Charmed baryons at Belle and Belle II

Hadron 2025

Jing Yuan (Jilin University, China)
On behalf of Belle and Belle II collaborations
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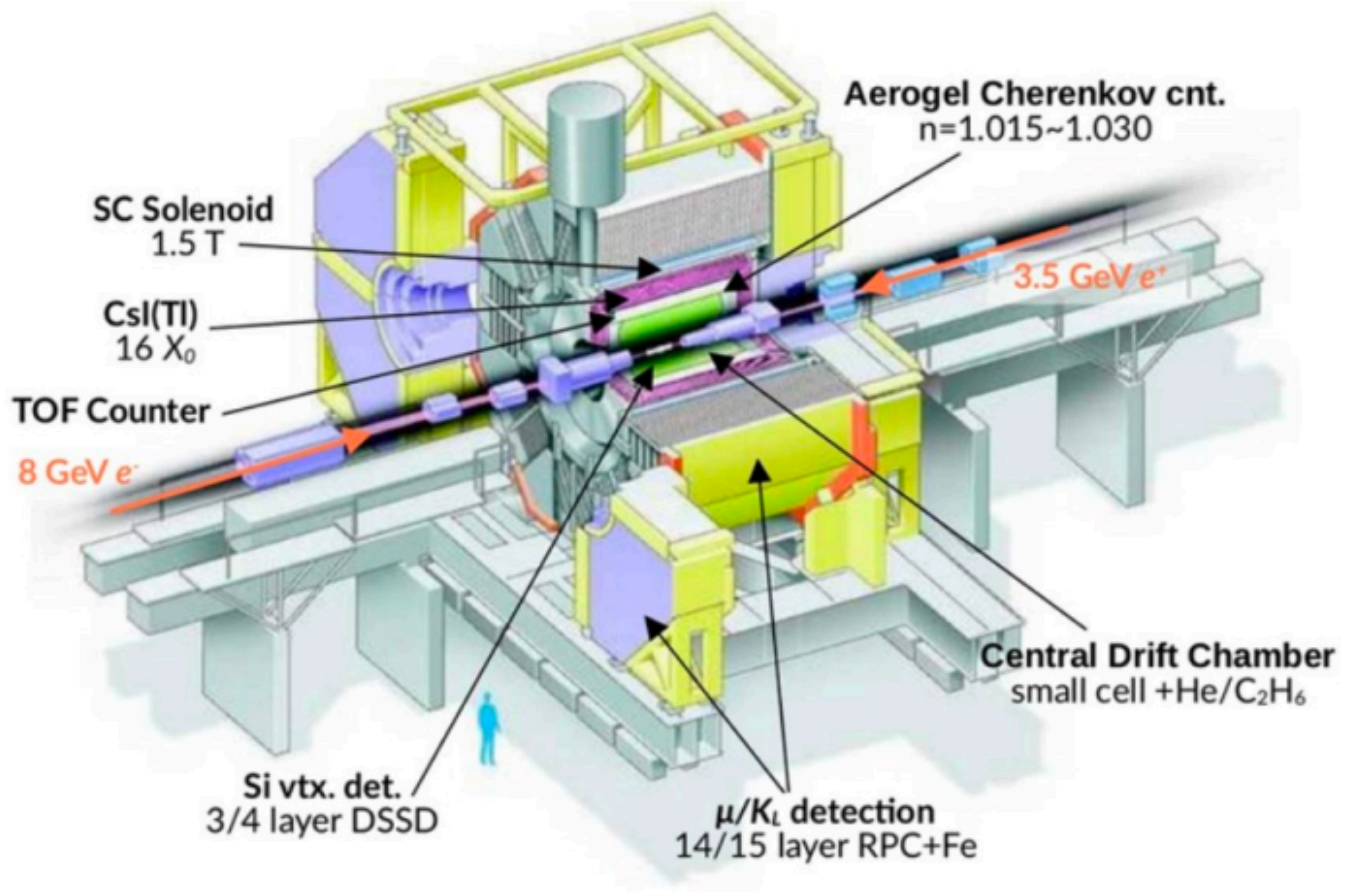
Belle and Belle II experiments

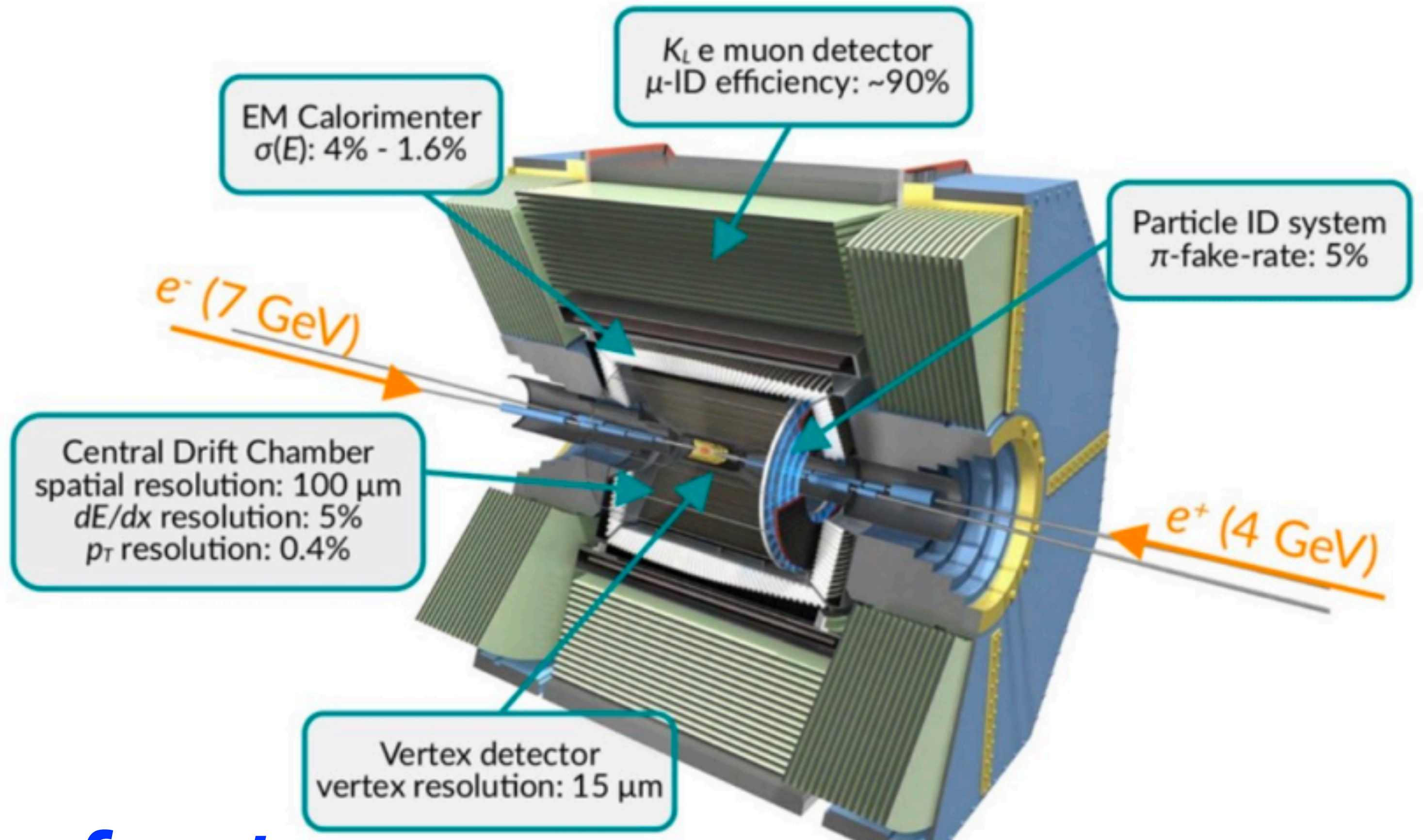
- **Belle experiment**
  - e^+e^- collision experiment located @ KEK
  - B factory, built to study B mesons’ mixing, decay and CP violation.
  - 1999~2010, $1\ \mathrm{ab}^{-1}$ data sample

Belle detector



- **Belle II experiment**
  - Updated version of Belle
  - Built to search for new physics out of the standard model
  - Started collecting collision data from 2019

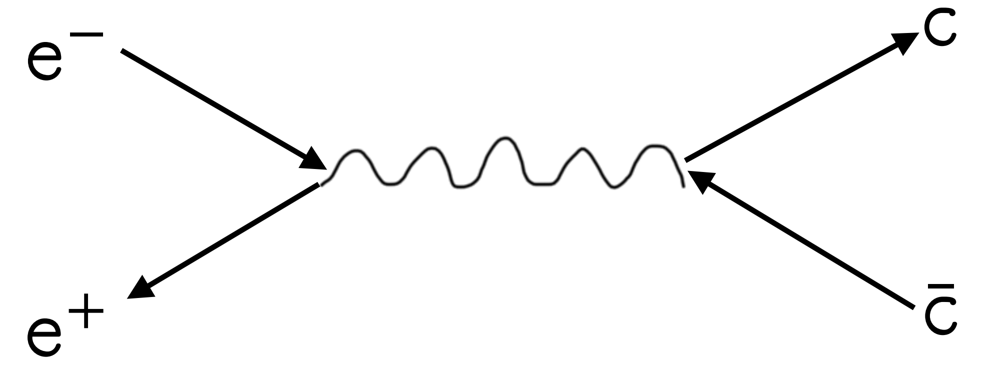
Belle II detector



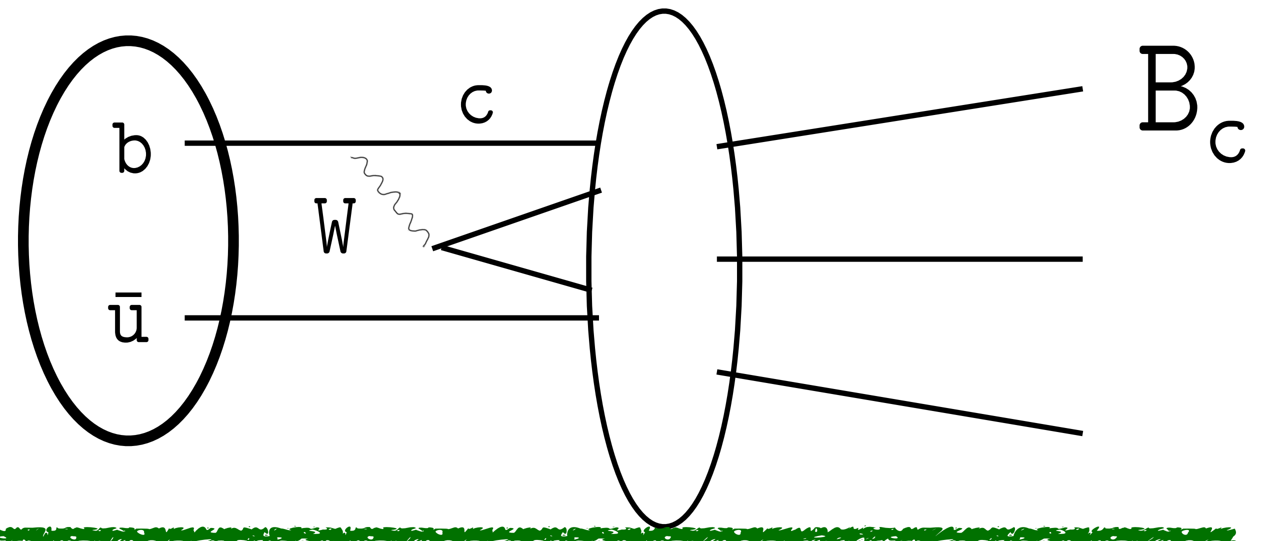
Belle and Belle II are not only B factory, but also τ-charm factory.

How are charm baryons produced @ Belle (II)?

$e^+e^- \rightarrow c\bar{c}$



$c\bar{c}$ are produced by e^+e^- directly



$b \rightarrow c$

c is produced by $b \rightarrow c$ weak decay

c quark hadronizes into charmed baryon

- ✗ Only relative branching fractions can be measured. The absolute value can be obtained only by reference channel.
- ✗ High level background.
- ✓ Large data sample.

- ✓ The absolute branching fractions can be obtained, because the cross section of $B\bar{B}$ is precisely measured.
- ✓ Clean signal.
- ✗ Small data statistic.
- ✗ Relatively complex analysis procedure.

Selected analyses

- Search for charmed baryons in the $\Lambda_c^+\eta$ system and measurement of the branching fractions of $\Lambda_c(2880)^+$ and $\Lambda_c(2940)^+$ decaying to $\Lambda_c^+\eta$ and pD^0 relative to $\Sigma_c(2455)\pi$

- Search for the semileptonic decays $\Xi_c^0 \to \Xi^0\ell^+\ell^-$

- First observation of $\Lambda\pi^+$ and $\Lambda\pi^-$ signals near the $\bar{K}N$ $(I = 1)$ mass threshold in $\Lambda_c^+ \to \Lambda\pi^+\pi^+\pi^-$ decay

- Observations of the singly Cabbibo-suppressed decays $\Xi_c^+ \to pK_S^0$, $\Xi_c^+ \to \Lambda\pi^+$, and $\Xi_c^+ \to \Sigma^0\pi^+$ at Belle and Belle II

- Search for CP violation and measurement of branching fractions and decay asymmetry parameters for $\Lambda_c^+ \to \Lambda h^+$ and $\Lambda_c^+ \to \Sigma^0 h^+$ $(h = K, \pi)$

- Measurement of the Λ_c^+ lifetime

Search for charmed baryons in the $\Lambda_c^+\eta$ and pD^0 system

Belle data, $980\ \mathrm{fb}^{-1}$

Phys. Rev. D ***110****, 032021 (2024)*

- $\Lambda_c(2880)^+$ **and** $\Lambda_c(2940)^+$

- The $\Lambda_c(2880)^+$ was first observed by CLEO in the $\Lambda_c^+\pi^+\pi^-$ decay mode [1], and later reported by Babar in the pD^0 mass spectrum [2].

- The $\Lambda_c(2940)^+$ was first seen by BaBar in the pD^0 decay mode [3], and then confirmed by Belle in the $\Sigma_c(2455)\pi$ decay [4].

[1]: M. Artuso et al. (CLEO collaboration), Phys. Rev. Lett. **86**, 4479 (2001).
[2]: B. Aubert et al. (BaBar Collaboration), Phys. Rev. Lett. **98**, 012001 (2007).

- **Why** $\Lambda_c^+\eta$ **spectrum?**
  - A good channel to search for excited Λ_c^+ baryons.
  - Signal in $\Lambda_c^+\eta$ is likely to be an excited Λ_c^+ rather than Σ_c^+, which is dominated by $\Lambda_c^+\pi$.
  - A narrow enhancement was observed in the pK^- channel near the $\Lambda_c^+\eta$ threshold [5].

[3]: B. Aubert et al. (BaBar Collaboration), Phys. Rev. Lett. **98**, 012001 (2007).
[4]: R. Mizuk et al. (Belle Collaboration), Phys. Rev. Lett. **98**, 262001 (2007).
[5]: S. B. Yang et al. (Belle Collaboration), Phys. Rev. D **108**, L031104 (2023).

- **Why** pD **spectrum?**
  - An analogue to the NK system[6-8].
  - BaBar has reported $\Lambda_c(2880)^+$ and $\Lambda_c(2940)^+$ in the pD^0 mass spectrum [9], while Belle has not investigated it in direct e^+e^- annihilation.

[6]: N. Kaiser, P. B. Siegel, and W. Weise, Nucl. Phys. A **594**, 325 (1995).
[7]: E. Oset and A. Ramos, Nucl. Phys. A **635**, 99 (1998).
[8]: J. A. Oller and U. G. Meißner, Phys. Lett. B **500**, 263 (2001).
[9]: B. Aubert et al. (BaBar Collaboration), Phys. Rev. Lett. **98**, 012001 (2007).

Search for charmed baryons in the $\Lambda_c^+\eta$ and $\mathrm{p}D^0$ system

Belle data, 980 fb^{-1}

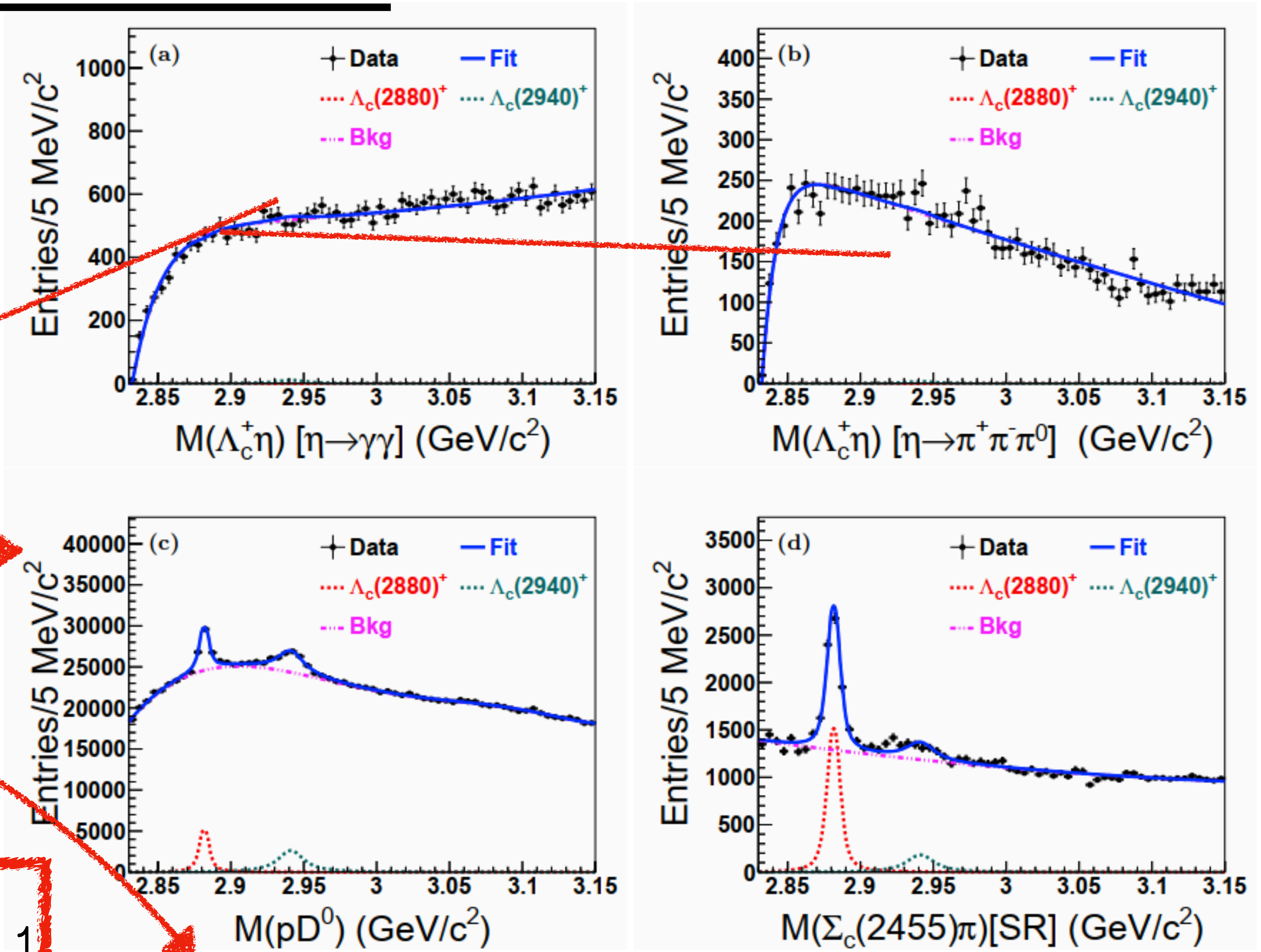
Phys. Rev. D ***110****, 032021 (2024)*

- Study for the first time the $\Lambda_c^+\eta$ system and search for singly-charmed baryons, measure relative branching fractions of $\Lambda_c(2880)^+/\Lambda_c(2940)^+ \to \Lambda_c^+\eta/\mathrm{p}D^0$.

No obvious $\Lambda_c(2880)^+$ or $\Lambda_c(2940)^+$ signals are seen in $\Lambda_c^+\eta$ spectra.

Clear $\Lambda_c(2880)^+$ and $\Lambda_c(2940)^+$ signals can be seen in $\mathrm{p}D^0$ spectra as well as the $\Sigma_c(2455)\pi$ signal region.

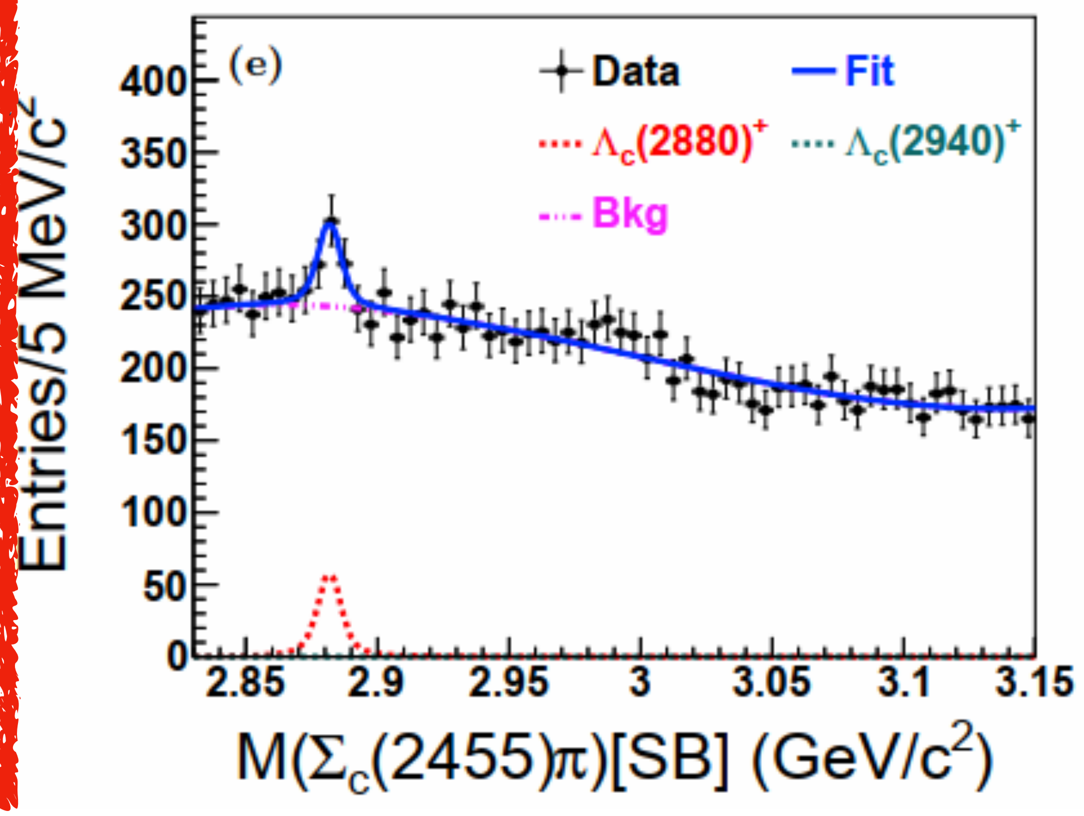
This background is expected and due to the $\Lambda_c(2880)^+ \to \Lambda_c^+\pi^+\pi^-$

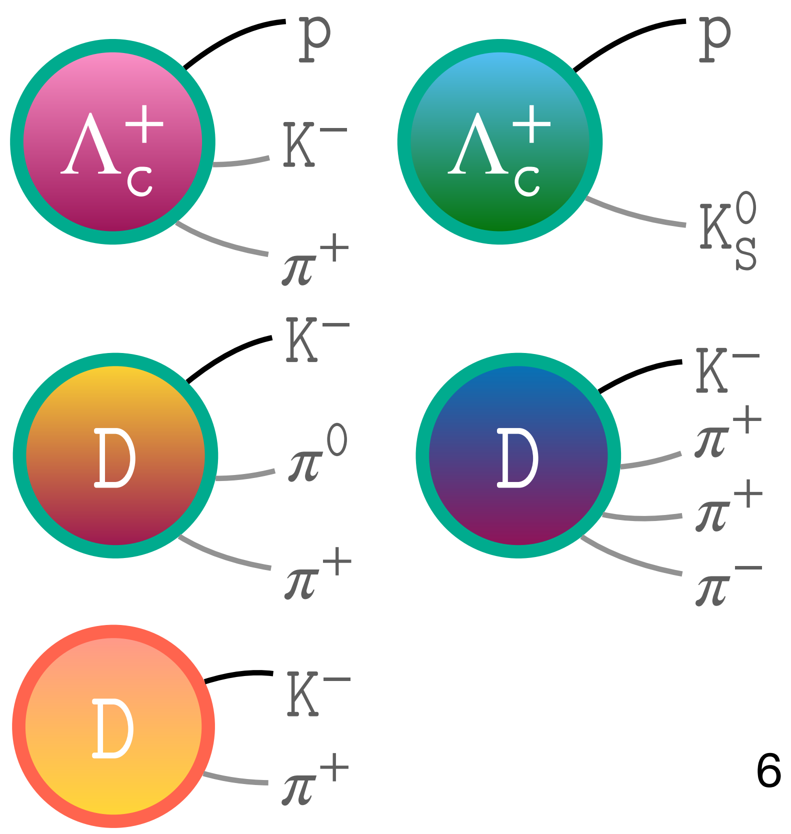


$$\frac{\Lambda_c(2880)^+ \to \Lambda_c^+\eta}{\Lambda_c(2880)^+ \to \Sigma_c(2455)\pi} < 0.13 \qquad \frac{\Lambda_c(2940)^+ \to \Lambda_c^+\eta}{\Lambda_c(2940)^+ \to \Sigma_c(2455)\pi} < 1.11$$

$$\frac{\Lambda_c(2880)^+ \to \mathrm{p}D}{\Lambda_c(2880)^+ \to \Sigma_c(2455)\pi} = 0.75 \pm 0.03(\mathrm{stat.}) \pm 0.07(\mathrm{syst.})$$

$$\frac{\Lambda_c(2940)^+ \to \mathrm{p}D}{\Lambda_c(2940)^+ \to \Sigma_c(2455)\pi} = 3.95 \pm 0.21(\mathrm{stat.}) \pm 0.56(\mathrm{syst.})$$





Search for the semileptonic decays $\Xi_c^0 \to \Xi^0 \ell^+ \ell^-$

Belle data, $980\ \mathrm{fb}^{-1}$

Phys. Rev. D ***109****, 052003 (2024)*

- Theoretical study of baryon semileptonic decays is complex due to W-exchange transitions [1-4] and poorly understood hadronic form factors.
- Experimentally, few neutrino-less semileptonic decays of baryons have been observed. Measurements exist for light-baryon octets and bottom baryons ($\Xi^0 \to \Lambda^0 e^+ e^-$, $\Sigma^+ \to p\mu^+\mu^-$ and $\Lambda_b \to \Lambda\mu^+\mu^-$) [5-9], but not for charmed baryons.
- The study of semileptonic decays of baryons provides an opportunity to test the Standard Model, and also can help in the understanding of the recent anomalies in meson FCNC processes.
- If observed, would also allow an LFU test to be performed.

[1]: R. M. Wang, Y. G. Xu, C. Hua, and X. D. Cheng, Phys. Rev. D **103**, 013007 (2021).
[2]: Y.-M. Wang, Y. Li, and C.-D. Lu, Eur. Phys. J. C **59**, 861 (2009).
[3]: T. Mannel and S. Recksiegel, J. Phys. G 24, 979 (1998).
[4]: G. Hiller, M. Knecht, F. Legger, and T. Schietinger, Phys. Lett. B **649**, 152 (2007).
[5]: J. R. Batley et al. (NA48 Collaboration), Phys. Lett. B **650**, 1 (2007).
[6]: H. Park et al.(HyperCP Collaboration), Phys. Rev. Lett. **94**, 021801 (2005).
[7]: T. Aaltonen et al. (CDF Collaboration), Phys. Rev. Lett. **107**, 201802 (2011).
[8]: R. Aaij et al. (LHCb Collaboration), Phys. Lett B **725**, 25 (2013).

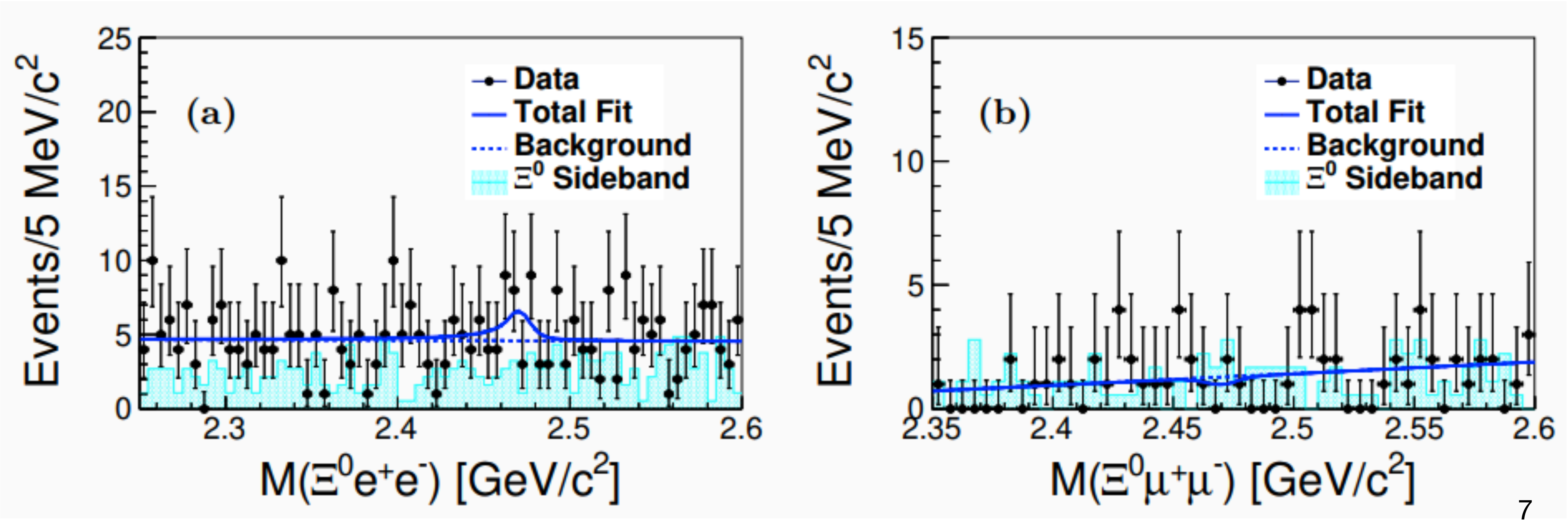
No significant signal observed, consistent with SM

$$\left.\begin{aligned} &\mathcal{B}(\Xi_c^0 \to \Xi^0 e^+ e^-) < 9.9 \times 10^{-5} \\ &\mathcal{B}(\Xi_c^0 \to \Xi^0 e^+ e^-) < 6.5 \times 10^{-5} \end{aligned}\right\}$$

experimental

$$\left.\begin{aligned} &\mathcal{B}(\Xi_c^0 \to \Xi^0 e^+ e^-) < 2.35 \times 10^{-6} \\ &\mathcal{B}(\Xi_c^0 \to \Xi^0 e^+ e^-) < 2.25 \times 10^{-6} \end{aligned}\right\}$$

theoretical

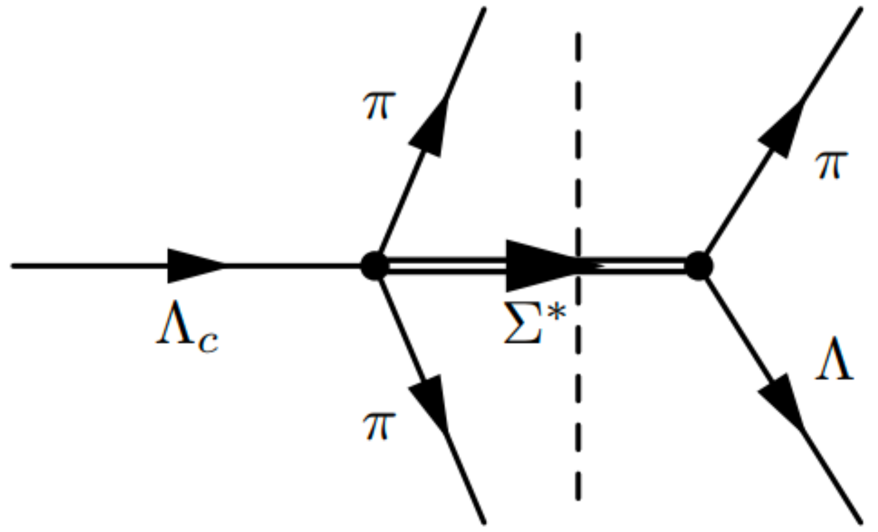


First Observation of $\Lambda\pi^+$ and $\Lambda\pi^-$ Signals near the $\mathrm{KN}^- \ (\mathrm{I} = 1)$ Mass Threshold in the $\Lambda_c^+ \to \Lambda\pi^+\pi^+\pi^-$ decay

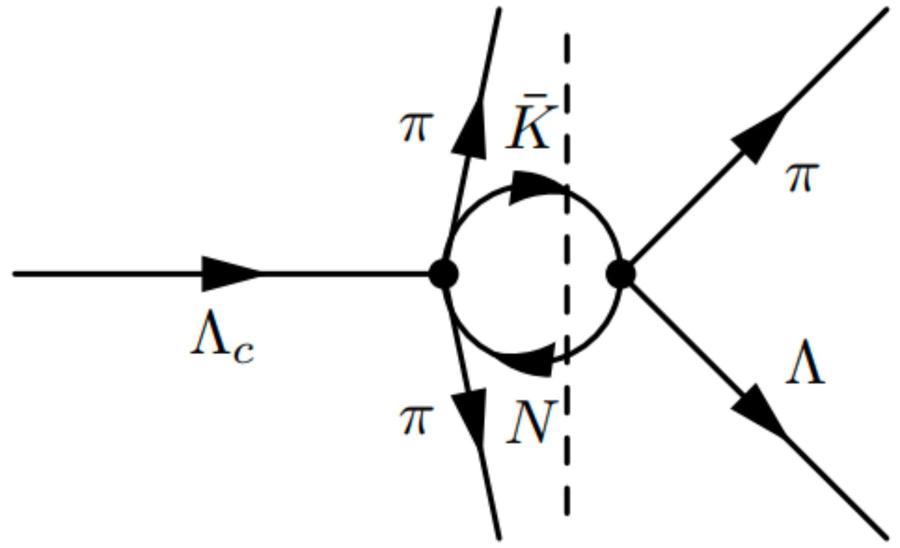
*Phys. Rev. Lett **130**, 151903*

Belle data, $980\ \mathrm{fb}^{-1}$

- **This is the first time to observe significant signal on $\Lambda\pi^+(\Lambda\pi^-)$ mass spectrum in $\Lambda_c^+ \to \Lambda\pi^+\pi^+\pi^-$ decay channel, which is close to $\bar{\mathrm{K}}\mathrm{N}$ threshold $(1435\ \mathrm{MeV/c^2})$.**
  - Investigate the spectrum structure on $\Lambda\pi^{+(-)}$ mass spectrum above the $\Sigma(1385)$. The traditional quark model did not predict any new excited state of Σ^* near $\Lambda(1405)$, thus the observation of signal can indicate new physics (such as exotic state or threshold effect).
  - The interaction of $\bar{\mathrm{K}}\mathrm{N}\ (\mathrm{I} = 1)$ is related to kaon condensation in neutron stars. It is probably not strong enough to form a bound state, but can produce a virtual state, which can be observed as a threshold cusp [1].



Search for Σ^* state



Study $\bar{\mathrm{K}}\mathrm{N}$ scattering with a cusp

[1]: J. Oller and U.-G. Meißner, Phys. Lett. B **500**, 263 (2001).

First Observation of $\Lambda\pi^+$ and $\Lambda\pi^-$ Signals near the KN^- $(\mathrm{I}=1)$ Mass Threshold in the $\Lambda_c^+ \to \Lambda\pi^+\pi^+\pi^-$ decay

Phys. Rev. Lett ***130****, 151903*

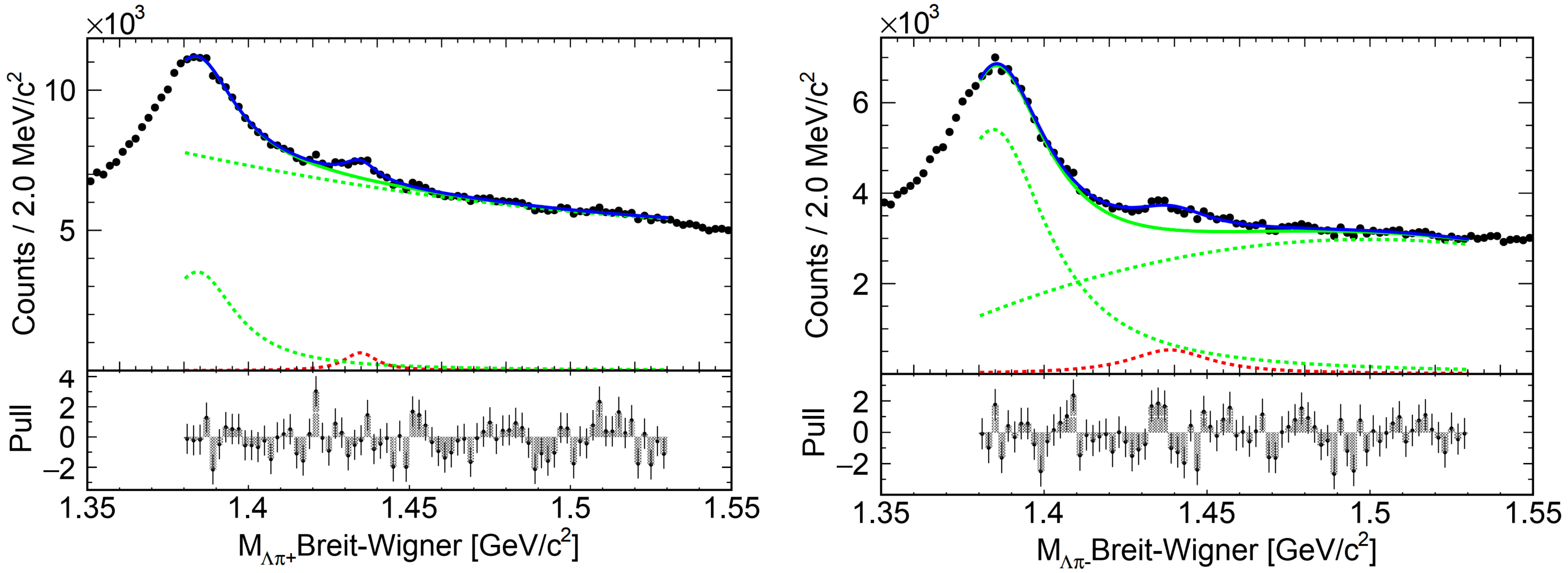
Belle data, $980\ \mathrm{fb}^{-1}$

Σ^* resonances

TABLE I. Breit-Wigner fitting results. The quoted errors are statistical only.

Mode	E_{BW} [MeV/c^2]	Γ [MeV/c^2]	χ^2 / NDF
$\Lambda\pi^+$	1434.3 ± 0.6	11.5 ± 2.8	74.4/68
$\Lambda\pi^-$	1438.5 ± 0.9	33.0 ± 7.5	92.3/68

$$f_{\mathrm{BW}} = \frac{\Gamma/2}{(E - E_{\mathrm{BW}})^2 + \Gamma^2/4},$$



Fit based on the two interpretations.

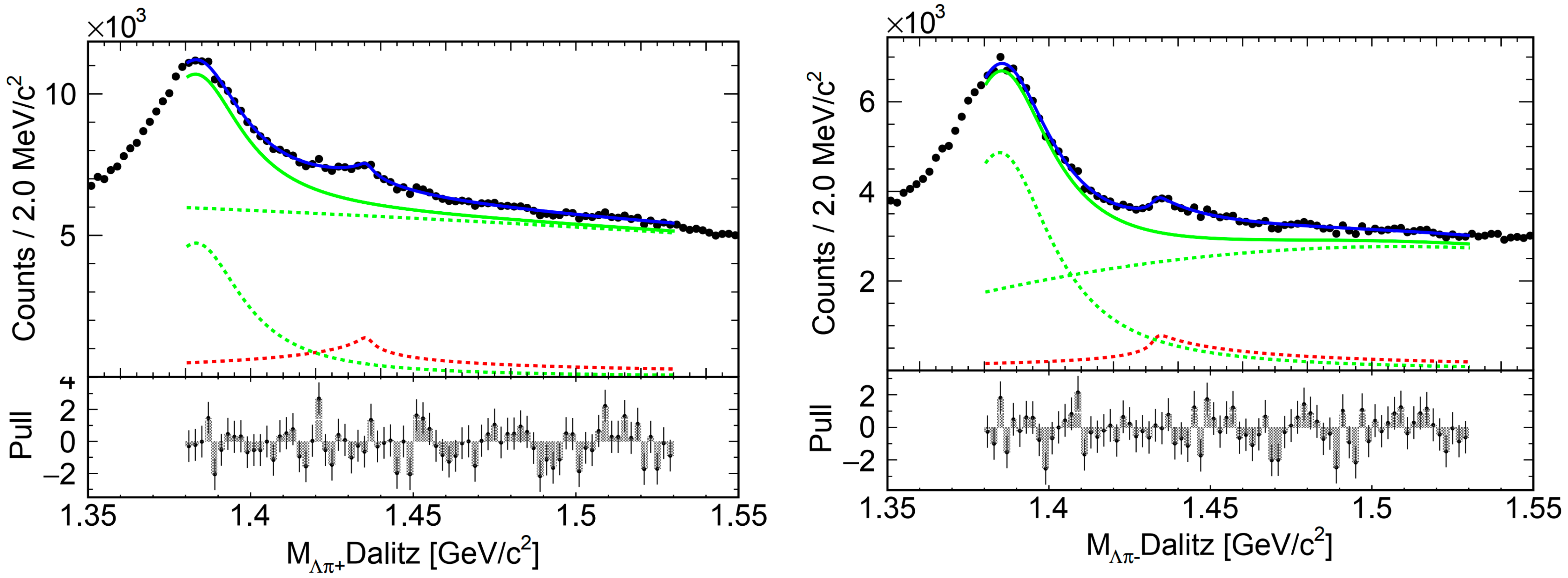
$\bar{\mathrm{K}} - \mathrm{N}$ rescattering

TABLE II. Dalitz model fitting results.

Mode	a[fm]	b[fm]	χ^2 / NDF
$\Lambda\pi^+$	0.48 ± 0.32	1.22 ± 0.83	68.9/68
$\Lambda\pi^-$	1.24 ± 0.57	0.18 ± 0.13	78.1/68

Also tested by Flatte parametrization

$$f_D = \frac{4\pi b}{(1+kb)^2 + (ka)^2}, E > m_{\bar{K}N}$$
$$= \frac{4\pi b}{(1+\kappa a)^2 + (\kappa b)^2}, E < m_{\bar{K}N},$$



The two fits give similar χ^2 s. →

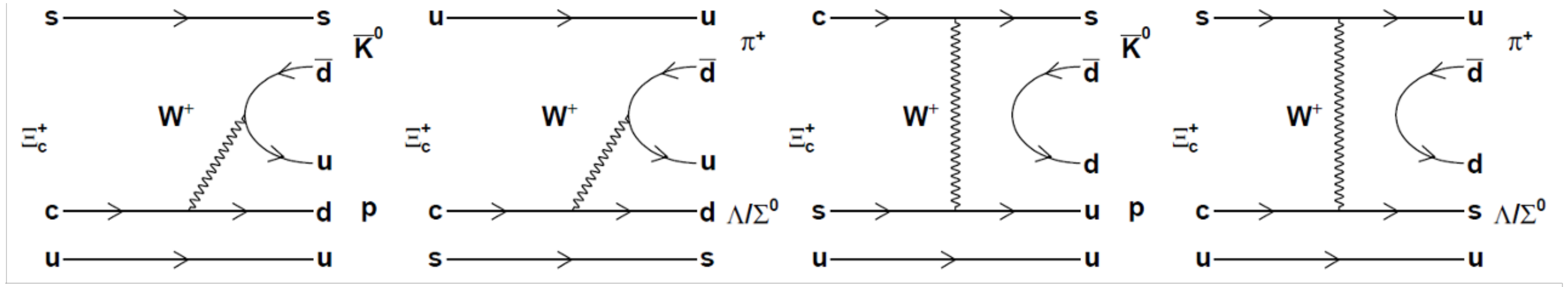
Due to the limitation of the statistic, we can not distinguish between Σ^* resonances and $\bar{\mathrm{K}}\mathrm{N}$ threshold cusps.

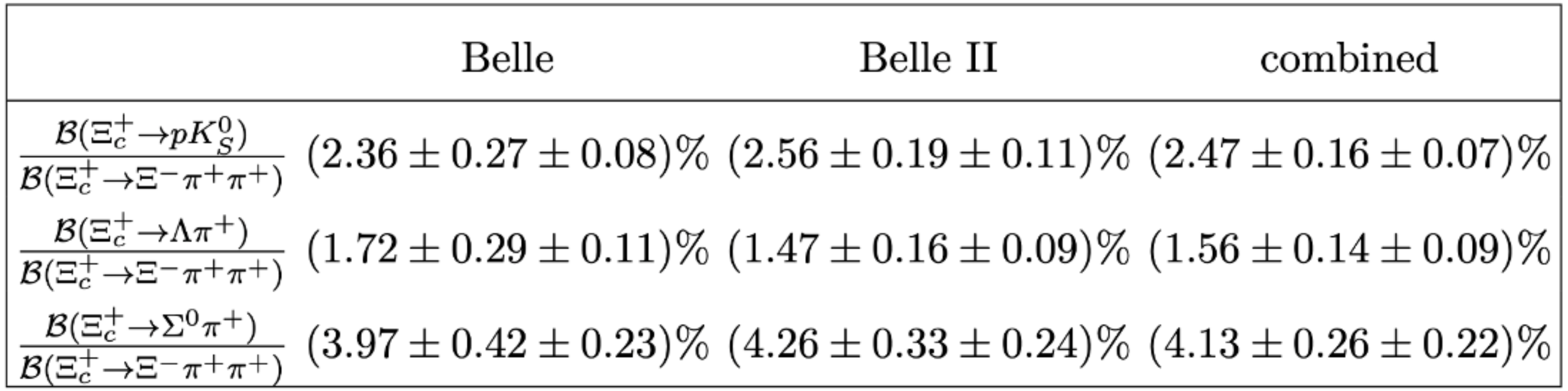
Observations of the singly Cabbibo-suppressed decays $\Xi_c^+ \to pK_S^0$, $\Xi_c^+ \to \Lambda\pi^+$, and $\Xi_c^+ \to \Sigma^0\pi^+$ at Belle and Belle II

Belle data, $980\ \mathrm{fb}^{-1}$ + Belle II data $428\ \mathrm{fb}^{-1}$

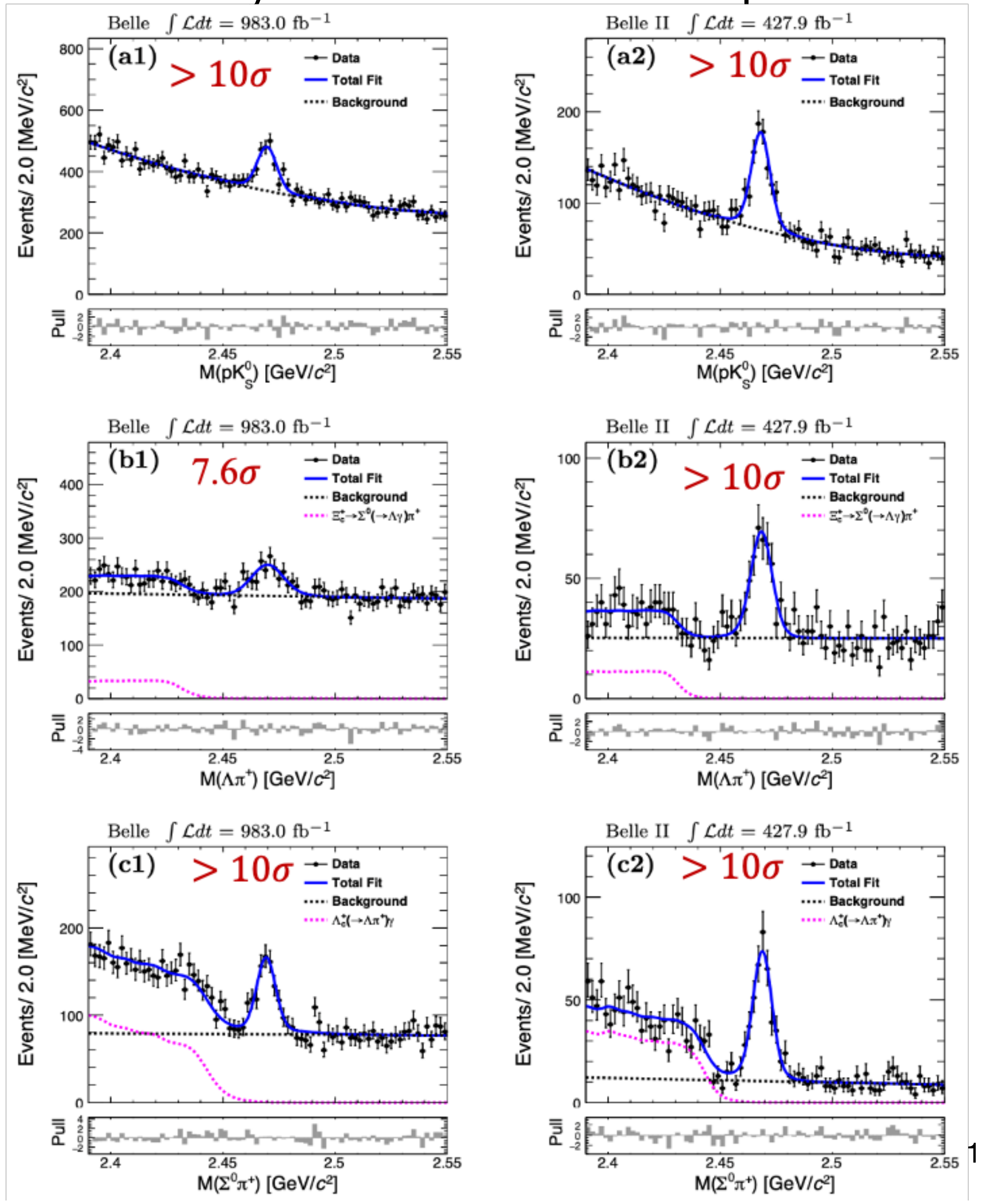
arXiv:2412.10677

- In the last few years, there has been a significant advance in the experimental and theoretical studies of hadronic weak decays of anti-triplet charmed baryons.
- Theoretical calculations for the two-body hadronic weak decays of Ξ_c^+ have been performed based on dynamical model calculations and $SU(3)_F$ flavor symmetry methods. Most of these decay channels have not yet been measured experimentally, especially the singly Cabibbo-suppressed (SCS) decays.
- The $\Xi_c^+ \to \Xi^-\pi^+\pi^+$ is used as the reference channel.





	Belle	Belle II	combined
$\frac{\mathcal{B}(\Xi_c^+ \to pK_S^0)}{\mathcal{B}(\Xi_c^+ \to \Xi^-\pi^+\pi^+)}$	$(2.36 \pm 0.27 \pm 0.08)\%$	$(2.56 \pm 0.19 \pm 0.11)\%$	$(2.47 \pm 0.16 \pm 0.07)\%$
$\frac{\mathcal{B}(\Xi_c^+ \to \Lambda\pi^+)}{\mathcal{B}(\Xi_c^+ \to \Xi^-\pi^+\pi^+)}$	$(1.72 \pm 0.29 \pm 0.11)\%$	$(1.47 \pm 0.16 \pm 0.09)\%$	$(1.56 \pm 0.14 \pm 0.09)\%$
$\frac{\mathcal{B}(\Xi_c^+ \to \Sigma^0\pi^+)}{\mathcal{B}(\Xi_c^+ \to \Xi^-\pi^+\pi^+)}$	$(3.97 \pm 0.42 \pm 0.23)\%$	$(4.26 \pm 0.33 \pm 0.24)\%$	$(4.13 \pm 0.26 \pm 0.22)\%$

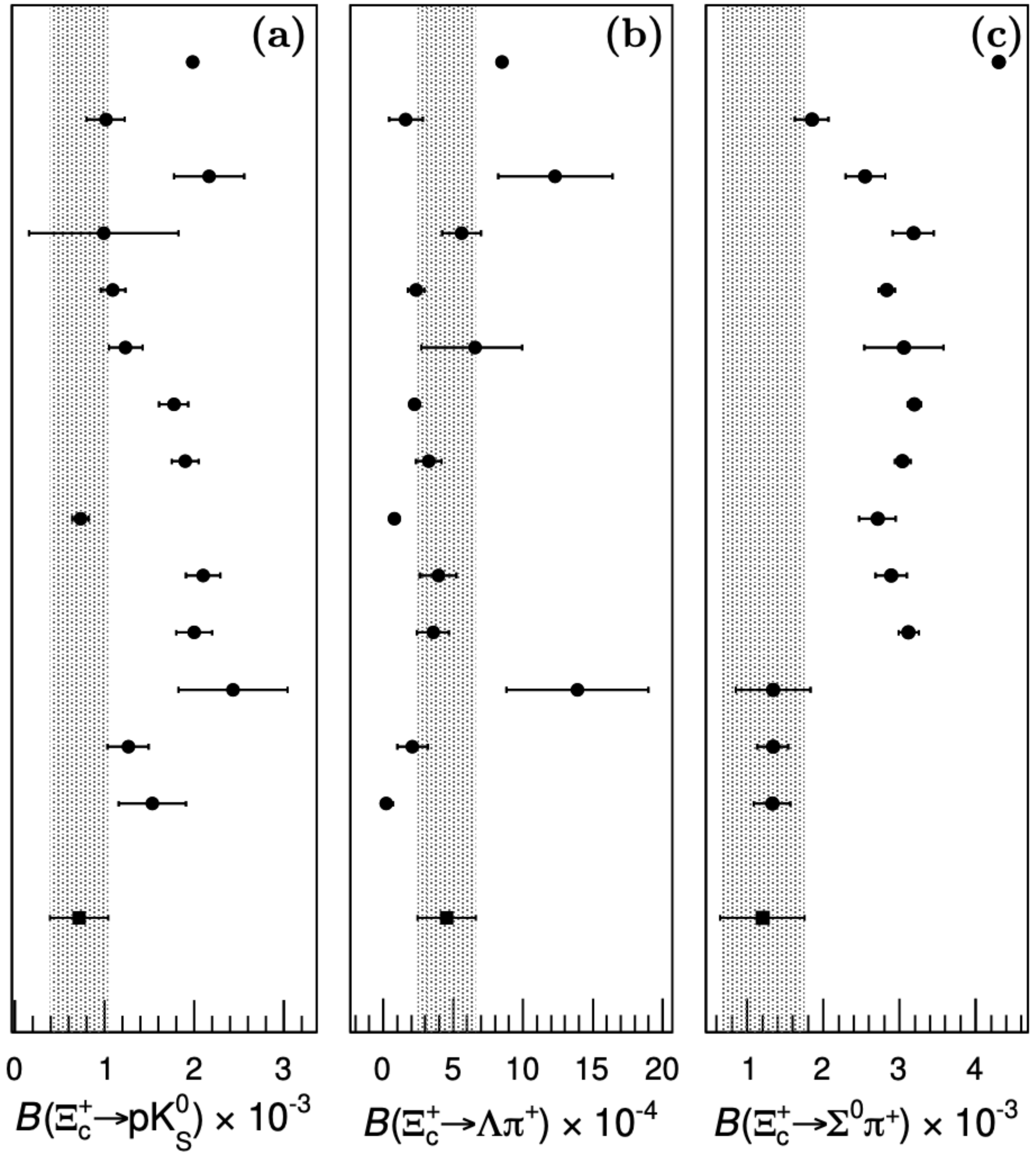


Observations of the singly Cabbibo-suppressed decays $\Xi_c^+ \to pK_S^0$, $\Xi_c^+ \to \Lambda\pi^+$, and $\Xi_c^+ \to \Sigma^0\pi^+$ at Belle and Belle II

Belle data, $980\ \mathrm{fb}^{-1}$ + Belle II data $428\ \mathrm{fb}^{-1}$

arXiv:2412.10677

Comparisons of measured (a) $\mathscr{B}(\Xi_c^+ \to pK_S^0)$, (b) $\mathscr{B}(\Xi_c^+ \to \Lambda\pi^+)$, and (c) $\mathscr{B}(\Xi_c^+ \to \Sigma^0\pi^+)$ with theoretical predictions [1-11].



Zou et. al [1]
Geng et. al [2]
Geng et. al [3]
Huang et. al [4]
Zhong et. al (I) [5]
Zhong et. al (II) [5]
Xing et. al (II) [6]
Geng et. al (II) [7]
Liu [8]
Zhong et. al (I) [9]
Zhong et. al (II) [9]
Zhao et. al [10]
Hsiao et. al (I) [11]
Hsiao et. al (II) [11]

Belle and Belle II
combined measurement

[1]: J. Zou, F. Xu, G. Meng, and H. Y. Cheng, Two-body hadronic weak decays of antitriplet charmed baryons, Phys. Rev. D **101** (2020) 014011.

[2]: C. Q. Geng, Y. K. Hsiao, C. W. Liu, and T. H. Tsai, Antitriplet charmed baryon decays with SU(3) flavor symmetry, Phys. Rev. D **97** (2018) 073006

[3]: C. Q. Geng, C. W. Liu, and T. H. Tsai, Asymmetries of anti-triplet charmed baryon decays, Phys. Lett. B **794** (2019) 19.

[4]: F. Huang, Z. P. Xing, and X. G. He, A global analysis of charmless two body hadronic decays for anti-triplet charmed baryons, JHEP **03** (2022) 143.

[5]: H. Zhong, F. Xu, Q. Wen, and Y. Gu,Weak decays of antitriplet charmed baryons from the perspective of flavor symmetry, JHEP **02** (2023) 235.

[6]: Z. P. Xing, X. G. He, F. Huang, and C. Yang, Global analysis of measured and unmeasured hadronic two-body weak decays of antitriplet charmed baryons, Phys. Rev. D **108** (2023) 053004.

[7]: C. Q. Geng, X. G. He, X. N. Jin, C. W. Liu, and C. Yang, Complete determination of $SU(3)_F$ amplitudes and strong phase in $\Lambda_c^+ \to \Xi^0 K^+$, Phys. Rev. D **109** (2024) L071302.

[8]: C. W. Liu, Nonleptonic two-body weak decays of charmed baryons, Phys. Rev. D **109** (2024) 033004.

[9]: H. Zhong, F. Xu, and H. Y. Cheng, Analysis of hadronic weak decays of charmed baryons in the topological diagrammatic approach, Phys. Rev. D **109** (2024) 114027.

[10]: H. J. Zhao, Y. L. Wang, Y. K. Hsiao, and Y. Yu, A diagrammatic analysis of two-body charmed baryon decays with flavor symmetry, JHEP **02** (2020) 165.

[11]: Y. K. Hsiao, Y. L. Wang, and H. J. Zhao, Equivalent $SU(3)_f$ approaches for two-body anti-triplet charmed baryon decays, JHEP **09** (2022) 035.

Search for CP violation and measurement of branching fractions and decay asymmetry parameters for $\Lambda_c^+ \to \Lambda h^+$ and $\Lambda_c^+ \to \Sigma^0 h^+$ $(\mathrm{h} = \mathrm{K}, \pi)$

Belle data, $980\ \mathrm{fb}^{-1}$ *Sci. Bull.* ***68****, (2023) 583-592*

- CP violation (CPV) is one of the essential requirements to form the matter-anti-matter asymmetrical universe [1]. In the standard model, the only source of CPV is the single complex phase in the CKM matrix, which is not enough to explain the observed asymmetry.
- The CPV has been observed in open charm mesons decay, not yet in baryons decay. An observation of CPV in charm decays much greater than 10^{-3} could indicate new physics beyond the SM [2-5].
- This paper reports A_{CP}^{dir}, A_{CP}^{α} and BF measurements for the SCS decays $\Lambda_c^+ \to \Lambda K^+$ and $\Lambda_c^+ \to \Sigma^0 K^+$, using the CF decays $\Lambda_c^+ \to \Lambda\pi^+$ and $\Lambda_c^+ \to \Sigma^0\pi^+$ as reference modes.
- The $A_{CP}^{\alpha}(\Lambda \to p\pi^-)$ can be extracted from $A_{CP}^{\alpha}(\mathrm{total}) = (\alpha_{\Lambda_c^+}\alpha_- - \alpha_{\bar{\Lambda}_c^-}\alpha^+)/(\alpha_{\Lambda_c^+}\alpha_- + \alpha_{\bar{\Lambda}_c^-}\alpha^+)$ from CF reference channels, with $\alpha_{\Lambda_c^+} = -\alpha_{\bar{\Lambda}_c^-}$ (SM).

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[1]: A.D. Sakharov, Violation of CP Invariance, C asymmetry, and baryon asymmetry of the universe, Pisma Zh. Eksp. Teor. Fiz. **5** (1967) 32.

[2]: D. Delepine, G. Faisel and C.A. Ramirez, Direct CP violation in D+ ! K0(K ̄ 0)π+ decays as a probe for new physics, Eur. Phys. J. C **80** (2020) 596

[3]: A. Dery and Y. Nir, Implications of the LHCb discovery of CP violation in charm decays, JHEP **12** (2019) 104

[4]: M. Chala, A. Lenz, A.V. Rusov and J. Scholtz, ΔA_{CP} within the Standard Model and beyond, JHEP **07** (2019) 161.

[5]: M. Saur and F.-S. Yu, Charm CP V : observation and prospects, Sci. Bull. **65** (2020) 1428.

Search for CP violation and measurement of branching fractions and decay asymmetry parameters for $\Lambda_c^+ \to \Lambda h^+$ and $\Lambda_c^+ \to \Sigma^0 h^+$ $(h = K, \pi)$

Belle data, $980\ \mathrm{fb}^{-1}$

Sci. Bull. **68**, (2023) 583-592

Using $1 \mp A_\varepsilon^{h^+}$ as weight factor to cover the $K^+(\pi^+)$ detection efficiency asymmetry.

$$A_{\rm raw} = \frac{N(\Lambda_c^+ \to f) - N(\bar{\Lambda}_c^- \to \bar{f})}{N(\Lambda_c^+ \to f) + N(\bar{\Lambda}_c^- \to \bar{f})}$$

$$A_{\rm raw} = A_{CP}^{\Lambda_c^+ \to \Lambda K^+} + A_{CP}^{\Lambda \to p\pi^-} + A_\varepsilon^{\Lambda} + A_\varepsilon^{K^+} + \underline{A_{\rm FB}^{\Lambda_c^+}}$$

Forward-background asymmetry of Λ_c^+ production

$$\Rightarrow$$

$$A_{\rm raw}^{\rm corr}(\Lambda_c^+ \to \Lambda K^+) - A_{\rm raw}^{\rm corr}(\Lambda_c^+ \to \Lambda \pi^+) = A_{CP}^{\rm dir}(\Lambda_c^+ \to \Lambda K^+) - \underline{A_{CP}^{\rm dir}(\Lambda_c^+ \to \Lambda \pi^+)}\,.$$

Cabibbo-flavoured process, no dir-CP violation in SM.

$$\Rightarrow \quad A_{CP}^{\rm dir}(\Lambda_c^+ \to \Lambda K^+)$$

No evidence of charm CP violation is found.

$$\boxed{\begin{aligned} A_{CP}^{\rm dir}(\Lambda_c^+ \to \Lambda K^+) &= (+2.1 \pm 2.6 \pm 0.1)\% \\ A_{CP}^{\rm dir}(\Lambda_c^+ \to \Sigma^0 K^+) &= (+2.5 \pm 5.4 \pm 0.4)\% \end{aligned}}$$

This is the first direct CP asymmetry measurement for SCS two-body decays of charmed baryons.

$$\frac{\mathcal{B}(\Lambda_c^+ \to \Lambda K^+)}{\mathcal{B}(\Lambda_c^+ \to \Lambda \pi^+)} = (5.05 \pm 0.13 \pm 0.09)\% \qquad \frac{\mathcal{B}(\Lambda_c^+ \to \Sigma^0 K^+)}{\mathcal{B}(\Lambda_c^+ \to \Sigma^0 \pi^+)} = (2.78 \pm 0.15 \pm 0.05)\%$$

$$\mathscr{B}(\Lambda_c^+ \to \Lambda K^+) = (6.57 \pm 0.17 \pm 0.11 \pm 0.35) \times 10^{-4}$$

$$\mathscr{B}(\Lambda_c^+ \to \Sigma^0 K^+) = (3.58 \pm 0.19 \pm 0.06 \pm 0.19) \times 10^{-4}$$

$$\frac{\mathcal{B}_{\rm sig}}{\mathcal{B}_{\rm ref}} = \frac{N_{\rm sig}/\varepsilon_{\rm sig}}{N_{\rm ref}/\varepsilon_{\rm ref}}$$

Branching fractions

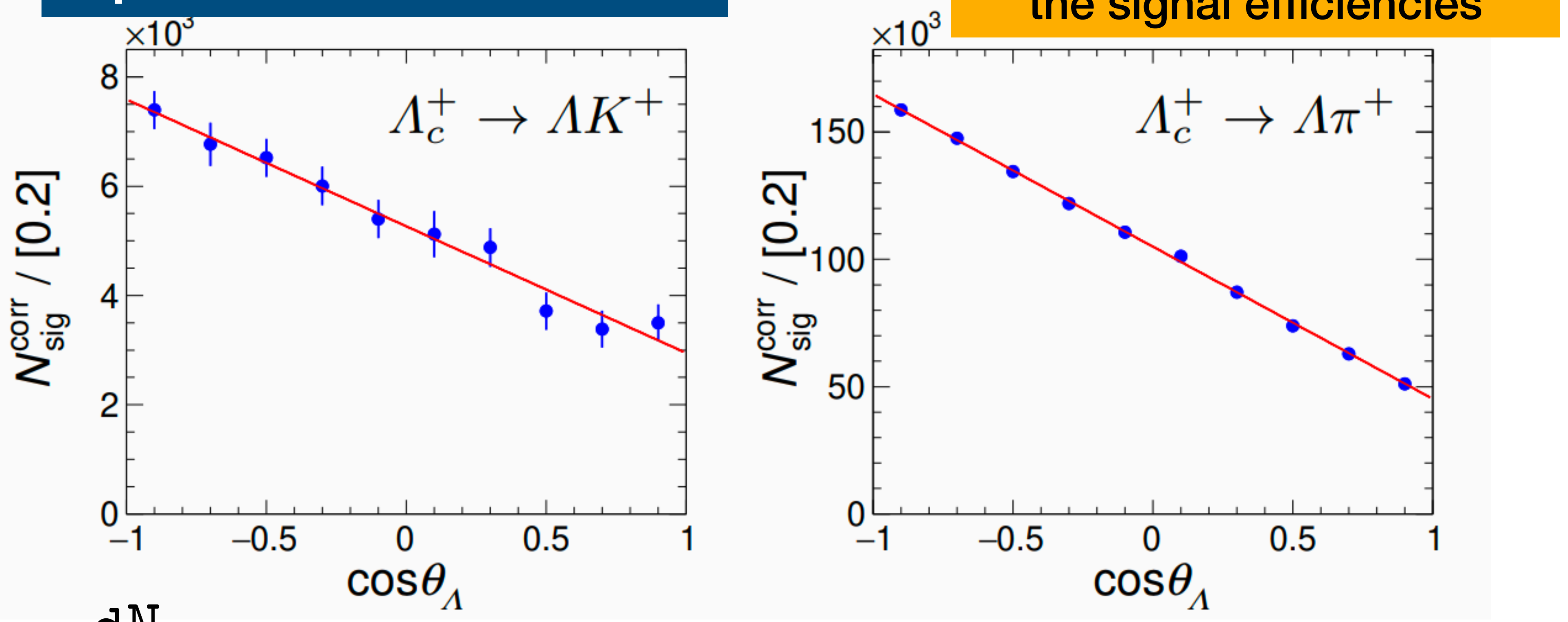
Search for CP violation and measurement of branching fractions and decay asymmetry parameters for $\Lambda_c^+ \to \Lambda h^+$ and $\Lambda_c^+ \to \Sigma^0 h^+$ $(h = K, \pi)$

Belle data, $980\ \mathrm{fb}^{-1}$

Sci. Bull. **68**, (2023) 583-592

α parameter extraction

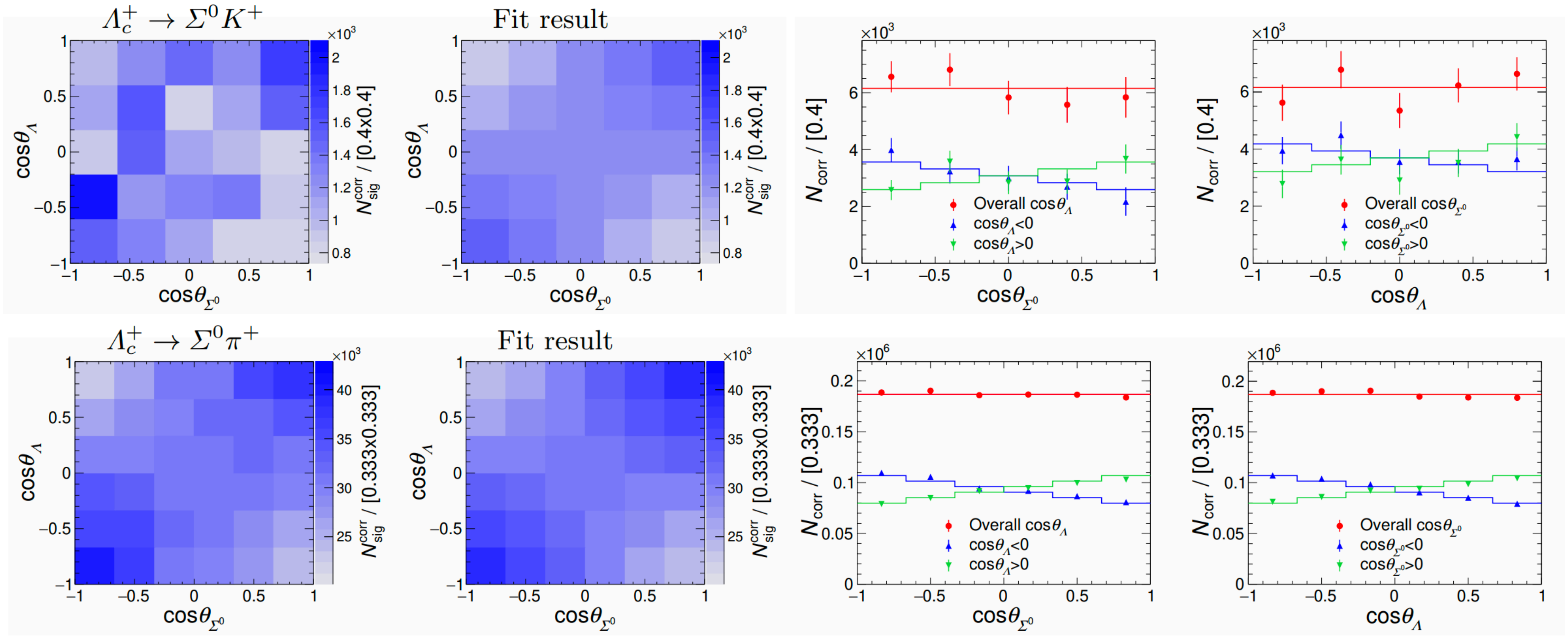
corrected bin-by-bin with the signal efficiencies



$$\frac{dN}{d\cos\theta_\Lambda} \propto 1 + \alpha_{\Lambda_c^+}\alpha_\Lambda \cos\theta_\Lambda \longleftarrow \alpha_\Lambda^{avg} = 0.7542 \pm 0.0026$$

$$\begin{aligned}
\alpha_{\Lambda_c^+}^{avg}(\Lambda_c^+ \to \Lambda K^+) &= -0.585 \pm 0.049 \pm 0.018\,,\\
\alpha_{\Lambda_c^+}^{avg}(\Lambda_c^+ \to \Lambda \pi^+) &= -0.755 \pm 0.005 \pm 0.003\,,\\
\alpha_{\Lambda_c^+}^{avg}(\Lambda_c^+ \to \Sigma^0 K^+) &= -0.54 \pm 0.18 \pm 0.09\,,\\
\alpha_{\Lambda_c^+}^{avg}(\Lambda_c^+ \to \Sigma^0 \pi^+) &= -0.463 \pm 0.016 \pm 0.008\,,
\end{aligned}$$

Consistent with the current world average, with better precision.



$$\frac{dN}{d\cos\theta_\Sigma^0 d\cos\theta_\Lambda} \propto 1 + \alpha_{\Lambda_c^+}\alpha_\Lambda \cos\theta_\Sigma^0 \cos\theta_\Lambda$$

The first measurement of hyperon CPV searches in CF charm decays. No evidence of Λ-hyperon CPV is found.

Measure the A_{CP}^α in $\Lambda_c^+ \to \Lambda h^+$ and $\Lambda_c^+ \to \Sigma^0 h^+$

Channel	$\alpha_{\Lambda_c^+}\alpha_-$	$\alpha_{\Lambda_c^-}\alpha_+$	$\alpha_{\Lambda_c^+}$	$\alpha_{\bar\Lambda_c^-}$	A_{CP}^α	W.A. A_{CP}^α
$\Lambda_c^+ \to \Lambda K^+$	-0.425 ± 0.053	-0.448 ± 0.053	$-0.566 \pm 0.071 \pm 0.028$	$0.592 \pm 0.070 \pm 0.079$	$-0.023 \pm 0.086 \pm 0.071$	–
$\Lambda_c^+ \to \Lambda \pi^+$	-0.590 ± 0.006	-0.570 ± 0.006	$-0.784 \pm 0.008 \pm 0.006$	$0.754 \pm 0.008 \pm 0.018$	$+0.020 \pm 0.007 \pm 0.014$	-0.07 ± 0.22
$\Lambda_c^+ \to \Sigma^0 K^+$	-0.43 ± 0.18	-0.37 ± 0.21	$-0.58 \pm 0.24 \pm 0.09$	$0.49 \pm 0.28 \pm 0.14$	$+0.08 \pm 0.35 \pm 0.14$	–
$\Lambda_c^+ \to \Sigma^0 \pi^+$	-0.340 ± 0.016	-0.358 ± 0.017	$-0.452 \pm 0.022 \pm 0.023$	$0.473 \pm 0.023 \pm 0.035$	$-0.023 \pm 0.034 \pm 0.030$	–

Search for hyperon CPV in $\Lambda \to p\pi$ in CF modes

$$A_{CP}^\alpha(\Lambda \to p\pi^-) = +0.013 \pm 0.007 \pm 0.011$$

Measurement of the Λ_c^+ lifetime

BelleII on/off-resonance data, $207.2\ \mathrm{fb}^{-1}$

*PRL **130**, (2023) 071802*

- Precise measurements of weakly decaying charm or bottom hadrons can help to search for physics beyond the standard model.
- The the heavy quark expansion (HQE) is an effective model to describe strong interactions at low energy, which provides a consistent framework for bottom hadrons. But for charm hadron lifetimes, HQE is not able to describe them satisfactorily [1~3].
- A precise, absolute measurement by Belle II may help to resolve the tension between Λ_c^+ lifetime measurements at e^+e^- colliders and other experiments and will substantially improve the world average [4~12].
- We report a precise measurement of the Λ_c^+ lifetime using $\Lambda_c^+ \rightarrow pK^-\pi^+$ decays reconstructed in data collected at or near the $\Upsilon(4S)$resonance.

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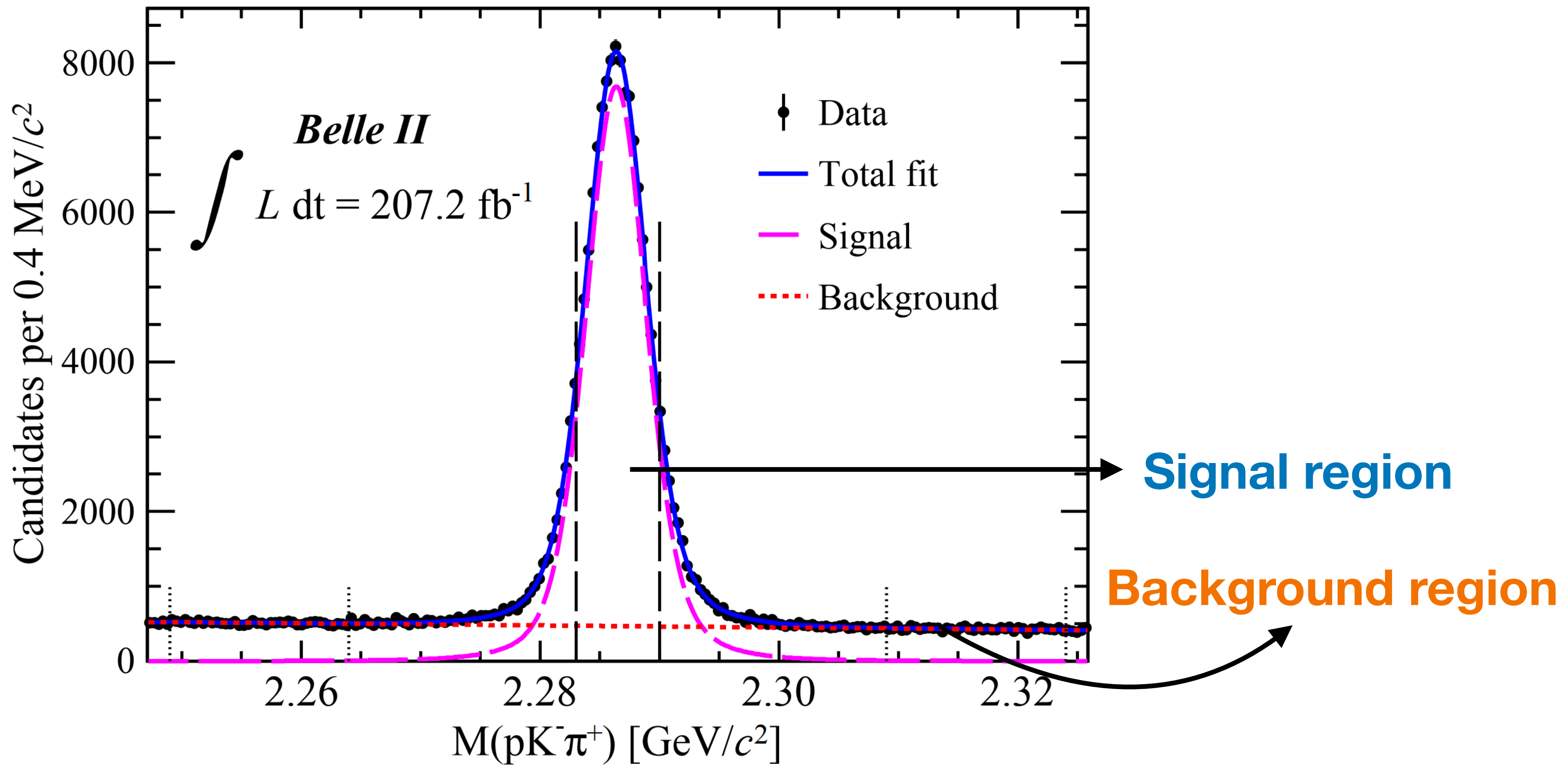
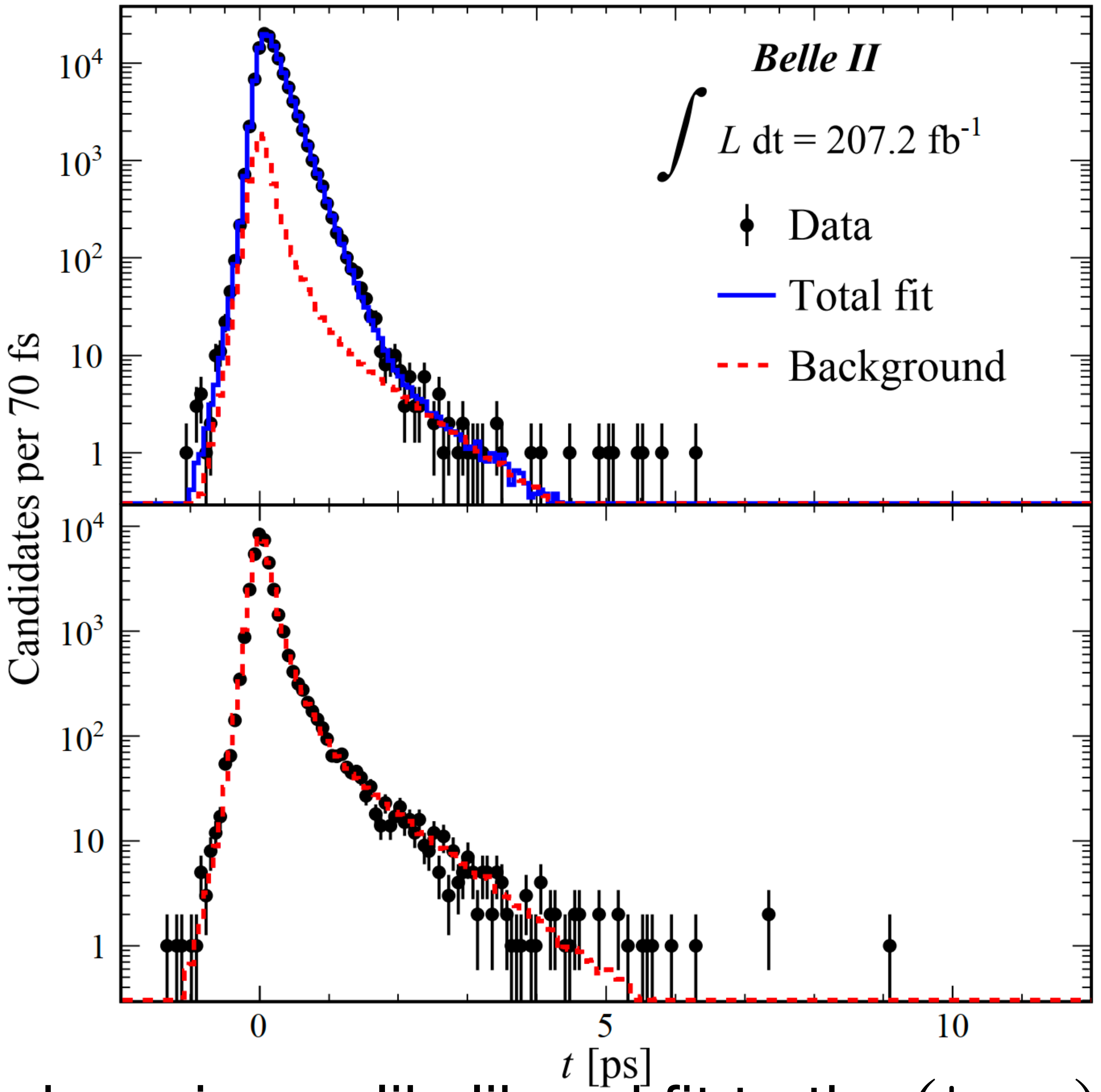
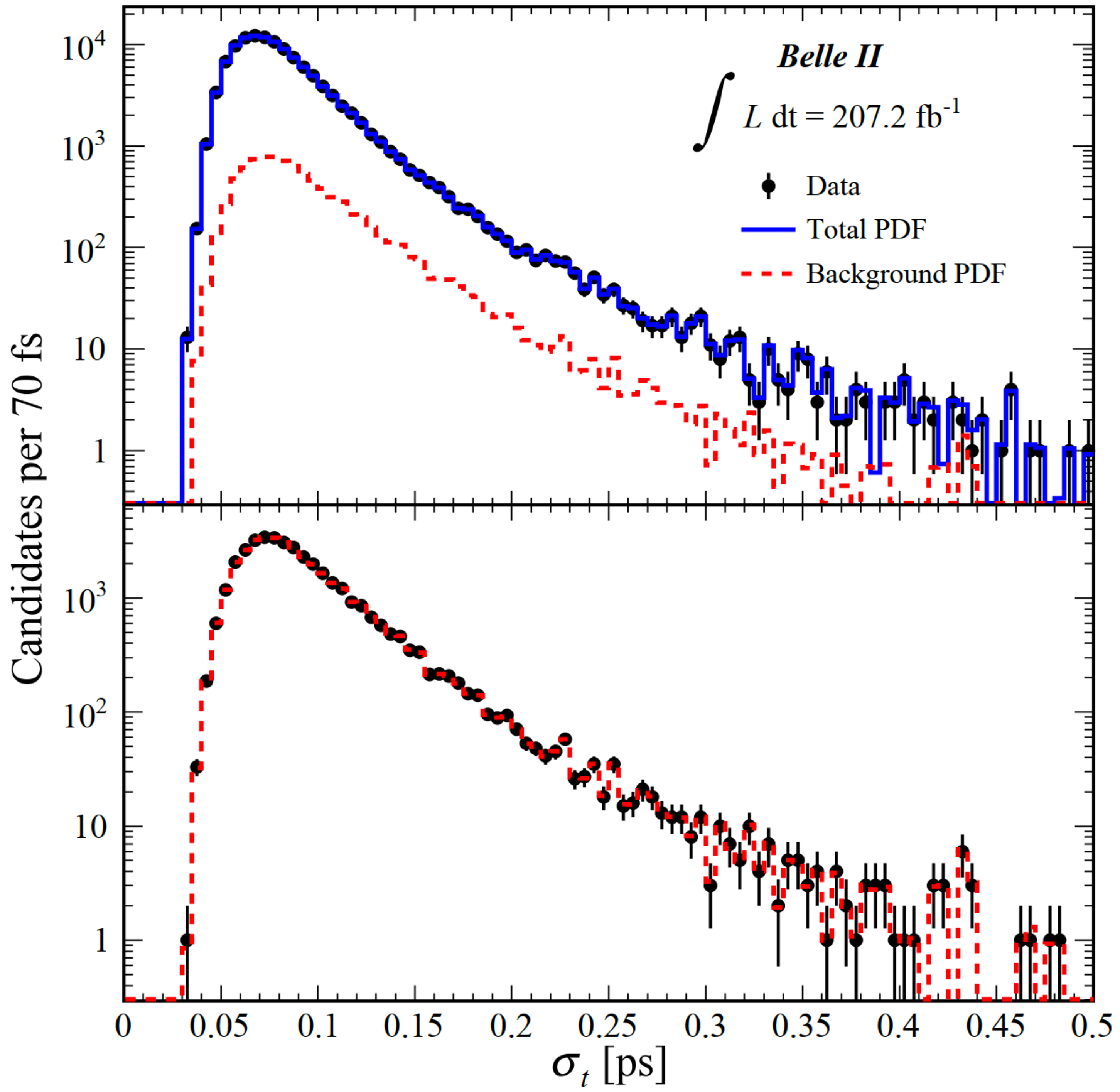
Measurement of the Λ_c^+ lifetime

BelleII on/off-resonance data, $207.2\ \mathtt{fb}^{-1}$

*PRL **130**, (2023) 071802*







- The Λ_c^+ lifetime is measured with an 2D unbinned maximum-likelihood fit to the $(\mathtt{t}, \sigma_\mathtt{t})$ distribution for events in the signal region.
  - Signal PDF: 1) Exponential function in t convolved with a Gaussian resolution function, which depends on $\sigma_\mathtt{t}$; 2) PDF for $\sigma_\mathtt{t}$ is a histogram template from background-subtracted signal candidates.
  - Background PDF: Empirical model of the sideband data
- To better constrain the background, a simultaneous fit to the events in the signal region and sidebands is performed.

$$\tau(\Lambda_c^+) = 203.20 \pm 0.89(\mathtt{stat}) \pm 0.77(\mathtt{sys})\ \mathtt{fs}$$

Most precise

Summary

- Belle's enduring legacy

  — Continues to yield critical insights in charm hadron dynamics even 10+ years post-data-taking

  — Maintains relevance through innovative analysis of its 980 fb^{-1} dataset

- Belle II's improvement

  — With enhanced of vertex resolution, Belle II has a improved detection precision.

  — Enabling unprecedented precision in charm flavor physics, CP violation studies, and beyond the Standard Model searches.

  — Started run2 taking.

Thank you!

Back Up

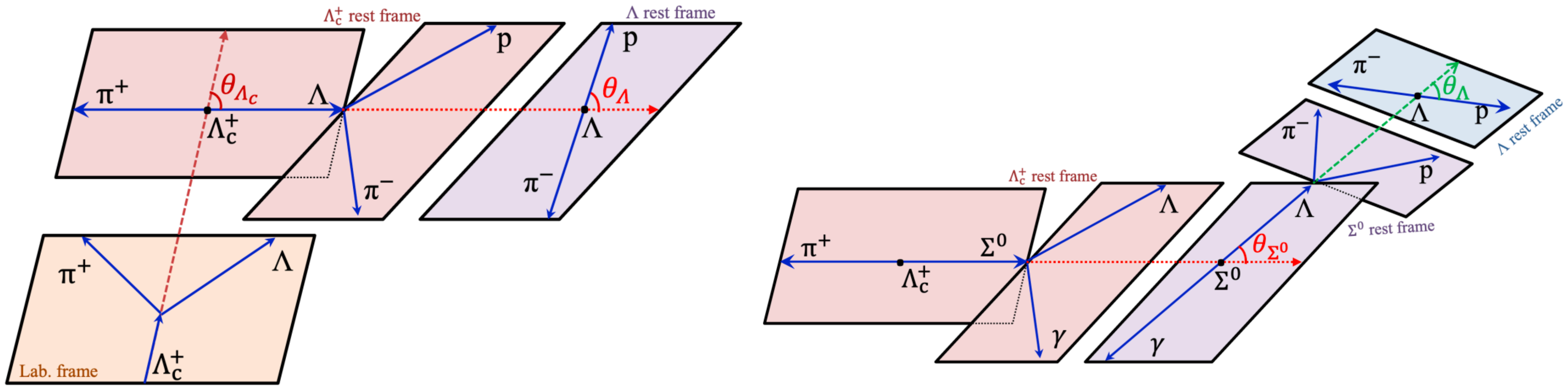


FIG. 5. Schematic plot showing the helicity angles: (left) $\theta_{\Lambda_c^+}$ and θ_Λ in $\Lambda_c^+ \to \Lambda\pi^+$, $\Lambda \to p\pi^-$; and (right) θ_{Σ^0} and θ_Λ in $\Lambda_c^+ \to \Sigma^0\pi^+$, $\Sigma^0 \to \gamma\Lambda$, $\Lambda \to p\pi^-$.

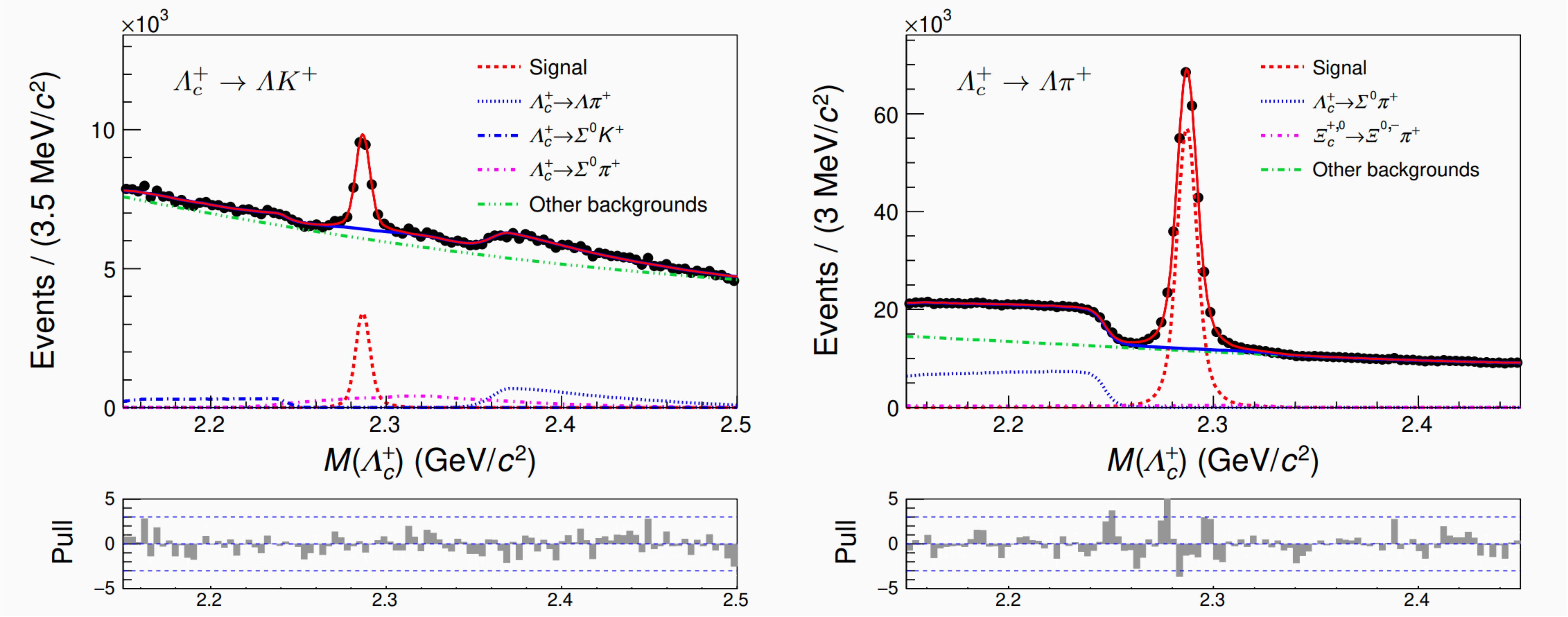


FIG. 6. The fit results of Λ_c^+ invariant mass distributions for $\Lambda_c^+ \to \Lambda K^+$ and $\Lambda_c^+ \to \Lambda\pi^+$ decays. The red curve shows the total fit result, and the blue curve the total background; the dashed curves show the components of signal and backgrounds. The fit qualities, χ^2 divided by the number of degrees of freedom, are $\chi^2/91 = 1.12$ and $\chi^2/91 = 1.38$, respectively.

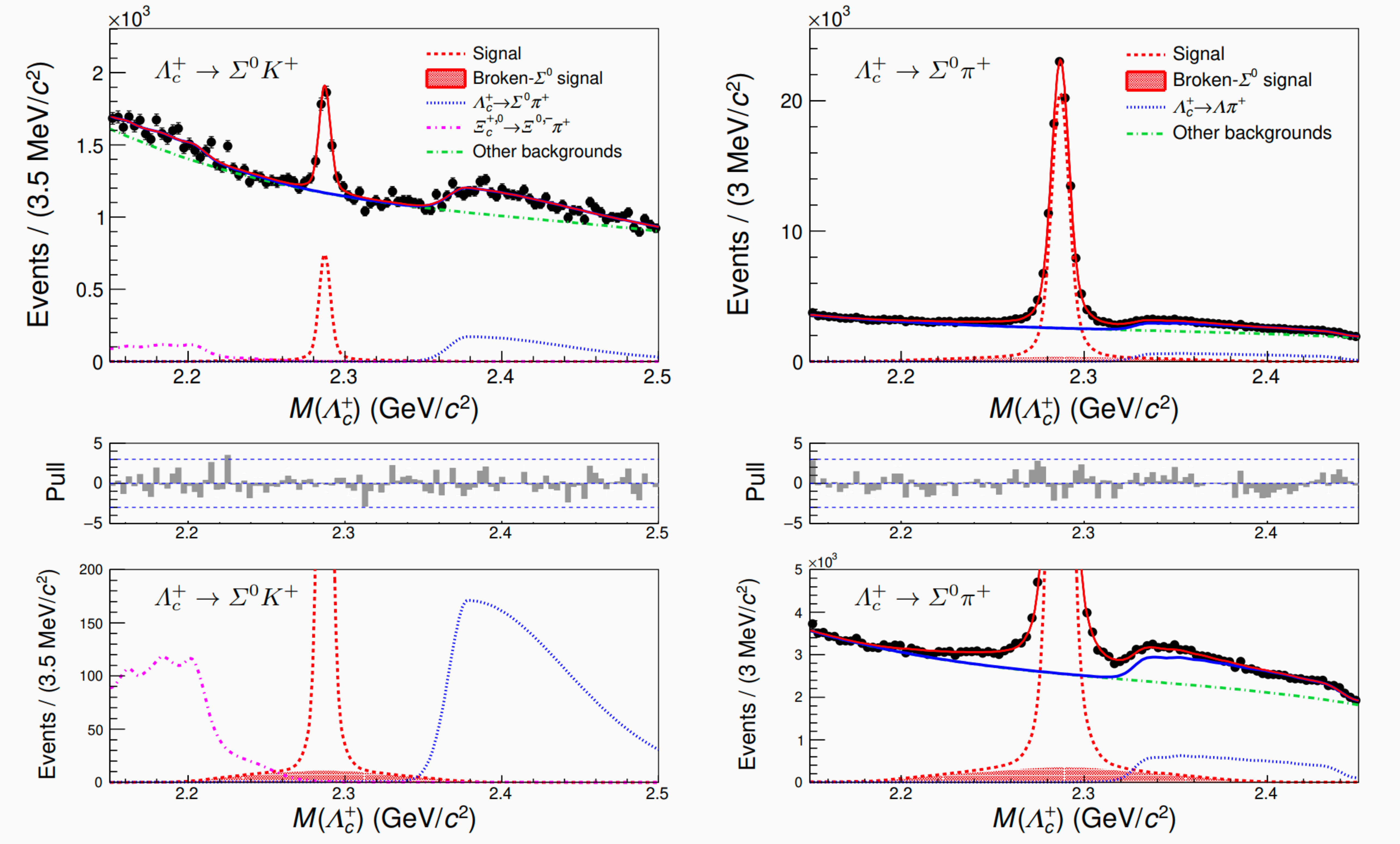


FIG. 7. The fit results of Λ_c^+ invariant mass distributions for $\Lambda_c^+ \to \Sigma^0 K^+$ and $\Lambda_c^+ \to \Sigma^0\pi^+$ decays. The red curve shows the total fit result, and the blue curve the total background; the dashed curves show the components of signal (including the broken-Σ^0 signal) and backgrounds. The fit qualities, χ^2 divided by the number of degrees of freedom, are $\chi^2/91 = 1.38$, and $\chi^2/92 = 1.07$, respectively. The bottoms figures are the enlarged view to show the distributions of broken-Σ^0 signal (red-filled histogram) and the peaking backgrounds more clearly.