Weak Decays of Triply Heavy Baryons

Ji Xu
Shanghai Jiao Tong University

24.04.2018 Beijing
2nd workshop on heavy quark physics

In collaboration with Wei Wang

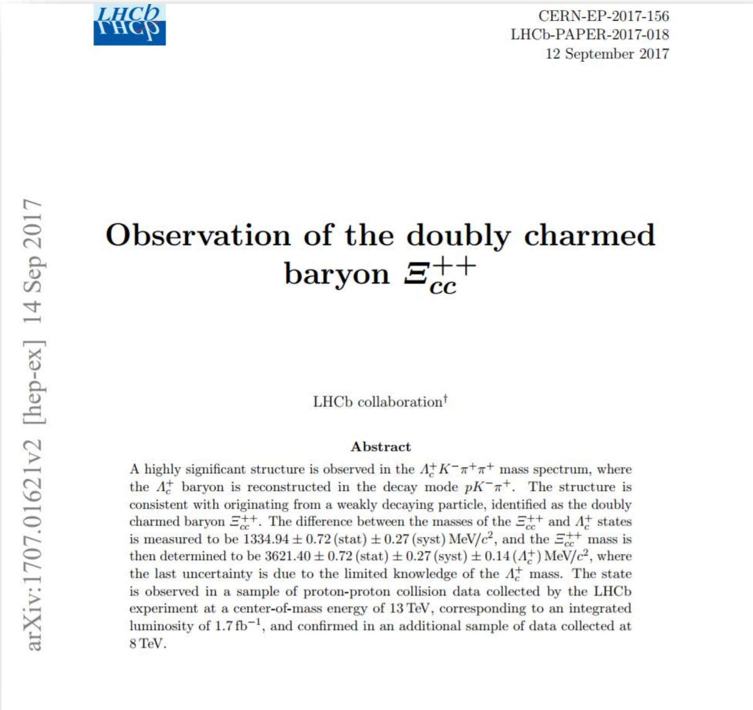
arXiv: 1803.01476

Contents:

- Background
- Lifetime and branching ratios
- SU(3) Analysis
- Golden channels
- Summary

Background

Discovery of Ξ_{cc}^{++}



LHCb

CERN-EP-2017-156
LHCb-PAPER-2017-018
12 September 2017

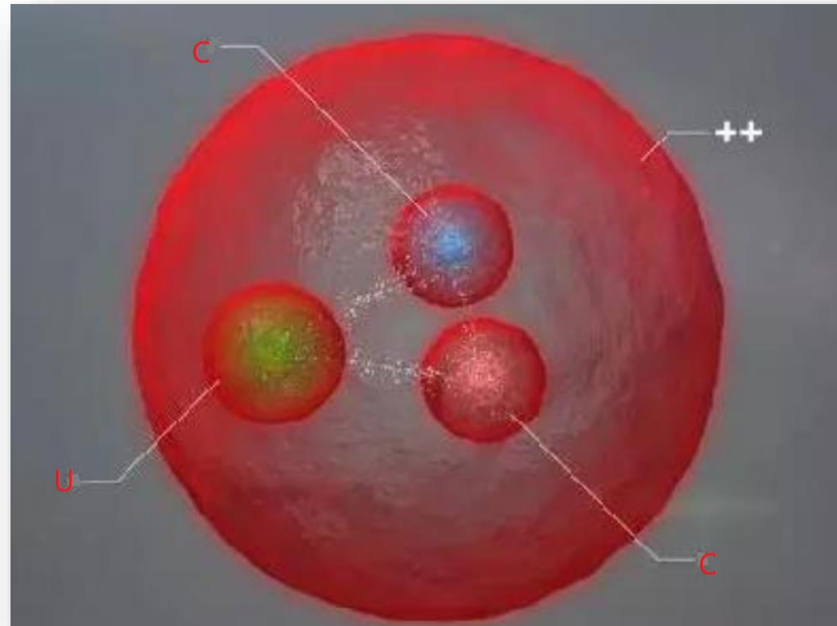
arXiv:1707.01621v2 [hep-ex] 14 Sep 2017

Observation of the doubly charmed baryon Ξ_{cc}^{++}

LHCb collaboration†

Abstract

A highly significant structure is observed in the $\Lambda_c^+ K^- \pi^+ \pi^+$ mass spectrum, where the Λ_c^+ baryon is reconstructed in the decay mode $pK^-\pi^+$. The structure is consistent with originating from a weakly decaying particle, identified as the doubly charmed baryon Ξ_{cc}^{++}. The difference between the masses of the Ξ_{cc}^{++} and Λ_c^+ states is measured to be $1334.94 \pm 0.72\,(\text{stat}) \pm 0.27\,(\text{syst})\,\text{MeV}/c^2$, and the Ξ_{cc}^{++} mass is then determined to be $3621.40 \pm 0.72\,(\text{stat}) \pm 0.27\,(\text{syst}) \pm 0.14\,(\Lambda_c^+)\,\text{MeV}/c^2$, where the last uncertainty is due to the limited knowledge of the Λ_c^+ mass. The state is observed in a sample of proton-proton collision data collected by the LHCb experiment at a center-of-mass energy of 13 TeV, corresponding to an integrated luminosity of $1.7\,\text{fb}^{-1}$, and confirmed in an additional sample of data collected at 8 TeV.

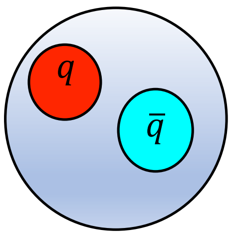


$$m_{\Xi_{cc}^{++}} = (3621.40 \pm 0.72 \pm 0.27 \pm 0.14)\text{MeV}.$$

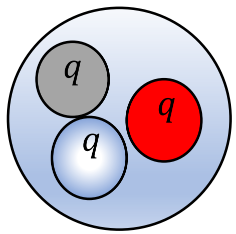
(See talk by Prof. Yu Fu-Sheng: Weak decyas of doubly heavy baryons
And Dr. EKLUND Lars: Searching for Xi_cc at LHCb)

Quark model

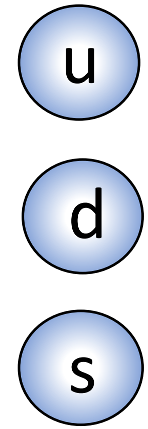
- In 1964, Gell-Mann and Zweig proposed a way to build the numerous hadrons out of three fundamental quarks.



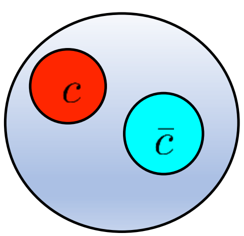
Meson

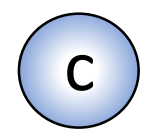


Baryon



- The 1974 discovery of the J/ψ (and thus the charm quark) ushered in a series of breakthroughs which are collectively known as the November Revolution.





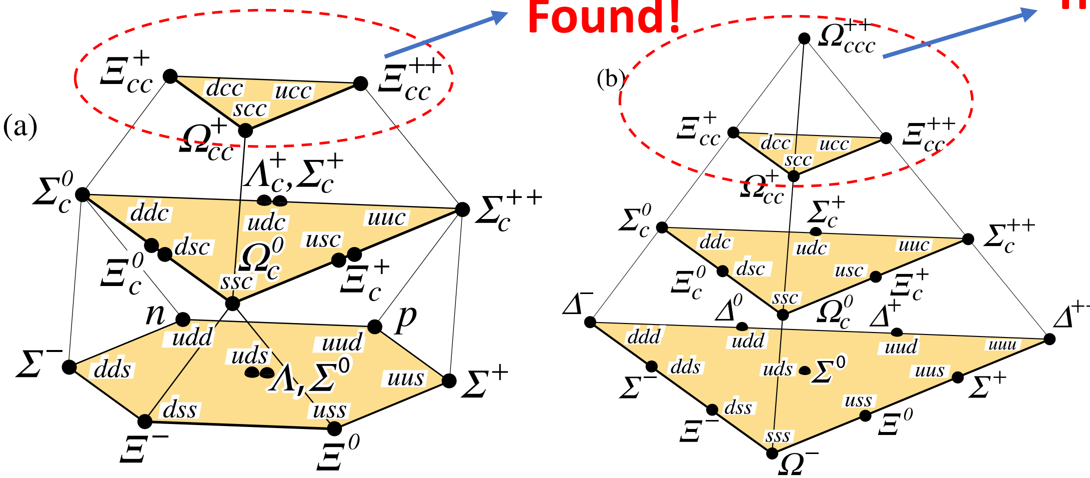
Quark model

- For baryons with four flavors u,d,s,c, a 20-plet for JP =1/2+ and JP =3/2+, respectively

Found!

Triply heavy baryon

$J^P = 1/2^+$



$J^P = 3/2^+$

Baryons with three heavy quarks：

The last missing pieces of the lowest-lying baryon multiplets in quark model !

Lifetime and branching ratios

- Previous studies of triply heavy baryons concentrated on three facets:

(1) Spectroscopy: Y. Jia, JHEP (2006); A. P. Martynenko, Phys. Lett. B (2008); Z. G. Wang, Commun. Theor. Phys. (2012)……

(2) Production: Y. Q. Chen and S. Z. Wu, JHEP 2011; M.A. Gomshi Nobary and R. Sepahvand, Phy.Rev.D(2005);

(3) Decays: C.Q.Geng, Y.K.Hsiao, C.W.Liu and T.H.Tsai, JHEP(2017)

	This work
$\Omega_{ccc}(\frac{3}{2}^+)$	4.99 ± 0.14
$\Omega_{ccb}(\frac{1}{2}^+)$	8.23 ± 0.13
$\Omega_{ccb}(\frac{3}{2}^+)$	8.23 ± 0.13
$\Omega_{bbc}(\frac{1}{2}^+)$	11.50 ± 0.11
$\Omega_{bbc}(\frac{3}{2}^+)$	11.49 ± 0.11
$\Omega_{bbb}(\frac{3}{2}^+)$	14.83 ± 0.10
$\Omega_{ccc}(\frac{3}{2}^-)$	5.11 ± 0.15
$\Omega_{ccb}(\frac{1}{2}^-)$	8.36 ± 0.13
$\Omega_{ccb}(\frac{3}{2}^-)$	8.36 ± 0.13
$\Omega_{bbc}(\frac{1}{2}^-)$	11.62 ± 0.11
$\Omega_{bbc}(\frac{3}{2}^-)$	11.62 ± 0.11
$\Omega_{bbb}(\frac{3}{2}^-)$	14.95 ± 0.11

(Z. G. Wang, Commun. Theor. Phys. 2012)

$$\Omega_{ccc}^{++} \to (\Xi_{cc}^{++}\bar{K}^0, \Omega_{cc}^{+}\pi^+, \Xi_c^+ D^+)$$

The cross sections at the LHC with √s = 7 TeV are found to reach the 0.1 nb level

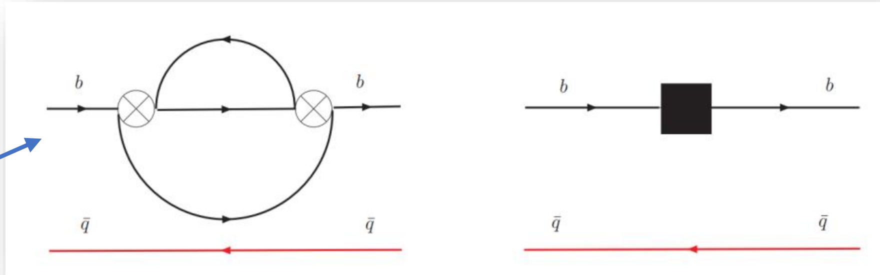
- Lifetimes or the total decay widths are among the most fundamental properties of the involved triply heavy baryons.

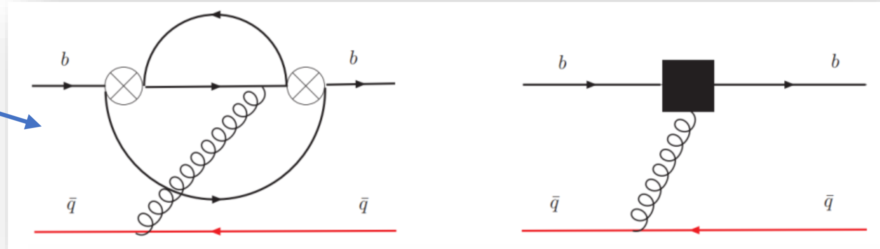
- A theoretical tools that describes the decay widths of inclusive decays is heavy quark expansion.

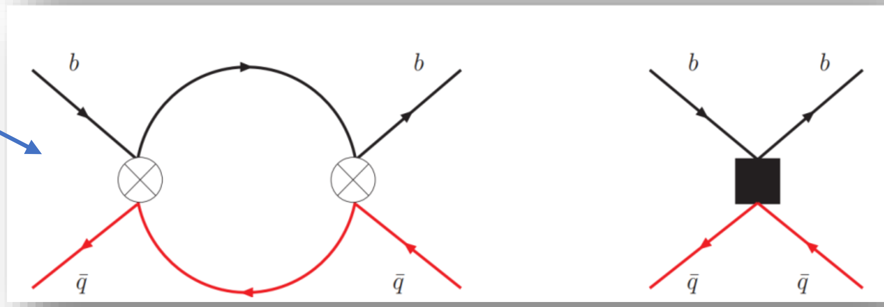
- The total decay rate is given by matrix elements of operators below:

(A. Lenz, Int. J. Mod. Phys. A, 2015)

$$
\Gamma(H) = \frac{G_F m_Q^5}{192\pi^3}|V_{CKM}|^2 \Bigg(c_{3,Q} \frac{\langle H|\bar{c}c|H\rangle}{2m_H} + \frac{c_{5,Q}}{m_Q^2}\frac{\langle H|\bar{Q}g_s\sigma_{\mu\nu}G^{\mu\nu}Q|H\rangle}{2m_H} + \frac{c_{6,Q}}{m_Q^3}\frac{\langle H|(\bar{Q}q)_\Gamma(\bar{q}Q)_\Gamma|H\rangle}{m_H} \Bigg).
$$







- $c_{3,c}$ = 6.29±0.72 at LO and 11.61±1.55 at NLO. **(A. Lenz, Int. J. Mod. Phys. A, 2015)**

$$\Gamma(\Omega_{ccc}^{++}) = \begin{cases} (2.18 \pm 0.25) \times 10^{-12}\text{GeV}, & \text{LO} \\ (4.03 \pm 0.54) \times 10^{-12}\text{GeV}, & \text{NLO} \end{cases},$$

$$\tau(\Omega_{ccc}^{++}) = \begin{cases} (302 \pm 35) \times 10^{-15}s, & \text{LO} \\ (164 \pm 22) \times 10^{-15}s, & \text{NLO} \end{cases}.$$

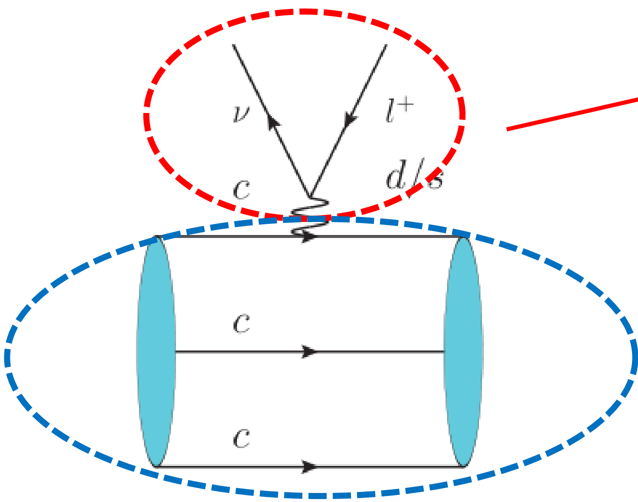
$$\Gamma(\Omega_{bbb}^{-}) = \begin{cases} (1.47 \pm 0.01) \times 10^{-12}\text{GeV}, & \text{LO} \\ (1.92 \pm 0.02) \times 10^{-12}\text{GeV}, & \text{NLO} \end{cases},$$

$$\tau(\Omega_{bbb}^{-}) = \begin{cases} (0.45 \pm 0.03) \times 10^{-12}s, & \text{LO} \\ (0.34 \pm 0.04) \times 10^{-12}s, & \text{NLO} \end{cases}.$$

- For process: $\Omega_{ccc}^{++} \to \Omega_{cc}^{+}\, \ell^{+}\nu$, leptonic amplitudes can be calculated in electroweak perturbation theory. While the hadronic matrix element can be parametrized in terms of form factors:

The $c \to q\bar{\ell}\nu$ transition is induced by the effective electro-weak Hamiltonian:

$$\mathcal{H}_{e.w.} = \frac{G_F}{\sqrt{2}}\left[V_{cq}^{*}\bar{q}\gamma^{\mu}(1-\gamma_5)c\bar{\nu}_{\ell}\gamma_{\mu}(1-\gamma_5)\ell\right] + h.c.,$$



$$\Gamma(\Omega_{ccc}^{++} \to \Omega_{cc}^{+} l^{+}\nu) = 1.41 \times 10^{-13}\mathrm{GeV}$$

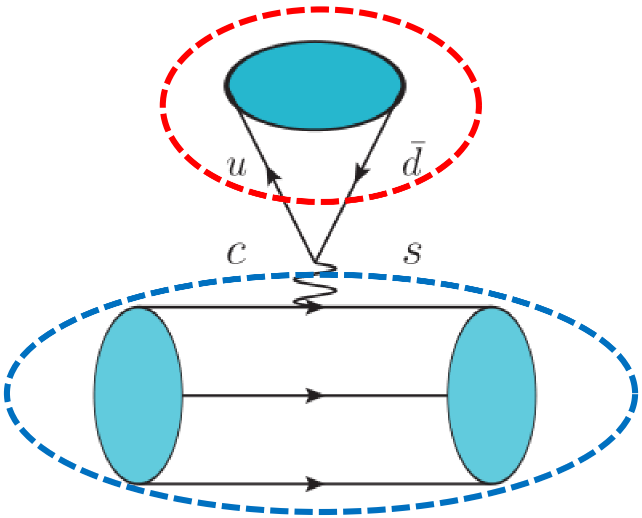
$$\mathcal{B}(\Omega_{ccc}^{++} \to \Omega_{cc}^{+} l^{+}\nu) = 3.6\%$$

$$\langle \Omega_{cc}^{+}(p')|\bar{s}\gamma^{\mu}c|\Omega_{ccc}^{++}(p)\rangle = \bar{u}(p')\left[\frac{f_1\gamma^{\mu}P^{\alpha}}{m_{\Omega_{ccc}^{++}} - m_{\Omega_{cc}^{+}}} + \frac{f_2 P^{\mu}P^{\alpha}}{m^2_{\Omega_{ccc}^{++}} - m^2_{\Omega_{cc}^{+}}} + \frac{if_3\sigma^{\mu\nu}q_{\nu}P^{\alpha}}{m^2_{\Omega_{ccc}^{++}}} + f_4 g^{\alpha\mu}\right]u^{\alpha}(p),$$

$$\langle \Omega_{cc}^{+}(p')|\bar{s}\gamma^{\mu}\gamma_5 c|\Omega_{ccc}^{++}(p)\rangle = \bar{u}(p')\left[\frac{g_1\gamma^{\mu}P^{\alpha}}{m_{\Omega_{ccc}^{++}} + m_{\Omega_{cc}^{+}}} + \frac{g_2 P^{\mu}P^{\alpha}}{m^2_{\Omega_{ccc}^{++}} - m^2_{\Omega_{cc}^{+}}} + \frac{ig_3\sigma^{\mu\nu}q_{\nu}P^{\alpha}}{m^2_{\Omega_{ccc}^{++}}} + g_4 g^{\alpha\mu}\right]\gamma_5 u^{\alpha}(p),$$

- For process: $\Omega_{ccc}^{++} \to \Omega_{cc}^{+}\ \pi^{+}$, one may use the factorization approach to predict its decay widths. Using the form factors, we have the decay width:

$$\Gamma(\Omega_{ccc}^{++} \to \Omega_{cc}^{+}\pi^{+}) = \frac{\sqrt{\lambda}G_F^2}{64\pi m_{\Omega_{ccc}^{++}}^3}|V_{cs}V_{ud}|^2 f_\pi^2 \left[|H_{t,-1/2}^{V,1/2}|^2 + |H_{t,-1/2}^{A,1/2}|^2\right]$$



$$\Gamma(\Omega_{ccc}^{++} \to \Omega_{cc}^{+}\pi^{+}) = 6.20 \times 10^{-14}\text{GeV}.$$

$$\mathcal{B}(\Omega_{ccc}^{++} \to \Omega_{cc}^{+}\pi^{+}) = 1.5\%.$$

- Some literature shows that 10^4 - 10^5 events of triply heavy baryons Ω_{ccc}^{++} can be accumulated for 10 fb^{-1} integrated luminosity at LHC.

(Y. Q. Chen and S. Z. Wu, JHEP 2011)

$$\Gamma(\Omega_{ccc}^{++} \to \Omega_{cc}^{+} l^{+} \nu) \;=\; 1.41 \times 10^{-13} \mathrm{GeV}$$

$$\mathcal{B}(\Omega_{ccc}^{++} \to \Omega_{cc}^{+} l^{+} \nu) \;=\; 3.6\%$$

$$\Gamma(\Omega_{ccc}^{++} \to \Omega_{cc}^{+} \pi^{+}) \;=\; 6.20 \times 10^{-14} \mathrm{GeV}.$$

$$\mathcal{B}(\Omega_{ccc}^{++} \to \Omega_{cc}^{+} \pi^{+}) \;=\; 1.5\%.$$

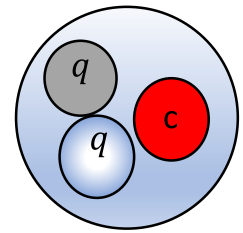
Events $(\Omega_{ccc}^{++} \to \Omega_{cc}^{+} \pi^{+})$ ~ $(10^4 - 10^5) \times 1.5\% = (150\text{-}1500)$

SU(3) Analysis

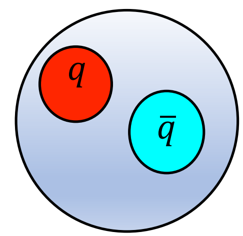
SU(3) light flavor symmetry is a powerful tool to analize decays of heavy hadrons.

m_u~2.2 MeV m_d~4.7 MeV m_s~96 MeV Λ_{QCD}~225 MeV

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



$$M_8 = \begin{pmatrix} \frac{\pi^0}{\sqrt{2}} + \frac{\eta}{\sqrt{6}} & \pi^+ & K^+ \\ \pi^- & -\frac{\pi^0}{\sqrt{2}} + \frac{\eta}{\sqrt{6}} & K^0 \\ K^- & \bar{K}^0 & -2\frac{\eta}{\sqrt{6}} \end{pmatrix}.$$



......

Triply heavy baryon belongs to SU(3) singlet.

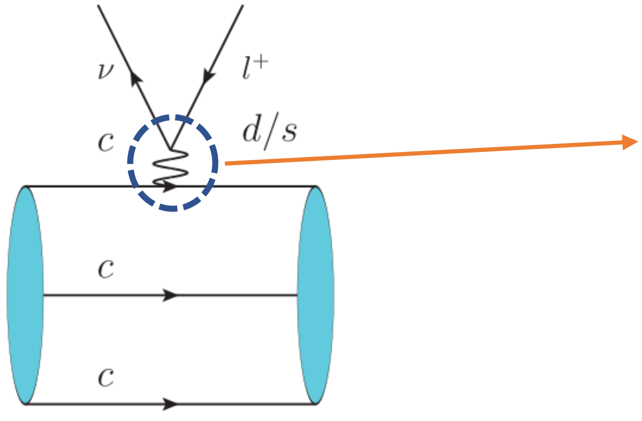
Ω_{ccc}^{++} Ω_{ccb}^{+} Ω_{cbb}^{0} Ω_{bbb}^{-}

SEMI-LEPTONIC Ω_{ccc}^{++} DECAY

The $c \to q\bar{\ell}\nu$ transition is induced by the effective electro-weak Hamiltonian:

$$\mathcal{H}_{e.w.} = \frac{G_F}{\sqrt{2}}\left[V_{cq}^{*}\bar{q}\gamma^{\mu}(1-\gamma_5)c\bar{\nu}_{\ell}\gamma_{\mu}(1-\gamma_5)\ell\right] + h.c.,$$

The heavy-to-light quark operators will form an SU(3) triplet , denoted as H3, with the components :

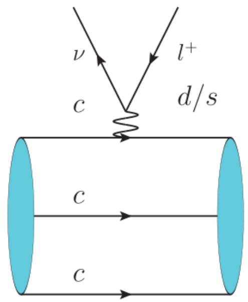


(a)

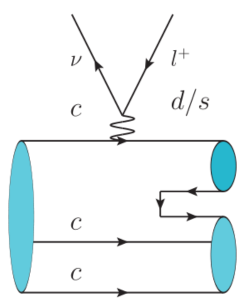
$$H_3 = \begin{pmatrix} 0 \\ V_{cd}^{*} \\ V_{cs}^{*} \end{pmatrix} .$$

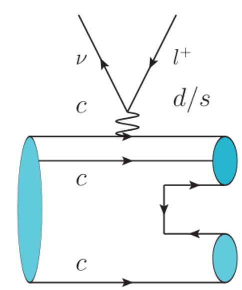
SEMI-LEPTONIC $\boldsymbol{\Omega_{ccc}^{++}}$ DECAY

- At hadron level, the effective Hamiltonian for three-body and four-body semileptonic Ω_{ccc}^{++} decays can be constructed as:



$$\begin{aligned}\mathcal{H}_{\rm eff} \;=\; & a_1\Omega_{ccc}(\overline{T}_{cc})_i(H_3)^i\;\bar\nu_\ell\ell + a_2\Omega_{ccc}(\overline{T}_{cc})_i(M_8)^i_j(H_3)^j\;\bar\nu_\ell\ell \\ & + a_3\Omega_{ccc}(\overline{T}_{c\bar3})_{[ij]}\overline{D}^i(H_3)^j\;\bar\nu_\ell\ell + a_4\Omega_{ccc}(\overline{T}_{c6})_{\{ij\}}\overline{D}^i(H_3)^j\;\bar\nu_\ell\ell.\end{aligned}$$





SEMI-LEPTONIC Ω_{ccc}^{++} DECAY

channel	amplitude	channel	amplitude
$\Omega_{ccc}^{++} \to \Xi_{cc}^{+} \ell^+ \nu_\ell$	$a_1 V_{cd}^*$	$\Omega_{ccc}^{++} \to \Lambda_c^+ D^0 \ell^+ \nu_\ell$	$a_3 V_{cd}^*$
$\Omega_{ccc}^{++} \to \Omega_{cc}^{+} \ell^+ \nu_\ell$	$a_1 V_{cs}^*$	$\Omega_{ccc}^{++} \to \Xi_c^+ D^0 \ell^+ \nu_\ell$	$a_3 V_{cs}^*$
$\Omega_{ccc}^{++} \to \Xi_{cc}^{++} \pi^- \ell^+ \nu_\ell$	$a_2 V_{cd}^*$	$\Omega_{ccc}^{++} \to \Xi_c^0 D^+ \ell^+ \nu_\ell$	$a_3 V_{cs}^*$
$\Omega_{ccc}^{++} \to \Xi_{cc}^{++} K^- \ell^+ \nu_\ell$	$a_2 V_{cs}^*$	$\Omega_{ccc}^{++} \to \Xi_c^0 D_s^+ \ell^+ \nu_\ell$	$-a_3 V_{cd}^*$
$\Omega_{ccc}^{++} \to \Xi_{cc}^{+} \pi^0 \ell^+ \nu_\ell$	$-\frac{a_2 V_{cd}^*}{\sqrt{2}}$	$\Omega_{ccc}^{++} \to \Sigma_c^+ D^0 \ell^+ \nu_\ell$	$\frac{a_4 V_{cd}^*}{\sqrt{2}}$
$\Omega_{ccc}^{++} \to \Xi_{cc}^{+} \overline{K}^0 \ell^+ \nu_\ell$	$a_2 V_{cs}^*$	$\Omega_{ccc}^{++} \to \Sigma_c^0 D^+ \ell^+ \nu_\ell$	$a_4 V_{cd}^*$
$\Omega_{ccc}^{++} \to \Xi_{cc}^{+} \eta \ell^+ \nu_\ell$	$\frac{a_2 V_{cd}^*}{\sqrt{6}}$	$\Omega_{ccc}^{++} \to \Xi_c'^+ D^0 \ell^+ \nu_\ell$	$\frac{a_4 V_{cs}^*}{\sqrt{2}}$
$\Omega_{ccc}^{++} \to \Omega_{cc}^{+} K^0 \ell^+ \nu_\ell$	$a_2 V_{cd}^*$	$\Omega_{ccc}^{++} \to \Xi_c'^0 D^+ \ell^+ \nu_\ell$	$\frac{a_4 V_{cs}^*}{\sqrt{2}}$
$\Omega_{ccc}^{++} \to \Omega_{cc}^{+} \eta \ell^+ \nu_\ell$	$-\sqrt{\frac{2}{3}} a_2 V_{cs}^*$	$\Omega_{ccc}^{++} \to \Xi_c'^0 D_s^+ \ell^+ \nu_\ell$	$\frac{a_4 V_{cd}^*}{\sqrt{2}}$
		$\Omega_{ccc}^{++} \to \Omega_c^0 D_s^+ \ell^+ \nu_\ell$	$a_4 V_{cs}^*$

- The light pseudoscalar mesons can be replaced by their vector counterparts. For instance the K^0 can be replaced by a K^{*0}, which is reconstructed by the $K^-\pi^+$ final state.
- Inspired by the experimental data on D meson decays, we can infer that branching fractions for the c $\to$ s channels are about a few percents.
- A number of relations for decay widths can be easily read off from this table:

$$\Gamma(\Omega_{ccc}^{++} \to \Xi_{cc}^{++} K^- \ell^+ \nu_\ell) = \Gamma(\Omega_{ccc}^{++} \to \Xi_{cc}^{+} \overline{K}^0 \ell^+ \nu_\ell) = \frac{3}{2}\Gamma(\Omega_{ccc}^{++} \to \Omega_{cc}^{+} \eta \ell^+ \nu_\ell).$$

NON-LEPTONIC Ω_{ccc}^{++} DECAY

- Nonleptonic charm quark decays into light quarks are classified into three groups:

$$c \to s\bar{d}u, \quad c \to u\bar{d}d/\bar{s}s, \quad c \to d\bar{s}u.$$

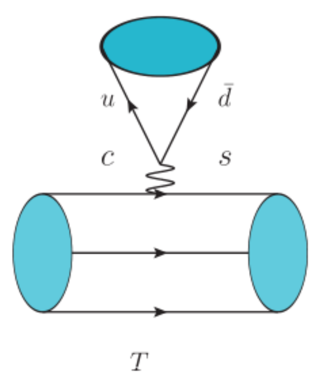
- These operators transform under the flavor SU(3) symmetry as

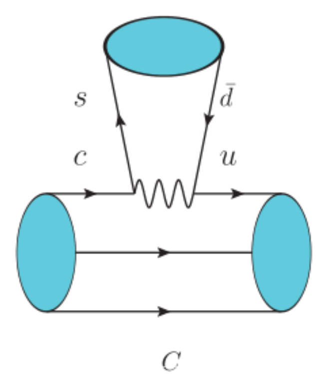
$$\mathbf{3} \otimes \bar{\mathbf{3}} \otimes \mathbf{3} = \mathbf{3} \oplus \mathbf{3} \oplus \bar{\mathbf{6}} \oplus \mathbf{15}.$$

- Decays into a doubly-charmed baryon and one light meson

$$\mathcal{H}_{eff} = a_1 \Omega_{ccc} (\overline{T}_{cc})_i (M_8)^k_j (H_{\bar{6}})^{ij}_k + a_2 \Omega_{ccc} (\overline{T}_{cc})_i (M_8)^k_j (H_{15})^{ij}_k .$$

(15:30-15:30 Talk given by Mr. Shi, Yu-Ji)





NON-LEPTONIC Ω_{ccc}^{++} DECAY

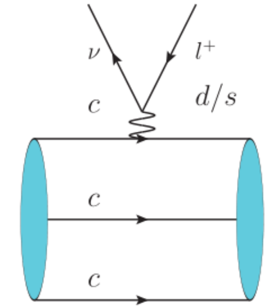
channel	amplitude	channel	amplitude
Cabibbo-allowed	channels	Singly Cabibbo-suppressed	channels
$\Omega_{ccc}^{++} \to \Xi_{cc}^{++}\overline{K}^0$	$(a_2 - a_1)V_{ud}V_{cs}^*$	$\Omega_{ccc}^{++} \to \Xi_{cc}^{++}\pi^0$	$\frac{(a_2-a_1)V_{us}V_{cs}^*}{\sqrt{2}}$
$\Omega_{ccc}^{++} \to \Omega_{cc}^{+}\pi^+$	$(a_1 + a_2)V_{ud}V_{cs}^*$	$\Omega_{ccc}^{++} \to \Xi_{cc}^{++}\eta$	$\sqrt{\frac{3}{2}}\,(a_1 - a_2)\,V_{us}V_{cs}^*$
Doubly Cabibbo-suppressed	channels	$\Omega_{ccc}^{++} \to \Xi_{cc}^{+}\pi^+$	$(a_1 + a_2)\,(-V_{us}V_{cs}^*)$
$\Omega_{ccc}^{++} \to \Xi_{cc}^{++}K^0$	$(a_1 - a_2)\,(-V_{us}V_{cd}^*)$	$\Omega_{ccc}^{++} \to \Omega_{cc}^{+}K^+$	$(a_1 + a_2)\,V_{us}V_{cs}^*$
$\Omega_{ccc}^{++} \to \Xi_{cc}^{+}K^+$	$(a_1 + a_2)\,V_{us}V_{cd}^*$		

- The light pseudoscalar mesons can be replaced by their vector counterparts.
- Some CKM allowed channels are about a few percents.
- A number of relations for decay widths can be read off from this table:

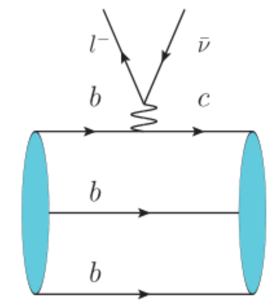
$$\Gamma(\Omega_{ccc}^{++} \to \Xi_{cc}^{++}\eta) = 3\Gamma(\Omega_{ccc}^{++} \to \Xi_{cc}^{++}\pi^0) \quad \Gamma(\Omega_{ccc}^{++} \to \Xi_{cc}^{+}\pi^+) = \Gamma(\Omega_{ccc}^{++} \to \Omega_{cc}^{+}K^+)$$

SEMI-LEPTONIC DECAYS

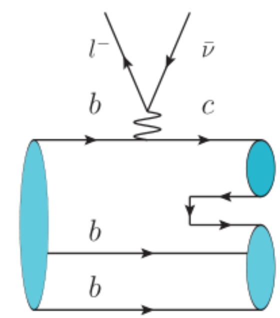
1. $\Omega_{ccc}^{++} \to T_{cc}\ \nu_\ell \bar{\ell}$



2. $\Omega_{ccc}^{++} \to T_{cc}\ M\ \nu_\ell \bar{\ell}$
3. $\Omega_{ccc}^{++} \to T_{c\bar{3},6}\ D\ \nu_\ell \bar{\ell}$
4. $\Omega_{bbb}^{-} \to \Omega_{cbb}^{0}\ \bar{\nu}_\ell \ell$



5. $\Omega_{bbb}^{-} \to T_{bb}\ D\ \bar{\nu}_\ell \ell$
6. $\Omega_{bbb}^{-} \to T_{bc}\ B\ \bar{\nu}_\ell \ell$
7. $\Omega_{bbb}^{-} \to T_{bb}\ \bar{\nu}_\ell \ell$
8. $\Omega_{bbb}^{-} \to T_{bb}\ M\ \bar{\nu}_\ell \ell$



9. $\Omega_{bbb}^{-} \to T_{b\bar{3},6}\ B\ \bar{\nu}_\ell \ell$

Similar semi-leptonic decays of Ω_{ccb}^{+} and Ω_{cbb}^{0} have also been considered.

NON-LEPTONIC $\mathbf{\Omega_{ccc}^{++}}$ DECAY

1. $\Omega_{ccc}^{++} \to T_{cc}\ M$
2. $\Omega_{ccc}^{++} \to T_{cc}\ M\ M$
3. $\Omega_{ccc}^{++} \to T_{c\bar{3},6}\ D$
4. $\Omega_{ccc}^{++} \to T_{c\bar{3},6}\ D\ M$

NON-LEPTONIC $\mathbf{\Omega_{bbb}^{-}}$ DECAY

1. $\Omega_{bbb}^{-} \to T_{bb}\ J/\psi$
2. $\Omega_{bbb}^{-} \to T_{bb}\ J/\psi\ M$
3. $\Omega_{bbb}^{-} \to T_{b\bar{3},6}\ J/\psi\ B$
4. $\Omega_{bbb}^{-} \to \Omega_{cbb}^{0}\ \overline{D}$
5. $\Omega_{bbb}^{-} \to \Omega_{cbb}^{0}\ \overline{D}\ M$

NON-LEPTONIC $\Omega_{\mathbf{bbb}}^{-}$ DECAY

6. $\Omega_{bbb}^{-} \to \Omega_{cbb}\ M$
7. $\Omega_{bbb}^{-} \to \Omega_{cbb}\ M\ M$
8. $\Omega_{bbb}^{-} \to T_{bb}\ D$
9. $\Omega_{bbb}^{-} \to T_{bb}\ D\ M$
10. $\Omega_{bbb}^{-} \to T_{b\bar{3},6}\ D\ B$
11. $\Omega_{bbb}^{-} \to T_{bb}\ \overline{D}$
12. $\Omega_{bbb}^{-} \to T_{bb}\ \overline{D}\ M$
13. $\Omega_{bbb}^{-} \to T_{b\bar{3},6}\ \overline{D}\ B$
14. $\Omega_{bbb}^{-} \to T_{bb}\ M$
15. $\Omega_{bbb}^{-} \to T_{bb}\ M\ M$
16. $\Omega_{bbb}^{-} \to T_{b\bar{3},6}\ B$
17. $\Omega_{bbb}^{-} \to T_{b\bar{3},6}\ B\ M$

Similar non-leptonic decays of Ω_{ccb}^{+} and Ω_{cbb}^{0} have also been considered.

arXiv: 1803.01476

Golden channels

- Based on the above analysis, we first give a collection of the CKM allowed decay channels for the Ω_{ccc}^{++}

channel	channel	channel	channel
$\Omega_{ccc}^{++} \to \Omega_{cc}^{+} \ell^+ \nu_\ell$	$\Omega_{ccc}^{++} \to \Xi_c^{\prime +} D^0 \ell^+ \nu_\ell$	$\Omega_{ccc}^{++} \to \Xi_c^{0} D^+ \ell^+ \nu_\ell$	$\Omega_{ccc}^{++} \to \Xi_{cc}^{+} \overline{K}^0 \ell^+ \nu_\ell$
$\Omega_{ccc}^{++} \to \Xi_c^{+} D^0 \ell^+ \nu_\ell$	$\Omega_{ccc}^{++} \to \Xi_c^{\prime 0} D^+ \ell^+ \nu_\ell$	$\Omega_{ccc}^{++} \to \Xi_{cc}^{++} K^- \ell^+ \nu_\ell$	$\Omega_{ccc}^{++} \to \Omega_c^{0} D_s^+ \ell^+ \nu_\ell$
$\Omega_{ccc}^{++} \to \Xi_{cc}^{++} \overline{K}^0$	$\Omega_{ccc}^{++} \to \Omega_{cc}^{+} \pi^+$		
$\Omega_{ccc}^{++} \to \Xi_{cc}^{++} \overline{K}^0 \pi^0$	$\Omega_{ccc}^{++} \to \Xi_{cc}^{+} \pi^+ \overline{K}^0$	$\Omega_{ccc}^{++} \to \Xi_{cc}^{++} K^- \pi^+$	$\Omega_{ccc}^{++} \to \Omega_{cc}^{+} K^+ \overline{K}^0$
$\Omega_{ccc}^{++} \to \Xi_c^{+} D^+$	$\Omega_{ccc}^{++} \to \Xi_c^{\prime +} D^+$		
$\Omega_{ccc}^{++} \to \Lambda_c^{+} D^+ \overline{K}^0$	$\Omega_{ccc}^{++} \to \Xi_c^{+} D_s^+ \overline{K}^0$	$\Omega_{ccc}^{++} \to \Xi_c^{+} D^+ \pi^0$	$\Omega_{ccc}^{++} \to \Xi_c^{0} D^+ \pi^+$
$\Omega_{ccc}^{++} \to \Xi_c^{+} D^0 \pi^+$			
$\Omega_{ccc}^{++} \to \Sigma_c^{++} D^0 \overline{K}^0$	$\Omega_{ccc}^{++} \to \Xi_c^{\prime 0} D^+ \pi^+$	$\Omega_{ccc}^{++} \to \Xi_c^{\prime +} D^0 \pi^+$	$\Omega_{ccc}^{++} \to \Omega_c^{0} D^+ K^+$
$\Omega_{ccc}^{++} \to \Sigma_c^{++} D^+ K^-$	$\Omega_{ccc}^{++} \to \Xi_c^{\prime +} D_s^+ \overline{K}^0$	$\Omega_{ccc}^{++} \to \Xi_c^{\prime +} D^+ \pi^0$	$\Omega_{ccc}^{++} \to \Omega_c^{0} D_s^+ \pi^+$
$\Omega_{ccc}^{++} \to \Sigma_c^{+} D^+ \overline{K}^0$			

- Nonleptonic Ω_{ccc}^{++} decay such as $\Omega_{ccc}^{++} \to \Xi_{cc}^{++} K^- \pi^+$ might be used to search for Ω_{ccc}^{++} especially at LHC, since their branching fractions are sizable, and the final state can be easily to identify. This will make use of the doubly heavy baryon Ξ_{cc}^{++} which has been just discovered by LHCb.

- Based on the above analysis, we first give a collection of the CKM allowed decay channels for the Ω_{bbb}^-

channel	channel	channel	channel
$\Omega_{bbb}^- \to \Xi_{bb}^0 D^0 \ell^- \bar{\nu}_\ell$	$\Omega_{bbb}^- \to \Xi_{bc}^+ B^- \ell^- \bar{\nu}_\ell$	$\Omega_{bbb}^- \to \Omega_{bb}^- D_s^+ \ell^- \bar{\nu}_\ell$	$\Omega_{bbb}^- \to \Omega_{bc}^0 \overline{B}_s^0 \ell^- \bar{\nu}_\ell$
$\Omega_{bbb}^- \to \Xi_{bb}^- D^+ \ell^- \bar{\nu}_\ell$	$\Omega_{bbb}^- \to \Xi_{bc}^0 \overline{B}^0 \ell^- \bar{\nu}_\ell$		
$\Omega_{bbb}^- \to \Omega_{bb}^- J/\psi$	$\Omega_{bbb}^- \to \Xi_b^{\prime 0} B^- J/\psi$	$\Omega_{bbb}^- \to \Xi_{bb}^0 K^- J/\psi$	$\Omega_{bbb}^- \to \Omega_b^- \overline{B}_s^0 J/\psi$
$\Omega_{bbb}^- \to \Xi_b^0 B^- J/\psi$	$\Omega_{bbb}^- \to \Xi_b^{\prime -} \overline{B}^0 J/\psi$	$\Omega_{bbb}^- \to \Xi_{bb}^- \overline{K}^0 J/\psi$	$\Omega_{bbb}^- \to \Xi_b^- \overline{B}^0 J/\psi$
$\Omega_{bbb}^- \to \Omega_{bbc}^0 D_s^-$	$\Omega_{bbb}^- \to \Omega_{bbc}^0 D^- \overline{K}^0$	$\Omega_{bbb}^- \to \Omega_{bbc}^0 \overline{D}^0 K^-$	
$\Omega_{bbb}^- \to \Omega_{bbc}^0 \pi^-$	$\Omega_{bbb}^- \to \Omega_{bbc}^0 K^0 K^-$		
$\Omega_{bbb}^- \to \Xi_{bb}^- D^0$	$\Omega_{bbb}^- \to \Xi_{bb}^- D^+ \pi^-$	$\Omega_{bbb}^- \to \Xi_{bb}^- D^0 \pi^0$	$\Omega_{bbb}^- \to \Omega_{bb}^- D^0 K^0$
$\Omega_{bbb}^- \to \Lambda_b^0 B^- D^0$	$\Omega_{bbb}^- \to \Sigma_b^- B^- D^+$	$\Omega_{bbb}^- \to \Xi_b^- \overline{B}_s^0 D^0$	$\Omega_{bbb}^- \to \Xi_b^{\prime -} B^- D_s^+$
$\Omega_{bbb}^- \to \Xi_{bb}^0 D^0 \pi^-$	$\Omega_{bbb}^- \to \Sigma_b^- \overline{B}^0 D^0$	$\Omega_{bbb}^- \to \Omega_{bb}^- D_s^+ \pi^-$	$\Omega_{bbb}^- \to \Xi_b^{\prime -} \overline{B}_s^0 D^0$
$\Omega_{bbb}^- \to \Xi_b^- B^- D_s^+$	$\Omega_{bbb}^- \to \Xi_{bb}^- D_s^+ K^-$	$\Omega_{bbb}^- \to \Sigma_b^0 B^- D^0$	

- For nonleptonic decays of Ω_{bbb}^- , the largest branching fraction might reach 10^{-3}. Taking into account its daughter decays, we expect the branching fraction for Ω_{bbb}^- decaying into charmless final state is at most 10^{-9}. Thus the triply bottom baryon can be only observed with a large amount of data in future, such as the high luminosity LHC.

Summary

Summary

- On experimental side, light hadrons with no heavy quark, singly heavy baryons, and doubly heavy baryons have been established, but triply heavy baryons are still missing.

- In this work we study semileptonic and nonleptonic weak decays of triply heavy baryons Ω_{ccc}^{++} Ω_{ccb}^{+} Ω_{cbb}^{0} Ω_{bbb}^{-} by using SU(3) flavor symmetry.

- We point out that branching fractions for Cabibbo allowed processes showed below may reach a few percents,

$$\Omega_{ccc}^{++} \to (\Xi_{cc}^{++}\overline{K}^0, \Xi_{cc}^{++}K^-\pi^+, \Omega_{cc}^{+}\pi^+, \Xi_c^+D^+, \Xi_c^{\prime}D^+, \Lambda_c D^+\overline{K}^0, \Xi_c^+D^0\pi^+, \Xi_c^0D^+\pi^+)$$

- We suggest our experimental colleagues to perform a search at hadron colliders and the electron and positron collisions in future, which will presumably lead to discoveries of triply heavy baryons and complete the baryon multiplets.

Thank you !