

Decoding weak phase amplitudes in charmed baryon decays

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In this paper, we present a strategy to decode decay amplitudes with different weak phases in two-body charmed baryon decays, addressing a long-standing challenge to understanding CP violation in this sector. Using $SU(3)$ flavor symmetry, we disentangle the amplitudes defined through $M = \lambda_s A_s + \lambda_b A_b$ ($\lambda_i = V_{ui} V_{ci}^*$), enabling a data-driven determination of their relative hierarchy across Cabibbo-favored, singly, and doubly Cabibbo-suppressed modes. Applying this framework to current data, we find that the ratio A_b/A_s is approximately 100 times larger than expectation of $\mathcal{O}(1)$ at 2.1σ level. This unexpected pattern may be accommodated by $SU(3)$ breaking effects, but it can also point to new physics. We further show that the Lee-Yang parameters provide an independent and complementary probe. To resolve this ambiguity in the origin of the enhancement, we propose a decisive discriminator using decay modes insensitive to large $SU(3)$ breaking, in particular $\Xi_c^0 \rightarrow pK^-$ and $\Xi_c^0 \rightarrow \Sigma^+ \pi^-$ as golden channels. Measurements of these modes will distinguish between symmetry breaking effects and new physics, establishing a clean pathway to probe CP violation in the charm baryon sector.

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Introduction. Charge-parity (CP) violation is a crucial ingredient for understanding the matter-antimatter asymmetry of the universe. In the Standard Model (SM), CP violation in charm decays is expected to be tiny due to the Cabibbo-Kobayashi-Maskawa (CKM) suppression. However, this picture has been challenged by the LHCb Collaboration [1,2], which reported the larger-than-expected CP violation in neutral D -meson decays. This raises a natural question of whether similar effects may also arise in the charmed baryon sector.

Two-body charmed-baryon decays provide a particularly clean and largely unexplored arena for addressing this question. For the modes $B_c \rightarrow BP$, where B_c denotes the charm baryon, B the light baryon and P the meson, the decay amplitudes exhibit a rich structure [3–7]. These channels are organized into Cabibbo-favored (CF), singly Cabibbo-suppressed (SCS), and doubly Cabibbo-suppressed (DCS) classes, offering a natural framework for separating contributions with different CKM hierarchies. Each decay receives parity-conserving and parity-violating amplitudes, allowing

the decay matrix element $\mathcal{M}$ and width Γ as [8]

$$\begin{aligned} \mathcal{M} &= i\bar{u}_B(F - G\gamma_5)u_{B_c}, \quad |M|^2 = |F|^2 + \kappa^2|G|^2 \\ \Gamma &= \frac{p_B}{8\pi} \frac{(m_{B_c} + m_B)^2 - m_P^2}{m_{B_c}^2} |M|^2. \end{aligned} \quad (1)$$

Here $\kappa = p_B/(E_B + m_B)$, E_B and p_B are the energy and momentum of B in the rest frame of B_c . Throughout this work, F and G denote the full amplitude structures, including both the purely hadronic contributions and the corresponding CKM factors. For a final-state pseudoscalar meson, its negative intrinsic parity implies that scalar term F describes the parity-violating S -wave contribution, whereas the γ_5 term G describes the parity-conserving P -wave contribution.

Observable CP violation arises only in SCS transitions, where amplitudes with different weak phases can interfere. The dominant tree-level amplitudes scale with $\lambda_d = V_{cd}^* V_{ud}$ or $\lambda_s = V_{cs}^* V_{us}$, while penguin amplitudes are proportional to the much smaller combination $\lambda_b = V_{cb}^* V_{ub}$. Using the unitarity relation $\lambda_d = -\lambda_s - \lambda_b$, the two parity amplitudes for SCS can be parametrized as $F = \lambda_s A_s^f + \lambda_b A_b^f$ and $G = \lambda_s A_s^g + \lambda_b A_b^g$, where the superscripts f, g label the F- and G-type parity structures, respectively, while the subscripts s, b indicate the hadronic components associated with corresponding CKM factors. In particular, A_b receives not only penguin contributions but also specific tree components after the CKM rearrangement. Since both A_s and A_b

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receive the tree-level contributions with comparable Wilson coefficients, one naively expects $A_b/A_s \sim \mathcal{O}(1)$, implying $|\lambda_b A_b/\lambda_s A_s| \sim \mathcal{O}(10^{-3})$. Interference among them can generate observable CP violation, making charmed baryons a sensitive probe of both hadronic dynamics and possible new physics [9,10].

In this Letter, we develop a data-driven $SU(3)$ strategy that combines CF, SCS, and DCS modes, to separate A_b and A_s without relying on direct CPV measurements. Current data favor $A_b/A_s = \mathcal{O}(100)$, a 2.1σ departure from the naive $\mathcal{O}(1)$ expectation. We examine whether this enhancement can arise from $\mathcal{O}(10\%)$ $SU(3)$ breaking effects, and identify $\Xi_c^0 \rightarrow pK^-$ and $\Xi_c^0 \rightarrow \Sigma^+\pi^-$ as breaking insensitive channels that discriminate symmetry breaking from new physics.

Charmed baryon decay amplitudes. We employ the irreducible representation amplitudes (IRA) of $SU(3)$ flavor symmetry for anti-triplet charmed baryons B_c decays into an octet baryon B and a pseudoscalar meson P . The two light quarks in a ground-state charmed baryon form an anti-triplet $\bar{3}$ and a sextet 6 under $3 \otimes 3 = 6 \oplus \bar{3}$. The initial anti-triplet is indicated by $(B_c)^{ij}$ or equivalently $(B_c)_k = \frac{1}{2}\epsilon_{kij}(B_c)^{ij} = (\Xi_c^0, -\Xi_c^+, \Lambda_c^+)$. The final states comprise baryon octet $B: (n, p, \Lambda^0, \Sigma^{\pm,0}, \Xi^{\pm,0})$, meson octet $P_8: (\pi^{\pm,0}, K^{\pm,0}, \bar{K}^0, \eta_8)$ and singlet η_1 , as detailed in Refs. [9,11]. The effective Lagrangian contains 3, $\bar{6}$ and 15 components, with CF, SCS, and DCS parts distinguished by their CKM factors [10]

$$\begin{aligned}\mathcal{L}_{\text{eff}}^{\text{CF}} &= -\frac{G_F}{\sqrt{2}} V_{cs}^* V_{ud} \{C_+[(\bar{u}d)_L(\bar{s}c)_L + (\bar{s}d)_L(\bar{u}c)_L]_{15} + C_-[(\bar{u}d)_L(\bar{s}c)_L - (\bar{s}d)_L(\bar{u}c)_L]_{\bar{6}}\}, \\ \mathcal{L}_{\text{eff}}^{\text{DCS}} &= -\frac{G_F}{\sqrt{2}} V_{cd}^* V_{us} \{C_+[(\bar{u}s)_L(\bar{d}c)_L + (\bar{d}s)_L(\bar{u}c)_L]_{15} + C_-[(\bar{u}s)_L(\bar{d}c)_L - (\bar{d}s)_L(\bar{u}c)_L]_{\bar{6}}\}, \\ \mathcal{L}_{\text{eff}}^{\text{SCS}} &= -\frac{G_F}{\sqrt{2}} \frac{\lambda_s - \lambda_d}{2} \{C_+[(\bar{u}s)_L(\bar{s}c)_L + (\bar{s}s)_L(\bar{u}c)_L - (\bar{d}d)_L(\bar{u}c)_L - (\bar{u}d)_L(\bar{d}c)_L]_{15} \\ &\quad + C_-[(\bar{u}s)_L(\bar{s}c)_L - (\bar{s}s)_L(\bar{u}c)_L + (\bar{d}d)_L(\bar{u}c)_L - (\bar{u}d)_L(\bar{d}c)_L]_{\bar{6}}\}, \\ &\quad + \frac{G_F \lambda_b}{\sqrt{2} 4} \left\{ C_+[(\bar{u}d)_L(\bar{d}c)_L + (\bar{d}d)_L(\bar{u}c)_L + (\bar{s}s)_L(\bar{u}c)_L + (\bar{u}s)_L(\bar{s}c)_L - 2(\bar{u}u)_L(\bar{u}c)_L]_{15} \right. \\ &\quad \left. + C_+ \sum_{q=u,d,s} [(\bar{u}q)_L(\bar{q}c)_L + (\bar{q}q)_L(\bar{u}c)_L]_{3_+} + 2C_- \sum_{q=d,s} [(\bar{u}q)_L(\bar{q}c)_L - (\bar{q}q)_L(\bar{u}c)_L]_{3_-} \right\}. \quad (2)\end{aligned}$$

Here, we define $(\bar{q}_1 q_2)_L \equiv \bar{q}_1 \gamma_\mu (1 - \gamma_5) q_2$. The subscripts on the square bracket label the $SU(3)$ representations, with $3 \otimes 3 \otimes \bar{3} = 15 \oplus \bar{6} \oplus 3_+ \oplus 3_-$. The Wilson coefficients are written as $C_\pm = C_1 \pm C_2$ since the current-current operators Q_1 and Q_2 are more conveniently combined as $Q_\pm = (Q_1 \pm Q_2)/2$, where $Q_1 = (\bar{q}_{1\alpha} c_\beta)_L (\bar{q}_{3\beta} q_{2\alpha})_L$ and $Q_2 = (\bar{q}_{1\alpha} c_\alpha)_L (\bar{q}_{3\beta} q_{2\beta})_L$. For SCS processes, the effective Lagrangian is decomposed into two distinct parts; one proportional to $\lambda_s - \lambda_d$ and another proportional to λ_b . For the latter, the $SU(3)$ triplet representation originates from penguin operators, which have not been shown explicitly above and are conventionally expressed as $\lambda_b \sum_{i=3}^6 C_i O_i$ [12,13]. The $\bar{15}$ representation arises from the interference of

tree operators, using the identity $\lambda_d = -\lambda_s - \lambda_b$. Therefore, the decay amplitudes can be categorized into a dominant tree amplitude proportional to λ_s and a smaller component proportional to λ_b , $M = \lambda_s A_s + \lambda_b A_b$.

Considering only the flavor structure, five $SU(3)$ contraction can be constructed for $H(15)$, but the Körner-Pati-Woo (KPW) theorem reduces them to a single independent term after imposing the quark color-symmetry constraints [14–16]. By applying the KPW theorem and using the explicit forms of the initial and final states along with the effective Lagrangian, the parity-violating amplitudes F , including penguin contributions, can be expressed in terms of invariant decay amplitudes as [11,17]

$$\begin{aligned}\mathcal{F}^{\text{IRA}} &= \tilde{f}^a(\eta_1)(\bar{\mathbf{B}})_k^j \mathcal{H}(\bar{\mathbf{6}})_{ij}(\mathbf{B}_c)^{ik} + \tilde{f}^b(P_8^\dagger)_k^l(\bar{\mathbf{B}})_j^k \mathcal{H}(\bar{\mathbf{6}})_{il}(\mathbf{B}_c)^{ij} + \tilde{f}^c(P_8^\dagger)_j^l(\bar{\mathbf{B}})_l^k \mathcal{H}(\bar{\mathbf{6}})_{ik}(\mathbf{B}_c)^{ij} + \tilde{f}^d(P_8^\dagger)_j^l(\bar{\mathbf{B}})_l^k \mathcal{H}(\bar{\mathbf{6}})_{kl}(\mathbf{B}_c)^{ij} \\ &\quad + \tilde{f}^e(P_8^\dagger)_k^l(\bar{\mathbf{B}})_j^i \mathcal{H}(\mathbf{15})_l^{jk}(\mathbf{B}_c)_i + \tilde{f}_3^a(\eta_1)(\bar{\mathbf{B}})_i^j \mathcal{H}(\mathbf{3})^i(\mathbf{B}_c)_j + \tilde{f}_3^b(P_8^\dagger)_k^i(\bar{\mathbf{B}})_m^k \mathcal{H}(\mathbf{3})^m(\mathbf{B}_c)_i + \tilde{f}_3^c(P_8^\dagger)_k^m(\bar{\mathbf{B}})_m^k \mathcal{H}(\mathbf{3})^i(\mathbf{B}_c)_i \\ &\quad + \tilde{f}_3^d(P_8^\dagger)_n^m(\bar{\mathbf{B}})_m^k \mathcal{H}(\mathbf{3})^n(\mathbf{B}_c)_k + \tilde{f}_1^v(\mathbf{B}_c)^{il} \mathcal{H}(\bar{\mathbf{6}})_{ij}(\bar{\mathbf{B}})_l^j P_k^i \hat{M}_m^k - \bar{\mathbf{B}}_l^k P_k^m \hat{M}_m^j + \tilde{f}_2^v(\mathbf{B}_c)^{il} \mathcal{H}(\bar{\mathbf{6}})_{ij} \bar{\mathbf{B}}_m^j P_l^k \hat{M}_k^m. \quad (3)\end{aligned}$$

The relevant symbols are summarized as follows: charmed baryon B_c , final state baryon $\bar{\mathbf{B}}$, final state meson $P_8^\dagger/\eta_1$, the effective weak Hamiltonian $\mathcal{H}(a)$ with representation

$a = 3, \bar{6}, 15$, where the repeated flavor indices i, j, k, l, m , $n = 1, 2, 3$ is summed. Each $SU(3)$ -invariant amplitude $\tilde{f}$ is associated with an independent, *a priori* undetermined

parameter. The coefficients $\tilde{f}_3^a, \tilde{f}_3^b, \tilde{f}_3^c, \tilde{f}_3^d$ encode not only penguin contributions but also specific tree-level terms. The last two lines $\tilde{f}_{1,2}^v$ represent $SU(3)$ breaking effects, dominated by the strange-quark condensate $\langle \bar{s}s \rangle$ with mass spurion $\hat{M} \propto \text{diag}(0, 0, 1)$, as discussed in Ref. [10]. Later, we will find that these $SU(3)$ breaking terms may play an important role in explaining existing data. The parity-conserving G amplitudes admit an analogous decomposition.

Decoding hierarchy and unexpected enhancement. From the expansion in Eq. (3), one obtains the decay amplitudes for individual channels as summarized in Table I. Note that A_s and A_b denote the pure hadronic amplitudes without CKM factor, each given by a specific linear combination of the parameters $\tilde{f}$. Multiplying A_s by $V_{ud}V_{cs}^*$, λ_s , and $V_{us}V_{cd}^*$ yields the CF, SCS, and DCS amplitudes, respectively, while the $\lambda_b A_b$ term occurs only in the SCS sector, as shown in Table I. To isolate A_b , we establish relations among CF, DCS, and SCS amplitudes. Once A_s is fixed from CF modes, A_b can therefore be extracted from the SCS amplitudes.

To elucidate how our methods decodes A_b amplitudes using Table I, we first express the decay amplitudes F in terms of the CF, SCS, and DCS ones, given by

$$\begin{aligned} F(CF) &= V_{ud}V_{cs}^*(T_s^f + T_{v,C}^f) = V_{ud}V_{cs}^*A_{s,C}^f, \\ F(SCS) &= \sigma\lambda_s T_s^f + \lambda_b T_b^f + T_{v,S}^f(\lambda_s + \lambda_b/2) \\ &= \sigma\lambda_s A_{s,S}^f + \lambda_b A_{b,S}^f, \sigma = \pm 1, \\ F(DCS) &= V_{us}V_{cd}^*(T_s^f + T_{v,D}^f) = V_{us}V_{cd}^*A_{s,D}^f, \end{aligned} \quad (4)$$

where we define $A_{s,S}^f = T_s^f + \sigma T_{v,S}^f$ and $A_{b,S}^f = T_b^f + T_{v,S}^f/2$ with the subscript C, S, D serving as abbreviations of CF, SCS and DCS, respectively. Here $T_s(T_b)$ is the pure hadronic amplitude without CKM factor $\lambda_s(\lambda_b)$ as listed in the third column of Table I, while T_v denotes the dominant $SU(3)$ breaking correction in the fourth column. In the absence of such specification, the general notations A_s^f and A_b^f are employed. And the sign of $\sigma = \pm 1$ depends on the specific CF and SCS decay chains. Each amplitude $A_{s,b}$ represents specific linear combinations of the reduced amplitudes $\tilde{f}$ listed in Table I. The amplitude A_s^f contains only tree-level contributions, whereas A_b^f receives both tree-level and penguin contributions. The G amplitudes can be written similarly, with A^f replaced by A^g .

The ratios of the squared amplitudes between SCS and CF (or DCS) channels can then be expressed as

$$\begin{aligned} \frac{|M(SCS)|^2}{|M(CF)|^2} &= \frac{|V_{us}|^2}{|V_{ud}|^2} (1 + 2\sigma \text{Re}(R_T^P) + O(\lambda_b^2)), \\ \frac{|M(SCS)|^2}{|M(DCS)|^2} &= \frac{|V_{cs}|^2}{|V_{cd}|^2} (1 + 2\sigma \text{Re}(R_T^P) + O(\lambda_b^2)), \end{aligned} \quad (5)$$

where

$$R_T^P = \frac{(A_{s,C/D}^f + \frac{\sigma}{2}A_v)A_v^* + \frac{\lambda_b^*}{\lambda_s^*}A_{s,S}^f A_{b,S}^{f*} + \kappa^2(f \rightarrow g)}{|A_{s,C/D}^f|^2 + \kappa^2|A_{s,C/D}^g|^2}, \quad (6)$$

we define $A_v = A_{s,S} - \sigma A_{s,C/D}$. Here the dimensionless quantity R_T^P quantifies the deviation of SCS amplitude from

TABLE I. Representative decay channel with $SU(3)_F$ amplitudes F and experimental data. The G amplitudes can be written in a similar way by replacing f_i with g_i .

	Channel	Amplitude F	$SU(3)$ breaking T_v	Br_{exp}	α_{exp}
CF	$\Xi_c^0 \rightarrow \Sigma^+ K^-$	$-\tilde{f}^c V_{ud}V_{cs}^*$		0.18(4)%	
	$\Lambda_c^+ \rightarrow \Xi^0 K^+$	$\tilde{f}^c V_{ud}V_{cs}^*$	$\tilde{f}_2^v V_{ud}V_{cs}^*$	0.55(7)%	0.01(16)
SCS	$\Xi_c^0 \rightarrow \Sigma^+ \pi^-$	$\tilde{f}^c \lambda_s + \lambda_b(\tilde{f}_3^b + \tilde{f}_3^c + \tilde{f}^c/2)$			
	$\Xi_c^0 \rightarrow p K^-$	$-\tilde{f}^c \lambda_s + \lambda_b(\tilde{f}_3^b + \tilde{f}_3^c - \tilde{f}^c/2)$			
DCS	$\Xi_c^0 \rightarrow p \pi^-$	$V_{us}V_{cd}^* \tilde{f}^c$			
	$\Xi_c^+ \rightarrow n \pi^+$	$-V_{us}V_{cd}^* \tilde{f}^c$			
CF	$\Xi_c^0 \rightarrow \Xi^- \pi^+$	$(\tilde{f}^e - \tilde{f}^b) V_{ud}V_{cs}^*$		1.43(27)%	-0.640(51)
SCS	$\Xi_c^0 \rightarrow \Sigma^- \pi^+$	$-(\tilde{f}^e - \tilde{f}^b)\lambda_s + \lambda_b(\tilde{f}_3^c + \tilde{f}_3^d - \frac{\tilde{f}^e}{4} + \frac{\tilde{f}^b - \tilde{f}^e}{2})$			
	$\Xi_c^0 \rightarrow \Xi^- K^+$	$(\tilde{f}^e - \tilde{f}^b)\lambda_s + \lambda_b(\tilde{f}_3^c + \tilde{f}_3^d - \frac{\tilde{f}^e}{4} - \frac{\tilde{f}^b - \tilde{f}^e}{2})$	$\tilde{f}_1^v(\lambda_s + \lambda_b/2)$	0.039(11)%	
DCS	$\Xi_c^0 \rightarrow \Sigma^- K^+$	$-V_{us}V_{cd}^*(\tilde{f}^e - \tilde{f}^b)$	$-\tilde{f}_1^v V_{us}V_{cd}^*$		
CF	$\Xi_c^0 \rightarrow \Xi^0 \pi^0$	$\frac{(\tilde{f}^b - \tilde{f}^d)}{\sqrt{2}} V_{ud}V_{cs}^*$		0.69(14)%	-0.90(28)
SCS	$\Lambda_c^+ \rightarrow \Sigma^+ K_S$	$\frac{(\tilde{f}^b - \tilde{f}^d)}{\sqrt{2}} \lambda_s + \lambda_b \frac{\tilde{f}_3^b + (\tilde{f}^b - \tilde{f}^d)/2}{\sqrt{2}}$	$-\frac{\tilde{f}_1^v}{\sqrt{2}}(\lambda_s + \lambda_b/2)$	0.048(14)%	
	$\Lambda_c^+ \rightarrow \Sigma^0 K^+$	$\frac{(\tilde{f}^b - \tilde{f}^d)}{\sqrt{2}} \lambda_s + \lambda_b \frac{\tilde{f}_3^b + (\tilde{f}^b - \tilde{f}^d)/2}{\sqrt{2}}$	$-\frac{\tilde{f}_1^v}{\sqrt{2}}(\lambda_s + \lambda_b/2)$	0.0373(31)%	-0.54(20)

its $SU(3)$ -related CF or DCS reference. Note that R_T^P receives two distinct contributions, $SU(3)$ breaking term A_v and λ_b/λ_s suppressed term. Since amplitude ratios are directly related to branching fractions and other decay observables, R_T^P can be expressed in terms of the corresponding branching-fraction ratio as

$$\begin{aligned} \text{Re}(R_T^P) &= \frac{1}{2\sigma}(ar_a - 1) = \frac{1}{2\sigma}(cr_c - 1), \\ \text{with } a &= \frac{K(\text{CF})|V_{ud}|^2}{K(\text{SCS})|V_{us}|^2}, \quad c = \frac{K(\text{DCS})|V_{cd}|^2}{K(\text{SCS})|V_{cs}|^2}, \\ K(X) &= \tau_{B_c} p_B ((1 + m_B/m_{B_c})^2 - m_p^2/m_{B_c}^2). \end{aligned} \quad (7)$$

where we define $r_a = Br(\text{SCS})/Br(\text{CF})$ and $r_c = Br(\text{SCS})/Br(\text{DCS})$. Here τ_{B_c} and $K(X)$ denote the lifetime of charmed baryon, and phase-space factor for the decay channel X , respectively. We also define the factors a, c to explain the differences in phase-space and CKM factors between the paired modes. Since A_b also contains tree amplitudes, it is natural to expect A_s and A_b to be of the same order, $A_b/A_s = \mathcal{O}(1)$. This implies $R_T^P \sim T_v/A_{s,C} + \lambda_b/\lambda_s$, so that the value R_T^P is controlled by the interplay between $SU(3)$ breaking effects and the CKM-suppressed ratio λ_b/λ_s . In the exact symmetry limit $T_v \rightarrow 0$, it reduces to $R_T^P \sim 10^{-3}$.

From Table I, three paired CF-SCS branching fractions have been measured experimentally in Refs. [8,18], yielding the following ratios as

$$\begin{aligned} \text{Re}(R_T^P)_{\text{exp}} \Big|_{\Xi_c^0 \rightarrow \Xi^- K^+} &= -0.21(10), \\ \text{Re}(R_T^P)_{\text{exp}} \Big|_{\Xi_c^0 \rightarrow \Xi^0 \pi^0} &= 0.10(21), \\ \text{Re}(R_T^P)_{\text{exp}} \Big|_{\Lambda_c^+ \rightarrow \Sigma^0 K^+} &= -0.03(10), \end{aligned} \quad (8)$$

where the superscript and subscript on $\text{Re}(R_T^P)$ denote SCS and CF, respectively. The extracted central values are of $\mathcal{O}(0.1)$, about two orders of magnitude above the naive expectation $\sim 10^{-3}$ in the exact $SU(3)$ symmetry limit discussed above.

In the limit of exact $SU(3)$ symmetry, the absence of A_b causes the ratio vanish. However, for $\Xi_c^0 \rightarrow \Xi^- \pi^+$ and $\Xi_c^0 \rightarrow \Xi^- K^+$, the extracted ratio departs from zero at the 2.1σ level, indicating a non-negligible contribution from $\lambda_b A_b$. A naive data analysis indicates $\text{Re}(R_T^P)$ can reach $\mathcal{O}(10\%)$, implying a comparable CP violation effect. Such a value requires the underlying hadronic ratio, $\text{Re}(e^{i\delta_{CP}}(A_b^{f*}/A_s^{f*} + \kappa^2 A_s^g A_b^{g*}/|A_s^f|^2)(1 + \kappa^2 |A_s^f/A_s^f|^2))$ to be of order $\mathcal{O}(100)$, roughly two orders of magnitude above the naive expectation of $\mathcal{O}(1)$, after factoring out the CKM factor λ_s/λ_b . Here δ_{CP} is the relative weak phase between λ_s and λ_b . This points to an unexpected enhancement in these decays.

Additionally, the Lee-Yang parameters provide an independent handle on the extraction of the A_b amplitude [19]. For CF and DCS processes, we have

$$\alpha_{CF,DCS} = \frac{2\kappa \text{Re}(F^* G)}{|F|^2 + \kappa^2 |G|^2} = \frac{2\kappa \text{Re}(A_{s,C/D}^{f*} A_{s,C/D}^g)}{|A_{s,C/D}^f|^2 + \kappa^2 |A_{s,C/D}^g|^2}, \quad (9)$$

Analogous expressions for $\beta_{CF,DCS}$ and $\gamma_{CF,DCS}$ are obtained by replacing the numerator $\text{Re}(F^* G)$ in α with $\text{Im}(F^* G)$ and $|F|^2 - \kappa^2 |G|^2$, respectively. Here the CKM factors contained in F, G cancel in the numerator and denominator.

For SCS corresponding processes, we would have

$$\alpha_{SCS} = \frac{2\kappa \text{Re}((A_{s,S}^{f*} + (z A_{b,S}^f)^*)(A_{s,S}^g + z A_{b,S}^g))}{|A_{s,S}^f + z A_{b,S}^f|^2 + \kappa^2 |A_{s,S}^g + z A_{b,S}^g|^2}, \quad (10)$$

where we define $z = \sigma \lambda_b/\lambda_s$. Analogous expressions hold for β_{SCS} and γ_{SCS} . Note that these observables provide independent sensitivity to the A_b contribution. They are parametrized by the relative deviations $X_{SCS} - X_{CF/DCS}$, where $X = \alpha, \beta, \gamma$. These ratios can be expressed by

$$\begin{aligned} \alpha_{SCS} - \alpha_{CF/DCS} &= 2 \text{Re}(R_T^P(\alpha)) + \mathcal{O}(\lambda_b^2), \\ \beta_{SCS} - \beta_{CF/DCS} &= 2 \text{Im}(R_T^P(\beta)) + \mathcal{O}(\lambda_b^2), \\ \gamma_{SCS} - \gamma_{CF/DCS} &= -4 \text{Re}(R_T^P(\gamma)) + \mathcal{O}(\lambda_b^2), \end{aligned} \quad (11)$$

with the components as

$$\begin{aligned} R_T^P(\alpha) &= \frac{1}{2}(\alpha_{SCS}|_{z \rightarrow 0} - \alpha_{CF/DCS}) \\ &\quad + \kappa z \frac{(A_{s,S}^f A_{b,S}^g - A_{b,S}^f A_{s,S}^g)((A_{s,S}^{f*})^2 - \kappa^2 (A_{s,S}^{g*})^2)}{(|A_{s,S}^f|^2 + \kappa^2 |A_{s,S}^g|^2)^2}, \\ R_T^P(\beta) &= \frac{1}{2}(\beta_{SCS}|_{z \rightarrow 0} - \beta_{CF/DCS}) \\ &\quad + \kappa z \frac{(A_{s,S}^{f*})^2 + \kappa^2 (A_{s,S}^{g*})^2}{(|A_{s,S}^f|^2 + \kappa^2 |A_{s,S}^g|^2)^2} (A_{s,S}^f A_{b,S}^g - A_{s,S}^g A_{b,S}^f), \\ R_T^P(\gamma) &= -\frac{1}{4}(\gamma_{SCS}|_{z \rightarrow 0} - \gamma_{CF/DCS}) \\ &\quad + \kappa^2 z \frac{A_{s,S}^{f*} A_{s,S}^{g*} (A_{s,S}^f A_{b,S}^g - A_{s,S}^g A_{b,S}^f)}{(|A_{s,S}^f|^2 + \kappa^2 |A_{s,S}^g|^2)^2}. \end{aligned} \quad (12)$$

Note that the first terms in $R_T^P(\alpha, \beta, \gamma)$ arise from the breaking effects, and therefore vanish in the exact $SU(3)$ symmetry limit. As an illustration, consider the paired CF-SCS system, $\Xi_c^0 \rightarrow \Xi^0 \pi^0$ and $\Lambda_c^+ \rightarrow \Sigma^0 K^+$, where the measured α values are $-0.90(28)$ and $-0.54(20)$, respectively. This suggests

$$\alpha(\Lambda_c^+ \rightarrow \Sigma^0 K^+) - \alpha(\Xi_c^0 \rightarrow \Xi^0 \pi^0) = 0.36 \pm 0.34. \quad (13)$$

In the exact $SU(3)$ symmetry, it exhibits a similarly large enhancement of the hadronic amplitude albeit within 1σ level, consistent with the pattern identified in R_T^P . A systematic investigation of these observables therefore provides an independent and complementary probe.

Possible Explanation. Such an enhancement is difficult to attribute to ordinary QCD dynamics alone. It may still reflect the limited precision of current data, but it could also point to additional underlying dynamics. If confirmed with higher accuracy, it would call for a nontrivial explanation, most notably enhanced $SU(3)$ flavor breaking or new physics with additional CP violation phases.

We first examine whether the observed enhancement can be accommodated within $SU(3)$ breaking. As shown in Table I, all three channel pairs in Eq. (8) receive sizable $SU(3)$ breaking corrections. Using the central values of the global fit parameters from Ref. [10] together with Eq. (6), we predict $\text{Re}(R_T^P) = (-0.13, -0.14, -0.14)$ for the three pairs, respectively. Similarly, we predict $\text{Re}(R_T^P(\alpha)) = -0.08$ between $\Lambda_c^+ \rightarrow \Sigma^0 K^+$ and $\Xi_c^0 \rightarrow \Xi^0 \pi^0$. These values remain consistent with current experimental results within uncertainties, suggesting that $SU(3)$ breaking provides a viable explanation of the observed enhancement. In particular, a typical breaking size of $T_v/A_s \sim 10\%$ is already sufficient to reproduce the data, without requiring a large intrinsic enhancement of A_b/A_s .

To determine whether the enhancement truly originates from dominant $SU(3)$ breaking effects in Ref. [10], it is essential to study decay modes that are relatively insensitive to such corrections. From Table I, several CF-SCS paired channels satisfy this criterion, including $\Xi_c^0 \rightarrow \Sigma^+ K^- - \Xi_c^0 \rightarrow \Sigma^+ \pi^-$, $\Xi_c^0 \rightarrow \Sigma^+ K^- - \Xi_c^0 \rightarrow p K^-$, $\Xi_c^0 \rightarrow \Xi^- \pi^+ - \Xi_c^0 \rightarrow \Sigma^- \pi^+$. We focus on CF-SCS pairs because DCS modes are experimentally more challenging. Currently, no data are available for these paired channels, highlighting the need for dedicated measurements.

Among them, $\Xi_c^0 \rightarrow \Sigma^+ \pi^-$ and $\Xi_c^0 \rightarrow p K^-$ are particularly promising and may serve as golden channels for CP violation searches. Their W -exchange topology suppresses the tree amplitude $\lambda_s A_s$ [20], enhancing the relative impact of $\lambda_b A_b$ terms to make sizable CP violation feasible. Observation of a similar enhancement in modes insensitive to these dominant $SU(3)$ breaking effects would provide a clean test of its dynamical origin. Its presence would strongly favor new physics, whereas its absence would point to $SU(3)$ breaking effects as the dominant explanation.

Conclusion. We have developed an $SU(3)$ -based, data-driven strategy to disentangle the $\lambda_s A_s$ and $\lambda_b A_b$ amplitudes in SCS charmed-baryon decays. Current data indicate an enhancement of A_b/A_s over the naive $O(1)$ expectation at the 2.1σ level, which can be accommodated by $O(10\%)$ $SU(3)$ breaking but may also signal new physics. Lee-Yang parameters provide an independent test. In particular, the $SU(3)$ -insensitive modes $\Xi_c^0 \rightarrow \Sigma^+ \pi^-$ and $\Xi_c^0 \rightarrow p K^-$, where the tree contribution is suppressed, offer clean discriminants between the two possibilities. Precise measurements of their branching fractions and Lee-Yang parameters can therefore directly probe CP violation in the charm-baryon sector.

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