Study on the Charmed Baryons in the BESIII Experiment

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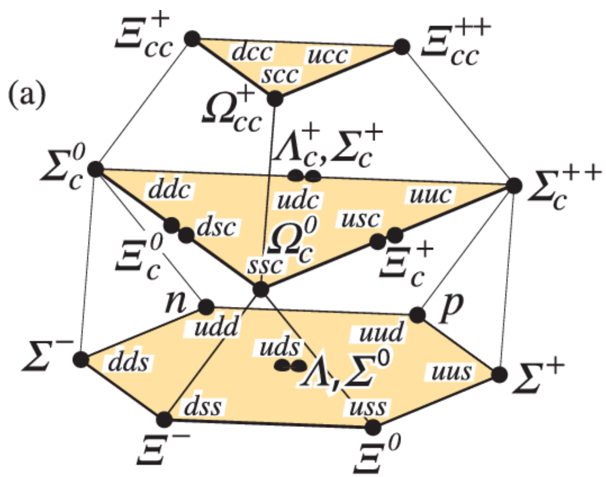
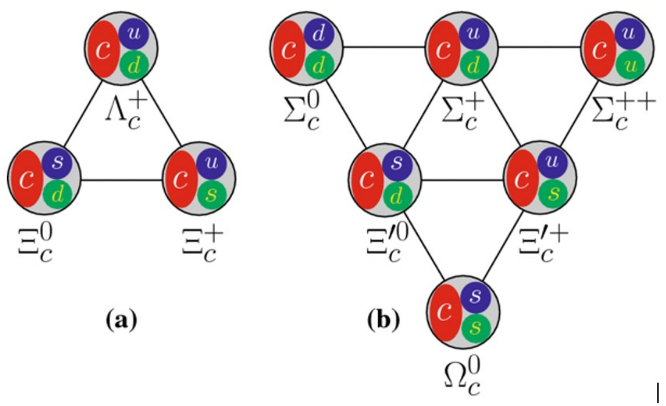
The charmed baryon family

- Singly charmed baryons
  - Established ground states:
    Λ_c^+, Σ_c, $\Xi_c^{(\prime)}$, Ω_c
  - Excited states are being explored
- Doubly charmed baryons(Ξ_{cc}^{++}) observed in recent year.
- No observations of triply charmed baryons.

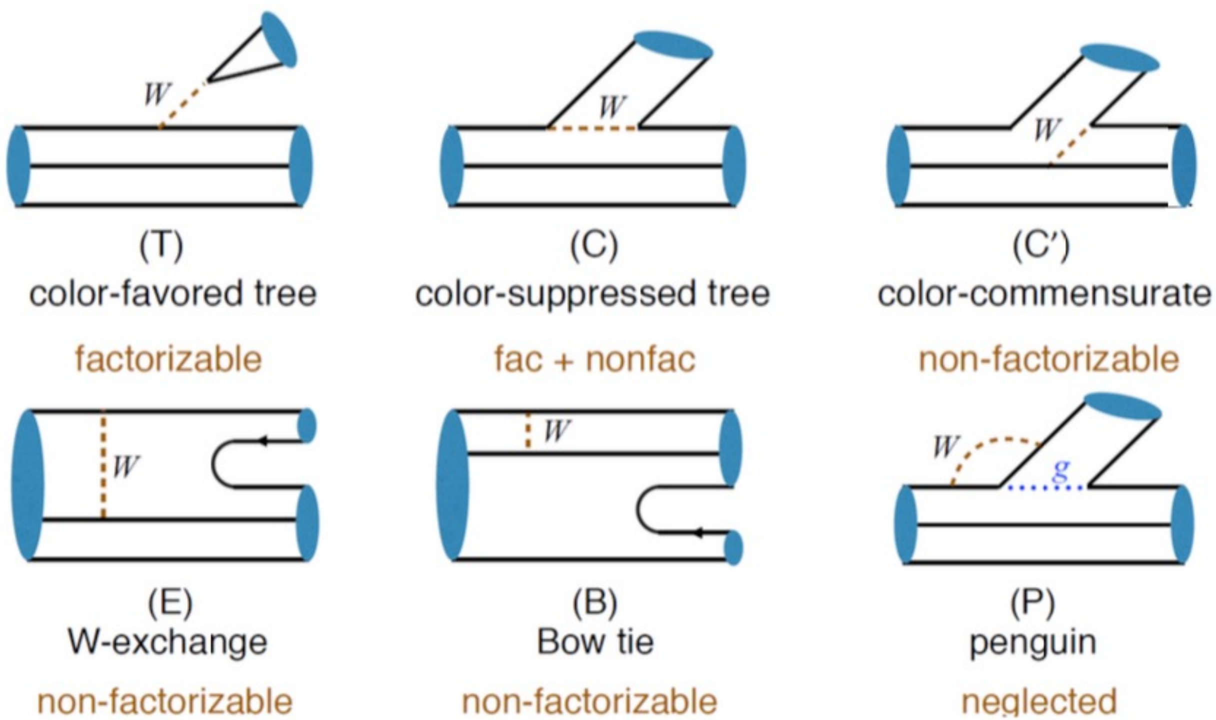


✓ Λ_c^+ decay only weakly, many experimental progress since 2014.
✓ Σ_c: $B(\Sigma_c \to \Lambda_c^+\pi)\sim100\%$, $B(\Sigma_c \to \Lambda_c^+\gamma)$?
✓ Ξ_c : decay only weakly; absolute BF measured with poor precision
✓ Ω_c:decay only weakly; no absolute BF measured.



Weak decay picture in theory

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

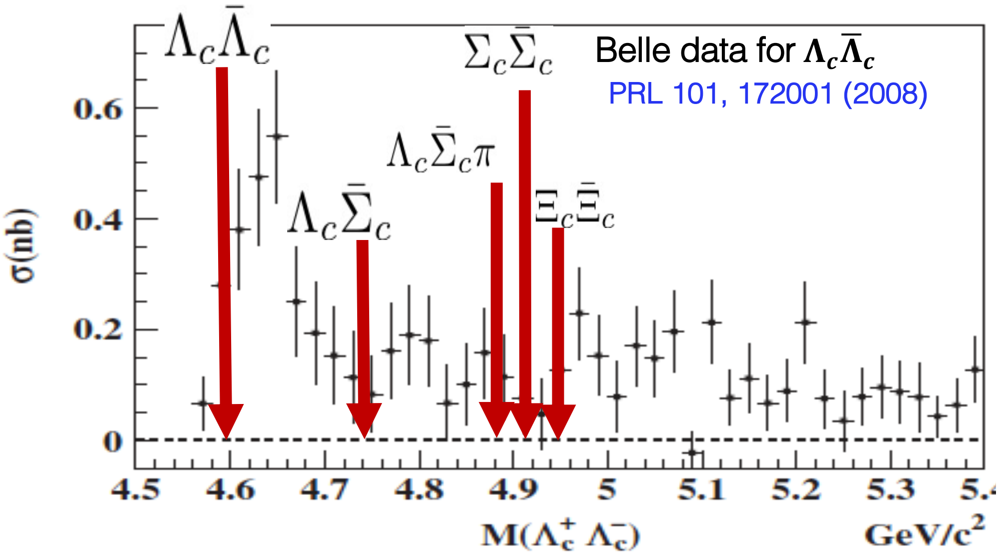


- Phenomenology aim at explain data and predict important observables.
- Calculate what they can(HQET, factorization)+parametrize what they cannot + some non-perturbations extracted from data=> explain and predict.

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.
- accessible to $\Sigma_c/\Xi_c/\Lambda_c^*$ prod. & decays

Λ_c^+ BF studies

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Λ_c^+ Mode	BF($\times10^{-3}$)	Experiment	Λ_c^+ Mode	BF($\times10^{-3}$)	Experiment
$\Lambda_c^+\to\Lambda e^+\nu_e$	$23.7\pm5.1(37\%)^\dagger$	ARGUS(1991)[24]	$\Lambda_c^+\to pK^-e^+\nu_e$	$0.88\pm0.18(20\%)$	BESIII(2022)[29]
	$26.8\pm5.1(19\%)^\dagger$	CELO(1994)[25]	$\Lambda_c^+\to\Lambda(1405)e^+\nu_e$, $\Lambda(1405)\to pK^-$	$0.42\pm0.19(45\%)$	BESIII(2022)[29]
	$36.3\pm4.3(12\%)$	BESIII(2015)[30]			
	$35.6\pm1.3(3.6\%)$	BESIII(2022)[31]	$\Lambda_c^+\to\Lambda(1520)e^+\nu_e$	$1.0\pm0.5(50\%)$	BESIII(2022)[29]
$\Lambda_c^+\to\Lambda\mu^+\nu_\mu$	$34.9\pm5.3(15\%)$	BESIII(2017)[32]	$\Lambda_c^+\to pK_S^0\pi^-e^+\nu_e$	<0.33	BESIII(2023)[33]
	$34.8\pm1.7(4.9\%)$	BESIII(2023)[34]	$\Lambda_c^+\to\Lambda\pi^+\pi^-e^+\nu_e$	<0.39	BESIII(2023)[33]
$\Lambda_c^+\to e^+X$	$39.5\pm3.5(8.9\%)$	BESIII(2018)[35]	$\Lambda_c^+\to ne^+\nu_e$	3.57 ± 0.37 (10%)	BESIII(2025)[36]
	$40.6\pm1.3(3.2\%)$	BESIII(2023)[37]			
Ξ_c Mode	BF($\times10^{-3}$)	Experiment	Ξ_c Mode	BF($\times10^{-3}$)	Experiment
$\Xi_c^0\to\Xi^-e^+\nu_e$	$13.7\pm7.7(56\%)^\dagger$	ARGUS(1993)[26]	$\Xi_c^0\to\Xi^-\mu^+\nu_\mu$	$10.1\pm2.1(21\%)^\dagger$	Belle(2021)[38]
	$44.3^{+16.6}_{-17.8}(40\%)^\dagger$	CLEO(1995)[27]	$\Xi_c^+\to\Xi^0e^+\nu_e$	$67\pm39(58\%)^\dagger$	CLEO(1995)[27]
	$19.7\pm5.3(27\%)^\dagger$	ALICE(2021)[39]			
	$10.4\pm2.1(20\%)^\dagger$	Belle(2021)[38]			
Ω_c^0 Mode	Ratio	Experiment	Ω_c^0 Mode	Ratio	Experiment
$\Omega_c^0\to\Omega^0e^+\nu_e$	$2.4\pm1.1(47\%)$	CLEO(2002)[28]	$\Omega_c^0\to\Omega^0\mu^+\nu_\mu$	$1.94\pm0.21(11\%)$	Belle(2022)[40]
	$1.98\pm0.15(7.7\%)$	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	Mode	BF	Experiment
Nucleon-involved					
$\Lambda_c^+\to n\pi^+$	0.66 ± 0.13	BESIII(2022)[126]	$\Lambda_c^+\to nK^+\pi^0$	<0.71	BESIII(2024)[107]
$\Lambda_c^+\to p\pi^0$	<0.27	BESIII(2017)[117]	$\Lambda_c^+\to n\pi^+\pi^0$	0.64 ± 0.09	BESIII(2023)[129]
	<0.08	Belle(2021)[109]	$\Lambda_c^+\to nK_S^0K^+$	$0.39^{+0.17}_{-0.14}$	BESIII(2024)[91]
	$0.16^{+0.07}_{-0.06}$	BESIII(2024)[118]	$\Lambda_c^+\to n\pi^+\pi^-\pi^+$	0.45 ± 0.08	BESIII(2023)[129]
	0.18 ± 0.04	BESIII(2025)[119]	$\Lambda_c^+\to p\pi^+\pi^-$	3.91 ± 0.40	BESIII(2016)[127]
$\Lambda_c^+\to p\eta$	1.24 ± 0.30	BESIII(2017)[117]		4.72 ± 0.28	LHCb(2018)[138]
	1.42 ± 0.12	Belle(2021)[109]	$\Lambda_c^+\to pK^+K^-$	1.08 ± 0.07	LHCb(2018)[138]
	1.57 ± 0.12	BESIII(2023)[120]	$\Lambda_c^+\to p(K^+K^-)_{\text{non-}\phi}$	0.55 ± 0.14	BESIII(2016)[127]
	1.63 ± 0.33	BESIII(2024)[118]	$\Lambda_c^+\to pK_S^0K_S^0$	0.24 ± 0.02	Belle(2023)[146]
	1.67 ± 0.80	LHCb(2024)[121]	$\Lambda_c^+\to p\phi\pi^0$	<0.15	Belle(2017)[147]
$\Lambda_c^+\to p\eta'$	$0.56^{+0.25}_{-0.21}$	BESIII(2022)[123]	$\Lambda_c^+\to(pK^+K^-\pi^0)_{\text{NR}}$	<0.06	Belle(2017)[147]
	0.47 ± 0.10	Belle(2022)[122]	$\Lambda_c^+\to pK^+\pi^-$	0.16 ± 0.02	Belle(2016)[137]
$\Lambda_c^+\to p\rho$	1.52 ± 0.44	LHCb(2024)[121]		0.10 ± 0.01	LHCb(2018)[138]
$\Lambda_c^+\to p\omega$	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]	$\Lambda_c^+\to\Lambda K^+\pi^0$	<2.0	BESIII(2024)[107]
	0.66 ± 0.04	Belle(2023)[132]		1.49 ± 0.29	BESIII(2024)[135]
$\Lambda_c^+\to\Lambda K^{*+}$	$2.40\pm0.59(\theta_0=0^\circ)$	BESIII(2025)[134]	$\Lambda_c^+\to\Lambda K_S^0\pi^+$	1.73 ± 0.29	BESIII(2025)[134]
	$5.21\pm0.75(\theta_0=109^\circ)$	BESIII(2025)[134]	$\Lambda_c^+\to\Lambda K^+\pi^+\pi^-$	0.41 ± 0.15	BESIII(2024)[135]
	$1.29\pm0.44(\theta_0=221^\circ)$	BESIII(2025)[134]			
Σ-involved					
$\Lambda_c^+\to\Sigma^0K^+$	0.47 ± 0.10	BESIII(2022)[133]	$\Lambda_c^+\to\Sigma^+K^+\pi^-$	2.00 ± 0.28	BESIII(2023)[150]
	0.36 ± 0.03	Belle(2023)[132]	$\Lambda_c^+\to\Sigma^+K^+\pi^-\pi^0$	<0.01	BESIII(2023)[150]
$\Lambda_c^+\to\Sigma^+K_S^0$	0.48 ± 0.14	BESIII(2022)[133]	$\Lambda_c^+\to\Sigma^0K^+\pi^0$	<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	Mode	BF	Experiment
Nucleon-involved					
$\Lambda_c^+\to pK_S^0$	1.52 ± 0.09	BESIII(2016)[80]	$\Lambda_c^+\to nK_S^0\pi^+$	1.82 ± 0.25	BESIII(2017)[90]
$\Lambda_c^+\to pK_L^0$	1.67 ± 0.07	BESIII(2024)[89]		1.86 ± 0.09	BESIII(2024)[91]
$\Lambda_c^+\to p\bar{K}_0^*(700)^0\to pK^-\pi^+$	0.19 ± 0.06	LHCb(2023)[86]	$\Lambda_c^+\to nK_S^0\pi^+\pi^0$	0.85 ± 0.13	BESIII(2024)[92]
$\Lambda_c^+\to p\bar{K}^*(892)^0\to pK^-\pi^+$	1.38 ± 0.08	LHCb(2023)[86]	$\Lambda_c^+\to nK^-\pi^+\pi^+$	1.90 ± 0.12	BESIII(2023)[129]
$\Lambda_c^+\to p\bar{K}_0^*(1430)^0\to pK^-\pi^+$	0.92 ± 0.18	LHCb(2023)[86]	$\Lambda_c^+\to pK_S^0\pi^0$	1.87 ± 0.14	BESIII(2016)[80]
$\Lambda_c^+\to\Delta(1232)^{++}K^-\to p\pi^+K^-$	1.78 ± 0.05	LHCb(2023)[86]		2.12 ± 0.11	Belle(II)(2025)[144]
$\Lambda_c^+\to\Delta(1600)^{++}K^-\to p\pi^+K^-$	0.28 ± 0.10	LHCb(2023)[86]	$\Lambda_c^+\to pK_L^0\pi^0$	2.02 ± 0.14	BESIII(2024)[89]
$\Lambda_c^+\to\Delta(1700)^{++}K^-\to p\pi^+K^-$	0.24 ± 0.06	LHCb(2023)[86]	$\Lambda_c^+\to pK_S^0\eta$	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					
$\Lambda_c^+\to\Lambda\pi^+$	1.24 ± 0.08	BESIII(2016)[80]	$\Lambda_c^+\to\Lambda\pi^+\pi^0$	7.01 ± 0.42	BESIII(2016)[80]
	1.31 ± 0.09	BESIII(2023)[126]	$\Lambda_c^+\to\Lambda\pi^+\eta$	1.84 ± 0.26	BESIII(2019)[94]
$\Lambda_c^+\to\Lambda\rho(770)^+$	4.06 ± 0.52	BESIII(2022)[93]		1.84 ± 0.13	Belle(2021)[95]
$\Lambda_c^+\to\Lambda a_0(980)^+$	1.23 ± 0.21	BESIII(2025)[94]		1.94 ± 0.13	BESIII(2025)[148]
$\Lambda_c^+\to\Lambda(1405)\pi^+\to pK^-\pi^+$	0.48 ± 0.19	LHCb(2023)[86]	$\Lambda_c^+\to\Lambda\pi^+\pi^-\pi^+$	3.81 ± 0.30	BESIII(2016)[80]
$\Lambda_c^+\to\Lambda(1520)\pi^+\to pK^-\pi^+$	0.12 ± 0.02	LHCb(2023)[86]	$\Lambda_c^+\to\Lambda K_S^0K^+$	0.30 ± 0.03	BESIII(2025)[134]
$\Lambda_c^+\to\Lambda(1600)\pi^+\to pK^-\pi^+$	0.32 ± 0.12	LHCb(2023)[86]		0.31 ± 0.05	BESIII(2025)[108]
$\Lambda_c^+\to\Lambda(1670)\pi^+\to pK^-\pi^+$	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]	$\Lambda_c^+\to\Sigma^+\pi^+\pi^-$	4.25 ± 0.31	BESIII(2016)[80]
$\Lambda_c^+\to\Sigma^+\eta$	0.41 ± 0.20	BESIII(2018)[96]		4.57 ± 0.28	Belle(2018)[149]
	0.31 ± 0.05	Belle(2023)[98]	$\Lambda_c^+\to\Sigma^+\pi^0\pi^0$	1.57 ± 0.15	Belle(2018)[149]
	0.38 ± 0.06	BESIII(2025)[97]	$\Lambda_c^+\to\Sigma^0\pi^+\pi^0$	3.65 ± 0.30	Belle(2018)[149]
$\Lambda_c^+\to\Sigma^+\eta'$	1.34 ± 0.56	BESIII(2018)[96]	$\Lambda_c^+\to\Sigma^0\pi^+\eta$	0.76 ± 0.08	Belle(2021)[95]
	0.42 ± 0.09	Belle(2023)[98]	$\Lambda_c^+\to\Sigma^-\pi^+\pi^+$	1.81 ± 0.19	BESIII(2017)[105]
	0.57 ± 0.18	BESIII(2025)[97]	$\Lambda_c^+\to\Sigma^-\pi^+\pi^+\pi^0$	2.11 ± 0.36	BESIII(2017)[105]
$\Lambda_c^+\to\Sigma^+\omega$	1.56 ± 0.21	BESIII(2016)[80]	$\Lambda_c^+\to\Sigma^+K^+K^-$	0.38 ± 0.05	BESIII(2023)[150]
$\Lambda_c^+\to\Sigma^+\phi$	0.41 ± 0.09	BESIII(2023)[150]	$\Lambda_c^+\to\Sigma^+K^+K^-_{\text{non-}\phi}$	0.20 ± 0.04	BESIII(2023)[150]
$\Lambda_c^+\to\Sigma^0\pi^+$	1.27 ± 0.09	BESIII(2016)[80]	$\Lambda_c^+\to\Sigma^0K_S^0K^+$	0.08 ± 0.03	BESIII(2025)[108]
	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]	$\Lambda_c^+\to\Xi^0K^+\pi^0$	0.78 ± 0.17	BESIII(2024)[107]
$\Lambda_c^+\to\Xi(1530)^0K^+$	0.50 ± 0.10	BESIII(2018)[106]	$\Lambda_c^+\to\Xi^0K_S^0\pi^+$	0.37 ± 0.06	BESIII(2025)[108]
	0.60 ± 0.11	BESIII(2024)[107]			

Λ_c^+ decay asymmetry studies

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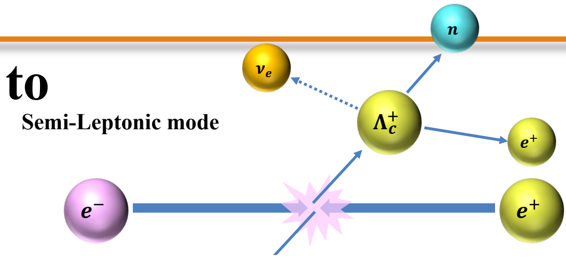
Mode	α	Experiment
Nucleon-involved		
$\Lambda_c^+ \to pK_S^0$	-0.75 ± 0.10	LHCb(2024)[160]
	$-0.92^{+0.14}_{-0.09}$	BESIII(2025)[159]
$\Lambda_c^+ \to p\bar{K}_0^*(700)^0$	-0.1 ± 0.7	LHCb(2023)[91]
$\Lambda_c^+ \to p\bar{K}_0^*(892)^0$	0.87 ± 0.03	LHCb(2023)[91]
$\Lambda_c^+ \to p\bar{K}_0^*(1430)^0$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

Mode	β	Experiment
$\Lambda_c^+ \to \Lambda\pi^+$	0.378 ± 0.015	LHCb(2024)[160]
	$0.37^{+0.17}_{-0.25}$	BESIII(2025)[159]
$\Lambda_c^+ \to \Sigma^0\pi^+$	$0.70^{+0.14}_{-0.48}$	BESIII(2025)[159]
$\Lambda_c^+ \to \Sigma^+\pi^0$	$0.76^{+0.05}_{-0.24}$	BESIII(2025)[159]
$\Lambda_c^+ \to \Xi^0 K^+$	-0.64 ± 0.70	BESIII(2024)[161]
$\Lambda_c^+ \to \Lambda K^+$	0.33 ± 0.08	LHCb(2024)[160]

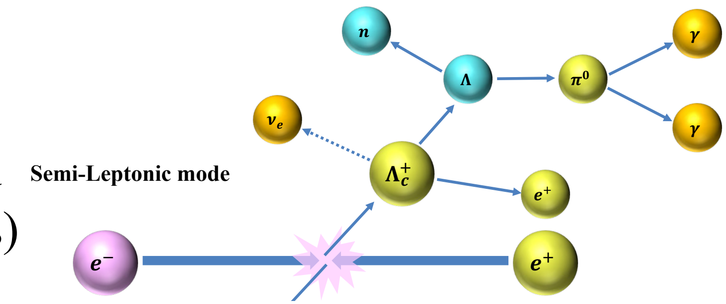
Mode	γ	Experiment
$\Lambda_c^+ \to \Lambda\pi^+$	0.491 ± 0.012	LHCb(2024)[160]
	$0.64^{+0.10}_{-0.20}$	BESIII(2025)[159]
$\Lambda_c^+ \to \Sigma^0\pi^+$	$-0.50^{+0.59}_{-0.30}$	BESIII(2025)[159]
$\Lambda_c^+ \to \Sigma^+\pi^0$	$-0.26^{+0.48}_{-0.38}$	BESIII(2025)[159]
$\Lambda_c^+ \to \Xi^0 K^+$	-0.77 ± 0.59	BESIII(2024)[161]
$\Lambda_c^+ \to \Lambda K^+$	-0.799 ± 0.041	LHCb(2024)[160]

Hunting for $\Lambda_c^+ \rightarrow n e^+ \nu$

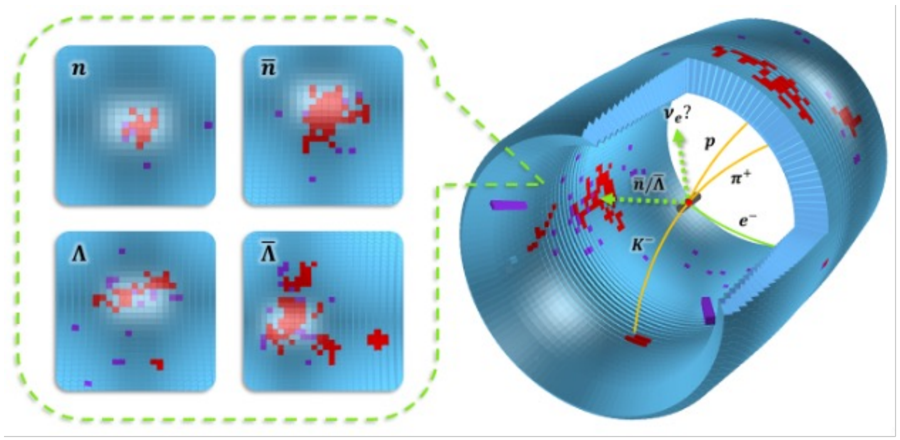
- **Important process of semi-leptonic Λ_c^+ decay to probe strong dynamics in charmed baryon**

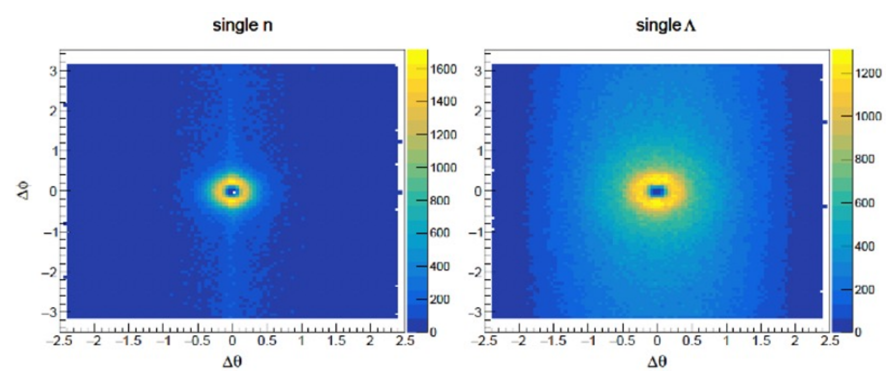


- **Challenges:**
  - ✓ neutrino is missing in detection
  - ✓ dominant backgrounds from $\Lambda_c^+ \rightarrow \Lambda(\rightarrow n\pi^0)e^+\nu$, with ~10x yields than that of the pursuing signals
  - ✓ elusive neutron detection due to neutral charge and contaminations from the photon showers (& noises) in electro-magnetic calorimeter (EMC)



Need advanced Machine Learning tool to identify neutron showers in EMC

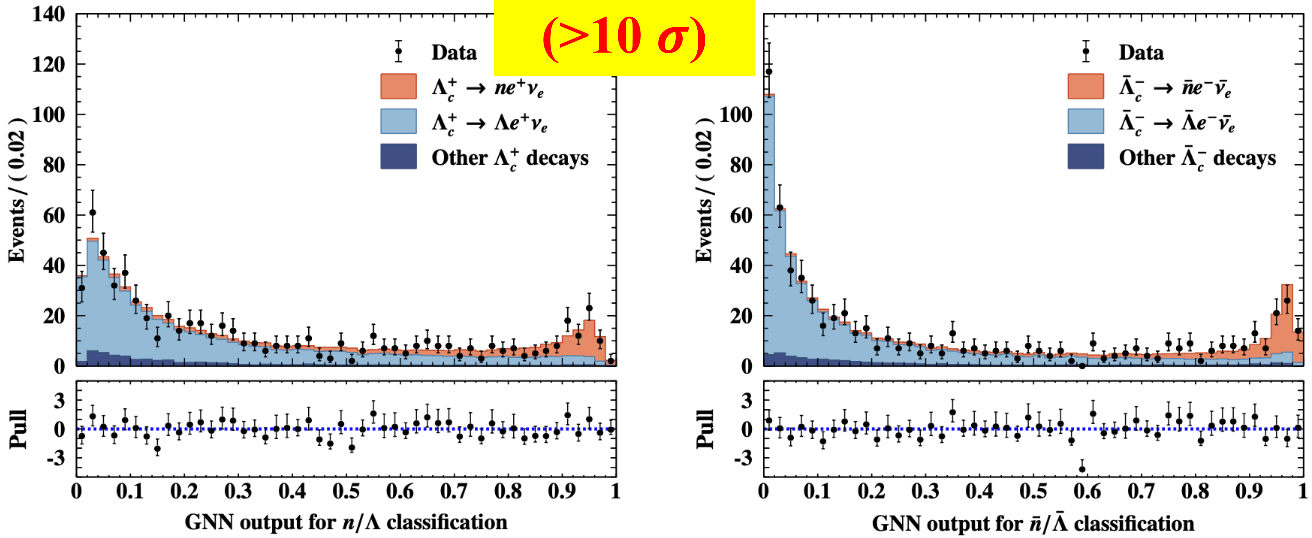




Observation of $\Lambda_c^+ \to n e^+ \nu$

Nature Comm. 16, 681 (2025)

(>10 σ)



good control of systematics on GNN training

- **Model settings**: network weight initialization, batch processing sequence and dropout layer are randomly varied
- **Domain shift**: validation of independent control sample via $J/\psi \to \Sigma^+(n\pi^+)\bar{\Sigma}^-(\bar{p}\pi^0)$ and $J/\psi \to \Xi^-(\Lambda\pi^-)\bar{\Xi}^+(\bar{\Lambda}\pi^+)$

$$\mathcal{B}(\Lambda_c^+ \to n e^+ \nu_e) = (0.357 \pm 0.034_{\text{stat.}} \pm 0.014_{\text{syst.}})\%$$

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

PRL 132, 031801(2024)

Theory or experiment	$\mathcal{B}(\Lambda_c^+ \to \Xi^0 K^+)$ ($\times 10^{-3}$)	$\alpha_{\Xi^0 K^+}$	$\|A\|$ ($\times 10^{-2} G_F$ GeV^2)	$\|B\|$ ($\times 10^{-2} G_F$ 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.

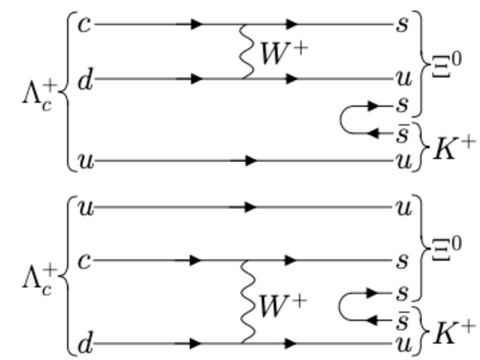


FIG. 1. Feynman diagrams for $\Lambda_c^+ \to \Xi^0 K^+$

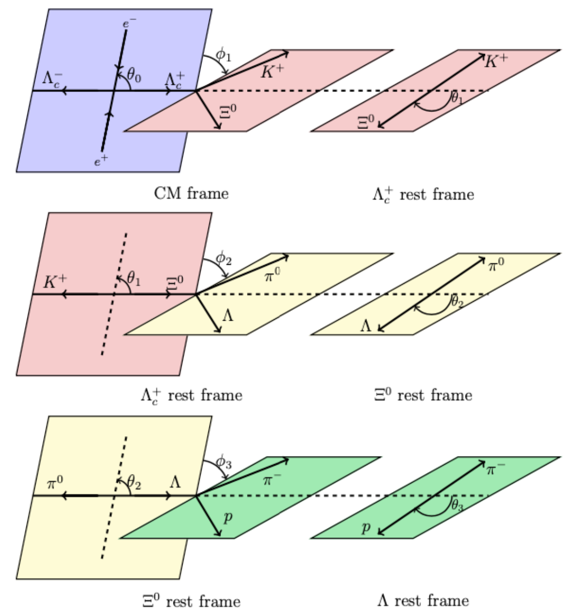
Decay asymmetry for pure W-exchange process $\Lambda_c^+ \to \Xi^0 K^+$

PRL 132, 031801(2024)

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

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}

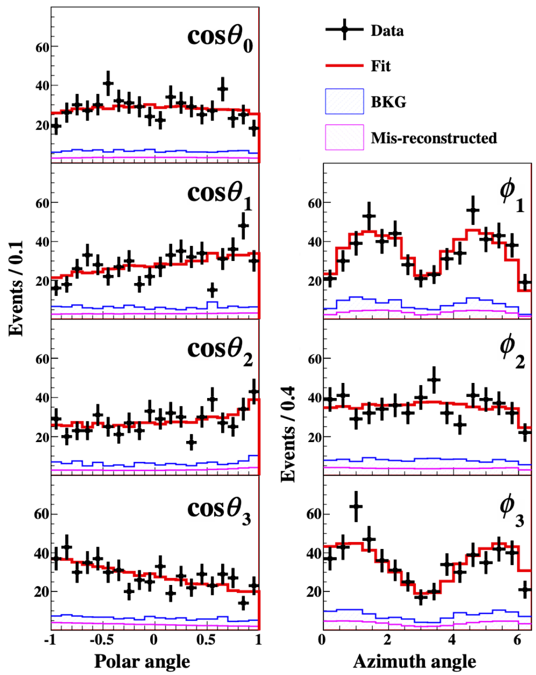
$$
\begin{aligned}
&\frac{d\Gamma}{d\cos\theta_0\ d\cos\theta_1\ d\cos\theta_2\ d\cos\theta_3\ d\phi_1\ d\phi_2\ d\phi_3} \\
&\propto 1 + \alpha_0\cos^2\theta_0 \\
&+ (1+\alpha_0\cos^2\theta_0)\ \alpha_{\Xi^0 K^+}\alpha_{\Lambda\pi^0}\cos\theta_2 \\
&+ (1+\alpha_0\cos^2\theta_0)\ \alpha_{\Xi^0 K^+}\alpha_{p\pi^-}\cos\theta_2\cos\theta_3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

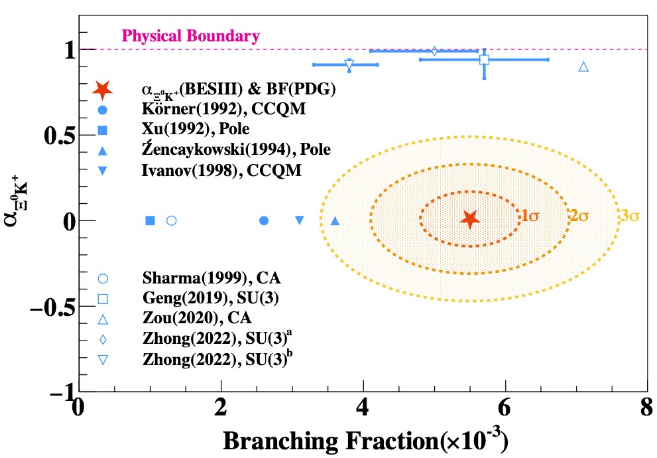


- The joint angular distribution for $\Lambda_c^+ \to \Xi^0 K^+$ is derived based on helicity amplitude.

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

PRL 132, 031801(2024)





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

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

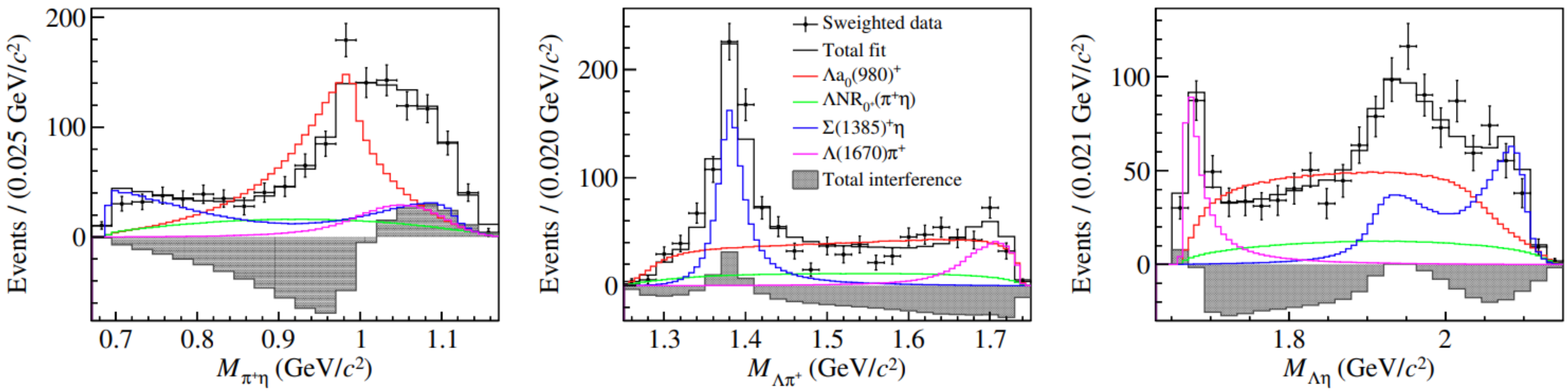
$$\alpha_{\Xi^0K^+} = \frac{2\kappa|A||B|\cos(\delta_p - \delta_s)}{|A|^2 + \kappa^2|B|^2},$$

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

- 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 $\alpha_{\Xi^0K^+}$ and $\mathcal{B}(\Lambda_c^+ \to \Xi^0 K^+)$ simultaneously.

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

PRL 134, 021901 (2025)



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

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

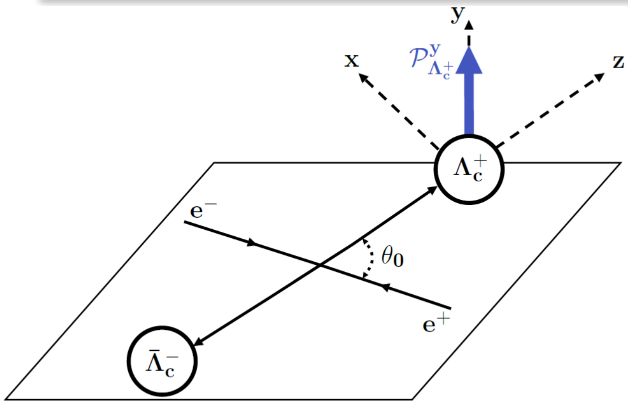
$$\alpha_{\Lambda(1670)\pi^+} = \frac{\left|H^{\Lambda_c^+\to\Lambda(1670)\pi^+}_{\frac{1}{2},0}\right|^2 - \left|H^{\Lambda_c^+\to\Lambda(1670)\pi^+}_{-\frac{1}{2},0}\right|^2}{\left|H^{\Lambda_c^+\to\Lambda(1670)\pi^+}_{\frac{1}{2},0}\right|^2 + \left|H^{\Lambda_c^+\to\Lambda(1670)\pi^+}_{-\frac{1}{2},0}\right|^2}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

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	$0.21 \pm 0.27 \pm 0.33$
ΛNR_{0^+}	15.4 ± 5.3	6.7σ	$\cdots$

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

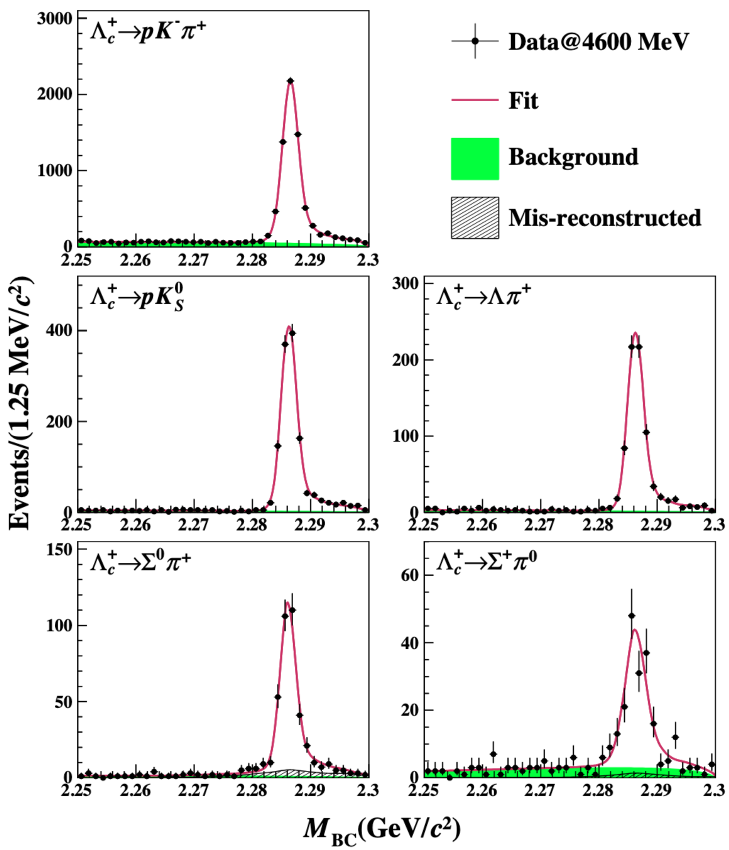
Production and Decay Dynamics of the Λ_c^+

arXiv 2508.11400



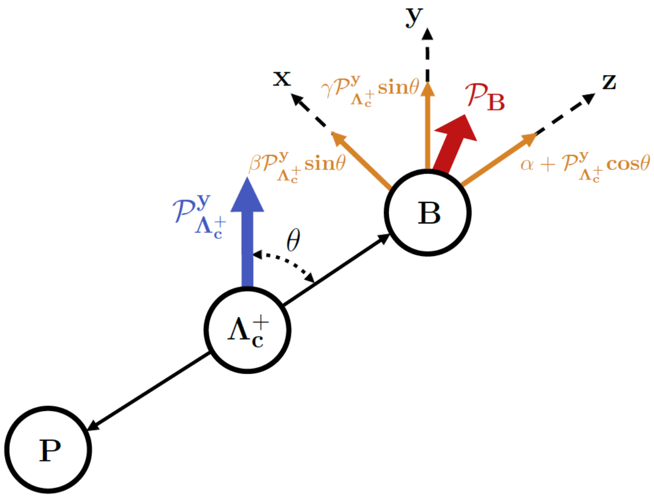
$$\mathcal{P}^{y}_{\Lambda_c^+}(\cos\theta_0) = \frac{3}{2(3+\alpha_0)}\sqrt{1-\alpha_0^2}\sin\theta_0\cos\theta_0\sin\Delta\Phi$$

- Measured transverse polarization using 587 fb^{-1} in 2018 but not found. [BESIII, PRD 100, 072004 (2019)]
- Using 6.4 fb^{-1} collected from 4.6-4.95 GeV, observe transverse polarization in multiple energy points.
- Joint angular analyses of the cascade decays of $\Lambda_c \to pK_s, \Lambda\pi^+, \Sigma^+\pi^0$ and $\Sigma^0\pi^+$ and amplitude analysis of $\Lambda_c \to pK^-\pi^+$



Production and Decay Dynamics of the Λ_c^+

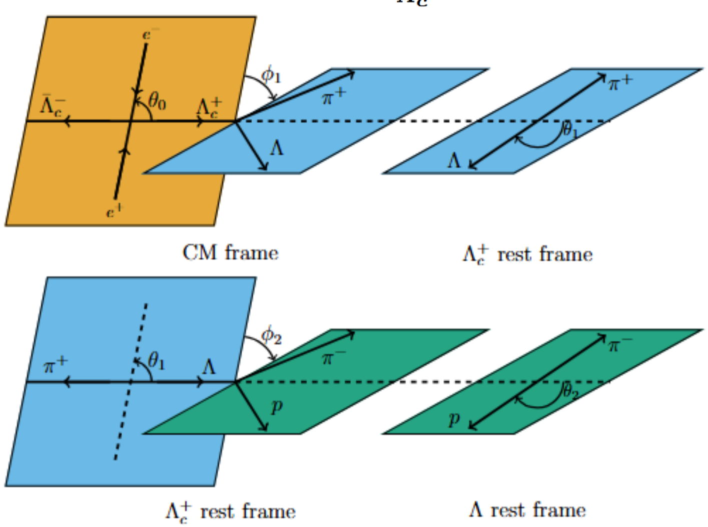
arXiv 2508.11400



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

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

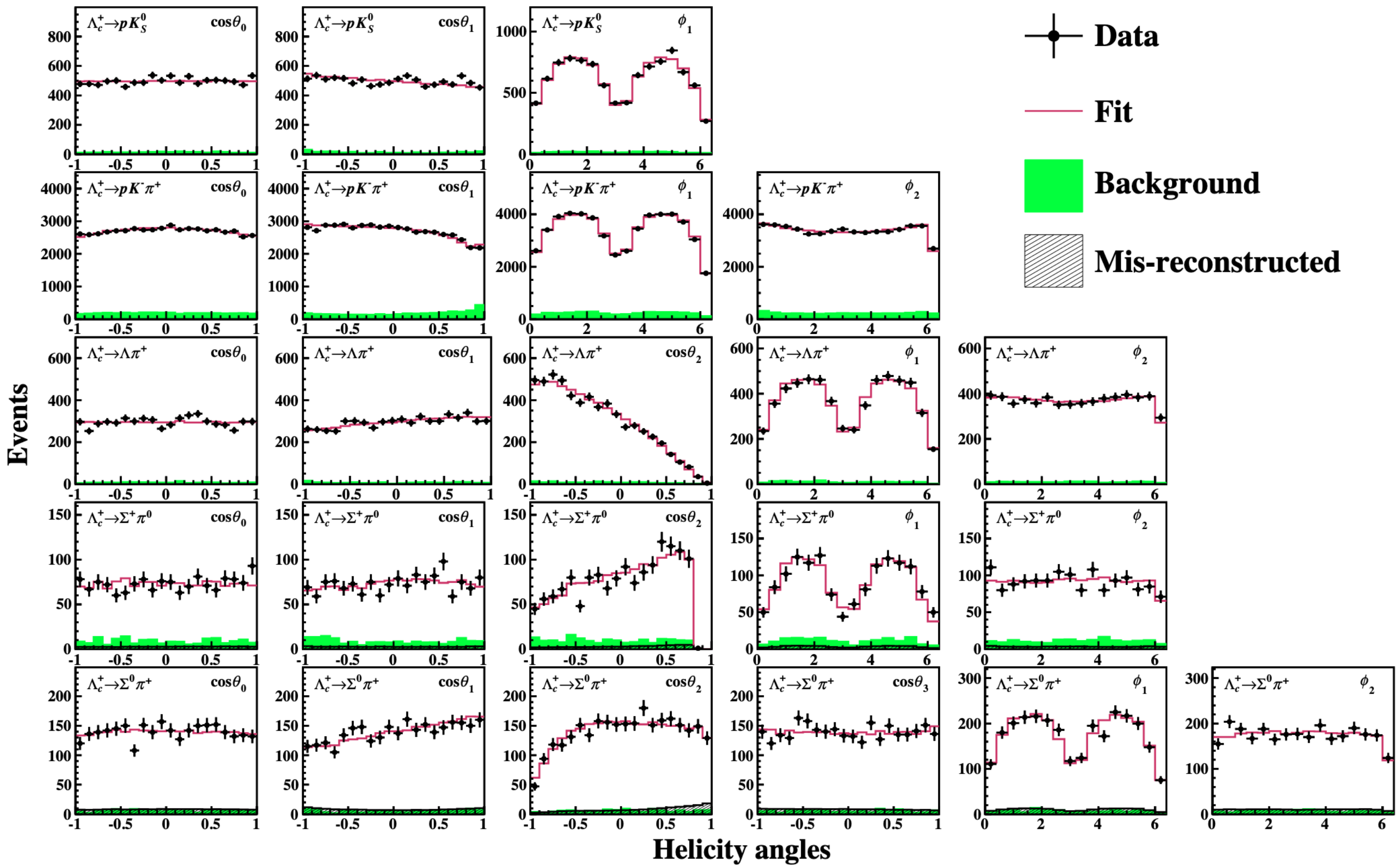
$$\boldsymbol{\mathcal{P}}_B = \frac{(\alpha + \boldsymbol{\mathcal{P}}^{y}_{\Lambda_c^+}\cdot\hat{\boldsymbol{n}})\hat{\boldsymbol{n}} + \beta(\boldsymbol{\mathcal{P}}^{y}_{\Lambda_c^+}\times\hat{\boldsymbol{n}}) + \gamma\hat{\boldsymbol{n}}\times(\boldsymbol{\mathcal{P}}^{y}_{\Lambda_c^+}\times\hat{\boldsymbol{n}})}{1+\alpha\boldsymbol{\mathcal{P}}^{y}_{\Lambd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



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

Production and Decay Dynamics of the Λ_c^+

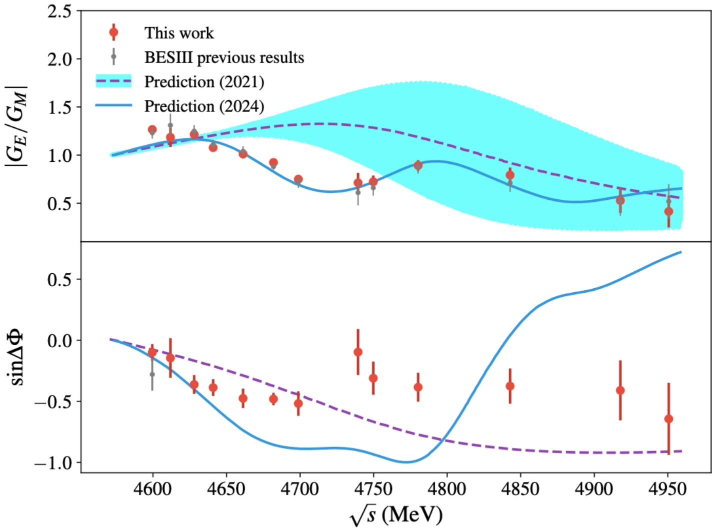
arXiv 2508.11400

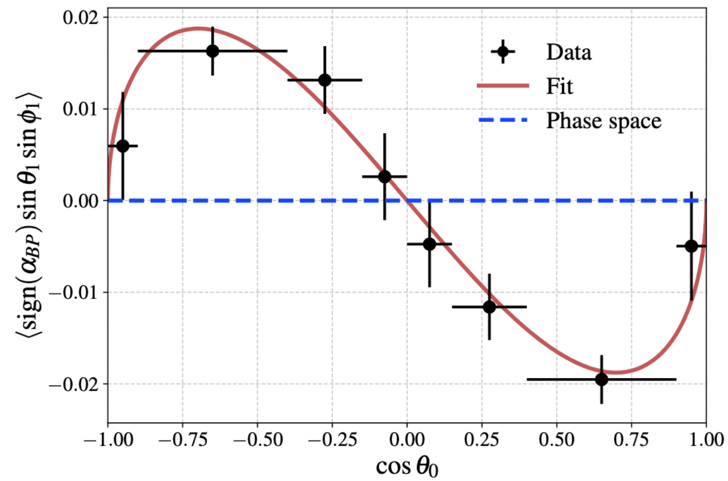


- Simultaneous fits to 23 angles of 5 channels at 13 energy points
- Established a new method to enhance the precisions of the decay asymmetries $\Lambda_c \to pK_S, \Lambda\pi^+, \Sigma^+\pi^0$ and $\Sigma^0\pi^+$

Production and Decay Dynamics of the Λ_c^+

arXiv 2508.11400



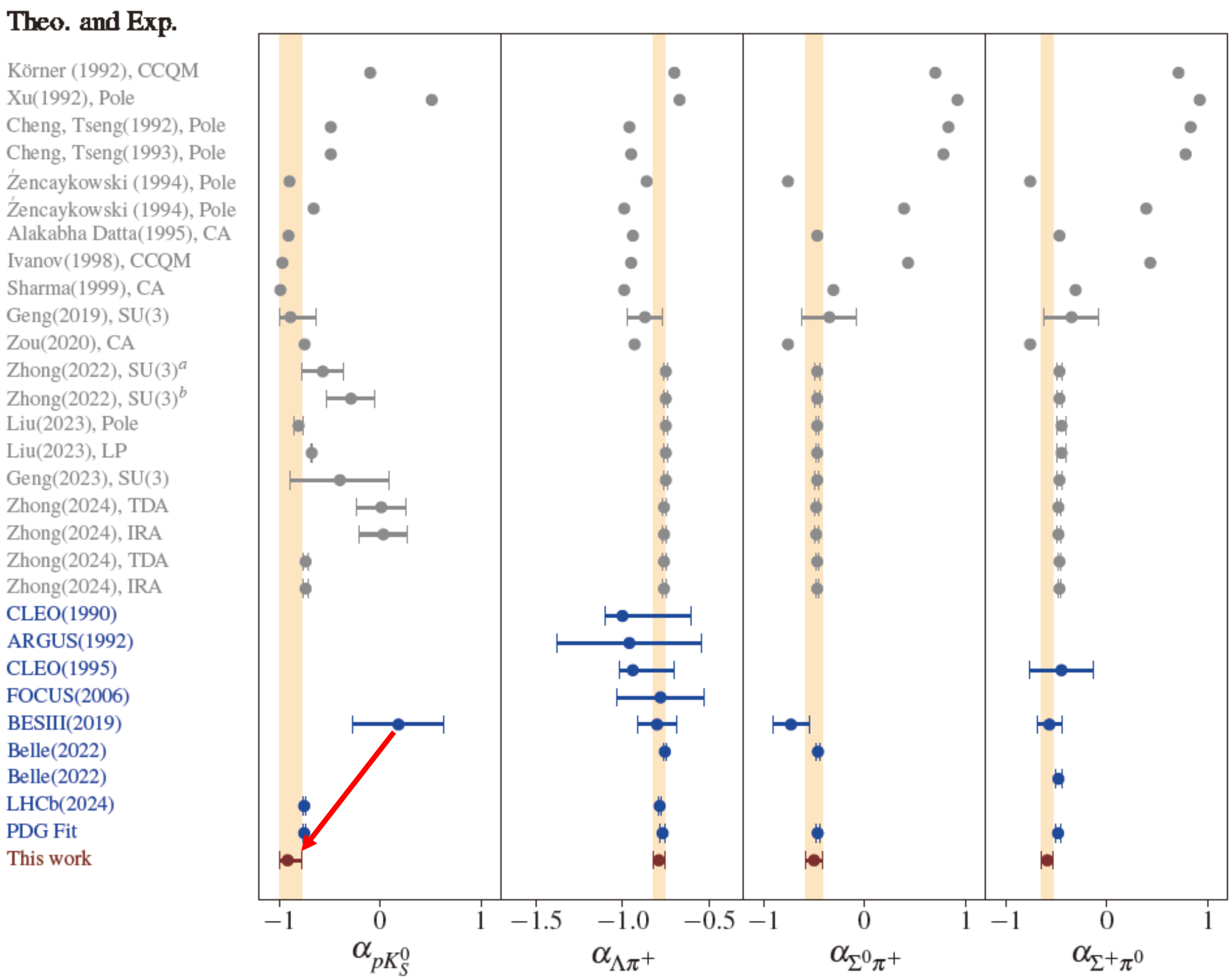


$\sqrt{s}$ [MeV]	α_0 in previous work [21, 92]	α_0 in this work	$\sin\Delta\Phi$	SL	$\sqrt{\langle \lvert \mathcal{P}^y_{\Lambda_c^+} \rvert^2 \rangle}$(%)
4600	$-0.20 \pm 0.04 \pm 0.02$	$-0.226 \pm 0.030 \pm 0.004$	$-0.100 \pm 0.068 \pm 0.009$	2.2σ	$3.90^{+2.62}_{-2.43} \pm 0.36$
4612	$-0.26 \pm 0.09 \pm 0.01$	$-0.160 \pm 0.083 \pm 0.004$	$-0.145 \pm 0.160 \pm 0.030$	1.1σ	$5.57^{+5.87}_{-3.83} \pm 1.15$
4628	$-0.21 \pm 0.04 \pm 0.01$	$-0.181 \pm 0.038 \pm 0.001$	$-0.363 \pm 0.077 \pm 0.012$	6.8σ	$14.02 \pm 2.95 \pm 0.46$
4641	$-0.09 \pm 0.05 \pm 0.01$	$-0.060 \pm 0.039 \pm 0.003$	$-0.388 \pm 0.067 \pm 0.015$	7.6σ	$14.47 \pm 2.49 \pm 0.56$
4661	$-0.02 \pm 0.05 \pm 0.01$	$0.008 \pm 0.044 \pm 0.003$	$-0.476 \pm 0.078 \pm 0.021$	8.5σ	$17.33 \pm 2.82 \pm 0.76$
4682	$0.15 \pm 0.03 \pm 0.01$	$0.102 \pm 0.029 \pm 0.003$	$-0.481 \pm 0.048 \pm 0.021$	14.1σ	$16.82 \pm 1.64 \pm 0.74$
4699	$0.34 \pm 0.07 \pm 0.01$	$0.305 \pm 0.055 \pm 0.010$	$-0.518 \pm 0.097 \pm 0.028$	7.1σ	$16.17 \pm 3.05 \pm 0.88$
4740	$0.49 \pm 0.16 \pm 0.03$	$0.358 \pm 0.126 \pm 0.008$	$-0.097 \pm 0.185 \pm 0.016$	0.4σ	$2.92^{+5.00}_{-2.01} \pm 0.48$
4750	$0.42 \pm 0.10 \pm 0.01$	$0.347 \pm 0.079 \pm 0.004$	$-0.311 \pm 0.134 \pm 0.019$	3.1σ	$9.43^{+3.98}_{-4.00} \pm 0.58$
4781	$0.17 \pm 0.07 \pm 0.01$	$0.157 \pm 0.062 \pm 0.007$	$-0.385 \pm 0.115 \pm 0.028$	5.1σ	$13.11^{+3.81}_{-3.88} \pm 0.95$
4843	$0.38 \pm 0.10 \pm 0.01$	$0.282 \pm 0.089 \pm 0.019$	$-0.376 \pm 0.140 \pm 0.034$	3.6σ	$11.92^{+4.19}_{-4.31} \pm 1.07$
4918	$0.62 \pm 0.17 \pm 0.01$	$0.612 \pm 0.150 \pm 0.019$	$-0.410 \pm 0.246 \pm 0.024$	1.9σ	$9.67^{+5.03}_{-5.36} \pm 0.61$
4951	$0.63 \pm 0.21 \pm 0.01$	$0.744 \pm 0.179 \pm 0.007$	$-0.644 \pm 0.304 \pm 0.058$	1.8σ	$12.35^{+7.57}_{-7.19} \pm 1.13$

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

Production and Decay Dynamics of the Λ_c^+

arXiv 2508.11400

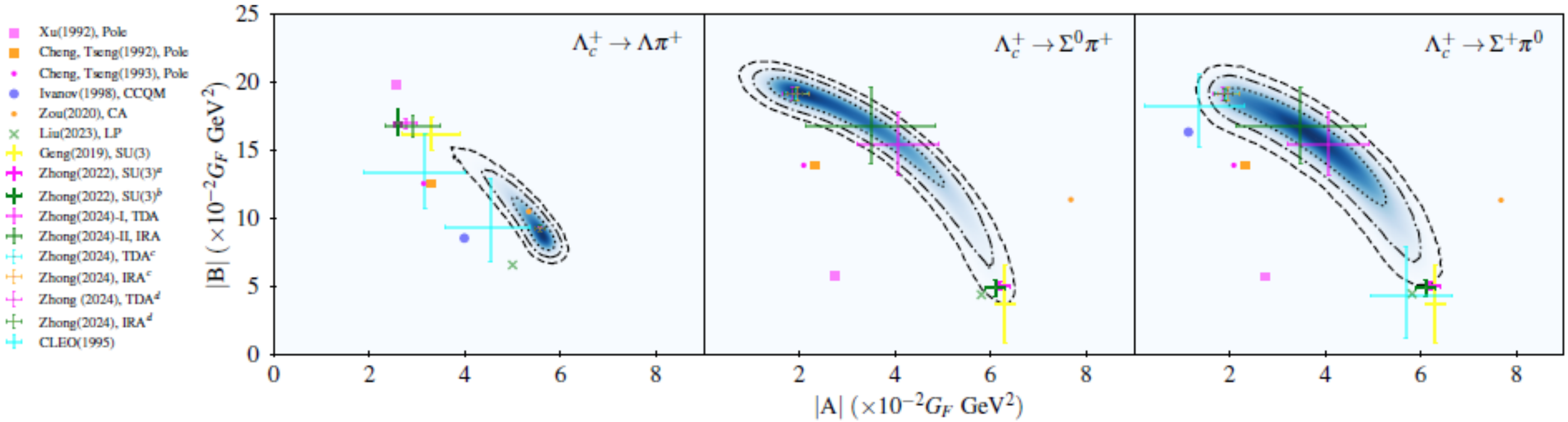


Production and Decay Dynamics of the Λ_c^+

arXiv 2508.11400

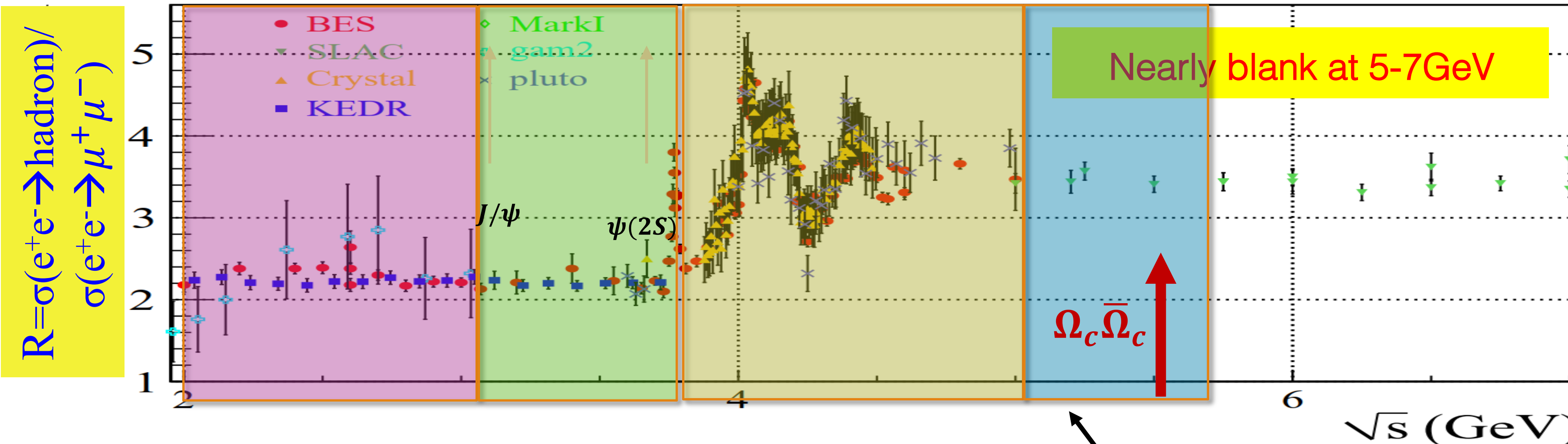
Parameter	$\Lambda_c^+ \to pK_S^0$	$\Lambda_c^+ \to \Lambda\pi^+$	$\Lambda_c^+ \to \Sigma^0\pi^+$	$\Lambda_c^+ \to \Sigma^+\pi^0$
$\langle\alpha_{BP}\rangle$	$-0.918^{+0.133}_{-0.082} \pm 0.031$	$-0.790 \pm 0.032 \pm 0.009$	$-0.502 \pm 0.080 \pm 0.009$	$-0.590 \pm 0.049 \pm 0.022$
$\langle\Delta_{BP}\rangle$	$\cdots$	$0.637 \pm 0.444 \pm 0.014$	$2.190 \pm 0.730 \pm 0.029$	$1.901 \pm 0.603 \pm 0.040$
$\langle\beta_{BP}\rangle$	$\cdots$	$0.365^{+0.173}_{-0.246} \pm 0.010$	$0.704^{+0.143}_{-0.480} \pm 0.015$	$0.764^{+0.051}_{-0.237} \pm 0.018$
$\langle\gamma_{BP}\rangle$	$\cdots$	$0.637^{+0.103}_{-0.202} \pm 0.011$	$-0.502^{+0.591}_{-0.303} \pm 0.021$	$-0.262^{+0.478}_{-0.383} \pm 0.031$
$\langle\Delta_S\rangle$	$\cdots$	$2.71^{+0.28}_{-0.17} \pm 0.02$	$2.19^{+0.49}_{-0.13} \pm 0.02$	$2.23^{+0.19}_{-0.06} \pm 0.03$
$\tan\langle\Delta_S\rangle$	$\cdots$	$-0.46^{+0.31}_{-0.22} \pm 0.02$	$-1.40^{+0.90}_{-0.47} \pm 0.05$	$-1.29^{+0.41}_{-0.19} \pm 0.08$

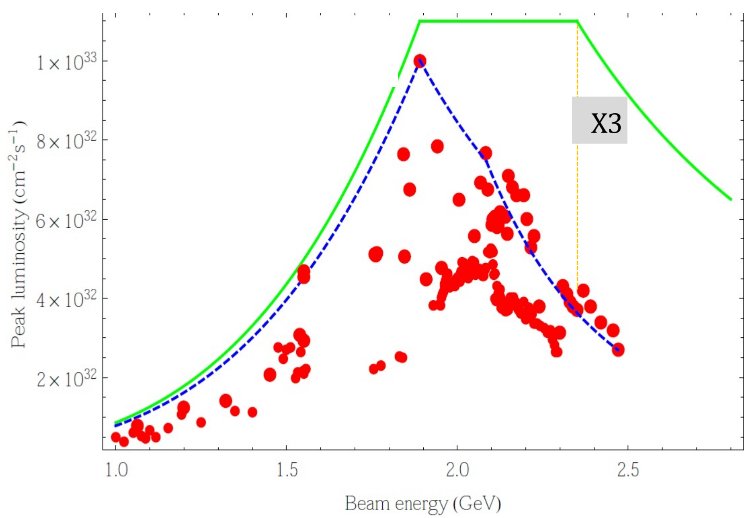
Parameter	$\Lambda_c^+ \to pK_S^0$	$\Lambda_c^+ \to \Lambda\pi^+$	$\Lambda_c^+ \to \Sigma^0\pi^+$	$\Lambda_c^+ \to \Sigma^+\pi^0$
$A_{CP}^{\alpha_{BP}}$	$0.079^{+0.115}_{-0.101} \pm 0.019$	$0.002 \pm 0.047 \pm 0.017$	$0.206^{+0.188}_{-0.156} \pm 0.028$	$-0.086 \pm 0.081 \pm 0.029$
$\tan\phi_{CP}$	$\cdots$	$0.232 \pm 0.242 \pm 0.025$	$0.393 \pm 0.651 \pm 0.042$	$-0.007 \pm 0.474 \pm 0.034$
$\tan\Delta_S$	$\cdots$	$-0.475 \pm 0.242 \pm 0.029$	$-1.411 \pm 0.672 \pm 0.062$	$-1.297 \pm 0.478 \pm 0.068$



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	15 fb^{-1} at different $\sqrt{s}$	1490/600 days
4.74 GeV	$\Sigma_c^+\bar{\Lambda}_c^-$ cross-section	N/A	1.0 fb^{-1}	100/40 days
4.91 GeV	$\Sigma_c\bar{\Sigma}_c$ cross-section	N/A	1.0 fb^{-1}	120/50 days
4.95 GeV	Ξ_c decays	N/A	1.0 fb^{-1}	130/50 days

- Began a new round of Λ_c^+ data taking at 4.68 GeV on Feb.27 2026
- Very smooth data taking
- BEPCII-U reached the designed luminosity at E_beam= 2.35 GeV

Summary

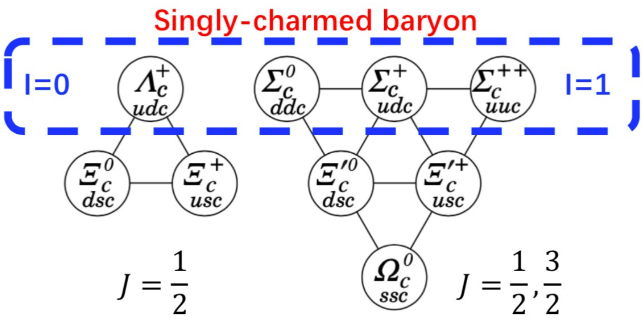
- In recent years, experimental activities on charmed baryons are reviving, esp. at BESIII
- Threshold data at BESIII opens a new door to direct measurements of the decays ➔comprehensive and systematic studies of charmed baryon decays
  - ✓ BESIII has published several world-leading results based on ~80 M Λ_c^+ samples
  - ✓ Additional >160 M Λ_c^+ samples are collecting now
  - ✓ More efforts on hadronic decays with $n/\Sigma/\Xi$ particles & semi-leptonic decays
- Opportunity in other charmed baryons:
  Plan to take data up to 5.6 GeV to cover all the ground-state charmed baryons

Thanks!

Backup

Energy thresholds

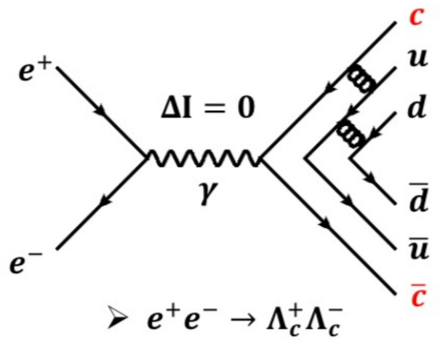
- ✓ $e^+e^- \to \Lambda_c^+\bar{\Sigma}_c^-$ 4.74~4.87 GeV
- ✓ $e^+e^- \to \Lambda_c^+\bar{\Lambda}_c^-(2595)(\bar{\Sigma}_c\,\pi)$ 4.88 GeV
- ✓ $e^+e^- \to \Sigma_c\,\bar{\Sigma}_c$ 4.91 GeV
- ✓ $e^+e^- \to \Xi_c\,\bar{\Xi}_c$ 4.95 GeV

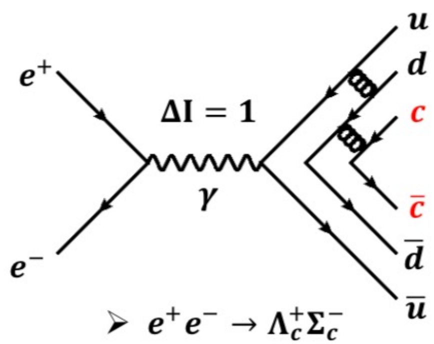


The Born cross-section **ratios** between $\Lambda_c^+\Lambda_c^- + c.c.$ and $\Lambda_c^-\Sigma_c^+ + c.c.$ at different energy points can provide more information about the production of $c\bar{c}$ or $q\bar{q}$ from vacuum.

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

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Hyperon decays and *CP* nonconservation

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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*

$$\Delta = \frac{\Gamma - \bar{\Gamma}}{\Gamma + \bar{\Gamma}} \approx \sqrt{2}\frac{T_{\frac{3}{2}}}{T_{\frac{1}{2}}} \sin\Delta_s \sin\phi_{CP} \qquad -5.4\times10^{-7}$$

Easiest to measure

$$A = \frac{\Gamma\alpha + \bar{\Gamma}\bar{\alpha}}{\Gamma\alpha - \bar{\Gamma}\bar{\alpha}} \approx \tan\Delta_s \tan\phi_{CP} \qquad -0.5\times10^{-4}$$

Polarization of decayed baryon needs to be measured

$$B = \frac{\Gamma\beta + \bar{\Gamma}\bar{\beta}}{\Gamma\alpha - \bar{\Gamma}\bar{\alpha}} \approx \tan\phi_{CP} \qquad 3.0\times10^{-3}$$