Charm Baryon Decays with SU(3)$_F$ symmetry
利用SU(3)$_F$對稱性研究粲重子衰變

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第二屆理論實驗聯合研討會:重子譜和衰變

(2018年12月15-16日)

蘭州大學
LANZHOU UNIVERSITY

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Introduction

Charm

China element

中国元素

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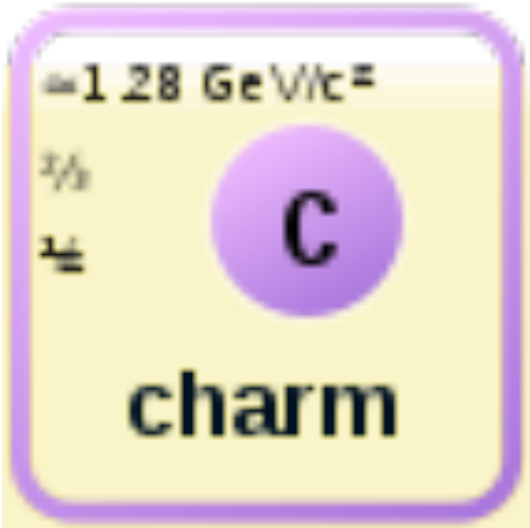
中国元素



charm

KK[tʃɑrm] DJ[tʃɑ:m] 美式

n. 魅力[C][U]；嫵媚[P]

粒子物理标准模型

中国大陆

粒子物理標準模型

港澳台

- **Introduction**

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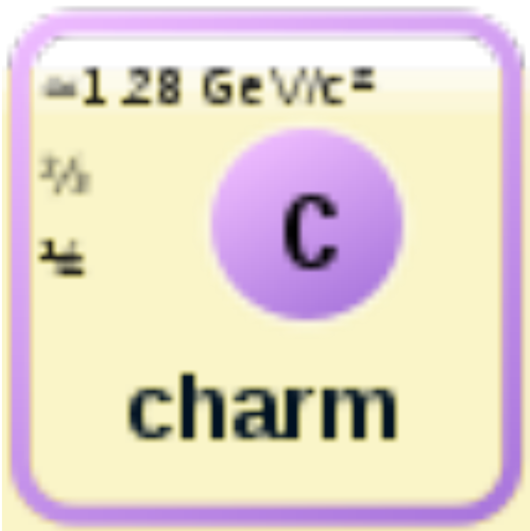

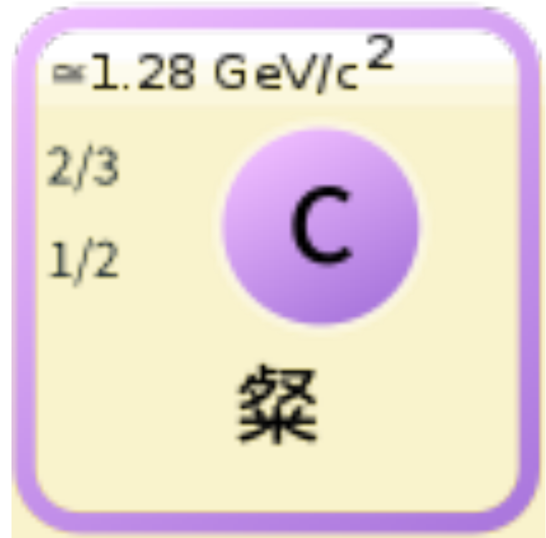

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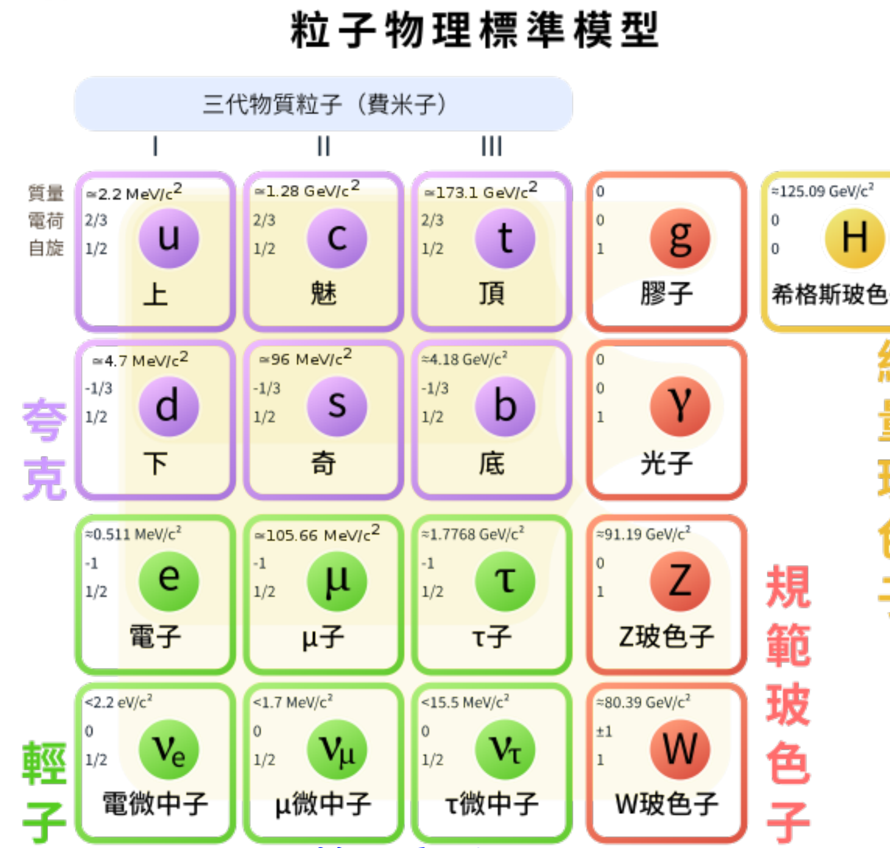

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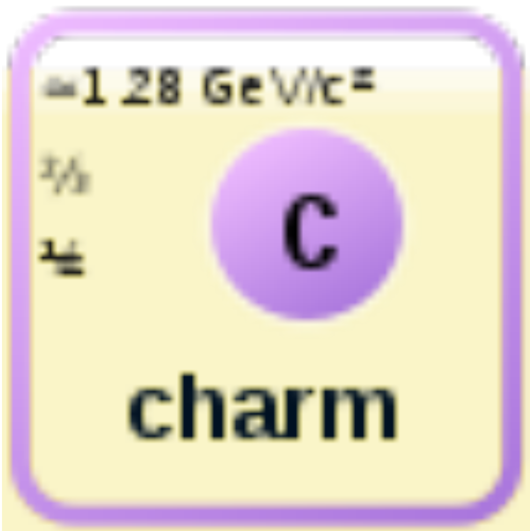
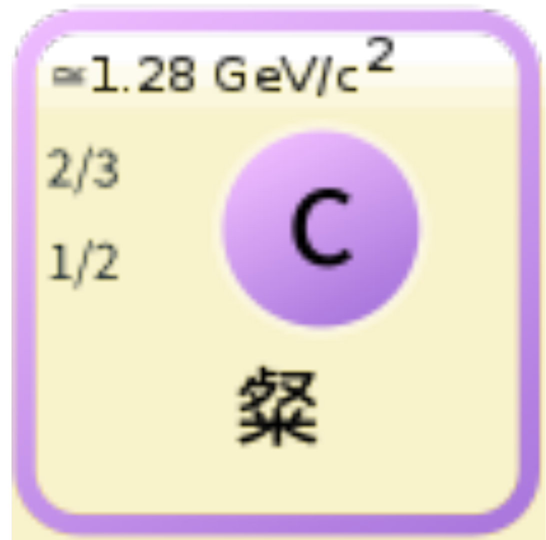
鮮明華美的樣子。詩經．唐風．葛生：「角枕粲兮，錦衾爛兮。」文選．曹植．贈徐幹詩：「圓景光未滿，眾星粲以繁。」

明白、清楚。漢書．卷八．宣帝紀：「骨肉之親粲而不殊。」顏師古．注：「粲，明也。殊，絕也。」

- **Introduction** Charm *China element* 中国元素





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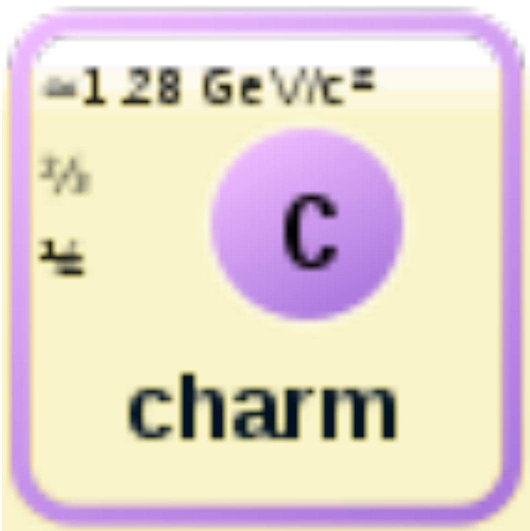
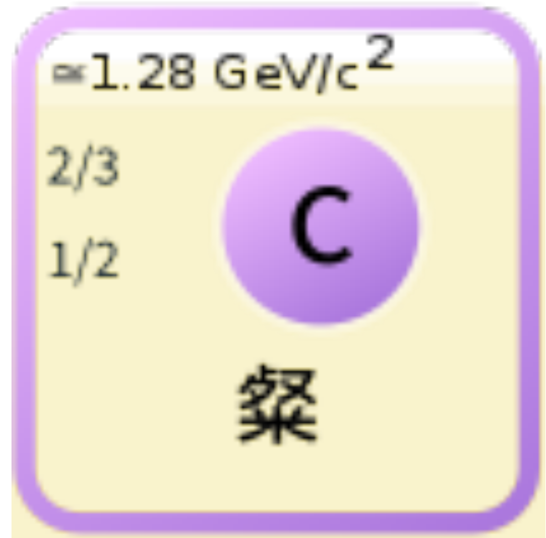
迷惑。說郛・卷六十・玄中記：「能知千里外事，善蠱魅，使人迷惑。」

- **Introduction** Charm *China element* 中国元素





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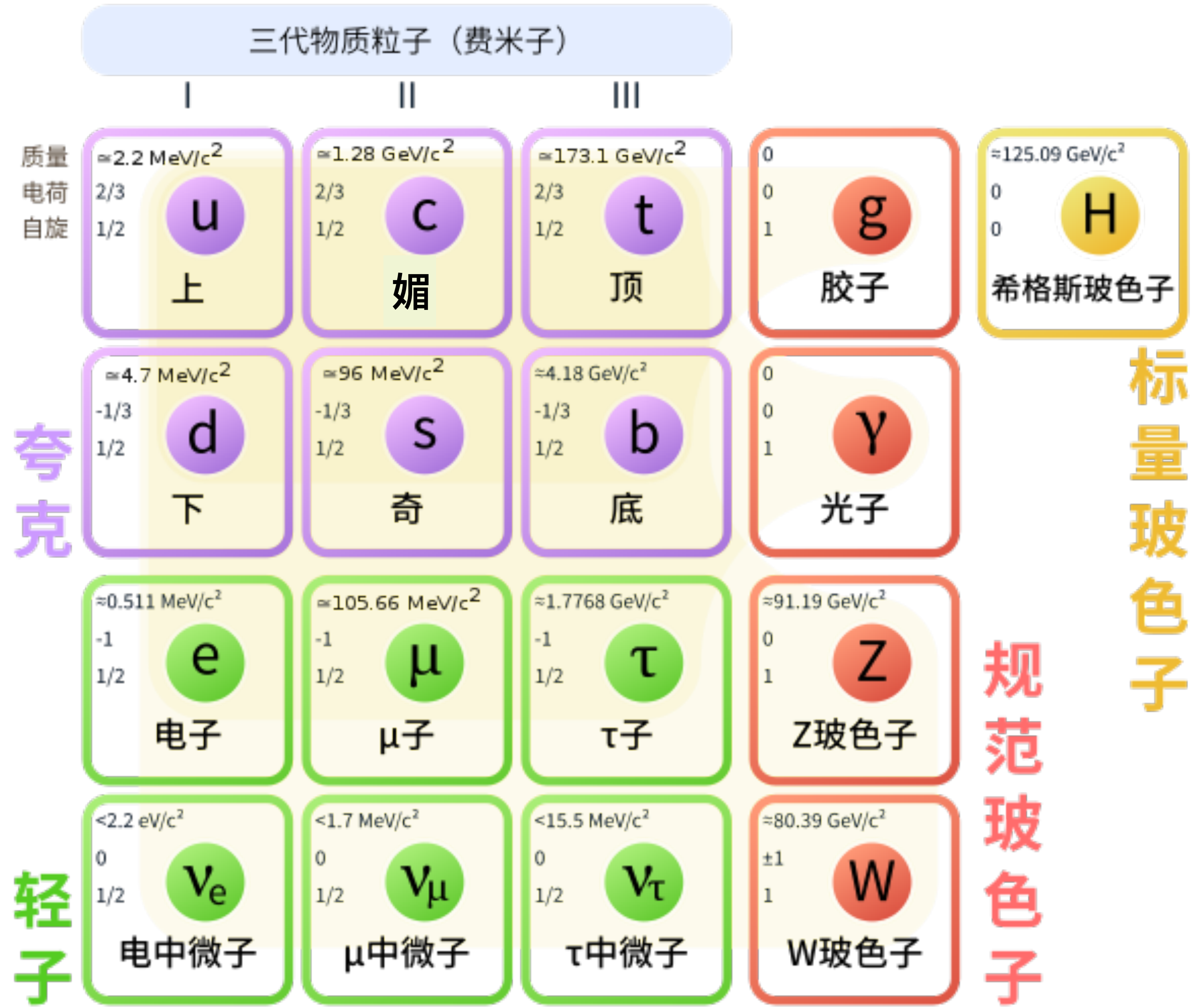
【媚】嬌豔、美好、可愛。如：「嬌媚」、「嫵媚」、「風光明媚」。文選．陸機．文賦：「石韞玉而山輝，水懷珠而川媚。」

• Introduction

粒子物理标准模型



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Charm Quark 媚夸克

History for Charm in Theory

In 1956, Sakata model: $\begin{pmatrix} & p & \\ n & & \Lambda \end{pmatrix} \begin{pmatrix} & \nu & \\ e & & \mu \end{pmatrix}$ S. Sakata, Prog. Theor. Phys. **16** (1956), 686.

In 1959 and 1962, Marshak: **Kiev symmetry** Lepton-Baryon symmetry

R. Marshak, rapporteur talk at 9th International Conference on High Energy Physics, Kiev, Ukraine, 1959.

R. Marshak, rapporteur talk at 11th International Conference on High Energy Physics, CERN, July 1962.

In 1962, Sakata et al (Nagoya); Katayama et al (Tokyo): $\begin{pmatrix} p & V^+ \\ n & \Lambda \end{pmatrix} \begin{pmatrix} \nu_1 & \nu_2 \\ e & \mu \end{pmatrix}$

Z. Maki, M. Nakagava and S. Sakata, Prog. Theor. Phys. **28** (1962), 870.

Y. Katayama, K. Matumoto, S. Tanaka and E. Yamada, Prog. Theor. Phys. **28** (1962),675.

In 1964, Bjorken & Glashow: **Proposed a 4th quark and invented the name "Charm"**

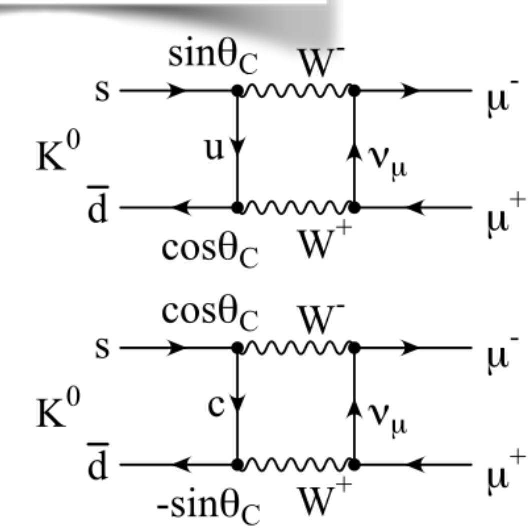
B.J. Bjorken and S. Glashow, Phys. Lett. 11 (1964) 255.

In 1970, Glashow, Iliopoulos and Maiani (GIM): **GIM mechanism**

S. Glashow, Iliopoulos and Maiani, Phys. Rev. D2 (1970) 1285.

$$K^0 \to \mu^+ + \mu^-$$

$$\underbrace{\mathcal{M}_1 \propto \sin\theta_C \cos\theta_C \, , \, \mathcal{M}_2 \propto -\sin\theta_C \cos\theta_C}_{0}$$



The 1974 November Revolution of HEP: Discovery of a new QUARK — Charm (c)

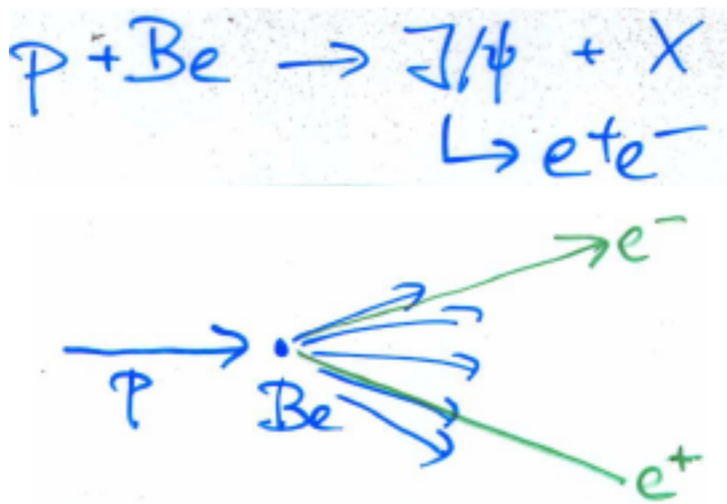
苏联十月革命 (November 1917)

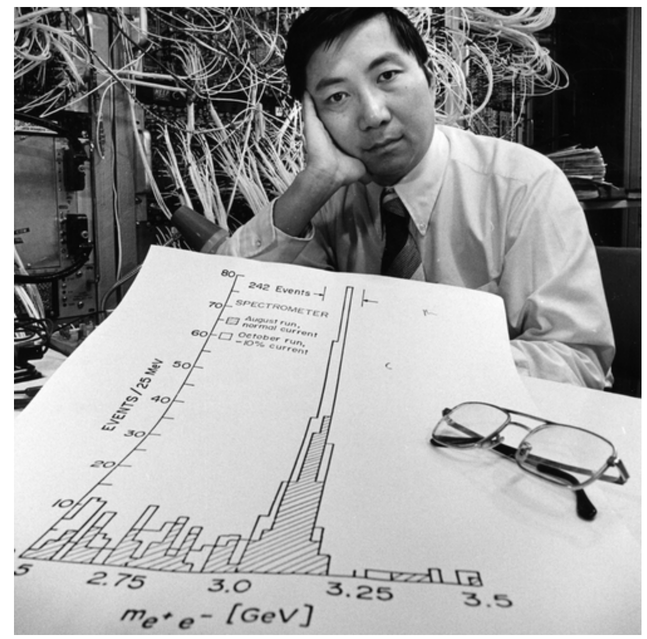
$J/\psi = c\bar{c}$

44年前(1974)
11月10,11日

At the East coast of US: Received by PRL on Nov. 12, 1974

Brookhaven (Proton Synchrotron)





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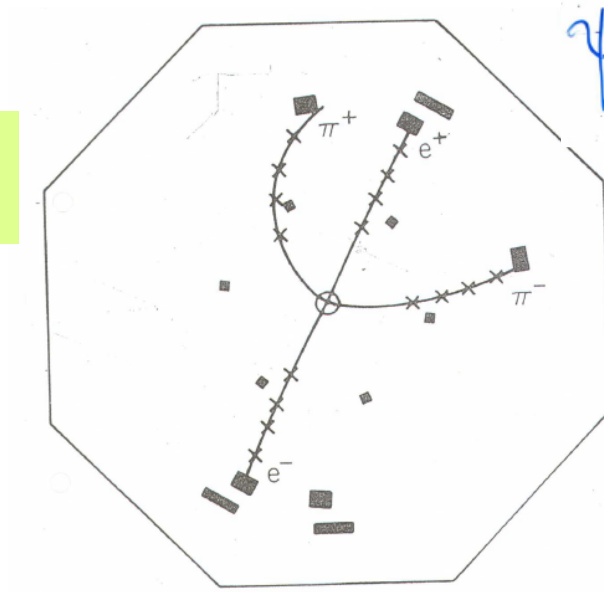
J

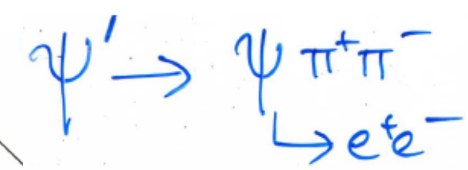
At the West coast of US: Received by PRL on Nov. 13, 1974

B. Richter

SLAC (e^+e^- collider)

Nov. 10, 1974





ψ

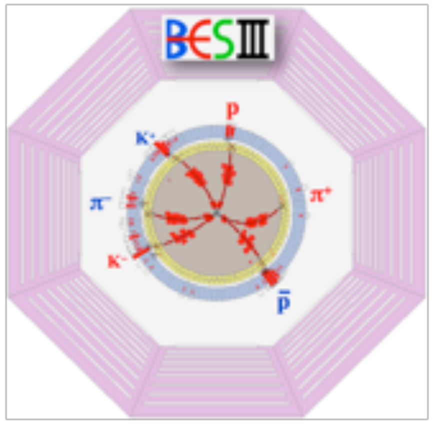
Nov. 11, 1974
Ting and Richter met at SLAC

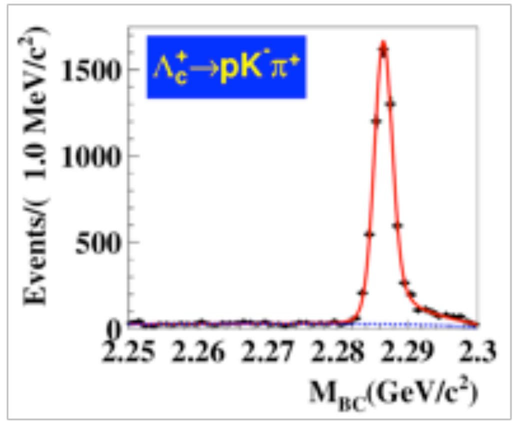
丁與Sau-Lan Wu通話定稿

Nobel Physics Prize 1976

Recent experimental developments in charmed baryons:

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



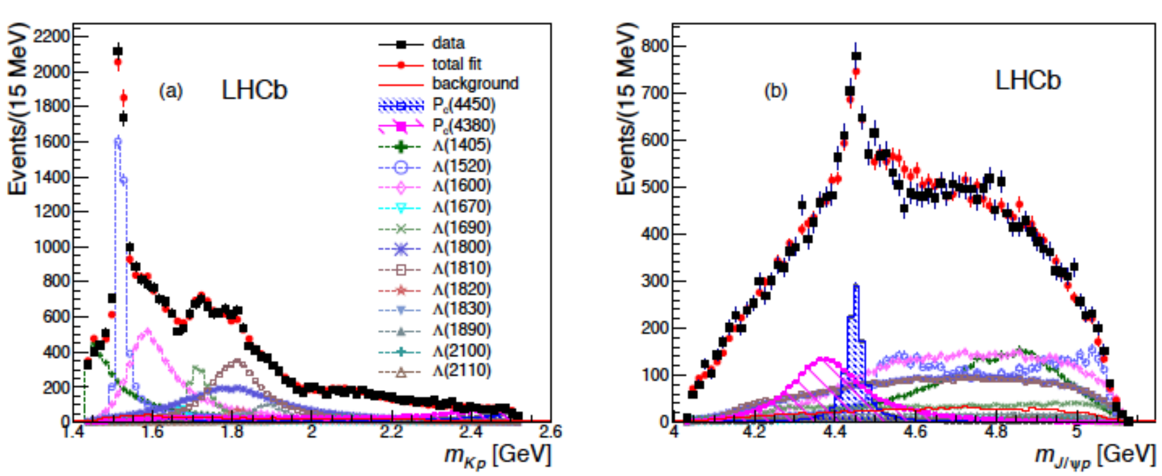


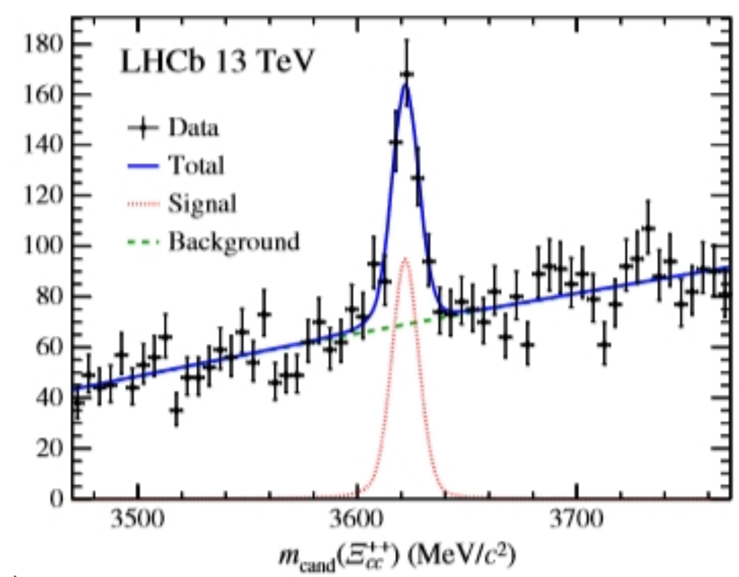
A uniquely clean background to study Charm Baryons

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

Many newly measured charmed baryon decays.

- **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）**





Extensive recent theoretical studies on weak decays of charmed baryons (cross-strait 海峡两岸):

- H.Y. Cheng *et al* in 1990s and recently:

H.Y. Cheng, X.W. Kang and F.R. Xu, ``Singly Cabibbo-suppressed hadronic decays of Λ_c^+," Phys. Rev. D97, 074028 (2018)

- C.D. Lü, W. Wang, F.S. Yu ……. :

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

F.S. Yu, H.Y. Jiang, R.H. Li, C.D. Lü, W. Wang, Z.T. Zhou, ``Discovery Potentials of Doubly Charmed Baryons," Chin. Phys. C42, 051001 (2018)

W. Wang, Z.P. Xing and J. Xu,``Weak Decays of Doubly Heavy Baryons: SU(3) Analysis," Eur. Phys. J. C77, 800 (2017)

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)

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

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Studies of charmed baryons with $SU(3)_F$ flavor symmetry

- *C.Q. Geng, Y.K. Hsiao, Y.H. Lin and L.L. Liu ``Non-leptonic two-body weak decays of $\Lambda_c(2286)$,'' Phys. Lett. B776, 265 (2017).*
- *C.Q. Geng, Y.K. Hsiao, C.W. Liu and T.H. Tsai, "Charmed Baryon Weak Decays with SU(3) Flavor Symmetry," JHEP 1711, 147 (2017).*
- *C.Q. Geng, Y.K. Hsiao, C.W. Liu and T.H. Tsai, "Anti-triplet charmed baryon decays with SU(3) Flavor Symmetry," Phys. Rev. D97, 073006 (2018).*
- *C.Q. Geng, Y.K. Hsiao, C.W. Liu and T.H. Tsai, "SU(3) symmetry breaking in charmed baryon decays," Eur. Phys. J. C78, 593 (2018).*
- *C.Q. Geng, Y.K. Hsiao, C.W. Liu and T.H. Tsai, "Three-body charmed baryon Decays with SU(3) flavor symmetry," arXiv:1810.01079 [hep-ph].*

QCD

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

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

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

$SU(n)_F$ Flavor Symmetry

Three light quarks: q=u,d,s

$SU(3)_F$ Flavor Symmetry

$SU(3)_C: \ 3\otimes3\otimes3=10_S\oplus8_{MS}\oplus8_{MA}\oplus1_A$

$SU(3)_F: \ 3\otimes3\otimes3=10_S\oplus8_{MS}\oplus8_{MA}\oplus1_A$

$SU(2)_{spin}: \ 2\otimes2\otimes2=4_S\oplus2_{MS}\oplus2_{MA}$

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

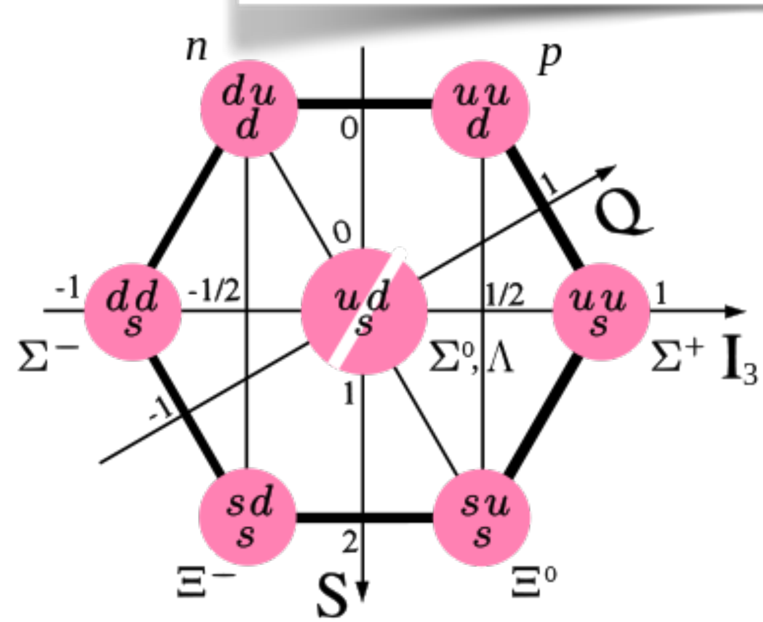
Pauli Exclusion Principle

Totally antisymmetric states

Space: L=0 Symmetric

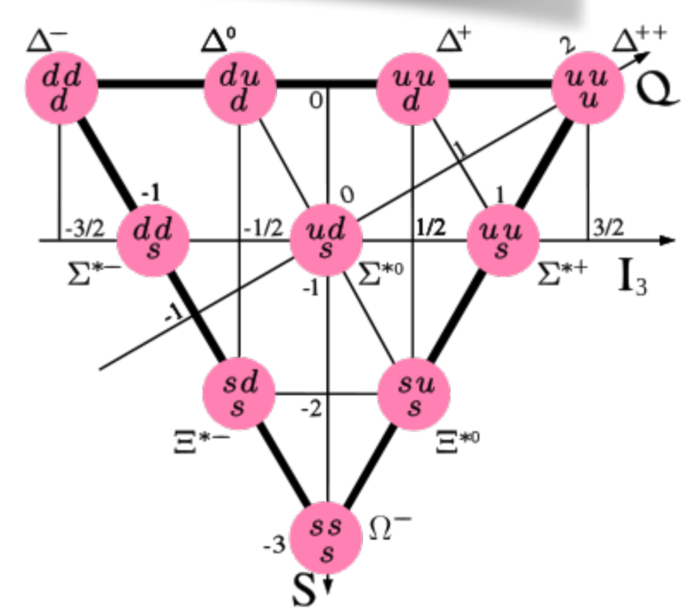
$(SU(3)_C, SU(3)_F, SU(2)_{spin})$

Antisymmetric — Symmetric



$(1, 8, 2)=B_n$

spin=1/2



$(1, 10, 4)$

spin=3/2

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

$SU(4)_F: \ 4\otimes4\otimes4=20_S\oplus20_{MS}\oplus20_{MA}\oplus\bar{4}_A$

$SU(3)_C: \ 3\otimes3\otimes3=10_S\oplus8_{MS}\oplus8_{MA}\oplus1_A$

$SU(2)_{spin}: \ 2\otimes2\otimes2=4_S\oplus2_{MS}\oplus2_{MA}$

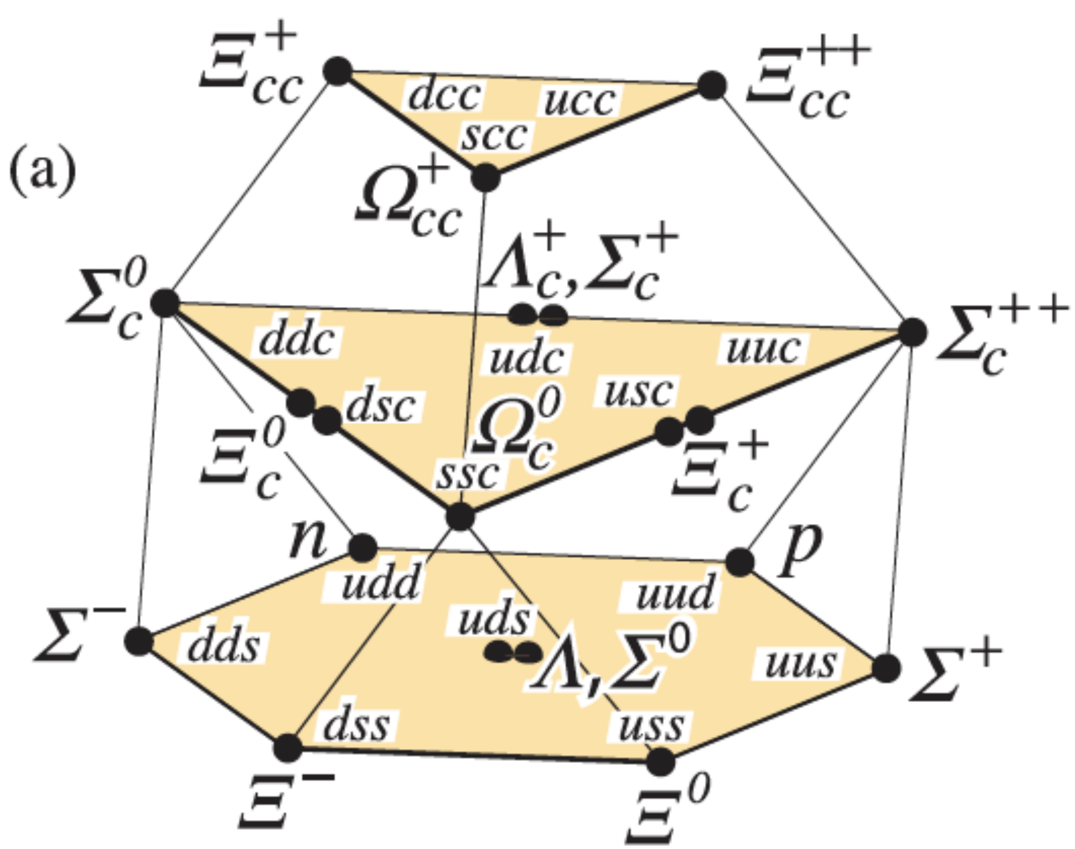
Space: L=0 Symmetric

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

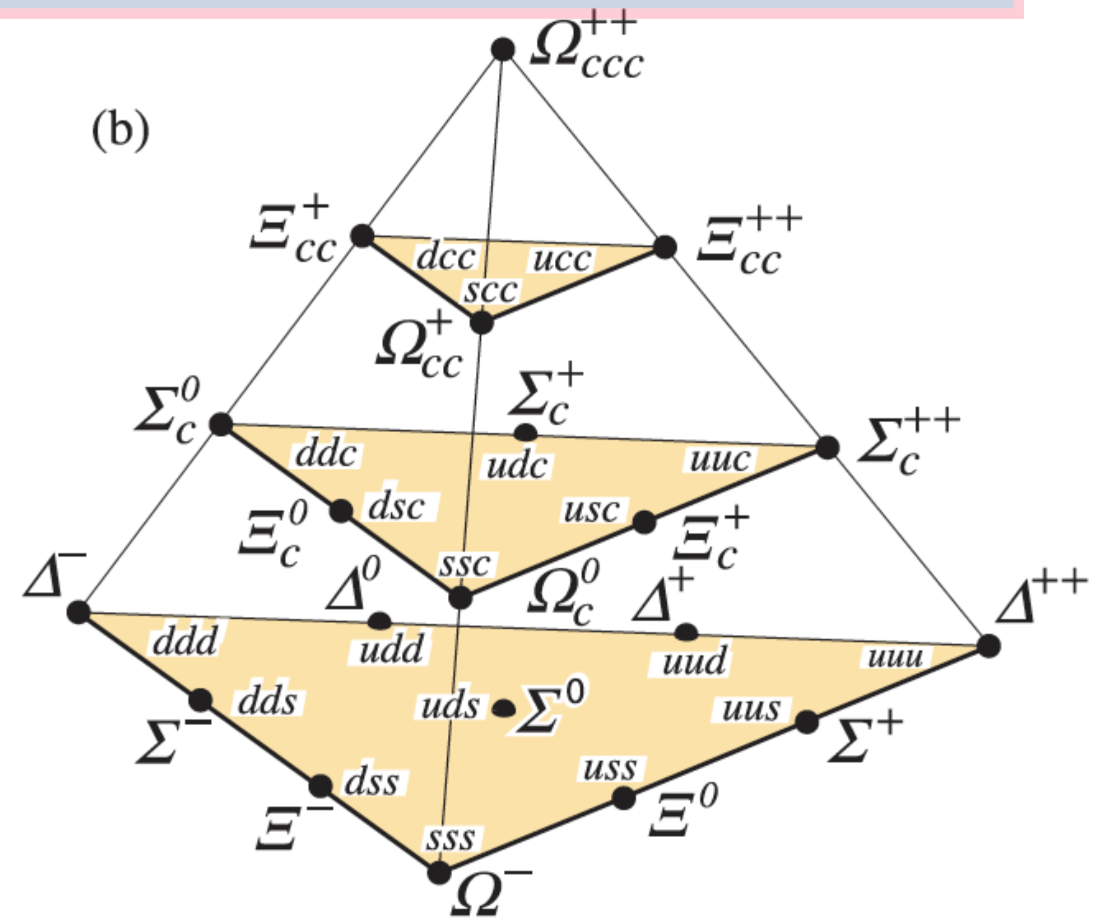
Antisymmetric Symmetric

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.



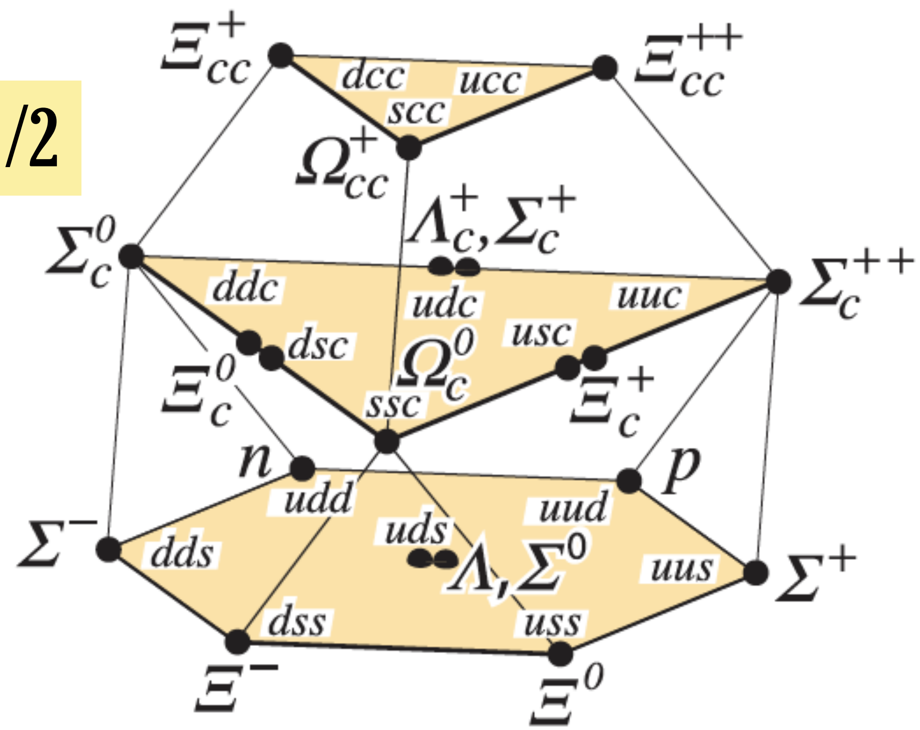
$(1, 20, 2)$
spin=1/2



$(1, 20, 4)$
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

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

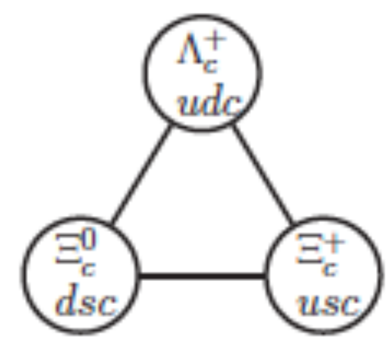
Charmed Baryons ($J^P=1/2^+$) with SU(3)$_F$

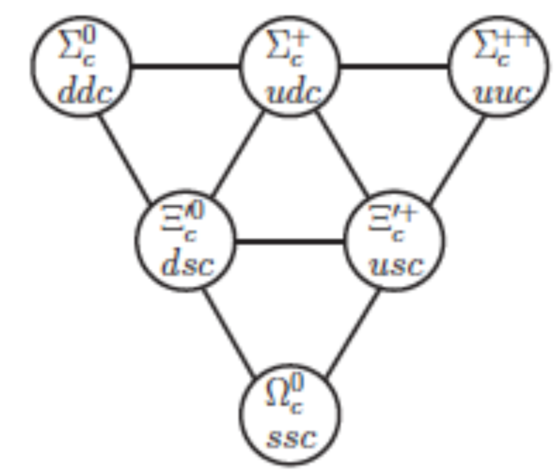
SU(3)$_F$: $3\otimes3=\bar{3}\oplus6$

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

sextet (6)

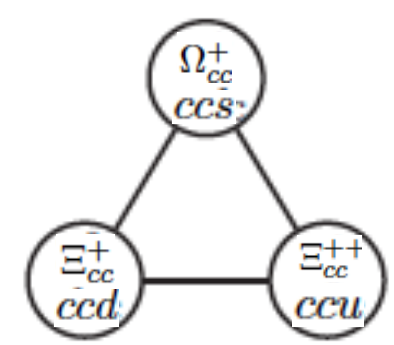
$$B_c = (\Xi_c^0, -\Xi_c^+, \Lambda_c^+) \quad B'_c = \begin{pmatrix} \Sigma_c^{++} & \frac{1}{\sqrt{2}}\Sigma_c^+ & \frac{1}{\sqrt{2}}\Xi_c'^+ \\ \frac{1}{\sqrt{2}}\Sigma_c^+ & \Sigma_c^0 & \frac{1}{\sqrt{2}}\Xi_c'^0 \\ \frac{1}{\sqrt{2}}\Xi_c'^+ & \frac{1}{\sqrt{2}}\Xi_c'^0 & \Omega_c^0 \end{pmatrix}$$





SU(3)$_F$: 3

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



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

The effective Hamiltonian for the semileptonic $c \to q\, l^+ \nu_l$ transition with q=(d or s):

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

$$(\bar{q}_1 q_2)_{V-A} = \bar{q}_1 \gamma_\mu (1-\gamma_5) q_2$$
$$(\bar{u}_\nu v_\ell)_{V-A} = \bar{u}_\nu \gamma^\mu (1-\gamma_5) v_\ell$$

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

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

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

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

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

$$O_\pm = \frac{1}{2}[(\bar{u}d)_{V-A}(\bar{s}c)_{V-A} \pm (\bar{s}d)_{V-A}(\bar{u}c)_{V-A}]$$

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

$$O'_\pm = \frac{1}{2}[(\bar{u}s)_{V-A}(\bar{d}c)_{V-A} \pm (\bar{d}s)_{V-A}(\bar{u}c)_{V-A}]$$

$$\hat{O}_\pm \equiv O^d_\pm - O^s_\pm$$

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 $\bar{3}\times 3\times\bar{3} = \bar{3} + \bar{3}' + 6 + \overline{15}$

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

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

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

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

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

$$H_2^{12}(\overline{15}) = H_2^{21}(\overline{15}) = -H_3^{13}(\overline{15}) = -H_3^{31}(\overline{15}) = s_c\,,$$

$$H_3^{12}(\overline{15}) = H_3^{21}(\overline{15}) = -s_c^2\,,$$

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

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

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

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

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

Semileptonic decays of charmed baryons

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

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

Under SU(3)$_F$ flavor symmetry:

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

$\mathbf{B}_c \to \mathbf{B}_n$	T-amp	
$\Xi_c^0 \to \Xi^-$	α_1	
$\Xi_c^+ \to \Xi^0$	α_1	
$\Lambda_c^+ \to \Lambda^0$	$-\sqrt{\frac{2}{3}}\alpha_1$	$\mathcal{B}(\Lambda_c^+ \to \Lambda^0 e^+ \nu_e) = (3.6 \pm 0.4) \times 10^{-2}$
$\Xi_c^0 \to \Sigma^-$	$-\alpha_1 s_c$	
$\Xi_c^+ \to \Sigma^0$	$\sqrt{\frac{1}{2}}\alpha_1 s_c$	
$\Xi_c^+ \to \Lambda^0$	$-\sqrt{\frac{1}{6}}\alpha_1 s_c$	
$\Lambda_c^+ \to n$	$-\alpha_1 s_c$	$\mathcal{B}(\Lambda_c^+ \to n e^+ \nu_e) = (3.76 \pm 0.42) \times 10^{-3}$

Experimental Data

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

• Semileptonic decays of charmed baryons

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

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

Under SU(3)$_F$ flavor symmetry:

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

$\mathbf{B}_c \to \mathbf{B}_n$	T-amp	
$\Xi_c^0 \to \Xi^-$	α_1	$\mathcal{B}(\Xi_c^0 \to \Xi^- e^+ \nu_e) = (2.54 \pm 0.28) \times 10^{-2}$
$\Xi_c^+ \to \Xi^0$	α_1	$\mathcal{B}(\Xi_c^+ \to \Xi^0 e^+ \nu_e) = (10.1 \pm 1.1) \times 10^{-2}$
$\Lambda_c^+ \to \Lambda^0$	$-\sqrt{\frac{2}{3}}\alpha_1$	$\mathcal{B}(\Lambda_c^+ \to \Lambda^0 e^+ \nu_e) = (3.6 \pm 0.4) \times 10^{-2}$
$\Xi_c^0 \to \Sigma^-$	$-\alpha_1 s_c$	$\mathcal{B}(\Xi_c^0 \to \Sigma^- e^+ \nu_e) = (1.63 \pm 0.18) \times 10^{-3}$
$\Xi_c^+ \to \Sigma^0$	$\sqrt{\frac{1}{2}}\alpha_1 s_c$	$\mathcal{B}(\Xi_c^+ \to \Sigma^0 e^+ \nu_e) = (3.23 \pm 0.36) \times 10^{-3}$
$\Xi_c^+ \to \Lambda^0$	$-\sqrt{\frac{1}{6}}\alpha_1 s_c$	$\mathcal{B}(\Xi_c^+ \to \Lambda^0 e^+ \nu_e) = (1.25 \pm 0.14) \times 10^{-3}$
$\Lambda_c^+ \to n$	$-\alpha_1 s_c$	$\mathcal{B}(\Lambda_c^+ \to n e^+ \nu_e) = (3.76 \pm 0.42) \times 10^{-3}$

Experimental Data

TABLE I. Charmed baryon semileptonic decay branching ratio from original paper

Decay mode	SU(3) new results	LF [3]	MBM [4]	NRQM [4]	HQET+ NRQM[5]	LQCD [6, 7]	RQM [8]	CQM [9, 10]	CLEO [1, 2, 11]	Data [1]
$10^2\mathcal{B}(\Lambda_c^+ \to \Lambda^0 e^+ \nu_e)$	3.60 ± 0.40	1.63	2.96	3.60	1.42	3.8	3.24	2.78	-	3.60 ± 0.40
$10^2\mathcal{B}(\Xi_c^+ \to \Xi^0 e^+ \nu_e)$	10.1 ± 1.1	5.39	1.33	1.01	–	–	–	–	3.4 ± 2.2	–
$10^2\mathcal{B}(\Xi_c^0 \to \Xi^- e^+ \nu_e)$	2.54 ± 0.28	1.35	0.40	0.30	0.83	–	–	–	4.87 ± 1.74	–
$10^3\mathcal{B}(\Lambda_c^+ \to n e^+ \nu_e)$	3.76 ± 0.42	2.01	2.20	3.40	–	4.10	2.68	2.07	-	—
$10^4\mathcal{B}(\Xi_c^+ \to \Sigma^0 e^+ \nu_e)$	32.33.6	18.7	4.42	4.42	–	–	–	–	–	–
$10^4\mathcal{B}(\Xi_c^+ \to \Lambda^0 e^+ \nu_e)$	12.5 ± 1.4	8.22	8.84	8.84	–	–	–	–	–Z	–
$10^4\mathcal{B}(\Xi_c^0 \to \Sigma^- e^+ \nu_e)$	16.3 ± 1.8	9.47	2.24	1.12	–	–	–	–	–	–

TABLE II. Charmed baryon semileptonic decay branching ratio reproduction

Decay mode	SU(3) new results	SU(3)* equal phase space	LF [3]	MBM [4]	NRQM [4]	HQET+ NRQM[5]	LQCD [6, 7]	CLEO [1, 2]	Data [1]
$10^2\mathcal{B}(\Lambda_c^+ \to \Lambda^0 e^+\nu_e)$	3.60 ± 0.40	3.60 ± 0.40	1.52	2.75	3.40	1.43	3.8	–	3.60 ± 0.40
$10^2\mathcal{B}(\Xi_c^+ \to \Xi^0 e^+\nu_e)$	10.1 ± 1.1	9.48 ± 1.05	5.09	1.34	1.04	–	–	2.2 ± 1.2	–
$10^2\mathcal{B}(\Xi_c^0 \to \Xi^- e^+\nu_e)$	2.54 ± 0.28	2.39 ± 0.27	1.27	0.27	1.90	0.86	–	6.26 ± 2.24	–
$10^3\mathcal{B}(\Lambda_c^+ \to n e^+\nu_e)$	3.76 ± 0.42	2.64 ± 0.29	1.68	1.91	3.11	–	4.10	–	–
$10^3\mathcal{B}(\Xi_c^+ \to \Sigma^0 e^+\nu_e)$	3.23 ± 0.36	2.32 ± 0.26	1.63	0.33	0.28	–	–	–	–
$10^4\mathcal{B}(\Xi_c^+ \to \Lambda^0 e^+\nu_e)$	12.5 ± 1.4	7.7 ± 0.9	6.97	10.8	8.39	–	–	–	–
$10^4\mathcal{B}(\Xi_c^0 \to \Sigma^- e^+\nu_e)$	16.3 ± 1.8	11.7 ± 1.3	8.19	1.21	0.97	–	–	–	–

[1] M. Tanabashi *et al.* [Particle Data Group], Phys. Rev. D**98**, 030001 (2018).

[2] J. P. Alexander *et al.* [CLEO Collaboration], Phys. Rev. Lett. **74**, 3113 (1995).

[3] Z. X. Zhao, Chin. Phys. C**42**, 093101 (2018).

[4] R. Perez-Marcial et al., Phys. Rev. D**40**, 2955 (1989).

[5] H. Y. Cheng and B. Tseng, Phys. Rev. D**53**, 1457 (1996).

[6] S. Meinel, Phys. Rev. D**97**, 034511 (2018).

[7] S. Meinel, Phys. Rev. Lett. **118**, 082001 (2017).

after timing factor 2 → SU(3) results

TABLE II. Charmed baryon semileptonic decay branching ratio reproduction

Decay mode	SU(3) new results	SU(3)* equal phase space	LF [3]	MBM [4]	NRQM [4]	HQET+ NRQM[5]	LQCD [6, 7]	CLEO [1, 2]	Data [1]
$10^2\mathcal{B}(\Lambda_c^+ \to \Lambda^0 e^+ \nu_e)$	3.60 ± 0.40	3.60 ± 0.40	1.52	2.75	3.40	1.43	3.8	–	3.60 ± 0.40
$10^2\mathcal{B}(\Xi_c^+ \to \Xi^0 e^+ \nu_e)$	10.1 ± 1.1	9.48 ± 1.05	5.09	1.34	1.04	–	–	2.2 ± 1.2	–
$10^2\mathcal{B}(\Xi_c^0 \to \Xi^- e^+ \nu_e)$	2.54 ± 0.28	2.39 ± 0.27	1.27	0.27	1.90	0.86	–	6.26 ± 2.24	–
$10^3\mathcal{B}(\Lambda_c^+ \to n e^+ \nu_e)$	3.76 ± 0.42	2.64 ± 0.29	1.68	1.91	3.11	–	4.10	–	–
$10^3\mathcal{B}(\Xi_c^+ \to \Sigma^0 e^+ \nu_e)$	3.23 ± 0.36	2.32 ± 0.26	1.63	0.33	0.28	–	–	–	–
$10^4\mathcal{B}(\Xi_c^+ \to \Lambda^0 e^+ \nu_e)$	12.5 ± 1.4	7.7 ± 0.9	6.97	10.8	8.39	–	–	–	–
$10^4\mathcal{B}(\Xi_c^0 \to \Sigma^- e^+ \nu_e)$	16.3 ± 1.8	11.7 ± 1.3	8.19	1.21	0.97	–	–	–	–

[1] M. Tanabashi *et al.* [Particle Data Group], Phys. Rev. D**98**, 030001 (2018).

[2] J. P. Alexander *et al.* [CLEO Collaboration], Phys. Rev. Lett. **74**, 3113 (1995).

[3] Z. X. Zhao, Chin. Phys. C**42**, 093101 (2018).

[4] R. Perez-Marcial et al., Phys. Rev. D**40**, 2955 (1989).

[5] H. Y. Cheng and B. Tseng, Phys. Rev. D**53**, 1457 (1996).

[6] S. Meinel, Phys. Rev. D**97**, 034511 (2018).

[7] S. Meinel, Phys. Rev. Lett. **118**, 082001 (2017).

Two-body nonleptonic decays of charmed baryons

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

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

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

$$\mathcal{A}(\mathbf{B}_c \to \mathbf{B}_n M) = \langle \mathbf{B}_n M | \mathcal{H}_{eff} | \mathbf{B}_c \rangle = \frac{G_F}{\sqrt{2}} T(\mathbf{B}_c \to \mathbf{B}_n M)$$

Under SU(3)$_F$ flavor symmetry:

$$T(\mathbf{B}_c \to \mathbf{B}_n M) = T(\mathcal{O}_6) + T(\mathcal{O}_{\overline{15}})$$

$$T(\mathcal{O}_6) = a_1 H_{ij}(6) T^{ik} (\mathbf{B}_n)_k^l (M)_l^j + a_2 H_{ij}(6) T^{ik} (M)_k^l (\mathbf{B}_n)_l^j + a_3 H_{ij}(6) (\mathbf{B}_n)_k^i (M)_l^j T^{kl}$$

$$T_{ij} \equiv (\mathbf{B}_c)_k \epsilon^{ijk}$$

$$\begin{aligned} T(\mathcal{O}_{\overline{15}}) = {} & a_4 H_{li}^k(\overline{15}) (\mathbf{B}_c)^j (M)_j^i (\mathbf{B}_n)_k^l + a_5 (\mathbf{B}_n)_j^i (M)_i^l H(\overline{15})_l^{jk} (\mathbf{B}_c)_k \\ & + a_6 (\mathbf{B}_n)_l^k (M)_j^i H(\overline{15})_i^{jl} (\mathbf{B}_c)_k + a_7 (\mathbf{B}_n)_i^l (M)_j^i H(\overline{15})_l^{jk} (\mathbf{B}_c)_k \end{aligned}$$

Two reasons:

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

Assumption →

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

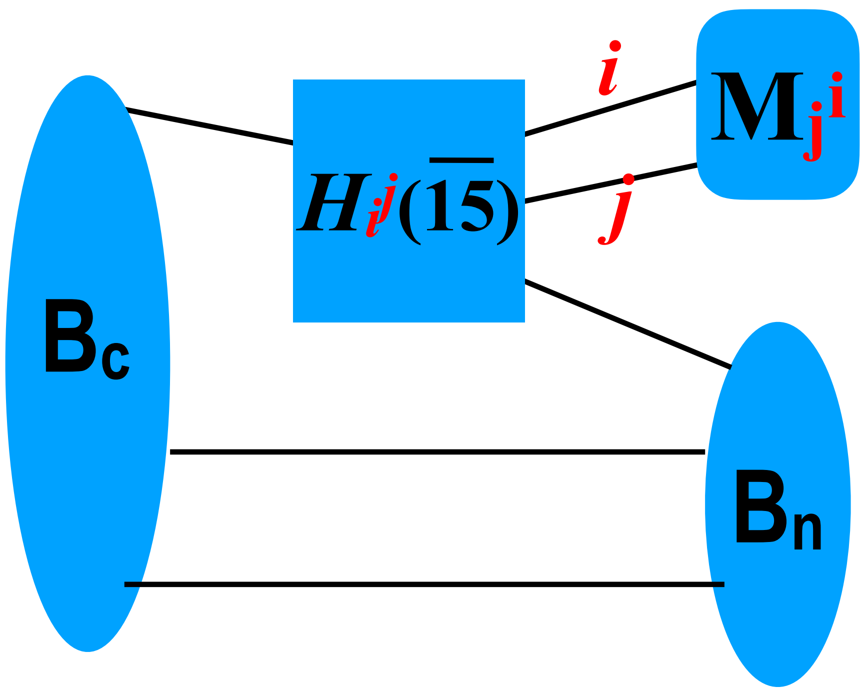
1. $(c_-/c_+)^2 \sim 5.5$;
2. $\mathcal{O}_{\overline{15}} = \frac{1}{2}(\bar{u}d\bar{s} + \bar{s}d\bar{u})c$ is symmetric, whereas the baryon wave function is totally antisymmetric in color indices. → **Vanishing nonfactorizable contributions**

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

$$T(\mathcal{O}_{\overline{15}}) = a_4 H^k_{li}(\overline{15})(\mathrm{B}_c)^j(M)^i_j(\mathrm{B}_n)^l_k + a_5(\mathrm{B}_n)^i_j(M)^l_i H(\overline{15})^{jk}_l(\mathrm{B}_c)_k$$
$$+ a_6(\mathrm{B}_n)^k_l(M)^i_j H(\overline{15})^{jl}_i(\mathrm{B}_c)_k + a_7(\mathrm{B}_n)^l_i(M)^i_j H(\overline{15})^{jk}_l(\mathrm{B}_c)_k$$

$$a_6(\mathrm{B}_n)^k_l(M)^i_j H(\overline{15})^{jl}_i(\mathrm{B}_c)_k$$

the only term which leads to factorizable contributions to $\mathbf{B}_c \to \mathbf{B}_n M$



Cabibbo-allowed

channel	amplitude
$\Xi_c^0 \to \Sigma^+ K^-$	$2a_2$
$\Xi_c^0 \to \Sigma^0 \bar{K}^0$	$\sqrt{2}(-a_2 - a_3 + \frac{a_6}{2})$
$\Xi_c^0 \to \Xi^0 \pi^0$	$\sqrt{2}(-a_1 + a_3)$
$\Xi_c^0 \to \Xi^0 \eta$	$\frac{\sqrt{6}}{3}(a_1 - 2a_2 - a_3)$
$\Xi_c^0 \to \Xi^- \pi^+$	$2a_1 + a_6$
$\Xi_c^0 \to \Lambda^0 \bar{K}^0$	$\frac{\sqrt{6}}{3}(-2a_1 + a_2 + a_3 + \frac{a_6}{2})$
$\Xi_c^+ \to \Sigma^+ \bar{K}^0$	$2a_3 - a_6$
$\Xi_c^+ \to \Xi^0 \pi^+$	$-2a_3 - a_6$
$\Lambda_c^+ \to \Sigma^+ \pi^0$	$\sqrt{2}(a_1 - a_2 - a_3)$
$\Lambda_c^+ \to \Sigma^+ \eta$	$\frac{\sqrt{6}}{3}(-a_1 - a_2 + a_3)$
$\Lambda_c^+ \to \Sigma^0 \pi^+$	$\sqrt{2}(-a_1 + a_2 + a_3)$
$\Lambda_c^+ \to \Xi^0 K^+$	$-2a_2$
$\Lambda_c^+ \to p \bar{K}^0$	$-2a_1 + a_6$
$\Lambda_c^+ \to \Lambda^0 \pi^+$	$\frac{\sqrt{6}}{3}(-a_1 - a_2 - a_3 - a_6)$

Cabibbo-suppressed

channel	amplitude
$\Xi_c^0 \to \Sigma^+ \pi^-$	$2a_2$
$\Xi_c^0 \to \Sigma^0 \pi^0$	$a_1 + a_2 - \frac{a_6}{2}$
$\Xi_c^0 \to \Sigma^0 \eta$	$\frac{\sqrt{3}}{3}(-a_1 - a_2 - 2a_3 + \frac{3}{2}a_6)$
$\Xi_c^0 \to \Sigma^- \pi^+$	$2a_1 + a_6$
$\Xi_c^0 \to \Xi^0 K^0$	$-2a_1 + 2a_2 + 2a_3$
$\Xi_c^0 \to \Xi^- K^+$	$-2a_1 - a_6$
$\Xi_c^0 \to p K^-$	$-2a_2$
$\Xi_c^0 \to n \bar{K}^0$	$2a_1 - 2a_2 - 2a_3$
$\Xi_c^0 \to \Lambda^0 \pi^0$	$\frac{1}{\sqrt{3}}(-a_1 - a_2 + 2a_3 - \frac{a_6}{2})$
$\Xi_c^0 \to \Lambda^0 \eta$	$-a_1 - a_2 + \frac{a_6}{2}$
$\Xi_c^+ \to \Sigma^+ \pi^0$	$\sqrt{2}(-a_1 + a_2 + \frac{a_6}{2})$
$\Xi_c^+ \to \Sigma^+ \eta$	$\frac{\sqrt{6}}{3}(a_1/3 + a_2 + 2a_3 - \frac{3}{2}a_6)$
$\Xi_c^+ \to \Sigma^0 \pi^+$	$\sqrt{2}(a_1 - a_2 + \frac{a_6}{2})$
$\Xi_c^+ \to \Xi^0 K^+$	$2a_2 + 2a_3 + a_6$
$\Xi_c^+ \to p \bar{K}^0$	$2a_1 - 2a_3$
$\Xi_c^+ \to \Lambda^0 \pi^+$	$\frac{\sqrt{6}}{3}(a_1 + a_2 - 2a_3 - \frac{a_6}{2})$
$\Lambda_c^+ \to \Sigma^+ K^0$	$2a_1 - 2a_3$
$\Lambda_c^+ \to \Sigma^0 K^+$	$\sqrt{2}(a_1 - a_3)$
$\Lambda_c^+ \to p \pi^0$	$\sqrt{2}(a_2 + a_3 - \frac{a_6}{2})$
$\Lambda_c^+ \to p \eta$	$\frac{\sqrt{6}}{3}(-2a_1 + a_2 - a_3 + \frac{3}{2}a_6)$
$\Lambda_c^+ \to n \pi^+$	$2a_2 + 2a_3 + a_6$
$\Lambda_c^+ \to \Lambda^0 K^+$	$\frac{\sqrt{6}}{3}(a_1 - 2a_2 + a_3 + a_6)$

doubly Cabibbo-suppressed

channel	amplitude
$\Xi_c^0 \to \Sigma^0 K^0$	$\sqrt{2}(a_1 - \frac{a_6}{2})$
$\Xi_c^0 \to \Sigma^- K^+$	$-2a_1 - a_6$
$\Xi_c^0 \to p\pi^-$	$-2a_2$
$\Xi_c^0 \to n\pi^0$	$\sqrt{2}a_2$
$\Xi_c^0 \to n\eta$	$\frac{\sqrt{6}}{3}(2a_1 - a_2 - 2a_3)$
$\Xi_c^0 \to \Lambda^0 K^0$	$\frac{\sqrt{6}}{3}(-a_1 + 2a_2 + 2a_3 - \frac{a_6}{2})$
$\Xi_c^+ \to \Sigma^+ K^0$	$-2a_1 + a_6$
$\Xi_c^+ \to \Sigma^0 K^+$	$\sqrt{2}(-a_1 - \frac{a_6}{2})$
$\Xi_c^+ \to p\pi^0$	$-\sqrt{2}a_2$
$\Xi_c^+ \to p\eta$	$\frac{\sqrt{6}}{3}(2a_1 - a_2 - 2a_3)$
$\Xi_c^+ \to n\pi^+$	$-2a_2$
$\Xi_c^+ \to \Lambda^0 K^+$	$\frac{\sqrt{6}}{3}(-a_1 + 2a_2 + 2a_3 + \frac{a_6}{2})$
$\Lambda_c^+ \to pK^0$	$2a_3 - a_6$
$\Lambda_c^+ \to nK^+$	$-2a_3 - a_6$

TABLE 2. The data of the $\mathbf{B}_c \to \mathbf{B}_n M$ decays.

Branching ratios	Data [4, 7]	Branching ratios	Data [4, 7]
$10^2\mathcal{B}(\Lambda_c^+ \to p\bar{K}^0)$	3.16 ± 0.16	$10^2\mathcal{B}(\Lambda_c^+ \to \Sigma^+\eta)$	0.70 ± 0.23
$10^2\mathcal{B}(\Lambda_c^+ \to \Lambda\pi^+)$	1.30 ± 0.07	$10^4\mathcal{B}(\Lambda_c^+ \to \Lambda K^+)$	6.1 ± 1.2
$10^2\mathcal{B}(\Lambda_c^+ \to \Sigma^+\pi^0)$	1.24 ± 0.10	$10^4\mathcal{B}(\Lambda_c^+ \to \Sigma^0 K^+)$	5.2 ± 0.8
$10^2\mathcal{B}(\Lambda_c^+ \to \Sigma^0\pi^+)$	1.29 ± 0.07	$10^4\mathcal{B}(\Lambda_c^+ \to p\eta)$	12.4 ± 3.0
$10^2\mathcal{B}(\Lambda_c^+ \to \Xi^0 K^+)$	0.50 ± 0.12	$\mathcal{R} = \frac{\mathcal{B}(\Xi_c^0 \to \Lambda\bar{K}^0)}{\mathcal{B}(\Xi_c^0 \to \Xi^-\pi^+)}$	0.420 ± 0.056

$10^4\mathcal{B}(\Lambda_c^+ \to p\pi^0) = 0.80 \pm 1.36$

11 data points above to fit with 7 real parameters:

$$a_1, a_2 e^{i\delta_{a_2}}, a_3 e^{i\delta_{a_3}}, a_6 e^{i\delta_{a_6}}$$

The minimum χ^2 fit:

$$\chi^2 = \sum_i \left(\frac{\mathcal{B}^i_{th} - \mathcal{B}^i_{ex}}{\sigma^i_{ex}}\right)^2 + \sum_j \left(\frac{\mathcal{R}^j_{th} - \mathcal{R}^j_{ex}}{\sigma^j_{ex}}\right)^2$$

$$(a_1, a_2, a_3, a_6) = (0.271 \pm 0.006, 0.126 \pm 0.010, 0.051 \pm 0.012, 0.055 \pm 0.030)\ GeV^3$$

$$(\delta_{a_2}, \delta_{a_3}, \delta_{a_6}) = (82 \pm 6, -20 \pm 24, 40 \pm 36)^\circ$$

$$\chi^2/d.o.f = 1.8/4 \simeq 0.5$$

BRs of Cabibbo-allowed decays

channel	$10^3 \mathrm{BR}_{th}$	$10^3 \mathrm{BR}_{EX}$
$\Xi_c^0 \to \Sigma^+ K^-$	3.7 ± 0.6	-
$\Xi_c^0 \to \Sigma^0 \bar{K}^0$	1.0 ± 0.6	-
$\Xi_c^0 \to \Xi^0 \pi^0$	6.1 ± 1.1	-
$\Xi_c^0 \to \Xi^0 \eta$	3.1 ± 0.6	-
$\Xi_c^0 \to \Xi^- \pi^+$	20.3 ± 0.9	-
$\Xi_c^0 \to \Lambda^0 \bar{K}^0$	9.3 ± 0.9	-
$\Xi_c^+ \to \Sigma^+ \bar{K}^0$	2.1 ± 1.5	-
$\Xi_c^+ \to \Xi^0 \pi^+$	4.2 ± 1.9	
$\Lambda_c^+ \to \Sigma^+ \pi^0$	12.6 ± 2.1	12.4 ± 1.0
$\Lambda_c^+ \to \Sigma^+ \eta$	5.4 ± 1.0	7.0 ± 2.3
$\Lambda_c^+ \to \Sigma^0 \pi^+$	12.6 ± 2.1	12.9 ± 0.7
$\Lambda_c^+ \to \Xi^0 K^+$	5.9 ± 1.0	5.9 ± 1.0
$\Lambda_c^+ \to p \bar{K}^0$	31.3 ± 1.6	31.6 ± 1.6
$\Lambda_c^+ \to \Lambda^0 \pi^+$	13.1 ± 1.6	13.0 ± 0.7

BRs of Cabibbo-suppressed decays

channel	$10^4\mathrm{BR}_{th}$	$10^4\mathrm{BR}_{EX}$
$\Xi_c^0 \to \Sigma^+\pi^-$	2.2 ± 0.4	-
$\Xi_c^0 \to \Sigma^0\pi^0$	2.8 ± 0.3	-
$\Xi_c^0 \to \Sigma^0\eta$	1.0 ± 0.2	-
$\Xi_c^0 \to \Sigma^-\pi^+$	11.7 ± 0.5	-
$\Xi_c^0 \to \Xi^0 K^0$	6.2 ± 1.0	-
$\Xi_c^0 \to \Xi^- K^+$	9.8 ± 0.4	-
$\Xi_c^0 \to pK^-$	2.3 ± 0.4	-
$\Xi_c^0 \to n\bar{K}^0$	7.8 ± 1.3	-
$\Xi_c^0 \to \Lambda^0\pi^0$	1.0 ± 0.3	-
$\Xi_c^0 \to \Lambda^0\eta$	2.7 ± 0.3	-
$\Xi_c^+ \to \Sigma^+\pi^0$	20.3 ± 2.0	-
$\Xi_c^+ \to \Sigma^+\eta$	8.2 ± 1.9	-
$\Xi_c^+ \to \Sigma^0\pi^+$	23.5 ± 2.3	-
$\Xi_c^+ \to \Xi^0 K^+$	9.8 ± 3.3	-
$\Xi_c^+ \to p\bar{K}^0$	29.2 ± 5.2	-
$\Xi_c^+ \to \Lambda^0\pi^+$	5.1 ± 2.1	-
$\Lambda_c^+ \to \Sigma^+ K^0$	11.4 ± 2.0	-
$\Lambda_c^+ \to \Sigma^0 K^+$	5.7 ± 1.0	5.2 ± 0.8
$\Lambda_c^+ \to p\pi^0$	1.3 ± 0.7	0.8 ± 1.3
$\Lambda_c^+ \to p\eta$	13.0 ± 1.0	12.4 ± 3.0
$\Lambda_c^+ \to n\pi^+$	6.1 ± 2.0	-
$\Lambda_c^+ \to \Lambda^0 K^+$	6.4 ± 0.9	6.1 ± 1.2

Remarks on $\Lambda_c \to p\pi^0$

channel	$10^4 \mathrm{BR}_{th}$ Our results	$10^4 \mathrm{BR}_{EX}$ Data	$10^4 \mathrm{BR}_{th}$ PoCA
$\Lambda_c^+ \to \Sigma^+ K^0$	11.4 ± 2.0	-	14.4
$\Lambda_c^+ \to \Sigma^0 K^+$	5.7 ± 1.0	5.2 ± 0.8	7.18
$\Lambda_c^+ \to p\pi^0$	1.3 ± 0.7	0.8 ± 1.3 (<2.7)	0.75
$\Lambda_c^+ \to p\eta$	13.0 ± 1.0	12.4 ± 3.0	12.8
$\Lambda_c^+ \to n\pi^+$	6.1 ± 2.0	-	2.66
$\Lambda_c^+ \to \Lambda^0 K^+$	6.4 ± 0.9	6.1 ± 1.2	10.6

Our result of $Br(\Lambda_c^+ \to p\pi^0) = (1.3 \pm 0.7) \times 10^{-4}$ is consistent with the data of $< 2.7 \times 10^{-4}$ as well as that of 0.75×10^{-4} by PoCA.

H.Y. Cheng, X.W. Kang and F.R. Xu, ``Singly Cabibbo-suppressed hadronic decays of Λ_c^+,'' Phys. Rev. D97, 074028 (2018)

BRs of DCS decays

channel	$10^5 \mathrm{BR}_{th}$
$\Xi_c^0 \to \Sigma^0 K^0$	2.1 ± 0.1
$\Xi_c^0 \to \Sigma^- K^+$	5.8 ± 0.3
$\Xi_c^0 \to p\pi^-$	1.3 ± 0.2
$\Xi_c^0 \to n\pi^0$	0.7 ± 0.1
$\Xi_c^0 \to n\eta$	2.5 ± 0.4
$\Xi_c^0 \to \Lambda^0 K^0$	0.7 ± 0.3
$\Xi_c^+ \to \Sigma^+ K^0$	16.8 ± 0.9
$\Xi_c^+ \to \Sigma^0 K^+$	11.4 ± 0.5
$\Xi_c^+ \to p\pi^0$	2.6 ± 0.4
$\Xi_c^+ \to p\eta$	9.7 ± 1.6
$\Xi_c^+ \to n\pi^+$	5.1 ± 0.9
$\Xi_c^+ \to \Lambda^0 K^+$	3.0 ± 1.1
$\Lambda_c^+ \to pK^0$	0.3 ± 0.2
$\Lambda_c^+ \to nK^+$	0.6 ± 0.3

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	$10^3 BR_{th}$	$10^2 R_{K^0_{S,L}}$	
$\Xi^0_c \to \Sigma^0 K^0_L$	$-a_2 - a_3 + \frac{a_6}{2} + a_1 s_c^2 - \frac{a_6 s_c^2}{2}$	0.5 ± 0.3	$10.0^{+5.9}_{-5.3}$	9.1±1.6
$\Xi^0_c \to \Sigma^0 K^0_S$	$a_2 + a_3 - \frac{a_6}{2} - \frac{a_6 s_c^2}{2} + a_1 s_c^2$	0.6 ± 0.3		
$\Xi^0_c \to \Lambda^0 K^0_L$	$\frac{1}{\sqrt{3}}(-2a_1 + a_2 + a_3 + \frac{a_6}{2} - a_1 s_c^2 + 2a_2 s_c^2 + 2a_3 s_c^2 - \frac{a_6}{2} s_c^2)$	4.8 ± 0.5	$-4.4^{+0.6}_{-0.7}$	-3.7±0.4
$\Xi^0_c \to \Lambda^0 K^0_S$	$\frac{1}{\sqrt{3}}(2a_1 - a_2 - a_3 - \frac{a_6}{2} - a_1 s_c^2 + 2a_2 s_c^2 + 2a_3 s_c^2 - \frac{a_6}{2} s_c^2)$	4.4 ± 0.4		
$\Xi^+_c \to \Sigma^+ K^0_L$	$\sqrt{2}(a_3 - \frac{a_6}{2} - a_1 s_c^2 + \frac{a_6}{2} s_c^2)$	0.8 ± 0.8	$25.7^{+25.7}_{-18.0}$	-11.3 ~ 39.0
$\Xi^+_c \to \Sigma^+ K^0_S$	$\sqrt{2}(-a_3 + \frac{a_6}{2} - a_1 s_c^2 + \frac{a_6}{2} s_c^2)$	1.5 ± 0.8		
$\Lambda^+_c \to p K^0_L$	$\sqrt{2}(-a_1 + \frac{a_6}{2} + a_3 s_c^2 - \frac{a_6}{2} s_c^2)$	15.5 ± 0.8	$1.1^{+0.7}_{-0.6}$	-1.0 ~ 8.7
$\Lambda^+_c \to p K^0_S$	$\sqrt{2}(a_1 - \frac{a_6}{2} + a_3 s_c^2 - \frac{a_6}{2} s_c^2)$	15.8 ± 0.8		

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

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

$$\mathcal{A}(\mathbf{B}_c \to \mathbf{B}_n M M') \equiv (G_F/\sqrt{2}) T(\mathbf{B}_c \to \mathbf{B}_n M M')$$

Under SU(3)$_F$ flavor symmetry:

$$T^{ij} = (\mathbf{B}_c)_a \epsilon^{aij}$$

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

Assumptions:

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

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

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

T-amplitudes of $\Lambda_c^+ \to \mathbf{B_n} M M'$

CF mode	T-amp
$\Sigma^+\pi^0\pi^0$	$4a_1 + 2a_2 + 2a_3 + 2a_4 - 2a_5$
$\Sigma^+\pi^+\pi^-$	$4a_1 + 2a_2 + 2a_3 - 2a_5 - 2a_6$
$\Sigma^+K^0\bar{K}^0$	$4a_1 + 2a_2 + 2a_3$
$\Sigma^+K^+K^-$	$4a_1 - 2a_5$
$\Sigma^+\eta^0\eta^0$	$4a_1 + \frac{2a_2}{3} + \frac{2a_3}{3} + \frac{2a_4}{3} - \frac{2a_5}{3}$
$\Sigma^0\pi^0\pi^+$	$-2a_4 - 2a_6$
$\Sigma^0K^+\bar{K}^0$	$\sqrt{2}a_2 + \sqrt{2}a_3 + \sqrt{2}a_5$
$\Sigma^-\pi^+\pi^+$	$-4a_4 - 4a_6$
$\Xi^0\pi^0K^+$	$-\sqrt{2}a_5$
$\Xi^0\pi^+K^0$	$-2a_5 - 2a_6$
$\Xi^-\pi^+K^+$	$-2a_6$
$p\pi^0\bar{K}^0$	$-\sqrt{2}a_3 - \sqrt{2}a_4$
$p\pi^+K^-$	$2a_3 - 2a_6$
$p\bar{K}^0\eta^0$	$-\frac{\sqrt{6}a_3}{3} + \frac{\sqrt{6}a_4}{3}$
$n\pi^+\bar{K}^0$	$-2a_4 - 2a_6$
$\Lambda^0\pi^+\eta^0$	$-\frac{2a_2}{3} + \frac{2a_3}{3} - \frac{2a_5}{3} - 2a_6$
$\Lambda^0K^+\bar{K}^0$	$-\frac{\sqrt{6}a_2}{3} + \frac{\sqrt{6}a_3}{3} - \frac{\sqrt{6}a_5}{3}$

CS mode	T-amp/t_c
$\Sigma^+\pi^0K^0$	$\sqrt{2}a_2 + \sqrt{2}a_3 + 2\sqrt{2}a_4$
$\Sigma^+\pi^-K^+$	$-2a_2 - 2a_3 + 2a_6$
$\Sigma^+K^0\eta^0$	$\frac{\sqrt{6}a_2}{3} + \frac{\sqrt{6}a_3}{3} - \frac{2\sqrt{6}a_4}{3}$
$\Sigma^0\pi^+K^0$	$-\sqrt{2}a_2 - \sqrt{2}a_3 - 2\sqrt{2}a_4$
$\Sigma^0K^+\eta^0$	$\frac{\sqrt{3}a_2}{3} + \frac{\sqrt{3}a_3}{3} - \frac{2\sqrt{3}a_4}{3}$
$\Sigma^-\pi^+K^+$	$4a_4 + 2a_6$
$p\pi^0\pi^0$	$-4a_1 - 2a_2 + 2a_5$
$p\pi^0\eta^0$	$\frac{2\sqrt{3}a_2}{3} - \frac{2\sqrt{3}a_4}{3} + \frac{2\sqrt{3}a_5}{3}$
$p\pi^+\pi^-$	$-4a_1 - 2a_2 + 2a_5$
pK^+K^-	$-4a_1 - 2a_3 + 2a_5 + 2a_6$
$p\eta^0\eta^0$	$-4a_1 - \frac{2a_2}{3} - \frac{8a_3}{3} + \frac{4a_4}{3} + \frac{2a_5}{3}$
$n\pi^+\eta^0$	$\frac{2\sqrt{6}a_2}{3} - \frac{2\sqrt{6}a_4}{3} + \frac{2\sqrt{6}a_5}{3}$
$nK^+\bar{K}^0$	$2a_2 + 2a_4 + 2a_5 + 2a_6$
$\Lambda^0\pi^0K^+$	$\frac{\sqrt{3}a_2}{3} - \frac{\sqrt{3}a_3}{3} - \frac{2\sqrt{3}a_5}{3}$
$\Lambda^0\pi^+K^0$	$\frac{\sqrt{6}a_2}{3} - \frac{\sqrt{6}a_3}{3} - \frac{2\sqrt{6}a_5}{3}$
$\Lambda^0K^+\eta^0$	$-\frac{a_2}{3} + \frac{a_3}{3} + \frac{2a_5}{3} + 2a_6$

DCS mode	T-amp/t_c^2
$\Sigma^+K^0K^0$	$4a_4$
$\Sigma^0K^0K^+$	$2\sqrt{2}a_4$
$\Sigma^-K^+K^+$	$-4a_4$
$p\pi^0K^0$	$-\sqrt{2}a_2$
$p\pi^-K^+$	$2a_2$
$pK^0\eta^0$	$-\frac{\sqrt{6}a_2}{3} - \frac{2\sqrt{6}a_4}{3}$
$n\pi^0K^+$	$-\sqrt{2}a_2$
$n\pi^+K^0$	$-2a_2$
$nK^+\eta^0$	$\frac{\sqrt{6}a_2}{3} + \frac{2\sqrt{6}a_4}{3}$

T-amplitudes of $\Xi_c^+ \to \mathbf{B_n} M M'$

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

T-amplitudes of $\Xi_c^0 \to \mathbf{B_n} M M'$

CF mode	T-amp	CS mode	T-amp/t_c	DCS mode	T-amp/t_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^-	$4a_1+2a_2+2a_3$
$pK^-\bar{K}^0$	$2a_6$	$p\pi^-\bar{K}^0$	$-2a_5$	$n\eta^0\eta^0$	$4a_1+\frac{8a_2}{3}+\frac{8a_3}{3}$
$n\bar{K}^0\bar{K}^0$	$4a_4+4a_6$	$pK^-\eta^0$	$\frac{\sqrt{6}a_5}{3}+\sqrt{6}a_6$		$+\frac{8a_4}{3}-\frac{2a_5}{3}$
$\Lambda^0\pi^0\bar{K}^0$	$-\sqrt{3}(\frac{a_2}{3}+\frac{2a_3}{3}+a_4+\frac{a_5}{3})$	$n\pi^0\bar{K}^0$	$\sqrt{2}a_2+\sqrt{2}a_3+\sqrt{2}a_5-\sqrt{2}a_6$	$\Lambda^0\pi^0K^0$	$-\sqrt{3}(\frac{2a_2}{3}+\frac{a_3}{3}+\frac{2a_5}{3})$
$\Lambda^0\pi^+K^-$	$\frac{\sqrt{6}a_2}{3}+\frac{2\sqrt{6}a_3}{3}+\frac{\sqrt{6}a_5}{3}$	$n\pi^+K^-$	$-2a_2-2a_3-2a_5$	$\Lambda^0\pi^-K^+$	$\sqrt{6}(\frac{2a_2}{3}+\frac{a_3}{3}+\frac{2a_5}{3})$
		$n\bar{K}^0\eta^0$	$\sqrt{6}(\frac{a_2}{3}+\frac{a_3}{3}+\frac{4a_4}{3}+\frac{a_5}{3}+a_6)$		
		$\Lambda^0\pi^0\pi^0$	$\sqrt{6}(-2a_1-\frac{2a_2}{3}-\frac{a_3}{3}+\frac{a_5}{3})$		
		$\Lambda^0\pi^0\eta^0$	$\sqrt{2}(\frac{2a_2}{3}+\frac{a_3}{3}-a_4-\frac{a_5}{3}-a_6)$		
		$\Lambda^0\pi^+\pi^-$	$\sqrt{6}(-2a_1-\frac{2a_2}{3}-\frac{a_3}{3}+\frac{a_5}{3})$		
		$\Lambda^0K^0\bar{K}^0$	$\sqrt{6}(-2a_1-a_2-a_3-a_4+a_5)$		
		$\Lambda^0K^+K^-$	$\sqrt{6}(-2a_1-\frac{a_2}{3}-\frac{2a_3}{3}+\frac{2a_5}{3})$		
		$\Lambda^0\eta^0\eta^0$	$\sqrt{6}(-2a_1-\frac{2a_2}{3}-a_3+\frac{2a_4}{3}$		
			$+a_5+2a_6)$		

The data of $\mathcal{B}(\Lambda_c^+ \to \mathbf{B_n} MM)$

	data	our results		data	our results
$10^2\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+)$	3.4 ± 0.4	3.3 ± 1.0	$10^3\mathcal{B}(\Lambda_c^+ \to \Xi^- K^+\pi^+)$	6.2 ± 0.6	6.3 ± 0.6
$10^2\mathcal{B}(\Lambda_c^+ \to p\bar{K}^0\eta)$	1.6 ± 0.4	0.9 ± 0.1	$10^2\mathcal{B}(\Xi_c^+ \to \Xi^-\pi^+\pi^+)$	6.1 ± 3.1	7.2 ± 2.0
$10^3\mathcal{B}(\Lambda_c^+ \to \Lambda^0 K^+\bar{K}^0)$	5.6 ± 1.1	5.7 ± 1.1	$10^3\mathcal{B}(\Lambda_c^+ \to p\pi^-\pi^+)$	4.2 ± 0.4	4.7 ± 1.6
$10^2\mathcal{B}(\Lambda_c^+ \to \Lambda^0\pi^+\eta)$	2.2 ± 0.5	2.1 ± 0.9	$10^4\mathcal{B}(\Lambda_c^+ \to pK^-K^+)$	5.2 ± 1.2	5.1 ± 2.1
$10^2\mathcal{B}(\Lambda_c^+ \to \Sigma^+\pi^+\pi^-)$	4.4 ± 0.3	4.4 ± 3.5	$10^4\mathcal{B}(\Lambda_c^+ \to pK^+\pi^-)$	1.0 ± 0.1	1.0 ± 0.1
$10^2\mathcal{B}(\Lambda_c^+ \to \Sigma^-\pi^+\pi^+)$	1.9 ± 0.2	1.9 ± 1.3			
$10^2\mathcal{B}(\Lambda_c^+ \to \Sigma^0\pi^+\pi^0)$	2.2 ± 0.8	1.0 ± 0.8			
$10^2\mathcal{B}(\Lambda_c^+ \to \Sigma^+\pi^0\pi^0)$	1.3 ± 0.1	1.3 ± 1.3			
$10^3\mathcal{B}(\Lambda_c^+ \to \Sigma^+ K^+\pi^-)$	2.1 ± 0.6	3.0 ± 0.4			

14 data points above to fit with 11 real parameters:

$$a_1, a_2 e^{i\delta_{a_2}}, a_3 e^{i\delta_{a_3}}, a_4 e^{i\delta_{a_4}}, a_5 e^{i\delta_{a_5}}, a_6 e^{i\delta_{a_6}}$$

$$(a_1, a_2, a_3, a_4, a_5, a_6) = (9.1 \pm 0.6, 4.6 \pm 0.2, 8.2 \pm 0.3, 2.9 \pm 0.4, 15.4 \pm 1.4, 4.2 \pm 0.2)\,\mathrm{GeV}^2$$

$$(\delta_{a_2}, \delta_{a_3}, \delta_{a_4}, \delta_{a_5}, \delta_{a_6}) = (164 \pm 5, 135 \pm 5, -30 \pm 13, 24 \pm 3, 120 \pm 10)^\circ$$

$$\chi^2/d.o.f = 8.4/3 = 2.8$$

BRs of $\Lambda_c \to \mathbf{B_n} M_1 M_2$

CF mode	our result	CS mode	our result	DCS mode	our result
$10^2\mathcal{B}_{\Sigma^+\pi^0\eta^0}$	3.5 ± 0.8	$10^4\mathcal{B}_{\Sigma^+\pi^0K^0}$	8.6 ± 2.6	$10^6\mathcal{B}_{\Sigma^+K^0K^0}$	2.0 ± 0.5
$10^3\mathcal{B}_{\Sigma^+K^0\bar{K}^0}$	5.2 ± 1.2	$10^5\mathcal{B}_{\Sigma^+K^0\eta^0}$	3.5 ± 0.4	$10^6\mathcal{B}_{\Sigma^0K^0K^+}$	2.0 ± 0.6
$10^3\mathcal{B}_{\Sigma^+K^+K^-}$	3.0 ± 0.7	$10^3\mathcal{B}_{\Sigma^0\pi^0K^+}$	1.2 ± 0.3	$10^6\mathcal{B}_{\Sigma^-K^+K^+}$	2.0 ± 0.5
$10^7\mathcal{B}_{\Sigma^+\eta^0\eta^0}$	2.8 ± 0.6	$10^4\mathcal{B}_{\Sigma^0\pi^+K^0}$	8.3 ± 2.5	$10^5\mathcal{B}_{p\pi^0K^0}$	5.0 ± 0.5
$10^2\mathcal{B}_{\Sigma^0\pi^+\eta^0}$	3.4 ± 0.8	$10^5\mathcal{B}_{\Sigma^0K^+\eta^0}$	1.8 ± 0.2	$10^5\mathcal{B}_{n\pi^0K^+}$	5.0 ± 0.5
$10^2\mathcal{B}_{\Sigma^0K^+\bar{K}^0}$	0.5 ± 0.1	$10^4\mathcal{B}_{\Sigma^-\pi^+K^+}$	3.3 ± 2.3	$10^4\mathcal{B}_{n\pi^+K^0}$	1.0 ± 0.1
$10^2\mathcal{B}_{\Xi^0\pi^0K^+}$	4.5 ± 0.8	$10^3\mathcal{B}_{p\pi^0\pi^0}$	2.4 ± 0.8		
$10^2\mathcal{B}_{\Xi^0\pi^+K^0}$	8.7 ± 1.7	$10^3\mathcal{B}_{p\pi^0\eta^0}$	3.7 ± 0.9		
$10^2\mathcal{B}_{p\pi^0\bar{K}^0}$	2.8 ± 0.6	$10^3\mathcal{B}_{pk^0\bar{K}^0}$	4.3 ± 1.0		
$10^2\mathcal{B}_{n\pi^+\bar{K}^0}$	0.9 ± 0.8	$10^4\mathcal{B}_{p\eta^0\eta^0}$	4.7 ± 1.0		
		$10^3\mathcal{B}_{n\pi^+\eta^0}$	7.3 ± 1.8		
		$10^3\mathcal{B}_{nK^+\bar{K}^0}$	5.9 ± 1.3		
		$10^3\mathcal{B}_{\Lambda^0\pi^0K^+}$	4.5 ± 0.8		
		$10^3\mathcal{B}_{\Lambda^0\pi^+K^0}$	8.8 ± 1.5		
		$10^4\mathcal{B}_{\Lambda^0K^+\eta^0}$	1.9 ± 0.6		

BRs of $\Xi_c^+ \to \mathbf{B_n} M_1 M_2$

CF mode	our result
$10^3\mathcal{B}_{\Sigma^+\pi^0\bar{K}^0}$	5.4 ± 4.0
$10^2\mathcal{B}_{\Sigma^+\pi^+K^-}$	6.1 ± 0.6
$10^3\mathcal{B}_{\Sigma^+\bar{K}^0\eta^0}$	4.6 ± 0.6
$10^2\mathcal{B}_{\Sigma^0\pi^+\bar{K}^0}$	1.2 ± 0.3
$10^2\mathcal{B}_{\Xi^0\pi^0\pi^+}$	1.9 ± 0.5
$10^2\mathcal{B}_{\Xi^0\pi^+\eta^0}$	1.0 ± 0.2
$10^3\mathcal{B}_{\Xi^0K^+\bar{K}^0}$	4.9 ± 0.5
$10^2\mathcal{B}_{p\bar{K}^0\bar{K}^0}$	4.3 ± 1.2
$10^2\mathcal{B}_{\Lambda^0\pi^+\bar{K}^0}$	4.6 ± 1.2

CS mode	our result
$10^3\mathcal{B}_{\Sigma^+\pi^0\eta^0}$	9.6 ± 1.8
$10^3\mathcal{B}_{\Sigma^+\pi^+\pi^-}$	5.1 ± 2.0
$10^3\mathcal{B}_{\Sigma^+K^0\bar{K}^0}$	5.4 ± 1.3
$10^3\mathcal{B}_{\Sigma^+K^+K^-}$	1.0 ± 0.4
$10^4\mathcal{B}_{\Sigma^+\eta^0\eta^0}$	1.8 ± 1.0
$10^3\mathcal{B}_{\Sigma^0\pi^0\pi^+}$	5.6 ± 0.5
$10^3\mathcal{B}_{\Sigma^0\pi^+\eta^0}$	9.4 ± 1.8
$10^3\mathcal{B}_{\Sigma^0K^+\bar{K}^0}$	4.4 ± 0.9
$10^2\mathcal{B}_{\Sigma^-\pi^+\pi^+}$	1.1 ± 0.1
$10^3\mathcal{B}_{\Xi^0\pi^0K^+}$	6.4 ± 1.6
$10^2\mathcal{B}_{\Xi^0\pi^+K^0}$	1.9 ± 0.4
$10^4\mathcal{B}_{\Xi^0K^+\eta^0}$	1.3 ± 0.3
$10^4\mathcal{B}_{\Xi^-\pi^+K^+}$	8.3 ± 5.3
$10^2\mathcal{B}_{p\pi^0K^0}$	2.4 ± 0.2
$10^2\mathcal{B}_{p\pi^+K^-}$	2.4 ± 0.3
$10^3\mathcal{B}_{n\pi^+K^0}$	5.5 ± 0.5
$10^2\mathcal{B}_{\Lambda^0\pi^+\eta^0}$	1.7 ± 0.3
$10^3\mathcal{B}_{\Lambda^0K^+\bar{K}^0}$	4.7 ± 1.0

DCS mode	our result
$10^4\mathcal{B}_{\Sigma^+\pi^0K^0}$	2.6 ± 0.2
$10^4\mathcal{B}_{\Sigma^+\pi^-K^+}$	1.4 ± 0.3
$10^6\mathcal{B}_{\Sigma^+K^0\eta^0}$	2.0 ± 1.4
$10^6\mathcal{B}_{\Sigma^0\pi^0K^+}$	7.6 ± 5.9
$10^4\mathcal{B}_{\Sigma^0\pi^+K^0}$	2.5 ± 0.2
$10^6\mathcal{B}_{\Sigma^0K^+\eta^0}$	1.0 ± 0.7
$10^4\mathcal{B}_{\Sigma^-\pi^+K^+}$	1.3 ± 0.1
$10^6\mathcal{B}_{\Xi^0K^0K^+}$	3.0 ± 1.9
$10^6\mathcal{B}_{\Xi^-K^+K^+}$	5.7 ± 3.2
$10^4\mathcal{B}_{p\pi^0\pi^0}$	7.2 ± 1.8
$10^3\mathcal{B}_{p\pi^0\eta^0}$	1.1 ± 0.2
$10^3\mathcal{B}_{p\pi^+\pi^-}$	1.4 ± 0.4
$10^4\mathcal{B}_{pK^0\bar{K}^0}$	7.7 ± 1.7
$10^4\mathcal{B}_{pK^+K^-}$	1.6 ± 1.2
$10^5\mathcal{B}_{p\eta^0\eta^0}$	9.3 ± 4.5
$10^3\mathcal{B}_{n\pi^+\eta^0}$	2.1 ± 0.4
$10^3\mathcal{B}_{nK^+\bar{K}^0}$	1.6 ± 0.3
$10^4\mathcal{B}_{\Lambda^0\pi^0K^+}$	5.0 ± 1.0
$10^4\mathcal{B}_{\Lambda^0\pi^+K^0}$	9.7 ± 2.0
$10^5\mathcal{B}_{\Lambda^0K^+\eta^0}$	9.0 ± 2.2

BRs of $\Xi_c^0 \to \mathbf{B_n} M_1 M_2$

CF mode	our result
$10^2\mathcal{B}_{\Sigma^+\pi^0K^-}$	8.8 ± 1.5
$10^1\mathcal{B}_{\Sigma^+\pi^-\bar{K}^0}$	1.8 ± 0.3
$10^3\mathcal{B}_{\Sigma^+K^-\eta^0}$	5.2 ± 0.9
$10^2\mathcal{B}_{\Sigma^0\pi^0\bar{K}^0}$	4.4 ± 1.1
$10^2\mathcal{B}_{\Sigma^0\pi^+K^-}$	5.4 ± 1.2
$10^3\mathcal{B}_{\Sigma^0\bar{K}^0\eta^0}$	1.4 ± 0.3
$10^2\mathcal{B}_{\Xi^0\pi^0\pi^0}$	8.1 ± 1.9
$10^2\mathcal{B}_{\Xi^0\pi^0\eta^0}$	1.2 ± 0.2
$10^1\mathcal{B}_{\Xi^0\pi^+\pi^-}$	1.3 ± 0.3
$10^3\mathcal{B}_{\Xi^0K^+K^-}$	3.6 ± 0.9
$10^4\mathcal{B}_{\Xi^0\eta^0\eta^0}$	2.2 ± 0.9
$10^3\mathcal{B}_{\Xi^-\pi^0\pi^+}$	4.6 ± 1.2
$10^2\mathcal{B}_{\Xi^-\pi^+\eta^0}$	1.1 ± 0.1
$10^2\mathcal{B}_{pK^-\bar{K}^0}$	1.2 ± 0.1
$10^3\mathcal{B}_{n\bar{K}^0\bar{K}^0}$	6.4 ± 6.3
$10^2\mathcal{B}_{\Lambda^0\pi^0\bar{K}^0}$	2.0 ± 0.6
$10^2\mathcal{B}_{\Lambda^0\pi^+K^-}$	5.9 ± 0.8

CS mode	our result
$10^4\mathcal{B}_{\Sigma^+\pi^0\pi^-}$	7.2 ± 0.7
$10^3\mathcal{B}_{\Sigma^+\pi^-\eta^0}$	5.7 ± 0.9
$10^3\mathcal{B}_{\Sigma^+K^0K^-}$	2.4 ± 0.4
$10^3\mathcal{B}_{\Sigma^0\pi^0\pi^0}$	1.3 ± 0.3
$10^3\mathcal{B}_{\Sigma^0\pi^0\eta^0}$	1.9 ± 0.4
$10^4\mathcal{B}_{\Sigma^0K^+K^-}$	9.7 ± 1.7
$10^5\mathcal{B}_{\Sigma^0\eta^0\eta^0}$	2.3 ± 1.2
$10^4\mathcal{B}_{\Sigma^-\pi^0\pi^+}$	7.1 ± 0.6
$10^4\mathcal{B}_{\Sigma^-\pi^+\eta^0}$	6.3 ± 2.0
$10^4\mathcal{B}_{\Sigma^-K^+\bar{K}^0}$	2.9 ± 0.6
$10^3\mathcal{B}_{\Xi^0\pi^0K^0}$	3.0 ± 0.7
$10^3\mathcal{B}_{\Xi^0\pi^-K^+}$	4.8 ± 0.9
$10^4\mathcal{B}_{\Xi^-\pi^0K^+}$	6.2 ± 1.3
$10^4\mathcal{B}_{\Xi^-\pi^+K^0}$	7.2 ± 1.5
$10^3\mathcal{B}_{p\pi^0K^-}$	9.5 ± 1.6
$10^2\mathcal{B}_{p\pi^-\bar{K}^0}$	1.9 ± 0.3
$10^3\mathcal{B}_{pK^-\eta^0}$	1.8 ± 0.3
$10^3\mathcal{B}_{n\pi^0\bar{K}^0}$	5.2 ± 1.3
$10^2\mathcal{B}_{n\pi^+K^-}$	1.5 ± 0.3
$10^3\mathcal{B}_{n\bar{K}^0\eta^0}$	1.9 ± 0.6
$10^3\mathcal{B}_{\Lambda^0\pi^0\pi^0}$	5.3 ± 1.5
$10^3\mathcal{B}_{\Lambda^0\pi^0\eta^0}$	2.2 ± 0.4
$10^2\mathcal{B}_{\Lambda^0\pi^+\pi^-}$	1.1 ± 0.3
$10^4\mathcal{B}_{\Lambda^0K^+K^-}$	3.0 ± 2.5
$10^4\mathcal{B}_{\Lambda^0\eta^0\eta^0}$	2.4 ± 1.4

DCS mode	our result
$10^5\mathcal{B}_{\Sigma^+\pi^-K^0}$	3.4 ± 0.3
$10^5\mathcal{B}_{\Sigma^0\pi^-K^+}$	6.5 ± 0.5
$10^7\mathcal{B}_{\Sigma^0K^0\eta^0}$	2.6 ± 1.7
$10^5\mathcal{B}_{\Sigma^-\pi^0K^+}$	6.4 ± 0.5
$10^5\mathcal{B}_{\Sigma^-\pi^+K^0}$	3.4 ± 0.7
$10^7\mathcal{B}_{\Sigma^-K^+\eta^0}$	5.1 ± 3.4
$10^6\mathcal{B}_{\Xi^0K^0K^0}$	1.5 ± 1.1
$10^7\mathcal{B}_{\Xi^-K^0K^+}$	7.1 ± 6.7
$10^4\mathcal{B}_{p\pi^-\eta^0}$	5.4 ± 0.9
$10^4\mathcal{B}_{pK^0K^-}$	4.2 ± 0.7
$10^4\mathcal{B}_{n\pi^0\pi^0}$	1.8 ± 0.5
$10^4\mathcal{B}_{n\pi^0\eta^0}$	2.7 ± 0.5
$10^4\mathcal{B}_{n\pi^+\pi^-}$	3.6 ± 0.9
$10^5\mathcal{B}_{nK^0\bar{K}^0}$	3.9 ± 2.9
$10^4\mathcal{B}_{nK^+K^-}$	2.0 ± 0.5
$10^5\mathcal{B}_{n\eta^0\eta^0}$	2.4 ± 1.2
$10^4\mathcal{B}_{\Lambda^0\pi^0K^0}$	1.3 ± 0.3
$10^4\mathcal{B}_{\Lambda^0\pi^-K^+}$	2.5 ± 0.5
$10^5\mathcal{B}_{\Lambda^0K^0\eta^0}$	2.3 ± 0.6

• Summary

♥ We have studied the weak decays of charmed baryons $\mathrm{B}_c = (\Xi_c^0, -\Xi_c^+, \Lambda_c^+)$ based on $SU(3)_F$ flavor symmetry.

♥ From the measured semileptonic decay of $\mathcal{B}(\Lambda_c^+ \to \Lambda^0 e^+ \nu_e) = (3.6 \pm 0.4) \times 10^{-2}$ we can predict other semileptonic decays of $\mathbf{B_c}$, such as $\mathcal{B}(\Lambda_c^+ \to n e^+ \nu_e) = (3.76 \pm 0.42) \times 10^{-3}$

♥ For the two-body decays of $\mathbf{B}_c \to \mathbf{B}_n M$, we have obtained a good fit for the 7 parameters without $H(\overline{15})$. By including the factorizable contributions from $H(\overline{15})$, we have found that $Br(\Lambda_c^+ \to p\pi^0) = (1.3 \pm 0.7) \times 10^{-4}$, which agrees with the current experimental upper limit of 2.7×10^{-4}.

♥ We have examined K_S-K_L asymmetries in the charmed baryon decays, which agree with those in the literature.

♥ By considering only the S-wave contributions from $M_1 M_2$ and neglecting $H(\overline{15})$ as well as the nonresonant data points, we have systematically predicted the three-body decays of $\mathbf{B}_c \to \mathbf{B}_n M_1 M_2$ for the first time.

☞ ♦ Rich physics for Charmed Baryons at BESIII, LHCb, BELLEII ……

More theoretical and experimental studies are needed.

Thank you!

謝謝！