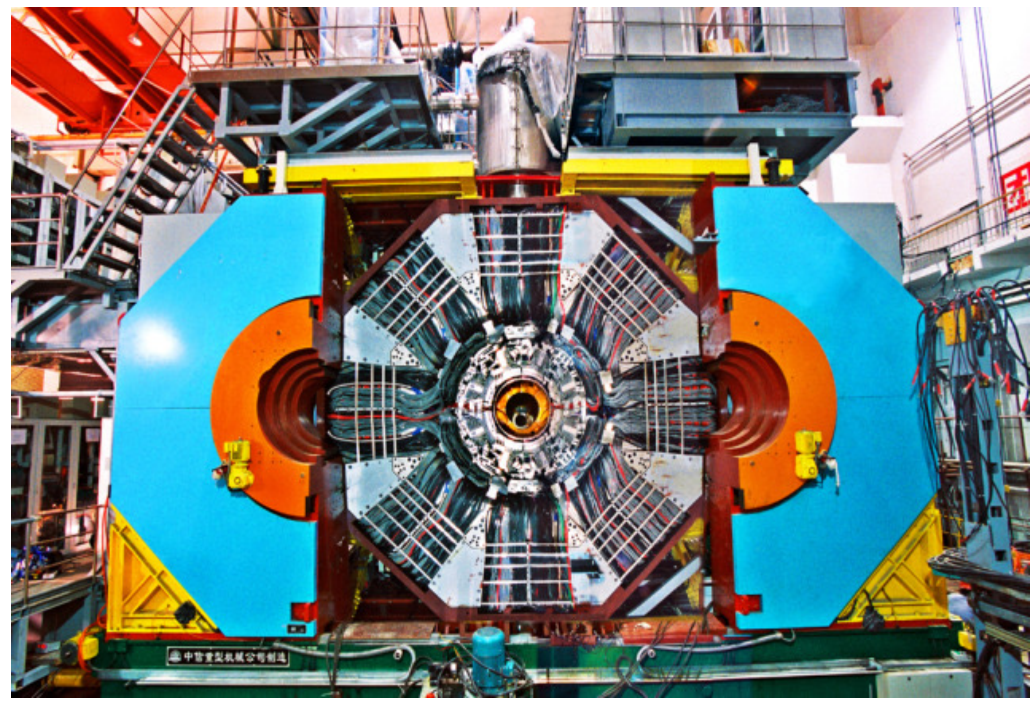
Charm baryon physics at BESIII

Lei Li (BESIII Collaboration)

Renmin University of China

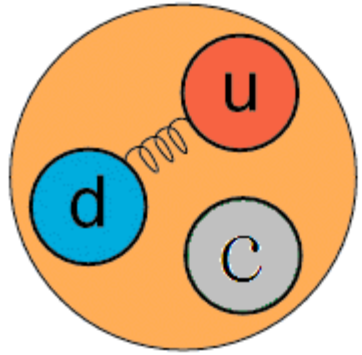


The 29th International Workshop on Weak Interactions and Neutrinos, July 2-8, 2023

Outline

- **Introduction**
- **Charm baryon physics at BESIII**
  - ✓ Λ_c^+ semi-leptonic decays
  - ✓ Λ_c^+ hadronic decays
- **Summary**

Λ_c^+ cornerstone of charmed baryon spectroscopy



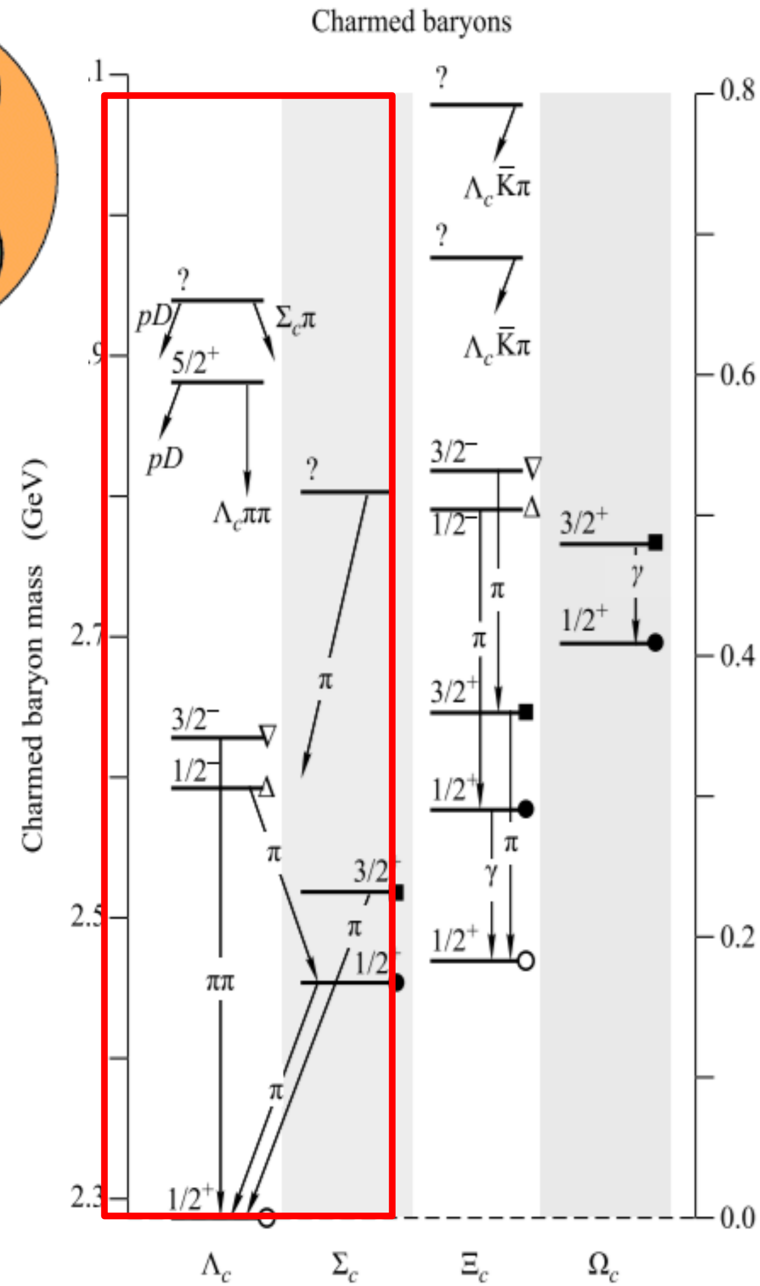
Quark model picture:

a heavy quark (c) with a unexcited spin-zero diquark (u-d)
Heavy Quark Effective Theory predicts that Λ_c may provide more powerful test on internal dynamics than D/D_s

Cornerstone of charmed baryons:

Λ_c^+ is the lightest charmed baryon, most of charmed baryons will eventually decay to Λ_c

Essential input for study the decays of b-flavored hadrons involving Λ_c in final state



Status of Λ_c^+ measurement [PDG2015]:

- *poorly understood compared to charm mesons total BF~60%, large uncertainties(>20%)*
- *Relative measurement*
- *No neutron mode has been observed yet.*

Λ_c^+ Measurements [PDG2015]

Λ_c^+ DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	ΔB/B
Hadronic modes with a p: $S=-1$ final states				
$p\overline{K}^0$		(3.21± 0.30) %		9.3%
$pK^-\pi^+$		(6.84$^{+0.32}_{-0.40}$) %		5.8%
$p\overline{K}^*(892)^0$	[q]	(2.13± 0.30) %		14.1%
$\Delta(1232)^{++}K^-$		(1.18± 0.27) %		22.9%
$\Lambda(1520)\pi^+$	[q]	(2.4 ± 0.6) %		25.0%
$pK^-\pi^+$ nonresonant		(3.8 ± 0.4) %		10.5%
$p\overline{K}^0\pi^0$		(4.5 ± 0.6) %		13.3%
$p\overline{K}^0\eta$		(1.7 ± 0.4) %		23.5%
$p\overline{K}^0\pi^+\pi^-$		(3.5 ± 0.4) %		11.4%
$pK^-\pi^+\pi^0$		(4.6 ± 0.8) %		13.0%
$pK^*(892)^-\pi^+$	[q]	(1.5 ± 0.5) %		33.3%
$p(K^-\pi^+)_{\text{nonresonant}}\pi^0$		(5.0 ± 0.9) %		18.0%
$\Delta(1232)\overline{K}^*(892)$		seen		
$pK^-\pi^+\pi^+\pi^-$		(1.5 ± 1.0) × 10^{-3}		66.7%
$pK^-\pi^+\pi^0\pi^0$		(1.1 ± 0.5) %		45.4%
Hadronic modes with a p: $S=0$ final states				
$p\pi^+\pi^-$		(4.7 ± 2.5) × 10^{-3}		45.4%
$pf_0(980)$	[q]	(3.8 ± 2.5) × 10^{-3}		53.2%
$p\pi^+\pi^+\pi^-\pi^-$		(2.5 ± 1.6) × 10^{-3}		64.0%
pK^+K^-		(1.1 ± 0.4) × 10^{-3}		36.4%
$p\phi$	[q]	(1.12± 0.23) × 10^{-3}		
pK^+K^- non-ϕ		(4.8 ± 1.9) × 10^{-4}		
Hadronic modes with a hyperon: $S=-1$ final states				
$\Lambda\pi^+$		(1.46± 0.13) %		8.9%
$\Lambda\pi^+\pi^0$		(5.0 ± 1.3) %		26.0%
$\Lambda\rho^+$		< 6 %	CL=95%	
$\Lambda\pi^+\pi^+\pi^-$		(3.59± 0.28) %		7.8%
$\Sigma(1385)^+\pi^+\pi^-$, $\Sigma^{*+}\to\Lambda\pi^+$		(1.0 ± 0.5) %		20.0%
$\Sigma(1385)^-\pi^+\pi^+$, $\Sigma^{*-}\to\Lambda\pi^-$		(7.5 ± 1.4) × 10^{-3}		18.7%
$\Lambda\pi^+\rho^0$		(1.4 ± 0.6) %		42.8%
$\Sigma(1385)^+\rho^0$, $\Sigma^{*+}\to\Lambda\pi^+$		(5 ± 4) × 10^{-3}		80.0%
$\Lambda\pi^+\pi^+\pi^-$ nonresonant		< 1.1 %	CL=90%	
$\Lambda\pi^+\pi^+\pi^-\pi^0$ total		(2.5 ± 0.9) %		36.0%
$\Lambda\pi^+\eta$	[q]	(2.4 ± 0.5) %		20.8%
$\Sigma(1385)^+\eta$	[q]	(1.16± 0.35) %		30.2%
$\Lambda\pi^+\omega$	[q]	(1.6 ± 0.6) %		37.5%
$\Lambda\pi^+\pi^+\pi^-\pi^0$, no η or ω		< 9 × 10^{-3}	CL=90%	
$\Lambda K^+\overline{K}^0$		(6.4 ± 1.3) × 10^{-3}	S=1.6	20.3%
$\Xi(1690)^0K^+$, $\Xi^{*0}\to\Lambda\overline{K}^0$		(1.8 ± 0.6) × 10^{-3}		33.3%
$\Sigma^0\pi^+$		(1.43± 0.14) %		10.0%
$\Sigma^+\pi^0$		(1.37± 0.30) %		21.9%
$\Sigma^+\eta$		(7.5 ± 2.5) × 10^{-3}		33.3%
$\Sigma^+\pi^+\pi^-$		(4.9 ± 0.5) %		10.2%
$\Sigma^+\rho^0$		< 1.8 %	CL=95%	
$\Sigma^-\pi^+\pi^+$		(2.3 ± 0.4) %		17.4%
$\Sigma^0\pi^+\pi^0$		(2.5 ± 0.9) %		36.0%
$\Sigma^0\pi^+\pi^+\pi^-$		(1.13± 0.31) %		27.4%
$\Sigma^+\pi^+\pi^-\pi^0$		—		
$\Sigma^+\omega$	[q]	(3.7 ± 1.0) %		27.1%
$\Sigma^+K^+K^-$		(3.8 ± 0.6) × 10^{-3}		15.8%
$\Sigma^+\phi$	[q]	(4.3 ± 0.7) × 10^{-3}		16.3%
$\Xi(1690)^0K^+$, $\Xi^{*0}\to\Sigma^+K^-$		(1.11± 0.29) × 10^{-3}		26.2%
$\Sigma^+K^+K^-$ nonresonant		< 9 × 10^{-4}	CL=90%	
Ξ^0K^+		(5.3 ± 1.3) × 10^{-3}		24.5%
$\Xi^-K^+\pi^+$		(7.0 ± 0.8) × 10^{-3}	S=1.1	11.4%
$\Xi(1530)^0K^+$	[q]	(3.5 ± 1.0) × 10^{-3}		28.6%
Hadronic modes with a hyperon: $S=0$ final states				
ΛK^+		(6.9 ± 1.4) × 10^{-4}		20.3%
$\Lambda K^+\pi^+\pi^-$		< 6 × 10^{-4}	CL=90%	
Σ^0K^+		(5.7 ± 1.0) × 10^{-4}		17.5%
$\Sigma^0K^+\pi^+\pi^-$		< 2.9 × 10^{-4}	CL=90%	
$\Sigma^+K^+\pi^-$		(2.3 ± 0.7) × 10^{-3}		30.4%
$\Sigma^+K^*(892)^0$	[q]	(3.8 ± 1.2) × 10^{-3}		31.6%
$\Sigma^-K^+\pi^+$		< 1.3 × 10^{-3}	CL=90%	
Doubly Cabibbo-suppressed modes				
$pK^+\pi^-$		< 3.1 × 10^{-4}	CL=90%	
Semileptonic modes				
$\Lambda\ell^+\nu_\ell$	[r]	(2.8 ± 0.4) %		
$\Lambda e^+\nu_e$		(2.9 ± 0.5) %		17.2%
$\Lambda\mu^+\nu_\mu$		(2.7 ± 0.6) %		22.2%

HTTP://PDG.LBL.GOV Page 32 Created: 10/6/2015 12

- ✓ *Total branching fraction ~60%.*
- ✓ *Lots of unknown decay channels*
- ✓ *Quite large uncertainties(>20%)*
- ✓ *Most BFs are measured relative to $\Lambda_c^+\to pK^-\pi^+$*

Λ_c^+ Measurements [PDG2022]

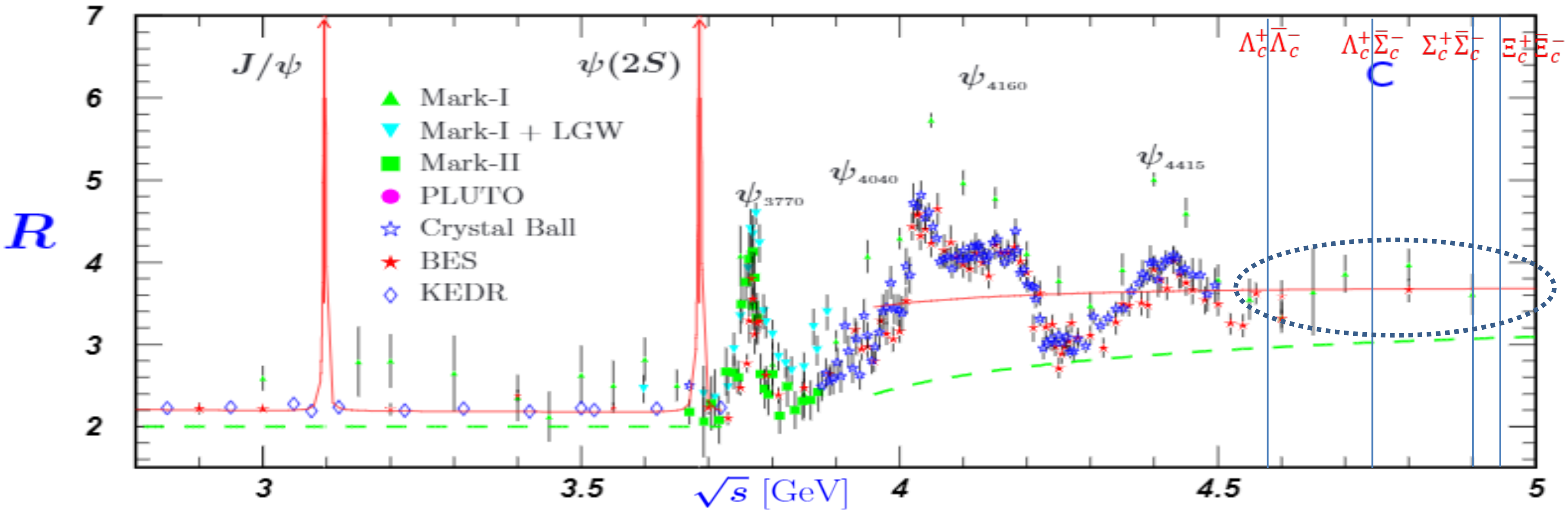
衰变分支比测量精度ΔB/B

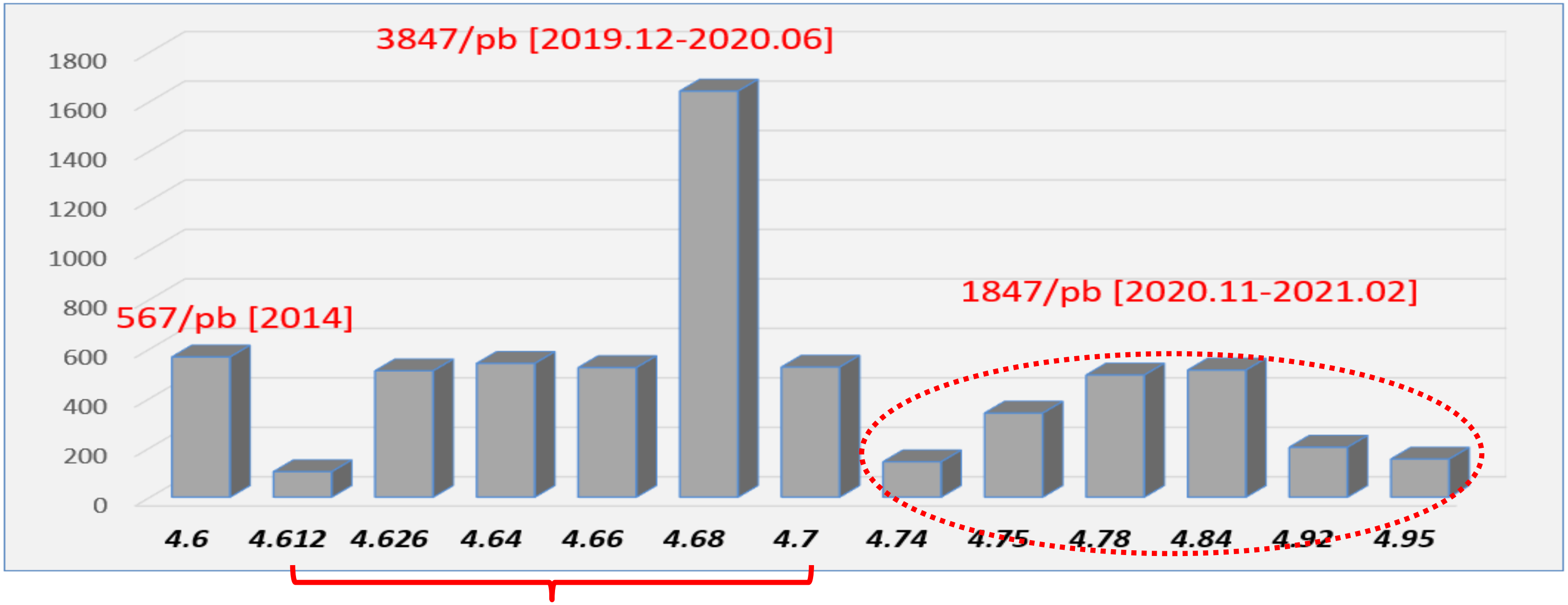
Λ_c^+ DECAY MODES		Fraction (Γ_i/Γ)	Confidence	ΔB/B
Hadronic modes with a p or n: $S=-1$ final states				
pK_S^0		(1.59 ± 0.08) %	S=1.1	5.0%
$pK^-\pi^+$		(6.28 ± 0.32) %	S=1.4	5.1%
$p\overline{K}^*(892)^0$	[r]	(1.96 ± 0.27) %		13.8%
$\Delta(1232)^{++}K^-$		(1.08 ± 0.25) %		23.1%
$\Lambda(1520)\pi^+$	[r]	(2.2 ± 0.5) %		22.7%
$pK^-\pi^+$ nonresonant		(3.5 ± 0.4) %		11.5%
$pK_S^0\pi^0$		(1.97 ± 0.13) %	S=1.1	6.6%
$nK_S^0\pi^+$		(1.82 ± 0.25) %		13.7%
$p\overline{K}^0\eta$		$(8.3\pm1.8)\times10^{-3}$		21.7%
$pK_S^0\pi^+\pi^-$		(1.60 ± 0.12) %	S=1.1	7.5%
$pK^-\pi^+\pi^0$		(4.46 ± 0.30) %	S=1.5	6.8%
$pK^*(892)^-\pi^+$	[r]	(1.4 ± 0.5) %		35.7%
$p(K^-\pi^+)_{\text{nonresonant}}\pi^0$		(4.6 ± 0.8) %		17.4%
$\Delta(1232)\overline{K}^*(892)$		seen		
$pK^-2\pi^+\pi^-$		$(1.4\pm0.9)\times10^{-3}$		64.3%
$pK^-\pi^+2\pi^0$		(1.0 ± 0.5) %		50.0%
Hadronic modes with a p: $S=0$ final states				
$p\pi^0$		$<8\times10^{-5}$	CL=90%	
$p\eta$		$(1.42\pm0.12)\times10^{-3}$		8.4%
$p\omega(782)^0$		$(8.3\pm1.1)\times10^{-4}$		13.2%
$p\pi^+\pi^-$		$(4.61\pm0.28)\times10^{-3}$		6.0%
$pf_0(980)$	[r]	$(3.5\pm2.3)\times10^{-3}$		65.7%
$p2\pi^+2\pi^-$		$(2.3\pm1.4)\times10^{-3}$		60.8%
pK^+K^-		$(1.06\pm0.06)\times10^{-3}$		5.6%
$p\phi$	[r]	$(1.06\pm0.14)\times10^{-3}$		13.2%
pK^+K^- non-ϕ		$(5.3\pm1.2)\times10^{-4}$		22.6%
$p\phi\pi^0$		$(10\pm4)\times10^{-5}$		40.0%
$pK^+K^-\pi^0$ nonresonant		$<6.3\times10^{-5}$	CL=90%	
Inclusive modes				
e^+ anything		(3.95 ± 0.35) %		8.9%
p anything		(50 ± 16) %		32.0%
n anything		(50 ± 16) %		32.0%
Λ anything		$(38.2^{+2.9}_{-2.4})$ %		~7.0%
K_S^0 anything		(9.9 ± 0.7) %		7.1%
3prongs		(24 ± 8) %		33.3%

Mode		Fraction (Γ_i/Γ)	Scale / CL	ΔB/B
Hadronic modes with a hyperon: $S=-1$ final states				
$\Lambda\pi^+$		(1.30 ± 0.07) %	S=1.1	5.4%
$\Lambda(1670)\pi^+$, $\Lambda(1670)\to\eta\Lambda$		$(3.5\pm0.5)\times10^{-3}$		14.3%
$\Lambda\pi^+\pi^0$		(7.1 ± 0.4) %	S=1.1	5.6%
$\Lambda\rho^+$		<6 %	CL=95%	
$\Lambda\pi^-2\pi^+$		(3.64 ± 0.29) %	S=1.4	8.0%
$\Sigma(1385)^+\pi^+\pi^-$, $\Sigma^{*+}\to\Lambda\pi^+$		(1.0 ± 0.5) %		50.0%
$\Sigma(1385)^-2\pi^+$, $\Sigma^{*-}\to\Lambda\pi^-$		$(7.6\pm1.4)\times10^{-3}$		18.4%
$\Lambda\pi^+\rho^0$		(1.5 ± 0.6) %		40.0%
$\Sigma(1385)^+\rho^0$, $\Sigma^{*+}\to\Lambda\pi^+$		$(5\pm4)\times10^{-3}$		80.0%
$\Lambda\pi^-2\pi^+$ nonresonant		<1.1 %	CL=90%	
$\Lambda\pi^-\pi^02\pi^+$ total		(2.3 ± 0.8) %		34.8%
$\Lambda\pi^+\eta$	[r]	(1.84 ± 0.26) %		14.1%
$\Sigma(1385)^+\eta$	[r]	$(9.1\pm2.0)\times10^{-3}$		21.9%
$\Lambda\pi^+\omega$	[r]	(1.5 ± 0.5) %		33.3%
$\Lambda\pi^-\pi^02\pi^+$, no η or ω		$<8\times10^{-3}$	CL=90%	
$\Lambda K^+\overline{K}^0$		$(5.7\pm1.1)\times10^{-3}$	S=1.9	19.3%
$\Xi(1690)^0K^+$, $\Xi^{*0}\to\Lambda\overline{K}^0$		$(1.6\pm0.5)\times10^{-3}$		31.2%
$\Sigma^0\pi^+$		(1.29 ± 0.07) %	S=1.1	5.4%
$\Sigma^0\pi^+\eta$		$(7.5\pm0.8)\times10^{-3}$		10.7%
$\Sigma^+\pi^0$		(1.25 ± 0.10) %		8.0%
$\Sigma^+\eta$		$(4.4\pm2.0)\times10^{-3}$		45.4%
$\Sigma^+\eta'$		(1.5 ± 0.6) %		40.0%
$\Sigma^+\pi^+\pi^-$		(4.50 ± 0.25) %	S=1.3	5.6%
$\Sigma^+\rho^0$		<1.7 %	CL=95%	
$\Sigma^-2\pi^+$		(1.87 ± 0.18) %		9.6%
$\Sigma^0\pi^+\pi^0$		(3.5 ± 0.4) %		11.4%
$\Sigma^+\pi^0\pi^0$		(1.55 ± 0.15) %		9.7%
$\Sigma^0\pi^-2\pi^+$		(1.11 ± 0.30) %		27.0%
$\Sigma^+\pi^+\pi^-\pi^0$		—		
$\Sigma^+\omega$	[r]	(1.70 ± 0.21) %		12.4%
$\Sigma^-\pi^02\pi^+$		(2.1 ± 0.4) %		19.0%
$\Sigma^+K^+K^-$		$(3.5\pm0.4)\times10^{-3}$	S=1.1	11.4%
$\Sigma^+\phi$	[r]	$(3.9\pm0.6)\times10^{-3}$	S=1.1	15.4%
$\Xi(1690)^0K^+$, $\Xi^{*0}\to\Sigma^+K^-$		$(1.02\pm0.25)\times10^{-3}$		24.5%
$\Sigma^+K^+K^-$ nonresonant		$<8\times10^{-4}$	CL=90%	
Ξ^0K^+		$(5.5\pm0.7)\times10^{-3}$		12.7%
$\Xi^-K^+\pi^+$		$(6.2\pm0.6)\times10^{-3}$	S=1.1	9.7%
$\Xi(1530)^0K^+$		$(4.3\pm0.9)\times10^{-3}$	S=1.1	20.9%
Hadronic modes with a hyperon: $S=0$ final states				
ΛK^+		$(6.1\pm1.2)\times10^{-4}$		19.7%
$\Lambda K^+\pi^+\pi^-$		$<5\times10^{-4}$	CL=90%	
Σ^0K^+		$(5.2\pm0.8)\times10^{-4}$		15.4%
$\Sigma^0K^+\pi^+\pi^-$		$<2.6\times10^{-4}$	CL=90%	
$\Sigma^+K^+\pi^-$		$(2.1\pm0.6)\times10^{-3}$		28.6%
$\Sigma^+K^*(892)^0$	[r]	$(3.5\pm1.0)\times10^{-3}$		28.6%
$\Sigma^-K^+\pi^+$		$<1.2\times10^{-3}$	CL=90%	
Doubly Cabibbo-suppressed modes				
$pK^+\pi^-$		$(1.11\pm0.18)\times10^{-4}$		16.2%
Semileptonic modes				
$\Lambda e^+\nu_e$		(3.6 ± 0.4) %		11.1%
$\Lambda\mu^+\nu_\mu$		(3.5 ± 0.5) %		14.3%

Measurements for Λ_c^+ decays are greatly improved, with great efforts from BESIII, LHCb and Belle.

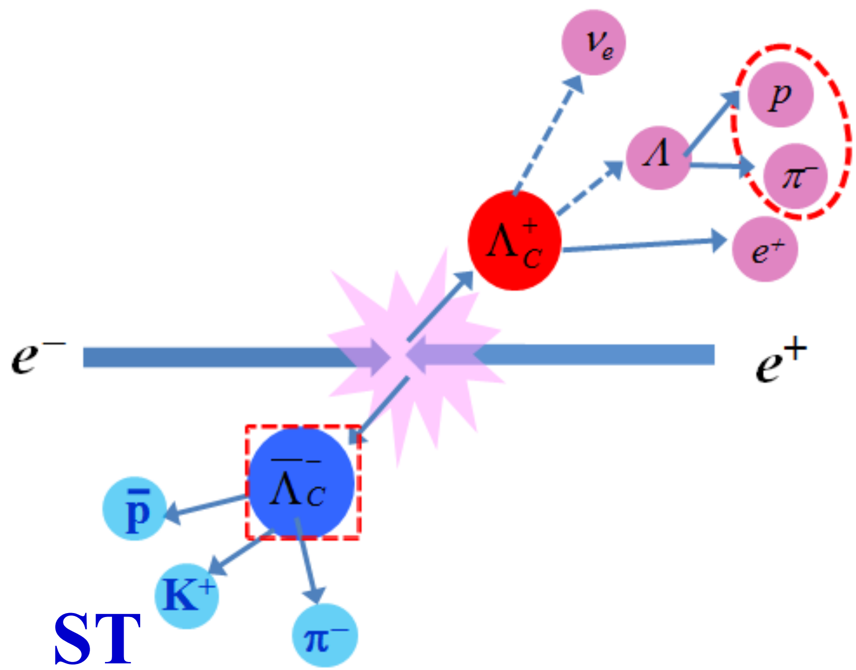
Data sets for charm baryon studies at BESIII





DT Technique

Example:



✓Single Tags (ST)

$$M_{\rm BC} = \sqrt{E^2_{\rm beam} - |\vec{p}_{\bar{\Lambda}_c^-}|^2}$$

✓Double Tags (DT)

$$U_{\rm miss} = E_{\rm miss} - c|\vec{p}_{\rm miss}|$$

✓Branching Fraction (BF)

$$\mathcal{B}_{\rm SL} = \frac{N^{\rm semi}}{N^{\rm tag} \times \epsilon}$$

Clean sample of ST charmed baryons can be fully reconstructed by hadronic decays with large BFs. Based on this, one can access to absolute BFs and dynamics in the decays.

Reconstruction of Λ_c ST baryons

❑ Fourteen ST modes:

PDG2022

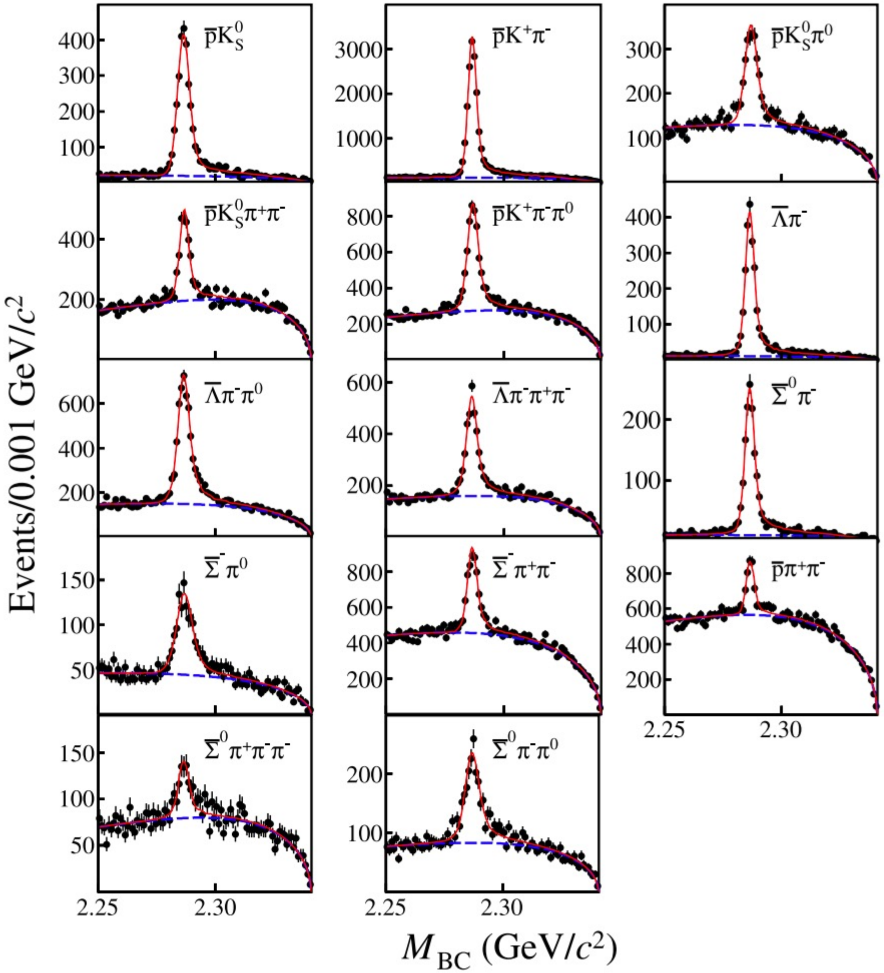
$\bar{\Lambda}_c^- \to$	Branching fraction
$\bar{p}\bar{K}^0$	$(3.18 \pm 0.16)\%$
$\bar{p}K^+\pi^-$	$(6.28 \pm 0.32)\%$
$\bar{p}\bar{K}^0\pi^0$	$(3.94 \pm 0.26)\%$
$\bar{p}\bar{K}^0\pi^+\pi^-$	$(3.20 \pm 0.24)\%$
$\bar{p}K^+\pi^-\pi^0$	$(4.46 \pm 0.30)\%$
$\bar{\Lambda}\pi^-$	$(1.30 \pm 0.07)\%$
$\bar{\Lambda}\pi^-\pi^0$	$(7.10 \pm 0.40)\%$
$\bar{\Lambda}\pi^-\pi^+\pi^-$	$(3.64 \pm 0.29)\%$
$\bar{\Sigma}^0\pi^-$	$(1.29 \pm 0.07)\%$
$\bar{\Sigma}^-\pi^0$	$(1.25 \pm 0.10)\%$
$\bar{\Sigma}^-\pi^+\pi^-$	$(4.50 \pm 0.25)\%$
$\bar{p}^-\pi^+\pi^-$	$(0.46 \pm 0.03)\%$
$\bar{\Sigma}^0\pi^+\pi^-\pi^-$	$(1.11 \pm 0.30)\%$
$\bar{\Sigma}^0\pi^-\pi^0$	$(3.50 \pm 0.40)\%$

~45%

Currently, the total measured BFs for Λ_c decays is roughly 70%.

Reconstruction of Λ_c ST baryons

- The M_{BC} distritbutions at $\sqrt{s} = 4.68$ GeV.



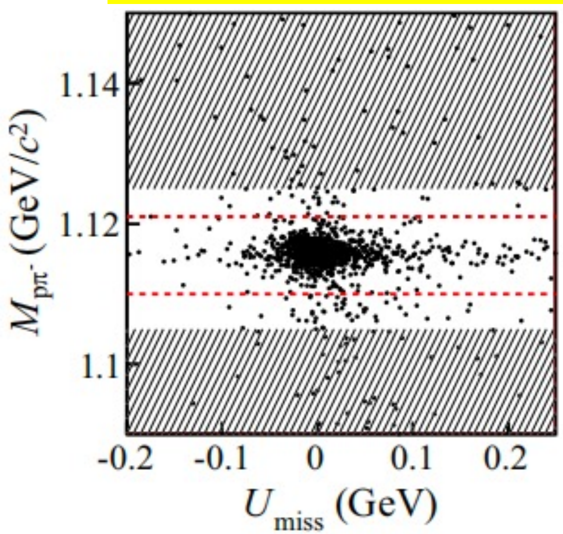
Mode	ΔE (GeV)	N_{ST}
$\bar{p}\bar{K}^0$	[−0.031, 0.033]	7688 ± 98
$\bar{p}K^+\pi^-$	[−0.030, 0.039]	45842 ± 235
$\bar{p}\bar{K}^0\pi^0$	[−0.049, 0.052]	4448 ± 109
$\bar{p}\bar{K}^0\pi^+\pi^-$	[−0.048, 0.049]	4962 ± 110
$\bar{p}K^+\pi^-\pi^0$	[−0.043, 0.051]	10670 ± 161
$\bar{\Lambda}\pi^-$	[−0.031, 0.034]	6089 ± 82
$\bar{\Lambda}\pi^-\pi^0$	[−0.044, 0.057]	11933 ± 143
$\bar{\Lambda}\pi^-\pi^+\pi^-$	[−0.043, 0.045]	7163 ± 122
$\bar{\Sigma}^0\pi^-$	[−0.032, 0.040]	3883 ± 69
$\bar{\Sigma}^-\pi^0$	[−0.050, 0.060]	2289 ± 70
$\bar{\Sigma}^-\pi^+\pi^-$	[−0.043, 0.052]	8206 ± 161
$\bar{p}^-\pi^+\pi^-$	[−0.040, 0.040]	4199 ± 139
$\bar{\Sigma}^0\pi^+\pi^-\pi^-$	[−0.030, 0.030]	1290 ± 64
$\bar{\Sigma}^0\pi^-\pi^0$	[−0.030, 0.032]	3606 ± 90

Totally, 122 268±474 ST events are reconstructed with 14 ST modes.

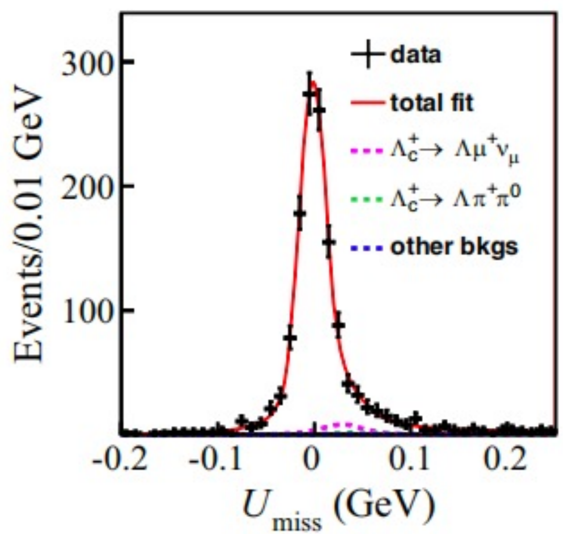
Study of $\Lambda_c^+ \to \Lambda e^+ \nu_e$

- The measurement is done with 4.4/fb data from $\sqrt{s} = 4.6 - 4.7$ GeV.
- The precision of the BF is improved by threefold, providing necessary inputs for testing various theoretical models.
- The first determination of form factors in $\Lambda_c^+ \to \Lambda e^+ \nu_e$ decays.

PRL129(2022)231803



$N^{DT} = 1253 \pm 39$



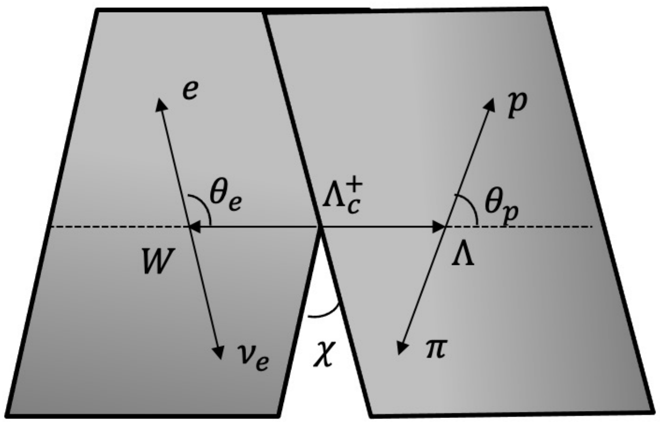
Comparisons between measurement and theoretical predictions.

	$\mathcal{B}(\Lambda_c^+ \to \Lambda e^+ \nu_e)$ (%)	
Constituent quark model (HONR) [9]	4.25	×
Light-front approach [10]	1.63	×
Covariant quark model [11]	2.78	×
Relativistic quark model [12]	3.25	×
Non-relativistic quark model [13]	3.84	
Light-cone sum rule [14]	3.0 ± 0.3	
Lattice QCD [15]	3.80 ± 0.22	
$SU(3)$ [16]	3.6 ± 0.4	
Light-front constituent quark model [17]	3.36 ± 0.87	
MIT bag model [17]	3.48	
Light-front quark model [18]	4.04 ± 0.75	
This Letter	$3.56 \pm 0.11 \pm 0.07$	

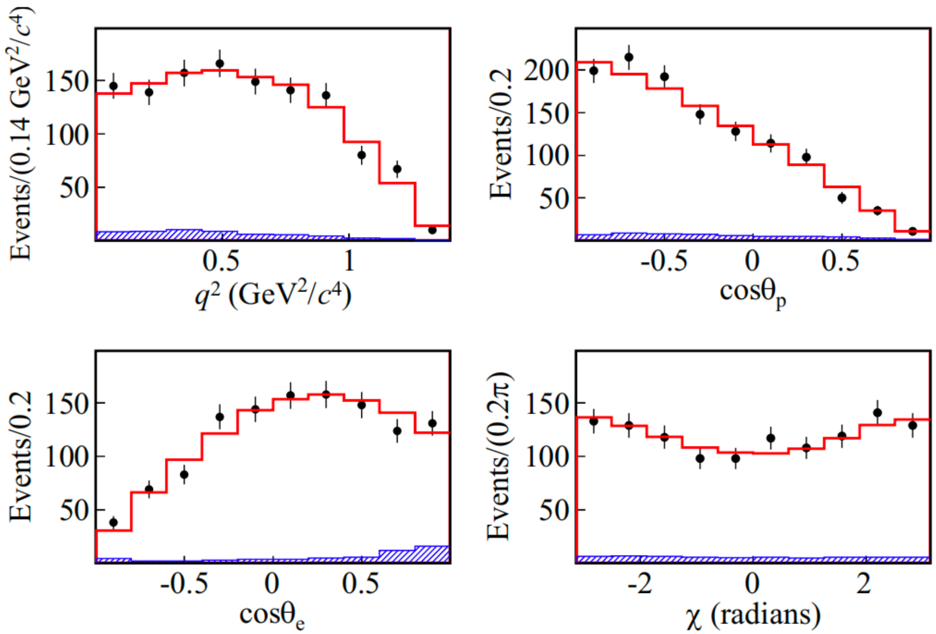
$B[\Lambda_c^+ \to \Lambda e^+ \nu_e] = (3.56 \pm 0.11 \pm 0.07)\%$

Study of the kinematics in $\Lambda_c^+ \rightarrow \Lambda e^+ \nu_e$ decay:

$$\frac{d^4\Gamma}{dq^2 d\cos\theta_e d\cos\theta_p d\chi} = \frac{G_F^2|V_{cs}|^2}{2(2\pi)^4} \cdot \frac{Pq^2}{24M_{\Lambda_c}^2} \left\{ \frac{3}{8}(1-\cos\theta_e)^2 |H_{\frac{1}{2}1}|^2 (1+\alpha_\Lambda\cos\theta_p) + \frac{3}{8}(1+\cos\theta_e)^2 |H_{-\frac{1}{2}-1}|^2 (1-\alpha_\Lambda\cos\theta_p) \right.$$
$$+ \frac{3}{4}\sin^2\theta_e [|H_{\frac{1}{2}0}|^2(1+\alpha_\Lambda\cos\theta_p) + |H_{-\frac{1}{2}0}|^2(1-\alpha_\Lambda\cos\theta_p)] + \frac{3}{2\sqrt{2}}\alpha_\Lambda\cos\chi\sin\theta_e\sin\theta_p$$
$$\left. \times [(1-\cos\theta_e)H_{-\frac{1}{2}0}H_{\frac{1}{2}1} + (1+\cos\theta_e)H_{\frac{1}{2}0}H_{-\frac{1}{2}-1}] \right\}$$



PRL129(2022)231803

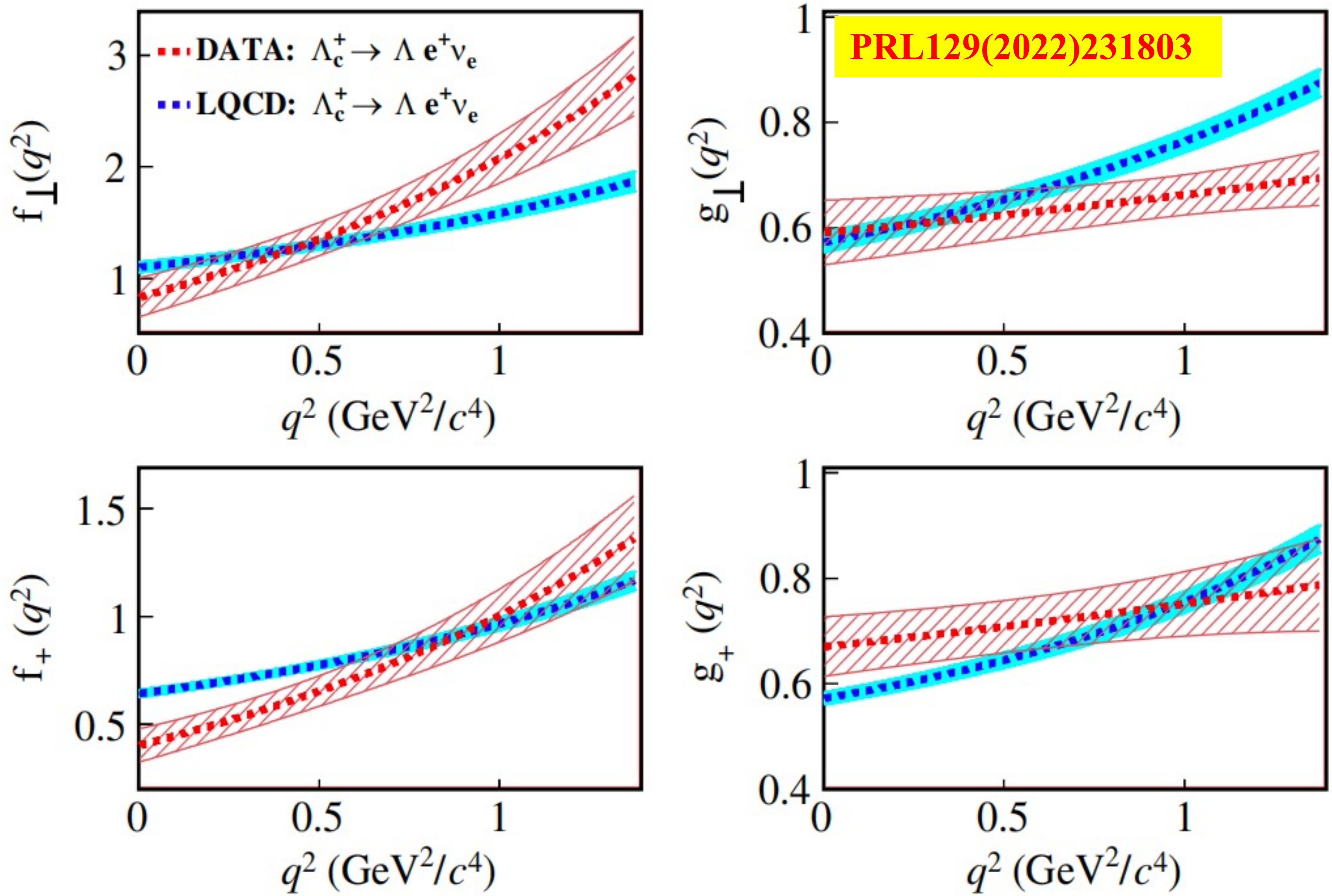


Parameters	$\alpha_1^{g_\perp}$	$\alpha_1^{f_\perp}$	r_{f_+}	$r_{f_\perp}$	r_{g_+}
Values	$1.43 \pm 2.09 \pm 0.16$	$-8.15 \pm 1.58 \pm 0.05$	$1.75 \pm 0.32 \pm 0.01$	$3.62 \pm 0.65 \pm 0.02$	$1.13 \pm 0.13 \pm 0.01$
Coefficients	$\alpha_1^{g_\perp}$	$\alpha_1^{f_\perp}$	r_{f_+}	$r_{f_\perp}$	r_{g_+}
$a_0^{g_\perp}$	−0.64	0.60	−0.66	−0.83	−0.40
$\alpha_1^{g_\perp}$		−0.63	0.62	0.53	−0.33
$\alpha_1^{f_\perp}$			−0.79	−0.67	−0.07
r_{f_+}				0.57	−0.09
$r_{f_\perp}$					0.39

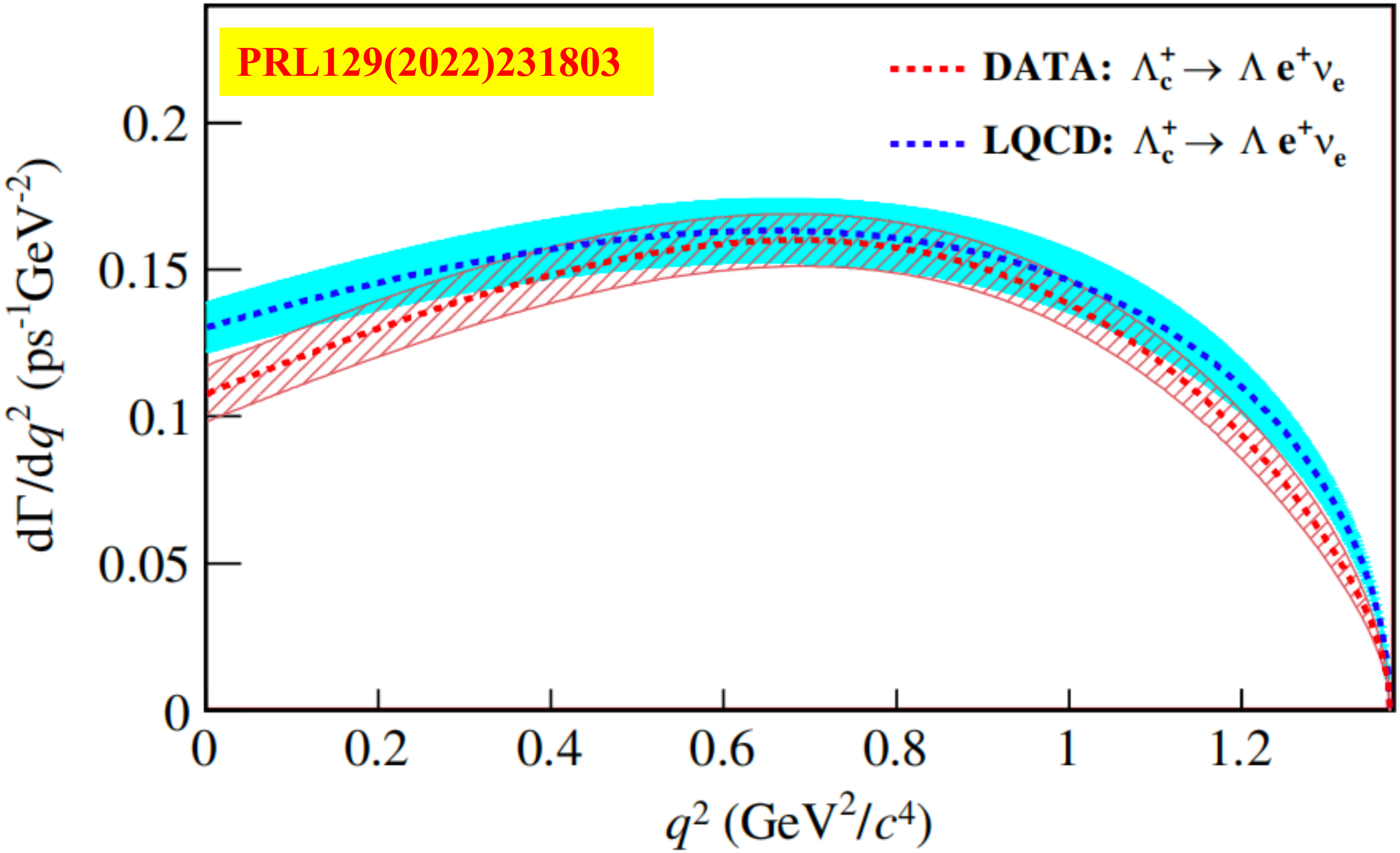
- Helicity amplitude:

$$H^V_{\frac{1}{2}1} = \sqrt{2Q_-}f_\perp(q^2), \qquad H^A_{\frac{1}{2}1} = \sqrt{2Q_+}g_\perp(q^2),$$
$$H^V_{\frac{1}{2}0} = \sqrt{Q_-/q^2}f_+(q^2)(M_{\Lambda_c}+M_\Lambda),$$
$$H^A_{\frac{1}{2}0} = \sqrt{Q_+/q^2}g_+(q^2)(M_{\Lambda_c}-M_\Lambda),$$

Comparisons between data and LQCD prediction

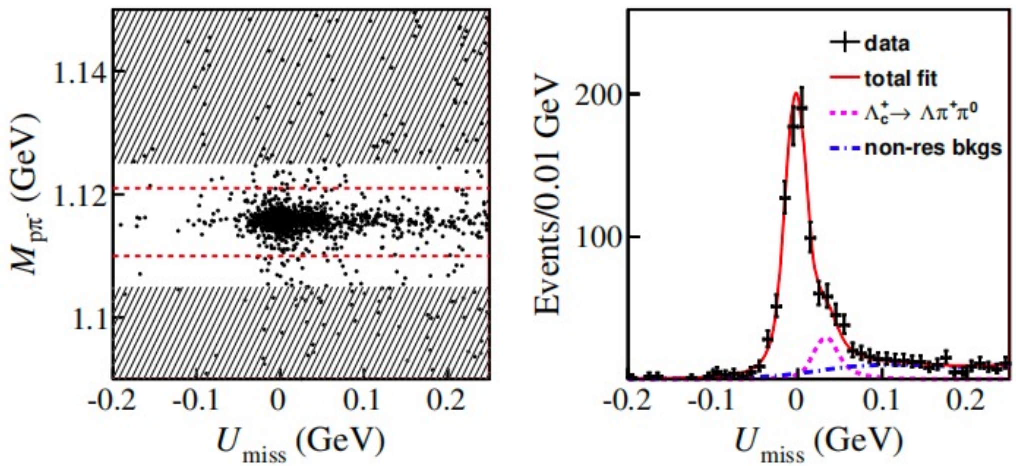


Comparisons between data and LQCD prediction



Study of $\Lambda_c^+ \rightarrow \Lambda\mu^+\nu_\mu$

- The precision of the BF is improved by threefold, providing necessary inputs for testing various theoretical models. arXiv: 2306.02624



$$\mathbf{BF}(\Lambda_c^+ \to \Lambda\mu^+\nu_\mu) = (3.48 \pm 0.14 \pm 0.10)\%$$

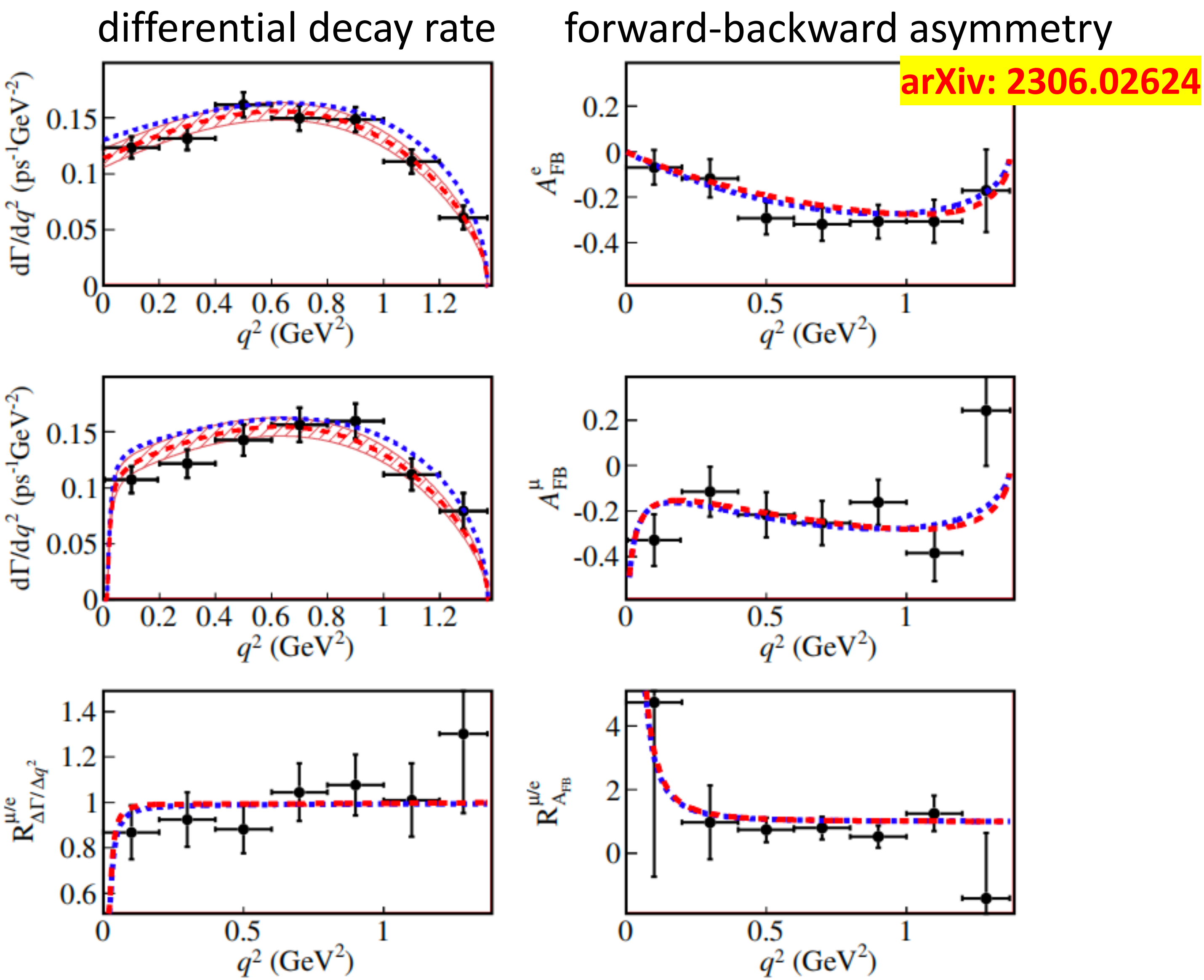
	$\mathcal{B}(\Lambda_c^+ \to \Lambda\mu^+\nu_\mu)$ [%]
Covariant quark model [20]	2.69
Relativistic quark model [21]	3.14
Constituent quark model (HONR) [47]	4.25
Non-relativistic quark model [48]	3.72
Lattice QCD [30]	3.69 ± 0.22
Light-cone sum rule [49]	3.0 ± 0.3
$SU(3)$ [25]	3.5 ± 0.5
Light-front constituent quark model [27]	3.21 ± 0.85
MIT bag model [27]	3.38
Light-front quark model [22]	3.90 ± 0.73
This work	$3.48 \pm 0.14 \pm 0.10$

- The differential decay rate and forward-backward asymmetry in the lepton system system are measured for the first time, to provide data for the test of the LFU using the charmed baryon SL decays.

$$\Delta\Gamma_i = \int_i \frac{d\Gamma}{dq^2} dq^2 = \sum_{j=1}^{N_{\rm bins}} (\epsilon^{-1})_{ij} N_{\rm DT}^j / (\tau_{\Lambda_c} \times N^{\rm ST})$$

$$A_{\rm FB}^\ell(q^2) = \frac{\int_0^1 \frac{d^2\Gamma}{dq^2 d\cos\theta_\ell} d\cos\theta_\ell - \int_{-1}^0 \frac{d^2\Gamma}{dq^2 d\cos\theta_\ell} d\cos\theta_\ell}{\int_0^1 \frac{d^2\Gamma}{dq^2 d\cos\theta_\ell} d\cos\theta_\ell + \int_{-1}^0 \frac{d^2\Gamma}{dq^2 d\cos\theta_\ell} d\cos\theta_\ell}$$

Test of LFU with $\Lambda_c^+ \rightarrow \Lambda\mu^+\nu_\mu$ and $\Lambda_c^+ \rightarrow \Lambda e^+\nu_e$



- No clear evidence for the LFU is found in current data size.

Observation of $\Lambda_c^+ \rightarrow pK^-e^+\nu_e$

Phys. Rev. D 106, 112010 (2023)

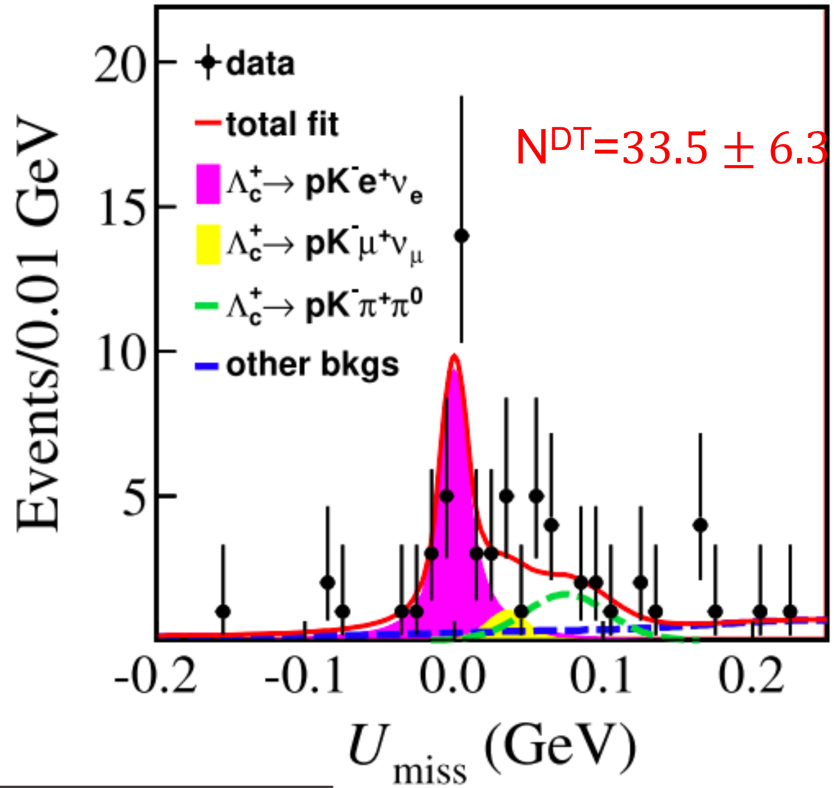
- The new observed SL decay mode：

  $\mathrm{BF}(\Lambda_c^+ \to pK^- e^+ \nu_e) = (0.88 \pm 0.15 \pm 0.07)\times 10^{-3}$

  Significance: 8.2σ

- This work provide a clear confirmation that the SL Λ_c^+ decays are not saturated by the $\Lambda \ell^+ \nu_\ell$ final state.

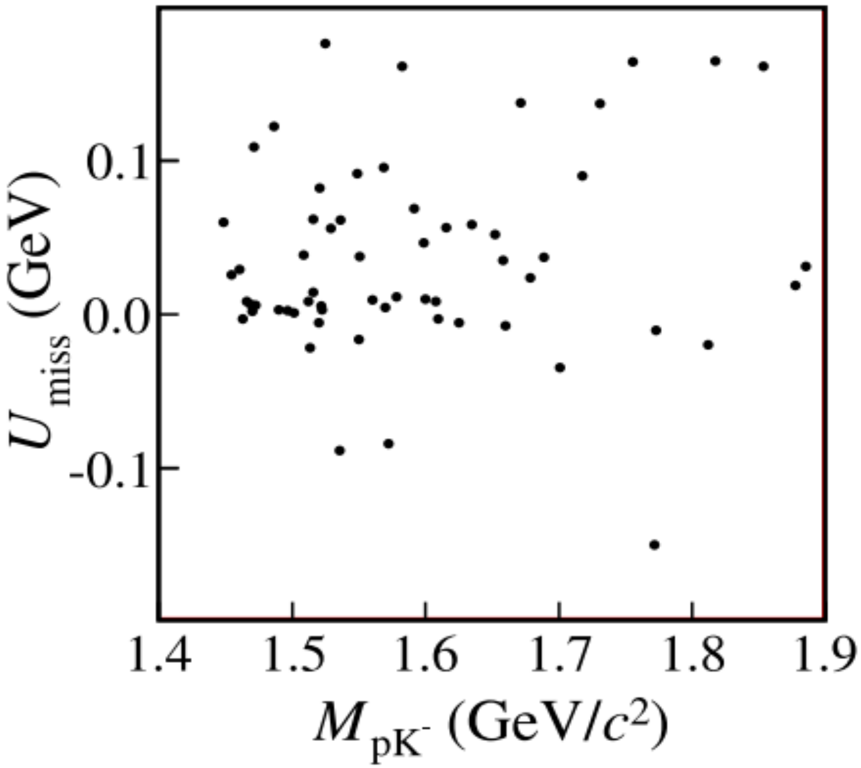
- Study of pK^- mass spectrum can be used to understand the nature of excited Λ^* states.

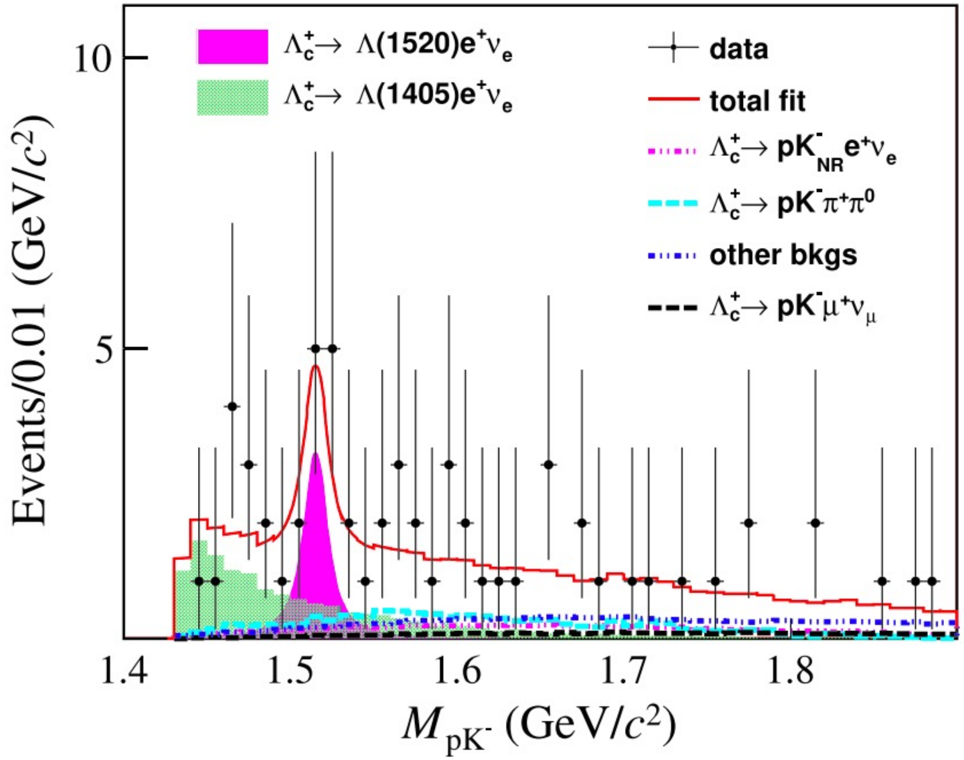


	$\mathcal{B}(\Lambda_c^+ \to \Lambda(1520)e^+\nu_e)$	$\mathcal{B}(\Lambda_c^+ \to \Lambda(1405)e^+\nu_e)$
Constituent quark model [8]	1.01	3.04
Molecular state [9]	...	0.02
Nonrelativistic quark model [10]	0.60	2.43
Lattice QCD [12,13]	0.512 ± 0.082	...
Measurement	$1.02 \pm 0.52 \pm 0.11$	$\frac{0.42\pm0.19\pm0.04}{\mathcal{B}(\Lambda(1405)\to pK^-)}$

Evidence of $\Lambda_c^+ \to \Lambda^*(\to pK^-)e^+\nu_e$

Phys. Rev. D 106, 112010 (2023)



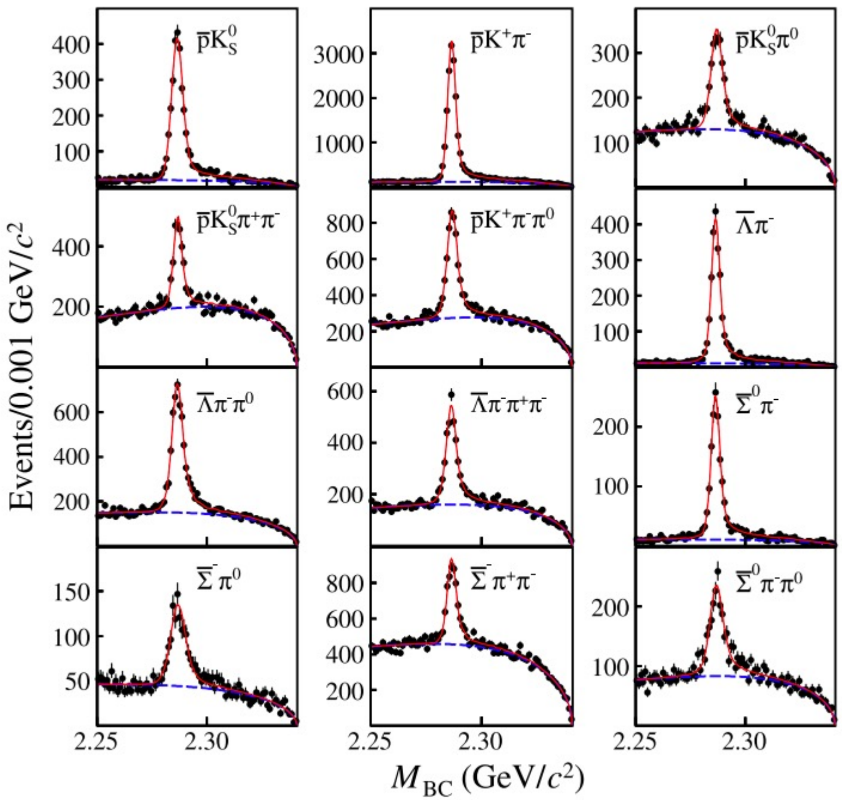


$\text{BF}(\Lambda_c^+ \to \Lambda(1520)[\to pK^-]e^+\nu_e) = (0.23 \pm 0.12 \pm 0.02)\times10^{-3}$ Significance: 3.3σ

$\text{BF}(\Lambda_c^+ \to \Lambda(1405)[\to pK^-]e^+\nu_e) = (0.42 \pm 0.19 \pm 0.04)\times10^{-3}$ Significance: 3.2σ

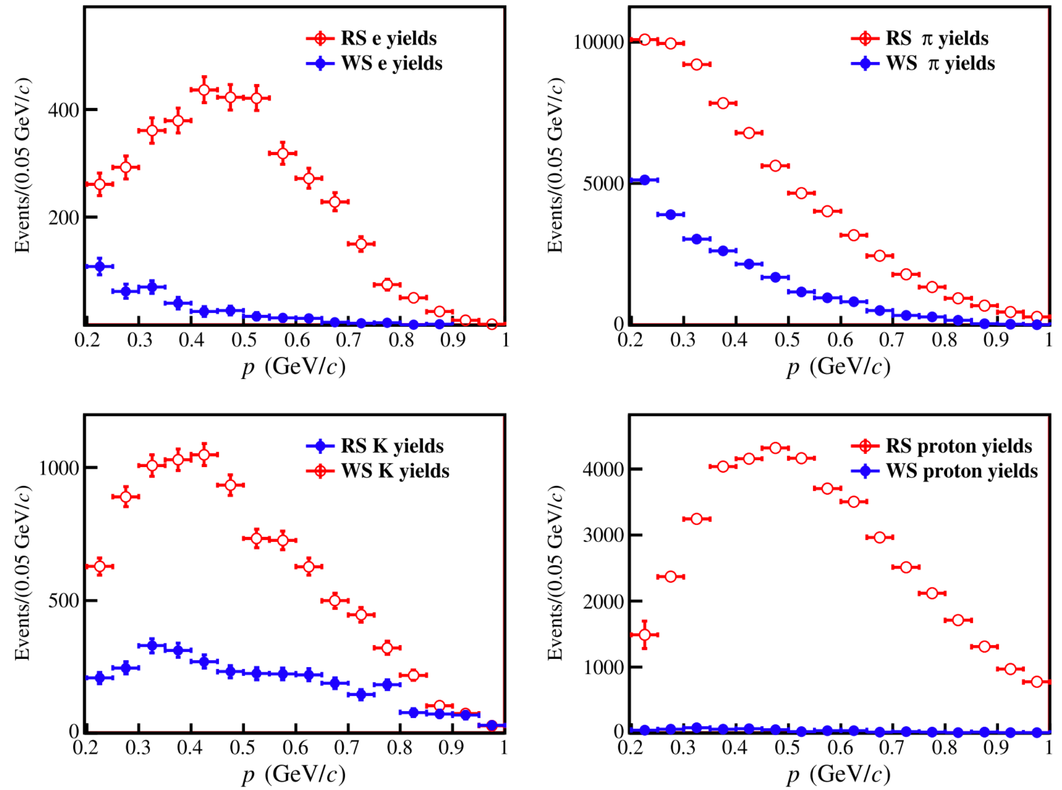
Inclusive SL decay $\Lambda_c^+ \rightarrow e^+X$

- 12 STs are used in this analysis



$$N^{ST} = 115437 \pm 446$$

- DT yields: *Phys. Rev. D 107, 052005 (2023)*

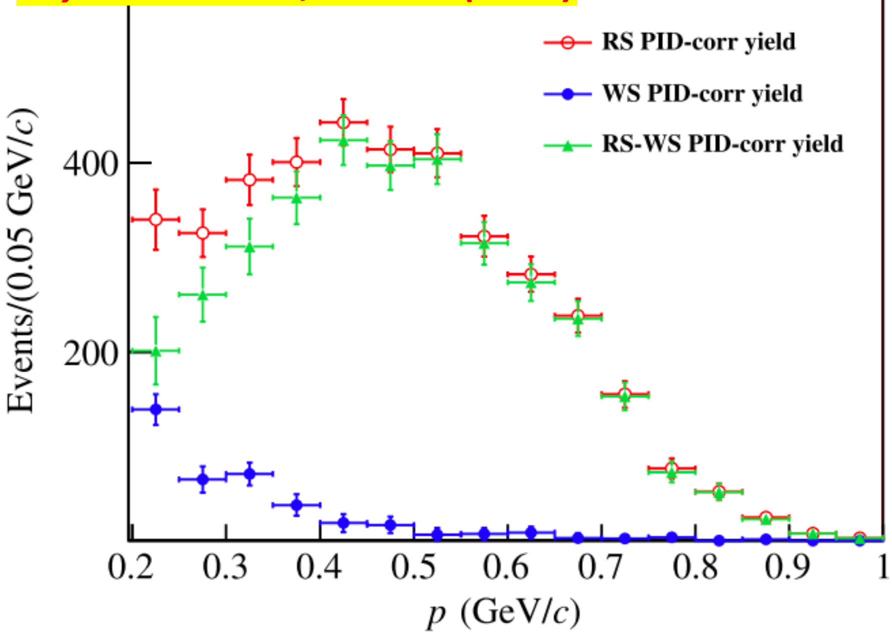


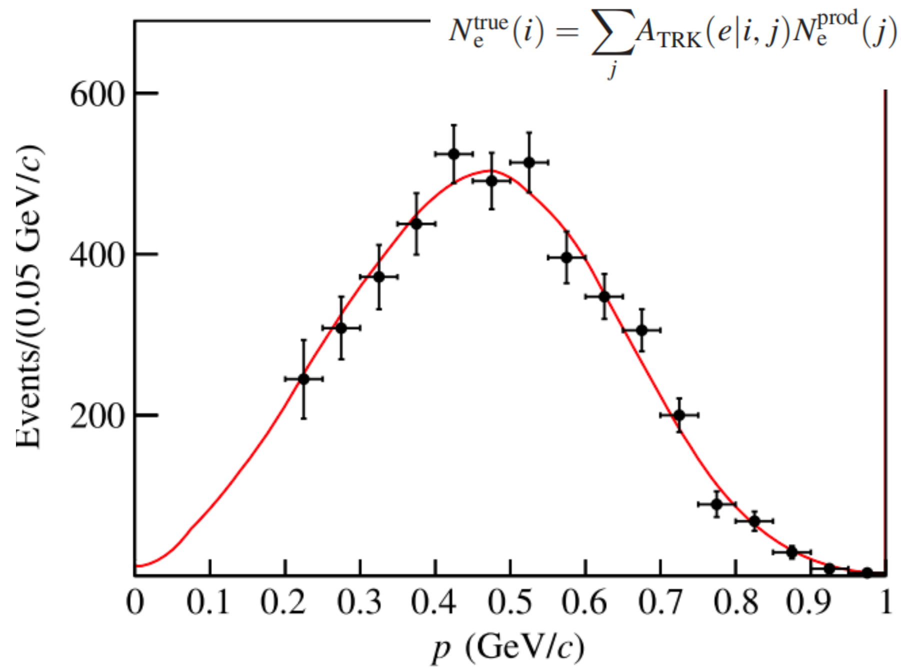
✓ Unfolding method to obtain true signal yields. The matrix can be obtained using selected control samples.

$$\begin{bmatrix} N_e^{\rm obs} \\ N_\pi^{\rm obs} \\ N_K^{\rm obs} \\ N_p^{\rm obs} \end{bmatrix} = \begin{bmatrix} P_{e\to e} & P_{\pi\to e} & P_{K\to e} & P_{p\to e} \\ P_{e\to\pi} & P_{\pi\to\pi} & P_{K\to\pi} & P_{p\to\pi} \\ P_{e\to K} & P_{\pi\to K} & P_{K\to K} & P_{p\to K} \\ P_{e\to p} & P_{\pi\to p} & P_{K\to p} & P_{p\to p} \end{bmatrix} \begin{bmatrix} N_e^{\rm true} \\ N_\pi^{\rm true} \\ N_K^{\rm true} \\ N_p^{\rm true} \end{bmatrix}$$

Inclusive SL decay $\Lambda_c^+ \to e^+X$

Phys. Rev. D 107, 052005 (2023)





Correction (see text)	RS yields	WS yields
Observed yields	3706 ± 71	394 ± 31
PID unfolding yields	3865 ± 80	376 ± 33
WS subtraction	3489 ± 87	
Tracking unfolding yields	4333 ± 107	
Extrapolation	4692 ± 117	

$\mathrm{BF}(\Lambda_c^+ \to \mathrm{X}e^+\nu_e) = (4.06 \pm 0.10 \pm 0.09)\%$

The precision is improved by threefold.

$$\frac{\Gamma(\Lambda_c^+ \to \mathrm{X}e^+\nu_e)}{\Gamma(D_s^+ \to \mathrm{X}e^+\nu_e)} = 1.28 \pm 0.05$$

$\mathrm{BF}(\Lambda_c^+ \to \mathrm{X}e^+\nu_e) = (4.06 \pm 0.10 \pm 0.09)\%$

$\mathrm{BF}(\Lambda_c^+ \to \Lambda e^+\nu_e) = (3.56 \pm 0.11 \pm 0.07)\%$

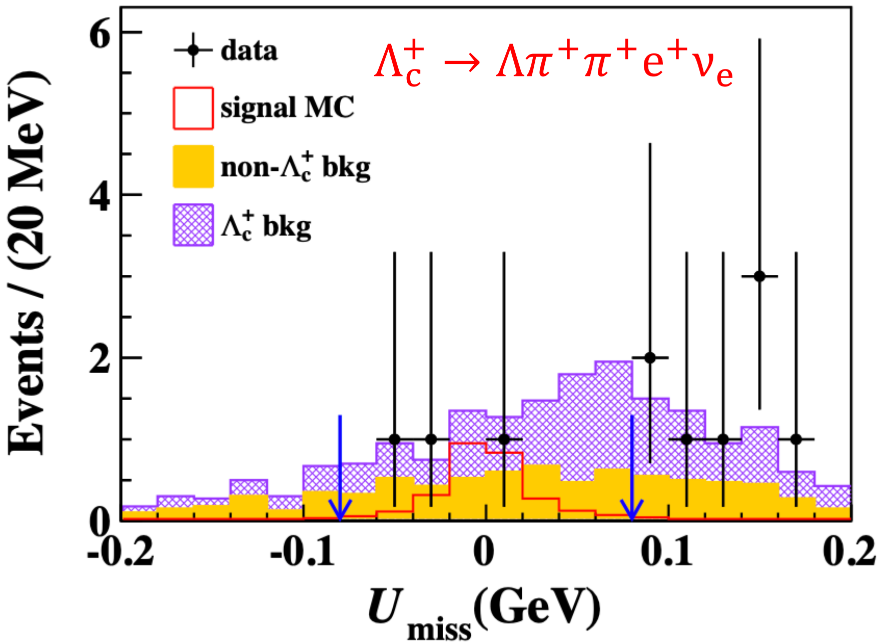
$\mathrm{BF}(\Lambda_c^+ \to pK^- e^+\nu_e) = (0.88 \pm 0.15 \pm 0.07)\times 10^{-3}$

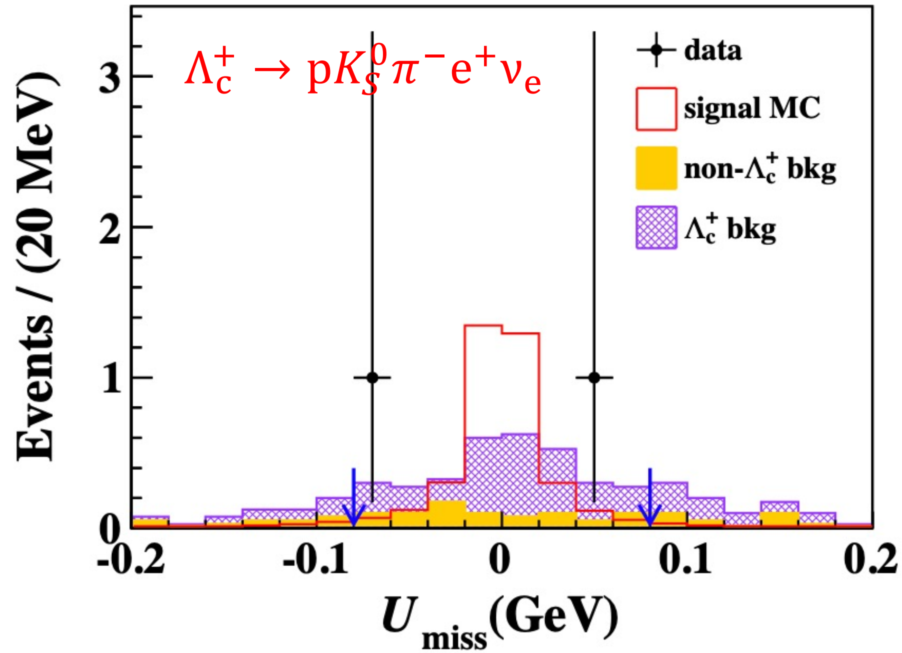
Unknown decay: 0.5%

Search for $\Lambda_c^+ \to \Lambda\pi^+\pi^- e^+\nu_e$ and $\Lambda_c^+ \to pK_s^0\pi^- e^+\nu_e$

- **Searches for SL decay modes using 4.5/fb data**

arXiv: 2302.07529





$\mathrm{BF}(\Lambda_c^+ \to \Lambda\pi^+\pi^+e^+\nu_e) < 3.9\times10^{-4}$

$\mathrm{BF}(\Lambda_c^+ \to pK_S^0\pi^-e^+\nu_e) < 3.3\times10^{-4}$

Decay mode	N^{obs}	$\varepsilon^{\mathrm{sig}}$ (%)	$N_{\mathrm{bkg1}}^{\mathrm{SB}}$	$N_{\mathrm{bkg2}}^{\mathrm{MC}} \pm \sigma_{\mathrm{bkg2}}^{\mathrm{MC}}$	N^{DT}
$\Lambda_c^+ \to \Lambda\pi^+\pi^-e^+\nu_e$	3	9.69 ± 0.03	9	4.8 ± 0.4	2.9
$\Lambda_c^+ \to pK_S^0\pi^-e^+\nu_e$	2	13.58 ± 0.02	0	2.2 ± 0.3	3.8

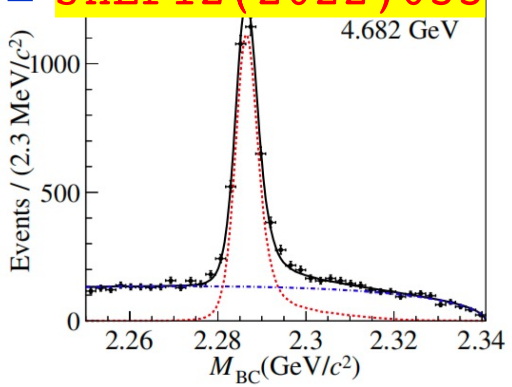
Upper limits at 90% C.L.

- **The BFs are set at 90% C.L. for the two decays.**

Amplitude analysis of $\Lambda_c^+ \to \Lambda\pi^+\pi^0$

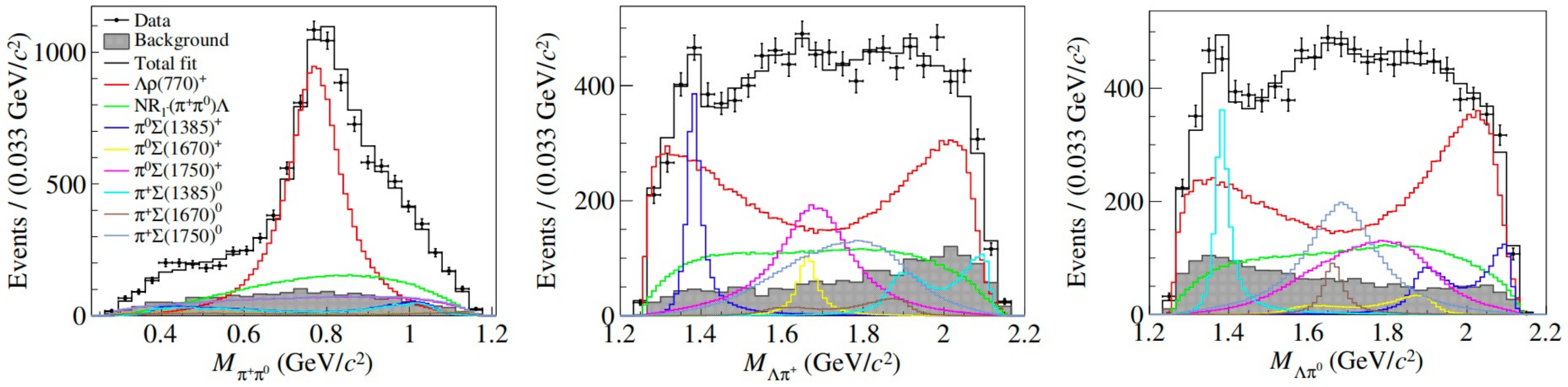
- First amplitude analysis of $\Lambda_c^+ \to \Lambda\pi^+\pi^0$. The analysis will provide important inputs to improve the theoretical calculations for decays of $\Lambda_c^+ \to \Lambda\rho(770)^+$ and $\Lambda_c^+ \to \Sigma(1385)\pi$.
- The single tag method is applied to select $\Lambda_c^+ \to \Lambda\pi^+\pi^0$ events.
- The signal region is defined within $2.282 < M_{BC} < 2.292$ GeV/c^2. The signal purity is ~80%.

JHEP12(2022)033



$$M_{BC} = \sqrt{E_{beam}^2 - |\vec{p}_{ST}|^2}$$

- Projections of the fit results:



- Numerical results of the BFs and decay asymmetry parameters.

	Result
$\frac{\mathcal{B}(\Lambda_c^+\to\Lambda\rho(770)^+)}{\mathcal{B}(\Lambda_c^+\to\Lambda\pi^+\pi^0)}$	$(57.2 \pm 4.2 \pm 4.9)\%$
$\frac{\mathcal{B}(\Lambda_c^+\to\Sigma(1385)^+\pi^0)\cdot\mathcal{B}(\Sigma(1385)^+\to\Lambda\pi^+)}{\mathcal{B}(\Lambda_c^+\to\Lambda\pi^+\pi^0)}$	$(7.18 \pm 0.60 \pm 0.64)\%$
$\frac{\mathcal{B}(\Lambda_c^+\to\Sigma(1385)^0\pi^+)\cdot\mathcal{B}(\Sigma(1385)^0\to\Lambda\pi^0)}{\mathcal{B}(\Lambda_c^+\to\Lambda\pi^+\pi^0)}$	$(7.92 \pm 0.72 \pm 0.80)\%$
$\mathcal{B}(\Lambda_c^+ \to \Lambda\rho(770)^+)$	$(4.06 \pm 0.30 \pm 0.35 \pm 0.23) \times 10^{-2}$
$\mathcal{B}(\Lambda_c^+ \to \Sigma(1385)^+\pi^0)$	$(5.86 \pm 0.49 \pm 0.52 \pm 0.35) \times 10^{-3}$
$\mathcal{B}(\Lambda_c^+ \to \Sigma(1385)^0\pi^+)$	$(6.47 \pm 0.59 \pm 0.66 \pm 0.38) \times 10^{-3}$
$\alpha_{\Lambda\rho(770)^+}$	$-0.763 \pm 0.053 \pm 0.045$
$\alpha_{\Sigma(1385)^+\pi^0}$	$-0.917 \pm 0.069 \pm 0.056$
$\alpha_{\Sigma(1385)^0\pi^+}$	$-0.789 \pm 0.098 \pm 0.056$

$\mathrm{BF}(\Lambda_c^+ \to \Lambda\pi^+\pi^0)$
$= (7.1 \pm 0.4)\%$

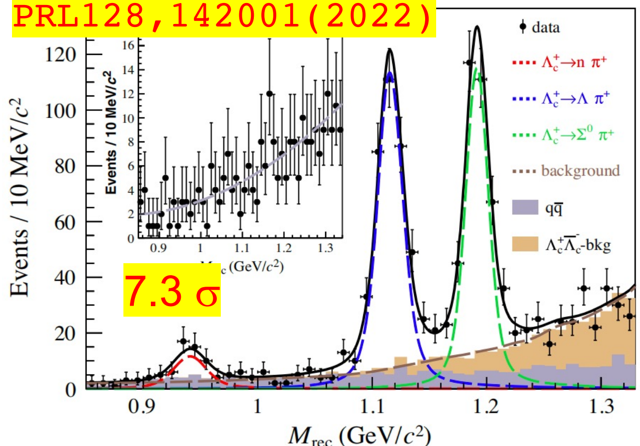
- The comparisons among measurements, theoretical calculations.

	Theoretical calculation		This work	PDG
$10^2 \times \mathcal{B}(\Lambda_c^+ \to \Lambda\rho(770)^+)$	4.81 ± 0.58 [13]	4.0 [14, 15]	4.06 ± 0.52	< 6
$10^3 \times \mathcal{B}(\Lambda_c^+ \to \Sigma(1385)^+\pi^0)$	2.8 ± 0.4 [16]	2.2 ± 0.4 [17]	5.86 ± 0.80	—
$10^3 \times \mathcal{B}(\Lambda_c^+ \to \Sigma(1385)^0\pi^+)$	2.8 ± 0.4 [16]	2.2 ± 0.4 [17]	6.47 ± 0.96	—
$\alpha_{\Lambda\rho(770)^+}$	-0.27 ± 0.04 [13]	-0.32 [14, 15]	-0.763 ± 0.070	—
$\alpha_{\Sigma(1385)^+\pi^0}$	$-0.91^{+0.45}_{-0.10}$ [17]		-0.917 ± 0.089	—
$\alpha_{\Sigma(1385)^0\pi^+}$	$-0.91^{+0.45}_{-0.10}$ [17]		-0.79 ± 0.11	—

Study of singly cabibbo-suppressed decays

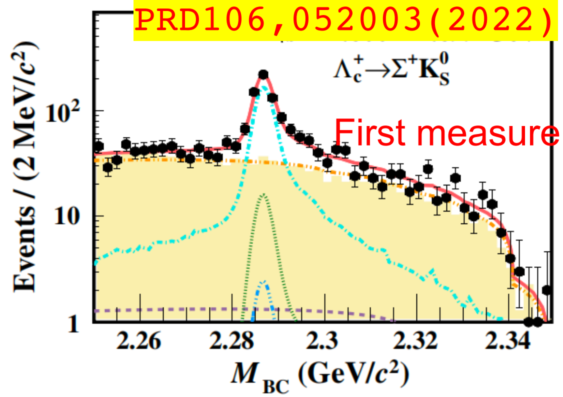
- Observation of $\Lambda_c^+ \rightarrow n\pi^+$

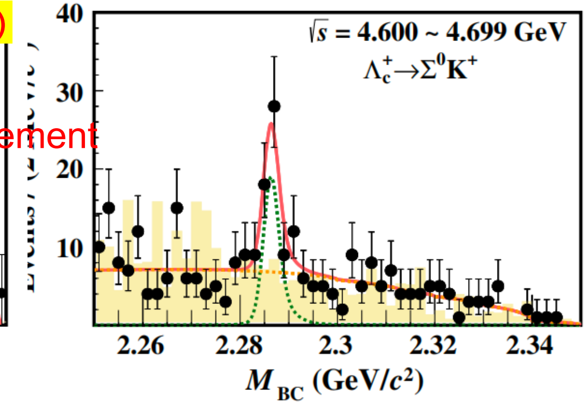
PRL128,142001(2022)



- Measurement of $\Lambda_c^+ \rightarrow \Sigma^0 K^+$ and $\Lambda_c^+ \rightarrow \Sigma^+ K^0$

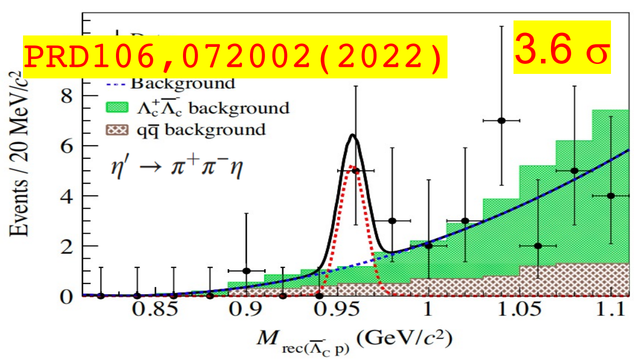
PRD106,052003(2022)

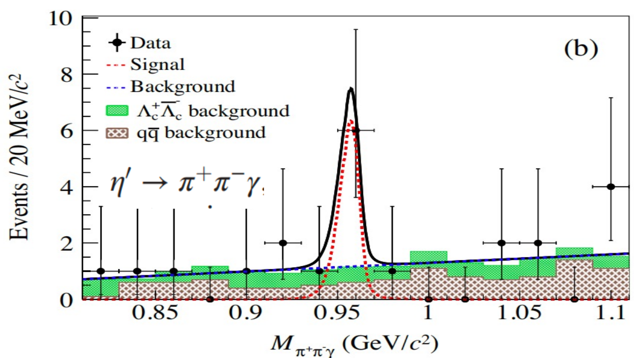




- Measurement of $\Lambda_c^+ \rightarrow p\eta'$

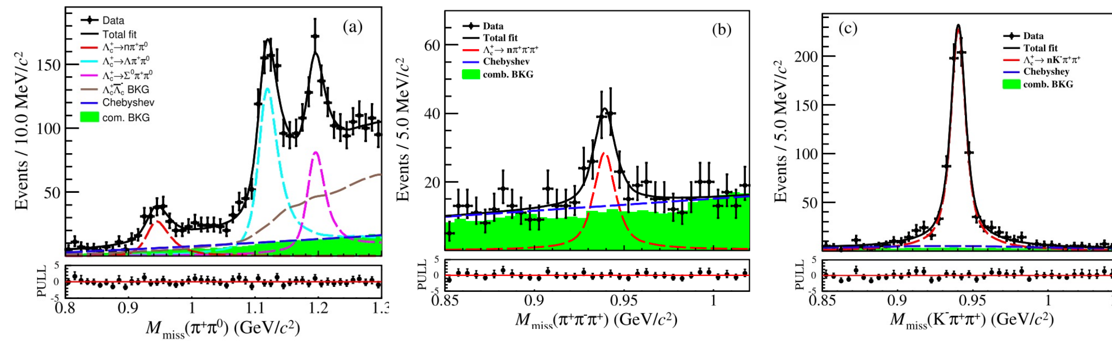
PRD106,072002(2022)





- Measurements of $\Lambda_c^+ \rightarrow n\pi^+\pi^0$, $n\pi^+\pi^+\pi^-$ and $nK^-\pi^+\pi^+$

CPC47,023001(2023)



BESIII results:

$$\mathcal{B}(\Lambda_c^+ \rightarrow n\pi^+) = (6.6 \pm 1.2_{\rm stat} \pm 0.4_{\rm syst}) \times 10^{-4}$$
$$\mathcal{B}(\Lambda_c^+ \rightarrow n\eta') = (5.62^{+2.46}_{-2.04} \pm 0.26) \times 10^{-4}$$
$$\mathcal{B}(\Lambda_c^+ \rightarrow \Sigma^0 K^+) = (4.7 \pm 0.9_{\rm stat} \pm 0.3_{\rm syst}) \times 10^{-4}$$
$$\mathcal{B}(\Lambda_c^+ \rightarrow \Sigma^+ K_S^0) = (4.8 \pm 1.4_{\rm stat} \pm 0.4_{\rm syst}) \times 10^{-4}$$
$$\mathcal{B}(\Lambda_c^+ \rightarrow n\pi^+\pi^0) = (0.64 \pm 0.09_{\rm stat} \pm 0.02_{\rm syst})\%$$
$$\mathcal{B}(\Lambda_c^+ \rightarrow n\pi^+\pi^-\pi^+) = (0.45 \pm 0.07_{\rm stat} \pm 0.03_{\rm syst})\%$$
$$\mathcal{B}(\Lambda_c^+ \rightarrow nK^-\pi^+\pi^+) = (1.90 \pm 0.08_{\rm stat} \pm 0.09_{\rm syst})\%$$

Summary

- Recent results on Λ_c^+ SL and hadronic decays at BESIII are reported.

- These measurements provide important inputs for understanding the decay property of charmed baryon.

- More works will be reported in the future.

THANKS!