

Measurenet of the E_c Abosute Branching Fraction at Belle

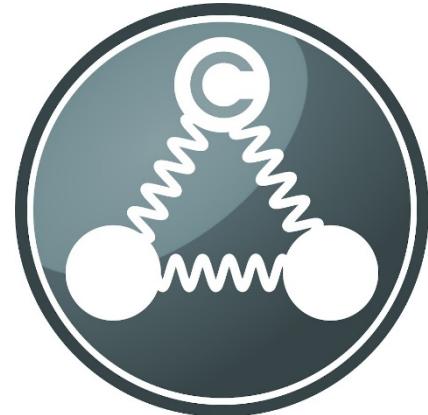


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On behalf of Belle collaboration
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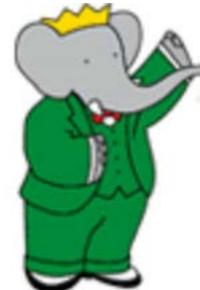
Introduction

- Charm energy scale, $\alpha_s \sim 1$:
 - boundary of (non-)perturbative
 - platform for strong interaction study
- **Charmed baryons** offer more information:
 - W-exchange diagrams can contribute without the helicity suppression
 - Internal W emission is significant.
 - Parity violation is readily observable because the decay of the daughter hyperon also violates parity.
 - Testing heavy quark symmetry and light quark chiral symmetry



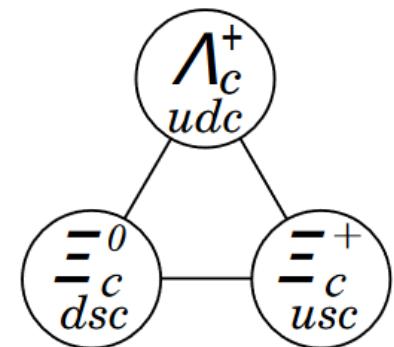
Introduction

- Charmed Baryons are **difficult** to produce
 - no resonant production mechanisms
 - continuum production with small cross-sections
- Products in the **decays** of heavy mesons
Or **high energy** colliders



Introduction

- In SU(3) anti-triplet charmed baryons, only Λ_c absolute Branching Fractions were measured by Belle [PRL 113, 042002] and BESIII [PRL 116,052001].
 - Since Ξ_c^0 [PRL 62,863(1989)] and Ξ_c^+ [PLB 122,455(1983)] were discovered ~ 30 years ago, no absolute BRs could be measured.
 - For Ξ_c^0 , the Brs are all measured with ratios to $\Xi^- \pi^+$
 - For Ξ_c^+ , the Brs are all measured with ratios to $\Xi^- \pi^+ \pi^+$
- So called reference modes



Introduction

- $\Xi_c^0 \rightarrow p K^- K^- \pi^+$ and $\Xi_c^+ \rightarrow p K^- \pi^+$ are the fundamental channels to reconstruct Ξ_c^0 and Ξ_c^+ at hadron collider such as LHCb
 - Their BRs are important input for bottom baryons and double charmed baryons study.
- In theory:
 - $\mathcal{B}(\Xi_c^0 \rightarrow \Xi^- \pi^+) \approx 1.12\% \text{ or } 0.74\%$ [PRD48,4188]
 - $\mathcal{B}(\Xi_c^+ \rightarrow \Xi^- \pi^+ \pi^+) = (1.47 \pm 0.84)\%$ [PRD97,073006]
 - $\mathcal{B}(\Xi_c^+ \rightarrow p K^- \pi^+) = (2.2 \pm 0.8)\%$ [EPJC78,224; CPC42, 051001]
- The decay $B \rightarrow \Lambda_c^- \Xi_c$, proceed via $b \rightarrow c \bar{c} s$ transitions, $\text{BR} \sim 10^{-3}$ in theoretical calculation
 - A good chance to analysis $B \rightarrow \Lambda_c^- \Xi_c$ decay in Belle.

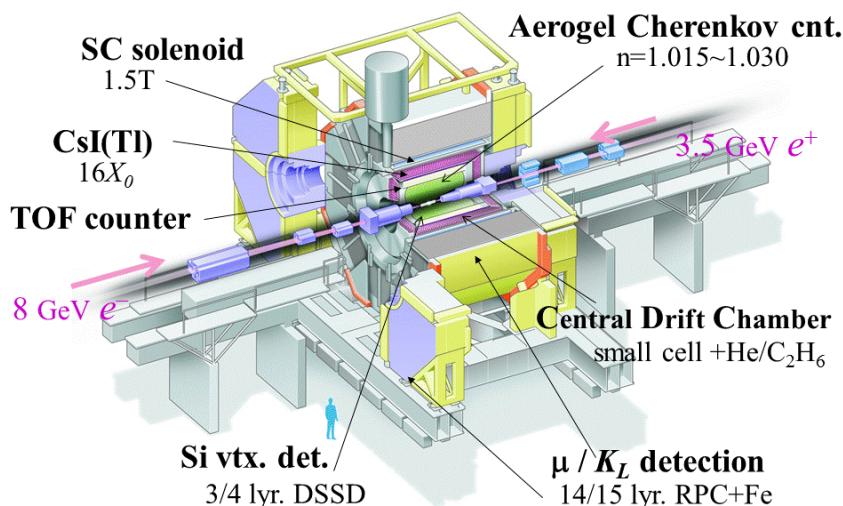
Introduction

Measured by Ξ_c exclusive decay

$$\mathcal{B}(\Xi_c \rightarrow xxx) = \frac{\mathcal{B}(B \rightarrow \Lambda_c^- \Xi_c) \mathcal{B}(\Xi_c \rightarrow xxx)}{\mathcal{B}(B \rightarrow \Lambda_c^- \Xi_c)}$$

Measured by Ξ_c inclusive decay

Belle Detector



$\sim 711 \text{ fb}^{-1} Y(4S)$

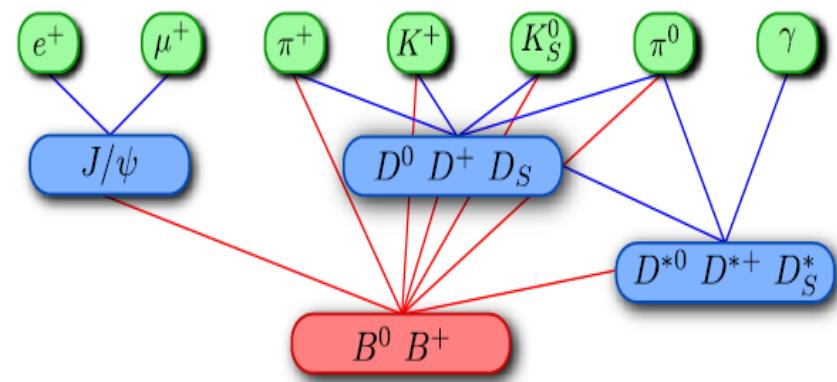
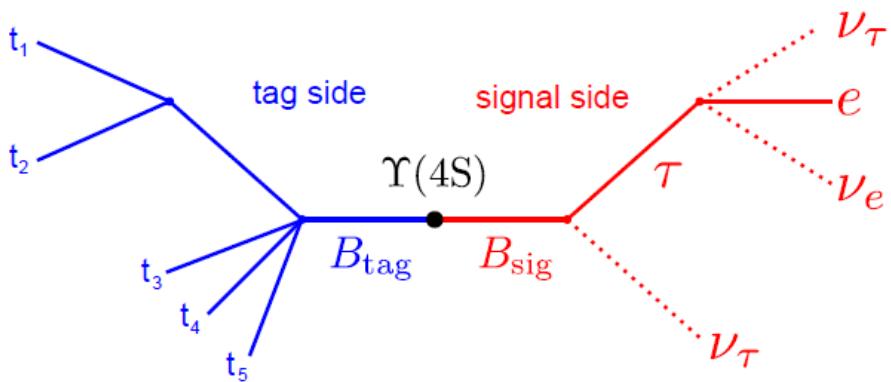
772M $B\bar{B}$ data sample

B meson tagging

- B meson comes from $\Upsilon(4S) \rightarrow B\bar{B}$
- If we reconstruct a B_{tag} , the recoil is B_{sig}
- 1042 B decay channel, 71 neural networks
- An overall efficiency:

0.36% for B^+

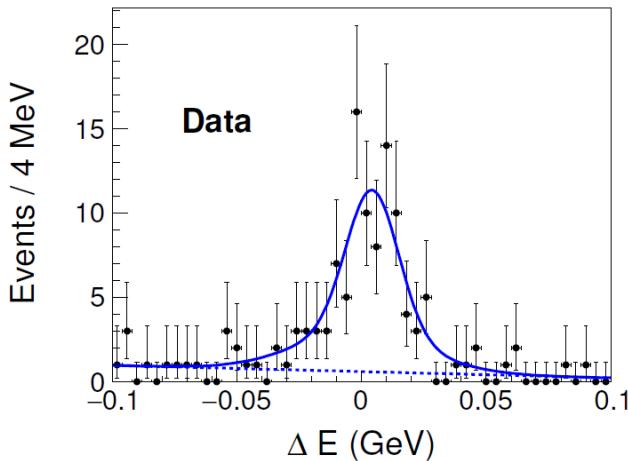
0.24% for B^0



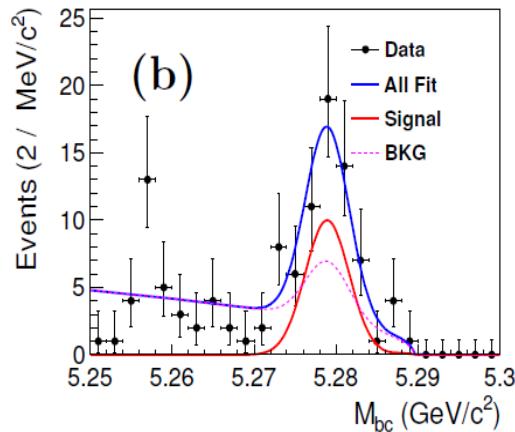
So called **Full Reconstruction algorithm (FR)**

E_c^0

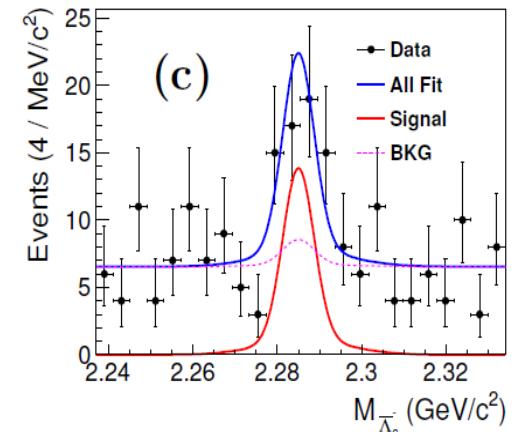
inclusive measurement



$$\Delta E = \sum_i E_i - E_{beam}$$



$$M_{bc} = \sqrt{E_{beam}^2 - (\sum_i \vec{p}_i)^2}$$



double-Gaussian functions
for M_{bc} signal

$$f(M_1, M_2) = N_{sb}^{\text{sig}} s_1(M_1) s_2(M_2) + N_{sb}^{\text{bg}} s_1(M_1) b_2(M_2) + N_{bs}^{\text{bg}} b_1(M_1) s_2(M_2) + N_{bb}^{\text{bg}} b_1(M_1) b_2(M_2),$$

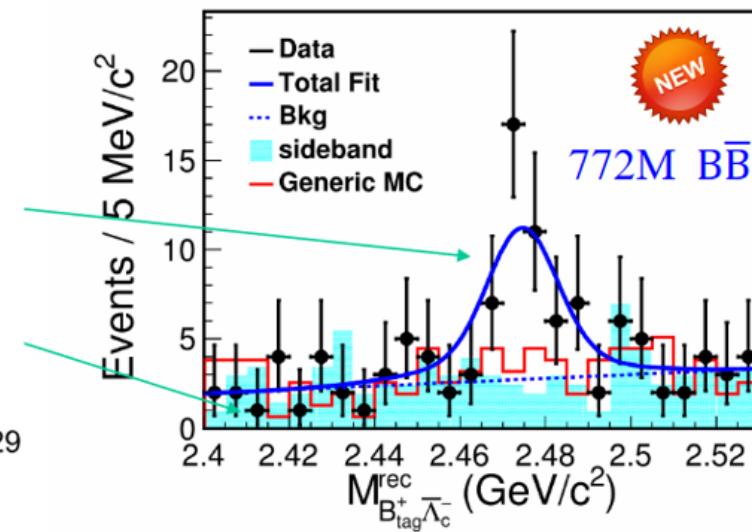
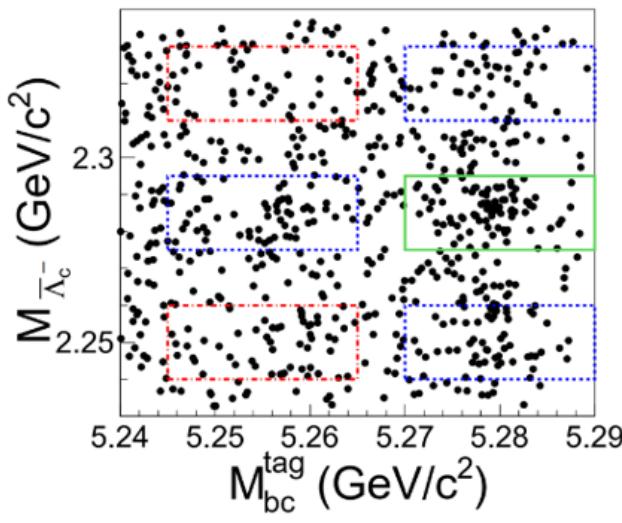
ARGUS function for M_{bc} BKG

double-Gaussian functions
for M_{Λ_c} signal

1st-order Chebychev polynomial function
for M_{Λ_c} BKG

Ξ_c^0 inclusive measurement

- Λ_c^- reconstructed via $\bar{p}K^+\pi^-$ and $\bar{p}K_s^0$
- Tagged a B^+ with FR algorithm

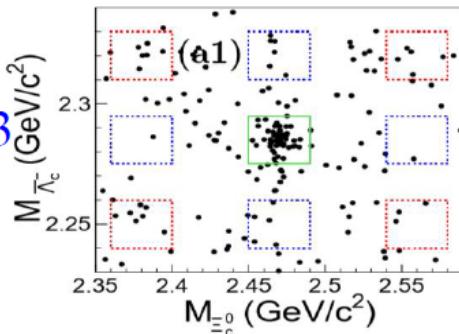


- Fitted result: $N(\Xi_c^0) = 40.9 \pm 9.0, 5.5\sigma$
- $\mathcal{B}(B^- \rightarrow \Lambda_c^- \Xi_c^0) = (9.51 \pm 2.10 \pm 0.88) \times 10^{-4}$

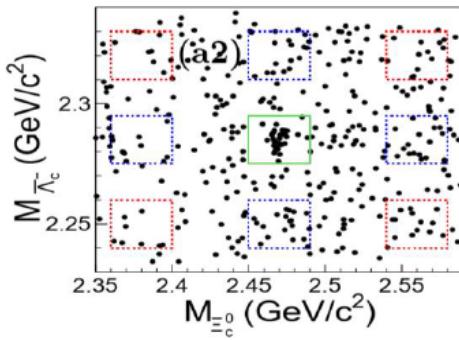
E_c^0 exclusive measurement

$\Xi^- \pi^+$

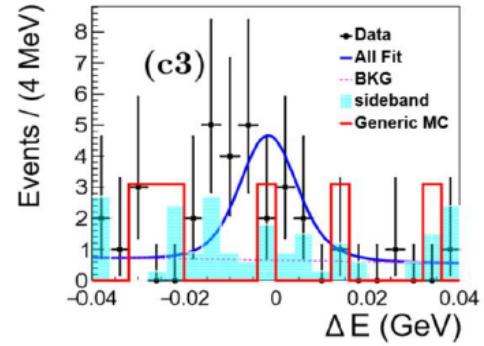
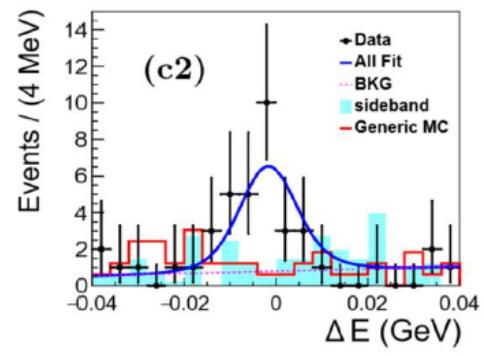
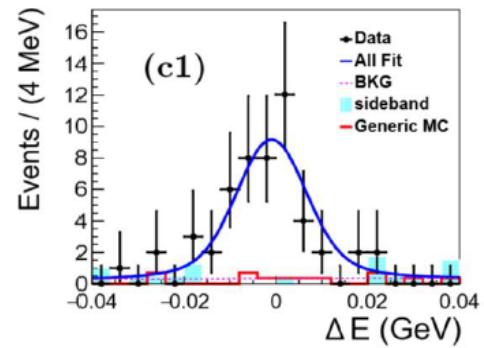
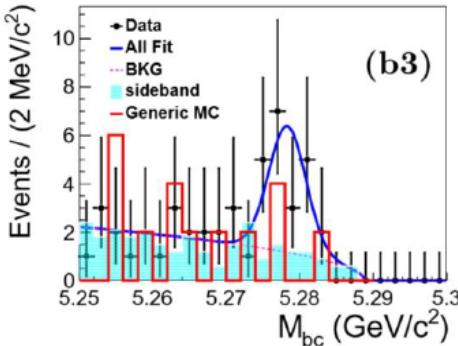
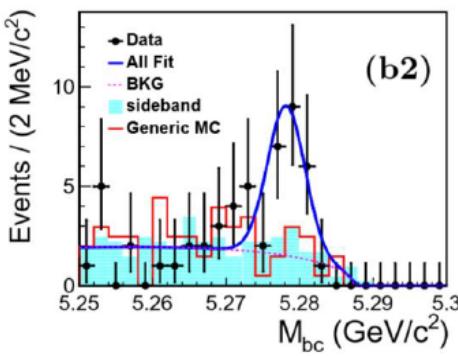
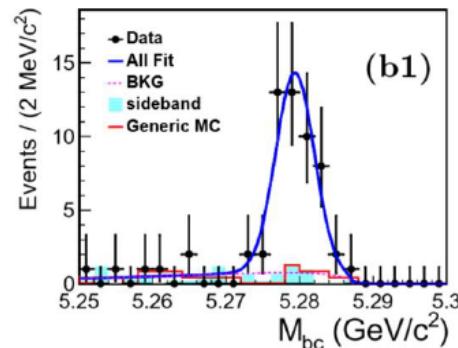
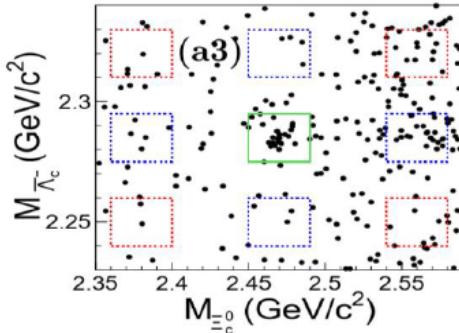
$$44.8 \pm 7.3 \quad 9.5\sigma$$



$\Lambda K^- \pi^+$

$$24.1 \pm 5.5 \quad 6.8\sigma$$


$pK^- K^- \pi^+$

$$16.6 \pm 5.4 \quad 4.6\sigma$$


Ξ_c^0 BRs measurement

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

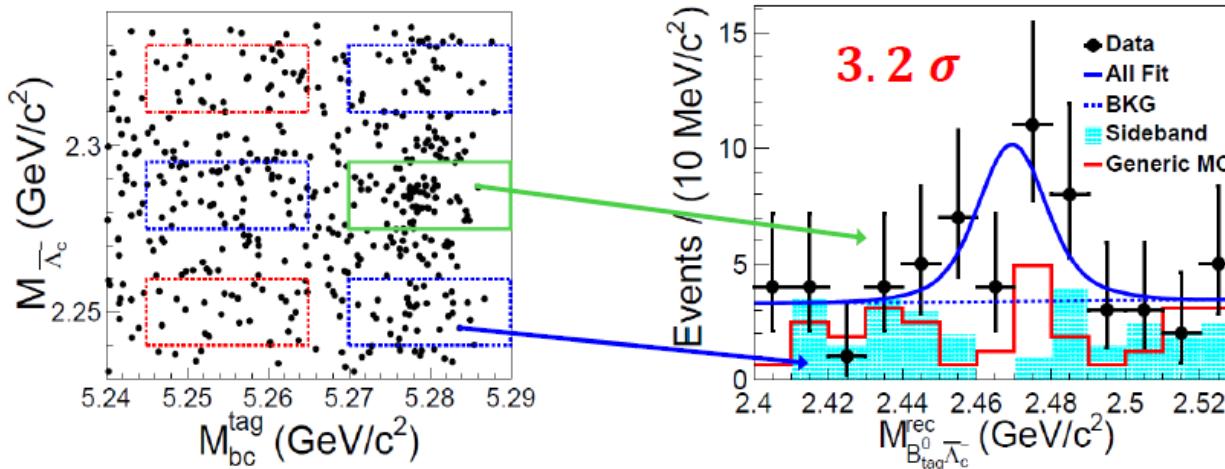
Channel	Br/Ration	Theory	PDG
$\mathcal{B}(B^- \rightarrow \bar{\Lambda}_c^- \Xi_c^0)$	$(9.51 \pm 2.10 \pm 0.88) \times 10^{-4}$	$\sim 10^{-3}$	
$\mathcal{B}(B^- \rightarrow \bar{\Lambda}_c^- \Xi_c^0) \mathcal{B}(\Xi_c^0 \rightarrow \Xi^- \pi^+)$	$(1.71 \pm 0.28 \pm 0.15) \times 10^{-5}$		$(2.4 \pm 0.9) \times 10^{-5}$
$\mathcal{B}(B^- \rightarrow \bar{\Lambda}_c^- \Xi_c^0) \mathcal{B}(\Xi_c^0 \rightarrow \Lambda K^- \pi^+)$	$(1.11 \pm 0.26 \pm 0.10) \times 10^{-5}$		$(2.1 \pm 0.9) \times 10^{-5}$
$\mathcal{B}(B^- \rightarrow \bar{\Lambda}_c^- \Xi_c^0) \mathcal{B}(\Xi_c^0 \rightarrow p K^- K^- \pi^+)$	$(5.47 \pm 1.78 \pm 0.57) \times 10^{-6}$		
$\mathcal{B}(\Xi_c^0 \rightarrow \Xi^- \pi^+)$	$(1.80 \pm 0.50 \pm 0.14)\%$		
$\mathcal{B}(\Xi_c^0 \rightarrow \Lambda K^- \pi^+)$	$(1.17 \pm 0.37 \pm 0.09)\%$		
$\mathcal{B}(\Xi_c^0 \rightarrow p K^- K^- \pi^+)$	$(0.58 \pm 0.23 \pm 0.05)\%$		
$\mathcal{B}(\Xi_c^0 \rightarrow \Lambda K^- \pi^+)/\mathcal{B}(\Xi_c^0 \rightarrow \Xi^- \pi^+)$	$0.65 \pm 0.18 \pm 0.04$		1.07 ± 0.14
$\mathcal{B}(\Xi_c^0 \rightarrow p K^- K^- \pi^+)/\mathcal{B}(\Xi_c^0 \rightarrow \Xi^- \pi^+)$	$0.32 \pm 0.12 \pm 0.07$		0.34 ± 0.04

- We have performed an analysis of $B^- \rightarrow \bar{\Lambda}_c^- \Xi_c^0$ inclusively and exclusively
- First model-independent measurement of absolute Brs of Ξ_c^0 decays
- The branching fraction $B(B^- \rightarrow \bar{\Lambda}_c^- \Xi_c^0)$ is measured for the first time
- The measured $B(\Xi_c^0 \rightarrow \Xi^- \pi^+)$ can be used to determine the BR of other Ξ_c^0 decays.¹¹

PRL 122, 082001

E_c^+ inclusive measurement

- Λ_c^- reconstructed via $\bar{p}K^+\pi^-$
- Tagged a B^0 with FR algorithm



- Fitted result: $N(E_c^+) = 18.8 \pm 6.8, 3.2\sigma$
- $\mathcal{B}(\bar{B}^0 \rightarrow \Lambda_c^- E_c^+) = (1.16 \pm 0.42 \pm 0.15) \times 10^{-4}$

Ξ_c^+ exclusive measurement

$$\Xi_c^+ \rightarrow \Xi^- \pi^+ \pi^+$$

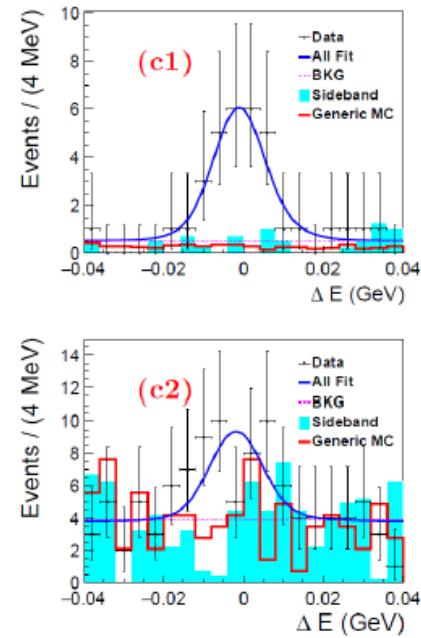
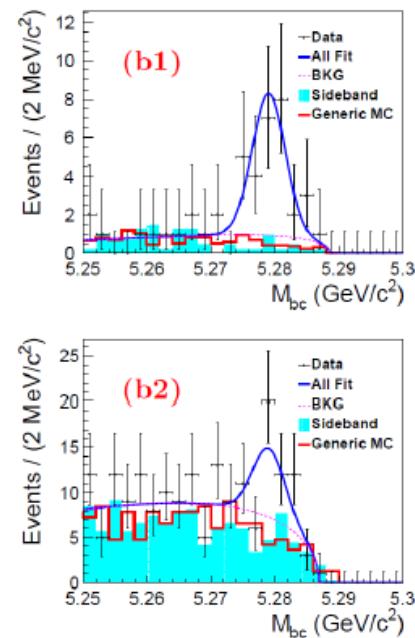
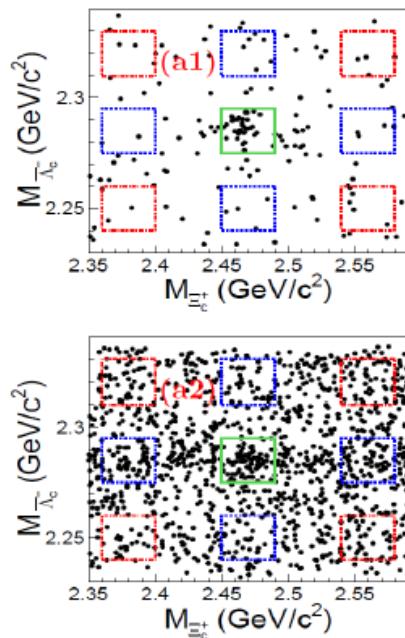
$N = 24.2 \pm 5.4$

6.9σ

$$\Xi_c^+ \rightarrow p K^- \pi^+$$

$N = 24.0 \pm 6.9$

4.5σ



Ξ_c^+ exclusive measurement

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

- First model-independent $\mathcal{B}(\bar{B}^0 \rightarrow \bar{\Lambda}_c^- \Xi_c^+)$ measurement
- $\mathcal{B}(\Xi_c^+ \rightarrow \Xi^- \pi^+ \pi^+)$ can be used to determine the BRs of other Ξ_c^+ decay
- $\mathcal{B}(\Xi_c^+ \rightarrow p \bar{K}^- \pi^+)$ is smaller theory prediction
 - Indicating a large U-spin symmetry breaking?

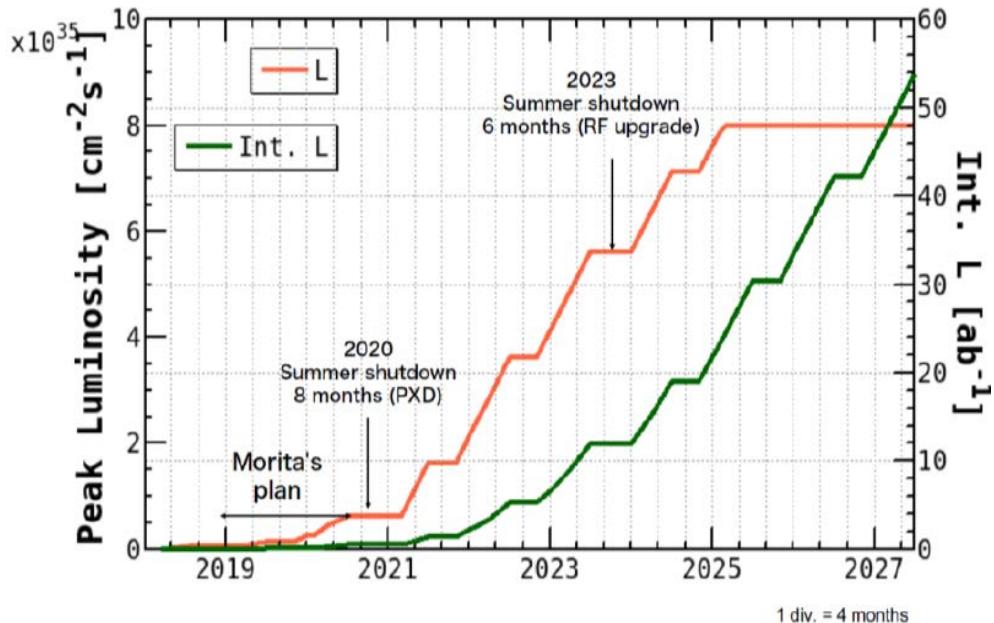
Summary

- We studied $B \rightarrow \Lambda_c^- \Xi_c^{0,+}$ with $\Xi_c^{0,+}$ decay exclusively and inclusively.
- The absolutely $\Xi_c^{0,+}$ decay branching fractions are measured:

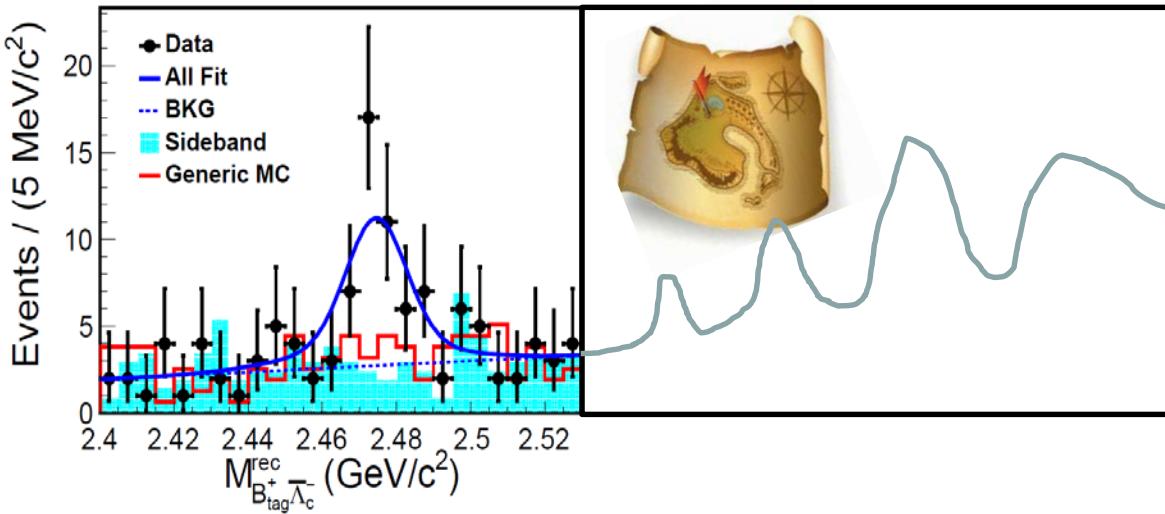
Ξ_c^+	
$\mathcal{B}(\Xi_c^0 \rightarrow \Xi^- \pi^+)$	$(1.80 \pm 0.50 \pm 0.14)\%$
$\mathcal{B}(\Xi_c^0 \rightarrow \Lambda K^- \pi^+)$	$(1.17 \pm 0.37 \pm 0.09)\%$
$\mathcal{B}(\Xi_c^0 \rightarrow p K^- K^- \pi^+)$	$(0.58 \pm 0.23 \pm 0.05)\%$

Ξ_c^+	
$\mathcal{B}(\Xi_c^+ \rightarrow \Xi^- \pi^+ \pi^+)$	$(2.86 \pm 1.21 \pm 0.38)\%$
$\mathcal{B}(\Xi_c^+ \rightarrow p K^- \pi^+)$	$(0.45 \pm 0.21 \pm 0.07)\%$

Prospective



- Belle2 is running
- More precise Brs measurements
 - Charmed baryons spectrum study can be performed



Back Up

- HadonB(J) skim;

1. $|dr| < 0.5$ and $|dz| < 2\text{cm}$; $\text{Pt} > 0.1\text{GeV}$ for all charged tracks;
2. Pt for all charged particle $> 0.1\text{GeV}/c$;

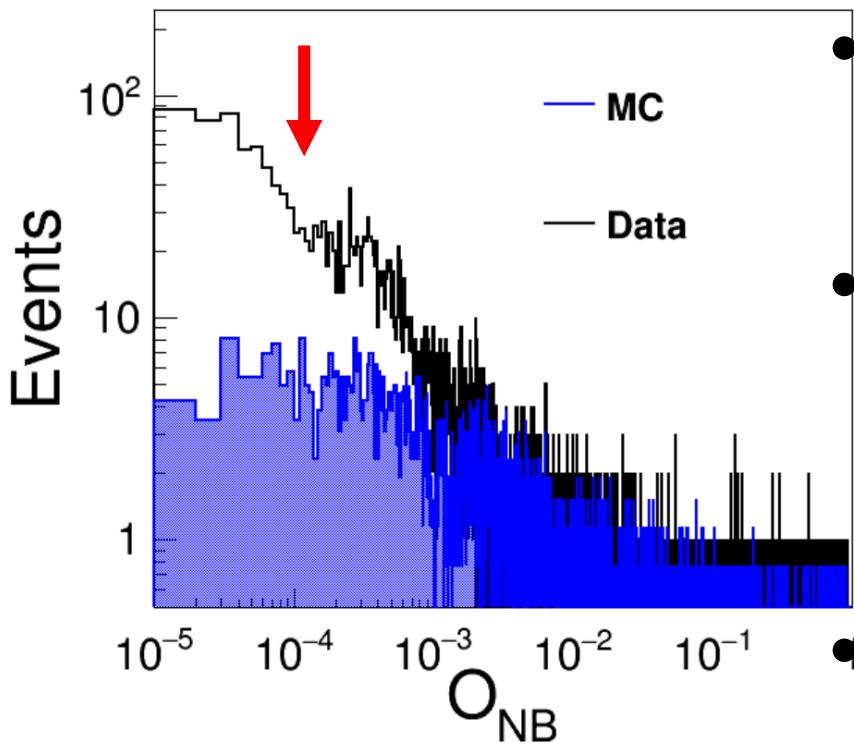
- For particle identification:

1. $\frac{\mathcal{L}(\pi)}{\mathcal{L}(\pi)+\mathcal{L}(K)} > 0.6$ for π ;
2. $\frac{\mathcal{L}(K)}{\mathcal{L}(K)+\mathcal{L}(\pi)} > 0.6$ for K ;
3. $\frac{\mathcal{L}(p)}{\mathcal{L}(p)+\mathcal{L}(\pi)} > 0.6$ and $\frac{\mathcal{L}(p)}{\mathcal{L}(p)+\mathcal{L}(K)} > 0.6$ for (anti-)proton;

- Apply vertex and mass fit for $\Lambda_c^+(\Xi_c^0)$ candidates, vote events with $\chi^2/ndf > 15$
- K_S candidates are selected by nisKsFinder and Applied vertex and mass fit, vote events with $\chi^2/ndf > 50$
- Λ candidates from Vee2 bank, Applied vertex and mass fit, vote events with $\chi^2/ndf > 50$

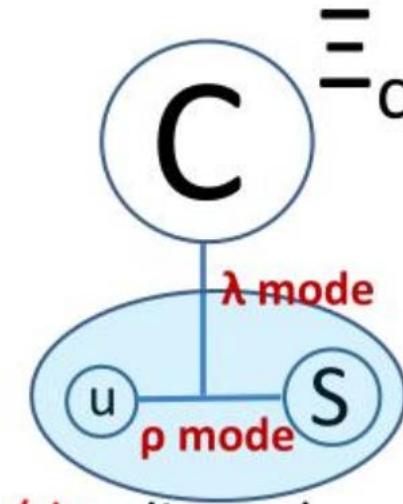
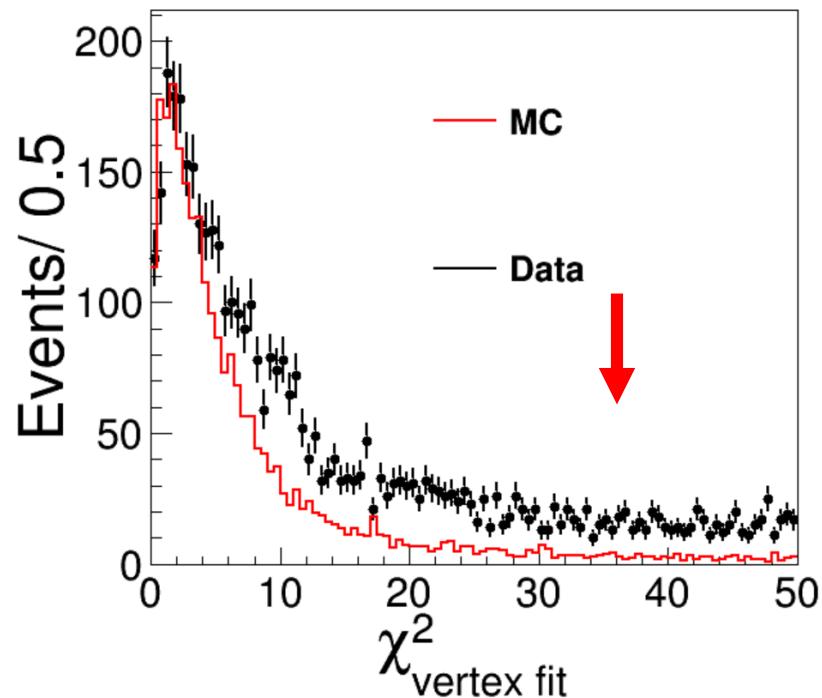
Full Reconstruction

Neural network(NN) based full reconstruction used to tag B^\pm .



- tag B^\pm cont_NBRank are required to be 1
- NN output with continuum suppression are required:
 $\log(O_{NB}) > -4$
- Λ_c^\pm have opposite charge with tag B^\pm .

$\Lambda_c^+ \rightarrow p K^- \pi^+$ mode



$\chi^2_{\text{mass vertex}}$ distribution of mass and vertex fit to Λ_c^+ . MC histogram is normalized to the data according to the first 5 bins.
Red arrows indicate the cut we applied:

$$\chi^2_{\text{mass vertex}} < 15$$