

Updated Results of Charmed Baryon Decays with SU(3) Flavor Symmetry

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2019年理论与实验联合专题研讨会：粲物理

广州，广东

Nov. 22-24, 2019



暨南大学物理学系
DEPARTMENT OF PHYSICS JINAN UNIVERSITY

Outline

- History of Charm Quark
- Recent Progresses in Charmed Baryon Decays
- Charmed Baryons with $SU(3)_F$ Flavor Symmetry
- Updated Results of Charmed Baryon Decays with $SU(3)_F$
- Summary

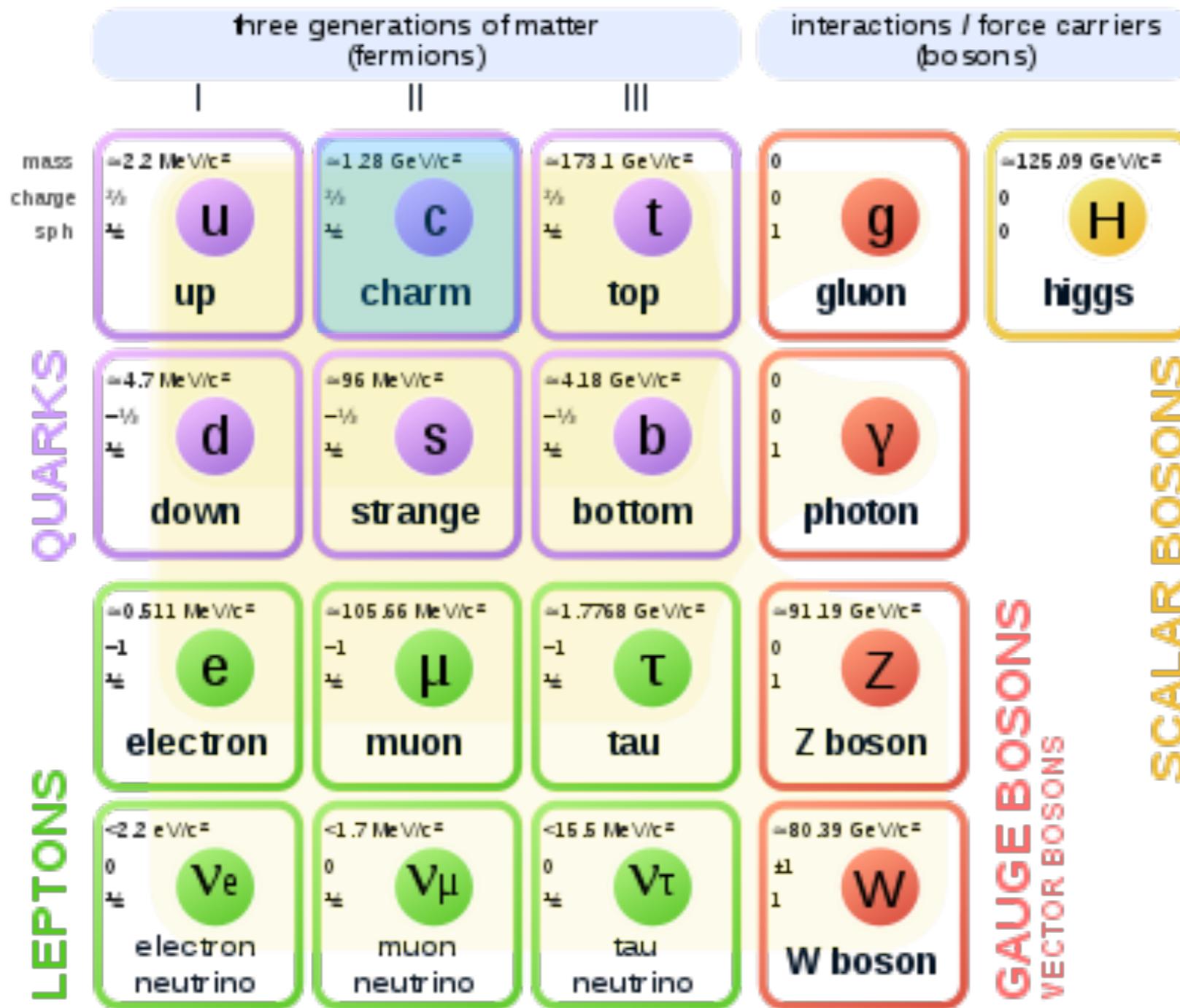
• History of Charm Quark

Charm

China element

中国元素

Standard Model of Elementary Particles



History of Charm Quark in Theory

In 1956, Sakata model: $\begin{pmatrix} \text{甲} \\ \text{乙} \end{pmatrix} \begin{pmatrix} \nu \\ e \end{pmatrix}$ S. Sakata, Prog. Theor. Phys. 16 (1956), 686.

In 1959 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): $\begin{pmatrix} \text{甲} & \text{丁} \\ \text{乙} & \text{丙} \end{pmatrix} \begin{pmatrix} \nu_1 & \nu_2 \\ e & \mu \end{pmatrix}$

Z. Maki, M. Nakagawa 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

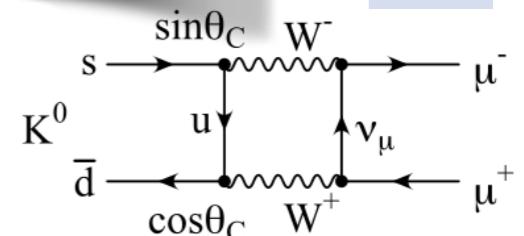
$$\begin{pmatrix} u \\ d \end{pmatrix} \quad \begin{pmatrix} c \\ s \end{pmatrix}$$

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

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

$$\mathcal{M}_1 \propto \sin\theta_C \cos\theta_C$$

0



History of Charm Quark in Experiment

J. J. Aubert,
J. Leong, T. M.
Laboratory for

We report
proximate
measuring
National I

This experiment is
study the behavior of
 e^+e^-x reactions¹ and
which decay into e^+e^-

We use a slow extr
haven National Labo
synchrotron. The be
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an extended target,
mil Be, to enable us
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same origin. The be
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(a)

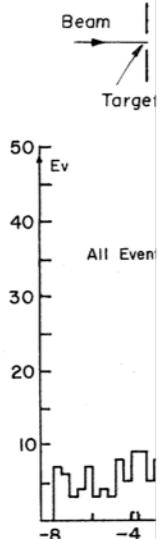


FIG. 1. (a) Simplified
of those events with 3.0

VOLUME 33, NUMBER 23

proximate
ly 6-GeV electrons
extremes. Thus, a
 π^0 , ρ^0 , or prop
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duce multitrack coin
problem of operating
eight vertical and e
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Behind the largest
are two banks of 25
diation lengths each
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from electrons and
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monitored with a P
high voltages are c

The magnets were
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mapped at various
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Figure 1(b) shows
between the e^+ and
 $2.5 < m < 3.5$ GeV.
is observed. This
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two arms was made
cut distinction betw
Figure 1(c) shows t
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To ensure that th
real particle ($J = e$)
were made. We lis
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B. M. Ba
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N. Feind,

J. J.

G. S.

Lawrence

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$E = 3.1$

$\Gamma \leq 1.3$

(full width)
tainty in t

cations system is not functioning
for charm separation from s
acting particles. However, outside

and we there
strongly inter
the peak the
sly measured

celently.

*Work supported by the U. S.
mission.

†Present address: Laboratoire
Linéaire, Centre d'Orsay de l'
Orsay, France.

‡Permanent address: Institut
Orsay, France.

§Permanent address: Centre
Saclay, Saclay, France.

¶The apparatus is described
to be published.

¶The detection-efficiency detec
cribed in a future publication.

¶While preparing this manus
that the Massachusetts Institute
studying the reaction $p\bar{p} \rightarrow e^+e^-$
tional Laboratory has observed
 e^+e^- mass distribution at about
et al., preceding Letter [Phys.
(1974)].

¶G. Bonneau and F. Martin, N
(1971).

μ -pair cross section. Since a large $\pi\pi$ or KK
branching ratio would be unexpected for a reso
nance this massive, the two-body enhancement
observed is probably but not conclusively in the
 μ -pair channel.

The e^+e^- hadron cross section is presumed
to go through the one-photon intermediate state
with angular momentum, parity, and charge con
jugation quantum numbers $J^{PC} = 1^{++}$. It is dif
ficult to understand how, without involving new
quantum numbers or selection rules, a resonance
in this state which decays to hadrons could be so
narrow.

We wish to thank the SPEAR operations staff
for providing the stable conditions of machine
performance necessary for this experiment.
Special monitoring and control techniques were
developed on very short notice and performed ex
-

Preliminary Result of Frascati (ADONE) on the Nature of a New 3.1-GeV Resonance Produced in e^+e^- Annihilation*

C. Bacci, R. Balbini Celio, M. Berna-Rodini, G. Caton, R. Del Fabbro, M. G. Locci, C. Mencuccini, G. P. Murtas, G. Penso, G. S. M. Spini, M. Spano, B. Stella, and V. Valente

The Gamma-Gamma Group, Laboratori Nazionali di Frascati, Frascati, Italy
and

B. Bartoli, D. Bisello, B. Esposito, F. Felicetti, P. Monacelli, M. Nigro, L. Piano Mortemi, M. Piccolo, F. Ronga, F. Sebastiani, L. Trasatti, and
The Magnet Experimental Group for ADONE, Laboratori Nazionali di Frascati, Italy

and

G. Barbarino, G. Barbiellini, C. Bemporad, R. Biancastelli, F. Cevenini, F. Costantini, P. Lariccia, P. Parascandalo, E. Sassi, C. Spencer, I. U. Troya, and S. Vitale

The Baryon-Antibaryon Group, Laboratori Nazionali di Frascati, Frascati, Italy
(Received 18 November 1974)

We report on the results at ADONE to study the properties of the newly found particle.

Soon after the news that a particle of 3.1 GeV with a width consistent with zero had been ob
served at Brookhaven National Laboratory by the Massachusetts Institute of Technology group,¹ it was immediately decided to push ADONE beyond its nominal limit of energy (2×1.5 GeV) to look

for this particle. On the following day the information had reached us that a similar particle had also been observed at SPEAR with a width exactly 3.10 GeV with a narrow width.

Three experiments³ [the Magnet Experimental G

Experimental Observation of a Heavy Particle **J**

J. J. Aubert, U. Becker, P. J. Biggs, J. Burger, M. Chen, G. Everhart, P. Goldhagen,

J. Leong, T. McCorriston, T. G. Rho
Laboratory for Nuclear Science and Defense

Samuel C. C. Ting

*Massachusetts Institute of Technology
Cambridge, Massachusetts 02139*

Sau Lan Wu

and

Y. Y. Lee

Bell Telephone Laboratories

(Received 12 November 1974)

We report the observation of a heavy particle *J*, with mass $m = 3.1$ GeV and width approximately zero. The observation was made from the reaction $p + Be \rightarrow e^+ + e^- + x$ by measuring the e^+e^- mass spectrum with a precise pair spectrometer at the Brookhaven National Laboratory's 30-GeV alternating-gradient synchrotron.

Discovery of a Narrow Resonance in e^+e^- Annihilation*

J.-E. Augustin,[†] A. M. Boyarski, M. Breidenbach, F. Bulos, J. T. Dakin, G. J. Feldman,
G. E. Fischer, D. Fryberger, G. Hanson, B. Jean-Marie,[†] R. R. Larsen, V. Lüth,

B. Richter
C. von, C. C. Morehouse, J. M. Paterson, M. L. Perl,
Rapidis, R. F. Schwitters, W. M. Tanenbaum,
and F. Vannucci[‡]

Stanford Linear Accelerator Center, Stanford University, Stanford, California 94305

and

G. S. Abrams, D. Briggs, W. Chinowsky, C. E. Friedberg, G. Goldhaber, R. J. Hollebeek,
J. A. Kadyk, B. Lulu, F. Pierre,[§] G. H. Trilling, J. S. Whitaker,
J. Wiss, and J. E. Zipse

Lawrence Berkeley Laboratory

Berkeley, California 94720

(Received 13 November 1974)

We have observed a very sharp peak in the cross section for $e^+e^- \rightarrow$ hadrons, e^+e^- , and possibly $\mu^+\mu^-$ at a center-of-mass energy of 3.105 ± 0.003 GeV. The upper limit to the full width at half-maximum is 1.3 MeV.

The 1974 November Revolution of HEP:

Discovery of a new QUARK — Charm (c)

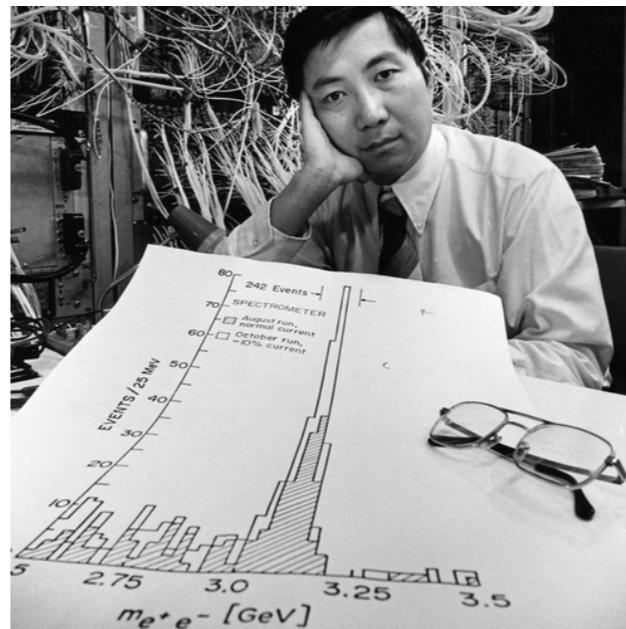
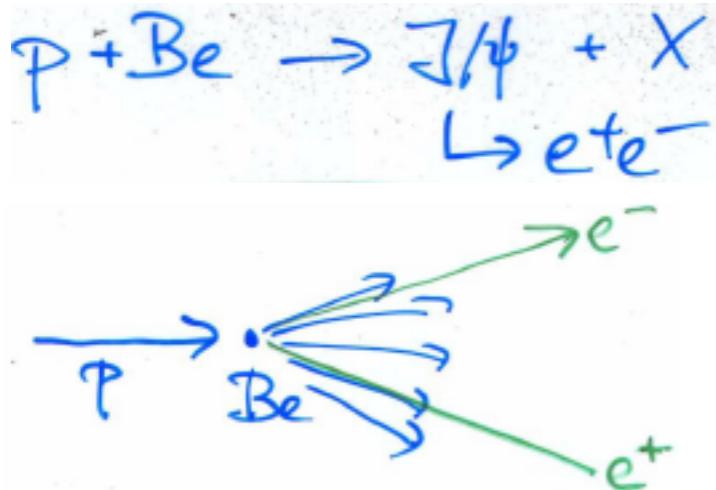
苏联十月革命 (November 1917)

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

1974年11月11日
45年前

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

Brookhaven (Proton Synchrotron)



丁肇中



J

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

B. Richter

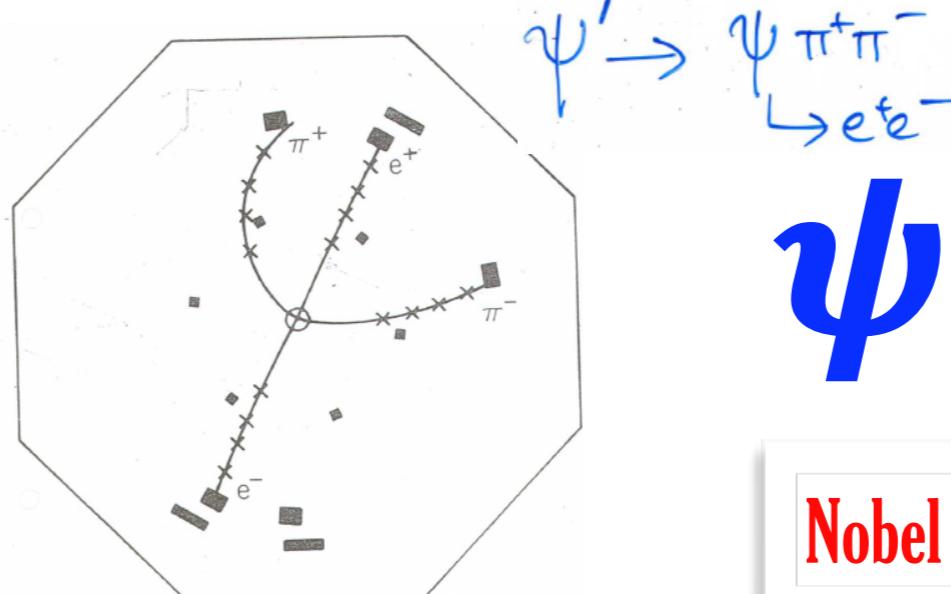
SLAC (e+e- collider)

Nov. 10, 1974

Nov. 11, 1974

Ting and Richter
met at SLAC

丁與Sau-Lan Wu通話定稿



ψ



Nobel Physics Prize 1976

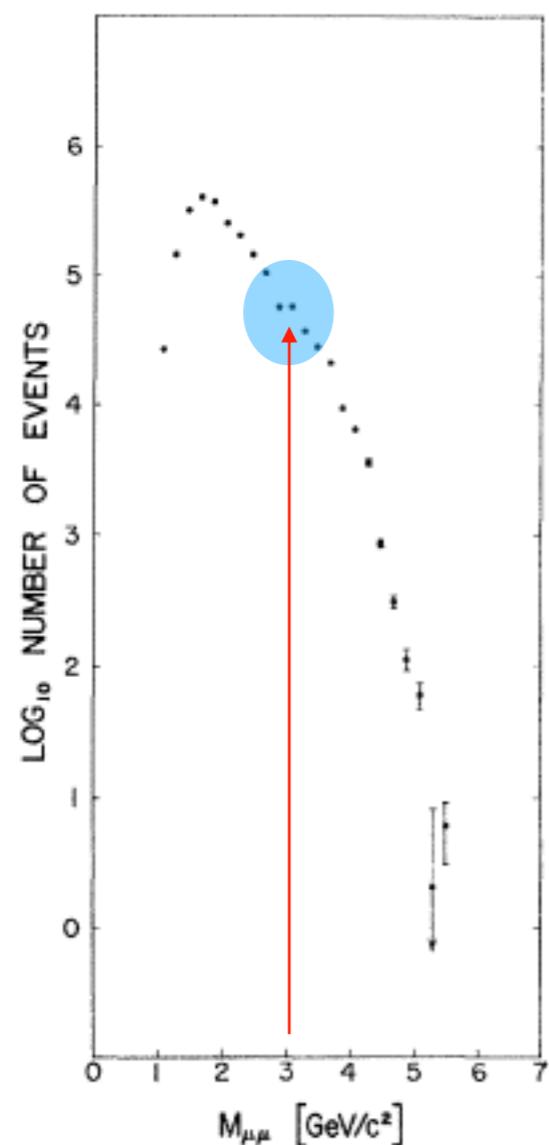
proximately 10^{-34} cm².

The most striking feature of J is the possibility that it may be one of the theoretically suggested charmed particles² or a 's³ or Z_0 's,⁴ etc. In order to study the real nature of J ,⁵ measurements are now underway on the various decay modes, e.g., an $e\pi\nu$ mode would imply that J is weakly interacting in nature.

¹The first work on $p + p \rightarrow \mu^+ + \mu^- + x$ was done by L. M. Lederman *et al.*, Phys. Rev. Lett. 25, 1523 (1970).

E. D. Weiner for help and assistance. We thank also M. Deutsch, V. F. Weisskopf, T. T. Wu, S. Drell, and S. Glashow for many interesting conversations.

[†]Accepted without review under policy announced in Editorial of 20 July 1964 [Phys. Rev. Lett. 13, 79 (1964)].



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eind,
and

S. Weinberg, Phys. Rev. Lett. 19, 1264 (1967), and 27, 1688 (1971), and Phys. Rev. D 5, 1412, 1962 (1972).

⁵After completion of this paper, we learned of a similar result from SPEAR. B. Richter and W. Panofsky, private communication; Letter [b] to be published.

⁶S. D. Drell and T. M. Yan, Phys. Rev. Lett. 25, 1523 (1970). A contradiction with the data.

Oops! — Leon! (miss charm)

PHYS 1977: Repeat of J/ψ at 9.5 GeV r 1970

ervation of M

Ooops! — Leon! (find beauty)

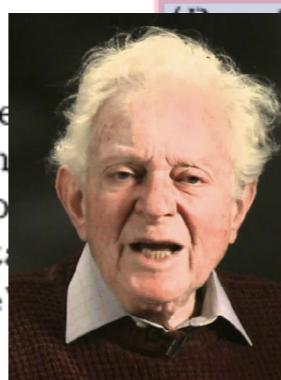
son, G. S. Hicks, L. M. Lede ..., +, ..., York, New York 10027, and Brookhaven National Laboratory, Upton, New York 11973

G. Pope
pton, New York 11973

Y: Upsilon

E. Zavattini

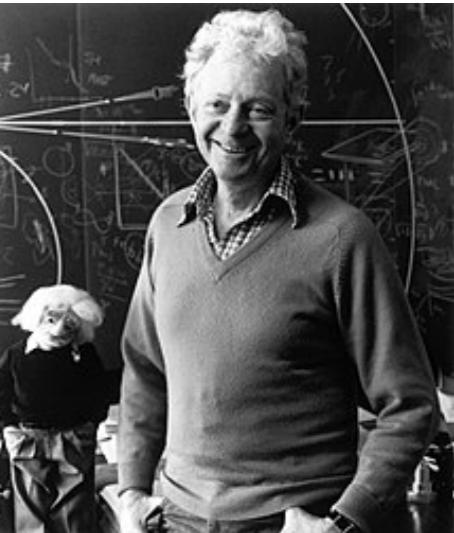
CERN Laboratory, Gen



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$m_{\mu\mu} < 6.7$ GeV/c² have been observed in collisions of nucleons. $\mu \approx 1$ GeV/c² and increasing

錯失媚，找到美！



L. Lederman





Kiyoshi Niu

日本学者

Prog. Theor. Phys. Vol. 46 (1971), No. 5

**A Possible Decay in Flight
of a New Type Particle**

Kiyoshi NIU, Eiko MIKUMO
and Yasuko MAEDA*

Institute for Nuclear Study

University of Tokyo

**Yokohama National University*

August 9, 1971

A pair of naked **charm** particles was discovered in 1971
in a **cosmic-ray** interaction, three years prior to the discovery
of the hidden charm particle, J/Ψ , in western countries.

三代物质粒子（费米子）

“王竹溪1951年任中国物理学会物理学名词委员会副主任，数年后改任主任，一直到他去世。粲夸克先译为魅夸克，虽然意思差不多，但终究不够贴切。英文charm既有魔力和娇媚之意，又可作美好解。魅字只含前两种意思，不能释作美好，而且由于是常用字，容易引起误解。后来王竹溪建议改用稀见字粲，取《诗经·唐风·绸缪》“今夕何夕，见此粲者”句中“粲”字为美物之意，既表达了charm的原意，又与charm谐音。”

为什么不能用常用字？
有多少14亿中国人以及全世界的华人会写粲的？
有100万吗？只要是懂英文的，都会写 charm。
与up上, down下, strange奇的取名不配！

Charm Quark 媚夸克？

Charm

Charm Quark 丁夸克

不忘初心

质量 电荷 自旋	$\approx 2.2 \text{ MeV}/c^2$ 2/3 1/2 上	$\approx 1.28 \text{ GeV}/c^2$ 2/3 1/2 丁	$\approx 173.1 \text{ GeV}/c^2$ 2/3 1/2 顶	0 0 1 g 胶子	$\approx 125.09 \text{ GeV}/c^2$ 0 0 希格斯玻色子
夸克	$\approx 4.7 \text{ MeV}/c^2$ -1/3 1/2 d 下	$\approx 96 \text{ MeV}/c^2$ -1/3 1/2 s 奇	$\approx 4.18 \text{ GeV}/c^2$ -1/3 1/2 b 底	0 0 1 γ 光子	
轻子	$\approx 0.511 \text{ MeV}/c^2$ -1 1/2 e 电子	$\approx 105.66 \text{ MeV}/c^2$ -1 1/2 μ μ 子	$\approx 1.7768 \text{ GeV}/c^2$ -1 1/2 τ τ 子	0 1 Z Z玻色子	
	$< 2.2 \text{ eV}/c^2$ 0 1/2 ν_e 电中微子	$< 1.7 \text{ MeV}/c^2$ 0 1/2 ν_μ μ 中微子	$< 15.5 \text{ MeV}/c^2$ 0 1/2 ν_τ τ 中微子	± 1 1 W W玻色子	

标量玻色子

规范玻色子

牢记使命

甲 丁 乙 丙

初心：charm的来源，真正意思 rk 丁夸克

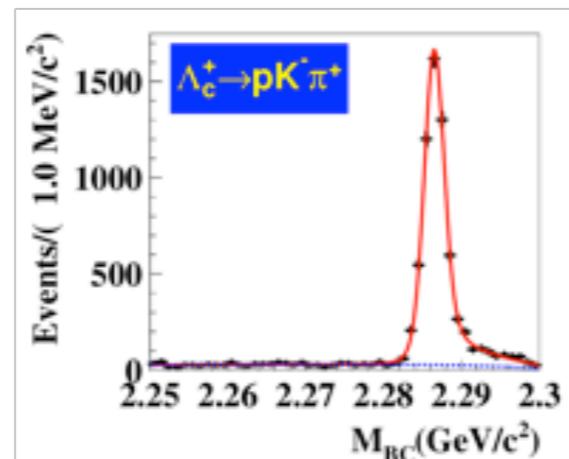
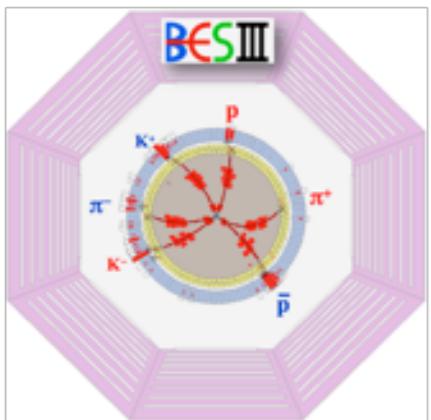
使命：体现真正意思，普及大众，有故事；而不是咬文嚼字让一般大众无法认识它的含义，甚至读写。“丁”即可以跟中国姓相关，也可以认为是第四个夸克，且人人可读写。

Recent Progresses in Charmed Baryon Decays

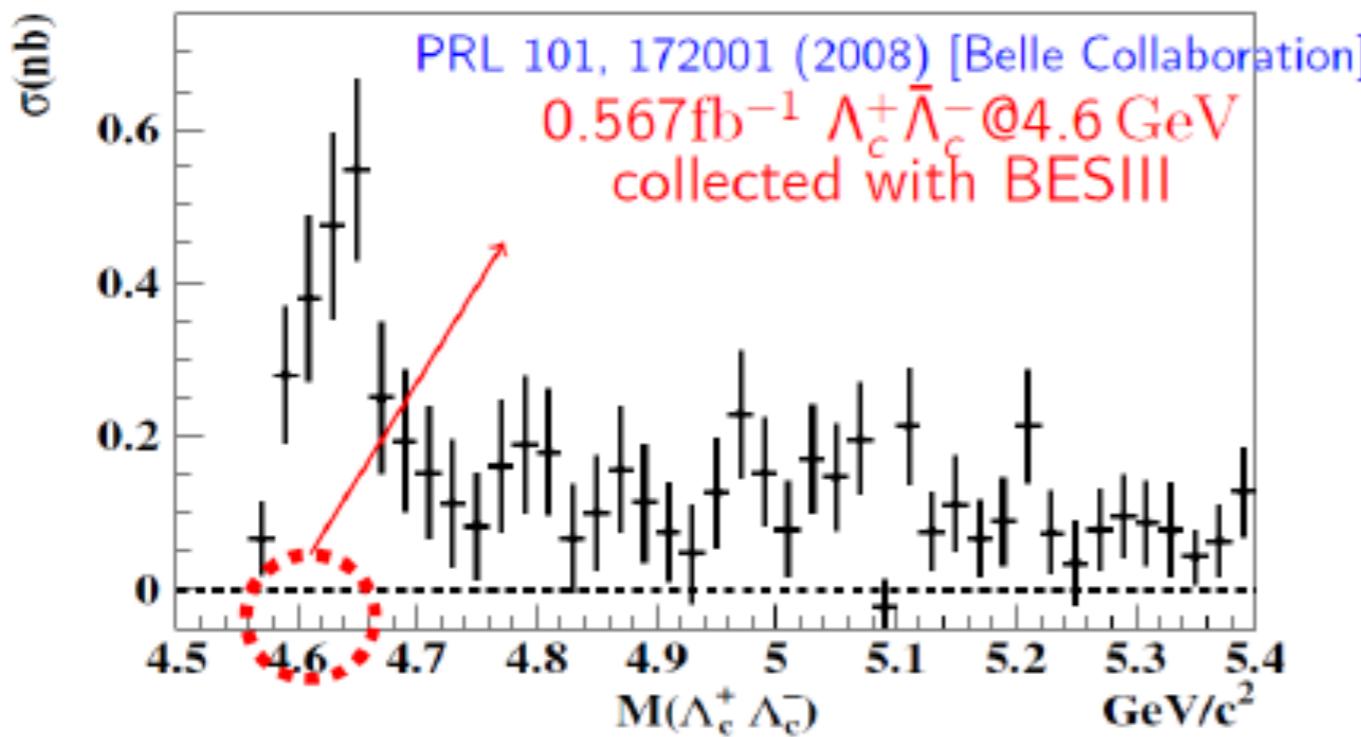
Recent experimental developments in charmed baryons:

Talk: 吕晓睿

BESIII at the Beijing Electron Positron Collider (BEPCII)

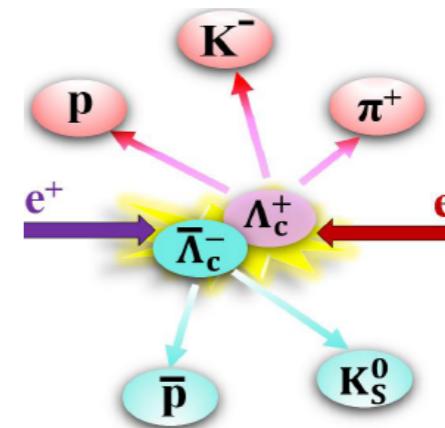


$$\mathcal{B}(\Lambda_c^+ \rightarrow p K^- \pi^+)_{\text{BESIII}} = (5.84 \pm 0.27 \pm 0.23)\%$$



如果BEPCII质心系能量能够提高到4.95 GeV以上

BEPCII: a τ -c Factory
Around $E_{\text{cms}} \sim 4.6 \text{ GeV}$



A uniquely clean background
to study Charm Baryons



E_c衰变绝对分支比

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

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

Many newly measured
charmed baryon decays.

- [1] M. Ablikim *et al.* [BESIII Collaboration], Phys. Rev. Lett. **115**, 221805 (2015).
- [2] M. Ablikim *et al.* [BESIII Collaboration], Phys. Rev. Lett. **116**, 052001 (2016).
- [3] M. Ablikim *et al.* [BESIII Collaboration], Phys. Rev. Lett. **117**, 232002 (2016).
- [4] M. Ablikim *et al.* [BESIII Collaboration], Phys. Lett. B **767**, 42 (2017).
- [5] M. Ablikim *et al.* [BESIII Collaboration], Phys. Rev. D **95**, 111102 (2017).
- [6] M. Ablikim *et al.* [BESIII Collaboration], Phys. Lett. B **783**, 200 (2018).
- [7] M. Ablikim *et al.* [BESIII Collaboration], arXiv:1811.08028 [hep-ex].
- [8] M. Ablikim *et al.* [BESIII Collaboration], Phys. Rev. Lett. **121**, 062003 (2018).
- [9] M. Ablikim *et al.* [BESIII Collaboration], Phys. Rev. Lett. **121**, 251801 (2018).
- [10] M. Ablikim *et al.* [BESIII Collaboration], Phys. Rev. D **99**, 032010 (2019).
- [11] M. Ablikim *et al.* [BESIII Collaboration], Phys. Rev. D **100**, 072004 (2019).



BELLE at the KEK-B factory

Talk: 沈成平

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



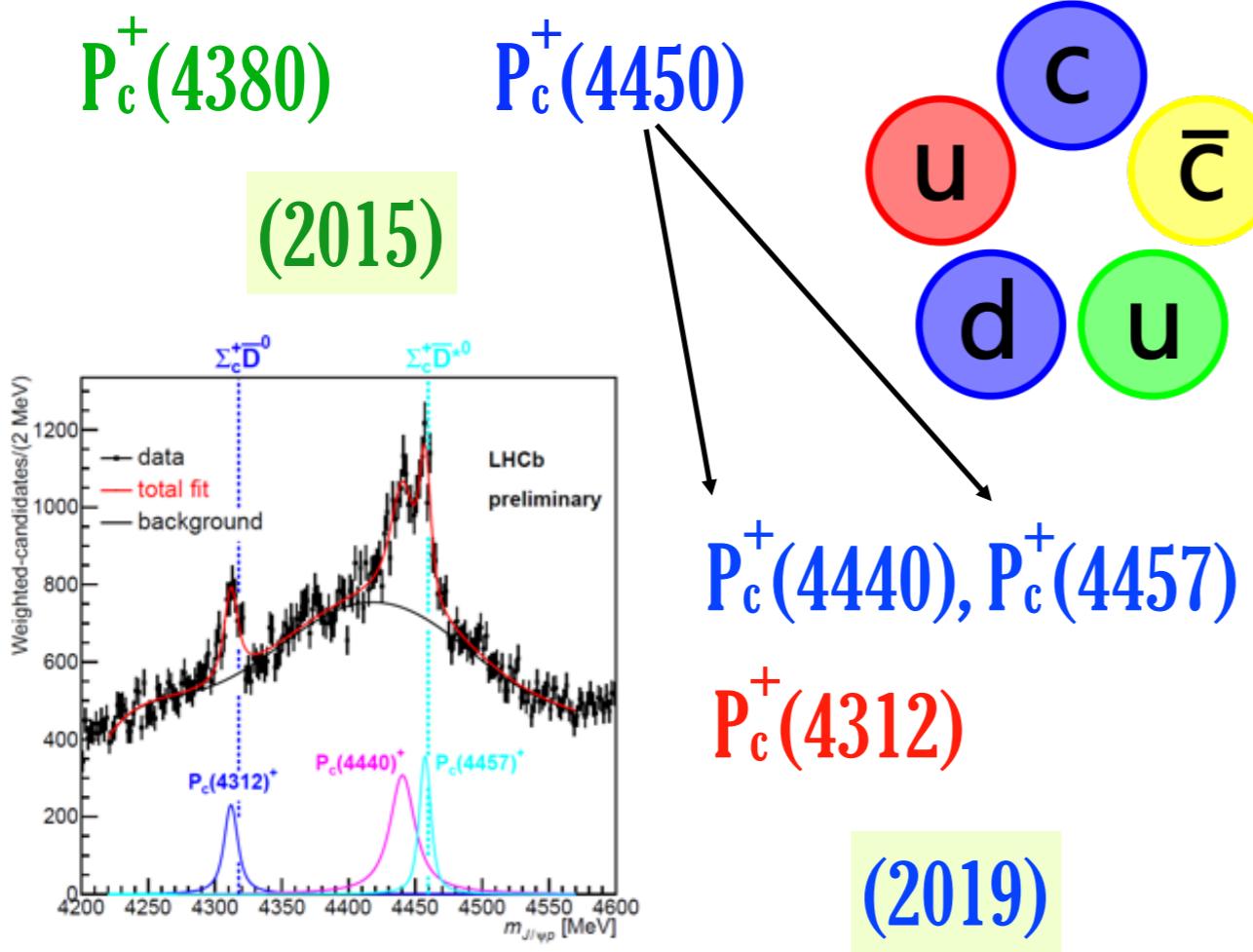
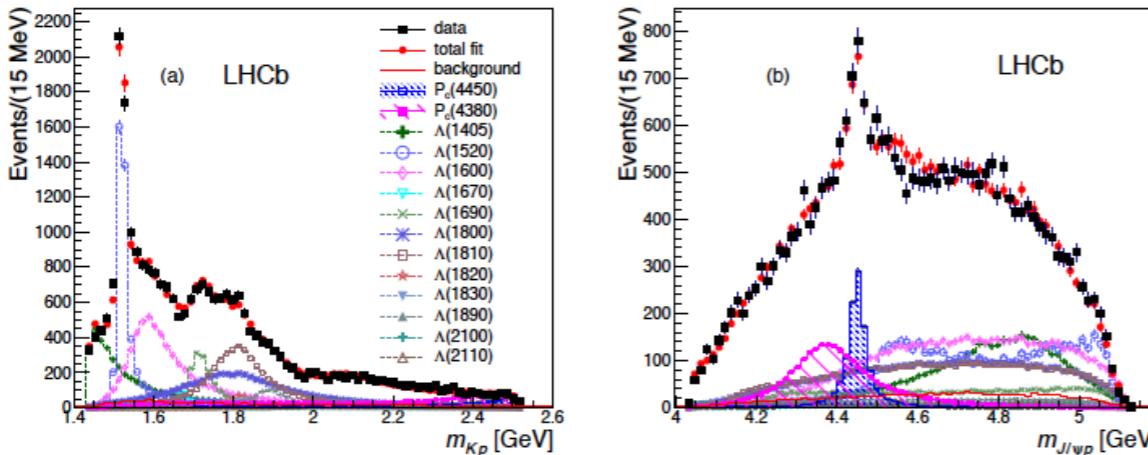
Decay channel	Absolute (*Relative) branching ratio
$\Lambda_c^+ \rightarrow p K^- \pi^+$	$(6.84 \pm 0.24^{+0.21}_{-0.27}) \times 10^{-2}$ [1]
$\Lambda_c^+ \rightarrow p K^+ \pi^-$	$*(2.35 \pm 0.27 \pm 0.21) \times 10^{-3}$ [2]
$\Lambda_c^+ \rightarrow \phi p \pi^0$	$< 1.53 \times 10^{-4}$ [3]
$\Lambda_c^+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

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



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



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



Talk: 谢跃红

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

R. Aaij et al. [LHCb Collaboration], Phys. Rev. D100, 032001 (2019).

Abstract

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

$$\text{LHCb } (\tau_{\Lambda_c^+}, \tau_{\Xi_c^+}, \tau_{\Xi_c^0}) = (203.5 \pm 2.2, 456.8 \pm 5.5, 154.5 \pm 2.5) \text{ fs}$$

$$\text{PDG2018 } (\tau_{\Lambda_c^+}, \tau_{\Xi_c^+}, \tau_{\Xi_c^0}) = (200 \pm 6, 442 \pm 26, 112 \pm 12) \text{ fs}$$

$$\text{Averaged Values } (\tau_{\Lambda_c^+}, \tau_{\Xi_c^+}, \tau_{\Xi_c^0}) = (203.1 \pm 2.1, 456.2 \pm 5.4, 153.0 \pm 2.5) \text{ fs}$$

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• Charmed Baryon with $SU(3)_F$ Flavor Symmetry

QCD

Three light quarks
 $q=u,d,s$

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

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

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

**$SU(3)_F$
Flavor
Symmetry**

$$SU(3)_C : 3 \otimes 3 \otimes 3 = 10_S \oplus 8_{Ms} \oplus 8_{Ma} \oplus 1_A$$

$$SU(3)_F : 3 \otimes 3 \otimes 3 = 10_S \oplus 8_{Ms} \oplus 8_{Ma} \oplus 1_A$$

$$SU(2)_{\text{spin}} : 2 \otimes 2 \otimes 2 = 4_S \oplus 2_{Ms} \oplus 2_{Ma}$$

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

Pauli Exclusion Principle

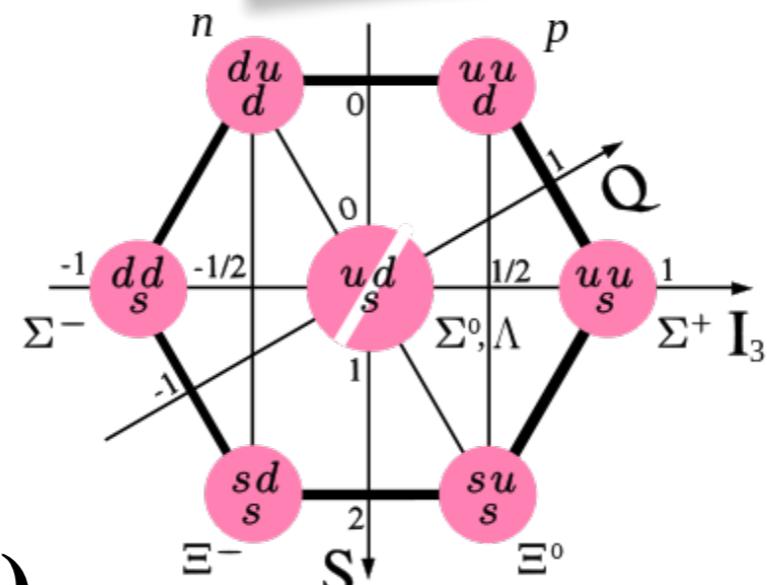
Totally antisymmetric states

Space: L=0 Symmetric

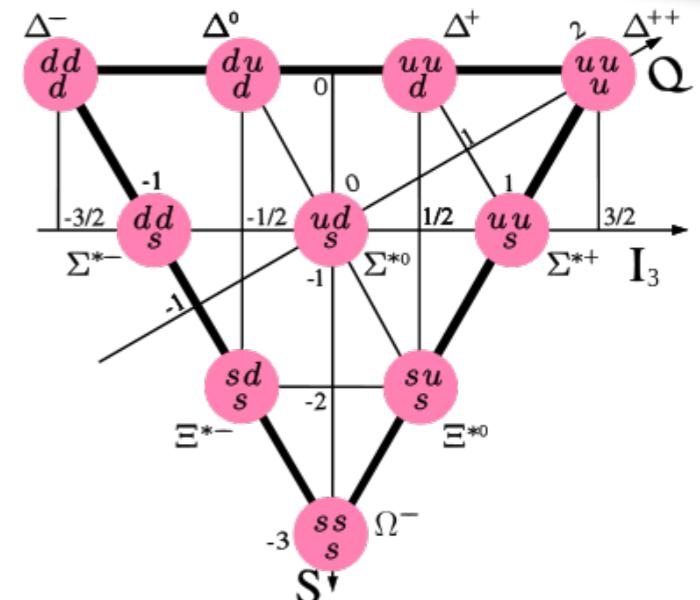
($SU(3)_C$, $SU(3)_F$, $SU(2)_{\text{spin}}$)

Antisymmetric

Symmetric



(1, 8, 2)
 $spin=1/2$



(1, 10, 4)
 $spin=3/2$

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

$SU(4)_F : 4 \otimes 4 \otimes 4 = 20_S \oplus 20_{Ms} \oplus 20_{Ma} \oplus \bar{4}_A$

$SU(3)_C : 3 \otimes 3 \otimes 3 = 10_S \oplus 8_{Ms} \oplus 8_{Ma} \oplus 1_A$

$SU(2)_{\text{spin}} : 2 \otimes 2 \otimes 2 = 4_S \oplus 2_{Ms} \oplus 2_{Ma}$

Space: L=0 Symmetric

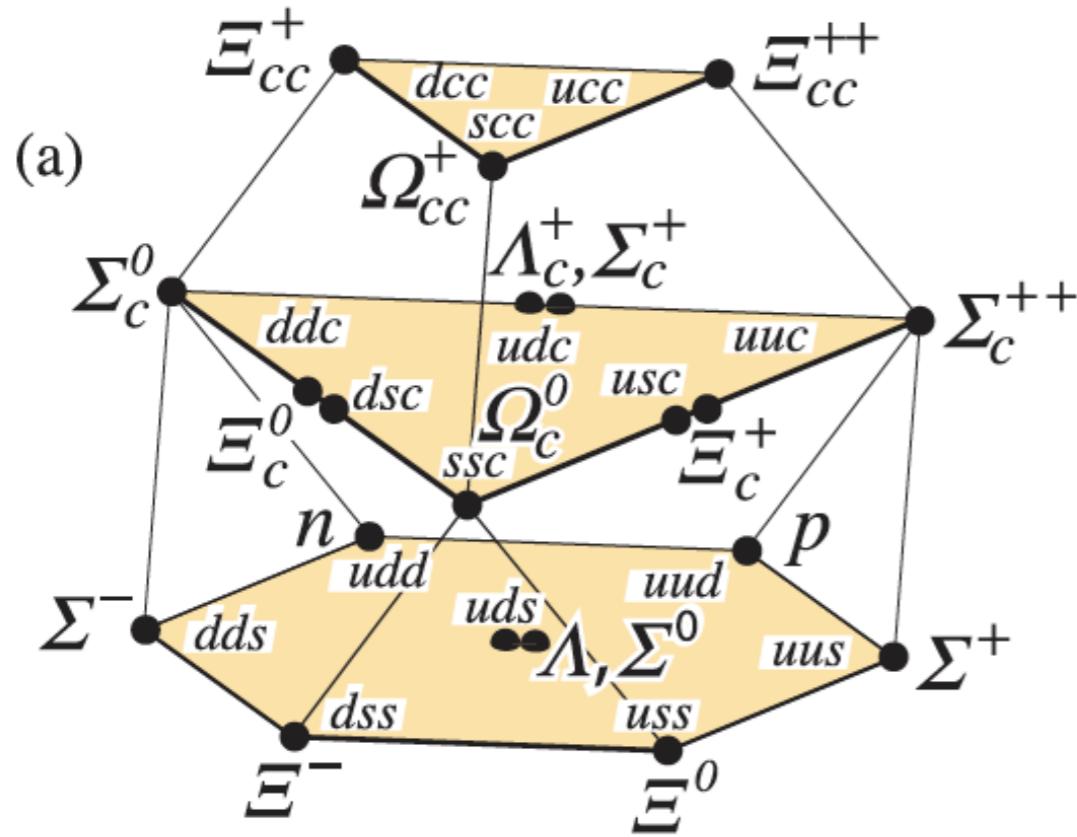
($SU(3)_C$, $SU(4)_F$, $SU(2)_{\text{spin}}$)

Antisymmetric

Symmetric

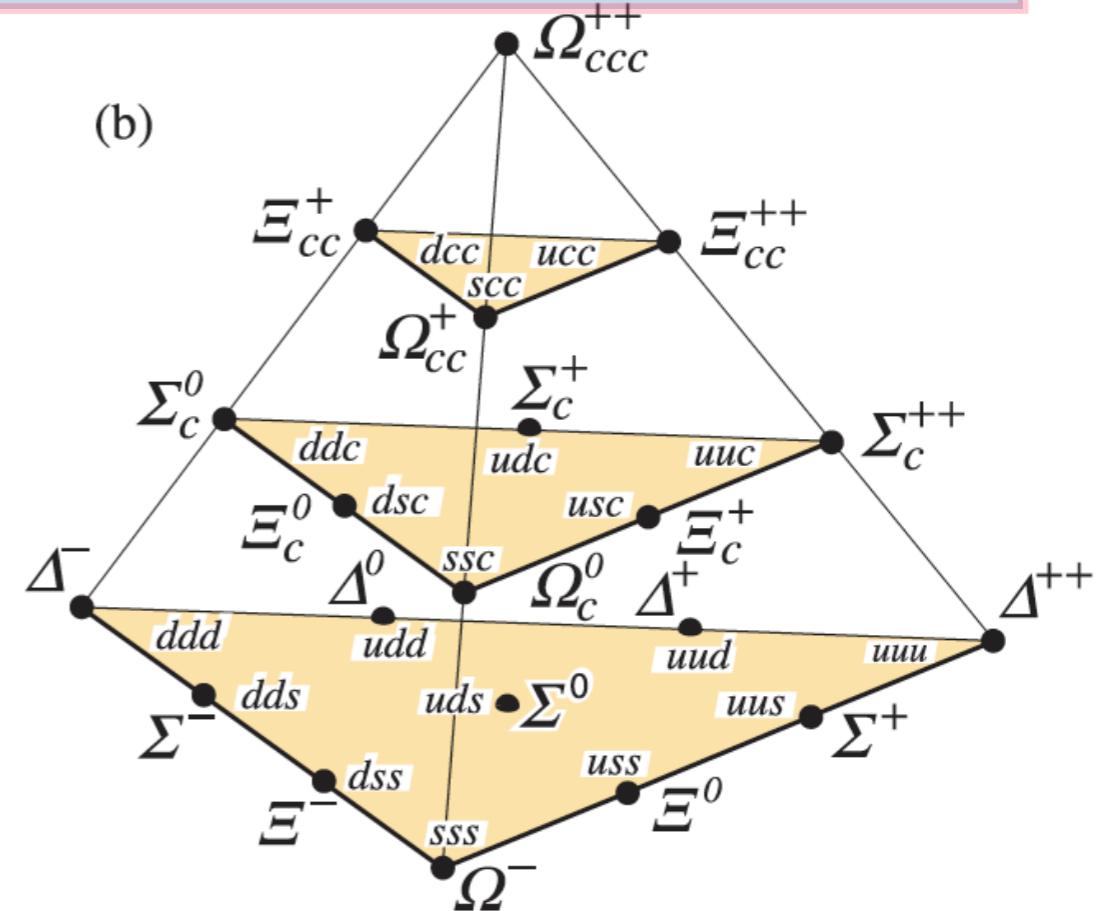
$SU(4)$ multiplets of baryons made of u , d , s , and c quarks.

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



(1, 20, 2)
Mixed-symmetric
 $\text{spin}=1/2$

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

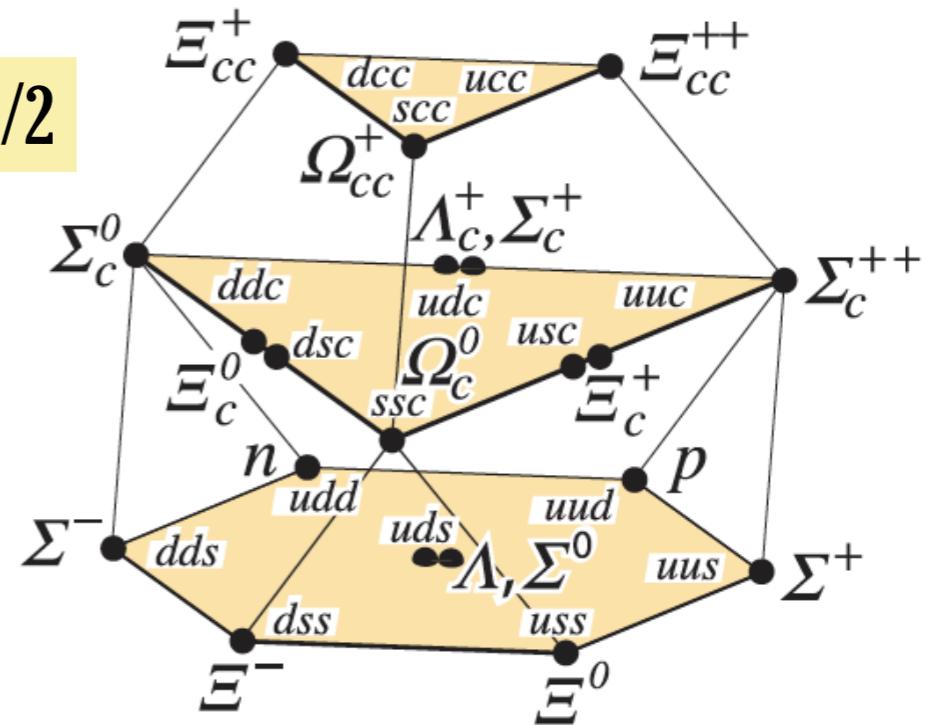


(1, 20, 4)
Totally-symmetric
 $\text{spin}=3/2$

20-plet of $SU(4)_F$ with $\overline{8} \oplus 3 \oplus 6 \oplus 3$ of $SU(3)_F$

$$\boxed{\text{SU(3)F : 8}} \quad B_n = \begin{pmatrix} \frac{1}{\sqrt{6}}\Lambda + \frac{1}{\sqrt{2}}\Sigma^0 & \Sigma^+ & p \\ \Sigma^- & \frac{1}{\sqrt{6}}\Lambda - \frac{1}{\sqrt{2}}\Sigma^0 & n \\ \Xi^- & \Xi^0 & -\sqrt{\frac{2}{3}}\Lambda \end{pmatrix}$$

spin=1/2



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

$$\text{SU}(3)_F: \ 3 \otimes 3 = \bar{3} \oplus 6$$

anti-triplet (3)

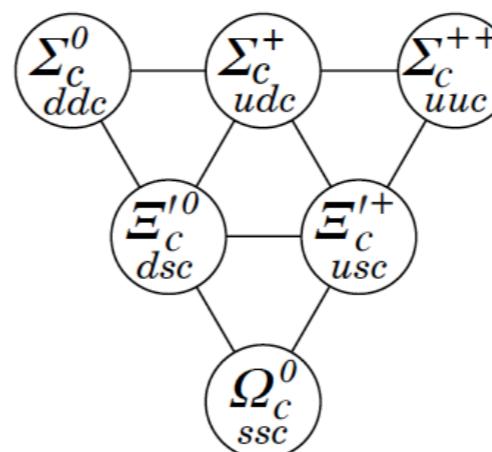
$$\mathbf{B}_c = (\Xi_c^0, -\Xi_c^+, \Lambda_c^+)$$

2286 MeV

2470 MeV

2468 MeV

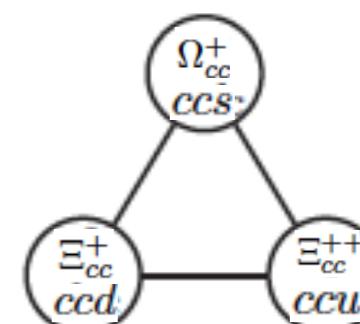
sextet (6)



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

SU(3)_F : 3

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



Effective Hamiltonians for charmed baryon decays with $SU(3)_F$

The effective Hamiltonian for the semileptonic $c \rightarrow q l^\pm \nu_l$ transition with $q=(d \text{ or } s)$:

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

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

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

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

Cabibbo-allowed

Cabibbo-suppressed

doubly Cabibbo-suppressed

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

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

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

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

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

$$\hat{O}_\pm \equiv O_\pm^d - O_\pm^s$$

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

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

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

$$\begin{aligned}\mathcal{O}_6 &= \frac{1}{2}(\bar{u}d\bar{s} - \bar{s}d\bar{u})c, & \hat{\mathcal{O}}_6 &= \frac{1}{2}(\bar{u}d\bar{d} - \bar{d}d\bar{u} + \bar{s}s\bar{u} - \bar{u}s\bar{s})c, & \mathcal{O}'_6 &= \frac{1}{2}(\bar{u}s\bar{d} - \bar{d}s\bar{u})c, \\ \mathcal{O}_{\bar{15}} &= \frac{1}{2}(\bar{u}d\bar{s} + \bar{s}d\bar{u})c, & \hat{\mathcal{O}}_{\bar{15}} &= \frac{1}{2}(\bar{u}d\bar{d} + \bar{d}d\bar{u} - \bar{s}s\bar{u} - \bar{u}s\bar{s})c, & \mathcal{O}'_{\bar{15}} &= \frac{1}{2}(\bar{u}s\bar{d} + \bar{d}s\bar{u})c,\end{aligned}$$

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

$$\begin{aligned}H_{22}(6) &= 2, H_{23}(6) = H_{32}(6) = -2s_c, H_{33}(6) = 2s_c^2 \\ H_2^{13}(\bar{15}) &= H_2^{31}(\bar{15}) = 1, \\ H_2^{12}(\bar{15}) &= H_2^{21}(\bar{15}) = -H_3^{13}(\bar{15}) = -H_3^{31}(\bar{15}) = s_c, \\ H_3^{12}(\bar{15}) &= H_3^{21}(\bar{15}) = -s_c^2,\end{aligned}$$

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

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

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

$$c_+^1 = 1 - \frac{\alpha_s}{2\pi} \ln \frac{M_W^2}{\mu^2}$$

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

$$c_+ = \left(\frac{\alpha(M_W^2)}{\alpha(\mu^2)} \right)^{\frac{6}{33-2N_f}}$$

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

• Updated Results of Charmed Baryon Decays with $SU(3)_F$

Semileptonic decays of charmed baryons

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

TABLE I. Decay branching ratios of $B_c \rightarrow B_n \ell^+ \nu_\ell$ based on $SU(3)_f$ with $\mathcal{B}(\Xi_c^0 \rightarrow \Xi^- e^+ \nu_e)$ in PDG and $\mathcal{B}(\Xi_c^+ \rightarrow \Xi^0 e^+ \nu_e)$ extracted from the measurement on $\mathcal{B}(\Xi_c^+ \rightarrow \Xi^- \pi^+ \pi^+)$ by BELLE [1] and $\frac{\mathcal{B}(\Xi_c^0 \rightarrow \Xi^- e^+ \nu_e)}{\mathcal{B}(\Xi_c^+ \rightarrow \Xi^- \pi^+ \pi^+)}$ in PDG [2, 3].

U
P
D
A
T
E
D

Branching ratio	$SU(3)_f$	HQET [4]	LF [5]	MBM	NRQM	LQCD	Data
$10^2 \mathcal{B}(\Lambda_c^+ \rightarrow \Lambda e^+ \nu_e)$	3.4 ± 0.3	1.42	1.63	3.86	4.86	3.80 ± 0.22 [7]	3.6 ± 0.4 [2]
$10^2 \mathcal{B}(\Lambda_c^+ \rightarrow \Lambda \mu^+ \nu_\mu)$	3.2 ± 0.3	-	-	3.76	4.74	3.69 ± 0.22 [7]	3.5 ± 0.5 [2]
$10^2 \mathcal{B}(\Xi_c^+ \rightarrow \Xi^0 e^+ \nu_e)$	11.4 ± 1.0	-	5.39	13.6	17.1	-	$6.6^{+3.7}_{-3.5}$ [1–3]
$10^2 \mathcal{B}(\Xi_c^+ \rightarrow \Xi^0 \mu^+ \nu_\mu)$	10.8 ± 1.0	-	-	13.3	16.6	-	-
$10^2 \mathcal{B}(\Xi_c^0 \rightarrow \Xi^- e^+ \nu_e)$	3.7 ± 0.3	0.86	1.35	4.56	5.68	-	1.8 ± 1.2 [2]
$10^2 \mathcal{B}(\Xi_c^0 \rightarrow \Xi^- \mu^+ \nu_\mu)$	3.6 ± 0.3	-	-	4.44	5.52	-	-
$10^3 \mathcal{B}(\Lambda_c^+ \rightarrow n e^+ \nu_e)$	5.3 ± 0.5	-	2.01	3.33	5.32	4.10 ± 0.29 [8]	-
$10^3 \mathcal{B}(\Xi_c^+ \rightarrow \Sigma^0 e^+ \nu_e)$	4.9 ± 0.4	-	1.87	3.62	5.60	-	-
$10^4 \mathcal{B}(\Xi_c^+ \rightarrow \Lambda e^+ \nu_e)$	23.2 ± 2.0	-	8.22	15.1	22.4	-	-
$10^4 \mathcal{B}(\Xi_c^0 \rightarrow \Sigma^- e^+ \nu_e)$	33.0 ± 2.9	-	9.47	25.2	39.2	-	-

UPDATED

TABLE II. $SU(3)_f$, MBM and NRQM averaged up-down asymmetries

Asymmetry $\langle \alpha \rangle$	SU(3)	MBM	NRQM	Data
$\Lambda_c^+ \rightarrow \Lambda \ell^+ \nu_\ell$	-0.86 ± 0.04	-0.729	-0.504	-0.86 ± 0.04
$\Xi_c^+ \rightarrow \Xi^0 \ell^+ \nu_\ell$	-0.83 ± 0.04	-0.732	-0.516	-
$\Xi_c^0 \rightarrow \Xi^- \ell^+ \nu_\ell$	-0.83 ± 0.04	-0.737	-0.515	-
$\Lambda_c^+ \rightarrow n \ell^+ \nu_\ell$	-0.89 ± 0.04	-0.680	-0.379	-
$\Xi_c^+ \rightarrow \Sigma^0 \ell^+ \nu_\ell$	-0.85 ± 0.04	-0.741	-0.426	-
$\Xi_c^+ \rightarrow \Lambda \ell^+ \nu_\ell$	-0.86 ± 0.04	-0.680	-0.377	-
$\Xi_c^0 \rightarrow \Sigma^- \ell^+ \nu_\ell$	-0.85 ± 0.04	-0.734	-0.424	-

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

Two-body nonleptonic decays of charmed baryons

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

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

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

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

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

spin-dependent amplitude

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

Decay rate:

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

Differential decay rate:

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

Up-down asymmetry:

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

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

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

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

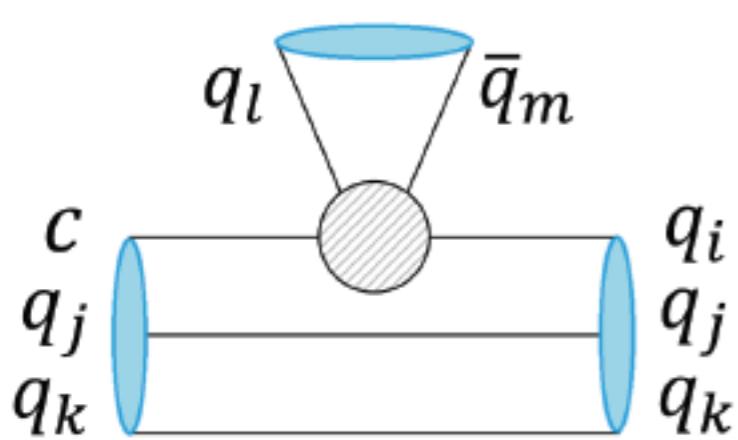
$$\mathcal{M}(\text{B}_c \rightarrow \text{B}_n M) = i\bar{u}_{\text{B}_n} (A - B\gamma_5) u_{\text{B}_c}$$

spin-dependent amplitude

$$A_{(\text{B}_c \rightarrow \text{B}_n M)} =$$

$$a_0 H(6)_{ij} (\text{B}'_c)^{ik} (\text{B}_n)^j_k (M)^l_l + a_1 H(6)_{ij} (\text{B}'_c)^{ik} (\text{B}_n)^l_k (M)^j_l + a_2 H(6)_{ij} (\text{B}'_c)^{ik} (M)^l_k (\text{B}_n)^j_l + \\ a_3 H(6)_{ij} (\text{B}_n)^i_k (M)^j_l (\text{B}'_c)^{kl} + a'_0 (\text{B}_n)^i_j (M)^l_l H(\overline{15})^{jk}_i (\text{B}_c)_k + a_4 H(\overline{15})^l_k (\text{B}_c)_j (M)^i_i (\text{B}_n)^k_l + \\ a_5 (\text{B}_n)^i_j (M)^l_i H(\overline{15})^{jk}_l (\text{B}_c)_k + a_6 (\text{B}_n)^i_i (M)^m_l H(\overline{15})^l_m (\text{B}_c)_j + a_7 (\text{B}_n)^l_i (M)^i_j H(\overline{15})^{jk}_l (\text{B}_c)_k,$$

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



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

Two reasons:

1. $(c_-/c_+)^2 \sim 5.5$;
2. $\mathcal{O}_{\overline{15}} = \frac{1}{2}(\bar{u}d\bar{s} + \bar{s}d\bar{u})c$

Assumption

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

is symmetric, whereas the baryon wave function is totally antisymmetric in color indices.

Vanishing nonfactorizable contributions

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

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

UPDATED

Channel	$10^3 \mathcal{B}_{exp}$	α_{exp}
$\Lambda_c^+ \rightarrow \Lambda^0 \pi^+$	13.0 ± 0.7	-0.80 ± 0.11
$\Lambda_c^+ \rightarrow p K_S$	15.8 ± 0.8	$*0.18 \pm 0.45$
$\Lambda_c^+ \rightarrow \Sigma^0 \pi^+$	12.9 ± 0.7	-0.57 ± 0.12
$\Lambda_c^+ \rightarrow \Sigma^+ \pi^0$	12.4 ± 1.0	-0.73 ± 0.18
$\Lambda_c^+ \rightarrow \Sigma^+ \eta$	4.1 ± 2.0	
$\Lambda_c^+ \rightarrow \Sigma^+ \eta'$	13.4 ± 5.7	
$\Lambda_c^+ \rightarrow \Xi^0 K^+$	5.9 ± 1.0	$*0.77 \pm 0.78$
$\Lambda_c^+ \rightarrow p \pi^0$	0.08 ± 0.13	
$\Lambda_c^+ \rightarrow p \eta$	1.24 ± 0.3	
$\Lambda_c^+ \rightarrow \Lambda^0 K^+$	0.61 ± 0.12	
$\Lambda_c^+ \rightarrow \Sigma^0 K^+$	0.52 ± 0.08	
$\Xi_c^0 \rightarrow \Xi^- \pi^+$	18.0 ± 5.2	-0.6 ± 0.4
$\Xi_c^+ \rightarrow \Xi^0 \pi^+$	16 ± 8	
$\Xi_c^0 \rightarrow \Lambda^0 K_S^0$		
$**\mathcal{R}_{\Xi_c^0}$	$**0.210 \pm 0.028$	

C.Q. Geng, C.W. Liu and
charmed baryon decays,'

18 data points above

$$(a_1, a_2, a_3,$$

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

*Not included in the d

** $\mathcal{R}_{\Xi_c^0} \equiv \mathcal{B}(\Xi_c^0 \rightarrow \Lambda K_S^0)/$

$10^3 \mathcal{B}_{dm}$	α_{dm}	of anti-triplet
13.0	-0.93	2019).
10.6	-0.75	
22.4	-0.76	parameters:
22.4	-0.76	
7.4	-0.95	, b_6, \tilde{b})
—		
7.3	+0.90	$a_1 + a_2 - a_3$)
0.13	-0.97	
1.28	-0.55	$b_1 + b_2 - b_3$)
1.07	-0.96	
0.72	-0.73	$0) = 1.3$
64.7	-0.95	
17.2	-0.78	
6.7	-0.86	

Talk: 徐繁荣

Zou-Xu-Meng- Cheng
arXiv:1910.13626

$$(a_1, a_2, a_3, a_6, \tilde{a}) = (3.79 \pm 0.41, -1.61 \pm 0.21, 1.20 \pm 0.40, -0.13 \pm 0.72, 2.44 \pm 0.00, 10^{-2} G_F \text{GeV}^2,$$

$$(b_1, b_2, b_3, b_6, \tilde{b}) = (-10.80 \pm 1.16, -7.06 \pm 1.05, 0.77 \pm 1.46, -3.51 \pm 2.03, 10.98 \pm 4.78) 10^{-2} G_F \text{GeV}^2.$$

UPDATERED

Cabibbo Allowed

channel	$10^3 \mathcal{B}$	α	channel	$10^3 \mathcal{B}$	α
$\Lambda_c^+ \rightarrow \Lambda^0 \pi^+$	12.8 ± 0.7	-0.76 ± 0.09	$\Xi_c^0 \rightarrow \Lambda^0 K_S$	6.6 ± 0.4	$-0.89^{+0.13}_{-0.11}$
$\Lambda_c^+ \rightarrow p K_S$	15.8 ± 0.8	$-0.99^{+0.05}_{-0.01}$	$\Xi_c^0 \rightarrow \Lambda^0 K_L$	7.2 ± 0.4	-0.87 ± 0.13
$\Lambda_c^+ \rightarrow p K_L$	15.6 ± 0.8	$-1.00^{+0.02}_{-0}$	$\Xi_c^0 \rightarrow \Lambda^0 \bar{K}^0$	13.8 ± 0.8	$-0.88^{+0.13}_{-0.12}$
$\Lambda_c^+ \rightarrow p \bar{K}^0$	31.3 ± 1.6	$-1.00^{+0.04}_{-0}$	$\Xi_c^0 \rightarrow \Sigma^0 K_S$	0.6 ± 0.6	0.18 ± 0.79
$\Lambda_c^+ \rightarrow \Sigma^0 \pi^+$	12.6 ± 0.6	-0.60 ± 0.10	$\Xi_c^0 \rightarrow \Sigma^0 K_L$	0.5 ± 0.5	$0.72^{+0.28}_{-0.44}$
$\Lambda_c^+ \rightarrow \Sigma^+ \pi^0$	12.6 ± 0.6	-0.60 ± 0.10	$\Xi_c^0 \rightarrow \Sigma^0 \bar{K}^0$	1.1 ± 1.1	$0.45^{+0.55}_{-0.63}$
$\Lambda_c^+ \rightarrow \Sigma^+ \eta$	2.9 ± 1.3	$-0.71^{+0.68}_{-0.29}$	$\Xi_c^0 \rightarrow \Sigma^+ K^-$	7.4 ± 1.4	$0.94^{+0.06}_{-0.08}$
$\Lambda_c^+ \rightarrow \Sigma^+ \eta'$	14.5 ± 5.9	$0.98^{+0.02}_{-0.08}$	$\Xi_c^0 \rightarrow \Xi^0 \pi^0$	9.8 ± 1.4	$-0.96^{+0.05}_{-0.04}$
$\Lambda_c^+ \rightarrow \Xi^0 K^+$	5.7 ± 0.9	$1.0^{+0}_{-0.03}$	$\Xi_c^0 \rightarrow \Xi^0 \eta$	12.8 ± 2.3	0.78 ± 0.17
$\Xi_c^+ \rightarrow \Sigma^+ K_S$	$3.6^{+4.4}_{-3.6}$	$0.75^{+0.25}_{-0.31}$	$\Xi_c^0 \rightarrow \Xi^0 \eta'$	11.7 ± 5.6	$1.00^{+0}_{-0.06}$
$\Xi_c^+ \rightarrow \Sigma^+ K_L$	$2.9^{+3.7}_{-2.9}$	$1.0^{+0}_{-0.08}$	$\Xi_c^0 \rightarrow \Xi^- \pi^+$	29.1 ± 1.4	$-1.00^{+0.03}_{-0}$
$\Xi_c^+ \rightarrow \Sigma^+ \bar{K}^0$	$6.3^{+8.1}_{-6.3}$	$0.91^{+0.09}_{-0.15}$			
$\Xi_c^+ \rightarrow \Xi^0 \pi^+$	4.2 ± 1.7	$-0.49^{+0.60}_{-0.51}$			

TABLE V. Summary of our results with $SU(3)_F$ and those in the literature for the up-down asymmetries of the Cabibbo-allowed charmed baryon decays, where the data, KK, XK, CT, UVK, Zen, Iva, SV1, and SV2 are from the PDG [2], Korner and Kramer [27], Xu and Kamal [28], Cheng and Tseng [30], Uppal, Verma and Khanna [31], HY Cheng et al. [33], Sharma and Verma [34], and Sharma and Verma [35].

Cabibbo Allowed

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channel	updated result	BESIII C Phys. Rev. D HY Cheng et al, arXiv:1910.13626	ref. [33], Sharma and Verma [35]	Zen	Iva	SV1	SV2 (SV2')
$\Lambda_c^+ \rightarrow \Lambda^0 \pi^+$	-0.76 ± 0.09	-0.80 ± 0.11	-0.93	-0.99	-0.87	-0.99	-0.95
$\Lambda_c^+ \rightarrow p K_s^0$	$-0.99^{+0.05}_{-0.01}$	*0.18 ± 0.45	-0.75	(-0.95)	(-0.85)	-0.90	-0.99
$\Lambda_c^+ \rightarrow \Sigma^0 \pi^+$	-0.60 ± 0.10	*0.57 ± 0.12	-0.76	(-0.49)	(-0.99)	-0.49	-0.66
$\Lambda_c^+ \rightarrow \Sigma^+ \pi^0$	-0.60 ± 0.10	*0.73 ± 0.18	-0.76	(0.78)	(-0.32)	0.39	0.43
$\Lambda_c^+ \rightarrow \Sigma^+ \eta$	$-0.71^{+0.68}_{-0.29}$		-0.95	-0.49	-0.32	0.39	0.43
$\Lambda_c^+ \rightarrow \Sigma^+ \eta'$	$0.98^{+0.02}_{-0.08}$		—	(0.78)	(-0.32)	-0.31	0.31
$\Lambda_c^+ \rightarrow \Xi^0 K^+$	$1.00^{+0.00}_{-0.03}$	*0.77 ± 0.78	0.90	-0.94	0	0.55	-0.99
$\alpha(\Lambda_c^+ \rightarrow \Xi^0 K^+)_{dynamical\ model} = 0.90$							

$$\alpha(\Lambda_c^+ \rightarrow \Xi^0 K^+)_{SU(3)} = 1.00^{+0.00}_{-0.03}$$

Zou, Xu, Meng, HY Cheng, arXiv:1910.13626 (2019)

The signal processes $\Lambda_c^+ \rightarrow \Xi^{(*)0} K^+$ are simulated by taking into account the angular dependences $1 + \alpha_{\Xi^{(*)} K} \cos^2 \theta_K$. We obtain the parameters $\alpha_{\Xi K} = 0.77 \pm 0.78$ and $\alpha_{\Xi^* K} = -1.00 \pm 0.34$ from fits to data, where the statistical uncertainties are dominant.

BESIII

Cabibbo Suppressed

channel	$10^4 \mathcal{B}$	α	channel	$10^4 \mathcal{B}$	α
$\Lambda_c^+ \rightarrow \Lambda^0 K^+$	6.6 ± 0.9	0.05 ± 0.26	$\Xi_c^0 \rightarrow \Lambda^0 \pi^0$	2.9 ± 1.0	0.07 ± 0.22
$\Lambda_c^+ \rightarrow p \pi^0$	1.2 ± 1.2	0.36 ± 0.53	$\Xi_c^0 \rightarrow \Lambda^0 \eta$	7.9 ± 2.6	-0.12 ± 0.24
$\Lambda_c^+ \rightarrow p \eta$	11.3 ± 3.2	$-1.00^{+0.05}_{-0}$	$\Xi_c^0 \rightarrow \Lambda^0 \eta'$	20.9 ± 10.9	$1.00^{+0}_{-0.09}$
$\Lambda_c^+ \rightarrow p \eta'$	22.7 ± 10.9	$1.00^{+0}_{-0.07}$	$\Xi_c^0 \rightarrow p K^-$	5.8 ± 1.3	0.83 ± 0.11
$\Lambda_c^+ \rightarrow n \pi^+$	7.6 ± 1.2	0.28 ± 0.13	$\Xi_c^0 \rightarrow n \bar{K}^0$	10.6 ± 0.6	-0.76 ± 0.11
$\Lambda_c^+ \rightarrow \Sigma^0 K^+$	5.2 ± 0.7	$-0.97^{+0.04}_{-0.03}$	$\Xi_c^0 \rightarrow \Sigma^0 \pi^0$	5.0 ± 0.9	-0.69 ± 0.23
$\Lambda_c^+ \rightarrow \Sigma^+ K^0$	10.4 ± 1.4	$-0.97^{+0.04}_{-0.03}$	$\Xi_c^0 \rightarrow \Sigma^0 \eta$	1.6 ± 0.9	$-0.32^{+0.75}_{-0.68}$
UPDATE	$\Xi_c^+ \rightarrow \Lambda^0 \pi^+$	12.0 ± 4.3	$\Xi_c^0 \rightarrow \Sigma^0 \eta'$	4.4 ± 2.4	$0.96^{+0.04}_{-0.15}$
	$\Xi_c^+ \rightarrow p \bar{K}^0$	46.3 ± 7.3	$\Xi_c^0 \rightarrow \Sigma^+ \pi^-$	4.7 ± 0.9	$0.92^{+0.08}_{-0.09}$
	$\Xi_c^+ \rightarrow \Sigma^0 \pi^+$	26.5 ± 2.5	$\Xi_c^0 \rightarrow \Sigma^- \pi^+$	18.1 ± 0.8	-0.99 ± 0.01
	$\Xi_c^+ \rightarrow \Sigma^+ \pi^0$	25.0 ± 5.9	$\Xi_c^0 \rightarrow \Xi^0 K^0$	9.4 ± 0.4	-0.55 ± 0.09
	$\Xi_c^+ \rightarrow \Sigma^+ \eta$	13.3 ± 8.8	$\Xi_c^0 \rightarrow \Xi^- K^+$	12.6 ± 0.7	$-1.00^{+0.03}_{-0}$
	$\Xi_c^+ \rightarrow \Sigma^+ \eta'$	34.8 ± 17.9			
	$\Xi_c^+ \rightarrow \Xi^0 K^+$	7.6 ± 1.3			
		0.41 ± 0.19			

Cabibbo Suppressed: Up-down Asymmetries

UPDATED

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

channel	our result	UVK ^(t)	SV2 ^(t)	CKX	Zou-Xu-Meng- Cheng arXiv:1910.13626
$\Lambda_c^+ \rightarrow p\pi^0$	0.36 ± 0.53	0.82 (0.85)	0.05 (0.05)	-0.95	-0.97
$\Lambda_c^+ \rightarrow p\eta$	$-1.00^{+0.05}_0$	-1.00 (-0.79)	-0.74 (-0.45)	-0.56	-0.55
$\Lambda_c^+ \rightarrow p\eta'$	$1.00^{+0}_{-0.07}$	0.87 (0.87)	-0.97 (-0.99)	—	—
$\Lambda_c^+ \rightarrow n\pi^+$	0.28 ± 0.13	-0.13 (0.68)	0.05 (0.05)	-0.90	-0.73
$\Lambda_c^+ \rightarrow \Lambda^0 K^+$	0.05 ± 0.26	-0.99 (-0.99)	-0.54 (0.97)	-0.96	-0.96
$\Lambda_c^+ \rightarrow \Sigma^0 K^+$	$-0.97^{+0.04}_{-0.03}$	-0.80 (-0.80)	0.68 (-0.98)	-0.73	-0.73
$\Lambda_c^+ \rightarrow \Sigma^+ K^0$	$-0.97^{+0.04}_{-0.03}$	-0.80 (-0.80)	0.68 (-0.98)	-0.74	-0.73

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

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

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

Doubly Cabibbo Suppressed

channel	$10^5 \mathcal{B}$	α
$\Lambda_c^+ \rightarrow p K^0$	0.8 ± 1.1	$0.97^{+0.03}_{-0.12}$
$\Lambda_c^+ \rightarrow n K^+$	0.5 ± 0.2	$-0.61^{+0.76}_{-0.39}$
$\Xi_c^+ \rightarrow \Lambda^0 K^+$	3.1 ± 0.5	0.50 ± 0.16
$\Xi_c^+ \rightarrow p \pi^0$	5.3 ± 1.2	0.81 ± 0.12
$\Xi_c^+ \rightarrow p \eta$	19.8 ± 7.6	-0.58 ± 0.12
$\Xi_c^+ \rightarrow p \eta'$	35.3 ± 20.4	$0.97^{+0.03}_{-0.15}$
$\Xi_c^+ \rightarrow n \pi^+$	10.7 ± 2.4	0.81 ± 0.12
$\Xi_c^+ \rightarrow \Sigma^0 K^+$	12.1 ± 0.6	$-1.00^{+0.02}_{-0.0}$
$\Xi_c^+ \rightarrow \Sigma^+ K^0$	18.6 ± 1.6	$-0.96^{+0.11}_{-0.04}$
$\Xi_c^0 \rightarrow \Lambda^0 K^0$	0.9 ± 0.3	0.00 ± 0.33
$\Xi_c^0 \rightarrow p \pi^-$	3.6 ± 0.8	0.81 ± 0.12
$\Xi_c^0 \rightarrow n \pi^0$	1.8 ± 0.4	0.81 ± 0.12
$\Xi_c^0 \rightarrow n \eta$	6.6 ± 2.5	-0.58 ± 0.12
$\Xi_c^0 \rightarrow n \eta'$	11.8 ± 6.9	$0.97^{+0.03}_{-0.15}$
$\Xi_c^0 \rightarrow \Sigma^0 K^0$	3.1 ± 0.3	$-0.96^{+0.11}_{-0.04}$
$\Xi_c^0 \rightarrow \Sigma^- K^+$	8.1 ± 0.4	$-1.00^{+0.02}_{-0.0}$

UPDATED

Three-body nonleptonic decays of charmed baryons

$$B_c \rightarrow B_n MM'$$

J.Y. Cen, C.Q. Geng, C.W. Liu and T.H. Tsai, “Up-down asymmetries in charmed baryon three-body decays,” Eur. Phys. J. C79, 946 (2019).

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

Under $SU(3)_F$ flavor symmetry:

$$\begin{aligned} A(B_c \rightarrow B_n MM') = & a_1 (\bar{B}_n)_i^k (M)_l^m (M)_m^l H(6)_{jk} T^{ij} + a_2 (\bar{B}_n)_i^k (M)_j^m (M)_m^l H(6)_{kl} T^{ij} \\ & + a_3 (\bar{B}_n)_i^k (M)_k^m (M)_m^l H(6)_{jl} T^{ij} + a_4 (\bar{B}_n)_i^k (M)_j^l (M)_k^m H(6)_{lm} T^{ij} \\ & + a_5 (\bar{B}_n)_k^l (M)_j^m (M)_m^k H(6)_{il} T^{ij} + a_6 (\bar{B}_n)_k^l (M)_j^m (M)_l^k H(6)_{im} T^{ij} \end{aligned}$$

$$B(B_c \rightarrow B_n MM') = A(B_c \rightarrow B_n MM') \{a_i \rightarrow b_i\}$$

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

Remarks:

1. Consider only the S-wave ($L=0$) contributions from MM' in the amplitudes.
2. Neglect the contributions from $H(\overline{15})$.
3. Take the data with only the non-resonant parts.

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

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

16 data points above to fit with 12 real parameters:

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

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

TABLE VI. Numerical results for $\mathcal{B}(\Lambda_c^+ \rightarrow \mathbf{B}_n MM')$.

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

 TABLE IX. Numerical results for $\langle \alpha \rangle (\Lambda_c^+ \rightarrow \mathbf{B}_n MM')$.

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

• Summary

- We have studied the weak decays of charmed baryons based on SU(3)_F flavor symmetry.

👉 ◆ Rich physics for Charmed Baryons at BESIII, LHCb, Belle(II)

More theoretical and experimental studies are needed.

甲 丁
乙 丙

粒子物理标准模型

三代物质粒子（费米子）				
I	II	III		
质量 电荷 自旋	$\approx 2.2 \text{ MeV}/c^2$ 2/3 1/2 u 上	$\approx 1.28 \text{ GeV}/c^2$ 2/3 1/2 c 丁	$\approx 173.1 \text{ GeV}/c^2$ 2/3 1/2 t 顶	0 0 g 胶子
	$\approx 4.7 \text{ MeV}/c^2$ -1/3 1/2 d 下	$\approx 96 \text{ MeV}/c^2$ -1/3 1/2 s 奇	$\approx 4.18 \text{ GeV}/c^2$ -1/3 1/2 b 底	0 0 1 γ 光子
	$\approx 0.511 \text{ MeV}/c^2$ -1 1/2 e 电子	$\approx 105.66 \text{ MeV}/c^2$ -1 1/2 μ μ 子	$\approx 1.7768 \text{ GeV}/c^2$ -1 1/2 τ τ 子	0 1 Z Z 玻色子
	$<2.2 \text{ eV}/c^2$ 0 1/2 ν_e 电中微子	$<1.7 \text{ MeV}/c^2$ 0 1/2 ν_μ μ 中微子	$<15.5 \text{ MeV}/c^2$ 0 1/2 ν_τ τ 中微子	± 1 1 W W 玻色子

标量玻色子
规范玻色子

Charm Quark 丁夸克

Charmed Baryon

丁重子

Super τ -Charm Factory

超级 τ -丁工厂

丁-丁

