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

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Outline

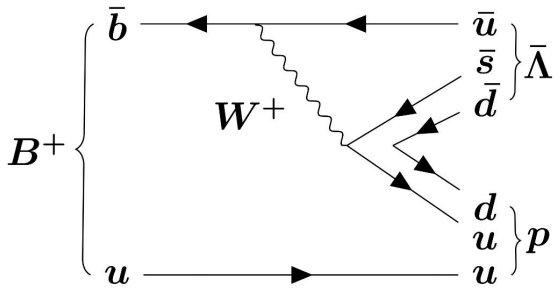
- Introduction
- Analysis Strategy
- Event Selection and Mass Fit
- Decay parameter measurement
- Branching fraction measurement
- Summary

Introduction

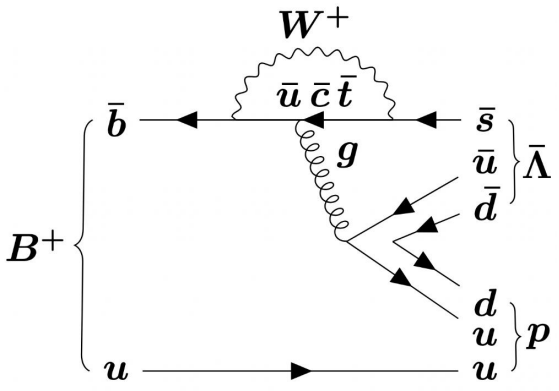
- A few two-body baryonic B-decay processes have been observed:
  - $\mathcal{B}(B^+ \to p\overline{\Lambda}(1520)) = \left(3.9^{+1.0}_{-0.9} \pm 0.1 \pm 0.3\right) \times 10^{-7}$ PRD 88 (2013) 052015
  - $\mathcal{B}(B^0 \to p\overline{p}) = (1.25 \pm 0.27 \pm 0.18) \times 10^{-8}$ ($b \to u$ tree level) PRL 119 (2017) 232001
- Search for $B^+ \to p\overline{\Lambda}$
  - $\mathcal{B}(B^+ \to p\overline{\Lambda}) = \left(2.4^{+1.0}_{-0.8} \pm 0.3\right) \times 10^{-7}$, LHCb Run1 data, 4.2σ ($b \to s$ penguin) JHEP 04 (2017) 162

    → More precise measurements needed!

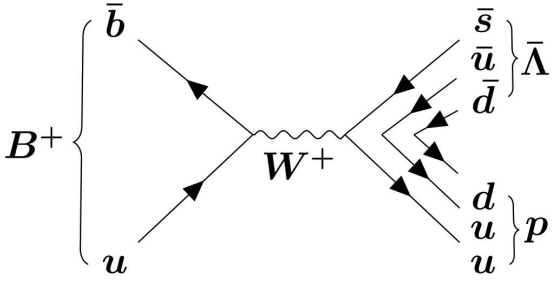
  - Study the dynamical enhancement at the baryon-antibaryon threshold ($\Gamma(B \to P_1 P_2 M) > \Gamma(B \to P_1 P_2)$) PRD 66 (2002) 014020



(a) Tree-level



(b) Penguin



(c) Annihilation

➢ Introduction

■ Search for $B^+ \to p\overline{\Lambda}$

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

Mode	$B^0 \to K^+\pi^-$	$B_s^0 \to K^+K^-$	$\Lambda_b \to pK^-$	$B^+ \to p\overline{\Lambda}$
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 $\Lambda_b \to pK^-$ CP asymmetry.
  - May be due to partial-wave cancellation. PRL. 134290 (2025) 221801
- A theoretical prediction for the CP asymmetry in $B^+ \to p\overline{\Lambda}$ 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 $B^+ \to p\overline{\Lambda}$ decay rate and angular distribution.

Introduction

- Measurement $B^+ \to p\overline{\Lambda}$ decay parameter

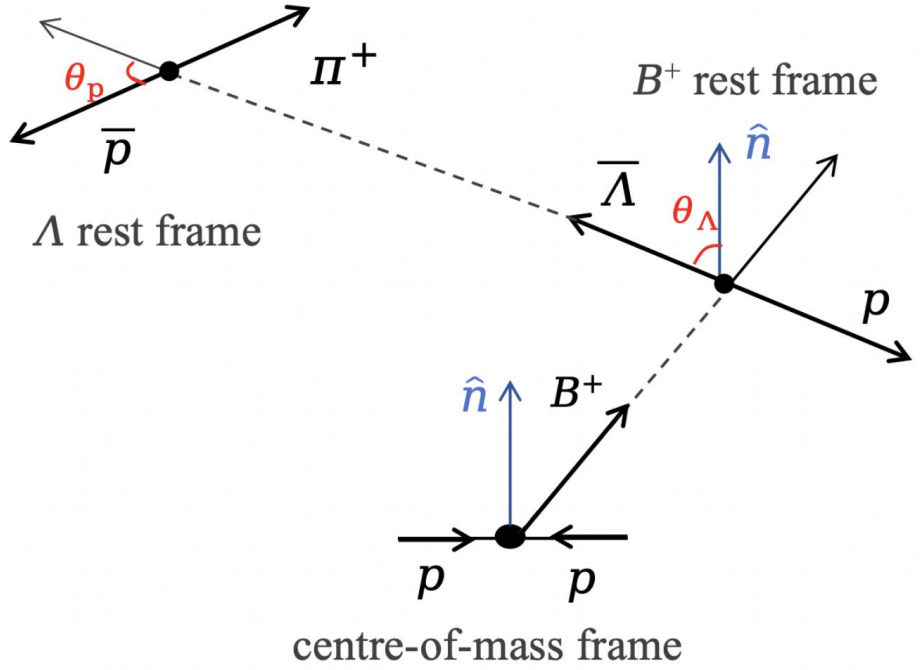
  - The spin-0 B^+ meson $\to$ $H_p = H_{\overline{\Lambda}} = +\frac{1}{2}$ or $-\frac{1}{2}$
  - Theoretical predictions indicate that the decay parameter α_B, which describes the $\overline{\Lambda}$ polarization is: [arXiv:2306.14280]

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

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

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

[arXiv:2204.11058v3]



Analysis Strategy

Objetives

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

Event Selection

- ✓ LHCb Run2 data.
- ✓ Normalization channel: $\mathcal{B}(B^+ \to K^0_S\pi^+) = \frac{1}{2} \times (2.39 \pm 0.06) \times 10^{-5}$, $\mathcal{B}(K^0_S \to \pi^+\pi^-) = (69.20 \pm 0.05)\%$.
- ✓ 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

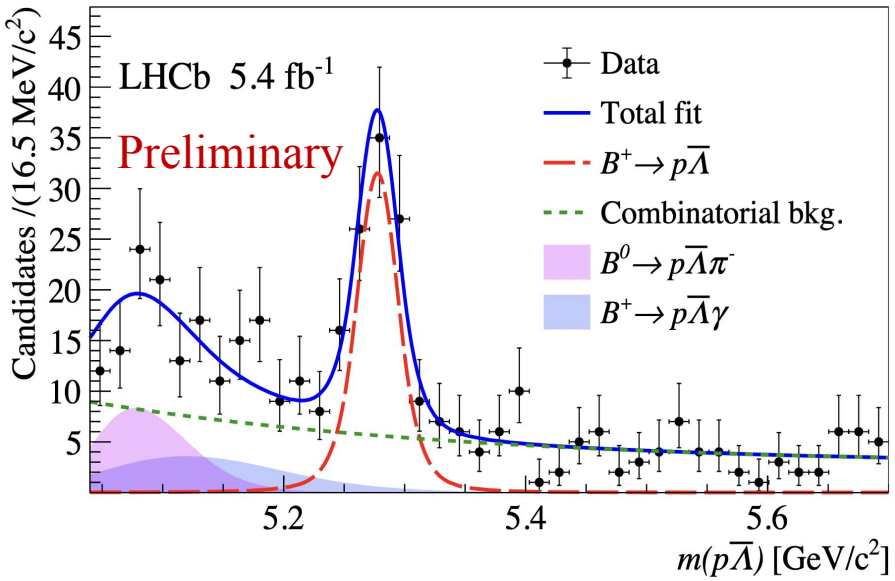
- Full selection:

  (1) Online reconstruction and selection. (2) Veto peaking background.

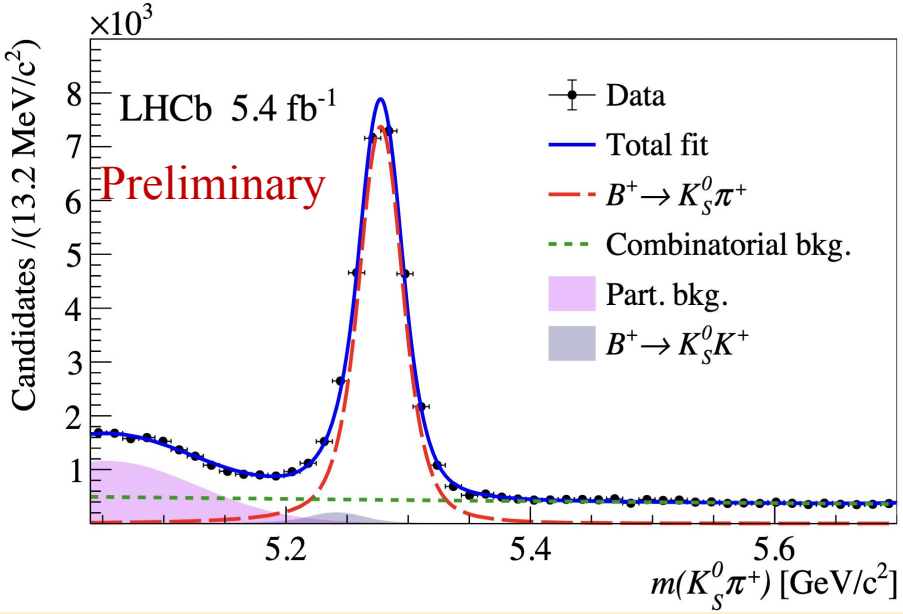
  (3) Multi-class Boosted Decision Trees (BDT) for background discrimination. (4) Strict vertex cut.

- Simultaneous fits.

  1-D simultaneous fit to $B^+ \to K^0_S \pi^+$ Data and $B^+ \to p\overline{\Lambda}^0$ Data.



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

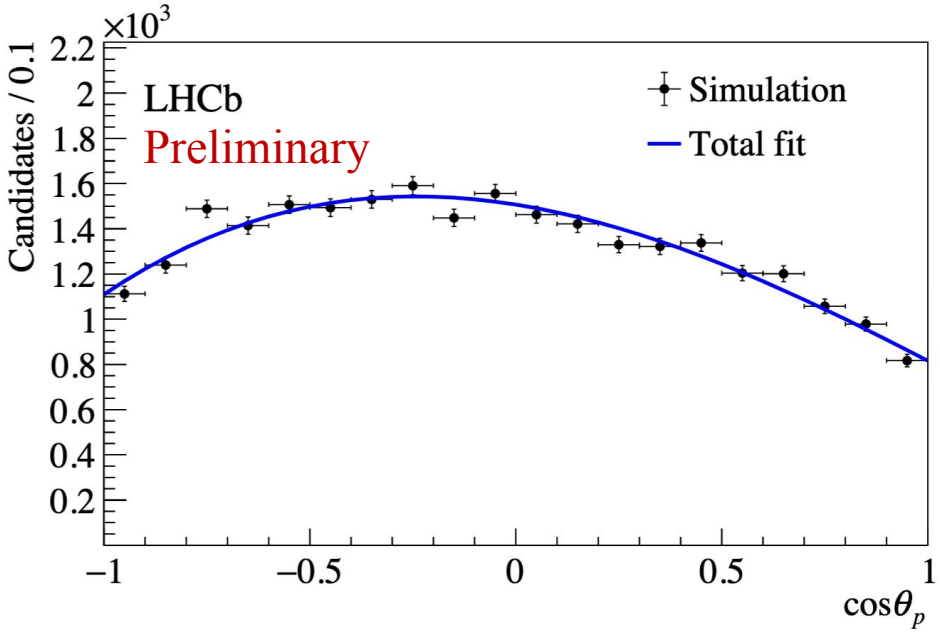


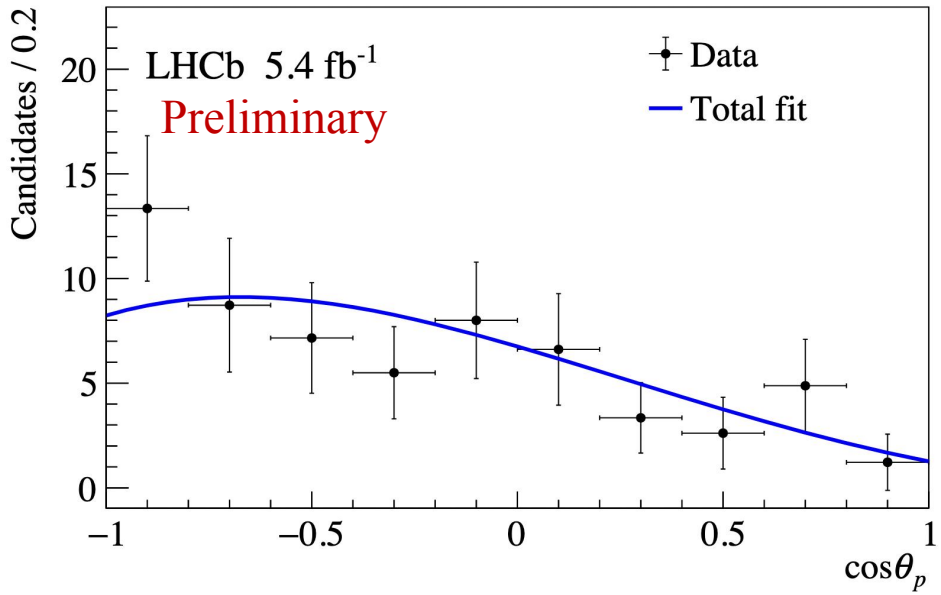
Total Yields: $N(B^+ \to K^0_s \pi^+) = 28495 \pm 220$

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: $\frac{dN}{dcos\theta_p} \propto (1 - \alpha_\Lambda\ \alpha_B cos\theta_p) \cdot \epsilon(cos\theta_p)$, here $\alpha_\Lambda^{avg} = 0.755 \pm 0.003$





➢ 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 $p\overline{\Lambda}$ 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
	$B^+ \to K^0_S \pi^+$ Part. bkg.	0.002
	$B^+ \to K^0_S \pi^+$ Mis-id. bkg.	0.001
	$B^+ \to p\bar{\Lambda}$ Part. bkg.	0.001
	$B^+ \to p\bar{\Lambda}$ Part. bkg. fraction	0.026
	mass fit in two $\cos\theta_p$ bins	0.009
Total	σ_{sys}	0.071

➢ Decay parameter measurement

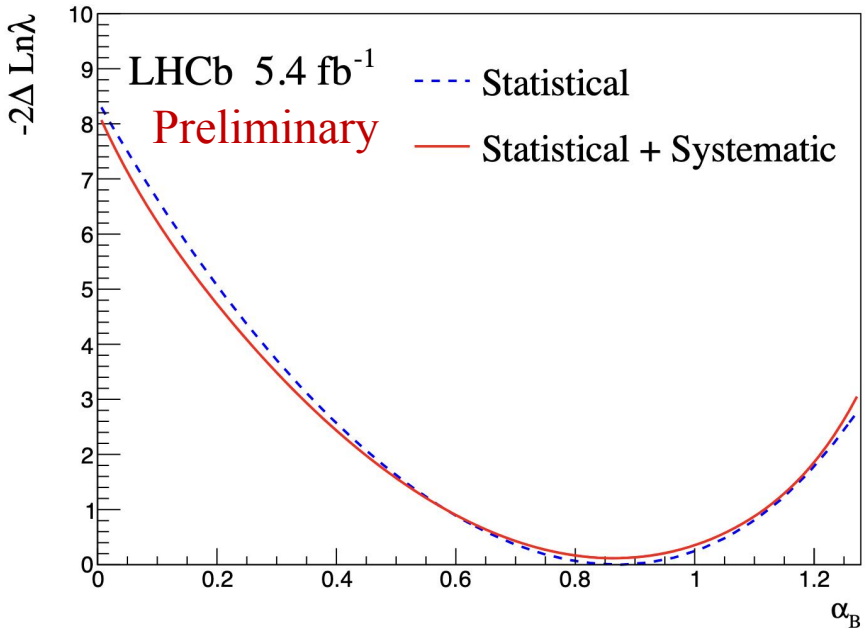
- Decay parameter:

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

Consistant 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 $B^+ \to p\overline{\Lambda}$ decay



The total statistical significance: around 2.9 standard deviations

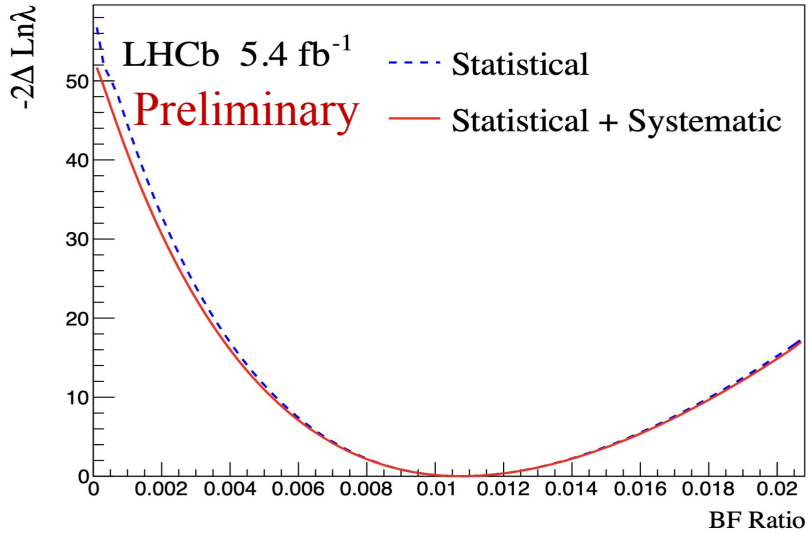
Branching fraction measurement

Branching fraction measurement

- Branch Fraction Ratio

$$\mathcal{R}_{\mathcal{B}} = \frac{\mathcal{B}(B^+ \to p\overline{\Lambda})}{\mathcal{B}(B^+ \to K^0_S \pi^+)} = \frac{\mathcal{B}(K^0_S \to \pi^+\pi^-)}{\mathcal{B}(\Lambda \to p\overline{\Lambda})} \times \frac{N(B^+ \to p\overline{\Lambda})}{N(B^+ \to K^0_S \pi^+)} \times \frac{\epsilon_{B^+ \to K^0_S \pi^+}}{\epsilon_{B^+ \to p\overline{\Lambda}}}$$

- ✓ Measured Run2 result: $\mathcal{R}_{\mathcal{B}}^{run2} = (1.01 \pm 0.14(stat.)) \times 10^{-2}$
- ✓ 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) $\mathcal{B}(K_S^0 \to \pi^+\pi^-)/\mathcal{B}(\Lambda \to p\pi^-)$

⇒ Total Relative Systematic Uncertainty : 3.9%

➢ Branching fraction measurement

■ Branch Fraction Ratio:

$$\mathcal{R}_{\mathcal{B}} = \frac{\mathcal{B}(B^+ \to p\overline{\Lambda})}{\mathcal{B}(B^+ \to K^0_S \pi^+)} = \frac{\mathcal{B}(K^0_S \to \pi^+\pi^-)}{\mathcal{B}(\Lambda \to p\overline{\Lambda})} \times \frac{N(B^+ \to p\overline{\Lambda})}{N(B^+ \to K^0_S \pi^+)} \times \frac{\epsilon_{B^+ \to K^0_S \pi^+}}{\epsilon_{B^+ \to p\overline{\Lambda}}}$$

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

■ Branch Fraction:

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

- Consistant 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: $B^+ \to p\overline{\Lambda}\pi^0$: $(3.0^{+0.7}_{-0.6}) \times 10^{-6}$, $B^0 \to p\overline{\Lambda}\pi^-$: $(3.16 \pm 0.24) \times 10^{-6}$

Threshold Enhancement

Summary

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

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

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

- The decay parameter of the $B^+ \to p\overline{\Lambda}$ 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, $\mathcal{B}_{b\to u\bar{u}s} > \mathcal{B}_{b\to u\bar{u}d}$, but in b-baryon decays, $\mathcal{B}_{b\to u\bar{u}s} \sim \mathcal{B}_{b\to u\bar{u}d}$, *e.g.*

$$\mathcal{B}(B^+ \to p\bar{\Lambda}) = (1.24 \pm 0.18) \times 10^{-7} > \mathcal{B}(B^+ \to p\bar{p}) = (1.25 \pm 0.27 \pm 0.18) \times 10^{-8},$$

$$\mathcal{B}(B_s^0 \to K^+K^-) = (2.72 \pm 0.23) \times 10^{-5} > \mathcal{B}(B_s^0 \to \pi^+K^-) = (5.9 \pm 0.7) \times 10^{-6},$$

$$\mathcal{B}(B^0 \to K^+\pi^-) = (2.00 \pm 0.04) \times 10^{-5} > \mathcal{B}(B^0 \to \pi^+\pi^-) = (5.37 \pm 0.20) \times 10^{-6},$$

$$\mathcal{B}(\Lambda_b^0 \to pK^-) = (4.6 \pm 0.8) \times 10^{-6} \sim \mathcal{B}(\Lambda_b^0 \to p\pi^-) = (5.5 \pm 1.0) \times 10^{-6}$$

✓ Experimental CP asymmetry results

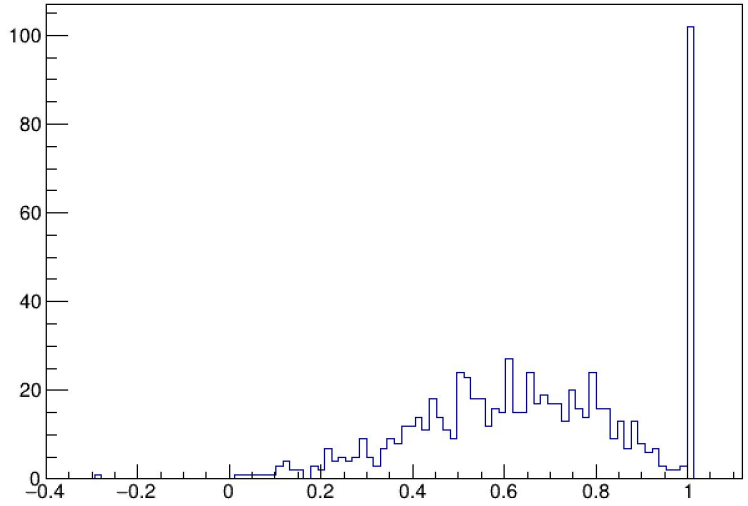
	$b \to u\bar{u}s$				$b \to u\bar{u}d$			
Mode	$B^0 \to K^+\pi^-$	$B_s^0 \to K^+K^-$	$\Lambda_b \to pK^-$	$B^+ \to p\bar{\Lambda}$	$B^0 \to \pi^+\pi^-$	$B_s^0 \to \pi^+K^-$	$\Lambda_b \to p\pi^-$	$B^0 \to p\bar{p}$
A_{CP}(%)	8.24 ± 0.47 JHEP 03 (2021) 075	16.2 ± 3.5 JHEP 03 (2021) 075	-1.4 ± 0.8 PRD 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 $B^+ \to p\bar{\Lambda}$ decay to follow with LHCb Run 3 data.

Thank you for your attention !

Back up

✓ Toy dtudy



$P^{toy} > 0.9999$