Baryonic B Decays

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FPCP 2010, Torino, Italy

May. 26, 2010

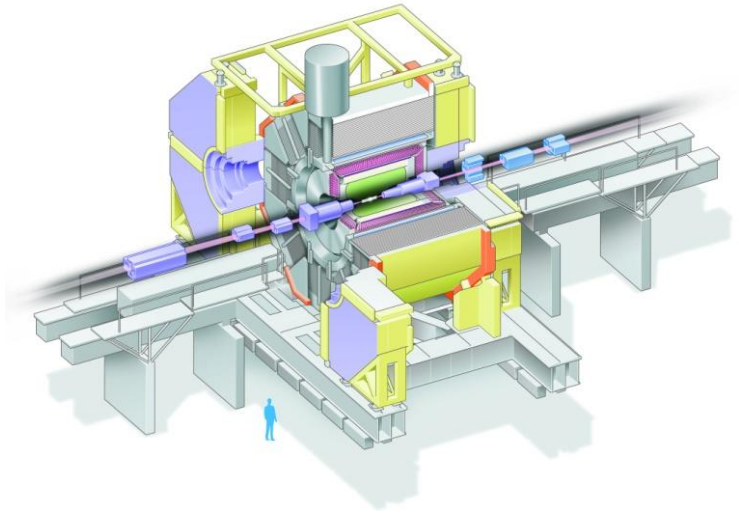
Outline

- Introduction
  - Profound baryonic decays: a unique feature of B meson
  - Well established after few years of B-factory running
    - ✓(BF(4-body)>) BF(3-body) > BF(2-body)
    - ✓threshold enhancement in the baryon-antibaryon system
  - Searching ground for exotic states
  - May have unexpectedly large CP violation in charmless modes
- Charmed baryonic decays
- Charmless baryonic decays
- Summary

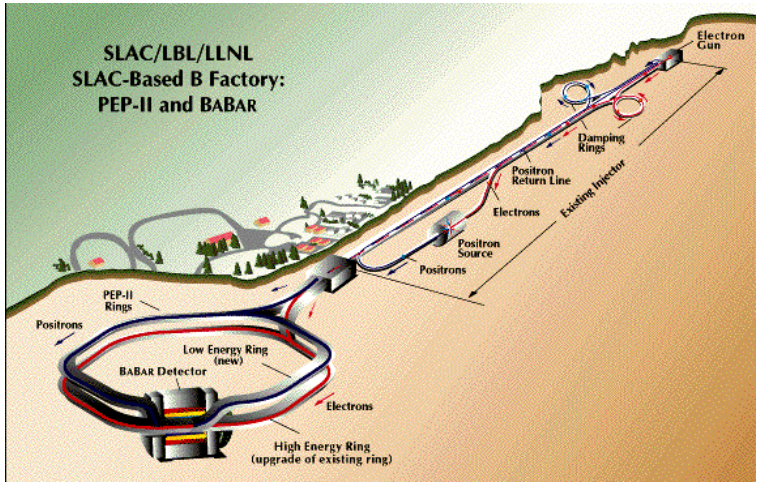
Two B Factories

KEK

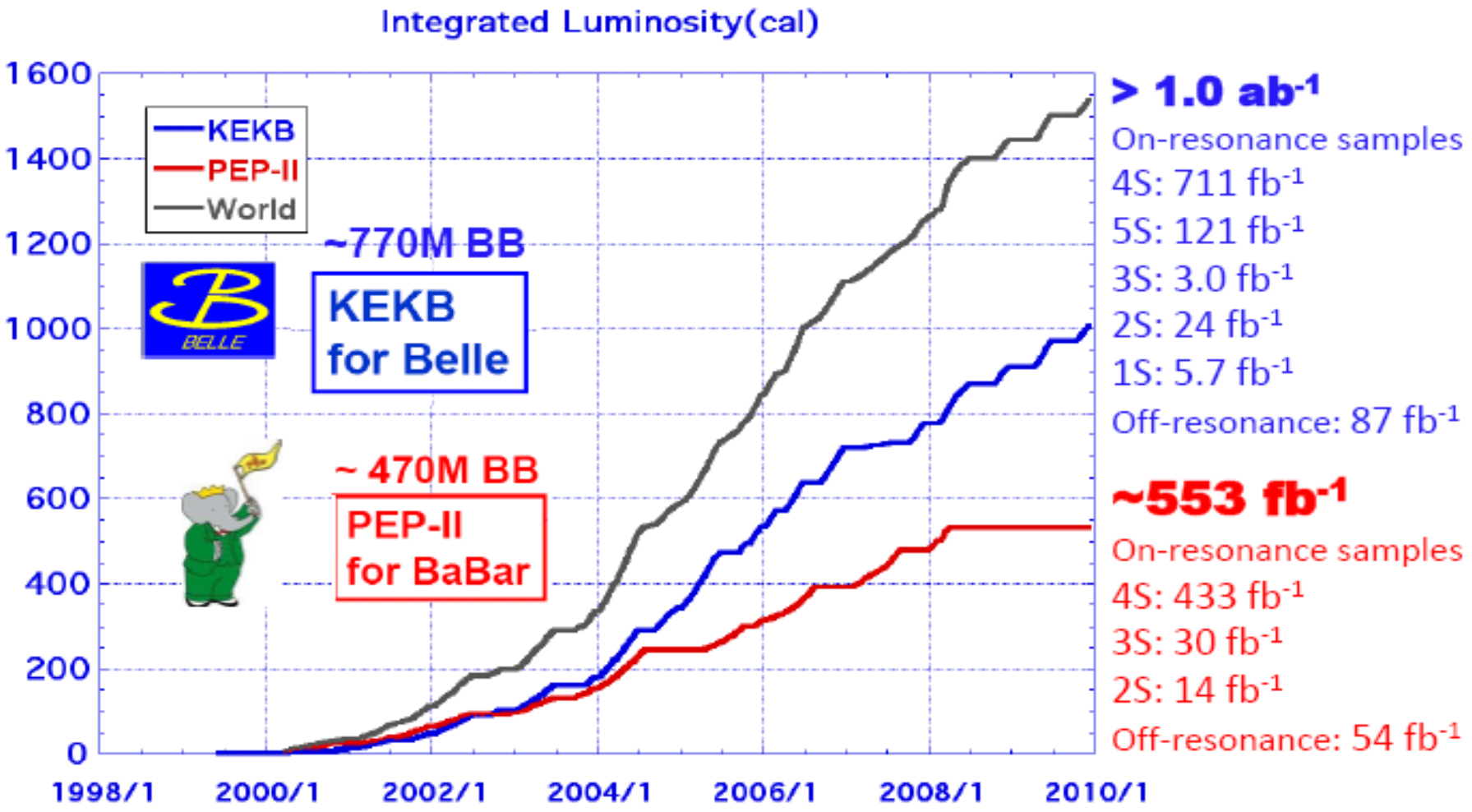
Belle



SLAC



BaBar



- final Belle data taking is ongoing (~1 month)
- large data sample has been reprocessed and is ready to be analyzed

Charmed baryonic decays

Recent results:

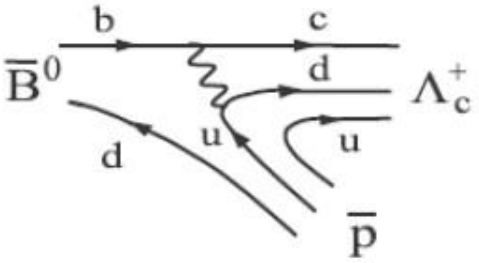
$$\overline{B}^0 \to \Lambda_c^+ \overline{p}\,; \quad B^- \to \Lambda_c^+ \overline{p}\,\pi^-$$

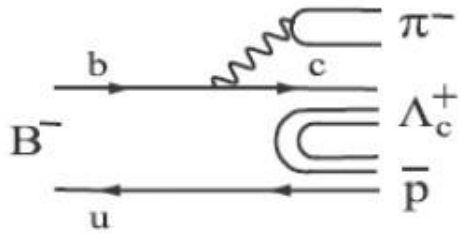
$$\overline{B}^0 \to \Lambda_c^+ \overline{p}\,K^-\pi^+$$

semileptonic B decays into Λ_c^+

$\overline{B}^0 \to \Lambda_c^+ \overline{p}\,;\ B^- \to \Lambda_c^+ \overline{p}\pi^-$

PRD 78, 112003 (2008)
$(383\,\mathrm{M}\,B\overline{B})$





	$\mathrm{BF}(\overline{B}^0 \to \Lambda_c^+ \overline{p})(\times 10^{-5})$	$\mathrm{BF}(B^- \to \Lambda_c^+ \overline{p}\pi^-)(\times 10^{-4})$
Babar	1.89±0.21±0.06±0.49	3.38±0.12±0.12±0.88
Belle	$2.19^{+0.56}_{-0.49} \pm 0.32 \pm 0.57$	2.01±0.15±0.20±0.52

PRL 90, 121802(2003) $(85\,\mathrm{M}\,B\overline{B})$

PRL 97,242001(2006) $(152\,\mathrm{M}\,B\overline{B})$

$$\frac{BF(B^- \to \Lambda_c^+ \overline{p}\pi^-)}{BF(\overline{B}^0 \to \Lambda_c^+ \overline{p})} = 15.4 \pm 1.8 \pm 0.3$$

consistent with theoretical description in
W.-S. Hou and A. Soni, PRL 86, 4247 (2001)

$\overline{B}^0 \to \Lambda_c^+ \bar{p}$; $B^- \to \Lambda_c^+ \bar{p} \pi^-$

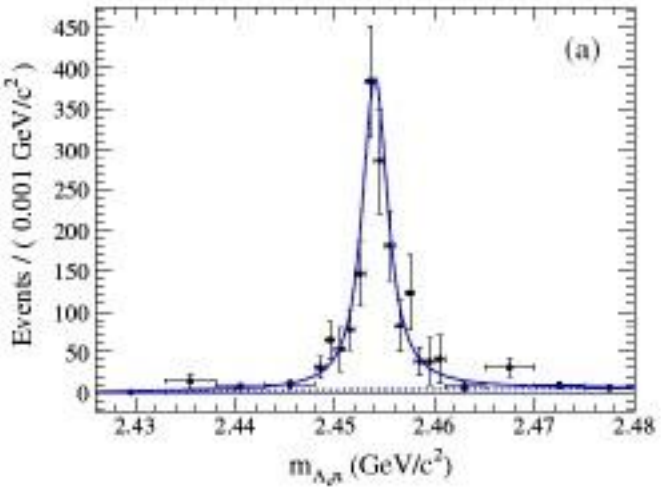
PRD 78, 112003 (2008)
(383M $B\bar{B}$)

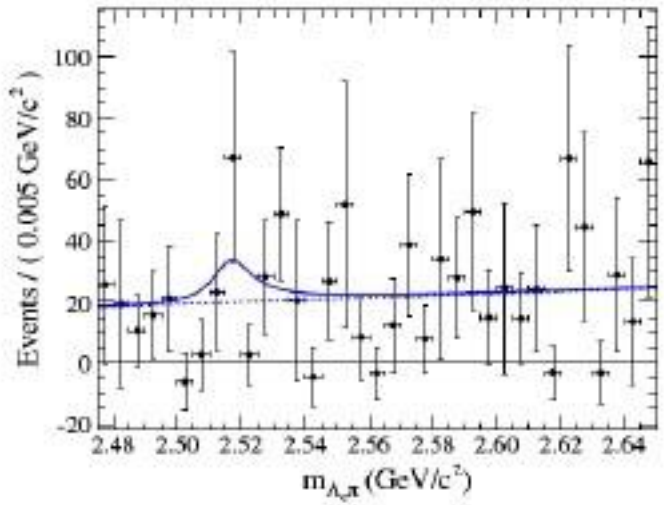
Quasi two-body decay $\Sigma_c \to \Lambda_c^+ \pi^-$

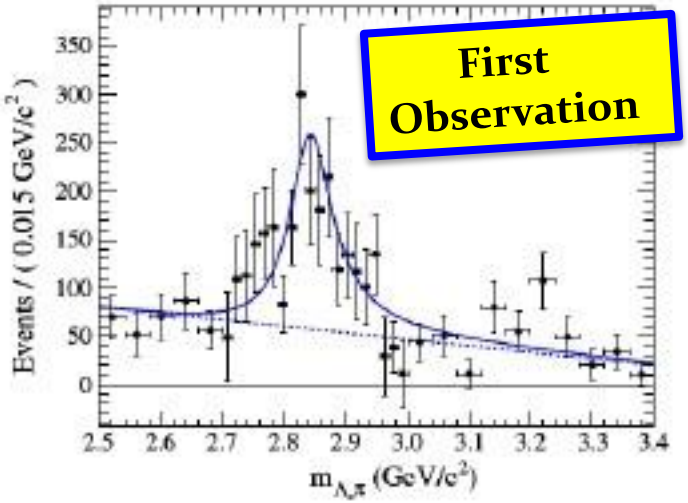
$$\frac{BF(B^- \to \Sigma_c(2455)^0 \bar{p})}{BF(B^- \to \Lambda_c^+ \bar{p}\pi^-)} = (12.3 \pm 1.2 \pm 0.8) \times 10^{-2}$$

$$\frac{BF(B^- \to \Sigma_c(2520)^0 \bar{p})}{BF(B^- \to \Lambda_c^+ \bar{p}\pi^-)} < 0.9 \times 10^{-2} \ @90\%CL$$

$$\frac{BF(B^- \to \Sigma_c(2800)^0 \bar{p})}{BF(B^- \to \Lambda_c^+ \bar{p}\pi^-)} = (11.7 \pm 2.3 \pm 2.4) \times 10^{-2}$$





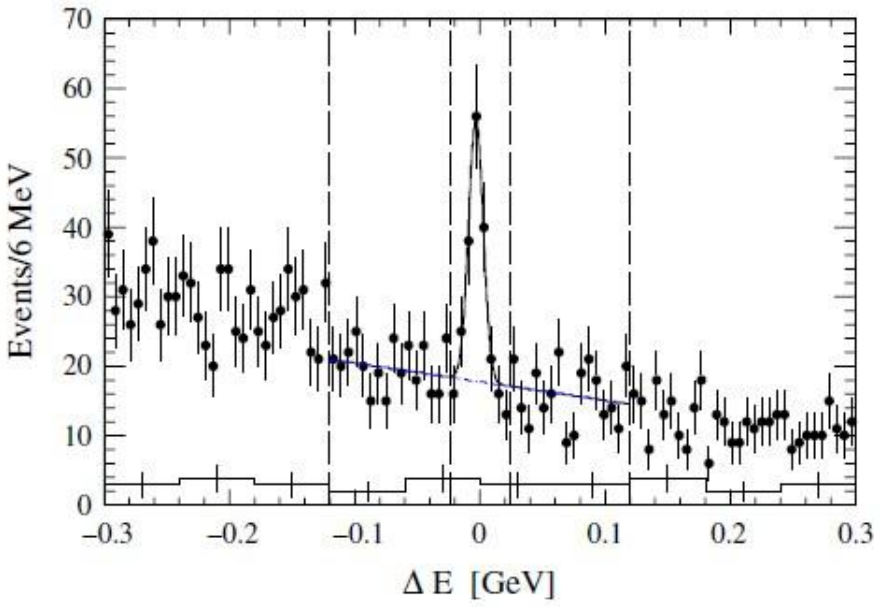


- first observation of $\Sigma_c(2800)^0$
  $M = (2846 \pm 8 \pm 10)\ \text{MeV},\ \Gamma = 86^{+33}_{-22}\ \text{MeV}$
- about ¼ of $B^- \to \Lambda_c^+ \bar{p} \pi^-$ decays through a Σ_c resonance.

$\overline{B}^0 \to \Lambda_c^+ \overline{p} K^- \pi^+$

PRD 80, 051105 (R) (2009)
467 M $B\overline{B}$

- Study one Cabibbo-suppressed mode and compare it with a favored mode



$$BF(\overline{B}^0 \to \Lambda_c^+ \overline{p} K^- \pi^+) = (4.33 \pm 0.82 \pm 0.33 \pm 1.13) \times 10^{-5}$$

$BF(\overline{B}^0 \to \Lambda_c^+ \overline{p} \pi^- \pi^+) = (12.6 \pm 1.3 \pm 0.33) \times 10^{-4}$ CLEO PRD 66, 091101 (2002)
Belle PRD 75, 011101 (2007)

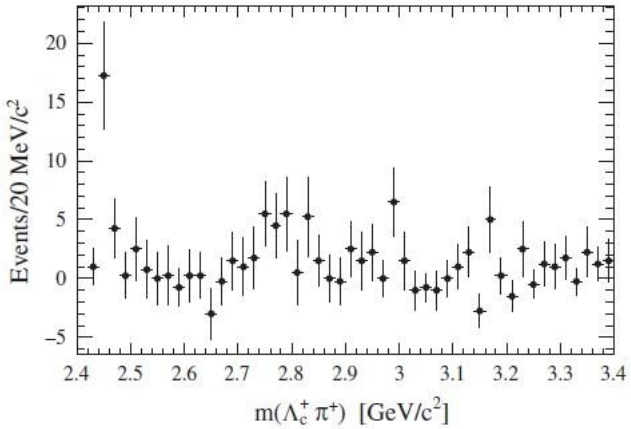
Ratio = 0.038 ± 0.009

$|V_{us}/V_{ud}|^2 = (0.0536 \pm 0.0020)$ (PDG 2008)

$\overline{B}^0 \to \Lambda_c^+ \overline{p} K^- \pi^+$

PRD 80, 051105 (R) (2009)
$467\,\mathrm{M}\,B\overline{B}$

Intermediate states $\Sigma_c(2455)^{++}$ and $\overline{K}^{*0}$

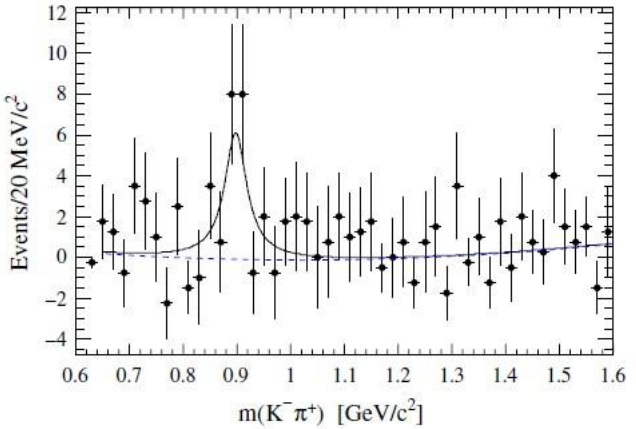


$$BF(\overline{B}^0 \to \Sigma_c(2455)^{++}\,\overline{p}\,K^-) = (1.11 \pm 0.30 \pm 0.09 \pm 0.29) \times 10^{-5}$$

$$BF(\overline{B}^0 \to \Sigma_c(2455)^{++}\,\overline{p}\,\pi^-) = (2.3 \pm 0.3 \pm 0.6) \times 10^{-4}$$

CLEO PRD 66, 091101 (2002)
Belle PRD 75, 011101 (2007)

Ratio = 0.048±0.016



$$BF(\overline{B}^0 \to \Lambda_c^+\,\overline{p}\,\overline{K}^{*0}) < 2.42 \times 10^{-5} \quad @90\%\mathrm{CL}$$

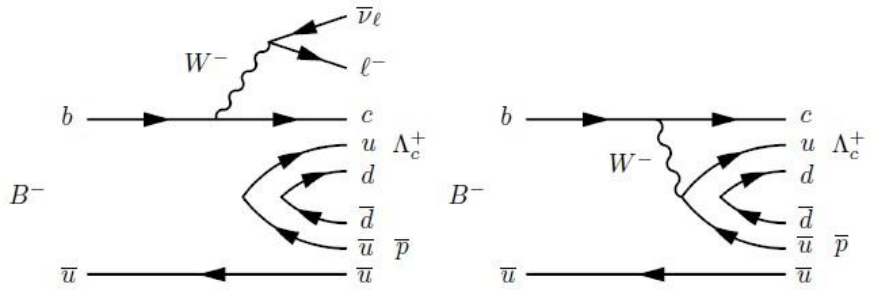
Semileptonic decays into Λ_c^+

hep-ex 0808.0011

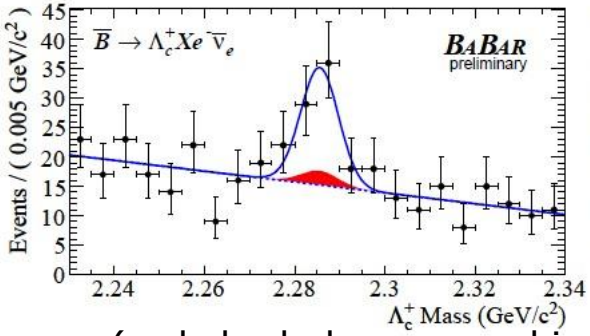
460 M $B\bar{B}$

- Compare baryonic decays with hadronic decays

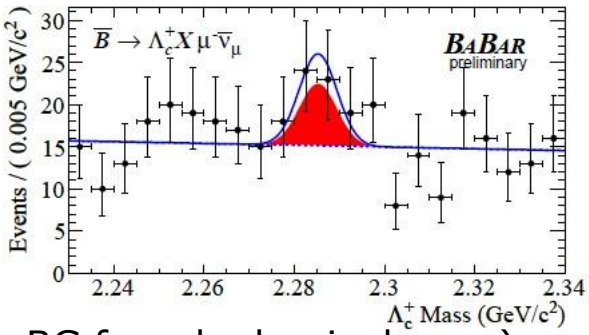
$$\frac{\mathcal{B}(\overline{B} \to DX\ell^-\overline{\nu}_\ell)}{\mathcal{B}(\overline{B} \to D/\overline{D}X)} \sim \frac{\mathcal{B}(\overline{B} \to \Lambda_c^+ X\ell^-\overline{\nu}_\ell)}{\mathcal{B}(\overline{B} \to \Lambda_c^+/\overline{\Lambda}_c^- X)} ?$$



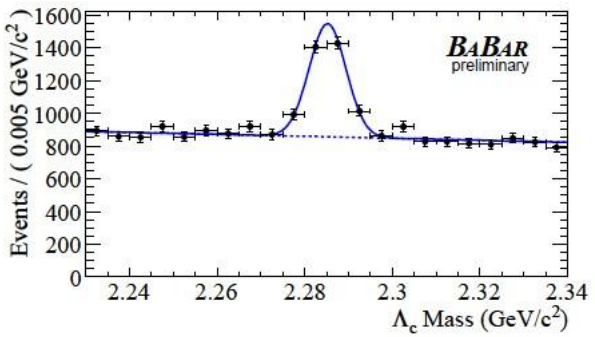
$\Lambda_c^+/\overline{\Lambda}_c^- X e^- \overline{\nu}_e$



$\Lambda_c^+/\overline{\Lambda}_c^- X \mu^- \overline{\nu}_\mu$



$\Lambda_c^+/\overline{\Lambda}_c^- X$



(red shaded area: peaking BG from hadronic decays)

!!Preliminary!!

$$\frac{BF(\overline{B} \to \Lambda_c^+ X e^- \overline{\nu}_e)}{BF(\overline{B} \to \Lambda_c^+/\overline{\Lambda}_c^- X)} = (3.9 \pm 1.0 \pm 1.1)\%$$

$$\frac{BF(\overline{B} \to \Lambda_c^+ X \mu^- \overline{\nu}_\mu)}{BF(\overline{B} \to \Lambda_c^+/\overline{\Lambda}_c^- X)} = (1.5 \pm 1.7 \pm 1.7)\%$$

First observation

$$\frac{BF(\overline{B} \to \Lambda_c^+ X e^- \overline{\nu}_e)}{BF(\overline{B} \to \Lambda_c^+/\overline{\Lambda}_c^- X)} < 5\% \quad @90\%CL$$

CLEO PRD 57, 6604 (1998)

Charmless baryonic decays

Recent results:

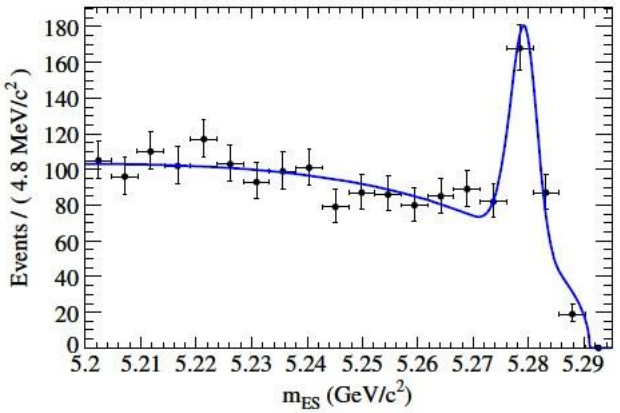
$$B^0 \to p\bar{\Lambda}\pi^-$$

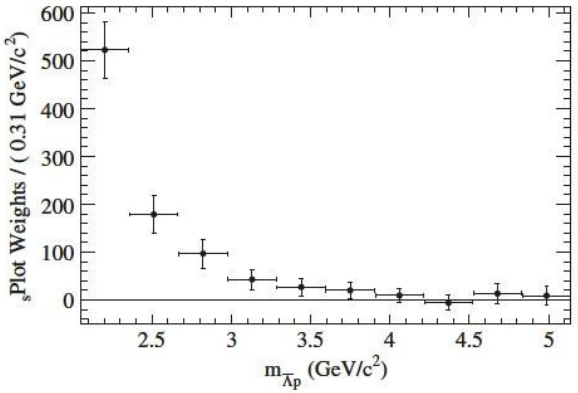
$$B \to \Lambda\bar{\Lambda}h$$

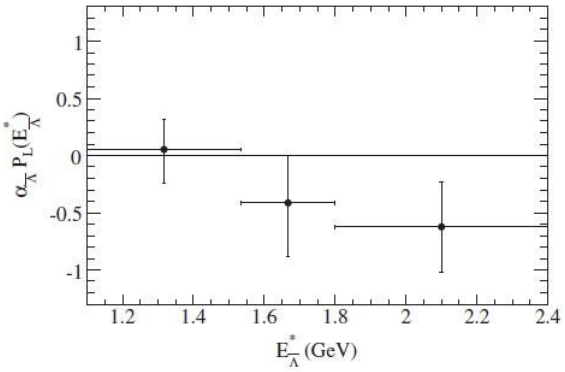
$$B^+ \to p\bar{\Lambda}\pi^+\pi^-$$

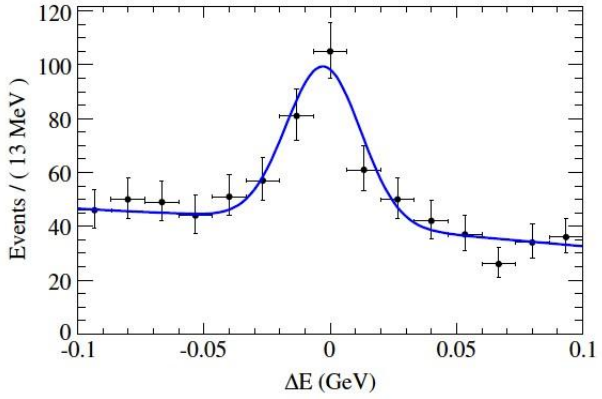
$B^0 \to p\bar{\Lambda}\pi^-$

PRD 79, 112009 (2009)
467 M $B\bar{B}$









- $BF(B^0 \to p\bar{\Lambda}\pi^-) = (3.07 \pm 0.31 \pm 0.23) \times 10^{-6}$
  $A_{ch} = -0.10 \pm 0.10 \pm 0.02$

Belle PRD 76, 052004 (2007) 449 M $B\bar{B}$
$BF(B^0 \to p\bar{\Lambda}\pi^-) = (3.23^{+0.33}_{-0.29} \pm 0.29) \times 10^{-6}$
$A_{ch} = -0.02 \pm 0.10 \pm 0.03$ $A_\theta = -0.41 \pm 0.11 \pm 0.03$

- near-threshold enhancement also seen
- $\bar{\Lambda}$ polarization study
  - consistent with full longitudinal right-handed polarization at large $E^*_{\bar{\Lambda}}$

$B \to \Lambda\bar{\Lambda}h$

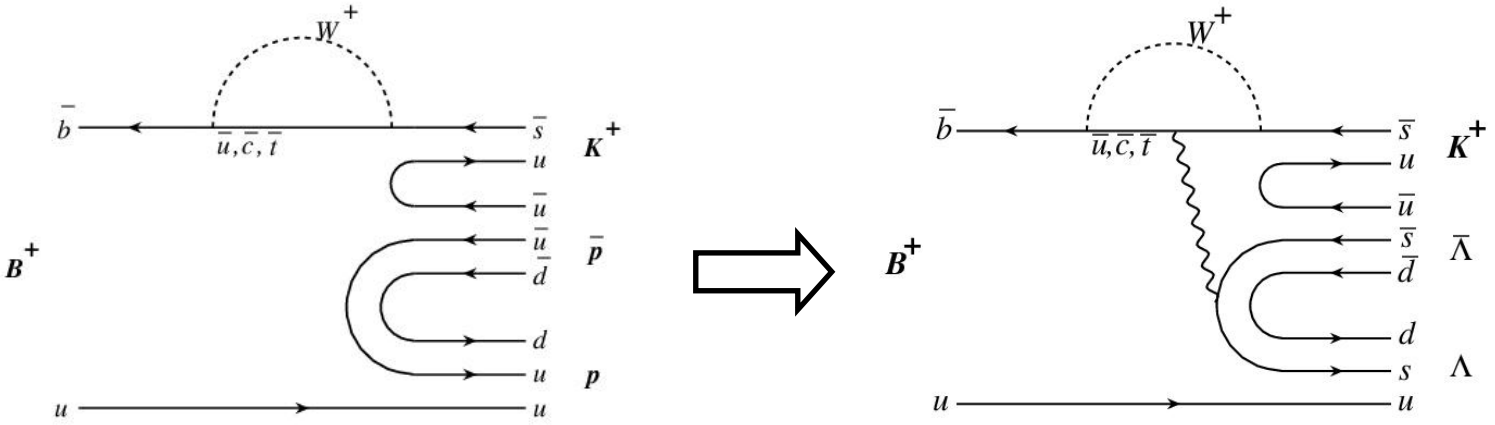
PRD 79, 052006 (2009)
$657\,\mathrm{M}\,B\bar{B}$

$B \to \Lambda\bar{\Lambda}h, h = K^{\pm}, K^{*(\pm,0)}, \bar{D}_0$
PRD 79, 052006 (2009)

$B \to p\bar{\Lambda}h, h = \pi^{\pm}, K^{\pm}, K^{*(\pm,0)}$
PRD 76, 052004 (2007)

$B \to p\bar{p}h, h = \pi^{\pm}, K^{\pm}, K^{*(\pm,0)}$
PRL 100, 251801 (2008)

- Compare $\Lambda\bar{\Lambda}h$ with $p\bar{p}h$ results to understand the dominant underlying physics
- "h" for π^+, K^+, K^0, K^{*+}, K^{*0}



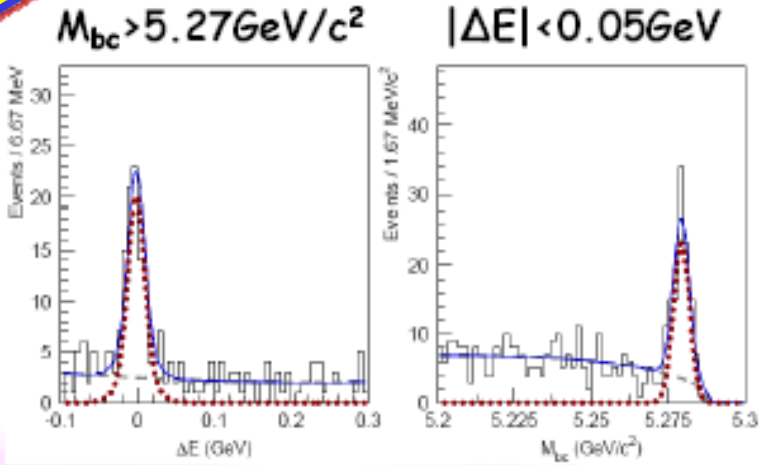
$B \to \Lambda\bar{\Lambda}h$

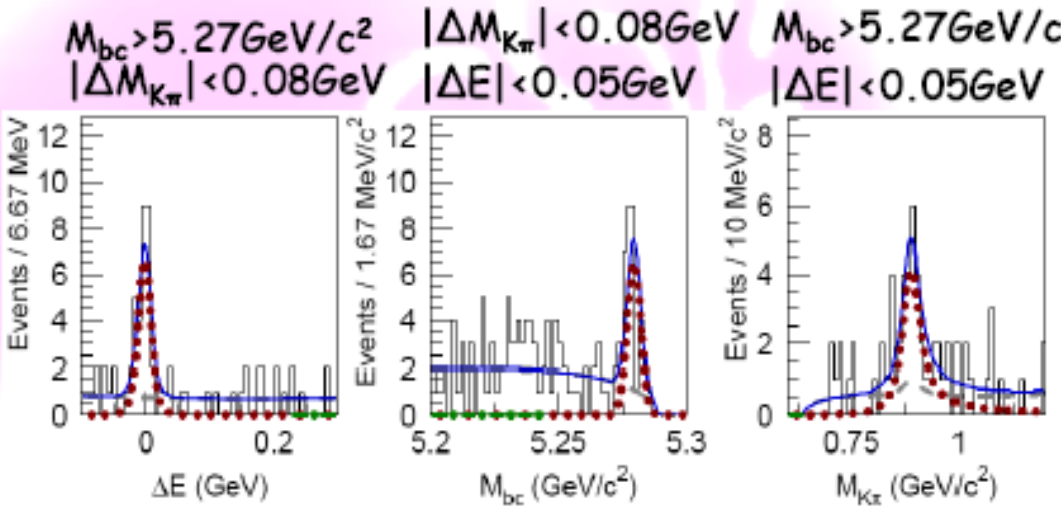
PRD 79, 052006 (2009)
657 M $B\bar{B}$

- BF($B^0 \to \Lambda\bar{\Lambda}K^0$)= $(4.76\,^{+0.84}_{-0.68} \pm 0.61) \times 10^{-6}$
  significance : 12.5 σ
- BF($B^0 \to \Lambda\bar{\Lambda}K^{*0}$)= $(2.46\,^{+0.87}_{-0.72} \pm 0.34) \times 10^{-6}$
  significance : 9.0 σ

First observation

Mode	Significance
$B^+ \to \Lambda\bar{\Lambda}K^{*+}$	3.7 σ
$B^0 \to \Lambda\bar{\Lambda}D^0$	3.4 σ
$B^+ \to \Lambda\bar{\Lambda}\pi^+$	2.5 σ

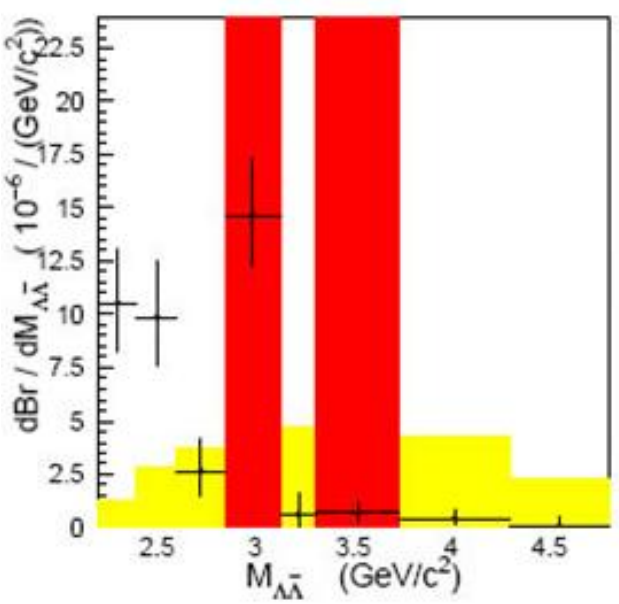




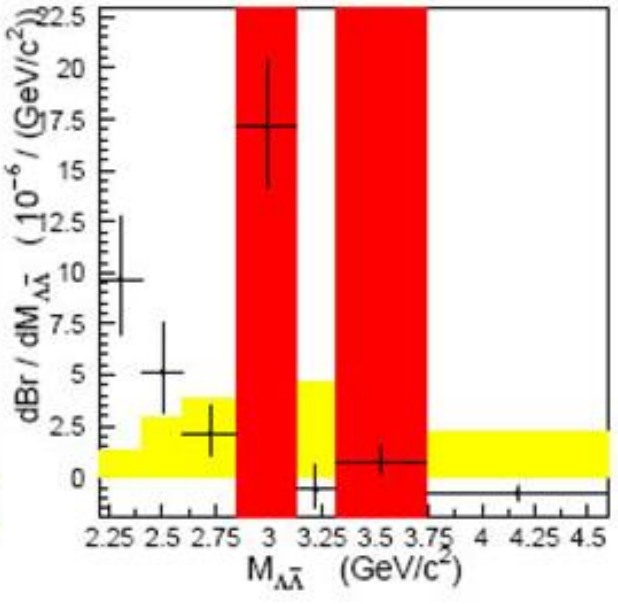
$B \to \Lambda\overline{\Lambda}h$

PRD 79, 052006 (2009)
657 M $B\overline{B}$

- A threshold enhancement is also present in these newly observed modes.



$B^0 \to \Lambda\,\overline{\Lambda}\,K^0$



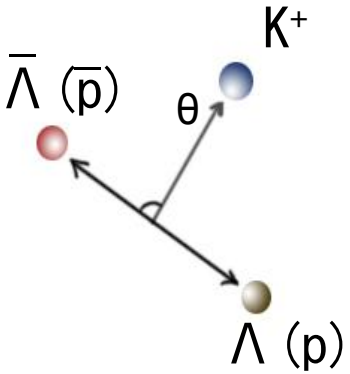
$B^0 \to \Lambda\,\overline{\Lambda}\,K^{*0}$

threshold enhancement: in baryonic B decays, a signal enhancement in the baryon-antibaryon system

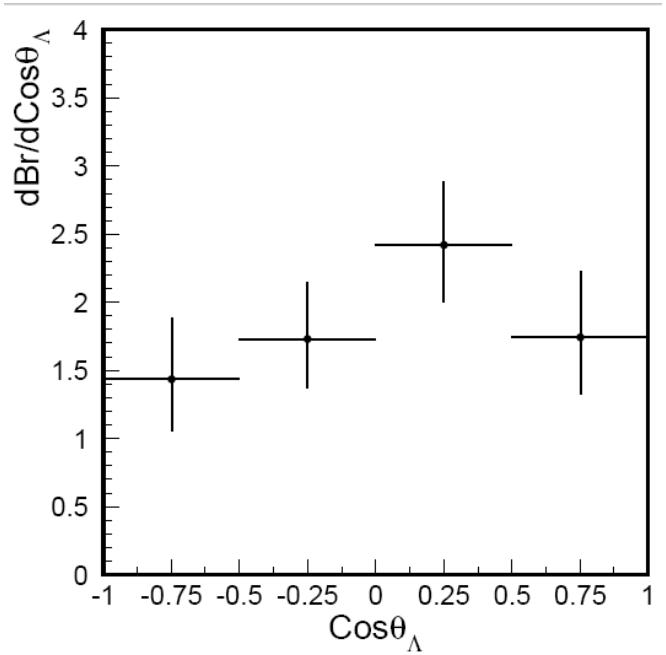
$B \to \Lambda\bar{\Lambda}h$

PRD 79, 052006 (2009)
657 M $B\bar{B}$

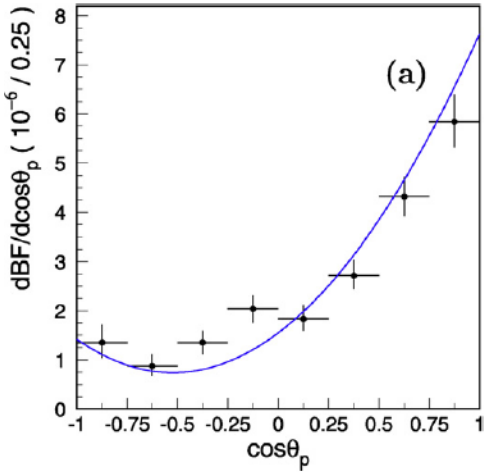
- Fit results in bins of $\cos\theta_\Lambda$ with $M_{\bar{\Lambda}\Lambda}$<2.85GeV/c^2



Angular distribution of $B^+ \to \Lambda\bar{\Lambda}K^+$



Angular distribution of $B^+ \to p\bar{p}K^+$



Belle PLB659, 80-86 (2008)

Comparison between $p\bar{p}h$ and $\Lambda\bar{\Lambda}h$

Branching Fractions (10^{-6})		Branching Fractions (10^{-6})	
$B^0 \to p\bar{p}K^0$	$2.51^{+0.35}_{-0.29} \pm 0.21$	$B^0 \to \Lambda\bar{\Lambda}K^0$	$4.76^{+0.84}_{-0.68} \pm 0.61$
$B^0 \to p\bar{p}K^{*0}$	$1.18^{+0.29}_{-0.25} \pm 0.11$	$B^0 \to \Lambda\bar{\Lambda}K^{*0}$	$2.46^{+0.87}_{-0.72} \pm 0.34$
$B^+ \to p\bar{p}K^+$	$5.54^{+0.27}_{-0.25} \pm 0.36$	$B^+ \to \Lambda\bar{\Lambda}K^+$	$3.38^{+0.41}_{-0.36} \pm 0.41$
$B^+ \to p\bar{p}K^{*+}$	$3.38^{+0.73}_{-0.60} \pm 0.39$	$B^+ \to \Lambda\bar{\Lambda}K^{*+}$	$2.19^{+1.13}_{-0.88} \pm 0.33$
$B^+ \to p\bar{p}\pi^+$	$1.60^{+0.22}_{-0.19} \pm 0.12$	$B^+ \to \Lambda\bar{\Lambda}\pi^+$	< 0.94

PLB659:80 (2008)

PRD79:052006 (2009)

PRL100:251801 (2008)

- the branching fractions indicate no one to one correspondence
  - comparably smaller BF($B^+ \to \Lambda\bar{\Lambda}\pi^+$)
  - considerably larger BF($B^0 \to \Lambda\bar{\Lambda}K^0$)
- lack of peaking feature in $\cos\theta_\Lambda$ distribution for $B^+ \to \Lambda\bar{\Lambda}K^+$
- the underlying physics between $B \to \Lambda\bar{\Lambda}h$ and $B \to p\bar{p}h$ might be different

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

PRD 80, 111103 (R) (2009)
657 M $B\bar{B}$

- Many 3-body charmless baryonic decays have been studied.
- How about 4-body modes?
  - BF hierarchy ?
  - Threshold-enhancement?

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

PRD 79, 052006 (2009)

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

PRD 76, 052004 (2007)

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

PRL 100, 251801 (2008)

charmed modes: b→c tree diagram

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

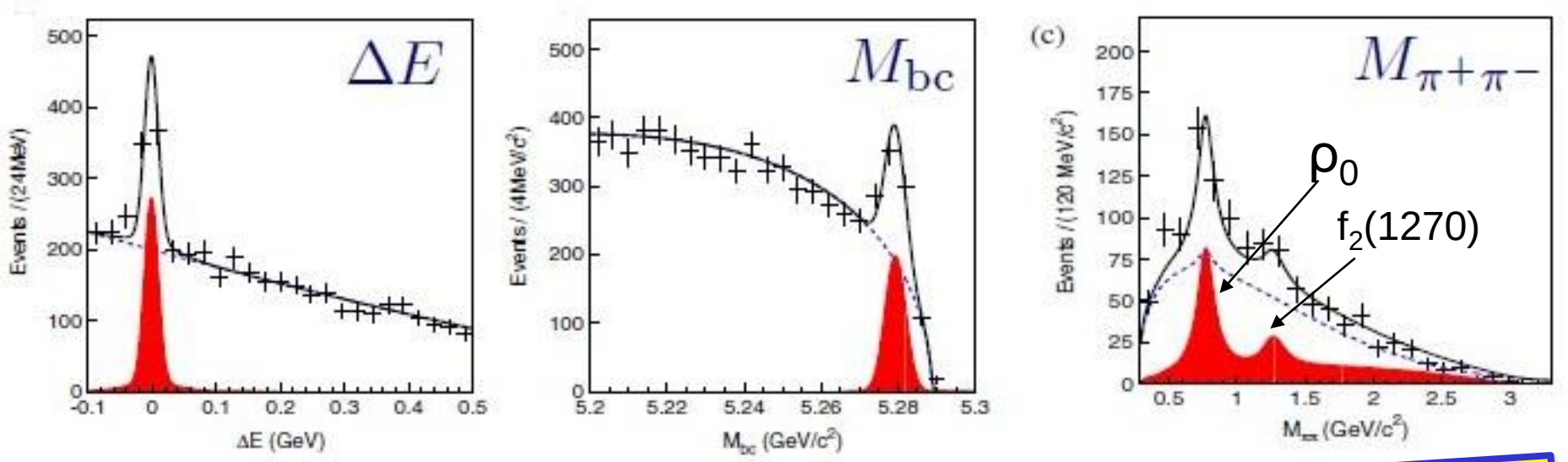
b→s penguin or b →u tree diagrams

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

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

PRD 80, 111103 (R) (2009)

657 M $B\bar{B}$



First observation

BF($B^+ \to p\bar{\Lambda}\pi^+\pi^-$) = $(5.92\ ^{+0.88}_{-0.84} \pm 0.69) \times 10^{-6}$ **(9.1σ)**

intermediate 3-body decays

BF($B^+ \to p\bar{\Lambda}\rho^0$) = $(4.78\ ^{+0.67}_{-0.64} \pm 0.60) \times 10^{-6}$ **(9.5σ)**

BF($B^+ \to p\bar{\Lambda}f_2(1270)$) = $(2.03\ ^{+0.77}_{-0.72} \pm 0.27) \times 10^{-6}$ **(3σ)**

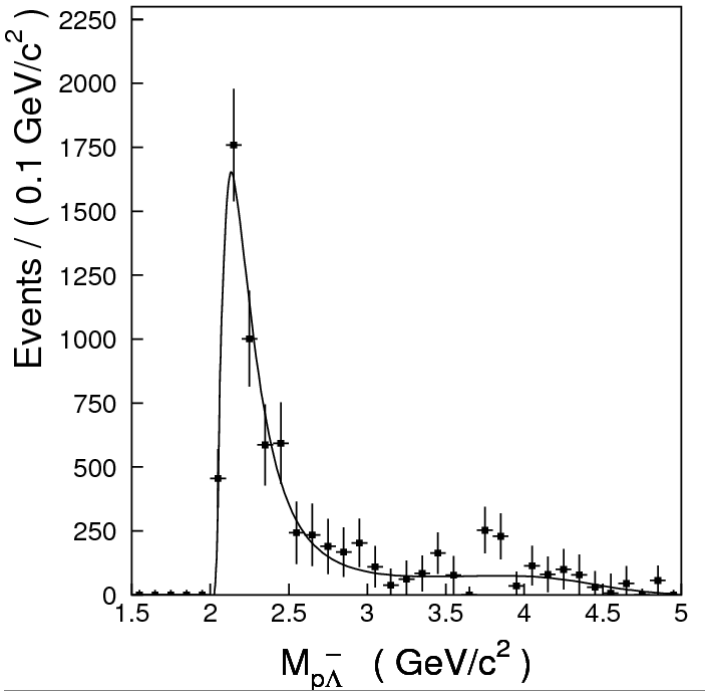
$$\mathrm{BF}(B^+ \to p\bar{\Lambda}\pi^+\pi^-)_{tot} = (11.28^{+0.91}_{-0.72} \pm 1.03) \times 10^{-6}$$

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

PRD 80, 111103 (R) (2009)

$657\,\mathrm{M}\,B\bar{B}$

- first observation of 4-body charmless baryonic decay
- BF(4-body)> BF(3-body)> BF(2-body)
- Multi-body hierarchy holds for charmless baryonic B decays
- near-threshold enhancement also seen



Summary

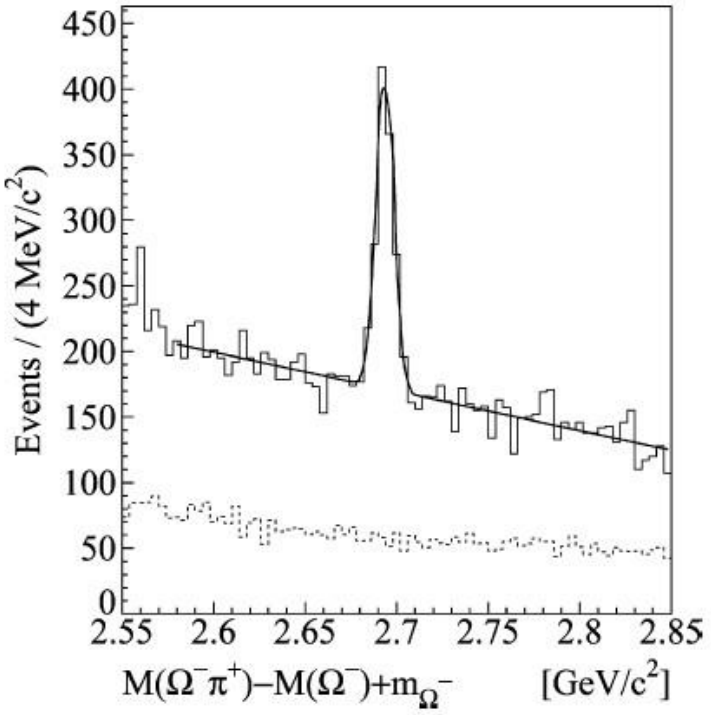
- ✓More baryonic modes have been observed
  - ➢ $B^- \to \Sigma_c(2800)^0 \bar{p}$
  - ➢ $B \to \Lambda\bar{\Lambda}K^0, B \to \Lambda\bar{\Lambda}K^{*0}, B^+ \to p\bar{\Lambda}\pi^+\pi^-$
- ✓Threshold-enhancement exists in all modes examined so far
- ✓Comparison between $p\bar{p}h$ and $\Lambda\bar{\Lambda}h$ shows that the dominant underlying decay diagrams may be different
- ✓First 4-body charmless baryonic decay has been observed
- ✓BR(4-body)≥BR(3-body)>BR(2-body), for both charm and charmless baryonic modes.

BACKUP slides

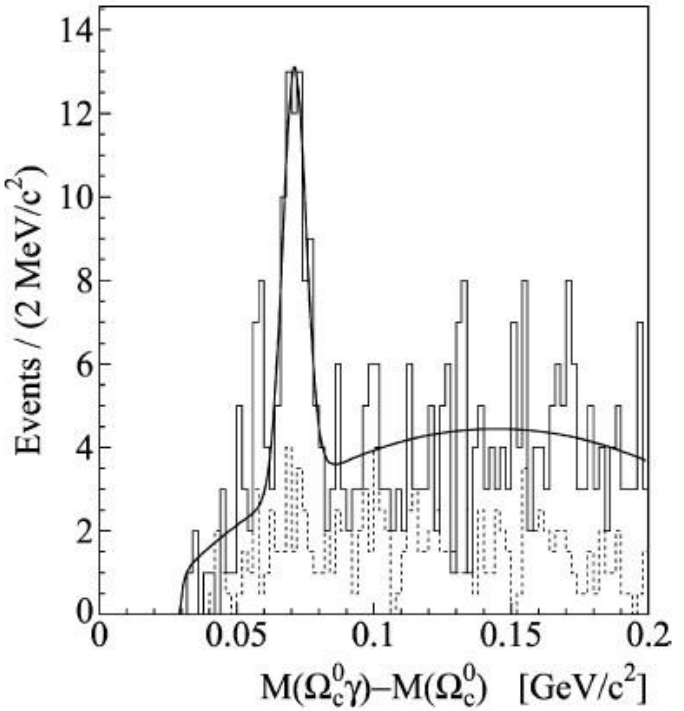
charmed double strange baryons Ω_c^0 and Ω_c^{*0}

PLB 672 1-5 (2009)
657 M BB

$\Omega_c^0 \to \Omega^- \pi^+$

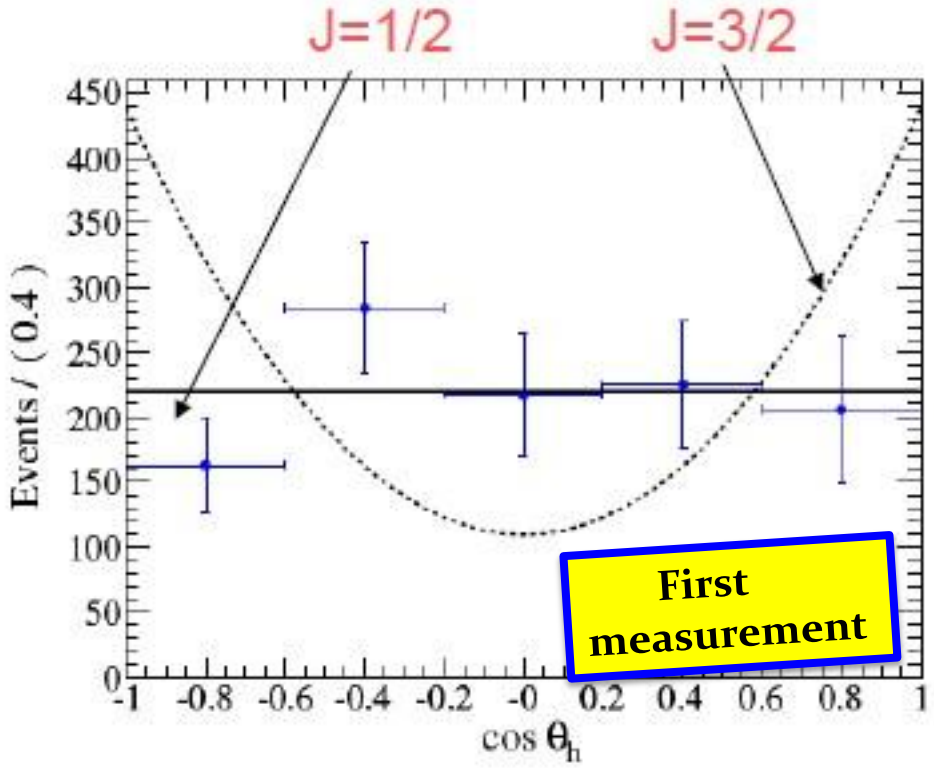


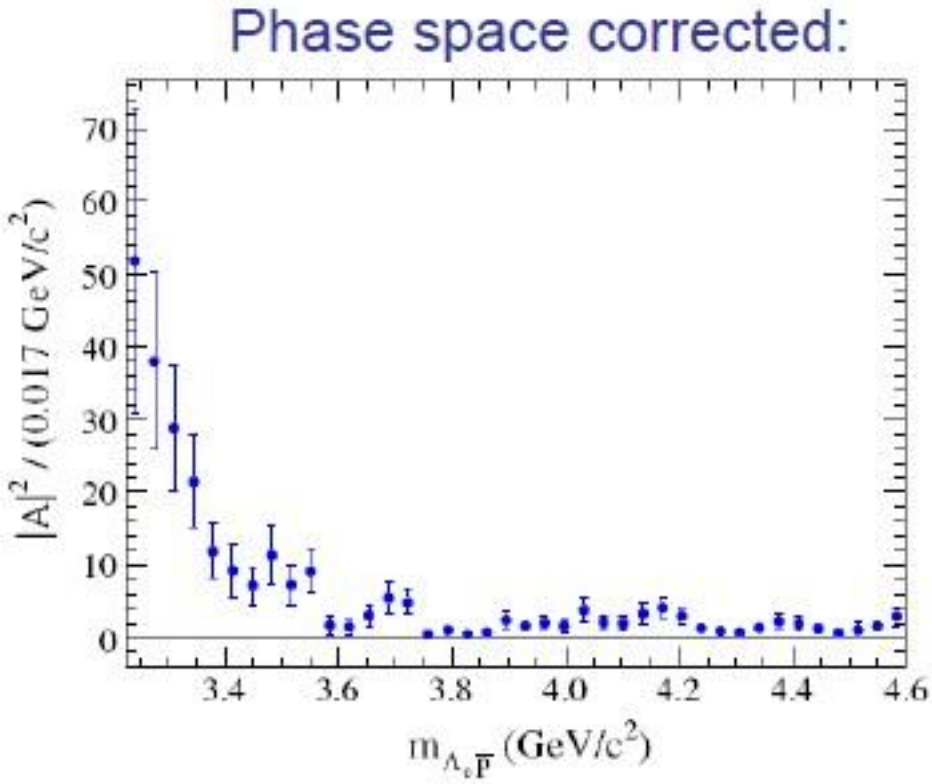
$\Omega_c^{*0} \to \Omega_c^0 \gamma$



	Ω_c^0 mass	$\Delta M(\Omega_c^{*0} - \Omega_c^0)$	
BaBar	2693.3±0.6 MeV/c²	70.8±1.0±1.1 MeV/c²	PRL 97 232001 (2006)
Belle	$2693.6 \pm 0.3^{+1.8}_{-1.5}$ MeV/c²	$70.7 \pm 0.9^{+1.0}_{-0.9}$ MeV/c²	PLB 672 1-5 (2009)

Spin of $\Sigma_c(2455)^0$ and $\Lambda_c^+ p$ Threshold Enhancement



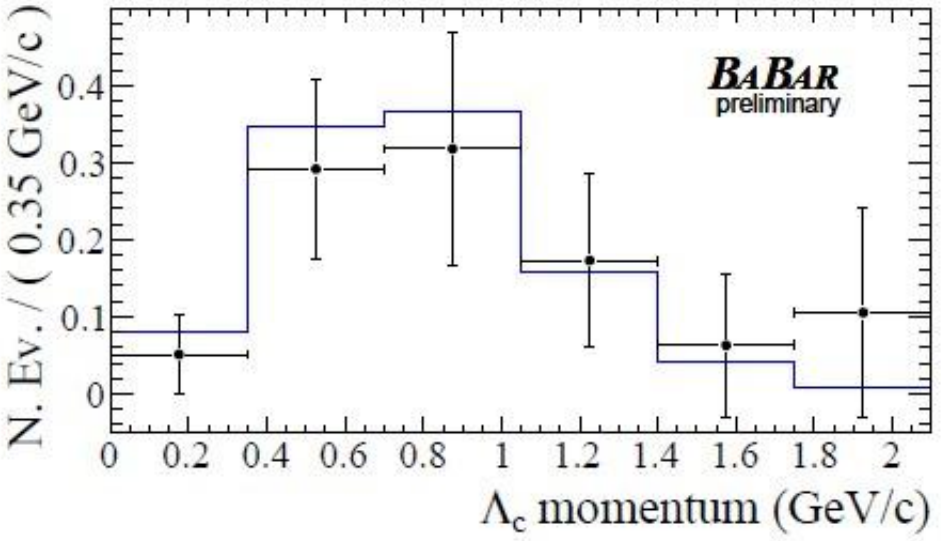


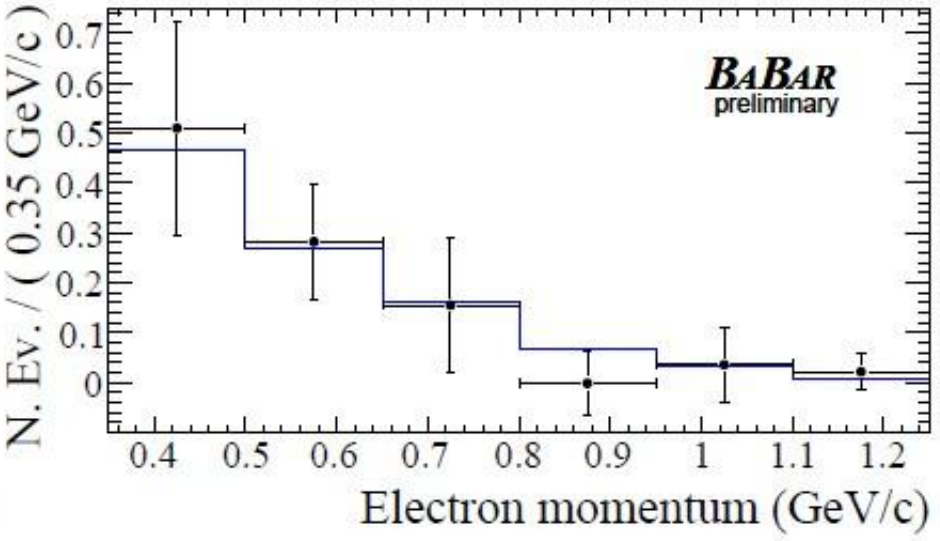
- $\Sigma_c(2455)^0$ is consistent with J=1/2, with J=3/2 excluded at >4σ level.
- Threshold enhancement common in other baryonic modes as:

$$B \to p\bar{p}K \text{ and } B \to Dp\bar{p}(\pi)$$

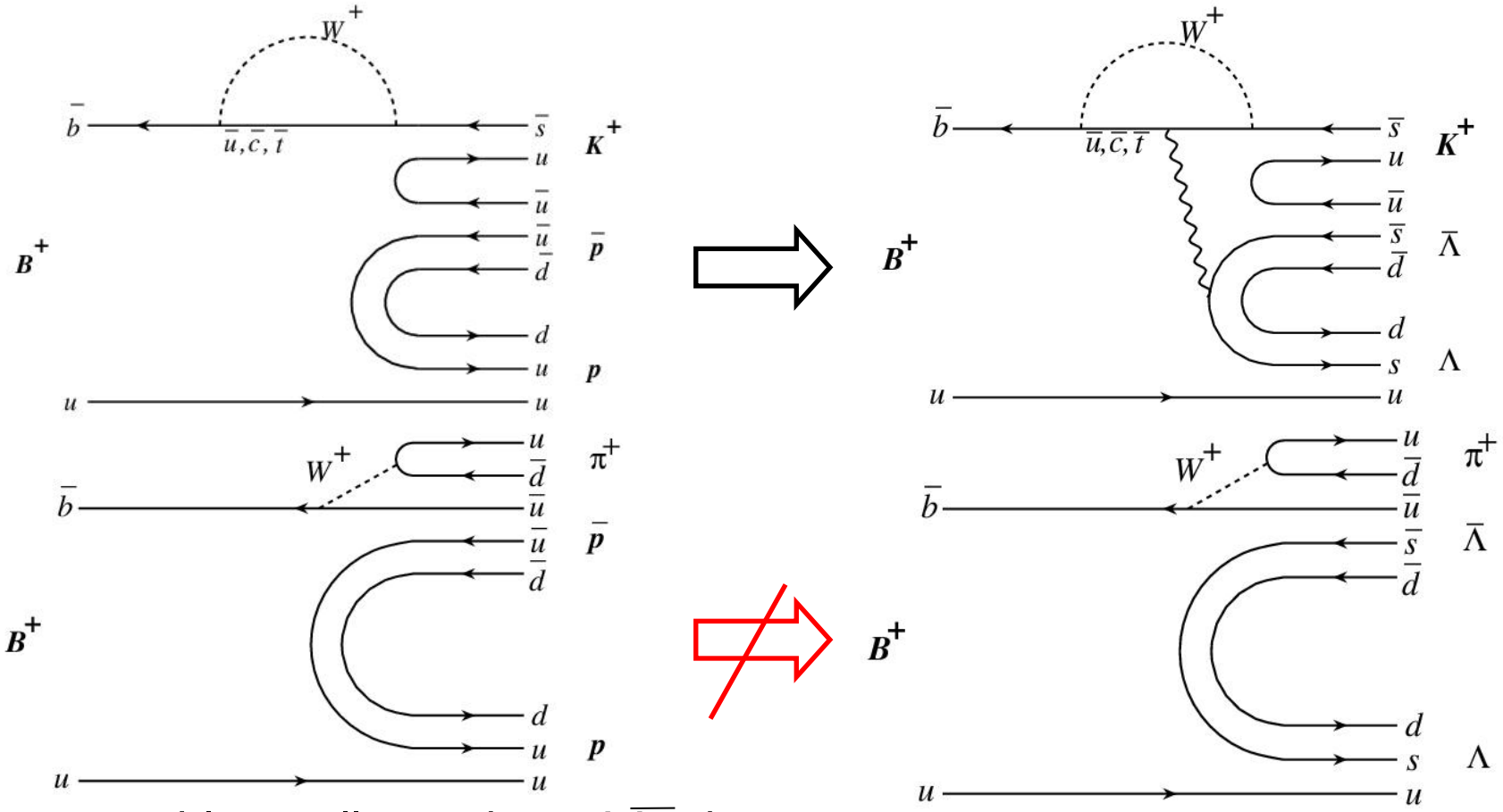
Semileptonic decays into Λ_c^+

BaBar hep-ex 0808.0011
(preliminary)





Discussion based on quark diagrams



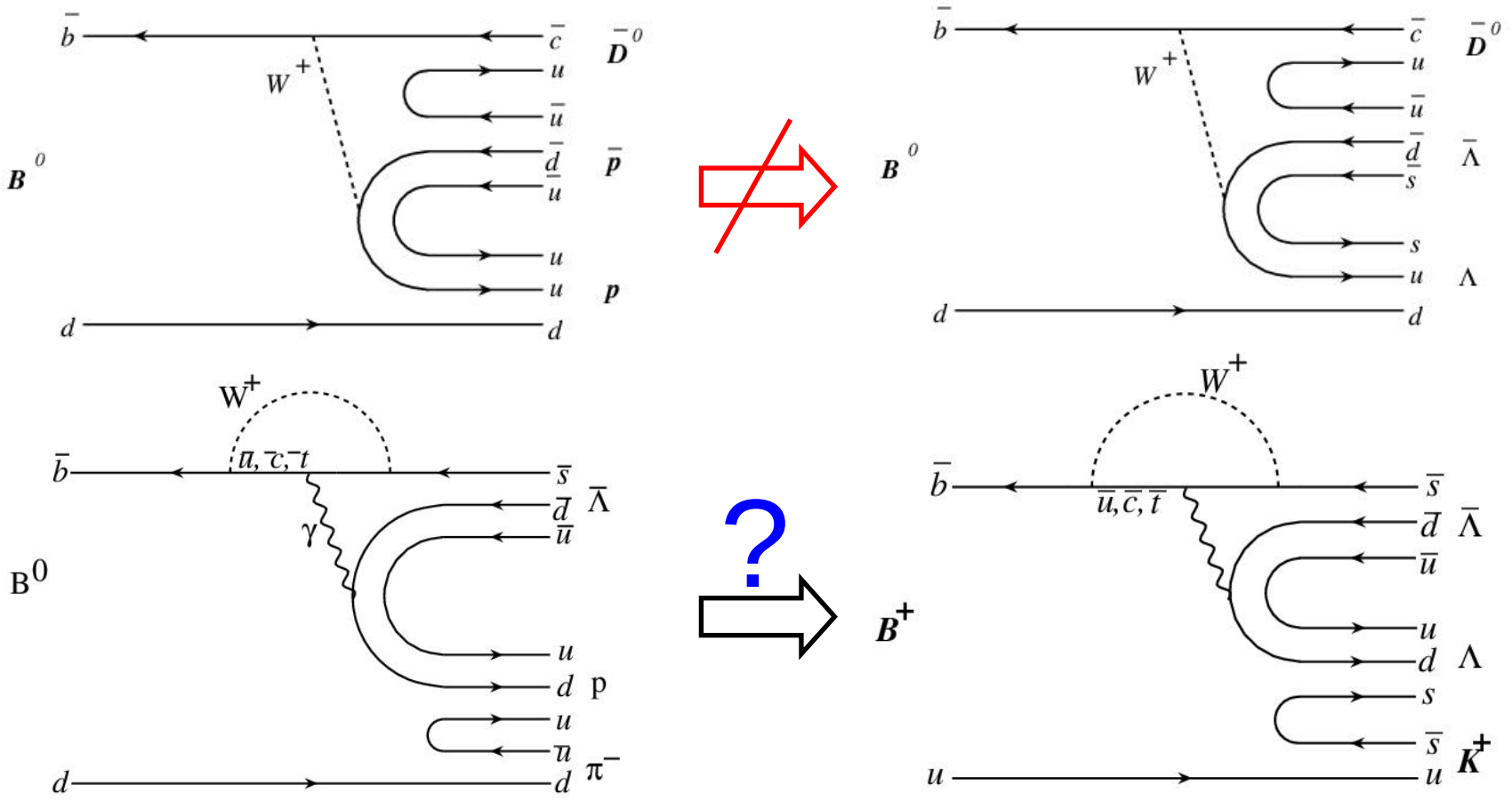
comparably smaller BF($B^+ \to \Lambda\bar{\Lambda}\pi^+$)

considerably larger BF($B^0 \to \Lambda\bar{\Lambda}K^0$)

lack of peaking feature in $\cos\theta_\Lambda$ distribution for $B^+ \to \Lambda\bar{\Lambda}K^+$

→ **$B \to \Lambda\bar{\Lambda}h \neq B \to p\bar{p}h$?**

cont'd



- B to $\bar{\Lambda}\Lambda K$ mode might behave like B to $p\bar{\Lambda}\pi$ mode?

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

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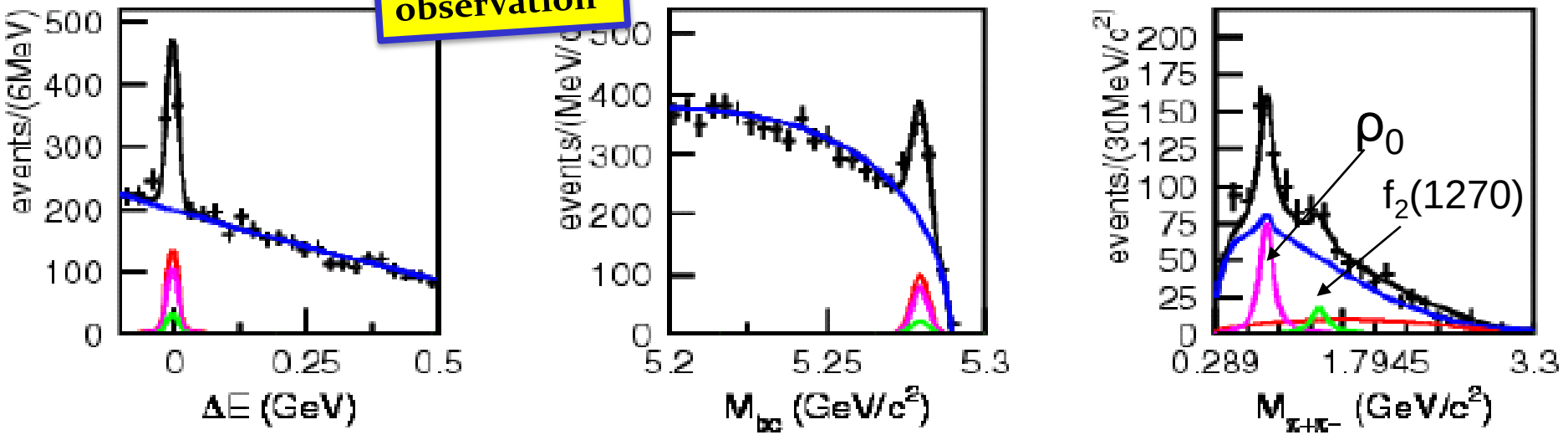
657 M $B\bar{B}$



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

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

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

Blue: background

Black: total