Baryon Studies at Belle

PHIPSI19

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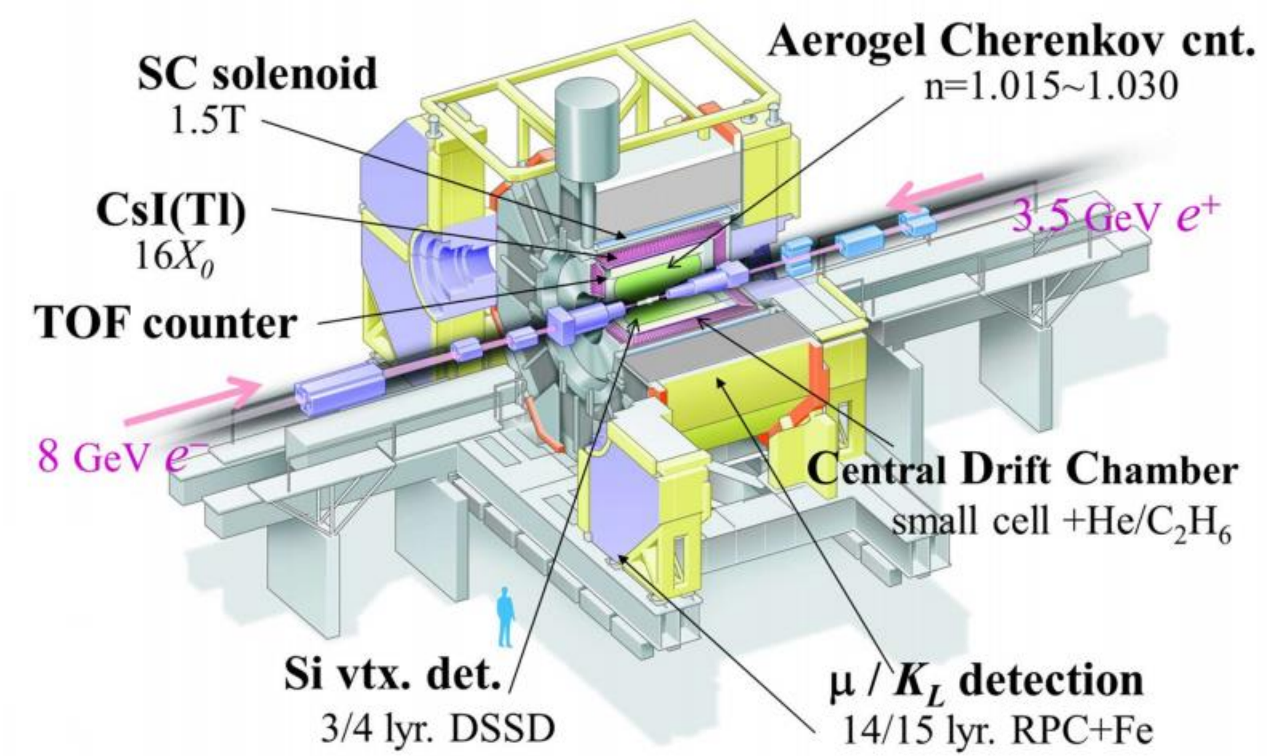
Belle Experiment



- Physics beamtime: 1999~2010 years
- $\sqrt{s}$= ~10.6 GeV
- Huge statistics, $\sim 10^9$ $B\bar{B}$ pairs, ~1 ab^{-1}integrated luminosity
- Baryon production at Belle
  - B meson decay.
  - $e^+e^- \to c\bar{c}$, direct production of charmed baryons.
  - $\Upsilon(1s)$ decay, enhanced baryon fraction.

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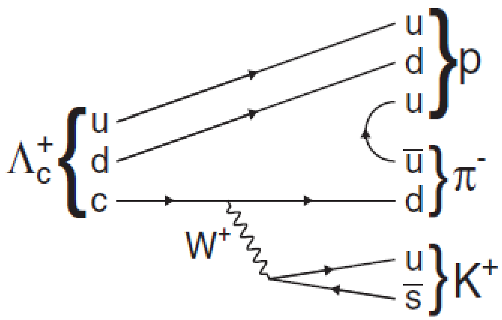
1. Decays of Λ_c^+

Doubly Cabibbo-Suppressed Decay, $\Lambda_c^+ \rightarrow pK^+\pi^-$

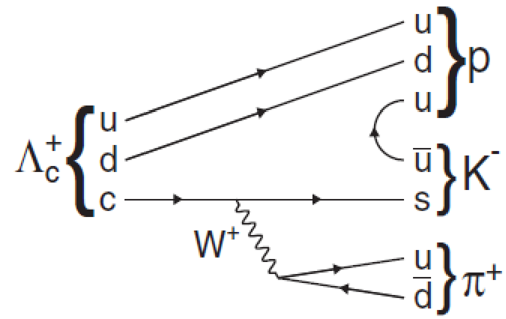
- Doubly Cabibbo-suppressed decay: $c \rightarrow d$ and $W^+ \rightarrow u\bar{s}$ at the same time.

→ $\frac{B(\Lambda_c^+ \rightarrow pK^+\pi^-)}{B(\Lambda_c^+ \rightarrow pK^-\pi^+)}$ is expected to be lower than $\tan^4\theta_C (= 0.00285)$.

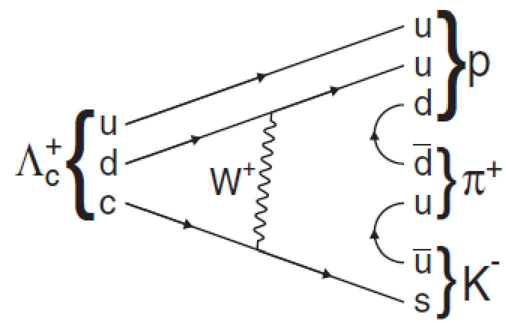
Doubly Cabibbo-Suppressed (DCS) Decay, $\Lambda_c^+ \rightarrow pK^+\pi^-$



Cabibbo-Favored (CF) Decay, $\Lambda_c^+ \rightarrow pK^-\pi^+$



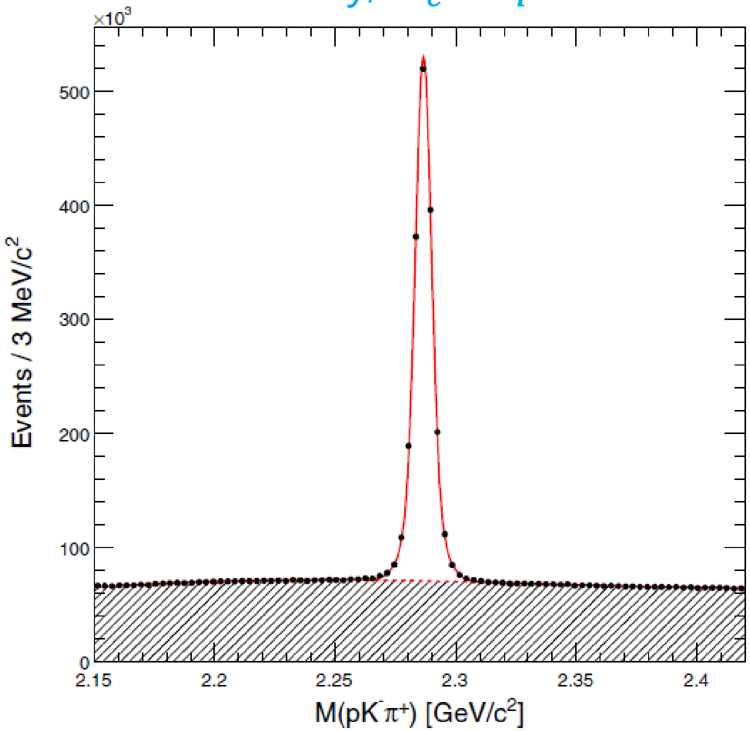
The W-exchange decay channel is forbidden in DCS.



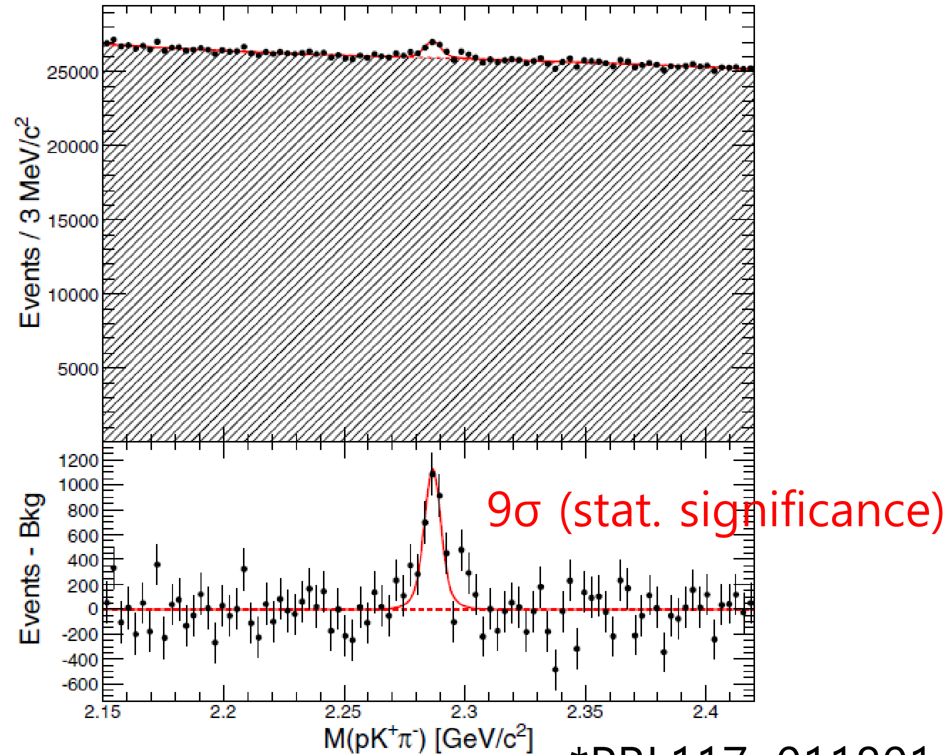
- The contribution of W-exchange channel can be extracted.

- Using the full data sample of Belle, 980 fb^{-1}, we clearly observed the DCS decay.

CF Decay, $\Lambda_c^+ \to pK^-\pi^+$



DCS Decay, $\Lambda_c^+ \to pK^+\pi^-$



*PRL117, 011801

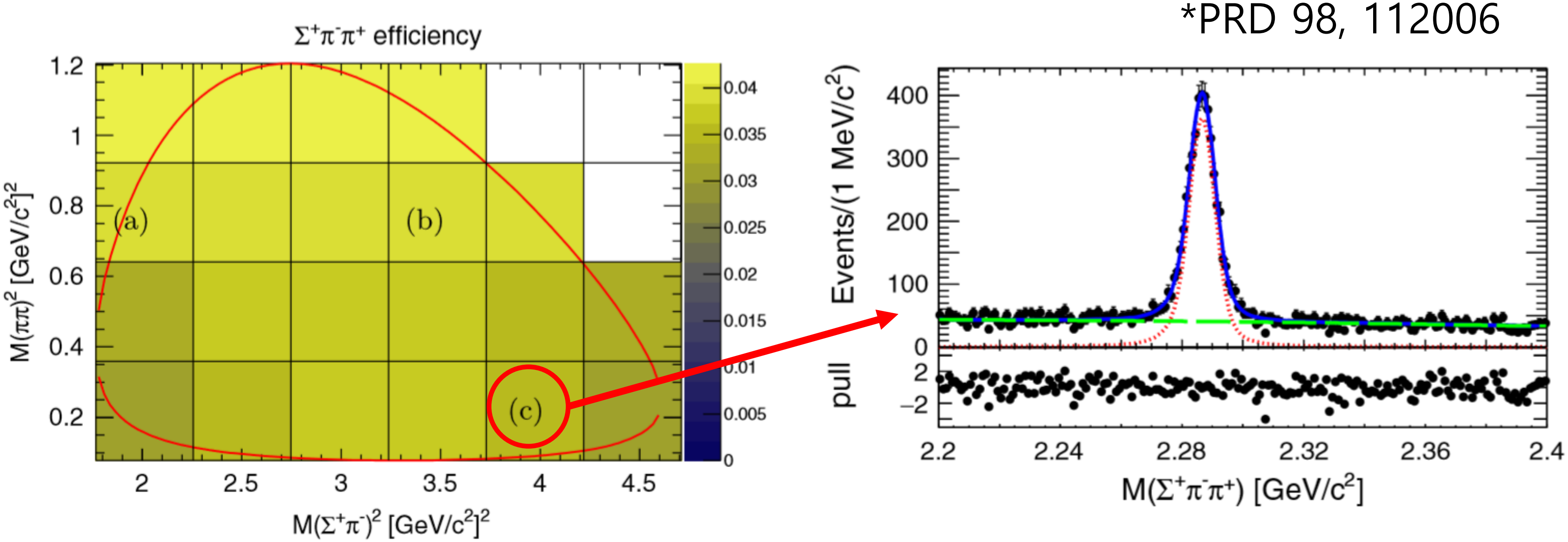
- $\frac{B(\Lambda_c^+ \to pK^+\pi^-)}{B(\Lambda_c^+ \to pK^-\pi^+)} = (2.35 \pm 0.27(Stat.) \pm 0.21(Syst.)) \times 10^{-3}$
- Comparing with the theoretical expectation (0.28%), the contribution of W-exchange channel is not large.

$\Lambda_c \to \Sigma\pi\pi$ Decays

- $\Sigma - \pi$ scattering length and $\Lambda(1405)$ study.
- 711 fb^{-1} data sample an energy at or near the $\Upsilon(4S)$.
- Signal yield extracted using a model-independent way:

Efficiency for each bin. → Yield for each bin → Efficiency-corrected yield for each bin. → Add them.

*PRD 98, 112006



- The most precise measurement.

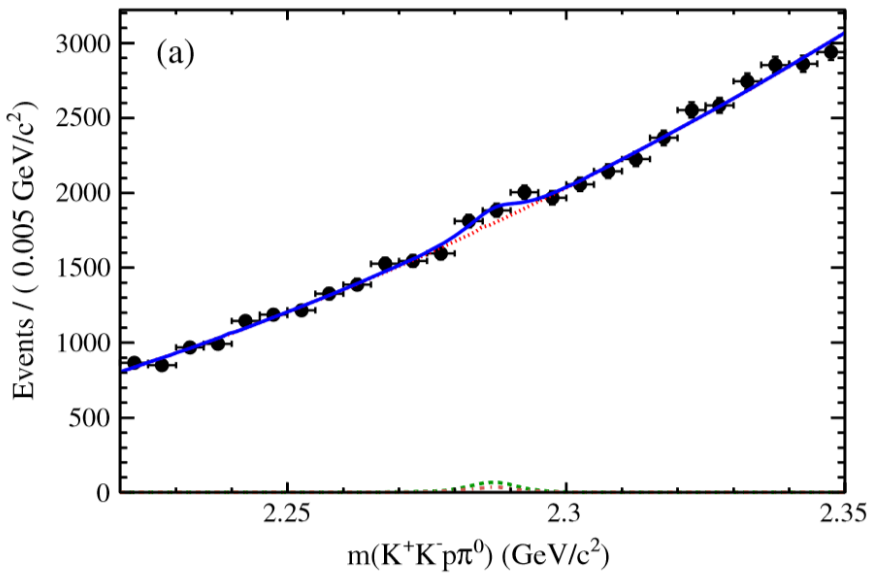
*PRD 98, 112006

Decay Ratio	Branching Fraction Ratio
$\frac{B(\Lambda_c^+ \to \Sigma^+\pi^-\pi^+)}{B(\Lambda_c^+ \to pK^-\pi^+)}$	0.719±0.003±0.024 *First measurement
$\frac{B(\Lambda_c^+ \to \Sigma^0\pi^+\pi^0)}{B(\Lambda_c^+ \to pK^-\pi^+)}$	0.575±0.005±0.036
$\frac{B(\Lambda_c^+ \to \Sigma^+\pi^0\pi^0)}{B(\Lambda_c^+ \to pK^-\pi^+)}$	0.247±0.006±0.019

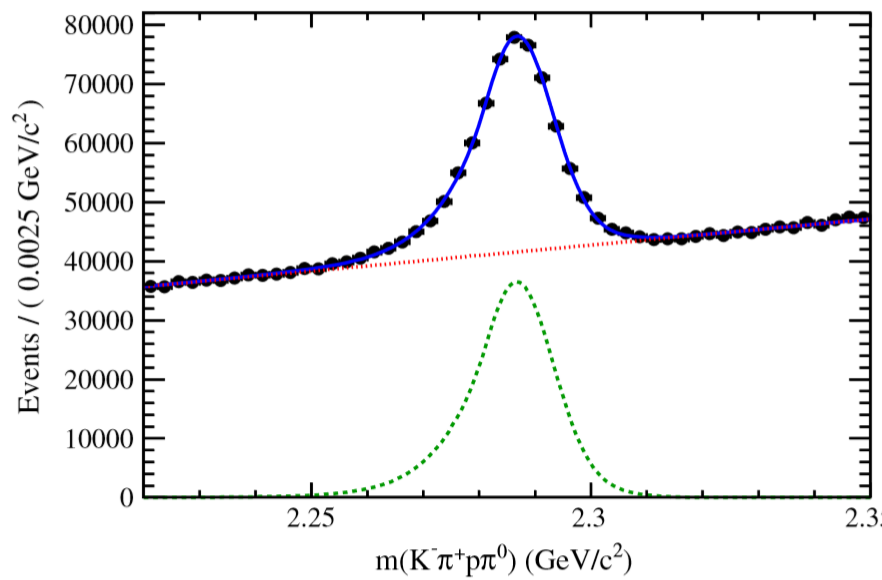
$\Lambda_c^+ \to K^- K^+ p \pi^0$ and $\Lambda_c^+ \to p K^- \pi^+ \pi^0$

- Hidden-strangeness pentaquark, $P_s^+(uuds\bar{s})$, search.
- 915 fb^{-1} data sample at or near the $\Upsilon(4S)$ and $\Upsilon(5S)$.

$\Lambda_c^+ \to K^- K^+ p \pi^0$



$\Lambda_c^+ \to p K^- \pi^+ \pi^0$



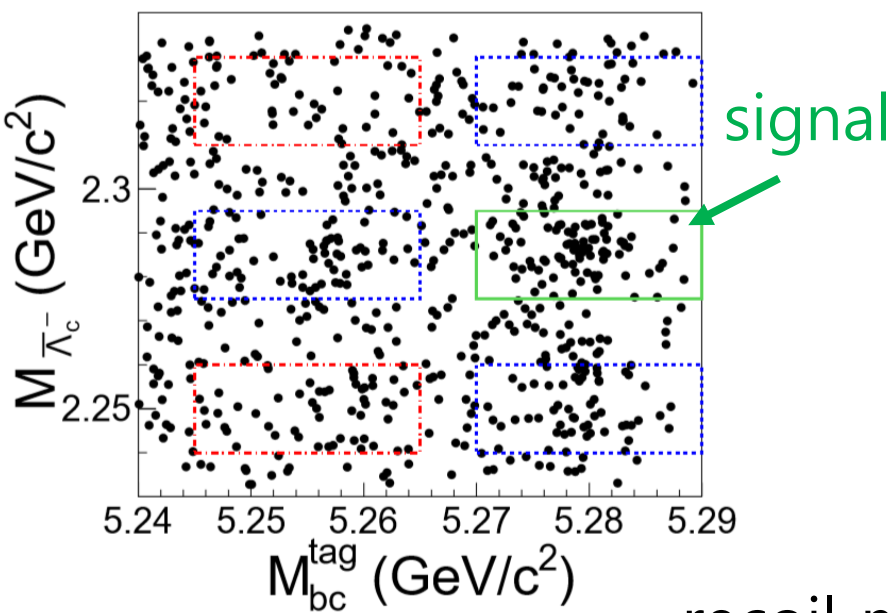
*PRD 96, 051102(R)

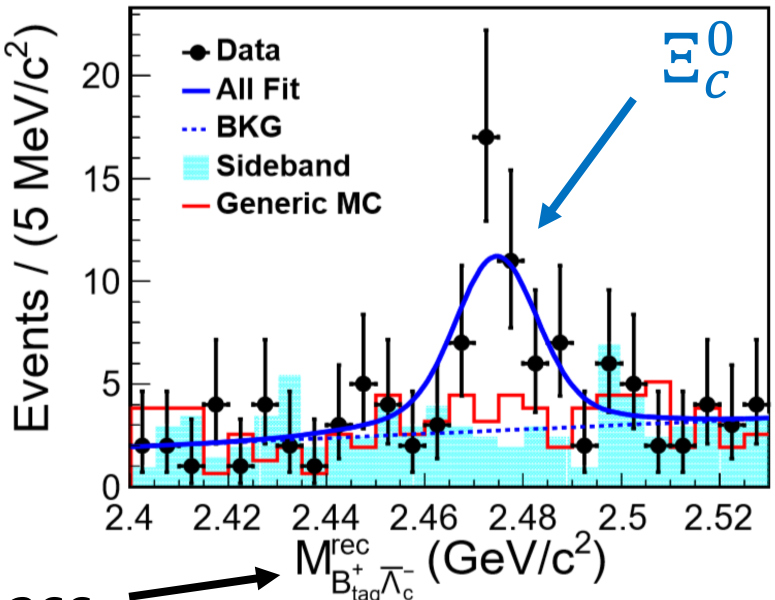
- $B(\Lambda_c^+ \to K^- K^+ p \pi^0)_{NR} < 6.3 \times 10^{-5}$, first upper limit report (less than 3σ significance).
- $\frac{B(\Lambda_c^+ \to p K^- \pi^+ \pi^0)}{B(\Lambda_c^+ \to p K^- \pi^+)}$ =0.685±0.007±0.018, the most precise measurement.

2. Study of Ξ_c and Ω_c

Absolute Branching Fractions of Ξ_c^0 Decays

- $772 \times 10^6\ B\bar{B}$ pairs.
- 1st Step: Inclusive analysis of $B^- \to \bar{\Lambda}_c^- \Xi_c^0$ using a missing mass technique:
  B^+ tag using a neural network.
  → $\bar{\Lambda}_c^-$ reconstruction from remaining tracks.
  → 'Recoil mass' calculation.





*PRL 122 082001

→ Absolute $\mathcal{B}(B^- \to \bar{\Lambda}_c^- \Xi_c^0) = (9.51 \pm 2.10 \pm 0.88) \times 10^{-4}$.

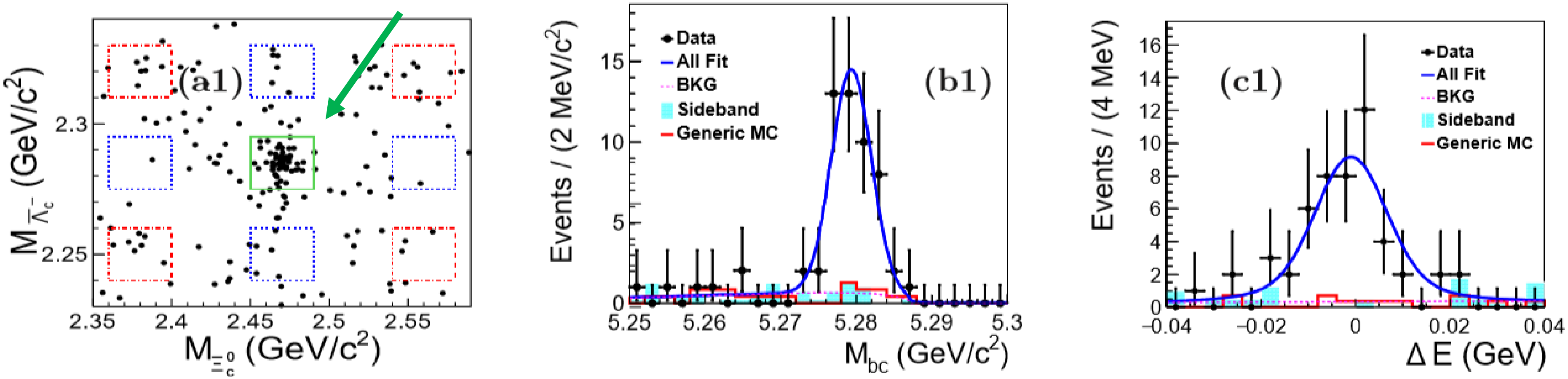
- 2^{nd} Step: Exclusive analysis of $B^- \to \overline{\Lambda}_c^- \Xi_c^0$ & Ξ_c^0 decays

ex) $\Xi_c^0 \to \Xi^- \pi^+$

signal

2D fitting

*PRL 122 082001



→ $B(B^- \to \overline{\Lambda}_c^- \Xi_c^0) \times B(\Xi_c^0 \to \Xi^- \pi^+) = (1.71 \pm 0.28) \times 10^{-5}$

- First absolute branching fractions: $B(\Xi_c^0 \to \Xi^- \pi^+) = 1.80 \pm 0.50 \pm 0.14\%$

$B(\Xi_c^0 \to \Lambda K^- \pi^+) = 1.17 \pm 0.37 \pm 0.09\%$

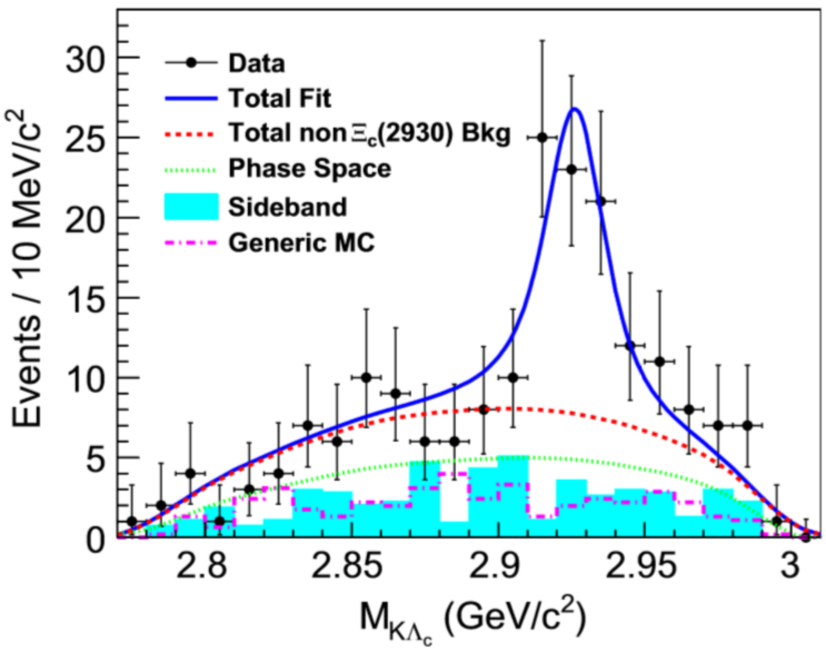
$B(\Xi_c^0 \to p K^- K^- \pi^+) = 0.58 \pm 0.23 \pm 0.05\%$

$\Xi_c(2930)^0$ and $\Xi_c(2930)^+$

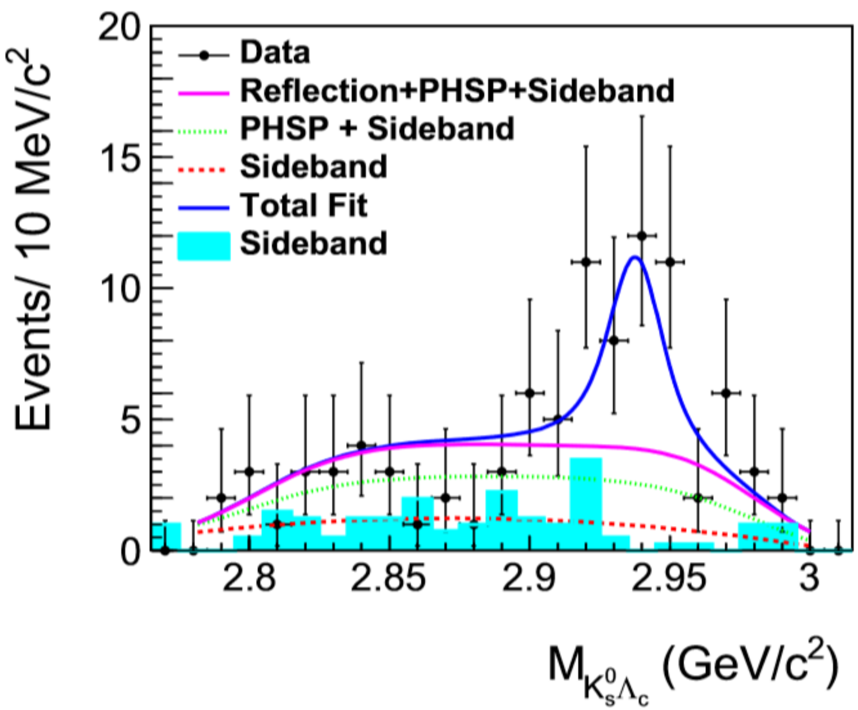
- 772×10^6 $B\bar{B}$ pairs.

*EPJC 78:928 and 78:252

$\Xi_c(2930)^0 \to K^-\Lambda_c^+$ in $B^- \to K^-\Lambda_c^+\bar{\Lambda}_c^-$



$\Xi_c(2930)^+ \to K_s^0\Lambda_c^+$ in $B^0 \to K_s^0\Lambda_c^+\bar{\Lambda}_c^-$

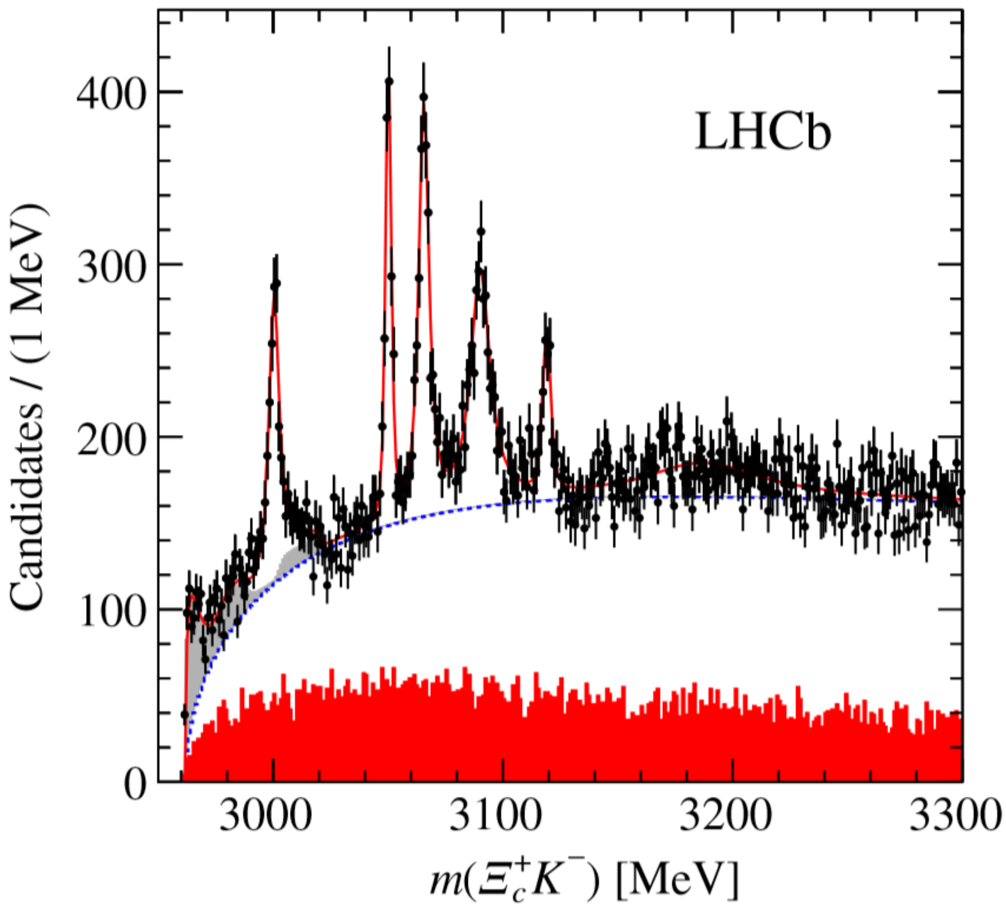


- $\Xi_c(2930)^0$: 5.1σ significance, $M = 2928.9 \pm 3.0\,^{+0.9}_{-12.0}$ MeV
- $\Xi_c(2930)^+$: larger than 3.5σ significance, $M = 2942.3 \pm 4.4$ MeV

Excited Ω_c^0 Baryons

- LHCb reported 5 narrow Ω_c^* resonances in $\Omega_c^* \to \Xi_c^+ K^-$.

*LHCb Collaboration, PRL 118 182001

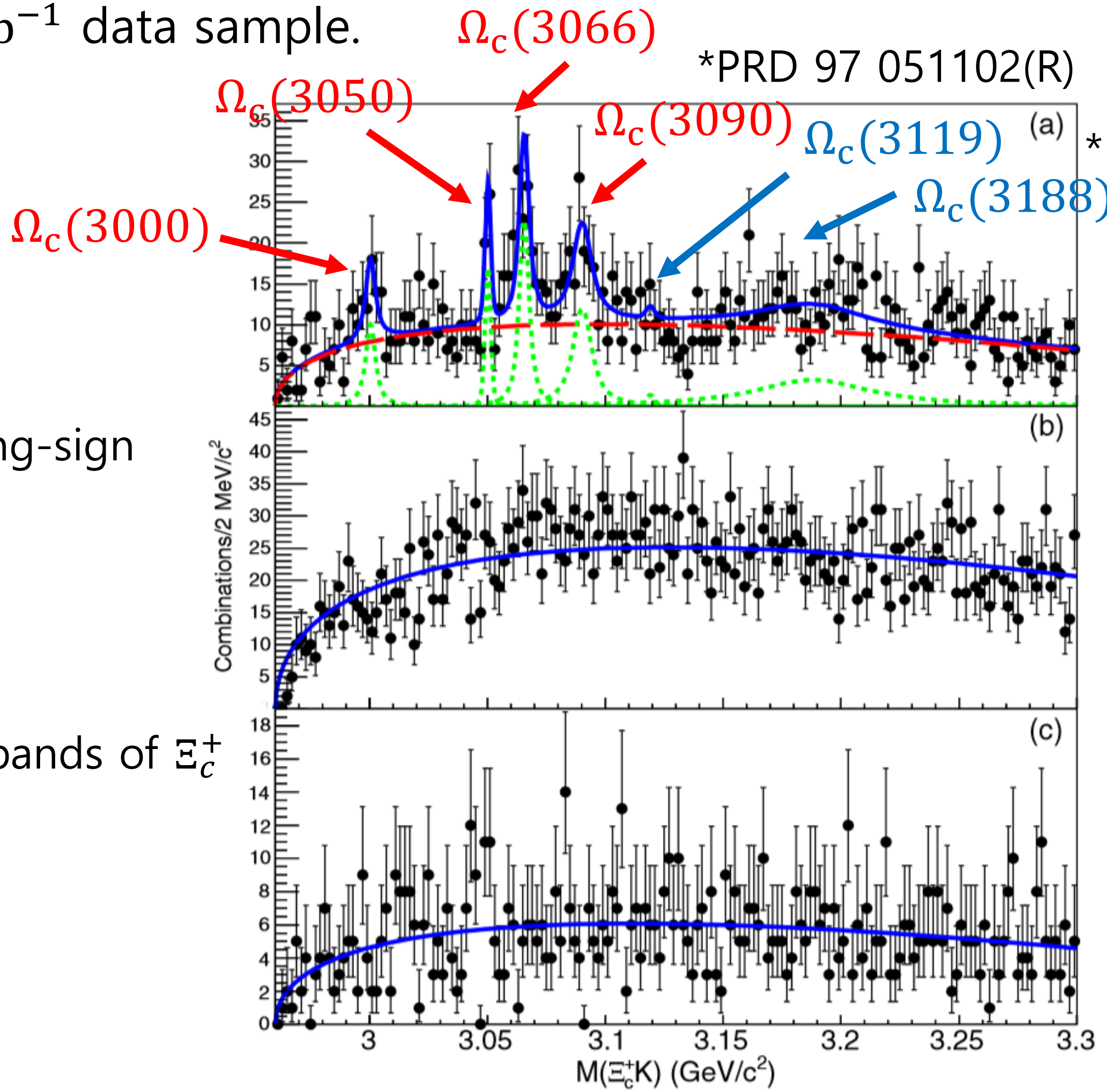


→ We can confirm them.

- 980 fb^{-1} data sample.

(b) wrong-sign

(c) sidebands of Ξ_c^+



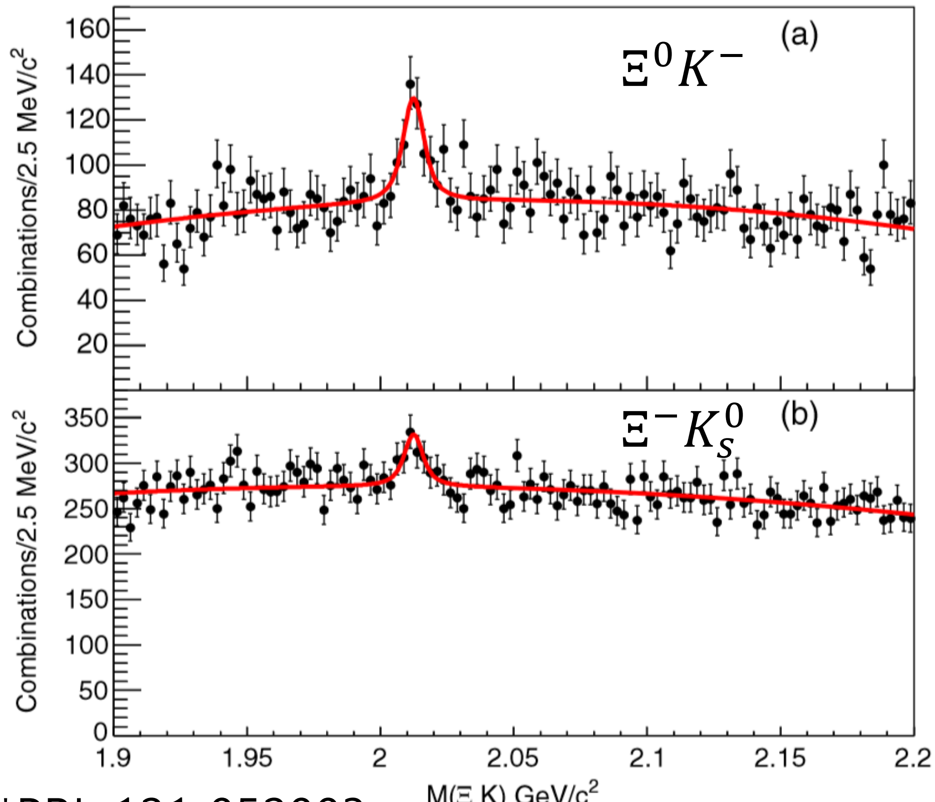
*PRD 97 051102(R)

- Significant signals for $\Omega_c(3066)$ and $\Omega_c(3090)$. Less significant for $\Omega_c(3000)$ and $\Omega_c(3050)$. We cannot confirm $\Omega_c(3119)$.

3. Observation of Hyperons

Excited Ω^- baryon

- $\Upsilon(1S)$, $\Upsilon(2S)$, and $\Upsilon(3S)$ resonances data sample which contains enhanced baryon fraction.
- Large gap (~600 MeV/c^2) between Ω^- and Ω^{*-} because $\Omega^{*-} \to \Omega^-\pi^0$ is highly suppressed.
- Search Ω^{*-} by $\Omega^{*-} \to \Xi K$ decay (analogous to $\Omega_c^* \to \Xi_c^+ K^-$)

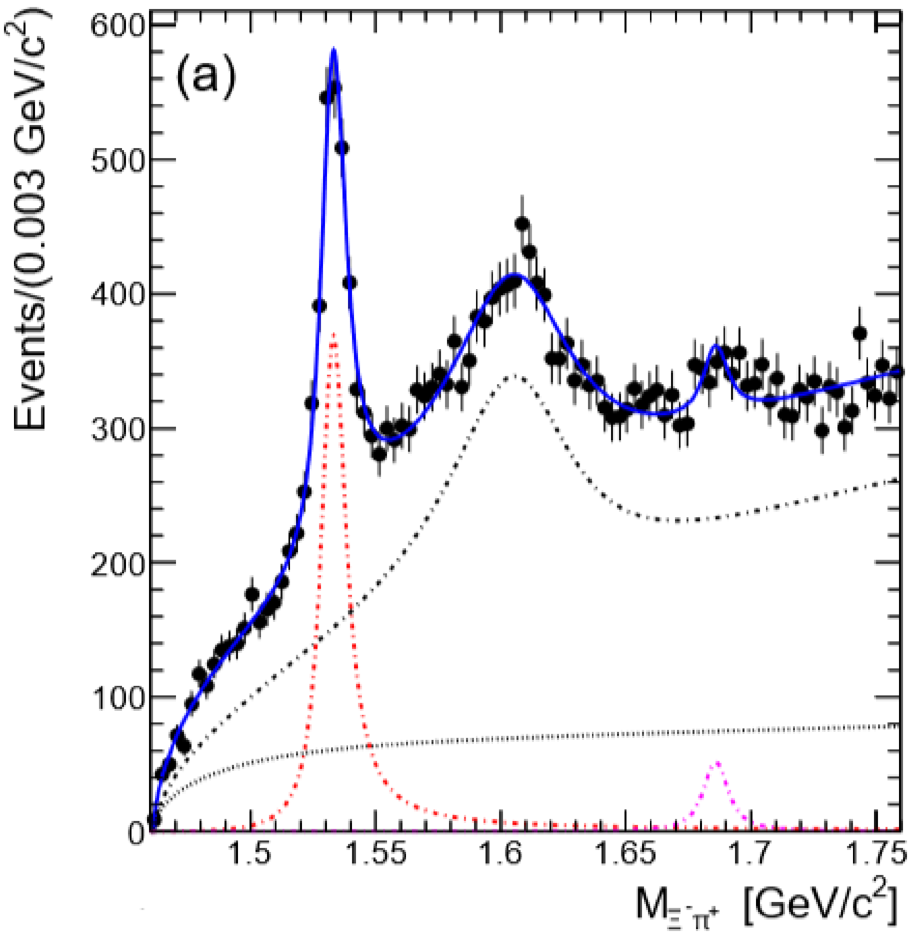


- Ω (2212):
M=2012.4±0.7±0.6 MeV,
$\Gamma = 6.4^{+2.5}_{-2.0} \pm 1.6$ MeV
- $\frac{3}{2}^-$ state in quark model?

*PRL 121 052003

$\Xi(1620)^0$

- 980 fb^{-1} data sample.
- Search for $\Xi^{*0} \rightarrow \Xi^-\pi^+$ in $\Xi_c^+ \rightarrow \Xi^-\pi^+\pi^+$



- $\Xi(1620)^0$: M=1610.4±6.0 MeV, Γ=60.0±4.8 MeV
- Difficult to explain them by constituent quark models. Exotic hadron?
- Analogous to $\Lambda(1405)$? Two poles in S=-2 sector?

*PRL 122 072501

4. Summary

Summary

Belle beamtime was over ~10 years ago, but new results are still coming out.

1. New Λ_c^+ decays were observed and several branching ratios were precisely measured.
- $\Lambda_c^+ \rightarrow pK^+\pi^-$, $\Lambda_c \rightarrow \Sigma\pi\pi$, and $\Lambda_c^+ \rightarrow pK^-\pi^+\pi^0$
2. We observed $\Xi_c(2930)^0$ and Ω_c^* resonances, and measured absolute branching fractions of Ξ_c^0 decays.
3. We reported observation of new hyperons, Ω(2212) and $\Xi(1620)^0$.

There are still many ongoing analyzes for baryon studies.

*Backup

Branching Fractions of Ω_c^0 Decays

- Precise measurements of Ω_c^0 decay branching fractions.
- Using 980 fb^{-1} data sample.

*PRD 97 032001(R)

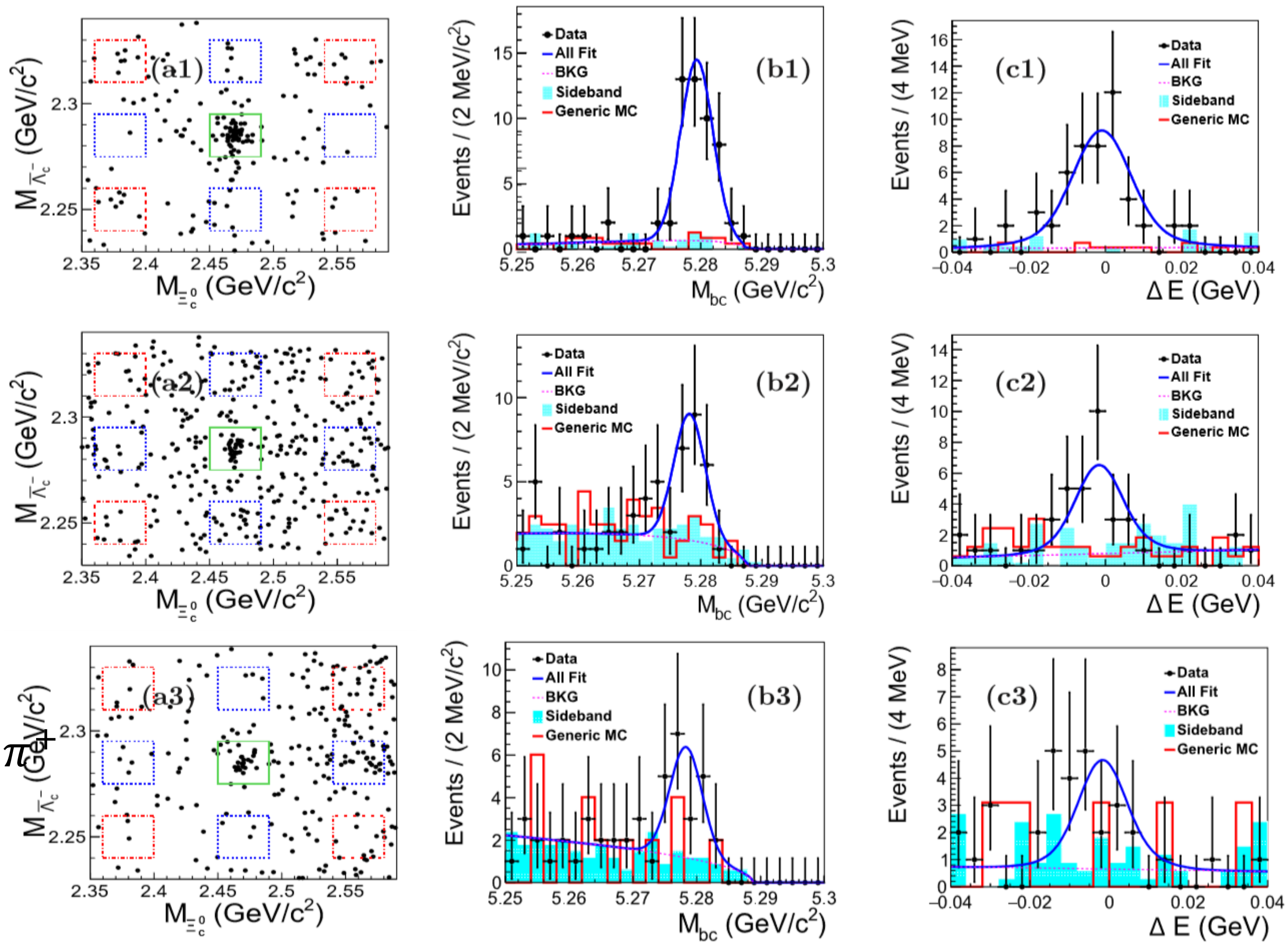
Decay Ratio ($/B(\Omega_c^0 \to \Omega^-\pi^+)$)	Branching Fraction Ratio
$B(\Omega_c^0 \to \Omega^-\pi^+\pi^0)$	2.00±0.17±0.11
$B(\Omega_c^0 \to \Omega^-\pi^+\pi^-\pi^+)$	0.32±0.05±0.02
$B(\Omega_c^0 \to \Xi^-\pi^+K^-\pi^+)$	0.68±0.07±0.03
$B(\Omega_c^0 \to \Xi^-K^-\pi^+)$	1.20±0.16±0.08
$B(\Omega_c^0 \to \Xi^-\overline{K}^0\pi^+)$	2.12±0.24±0.14
$B(\Omega_c^0 \to \Xi^0\overline{K}^0)$	1.64±0.26±0.12
$B(\Omega_c^0 \to \Lambda\overline{K}^0\overline{K}^0)$	1.72±0.32±0.14
$B(\Omega_c^0 \to \Sigma^+K^-K^-\pi^+)$	<0.32

Absolute Branching Fractions of Ξ_c^0 Decays

- Exclusive analysis of $B^- \to \overline{\Lambda}_c^- \Xi_c^0$ & Ξ_c^0 decays

*PRL 122 082001

1. $\Xi_c^0 \to \Xi^- \pi^+$
2. $\Xi_c^0 \to \Lambda K^- \pi^+$
3. $\Xi_c^0 \to p K^- K^- \pi^+$



Excited Ω^- baryon

- Not $\Upsilon(1S)$, $\Upsilon(2S)$, and $\Upsilon(3S)$ resonances data sample.