SU(3) symmetry and its breaking effects in semileptonic heavy baryon decays

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OutLine

Introduction

- Precision CKM matrix elements;

- Charmed baryons semileptonic decays provide an ideal platform to study the strong and weak interactions.

- Important for the experimental researches of heavy baryons:

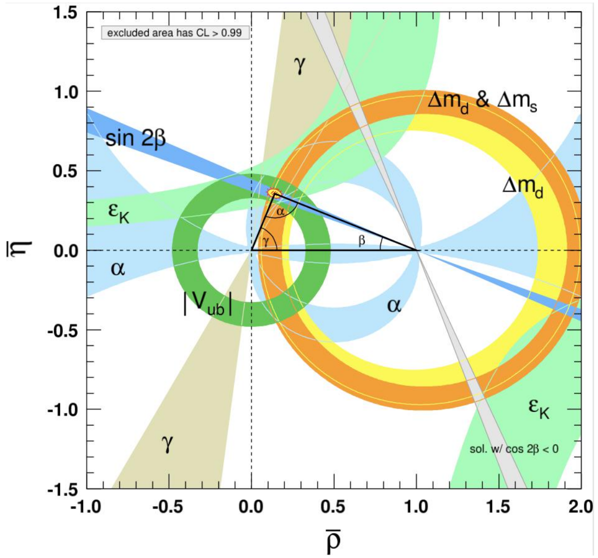
  - Studies of doubly-charmed baryon Ξ_{cc}^{++} decay

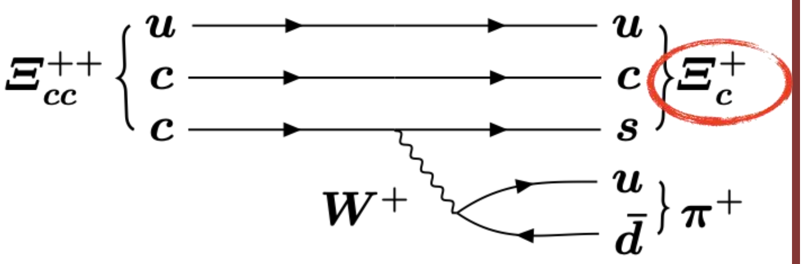
    R. Aaij et al. [LHCb], PRL121, 162002 (2018)

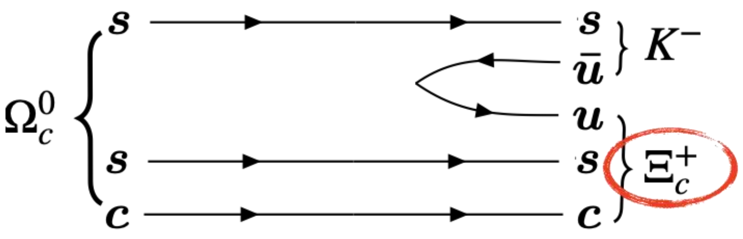
  - Discovery of new exotic hadron candidates Ω_c

    R. Aaij et al. [LHCb], PRL118, 182001(2017)

  - ......



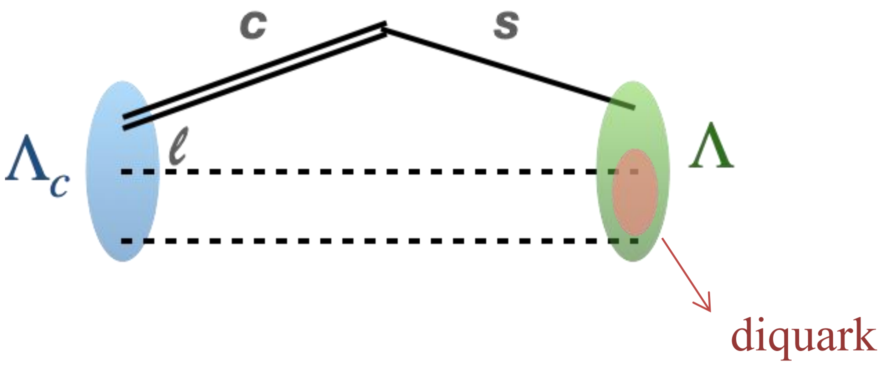




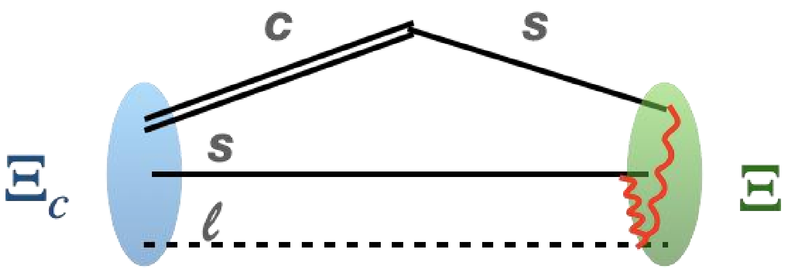
Introduction

- contains more versatile decay modes

iso-singlet



iso-doublet



- A different pattern between inclusive and exclusive decays of and D:

$$\frac{\mathscr{B}(\Lambda_c^+ \to X e^+ \nu_e) = (3.95 \pm 0.34 \pm 0.09)\,\%}{\mathscr{B}(\Lambda_c^+ \to \Lambda e^+ \nu_e) = (3.63 \pm 0.38 \pm 0.20)\,\%}$$

$\boxed{\sim 1}$

$$\frac{\mathscr{B}(D^0 \to X e^+ \nu_e) = (6.49 \pm 0.11)\,\%}{\mathscr{B}(D^0 \to K\Lambda_c e^+ \nu_e) = (3.542 \pm 0.035)\,\%}$$

$\boxed{\sim 2}$

M.Ablikim et al.[BESIII],PRL121,251801(2018)

Data on experiments

✓ Experimental

PRL 115, 221805 (2015) PHYSICAL REVIEW LETTERS week ending 27 NOVEMBER 2015

Measurement of the Absolute Branching Fraction for $\Lambda_c^+ \to \Lambda e^+ \nu_e$

BES-III; PRL 115,221805(2015)

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

ALICE

CERN

CERN-EP-2021-084
10 May 2021

Measurement of the cross sections of Ξ_c^0 and Ξ_c^+ baryons and of the branching-fraction ratio $\mathrm{BR}(\Xi_c^0 \to \Xi^- e^+ \nu_e)/\mathrm{BR}(\Xi_c^0 \to \Xi^- \pi^+)$ in pp collisions at $\sqrt{s} = 13$ TeV

ALICE Collaboration[*]

PHYSICAL REVIEW LETTERS 127, 121803 (2021)

Measurements of the Branching Fractions of the Semileptonic Decays $\Xi_c^0 \to \Xi^- \ell^+ \nu_\ell$ and the Asymmetry Parameter of $\Xi_c^0 \to \Xi^- \pi^+$

Belle; PRL 127,121803(2021)

Belle Collaboration

First observation of $\Lambda_c \to p\eta'$

JHEP 03(2022)090

First search for the weak radiative decays $\Lambda_c \to \Sigma^+\gamma$ and $\Xi_c^0 \to \Xi^0\gamma$

arXiv:2206.12517

LHCb

$R(\Lambda_c) = 0.242 \pm 0.026 \pm 0.040 \pm 0.059$

Theoretical tools for Charm

- ✓Quark Model:
  Light-Front Quark Model....
- ✓QCD Sum rules(arxiv:2103.09436)
- ✓Light-Cone Sum rules
- ✓**SU(3) symmetry**

  Cai-Dian Lü, Wei Wang, Fu-Sheng Yu, PRD 93,056008

  Xiao-Gang He, Yu-Ji Shi, Wei Wang, Eur. Phys.J.C 78,56

  C.Q. Geng, Chia-Wei Liu, and Tien-Hsueh Tsia and Yao Yu, Phys.Rev.D 99(2019)11, 114022

Data

✓ Lattice

$\Lambda_c \to \Lambda l^+ \nu_l$ **Form Factors and Decay Rates from Lattice QCD with Physical Quark Masses**

Stefan Meinel

Department of Physics, University of Arizona, Tucson, Arizona 85721, USA and RIKEN BNL Research Center, Brookhaven National Laboratory, Upton, New York 11973, USA

Phys.Rev.Lett. 118 (2017) 8, 082001

First lattice QCD calculation of semileptonic decays of charmed-strange baryons Ξ_c^*

To cite this article: Qi-An Zhang *et al* 2022 *Chinese Phys. C* **46** 011002

Chin Phys. C46 011002

PDG $\mathcal{B}\left(\Xi_c^0 \to \Xi^- e^+ \nu_e\right) = (1.8 \pm 1.2)\,\%$

Belle $\mathcal{B}\left(\Xi_c^0 \to \Xi^- e^+ \nu_e\right) = (1.31 \pm 0.04 \pm 0.07 \pm 0.38)\,\%$

ALICE $\mathcal{B}\left(\Xi_c^0 \to \Xi^- e^+ \nu_e\right) = (1.27 \pm 0.06 \pm 0.10 \pm 0.37)\,\%$

$$\mathcal{B}\left(\Xi_c^0 \to \Xi^- e^+ \nu_e\right) = (2.38 \pm 0.30 \pm 0.32 \pm 0.07)\%$$

$$\mathcal{B}\left(\Xi_c^0 \to \Xi^- e^+ \nu_e\right) = (2.29 \pm 0.29 \pm 0.30 \pm 0.06)\%$$

SU(3) symmetry

SU(3) relations

- The low-energy effective Hamiltonian

$$(H_3)^1 = 0, \quad (H_3)^2 = V_{cd}^*, \quad (H_3)^3 = V_{cs}^*.$$

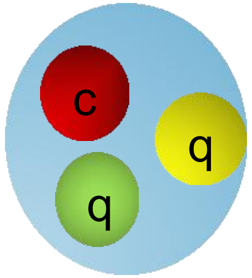
Amplitude: $$H_{\lambda,\lambda_w} = a_1^{\lambda,\lambda_w} \times (T_{c\bar{3}})^{[ij]}(H_3)^k \epsilon_{ikm}(T_8)_j^m,$$

a_1^{λ,λ_w} :SU(3) irreducible nonperturbative amplitude

expand

$\Lambda_c^+ \to \Lambda^0 \ell^+ \nu_\ell$	$-\sqrt{\frac{2}{3}} a_1^{\lambda,\lambda_w} V_{cs}^*$	$\Xi_c^+ \to \Xi^0 \ell^+ \nu_\ell$	$-a_1^{\lambda,\lambda_w} V_{cs}^*$
$\Lambda_c^+ \to n \ell^+ \nu_\ell$	$a_1^{\lambda,\lambda_w} V_{cd}^*$	$\Xi_c^0 \to \Sigma^- \ell^+ \nu_\ell$	$a_1^{\lambda,\lambda_w} V_{cd}^*$
$\Xi_c^+ \to \Sigma^0 \ell^+ \nu_\ell$	$\frac{a_1^{\lambda,\lambda_w} V_{cd}^*}{\sqrt{2}}$	$\Xi_c^0 \to \Xi^- \ell^+ \nu_\ell$	$a_1^{\lambda,\lambda_w} V_{cs}^*$
$\Xi_c^+ \to \Lambda^0 \ell^+ \nu_\ell$	$-\frac{a_1^{\lambda,\lambda_w} V_{cd}^*}{\sqrt{6}}$		

$$\Gamma(\Xi_c^0 \to \Xi^- \ell^+ \nu_\ell) = \Gamma(\Xi_c^+ \to \Xi^0 \ell^+ \nu_\ell) = \frac{3}{2}\Gamma(\Lambda_c^+ \to \Lambda^0 \ell^+ \nu_\ell)$$



$$T_{c\bar{3}} = \begin{array}{cc} & \begin{array}{ccc} \mathbf{u} & \mathbf{d} & \mathbf{s} \end{array} \\ & \begin{pmatrix} 0 & \Lambda_c^+ & \Xi_c^+ \\ -\Lambda_c^+ & 0 & \Xi_c^0 \\ -\Xi_c^+ & -\Xi_c^0 & 0 \end{pmatrix} \begin{array}{c} \mathbf{u} \\ \mathbf{d} \\ \mathbf{s} \end{array} \end{array}$$

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

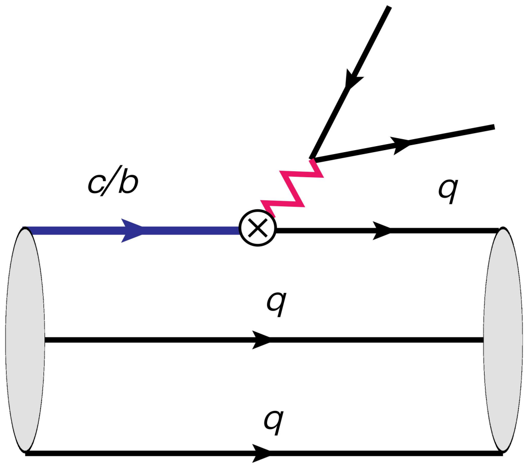
SU(3) symmetry

- Semileptonic charmed baryons decays

$$\Gamma(\Xi_c^0 \to \Xi^- \ell^+ \nu_\ell) = \Gamma(\Xi_c^+ \to \Xi^0 \ell^+ \nu_\ell) = \frac{3}{2}\Gamma(\Lambda_c^+ \to \Lambda^0 \ell^+ \nu_\ell)$$

- The SU(3) predictions for Ξ_c decays

Channel	experiment data(%)	SU(3) symmetry(%)
$\Lambda_c \to \Lambda e^+ \nu_e$	3.6 ± 0.4[1]	3.6 ± 0.4
$\Lambda_c \to \Lambda \mu^+ \nu_\mu$	3.5 ± 0.5[1]	3.5 ± 0.5
$\Xi_c^+ \to \Xi^0 e^+ \nu_e$	7 ± 4[1]	12.7 ± 1.35
$\Xi_c^0 \to \Xi^- e^+ \nu_e$	1.54 ± 0.35[2, 3]	4.10 ± 0.46
$\Xi_c^0 \to \Xi^- \mu^+ \nu_\mu$	1.27 ± 0.44[3]	3.98 ± 0.57



[1]BES-III; PRL 115,221805(2015)
[2]Particle Data Group
[3]ALICE; arXiv:2105.05187
[4]Belle; PRL 127,121803(2021)

2σ standard deviation
6σ standard deviation
5σ standard deviation

Semileptonic anti-triplet charmed baryon decay

- **Using helicity amlitude method, the amplitude**

$$\mathcal{A}(B_c \to B_q \ell^+ \nu_\ell) = \frac{G_F}{\sqrt{2}} V_{cq}^* \boxed{\langle B_q | \bar{q}\gamma^\mu (1-\gamma_5) c | B_c \rangle} \langle \ell^+ \nu_\ell | \bar{\nu}_\ell \gamma^\nu (1-\gamma_5) \ell | 0 \rangle g_{\mu\nu}$$

$$\boxed{H_{\lambda,\lambda_w} = \langle B_q | \bar{q}\gamma^\mu (1-\gamma_5) c | B_c \rangle \epsilon_\mu^*(\lambda_w)}$$

form factors

Defination:

$$a_1^{\lambda,\lambda_w} = \bar{u}(\lambda)\left[\boxed{f_1\gamma^\mu} + f_2 \frac{i\sigma^{\nu\mu}}{M_i} q^\nu + f_3 \frac{q^\mu}{M_i}\right] u(\lambda_i)\epsilon_\mu^*(\lambda_w)$$
$$-\bar{u}(\lambda)\left[\boxed{f_1'\gamma^\mu} + f_2' \frac{i\sigma^{\nu\mu}}{M_i} q^\nu + f_3' \frac{q^\mu}{M_i}\right] \gamma_5 u(\lambda_i)\epsilon_\mu^*(\lambda_w)$$

$$H_{\lambda,\lambda_w} = a_1^{\lambda,\lambda_w} \times (T_{c\bar{3}})^{[ij]} (H_3)^k \epsilon_{ikm} (T_8)_j^m,$$

- **Experimental and fit data**

channel	branching ratio(%)	
	experimental data	fit data
$\Lambda_c^+ \to \Lambda^0 e^+ \nu_e$	3.60 ± 0.40	1.94 ± 0.18
$\Lambda_c^+ \to \Lambda^0 \mu^+ \nu_\mu$	3.5 ± 0.5	1.87 ± 0.176
$\Xi_c^+ \to \Xi^0 e^+ \nu_e$	7.0 ± 4.0	6.53 ± 0.60
$\Xi_c^0 \to \Xi^- e^+ \nu_e$	1.54 ± 0.35	2.17 ± 0.20
$\Xi_c^0 \to \Xi^- \mu^+ \nu_\mu$	1.27 ± 0.44	2.09 ± 0.19
$\chi^2/d.o.f = 14.3$	$f_1 = 1.05 \pm 0.30$	$f_1' = 0.11 \pm 0.95$

SU(3) symmetry not good symmetry

SU(3) symmetry breaking

- **Neglecting the masses of u and d quark, the mass Matrix can be written as:**

$$M = \begin{pmatrix} m_u & 0 & 0 \\ 0 & m_d & 0 \\ 0 & 0 & m_s \end{pmatrix}$$

$$\sim m_s \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 1 \end{pmatrix} = m_s \times \omega.$$

- **Helicity amplitude**

$$H_{\lambda,\lambda_W} = a_1^{\lambda,\lambda_w} \times (T_{c\bar{3}})^{[ij]}(H_3)^k \epsilon_{ikm}(T_8)^m_j$$

$$\boxed{\begin{aligned} &+a_2^{\lambda,\lambda_w} \times (T_{c\bar{3}})^{[in]}(H_3)^k \epsilon_{ikm}(T_8)^m_j \omega^j_n \\ &+a_3^{\lambda,\lambda_w} \times (T_{c\bar{3}})^{[in]}(H_3)^k \epsilon_{kjm}(T_8)^m_i \omega^j_n \\ &+a_4^{\lambda,\lambda_w} \times (T_{c\bar{3}})^{[in]}(H_3)^k \epsilon_{jim}(T_8)^m_k \omega^j_n \\ &+a_5^{\lambda,\lambda_w} \times (T_{c\bar{3}})^{[ij]}(H_3)^k \epsilon_{inm}(T_8)^m_j \omega^n_k \end{aligned}}$$

Symmetry breaking term

SU(3) symmetry breaking in helicity amplitude

✓Amplitude :

channel	amplitude II
$\Lambda_c^+ \to \Lambda^0 l^+ \nu$	$-\sqrt{\frac{2}{3}}(a_1^{\lambda,\lambda_w} + a_5^{\lambda,\lambda_w})V_{cs}^*$
$\Lambda_c^+ \to n l^+ \nu$	$a_1 V_{cd}^*$
$\Xi_c^+ \to \Sigma^0 \ell^+ \nu_\ell$	$\frac{(a_1^{\lambda,\lambda_w} + a_3^{\lambda,\lambda_w} - a_4^{\prime\lambda,\lambda_w})V_{cd}^*}{\sqrt{2}}$
$\Xi_c^+ \to \Lambda^0 \ell^+ \nu_\ell$	$-\frac{(a_1^{\lambda,\lambda_w} + 2a_2^{\prime\lambda,\lambda_w} - a_3^{\lambda,\lambda_w} - a_4^{\prime\lambda,\lambda_w})V_{cd}^*}{\sqrt{6}}$
$\Xi_c^+ \to \Xi^0 \ell^+ \nu_\ell$	$-(a_1^{\lambda,\lambda_w} + a_2^{\prime\lambda,\lambda_w} - a_4^{\prime\lambda,\lambda_w} + a_5^{\lambda,\lambda_w})V_{cs}^*$
$\Xi_c^0 \to \Sigma^- \ell^+ \nu_\ell$	$(a_1^{\lambda,\lambda_w} + a_3^{\lambda,\lambda_w} - a_4^{\prime\lambda,\lambda_w})V_{cd}^*$
$\Xi_c^0 \to \Xi^- \ell^+ \nu_\ell$	$(a_1^{\lambda,\lambda_w} + a_2^{\prime\lambda,\lambda_w} - a_4^{\prime\lambda,\lambda_w} + a_5^{\lambda,\lambda_w})V_{cs}^*$

$$a_1^{\lambda,\lambda_w} + a_5^{\lambda,\lambda_w} = f_1(q^2) \times \bar{u}(\lambda)\gamma^\mu u(\lambda_i)\epsilon_\mu^*(\lambda_w)$$
$$-f_1'(q^2) \times \bar{u}(\lambda)\gamma^\mu\gamma_5 u(\lambda_i)\epsilon_\mu^*(\lambda_w)$$

Heavy quark Limit

➢Constant

$a_i^{\lambda,\lambda_w}(i = 1,2,3,4,5) =$ Constant

➢ Pole model

$$f_i(q^2) = \frac{f_i}{1 - \frac{q^2}{m_p^2}}$$

$$f_i = f_i(q^2 = 0)$$

$$m_p = 2.061$$

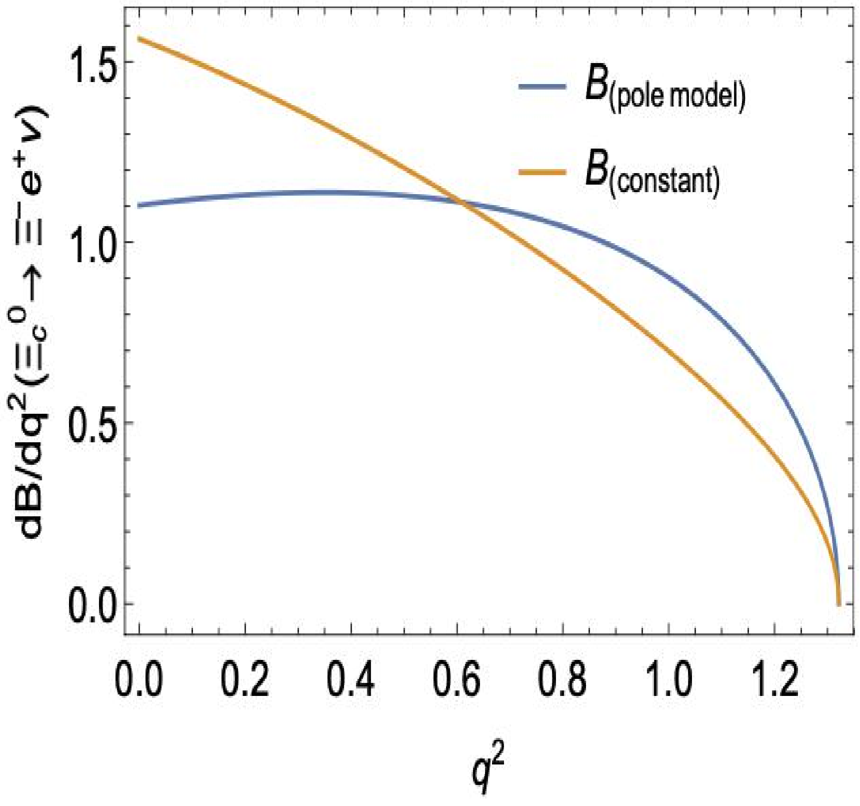
the average mass of D and Ds

SU(3) symmetry breaking in helicity amplitude

✓Experimental data and fit results

channel	branching ratio(%)		
	experimental data	fit data(pole model)	fit data(constant).
$\Lambda_c^+ \to \Lambda^0 e^+ \nu_e$	3.6 ± 0.4	3.61 ± 0.32	3.62 ± 0.32
$\Lambda_c^+ \to \Lambda^0 \mu^+ \nu_\mu$	3.5 ± 0.5	3.48 ± 0.30	3.45 ± 0.30
$\Xi_c^+ \to \Xi^0 e^+ \nu_e$	7.0 ± 4.0	3.89 ± 0.73	3.92 ± 0.73
$\Xi_c^0 \to \Xi^- e^+ \nu_e$	1.54 ± 0.35	1.29 ± 0.24	1.31 ± 0.24
$\Xi_c^0 \to \Xi^- \mu^+ \nu_\mu$	1.27 ± 0.44	1.24 ± 0.23	1.24 ± 0.23
fit parameter (pole model)	$f_1 = 1.01 \pm 0.87,\ \delta f_1 = -0.51 \pm 0.92$ $f_1' = 0.60 \pm 0.49,\ \delta f_1' = -0.23 \pm 0.41$		$\chi^2/d.o.f = 1.6$
fit parameter (constant)	$f_1 = 0.86 \pm 0.92,\ \delta f_1 = -0.25 \pm 0.88$ $f_1' = 0.85 \pm 0.36,\ \delta f_1' = -0.43 \pm 0.50$		$\chi^2/d.o.f = 1.9$

✓Differential decay branching fraction



Symmetry breaking caused by the $\Xi_c^0 - \Xi_c^{\prime 0/+}$

$$\Xi_c^{0/+mass} = \cos\theta \times \Xi_c^{0/+} + \sin\theta \times \Xi_c^{0/+\prime}$$

✓Amplitude :

channel	amplitude
$\Sigma_c^{++} \to \Sigma^+ l^+ \nu$	$-\left(c_1^{\lambda,\lambda_w} + c_5^{\lambda,\lambda_w}\right) V_{cs}^*$
$\Sigma_c^{++} \to p l^+ \nu$	$c_1^{\lambda,\lambda_w} V_{cd}^*$
$\Sigma_c^{+} \to \Sigma^0 l^+ \nu$	$\left(c_1^{\lambda,\lambda_w} + c_5^{\lambda,\lambda_w}\right) V_{cs}^*$
$\Sigma_c^{+} \to n l^+ \nu$	$\frac{c_1 V_{cd}^*}{\sqrt{2}}$
$\Xi_c^{\prime +} \to \Sigma^0 l^+ \nu$	$-\frac{1}{2}\left(c_1^{\lambda,\lambda_w} - c_3^{\lambda,\lambda_w} + c_4^{\lambda,\lambda_w}\right) V_{cd}^*$
$\Xi_c^{\prime +} \to \Lambda^0 l^+ \nu$	$\frac{\left(-3c_1^{\lambda,\lambda_w} - 2c_2^{\lambda,\lambda_w} + c_3^{\lambda,\lambda_w} + c_4^{\lambda,\lambda_w}\right) V_{cd}^*}{2\sqrt{3}}$
$\Xi_c^{\prime +} \to \Xi^0 l^+ \nu$	$-\frac{\left(c_1^{\lambda,\lambda_w} + c_2^{\lambda,\lambda_w} - c_4^{\lambda,\lambda_w} + c_5^{\lambda,\lambda_w}\right) V_{cs}^*}{\sqrt{2}}$
$\Xi_c^{0} \to \Sigma^- l^+ \nu$	$\left(c_1^{\lambda,\lambda_w} + c_5^{\lambda,\lambda_w}\right) V_{cs}^*$
$\Xi_c^{\prime 0} \to \Sigma^- l^+ \nu$	$-\frac{\left(c_1^{\lambda,\lambda_w} - c_3^{\lambda,\lambda_w} + c_4^{\lambda,\lambda_w}\right) V_{cd}^*}{\sqrt{2}}$
$\Xi_c^{\prime 0} \to \Xi^- l^+ \nu$	$\frac{\left(c_1^{\lambda,\lambda_w} + c_2^{\lambda,\lambda_w} - c_4^{\lambda,\lambda_w} + c_5^{\lambda,\lambda_w}\right) V_{cs}^*}{\sqrt{2}}$
$\Omega_c^{0} \to \Xi^- l^+ \nu$	$-\left(c_1^{\lambda,\lambda_w} + c_2^{\lambda,\lambda_w} - c_3^{\lambda,\lambda_w}\right) V_{cd}^*$

✓ **Helicity amplitude**

$$H_{\lambda,\lambda_W} = c_1^{\lambda,\lambda_w} \times (T_{c6})^{\{ij\}} (H_3)^k \epsilon_{ikm} (T_8)_j^m$$

$$+c_2^{\lambda,\lambda_w} \times (T_{c6})^{\{in\}} (H_3)^k \epsilon_{ikm} (T_8)_j^m \omega_n^j$$

$$+c_3^{\lambda,\lambda_w} \times (T_{c6})^{\{in\}} (H_3)^k \epsilon_{kjm} (T_8)_i^m \omega_n^j$$

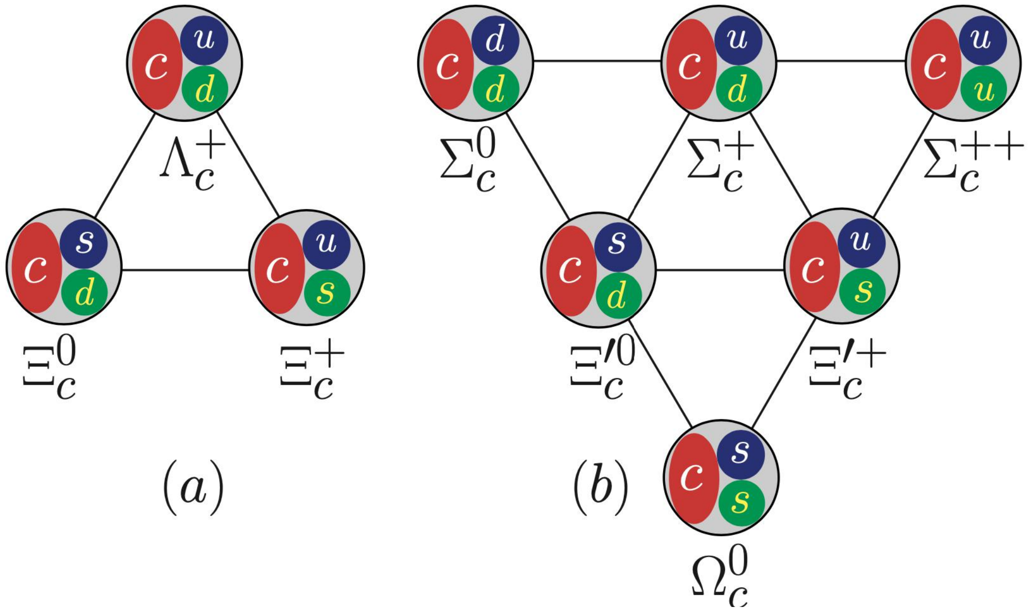
$$+c_4^{\lambda,\lambda_w} \times (T_{c6})^{\{in\}} (H_3)^k \epsilon_{jim} (T_8)_k^m \omega_n^j$$

$$+c_5^{\lambda,\lambda_w} \times (T_{c6})^{[ij]} (H_3)^k \epsilon_{inm} (T_8)_j^m \omega_k^n$$

Symmetry breaking caused by the $\Xi_c^0 - \Xi_c^{\prime 0/+}$

✓Amplitude for mass mixing :

channel	amplitude I
$\Lambda_c^+ \to \Lambda^0 l^+ \nu$	$-\sqrt{\frac{2}{3}}(a_1^{\lambda,\lambda_w} + a_5^{\lambda,\lambda_w})V_{cs}^*$
$\Lambda_c^+ \to n l^+ \nu$	$a_1 V_{cd}^*$
$\Xi_c^+ \to \Sigma^0 \ell^+ \nu_\ell$	$\frac{(a_1^{\lambda,\lambda_w} + a_3^{\lambda,\lambda_w} - a_4^{\lambda,\lambda_w} - \frac{c_1^{\lambda,\lambda_w}}{\sqrt{2}}\theta)V_{cd}^*}{\sqrt{2}}$
$\Xi_c^+ \to \Lambda^0 \ell^+ \nu_\ell$	$-\frac{(a_1^{\lambda,\lambda_w} + 2a_2^{\lambda,\lambda_w} - a_3^{\lambda,\lambda_w} - a_4^{\lambda,\lambda_w} + \frac{3c_1^{\lambda,\lambda_w}}{\sqrt{2}}\theta)V_{cd}^*}{\sqrt{6}}$
$\Xi_c^+ \to \Xi^0 \ell^+ \nu_\ell$	$-(a_1^{\lambda,\lambda_w} + a_2^{\lambda,\lambda_w} - a_4^{\lambda,\lambda_w} + a_5^{\lambda,\lambda_w} + \frac{c_1^{\lambda,\lambda_w}}{\sqrt{2}}\theta)V_{cs}^*$
$\Xi_c^0 \to \Sigma^- \ell^+ \nu_\ell$	$(a_1^{\lambda,\lambda_w} + a_3^{\lambda,\lambda_w} - a_4^{\lambda,\lambda_w} - \frac{c_1^{\lambda,\lambda_w}}{\sqrt{2}}\theta)V_{cd}^*$
$\Xi_c^0 \to \Xi^- \ell^+ \nu_\ell$	$(a_1^{\lambda,\lambda_w} + a_2^{\lambda,\lambda_w} - a_4^{\lambda,\lambda_w} + a_5^{\lambda,\lambda_w} + \frac{c_1^{\lambda,\lambda_w}}{\sqrt{2}}\theta)V_{cs}^*$



➢ Leading order

$$H^{mass}_{\lambda,\lambda_w} \propto V_{cs}^*(a_1^{\lambda,\lambda_w} + a_2^{\lambda,\lambda_w} - a_4^{\lambda,\lambda_w} + a_5^{\lambda,\lambda_w} + \frac{c_1^{\lambda,\lambda_w}}{\sqrt{2}}\theta)$$

Neglect the $O(m_s^2)$ and higher order corrections

Prediciton

✓Amplitude :

channel	amplitude I
$\Lambda_c^+ \to \Lambda^0 l^+ \nu$	$-\sqrt{\frac{2}{3}}(a_1^{\lambda,\lambda_w} + a_5^{\lambda,\lambda_w})V_{cs}^*$
$\Lambda_c^+ \to n l^+ \nu$	$a_1 V_{cd}^*$
$\Xi_c^+ \to \Sigma^0 \ell^+ \nu_\ell$	$\frac{(a_1^{\lambda,\lambda_w} + a_3^{\lambda,\lambda_w} - a_4^{\lambda,\lambda_w} - \frac{c_1^{\lambda,\lambda_w}}{\sqrt{2}}\theta)V_{cd}^*}{\sqrt{2}}$
$\Xi_c^+ \to \Lambda^0 \ell^+ \nu_\ell$	$-\frac{(a_1^{\lambda,\lambda_w} + 2a_2^{\lambda,\lambda_w} - a_3^{\lambda,\lambda_w} - a_4^{\lambda,\lambda_w} + \frac{3c_1^{\lambda,\lambda_w}}{\sqrt{2}}\theta)V_{cd}^*}{\sqrt{6}}$
$\Xi_c^+ \to \Xi^0 \ell^+ \nu_\ell$	$-(a_1^{\lambda,\lambda_w} + a_2^{\lambda,\lambda_w} - a_4^{\lambda,\lambda_w} + a_5^{\lambda,\lambda_w} + \frac{c_1^{\lambda,\lambda_w}}{\sqrt{2}}\theta)V_{cs}^*$
$\Xi_c^0 \to \Sigma^- \ell^+ \nu_\ell$	$(a_1^{\lambda,\lambda_w} + a_3^{\lambda,\lambda_w} - a_4^{\lambda,\lambda_w} - \frac{c_1^{\lambda,\lambda_w}}{\sqrt{2}}\theta)V_{cd}^*$
$\Xi_c^0 \to \Xi^- \ell^+ \nu_\ell$	$(a_1^{\lambda,\lambda_w} + a_2^{\lambda,\lambda_w} - a_4^{\lambda,\lambda_w} + a_5^{\lambda,\lambda_w} + \frac{c_1^{\lambda,\lambda_w}}{\sqrt{2}}\theta)V_{cs}^*$

✓Estimate :

$$\mathcal{B}(\Lambda_c^+ \to n e^+ \nu_e) = (0.520 \pm 0.046)\%$$

$$\mathcal{B}(\Lambda_c^+ \to n \mu^+ \mu_\nu) = (0.506 \pm 0.045)\%$$

Assuming a_5^{λ,λ_w} giving no contribution

Prediciton

✓Amplitude :

channel	amplitude I
$\Lambda_c^+ \to \Lambda^0 l^+ \nu$	$-\sqrt{\frac{2}{3}}(a_1^{\lambda,\lambda_w} + a_5^{\lambda,\lambda_w})V_{cs}^*$
$\Lambda_c^+ \to n l^+ \nu$	$a_1 V_{cd}^*$
$\Xi_c^+ \to \Sigma^0 \ell^+ \nu_\ell$	$\frac{(a_1^{\lambda,\lambda_w}+a_3^{\lambda,\lambda_w}-a_4^{\lambda,\lambda_w}-\frac{c_1^{\lambda,\lambda_w}}{\sqrt{2}}\theta)V_{cd}^*}{\sqrt{2}}$
$\Xi_c^+ \to \Lambda^0 \ell^+ \nu_\ell$	$-\frac{(a_1^{\lambda,\lambda_w}+2a_2^{\lambda,\lambda_w}-a_3^{\lambda,\lambda_w}-a_4^{\lambda,\lambda_w}+\frac{3c_1^{\lambda,\lambda_w}}{\sqrt{2}}\theta)V_{cd}^*}{\sqrt{6}}$
$\boxed{\Xi_c^+ \to \Xi^0 \ell^+ \nu_\ell}$	$\boxed{-(a_1^{\lambda,\lambda_w} + a_2^{\lambda,\lambda_w} - a_4^{\lambda,\lambda_w} + a_5^{\lambda,\lambda_w} + \frac{c_1^{\lambda,\lambda_w}}{\sqrt{2}}\theta)V_{cs}^*}$
$\Xi_c^0 \to \Sigma^- \ell^+ \nu_\ell$	$(a_1^{\lambda,\lambda_w} + a_3^{\lambda,\lambda_w} - a_4^{\lambda,\lambda_w} - \frac{c_1^{\lambda,\lambda_w}}{\sqrt{2}}\theta)V_{cd}^*$
$\boxed{\Xi_c^0 \to \Xi^- \ell^+ \nu_\ell}$	$\boxed{(a_1^{\lambda,\lambda_w} + a_2^{\lambda,\lambda_w} - a_4^{\lambda,\lambda_w} + a_5^{\lambda,\lambda_w} + \frac{c_1^{\lambda,\lambda_w}}{\sqrt{2}}\theta)V_{cs}^*}$

✓Estimate :

$$\mathcal{B}(\Xi_c^+ \to \Sigma^0 e^+ \nu_e) = (0.496 \pm 0.046)\%$$
$$\mathcal{B}(\Xi_c^+ \to \Sigma^0 \mu^+ \nu_\mu) = (0.481 \pm 0.044)\%$$

$$\mathcal{B}(\Xi_c^+ \to \Lambda^0 e^+ \nu_e) = (0.067 \pm 0.013)\%$$
$$\mathcal{B}(\Xi_c^+ \to \Lambda^0 \mu^+ \nu_\mu) = (0.069 \pm 0.0213)\%$$

$$\mathcal{B}(\Xi_c^0 \to \Sigma^- e^+ \nu_e) = (0.333 \pm 0.031)\%$$
$$\mathcal{B}(\Xi_c^0 \to \Sigma^- \mu^+ \nu_\nu) = (0.323 \pm 0.029)\%$$

Assuming $a_2^{\lambda,\lambda_w}, a_3^{\lambda,\lambda_w}, a_5^{\lambda,\lambda_w}$ giving no contribution

Summary

- We have analzyed the latest data on charmed baryon decays, and found large deviations from SU(3) symmetry;
- We obtain a reasonable description of all relevent data with SU(3) symmetry breaking effect;
- As an estimation, we give the branching ratios for $\Lambda_c \to n\ell^+\nu_\ell, \Xi_c \to \Sigma^0\ell^+\nu_\ell,$ $\Xi_c^+ \to \Lambda^0\ell^+\nu_\ell, \Xi_c^0 \to \Sigma^-\ell^+\nu_\ell$

Thanks!

Backup

backup

channel	amplitude II
$\Lambda_c^+ \to \Lambda^0 l^+ \nu$	$-\sqrt{\frac{2}{3}}(a_1^{\lambda,\lambda_w} + a_5^{\lambda,\lambda_w})V_{cs}^*$
$\Lambda_c^+ \to n l^+ \nu$	$a_1 V_{cd}^*$
$\Xi_c^+ \to \Sigma^0 \ell^+ \nu_\ell$	$\frac{(a_1^{\lambda,\lambda_w} + a_3^{\lambda,\lambda_w} - a_4'^{\lambda,\lambda_w})V_{cd}^*}{\sqrt{2}}$
$\Xi_c^+ \to \Lambda^0 \ell^+ \nu_\ell$	$-\frac{(a_1^{\lambda,\lambda_w} + 2a_2'^{\lambda,\lambda_w} - a_3^{\lambda,\lambda_w} - a_4'^{\lambda,\lambda_w})V_{cd}^*}{\sqrt{6}}$
$\Xi_c^+ \to \Xi^0 \ell^+ \nu_\ell$	$-(a_1^{\lambda,\lambda_w} + a_2'^{\lambda,\lambda_w} - a_4'^{\lambda,\lambda_w} + a_5^{\lambda,\lambda_w})V_{cs}^*$
$\Xi_c^0 \to \Sigma^- \ell^+ \nu_\ell$	$(a_1^{\lambda,\lambda_w} + a_3^{\lambda,\lambda_w} - a_4'^{\lambda,\lambda_w})V_{cd}^*$
$\Xi_c^0 \to \Xi^- \ell^+ \nu_\ell$	$(a_1^{\lambda,\lambda_w} + a_2'^{\lambda,\lambda_w} - a_4'^{\lambda,\lambda_w} + a_5^{\lambda,\lambda_w})V_{cs}^*$

$$a_1^{\lambda,\lambda_w} + a_5^{\lambda,\lambda_w} = f_1(q^2) \times \bar{u}(\lambda)\gamma^\mu u(\lambda_i)\epsilon_\mu^*(\lambda_w) - f_1'(q^2) \times \bar{u}(\lambda)\gamma^\mu\gamma_5 u(\lambda_i)\epsilon_\mu^*(\lambda_w)$$

$$a_2^{\lambda,\lambda_w} - a_4^{\lambda,\lambda_w} = \delta f_1(q^2) \times \bar{u}(\lambda)\gamma^\mu u(\lambda_i)\epsilon_\mu^*(\lambda_w) - \delta f_1'(q^2) \times \bar{u}(\lambda)\gamma^\mu\gamma_5 u(\lambda_i)\epsilon_\mu^*(\lambda_w)$$

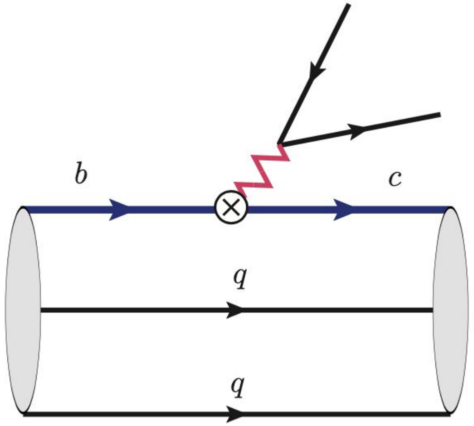
$$a_3^{\lambda,\lambda_w} = \Delta f_1(q^2) \times \bar{u}(\lambda)\gamma^\mu u(\lambda_i)\epsilon_\mu^*(\lambda_w) - \Delta f_1'(q^2) \times \bar{u}(\lambda)\gamma^\mu\gamma_5 u(\lambda_i)\epsilon_\mu^*(\lambda_w)$$

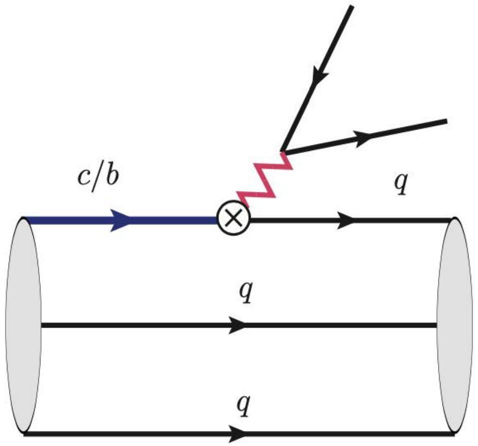
SU(3) symmetry in anti-triplet beauty baryons

- Helicity amplitude in SU(3) analysis

$$H_{\lambda,\lambda_w} = b_1^{\lambda,\lambda_w} \times (T_{b\bar{3}})^{[ij]}(H_3')^k \epsilon_{ikm}(T_8)_j^m + e_1^{\lambda,\lambda_w} \times (T_{b\bar{3}})^{[ij]}(T_{c\bar{3}})_{[ij]}$$

channel	amplitude	branching fraction (%)
$\Lambda_b^0 \to p\ell^-\bar{\nu}_\ell$	b_1^{λ,λ_w}	4.1 ± 1.0(input)[1]
$\Xi_b^0 \to \Sigma^+\ell^-\bar{\nu}_\ell$	$-b_1^{\lambda,\lambda_w}$	4.1 ± 1.0
$\Xi_b^- \to \Sigma^0\ell^-\bar{\nu}_\ell$	$\frac{b_1^{\lambda,\lambda_w}}{\sqrt{2}}$	2.2 ± 0.5
$\Xi_b^- \to \Lambda^0\ell^-\bar{\nu}_\ell$	$\frac{b_1^{\lambda,\lambda_w}}{\sqrt{6}}$	0.7 ± 0.2
$\Lambda_b^0 \to \Lambda_c^+\ell^-\bar{\nu}_\ell$	$2e_1^{\lambda,\lambda_w}$	$6.2^{+1.4}_{-1.3}$(input)[2]
$\Xi_b^0 \to \Xi_c^+\ell^-\bar{\nu}_\ell$	$2e_1^{\lambda,\lambda_w}$	$6.2^{+1.4}_{-1.3}$
$\Xi_b^- \to \Xi_c^0\ell^-\bar{\nu}_\ell$	$2e_1^{\lambda,\lambda_w}$	$6.6^{+1.5}_{-1.4}$





SU(3) symmetry breaking in anti-triplet beauty baryons

- Helicity amplitude in SU(3) analysis

channel	amplitude
$\Lambda_b^0 \to p\ell^-\bar{\nu}_\ell$	b_1^{λ,λ_w}
$\Xi_b^0 \to \Sigma^+\ell^-\bar{\nu}_\ell$	$-b_1^{\lambda,\lambda_w} + b_3^{\lambda,\lambda_w} - b_4^{\lambda,\lambda_w}$
$\Xi_b^- \to \Sigma^0\ell^-\bar{\nu}_\ell$	$\frac{b_1^{\lambda,\lambda_w} - b_3^{\lambda,\lambda_w} - b_4^{\lambda,\lambda_w}}{\sqrt{2}}$
$\Xi_b^- \to \Lambda^0\ell^-\bar{\nu}_\ell$	$\frac{b_1^{\lambda,\lambda_w} + 2b_2^{\lambda,\lambda_w} + b_3^{\lambda,\lambda_w} - b_4^{\lambda,\lambda_w}}{\sqrt{6}}$
$\Lambda_b^0 \to \Lambda_c^+\ell^-\bar{\nu}_\ell$	$2e_1^{\lambda,\lambda_w}$
$\Xi_b^0 \to \Xi_c^+\ell^-\bar{\nu}_\ell$	$2e_1^{\lambda,\lambda_w} + e_2^{\lambda,\lambda_w}$
$\Xi_b^- \to \Xi_c^0\ell^-\bar{\nu}_\ell$	$2e_1^{\lambda,\lambda_w} + e_2^{\lambda,\lambda_w}$

$$\Gamma(\Xi_b^- \to \Sigma^0\ell^-\bar{\nu}_\ell) = \frac{1}{2}\Gamma(\Xi_b^0 \to \Sigma^+\ell^-\bar{\nu}_\ell)$$
$$\Gamma(\Xi_b^0 \to \Xi_c^+\ell^-\bar{\nu}_\ell) = \Gamma(\Xi_b^- \to \Xi_c^0\ell^-\bar{\nu}_\ell)$$

- **Helicity amplitude**

$$\begin{aligned}
H_{\lambda,\lambda_w} = {} & b_1^{\lambda,\lambda_w} \times (T_{b\bar{3}})^{[ij]}(H_3')^k \epsilon_{ikm}(T_8)^m_j \\
& \boxed{\begin{aligned} &+b_2^{\lambda,\lambda_w} \times (T_{b\bar{3}})^{[in]}(H_3')^k \epsilon_{ikm}(T_8)^m_j \omega^j_n \\
&+b_3^{\lambda,\lambda_w} \times (T_{c\bar{3}})^{[in]}(H_3')^k \epsilon_{jkm}(T_8)^m_i \omega^j_n \\
&+b_4^{\lambda,\lambda_w} \times (T_{c\bar{3}})^{[in]}(H_3')^k \epsilon_{ikm}(T_8)^m_j \omega^j_n \\
&+b_5^{\lambda,\lambda_w} \times (T_{c\bar{3}})^{[ij]}(H_3')^k \epsilon_{inm}(T_8)^m_j \omega^n_k \end{aligned}} \\
& +e_1^{\lambda,\lambda_w} \times (T_{b\bar{3}})^{[ij]}(T_{c\bar{3}})_{[ij]} \\
& \boxed{+e_2^{\lambda,\lambda_w} \times (T_{b\bar{3}})^{[ij]}(T_{c\bar{3}})_{[kj]}}
\end{aligned}$$

Symmetry breaking term