

Two-body nonleptonic decays of $\Omega_b \rightarrow \Omega_c$ beyond tree level

Z. Neishabouri,¹ K. Azizi^{1,2,*} and H. R. Moshfegh^{1,3}

¹*Department of Physics, University of Tehran, North Karegar Avenue, Tehran 14395-547, Iran*

²*Department of Physics, Dogus University, Dudullu-Ümraniye, 34775 Istanbul, Türkiye*

³*Centro Brasileiro de Pesquisas Físicas (CBPF),*

Rua Doutor Xavier Sigaud, 150, URCA, Rio de Janeiro CEP 22290-180, RJ, Brazil



(Received 2 January 2026; accepted 2 March 2026; published 18 March 2026)

We study the nonleptonic decays of $\Omega_b \rightarrow \Omega_c P(V)$ with eight pseudoscalar and vector mesons using the naive factorization approach. We analyze all relevant topologies (the tree-level, color-suppressed, and penguin topologies) of these decays and calculate the decay amplitude for each separately. We determine the decay rates and branching ratios and compare our results with those from other theoretical predictions. The results obtained may be useful for the analysis of the related data in both ongoing and future experiments.

DOI: [10.1103/mtyl-scfm](https://doi.org/10.1103/mtyl-scfm)

I. INTRODUCTION

The study of weak decays in hadrons serves as a powerful tool for probing their internal dynamics, testing the interplay between weak and strong interactions, validating models such as the quark model, and extracting standard model (SM) parameters including the Cabibbo-Kobayashi-Maskawa (CKM) matrix elements. Heavy hadrons incorporating bottom (b) or charm (c) quarks possess a wide variety of accessible decay channels due to their large masses, and their decays provide particularly valuable information for understanding the underlying interactions in particle physics.

The observation of lepton flavor universality violation in specific decay channels of B mesons [1–3] and the discovery of charge conjugation-parity (CP) violation in B-meson systems [4–9] have significantly increased expectations for detecting new physics beyond the SM in hadrons containing bottom quarks. These findings have driven extensive experimental and theoretical studies focused on heavy hadron decays to search for possible new physics effects that could explain such anomalies. In recent years, a wide range of decays of heavy hadrons have been observed across multiple experiments, particularly by the LHCb Collaboration [10–19], providing rich data for analysis. Concurrently, numerous theoretical frameworks have been developed to study nonleptonic and semileptonic

decays of these hadrons. These include approaches such as factorization methods, light-cone sum rules, QCD sum rules, covariant constituent quark models, and the MIT bag model, among others [20–29]. Together, these experimental and theoretical advances have significantly deepened our understanding of heavy hadron decay dynamics and help to test the SM rigorously.

Compared with semileptonic decays, which involve both leptons and hadrons, nonleptonic decays featuring exclusively hadronic final states exhibit far more complex QCD dynamics. This arises from the more intricate strong interaction effects within exclusive hadronic environments, as opposed to hybrid leptonic-hadronic configurations. Nonleptonic decays facilitate profound insights into short-distance and long-range dynamical interactions while serving as key arenas for detecting CP violation. CP violation refers to the asymmetry under the combined operations of charge conjugation (C) and parity (P). It manifests primarily through direct and indirect mechanisms in weak decays and probes the phases of the CKM matrix in the SM. Direct CP violation arises from interference between two amplitudes bearing distinct weak and strong phases, where weak phases reverse under CP conjugation, while strong phases remain invariant. Within the SM, weak phases originate from the complex entries of the (CKM) matrix, whereas strong phases emerge from hadronic final-state interactions. It appears as rate asymmetries A_{CP} in decays such as $B^0 \rightarrow K^+ \pi^-$ and $B_s^0 \rightarrow K^- \pi^+$, where observed values are $-0.0824 \pm 0.0033 \pm 0.0033$ and $0.236 \pm 0.013 \pm 0.011$, respectively [30]. The CP asymmetry for a decay $P \rightarrow f$ is defined as

$$A_{CP} = \frac{\Gamma(P \rightarrow f) - \Gamma(\bar{P} \rightarrow \bar{f})}{\Gamma(P \rightarrow f) + \Gamma(\bar{P} \rightarrow \bar{f})}. \quad (1)$$

*Contact author: kazem.azizi@ut.ac.ir

Published by the American Physical Society under the terms of the [Creative Commons Attribution 4.0 International license](https://creativecommons.org/licenses/by/4.0/). Further distribution of this work must maintain attribution to the author(s) and the published article's title, journal citation, and DOI. Funded by SCOAP³.

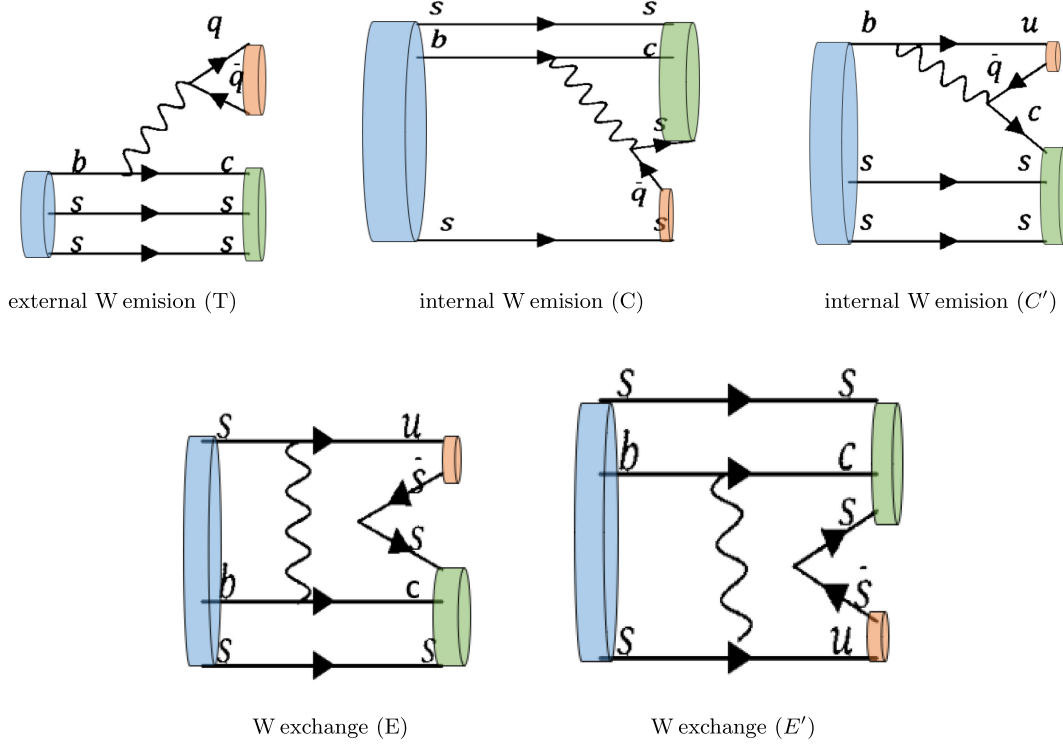
This asymmetry becomes nonzero only when at least two contributing amplitudes differ simultaneously in their strong phases (from final-state rescattering) and weak phases (from CKM factors in the SM). In nonleptonic B and D decays, interference between tree-level and penguin amplitudes provides the required phase differences. Experiments such as LHCb and Belle determine A_{CP} from ratios of decay rates, finding percent-level asymmetries in channels like $D^0 \rightarrow \pi^+\pi^-$ [31], which place stringent tests on SM predictions. In baryon decays, for instance, $\Lambda_b \rightarrow p\pi^-$ [32], asymmetries as large as $O(10\%)$ have been reported, offering a sensitive probe of possible contributions beyond simple tree-dominated dynamics. The observations mark the first instance of CP violation and a nonzero A_{CP} in baryons, observed in the $\Lambda_b^0 \rightarrow pK^-\pi^+\pi^-$ decay mode, by 5.2 standard deviations [33]. Indirect CP violation occurs through mixing in neutral meson systems, such as $K^0 - \bar{K}^0$, where the CP eigenstates differ from the mass eigenstates. It is characterized by the parameter $\epsilon \approx 2.3 \times 10^{-3}$ [10] in the kaon sector, reflecting CP -violating differences in the lifetimes and phases of CP -even and CP -odd components, even in the absence of strong-phase differences in the decay amplitudes. CP violation constitutes one of the three Sakharov conditions necessary to account for the observed matter-antimatter asymmetry in the Universe [34]. However, its predicted magnitude within the SM remains negligible, implying the potential involvement of additional mechanisms. Nonleptonic decays emerge as a prime laboratory for probing CP violation through their rich interplay of weak and strong dynamics.

This study focuses on the two-body nonleptonic decay of Ω_b , the heaviest singly heavy baryon, into an Ω_c . While the decay channel $\Omega_b \rightarrow \Omega_c\pi$ has been experimentally observed with a significance of 3.3σ [35], other decay modes involving different mesons remain yet to be detected. This highlights the ongoing exploration and need for further experimental efforts in uncovering additional Ω_b decay processes. This decay mode has also been analyzed within various theoretical frameworks. Two main approaches realize approximate SU(3) flavor symmetry in QCD for two-body nonleptonic decays: the reducible method and the topological method. Topological diagrams, in particular, provide an intuitive representation of the strong-interaction dynamics embedded in weak decay processes, incorporating both perturbative and nonperturbative QCD effects. In two-body nonleptonic baryon decays governed by quark color-flavor dynamics, five distinct topological diagrams contribute via W-boson exchange, classified into reducible tree-level diagrams and irreducible W-exchange diagrams. These topologies reflect different mechanisms by which the weak interaction mediates the baryon decay processes. In tree-level diagrams, a necessary condition is that two quarks are shared by the parent and daughter baryons and the W boson is emitted either externally or internally. The difference

between them is that the quark produced by the weak transition goes into the final-state baryon or meson. These diagrams can be factorized. However, the three different types of W-exchange diagrams are not factorable. Tree-level processes typically dominate, yet W-exchange contributions can amplify branching ratios by up to 30% in decays like $\Lambda_b \rightarrow \Lambda_c$ [36,37].

The simplest model for the nonleptonic decay $\Omega_b \rightarrow \Omega_c$ features a $b \rightarrow c$ quark transition accompanied by W-boson emission, which subsequently decays into a quark-antiquark pair to form a meson. Although this tree-level emission mode represents the dominant pathway, other scenarios, such as internal W-boson exchange, warrant further investigation to fully characterize the decay dynamics. In Fig. 1, diagram T represents a color-allowed tree-level process with external W-boson emission, whereas diagrams C and C' denote color-suppressed configurations involving internal W emission. Charge conservation necessitates a negatively charged meson in the final state. Consequently, diagram C permits a strange quark (s) transition, generating kaon $K^{(*)}$, D_s , or D_s^* mesons, while diagram C' remains forbidden due to its inability to produce such a meson. The E and E' diagrams, involving W-exchange processes, are prohibited by charge conservation. The third W-exchange “bow-tie” topology requires spectator light quark involvement in meson formation, rendering it inaccessible for this decay. Penguin diagrams manifest as higher-order loop contributions within the SM. In particle physics, penguin topologies refer to specific loop diagrams in weak decays where flavor-changing neutral currents arise through higher-order processes. These loops typically involve virtual particles that mediate transitions between quarks, contributing to rare decay modes and CP violation. Loop diagrams incorporate different internal quarks (e.g., top or charm), giving rise to interference pathways with unique phases. This unitarity driven interference produces differences between decay amplitudes and their CP -conjugate counterparts, rendering CP violation experimentally observable.

In Fig. 2, the penguin diagrams relevant to these decays are shown; they can hadronize into $D^{(*)}$ and $D_s^{(*)}$ mesons. Consequently, their occurrence probability is lower than that of tree-level topologies, and they do not significantly modify the total decay rate. Nevertheless, they can generate additional complex phases that participate in amplitude interference and therefore play a crucial role in the size of CP violation. Theoretical analyses of nonleptonic decays rely on factorization theorems, which constitute fundamental tools within perturbative QCD frameworks. These theorems separate physics across different energy scales, distinguishing perturbatively computable short-distance interactions from nonperturbative long-distance effects. The factorization theorem extends the Euclidean operator product expansion to timelike kinematics, with rigorous proofs derived from perturbative QCD through

FIG. 1. All possible flavor-color topologies for $\Omega_b \rightarrow \Omega_c M$ decay.

Feynman diagram analysis in the Collins-Soper-Sterman formalism [38–40]. Heavy quark masses further suppress strong-interaction effects through systematic expansions in heavy quark effective theory. Naive factorization was initially applied to B-meson decays and later generalized to heavy-baryon systems. Naive factorization assumes that the hadronic matrix element of a four-quark operator can be written as the product of two single-hadron matrix elements, neglecting non-factorizable effects such as hard-gluon exchange and spectator interactions.

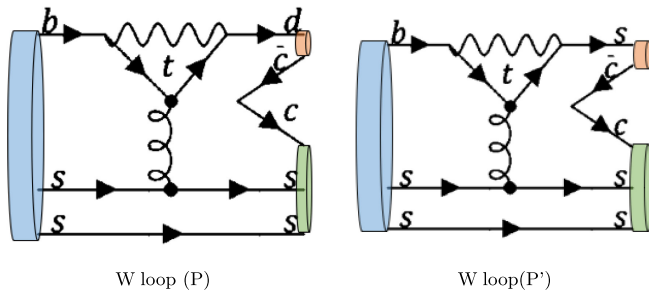
In this study, we employ the naive factorization approach, which enables a comprehensive calculation of all topologies relevant to these decays. Form factors have been calculated using the QCD sum rules method, which is one of the powerful and predictive models in the

nonperturbative regime of QCD. This method has provided good predictions and results comparable to experiments so far, making it a reliable nonperturbative approach for studying hadronic decays.

This paper is organized as follows. In Sec. II, decay amplitudes are derived based on the relevant topological diagrams. In Sec. III, decay rates are calculated. Section IV presents numerical analyses and results, and Sec. V contains the conclusions. Two appendixes are provided to present some details of the calculations.

II. THE DECAY AMPLITUDE

A large category of weak decays in the SM proceed via W-boson exchange; given $m_W \gg m_b \gg m_{\Lambda_{\text{QCD}}}$, an effective Hamiltonian describes these processes by integrating out the heavy W boson [41]. The effective Hamiltonian allows expressing the effects of W-boson exchange in terms of local operators and Wilson coefficients. This formalism simplifies the description of weak decays by separating short-distance physics (encoded in Wilson coefficients) from long-distance hadronic effects (described by local operators). Given the mass difference between Ω_b and Ω_c , we analyze eight pseudoscalar and vector mesons that could potentially be produced in this decay. The decay $\Omega_b \rightarrow \Omega_c \pi(\rho)$ occurs via external W emission at the quark level through the transition $b \rightarrow c \bar{u} d$, as shown by diagram T in Fig. 1. The effective Hamiltonian for this decay is defined as follows:

FIG. 2. All possible W-loop diagrams (penguin) for $\Omega_b \rightarrow \Omega_c M$ decay.

$$H_{\text{eff}} = \frac{G_F}{\sqrt{2}} V_{cb} V_{ud}^* \{C_1(\mu) O_1^d + C_2(\mu) O_2^d\}, \quad (2)$$

where G_F denotes the Fermi coupling constant, V_{cb} and V_{ud} represent CKM matrix elements, and C_1, C_2 are the associated Wilson coefficients. The operators O_1 and O_2 constitute four-quark local operators, explicitly defined as

$$O_1^d = (\bar{d}_i u_i)_{V-A} (\bar{c}_j b_j)_{V-A}, \quad O_2^d = (\bar{d}_i u_j)_{V-A} (\bar{c}_j b_i)_{V-A}, \quad (3)$$

where $(\bar{q}_1 q_2)_{V\pm A} = \bar{q}_1 \gamma^\mu (1 \pm \gamma_5) q_2$ and i, j denote the color indices. To obtain the decay amplitude, the effective Hamiltonian is sandwiched between the initial and final hadron states. This procedure involves calculating the matrix element,

$$\begin{aligned} \mathcal{A}(\Omega_b \rightarrow \Omega_c M) &= \langle \Omega_c M | \mathcal{H}_{\text{eff}} | \Omega_b \rangle \\ &= \frac{G_F}{\sqrt{2}} V_{bc} V_{ud}^* \sum_{i=1,2} C_i(\mu) \langle \Omega_c M | O_i | \Omega_b \rangle, \end{aligned} \quad (4)$$

where M denotes the meson (pseudoscalar or vector). In the next step, using the naive factorization method, the hadronic matrix element is separated into two distinct parts,

$$\langle \Omega_c M | O_i | \Omega_b \rangle \rightarrow \langle M | \mathcal{J}_{ud}^\mu | 0 \rangle \otimes \langle \Omega_c | \mathcal{J}_{\mu,cb} | \Omega_b \rangle, \quad (5)$$

where $\mathcal{J}_{ud}^\mu$ and $\mathcal{J}_{\mu,cb}$ represent the $V - A$ currents with the quark flavor ud and cb , respectively. The decay amplitude then takes the form

$$\begin{aligned} \mathcal{A}(\Omega_b \rightarrow \Omega_c M) &= \frac{G_F}{\sqrt{2}} V_{bc} V_{ud}^* \left\{ C_1(\mu) \langle M | \bar{d}_i \gamma^\mu (1 - \gamma_5) u_i | 0 \rangle \langle \Omega_c | \bar{c}_j \gamma^\mu (1 - \gamma_5) b_j | \Omega_b \rangle \right. \\ &\quad \left. + C_2(\mu) \langle M | \bar{d}_i \gamma^\mu (1 - \gamma_5) u_j | 0 \rangle \langle \Omega_c | \bar{c}_j \gamma^\mu (1 - \gamma_5) b_i | \Omega_b \rangle \right\}. \end{aligned} \quad (6)$$

Using the Fierz identity in color space,

$$(T_a)_{ij} (T_a)_{kl} = \frac{1}{2} \left(\delta_{il} \delta_{kj} - \frac{1}{N_c} \delta_{ij} \delta_{kl} \right). \quad (7)$$

After applying the above relation, the two matrix elements in the decay amplitude become identical. Thus, the amplitude of this decay can be written as

$$\mathcal{A} = \langle \Omega_c M | \mathcal{H}_{\text{eff}} | \Omega_b \rangle = \frac{G_F}{\sqrt{2}} V_{bc} V_{ud}^* a_1(\mu) \langle M | \bar{d} \gamma^\mu (1 - \gamma_5) u | 0 \rangle \langle \Omega_c | \bar{c} \gamma_\mu (1 - \gamma_5) b | \Omega_b \rangle, \quad (8)$$

where $a_1(\mu)$ is the effective Wilson coefficient defined through $a_1(\mu) = C_1(\mu) + C_2(\mu)/N_c$. In Eq. (8), the first matrix element corresponds to the meson decay constant, while the second transition matrix element is parametrized in terms of baryonic transition form factors. We now apply this formalism to analyze various decay channels. First we examine the decay amplitude of $\Omega_b \rightarrow \Omega_c K_u (K_u^*)$ with the quark-level transition $b \rightarrow c \bar{u} s$. This decay can occur via both external (T) and (C) internal W emission topologies, as shown in Fig. 1. The effective Hamiltonian describing this decay is expressed as follows:

$$H_{\text{eff}} = \frac{G_F}{\sqrt{2}} \{V_{cb} V_{us}^* (C_1(\mu) O_1^s + C_2(\mu) O_2^s)\}, \quad (9)$$

where the four-quark operators are

$$O_1^s = (\bar{s}_i u_i)_{V-A} (\bar{c}_j b_j)_{V-A}, \quad O_2^s = (\bar{s}_i u_j)_{V-A} (\bar{c}_j b_i)_{V-A}. \quad (10)$$

The decay amplitude is obtained by sandwiching the effective Hamiltonian between the initial and the final hadronic states. Using factorization hypothesis and the Fierz identity, the amplitude can be expressed distinctly for the two topologies: (1) For the external W emission (color allowed), the amplitude factorizes into the product of a meson decay constant and a baryon transition form factor, reflecting the color-favored topology in which the W boson directly produces the meson. (2) For the internal W emission (color suppressed), the amplitude involves color rearrangement via the Fierz transformation, leading to suppression due to color mismatch. This contribution factorizes similarly but is multiplied by $1/N_c$ color-suppression factor. Accordingly, the amplitudes can be written as

$$\begin{aligned}\mathcal{A}_1 &= \langle \Omega_c K^{(*)} | \mathcal{H}_{\text{eff}} | \Omega_b \rangle^T = \frac{G_F}{\sqrt{2}} V_{bc} V_{us}^* a_1(\mu) \langle K^{(*)} | \bar{s} \gamma^\mu (1 - \gamma_5) u | 0 \rangle \langle \Omega_c | \bar{c} \gamma_\mu (1 - \gamma_5) b | \Omega_b \rangle, \\ \mathcal{A}_2 &= \langle \Omega_c K^{(*)} | \mathcal{H}_{\text{eff}} | \Omega_b \rangle^C = \frac{G_F}{\sqrt{2}} V_{bc} V_{us}^* a_2(\mu) \langle K^{(*)} | \bar{s} \gamma^\mu (1 - \gamma_5) u | 0 \rangle \langle \Omega_c | \bar{c} \gamma_\mu (1 - \gamma_5) b | \Omega_b \rangle,\end{aligned}\quad (11)$$

where $a_2(\mu)$ is defined as $a_2(\mu) = C_2(\mu) + C_1(\mu)/N_c$. The next decay is $\Omega_b \rightarrow \Omega_c D(D^*)$, which occurs dominantly via external W emission (T) as shown in Fig. 1. In addition to the leading tree-level contribution, this decay channel can receive subdominant contributions from higher-order penguin loop diagrams (P), shown in Fig. 2. These penguin contributions introduce small corrections and possible CP -violating phases but are generally suppressed compared to the tree-level amplitude. The effective Hamiltonian corresponding to this decay is

$$H_{\text{eff}} = \frac{G_F}{\sqrt{2}} \left\{ V_{bc} V_{cd}^* (C_1 O_1^c + C_2 O_2^c) + V_{tb} V_{td}^* \sum_{n=3}^{10} C_n O_n \right\}, \quad (12)$$

where O_n are quark operators and are given by

$$\begin{aligned}O_1^c &= (\bar{q}_i^c c_i)_{V-A} (\bar{c}_j b_j)_{V-A}, & O_2^c &= (\bar{q}_i^c c_j)_{V-A} (\bar{c}_j b_i)_{V-A}, \\ O_3 &= (\bar{q}_i^c b_i)_{V-A} \sum_q (\bar{q}_j q_j)_{V-A}, & O_4 &= (\bar{q}_i^c b_j)_{V-A} \sum_q (\bar{q}_j q_i)_{V-A}, \\ O_5 &= (\bar{q}_i^c b_i)_{V-A} \sum_q (\bar{q}_j q_j)_{V+A}, & O_6 &= (\bar{q}_i^c b_j)_{V-A} \sum_q (\bar{q}_j q_i)_{V+A}, \\ O_7 &= (\bar{q}_i^c b_i)_{V-A} \sum_q \frac{3}{2} e_q (\bar{q}_j q_j)_{V+A}, & O_8 &= (\bar{q}_i^c b_j)_{V-A} \sum_q \frac{3}{2} e_q (\bar{q}_j q_i)_{V+A}, \\ O_9 &= (\bar{q}_i^c b_i)_{V-A} \sum_q \frac{3}{2} e_q (\bar{q}_j q_j)_{V-A}, & O_{10} &= (\bar{q}_i^c b_j)_{V-A} \sum_q \frac{3}{2} e_q (\bar{q}_j q_i)_{V-A}.\end{aligned}\quad (13)$$

Here, the sum over q runs over all quark flavors, and q' corresponds to d and s for the final-state mesons $D^{(*)}$ and $D_s^{(*)}$, respectively. The effective Hamiltonian operators are categorized as follows: O_1 and O_2 are current-current operators representing tree-level four-quark interactions. O_3 – O_6 are QCD penguin operators accounting for gluonic loop corrections. O_7 – O_{10} are electroweak penguin operators that include photon and Z-boson mediated loop effects.

The amplitude of decay to D meson, as an example, is expressed as

$$\mathcal{A} = \langle \Omega_c D | \mathcal{H}_{\text{eff}} | \Omega_b \rangle = \frac{G_F}{\sqrt{2}} [V_{bc} V_{cd}^* a_1 - V_{tb} V_{td}^* (a_4 + a_{10} + R(a_6 + a_8))] \langle D | \bar{d} \gamma^\mu (1 - \gamma_5) c | 0 \rangle \langle \Omega_c | \bar{c} \gamma_\mu (1 - \gamma_5) b | \Omega_b \rangle. \quad (14)$$

For the vector meson (D^*), the contributions from the operators O_5 – O_8 vanish due to the Dirac and color structure of these operators. The amplitude becomes

$$\mathcal{A} = \langle \Omega_c D^* | \mathcal{H}_{\text{eff}} | \Omega_b \rangle = \frac{G_F}{\sqrt{2}} [V_{bc} V_{cd}^* a_1 - V_{tb} V_{td}^* (a_4 + a_{10})] \langle D^* | \bar{d} \gamma^\mu (1 - \gamma_5) c | 0 \rangle \langle \Omega_c | \bar{c} \gamma_\mu (1 - \gamma_5) b | \Omega_b \rangle, \quad (15)$$

where Wilson coefficients are obtained as

$$a_{2i-1} = C_{2i-1} + \frac{1}{N_c} C_{2i}, \quad a_{2i} = C_{2i} + \frac{1}{N_c} C_{2i-1}, \quad i = 1, 2, \dots, 5, \quad (16)$$

with

$$R = \frac{2m_{D_{q'}}^2}{(m_b - m_c)(m_{q'} + m_c)}. \quad (17)$$

The derivation of the penguin-operator coefficients is presented in Appendix A. The last decay of $\Omega_b \rightarrow \Omega_c D_s(D_s^*)$ with the quark-level transition $b \rightarrow c \bar{c} s$ can proceed via both external and internal W-emission diagrams, where the W boson is

emitted outside or inside the quark lines, respectively. Additionally, this decay can also occur through penguin loop diagrams (P') in Fig. 2, which involve flavor-changing neutral current processes mediated by virtual loops. The effective Hamiltonian for this decay at the quark level can be written as

$$H_{\text{eff}} = \frac{G_F}{\sqrt{2}} \left\{ V_{bc} V_{cs}^* (C_1 O_1^c + C_2 O_2^c) + V_{tb} V_{ts}^* \sum_{n=3}^{10} C_n O_n \right\}. \quad (18)$$

The color-allowed (T) and color-suppressed (C) amplitudes in Fig. 2, denoted by $\mathcal{A}_1$ and $\mathcal{A}_2$, respectively, can be written as

$$\begin{aligned} \mathcal{A}_1 &= \langle \Omega_c D_s | \mathcal{H}_{\text{eff}} | \Omega_b \rangle = \frac{G_F}{\sqrt{2}} [V_{bc} V_{cs}^* a_1 - V_{tb} V_{ts} (a_4 + a_{10} + R(a_6 + a_8))] \langle D_s | \bar{s} \gamma^\mu (1 - \gamma_5) c | 0 \rangle \langle \Omega_c | \bar{c} \gamma_\mu (1 - \gamma_5) b | \Omega_b \rangle, \\ \mathcal{A}_1 &= \langle \Omega_c D_s^* | \mathcal{H}_{\text{eff}} | \Omega_b \rangle = \frac{G_F}{\sqrt{2}} [V_{bc} V_{cs}^* a_1 - V_{tb} V_{ts} (a_4 + a_{10})] \langle D_s^* | \bar{s} \gamma^\mu (1 - \gamma_5) c | 0 \rangle \langle \Omega_c | \bar{c} \gamma_\mu (1 - \gamma_5) b | \Omega_b \rangle, \\ \mathcal{A}_2 &= \langle \Omega_c D_s^{(*)} | \mathcal{H}_{\text{eff}} | \Omega_b \rangle = \frac{G_F}{\sqrt{2}} V_{bc} V_{cs}^* a_2 \langle D_s^{(*)} | \bar{s} \gamma^\mu (1 - \gamma_5) c | 0 \rangle \langle \Omega_c | \bar{c} \gamma_\mu (1 - \gamma_5) b | \Omega_b \rangle. \end{aligned} \quad (19)$$

The combination of the Wilson coefficients is obtained in the same way as in the previous decays. The decay amplitude in all the above decays is expressed as a product of the Wilson coefficients, the CKM matrix elements, and the Fermi coupling constant, arranged within two matrix elements. By definition, the matrix element representing the coupling of the meson current to the vacuum is called the decay constant. For pseudoscalar mesons $P(p)$, it is defined as

$$\langle P(q) | \bar{q}_i \gamma^\mu (1 - \gamma_5) q'_i | 0 \rangle = i f_P q^\mu, \quad (20)$$

while for vector mesons $V(q)$, it is given by

$$\langle V(q) | \bar{q}_i \gamma^\mu (1 - \gamma_5) q'_i | 0 \rangle = m_V f_V \epsilon^{*\mu}, \quad (21)$$

where f_P and f_V are the decay constants of the pseudoscalar and vector mesons, respectively. m_V and q^μ denote the mass

and four-momentum of the vector and pseudoscalar mesons, respectively, and ϵ^μ is the polarization vector of the vector meson. These parameters quantify the overlap of the meson wave function at the origin and are crucial inputs for factorization-based amplitude calculations in heavy-baryon decays. The matrix element representing the transition between the initial and the final baryon states is expressed in terms of transition form factors, which encapsulate the nonperturbative QCD dynamics of the baryon. These form factors can be calculated using various theoretical approaches such as lattice QCD, QCD sum rules, or quark models. The matrix element receives contributions from both vector and axial-vector currents, each parametrized by three independent form factors. The general expression for the baryon transition matrix element is given by

$$\begin{aligned} \langle \Omega_c(p', s') | V^\mu | \Omega_b(p, s) \rangle &= \bar{u}_{\Omega_c}(p', s') \left[F_1(q^2) \gamma^\mu + F_2(q^2) \frac{p^\mu}{m_{\Omega_b}} + F_3(q^2) \frac{p'^\mu}{m_{\Omega_c}} \right] u_{\Omega_b}(p, s), \\ \langle \Omega_c(p', s') | A^\mu | \Omega_b(p, s) \rangle &= \bar{u}_{\Omega_c}(p', s') \left[G_1(q^2) \gamma^\mu + G_2(q^2) \frac{p^\mu}{m_{\Omega_b}} + G_3(q^2) \frac{p'^\mu}{m_{\Omega_c}} \right] \gamma_5 u_{\Omega_b}(p, s). \end{aligned} \quad (22)$$

In this article, we employ the form factors from our previous work [42]. In this study, the form factors have been calculated up to sixth-order nonperturbative contributions (dimension-six condensates) and the decay form factors for $\Omega_b \rightarrow \Omega_c \ell \bar{\nu}_\ell$ were calculated for the first time using QCD sum rules and were found to be in excellent agreement with results from other theoretical methods. The decay amplitude for a pseudoscalar meson can be written using the baryonic transition matrix element (22), the pseudoscalar meson matrix element (20), the Dirac equation, and the relation $q = p - p'$ as follows:

$$\begin{aligned} \mathcal{A}_{\Omega_b \rightarrow \Omega_c P} &= \frac{G_F}{\sqrt{2}} f_P C_{\text{eff}} \bar{u}_{\Omega_c} \frac{1}{2 m_{\Omega_b} m_{\Omega_c}} \left\{ 2 F_1 m_{\Omega_b} (m_{\Omega_b} - m_{\Omega_c}) m_{\Omega_c} + F_2 m_{\Omega_c} (3 m_{\Omega_b}^2 + m_{\Omega_c}^2 - q^2) \right. \\ &\quad - F_3 m_{\Omega_b} (m_{\Omega_b}^2 + 3 m_{\Omega_c}^2 - q^2) + [2 G_1 m_{\Omega_b} m_{\Omega_c} (m_{\Omega_b} + m_{\Omega_c}) + G_3 m_{\Omega_b} (m_{\Omega_b}^2 + 3 m_{\Omega_c}^2 - q^2) \\ &\quad \left. + G_2 m_{\Omega_c} (-3 m_{\Omega_b}^2 - m_{\Omega_c}^2 + q^2) \gamma_5 \right\} u_{\Omega_b}. \end{aligned} \quad (23)$$

TABLE I. Types of topologies and the corresponding coefficient for each decay.

Decay	Topology	C_{eff}
$\Omega_b \rightarrow \Omega_c \pi(\rho)$	T	$[V_{bc} V_{ud} a_1]$
$\Omega_b \rightarrow \Omega_c K(K^*)$	T,C	$[V_{bc} V_{us}(a_1 + a_2)]$
$\Omega_b \rightarrow \Omega_c D$	T,P	$[V_{bc} V_{cd} a_1 - V_{tb} V_{td}(a_4 + a_{10} + R(a_6 + a_8))]$
$\Omega_b \rightarrow \Omega_c D^*$	T,P	$[V_{bc} V_{cd} a_1 - V_{tb} V_{td}(a_4 + a_{10})]$
$\Omega_b \rightarrow \Omega_c D_s$	T, C, P'	$[V_{bc} V_{cs}(a_1 + a_2) - V_{tb} V_{td}(a_4 + a_{10} + R(a_6 + a_8))]$
$\Omega_b \rightarrow \Omega_c D_s^*$	T, C, P'	$[V_{bc} V_{cs}(a_1 + a_2) - V_{tb} V_{td}(a_4 + a_{10})]$

The factorized decay amplitude for a vector meson V can be written as

$$\mathcal{A}_{\Omega_b \rightarrow \Omega_c V} = \frac{G_F}{\sqrt{2}} m_V f_V C_{\text{eff}} \bar{u}_{\Omega_c} \epsilon^{*\mu} \left(F_1 \gamma_\mu + F_2 \frac{p_\mu}{m_{\Omega_b}} + F_3 \frac{p'_\mu}{m_{\Omega_c}} - G_1 \gamma_\mu \gamma_5 - G_2 \frac{p_\mu \gamma_5}{m_{\Omega_b}} - G_3 \frac{p'_\mu \gamma_5}{m_{\Omega_c}} \right) u_{\Omega_b}. \quad (24)$$

The polarization relations $\sum_\lambda \epsilon_\lambda^{*\mu}(q) \epsilon_\lambda^\nu(q) = -g_{\mu\nu} + \frac{q_\mu q_\nu}{m_V^2}$ will be used when squaring the amplitude. The parameter C_{eff} is a factor that incorporates CKM matrix elements and effective Wilson coefficients, which vary for each decay depending on the topology type. In Table I, this factor is provided for each decay channel. In the next section, we present the procedure for obtaining the decay rate using the transition amplitudes.

III. DECAY RATES

The decay rate for any two-body decay ($A \rightarrow B + C$) is generally obtained from Fermi's golden rule as follows [43]:

$$\Gamma_{fi} = \frac{p_c}{32\pi^2 m_A^2} \int |\mathcal{A}_{fi}|^2 d\Omega, \quad (25)$$

where the center-of-mass frame momentum of final-state particles is given by $p_c = \frac{1}{2m_A} \lambda^{\frac{1}{2}}(m_A^2, m_B^2, m_C^2)$ and integral is taken over the phase space. The decay rate is obtained by inserting the squared decay amplitude and the masses of the hadrons. The differential decay rate can also be written in terms of helicity amplitudes. It is important to note that choosing between the direct decay rate formula and the helicity formalism depends on how the hadronic current is expanded in terms of form factors. In the standard helicity expressions [44,45], the baryonic current is parametrized using γ^μ , $\sigma_{\mu\nu} q_\nu$, and q^μ ; with this choice, contracting with the q^μ coming from the meson matrix element, remove the contribution of the form factor F_2 and G_2 in pseudoscalar decays, and similarly once the vector-meson polarization is included, F_3 and G_3 drop out of the decay rate for vector mesons. In contrast, in the present work, the baryonic current is

expanded in terms of γ^μ , p^μ , and p'^μ . With this parametrization, all three form factors F_1 , F_2 , and F_3 (and analogously G_1 , G_2 , G_3) enter the scalar combinations that build the decay rate, so none of them drop out. For this reason, one must use the direct expression for the differential decay rate of spin-1/2 to spin-1/2 baryon with the factor $\frac{1}{2s+1}$,

$$\Gamma = \frac{\lambda^{1/2}(m_{\Omega_b}^2, m_{\Omega_c}^2, m_M^2)}{32\pi m_{\Omega_b}^3} |\mathcal{A}|^2, \quad (26)$$

decay formula where $\lambda(m_{\Omega_b}^2, m_{\Omega_c}^2, m_M^2) = m_{\Omega_b}^4 + m_{\Omega_c}^4 + m_M^4 - 2m_{\Omega_b}^2 m_{\Omega_c}^2 - 2m_{\Omega_b}^2 m_M^2 - 2m_{\Omega_c}^2 m_M^2$. Appendix B contains explicit expressions for $|\mathcal{A}|^2$ for both the pseudo-scalar and vector-meson cases.

IV. NUMERICAL ANALYSIS

In this section, we present the input parameters used to calculate the decay rates. The first quantities appearing in the effective Hamiltonian are the Wilson coefficients. The Wilson coefficients are solutions of the renormalization group equations that relate the short-distance effects from a high-energy scale to the long-distance effects at a lower-energy scale and are scale dependent. These coefficients have been calculated at next-to-leading order in the scale of the b quark mass, given as follows [41,46–48]:

$$\begin{aligned} C_1 &= 1.117, & C_2 &= -0.257, \\ C_3 &= 0.017, & C_4 &= -0.044, \\ C_5 &= 0.011, & C_6 &= -0.056, \\ C_7 &= -1 \times 10^{-5}, & C_8 &= 5 \times 10^{-4}, \\ C_9 &= -0.010, & C_{10} &= 0.002. \end{aligned} \quad (27)$$

The next parameters to be included are the decay constants, which are derived from the matrix elements coupling the meson current to the vacuum. These decay constants are reported in Table II. Additional input parameters such as the masses of the hadrons and participating quarks, as well as the elements of the

TABLE II. Decay constants of the pseudoscalar and vector mesons.

Decay constants (MeV)	Value	Decay constants (MeV)	Value
f_π	130.2 [10,49]	f_ρ	218.3 [50]
f_K	155.6 [10,49]	f_{K^*}	210 [51]
f_D	203.7 [49]	f_{D^*}	245 ± 20 [52]
f_{D_s}	246.0 [49]	$f_{D_s^*}$	272 ± 16 [52]

CKM matrix used in the numerical calculations, are presented in Table III.

The fitted function for the form factors obtained in [42],

$$\mathcal{F}(q^2) = \frac{\mathcal{F}(0)}{\left(1 - a_1 \frac{q^2}{m_{\Omega_b}^2} + a_2 \frac{q^4}{m_{\Omega_b}^4} + a_3 \frac{q^6}{m_{\Omega_b}^6} + a_4 \frac{q^8}{m_{\Omega_b}^8}\right)}, \quad (28)$$

is used to compute the form factors at the momentum transfer squared q^2 , where it is taken as the squared meson mass. The values of the form factors for each decay channel, evaluated at $q^2 = m_{\text{meson}}^2$, are listed in Table IV. These values serve as the essential inputs for accurately calculating the decay rates within the factorization framework using the obtained amplitudes.

TABLE III. Input parameters used in calculations.

Parameters	Values
m_{Ω_b}	$(6045.8 \pm 0.8) \text{ MeV}$ [10]
m_{Ω_c}	$(2695.3 \pm 0.4) \text{ MeV}$ [10]
m_π	139.57 MeV [10]
m_ρ	770 MeV [10]
m_K	$(493.677 \pm 0.013) \text{ MeV}$ [10]
m_{K^*}	$(891.67 \pm 0.26) \text{ MeV}$ [10]
m_D	$(189.5 \pm 0.4) \text{ MeV}$ [10]
m_{D^*}	$(2010.26 \pm 0.05) \text{ MeV}$ [10]
m_{D_s}	$(1968.35 \pm 0.07) \text{ MeV}$ [10]
$m_{D_s^*}$	$(2106.6 \pm 3.4) \text{ MeV}$ [10]
m_b	$(4.18^{+0.03}_{-0.02}) \text{ GeV}$ [10]
m_c	$(1.27 \pm 0.02) \text{ GeV}$ [10]
G_F	$1.17 \times 10^{-5} \text{ GeV}^{-2}$ [10]
V_{cb}	0.040 [10]
V_{ud}	0.974 [10]
V_{us}	0.226 [10]
V_{cd}	0.226 [10]
V_{cs}	0.973 [10]
V_{td}	0.0086 [10]
V_{ts}	0.0415 [10]
τ_{Ω_b}	$1.64 \pm 0.16 \times 10^{-12} \text{ s}$ [10]

By substituting the form factors into the decay rate expressions given in Table III, the decay rates and branching ratios for the pseudoscalar (π, K, D, D_s) and vector (ρ, K^*, D^*, D_s^*) mesons are obtained and reported in Tables V and VI. These tables include the other predictions in the literature, as well. The obtained decay rates and branching ratios in the present study, considering the uncertainties, are overall in good agreement with the other existing predictions. It is worth mentioning that different references use different form factors calculated via different approaches and consider different topological contributions: The differences among the presented results for some channels can be attributed in the first stage to the different form factors used in these references as well as different topologies considered. The choice of form factors and their behavior in terms of q^2 as well as their values at $q^2 = m_{\text{meson}}^2$ play important role in enhancing our results for the branching ratios in some channels in Table VI. References [51,53–55] calculate the related form factors using the light-front method and examine nonleptonic decays only at the tree level (color allowed). References [37,50] employ the covariant confined quark model and investigate the decays at the tree level (color allowed), incorporating QCD penguin operators. Reference [56] uses the nonrelativistic quark model to determine form factors and calculates the decay rates at the tree level including color-suppressed contributions. Reference [57] employs the independent quark model within a relativistic framework and examines the corresponding decays at the tree level (color allowed). In contrast, the present work provides the most complete analysis of the nonleptonic decay $\Omega_b \rightarrow \Omega_c$ incorporating tree-level, color-suppressed, and penguin topologies. To illustrate the impact of each topology on the decay rates, the partial decay rates corresponding to individual topological contributions for each decay channel are listed in Table VII. This decomposition allows for a clear assessment of the relative importance of different topologies across various decay modes. As shown, although the pure decay rates from color-suppressed and penguin diagrams are small, they can significantly affect the total decay rates and should not be neglected. These results provide a comprehensive reference for analyzing asymmetry effects and their role in different decay channels from the viewpoint of CP violation effects.

TABLE IV. Transition form factors of the nonleptonic $\Omega_b \rightarrow \Omega_c M$ weak decays with emitting a pseudoscalar or vector meson at $q^2 = m_{\text{meson}}^2$.

Transition	$F_1(q^2)$	$F_2(q^2)$	$F_3(q^2)$	$G_1(q^2)$	$G_2(q^2)$	$G_3(q^2)$
$\Omega_b \rightarrow \Omega_c \pi^-$	-0.290 ± 0.080	0.680 ± 0.200	-0.038 ± 0.012	-0.020 ± 0.006	0.41 ± 0.10	0.450 ± 0.120
$\Omega_b \rightarrow \Omega_c K^-$	-0.293 ± 0.081	0.686 ± 0.202	-0.039 ± 0.012	-0.020 ± 0.007	0.414 ± 0.110	0.454 ± 0.120
$\Omega_b \rightarrow \Omega_c D^-$	-0.333 ± 0.092	0.771 ± 0.226	-0.047 ± 0.015	-0.021 ± 0.006	0.468 ± 0.120	0.517 ± 0.150
$\Omega_b \rightarrow \Omega_c D_s^-$	-0.339 ± 0.093	0.782 ± 0.230	-0.048 ± 0.015	-0.021 ± 0.007	0.475 ± 0.120	0.525 ± 0.151
$\Omega_b \rightarrow \Omega_c \rho^-$	-0.297 ± 0.082	0.694 ± 0.204	-0.039 ± 0.012	-0.020 ± 0.007	0.419 ± 0.112	0.460 ± 0.122
$\Omega_b \rightarrow \Omega_c K^{*-}$	-0.299 ± 0.082	0.699 ± 0.206	-0.040 ± 0.013	-0.020 ± 0.006	0.422 ± 0.103	0.464 ± 0.124
$\Omega_b \rightarrow \Omega_c D^{*-}$	-0.341 ± 0.094	0.786 ± 0.231	-0.049 ± 0.015	-0.021 ± 0.007	0.478 ± 0.119	0.528 ± 0.141
$\Omega_b \rightarrow \Omega_c D_s^{*-}$	-0.347 ± 0.096	0.799 ± 0.235	-0.050 ± 0.016	-0.021 ± 0.006	0.487 ± 0.130	0.538 ± 0.144

TABLE V. Decay widths (in $\times 10^{15}$ GeV) for the nonleptonic $\Omega_b \rightarrow \Omega_c M$ transition at different channels.

	This work	[37]	[53]	[56]
$\Gamma[\Omega_b \rightarrow \Omega_c \pi]$	1.809 ± 0.925	2.32	1.68	2.09
$\Gamma[\Omega_b \rightarrow \Omega_c K]$	0.171 ± 0.085	...	0.136	...
$\Gamma[\Omega_b \rightarrow \Omega_c D]$	0.202 ± 0.099	...	0.226	...
$\Gamma[\Omega_b \rightarrow \Omega_c D_s]$	6.185 ± 3.045	...	7.17	7.62
$\Gamma[\Omega_b \rightarrow \Omega_c \rho]$	5.047 ± 2.495	...	4.54	2.73
$\Gamma[\Omega_b \rightarrow \Omega_c K^*]$	0.302 ± 0.149	...	0.228	...
$\Gamma[\Omega_b \rightarrow \Omega_c D^*]$	0.274 ± 0.133	...	0.214	...
$\Gamma[\Omega_b \rightarrow \Omega_c D_s^*]$	7.446 ± 3.626	...	4.90	2.45

TABLE VI. Branching ratios in $\times 10^{-3}$ for the nonleptonic $\Omega_b \rightarrow \Omega_c M$ transition at different channels.

	This work	[50]	[51]	[53]	[56]	[57]	[54]	[55]
$\text{Br}[\Omega_b \rightarrow \Omega_c \pi]$	4.657 ± 2.305	1.88	2.82	4.00	4.92	2.54	$1.33^{+0.62}_{-0.46}$	$1.10^{+0.85}_{-0.55}$
$\text{Br}[\Omega_b \rightarrow \Omega_c K]$	0.427 ± 0.211	...	0.22	0.326	...	0.20	$0.10^{+0.05}_{-0.03}$	$0.08^{+0.07}_{-0.04}$
$\text{Br}[\Omega_b \rightarrow \Omega_c D]$	0.503 ± 0.247	0.24	0.52	0.636	...	0.46	$0.18^{+0.11}_{-0.08}$	$0.15^{+0.14}_{-0.08}$
$\text{Br}[\Omega_b \rightarrow \Omega_c D_s]$	15.411 ± 7.589	...	13.5	17.1	17.9	12.2	$4.75^{+2.85}_{-1.97}$	$4.03^{+3.72}_{-2.21}$
$\text{Br}[\Omega_b \rightarrow \Omega_c \rho]$	12.575 ± 6.216	5.43	7.92	10.8	12.8	7.43	$1.63^{+1.17}_{-0.75}$	$3.07^{+2.41}_{-1.53}$
$\text{Br}[\Omega_b \rightarrow \Omega_c K^*]$	0.751 ± 0.380	...	0.41	0.544	...	0.32	$0.082^{+0.058}_{-0.037}$	$0.16^{+0.12}_{-0.08}$
$\text{Br}[\Omega_b \rightarrow \Omega_c D^*]$	0.684 ± 0.334	0.30	0.48	0.511	...	0.39	$0.088^{+0.055}_{-0.035}$	$0.16^{+0.13}_{-0.08}$
$\text{Br}[\Omega_b \rightarrow \Omega_c D_s^*]$	18.553 ± 9.036	...	9.73	11.7	9.73	9.44	$1.84^{+1.11}_{-0.71}$	$3.18^{+2.69}_{-1.61}$

TABLE VII. The pure contribution of the decay rate corresponding to each topology (in $\times 10^{15}$ GeV) for $\Omega_b \rightarrow \Omega_c M$ transition at different channels.

	Tree level	Color suppressed	Penguin	Total decay
$\Gamma[\Omega_b \rightarrow \Omega_c \pi]$	1.869	...	...	1.869
$\Gamma[\Omega_b \rightarrow \Omega_c \rho]$	5.047	...	...	5.047
$\Gamma[\Omega_b \rightarrow \Omega_c K]$	0.139	0.002	...	0.171
$\Gamma[\Omega_b \rightarrow \Omega_c K^*]$	0.244	0.003	...	0.302
$\Gamma[\Omega_b \rightarrow \Omega_c D]$	0.158	...	0.003	0.202
$\Gamma[\Omega_b \rightarrow \Omega_c D^*]$	0.255	...	0.0004	0.274
$\Gamma[\Omega_b \rightarrow \Omega_c D_s]$	4.744	0.059	0.004	6.185
$\Gamma[\Omega_b \rightarrow \Omega_c D_s^*]$	5.933	0.074	0.0004	7.446

V. CONCLUSION

In this study, we investigated the nonleptonic two-body decays of $\Omega_b \rightarrow \Omega_c$ in both the pseudoscalar and vector channels including eight allowed mesonic modes. We examined all possible contributions to the related amplitudes incorporating the tree-level, color-suppressed, and penguin topologies for these decays and computed the decay amplitudes for all these channels. The decay rate and branching ratio for each decay were calculated considering all possible contributions from the tree-level, color-suppressed and penguin configurations, and the results were compared with predictions from other existing theories. The contributions of each topology for different mesonic channels were also given separately: Though the contributions from the color-suppressed and penguin diagrams are small, they have significant effects to the total decay rates and branching fractions. Our results can be used in ongoing and future experiments: The results can play a significant role in exact determination of the lifetime as well as other properties and internal structure of the relatively less-known Ω_b baryon as one of the important members of the single heavy spin-1/2 baryon family.

ACKNOWLEDGMENTS

K. A. thanks the Iran National Science Foundation (INSF) for the partial financial support supplied under the elites Grant No. 40405095.

DATA AVAILABILITY

No data were created or analyzed in this study.

APPENDIX A: THE PENGUIN-OPERATOR COEFFICIENTS

The QCD penguin operator O_3 is written as follows:

$$O_3 = (\bar{d}_i b_i)_{V-A} \sum_q (\bar{q}_j q_j)_{V-A}. \quad (A1)$$

This representation of the O_3 operator is unsuitable and cannot produce $\Omega_b \rightarrow \Omega_c D$. Fierz transformations rearrange bilinears in four-fermion interactions, expressed as

$$(\bar{\psi}_1 \Gamma^A \psi_2)(\bar{\psi}_3 \Gamma_A \psi_4) = \sum_B C^{AB} (\bar{\psi}_1 \Gamma^B \psi_4)(\bar{\psi}_3 \Gamma_B \psi_2), \quad (A2)$$

where Γ^A form a basis of Dirac matrices and C^{AB} are Fierz coefficients. The coefficients are derived from

$$C^{AB} = \frac{1}{16N_B} \text{Tr}(\Gamma_a^A \Gamma_b^B \Gamma_a^A \Gamma_b^B), \quad (A3)$$

where N_B is the number of γ matrices in each group B : In our case $N_B = 4$. After a Fierz transformation, it takes the form

$$O_3 = (\bar{d}_i c_j)_{V-A} (\bar{c}_j b_i)_{V-A}. \quad (A4)$$

A further transformation then places the colors i and j adjacent to each other,

$$O_3 = (\bar{d}_i c_i)_{V-A} (\bar{c}_j b_j)_{V-A}, \quad (A5)$$

where the color rearrangement introduces a factor of $1/3$, and the operator O_3 ultimately takes the form

$$O_3 = \frac{1}{3} C_3 O_1. \quad (A6)$$

For the operator O_4 , we apply the Fierz transformation once to place the quarks adjacent to each other, yielding

$$\begin{aligned} O_4 &= (\bar{d}_i b_j)_{V-A} \sum_q (\bar{q}_j q_i)_{V-A}, \\ O_4 &= (\bar{d}_i c_i)_{V-A} (\bar{c}_j b_j)_{V-A}, \\ O_4 &= C_4 O_1. \end{aligned} \quad (A7)$$

The operators O_5 – O_8 are of the form $(V-A) \otimes (V+A)$, in which the following transformations are employed. The operator O_6 , for instance, is initially given by

$$O_6 = (\bar{d}_i b_j)_{V-A} \sum_q (\bar{q}_j q_i)_{V+A}, \quad (A8)$$

so we have

$$\gamma_\mu(1-\gamma_5) \otimes \gamma_\mu(1+\gamma_5) \rightarrow -2(1-\gamma_5)(1+\gamma_5). \quad (A9)$$

After applying the Fierz transformation and factorization, the matrix element factorizes into

$$\begin{aligned} \langle \Omega_c M | O_6 | \Omega_b \rangle \\ = -2 \sum_{q'} \langle M | \bar{q}(1+\gamma_5) q' | 0 \rangle \langle \Omega_c | \bar{c}(1-\gamma_5) b | \Omega_b \rangle. \end{aligned} \quad (A10)$$

We can begin with the meson matrix element

$$\langle D | \bar{d} \gamma_\mu (1-\gamma_5) c | 0 \rangle = i f_D q_\mu, \quad (A11)$$

at which we contract both sides with q^μ , where q^μ is the meson four-momentum. Then, q^2 is replaced by m_M^2 , the squared mass of the meson, since the on-shell condition for the meson gives $q^2 = m_M^2$,

$$\langle D | \bar{d} \not{q} (1-\gamma_5) c | 0 \rangle = i f_D m_D^2. \quad (A12)$$

We have $q_D = q_d + q_c$, where q_D is the four-momentum of the D meson and q_d and q_c are the four-momenta of the constituent d and c quarks, respectively,

$$\langle D | \bar{d} (\not{q}_d + \not{q}_c) (1-\gamma_5) c | 0 \rangle = i f_D m_D^2. \quad (A13)$$

By substituting from the Dirac equation,

$$\langle D|\bar{d}(1+\gamma_5)c|0\rangle = -if_D \frac{m_D^2}{(m_d + m_c)}. \quad (\text{A14})$$

The same argument is applied to the baryon matrix element.

APPENDIX B: THE SQUARED AMPLITUDES

The squared amplitude for the decay $\Omega_b \rightarrow \Omega_c P$ is given by

$$\begin{aligned} |\mathcal{A}|^2 = & \left(\frac{G_F}{\sqrt{2}} f_P C_{\text{eff}} \right)^2 \frac{1}{2m_{\Omega_b}^2 m_{\Omega_c}^2} \{ -F_3^2 m_{\Omega_b}^2 m_z (m_{\Omega_b}^2 + 3m_{\Omega_c}^2 - q^2)^2 + G_3^2 m_{\Omega_b}^2 m_{z'} (m_{\Omega_b}^2 + 3m_{\Omega_c}^2 - q^2)^2 \\ & + 2G_3 m_{\Omega_b} m_{\Omega_c} [2G_1 m_{\Omega_b} m_+ + G_2 (-3m_{\Omega_b}^2 - m')] [m_{\Omega_b}^4 + 2m_{\Omega_b}^3 m_{\Omega_c} + 3m_{\Omega_c}^4 \\ & + m_{\Omega_b}^2 (4m_{\Omega_c}^2 - 2q^2) - 4m_{\Omega_c}^2 q^2 + q^4 + m_{\Omega_b} (6m_{\Omega_c}^3 - 2m_{\Omega_c} q^2)] + 2F_3 m_{\Omega_b} m_{\Omega_c} [2F_1 m_{\Omega_b} m_- \\ & + F_2 (3m_{\Omega_b}^2 + m')] [m_{\Omega_b}^4 - 2m_{\Omega_b}^3 m_{\Omega_c} + 3m_{\Omega_c}^4 + m_{\Omega_b}^2 (4m_{\Omega_c}^2 - 2q^2) - 4m_{\Omega_c}^2 q^2 + q^4 \\ & + m_{\Omega_b} (-6m_{\Omega_c}^3 + 2m_{\Omega_c} q^2)] + m_{\Omega_c}^2 [-4F_1^2 m_{\Omega_b}^2 m_z^2 - F_2^2 (3m_{\Omega_b}^2 + m')^2 m_z + m_{z'} (2G_1 m_{\Omega_b} m_+ + G_2 (-3m_{\Omega_b}^2 - m'))^2 \\ & - 4F_1 F_2 m_{\Omega_b} m_- (3m_{\Omega_b}^4 - 6m_{\Omega_b}^3 m_{\Omega_c} + 4m_{\Omega_b}^2 m' + m'^2 - 2m_{\Omega_b} m_{\Omega_c} m')] \}. \end{aligned} \quad (\text{B1})$$

For the decay $\Omega_b \rightarrow \Omega_c V$, we have

$$\begin{aligned} |\mathcal{A}|^2 = & \left(\frac{G_F}{\sqrt{2}} f_V m_V C_{\text{eff}} \right)^2 \frac{1}{2m_{\Omega_b}^2 m_{\Omega_c}^2 q^2} \{ 2G_3 m_{\Omega_b} m_{\Omega_c} m_{z'} [-G_2 (3m_{\Omega_b}^4 + 2m_{\Omega_b}^2 (5m_{\Omega_c}^2 - 3q^2) + 3m'^2) \\ & + 2G_1 m_{\Omega_b} (m_{\Omega_b}^3 + m_{\Omega_b}^2 m_{\Omega_c} + 3m_{\Omega_b} m_{\Omega_c}^2 + 3m_{\Omega_c}^3 - m_{\Omega_b} q^2 - 3m_{\Omega_c} q^2)] \\ & + 2F_3 m_{\Omega_b} m_{\Omega_c} m_z [F_2 (3m_{\Omega_b}^4 + 2m_{\Omega_b}^2 (5m_{\Omega_c}^2 - 3q^2) + 3m'^2) \\ & + 2F_1 m_{\Omega_b} (m_{\Omega_b}^3 - m_{\Omega_b}^2 m_{\Omega_c} + 3m_{\Omega_b} m_{\Omega_c}^2 - 3m_{\Omega_c}^3 - m_{\Omega_b} q^2 + 3m_{\Omega_c} q^2)] \\ & + F_3^2 m_{\Omega_b}^2 [-m_{\Omega_b}^6 + 2m_{\Omega_b}^5 m_{\Omega_c} - m'^2 (9m_{\Omega_c}^2 - q^2) + m_{\Omega_b}^4 (-7m_{\Omega_c}^2 + 3q^2) + 4m_{\Omega_b}^3 (3m_{\Omega_c}^3 - m_{\Omega_c} q^2) \\ & + 2m_{\Omega_b} m_{\Omega_c} (9m_{\Omega_c}^4 - 10m_{\Omega_c}^2 q^2 + q^4) - 3m_{\Omega_b}^2 (5m_{\Omega_c}^4 - 6m_{\Omega_c}^2 q^2 + q^4)] \\ & + G_3^2 m_{\Omega_b}^2 [m_{\Omega_b}^6 + 2m_{\Omega_b}^5 m_{\Omega_c} + m_{\Omega_b}^4 (7m_{\Omega_c}^2 - 3q^2) + m'^2 (9m_{\Omega_c}^2 - q^2) + 4m_{\Omega_b}^3 (3m_{\Omega_c}^3 - m_{\Omega_c} q^2) \\ & + 2m_{\Omega_b} m_{\Omega_c} (9m_{\Omega_c}^4 - 10m_{\Omega_c}^2 q^2 + q^4) + 3m_{\Omega_b}^2 (5m_{\Omega_c}^4 - 6m_{\Omega_c}^2 q^2 + q^4)] \\ & + m_{\Omega_c}^2 [4G_1^2 m_{\Omega_b}^6 - 12G_1 G_2 m_{\Omega_b}^6 + 9G_2^2 m_{\Omega_b}^6 + 16G_1^2 m_{\Omega_b}^5 m_{\Omega_c} - 36G_1 G_2 m_{\Omega_b}^5 m_{\Omega_c} + 18G_2^2 m_{\Omega_b}^5 m_{\Omega_c} \\ & + 24G_1^2 m_{\Omega_b}^4 m_{\Omega_c}^2 - 40G_1 G_2 m_{\Omega_b}^4 m_{\Omega_c}^2 + 15G_2^2 m_{\Omega_b}^4 m_{\Omega_c}^2 + 16G_1^2 m_{\Omega_b}^3 m_{\Omega_c}^3 - 24G_1 G_2 m_{\Omega_b}^3 m_{\Omega_c}^3 + 12G_2^2 m_{\Omega_b}^3 m_{\Omega_c}^3 \\ & + 4G_1^2 m_{\Omega_b}^2 m_{\Omega_c}^4 - 12G_1 G_2 m_{\Omega_b}^2 m_{\Omega_c}^4 + 7G_2^2 m_{\Omega_b}^2 m_{\Omega_c}^4 - 4G_1 G_2 m_{\Omega_b} m_{\Omega_c}^5 + 2G_2^2 m_{\Omega_b} m_{\Omega_c}^5 + G_2^2 m_{\Omega_c}^6 \\ & + 4G_1^2 m_{\Omega_b}^4 q^2 + 24G_1 G_2 m_{\Omega_b}^4 q^2 - 19G_2^2 m_{\Omega_b}^4 q^2 - 40G_1^2 m_{\Omega_b}^3 m_{\Omega_c} q^2 + 40G_1 G_2 m_{\Omega_b}^3 m_{\Omega_c} q^2 - 20G_2^2 m_{\Omega_b}^3 m_{\Omega_c} q^2 \\ & + 4G_1^2 m_{\Omega_b}^2 m_{\Omega_c}^2 q^2 + 24G_1 G_2 m_{\Omega_b}^2 m_{\Omega_c}^2 q^2 - 18G_2^2 m_{\Omega_b}^2 m_{\Omega_c}^2 q^2 + 8G_1 G_2 m_{\Omega_b} m_{\Omega_c}^3 q^2 - 4G_2^2 m_{\Omega_b} m_{\Omega_c}^3 q^2 - 3G_2^2 m_{\Omega_c}^4 q^2 \\ & - 8G_1^2 m_{\Omega_b}^2 q^4 - 12G_1 G_2 m_{\Omega_b}^2 q^4 + 11G_2^2 m_{\Omega_b}^2 q^4 - 4G_1 G_2 m_{\Omega_b} m_{\Omega_c} q^4 + 2G_2^2 m_{\Omega_b} m_{\Omega_c} q^4 + 3G_2^2 m_{\Omega_c}^2 q^4 - G_2^2 q^6 \\ & - 4F_1 F_2 m_{\Omega_b} (3m_{\Omega_b}^5 - 9m_{\Omega_b}^4 m_{\Omega_c} + 2m_{\Omega_b}^3 (5m_{\Omega_c}^2 - 3q^2) + 3m_{\Omega_b} m'^2 - m_{\Omega_c} m'^2 \\ & + m_{\Omega_b}^2 (-6m_{\Omega_c}^3 + 10m_{\Omega_c} q^2)) - 4F_1^2 m_{\Omega_b}^2 (m_{\Omega_b}^4 - 4m_{\Omega_b}^3 m_{\Omega_c} + m_{\Omega_c}^4 + m_{\Omega_b}^2 q^2 - 2q^4 + m_{\Omega_b}^2 (6m_{\Omega_c}^2 + q^2) \\ & + m_{\Omega_b} (-4m_{\Omega_c}^3 + 10m_{\Omega_c} q^2)) + F_2^2 (-9m_{\Omega_b}^6 + 18m_{\Omega_b}^5 m_{\Omega_c} + 2m_{\Omega_b} m_{\Omega_c} (m_{\Omega_c}^2 - q^2)^2 - (m_{\Omega_c}^2 - q^2)^3 \\ & + m_{\Omega_b}^4 (-15m_{\Omega_c}^2 + 19q^2) + 4m_{\Omega_b}^3 (3m_{\Omega_c}^3 - 5m_{\Omega_c} q^2) + m_{\Omega_b}^2 (-7m_{\Omega_c}^4 + 18m_{\Omega_c}^2 q^2 - 11q^4))] \}, \end{aligned} \quad (\text{B2})$$

where $m_z = m_{\Omega_b}^2 - 2m_{\Omega_b} m_{\Omega_c} + m_{\Omega_c}^2 - q^2$, $m_{z'} = m_{\Omega_b}^2 + 2m_{\Omega_b} m_{\Omega_c} + m_{\Omega_c}^2 - q^2$, $m_+ = m_{\Omega_b} + m_{\Omega_c}$, $m_- = m_{\Omega_b} - m_{\Omega_c}$, $m' = m_{\Omega_c}^2 - q^2$.

- [1] J. P. Lees *et al.* (BABAR Collaboration), Evidence for an excess of $\bar{B} \rightarrow D^{(*)} \tau^- \bar{\nu}_\tau$ decays, *Phys. Rev. Lett.* **109**, 101802 (2012).
- [2] R. Aaij *et al.* (LHCb Collaboration), Test of lepton universality using $B^+ \rightarrow K^+ \ell^+ \ell^-$ decays, *Phys. Rev. Lett.* **113**, 151601 (2014).
- [3] R. Aaij *et al.* (LHCb Collaboration), Measurement of the ratio of branching fractions $\mathcal{B}(B_c^+ \rightarrow J/\psi \tau^+ \nu_\tau) / \mathcal{B}(B_c^+ \rightarrow J/\psi \mu^+ \nu_\mu)$, *Phys. Rev. Lett.* **120**, 121801 (2018).
- [4] K. Abe *et al.* (Belle Collaboration), Observation of large CP violation in the neutral B meson system, *Phys. Rev. Lett.* **87**, 091802 (2001).
- [5] B. Aubert *et al.* (BABAR Collaboration), Measurement of CP violating asymmetries in B^0 decays to CP eigenstates, *Phys. Rev. Lett.* **86**, 2515 (2001).
- [6] J. H. Christenson, J. W. Cronin, V. L. Fitch, and R. Turlay, Evidence for the 2π decay of the K_S^0 meson, *Phys. Rev. Lett.* **13**, 138 (1964).
- [7] A. Abashian *et al.* (Belle Collaboration), Measurement of the CP violation parameter $\sin 2\phi_1$ in B_d^0 meson decays, *Phys. Rev. Lett.* **86**, 2509 (2001).
- [8] Y. Chao *et al.* (Belle Collaboration), Evidence for direct CP violation in $B^0 \rightarrow K^+ \pi^-$ decays, *Phys. Rev. Lett.* **93**, 191802 (2004).
- [9] B. Aubert *et al.* (BABAR Collaboration), Observation of direct CP violation in $B^0 \rightarrow K^+ \pi^-$ decays, *Phys. Rev. Lett.* **93**, 131801 (2004).
- [10] S. Navas *et al.* (Particle Data Group), Review of particle physics, *Phys. Rev. D* **110**, 030001 (2024).
- [11] R. Aaij *et al.* (LHCb Collaboration), Study of the kinematic dependences of Λ_b^0 production in pp collisions and a measurement of the $\Lambda_b^0 \rightarrow \Lambda_c^+ \pi^-$ branching fraction, *J. High Energy Phys.* **08** (2014) 143.
- [12] R. Aaij *et al.* (LHCb Collaboration), Searches for Λ_b^0 and Ξ_b^0 decays to $K_S^0 p \pi^-$ and $K_S^0 p K^-$ final states with first observation of the $\Lambda_b^0 \rightarrow K_S^0 p \pi^-$ decay, *J. High Energy Phys.* **04** (2014) 087.
- [13] R. Aaij *et al.* (LHCb Collaboration), Observation of the decay $\Lambda_b^0 \rightarrow \Lambda_c^+ \tau^- \bar{\nu}_\tau$, *Phys. Rev. Lett.* **128**, 191803 (2022).
- [14] G. Aad *et al.* (ATLAS Collaboration), Measurement of the branching ratio $\Gamma(\Lambda_b^0 \rightarrow \psi(2S) \Lambda^0) / \Gamma(\Lambda_b^0 \rightarrow J/\psi \Lambda^0)$ with the ATLAS detector, *Phys. Lett. B* **751**, 63 (2015).
- [15] I. Heredia-De La Cruz (D0 Collaboration), Measurement of the production fraction times branching fraction $f(b \rightarrow \Lambda_b) \times \mathcal{B}(\Lambda_b \rightarrow J \wedge \psi \Lambda)$, *arXiv:1109.6083*.
- [16] T. Aaltonen *et al.* (CDF Collaboration), Observation of the Ω_b^- and measurement of the properties of the Ξ_b^- and Ω_b^- , *Phys. Rev. D* **80**, 072003 (2009).
- [17] T. Aaltonen *et al.* (CDF Collaboration), Measurement of the masses and widths of the bottom baryons Σ_b^{+-} and Σ_b^{*+-} , *Phys. Rev. D* **85**, 092011 (2012).
- [18] R. Aaij *et al.* (LHCb Collaboration), Study of the production of Λ_b^0 and $\bar{B}^0$ hadrons in pp collisions and first measurement of the $\Lambda_b^0 \rightarrow J/\psi p K^-$ branching fraction, *Chin. Phys. C* **40**, 011001 (2016).
- [19] R. Aaij *et al.* (LHCb Collaboration), Evidence for the strangeness-changing weak decay $\Xi_b^- \rightarrow \Lambda_b^0 \pi^-$, *Phys. Rev. Lett.* **115**, 241801 (2015).
- [20] Q. P. Xu and A. N. Kamal, Inclusive decays of bottom baryons, *Phys. Rev. D* **47**, 2849 (1993).
- [21] R. Mohanta, A. K. Giri, and M. P. Khanna, Charmless two-body hadronic decays of Λ_b baryon, *Phys. Rev. D* **63**, 074001 (2001).
- [22] C. Q. Geng, C. W. Liu, and T. H. Tsai, Nonleptonic two-body weak decays of Λ_b in modified MIT bag model, *Phys. Rev. D* **102**, 034033 (2020).
- [23] Z. Neishabouri and K. Azizi, Investigation of the semileptonic decays $\Xi_b^{(\prime)} \rightarrow \Xi_c^{(\prime)} \ell \bar{\nu}_\ell$, *Phys. Rev. D* **112**, 054009 (2025).
- [24] R. N. Faustov and V. O. Galkin, Semileptonic decays of Λ_b baryons in the relativistic quark model, *Phys. Rev. D* **94**, 073008 (2016).
- [25] R. L. Singleton, Semileptonic baryon decays with a heavy quark, *Phys. Rev. D* **43**, 2939 (1991).
- [26] M. A. Ivanov, V. E. Lyubovitskij, J. G. Korner, and P. Kroll, Heavy baryon transitions in a relativistic three quark model, *Phys. Rev. D* **56**, 348 (1997).
- [27] L. Khajouei and K. Azizi, Semileptonic and nonleptonic weak decays of bottom baryons $\Omega_b^{(*)}$, *arXiv:2510.01429*.
- [28] T. M. Aliev, K. Azizi, and A. Ozpineci, Radiative decays of the heavy flavored baryons in light cone QCD sum rules, *Phys. Rev. D* **79**, 056005 (2009).
- [29] K. Azizi, R. Khosravi, and F. Falahati, Analyzing of the $B(q) \rightarrow D(q)(D^*(q))$ P and $B(q) \rightarrow D(q)(D^*(q))$ V decays within the factorization approach in QCD, *Int. J. Mod. Phys. A* **24**, 5845 (2009).
- [30] R. Aaij *et al.* (LHCb Collaboration), Observation of CP violation in two-body $B_{(s)}^0$ -meson decays to charged pions and kaons, *J. High Energy Phys.* **03** (2021) 075.
- [31] R. Aaij *et al.* (LHCb Collaboration), Observation of CP violation in charm decays, *Phys. Rev. Lett.* **122**, 211803 (2019).
- [32] R. Aaij *et al.* (LHCb Collaboration), Measurement of CP asymmetries in $\Lambda_b^0 \rightarrow p \pi^-$ decays, *Phys. Rev. D* **111**, 092004 (2025).
- [33] R. Aaij *et al.* (LHCb Collaboration), Observation of charge-parity symmetry breaking in baryon decays, *Nature (London)* **643**, 1223 (2025).
- [34] A. D. Sakharov, Violation of CP invariance, C asymmetry, and baryon asymmetry of the universe, *Pis'ma Zh. Eksp. Teor. Fiz.* **5**, 32 (1967).
- [35] T. A. Aaltonen *et al.* (CDF Collaboration), Mass and lifetime measurements of bottom and charm baryons in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV, *Phys. Rev. D* **89**, 072014 (2014).
- [36] C. Q. Zhang, J. M. Li, M. K. Jia, and Z. Rui, Nonleptonic two-body decays of $\Lambda_b \rightarrow \Lambda_c \pi, \Lambda_c K$ in the perturbative QCD approach, *Phys. Rev. D* **105**, 073005 (2022).
- [37] M. A. Ivanov, J. G. Korner, V. E. Lyubovitskij, and A. G. Rusetsky, Exclusive nonleptonic bottom to charm baryon decays including nonfactorizable contributions, *Mod. Phys. Lett. A* **13**, 181 (1998).
- [38] S. Catani and L. Trentadue, Resummation of the QCD perturbative series for hard processes, *Nucl. Phys.* **B327**, 323 (1989).
- [39] J. C. Collins and D. E. Soper, Back-to-back jets in QCD, *Nucl. Phys.* **B193**, 381 (1981); **B213**, 545(E) (1983).

- [40] J. C. Collins, D. E. Soper, and G. F. Sterman, Transverse momentum distribution in Drell-Yan pair and W and Z boson production, *Nucl. Phys.* **B250**, 199 (1985).
- [41] G. Buchalla, A. J. Buras, and M. E. Lautenbacher, Weak decays beyond leading logarithms, *Rev. Mod. Phys.* **68**, 1125 (1996).
- [42] Z. Neishabouri, K. Azizi, and H. R. Moshfegh, Semileptonic $\Omega_b \rightarrow \Omega_c \ell \nu^- \ell$ transition in full QCD, *Phys. Rev. D* **110**, 014010 (2024).
- [43] M. Thomson, *Modern Particle Physics* (Cambridge University Press, Cambridge, England, 2013), ISBN 978-1-107-03426-6, 978-1-139-52536-7.
- [44] A. Faessler, T. Gutsche, M. A. Ivanov, J. G. Körner, and V. E. Lyubovitskij, Semileptonic decays of double heavy baryons in a relativistic constituent three-quark model, *Phys. Rev. D* **80**, 034025 (2009).
- [45] T. Gutsche, M. A. Ivanov, J. G. Körner, V. E. Lyubovitskij, V. V. Lyubushkin, and P. Santorelli, Theoretical description of the decays $\Lambda_b \rightarrow \Lambda^{(*)}(\frac{1}{2}^{\pm}, \frac{3}{2}^{\pm}) + J/\psi$, *Phys. Rev. D* **96**, 013003 (2017).
- [46] A. J. Buras, M. Jamin, and M. E. Lautenbacher, Two loop anomalous dimension matrix for Delta S = 1 weak nonleptonic decays. 2. O(alpha-alpha-s), *Nucl. Phys.* **B400**, 75 (1993).
- [47] M. Ciuchini, E. Franco, G. Martinelli, and L. Reina, The Delta S = 1 effective Hamiltonian including next-to-leading order QCD and QED corrections, *Nucl. Phys.* **B415**, 403 (1994).
- [48] N. G. Deshpande and X. G. He, Gluonic penguin B decays in standard and two Higgs doublet models, *Phys. Lett. B* **336**, 471 (1994).
- [49] S. Narison, A fresh look into $m_{c,b}$ and precise $f_{D(s),B(s)}$ from heavy-light QCD spectral sum rules, *Phys. Lett. B* **718**, 1321 (2013).
- [50] T. Gutsche, M. A. Ivanov, J. G. Körner, and V. E. Lyubovitskij, Nonleptonic two-body decays of single heavy baryons Λ_Q, Ξ_Q , and Ω_Q ($Q = b, c$) induced by W emission in the covariant confined quark model, *Phys. Rev. D* **98**, 074011 (2018).
- [51] Y. S. Li and X. Liu, Restudy of the color-allowed two-body nonleptonic decays of bottom baryons Ξ_b and Ω_b supported by hadron spectroscopy, *Phys. Rev. D* **105**, 013003 (2022).
- [52] D. Becirevic, P. Boucaud, J. P. Leroy, V. Lubicz, G. Martinelli, F. Mescia, and F. Rapuano, Nonperturbatively improved heavy—light mesons: Masses and decay constants, *Phys. Rev. D* **60**, 074501 (1999).
- [53] Z. X. Zhao, Weak decays of heavy baryons in the light-front approach, *Chin. Phys. C* **42**, 093101 (2018).
- [54] C. K. Chua, Color-allowed bottom baryon to s-wave and p-wave charmed baryon nonleptonic decays, *Phys. Rev. D* **100**, 034025 (2019); *Phys. Rev. D* **100**, 034025 (2019).
- [55] C. K. Chua, Color-allowed bottom baryon to s-wave and p-wave charmed baryon non-leptonic decays, *Proc. Sci., EPS-HEP2019* (2020) 471 [arXiv:1905.00153v2].
- [56] H. Y. Cheng, Nonleptonic weak decays of bottom baryons, *Phys. Rev. D* **56**, 2799 (1997); **99**, 079901(E) (2019).
- [57] R. V. Patel, M. Shah, S. Patel, and B. Pandya, Singly heavy Ω baryon spectroscopy in the relativistic framework of an independent quark model, *Phys. Rev. D* **112**, 056025 (2025).