

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

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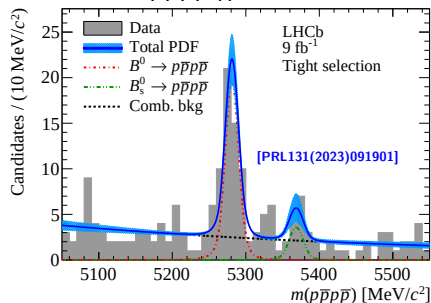
- Two-body Charmless Baryonic decays have been searched for at LHCb

Decay mode	Measured $\mathcal{B}$	Ref.
$B^0 \rightarrow p\bar{p}$	$(1.25 \pm 0.27 \pm 0.18) \times 10^{-8}$	PRL 119 (2017) 232001
$\bar{B}^+ \rightarrow p\bar{\Lambda}^0$	$(2.4^{+1.0}_{-0.8} \pm 0.3) \times 10^{-7}$	JHEP 04 (2017) 162
$\bar{B}^+ \rightarrow p\bar{\Lambda}(1520)$	$(3.9^{+1.0}_{-0.9} \pm 0.1 \pm 0.3) \times 10^{-7}$	PRD 88 (2013) 052015

- The only observed purely four-body baryonic decay is $\bar{B}^0 \rightarrow p\bar{p}pp$
- No clear evidence of threshold enhancement is found in $\bar{B}^0 \rightarrow p\bar{p}pp$ given the statistics

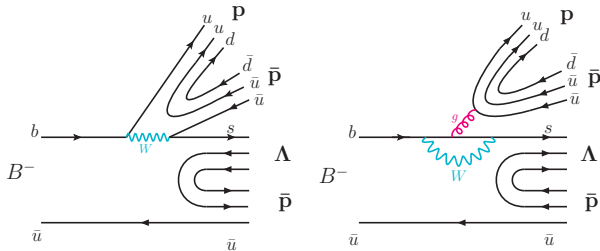
mode	Branching fraction $\mathcal{B}$
$B^0 \rightarrow p\bar{p}pp$	$(2.21 \pm 0.37 \pm 0.38 \pm 0.09) \times 10^{-8}$
$\bar{B}_s^0 \rightarrow p\bar{p}pp$	$(2.40 \pm 1.01 \pm 0.20 \pm 0.19) \times 10^{-8}$

[PRL131(2023)091901]

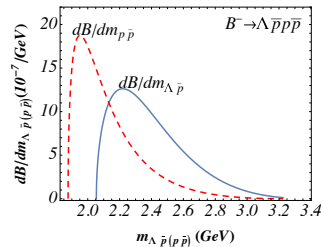


Motivation

- $B^+ \rightarrow \bar{\Lambda}^0 p \bar{p} p$ is dominated by $b \rightarrow s$ transition[*], at tree level $b \rightarrow u$ and $W \rightarrow \bar{u}s$ are color suppressed
- Prediction of $\mathcal{B}(B^+ \rightarrow \bar{\Lambda}^0 p \bar{p} p) = (7.4_{-0.2}^{+0.6} \pm 0.03_{-2.6}^{+3.6}) \times 10^{-7}$ [*] and expect $\mathcal{O} \sim 10^2$ events (with Run2 restripped data in 2023)
- Probably the best chance to study double threshold effect



*[PLB845(2023)138158]



Analysis strategy

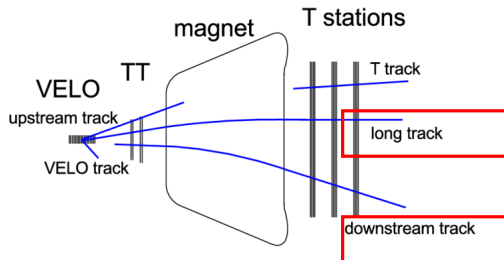
- Blind signal region $\pm 250 \text{ MeV}/c^2$ around B^+ mass
- Normalization channel: $\mathcal{B}(B^+ \rightarrow J/\psi K^+) \times \mathcal{B}(J/\psi \rightarrow pK\bar{\Lambda} + c.c.) = (8.77 \pm 1.14) \times 10^{-7}$

➤ BF measured from simultaneous fits to signal and normalization channels

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

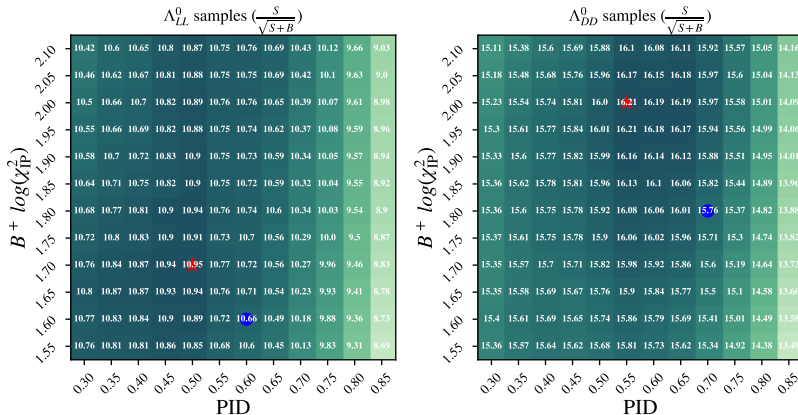
➤ Measure $\mathcal{B}(B^+ \rightarrow \bar{\Lambda}^0 p J/\psi(\rightarrow p\bar{p}))$ as cross-check of fit model/efficiencies

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



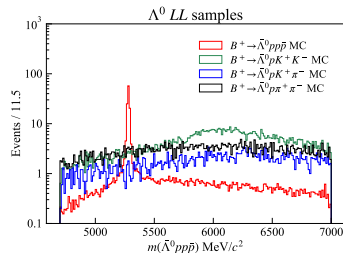
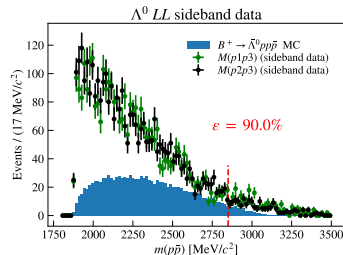
Dataset and offline selections

- 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_{IP}^2 are optimized to maximize significance



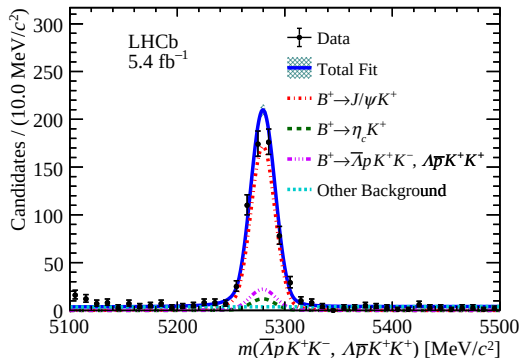
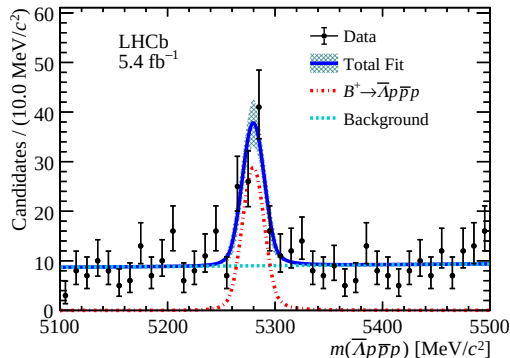
⇒ Charmonium contribution, e.g., $B^+ \rightarrow \bar{\Lambda}^0 p J/\psi (\rightarrow p\bar{p})$, $\bar{\Lambda}^0 p \eta_c (\rightarrow p\bar{p}) \Rightarrow m(p\bar{p}) < 2850 \text{ MeV}$

⇒ Mis-ID background: Negligible contribution due to double misidentification and mass shifts to the far right of the spectra



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

- 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



$$N(B^+ \rightarrow \bar{\Lambda}^0 p \bar{p} p) = (27.2 \pm 4.4) + (51.1 \pm 8.1), \text{significance} > 5\sigma$$

Fit result: $\text{abs}(m(\bar{p}p) - M_{\eta_c(J/\psi)}) < 40(30) \text{ MeV}/c^2$

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

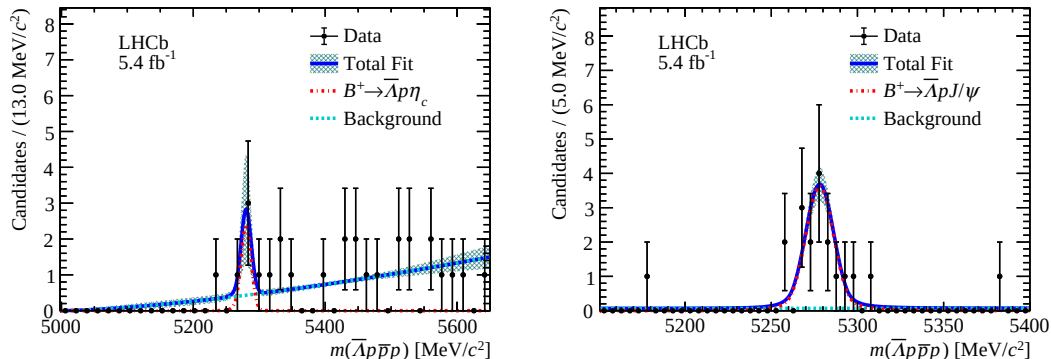


Figure 1: left: $\text{abs}(m(\bar{p}p) - M_{\eta_c}) < 40 \text{ MeV}/c^2$, right: $\text{abs}(m(\bar{p}p) - M_{J/\psi}) < 30 \text{ MeV}/c^2$

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

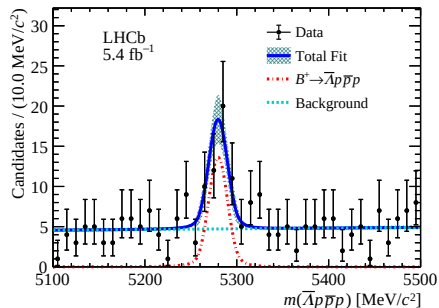
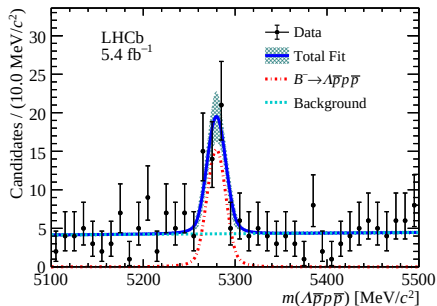
Systematic source	$\mathcal{B}(B^+ \rightarrow \bar{\Lambda}^0 p \bar{p} p)$	$\mathcal{B}(B^+ \rightarrow \bar{\Lambda}^0 \eta_c (\rightarrow p \bar{p} p))$
Simulated sample size	0.6	0.6
Kinematic correction	1.4	1.4
Tracking	1.2	1.2
PID	3.1	2.0
Signal shape	2.9	31.1
Background shape	1.2	2.4
Model correction (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

- $\mathcal{B}(B^+ \rightarrow \bar{\Lambda}^0 p \bar{p} p) = (2.15 \pm 0.35_{\text{stat.}} \pm 0.12_{\text{syst.}} \pm 0.28_{\text{ext.}}) \times 10^{-7}$
- $\mathcal{B}(B^+ \rightarrow \bar{\Lambda} p \eta_c (\rightarrow p \bar{p})) = (8.3 \pm 5.4_{\text{stat.}} \pm 3.2_{\text{syst.}} \pm 1.1_{\text{ext.}}) \times 10^{-9}$
- Prediction: $\mathcal{B}(B^+ \rightarrow \bar{\Lambda}^0 p \bar{p} p) = (7.4_{-0.2}^{+0.6} \pm 0.03_{-2.6}^{+3.6}) \times 10^{-7}$ [PLB845(2023)138158]

$$\mathcal{A}_{\text{CP}} = \mathcal{A}_{\text{raw}} - \mathcal{A}_{\text{P}}(B^+) - \sum_{i=1}^3 \mathcal{A}_{\text{D}}(p_i) - \mathcal{A}_{\text{D}}(\Lambda \rightarrow p\pi^-) - \mathcal{A}_{\text{PID}} - \mathcal{A}_{\text{trigger}}$$

$$= (5.4 \pm 15.6 \pm 2.4)\%$$

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



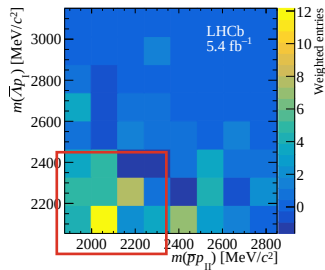
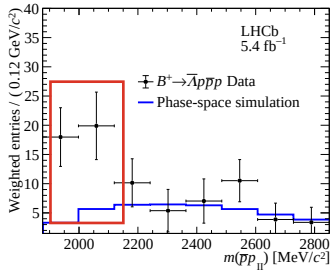
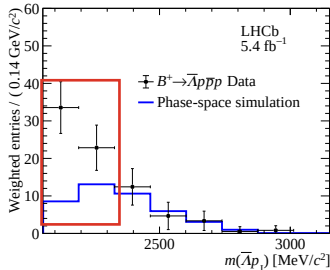
➤ Background-subtracted dataset to study the mass Spectra

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

$$m(\bar{\Lambda} p_I) = \min(m(\bar{\Lambda} p), m(\bar{\Lambda} p'))$$

$$m(\bar{\Lambda} p_{II}) = \max(m(\bar{\Lambda} p), m(\bar{\Lambda} p'))$$

$$\Rightarrow B^+ \rightarrow (\bar{\Lambda}^0 p_I)(\bar{p} p_{II})$$

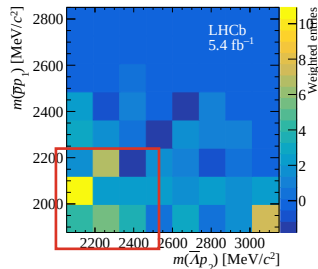
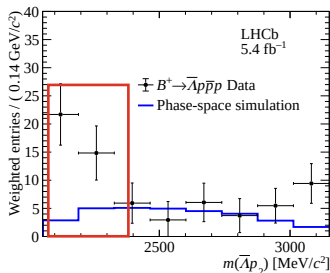
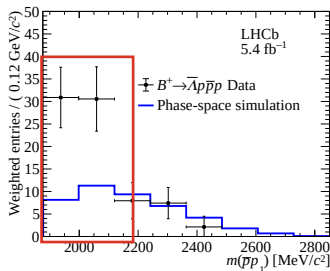


- To distinguish two protons in $B^+ \rightarrow \bar{\Lambda}^0 p \bar{p} p'$, order them based on their invariant mass with $\bar{p}$:

$$m(\bar{p}p_1) = \min(m(\bar{p}p), m(\bar{p}p'))$$

$$m(\bar{p}p_2) = \max(m(\bar{p}p), m(\bar{p}p'))$$

$$\Rightarrow B^+ \rightarrow (\bar{p}p_1)(\bar{\Lambda}^0 p_2)$$



- First observation of B^+ purely four-body baryonic decay:

$$\mathcal{B}(B^+ \rightarrow \bar{\Lambda}^0 p \bar{p} p) = (2.15 \pm 0.35_{\text{stat.}} \pm 0.12_{\text{syst.}} \pm 0.28_{\text{ext.}}) \times 10^{-7}$$

- 2σ lower than the prediction: $\mathcal{B} = (7.4_{-0.2}^{+0.6} \pm 0.03_{-2.6}^{+3.6}) \times 10^{-7}$

- A double threshold enhancement is observed by exploring the mass spectra

- CP asymmetry is measured to be: $\mathcal{A}_{\text{CP}} = (5.4 \pm 15.6_{\text{stat.}} \pm 2.4_{\text{syst.}})\%$

- $\mathcal{B}(B^+ \rightarrow \bar{\Lambda} p \eta_c (\rightarrow p \bar{p}))$ is measured to be $(8.3 \pm 5.4_{\text{stat.}} \pm 3.2_{\text{syst.}} \pm 1.1_{\text{ext.}}) \times 10^{-9}$