BESIII上粲重子半轻衰变研究进展与展望

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“粲强子衰变和标准模型的精确检验”

2025夏季年会

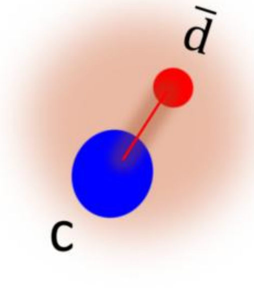
2025/08/14 贵阳

Outline

- **Introduction**
- **BESIII experiment**
- **Selected results**
- **Project II**
- **Outlook**
- **Summary**

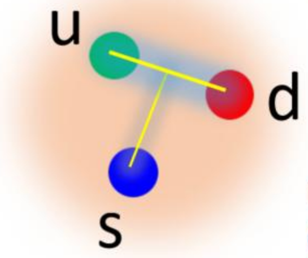
Introduction

- ➢ Λ_c^+ is the ground state charmed baryon, >40 years, characteristics still not very clear.
- ➢ Provides important information to understand strong and weak interactions.
- ➢ Most of the charmed baryons will eventually decay to Λ_c^+.
- ➢ Complementary to charmed mesons (W-exchange).
- ➢ Calculation is difficult, many phenomenology methods are developed, most need experimental results input.



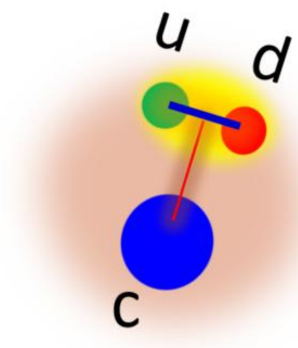
→ Charmed meson ($D^+[c\bar{d}]$)

$m_d << m_c$ → quark + heavy quark (q) (Q)



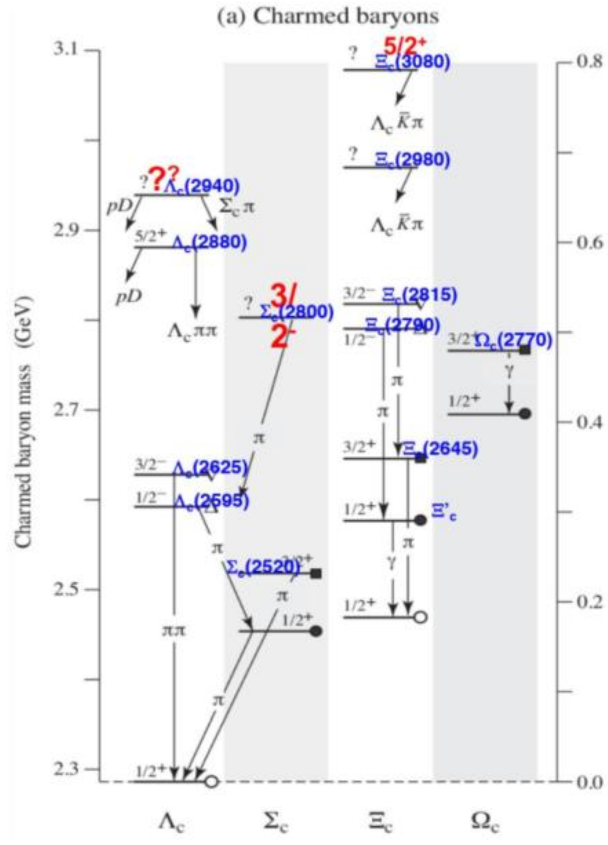
→ Strange baryons ($\Lambda[uds]$)

$m_u, m_d \approx m_s$ → (qqq) uniform



→ Charmed baryon ($\Lambda_c[udc]$)

$m_u, m_d << m_c$ → diquark + quark (qq) (Q)



Λ_c^+ semi-leptonic decays

- Weak and strong interaction could be separated, test various QCD-derived phenomenology models
- Important role in understanding of the dynamics of charm baryon decays
- Similar with but complemented to charmed meson decays, precise test SM and search for new physics
  - ✓ BFs
  - ✓ Decay asymmetry and FFs
  - ✓ $|V_{cs}|$ and $|V_{cd}|$
  - ✓ LFU test
  - ✓ …
- Important input for implementing and calibrating the LQCD calculations

Experiment side

- **Only $\Lambda_c^+ \to \Lambda e^+ \nu$ was measured before 2014**
  - Mark II 1982 and PEP 1989 with limited significance
  - Observed by ARGUS 1991
  - Decay asymmetry & FFs by CLEO till 2005

均被BESIII结果取代

- **BESIII measured several BFs using 0.567 fb^{-1} threshold data 2014**
  - $\mathcal{B}(\Lambda_c^+ \to \Lambda e^+ \nu) = (3.63 \pm 0.38_{stat.} \pm 0.20_{syst.})\%$
  - $\mathcal{B}(\Lambda_c^+ \to \Lambda \mu^+ \nu) = (3.49 \pm 0.46_{stat.} \pm 0.27_{syst.})\%$
  - $\mathcal{B}(\Lambda_c^+ \to X e^+ \nu) = (3.95 \pm 0.34_{stat.} \pm 0.09_{syst.})\%$
  - $\mathcal{B}(\Lambda_c^+ \to \Lambda \mu^+ \nu)/\mathcal{B}(\Lambda_c^+ \to \Lambda e^+ \nu) = 0.96 \pm 0.16 \pm 0.04$
  - $\mathcal{B}(\Lambda_c^+ \to \Lambda e^+ \nu)/\mathcal{B}(\Lambda_c^+ \to X e^+ \nu) = 0.919 \pm 0.125 \pm 0.054$

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统计误差主导

Experiment side

➢ BESIII took 3.9 fb^{-1} thereshold data 2020-2021

- Precise studies of golden channel $\Lambda_c^+ \to \Lambda l^+ \nu$(BFs, LFU, FFs…)
- Observation of second SL, $\mathcal{B}(\Lambda_c^+ \to pK^- e^+ \nu) = (0.88 \pm 0.17 \pm 0.07) \times 10^{-3}$
- Updated $\mathcal{B}(\Lambda_c^+ \to X e^+ \nu) = (4.06 \pm 0.10 \pm 0.09)\%$
- $\mathcal{B}(\Lambda_c^+ \to \Lambda \pi^+ \pi^- e^+ \nu) < 3.9 \times 10^{-4}$@90%CL.
- $\mathcal{B}\left(\Lambda_c^+ \to p K_S^0 \pi^- e^+ \nu\right) < 3.9 \times 10^{-4}$@90%CL.

与理论预言有所分歧

2022-2023发表
几乎全为电子道

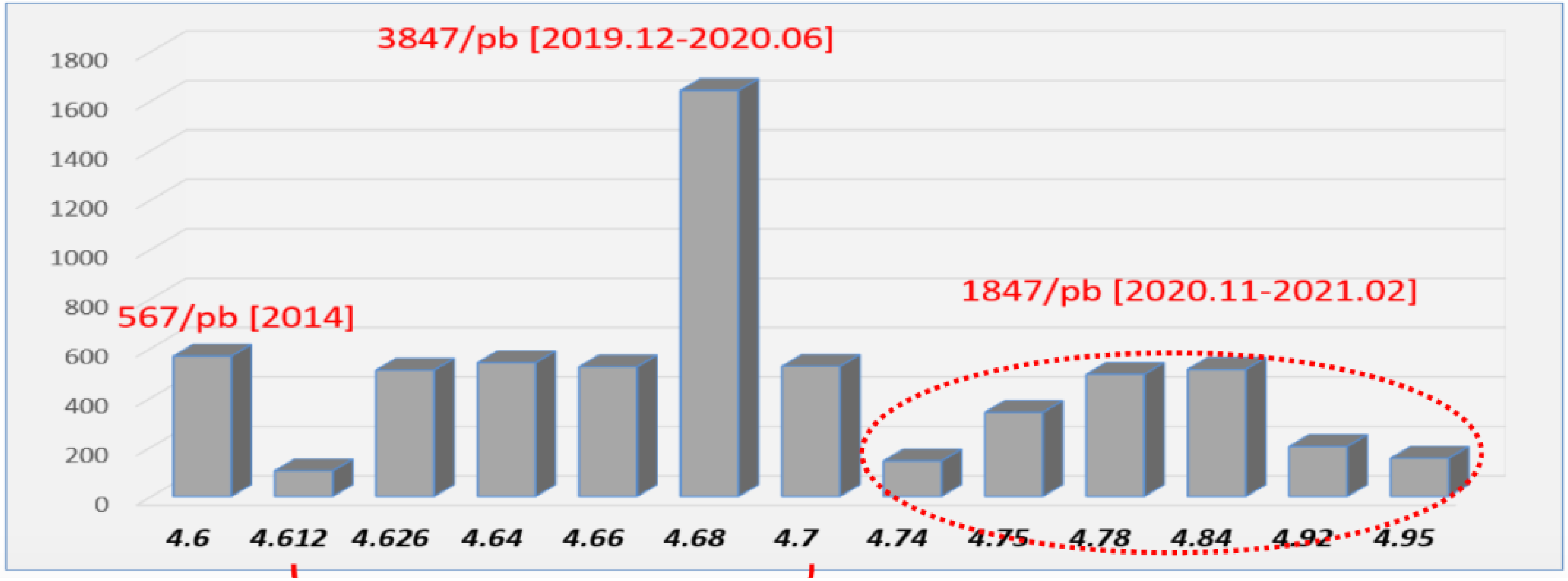
➢ BESIII took 1.93 fb^{-1} data 2021 and what's next?

- ☐ μ^+ channels
- ☐ n/K_L channels
- ☐ "Rare" channels
- ☐ More variables
- ☐ Λ^* channels
- ☐ …

包括但不限于课题二

Λ_c^+ results and data

- ➢Published 17 (7 PRLs)+28 (1 NC+4 PRLs)
  - ✓ SL: 3 (2 PRLs)+6 (1 NC+1 PRL)



- ✓ 6.4 fb^{-1} ~1 M $\Lambda_c^+\bar{\Lambda}_c^-$ available
- ☐ Request another 9 fb^{-1} 4.68 GeV 2025/26, more will come

BESIII Λ_c^+ results

- Published 17 (7 PRLs)+28 (1 NC+4 PRLs)
  - ✓ SL: 3 (2 PRLs)+6 (1 NC+1 PRL)

- $\Lambda_c^+ \to \Lambda e^+ \nu$ PRL 115. 221805 (2015)
- $\Lambda_c^+ \to \Lambda \mu^+ \nu$ PLB 767. 42 (2017)
- $\Lambda_c^+ \to X e^+ \nu$ PRL 121. 251801 (2018)

- $\Lambda_c^+ \to \Lambda e^+/\mu^+ \nu$ PRL 129.231803 (2022). PRD 108.L031105 (2023).
- $\Lambda_c^+ \to p K^- e^+ \nu$ PRD 106.112010 (2022).
- $\Lambda_c^+ \to X e^+ \nu$ PRD 107.052005 (2023).
- $\Lambda_c^+ \to \Lambda \pi^+ \pi^- e^+ \nu,\ p K_S^0 \pi^- e^+ \nu$ PLB 843.137993 (2023).
- $\Lambda_c^+ \to n e^+ \nu$ Nat. Comm. 16, 681 (2025).

Λ_c^+ SL status

Semileptonic modes

Γ_{93}	$\Lambda e^+ \nu_e$	(3.56 ± 0.13) %		
Γ_{94}	$\Lambda \pi^+ \pi^- e^+ \nu_e$	< 3.9	$\times 10^{-4}$	CL=90%
Γ_{95}	$p K^- e^+ \nu_e$	$(8.8 \pm 1.8) \times 10^{-4}$		
Γ_{96}	$p K_S^0 \pi^- e^+ \nu_e$	< 3.3	$\times 10^{-4}$	CL=90%
Γ_{97}	$\Lambda(1520) e^+ \nu_e$	$(1.0 \pm 0.5) \times 10^{-3}$		
Γ_{98}	$\Lambda(1405)^0 e^+ \nu_e,\ \Lambda^0 \to pK^-$	$(4.2 \pm 1.9) \times 10^{-4}$		
Γ_{99}	$\Lambda \mu^+ \nu_\mu$	(3.48 ± 0.17) %		

PDG 2025 All from BESIII

- ✓ Based on $Xe^+\nu$ and the known channels:

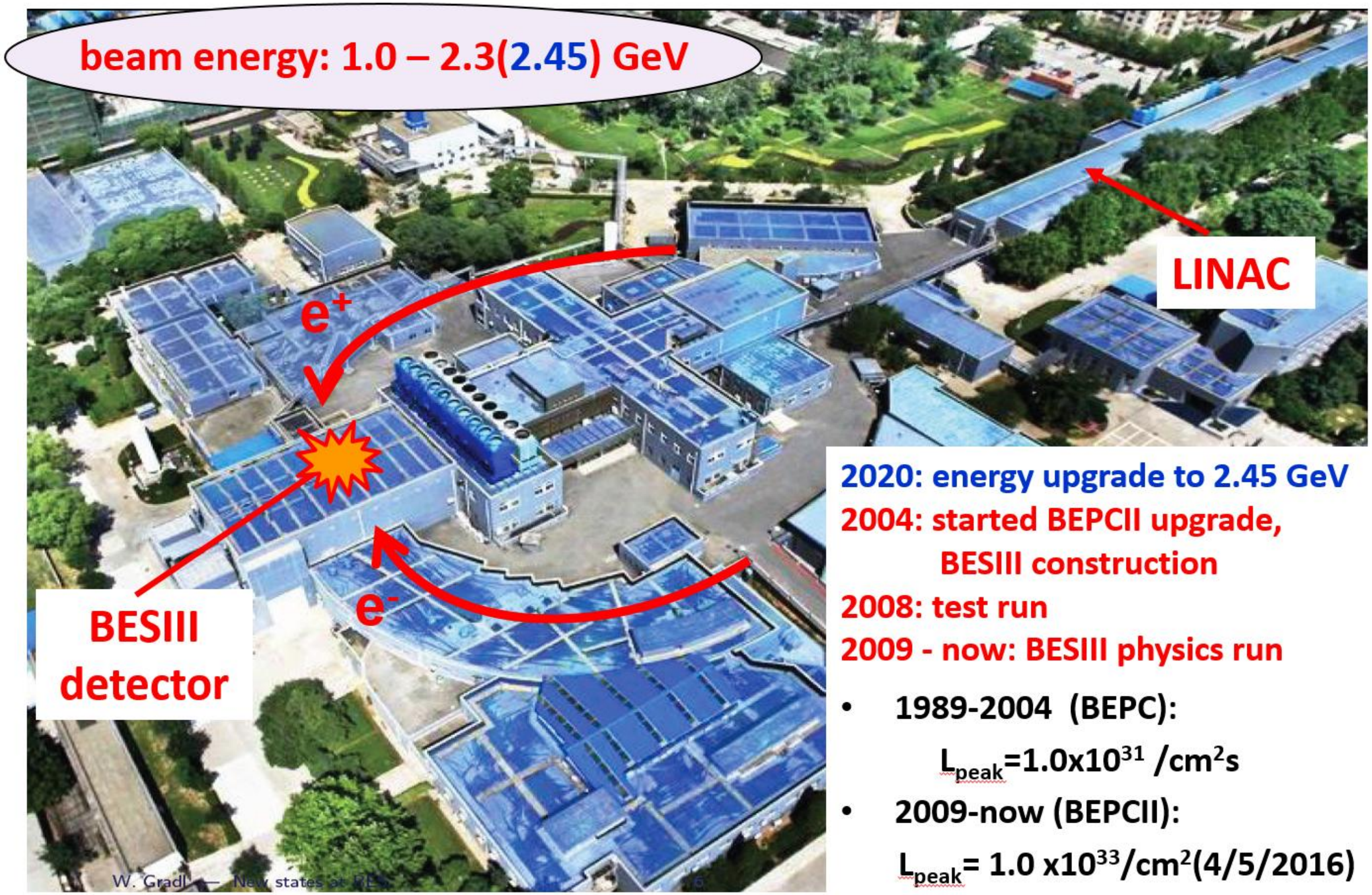
$$\mathcal{B}(\Lambda_c^+ \to non[\Lambda, n, pK]e^+\nu) = (0.55 \pm 1.53 \pm 1.15) \times 10^{-3}$$

- ✓ Chance to $\Lambda_c^+ \to \Lambda^*/N^{(*)}$…

Λ_c^+ SL status

Λ_c^+ Mode	BF($\times 10^{-3}$)	Experiment	Λ_c^+ Mode	BF($\times 10^{-3}$)	Experiment
$\Lambda_c^+ \to \Lambda e^+ \nu_e$	23.7±5.1(37%)†	ARGUS(1991)[24]	$\Lambda_c^+ \to pK^- e^+ \nu_e$	0.88±0.18(20%)	BESIII(2022)[29]
	26.8±5.1(19%)†	CELO(1994)[25]	$\Lambda_c^+ \to \Lambda(1405) e^+ \nu_e$, $\Lambda(1405) \to pK^-$	0.42±0.19(45%)	BESIII(2022)[29]
	36.3±4.3(12%)	BESIII(2015)[30]			
	35.6±1.3(3.6%)	BESIII(2022)[31]	$\Lambda_c^+ \to \Lambda(1520) e^+ \nu_e$	1.0±0.5(50%)	BESIII(2022)[29]
$\Lambda_c^+ \to \Lambda \mu^+ \nu_\mu$	34.9±5.3(15%)	BESIII(2017)[32]	$\Lambda_c^+ \to pK_S^0 \pi^- e^+ \nu_e$	<0.33	BESIII(2023)[33]
	34.8±1.7(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±3.5(8.9%)	BESIII(2018)[35]	$\Lambda_c^+ \to n e^+ \nu_e$	3.57±0.37 (10%)	BESIII(2025)[36]
	40.6±1.3(3.2%)	BESIII(2023)[37]			

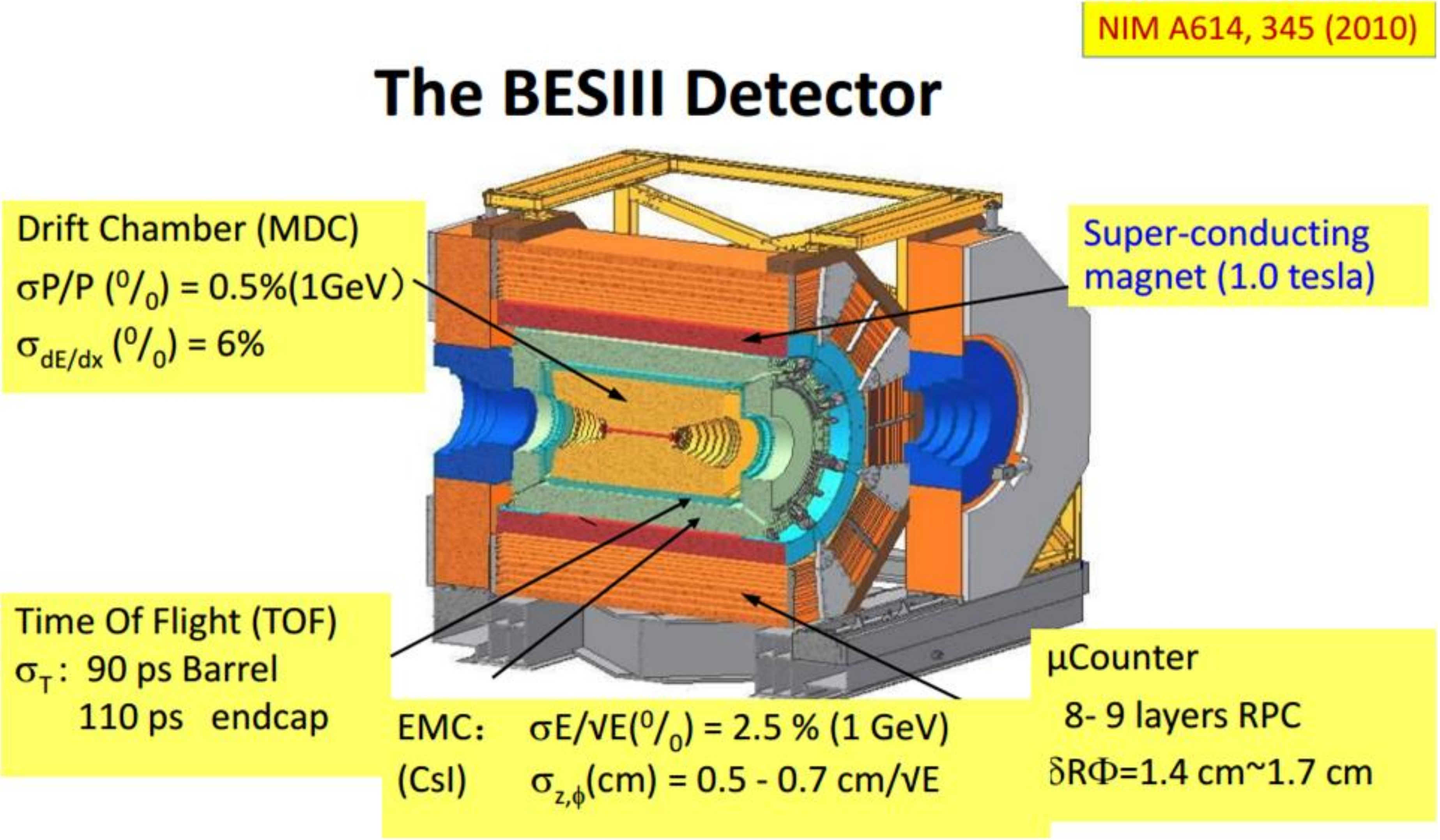
BEPCII



2020: energy upgrade to 2.45 GeV
2004: started BEPCII upgrade, BESIII construction
2008: test run
2009 - now: BESIII physics run

- **1989-2004 (BEPC):**
  L_{peak}=1.0x10^{31} /cm^{2}s
- **2009-now (BEPCII):**
  L_{peak}= 1.0 x10^{33}/cm^2(4/5/2016)

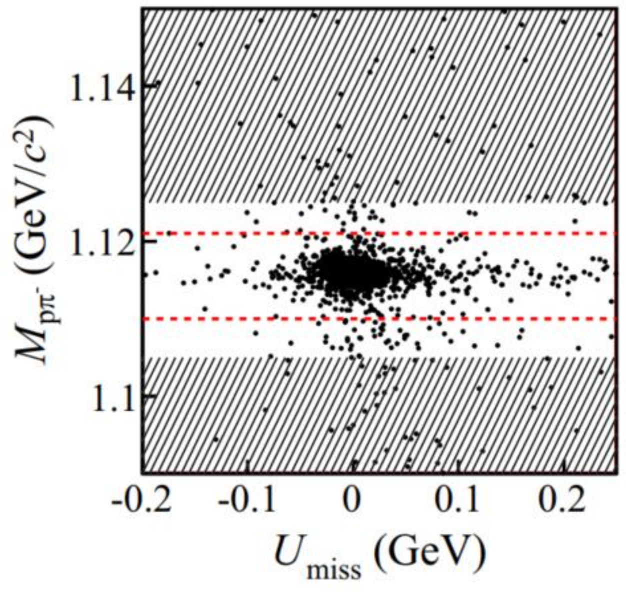
BESIII detector

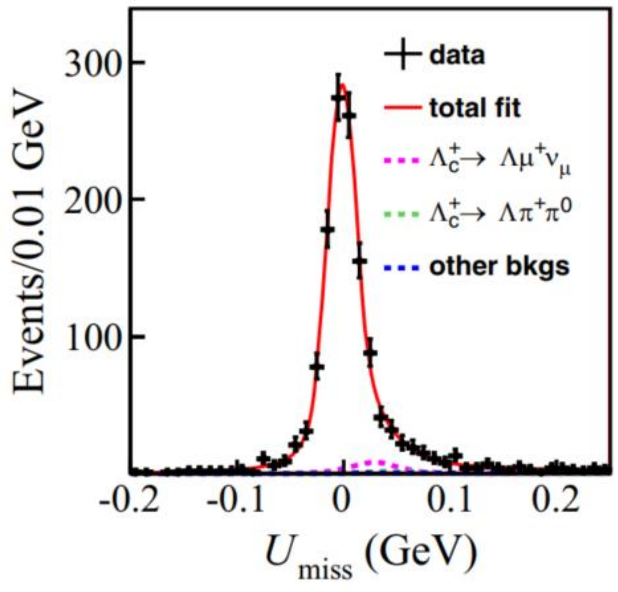


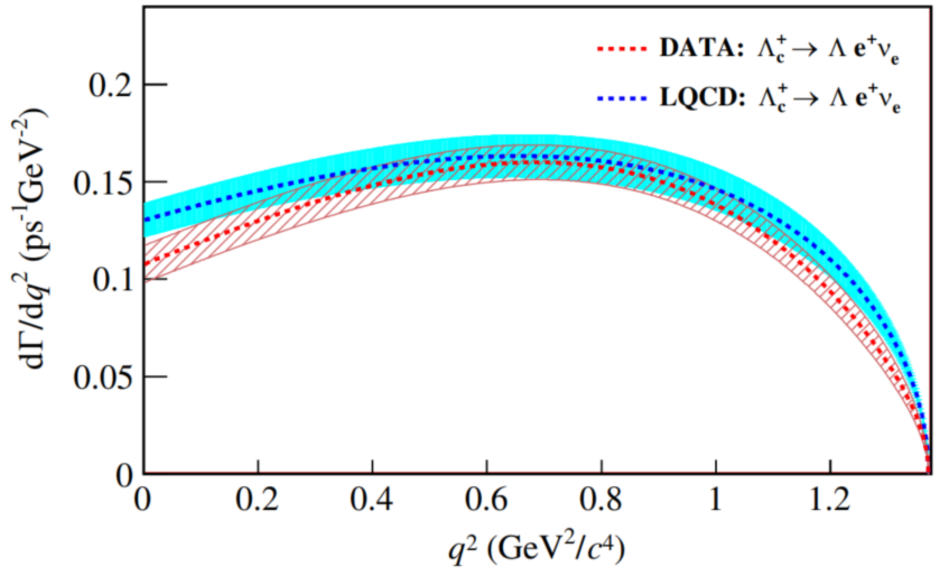
BFs of $\Lambda_c^+ \to \Lambda e^+ \nu$

PRL 129.231803 (2022)

- Updated BFs
- First comparisons on differential decay rates and FFs with LQCD.
- $\mathrm{N}(\Lambda_c^+ \to \Lambda e^+ \nu) = 1253 \pm 39$







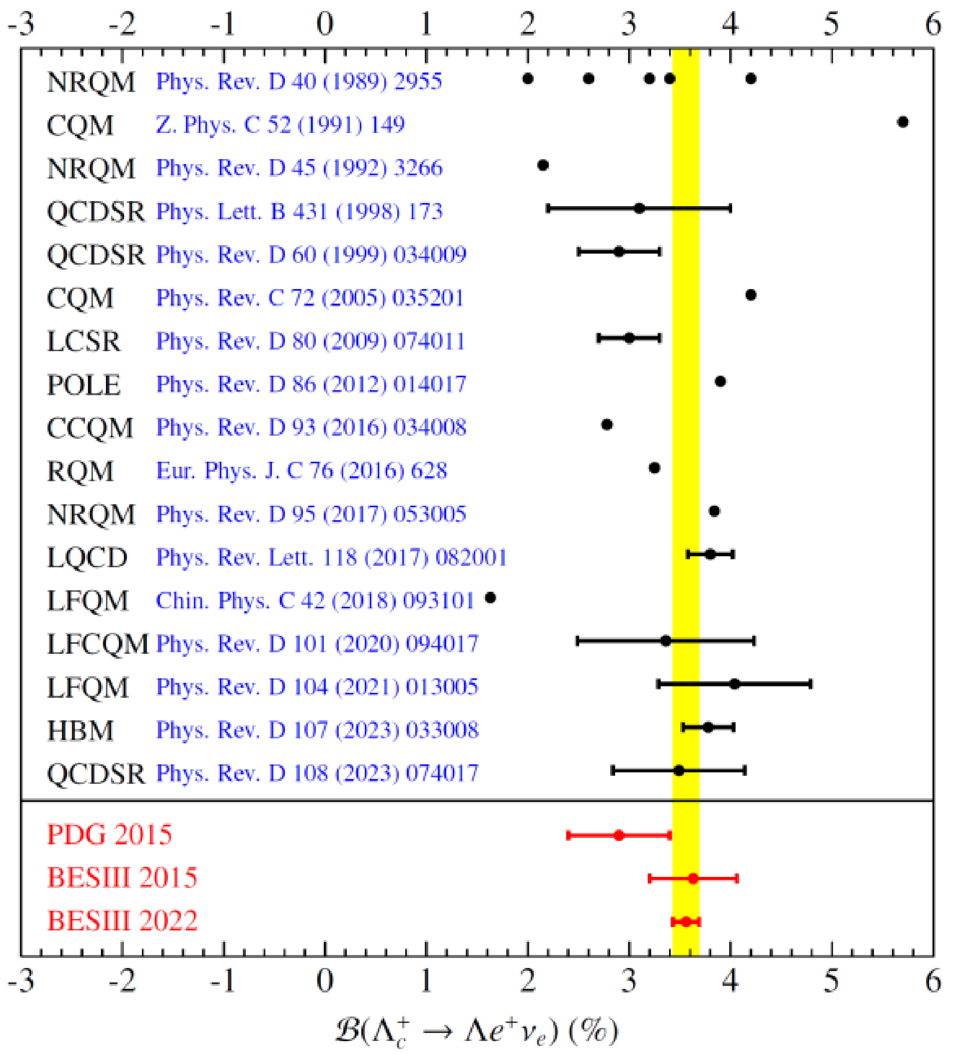
Fair agreement

BFs of $\Lambda_c^+ \to \Lambda e^+ \nu$

PRL 129.231803 (2022)

- Updated BFs
- Disfavor some predictions @95% CL.
- $|V_{cs}| = 0.936 \pm 0.017 \pm 0.024 \pm 0.007$, consistent with 0.939 ± 0.038 from $D \to Kl\nu$.

	$\mathcal{B}(\Lambda_c^+ \to \Lambda e^+ \nu_e)$ (%)
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	$3.56 \pm 0.11 \pm 0.07$

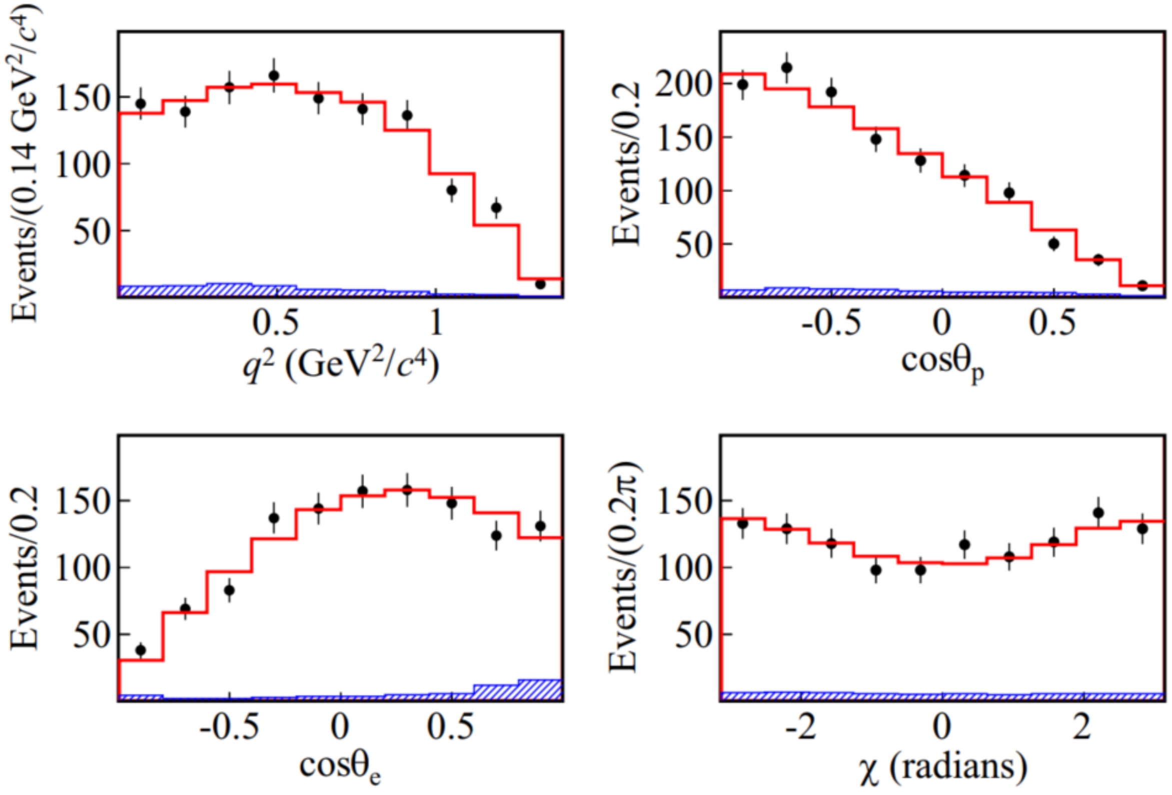


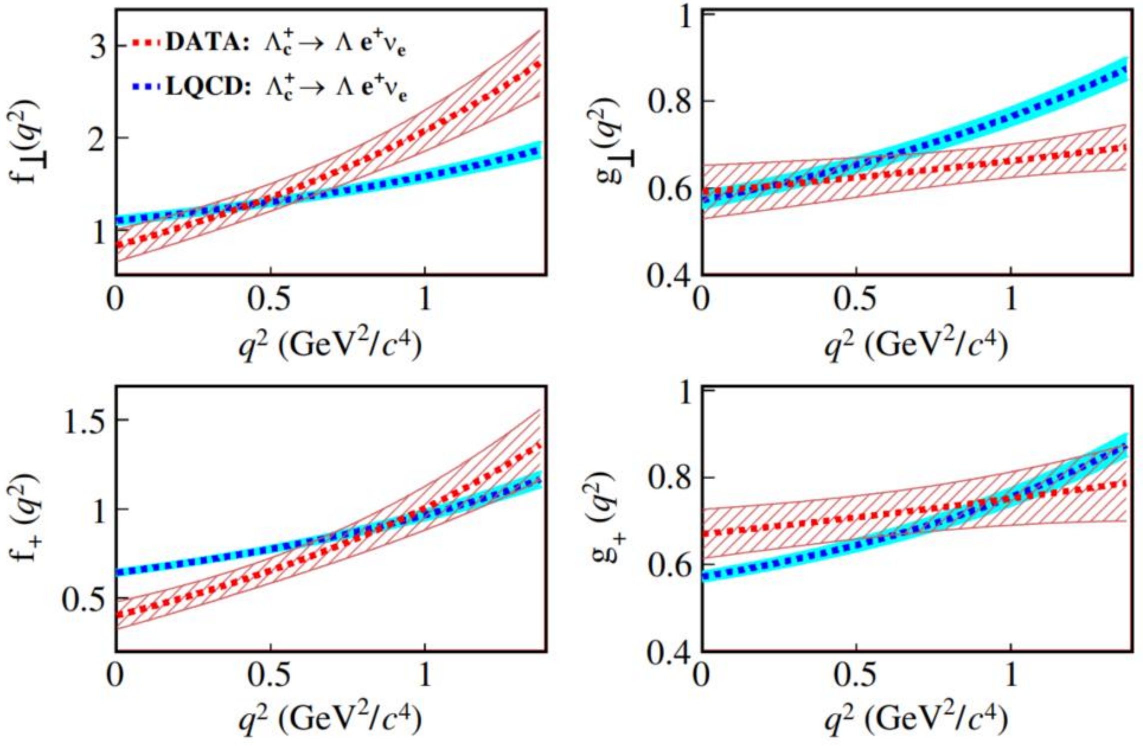
FFs of $\Lambda_c^+ \to \Lambda e^+ \nu$

PRL 129.231803 (2022)

➢ First comparisons on FFs with LQCD.

Four-dimensional fit



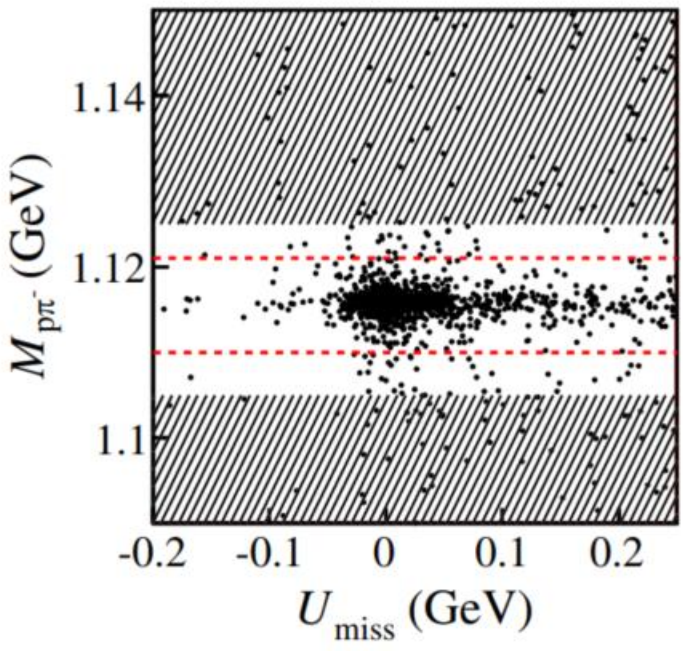


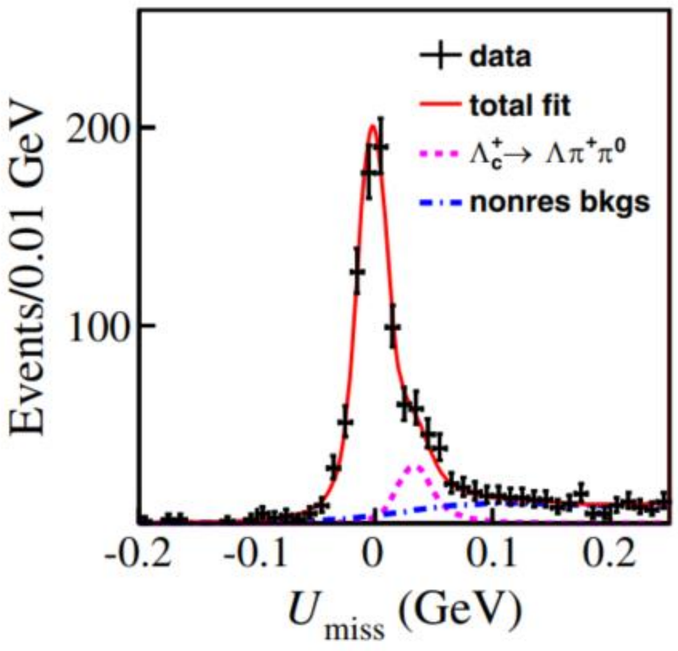
- Different kinematic behavior
- Statistical uncertainty dominates

BFs of $\Lambda_c^+ \to \Lambda\mu^+\nu$

PRD 108.L031105 (2023)

- BFs is measured.
- 3 times more precise than prior world average.



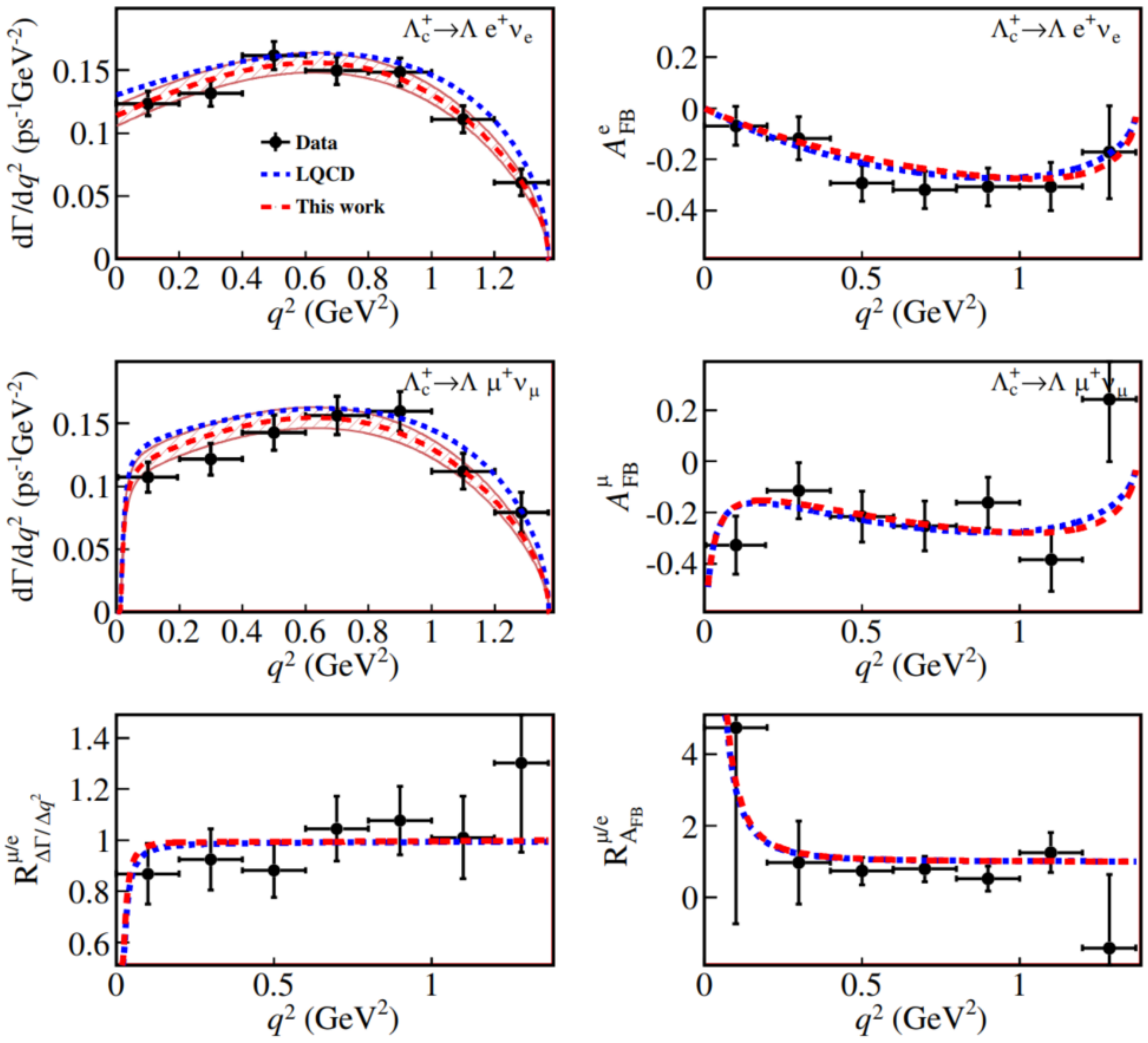


$$N(\Lambda_c^+ \to \Lambda\mu^+\nu) = 752 \pm 31$$

$$\mathcal{B}(\Lambda_c^+ \to \Lambda\mu^+\nu) = (3.48 \pm 0.14_{stat.} \pm 0.10)\%$$

BFs, A_{FB}^{l} and LFU of $\Lambda_c^+ \to \Lambda l^+ \nu$

PRD 108.L031105 (2023)



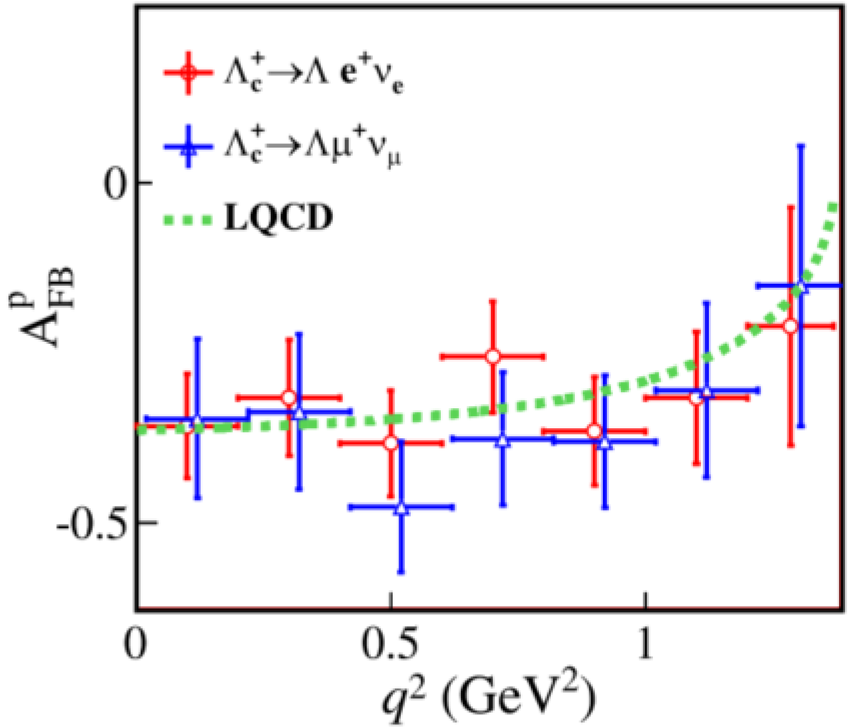
- ✓ Differential decay rates, consistent with LQCD.
- ✓ Forward-backward asymmetries, no LFUV.
- ✓ First LFU test reported, $R(\frac{e^+}{\mu^+}) = 0.98 \pm 0.05_{stat.} \pm 0.03$, compatible with LQCD 0.97.

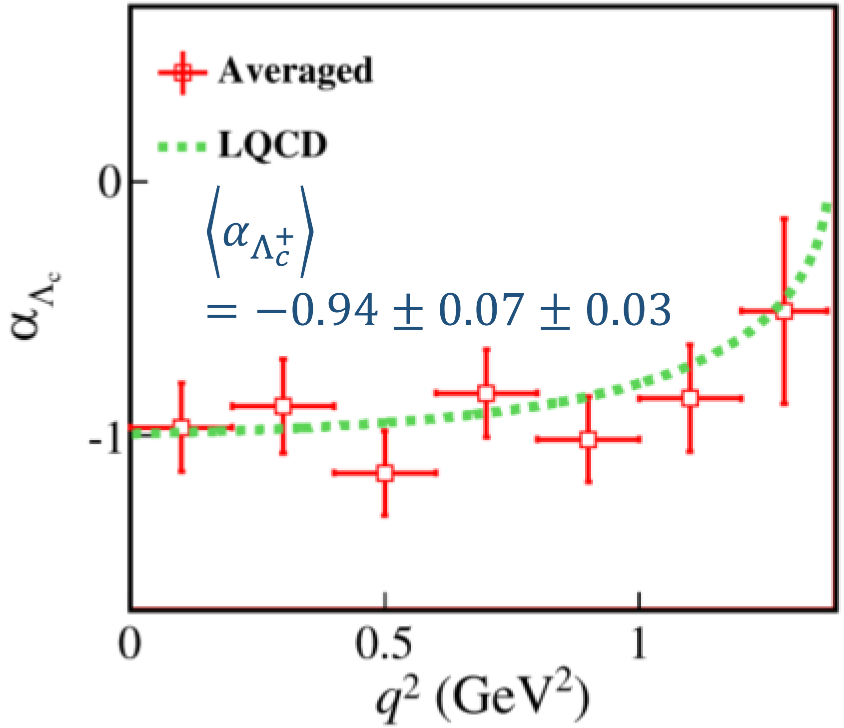
A_{FB}^{p} and $\alpha_{\Lambda_c^+}$ of $\Lambda_c^+ \to \Lambda l^+ \nu$

PRD 108.L031105 (2023)

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

$$\alpha_{\Lambda_c}(q^2) = \frac{2}{\alpha_\Lambda}[A_{\rm FB}^{p}(q^2)]$$





Comparisons of $\Lambda_c^+ \to \Lambda\mu^+\nu$

PRD 108.L031105 (2023)

TABLE I. Comparisons of $\mathcal{B}(\Lambda_c^+ \to \Lambda\mu^+\nu_\mu)$ (in %), $\langle\alpha_{\Lambda_c}\rangle$, $\langle A_{FB}^e\rangle$, and $\langle A_{FB}^\mu\rangle$ from theories and measurement.

	$\mathcal{B}(\Lambda_c^+ \to \Lambda\mu^+\nu_\mu)$	$\langle\alpha_{\Lambda_c}\rangle$	$\langle A_{FB}^e\rangle$	$\langle A_{FB}^\mu\rangle$
CQM [20]	2.69	−0.87	−0.2	−0.21
RQM [21]	3.14	−0.86	−0.209	−0.242
CQM(HONR) [49]	4.25			
NRQM [50]	3.72			
HBM [24]	3.67 ± 0.23	−0.826	−0.176(5)	−0.143(6)
LQCD [28]	3.69 ± 0.22	−0.874(10)	−0.201(6)	−0.169(7)
LCSR [51]	3.0 ± 0.3			
$SU(3)$ [25]	3.6 ± 0.4	−0.86(4)		
LFCQM [27]	3.21 ± 0.85	−0.97(3)		
MBM [27]	3.38	−0.83		
LFQM [22]	3.90 ± 0.73	−0.87(9)	0.20(5)	0.16(4)
LFCQM [26]	3.40 ± 1.02	−0.97(3)		
$SU(3)$ [52]	3.45 ± 0.30			
This work	3.48 ± 0.17	−0.94(8)	−0.24(3)	−0.22(4)

- BFs disfavor [20] and [49] >95%CL.
- Decay asymmetry consistent with all the predictions.
- Lepton FB asymmetry differ from LFQM in [22].

T asymmetry of $\Lambda_c^+ \to \Lambda l^+ \nu$

PRD 108.L031105 (2023)

$$\mathcal{T}_p = \frac{[(\int_{-\pi}^{0} - \int_{0}^{\pi}) d\chi][(\int_{0}^{1} - \int_{-1}^{0}) d\cos\theta_p]\Gamma^{\ell}_{\chi,\cos\theta_p}}{\alpha_\Lambda \Gamma^{\ell}}$$

$$\mathcal{T}_p(\Lambda_c^+ \to \Lambda e^+ \nu) = -0.021 \pm 0.041 \pm 0.001$$

$$\mathcal{T}_p(\Lambda_c^+ \to \Lambda \mu^+ \nu) = 0.068 \pm 0.055 \pm 0.002$$

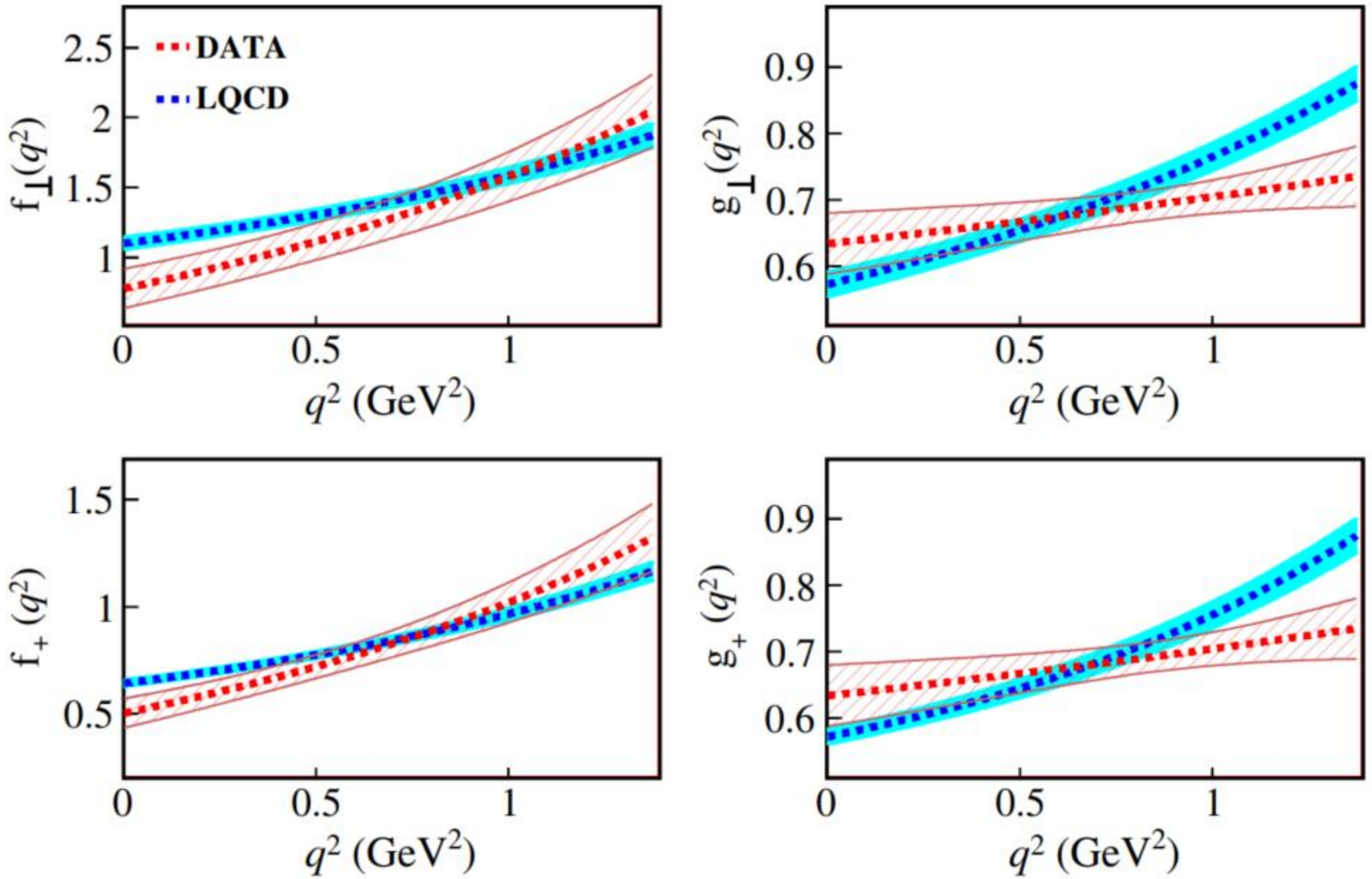
✓ Consistent with 0 of SM.

✓ No indication of new physics.

FFs of $\Lambda_c^+ \to \Lambda l^+ \nu$

PRD 108.L031105 (2023)

- Simultaneous fit with helicity amplitudes

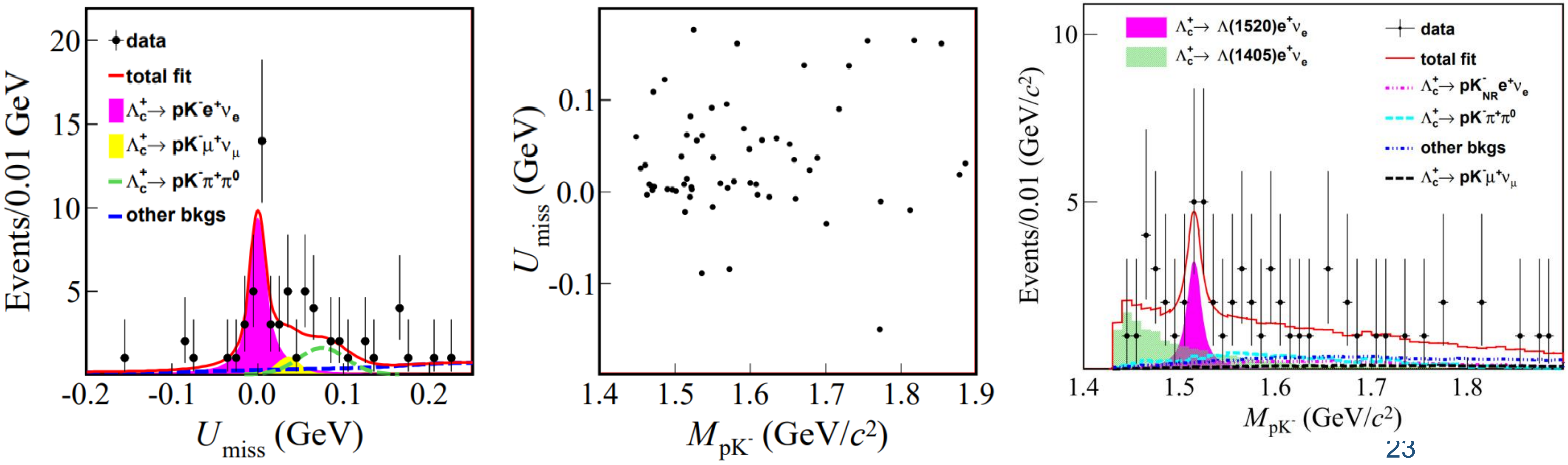


More precise

$\Lambda_c^+ \to pK^- e^+ \nu$

PRD 106.112010 (2022)

- Second observed SL decay
- $\mathcal{B}(\Lambda_c^+ \to pK^- e^+ \nu) = (0.88 \pm 0.17 \pm 0.07) \times 10^{-3}$ with 8.2 σ.
- Evidence for $\Lambda(1405)$ and $\Lambda(1520)$ in pK^- spectrum:
  - $\mathcal{B}(\Lambda_c^+ \to \Lambda(1520) e^+ \nu) = (1.02 \pm 0.52 \pm 0.11) \times 10^{-3}$ with 3.3 σ.
  - $\mathcal{B}(\Lambda_c^+ \to \Lambda(1405)[\to pK] e^+ \nu) = (0.42 \pm 0.19 \pm 0.04) \times 10^{-3}$ with 3.2 σ.



$\Lambda_c^+ \to pK^- e^+ \nu$

PRD 106.112010 (2022)

TABLE I. Comparison of $\mathcal{B}(\Lambda_c^+ \to \Lambda(1520)/\Lambda(1405)e^+\nu_e)$ [in $\times 10^{-3}$] between theoretical calculations and this measurement. The BF of $\Lambda(1405) \to pK^-$ is unknown [2].

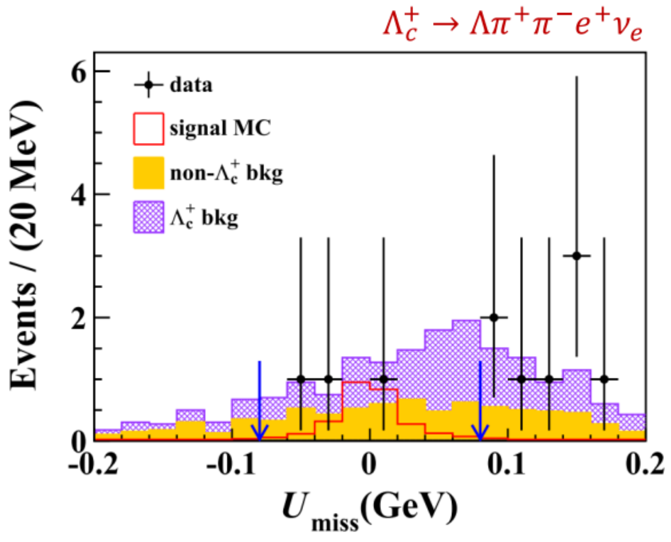
	$\mathcal{B}(\Lambda_c^+ \to \Lambda(1520)e^+\nu_e)$	$\mathcal{B}(\Lambda_c^+ \to \Lambda(1405)e^+\nu_e)$
Constituent quark model [8]	1.01	3.04
Molecular state [9]	...	0.02
Nonrelativistic quark model [10]	0.60	2.43
Lattice QCD [12,13]	0.512 ± 0.082	...
Measurement	$1.02 \pm 0.52 \pm 0.11$	$\frac{0.42 \pm 0.19 \pm 0.04}{\mathcal{B}(\Lambda(1405) \to pK^-)}$

Need more data and more detailed study!

$\Lambda_c^+ \to \Lambda\pi^+\pi^-e^+\nu$ and $\Lambda_c^+ \to pK_S^0\pi^-e^+\nu$

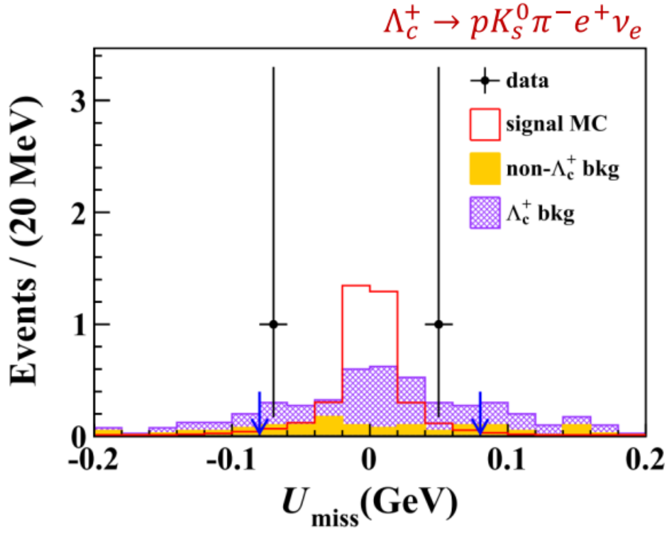
PLB 843, 137933 (2023)

- Search for Λ^*:
  - $\mathcal{B}(\Lambda(1520) \to \Lambda\pi^+\pi^-) = (10 \pm 1)\%$
  - Excited Λ^* could decay to $pK^*(892)^-$
- Upper limits @90%CL.:
  - $\mathcal{B}(\Lambda_c^+ \to \Lambda\pi^+\pi^-e^+\nu) < 3.9 \times 10^{-4}$
  - $\mathcal{B}\left(\Lambda_c^+ \to pK_S^0\pi^-e^+\nu\right) < 3.3 \times 10^{-4}$
  - $\mathcal{B}(\Lambda_c^+ \to \Lambda(1520)e^+\nu) < 4.3 \times 10^{-3}$
  - $\mathcal{B}(\Lambda_c^+ \to \Lambda(1600)e^+\nu) < 9.0 \times 10^{-3}$



The BFs for $\Lambda_c^+ \to \Lambda^* e^+\nu_e$ predicted by different theoretical models, in units of 10^{-4}.

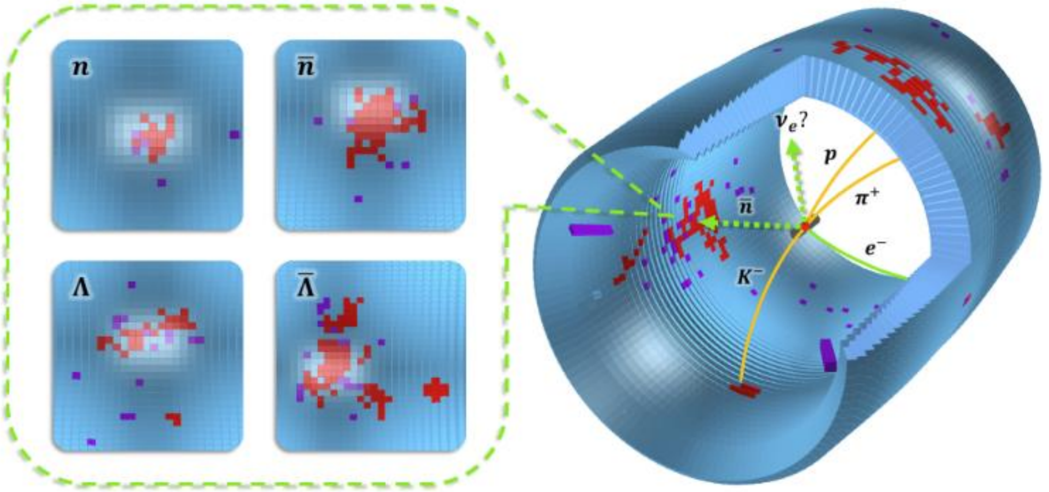
Λ^* state	CQM [8]	NRQM [9]	LFQM [10]	LQCD [11]
$\Lambda(1520)$	10.00	5.94	--	5.12 ± 0.82
$\Lambda(1600)$	4.00	1.26	(0.7 ± 0.2)	--
$\Lambda(1890)$	--	3.16×10^{-2}	--	--
$\Lambda(1820)$	--	1.32×10^{-2}	--	--

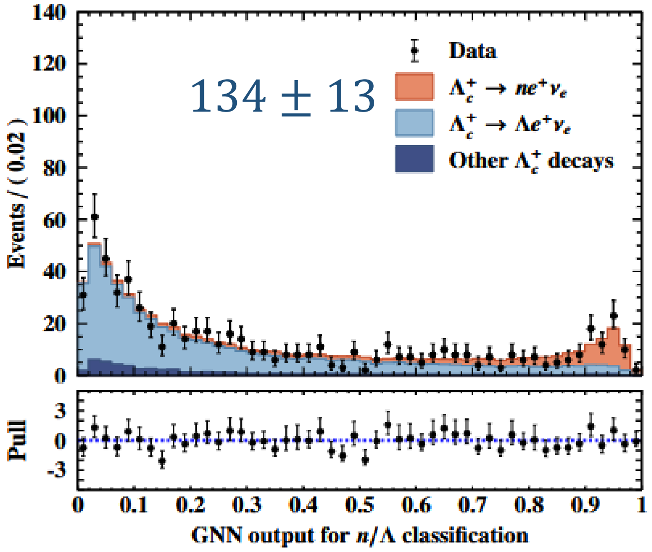


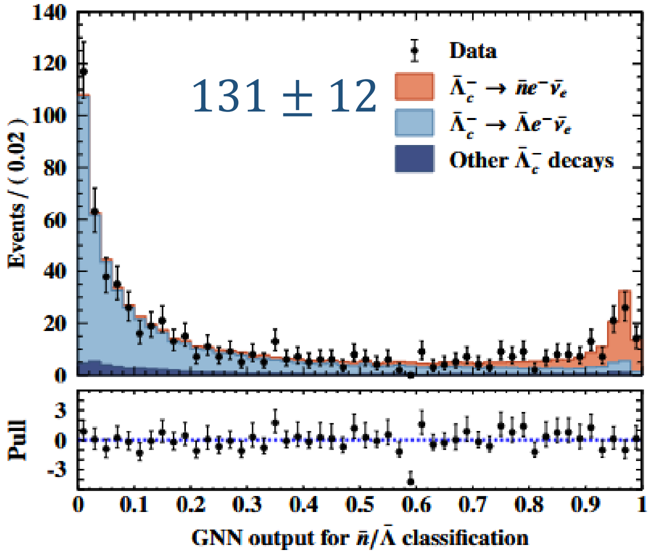
$\Lambda_c^+ \to n e^+ \nu$

Nat. Comm. 16, 681 (2025)

- Λ_c^+ CS transition $c \to d l^+ \nu$ beta decay never been observed
- Big challenge due to two missing particles n and ν, extensive bkg. from $\Lambda_c^+ \to \Lambda(n\pi^0)e^+\nu$
- DT with Graph Neural Network(GNN) is used for 3-D classification
- Validated with control samples of $J/\psi \to \bar{p}\pi^+ n$, $J/\psi \to \bar{p}K^+\Lambda$ and c.c.
- Further cross check on $\mathcal{B}(\Lambda_c^+ \to \Lambda e^+ \nu)$

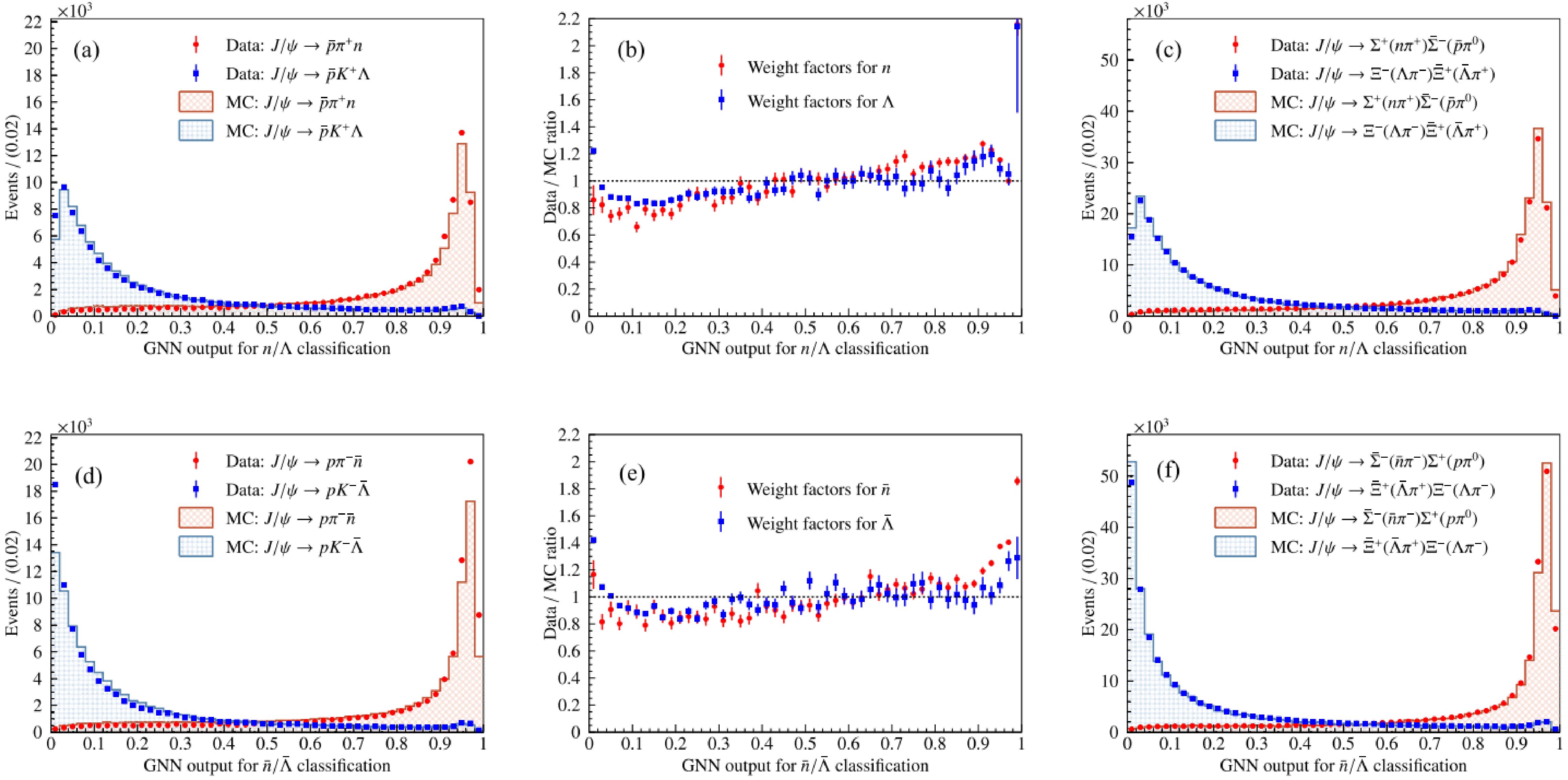






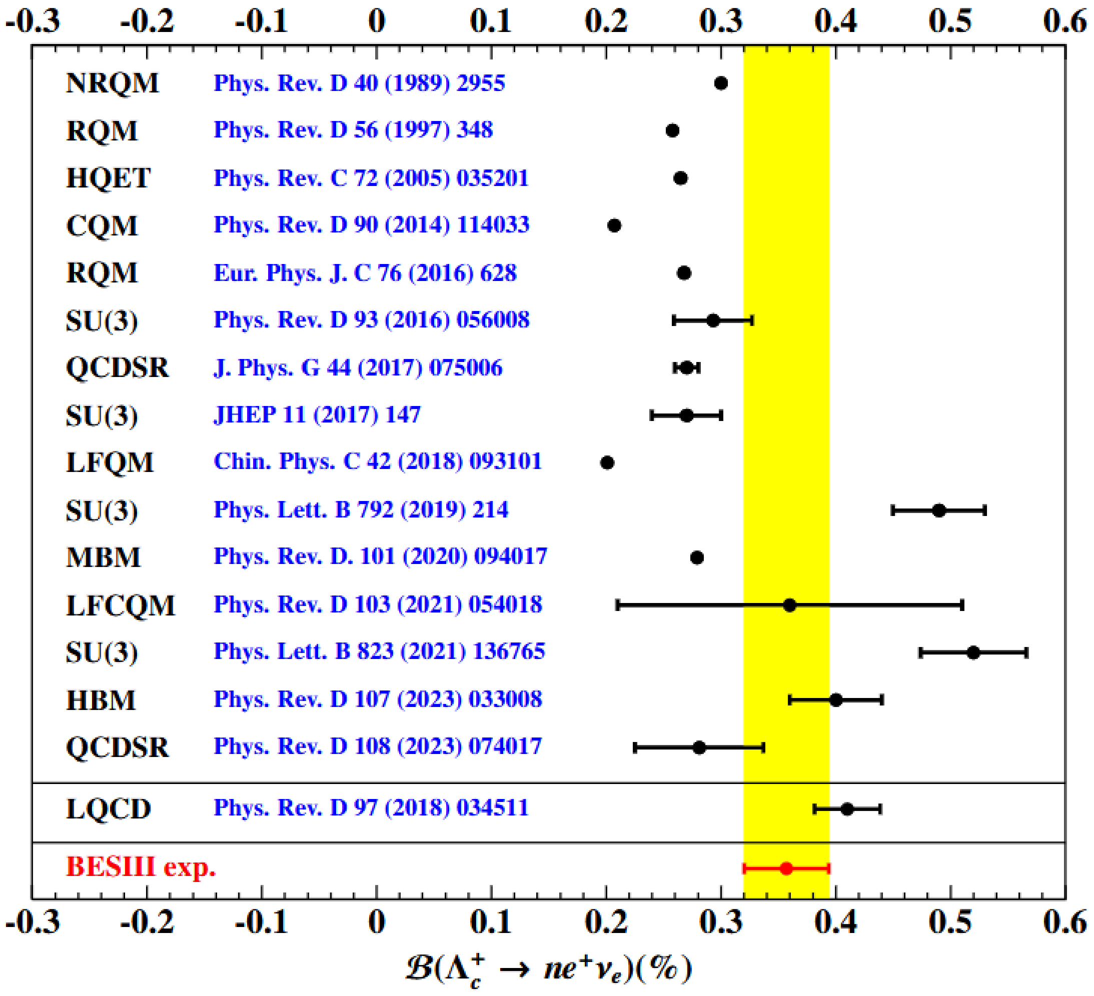
$\Lambda_c^+ \to n e^+ \nu$

Nat. Comm. 16, 681 (2025)



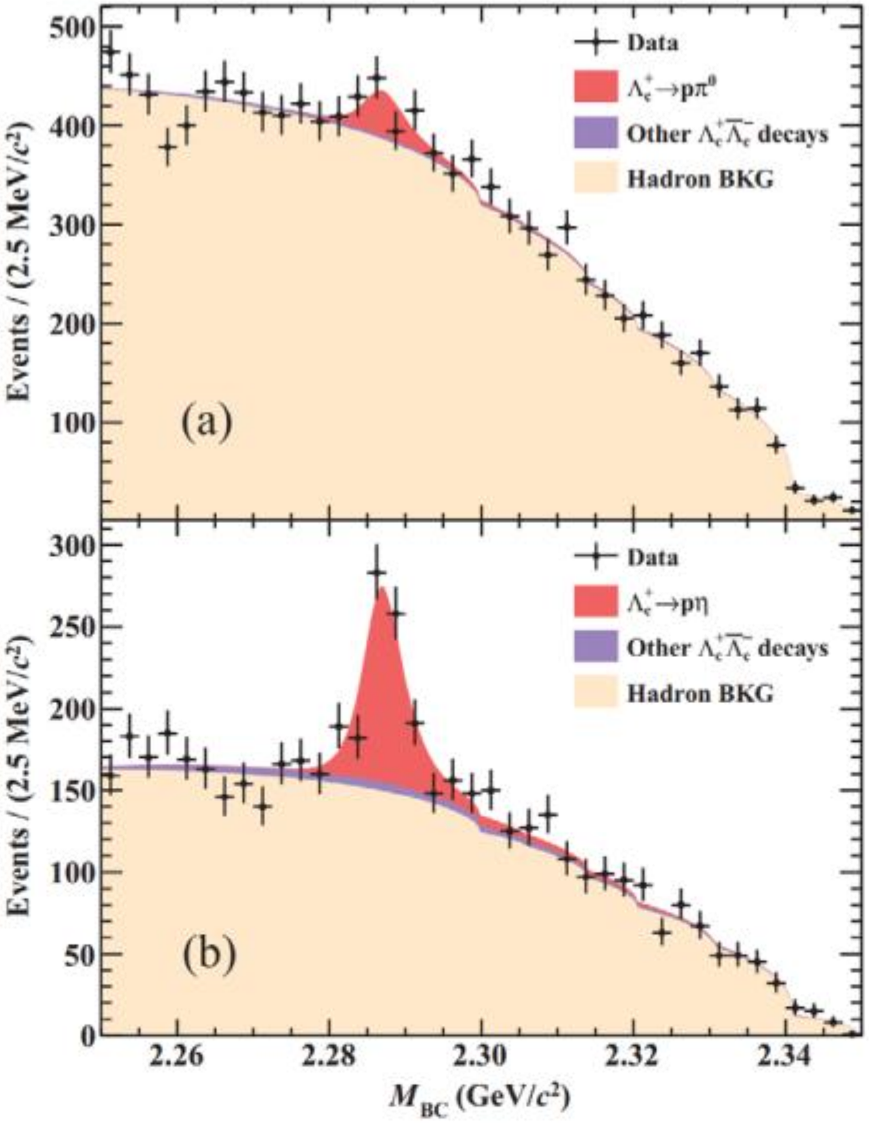
$\Lambda_c^+ \to ne^+\nu$

Nat. Comm. 16, 681 (2025)

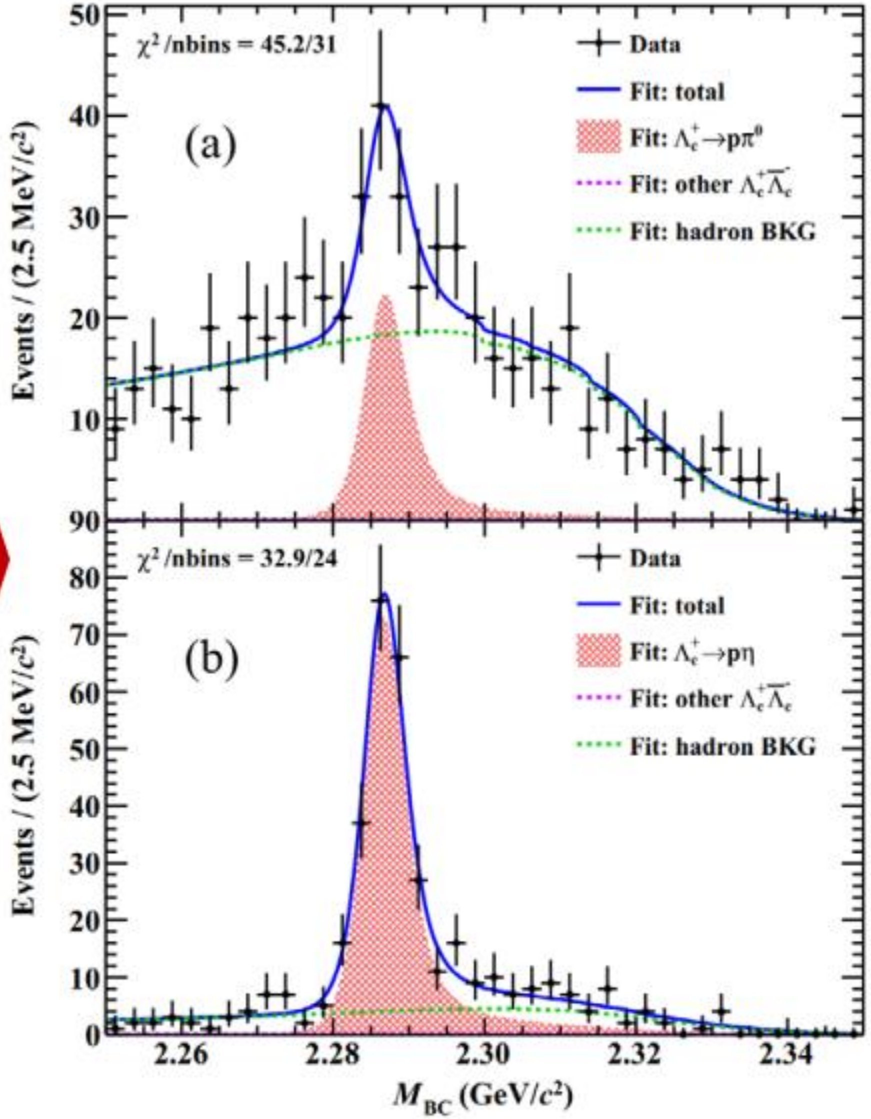


- ✓ $\mathcal{B}(\Lambda_c^+ \to ne^+\nu) = (3.57 \pm 0.34_{stat.} \pm 0.14_{syst.}) \times 10^{-3}$, consistent and precision comparable to LQCD.
- ✓ $|V_{cd}| = 0.208 \pm 0.011 \pm 0.007 \pm 0.001$, first from charmed baryon decay and consistent with the world average value (0.221±0.004).
- ✓ Test various theoretical models.
- ✓ Power of modern machine learning techniques.

ML example



DNN veto



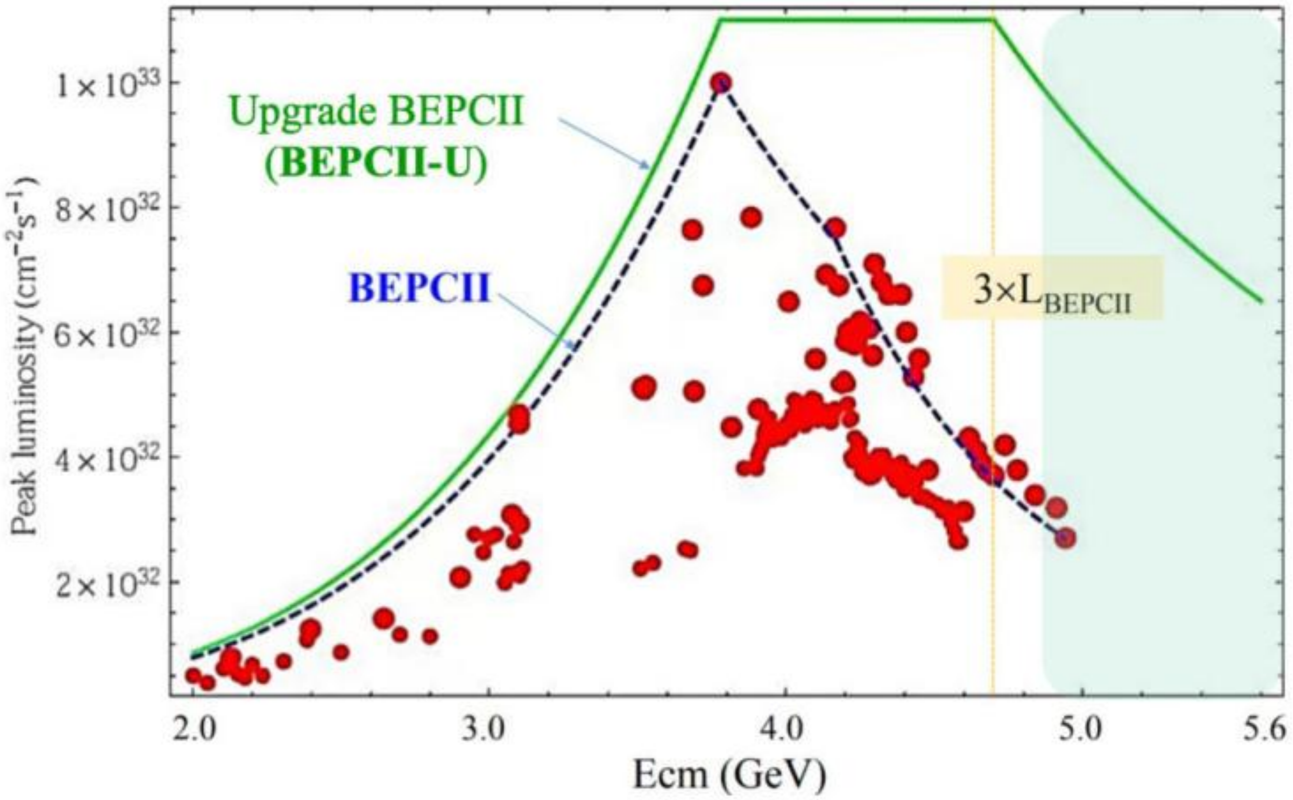
BESIII Λ_c^+ SL opportunities

Lots of channels to be and being studied:

- ✓ $\Lambda_c^+ \to \Sigma^{+/-}\pi^{-/+}e^+\nu$(BAM-589, CWR)
- ✓ $\Lambda_c^+ \to p\pi^-e^+\nu$ (BAM-736)
- ☐ $\Lambda_c^+ \to pK^-e^+\nu$ (ML)
- ☐ $\Lambda_c^+ \to pK^-\mu^+\nu$
- ☐ $\Lambda_c^+ \to p\pi^-\mu^+\nu$
- ☐ $\Lambda_c^+ \to n\mu^+\nu$ (ML)
- ☐ $\Lambda_c^+ \to nK_S^0e^+\nu$ (ML)
- ☐ $\Lambda_c^+ \to \Sigma^0\pi^0 l^+\nu$ 、$\Sigma^0e^+\nu$、$\Lambda\pi^0e^+\nu$、 $\Lambda\pi^+\pi^-e^+\nu$、$pK_S^0\pi^-e^+\nu$
- ☐ $\Lambda_c^+ \to pK^-\pi^+e^+\nu$
- ☐ $\Lambda_c^+ \to p\pi^+\pi^-e^+\nu$

Outlook

➢ 9 fb^{-1} more data at 4.68 GeV has been approved and will be collected during 2025-2026 (~180 days)



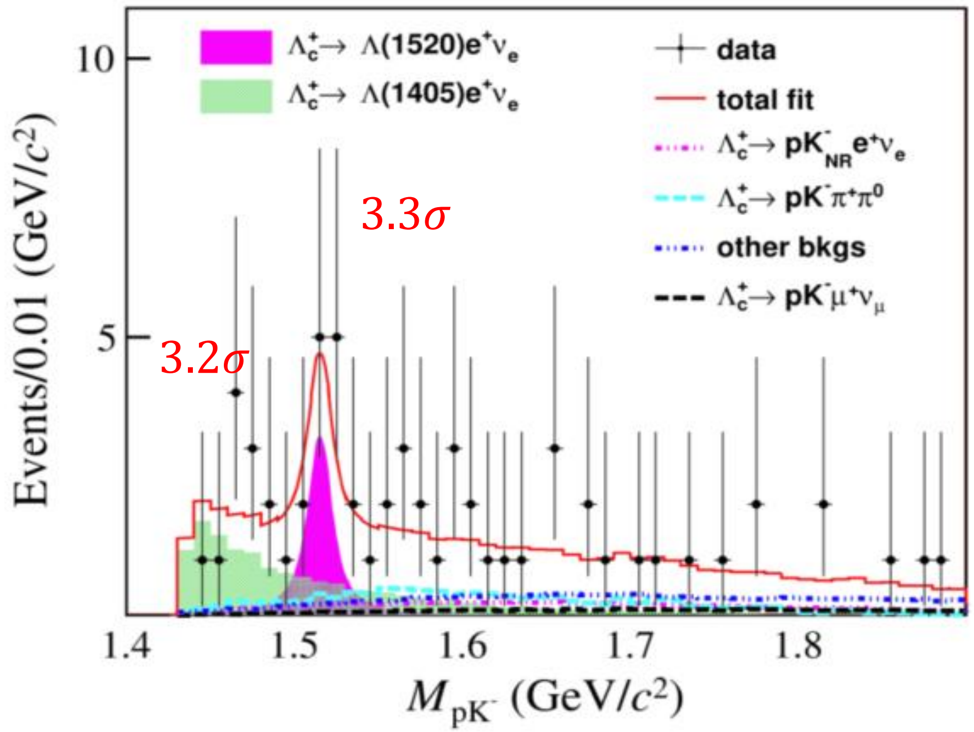
Outlook

➢ 9 fb^{-1} more data at 4.68 GeV has been approved and will be collected during 2025-2026 (~180 days)

Decay channel	Branching fraction
$\Lambda_c^+ \to \Lambda e^+ \nu_e$	$(3.56 \pm 0.11_{stat} \pm 0.07_{syst})\%$
$\Lambda_c^+ \to \Lambda \mu^+ \nu_\mu$	$(3.48 \pm 0.14_{stat} \pm 0.10_{syst})\%$
$\Lambda_c^+ \to n e^+ \nu_e$	$(3.57 \pm 0.34_{stat} \pm 0.14_{syst}) \times 10^{-3}$
$\Lambda_c^+ \to p K^- e^+ \nu_e$	$(0.88 \pm 0.17_{stat} \pm 0.07_{syst}) \times 10^{-3}$

Outlook

- 9 fb^{-1} more data at 4.68 GeV has been approved and will be collected during 2025-2026 (~180 days)
  - ✓ Several hadronic and SL channels could be observed



Summary

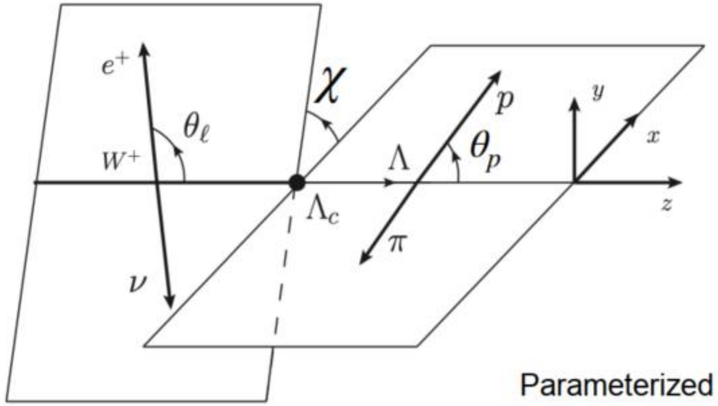
- BESIII has **dominant Λ_c^+ SL decays since 2015**, many channels were first observed and several physical observables were measured(e.g. BFs, FFs).
- Milestone channel **$\Lambda_c^+ \to ne^+\nu$ was firstly observed and studied with new method**, which provide opportunity to many analysis of BESIII.
- More channels in **Project II are ongoing,** good opportunities to study charmed baryon dynamics and test SM.
- 2025/26 BEPCII-U will be more efficient and 9 fb^{-1} more data will be obtained at 4.68 GeV.
- Very welcome predictions from theory and suggestions from theorists.

Thanks for your attention!

BACK UP

Decay dynamics of $\Lambda_c^+ \to \Lambda e^+ \nu_e$

Definition of the polar and the azimuthal angles



4D fit to extract FFs

- $e^+\nu_e$ mass squared: q^2
- $\Lambda \to p\pi^-$ helicity angle: θ_p
- $W^+ \to e^+\nu_e$ helicity angle: θ_e
- Acoplanarity angle between Λ and W^+: χ

Differential decay width

Helicity amplitudes:

$$H_{\lambda_\Lambda \lambda_W} = H^V_{\lambda_\Lambda \lambda_W} - H^A_{\lambda_\Lambda \lambda_W} \text{ and } H^{V(A)}_{-\lambda_\Lambda -\lambda_W} = +(-)H^{V(A)}_{\lambda_\Lambda \lambda_W}$$

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

Neglect lepton mass term

Parameterized by "***Weinberg form factor***"

$$H^V_{\frac{1}{2}1} = \sqrt{2Q_-}\left[F_1^V(q^2) + \frac{(M_{\Lambda_c^+}+M_\Lambda)}{M_{\Lambda_c^+}}F_2^V(q^2)\right],$$
$$H^A_{\frac{1}{2}1} = \sqrt{2Q_+}\left[F_1^A(q^2) - \frac{(M_{\Lambda_c^+}-M_\Lambda)}{M_{\Lambda_c^+}}F_2^A(q^2)\right],$$
$$H^V_{\frac{1}{2}0} = \sqrt{\frac{Q_-}{q^2}}\left[(M_{\Lambda_c^+}+M_\Lambda)F_1^V(q^2) + \frac{q^2}{M_{\Lambda_c^+}}F_2^V(q^2)\right],$$
$$H^A_{\frac{1}{2}0} = \sqrt{\frac{Q_+}{q^2}}\left[(M_{\Lambda_c^+}-M_\Lambda)F_1^A(q^2) - \frac{q^2}{M_{\Lambda_c^+}}F_2^A(q^2)\right].$$

$$F_1^V(q^2) = \frac{1}{(M_{\Lambda_c^+}+M_\Lambda)^2-q^2}[f_+(q^2)(M_{\Lambda_c^+}+M_\Lambda)^2 - f_\perp(q^2)\cdot q^2],$$
$$F_2^V(q^2) = \frac{M_{\Lambda_c^+}\cdot(M_{\Lambda_c^+}+M_\Lambda)}{(M_{\Lambda_c^+}+M_\Lambda)^2-q^2}[f_\perp(q^2) - f_+(q^2)],$$
$$F_1^A(q^2) = \frac{1}{(M_{\Lambda_c^+}-M_\Lambda)^2-q^2}[g_+(q^2)(M_{\Lambda_c^+}-M_\Lambda)^2 - g_\perp(q^2)\cdot q^2],$$
$$F_2^A(q^2) = \frac{M_{\Lambda_c^+}\cdot(M_{\Lambda_c^+}-M_\Lambda)}{(M_{\Lambda_c^+}-M_\Lambda)^2-q^2}[g_+(q^2) - g_\perp(q^2)].$$

The relation between "***Weinberg form factor***" & "***Helicity form factor***"

Parameterized by "***Helicity form factor***"

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

Following LQCD