Charmed Baryon Results from Belle

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on behalf of Belle collaboration

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Outline

- **Introduction to Belle experiment**
- $\Xi_c^0 \to \Xi^0 \phi(\to K^+K^-)$
- Evidence for $\Omega_c^0 \to \pi^+\Omega(2012)^-$
- Measurements of $\mathcal{B}\left(\Xi_c^0 \to \Xi^- l\, \nu\right)$ and $\mathcal{A}_{cp}$ of $\Xi_c^0 \to \Xi^-\pi^+$
- $\Xi_c^0 \to \Lambda\overline{K}^{*0}$, $\Sigma^0\overline{K}^{*0}$, and Σ^+K^{*-}
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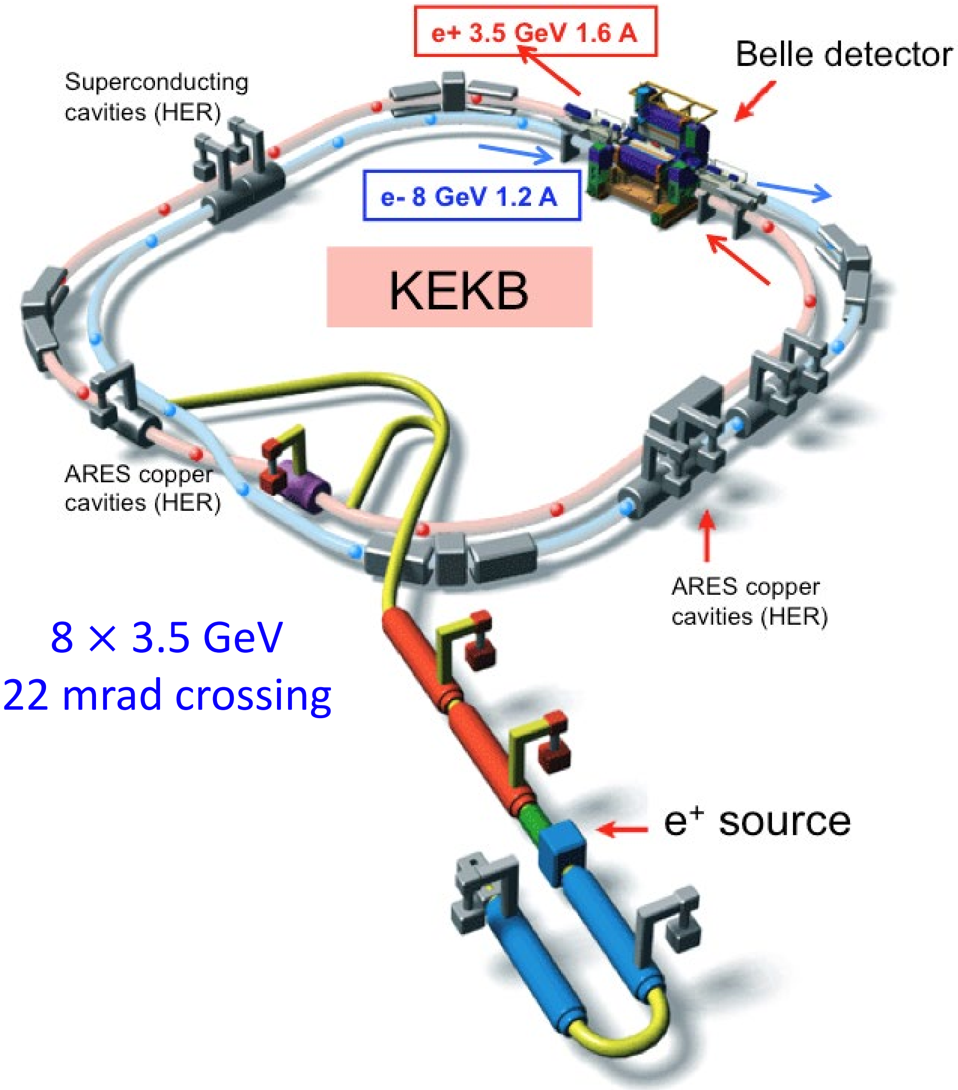
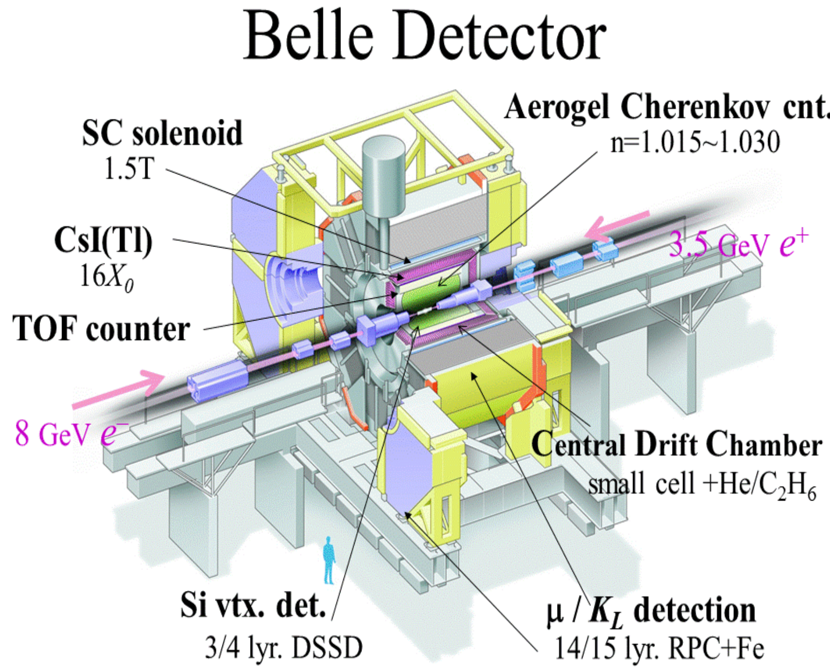
- Summary

Belle experiment and data samples



8 × 3.5 GeV
22 mrad crossing



Data taking: 1999 – 2010

On/off/Scan $\Upsilon(nS)$ peaks

Total luminosity: 980 fb^{-1}

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

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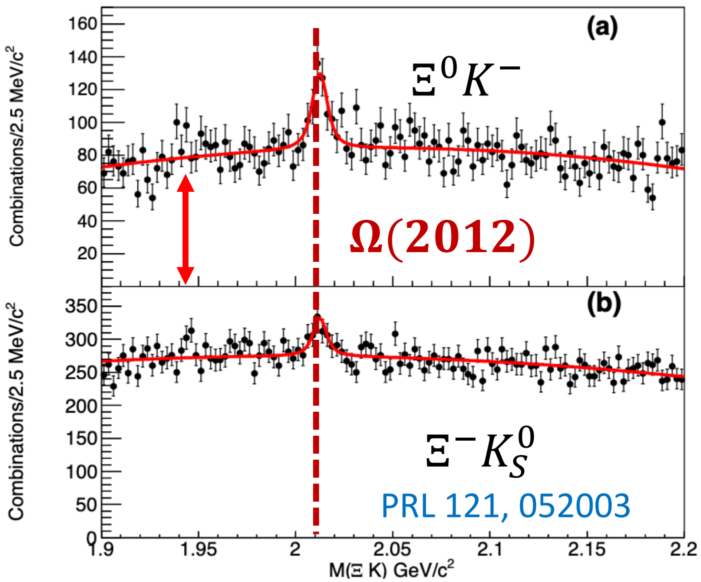
$\Xi_c^0 \to \Xi^0 \phi(\to K^+K^-)$

PRD.103.112002



- Belle recently discovered $\Omega(2012)$ excited baryon via ΞK decay.

- There should be a partner of $\Omega(2012\ )$ near 1.95 GeV

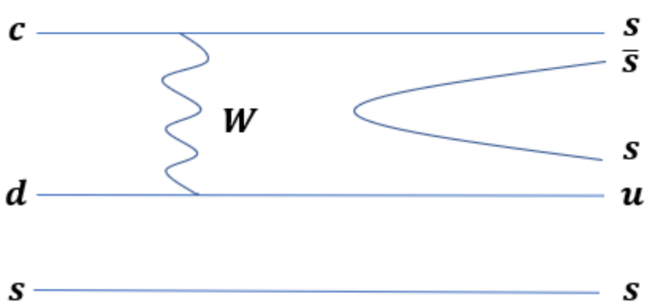
PRD 100, 032006

- $\Xi_c^0 \to \Xi^0 \phi(\ K^+K^-)$ with polarized $\phi \to K^+K^-$ could produce peaks in the ΞK invariant mass spectra.

PRD 88, 114018

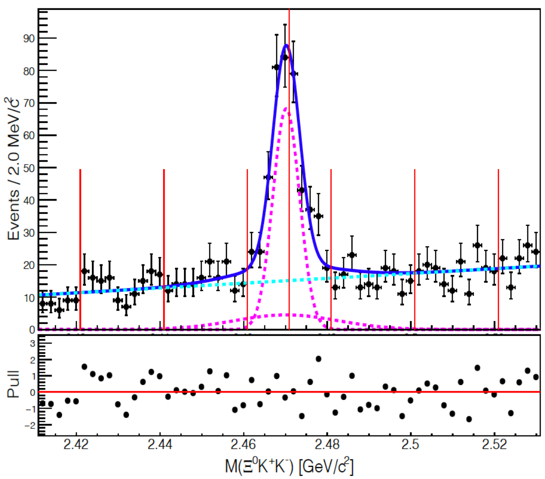
- $\Xi_c^0 \to \Xi^0 \phi(\ K^+K^-)$ can only proceed via W-exchange together with ss production, add to our knowledge of the weak decay of charmed baryons

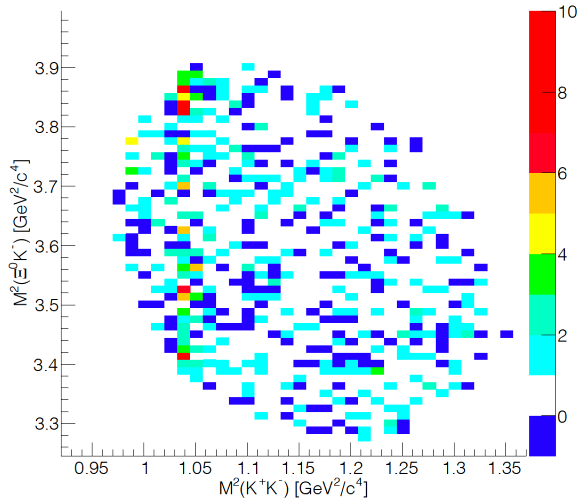
Cabbibo Allowed W-Exchange
ssbar “popping”



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

PRD.103.112002

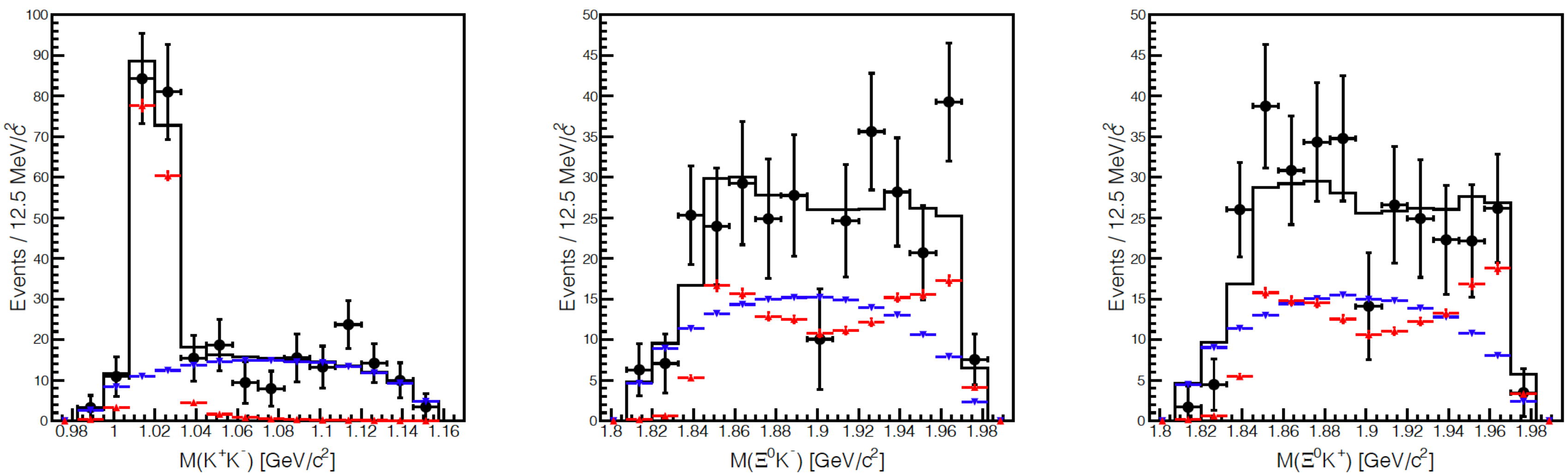




$$\frac{\mathcal{B}(\Xi_c^0 \to \Xi^0 \phi(\to K^+K^-))}{\mathcal{B}(\Xi_c^0 \to \Xi^- \pi^+)}$$
$$= 0.036 \pm 0.004\ (\text{stat.}) \pm 0.002\ (\text{syst.})$$
$$\frac{\mathcal{B}(\Xi_c^0 \to \Xi^0 K^+K^-)}{\mathcal{B}(\Xi_c^0 \to \Xi^- \pi^+)}$$
$$= 0.039 \pm 0.004\ (\text{stat.}) \pm 0.002\ (\text{syst.})$$

$\Xi_c^0 \to \Xi^0 \phi(\to K^+K^-)$ will not contribute to event excesses in the $\mathrm{M}_{\Xi K}$ near 1.95 GeV.

All $\Xi_c^0 \to \Xi^0 \phi$ $\Xi_c^0 \to \Xi^0 K^+K^-$



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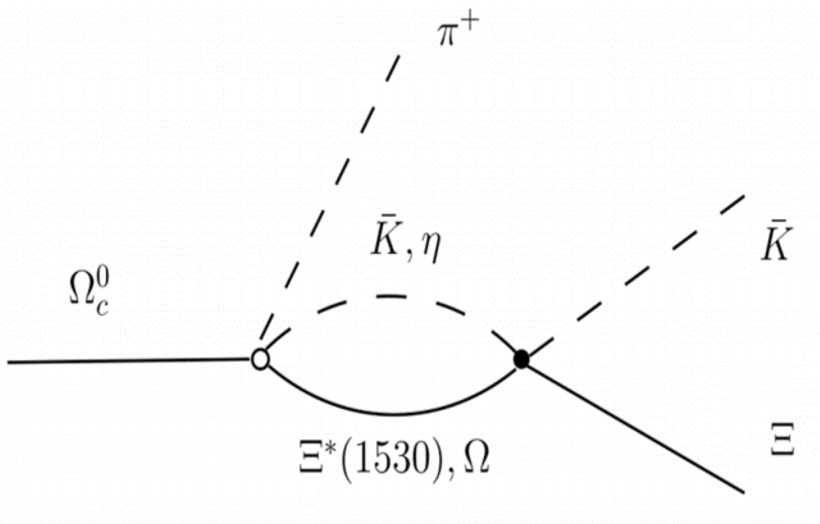
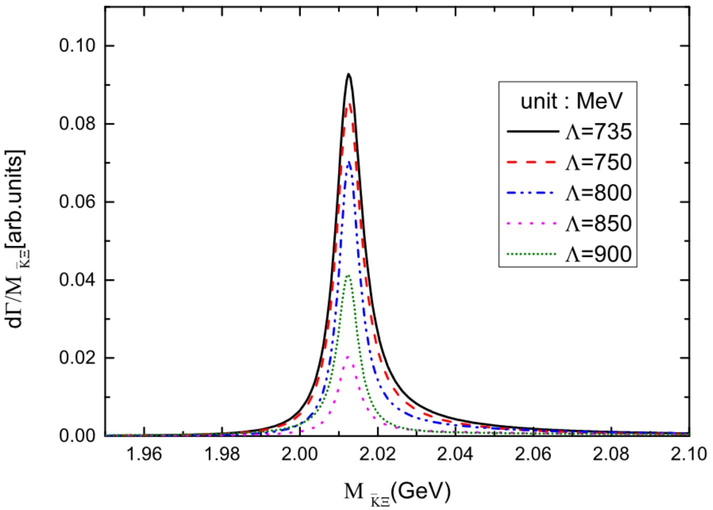
Evidence for $\Omega_c^0 \to \pi^+\Omega(2012)^-$

Motivation:

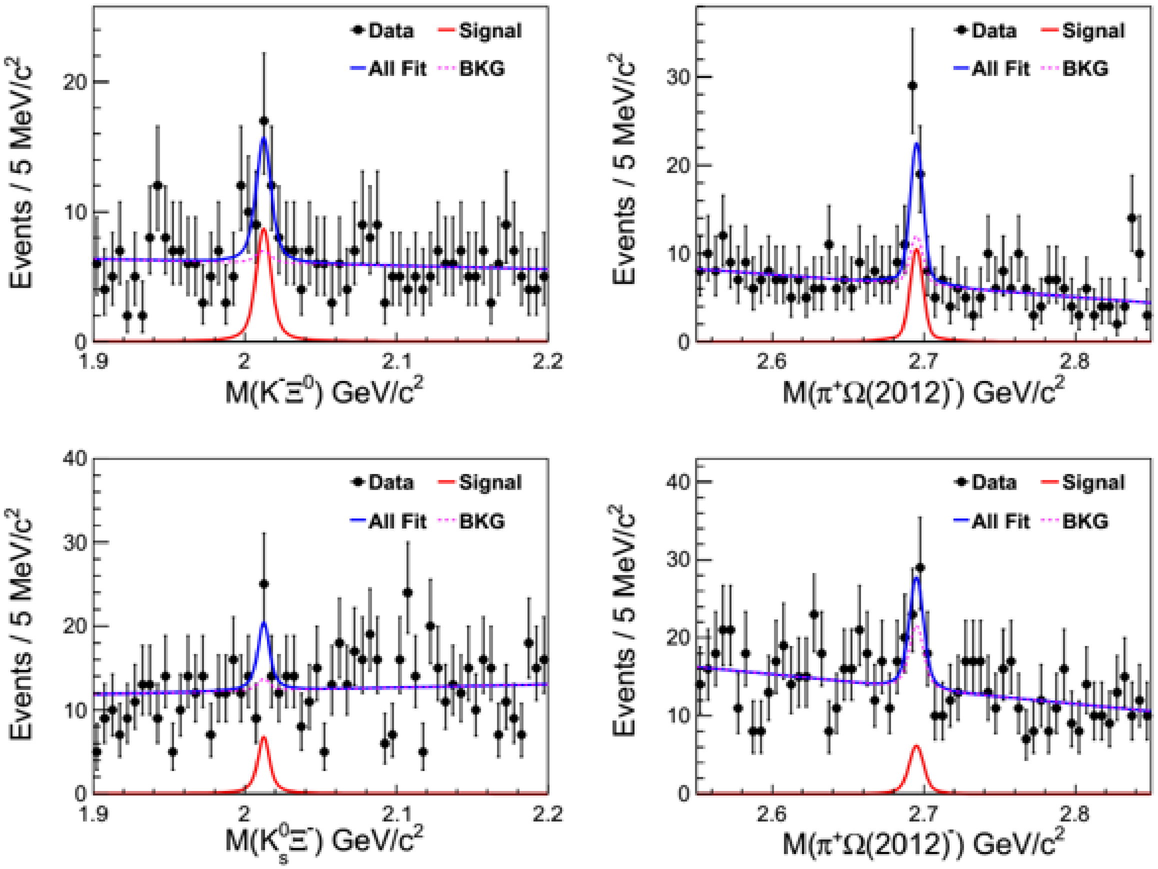
- Searching for new production model is very important to understand the nature of $\Omega(2012)^-$;
- A theoretical study of the $\Omega(2012)^-$ in the nonleptonic weak decays of $\Omega_c^0 \to \pi^+\bar{K}\,\Xi(1530)(\eta\Omega) \to \pi^+(\bar{K}\pi\Xi)^-$ and $(\bar{K}\Xi)^-$ was reported; the authors 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 extract the $\Omega(2012)^-$ signal events from Ω_c^0 decay, a 2D maximum-likelihood fit is performed to $M(K^-\Xi^0)/M(K_S^0\Xi^-)$ and $M(\pi^-\Omega(2012))$.



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

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

$= (9.6 \pm 3.2(\mathrm{stat.}) \pm 1.8(\mathrm{syst.}))\%$

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

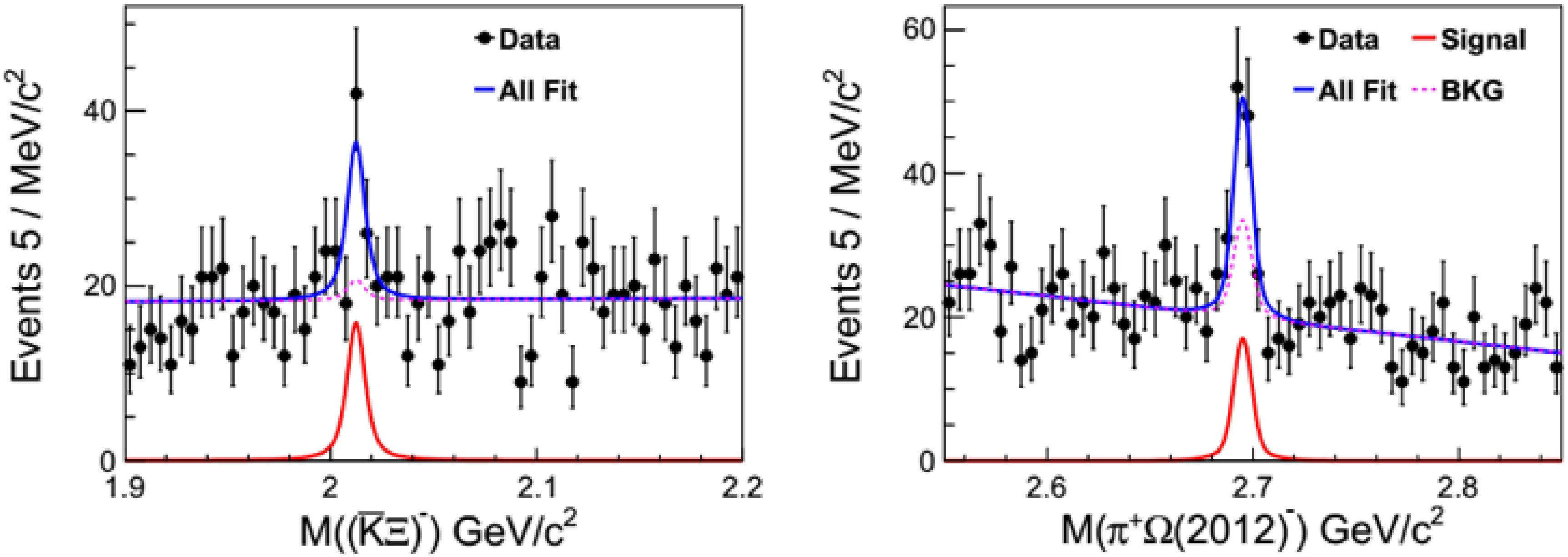
$$\frac{Br(\Omega_c^0 \to \pi^+\Omega(2012)^-)Br(\Omega(2012)^- \to \bar{K}^0\Xi^-)}{Br(\Omega_c^0 \to \pi^+\bar{K}^0\Xi^-)}$$

$= (5.5 \pm 2.8(\mathrm{stat.}) \pm 0.7(\mathrm{syst.}))\%$

- The statistical significance 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 $\Omega_c^0 \to \pi^+\Omega(2012)^-$

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



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

Signal significance: 4.2σ
(including systematic uncertainties)

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

$$= 0.220 \pm 0.059(\mathrm{stat.}) \pm 0.035(\mathrm{syst.})$$

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$\mathcal{B}\left(\Xi_c^0 \to \Xi^- l\, \nu\right)$ and $\mathcal{A}_{cp}$ of $\Xi_c^0 \to \Xi^- \pi^+$

- 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

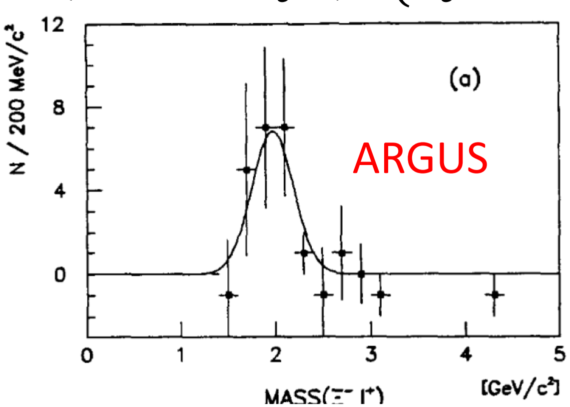
  - ARGUS: $495.0\ \mathrm{pb}^{-1}$ at $\Upsilon(1S, 2S, 3S)$ and off_res energy points; **18 events;** PLB 303, 368(1993)

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

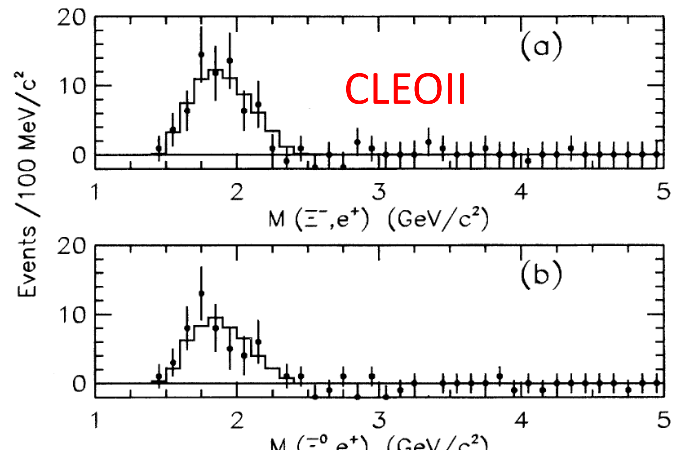
  - CLEOII: $2.1\mathrm{fb}^{-1}$ at and bellow $\Upsilon(4S)$ energy point; **54 signal events**; PRL 74 16(1995)

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

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

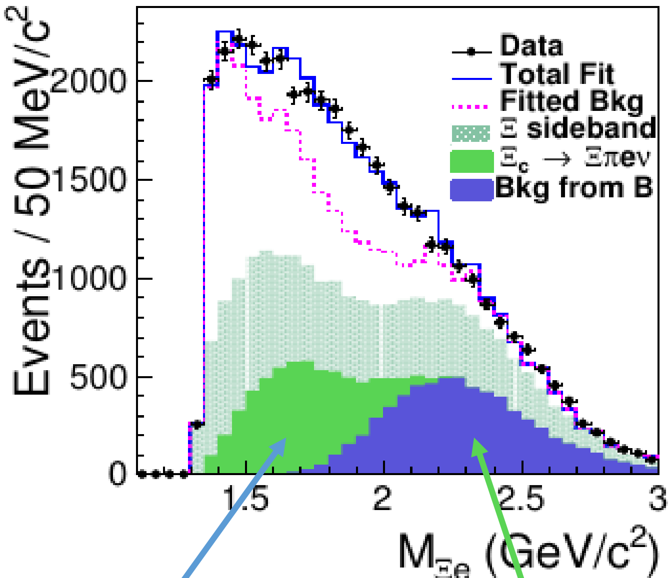


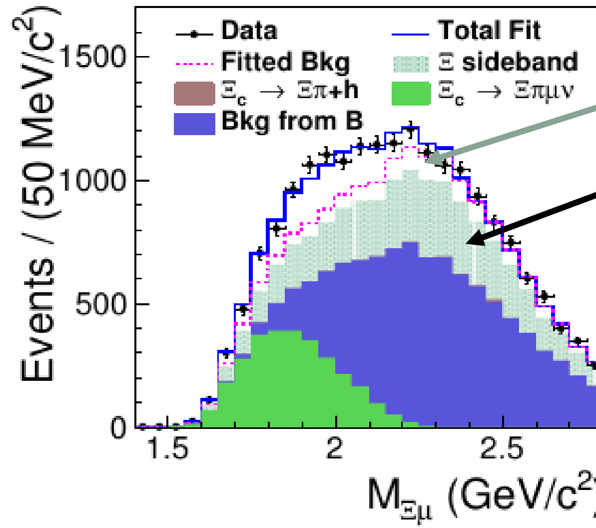
$$\frac{\mathrm{BR}(\Xi_c^0 \to \Xi^- l^+ X)}{\mathrm{BR}(\Xi_c^0 \to \Xi^- \pi^+)} = 0.96 \pm 0.43 \pm 0.18$$



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

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



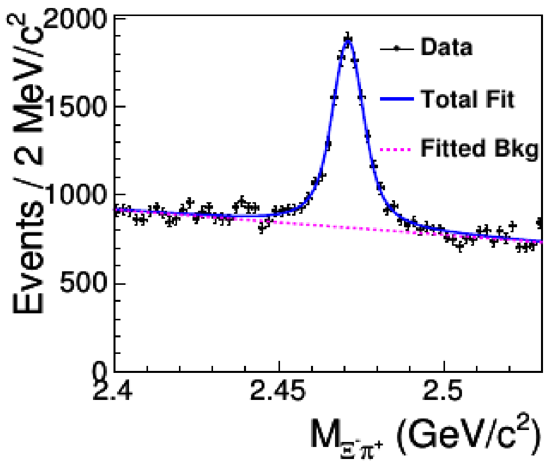


$\Xi^-\ell^-$ wrong sign

Ξ^- sideband

$\Xi_c^0 \to \Xi^-\pi l\, \nu$

B decay



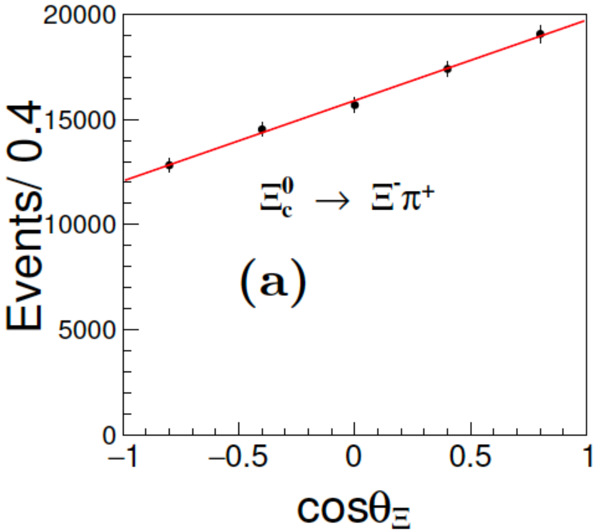
More types of backgrounds are considered such as:

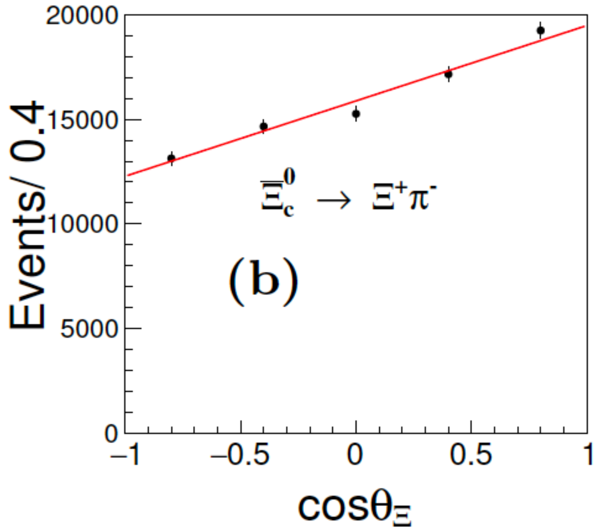
✓$\Xi_c^0 \to \Xi^-\pi l\, \nu$

✓$B^- \to \Xi + \textbf{hardons}, B^+ \to D^0 e^+ \nu_e$

✓$\Xi_c^0 \to \Xi^- n\pi, n = 1,2,3 \ldots$

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

	value	*theory*	old result:
$\mathcal{B}(\Xi_c^0 \to \Xi^- e^+\nu_e)$	$(1.31 \pm 0.39)\%$	$(2.38 \pm 0.44)\%/(3.4 \pm 1.7)\%$ LQCD/QCD sum rule	$(1.9 \pm 1.2)\%$
$\mathcal{B}(\Xi_c^0 \to \Xi^- \mu^+\nu_\mu)$	$(1.27 \pm 0.39)\%$	$(2.29 \pm 0.43)\%$	
$\mathcal{B}(\Xi_c^0 \to \Xi^- e^+\nu_e)/\mathcal{B}(\Xi_c^0 \to \Xi^- \mu^+\nu_\mu)$	1.03 ± 0.09	1.040 ± 0.004	
$\alpha_{\Xi^-\pi^+}$	-0.60 ± 0.045		-0.60 ± 0.4
$\alpha_{\Xi^+\pi^-}$	0.58 ± 0.045		
$\mathcal{A}$	0.015 ± 0.056		

$$\mathcal{A}_{CP} = (\alpha^+ + \alpha^-)/(\alpha^+ - \alpha^-)$$

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$\Xi_c^0 \to \Lambda\overline{K}^{*0}$, $\Sigma^0\overline{K}^{*0}$, and Σ^+K^{*-}

- It is difficult 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.

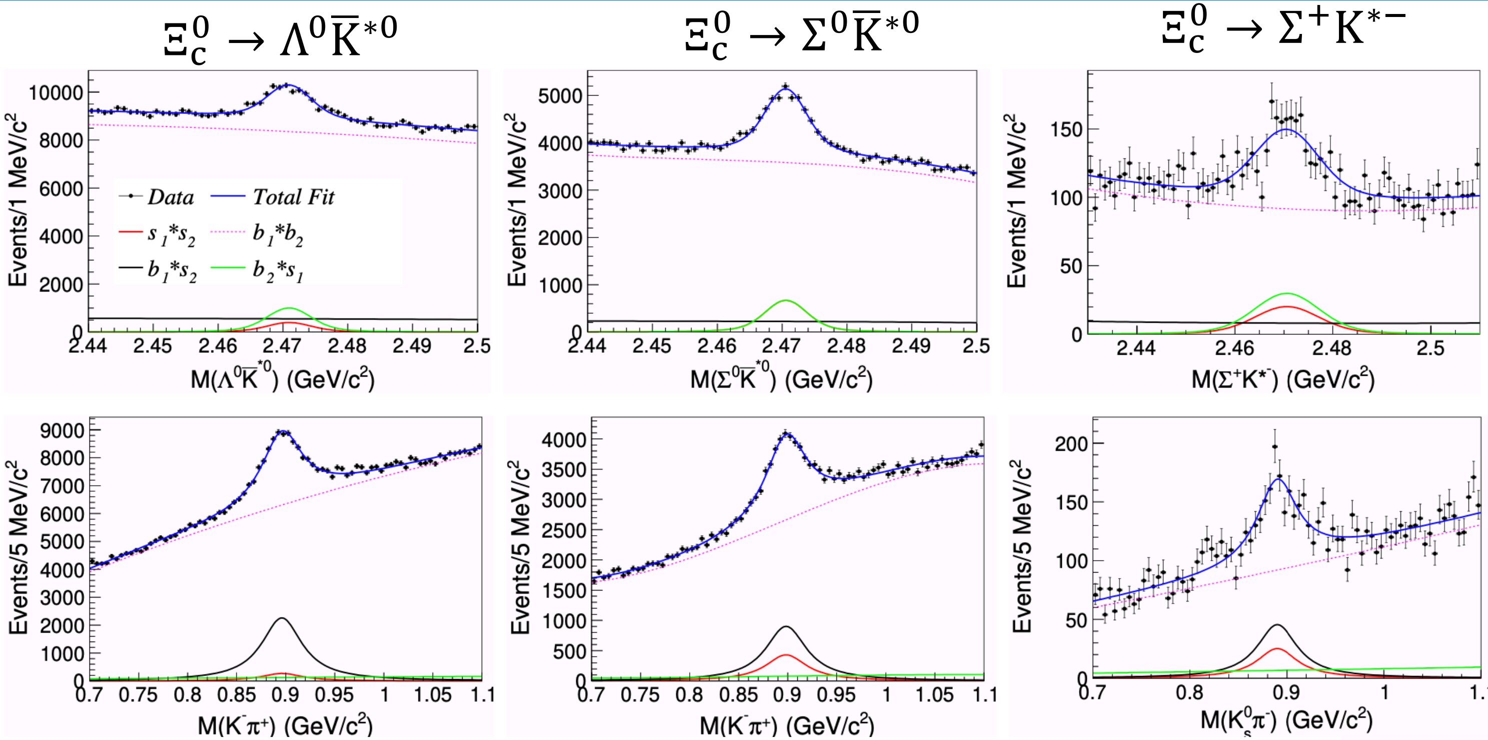
Decay branching fractions (%) and asymmetry parameters of the Cabibbo favored $B_c \to B_n + V$ decays in QCD and $SU(3)_F$ approach.

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)

$\Xi_c^0 \to \Lambda\overline{K}^{*0}$, $\Sigma^0\overline{K}^{*0}$, and Σ^+K^{*-}

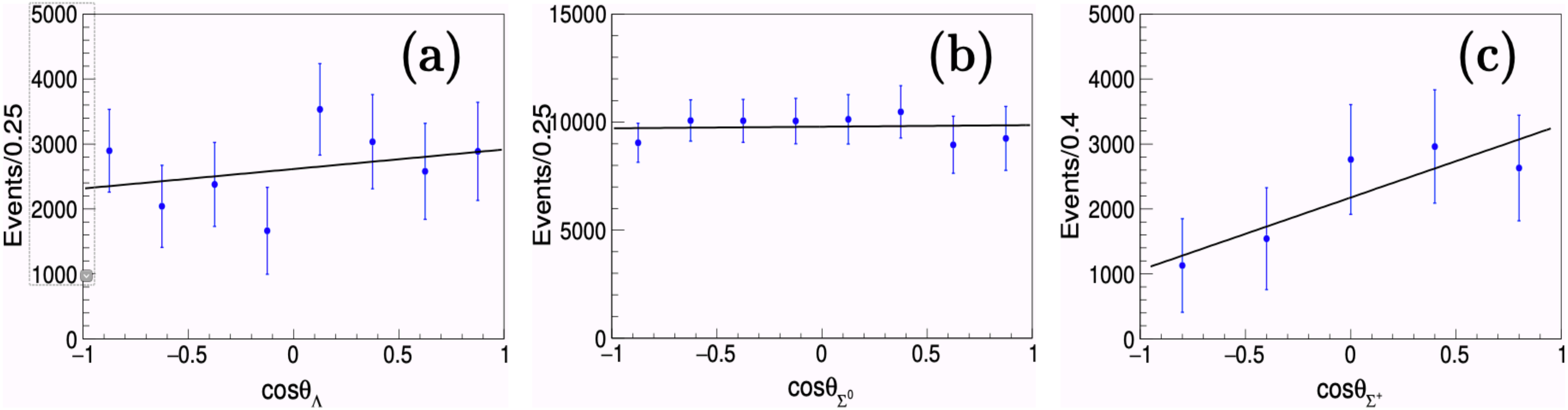


$\mathcal{B}(\Xi_c^0 \to \Lambda\bar{K}^{*0})/\mathcal{B}(\Xi_c^0 \to \Xi^-\pi^+)$	$0.18 \pm 0.02(\text{stat.}) \pm 0.01(\text{syst.})$
$\mathcal{B}(\Xi_c^0 \to \Sigma^0\bar{K}^{*0})/\mathcal{B}(\Xi_c^0 \to \Xi^-\pi^+)$	$0.69 \pm 0.03(\text{stat.}) \pm 0.03(\text{syst.})$
$\mathcal{B}(\Xi_c^0 \to \Sigma^+K^{*-})/\mathcal{B}(\Xi_c^0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

JHEP 2021, 160

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

JHEP 2021, 160



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.

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

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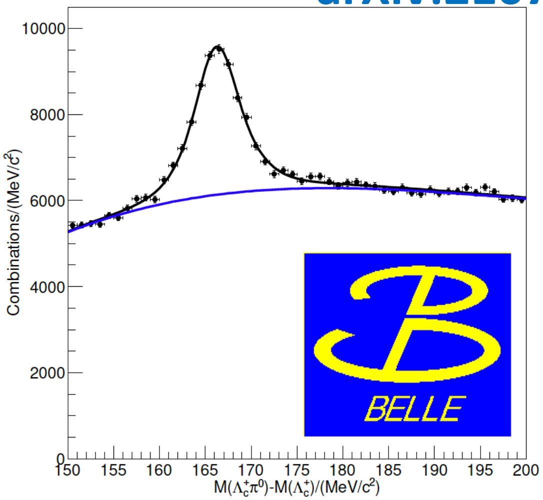
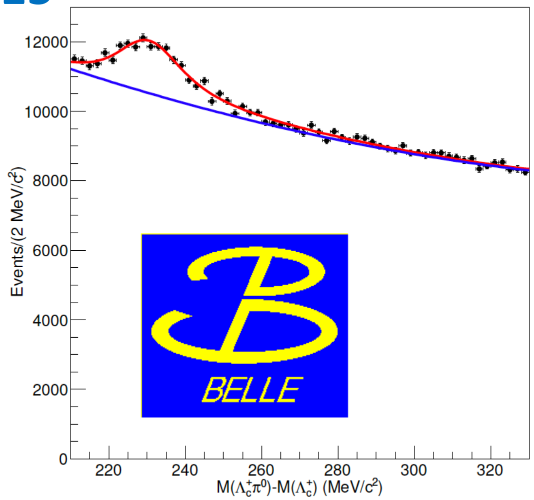
Masses and Widths of the $\Sigma_c(2455)^+$ and $\Sigma_c(2520)^+$

arXiv:2107.05615





$$M_{\Sigma_c(2455)^+} - M_{\Lambda_c^+} = 166.17 \pm 0.05^{+0.16}_{-0.07}\ \mathrm{MeV}/c^2$$

$$\Gamma_{\Sigma_c(2455)^+} = 2.3 \pm 0.3 \pm 0.3\ \mathrm{MeV}/c^2$$

$$M_{\Sigma_c(2520)^+} - M_{\Lambda_c^+} = 230.9 \pm 0.5^{+0.5}_{-0.1}\ \mathrm{MeV}/c^2$$

$$\Gamma_{\Sigma_c(2520)^+} = 17.2^{+2.3}_{-2.1}\,{}^{+0.31}_{0.7}\ \mathrm{MeV}/c^2.$$

Consistent with theories:

Phys. Lett. B 808, 135619

Phys. Rev. D 92, 074014

Phys. Rev. D 12 2077

- Little experimental information on the singly-charged Σ_c^+, due to lower efficiency, higher backgrounds of π^0 transitions

- CLEOII measured the mass, set the limits on width

  Phys. Rev. Lett. 86, 1167

$$M(\Sigma_c^+) - M(\Lambda_c^+) = (166.4 \pm 0.2 \pm 0.3)\ \mathrm{MeV}$$

$$M(\Sigma_c^{*+}) - M(\Lambda_c^+) = (231.0 \pm 1.1 \pm 2.0)\ \mathrm{MeV}$$

- Useful to check the quark model predictions

- Critical to study the $\Lambda_c(2593)^+$, whose pole mass appears to be between the $\Sigma_c(2455)^+\,\pi^0$ and $\Sigma_c(2455)^{++}\,\pi^-$

Summary

- $\Xi_c^0 \to \Xi^0 \phi(\to K^+ K^-)$
  - Branching fraction measured
  - event excesses in the $M_{\Xi K}$ near 1.95 GeV not from $\Xi_c^0 \to \Xi^0 \phi$
- **Evidence for $\Omega_c^0 \to \pi^+ \Omega(2012)^-$**
  - Branching fraction measured with 4.2σ signal
- **Measurements of $\mathcal{B}(\Xi_c^0 \to \Xi^- l\, \nu)$ and $\mathcal{A}_{cp}$ of $\Xi_c^0 \to \Xi^- \pi^+$**
  - Error reduce by 1 order
- $\Xi_c^0 \to \Lambda \overline{K}^{*0}$**,** $\Sigma^0 \overline{K}^{*0}$**, and** $\Sigma^+ K^{*-}$
  - First observation
- **Determined masses and widths of the $\Sigma_c(2455)^+$ and $\Sigma_c(2520)^+$**

Thank you!

Thank you!

Backup: Jp of Xic2970

The uncertainty will be dominated by the BF of the ground-state Ξ_c baryons. Such uncertainties are avoided by calculating the ratio in a different way, with inclusive measurements of Ξ_c^0 and Ξ_c^+ and an assumption of isospin symmetry in their inclusive cross sections. We note that this assumption is confirmed within 15% in the $\Sigma_c^{(*)}$ case.

TABLE III. Result of the angular analysis of the decay $\Xi_c(2970)^+ \to \Xi_c(2645)^0\pi^+$. Here, n.d.f. denotes the number of degrees of freedom.

Spin hypothesis	1/2	3/2	5/2
χ^2/n.d.f.	9.3/9	7.7/7	7.5/6
Probability	41%	36%	28%
T	⋯	-0.5 ± 1.1	0.7 ± 1.6
ρ_{11}	0.5	0.13 ± 0.26	0.08 ± 0.27
ρ_{33}	⋯	0.37 ± 0.26	0.12 ± 0.09
ρ_{55}	⋯	⋯	0.30 ± 0.28

TABLE IV. Expected angular distribution for spin-parity hypotheses of $\Xi_c(2970)^+$ with an assumption that the lowest partial wave dominates.

J^P	Partial wave	$W(\theta_c)$
$1/2^+$	P	$1 + 3\cos^2\theta_c$
$1/2^-$	D	$1 + 3\cos^2\theta_c$
$3/2^+$	P	$1 + 6\sin^2\theta_c$
$3/2^-$	S	1
$5/2^+$	P	$1 + (1/3)\cos^2\theta_c$
$5/2^-$	D	$1 + (15/4)\sin^2\theta_c$

J^P	$1/2^\pm$	$3/2^-$	$5/2^+$
χ^2/n.d.f.	6.4/9	32.2/9	22.3/9
Exclusion level (s.d.)	⋯	5.5	4.8

$$R = \frac{N^*}{\mathcal{E}^* \times \frac{N(\Xi_c^+)}{\epsilon^+}} \Bigg/ \frac{N'}{\sum_i \mathcal{E}'_i \times \frac{N(\Xi_c^0)_i}{\epsilon_i^0}}.$$

Backup: Xic to Xi KK

Values of Helicity Amplitudes for EvtGen HELAMP class

On-Shell Decay:

$$q^2 = (p_{\Xi_c^0} - p_{\Xi^0})^2 = m_\varphi^2$$

$$H_{+\frac{1}{2}0} = -1.091 \qquad H_{-\frac{1}{2}0} = 4.123$$

$$H_{+\frac{1}{2}+1} = -2.2305 \qquad H_{-\frac{1}{2}-1} = 4.2955$$

```
Decay Xi_c0
0.90 Xi- pi+ PHSP;
0.065 Xi0 phi HELAMP 2.2305 3.14159265359 1.091 3.14159265359 4.123 0.0 4.2955 0.0;
0.035 Xi0 K+ K- PHSP;
Enddecay
```

$H_{+\frac{1}{2}+1}$ $H_{+\frac{1}{2}0}$ $H_{-\frac{1}{2}0}$ $H_{-\frac{1}{2}-1}$

In Resonant/Mixed MC, the phi is decayed through VSS as expected

Non-Resonant
$\Xi_c^0 \to \Xi^0 K^+ K^-$

Resonant
$\Xi_c^0 \to \Xi^0 (\phi \to K^+ K^-)$

Normalization
$\Xi_c^0 \to \Xi^- \pi^+$

Mixed
$\Xi_c^0 \to 0.9*[\Xi^- \pi^+] +$
$\Xi^0 [0.065*(\phi \to K^+ K^-) + 0.035*(K^+ K^-)]$

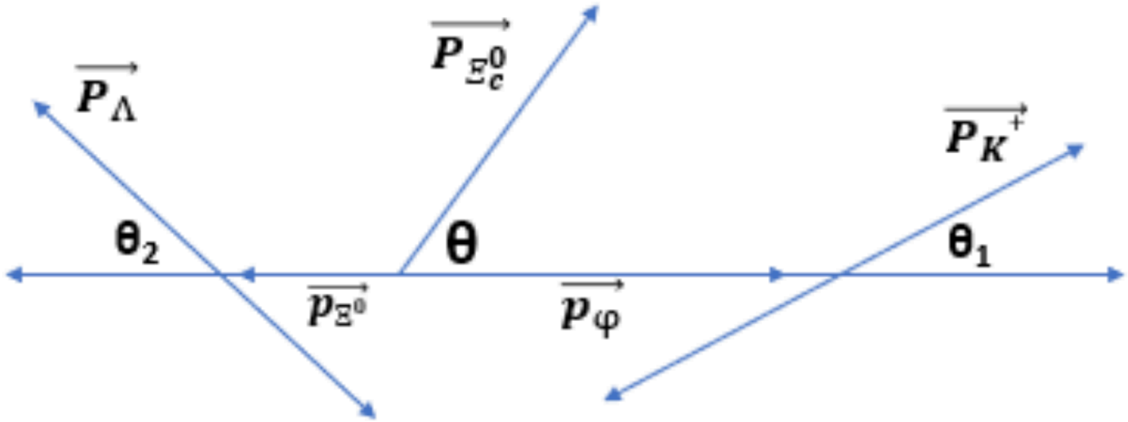
Truth:
$\Gamma(\Xi^0\phi) / \Gamma(\Xi_c^0 \to \Xi^-\pi^+) =$ **0.07222…**
$\Gamma(\Xi^0 K^+ K^-) / \Gamma(\Xi_c^0 \to \Xi^-\pi^+) =$ **0.03888…**

Backup: Xic to Xi KK

These topological substructures are due to the helicity angles of the Xic0 polarizing the in the ½ -> ½ + 1 resonant decay process

Polarization is defined:

$$\vec{P} = \frac{\hat{z}\ x\ \vec{p}}{p}$$



Ξ_c^0 decays with polarization $\overrightarrow{P_{\Xi_c^0}}$
into a resonant **$\phi \to K^+K^-$**
and "spin-conserving" **$\Xi^0 \to \Lambda\pi^0$**
Weak (Non-Parity Conserving) ½ -> ½ 1 decay

Polarization Angles θ, θ_1, and θ_2 describe the full angular distribution of the azimuthally independent (real) final state $\Xi^0K^+K^-$

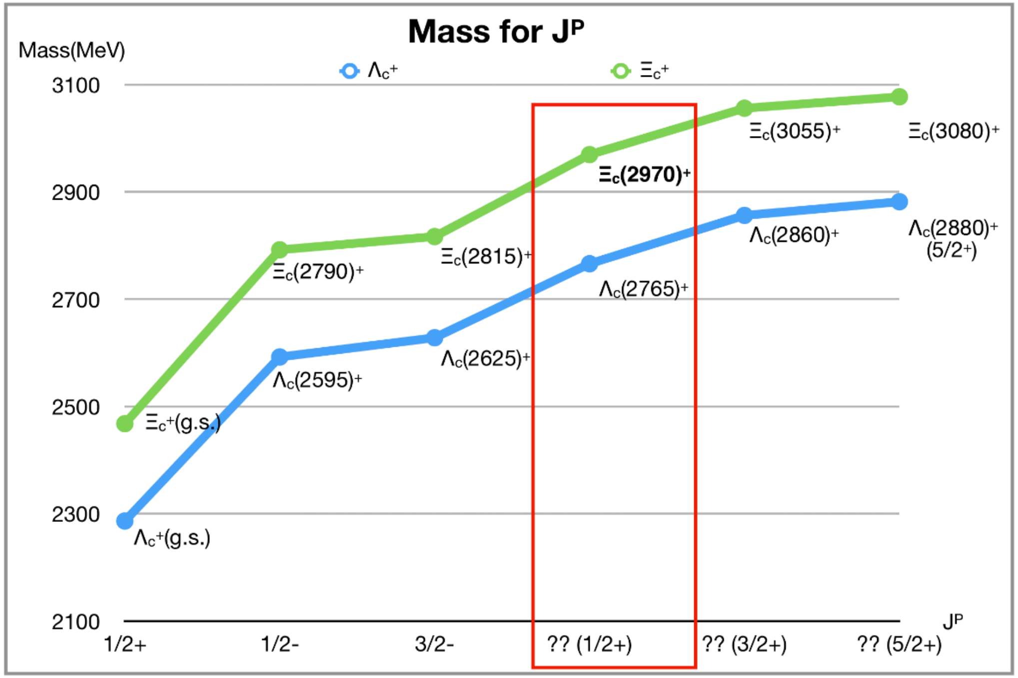
Backup: Sigmac mass and width

A fit is made to Fig. 2 using a third-order Chebychev polynomial function to represent the background, and a P-wave relativistic Breit-Wigner function convolved with the previously described double-Gaussian resolution function, taking into account the small mass offset. The Breit-Wigner signal function includes a Blatt-Weisskopf barrier factor, with radius parameter of R = 3 GeV .

Outline

- Introduction to Belle experiment
- **Spin and parity determination of $\Xi_c(2970)^+$**
- $\Xi_c^0 \to \Xi^0 \phi(\to K^+K^-)$
- Evidence for $\Omega_c^0 \to \pi^+\Omega(2012)^-$
- Measurements of $\mathcal{B}\left(\Xi_c^0 \to \Xi^- l\,\nu\right)$ and $\mathcal{A}_{cp}$ of $\Xi_c^0 \to \Xi^-\pi^+$
- $\Xi_c^0 \to \Lambda\overline{K}^{*0}$, $\Sigma^0\overline{K}^{*0}$, and Σ^+K^{*-}
- Masses and Widths of the $\Sigma_c(2455)^+$ and $\Sigma_c(2520)^+$

J^p of $\Xi_c(2970)^+$

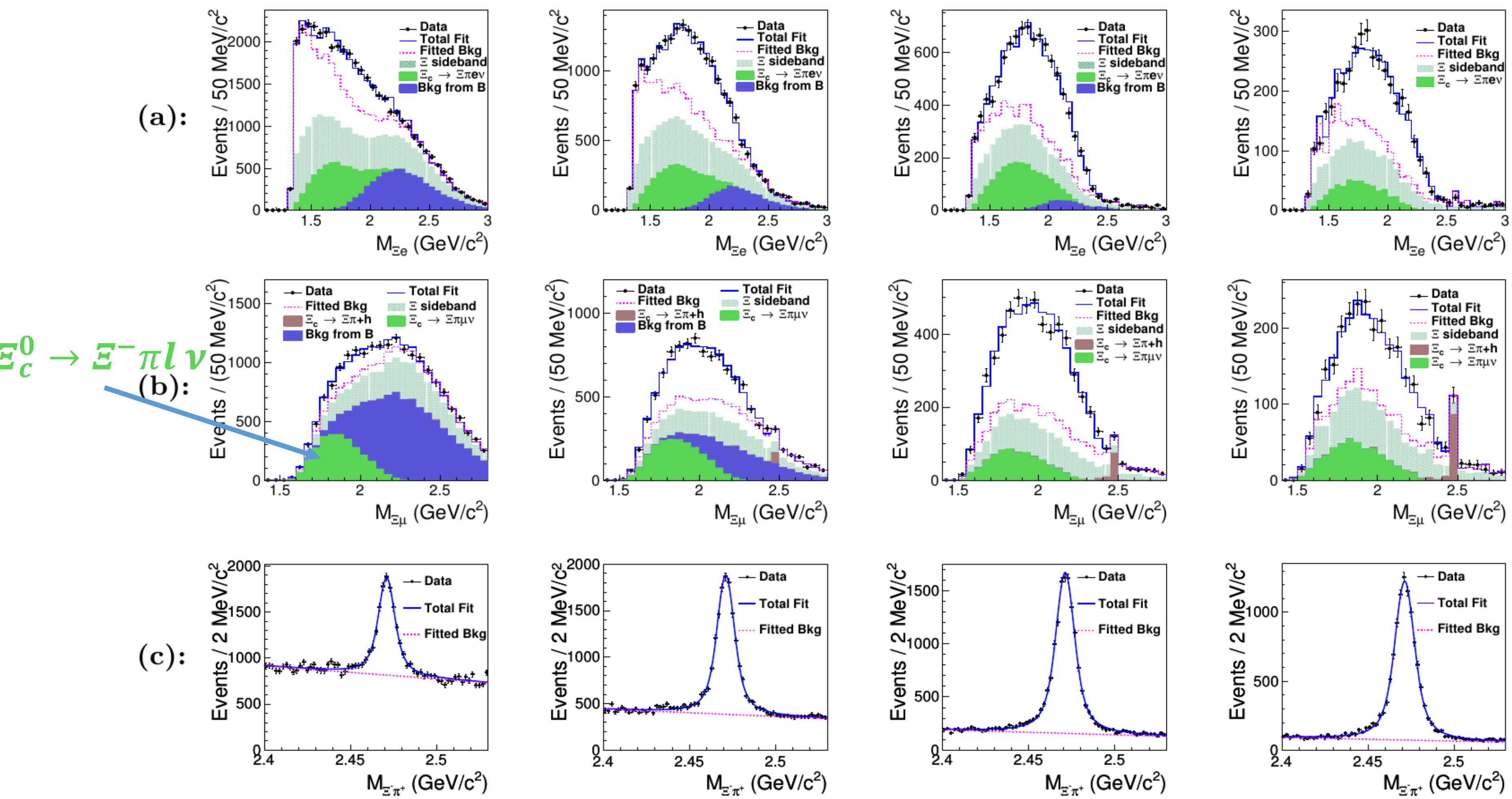


PRD 103, L111101 (2021)

- No experimental determination J^p for Charmed baryons
- Low excited Ξ_c states can be uniquely identified as particular states predicted by the quark model
- Identification failed in higher excitation region, due to multiple states within the typical mass accuracy of quark-model predictions.

- Similar tendency in mass of the excited states of Λ_c and Ξ_c
- It is conceivable that $\Xi_c(2970)$ is the counter part of $\Lambda_c(2675)$.[PRD 75, 014006 (2007)]

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



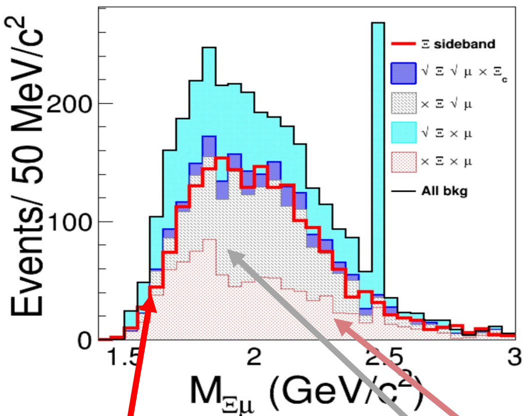
$p^*_{\Xi^- X}/p^*_{\max}$ region: (0.45, 0.55) (0.55, 0.65) (0.65, 0.75) > 0.75

$p^*_{\Xi\ell(\pi)}$ 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 $\mathcal{B}(\Xi_c^0 \to \Xi^- l\, \nu\,)$

Data-driven method used to describe background shape

- BKG candidates from generic MC
- Filled histograms are stacked.

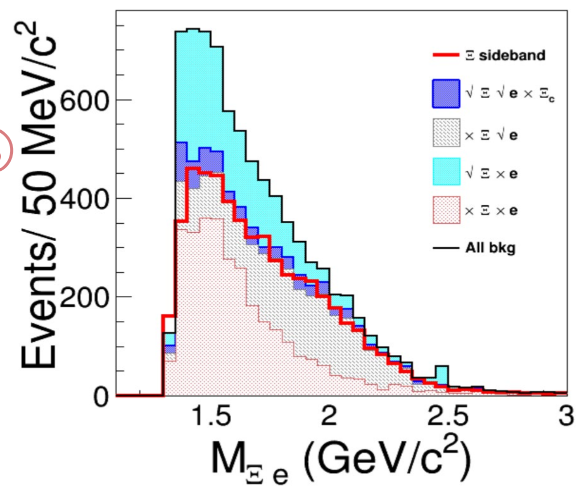


Background component

	Ξ	ℓ	Ξ_c^0
①	√	×	√ or ×
②	×	√	√ or ×
③	×	×	×
④	√	√	×

$\Xi^-\ell^-$ is the combination of the same charged $\Xi^-$and ℓ^-

- Ξ^- sideband from $\Xi^-\mu^+$: ②+③
- $\Xi^-\mu^-$ selection: ①+③+④
- Ξ^- sideband from $\Xi^-\mu^-$: ③



For data under resonance:
Backgrounds such as:

$B^- \to \Xi + \text{hardons}$

$B^+ \to D^0 e^+ \nu_e$

are **not covered in this method**

J^p of $\Xi_c(2970)^+$

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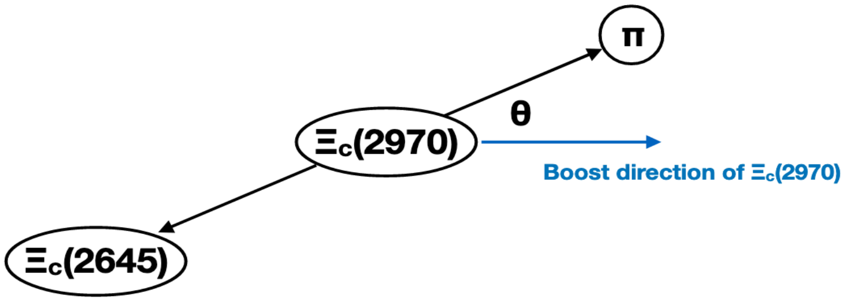
- Parity:

  Ratio of partial width

  $$\frac{\Gamma(\Xi_c(2970)\to\Xi_c(2656)\pi)}{\Gamma(\Xi_c(2970)\to\Xi'_c\pi)}$$



- Spin:
  - $\cos\theta_h$, $\cos\theta_c$

  θ_h: helicity angle of $\Xi_c(2970)$

  θ_c: helicity angle of $\Xi_c(2645)$

$\Xi_c(2970) \to \Xi_c(2645)\pi$

- Expected helicity angle distribution $W_J(\theta)$ for $J \to 3/2+0$:

$\boldsymbol{\theta_h}$

$$W_{\frac{1}{2}} = constant$$

$$W_{\frac{3}{2}} = \rho_{33}(1 + T(\frac{3}{2}\cos^2\theta - \frac{1}{2})) + \rho_{11}(1 + T(-\frac{3}{2}\cos^2\theta + \frac{1}{2}))$$

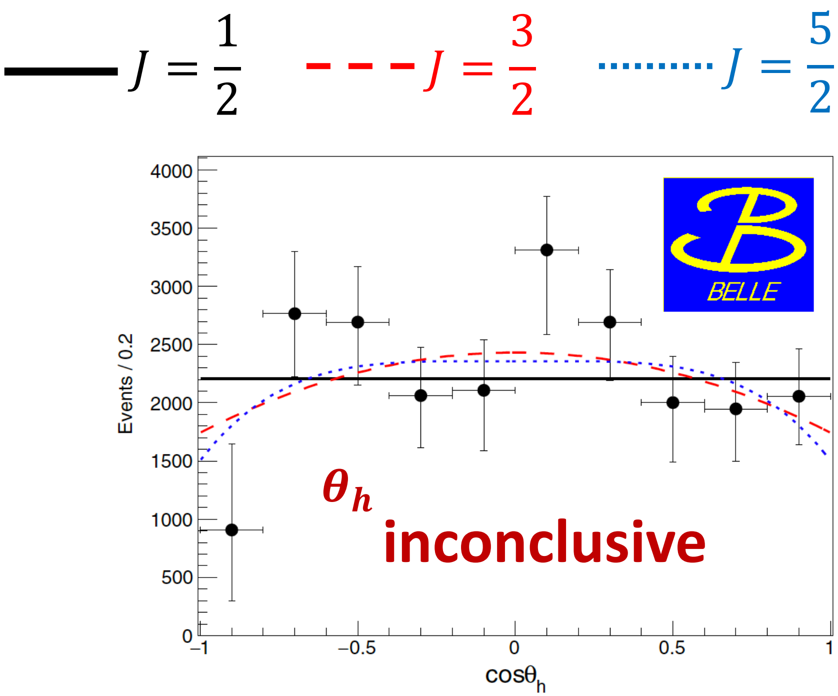
$$\begin{aligned} W_{\frac{5}{2}} = \frac{3}{32}[&\rho_{55}5((-\cos^4\theta - 2\cos^2\theta + 3) + T(-5\cos^4\theta + 6\cos^2\theta - 1) \\ &+ \rho_{33}((15\cos^4\theta - 10\cos^2\theta + 11) + T(75\cos^4\theta - 66\cos^2\theta + 7)) \\ &+ \rho_{11}2((-5\cos^4\theta + 10\cos^2\theta + 3) + T(-25\cos^4\theta + 18\cos^2\theta - 1)] \end{aligned}$$

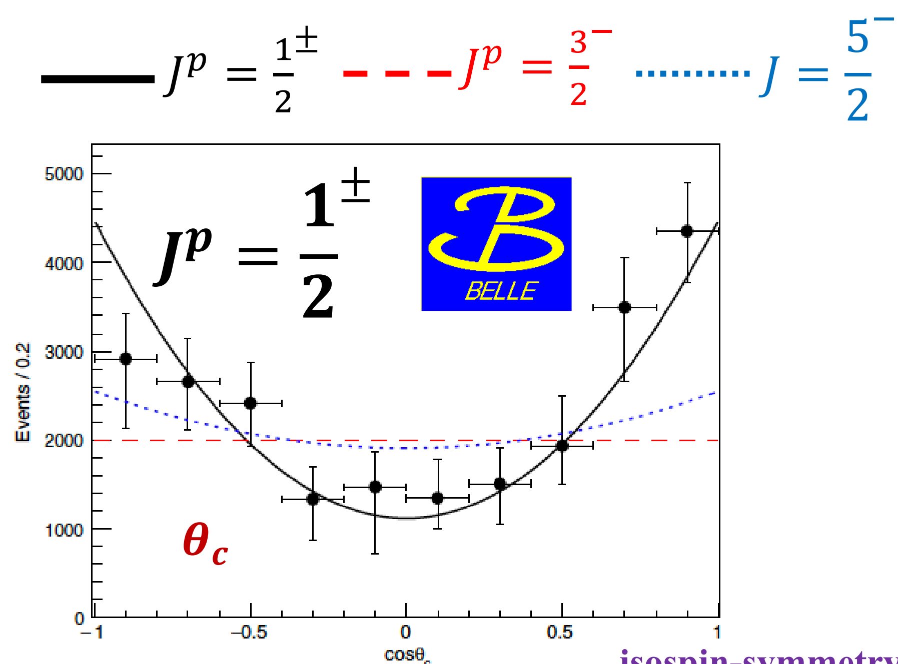
,where $T = \frac{|T(p,\frac{3}{2},0)|^2 - |T(p,\frac{1}{2},0)|^2}{|T(p,\frac{3}{2},0)|^2 + |T(p,\frac{1}{2},0)|^2}$ and $T(p,\lambda_1,\lambda_2)$ is the matrix element of two body decay with helicity of daughter particles to be λ_1 and λ_2.

$\boldsymbol{\theta_c}$

J^P	Partial wave	$W(\theta_c)$
$1/2^+$	P	$1+3\cos^2\theta_c$
$1/2^-$	D	$1+3\cos^2\theta_c$
$3/2^+$	P	$1+6\sin^2\theta_c$
$3/2^-$	S	1
$5/2^+$	P	$1+(1/3)\cos^2\theta_c$
$5/2^-$	D	$1+(15/4)\sin^2\theta_c$

J^p of $\Xi_c(2970)^+$





isospin-symmetry breaking effects

$$R = \frac{\Gamma(\Xi_c(2970)^+ \to \Xi_c(2656)^0 \pi^+)}{\Gamma(\Xi_c(2970) \to \Xi_c'^0 \pi^+)} = 1.67 \pm 0.29(stat.)^{+0.15}_{-0.09}(syst.) \pm 0.25$$

$$R = \begin{cases} 1.06 \text{ for } J^p = \frac{1}{2}^+ \text{ with light-quark degrees of freedom } s_l = 0 \\ 0.26 \text{ for } J^p = \frac{1}{2}^+ \text{ with light-quark degrees of freedom } s_l = 1 \\ \ll 1 \text{ for } J^p = \frac{1}{2}^- \text{ since } \Xi_c'^0\pi^+ \text{ is in S wave while that to } \Xi_c(2656)^0\pi^+ \text{ in D wave} \end{cases}$$