22 Lomonosov Conference on Elementary Particle Physics

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Moscow State University

Charmed baryons at Belle and Belle II

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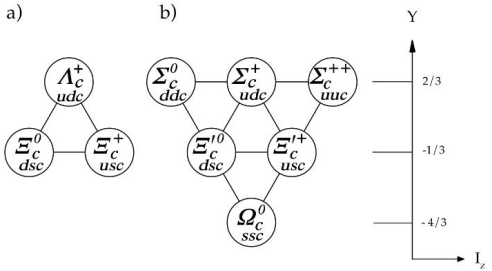
Charmed baryons topics

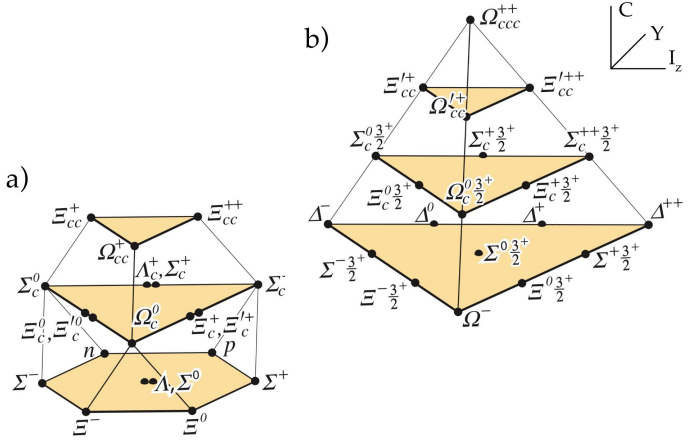
spectroscopy

- mass
- width
- quantum numbers (I^G, J^{PC})



week decays

- lifetime hierarchy
- branching fractions



strong decays of excited states

- dynamics & probabilities

Introduction

In the past two decades, many new excited charmed baryon states have been discovered by BaBar, Belle, CLEO and LHCb. **[Chin. J. Phys. 78 (2022) 324]**

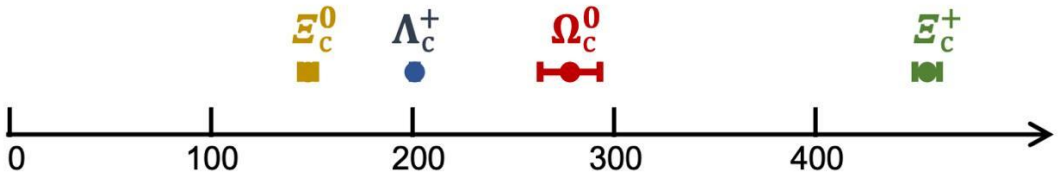
- Theoretical interest peaked ~ early 1990s
- But we still do not have a good phenomenological model
- Lifetimes of the heavy baryons are commonly analyzed within the framework of heavy quark expansion (HQE)
- Prediction by HQE :

$$\tau(\Xi^{+}_{C}) > \tau(\Lambda^{+}_{C}) > \tau(\Xi^{0}_{C}) > \tau(\Omega^{0}_{C})$$

is in agreement with experiments before 2018

Lifetime of charmed baryons

High influence of spectator quarks!



Lifetime hierarchy of charmed baryons, fs [PDG 2024]

[Chin. J. Phys. 78 (2022) 324]

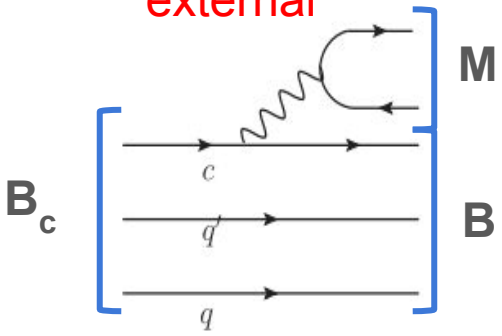
Evolution of the charmed baryon lifetimes measured in units of 10^{-13} s.

	$\tau(\Xi_c^+)$	$\tau(\Lambda_c^+)$	$\tau(\Xi_c^0)$	$\tau(\Omega_c^0)$
PDG (2004–2018) [5]	4.42 ± 0.26	2.00 ± 0.06	$1.12^{+0.13}_{-0.10}$	0.69 ± 0.12
LHCb (2018) [6]				2.68 ± 0.26
LHCb (2019) [125]	4.57 ± 0.06	2.035 ± 0.022	1.545 ± 0.026	
PDG (2020) [31]	4.56 ± 0.05	2.024 ± 0.031	1.53 ± 0.06	2.68 ± 0.26
LHCb (2021) [126]			1.480 ± 0.032	2.765 ± 0.141
WA (2021)	4.56 ± 0.05	2.024 ± 0.031	1.520 ± 0.020	2.745 ± 0.124

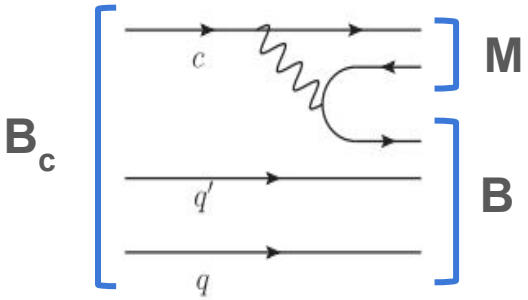
Weak decays

B_c - charmed baryon; B - daughter baryon; M - daugther meson

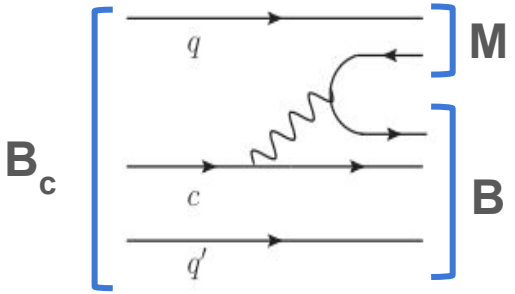
external



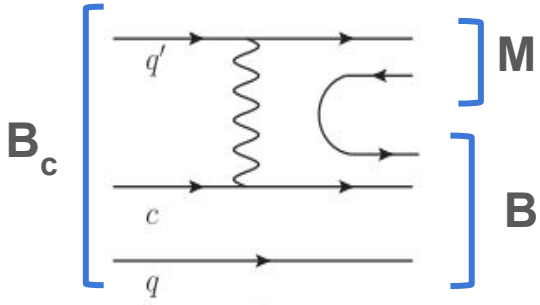
internal

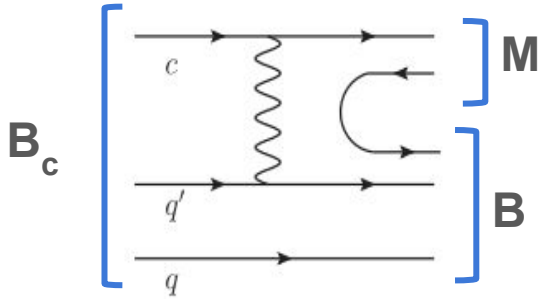


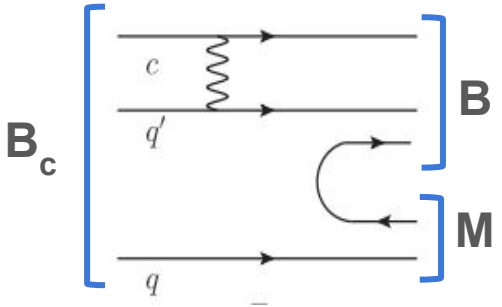
inner



W - emission





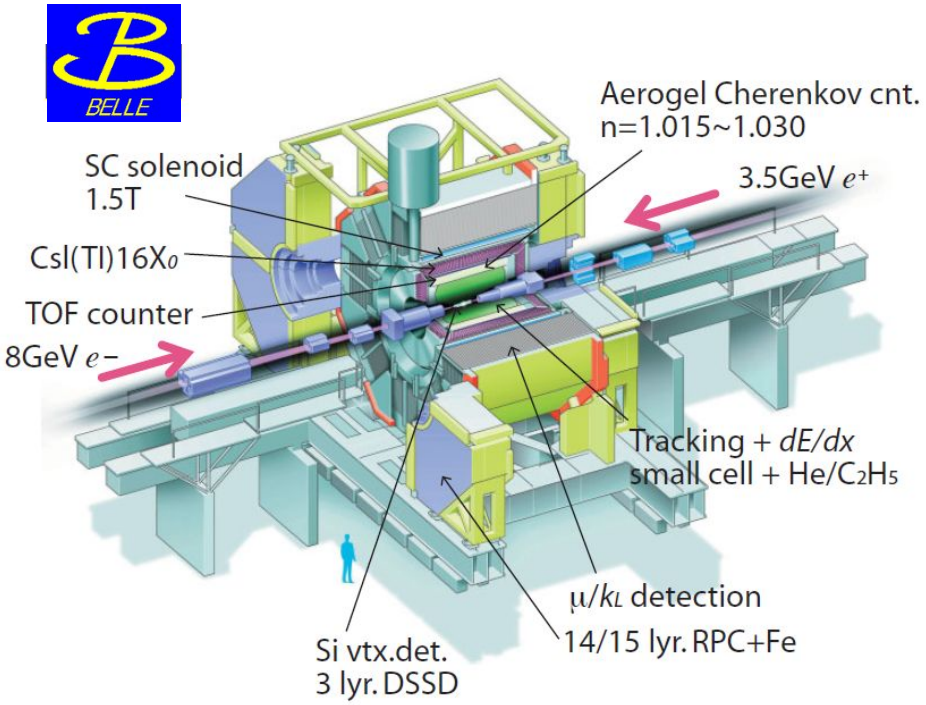


W - exchange

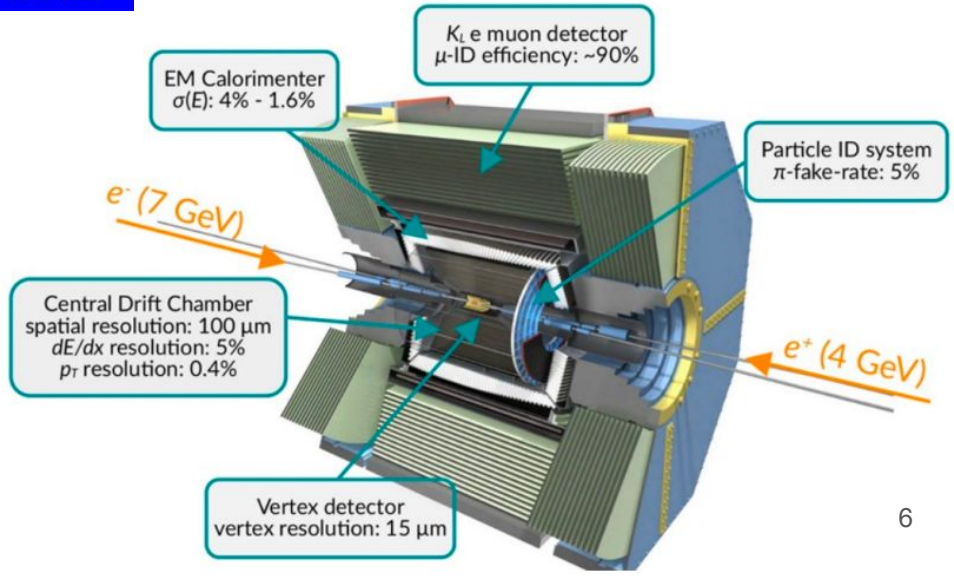
Belle/Belle II detector

Belle/Belle II is universal 4π magnetic spectrometer

asymmetrical beams



- upgraded version of Belle
- start in 2019



1999-2010 data collection, ~ 1ab^{-1}

Overview of selected analysis

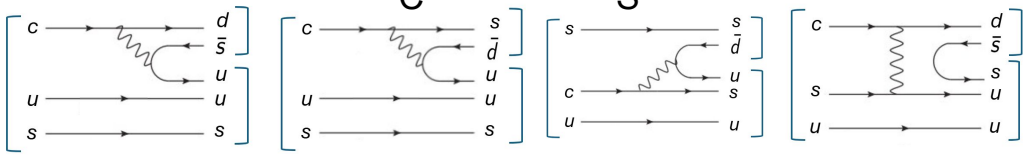
- Measurements of the branching fractions (BF) of $\Xi_c^+ \to \Sigma^+ K_S^0$, $\Xi^0 \pi^+$, and $\Xi^0 K^+$
- Observations of the singly Cabibbo-suppressed (SCS) decays $\Xi_c^+ \to p K_S^0$, $\Lambda \pi^+$, and $\Sigma^0 \pi^+$
- Measurement of the BF of $\Lambda_c^+ \to p K_S^0 \pi^0$
- Measurements of the BF of $\Xi_c^0 \to \Xi^0 \pi^0$, $\Xi^0 \eta$, and $\Xi^0 \eta'$ and asymmetry parameter of $\Xi_c^0 \to \Xi^0 \pi^0$

Measurements of the BF of $\Xi^+_c \to \Sigma^+ K^0_S$, $\Xi^0 \pi^+$, and $\Xi^0 K^+$

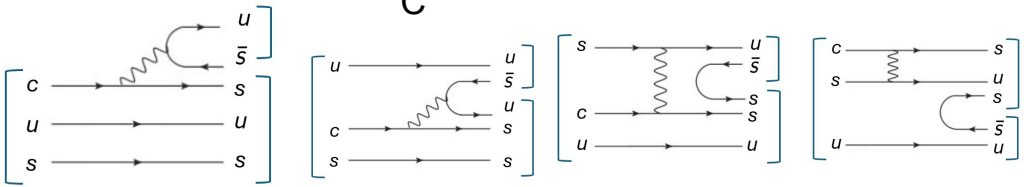
Belle, $980\,fb^{-1}$ + Belle II, $428\,fb^{-1}$

submitted to JHEP arXiv:2503.17643v1

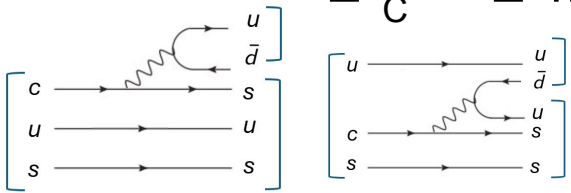
$\Xi^+_c \to \Sigma^+ K^0_S$

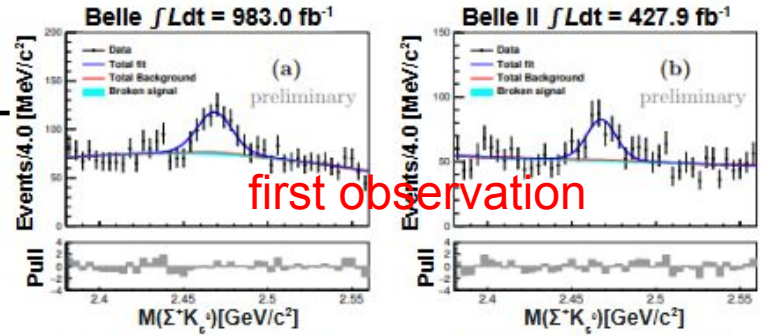


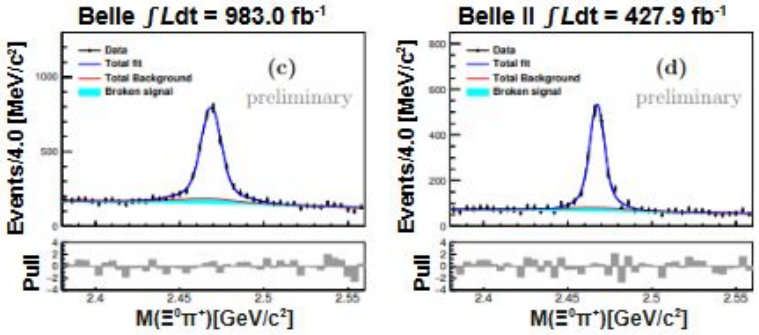
$\Xi^+_c \to \Xi^0 K^+$

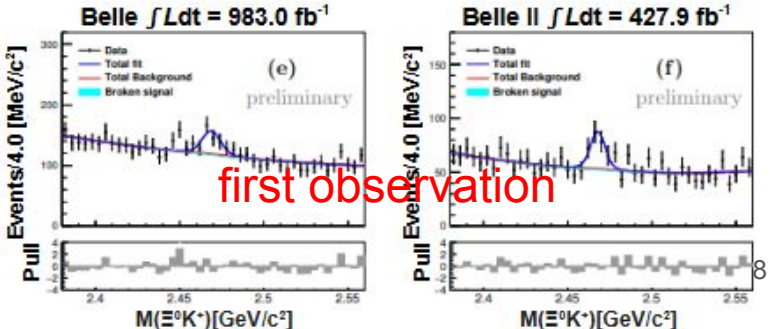


$\Xi^+_c \to \Xi^0 \pi^+$









Measurements of the BF of $\Xi^+_c \to \Sigma^+ K^0_S$, $\Xi^0 \pi^+$, and $\Xi^0 K^+$

arXiv:2503.17643v1

$$\frac{\mathcal{B}(\Xi_c^+ \to \Sigma^+ K_S^0)}{\mathcal{B}(\Xi_c^+ \to \Xi^- \pi^+ \pi^+)} = 0.067 \pm 0.007 \pm 0.003,$$

$$\frac{\mathcal{B}(\Xi_c^+ \to \Xi^0 \pi^+)}{\mathcal{B}(\Xi_c^+ \to \Xi^- \pi^+ \pi^+)} = 0.248 \pm 0.005 \pm 0.009,$$

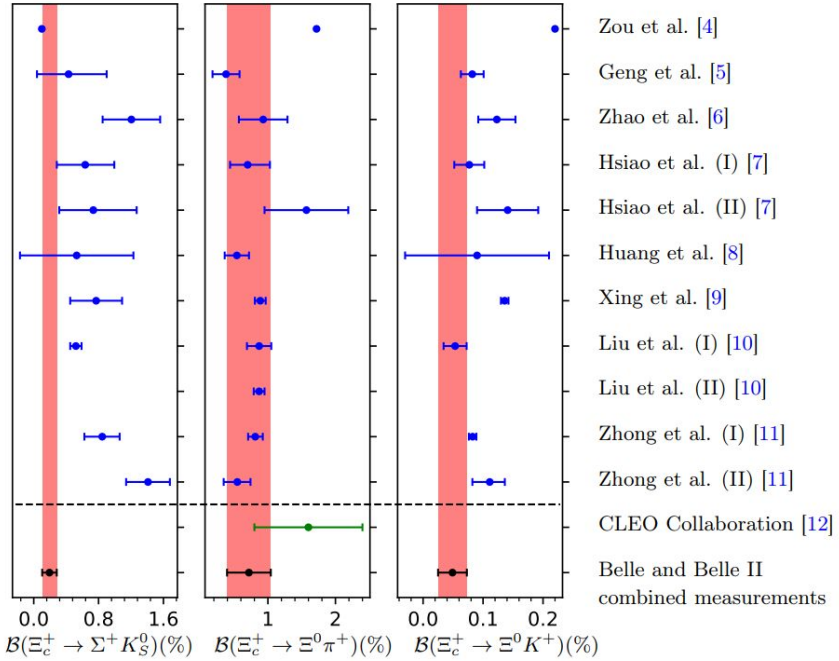
$$\frac{\mathcal{B}(\Xi_c^+ \to \Xi^0 K^+)}{\mathcal{B}(\Xi_c^+ \to \Xi^- \pi^+ \pi^+)} = 0.017 \pm 0.003 \pm 0.001.$$

stat. syst.

first measurement !

$$\mathcal{B}(\Xi_c^+ \to \Xi^0 K^+)/\mathcal{B}(\Xi_c^+ \to \Xi^0 \pi^+) = 0.068 \pm 0.010 \pm 0.004.$$

stat. syst.

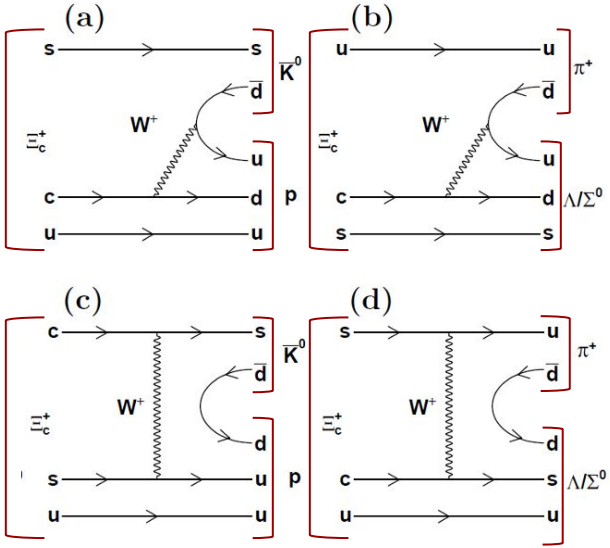


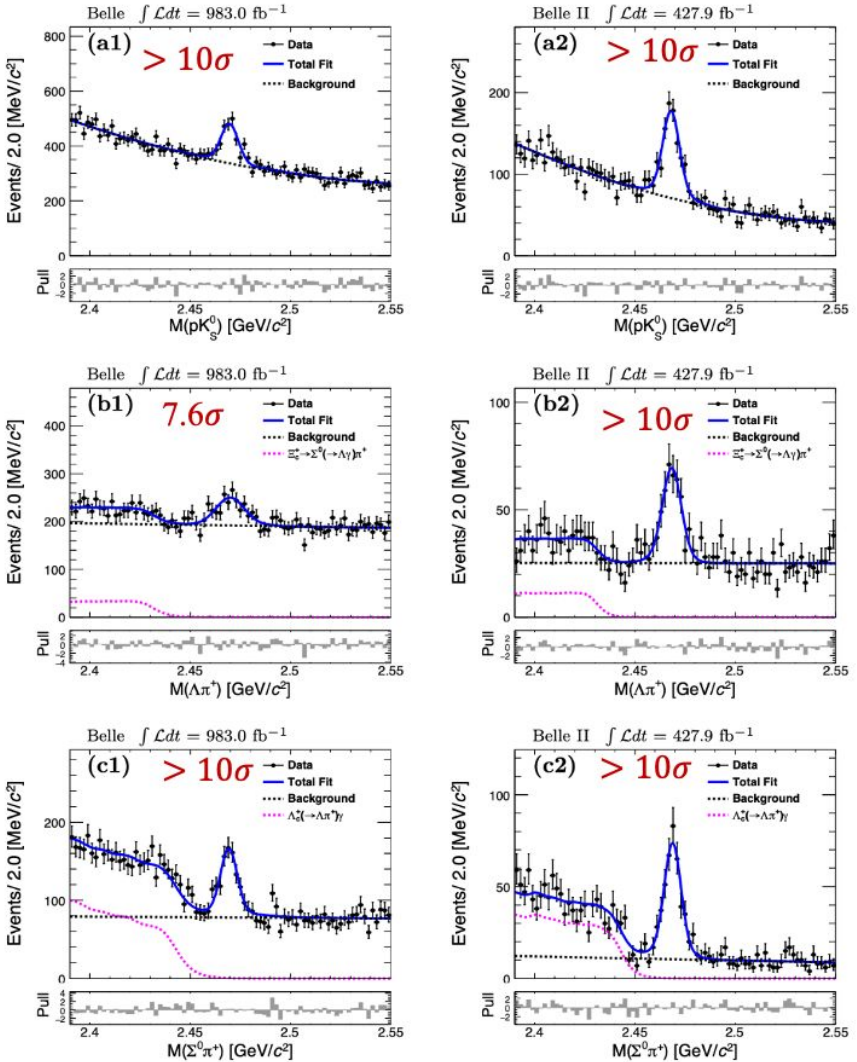
BF of $\Xi^+_c \to \Sigma^+ K^0_S$ lower than the central values predicted by most theoretical papers

Observations of the SCS decays $\Xi_c^+ \to pK_S^0$, $\Lambda\pi^+$, and $\Sigma^0\pi^+$

Belle, $980\,fb^{-1}$ + Belle II, $428\,fb^{-1}$ JHEP 03 (2025) 061

first measurements of SCS decays





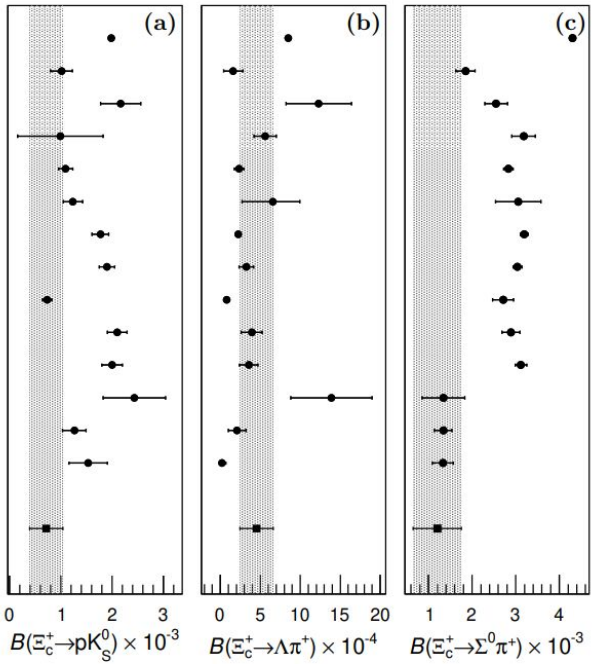
Observations of the SCS decays $\Xi^+_c \to pK^0_S$, $\Lambda\pi^+$, and $\Sigma^0\pi^+$

JHEP 03 (2025) 061

Comparisons of measured SCS deacy with with theoretical predictions

Theoretical predictions are in poor agreement with experimental values

	Belle	Belle II	combined (stat. syst.)
$\frac{\mathcal{B}(\Xi_c^+\to pK_S^0)}{\mathcal{B}(\Xi_c^+\to\Xi^-\pi^+\pi^+)}$	$(2.36 \pm 0.27 \pm 0.08)\%$	$(2.56 \pm 0.19 \pm 0.11)\%$	$(2.47 \pm 0.16 \pm 0.07)\%$
$\frac{\mathcal{B}(\Xi_c^+\to\Lambda\pi^+)}{\mathcal{B}(\Xi_c^+\to\Xi^-\pi^+\pi^+)}$	$(1.72 \pm 0.29 \pm 0.11)\%$	$(1.47 \pm 0.16 \pm 0.09)\%$	$(1.56 \pm 0.14 \pm 0.09)\%$
$\frac{\mathcal{B}(\Xi_c^+\to\Sigma^0\pi^+)}{\mathcal{B}(\Xi_c^+\to\Xi^-\pi^+\pi^+)}$	$(3.97 \pm 0.42 \pm 0.23)\%$	$(4.26 \pm 0.33 \pm 0.24)\%$	$(4.13 \pm 0.26 \pm 0.22)\%$

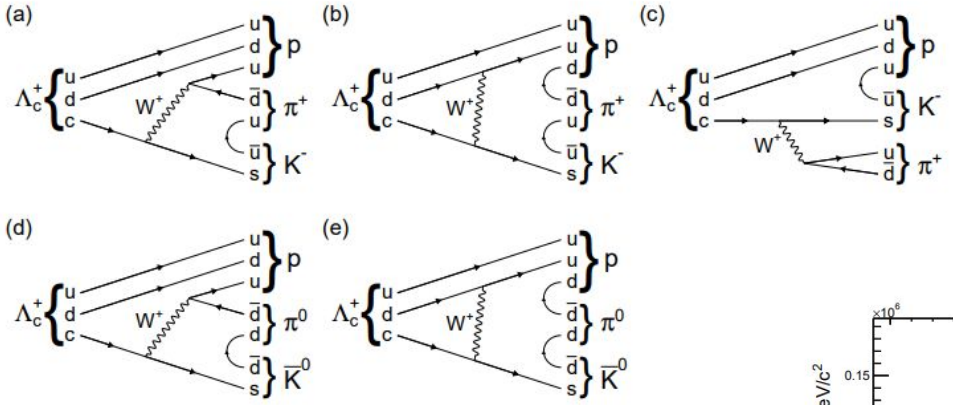


Zou et al. [12]
Geng et al. [13]
Geng et al. [14]
Huang et al. [15]
Zhong et al. (I) [16]
Zhong et al. (II) [16]
Xing et al. [17]
Geng et al. [18]
Liu [19]
Zhong et al. (I) [20]
Zhong et al. (II) [20]
Zhao et al. [21]
Hsiao et al. (I) [22]
Hsiao et al. (II) [22]

Belle and Belle II combined measurement

Measurement of the BF of $\Lambda^+_c \to pK^0_S\pi^0$

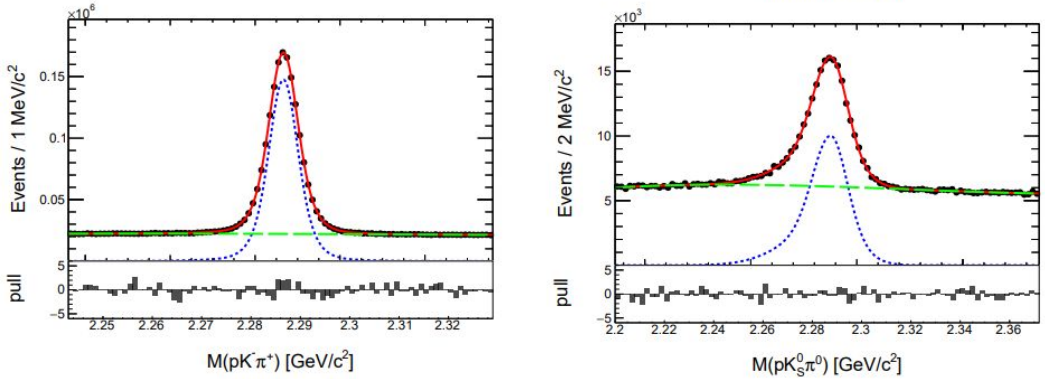
Belle, $980\,fb^{-1}$



arXiv:2503.04371v2 accepted by PRD

examining the isospin properties of the weak interaction

$$\frac{\mathcal{B}(\Lambda_c^+ \to pK_S^0\pi^0)}{\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+)} = 0.339 \pm 0.002 \pm 0.009,$$



Using PDG value of

$$\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+) = (6.24 \pm 0.28)\%$$

$$\mathcal{B}(\Lambda_c^+ \to pK_S^0\pi^0) = (2.12 \pm 0.01 \pm 0.05 \pm 0.10)\%,$$

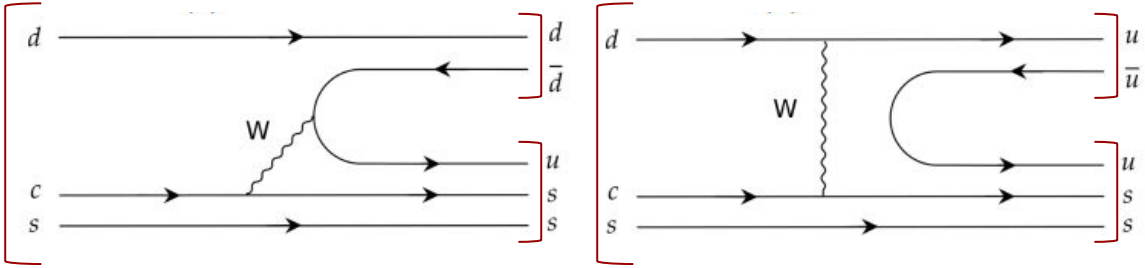
stat. syst.

This measurement improves uncertainty of previous CLEO result

Measurements of the BF of $\Xi^0_c \to \Xi^0\pi^0$, $\Xi^0\eta$, and $\Xi^0\eta'$ and asymmetry parameter of $\Xi^0_c \to \Xi^0\pi^0$

Belle, $980\,fb^{-1}$ + Belle II, $428\,fb^{-1}$

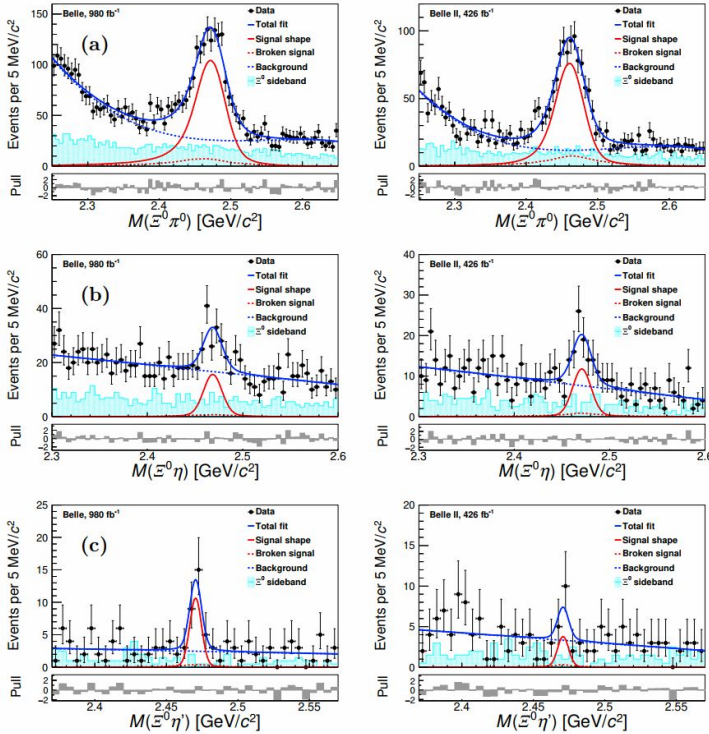
JHEP 10 (2024) 045



First measurement

Mode	Belle	Belle II	Combined
$\mathcal{B}(\Xi_c^0 \to \Xi^0\pi^0)/\mathcal{B}(\Xi_c^0 \to \Xi^-\pi^+)$	$0.47 \pm 0.02 \pm 0.03$	$0.51 \pm 0.03 \pm 0.05$	$0.48 \pm 0.02 \pm 0.03$
$\mathcal{B}(\Xi_c^0 \to \Xi^0\eta)/\mathcal{B}(\Xi_c^0 \to \Xi^-\pi^+)$	$0.10 \pm 0.02 \pm 0.01$	$0.14 \pm 0.02 \pm 0.02$	$0.11 \pm 0.01 \pm 0.01$
$\mathcal{B}(\Xi_c^0 \to \Xi^0\eta')/\mathcal{B}(\Xi_c^0 \to \Xi^-\pi^+)$	$0.12 \pm 0.03 \pm 0.01$	$0.06 \pm 0.03 \pm 0.01$	$0.08 \pm 0.02 \pm 0.01$

stat. syst.



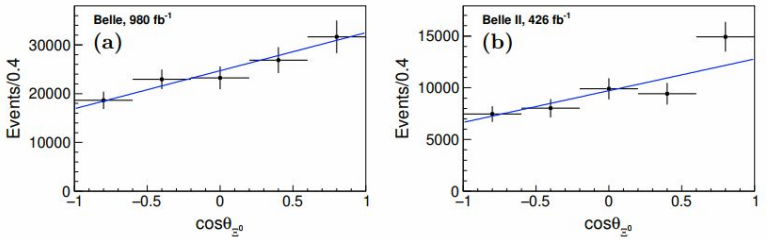
Measurements of the BF of $\Xi^0_c \to \Xi^0\pi^0$, $\Xi^0\eta$, and $\Xi^0\eta'$ and asymmetry parameter of $\Xi^0_c \to \Xi^0\pi^0$

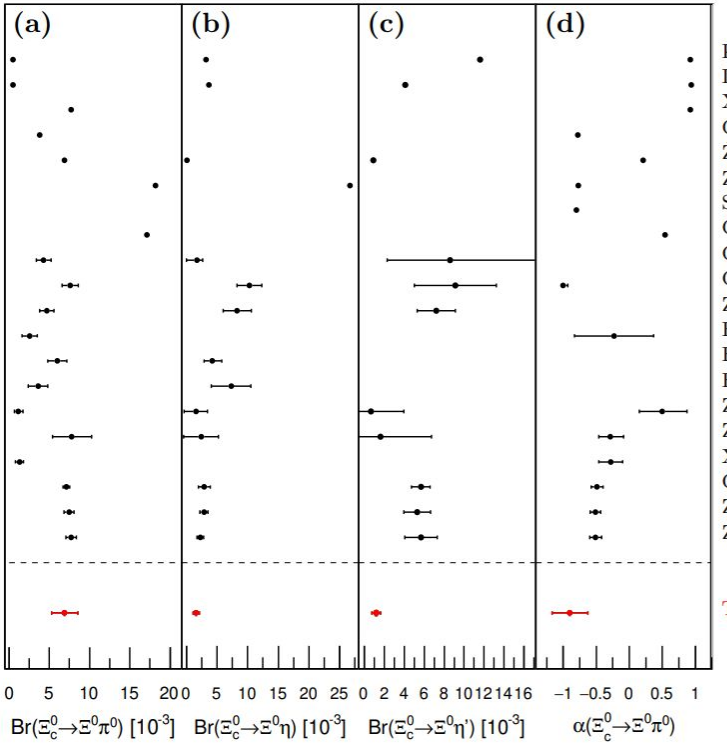
Asymmetry parameter of $\Xi^0_c \to \Xi^0\pi^0$

$\cos\theta_{\Xi^0}$	$(-1.0, -0.6)$	$(-0.6, -0.2)$	$(-0.2, 0.2)$	$(0.2, 0.6)$	$(0.6, 1.0)$
Belle	$\frac{260\pm25}{1.40}$	$\frac{296\pm26}{1.29}$	$\frac{266\pm27}{1.14}$	$\frac{265\pm27}{0.99}$	$\frac{224\pm24}{0.71}$
Belle II	$\frac{176\pm18}{2.37}$	$\frac{167\pm18}{2.08}$	$\frac{194\pm20}{1.96}$	$\frac{151\pm17}{1.60}$	$\frac{176\pm17}{1.18}$

$$\frac{dN}{d\cos\theta_{\Xi^0}} \propto 1 + \alpha(\Xi_c^0 \to \Xi^0 h^0)\alpha(\Xi^0 \to \Lambda\pi^0)\cos\theta_{\Xi^0},$$

*angle between the **p**(Λ) and the direction opposite to the Ξ^0_c momentum vector in the Ξ^0 frame





Körner, Krämer [5]
Ivanov et al. [6],
Xu, Kamal [7],
Cheng, Tseng [8],
Żenczykowski [9],
Zou et al. [10],
Sharma, Verma [11
Cheng, Tseng [8],
Geng et al. [12],
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Zhong et al. [17],
Zhong et al. [17].
Xing et al. [18],
Geng et al. [19],
Zhong et al. [20],
Zhong et al. [20],

This measurement

Conclusion

- Study of charmed baryon is an important way to understand the non-perturbative dynamics of quantum chromodynamics
- Lifetime (as branching fraction) plays a crucial role in weak decays research of the charmed baryons
- There are width dispersion between different theoretical prediction of branching fraction of charmed baryons
- We hope our experimental results will help to improve theoretical models
- Belle II starts new data taking in November 2025