First observation of the Charmless Baryonic decay $B^+ \to \bar{\Lambda}^0 p \bar{p} p$

arXiv:2508.16259

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Outline

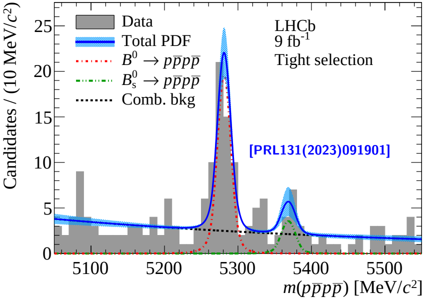
- Two-body Charmless Baryonic decays have been searched for at LHCb

Decay mode	Measued $\mathcal{B}$	Ref.
$\bar{B}^0 \to p\bar{p}$	$(1.25 \pm 0.27 \pm 0.18) \times 10^{-8}$	PRL 119 (2017) 232001
$\bar{B}^+ \to p\bar{\Lambda}^0$	$(2.4^{+1.0}_{-0.8} \pm 0.3) \times 10^{-7}$	JHEP 04 (2017) 162
$\bar{B}^+ \to p\bar{\Lambda}^0$	$(1.24 \pm 0.17 \pm 0.05 \pm 0.03) \times 10^{-7}$	LHCb-PAPER-2025-044 [New Result]
$\bar{B}^+ \to p\bar{\Lambda}(1520)$	$(3.9^{+1.0}_{-0.9} \pm 0.1 \pm 0.3) \times 10^{-7}$	PRD 88 (2013) 052015

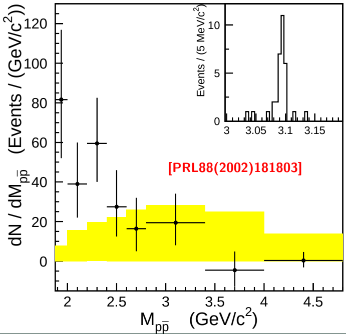
- The only observed purely four-body baryonic decay is $\bar{B}^0 \to p\bar{p}p\bar{p}$

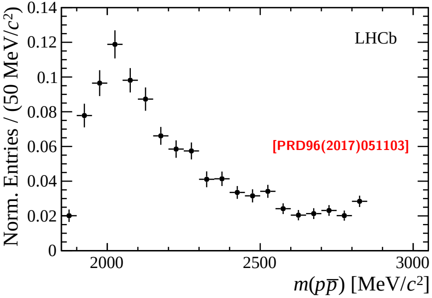
mode	Branching fraction $\mathcal{B}$
$\bar{B}^0 \to p\bar{p}p\bar{p}$	$(2.21 \pm 0.37 \pm 0.38 \pm 0.09) \times 10^{-8}$
$\bar{B}^0_s \to p\bar{p}p\bar{p}$	$(2.40 \pm 1.01 \pm 0.20 \pm 0.19) \times 10^{-8}$

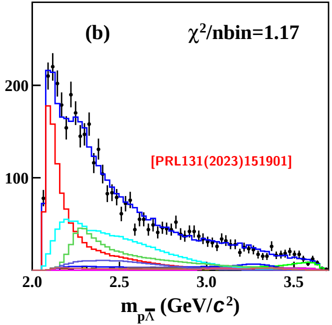
[PRL**131**(2023)091901]



- A well-known phenomenon in B baryonic decays is the **threshold enhancement effect**
- First observed by the Belle in the three-body baryonic decay $B^+ \to p\bar{p}K^+$
- Other B baryonic decays show similar behavior, e.g., $B^+ \to \bar{\Lambda}phh'$ (Belle) and $B^0 \to p\bar{p}hh'$ (LHCb)
- Narrow structure near the $p\bar{\Lambda}$ threshold in $e^+e^- \to pK^-\bar{\Lambda} + c.c.$ by BESIII
- **The baryon-antibaryon spectra in B multi-body purely baryonic decays have not been studied**

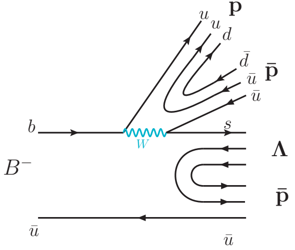


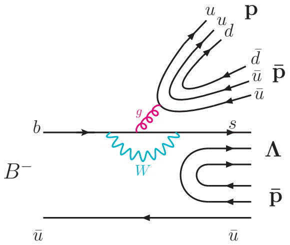


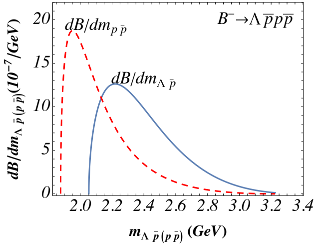


Motivation

- $B^+ \to \bar{\Lambda}^0 p\bar{p}p$ is dominated by b→s transition[*], at tree level $b \to u$ and $W \to \bar{u}s$ are color suppressed
- Prediction of $\mathcal{B}(B^+ \to \bar{\Lambda}^0 pp\bar{p}) = (7.4^{+0.6}_{-0.2} \pm 0.03^{+3.6}_{-2.6}) \times 10^{-7}$[*]
- **The best chance to study the baryon-antibaryon spectra and double threshold effect in a purely baryonic decay**







*[PLB**845**(2023)138158]

Analysis strategy

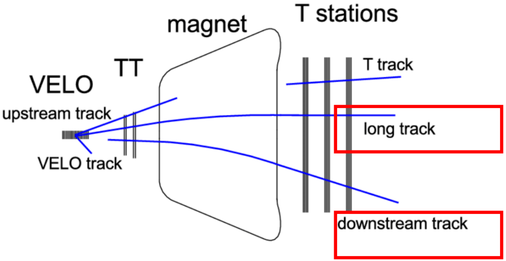
- Blind signal region $\pm 250\ \mathrm{MeV}/c^2$ around B^+ mass
- Normalization channel: $\mathcal{B}(B^+ \to J/\psi K^+) \times \mathcal{B}(J/\psi \to pK\bar{\Lambda} + c.c.) = (8.77 \pm 1.14) \times 10^{-7}$

➢ BF measured from simultaneous fits to signal and normalization channels

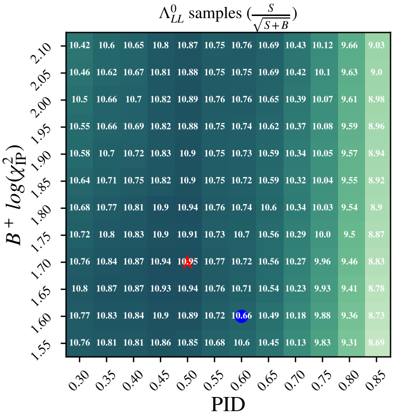
$$\mathcal{B}(B^+ \to \bar{\Lambda}^0 pp\bar{p}) = \frac{N(B^+ \to \bar{\Lambda}^0 pp\bar{p})}{N(B^+ \to J/\psi(\to pK\bar{\Lambda})K^+)} \times \frac{\epsilon_{B^+ \to J/\psi(\to pK\bar{\Lambda})K^+}}{\epsilon_{B^+ \to \bar{\Lambda}^0 pp\bar{p}}} \times \mathcal{B}(B^+ \to J/\psi(\to pK\bar{\Lambda})K^+)$$

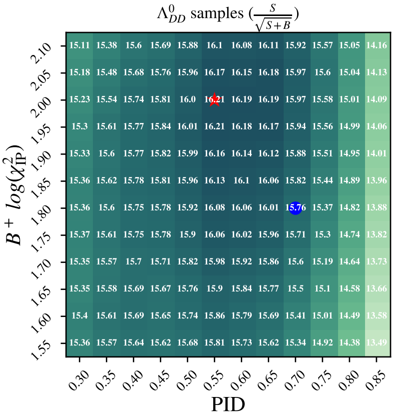
➢ Measure $\mathcal{B}(B^+ \to \bar{\Lambda}^0 pJ/\psi(\to p\bar{p}))$ as cross-check of fit model/efficiencies

➢ Measure (uplimit of) $\mathcal{B}(B^+ \to \bar{\Lambda}^0 p\eta_c(\to p\bar{p}))$ in charmonium region



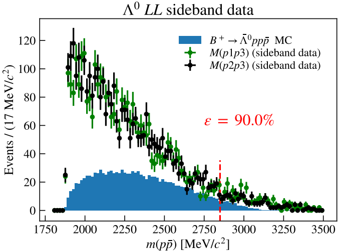
- Using 2016-2018 pp collision data (Run2) with total integrated luminosity of 5.4 fb^{-1}
- Stripping/Trigger selections optimized for hadronic B decays
- PID and χ^2_{IP} are optimzed to maximize significance

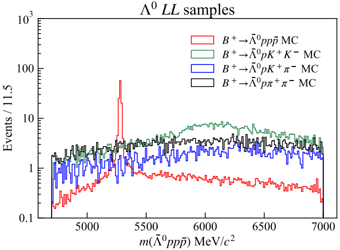




$\Rightarrow$ Charmonium contribution, e.g., $B^+ \to \bar{\Lambda}^0 p J/\psi(\to p\bar{p}), \bar{\Lambda}^0 p \eta_c(\to p\bar{p}) \Rightarrow m(p\bar{p}) < 2850$ MeV

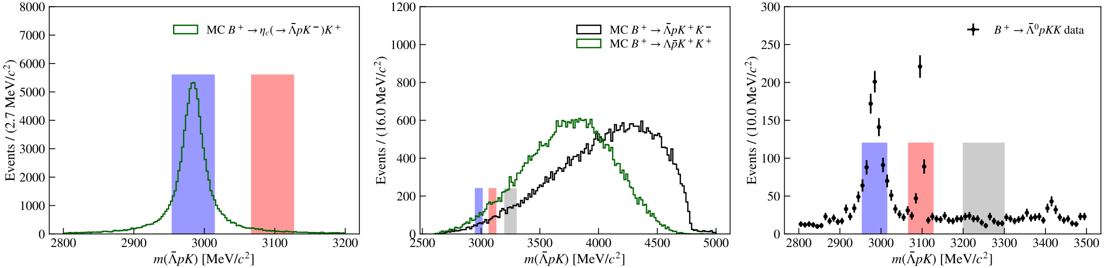
$\Rightarrow$ Mis-ID backgroud: Negligible contribution due to double misidentification and mass shifts to the far right of the spectra





⇒ $B^+ \to \bar{\Lambda}^0 p \eta_c (\to pK\bar{\Lambda})$, $B^+ \to \bar{\Lambda} p K^+ K^-$ and $B^+ \to \Lambda \bar{p} K^+ K^+$ decays can contaminate $m(\bar{\Lambda} pK)$

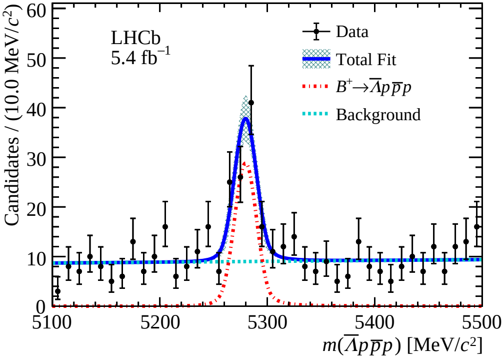
⇒ A data-driven method is employed to determine the yields within $|m(\bar{\Lambda}pK) - m(J/\psi)| < 30\ \mathrm{MeV}/c^2$

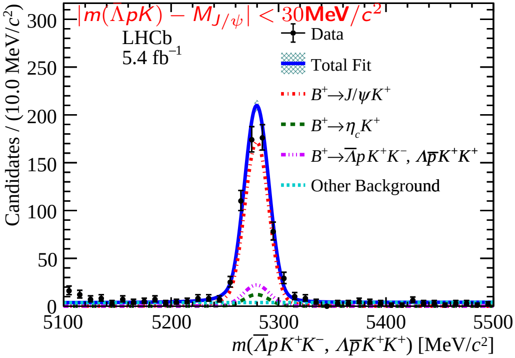


- Fit the $B^+ \to \bar{\Lambda} pKK$ data within $|m(\bar{\Lambda}pK) - m(\eta_c)| < 30\ \mathrm{MeV}/c^2$ and $3200 < m(\bar{\Lambda}pK) < 3300\ \mathrm{MeV}/c^2$ to extract the background yields
- Propagate yields to the $|m(\bar{\Lambda}pK) - m(J/\psi)| < 30\ \mathrm{MeV}/c^2$ mass region by using the ratio of integrals of background in these two regions

Fit result: $m(\bar{p}p) < 2850\ \mathrm{MeV}/c^2$

- 1-D simultaneous fit to **Real Data** in the dimension of $m(\bar{\Lambda}p\bar{p}p)$ and $m(\bar{\Lambda}pKK)$
- Signal shape: Double Side Crystall Ball function + Background shape: 1st (2nd) Polynomial function





$$\begin{aligned} &\textbf{Signal Channel:} && N(B^+ \to \bar{\Lambda}^0 p\bar{p}p) = 78 \pm 12,\ \text{significance} > 5\sigma, \\ &\text{Normalization Channel:} && N(B^+ \to J/\psi(\to pK\bar{\Lambda})K^+) = 545 \pm 25. \end{aligned} \tag{1}$$

- 1-D simultaneous fit to **Real Data** of signal data within $m(\bar{\Lambda}p\bar{p}p)$

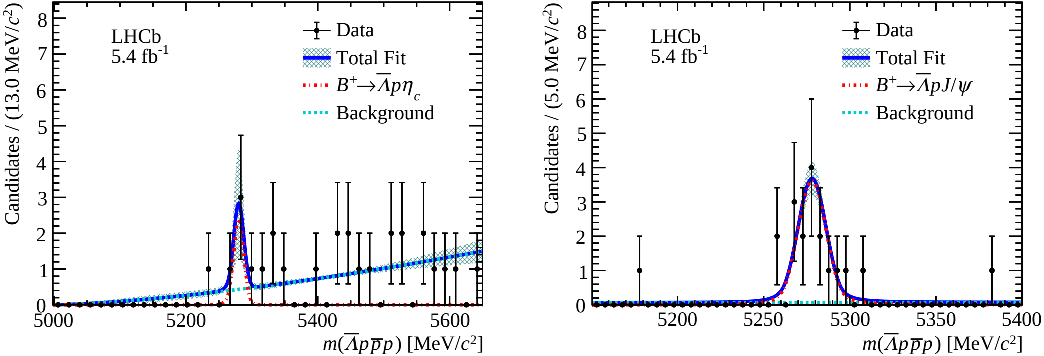


Figure 1: left: abs$(m(\bar{p}p) - M_{\eta_c}) < 40$ MeV$/c^2$, right: abs$(m(\bar{p}p) - M_{J/\psi}) < 30$ MeV$/c^2$

$$N(B^+ \to \bar{\Lambda}^0 p \eta_c(\to \bar{p}p)) = (2.9 \pm 1.9)$$

$N(B^+ \to \bar{\Lambda}^0 p J/\psi(\to \bar{p}p)) = (16.4 \pm 4.2)$, Consistent with expectation

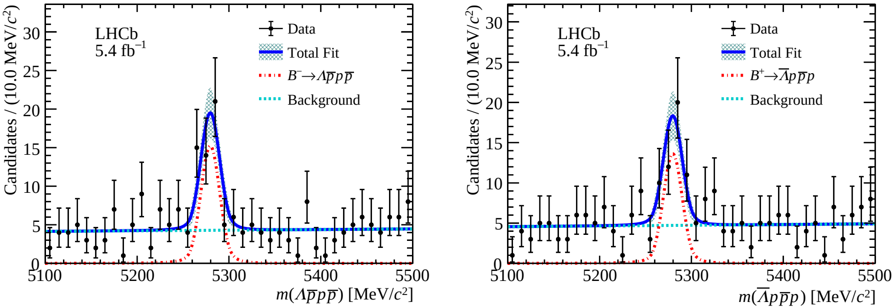
Systematic Uncertainties

Systematic source	$\mathcal{B}(B^+ \to \bar{\Lambda}^0 p\bar{p}p)$	$\mathcal{B}(B^+ \to \bar{\Lambda}^0 \eta_c(\to p\bar{p}p))$
Simulated sample size	0.6	0.6
Kinematic correction	1.4	1.4
Tracking	1.2	1.2
PID	3.1	2.0
Signal shape	2.9	31.1
Background shape	1.2	2.4
Model correction (signal)	2.7	/
Model correction (normalization)	1.6	1.6
Nonresonant	/	22.9
Total systematic	5.8	38.8
Statistical uncertainty	16.4	65.5

- $\mathcal{B}(B^+ \to \bar{\Lambda}^0 p\bar{p}p) = (2.15 \pm 0.35_{\text{stat.}} \pm 0.12_{\text{syst.}} \pm 0.28_{\text{ext.}}) \times 10^{-7}$
- $\mathcal{B}(B^+ \to \bar{\Lambda} p\eta_c(\to p\bar{p})) = (8.3 \pm 5.4_{\text{stat.}} \pm 3.2_{\text{syst.}} \pm 1.1_{\text{ext.}}) \times 10^{-9}$
- Prediction: $\mathcal{B}(B^+ \to \bar{\Lambda}^0 p\bar{p}p) = (7.4^{+0.6}_{-0.2} \pm 0.03^{+3.6}_{-2.6}) \times 10^{-7}$[PLB**845**(2023)138158]

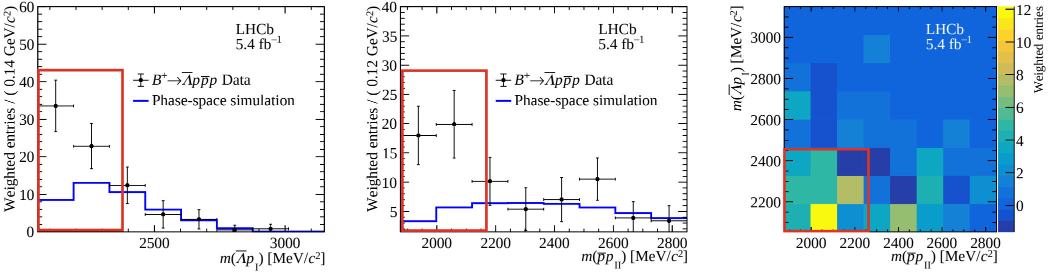
$$\mathcal{A}_{\rm CP} = \mathcal{A}_{\rm raw} - \mathcal{A}_{\rm P}(B^+) - \sum_{i=1}^{3}\mathcal{A}_{\rm D}(p_i) - \mathcal{A}_{\rm D}(\Lambda \to p\pi^-) - \mathcal{A}_{\rm PID} - \mathcal{A}_{\rm trigger}$$
$$= (5.4 \pm 15.6 \pm 2.4)\%$$

- The experimental asymmetry follows the approach in the $\Lambda_b \to ph^-$ and $B \to hhh$ analysis
- Systematics from alternative fit models: Gauss+DSCB, 2nd order polynomial



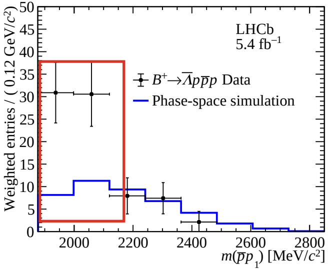
- Background-subtracted dataset to study the mass Spectra
  - To distinguish two protons in $B^+ \to \bar{\Lambda}^0 p\bar{p}p'$, order them based on their invariant mass with $\bar{\Lambda}$:

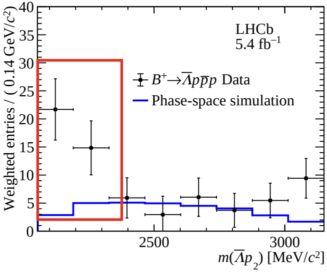
$$m(\bar{\Lambda}p_I) = min(m(\bar{\Lambda}p), m(\bar{\Lambda}p'))$$
$$m(\bar{\Lambda}p_{II}) = max(m(\bar{\Lambda}p), m(\bar{\Lambda}p'))$$
$$\Rightarrow B^+ \to (\bar{\Lambda}^0 p_I)(\bar{p}p_{II})$$

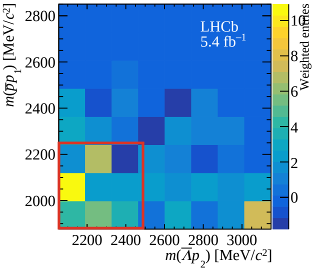


- To distinguish two protons in $B^+ \to \bar{\Lambda}^0 p \bar{p} p'$, order them based on their invariant mass with $\bar{p}$:

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







Summary

- First observation of B^+ purely four-body baryonic decay:
  $$\mathcal{B}(B^+ \to \bar{\Lambda}^0 p\bar{p}p) = (2.15 \pm 0.35_{\rm stat.} \pm 0.12_{\rm syst.} \pm 0.28_{\rm ext.}) \times 10^{-7}$$
- 2σ lower than the prediction: $\mathcal{B} = (7.4^{+0.6}_{-0.2} \pm 0.03^{+3.6}_{-2.6}) \times 10^{-7}$
- A double threshold enhancement is observed for the first time by exploring the mass spectra
- CP asymmetry is measured to be: $\mathcal{A}_{\rm CP} = (5.4 \pm 15.6_{stat.} \pm 2.4_{syst.})\%$
- $\mathcal{B}(B^+ \to \bar{\Lambda} p \eta_c (\to p\bar{p}))$ is measured to be $(8.3 \pm 5.4_{\rm stat.} \pm 3.2_{\rm syst.} \pm 1.1_{\rm ext.}) \times 10^{-9}$