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

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The charmless baryonic decay $B^+ \to \bar{\Lambda} p \bar{p} p$ is observed using proton-proton collision data recorded by the LHCb experiment, corresponding to an integrated luminosity of 5.4 fb^{-1}. The branching fraction for this decay is measured for the first time relative to that of the topologically similar decay $B^+ \to J/\psi K^+$, with $J/\psi \to \bar{\Lambda} p K^-$. The background-subtracted invariant-mass distributions of $\bar{\Lambda} p$ and $\bar{p} p$ pairs exhibit pronounced enhancements at both kinematic thresholds, in contrast to a uniform phase-space distribution. A measurement of the CP asymmetry for this decay is also reported.

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1. Introduction

In the Standard Model (SM), B-meson decays to the final states containing both baryons and mesons proceed through $b \to u$ tree-level transitions and $b \to s(d)$ electroweak penguin diagrams, providing a valuable laboratory for studying direct CP violation and for testing hadronic models [1, 2]. Such decays exhibit a unique feature known as threshold enhancement: a pronounced peak near the invariant-mass threshold of the baryon–antibaryon pair [3, 4]. Purely baryonic B decays, being highly suppressed in the SM, offer enhanced sensitivity to potential contributions from physics beyond the SM.

The decay $B^+ \to \bar{\Lambda} p \bar{p} p$,[1] which contains two baryon–antibaryon pairs in the final state, offers a promising opportunity to study the mass spectra of baryon pairs and explore baryon-pair formation mechanisms [5]. In addition, owing to the interference between tree-level and penguin diagrams in the low $m(\bar{\Lambda} p)$ and $m(\bar{p} p)$ mass regions, sizeable direct CP asymmetries are possible [6].

This poster presents the first observation of the charmless baryonic decay $B^+ \to \bar{\Lambda} p \bar{p} p$, using proton-proton ($pp$) collision data collected by the LHCb experiment over the period 2016–2018 at a center-of-mass energy $\sqrt{s}$ =13 TeV and corresponding to an integrated luminosity of approximately 5.4 fb^{-1}. In addition, this poster also reports a study of the $m(\bar{\Lambda} p)$ and $m(\bar{p} p)$ spectra, as well as the CP asymmetry, in a purely baryonic four-body decay.

2. Study of the $B^+ \to \bar{\Lambda} p \bar{p} p$ decay

2.1 Branching fraction measurement

The branching fraction of the $B^+ \to \bar{\Lambda} p \bar{p} p$ decay is measured relative to that of the topologically similar normalization mode, $B^+ \to J/\psi K^+$, with $J/\psi \to \bar{\Lambda} p K^-$, using a simultaneous fit across all data-taking periods. The invariant-mass distributions $m(\bar{\Lambda} p \bar{p} p)$ with the requirement $m(\bar{p} p) < 2850\ \mathrm{MeV}/c^2$, and $m(\bar{\Lambda} p K K)$ for signal and normalization channels, respectively, are shown in Fig. 1. Unbinned maximum-likelihood fits are performed to determine the signal yield and branching fraction. The signal shapes are described by a modified Gaussian function with tails on both sides of the peak (double-sided Crystal Ball [7], DSCB) whose values are fixed from simulation. The B^+ mass and width are allowed to vary independently. The background shapes are described by linear functions with coefficients that are free to vary. The B^+ signal yield obtained from the fit to the $m(\bar{\Lambda} p \bar{p} p)$ selected candidates is $N(B^+ \to \bar{\Lambda} p \bar{p} p) = 78 \pm 12$ events, accounting for statistical uncertainties only. The absolute branching fraction is determined to be $\mathcal{B}(B^+ \to \bar{\Lambda} p \bar{p} p) = (2.15 \pm 0.35 \pm 0.12 \pm 0.28) \times 10^{-7}$, where the first uncertainty is statistical, the second systematic, and the third arises from the external branching fraction of the normalization channel.

2.2 Double threshold enhancement

The background-subtracted invariant-mass spectra of $\bar{\Lambda} p$ and $\bar{p} p$ pairs, obtained using the *sPlot* technique in the $m(\bar{\Lambda} p \bar{p} p)$ dimension [8], are shown in Fig. 2 and 3. The two identical protons in the final state are distinguished based on the invariant masses formed with the $\bar{\Lambda}$ and $\bar{p}$

[1] The inclusion of charge-conjugate processes is implied throughout, except in the discussion of asymmetries.

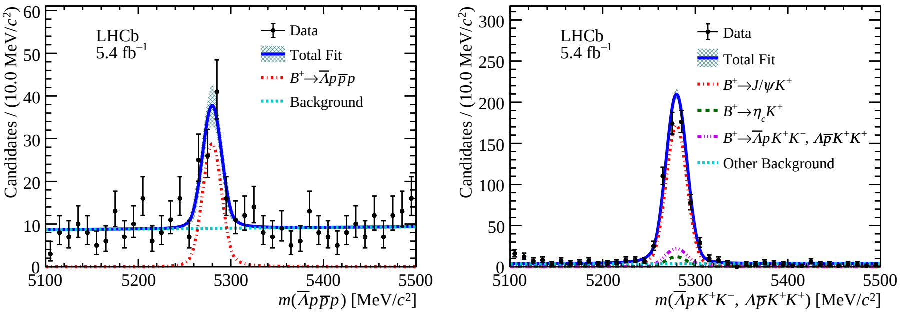

Figure 1: Invariant-mass distributions of (left) $B^+ \to \bar{\Lambda} p \bar{p} p$ with $m(\bar{p}p) < 2850$ MeV$/c^2$ and (right) $B^+ \to J/\psi(\to \bar{\Lambda} p K^-) K^+$ candidates. The fit results are shown together with the fit model components. The hashed cyan bands represent the $\pm 1\sigma$ model uncertainties from the covariance matrices of the best-fit parameters.

baryons. The proton that yields the lower invariant mass $m(\bar{\Lambda}p)$ $(m(\bar{p}p))$ is labeled as p_{I} (p_1). The other proton, p_{II} (p_2), is paired with the antiproton $(\bar{\Lambda})$ to form the second baryon–antibaryon combination.

A double threshold enhancement is observed in Fig. 2 and 3, indicated by the clear accumulation of events in the lower left-hand corner of the weighted $(m(\bar{\Lambda}p),\ m(\bar{p}p))$ distribution, as well as by the peaks near the kinematic thresholds in the $m(\bar{\Lambda}p)$ and $m(\bar{p}p)$ spectra.

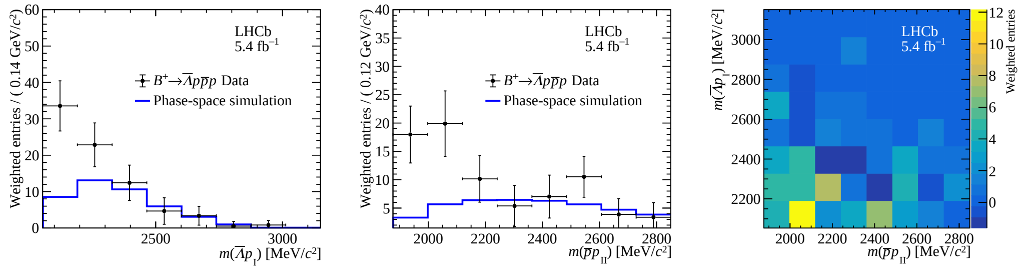

Figure 2: Distributions of background-subtracted (left) $m(\bar{\Lambda}p_{\mathrm{I}})$ and (middle) $m(\bar{p}p_{\mathrm{II}})$ for $B^+ \to \bar{\Lambda} p \bar{p} p$ events in data compared with phase-space simulation, where the proton p_{I} yields the lower invariant mass $m(\bar{\Lambda}p)$ with $\bar{\Lambda}$ baryon. (Right) Two-dimensional distribution of $m(\bar{\Lambda}p_{\mathrm{I}})$ and $m(\bar{p}p_{\mathrm{II}})$ in data.

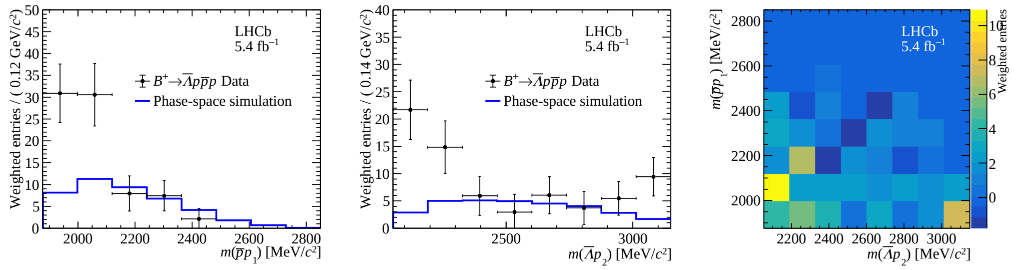

Figure 3: Distributions of background-subtracted (left) $m(\bar{p}p_1)$ and (middle) $m(\bar{\Lambda}p_2)$ for $B^+ \to \bar{\Lambda} p \bar{p} p$ events in data compared with phase-space simulation, where the proton p_1 yields the lower invariant mass with antiproton. (Right) Two-dimensional distribution of $m(\bar{p}p_1)$ and $m(\bar{\Lambda}p_2)$ in data.

2.3 *CP* measurement

The CP asymmetry of the $B^+ \to \bar{\Lambda} p \bar{p} p$ decay rate integrated over the phase space is measured by fitting the B^+ and B^- samples separately, as shown in Fig. 4, using the same procedure as for the branching fraction measurement. The yields vary independently, while the shape parameters are shared between the B^+ and B^- candidates. The raw asymmetry ($A_{\rm raw}$) between the B^+ and B^- signal yields is found to be $(5.6 \pm 15.5)\%$. To obtain the CP asymmetry, this must be corrected by

$$\mathcal{A}_{CP} = A_{\rm raw} - A_{\rm prod} - A_{\rm det},$$

where $A_{\rm prod}$ is the production asymmetry of $B^\pm$ mesons and $A_{\rm det}$ is the sum of the instrumental asymmetries in detection, particle identification, and trigger of particles and antiparticles. Altogether with the uncertainties on external asymmetries, the CP asymmetry is measured to be $\mathcal{A}_{CP} = (5.4 \pm 15.6 \pm 2.4)\%$, where the first uncertainty is statistical, and the second systematic.

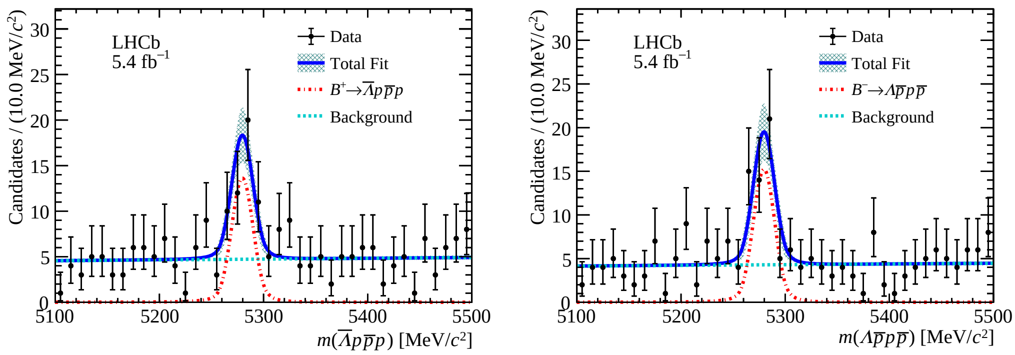

Figure 4: Invariant-mass distribution of (left) $B^+ \to \bar{\Lambda} p \bar{p} p$ and (right) $B^- \to \Lambda \bar{p} p \bar{p}$ candidates. The fit results for these samples are shown together with the fit model components. The hashed cyan bands represent the 1σ model uncertainty on the covariance matrix of the best-fit parameters.

3. Conclusion

A new charmless and purely baryonic decay mode of the B^+ meson, $B^+ \to \bar{\Lambda} p \bar{p} p$, is observed for the first time [10]. The measured branching fraction is lower than, but in reasonable agreement with, a SM prediction of $\mathcal{B}(B^+ \to \bar{\Lambda} p \bar{p} p) = (7.4^{+0.6}_{-0.2} \pm 0.03^{+3.6}_{-2.6}) \times 10^{-7}$ [5], where the uncertainty arises from nonfactorizable QCD corrections, the CKM matrix-element inputs, and form-factor modeling. The CP asymmetry is measured to be $\mathcal{A}_{CP} = (5.4 \pm 15.6 \pm 2.4)\%$, with the first uncertainty statistical and the second systematic. The background-subtracted mass spectra exhibit a clear double-threshold enhancement in both baryon–antibaryon invariant-mass distributions close to their thresholds, which plays an enhancing factor [5] in the $B^+ \to \bar{\Lambda} p \bar{p} p$ decay and may reveal resonant structures such as the $X(1835)$ baryonium bound state [9].

The measurement of $\mathcal{B}(B^+ \to \bar{\Lambda} p \bar{p} p)$ constrains models of perturbative QCD effects in multibody baryonic final states, particularly in regions where large theoretical uncertainties remain [5]. The threshold enhancements manifested in this study highlight the rich dynamics of baryonic B decays and should stimulate further theoretical studies.

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