

Probing direct CP violation in $\Lambda_b^0 \rightarrow P_c^+ h^-$ ($h = \pi, K$) with final-state rescattering

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The LHCb Collaboration recently reported a measurement of the difference in direct CP asymmetries for the decays $\Lambda_b^0 \rightarrow J/\psi p h^-$ (with $h = K, \pi$), offering new experimental constraints on the decay dynamics of heavy baryons into charmonium final states. Inspired by these findings, we explore the branching ratios and direct CP violations for the decays $\Lambda_b^0 \rightarrow P_c^+ (4312, 4440, 4457) h^-$ within the framework of final-state rescattering. Our analysis indicates that the branching fractions for $\Lambda_b^0 \rightarrow P_c^+ \pi^-$ lie around the 10^{-6} level, with the corresponding direct CP asymmetries approaching approximately 1%. In contrast, the direct CP violation for the decay $\Lambda_b^0 \rightarrow P_c^+ K^-$ is found to be very small, while its branching ratios show a strong dependence on the spin assignments of the P_c states. These predictions may provide useful guidance for more precise CP measurements and amplitude analyses in the P_c region in future experiments.

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I. INTRODUCTION

CP violation is one of the essential building blocks for understanding the dynamical origin of the baryon-antibaryon asymmetry observed in the Universe. In 2025, the LHCb Collaboration reported the first confirmation of CP asymmetry in the baryon decay via the multibody decaying channel $\Lambda_b^0 \rightarrow p K^- \pi^+ \pi^-$ with a significance of 5.2σ [1]. Specifically, the experimental studies reported localized CP asymmetries across different phase space regions of the Dalitz plot. These experimental measurements are either consistent with theoretical prediction based on the $N\pi \rightarrow N\pi\pi$ rescatterings [2], or interpreted via final state

interaction calculations with the hadron scattering framework [3,4]. It opens a new avenue for studying QCD dynamics through flavor CP violation, offering opportunities for precision tests of the Standard Model and future constraints on possible new physics.

Recently, the LHCb Collaboration measured the CP asymmetry difference ΔA_{CP} in the charmonium-mediated decays $\Lambda_b^0 \rightarrow J/\psi p h^-$ ($h = K, \pi$). The observable defined as $\Delta A_{CP} \equiv A_{CP}(\Lambda_b^0 \rightarrow J/\psi p \pi^-) - A_{CP}(\Lambda_b^0 \rightarrow J/\psi p K^-)$, was determined to be $(4.31 \pm 1.06 \pm 0.28)\%$ [5]. The decay mode $\Lambda_b^0 \rightarrow J/\psi p K^-$ proceeds through the quark level transition $b \rightarrow c\bar{c}s$, in which the relevant weak phases are nearly aligned. As a result, the Standard Model predicts a highly suppressed direct CP asymmetry in this channel. In contrast, the decay $\Lambda_b^0 \rightarrow J/\psi p \pi^-$ proceeds via $b \rightarrow c\bar{c}d$, which involves a sizable weak phase difference and can therefore exhibit a potentially significant CP asymmetry. Under the assumption that $A_{CP}(\Lambda_b^0 \rightarrow J/\psi p K^-)$ is negligibly small, a nonzero ΔA_{CP} becomes a sensitive probe of CP violation in $\Lambda_b^0 \rightarrow J/\psi p \pi^-$. Notably, the Dalitz analysis presented in [5] shows a comparatively larger asymmetry in the kinematic region where $J/\psi p$ invariant mass lies near the pentaquark states P_c . This observation suggests that the region may provide a

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particularly promising window for probing direct CP asymmetry in the decay $\Lambda_b^0 \rightarrow P_c^+ \pi^-$. Such a measurement, if experimentally confirmed, would constitute the first observation of CP violation in a decay involving the pentaquark states. Motivated by this prospect, we investigate CP asymmetry in $\Lambda_b^0 \rightarrow P_c^+ h^-$ in the present work.

In recent years, CP violation in baryon decays has been studied extensively [2–4,6–22]. For example, recent pQCD calculations indicate that the mechanism of CP violation in baryon decays differs markedly from that in meson decays: a partial cancellation between the S - and P -wave contributions suppresses the direct CP asymmetry. This mechanism provides a new dynamical interpretation of the currently small CPV observed in two-body Λ_b decays. However, for processes involving pentaquark final states, short-distance factorization approaches such as pQCD/QCDF generally require nonperturbative inputs, in particular light-cone distribution amplitudes (LCDAs). At present, these inputs for pentaquark states are still poorly constrained, so fully reliable quantitative predictions within factorization frameworks remain challenging. In this context, the final-state-interaction (FSI) approach is more suitable for the present work, since it can effectively incorporate long-distance hadronic dynamics and strong phases without relying on pentaquark LCDAs.

FSI has been successfully applied to nonleptonic decays of heavy hadrons. In this framework, long-distance amplitudes are treated at the hadron level, allowing a systematic estimate of nonfactorizable contributions to topological amplitudes [23,24]. For CP -violation mechanisms, FSI provides a picture different from QCD factorization: the strong phase is generated primarily by hadronic rescattering in the final state, rather than by quark–antiquark loop effects (the BSS mechanism) [25]. By introducing quasi-two-body intermediate processes involving resonant states, FSI also offers a practical computational strategy for multibody decays. Studies of two-body B -meson final states already showed that rescattering can be crucial for both branching fractions and direct CP asymmetries, and that the absorptive part of the full amplitude can be extracted by combining short-distance amplitudes with long-distance scattering amplitudes via the optical theorem [23]. In recent years, this approach has been extended from mesonic to baryonic systems [3,4,21,22,26–33]. In Ref. [22], charmed-baryon decays were studied in the rescattering framework using a loop-integration formalism in place of the optical theorem; with only one model parameter, the branching fractions of eight channels can be described simultaneously. Applied further to bottom-baryon decays, the same framework with two model parameters accounts for five branching fractions and CP -violating observables [21]. In addition, FSI can naturally accommodate processes involving excited states [3,4]. In this context, at the phenomenological level, it provides important guidance for experimental measurements and

preliminary theoretical investigations, despite suffering from systematic uncertainties that are difficult to improve further. Here, we extend the approach to the decays $\Lambda_b^0 \rightarrow P_c^+ h^-$.

On the other hand, the LHCb Collaboration has discovered three hidden-charm pentaquark candidates $P_c(4312)^+$, $P_c(4440)^+$, and $P_c(4457)^+$ in the $J/\psi p K^-$ decay [34]. Various theoretical scenarios were proposed to reveal the nature of these pentaquark states, including hadronic molecules [35–53], compact pentaquark [54–60], baryo-charmonium [61], and kinematical effects [62,63]. Among the various theoretical interpretations, the hadronic molecular picture is the most favored. This is because both the masses and the mass splittings of these pentaquark states can be naturally accommodated within the heavy-quark spin symmetry (HQSS) multiplet framework [42]. In this picture, the $P_c(4312)^+$ is interpreted as a $\Sigma_c \bar{D}$ bound state with $J^P = \frac{1}{2}^-$, while the $P_c(4440)^+$ and $P_c(4457)^+$ are treated as $\Sigma_c \bar{D}^*$ bound states with either $J^P = \frac{1}{2}^-$ or $\frac{3}{2}^-$. However, the spin-parity quantum numbers of the $P_c(4440)^+$ and $P_c(4457)^+$ have not yet been determined experimentally. While a number of theoretical studies have proposed various physical observables to discriminate between possible spin assignments for these states, no promising observable has yet been established. In the two body decays $\Lambda_b^0 \rightarrow P_c^+ h^-$, CP violations may offer new insights into the internal structures of three pentaquark states and spin order of $P_c(4440)^+$ and $P_c(4457)^+$. Therefore, we will compute the branching fractions and direct CP violation of the two-body decays $\Lambda_b^0 \rightarrow P_c^+ h^-$ assuming the three pentaquark states as the hadronic molecules.

The paper is organized as follows. In Sec. II, we concisely introduce the theoretical framework. Since many details of the computational methodology have already been presented in our previous work [21], we focus here only on new aspects. In Sec. III, we present the numerical results for the helicity amplitudes, branching ratios, and CP asymmetries. Finally, we provide a summary in Sec. IV. The effective Lagrangian and the analytical expressions for the long-distance amplitudes are collected in the Appendixes.

II. THEORETICAL FRAMEWORK

Under final states interaction approach, the decays $\Lambda_b^0 \rightarrow P_c^+ h^-$ can be viewed as a two-step process: first, the Λ_b^0 decays into a pair of intermediate hadrons, which then undergo rescattering via the exchange of a single hadron, ultimately transforming into the final states of concern. Within this framework, the underlying physical picture is described by the triangle diagrams illustrated in Fig. 1. In this work, the triangle loops incorporate the pseudoscalar-meson octet P_8 , the baryon octet B_8 , the

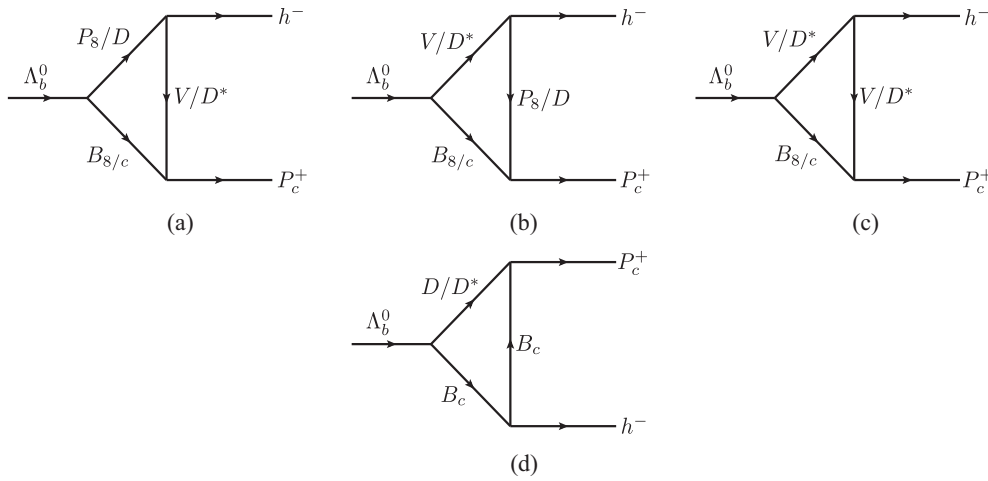


FIG. 1. The triangle diagrams of $\Lambda_b^0 \rightarrow P_c^+ h^-$ considered in this work, where the B_c, B_8 represent charmed and octet light baryons, and P, V, D, D^* are pseudoscalar and vector octet, D and D^* mesons, respectively. (a) represents rescattering between a pseudoscalar meson and a baryon via vector-meson exchange; (b) represents rescattering between a vector meson and a baryon via pseudoscalar-meson exchange; (c) represents rescattering between a vector meson and a baryon via vector-meson exchange; and (d) represents rescattering between a charmed meson and a charmed baryon via charmed-baryon exchange.

charmed mesons $D^{(*)}$, as well as the charmed baryons B_c (i.e., the antitriplet B_3 and the sextet B_6).

To calculate the triangle diagrams above, we treat the weak vertices within the naive factorization approach, while the Feynman rules for the strong vertices are derived

from effective hadronic Lagrangians. The former have been introduced comprehensively in our previous work [21]. As an illustration, we consider diagram (a) in Fig. 1 as an example. The corresponding amplitude is expressed as an integral over the internal momentum k :

$$\begin{aligned} \mathcal{M}[D, B_c, D^*; P_c^{1/2-}] &= \int \frac{d^4 k}{(2\pi)^4} g_{D^* D P} g_{D^* \Lambda_c^+ P_c}^{1/2-} p_{3\alpha} \bar{u}(p_4) \gamma^\nu \gamma_5 \left(g_{\mu\nu} - \frac{p_{4\mu} p_{4\nu}}{m_{P_c}^2} \right) \left(-g^{\alpha\mu} + \frac{k^\alpha k^\mu}{m_k^2} \right) \\ &\quad \times (p_2 + m_2)(A + B\gamma_5) u(p_i) \frac{\mathcal{F}}{(p_1^2 - m_1^2)(p_2^2 - m_2^2)(k^2 - m_k^2)}. \end{aligned} \quad (2.1)$$

The momenta p_i, p_3 , and p_4 represent those of the initial baryon Λ_b^0 , the final-state meson h^- , and the pentaquark P_c , respectively, while p_1, p_2 , and k denote the momenta of the intermediate particles. Here, the notation $\mathcal{M}[D, B_c, D^*; P_c^{1/2-}]$ denotes the triangle amplitude, in which D and B_c are the intermediate particles produced at the weak vertex, D^* is the exchanged particle in the scattering loop, and $P_c^{1/2-}$ is the final pentaquark state with spin parity $J^P = 1/2^-$.

The effective form factor $\mathcal{F}$ follows the same parametrization as in our previous work: $\mathcal{F}(\Lambda, m_k) = \Lambda^4 / ((k^2 - m_k^2)^2 + \Lambda^4)$, where Λ is a model parameter [21]. For the decay $\Lambda_b^0 \rightarrow P_c^+ h^-$, the rescattering processes $\Lambda_c^+ D_{(s)}^- \rightarrow P_c^+ h^-$ and $p\pi^-(K^-) \rightarrow P_c^+ h^-$ involve different intermediate particles and hence exhibit distinct off-shell effects in the loop. Accordingly, we introduce two model parameters, Λ_{charm} and $\Lambda_{\text{charmless}}$, to characterize these two distinct rescattering modes, following the method used in our previous work on two-body charmless nonleptonic Λ_b^0 decays [21]. Recently, the LHCb Collaboration performed a binned

Dalitz-plot analysis of the direct CP asymmetry in $\Lambda_b^0 \rightarrow p K_S^0 \pi^-$ and found that A_{CP} in the phase space region dominated by $K^*(892)^-$ approaches zero, indicating small CP asymmetry in this channel [64]—consistent with our theoretical prediction [21]. It largely boosts our confidence, and hence we adopt similar values for the model parameters Λ in the decays $\Lambda_b^0 \rightarrow P_c^+ h^-$. Finally, the full amplitude expressions for all triangle diagrams are collected in Appendix B.

III. NUMERICAL RESULTS AND DISCUSSIONS

A. Input parameters

The global input parameters used in this work are summarized as follows. The masses of the three final-state pentaquark states P_c^+ are taken as 4.312, 4.440, and 4.457 GeV, respectively. The baryon and meson masses are $m_{\Lambda_b^0} = 5.619$, $m_{\Lambda_c^+} = 2.286$, $m_p = 0.938$, $m_D = 1.869$, $m_\pi = 0.140$, $m_{D^*} = 2.010$, and $m_\rho = 0.770$ GeV. The quark masses are current masses with values $m_u = 2.16$ MeV, $m_d = 4.70$ MeV, $m_s = 93.5$ MeV, $m_c = 1.27$ GeV,

TABLE I. The values of the pentaquark states couplings to their constituents. The coupling constants are dimensionless.

	$P_c^+(4312)$	$P_c^+(4440)$	$P_c^+(4457)$
$g_{P_c^{1/2}\pi N}$	0.1185	0.0402	0.0238
$g_{P_c^{3/2}\pi N}$		0.0006	0.0003
$g_{P_c^{1/2}\Lambda_c D}$	0.0775	0.2019	0.1714
$g_{P_c^{3/2}\Lambda_c D}$		0.9179	0.8528
$g_{P_c^{1/2}\Lambda_c D^*}$	0.4565	0.2938	0.2655
$g_{P_c^{3/2}\Lambda_c D^*}$		0.3753	0.3675
$g_{P_c^{1/2}\rho N}$	0.0009	0.0185	0.0092
$g_{P_c^{3/2}\rho N}$		0.0278	0.0160
$g_{P_c^{1/2}\Sigma_c D}$	1.8913	0.2744	0.2411
$g_{P_c^{3/2}\Sigma_c D}$		1.9379	2.0067
$g_{P_c^{1/2}\Sigma_c D^*}$		1.3581	0.9252
$g_{P_c^{3/2}\Sigma_c D^*}$		2.3522	1.6024
$g_{P_c^{1/2}\omega p}$	0.0017	0.0361	0.0208
$g_{P_c^{3/2}\omega p}$		0.0560	0.0322

$m_b = 4.18$ GeV, from Ref. [65]. The CKM matrix elements are adopted at leading order of Wolfenstein parameterization with $A = 0.823$, $\rho = 0.141$, $\eta = 0.349$, and $\lambda = 0.225$ [65]. The heavy-to-light transition form factors

for $\Lambda_b^0 \rightarrow p$ and Λ_c^+ are taken from Ref. [66]. The decay constants are $f_\pi = 130.3$ and $f_D = 212$ MeV for pseudo-scalar mesons, and $f_\rho = 216$ and $f_{D^*} = 230$ MeV for vector mesons [66]. The couplings of the pentaquark states to charmed baryons and mesons, as well as to protons and light mesons, are extracted from their partial widths, as shown in Table IV of Ref. [67]. The pentaquark-state couplings used in this work are summarized in Table I. The remaining couplings can be found in our previous work [21].

B. Numerical results

Using the model parameters $\Lambda_{\text{charm}} = 1.0$ GeV and $\Lambda_{\text{charmless}} = 0.5$ GeV, we present the helicity amplitudes for the decays $\Lambda_b^0 \rightarrow P_c^+ \pi^-$ and $\Lambda_b^0 \rightarrow P_c^+ K^-$ in Tables II and III, respectively. These amplitudes can be directly tested in future experiments through partial-wave analyses. The notation follows that of our previous work. For instance, $\mathcal{N}\mathcal{C}$ ($\mathcal{C}$) denotes the total amplitude arising from light-hadron (charmed-hadron) scattering. We emphasize that the helicity amplitudes listed in Tables II and III do not include CKM factors. The CKM symbols shown in the tables serve only to distinguish the different contributions.

The branching ratios and direct CP asymmetries are calculated by

$$\text{BR}[\Lambda_b^0 \rightarrow P_c^+ \pi^- (P_c^+ K^-)] = \frac{|p_c|}{8\pi M_{\Lambda_b}^2 \Gamma_{\Lambda_b^0}} \frac{1}{2} (|H_{+1/2}|^2 + |H_{-1/2}|^2), \quad a_{CP}^{\text{dir}} = \frac{\Gamma - \bar{\Gamma}}{\Gamma + \bar{\Gamma}}, \quad (3.1)$$

where p_c is the final P_c^+ momentum in the Λ_b^0 rest frame, and $1/2$ in $\text{BR}[\Lambda_b^0 \rightarrow P_c^+ \pi^- (P_c^+ K^-)]$ accounts for the initial spin average. Using the model parameters $\Lambda_{\text{charm}} = 1.0 \pm 0.1$ GeV and $\Lambda_{\text{charmless}} = 0.5 \pm 0.1$ GeV, we present the branching ratios and CP violations in Tables IV and V, respectively.

C. Discussions

Some discussions are in order:

- (i) In Table IV, we present the results of the CP asymmetries and branching ratios for the decay $\Lambda_b^0 \rightarrow P_c^+ \pi^-$. Notably, for the pentaquark states $P_c(4440)$ and $P_c(4457)$ with spin-parity $J^P = 1/2^-$, the CP asymmetries are estimated to be of order $\mathcal{O}(1\%)$. These values not only differ in sign but also are larger in magnitude than those for the $J^P = 3/2^-$ assignment. Therefore, we conclude that our predictions may help to determine the spin order of

TABLE II. Helicity amplitudes of $\Lambda_b^0 \rightarrow P_c^+ \pi^- (10^{-8})$ with different CKM factors.

Decay modes	$H_{-\frac{1}{2}}(V_{ub}V_{ud}^*)$	$H_{-\frac{1}{2}}(V_{cb}V_{cd}^*)$	$H_{-\frac{1}{2}}(V_{tb}V_{td}^*)$	$H_{\frac{1}{2}}(V_{ub}V_{ud}^*)$	$H_{\frac{1}{2}}(V_{cb}V_{cd}^*)$	$H_{\frac{1}{2}}(V_{tb}V_{td}^*)$
$\mathcal{N}\mathcal{C}(\Lambda_b^0 \rightarrow P_c^{1/2}(4312)\pi^-)$	$-4.251 + 2.360i$	...	$-0.081 + 0.052i$	$-2.367 - 2.471i$	...	$-0.044 - 0.054i$
$\mathcal{C}(\Lambda_b^0 \rightarrow P_c^{1/2}(4312)\pi^-)$	...	$-69.983 - 318.344i$	$10.812 - 12.316i$	...	$-382.465 + 246.552i$	$-5.204 + 13.197i$
$\mathcal{N}\mathcal{C}(\Lambda_b^0 \rightarrow P_c^{1/2}(4440)\pi^-)$	$1.983 - 0.691i$	...	$0.334 - 0.028i$	$-10.926 - 0.447i$	...	$-0.060 + 0.006i$
$\mathcal{C}(\Lambda_b^0 \rightarrow P_c^{1/2}(4440)\pi^-)$	...	$140.611 - 44.374i$	$7.102 - 1.664i$	...	$-240.355 + 126.605i$	$-8.163 + 7.778i$
$\mathcal{N}\mathcal{C}(\Lambda_b^0 \rightarrow P_c^{3/2}(4440)\pi^-)$	$-4.478 + 5.027i$	...	$-0.147 + 0.117i$	$2.139 - 2.156i$	...	$-0.092 - 0.016i$
$\mathcal{C}(\Lambda_b^0 \rightarrow P_c^{3/2}(4440)\pi^-)$	...	$-226.499 + 200.560i$	$-7.279 + 6.803i$	...	$4.713 + 161.707i$	$-3.638 + 8.335i$
$\mathcal{N}\mathcal{C}(\Lambda_b^0 \rightarrow P_c^{1/2}(4457)\pi^-)$	$1.457 - 0.368i$	...	$0.178 - 0.015i$	$-5.772 - 0.311i$	...	$-0.036 + 0.001i$
$\mathcal{C}(\Lambda_b^0 \rightarrow P_c^{1/2}(4457)\pi^-)$	...	$134.438 - 40.664i$	$6.649 - 1.436i$	...	$-218.503 + 112.139i$	$-7.615 + 6.932i$
$\mathcal{N}\mathcal{C}(\Lambda_b^0 \rightarrow P_c^{3/2}(4457)\pi^-)$	$-2.722 + 3.063i$	...	$-0.088 + 0.071i$	$1.129 - 1.304i$	...	$-0.055 - 0.010i$
$\mathcal{C}(\Lambda_b^0 \rightarrow P_c^{3/2}(4457)\pi^-)$	...	$-217.008 + 182.601i$	$-7.161 + 6.320i$	...	$-5.088 + 141.572i$	$-4.009 + 7.729i$

TABLE III. Helicity amplitudes of $\Lambda_b^0 \rightarrow P_c^+ K^-$ (10^{-8}) with different CKM factors.

Decay modes	$H_{-\frac{1}{2}}(V_{ub}V_{us}^*)$	$H_{-\frac{1}{2}}(V_{cb}V_{cs}^*)$	$H_{-\frac{1}{2}}(V_{tb}V_{ts}^*)$	$H_{\frac{1}{2}}(V_{ub}V_{us}^*)$	$H_{\frac{1}{2}}(V_{cb}V_{cs}^*)$	$H_{\frac{1}{2}}(V_{tb}V_{ts}^*)$
$\mathcal{NC}(\Lambda_b^0 \rightarrow P_c^{1/2}(4312)K^-)$	$0.131 - 0.088i$	$\dots$	$-0.013 - 0.001i$	$0.347 - 0.174i$	$\dots$	$-0.003 - 0.004i$
$\mathcal{C}(\Lambda_b^0 \rightarrow P_c^{1/2}(4312)K^-)$	$\dots$	$66.239 - 368.781i$	$2.122 - 14.156i$	$\dots$	$-86.776 - 282.747i$	$-3.794 + 15.176i$
$\mathcal{NC}(\Lambda_b^0 \rightarrow P_c^{1/2}(4440)K^-)$	$9.647 - 0.045i$	$\dots$	$-0.156 + 0.015i$	$9.887 - 0.543i$	$\dots$	$-0.033 - 0.022i$
$\mathcal{C}(\Lambda_b^0 \rightarrow P_c^{1/2}(4440)K^-)$	$\dots$	$169.175 - 230.984i$	$6.391 - 8.942i$	$\dots$	$-228.386 + 73.249i$	$-9.268 + 6.007i$
$\mathcal{NC}(\Lambda_b^0 \rightarrow P_c^{3/2}(4440)K^-)$	$4.766 - 0.864i$	$\dots$	$0.167 - 0.026i$	$3.216 - 0.454i$	$\dots$	$0.228 - 0.040i$
$\mathcal{C}(\Lambda_b^0 \rightarrow P_c^{3/2}(4440)K^-)$	$\dots$	$-84.380 + 98.379i$	$-4.629 + 5.176i$	$\dots$	$-27.335 + 26.260i$	$-4.998 + 6.242i$
$\mathcal{NC}(\Lambda_b^0 \rightarrow P_c^{1/2}(4457)K^-)$	$5.969 - 0.031i$	$\dots$	$-0.096 + 0.009i$	$6.112 - 0.332i$	$\dots$	$-0.021 - 0.014i$
$\mathcal{C}(\Lambda_b^0 \rightarrow P_c^{1/2}(4457)K^-)$	$\dots$	$162.182 - 203.396i$	$6.181 - 7.971i$	$\dots$	$-211.658 + 67.265i$	$-8.668 + 5.326i$
$\mathcal{NC}(\Lambda_b^0 \rightarrow P_c^{3/2}(4457)K^-)$	$2.717 - 0.496i$	$\dots$	$0.096 - 0.015i$	$1.847 - 0.266i$	$\dots$	$0.130 - 0.023i$
$\mathcal{C}(\Lambda_b^0 \rightarrow P_c^{3/2}(4457)K^-)$	$\dots$	$-85.416 + 95.409i$	$-4.760 + 5.005i$	$\dots$	$-28.593 + 25.610i$	$-5.197 + 6.024i$

$P_c(4440)$ and $P_c(4457)$ if a nonzero CP asymmetry in $\Lambda_b^0 \rightarrow P_c^+ \pi^-$ is determined by future experiments.

- (ii) In Table V, we present the results of the CP asymmetries and branching ratios for the decay $\Lambda_b^0 \rightarrow P_c^+ K^-$. Our results are generally comparable with those obtained in our previous work [53] for most channels. However, the last entry in Table V, corresponding to $\Lambda_b^0 \rightarrow P_c^{3/2}(4457)K^-$, shows a noticeable deviation from the previous result. This deviation mainly originates from the different values of the $P_c^{3/2}\Lambda_c D^*$ coupling adopted in the two analyses. Since this channel is dominated by the rescattering process $\Lambda_b^0 \rightarrow \bar{D}_s^{(*)}\Lambda_c^+ \rightarrow P_c K^-$, the change in this coupling input gives rise to a sizable difference in the predicted branching ratio.

Within the set of intermediate states considered in this work, our results indicate that pentaquark production in Λ_b^0 decays is mainly driven by the weak transitions $\Lambda_b^0 \rightarrow \bar{D}_s^{(*)}\Lambda_c^+$. In principle, excited charmed-strange mesons and Λ_c^+ baryons may also contribute to the rescattering amplitudes. However, a systematic inclusion of such excited intermediate states would require additional inputs, such as the relevant weak transition form factors and the strong couplings entering the rescattering vertices, which are not well constrained at present. Consequently, a systematic treatment of these channels would introduce many

additional input parameters and enlarge the theoretical uncertainties. To strike a balance between a more complete treatment and the controllability of theoretical uncertainties, the present study is restricted to these ground-state intermediate states. A more complete coupled-channel analysis including such excited states is left for future work.

For the pentaquark states $P_c(4440)$ and $P_c(4457)$, we find that the branching ratios for the $J^P = 1/2^-$ assignment are approximately one order of magnitude larger than those for the $J^P = 3/2^-$ assignment. This difference could also help us to determine the spin order of $P_c(4440)$ and $P_c(4457)$ in the future experiment. The CP asymmetry for the decay $\Lambda_b^0 \rightarrow P_c^+ K^-$ is very small since the helicity amplitudes in Table III are dominated by a single component with CKM factor $V_{cb}V_{cs}^*$.

TABLE IV. The numerical results for the branching ratio and CP violation in $\Lambda_b^0 \rightarrow P_c^+ \pi^-$.

Decay modes	BR(10^{-6})	Direct $CP(10^{-2})$
$\Lambda_b^0 \rightarrow P_c^{1/2-}(4312)\pi^-$	$4.27^{+1.13}_{-0.98}$	$0.13^{+0.08}_{-0.09}$
$\Lambda_b^0 \rightarrow P_c^{1/2-}(4440)\pi^-$	$1.12^{+0.19}_{-0.14}$	$-1.69^{+0.44}_{-0.28}$
$\Lambda_b^0 \rightarrow P_c^{3/2-}(4440)\pi^-$	$1.44^{+0.73}_{-0.49}$	$0.72^{+0.43}_{-0.34}$
$\Lambda_b^0 \rightarrow P_c^{1/2-}(4457)\pi^-$	$0.94^{+0.13}_{-0.10}$	$-1.18^{+0.26}_{-0.18}$
$\Lambda_b^0 \rightarrow P_c^{3/2-}(4457)\pi^-$	$1.21^{+0.57}_{-0.38}$	$0.58^{+0.37}_{-0.30}$

TABLE V. The numerical results for the branching ratio and CP violation in $\Lambda_b^0 \rightarrow P_c^+ K^-$.

Decay modes	BR(10^{-6})	Direct $CP(10^{-2})$
$\Lambda_b^0 \rightarrow P_c^{1/2-}(4312)K^-$		
This work	$51.70^{+12.41}_{-10.80}$	-6.71×10^{-4}
Previous work [53]	35.18/98.88	$\dots$
$\Lambda_b^0 \rightarrow P_c^{1/2-}(4440)K^-$		
This work	$28.56^{+3.31}_{-2.81}$	$0.05^{+0.01}_{-0.01}$
Previous work [53]	15.30	$\dots$
$\Lambda_b^0 \rightarrow P_c^{3/2-}(4440)K^-$		
This work	$3.55^{+0.35}_{-0.33}$	$-0.10^{+0.02}_{-0.01}$
Previous work [53]	5.21	$\dots$
$\Lambda_b^0 \rightarrow P_c^{1/2-}(4457)K^-$		
This work	$23.56^{+2.46}_{-2.08}$	$0.03^{+0.005}_{-0.005}$
Previous work [53]	27.23	$\dots$
$\Lambda_b^0 \rightarrow P_c^{3/2-}(4457)K^-$		
This work	$3.41^{+0.30}_{-0.29}$	$-0.06^{+0.01}_{-0.01}$
Previous work [53]	0.48	$\dots$

TABLE VI. Ratio of branching fractions: $\text{BR}(\Lambda_b^0 \rightarrow P_c^+ \pi^-) / \text{BR}(\Lambda_b^0 \rightarrow P_c^+ K^-)$.

BR ratio	Value
$\text{BR}(\Lambda_b^0 \rightarrow P_c^{1/2}(4312)\pi^-) / \text{BR}(\Lambda_b^0 \rightarrow P_c^{1/2}(4312)K^-)$	$0.083^{+0.002}_{-0.002}$
$\text{BR}(\Lambda_b^0 \rightarrow P_c^{1/2}(4440)\pi^-) / \text{BR}(\Lambda_b^0 \rightarrow P_c^{1/2}(4440)K^-)$	$0.039^{+0.002}_{-0.001}$
$\text{BR}(\Lambda_b^0 \rightarrow P_c^{3/2}(4440)\pi^-) / \text{BR}(\Lambda_b^0 \rightarrow P_c^{3/2}(4440)K^-)$	$0.406^{+0.151}_{-0.109}$
$\text{BR}(\Lambda_b^0 \rightarrow P_c^{1/2}(4457)\pi^-) / \text{BR}(\Lambda_b^0 \rightarrow P_c^{1/2}(4457)K^-)$	$0.040^{+0.001}_{-0.001}$
$\text{BR}(\Lambda_b^0 \rightarrow P_c^{3/2}(4457)\pi^-) / \text{BR}(\Lambda_b^0 \rightarrow P_c^{3/2}(4457)K^-)$	$0.355^{+0.125}_{-0.089}$

- (iii) We also estimate the ratio $\text{BR}(\Lambda_b^0 \rightarrow P_c^+ \pi^-) / \text{BR}(\Lambda_b^0 \rightarrow P_c^+ K^-)$ and present the results in Table VI. The relative decay rates were estimated only by assuming the dominance of the external W-emission amplitude in Ref. [68]

$$\frac{\text{BR}(\Lambda_b^0 \rightarrow P_c^+ \pi^-)}{\text{BR}(\Lambda_b^0 \rightarrow P_c^+ K^-)} \approx 0.07 \sim 0.08, \quad (3.2)$$

which is consistent with our results for the spin-1/2 assignment. It is noting that Eq. (3.2) should be viewed as a naive CKM power counting, which implicitly assumes the reduced hadronic amplitudes of the π and K channels are approximately the same. This assumption is roughly valid for the $J^P = 1/2^-$ assignment, but it breaks down for the $J^P = 3/2^-$. In our rescattering model, the smallness of the $\Lambda_b^0 \rightarrow P_c^{3/2} K^-$ branching ratios mainly originates from the destructive interference among the charmed triangle amplitudes. Such a strong cancellation however does not appear in the $P_c^{3/2} \pi$ channel. This difference is related to the different rescattering topologies in the two channels. As listed in Appendix C, within the dominant charmed rescattering contributions considered in this work, the $P_c^{3/2} \pi$ mode contains long-distance Σ_c^{++} - and $D^{(*)}$ -exchange contributions, while the corresponding $P_c^{3/2} K$ mode is generated only through meson-exchange diagrams. Therefore, the amplitude of the $P_c^{3/2} K$ mode is relatively small, and the naive CKM realtion in Eq. (3.2) is no longer applicable. In addition, for $\Lambda_b^0 \rightarrow P_c^{3/2} h$, the lowest allowed partial wave is a P wave. This effect further suppresses the $P_c^{3/2} K$ branching ratio since the K channel has a smaller final-state momentum than the π channel.

- (iv) Recently, the LHCb Collaboration measured the CP -asymmetry difference ΔA_{CP} in $\Lambda_b^0 \rightarrow J/\psi p h^-$ ($h = \pi, K$) decays [5], providing evidence for a nonzero difference in direct CP asymmetries between the two decay modes. Owing to the different CKM structures, $\Lambda_b^0 \rightarrow J/\psi p \pi^-$ is expected to be more likely to exhibit a larger direct CP asymmetry than $\Lambda_b^0 \rightarrow J/\psi p K^-$. Furthermore, the paper presents

the raw asymmetry A_{raw} across the two-dimensional Dalitz phase space of $\Lambda_b^0 \rightarrow J/\psi p \pi^-$. In the region where $m^2(J/\psi p)$ is close to the known P_c states, the contrast is enhanced, providing a potential window to search for CP violation associated with hidden-charm pentaquark production and to test our predictions for $\Lambda_b^0 \rightarrow P_c h^-$. Our numerical results appear unable to fully account for the experimentally observed ΔA_{CP} , suggesting the presence of additional contributions beyond those considered in our current framework.

IV. SUMMARY

Within the final-state rescattering mechanism, we investigate the branching ratios and CP asymmetries for the decays $\Lambda_b^0 \rightarrow P_c^+ h^-$ (with $h = K, \pi$), where the P_c states refer to $P_c(4312)$, $P_c(4440)$, and $P_c(4457)$. Treating these pentaquark states as molecular candidates, we examine two possible spin-parity assignments for $P_c(4440)$ and $P_c(4457)$ as the $\bar{D}^* \Sigma_c$ molecules: either $J^P = 1/2^-$ and $3/2^-$, or $J^P = 3/2^-$ and $1/2^-$. Our results indicate that the branching ratios of $\Lambda_b^0 \rightarrow P_c^+ \pi^-$ are to be of order 10^{-6} and show little sensitivity to the spin assignment of the pentaquark states, while the corresponding CP asymmetries are expected to be order of $\mathcal{O}(1\%)$. In contrast, the branching ratios for the decays $\Lambda_b^0 \rightarrow P_c^+ K^-$ are strongly dependent on the spin assignments. They reach at the 10^{-5} level for the $J^P = 1/2^-$ assignment, but fall to the 10^{-6} for $J^P = 3/2^-$. The CP asymmetries in this channel are found to be extremely small. We look forward to future experimental tests of our predictions, particularly regarding the CP violating for the decays $\Lambda_b^0 \rightarrow P_c^+ \pi^-$. Since the spin quantum numbers of the P_c states remain to be established, the physical observables computed in this work could provide new insights toward establishing them.

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DATA AVAILABILITY

There are no publicly available research data or software supporting this manuscript. Requests for further information or data should be sent to the authors.

APPENDIX A: EFFECTIVE LAGRANGIAN

- (i) The effective Lagrangians for the couplings of the pentaquark states to baryon-meson channels are taken from Refs. [53,67,69].

$$\begin{aligned}
 \mathcal{L}_{P_c N \pi}^{1/2^-} &= g_{P_c N \pi}^{1/2} \bar{N} \vec{\tau} \cdot \vec{\pi} P_c + \text{H.c.}, \\
 \mathcal{L}_{P_c N \pi}^{3/2^-} &= \frac{g_{P_c N \pi}^{3/2}}{m_\pi^2} \bar{N} \gamma_5 \gamma_\mu \vec{\tau} \cdot \partial^\mu \partial_\nu \vec{\pi} P_c^\nu + \text{H.c.}, \\
 \mathcal{L}_{P_c N \rho}^{1/2^-} &= g_{P_c N \rho}^{1/2} \bar{N} \gamma_5 \left(g_{\mu\nu} - \frac{p_\mu p_\nu}{m_{P_c}^2} \right) \gamma^\nu P_c \rho^\mu + \text{H.c.}, \\
 \mathcal{L}_{P_c N \rho}^{3/2^-} &= g_{P_c N \rho}^{3/2} \bar{N} P_{c\mu} \rho^\mu + \text{H.c.}, \\
 \mathcal{L}_{P_c \Lambda_c \bar{D}}^{1/2^-} &= g_{P_c \Lambda_c \bar{D}}^{1/2} P_c \Lambda_c \bar{D} + \text{H.c.}, \\
 \mathcal{L}_{P_c \Lambda_c \bar{D}}^{3/2^-} &= \frac{g_{P_c \Lambda_c \bar{D}}^{3/2}}{m_{\bar{D}}^2} \bar{\Lambda}_c \gamma_5 \gamma_\mu \partial^\mu \partial^\nu \bar{D} P_{c\nu}^+ + \text{H.c.}, \\
 \mathcal{L}_{P_c \Lambda_c \bar{D}^*}^{1/2^-} &= g_{P_c \Lambda_c \bar{D}^*}^{1/2} \bar{\Lambda}_c \gamma_5 \left(g_{\mu\nu} - \frac{p_\mu p_\nu}{m_{P_c}^2} \right) \gamma^\nu P_c D^{*\mu} + \text{H.c.}, \\
 \mathcal{L}_{P_c \Lambda_c \bar{D}^*}^{3/2^-} &= g_{P_c \Lambda_c \bar{D}^*}^{3/2} \bar{\Lambda}_c P_{c\mu} D^{*\mu} + \text{H.c.}
 \end{aligned} \tag{A1}$$

- (ii) The Lagrangians involving $D^{(*)}$ mesons, pseudoscalar meson octet P_8 , and vector meson octet V :

$$\begin{aligned}
 \mathcal{L}_{VP_8 P_8} &= \frac{i g_{\rho\pi\pi}}{\sqrt{2}} \text{Tr}[V^\mu [P_8, \partial_\mu P_8]], \\
 \mathcal{L}_{VVP_8} &= \frac{4 g_{VVP_8}}{f_{P_8}} \epsilon^{\mu\nu\alpha\beta} \text{Tr}(\partial_\mu V_\nu \partial_\alpha V_\beta P_8), \\
 \mathcal{L}_{D^* D P_8} &= -i g_{D^* D P_8} (D^i \partial^\mu P_{8ij} D_\mu^{*j\dagger} - D_\mu^{*i} \partial^\mu P_{8ij} D^{j\dagger}), \\
 \mathcal{L}_{D^* D^* P_8} &= \frac{1}{2} g_{D^* D^* P_8} \epsilon_{\mu\nu\alpha\beta} D_i^{*\mu} \partial^\nu P_8^{ij} \partial^{\alpha\beta} D_j^{*\dagger}, \\
 \mathcal{L}_{P_8 B_6 B_3} &= g_{P_8 B_6 B_3} \text{Tr}[\bar{B}_6 i \gamma_5 P_8 B_3] + \text{H.c.}
 \end{aligned} \tag{A2}$$

The matrices under SU(3) flavor group representations are given:

$$\begin{aligned}
 P &= \begin{pmatrix} \frac{\pi^0}{\sqrt{2}} + \frac{\eta}{\sqrt{6}} & \pi^+ & K^+ \\ \pi^- & -\frac{\pi^0}{\sqrt{2}} + \frac{\eta}{\sqrt{6}} & K^0 \\ K^- & \bar{K}^0 & -\sqrt{\frac{2}{3}}\eta \end{pmatrix}, & B_6 &= \begin{pmatrix} \Sigma_c^{++} & \frac{1}{\sqrt{2}}\Sigma_c^+ & \frac{1}{\sqrt{2}}\Xi_c'^+ \\ \frac{1}{\sqrt{2}}\Sigma_c^+ & \Sigma_c^0 & \frac{1}{\sqrt{2}}\Xi_c'^0 \\ \frac{1}{\sqrt{2}}\Xi_c'^+ & \frac{1}{\sqrt{2}}\Xi_c'^0 & \Omega_c \end{pmatrix}, \\
 V &= \begin{pmatrix} \frac{\rho^0}{\sqrt{2}} + \frac{\omega}{\sqrt{2}} & \rho^+ & K^{*+} \\ \rho^- & -\frac{\rho^0}{\sqrt{2}} + \frac{\omega}{\sqrt{2}} & K^{*0} \\ K^{*-} & \bar{K}^{*0} & \phi \end{pmatrix}, & B_3 &= \begin{pmatrix} 0 & \Lambda_c^+ & \Xi_c^+ \\ -\Lambda_c^+ & 0 & \Xi_c^0 \\ -\Xi_c^+ & -\Xi_c^0 & 0 \end{pmatrix}, \\
 B_8 &= \begin{pmatrix} \frac{\Sigma^0}{\sqrt{2}} + \frac{\Lambda}{\sqrt{6}} & \Sigma^+ & p \\ \Sigma^- & -\frac{\Sigma^0}{\sqrt{2}} + \frac{\Lambda}{\sqrt{6}} & n \\ \Xi^- & \Xi^0 & -\frac{2}{\sqrt{6}}\Lambda \end{pmatrix}, & D &= (D^0, D^+, D_s^+).
 \end{aligned}$$

APPENDIX B: AMPLITUDES OF TRIANGLE DIAGRAM

The amplitudes of $\Lambda_b^0 \rightarrow P_c^{1/2-} h^-$:

$$M[V, B_8, P_8] = \int \frac{d^4 k}{(2\pi)^4} g_{P_8 B_8 P_c}^{1/2-} g_{V P_8 P_8} \bar{u}(p_4) (\not{p}_2 + m_2) \left(-g^{\mu\nu} + \frac{p_1^\mu p_1^\nu}{m_1^2} \right) \left(A_1 \gamma_\mu \gamma_5 + A_2 \frac{p_{2\mu}}{m_i} \gamma_5 + B_1 \gamma_\mu + B_2 \frac{p_{2\mu}}{m_i} \right) \\ \times u(p_i) (p_{3\nu} - k_\nu) \frac{i^3 \mathcal{F}}{(p_1^2 - m_1^2)(p_2^2 - m_2^2)(k^2 - m_k^2)}, \quad (\text{B1})$$

$$M[D^*, B_c, \bar{D}] = \int \frac{d^4 k}{(2\pi)^4} g_{D B_c P_c}^{1/2-} g_{D^* D P_8} \bar{u}(p_4) (\not{p}_2 + m_2) p_3^\alpha \left(-g_{\mu\alpha} + \frac{p_{1\mu} p_{1\alpha}}{m_1^2} \right) \left(A_1 \gamma_\mu \gamma_5 + A_2 \frac{p_{2\mu}}{m_i} \gamma_5 + B_1 \gamma_\mu + B_2 \frac{p_{2\mu}}{m_i} \right) \\ \times u(p_i) \frac{i^3 \mathcal{F}}{(p_1^2 - m_1^2)(p_2^2 - m_2^2)(k^2 - m_k^2)}, \quad (\text{B2})$$

$$M[D^*, B_c, \bar{D}^*] = \int \frac{d^4 k}{(2\pi)^4} (-1) g_{D^* B_c P_c}^{1/2-} g_{D^* D^* P_8} \bar{u}(p_4) \gamma^\nu \gamma_5 \left(g_{\mu\nu} - \frac{p_{4\mu} p_{4\nu}}{m_{P_c}^2} \right) (\not{p}_2 + m_2) \left(-g_{\mu\beta} + \frac{k_\mu k_\beta}{m_k^2} \right) \left(-g_{n\mu} + \frac{p_{1n} p_{1\mu}}{m_1^2} \right) \\ \times \epsilon^{mna\beta} p_{1m} k_a \left(A_1 \gamma_t \gamma_5 + A_2 \frac{p_{2t}}{m_i} \gamma_5 + B_1 \gamma_t + B_2 \frac{p_{2t}}{m_i} \right) u(p_i) \frac{i^3 \mathcal{F}}{(p_1^2 - m_1^2)(p_2^2 - m_2^2)(k^2 - m_k^2)}, \quad (\text{B3})$$

$$M[D, B_c, \bar{D}^*] = \int \frac{d^4 k}{(2\pi)^4} i \cdot g_{D^* D P_8} g_{D^* B_c P_c}^{1/2-} p_{3\alpha} \bar{u}(p_4) \gamma^\nu \gamma_5 \left(g_{\mu\nu} - \frac{p_{4\mu} p_{4\nu}}{m_{P_c}^2} \right) \left(-g^{\alpha\mu} + \frac{k^\alpha k^\mu}{m_k^2} \right) (\not{p}_2 + m_2) \\ \times (A + B \gamma_5) u(p_i) \frac{i^3 \mathcal{F}}{(p_1^2 - m_1^2)(p_2^2 - m_2^2)(k^2 - m_k^2)}, \quad (\text{B4})$$

$$M[D, B_c, B_c] = \int \frac{d^4 k}{(2\pi)^4} g_{P_8 B_6 B_3} g_{P_c B_c D}^{1/2-} \bar{u}(p_4) (k + m_k) \gamma_5 (\not{p}_2 + m_2) (A + B \gamma_5) u(p_i) \\ \times \frac{i^3 \mathcal{F}}{(p_1^2 - m_1^2)(p_2^2 - m_2^2)(k^2 - m_k^2)}, \quad (\text{B5})$$

$$M[D^*, B_c, B_c] = \int \frac{d^4 k}{(2\pi)^4} i g_{P_c B_c D^*}^{1/2-} g_{B_3 B_6 P_8} \bar{u}(p_4) \gamma^\nu \gamma_5 \left(g_{\mu\nu} - \frac{p_{4\mu} p_{4\nu}}{m_{P_c}^2} \right) (k + m_k) \gamma_5 (\not{p}_2 + m_2) \left(-g^{\mu\alpha} + \frac{p_1^\alpha p_1^\mu}{m_1^2} \right) \\ \times \left(A_1 \gamma_\alpha \gamma_5 + A_2 \frac{p_{2\alpha}}{m_i} \gamma_5 + B_1 \gamma_\alpha + B_2 \frac{p_{2\alpha}}{m_i} \right) u(p_i) \frac{i^3 \mathcal{F}}{(p_1^2 - m_1^2)(p_2^2 - m_2^2)(k^2 - m_k^2)}, \quad (\text{B6})$$

$$M[P_8, B_8, V] = \int \frac{d^4 k}{(2\pi)^4} (-i) g_{P_c B_8 V}^{1/2} g_{V P_8 P_8} \bar{u}(p_4) \gamma_5 \left(g_{\mu\nu} - \frac{p_{4\mu} p_{4\nu}}{m_{P_c}^2} \right) \gamma^\nu (\not{p}_2 + m_2) \left(-g^{\mu\alpha} + \frac{k^\mu k^\alpha}{m_k^2} \right) \\ \times (A + B \gamma_5) u(p_i) (p_{1\alpha} + p_{3\alpha}) \frac{i^3 \mathcal{F}}{(p_1^2 - m_1^2)(p_2^2 - m_2^2)(k^2 - m_k^2)}. \quad (\text{B7})$$

The amplitudes for $\Lambda_b^0 \rightarrow P_c^{3/2-} h^-$ are

$$M[V, B_8, P_8] = \int \frac{d^4 k}{(2\pi)^4} (-1) \frac{g_{P_8 B_8 P_c}^{3/2-}}{m_{P_8}^2} g_{V P_8 P_8} \bar{u}_\alpha(p_4) \gamma_5 k k^\alpha (\not{p}_2 + m_2) \left(-g^{\mu\nu} + \frac{p_1^\mu p_1^\nu}{m_1^2} \right) \\ \times \left(A_1 \gamma_\mu \gamma_5 + A_2 \frac{p_{2\mu}}{m_i} \gamma_5 + B_1 \gamma_\mu + B_2 \frac{p_{2\mu}}{m_i} \right) u(p_i) (p_{3\nu} - k_\nu) \frac{i^3 \mathcal{F}}{(p_1^2 - m_1^2)(p_2^2 - m_2^2)(k^2 - m_k^2)}, \quad (\text{B8})$$

$$M[D^*, B_c, \bar{D}^*] = \int \frac{d^4 k}{(2\pi)^4} (-1) g_{P_c B_c D^*}^{3/2-} g_{D^* D^* P_8} \bar{u}(p_4) (\not{p}_2 + m_2) \left(-g_{\mu\beta} + \frac{k_\mu k_\beta}{m_k^2} \right) \left(-g_{nt} + \frac{p_{1n} p_{1t}}{m_1^2} \right) \varepsilon^{mna\beta} p_{1m} k_\alpha \\ \times \left(A_1 \gamma_t \gamma_5 + A_2 \frac{p_{2t}}{m_i} \gamma_5 + B_1 \gamma_t + B_2 \frac{p_{2t}}{m_i} \right) u(p_i) \frac{i^3 \mathcal{F}}{(p_1^2 - m_1^2)(p_2^2 - m_2^2)(k^2 - m_k^2)}, \quad (\text{B9})$$

$$M[D, B_c, \bar{D}^*] = \int \frac{d^4 k}{(2\pi)^4} (-i) g_{D^* D P_8} g_{P_c B_c D^*}^{3/2-} p_{3\alpha} \bar{u}_\mu(p_4) \left(-g^{\alpha\mu} + \frac{k^\alpha k^\mu}{m_k^2} \right) (\not{p}_2 + m_2) (A + B \gamma_5) \\ \times u(p_i) \frac{i^3 \mathcal{F}}{(p_1^2 - m_1^2)(p_2^2 - m_2^2)(k^2 - m_k^2)}, \quad (\text{B10})$$

$$M[D^*, B_c, B_c] = \int \frac{d^4 k}{(2\pi)^4} (-i) g_{P_c B_c D^*}^{3/2-} g_{B_3 B_6 P_8} \bar{u}^\alpha(p_4) (k + m_k) \gamma_5 (\not{p}_2 + m_2) \left(-g_{\alpha\mu} + \frac{p_{1\alpha} p_{1\mu}}{m_1^2} \right) \\ \times \left(A_1 \gamma_\mu \gamma_5 + A_2 \frac{p_{2\mu}}{m_i} \gamma_5 + B_1 \gamma_\mu + B_2 \frac{p_{2\mu}}{m_i} \right) u(p_i) \frac{i^3 \mathcal{F}}{(p_1^2 - m_1^2)(p_2^2 - m_2^2)(k^2 - m_k^2)}, \quad (\text{B11})$$

$$M[P_8, B_8, V] = \int \frac{d^4 k}{(2\pi)^4} (-i) g_{P_c B_8 V}^{3/2-} g_{V P_8 P_8} \bar{u}^\mu(p_4) (\not{p}_2 + m_2) \left(-g^{\mu\alpha} + \frac{k^\mu k^\alpha}{m_k^2} \right) (A + B \gamma_5) u(p_i) \\ \times (p_{1\alpha} + p_{3\alpha}) \frac{i^3 \mathcal{F}}{(p_1^2 - m_1^2)(p_2^2 - m_2^2)(k^2 - m_k^2)}, \quad (\text{B12})$$

$$M[D^*, B_c, \bar{D}] = \int \frac{d^4 k}{(2\pi)^4} \frac{g_{P_c B_c D}^{3/2-}}{m_D^2} g_{D^* D P_8} \bar{u}_\nu(p_4) \gamma_5 k k^\nu (\not{p}_2 + m_2) p_3^\alpha \left(-g_{\mu\alpha} + \frac{p_{1\mu} p_{1\alpha}}{m_1^2} \right) \\ \times \left(A_1 \gamma_\mu \gamma_5 + A_2 \frac{p_{2\mu}}{m_i} \gamma_5 + B_1 \gamma_\mu + B_2 \frac{p_{2\mu}}{m_i} \right) u(p_i) \frac{i^3 \mathcal{F}}{(p_1^2 - m_1^2)(p_2^2 - m_2^2)(k^2 - m_k^2)}, \quad (\text{B13})$$

$$M[D, B_c, B_c] = \int \frac{d^4 k}{(2\pi)^4} (-1) \frac{g_{P_c B_c D}^{3/2-}}{m_D^2} g_{P_8 B_6 B_3} \bar{u}_\nu(p_4) \gamma_5 \not{p}_1 p_1^\nu (k + m_k) \gamma_5 (\not{p}_2 + m_2) \\ \times (A + B \gamma_5) u(p_i) \frac{i^3 \mathcal{F}}{(p_1^2 - m_1^2)(p_2^2 - m_2^2)(k^2 - m_k^2)}. \quad (\text{B14})$$

APPENDIX C: FULL EXPRESSIONS OF AMPLITUDES

Here, we give the full amplitudes of all Λ_b^0 decay channels considered in this work:

$$\mathcal{A}(\Lambda_b^0 \rightarrow P_c^{1/2-} \pi^-) = \mathcal{M}(D^{*-}, \Lambda_c^+, \bar{D}^0; P_c^{1/2-}) + \mathcal{M}(D^{*-}, \Lambda_c^+, \bar{D}^{*0}; P_c^{1/2-}) + \mathcal{M}(D^-, \Lambda_c^+, \bar{D}^{*0}; P_c^{1/2-}) \\ + \mathcal{M}(D^-, \Lambda_c^+, \Sigma_c^{++}; P_c^{1/2-}) + \mathcal{M}(D^{*-}, \Lambda_c^+, \Sigma_c^{++}; P_c^{1/2-}) + \mathcal{M}(\rho^-, p, \pi^0; P_c^{1/2-}) \\ + \mathcal{M}(\pi^-, p, \rho^0; P_c^{1/2-}) + \mathcal{M}(\rho^-, p, \omega; P_c^{1/2-}), \quad (\text{C1})$$

$$\mathcal{A}(\Lambda_b^0 \rightarrow P_c^{3/2-} \pi^-) = \mathcal{M}(D^{*-}, \Lambda_c^+, \bar{D}^0; P_c^{3/2-}) + \mathcal{M}(D^{*-}, \Lambda_c^+, \bar{D}^{*0}; P_c^{3/2-}) + \mathcal{M}(D^-, \Lambda_c^+, \bar{D}^{*0}; P_c^{3/2-}) \\ + \mathcal{M}(D^-, \Lambda_c^+, \Sigma_c^{++}; P_c^{3/2-}) + \mathcal{M}(D^{*-}, \Lambda_c^+, \Sigma_c^{++}; P_c^{3/2-}) + \mathcal{M}(\rho^-, p, \pi^0; P_c^{3/2-}) \\ + \mathcal{M}(\pi^-, p, \rho^0; P_c^{3/2-}) + \mathcal{M}(\rho^-, p, \omega; P_c^{3/2-}), \quad (\text{C2})$$

$$\begin{aligned}
\mathcal{A}(\Lambda_b^0 \rightarrow P_c^{1/2^-} K^-) &= \mathcal{M}(D_s^-, \Lambda_c^+, \bar{D}^{*0}; P_c^{1/2^-}) + \mathcal{M}(D_s^{*-}, \Lambda_c^+, \bar{D}^0; P_c^{1/2^-}) + \mathcal{M}(D_s^{*-}, \Lambda_c^+, \bar{D}^{*0}; P_c^{1/2^-}) \\
&+ \mathcal{M}(K^{*-}, p, \pi^0; P_c^{1/2^-}) + \mathcal{M}(K^{*-}, p, \rho^0; P_c^{1/2^-}) + \mathcal{M}(K^{*-}, p, \omega; P_c^{1/2^-}) \\
&+ \mathcal{M}(K^-, p, \rho^0; P_c^{1/2^-}) + \mathcal{M}(K^-, p, \omega; P_c^{1/2^-}),
\end{aligned} \tag{C3}$$

$$\begin{aligned}
\mathcal{A}(\Lambda_b^0 \rightarrow P_c^{3/2^-} K^-) &= \mathcal{M}(D_s^-, \Lambda_c^+, \bar{D}^{*0}; P_c^{3/2^-}) + \mathcal{M}(D_s^{*-}, \Lambda_c^+, \bar{D}^0; P_c^{3/2^-}) + \mathcal{M}(D_s^{*-}, \Lambda_c^+, \bar{D}^{*0}; P_c^{3/2^-}) \\
&+ \mathcal{M}(K^{*-}, p, \pi^0; P_c^{3/2^-}) + \mathcal{M}(K^{*-}, p, \rho^0; P_c^{3/2^-}) + \mathcal{M}(K^{*-}, p, \omega; P_c^{3/2^-}) \\
&+ \mathcal{M}(K^-, p, \rho^0; P_c^{3/2^-}) + \mathcal{M}(K^-, p, \omega; P_c^{3/2^-}).
\end{aligned} \tag{C4}$$

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