中国科学院大学
University of Chinese Academy of Sciences

LHCb实验上b强子纯重子衰变的研究进展

第八届全国重味物理和量子色动力学研讨会

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2026年4月

重庆

Outline

LHCb experiment

Baryonic decay of B meson

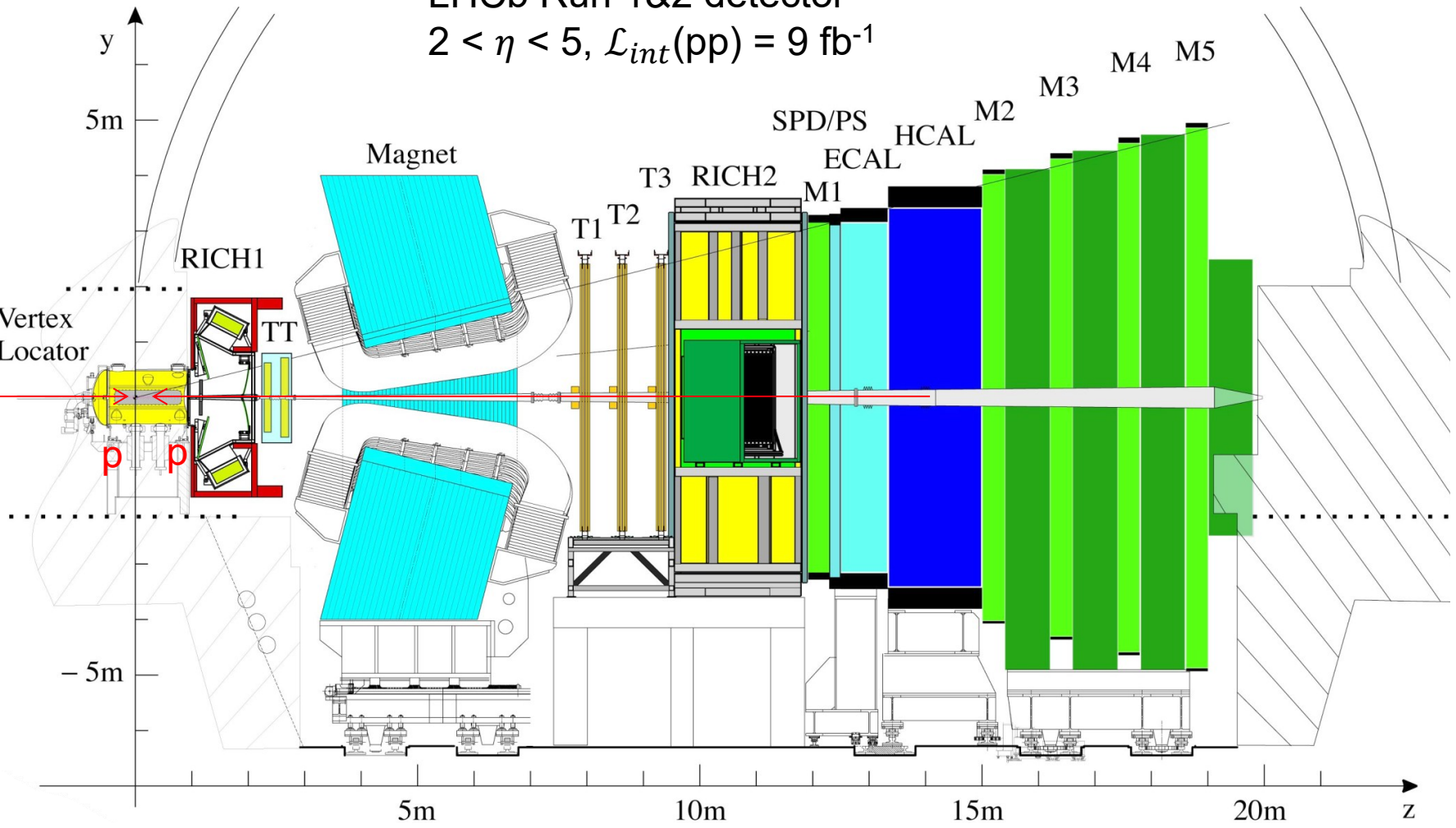
- Charmless
  - $B^+ \to p\bar{\Lambda}$
  - $B^+ \to p\bar{p}p\bar{\Lambda}$
- charmed
  - $B^0_{(s)} \to \Lambda_c^+ \bar{\Lambda}_c^-$

Summary and outlook

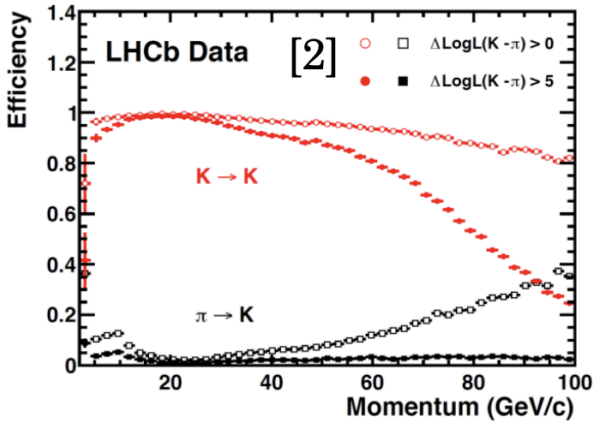
LHCb Run1&Run2 detector

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

LHCb Run 1&2 detector
$2 < \eta < 5$, $\mathcal{L}_{int}$(pp) = 9 fb^{-1}



- **Excellent tracking and vertexing**
  - $\sigma(p)/p < 1\%$ @ $\epsilon_{\text{track}} > 96\%$
  - $\sigma(\text{IP}) = (15 + 29/p_T)\ \mu m$
- **Excellent PID**
  - $\epsilon_{\text{PID}}(K) \approx 95\%$ @ $\text{MisID}(\pi \to K) \approx 5\%$
  - $\epsilon_{\text{PID}}(\mu) \approx 97\%$ @ $\text{MisID}(\pi \to \mu) \approx 3\%$

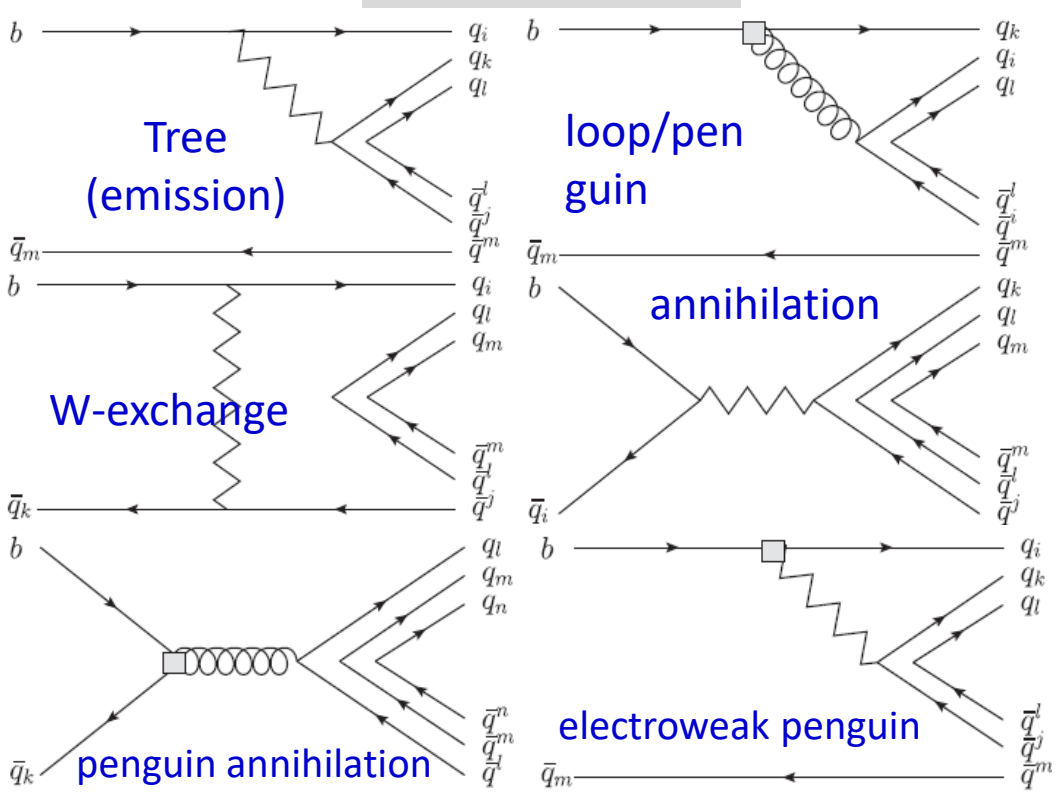


JINST3 (2008) S08005
IJMPA 30 (2015) 1530022

Two−body charmless baryonic decays of B meson

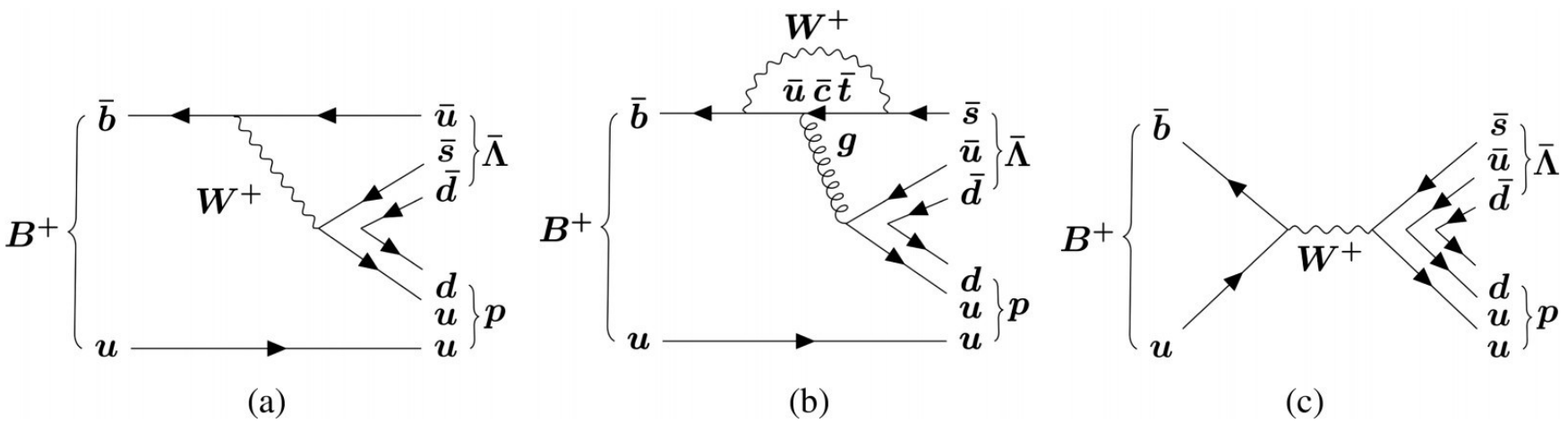
- Provides information on the dynamics of B decays and tests QCD based models of the hadronization process

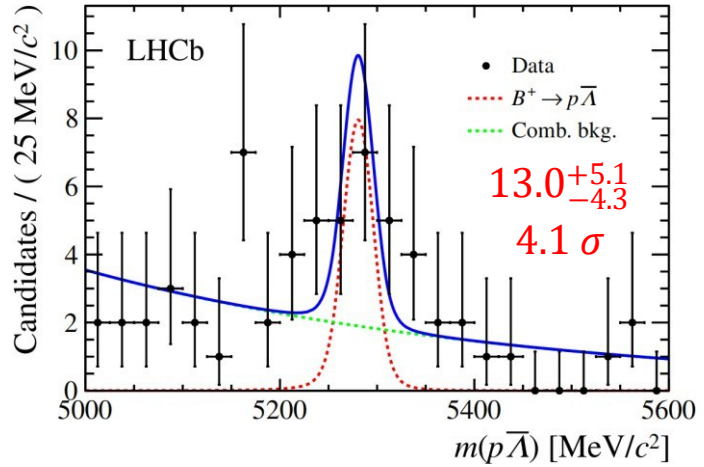
PRD 95, 096004 (2017)



- $B^0 \to p\bar{p}$ 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 $B^+ \to p\bar{\Lambda}$ decay

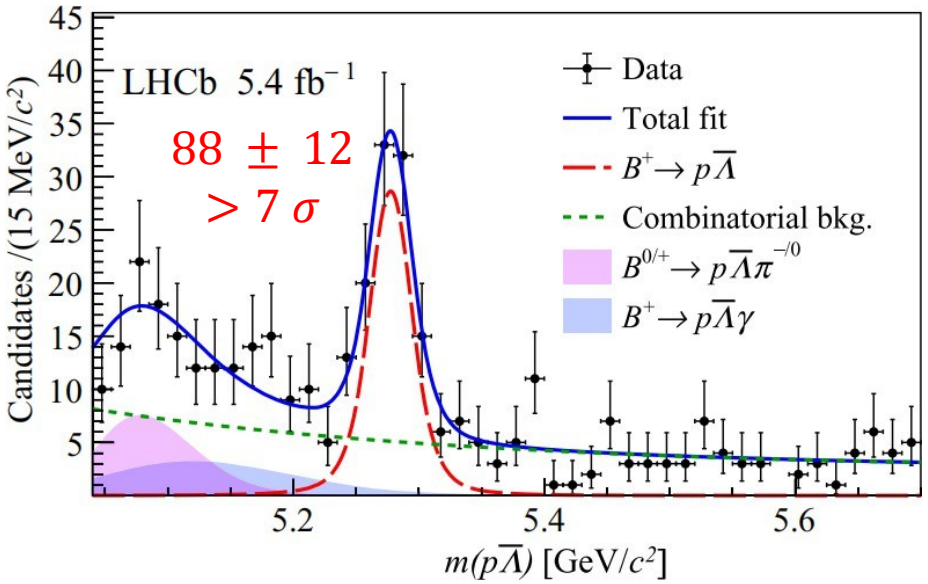


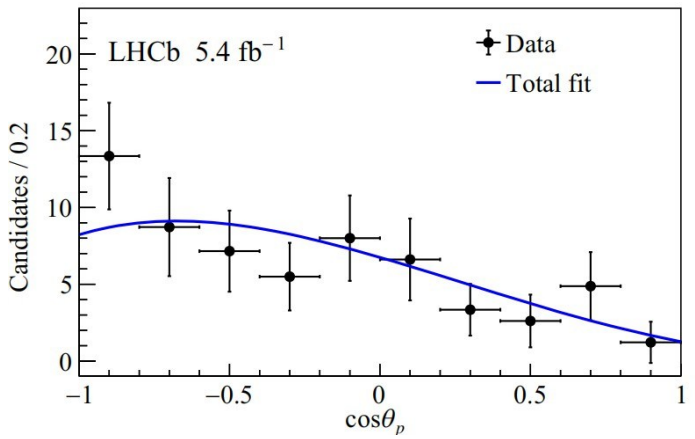


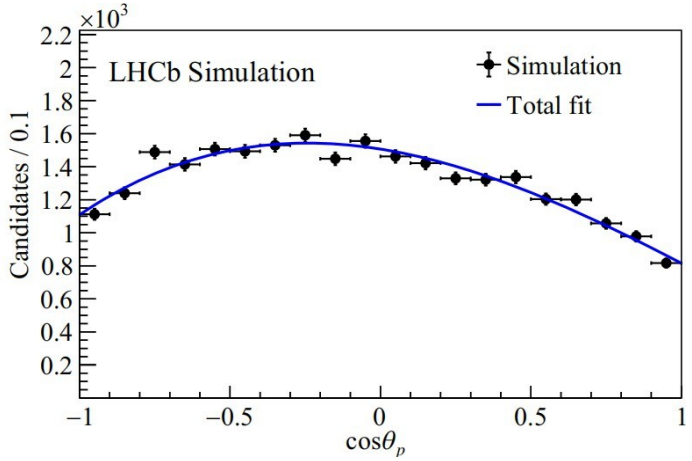
JHEP04(2017)162

- CP-violation of $B_s^0 \to K^+K^-$ and $B^0 \to K^+\pi^-$ can reach to ~10%
- Why $A_{\mathrm{CP}}(\Lambda_b^0 \to pK^-) = (-1.14 \pm 0.17)\%$
- Theoretical studies for $A_{\mathrm{CP}}(B^+ \to p\bar{\Lambda})$ could reach 10%, but S-wave and P-wave amplitudes cancellation could suppress CPV
- LHCb have searched this decay with Run 1 data, an evidence has been seen

First observation of the $B^+ \to p\bar{\Lambda}$ decay







PRL 136, 051802 (2026)

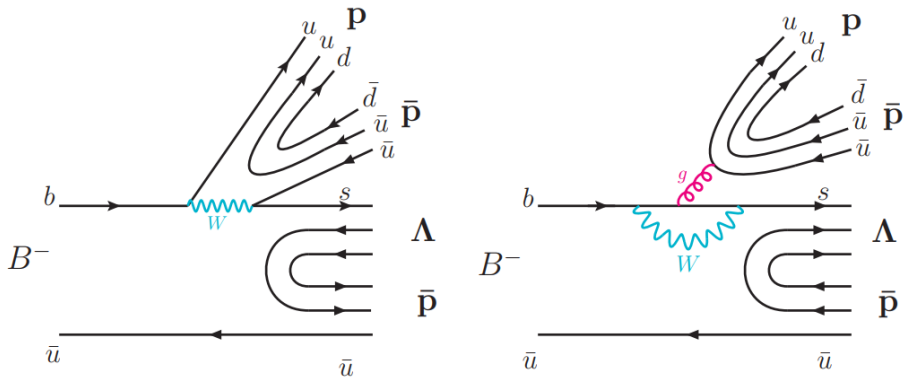
$$\mathcal{B}(B^+ \to p\bar{\Lambda}) = (1.24 \pm 0.17 \pm 0.05 \pm 0.03) \times 10^{-7}$$

$$\alpha_B = 0.87^{+0.26}_{-0.29} \pm 0.09,$$

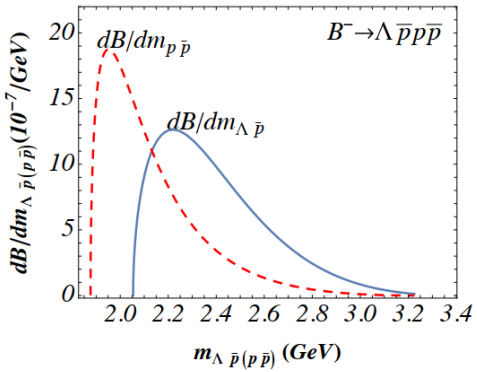
- Consistent with available theoretical predictions
- $\alpha_B \neq 0$ indicates a strong interference between the competing S-wave and P-wave amplitudes
- CPV of $B^+ \to p\bar{\Lambda}$ will become feasible

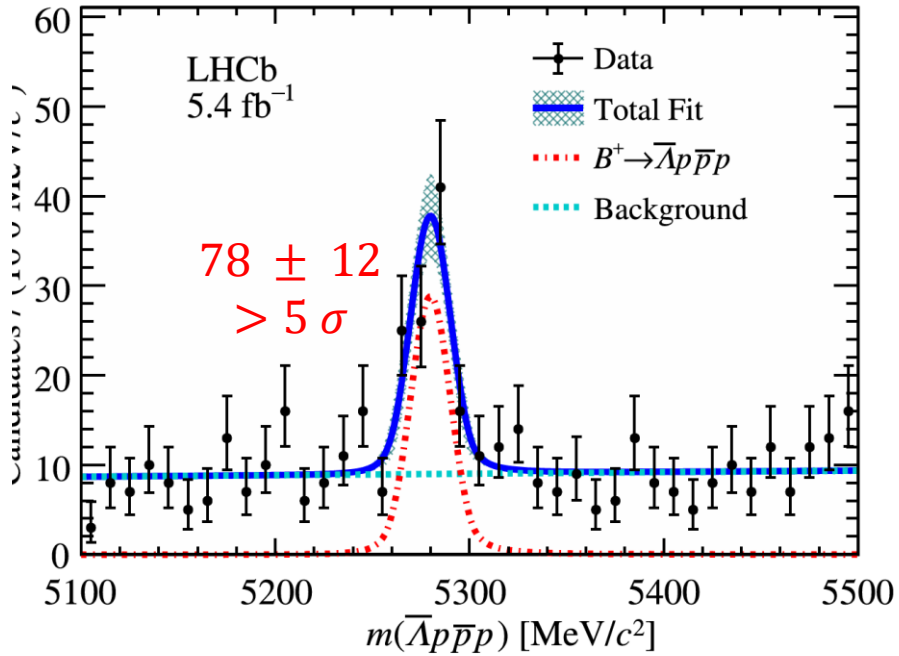
First observation of the $B^+ \to p\bar{p}p\bar{\Lambda}$ decay

- Threshold enhancement is seen in many b multi-body baryonic decays
- $B^+ \to p\bar{p}p\bar{\Lambda}$ is the best channel to study double threshold (both $p\bar{p}$ and $p\bar{\Lambda}$) effect in a purely baryonic decay.



PLB 845(2023)138158





- LHCb result: $\mathcal{B}(B^+ \to \bar{\Lambda}p\bar{p}p) = (2.15 \pm 0.35 \pm 0.12 \pm 0.28) \times 10^{-7}$
- 2σ lower than the theoretical result:

$$\mathcal{B}(B^+ \to \bar{\Lambda}p\bar{p}p) = (7.4^{+0.6}_{-0.2} \pm 0.03^{+3.6}_{-2.6}) \times 10^{-7}$$

PLB 845(2023)138158

PRL 135, 261901 (2025)

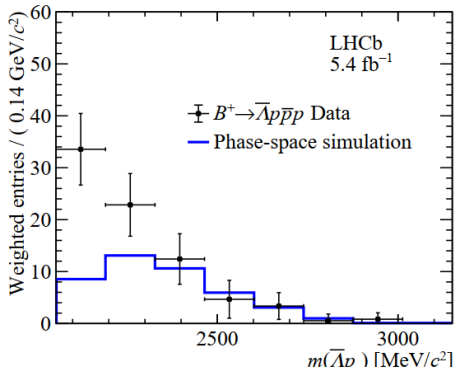
$$\mathcal{A}_{CP} = (5.4 \pm 15.6 \pm 2.4)\%.$$

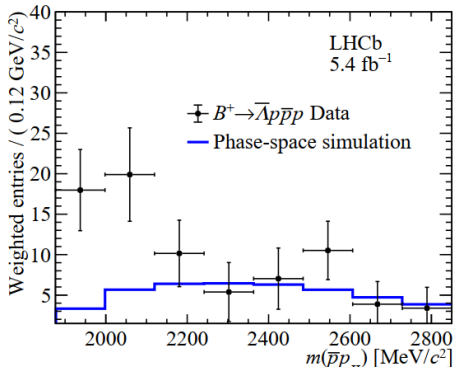
First observation of $B^+ \to p\bar{p}p\bar{\Lambda}$ decay

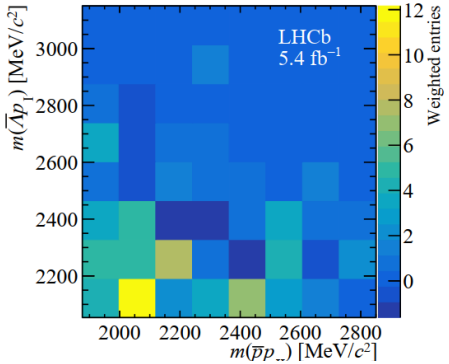
- Background-subtracted invariant-mass spectra

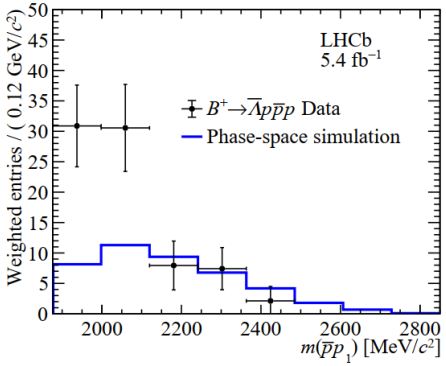
$$m(\bar{\Lambda}p_I) = min(m(\bar{\Lambda}p), m(\bar{\Lambda}p'))$$
$$m(\bar{\Lambda}p_{II}) = max(m(\bar{\Lambda}p), m(\bar{\Lambda}p'))$$
$$\Rightarrow B^+ \to (\bar{\Lambda}^0 p_I)(\bar{p}p_{II})$$

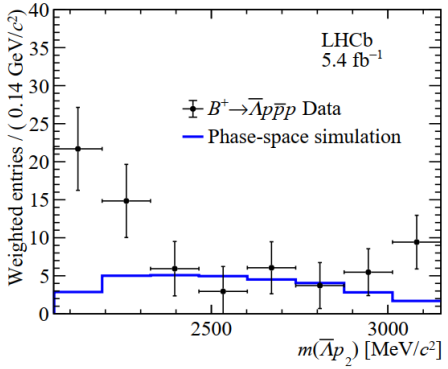
$$m(\bar{p}p_1) = min(m(\bar{p}p), m(\bar{p}p'))$$
$$m(\bar{p}p_2) = max(m(\bar{p}p), m(\bar{p}p'))$$
$$\Rightarrow B^+ \to (\bar{p}p_1)(\bar{\Lambda}^0 p_2)$$

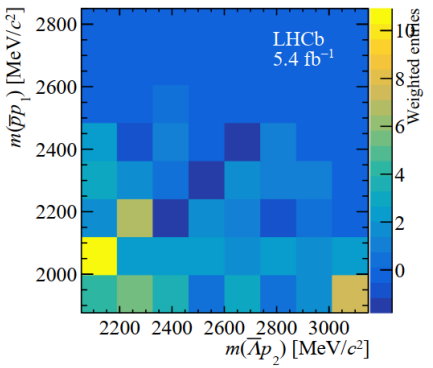






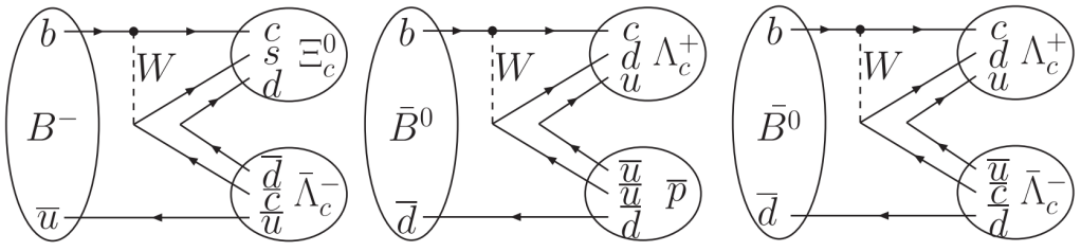




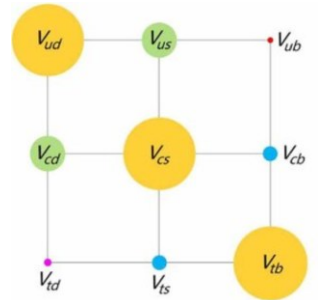


A clear double-threshold enhancement in both baryon-antibaryon invariant-mass distributions!

Two-body charmed baryonic decays of B meson



(a) $A \propto V_{cb}^* V_{cs}$ (b) $A \propto V_{cb}^* V_{ud}$ (c) $A \propto V_{cb}^* V_{cd}$



- A puzzle in B meson charmed baryonic decays:
- Naïvely considering CKM, $|V_{cb}^* V_{cs}| \sim |V_{cb}^* V_{ud}|$, but the experimental measurements differs by ~2-orders of magnitude

$$\mathcal{B}(B^- \to \Xi_c^0 \bar{\Lambda}_c^-) = (9.51 \pm 2.10 \pm 0.88) \times 10^{-4}$$
$$\mathcal{B}(\bar{B}^0 \to \bar{p}\Lambda_c^+) = (1.54 \pm 0.18) \times 10^{-5}$$

➔ some mechanism to enhance or suppress this $b \to c$ baryonic two-body decay

➔ It is important to study other two-body decays to understand charmed baryonic B decays.

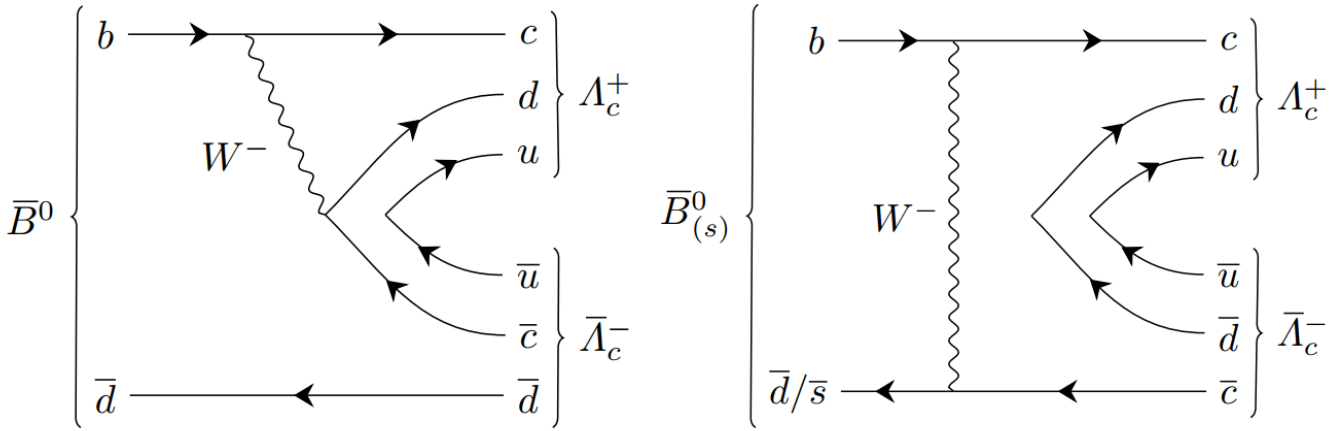
Two−body charmed baryonic decays of B meson

- For doubly charmed decay, only $B^0 \to \bar{\Xi}_c^- \Lambda_c^+$ and $B^+ \to \bar{\Xi}_c^0 \Lambda_c^+$ are observed before this work.
  - Both are dominated by W-emission topology. PRD 100 (2019) 3, 031101 , PRL 122 (2019) 8, 082001
- LHCb measured the upper limits on $\mathcal{B}\left(B^0_{(s)} \to \Lambda_c^+ \bar{\Lambda}_c^-\right)$ decays PR112 (2014) 202001
  - using 3fb^{-1} *pp* Run 1 data
  - $\mathcal{B}(\bar{B}^0 \to \Lambda_c^+ \bar{\Lambda}_c^-) < 1.6 \times 10^{-5}$ at 95% CL $\quad \mathcal{B}(\bar{B}_s^0 \to \Lambda_c^+ \bar{\Lambda}_c^-) < 8.0 \times 10^{-5}$ at 95% CL

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

suggests a tension with naïve U-spin symmetry

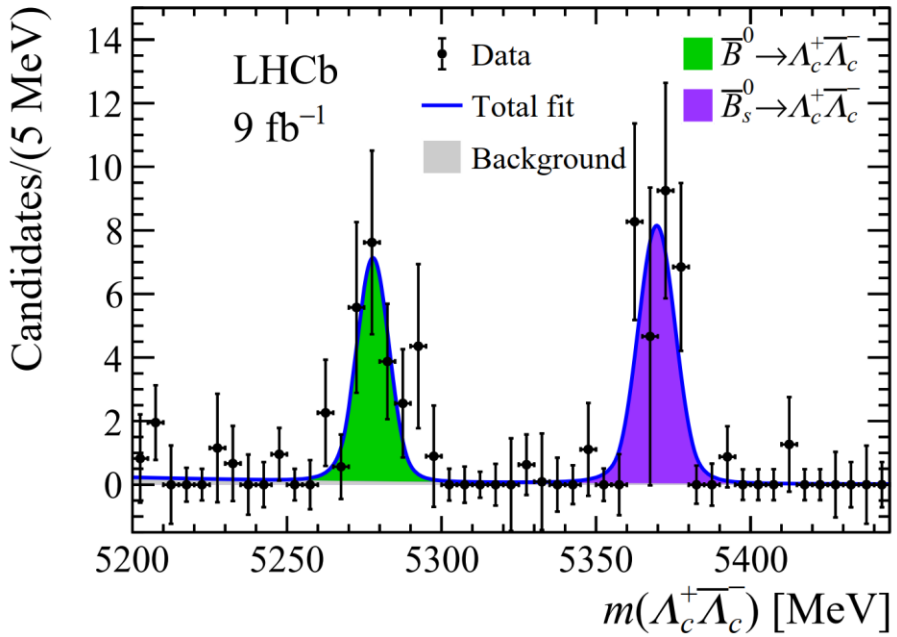
➔ Need an investigation with larger statistics!



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

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

- Based on all Run1&Run2 data, a two-step fit to separate the genuine $\Lambda_c^+ \overline{\Lambda}_c^-$ candidates from backgrounds
  - Clear signal peaks are seen. $N(\bar{B}^0 \to \Lambda_c^+ \overline{\Lambda}_c^-) = 19.0^{+5.0}_{-5.2}$ $N(\bar{B}_s^0 \to \Lambda_c^+ \overline{\Lambda}_c^-) = 25.1 \pm 6.7$



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

- The first experimental verification of the W-exchange process
- A hint for $SU(3)_f$ breaking
- Consistent with some theoretical predictions
- Such effects may be important for improving predictions of CP -violating

Summary & outlook

- LHCb Run3: ~ 25 fb^{-1} pp data
  - $2\times$ trigger efficiency for hadronic final states
- In LHCb, more studies on (charmed or charmless) baryonic B decays are ongoing:
  - Two body decays expected to be observed: $B^0 \to \Lambda_c^+ \overline{\Lambda}_c^-$, $\bar{B}_s^0 \to \Lambda_c^+ \bar{\Xi}_c^-$, $B_{(s)}^0 \to \Xi_c^+ \bar{\Xi}_c^-$, $B_s^0 \to \Lambda_c^+ \bar{p}$, $B_{(s)}^0 \to \Lambda\overline{\Lambda}/\Xi\bar{\Xi}/\Omega\overline{\Omega}$, ……
  - Threshold enhancement or di-baryon: $B_s^0 \to p\bar{p}p\bar{p}$, $\Lambda_b^0 \to \Lambda p\bar{p}$, $\Lambda_b^0 \to \Lambda_c^+ \bar{p}\Lambda$, ……

Thanks!