Beauty baryon decays at LHCb

Yanxi Wu (Peking University)
On behalf of LHCb collaboration

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Introduction

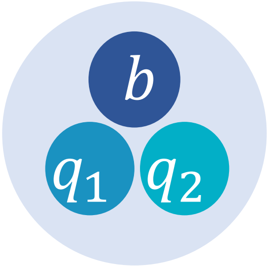
- Heavy baryons are useful systems to study the weak and strong dynamics at low energy of flavor physics
- Much progress in beauty mesons, while many aspects of beauty baryons are largely unknown.

Production

Mass & lifetime

New decay modes

Beauty baryon



Decay parameters

CP asymmetries

New hadron states

Beauty baryons are produced copiously at LHC

opening up new avenues, improving the precision

LHCb experiment

- A single-arm forward region spectrometer covering $2 < \eta < 5$
- Optimised for beauty and charm physics

High Vertex resolution

$\sigma_{\text{IP}} \sim 20\ \mu\text{m}$

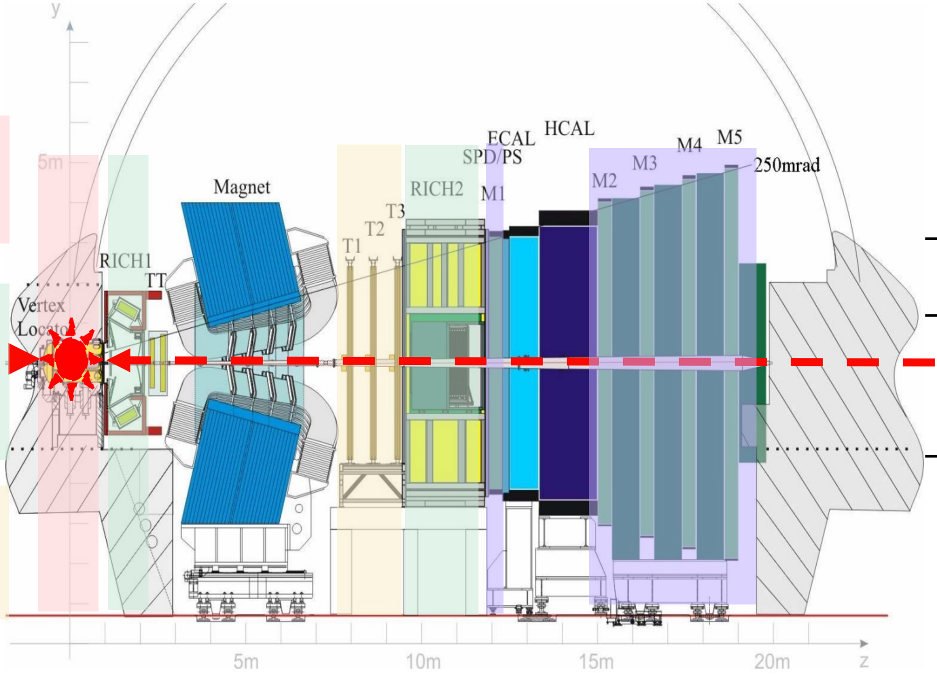
Crucial particle identification

$\epsilon(K \to K) \sim 95\%$

mis-ID $\epsilon(\pi \to K) \sim 5\%$

Good momentum resolution

$\sigma_p/p \sim 0.5\% - 1\%\ (5 - 200\ \text{GeV})$



	Years	$\sqrt{s}$	Luminosity
Run1	2011/12	7/8TeV	$\sim 3\ \text{fb}^{-1}$
Run2	2015/16/17/18	13TeV	$\sim 6\ \text{fb}^{-1}$

[JINST 3 (2008) S08005] [IJMPA 30 (2015) 1530022]

Outline

- Production, mass and branching fraction:
  - Observation of $\Xi_b^0 \to \Xi_c^+ D_s^-$ and $\Xi_b^- \to \Xi_c^0 D_s^-$ decays [Eur. Phys. J. C 84, 237 (2024)]
- New decay mode:
  - NEW First observation of the $\Lambda_b^0 \to D^+ D^- \Lambda$ decay [JHEP07(2024)140]
  - Observation and branching fraction measurement of the decay $\Xi_b^- \to \Lambda_b^0 \pi^-$ [Phys. Rev. D 108, 072002 (2023)]
- Lifetime:
  - NEW Precision measurement of the Ξ_b^- baryon lifetime [arXiv: 2406.12111]
- Decay parameters and CPV
  - NEW Measurement of Λ_b^0, Λ_c^+ and Λ decay parameters using $\Lambda_b^0 \to \Lambda_c^+ h^-$ decays [LHCb-PAPER-2024-017]

Observation of $\Xi_b^0 \to \Xi_c^+ D_s^-$ and $\Xi_b^- \to \Xi_c^0 D_s^-$ decays

[Eur. Phys. J. C 84, 237 (2024)]

Motivation

- According to the quark model, Λ_b^0, Ξ_b^0 and Ξ_b^- form an **SU(3) flavour multiplet**

Λ_b^0 (b u d) $\to \Lambda_c^+ D_s^-$

Ξ_b^0 (b s u) $\to \Xi_c^+ D_s^-$

Ξ_b^- (b s d) $\to \Xi_c^0 D_s^-$

- According to heavy quark effective theory, they should have **approximately the same partial width**
[Phys. Rept. 245 (1994) 259], [Phys. Rev. D 100 (2019) 034025]

- $\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+ D_s^-) = (1.10 \pm 0.10) \times 10^{-2}$ [Phys. Rev. Lett. 112 (2014) 202001]
- no measurements for $\Xi_b^{0(-)} \to \Xi_c^{+(0)} D_s^-$

➢ Test the SU(3) symmetry, give insights into the dynamics of beauty-baryon weak decays.

Analysis strategy

- Measure the relative production rates of the decays

$$\mathcal{R}\left(\frac{\Xi_b^0}{\Lambda_b^0}\right) \equiv \frac{\sigma(\Xi_b^0)}{\sigma(\Lambda_b^0)} \times \frac{\mathcal{B}(\Xi_b^0 \to \Xi_c^+ D_s^-)}{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+ D_s^-)},$$

$$\mathcal{R}\left(\frac{\Xi_b^-}{\Lambda_b^0}\right) \equiv \frac{\sigma(\Xi_b^-)}{\sigma(\Lambda_b^0)} \times \frac{\mathcal{B}(\Xi_b^- \to \Xi_c^0 D_s^-)}{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+ D_s^-)},$$

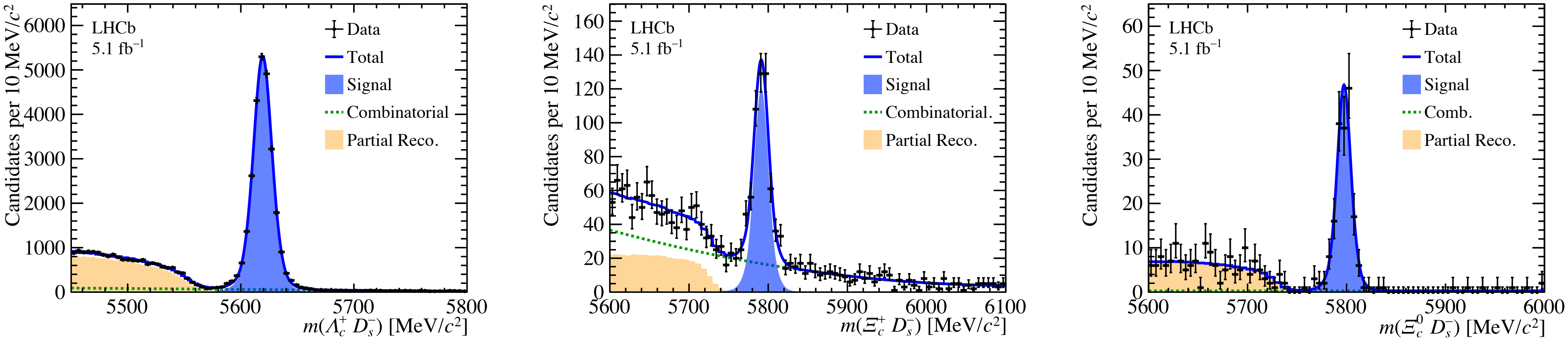
$$\mathcal{R}\left(\frac{\Xi_b^0}{\Xi_b^-}\right) \equiv \frac{\sigma(\Xi_b^0)}{\sigma(\Xi_b^-)} \times \frac{\mathcal{B}(\Xi_b^0 \to \Xi_c^+ D_s^-)}{\mathcal{B}(\Xi_b^- \to \Xi_c^0 D_s^-)}$$

- Provide measurements of the $\boldsymbol{H_b}$ **production cross-section ratios**, assuming $\frac{\mathcal{B}(\Xi_b^0 \to \Xi_c^+ D_s^-)}{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+ D_s^-)} \approx 1$

- **Test Isospin symmetry**: assure that $\frac{\sigma(\Xi_b^0)}{\sigma(\Xi_b^-)} \approx 1$ to a good approximation, resulting $\mathcal{R}\left(\frac{\Xi_b^0}{\Xi_b^-}\right) \approx 1$ at leading order

Results

- Fit results of $m(H_c D_s)$



$$\mathcal{R}\left(\frac{\Xi_b^0}{\Lambda_b^0}\right) = (15.8 \pm 1.1 \pm 0.6 \pm 7.7)\%,$$

$$\mathcal{R}\left(\frac{\Xi_b^-}{\Lambda_b^0}\right) = (16.9 \pm 1.3 \pm 0.9 \pm 4.3)\%,$$

$$\mathcal{R}\left(\frac{\Xi_b^0}{\Xi_b^-}\right) = (93.6 \pm 9.6 \pm 6.1 \pm 51.0)\%$$

- Consistent with SU(3) flavour symmetry
- Consistent with several predictions for relative production rates and decay branching fractions.

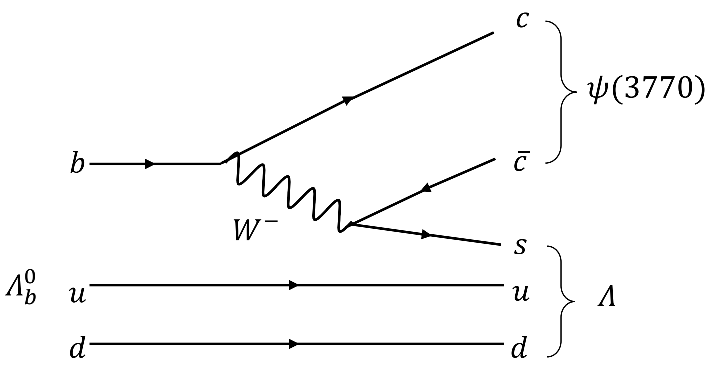
[Phys. Rev. D 100 (2019) 034025] [Phys. Lett. B 751 (2015) 127]
[Eur. Phys. J. C 78 (2018) 224] [Phys. Rev. D 105 (2022) 013003]

NEW

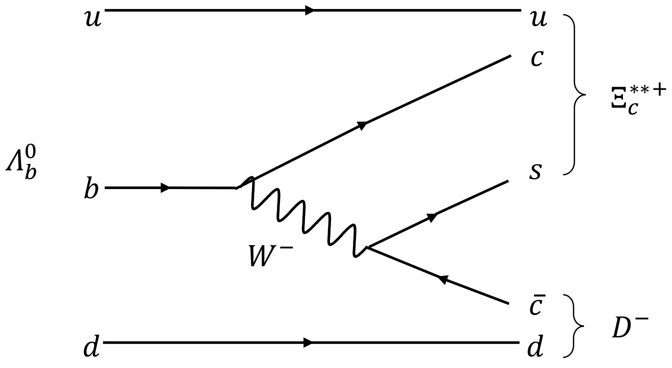
First observation of the $\Lambda_b^0 \to D^+ D^- \Lambda$ decay

[JHEP07(2024)140]

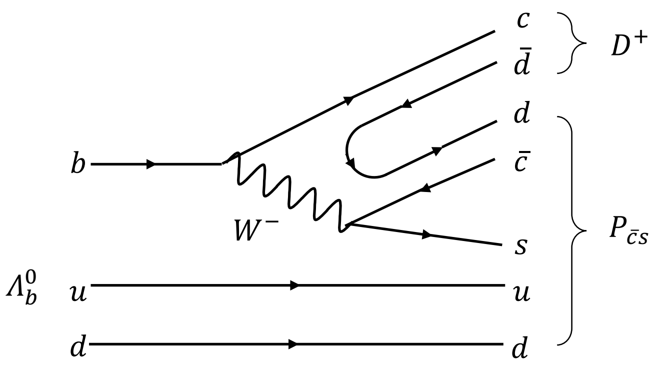
- $\Lambda_b^0 \to D^+ D^- \Lambda$ mediated by $b \to c\bar{c}s$, it is predicted via two types of two-body **intermediate states** [Phys. Rev. D 103, 114013 (2021)]
  - a Λ baryon and a charmonium resonance
  - a charmed baryon and a D meson



$\psi(3770) \to D\bar{D}$



$\Xi_c^{**} \to D\Lambda$



$P_{\bar{c}s} \to \Lambda\bar{D}$

- $\Lambda_b^0 \to D^+ D^- \Lambda$ Not observed yet

NEW

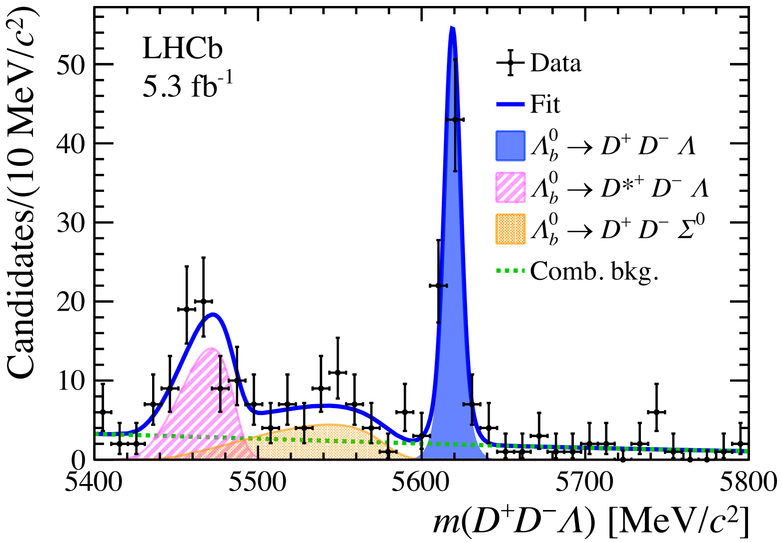
First observation of the $\Lambda_b^0 \to D^+D^-\Lambda$ decay

[JHEP07(2024)140]

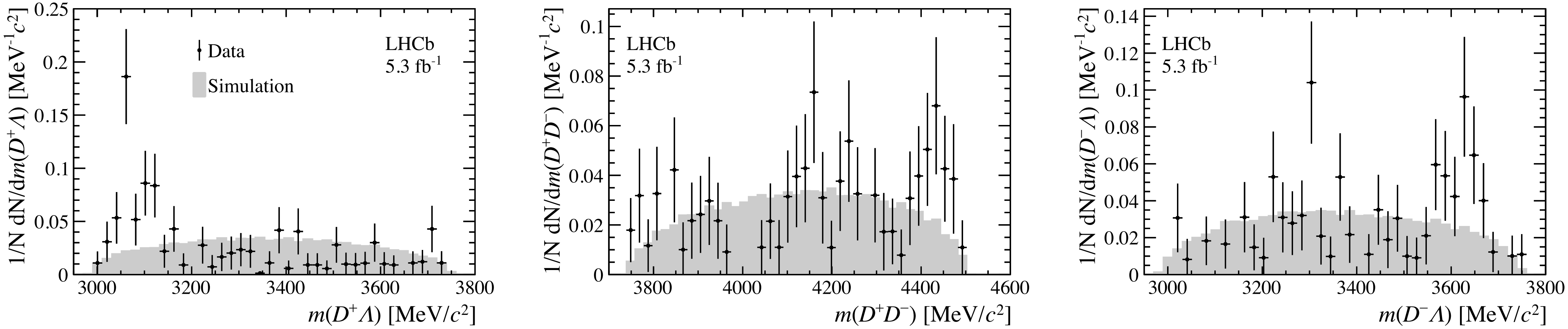
- First observation of $\Lambda_b^0 \to D^+D^-\Lambda$ decay
  - Statistical significance ~ 16σ
- Branching fraction measured

$$\mathcal{B}(\Lambda_b^0 \to D^+D^-\Lambda) = (1.24 \pm 0.15 \pm 0.10 \pm 0.28 \pm 0.11)\times 10^{-4}$$

Stat. Syst. Ref. channel



- Two-body invariant masses:

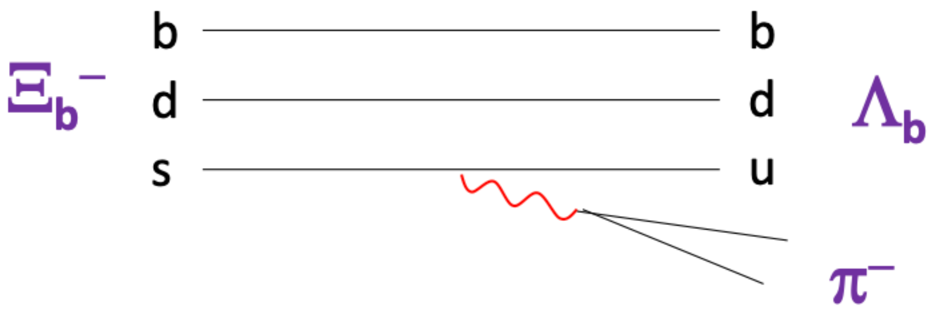


Observation and branching fraction measurement of the decay $\Xi_b^- \to \Lambda_b^0 \pi^-$

[Phys. Rev. D 108, 072002 (2023)]

Introduction

- Mediated by $s \to u\bar{u}d$, where the b quark is a spectator

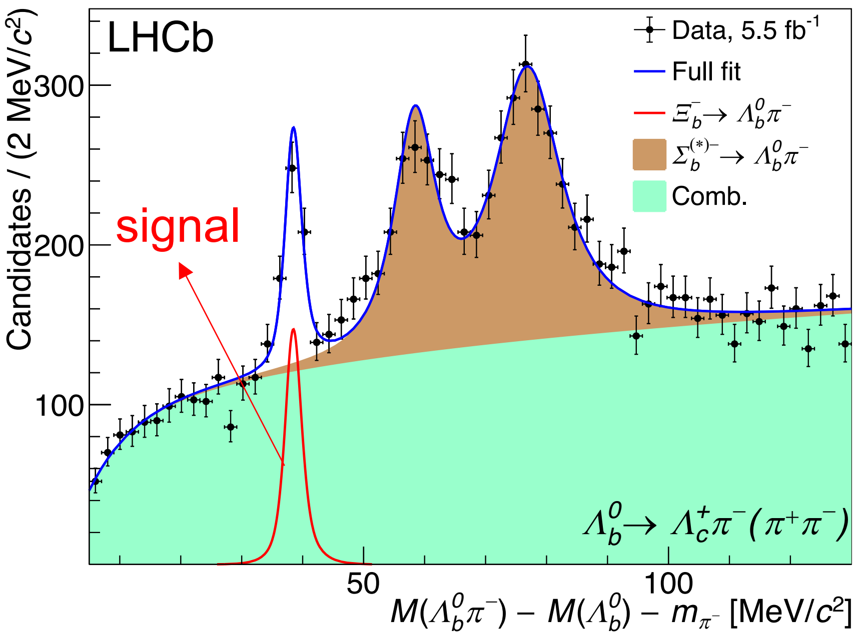


- A previous LHCb study using Run1 dataset shows an evidence (3.2σ) for this decay [PRL115 (2015) 241801]
- Updated with Run2 dataset
- Normalizing the signal yield to that of inclusively produced Λ_b^0

$$r_s \equiv \frac{f_{\Xi_b^-}}{f_{\Lambda_b^0}} \mathcal{B}(\Xi_b^- \to \Lambda_b^0 \pi^-)$$

Results

[Phys. Rev. D 108, 072002 (2023)]



$$r = (7.3 \pm 0.8 \pm 0.6) \times 10^{-4}$$

$$\mathcal{B}(\Xi_b^- \to \Lambda_b^0 \pi^-) = (0.89 \pm 0.10 \pm 0.07 \pm 0.29)\%$$

Using the independent $f_{\Xi_b^-}/f_{\Lambda_b^0}$ measurement from [PRD 99 (2019) 052006]

- Three times better statistical precision than Run1
- Consistent with some predictions
  - [JHEP03(2016)028] [PLB 750. (2015) 653] [PRD 93 (2016) 034020]
- Extra contribution to the Ξ_b^- decay width should be considered for **lifetime** comparison between experiment and theory predictions, where the predictions only consider the decay of the b quark.

NEW

Precision measurement of the Ξ_b^- baryon lifetime

[arXiv: 2406.12111]

Submitted to PRD

Introduction

NEW

Precision measurement of the Ξ_b^- lifetime

[arXiv: 2406.12111]

- The heavy quark expansion (HQE) framework can predict the inclusive decay rates of beauty hadrons
  - Calculate b-hadron parameters required for determination of CKM matrix elements
  - Provide constraints on physics beyond the Standard Model

Test HQE? ⟶ confront its predictions of lifetimes

Needs to be updated!

Lifetimes	Theoretical uncertainties	Experimental uncertainties
$\tau_{\Xi_b^-}/\tau_{\Lambda_b^0}$	1.9%	2.5%
$\tau_{\Omega_b^-}/\tau_{\Lambda_b^0}$	4.2%	11%

[JHEP 04 (2023) 034]

- Available measurement by LHCb limited by statistics, using only Run 1 data
- Update measurement of Ξ_b^- lifetime using Run2 data

Analysis strategy

- Measure lifetime ratio $\tau_{\Xi_b^-}/\tau_{\Lambda_b^0}$
  - Using Run2 data
- Reconstrcution: $\Xi_b^- \to \Xi_c^0\pi^-,\ \ \Xi_c^0 \to pK^-K^-\pi^+$
  - Normalization: $\Lambda_b^0 \to \Lambda_c^+\pi^-,\ \ \Lambda_c^+ \to pK^-\pi^+$
- Measure the ratio of efficiency-corrected signal yields as a function of decay time

$$R(t) \equiv \frac{N[\Xi_b^- \to \Xi_c^0\pi^-](t)}{N[\Lambda_b^0 \to \Lambda_c^+\pi^-](t)} \cdot \frac{\epsilon[\Lambda_b^0 \to \Lambda_c^+\pi^-](t)}{\epsilon[\Xi_b^- \to \Xi_c^0\pi^-](t)} = R_0 \exp(\lambda t)$$

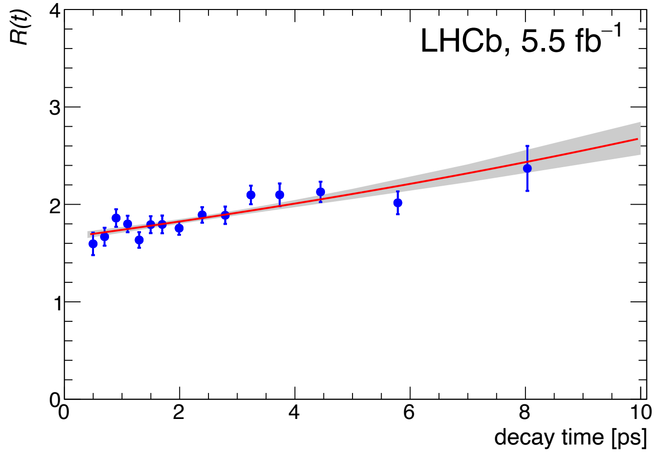
$$\lambda \equiv \frac{1}{\tau_{\Lambda_b^0}} - \frac{1}{\tau_{\Xi_b^-}}$$

$$\frac{\tau_{\Xi_b^-}}{\tau_{\Lambda_b^0}} = \frac{1}{1-\lambda\tau_{\Lambda_b^0}} \qquad (\tau_{\Lambda_b^0} = 1.464 \pm 0.010\ \text{ps})$$

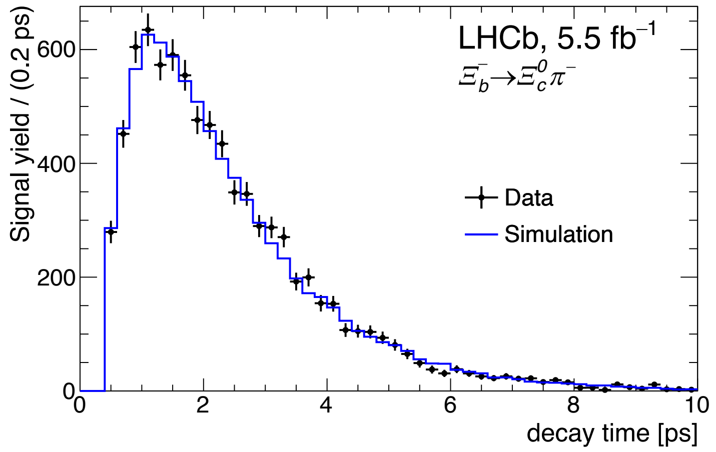
[Prog. Theor. Exp. Phys. 2022 (2022) 083C01]

Results

NEW



[Phys. Rev. Lett. 113 (2014) 242002]



- The most precise measurement of the Ξ_b^- baryon lifetime
- Improves on the world-average value by about a factor of two.

	Run1	Run2	**Run1+2**
$\frac{\tau_{\Xi_b^-}}{\tau_{\Lambda_b^0}}$	$1.089 \pm 0.026 \pm 0.011$	$1.076 \pm 0.013 \pm 0.006$	$\mathbf{1.077 \pm 0.012 \pm 0.007}$
$\tau_{\Xi_b^-}$ (ps)	$1.599 \pm 0.041 \pm 0.022$	$1.575 \pm 0.019 \pm 0.009 \pm 0.011$	$\mathbf{1.577 \pm 0.018 \pm 0.010 \pm 0.011}$

Consistent with HQE expectation:

$$\frac{\tau_{\Xi_b^-}}{\tau_{\Lambda_b^0}} = 1.078 \pm 0.021$$

[JHEP 04 (2023) 034]

s-quark decay $\Xi_b^- \to \Lambda_b^0\pi^-$ would reduce HQE prediction by ~1%.

Still in agreement!

[Phys. Rev. D108 (2023) 072002]

NEW

Measurement of Λ_b^0, Λ_c^+ and Λ decay parameters using $\Lambda_b^0 \to \Lambda_c^+ h^-$ decays

[LHCb-PAPER-2024-017]
In preparation

Introduction

- Decay parameters first proposed by Lee and Yang (1957)
  - for $\frac{1}{2}^+ \to \frac{1}{2}^+ 0^-$ decays

$$\alpha \equiv \frac{2Re(s*p)}{|s|^2+|p|^2}, \qquad \beta \equiv \frac{2Im(s*p)}{|s|^2+|p|^2}, \qquad \gamma \equiv \frac{|s|^2-|p|^2}{|s|^2+|p|^2}$$

  - With $\alpha^2+\beta^2+\gamma^2=1$, where s: S-wave amplitude, and p: P-wave amplitude
- Decay parameters provide an excellent understanding of the baryon decay dynamics and are used to probe the matter–antimatter asymmetry
- CP violation can be quantified by

$$A_\alpha = \frac{\alpha+\bar{\alpha}}{\alpha-\bar{\alpha}} = -\tan\Delta\delta\tan\Delta\phi\,, \qquad R_\beta = \frac{\beta+\bar{\beta}}{\alpha-\bar{\alpha}} = \tan\Delta\phi$$

  - $\bar{\alpha}, \bar{\beta}$: decay parameters of anti-baryon decay
  - $\Delta\delta$: strong phase difference, $\Delta\phi$: weak phase difference between the S and P wave amplitudes

Analysis overview

- Status of decay parameters measurement:
  - Λ_c^+: several decays measured by Belle and BESIII [Phys. Rev. D 107, 032003] [Science Bulletin, Volume 68, Issue 6, 2023, pp. 583-592]
  - Λ: Precisely measured by BESIII [Phys. Rev. D 106, 052003 (2022)]
  - Λ_b^0: no result for $\frac{1}{2}^+ \to \frac{1}{2}^+ 0^-$ decays
- Decay channels considered in this work

$$\Lambda_b^0 \to \Lambda_c^+ h_1^- \begin{cases} \Lambda_c^+ \to \Lambda h_2^+, \Lambda \to p\pi^- \ (h_{1,2} = \pi, K) \\ \Lambda_c^+ \to p K_S^0 \end{cases}$$

- Decay parameters extracted from angular distributions

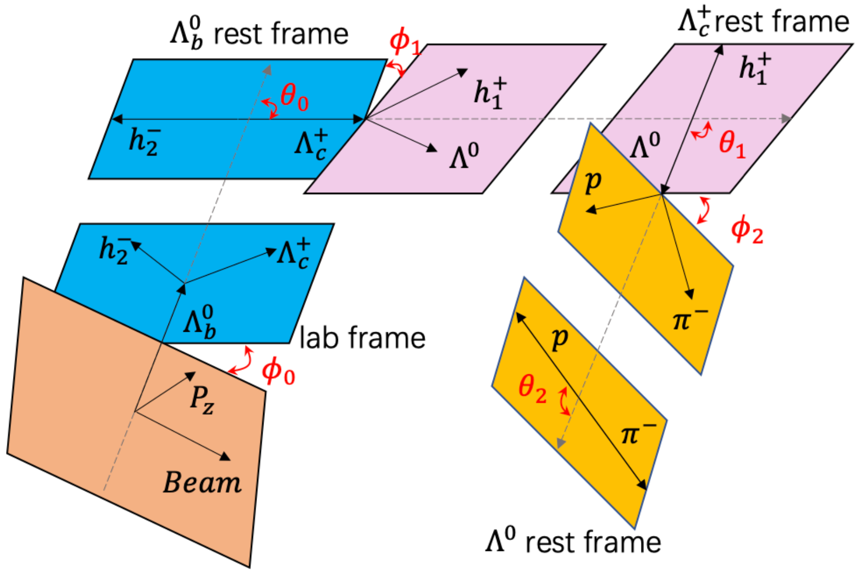
Angular analysis

NEW

- For three-step cascade decays:

$\Lambda_b^0 \to \Lambda_c^+ h_1^-, \Lambda_c^+ \to \Lambda h_2^+, \Lambda \to p\pi^-$ $(h_{1,2} = \pi, K)$

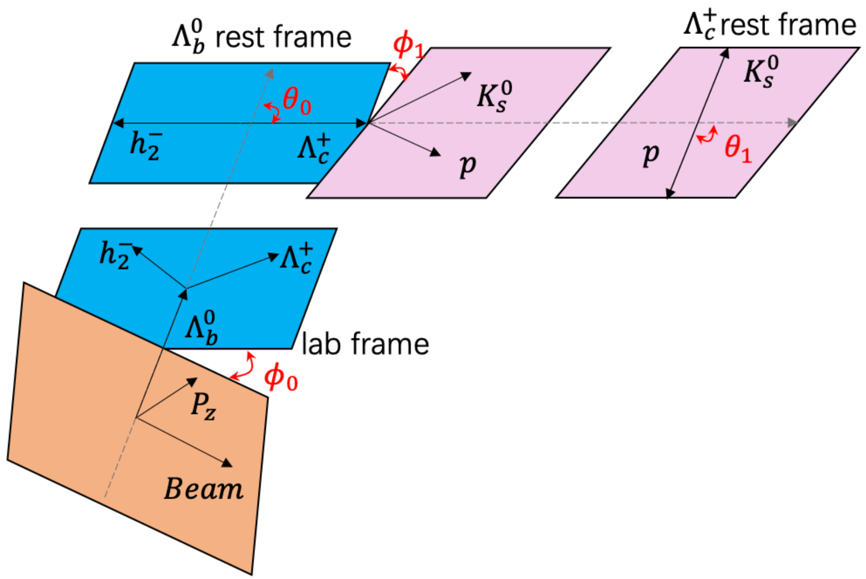
$\Omega \equiv (\theta_0, \theta_1, \phi_1, \theta_2, \phi_2)$



- For two-step cascade decays:

$\Lambda_b^0 \to \Lambda_c^+ h^-, \Lambda_c^+ \to pK_S^0$

$\Omega \equiv (\theta_0, \theta_1, \phi_1)$



Results

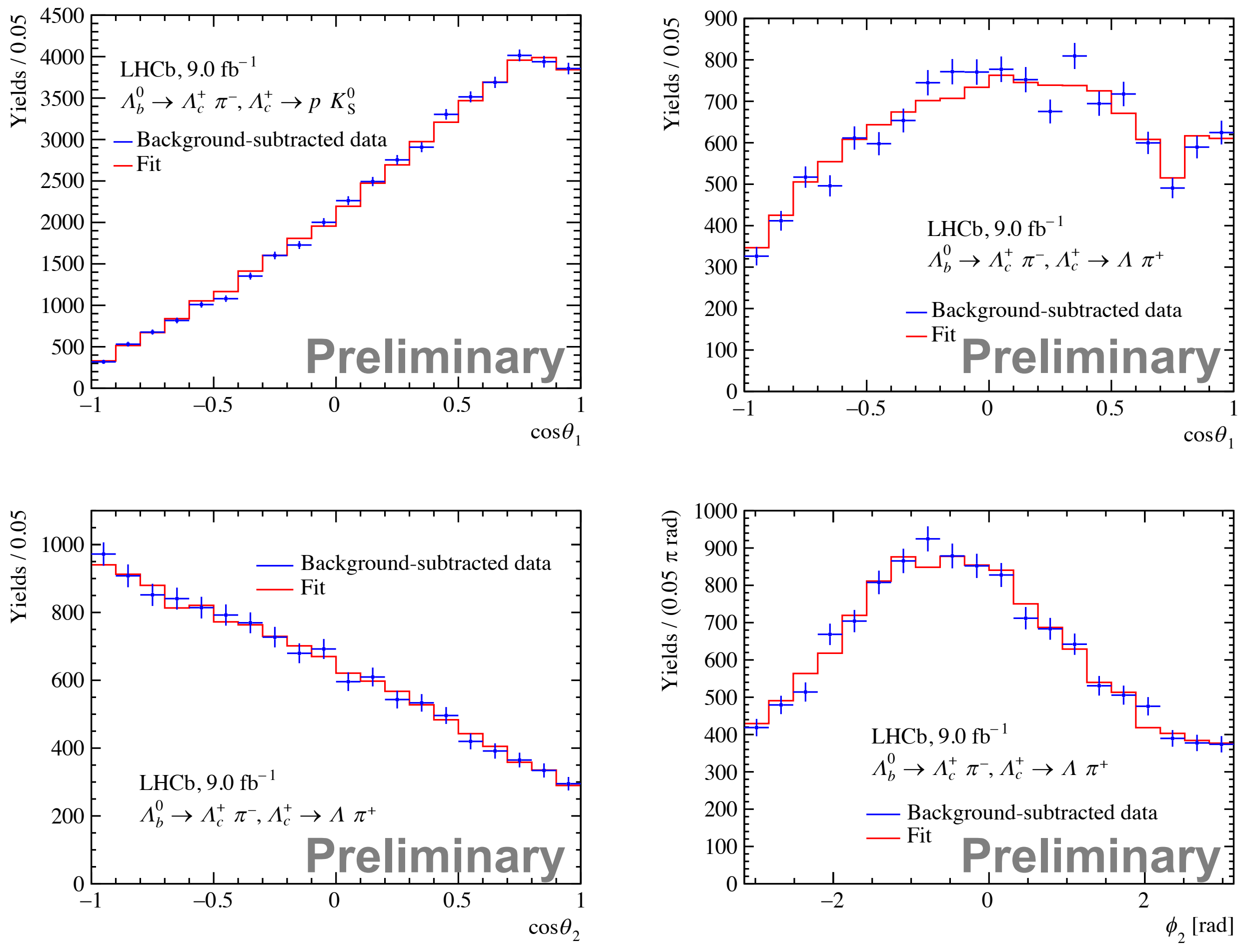
NEW

Measurement of Λ_b^0, Λ_c^+ and Λ decay parameters

[LHCb-PAPER-2024-017]

- First measurement of decay parameters of $\Lambda_b^0 \to \Lambda_c^+ h^-$
- Precise measurements of β, γ of $\Lambda_c^+ \to \Lambda h^+$
- Precision of α of $\Lambda_c^+ \to \Lambda h^+ / pK_S^0$ improves significantly
- Independent measurement for $\Lambda \to p\pi^-$, consistent with BESIII
- Negligible CP violation in these processes

Decay	$\langle\alpha\rangle$	A_α
$\Lambda_b^0 \to \Lambda_c^+ \pi^-$	$-1.003 \pm 0.008 \pm 0.005$	$0.007 \pm 0.008 \pm 0.005$
$\Lambda_b^0 \to \Lambda_c^+ K^-$	$-0.964 \pm 0.028 \pm 0.015$	$-0.032 \pm 0.029 \pm 0.006$
$\Lambda_c^+ \to \Lambda \pi^+$	$-0.785 \pm 0.006 \pm 0.003$	$-0.003 \pm 0.008 \pm 0.002$
$\Lambda_c^+ \to \Lambda K^+$	$-0.516 \pm 0.041 \pm 0.021$	$0.102 \pm 0.080 \pm 0.023$
$\Lambda_c^+ \to pK_S^0$	$-0.754 \pm 0.008 \pm 0.006$	$-0.014 \pm 0.011 \pm 0.008$
$\Lambda \to p\pi^-$	$0.733 \pm 0.012 \pm 0.006$	$-0.022 \pm 0.016 \pm 0.007$



* More detailed results in the BackUp

Summary

- LHCb is a factory of beauty baryons
- With LHCb analysis, we can greatly improve knowledge about…
  - New decay modes: $\Xi_b^0 \to \Xi_c^+ D_s^-$ and $\Xi_b^- \to \Xi_c^0 D_s^-$, $\Lambda_b^0 \to D^+ D^- \Lambda$, $\Xi_b^- \to \Lambda_b^0 \pi^-$
  - More precise mass and lifetime about Ξ_b^0 and Ξ_b^-
  - First measurement of decay parameters of $\Lambda_b^0 \to \Lambda_c^+ h^-$, more precise ones of Λ_c^+
- Open the door to …
  - Search for exotic states
  - Test and constrain theoretical models
  - Search for new physics

Looking forward to Run3!

Thanks for your attention

BackUp

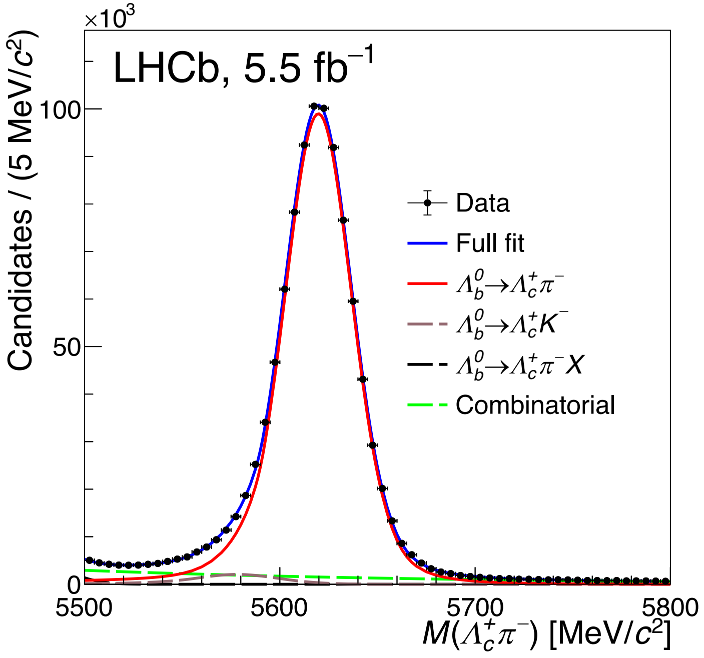
Mass fit & systematics

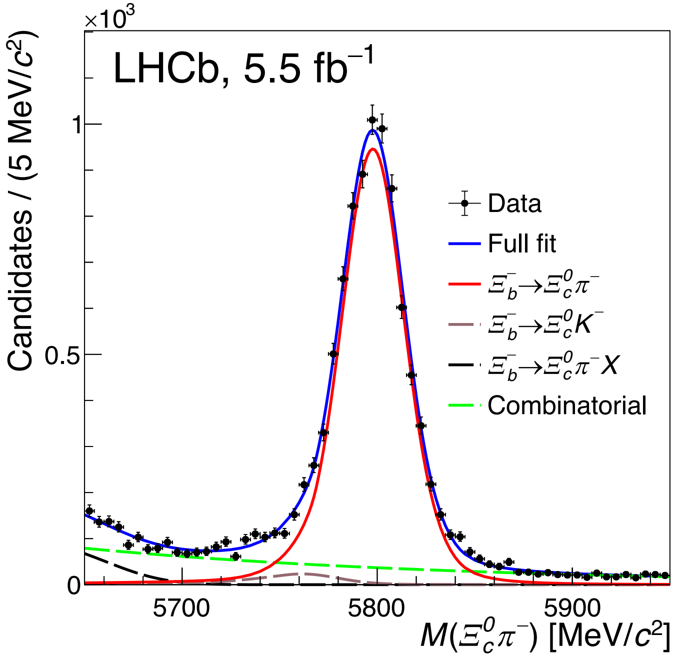
- Model:
  - Signal: two crystal ball
  - Σ_b^{*-}: BW
  - Comb,: threshold function
- Signal yield: 126 ± 19 for $\Lambda_c^+\pi^-$, 154 ± 23 for $\Lambda_c^+\pi^-\pi^+\pi^-$
- Significance: 11σ
- $\frac{f_{\Xi_b^-}}{f_{\Lambda_b^0}} = (8.2 \pm 0.7 \pm 0.6 \pm 2.5)\%$ at $\sqrt{s} = 13$ TeV

- Systematics:

Source	Value (%)	
	$\Lambda_c^+\pi^-$	$\Lambda_c^+\pi^-\pi^+\pi^-$
Ξ_b^- signal shape	1.4	2.4
Ξ_b^- background shape	3.1	1.8
Λ_b^0 signal shape	0.3	0.8
Λ_b^0 background shape	0.1	0.7
Geom. acceptance	1.8	1.8
Sim. weights & sample sizes	3.6	3.4
Trigger efficiency	1.7	0.4
Ξ_b^- p_T spectrum	3.2	5.6
IP resolution	1.3	0.7
BDT2 efficiency	3.0	3.5
Tracking efficiency	3.3	3.3
Multiple candidates	0.5	2.6
Ξ_b^- lifetime	3.0	2.5
Total	8.5	9.7

Mass fit & systematics





Model:
- Signal: 2 Crystal Ball functions
- misID: 2 Crystal Ball functions
- Missing X: ARGUS
- Comb. Bkg.: exponential function

Mode	TOS	TIS	TOS + TIS
Ξ_b^-	4363 ± 76	3976 ± 71	8303 ± 107
Λ_b^0 ($\times 10^3$)	519.9 ± 0.9	408.0 ± 0.8	928.4 ± 1.2

Source	Value (%)
Simulated sample size	0.43
Signal shape	0.07
Background shape	0.01
χ^2_{IP} scaling	0.20
Truth matching	0.07
Bin width in mass	0.03
Mass fit range	0.18
Bin width in time	0.06
BDT requirement	0.21
Λ_b^0 lifetime	0.05
Total	0.57

Status

Λ_c^+

- Decay parameter measurements

$\alpha(\Lambda_c^+ \to \Lambda\pi^+) = -0.80 \pm 0.11 \pm 0.02$ [BESIII]
$\alpha(\Lambda_c^+ \to \Sigma^+\pi^0) = -0.57 \pm 0.10 \pm 0.07$ [BESIII]
$\alpha(\Lambda_c^+ \to \Sigma^0\pi^+) = -0.73 \pm 0.17 \pm 0.07$ [BESIII]
$\alpha(\Lambda_c^+ \to pK_S^0) = 0.18 \pm 0.43 \pm 0.14$ [BESIII]
$\alpha(\Lambda_c^+ \to \Lambda l^+\nu_l) = -0.86 \pm 0.03 \pm 0.02$ [CLEO-c]

- Measurements of CP asymmetry of decay parameter

$A_\alpha(\Lambda_c^+ \to \Lambda e^+\nu_e) = 0.00 \pm 0.03 \pm 0.02$ [CLEO-c]
$A_\alpha(\Lambda_c^+ \to \Lambda\pi^+) = -0.07 \pm 0.19 \pm 0.24$ [FOCUS]

- New measurements from Belle

$\alpha(\Lambda_c^+ \to \Sigma^+\pi^0) = -0.48 \pm 0.02 \pm 0.02$
$\alpha(\Lambda_c^+ \to \Sigma^+\eta) = -0.99 \pm 0.03 \pm 0.05$
$\alpha(\Lambda_c^+ \to \Sigma^+\eta') = -0.46 \pm 0.06 \pm 0.03$
[Phys. Rev. D 107, 032003]

$\alpha(\Lambda_c^+ \to \Lambda K^+) = -0.585 \pm 0.049 \pm 0.018$
$\alpha(\Lambda_c^+ \to \Lambda\pi^+) = -0.755 \pm 0.005 \pm 0.003$
$\alpha(\Lambda_c^+ \to \Sigma^0 K^+) = -0.54 \pm 0.18 \pm 0.09$
$\alpha(\Lambda_c^+ \to \Sigma^0\pi^+) = -0.463 \pm 0.016 \pm 0.008$
[Science Bulletin, Volume 68, Issue 6, 2023, pp. 583-592]

Λ_b^0 & Λ

- Λ_b^0 decay parameter measurements

$\alpha(\Lambda_b^0 \to J/\Psi\,\Lambda) = -0.017 \pm 0.026$ [LHCb, CMS, ATLAS]

- Theoretical predictions in the Standard Model

$\alpha(\Lambda_b^0 \to \Lambda_c^+\pi^-) = -0.9999 \pm 0.0224$
$\alpha(\Lambda_b^0 \to \Lambda_c^+K^-) = -0.9998 \pm 0.0241$
[Phys. Rev. D 99, 014023 (2019)]

- Λ decay parameter measurements

$\alpha(\Lambda \to p\pi^-) = 0.7519 \pm 0.0036 \pm 0.0024$
$\bar{\alpha}(\bar{\Lambda} \to \bar{p}\pi^+) = -0.7559 \pm 0.0036 \pm 0.0030$
[Phys. Rev. D 106, 052003 (2022)]

Precisely measured by BESIII

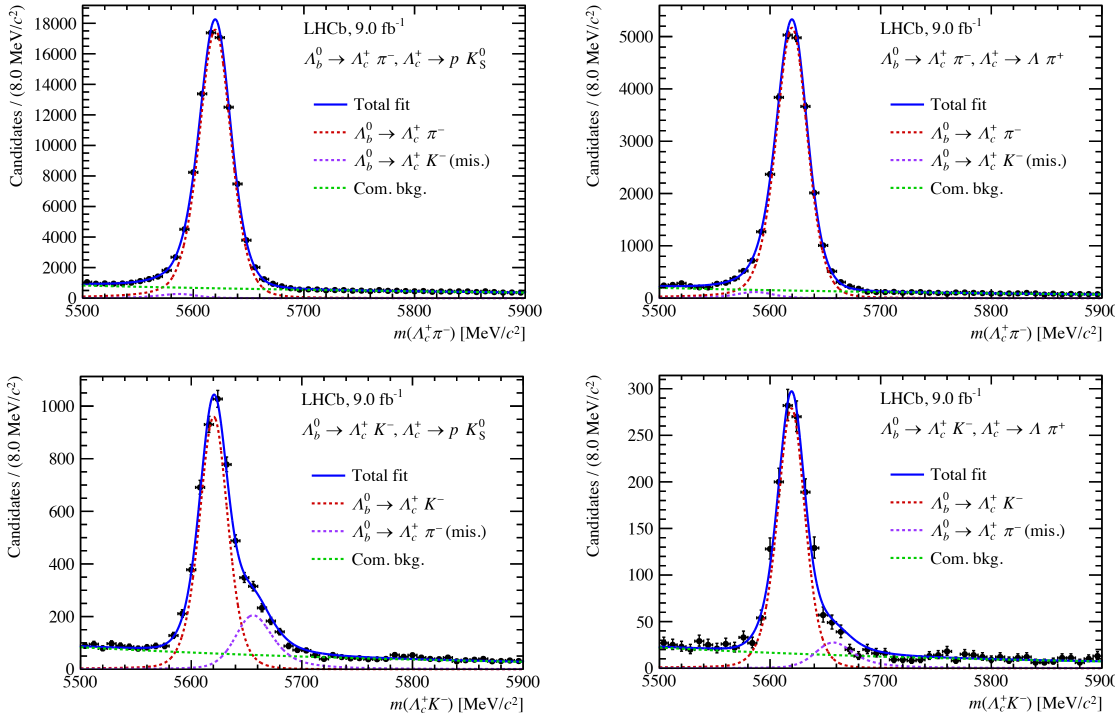
Selection and mass fit

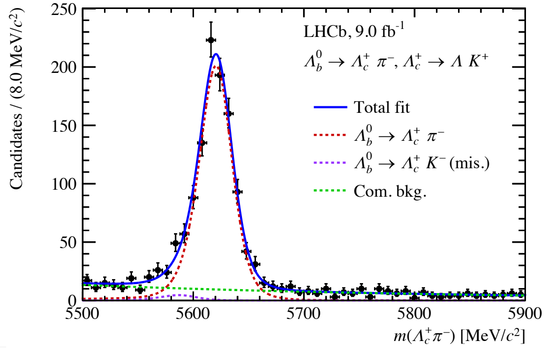
Measurement of Λ_b^0, Λ_c^+ and Λ decay parameters

[LHCb-PAPER-2024-017]

- Selection:
  - Large transverse momentum (final states)
  - Inconsistent with being directly produced from any PV (final states)
  - Good-quality vertex displaced from PV
  - $\Lambda(K_S^0)$ within $\pm 26(20)\ \mathrm{MeV}/c^2$
  - PID
  - BDT

- Mass fit:





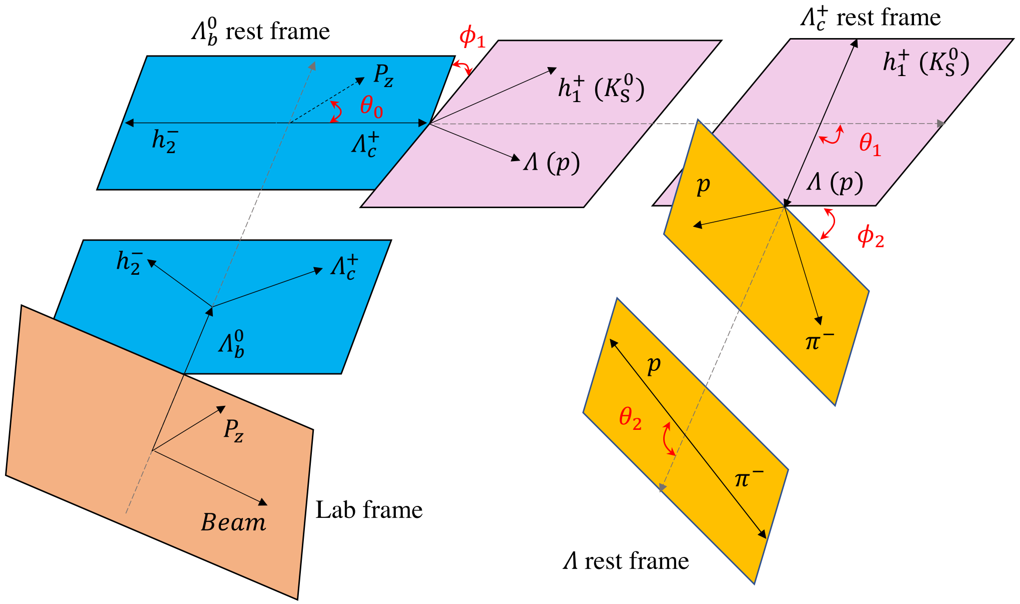
Signal: Hypatia
Comb.bkg.: exponential
misID bkg.: Hypatia

Yield~$10^3 - 10^4$

Angular analysis

NEW

Measurement of Λ_b^0, Λ_c^+ and Λ decay parameters
[LHCb-PAPER-2024-017]



- For three-step cascade decays:

$\Omega \equiv (\theta_0, \theta_1, \phi_1, \theta_2, \phi_2)$

$$\frac{d^3\Gamma}{d\cos\theta_1 d\cos\theta_2 d\phi_2} \propto (1 + \alpha_{\Lambda_b^0}^{\Lambda_c^+ h_2^-}\alpha_{\Lambda_c^+}^{\Lambda h_1^+}\cos\theta_1 + \alpha_{\Lambda_c^+}^{\Lambda h_1^+}\alpha_{\Lambda}^{p\pi^-}\cos\theta_2 + \alpha_{\Lambda_b^0}^{\Lambda_c^+ h_2^-}\alpha_{\Lambda}^{p\pi^-}\cos\theta_1\cos\theta_2 - \alpha_{\Lambda_b^0}^{\Lambda_c^+ h_2^-}\gamma_{\Lambda_c^+}^{\Lambda h_1^+}\alpha_{\Lambda}^{p\pi^-}\sin\theta_1\sin\theta_2\cos\phi_2 + \alpha_{\Lambda_b^0}^{\Lambda_c^+ h_2^-}\beta_{\Lambda_c^+}^{\Lambda h_1^+}\alpha_{\Lambda}^{p\pi^-}\sin\theta_1\sin\theta_2\sin\phi_2)$$

- For two-step cascade decays:

$\Omega \equiv (\theta_0, \theta_1, \phi_1)$

$$\frac{d\Gamma}{d\cos\theta_1} \propto 1 + \alpha_{\Lambda_b^0}^{\Lambda_c^+ h_2^-}\alpha_{\Lambda_c^+}^{pK_S^0}\cos\theta_1$$

* Λ_b^0 polarization consistent with zero at LHC
[J. High Energ. Phys. 2020, 110]

Angular analysis

NEW

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- Likelihood and signal PDF

The logarithm of the likelihood function ($\log \mathcal{L}$) is constructed as

$$\log \mathcal{L}(\vec{\nu}) = \sum_{k=1}^{5} \left(\mathcal{C}_k \sum_{i \in \text{data}_k} w_{k,i} \times \log \left[\mathcal{P}_k(\vec{\Omega}_k^i | \vec{\nu}) \right] \right), \tag{4}$$

where $\vec{\nu}$ is the set of decay parameters, $\vec{\Omega}$ is the set of angular variables, and $\mathcal{P}(\vec{\Omega}|\vec{\nu})$ represents the signal probability density function (PDF). The subscript k runs over the five Λ_b^0 cascade decays, and the subscript i runs over all the candidates of the k-th decay, data_k. The *sPlot* weight $w_{k,i}$ in the $\log \mathcal{L}$ is used to subtract the contribution of background candidates [58]. The constants $\mathcal{C}_k \equiv \sum_{i \in \text{data}_k} w_{k,i} / \sum_{i \in \text{data}_k} w_{k,i}^2$ aim for correcting the reported statistical uncertainties [60]. The signal PDF $\mathcal{P}_k(\vec{\Omega}_k|\vec{\nu})$ of the k-th Λ_b^0 decay is formulated as

$$\mathcal{P}_k(\vec{\Omega}_k|\vec{\nu}) = \frac{\epsilon_k(\vec{\Omega}_k) \cdot f_k(\vec{\Omega}_k|\vec{\nu})}{\int d\vec{\Omega}_k \; \epsilon_k(\vec{\Omega}_k) \cdot f_k(\vec{\Omega}_k|\vec{\nu})}, \tag{5}$$

Decay parameter results

NEW

Measurement of Λ_b^0, Λ_c^+ and Λ decay parameters
[LHCb-PAPER-2024-017]

Table 1: Measurements of α parameters and their CP asymmetries for $\Lambda_b^0 \to \Lambda_c^+ \pi^-$, $\Lambda_b^0 \to \Lambda_c^+ K^-$, $\Lambda_c^+ \to \Lambda\pi^+$, $\Lambda_c^+ \to \Lambda K^+$, $\Lambda_c^+ \to pK_S^0$ and $\Lambda \to p\pi^-$ decays. The first uncertainties are statistical and the second are systematic.

Decay	α	$\bar{\alpha}$	$\langle\alpha\rangle$	A_α
$\Lambda_b^0 \to \Lambda_c^+ \pi^-$	$-1.010 \pm 0.011 \pm 0.003$	$0.996 \pm 0.011 \pm 0.003$	$-1.003 \pm 0.008 \pm 0.005$	$0.007 \pm 0.008 \pm 0.005$
$\Lambda_b^0 \to \Lambda_c^+ K^-$	$-0.933 \pm 0.042 \pm 0.014$	$0.995 \pm 0.036 \pm 0.013$	$-0.964 \pm 0.028 \pm 0.015$	$-0.032 \pm 0.029 \pm 0.006$
$\Lambda_c^+ \to \Lambda\pi^+$	$-0.782 \pm 0.009 \pm 0.004$	$0.787 \pm 0.009 \pm 0.003$	$-0.785 \pm 0.006 \pm 0.003$	$-0.003 \pm 0.008 \pm 0.002$
$\Lambda_c^+ \to \Lambda K^+$	$-0.569 \pm 0.059 \pm 0.028$	$0.464 \pm 0.058 \pm 0.017$	$-0.516 \pm 0.041 \pm 0.021$	$0.102 \pm 0.080 \pm 0.023$
$\Lambda_c^+ \to pK_S^0$	$-0.744 \pm 0.012 \pm 0.009$	$0.765 \pm 0.012 \pm 0.007$	$-0.754 \pm 0.008 \pm 0.006$	$-0.014 \pm 0.011 \pm 0.008$
$\Lambda \to p\pi^-$	$0.717 \pm 0.017 \pm 0.009$	$-0.748 \pm 0.016 \pm 0.007$	$0.733 \pm 0.012 \pm 0.006$	$-0.022 \pm 0.016 \pm 0.007$

Table 2: Measurements of the decay parameters β and γ, the phase difference Δ and the CP asymmetry R_β for $\Lambda_c^+ \to \Lambda\pi^+$, $\Lambda_c^+ \to \Lambda K^+$ decays and their charge-conjugated decays. The first uncertainties are statistical and the second are systematic.

Decay	$\Lambda_c^+ \to \Lambda\pi^+$	$\Lambda_c^+ \to \Lambda K^+$
β	$0.368 \pm 0.019 \pm 0.008$	$0.35 \pm 0.12 \pm 0.04$
$\bar{\beta}$	$-0.387 \pm 0.018 \pm 0.010$	$-0.32 \pm 0.11 \pm 0.03$
γ	$0.502 \pm 0.016 \pm 0.006$	$-0.743 \pm 0.067 \pm 0.024$
$\bar{\gamma}$	$0.480 \pm 0.016 \pm 0.007$	$-0.828 \pm 0.049 \pm 0.013$
Δ	$0.633 \pm 0.036 \pm 0.013$	$2.70 \pm 0.17 \pm 0.04$
$\bar{\Delta}$	$-0.678 \pm 0.035 \pm 0.013$	$-2.78 \pm 0.13 \pm 0.03$
R_β	$0.012 \pm 0.017 \pm 0.005$	$-0.04 \pm 0.15 \pm 0.02$