Recent Study of Hadronic Λ_c^+ Decays at Belle

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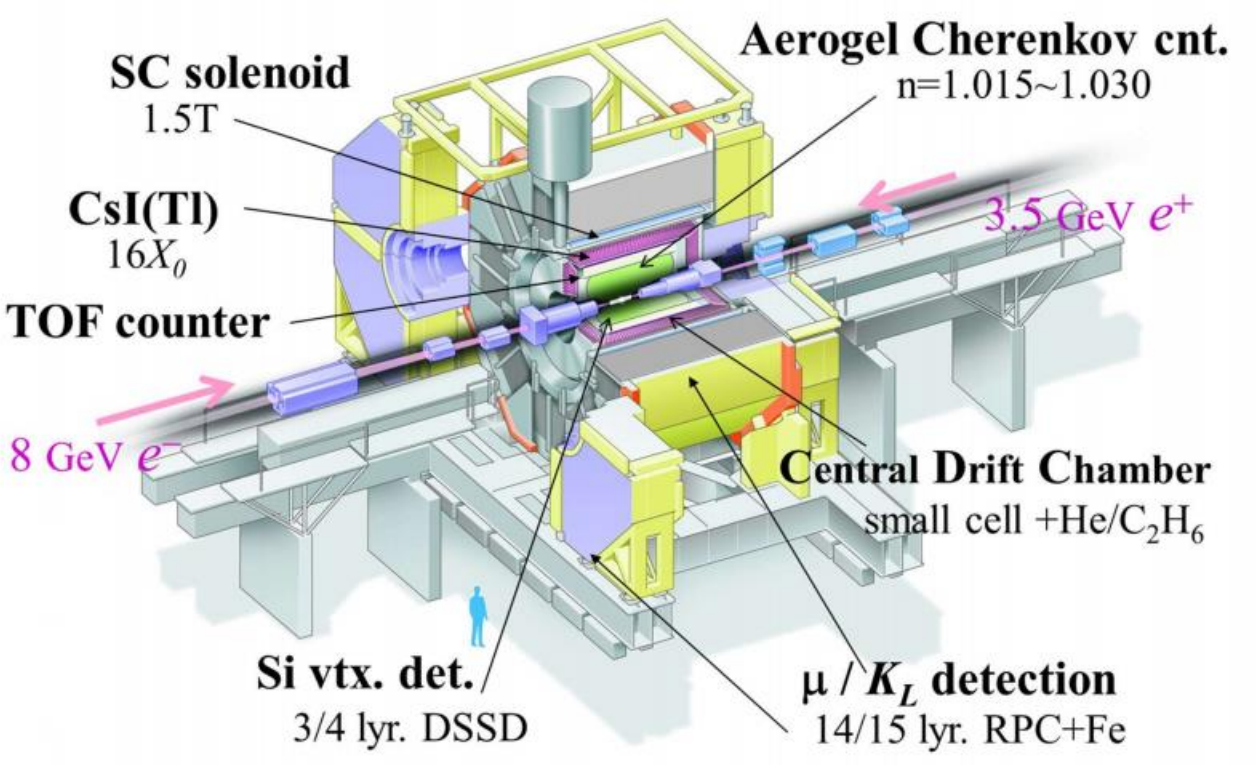
(for Belle Collaboration)

Belle Experiment



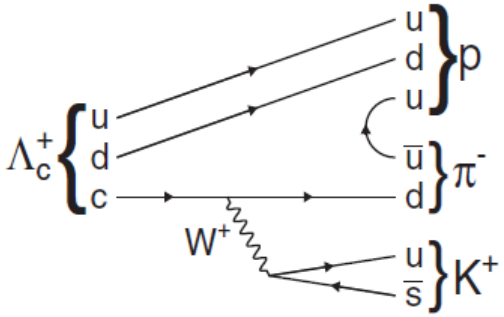
- Physics beamtime: 1999~2010 years
- $\sqrt{s}$= ~10.6 GeV
- Huge statistics, ~10^9 $B\bar{B}$ pairs, ~1 ab^{-1}integrated luminosity
- Baryon production at Belle
  - B meson decay.
  - $e^+e^- \rightarrow c\bar{c}$, direct production of charmed baryons.
  - $\Upsilon(1s)$ decay, enhanced baryon fraction.

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

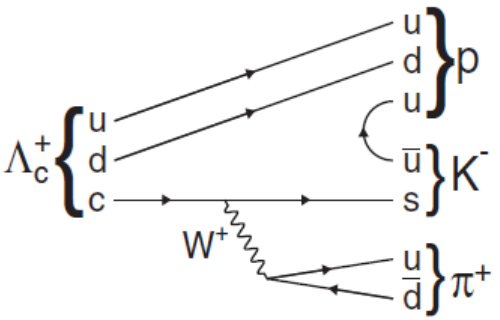
- Doubly Cabibbo-suppressed decay: $c \to d$ and $W^+ \to u\bar{s}$ at the same time.

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

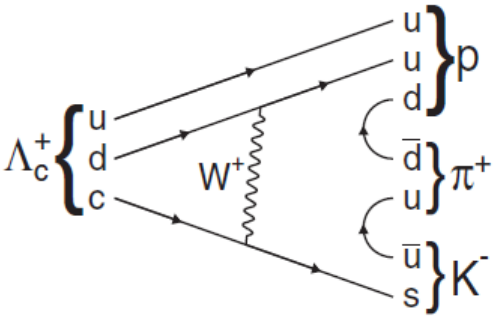
Doubly Cabibbo-Suppressed (DCS) Decay, $\Lambda_c^+ \to pK^+\pi^-$



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



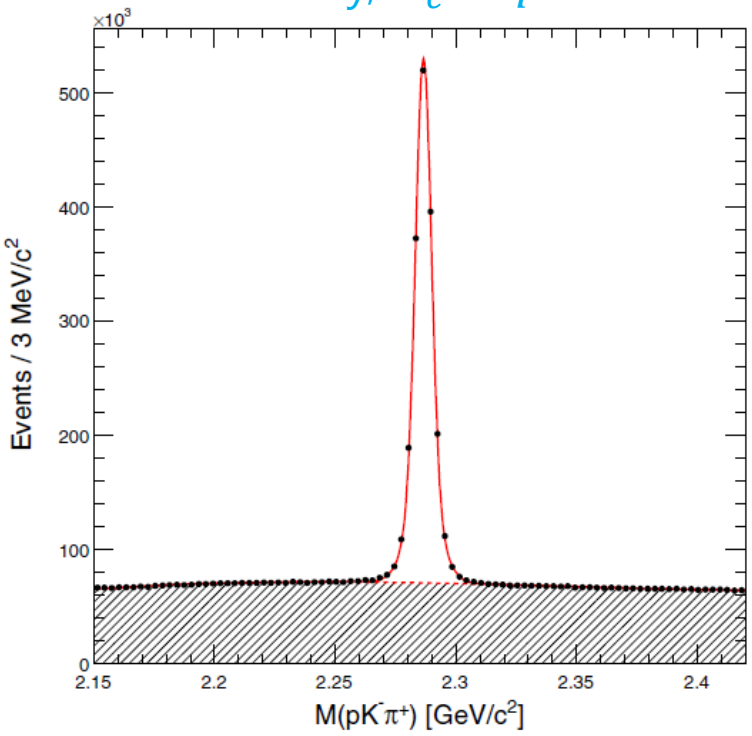
The W-exchange decay channel is forbidden in DCS.



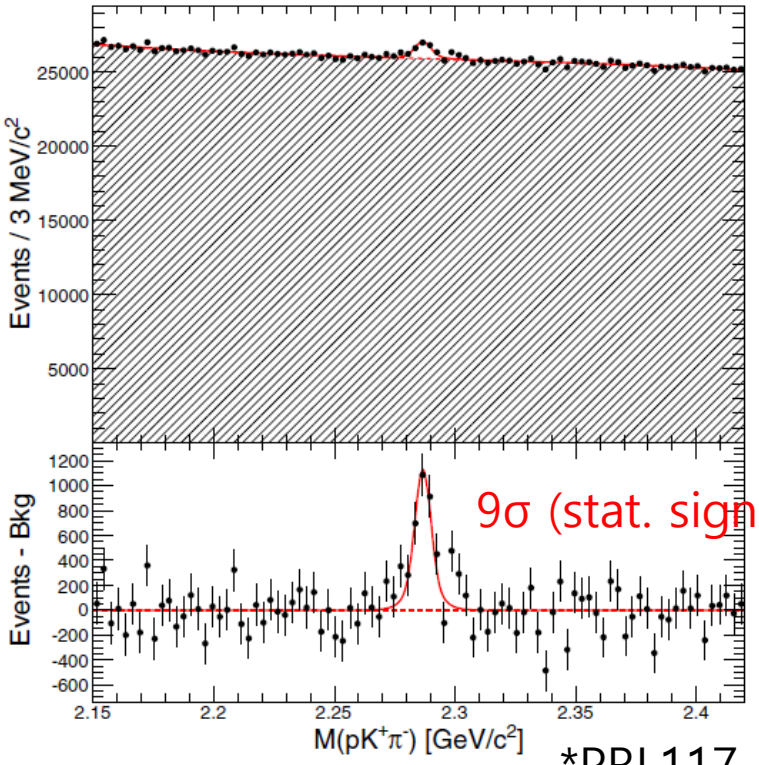
- The contribution of W-exchange channel can be extracted.

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



9σ (stat. significance)

*PRL117, 011801

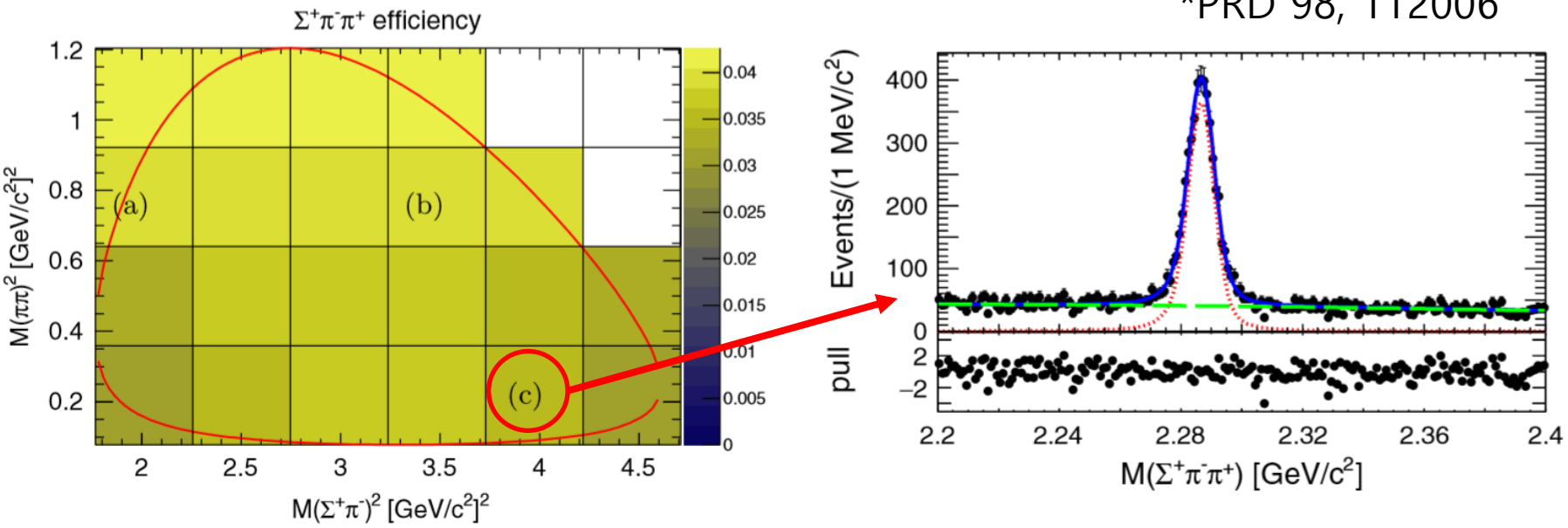
- $\frac{B(\Lambda_c^+ \to pK^+\pi^-)}{B(\Lambda_c^+ \to pK^-\pi^+)} = (2.35 \pm 0.27(Stat.) \pm 0.21(Syst.)) \times 10^{-3}$
- Comparing with the theoretical expectation (0.28%), the contribution of W-exchange channel is not large.

$\Lambda_c \to \Sigma\pi\pi$ 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.

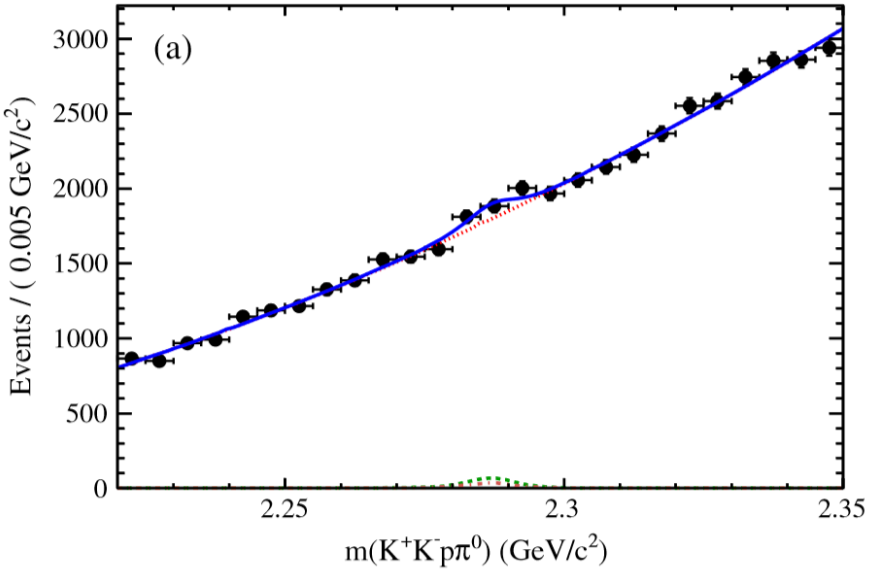
*PRD 98, 112006

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

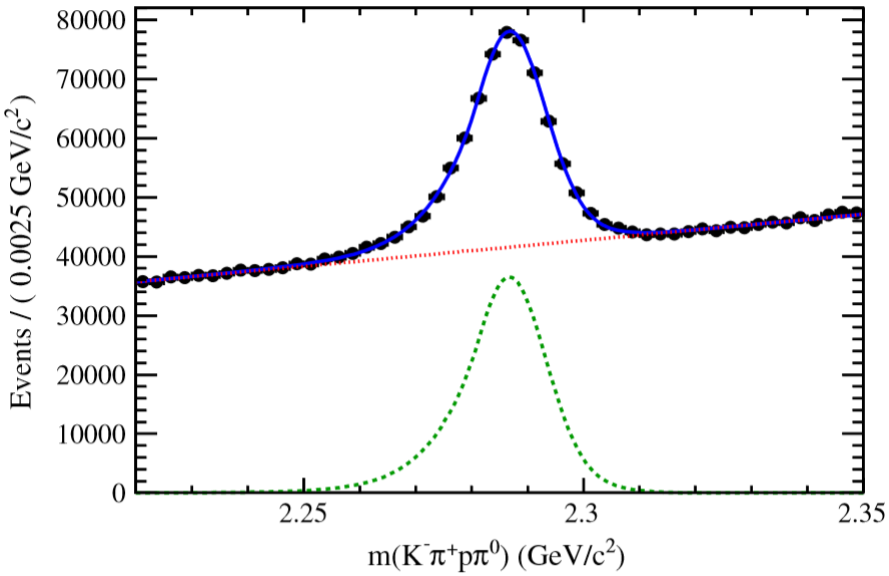
$\Lambda_c^+ \to pK^-K^+\pi^0$ and $\Lambda_c^+ \to pK^-\pi^+\pi^0$

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

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



$\Lambda_c^+ \to pK^-\pi^+\pi^0$

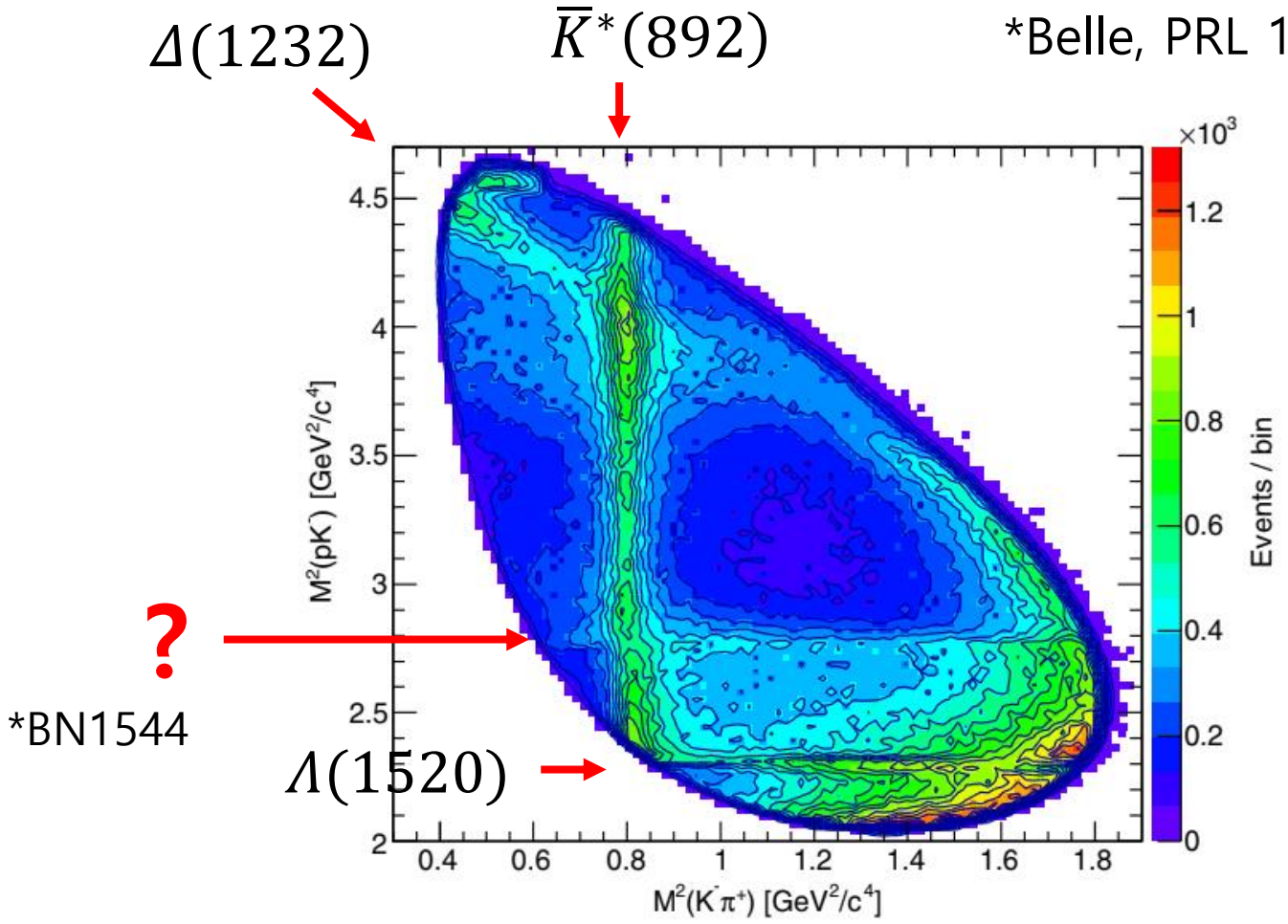


*PRD 96, 051102(R)

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

Motivation

- A new pK^- peak in $\Lambda_c^+ \to pK^-\pi^+$: a new resonance Λ^*?:



→ Strong coupling to $\Lambda\eta$?

- Branching fraction of $\Lambda_c^+ \to \Lambda\eta\pi^+$
  - Precise measurement by using the Belle data sample.

Experiment	Number of Signal Events	$\mathcal{B}(\Lambda_c^+ \to \eta\Lambda\pi^+)/\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+)$
CLEO [6]	11	$0.41 \pm 0.17 \pm 0.10$
CLEO [7]	116	$0.35 \pm 0.05 \pm 0.06$
Experiment	Number of Signal Events	$\mathcal{B}(\Lambda_c^+ \to \eta\Sigma(1385)^+)/\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+)$
CLEO [7]	54	$0.17 \pm 0.04 \pm 0.03$

- Hyperon study in $\Lambda_c^+ \to \Lambda\eta\pi^+$ weak decay.
  - ex) $\Lambda(1670)$

VALUE (MeV)	*DOCUMENT ID*	*TECN*	*COMMENT*
1660 to 1680 (≈ 1670) OUR ESTIMATE			

VALUE (MeV)	*DOCUMENT ID*	*TECN*	*COMMENT*
25 to 50 (≈ 35) OUR ESTIMATE			

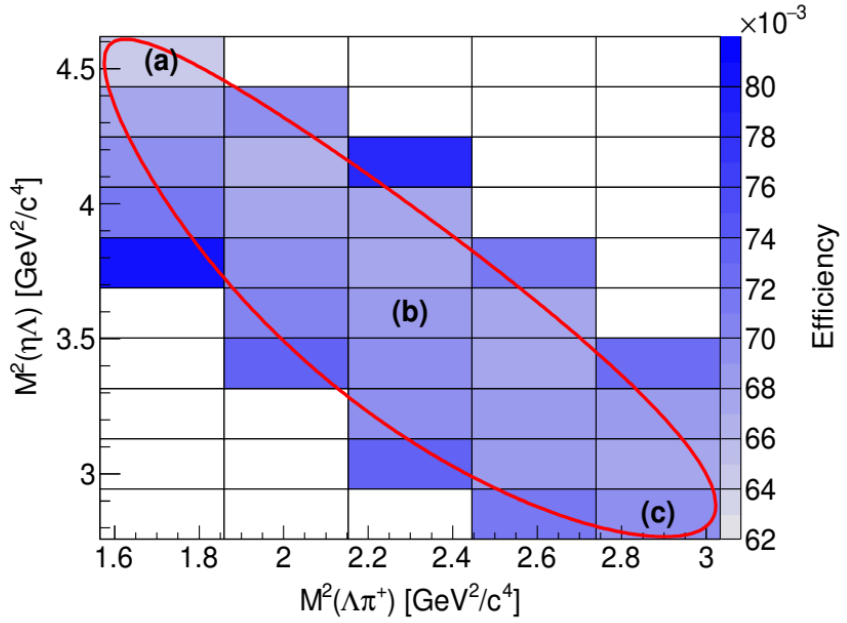
→ Only partial wave analysis results in PDG

Efficiency Estimation over Dalitz Plots

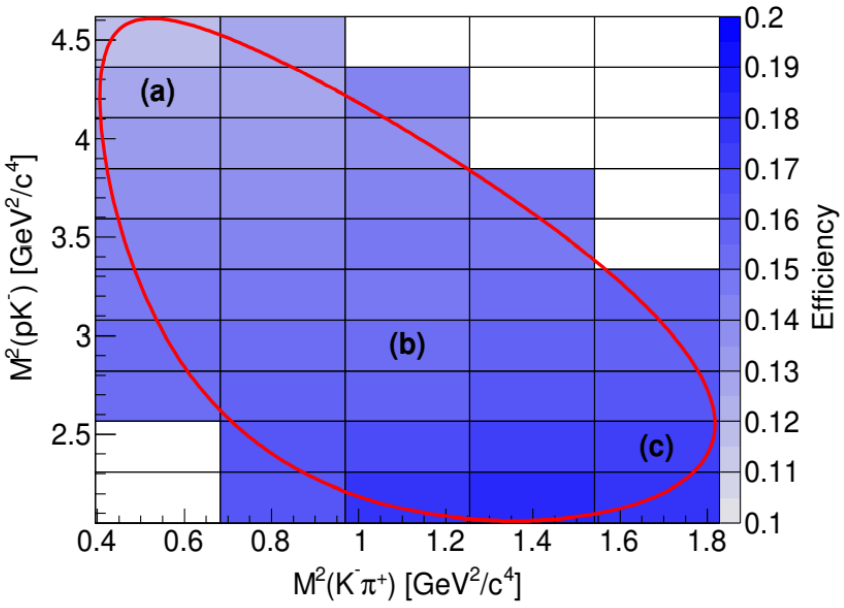
- Efficiency estimated over the Dalitz plots.

→ To avoid uncertainty from resonant structures.

$\Lambda_c^+ \to \Lambda\eta\pi^+$



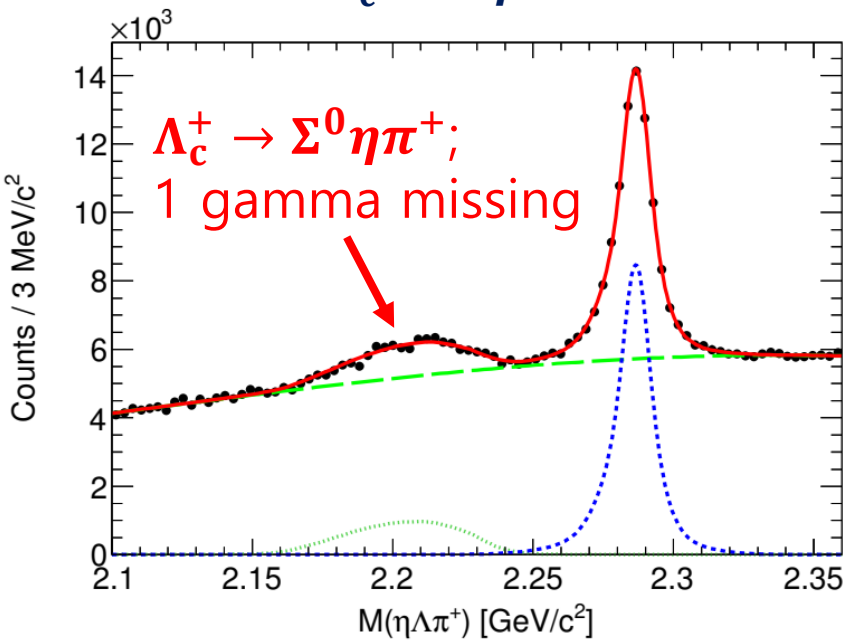
$\Lambda_c^+ \to pK^-\pi^+$



Signal Extraction over Dalitz Plane

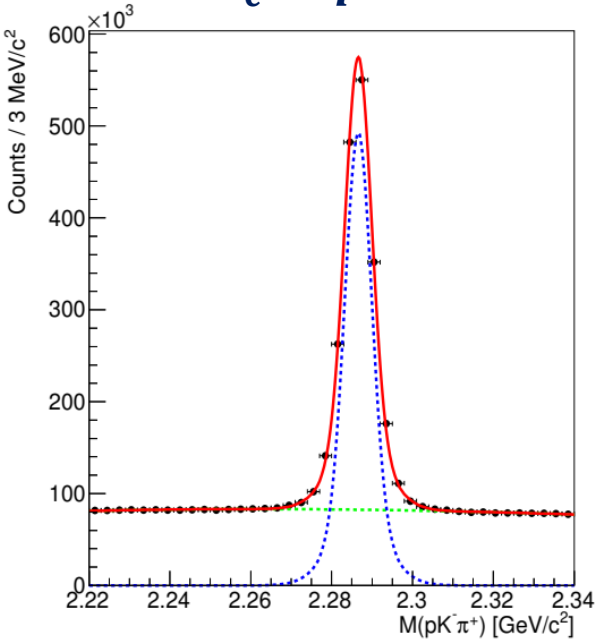
- $M(\Lambda\eta\pi^+)$ and $M(pK^-\pi^+)$ spectra

$\Lambda_c^+ \to \Lambda\eta\pi^+$



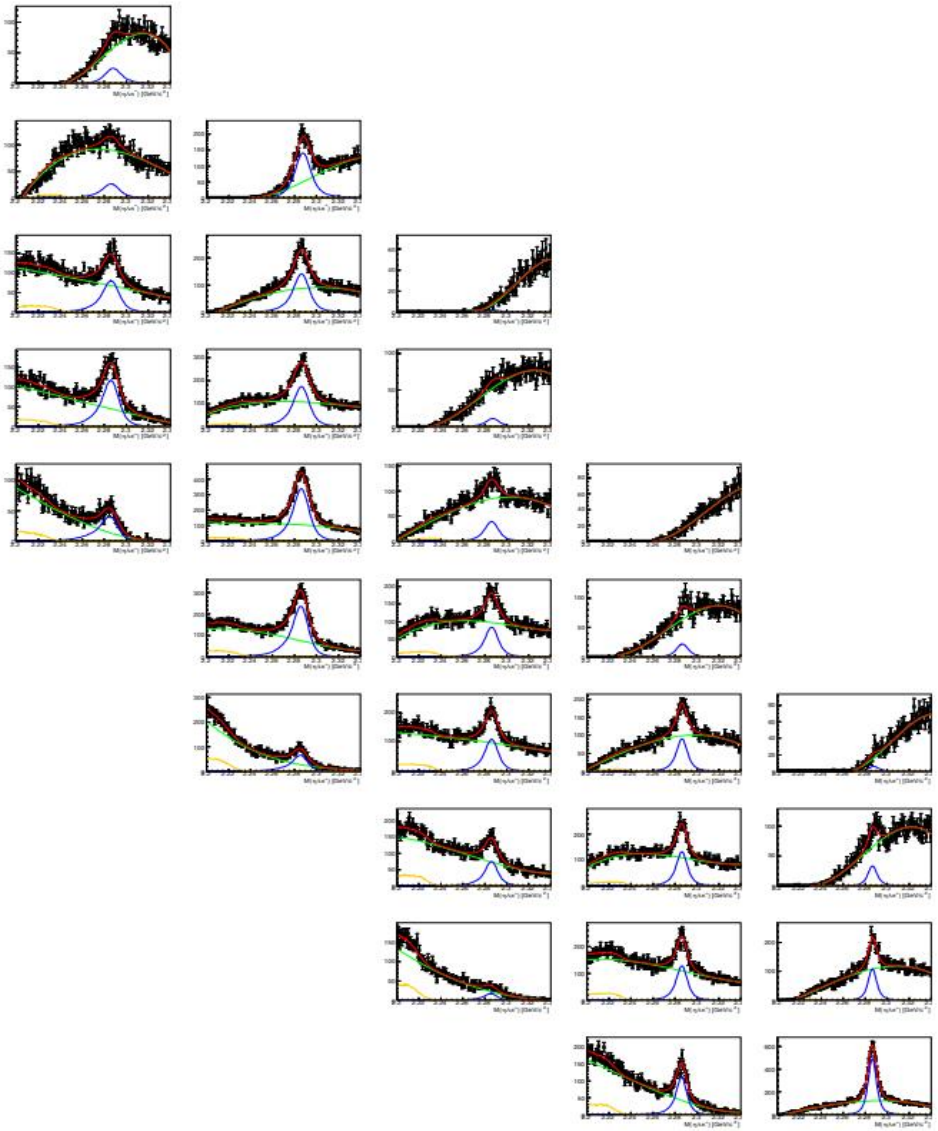
$\Lambda_c^+ \to \Lambda\eta\pi^+$: a gaussian + two bifurcated gaussian functions
$\Lambda_c^+ \to \Sigma^0\eta\pi^+$: signal MC sample
Background: polynomial function

$\Lambda_c^+ \to pK^-\pi^+$



$\Lambda_c^+ \to pK^-\pi^+$: two gaussian functions
Background: polynomial function

- $\Lambda\eta\pi^+$ signal extraction over Dalitz plot

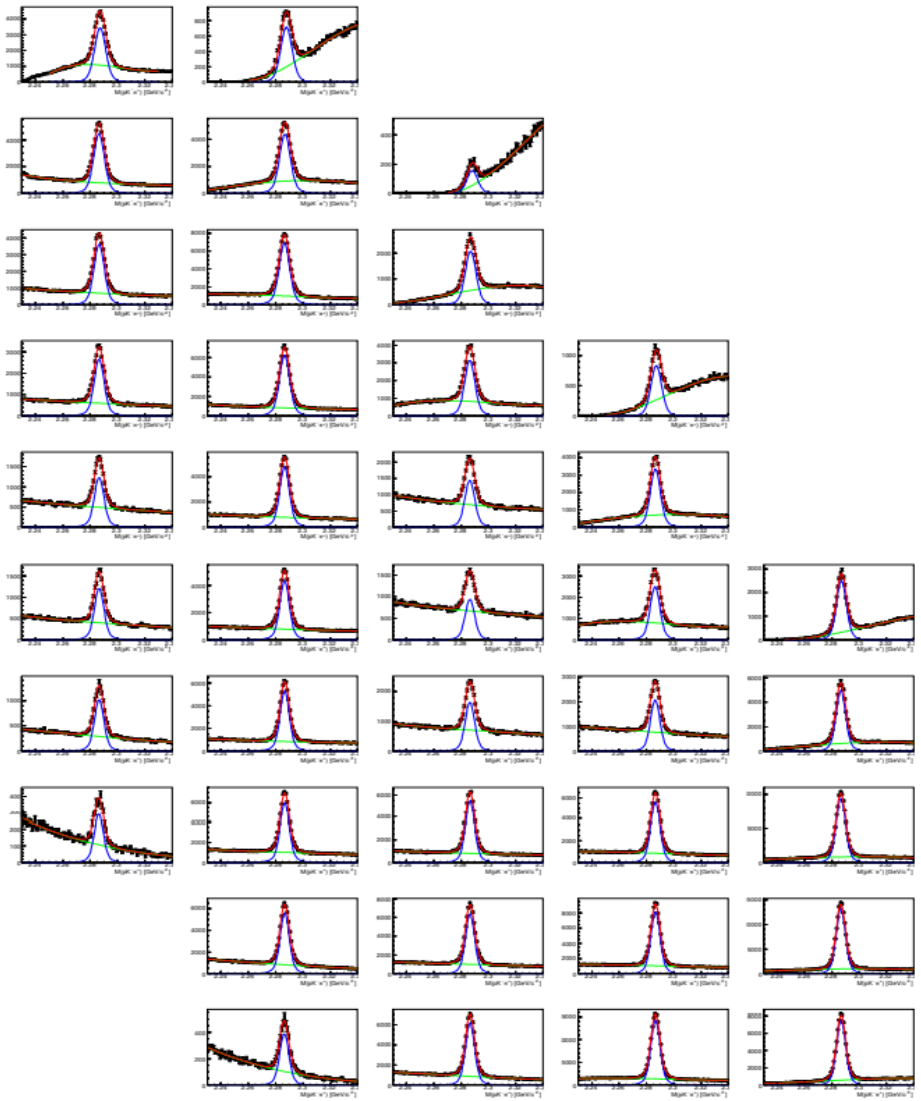


$$y = \sum_i \frac{y_i}{e_i}$$

* i: each bin

→ 741000 ± 7000

- $pK^-\pi^+$ signal extraction over Dalitz plot



$$y = \sum_i \frac{y_i}{e_i}$$

* i: each bin

→ 10047000 ± 10000

- Branching fractions

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

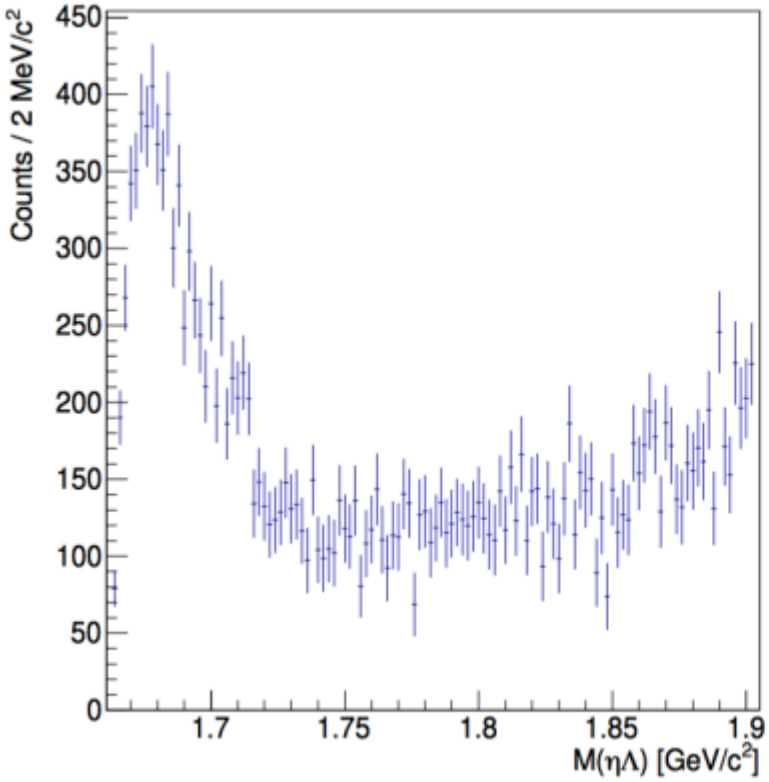
Decay Mode	$\frac{\mathcal{B}(\text{Decay Mode})}{\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+)}$	$\mathcal{B}(\text{Decay Mode})[\%]$
$\Lambda_c^+ \to \eta\Lambda\pi^+$	$0.293 \pm 0.003 \pm 0.014$	$1.84 \pm 0.02 \pm 0.09 \pm 0.09\%$
$\Lambda_c^+ \to \eta\Sigma^0\pi^+$	$0.120 \pm 0.006 \pm 0.006$	$(7.56 \pm 0.39 \pm 0.37 \pm 0.39) \times 10^{-3}$

* $\Lambda_c^+ \to \Sigma^0\eta\pi^+$ yields are not extracted over Dalitz plot.

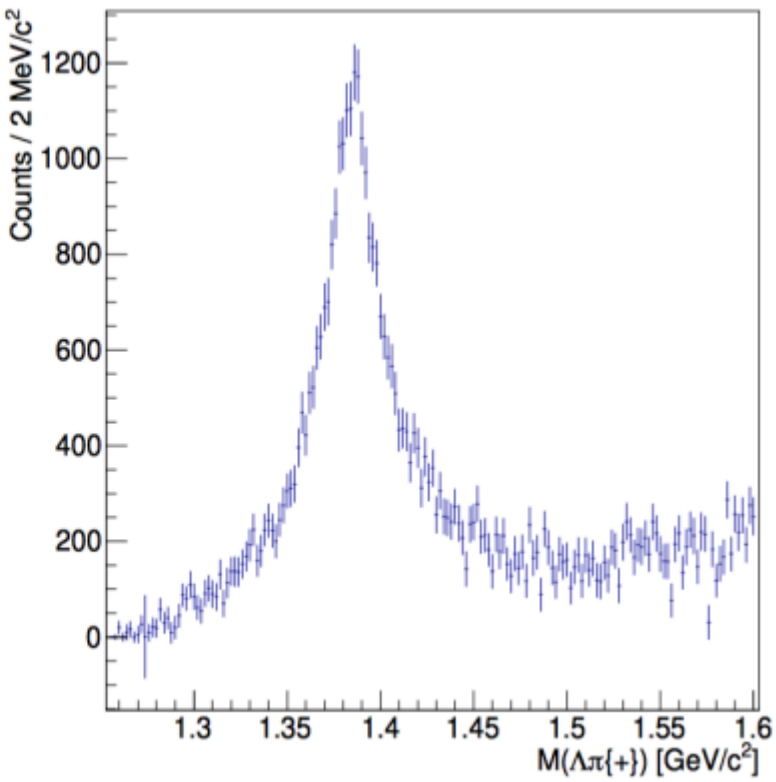
$M(\Lambda\eta)$ and $M(\Lambda\pi^+)$ Spectra

- Λ_c^+ yields as a function of $M(\Lambda\eta)$ and $M(\Lambda\pi^+)$
  - By fitting the $M(\Lambda\eta\pi^+)$ distributions for each bin.

$M(\Lambda\eta)$



$M(\Lambda\pi^+)$



PDFs for $\Lambda(1670)$ and $\Sigma(1385)^+$ peaks

- Relativistic partial width BW function,

$$\frac{dN}{dm} \propto \frac{m\Gamma(m)}{\left(m^2 - m_0^2\right)^2 + m_0^2\left(\Gamma(m) + \Gamma_{\text{others}}\right)^2},$$

with

$$\Gamma(m) = \Gamma_0 \frac{m_0}{m}\left(\frac{q}{q_0}\right)^{2L+1} F(q),$$

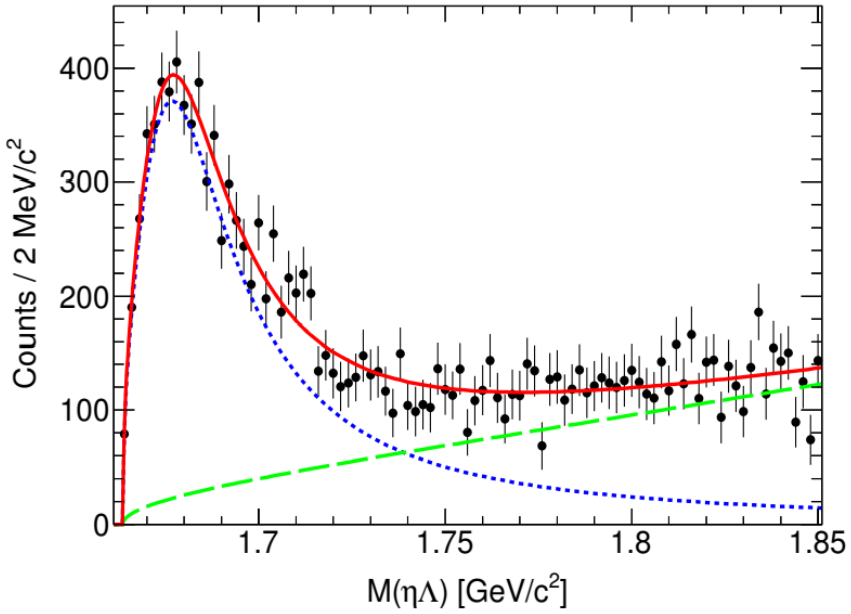
*Γ_{others}: sum of partial widths for other decays

$F(q)$: 1 for S-wave and $(1 + R^2 q_0^2)/(1 + R^2 q^2)$ for P-wave

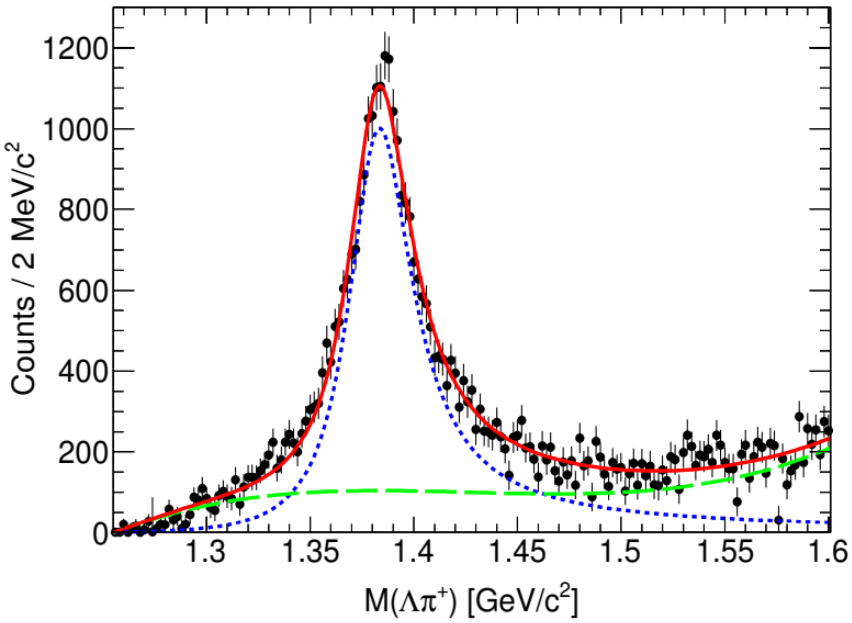
Fits to $M(\Lambda\eta)$ and $M(\Lambda\pi^+)$ Spectra

- Fit results

$M(\Lambda\eta)$



$M(\Lambda\pi^+)$



Resonances	Mass [MeV/c^2]	Width [MeV]
$\Lambda(1670)$	$1674.3 \pm 0.8 \pm 4.9$	$36.1 \pm 2.4 \pm 4.8$
$\Sigma(1385)^+$	$1384.8 \pm 0.3 \pm 1.4$	$38.1 \pm 1.5 \pm 2.1$

Branching Fractions	Relative to $\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+)$	Absolute Value Using $\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+)_{pdg}$
$\mathcal{B}(\Lambda_c^+ \to \Lambda(1670)\pi^+)$ $\times\mathcal{B}(\Lambda(1670) \to \eta\Lambda)$	$(5.54 \pm 0.29 \pm 0.73) \times 10^{-2}$	$(3.48 \pm 0.19 \pm 0.46 \pm 0.18) \times 10^{-3}$
$\mathcal{B}(\Lambda_c^+ \to \eta\Sigma(1385)^+)$	$0.192 \pm 0.006 \pm 0.016$	$1.21 \pm 0.04 \pm 0.10 \pm 0.06\%$

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.
- $\Lambda_c^+ \to pK^+\pi^-$, $\Lambda_c \to \Sigma\pi\pi$, and $\Lambda_c^+ \to pK^-\pi^+\pi^0$
2. We will soon publish new results of $\Lambda_c^+ \to \Lambda\eta\pi^+$ decay.
3. Analysis of $\Lambda_c^+ \to pK_s^0\pi^0$ decay is in progress by 김영준.

There are still many ongoing analyzes for baryon studies.