Charmed baryon Λ_c^+ decays at BESIII

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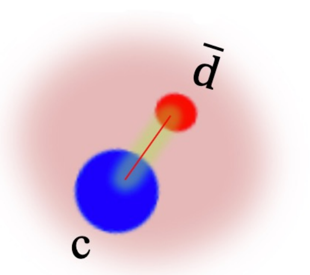
PhiPsi2022, Shanghai, 15-19 August 2022

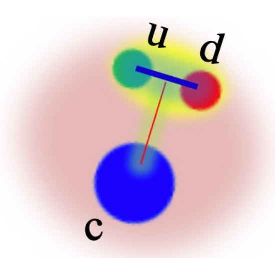
Outline

- Introduction
- Decays involve neutron
  - $\Lambda_c^+ \to n\pi^+$
  - $\Lambda_c^+ \to n\pi^+\pi^0$, $n\pi^+\pi^-\pi^+$ and $nK^-\pi^+\pi^+$
- Partial wave analysis
  - $\Lambda_c^+ \to \Lambda\pi^+\pi^0$
- Singly-Cabbibo-Suppressed decays
  - $\Lambda_c^+ \to \Sigma^0 K^+$ and $\Sigma^+ K_S^0$
- $\Sigma^+ h^+ h^- (\pi^0)$ decays
  - $\Lambda_c^+ \to \Sigma^+ K^+ K^-$, $\Sigma^+ K^+ \pi^-$ and $\Sigma^+ K^+ \pi^- \pi^0$
- Semi-leptonic decays
  - $\Lambda_c^+ \to pK^- e^+ \nu_e$
  - $\Lambda_c^+ \to \Lambda e^+ \nu_e$
  - $\Lambda_c^+ \to \Lambda\pi^+\pi^- e^+ \nu_e$ and $pK_S^0 \pi^- e^+ \nu_e$
- Summary

Why Λ_c^+ is interesting?

- An important intermediate particle
  - Cornerstone of the charmed baryon spectra
  - Many b-baryons decay to Λ_c^+
- Its decays reveal information of strong- and weak-interactions in charm region, complementary to charmed mesons

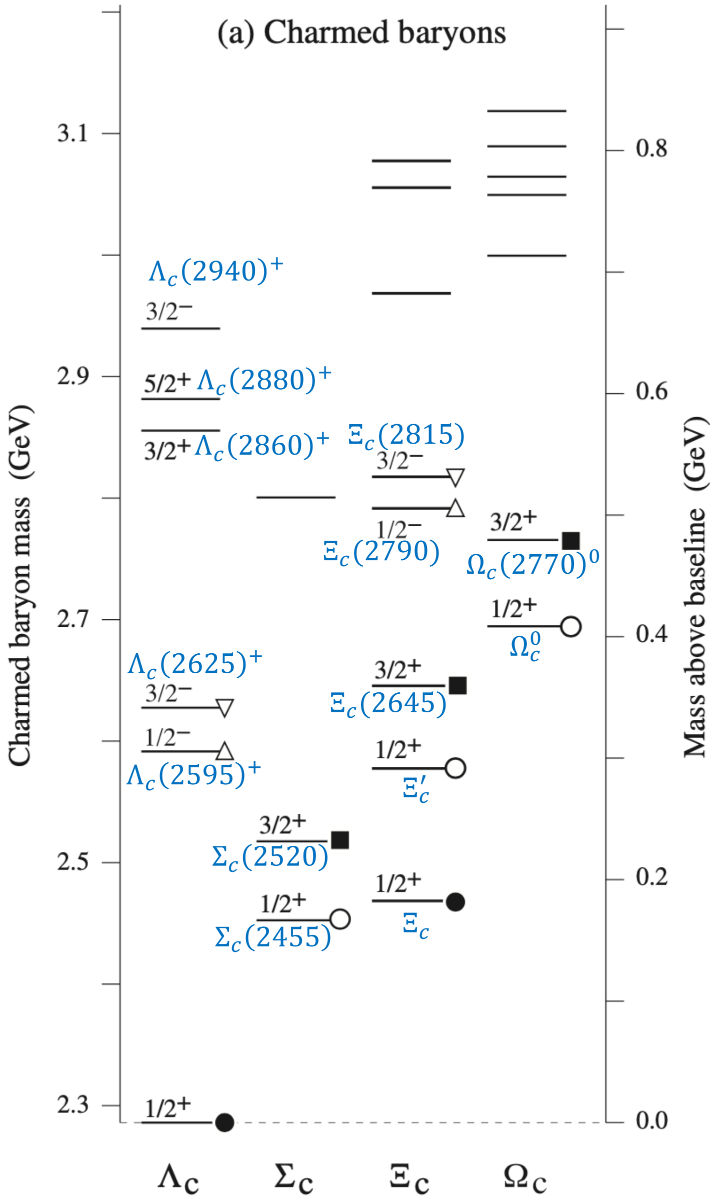




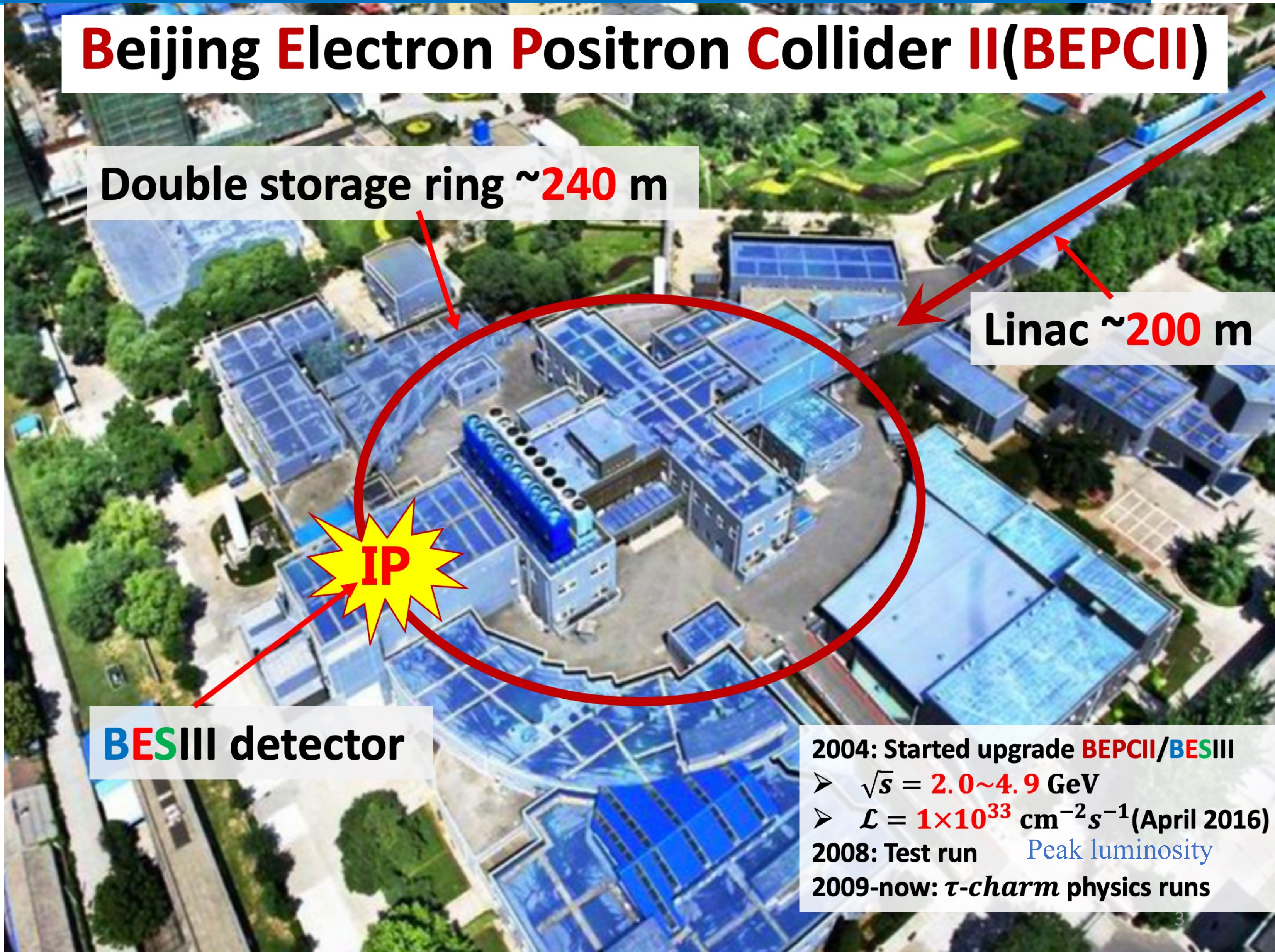
→ Charmed meson ($D^+[c\bar{d}]$)
$m_d << m_c$ → **quark + heavy quark**
(q) (Q)

→ Charmed baryon ($\Lambda_c[udc]$)
m_u, $m_d << m_c$ → **diquark + quark**
(qq) (Q)

Non-trivial nonperturbative effects



Introduction -- BEPCII



Beijing Spectrometer(BESIII) Experiment

Superconducting solenoid (1T)

RPC Muon Counter

9 layers (barrel) + 8 layers (end-caps)

93% coverage of the full solid angle

Electromagnetic CsI(Tl) Calorimeter

$\sigma_E/E < 2.5\%$ @ 1 GeV (barrel)

$\sigma_E/E < 5\%$ @ 1 GeV (end-caps)

Time-of-Flight

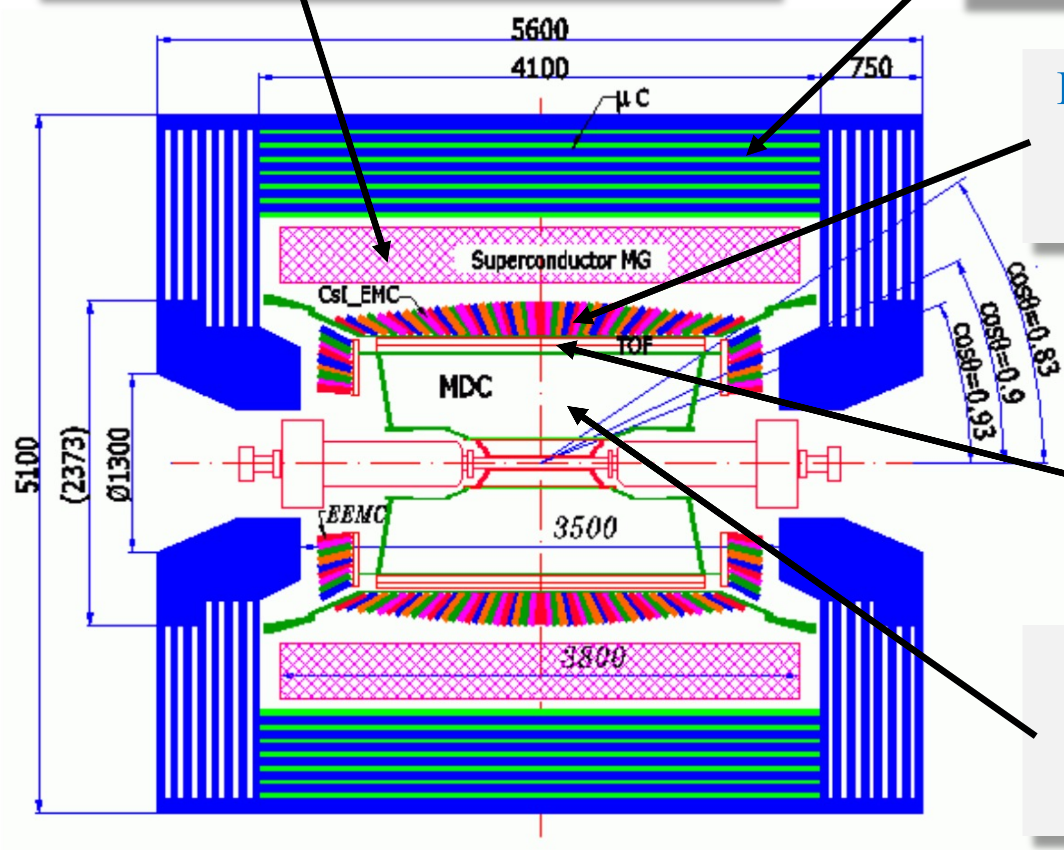
$\sigma_t = 90$ ps (barrel)

$\sigma_t = 120$ ps (end-caps)

Main Drift Chamber

$\sigma_{r\phi} = 130$ μm (single wire)

$\sigma_{pt}/p_t = 0.5\%$ @ 1 GeV



Introduction -- Charm data and analysis method

- Data produced near threshold without accompanying hadrons

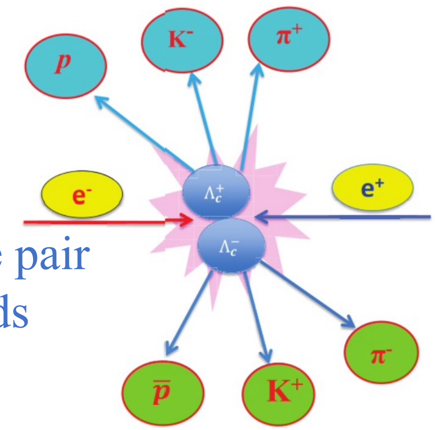
Data samples	$\sqrt{s}$ (GeV)	Int. $\mathcal{L}$ (pb^{-1})
$\Lambda_c^+\bar{\Lambda}_c^-$	4.600	586.9
	4.612	103.8
	4.628	521.5
	4.641	552.4
	4.661	529.6
	4.682	1669.3
	4.699	536.1

- Single tag (ST):

$$\mathcal{B}(\Lambda_c \to f) = \frac{N_{ST}}{2\times N_{pair}^{tot} \times \epsilon_{ST}}$$

ϵ_{ST}: ST detection efficacy

- Only reconstruct one of the pair
- Relative higher backgrounds
- Higher efficiencies



$$M_{BC} \equiv \sqrt{E_{beam}^2 - p_{\Lambda_c}^2}$$
$$\Delta E \equiv E_{\Lambda_c} - E_{beam}$$

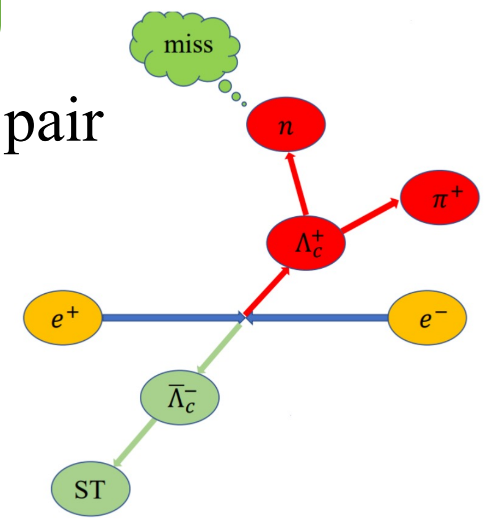
- Double tag (DT): reconstruct both particles in the pair

$$\mathcal{B}(\Lambda_c \to f) = \frac{N_{DT}}{N_{ST} \cdot \epsilon_{DT}}$$

$\epsilon_{DT} = \frac{\sum N_{ST}^i \times \epsilon_{DT}^i / \epsilon_{ST}^i}{\sum N_{ST}^i}$: Averaged DT efficiency

- Clean bkg in DT method
- Be able to extract missing particle

$$E_{miss} = E_{beam} - \sum_f E_f \qquad \vec{p}_{miss} = \vec{p}_{\Lambda_c} - \sum_f \vec{p}_f$$
$$M_{miss}^2 = E_{miss}^2 - p_{miss}^2 \qquad U_{miss} = E_{miss} - |\vec{p}_{miss}|$$



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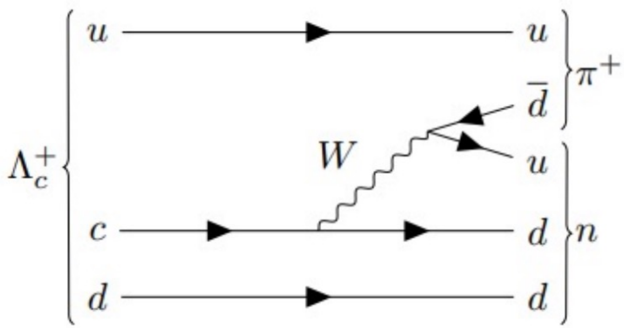
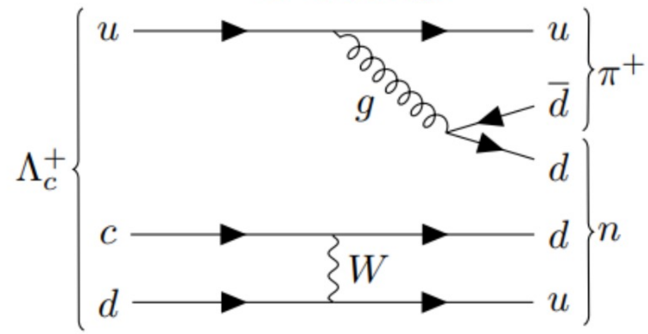
First observation of $\Lambda_c^+ \to n\pi^+$

- $\Lambda_c^+ \to n\pi^+$ is Singly-Cabbibo-Suppressed decay, containing non-factorizable contributions

Internal W emission

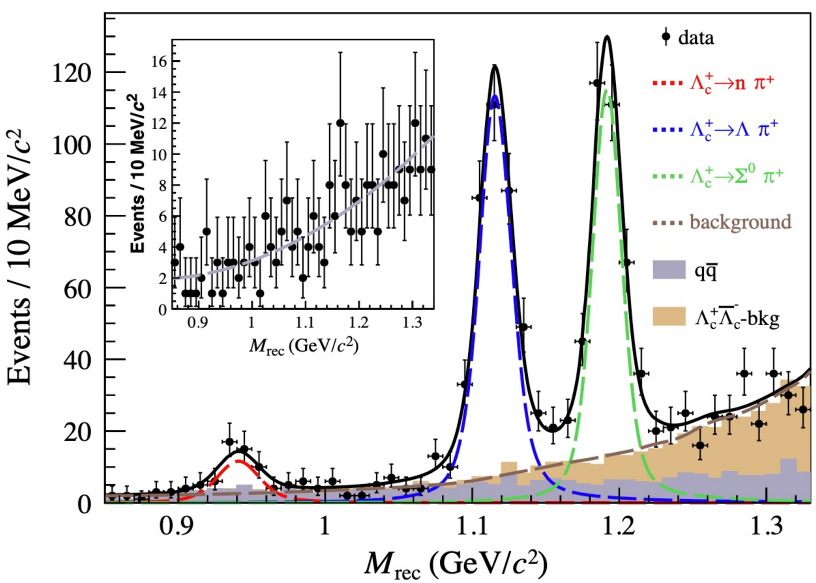


W exchange



Unneglected non-perturbative effects

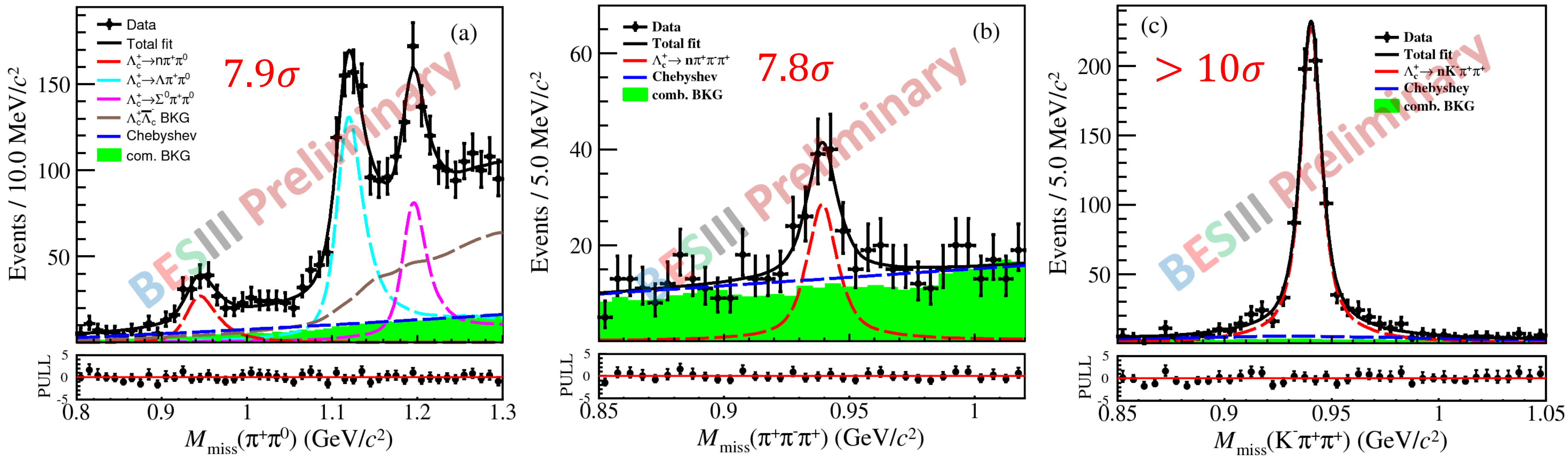
- Using double tag and extract neutron through missing technique



- First observation, 7.3 σ significance
  - $\mathcal{B}(\Lambda_c^+ \to n\pi^+) = (6.6 \pm 1.2 \pm 0.4)\times 10^{-4}$
- $\mathcal{B}(\Lambda_c^+ \to n\pi^+)/\mathcal{B}(\Lambda_c^+ \to p\pi^0) > 7.2$ at 90% CL.
  - $\mathcal{B}(\Lambda_c^+ \to p\pi^0) < 8.0\times 10^{-5}$ at 90% CL. by Belle [Phys. Rev. D 103, 072004 (2021)]
  - Disagree with most theoretical predictions by phenomenological models
- Agree with previous results:
  - $\mathcal{B}(\Lambda_c^+ \to \Lambda\pi^+) = (1.31 \pm 0.08 \pm 0.05)\%$
  - $\mathcal{B}(\Lambda_c^+ \to \Sigma^0\pi^+) = (1.22 \pm 0.08 \pm 0.07)\%$

Measurement of $\Lambda_c^+ \to n\pi^+\pi^0$, $n\pi^+\pi^-\pi^+$ and $nK^-\pi^+\pi^+$

- Firstly measured, no previous theoretical calculation



- Absolute BFs results:
  - $\mathcal{B}(\Lambda_c^+ \to n\pi^+\pi^0) = (0.64 \pm 0.09 \pm 0.02)\%$
  - $\mathcal{B}(\Lambda_c^+ \to n\pi^+\pi^-\pi^+) = (0.45 \pm 0.07 \pm 0.03)\%$
  - $\mathcal{B}(\Lambda_c^+ \to nK^-\pi^+\pi^+) = (1.90 \pm 0.08 \pm 0.09)\%$

Provide significant input for future theoretical calculations of Λ_c^+ decays involving neutron!

- Relative BFs results: → Previous slide
  - $\mathcal{B}(\Lambda_c^+ \to n\pi^+\pi^0)/\mathcal{B}(\Lambda_c^+ \to n\pi^+) = 9.7 \pm 2.2$ → Significantly larger than one, reveals possible abundant intermediates in $n\pi^+\pi^0$ final states
  - $\mathcal{B}(\Lambda_c^+ \to n\pi^+\pi^-\pi^+)/\mathcal{B}(\Lambda_c^+ \to nK^-\pi^+\pi^+) = 0.24 \pm 0.04$
  - $\mathcal{B}(\Lambda_c^+ \to p\pi^-\pi^+)/\mathcal{B}(\Lambda_c^+ \to n\pi^+\pi^0) = 0.72 \pm 0.13$ ← PDG

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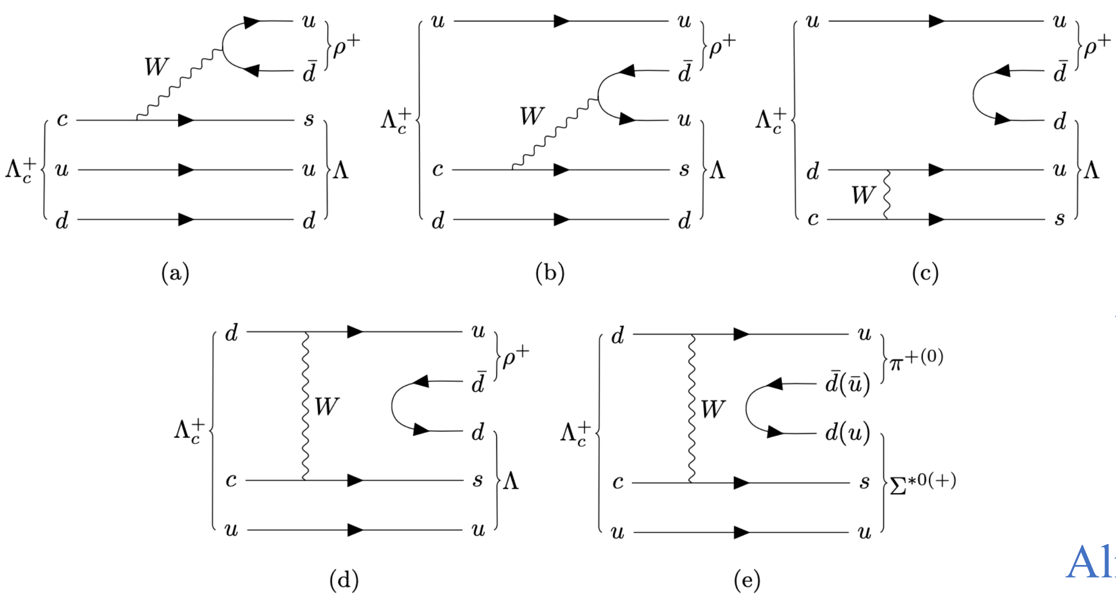
Partial wave analysis of $\Lambda_c^+ \to \Lambda\pi^+\pi^0$

- First charmed baryon decays PWA at BESIII
- Intermediate processes in $\Lambda_c^+ \to \Lambda\pi^+\pi^0$ are interesting in theoretical calculations



$\Lambda_c^+ \to \Lambda\rho^+$ consists of both factorizable and non-factorizable contributions

$\Lambda_c^+ \to \Sigma(1385)\pi$ regarded as pure non-factorizable contributions

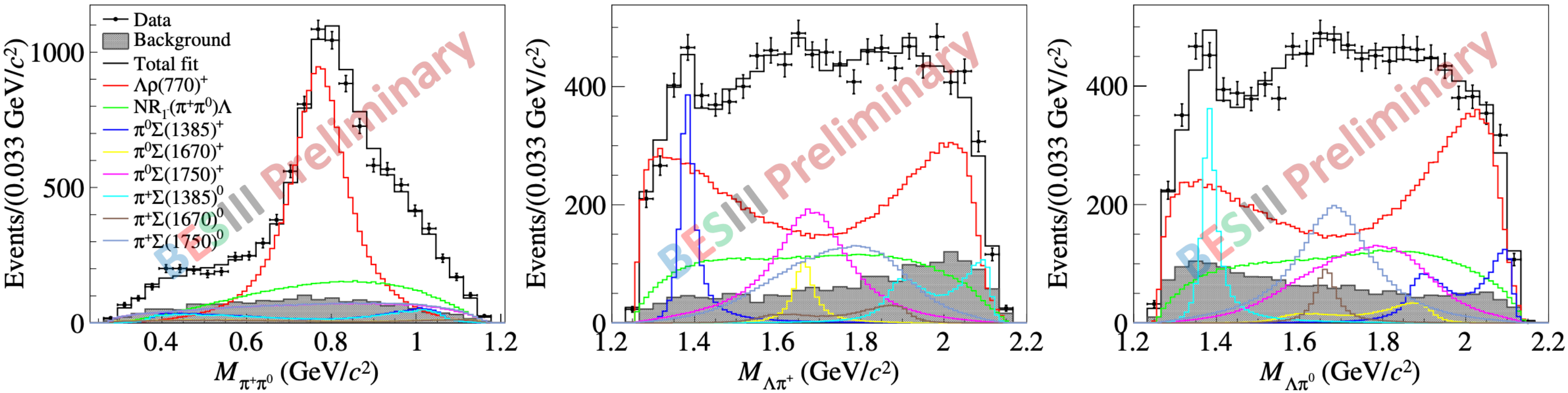
- Use new-developed TensorFlow based package TF-PWA* to perform the PWA fit
- Use helicity formalism to construct the full decay amplitude
- PWA is able to extract the intermediate processes explicitly

Alignment angles correctly considered

$$\mathcal{A}_{\lambda_{\Lambda_c^+},\lambda_p} = (A^{\rho}_{\lambda_{\Lambda_c^+},\lambda_p} + A^{NR}_{\lambda_{\Lambda_c^+},\lambda_p}) + \sum_{\lambda_p'} (\sum A^{\Sigma^{*+}}_{\lambda_{\Lambda_c^+},\lambda_p'}) D^{1/2}_{\lambda_p',\lambda_p}(\alpha_p,\beta_p,\gamma_p) + \sum_{\lambda_p'} (\sum A^{\Sigma^{*0}}_{\lambda_{\Lambda_c^+},\lambda_p'}) D^{1/2}_{\lambda_p',\lambda_p}(\alpha_p',\beta_p',\gamma_p')$$

Partial wave analysis of $\Lambda_c^+ \to \Lambda\pi^+\pi^0$

- Use single tag method, extract around 10k signal candidates with purities > 80%
- Fit results on invariant mass spectra:



- Results of BFs and weak decays asymmetry α parameters:

	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 ± 0.066	—
$\alpha_{\Sigma(1385)^+\pi^0}$	$-0.91^{+0.45}_{-0.10}$ [17]		-0.917 ± 0.083	—
$\alpha_{\Sigma(1385)^0\pi^+}$	$-0.91^{+0.45}_{-0.10}$ [17]		-0.79 ± 0.11	—

α extracted through results of internal partial wave amplitudes

First measurements

Ref. [13]: Phys. Rev. D 101 (2020) 053002.
Ref. [14,15]: Phys. Rev. D 46 (1992) 1042; Phys. Rev. D 55 (1997) 1697.
Ref. [16]: Eur. Phys. J. C 80 (2020) 1067.
Ref. [17]: Phys. Rev. D 99 (2019) 114022.

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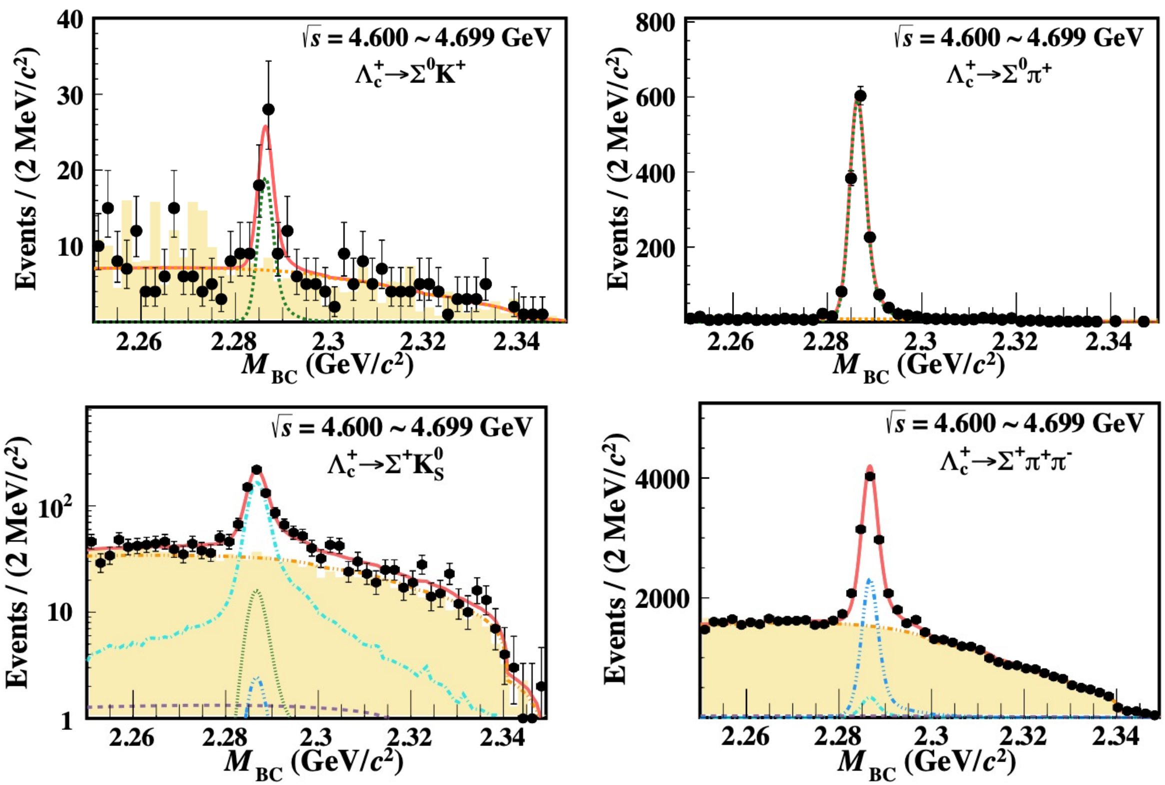
Measurement of $\Lambda_c^+ \to \Sigma^0 K^+$ and $\Sigma^+ K_S^0$

- Many theoretical calculations arises on these two SCS decays
- Precise measurement can provide crucial information for test various theoretical models

	$\mathcal{B}(\Lambda_c^+ \to \Sigma^0 K^+)$	$\mathcal{B}(\Lambda_c^+ \to \Sigma^+ K_S^0)$
QCD corrections	2(8)	2(4)
MIT bag model	7.2 ± 1.8	7.2 ± 1.8
Diagrammatic analysis	5.5 ± 1.6	9.6 ± 2.4
$SU(3)_F$ flavor symmetry	5.4 ± 0.7	5.4 ± 0.7
IRA method	5.0 ± 0.6	1.0 ± 0.4
PDG 2020	5.2 ± 0.8	/

- Relative BFs extracted through simultaneous fits:



- $\mathcal{R}_{\Sigma^0 K^+} = (3.61 \pm 0.73 \pm 0.05) \times 10^{-2}$
- $\mathcal{R}_{\Sigma^+ K_S^0} = (1.06 \pm 0.31 \pm 0.04) \times 10^{-2}$
- With input BFs of reference channels:

$$\mathcal{B}(\Lambda_c^+ \to \Sigma^0 K^+) = (4.7 \pm 0.9 \pm 0.1 \pm 0.3) \times 10^{-4}$$

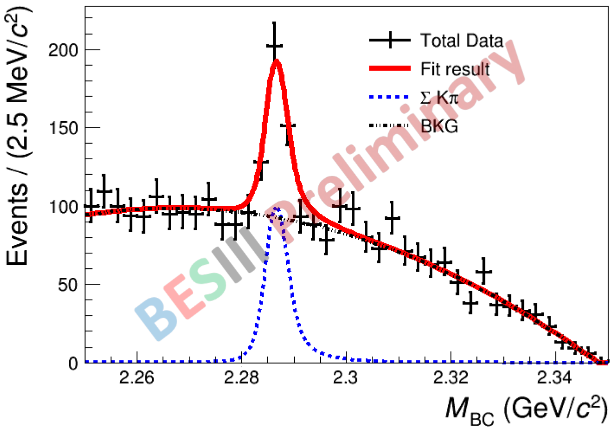
Improved precision

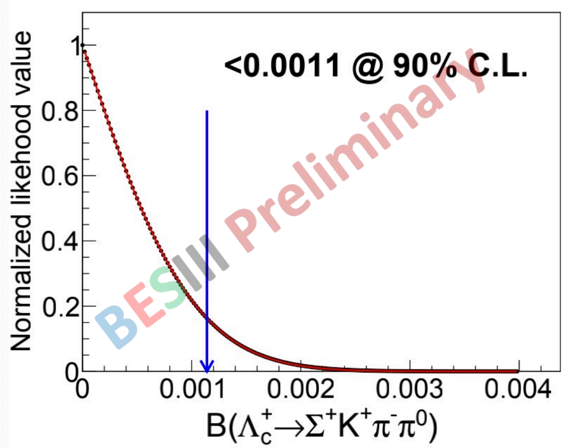
$$\mathcal{B}(\Lambda_c^+ \to \Sigma^+ K_S^0) = (4.8 \pm 1.4 \pm 0.2 \pm 0.3) \times 10^{-4}$$

First measurement

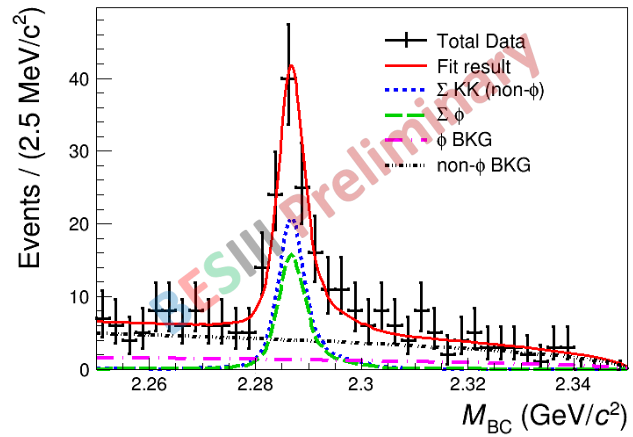
Measurement of $\Lambda_c^+ \to \Sigma^+ K^+ K^-$, $\Sigma^+ K^+ \pi^-$ and $\Sigma^+ K^+ \pi^- \pi^0$

- Several $\Lambda_c^+ \to \Sigma^+ h^+ h^- (\pi^0)$ modes also measured
- $\Sigma^+ K^+ K^-$ final states also containing $\Sigma^+ \phi$ contributions
- Relative BFs extracted, $\Sigma^+ \pi^+ \pi^-$ as reference





2D fit M_{BC} vs. M_{KK}



Results	Relative Branching Fraction to $\Lambda_c^+ \to \Sigma^+\pi^+\pi^-$ ($\times 10^{-2}$)		Branching Fraction (%)		
Decay mode	RBF (Belle)	RBF (This work)	This work	PDG	Theoretical Prediction
$\Lambda_c^+ \to \Sigma^+ K^+ K^-$	$7.6 \pm 0.7 \pm 0.9$	$7.33 \pm 0.80 \pm 0.31$	$0.330 \pm 0.036 \pm 0.014 \pm 0.018$	0.35 ± 0.04	0.25 ± 0.03
$\Lambda_c^+ \to \Sigma^+ K^+ \pi^-$	$4.7 \pm 1.1 \pm 0.8$	$4.51 \pm 0.52 \pm 0.23$	$0.202 \pm 0.023 \pm 0.011 \pm 0.011$	0.21 ± 0.06	0.25 ± 0.03
$\Lambda_c^+ \to \Sigma^+ K^+ \pi^- \pi^0$	-	< 2.4	< 0.11	-	-
$\Lambda_c^+ \to \Sigma^+ \phi$	$8.5 \pm 1.2 \pm 1.2$	$9.2 \pm 1.8 \pm 0.6$	$0.414 \pm 0.080 \pm 0.027 \pm 0.023$	0.39 ± 0.06	-
$\Lambda_c^+ \to \Sigma^+ K^+ K^-$ (non $-\ \phi$)	-	$4.38 \pm 0.79 \pm 0.16$	$0.197 \pm 0.036 \pm 0.007 \pm 0.011$	-	-

More precise
First measurement
Consistent

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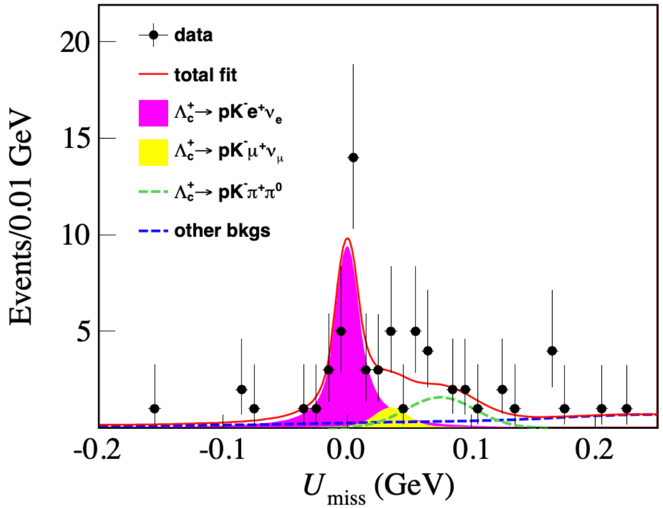
Measurement of $\Lambda_c^+ \to pK^-e^+\nu_e$

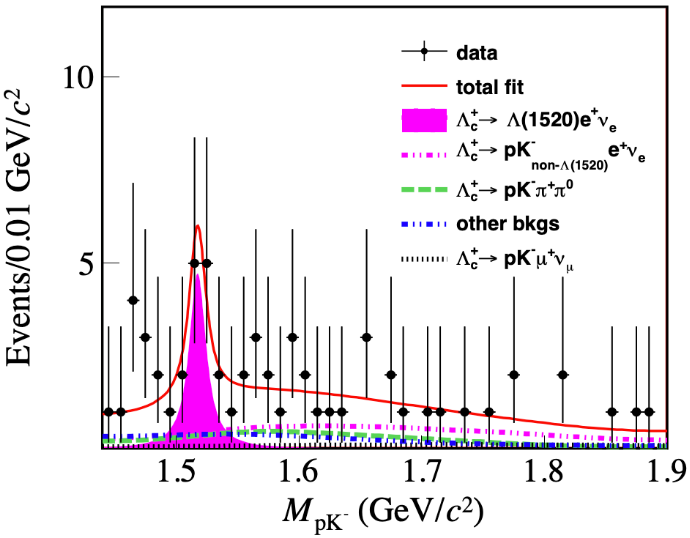
BESIII

- First study of Λ_c^+ decaying into semi-leptonically into inclusive pK^- system
- Double tag method and missing technique



- Fit to U_{miss}
  - $\mathcal{B}(\Lambda_c^+ \to pK^-e^+\nu_e) = (0.82 \pm 0.15 \pm 0.06)\times 10^{-3}$
  - First observation with 8.2 σ significance
  - Semi-leptonic decays not saturated by $\Lambda l^+\nu_l$!

	$\mathcal{B}(\Lambda_c^+ \to \Lambda(1520)e^+\nu_e)$ [$\times 10^{-3}$]
Constituent quark model	1.01
Nonrelativistic quark model	0.60
Lattice QCD	$0.512 \pm 0.082 \pm 0.008$
Measurement	$1.36 \pm 0.56 \pm 0.14$



- Also study with M_{pK^-} spectrum
- 2D fit to M_{pK^-} vs. U_{miss}
  - Evidence with 3.3 σ for $\Lambda(1520)e^+\nu_e$
  - $\mathcal{B}(\Lambda_c^+ \to \Lambda(1520)e^+\nu_e) = (1.36 \pm 0.56 \pm 0.14)\times 10^{-3}$

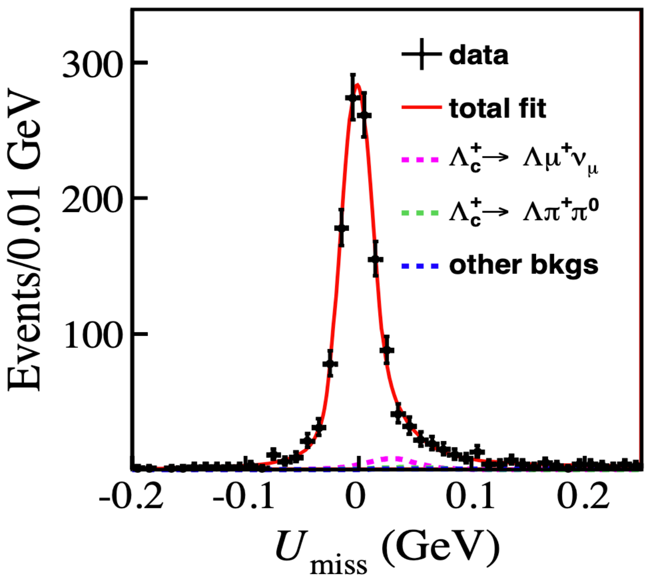
Invaluable in extending the understanding of semi-leptonic decays of Λ_c^+!

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

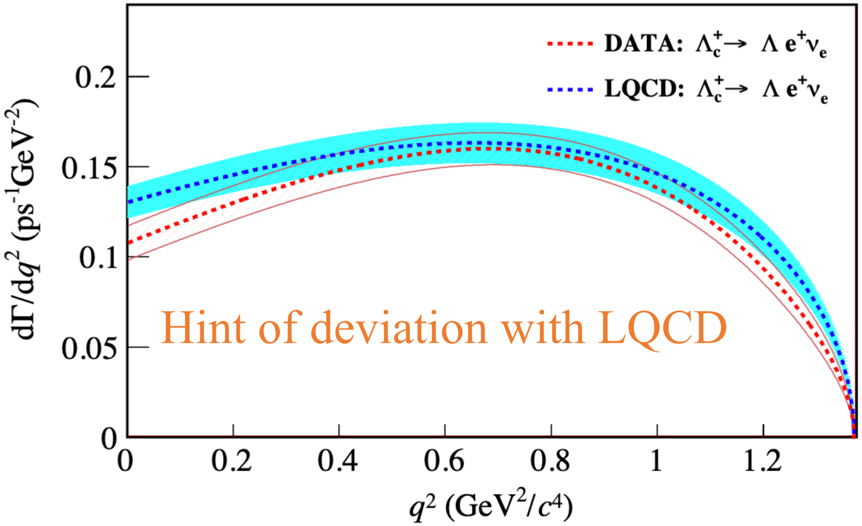
- $\Lambda_c^+ \to \Lambda e^+ \nu_e$ measured more precisely at BESIII with larger data samples than 2015
- Double tag method and missing technique
- Most precise measurement
  - $\mathcal{B}(\Lambda_c^+ \to \Lambda e^+ \nu_e) = (3.56 \pm 0.11 \pm 0.07)\%$
- Comparison with theoretical models:

Disfavor at C.L. more than 95%

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



- Form factors $\Lambda_c^+ \to \Lambda$ firstly measured
- Provide first direct comparisons to LQCD
- Provide important inputs in understanding the Λ_c^+ semi-leptonic decays



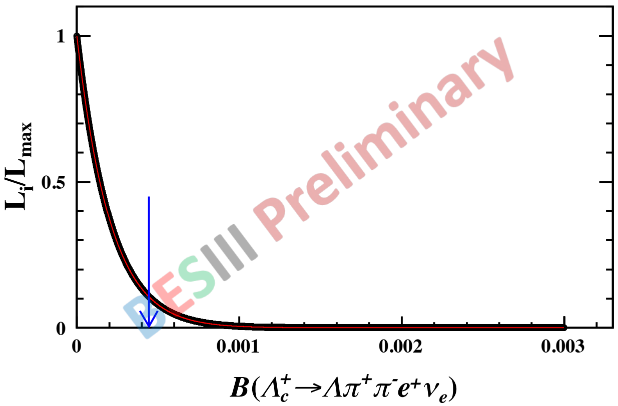
Search for $\Lambda_c^+ \to \Lambda\pi^+\pi^-e^+\nu_e$ and $pK_S^0\pi^-e^+\nu_e$

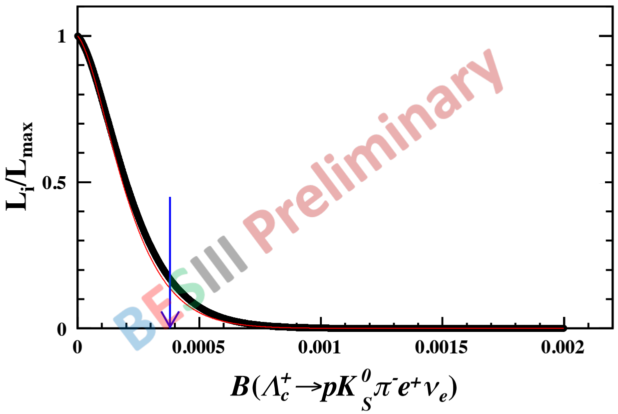
- Also search for other non-$\Lambda l^+\nu_l$ semi-leptonic modes
- Double tag method and missing technique
- $\Lambda\pi^+\pi^-$ and $pK_S^0\pi^-$ are able to tag Λ^*

[1] Phys. Rev. D 95, 053005 (2017).
[2] Phys. Rev. C 72, 035201 (2005).
[3] Phys. Rev. D 93, 014021 (2016).
[4] Phys. Rev. D 104, 013005 (2021).
[5] Phys. Rev. D 105, L051505 (2022).

State J^P	Constituent quark model		Chiral unitary approach[3]	Light-font quark model[4]	Lattice QCD[5]
	Hussain and Roberts[1]	Pervin, Roberts and Capstick[2]			
$\Lambda(1405)\ {}^1/_2{}^-$	2.4×10^{-3}	3.8×10^{-2}	$(2-5)\times10^{-5}$	$(3.1\pm0.8)\times10^{-3}$	-----
$\Lambda(1520)\ {}^3/_2{}^-$	5.94×10^{-4}	1.00×10^{-3}	-----	-----	$(5.12\pm0.82)\times10^{-4}$
$\Lambda(1600)\ {}^1/_2{}^+$	1.26×10^{-4}	4.00×10^{-4}	-----	$(7\pm2)\times10^{-5}$	-----
$\Lambda(1890)\ {}^3/_2{}^+$	3.16×10^{-6}	-----	-----	-----	-----
$\Lambda(1820)\ {}^5/_2{}^+$	1.32×10^{-6}	-----	-----	-----	-----

- Upper limit @ 90% C.L. extracted for the first time through likelihood scan:





Upper limit:
- $\mathcal{B}(\Lambda_c^+ \to \Lambda\pi^+\pi^-e^+\nu_e) < 4.4\times10^{-4}$
- $\mathcal{B}(\Lambda_c^+ \to pK_S^0\pi^-e^+\nu_e) < 3.8\times10^{-4}$

Assuming all from $\Lambda(1520,1600)$:
- $\mathcal{B}(\Lambda_c^+ \to \Lambda(1520)e^+\nu_e) < 0.49\%$
- $\mathcal{B}(\Lambda_c^+ \to \Lambda(1600)e^+\nu_e) < 1.0\%$

Summary

- Using data samples of $\Lambda_c^+\overline{\Lambda}_c^-$ pair production with 4.5 fb^{-1} integrated luminosity collected by BESIII, many significant measurements performed
- Λ_c^+ decays involve neutron $n\pi^+(\pi^0)$ and $nh^+h^-h^+$ firstly measured
- First PWA of $\Lambda_c^+ \to \Lambda\pi^+\pi^0$ at BESIII performed
- SCS decays $\Lambda_c^+ \to \Sigma^0 K^+$ with improved measurement, and $\Lambda_c^+ \to \Sigma^+ K_S^0$ firstly measured
- $\Sigma^+ h^+ h^-(\pi^0)$ decays measured, consistent with PDG results
- Significant achievement on semi-leptonic decays
  - $\Lambda_c^+ \to pK^- e^+\nu_e$ firstly observed with 8.2 σ significance
  - $\Lambda_c^+ \to \Lambda e^+\nu_e$ with improved measurement, first direct comparison of $\frac{\mathrm{d}\Gamma}{\mathrm{d}q^2}$
  - $\Lambda_c^+ \to \Lambda\pi^+\pi^- e^+\nu_e$ and $pK_S^0\pi^- e^+\nu_e$ upper limit firstly obtained
- BESIII has made pretty good progresses on the exploration of the charmed baryon Λ_c^+ decays!

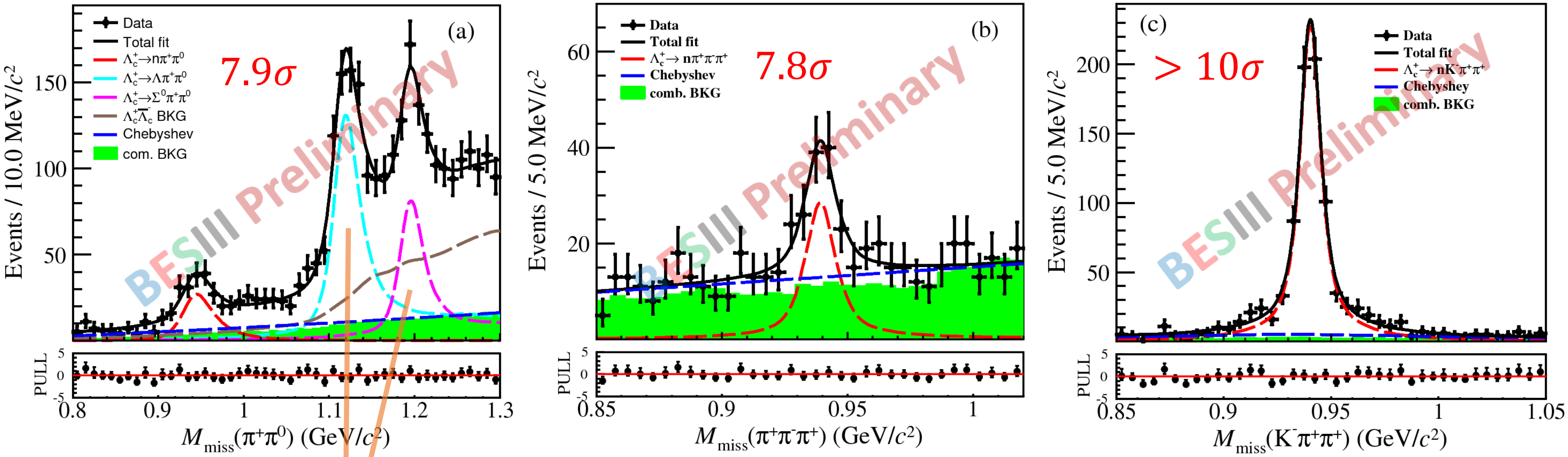
More results will be released in the future!

Thanks for listening!

Backup

Measurement of $\Lambda_c^+ \to n\pi^+\pi^0$, $n\pi^+\pi^-\pi^+$ and $nK^-\pi^+\pi^+$

- Firstly measured, no previous theoretical calculation



- Can also give results for $\Lambda_c^+ \to \Lambda\pi^+\pi^0$ and $\Sigma^0\pi^+\pi^0$:
  - $\mathcal{B}(\Lambda_c^+ \to \Lambda\pi^+\pi^0) = (6.52 \pm 0.43_{\mathrm{stat.}})\%$
  - $\mathcal{B}(\Lambda_c^+ \to \Sigma^0\pi^+\pi^0) = (3.77 \pm 0.47_{\mathrm{stat.}})\%$

Consist with PDG results:
$(7.1 \pm 0.4)\%$
$(2.5 \pm 0.4)\%$

Partial wave analysis of $\Lambda_c^+ \to \Lambda\pi^+\pi^0$ -- Definition of α

- Decay asymmetry parameters is defined under angular distribution
- Only considering angular distribution, LS-coupling formula reads:

$$H_{\lambda_1,\lambda_2} = \sum_{ls} g_{ls}\sqrt{\frac{2l+1}{2J_0+1}}\langle ls, 0\ \delta | J_0, \delta\rangle\langle J_1 J_2, \lambda_1\ \ -\lambda_2 | s, \delta\rangle$$

- For the decay $\Lambda_c^+ \to \Lambda\rho(770)^+$, the differential width formula reads:

$$\frac{\mathrm{d}\Gamma}{\mathrm{d}\cos\Theta_\Lambda} \propto 1 + \alpha_{\Lambda\rho(770)^+}\cdot\alpha_\Lambda\cdot\cos\Theta_\Lambda$$

Θ_Λ is helicity angle of $\Lambda \to p\pi^-$ in this decay chain

- Decay asymmetry parameter defined as:

$$\alpha_{\Lambda\rho(770)^+} = \frac{|H^\rho_{\frac{1}{2},1}|^2 - |H^\rho_{-\frac{1}{2},-1}|^2 + |H^\rho_{\frac{1}{2},0}|^2 - |H^\rho_{-\frac{1}{2},0}|^2}{|H^\rho_{\frac{1}{2},1}|^2 + |H^\rho_{-\frac{1}{2},-1}|^2 + |H^\rho_{\frac{1}{2},0}|^2 + |H^\rho_{-\frac{1}{2},0}|^2}$$

$$= \frac{\sqrt{\frac{1}{9}}\cdot 2\cdot\Re\left(g^\rho_{0,\frac{1}{2}}\cdot\bar{g}^\rho_{1,\frac{1}{2}} - g^\rho_{1,\frac{3}{2}}\cdot\bar{g}^\rho_{2,\frac{3}{2}}\right) - \sqrt{\frac{8}{9}}\cdot 2\cdot\Re\left(g^\rho_{0,\frac{1}{2}}\cdot\bar{g}^\rho_{1,\frac{3}{2}} + g^\rho_{1,\frac{1}{2}}\cdot\bar{g}^\rho_{2,\frac{3}{2}}\right)}{|g^\rho_{0,\frac{1}{2}}|^2 + |g^\rho_{1,\frac{1}{2}}|^2 + |g^\rho_{1,\frac{3}{2}}|^2 + |g^\rho_{2,\frac{3}{2}}|^2}$$

Partial wave analysis of $\Lambda_c^+ \to \Lambda\pi^+\pi^0$ -- Definition of α

- For the decay $\Lambda_c^+ \to \Sigma(1385)\pi$, the differential width formula reads:

$$\frac{\mathrm{d}\Gamma}{\mathrm{d}\cos\theta_{ee}\mathrm{d}\cos\theta_{\Lambda_c^+}\mathrm{d}\cos\theta_{\Sigma^*}\mathrm{d}\phi^{ee}_{\Lambda_c^+}} \propto (7+9\cos(2\theta_{\Sigma^*}))\cdot$$

$$\left(1+\alpha_0\cos^2(\theta_{ee})+\alpha_{\Sigma^*\pi}\sqrt{1-\alpha_0^2}\sin\Delta_0\cos\theta_{ee}\sin\theta_{ee}\sin\theta_{\Lambda_c^+}\sin\phi^{ee}_{\Lambda_c^+}\right)$$

- Decay asymmetry parameter defined as:

$$\alpha_{\Sigma(1385)\pi} = \frac{|H^{\Sigma(1385)}_{0,\frac{1}{2}}|^2 - |H^{\Sigma(1385)}_{0,-\frac{1}{2}}|^2}{|H^{\Sigma(1385)}_{0,\frac{1}{2}}|^2 + |H^{\Sigma(1385)}_{0,-\frac{1}{2}}|^2} = \frac{2\Re\left(g^{\Sigma(1385)}_{1,\frac{3}{2}}\cdot\bar{g}^{\Sigma(1385)}_{2,\frac{3}{2}}\right)}{|g^{\Sigma(1385)}_{1,\frac{3}{2}}|^2 + |g^{\Sigma(1385)}_{2,\frac{3}{2}}|^2}$$