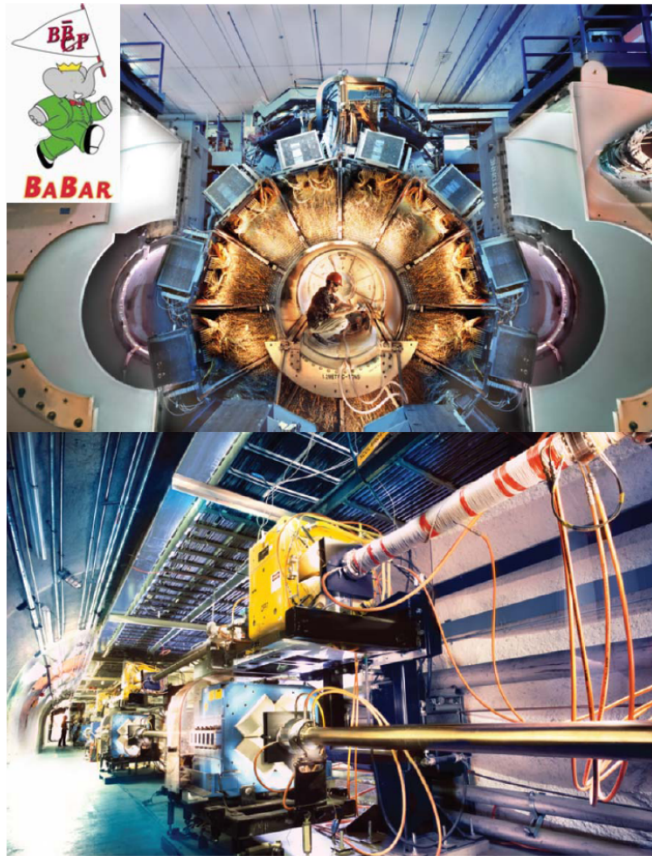
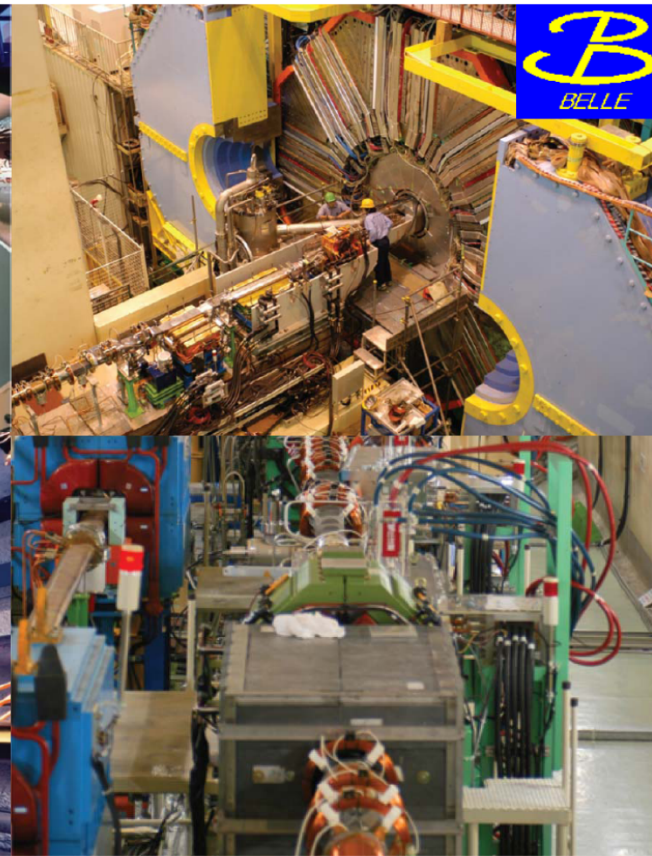


# Hadronic B Decays related to QCD at Belle and BaBar

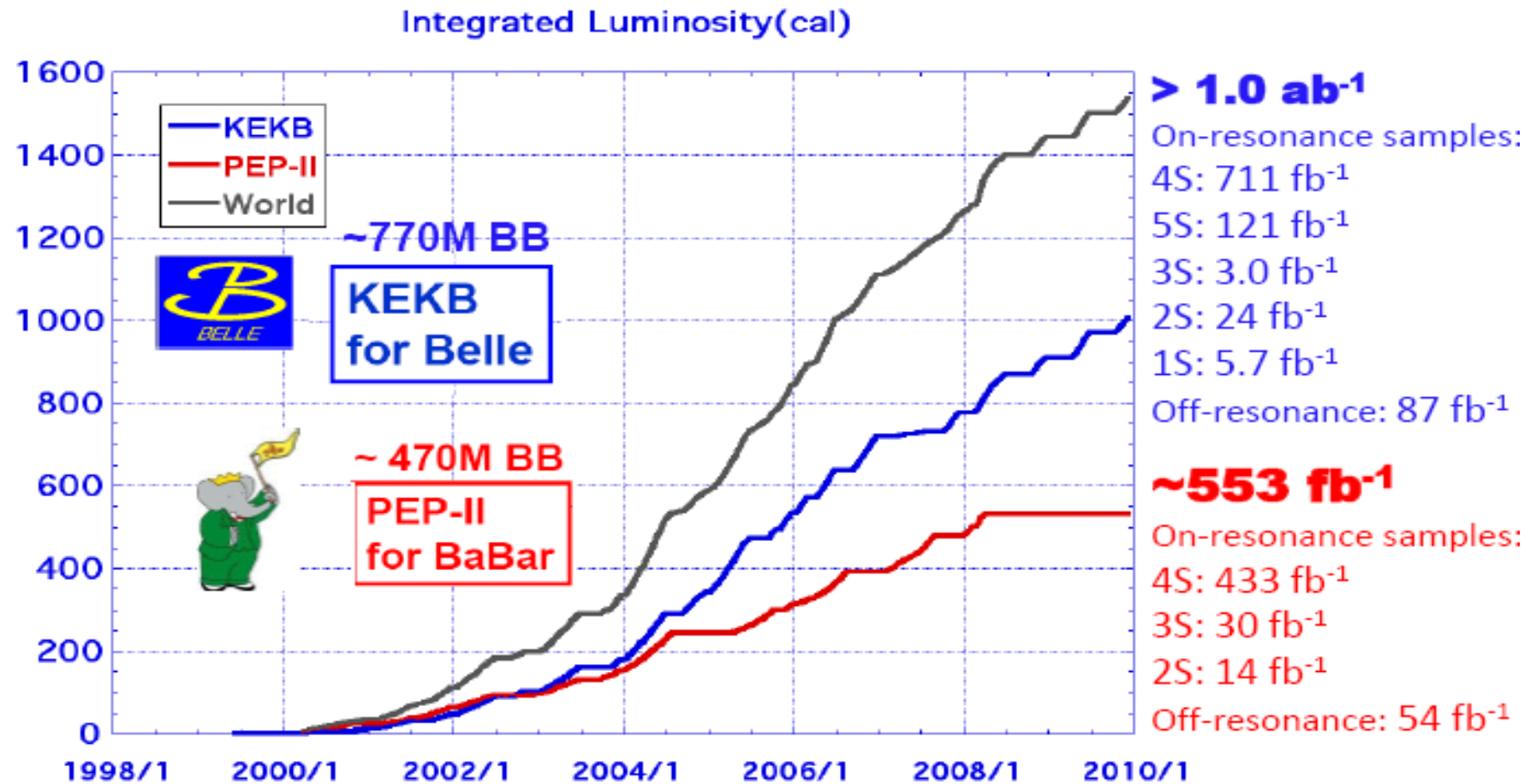
PEP-II and BaBar



KEKB and Belle



# Luminosity at the B Factories



# Taking shifts @ Belle control room



- Belle stopped taking data since the **end of December in 2009**.
- Final Belle running will be in Spring, 2010. (~1 month)
- Belle will be upgraded to Belle-II. (~3 years)



# Outline

- Baryonic B Decays

$$B^+ \rightarrow p \bar{\Lambda} \pi^+ \pi^-$$

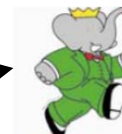
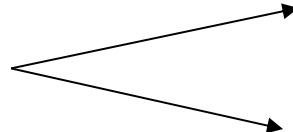
#BB-bar Events



657M PRD 80: 111103(R), 2009

- B decays to VV mode

$$B^0 \rightarrow \rho^0 K^{*0}$$

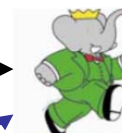
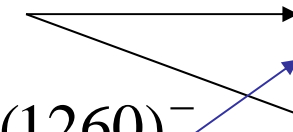


232M PRL 97, 201801, 2006



657M PRD 80: 051103(R), 2009

$$B^0 \rightarrow K^{*0} \bar{K}^{*0}$$



383M PRL 100, 081801, 2008

465M PRD 80, 092007, 2009

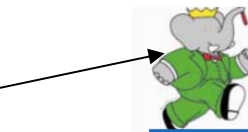
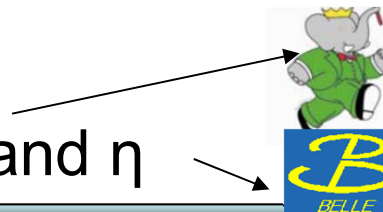
$$B^0 \rightarrow a_1(1260)^+ a_1(1260)^-$$



657M arXiv:1001.4595

- Hadronic penguins

– Final States with  $\eta'$  and  $\eta$



467M preliminary



657M arXiv:0910.4751, 2010

# Baryonic B Decays

- First 4-body charmless baryonic decay has been observed

- Motivation:

**b→c tree diagram**

$$Br(B^0 \rightarrow p\bar{\Lambda}_c^- \pi^+ \pi^-) > Br(B^+ \rightarrow p\bar{\Lambda}_c^- \pi^+) > Br(B^0 \rightarrow p\bar{\Lambda}_c^-)$$



**First Observation**

**b→s penguin or b →u tree diagrams**

$$Br(B^+ \rightarrow p\bar{\Lambda} \pi^+ \pi^-) > Br(B^0 \rightarrow p\bar{\Lambda} \pi^-) > Br(B^+ \rightarrow p\bar{\Lambda})$$

- Br(4-body) > Br(3-body) > Br(2-body)

# Baryonic B Decays

- Threshold enhancement is same for all baryonic decays.

$$B \rightarrow \Lambda \bar{\Lambda} h, h = K^{\pm}, K^{*(\pm,0)}, \bar{D}_0$$

657M PRD 79, 052006 (2009)

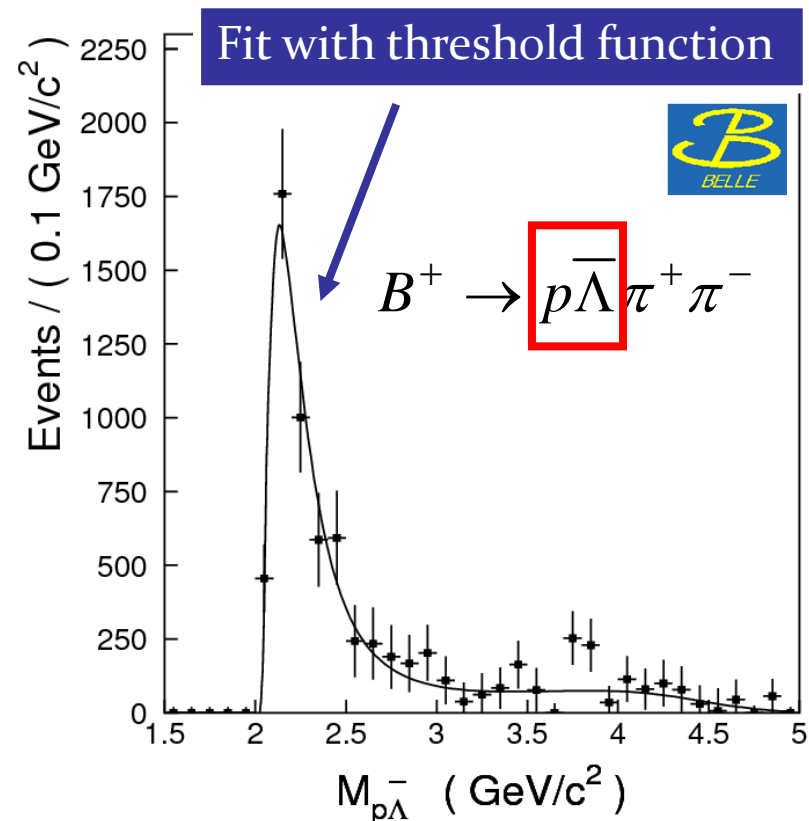
$$B \rightarrow p \bar{\Lambda} h, h = \pi^{\pm}, K^{\pm}, K^{*(\pm,0)}$$

PRD 76, 052004 (2007)

$$B \rightarrow p \bar{p} h, h = \pi^{\pm}, K^{\pm}, K^{*(\pm,0)}$$

PRL 100, 251801 (2008)

605fb<sup>-1</sup> PRD 80, 111103(R) (2009)

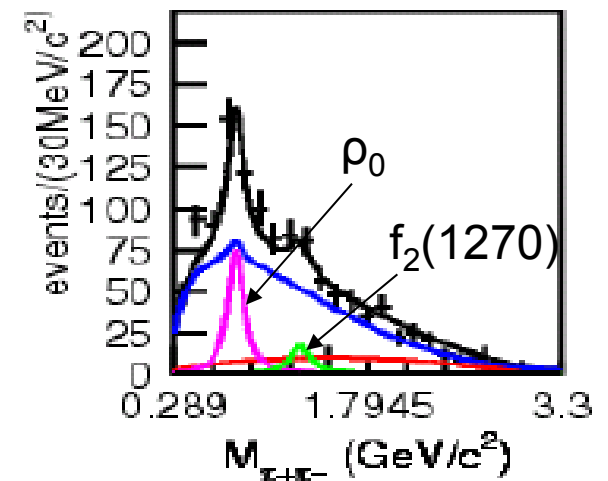
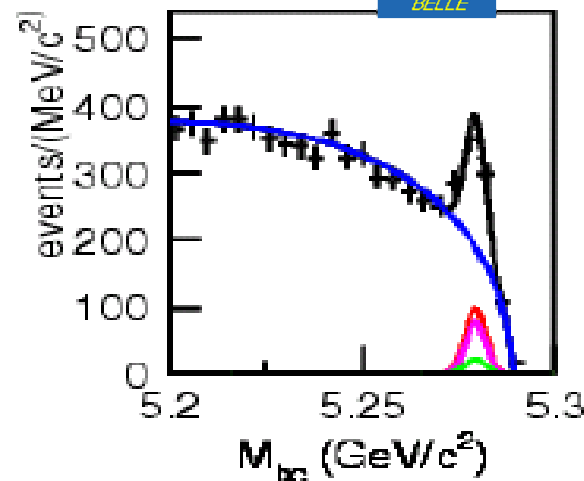
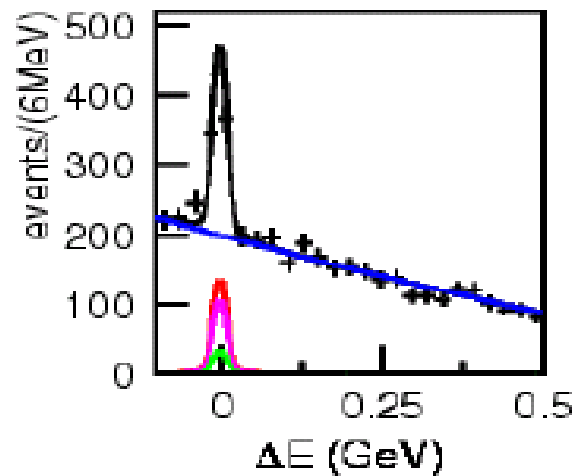


# Baryonic B Decays



605fb<sup>-1</sup>

PRD 80: 111103(R) 2009



Red line:  $\text{BF}(B^+ \rightarrow p\bar{\Lambda}\pi^+\pi^-) = (5.92^{+0.88}_{-0.84} \pm 0.69) \times 10^{-6}$  Significance = 9.1 $\sigma$

Purple:  $\text{BF}(B^+ \rightarrow p\bar{\Lambda}\rho^0) = (4.78^{+0.67}_{-0.64} \pm 0.60) \times 10^{-6}$  Significance = 9.5 $\sigma$

Green:  $\text{BF}(B^+ \rightarrow p\bar{\Lambda}f_2(1270)) = (2.03^{+0.77}_{-0.72} \pm 0.27) \times 10^{-6}$  Significance = 3 $\sigma$

Blue: background

Intermediate 3-body decay

Black: total

# B decays to VV mode

$$B^0 \rightarrow \rho^0 K^{*0}$$

- Motivation: *BABAR*, PRL **93**, 231804 (2004); Belle, PRL **94**, 221804 (2005).
  - Measurements of  $f_L$  in rare B decays to VV, such as  $B \rightarrow \phi K^*$ , have revealed an **unexpectedly large fraction of transverse polarization**. ( $f_L \sim 0.5$ ) **polarization puzzle**
  - This implies that non-factorizable contributions to the decay amplitude play a significant role.
  - **Further information** about these effects can be obtained with Br and  $f_L$  in  $B^0 \rightarrow \rho^0 K^{*0}$  (also  $b \rightarrow s$  penguin-dominated).

*BABAR*, PRL 97, 201801, 2006

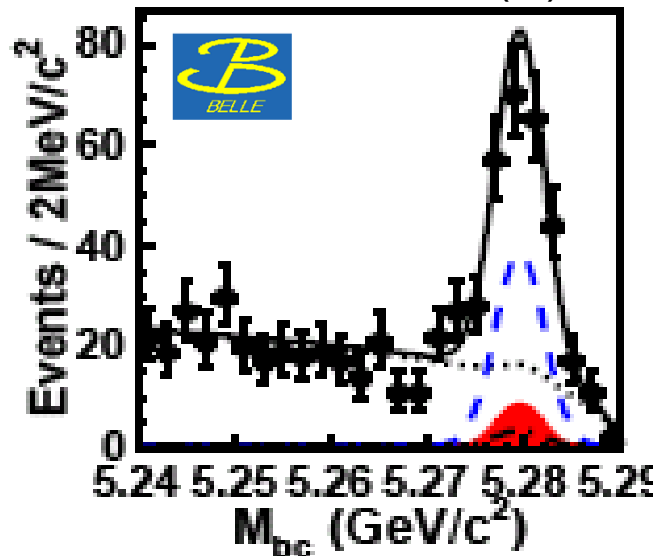


# B decays to VV mode

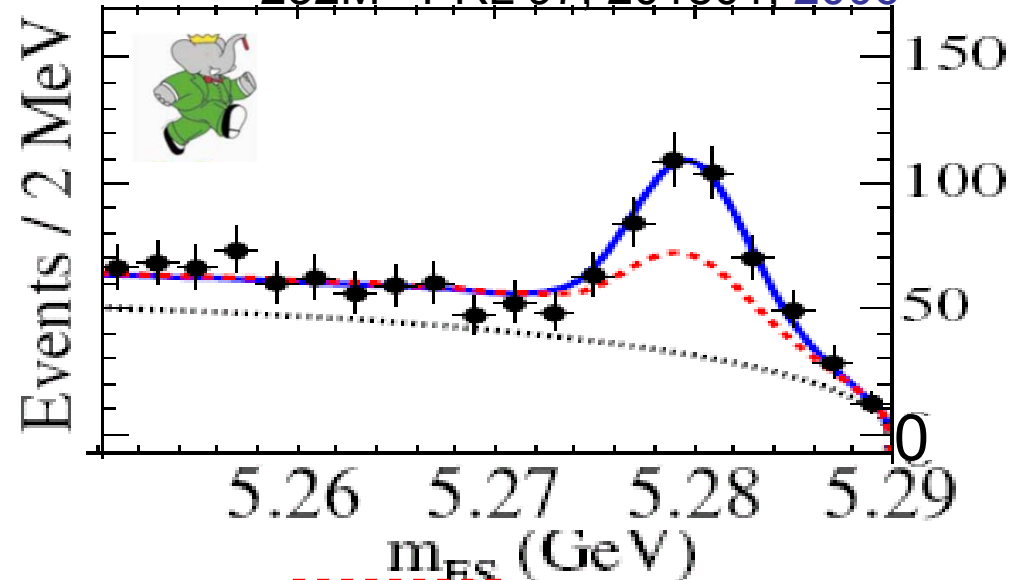
Observation?

$$B^0 \rightarrow \rho^0 K^{*0}$$

657M PRD 80: 051103(R), 2009



232M PRL 97: 201801, 2006



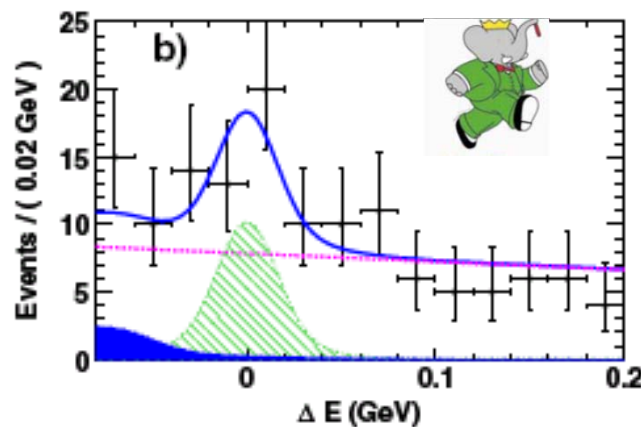
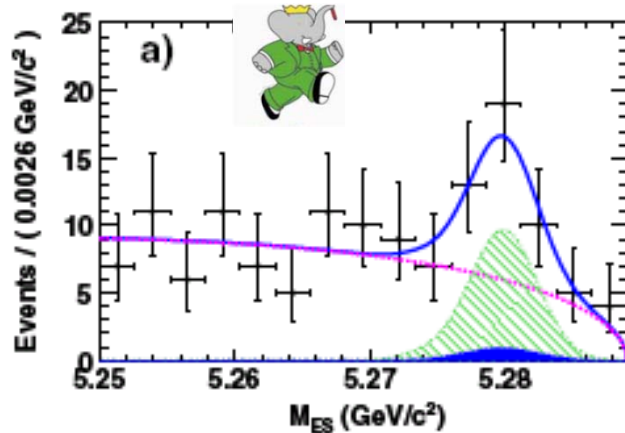
	Y (events)	$\epsilon$ (%)	S ( $\sigma$ )	Br ( $10^{-6}$ )
BaBar	$185 \pm 30$	22.9	5.3	$5.6 \pm 0.9 \pm 1.3$
Belle	$77.6 \pm 20$	5.73	2.7	$< 3.4$

$f_L \sim 0.57$

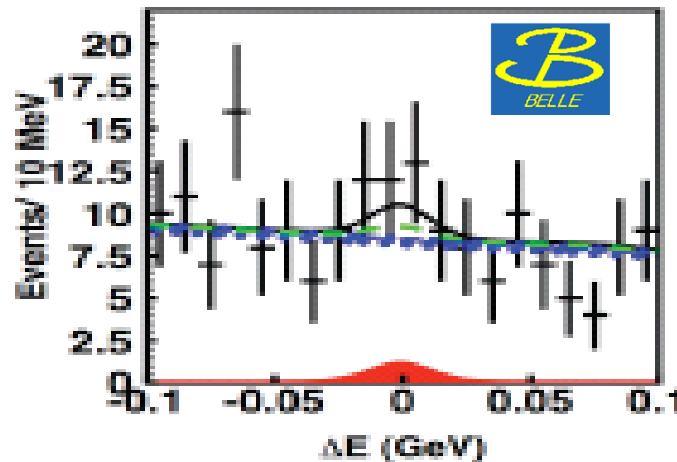
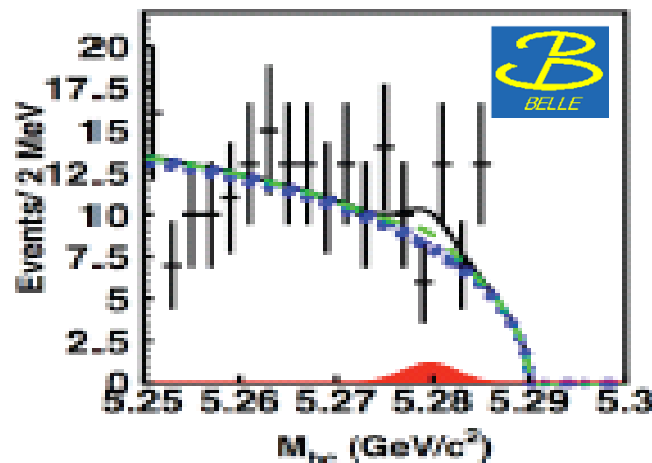
# B decays to VV mode

Observation?

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



383M  
PRL 100, 081801, 2008



657M  
arXiv:1001.4595, 2010  
submitted to PRD(R)

# B decays to VV mode

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



383M  
PRL 100, 081801, 2008



657M

Preliminary

arXiv:1001.4595, 2010  
submitted to PRD(R)

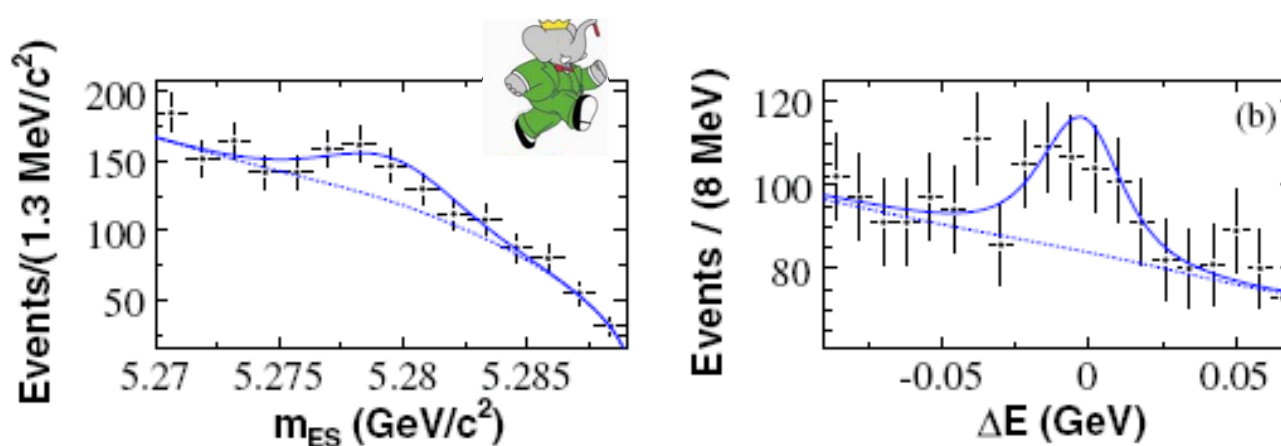


	Y (events)	$\epsilon$ (%)	S ( $\sigma$ )	Br ( $10^{-6}$ )
BaBar	$33.5 \pm_{8.1}^{9.1}$	6.8	6	$1.28 \pm_{0.30}^{0.35} \pm 0.11$
Belle	$7.7 \pm_{8.5}^{9.7} \pm_{2.2}^{2.8}$	4.43	0.9	<0.8

$f_L \sim 0.80$

# B decays to VV mode

$$B^0 \rightarrow a_1(1260)^+ a_1(1260)^-$$



465M  
PRD 80, 092007, **2009**

	Y (events)	$\epsilon$ (%)	S ( $\sigma$ )	Br ( $10^{-6}$ )	Observation
BaBar	<b><math>545 \pm 118</math></b>	<b>10</b>	<b>5</b>	<b><math>11.8 \pm 2.6 \pm 1.6</math></b>	

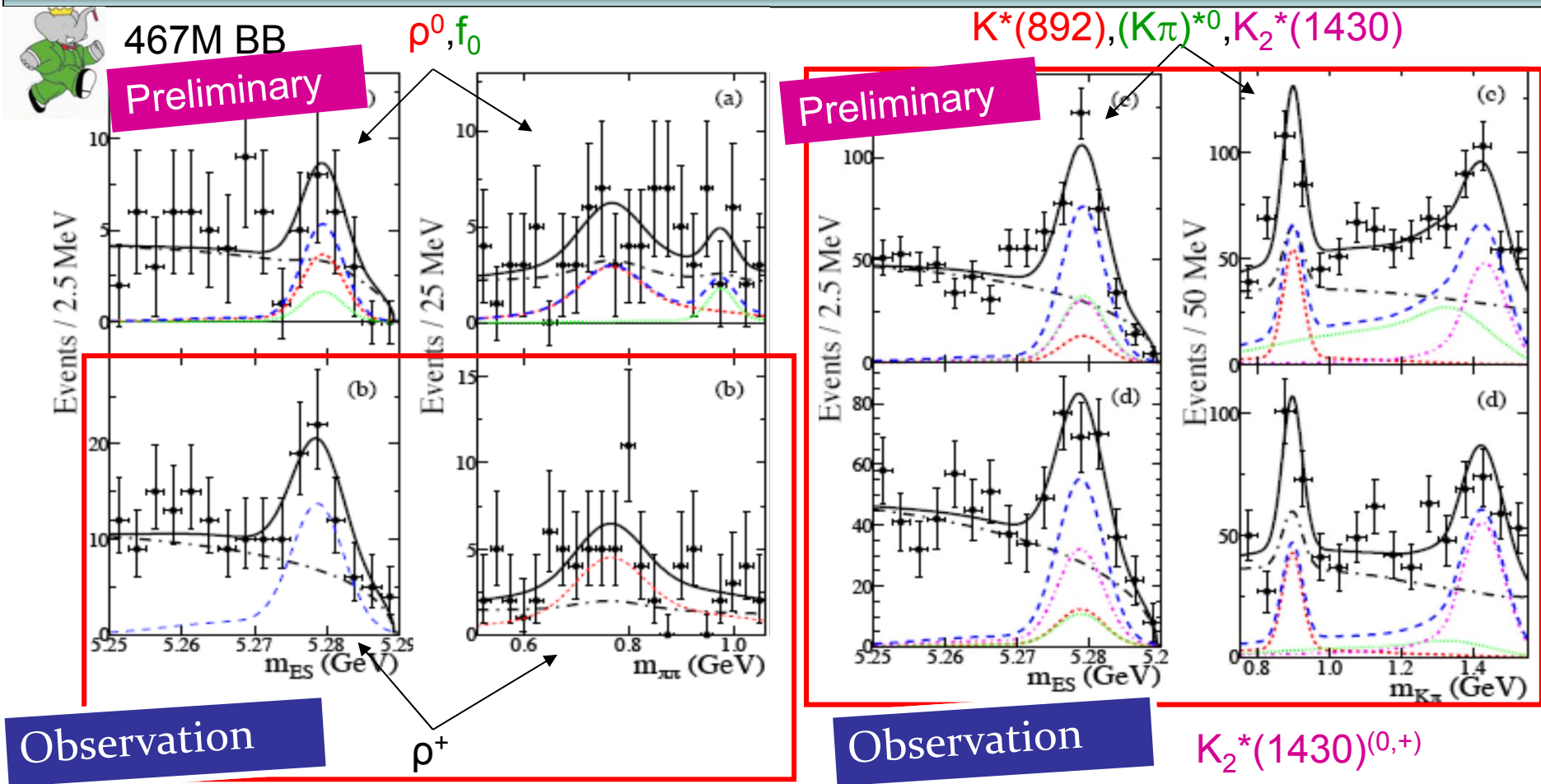
Showing the agreement with the theoretical expectations

H.-Y. Cheng and K.-C. Yang, Phys. Rev. D 78, 094001 (2008).

$$f_L = 0.31 \pm 0.22 \pm 0.10$$

# Hadronic penguins: Exclusive

$$B \rightarrow \eta' (\rho, f_0, K^*(892), K_2^*(1430))$$





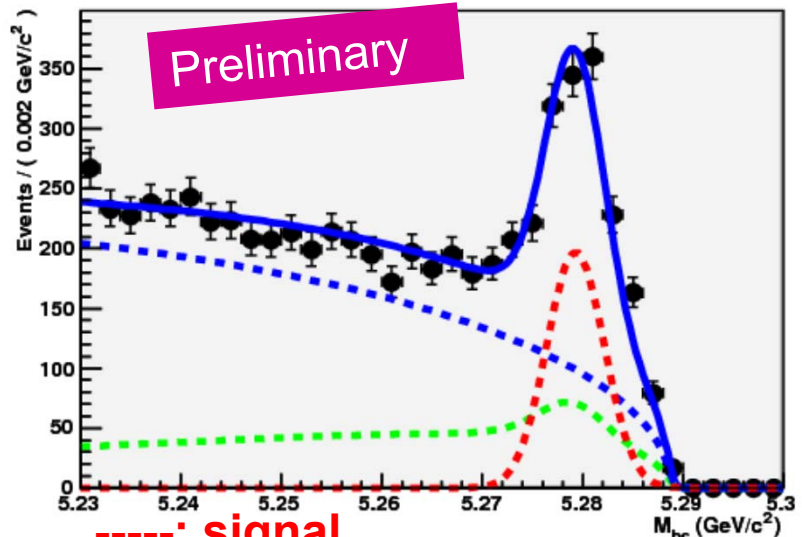
# Hadronic penguins: Inclusive

$$B \rightarrow X_s \eta$$



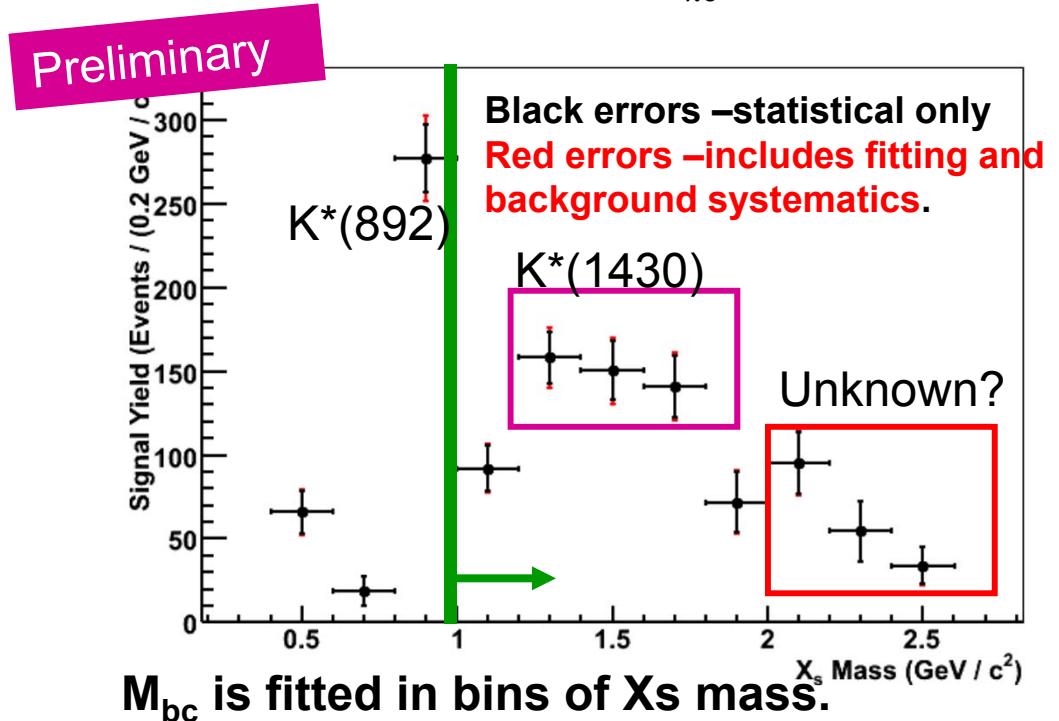
657M BB Sum of exclusive modes  $B \rightarrow X_s \eta$

arXiv:0910.4751, 2010



Signal yield ( $M_{X_s} > 1.0$  GeV/c<sup>2</sup>) =  
**17.6 $\sigma$  statistical significance**

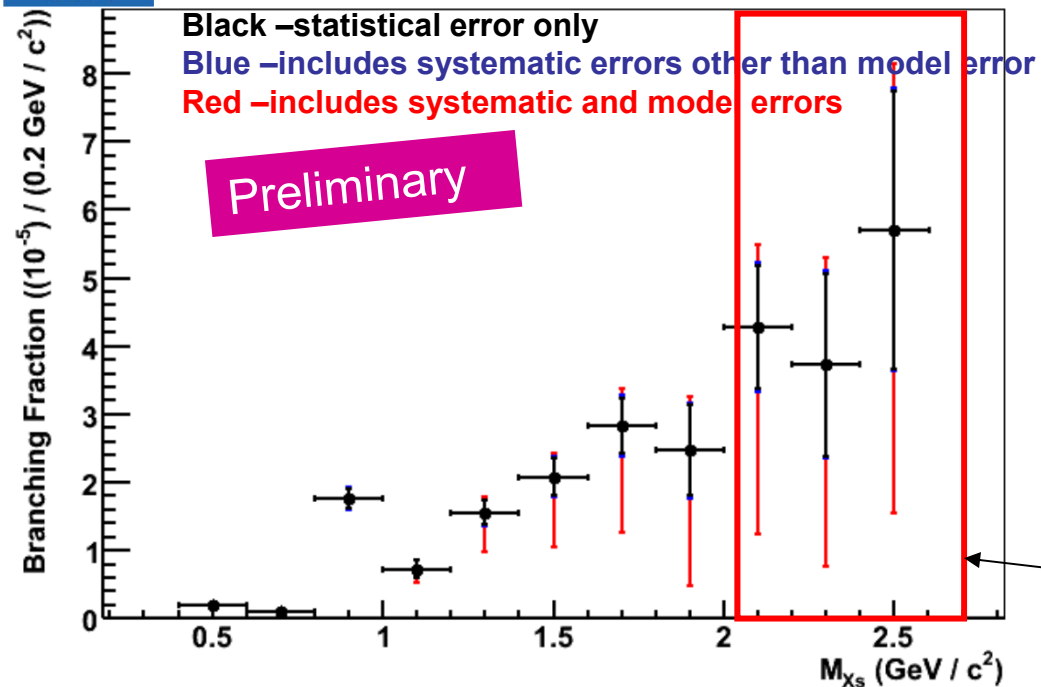
$\gamma \gamma$   
 $K n \pi (n \leq 4, n_{\pi^0} \leq 1)$



# Hadronic penguins: Inclusive

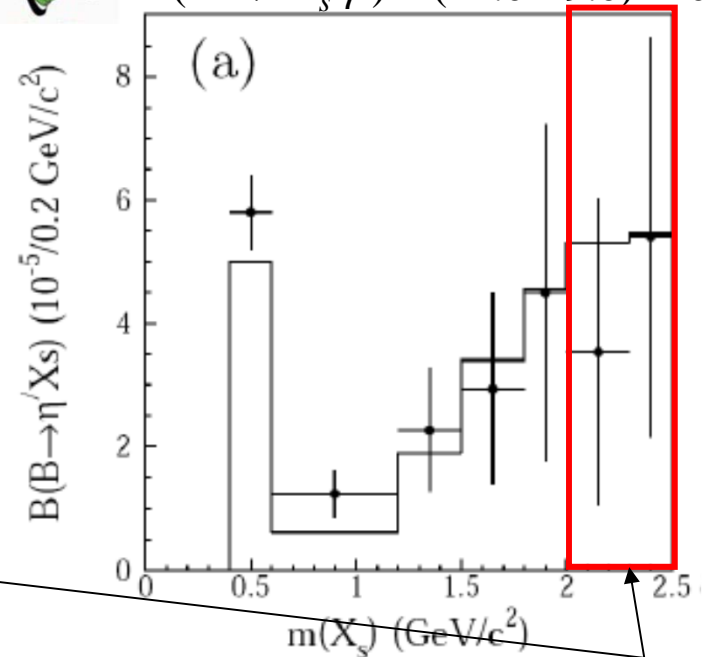


657M BB [arXiv:0910.4751](https://arxiv.org/abs/0910.4751), 2010



BaBar PRL 93, 061801, 2004

$$Br(B \rightarrow X_s \eta') = (42.0 \pm 9.0) \times 10^{-5}$$



Unknown?

**Belle partial branching fraction for  $X_s$  mass range 0.4 –2.6  $\text{GeV}/c^2$ :**

$$Br(B \rightarrow X_s \eta) = (25.5 \pm 2.7(stat) \pm 1.6(sys) \pm_{14.1}^{3.8} (model)) \times 10^{-5}$$

# Summary

- Baryonic B decays



- Threshold enhancement exists in the invariant mass of two baryons. eg.

$$M_{p\bar{\Lambda}}, M_{p\bar{p}}, M_{\Lambda\bar{\Lambda}}$$

- BR(4-body) > BR(3-body) > BR(2-body), for both charm and charmless baryonic mode.

- B → VV mode



- Belle and BaBar knew their inconsistency modes.



$$B^0 \rightarrow \rho^0 K^{*0}, K^{*0} \overline{K^{*0}}$$

# Summary

- Hadronic penguins



- Exclusive  $\eta'$  modes

- Observations of

Preliminary

$$B \rightarrow \eta' \rho^+, \eta' K_2^*(1430)^{(0,+)}$$

- **Unexpected enhancements** of  $K_2^*(1430)$  over  $K^*(892)$



- Inclusive  $X_s \eta$  mode

- **Belle partial branching fraction for  $X_s$  mass range 0.4 – 2.6 GeV/c<sup>2</sup>:**

Preliminary

$$Br(B \rightarrow X_s \eta) = (25.5 \pm 2.7(stat) \pm 1.6(sys) \pm_{14.1}^{3.8} (model)) \times 10^{-5}$$

- **Both  $X_s \eta$  and  $X_s \eta'$  contains signals beyond the known  $K^*(892, 1430)$ .**