Analysis of Charmed Baryon Two-Body Decays and CP Violation within SU(3) Flavor Symmetry

Jin Sun

Institute for Basic Science, Korea

Author ID

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Work with Yu-Ji Shi, Zhi-Peng Xing,

Ye Xing, Ruilin Zhu,

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1 Introduction

2 Charmed baryon two-body decay

3 Global analysis and CP violation

4 Conclusion

1 Introduction

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Research logic

sunjin0810@ibs.re.kr

Why CP violation in charmed baryon?

SU(3) flavor symmetry (IRA and TDA)

What can current data do?

Global analysis for real and complex form factors

Observable CPV in channels

$$A_{CP}(B_c \to BM) = \frac{\Gamma(B_c \to BM) - \Gamma(\bar{B}_c \to \bar{B}\bar{M})}{\Gamma(B_c \to BM) + \Gamma(\bar{B}_c \to \bar{B}\bar{M})}$$

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Why CP violation

1. **Explain the matter-antimatter asymmetry**

   Sakharov condition $n_B/s \sim 8.8 \times 10^{-11}$

2. **Search for BSM new physics**

   NP models with CPV source?

3. **Besides meson systems, baryon sector?**

   Only K/D/B meson?

4. **CPV in b-baryon sector is observed at LHCb**

   Charm-baryon?

Analyze the CPV in charmed baryons

Experimental search

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Physics Letters B 787 (2018) 124–133

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Physics Letters B

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Search for CP violation in $\Lambda_b^0 \to pK^-$ and $\Lambda_b^0 \to p\pi^-$ decays

LHCb Collaboration

PHYSICAL REVIEW D **104,** 052010 (2021)

Search for CP violation in $\Xi_b^- \to pK^-K^-$ decays

R. Aaij *et al.**
(LHCb Collaboration)

PHYSICAL REVIEW LETTERS **129,** 131801 (2022)

Precise Measurements of Decay Parameters and CP Asymmetry with Entangled Λ-$\bar{\Lambda}$ Pairs

PHYSICAL REVIEW LETTERS **133,** 101902 (2024)

Strong and Weak CP Tests in Sequential Decays of Polarized Σ^0 Hyperons

M. Ablikim *et al.**
(BESIII Collaboration)

Stringent test of CP symmetry in Σ^+ hyperon decays

BESIII Collaboration • Medina Ablikim (Beijing, Inst. High Energy Phys.) Show All(703)

Mar 21, 2025

9 pages

PHYSICAL REVIEW LETTERS **134,** 101802 (2025)

estion Featured in Physics

Study of Λ_b^0 and Ξ_b^0 Decays to $\Lambda h^+h'^-$ and Evidence for CP Violation in $\Lambda_b^0 \to \Lambda K^+K^-$ Decays

R. Aaij *et al.**
(LHCb Collaboration)

PHYSICAL REVIEW D **111,** 092004 (2025)

Measurement of CP asymmetries in $\Lambda_b^0 \to ph^-$ decays

R. Aaij *et al.**
(LHCb Collaboration)

Observation of charge-parity symmetry breaking in baryon decays

LHCb Collaboration • Roel Aaij (Nikhef, Amsterdam) Show All(1156)

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29 pages

e-Print: 2503.16954 [hep-ex]

Report number: LHCb-PAPER-2024-054, CERN-EP-2025-031

Experiments: CERN-LHC-LHCb

View in: CERN Document Server, HAL Science Ouverte, ADS Abstract Service

Theory research

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PHYSICAL REVIEW LETTERS **134**, 221801 (2025)

Establishing *CP* Violation in *b*-Baryon Decays

Jia-Jie Han,[1] Ji-Xin Yu,[1,*] Ya Li,[2,†] Hsiang-nan Li,[3,‡] Jian-Peng Wang,[1,§] Zhen-Jun Xiao,[4,∥] and Fu-Sheng Yu[1,¶]

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Letter

***U*-spin conjugate *CP* violation relations in bottom baryon decays**

Bo-Nan Zhang [a], Di Wang [b,*]

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Article

Large CP violation in charmed baryon decays

Xiao-Gang He [*], Chia-Wei Liu [*]

New horizon in particle physics: first observation of CP violation in baryon decays

Fu-Sheng Yu (Lanzhou U. (main)), Cai-Dian Lü (Beijing, Inst. High Energy Phys. and Beijing, GUCAS) (

Published in: *Sci.Bull.* 70 (2025) 2035-2036 • e-Print: 2504.15008 [hep-ph]

reference search

PHYSICAL REVIEW D **112**, 033010 (2025)

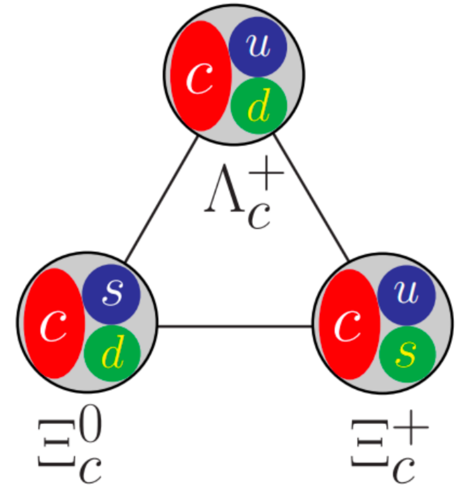
Implications of recent LHCb data on *CP* violation in *b*-baryon four-body decays

Qi Chen,[1] Xin Wu,[1] Zhi-Peng Xing,[*] and Ruilin Zhu
ent of Physics and Institute of Theoretical Physics, Nanjing Normal University

Some others....

기초과학연구원
Institute for Basic Science
sunjin0810@ibs.re.kr

SU(3) flavor symmetry



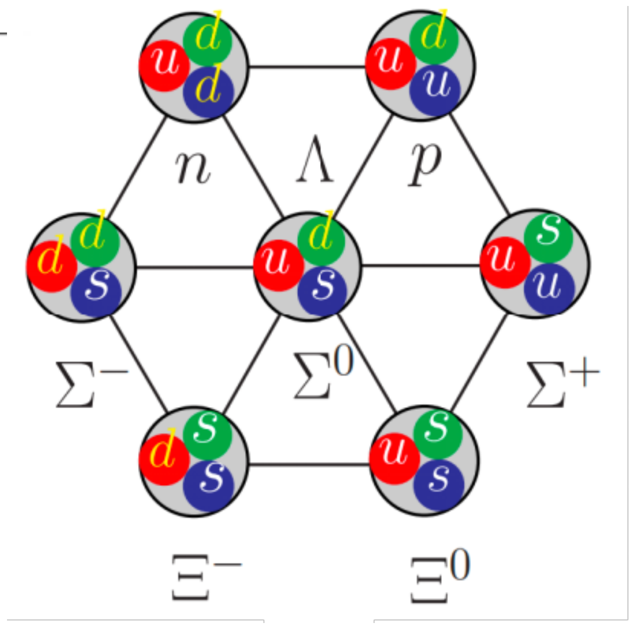
Advantages

1. **Extension of isospin symmetry**

   $u, d \rightarrow u, d, s$

2. **No dynamics to relate process**

$\Lambda_c^+ \rightarrow \Sigma^0\pi^+$	1.29 ± 0.07
$\Lambda_c^+ \rightarrow \Sigma^+\pi^0$	1.25 ± 0.10



Disadvantages

1. Symmetry breaking by mass
2. **Need more data to analyze**

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What can SU(3) do ??

1. **Without data**

   Obtain symmetry relation, derive the channel with larger Br

2. **few data**

   predict some unobserved channels by symmetry relation

3. **More data—(we are at now)**

   determine SU(3) amplitude and predict Br of all types channels

4. **Enough data**

   determine strong phase and then predict CPV

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Decay amplitudes

IRA

SU(3) singlet amplitude

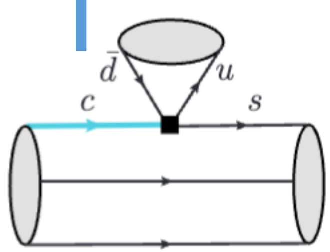
1. **triplet quark, anti-triplet anti-quark**
2. **2 quarks composed as triplet and sextet**

$$
\begin{aligned}
\mathcal{M}^{IRA} &= a_{15} \times (T_{c\bar{3}})_i (H_{15})^{\{ik\}}_j (\overline{T_8})^j_k P^l_l \\
&+ b_{15} \times (T_{c\bar{3}})_i (H_{15})^{\{ik\}}_j (\overline{T_8})^l_k P^j_l \\
&+ c_{15} \times (T_{c\bar{3}})_i (H_{15})^{\{ik\}}_j (\overline{T_8})^j_l P^l_k \\
&+ d_{15} \times (T_{c\bar{3}})_i (H_{15})^{\{jk\}}_l (\overline{T_8})^l_j P^i_k \\
&+ e_{15} \times (T_{c\bar{3}})_i (H_{15})^{\{jk\}}_l (\overline{T_8})^i_j P^l_k \\
&+ a_6 \times (T_{c\bar{3}})^{[ik]} (H_{\bar{6}})_{\{ij\}} (\overline{T_8})^j_k P^l_l \\
&+ b_6 \times (T_{c\bar{3}})^{[ik]} (H_{\bar{6}})_{\{ij\}} (\overline{T_8})^l_k P^j_l \\
&+ c_6 \times (T_{c\bar{3}})^{[ik]} (H_{\bar{6}})_{\{ij\}} (\overline{T_8})^j_l P^l_k \\
&+ d_6 \times (T_{c\bar{3}})^{[lk]} (H_{\bar{6}})_{\{ij\}} (\overline{T_8})^i_k P^j_l \\
&+ a_3 \times (T_{c\bar{3}})_i (H_3)^k (\overline{T_8})^i_l P^l_k \\
&+ b_3 \times (T_{c\bar{3}})_i (H_3)^k (\overline{T_8})^i_k P^l_l \\
&+ c_3 \times (T_{c\bar{3}})_i (H_3)^i (\overline{T_8})^k_l P^l_k \\
&+ d_3 \times (T_{c\bar{3}})_i (H_3)^l (\overline{T_8})^k_l P^i_k
\end{aligned}
$$

TDA

Upper index: (anti)quark annihilation (creation)
Lower index: (anti)quark creation (annihilation)

$$
\begin{aligned}
\mathcal{A}^{TDA}_u &= \bar{a}_1 T^{[ij]}_{c\bar{3}} H^{kl}_m (\overline{T}_8)_{ijk} P^m_l + \bar{a}_2 T^{[ij]}_{c\bar{3}} H^{kl}_m (\overline{T}_8)_{ijl} P^m_k \\
&+ \bar{a}_3 T^{[ij]}_{c\bar{3}} H^{kl}_i (\overline{T}_8)_{jkl} P^m_m \\
&+ \bar{a}_4 T^{[ij]}_{c\bar{3}} H^{kl}_i (\overline{T}_8)_{jkm} P^m_l \\
&+ \bar{a}_5 T^{[ij]}_{c\bar{3}} H^{kl}_i (\overline{T}_8)_{jlk} P^m_m + \bar{a}_6 T^{[ij]}_{c\bar{3}} H^{kl}_i (\overline{T}_8)_{jmk} P^m_l \\
&+ \bar{a}_7 T^{[ij]}_{c\bar{3}} H^{kl}_i (\overline{T}_8)_{ilm} P^m_k + \bar{a}_8 T^{[ij]}_{c\bar{3}} H^{kl}_i (\overline{T}_8)_{jml} P^m_k \\
&+ \bar{a}_9 T^{[ij]}_{c\bar{3}} H^{kl}_i (\overline{T}_8)_{klj} P^m_m + \bar{a}_{10} T^{[ij]}_{c\bar{3}} H^{kl}_i (\overline{T}_8)_{kmj} P^m_l \\
&+ \bar{a}_{11} T^{[ij]}_{c\bar{3}} H^{kl}_i (\overline{T}_8)_{lmj} P^m_k + \bar{a}_{12} T^{[ij]}_{c\bar{3}} H^{kl}_i (\overline{T}_8)_{klm} P^m_j \\
&+ \bar{a}_{13} T^{[ij]}_{c\bar{3}} H^{kl}_i (\overline{T}_8)_{kml} P^m_j + \bar{a}_{14} T^{[ij]}_{c\bar{3}} H^{kl}_i (\overline{T}_8)_{lmk} P^m_j \\
&+ \bar{a}_{15} T^{[ij]}_{c\bar{3}} H^{kl}_m (\overline{T}_8)_{ikj} P^m_l + \bar{a}_{16} T^{[ij]}_{c\bar{3}} H^{kl}_m (\overline{T}_8)_{ilj} P^k_m \\
&+ \bar{a}_{17} T^{[ij]}_{c\bar{3}} H^{kl}_m (\overline{T}_8)_{ikl} P^m_j + \bar{a}_{18} T^{[ij]}_{c\bar{3}} H^{kl}_m (\overline{T}_8)_{ilk} P^m_j \\
&+ \bar{a}_{19} T^{[ij]}_{c\bar{3}} H^{kl}_m (\overline{T}_8)_{klj} P^m_i .
\end{aligned}
$$



$T_1(\bar{a}_1, \bar{a}_{15})$

Charmed baryon decay

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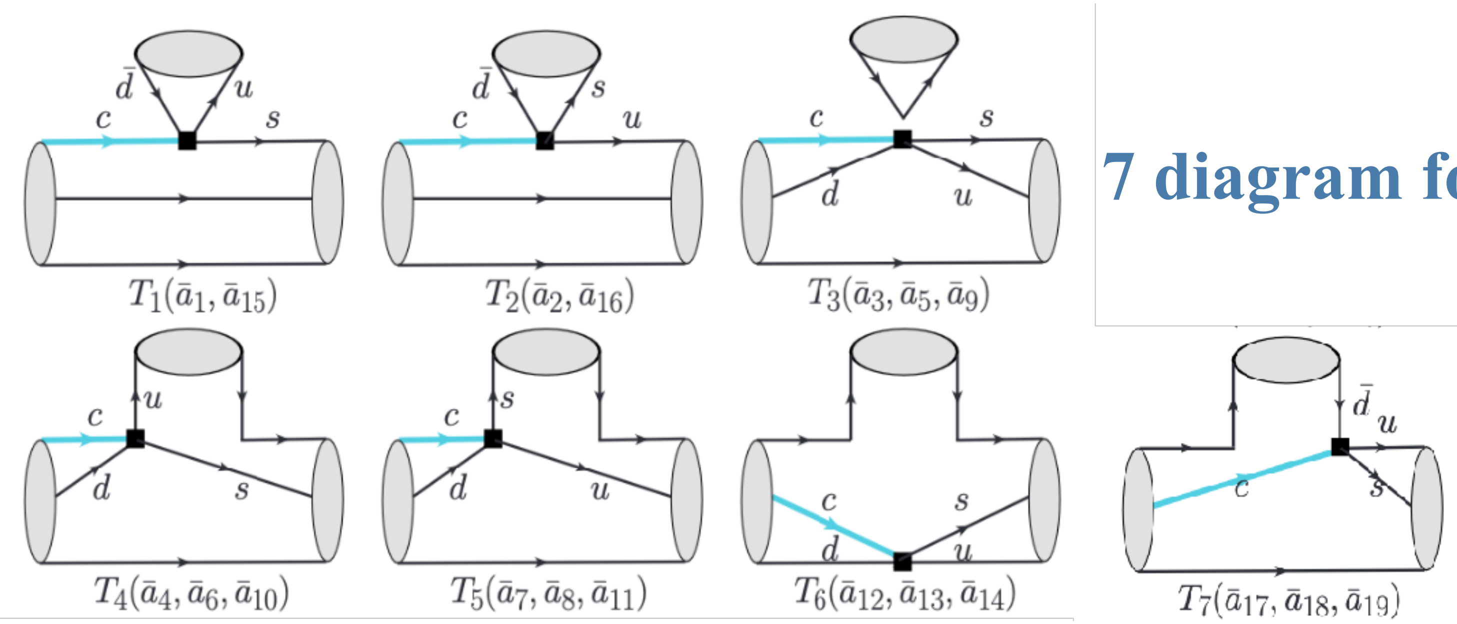
Topological diagrammatic approach(TDA)



7 diagram for 19 amplitude

Irreducible representation amplitude(IRA)

9 amplitudes

$$H_k^{ij} \rightarrow 3 \otimes \bar{3} \otimes 3 = 3 \oplus 3 \oplus \bar{6} \oplus 15$$

Dismatch??

Charmed baryon decay

sunjin0810@ibs.re.kr

Equivalence

TDA ⟺ **IRA**

$$
\begin{aligned}
&\bar{a}_1 = b_6 - d_6 + e_{15}, \quad \bar{a}_2 = d_6 - b_6 + e_{15}, \quad \bar{a}_3 = -\frac{a}{2}, \\
&\bar{a}_4 = \frac{1}{2}(-c_6 + c_{15}), \quad \bar{a}_5 = \frac{1}{2}a', \quad \bar{a}_7 = \frac{1}{2}(c_6 + c_{15}), \\
&\bar{a}_6 = \frac{1}{2}(-b_6 - c_6 - e_{15} + d_{15}) + \frac{1}{4}(a + a'), \\
&\bar{a}_8 = \frac{1}{2}(b_6 + c_6 + d_{15} - e_{15}) - \frac{1}{4}(a + a'), \\
&\bar{a}_9 = \frac{1}{2}(a + a'), \quad \bar{a}_{12} = c_6, \quad \bar{a}_{15} = \frac{1}{2}(b_6 - d_6 + e_{15}), \\
&\bar{a}_{10} = \frac{1}{2}(-b_6 - c_{15} + d_{15} - e_{15}) + \frac{1}{4}(a + a'), \\
&\bar{a}_{11} = \frac{1}{2}(b_6 - c_{15} + d_{15} - e_{15}) - \frac{1}{4}(a + a')), \\
&\bar{a}_{13} = \frac{1}{2}(-e_{15} + b_{15} + c_6 + d_{15}) - \frac{1}{4}(a' - a) \\
&\bar{a}_{14} = \frac{1}{2}(-e_{15} + b_{15} - c_6 + d_{15}) - \frac{1}{4}(a' - a) \\
&\bar{a}_{16} = \frac{1}{2}(-b_6 + d_6 + e_{15}), \quad \bar{a}_{17} = \frac{1}{2}(d_6 + e_{15} - b_{15}), \\
&\bar{a}_{18} = \frac{1}{2}(-d_6 + e_{15} - b_{15}), \quad \bar{a}_{19} = d_6. \qquad (3)
\end{aligned}
$$

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Regular Article - Theoretical Physics

Unification of flavor SU(3) analyses of heavy Hadron weak decays

Xiao-Gang He[1,2,3,4,a], Yu-Ji Shi[1,b], Wei Wang[1,c]

[1] INPAC, SKLPPC, MOE KLPPC, School of Physics and Astronomy, Shanghai Jiao Tong University, Shanghai 200240, China
[2] T.-D. Lee Institute, Shanghai Jiao Tong University, Shanghai 200240, China
[3] Department of Physics, National Taiwan University, Taipei 106, Taiwan
[4] National Center for Theoretical Sciences, Hsinchu 300, Taiwan

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Flavor *SU*(3) topological diagram and irreducible representation amplitudes for heavy meson charmless hadronic decays: mismatch and equivalence

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TDA is very intuitive,
IRA gives independent amplitudes

SU(3) analysis

channel	exp Br(%)	exp α	Case I Br(%)	Case I α
$\Lambda_c^+ \to p\pi^0$	0.0156(75)		0.0174(53)	
$\Lambda_c^+ \to pK_S^0$	1.59(7)	0.2(5)	1.646(48)	0.41(12)
$\Lambda_c^+ \to pK_L^0$	1.67(7)		1.646(48)	
$\Lambda_c^+ \to p\eta$	0.158(11)		0.158(11)	
$\Lambda_c^+ \to p\eta'$	0.048(9)		0.0464(61)	
$\Lambda_c^+ \to \Lambda\pi^+$	1.29(5)	−0.755(6)	1.305(47)	−0.7538(60)
$\Lambda_c^+ \to \Sigma^0\pi^+$	1.27(6)	−0.466(18)	1.259(46)	−0.471(15)
$\Lambda_c^+ \to \Sigma^+\pi^0$	1.24(9)	−0.484(27)	1.273(46)	−0.469(15)
$\Lambda_c^+ \to \Xi^0 K^+$	0.55(7)	0.01(16)	0.417(29)	
$\Lambda_c^+ \to \Lambda^0 K^+$	0.0642(31)	−0.58(5)	0.0641(29)	−0.556(44)
$\Lambda_c^+ \to \Sigma^+\eta$	0.32(5)	−0.99(6)	0.327(49)	−0.9998(35)
$\Lambda_c^+ \to \Sigma^+\eta'$	0.41(8)	−0.46(7)	0.416(65)	−0.455(64)
$\Lambda_c^+ \to \Sigma^0 K^+$	0.0370(31)	−0.54(20)	0.0376(18)	−0.9971(36)
$\Lambda_c^+ \to n\pi^+$	0.066(13)		0.0641(23)	
$\Lambda_c^+ \to \Sigma^+ K_S^0$	0.047(14)		0.0311(29)	
$\Xi_c^+ \to \Xi^0\pi^+$	1.6(8)		0.880(78)	
$\Xi_c^0 \to \Lambda K_S^0$	0.32(6)		0.248(29)	
$\Xi_c^0 \to \Xi^-\pi^+$	1.43(27)	−0.640(51)	1.17(18)	−0.701(45)
$\Xi_c^0 \to \Xi^- K^+$	0.039(11)		0.0520(80)	
$\Xi_c^0 \to \Sigma^0 K_S^0$	0.054(16)		0.056(16)	
$\Xi_c^0 \to \Sigma^+ K^-$	0.18(4)		0.189(38)	
$\Xi_c^0 \to \Xi^0\pi^0$	0.69(14)	−0.90(28)	0.153(48)	−0.45(13)
$\Xi_c^0 \to \Xi^0\eta$	0.16(4)		0.166(37)	
$\Xi_c^0 \to \Xi^0\eta'$	0.12(4)		0.125(38)	

sunjin0810@ibs.re.kr

Global fits

1. Real form factors

37experimental data

Exclude the red parts

$\chi^2/dof = 1.58$

$$\alpha(\Lambda_c^+ \to \Xi^0 K^+) = 0.957 \pm 0.018$$

$$Br(\Xi_c^0 \to \Xi^0\pi^0) = (0.152 \pm 0.048)\,\%$$

How to explain?

Strong Phases?

Penguin diagram?

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Strong phases

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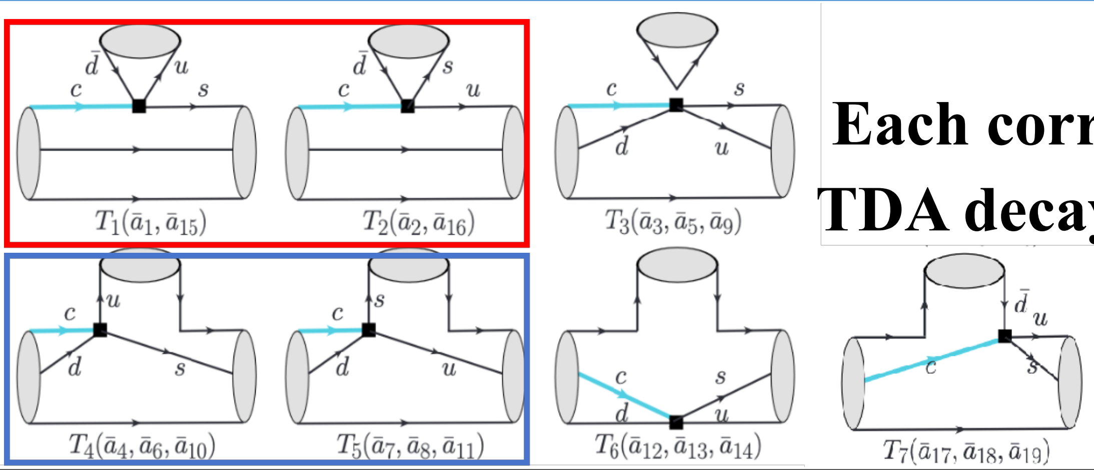

Each corresponds to more than one TDA decay amplitudes

$$\mathscr{M}_{T_1} = \mathscr{M}_{T_2}, \quad \mathscr{M}_{T_4} = \mathscr{M}_{T_5}$$

Form factors	TDA				
Vector(f)	T_1	T_2	T_3	T_4	T_5
	$f_1 = 0.0813(47)$	$f_2 = 0.0247(58)$	$f_3 = -0.0052(14)$	$f_4 = -0.0084(11)$	$f_7 = 0.0149(41)$
	$f_{15} = 0.0406(24)$	$f_{16} = 0.0123(29)$	$f_5 = 0.0003(36)$	$f_6 = -0.0527(42)$	$f_8 = -0.0156(40)$
			$f_9 = 0.0055(38)$	$f_{10} = -0.0443(44)$	$f_{11} = -0.0305(59)$
	T_6	T_7			
	$f_{12} = 0.0234(42)$	$f_{17} = 0.0271(18)$			
	$f_{13} = -0.0252(33)$	$f_{18} = 0.0361(41)$			
	$f_{14} = -0.0486(36)$	$f_{19} = -0.0090(40)$			
Axial-vector(g)	T_1	T_2	T_3	T_4	T_5
	$g_1 = -0.0982(86)$	$g_2 = 0.1323(77)$	$g_3 = 0.0147(39)$	$g_4 = -0.0436(31)$	$g_7 = 0.0460(84)$
	$g_{15} = -0.0491(43)$	$g_{16} = 0.0662(38)$	$g_5 = 0.012(22)$	$g_6 = 0.026(12)$	$g_8 = -0.058(14)$
			$g_9 = -0.002(22)$	$g_{10} = 0.070(11)$	$g_{11} = -0.104(15)$
	T_6	T_7			
	$g_{12} = 0.0896(90)$	$g_{17} = -0.0591(37)$			
	$g_{13} = 0.052(14)$	$g_{18} = 0.0023(58)$			
	$g_{14} = -0.037(13)$	$g_{19} = -0.0614(73)$			

New form factors

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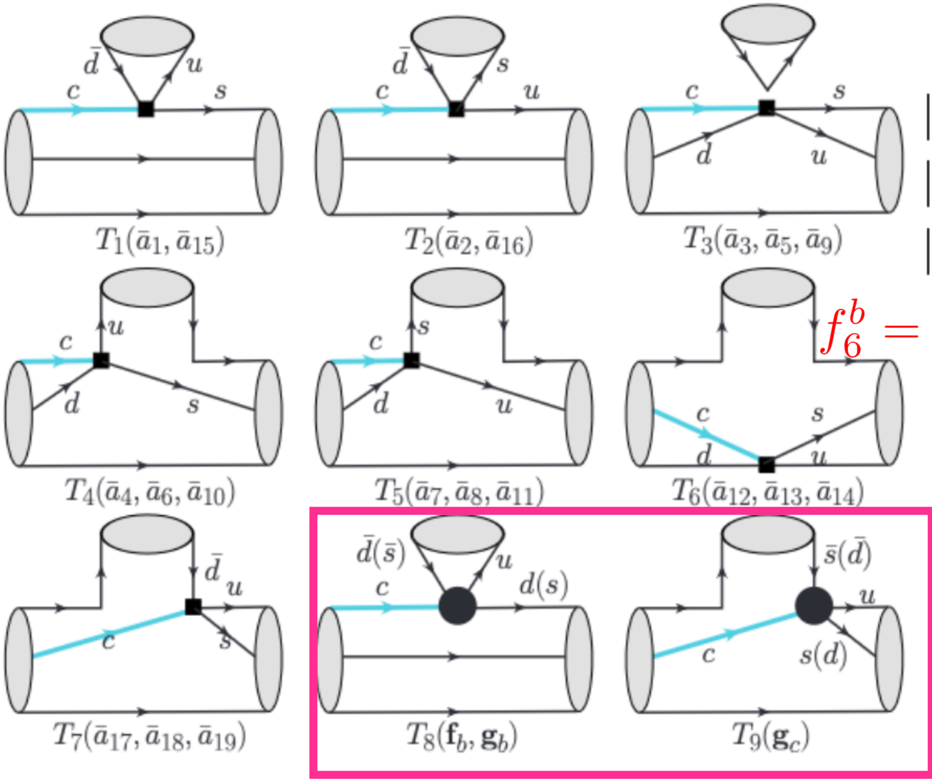

$$|A_{1,15}| = A_{T_1}, \quad |A_{2,16}| = A_{T_2}, \quad |A_{3,5,9}| = A_{T_3}$$
$$|A_{4,6,10}| = A_{T_4}, \quad |A_{7,8,11}| = A_{T_5},$$
$$|A_{12,13,14}| = A_{T_6}, \quad |A_{17,18,19}| = A_{T_7}, \; A = f, g.$$

$f_6^b = 0.0193 \pm 0.047$ $\quad g_{15}^c = 0.0024 \pm 0.0089$

$$f^a = -\frac{f_{T_6}}{2}, \quad f^{a\prime} = \frac{1}{2} f_{T_6} - f_{T_3}, \quad f_6^b = \boxed{\frac{3}{2}\mathbf{f}_b},$$
$$f_{15}^b = -f_{T_6} - f_{T_7}, \quad f_6^c = f_{T_6} + f_{T_4}, \quad f_{15}^c = f_{T_4},$$
$$f_6^d = \boxed{-\frac{3}{2}\mathbf{f}_b} - f_{T_7}, \quad f_{15}^d = -2 f_{T_4} - f_{T_6},$$
$$f_{15}^e = \boxed{-\frac{3}{2}\mathbf{f}_b} + 3 f_{T_1} + 2 f_{T_4} + f_{T_6} + f_{T_7},$$
$$g^a = g_{T_4} + \frac{g_{T_6}}{2}, \quad g^{a\prime} = g_{T_4} + g_{T_3} - \frac{g_{T_6}}{2}, \; g_{15}^c = 0$$
$$g_6^b = -3 g_{T_1} + \boxed{\frac{3}{2}\mathbf{g}_b} - 2 g_{T_4}, \quad g_{15}^b = \boxed{\frac{\mathbf{g}_c}{2}} + g_{T_6} + g_{T_7},$$
$$g_6^c = g_{T_6}, \quad g_6^d = 3 g_{T_1} - \boxed{\frac{3}{2}\mathbf{g}_b} - g_{T_7} + \boxed{\frac{\mathbf{g}_c}{2}}, \quad g_{15}^d = g_T$$
$$g_{15}^e = -g_{T_6} - g_{T_7} - \boxed{\frac{\mathbf{g}_c}{2} - \frac{3}{2}\mathbf{g}_b}.$$

$$\mathrm{f}_b = f_{T_1} - f_{T_2},$$
$$\mathrm{g}_b = g_{T_1} - g_{T_2}$$
$$\mathrm{g}_c = -g_{18} - g_{T_7}$$

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sunjin0810@ibs.re.kr

New form factor $\mathrm{f}_b = \mathrm{f}_b^S + \boxed{\mathrm{f}_b^P} e^{i\phi^P}$

Source: symmetry breaking, penguin, FSR, NP

$$A^q_{6,15} = e^{i\phi_1}\left(\mathcal{R}e(A^q_{6,15}) + \mathcal{I}m(A^q_{6,15})\right),$$

$$f_6^b = \frac{3}{2}\left(e^{i\phi_1}(\mathcal{R}e(\mathrm{f}_b^S) + \mathcal{I}m(\mathrm{f}_b^S)) + e^{i\phi^P}(\mathcal{R}e(\mathrm{f}_b^P) + \mathcal{I}m(\mathrm{f}_b^P))\right),$$

$$f_6^d = e^{i\phi_1}(\mathcal{R}e(f_6^d) + \mathcal{I}m(f_6^d)) - e^{i\phi^P}\frac{3}{2}(\mathcal{R}e(\mathrm{f}_b^P) + \mathcal{I}m(\mathrm{f}_b^P)),$$

$$f_{15}^e = e^{i\phi_1}(\mathcal{R}e(f_{15}^e) + \mathcal{I}m(f_{15}^e)) - e^{i\phi^P}\frac{3}{2}(\mathcal{R}e(\mathrm{f}_b^P) + \mathcal{I}m(\mathrm{f}_b^P)),\ A = f, g,$$

$\mathrm{f}_b^P \neq 0$ $\Rightarrow$

CP violation

$$\mathcal{H}_{eff} = \frac{G_F}{\sqrt{2}}\left(\sum_{\lambda,i=1,2} C_i \lambda O_i - \sum_{j=3}^{6} C_j \lambda_b O_j\right) + h.c.,$$

$$\boxed{A_{CP}^{\Lambda_c^+\to n\pi^+} = -0.0052(39),}$$

$$A_{CP}^{\Xi_c^+\to\Xi^0 K^+} = -0.0052(39).$$

$$A_{CP} \sim 10^{-3}$$

$\Downarrow$

Share same SU(3) amplitudes $-\sin\theta(c_6 - c_{15} + \boxed{d_6 + e_{15}})$

Penguin contribution

sunjin0810@ibs.re.kr

$$\mathcal{H}_{eff} = \frac{G_F}{\sqrt{2}}\left(\sum_{\lambda,i=1,2} C_i \lambda O_i - \sum_{j=3}^{6} C_j \lambda_b O_j\right) + h.c.,$$

$$\lambda = V_{cq}^* V_{uq'}$$

$$\lambda_b = V_{cb}^* V_{ub}$$

$$O_1^{q_1\bar{q}_2 q_3} = (\bar{q}_{1\alpha} c_\beta)_{V-A} (\bar{q}_{3_\beta} q_{2_\alpha})_{V-A} \qquad O_{3,5}^{u\bar{q}q} = (\bar{u}_\alpha c_\alpha)_{V-A} \sum_{q=u,d,s} (\bar{q}_\beta q_\beta)_{V\mp A}$$

Both $O_{1,2}$ and penguin operators contribute to H_3.

Analyze the contribution without distinguish source

$$(H_{\bar{6}})^{31}_3 = -(H_{\bar{6}})^{13}_3 = (H_{\bar{6}})^{12}_2 = -(H_{\bar{6}})^{21}_2 = \frac{1}{2}(\lambda_s - \lambda_d)$$

$$c \to ud\bar{d}/s\bar{s} \qquad (H_{15})^{31}_3 = (H_{15})^{13}_3 = \frac{3}{4}\lambda_s - \frac{1}{4}\lambda_d = \frac{\lambda_s - \lambda_d}{2} - \frac{\lambda_b}{4},$$

$$(H_{15})^{21}_2 = (H_{15})^{12}_2 = \frac{3}{4}\lambda_d - \frac{1}{4}\lambda_s = \frac{\lambda_d - \lambda_s}{2} - \frac{\lambda_b}{4},$$

$$\lambda_b \sim O(10^{-4}) \ll \lambda_{d,s} \qquad \boxed{(H_{15})^{11}_1 = \frac{\lambda_b}{2},\ (H_3)^1 = -\lambda_b.} \qquad \lambda_b F_P \sim 0.01$$

Need enough data to determine CP violation

1 Introduction

2 Charmed baryon two-body decay

3 Global analysis and CP violation

4 Conclusion

Conclusion

sunjin0810@ibs.re.kr

1. **SU(3) flavor symmetry proves valuable for analyzing charmed baryon two-body decays in light of current experimental data.**

2. **The global fit shows that charmed baryon two body decays may have large CPV**

3. **Both strong phase and penguin operator can explain the data**

기초과학연구원
Institute for Basic Science

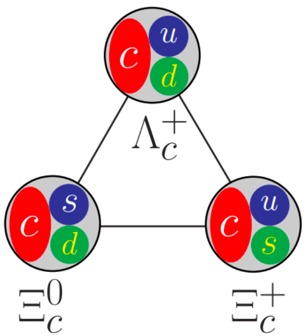
Thanks!
谢谢

Charmed baryon decay

Components

sunjin0810@ibs.re.kr

Charmed baryon



$$T_{c\bar{3}} = \begin{pmatrix} 0 & \Lambda_c^+ & \Xi_c^+ \\ -\Lambda_c^+ & 0 & \Xi_c^0 \\ -\Xi_c^+ & -\Xi_c^0 & 0 \end{pmatrix}$$

Baryon octant

$$T_8 = \begin{pmatrix} \frac{\Sigma^0}{\sqrt{2}} + \frac{\Lambda}{\sqrt{6}} & \Sigma^+ & p \\ \Sigma^- & -\frac{\Sigma^0}{\sqrt{2}} + \frac{\Lambda}{\sqrt{6}} & n \\ \Xi^- & \Xi^0 & -\frac{2\Lambda}{\sqrt{6}} \end{pmatrix}$$

Meson octant

$$P = \begin{pmatrix} \frac{\pi^0+\eta_q}{\sqrt{2}} & \pi^+ & K^+ \\ \pi^- & \frac{-\pi^0+\eta_q}{\sqrt{2}} & K^0 \\ K^- & \bar{K}^0 & \eta_s \end{pmatrix}$$

Physical meson

$$\begin{pmatrix} \eta \\ \eta' \end{pmatrix} = \begin{pmatrix} \cos\phi & -\sin\phi \\ \sin\phi & \cos\phi \end{pmatrix} \begin{pmatrix} \eta_q \\ \eta_s \end{pmatrix}, \qquad \phi = (39.3 \pm 1.0)^\circ$$

Hamiltonian

$$3 \otimes \bar{3} \otimes 3 = 3 \oplus 3 \oplus \bar{6} \oplus 15$$

$$(H_{\bar{6}})^{31}_2 = -(H_{\bar{6}})^{13}_2 = (H_{15})^{31}_2 = (H_{15})^{13}_2 = 1,$$
$$(H_{15})^{31}_3 = (H_{15})^{13}_3 = -(H_{15})^{21}_2 = -(H_{15})^{12}_2 = \sin\theta$$
$$(H_{\bar{6}})^{31}_3 = -(H_{\bar{6}})^{13}_3 = (H_{\bar{6}})^{12}_2 = -(H_{\bar{6}})^{21}_2 = \sin\theta, \quad ($$

Contract all index to construct SU(3) invariant amplitudes

기초과학연구원 Institute for Basic Science
sunjin0810@ibs.re.kr

Each amplitude is expressed by parity-violating and conserving form factors

$$q_6 = G_F \bar{u}(f_6^q - g_6^q \gamma_5)u, \quad q = a, b, c, d,$$
$$q_{15} = G_F \bar{u}(f_{15}^q - g_{15}^q \gamma_5)u, \quad q = a, b, c, d, e.$$

amplitudes appear in terms of the combination $a_6 \pm a_{15}$

$$f^a = f_6^a - f_{15}^a, \quad g^a = g_6^a - g_{15}^a, \quad f^{a'} = f_6^a + f_{15}^a, \quad g^{a'} = g_6^a + g_{15}^a$$

Observables

Branching ratio

$$\frac{d\Gamma}{d\cos\theta_M} = \frac{G_F^2 |\vec{p}_{B_n}|(E_{B_n} + M_{B_n})}{8\pi M_{B_c}} (|F|^2 + \kappa^2 |G|^2) \times (1 + \alpha \hat{\omega}_i \cdot \hat{p}_{B_n}),$$

Polarization asymmetry

$$\boxed{\alpha = \frac{2\mathrm{Re}(\mathrm{F} * \mathrm{G})\kappa}{(|F|^2 + \kappa^2 |G|^2)}}, \quad \beta = \frac{2\mathrm{Im}(F^* G)\kappa}{(|F|^2 + \kappa^2 |G|^2)},$$
$$\gamma = \frac{|F|^2 - |\kappa G|^2}{(|F|^2 + \kappa^2 |G|^2)}, \quad \kappa = \frac{|\vec{p}_{B_n}|}{(E_{B_n} + M_{B_n})}.$$

기초과학연구원 Institute for Basic Science
sunjin0810@ibs.re.kr

Fits for new factors

Form factors	Case III (χ^2/d.o.f = 7.03/7 = 1.004)				
	Real part			Imaginary part	
Vector(f)	$f^a = -0.0289(61)$	$f_6^c = 0.010(10)$	$f_6^d = -0.008(17)$	$f_{T_1} = -0.0176(37)$	$f_{T_4} = -0.0019(81)$
	$f^{a\prime} = -0.01(50)$	$\mathrm{Re}(\mathbf{f}_b^S) = 0.0003(114)$	$\mathrm{Re}(\mathbf{f}_b^P) = 0.000051(40)$	$\mathrm{Im}(\mathbf{f}_b^S) = -0.0105(36)$	$\mathrm{Im}(\mathbf{f}_b^P) = -0.000049(80)$
	$f_{15}^b = 0.0326(72)$	$f_{15}^c = -0.0038(59)$	$f_{15}^d = -0.004(16)$	$f_{T_6} = -0.0192(71)$	$f_{T_7} = 0.031(12)$
	$f_{15}^e = -0.0338(76)$				
Axial-vector(g)	$g^a = -0.014(18)$	$g_6^b = 0.083(41)$	$g_6^c = -0.023(39)$	$g_{T_1} = -0.016(18)$	$g_{T_3} = -0.08(1.52)$
	$g_6^d = 0.031(21)$	$g^{a\prime} = 0.05(49)$		$g_{T_4} = 0.068(36)$	$g_{T_6} = 0.031(26)$
	$g_{15}^b = -0.153(31)$	$g_{15}^c = -0.006(26)$	$g_{15}^d = -0.029(13)$	$g_{T_7} = -0.039(47)$	
	$g_{15}^e = -0.016(20)$				

Non-zero f_P may introduce observable CP violation

Institute for Basic Science
sunjin0810@ibs.re.kr

New data

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Measurements of the branching fractions of $\Xi_c^+ \to \Sigma^+ K_S^0$, $\Xi_c^+ \to \Xi^0 \pi^+$, and $\Xi_c^+ \to \Xi^0 K^+$ at Belle and Belle II

The Belle and the Belle II collaboration

JHEP08(2025)195

Compare with new data, the penguin diagram analysis is more reasonable

$$\mathcal{B}(\Xi_c^+ \to \Sigma^+ K_S^0) = (0.194 \pm 0.021 \pm 0.009 \pm 0.087)\%,$$
$$\mathcal{B}(\Xi_c^+ \to \Xi^0 \pi^+) = (0.728 \pm 0.014 \pm 0.027 \pm 0.326)\%,$$
$$\mathcal{B}(\Xi_c^+ \to \Xi^0 K^+) = (0.049 \pm 0.007 \pm 0.003 \pm 0.022)\%,$$

Data	Penguin diagram	Strong phase
$Br(\Xi_c^+ \to \Sigma^+ K_S^0)$	$(1.10 \pm 0.35)\,\%$	$(0.65 \pm 0.27)\,\%$
$Br(\Xi_c^+ \to \Xi^0 \pi^+)$	$(0.71 \pm 0.12)\,\%$	$(2.02 \pm 0.32)\,\%$
$Br(\Xi_c^+ \to \Xi^0 K^+)$	$(0.078 \pm 0.015)\,\%$	$(0.168 \pm 0.018)\,\%$