University of Chinese Academy of Sciences

LHCb实验上B介子两体纯重子衰变的研究进展

第22届全国重味物理和CP破坏研讨会

中国科学院大学 任赞

2025年10月26日

中国・北京

Outline

LHCb experiment

Two-body baryonic decay of B meson

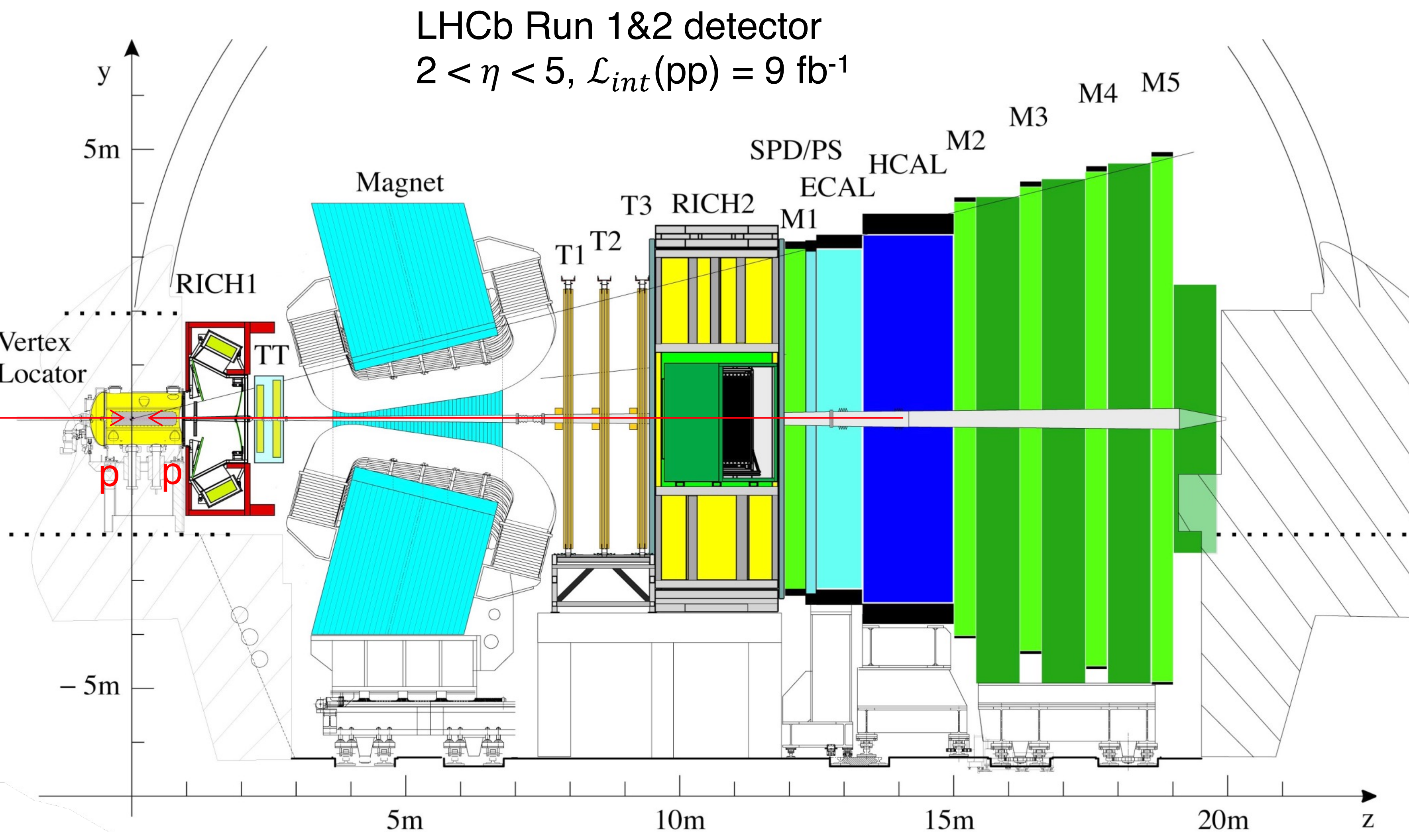
- charmless
- charmed

New

Summary & outlook

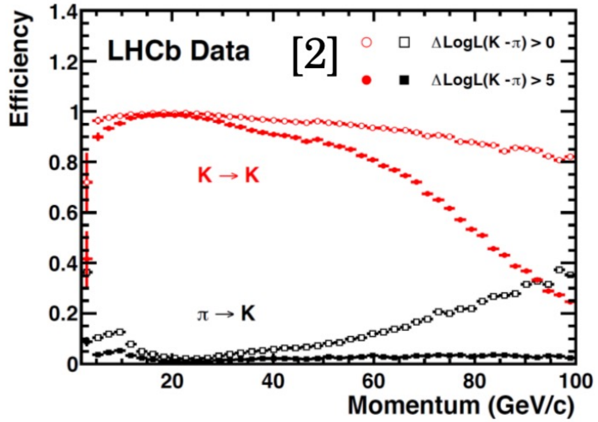
LHCb Run1&Run2 detector

- Single-arm, forward. Specifically designed for heavy-flavour physics.



➢ Excellent tracking and vertexing
- $\sigma(p)/p < 1\%$ @ $\epsilon_{\text{track}} > 96\%$
- $\sigma(\text{IP}) = (15 + 29/p_T)\ \mu m$

➢ Excellent PID
- $\epsilon_{\text{PID}}(K) \approx 95\%$ @ $\text{MisID}(\pi \to K) \approx 5\%$
- $\epsilon_{\text{PID}}(\mu) \approx 97\%$ @ $\text{MisID}(\pi \to \mu) \approx 3\%$

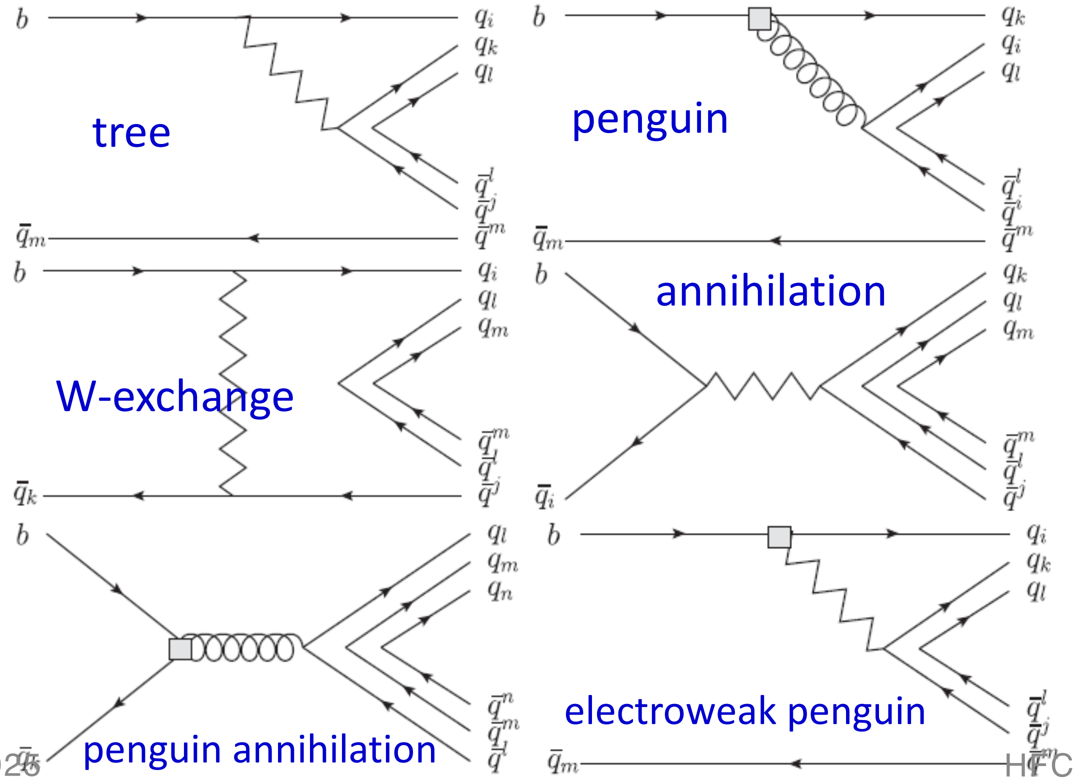


JINST3 (2008) S08005
IJMPA 30 (2015) 1530022

Two–body charmless baryonic decays of B meson

- Provides information on the dynamics of B decays and tests QCD based models of the hadronization process
- Discriminate models and extract both tree and penguin amplitudes of charmless two-body baryonic decays

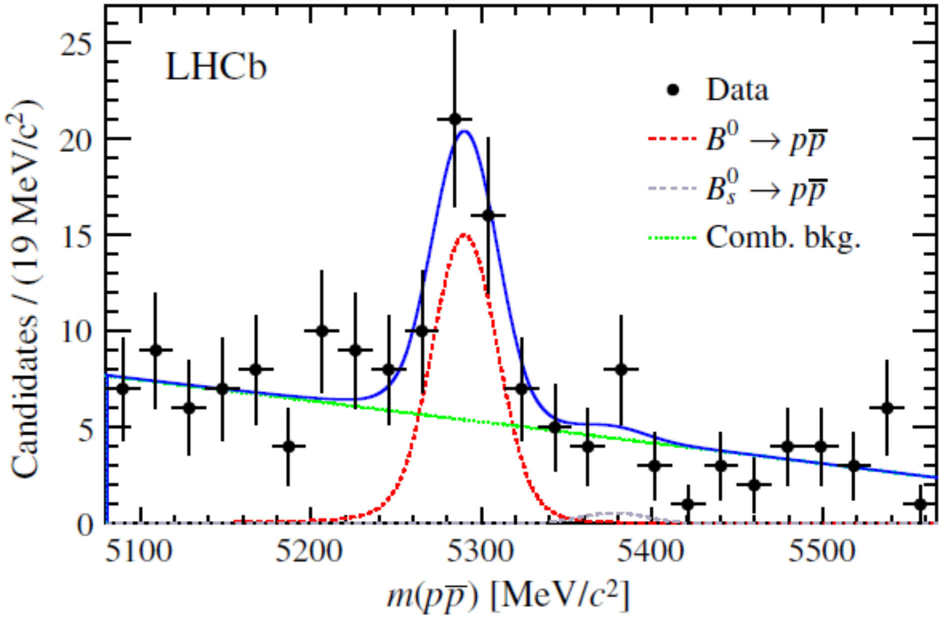
PRD 95, 096004 (2017)



- $B^0 \to p\bar{p}$ and $B^+ \to p\bar{\Lambda}$ as inputs to predict other $B \to \mathfrak{B}_1\mathfrak{B}_2$
- Baryonic B decays are also interesting in the study of CP violation
- Pure penguin modes are expected to be sensitive to new physics contributions

Search for $B^0_{(s)} \to p\bar{p}$ decay

PRL 119, 232001 (2017)



- First observation of $B^0 \to p\bar{p}$ with Run 1 data
- $\mathcal{B}(B^0 \to p\bar{p}) = (1.25 \pm 0.27 \pm 0.18)\times 10^{-8}$
- $\mathcal{B}(B_s^0 \to p\bar{p}) < 1.5\times 10^{-8}$@90% CL
- Some predictions expect $B_s^0 \to p\bar{p}$ to be further suppressed (**negligible** penguin-level gluon-exchange and annihilation contributions)

PRD 89, 056003 (2014), PRD 95, 096004 (2017)

- Other predictions expect $B_s^0 \to p\bar{p}$ rates is similar to that of $B^0 \to p\bar{p}$ (penguin-level gluon-exchange and annihilation contributions **can not be neglected**)

JHEP2004, 035 (2020)

- Updated search for $B_s^0 \to p\bar{p}$ decay is needed

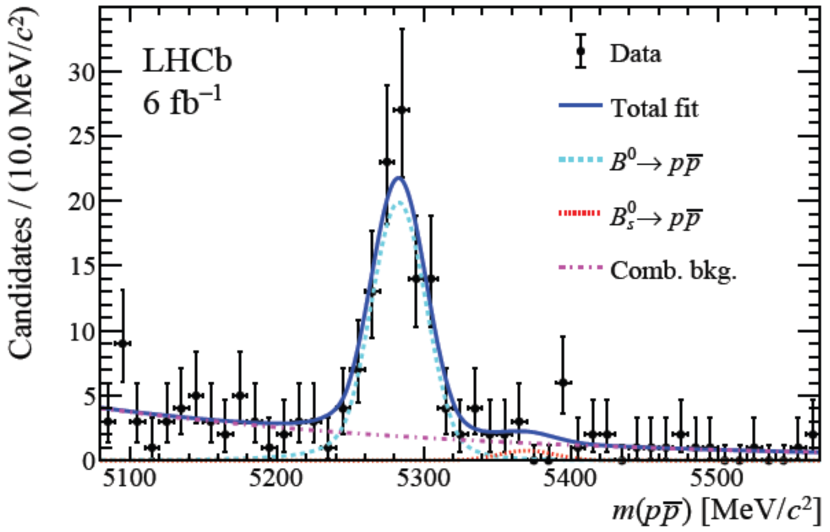
Search for $B_s^0 \to p\bar{p}$ with Run 2 data

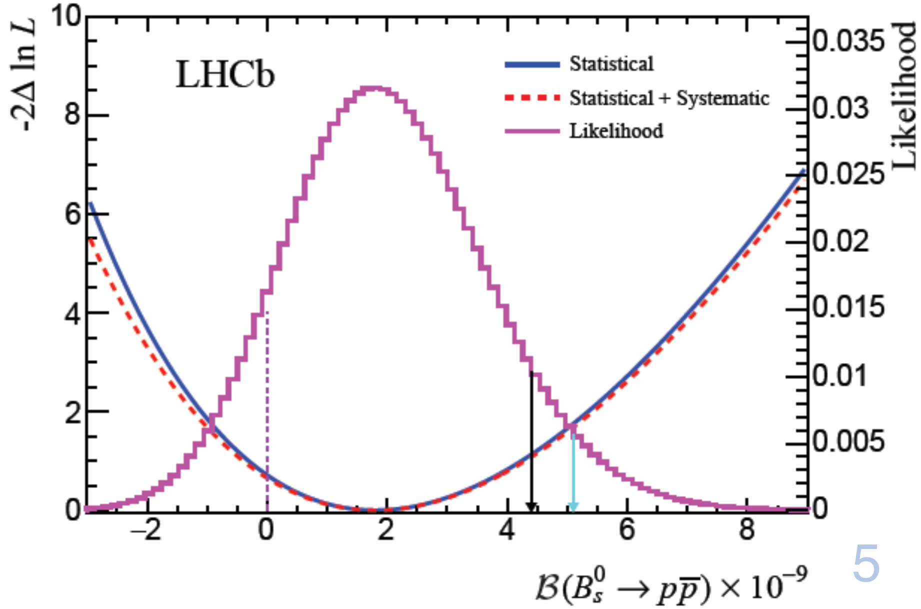
- $N(B^0 \to p\bar{p}) = 98 \pm 11(16.2\sigma)$
- $N(B_s^0 \to p\bar{p}) = 4 \pm 5(0.9\sigma)$
- $\mathcal{B}(B^0 \to p\bar{p}) = (1.27 \pm 0.15 \pm 0.05 \pm 0.04)\times 10^{-8}$
  - Consistent with Run 1
- Upper Limit on $\mathcal{B}(B_s^0 \to p\bar{p})$
  - $< 15\times 10^{-9}$@90% CL (Run 1)

improved by a factor of 3

  - $< 4.5(5.1)\times 10^{-9}$@90%(95%) CL (Run 2)
- ➔ $\mathcal{B}(B_s^0 \to p\bar{p})$ is further suppressed!

PRD108 (2023) 12007





Two–body charmed baryonic decays of B meson

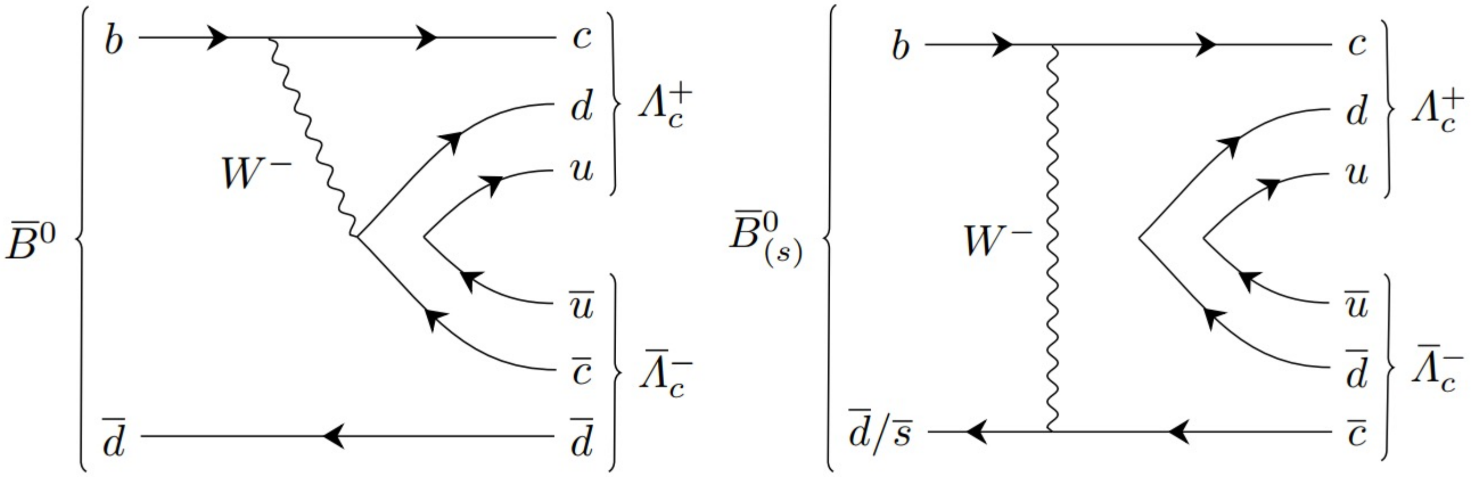
- Before this work, the only observed decays are $B^0 \to \Xi_c^- \Lambda_c^+$ and $B^+ \to \Xi_c^0 \Lambda_c^+$。
  - Both are dominated by W-emission topology。

PRD 100 (2019) 3, 031101 , PRL 122 (2019) 8, 082001

- LHCb measured the upper limits on $\mathcal{B}(B_{(s)}^0 \to \Lambda_c^+ \overline{\Lambda}_c^-)$ decays
  - using 3fb^{-1} *pp* Run 1 data
  - $\mathcal{B}(\bar{B}^0 \to \Lambda_c^+ \overline{\Lambda}_c^-) < 1.6\times10^{-5}$ at 95% CL
  - $\mathcal{B}(\bar{B}_s^0 \to \Lambda_c^+ \overline{\Lambda}_c^-) < 8.0\times10^{-5}$ at 95% CL

PR112 (2014) 202001

suggests a tension with naïve U-spin symmetry
➔ Need an investigation with larger statistics!



$\bar{B}_s^0 \to \Lambda_c^+ \overline{\Lambda}_c^-$ can only proceed via W-exchange/annihilation diagram.

Search for $\bar{B}^0_{(s)} \to \Lambda_c^+ \bar{\Lambda}_c^-$ decays at LHCb

- Full Run1&2 data is used, corresponding to $\mathcal{L} = 9$fb^{-1}
- The $\bar{B}^0 \to D_s^- D^+$ and $\bar{B}_s^0 \to D_s^+ D_s^-$ decays chosen as normalization modes.

$$\mathcal{B}(\overline{B}^0 \to \Lambda_c^+ \overline{\Lambda}_c^-) = \mathcal{B}(\overline{B}^0 \to D_s^- D^+) \cdot \frac{\mathcal{B}_{D_s^+} \mathcal{B}_{D^+}}{\mathcal{B}^2_{\Lambda_c^+}} \cdot \frac{N(\overline{B}^0 \to \Lambda_c^+ \overline{\Lambda}_c^-)}{N(\overline{B}^0 \to D_s^- D^+)} \cdot \frac{\epsilon(\overline{B}^0 \to D_s^- D^+)}{\epsilon(\overline{B}^0 \to \Lambda_c^+ \overline{\Lambda}_c^-)},$$

$$\mathcal{B}(\overline{B}_s^0 \to \Lambda_c^+ \overline{\Lambda}_c^-) = \mathcal{B}(\overline{B}_s^0 \to D_s^+ D_s^-) \cdot \frac{\mathcal{B}^2_{D_s^+}}{\mathcal{B}^2_{\Lambda_c^+}} \cdot \frac{N(\overline{B}_s^0 \to \Lambda_c^+ \overline{\Lambda}_c^-)}{N(\overline{B}_s^0 \to D_s^+ D_s^-)} \cdot \frac{\epsilon(\overline{B}_s^0 \to D_s^+ D_s^-)}{\epsilon(\overline{B}_s^0 \to \Lambda_c^+ \overline{\Lambda}_c^-)},$$

- Event selection based on:
  - tracking quality, vertex quality, vertex separation, flight distance, IP, …
  - kinematic variables
  - PID information
  - Vetoes on cross-feed among $D_s^\pm, D^\pm, \Lambda_c^\pm$ due to charged tracks' misidentification.
- Challenges in analysis techniques:
  - The singly-charmed and charmless decays dominate the physical backgrounds.
  - Correlations among $m(B)$, $m(pK^-\pi^+)$, and $m(\bar{p}K^+\pi^-)$ for singly-charmed components also be of huge influence.

Search for $\overline{B}^0_{(s)} \to \Lambda_c^+ \overline{\Lambda}_c^-$ decays at LHCb

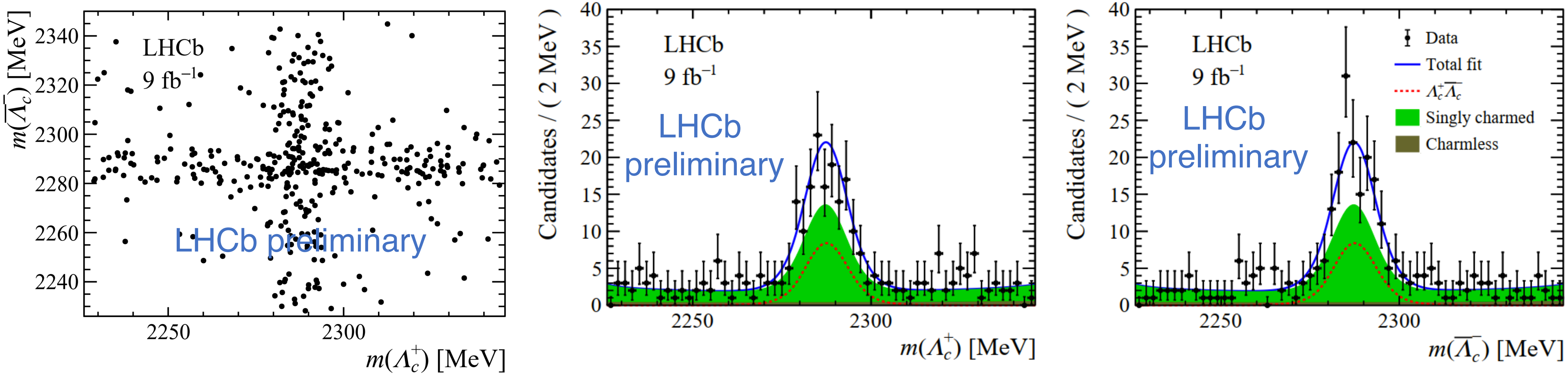
New

- A two-step fit to separate the genuine $\Lambda_c^+ \overline{\Lambda}_c^-$ candidates from backgrounds
  - 1st step: a 2D fit to $\Lambda_c^+ - \overline{\Lambda}_c^-$ mass distribution in **each** B mass bin

➔ PDF is constructed from $S_{\Lambda_c^+} S_{\overline{\Lambda}_c^-}$, $S_{\Lambda_c^+} B_{\overline{\Lambda}_c^-}$/ $B_{\Lambda_c^+} S_{\overline{\Lambda}_c^-}$, and $B_{\Lambda_c^+} B_{\overline{\Lambda}_c^-}$ components (S=peaking signal, B=background)

➔ yield and corresponding uncertainty for **doubly charmed** component is determined (bin-by-bin).

LHCb-PAPER-2025-053 in preparation

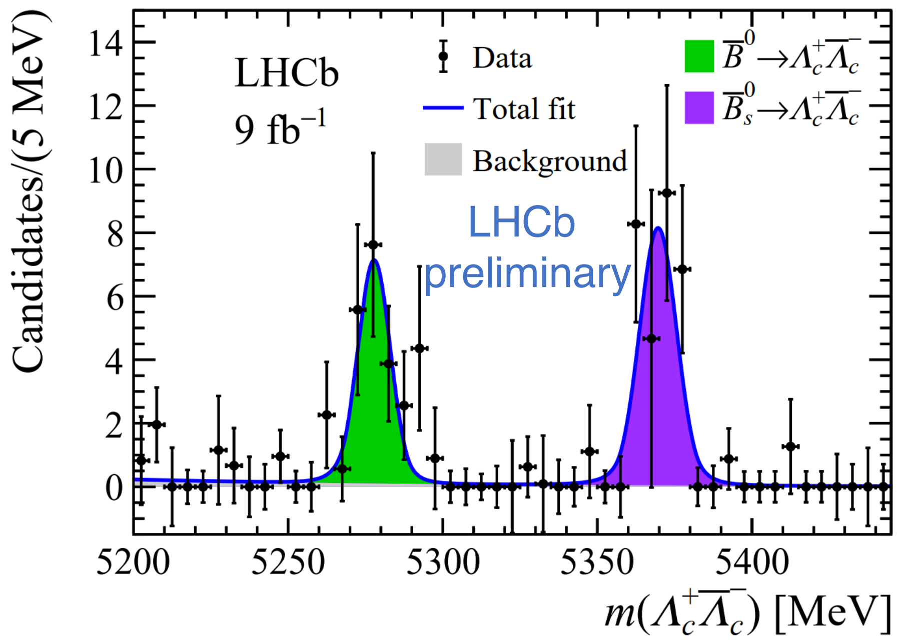


The $\Lambda_c^+ - \overline{\Lambda}_c^-$ mass distributions with the fit results overlaid, where results from all individual $m(B)$ bins are combined to improve visibility.

Search for $\bar{B}^0_{(s)} \to \Lambda_c^+ \bar{\Lambda}_c^-$ decays at LHCb

New

- A two-step fit to separate the genuine $\Lambda_c^+ \bar{\Lambda}_c^-$ candidates from backgrounds
  - 2nd step: Fit to the resulting $m(\Lambda_c^+ \bar{\Lambda}_c^-)$ distribution from the previous step
    - Clear signal peaks are seen.



LHCb-PAPER-2025-053 in preparation

- Signal yields:

LHCb preliminary

$$N(\bar{B}^0 \to \Lambda_c^+ \bar{\Lambda}_c^-) = 19.0^{+5.0}_{-5.2}$$

$$N(\bar{B}_s^0 \to \Lambda_c^+ \bar{\Lambda}_c^-) = 25.1 \pm 6.7$$

- For normalization decay modes, a similar approach is used to extra the signal yields.

$$N(\bar{B}^0 \to D_s^- D^+) = 26171 \pm 164$$

$$N(\bar{B}_s^0 \to D_s^+ D_s^-) = 2926 \pm 65$$

Search for $\bar{B}^0_{(s)} \to \Lambda_c^+ \bar{\Lambda}_c^-$ decays at LHCb

New

- Systematic uncertainties from numerous and complex sources are carefully evaluated.
- The fit strategy is also cross-checked by pseudo-experiments and found to be credible.

LHCb-PAPER-2025-053 in preparation

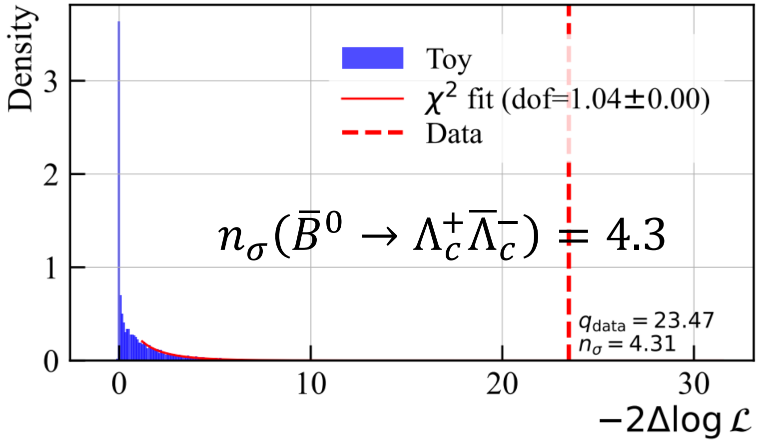
Source	$\frac{\mathcal{B}(\bar{B}^0 \to \Lambda_c^+ \bar{\Lambda}_c^-)}{\mathcal{B}(\bar{B}^0 \to D_s^- D^+)}$	$\frac{\mathcal{B}(\bar{B}_s^0 \to \Lambda_c^+ \bar{\Lambda}_c^-)}{\mathcal{B}(\bar{B}_s^0 \to D_s^+ D_s^-)}$
Λ_c^+ mass resolution	2.1%	4.3%
$\bar{B}^0_{(s)}$ mass resolution	0.2%	0.5%
Fit bias and binning scheme	5.7%	1.2%
Λ_c^+ or $D_{(s)}^+$ lineshape	0.2%	0.2%
$\bar{B}^0_{(s)}$ signal lineshape	3.6%	0.5%
Background lineshape	1.4%	7.1%
Lineshape of misidentified decay	–	0.1%
Simulated sample size	1.7%	1.8%
Tracking efficiency	1.3%	1.6%
PID correction	0.7%	0.9%
Kinematical correction	0.2%	0.3%
Λ_c^+ Dalitz plot and polarization correction	3.6%	4.3%
$\bar{B}_s^0$ lifetime difference	–	0.6%
Total	8.4%	9.9%

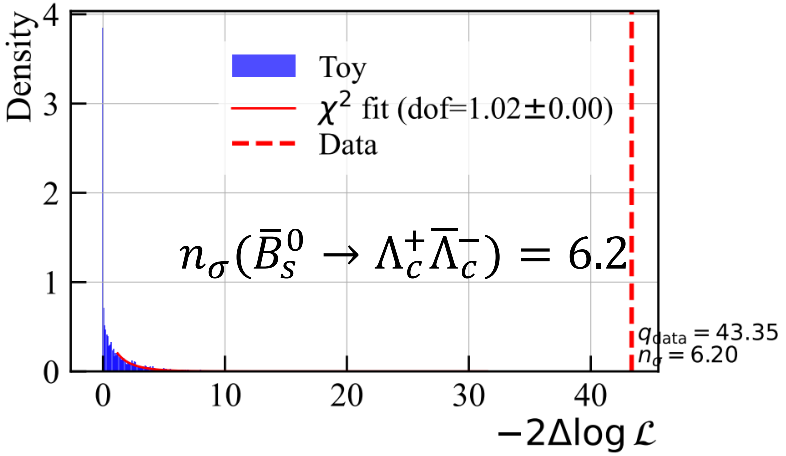
LHCb preliminary

Search for $\bar{B}^0_{(s)} \to \Lambda_c^+ \bar{\Lambda}_c^-$ decays at LHCb

New

- Significances after considering systematics:





- First observation of $\bar{B}^0_s \to \Lambda_c^+ \bar{\Lambda}_c^-$ and first evidence of $\bar{B}^0 \to \Lambda_c^+ \bar{\Lambda}_c^-$.
- The measured branching fractions:

LHCb-PAPER-2025-053 in preparation

$$\mathcal{B}(\bar{B}^0 \to \Lambda_c^+ \bar{\Lambda}_c^-) = (1.01^{+0.27}_{-0.28} \pm 0.08 \pm 0.15) \times 10^{-5},$$
$$\mathcal{B}(\bar{B}^0_s \to \Lambda_c^+ \bar{\Lambda}_c^-) = (5.0 \pm 1.3 \pm 0.5 \pm 0.8) \times 10^{-5},$$

LHCb preliminary

Uncertainties are statistical, systematic, and external contributions from branching fractions of intermediate $D_s^\pm, D^\pm, \Lambda_c^\pm$ decays and normalization channels.

Results and discussion

- The observation of $\bar{B}_s^0 \to \Lambda_c^+ \overline{\Lambda}_c^-$ decay represents the first experimental verification of the *W*-exchange process in baryonic B decays.
- The measured BF for $\bar{B}^0 \to \Lambda_c^+ \overline{\Lambda}_c^-$ decay is in tension with the simple $SU(3)_f$ symmetry prediction arising solely from the *W*-emission diagram.

$$SU(3)_f \text{ symmetry prediction} = |V_{cd}/V_{cs}|^2(\tau_{B^0}/\tau_{B^+})\mathcal{B}(B^- \to \Xi_c^0 \overline{\Lambda}_c^-) = (4.7 \pm 1.1) \times 10^{-5}$$

- A rough comparison with theoretical predictions

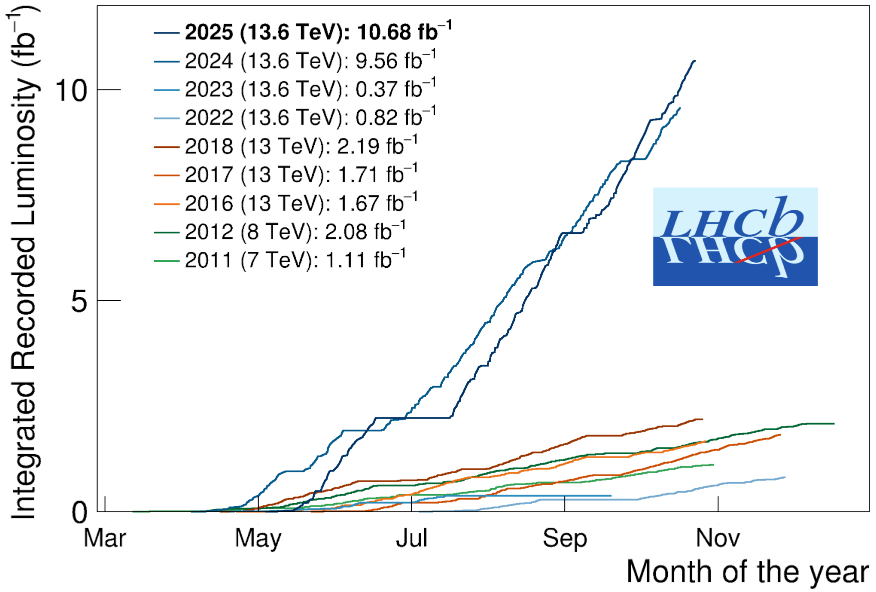
LHCb latest result	pQCD **without** the subleading correction [arXiv:2409.16113]	pQCD **with** the subleading correction [arXiv:2409.16113]	SU(3) effective [JHEP11,117(2023)]	Long-distance, FSI [PRD110(2024)11, 113008)]	[PRD79:114004(2009)]
$\mathcal{B}(\overline{B}^0 \to \Lambda_c^+ \overline{\Lambda}_c^-) = (1.01^{+0.27}_{-0.28} \pm 0.08 \pm 0.15) \times 10^{-5}$	$(4.0^{+2.5+1.7+0.7+0.6}_{-1.4-1.3-0.6-0.4}) \times 10^{-6}$	$(8.8^{+4.4+3.5+1.1+1.0}_{-2.8-3.6-0.9-0.6}) \times 10^{-6}$	$2.1^{+1.0}_{-0.8} \times 10^{-5}$		$0.52^{+0.23+0.06+0.26+0}_{-0.11-0.03-0.15-0}$ 10^{-4}
$\mathcal{B}(\overline{B}_s^0 \to \Lambda_c^+ \overline{\Lambda}_c^-) = (5.0 \pm 1.3 \pm 0.5 \pm 0.8) \times 10^{-5}$,	$(5.0^{+0.7+0.3+1.4+1.4}_{-0.6-0.5-0.9-1.0}) \times 10^{-5}$	$(4.0^{+0.7+0.2+0.9+1.0}_{-0.3-0.1-0.7-0.8}) \times 10^{-5}$	$8.1^{+1.7}_{-1.5} \times 10^{-5}$	$> 4.7 \times 10^{-5}$	

LHCb preliminary

- The measured $\mathcal{B}(\bar{B}_{(s)}^0 \to \Lambda_c^+ \overline{\Lambda}_c^-)$ is well consistent with some theoretical predictions, like pQCD.
  - …… while others are not.
  - The relative uncertainty of the theoretical calculation is relatively large.
  - Need more investigation.

Summary & outlook

- With the 9fb^{-1} *pp* data collected by LHCb detector, $\bar{B}^0 \to \Lambda_c^+ \overline{\Lambda}_c^-$ is seen for the 1st time as an evidence, and $\bar{B}_s^0 \to \Lambda_c^+ \overline{\Lambda}_c^-$ is observed.
- LHCb Run3: ~ 25 fb^{-1} pp data
  - $2\times$ trigger efficiency for hadrons



JINST 19 (2024) P05065

- In LHCb, more studies on 2-body (charmed or charmless) baryonic B decays are ongoing:
  - improved measurement of $B^+ \to p\overline{\Lambda}$ (coming soon!) with Run2 data
  - improved measurement of $\bar{B}^0 \to \Lambda_c^+ \bar{p}$ and search for $\bar{B}^0 \to \Lambda_c^+ \bar{p}$
  - search for $\bar{B}_{(s)}^0 \to \Xi_c^+ \overline{\Xi}_c^-$
  - search for $B_s^0 \to \Xi_c^- \Lambda_c^+$ with Run3 data
  - ……

Thanks!