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Observable CP-violation in charmed baryons decays with SU(3) symmetry analysis

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work with **Jin Sun, Ruilin Zhu**

arxiv:2407.00426

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- Background of charmed baryon two body decays (CBTD)
- Global analysis of CBTD in IRA
- Equivalence of IRA and TDA in CBTD
- The strong phase of each diagram and possible the CPV

The charmed baryon two body decays(CBTD)

- Lower threshold
- More experiment data
- Richer phenomena
- Good in SU(3) symmetry

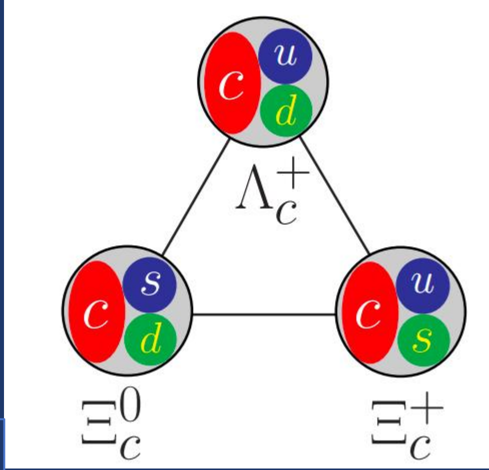
The charmed baryon two body decays(CBTD)

Symmetry analysis: $SU(3)_F$ symmetry!

- No dynamics
- SU(3) relations

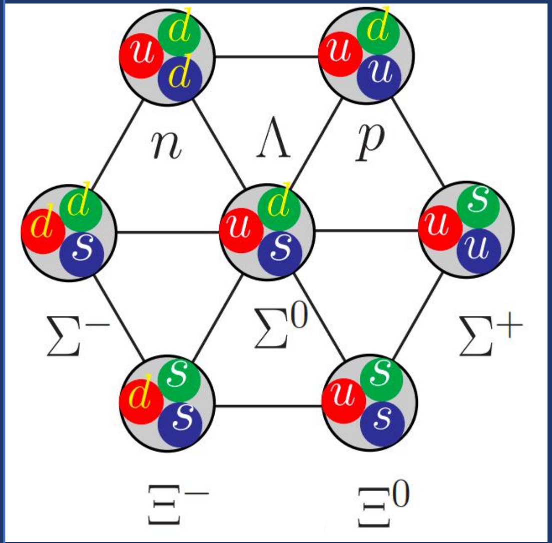
$$\Gamma(\Lambda_c^+ \to \Sigma^0\pi^+) = \Gamma(\Lambda_c^+ \to \Sigma^+\pi^0)$$

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



SU(3) analysis in recent years:

- Nucl. Phys. B 956, 115048 (2020)
- JHEP 02, 165 (2020)
- JHEP 03, 143 (2022)
- JHEP 03, 143 (2022)
- Eur. Phys. J. C 82, no.4, 297 (2022)
- JHEP 09, 035 (2022)
- JHEP 02, 235 (2023)
- arXiv:2301.07443
- Phys. Rev. D 108, no.5, 053004 (2023)
- Phys. Rev. D 109, no.11, 114027 (2024)
- Phys. Rev. D 109, no.7, L071302 (2024)
- arXiv:2401.15926
- arXiv:2404.19166



The charmed baryon two body decays(CBTD)

Channel	Branching ratio: Latest measurement in 2022 (%)	Experimental data (%)	Previous work (%) [14]	This work (%)
$\Lambda_c^+ \to pK_S^0$	$\cdots$	1.59 ± 0.08 [37]	1.587 ± 0.077	1.606 ± 0.077
$\Lambda_c^+ \to p\eta$	$\cdots$	0.142 ± 0.012 [37]	0.127 ± 0.024	0.141 ± 0.011
$\Lambda_c^+ \to p\eta'$	$0.0562^{+0.0246}_{-0.0204} \pm 0.0026$ [30] $0.0473 \pm 0.0082 \pm 0.0046 \pm 0.0024$ [34]	0.0484 ± 0.0091 [30,34]	0.27 ± 0.38	0.0468 ± 0.0066
$\Lambda_c^+ \to \Lambda\pi^+$	$1.31 \pm 0.08 \pm 0.05$ [33]	1.30 ± 0.06 [33,37]	1.307 ± 0.069	1.328 ± 0.055
$\Lambda_c^+ \to \Sigma^0\pi^+$	$1.22 \pm 0.08 \pm 0.07$ [33]	1.27 ± 0.06 [33,37]	1.272 ± 0.056	1.260 ± 0.046
$\Lambda_c^+ \to \Sigma^+\pi^0$	$\cdots$	1.25 ± 0.10 [37]	1.283 ± 0.057	1.274 ± 0.047
$\Lambda_c^+ \to \Xi^0 K^+$	$\cdots$	0.55 ± 0.07 [37]	0.548 ± 0.068	0.430 ± 0.030
$\Lambda_c^+ \to \Lambda^0 K^+$	$0.0621 \pm 0.0044 \pm 0.0026 \pm 0.0034$ [31] $0.0657 \pm 0.0017 \pm 0.0011 \pm 0.0035$ [35]	0.064 ± 0.003 [31,35,37]	0.064 ± 0.010	0.0646 ± 0.0028
$\Lambda_c^+ \to \Sigma^+\eta$	$0.416 \pm 0.075 \pm 0.021 \pm 0.033$ [36]	0.32 ± 0.043 [36,37]	0.45 ± 0.19	0.329 ± 0.042
$\Lambda_c^+ \to \Sigma^+\eta'$	$0.314 \pm 0.035 \pm 0.011 \pm 0.025$ [36]	0.437 ± 0.084 [36,37]	1.5 ± 0.6	0.444 ± 0.070
$\Lambda_c^+ \to \Sigma^0 K^+$	$0.047 \pm 0.009 \pm 0.001 \pm 0.003$ [32] $0.0358 \pm 0.0019 \pm 0.0006 \pm 0.0019$ [35]	0.0382 ± 0.0025 [32,35,37]	0.0504 ± 0.0056	0.0381 ± 0.0017
$\Lambda_c^+ \to n\pi^+$	$0.066 \pm 0.012 \pm 0.004$ [33]	0.066 ± 0.0126 [33]	0.035 ± 0.011	0.0651 ± 0.0026
$\Lambda_c^+ \to \Sigma^+ K_S^0$	$0.048 \pm 0.014 \pm 0.002 \pm 0.003$ [32]	0.048 ± 0.0145 [32]	0.0103 ± 0.0042	0.0327 ± 0.0029
$\Xi_c^+ \to \Xi^0\pi^+$	$\cdots$	1.6 ± 0.8 [37]	0.54 ± 0.18	0.887 ± 0.080
$\Xi_c^0 \to \Lambda K_S^0$	$\cdots$	0.32 ± 0.07 [37]	0.334 ± 0.065	0.261 ± 0.043
$\Xi_c^0 \to \Xi^-\pi^+$	$\cdots$	1.43 ± 0.32 [37]	1.21 ± 0.21	1.06 ± 0.20
$\Xi_c^0 \to \Xi^- K^+$	$\cdots$	0.039 ± 0.012 [37]	0.047 ± 0.0083	0.0474 ± 0.0090
$\Xi_c^0 \to \Sigma^0 K_S^0$	$\cdots$	0.054 ± 0.016 [37]	0.069 ± 0.024	0.054 ± 0.016
$\Xi_c^0 \to \Sigma^+ K^-$	$\cdots$	0.18 ± 0.04 [37]	0.221 ± 0.068	0.188 ± 0.039

Channel	Asymmetry parameter α: Lastest measurement in 2022	Experimental data	Previous work [14]	This work
$\alpha(\Lambda_c^+ \to pK_S^0)$	$\cdots$	0.18 ± 0.45 [37]	0.19 ± 0.41	0.49 ± 0.20
$\alpha(\Lambda_c^+ \to \Lambda\pi^+)$	$-0.755 \pm 0.005 \pm 0.003$ [35]	-0.755 ± 0.0058 [35,37]	-0.841 ± 0.083	-0.7542 ± 0.0058
$\alpha(\Lambda_c^+ \to \Sigma^0\pi^+)$	$-0.463 \pm 0.016 \pm 0.008$ [35]	-0.466 ± 0.0178 [35,37]	-0.605 ± 0.088	-0.471 ± 0.015
$\alpha(\Lambda_c^+ \to \Sigma^+\pi^0)$	$-0.48 \pm 0.02 \pm 0.02$ [36]	-0.48 ± 0.03 [36,37]	-0.603 ± 0.088	-0.468 ± 0.015
$\alpha(\Xi_c^0 \to \Xi^-\pi^+)$	$\cdots$	-0.64 ± 0.051 [37]	-0.56 ± 0.32	-0.654 ± 0.050
$\alpha(\Lambda_c^+ \to \Sigma^0 K^+)$	$-0.54 \pm 0.18 \pm 0.09$ [35]	-0.54 ± 0.20 [35]	-0.953 ± 0.040	-0.9958 ± 0.0045
$\alpha(\Lambda_c^+ \to \Lambda K^+)$	$-0.585 \pm 0.049 \pm 0.018$ [35]	-0.585 ± 0.052 [35]	-0.24 ± 0.15	-0.545 ± 0.046
$\alpha(\Lambda_c^+ \to \Sigma^+\eta)$	$-0.99 \pm 0.03 \pm 0.05$ [36]	-0.99 ± 0.058 [36]	0.3 ± 3.8	-0.970 ± 0.046
$\alpha(\Lambda_c^+ \to \Sigma^+\eta')$	$-0.46 \pm 0.06 \pm 0.03$ [36]	-0.46 ± 0.067 [36]	0.8 ± 1.9	-0.455 ± 0.064

$$f^a = 0.0155 \pm 0.0040 \qquad f^c_6 = 0.0356 \pm 0.0071$$
$$f^b_{15} = -0.0161 \pm 0.0042 \qquad f^d_{15} = -0.0253 \pm 0.0031$$
$$g^a = -0.039 \pm 0.012 \qquad g^c_6 = 0.121 \pm 0.019$$
$$g^b_{15} = 0.1134 \pm 0.0074 \qquad g^d_{15} = -0.0387 \pm 0.0085$$

$$f^b_6 = 0.0215 \pm 0.0092 \qquad f^d_6 = -0.0138 \pm 0.0080$$
$$f^c_{15} = 0.0149 \pm 0.0080 \qquad f^e_{15} = 0.0798 \pm 0.0087$$
$$g^b_6 = -0.240 \pm 0.011 \qquad g^d_6 = -0.067 \pm 0.014$$
$$g^c_{15} = 0.014 \pm 0.018 \qquad g^e_{15} = 0.0209 \pm 0.0092$$

SU(3) symmetry parameters from fitting (χ^2/d.o.f. $= 1.21$)

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The charmed baryon two body decays(CNTD)

$\Xi_c^0 \to \Xi^0\eta$	$\cos\phi(2a_6+2a_{15}+b_6+b_{15}-d_6+d_{15})/\sqrt{2}-\sin\phi(a_6+a_{15}+c_6+c_{15})$
$\Xi_c^0 \to \Xi^0\eta'$	$\sin\phi(2a_6+2a_{15}+b_6+b_{15}-d_6+d_{15})/\sqrt{2}+\cos\phi(a_6+a_{15}+c_6+c_{15})$
$\Xi_c^0 \to \Sigma^0\eta$	$\sin\theta(\ cos\phi\,(2a_6+2a_{15}+b_6+b_{15}+c_6+c_{15}+d_{15}-e_{15})/2$ $-\sin\phi\,(a_6+a_{15}-d_6+e_{15})/\sqrt{2})$
$\Xi_c^0 \to \Sigma^0\eta'$	$\sin\theta(\sin\phi\,(2a_6+2a_{15}+b_6+b_{15}+c_6+c_{15}+d_{15}-e_{15})/2$ $-\cos\phi\,(a_6+a_{15}-d_6+e_{15})/\sqrt{2})$
$\Xi_c^0 \to \Lambda\eta$	$(-\cos\phi\,(6a_6+6a_{15}+b_6+b_{15}+c_6+c_{15}-2d_6+3d_{15}+e_{15})/(2\sqrt{3})$ $-\sin\phi\,(-3a_6-3a_{15}-2b_6-2b_{15}-2c_6-2c_{15}+d_6+e_{15})/\sqrt{6})\sin\theta$
$\Xi_c^0 \to \Lambda\eta'$	$(-\sin\phi\,(6a_6+6a_{15}+b_6+b_{15}+c_6+c_{15}-2d_6+3d_{15}+e_{15})/(2\sqrt{3})$ $+\cos\phi\,(-3a_6-3a_{15}-2b_6-2b_{15}-2c_6-2c_{15}+d_6+e_{15})/\sqrt{6})\sin\theta$
$\Xi_c^0 \to n\eta$	$\sin^2\theta(\cos\phi\,(2a_6+2a_{15}+c_6+c_{15}+d_{15})/\sqrt{2}$ $-\sin\phi\,(a_6+a_{15}+b_6+b_{15}-d_6))$
$\Xi_c^0 \to n\eta'$	$\sin^2\theta(\sin\phi\,(2a_6+2a_{15}+c_6+c_{15}+d_{15})/\sqrt{2}$ $+\cos\phi\,(a_6+a_{15}+b_6+b_{15}-d_6))$

$$Br(\Xi_c^0 \to \Xi^0\eta) \sim [0.193, 0.446]\%,$$
$$Br(\Xi_c^0 \to \Sigma^0\eta) \sim [0.0118, 0.0333]\%,$$
$$Br(\Xi_c^0 \to \Lambda^0\eta) \sim [0.0039, 0.0139]\%,$$
$$Br(\Xi_c^0 \to n\eta) \sim [0.00009, 0.00066]\%.$$
$$Br(\Xi_c^0 \to \Xi^0\eta') \geq 0.002\%,$$
$$Br(\Xi_c^0 \to \Sigma^0\eta') \geq 9\times 10^{-7},$$
$$Br(\Xi_c^0 \to \Lambda^0\eta') \geq 4.8\times 10^{-6},$$
$$Br(\Xi_c^0 \to n\eta') \geq 6\times 10^{-8}.$$

There is one parameter a’ still can not be determine.

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The charmed baryon two body decays(CBTD)

$$Br(\Lambda_c^+ \to p\pi^0) = (0.0156^{-0.0072}_{-0.0058} \pm 0.002)\%,$$
$$Br(\Lambda_c^+ \to p\eta) = (0.163 \pm 0.031 \pm 0.011)\%,$$
$$Br(\Lambda_c^+ \to pK_L) = (1.67 \pm 0.06 \pm 0.04)\%,$$
$$Br(\Xi_c^0 \to \Xi^0\pi^0) = (0.69 \pm 0.03 \pm 0.05 \pm 0.13)\%,$$
$$Br(\Xi_c^0 \to \Xi^0\eta) = (0.16 \pm 0.02 \pm 0.02 \pm 0.03)\%,$$
$$Br(\Xi_c^0 \to \Xi^0\eta') = (0.12 \pm 0.03 \pm 0.01 \pm 0.02)\%,$$
$$\alpha(\Xi_c^0 \to \Xi^0\pi^0) = -0.90 \pm 0.15 \pm 0.23.$$

Possible to determine the last one amplitude in IRA

Phys. Rev. D 109, no.9, L091101 (2024)
arXiv:2406.04642
arXiv:2406.18083

The charmed baryon two body decays(CBTD)

$$\langle P, T_8 | i\mathcal{H} | T_{c\bar{3}} \rangle$$

$$T_{8ijk} = \epsilon_{ijm} T_{8k}^{m}$$

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

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

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

SU(3) decompositions in IRA

$$(H_{\bar{6}})_2^{31} = -(H_{\bar{6}})_2^{13} = 1, \quad (H_{15})_2^{31} = (H_{15})_2^{13} = 1,$$
$$(H_{15})_3^{31} = (H_{15})_3^{13} = -(H_{15})_2^{21} = -(H_{15})_2^{12} = \sin\theta,$$
$$(H_{\bar{6}})_3^{31} = -(H_{\bar{6}})_3^{13} = (H_{\bar{6}})_2^{12} = -(H_{\bar{6}})_2^{21} = \sin\theta,$$
$$(H_{\bar{6}})_3^{21} = -(H_{\bar{6}})_3^{12} = (H_{15})_3^{21} = (H_{15})_3^{12} = \sin^2\theta,$$

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The charmed baryon two body decays(CBTD)

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

SU(3) decompositions in IRA

$$
\begin{aligned}
&(H_{\bar{6}})^{31}_2 = -(H_{\bar{6}})^{13}_2 = 1, \quad (H_{15})^{31}_2 = (H_{15})^{13}_2 = 1, \\
&(H_{15})^{31}_3 = (H_{15})^{13}_3 = -(H_{15})^{21}_2 = -(H_{15})^{12}_2 = \sin\theta, \\
&(H_{\bar{6}})^{31}_3 = -(H_{\bar{6}})^{13}_3 = (H_{\bar{6}})^{12}_2 = -(H_{\bar{6}})^{21}_2 = \sin\theta, \\
&(H_{\bar{6}})^{21}_3 = -(H_{\bar{6}})^{12}_3 = (H_{15})^{21}_3 = (H_{15})^{12}_3 = \sin^2\theta,
\end{aligned}
$$

The charmed baryon two body decays(CBTD)

channel	exp		Case I	
	Br(%)	α	Br(%)	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)
$\Lambda_c^+ \to \Xi^0K^+$	0.55(7)	0.01(16)	0.417(29)	
$\Lambda_c^+ \to \Lambda^0K^+$	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)
$\Lambda_c^+ \to \Sigma^0K^+$	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)	
$\Xi_c^0 \to \Sigma^0K_S^0$	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)	

35 experimental data

$$\chi^2/d.o.f = 1.28$$

excluded data

$$\alpha(\Lambda_c^+ \to \Xi^0 K^+) = 0.01 \pm 0.16 \pm 0.03$$

$$Br(\Xi_c^0 \to \Xi^0\pi^0) = (0.069 \pm 0.03 \pm 0.05 \pm 0.13)\%$$

predicetion

$$\alpha(\Lambda_c^+ \to \Xi^0 K^+) = 0.960 \pm 0.017$$

$$Br(\Xi_c^0 \to \Xi^0\pi^0) = (0.153 \pm 0.48)\%$$

Need consider the strong phase ?

The charmed baryon two body decays(CBTD)

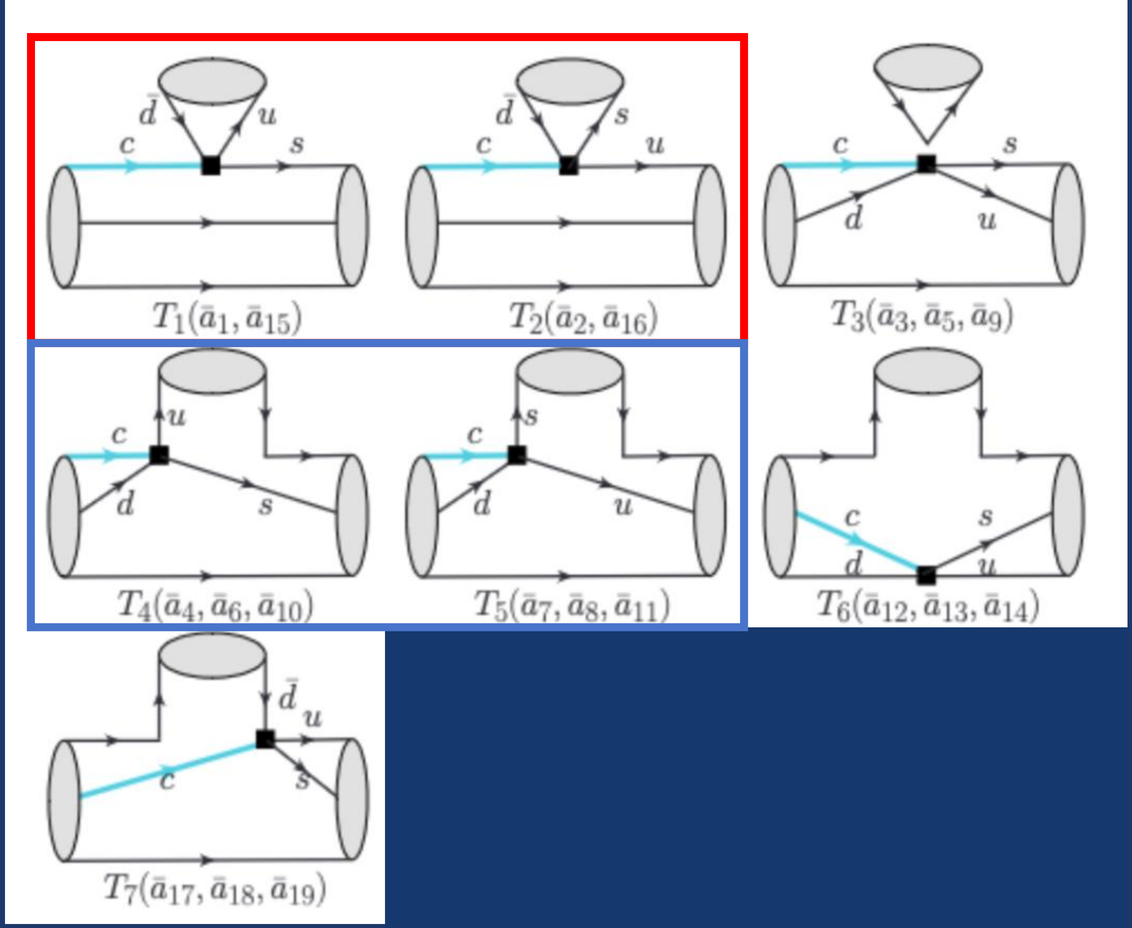
Equivalence

$$
\begin{aligned}
\mathcal{A}_u^{TDA} = {} & \bar{a}_1 T_{c\bar{3}}^{[ij]} H_m^{kl} (\overline{T}_8)_{ijk} P_l^m + \bar{a}_2 T_{c\bar{3}}^{[ij]} H_m^{kl} (\overline{T}_8)_{ijl} P_k^m \\
& + \bar{a}_3 T_{c\bar{3}}^{[ij]} H_i^{kl} (\overline{T}_8)_{jkl} P_m^m \\
& + \bar{a}_4 T_{c\bar{3}}^{[ij]} H_i^{kl} (\overline{T}_8)_{jkm} P_l^m \\
& + \bar{a}_5 T_{c\bar{3}}^{[ij]} H_i^{kl} (\overline{T}_8)_{jlk} P_m^m + \bar{a}_6 T_{c\bar{3}}^{[ij]} H_i^{kl} (\overline{T}_8)_{jmk} P_l^m \\
& + \bar{a}_7 T_{c\bar{3}}^{[ij]} H_i^{kl} (\overline{T}_8)_{ilm} P_k^m + \bar{a}_8 T_{c\bar{3}}^{[ij]} H_i^{kl} (\overline{T}_8)_{jml} P_k^m \\
& + \bar{a}_9 T_{c\bar{3}}^{[ij]} H_i^{kl} (\overline{T}_8)_{klj} P_m^m + \bar{a}_{10} T_{c\bar{3}}^{[ij]} H_i^{kl} (\overline{T}_8)_{kmj} P_l^m \\
& + \bar{a}_{11} T_{c\bar{3}}^{[ij]} H_i^{kl} (\overline{T}_8)_{lmj} P_k^m + \bar{a}_{12} T_{c\bar{3}}^{[ij]} H_i^{kl} (\overline{T}_8)_{klm} P_j^m \\
& + \bar{a}_{13} T_{c\bar{3}}^{[ij]} H_i^{kl} (\overline{T}_8)_{kml} P_j^m + \bar{a}_{14} T_{c\bar{3}}^{[ij]} H_i^{kl} (\overline{T}_8)_{lmk} P_j^m \\
& + \bar{a}_{15} T_{c\bar{3}}^{[ij]} H_m^{kl} (\overline{T}_8)_{ikj} P_l^m + \bar{a}_{16} T_{c\bar{3}}^{[ij]} H_m^{kl} (\overline{T}_8)_{ilj} P_m^k \\
& + \bar{a}_{17} T_{c\bar{3}}^{[ij]} H_m^{kl} (\overline{T}_8)_{ikl} P_j^m + \bar{a}_{18} T_{c\bar{3}}^{[ij]} H_m^{kl} (\overline{T}_8)_{ilk} P_j^m \\
& + \bar{a}_{19} T_{c\bar{3}}^{[ij]} H_m^{kl} (\overline{T}_8)_{klj} P_i^m .
\end{aligned}
$$

$$
\begin{aligned}
A_6^T &= \frac{1}{2} (\bar{a}_3 - \bar{a}_5 - 2\bar{a}_9 - \bar{a}_{13} + \bar{a}_{14}) , \\
B_6^T &= \frac{1}{2} (\bar{a}_{13} - \bar{a}_{14} - \bar{a}_{17} + \bar{a}_{18} - 2\bar{a}_{19}) , \\
C_6^T &= \frac{1}{2} (\bar{a}_4 - \bar{a}_7 - \bar{a}_{10} + \bar{a}_{11} - 2\bar{a}_{12}) , \\
D_6^T &= \frac{1}{2} (\bar{a}_6 - \bar{a}_8 + \bar{a}_{10} - \bar{a}_{11} - \bar{a}_{13} + \bar{a}_{14}) , \\
E_6^T &= \frac{1}{2} (2\bar{a}_1 - 2\bar{a}_2 - \bar{a}_6 + \bar{a}_8 - \bar{a}_{10} + \bar{a}_{11} + \bar{a}_{13} \\
&\quad - \bar{a}_{14} + \bar{a}_{15} - \bar{a}_{16} - \bar{a}_{17} + \bar{a}_{18} - 2\bar{a}_{19}) , \\
A_{15}^T &= \frac{1}{2} (\bar{a}_3 + \bar{a}_5 - \bar{a}_{13} - \bar{a}_{14}) , \\
B_{15}^T &= \frac{1}{2} (\bar{a}_{13} + \bar{a}_{14} - \bar{a}_{17} - \bar{a}_{18}) , \\
C_{15}^T &= \frac{1}{2} (\bar{a}_4 + \bar{a}_7 - \bar{a}_{10} - \bar{a}_{11}) , \\
D_{15}^T &= \frac{1}{2} (\bar{a}_6 + \bar{a}_8 + \bar{a}_{10} + \bar{a}_{11} + \bar{a}_{13} + \bar{a}_{14}) , \\
E_{15}^T &= \frac{1}{2} (2\bar{a}_1 + 2\bar{a}_2 - \bar{a}_6 - \bar{a}_8 - \bar{a}_{10} - \bar{a}_{11} \\
&\quad - \bar{a}_{13} - \bar{a}_{14} + \bar{a}_{15} + \bar{a}_{16} + \bar{a}_{17} + \bar{a}_{18}) .
\end{aligned}
$$

$$
\begin{aligned}
\mathcal{A}_u^{IRA} = {} & A_6^T (T_{c\bar{3}})_i (H_6)_j^{[ik]} (\overline{T}_8)_k^j P_l^l \\
& + B_6^T (T_{c\bar{3}})_i (H_6)_j^{[ik]} (\overline{T}_8)_k^l P_l^j \\
& + C_6^T (T_{c\bar{3}})_i (H_6)_j^{[ik]} (\overline{T}_8)_l^j P_k^l \\
& + E_6^T (T_{c\bar{3}})_i (H_6)_l^{[jk]} (\overline{T}_8)_j^i P_k^l \\
& + D_6^T (T_{c\bar{3}})_i (H_6)_l^{[jk]} (\overline{T}_8)_j^l P_k^i \\
& + A_{15}^T (T_{c\bar{3}})_i (H_{\overline{15}})_j^{\{ik\}} (\overline{T}_8)_k^j P_l^l \\
& + B_{15}^T (T_{c\bar{3}})_i (H_{\overline{15}})_j^{\{ik\}} (\overline{T}_8)_k^l P_l^j \\
& + C_{15}^T (T_{c\bar{3}})_i (H_{\overline{15}})_j^{\{ik\}} (\overline{T}_8)_l^j P_k^l \\
& + E_{15}^T (T_{c\bar{3}})_i (H_{\overline{15}})_l^{\{jk\}} (\overline{T}_8)_j^i P_k^l \\
& + D_{15}^T (T_{c\bar{3}})_i (H_{\overline{15}})_l^{\{ik\}} (\overline{T}_8)_j^l P_k^i .
\end{aligned}
$$

The charmed baryon two body decays(CBTD)



$$
\begin{aligned}
\mathcal{M} = \quad & a_{15} \times (T_{c\bar{3}})_i (H_{\overline{15}})_j^{\{ik\}} (\overline{T_8})_k^j P_l^l \\
+ \; & b_{15} \times (T_{c\bar{3}})_i (H_{\overline{15}})_j^{\{ik\}} (\overline{T_8})_k^l P_l^j \\
+ \; & c_{15} \times (T_{c\bar{3}})_i (H_{\overline{15}})_j^{\{ik\}} (\overline{T_8})_l^j P_k^l \\
+ \; & d_{15} \times (T_{c\bar{3}})_i (H_{\overline{15}})_l^{\{jk\}} (\overline{T_8})_j^l P_k^i \\
+ \; & e_{15} \times (T_{c\bar{3}})_i (H_{\overline{15}})_l^{\{jk\}} (\overline{T_8})_j^i P_k^l \\
+ \; & a_6 \times (T_{c\bar{3}})^{[ik]} (H_{\bar{6}})_{\{ij\}} (\overline{T_8})_k^j P_l^l \\
+ \; & b_6 \times (T_{c\bar{3}})^{[ik]} (H_{\bar{6}})_{\{ij\}} (\overline{T_8})_k^l P_l^j \\
+ \; & c_6 \times (T_{c\bar{3}})^{[kl]} (H_{\bar{6}})_{\{ij\}} (\overline{T_8})_l^j P_k^l \\
+ \; & d_6 \times (T_{c\bar{3}})^{[ik]} (H_{\bar{6}})_{\{ij\}} (\overline{T_8})_k^i P_l^j .
\end{aligned}
$$

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The charmed baryon two body decays(CBTD)

$$\bar{a}_1 = b_6 - d_6 + e_{15}, \quad \bar{a}_2 = d_6 - b_6 + e_{15}, \quad \bar{a}_3 = -\frac{a}{2},$$

$$\bar{a}_4 = \frac{1}{2}(-c_6 + c_{15}), \quad \bar{a}_5 = \frac{1}{2}a', \quad \bar{a}_7 = \frac{1}{2}(c_6 + c_{15}),$$

$$\bar{a}_6 = \frac{1}{2}(-b_6 - c_6 - e_{15} + d_{15}) + \frac{1}{4}(a + a'),$$

$$\bar{a}_8 = \frac{1}{2}(b_6 + c_6 + d_{15} - e_{15}) - \frac{1}{4}(a + a'),$$

$$\bar{a}_9 = \frac{1}{2}(a + a'), \quad \bar{a}_{12} = c_6, \quad \bar{a}_{15} = \frac{1}{2}(b_6 - d_6 + e_{15}),$$

$$\bar{a}_{10} = \frac{1}{2}(-b_6 - c_{15} + d_{15} - e_{15}) + \frac{1}{4}(a + a'),$$

$$\bar{a}_{11} = \frac{1}{2}(b_6 - c_{15} + d_{15} - e_{15}) - \frac{1}{4}(a + a')),$$

$$\bar{a}_{13} = \frac{1}{2}(-e_{15} + b_{15} + c_6 + d_{15}) - \frac{1}{4}(a' - a)$$

$$\bar{a}_{14} = \frac{1}{2}(-e_{15} + b_{15} - c_6 + d_{15}) - \frac{1}{4}(a' - a)$$

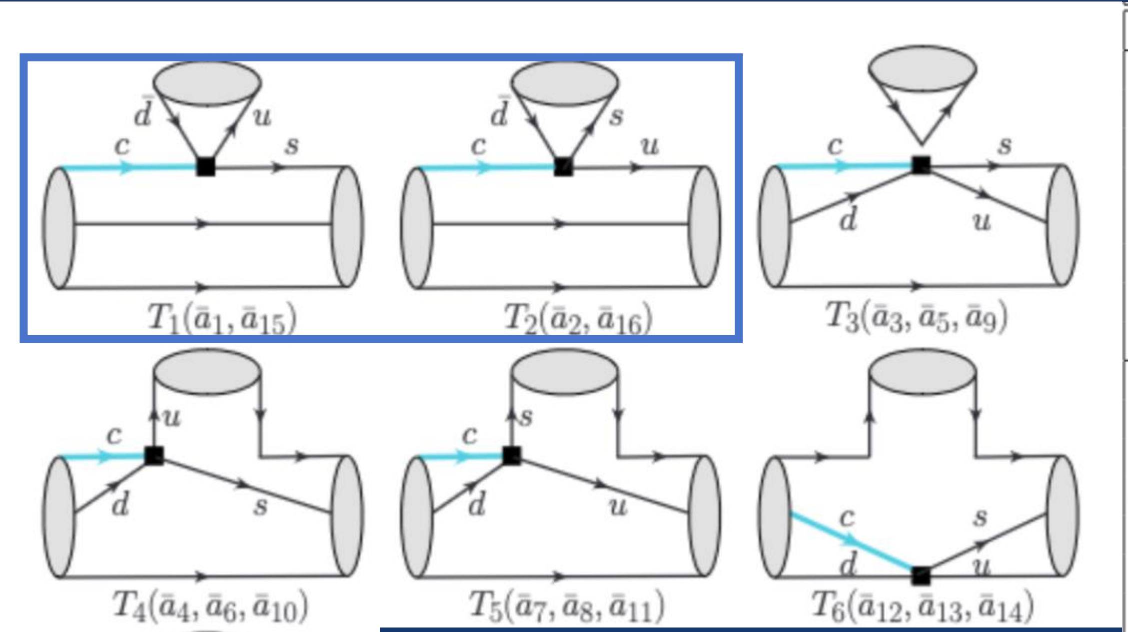
$$\bar{a}_{16} = \frac{1}{2}(-b_6 + d_6 + e_{15}), \quad \bar{a}_{17} = \frac{1}{2}(d_6 + e_{15} - b_{15}),$$

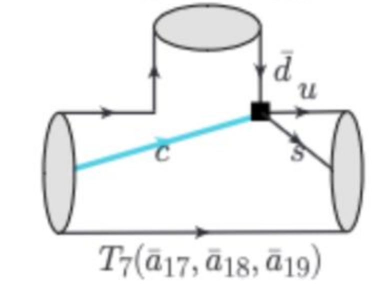
$$\bar{a}_{18} = \frac{1}{2}(-d_6 + e_{15} - b_{15}), \quad \bar{a}_{19} = d_6.$$

form factors	Case I (χ^2/d.o.f=1.28)				
vector(f)	$f^a = 0.0101(28)$	$f_6^b = 0.0187(40)$	$f_6^c = 0.0237(36)$	$f_6^d = -0.0093(37)$	$f^{a'} = -0.003(101)$
	$f_{15}^b = -0.0100(34)$	$f_{15}^c = 0.0073(34)$	$f_{15}^d = -0.0156(22)$	$f_{15}^e = 0.0537(35)$	
axial-vector(g)	$g^a = -0.0266(78)$	$g_6^b = -0.1784(55)$	$g_6^c = 0.0878(91)$	$g_6^d = -0.0556(72)$	$g^{a'} = 0.05(44)$
	$g_{15}^b = 0.0746(48)$	$g_{15}^c = 0.0075(90)$	$g_{15}^d = -0.0219(57)$	$g_{15}^e = 0.0189(34)$	

form factors	TDA				
vector(f)	T_1	T_2	T_3	T_4	T_5
	$f_1 = 0.0817(45)$ $f_{15} = 0.0409(23)$	$f_2 = 0.0257(50)$ $f_{16} = 0.0129(25)$	$f_3 = -0.0051(14)$ $f_5 = -0.002(50)$ $f_9 = 0.003(50)$	$f_4 = -0.0082(12)$ $f_6 = -0.054(26)$ $f_{10} = -0.046(26)$	$f_7 = 0.0155(33)$ $f_8 = -0.015(25)$ $f_{11} = -0.031(24)$
	T_6	T_7			
	$f_{12} = 0.0237(36)$ $f_{13} = -0.024(25)$ $f_{14} = -0.048(24)$	$f_{17} = 0.0272(18)$ $f_{18} = 0.0365(35)$ $f_{19} = -0.0093(37)$			
axial-vector(g)	T_1	T_2	T_3	T_4	T_5
	$g_1 = -0.1039(86)$ $g_{15} = -0.0519(43)$	$g_2 = 0.1416(77)$ $g_{16} = 0.0708(38)$	$g_3 = 0.0133(39)$ $g_5 = 0.03(22)$ $g_9 = 0.01(22)$	$g_4 = -0.0401(30)$ $g_6 = 0.03(11)$ $g_{10} = 0.07(11)$	$g_7 = 0.0477(86)$ $g_8 = -0.07(11)$ $g_{11} = -0.12(11)$
	T_6	T_7			
	$g_{12} = 0.0878(91)$ $g_{13} = 0.04(11)$ $g_{14} = -0.05(11)$	$g_{17} = -0.0557(37)$ $g_{18} = -0.00004(564)$ $g_{19} = -0.0556(72)$			

The charmed baryon two body decays(CBTD)





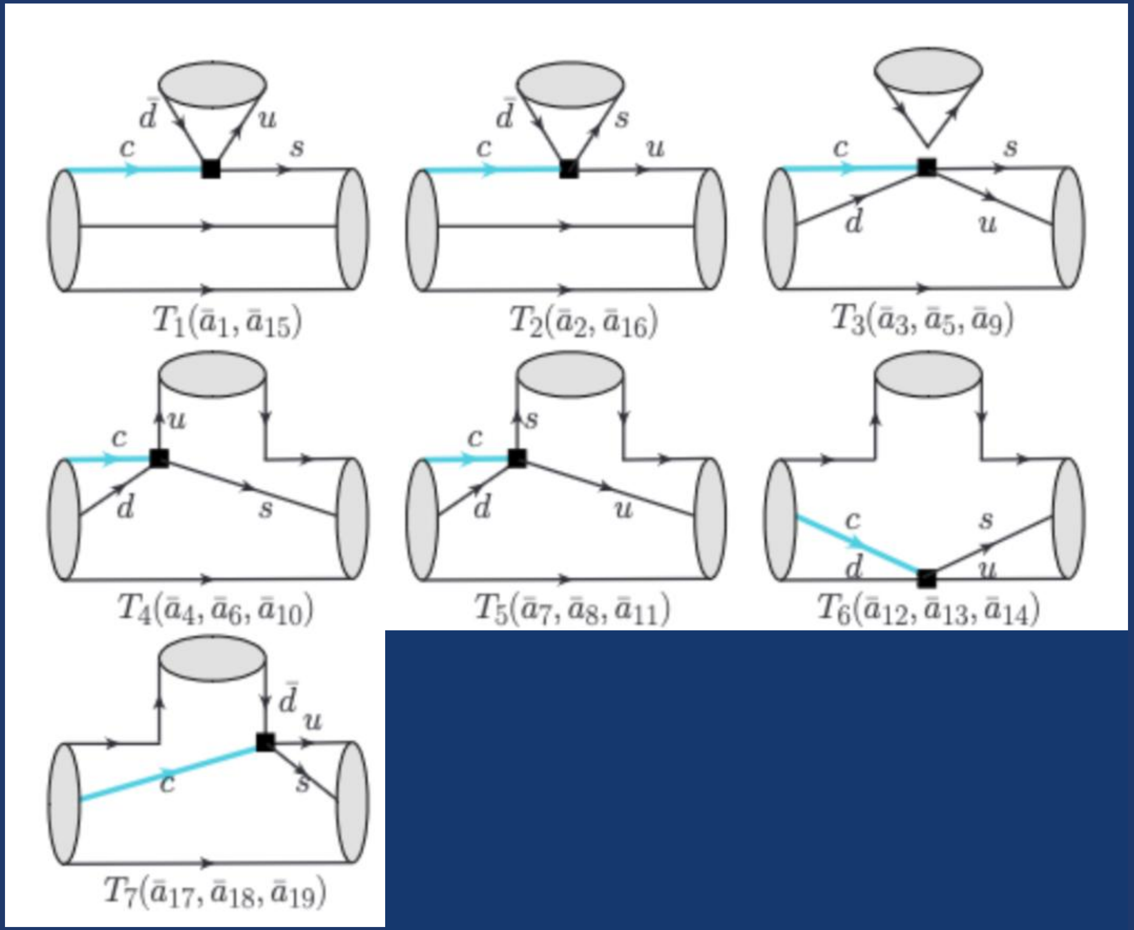
form factors	TDA				
	T_1	T_2	T_3	T_4	T_5
vector(f)	$f_1 = 0.0817(45)$ $f_{15} = 0.0409(23)$	$f_2 = 0.0257(50)$ $f_{16} = 0.0129(25)$	$f_3 = -0.0051(14)$ $f_5 = -0.002(50)$ $f_9 = 0.003(50)$	$f_4 = -0.0082(12)$ $f_6 = -0.054(26)$ $f_{10} = -0.046(26)$	$f_7 = 0.0155(33)$ $f_8 = -0.015(25)$ $f_{11} = -0.031(24)$
	T_6	T_7			
	$f_{12} = 0.0237(36)$ $f_{13} = -0.024(25)$ $f_{14} = -0.048(24)$	$f_{17} = 0.0272(18)$ $f_{18} = 0.0365(35)$ $f_{19} = -0.0093(37)$			
	T_1	T_2	T_3	T_4	T_5
axial-vector(g)	$g_1 = -0.1039(86)$ $g_{15} = -0.0519(43)$	$g_2 = 0.1416(77)$ $g_{16} = 0.0708(38)$	$g_3 = 0.0133(39)$ $g_5 = 0.03(22)$ $g_9 = 0.01(22)$	$g_4 = -0.0401(30)$ $g_6 = 0.03(11)$ $g_{10} = 0.07(11)$	$g_7 = 0.0477(86)$ $g_8 = -0.07(11)$ $g_{11} = -0.12(11)$
	T_6	T_7			
	$g_{12} = 0.0878(91)$ $g_{13} = 0.04(11)$ $g_{14} = -0.05(11)$	$g_{17} = -0.0557(37)$ $g_{18} = -0.00004(564)$ $g_{19} = -0.0556(72)$			

Ko¨rner-Pati-Woo (KPW) theorem

$$T_1, T_2 \sim 0.1 \quad \Longleftrightarrow$$

$$\begin{aligned} F(T_{c\bar{3}} \to \mathbf{B}P) \;=\; & \tilde{f}^a (P^\dagger)^l_i \mathcal{H}(\bar{\mathbf{6}})_{ij} T^{ik}_c (\mathbf{B}^\dagger)^j_k + \tilde{f}^b \mathcal{H}(\bar{\mathbf{6}})_{ij} T^{ik}_c (\mathbf{B}^\dagger)^l_k (P^\dagger)^j_l + \tilde{f}^c \mathcal{H}(\bar{\mathbf{6}})_{ij} T^{ik}_c (P^\dagger)^l_k (\mathbf{B}^\dagger)^j_l \\ & + \tilde{f}^d \mathcal{H}(\bar{\mathbf{6}})_{ij} (\mathbf{B}^\dagger)^i_k (P^\dagger)^j_l T^{kl}_c + \tilde{f}^e (\mathbf{B}^\dagger)^j_i \mathcal{H}(\mathbf{15})^{ik}_l (P^\dagger)^l_k (T_{c\bar{3}})_j \,, \end{aligned}$$

The charmed baryon two body decays(CBTD)



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

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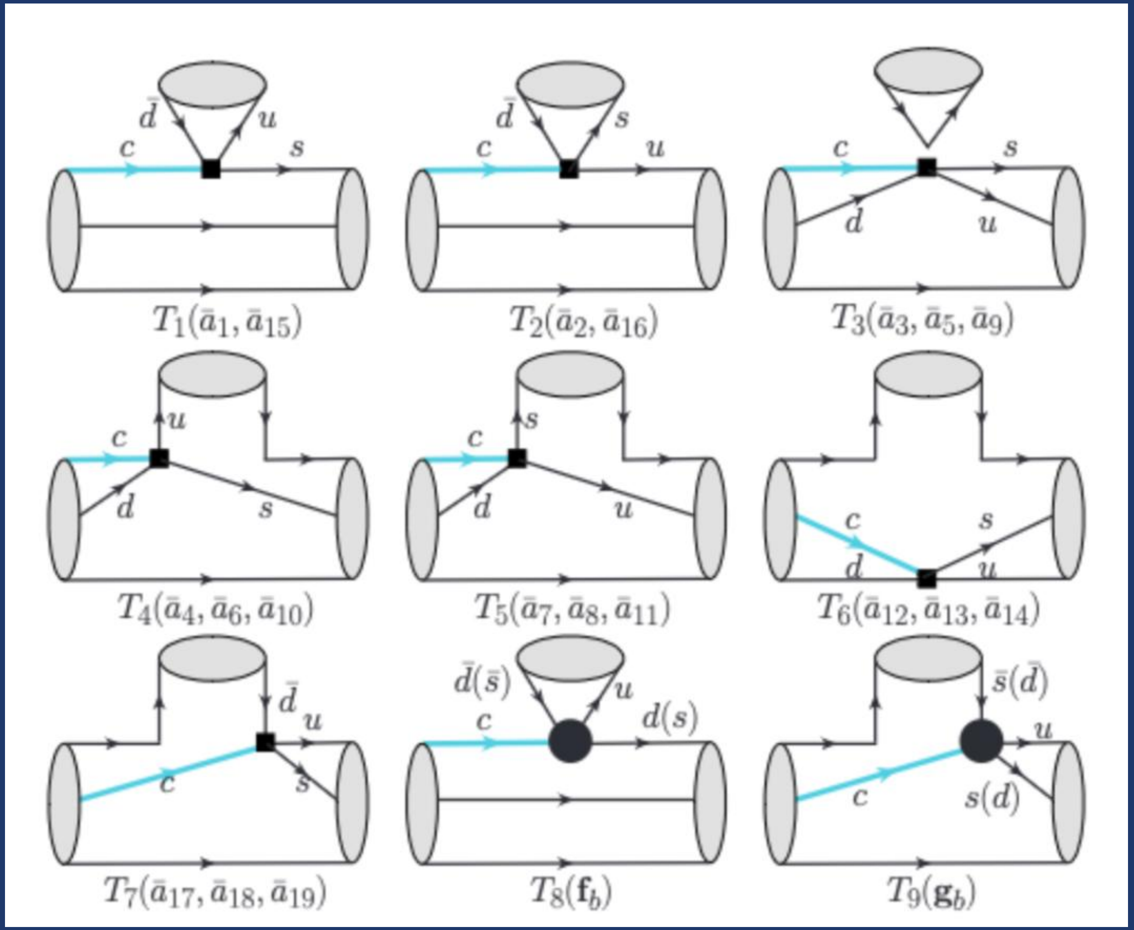
The charmed baryon two body decays(CBTD)

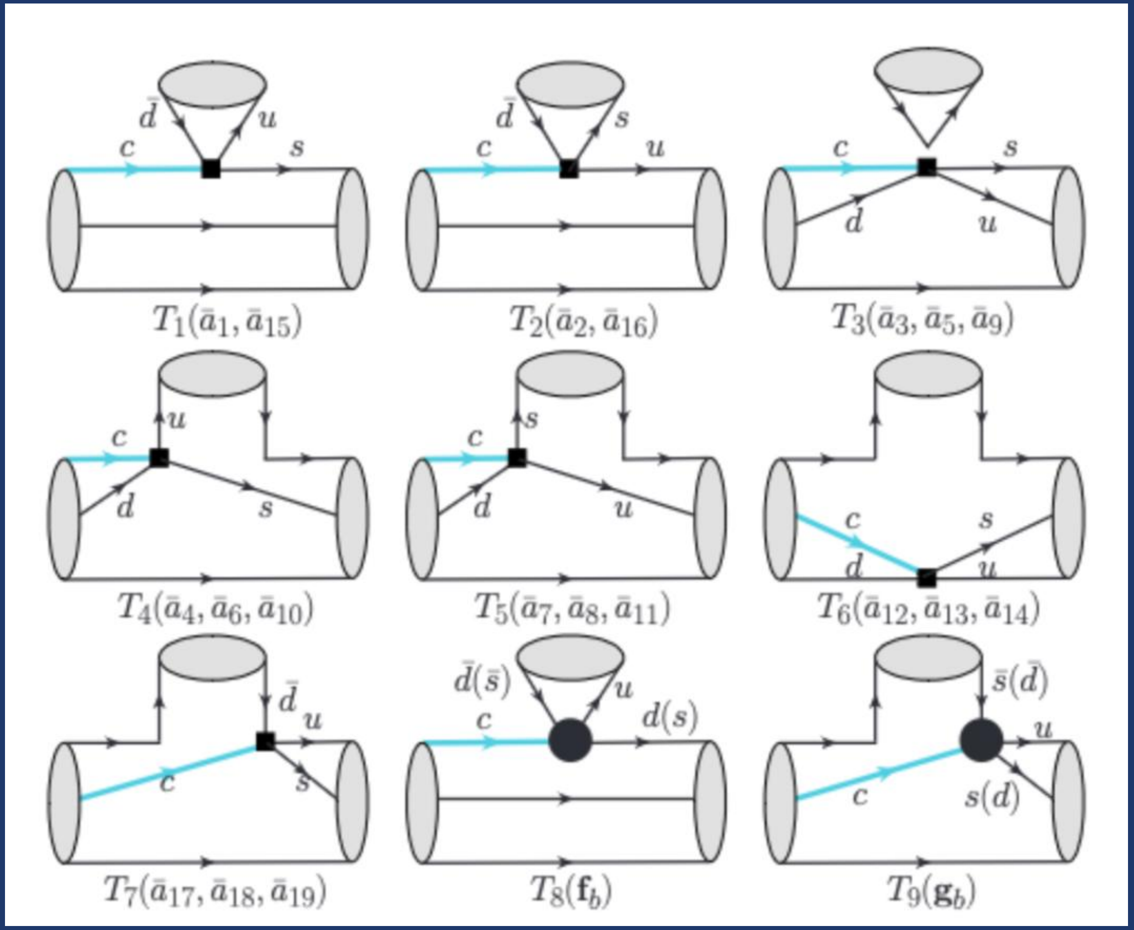


$$\mathfrak{f}_b = f_{T_1} - f_{T_2} \text{ and } \mathfrak{g}_b = -g_{18} - g_{T_7}$$

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

$$f^a = -\frac{f_{T_6}}{2}, \quad f^{a'} = \frac{1}{2} f_{T_6} - f_{T_3}, \quad f_6^b = \frac{3}{2}\mathfrak{f}_b,$$
$$f_{15}^b = -f_{T_6} - f_{T_7}, \quad f_6^c = f_{T_6} + f_{T_4}, \quad f_{15}^c = f_{T_4},$$
$$f_6^d = -\frac{3}{2}\mathfrak{f}_b - f_{T_7}, \quad f_{15}^d = -2f_{T_4} - f_{T_8},$$
$$f_{15}^e = -\frac{3}{2}\mathfrak{f}_b + 3f_{T_1} + 2f_{T_4} + f_{T_8} + f_{T_7},$$
$$g^a = g_{T_4} + \frac{g_{T_3}}{2}, \quad g^{a'} = g_{T_2} + g_{T_3} - \frac{g_{T_6}}{2}, \quad g_{15}^c = 0$$
$$g_6^b = -3g_{T_1} - 2g_{T_4}, \quad g_{15}^b = -g_{15}^e = \frac{\mathfrak{g}_b}{2} + g_{T_8} + g_{T_7},$$
$$g_6^c = g_{T_6}, \quad g_6^d = 3g_{T_1} - g_{T_7} + \frac{\mathfrak{g}_b}{2}, \quad g_{15}^d = g_{T_8},$$

The charmed baryon two body decays(CBTD)



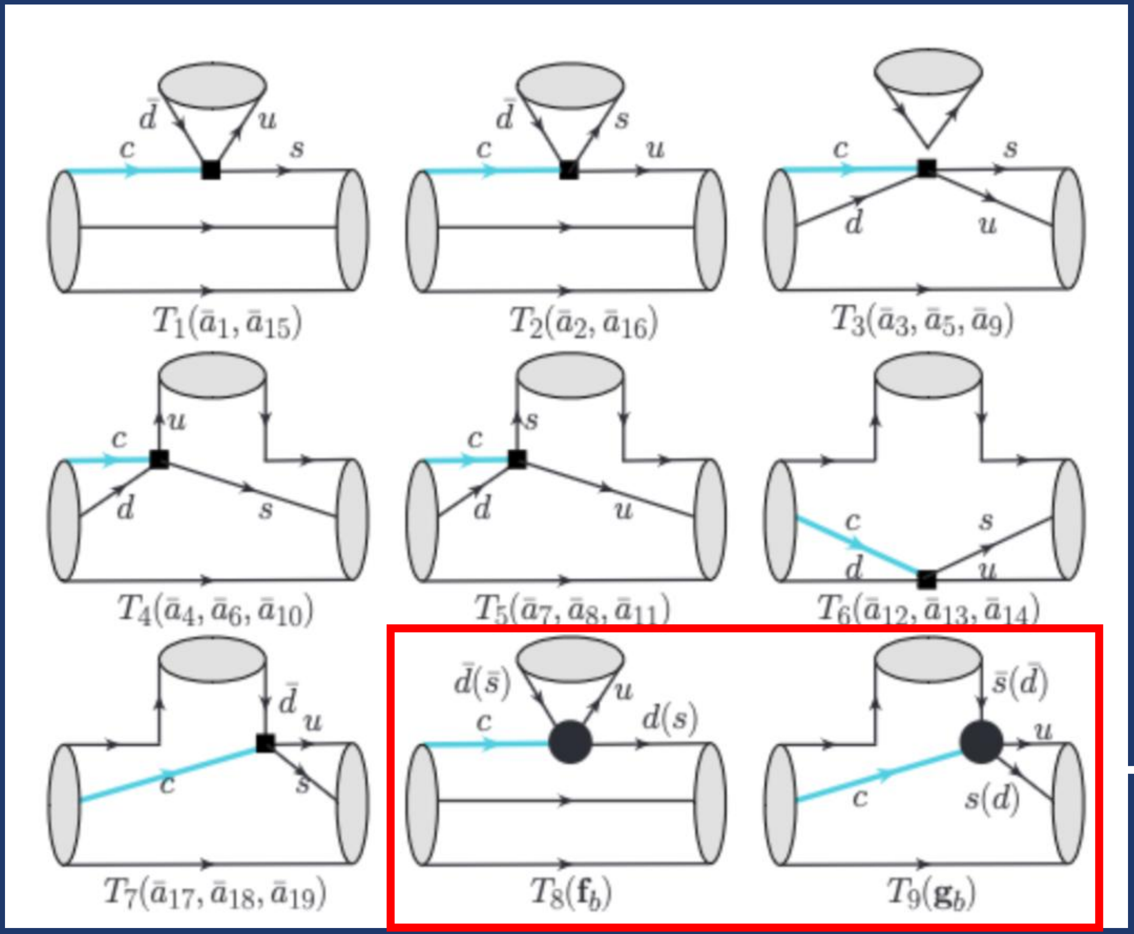
$$|A_{1,15}| = A_{T_1} = |A_{2,16}| = A_{T_2}, \quad |A_{3,5,9}| = A_{T_3},$$
$$|A_{4,6,10}| = A_{T_4} = |A_{7,8,11}| = A_{T_5},$$
$$|A_{12,13,14}| = A_{T_6}, \quad |A_{17,18,19}| = A_{T_7}, \quad A = f, g.$$

$f_6^b = 0.0187 \pm 0.0040$ $\qquad$ $g_{15}^c = 0.0075 \pm 0.0090$

$$f^a = -\frac{f_{T_6}}{2}, \quad f^{a'} = \frac{1}{2} f_{T_6} - f_{T_3}, \quad f_6^b = \frac{3}{2}\mathfrak{f}_b,$$
$$f_{15}^b = -f_{T_6} - f_{T_7}, \quad f_6^c = f_{T_6} + f_{T_4}, \quad f_{15}^c = f_{T_4},$$
$$f_6^d = -\frac{3}{2}\mathfrak{f}_b - f_{T_7}, \quad f_{15}^d = -2f_{T_4} - f_{T_6},$$
$$f_{15}^e = -\frac{3}{2}\mathfrak{f}_b + 3f_{T_1} + 2f_{T_4} + f_{T_6} + f_{T_7},$$
$$g^a = g_{T_4} + \frac{g_{T_3}}{2}, \quad g^{a'} = g_{T_2} + g_{T_3} - \frac{g_{T_6}}{2}, \quad g_{15}^c = 0$$
$$g_6^b = -3g_{T_1} - 2g_{T_4}, \quad g_{15}^b = -g_{15}^e = \frac{\mathfrak{g}_b}{2} + g_{T_6} + g_{T_7},$$
$$g_6^c = g_{T_6}, \quad g_6^d = 3g_{T_1} - g_{T_7} + \frac{\mathfrak{g}_b}{2}, \quad g_{15}^d = g_{T_3},$$

$\mathfrak{f}_b = f_{T_1} - f_{T_2}$ and $\mathfrak{g}_b = -g_{18} - g_{T_7}$

The charmed baryon two body decays(CBTD)



Symmetry breaking

Penguin

$$O_{3,5} = (\bar{u}_\alpha c_\alpha)_{V-A} \sum_{q=u,d,s} (\bar{q}_\beta q_\beta)_{V\mp A};$$

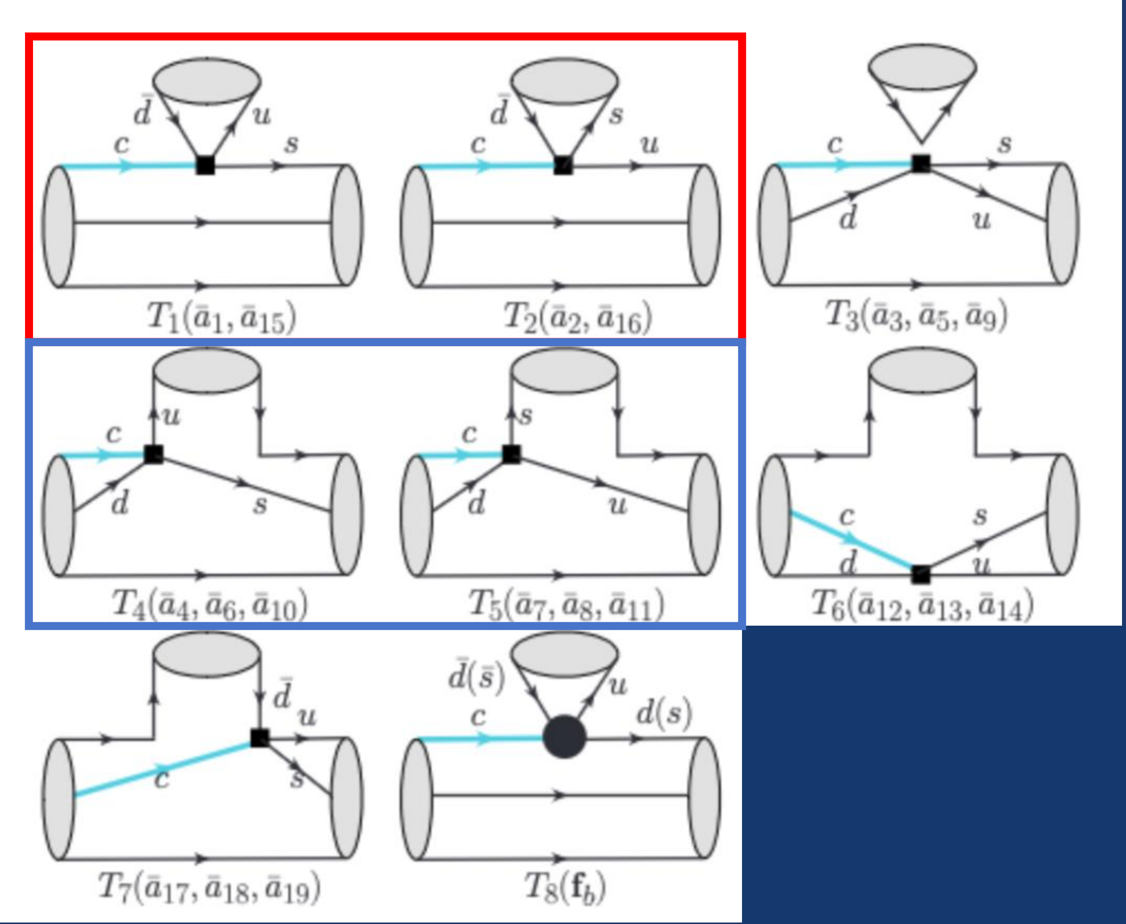
$$O_{4,6} = (\bar{u}_\beta c_\alpha)_{V-A} \sum_{q=u,d,s} (\bar{q}_\alpha q_\beta)_{V\mp A};$$

New physics $c \to u\bar{q}q$

New weak phase

The charmed baryon two body decays(CBTD)

35 experimental data ⟷ Strong phase ⟷ 35 parameters



Add strong phase corresponding to TDA diagram

18+11-1=28 parameters

$$
\begin{aligned}
A^q_{6,15} &= e^{i\phi_1}\Big(\mathcal{R}e(A^q_{6,15}) + \mathcal{I}m(A^q_{6,15})\Big) = |A^q_i| e^{i\phi_1} e^{i\delta^q_i}, \\
f^b_6 &= e^{i\phi}\Big(\mathcal{R}e(f^b_6) + \frac{3}{2}\mathcal{I}m(\mathbf{f}_b)\Big) = |f^b_6| e^{i\phi} e^{i\delta^b_6}, \\
f^d_6 &= e^{i\phi_1}\Big(\mathcal{R}e(f^d_6) + \mathcal{I}m(f^d_6) + \mathcal{R}e(f^b_6)\Big) \\
&\quad - e^{i\phi}\Big(\mathcal{R}e(f^b_6) + \frac{3}{2}\mathcal{I}m(\mathbf{f}_b)\Big), \\
f^e_{15} &= e^{i\phi_1}\Big(\mathcal{R}e(f^e_{15}) + \mathcal{I}m(f^e_{15}) + \mathcal{R}e(f^b_6)\Big) \\
&\quad - e^{i\phi}\Big(\mathcal{R}e(f^b_6) + \frac{3}{2}\mathcal{I}m(\mathbf{f}_b)\Big), A = f, g, \qquad (6)
\end{aligned}
$$

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The charmed baryon two body decays(CBTD)

$$A^q_{6,15} = e^{i\phi_1}\left(\mathcal{R}e(A^q_{6,15}) + \mathcal{I}m(A^q_{6,15})\right) = |A^q_i|e^{i\phi_1}e^{i\delta^q_i},$$
$$f^b_6 = e^{i\phi}\left(\mathcal{R}e(f^b_6) + \frac{3}{2}\mathcal{I}m(\mathbf{f}_b)\right) = |f^b_6|e^{i\phi}e^{i\delta^b_6},$$
$$f^d_6 = e^{i\phi_1}\left(\mathcal{R}e(f^d_6) + \mathcal{I}m(f^d_6) + \mathcal{R}e(f^b_6)\right) - e^{i\phi}\left(\mathcal{R}e(f^b_6) + \frac{3}{2}\mathcal{I}m(\mathbf{f}_b)\right),$$
$$f^e_{15} = e^{i\phi_1}\left(\mathcal{R}e(f^e_{15}) + \mathcal{I}m(f^e_{15}) + \mathcal{R}e(f^b_6)\right) - e^{i\phi}\left(\mathcal{R}e(f^b_6) + \frac{3}{2}\mathcal{I}m(\mathbf{f}_b)\right), A = f, g, \quad (6)$$

Generally, new weak phase can not be determined without the anti-baryon decay data.

- In SU(3) symmetry, strong phase is global phase.
- New weak phase only entry the Cabibbo-suppressed processess.

Determine the strong phase by Cabibbo-allowed and doublely Cabibbo-supressed processes

→ Determine the weak phase by Cabibbo-supressed processes

→ If there is not necessary to add the new weak phase, the fit result of new weak phase should equal to zero with its error.

The charmed baryon two body decays(CBTD)

form factors	Case II (χ^2/d.o.f=0.597)				
	real part			imaginary part	
vector(f)	$f^a = -0.0368(84)$	$f_6^b = 0.0075(49)$	$f_6^c = 0.017(13)$	$f_{T_1} = -0.0119(35)$	$f_{T_4} = 0.0080(92)$
	$f_6^d = 0.006(27)$	$f^{a\prime} = -0.008(332)$	$\mathbf{f}_b = -0.0013(58)$	$f_{T_6} = -0.018(14)$	$f_{T_7} = 0.014(13)$
	$f_{15}^b = 0.0201(71)$	$f_{15}^c = -0.0055(65)$	$f_{15}^d = -0.018(20)$		
	$f_{15}^e = -0.0130(61)$				
axial-vector(g)	$g^a = -0.022(38)$	$g_6^b = 0.035(15)$	$g_6^c = -0.036(21)$	$g_{T_1} = -0.024(51)$	$g_{T_3} = -0.18(60)$
	$g_6^d = 0.03(10)$	$g^{a\prime} = 0.13(38)$		$g_{T_4} = 0.11(12)$	$g_{T_6} = 0.018(52)$
	$g_{15}^b = -0.197(24)$	$g_{15}^c = -0.024(65)$	$g_{15}^d = -0.015(74)$	$g_{T_7} = 0.02(10)$	weak phase
	$g_{15}^e = -0.005(55)$				$\phi = -1.16(85)$

Using all 35 experimental data

Penguin weak phase: $\delta_p = -1.147 \pm 0.026$

Determine the strong phase by Cabibbo-allowed and doublely Cabibbo-supressed processes

Determine the weak phase by Cabibbo-supressed processes

If there is not necessary to add the new weak phase, the fit result of new weak phase should equal to zero with its error.

The CPV in CBTD

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

Different strong phase and weak phase

$$A_{CP} = \frac{Br(B_c \to BP) - Br(\bar{B}_c \to \bar{B}\bar{P})}{Br(B_c \to BP) + Br(\bar{B}_c \to \bar{B}\bar{P})} \propto \sin(\phi_1 - \phi_2)\sin(\delta_1 - \delta_2)$$

$V_{cb}^* V_{ub} \sim O(10^{-4})$ ⇒ $A_{CP} \sim O(10^{-4})$

Our work $f_b \sim O(10^{-3})$ ⇒ $A_{CP} \sim O(10^{-3})$

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The CPV in CBTD

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

Our work $\mathrm{f}_b \sim O(10^{-3})$ ⇒ $A_{CP} \sim O(10^{-3})$

Prediction

$$A_{CP}^{\Lambda_c^+\to p\eta} = -0.047(45),\ A_{CP}^{\Lambda_c^+\to n\pi^+} = -0.33(28),\ A_{CP}^{\Xi_c^+\to\Xi^0 K^+} = -0.39(32)$$

~ 0.001 ~ 0.01

We need more data to reduce the error

Conclusion

- An global analysis of CBTD in IRA are given within chi^2/d.o.f=1.28.
- The equivalence of TDA and IRA shows T1 T2 diagram are dominant.
- By considering the differentence of IRA and TDA in numerical analysis, we add a new weak phase in our work.
- By determineing the weak phase in global analysis phi=-1.16(85), we observe that the fit vaule aligns with expectations for the QCD penguin's weak phase.

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The penguin contribution in CBTD

decompositions in IRA

$$H_k^{ij} = \frac{1}{2}(H_{15})_k^{ij} - \frac{1}{2}(H_{\bar{6}})_k^{ij} - \frac{1}{8}(H_3)_k^{ij} + \frac{3}{8}(H_{3\prime})_k^{ij}$$

$$(H_{15})_k^{ij} = -\frac{1}{4}(H_m^{im}\delta_k^j + H_m^{jm}\delta_k^i + H_m^{mi}\delta_k^j + H_m^{mj}\delta_k^i) + H_k^{ij} + H_k^{ji},$$

$$(H_{\bar{6}})_k^{ij} = \frac{1}{2}(H_m^{im}\delta_k^j - H_m^{jm}\delta_k^i - H_m^{mi}\delta_k^j + H_m^{mj}\delta_k^i) - H_k^{ij} + H_k^{ji},$$

$$(H_3)_k^{ij} = H_m^{mi}\delta_k^j + H_m^{jm}\delta_k^i,$$

$$(H_{3\prime})_k^{ij} = H_m^{im}\delta_k^j + H_m^{mj}\delta_k^i.$$

operator in Eq. 2. For the $c \to s\bar{d}u$ operator, the IRA Hamiltonian are

$$(H_{\bar{6}})_2^{31} = -(H_{\bar{6}})_2^{13} = (H_{15})_2^{31} = (H_{15})_2^{13} = V_{cs}^* V_{ud}, \quad (5)$$

while, for doubly Cabibbo-surpressed induced by the $c \to d\bar{s}u$ transition, we have

$$(H_{\bar{6}})_3^{21} = -(H_{\bar{6}})_3^{12} = (H_{15})_3^{21} = (H_{15})_3^{12} = V_{cd}^* V_{us}. \quad (6)$$

For the transition $c \to u\bar{d}d$, we have

$$\begin{aligned} &(H_3)^1 = \lambda_d, \quad (H_{\bar{6}})_2^{21} = -(H_{\bar{6}})_2^{12} \\ &= (H_{\bar{6}})_3^{13} = -(H_{\bar{6}})_3^{31} = \frac{1}{2}\lambda_d, \frac{1}{3}(H_{15})_2^{21} = \frac{1}{3}(H_{15})_2^{12} \\ &= -\frac{1}{2}(H_{15})_1^{11} = -(H_{15})_3^{13} = -(H_{15})_3^{31} = \frac{1}{4}\lambda_d, \quad (7) \end{aligned}$$

where $\lambda_d = V_{cd}^* V_{ud}$ and $(H_3)^i = (H_3)_k^{ji}\delta_j^k$. Meanwhile, for the transition $c \to u\bar{s}s$, we have

$$\begin{aligned} &(H_3)^1 = \lambda_s, \quad (H_{\bar{6}})_2^{12} = -(H_{\bar{6}})_2^{21} \\ &= (H_{\bar{6}})_3^{31} = -(H_{\bar{6}})_3^{13} = \frac{1}{2}\lambda_s, \frac{1}{3}(H_{15})_3^{31} = \frac{1}{3}(H_{15})_3^{13} \\ &= -\frac{1}{2}(H_{15})_1^{11} = -(H_{15})_2^{12} = -(H_{15})_2^{21} = \frac{1}{4}\lambda_s, \quad (8) \end{aligned}$$

where $\lambda_s = V_{cs}^* V_{us}$. Combining all Hamiltonian matrix

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by $\lambda_b + \lambda_d + \lambda_s = 0$. For clearly showing the source, we give the Hamiltonian matrix of $c \to ud\bar{d}/s\bar{s}$ as

$$(H_{\bar{6}})^{31}_{3} = -(H_{\bar{6}})^{13}_{3} = (H_{\bar{6}})^{12}_{2} = -(H_{\bar{6}})^{21}_{2} = \frac{1}{2}(\lambda_s - \lambda_d),$$
$$(H_{15})^{31}_{3} = (H_{15})^{13}_{3} = \frac{3}{4}\lambda_s - \frac{1}{4}\lambda_d = \frac{\lambda_s - \lambda_d}{2} - \frac{\lambda_b}{4},$$
$$(H_{15})^{21}_{2} = (H_{15})^{12}_{2} = \frac{3}{4}\lambda_d - \frac{1}{4}\lambda_s = \frac{\lambda_d - \lambda_s}{2} - \frac{\lambda_b}{4},$$
$$(H_{15})^{11}_{1} = \frac{\lambda_b}{2}, (H_3)^1 = -\lambda_b. \quad (9)$$

One can see that the $(H_{15})^{11}_{1}$ and $(H_3)^1$ are proportional to λ_b and it will introduce a new weak phase. It violate traditional understanding of the weak decays. One can easily find that when we consider the $c \to ud\bar{d}$ or $c \to us\bar{s}$ process separately, the new CKM matrix will not involve.

We find that the Hamiltonian which are proportional to λ_b come form the trace of H^{ij}_{k}. However in the decomposition relation of IRA Hamiltonian Eq. 4, the H_{15} and $H_{\bar{6}}$ are traceless and the trace are absorbed into H_3. As a result, since the weak interaction Hamiltonian obey the symmetry of three generate quarks $\{\{u,d\},\{c,s\},\{t,b\}\}$ instead of $\{u,d,s\}$ symmetry, the traceless of H_{15} is breaking. If we use the H^{11}_{1} to represent the $c \to ub\bar{b}$ transition, the $(H_3)^1 = \lambda_d + \lambda_s + \lambda_b = 0$ and λ_b are canceled in each element of H_{15}. In summary, the λ_b is IRA Hamiltonian come from the $\{u,d,s\}$ symmetry breaking in the weak interaction. Fortunately, this symmetry breaking of Hamiltonian will only determine the possible decay channel and the ratio of amplitude will not be affected. Therefore we can just omit the λ_b in IRA Hamiltonian of Eq. 9 and the non-physical results will disappeared.

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

form factors	Case I (χ^2/d.o.f=0.945)				
vector(f)	$f^a = -0.0615(34)$	$f^b_6 = 0.0592(32)$	$f^c_6 = 0.0186(49)$	$f^d_6 = 0.0064(36)$	
	$f^{a\prime} = -0.016(13)$	$f^b_{15} = -0.0089(17)$	$f^c_{15} = -0.0213(23)$	$f^d_{15} = -0.0056(44)$	$f^e_{15} = -0.0250(27)$
	$f^a_3 = 0.0058(10)$	$f^b_3 = -0.0270(24)$	$f^c_3 = -6 * 10^{-20}(10^{-11})$	$f^d_3 = 0.03076(91)$	
axial-vector(g)	$g^a = 0.126(10)$	$g^b_6 = -0.186(14)$	$g^c_6 = -0.0437(61)$	$g^d_6 = 0.037(12)$	
	$g^{a\prime} = 0.160(32)$	$g^b_{15} = 0.056(11)$	$g^c_{15} = -0.043(18)$	$g^d_{15} = 0.006(16)$	$g^e_{15} = -0.104(12)$
	$g^a_3 = 0.0215(28)$	$g^b_3 = 0.0210(94)$	$g^c_3 = 10^{-18}(10^{-10})$	$g^d_3 = -0.0818(52)$	

$$\lambda_b \times F_P \sim 0.01$$