

Observation of the rare baryonic decay $B^+ \rightarrow p \bar{\Lambda}$ and measurement of its weak decay parameter

Ganrong Wang

Central China Normal University, wuhan, China

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Outline

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- ◆ Analysis Strategy
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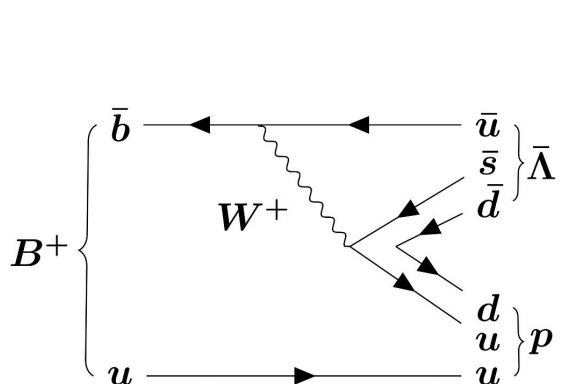
➤ Introduction

■ A few two-body baryonic B-decay processes have been observed:

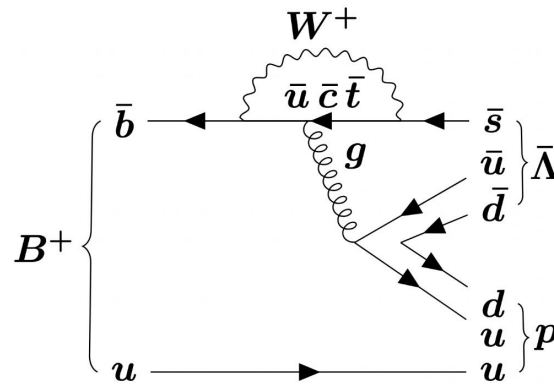
- $\mathcal{B}(B^+ \rightarrow p \bar{\Lambda}(1520)) = (3.9_{-0.9}^{+1.0} \pm 0.1 \pm 0.3) \times 10^{-7}$ [PRD 88 \(2013\) 052015](#)
- $\mathcal{B}(B^0 \rightarrow p \bar{p}) = (1.25 \pm 0.27 \pm 0.18) \times 10^{-8}$ ($b \rightarrow u$ tree level) [PRL 119 \(2017\) 232001](#)

■ Search for $B^+ \rightarrow p \bar{\Lambda}$

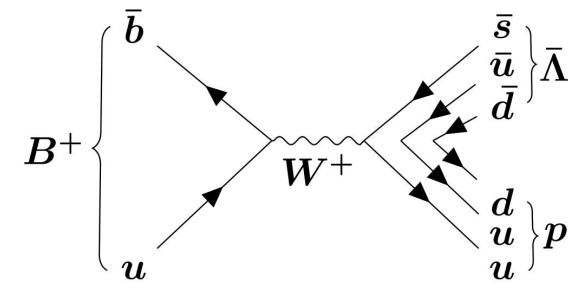
- $\mathcal{B}(B^+ \rightarrow p \bar{\Lambda}) = (2.4_{-0.8}^{+1.0} \pm 0.3) \times 10^{-7}$, LHCb Run1 data, 4.2σ ($b \rightarrow s$ penguin) [JHEP 04 \(2017\) 162](#)
 → More precise measurements needed! [PRD 66 \(2002\) 014020](#)
- Study the dynamical enhancement at the baryon-antibaryon threshold ($\Gamma(B \rightarrow P_1 P_2 M) > \Gamma(B \rightarrow P_1 P_2)$)



(a) Tree-level



(b) Penguin



(c) Annihilation

➤ Introduction

■ Search for $B^+ \rightarrow p \bar{\Lambda}$

- First step towards studying CP violation in $B^+ \rightarrow p \bar{\Lambda}$ decay.
- $\bar{b} \rightarrow u \bar{u} \bar{s}$ quark transition

Mode	$B^0 \rightarrow K^+ \pi^-$	$B_s^0 \rightarrow K^+ K^-$	$\Lambda_b \rightarrow p K^-$	$B^+ \rightarrow p \bar{\Lambda}$
A_{CP}	$(8.24 \pm 0.47)\%$ JHEP 03 (2021) 075	$(16.2 \pm 3.5)\%$ JHEP 03 (2021) 075	$(-1.14 \pm 0.76)\%$ PRD 111 (2025), 092004	--

- Anomaly in $\Lambda_b \rightarrow p K^-$ CP asymmetry.
 - May be due to partial-wave cancellation. [PRL 134290 \(2025\) 221801](#)
- A theoretical prediction for the CP asymmetry in $B^+ \rightarrow p \bar{\Lambda}$ is up to 10%. [JHEP 03 \(2021\) 075](#)
 - Could be suppressed by cancellation between the S-wave and P-wave amplitudes?



Investigation of CP violation in the $B^+ \rightarrow p \bar{\Lambda}$ decay rate and angular distribution.

➤ Introduction

■ Measurement $B^+ \rightarrow p \bar{\Lambda}$ decay parameter

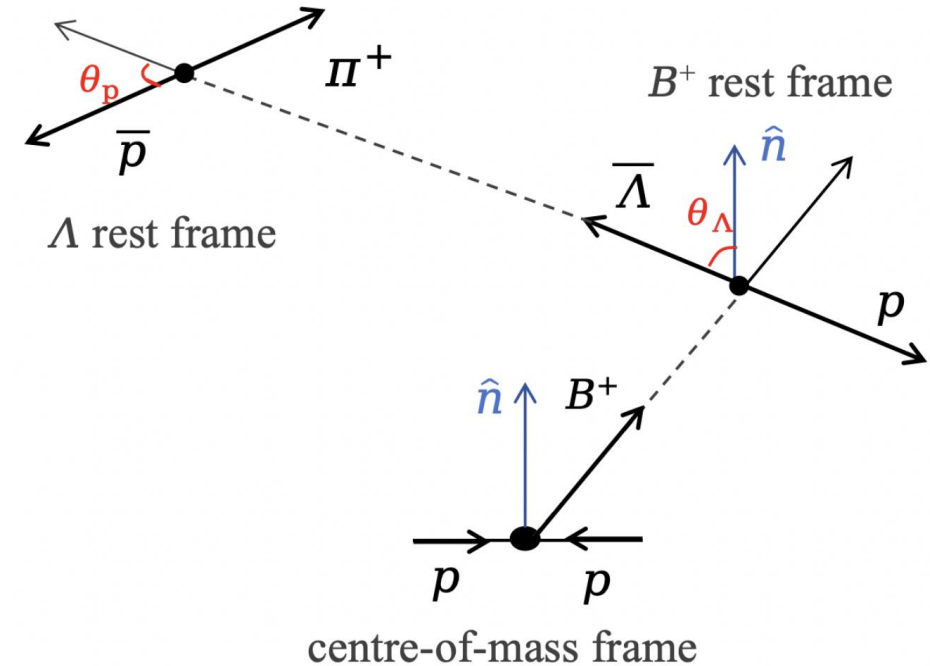
- The spin-0 B^+ meson $\rightarrow H_p = H_{\bar{\Lambda}} = +\frac{1}{2}$ or $-\frac{1}{2}$
- Theoretical predictions indicate that the decay parameter α_B , which describes the $\bar{\Lambda}$ polarization is: [\[arXiv:2306.14280\]](https://arxiv.org/abs/2306.14280)

$$\alpha_B = \frac{|H_{+1/2}|^2 - |H_{-1/2}|^2}{|H_{+1/2}|^2 + |H_{-1/2}|^2} = \frac{2\text{Re}(A_S \cdot A_P)}{|A_S|^2 + |A_P|^2} \approx 0.6$$

- The angular distribution of the $B^+ \rightarrow p \bar{\Lambda}$ decay:

$$\frac{d\Gamma}{d\cos\theta_p} \propto 1 - \alpha_{\Lambda} \alpha_B \cos\theta_p, \text{ here } \alpha_{\Lambda}^{avg} = 0.755 \pm 0.003$$

[\[arXiv:2204.11058v3\]](https://arxiv.org/abs/2204.11058v3)



➤ Analysis Strategy

■ Objectives

- ✓ Search for $B^+ \rightarrow p \bar{\Lambda} (\Lambda \rightarrow p \pi^-)$ and measure the $\bar{\Lambda}$ polarization in the $B^+ \rightarrow p \bar{\Lambda}$.

■ Event Selection

- ✓ LHCb Run2 data.
- ✓ Normalization channel: $\mathcal{B}(B^+ \rightarrow K_S^0 \pi^+) = \frac{1}{2} \times (2.39 \pm 0.06) \times 10^{-5}$, $\mathcal{B}(K_S^0 \rightarrow \pi^+ \pi^-) = (69.20 \pm 0.05)\%$.
- ✓ Main event selection procedure:
 - (1) Online selection. (2) Veto peaking background. (3) Multi-class Boosted Decision Trees (BDT) for background discrimination.
 - (4) Strict vertex cut.
- ✓ Efficiency correction

■ Mass Fit

- ✓ Simultaneous fits are performed on the signal and normalization channels.

■ Angular Fit

- ✓ Simultaneous fits are performed on the simulation and background-subtracted data.

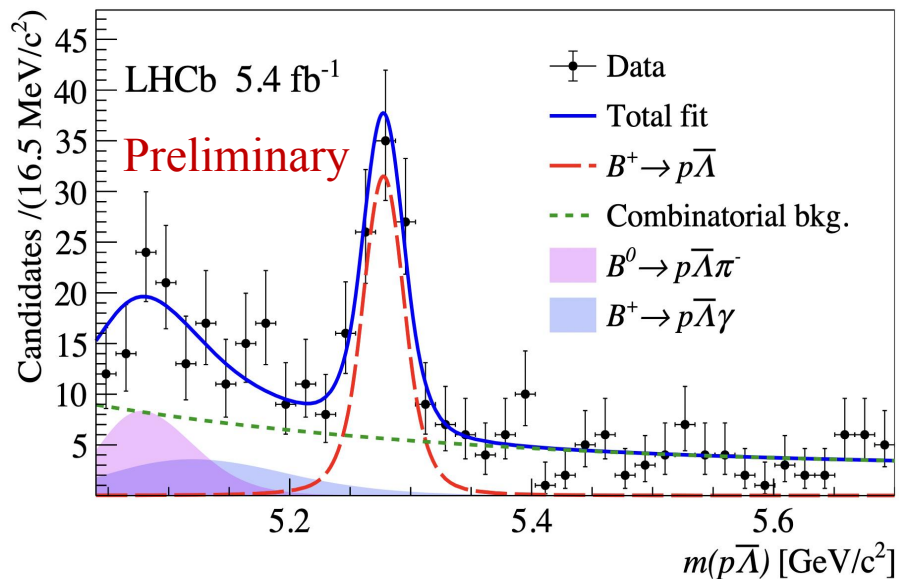
➤ Event Selection and Mass Fit

■ Full selection:

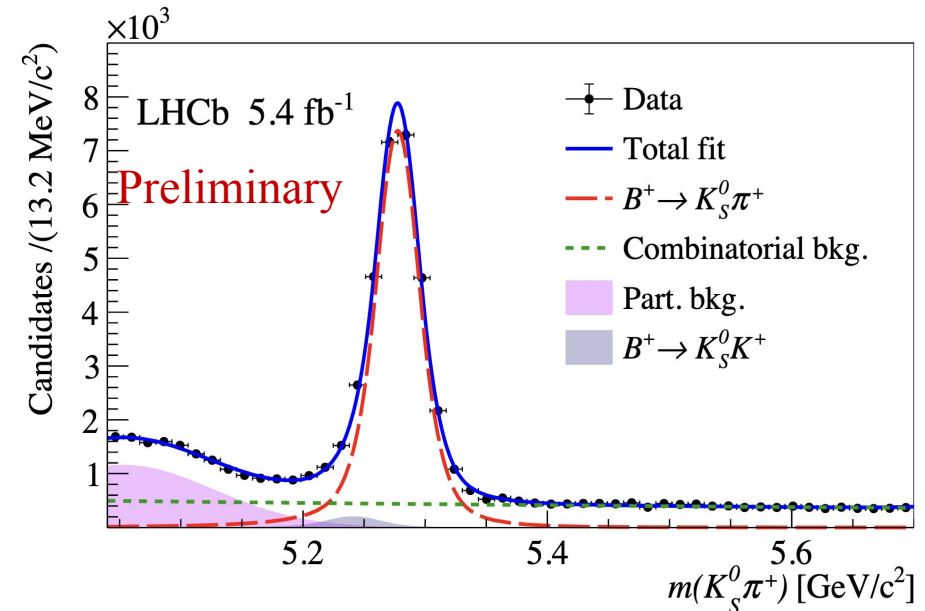
- (1) Online reconstruction and selection. (2) Veto peaking background.
- (3) Multi-class Boosted Decision Trees (BDT) for background discrimination. (4) Strict vertex cut.

■ Simultaneous fits.

1-D **simultaneous fit** to $B^+ \rightarrow K_S^0 \pi^+$ Data and $B^+ \rightarrow p \bar{\Lambda}^0$ Data.



Total Yields: $N(B^+ \rightarrow p \bar{\Lambda}) = 88 \pm 12$



Total Yields: $N(B^+ \rightarrow K_S^0 \pi^+) = 28495 \pm 220$

Decay Parameter Measurement

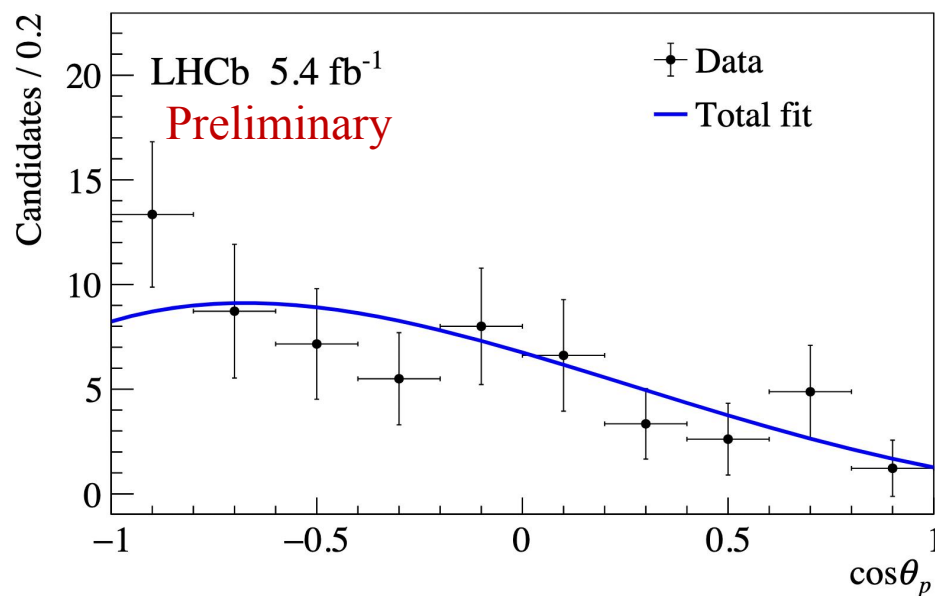
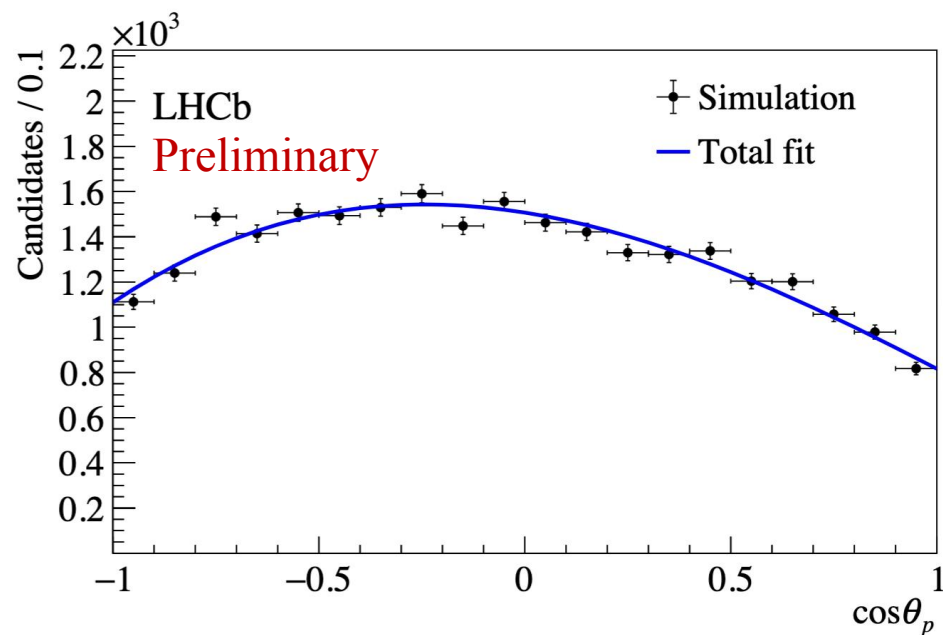
➤ Decay parameter measurement

■ Simulation:

- Model the effects of detector resolution(negligible), acceptance, and selection criteria on the signal: $\epsilon(\cos\theta_p)$

■ Angular Fit

- Simultaneous fits: simulated acceptance shape and the background-subtracted data.
- Angular distribution PDF: $\frac{dN}{d\cos\theta_p} \propto (1 - \alpha_A \alpha_B \cos\theta_p) \cdot \epsilon(\cos\theta_p)$, here $\alpha_\Lambda^{v g} = 0.755 \pm 0.003$



➤ Decay parameter measurement

■ Relative Systematic Uncertainty:

Fitting biases and the effects of physical boundaries($\alpha_B \subset [-1,1]$)

Fitting procedure

The assumption of no correlation between the $p\bar{\Lambda}$ mass and the angular variable

Uncertainty source		ΔP
Toy studies	boundary affects	0.065
Acceptance	modelling with 3-chebv.	0.003
	modelling without gbw	0.005
Background subtraction	signal	0.000
	combinatorial	0.007
	$B^+ \rightarrow K_S^0 \pi^+$ Part. bkg.	0.002
	$B^+ \rightarrow K_S^0 \pi^+$ Mis-id. bkg.	0.001
	$B^+ \rightarrow p\bar{\Lambda}$ Part. bkg.	0.001
	$B^+ \rightarrow p\bar{\Lambda}$ Part. bkg. fraction	0.026
	mass fit in two $\cos \theta_p$ bins	0.009
Total	σ_{sys}	0.071

➤ Decay parameter measurement

■ Decay parameter:

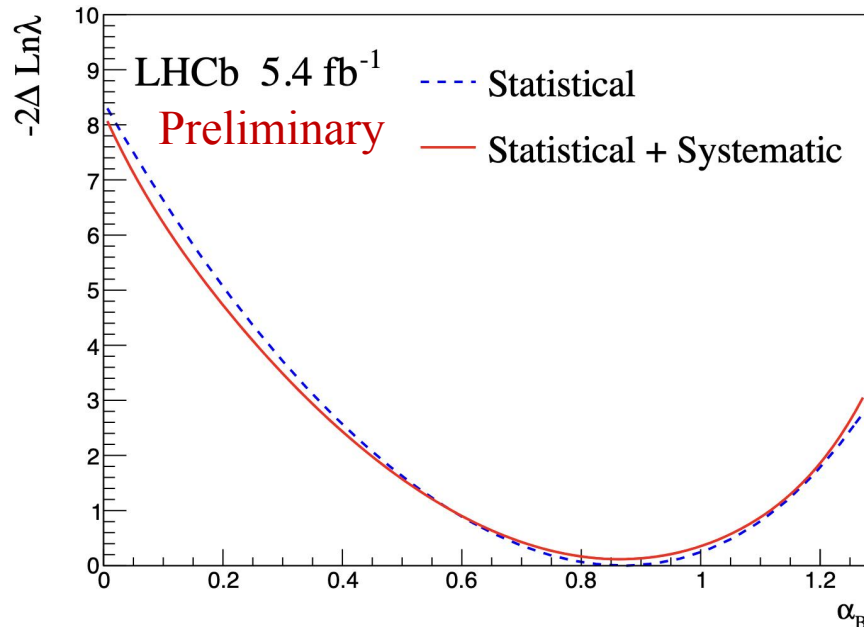
$$\alpha_B = 0.87^{+0.26}_{-0.29}(\text{stat.}) \pm 0.09(\text{syst.})$$

Consistent with theoretical prediction: $\alpha_B \approx 0.6$

[PRL B846 \(2023\) 138240](#)



$\alpha_B \neq 0$, indicates a strong interference between the competing S-wave and P-wave amplitudes of the $B^+ \rightarrow p \bar{\Lambda}$ decay



The total statistical significance: around **2.9** standard deviations

Branching fraction measurement

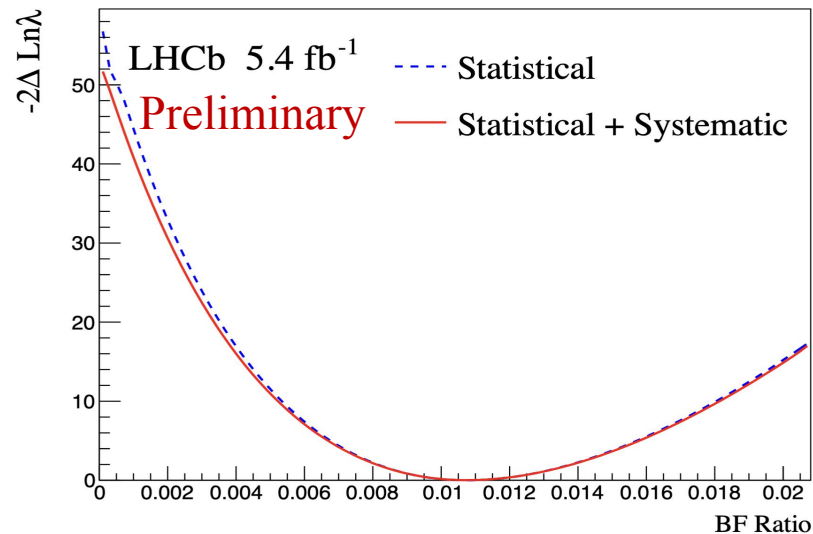
➤ Branching fraction measurement

■ Branch Fraction Ratio

$$\mathcal{R}_B = \frac{\mathcal{B}(B^+ \rightarrow p \bar{\Lambda})}{\mathcal{B}(B^+ \rightarrow K_S^0 \pi^+)} = \frac{\mathcal{B}(K_S^0 \rightarrow \pi^+ \pi^-)}{\mathcal{B}(\Lambda \rightarrow p \bar{\Lambda})} \times \frac{N(B^+ \rightarrow p \bar{\Lambda})}{N(B^+ \rightarrow K_S^0 \pi^+)} \times \frac{\epsilon_{B^+ \rightarrow K_S^0 \pi^+}}{\epsilon_{B^+ \rightarrow p \bar{\Lambda}}}$$

✓ Measured Run2 result: $\mathcal{R}_B^{run2} = (1.01 \pm 0.14(stat.)) \times 10^{-2}$

✓ Significance



The total statistical significance:
Over **7** standard deviations

➤ Branching fraction measurement

■ Relative Systematic Uncertainty:

- Fitting procedure
 - (1) Intrinsic fit bias in the maximum-likelihood fit.
 - (2) Fit component model choice.
- Efficiency determination
 - (3) Finite size of the simulation samples
 - (4) Several corrections applied to simulation samples: Kinematic, tracking, particle identification, hardware-trigger efficiency, $\overline{\Lambda}$ polarization.
- External branching fraction
 - (5) $\mathcal{B}(K_S^0 \rightarrow \pi^+ \pi^-) / \mathcal{B}(\Lambda \rightarrow p \pi^-)$



Total Relative Systematic Uncertainty : 3.9%

➤ Branching fraction measurement

■ Branch Fraction Ratio:

$$\mathcal{R}_B = \frac{\mathcal{B}(B^+ \rightarrow p\bar{\Lambda})}{\mathcal{B}(B^+ \rightarrow K_S^0 \pi^+)} = \frac{\mathcal{B}(K_S^0 \rightarrow \pi^+ \pi^-)}{\mathcal{B}(\Lambda \rightarrow p\bar{\Lambda})} \times \frac{N(B^+ \rightarrow p\bar{\Lambda})}{N(B^+ \rightarrow K_S^0 \pi^+)} \times \frac{\epsilon_{B^+ \rightarrow K_S^0 \pi^+}}{\epsilon_{B^+ \rightarrow p\bar{\Lambda}}}$$

- ✓ Measured Run2 result: $\mathcal{R}_B^{run2} = (1.01 \pm 0.14(stat.) \pm 0.04(syst.)) \times 10^{-2}$
- ✓ Significance(Profile-likelihood scan): Over 7 standard deviations
- ✓ Previous Run1 result: $\mathcal{R}_B^{run1} = (2.02 \pm 0.88 \pm 0.23) \times 10^{-2}$
- ✓ Combined Run1 and Run2 result: $\mathcal{R}_B^{run1\&2} = (1.04 \pm 0.14(stat.) \pm 0.04(syst.)) \times 10^{-2}$

■ Branch Fraction:

$$\mathcal{B}(B^+ \rightarrow p\bar{\Lambda}) = (1.24 \pm 0.17(stat.) \pm 0.05(syst.) \pm 0.03(norm.)) \times 10^{-7}$$

- Consistent with theoretical prediction: QCD sum rule ($< 3 \times 10^{-6}$), Pole model(2.2×10^{-7}).
[Nucl. Phys. B345\(1990\) 137](#)
[PRD 66 \(2002\) 014020](#)
- Lower than the corresponding 3-body decay: $B^+ \rightarrow p\bar{\Lambda}\pi^0: (3.0_{-0.6}^{+0.7}) \times 10^{-6}$, $B^0 \rightarrow p\bar{\Lambda}\pi^-: (3.16 \pm 0.24) \times 10^{-6}$

➤ Summary

- The $B^+ \rightarrow p\bar{\Lambda}$ decay is observed for the first time and the absolute branching fraction are measured as:

$$\mathcal{B}(B^+ \rightarrow p\bar{\Lambda}) = (1.24 \pm 0.17(stat.) \pm 0.05(syst.) \pm 0.03(norm.)) \times 10^{-7},$$

lower than that of the three-body decay($B^+ \rightarrow p\bar{\Lambda}\pi^0$) providing further evidence for the threshold enhancement mechanism.

- The decay parameter of the $B^+ \rightarrow p\bar{\Lambda}$ process is determined to be:

$$\alpha_B = 0.87^{+0.26}_{-0.29}(stat.) \pm 0.09(syst.),$$

indicating the presence of comparable S-wave and P-wave decay amplitudes.

➤ Summary

■ Discussion and Outlook

✓ In *B*-meson decays, $\mathcal{B}_{b \rightarrow u \bar{u} s} > \mathcal{B}_{b \rightarrow u \bar{u} d}$, but in *b*-baryon decays, $\mathcal{B}_{b \rightarrow u \bar{u} s} \sim \mathcal{B}_{b \rightarrow u \bar{u} d}$, *e.g.*

$$\begin{aligned} \mathcal{B}(B^+ \rightarrow p \bar{\Lambda}) &= (1.24 \pm 0.18) \times 10^{-7} > \mathcal{B}(B^+ \rightarrow p \bar{p}) = (1.25 \pm 0.27 \pm 0.18) \times 10^{-8}, \\ \mathcal{B}(B_s^0 \rightarrow K^+ K^-) &= (2.72 \pm 0.23) \times 10^{-5} > \mathcal{B}(B_s^0 \rightarrow \pi^+ K^-) = (5.9 \pm 0.7) \times 10^{-6}, \\ \mathcal{B}(B^0 \rightarrow K^+ \pi^-) &= (2.00 \pm 0.04) \times 10^{-5} > \mathcal{B}(B^0 \rightarrow \pi^+ \pi^-) = (5.37 \pm 0.20) \times 10^{-6}, \\ \mathcal{B}(\Lambda_b^0 \rightarrow p K^-) &= (4.6 \pm 0.8) \times 10^{-6} \sim \mathcal{B}(\Lambda_b^0 \rightarrow p \pi^-) = (5.5 \pm 1.0) \times 10^{-6} \end{aligned}$$

✓ Experimental CP asymmetry results

	$\bar{b} \rightarrow u \bar{u} s$				$\bar{b} \rightarrow u \bar{u} d$			
Mode	$B^0 \rightarrow K^+ \pi^-$	$B_s^0 \rightarrow K^+ K^-$	$\Lambda_b \rightarrow p K^-$	$B^+ \rightarrow p \bar{\Lambda}$	$B^0 \rightarrow \pi^+ \pi^-$	$B_s^0 \rightarrow \pi^+ K^-$	$\Lambda_b \rightarrow p \pi^-$	$B^0 \rightarrow p \bar{p}$
$A_{CP}(\%)$	8.24 ± 0.47 JHEP 03 (2021) 075	16.2 ± 3.5 JHEP 03 (2021) 075	-1.4 ± 0.8 PRD 111 (2025) 092004	—	31.4 ± 3.0 JHEP 03 (2021) 075	23.6 ± 1.7 JHEP 03 (2021) 075	0.4 ± 1.0 PRD 111 (2025) 092004	—

✓ Expect CP violation measurements on $B^+ \rightarrow p \bar{\Lambda}$ decay to follow with LHCb Run 3 data.

Thank you for your attention !

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