



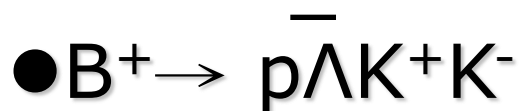
Recent results of many-body baryonic B decays from Belle

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on behalf of the Belle Collaboration

2019/2/10-2019/2/16

- Introduction



- charge conjugate modes included

- Summary





Motivations for $B \rightarrow p\bar{\Lambda}KK$

- $b \rightarrow s$ penguin loop probes new physics due to new heavy particle's contribution
- Most baryonic B decays show threshold enhancement and angular asymmetry
- Hierarchical structure

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

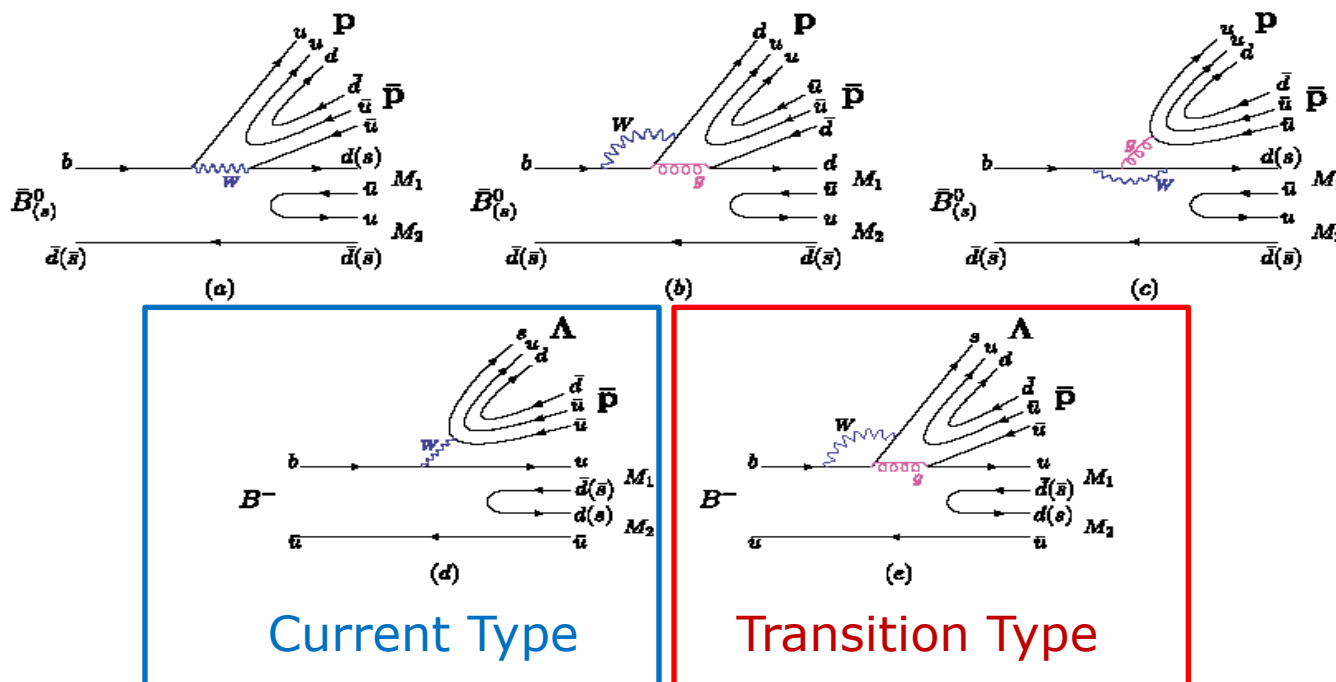
A. J. Bevan *et al.*, *The Physics of the B Factories* EPJ C74:3026 (2014)

- Evidence of CP violation in baryonic B decays

R Aaij *et al.*, LHCb collaboration
PRL 113:141801 (2014)

Four-body decays - a test for generalized factorization

- Four-body baryonic B decays can be estimated by a generalized factorization approach





Related Theoretical predictions

Branching ratios	Our results	Data
$10^6 \mathcal{B}(B^- \rightarrow \Lambda \bar{p} \pi^+ \pi^-)$	$3.7_{-0.5}^{+1.2} \pm 0.1 \pm 0.9$	5.9 ± 1.1
$10^6 \mathcal{B}(B^- \rightarrow \Lambda \bar{p} K^+ K^-)$	$3.0_{-0.5}^{+1.1} \pm 0.1 \pm 0.7$	-
$10^6 \mathcal{B}(\bar{B}^0 \rightarrow p \bar{p} \pi^+ \pi^-)$	$3.0_{-0.3}^{+0.5} \pm 0.3 \pm 0.7$	3.0 ± 0.3
$10^6 \mathcal{B}(\bar{B}^0 \rightarrow p \bar{p} \pi^\pm K^\mp)$	$6.6 \pm 0.5 \pm 0.0 \pm 2.3$	6.6 ± 0.5

Y.K. Hsiao and C.Q. Geng
PLB 770:348-351(2017)

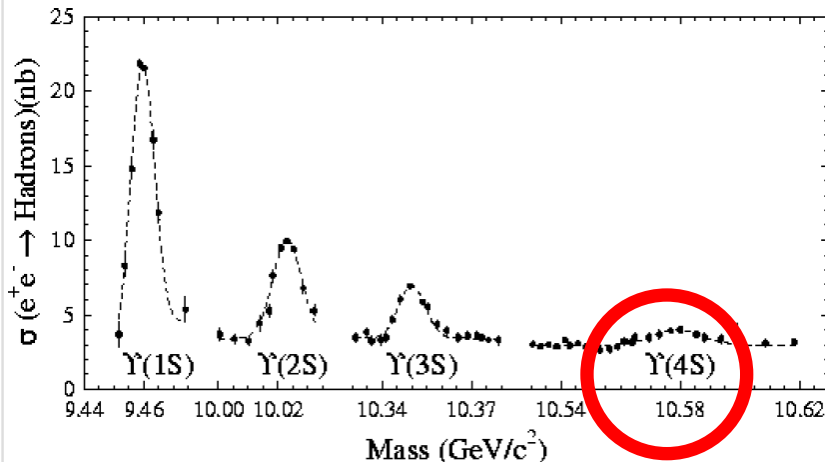
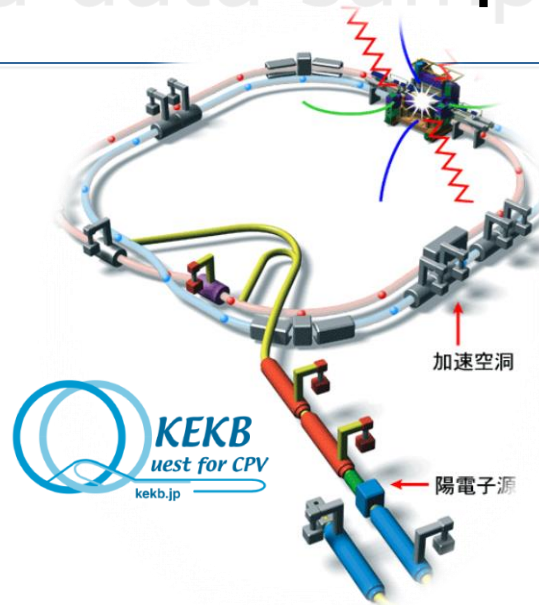
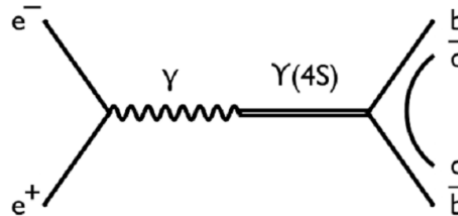
decay mode	our result	data
$B^- \rightarrow \Lambda \bar{p} \rho^0$	$3.28_{-0.31}^{+0.66} \pm 0.31$	4.78 ± 0.90
$\bar{B}^0 \rightarrow \Lambda \bar{p} \rho^+$	$3.01_{-0.29}^{+0.62} \pm 0.31$	-
$B^- \rightarrow \Lambda \bar{p} \phi$	$1.51_{-1.46}^{+1.49} \pm 0.28$	-
$B^- \rightarrow \Lambda \bar{\Lambda} K^{*-}$	$1.91_{-0.14}^{+0.52} \pm 0.20$	2.19 ± 1.18
$\bar{B}^0 \rightarrow \Lambda \bar{\Lambda} \bar{K}^{*0}$	$1.76_{-0.13}^{+0.47} \pm 0.18$	2.46 ± 0.93

C.Q. Geng and Y.K. Hsiao
PRD 85:017501(2012)

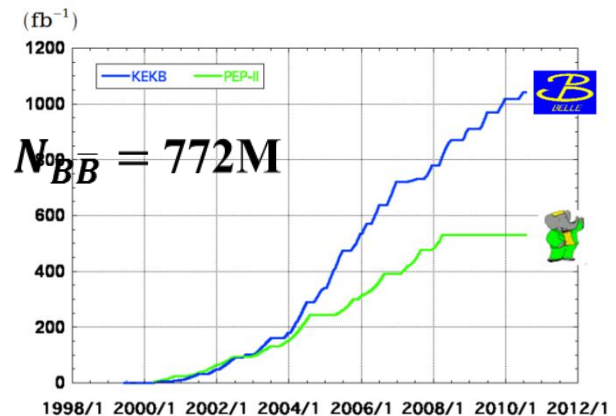


KEKB factory and data sample

- An asymmetric energy e^+e^- collider at KEK.
- LER(e^+): 3.5 GeV
HER(e^-): 8 GeV
Crossing angle: ± 11 mrad
- Target: $e^+e^- \rightarrow \Upsilon(4S) \rightarrow B\bar{B}$
- Main background: $e^+e^- \rightarrow q\bar{q}$ ($q = u, d, s, c$) with about 3 times larger cross section.
- The CM energy of e^+e^- are set to be $\Upsilon(4S)$ resonance

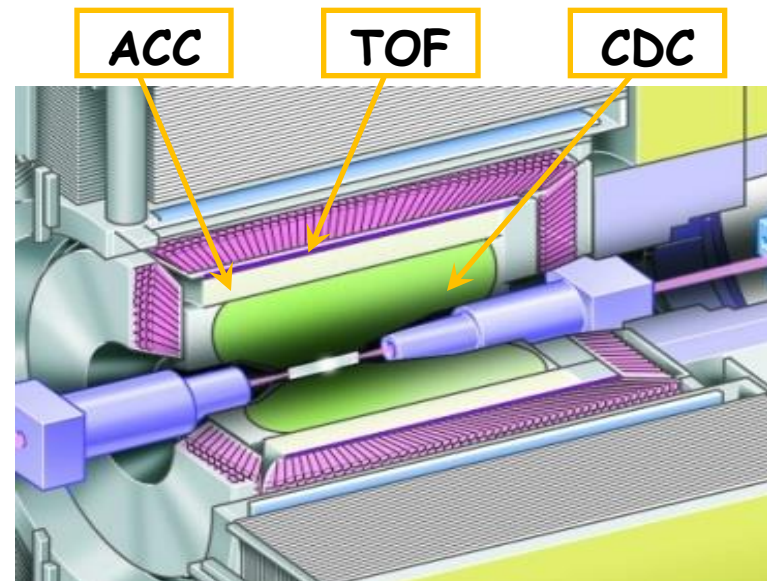


Integrated luminosity of B factories



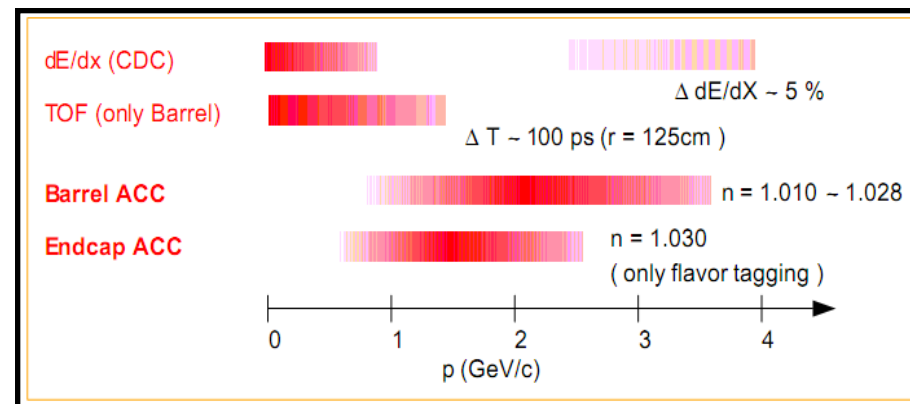
- > 1 ab⁻¹**
- On resonance:**
 $\Upsilon(5S)$: 121 fb⁻¹
 $\Upsilon(4S)$: 711 fb⁻¹
 $\Upsilon(3S)$: 3 fb⁻¹
 $\Upsilon(2S)$: 25 fb⁻¹
 $\Upsilon(1S)$: 6 fb⁻¹
- Off reson./scan:**
 ~ 100 fb⁻¹
- ~ 550 fb⁻¹**
- On resonance:**
 $\Upsilon(4S)$: 433 fb⁻¹
 $\Upsilon(3S)$: 30 fb⁻¹
 $\Upsilon(2S)$: 14 fb⁻¹
- Off resonance:**
 ~ 54 fb⁻¹

- **Charged particle: e, μ, π, K, p**
 - **ACC:** Silica aerogel for Cerenkov light detected by FM-PMT
 - **TOF:** Plastic scintillator with Timing resolution ~ 100 ps
 - **CDC:** Wire drift chamber with He/C_2H_6 for dE/dx , p_t , and p_z of charged track
 - $\mathcal{L}_i = \mathcal{L}_i^{CDC} \times \mathcal{L}_i^{TOF} \times \mathcal{L}_i^{ACC}$

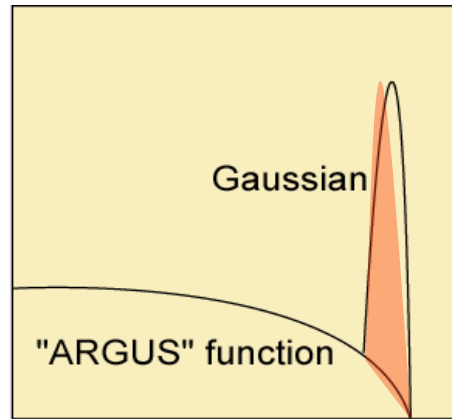


- **ECL:** Calorimeter cluster information for e, γ , and $\pi^0 \rightarrow \gamma\gamma$
- **KLM:** Information for K_L^0 and μ

- $K_S^0 \rightarrow \pi^+ \pi^-$
- $\Lambda \rightarrow p \pi^-$
- $\gamma \rightarrow e^+ e^-$



B Signal Reconstruction

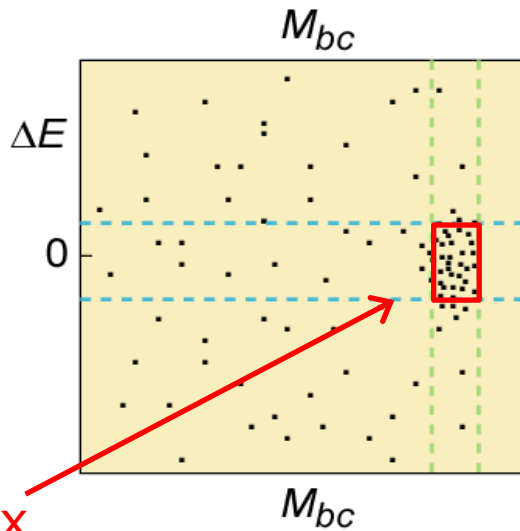


$$\mathbf{BF = N_{sig}/\epsilon/N_{BB}}$$

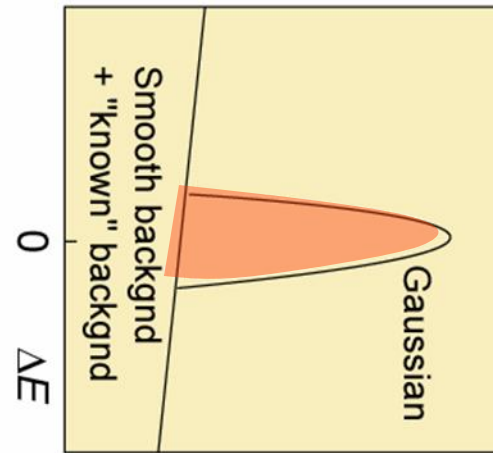
$$\Delta E = E(B \text{ cand.}) - E_{beam}$$

$$M_{bc} = \sqrt{E_{beam}^2 - P(B \text{ cand.})^2}$$

(all in CM frame)



Signal Box



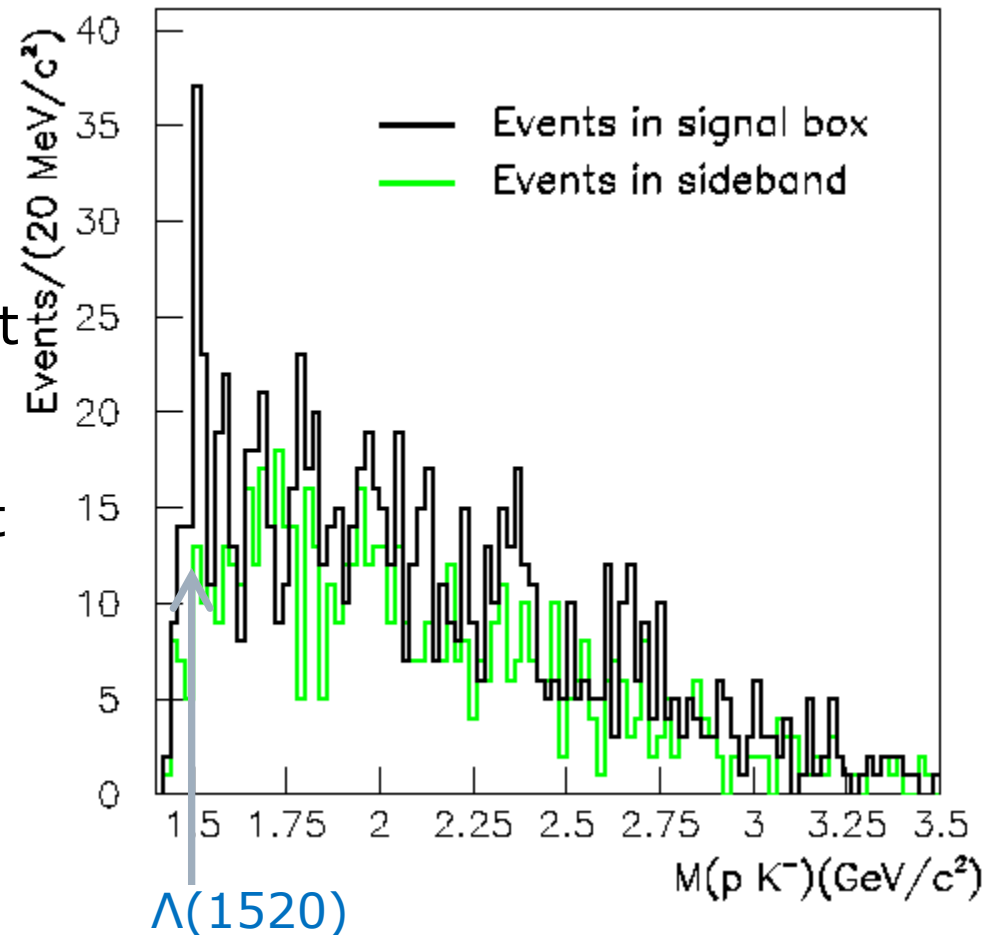
Intermediate resonances

Found many intermediate Resonances:

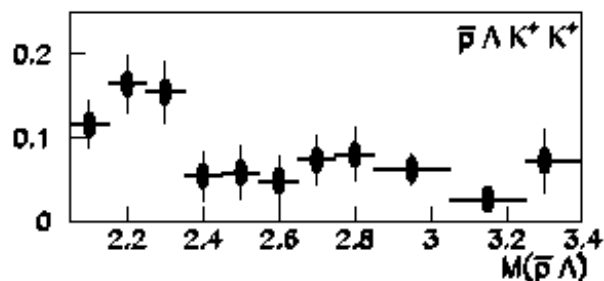
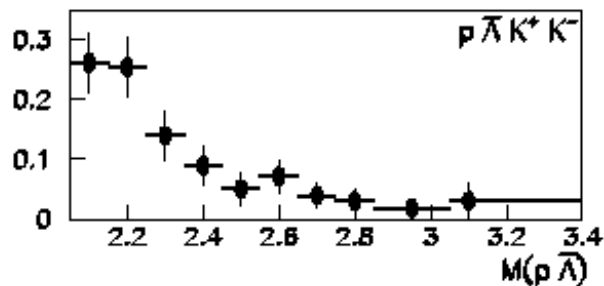
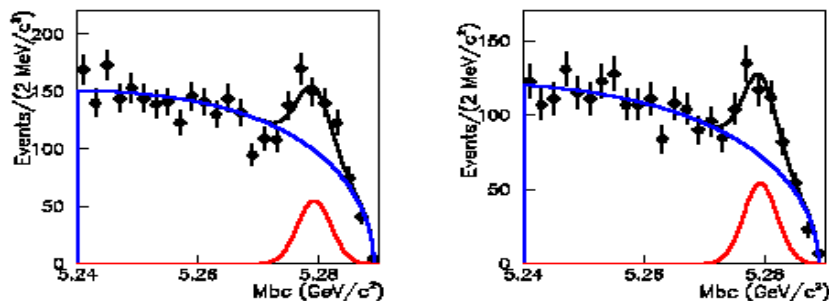
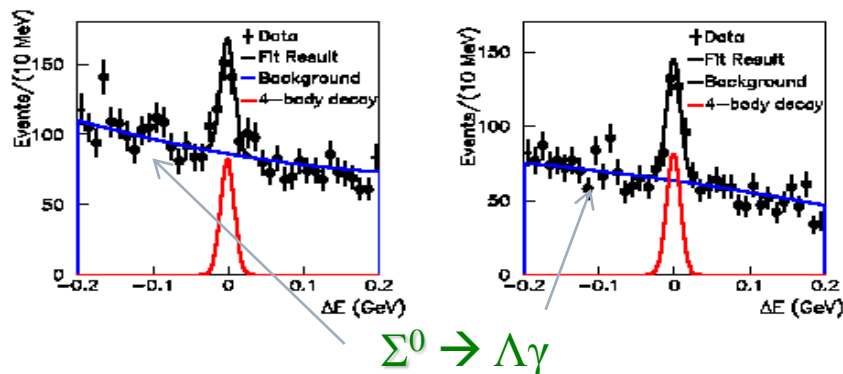
J/ψ η_c χ_c in $p\bar{\Lambda} K^-$ mass plot
 $\bar{p}\Lambda K^+$

Φ in K^+K^- mass plot

$\Lambda(1520)$ in pK^- mass plot



Vetoing all visible resonances



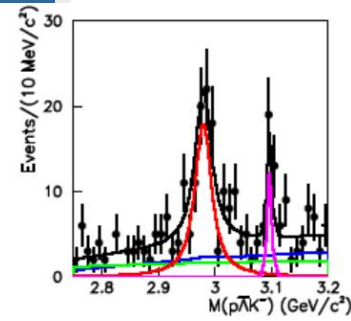
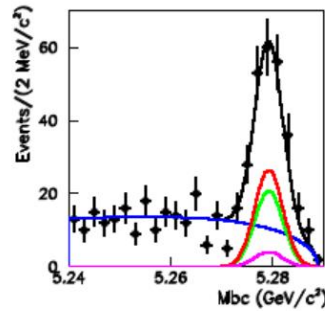
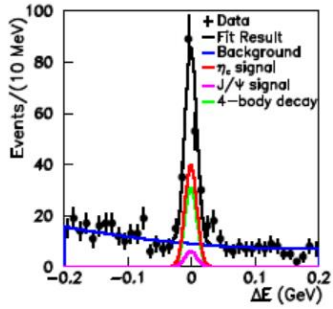
threshold effect observed

4-body decays

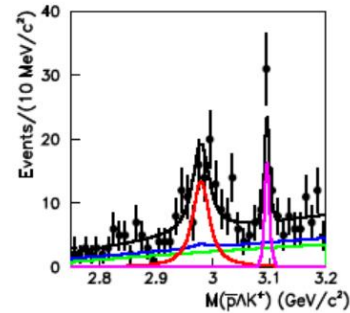
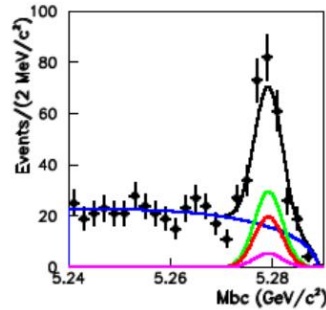
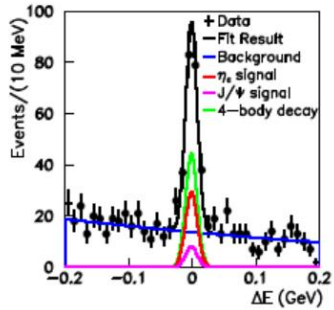
Mode	N_s	$\epsilon_{\text{eff}}(\%)$	sys(%)	sig (σ)
$B^+ \rightarrow p \bar{\Lambda} K^+ K^-$	$190.1^{+20.3}_{-19.6}$	5.84	12.2	11.7
$B^+ \rightarrow \bar{p} \Lambda K^+ K^+$	$188.0^{+19.2}_{-18.4}$	6.40	11.8	12.7



$$B^+ \rightarrow \eta_c K^+ (\eta_c \rightarrow p \bar{\Lambda} K^-) \text{ \& } B^+ \rightarrow J/\psi K^+ (J/\psi \rightarrow p \bar{\Lambda} K^-)$$



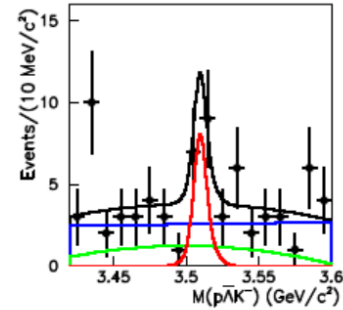
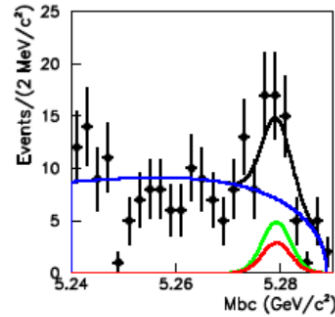
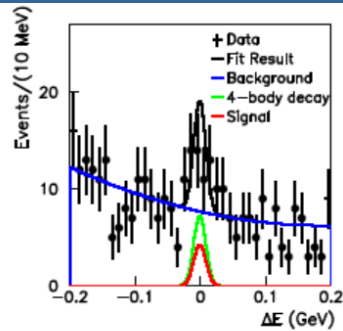
$$p \bar{\Lambda} K^+ K^-$$



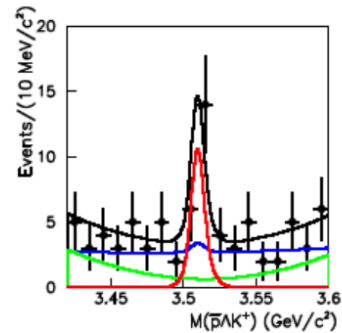
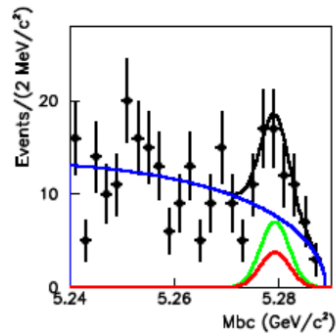
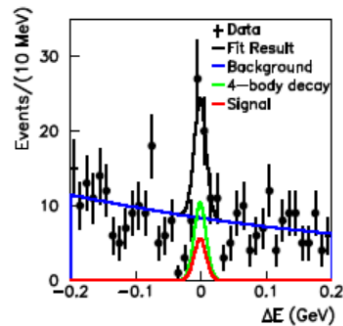
$$\bar{p} \Lambda K^+ K^+$$

$(B^+ \rightarrow J/\psi K^+)$	$19.0^{+5.7}_{-5.0}$	6.57	7.83	4.92	$(B^+ \rightarrow \eta_c K^+)$	$89.7^{+14.1}_{-13.3}$	7.19	5.91	8.46
$\times (J/\psi \rightarrow p \bar{\Lambda} K^-)$					$\times (\eta_c \rightarrow p \bar{\Lambda} K^-)$				
$(B^+ \rightarrow J/\psi K^+)$	$25.5^{+6.6}_{-5.9}$	6.56	5.90	5.50	$(B^+ \rightarrow \eta_c K^+)$	$67.0^{+14.1}_{-13.3}$	7.36	7.55	5.63
$\times (J/\psi \rightarrow \bar{p} \Lambda K^+)$					$\times (\eta_c \rightarrow \bar{p} \Lambda K^+)$				
Total significance of the J/ψ mode				7.38	Total significance of the η_c mode				10.2

$B^+ \rightarrow \chi_{c1} K^+$



$p\bar{\Lambda}K^+K^-$



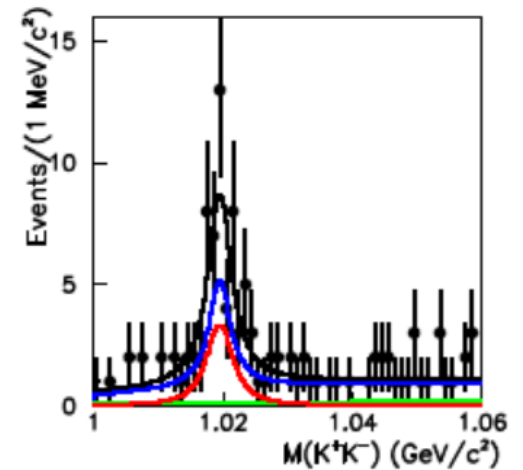
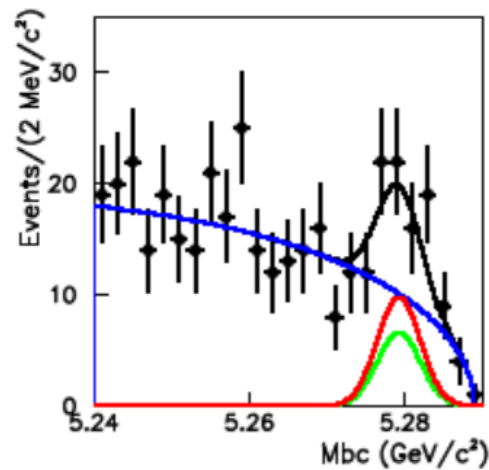
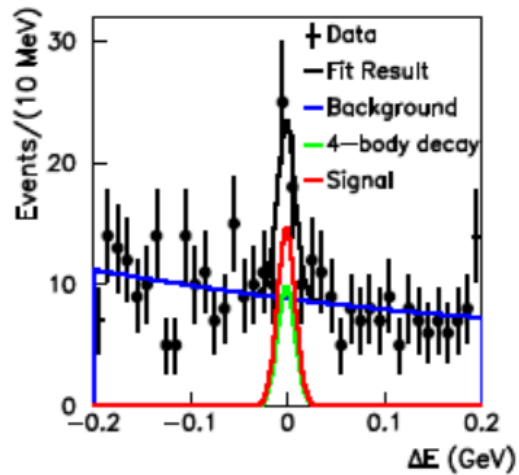
$\bar{p}\Lambda K^+K^+$

$(B^+ \rightarrow \chi_{c1} K^+)$	$10.2^{+4.6}_{-3.9}$	7.39	11.9	3.18
$\times (\chi_{c1} \rightarrow p\bar{\Lambda}K^-)$				
$(B^+ \rightarrow \chi_{c1} K^+)$	$13.4^{+5.0}_{-4.3}$	6.38	10.5	3.79
$\times (\chi_{c1} \rightarrow \bar{p}\Lambda K^+)$				

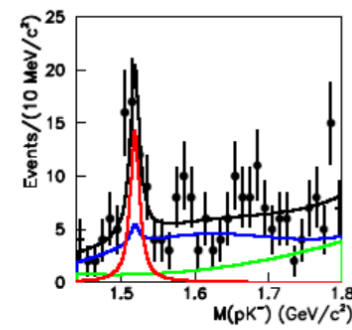
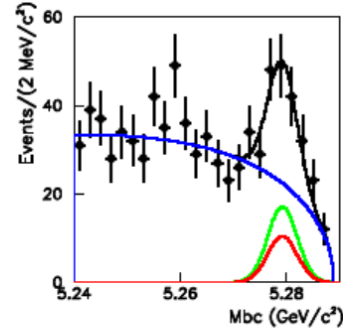
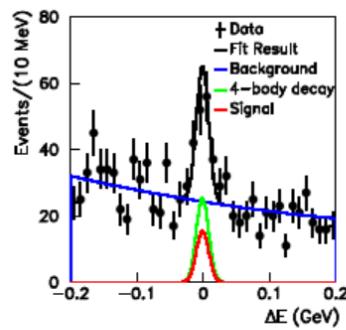
Total significance of the χ_{c1} mode

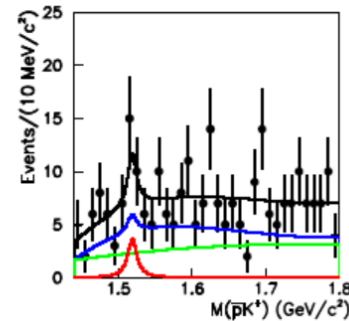
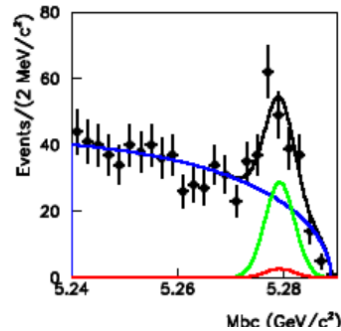
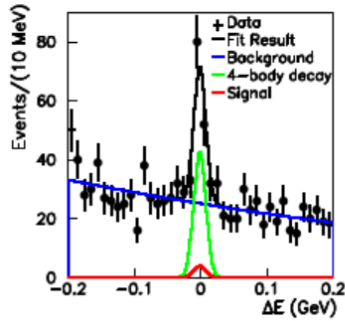
4.95

$$B^+ \rightarrow p\bar{\Lambda}\phi$$



Mode	N_s	$\epsilon_{\text{eff}}(\%)$	sys(%)	sig (σ)
$(B^+ \rightarrow p\bar{\Lambda}\phi)$	23.2 ± 6.1	7.52	9.53	5.15
$\times (\phi \rightarrow K^+K^-)$				

$$B^+ \rightarrow \Lambda(1520)\bar{\Lambda}K^+ \quad \& \quad B^+ \rightarrow \bar{\Lambda}(1520)\Lambda K^+$$


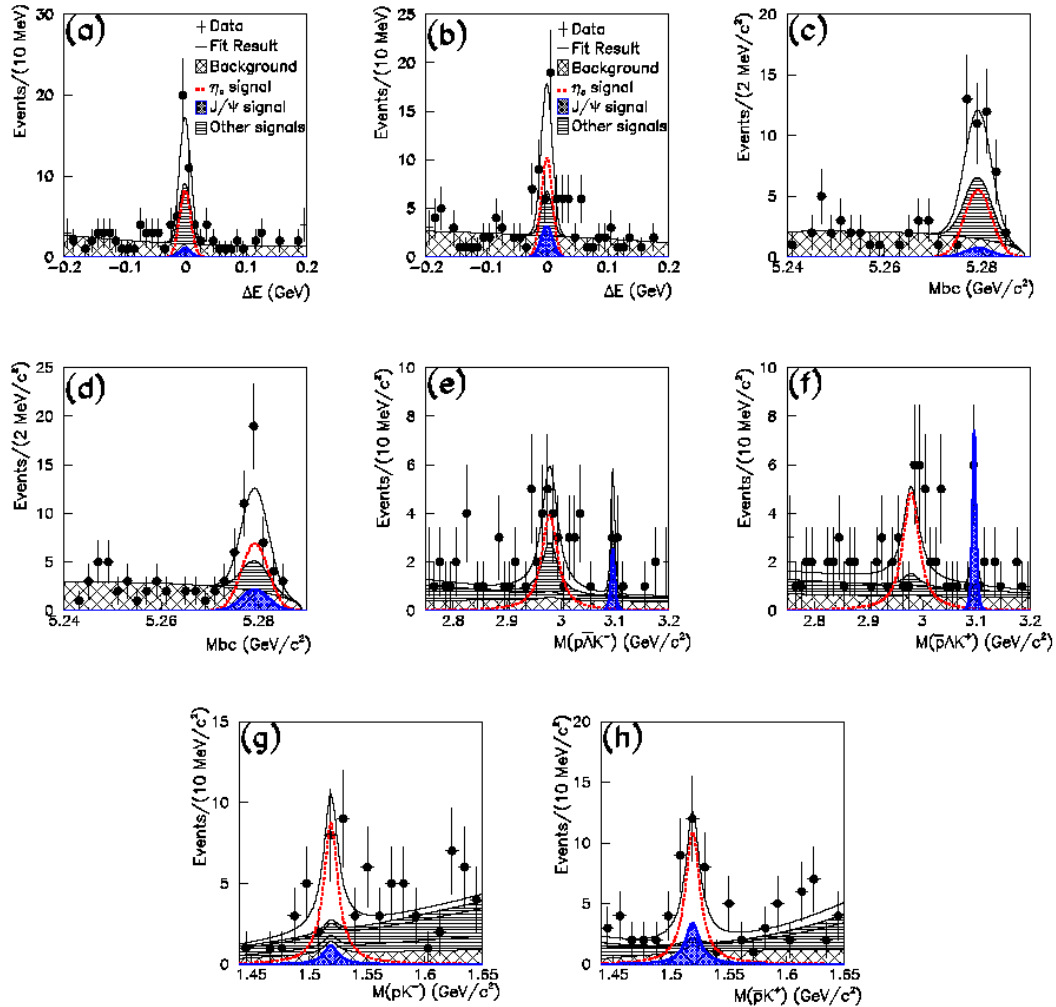
$$p\bar{\Lambda}K^+K^-$$


$$\bar{p}\Lambda K^+K^+$$

Mode	N_s	$\epsilon_{\text{eff}}(\%)$	sys(%)	sig (σ)
$(B^+ \rightarrow \Lambda(1520)\bar{\Lambda}K^+)$ $\times (\Lambda(1520) \rightarrow pK^-)$	30.3 ± 8.6	7.60	10.5	4.08
$(B^+ \rightarrow \bar{\Lambda}(1520)\Lambda K^+)$ $\times (\bar{\Lambda}(1520) \rightarrow \bar{p}K^+)$	19.8	5.70	90% C.L.	

$$B^+ \rightarrow J/\psi K^+ \quad (J/\psi \rightarrow \Lambda(1520)\bar{\Lambda})$$

$$B^+ \rightarrow \eta_c K^+ \quad (\eta_c \rightarrow \Lambda(1520)\Lambda)$$



Summary of measurements

✦ new observation

Mode	Branching fraction
✦ $B^+ \rightarrow p\bar{\Lambda}K^+K^-$	$(4.10^{+0.45}_{-0.43} \pm 0.50) \times 10^{-6}$
✦ $B^+ \rightarrow \bar{p}\Lambda K^+K^+$	$(3.70^{+0.39}_{-0.37} \pm 0.44) \times 10^{-6}$
✦ $B^+ \rightarrow p\bar{\Lambda}\phi$	$(7.95 \pm 2.09 \pm 0.77) \times 10^{-7}$
✦ $\eta_c \rightarrow p\bar{\Lambda}K^- + \text{c.c.}$	$(2.83^{+0.36}_{-0.34} \pm 0.35) \times 10^{-3}$
$J/\psi \rightarrow p\bar{\Lambda}K^- + \text{c.c.}$	$(8.32^{+1.63}_{-1.45} \pm 0.49) \times 10^{-4}$
$\chi_{c1} \rightarrow p\bar{\Lambda}K^- + \text{c.c.}$	$(9.15^{+2.63}_{-2.25} \pm 0.86) \times 10^{-4}$
$B^+ \rightarrow \Lambda(1520)\bar{\Lambda}K^+$	$(2.23 \pm 0.63 \pm 0.25) \times 10^{-6}$
$\eta_c \rightarrow \Lambda(1520)\bar{\Lambda} + \text{c.c.}$	$(3.48 \pm 1.48 \pm 0.46) \times 10^{-3}$
$J/\psi \rightarrow \Lambda(1520)\bar{\Lambda} + \text{c.c.}$	$< 1.80 \times 10^{-3}$
$B^+ \rightarrow \bar{\Lambda}(1520)\Lambda K^+$	$< 2.08 \times 10^{-6}$

Theoretical prediction

$$(3.0 \pm \text{***}) \times 10^{-6}$$

$$(1.5 \pm \text{***}) \times 10^{-6}$$

PDG value

$$(8.9 \pm 1.6) \times 10^{-4}$$

$$2^*(4.1 \pm 0.4) \times 10^{-4}$$



Summary

- Many more baryonic B decays are observed and a generalized factorization picture can describe data
- Threshold effect persists
- Three-body Baryonic decays could be useful to understand the charmonium system
- Many less significant decays will be measured in the near future with super B factories