復旦大學
FUDAN UNIVERSITY

Recent results on baryons and charmed baryons at Belle

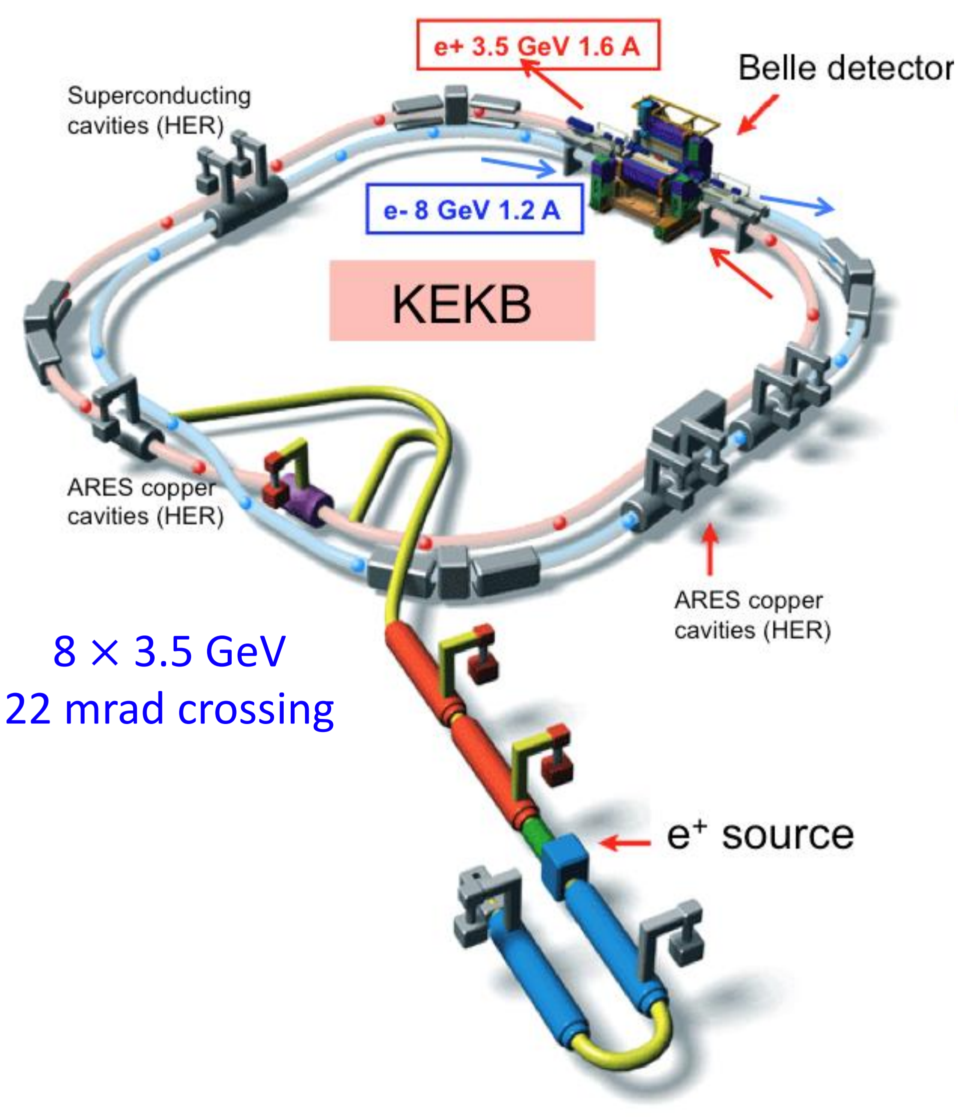
Chengping Shen shencp@fudan.edu.cn

Outline

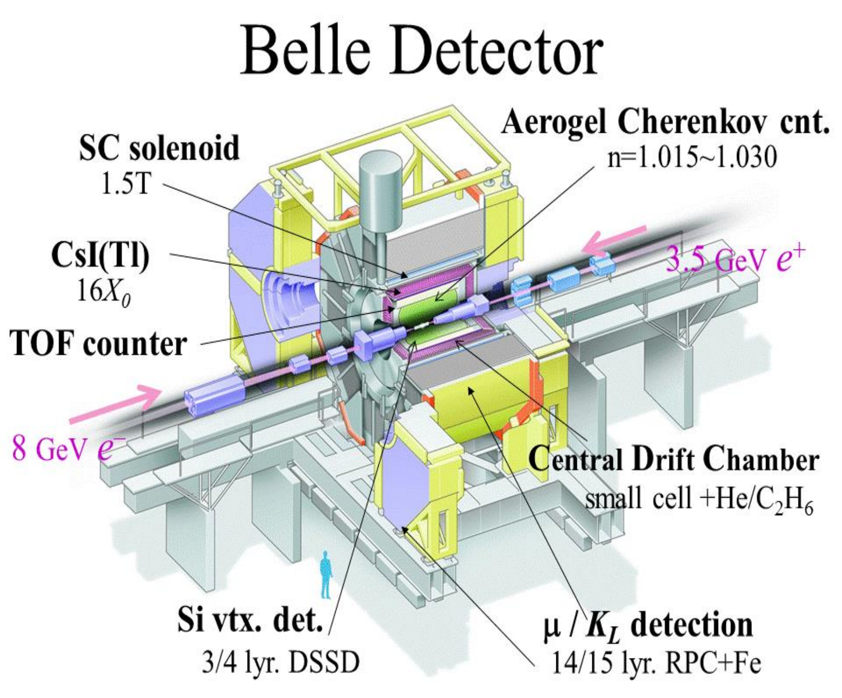
- Recent results on baryons at Belle
- Recent results on charmed baryons at Belle
- Belle II status and prospects

- Summary

Belle experiment and data samples



8 × 3.5 GeV
22 mrad crossing



Data taking: 1999 – 2010

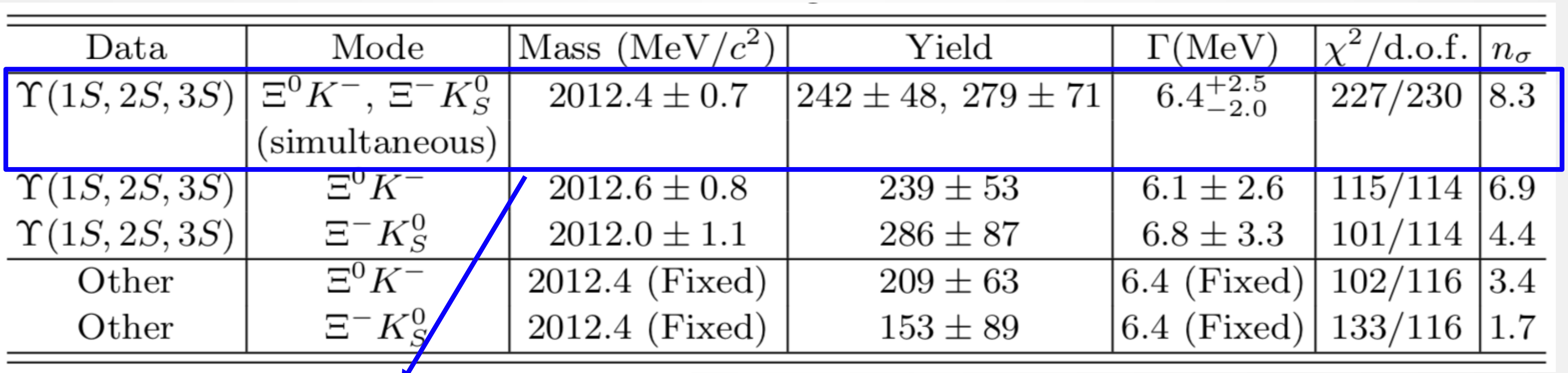
On/off/Scan Υ(nS) peaks

Total luminosity: 980 fb^{-1}

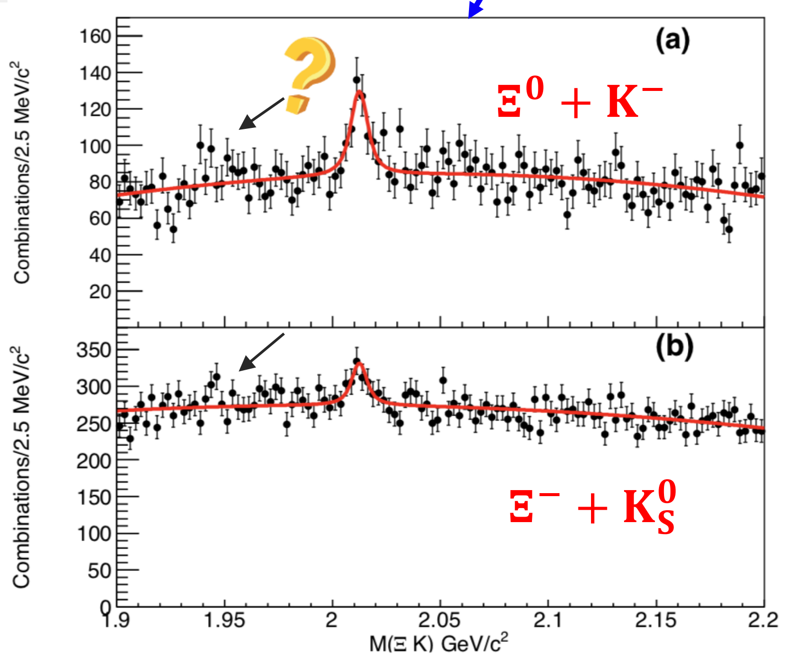
772M $B\bar{B}$ events @$\Upsilon(4S)$

Observation of an excited Ω^- baryon

$$\mathcal{R} = \frac{\mathcal{B}(\Omega^{*-} \to \Xi^0 K^-)}{\mathcal{B}(\Omega^{*-} \to \Xi^- \overline{K}^0)} = 1.2 \pm 0.3$$



Data	Mode	Mass (MeV/c^2)	Yield	Γ(MeV)	χ^2/d.o.f.	n_σ
$\Upsilon(1S,2S,3S)$	$\Xi^0 K^-$, $\Xi^- K_S^0$ (simultaneous)	2012.4 ± 0.7	242 ± 48, 279 ± 71	$6.4^{+2.5}_{-2.0}$	227/230	8.3
$\Upsilon(1S,2S,3S)$	$\Xi^0 K^-$	2012.6 ± 0.8	239 ± 53	6.1 ± 2.6	115/114	6.9
$\Upsilon(1S,2S,3S)$	$\Xi^- K_S^0$	2012.0 ± 1.1	286 ± 87	6.8 ± 3.3	101/114	4.4
Other	$\Xi^0 K^-$	2012.4 (Fixed)	209 ± 63	6.4 (Fixed)	102/116	3.4
Other	$\Xi^- K_S^0$	2012.4 (Fixed)	153 ± 89	6.4 (Fixed)	133/116	1.7



PRL 121, 052003 (2018)

- The gap in the spectrum between the ground state and this excited state (~340 MeV) is smaller than in other Ω^- excited states, which is closer to the negative-parity orbital excitations of many other baryons.
- The narrow width observed implies that the quantum number $J^P = \frac{3}{2}^-$ is preferable.

Theoretical interpretation for the $\Omega^*(2012)$

It is generally accepted that $\Omega^*(2012)$ is 1P orbital excitation of the ground state Ω baryon with the three strange quarks, whose quantum numbers are $J^P = \frac{3}{2}^-$.

Notably, the newly observed $\Omega^*(2012)$ is revealed as a KΞ(1530) hadronic molecule. [PRD 98, 054009 (2018), PRD 98, 056013 (2018), arXiv:1807.02145, arXiv:1807.06485, arXiv:1807.06485, ...]

The $K\Xi\pi$ three-body component is largely dominant.

From PRD 98, 056013 (2018)

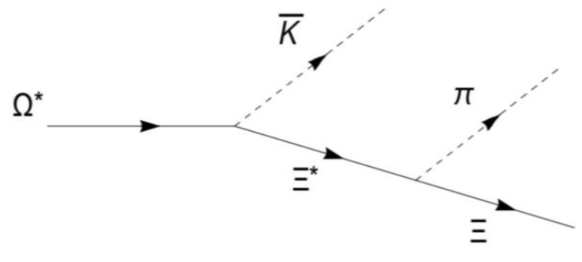
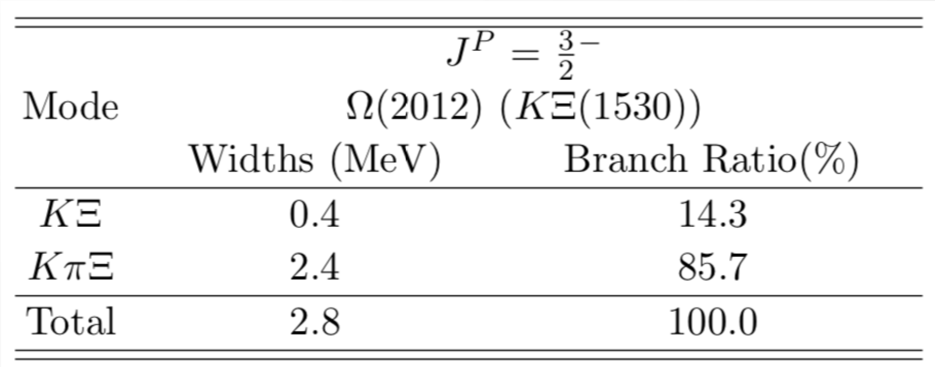


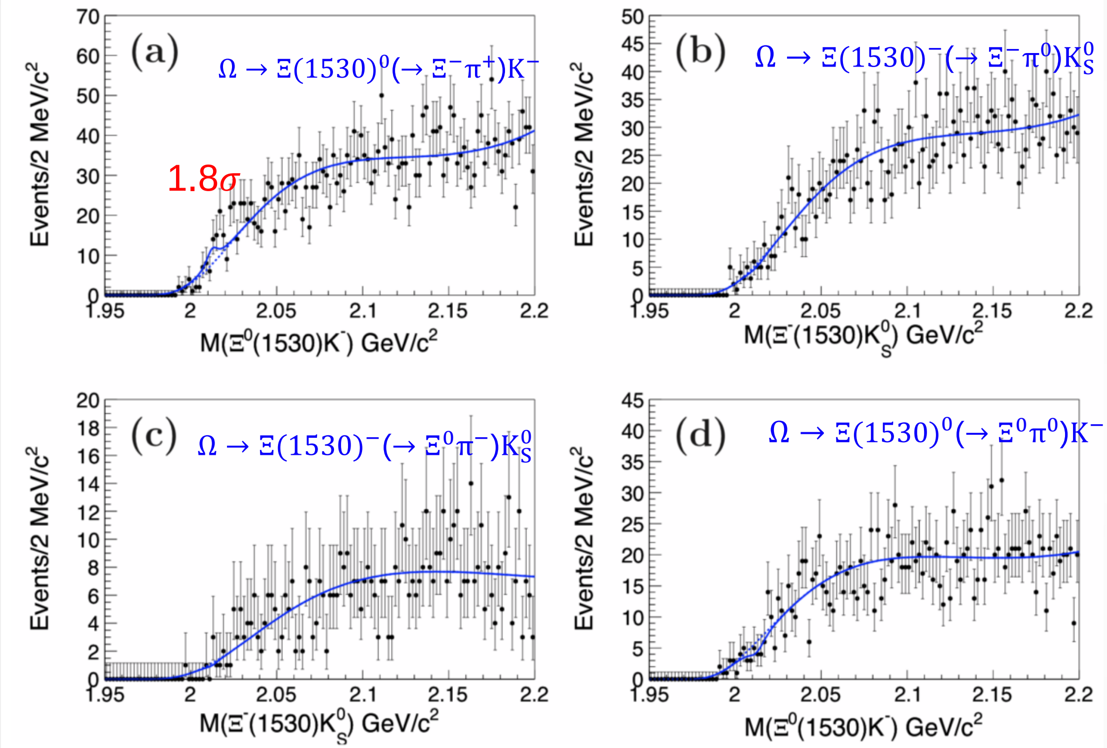
FIG. 1: The three-body decays of Ω(2012) in the $K\Xi(1530)$ molecular picture.



	$J^P = \frac{3}{2}-$	
Mode	$\Omega(2012)$ $(K\Xi(1530))$	
	Widths (MeV)	Branch Ratio(%)
$K\Xi$	0.4	14.3
$K\pi\Xi$	2.4	85.7
Total	2.8	100.0

Search for $\Omega(2012) \to K\Xi(1530) \to K\pi\Xi$

We use the same data samples to search for $\Omega(2012) \to K\Xi(1530) \to K\pi\Xi$ in the decay of the narrow resonances $\Upsilon(1S)$, $\Upsilon(2S)$, and $\Upsilon(3S)$.



No clear $\Omega(2012)$ signals are observed.
We give the upper limits on the ratios of the branching fractions at 90% C.L. as below.

Mode	N^{Fit}	N^{UL}
$\Omega \to \Xi(1530)^0(\to \Xi^-\pi^+)K^-$	22.5±12.9	41.0
$\Omega \to \Xi(1530)^-(\to \Xi^-\pi^0)K_S^0$	-3.5±11.6	16.6
$\Omega \to \Xi(1530)^-(\to \Xi^0\pi^-)K_S^0$	-1.0±3.6	7.2
$\Omega \to \Xi(1530)^0(\to \Xi^0\pi^0)K^-$	-12.0±9.8	13.2

$$R^{\Xi^-\pi^+K^-}_{\Xi^-\bar{K}^0} = \frac{\mathcal{B}(\Omega \to \Xi(1530)^0(\to \Xi^-\pi^+)K^-)}{\mathcal{B}(\Omega \to \Xi^-\bar{K}^0)} < 9.3\%$$

$$R^{\Xi^-\pi^0\bar{K}^0}_{\Xi^-\bar{K}^0} = \frac{\mathcal{B}(\Omega \to \Xi(1530)^-(\to \Xi^-\pi^0)\bar{K}^0)}{\mathcal{B}(\Omega \to \Xi^-\bar{K}^0)} < 81.1\%$$

$$R^{\Xi^0\pi^-\bar{K}^0}_{\Xi^0K^-} = \frac{\mathcal{B}(\Omega \to \Xi(1530)^-(\to \Xi^0\pi^-)\bar{K}^0)}{\mathcal{B}(\Omega \to \Xi^0K^-)} < 21.3\%$$

$$R^{\Xi^0\pi^0K^-}_{\Xi^0K^-} = \frac{\mathcal{B}(\Omega \to \Xi(1530)^0(\to \Xi^0\pi^0)K^-)}{\mathcal{B}(\Omega \to \Xi^0K^-)} < 30.4\%$$

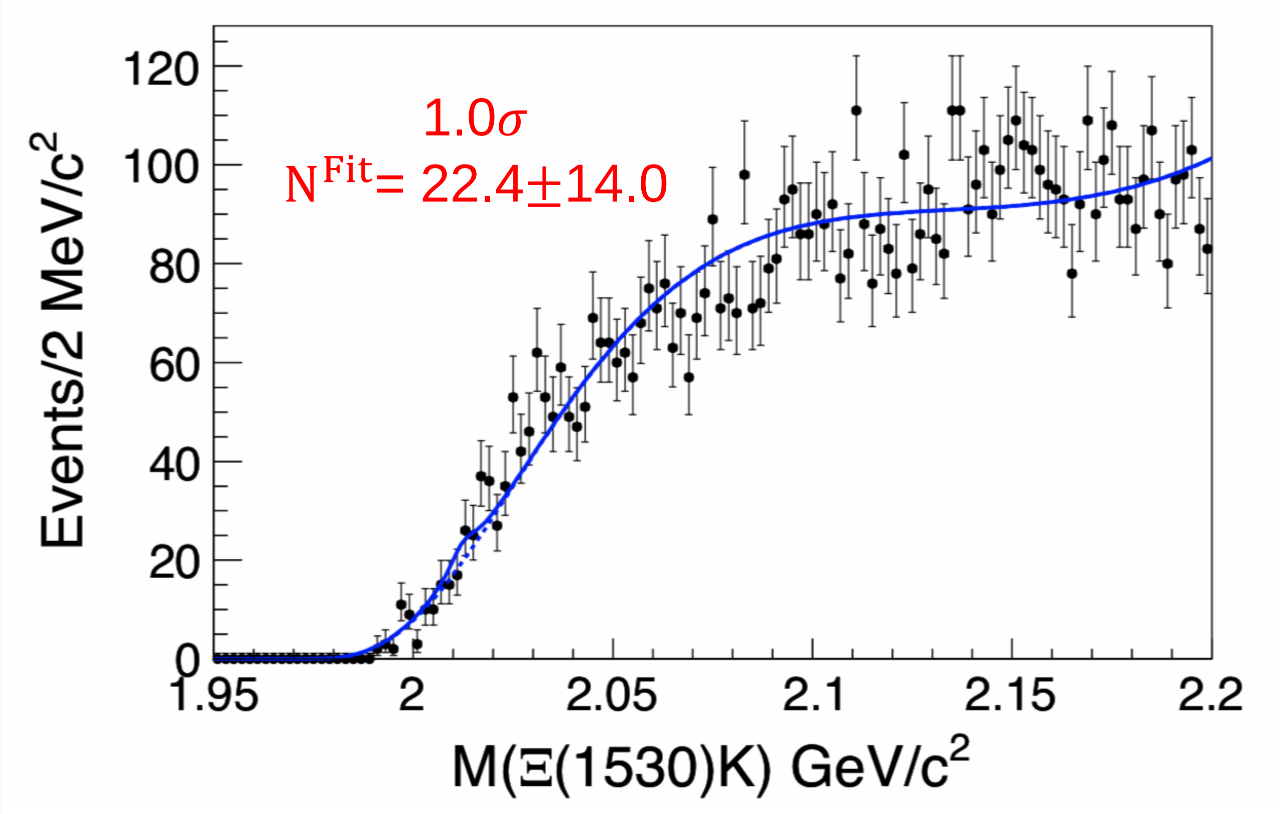
$$R^{\Xi^-\pi^+K^-}_{\Xi^0K^-} = \frac{\mathcal{B}(\Omega \to \Xi(1530)^0(\to \Xi^-\pi^+)K^-)}{\mathcal{B}(\Omega \to \Xi^0K^-)} < 7.8\%$$

$$R^{\Xi^0\pi^-\bar{K}^0}_{\Xi^-\bar{K}^0} = \frac{\mathcal{B}(\Omega \to \Xi(1530)^-(\to \Xi^-\pi^0)\bar{K}^0)}{\mathcal{B}(\Omega \to \Xi^-\bar{K}^0)} < 25.6\%$$

S.Jia, *C.P.Shen et al (Belle)
PRD 100, 032006 (2019)

Search for $\Omega(2012) \to K\Xi(1530) \to K\pi\Xi$

A simultaneous fit to all three-body decay modes is performed.



$$R_{\Xi K}^{\Xi\pi K} = \frac{\mathcal{B}(\Omega\to\Xi(1530)(\to\Xi\pi)K)}{\mathcal{B}(\Omega\to\Xi K)} = (6.0\pm3.7(\text{stat.})\pm1.3(\text{syst.}))\%$$

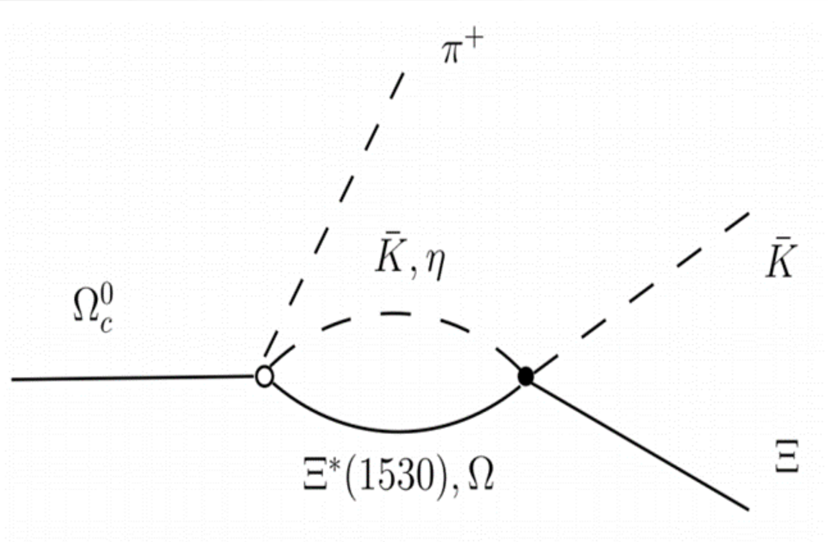
$$R_{\Xi K}^{\Xi\pi K} = \frac{\mathcal{B}(\Omega\to\Xi(1530)(\to\Xi\pi)K)}{\mathcal{B}(\Omega\to\Xi K)} < 11.9\% \text{ at } 90\% \text{ C.L.}$$

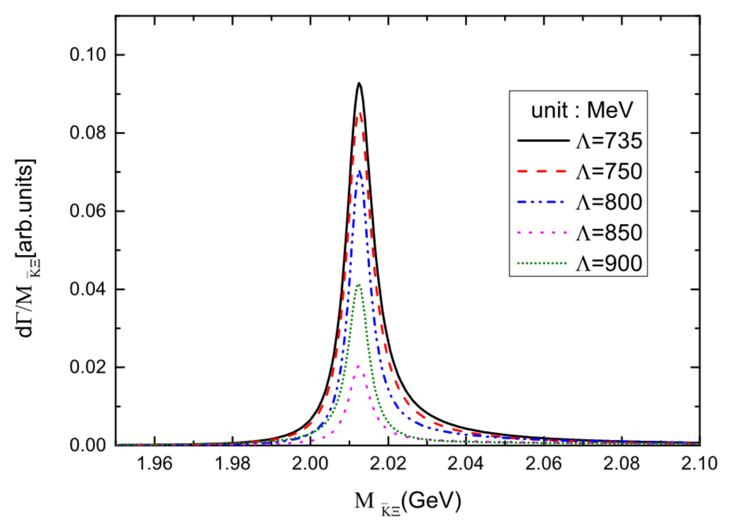
Evidence for $\Omega_c^0 \to \pi^+\Omega(2012)^- \to \pi^+(\bar{K}\Xi)^-$

Motivation:

- Searching for new production model is very important to understand the nature of $\Omega(2012)^-$;
- A theoretical study of the $\Omega(2012)^-$ in the nonleptonic weak decays of $\Omega_c^0 \to \pi^+\bar{K}\ \Xi(1530)(\eta\Omega) \to \pi^+(\bar{K}\pi\Xi)^-$ and $(\bar{K}\Xi)^-$was reported; the authors predicted the clearly $\Omega(2012)^-$peak in the $(\bar{K}\Xi)^-$ invariant mass spectrum of the $\Omega_c^0 \to \pi^+(\bar{K}\Xi)^-$.

[PRD 102, 076009 (2020)]

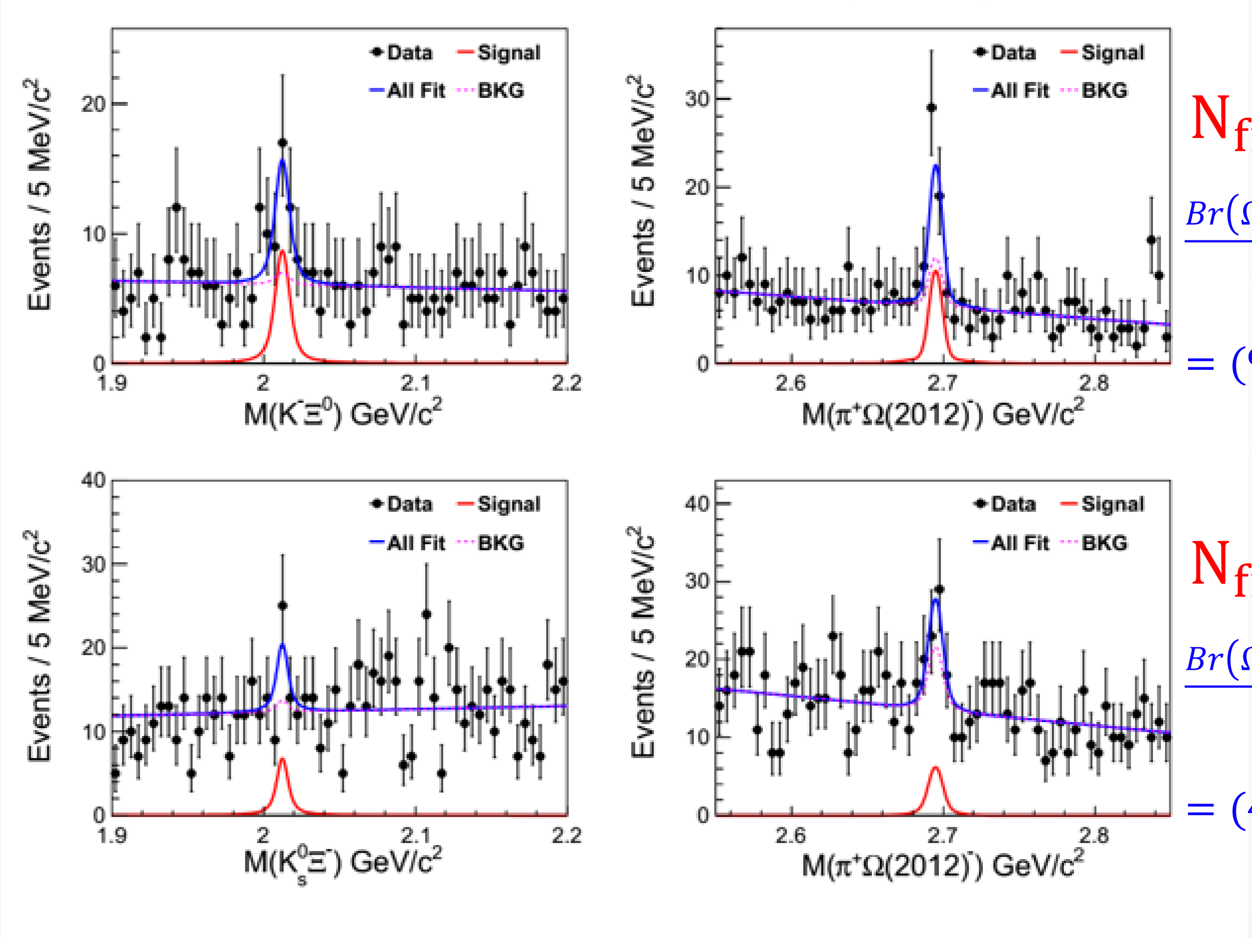




Evidence for $\Omega_c^0 \to \pi^+\Omega(2012)^- \to \pi^+(\bar{K}\Xi)^-$

preliminary

- To extract the $\Omega(2012)^-$ signal events from Ω_c^0 decay, a 2D maximum-likelihood fit is performed to $M(\mathrm{K}^-\Xi^0)/M(K_S^0\Xi^-)$ and $M(\pi^-\Omega(2012))$.



$$\mathrm{N_{fit}}\left(\mathrm{K}^-\Xi^0\right) = 28.3 \pm 8.9$$

$$\frac{Br\left(\Omega_c^0 \to \pi^+\Omega(2012)^-\right)Br\left(\Omega(2012)^- \to K^-\Xi^0\right)}{Br\left(\Omega_c^0 \to \pi^+K^-\Xi^0\right)}$$

$$= (9.64 \pm 3.04(\mathrm{stat.}) \pm 1.89(\mathrm{syst.}))\%$$

$$\mathrm{N_{fit}}\left(\mathrm{K_S^0}\Xi^-\right) = 17.9 \pm 8.9$$

$$\frac{Br\left(\Omega_c^0 \to \pi^+\Omega(2012)^-\right)Br\left(\Omega(2012)^- \to \bar{K}^0\Xi^-\right)}{Br\left(\Omega_c^0 \to \pi^+\bar{K}^0\Xi^-\right)}$$

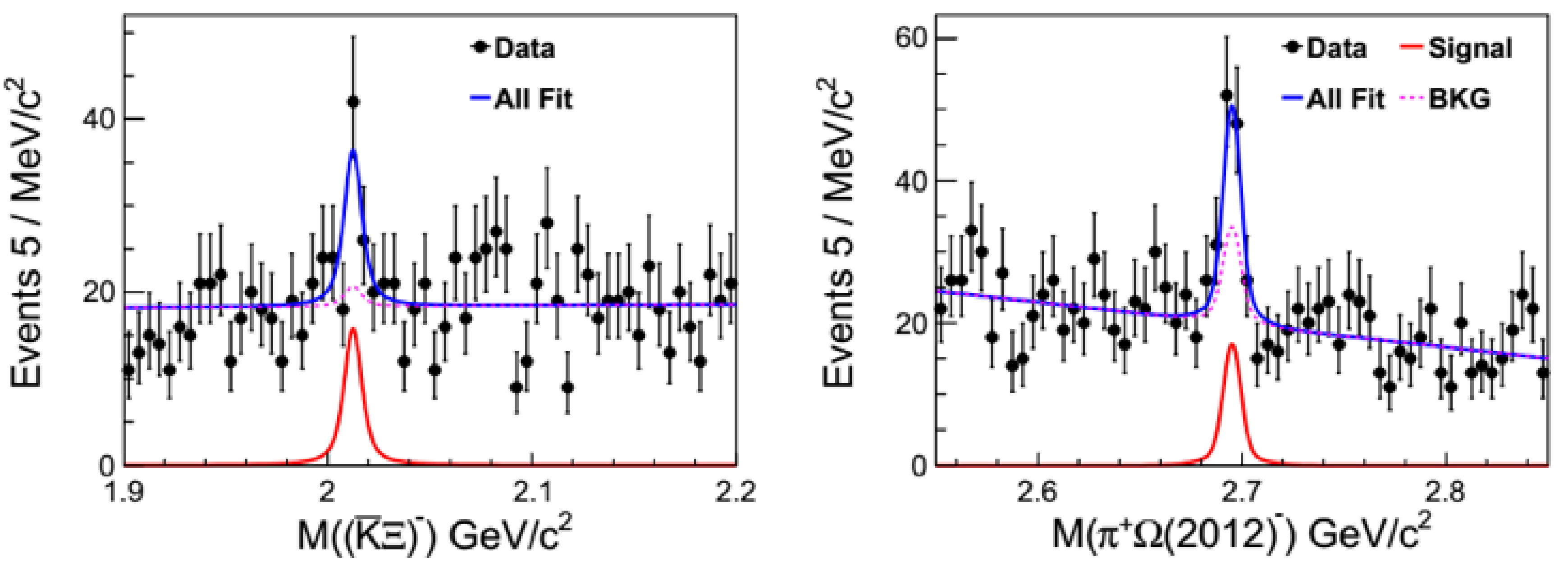
$$= (4.62 \pm 2.30(\mathrm{stat.}) \pm 0.75(\mathrm{syst.}))\%$$

- The statistical significances of $\Omega_c^0 \to \pi^+\Omega(2012)^- \to \pi^+K^-\Xi^0$ and $\Omega_c^0 \to \pi^+\Omega(2012)^- \to \pi^+K_S^0\Xi^-$ decays are 4.0σ and 2.3σ, respectively.

Evidence for $\Omega_c^0 \to \pi^+\Omega(2012)^- \to \pi^+(\bar{K}\Xi)^-$

- A 2D un-binned maximum-likelihood simultaneous fit is performed to $M((\bar{K}\Xi)^-)$ and $M(\pi^+\Omega(2012)^-)$ distributions.

preliminary



$\mathrm{N_{fit}} = 46.6 \pm 12.3$

Signal significance: 4.2σ

(including systematic uncertainties)

$$\frac{Br\left(\Omega_c^0 \to \pi^+\Omega(2012)^-\right) \times Br\left(\Omega(2012)^- \to (\bar{K}\Xi)^-\right)}{Br\left(\Omega_c^0 \to \pi^+(\bar{K}\Xi)^-\right)} = (6.50 \pm 1.22(\mathrm{stat.}) \pm 0.94(\mathrm{syst.}))\%$$

Measurements of Branching Fractions of $\Lambda_c^+ \to p\pi^0$ and $\Lambda_c^+ \to p\eta$ decays at Belle

Motivation:

- **The weak decay of charmed baryons is very useful for testing many contradictory theoretical models and methods**. However, the cognition and exploration of charmed baryon goes pretty slowly.

- The precision of measurement of the decay branching fraction remains poor for many Cabibbo-favored (CF) decays and even worse for some decays dominated by Cabibbo-suppressed even though many different experiments like Belle and BESIII have hard work on improving the measurement results of charmed baryons.

- In theory, the singly Cabibbo-suppressed (SCS) decays $\Lambda_c^+ \to p\pi^0$ and $\Lambda_c^+ \to p\eta$ proceed dominantly through internal W-emission and W-exchange. The measurement of these two decay branching fractions may **be interesting to study the underlying dynamic of charmed baryon decays.**

- In experiment, BESIII report the branching fractions of these two SCS decays, which are $\mathcal{B}(\Lambda_c^+ \to p\pi^0) < 2.7 \times 10^{-4}$ at 90% confidence level and $\mathcal{B}(\Lambda_c^+ \to p\eta) = (1.24 \pm 0.30) \times 10^{-3}$.

- In this analysis, we utilize the much higher statistic sample of Λ_c^+ collected by Belle detector to improve the measurement precision.

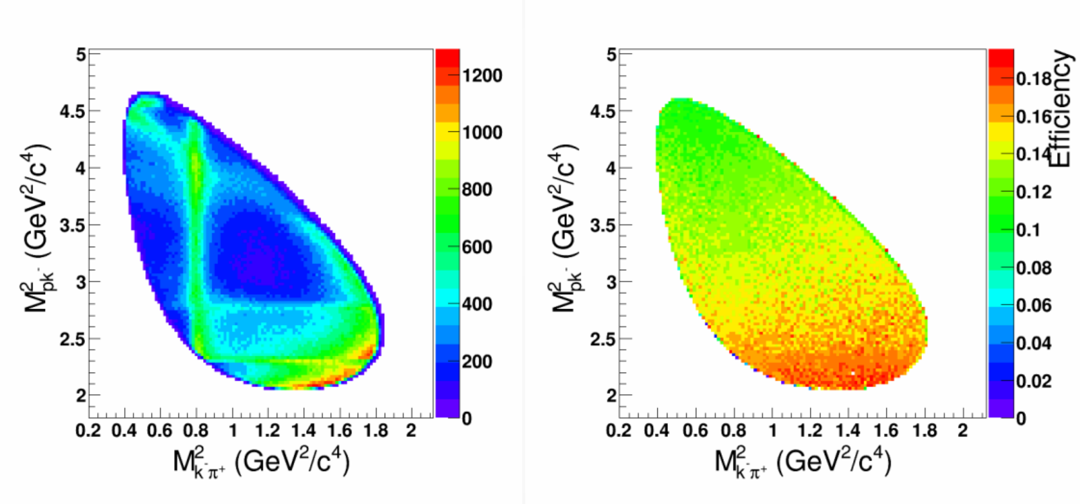
Measurement of $\Lambda_c^+ \to pK^-\pi^+$ decay

PRD103, 072004 (2021)

A method of branching ratio with respect to CF decay $\Lambda_c^+ \to pK^-\pi^+$ (reference mode) is applied to measure the branching fractions of two SCS decays.

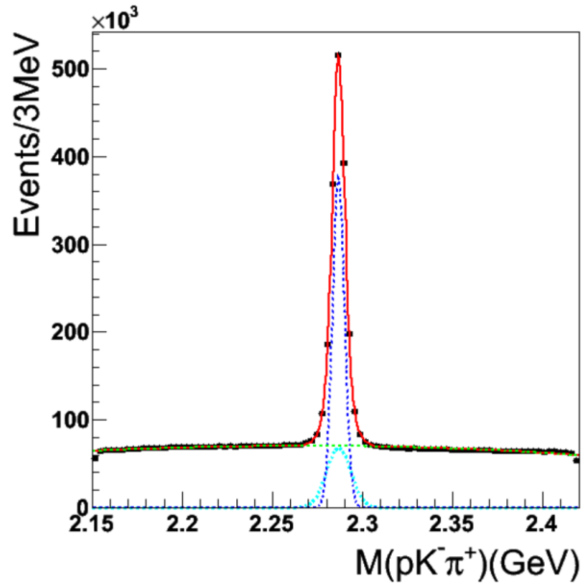
$$\frac{B(SCS)}{B(CF)} = \frac{N^{obs}(SCS)}{\epsilon^{MC}(SCS)} \times \frac{\epsilon^{MC}(CF)}{N^{obs}(CF)}$$

Signal efficiency estimation: Dalitz method.



Left: Dalitz plot from data; Right: Dalitz plot of efficiency from signal MC.

$$\varepsilon = \sum s_i / \sum_j (s_j/\varepsilon_j) = \left(\mathbf{14.06 \pm 0.01}\right)\%.$$



Fit to M($pK^-\pi^+$) from data.

double Gaussian + second-order polynomial

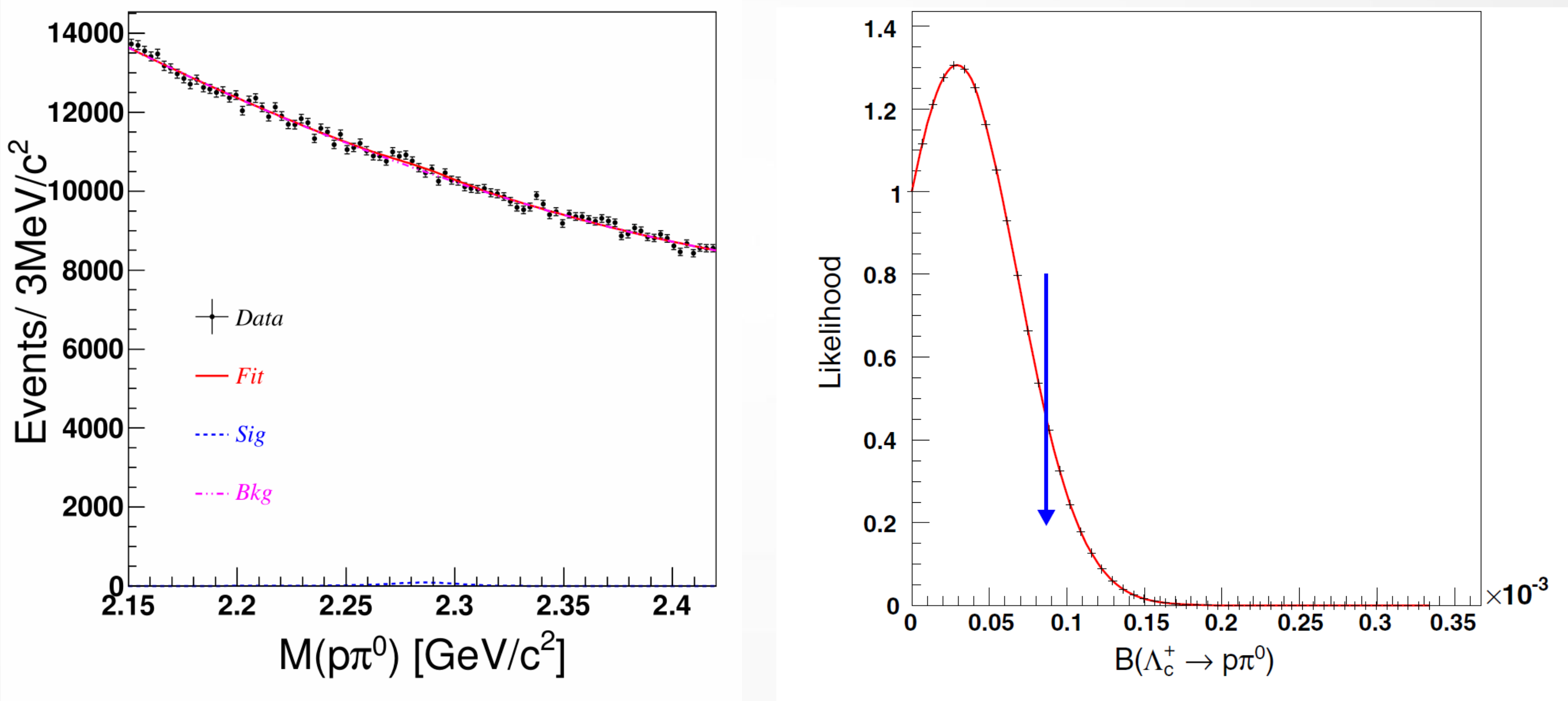
Yield: **1476200 ± 1560**
χ^2/ndf=1.06

Measurement of $\Lambda_c^+ \to p\pi^0$ $(\to \gamma\gamma)$ decay

PRD103, 072004 (2021)

- The efficiency estimated from signal MC sample is $(\mathbf{8.891} \pm \mathbf{0.030})\%$.

- There is no obvious signal excess in M($p\pi^0$) from data. We set an upper limit on branching fraction of $\boldsymbol{B(\Lambda_c^+ \to p\pi^0) < 8 \times 10^{-5}}$ at 90% C.L., reducing the value to more than half of the current best upper limit of 2.7×10^{-4}.

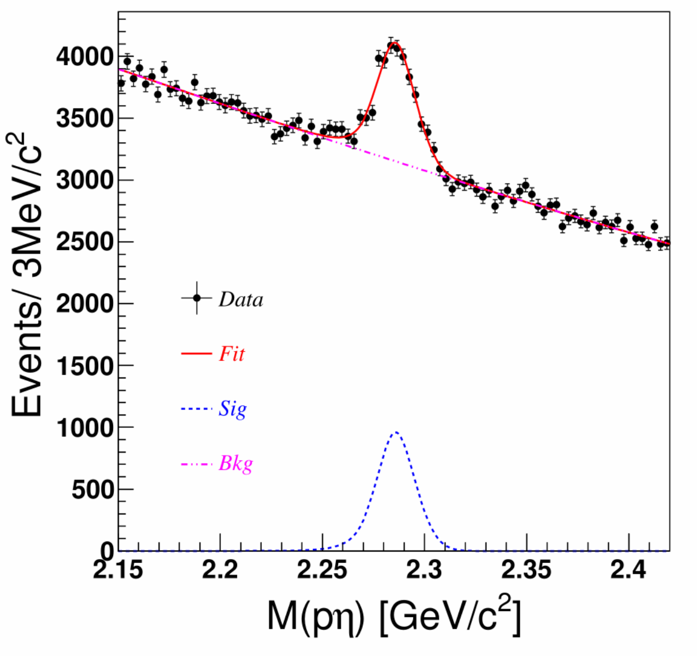


Left: fit to the invariant mass distribution of $p\pi^0$ with a fixed signal yield of **1269**. Right: The likelihood distribution changing with the branching fraction with the systematic uncertainty involved.

Measurement of $\Lambda_c^+ \to p\eta(\to \gamma\gamma)$decay

PRD103, 072004 (2021)

- The efficiency estimated from signal MC sample is $(\mathbf{8.279} \pm \mathbf{0.030})\%$.



Gaussian + CB for signal.
Second-order polynomial for background.

Yield: $\mathbf{7734 \pm 263}$
χ^2/ndf=1.23

- A significant Λ_c^+ signal is observed in M($p\eta$) distribution from data. The branching fraction is $\mathbf{B(\Lambda_c^+ \to p\eta) = (1.42 \pm 0.05 \pm 0.11) \times 10^{-3}}$, which is consistent with the latest BESIII measured result of $(1.24 \pm 0.30) \times 10^{-3}$ with much improved precision.
- The measured $\mathbf{B(\Lambda_c^+ \to p\eta)}$ is at least an order of magnitude larger than $\mathbf{B(\Lambda_c^+ \to p\pi^0)}$, which is consistent with the theoretical prediction of an internal W-emission mechanism involving an s quark in $\Lambda_c^+ \to p\eta$.

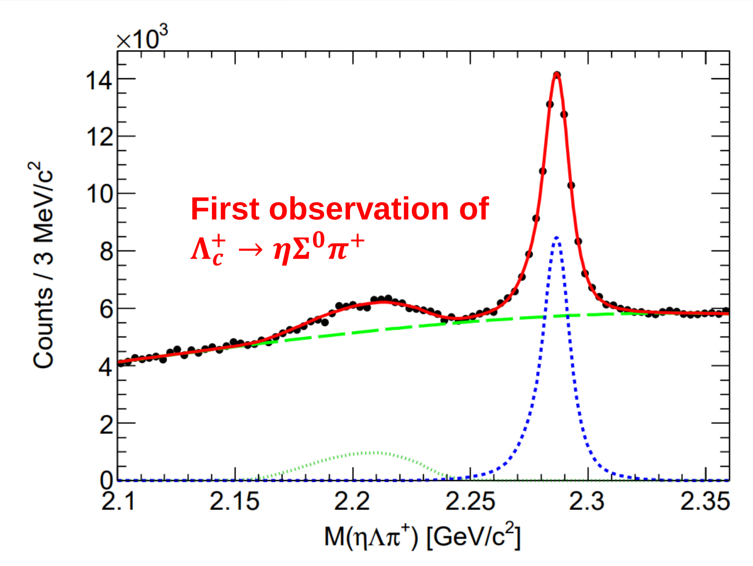
Measurements of $\Lambda_c^+ \to \eta\Lambda\pi^+$ and $\Lambda_c^+ \to \eta\Sigma^0\pi^+$

- A method to measure the branching fractions of above two decays is:

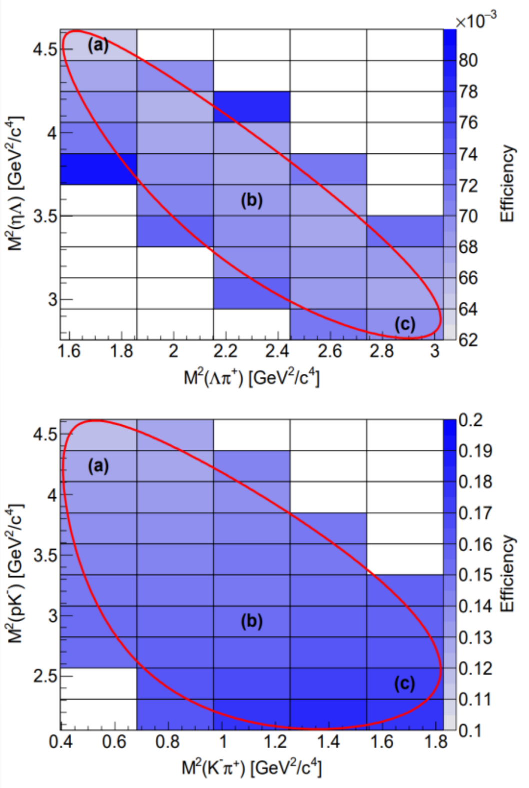
PRD 103, 052005 (2021)

$$\frac{\mathcal{B}(\text{Decay mode})}{\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+)} = \frac{y\,(\text{Decay mode})}{\mathcal{B}_{\text{PDG}} \times y(\Lambda_c^+ \to pK^-\pi^+)}$$

(y is the efficiency-corrected yield).



Fit to the M($\eta\Lambda\pi^+$) distribution. The structure near 2.286 GeV/c^2 is from $\Lambda_c^+ \to \eta\Lambda\pi^+$; The other one is from $\Lambda_c^+ \to \eta\Sigma^0\pi^+$ with a missing photon from the Σ^0 decay.



Dalitz plots for decay and reference mode.

The extracted yields are efficiency-corrected in each bin and summed up over the Dalitz plots.

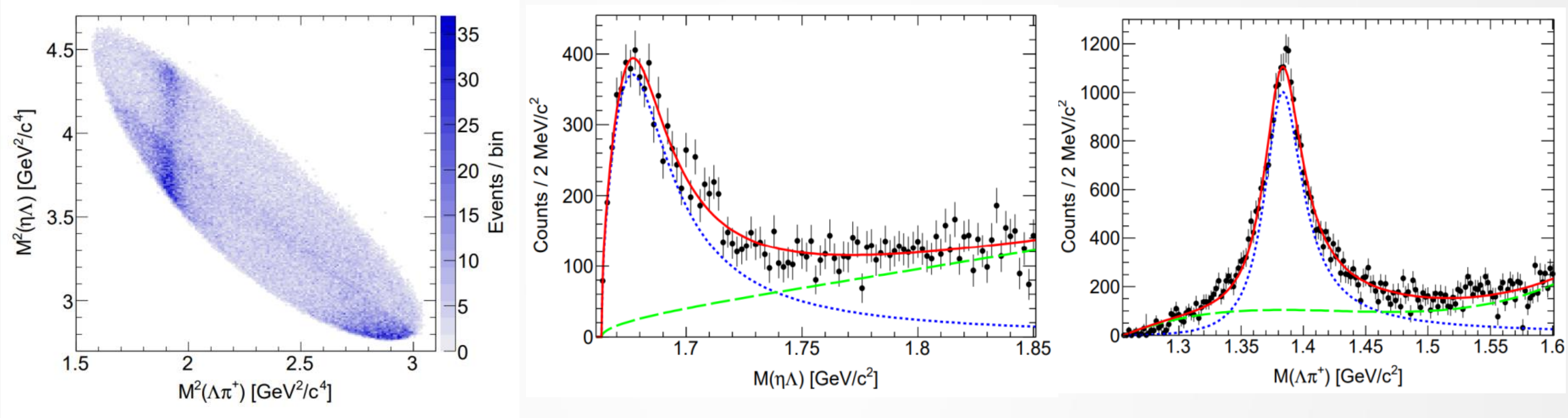
Decay mode	$y(\times 10^5)$	Branching Fraction	Reference mode	$y(\times 10^5)$
$\Lambda_c^+ \to \eta\Lambda\pi^+$	(7.41 ± 0.07)	$(1.84 \pm 0.02 \pm 0.09)\%$	$\Lambda_c^+ \to pK^-\pi^+$	(100.47 ± 0.10)
$\Lambda_c^+ \to \eta\Sigma^0\pi^+$	(3.05 ± 0.16)	$(7.56 \pm 0.39 \pm 0.37) \times 10^{-3}$		

Measurements of $\Lambda_c^+ \to \Lambda(1670)\pi^+$ and $\Lambda_c^+ \to \eta\Sigma(1385)^+$

PRD 103, 052005 (2021)

- $\Lambda_c^+ \to \Lambda(1670)\pi^+$ and $\Lambda_c^+ \to \eta\Sigma(1385)^+$ are visible in Dalitz plot.
- Fit to the M($\eta\Lambda\pi^+$) distributions in every 2 MeV/c^2 bin of the M($\eta\Lambda$) and M($\Lambda\pi^+$) distributions to extract the signal yields.
- Clear $\Lambda(1670)$ and $\Sigma(1385)^+$ signals show up.

(First observation of the $\Lambda(1670)$ in $\Lambda_c^+ \to \Lambda(1670)\pi^+$.)



Left: Dalitz plot for $\Lambda_c^+ \to \eta\Lambda\pi^+$ from data. Middle: fit to the M($\eta\Lambda\pi^+$) distributions in each M($\eta\Lambda$) bin. Right: fit to the M($\eta\Lambda\pi^+$) distributions in each M($\Lambda\pi^+$) bin.

Decay mode	Yield	$y(\times 10^5)$	Branching Fraction
$\Lambda_c^+ \to \Lambda(1670)\pi^+$	9760 ± 519	(1.40 ± 0.07)	$(3.48 \pm 0.19 \pm 0.46) \times 10^{-3}$ *
$\Lambda_c^+ \to \eta\Sigma(1385)^+$	29372 ± 875	(4.23 ± 0.13)	$(1.21 \pm 0.04 \pm 0.16)\%$

*$B(\Lambda_c^+ \to \Lambda(1670)\pi^+) \times B(\Lambda(1670) \to \eta\Lambda)$

Measurements of absolute Brs of Ξ_c^0

Summary of the measured branching fractions and the ratios of Ξ_c^0 decays

Y.B.Li, C.P.Shen et al (Belle) PRL122, 082001 (2019)

BF	Result	Theory	PDG
$\mathcal{B}(B^-\to \bar{\Lambda}_c^-\Xi_c^0)$	$(9.51\pm2.10\pm0.88)\times10^{-4}$	$\sim 10^{-3}$	
$\mathcal{B}(B^-\to \bar{\Lambda}_c^-\Xi_c^0)\mathcal{B}(\Xi_c^0\to\Xi^-\pi^+)$	$(1.71\pm0.28\pm0.15)\times10^{-5}$		$(2.4\pm0.9)\times10^{-5}$
$\mathcal{B}(B^-\to \bar{\Lambda}_c^-\Xi_c^0)\mathcal{B}(\Xi_c^0\to\Lambda K^-\pi^+)$	$(1.11\pm0.26\pm0.10)\times10^{-5}$		$(2.1\pm0.9)\times10^{-5}$
$\mathcal{B}(B^-\to \bar{\Lambda}_c^-\Xi_c^0)\mathcal{B}(\Xi_c^0\to pK^-K^-\pi^+)$	$(5.47\pm1.78\pm0.57)\times10^{-6}$		
$\mathcal{B}(\Xi_c^0\to\Xi^-\pi^+)$	$(1.80\pm0.50\pm0.14)\%$	1.12% or 0.74%	
$\mathcal{B}(\Xi_c^0\to\Lambda K^-\pi^+)$	$(1.17\pm0.37\pm0.09)\%$		
$\mathcal{B}(\Xi_c^0\to pK^-K^-\pi^+)$	$(0.58\pm0.23\pm0.05)\%$		
$\mathcal{B}(\Xi_c^0\to\Lambda K^-\pi^+)/\mathcal{B}(\Xi_c^0\to\Xi^-\pi^+)$	$0.65\pm0.18\pm0.04$		1.07 ± 0.14
$\mathcal{B}(\Xi_c^0\to pK^-K^-\pi^+)/\mathcal{B}(\Xi_c^0\to\Xi^-\pi^+)$	$0.32\pm0.12\pm0.07$		0.34 ± 0.04

- We have performed an analysis of $B^-\to\bar{\Lambda}_c^-\Xi_c^0$ inclusively and exclusively
- First model-independent measurement of absolute Brs of Ξ_c^0 decays
- The branching fraction $B(B^-\to\bar{\Lambda}_c^-\Xi_c^0)$ is measured for the first time
- The $B(\Xi_c^0\to\Xi^-\pi^+)$ can be used to determine the BR of other Ξ_c^0 decays.

Measurement of Ξ_c^+ absolute BRs

Y. B. Li. C. P. Shen et al (Belle) PRD 100, 031101 (2019)

BF	Result	Theory	PDG
$\mathcal{B}(\bar{B}^0 \to \bar{\Lambda}_c^- \Xi_c^+)$	$(1.16 \pm 0.42 \pm 0.15) \times 10^{-3}$	$\sim 10^{-3}$	
$\mathcal{B}(\bar{B}^0 \to \bar{\Lambda}_c^- \Xi_c^+))\mathcal{B}(\Xi_c^+ \to \Xi^- \pi^+ \pi^+)$	$(3.32 \pm 0.74 \pm 0.33) \times 10^{-5}$		$(1.8 \pm 1.8) \times 10^{-5}$
$\mathcal{B}(\bar{B}^0 \to \bar{\Lambda}_c^- \Xi_c^+)\mathcal{B}(\Xi_c^+ \to p K^- \pi^+)$	$(5.27 \pm 1.51 \pm 0.69) \times 10^{-5}$		
$\mathcal{B}(\Xi_c^+ \to \Xi^- \pi^+ \pi^+)$	$(2.86 \pm 1.21 \pm 0.38)\%$	$(1.47 \pm 0.84)\%$	
$\mathcal{B}(\Xi_c^+ \to p K^- \pi^+)$	$(0.45 \pm 0.21 \pm 0.07)\%$	$(2.2 \pm 0.8)\%$	
$\mathcal{B}(\Xi_c^+ \to p K^- \pi^+)/\mathcal{B}(\Xi_c^+ \to \Xi^- \pi^+ \pi^+)$	$0.16 \pm 0.06 \pm 0.02$		0.21 ± 0.04

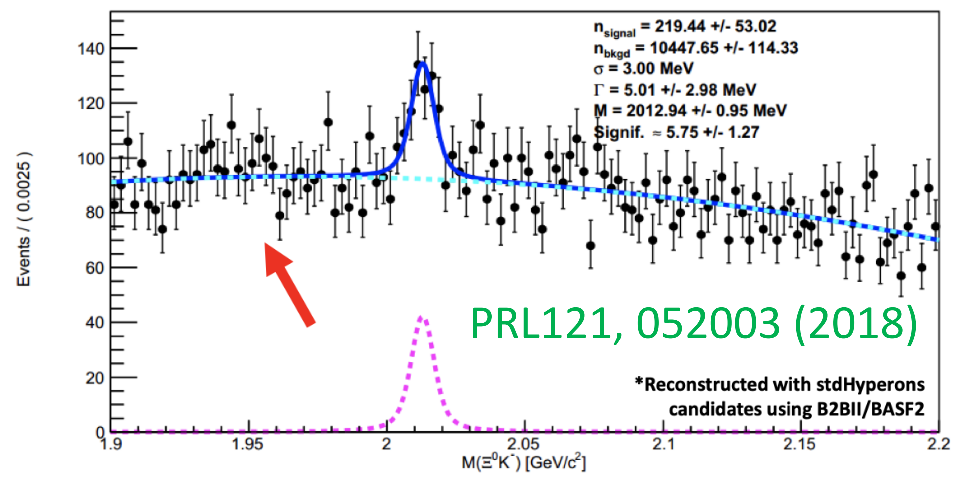
- First model –independent $\mathcal{B}\left(\bar{B}^0 \to \bar{\Lambda}_c^- \Xi_c^+\right)$ measurement
- $\mathcal{B}(\Xi_c^+ \to \Xi^- \pi^+ \pi^+)$ can be used to determine the BR of other Ξ_c^+ decay

Measurement of the Resonant and Non-Resonant Branching Ratios in $\Xi_c^0 \to \Xi^0 K^+ K^-$

arXiv: 2012.05607 (2020)

Motivation:

- Background Motivation in Excited Ω Searches

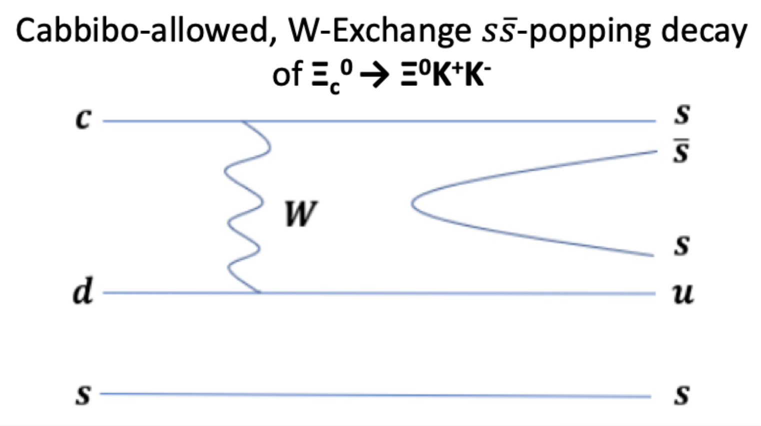


PRL121, 052003 (2018)

*Reconstructed with stdHyperons candidates using B2BII/BASF2

From quark model predictions, it can be expected that Ω(2012) could have a partner near 1.95 GeV/c^2 [PRD 101, 016002 (2020)] and low-statistics evidence of an excess in $M(\Xi^0 K^-)$ has been noticed.

- Spin-Polarized $\Xi_c^0 \to \Xi^0 \phi(\to K^+K^-)$ Substructure



Cabbibo-allowed, W-Exchange $s\bar{s}$-popping decay of $\Xi_c{}^0 \to \Xi^0 K^+ K^-$

A resonant $\phi(\to K^+K^-)$ in the decay channel $\Xi_c^0 \to \Xi^0 \phi(\to K^+K^-)$ is known to be polarized due to the spin helicities of the parent baryon decay (1/2 → 1/2 1).

Dalitz Plot

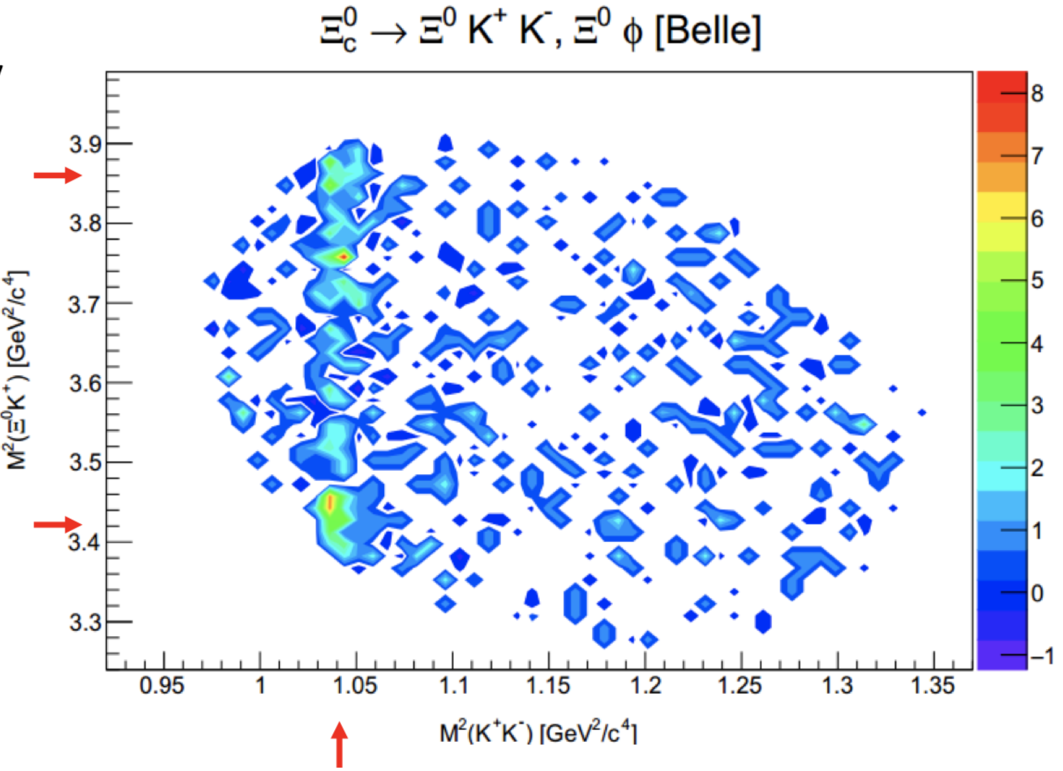
arXiv: 2012.05607 (2020)

(Ξ^0 Mass-Constrained, Sideband Subtracted)

Across the entire M($\Xi^0$$K^+K^-$) phasespace only a single resonance (**$\phi \rightarrow K^+K^-$**) at $M^2(K^+K^-)$ = **1.04 GeV²/c⁴** is observed

Along the resonant **ϕ** band, two non-uniform substructure peaks in the M($\Xi^0 K^\pm$) projections are indeed observed near $M^2(\Xi^0 K^-)$ = **3.85 GeV²/c⁴** and **3.425 GeV²/c⁴** due to the **½ → ½ 1** polarization of the **ϕ**

To study these resonant substructures, we ideally proceed with an amplitude analysis of the M($\Xi^0 K^+K^-$) phasespace using AmpTools (v.10.2)



Amplitude Model to Analyze the Dalitz Plot:

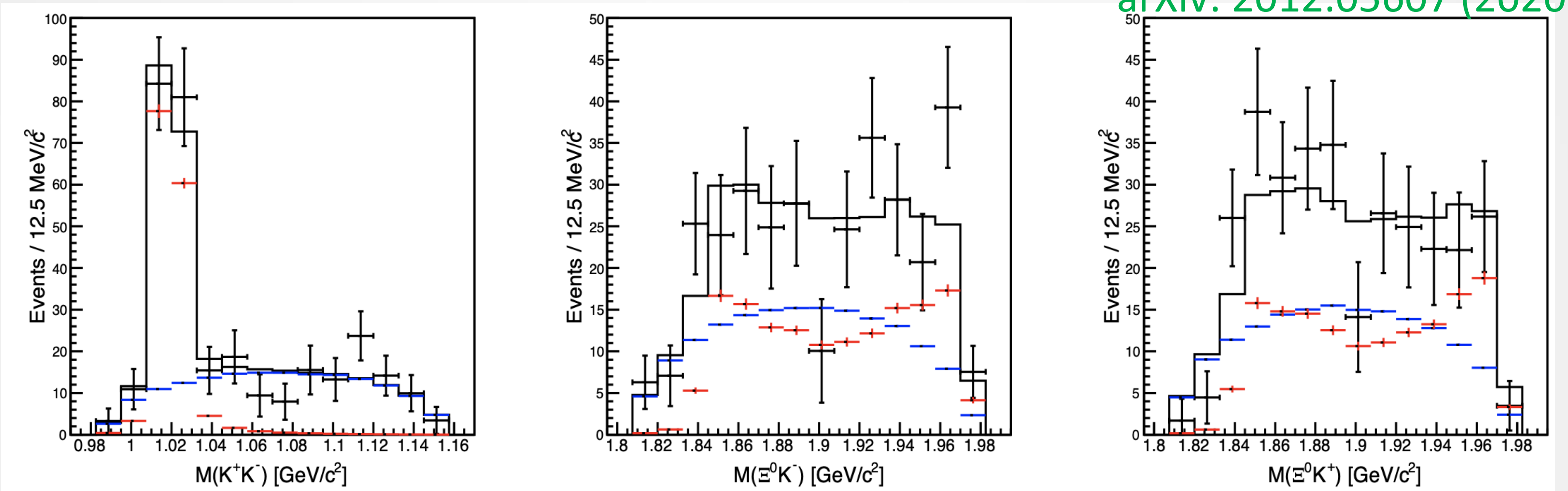
$$< \Xi_c^0 | \mathbf{H} | \Xi^0 K^+ K^- > = < \Xi_c^0 | \mathbf{H} | \Xi^0 K^+ K^- > + < \Xi_c^0 | \mathbf{H} | \Xi^0 \phi >$$

Direct process, phase space decays are modelled with a constant, phase space amplitude (A_{phsp})

Polarized resonances are modelled with a Breit-Wigner and Spin-Polarization amplitude

Amplitude Fit over the Belle Data Sample

arXiv: 2012.05607 (2020)



$\frac{\mathcal{B}(\Xi_c^0 \to \Xi^0 \phi(\to K^+K^-))}{\mathcal{B}(\Xi_c^0 \to \Xi^-\pi^+)}$	**0.036±0.004(stat.)±0.002(syst.)**
$\frac{\mathcal{B}(\Xi_c^0 \to \Xi^0 K^+K^-)}{\mathcal{B}(\Xi_c^0 \to \Xi^-\pi^+)}$	**0.039±0.004(stat.)±0.002(syst.)**

Resonant Amplitude
Non-Resonant Amplitude
Amplitude Sum (Resonant and Non-Resonant)

- The measurements of these Ξ_c^0 decay modes, which can only proceed via W-exchange together with $s\bar{s}$ production, add to our knowledge of the weak decay of charmed baryons.
- It is unlikely that contributions from these resonant $\Xi^0\phi(\to K^+K^-)$ decays will correlate to significant event excesses in the Ξ^0K^- reconstruction near 1.95 GeV.

Measurements of Brs and asymmetry parameters of $\Xi_c^0 \to \Lambda\overline{K}^{*0}$, $\Xi_c^0 \to \Sigma^0\overline{K}^{*0}$, and $\Xi_c^0 \to \Sigma^+K^{*-}$

arXiv:2104.10361

- There are some difficulties for the theoretical study in the non-leptonic decays of charmed baryons due to the failure of the factorization approach.
- Branching fraction measurements help to distinguish different theoretical models.
- The asymmetry parameters of Ξ_c^0 are still not well measured, which is important to test parity violation in charmed-baryon sectors.

Decay branching fractions (%) and asymmetry parameters of the Cabibbo favored B_c→B_n+V decay in QCD and $SU(3)_F$ approach.

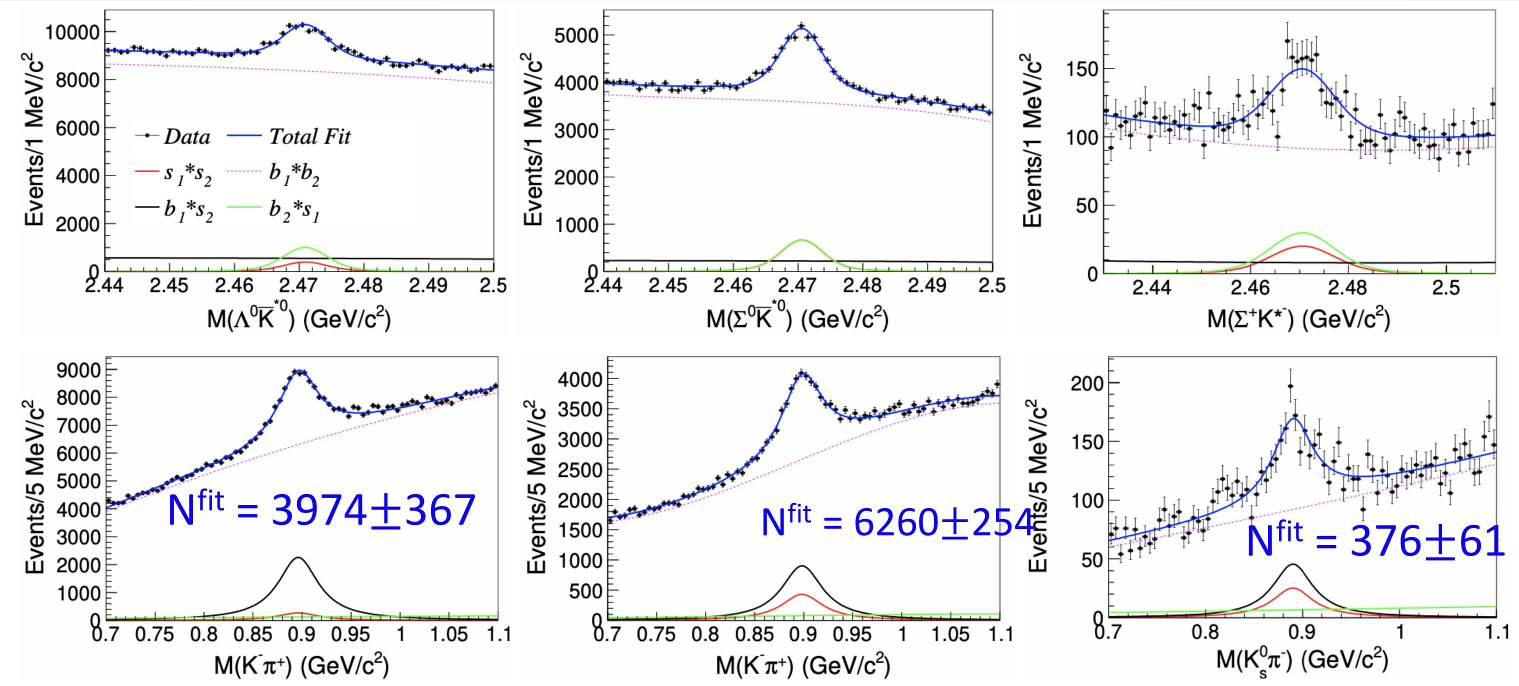
Branching fractions	KK [1]	Zen [2]	HYZ [3]	GLT [4]
$\Xi_c^0 \to \Lambda^0\overline{K}^{*0}$	1.55	1.15	0.46±0.21	1.37±0.26
$\Xi_c^0 \to \Sigma^0\overline{K}^{*0}$	0.85	0.77	0.27±0.22	0.42±0.23
$\Xi_c^0 \to \Sigma^+K^{*-}$	0.54	0.37	0.93±0.29	0.24±0.17

Asymmetry parameters	KK [1]	Zen [2]	GLT [4]
$\Xi_c^0 \to \Lambda^0\overline{K}^{*0}$	0.58	+0.49	-0.67±0.24
$\Xi_c^0 \to \Sigma^0\overline{K}^{*0}$	-0.87	+0.25	-0.42±0.62
$\Xi_c^0 \to \Sigma^+K^{*-}$	-0.60	+0.51	$-0.76^{+0.64}_{-0.24}$

[1] Z. Phys. C 55, 659 (1992) [2] Phys. Rev. D 50, 5787 (1994) [3] Phys. Lett. B 792, 35 (2019)
[4] Phys. Rev. D 101, 053002 (2020)

Measurements of Brs $\Xi_c^0 \to \Lambda\bar{K}^{*0}$, $\Xi_c^0 \to \Sigma^0\bar{K}^{*0}$, and $\Xi_c^0 \to \Sigma^+K^{*-}$

$\Xi_c^0 \to \Lambda^0\bar{K}^{*0}$ $\Xi_c^0 \to \Sigma^0\bar{K}^{*0}$ $\Xi_c^0 \to \Sigma^+K^{*-}$ arXiv:2104.10361



$N^{fit} = 3974 \pm 367$ $N^{fit} = 6260 \pm 254$ $N^{fit} = 376 \pm 61$

$\mathcal{B}(\Xi_c^0 \to \Lambda\bar{K}^{*0})/\mathcal{B}(\Xi_c^0 \to \Xi^-\pi^+)$	$0.18 \pm 0.02(\text{stat.}) \pm 0.01(\text{syst.})$
$\mathcal{B}(\Xi_c^0 \to \Sigma^0\bar{K}^{*0})/\mathcal{B}(\Xi_c^0 \to \Xi^-\pi^+)$	$0.69 \pm 0.03(\text{stat.}) \pm 0.03(\text{syst.})$
$\mathcal{B}(\Xi_c^0 \to \Sigma^+K^{*-})/\mathcal{B}(\Xi_c^0 \to \Xi^-\pi^+)$	$0.34 \pm 0.06(\text{stat.}) \pm 0.02(\text{syst.})$
$\mathcal{B}(\Xi_c^0 \to \Lambda\bar{K}^{*0})$	$(3.3 \pm 0.3(\text{stat.}) \pm 0.2(\text{syst.}) \pm 1.0(\text{ref.})) \times 10^{-3}$
$\mathcal{B}(\Xi_c^0 \to \Sigma^0\bar{K}^{*0})$	$(12.4 \pm 0.5(\text{stat.}) \pm 0.5(\text{syst.}) \pm 3.6(\text{ref.})) \times 10^{-3}$
$\mathcal{B}(\Xi_c^0 \to \Sigma^+K^{*-})$	$(6.1 \pm 1.0(\text{stat.}) \pm 0.4(\text{syst.}) \pm 1.8(\text{ref.})) \times 10^{-3}$

By using the reference mode $\Xi_c^0 \to \Xi^-\pi^+$ [arXiv: 2103.06496 (2021)], we calculate the absolute branching fractions with signal yields between reference and signal channels after efficiency corrections.

Asymmetry parameter extractions

arXiv:2104.10361

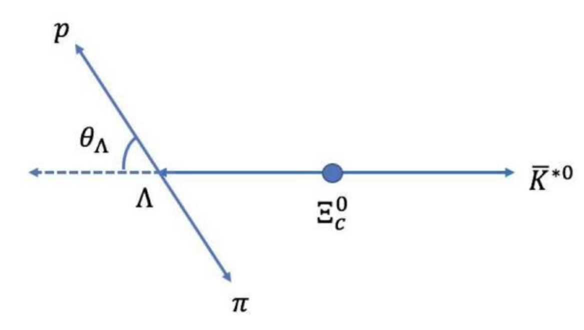
For $\Xi_c^0 \to \Lambda^0 \overline{K}^{*0}$, $\Xi_c^0 \to \Sigma^0 \overline{K}^{*0}$, and $\Xi_c^0 \to \Sigma^+ K^{*-}$, the differential decay rates [PRD 101, 053002 (2020)] are given by:

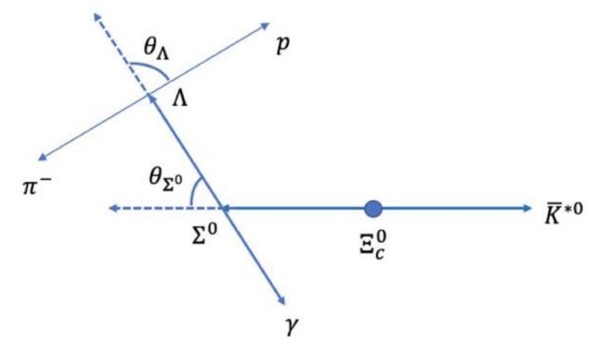
$$\frac{dN}{d\cos\theta_\Lambda} \propto 1 + \alpha(\Xi_c^0 \to \Lambda \overline{K}^{*0})\alpha(\Lambda \to p\pi^-)\cos\theta_\Lambda,$$

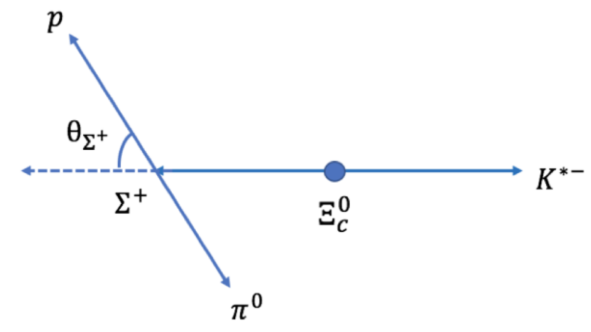
$$\frac{dN}{d\cos\theta_{\Sigma^0}} \propto 1 + \alpha(\Xi_c^0 \to \Sigma^0 \overline{K}^{*0})\alpha(\Sigma^0 \to \Lambda\gamma)\cos\theta_{\Sigma^0}, \text{ and}$$

$$\frac{dN}{d\cos\theta_{\Sigma^+}} \propto 1 + \alpha(\Xi_c^0 \to \Sigma^+ K^{*-})\alpha(\Sigma^+ \to p\pi^0)\cos\theta_{\Sigma^+}.$$

Definitions of θ_Λ, θ_{Σ^0}, and θ_{Σ^+}:



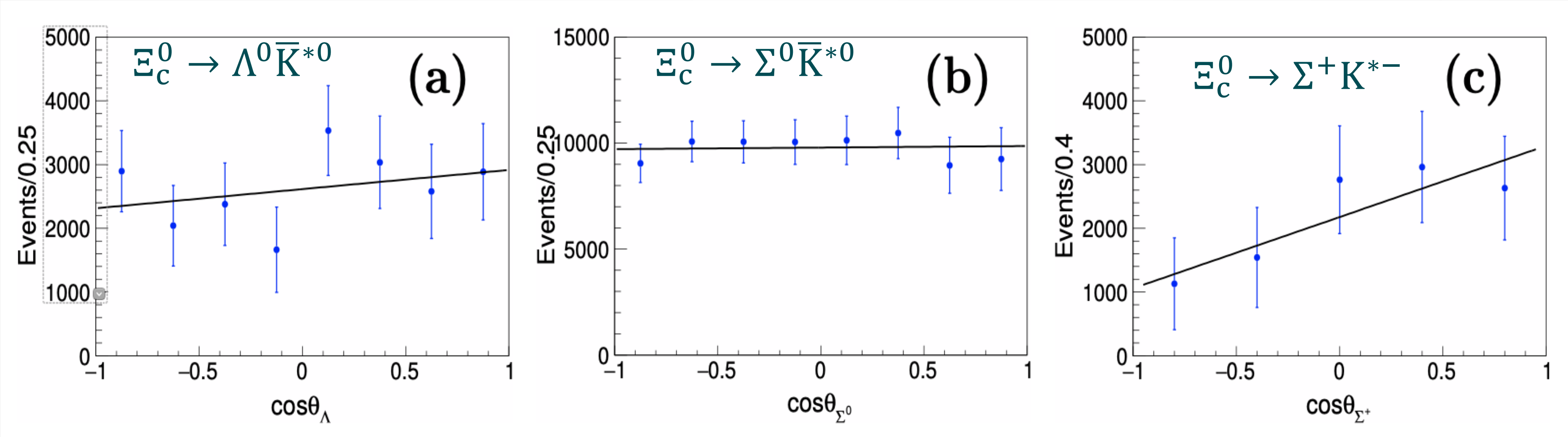




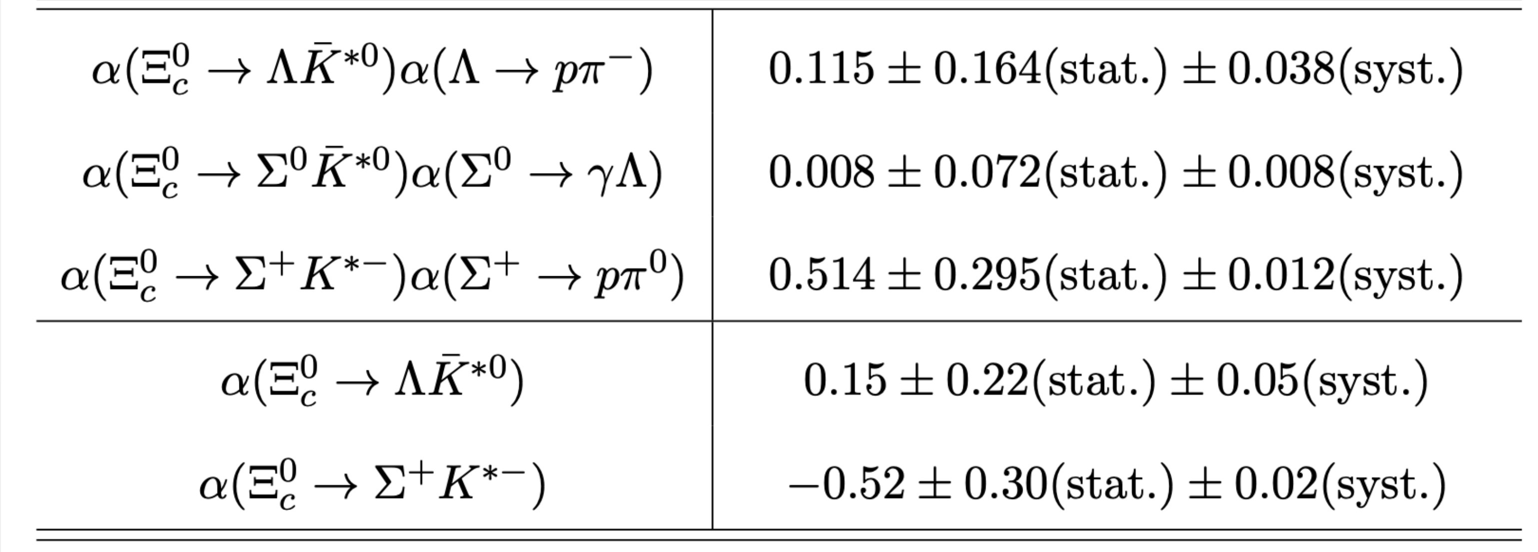
- This measurement is insensitive to production polarization of Ξ_c^0 in B-factory [PRD 63, 111102 (2001)].
- The asymmetry parameter $\alpha(\Sigma^0 \to \Lambda\gamma)$ is expected to be zero due to the case of parity conservation for an electromagnetic decay of $\Sigma^0 \to \Lambda\gamma$.

Asymmetry parameters

arXiv:2104.10361



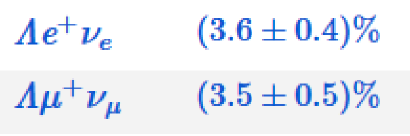
Note that $\alpha(\Lambda \to p\pi^-) = 0.747 \pm 0.010$ and $\alpha(\Sigma^+ \to p\pi^0) = -0.980 \pm 0.017$ from PDG.



$\alpha(\Xi_c^0 \to \Lambda\bar{K}^{*0})\alpha(\Lambda \to p\pi^-)$	$0.115 \pm 0.164(\text{stat.}) \pm 0.038(\text{syst.})$
$\alpha(\Xi_c^0 \to \Sigma^0\bar{K}^{*0})\alpha(\Sigma^0 \to \gamma\Lambda)$	$0.008 \pm 0.072(\text{stat.}) \pm 0.008(\text{syst.})$
$\alpha(\Xi_c^0 \to \Sigma^+ K^{*-})\alpha(\Sigma^+ \to p\pi^0)$	$0.514 \pm 0.295(\text{stat.}) \pm 0.012(\text{syst.})$
$\alpha(\Xi_c^0 \to \Lambda\bar{K}^{*0})$	$0.15 \pm 0.22(\text{stat.}) \pm 0.05(\text{syst.})$
$\alpha(\Xi_c^0 \to \Sigma^+ K^{*-})$	$-0.52 \pm 0.30(\text{stat.}) \pm 0.02(\text{syst.})$

Ξ_c semileptonic decay

- BESIII measured the $\mathcal{B}(\Lambda_c^+ \to \Lambda l^+ \nu)$ PRL 115, 221805(2015) & PLB 767, 42 (2017)



$\Lambda e^+ \nu_e$	$(3.6 \pm 0.4)\%$
$\Lambda \mu^+ \nu_\mu$	$(3.5 \pm 0.5)\%$

- $\mathcal{B}(\Xi_c \to \Xi\, l^+ \nu)$ was measured by ARGUS and CLEOII

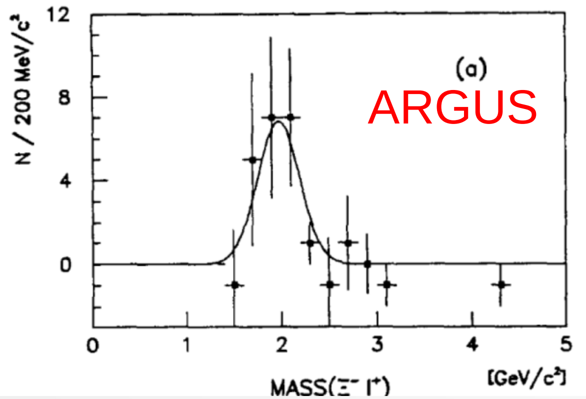
☐ ARGUS: $495.0\ \mathrm{pb}^{-1}$ at $\Upsilon(1S, 2S, 3S)$ and off_res energy points; **18 events;** PLB 303, 368(1993)

$$\sigma\left(e^+e^- \to \Xi_c^0 X\right)\mathcal{B}\left(\Xi_c^0 \to \Xi^- l^+ \nu_l\right) = 0.74 \pm 0.24 \pm 0.09\ \mathrm{pb}\quad l^+ = \mu^+\ or\ e^+$$

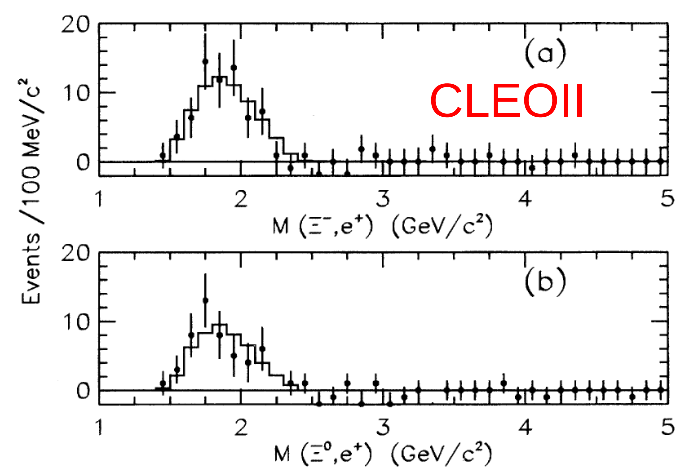
☐ CLEOII: $2.1\mathrm{fb}^{-1}$ at and bellow $\Upsilon(4S)$ energy point; **54 signal events**; PRL 74 16(1995)

$$\sigma\left(e^+e^- \to \Xi_c^0 X\right)\mathcal{B}\left(\Xi_c^0 \to \Xi^- e^+ \nu_e\right) = 0.63 \pm 0.12 \pm 0.10\ \mathrm{pb}$$

$$\sigma\left(e^+e^- \to \Xi_c^+ X\right)\mathcal{B}\left(\Xi_c^+ \to \Xi^0 e^+ \nu_e\right) = 1.55 \pm 0.33 \pm 0.25\ \mathrm{pb}$$



$$\frac{\mathrm{BR}(\Xi_c^0 \to \Xi^- l^+ X)}{\mathrm{BR}(\Xi_c^0 \to \Xi^- \pi^+)} = 0.96 \pm 0.43 \pm 0.18$$

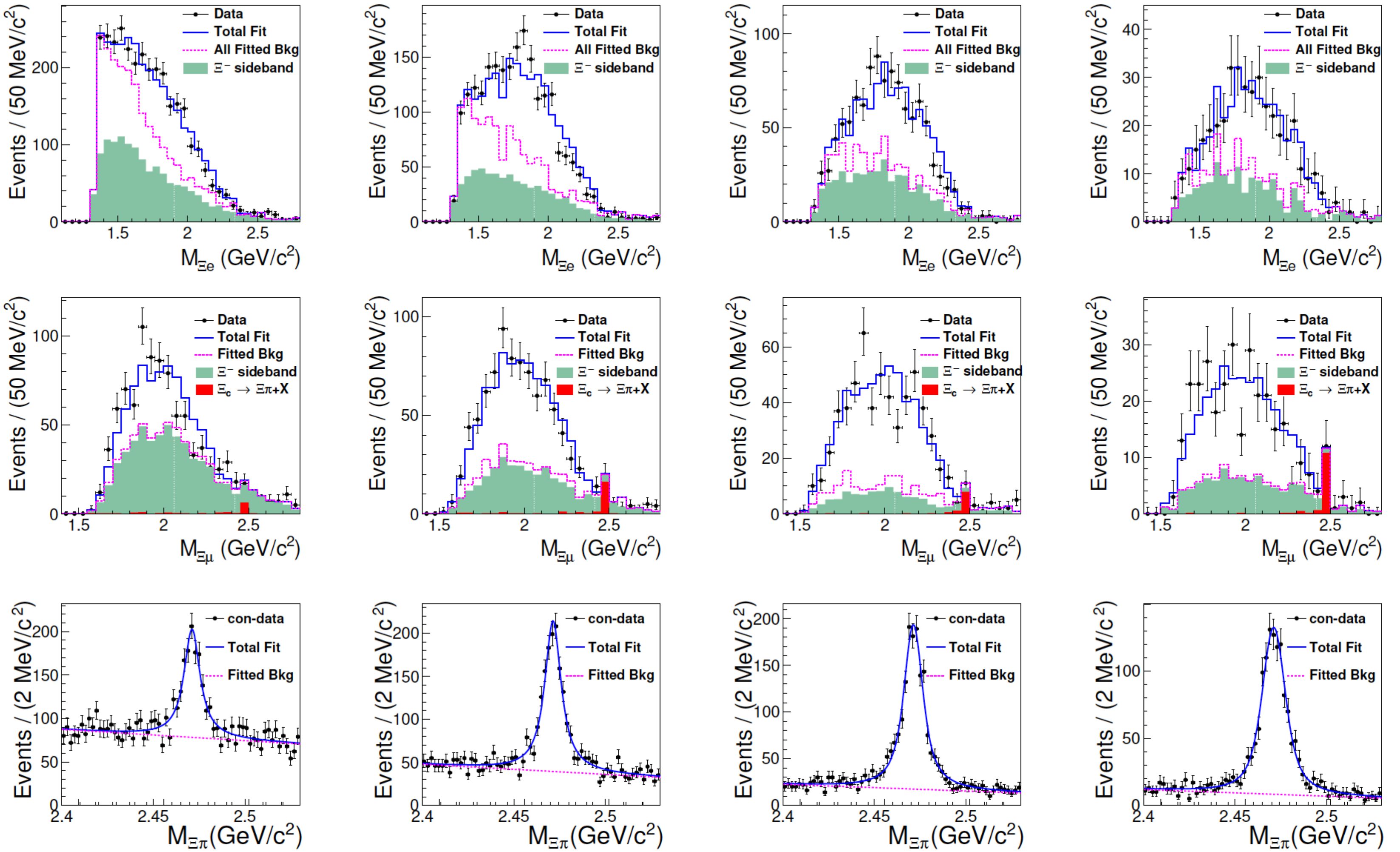


$$\mathcal{B}(\Xi_c^0 \to \Xi^- \pi^+)/\mathcal{B}(\Xi_c^0 \to \Xi^- e^+ \nu_e) = 0.32 \pm 0.10^{+0.05}_{-0.03}$$

Measurements of $\mathcal{B}(\Xi_c^0 \to \Xi^- l\, \nu\,)$

89.454 fb^{-1} continuum data below $\Upsilon(4S)$

arXiv:2103.06496



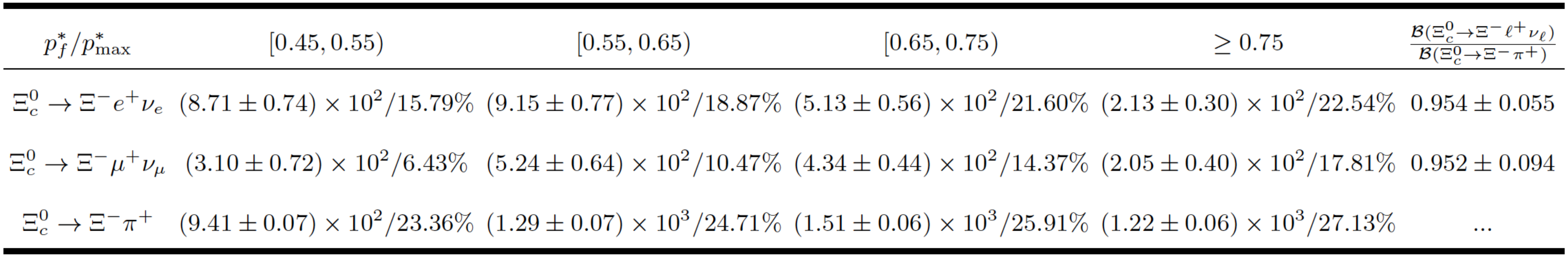
$\dfrac{p^*_{\Xi\ell(\pi)}}{p^*_{max}}$ [0.45, 0.55) [0.55, 0.65) [0.65, 0.75) ≥ 0.75

$p^*_{\Xi\ell(\pi)}$ is the momentum of $\Xi\ell(\pi)$ in center of mass system , $p^*_{max} = \sqrt{E^2_{beam} - M^2_{\Xi_c^0}}$

Measurements of $\mathcal{B}(\Xi_c^0 \to \Xi^- l\, \nu)$

arXiv:2103.06496

$$\mathcal{B}(\Xi_c^0 \to \Xi^- \ell^+ \nu_\ell) \equiv \frac{N_{\Xi_c^0} \cdot \mathcal{B}(\Xi_c^0 \to \Xi^- \ell^+ \nu_\ell)}{N_{\Xi_c^0} \cdot \mathcal{B}(\Xi_c^0 \to \Xi^- \pi^+)} \times \mathcal{B}(\Xi_c^0 \to \Xi^- \pi^+)$$



$p_f^*/p_{\max}^*$	$[0.45, 0.55)$	$[0.55, 0.65)$	$[0.65, 0.75)$	≥ 0.75	$\frac{\mathcal{B}(\Xi_c^0 \to \Xi^- \ell^+ \nu_\ell)}{\mathcal{B}(\Xi_c^0 \to \Xi^- \pi^+)}$
$\Xi_c^0 \to \Xi^- e^+ \nu_e$	$(8.71 \pm 0.74) \times 10^2/15.79\%$	$(9.15 \pm 0.77) \times 10^2/18.87\%$	$(5.13 \pm 0.56) \times 10^2/21.60\%$	$(2.13 \pm 0.30) \times 10^2/22.54\%$	0.954 ± 0.055
$\Xi_c^0 \to \Xi^- \mu^+ \nu_\mu$	$(3.10 \pm 0.72) \times 10^2/6.43\%$	$(5.24 \pm 0.64) \times 10^2/10.47\%$	$(4.34 \pm 0.44) \times 10^2/14.37\%$	$(2.05 \pm 0.40) \times 10^2/17.81\%$	0.952 ± 0.094
$\Xi_c^0 \to \Xi^- \pi^+$	$(9.41 \pm 0.07) \times 10^2/23.36\%$	$(1.29 \pm 0.07) \times 10^3/24.71\%$	$(1.51 \pm 0.06) \times 10^3/25.91\%$	$(1.22 \pm 0.06) \times 10^3/27.13\%$	$\cdots$

$$\mathcal{B}(\Xi_c^0 \to \Xi^-\ e^+ \nu_e) = (1.72 \pm 0.10(stat.) \pm 0.12(syst.) \pm 0.50)\%$$

$$\mathcal{B}(\Xi_c^0 \to \Xi^-\ \mu^+ \nu_\mu) = (1.71 \pm 0.17(stat.) \pm 0.13(syst.) \pm 0.50)\%$$

$$\mathcal{B}(\Xi_c^0 \to \Xi^-\ e^+ \nu_e)\ /\ \mathcal{B}(\Xi_c^0 \to \Xi^-\ \mu^+ \nu_\mu) = 1.00 \pm 0.11 \pm 0.09$$

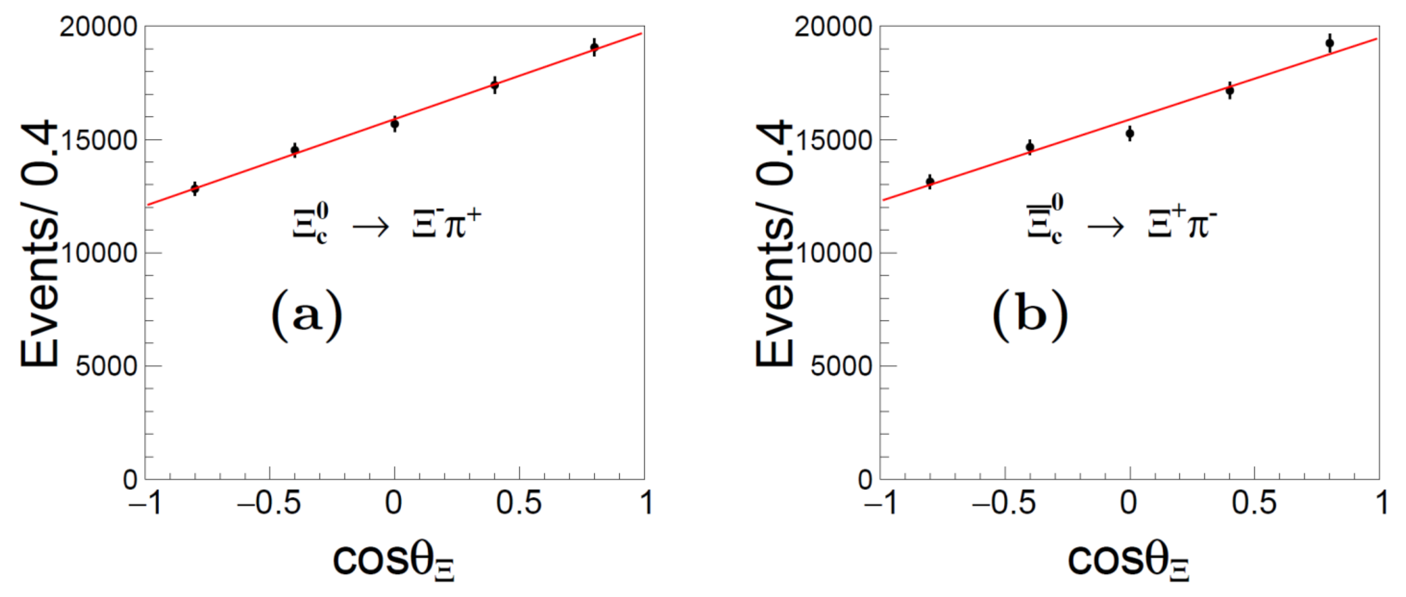
The result is consistent with the expectation of LFU.

Measurements of $\mathcal{A}_{cp}$ of $\Xi_c^0 \to \Xi^- \pi^+$

arXiv:2103.06496

$$\frac{dN}{d\cos\theta_\Xi} \propto 1 + \alpha_{\Xi^-\pi^+}\alpha_{\Xi^-} \cos\theta_\Xi$$

θ_Ξ: angle between the $\vec{p}_\Lambda$ and $-\vec{p}_{\Xi_c^0}$
in the Ξ^- rest frame



$$\alpha_{\Xi^-\pi^+} = -0.60 \pm 0.04 \pm 0.02$$

$$\alpha_{\Xi^+\pi^-} = 0.58 \pm 0.04 \pm 0.02$$

$$\mathcal{A} = \frac{\alpha_{\Xi^-\pi^+} - \alpha_{\Xi^+\pi^-}}{\alpha_{\Xi^-\pi^+} + \alpha_{\Xi^+\pi^-}} = 0.015 \pm 0.052 \pm 0.017.$$

The result is consistent with no *CP* violation.

Ξ_c worklist:

1. Measurement of absolute decay branching fractions

$$\mathcal{B}(\Xi_c^0 \to \Xi^-\pi^+) = (1.80 \pm 0.52)\%$$ PRL 122 082001

$$\mathcal{B}(\Xi_c^+ \to \Xi^-\pi^+\pi^+) = (2.86 \pm 1.27)\%$$ PRD 100 031101

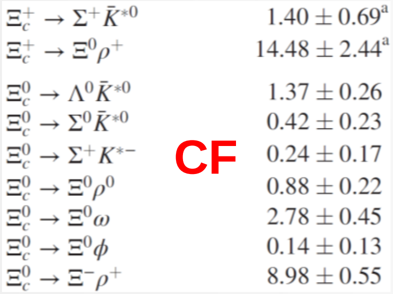
μ?
$$\mathcal{B}(\Xi_c^0 \to \Xi^- e^+\nu_e) = (1.8 \pm 1.2)\%$$ PDG

$$\mathcal{B}(\Xi_c^+ \to \Xi^0 e^+\nu_e) = (1.8^{+0.7}_{-0.8})\%$$ PDG, ratios to $\Xi^- 2\pi^+$

Need updated

2. Find more decay modes:

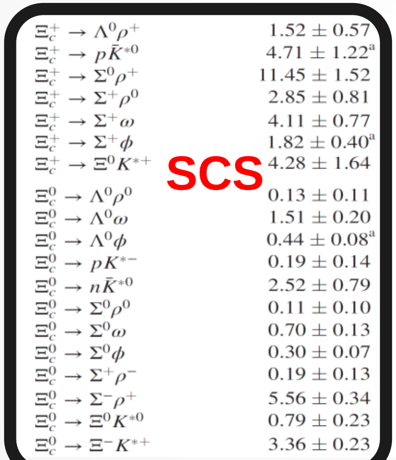
PRD 101, 053002



CF

%

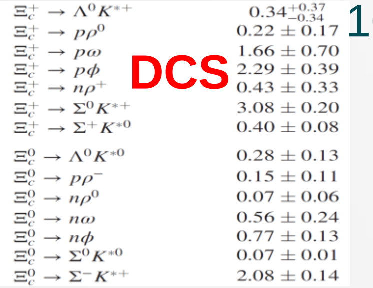
$\Xi_c^+ \to \Sigma^+\bar{K}^{*0}$	1.40 ± 0.69^a
$\Xi_c^+ \to \Xi^0\rho^+$	14.48 ± 2.44^a
$\Xi_c^0 \to \Lambda^0\bar{K}^{*0}$	1.37 ± 0.26
$\Xi_c^0 \to \Sigma^0\bar{K}^{*0}$	0.42 ± 0.23
$\Xi_c^0 \to \Sigma^+K^{*-}$	0.24 ± 0.17
$\Xi_c^0 \to \Xi^0\rho^0$	0.88 ± 0.22
$\Xi_c^0 \to \Xi^0\omega$	2.78 ± 0.45
$\Xi_c^0 \to \Xi^0\phi$	0.14 ± 0.13
$\Xi_c^0 \to \Xi^-\rho^+$	8.98 ± 0.55



SCS

10^{-3}

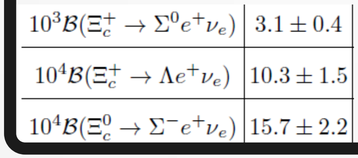
$\Xi_c^+ \to \Lambda^0\rho^+$	1.52 ± 0.57
$\Xi_c^+ \to p\bar{K}^{*0}$	4.71 ± 1.22^a
$\Xi_c^+ \to \Sigma^0\rho^+$	11.45 ± 1.52
$\Xi_c^+ \to \Sigma^+\rho^0$	2.85 ± 0.81
$\Xi_c^+ \to \Sigma^+\omega$	4.11 ± 0.77
$\Xi_c^+ \to \Sigma^+\phi$	1.82 ± 0.40^a
$\Xi_c^+ \to \Xi^0K^{*+}$	4.28 ± 1.64
$\Xi_c^0 \to \Lambda^0\rho^0$	0.13 ± 0.11
$\Xi_c^0 \to \Lambda^0\omega$	1.51 ± 0.20
$\Xi_c^0 \to \Lambda^0\phi$	0.44 ± 0.08^a
$\Xi_c^0 \to pK^{*-}$	0.19 ± 0.14
$\Xi_c^0 \to n\bar{K}^{*0}$	2.52 ± 0.79
$\Xi_c^0 \to \Sigma^0\rho^0$	0.11 ± 0.10
$\Xi_c^0 \to \Sigma^0\omega$	0.70 ± 0.13
$\Xi_c^0 \to \Sigma^0\phi$	0.30 ± 0.07
$\Xi_c^0 \to \Sigma^+\rho^-$	0.19 ± 0.13
$\Xi_c^0 \to \Sigma^-\rho^+$	5.56 ± 0.34
$\Xi_c^0 \to \Xi^0K^{*0}$	0.79 ± 0.23
$\Xi_c^0 \to \Xi^-K^{*+}$	3.36 ± 0.23



DCS

10^{-4}

$\Xi_c^+ \to \Lambda^0K^{*+}$	$0.34^{+0.37}_{-0.34}$
$\Xi_c^+ \to p\rho^0$	0.22 ± 0.17
$\Xi_c^+ \to p\omega$	1.66 ± 0.70
$\Xi_c^+ \to p\phi$	2.29 ± 0.39
$\Xi_c^+ \to n\rho^+$	0.43 ± 0.33
$\Xi_c^+ \to \Sigma^0K^{*+}$	3.08 ± 0.20
$\Xi_c^+ \to \Sigma^+K^{*0}$	0.40 ± 0.08
$\Xi_c^0 \to \Lambda^0K^{*0}$	0.28 ± 0.13
$\Xi_c^0 \to p\rho^-$	0.15 ± 0.11
$\Xi_c^0 \to n\rho^0$	0.07 ± 0.06
$\Xi_c^0 \to n\omega$	0.56 ± 0.24
$\Xi_c^0 \to n\phi$	0.77 ± 0.13
$\Xi_c^0 \to \Sigma^0K^{*0}$	0.07 ± 0.01
$\Xi_c^0 \to \Sigma^-K^{*+}$	2.08 ± 0.14



$10^3\mathcal{B}(\Xi_c^+ \to \Sigma^0 e^+\nu_e)$	3.1 ± 0.4
$10^4\mathcal{B}(\Xi_c^+ \to \Lambda e^+\nu_e)$	10.3 ± 1.5
$10^4\mathcal{B}(\Xi_c^0 \to \Sigma^- e^+\nu_e)$	15.7 ± 2.2

Semileptonic

PLB792, 214

3.Decay parameter measurement:

Ξ_c^0 DECAY PARAMETERS

α FOR $\Xi_c^0 \to \Xi^-\pi^+$	-0.6 ± 0.4

The only measurement with large error

4. Form factors

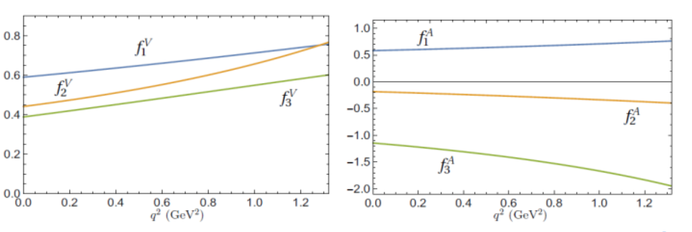


FIG. 1: Form factors of the weak $\Xi_c \to \Xi$ transitions.

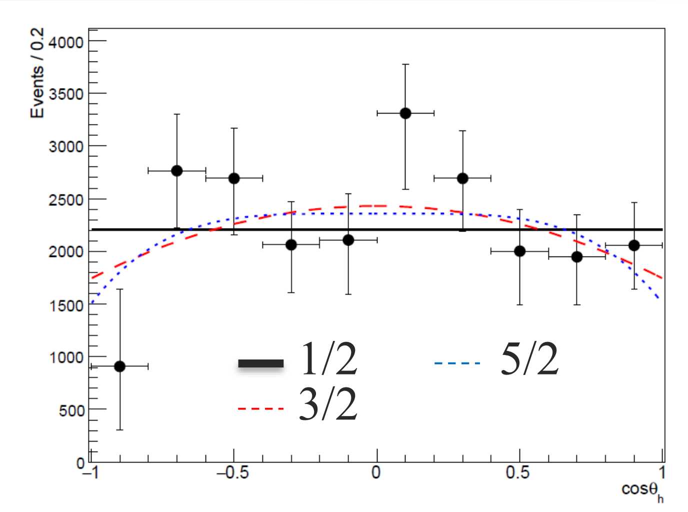
EPJC 79 695

Plentiful physics parameters need to be measured !

First Determination of the Spin and Parity of $\Xi_c(2970)^+$

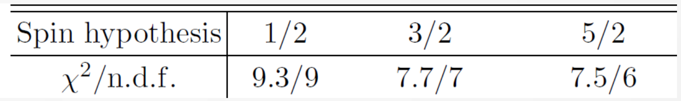
arXiv:2007.14700

- Report the first measurement of the spin-parity of a Ξ_c baryon
- There are many possibilities for J^P values of $\Xi_c(2970)^+$, including $1/2^+$, $3/2^-$, $5/2^+$ from different models
- Experimental determination of the spin-parity will provide important information to test these predictions and help decipher the nature of the state
- Decay modes: $\Xi_c(2970)^+ \to \Xi_c(2645)^0\pi^+$ and $\Xi_c'^0\pi^+$ with $\Xi_c(2645)^0 \to \Xi_c^+\pi^-$ and $\Xi_c'^0 \to \gamma\Xi_c^0$



The helicity angle θ_h of $\Xi_c(2970)^+$: the yield of $\Xi_c(2970)^+ \to \Xi_c(2645)^0\pi^+$ is obtained by fitting the invariant-mass distribution of $M(\Xi_c^+\pi^-\pi^+)$ for the $\Xi_c(2645)^0$ signal region and sidebands.

the best fit is obtained for the spin 1/2 hypothesis, the exclusion level of the spin 3/2 (5/2) hypothesis is as small as 0.8 (0.5) standard deviations.

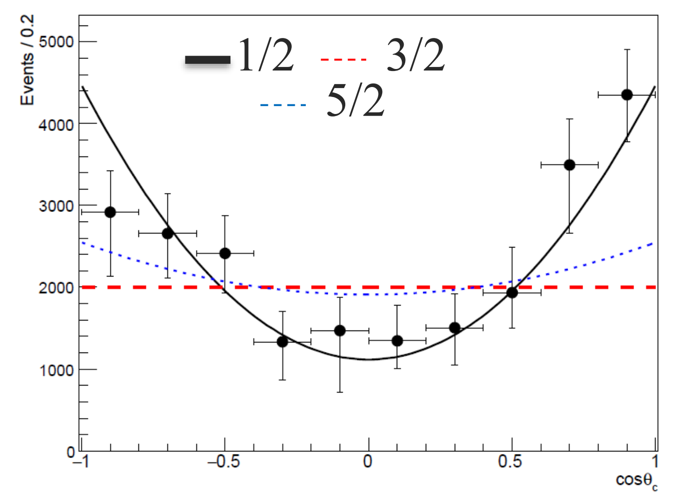


Spin hypothesis	1/2	3/2	5/2
χ^2/n.d.f.	9.3/9	7.7/7	7.5/6

First Determination of the Spin and Parity of $\Xi_c(2970)^+$

arXiv:2007.14700

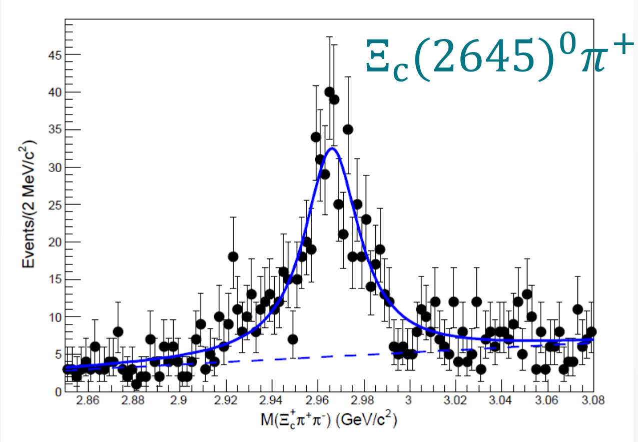
the helicity angle of $\Xi_c(2645)^0$

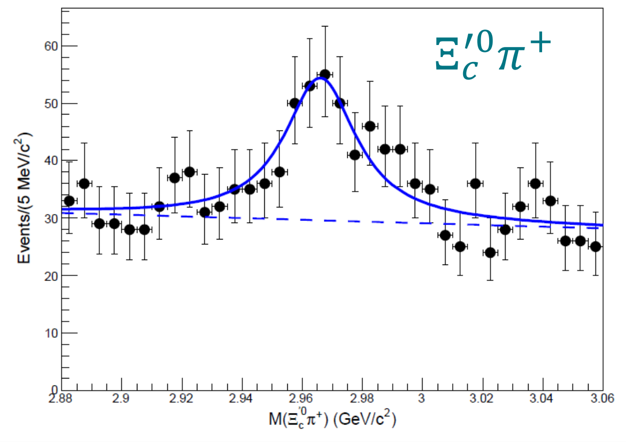


J^P	$1/2^\pm$	$3/2^-$	$5/2^+$
χ^2/n.d.f.	6.4/9	32.2/9	22.3/9
Probablility	0.69	1.8×10^{-4}	7.9×10^{-3}

the result to favor the $1/2^\pm$ hypothesis over the $3/2^-$ ($5/2^+$) one at the level of 5.1 (4.0) standard deviations.

R = $B[\Xi_c(2970)^+\to\Xi_c(2645)^0\pi^+]/B[\Xi_c(2970)^+\to\Xi_c'^0\pi^+]$ is sensitive to the parity of $\Xi_c(2970)^+$ [PRL 98, 262001 (2007); PRD 75, 014006 (2007).]

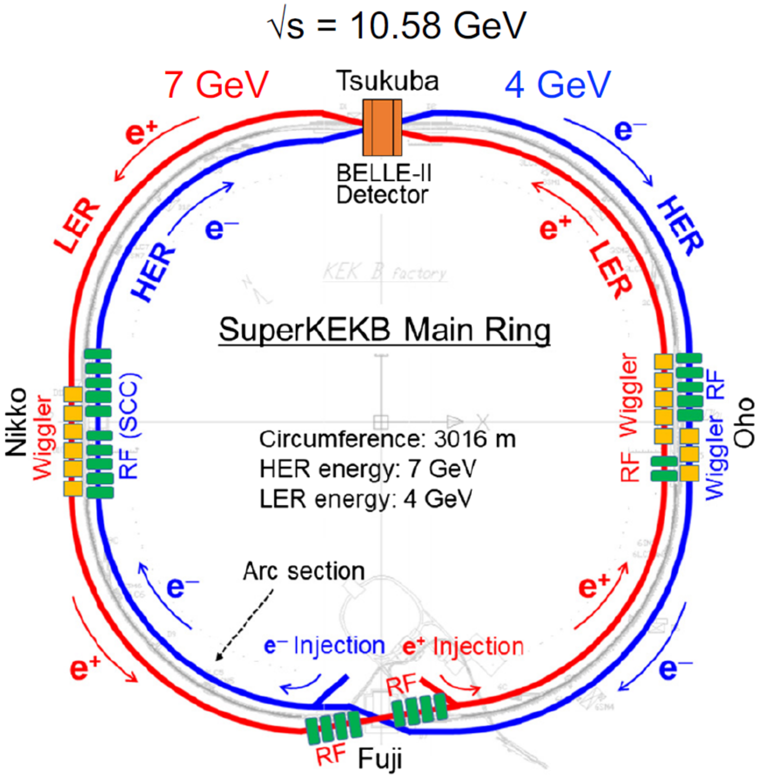




R = $1.67 \pm 0.29^{+0.15}_{-0.09} \pm 0.25$ [the last error is due to possible isospin-symmetry-breaking effects] : favor $1/2^+$ from heavy-quark spin symmetry prediction

SuperKEKB Collider

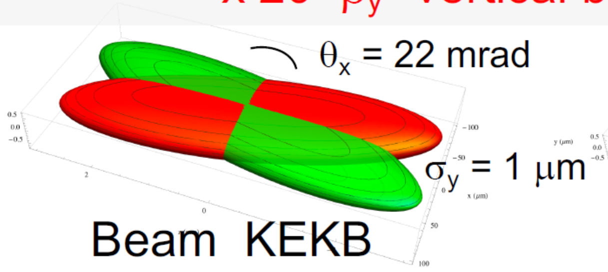
SuperKEKB is a new e^+e^- collider located at KEK (Tsukuba, Japan), it operates in the **intensity frontier** region with a target instantaneous luminosity of 6×10^{35} cm^{-2} s^{-1} which is 30 times larger than that of the previous KEKB collider.



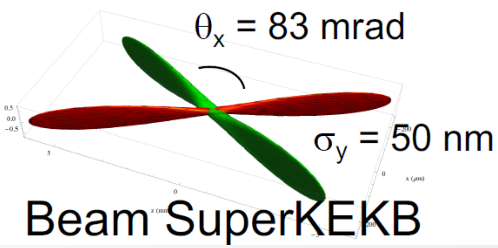
	Instantaneous luminosity ($cm^{-2}\,s^{-1}$)	Integrated recorded luminosity (ab^{-1})
Babar PEP-II	1×10^{34} cm^{-2} s^{-1}	0.55 0.43 Y(4S)
Belle KEKB	2.11×10^{34} cm^{-2} s^{-1}	1 0.71 (Y4S)
Belle II SuperKEKB	6×10^{35} cm^{-2} s^{-1}	50

$\mathcal{L}$ x 30 : x1.5 current increase

x 20 β_y^* vertical beta function decrease



Beam KEKB



Beam SuperKEKB

Current integrated luminosity

We kept SuperKEKB and Belle II running in 2020/2021 during the COVID-19 crisis, with extra effort from the local crew and the help of remote shifters

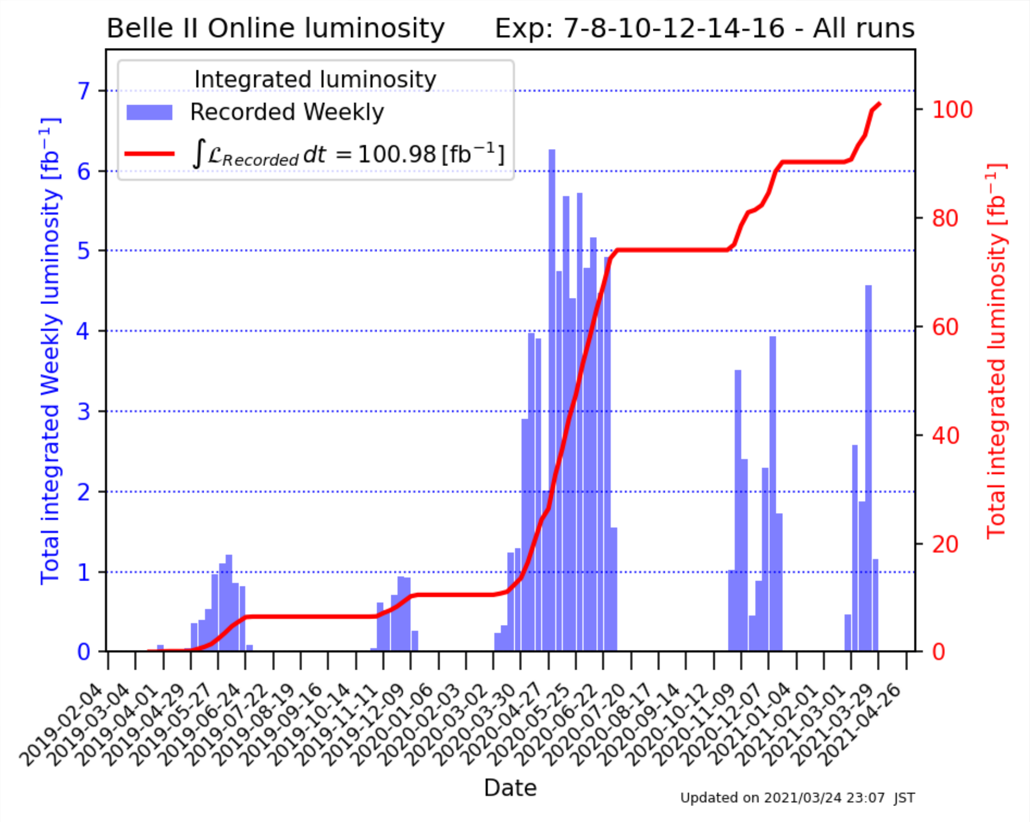
Luminosity world record

$2.11 \times 10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$
(KEK June 2009)

$2.14 \times 10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$
(LHC May 2018)

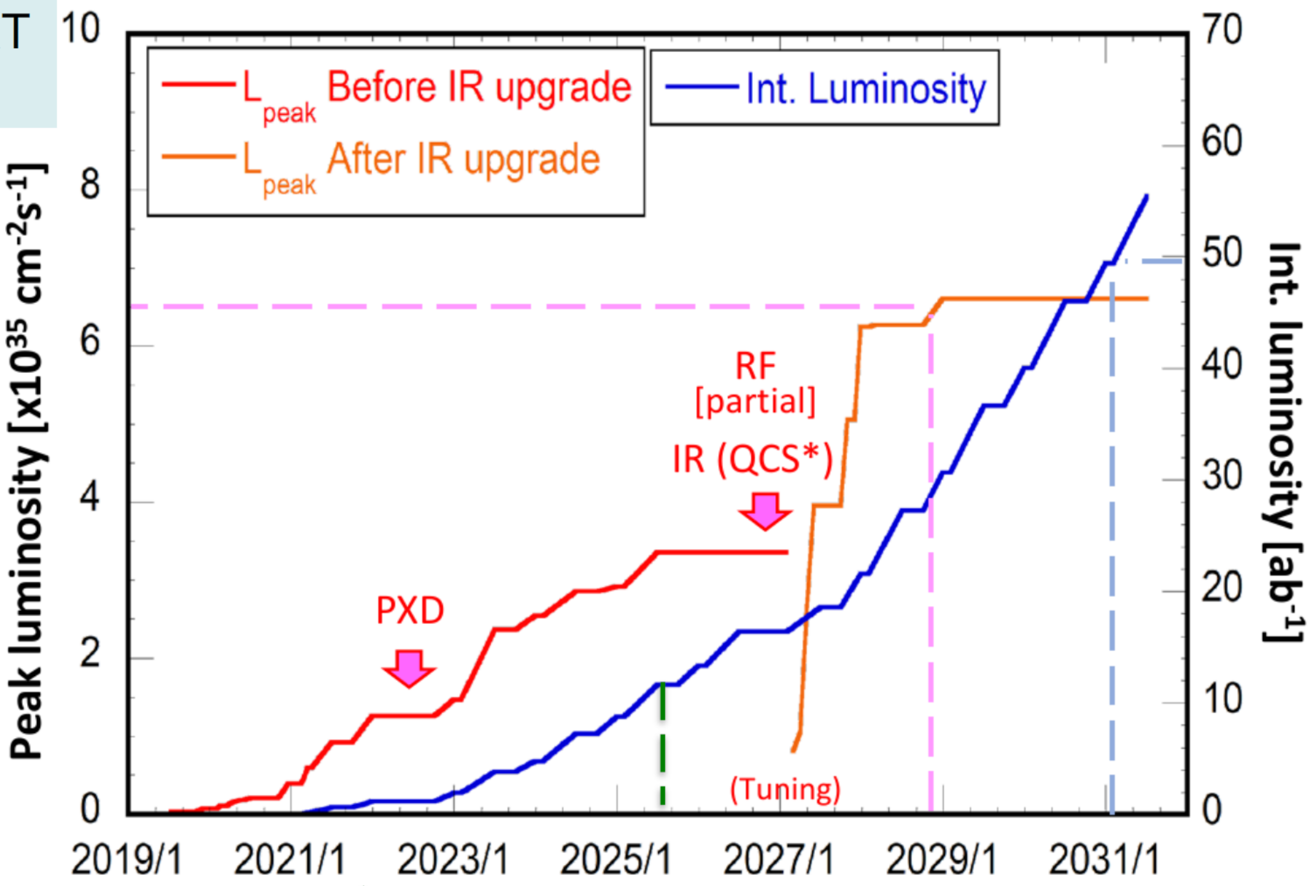
$2.4 \times 10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$
(SuperKEKB June 2020)

$$\int \mathcal{L}_{Recorded}\, dt = 100.98\, [\mathrm{fb}^{-1}]$$



Luminosity Plan

Submitted to MEXT roadmap 2020



$\int \mathcal{L} = 0.5 \div 1$ ab^{-1} in 2022

$\int \mathcal{L} = 10$ ab^{-1} in 2026

$\mathcal{L}_{peak} = 6\ 10^{35}$ cm^{-2} s^{-1} in 2029

$\int \mathcal{L} = 50$ ab^{-1} in 2031

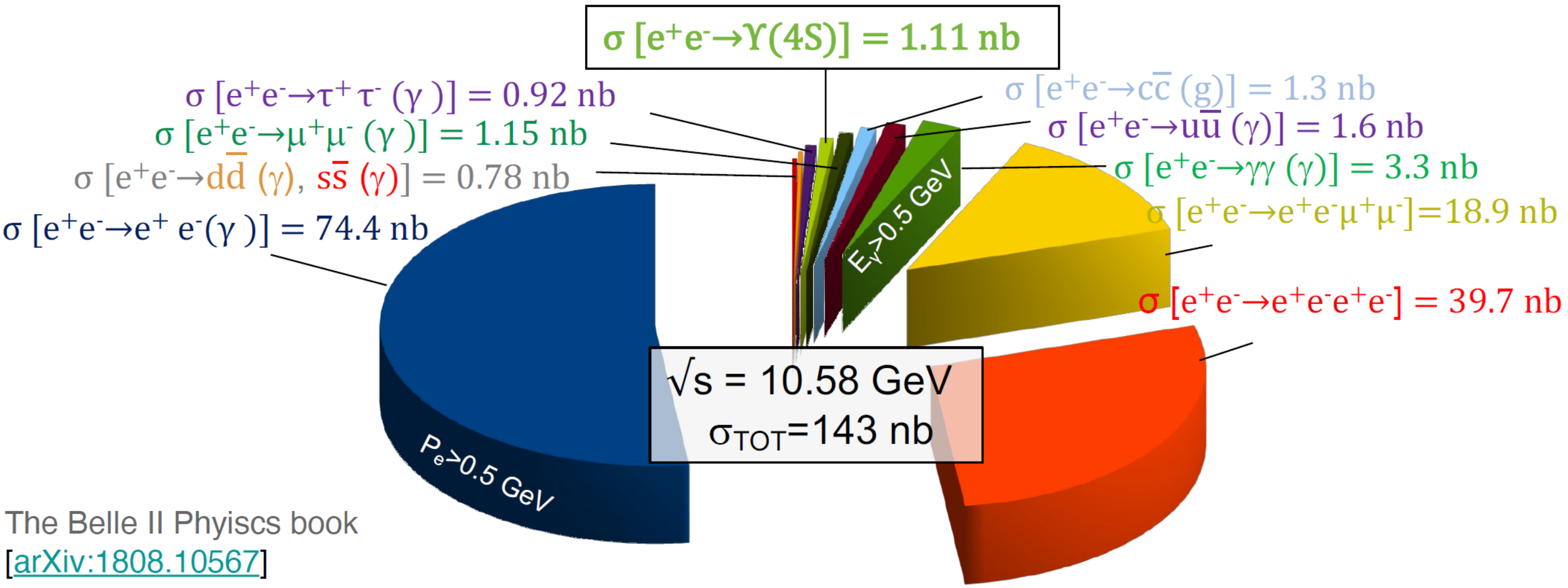
Belle II energy points

Energy scan

Υ(1s)	Υ(2s)	Υ(3s)	**Υ(4s)**	Υ(5s)	Υ(6s)
9.46 GeV	10.02 GeV	10.35 GeV	**10.58 GeV**	10.86 GeV	11.02 GeV

B^+B^- $(51.4\pm0.6)\%$

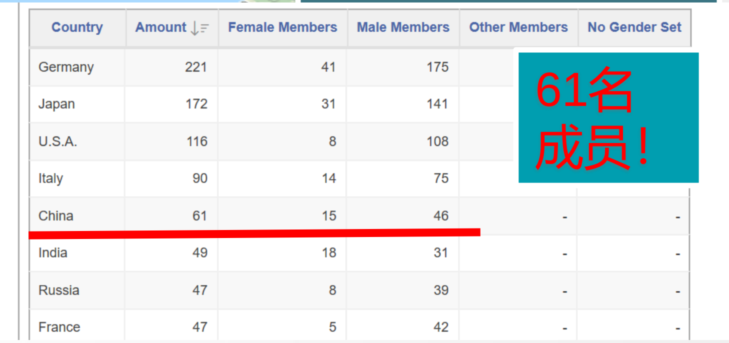
$B^0\overline{B}^0$ $(48.6\pm0.6)\%$



The Belle II Phyiscs book
[arXiv:1808.10567]

Belle II国际合作组与中国组

- ➢ 规模排第五，但是竞争很激烈。
- ➢ 需要考虑更多的研究内容！
- ➢ 需要更多的国内支持！



Country	Amount ↓	Female Members	Male Members	Other Members	No Gender Set
Germany	221	41	175		
Japan	172	31	141		
U.S.A.	116	8	108		
Italy	90	14	75		
China	61	15	46	-	-
India	49	18	31	-	-
Russia	47	8	39	-	-
France	47	5	42	-	-

61名成员！

- 合作组规模: 26个国家和地区，>120个研究单位, >1000名成员。
  - 50%为博士后及以上。
  - 众多实验室：KEK, IHEP(Beijing), BNL, SLAC, TRIUMF, DESY, LAL, INFN, BINP, …
- 中国组： 复旦，高能所，中科大等12个单位。
- 技术支持：
  - 网页: https://napp.fudan.edu.cn/belle2/ （复旦）
  - Indico: https://indico.ihep.ac.cn/category/109/ （高能所），https://napp.fudan.edu.cn/indico/ （复旦）

- 参与内容:
  - 物理分析：传统强项，但需要拓展研究领域
  - 硬件：高能所，复旦
  - 计算：高能所，复旦，北航；+科大，山大，南师
  - DAQ和触发：高能所，辽师，+山大
  - 探测器刻度：复旦，高能所，
  - 数据检查：中科大，北航

Summary

- We are still producing interesting results in baryons and charmed baryons using Belle data
- The expected Belle II data sample of 50 ab^{-1} will provide a lot of new opportunities for physics analyses
- Some of them are unique for Belle II, for example the absolute branching fraction measurement

Thanks a lot!

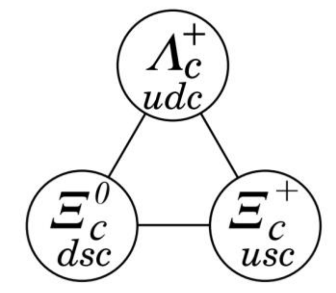
復旦大學
FUDAN UNIVERSITY

Thanks for your attention

沈成平　　shencp@buaa.edu.cn

Measurements of absolute Brs of Ξ_c^0

- Weak decays of charmed hadrons play an unique role in the study of strong interaction； the charmed-baryon sector also offers an unique and excellent laboratory for testing heavy-quark symmetry and light-quark chiral symmetry.
- For the charmed baryons of the SU(3) anti-triplet, only Λ_c absolute Brs were measured by Belle [PRL113,042002(2014), first time] and BESIII [PRL116,052001(2016)]
- Since Ξ_c^0 [PRL62,863(1989)] and Ξ_c^+[PLB122,455 (1983)] were discovered ~30 years ago, no absolute Brs could be measured.



- For Ξ_c^0, the Brs are all measured with ratios to the $\Xi^-\pi^+$, the so called reference mode.

Measurements of absolute Brs of Ξ_c^0

- Theory: $B(\Xi_c^0 \to \Xi^-\pi^+)$~1.12% or 0.74% [PRD48, 4188 (1993)], (2.24±0.34)% [JHEP03, 66(2018)], (1.91±0.17)% [1811.07265]
- The $B(\Xi_c^0 \to \Lambda K^-\pi^+)$/ $B(\Xi_c^0 \to \Xi^-\pi^+)$ = 1.07 ± 0.12± 0.07 and

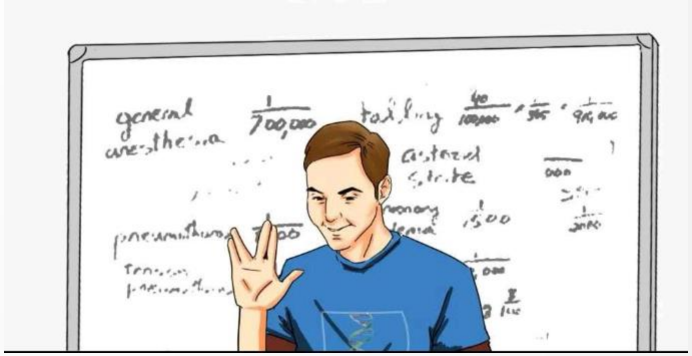
$B(\Xi_c^0 \to pK^-K^-\pi^+)$/ $B(\Xi_c^0 \to \Xi^-\pi^+)$= 0.33 ± 0.03±0.03 [PLB 605,237]

- $\Xi_c^0 \to pK^-K^-\pi^+$ plays a fundamental role in lots of bottom baryons study at LHCb .
- How to measure Ξ_c^0 absolute Brs ? Model Independent !

$$\mathcal{B}(\Xi_c^0 \to \Xi^-\pi^+) \equiv \frac{\mathcal{B}(B^- \to \bar{\Lambda}_c^- \Xi_c^0)\mathcal{B}(\Xi_c^0 \to \Xi^-\pi^+)}{\mathcal{B}(B^- \to \bar{\Lambda}_c^- \Xi_c^0)},$$

$$\mathcal{B}(\Xi_c^0 \to \Lambda K^-\pi^+) \equiv \frac{\mathcal{B}(B^- \to \bar{\Lambda}_c^- \Xi_c^0)\mathcal{B}(\Xi_c^0 \to \Lambda K^-\pi^+)}{\mathcal{B}(B^- \to \bar{\Lambda}_c^- \Xi_c^0)}.$$

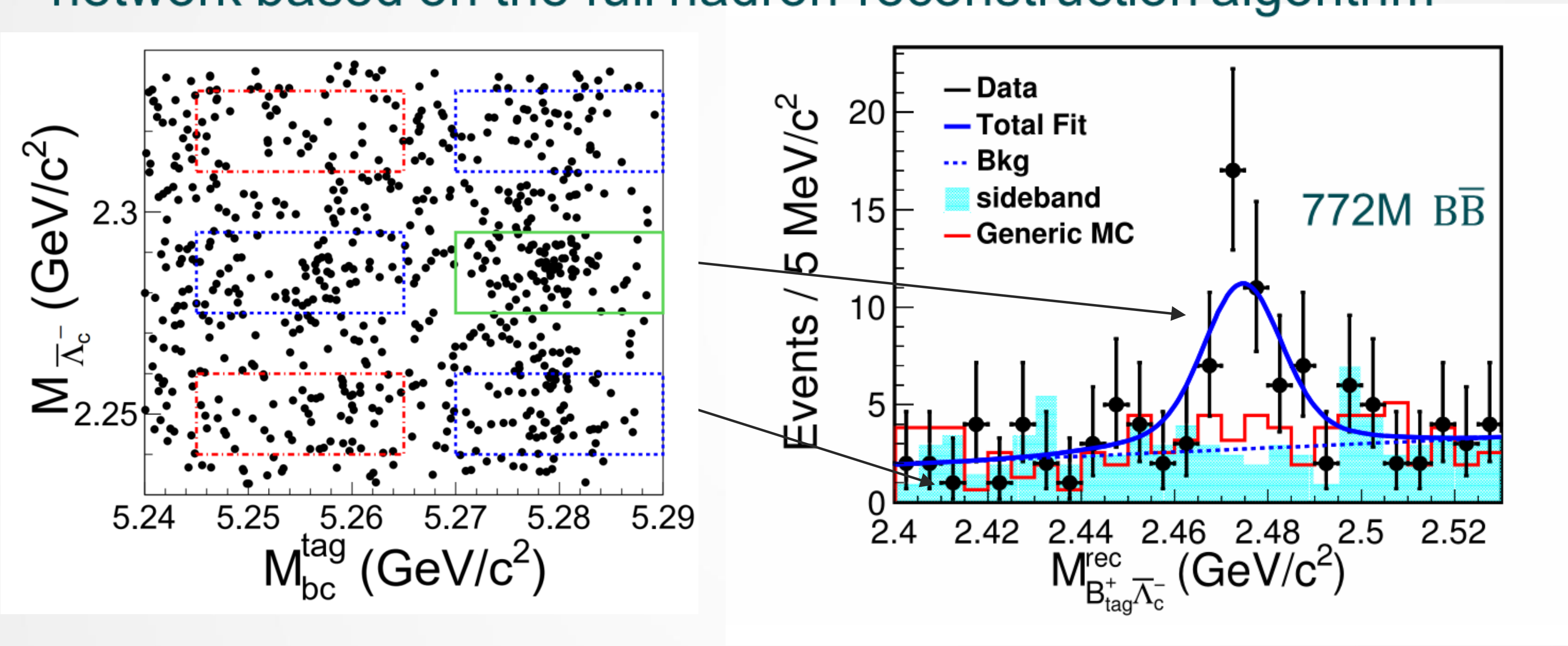
$$\mathcal{B}(\Xi_c^0 \to pK^-K^-\pi^+) \equiv \frac{\mathcal{B}(B^- \to \bar{\Lambda}_c^- \Xi_c^0)\mathcal{B}(\Xi_c^0 \to pK^-K^-\pi^+)}{\mathcal{B}(B^- \to \bar{\Lambda}_c^- \Xi_c^0)}.$$



- For inclusive $B^- \to \bar{\Lambda}_c^- \Xi_c^0$, Ξ_c^0 →anything, never measured before.
- For exclusive $B(B^- \to \bar{\Lambda}_c^- \Xi_c^0)$ $B(\Xi_c^0 \to \Xi^-\pi^+)$; $B(B^- \to \bar{\Lambda}_c^- \Xi_c^0)$ $B(\Xi_c^0 \to \Lambda K^-\pi^+)$, measured by Belle and BaBar with large errors.

Measurements of Br of $B^- \to \bar{\Lambda}_c^- \Xi_c^0$, $\Xi_c^0 \to$anything

- The $\bar{\Lambda}_c^-$ reconstructed via its $\bar{p}K^+\pi^-$ and $\bar{p}K_s^0$ decays
- A tagged B meson candidate, B_{tag}^+, is reconstructed using a neural network based on the full hadron-reconstruction algorithm



- An unbinned maximum likelihood fit: $N(\Xi_c^0)=40.9 \pm 9.0$, 5.5σ(stat.)
- $B(B^- \to \bar{\Lambda}_c^- \Xi_c^0$, $\Xi_c^0 \to$anything$) = (9.51 \pm 2.10 \pm 0.88) \times 10^{-4}$ for the first time

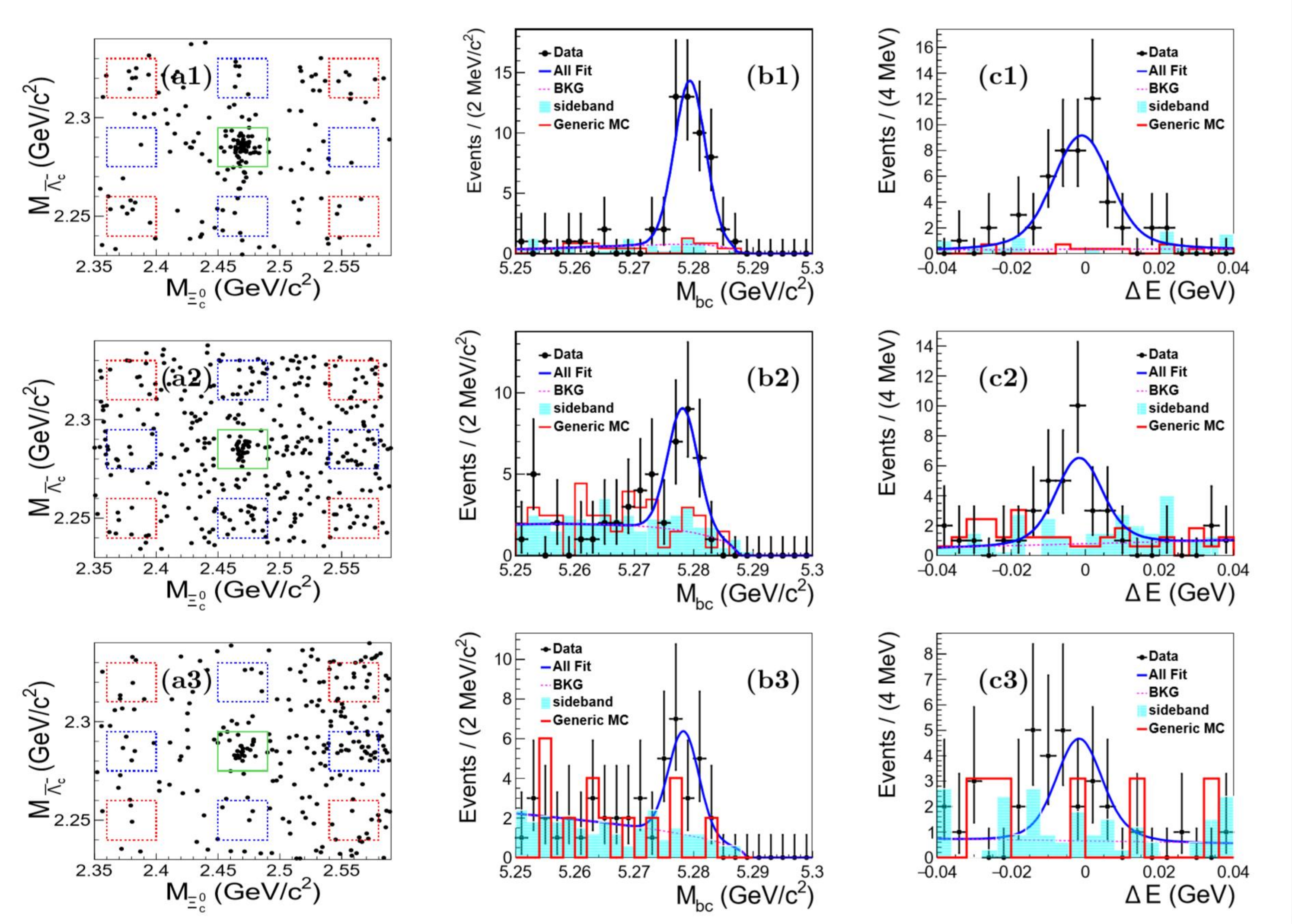
Y.B.Li, C.P.Shen et al. (Belle)
PRL122, 082001 (2019)

Measurements of Brs of $B^- \to \bar{\Lambda}_c^- \Xi_c^0$,with $\Xi_c^0 \to \Xi^-\pi^+$;$\Xi_c^0 \to \Lambda K^-\pi^+$; $\Xi_c^0 \to pK^-K^-\pi^+$

$\Xi^-\pi^+$
44.8 ± 7.3
9.5σ

$\Lambda K^-\pi^+$
24.1 ±5.5
6.8σ

$pK^-K^-\pi^+$
16.6 ± 5.4
4.6σ



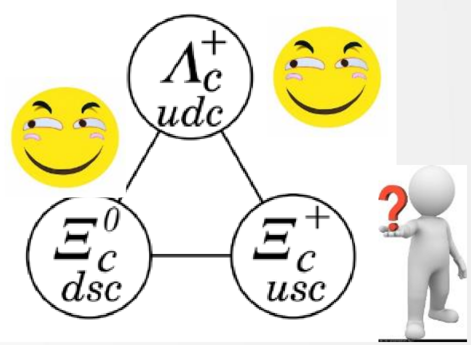
Y.B.Li, C.P.Shen et al (Belle) PRL122, 082001 (2019)

Measurements of absolute Brs of Ξ_c^+

复旦、北大

- The decays of charmed baryons in experiment are needed to extract the non-perturbative contribution thus important to constrain phenomenological models of strong interaction.

- For the SU(3) anti-triplet charmed baryons the branching fractions of $\boldsymbol{\Lambda_c^+}$ [PRL 113,042003(2014); PRL 116,052001(2016)] and Ξ_c^0 [PRL 122,082001(2019)] has been measured.



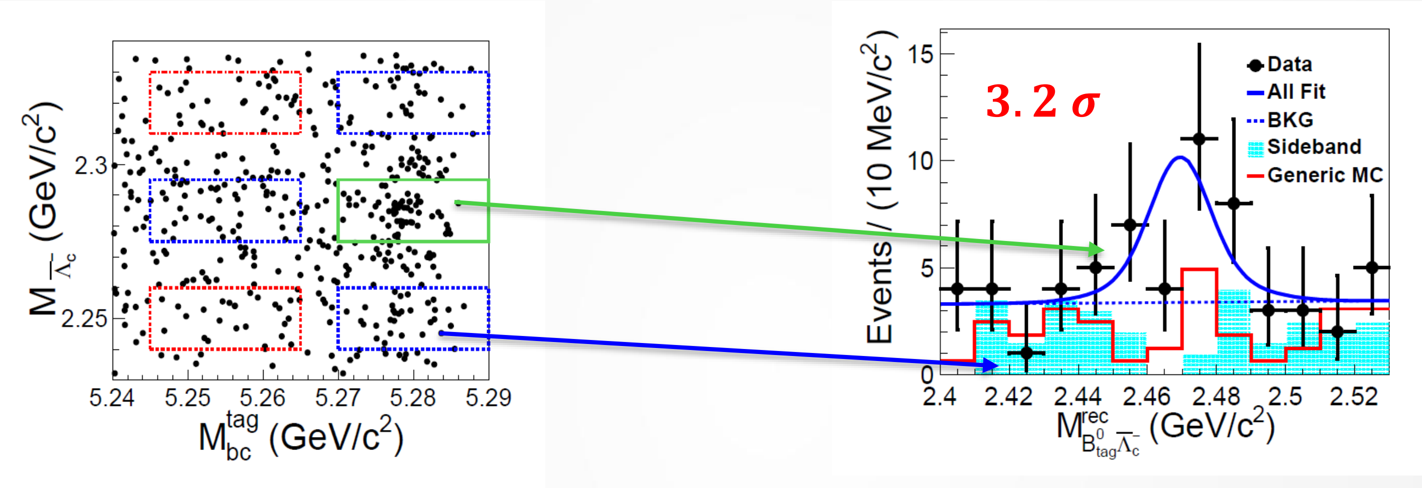
- The Brs of remaining Ξ_c^+ are all measured with ratio to the $\Xi_c^+ \to \Xi^- \pi^+ \pi^+$

- The comparison of Ξ_c^+ decays with those of Λ_c^+ and and Ξ_c^0 can also provide an important test of SU(3) flavor symmetry.

$\Xi_c^+ \to p\, K^- \pi^+$ is a particularly important decay mode as it is the one most often used to reconstruct Ξ_c^+ candidates at hadron collider experiments, such as LHCb. Theory predicts the B($\Xi_c^+ \to p\, K^- \pi^+$)=(2.2±0.8)% [EPJC 78, 224 (2018); Chin. Phys. C 42, 051001 (2018)].

Measurement of Ξ_c^+ absolute BRs

Measurement $\mathcal{B}\left(\bar{B}^0 \to \bar{\Lambda}_c^- \Xi_c^+\right)$ with $\Xi_c^+ \to anythings$



Y.B.Li, C.P.Shen et al (Belle)
PRD 100, 031101 (2019)

- reconstruct $\bar{\Lambda}_c^-$ via $\bar{p}K^+\pi^-$ decay mode
- tag a B^0 with neural network based Full-Reconstruction algorithm.
- An unbinned maximum likelihood fit: $N(\Xi_c^+) = 18.8 \pm 6.8$
- $\mathcal{B}\left(\bar{B}^0 \to \bar{\Lambda}_c^- \Xi_c^+\right) = [1.16 \pm 0.42(stat.) \pm 0.15(syst.)] \times 10^{-3}$

Measurement of Ξ_c^+ absolute BRs

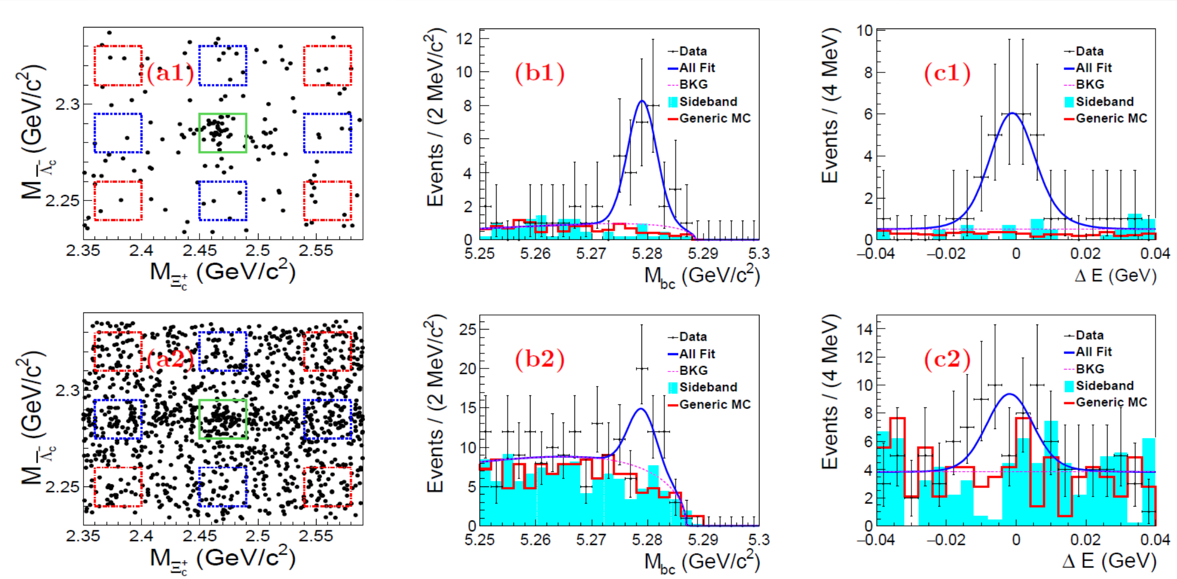
Measurement $\mathcal{B}(\bar{B}^0 \to \bar{\Lambda}_c^- \Xi_c^+)$
with $\Xi_c^+ \to \Xi^-\pi^+\pi^+$ or $pK^-\pi^+$

$\Xi_c^+ \to \Xi^-\pi^+\pi^+$
$N = 24.2 \pm 5.4$

6.9σ

$\Xi_c^+ \to pK^-\pi^+$
$N = 24.0 \pm 6.9$

4.5σ



Y. B. Li. C. P. Shen et al (Belle) PRD 100, 031101 (2019)