Charmed Baryon Weak Decays with SU(3) Flavor Symmetry

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Outline

- Introduction
- Effective Hamiltonians for Weak Decays of Charmed Baryons with SU(3) Flavor Symmetry
- Semileptonic decays of charmed baryons
- Two-body nonleptonic decays of charmed baryons
- Three-body nonleptonic decays of charmed baryons
- Summary

Introduction

QCD

Three light quarks
q=u,d,s

$$SU(3)_C \times SU(3)_L \times SU(3)_R \times U(1)_B \longrightarrow SU(3)_C \times SU(3)_{F=L+R} \times U(1)_B$$

	$SU(3)_C$	$SU(3)_L$	$SU(3)_R$	$U(1)_B$
q	3	3	1	1/3
$\bar{q}$	$\bar{3}$	1	$\bar{3}$	-1/3

$SU(3)_C$	$SU(3)_{F=L+R}$	$U(1)_B$
3	3	1/3
$\bar{3}$	$\bar{3}$	-1/3

$SU(3)_F$
Flavor
Symmetry

Introduction

QCD

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3	3	1/3
$\bar{3}$	$\bar{3}$	-1/3

$SU(3)_F$ Flavor Symmetry

$SU(3)_C: \; 3 \otimes 3 \otimes 3 = 10_S \oplus 8_{MS} \oplus 8_{MA} \oplus 1_A$

$SU(3)_F: \; 3 \otimes 3 \otimes 3 = 10_S \oplus 8_{MS} \oplus 8_{MA} \oplus 1_A$

$SU(2)_{spin}: \; 2 \otimes 2 \otimes 2 = 4_S \oplus 2_{MS} \oplus 2_{MA}$

Light physical allowed baryon states (q=u,d,s)

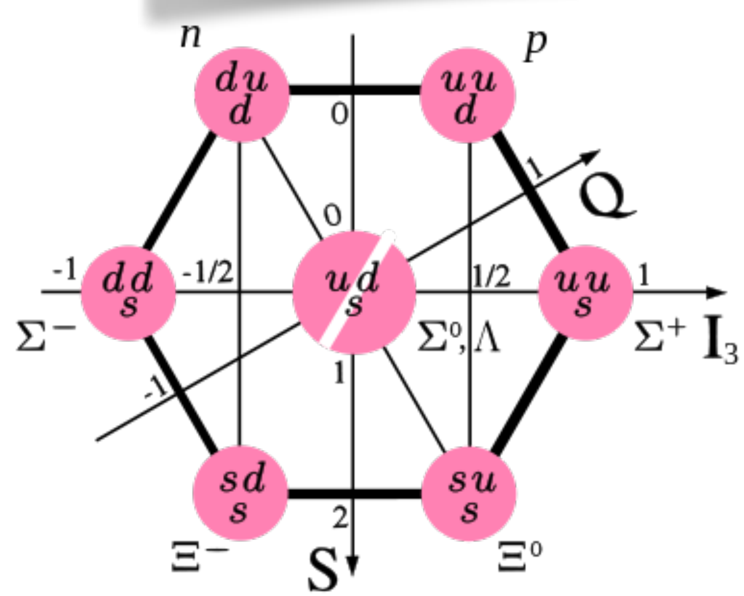
Pauli Exclusion Principle

Totally antisymmetric states

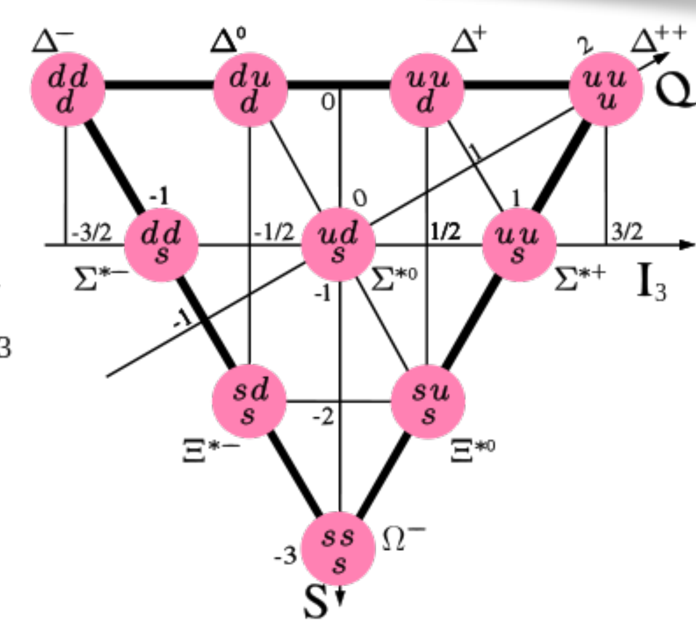
Space: L=0 Symmetric

$(\underline{SU(3)_C}, \underline{SU(3)_F, SU(2)_{spin}})$

Antisymmetric Symmetric



(1, 8, 2) **Octet**
spin=1/2



(1, 10, 4) **Decuplet**
spin=3/2

Four quarks: q=u,d,s,c

$SU(4)_F: \; 4 \otimes 4 \otimes 4 = 20_S \oplus 20_{M_S} \oplus 20_{M_A} \oplus \bar{4}_A$

$SU(3)_C: \; 3 \otimes 3 \otimes 3 = 10_S \oplus 8_{M_S} \oplus 8_{M_A} \oplus 1_A$

$SU(2)_{spin}: \; 2 \otimes 2 \otimes 2 = 4_S \oplus 2_{M_S} \oplus 2_{M_A}$

Space: L=0 Symmetric

$(SU(3)_C, \; SU(4)_F, \; SU(2)_{spin})$

Antisymmetric Symmetric

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Space: L=0 Symmetric

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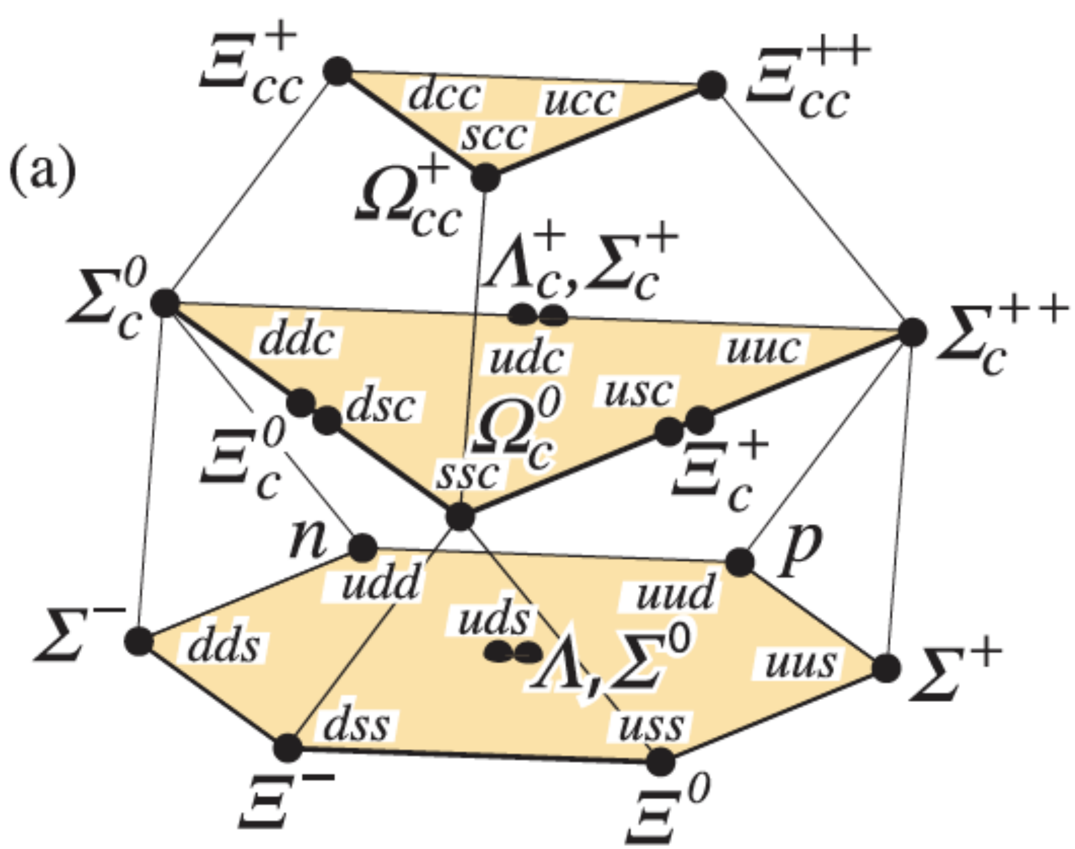
Antisymmetric Symmetric

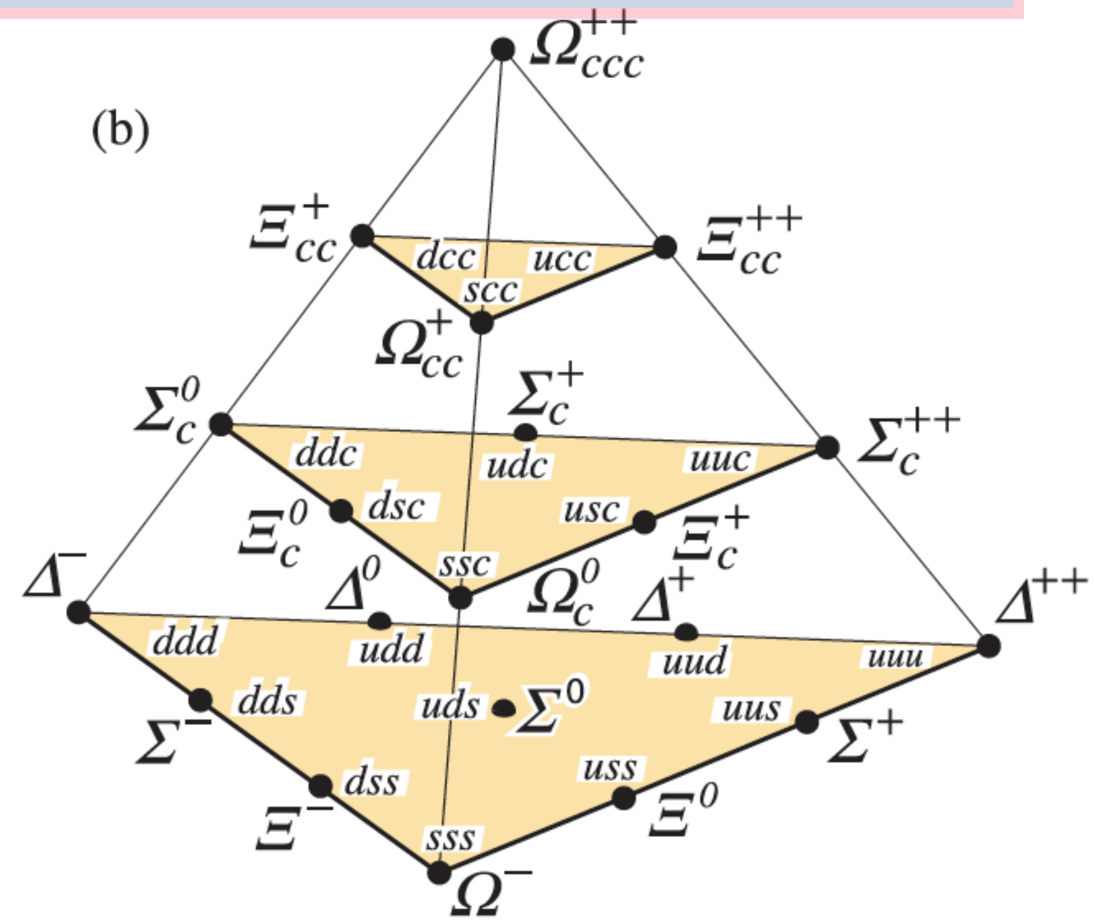
SU(4) multiplets of baryons made of u, d, s, and c quarks.

(a) The 20-plet with an SU(3) octet. (b) The 20-plet with an SU(3) decuplet.



(1, 20, 2)

spin=1/2

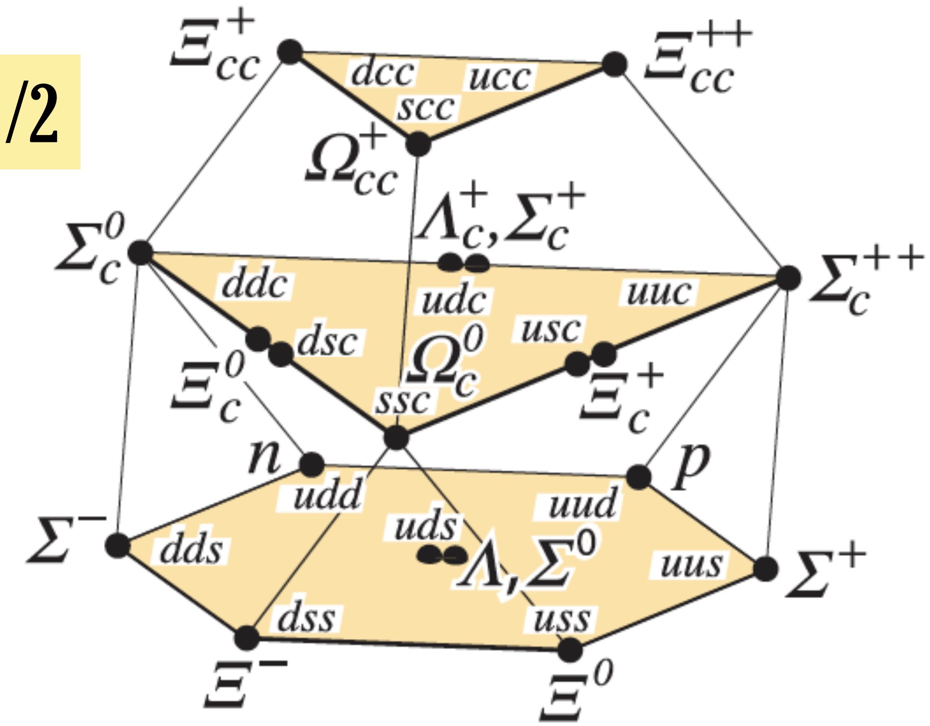


(1, 20, 4)

spin=3/2

20-plet of SU(4)$_F$ with $8\oplus\bar{3}\oplus6\oplus3$ of SU(3)$_F$

spin=1/2



SU(3)$_F$: 8

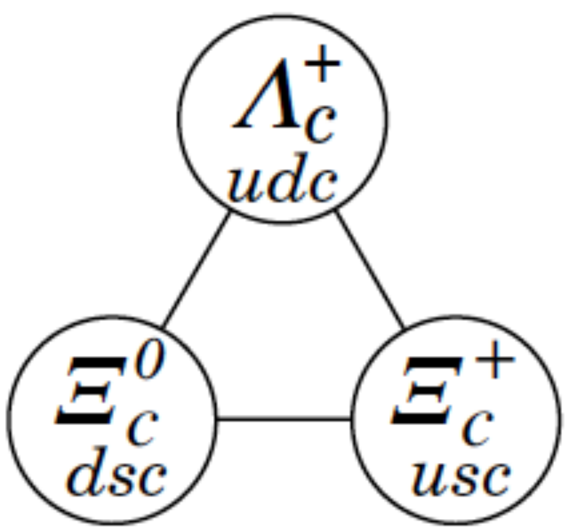
$$B_n = \begin{pmatrix} \frac{1}{\sqrt{6}}\Lambda + \frac{1}{\sqrt{2}}\Sigma^0 & \Sigma^+ & p \\ \Sigma^- & \frac{1}{\sqrt{6}}\Lambda - \frac{1}{\sqrt{2}}\Sigma^0 & n \\ \Xi^- & \Xi^0 & -\sqrt{\frac{2}{3}}\Lambda \end{pmatrix}$$

Charmed Baryons ($J^P=1/2^+$) with SU(3)$_F$

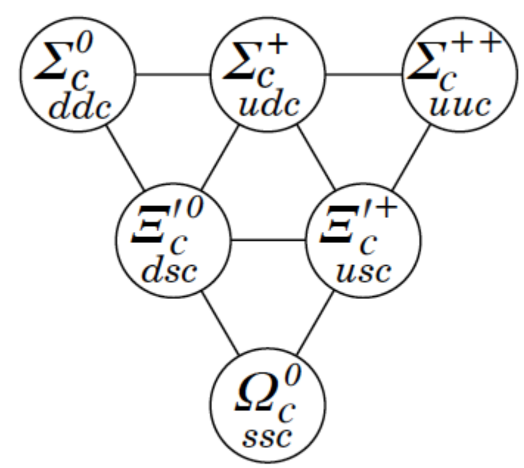
SU(3)$_F$: $3\otimes3=\bar{3}\oplus6$

anti-triplet ($\bar{3}$)

$$B_c = (\Xi_c^0, -\Xi_c^+, \Lambda_c^+)$$



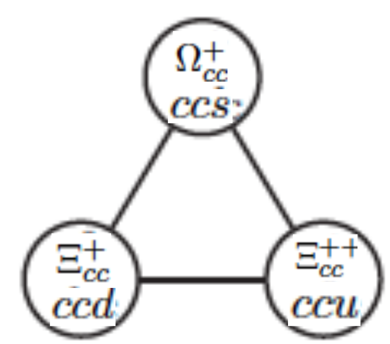
sextet (6)



$$B'_c = \begin{pmatrix} \Sigma_c^{++} & \frac{1}{\sqrt{2}}\Sigma_c^+ & \frac{1}{\sqrt{2}}\Xi_c^{\prime +} \\ \frac{1}{\sqrt{2}}\Sigma_c^+ & \Sigma_c^0 & \frac{1}{\sqrt{2}}\Xi_c^{\prime 0} \\ \frac{1}{\sqrt{2}}\Xi_c^{\prime +} & \frac{1}{\sqrt{2}}\Xi_c^{\prime 0} & \Omega_c^0 \end{pmatrix}$$

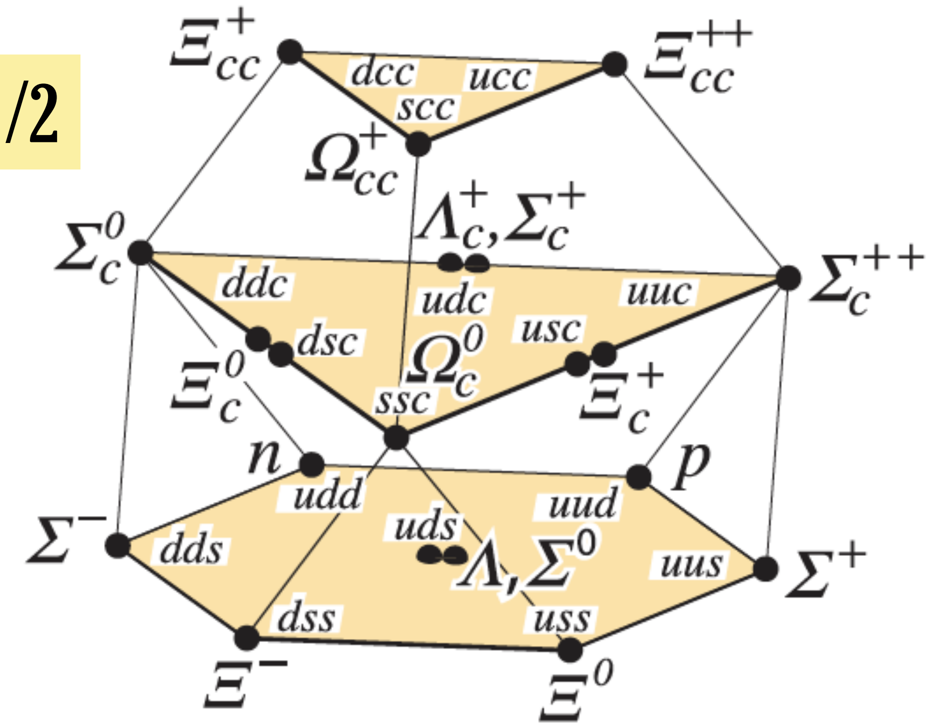
SU(3)$_F$: 3

$$B_{cc} = (\Xi_{cc}^{++}, \Xi_{cc}^{+}, \Omega_{cc}^{+})$$



20-plet of SU(4)$_F$ with $8\oplus\bar{3}\oplus6\oplus3$ of SU(3)$_F$

spin=1/2



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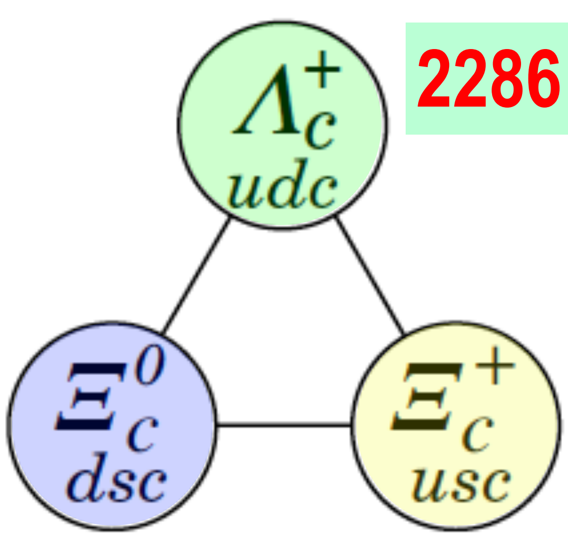
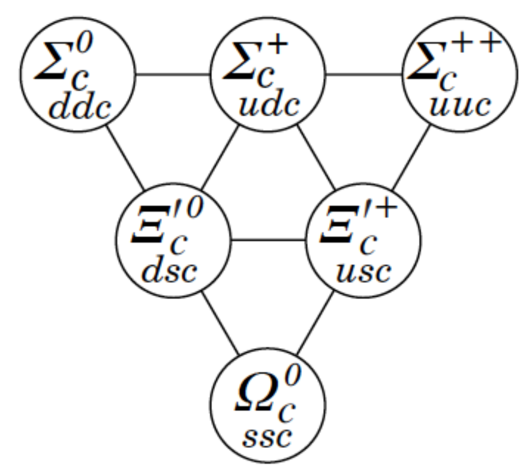


2286 MeV

2470 MeV

2468 MeV

sextet (6)



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SU(3)$_F$: 3

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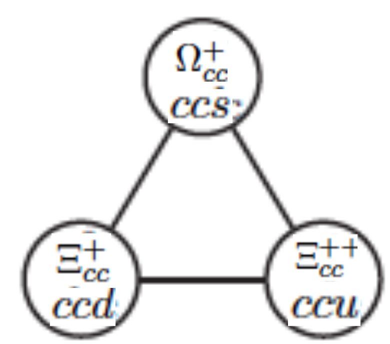
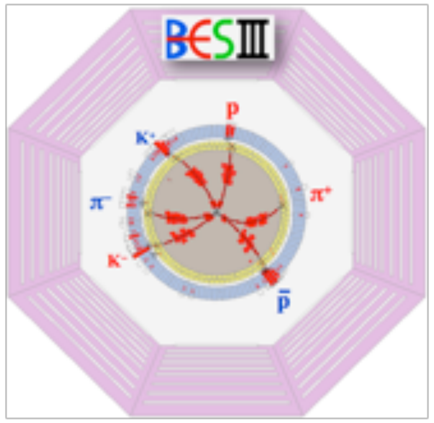


Recent experimental developments in charmed baryons:

BESIII at the *Beijing* Electron Positron Collider (BEPCII)

BEPCII: a τ-c Factory



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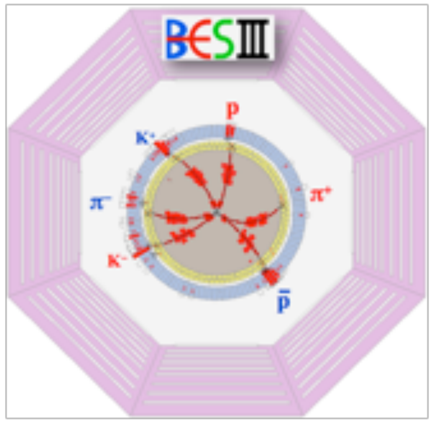
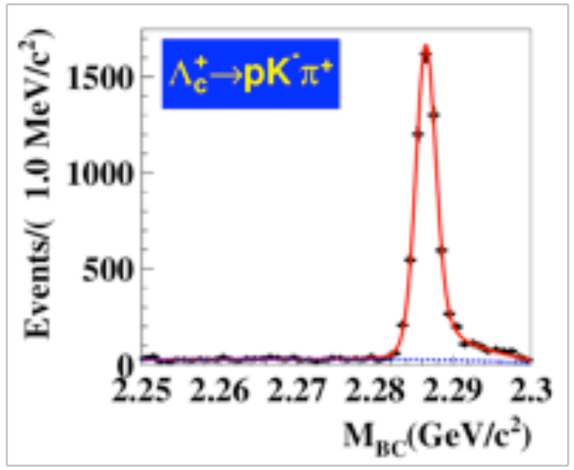
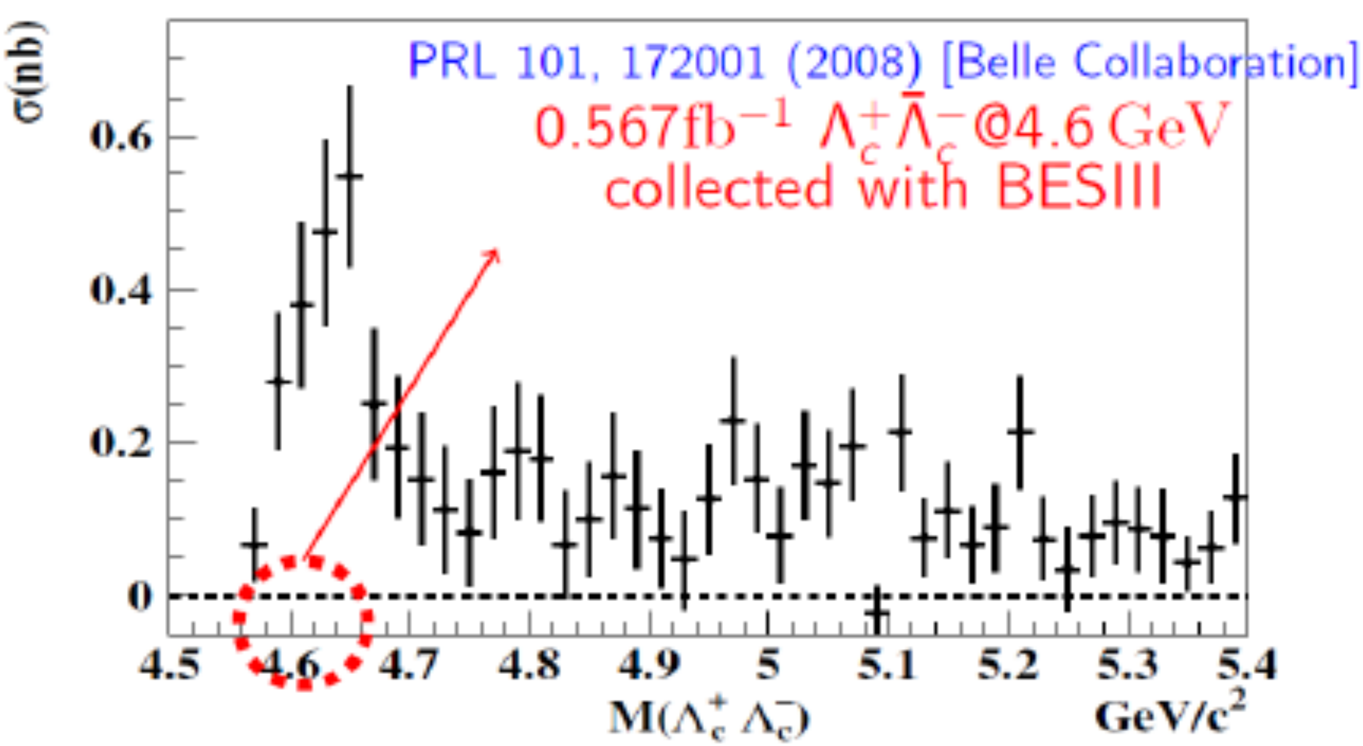


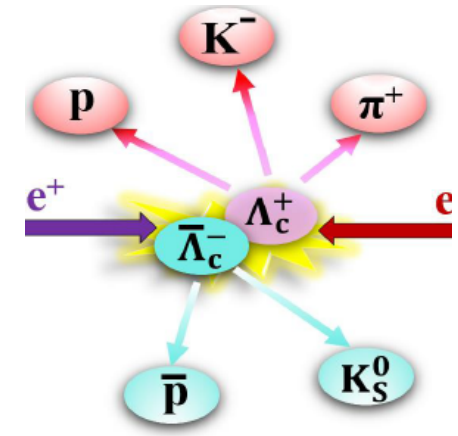


$$\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+)_{\mathrm{BESIII}} = (5.84 \pm 0.27 \pm 0.23)\%$$



BEPCII: a τ-c Factory

Around E_{cms} ~ 4.6 GeV

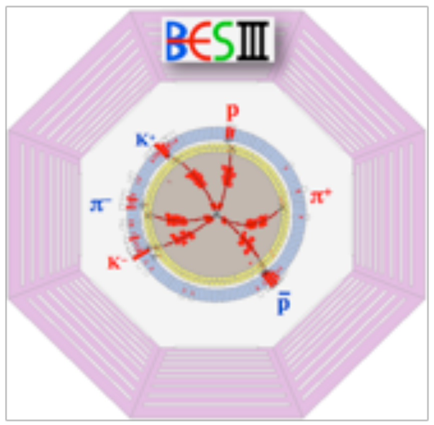


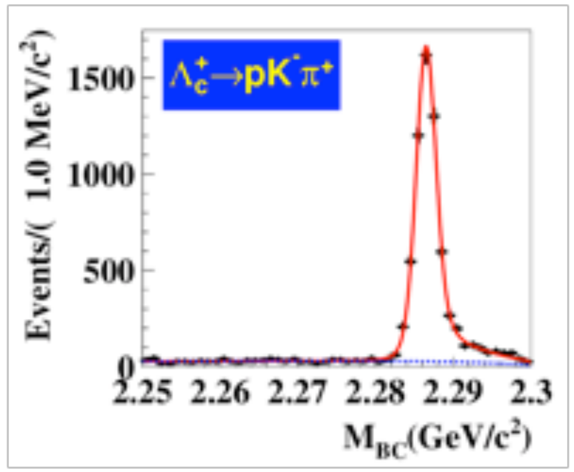
A uniquely clean background to study Charm Baryons

BESIII

Recent experimental developments in charmed baryons:

BESIII at the *Beijing* Electron Positron Collider (BEPCII)





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BEPCII: a τ-c Factory

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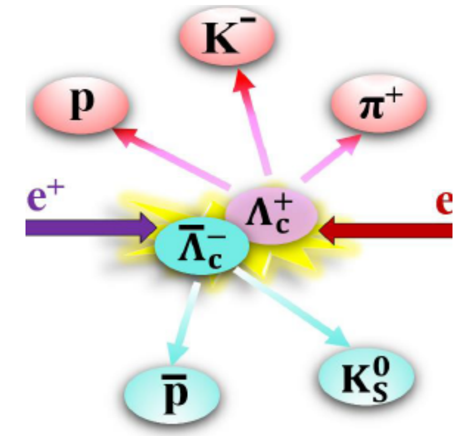

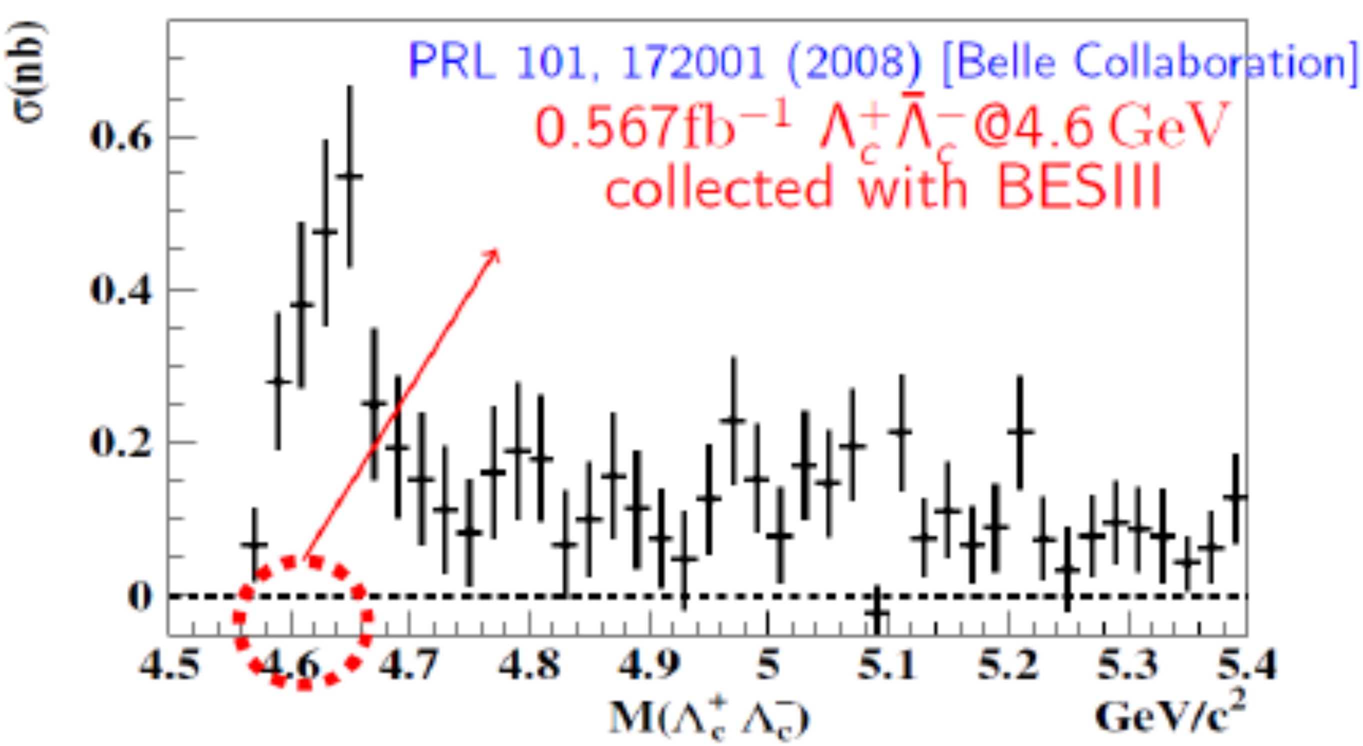

A uniquely clean background to study Charm Baryons

BESIII

At BEPCII: *If E_{CM}* ⟶ >4.95 GeV ⟶ Ξ_c: absolute rates

TABLE I. Experimental data for charmed baryons given by the BES-III collaboration, where the first and second uncertainties are statistic and systematic errors, respectively, while the relative branching ratios are measured $\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+)$ and X refers to any possible final state particles.

Decay channels	Absolute (∗Relative) branching ratio	Up-down asymmetry
$\Lambda_c^+ \to \Lambda e^+\nu_e$	$(3.63 \pm 0.38 \pm 0.20) \times 10^{-2}$ [1]	
$\Lambda_c^+ \to pK_S^0$	$(1.52 \pm 0.08 \pm 0.03) \times 10^{-2}$ [2]	$0.18 \pm 0.43 \pm 0.14$ [11]
$\Lambda_c^+ \to pK^-\pi^+$	$(5.84 \pm 0.27 \pm 0.23) \times 10^{-2}$ [2]	
$\Lambda_c^+ \to pK_S^0\pi^0$	$(1.87 \pm 0.13 \pm 0.05) \times 10^{-2}$ [2]	
$\Lambda_c^+ \to pK_S^0\pi^+\pi^-$	$(1.53 \pm 0.11 \pm 0.09) \times 10^{-2}$ [2]	
$\Lambda_c^+ \to pK^-\pi^+\pi^0$	$(4.53 \pm 0.23 \pm 0.30) \times 10^{-2}$ [2]	
$\Lambda_c^+ \to \Lambda\pi^+$	$(1.24 \pm 0.07 \pm 0.03) \times 10^{-2}$ [2]	$-0.80 \pm 0.11 \pm 0.02$ [11]
$\Lambda_c^+ \to \Lambda\pi^+\pi^0$	$(7.01 \pm 0.37 \pm 0.19) \times 10^{-2}$ [2]	
$\Lambda_c^+ \to \Lambda\pi^+\pi^-\pi^+$	$(3.81 \pm 0.24 \pm 0.18) \times 10^{-2}$ [2]	
$\Lambda_c^+ \to \Sigma^0\pi^+$	$(1.27 \pm 0.08 \pm 0.03) \times 10^{-2}$ [2]	$-0.73 \pm 0.17 \pm 0.07$ [11]
$\Lambda_c^+ \to \Sigma^+\pi^0$	$(1.18 \pm 0.10 \pm 0.03) \times 10^{-2}$ [2]	$-0.57 \pm 0.10 \pm 0.07$ [11]
$\Lambda_c^+ \to \Sigma^+\pi^+\pi^-$	$(4.25 \pm 0.24 \pm 0.20) \times 10^{-2}$ [2]	
$\Lambda_c^+ \to \Sigma^+\omega$	$(1.56 \pm 0.20 \pm 0.07) \times 10^{-2}$ [2]	
$\Lambda_c^+ \to p\pi^+\pi^-$	$*(6.70 \pm 0.48 \pm 0.25) \times 10^{-2}$ [3]	
$\Lambda_c^+ \to pK^+K^-$	$*(9.36 \pm 2.22 \pm 0.71) \times 10^{-3}$ [3]	
$\Lambda_c^+ \to p\phi$	$*(1.81 \pm 0.33 \pm 0.13) \times 10^{-2}$ [3]	
$\Lambda_c^+ \to \Lambda\mu^+\upsilon_\mu$	$(3.49 \pm 0.46 \pm 0.27) \times 10^{-2}$ [4]	
$\Lambda_c^+ \to p\pi^0$	$< 2.7 \times 10^{-4}$ [5]	
$\Lambda_c^+ \to p\eta$	$(1.24 \pm 0.28 \pm 0.10) \times 10^{-2}$ [5]	
$\Lambda_c^+ \to \Xi^0K^+$	$(5.90 \pm 0.86 \pm 0.39) \times 10^{-2}$ [6]	0.77 ± 0.78 [6]
$\Lambda_c^+ \to \Xi(1530)^0K^+$	$(5.02 \pm 0.99 \pm 0.31) \times 10^{-2}$ [6]	-1.00 ± 0.34 [6]
$\Lambda_c^+ \to \Sigma^+\eta'$	$1.34 \pm 0.53 \pm 0.21) \times 10^{-2}$ [7]	
$\Lambda_c^+ \to \Lambda X$	$38.2^{+2.8}_{-2.2} \pm 0.8) \times 10^{-2}$ [8]	
$\Lambda_c^+ \to Xe^+\nu_e$	$3.95 \pm 0.34 \pm 0.09) \times 10^{-2}$ [9]	
$\Lambda_c^+ \to \Lambda\eta\pi^+$	$1.84 \pm 0.21 \pm 0.15) \times 10^{-2}$ [10]	
$\Lambda_c^+ \to \Sigma(1385)^+\eta$	$(9.1 \pm 1.8 \pm 0.9) \times 10^{-3}$ [10]	

Many newly measured charmed baryon decays.

[1] M. Ablikim *et al.* [BESIII Collaboration], Phys. Rev. Lett. **115**, 221805 (2015).

[2] M. Ablikim *et al.* [BESIII Collaboration], Phys. Rev. Lett. **116**, 052001 (2016).

[3] M. Ablikim *et al.* [BESIII Collaboration], Phys. Rev. Lett. **117**, 232002 (2016).

[4] M. Ablikim *et al.* [BESIII Collaboration], Phys. Lett. B **767**, 42 (2017).

[5] M. Ablikim *et al.* [BESIII Collaboration], Phys. Rev. D **95**, 111102 (2017).

[6] M. Ablikim *et al.* [BESIII Collaboration], Phys. Lett. B **783**, 200 (2018).

[7] M. Ablikim *et al.* [BESIII Collaboration], arXiv:1811.08028 [hep-ex].

[8] M. Ablikim *et al.* [BESIII Collaboration], Phys. Rev. Lett. **121**, 062003 (2018).

[9] M. Ablikim *et al.* [BESIII Collaboration], Phys. Rev. Lett. **121**, 251801 (2018).

[10] M. Ablikim *et al.* [BESIII Collaboration], Phys. Rev. D **99**, 032010 (2019).

[11] M. Ablikim *et al.* [BESIII Collaboration], arXiv:1905.04707 [hep-ex].

BELLE at the KEK-B factory

TABLE II. Experimental data for charmed baryons given by the Belle Collaboration, where the first and second uncertainties are statistic and systematic errors, respectively, while he relative branching ratios are measured $\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+)$.

Decay channel	Absolute (*Relative) branching ratio
$\Lambda_c^+ \to pK^-\pi^+$	$(6.84 \pm 0.24^{+0.21}_{-0.27}) \times 10^{-2}$ [1]
$\Lambda_c^+ \to pK^+\pi^-$	$*(2.35 \pm 0.27 \pm 0.21) \times 10^{-3}$ [2]
$\Lambda_c^+ \to \phi p \pi^0$	$< 1.53 \times 10^{-4}$ [3]
$\Lambda_c^+ \to K^+K^-p\pi^0$	$< 6.3 \times 10^{-5}$ [3]
$\Lambda_c^+ \to K^-\pi^+p\pi^0$	$*(0.685 \pm 0.007 \pm 0.018)$ [3]
$\Lambda_c^+ \to \Sigma^+\pi^-\pi^+$	$*(0.719 \pm 0.003 \pm 0.024)$ [4]
$\Lambda_c^+ \to \Sigma^0\pi^+\pi^0$	$*(0.575 \pm 0.005 \pm 0.036)$ [4]
$\Lambda_c^+ \to \Sigma^+\pi^0\pi^0$	$*(0.247 \pm 0.006 \pm 0.019)$ [4]
$\Xi_c^0 \to \Xi^-\pi^+$	$(1.80 \pm 0.50 \pm 0.14) \times 10^{-2}$ [5]
$\Xi_c^0 \to \Lambda K^-\pi^+$	$(1.17 \pm 0.37 \pm 0.09) \times 10^{-2}$ [5]
$\Xi_c^0 \to pK^-K^-\pi^+$	$(5.8 \pm 2.3 \pm 0.5) \times 10^{-3}$ [5]
$\Xi_c^+ \to \Xi^-\pi^+\pi^+$	$(28.6 \pm 12.1 \pm 3.8) \times 10^{-3}$ [6]
$\Xi_c^+ \to pK^-\pi^+$	$(4.5 \pm 2.1 \pm 0.7) \times 10^{-3}$ [6]
$\Xi_c^+ \to p\overline{K}^*(892)^0$	$(2.5 \pm 1.6 \pm 0.4) \times 10^{-3}$ [6]

[1] A. Zupanc *et al.* [Belle Collaboration], Phys. Rev. Lett. **113**, 042002 (2014)

[2] S. B. Yang *et al.* [Belle Collaboration], Phys. Rev. Lett. **117**, 011801 (2016)

[3] B. Pal *et al.* [Belle Collaboration], Phys. Rev. D **96**, 051102 (2017)

[4] M. Berger *et al.* [Belle Collaboration], Phys. Rev. D **98**, 112006 (2018)

[5] Y. B. Li *et al.* [Belle Collaboration], Phys. Rev. Lett. **122**, 082001 (2019)

[6] Y. B. Li *et al.* [Belle Collaboration], arXiv:1904.12093 [hep-ex].

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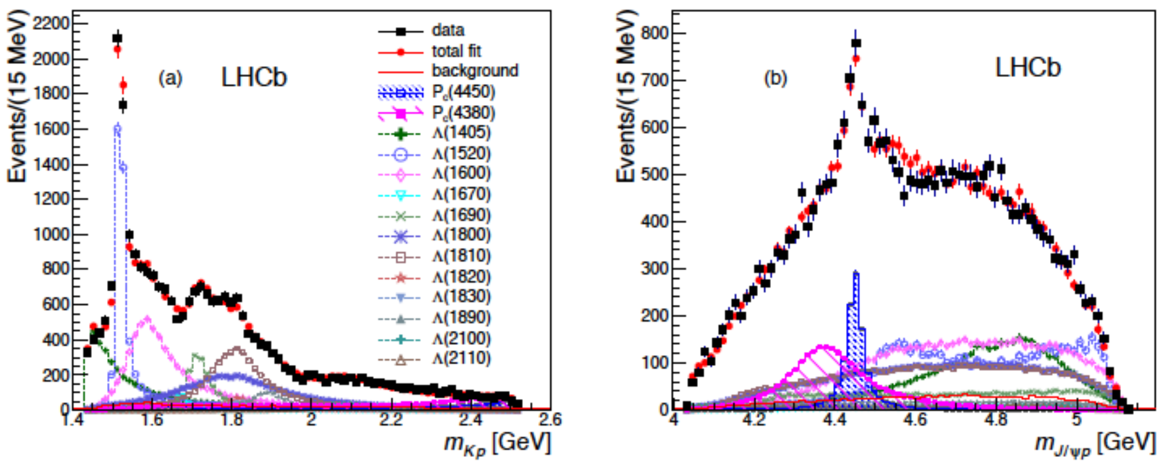
BELLE

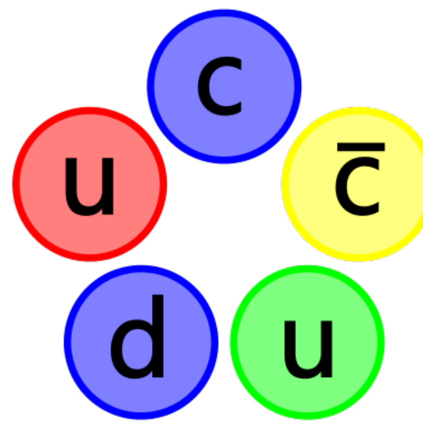
Belle II

LHCb discoveries pentaquark-like charm baryons P_c^+ ($uudc\bar{c}$) by the *Chinese* group（中国团队）

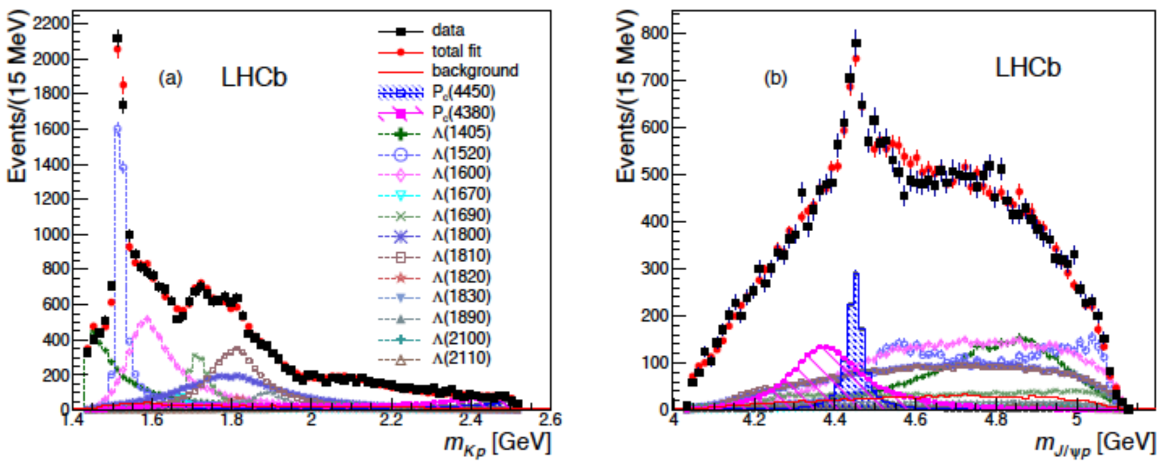


$P_c^+(4380)$ $P_c^+(4450)$

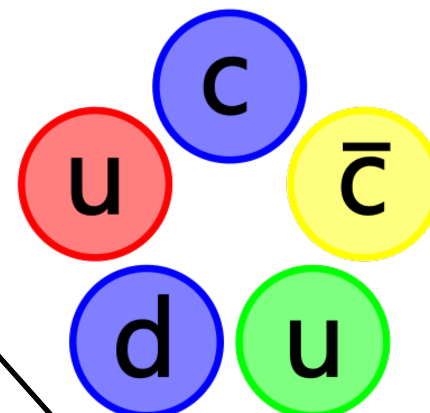
(2015)



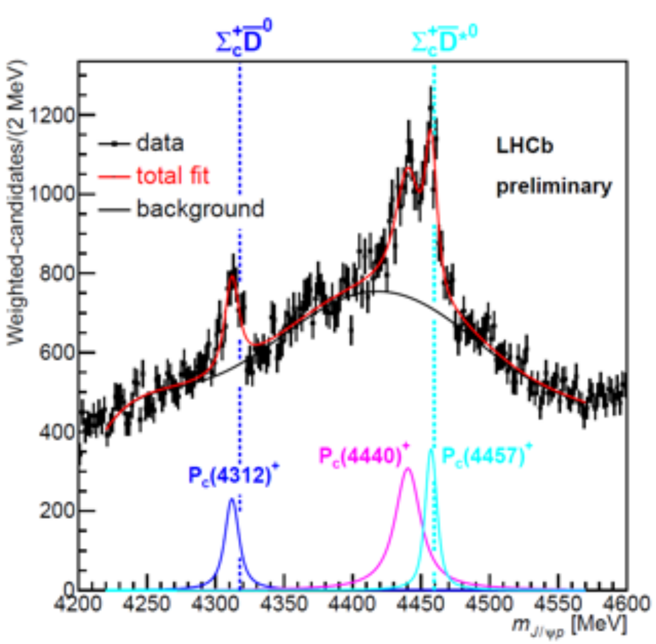
LHCb discoveries pentaquark-like charm baryons P_c^+ (uud$c\bar{c}$)
by the *Chinese* group（中国团队）



$P_c^+(4380)$ $P_c^+(4450)$



(2015)

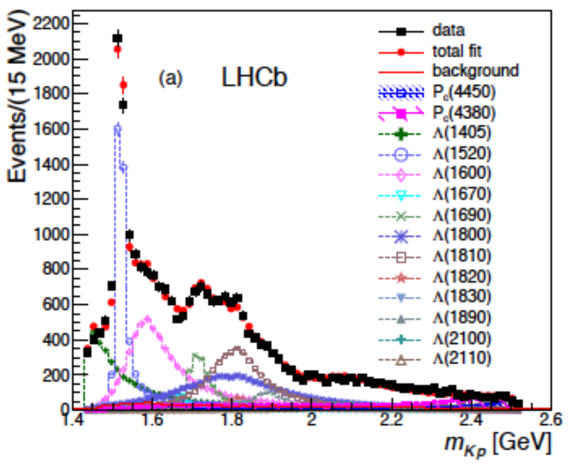


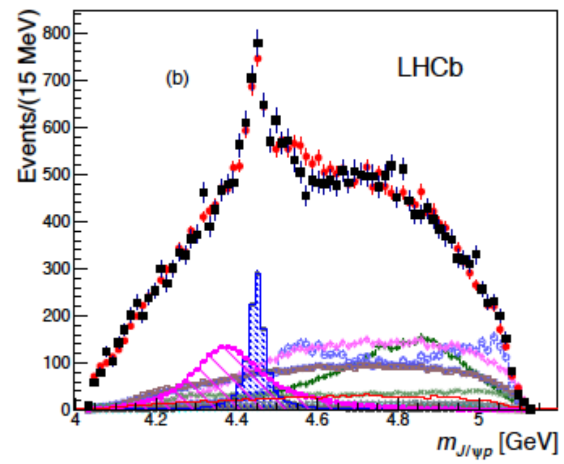
$P_c^+(4440)$, $P_c^+(4457)$

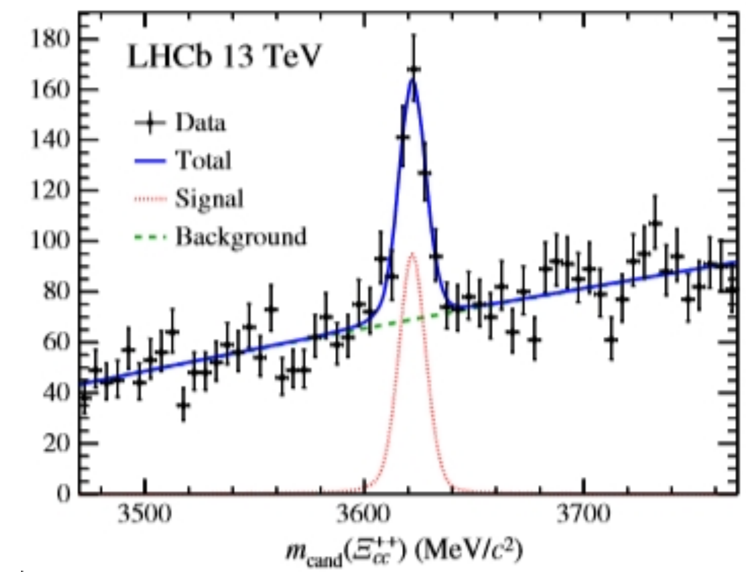
$P_c^+(4312)$

(2019)

LHCb discoveries pentaquark-like charm baryons P_c^+ (uud$c\bar{c}$) and the doubly-charmed baryon Ξ_{cc}^{++} by the *Chinese* group（中国团队）







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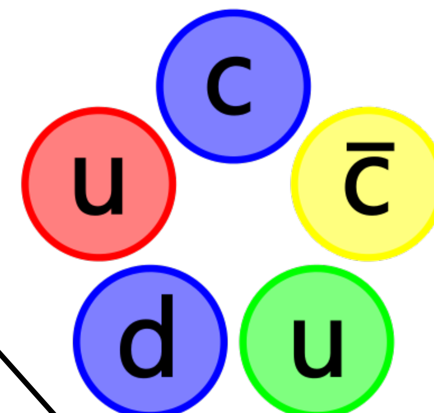

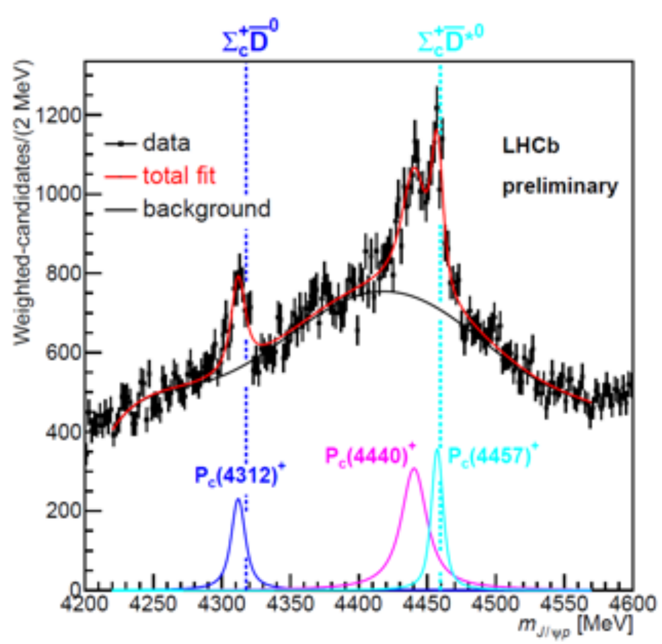

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(2019)

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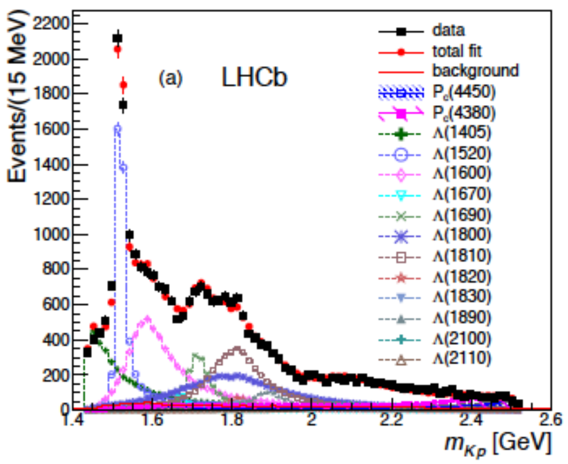

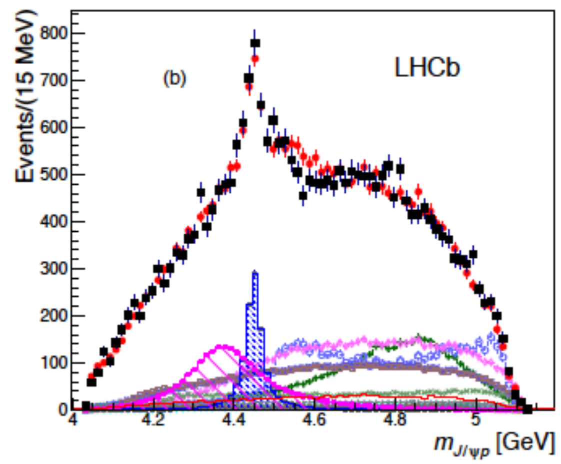

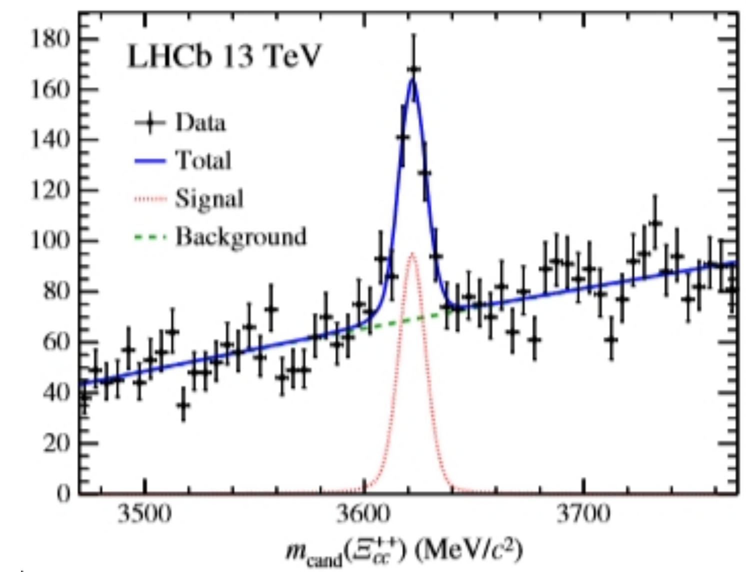

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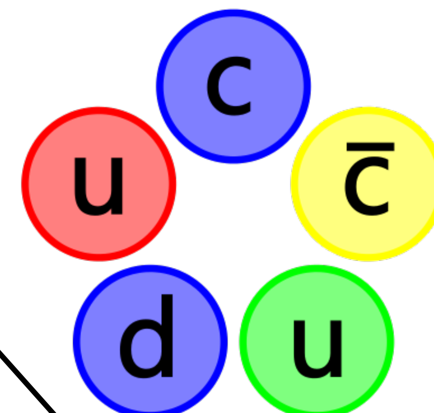
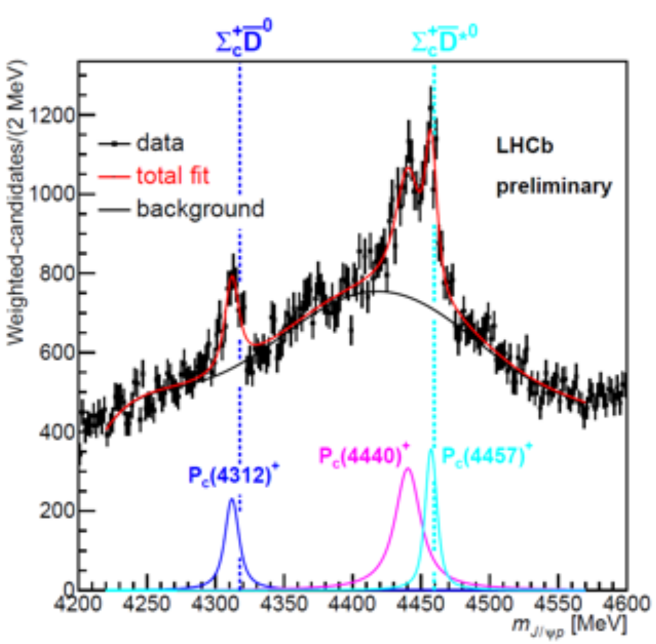


LHCb is a charm factory and has the world's largest sample of charm decays



$P_c^+(4440)$, $P_c^+(4457)$

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(2019)

Precision measurement of the Λ_c^+ Ξ_c^+ and Ξ_c^0 baryon lifetimes

arXiv:1906.08350
June 19, 2019

LHCb collaboration†

Abstract

We report measurements of the lifetimes of the Λ_c^+, Ξ_c^+ and Ξ_c^0 charm baryons using proton-proton collision data at center-of-mass energies of 7 and 8 TeV, corresponding to an integrated luminosity of $3.0\,\mathrm{fb}^{-1}$, collected by the LHCb experiment. The charm baryons are reconstructed through the decays $\Lambda_c^+ \to pK^-\pi^+$, $\Xi_c^+ \to pK^-\pi^+$ and $\Xi_c^0 \to pK^-K^-\pi^+$, and originate from semimuonic decays of beauty baryons. The lifetimes are measured relative to that of the D^+ meson, and are determined to be

$$\tau_{\Lambda_c^+} = 203.5 \pm 1.0 \pm 1.3 \pm 1.4 \text{ fs},$$
$$\tau_{\Xi_c^+} = 456.8 \pm 3.5 \pm 2.9 \pm 3.1 \text{ fs},$$
$$\tau_{\Xi_c^0} = 154.5 \pm 1.7 \pm 1.6 \pm 1.0 \text{ fs},$$

Recent results on charmed baryons with $SU(3)_F$ flavor symmetry

- *C.Q. Geng, C.W. Liu and T.H. Tsai, "Singly Cabibbo suppressed decays of Λ_c with SU(3) Flavor Symmetry," Phys. Lett. B790, 225 (2019).*
- *C.Q. Geng, C.W. Liu and T.H. Tsai, "Asymmetries of anti-triplet charmed baryon decays," Phys. Lett. B794, 19 (2019).*
- *J.Y. Cen, C.Q. Geng, C.W. Liu and T.H. Tsai, "Up-down asymmetries in charmed baryon three-body decays," arXiv:1906.01848 [hep-ph].*

This Talk

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This Talk

$$B_c \to B_n \ell^+ \nu_\ell$$

$$B_c = (\Xi_c^0, -\Xi_c^+, \Lambda_c^+) \qquad B_n = \begin{pmatrix} \frac{1}{\sqrt{6}}\Lambda + \frac{1}{\sqrt{2}}\Sigma^0 & \Sigma^+ & p \\ \Sigma^- & \frac{1}{\sqrt{6}}\Lambda - \frac{1}{\sqrt{2}}\Sigma^0 & n \\ \Xi^- & \Xi^0 & -\sqrt{\frac{2}{3}}\Lambda \end{pmatrix}$$

C.Q. Geng, C.W. Liu and T.H. Tsai, "Semileptonic Decays of Anti-triplet Charmed Baryons," Phys. Lett. B792, 214 (2019).

T.H. Tsai (蔡典学): Talk on July 24

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T.H. Tsai (蔡典学): Talk on July 24

$$\mathrm{B}_c \to \mathrm{B}_D M$$

$$\mathrm{B}_D = \frac{1}{\sqrt{3}} \left(\begin{pmatrix} \sqrt{3}\Delta^{++} & \Delta^+ & \Sigma'^+ \\ \Delta^+ & \Delta^0 & \frac{\Sigma'^0}{\sqrt{2}} \\ \Sigma'^+ & \frac{\Sigma'^0}{\sqrt{2}} & \Xi'^0 \end{pmatrix}, \begin{pmatrix} \Delta^+ & \Delta^0 & \frac{\Sigma'^0}{\sqrt{2}} \\ \Delta^0 & \sqrt{3}\Delta^- & \Sigma'^- \\ \frac{\Sigma'^0}{\sqrt{2}} & \Sigma'^- & \Xi'^- \end{pmatrix}, \begin{pmatrix} \Sigma'^+ & \frac{\Sigma'^0}{\sqrt{2}} & \Xi'^0 \\ \frac{\Sigma'^0}{\sqrt{2}} & \Sigma'^- & \Xi'^- \\ \Xi'^0 & \Xi'^- & \sqrt{3}\Omega^- \end{pmatrix} \right)$$

C.Q. Geng, C.W. Liu, T.H. Tsai and Y. Yu, "Charmed baryon weak decays with decuplet baryon and SU(3) flavor symmetry," Phys. Rev. D99, 114022 (2019).

C.W. Liu (刘佳韦): Talk on July 24

- **Effective Hamiltonians for weak decays of charmed baryons with SU(3) flavor symmetry**

The effective Hamiltonian for the semileptonic c ⟶ q l^+ ν_l transition with q=(d or s):

$$\mathcal{H}^{\ell}_{eff} = \frac{G_F}{\sqrt{2}} V_{cq} (\bar{q}c)_{V-A} (\bar{u}_\nu v_\ell)_{V-A}$$

$$(\bar{q}_1 q_2)_{V-A} = \bar{q}_1 \gamma_\mu (1-\gamma_5) q_2$$

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For the non-leptonic $c \to s u \bar{d}$, $c \to u q \bar{q}$ and $c \to u d \bar{s}$ transitions,

$$\mathcal{H}^{n\ell}_{eff} = \frac{G_F}{\sqrt{2}} \left\{ V_{cs}V_{ud}(c_+ O_+ + c_- O_-) + V_{cd}V_{ud}(c_+ \hat{O}_+ + c_- \hat{O}_-) + V_{cd}V_{us}(c_+ O'_+ + c_- O'_-) \right\}$$

$$(V_{cs}V_{ud}, V_{cd}V_{ud}, V_{cd}V_{us}) \simeq (1, -s_c, -s_c^2)$$

$$s_c \equiv \sin\theta_c = 0.2248$$

$$O_\pm = \frac{1}{2}[(\bar{u}d)_{V-A}(\bar{s}c)_{V-A} \pm (\bar{s}d)_{V-A}(\bar{u}c)_{V-A}]$$
$$O^q_\pm = \frac{1}{2}[(\bar{u}q)_{V-A}(\bar{q}c)_{V-A} \pm (\bar{q}q)_{V-A}(\bar{u}c)_{V-A}]$$
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Cabibbo-allowed

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Cabibbo-allowed

Cabibbo-suppressed

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Effective Hamiltonians for weak decays of charmed baryons with SU(3) flavor symmetry

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For the non-leptonic c → s u d̄, c → u q q̄ and c → u d s̄ transitions,

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Cabibbo-allowed | Cabibbo-suppressed | doubly Cabibbo-suppressed

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SU(3)$_F$: $(\bar{q}c)$ forms an anti-triplet $(\bar{3})$

$$\mathcal{H}^{\ell}_{eff} = \frac{G_F}{\sqrt{2}} H(\bar{3})(\bar{u}_\nu v_\ell)_{V-A}$$

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$(\bar{q}_i q^k)(\bar{q}_j c)$ with $\bar{q}_i q^k \bar{q}_j$ being decomposed as $\bar{3}\times 3\times\bar{3} = \bar{3}+\bar{3}'+6+\overline{15}$

$$\mathcal{O}_6 = \frac{1}{2}(\bar{u}d\bar{s}-\bar{s}d\bar{u})c\,,\quad \hat{\mathcal{O}}_6 = \frac{1}{2}(\bar{u}d\bar{d}-\bar{d}d\bar{u}+\bar{s}s\bar{u}-\bar{u}s\bar{s})c\,,\quad \mathcal{O}'_6 = \frac{1}{2}(\bar{u}s\bar{d}-\bar{d}s\bar{u})c\,,$$

$$\mathcal{O}_{\overline{15}} = \frac{1}{2}(\bar{u}d\bar{s}+\bar{s}d\bar{u})c\,,\quad \hat{\mathcal{O}}_{\overline{15}} = \frac{1}{2}(\bar{u}d\bar{d}+\bar{d}d\bar{u}-\bar{s}s\bar{u}-\bar{u}s\bar{s})c\,,\quad \mathcal{O}'_{\overline{15}} = \frac{1}{2}(\bar{u}s\bar{d}+\bar{d}s\bar{u})c\,,$$

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$$H_{22}(6) = 2\,,\ H_{23}(6) = H_{32}(6) = -2s_c\,,\ H_{33}(6) = 2s_c^2$$

$$H_2^{13}(\overline{15}) = H_2^{31}(\overline{15}) = 1\,,$$

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$$\mathcal{O}_{\overline{15}} = \frac{1}{2}(\bar{u}d\bar{s} + \bar{s}d\bar{u})c\,,\quad \hat{\mathcal{O}}_{\overline{15}} = \frac{1}{2}(\bar{u}d\bar{d} + \bar{d}d\bar{u} - \bar{s}s\bar{u} - \bar{u}s\bar{s})c\,,\quad \mathcal{O}'_{\overline{15}} = \frac{1}{2}(\bar{u}s\bar{d} + \bar{d}s\bar{u})c\,,$$

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The Hamiltonian without QCD corrections: $c_-^0 = c_+^0 = 1$

SU(3)$_F$: $(\bar{q}c)$ forms an anti-triplet $(\bar{3})$

$$\mathcal{H}^{\ell}_{eff} = \frac{G_F}{\sqrt{2}} H(\bar{3})(\bar{u}_\nu v_\ell)_{V-A}$$

$(\bar{q}_i q^k)(\bar{q}_j c)$ with $\bar{q}_i q^k \bar{q}_j$ being decomposed as $\bar{3}\times 3\times\bar{3} = \bar{3}+\bar{3}'+6+\overline{15}$

$$\mathcal{O}_6 = \frac{1}{2}(\bar{u}d\bar{s}-\bar{s}d\bar{u})c\,,\quad \hat{\mathcal{O}}_6 = \frac{1}{2}(\bar{u}d\bar{d}-\bar{d}d\bar{u}+\bar{s}s\bar{u}-\bar{u}s\bar{s})c\,,\quad \mathcal{O}'_6 = \frac{1}{2}(\bar{u}s\bar{d}-\bar{d}s\bar{u})c\,,$$

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$$H^{13}_2(\overline{15}) = H^{31}_2(\overline{15}) = 1\,,$$

$$H^{12}_2(\overline{15}) = H^{21}_2(\overline{15}) = -H^{13}_3(\overline{15}) = -H^{31}_3(\overline{15}) = s_c\,,$$

$$H^{12}_3(\overline{15}) = H^{21}_3(\overline{15}) = -s_c^2\,,$$

The Hamiltonian without QCD corrections: $c^0_- = c^0_+ = 1$

The first order QCD corrections: $c^1_- = 1 + \frac{\alpha_s}{2\pi}\ln\frac{M_W^2}{\mu^2}$ $\quad c^1_+ = 1 - \frac{\alpha_s}{2\pi}\ln\frac{M_W^2}{\mu^2}$

SU(3)$_F$: $(\bar{q}c)$ forms an anti-triplet $(\bar{3})$

$$\mathcal{H}^{\ell}_{eff} = \frac{G_F}{\sqrt{2}} H(\bar{3})(\bar{u}_\nu v_\ell)_{V-A}$$

$(\bar{q}_i q^k)(\bar{q}_j c)$ with $\bar{q}_i q^k \bar{q}_j$ being decomposed as $\bar{3}\times 3\times\bar{3} = \bar{3}+\bar{3}'+6+\overline{15}$

$$\mathcal{O}_6 = \frac{1}{2}(\bar{u}d\bar{s}-\bar{s}d\bar{u})c\,,\quad \hat{\mathcal{O}}_6 = \frac{1}{2}(\bar{u}d\bar{d}-\bar{d}d\bar{u}+\bar{s}s\bar{u}-\bar{u}s\bar{s})c\,,\quad \mathcal{O}'_6 = \frac{1}{2}(\bar{u}s\bar{d}-\bar{d}s\bar{u})c\,,$$

$$\mathcal{O}_{\overline{15}} = \frac{1}{2}(\bar{u}d\bar{s}+\bar{s}d\bar{u})c\,,\quad \hat{\mathcal{O}}_{\overline{15}} = \frac{1}{2}(\bar{u}d\bar{d}+\bar{d}d\bar{u}-\bar{s}s\bar{u}-\bar{u}s\bar{s})c\,,\quad \mathcal{O}'_{\overline{15}} = \frac{1}{2}(\bar{u}s\bar{d}+\bar{d}s\bar{u})c\,,$$

$$\mathcal{H}^{n\ell}_{eff} = \frac{G_F}{\sqrt{2}}\{c_- H(6) + c_+ H(\overline{15})\}$$

$$H_{22}(6) = 2\,, H_{23}(6) = H_{32}(6) = -2s_c\,, H_{33}(6) = 2s_c^2$$

$$H^{13}_2(\overline{15}) = H^{31}_2(\overline{15}) = 1\,,$$

$$H^{12}_2(\overline{15}) = H^{21}_2(\overline{15}) = -H^{13}_3(\overline{15}) = -H^{31}_3(\overline{15}) = s_c\,,$$

$$H^{12}_3(\overline{15}) = H^{21}_3(\overline{15}) = -s_c^2\,,$$

$$\alpha_s(\mu^2) = \frac{4\pi}{\left(\frac{33-2N_F}{3}\right)\ln\frac{\mu^2}{\Lambda^2_{QCD}}}$$

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Summing up all orders: $c_- = \left(\frac{\alpha(M_W^2)}{\alpha(\mu^2)}\right)^{\frac{-12}{33-2N_f}}$ $\quad c_+ = \left(\frac{\alpha(M_W^2)}{\alpha(\mu^2)}\right)^{\frac{6}{33-2N_f}}$

$$\frac{c_-}{c_+} = \frac{1}{c_+^3} = \left(\frac{\alpha(m_b^2)}{\alpha(M_W^2)}\right)^{\frac{18}{23}}\left(\frac{\alpha(m_c^2)}{\alpha(m_b^2)}\right)^{\frac{18}{25}} \sim 2.4$$

- **Semileptonic decays of charmed baryons**

$$\mathrm{B}_c \to \mathrm{B}_n \ell^+ \nu_\ell$$

$$\mathcal{M}(\mathrm{B}_c \to \mathrm{B}_n \ell^+ \nu_\ell) = \langle \mathrm{B}_n \ell^+ \nu_\ell | H^\ell_{eff} | \mathrm{B}_c \rangle = \frac{G_F}{\sqrt{2}} V_{cq} T(\mathrm{B}_c \to \mathrm{B}_n)(\bar{u}_\nu v_\ell)_{V-A}$$

Under $SU(3)_F$ flavor symmetry:

$$T(\mathrm{B}_c \to \mathrm{B}_n) = \alpha_1 (\mathrm{B}_n)^i_j H^j(\bar{3})(\mathrm{B}_c)_i$$

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$\mathrm{B}_c \to \mathrm{B}_n$	T-amp
$\Xi_c^0 \to \Xi^-$	α_1
$\Xi_c^+ \to \Xi^0$	α_1
$\Lambda_c^+ \to \Lambda^0$	$-\sqrt{\frac{2}{3}}\alpha_1$
$\Xi_c^0 \to \Sigma^-$	$-\alpha_1 s_c$
$\Xi_c^+ \to \Sigma^0$	$\sqrt{\frac{1}{2}}\alpha_1 s_c$
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$\Lambda_c^+ \to n$	$-\alpha_1 s_c$

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Experimental Data

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C.D. Lü, W. Wang and F.S. Yu, ``Test flavor SU(3) symmetry in exclusive Λ_c decays," Phys. Rev. D93, 056008 (2016)

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$\Lambda_c^+ \to \Lambda^0$	$-\sqrt{\frac{2}{3}}\alpha_1$	$\mathcal{B}(\Lambda_c^+ \to \Lambda^0 e^+ \nu_e) = (3.6 \pm 0.4) \times 10^{-2}$	1.63×10^{-2}
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$\Xi_c^+ \to \Lambda^0$	$-\sqrt{\frac{1}{6}}\alpha_1 s_c$	$\mathcal{B}(\Xi_c^+ \to \Lambda^0 e^+ \nu_e) = (1.25 \pm 0.14) \times 10^{-3}$	8.22×10^{-4}
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*Z.X. Zhao, ``Weak decays of heavy baryons in the light-front approach," Chin. Phys. C42, 093101 (2018)

- **Semileptonic decays of charmed baryons**

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SU(3) results $\longleftarrow$ after timing factor 2

*Z.X. Zhao, ``Weak decays of heavy baryons in the light-front approach," Chin. Phys. C42, 093101 (2018)

- **Semileptonic decays of ch**

C.Q. Geng, C.W. Liu and T.H. Tsai, "Semileptonic Decays of Anti-triplet Charmed Baryons," Phys. Lett. B792, 214 (2019).

$$B_c \to B_n \ell^+ \nu_\ell$$

T.H. Tsai: Talk on July 24

$$\mathcal{M}(B_c \to B_n \ell^+ \nu_\ell) = \langle B_n \ell^+ \nu_\ell | H^\ell_{eff} | B_c \rangle = \frac{G_F}{\sqrt{2}} V_{cq} T(B_c \to B_n)(\bar{u}_\nu v_\ell)_{V-A}$$

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Two-body nonleptonic decays of charmed baryons

$$\mathbf{B}_c = (\Xi_c^0, -\Xi_c^+, \Lambda_c^+)$$

$$\mathbf{B}_c \to \mathbf{B}_n M$$

$$\mathbf{B}_n = \begin{pmatrix} \frac{1}{\sqrt{6}}\Lambda + \frac{1}{\sqrt{2}}\Sigma^0 & \Sigma^+ & p \\ \Sigma^- & \frac{1}{\sqrt{6}}\Lambda - \frac{1}{\sqrt{2}}\Sigma^0 & n \\ \Xi^- & \Xi^0 & -\sqrt{\frac{2}{3}}\Lambda \end{pmatrix}$$

$$M = \begin{pmatrix} \frac{1}{\sqrt{2}}(\pi^0 + c_\phi \eta + s_\phi \eta') & \pi^+ & K^+ \\ \pi^- & \frac{1}{\sqrt{2}}(-\pi^0 + c_\phi \eta + s_\phi \eta') & K^0 \\ K^- & \bar{K}^0 & -s_\phi \eta + c_\phi \eta' \end{pmatrix}$$

$$\mathcal{M}(\mathbf{B}_c \to \mathbf{B}_n M) = i \bar{u}_{\mathbf{B}_n} (A - B\gamma_5) u_{\mathbf{B}_c}$$

spin-dependent amplitude

Note that A and B are relatively real if CP is conserved and FSIs are negligible.

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Decay rate:

$$\Gamma = \frac{p_{\mathbf{B}_n}}{8\pi}\left(\frac{(m_{\mathbf{B}_c} + m_{\mathbf{B}_n})^2 - m_M^2}{m_{\mathbf{B}_c}^2}|A|^2 + \frac{(m_{\mathbf{B}_c} - m_{\mathbf{B}_n})^2 - m_M^2}{m_{\mathbf{B}_c}^2}|B|^2\right)$$

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Differential decay rate:

$$\frac{d\Gamma}{d\theta} \propto 1 + \alpha \vec{P}_{\mathbf{B}_n}\cdot\hat{p}_{\mathbf{B}_n} = 1 + \alpha\cos\theta,$$

Up-down asymmetry:

$$\alpha = \frac{2\kappa\,\mathrm{Re}(A^*B)}{|A|^2 + \kappa^2|B|^2}, \quad \kappa = \frac{p_{\mathbf{B}_n}}{E_{\mathbf{B}_n} + m_{\mathbf{B}_n}}$$

$E_{\mathbf{B}_n}$ and $\vec{p}_{\mathbf{B}_n}$ the energy and three momentum of $\mathbf{B}_n$.

$$\alpha = \frac{d\Gamma(\vec{P}_{\mathbf{B}_n}\cdot\hat{p}_{\mathbf{B}_n} = +1) - d\Gamma(\vec{P}_{\mathbf{B}_n}\cdot\hat{p}_{\mathbf{B}_n} = -1)}{d\Gamma(\vec{P}_{\mathbf{B}_n}\cdot\hat{p}_{\mathbf{B}_n} = +1) + d\Gamma(\vec{P}_{\mathbf{B}_n}\cdot\hat{p}_{\mathbf{B}_n} = -1)}$$

the longitudinal polarization asymmetry, *i.e.* $P_{\mathbf{B}_n} = \alpha$.

$$\mathcal{M}(\mathrm{B}_c \to \mathrm{B}_n M) = i\overline{u}_{\mathbf{B}_n}\left(A - B\gamma_5\right)u_{\mathbf{B}_c}$$

spin-dependent amplitude

$$A_{(\mathbf{B}_c\to\mathbf{B}_nM)} =$$
$$a_0 H(6)_{ij}(\mathrm{B}_c')^{ik}(\mathrm{B}_n)^j_k(M)^l_l + a_1 H(6)_{ij}(\mathrm{B}_c')^{ik}(\mathrm{B}_n)^l_k(M)^j_l + a_2 H(6)_{ij}(\mathrm{B}_c')^{ik}(M)^l_k(\mathrm{B}_n)^j_l +$$
$$a_3 H(6)_{ij}(\mathrm{B}_n)^i_k(M)^j_l(\mathrm{B}_c')^{kl} + a_0'(\mathrm{B}_n)^i_j(M)^l_l H(\overline{15})^{jk}_i(\mathrm{B}_c)_k + a_4 H(\overline{15})^{li}_k(\mathrm{B}_c)_j(M)^j_i(\mathrm{B}_n)^k_l +$$
$$a_5(\mathrm{B}_n)^i_j(M)^l_i H(\overline{15})^{jk}_l(\mathrm{B}_c)_k + a_6(\mathrm{B}_n)^j_i(M)^m_l H(\overline{15})^{li}_m(\mathrm{B}_c)_j + a_7(\mathrm{B}_n)^l_i(M)^i_j H(\overline{15})^{jk}_l(\mathrm{B}_c)_k,$$

$$B_{(\mathbf{B}_c\to\mathbf{B}_nM)} = A_{(\mathbf{B}_c\to\mathbf{B}_nM)}\{a_i^{(\prime)} \to b_i^{(\prime)}\}$$

$$\mathcal{M}(\mathbf{B}_c \to \mathbf{B}_n M) = i\bar{u}_{\mathbf{B}_n}\left(A - B\gamma_5\right) u_{\mathbf{B}_c}$$

spin-dependent amplitude

$$A_{(\mathbf{B}_c \to \mathbf{B}_n M)} =$$

$$a_0 H(6)_{ij} (\mathbf{B}'_c)^{ik} (\mathbf{B}_n)^j_k (M)^l_l + a_1 H(6)_{ij} (\mathbf{B}'_c)^{ik} (\mathbf{B}_n)^l_k (M)^j_l + a_2 H(6)_{ij} (\mathbf{B}'_c)^{ik} (M)^l_k (\mathbf{B}_n)^j_l +$$

$$a_3 H(6)_{ij} (\mathbf{B}_n)^i_k (M)^j_l (\mathbf{B}'_c)^{kl} + a'_0 (\mathbf{B}_n)^i_j (M)^l_l H(\overline{15})^{jk}_i (\mathbf{B}_c)_k + a_4 H(\overline{15})^{li}_k (\mathbf{B}_c)_j (M)^j_i (\mathbf{B}_n)^k_l +$$

$$a_5 (\mathbf{B}_n)^i_j (M)^l_i H(\overline{15})^{jk}_l (\mathbf{B}_c)_k + a_6 (\mathbf{B}_n)^j_i (M)^m_l H(\overline{15})^{li}_m (\mathbf{B}_c)_j + a_7 (\mathbf{B}_n)^l_i (M)^i_j H(\overline{15})^{jk}_l (\mathbf{B}_c)_k,$$

$$B_{(\mathbf{B}_c \to \mathbf{B}_n M)} = A_{(\mathbf{B}_c \to \mathbf{B}_n M)} \{ a_i^{(\prime)} \to b_i^{(\prime)} \}$$

$$\mathcal{H}_{eff}^{n\ell} = \frac{G_F}{\sqrt{2}} \{ c_- H(6) + c_+ H(\overline{15}) \}$$

Assumption → $$\mathcal{H}_{eff}^{n\ell} = \frac{G_F}{\sqrt{2}} \{ c_- H(6) \}$$

Two reasons:

1. $(c_-/c_+)^2 \sim 5.5$**:**

2. $\mathcal{O}_{\overline{15}} = \frac{1}{2}(\bar{u}d\bar{s} + \bar{s}d\bar{u})c$ is symmetric, whereas the baryon wave function is totally antisymmetric in color indices.

→ **Vanishing nonfactorizable contributions**

$$\mathcal{M}(\mathrm{B}_c \to \mathrm{B}_n M) = i\bar{u}_{\mathrm{B}_n}\,(A - B\gamma_5)\,u_{\mathrm{B}_c}$$

spin-dependent amplitude

$$A_{(\mathrm{B}_c\to \mathrm{B}_n M)} =$$

$$a_0 H(6)_{ij}(\mathrm{B}'_c)^{ik}(\mathrm{B}_n)^j_k(M)^l_l + a_1 H(6)_{ij}(\mathrm{B}'_c)^{ik}(\mathrm{B}_n)^l_k(M)^j_l + a_2 H(6)_{ij}(\mathrm{B}'_c)^{ik}(M)^l_k(\mathrm{B}_n)^j_l +$$

$$a_3 H(6)_{ij}(\mathrm{B}_n)^i_k(M)^j_l(\mathrm{B}'_c)^{kl} + a'_0(\mathrm{B}_n)^i_j(M)^l_l H(\overline{15})^{jk}_i(\mathrm{B}_c)_k + a_4 H(\overline{15})^{li}_k(\mathrm{B}_c)_j(M)^j_i(\mathrm{B}_n)^k_l +$$

$$a_5(\mathrm{B}_n)^i_j(M)^l_i H(\overline{15})^{jk}_l(\mathrm{B}_c)_k + a_6(\mathrm{B}_n)^j_i(M)^m_l H(\overline{15})^{li}_m(\mathrm{B}_c)_j + a_7(\mathrm{B}_n)^l_i(M)^i_j H(\overline{15})^{jk}_l(\mathrm{B}_c)_k,$$

$$B_{(\mathrm{B}_c\to \mathrm{B}_n M)} = A_{(\mathrm{B}_c\to \mathrm{B}_n M)}\{a_i^{(\prime)} \to b_i^{(\prime)}\}$$

$$\mathcal{H}^{n\ell}_{eff} = \frac{G_F}{\sqrt{2}}\{c_- H(6) + c_+ H(\overline{15})\}$$

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→ Vanishing nonfactorizable contributions

$$\mathcal{M}(\mathbf{B}_c \to \mathbf{B}_n M) = i\bar{u}_{\mathbf{B}_n}(A - B\gamma_5)u_{\mathbf{B}_c}$$

spin-dependent amplitude

$$A_{(\mathbf{B}_c \to \mathbf{B}_n M)} =$$

$$a_0 H(6)_{ij}(\mathbf{B}'_c)^{ik}(\mathbf{B}_n)^j_k(M)^l_l + a_1 H(6)_{ij}(\mathbf{B}'_c)^{ik}(\mathbf{B}_n)^l_k(M)^j_l + a_2 H(6)_{ij}(\mathbf{B}'_c)^{ik}(M)^l_k(\mathbf{B}_n)^j_l +$$

$$a_3 H(6)_{ij}(\mathbf{B}_n)^i_k(M)^j_l(\mathbf{B}'_c)^{kl} + a'_0(\mathbf{B}_n)^i_j(M)^l_l H(\overline{15})^{jk}_i(\mathbf{B}_c)_k + a_4 H(\overline{15})^{li}_k(\mathbf{B}_c)_j(M)^j_i(\mathbf{B}_n)^k_l +$$

$$a_5(\mathbf{B}_n)^i_j(M)^l_i H(\overline{15})^{jk}_l(\mathbf{B}_c)_k + a_6(\mathbf{B}_n)^j_i(M)^m_l H(\overline{15})^{li}_m(\mathbf{B}_c)_j + a_7(\mathbf{B}_n)^l_i(M)^i_j H(\overline{15})^{jk}_l(\mathbf{B}_c)_k,$$

$$B_{(\mathbf{B}_c \to \mathbf{B}_n M)} = A_{(\mathbf{B}_c \to \mathbf{B}_n M)}\{a_i^{(\prime)} \to b_i^{(\prime)}\}$$

$$\mathcal{H}^{n\ell}_{eff} = \frac{G_F}{\sqrt{2}}\{c_- H(6) + c_+ H(\overline{15})\}$$

Assumption → $$\mathcal{H}^{n\ell}_{eff} = \frac{G_F}{\sqrt{2}}\{c_- H(6)\}$$

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→ **Vanishing nonfactorizable contributions**

What is about the factorizable parts of $H(\overline{15})$?

$$\mathcal{M}(\mathbf{B}_c \to \mathbf{B}_n M) = i\bar{u}_{\mathbf{B}_n}\left(A - B\gamma_5\right) u_{\mathbf{B}_c}$$

spin-dependent amplitude

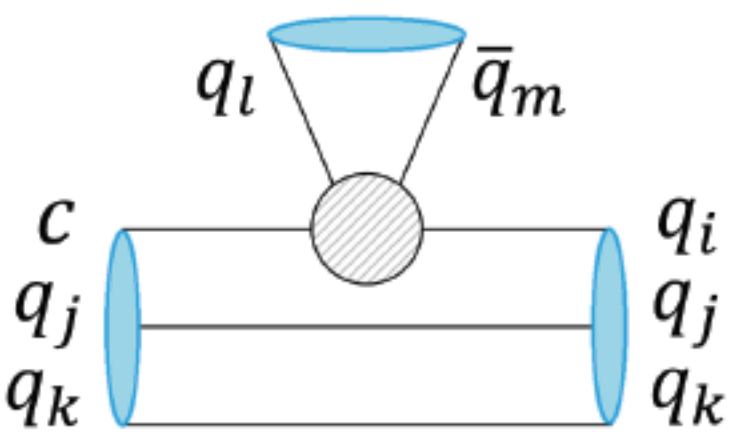
$$A_{(\mathbf{B}_c\to\mathbf{B}_n M)} =$$

$$a_0 H(6)_{ij}(\mathbf{B}_c')^{ik}(\mathbf{B}_n)^j_k(M)^l_l + a_1 H(6)_{ij}(\mathbf{B}_c')^{ik}(\mathbf{B}_n)^l_k(M)^j_l + a_2 H(6)_{ij}(\mathbf{B}_c')^{ik}(M)^l_k(\mathbf{B}_n)^j_l +$$

$$a_3 H(6)_{ij}(\mathbf{B}_n)^i_k(M)^j_l(\mathbf{B}_c')^{kl} + a_0'(\mathbf{B}_n)^i_j(M)^l_i H(\overline{15})^{jk}_l(\mathbf{B}_c)_k + a_4 H(\overline{15})^{li}_k(\mathbf{B}_c)_j(M)^j_i(\mathbf{B}_n)^k_l +$$

$$a_5(\mathbf{B}_n)^i_j(M)^l_i H(\overline{15})^{jk}_l(\mathbf{B}_c)_k + a_6(\mathbf{B}_n)^j_i(M)^m_l H(\overline{15})^{li}_m(\mathbf{B}_c)_j + a_7(\mathbf{B}_n)^l_i(M)^i_j H(\overline{15})^{jk}_l(\mathbf{B}_c)_k,$$

$$B_{(\mathbf{B}_c\to\mathbf{B}_n M)} = A_{(\mathbf{B}_c\to\mathbf{B}_n M)}\{a_i^{(\prime)} \to b_i^{(\prime)}\}$$



$$\mathcal{H}^{n\ell}_{eff} = \frac{G_F}{\sqrt{2}}\{c_- H(6) + c_+ H(\overline{15})\}$$

Assumption $\mathcal{H}^{n\ell}_{eff} = \frac{G_F}{\sqrt{2}}\{c_- H(6)\}$

Two reasons:

1. $(c_-/c_+)^2 \sim 5.5$:

2. $\mathcal{O}_{\overline{15}} = \frac{1}{2}(\bar{u}d\bar{s} + \bar{s}d\bar{u})c$ is symmetric, whereas the baryon wave function is totally antisymmetric in color indices.

→ Vanishing nonfactorizable contributions

What is about the factorizable parts of $H(\overline{15})$?

C.Q. Geng, C.W. Liu and T.H. Tsai, Phys. Lett. B790, 225 (2019).

Channel	$\mathcal{B}_{exp}$	α_{exp}
$\Lambda_c^+ \to \Lambda^0\pi^+$	$(13.0 \pm 0.7) \times 10^{-3}$	-0.91 ± 0.15
$\Lambda_c^+ \to pK_S^0$	$(15.8 \pm 0.8) \times 10^{-3}$	
$\Lambda_c^+ \to \Sigma^0\pi^+$	$(12.9 \pm 0.7) \times 10^{-3}$	
$\Lambda_c^+ \to \Sigma^+\pi^0$	$(12.4 \pm 1.0) \times 10^{-3}$	-0.45 ± 0.32
$\Lambda_c^+ \to \Sigma^+\eta$	$(4.1 \pm 2.0) \times 10^{-3}$	
$\Lambda_c^+ \to \Sigma^+\eta'$	$(13.4 \pm 5.7) \times 10^{-3}$	
$\Lambda_c^+ \to \Xi^0 K^+$	$(5.9 \pm 1.0) \times 10^{-3}$	*0.77 ± 0.78
$\Lambda_c^+ \to p\pi^0$	$(0.8 \pm 1.3) \times 10^{-4}$[41]	
$\Lambda_c^+ \to p\eta$	$(12.4 \pm 3.0) \times 10^{-4}$	
$\Lambda_c^+ \to \Lambda^0 K^+$	$(6.1 \pm 1.2) \times 10^{-4}$	
$\Lambda_c^+ \to \Sigma^0 K^+$	$(5.2 \pm 0.8) \times 10^{-4}$	
$\Xi_c^0 \to \Xi^-\pi^+$	$(1.80 \pm 0.52) \times 10^{-2}$	-0.6 ± 0.4
$\Xi_c^0 \to \Lambda^0 K_S^0$		
**$\mathcal{R}_{\Xi_c^0}$	0.210 ± 0.028	

*This value is not included in the data input.

**$\mathcal{R}_{\Xi_c^0} \equiv \mathcal{B}(\Xi_c^0 \to \Lambda K_S^0)/\mathcal{B}(\Xi_c^0 \to \Xi^-\pi^+)$.

C.Q. Geng, C.W. Liu and T.H. Tsai, "Asymmetries of anti-triplet charmed baryon decays," Phys. Lett. B794, 19 (2019).

16 data points above to fit with 10 real parameters:

$$(a_1, a_2, a_3, a_6, \tilde{a}, b_1, b_2, b_3, b_6, \tilde{b})$$

$$\tilde{a} \equiv a_0 + \frac{1}{3}(a_1 + a_2 - a_3)$$

$$\tilde{b} \equiv b_0 + \frac{1}{3}(b_1 + b_2 - b_3)$$

$$\chi^2/d.o.f = 0.5$$

$$(a_1, a_2, a_3, a_6, \tilde{a}) = (4.34 \pm 0.50, -1.33 \pm 0.32, 1.25 \pm 0.36, -0.26 \pm 0.64, 1.77 \pm 0.83)\, 10^{-2} G_F \mathrm{GeV}^2,$$

$$(b_1, b_2, b_3, b_6, \tilde{b}) = (-9.20 \pm 2.09, -8.03 \pm 1.19, 1.42 \pm 1.61, -4.05 \pm 2.48, 13.15 \pm 5.56)\, 10^{-2} G_F \mathrm{GeV}^2.$$

Channel	$\mathcal{B}_{exp}$	α_{exp}	$\mathcal{B}_{SU(3)_F}$	$\alpha_{SU(3)_F}$
$\Lambda_c^+ \to \Lambda^0\pi^+$	$(13.0 \pm 0.7) \times 10^{-3}$	-0.91 ± 0.15	$(13.0 \pm 0.7) \times 10^{-3}$	-0.87 ± 0.10
$\Lambda_c^+ \to pK_S^0$	$(15.8 \pm 0.8) \times 10^{-3}$		$(15.7 \pm 0.8) \times 10^{-3}$	$-0.89^{+0.26}_{-0.11}$
$\Lambda_c^+ \to \Sigma^0\pi^+$	$(12.9 \pm 0.7) \times 10^{-3}$		$(12.7 \pm 0.6) \times 10^{-3}$	-0.35 ± 0.27
$\Lambda_c^+ \to \Sigma^+\pi^0$	$(12.4 \pm 1.0) \times 10^{-3}$	-0.45 ± 0.32	$(12.7 \pm 0.6) \times 10^{-3}$	-0.35 ± 0.27
$\Lambda_c^+ \to \Sigma^+\eta$	$(4.1 \pm 2.0) \times 10^{-3}$		$(3.2 \pm 1.3) \times 10^{-3}$	-0.40 ± 0.47
$\Lambda_c^+ \to \Sigma^+\eta'$	$(13.4 \pm 5.7) \times 10^{-3}$		$(14.4 \pm 5.6) \times 10^{-3}$	$1.00^{+0.00}_{-0.17}$
$\Lambda_c^+ \to \Xi^0 K^+$	$(5.9 \pm 1.0) \times 10^{-3}$	*0.77 ± 0.78	$(5.6 \pm 0.9) \times 10^{-3}$	$0.94^{+0.06}_{-0.11}$
$\Lambda_c^+ \to p\pi^0$	$(0.8 \pm 1.3) \times 10^{-4}$[41]		$(1.2 \pm 1.2) \times 10^{-4}$	-0.05 ± 0.72
$\Lambda_c^+ \to p\eta$	$(12.4 \pm 3.0) \times 10^{-4}$		$(11.5 \pm 2.7) \times 10^{-4}$	$-0.96^{+0.30}_{-0.04}$
$\Lambda_c^+ \to \Lambda^0 K^+$	$(6.1 \pm 1.2) \times 10^{-4}$		$(6.5 \pm 1.0) \times 10^{-4}$	0.32 ± 0.30
$\Lambda_c^+ \to \Sigma^0 K^+$	$(5.2 \pm 0.8) \times 10^{-4}$		$(5.4 \pm 0.7) \times 10^{-4}$	$-1.00^{+0.06}_{-0.00}$
$\Xi_c^0 \to \Xi^-\pi^+$	$(1.80 \pm 0.52) \times 10^{-2}$	-0.6 ± 0.4	$(2.21 \pm 0.14) \times 10^{-2}$	$-0.98^{+0.07}_{-0.02}$
$\Xi_c^0 \to \Lambda^0 K_S^0$			$(5.0 \pm 0.3) \times 10^{-3}$	-0.70 ± 0.28
**$\mathcal{R}_{\Xi_c^0}$	0.210 ± 0.028			

*This value is not included in the data input. **$\mathcal{R}_{\Xi_c^0} \equiv \mathcal{B}(\Xi_c^0 \to \Lambda K_S^0)/\mathcal{B}(\Xi_c^0 \to \Xi^-\pi^+)$.

$$\chi^2/d.o.f = 0.5$$

$$(a_1, a_2, a_3, a_6, \tilde{a}) = (4.34 \pm 0.50, -1.33 \pm 0.32, 1.25 \pm 0.36, -0.26 \pm 0.64, 1.77 \pm 0.83)\, 10^{-2} G_F \mathrm{GeV}^2,$$

$$(b_1, b_2, b_3, b_6, \tilde{b}) = (-9.20 \pm 2.09, -8.03 \pm 1.19, 1.42 \pm 1.61, -4.05 \pm 2.48, 13.15 \pm 5.56)\, 10^{-2} G_F \mathrm{GeV}^2.$$

Cabibbo Allowed

channel	$10^3\mathcal{B}$	α
$\Lambda_c^+ \to \Lambda^0\pi^+$	13.0 ± 0.7	-0.87 ± 0.10
$\Lambda_c^+ \to p\bar{K}^0$	31.2 ± 1.6	$-0.90^{+0.22}_{-0.10}$
$\Lambda_c^+ \to \Sigma^0\pi^+$	12.7 ± 0.6	-0.35 ± 0.27
$\Lambda_c^+ \to \Sigma^+\pi^0$	12.7 ± 0.6	-0.35 ± 0.27
$\Lambda_c^+ \to \Sigma^+\eta$	3.2 ± 1.3	-0.40 ± 0.47
$\Lambda_c^+ \to \Sigma^+\eta'$	14.4 ± 5.6	$1.00^{+0.00}_{-0.17}$
$\Lambda_c^+ \to \Xi^0 K^+$	5.6 ± 0.9	$0.94^{+0.06}_{-0.11}$
$\Xi_c^+ \to \Sigma^+\bar{K}^0$	$8.6^{+9.4}_{-7.8}$	$0.98^{+0.02}_{-0.16}$
$\Xi_c^+ \to \Xi^0\pi^+$	3.8 ± 2.0	-0.32 ± 0.52
$\Xi_c^0 \to \Xi^-\pi^+$	22.1 ± 1.4	$-0.98^{+0.07}_{-0.02}$
$\Xi_c^0 \to \Lambda^0\bar{K}^0$	10.5 ± 0.6	-0.68 ± 0.28
$\Xi_c^0 \to \Sigma^0\bar{K}^0$	0.8 ± 0.8	-0.07 ± 0.90
$\Xi_c^0 \to \Sigma^+ K^-$	5.9 ± 1.1	0.81 ± 0.16
$\Xi_c^0 \to \Xi^0\pi^0$	7.6 ± 1.0	$-1.00^{+0.07}_{-0.00}$
$\Xi_c^0 \to \Xi^0\eta$	10.3 ± 2.0	$0.93^{+0.07}_{-0.19}$
$\Xi_c^0 \to \Xi^0\eta'$	9.1 ± 4.1	$0.98^{+0.02}_{-0.27}$

Cabibbo Allowed

TABLE V. Summary of our results with $SU(3)_F$ and those in the literature for the up-down asymmetries of the Cabibno-allowed charmed baryon decays, where the data, KK, XK, CT, UVK, Zen, Iva, SV1, and SV2 are from the PDG [2], Korner and Kramer [27], Xu and Kamal [28], Cheng and Tseng [30], Uppal, Verma and Khanna [31], Zenczykowski [32], Ivanov *el al*. [33], Sharma and Verma [34], and Sharma and Verma [16], respectively.

channel	our result	data	KK	XK	CT (CT′)	UVK (UVK′)	Zen	Iva	SV1	SV2 (SV2′)
$\Lambda_c^+ \to \Lambda^0 \pi^+$	-0.87 ± 0.10	-0.91 ± 0.15	-0.70	-0.67	-0.99 (-0.95)	-0.87 (-0.85)	-0.99	-0.95	-0.99	input
$\Lambda_c^+ \to p \bar{K}^0$	$-0.90^{+0.22}_{-0.10}$		-1.0	0.51	-0.90 (-0.49)	-0.99 (-0.99)	-0.66	-0.97	-0.99	-0.99 ± 0.39
$\Lambda_c^+ \to \Sigma^0 \pi^+$	-0.35 ± 0.27		0.70	0.92	-0.49 (0.78)	-0.32 (-0.32)	0.39	0.43	-0.31	-0.45 ± 0.32
$\Lambda_c^+ \to \Sigma^+ \pi^0$	-0.35 ± 0.27	-0.45 ± 0.32	0.70	0.92	-0.49 (0.78)	-0.32 (-0.32)	0.39	0.43	-0.31	input
$\Lambda_c^+ \to \Sigma^+ \eta$	-0.40 ± 0.47		0.33			-0.94 (-0.99)	0	0.55	-0.99	0.92 ± 0.47 (0.96 ± 0.34)
$\Lambda_c^+ \to \Sigma^+ \eta'$	$1.00^{+0.00}_{-0.17}$		-0.45			0.68 (0.68)	-0.91	-0.05	0.44 0.44	-0.75 ± 0.38 (-0.91 ± 0.40)
$\Lambda_c^+ \to \Xi^0 K^+$	$0.94^{+0.06}_{-0.11}$	0.77 ± 0.78	0	0		0	0	0	0	0

TABLE V. Summary of our results with $SU(3)_F$ and those in the literature for the up-down asymmetries of the Cabibno-allowed charmed baryon decays, where the data, KK, XK, CT, UVK, Zen, Iva, SV1, and SV2 are from the PDG [2], Korner and Kramer [27], Xu and Kamal [28], Cheng and Tseng [30], Uppal, Verma and Khanna [31], Zenczykowski [32], Ivanov *el al*. [33], Sharma and Verma [34], and Sharma and Verma [16], respectively.

Cabibbo Allowed

channel	our result	data	KK	XK	CT (CT′)	UVK (UVK′)	Zen	Iva	SV1	SV2 (SV2′)
$\Lambda_c^+ \to \Lambda^0\pi^+$	-0.87 ± 0.10	-0.91 ± 0.15	-0.70	-0.67	-0.99	-0.87	-0.99	-0.95	-0.99	input
					(-0.95)	(-0.85)				
$\Lambda_c^+ \to p\bar{K}^0$	$-0.90^{+0.22}_{-0.10}$		-1.0	0.51	-0.90	-0.99	-0.66	-0.97	-0.99	-0.99 ± 0.39
					(-0.49)	(-0.99)				
$\Lambda_c^+ \to \Sigma^0\pi^+$	-0.35 ± 0.27		0.70	0.92	-0.49	-0.32	0.39	0.43	-0.31	-0.45 ± 0.32
					(0.78)	(-0.32)				
$\Lambda_c^+ \to \Sigma^+\pi^0$	-0.35 ± 0.27	-0.45 ± 0.32	0.70	0.92	-0.49	-0.32	0.39	0.43	-0.31	input
					(0.78)	(-0.32)				
$\Lambda_c^+ \to \Sigma^+\eta$	-0.40 ± 0.47		0.33			-0.94	0	0.55	-0.99	0.92 ± 0.47
						(-0.99)				(0.96 ± 0.34)
$\Lambda_c^+ \to \Sigma^+\eta'$	$1.00^{+0.00}_{-0.17}$		-0.45			0.68	-0.91	-0.05	0.44	-0.75 ± 0.38
						(0.68)			0.44	(-0.91 ± 0.40)
$\Lambda_c^+ \to \Xi^0 K^+$	$0.94^{+0.06}_{-0.11}$	0.77 ± 0.78	0	0		0	0	0	0	0

$$\alpha(\Lambda_c^+ \to \Xi^0 K^+)_{SU(3)} = 0.94^{+0.06}_{-0.11}$$

$$\alpha(\Lambda_c^+ \to \Xi^0 K^+)_{exp} = 0.77 \pm 0.78$$

Cabibbo Allowed

TABLE V. Summary of our results with $SU(3)_F$ and those in the literature for the up-down asymmetries of the Cabibno-allowed charmed baryon decays, where the data, KK, XK, CT, UVK, Zen, Iva, SV1, and SV2 are from the PDG [2], Korner and Kramer [27], Xu and Kamal [28], Cheng and Tseng [30], Uppal, Verma and Khanna [31], Zenczykowski [32], Ivanov *el al.* [33], Sharma and Verma [34], and Sharma and Verma [16], respectively.

BESIII Collaboration, arXiv:1905.04707

channel	our result						Zen	Iva	SV1	SV2 (SV2′)
$\Lambda_c^+ \to \Lambda^0\pi^+$	-0.87 ± 0.10	**-0.80±0.11**	-0.70	-0.67	-0.99 (-0.95)	-0.87 (-0.85)	-0.99	-0.95	-0.99	input
$\Lambda_c^+ \to p\bar{K}^0$	$-0.90^{+0.22}_{-0.10}$	**0.18±0.45**	-1.0	0.51	-0.90 (-0.49)	-0.99 (-0.99)	-0.66	-0.97	-0.99	-0.99 ± 0.39
$\Lambda_c^+ \to \Sigma^0\pi^+$	-0.35 ± 0.27	**-0.73±0.18**	0.70	0.92	-0.49 (0.78)	-0.32 (-0.32)	0.39	0.43	-0.31	-0.45 ± 0.32
$\Lambda_c^+ \to \Sigma^+\pi^0$	-0.35 ± 0.27	**-0.57±0.12**	0.70	0.92	-0.49 (0.78)	-0.32 (-0.32)	0.39	0.43	-0.31	input
$\Lambda_c^+ \to \Sigma^+\eta$	-0.40 ± 0.47		0.33			-0.94 (-0.99)	0	0.55	-0.99	0.92 ± 0.47 (0.96 ± 0.34)
$\Lambda_c^+ \to \Sigma^+\eta'$	$1.00^{+0.00}_{-0.17}$		-0.45			0.68 (0.68)	-0.91	-0.05	0.44 0.44	-0.75 ± 0.38 (-0.91 ± 0.40)
$\Lambda_c^+ \to \Xi^0 K^+$	$0.94^{+0.06}_{-0.11}$	0.77 ± 0.78	0	0		0	0	0	0	0

$$\alpha(\Lambda_c^+ \to \Xi^0 K^+)_{SU(3)} = 0.94^{+0.06}_{-0.11}$$

$$\alpha(\Lambda_c^+ \to \Xi^0 K^+)_{exp} = 0.77 \pm 0.78$$

Cabibbo Allowed

TABLE V. Summary of our results with $SU(3)_F$ and those in the literature for the up-down asymmetries of the Cabibno-allowed charmed baryon decays, where the data, KK, XK, CT, UVK, Zen, Iva, SV1, and SV2 are from the PDG [2], Korner and Kramer [27], Xu and Kamal [28], Cheng and Tseng [30], Uppal, Verma and Khanna [31], Zenczykowski [32], Ivanov *el al.* [33], Sharma and Verma [34], and Sharma and Verma [16], respectively.

channel	new result	BESIII Collaboration, arXiv:1905.04707				)	Zen	Iva	SV1	SV2 (SV2′)
$\Lambda_c^+ \to \Lambda^0 \pi^+$	-0.78 ± 0.07	-0.80 ± 0.11	-0.70	-0.67	-0.99 (-0.95)	-0.87 (-0.85)	-0.99	-0.95	-0.99	input
$\Lambda_c^+ \to p K_S$	0.03 ± 0.29	0.18 ± 0.45	-1.0	0.51	-0.90 (-0.49)	-0.99 (-0.99)	-0.66	-0.97	-0.99	-0.99 ± 0.39
$\Lambda_c^+ \to \Sigma^0 \pi^+$	-0.57 ± 0.09	-0.73 ± 0.18	0.70	0.92	-0.49 (0.78)	-0.32 (-0.32)	0.39	0.43	-0.31	-0.45 ± 0.32
$\Lambda_c^+ \to \Sigma^+ \pi^0$	-0.57 ± 0.09	-0.57 ± 0.12	0.70	0.92	-0.49 (0.78)	-0.32 (-0.32)	0.39	0.43	-0.31	input
$\Lambda_c^+ \to \Sigma^+ \eta$	-0.44 ± 0.47		0.33			-0.94 (-0.99)	0	0.55	-0.99	0.92 ± 0.47 (0.96 ± 0.34)
$\Lambda_c^+ \to \Sigma^+ \eta'$	$0.83^{+0.17}_{-0.25}$		-0.45			0.68 (0.68)	-0.91	-0.05	0.44 0.44	-0.75 ± 0.38 (-0.91 ± 0.40)
$\Lambda_c^+ \to \Xi^0 K^+$	$1.00^{+0.00}_{-0.11}$	0.77 ± 0.78	0	0		0	0	0	0	0

$$\alpha(\Lambda_c^+ \to \Xi^0 K^+)_{SU(3)} = 1.00^{+0.00}_{-0.11}$$

$$\alpha(\Lambda_c^+ \to \Xi^0 K^+)_{exp} = 0.77 \pm 0.78$$

Cabibbo Suppressed

channel	$10^4\mathcal{B}$	α
$\Lambda_c^+ \to p\pi^0$	1.2 ± 1.2	-0.05 ± 0.72
$\Lambda_c^+ \to p\eta$	12.4 ± 3.5	$-0.94^{+0.26}_{-0.06}$
$\Lambda_c^+ \to p\eta'$	24.5 ± 14.6	$0.91^{+0.09}_{-0.21}$
$\Lambda_c^+ \to n\pi^+$	8.5 ± 2.0	0.12 ± 0.19
$\Lambda_c^+ \to \Lambda^0 K^+$	6.5 ± 1.0	0.32 ± 0.32
$\Lambda_c^+ \to \Sigma^0 K^+$	5.4 ± 0.7	$-1.00^{+0.06}_{-0.00}$
$\Lambda_c^+ \to \Sigma^+ K^0$	10.9 ± 1.5	$-1.0^{+0.06}_{-0.00}$
$\Xi_c^+ \to \Lambda^0\pi^+$	12.3 ± 4.1	-0.19 ± 0.24
$\Xi_c^+ \to p\bar{K}^0$	43.3 ± 7.8	$-0.93^{+0.09}_{-0.07}$
$\Xi_c^+ \to \Sigma^0\pi^+$	25.5 ± 2.6	-0.38 ± 0.27
$\Xi_c^+ \to \Sigma^+\pi^0$	26.9 ± 6.5	0.10 ± 0.43
$\Xi_c^+ \to \Sigma^+\eta$	15.5 ± 10.3	$0.58^{+0.42}_{-0.59}$
$\Xi_c^+ \to \Sigma^+\eta'$	34.6 ± 21.9	$0.72^{+0.28}_{-0.41}$
$\Xi_c^+ \to \Xi^0 K^+$	8.2 ± 1.9	0.17 ± 0.28
$\Xi_c^0 \to \Lambda^0\pi^0$	2.3 ± 0.8	-0.09 ± 0.23
$\Xi_c^0 \to \Lambda^0\eta$	6.4 ± 2.3	-0.42 ± 0.27
$\Xi_c^0 \to \Lambda^0\eta'$	16.4 ± 10.6	$0.87^{+0.13}_{-0.28}$
$\Xi_c^0 \to pK^-$	5.0 ± 1.1	0.67 ± 0.17
$\Xi_c^0 \to n\bar{K}^0$	7.5 ± 0.5	-0.47 ± 0.34
$\Xi_c^0 \to \Sigma^0\pi^0$	3.8 ± 0.7	$-0.88^{+0.19}_{-0.12}$
$\Xi_c^0 \to \Sigma^0\eta$	1.4 ± 0.8	0.09 ± 0.77
$\Xi_c^0 \to \Sigma^0\eta'$	3.3 ± 2.2	$0.70^{+0.30}_{-0.43}$
$\Xi_c^0 \to \Sigma^+\pi^-$	3.9 ± 0.8	0.78 ± 0.17
$\Xi_c^0 \to \Sigma^-\pi^+$	13.3 ± 0.9	$-1.00^{+0.02}_{-0.00}$
$\Xi_c^0 \to \Xi^0 K^0$	7.2 ± 0.4	-0.32 ± 0.25
$\Xi_c^0 \to \Xi^- K^+$	9.8 ± 0.6	$-0.95^{+0.06}_{-0.05}$

Cabibbo Suppressed

TABLE VI. Summary of our results with $SU(3)_F$ and those in the literature for the up-down asymmetries of the singly Cabibbo-suppressed charmed baryon decays, where UVK, SV2 and CKX are from Refs. [31], [16] and [37], respectively.

channel	our result	UVK$^{(\prime)}$	SV2$^{(\prime)}$	CKX
$\Lambda_c^+ \to p\pi^0$	-0.05 ± 0.72	0.82 (0.85)	0.05 (0.05)	−0.95
$\Lambda_c^+ \to p\eta$	$-0.94^{+0.26}_{-0.06}$	−1.00 (−0.79)	−0.74 (−0.45)	−0.56
$\Lambda_c^+ \to p\eta'$	$0.91^{+0.09}_{-0.21}$	0.87 (0.87)	−0.97 (−0.99)	
$\Lambda_c^+ \to n\pi^+$	0.12 ± 0.19	−0.13 (0.68)	0.05 (0.05)	−0.90
$\Lambda_c^+ \to \Lambda^0 K^+$	0.32 ± 0.32	−0.99 (−0.99)	−0.54 (0.97)	−0.96
$\Lambda_c^+ \to \Sigma^0 K^+$	$-1.00^{+0.06}_{-0.00}$	−0.80 (−0.80)	0.68 (−0.98)	−0.73
$\Lambda_c^+ \to \Sigma^+ K^0$	$-1.00^{+0.06}_{-0.00}$	−0.80 (−0.80)	0.68 (−0.98)	−0.74

[31] T. Uppal, R. C. Verma and M. P. Khanna, Phys. Rev. D **49**, 3417 (1994).

[16] K. K. Sharma and R. C. Verma, Phys. Rev. D **55**, 7067 (1997).

[37] H. Y. Cheng, X. W. Kang and F. Xu, Phys. Rev. D **97**, 074028 (2018).

Doubly Cabibbo Suppressed

channel	$10^5\mathcal{B}$	α
$\Lambda_c^+ \to pK^0$	$1.2^{+1.4}_{-1.2}$	$1.00^{+0}_{-0.09}$
$\Lambda_c^+ \to nK^+$	0.4 ± 0.2	$-0.41^{+0.62}_{-0.59}$
$\Xi_c^+ \to \Lambda^0 K^+$	3.3 ± 0.8	0.76 ± 0.24
$\Xi_c^+ \to p\pi^0$	6.0 ± 1.4	0.65 ± 0.17
$\Xi_c^+ \to p\eta$	20.4 ± 8.4	-0.75 ± 0.15
$\Xi_c^+ \to p\eta'$	40.1 ± 27.7	$0.80^{+0.20}_{-0.30}$
$\Xi_c^+ \to n\pi^+$	12.1 ± 2.8	0.65 ± 0.17
$\Xi_c^+ \to \Sigma^0 K^+$	11.9 ± 0.7	$-0.99^{+0.03}_{-0.01}$
$\Xi_c^+ \to \Sigma^+ K^0$	19.5 ± 1.7	$-0.82\pm^{+0.28}_{-0.18}$
$\Xi_c^0 \to \Lambda^0 K^0$	0.6 ± 0.2	0.32 ± 0.45
$\Xi_c^0 \to p\pi^-$	3.1 ± 0.7	0.65 ± 0.17
$\Xi_c^0 \to n\pi^0$	1.5 ± 0.4	0.65 ± 0.17
$\Xi_c^0 \to n\eta$	5.2 ± 2.1	-0.75 ± 0.15
$\Xi_c^0 \to n\eta'$	10.2 ± 7.1	$0.80^{+0.20}_{-0.30}$
$\Xi_c^0 \to \Sigma^0 K^0$	2.5 ± 0.2	$-0.82^{+0.28}_{-0.18}$
$\Xi_c^0 \to \Sigma^- K^+$	6.1 ± 0.4	$-0.99^{+0.03}_{-0.01}$

K_S-K_L asymmetries in charmed baryon decays

$$\mathrm{R}_{K^0_{S,L}}(\mathrm{B}_c \to \mathrm{B}_n K^0_{S,L}) = \frac{\Gamma(\mathrm{B}_c \to \mathrm{B}_n K^0_S) - \Gamma(\mathrm{B}_c \to \mathrm{B}_n K^0_L)}{\Gamma(\mathrm{B}_c \to \mathrm{B}_n K^0_S) + \Gamma(\mathrm{B}_c \to \mathrm{B}_n K^0_L)}$$

$K^0_S - K^0_L$ asymmetries between Cabbibo favored and doubly suppressed modes

channel	Irreducible amplitude for A	$10^3\mathcal{B}_{SU(3)_F}$	$\alpha_{SU(3)_F}$	$10^2\mathrm{R}_{K^0_{S,L}}$
$\Lambda_c^+ \to pK^0_S$	$\sqrt{2}\,((a_1 - \frac{a_6}{2}) + (a_3 - \frac{a_6}{2})s_c^2)$	15.7 ± 0.8	$-0.89^{+0.26}_{-0.11}$	0.9 ± 1.1
$\Lambda_c^+ \to pK^0_L$	$-\sqrt{2}\,((a_1 - \frac{a_6}{2}) - (a_3 - \frac{a_6}{2})s_c^2)$	15.5 ± 0.8	$-0.92^{+0.21}_{-0.08}$	
$\Xi_c^+ \to \Sigma^+ K^0_S$	$-\sqrt{2}\,((a_3 - \frac{a_6}{2}) + (a_1 - \frac{a_6}{2})s_c^2)$	$4.9^{+5.9}_{-4.2}$	$0.89^{+0.11}_{-0.46}$	11.8 ± 7.8
$\Xi_c^+ \to \Sigma^+ K^0_L$	$\sqrt{2}\,((a_3 - \frac{a_6}{2}) - (a_1 - \frac{a_6}{2})s_c^2)$	$3.9^{+5.1}_{-3.5}$	$1.00^{+0.00}_{-0.18}$	
$\Xi_c^0 \to \Sigma^0 K^0_S$	$(a_2 + a_3 - \frac{a_6}{2}) + (a_1 - \frac{a_6}{2})s_c^2$	0.5 ± 0.4	$-0.34^{+0.95}_{-0.66}$	17.0 ± 14.6
$\Xi_c^0 \to \Sigma^0 K^0_L$	$-(a_2 + a_3 - \frac{a_6}{2}) + (a_1 - \frac{a_6}{2})s_c^2$	$0.3^{+0.5}_{-0.3}$	0.28 ± 0.71	
$\Xi_c^0 \to \Lambda^0 K^0_S$	$\frac{1}{\sqrt{3}}((2a_1 - a_2 - a_3 - \frac{a_6}{2})$ $-(a_1 - 2a_2 - 2a_3 + \frac{a_6}{2})s_c^2)$	5.0 ± 0.3	-0.70 ± 0.28	-4.3 ± 0.3
$\Xi_c^0 \to \Lambda^0 K^0_L$	$-\frac{1}{\sqrt{3}}((2a_1 - a_2 - a_3 - \frac{a_6}{2})$ $+(a_1 - 2a_2 - 2a_3 + \frac{a_6}{2})s_c^2)$	5.5 ± 0.3	-0.66 ± 0.28	

K_S-K_L asymmetries in charmed baryon decays

$$R_{K^0_{S,L}}(B_c \to B_n K^0_{S,L}) = \frac{\Gamma(B_c \to B_n K^0_S) - \Gamma(B_c \to B_n K^0_L)}{\Gamma(B_c \to B_n K^0_S) + \Gamma(B_c \to B_n K^0_L)}$$

$K^0_S - K^0_L$ asymmetries between Cabbibo favored and doubly suppressed modes

channel	Irreducible amplitude for A	$10^3 \mathcal{B}_{SU(3)_F}$	$\alpha_{SU(3)_F}$	$10^2 R_{K^0_{S,L}}$	
$\Lambda_c^+ \to pK^0_S$	$\sqrt{2}\left((a_1 - \frac{a_6}{2}) + (a_3 - \frac{a_6}{2})s_c^2\right)$	15.7 ± 0.8	$-0.89^{+0.26}_{-0.11}$	0.9 ± 1.1	-1.0 ~ 8.7
$\Lambda_c^+ \to pK^0_L$	$-\sqrt{2}\left((a_1 - \frac{a_6}{2}) - (a_3 - \frac{a_6}{2})s_c^2\right)$	15.5 ± 0.8	$-0.92^{+0.21}_{-0.08}$		
$\Xi_c^+ \to \Sigma^+ K^0_S$	$-\sqrt{2}\left((a_3 - \frac{a_6}{2}) + (a_1 - \frac{a_6}{2})s_c^2\right)$	$4.9^{+5.9}_{-4.2}$	$0.89^{+0.11}_{-0.46}$	11.8 ± 7.8	-11.3 ~ 39.0
$\Xi_c^+ \to \Sigma^+ K^0_L$	$\sqrt{2}\left((a_3 - \frac{a_6}{2}) - (a_1 - \frac{a_6}{2})s_c^2\right)$	$3.9^{+5.1}_{-3.5}$	$1.00^{+0.00}_{-0.18}$		
$\Xi_c^0 \to \Sigma^0 K^0_S$	$(a_2 + a_3 - \frac{a_6}{2}) + (a_1 - \frac{a_6}{2})s_c^2$	0.5 ± 0.4	$-0.34^{+0.95}_{-0.66}$	17.0 ± 14.6	9.1±1.6
$\Xi_c^0 \to \Sigma^0 K^0_L$	$-(a_2 + a_3 - \frac{a_6}{2}) + (a_1 - \frac{a_6}{2})s_c^2$	$0.3^{+0.5}_{-0.3}$	0.28 ± 0.71		
$\Xi_c^0 \to \Lambda^0 K^0_S$	$\frac{1}{\sqrt{3}}((2a_1 - a_2 - a_3 - \frac{a_6}{2})$ $-(a_1 - 2a_2 - 2a_3 + \frac{a_6}{2})s_c^2)$	5.0 ± 0.3	-0.70 ± 0.28	-4.3 ± 0.3	-3.7±0.4
$\Xi_c^0 \to \Lambda^0 K^0_L$	$-\frac{1}{\sqrt{3}}((2a_1 - a_2 - a_3 - \frac{a_6}{2})$ $+(a_1 - 2a_2 - 2a_3 + \frac{a_6}{2})s_c^2)$	5.5 ± 0.3	-0.66 ± 0.28		

D. Wang, P.F. Guo, W.H. Long and F.S. Yu, ``K_S^0–K_L^0 asymmetries and CP violation in charmed baryon decays into neutral kaons," JHEP 1803, 066 (2018)

Three-body nonleptonic decays of charmed baryons

$$\mathrm{B}_c \to \mathrm{B}_n M M'$$

J.Y. Cen, C.Q. Geng, C.W. Liu and T.H. Tsai, "Up-down asymmetries in charmed baryon three-body decays," arXiv:1906.01848 [hep-ph].

$$\mathcal{M}(\mathbf{B_c} \to \mathbf{B_n} M M') = \langle \mathbf{B_n} M M' | \mathcal{H}_{eff} | \mathbf{B_c} \rangle = i\bar{u}_{\mathbf{B_n}}(A - B\gamma_5) u_{\mathbf{B_c}}$$

Under SU(3)$_F$ flavor symmetry:

$$\begin{aligned} A(\mathbf{B_c} \to \mathrm{B}_n M M') = {} & a_1 (\bar{\mathrm{B}}_n)^k_i (M)^m_l (M)^l_m H(6)_{jk} T^{ij} + a_2 (\bar{\mathrm{B}}_n)^k_i (M)^m_j (M)^l_m H(6)_{kl} T^{ij} \\ & + a_3 (\bar{\mathrm{B}}_n)^k_i (M)^m_k (M)^l_m H(6)_{jl} T^{ij} + a_4 (\bar{\mathrm{B}}_n)^k_i (M)^l_j (M)^m_k H(6)_{lm} T^{ij} \\ & + a_5 (\bar{\mathrm{B}}_n)^l_k (M)^m_j (M)^k_m H(6)_{il} T^{ij} + a_6 (\bar{\mathrm{B}}_n)^l_k (M)^m_j (M)^k_l H(6)_{im} T^{ij} \end{aligned}$$

$$B(\mathbf{B_c} \to \mathrm{B}_n M M') = A(\mathbf{B_c} \to \mathrm{B}_n M M')\{a_i \to b_i\}$$

$$T^{ij} = \epsilon^{ijk} (\mathbf{B_c})_k$$

Remarks:

1. Consider only the S-wave *(L=0) contributions from MM'* in the amplitudes.

2. Neglect the contributions from H($\overline{15}$).

3. Take the data with only the non-resonant parts.

TABLE I. A-amplitudes of $\Lambda_c^+ \to \mathbf{B_n} M M'$.

CF mode	A	CS mode	At_c^{-1}	DCS mode	At_c^{-2}
$\Sigma^+\pi^0\pi^0$	$4a_1+2a_2+2a_3+2a_4-2a_5$	$\Sigma^+\pi^0K^0$	$\sqrt{2}a_2+\sqrt{2}a_3+2\sqrt{2}a_4$	$\Sigma^+K^0K^0$	$4a_4$
$\Sigma^+\pi^+\pi^-$	$4a_1+2a_2+2a_3-2a_5-2a_6$	$\Sigma^+\pi^-K^+$	$-2a_2-2a_3+2a_6$	$\Sigma^0K^0K^+$	$2\sqrt{2}a_4$
$\Sigma^+K^0\bar{K}^0$	$4a_1+2a_2+2a_3$	$\Sigma^+K^0\eta^0$	$\frac{\sqrt{6}a_2}{3}+\frac{\sqrt{6}a_3}{3}-\frac{2\sqrt{6}a_4}{3}$	$\Sigma^-K^+K^+$	$-4a_4$
$\Sigma^+K^+K^-$	$4a_1-2a_5$	$\Sigma^0\pi^+K^0$	$-\sqrt{2}a_2-\sqrt{2}a_3-2\sqrt{2}a_4$	$p\pi^0K^0$	$-\sqrt{2}a_2$
$\Sigma^+\eta^0\eta^0$	$4a_1+\frac{2a_2}{3}+\frac{2a_3}{3}+\frac{2a_4}{3}-\frac{2a_5}{3}$	$\Sigma^0K^+\eta^0$	$\frac{\sqrt{3}a_2}{3}+\frac{\sqrt{3}a_3}{3}-\frac{2\sqrt{3}a_4}{3}$	$p\pi^-K^+$	$2a_2$
$\Sigma^0\pi^0\pi^+$	$-2a_4-2a_6$	$\Sigma^-\pi^+K^+$	$4a_4+2a_6$	$pK^0\eta^0$	$-\frac{\sqrt{6}a_2}{3}-\frac{2\sqrt{6}a_4}{3}$
$\Sigma^0K^+\bar{K}^0$	$\sqrt{2}a_2+\sqrt{2}a_3+\sqrt{2}a_5$	$p\pi^0\pi^0$	$-4a_1-2a_2+2a_5$	$n\pi^0K^+$	$-\sqrt{2}a_2$
$\Sigma^-\pi^+\pi^+$	$-4a_4-4a_6$	$p\pi^0\eta^0$	$\frac{2\sqrt{3}a_2}{3}-\frac{2\sqrt{3}a_4}{3}+\frac{2\sqrt{3}a_5}{3}$	$n\pi^+K^0$	$-2a_2$
$\Xi^0\pi^0K^+$	$-\sqrt{2}a_5$	$p\pi^+\pi^-$	$-4a_1-2a_2+2a_5$	$nK^+\eta^0$	$\frac{\sqrt{6}a_2}{3}+\frac{2\sqrt{6}a_4}{3}$
$\Xi^0\pi^+K^0$	$-2a_5-2a_6$	pK^+K^-	$-4a_1-2a_3+2a_5+2a_6$		
$\Xi^-\pi^+K^+$	$-2a_6$	$p\eta^0\eta^0$	$-4a_1-\frac{2a_2}{3}-\frac{8a_3}{3}+\frac{4a_4}{3}+\frac{2a_5}{3}$		
$p\pi^0\bar{K}^0$	$-\sqrt{2}a_3-\sqrt{2}a_4$	$n\pi^+\eta^0$	$\frac{2\sqrt{6}a_2}{3}-\frac{2\sqrt{6}a_4}{3}+\frac{2\sqrt{6}a_5}{3}$		
$p\pi^+K^-$	$2a_3-2a_6$	$nK^+\bar{K}^0$	$2a_2+2a_4+2a_5+2a_6$		
$p\bar{K}^0\eta^0$	$-\frac{\sqrt{6}a_3}{3}+\frac{\sqrt{6}a_4}{3}$	$\Lambda^0\pi^0K^+$	$\frac{\sqrt{3}a_2}{3}-\frac{\sqrt{3}a_3}{3}-\frac{2\sqrt{3}a_5}{3}$		
$n\pi^+\bar{K}^0$	$-2a_4-2a_6$	$\Lambda^0\pi^+K^0$	$\frac{\sqrt{6}a_2}{3}-\frac{\sqrt{6}a_3}{3}-\frac{2\sqrt{6}a_5}{3}$		
$\Lambda^0\pi^+\eta^0$	$-\frac{2a_2}{3}+\frac{2a_3}{3}-\frac{2a_5}{3}-2a_6$	$\Lambda^0K^+\eta^0$	$-\frac{a_2}{3}+\frac{a_3}{3}+\frac{2a_5}{3}+2a_6$		
$\Lambda^0K^+\bar{K}^0$	$-\frac{\sqrt{6}a_2}{3}+\frac{\sqrt{6}a_3}{3}-\frac{\sqrt{6}a_5}{3}$				

TABLE II. A-amplitudes of $\Xi_c^+ \to \mathbf{B_n} M M'$.

CF mode	A	CS mode	At_c^{-1}	DCS mode	At_c^{-2}
$\Sigma^+\pi^0\bar{K}^0$	$-\sqrt{2}a_2-\sqrt{2}a_4$	$\Sigma^+\pi^0\pi^0$	$-4a_1-2a_3+2a_5$	$\Sigma^+\pi^0K^0$	$-\sqrt{2}a_3$
$\Sigma^+\pi^+K^-$	$2a_2$	$\Sigma^+\pi^0\eta^0$	$\frac{2\sqrt{3}a_3}{3}-\frac{2\sqrt{3}a_4}{3}+\frac{2\sqrt{3}a_5}{3}$	$\Sigma^+\pi^-K^+$	$2a_3-2a_6$
$\Sigma^+\bar{K}^0\eta^0$	$-\frac{\sqrt{6}a_2}{3}+\frac{\sqrt{6}a_4}{3}$	$\Sigma^+\pi^+\pi^-$	$-4a_1-2a_3+2a_5+2a_6$	$\Sigma^+K^0\eta^0$	$-\frac{\sqrt{6}a_3}{3}-\frac{2\sqrt{6}a_4}{3}$
$\Sigma^0\pi^+\bar{K}^0$	$\sqrt{2}a_4$	$\Sigma^+K^+K^-$	$-4a_1-2a_2+2a_5$	$\Sigma^0\pi^0K^+$	a_3-2a_6
$\Xi^0\pi^0\pi^+$	$\sqrt{2}a_4$	$\Sigma^+\eta^0\eta^0$	$-4a_1-\frac{8a_2}{3}-\frac{2a_3}{3}+\frac{4a_4}{3}+\frac{2a_5}{3}$	$\Sigma^0\pi^+K^0$	$\sqrt{2}a_3$
$\Xi^0\pi^+\eta^0$	$-\frac{2\sqrt{6}a_2}{3}-\frac{\sqrt{6}a_4}{3}$	$\Sigma^0\pi^0\pi^+$	$2a_6$	$\Sigma^0K^+\eta^0$	$-\frac{\sqrt{3}a_3}{3}-\frac{2\sqrt{3}a_4}{3}$
$\Xi^0K^+\bar{K}^0$	$-2a_2$	$\Sigma^0\pi^+\eta^0$	$-\frac{2\sqrt{3}a_3}{3}+\frac{2\sqrt{3}a_4}{3}-\frac{2\sqrt{3}a_5}{3}$	$\Sigma^-\pi^+K^+$	$-2a_6$
$\Xi^-\pi^+\pi^+$	$-4a_4$	$\Sigma^0K^+\bar{K}^0$	$-\sqrt{2}a_3-\sqrt{2}a_4-\sqrt{2}a_5$	$\Xi^0K^0K^+$	$-2a_4-2a_6$
$p\bar{K}^0\bar{K}^0$	$4a_4$	$\Sigma^-\pi^+\pi^+$	$4a_6$	$\Xi^-K^+K^+$	$-4a_4-4a_6$
$\Lambda^0\pi^+\bar{K}^0$	$\sqrt{6}a_4$	$\Xi^0\pi^0K^+$	$\sqrt{2}a_2-\sqrt{2}a_4+\sqrt{2}a_5$	$p\pi^0\pi^0$	$4a_1-2a_5$
		$\Xi^0\pi^+K^0$	$2a_2+2a_4+2a_5+2a_6$	$p\pi^0\eta^0$	$-\frac{2\sqrt{3}a_5}{3}$
		$\Xi^0K^+\eta^0$	$-\frac{\sqrt{6}a_2}{3}+\frac{\sqrt{6}a_4}{3}-\frac{\sqrt{6}a_5}{3}$	$p\pi^+\pi^-$	$4a_1-2a_5$
		$\Xi^-\pi^+K^+$	$4a_4+2a_6$	$pK^0\bar{K}^0$	$4a_1+2a_2+2a_3$
		$p\pi^0\bar{K}^0$	$\sqrt{2}a_2+\sqrt{2}a_3$	pK^+K^-	$4a_1+2a_2+2a_3-2a_5-2a_6$
		$p\pi^+K^-$	$-2a_2-2a_3+2a_6$	$p\eta^0\eta^0$	$4a_1+\frac{8a_2}{3}+\frac{8a_3}{3}+\frac{8a_4}{3}-\frac{2a_5}{3}$
		$p\bar{K}^0\eta^0$	$\frac{\sqrt{6}a_2}{3}+\frac{\sqrt{6}a_3}{3}+\frac{4\sqrt{6}a_4}{3}$	$n\pi^+\eta^0$	$-\frac{2\sqrt{6}a_5}{3}$
		$n\pi^+\bar{K}^0$	$2a_6$	$nK^+\bar{K}^0$	$-2a_5-2a_6$
		$\Lambda^0\pi^+\eta^0$	$-\frac{4a_2}{3}-\frac{2a_3}{3}+2a_4+\frac{2a_5}{3}+2a_6$	$\Lambda^0\pi^0K^+$	$\frac{2\sqrt{3}a_2}{3}+\frac{\sqrt{3}a_3}{3}+\frac{2\sqrt{3}a_5}{3}$
		$\Lambda^0K^+\bar{K}^0$	$-\frac{2\sqrt{6}a_2}{3}-\frac{\sqrt{6}a_3}{3}-\sqrt{6}a_4+\frac{\sqrt{6}a_5}{3}$	$\Lambda^0\pi^+K^0$	$\frac{2\sqrt{6}a_2}{3}+\frac{\sqrt{6}a_3}{3}+\frac{2\sqrt{6}a_5}{3}$

TABLE III. A-amplitudes of $\Xi_c^0 \to \mathbf{B_n} M M'$.

CF mode	A	CS mode	At_c^{-1}	DCS mode	At_c^{-2}
$\Sigma^+\pi^0K^-$	$\sqrt{2}a_5$	$\Sigma^+\pi^0\pi^-$	$-\sqrt{2}a_6$	$\Sigma^+\pi^-K^0$	$-2a_6$
$\Sigma^+\pi^-\bar{K}^0$	$2a_5+2a_6$	$\Sigma^+\pi^-\eta^0$	$\frac{2\sqrt{6}a_5}{3}+\sqrt{6}a_6$	$\Sigma^0\pi^0K^0$	a_3-2a_6
$\Sigma^+K^-\eta^0$	$-\frac{\sqrt{6}a_5}{3}$	$\Sigma^+K^0K^-$	$2a_5$	$\Sigma^0\pi^-K^+$	$-\sqrt{2}a_3$
$\Sigma^0\pi^0\bar{K}^0$	$a_2+a_4+a_5+2a_6$	$\Sigma^0\pi^0\pi^0$	$2\sqrt{2}a_1+\sqrt{2}a_3-\sqrt{2}a_5-2\sqrt{2}a_6$	$\Sigma^0K^0\eta^0$	$\frac{\sqrt{3}a_3}{3}+\frac{2\sqrt{3}a_4}{3}$
$\Sigma^0\pi^+K^-$	$-\sqrt{2}a_2-\sqrt{2}a_5$	$\Sigma^0\pi^0\eta^0$	$-\frac{\sqrt{6}a_3}{3}+\frac{\sqrt{6}a_4}{3}+\frac{\sqrt{6}a_5}{3}+\sqrt{6}a_6$	$\Sigma^-\pi^0K^+$	$\sqrt{2}a_3$
$\Sigma^0\bar{K}^0\eta^0$	$\frac{\sqrt{3}a_2}{3}-\frac{\sqrt{3}a_4}{3}+\frac{\sqrt{3}a_5}{3}$	$\Sigma^0\pi^+\pi^-$	$2\sqrt{2}a_1+\sqrt{2}a_3-\sqrt{2}a_5$	$\Sigma^-\pi^+K^0$	$2a_3-2a_6$
$\Sigma^-\pi^+\bar{K}^0$	$2a_4+2a_6$	$\Sigma^0K^0\bar{K}^0$	$\sqrt{2}(2a_1+a_2+a_3+a_4-a_5)$	$\Sigma^-K^+\eta^0$	$-\frac{\sqrt{6}a_3}{3}-\frac{2\sqrt{6}a_4}{3}$
$\Xi^0\pi^0\eta^0$	$\frac{2\sqrt{3}a_2}{3}+\frac{2\sqrt{3}a_3}{3}+\frac{2\sqrt{3}a_4}{3}$	$\Sigma^0K^+K^-$	$2\sqrt{2}a_1+\sqrt{2}a_2$	$\Xi^0K^0K^0$	$-4a_4-4a_6$
$\Xi^0\pi^+\pi^-$	$-4a_1-2a_2-2a_3$	$\Sigma^0\eta^0\eta^0$	$\sqrt{2}(2a_1+\frac{4a_2}{3}+\frac{a_3}{3}-\frac{2a_4}{3}-\frac{a_5}{3})$	$\Xi^-K^0K^+$	$-2a_4-2a_6$
$\Xi^0K^0\bar{K}^0$	$-2(2a_1+a_2+a_3$	$\Sigma^-\pi^0\pi^+$	$-\sqrt{2}a_6$	$p\pi^-\eta^0$	$-\frac{2\sqrt{6}a_5}{3}$
	$-a_5-a_6)$	$\Sigma^-\pi^+\eta^0$	$-\frac{2\sqrt{6}a_3}{3}+\frac{2\sqrt{6}a_4}{3}+\sqrt{6}a_6$	pK^0K^-	$-2a_5-2a_6$
$\Xi^0K^+K^-$	$-4a_1+2a_5$	$\Sigma^-K^+\bar{K}^0$	$-2a_3-2a_4$	$n\pi^0\pi^0$	$4a_1-2a_5$
$\Xi^0\eta^0\eta^0$	$-2(2a_1+\frac{a_2}{3}+\frac{a_3}{3}$	$\Xi^0\pi^-K^+$	$2a_2+2a_3+2a_5$	$n\pi^0\eta^0$	$\frac{2\sqrt{3}a_5}{3}$
	$+\frac{a_4}{3}-\frac{4a_5}{3})$	$\Xi^0K^0\eta^0$	$\sqrt{6}(-\frac{a_2}{3}-\frac{a_3}{3}+\frac{2a_4}{3}-\frac{a_5}{3}+a_6)$	$n\pi^+\pi^-$	$4a_1-2a_5$
$\Xi^-\pi^0\pi^+$	$\sqrt{2}a_4$	$\Xi^-\pi^0K^+$	$\sqrt{2}a_3-\sqrt{2}a_4-\sqrt{2}a_6$	$nK^0\bar{K}^0$	$2(2a_1+a_2+a_3$
$\Xi^-\pi^+\eta^0$	$-\frac{2\sqrt{6}a_3}{3}-\frac{\sqrt{6}a_4}{3}$	$\Xi^-\pi^+K^0$	$2a_3+2a_4$		$-a_5-a_6)$
$\Xi^-K^+\bar{K}^0$	$-2a_3+2a_6$	$p\pi^0K^-$	$-\sqrt{2}a_5-\sqrt{2}a_6$	nK^+K^-	$4a_1+2a_2+2a_3$
$pK^-\bar{K}^0$	$2a_6$	$p\pi^-\bar{K}^0$	$-2a_5$	$n\eta^0\eta^0$	$4a_1+\frac{8a_2}{3}+\frac{8a_3}{3}$
$n\bar{K}^0\bar{K}^0$	$4a_4+4a_6$	$pK^-\eta^0$	$\frac{\sqrt{6}a_5}{3}+\sqrt{6}a_6$		$+\frac{8a_4}{3}-\frac{2a_5}{3}$
$\Lambda^0\pi^0\bar{K}^0$	$-\sqrt{3}(\frac{a_2}{3}+\frac{2a_3}{3}+a_4+\frac{a_5}{3})$	$n\pi^0\bar{K}^0$	$\sqrt{2}a_2+\sqrt{2}a_3+\sqrt{2}a_5-\sqrt{2}a_6$	$\Lambda^0\pi^0K^0$	$-\sqrt{3}(\frac{2a_2}{3}+\frac{a_3}{3}+\frac{2a_5}{3})$
$\Lambda^0\pi^+K^-$	$\frac{\sqrt{6}a_2}{3}+\frac{2\sqrt{6}a_3}{3}+\frac{\sqrt{6}a_5}{3}$	$n\pi^+K^-$	$-2a_2-2a_3-2a_5$	$\Lambda^0\pi^-K^+$	$\sqrt{6}(\frac{2a_2}{3}+\frac{a_3}{3}+\frac{2a_5}{3})$
		$n\bar{K}^0\eta^0$	$\sqrt{6}(\frac{a_2}{3}+\frac{a_3}{3}+\frac{4a_4}{3}+\frac{a_5}{3}+a_6)$		
		$\Lambda^0\pi^0\pi^0$	$\sqrt{6}(-2a_1-\frac{2a_2}{3}-\frac{a_3}{3}+\frac{a_5}{3})$		
		$\Lambda^0\pi^0\eta^0$	$\sqrt{2}(\frac{2a_2}{3}+\frac{a_3}{3}-a_4-\frac{a_5}{3}-a_6)$		
		$\Lambda^0\pi^+\pi^-$	$\sqrt{6}(-2a_1-\frac{2a_2}{3}-\frac{a_3}{3}+\frac{a_5}{3})$		
		$\Lambda^0K^0\bar{K}^0$	$\sqrt{6}(-2a_1-a_2-a_3-a_4+a_5)$		
		$\Lambda^0K^+K^-$	$\sqrt{6}(-2a_1-\frac{a_2}{3}-\frac{2a_3}{3}+\frac{2a_5}{3})$		
		$\Lambda^0\eta^0\eta^0$	$\sqrt{6}(-2a_1-\frac{2a_2}{3}-a_3+\frac{2a_4}{3}$		
			$+a_5+2a_6)$		

TABLE IV. The data inputs from Refs. [3, 28–31] and reproductions for $\mathcal{B}(\Lambda_c^+ \to \mathbf{B_n} MM)$.

	data	our results
$10^2\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+)$	3.4 ± 0.4	3.4 ± 0.5
$10^3\mathcal{B}(\Lambda_c^+ \to \Lambda^0 K^+ \bar{K}^0)$	5.6 ± 1.1	5.8 ± 1.0
$10^2\mathcal{B}(\Lambda_c^+ \to \Lambda^0 \pi^+ \eta)$	1.8 ± 0.3	1.7 ± 0.3
$10^2\mathcal{B}(\Lambda_c^+ \to \Sigma^+ \pi^+ \pi^-)$	4.4 ± 0.3	4.5 ± 0.3
$10^2\mathcal{B}(\Lambda_c^+ \to \Sigma^- \pi^+ \pi^+)$	1.9 ± 0.2	1.9 ± 0.3
$10^2\mathcal{B}(\Lambda_c^+ \to \Sigma^0 \pi^+ \pi^0)$	2.2 ± 0.8	1.0 ± 0.1
$10^3\mathcal{B}(\Lambda_c^+ \to \Sigma^+ K^+ \pi^-)$	2.1 ± 0.6	2.5 ± 0.3
$10^3\mathcal{B}(\Lambda_c^+ \to \Xi^- K^+ \pi^+)$	6.2 ± 0.6	6.1 ± 0.8
$10^3\mathcal{B}(\Lambda_c^+ \to p\pi^-\pi^+)$	4.2 ± 0.4	4.7 ± 0.4
$10^4\mathcal{B}(\Lambda_c^+ \to pK^-K^+)$	5.2 ± 1.2	5.0 ± 1.2
$10^2\mathcal{B}(\Lambda_c^+ \to p\bar{K}^0\eta)$	1.6 ± 0.4	0.7 ± 0.1
$10^2\mathcal{B}(\Lambda_c^+ \to \Sigma^+ \pi^0 \pi^0)$	1.3 ± 0.1	1.3 ± 0.2
$10^4\mathcal{B}(\Lambda_c^+ \to pK^+\pi^-)$	1.0 ± 0.1	1.0 ± 0.1
$10^2\mathcal{B}(\Xi_c^+ \to \Xi^- \pi^+ \pi^+)$	4.7 ± 1.7	5.4 ± 1.3
$10^2\mathcal{B}(\Xi_c^0 \to \Lambda^0 K^- \pi^+)$	1.9 ± 0.6	2.2 ± 0.6
$10^4\mathcal{B}(\Xi_c^0 \to \Lambda^0 K^- K^+)$	5.2 ± 1.9	6.2 ± 1.2

16 data points above to fit with 12 real parameters:

$$\chi^2/d.o.f = 9.6/4 = 2.4$$

a_i	result	b_i	result
a_1	9.2 ± 0.7	b_1	18.3 ± 0.9
a_2	-3.7 ± 0.5	b_2	-9.8 ± 2.4
a_3	-7.3 ± 0.4	b_3	4.4 ± 2.1
a_4	2.3 ± 0.4	b_4	-5.4 ± 2.9
a_5	11.5 ± 1.3	b_5	38.8 ± 2.2
a_6	-3.7 ± 0.2	b_6	12.7 ± 2.3

TABLE VI. Numerical results for $\mathcal{B}(\Lambda_c^+ \to \mathbf{B_n} M M')$.

CF mode	$10^3\mathcal{B}$	CS mode	$10^4\mathcal{B}$	DCS mode	$10^6\mathcal{B}$
$\Sigma^+\pi^0\eta^0$	6.6 ± 3.4	$\Sigma^+\pi^0K^0$	9.9 ± 2.8	$\Sigma^+K^0K^0$	1.3 ± 0.5
$\Sigma^+K^0\bar{K}^0$	2.9 ± 0.7	$\Sigma^+K^0\eta^0$	0.26 ± 0.06	$\Sigma^0K^0K^+$	1.3 ± 0.5
$\Sigma^+K^+K^-$	2.5 ± 0.3	$\Sigma^0\pi^0K^+$	7.8 ± 2.3	$\Sigma^-K^+K^+$	1.3 ± 0.5
$\Sigma^+\eta^0\eta^0$	$(3.2 \pm 0.4) \times 10^{-4}$	$\Sigma^0\pi^+K^0$	9.6 ± 2.7	$p\pi^0K^0$	50 ± 6
$\Sigma^0\pi^+\eta^0$	6.3 ± 3.2	$\Sigma^0K^+\eta^0$	0.13 ± 0.03	$pK^0\eta^0$	3.3 ± 2.7
$\Sigma^0K^+\bar{K}^0$	0.26 ± 0.09	$p\pi^0\pi^0$	24 ± 2	$n\pi^0K^+$	51 ± 6
$\Xi^0\pi^0K^+$	32 ± 6	$p\pi^0\eta^0$	34 ± 7	$n\pi^+K^0$	99 ± 11
$\Xi^0\pi^+K^0$	44 ± 8	$pK^0\bar{K}^0$	37 ± 8	$nK^+\eta^0$	3.4 ± 2.7
$p\pi^0\bar{K}^0$	23 ± 4	$p\eta^0\eta^0$	2.8 ± 1.2		
$n\pi^+\bar{K}^0$	11 ± 1	$n\pi^+\eta^0$	67 ± 13		
		$nK^+\bar{K}^0$	31 ± 9		
		$\Lambda^0\pi^0K^+$	35 ± 6		
		$\Lambda^0\pi^+K^0$	67 ± 11		
		$\Lambda^0K^+\eta^0$	0.45 ± 0.10		

TABLE IX. Numerical results for $\langle\alpha\rangle(\Lambda_c^+ \to \mathbf{B_n} M M')$.

CF mode	$\langle\alpha\rangle$	CS mode	$\langle\alpha\rangle$	DCS mode	$\langle\alpha\rangle$
$\Lambda_c^+ \to \Sigma^+\pi^0\pi^0$	0.85 ± 0.13	$\Lambda_c^+ \to \Sigma^+\pi^0K^0$	0.76 ± 0.22	$\Lambda_c^+ \to \Sigma^+K^0K^0$	-0.43 ± 0.32
$\Lambda_c^+ \to \Sigma^+\pi^0\eta^0$	0.81 ± 0.18	$\Lambda_c^+ \to \Sigma^+\pi^-K^+$	0.75 ± 0.15	$\Lambda_c^+ \to \Sigma^0K^0K^+$	-0.43 ± 0.32
$\Lambda_c^+ \to \Sigma^+\pi^+\pi^-$	0.16 ± 0.27	$\Lambda_c^+ \to \Sigma^+K^0\eta^0$	-0.05 ± 0.07	$\Lambda_c^+ \to \Sigma^-K^+K^+$	-0.43 ± 0.31
$\Lambda_c^+ \to \Sigma^+K^0\bar{K}^0$	0.68 ± 0.07	$\Lambda_c^+ \to \Sigma^0\pi^0K^+$	0.75 ± 0.10	$\Lambda_c^+ \to p\pi^0K^0$	$0.93^{+0.07}_{-0.10}$
$\Lambda_c^+ \to \Sigma^+K^+K^-$	-0.06 ± 0.11	$\Lambda_c^+ \to \Sigma^0\pi^+K^0$	0.75 ± 0.22	$\Lambda_c^+ \to p\pi^-K^+$	$0.93^{+0.07}_{-0.10}$
$\Lambda_c^+ \to \Sigma^+\eta^0\eta^0$	0.03 ± 0.00	$\Lambda_c^+ \to \Sigma^0K^+\eta^0$	-0.05 ± 0.07	$\Lambda_c^+ \to pK^0\eta^0$	-0.38 ± 0.45
$\Lambda_c^+ \to \Sigma^0\pi^0\pi^+$	$-0.96^{+0.07}_{-0.04}$	$\Lambda_c^+ \to \Sigma^-\pi^+K^+$	0.70 ± 0.70	$\Lambda_c^+ \to n\pi^0K^+$	$0.93^{+0.07}_{-0.10}$
$\Lambda_c^+ \to \Sigma^0\pi^+\eta^0$	0.81 ± 0.18	$\Lambda_c^+ \to p\pi^0\pi^0$	-0.95 ± 0.05	$\Lambda_c^+ \to n\pi^+K^0$	$0.93^{+0.07}_{-0.10}$
$\Lambda_c^+ \to \Sigma^0K^+\bar{K}^0$	0.30 ± 0.60	$\Lambda_c^+ \to p\pi^0\eta^0$	0.84 ± 0.09	$\Lambda_c^+ \to nK^+\eta^0$	-0.38 ± 0.45
$\Lambda_c^+ \to \Sigma^-\pi^+\pi^+$	$-0.96^{+0.07}_{-0.04}$	$\Lambda_c^+ \to p\pi^+\pi^-$	-0.95 ± 0.05		
$\Lambda_c^+ \to \Xi^0\pi^0K^+$	0.78 ± 0.03	$\Lambda_c^+ \to pK^0\bar{K}^0$	0.84 ± 0.05		
$\Lambda_c^+ \to \Xi^0\pi^+K^0$	0.96 ± 0.00	$\Lambda_c^+ \to pK^+K^-$	-0.91 ± 0.09		
$\Lambda_c^+ \to \Xi^-\pi^+K^+$	-0.78 ± 0.13	$\Lambda_c^+ \to p\eta^0\eta^0$	0.62 ± 0.21		
$\Lambda_c^+ \to p\pi^0\bar{K}^0$	0.11 ± 0.28	$\Lambda_c^+ \to n\pi^+\eta^0$	0.85 ± 0.09		
$\Lambda_c^+ \to p\pi^+K^-$	0.89 ± 0.10	$\Lambda_c^+ \to nK^+\bar{K}^0$	0.94 ± 0.03		
$\Lambda_c^+ \to p\bar{K}^0\eta^0$	-0.38 ± 0.22	$\Lambda_c^+ \to \Lambda^0\pi^0K^+$	0.97 ± 0.00		
$\Lambda_c^+ \to n\pi^+\bar{K}^0$	$-0.91^{+0.13}_{-0.09}$	$\Lambda_c^+ \to \Lambda^0\pi^+K^0$	0.97 ± 0.00		
$\Lambda_c^+ \to \Lambda^0\pi^+\eta^0$	0.54 ± 0.15	$\Lambda_c^+ \to \Lambda^0K^+\eta^0$	-0.28 ± 0.28		
$\Lambda_c^+ \to \Lambda^0K^+\bar{K}^0$	0.41 ± 0.08				

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☞ ♦ $SU(3)_F$ is a real flavor symmetry, which is very useful and powerful to study Charmed Baryons. The results can be tested by BESIII, LHCb, BELLE(II) ……

Thank you!

謝謝！

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