Prospects of studying baryonic B decays at BelleII

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2019/4/3

- Historical review
- Findings at LHCb
- Recent Belle results
- Tools development

  (for tagging neutral hadrons)
- Summary

National Taiwan University

NTU contributions

- First observation of rare baryonic *B* decays – threshold enhancement
- First observation of baryonic $b \to s\,\gamma$ decay
- Puzzle of angular asymmetry
- Total paper counts

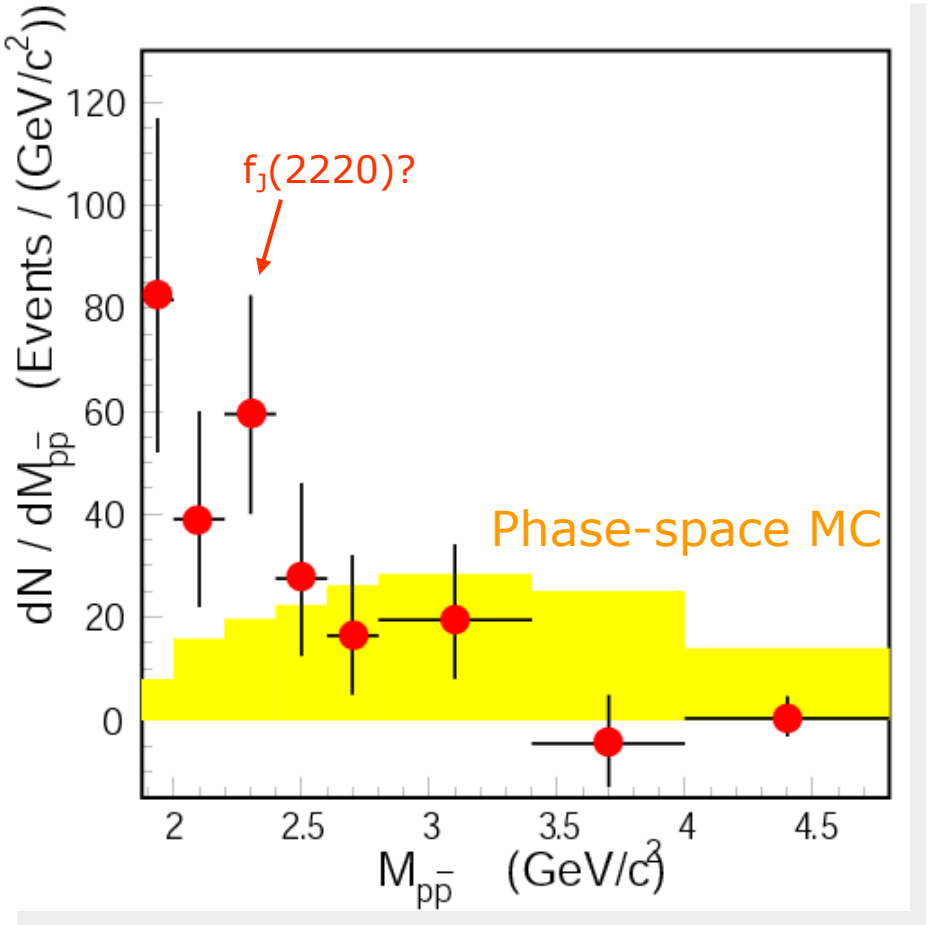
Phys.Rev.Lett.	8
Phys.Rev.D	9
Phys.Lett.B	2

First Observed Rare Baryonic B Decays in 2002: $B^{\pm} \to p\bar{p}K^{\pm}$

- Peak at Low Mass
- Baryon form factor?
  - Cheng & Yang PRD **66** 014020 ('02)
  - Chua, Hou, Tsai PRD **66** 054004 ('02)
- Quasi 2-body Decay?
  - Chua, Hou, Tsai PLB **544** 139 ('02)
  - Glueball?
- Baryonium
- Fragmentation
- Final state interaction

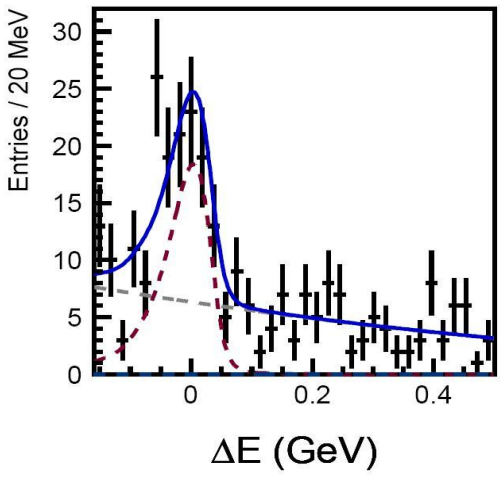
Threshold enhancement:

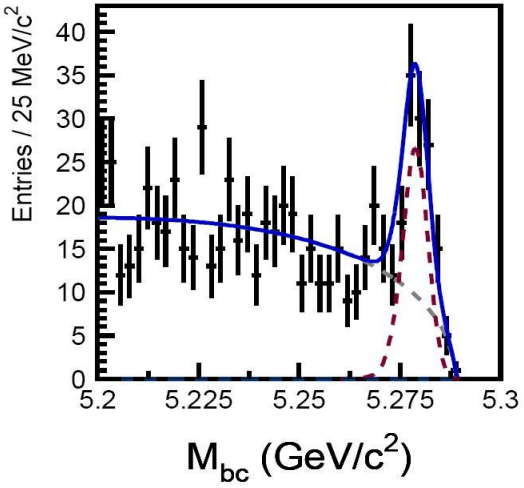
a universal feature of charmless baryonic *B* decays

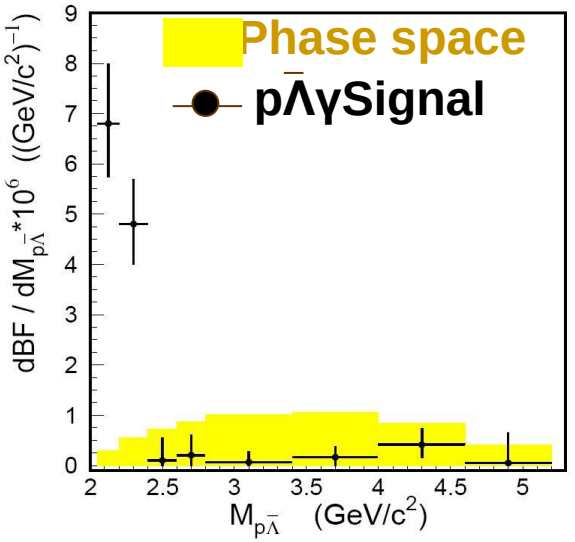


Study of $B^+ \to p\bar{\Lambda}\gamma$

414fb^{-1}







Signal yield:

Signal Yield for B→pΛ̄γ with $M_{p\bar{\Lambda}}$<2.4GeV/c^2: 95.3

Statistical Significance: 14.5σ

Full mass range:

BF(B→pΛ̄γ): $(2.45^{+0.44}_{-0.38} \pm 0.22) \times 10^{-6}$

Theoretical prediction:

***Pole Model**: Cheng and Yang Phys.Lett. B533 (2002)

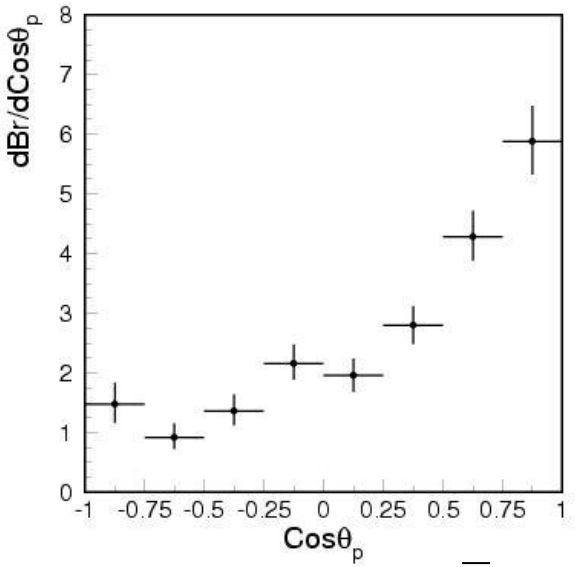
BF(B→ pΛ̄γ) ~ 1.2 x 10^{-6}

***QCD counting rules**: Geng and Hsiao Phys.Lett. B610 (2005)

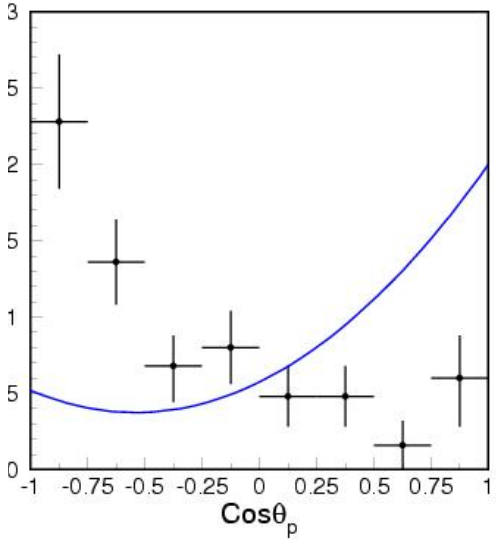
BF(B→ pΛ̄γ) ~ 1 x 10^{-6}

Angular asymmetry (puzzle)

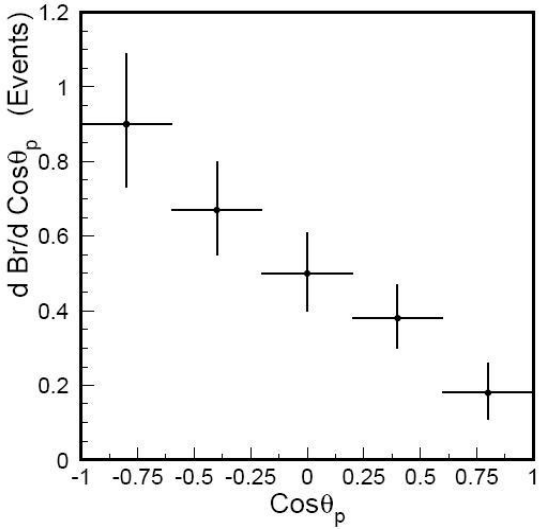
$B^- \to p\bar{p}K^-$

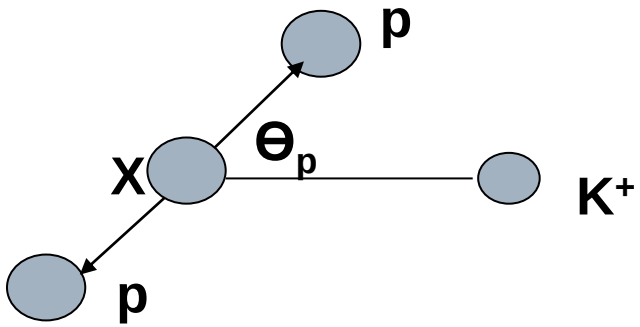


$B^- \to p\bar{p}\pi^-$



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





Proton against K^- ($\bar{p}$ against K^+)

Findings at LHCb

- Rare two-body baryonic *B* decays ~ 1×10^{-8}
  R Aaij *et al.*, LHCb collaboration PRL 119:232001 (2017)
- Evidence of direct CP violation in baryonic *B* decays
  R Aaij *et al.*, LHCb collaboration PRL 113:141801 (2014)
- Bayonic *Bs* decays
  R Aaij *et al.*, LHCb collaboration PRL 119:041802 (2017)
- Baryonic *Bc* decays
  R Aaij *et al.*, LHCb collaboration PRL 113:152003 (2014)
- Many 1st obs. of many-body *B* decays

Pentaquark found in $\Lambda^0_b \to J/\psi K^- p$!

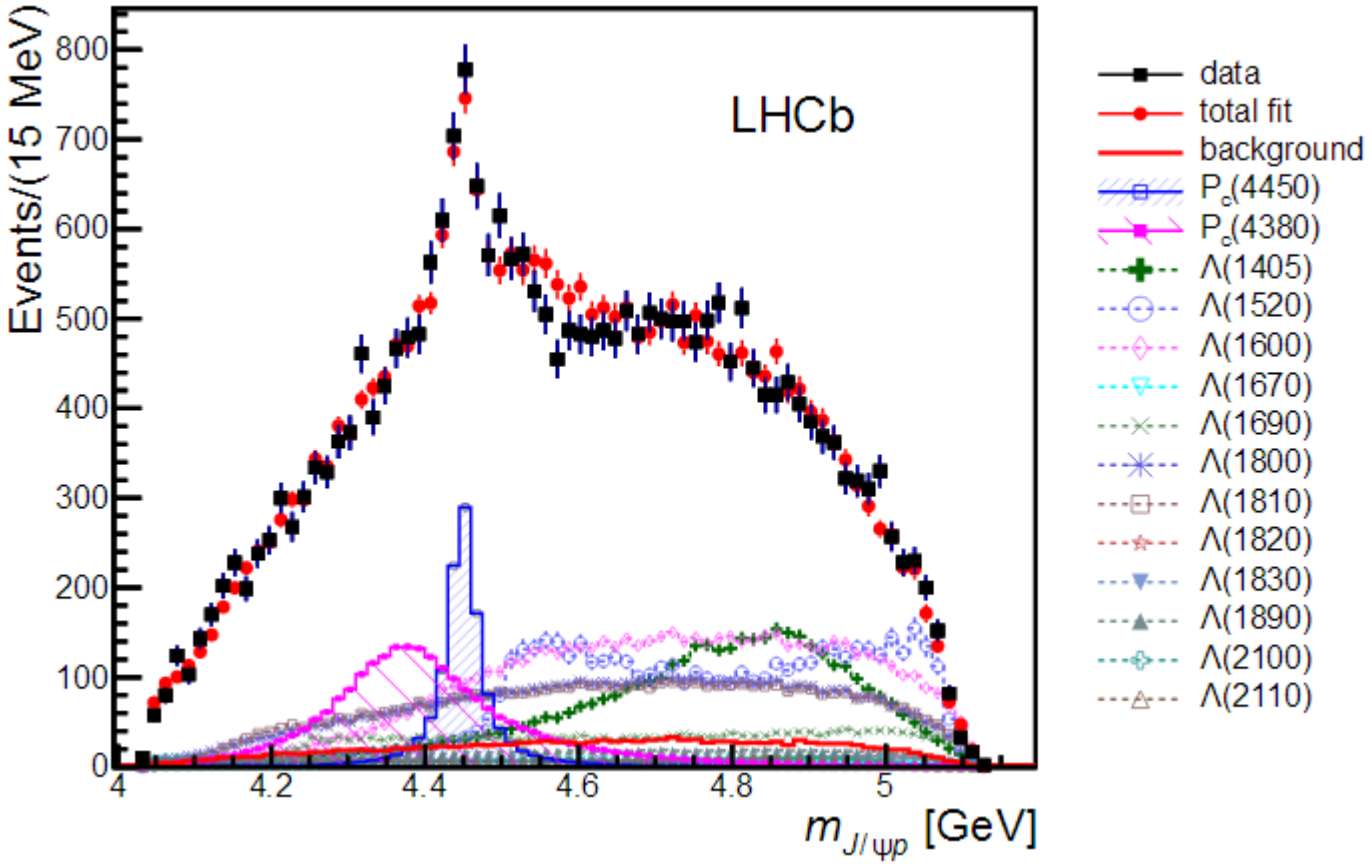
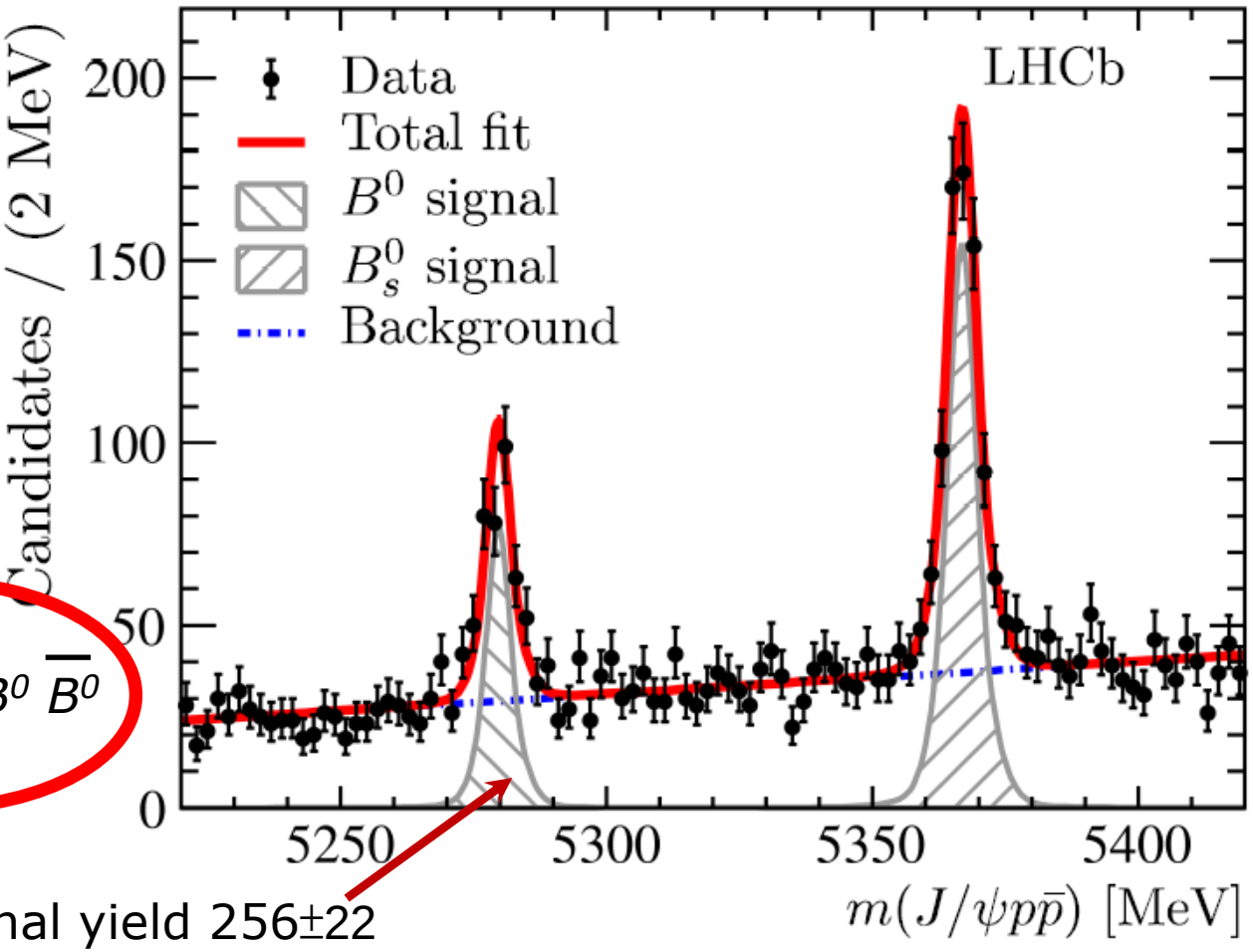


Figure 3b in "Observation of $J/\psi p$ resonances consistent with pentaquark states in $\Lambda^0_b \to J/\psi K^- p$ decays"
(arXiv:1507.03414 The LHCb collaboration)

Recent LHCb paper with $5.2\,\mathrm{fb}^{-1}$ data

$$\mathcal{B}(B^0 \to J/\psi p\bar{p}) = (4.51 \pm 0.40\,(\mathrm{stat}) \pm 0.44\,(\mathrm{syst})) \times 10^{-7}$$

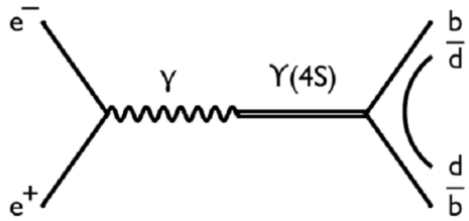


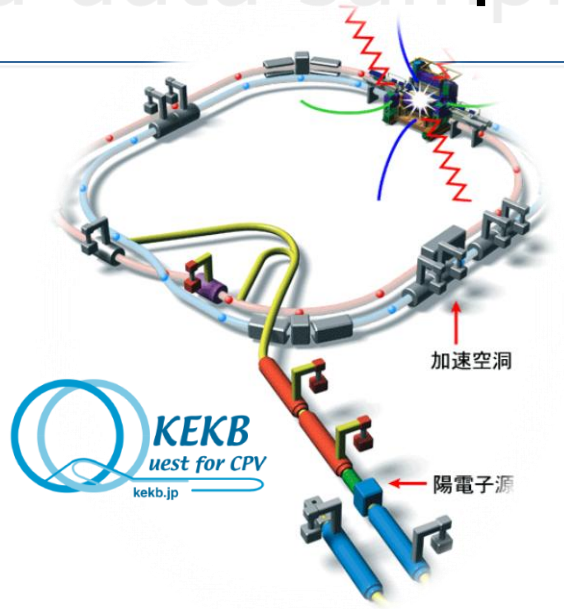
9,500 M B^0 $\overline{B^0}$

Signal yield 256±22

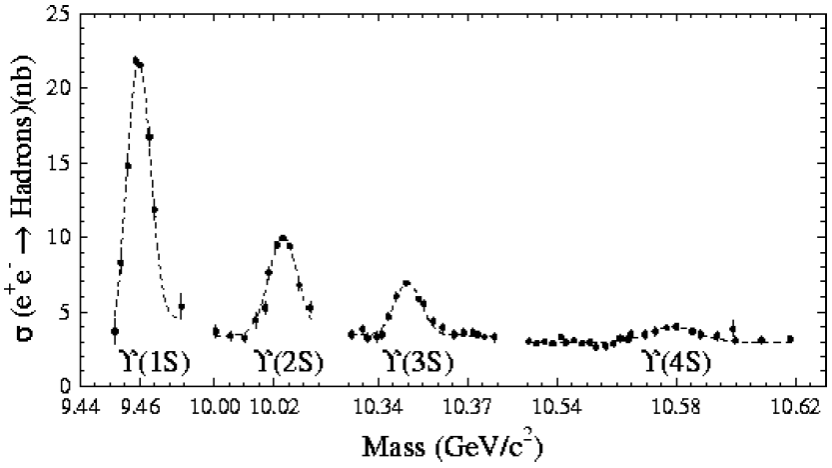
KEKB factory and data sample

- An asymmetric energy e^+e^- collider at KEK.
- LER(e^+): 3.5 GeV
  HER(e^-): 8 GeV
  Crossing angle: ± 11 mrad

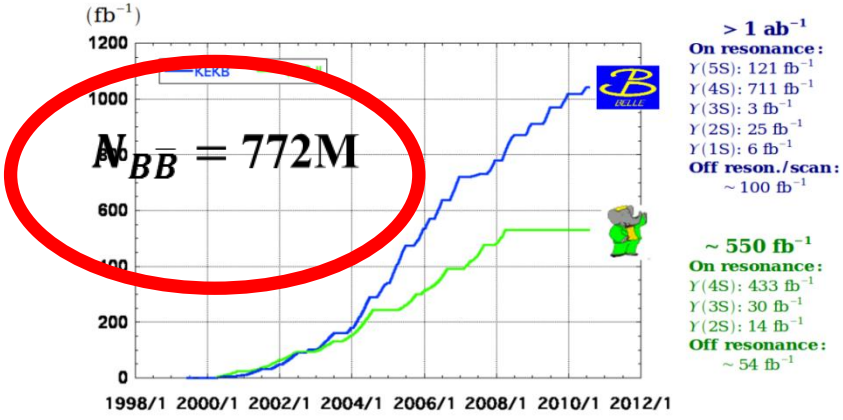




- Target: $e^+e^- \to \Upsilon(4S) \to B\bar{B}$
- Main background: $e^+e^- \to q\bar{q}$ $(q = u, d, s, c)$ with about 3 times larger cross section.
- The CM energy of e^+e^- are set to be $\Upsilon(4S)$ resonance



Integrated luminosity of B factories



http://www.lns.cornell.edu/public/lab-info/upsilon.html

Recent Belle measurements

- new observation

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

Theoretical prediction

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

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

PDG value

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

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

P.-C.Lu *et al.*
PRD99:032003(2019)

Related Theoretical predictions

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

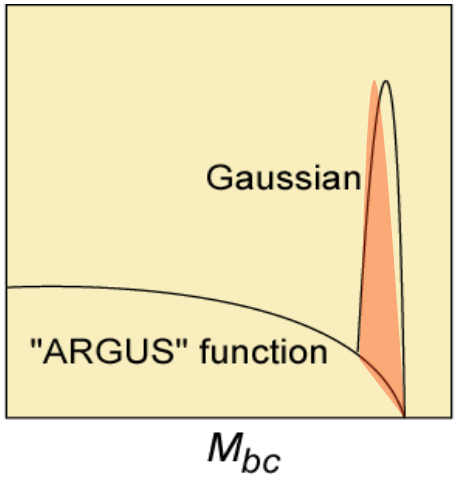
Y.K. Hsiao and C.Q. Geng
PLB 770:348-351(2017)

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

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

B Signal Reconstruction

BF = Nsig/ε/N_{BB}

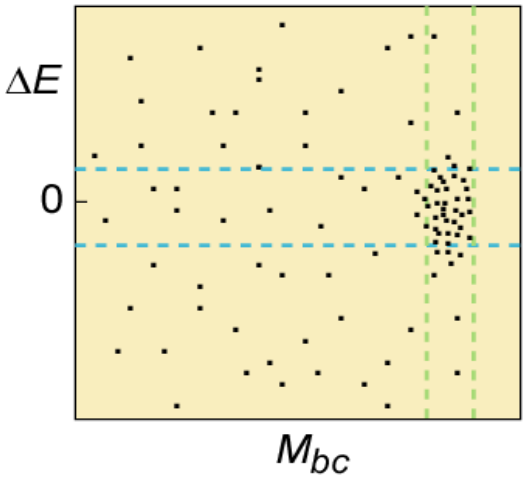


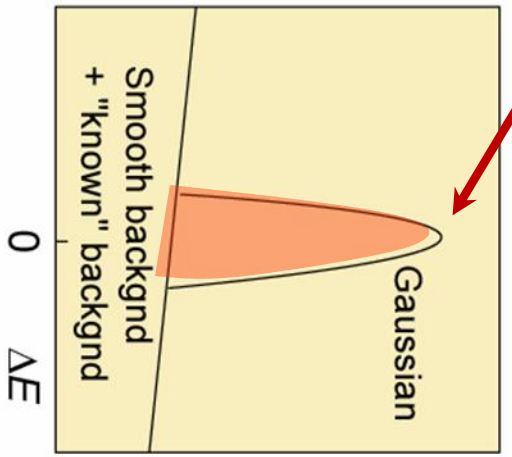
$$\Delta E = E(B\ \text{cand.}) - E_{beam}$$

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

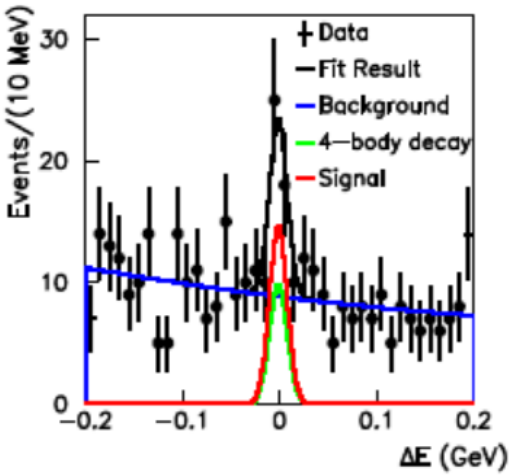
(all in CM frame)

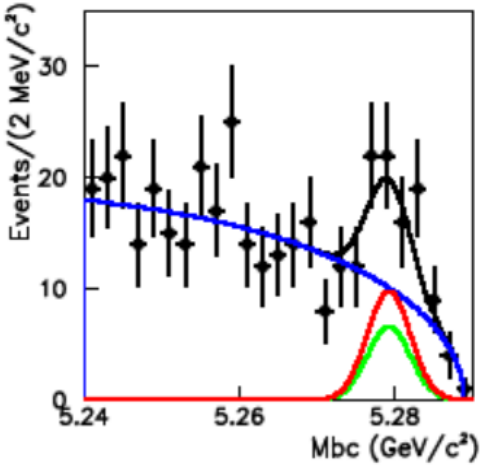
Known *B* meson energy

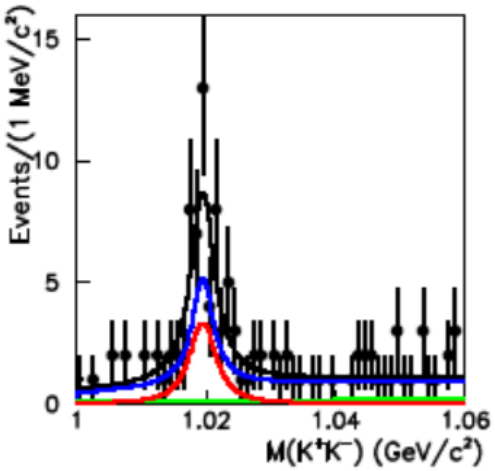




$B^+ \to p\bar{\Lambda}\phi$

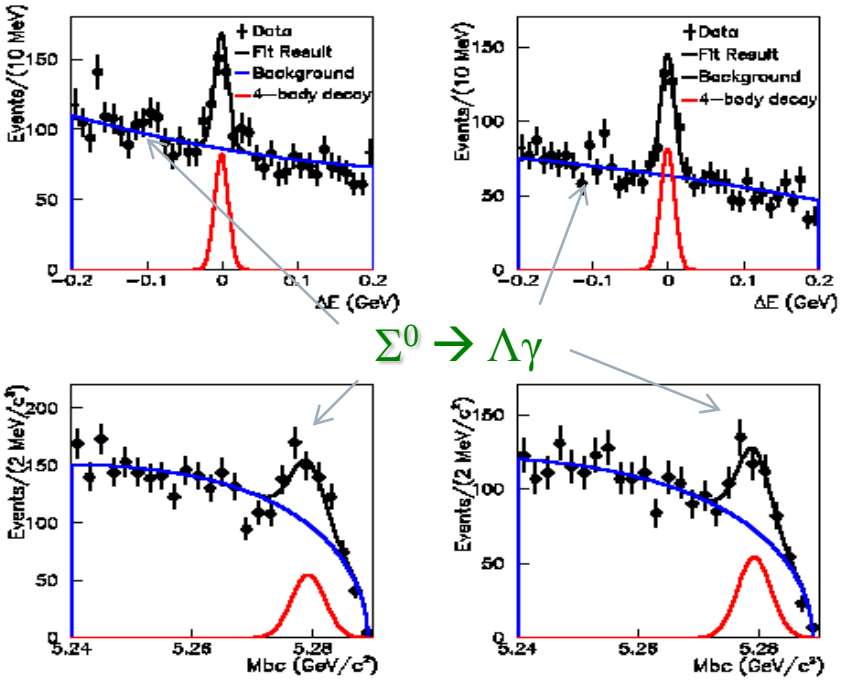




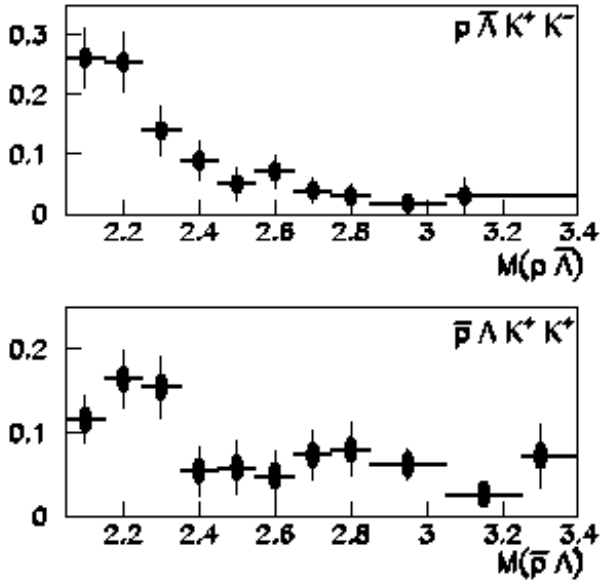


Mode	N_s	$\varepsilon_{\rm eff}(\%)$	sys(%)	sig (σ)
$(B^+ \to p\bar{\Lambda}\phi)$ $\times$ $(\phi \to K^+K^-)$	23.2±6.1	7.52	9.53	5.15

4-body decay after vetoing all visible resonances



$\Sigma^0 \to \Lambda\gamma$



threshold effect observed

4-body decays

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

Tools development

- Target neutrals: γ π^0 K_L neutron antineutron
- Using outer detector information to tag K_L, neutron and antineutron
- Using $\Lambda \to p\pi^-$ to obtain the systematics

  a tedious task to map out the full detector region with data and MC
- B mass information will be used to determine the momentum of neutral hadrons

Possible topics

- $B^+ \to p\bar{p}\rho^+$
- $B^0 \to p\bar{\Sigma}^0\pi^-$
- $B^0 \to p\bar{p}\pi^0$
- $B^- \to p\bar{p}l\nu$
- $B^0 \to p\bar{n}K^-$
- $\bar{B}^0 \to \bar{n}\Lambda\gamma$
- *etc.*
- Pentaquark confirmation/search

Summary

- Many interesting observations have been found in rare baryonic B decays
- With LHCb ahead, we still have some niches for decay modes with $\nu\,\gamma\,\pi^0$ and $\overline{n}$ in the final state
- More theoretical investigations are highly welcome
- Belle2 is taking collision data now

  Will publish the physics results of the targeted modes in two to three years