BESIII Experiment Overview

Pei-Rong Li（李培荣）

Lanzhou University

On behalf of the BESIII Collaboration

2025.10.25 @ Beijing

BEPCII @ IHEP

$E_{cm} = 2 - 4.95$ GeV

2004, started construction

2009-2024, BESIII Physics run

Design Luminosity:

$\mathcal{L}_D = 1 \times 10^{33} \text{cm}^{-2} s^{-1}$ @E_{cm}= 3.773 GeV

Peak luminosity:

2016 achieved $1.0 \times \mathcal{L}_D$

2023 achieved $1.1 \times \mathcal{L}_D$

Jul. 1, 2024 – Aug. 31, 2028:

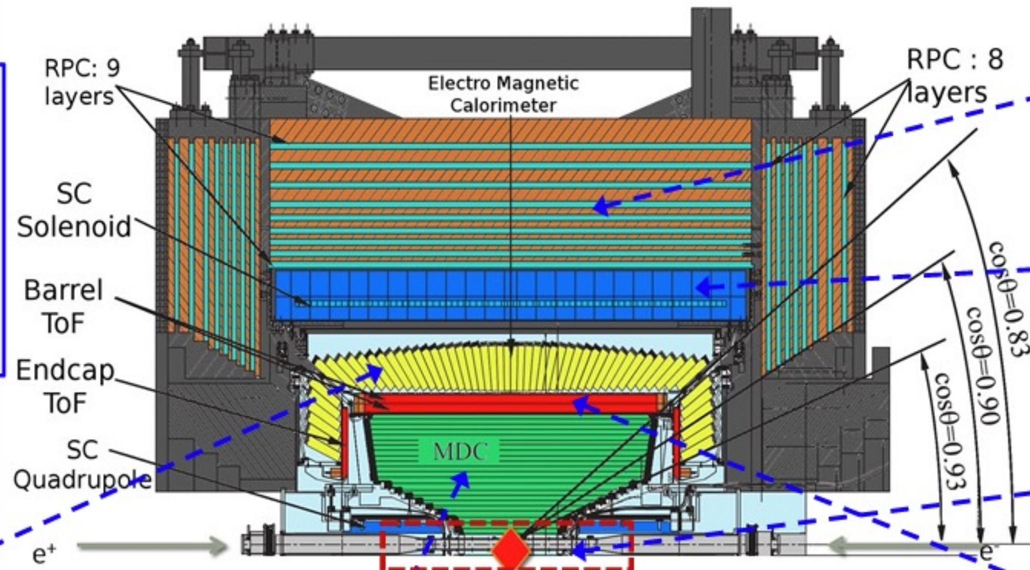
BEPCII upgrade → BEPCII-U

January 2025, restart

- Luminosity × 3 @E_{cm}= 4.7 GeV
- Beam energy up to 2.8 GeV (2028)

BESIII @ BEPCII

- Optimized for flavor physics
- Cover 93% of 4π solid angle



Muon counters (MUC)
$\sigma_{r\phi} = 1.4 - 1.7$ cm

Superconducting solenoid
1 Tesla Magnetic field

inner MDC

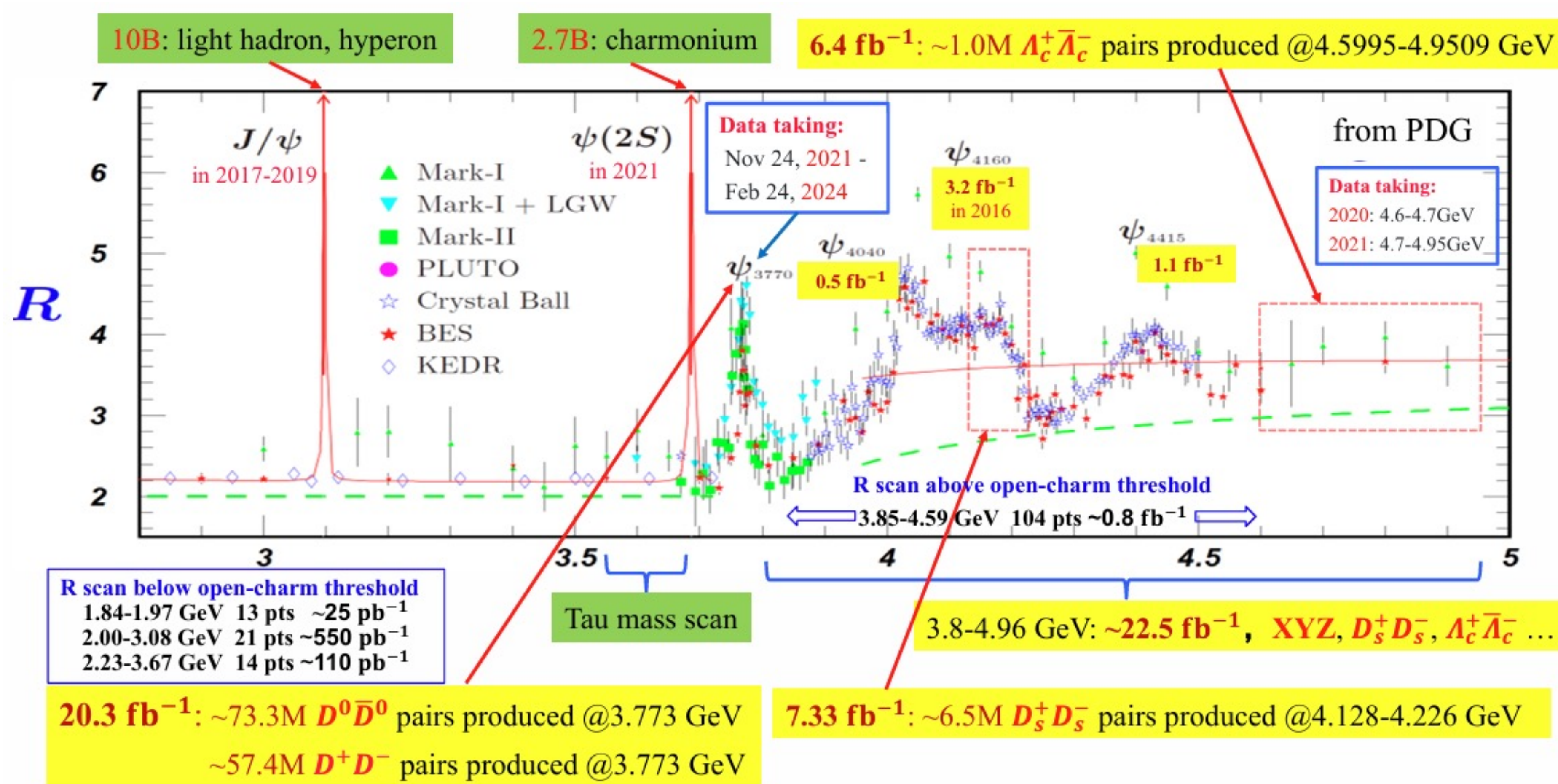
Electro Magnetic Calorimeter (EMC)
$\Delta E/E = 2.5\%$ @1.0 GeV
$\sigma_{\phi z} = 0.6$cm @ 1.0 GeV

Main Drift Chamber (MDC)
$\Delta P/P = 0.5\%$ @1.0 GeV
$\sigma_{xy} = 130$ um, $\sigma_{dE/dX} = 6 - 7\%$

Time Of Flight (TOF)
$\sigma_t = 90$ ps @ barrel
$\sigma_t = 60$ ps @ end cap (upgrade in 2016)

July 1 - December 31, 2024: Replace the inner MDC with 3 layers of cylindrical triple-GEM detectors

Datasets (totally ~50 fb^{-1} from 1.84 - 4.95 GeV)



- More $\Lambda_c^+\bar{\Lambda}_c^-$ data is collected soon.

CKM Matrix

- CKM matrix elements are fundamental parameters of the Standard Model (SM):

$$V_{\mathrm{CKM}} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + \mathcal{O}(\lambda^4)$$

Charm decays + LQCD
Expected precision < **1%** at BESIII

B decays + LQCD

- 3x3 unitary complex matrix
- 4 parameters: 3 mixing angles and 1 phase
- Unitarity: $\sum_i V_{ij}V_{ik}^* = \delta_{jk}$ and $\sum_j V_{ij}V_{kj}^* = \delta_{ik}$

- Any deviation of V_{CKM} from unitarity indicates new physics

Revised in PDG2024

$|V_{ud}|^2+|V_{us}|^2+|V_{ub}|^2=0.9984 \pm 0.0009$=1(SM)

$|V_{cd}|^2+|V_{cs}|^2+|V_{cb}|^2 = 1.001 \pm 0.007$ =1(SM)

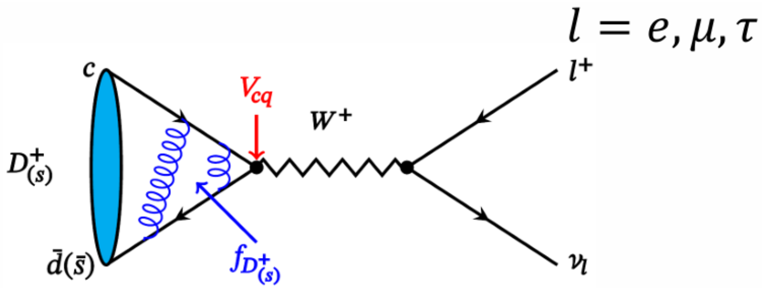
Precision: 0.7%

Precision: (0.6-1.8)%

$|V_{cd}| = 0.221 \pm 0.004$
$|V_{cs}| = 0.975 \pm 0.006$
$|V_{cb}| = 0.0410 \pm 0.0012$

- $\boldsymbol{D/D_s}$ **(Semi-)leptonic decays** provide direct measurements of $|V_{cs}|$ and $|V_{cd}|$

Charm leptonic decays



Decay rate

Decay constant $f_{D_{(s)}}$ (LQCD)

CKM matrix element

$$\boxed{\Gamma(D^+_{(s)} \to \ell^+ \nu_\ell)} = \frac{G_F^2}{8\pi} \boxed{f^2_{D^+_{(s)}}} \boxed{|V_{cd(s)}|^2} \boxed{m_\ell^2 m_{D^+_{(s)}} \left(1 - \frac{m_\ell^2}{m^2_{D^+_{(s)}}}\right)^2}$$

- **Charm leptonic decays involve weak and strong interactions**

  Weak interaction: annihilation of the quark-antiquark pair via W^+ → $|V_{cd(s)}|$

  Strong interaction: glue exchanges between charm quark and light quark → $f_{D_{(s)}}$

- Exp. decay rate + $|V_{cd(s)}|^{\text{CKMfitter}}$ → $f_{D_{(s)}}$

  Calibrate LQCD @charm

  Extrapolate to Beauty

- Exp. decay rate + $\boxed{f_{D_{(s)}} \text{ of LQCD}}$

  → **CKM matrix elements** $|V_{cd(s)}|$

High precision: **0.2%**
FLAG, *Eur. Phys. J. C* 80 (2020) 113

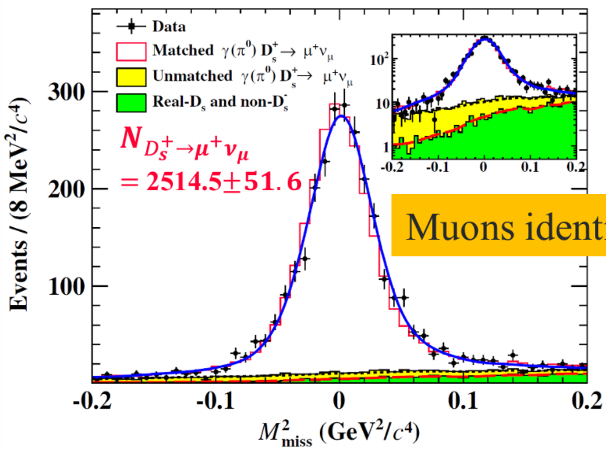
SM expected relative decay widths:

	$e^+\nu_e$	: $\mu^+\nu_\mu$	: $\tau^+\nu_\tau$
D^+	2.35×10^{-5}	: 1	: 2.67
D_s^+	2.35×10^{-5}	: 1	: 9.75

→ **Test lepton flavor universality (LFU)**

$|V_{cs}|$ from $D_s^+ \to \mu^+ \nu_\mu$

Phys. Rev. D 108, 112001 (2023)



Muons identified from MUC

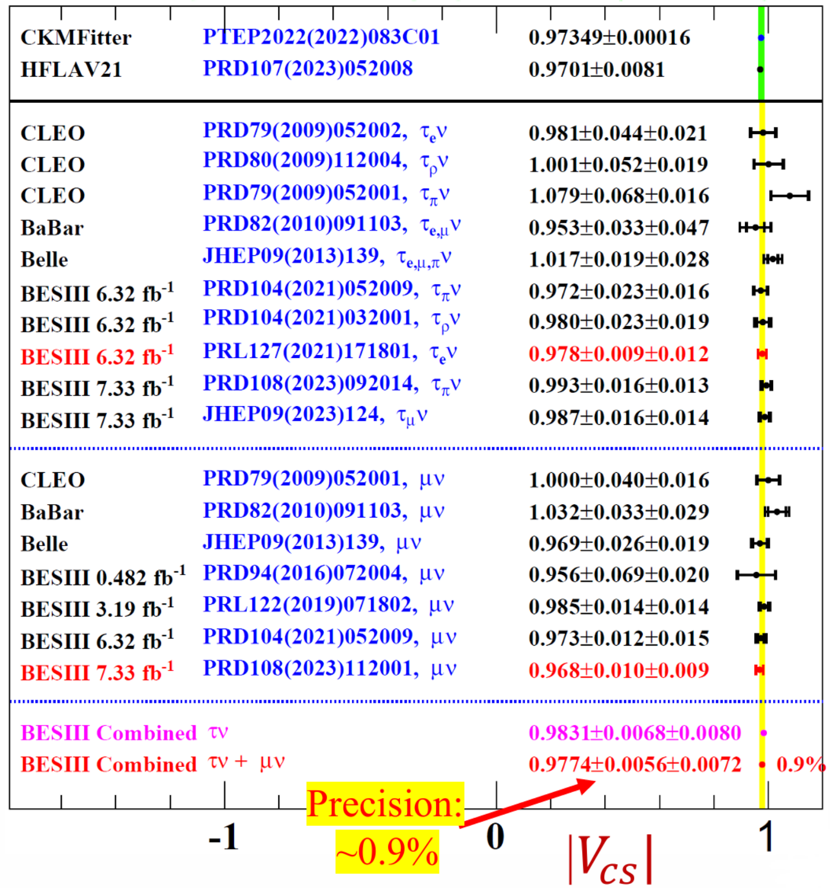
$$\mathcal{B}_{D_s^+\to\mu^+\nu_\mu} = (0.5294 \pm 0.0108_{\rm stat} \pm 0.0085_{\rm syst})\%$$

$$f_{D_s^+}|V_{cs}| = 241.8 \pm 2.5_{\rm stat} \pm 2.2_{\rm syst}\ \text{MeV}$$

$$f_{D_s^+} = 248.4 \pm 2.5_{\rm stat} \pm 2.2_{\rm syst}\ \text{MeV}$$

$$|V_{cs}| = 0.968 \pm 0.010_{\rm stat} \pm 0.009_{\rm syst}$$

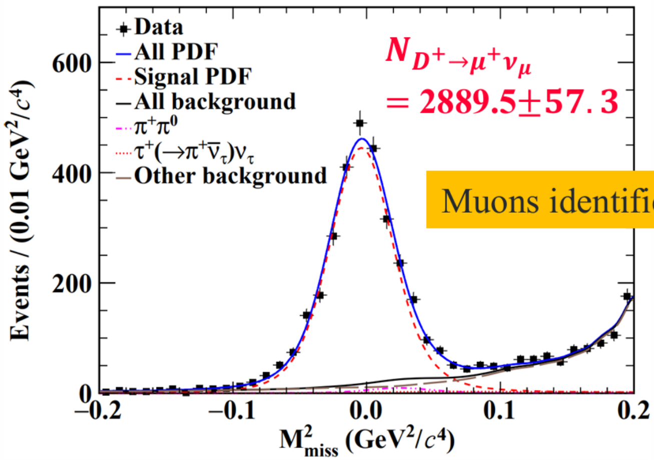
Precision : ~1.4%



Precision: ~0.9%

$|V_{cd}|$ from $D^+ \to \mu^+\nu_\mu$

Phys. Rev. Lett. 135, 061801 (2025)

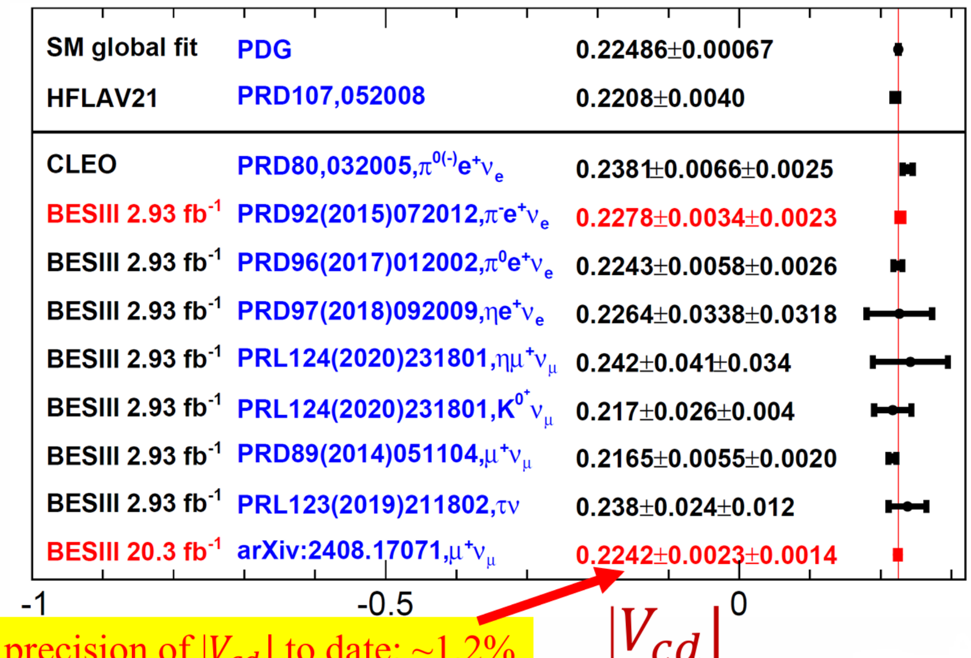


Muons identified from MUC

$$f_{D^+}|V_{cd}| = (47.53 \pm 0.48_{\rm stat} \pm 0.24_{\rm syst} \pm 0.12_{\rm input})\ \text{MeV}$$

$$f_{D^+} = (211.5 \pm 2.1_{\rm stat} \pm 1.1_{\rm syst} \pm 0.8_{\rm input})\ \text{MeV}$$

$$|V_{cd}| = 0.2242 \pm 0.0023_{\rm stat} \pm 0.0011_{\rm syst} \pm 0.0009_{\rm input}$$



$$\mathcal{B}_{D^+\to\mu^+\nu_\mu} = (3.98 \pm 0.08_{\rm stat.} \pm 0.04_{\rm syst.}) \times 10^{-4}$$

$$A_{\rm CP} = \frac{\mathcal{B}_{D^+\to\mu^+\nu_\mu} - \mathcal{B}_{D^-\to\mu^-\nu_\mu}}{\mathcal{B}_{D^+\to\mu^+\nu_\mu} + \mathcal{B}_{D^-\to\mu^-\nu_\mu}} = (1.8 \pm 2.0_{\rm stat.} \pm 0.8_{\rm syst.})\%$$

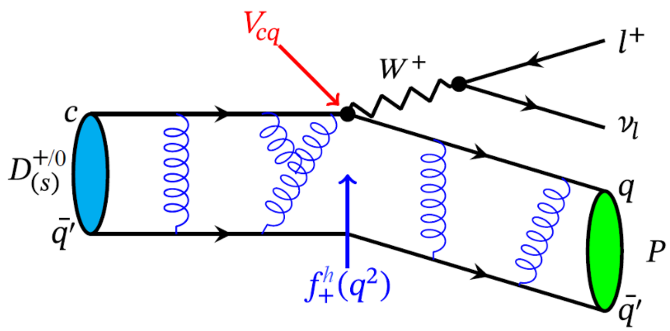
Taking from PDG
BESIII measurement will be released soon

$$\mathcal{R}_{\tau/\mu} = \frac{\mathcal{B}_{D^+\to\tau^+\nu_\tau}}{\mathcal{B}_{D^+\to\mu^+\nu_\mu}} = 3.02 \pm 0.68$$

SM=2.67

Highest precision of $|V_{cd}|$ to date: ~1.2%

Charm semi-leptonic decays



Partial decay rate

Form factor (LQCD)

CKM matrix element

$$\boxed{\frac{d\Gamma}{dq^2}} = X \frac{G_F^2}{24\pi^3} \boxed{|f_+^h(0)|}^2 \boxed{|V_{cq}|}^2 |\vec{p}_h|^3$$

($X = 1$ for K^-, π^-, $\bar{K}^0$, $\eta^{(\prime)}$; $X = \frac{1}{2}$ for π^0)

- **The weak and strong interactions can be separated:**

  Weak interaction: CKM matrix elements $|V_{cd(s)}|$

  Form factors $f_+^h(0)$ describe strong interaction can be calculated in LQCD

- Exp. partial decay rate → q^2 dependence of $f_+^{\pi(K)}(q^2)$,

  → **extract** $f_+^{\pi(K)}(0)$ with $|V_{cd(s)}|^{\text{CKMfitter}}$ as input → **calibrate QCD**

- Exp. partial decay rate + $\boxed{\text{LQCD calculation of } f_+^{\pi(K)}(0)}$

  → **CKM matrix elements** $|V_{cd(s)}|$

Low precision: **>2%**
FLAG, *Eur. Phys. J. C* 80 (2020) 113

$\left|f_{+}^{f_0}(0)\right|$ from $D_s^+ \to \pi^+\pi^- e^+\nu_e$

Phys. Rev. Lett. 132, 141901 (2024)

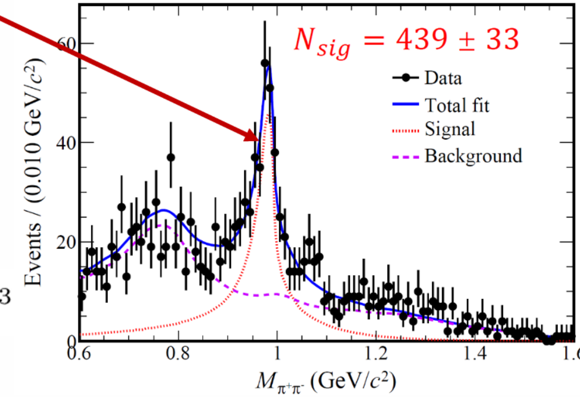
$$\frac{d^2\Gamma(D_s^+ \to f_0(980)e^+\nu_e)}{dsdq^2} = \frac{G_F^2|V_{cs}|^2}{192\pi^4 m_{D_s^+}^3}\lambda^{3/2}(m_{D_s^+}^2, s, q^2) \times \left|\boxed{f_+^{f_0}(q^2)}\right|^2 \boxed{P(s)}$$

Flatté model

$$P(s) = \frac{g_1\rho_{\pi\pi}}{|m_0^2 - s - i(g_1\rho_{\pi\pi} + g_2\rho_{K\bar{K}})|^2}$$

Simple pole parameterization

$$f_+^{f_0}(q^2) = \frac{f_+^{f_0}(0)}{1 - q^2/M_{\text{pole}}^2}$$



Observe $f_0(980)$

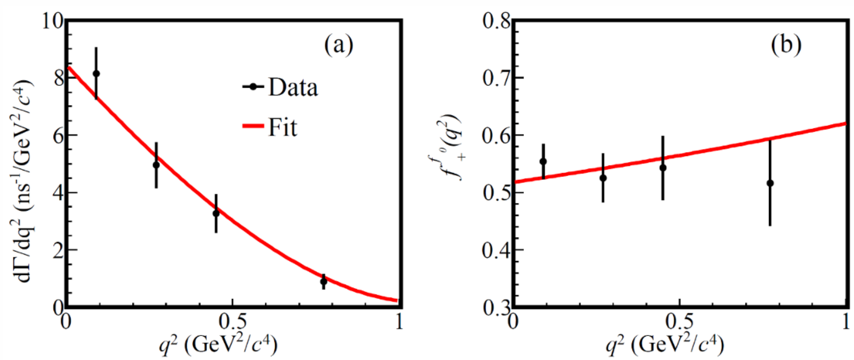
$$\mathcal{B}(D_s^+ \to f_0(980)e^+\nu_e, f_0(980) \to \pi+\pi-) = (1.72 \pm 0.13 \pm 0.19) \times 10^{-3}$$

$$\mathcal{B}(D_s^+ \to f_0(500)e^+\nu_e, f_0(500) \to \pi+\pi-) < 3.3 \times 10^{-4} \text{ @ } 90\%\ C.L.$$

Determine form factor

$$f_+^{f_0}(0)\,|V_{cs}| = 0.504 \pm 0.017_{\text{stat.}} \pm 0.035_{\text{syst.}}$$

$$f_+^{f_0}(0) = 0.518 \pm 0.018_{\text{stat.}} \pm 0.036_{\text{syst.}}$$

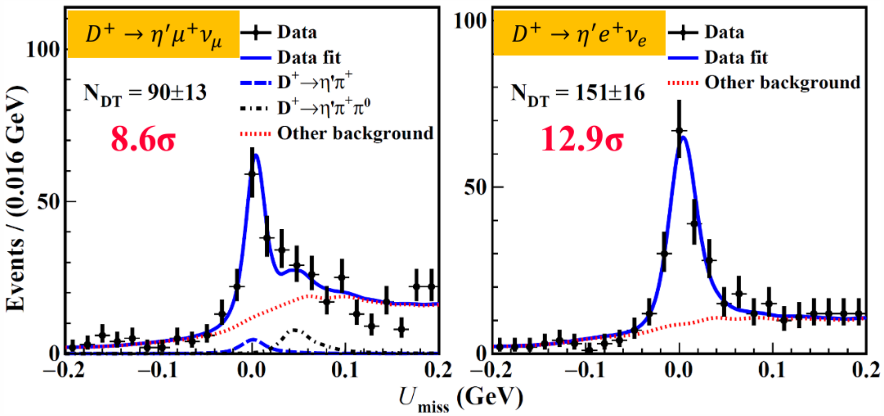


	This work	CLFD [6]	DR [6]	QCDSR [7]	QCDSR [8]	LCSR [9]	LFQM [11]	CCQM [12]
$f_+^{f_0}(0)$	$0.518 \pm 0.018_{\text{stat}} \pm 0.036_{\text{syst}}$	0.45	0.46	0.50 ± 0.13	0.48 ± 0.23	0.30 ± 0.03	0.24 ± 0.05	0.36 ± 0.02
Difference (σ)	...	1.7	1.4	0.1	0.2	4.3	4.3	2.8
ϕ in theory	...	$(32 \pm 4.8)^\circ$	$(41.3 \pm 5.5)^\circ$	35°	$(8^{+21}_{-8})^\circ$	...	$(56 \pm 7)^\circ$	31°

$f_+^{\eta'}$ and $|V_{cd}|$ from $D^+ \to \eta' l^+ \nu_l$

Phys. Rev. Lett. 134, 111801 (2025)

Observe $D^+ \to \eta' l^+ \nu_l$



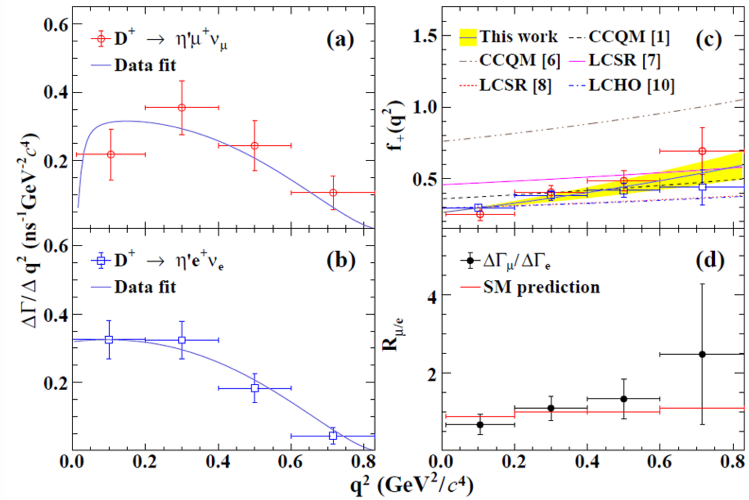
Decay	$\eta'\mu^+\nu_\mu$		$\eta' e^+\nu_e$	
η' decay	$\eta\pi^+\pi^-$	$\gamma\pi^+\pi^-$	$\eta\pi^+\pi^-$	$\gamma\pi^+\pi^-$
$\mathcal{B}$ $(\times10^{-4})$	$1.92\pm0.28\pm0.08$		$1.79\pm0.19\pm0.07$	

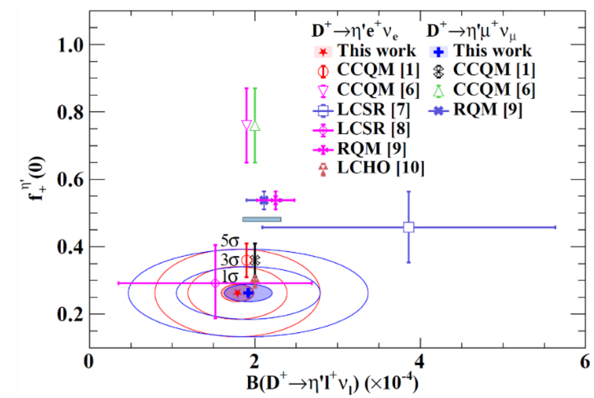
$$f_+^{\eta'}(0)|V_{cd}| = (5.92\pm0.56_{\rm stat}\pm0.13_{\rm syst})\times10^{-2}$$

→ Form factor: $f_+^{\eta'}(0) = 0.263\pm0.025_{\rm stat}\pm0.006_{\rm syst}$

→ LFU: $\mathcal{R}^{\eta'}_{\mu/e} = \dfrac{\mathcal{B}_{D^+\to\eta'\mu^+\nu_\mu}}{\mathcal{B}_{D^+\to\eta' e^+\nu_e}} = 1.07\pm0.19\pm0.03$

SM=0.94-0.95



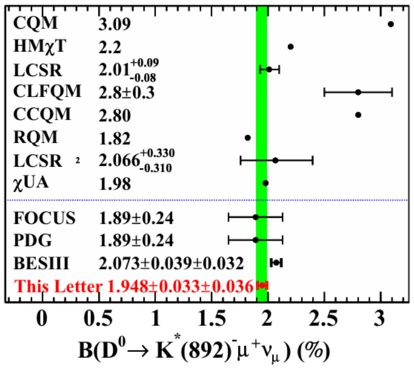


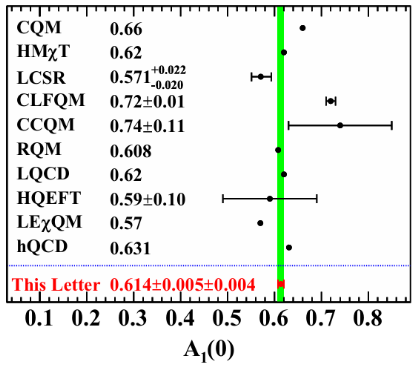
- Consistent with the some theoretical calculations within 2σ

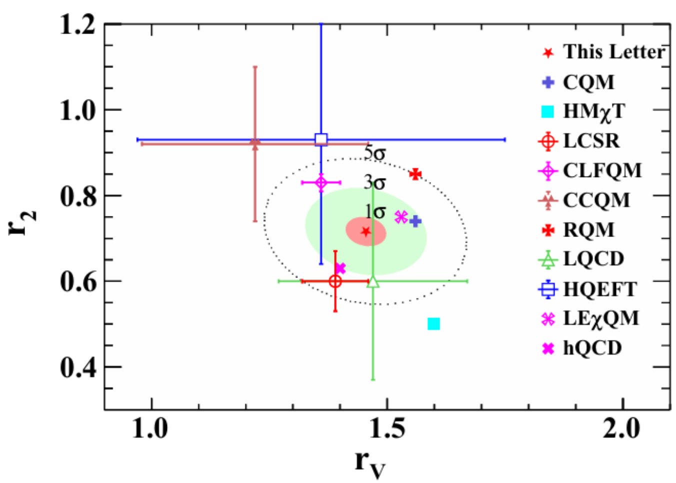
Study of $D^0 \to K^{*-}\mu^+\nu_\mu$

Phys. Rev. Lett. 135, 111803 (2025)

$$D^0 \to K^{*-}(K^-\pi^0)\mu^+\nu_\mu$$



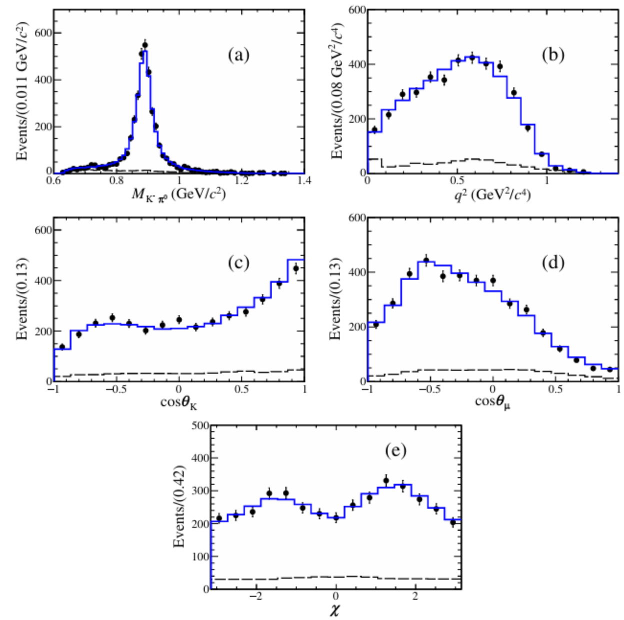




- Important input for theoretical calculation

Phys. Rev. Lett. 134, 011803 (2025)

$$D^0 \to K^{*-}(K_S^0\pi^-)\mu^+\nu_\mu$$



Theory	$\mathcal{B}$ (%)	r_V	r_2
LCSR [7,16]	$2.01^{+0.09}_{-0.08}$	1.39	0.60
χUA [17]	1.98	…	…
CCQM [6]	2.80	1.22 ± 0.24	0.92 ± 0.18
CQM [8,18]	3.09	1.56	0.74
LFQM [9]	…	1.36	0.83
HM$_\chi$T [10]	…	1.60	0.50
Experiments	$\mathcal{B}$ (%)	r_V	r_2
BESIII [39]	…	$1.46 \pm 0.07 \pm 0.02$	$0.67 \pm 0.06 \pm 0.01$
FOCUS [11]	1.89 ± 0.24	$1.71 \pm 0.68 \pm 0.34$	$0.91 \pm 0.37 \pm 0.10$
This Letter	$2.073 \pm 0.039 \pm 0.032$	$1.37 \pm 0.09 \pm 0.03$	$0.76 \pm 0.06 \pm 0.02$

Charmed mesons hadronic decays

Measurements of the BFs

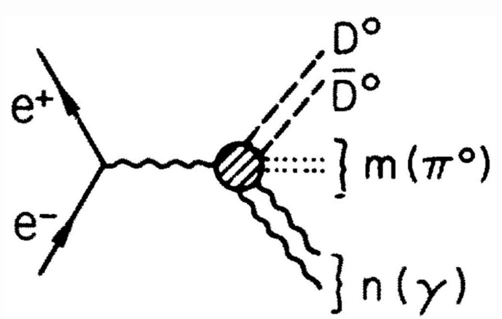
- Important component of heavy-flavor physics program
- Prob and calibrate non-perturbative QCD
- Understand SU(3) flavor symmetry and breaking effect
- Test theoretical calculations of BFs

Amplitude analysis of multi-body decays

- Information of $D \to VP, PP, SP, SV, VV, AP, AV, TP$ ...
- Light hadron spectroscopy

P: pseudo-scalar
V: vector
S: scalar
A: axial-vector
T: tensor

Quantum correlation and hadronic parameters



- $e^+e^- \to D^0\bar{D}^0 + m(\pi^0) + n(\gamma)$
- $C(D^0\bar{D}^0) = (-1)^{n+1}$
- [PRD 15, 1254 (1977)]

BF of D^0, D^+, D_s^+ hadronic decays

D_s^+ decays:

JHEP05(2024)335, 7.33fb^{-1}@4.178 – 4.226GeV

Mode	$\mathcal{B}$ (%)	$\mathcal{A}_{CP}$ (%)
$D_s^+ \to K_S^0 K^+$	$1.502 \pm 0.012 \pm 0.009$	$0.29 \pm 0.50 \pm 0.21$
$D_s^+ \to K^+K^-\pi^+$	$5.49 \pm 0.04 \pm 0.07$	$0.48 \pm 0.26 \pm 0.24$
$D_s^+ \to K_S^0 K^+\pi^0$	$1.47 \pm 0.02 \pm 0.02$	$-0.85 \pm 1.97 \pm 0.46$
$D_s^+ \to K_S^0 K_S^0 \pi^+$	$0.73 \pm 0.01 \pm 0.01$	$1.14 \pm 1.58 \pm 0.44$
$D_s^+ \to K^+K^-\pi^+\pi^0$	$5.50 \pm 0.05 \pm 0.11$	$-0.66 \pm 0.91 \pm 0.33$
$D_s^+ \to K_S^0 K^+\pi^+\pi^-$	$0.93 \pm 0.02 \pm 0.01$	$2.00 \pm 2.37 \pm 0.70$
$D_s^+ \to K_S^0 K^-\pi^+\pi^+$	$1.56 \pm 0.02 \pm 0.02$	$-0.24 \pm 1.05 \pm 1.07$
$D_s^+ \to \pi^+\pi^+\pi^-$	$1.09 \pm 0.01 \pm 0.01$	$-0.88 \pm 1.17 \pm 0.38$
$D_s^+ \to \pi^+\eta$	$1.69 \pm 0.02 \pm 0.02$	$-0.44 \pm 0.89 \pm 0.19$
$D_s^+ \to \pi^+\pi^0\eta$	$9.10 \pm 0.09 \pm 0.15$	$1.05 \pm 1.45 \pm 0.62$
$D_s^+ \to \pi^+\pi^+\pi^-\eta$	$3.08 \pm 0.06 \pm 0.05$	$2.42 \pm 2.85 \pm 0.78$
$D_s^+ \to \pi^+\eta'$	$3.95 \pm 0.04 \pm 0.07$	$-0.59 \pm 0.76 \pm 0.20$
$D_s^+ \to \pi^+\pi^0\eta'$	$6.17 \pm 0.12 \pm 0.14$	$-1.60 \pm 2.57 \pm 0.64$
$D_s^+ \to K_S^0\pi^+\pi^0$	$0.51 \pm 0.02 \pm 0.01$	$-2.17 \pm 4.65 \pm 1.10$
$D_s^+ \to K^+\pi^+\pi^-$	$0.620 \pm 0.009 \pm 0.006$	$1.81 \pm 2.01 \pm 0.45$

D^0, D^+ decays:

PRD 111 (2025) 092005, $20.3\ \text{fb}^{-1}$@3.773GeV

Signal decay	$\mathcal{B}_{\rm sig}(10^{-4})$	$\mathcal{B}_{\rm weight}(10^{-4})$	$\mathcal{B}_{\rm PDG}(10^{-4})$
$D^+ \to K^+K^-\pi^+\pi^+\pi^-$	$0.66 \pm 0.11 \pm 0.03$	...	2.3 ± 1.2
$D^+ \to \phi\pi^+\pi^+\pi^-$	$0.54 \pm 0.19 \pm 0.02$	...	...
$D^+ \to K_S^0 K^+\pi^+\pi^-\pi^0$	$2.51 \pm 0.34 \pm 0.14$	...	...
$D^+ \to K_S^0 K^+\eta_{\gamma\gamma}$	$2.17 \pm 0.24 \pm 0.08$	$2.27 \pm 0.22 \pm 0.05$	1.8 ± 0.5
$D^+ \to K_S^0 K^+\eta_{\pi^+\pi^-\pi^0}$	$2.90 \pm 0.59 \pm 0.15$		
$D^+ \to K_S^0 K^+\omega$	$2.02 \pm 0.35 \pm 0.10$	...	...

PRD 112 (2025) 012001, $7.9\ \text{fb}^{-1}$@3.773GeV

Signal decay	$\mathcal{B}_{\rm sig}(\times 10^{-4})$	$\mathcal{B}_{\rm FOCUS}(\times 10^{-4})$
$D^0 \to K^-3\pi^+2\pi^-$	$1.35 \pm 0.23 \pm 0.08$	$2.2 \pm 0.5 \pm 0.3$
$D^0 \to K^-2\pi^+\pi^-2\pi^0$	$19.0 \pm 1.1 \pm 1.5$	...
$D^+ \to K^-3\pi^+\pi^-\pi^0$	$6.57 \pm 0.69 \pm 0.33$	...

- Consistent with the world average.
- Precision has been significantly improved.

Amplitude analysis of $D_s^+ \to \pi^+\pi^+\pi^-\pi^0$

Phys. Rev. Lett. 134, 011904 (2025)

Observe of $D_s^+ \to f_0(980)\rho(770)^+$

$$\mathcal{B}(D_s^+ \to \pi^+\pi^+\pi^-\pi^0|_{\mathrm{non}-\eta}) = (2.04 \pm 0.08_{\mathrm{stat.}} \pm 0.05_{\mathrm{syst.}})\%$$

$$\mathcal{B}(D_s^+ \to \eta\pi^+) = (1.56 \pm 0.09_{\mathrm{stat.}} \pm 0.04_{\mathrm{syst.}})\%$$

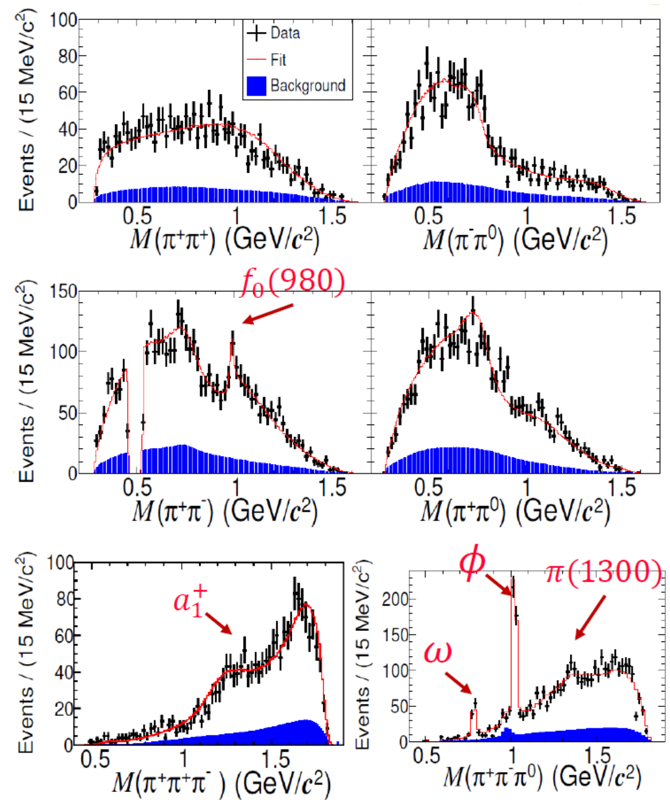
$$\boxed{\frac{\mathcal{B}(\phi(1020) \to \pi^+\pi^-\pi^0)}{\mathcal{B}(\phi(1020) \to K^+K^-)} = 0.230 \pm 0.014_{\mathrm{stat.}} \pm 0.010_{\mathrm{syst.}}}$$

Taking from $D_s^+ \to K^+K^-\pi^+$
BESIII, PRD 104, 012016 (2021)

Deviates from PDG value (0.313±0.010) by >4σ

Component	Phase (rad)	BF (10^{-3})
$f_0(1370)\rho^+$	0.0(fixed)	$5.08 \pm 0.80 \pm 0.43$
$f_0(980)\rho^+$	$3.99 \pm 0.13 \pm 0.07$	$2.57 \pm 0.44 \pm 0.20$
$f_2(1270)\rho^+$	$1.11 \pm 0.10 \pm 0.10$	$1.94 \pm 0.36 \pm 0.12$
$(\rho^+\rho^0)_S$	$1.10 \pm 0.18 \pm 0.10$	$0.71 \pm 0.25 \pm 0.12$
$(\rho(1450)^+\rho^0)_S$	$0.43 \pm 0.18 \pm 0.17$	$0.94 \pm 0.27 \pm 0.16$
$(\rho^+\rho(1450)^0)_P$	$4.58 \pm 0.16 \pm 0.09$	$1.75 \pm 0.27 \pm 0.08$
$\phi((\rho\pi) \to \pi^+\pi^-\pi^0)\pi^+$	$2.90 \pm 0.15 \pm 0.18$	$5.08 \pm 0.32 \pm 0.10$
$\omega((\rho\pi) \to \pi^+\pi^-\pi^0)\pi^+$	$3.22 \pm 0.21 \pm 0.09$	$1.41 \pm 0.17 \pm 0.06$
$a_1^+(\rho^0\pi^+)_S\pi^0$	$3.78 \pm 0.16 \pm 0.12$	$2.55 \pm 0.34 \pm 0.20$
$a_1^0((\rho\pi)_S \to \pi^+\pi^-\pi^0)\pi^+$	$4.82 \pm 0.15 \pm 0.12$	$1.29 \pm 0.39 \pm 0.24$
$\pi(1300)^0((\rho\pi)_P \to \pi^+\pi^-\pi^0)\pi^+$	$2.22 \pm 0.14 \pm 0.08$	$2.39 \pm 0.48 \pm 0.45$

W-annihilation decay
$BF = (1.92 \pm 0.30) \times 10^{-3}$
(PDG)



Amplitude analysis of $D_s^+ \to K_S^0 K_L^0 \pi^+$

Phys. Rev. Lett. 135, 161902 (2025)

Measurement of $\phi \to K_S^0 K_L^0$

$$\mathcal{B}_{D_s^+ \to K_S^0 K_L^0 \pi^+} = (1.86 \pm 0.06_{\rm stat} \pm 0.003_{\rm syst})\%$$

Amplitude	Phase (rad)	BF (%)
$D_s^+ \to \phi\pi^+$	0.0(fixed)	$1.32 \pm 0.05 \pm 0.04$
$D_s^+ \to K_L^0 K^*(892)^+$	$0.68 \pm 0.17 \pm 0.21$	$0.42 \pm 0.03 \pm 0.03$
$D_s^+ \to K_S^0 K^*(892)^+$	$-2.40 \pm 0.18 \pm 0.31$	$0.31 \pm 0.02 \pm 0.02$

$$\frac{\mathcal{B}(\phi(1020) \to K_S^0 K_L^0)}{\mathcal{B}(\phi(1020) \to K^+K^-)} = 0.597 \pm 0.023_{\rm stat} \pm 0.018_{\rm syst} \pm 0.016_{\rm PDG}$$

Taking from PDG

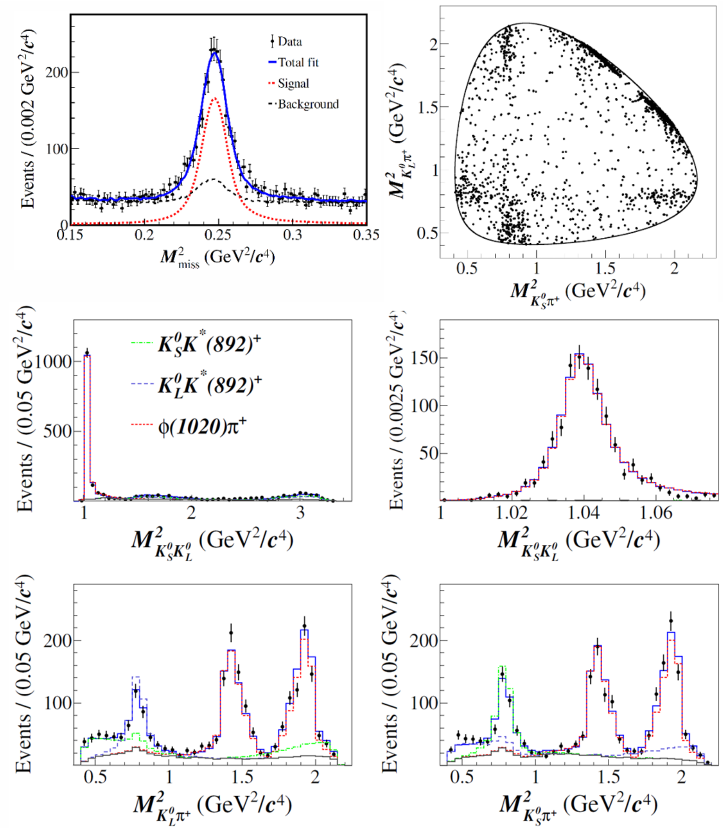
Deviates from PDG value (0.740±0.031) by $>3\sigma$

First observation of $K_S^0 - K_L^0$ asymmetry

$$\frac{\mathcal{B}(D_s^+ \to K_S^0 K^*(892)^+) - \mathcal{B}(D_s^+ \to K_L^0 K^*(892)^+)}{\mathcal{B}(D_s^+ \to K_S^0 K^*(892)^+) + \mathcal{B}(D_s^+ \to K_L^0 K^*(892)^+)} = (-13.4 \pm 5.0_{\rm stat} \pm 3.4_{\rm syst})\%$$

Model	DAT(F4)	DAT(F1′)
$D_s^+ \to \bar{K}^0 K^{*+}$	-0.164 ± 0.032	-0.159 ± 0.028

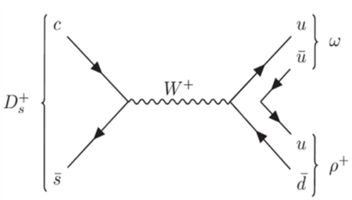
Predictions by H.-Y. Cheng *et al.*, PRD109, 073008（2024）



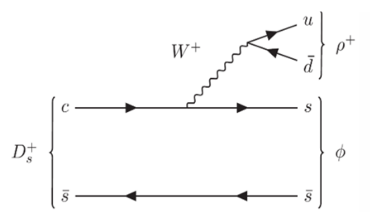
Amplitude analysis of $D_s^+ \to \pi^+\pi^+\pi^-\pi^0\pi^0$

Phys. Rev. Lett. 134. 201902(2025)

$D_s^+ \to \pi^+\pi^+\pi^-\pi^0\pi^0$



Pure W-annihilation



Pure W-external emission

Amplitude	BF (%)
$D_s^+ \to \rho(1450)^+\pi^0,\ \rho(1450)^+ \to \omega\pi^+$	$0.39 \pm 0.04\ ^{+0.03}_{-0.03}$
$D_s^+[S] \to a_1(1260)^0\rho^+,\ a_1(1260)^0[S] \to \rho^+\pi^-$	$0.23 \pm 0.02\ ^{+0.01}_{-0.01}$
$D_s^+[P] \to a_1(1260)^0\rho^+,\ a_1(1260)^0[S] \to \rho^+\pi^-$	$0.50 \pm 0.04\ ^{+0.02}_{-0.02}$
$D_s^+ \to a_1(1260)^0\rho^+,\ a_1(1260)^0 \to \rho^+\pi^-$	$0.50 \pm 0.04\ ^{+0.02}_{-0.02}$
$D_s^+[S] \to a_1(1260)^0\rho^+,\ a_1(1260)^0[S] \to \rho^-\pi^+$	$0.16 \pm 0.02\ ^{+0.01}_{-0.01}$
$D_s^+[P] \to a_1(1260)^0\rho^+,\ a_1(1260)^0[S] \to \rho^-\pi^+$	$0.17 \pm 0.01\ ^{+0.01}_{-0.01}$
$D_s^+ \to a_1(1260)^0\rho^+,\ a_1(1260)^0 \to \rho^-\pi^+$	$0.33 \pm 0.02\ ^{+0.02}_{-0.02}$
$D_s^+[S] \to a_1(1260)^+\rho^0,\ a_1(1260)^+[S] \to \rho^+\pi^0$	$0.41 \pm 0.05\ ^{+0.05}_{-0.05}$
$D_s^+[P] \to a_1(1260)^+\rho^0,\ a_1(1260)^+[S] \to \rho^+\pi^0$	$0.31 \pm 0.04\ ^{+0.02}_{-0.02}$
$D_s^+ \to a_1(1260)^+\rho^0,\ a_1(1260)^+ \to \rho^+\pi^0$	$0.73 \pm 0.07\ ^{+0.07}_{-0.07}$
$D_s^+ \to b_1(1235)^+\pi^0,\ b_1(1235)^+[S] \to \omega\pi^+$	$0.53 \pm 0.05\ ^{+0.03}_{-0.03}$
$D_s^+ \to b_1(1235)^0\pi^+,\ b_1(1235)^0[S] \to \omega\pi^0$	$0.72 \pm 0.06\ ^{+0.05}_{-0.05}$

Polarization puzzle

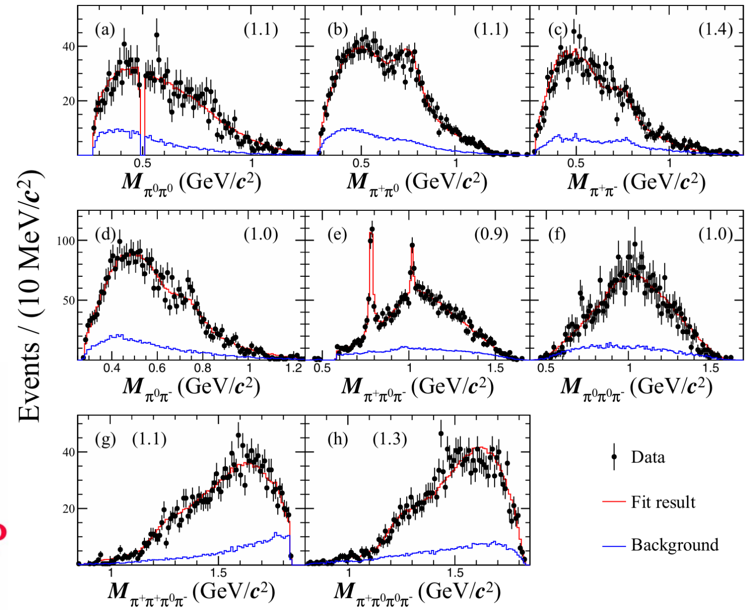
Amplitude	BF (%)
$D_s^+[S] \to \omega\rho^+$	$0.30 \pm 0.07\ ^{+0.02}_{-0.03}$
$D_s^+[P] \to \omega\rho^+$	$0.25 \pm 0.04\ ^{+0.04}_{-0.04}$
$D_s^+[D] \to \omega\rho^+$	$0.52 \pm 0.07\ ^{+0.04}_{-0.07}$
$D_s^+ \to \omega\rho^+$	$0.99 \pm 0.08\ ^{+0.05}_{-0.07}$
$D_s^+[S] \to \phi\rho^+$	$3.32 \pm 0.29\ ^{+0.19}_{-0.17}$
$D_s^+[P] \to \phi\rho^+$	$0.63 \pm 0.12\ ^{+0.05}_{-0.06}$
$D_s^+ \to \phi\rho^+$	$3.98 \pm 0.33\ ^{+0.21}_{-0.19}$

D>S>P

S>P>D

Naive prediction: PRL 128,011803

transverse dominates than longitudinal in charm decays



$$\frac{\mathcal{B}(\phi(1020) \to \pi^+\pi^-\pi^0)}{\mathcal{B}(\phi(1020) \to K^+K^-)} = 0.222 \pm 0.019_{\text{stat}} \pm 0.016_{\text{syst}}$$

Deviates from PDG value (0.313±0.010) by $>3\sigma$

CPV in hyperon decay

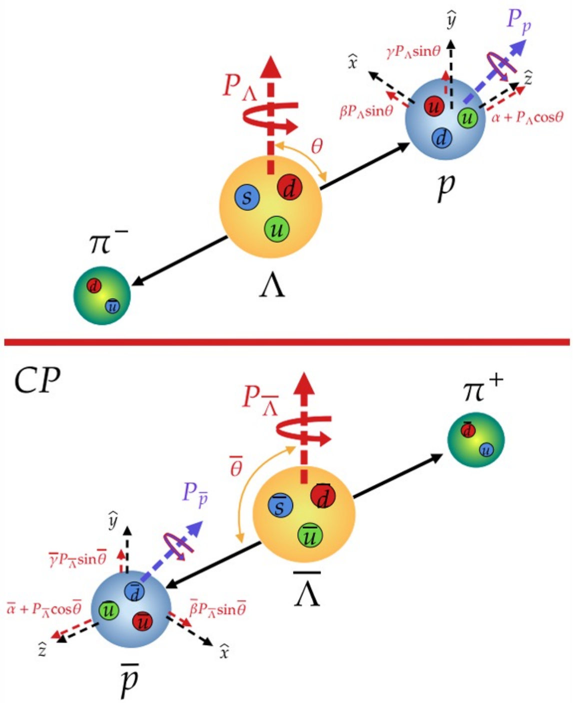
General Partial Wave Analysis of the Decay of a Hyperon of Spin ½

T. D. LEE* AND C. N. YANG

Institute for Advanced Study, Princeton, New Jersey

(Received October 22, 1957)

Phys. Rev. 108, 1645 (1957)



The amplitude of spin ½ baryon B_i decay to a spin ½ baryon B_f and π:

$$\mathcal{A} \sim S\sigma_0 + P\boldsymbol{\sigma}\cdot\hat{\boldsymbol{n}}$$

The decay parameters are defined as:

$$\alpha_Y = \frac{2\,\mathrm{Re}\,(S^*P)}{|S|^2+|P|^2},\quad \beta_Y = \frac{2\,\mathrm{Im}\,(S^*P)}{|S|^2+|P|^2},\quad \gamma_Y = \frac{|S|^2-|P|^2}{|S|^2+|P|^2}$$

Two complex amplitudes: **ϕ weak phase, δ strong phase**

$$S = \Sigma^i S_i e^{i(\phi_i^S+\delta_i^S)},\qquad P = \Sigma^i P_i e^{i(\phi_i^P+\delta_i^P)}$$

Under CP transformation:

$$\bar{S} = -\Sigma^i S_i e^{i(-\phi_i^S+\delta_i^S)},\qquad \bar{P} = \Sigma^i P_i e^{i(-\phi_i^P+\delta_i^P)}$$

If CP conserved: $S \xrightarrow{CP} -S$, $P \xrightarrow{CP} P$ $\Rightarrow$ $\alpha \xrightarrow{CP} \bar{\alpha} = -\alpha$, $\beta \xrightarrow{CP} \bar{\beta} = -\beta$

CPV observables

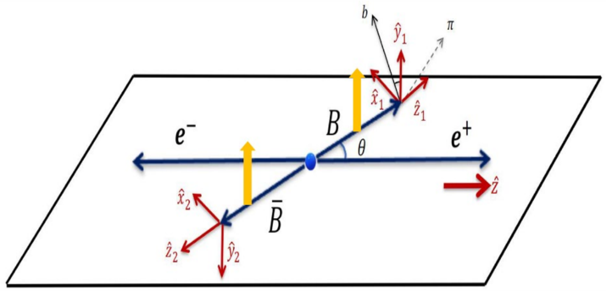
$$\begin{cases} \Delta = \frac{\Gamma-\bar{\Gamma}}{\Gamma+\bar{\Gamma}} \\ A = \frac{\Gamma\alpha+\bar{\Gamma}\bar{\alpha}}{\Gamma\alpha-\bar{\Gamma}\bar{\alpha}} \approx \frac{\alpha+\bar{\alpha}}{\alpha-\bar{\alpha}} + \Delta \\ B = \frac{\Gamma\beta+\bar{\Gamma}\bar{\beta}}{\Gamma\beta-\bar{\Gamma}\bar{\beta}} \approx \frac{\beta+\bar{\beta}}{\beta-\bar{\beta}} + \Delta \end{cases}$$

CP tests at BESIII

- **Polarized** and **entangled** hyperon-antihyperon pairs enable *CP* tests in hyperon decays

BESIII: a hyperon factory

10 billion J/ψ	2.7 billion $\psi(2S)$
1.9×10^7 $\Lambda\bar{\Lambda}$	1.0×10^6 $\Lambda\bar{\Lambda}$
1.2×10^7 $\Sigma^0\bar{\Sigma}^0$	0.6×10^6 $\Sigma^0\bar{\Sigma}^0$
1.5×10^7 $\Sigma^+\bar{\Sigma}^-$	0.6×10^6 $\Sigma^+\bar{\Sigma}^-$
1.2×10^7 $\Xi^0\bar{\Xi}^0$	0.6×10^6 $\Xi^0\bar{\Xi}^0$
1.0×10^7 $\Xi^+\bar{\Xi}^-$	0.8×10^6 $\Xi^+\bar{\Xi}^-$
	1.5×10^5 $\Omega^+\bar{\Omega}^-$



Angular distribution: $\frac{d\Gamma}{d\Omega} \propto 1 + \alpha_\psi \cos^2\theta$

Transverse polarization:

Nature Phys. 15, 631 (2019)

$$P_y(\cos\theta) = \frac{\sqrt{1-\alpha_\psi^2}\sin(\Delta\Phi)\cos\theta\sin\theta}{1+\alpha_\psi\cos^2\theta}$$

- **Sequentially decaying** multi-strange and charm hyperons enable
  - → Production and
  - → decay parameters

Phys. Rev. 108, 1645 (1957)

$$\alpha = \frac{2Re(S*P)}{|S|^2+|P|^2},\ \beta = \frac{2Im(S*P)}{|S|^2+|P|^2} = \sqrt{1-\alpha^2}\sin\phi$$

$$A_{CP} = \frac{\alpha_B+\alpha_{\bar{B}}}{\alpha_B-\alpha_{\bar{B}}},\ \phi_{CP} = \frac{\phi_B-\phi_{\bar{B}}}{2}$$

P and *S* are the *P* wave and *S* wave amplitudes in $\frac{1}{2}\to\frac{1}{2}+0$

Production parameters: α_ψ, $\Delta\Phi$

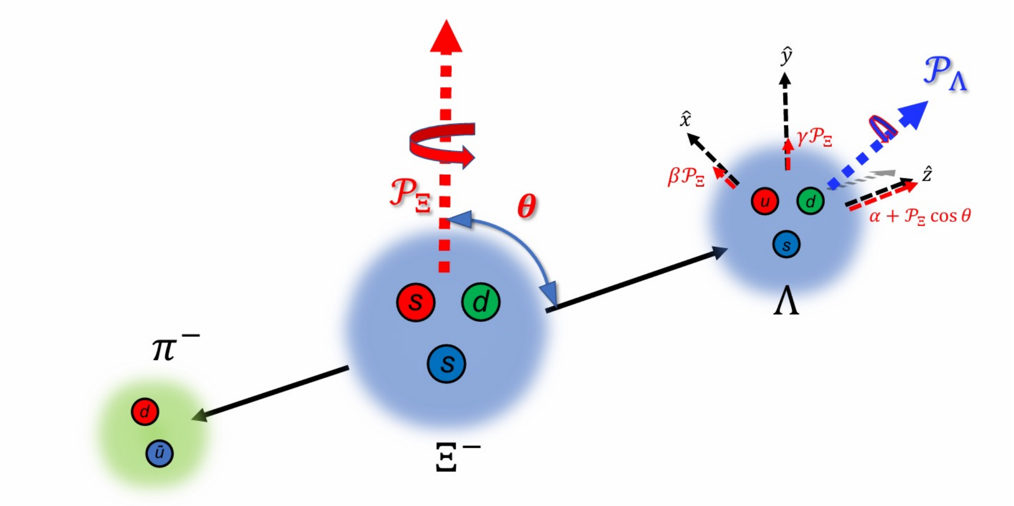
Decay parameters: α, ϕ

CP observables: A_{CP}, ϕ_{CP}

- A **combination** of the two approaches enables
  - → Separation of strong and weak decay phases → More sensitive *CP* tests!

CP tests at BESIII

- SM predicts small CP asymmetry.
- Sizeable CP violations prerequisite for Baryogenesis.
- Spin-carrying hyperons precision probe of CP symmetry.



BESIII:

Nature Phys. 15, p 631-634 (2019)

Phys. Rev. Lett. 125, 052004 (2020)

Nature 606, 64-69 (2022)

Phys. Rev. Lett. 129, 131801 (2022)

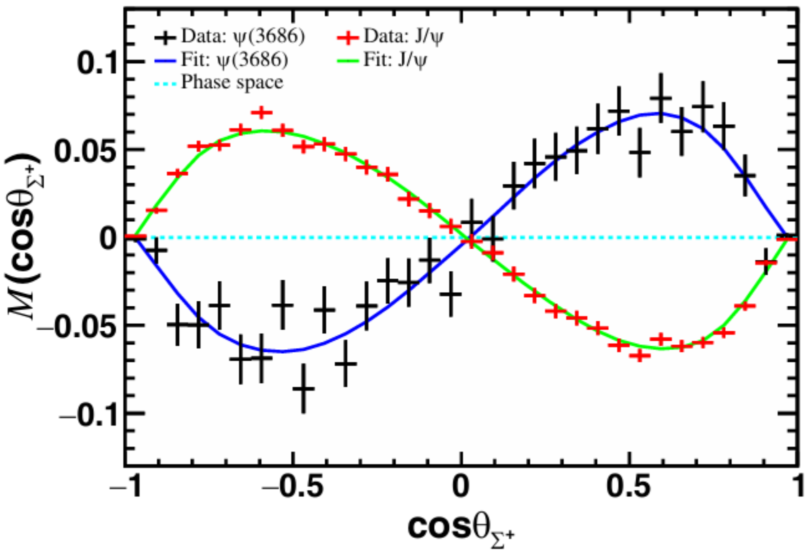
Phys. Rev. D 108, L031106 (2023)

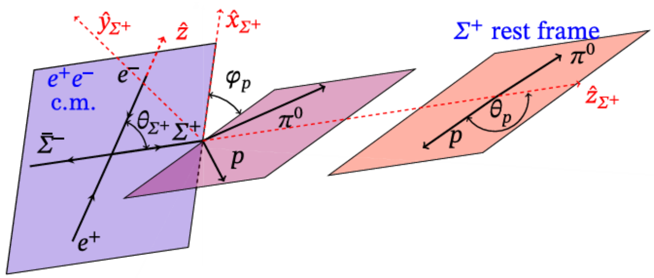
Phys. Rev. Lett. 133, 101902 (2024)

Phys. Rev. Lett. 135, 141804 (2025)

CP tests in $\Sigma^+ \to p\pi^0$

- Consistent with previous results but improved precisions .
- Sensitivity of A_{CP} in $\Sigma^+ \to p\pi^0$ decay is further improved.



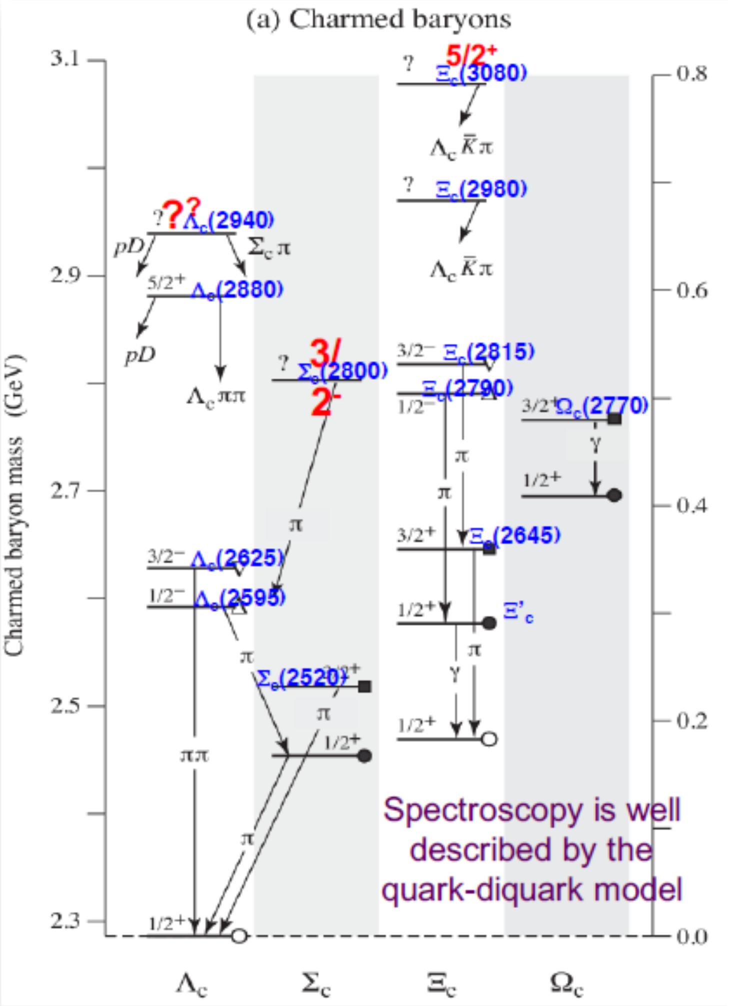


Parameter	This Letter	Previous result [22]
$\alpha_{J/\psi}$	$-0.5047 \pm 0.0018 \pm 0.0010$	$-0.508 \pm 0.006 \pm 0.004$
$\Delta\Phi_{J/\psi}$	$-0.2744 \pm 0.0033 \pm 0.0010$	$-0.270 \pm 0.012 \pm 0.009$
α_0	$-0.975 \pm 0.011 \pm 0.002$	$-0.998 \pm 0.037 \pm 0.009$
$\bar{\alpha}_0$	$0.999 \pm 0.011 \pm 0.004$	$0.990 \pm 0.037 \pm 0.011$
$\alpha_{\psi(3686)}$	$0.7133 \pm 0.0094 \pm 0.0065$	$0.682 \pm 0.030 \pm 0.011$
$\Delta\Phi_{\psi(3686)}$	$0.427 \pm 0.022 \pm 0.003$	$0.379 \pm 0.070 \pm 0.014$
$\langle\alpha_0\rangle$	$-0.9869 \pm 0.0011 \pm 0.0016$	$-0.994 \pm 0.004 \pm 0.002$
A_{CP}	$-0.0118 \pm 0.0083 \pm 0.0028$	$0.004 \pm 0.037 \pm 0.010$

Phys. Rev. Lett. **135**, 141804 (2025)

Renaissance on the charmed heavy baryon

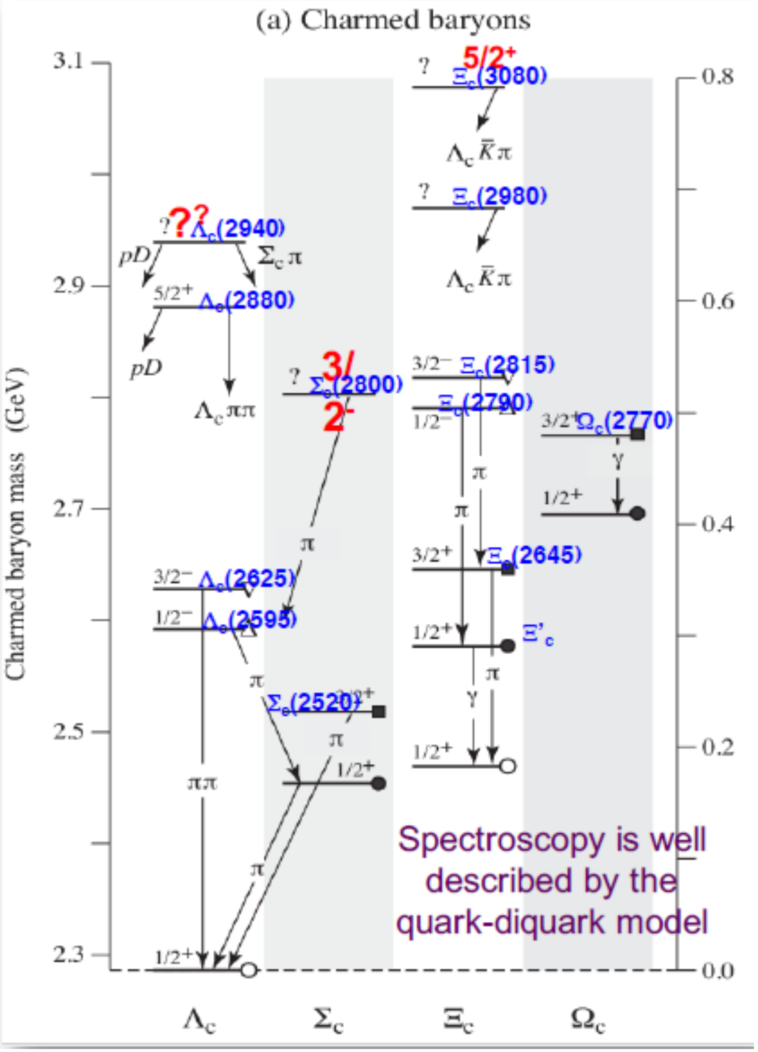
- Before 2014, the charmed baryons have been produced and studied at many experiments, notably fixed-target experiments (such as FOCUS and SELEX) and e^+e^- B-factories (ARGUS, CLEO, BABAR, and BELLE).
- Large uncertainties in experiment=>Retarder development in theory.
- Afterwards, more extensive measurements on charmed baryons are performed at BESIII, BELLE and LHCb.
  - The absolute BF measurements of $\Lambda_c^+ \to pK^-\pi^+$ at BESIII and BELL
  - The observation of the DCS mode $\Lambda_c^+ \to pK^+\pi^-$ at BELLE.
  - The observation of the doubly charmed baryon Ξ_{cc}^{++} at LHCb.
- These experimental progresses have revoked the activities in the theoretical efforts.



The charmed baryon family

- Singly charmed baryons
  - Established ground states:

    $\Lambda_c^+, \Sigma_c, \Xi_c^{(\prime)}, \Omega_c$
  - Excited states are being explored
- Doubly charmed baryons(Ξ_{cc}^{++}) observed in recent year.
- No observations of triply charmed baryons.



✓ Λ_c^+ decay only weakly, many experimental progress since 2014.

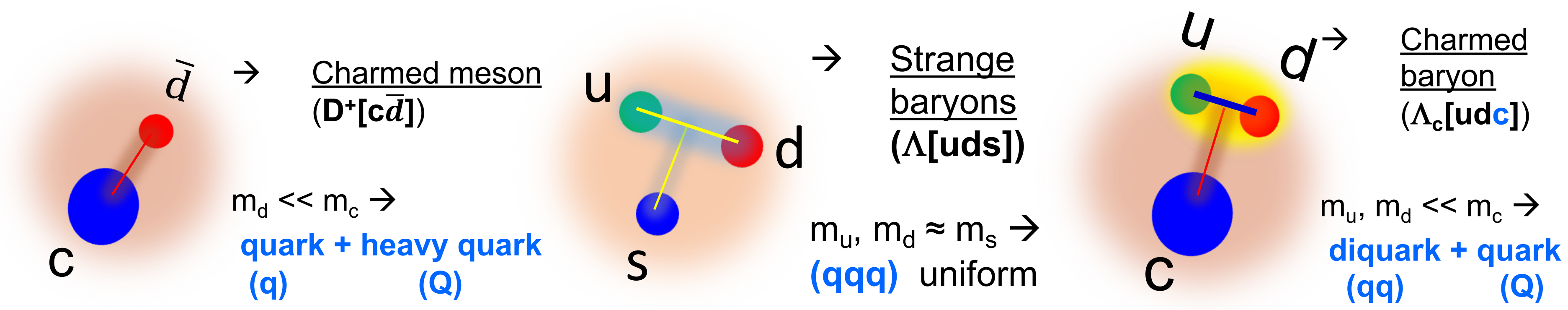
✓ Σ_c: B($\Sigma_c \to \Lambda_c^+\pi$)~100%, B($\Sigma_c \to \Lambda_c^+\gamma$)?

✓ Ξ_c : decay only weakly; no absolute BF measured, most relative to $\Xi^-\ \pi^+(\pi^+)$.

✓ Ω_c:decay only weakly; no absolute BF measured.

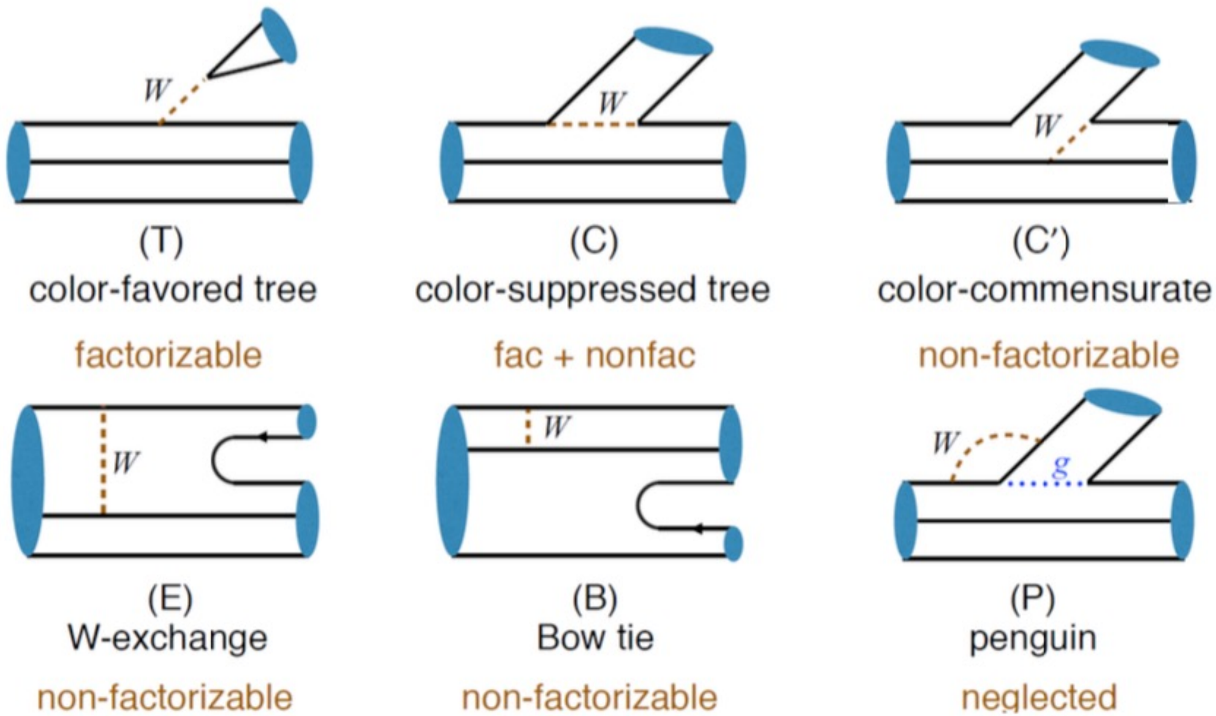
Λ_c^+: The lightest charmed baryon spectroscopy

- Most of the charmed baryons will eventually decay to Λ_c^+.
- The Λ_c^+ is one of important tagging hadrons in c-quark counting in the productions at high energy experiment.
- Naïve quark model picture: a heavy quark (c) with an unexcited spin-zero diquark (u-d). Diquark correlation is enhanced by weak Color Magnetic Interaction with a heavy quark(HQET).
- Λ_c^+ may reveal more information of strong- and weak-interactions in charm region, complementary to D/Ds



Λ_c^+ weak decay picture in theory

- Contrary to charmed meson, W-exchange contribution is important.(No color suppress and helicity suppress)

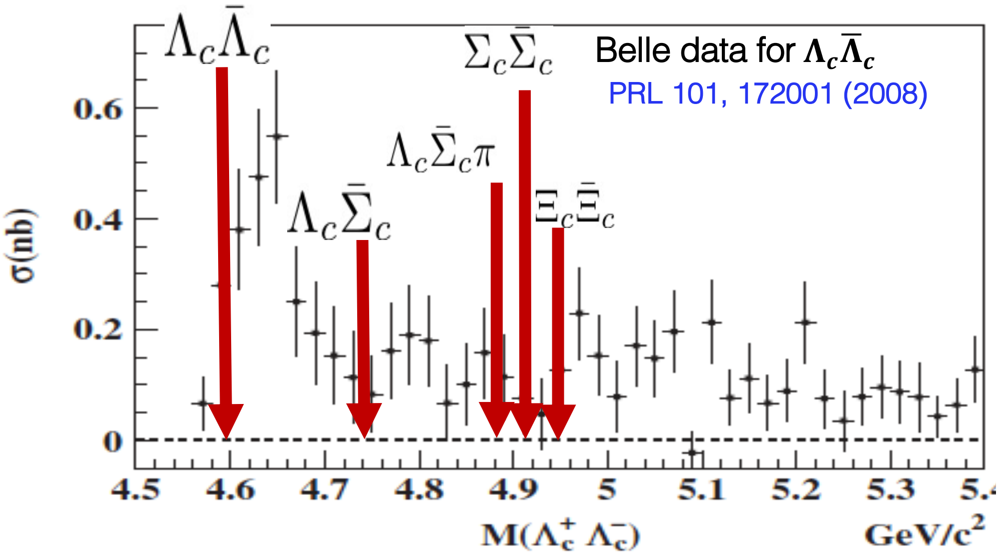


- Phenomenology aim at explain data and predict important observables.
- Calculate what they can(HQET, factorization)+parametrize what they cannot + some non-perturbations extracted from data=> explain and predict.

New data samples in 2020 and 2021

Two major changes in BEPCII machine:

- **max beam energy: 2.30→2.35(2020)→ 2.48 GeV(2021)**
- **top-up injection:** data taking efficiency increased by 20~30%



CPC46.113003(2022)

Sample	E_{cms}/MeV	$\mathscr{L}_{Bhabha}$/pb^{-1}
4610	4611.86±0.12±0.30	103.65±0.05±0.55
4620	4628.00±0.06±0.32	521.53±0.11±2.76
4640	4640.91±0.06±0.38	551.65±0.12±2.92
4660	4661.24±0.06±0.29	529.43±0.12±2.81
4680	4681.92±0.08±0.29	1667.39±0.21±8.84
4700	4698.82±0.10±0.36	535.54±0.12±2.84
4740	4739.70±0.20±0.30	163.87±0.07±0.87
4750	4750.05±0.12±0.29	366.55±0.10±1.94
4780	4780.54±0.12±0.30	511.47±0.12±2.71
4840	4843.07±0.20±0.31	525.16±0.12±2.78
4920	4918.02±0.34±0.34	207.82±0.08±1.10
4950	4950.93±0.36±0.38	159.28±0.07±0.84

Available data for charmed baryons

- ✓ 0.587 fb^{-1} at 4.6 GeV (35 days in 2014)
- ✓ 3.9 fb^{-1} scan at 4.61, 4.63, 4.64, 4.66, 4.68, 4.7 GeV (186 days in 2020)
- ✓ 1.93 fb^{-1} scan at 4.74, 4.75, 4.78, 4.84, 4.92, 4.95 GeV (99 days in 2021)
- 8x Λ_c data that those at 4.6GeV.(~0.77M $\Lambda_c^+\bar{\Lambda}_c^-$)
- accessible to $\Sigma_c/\Xi_c/\Lambda_c^*$ prod. & decays

Λ_c^+ BF studies

arXiv 2509.19141

Λ_c^+ Mode	BF($\times10^{-3}$)	Experiment
$\Lambda_c^+\to\Lambda e^+\nu_e$	$23.7\pm5.1(37\%)^\dagger$	ARGUS(1991)[24]
	$26.8\pm5.1(19\%)^\dagger$	CELO(1994)[25]
	$36.3\pm4.3(12\%)$	BESIII(2015)[30]
	$35.6\pm1.3(3.6\%)$	BESIII(2022)[31]
$\Lambda_c^+\to\Lambda\mu^+\nu_\mu$	$34.9\pm5.3(15\%)$	BESIII(2017)[32]
	$34.8\pm1.7(4.9\%)$	BESIII(2023)[34]
$\Lambda_c^+\to e^+X$	$39.5\pm3.5(8.9\%)$	BESIII(2018)[35]
	$40.6\pm1.3(3.2\%)$	BESIII(2023)[37]

Λ_c^+ Mode	BF($\times10^{-3}$)	Experiment
$\Lambda_c^+\to pK^-e^+\nu_e$	$0.88\pm0.18(20\%)$	BESIII(2022)[29]
$\Lambda_c^+\to\Lambda(1405)e^+\nu_e$, $\Lambda(1405)\to pK^-$	$0.42\pm0.19(45\%)$	BESIII(2022)[29]
$\Lambda_c^+\to\Lambda(1520)e^+\nu_e$	$1.0\pm0.5(50\%)$	BESIII(2022)[29]
$\Lambda_c^+\to pK_S^0\pi^-e^+\nu_e$	<0.33	BESIII(2023)[33]
$\Lambda_c^+\to\Lambda\pi^+\pi^-e^+\nu_e$	<0.39	BESIII(2023)[33]
$\Lambda_c^+\to ne^+\nu_e$	3.57 ± 0.37 (10%)	BESIII(2025)[36]

Ξ_c Mode	BF($\times10^{-3}$)	Experiment
$\Xi_c^0\to\Xi^-e^+\nu_e$	$13.7\pm7.7(56\%)^\dagger$	ARGUS(1993)[26]
	$44.3^{+16.6}_{-17.8}(40\%)^\dagger$	CLEO(1995)[27]
	$19.7\pm5.3(27\%)^\dagger$	ALICE(2021)[39]
	$10.4\pm2.1(20\%)^\dagger$	Belle(2021)[38]

Ξ_c Mode	BF($\times10^{-3}$)	Experiment
$\Xi_c^0\to\Xi^-\mu^+\nu_\mu$	$10.1\pm2.1(21\%)^\dagger$	Belle(2021)[38]
$\Xi_c^+\to\Xi^0e^+\nu_e$	$67\pm39(58\%)^\dagger$	CLEO(1995)[27]

Ω_c^0 Mode	Ratio	Experiment
$\Omega_c^0\to\Omega^0e^+\nu_e$	$2.4\pm1.1(47\%)$	CLEO(2002)[28]
	$1.98\pm0.15(7.7\%)$	Belle(2022)[40]

Ω_c^0 Mode	Ratio	Experiment
$\Omega_c^0\to\Omega^0\mu^+\nu_\mu$	$1.94\pm0.21(11\%)$	Belle(2022)[40]

Table 3. The determined BFs for the CS decays of the Λ_c^+ (in units of 10^{-3}). Upper limits are set at 90% confidence level.

Mode	BF	Experiment
Nucleon-involved		
$\Lambda_c^+\to n\pi^+$	0.66 ± 0.13	BESIII(2022)[126]
$\Lambda_c^+\to p\pi^0$	<0.27	BESIII(2017)[117]
	<0.08	Belle(2021)[109]
	$0.16^{+0.07}_{-0.06}$	BESIII(2024)[118]
	0.18 ± 0.04	BESIII(2025)[119]
$\Lambda_c^+\to p\eta$	1.24 ± 0.30	BESIII(2017)[117]
	1.42 ± 0.12	Belle(2021)[109]
	1.57 ± 0.12	BESIII(2023)[120]
	1.63 ± 0.33	BESIII(2024)[118]
	1.67 ± 0.80	LHCb(2024)[121]
$\Lambda_c^+\to p\eta'$	$0.56^{+0.25}_{-0.21}$	BESIII(2022)[123]
	0.47 ± 0.10	Belle(2022)[122]
$\Lambda_c^+\to p\rho$	1.52 ± 0.44	LHCb(2024)[121]
$\Lambda_c^+\to p\omega$	0.94 ± 0.39	LHCb(2018)[124]
	0.83 ± 0.11	Belle(2021)[125]
	1.11 ± 0.21	BESIII(2023)[120]
	0.98 ± 0.31	LHCb(2024)[121]
$\Lambda_c^+\to p\phi$	1.06 ± 0.22	BESIII(2016)[127]
Λ-involved		
$\Lambda_c^+\to\Lambda K^+$	0.62 ± 0.06	BESIII(2022)[131]
	0.66 ± 0.04	Belle(2023)[132]
$\Lambda_c^+\to\Lambda K^{*+}$	$2.40\pm0.59(\theta_0=0^\circ)$	BESIII(2025)[134]
	$5.21\pm0.75(\theta_0=109^\circ)$	BESIII(2025)[134]
	$1.29\pm0.44(\theta_0=221^\circ)$	BESIII(2025)[134]
Σ-involved		
$\Lambda_c^+\to\Sigma^0K^+$	0.47 ± 0.10	BESIII(2022)[133]
	0.36 ± 0.03	Belle(2023)[132]
$\Lambda_c^+\to\Sigma^+K_S^0$	0.48 ± 0.14	BESIII(2022)[133]

Mode	BF	Experiment
Nucleon-involved		
$\Lambda_c^+\to nK^+\pi^0$	<0.71	BESIII(2024)[107]
$\Lambda_c^+\to n\pi^+\pi^0$	0.64 ± 0.09	BESIII(2023)[129]
$\Lambda_c^+\to nK_S^0K^+$	$0.39^{+0.17}_{-0.14}$	BESIII(2024)[91]
$\Lambda_c^+\to n\pi^+\pi^-\pi^+$	0.45 ± 0.08	BESIII(2023)[129]
$\Lambda_c^+\to p\pi^+\pi^-$	3.91 ± 0.40	BESIII(2016)[127]
	4.72 ± 0.28	LHCb(2018)[138]
$\Lambda_c^+\to pK^+K^-$	1.08 ± 0.07	LHCb(2018)[138]
$\Lambda_c^+\to p(K^+K^-)_{\text{non-}\phi}$	0.55 ± 0.14	BESIII(2016)[127]
$\Lambda_c^+\to pK_S^0K_S^0$	0.24 ± 0.02	Belle(2023)[146]
$\Lambda_c^+\to p\phi\pi^0$	<0.15	Belle(2017)[147]
$\Lambda_c^+\to(pK^+K^-\pi^0)_{\rm NR}$	<0.06	Belle(2017)[147]
$\Lambda_c^+\to pK^+\pi^-$	0.16 ± 0.02	Belle(2016)[137]
	0.10 ± 0.01	LHCb(2018)[138]
Λ-involved		
$\Lambda_c^+\to\Lambda K^+\pi^0$	<2.0	BESIII(2024)[107]
	1.49 ± 0.29	BESIII(2024)[135]
$\Lambda_c^+\to\Lambda K_S^0\pi^+$	1.73 ± 0.29	BESIII(2025)[134]
$\Lambda_c^+\to\Lambda K^+\pi^+\pi^-$	0.41 ± 0.15	BESIII(2024)[135]
Σ-involved		
$\Lambda_c^+\to\Sigma^+K^+\pi^-$	2.00 ± 0.28	BESIII(2023)[150]
$\Lambda_c^+\to\Sigma^+K^+\pi^-\pi^0$	<0.01	BESIII(2023)[150]
$\Lambda_c^+\to\Sigma^0K^+\pi^0$	<1.8	BESIII(2024)[107]
	<0.50	BESIII(2024)[151]
$\Lambda_c^+\to\Sigma^0K^+\pi^+\pi^-$	<0.65	BESIII(2024)[151]
$\Lambda_c^+\to\Sigma^-K^+\pi^+$	0.38 ± 0.12	BESIII(2024)[136]

Table 2. Measurements of the BFs for the CF decays of the Λ_c^+ (in units of %).

Mode	BF	Experiment
Nucleon-involved		
$\Lambda_c^+\to pK_S^0$	1.52 ± 0.09	BESIII(2016)[80]
$\Lambda_c^+\to pK_L^0$	1.67 ± 0.07	BESIII(2024)[89]
$\Lambda_c^+\to p\bar{K}_0^*(700)^0\to pK^-\pi^+$	0.19 ± 0.06	LHCb(2023)[86]
$\Lambda_c^+\to p\bar{K}_0^*(892)^0\to pK^-\pi^+$	1.38 ± 0.08	LHCb(2023)[86]
$\Lambda_c^+\to p\bar{K}_0^*(1430)^0\to pK^-\pi^+$	0.92 ± 0.18	LHCb(2023)[86]
$\Lambda_c^+\to\Delta(1232)^{++}K^-\to p\pi^+K^-$	1.78 ± 0.05	LHCb(2023)[86]
$\Lambda_c^+\to\Delta(1600)^{++}K^-\to p\pi^+K^-$	0.28 ± 0.10	LHCb(2023)[86]
$\Lambda_c^+\to\Delta(1700)^{++}K^-\to p\pi^+K^-$	0.24 ± 0.06	LHCb(2023)[86]
Λ-involved		
$\Lambda_c^+\to\Lambda\pi^+$	1.24 ± 0.08	BESIII(2016)[80]
	1.31 ± 0.09	BESIII(2023)[126]
$\Lambda_c^+\to\Lambda\rho(770)^+$	4.06 ± 0.52	BESIII(2022)[93]
$\Lambda_c^+\to\Lambda a_0(980)^+$	1.23 ± 0.21	BESIII(2025)[94]
$\Lambda_c^+\to\Lambda(1405)\pi^+\to pK^-\pi^+$	0.48 ± 0.19	LHCb(2023)[86]
$\Lambda_c^+\to\Lambda(1520)\pi^+\to pK^-\pi^+$	0.12 ± 0.02	LHCb(2023)[86]
$\Lambda_c^+\to\Lambda(1600)\pi^+\to pK^-\pi^+$	0.32 ± 0.12	LHCb(2023)[86]
$\Lambda_c^+\to\Lambda(1670)\pi^+\to pK^-\pi^+$	0.07 ± 0.02	LHCb(2023)[86]
$\Lambda_c^+\to\Lambda(1670)\pi^+\to\Lambda\eta\pi^+$	0.27 ± 0.06	Belle(2021)[95]
	0.27 ± 0.06	BESIII(2025)[148]
$\Lambda_c^+\to\Lambda(1690)\pi^+\to pK^-\pi^+$	0.07 ± 0.02	LHCb(2023)[86]
$\Lambda_c^+\to\Lambda(2000)\pi^+\to pK^-\pi^+$	0.60 ± 0.07	LHCb(2023)[86]
Σ-involved		
$\Lambda_c^+\to\Sigma^+\pi^0$	1.18 ± 0.10	BESIII(2016)[80]
$\Lambda_c^+\to\Sigma^+\eta$	0.41 ± 0.20	BESIII(2018)[96]
	0.31 ± 0.05	Belle(2023)[98]
	0.38 ± 0.06	BESIII(2025)[97]
$\Lambda_c^+\to\Sigma^+\eta'$	1.34 ± 0.56	BESIII(2018)[96]
	0.42 ± 0.09	Belle(2023)[98]
	0.57 ± 0.18	BESIII(2025)[97]
$\Lambda_c^+\to\Sigma^+\omega$	1.56 ± 0.21	BESIII(2016)[80]
$\Lambda_c^+\to\Sigma^+\phi$	0.41 ± 0.09	BESIII(2023)[150]
$\Lambda_c^+\to\Sigma^0\pi^+$	1.27 ± 0.09	BESIII(2016)[80]
	1.22 ± 0.11	BESIII(2023)[126]
$\Lambda_c^+\to\Sigma(1385)^+\pi^0$	0.59 ± 0.08	BESIII(2022)[93]
$\Lambda_c^+\to\Sigma(1385)^+\eta$	0.91 ± 0.20	BESIII(2019)[94]
	1.21 ± 0.12	Belle(2021)[95]
	0.68 ± 0.08	BESIII(2025)[148]
$\Lambda_c^+\to\Sigma(1385)^0\pi^+$	0.65 ± 0.10	BESIII(2022)[93]
Ξ-involved		
$\Lambda_c^+\to\Xi^0K^+$	0.59 ± 0.09	BESIII(2018)[106]
$\Lambda_c^+\to\Xi(1530)^0K^+$	0.50 ± 0.10	BESIII(2018)[106]
	0.60 ± 0.11	BESIII(2024)[107]

Mode	BF	Experiment
Nucleon-involved		
$\Lambda_c^+\to nK_S^0\pi^+$	1.82 ± 0.25	BESIII(2017)[90]
	1.86 ± 0.09	BESIII(2024)[91]
$\Lambda_c^+\to nK_S^0\pi^+\pi^0$	0.85 ± 0.13	BESIII(2024)[92]
$\Lambda_c^+\to nK^-\pi^+\pi^+$	1.90 ± 0.12	BESIII(2023)[129]
$\Lambda_c^+\to pK_S^0\pi^0$	1.87 ± 0.14	BESIII(2016)[80]
	2.12 ± 0.11	Belle(II)(2025)[144]
$\Lambda_c^+\to pK_L^0\pi^0$	2.02 ± 0.14	BESIII(2024)[89]
$\Lambda_c^+\to pK_S^0\eta$	0.41 ± 0.09	BESIII(2021)[145]
	0.44 ± 0.03	Belle(2023)[146]
$\Lambda_c^+\to pK_S^0\pi^+\pi^-$	1.53 ± 0.14	BESIII(2016)[80]
$\Lambda_c^+\to pK_L^0\pi^+\pi^-$	1.69 ± 0.11	BESIII(2024)[89]
$\Lambda_c^+\to pK^-\pi^+$	$6.84^{+0.32}_{-0.36}$	Belle(2014)[81]
	5.84 ± 0.35	BESIII(2016)[80]
$\Lambda_c^+\to pK^-\pi^+\pi^0$	4.53 ± 0.38	BESIII(2016)[80]
	4.42 ± 0.21	Belle(2017)[147]
Λ-involved		
$\Lambda_c^+\to\Lambda\pi^+\pi^0$	7.01 ± 0.42	BESIII(2016)[80]
$\Lambda_c^+\to\Lambda\pi^+\eta$	1.84 ± 0.26	BESIII(2019)[94]
	1.84 ± 0.13	Belle(2021)[95]
	1.94 ± 0.13	BESIII(2025)[148]
$\Lambda_c^+\to\Lambda\pi^+\pi^-\pi^+$	3.81 ± 0.30	BESIII(2016)[80]
$\Lambda_c^+\to\Lambda K_S^0K^+$	0.30 ± 0.03	BESIII(2025)[134]
	0.31 ± 0.05	BESIII(2025)[108]
Σ-involved		
$\Lambda_c^+\to\Sigma^+\pi^+\pi^-$	4.25 ± 0.31	BESIII(2016)[80]
	4.57 ± 0.28	Belle(2018)[149]
$\Lambda_c^+\to\Sigma^+\pi^0\pi^0$	1.57 ± 0.15	Belle(2018)[149]
$\Lambda_c^+\to\Sigma^0\pi^+\pi^0$	3.65 ± 0.30	Belle(2018)[149]
$\Lambda_c^+\to\Sigma^0\pi^+\eta$	0.76 ± 0.08	Belle(2021)[95]
$\Lambda_c^+\to\Sigma^-\pi^+\pi^+$	1.81 ± 0.19	BESIII(2017)[105]
$\Lambda_c^+\to\Sigma^-\pi^+\pi^+\pi^0$	2.11 ± 0.36	BESIII(2017)[105]
$\Lambda_c^+\to\Sigma^+K^+K^-$	0.38 ± 0.05	BESIII(2023)[150]
$\Lambda_c^+\to\Sigma^+K^+K^-_{\text{non-}\phi}$	0.20 ± 0.04	BESIII(2023)[150]
$\Lambda_c^+\to\Sigma^0K_S^0K^+$	0.08 ± 0.03	BESIII(2025)[108]
Ξ-involved		
$\Lambda_c^+\to\Xi^0K^+\pi^0$	0.78 ± 0.17	BESIII(2024)[107]
$\Lambda_c^+\to\Xi^0K_S^0\pi^+$	0.37 ± 0.06	BESIII(2025)[108]

Λ_c^+ decay asymmetry studies

arXiv 2509.19141

Mode	α	Experiment	Mode	α	Experiment
Nucleon-involved			$\Lambda_c^+ \to \Lambda(1600)\pi^+$	0.2 ± 0.5	LHCb(2023)[91]
$\Lambda_c^+ \to pK_S^0$	-0.75 ± 0.10	LHCb(2024)[160]	$\Lambda_c^+ \to \Lambda(1670)\pi^+$	0.82 ± 0.08	LHCb(2023)[91]
	$-0.92^{+0.14}_{-0.09}$	BESIII(2025)[159]		0.21 ± 0.43	BESIII(2025)[153]
$\Lambda_c^+ \to p\bar{K}_0^*(700)^0$	-0.1 ± 0.7	LHCb(2023)[91]	$\Lambda_c^+ \to \Lambda(1690)\pi^+$	0.958 ± 0.034	LHCb(2023)[91]
$\Lambda_c^+ \to p\bar{K}_0^*(892)^0$	0.87 ± 0.03	LHCb(2023)[91]	$\Lambda_c^+ \to \Lambda(2000)\pi^+$	-0.57 ± 0.19	LHCb(2023)[91]
$\Lambda_c^+ \to p\bar{K}_0^*(1430)^0$	0.34 ± 0.14	LHCb(2023)[91]	**Σ-involved**		
$\Lambda_c^+ \to \Delta(1232)^{++}K^-$	0.55 ± 0.04	LHCb(2023)[91]	$\Lambda_c^+ \to \Sigma^+\pi^0$	-0.48 ± 0.03	Belle(2023)[103]
$\Lambda_c^+ \to \Delta(1600)^{++}K^-$	-0.50 ± 0.18	LHCb(2023)[91]		-0.59 ± 0.05	BESIII(2025)[159]
$\Lambda_c^+ \to \Delta(1700)^{++}K^-$	0.22 ± 0.08	LHCb(2023)[91]	$\Lambda_c^+ \to \Sigma^+\eta$	-0.99 ± 0.06	Belle(2023)[103]
Λ-involved			$\Lambda_c^+ \to \Sigma^+\eta'$	-0.46 ± 0.07	Belle(2023)[103]
$\Lambda_c^+ \to \Lambda\pi^+$	-0.785 ± 0.007	LHCb(2024)[160]	$\Lambda_c^+ \to \Sigma^0\pi^+$	-0.46 ± 0.02	Belle(2023)[137]
	-0.755 ± 0.006	Belle(2023)[137]		-0.50 ± 0.08	BESIII(2025)[159]
	-0.790 ± 0.033	BESIII(2025)[159]	$\Lambda_c^+ \to \Sigma(1385)^+\pi^0$	-0.917 ± 0.089	BESIII(2022)[98]
$\Lambda_c^+ \to \Lambda K^+$	-0.59 ± 0.05	Belle(2023)[137]	$\Lambda_c^+ \to \Sigma(1385)^+\eta$	-0.61 ± 0.16	BESIII(2025)[153]
	-0.52 ± 0.05	LHCb(2024)[160]	$\Lambda_c^+ \to \Sigma(1385)^0\pi^+$	-0.79 ± 0.11	BESIII(2022)[98]
$\Lambda_c^+ \to \Lambda\rho(770)^+$	-0.763 ± 0.070	BESIII(2022)[98]	$\Lambda_c^+ \to \Sigma^0K^+$	-0.54 ± 0.20	Belle(2023)[137]
$\Lambda_c^+ \to \Lambda a(980)^+$	$-0.91^{+0.20}_{-0.12}$	BESIII(2025)[153]	**Ξ-involved**		
$\Lambda_c^+ \to \Lambda(1405)\pi^+$	0.58 ± 0.28	LHCb(2023)[91]	$\Lambda_c^+ \to \Xi^0K^+$	0.01 ± 0.16	BESIII(2024)[161]
$\Lambda_c^+ \to \Lambda(1520)\pi^+$	0.93 ± 0.09	LHCb(2023)[91]			

Mode	β	Experiment	Mode	γ	Experiment
$\Lambda_c^+ \to \Lambda\pi^+$	0.378 ± 0.015	LHCb(2024)[160]	$\Lambda_c^+ \to \Lambda\pi^+$	0.491 ± 0.012	LHCb(2024)[160]
	$0.37^{+0.17}_{-0.25}$	BESIII(2025)[159]		$0.64^{+0.10}_{-0.20}$	BESIII(2025)[159]
$\Lambda_c^+ \to \Sigma^0\pi^+$	$0.70^{+0.14}_{-0.48}$	BESIII(2025)[159]	$\Lambda_c^+ \to \Sigma^0\pi^+$	$-0.50^{+0.59}_{-0.30}$	BESIII(2025)[159]
$\Lambda_c^+ \to \Sigma^+\pi^0$	$0.76^{+0.05}_{-0.24}$	BESIII(2025)[159]	$\Lambda_c^+ \to \Sigma^+\pi^0$	$-0.26^{+0.48}_{-0.38}$	BESIII(2025)[159]
$\Lambda_c^+ \to \Xi^0K^+$	-0.64 ± 0.70	BESIII(2024)[161]	$\Lambda_c^+ \to \Xi^0K^+$	-0.77 ± 0.59	BESIII(2024)[161]
$\Lambda_c^+ \to \Lambda K^+$	0.33 ± 0.08	LHCb(2024)[160]	$\Lambda_c^+ \to \Lambda K^+$	-0.799 ± 0.041	LHCb(2024)[160]

Recent studies on the Λ_c^+ measurments at BESIII

Semi-leptonic decay

- ✓ Form factors of $\Lambda_c^+ \to \Lambda e^+ \nu_e$ and $\Lambda\mu^+\nu_\mu$ — ***PRL129, 231803 (2022);*** *PRD108, L031105 (2023)*
- ✓ $\Lambda_c^+ \to pK^-e^+\nu_e$ — *PRD106, 112010 (2022)*
- ✓ Search for $\Lambda_c^+ \to \Lambda\pi^+\pi^-e^+\nu_e$ and $pK_s\pi^-e^+\nu_e$ — *PLB843, 137993 (2023)*
- ✓ $\Lambda_c^+ \to ne^+\nu_e$ — ***Nature Commun. 16, 681 (2025)***

Neutron-involved decay

- ✓ $\Lambda_c^+ \to n\pi^+$ — ***PRL 128, 142001 (2022)***
- ✓ $\Lambda_c^+ \to n\pi^+\pi^0, n\pi^+\pi^+\pi^-, \ nK^-\pi^+\pi^+$ — *CPC 47, 023001 (2023) (Cover Story)*
- ✓ $\Lambda_c^+ \to nK_sK^+$ — *PRD 109, 072010 (2024)*
- ✓ $\Lambda_c^+ \to \Sigma^-K^+\pi^+$ — *PRD 109, L071103 (2024)*
- ✓ $\Lambda_c^+ \to nK_s\pi^+\pi^0$ — *PRD 109, 053005 (2024)*

Hadronic CS decays

- ✓ $\Lambda_c^+ \to p\pi^0, p\eta, p\omega$ — *JHEP11, 137 (2023); PRD09, L091101 (2024); PRD111, L051101 (2025)*
- ✓ $\Lambda_c^+ \to \ p\eta'$ — *PRD106, 072002 (2022)*
- ✓ $\Lambda_c^+ \to \Lambda K^+, \Lambda K^+\pi^0, \Lambda K_s\pi^+$ — *PRD106, L111101 (2022); PRD109, 032003 (2024); PRD111, 012014 (2025)*
- ✓ $\Lambda_c^+ \to \Sigma^+K_s, \Sigma^0K^+(\pi^0, \pi^+\pi^-), \Sigma^+K^+\pi^-$ — *PRD106, 052003 (2022); JHEP09, 125 (2023);arXiv:2502.11047*
- ✓ ***Hadronic CF decays***
- ✓ PWA of $\Lambda_c^+ \to \Lambda\pi^+\pi^0$ and $\Lambda\pi^+\eta$ — *JHEP 12, 033(2022);* ***PRL134, 021901 (2025)***
- ✓ W-exchange-only process Ξ^0K^+ — ***PRL132, 031801 (2024)***
- ✓ $\Lambda_c^+ \to \Xi^0K^+\pi^0$ — *PRD109, 052001 (2024)*
- ✓ $\Lambda_c^+ \to pK_L, \ pK_L\pi^0, pK_L\pi^+\pi^-$ — *JHEP09, 007 (2024)*

Inclusive decay

- ✓ Improved BF of $\Lambda_c^+ \to e^+X$ — *PRD107, 052005 (2023)*
- ✓ First BF of $\bar{\Lambda}_c^- \to \bar{n}X$ — *PRD108, L031101 (2023)*
- ✓ First BF of $\bar{\Lambda}_c^- \to K_S^0X$ — *arXiv:2502.20821*

Rare decay

- ✓ $\Lambda_c^+ \to \gamma\Sigma^+$ — *PRD107, 052002 (2023)*

Production and excited Λ_c^+

- ✓ $\Lambda_c^+\bar{\Lambda}_c^-$ *lineshape and form factor* — ***PRL107, 052002 (2023)***
- ✓ $\Lambda_c\,(2595)^+$ *and* $\Lambda_c\,(2625)^+$ — *PRD109, L071104 (2024); PRD109, 112007 (2024); arXiv:2503.21413*

>33 papers are published

Recent studies on the Λ_c^+ measurments at BESIII

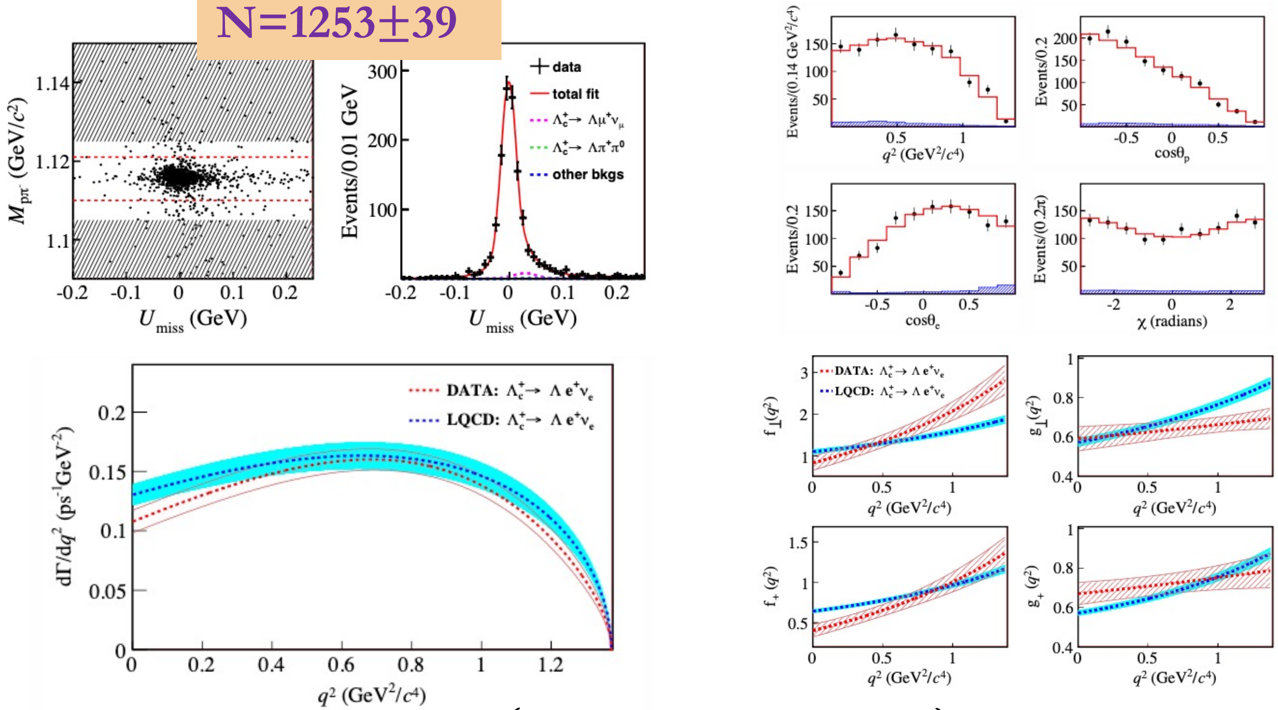
- Λ_c^+ leptonic decays
  - $\Lambda_c^+ \to \Lambda e^+\nu_e, \Lambda\mu^+\nu_\mu$ ✓ : PRL 129.231803 (2022). PRD 108.L031105 (2023).
  - $\Lambda_c^+ \to pK^-e^+\nu_e$: PRD 106.112010 (2022).
  - $\Lambda_c^+ \to Xe^+\nu_e$: PRD 107.052005 (2023).
  - $\Lambda_c^+ \to ne^+\nu_e$: Nature Commun. 16, 681 (2025).

- Λ_c^+ hadronic decays(two body)
  - $\Lambda_c^+ \to n\pi^+$ ✓ : PRL 128.142001 (2022).
  - $\Lambda_c^+ \to p\eta'$: PRD 106.072002 (2022).
  - $\Lambda_c^+ \to p\eta, p\omega$: JHEP 11.137 (2023).
  - $\Lambda_c^+ \to \Xi^0K^+$ ✓ : PRL 132, 031801(2024).
  - $\Lambda_c^+ \to \Sigma^+\eta'$: arXiv 2505.18004 (JHEP accepted).
  - $\Lambda_c^+ \to p\pi^0$: PRD 111, L051101 (2025).
  - $\Lambda_c^+ \to pK_S^0, \Lambda\pi^+, \Sigma^0\pi^+, \Sigma^+\pi^0$ ✓ : arXiv 2508.11400.
- Λ_c^+ hadronic decays(multi-body)
  - $\bar{\Lambda}_c^- \to \bar{n}X$: PRD 108.L031101 (2023).
  - $\Lambda_c^+ \to K_S^0X$: JHEP 06.194 (2025).
  - $\Lambda_c^+ \to nK_S^0\pi^+\pi^0$: PRD 109, 053005 (2024).
  - $\Lambda_c^+ \to \Lambda\pi^+\eta$ ✓ : PRL 134, 021901 (2025).
  - $\Lambda_c^+ \to \Sigma^0K^+\pi^0, \Sigma^0K^+\pi^+\pi^-$: CPC 49, 073001 (2025).
  - $\Lambda_c^+ \to \Lambda K_S^0K^+, \Lambda K^*\ \Lambda K_S^0\pi^+$: PRD 111, 012014 (2025).

Form factors of $\Lambda_c^+ \to \Lambda e^+ \nu_e$

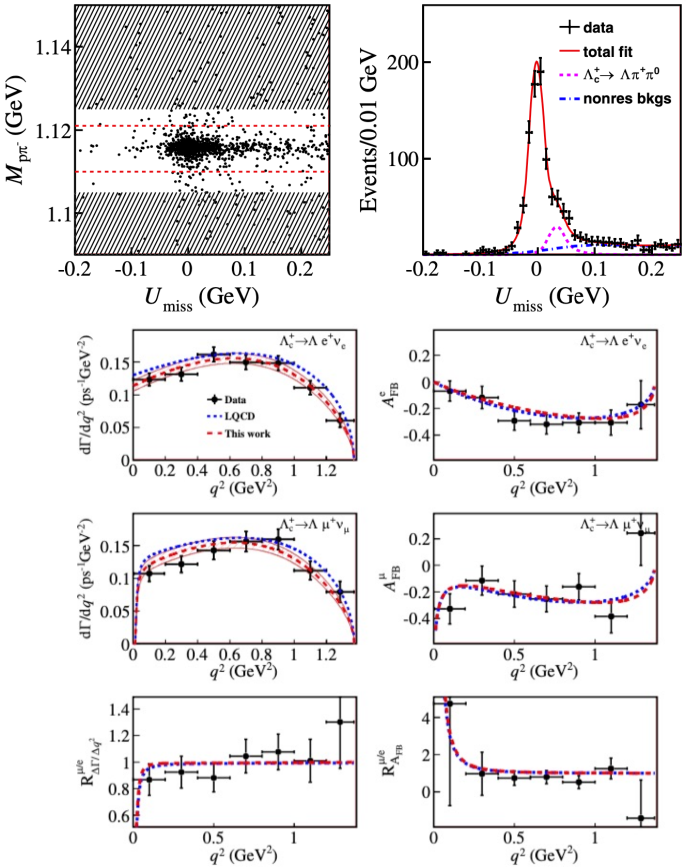
PRL 129,231803(2022)

N=1253±39



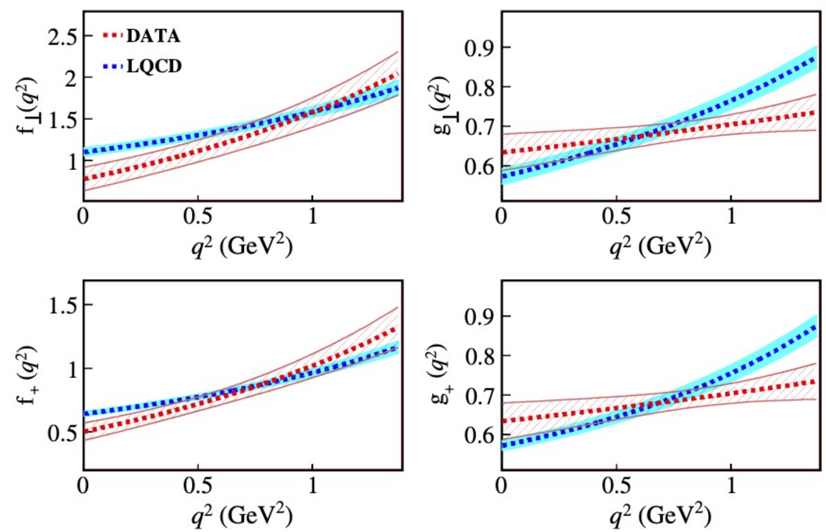
- BF is updated to be $\mathcal{B}(\Lambda_c^+ \to \Lambda e^+ \nu_e) = (3.56 \pm 0.11_{stat} \pm 0.07_{syst})\%$=>precision improved.
- Helicity amplitude deduced form factors can be extracted with 4D fitting to data.
- The differential decay rate is roughly consistent with LQCD calculation while discrepancies can be noticed on FFs show different kinematic behaviors.
- |Vcs| element from charmed baryons is measured to be $0.936 \pm 0.017_{\mathcal{B}} \pm 0.024_{\mathrm{LQCD}} \pm 0.007_{\tau_{\Lambda c}}$ which is consistent with the value obtained in charmed mesons decay.

Form factors of $\Lambda_c^+ \to \Lambda\mu^+\nu_\mu$



PRD 108.L031105 (2023)

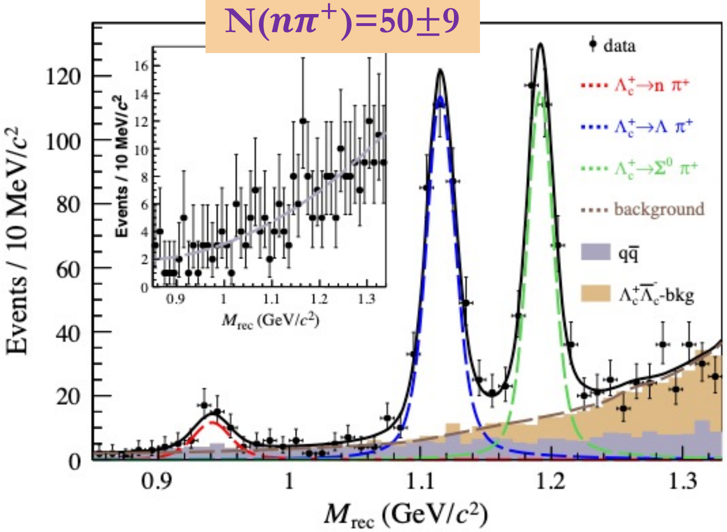
$$\frac{d^4\Gamma}{dq^2 d\cos\theta'_\ell d\cos\theta_p d\chi} = \frac{G_F^2|V_{cs}|^2}{2(2\pi)^4}\cdot\frac{Pq^2(1-m_\ell^2/q^2)^2}{24M_{\Lambda_c}^2}\Big\{\frac{3}{8}(1-\cos\theta'_\ell)^2|H_{\frac{1}{2}1}|^2(1+\alpha_\Lambda\cos\theta_p)$$
$$+\frac{3}{8}(1+\cos\theta'_\ell)^2|H_{-\frac{1}{2}-1}|^2(1-\alpha_\Lambda\cos\theta_p)$$
$$+\frac{3}{4}\sin^2\theta'_\ell[|H_{\frac{1}{2}0}|^2(1+\alpha_\Lambda\cos\theta_p)+|H_{-\frac{1}{2}0}|^2(1-\alpha_\Lambda\cos\theta_p)]+\frac{3}{2\sqrt{2}}\alpha_\Lambda\cos\chi\sin\theta'_\ell\sin\theta_p$$
$$\times[(1-\cos\theta'_\ell)H_{-\frac{1}{2}0}H_{\frac{1}{2}1}+(1+\cos\theta'_\ell)H_{\frac{1}{2}0}H_{-\frac{1}{2}-1}]+\mathcal{H}_{m_\ell^2}\Big\},$$



- BF is updated to be $\mathcal{B}(\Lambda_c^+ \to \Lambda\mu^+\nu_\mu)= (3.48 \pm 0.14_{stat} \pm 0.10_{syst})\%$=>3times more precise than prior results.
- Lepton flavor universality are reported $(0.98 \pm 0.05_{stat} \pm 0.03_{syst})$ =>compatible with Standard Model(0,97).
- Form-factors parameters for$\Lambda_c^+ \to \Lambda l^+\nu_l$ are determined to test and calibrate for LQCD.

First observation of $\Lambda_c^+ \to n\pi^+$

PRL 128.142001 (2022).



- First singly Cabibbo-suppressed Λ_c^+ decay involved neutron was observed(7.3σ).
- Absolute BF is measured to be $\mathcal{B}(\Lambda_c^+ \to n\pi^+) = (6.6 \pm 1.2_{stat} \pm 0.4_{syst}) \times 10^{-4}$.
  =>Consistent with SU(3) flavor asymmetry prediction[PLB790,225(2019),]
  =>twice larger than the dynamical calculation based on pole model and CA[PRD97,074028(2018)]
- $\mathcal{B}(\Lambda_c^+ \to \Lambda\pi^+) = (1.31 \pm 0.08_{stat} \pm 0.05_{syst}) \times 10^{-2}$=>Consistent with previous BESIII results
- $\mathcal{B}(\Lambda_c^+ \to \Sigma^0\pi^+) = (1.22 \pm 0.08_{stat} \pm 0.07_{syst}) \times 10^{-2}$ =>Consistent with previous BESIII results
- $R = \frac{\mathcal{B}(\Lambda_c^+ \to n\pi^+)}{\mathcal{B}(\Lambda_c^+ \to p\pi^0)} > 7.2$@90%$C.L.$ ($\mathcal{B}(\Lambda_c^+ \to p\pi^0) < 8.0 \times 10^{-5}$ @90%$C.L.$from Belle)
  =>Disagrees with SU(3) flavor asymmetry and dynamical calculation (2-4.7) while in consistent with SU(3) plus topological-diagram approach(9.6).

Decay asymmetry for pure W-exchange process $\Lambda_c^+ \to \Xi^0 K^+$

PRL 132, 031801(2024)

Theory or experiment	$\mathcal{B}(\Lambda_c^+ \to \Xi^0 K^+)$ $(\times 10^{-3})$	$\alpha_{\Xi^0 K^+}$	$\lvert A \rvert$ $(\times 10^{-2} G_F \text{ GeV}^2)$	$\lvert B \rvert$ $(\times 10^{-2} G_F \text{ GeV}^2)$	$\delta_p - \delta_s$ (rad)
Körner (1992), CCQM [7]	2.6	0	-	-	-
Xu (1992), Pole [8]	1.0	0	0	7.94	-
Źencaykowski (1994), Pole [9]	3.6	0	-	-	-
Ivanov (1998), CCQM [10]	3.1	0	-	-	-
Sharma (1999), CA [11]	1.3	0	-	-	-
Geng (2019), SU(3) [12]	5.7 ± 0.9	$0.94^{+0.06}_{-0.11}$	2.7 ± 0.6	16.1 ± 2.6	-
Zou (2020), CA [5]	7.1	0.90	4.48	12.10	-
Zhong (2022), SU(3)[a] [13]	$3.8^{+0.4}_{-0.5}$	$0.91^{+0.03}_{-0.04}$	3.2 ± 0.2	$8.7^{+0.6}_{-0.8}$	-
Zhong (2022), SU(3)[b] [13]	$5.0^{+0.6}_{-0.9}$	0.99 ± 0.01	$3.3^{+0.5}_{-0.7}$	$12.3^{+1.2}_{-1.8}$	-
BESIII (2018) [14]	$5.90 \pm 0.86 \pm 0.39$	-	-	-	-
PDG Fit (2022) [3]	5.5 ± 0.7	-	-	-	-

- $\Lambda_c^+ \to \Xi^0 K^+$ is pure W-exchange process which have significant contributions in charmed baryon decay.
- Nonfactorizable W-exchange diagram cannot be calculated using theoretical approaches.
-
- Long-standing puzzle on how large the S-wave amplitude.
- Experimental measurement of decay asymmetry is crucial and urgent.

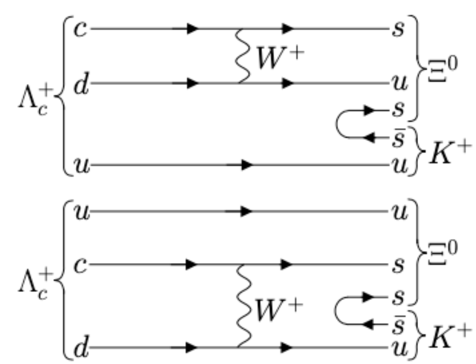


FIG. 1. Feynman diagrams for $\Lambda_c^+ \to \Xi^0 K^+$

Decay asymmetry for pure W-exchange process $\Lambda_c^+ \to \Xi^0 K^+$

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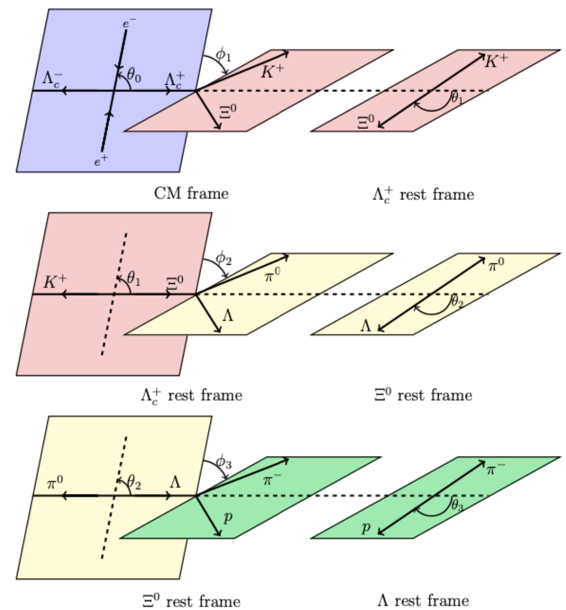
$$\alpha_{BP} = \frac{2\mathrm{Re}(s^*p)}{|s|^2+|p|^2}, \quad \beta_{BP} = \frac{2\mathrm{Im}(s^*p)}{|s|^2+|p|^2}, \quad \gamma_{BP} = \frac{|s|^2-|p|^2}{|s|^2+|p|^2},$$

Level	Decay	Helicity angle	Helicity amplitude
0	$e^+e^- \to \Lambda_c^+(\lambda_1)\,\bar{\Lambda}_c^-(\lambda_2)$	(θ_0)	A_{λ_1,λ_2}
1	$\Lambda_c^+ \to \Xi^0(\lambda_3)\,K^+$	(θ_1,ϕ_1)	B_{λ_3}
2	$\Xi^0 \to \Lambda(\lambda_4)\,\pi^0$	(θ_2,ϕ_2)	C_{λ_4}
3	$\Lambda \to p(\lambda_5)\,\pi^-$	(θ_3,ϕ_3)	D_{λ_5}

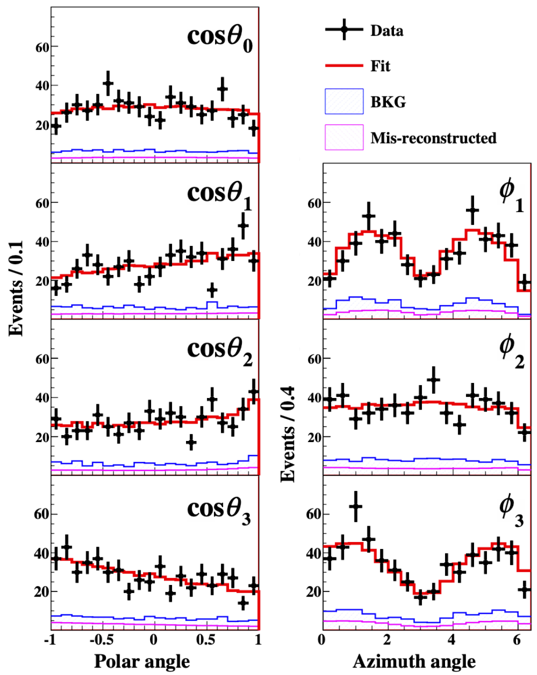
$$\begin{aligned}
&\frac{d\Gamma}{d\cos\theta_0\ d\cos\theta_1\ d\cos\theta_2\ d\cos\theta_3\ d\phi_1\ d\phi_2\ d\phi_3} \\
&\propto 1+\alpha_0\cos^2\theta_0 \\
&+(1+\alpha_0\cos^2\theta_0)\ \alpha_{\Xi^0K^+}\alpha_{\Lambda\pi^0}\cos\theta_2 \\
&+(1+\alpha_0\cos^2\theta_0)\ \alpha_{\Xi^0K^+}\alpha_{p\pi^-}\cos\theta_2\cos\theta_3 \\
&+(1+\alpha_0\cos^2\theta_0)\ \alpha_{\Lambda\pi^0}\alpha_{p\pi^-}\cos\theta_3 \\
&-(1+\alpha_0\cos^2\theta_0)\ \alpha_{\Xi^0K^+}\sqrt{1-\alpha^2_{\Lambda\pi^0}}\ \alpha_{p\pi^-}\sin\theta_2\sin\theta_3\cos(\Delta_{\Lambda\pi^0}+\phi_3) \\
&+\sqrt{1-\alpha_0^2}\ \sin\Delta_0\sin\theta_0\cos\theta_0\alpha_{\Xi^0K^+}\sin\theta_1\sin\phi_1 \\
&+\sqrt{1-\alpha_0^2}\ \sin\Delta_0\sin\theta_0\cos\theta_0\alpha_{\Lambda\pi^0}\sin\theta_1\sin\phi_1\cos\theta_2 \\
&+\sqrt{1-\alpha_0^2}\ \sin\Delta_0\sin\theta_0\cos\theta_0\alpha_{\Xi^0K^+}\alpha_{\Lambda\pi^0}\alpha_{p\pi^-}\sin\theta_1\sin\phi_1\cos\theta_3 \\
&+\sqrt{1-\alpha_0^2}\ \sin\Delta_0\sin\theta_0\cos\theta_0\alpha_{p\pi^-}\sin\theta_1\sin\phi_1\cos\theta_2\cos\theta_3 \\
&-\sqrt{1-\alpha_0^2}\ \sin\Delta_0\sin\theta_0\cos\theta_0\sqrt{1-\alpha^2_{\Lambda\pi^0}}\ \alpha_{p\pi^-}\sin\theta_1\sin\phi_1\sin\theta_2\sin\theta_3\cos(\Delta_{\Lambda\pi^0}+\phi_3) \\
&+\sqrt{1-\alpha_0^2}\ \sin\Delta_0\sin\theta_0\cos\theta_0\sqrt{1-\alpha^2_{\Xi^0K^+}}\ \alpha_{\Lambda\pi^0}\cos\phi_1\sin\theta_2\sin(\Delta_{\Xi^0K^+}+\phi_2) \\
&+\sqrt{1-\alpha_0^2}\ \sin\Delta_0\sin\theta_0\cos\theta_0\sqrt{1-\alpha^2_{\Xi^0K^+}}\ \alpha_{\Lambda\pi^0}\cos\theta_1\sin\phi_1\sin\theta_2\cos(\Delta_{\Xi^0K^+}+\phi_2) \\
&+\sqrt{1-\alpha_0^2}\ \sin\Delta_0\sin\theta_0\cos\theta_0\sqrt{1-\alpha^2_{\Xi^0K^+}}\ \alpha_{p\pi^-}\cos\theta_1\sin\phi_1\sin\theta_2\cos(\Delta_{\Xi^0K^+}+\phi_2)\cos\theta_3 \\
&+\sqrt{1-\alpha_0^2}\ \sin\Delta_0\sin\theta_0\cos\theta_0\sqrt{1-\alpha^2_{\Xi^0K^+}}\ \alpha_{p\pi^-}\cos\phi_1\sin\theta_2\sin(\Delta_{\Xi^0K^+}+\phi_2)\cos\theta_3 \\
&-\sqrt{1-\alpha_0^2}\ \sin\Delta_0\sin\theta_0\cos\theta_0\sqrt{1-\alpha^2_{\Xi^0K^+}}\sqrt{1-\alpha^2_{\Lambda\pi^0}}\ \alpha_{p\pi^-}\cos\theta_1\sin\phi_1\sin(\Delta_{\Xi^0K^+}+\phi_2)\sin\theta_3\sin(\Delta_{\Lambda\pi^0}+\phi_3) \\
&+\sqrt{1-\alpha_0^2}\ \sin\Delta_0\sin\theta_0\cos\theta_0\sqrt{1-\alpha^2_{\Xi^0K^+}}\ \sqrt{1-\alpha^2_{\Lambda\pi^0}}\ \alpha_{p\pi^-}\cos\theta_1\sin\phi_1\cos\theta_2\cos(\Delta_{\Xi^0K^+}+\phi_2)\sin\theta_3\cos(\Delta_{\Lambda\pi^0}+\phi_3) \\
&+\sqrt{1-\alpha_0^2}\ \sin\Delta_0\sin\theta_0\cos\theta_0\sqrt{1-\alpha^2_{\Xi^0K^+}}\sqrt{1-\alpha^2_{\Lambda\pi^0}}\ \alpha_{p\pi^-}\cos\phi_1\cos(\Delta_{\Xi^0K^+}+\phi_2)\sin\theta_3\sin(\Delta_{\Lambda\pi^0}+\phi_3) \\
&+\sqrt{1-\alpha_0^2}\ \sin\Delta_0\sin\theta_0\cos\theta_0\sqrt{1-\alpha^2_{\Xi^0K^+}}\sqrt{1-\alpha^2_{\Lambda\pi^0}}\ \alpha_{p\pi^-}\cos\phi_1\cos\theta_2\sin(\Delta_{\Xi^0K^+}+\phi_2)\sin\theta_3\cos(\Delta_{\Lambda\pi^0}+\phi_3)
\end{aligned}$$



- The joint angular distribution for $\Lambda_c^+ \to \Xi^0 K^+$ is derived based on helicity amplitude.

Decay asymmetry for pure W-exchange process $\Lambda_c^+ \to \Xi^0 K^+$

PRL 132, 031801(2024)

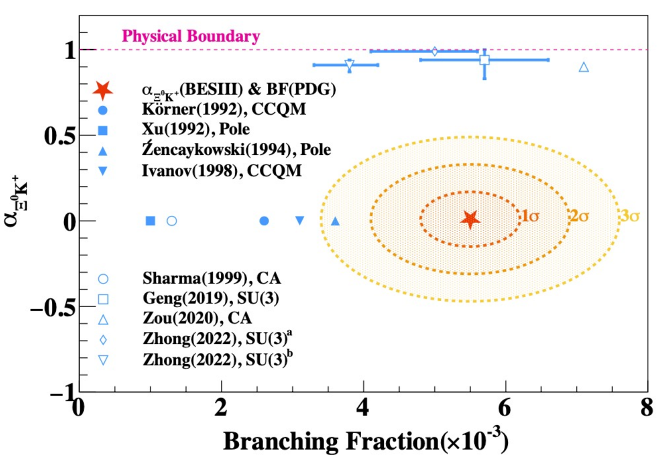


- From the fit, we obtain $\alpha_{\Xi^0 K^+} = 0.01 \pm 0.16_{stat} \pm 0.03_{syst}$ and $\beta_{\Xi^0 K^+} = -0.64 \pm 0.69_{stat} \pm 0.13_{syst}$ and $\gamma_{\Xi^0 K^+} = -0.77 \pm 0.58_{stat} \pm 0.11_{syst}$
- $\alpha_{\Xi^0 K^+}$ is in good agreement with zero=>strong identification for theoretical predictions.

$$\Gamma = \frac{\mathcal{B}(\Lambda_c^+ \to \Xi^0 K^+)}{\tau_{\Lambda_c^+}} = \frac{|\vec{p}_c|}{8\pi}\left[\frac{(m_{\Lambda_c^+} + m_{\Xi^0})^2 - m_{K^+}^2}{m_{\Lambda_c^+}^2}|A|^2 + \frac{(m_{\Lambda_c^+} - m_{\Xi^0})^2 - m_{K^+}^2}{m_{\Lambda_c^+}^2}|B|^2\right]$$

$$\alpha_{\Xi^0 K^+} = \frac{2\kappa|A||B|\cos(\delta_p - \delta_s)}{|A|^2 + \kappa^2|B|^2},$$

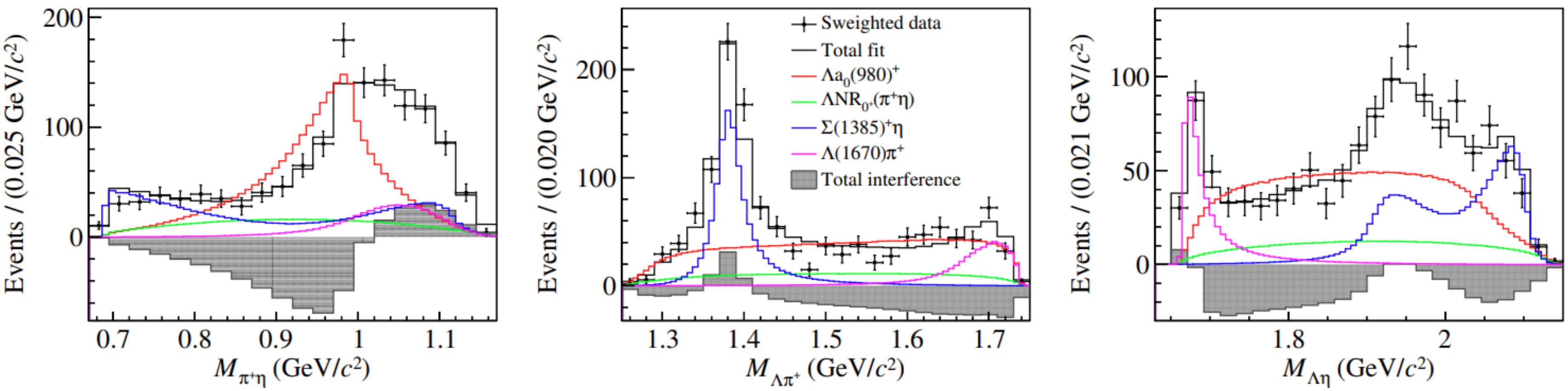
$$\Delta_{\Xi^0 K^+} = \arctan\frac{2\kappa|A||B|\sin(\delta_p - \delta_s)}{|A|^2 - \kappa^2|B|^2},$$



- Especially, $\cos(\delta_p - \delta_s)$ is measured to close to zero.=>not considered in previous literature.
- Fills the long-standing puzzle on how to model $\alpha_{\Xi^0 K^+}$ and $\mathcal{B}(\Lambda_c^+ \to \Xi^0 K^+)$ simultaneously.

Observation of $\Lambda_c^+ \to \Lambda a_0(980)^+$

PRL 134, 021901 (2025)



$$\alpha_{\Lambda a_0(980)^+} = \frac{\left|H^{\Lambda_c^+\to\Lambda a_0(980)^+}_{\frac{1}{2},0}\right|^2 - \left|H^{\Lambda_c^+\to\Lambda a_0(980)^+}_{-\frac{1}{2},0}\right|^2}{\left|H^{\Lambda_c^+\to\Lambda a_0(980)^+}_{\frac{1}{2},0}\right|^2 + \left|H^{\Lambda_c^+\to\Lambda a_0(980)^+}_{-\frac{1}{2},0}\right|^2} = \frac{2\,\mathrm{Re}\left(g^{\Lambda_c^+\to\Lambda a_0(980)^+}_{0,\frac{1}{2}}\, g^{\Lambda_c^+\to\Lambda a_0(980)^+ *}_{1,\frac{1}{2}}\right)}{\left|g^{\Lambda_c^+\to\Lambda a_0(980)^+}_{0,\frac{1}{2}}\right|^2 + \left|g^{\Lambda_c^+\to\Lambda a_0(980)^+}_{1,\frac{1}{2}}\right|^2},$$

$$\alpha_{\Sigma(1385)^+\eta} = \frac{\left|H^{\Lambda_c^+\to\Sigma(1385)^+\eta}_{\frac{1}{2},0}\right|^2 - \left|H^{\Lambda_c^+\to\Sigma(1385)^+\eta}_{-\frac{1}{2},0}\right|^2}{\left|H^{\Lambda_c^+\to\Sigma(1385)^+\eta}_{\frac{1}{2},0}\right|^2 + \left|H^{\Lambda_c^+\to\Sigma(1385)^+\eta}_{-\frac{1}{2},0}\right|^2} = \frac{2\,\mathrm{Re}\left(g^{\Lambda_c^+\to\Sigma(1385)^+\eta}_{1,\frac{3}{2}}\, g^{\Lambda_c^+\to\Lambda a_0(980)^+ *}_{2,\frac{3}{2}}\right)}{\left|g^{\Lambda_c^+\to\Lambda a_0(980)^+}_{1,\frac{3}{2}}\right|^2 + \left|g^{\Lambda_c^+\to\Lambda a_0(980)^+}_{2,\frac{3}{2}}\right|^2},$$

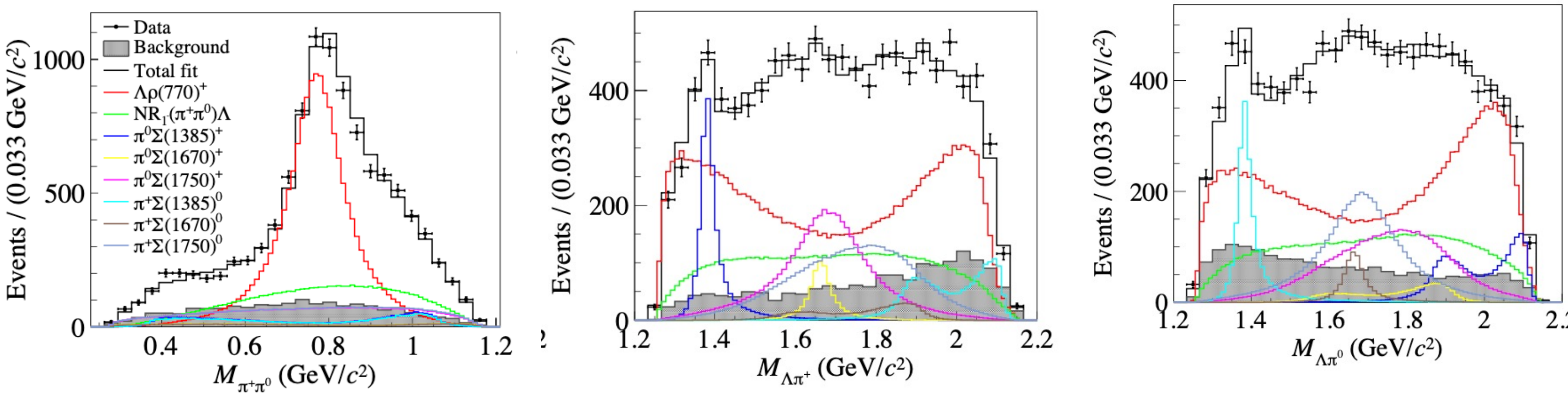
$$\alpha_{\Lambda(1670)\pi^+} = \frac{\left|H^{\Lambda_c^+\to\Lambda(1670)\pi^+}_{\frac{1}{2},0}\right|^2 - \left|H^{\Lambda_c^+\to\Lambda(1670)\pi^+}_{-\frac{1}{2},0}\right|^2}{\left|H^{\Lambda_c^+\to\Lambda(1670)\pi^+}_{\frac{1}{2},0}\right|^2 + \left|H^{\Lambda_c^+\to\Lambda(1670)\pi^+}_{-\frac{1}{2},0}\right|^2} = \frac{2\,\mathrm{Re}\left(g^{\Lambda_c^+\to\Lambda(1670)\pi^+}_{0,\frac{1}{2}}\, g^{\Lambda_c^+\to\Lambda(1670)\pi^+ *}_{1,\frac{1}{2}}\right)}{\left|g^{\Lambda_c^+\to\Lambda(1670)\pi^+}_{0,\frac{1}{2}}\right|^2 + \left|g^{\Lambda_c^+\to\Lambda(1670)\pi^+}_{1,\frac{1}{2}}\right|^2}.$$

Process	FF (%)	$\mathcal{S}$	α
$\Lambda a_0(980)^+$	$54.0 \pm 8.4 \pm 2.6$	13.1σ	$-0.91^{+0.18}_{-0.09} \pm 0.08$
$\Sigma(1385)^+\eta$	$30.4 \pm 2.6 \pm 0.7$	22.5σ	$-0.61 \pm 0.15 \pm 0.04$
$\Lambda(1670)\pi^+$	$14.1 \pm 2.8 \pm 1.2$	11.7σ	$0.21 \pm 0.27 \pm 0.33$
$\Lambda\mathrm{NR}_{0^+}$	15.4 ± 5.3	6.7σ	$\cdots$

- Partial wave analysis can also extract the decay asymmetry.
- More efficient!

PWA for $\Lambda_c^+ \to \Lambda\pi^+\pi^0$

JHEP12.033 (2022)

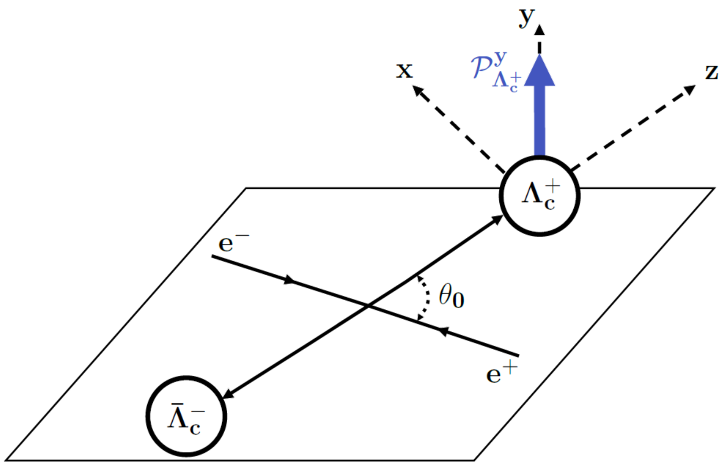


Process	Magnitude	Phase ϕ (rad)	FF (%)	Significance
$\Lambda\rho(770)^+$	1.0 (fixed)	0.0 (fixed)	57.2 ± 4.2	$36.9\,\sigma$
$\Sigma(1385)^+\pi^0$	0.43 ± 0.06	-0.23 ± 0.18	7.18 ± 0.60	$14.8\,\sigma$
$\Sigma(1385)^0\pi^+$	0.37 ± 0.07	2.84 ± 0.23	7.92 ± 0.72	$16.0\,\sigma$
$\Sigma(1670)^+\pi^0$	0.31 ± 0.08	-0.77 ± 0.23	2.90 ± 0.63	$5.1\,\sigma$
$\Sigma(1670)^0\pi^+$	0.41 ± 0.07	2.77 ± 0.20	2.65 ± 0.58	$5.2\,\sigma$
$\Sigma(1750)^+\pi^0$	1.75 ± 0.21	-1.73 ± 0.11	16.6 ± 2.2	$10.1\,\sigma$
$\Sigma(1750)^0\pi^+$	1.83 ± 0.21	1.34 ± 0.11	17.5 ± 2.3	$10.2\,\sigma$
$\Lambda + NR_{1^-}$	4.05 ± 0.47	2.16 ± 0.13	29.7 ± 4.5	$10.5\,\sigma$

- About 10K events survived which purity is larger than 80%.
- PWA based on helicity amplitude is performed.
- Interference mostly exist between $\Lambda\rho(770)$ and $\Sigma(1385)^{0/+}\pi^{+/0}$.

Production and Decay Dynamics of the Λ_c^+

arXiv 2508.11400

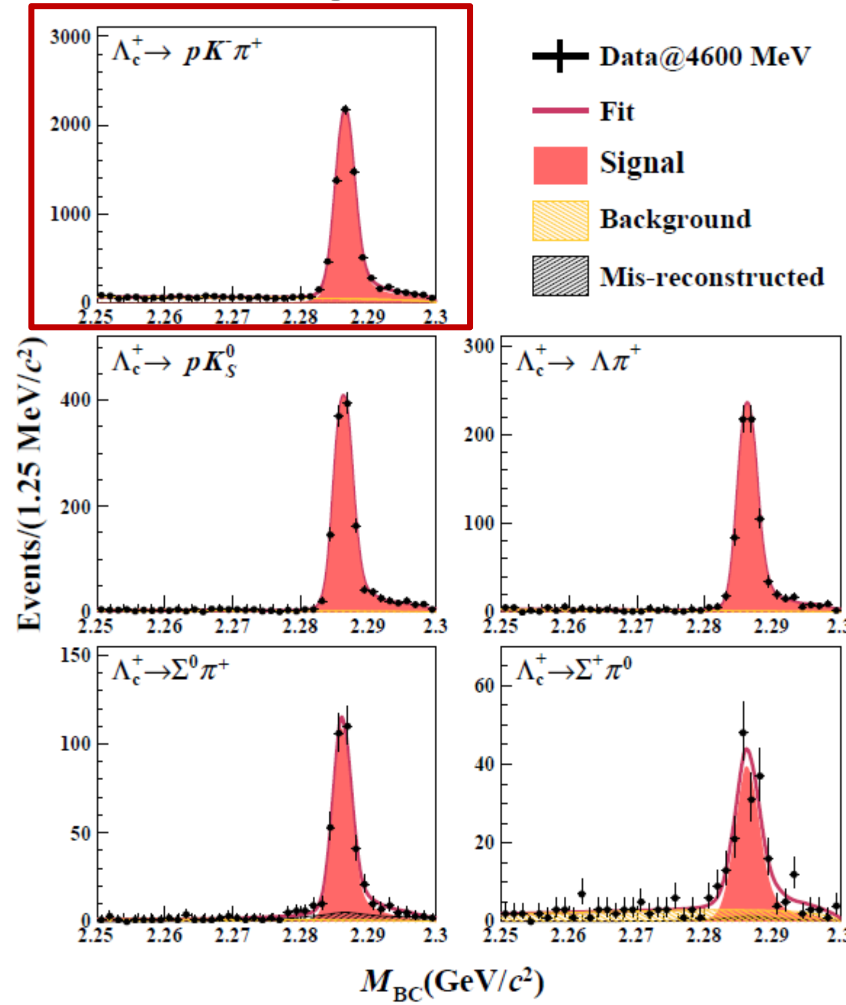


$$\mathcal{P}^y_{\Lambda_c^+}(\cos\theta_0) = \frac{3}{2(3+\alpha_0)}\sqrt{1-\alpha_0^2}\sin\theta_0\cos\theta_0\sin\Delta\Phi$$

- Measured transverse polarization using 587 fb^{-1} in 2018 but not found.

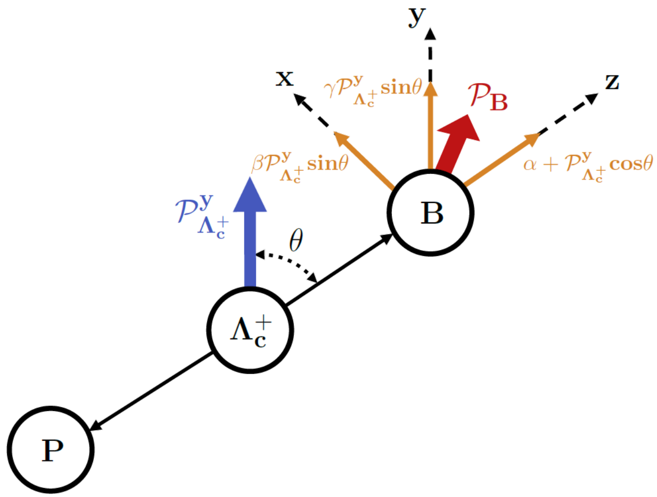
- Using 6.4 fb^{-1} collected from 4.6-4.95 GeV, observe transverse polarization in multiple energy points.

- Enhance $\mathcal{P}^y_{\Lambda_c^+}$ precision



Production and Decay Dynamics of the Λ_c^+

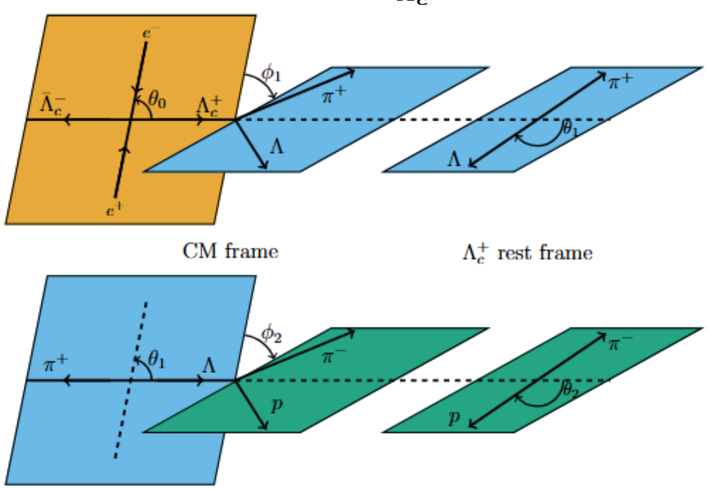
arXiv 2508.11400



$$\left[\begin{array}{c} \alpha = \dfrac{2\mathrm{Re}(s^*p)}{|s|^2+|p|^2} \quad \beta = \dfrac{2\mathrm{Im}(s^*p)}{|s|^2+|p|^2} \quad \gamma = \dfrac{|s|^2-|p|^2}{|s|^2+|p|^2} \\ \alpha^2+\beta^2+\gamma^2=1 \end{array}\right]$$

If parity violation exists: $\boldsymbol{\alpha},\ \boldsymbol{\beta} \neq \mathbf{0},\ \boldsymbol{\gamma} \neq -\mathbf{1}$

$$\boldsymbol{\mathcal{P}}_B = \frac{(\alpha + \boxed{\boldsymbol{\mathcal{P}}^{y}_{\Lambda_c^+}} \cdot \hat{\boldsymbol{n}})\hat{\boldsymbol{n}} + \beta(\boldsymbol{\mathcal{P}}^{y}_{\Lambda_c^+} \times \hat{\boldsymbol{n}}) + \gamma\hat{\boldsymbol{n}} \times (\boldsymbol{\mathcal{P}}^{y}_{\Lambda_c^+} \times \hat{\boldsymbol{n}})}{1 + \alpha\boldsymbol{\mathcal{P}}^{y}_{\Lambda_c^+} \cdot \hat{\boldsymbol{n}}}$$



CM frame $\quad$ Λ_c^+ rest frame

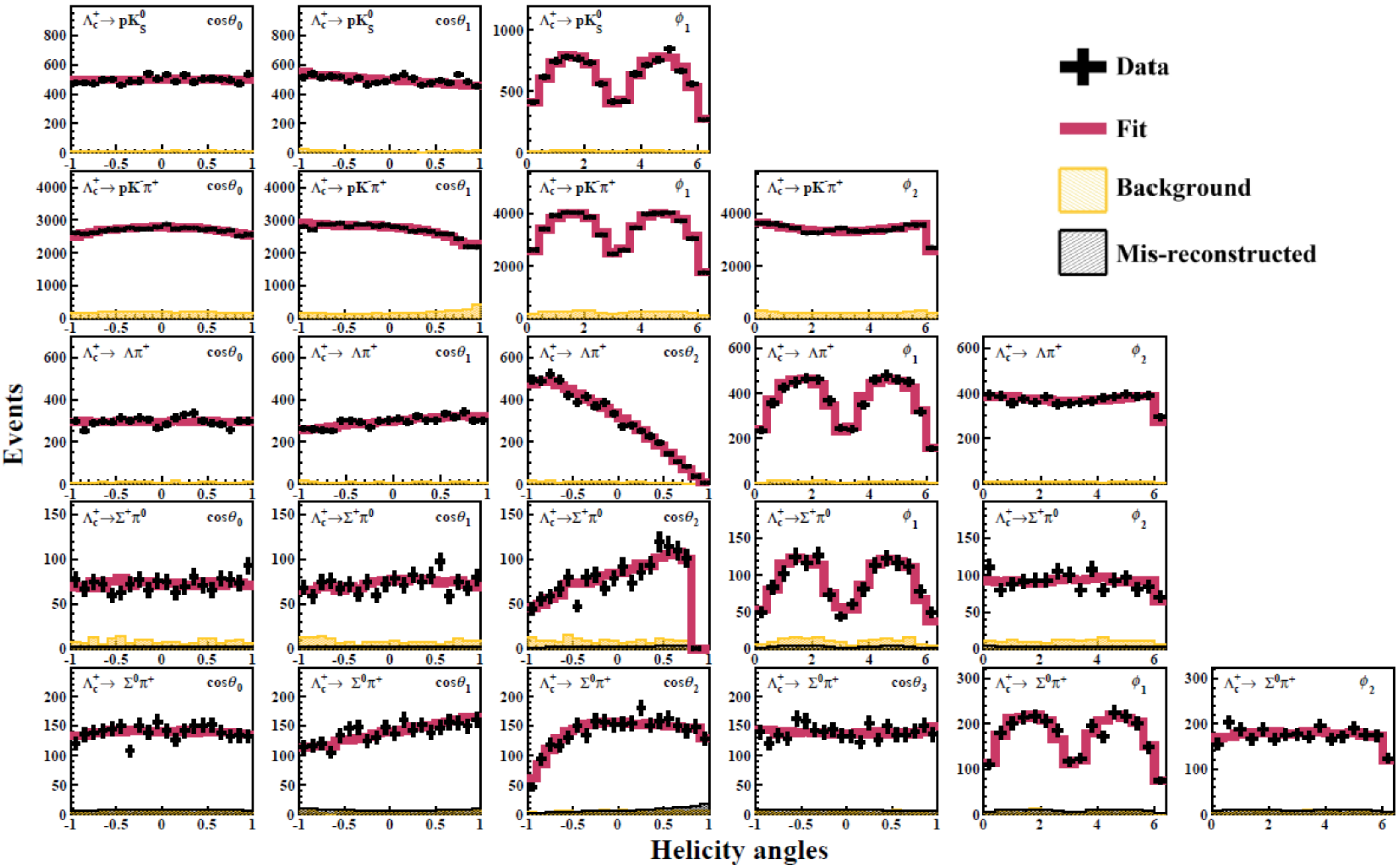
Λ_c^+ rest frame $\quad$ Λ rest frame

$$\begin{aligned}
&\frac{d\Gamma}{d\cos\theta_0\ d\cos\theta_1\ d\cos\theta_2\ d\phi_1\ d\phi_2} \\
&\propto 1 + \alpha_0\cos^2\theta_0 \\
&+ \sqrt{1-\alpha_0^2}\alpha_{p\pi^-}\sin\theta_0\cos\theta_0\sin\Delta\Phi\sin\theta_1\sin\phi_1\cos\theta_2 \\
&+ \sqrt{1-\alpha_0^2}\alpha_{p\pi^-}\sin\theta_0\cos\theta_0\sin\Delta\Phi\cos\theta_1\sin\phi_1\sin\theta_2 \\
&\times\sqrt{1-\alpha_{\Lambda\pi^+}^2}\cos(\Delta_{\Lambda\pi^+}+\phi_2) \\
&+ \sqrt{1-\alpha_0^2}\alpha_{p\pi^-}\sin\theta_0\cos\theta_0\sin\Delta\Phi\cos\phi_1\sin\theta_2 \\
&\times\sqrt{1-\alpha_{\Lambda\pi^+}^2}\sin(\Delta_{\Lambda\pi^+}+\phi_2) \\
&+ \sqrt{1-\alpha_0^2}\alpha_{\Lambda\pi^+}\sin\theta_0\cos\theta_0\sin\Delta\Phi\sin\theta_1\sin\phi_1 \\
&+ \alpha_0\alpha_{p\pi^-}\alpha_{\Lambda\pi^+}\cos^2\theta_0\cos\theta_2 \\
&+ \alpha_{p\pi^-}\alpha_{\Lambda\pi^+}\cos\theta_2,
\end{aligned}$$

Production and Decay Dynamics of the Λ_c^+

arXiv 2508.11400

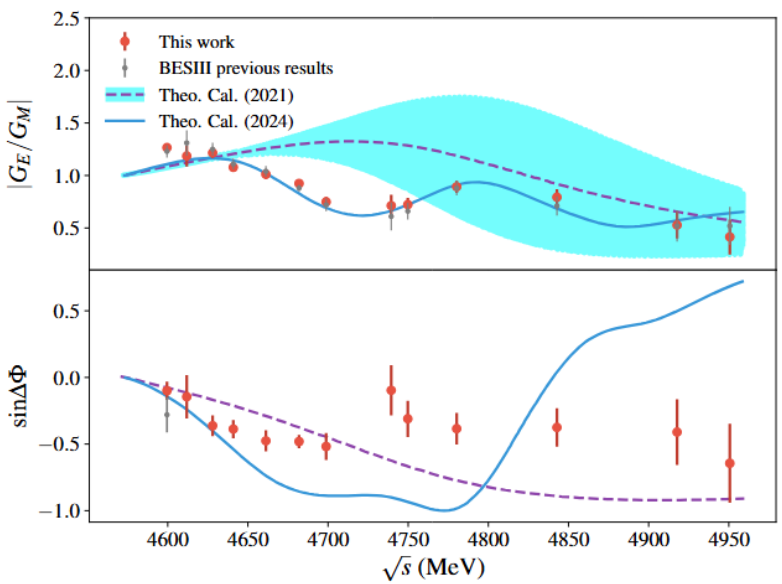
- 13 energy points, 5 channels with 23 angles

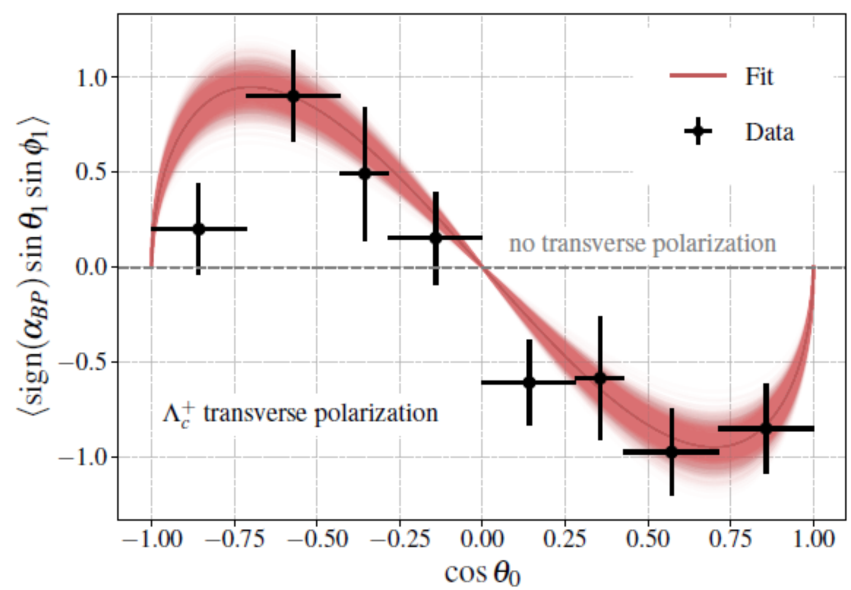


Production and Decay Dynamics of the Λ_c^+

arXiv 2508.11400

$\sqrt{s}$ [MeV]	α_0 in previous work [16, 82]	α_0 in this work	$\Delta\Phi$ [rad]	SL	$\mathcal{P}^{y,max}_{\Lambda_c^+}$
4600	$-0.20 \pm 0.04 \pm 0.02$	$-0.226 \pm 0.030 \pm 0.004$	$-0.100 \pm 0.069 \pm 0.009$	$2.2\ \sigma$	$-0.026 \pm 0.018 \pm 0.002$
4612	$-0.26 \pm 0.09 \pm 0.01$	$-0.160 \pm 0.083 \pm 0.004$	$-0.146 \pm 0.162 \pm 0.030$	$1.1\ \sigma$	$-0.038 \pm 0.042 \pm 0.008$
★ 4628	$-0.21 \pm 0.04 \pm 0.01$	$-0.181 \pm 0.038 \pm 0.001$	$-0.371 \pm 0.082 \pm 0.012$	$6.8\ \sigma$	$-0.095 \pm 0.020 \pm 0.003$
★ 4641	$-0.09 \pm 0.05 \pm 0.01$	$-0.060 \pm 0.039 \pm 0.003$	$-0.398 \pm 0.073 \pm 0.015$	$7.6\ \sigma$	$-0.099 \pm 0.017 \pm 0.004$
★ 4661	$-0.02 \pm 0.05 \pm 0.01$	$0.008 \pm 0.044 \pm 0.003$	$-0.496 \pm 0.088 \pm 0.021$	$8.5\ \sigma$	$-0.119 \pm 0.019 \pm 0.005$
★ 4682	$0.15 \pm 0.03 \pm 0.01$	$0.102 \pm 0.029 \pm 0.003$	$-0.502 \pm 0.054 \pm 0.021$	$14.1\ \sigma$	$-0.116 \pm 0.011 \pm 0.005$
★ 4699	$0.34 \pm 0.07 \pm 0.01$	$0.305 \pm 0.055 \pm 0.010$	$-0.545 \pm 0.114 \pm 0.028$	$7.1\ \sigma$	$-0.112 \pm 0.021 \pm 0.007$
4740	$0.49 \pm 0.16 \pm 0.03$	$0.358 \pm 0.126 \pm 0.008$	$-0.097 \pm 0.190 \pm 0.016$	$0.4\ \sigma$	$-0.020 \pm 0.039 \pm 0.004$
4750	$0.42 \pm 0.10 \pm 0.01$	$0.347 \pm 0.079 \pm 0.004$	$-0.316 \pm 0.142 \pm 0.019$	$3.1\ \sigma$	$-0.065 \pm 0.029 \pm 0.005$
★ 4781	$0.17 \pm 0.07 \pm 0.01$	$0.157 \pm 0.062 \pm 0.007$	$-0.395 \pm 0.126 \pm 0.028$	$5.1\ \sigma$	$-0.090 \pm 0.027 \pm 0.007$
4843	$0.38 \pm 0.10 \pm 0.01$	$0.282 \pm 0.089 \pm 0.019$	$-0.385 \pm 0.153 \pm 0.034$	$3.6\ \sigma$	$-0.082 \pm 0.031 \pm 0.008$
4918	$0.62 \pm 0.17 \pm 0.01$	$0.612 \pm 0.150 \pm 0.019$	$-0.423 \pm 0.272 \pm 0.024$	$1.9\ \sigma$	$-0.067 \pm 0.043 \pm 0.013$
4951	$0.63 \pm 0.21 \pm 0.01$	$0.744 \pm 0.179 \pm 0.007$	$-0.700 \pm 0.392 \pm 0.058$	$1.8\ \sigma$	$-0.086 \pm 0.050 \pm 0.030$





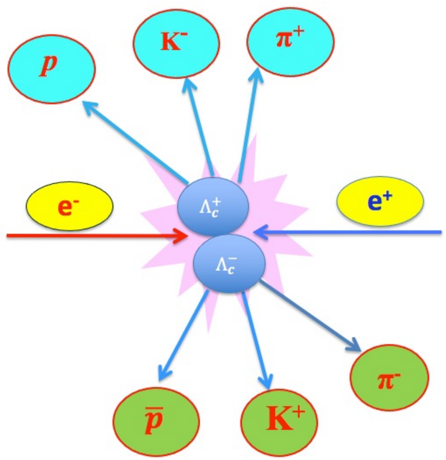
Production measurement near threshold

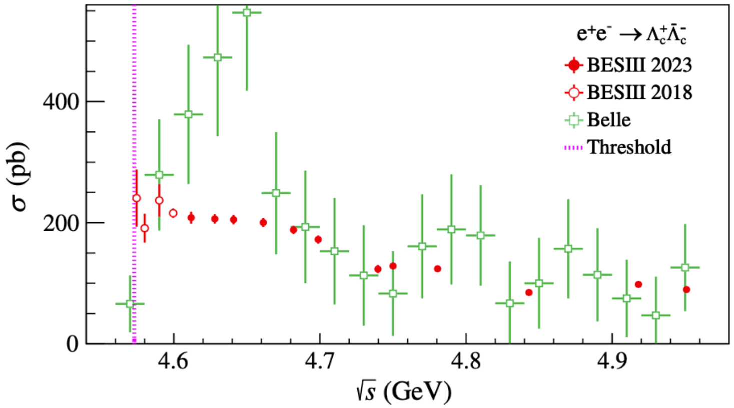
PhysRevLett.131.191901(2023)

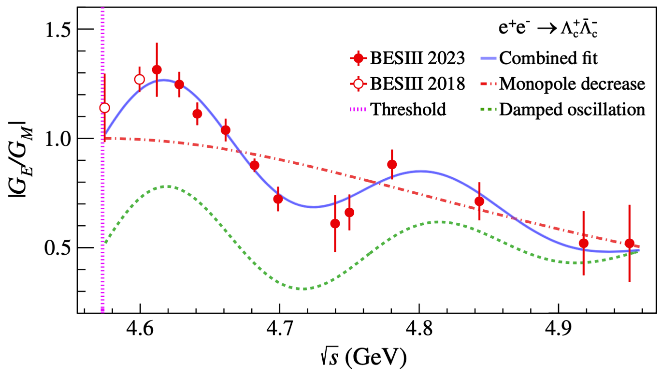
- $e^+e^- \to \Lambda_c^+ \Lambda_c^-$ cross section are measured at twelve energy points from 4.612-4.951GeV .

$$\sigma_{\pm} = \frac{N_{\rm ST}^{\pm}}{\varepsilon_{\rm ST}^{\pm} f_{\rm ISR} f_{\rm VP} \mathcal{L}_{\rm int} N_{\rm DT}} \sum_{n=1}^{9} \left(\frac{N_{\rm ST}^{\mp,n} \varepsilon_{\rm DT}^{n}}{\varepsilon_{\rm ST}^{\mp,n}} \right),$$

- Indicate no enhancement around Y(4630) resonance. =>Conflict with Belle.
- $|G_E/G_M|$ ratio are derived by fitting to angular distribution.
- The oscillations on $|G_E/G_M|$ ratio is significantly observed with higher frequency than that of the proton.

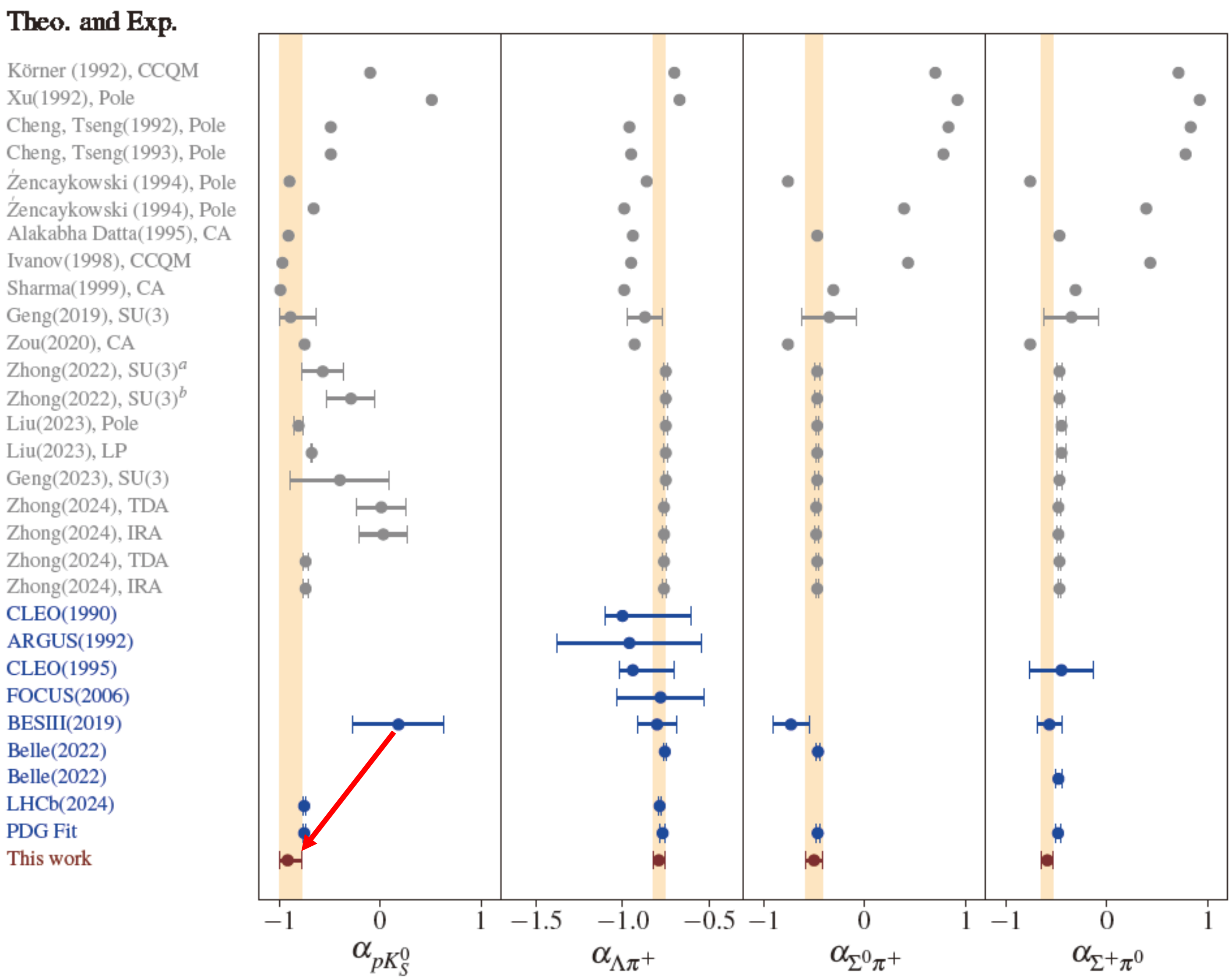






Production and Decay Dynamics of the Λ_c^+

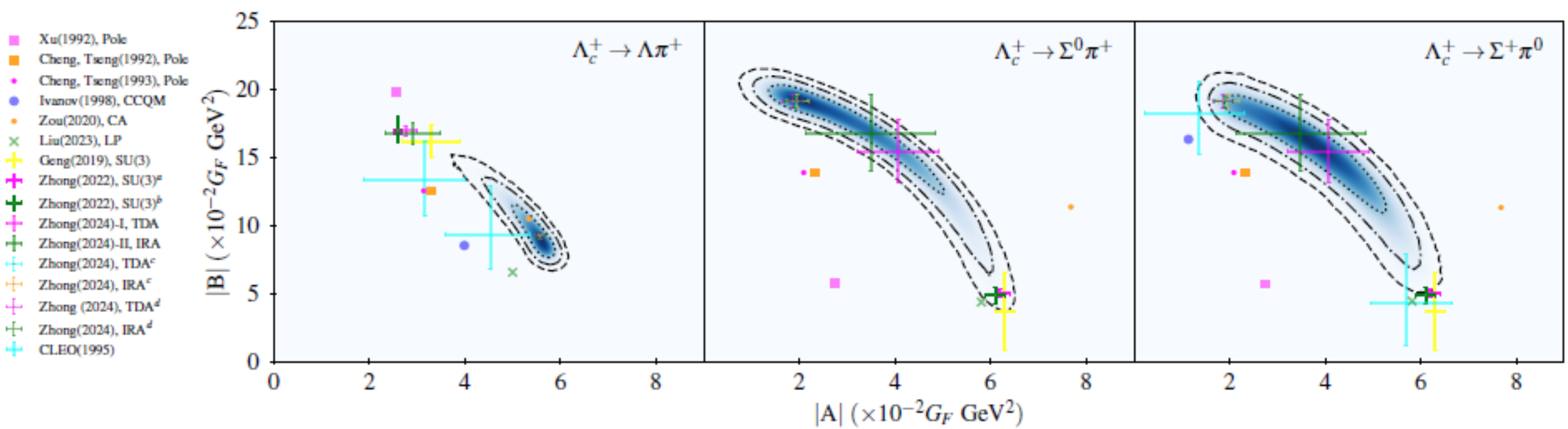
arXiv 2508.11400



Production and Decay Dynamics of the Λ_c^+

arXiv 2508.11400

Parameter	$\Lambda_c^+ \to pK_S^0$	$\Lambda_c^+ \to \Lambda\pi^+$	$\Lambda_c^+ \to \Sigma^0\pi^+$	$\Lambda_c^+ \to \Sigma^+\pi^0$
$\langle\alpha_{BP}\rangle$	$-0.918^{+0.133}_{-0.082} \pm 0.031$	$-0.790 \pm 0.032 \pm 0.009$	$-0.502 \pm 0.080 \pm 0.009$	$-0.590 \pm 0.049 \pm 0.022$
$\langle\Delta_{BP}\rangle$	$\cdots$	$0.637 \pm 0.444 \pm 0.014$	$2.190 \pm 0.730 \pm 0.029$	$1.901 \pm 0.603 \pm 0.040$
$\langle\beta_{BP}\rangle$	$\cdots$	$0.365^{+0.173}_{-0.246} \pm 0.010$	$0.704^{+0.143}_{-0.480} \pm 0.015$	$0.764^{+0.051}_{-0.237} \pm 0.018$
$\langle\gamma_{BP}\rangle$	$\cdots$	$0.637^{+0.103}_{-0.202} \pm 0.011$	$-0.502^{+0.591}_{-0.303} \pm 0.021$	$-0.262^{+0.478}_{-0.383} \pm 0.031$
$\delta_p - \delta_s$	$\cdots$	$2.71^{+0.28}_{-0.17} \pm 0.02$	$2.19^{+0.49}_{-0.13} \pm 0.02$	$2.23^{+0.19}_{-0.06} \pm 0.03$
$A_{CP}^{\alpha BP}$	$0.079^{+0.115}_{-0.101} \pm 0.019$	$0.002 \pm 0.047 \pm 0.017$	$0.206^{+0.188}_{-0.156} \pm 0.028$	$-0.086 \pm 0.081 \pm 0.085$
$\tan\phi_{CP}$	$\cdots$	$0.232 \pm 0.242 \pm 0.025$	$0.393 \pm 0.651 \pm 0.042$	$-0.007 \pm 0.474 \pm 0.034$
$\tan\Delta_s$	$\cdots$	$-0.475 \pm 0.242 \pm 0.029$	$-1.411 \pm 0.672 \pm 0.062$	$-1.297 \pm 0.478 \pm 0.068$



Strong phase convention in baryon decays

ScienceBulletin 02.030(2025)

$$\alpha = \frac{2\,\mathrm{Re}(S^{*}P)}{|S|^{2}+|P|^{2}}, \quad \beta = \frac{2\,\mathrm{Im}(S^{*}P)}{|S|^{2}+|P|^{2}}, \quad \gamma = \frac{|S|^{2}-|P|^{2}}{|S|^{2}+|P|^{2}}$$

$$\delta_P - \delta_S = 2\arctan\frac{\beta\times sign}{\sqrt{\alpha^2+\beta^2}+\alpha\times sign},$$

$$\alpha_1 = \frac{2|S||P|\cos(\delta_P-\delta_S)}{|S|^2+|P|^2}, \quad \beta_1 = \frac{2|S||P|\sin(\delta_P-\delta_S)}{|S|^2+|P|^2}. \qquad S_1 = |S|\mathrm{e}^{\mathrm{i}\delta_S}, \quad P_1 = |P|\mathrm{e}^{\mathrm{i}\delta_P},$$

$$\alpha_2 = \frac{2\widetilde{S}\widetilde{P}\cos(\delta_P-\delta_S)}{|\widetilde{S}|^2+|\widetilde{P}|^2}, \quad \beta_2 = \frac{2\widetilde{S}\widetilde{P}\sin(\delta_P-\delta_S)}{|\widetilde{S}|^2+|\widetilde{P}|^2}, \qquad S_2 = \widetilde{S}\mathrm{e}^{\mathrm{i}\delta_S}, P_2 = \widetilde{P}\mathrm{e}^{\mathrm{i}\delta_P},$$

$$\alpha_3 = \sin(2\zeta)\cos(\delta_P-\delta_S), \quad \beta_3 = \sin(2\zeta)\sin(\delta_P-\delta_S). \qquad S_3 = |\mathcal{A}|\sin\zeta\,\mathrm{e}^{\mathrm{i}\delta_S}, P_3 = |\mathcal{A}|\cos\zeta\,\mathrm{e}^{\mathrm{i}\delta_P}.$$

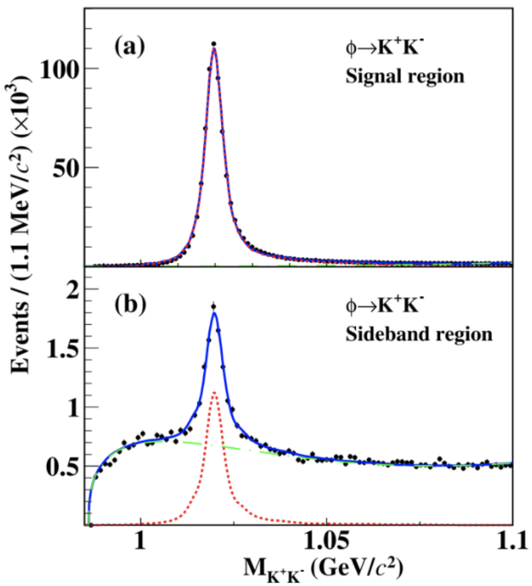
Table 1
Summary of experimental data on the parameters α, β, and ϕ and the phase shift, $\delta_P-\delta_S$, in various two-body nonleptonic decays of the Λ and Ξ hyperons and singly charmed baryon Λ_c^+.

Experiment	Process	α or $\langle\alpha\rangle$	β or $\langle\beta\rangle$	ϕ or $\langle\phi\rangle$ (rad)	$\delta_P-\delta_S$ (rad)	Value of *sign*	$\delta_P-\delta_S$ (rad) Eq. (10) with *sign*=1	Eq. (10) with *sign*=−1
Λ from π^-p (1963) [14]	$\Lambda\to p\pi^-$	0.62 ± 0.07	-0.18 ± 0.24	…	-0.26 ± 0.35[a]	Unknown	-0.28 ± 0.36	2.86 ± 0.36
Λ from π^-p (1967) [15]		0.645 ± 0.017	-0.103 ± 0.065	-0.14 ± 0.10	-0.16 ± 0.10[a]	Unknown	-0.16 ± 0.10	2.98 ± 0.10
E756 (2003) [18]	$\Xi^-\to\Lambda\pi^-$	-0.458 ± 0.012	-0.03 ± 0.04	-0.03 ± 0.05	0.06 ± 0.09	$+1$	-3.08 ± 0.09	0.06 ± 0.09
HyperCP (2004) [19]		-0.458 ± 0.012	-0.037 ± 0.015	-0.041 ± 0.016	0.080 ± 0.032	Unknown	-3.062 ± 0.031	0.079 ± 0.031
BESIII (2022) [20]		-0.373 ± 0.006	Positive	0.016 ± 0.016	-0.040 ± 0.037	Unknown	3.102 ± 0.036	-0.040 ± 0.036
BESIII (2022) [21]		-0.350 ± 0.018	Positive	0.073 ± 0.052	-0.20 ± 0.13	Unknown	2.95 ± 0.13	-0.19 ± 0.13
BESIII (2024) [22]		-0.371 ± 0.004	Negative	-0.013 ± 0.008	0.033 ± 0.023	Unknown	-3.109 ± 0.025	0.033 ± 0.025
BESIII (2023) [23]	$\Xi^0\to\Lambda\pi^0$	-0.377 ± 0.003	Positive	0.005 ± 0.007	-0.013 ± 0.017	Unknown	3.129 ± 0.017	-0.012 ± 0.017
LHCb (2024) [24]	$\Lambda_c^+\to\Lambda\pi^+$	-0.785 ± 0.007	0.378 ± 0.015	0.656 ± 0.027	2.693 ± 0.017	Unknown	2.693 ± 0.015	-0.449 ± 0.015
LHCb (2024) [24]	$\Lambda_c^+\to\Lambda K^+$	-0.516 ± 0.046	0.33 ± 0.08	2.75 ± 0.11	2.57 ± 0.19	Unknown	2.58 ± 0.12	-0.56 ± 0.12
BESIII (2024) [13]	$\Lambda_c^+\to\Xi^0K^+$	0.01 ± 0.16	-0.64 ± 0.70	3.84 ± 0.90	$-1.55(1.59)\pm0.25$[b]	$+1$	$-1.55(1.59)\pm0.25$	$1.59(-1.55)\pm0.25$

Lepton Number Violating(LNV)

Chin. Phys. C 49, 043001 (2025)

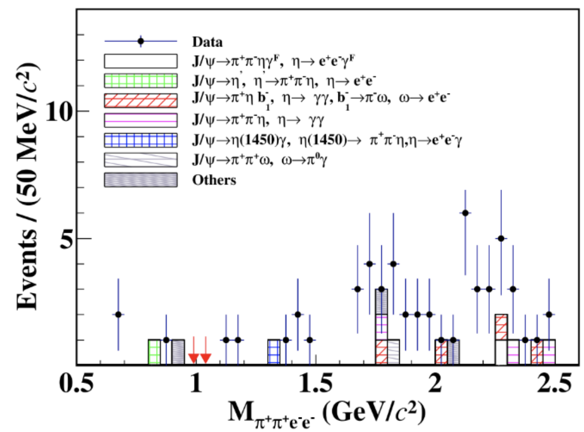
- Analysis of $\phi \to K^+K^-$

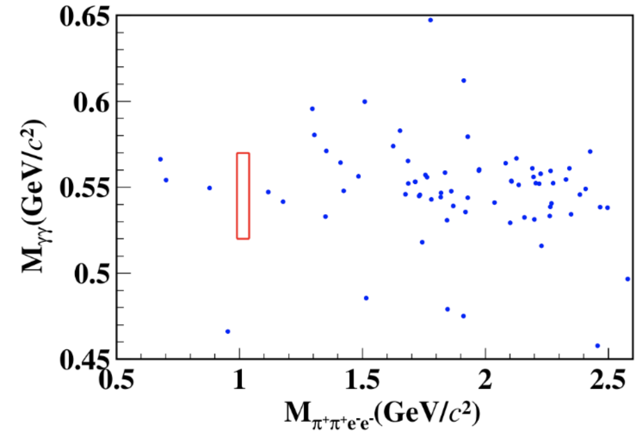


$$N^{\text{net}}_{K^+K^-} = N_{\text{signal}} - \frac{1}{2} \times N_{\text{sideband}} = 823764 \pm 1023.$$

$$\varepsilon_{KK} = \frac{N^{\text{MC}}_{\text{obs}}}{N^{\text{MC}}_{\text{total}}} = \frac{471297}{1000000} = (47.1 \pm 0.1)\%$$

- Analysis of $\phi \to \pi^+\pi^+e^-e^-$





No event is observed in the signal region

$\mathcal{B}(\phi \to \pi^+\pi^+e^-e^-) < 1.3 \times 10^{-5}$ (90% CL, TRolke)

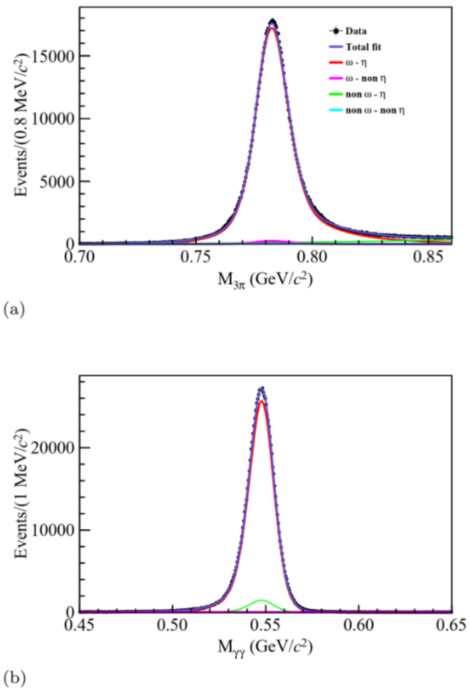
This is the first LNV signal constraint in ϕ meson composed of second generation quarks.

Search for the lepton number violation decay $\phi \to \pi^+\pi^+e^-e^-$ via $J/\psi \to \phi\eta^*$

Lepton Number Violating (LNV)

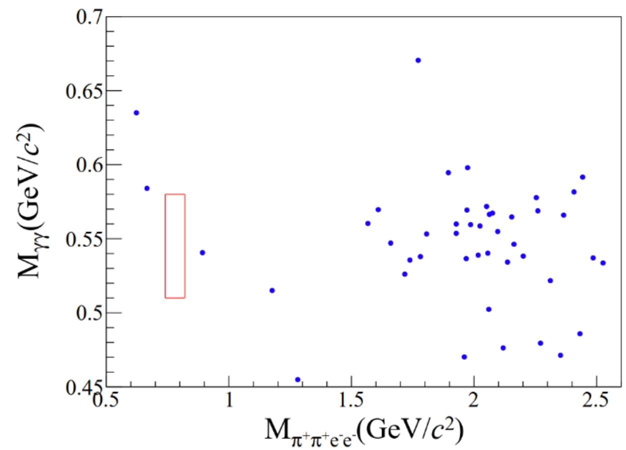
Chin. Phys. C 49, 103002 (2025)

- Analysis of $\omega \to \pi^+\pi^- \pi^0$



The projections of the 2D fit of the (a) $M_{3\pi}$ and (b) $M_{\gamma\gamma}$

- Analysis of $\omega \to \pi^+\pi^+ e^- e^-$



No event is observed in the signal region

$\mathcal{B}(\omega \to \pi^+\pi^+ e^- e^-) < 2.8 \times 10^{-6}$ (90% CL, Feldman-Cousins intervals)

This is the first experimental constraint on the LNV decay of the ω meson composed of first generation quarks.

For the signal channel $J/\psi \to \omega\eta$ with $\eta \to \gamma\gamma$ and $\omega \to \pi^+\pi^+ e^- e^-$, at least two reconstructed photons and

Lepton Number Violating(LNV)

J. High Energ. Phys. 2025, 109 (2025)

- Search for Majorana neutrino in $D_s^+ \to \phi\pi^- e^+ e^+$ decay
  - Assuming the LNV signal from Majorana neutrino

$$D_s^+ \to \phi e^+ \nu_m (\to \pi^- e^+)$$

  - Majorana neutrino mass:

    [0.20, 0.80] GeV in intervals of 0.05 GeV

  - Further requirement on the invariant mass of any $\pi^- e^+$ combination
  - Upper limits are calculated using Trolke due to the limited events.

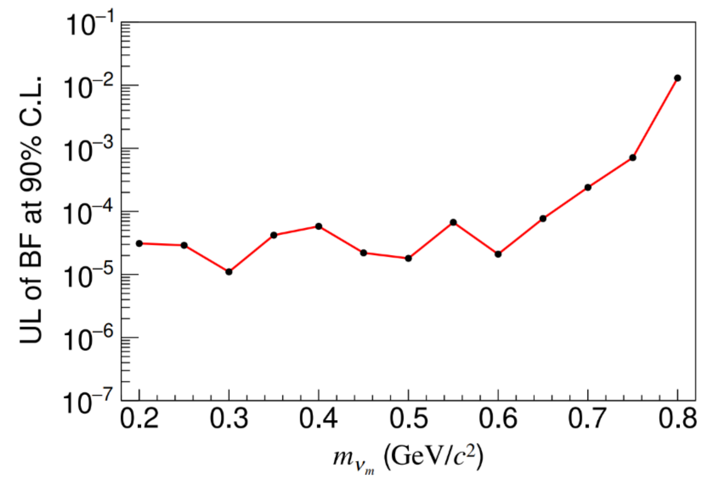


Figure 4. The ULs of the BFs at the 90% C.L. as a function of m_{ν_m} for the $D_s^+ \to \phi e^+ \nu_m (\to \pi^- e^+)$ decay.

Baryon Number Violation (BNV)

Phys. Rev. D 111, 112010 (2025)

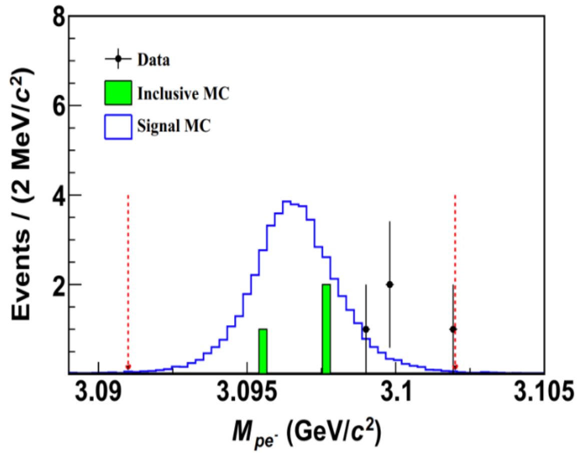
- Experimental constraints on proton decay have largely ruled out the simplest GUT models. Therefore, it is essential to explore other hadrons containing second-generation quarks.
- Search for the BNV/LNV decay $J/\psi \to pe^- + c.c.$ for the first time.
- Analysis:

$\psi(2S) \to \pi^+\pi^- J/\psi \qquad J/\psi \to pe^- + c.c.$

$$\mathcal{B}(J/\psi \to pe^-) = \frac{N^{\mathrm{sig}}}{N^{\mathrm{tot}}_{\psi(2S)} \cdot \mathcal{B}(\psi(2S) \to \pi^+\pi^- J/\psi\,) \cdot \epsilon}$$

This result provides stronger experimental constraints compared to similar scenarios, such as $D^0 \to \bar{p}e^+$ and $J/\psi \to \Lambda_c^+ e^-$

$N^{\mathrm{inc}} = 3 \quad \psi(3686) \to \pi^+\pi^- J/\psi, J/\psi \to e^+e^-\gamma^f\gamma^f$ or $e^+e^-\gamma^f$



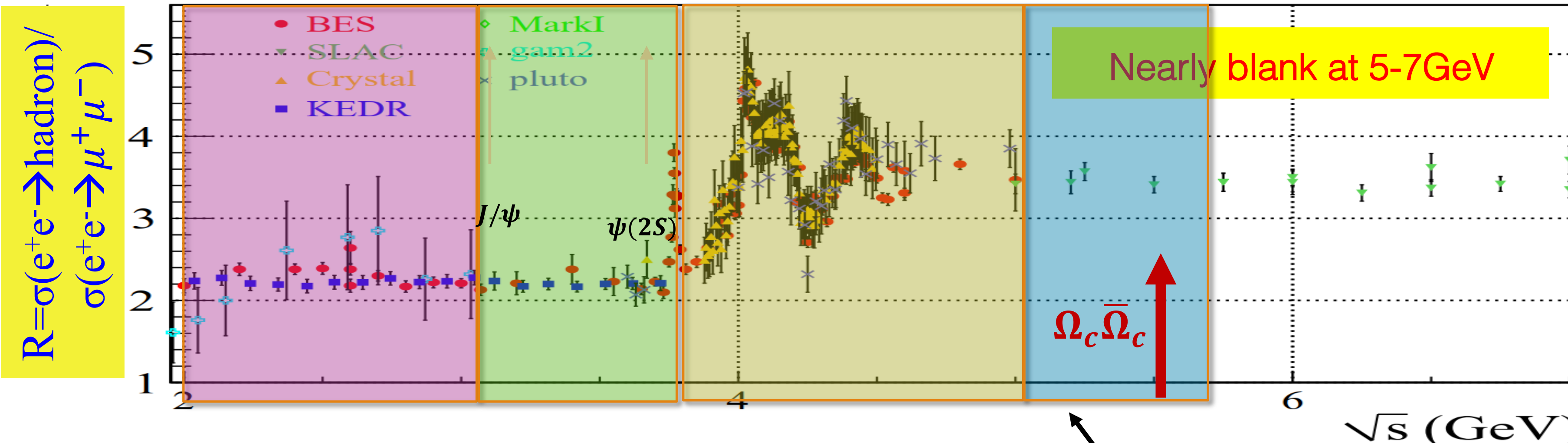
$N_{\mathrm{obs}} = 4$

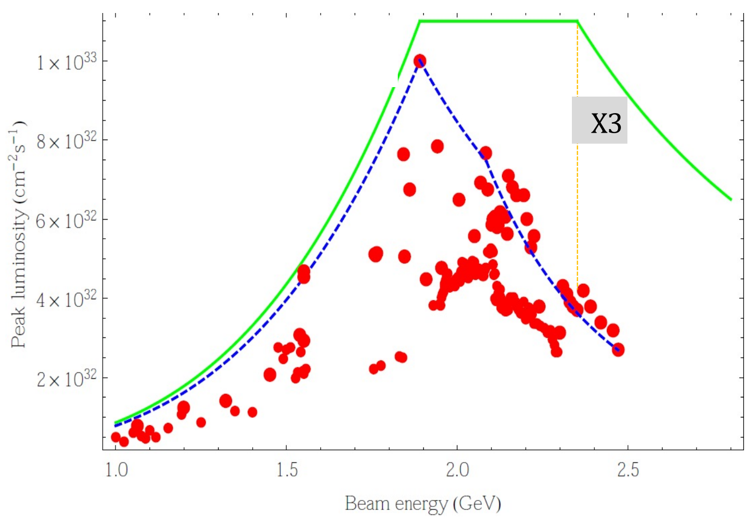
No obvious signal is observed

$$\mathcal{B}(J/\psi \to pe^-) < \frac{N^{\mathrm{up}}}{\mathcal{B}_\psi N^{\mathrm{tot}}_{\psi(3686)}} = 3.1 \times 10^{-8}$$ (90% CL, TRolke)

Proposal of the BEPCII upgrade

- optimized energy at 2.35 GeV with luminosity 3 times higher than the current BEPCII.





4.95 ~ 5.6 GeV: new energy coverage of BEPCII-upgrade

Energy thresholds

- ✓ $\Lambda_c^+\bar{\Sigma}_c^-$ 4.74 GeV
- ✓ $\Lambda_c^+\bar{\Sigma}_c\ \pi$ 4.88 GeV
- ✓ $\Sigma_c\ \bar{\Sigma}_c$ 4.91 GeV
- ✓ $\Xi_c\ \bar{\Xi}_c$ 4.95 GeV
- ✓ $\Omega_c^0\bar{\Omega}_c^0$ 5.4 GeV

Prospect Charm Baryons data sample at BESIII

Table 7.1. List of data samples collected by BESIII/BEPCII up to 2019, and the proposed samples for the remainder of the physics program. The right-most column shows the number of required data taking days with the current (T_C) and upgraded (T_U) machine. The machine upgrades include top-up implementation and beam current increase.

Energy	Physics motivations	Current data	Expected final data	T_C / T_U
1.8 - 2.0 GeV	R values Nucleon cross-sections	N/A	0.1 fb^{-1} (fine scan)	60/50 days
2.0 - 3.1 GeV	R values Cross-sections	Fine scan (20 energy points)	Complete scan (additional points)	250/180 days
J/ψ peak	Light hadron & Glueball J/ψ decays	3.2 fb^{-1} (10 billion)	3.2 fb^{-1} (10 billion)	N/A
$\psi(3686)$ peak	Light hadron & Glueball Charmonium decays	0.67 fb^{-1} (0.45 billion)	4.5 fb^{-1} (3.0 billion)	150/90 days
$\psi(3770)$ peak	$D^0/D^{\pm}$ decays	2.9 fb^{-1}	20.0 fb^{-1}	610/360 days
3.8 - 4.6 GeV	R values XYZ/Open charm	Fine scan (105 energy points)	No requirement	N/A
4.180 GeV	D_s decay XYZ/Open charm	3.2 fb^{-1}	6 fb^{-1}	140/50 days
4.0 - 4.6 GeV	XYZ/Open charm Higher charmonia cross-sections	16.0 fb^{-1} at different $\sqrt{s}$	30 fb^{-1} at different $\sqrt{s}$	770/310 days
4.6 - 4.9 GeV	Charmed baryon/XYZ cross-sections	0.56 fb^{-1} at 4.6 GeV	$\boxed{15\text{ fb}^{-1}\text{ at different }\sqrt{s}}$	1490/600 days
4.74 GeV	$\Sigma_c^+\bar{\Lambda}_c^-$ cross-section	N/A	$\boxed{1.0\text{ fb}^{-1}}$	100/40 days
4.91 GeV	$\Sigma_c\bar{\Sigma}_c$ cross-section	N/A	$\boxed{1.0\text{ fb}^{-1}}$	120/50 days
4.95 GeV	Ξ_c decays	N/A	$\boxed{1.0\text{ fb}^{-1}}$	130/50 days

Summary

- BEPCII energy upgrade during 2020-2021 has improved the BESIII capability by accumulating more statistics at different energy points.

- BESIII has been playing significant role in studying flavor physics of charm sector and searching for new physics. Many new important results have been published during 2025.

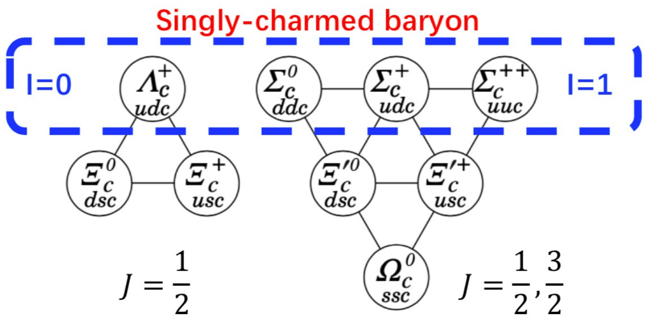
- Future BESIII will greatly extend the physics opportunities in study of flavor physics and search for new physics!

Thanks!

Backup

Energy thresholds

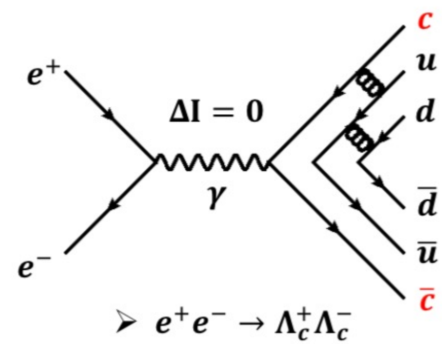
✓ $e^+e^- \to \Lambda_c^+\bar{\Sigma}_c^-$	4.74~4.87 GeV
✓ $e^+e^- \to \Lambda_c^+\bar{\Lambda}_c^-(2595)(\bar{\Sigma}_c\ \pi)$	4.88 GeV
✓ $e^+e^- \to \Sigma_c\ \bar{\Sigma}_c$	4.91 GeV
✓ $e^+e^- \to \Xi_c\ \bar{\Xi}_c$	4.95 GeV

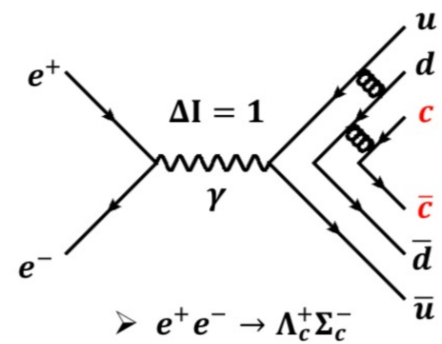


The Born cross-section **ratios** between $\Lambda_c^+\Lambda_c^- + c.c.$ and $\Lambda_c^-\Sigma_c^+ + c.c.$ at different energy points can provide more information about the production of $c\bar{c}$ or $q\bar{q}$ from vacuum.

BESIII **Cross sections for $e^+e^- \to \Lambda_c^+\bar{\Sigma}_c^-$ and $\Sigma_c\ \bar{\Sigma}_c$**

- **$e^+e^- \to \Lambda_c^+\bar{\Sigma}_c^-$ above 4.74 GeV:** An interesting isospin violating process to understand the QCD dynamics at charm sector
  - ✓ A cross section scan slightly above 4.74 GeV will be useful for comparison with that of $e^+e^- \to \Lambda_c^+\bar{\Lambda}_c^-$ and $\Lambda_c^+\bar{\Sigma}_c^-$
  - ✓ $\sigma(\Lambda_c^+\bar{\Sigma}_c^-)/\sigma(\Lambda_c^+\bar{\Lambda}_c^-)$ v.s. $\sigma(\Lambda\bar{\Sigma})/\sigma(\Lambda\bar{\Lambda})$
    ➔ vaccum pol. to $c\bar{c}$ v.s. $s\bar{s}$
  - ✓ If observed, study the polarizations and form factors
- **$e^+e^- \to \Sigma_c\ \bar{\Sigma}_c$ around 4.91 GeV:**
  - ✓ Cross section comparison with that of $e^+e^- \to \Lambda_c^+\bar{\Lambda}_c^-$
    ➔ good diquark v.s. bad diquark
  - ✓ Study the polarizations and form factors in $e^+e^- \to \Sigma_c^0\bar{\Sigma}_c^0$ and $\Sigma_c^+\bar{\Sigma}_c^-$





CP observable in hyperon decay

John F. Donoghue | Xiao-Gang He | Sandip Pakvasa

PHYSICAL REVIEW D VOLUME 34, NUMBER 3 1 AUGUST 1986

Hyperon decays and *CP* nonconservation

John F. Donoghue
Department of Physics and Astronomy, University of Massachusetts, Amherst, Massachusetts 01003

Xiao-Gang He and Sandip Pakvasa
Department of Physics and Astronomy, University of Hawaii at Manoa, Honolulu, Hawaii 96822
(Received 7 March 1986)

We study all modes of hyperon nonleptonic decay and consider the *CP*-odd observables which result. Explicit calculations are provided in the Kobayashi-Maskawa, Weinberg-Higgs, and left-right-symmetric models of *CP* nonconservation.

PRD 34,833 1986

SM Prediction of Λ decay

Not sensitive to *CPV*

$$\Delta=\frac{\Gamma-\bar{\Gamma}}{\Gamma+\bar{\Gamma}}\approx\sqrt{2}\frac{T_{\frac{3}{2}}}{T_{\frac{1}{2}}}\sin\Delta_s\sin\phi_{CP}$$

-5.4×10^{-7}

Easiest to measure

$$A=\frac{\Gamma\alpha+\bar{\Gamma}\bar{\alpha}}{\Gamma\alpha-\bar{\Gamma}\bar{\alpha}}\approx\tan\Delta_s\tan\phi_{CP}$$

-0.5×10^{-4}

Polarization of decayed baryon needs to be measured

$$B=\frac{\Gamma\beta+\bar{\Gamma}\bar{\beta}}{\Gamma\alpha-\bar{\Gamma}\bar{\alpha}}\approx\tan\phi_{CP}$$

3.0×10^{-3}