Hadronic and semileptonic decays of charm baryons with ALICE, LHCb, and Belle

Chong Kim

Pusan National University

LHCP 2024

12th Edition of the LHC Physics Conference

June 5, 2024

For the ALICE, LHCb, and Belle Collaboration

Motivation

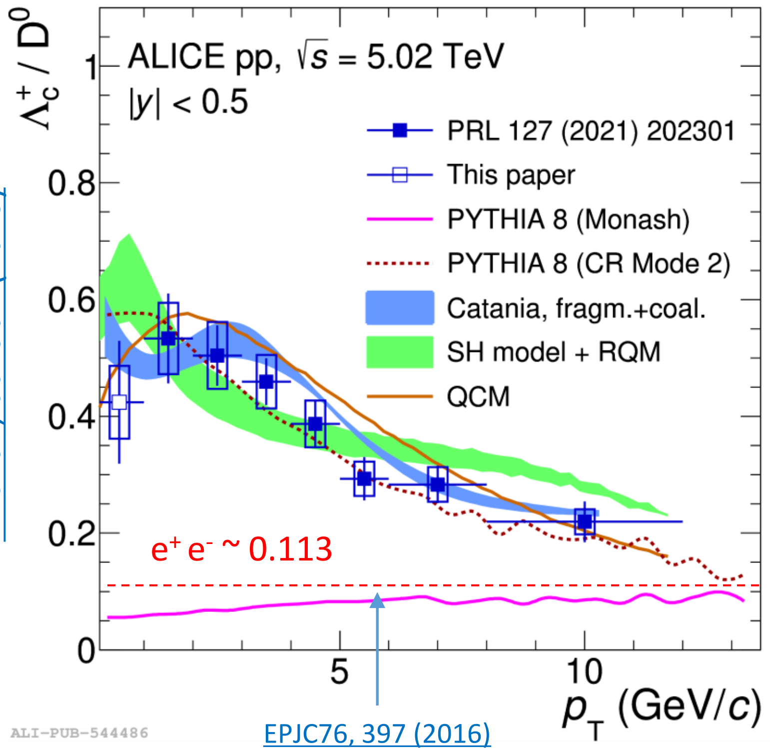
- **A few selectively chosen topics**
  - Why charm baryons matter
    - Lying in the transition region between the perturbative & non-perturbative energy scales in QCD
    - Hadronic form factors are not well known for baryons as they're for mesons
  - In this talk,
    - BF (branching fractions):
      crucial for the test/constrain of the theoretical models
    - LFU (lepton flavor universality):
      in Standard Model, charged weak current interaction has an identical coupling to all lepton generations
    - CP asymmetry parameter *A* via decay parameter α:
      an observable able to test CP violating process in the charm baryon sector
    - Characterizing charm-baryon states

ALICE

Motivation

Prompt Λ_c^+/D^0 in pp @ $\sqrt{s}$ = 5.02 TeV

PRC107, 064901 (2023)



EPJC76, 397 (2016)

PYTHIA 8 (Monash) / Eur. Phys. J. C 74, 3024 (2014)
Based on fragmentation functions from e^+e^-

PYTHIA 8 (CR Mode 2) / J. High Energy Phys. 08 (2015) 003
Color reconnection beyond leading order,
Introduce new junction topologies which results in increased baryon yield

Catania / Phys. Lett. B 821, 136622 (2021)
Thermalized system of gluons, light quarks and antiquarks (QGP).
Hadronization via coalescence and fragmentation

SH model / Phys. Lett. B 795, 117 (2019)
Replaces complexity of hadronization by thermo-statistical weights, governed by the masses of hadrons at a universal hadronization "temperature"

QCM / Chin. Phys. C 45, 113105 (2021)
Charm is combined with co-moving light antiquark or two quarks.
Abundances of charm baryon species are determined by thermal weights

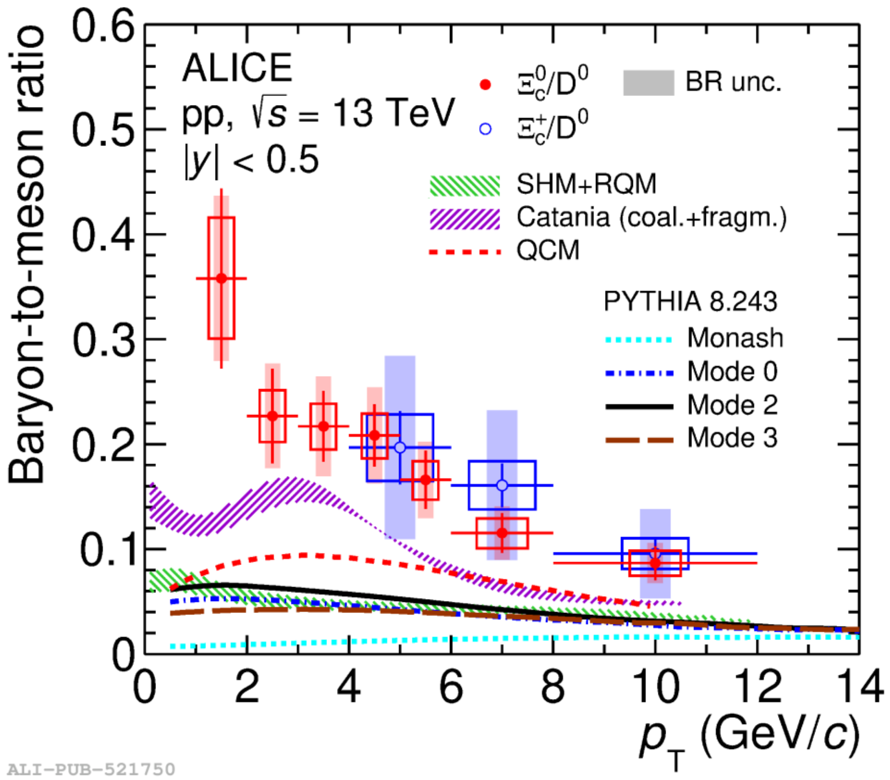
– Examples of measurements in ALICE (1/2)

- Significant baryon enhancement vs. e^+e^- result
- Models based on e^+e^-/e^-p fragmentation functions cannot describe the data

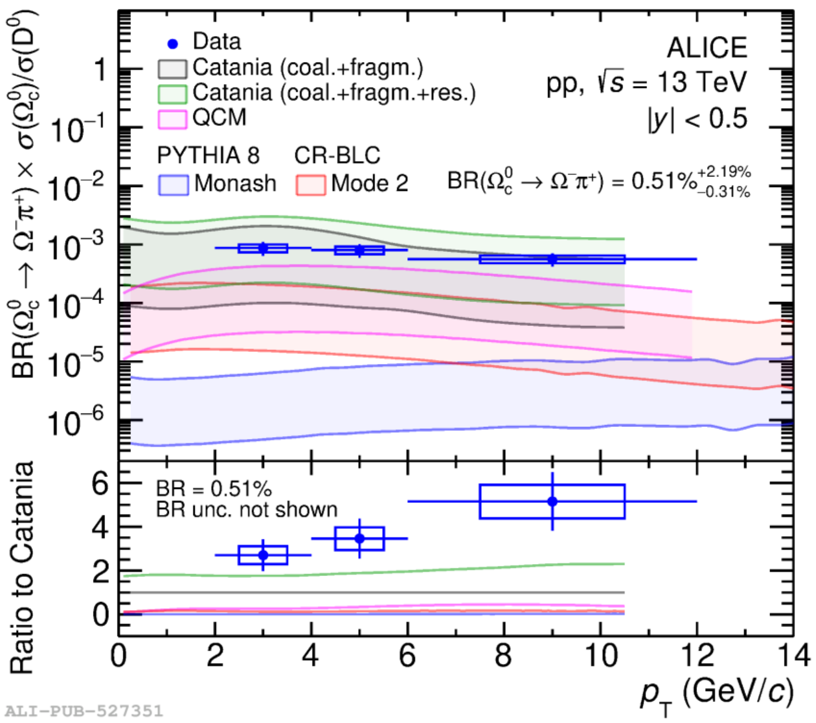
Motivation

Prompt $\Xi_c^{0,+}/D^0$ and Ω_c^0/D^0 in pp @ $\sqrt{s}$ = 13 TeV

PRL127, 272001 (2021)



PLB846 (2023) 137625



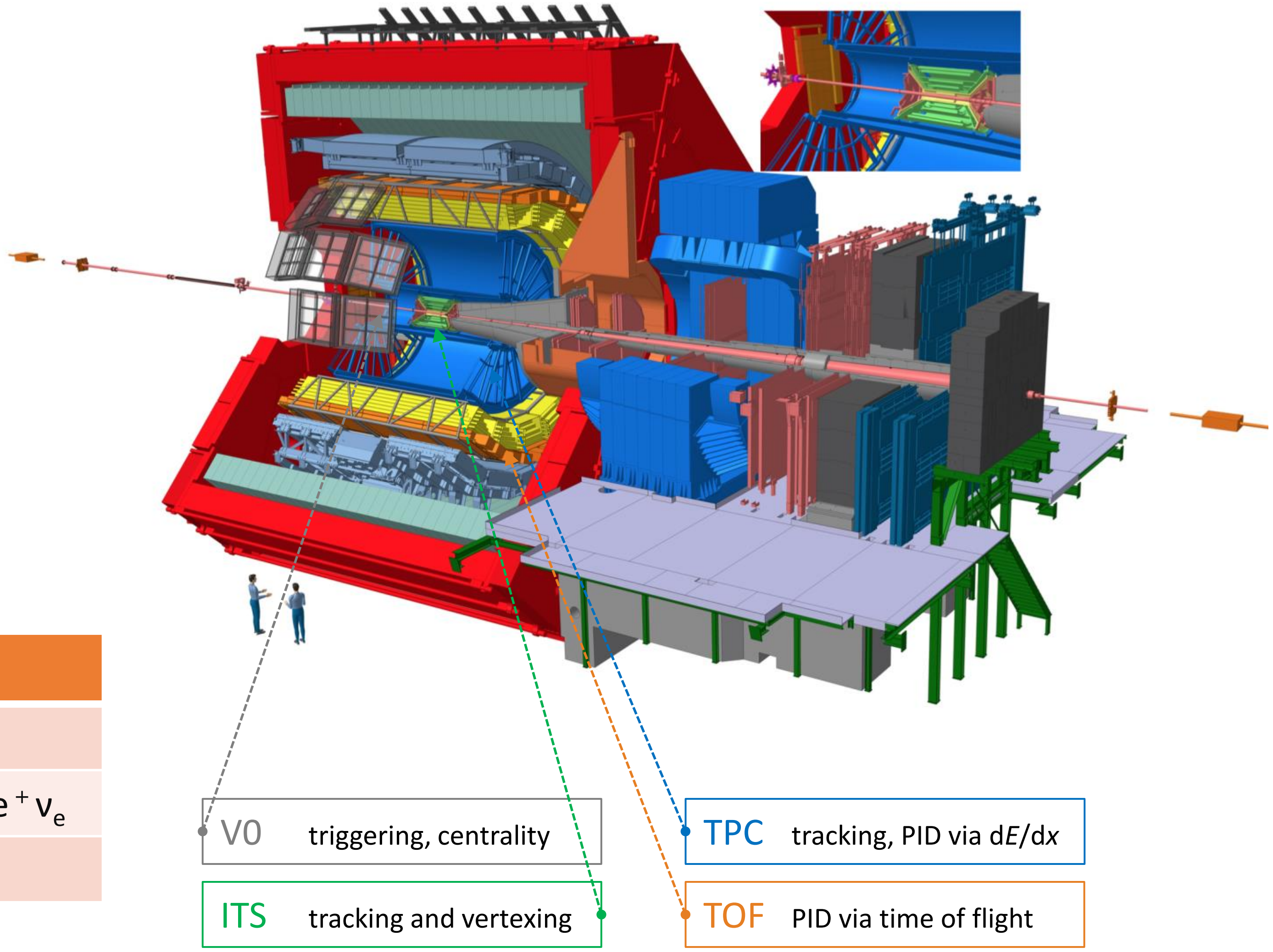
– Examples of measurements in ALICE (2/2)

- Even larger baryon enhancement vs. e^+e^- for charm-state baryons
- No absolute branching ratio is available for $\Omega_c^0 \rightarrow \Omega^- \pi^+$ yet: lack of measured BR does not allow to significantly constrain the models

- Catania: PLB821, 136622 (2021)
- PYTHIA8 Monash 2013: EPJC74 (2014) 3024
- PYTHIA8 CR Mode: JHEP 08 (2015) 003
- QCM: EPJC78 (2018) 344
- SHM: PLB795, 117 (2019)

Apparatus ALICE

ALICE apparatus in Run 1 and 2 (2010-2018)



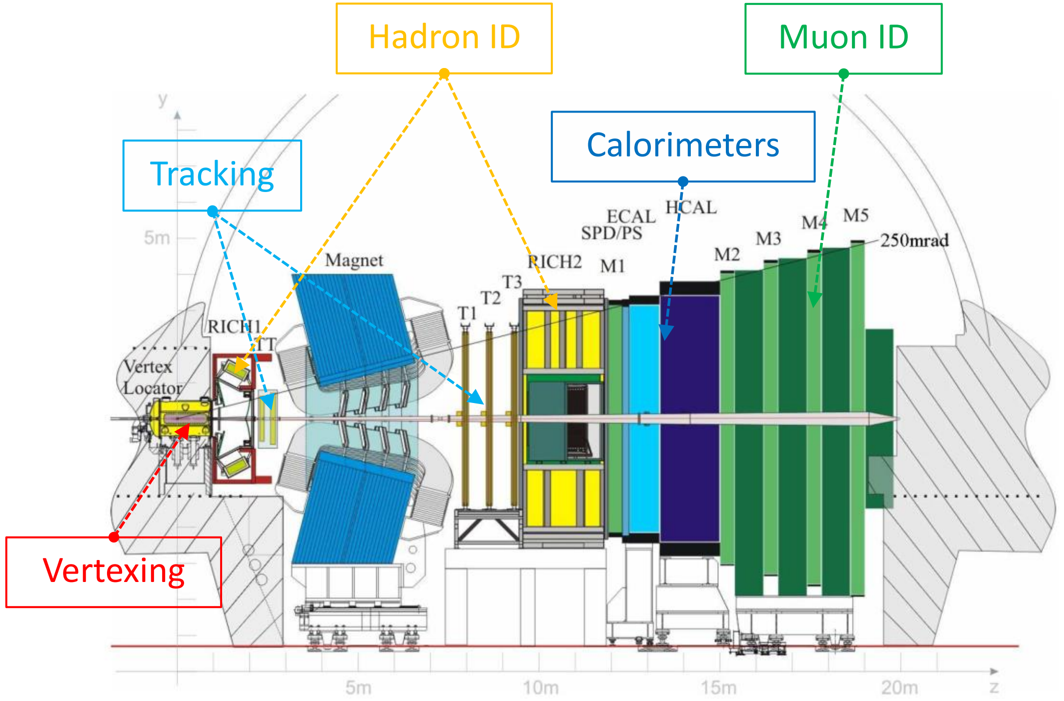
Data samples (Run 2)

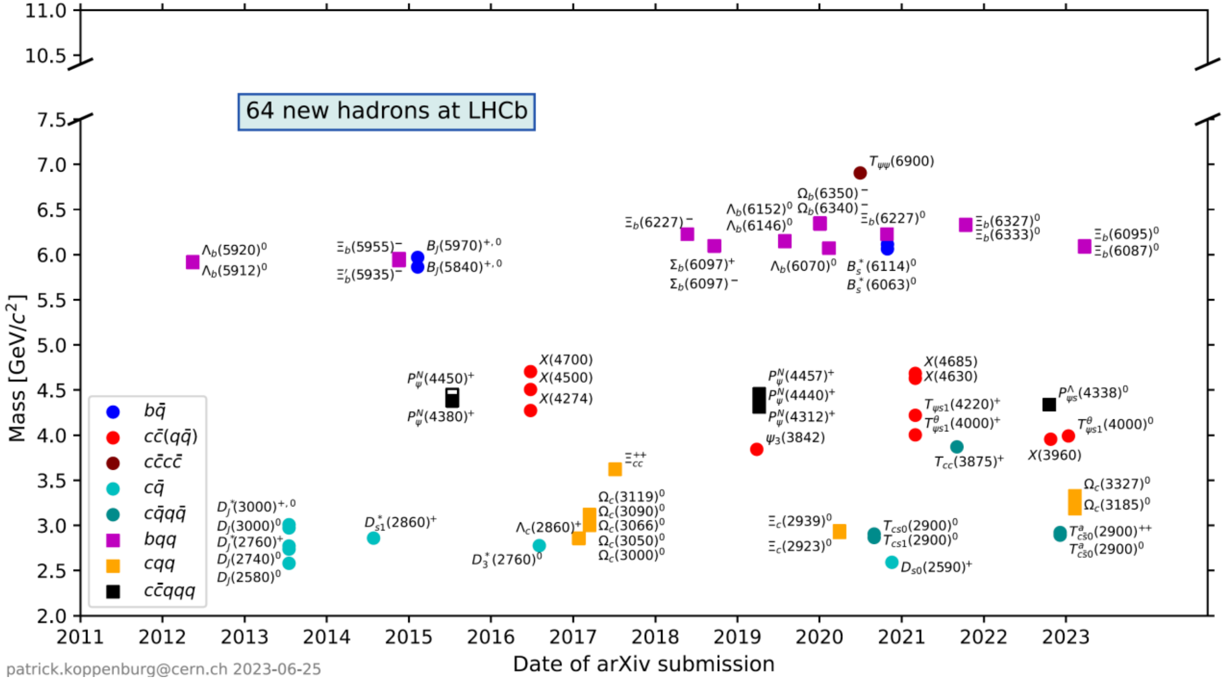
System	Energy (TeV)	L_{int}
pp	$\sqrt{s}$ = 5.02	~ 19 nb^{-1} (MB)
	$\sqrt{s}$ = 13	~ 32 nb^{-1} (MB)
p–Pb	$\sqrt{s_{NN}}$ = 5.02	~ 287 μb^{-1} (MB)
Pb–Pb	$\sqrt{s_{NN}}$ = 5.02	~ 130 μb^{-1} (0-10%)
		~ 56 μb^{-1} (30-50%)

Channels under study

Baryons	
Λ_c^+ (udc) → $\Lambda e^+ \nu_e$, $pK^- \pi^+$, pK_s^0	Ξ_c^+ (usc) → $\Xi^- \pi^+ \pi^+$
$\Sigma_c^{0,++}$ (ddc, uuc) → $\Lambda_c^+ \pi^{-,+}$	Ω_c^0 (ssc) → $\Omega^- \pi^+$, $\Omega^- e^+ \nu_e$
Ξ_c^0 (dsc) → $\Xi^- e^+ \nu_e$, $\Xi^- \pi^+$	

Apparatus LHCb





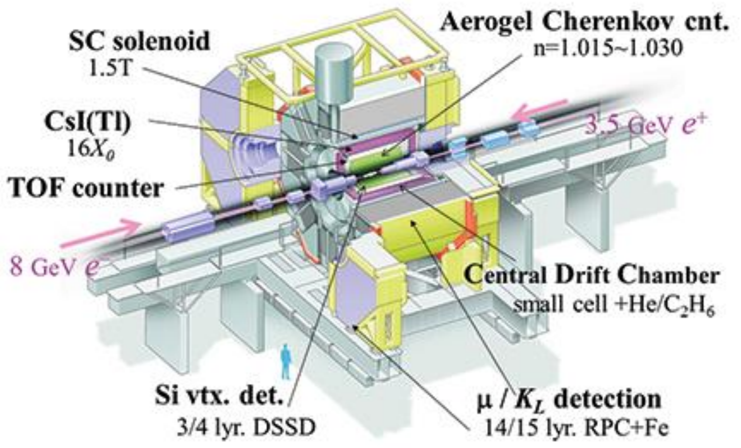
JINST 3 (2008) S08005, IJMPA 30 (2015) 1530022

– LHCb detector in Run 1 and 2 (2010-2018)

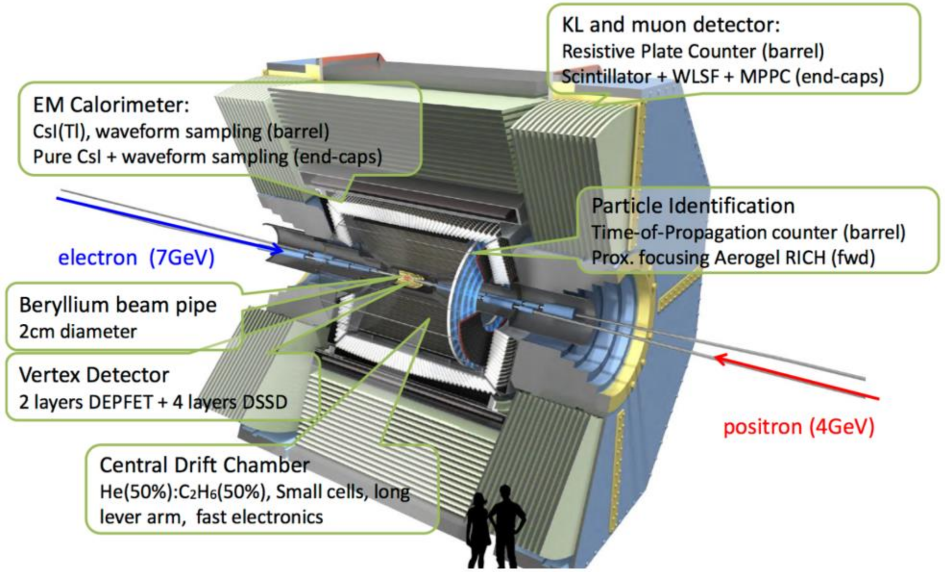
- Single arm forward spectrometer covering $2 < \eta < 5$
- Designed for the study of particles containing *b* or *c*
- Excellent vertexing, tracking, momentum resolution and PID

Apparatus   Belle & Belle II

Belle @ KEKB



Belle II @ SuperKEKB



- Belle and Belle II:
  - Asymmetric e^+e^- collisions at max. 10.58 GeV to produce Υ (4S) resonance
  - KEKB (2009 – 2010) : peak luminosity of 2 × 10^{34} $cm^{-2}s^{-1}$, L_{int} = 1 ab^{-1}
  - SuperKEKB (2019 –): peak luminosity of 4.7 × 10^{34} $cm^{-2}s^{-1}$, L_{int} = 0.42 ab^{-1} (* Run1 (2019 – 2022), Run2 (started 2024))
- Belle and Belle II are synergic to each other:
  - Belle data can be analyzed with the Belle II software framework
  - Common review procedures since 2023 summer

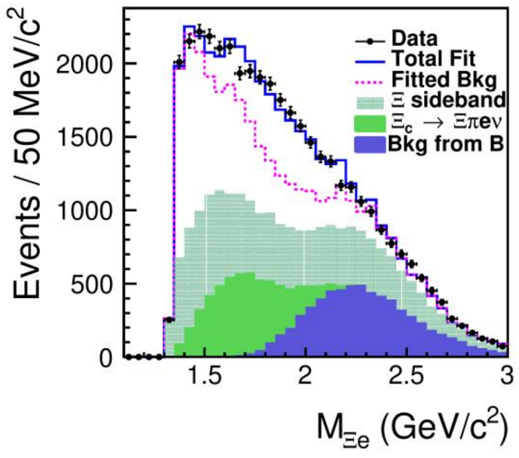
Branching fraction

- **Recent BF measurements**

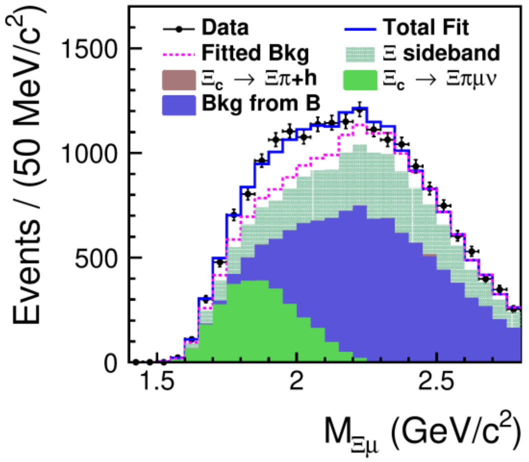
1. ALICE — $B\,(\Xi_c^0 \rightarrow \Xi^- e^+ \nu_e)\,/\,B\,(\Xi^- \pi^+)$, in pp @ 13 TeV : PRL127, 272001 (2021)
2. Belle — $B\,(\Xi_c^0 \rightarrow \Xi^- l^+ \nu_l)$, in e^+e^- : PRL127, 121803 (2021)
3. Belle — $B\,(\Xi_c^0 \rightarrow \Xi^0 l^+ l^-)$, in e^+e^- : PRD109, 052003 (2024) (* setting upper limits) New!
4. Belle + Belle II — $B\,(\Xi_c^0 \rightarrow \Xi^0 h^0)$, in e^+e^- : preliminary New!
5. ALICE — $B\,(\Omega_c^0 \rightarrow \Omega^- \pi)$, in pp @ 13 TeV : PLB846 (2023) 137625
6. Belle — $B\,(\Omega_c^0 \rightarrow \Omega^- l^+ \nu_l)\,/\,B\,(\Omega_c^0 \rightarrow \Omega^- \pi^+)$, in e^+e^- : PRD105, L091101 (2022)
7. ALICE — $B\,(\Omega_c^0 \rightarrow \Omega^- e^+ \nu_e)\,/\,B\,(\Omega_c^0 \rightarrow \Omega^- \pi^+)$, in pp @ 13 TeV : arXiv:2404.17272 (2024) New!
8. Belle — $B\,(\Omega_c^0 \rightarrow \Xi^- \pi^+)\,/\,B\,(\Omega_c^0 \rightarrow \Omega^- \pi^+)$, in e^+e^- : JHEP01(2023)055
9. LHCb — $B\,(\Omega_c^0 \rightarrow \Omega^- K^+, \Xi^- \pi^+)\,/\,\mathrm{B}\,(\Omega_c^0 \rightarrow \Omega^- \pi^+)$, in pp @ 13 TeV : PRL132, 081802 (2024) New!

Branching fraction $\Xi_c^0 \to \Xi^- l^+ \nu_l$ in e^+e^-

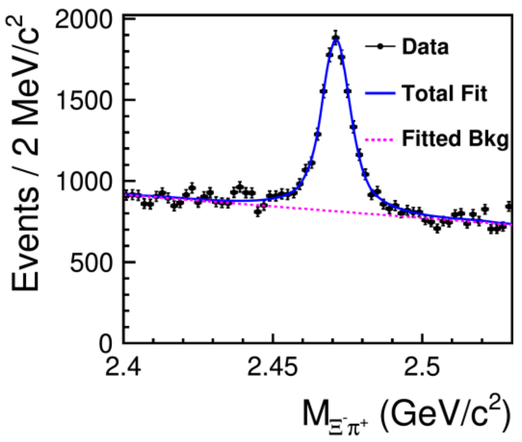
$\Xi_c^0 \to \Xi^- e^+ \nu_e$



$\Xi_c^0 \to \Xi^- \mu^+ \nu_\mu$



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



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

PRL127, 121803 (2021)

- Statistics:

  89.5 fb^{-1} (10.52 GeV) and 711 fb^{-1} (10.58 GeV)

- Branching fractions via electronic and muonic decay

  - $\mathcal{B}(\Xi_c^0 \to \Xi^- e^+ \nu_e)$: (1.31 ± 0.04 (stat) ± 0.07 (syst) ± 0.38)%

    $\mathcal{B}(\Xi_c^0 \to \Xi^- \mu^+ \nu_\mu)$: (1.27 ± 0.06 (stat) ± 0.10 (syst) ± 0.37)%

    * $\mathcal{B}(\Xi_c^0 \to \Xi^- \pi^+)$: (1.80 ± 0.52)% (PRL122, 082001 (2019))

  - $\mathcal{B}(\Xi_c^0 \to \Xi^- e^+ \nu_e) / \mathcal{B}(\Xi_c^0 \to \Xi^- \pi^+)$: 0.730 ± 0.021 (stat)

    * ARGUS: 0.96 ± 0.43 ± 0.18

    * CLEO: 3.1 ± 1.0 + 0.3 - 0.5

    * ALICE (2021): 1.38 ± 0.14 ± 0.22

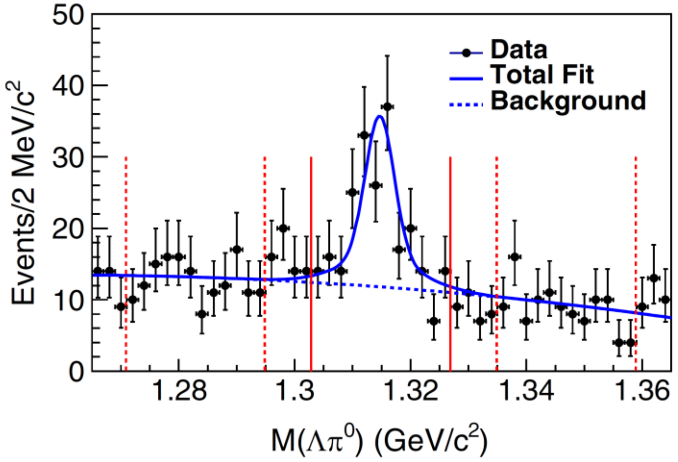
    $\mathcal{B}(\Xi_c^0 \to \Xi^- \mu^+ \nu_\mu) / \mathcal{B}(\Xi_c^0 \to \Xi^- \pi^+)$: 0.708 ± 0.033 (stat)

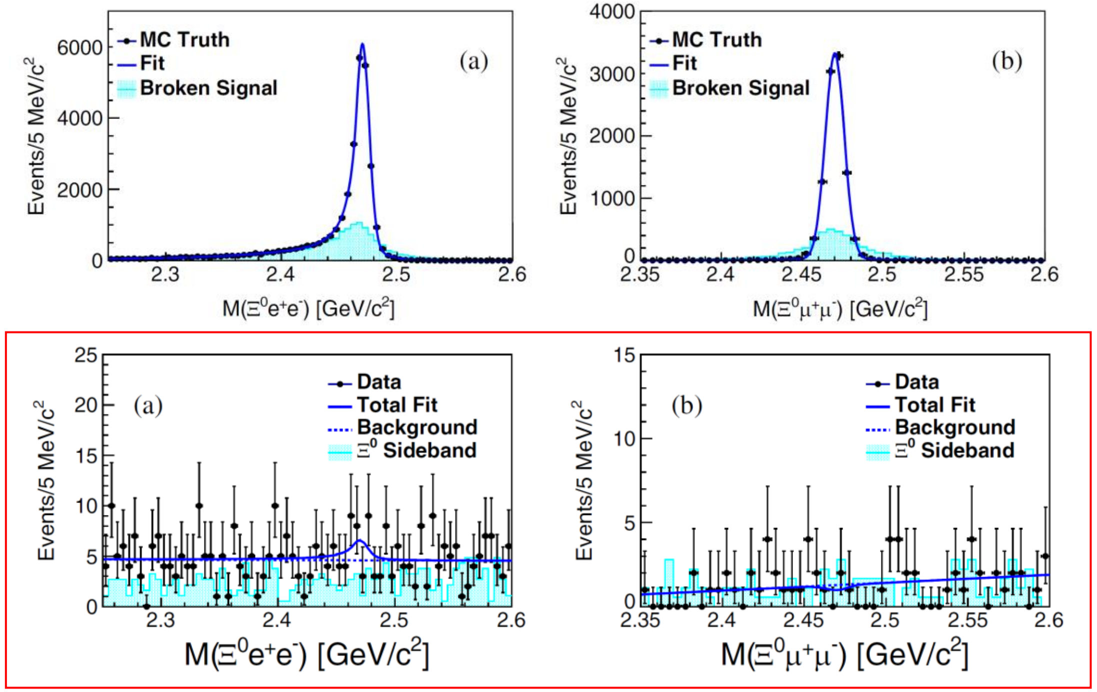
Branching fraction $\Xi_c^0 \to \Xi^0 l^+ l^-$ in e^+e^-

New!

PRD109, 052003 (2024)

$\Xi^0 \to \Lambda\pi^0$ candidates





– 1st search for rare semileptonic decay of charm baryon, with statistics of 980 fb^{-1}

- Few baryonic neutrino-less semileptonic decays measured, none for charm baryons
- No significant signals observed: set experimental upper limits at 90% CL, compatible with SM (PRD103, 013007)

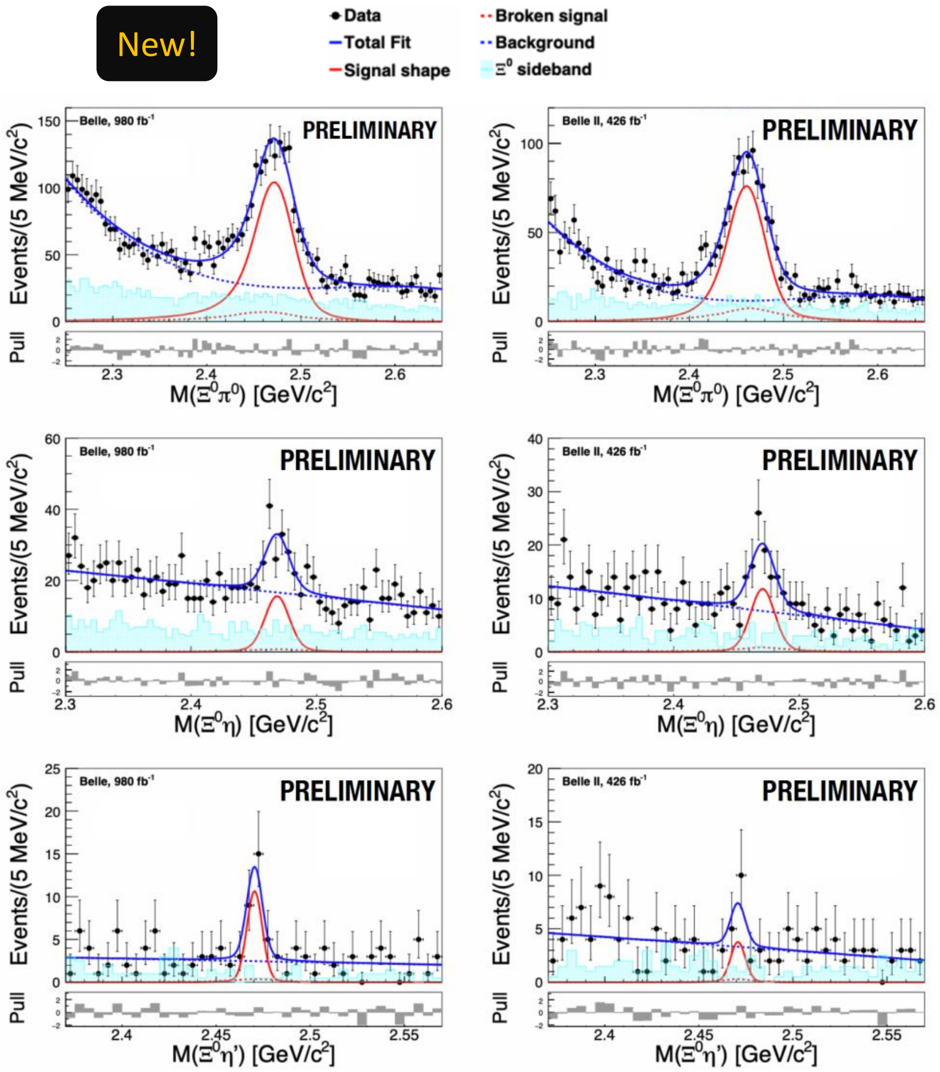
$B(\Xi_c^0 \to \Xi^0 e^+ e^-)$: 9.9×10^{-5} ↔ $B_{SM}(\Xi_c^0 \to \Xi^0 e^+ e^-) < 2.35 \times 10^{-6}$

$B(\Xi_c^0 \to \Xi^0 \mu^+ \mu^-)$: 6.4×10^{-5} ↔ $B_{SM}(\Xi_c^0 \to \Xi^0 \mu^+ \mu^-) < 2.25 \times 10^{-6}$

Branching fraction

$\Xi_c^0 \to \Xi^0 h^0$, where $h^0 = \pi^0$, η, and η' in e^+e^-

New!



– Providing a reference to clarify the theoretical picture

Several models have been proposed to deal with non-factorizable amplitudes from W-exchange and internal W-emission diagrams, yielding different predictions to these branching ratios

– 1st Belle + Belle II combined charm measurement

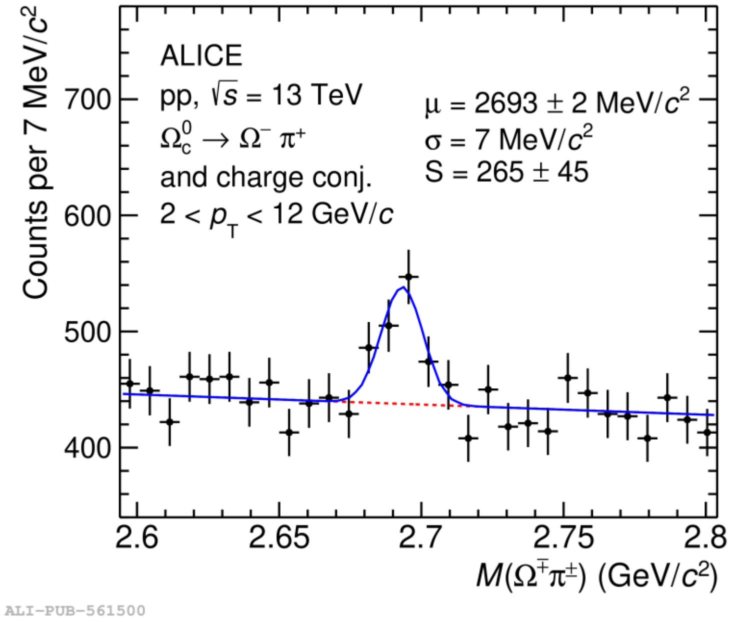
– 1st measurements of the following BRs:

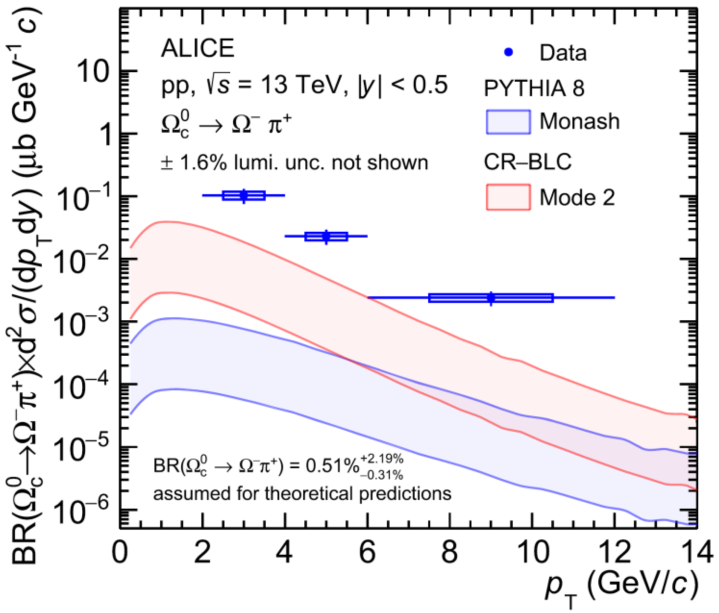
- $\mathcal{B}(\Xi_c^0 \to \Xi^0\pi^0) = (6.9 \pm 0.3\,(\text{stat}) \pm 0.5\,(\text{syst}) \pm 1.5\,(\text{norm})) \times 10^{-3}$
- $\mathcal{B}(\Xi_c^0 \to \Xi^0\eta) = (1.6 \pm 0.2\,(\text{stat}) \pm 0.2\,(\text{syst}) \pm 0.4\,(\text{norm})) \times 10^{-3}$
- $\mathcal{B}(\Xi_c^0 \to \Xi^0\eta') = (1.2 \pm 0.3\,(\text{stat}) \pm 0.1\,(\text{syst}) \pm 0.3\,(\text{norm})) \times 10^{-3}$

* Reference mode: $\Xi_c^0 \to \Xi^- \pi^+$

Branching fraction $\Omega_c^0 \to \Omega^- \pi^+$ in pp @ $\sqrt{s}$ = 13 TeV

PLB846 (2023) 137625





Ratio	ALICE (pp 13 TeV) $2 < p_T < 12$ GeV/c	Belle (e^+e^- 10.52 GeV) [28] visible
$BR(\Omega_c^0 \to \Omega^-\pi^+) \times \sigma(\Omega_c^0)/\sigma(\Lambda_c^+)$	$(1.96 \pm 0.42 \pm 0.13) \times 10^{-3}$	$(2.24 \pm 0.29 \pm 0.16) \times 10^{-4}$
$BR(\Omega_c^0 \to \Omega^-\pi^+) \times \sigma(\Omega_c^0)/\sigma(\Xi_c^0)$	$(3.99 \pm 0.96 \pm 0.96) \times 10^{-3}$	$(8.58 \pm 1.15 \pm 1.98) \times 10^{-4}$

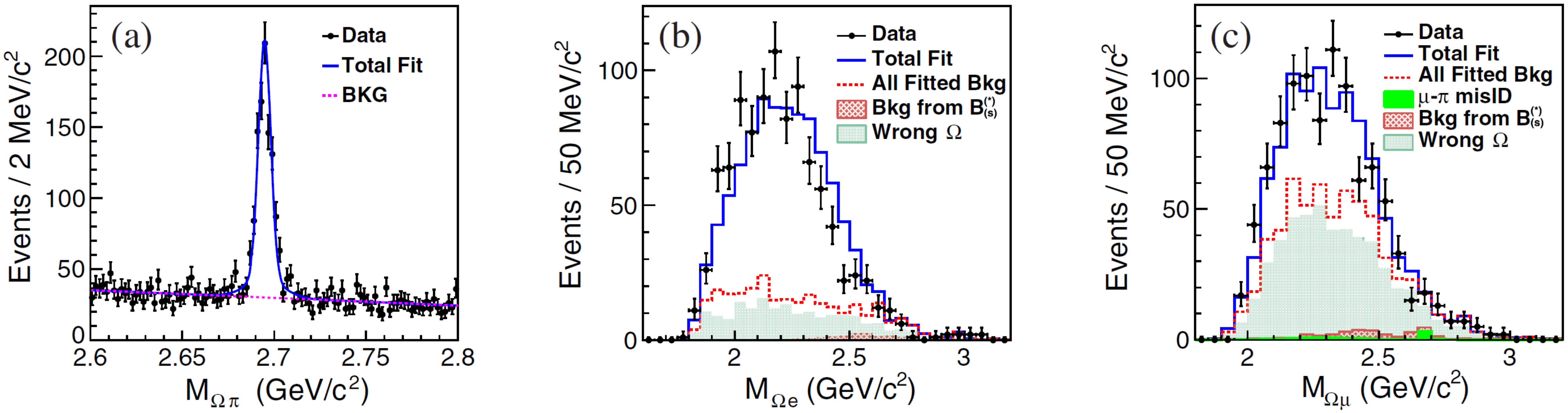
- Catania: PLB821, 136622 (2021)
- PYTHIA8 Monash 2013: EPJC74 (2014) 3024
- PYTHIA8 CR Mode: JHEP 08 (2015) 003
- QCM: EPJC78 (2018) 344

– 1st measurement of inclusive $\Omega_c^0 \to \Omega^- \pi^+$ in pp collisions at $\sqrt{s}$ = 13 TeV

p_T integrated Ω_c^0 cross section × baryon-to-baryon ratio suggests more frequent charm hadronization in pp than e^+e^-

Branching fraction $\Omega_c^0 \to \Omega^- l^+ \nu_l$ in e^+e^-

PRD105, L091101 (2022)



– 1st observation of $\Omega_c^0 \to \Omega^- \mu^+ \nu_\mu$

Statistics: 89.5 fb^{-1} (10.52 GeV), 711 fb^{-1} (10.58 GeV), and 121.1 fb^{-1} (10.86 GeV)

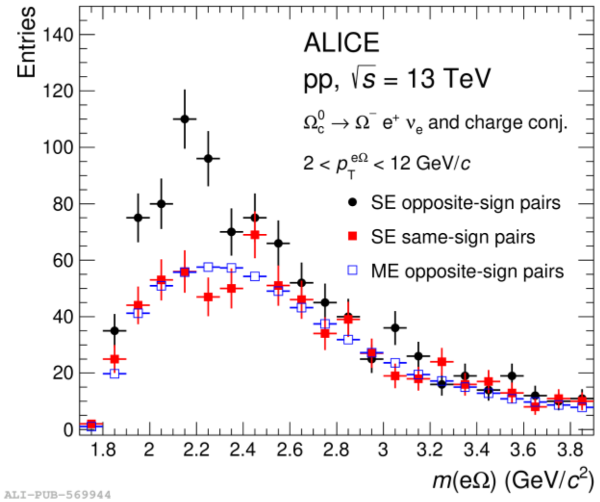
– Consistent with previous measurement and theoretical expectation

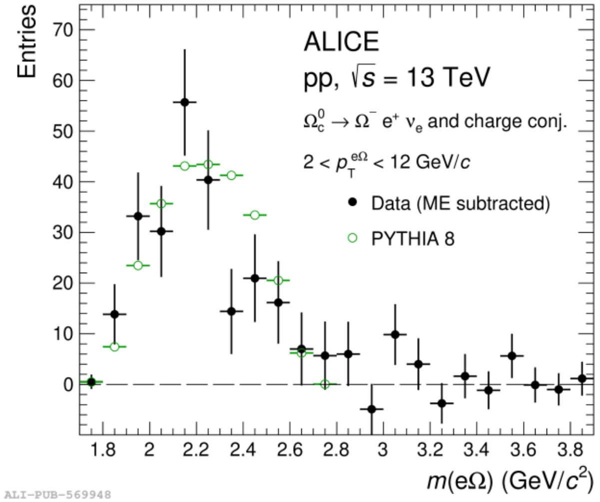
- $B(\Omega_c^0 \to \Omega^- e^+ \nu_e) / B(\Omega_c^0 \to \Omega^- \pi^+)$: 1.98 ± 0.13 (stat) ± 0.08 (syst) ↔ 2.4 ± 1.1 ± 0.2 (CLEO Collaboration)
- $B(\Omega_c^0 \to \Omega^- \mu^+ \nu_\mu) / B(\Omega_c^0 \to \Omega^- \pi^+)$: 1.94 ± 0.18 (stat) ± 0.10 (syst)

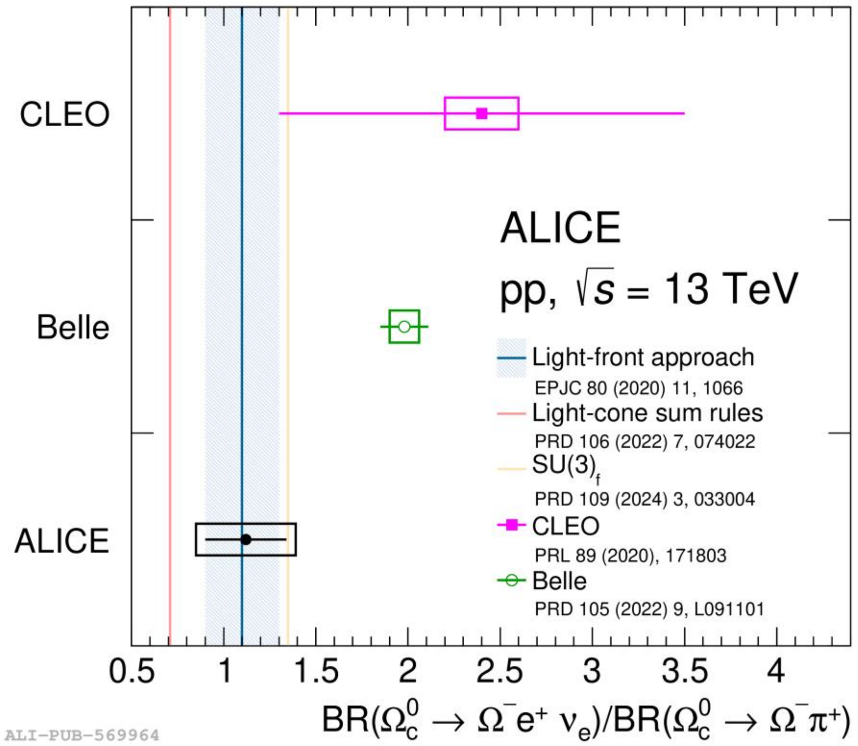
Branching fraction $\Omega_c^0 \rightarrow \Omega^- e^+ \nu_e$ in pp @ 13 TeV

New!

arXiv:2404.17272 (2024)





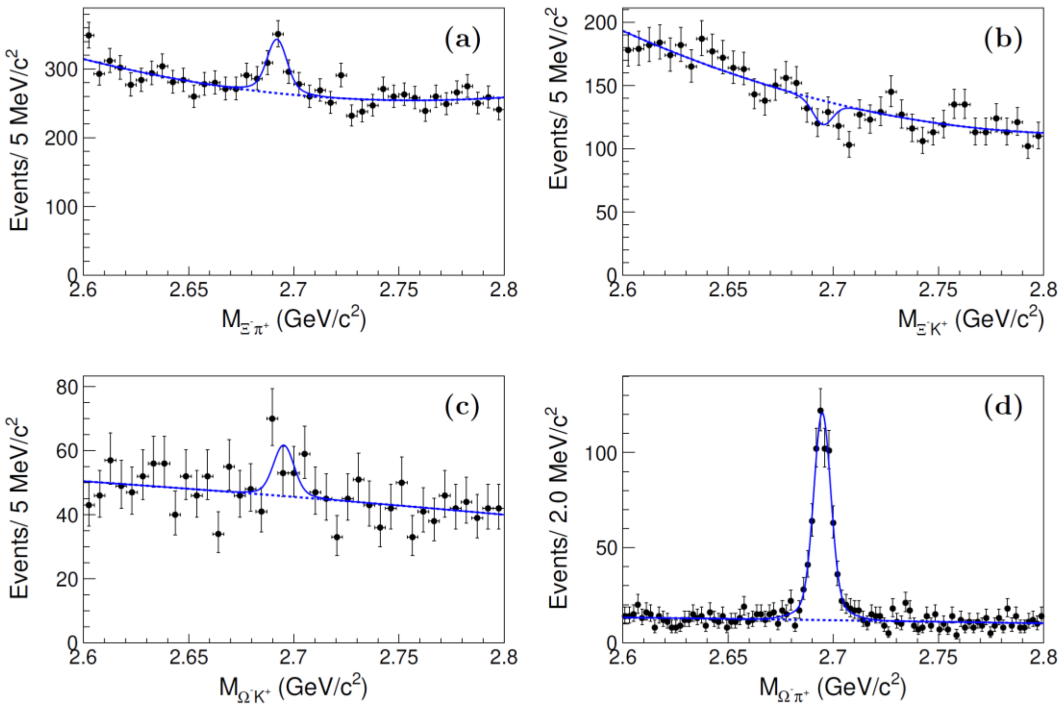


– BR × cross section and BF ratio measurement

- Statistics: (32.08 ± 0.51) nb^{-1}
- $B(\Omega_c^0 \rightarrow \Omega^- e^+ \nu_e) / B(\Omega_c^0 \rightarrow \Omega^- \pi^+)$: 1.12 ± 0.22 (stat) ± 0.27 (syst)

  → Consistent with theory and in agreement with Belle within 2.3σ

Branching fraction $\Omega_c^0 \to \Xi^- \pi^+$ in e^+e^-



JHEP01(2023)055

Theoretical predictions

- * No prediction is available for $\Omega_c^0 \to \Omega^- K^+$
- * BF of reference mode ($\Omega_c^0 \to \Omega^- \pi^+$): 9%

Decay modes	LFQM [16]	pole model and CA [17]
$\Omega_c^0 \to \Xi^- \pi^+$	1.96×10^{-3}	1.04×10^{-1}
$\Omega_c^0 \to \Xi^- K^+$	1.74×10^{-4}	1.06×10^{-2}

- LFQM: Chin. Phys. C 42 (2018) 093101
- Pole model and CA: Phys. Rev. D 101 (2020) 094033

– Search for singly/doubly Cabibbo-suppressed decays with statistics of 980 fb^{-1}

- 1^{st} evidence of $\Omega_c^0 \to \Xi^- \pi^+$ with 4.5σ significance

  → 2.4σ away from pole model and CA (current algebra)

- No significant signals are found for $\Omega_c^0 \to \Xi^- K^+$ and $\Omega_c^0 \to \Omega^- \pi^+$

$$\frac{\mathcal{B}(\Omega_c^0 \to \Xi^- \pi^+)}{\mathcal{B}(\Omega_c^0 \to \Omega^- \pi^+)} = [25.3 \pm 5.2(\text{stat.}) \pm 3.0(\text{syst.})]\,\%.$$

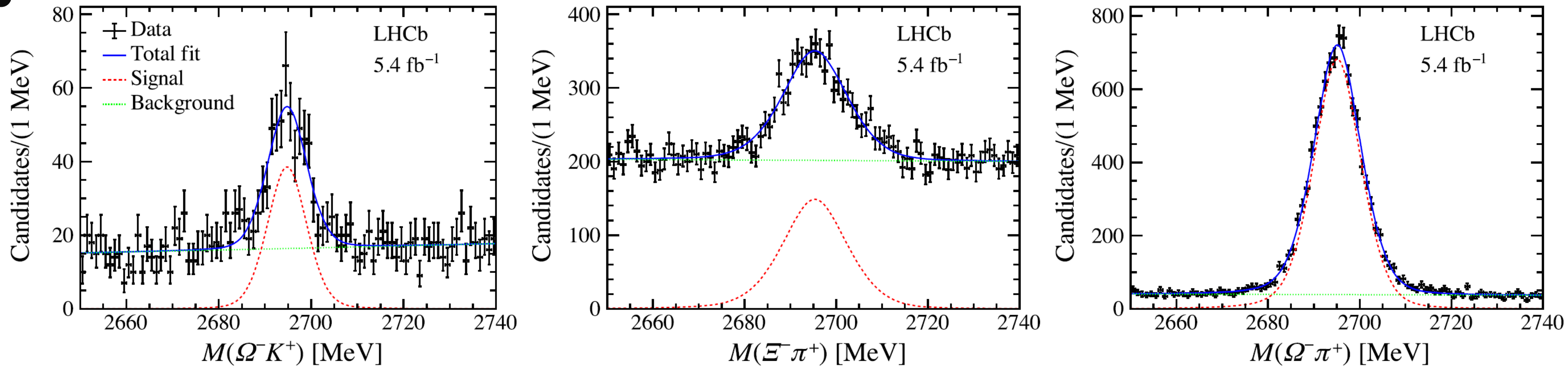
$$\frac{\mathcal{B}(\Omega_c^0 \to \Xi^- K^+)}{\mathcal{B}(\Omega_c^0 \to \Omega^- \pi^+)} < 0.070$$

$$\frac{\mathcal{B}(\Omega_c^0 \to \Omega^- K^+)}{\mathcal{B}(\Omega_c^0 \to \Omega^- \pi^+)} < 0.29.$$

Branching fraction $\Omega_c^0 \to \Omega^- K^+$ and $\Omega_c^0 \to \Xi^- \pi^+$ in pp @ $\sqrt{s}$ = 13 TeV

New!

PRL132, 081802 (2024)



- 1st observation of singly Cabibbo-suppressed two-body hadronic decays of Ω_c^0
  - The BFs are larger than the algebra calculation or LFQM
  - The non-factorizable contributions are necessary for accurate BF calculation

$$\frac{\mathcal{B}(\Omega_c^0 \to \Omega^- K^+)}{\mathcal{B}(\Omega_c^0 \to \Omega^- \pi^+)} = [6.08 \pm 0.51(\text{stat}) \pm 0.40(\text{syst})]\%,$$

$$\frac{\mathcal{B}(\Omega_c^0 \to \Xi^- \pi^+)}{\mathcal{B}(\Omega_c^0 \to \Omega^- \pi^+)} = [15.81 \pm 0.87(\text{stat}) \pm 0.44(\text{syst}) \pm 0.16(\text{ext})]\%$$

- Precise mass measurement of Ω_c^0
  - M (Ω_c^0) = 2695.28 ± 0.07 (stat) ± 0.27 (syst) ± 0.30 (ext) MeV
  - Most precise Ω_c^0 mass to the date: improves previous world average by a factor of 4

LFU and A_{CP}

- Recent BF measurements → **Lepton flavor universality (LFU) and CP asymmetry parameter (A_{CP})**

1. ALICE — $B(\Xi_c^0 \to \Xi^- e^+ \nu_e) / B(\Xi^- \pi^+)$, in pp @ 13 TeV : PRL127, 272001 (2021)
2. Belle — $B(\Xi_c^0 \to \Xi^- l^+ \nu_l)$, in e$^+e^-$: PRL127, 121803 (2021)
3. Belle — $B(\Xi_c^0 \to \Xi^0 l^+ l^-)$, in e$^+e^-$: PRD109, 052003 (2024) (* setting upper limits)
4. Belle + Belle II — $B(\Xi_c^0 \to \Xi^0 h^0)$, in e$^+$e$^-$: preliminary
5. ALICE — $B(\Omega_c^0 \to \Omega^- \pi)$, in pp @ 13 TeV : PLB846 (2023) 137625
6. Belle — $B(\Omega_c^0 \to \Omega^- l^+ \nu_l) / B(\Omega_c^0 \to \Omega^- \pi^+)$, in e$^+e^-$: PRD105, L091101 (2022)
7. ALICE — $B(\Omega_c^0 \to \Omega^- e^+ \nu_e) / B(\Omega_c^0 \to \Omega^- \pi^+)$, in pp @ 13 TeV : arXiv:2404.17272 (2024)
8. Belle — $B(\Omega_c^0 \to \Xi^- \pi^+) / B(\Omega_c^0 \to \Omega^- \pi^+)$, in e$^+e^-$: JHEP01(2023)055
9. LHCb — $B(\Omega_c^0 \to \Omega^- K^+, \Xi^- \pi^+) / B(\Omega_c^0 \to \Omega^- \pi^+)$, in pp @ 13 TeV : PRL132, 081802 (2024)

LFU and A_{CP}

– PRL127, 121803 (2021)

- $\mathcal{B}(\Xi_c^0 \to \Xi_c^- e^+ \nu_e)$: (1.31 ± 0.04 (stat) ± 0.07 (syst) ± 0.38)%

  $\mathcal{B}(\Xi_c^0 \to \Xi_c^- \mu^+ \nu_\mu)$: (1.27 ± 0.06 (stat) ± 0.10 (syst) ± 0.37)%

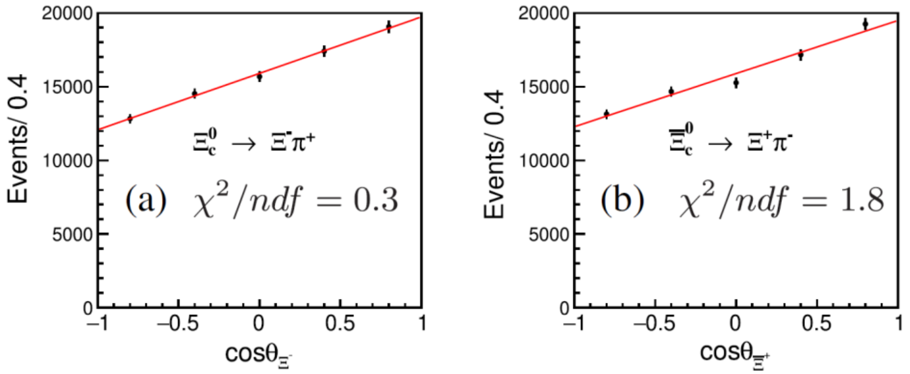
  $\mathcal{B}(\Xi_c^0 \to \Xi_c^- e^+ \nu_e) / \mathcal{B}(\Xi_c^0 \to \Xi_c^- \mu^+ \nu_\mu)$:

  1.03 ± 0.05 (stat) ± 0.07 (syst)

- $A_{CP} = (\alpha_{\Xi^-\pi^+} + \alpha_{\Xi^+\pi^-})/(\alpha_{\Xi^-\pi^+} - \alpha_{\Xi^+\pi^-})$

  = 0.024 ± 0.052 (stat) ± 0.014 (syst)

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



– PRD105, L091101 (2022)

- $\mathcal{B}(\Omega_c^0 \to \Omega_c^- e^+ \nu_e) / \mathcal{B}(\Omega_c^0 \to \Omega^- \pi^+)$: 1.98 ± 0.13 (stat) ± 0.08 (syst)

  $\mathcal{B}(\Omega_c^0 \to \Omega_c^- \mu^+ \nu_\mu) / \mathcal{B}(\Omega_c^0 \to \Omega^- \pi^+)$: 1.94 ± 0.18 (stat) ± 0.10 (syst)

  $\mathcal{B}(\Omega_c^0 \to \Omega_c^- e^+ \nu_e) / \mathcal{B}(\Omega_c^0 \to \Omega_c^- \mu^+ \nu_\mu)$:

  1.02 ± 0.10 (stat) ± 0.02 (syst) ↔ 1.03 ± 0.06 (LFU expectation)

– No surprises:

- Both LFU and A_{CP} are consistent with expectation of SM
- LFU ~ 1 , A_{CP} ~ 0

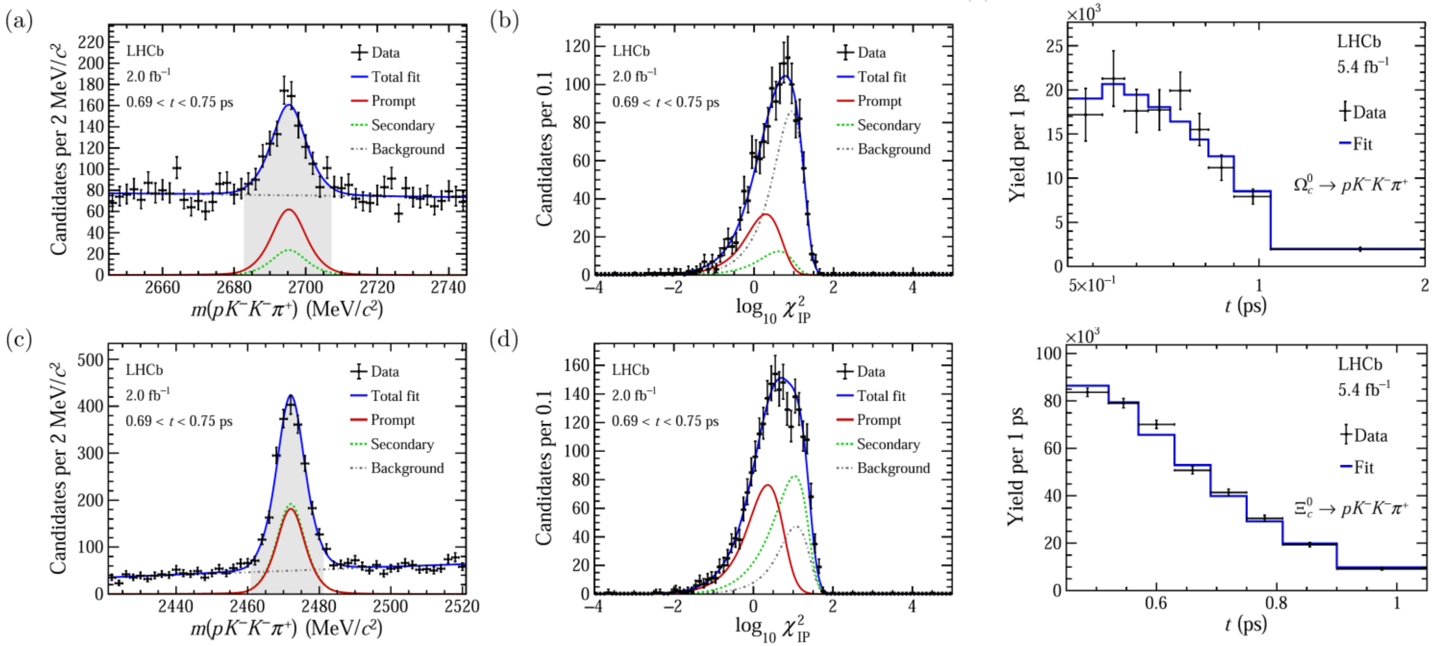
Characterizing charm states

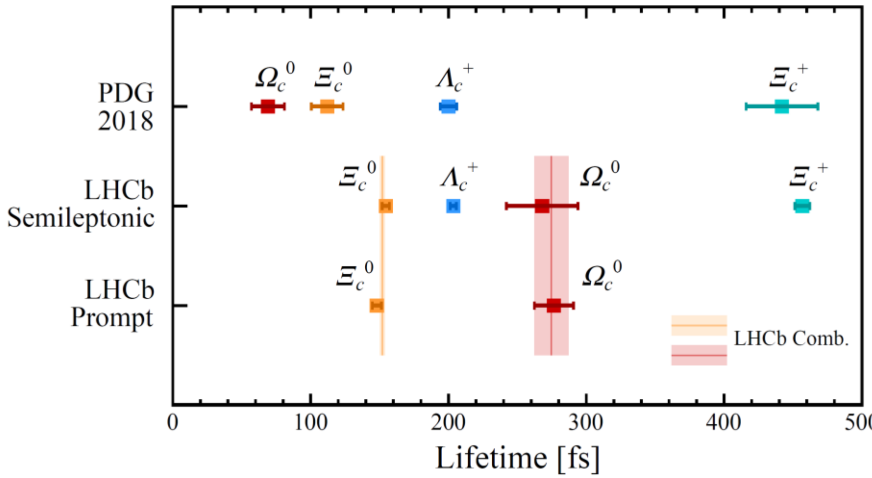
Lifetime measurement of Ω_c^0 and Ξ_c^0 in pp @ $\sqrt{s}$ = 13 TeV

Sci. Bull. 67 (2022) 479

Ω_c^0

Ξ_c^0





– Most precise Ω_c^0 lifetime measurement: factor 4 larger than previous world average

- Previous Ω_c^0 lifetime measurement via Ω_b^- with LHCb (PLR121, 092003 (2018)): 268 ± 24 ± 10 ± 2 (fs)
- $\tau(\Omega_c^0)$: 276.5 ± 13.4 (stat) ± 4.4 (syst) ± 0.7 (D^0 control mode) (fs) → improved by factor 2

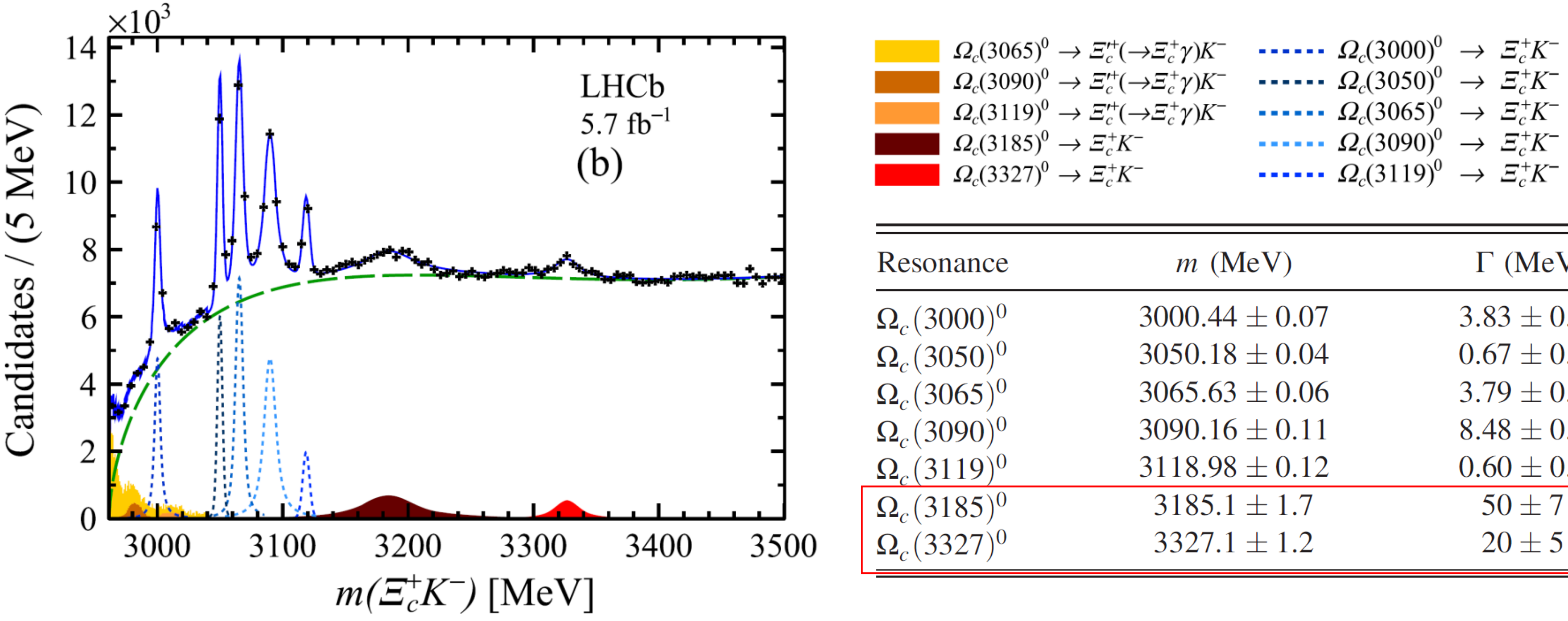
  $\tau(\Xi_c^0)$: 148.0 ± 2.3 (stat) ± 2.2 (syst) ± 0.2 (D^0 control mode) (fs)
- Charmed hadrons lifetime hierarchy: $\tau(\Xi_c^+) > \tau(\Omega_c^0) > \tau(\Lambda_c^+) > \tau(\Xi_c^0)$

Characterizing charm states

$\Omega_c^0 \to \Xi_c^+ K^-$ decay states in pp @ √s = 7, 8, and 13 TeV

New!

PRL131, 131902 (2023)



Resonance	m (MeV)	Γ (MeV)
$\Omega_c(3000)^0$	3000.44 ± 0.07	3.83 ± 0.23
$\Omega_c(3050)^0$	3050.18 ± 0.04	0.67 ± 0.17
$\Omega_c(3065)^0$	3065.63 ± 0.06	3.79 ± 0.20
$\Omega_c(3090)^0$	3090.16 ± 0.11	8.48 ± 0.44
$\Omega_c(3119)^0$	3118.98 ± 0.12	0.60 ± 0.63
$\Omega_c(3185)^0$	3185.1 ± 1.7	50 ± 7
$\Omega_c(3327)^0$	3327.1 ± 1.2	20 ± 5

– Confirmation of 2017 result (PRL118, 182001) with additional two new states

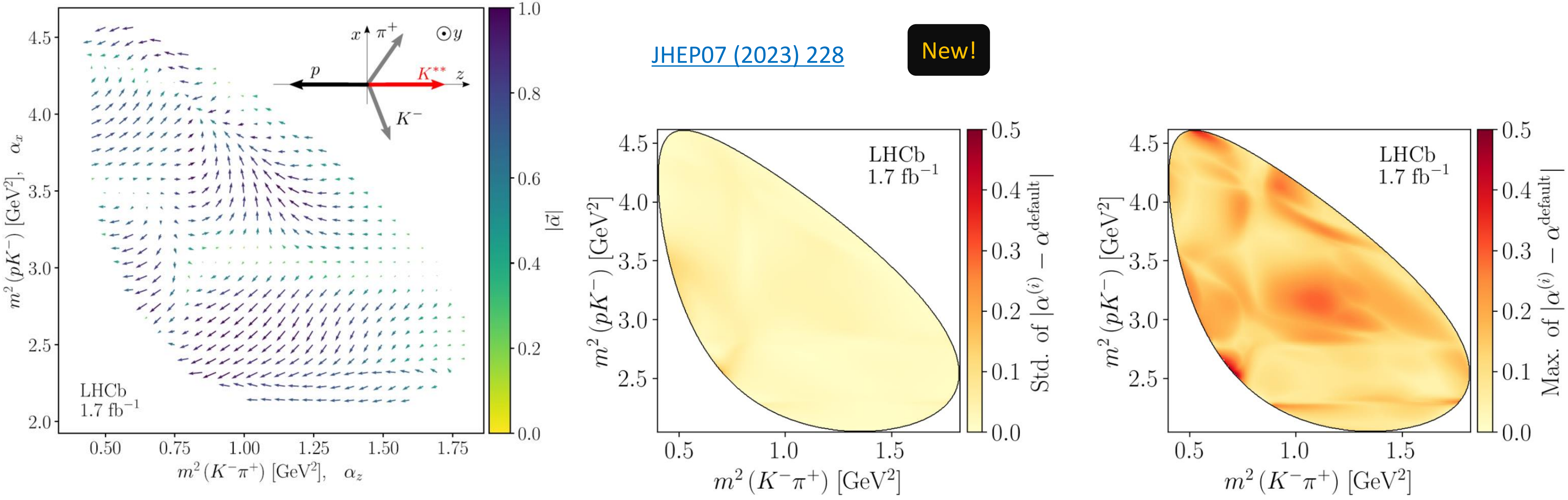
- Singly charmed baryon mass spectrum: can be systematically described by theory
- 5 previously observed states are confirmed: $\Omega_c(3000)^0$, $\Omega_c(3050)^0$, $\Omega_c(3065)^0$, $\Omega_c(3090)^0$, and $\Omega_c(3119)^0$; four of them confirmed by Belle (PRD 97 (2018) 5, 051102)
- Two newly observed states: $\Omega_c(3185)^0$ and $\Omega_c(3327)^0$

* See also: PRD104 (2021) 9, L091102
(excited Ω_c^0 in $\Omega_b^- \to \Xi_c^+ K^- \pi^-$)

Characterizing charm states Λ_c^+ polarimetry

JHEP07 (2023) 228

New!



– Polarization of the Cabibbo-favored $\Lambda_c^+ \to pK^-\pi^+$

- Based on $\Lambda_c^+ \to pK^-\pi^+$ transition amplitude analysis in LHCb (PRD108 (2023) 012023)
- A model-agnostic representation of the fermion decay rate, on the entire space of kinematic dimensions

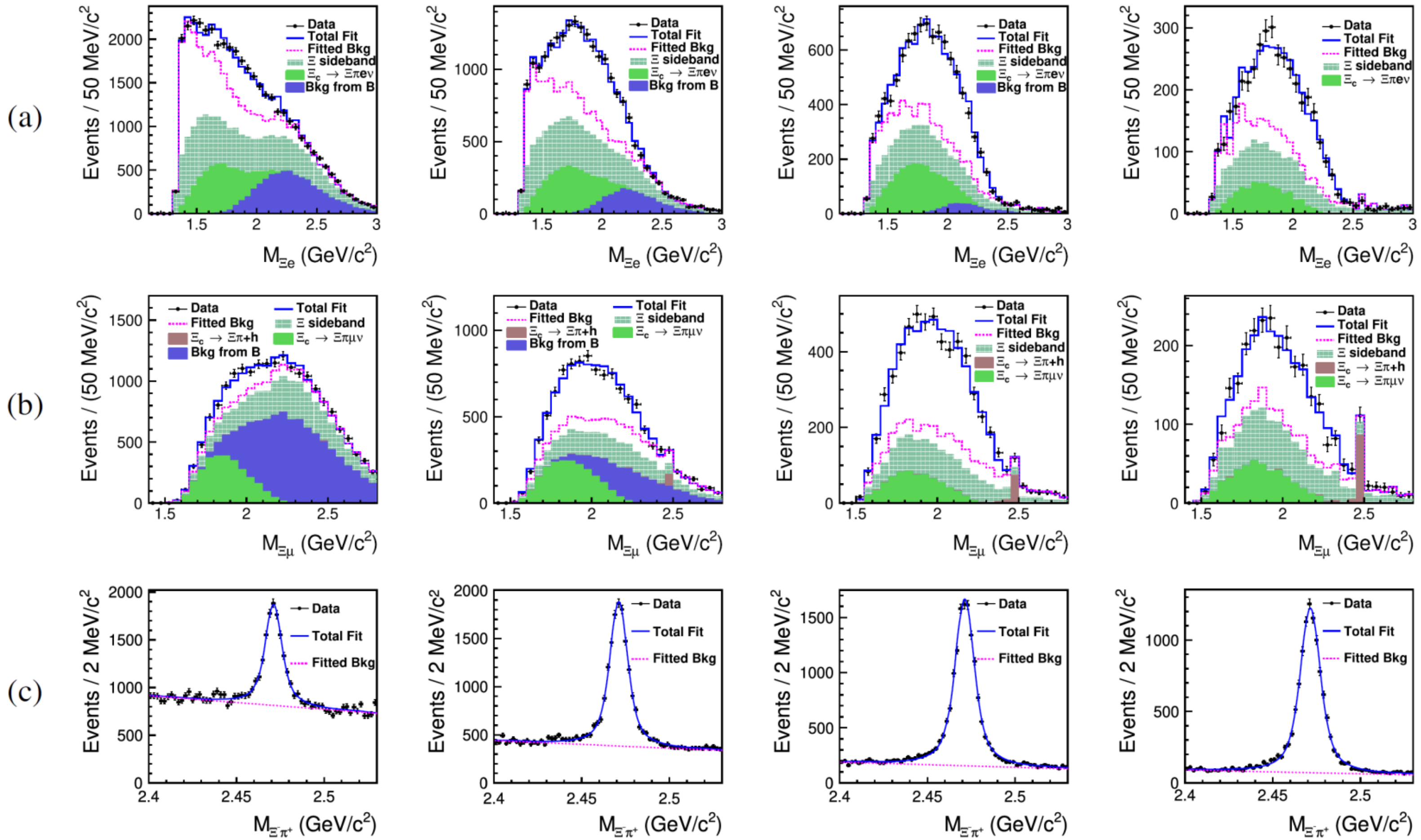
Summary

- **A few selectively chosen topics for charm hadronic/semileptonic decays**
  - Branching fraction measurements
    - 1st measurement of inclusive $\Omega_c^0 \to \Omega^- \pi^+$ in pp collisions at √s = 13 TeV by ALICE – more frequent hadronization in pp? Need precise BR measurements to conclude
    - 1st B ($\Xi_c^0 \to \Xi^0 h^0$) measurement by combined analysis of Belle + Belle II
    - Observation of Cabibbo-suppressed $\Omega_c^0 \to \Omega^- K^+$ and $\Omega_c^0 \to \Xi^- \pi^+$ by LHCb
  - LFU and A_{CP} by Belle
    - LFU ~ 1 and A_{CP} ~ 0
    - No surprises: consistent with the Standard Model
  - Characterizing charm-baryon states by LHCb
    - Lifetime measurements: most precise τ (Ω_c^0) with charmed hadrons lifetime hierarchy
    - $\Omega_c^0 \to \Xi_c^+ K^-$ excited states: confirm 2017 result with two new states
    - Polarimetry using $\Lambda_c^+ \to pK^- \pi^+$: mapping of kinematic-dependent polarimeter vector

Backup

Backup

BFs of $\Xi_c^0 \to \Xi^- l^+ \nu_l$ and Asymmetry parameter of $\Xi_c^0 \to \Xi^- \pi^+$



$p^*_{\Xi^- X}/p^*_{\max}$ region: (0.45, 0.55) (0.55, 0.65) (0.65, 0.75) (0.75,1)

Backup $\Xi_c^0 \to \Xi^0 h^0$

$\Xi_c \to \Xi^0 h^0$ Theoretical Predictions

BF in units of 10^{-3}

Reference	Model	$\mathcal{B}(\Xi_c^0 \to \Xi^0\pi^0)$	$\mathcal{B}(\Xi_c^0 \to \Xi^0\eta)$	$\mathcal{B}(\Xi_c^0 \to \Xi^0\eta')$	$\alpha(\Xi_c^0 \to \Xi^0\pi^0)$
Körner, Krämer [5]	quark	0.5	3.2	11.6	0.92
Xu, Kamal [7]	pole	7.7	-	-	0.92
Cheng, Tseng [8]	pole	3.8	-	-	-0.78
Cheng, Tseng [8]	CA	17.1	-	-	0.54
Żenczykowski [9]	pole	6.9	1.0	9.0	0.21
Ivanov *et al.* [6]	quark	0.5	3.7	4.1	0.94
Sharma, Verma [11]	CA	-	-	-	-0.8
Geng *et al.* [12]	$SU(3)_F$	4.3 ± 0.9	$1.7^{+1.0}_{-1.7}$	$8.6^{+11.0}_{-6.3}$	-
Geng *et al.* [13]	$SU(3)_F$	7.6 ± 1.0	10.3 ± 2.0	9.1 ± 4.1	$-1.00^{+0.07}_{-0.00}$
Zhao *et al.* [14]	$SU(3)_F$	4.7 ± 0.9	8.3 ± 2.3	7.2 ± 1.9	-
Zou *et al.* [10]	pole	18.2	26.7	-	-0.77
Huang *et al.* [15]	$SU(3)_F$	2.56 ± 0.93	-	-	-0.23 ± 0.60
Hsiao *et al.* [16]	$SU(3)_F$	6.0 ± 1.2	$4.2^{+1.6}_{-1.3}$	-	-
Hsiao *et al.* [16]	$SU(3)_F$-breaking	3.6 ± 1.2	7.3 ± 3.2	-	-
Zhong *et al.* [17]	$SU(3)_F$	$1.13^{+0.59}_{-0.49}$	1.56 ± 1.92	$0.683^{+3.272}_{-3.268}$	$0.50^{+0.37}_{-0.35}$
best fit → Zhong *et al.* [17]	$SU(3)_F$-breaking	$7.74^{+2.52}_{-2.32}$	$2.43^{+2.79}_{-2.90}$	$1.63^{+5.09}_{-5.14}$	$-0.29^{+0.20}_{-0.17}$
Xing *et al.* [18]	$SU(3)_F$	1.30 ± 0.51	-	-	-0.28 ± 0.18

Backup $\Xi_c^0 \to \Xi^0 h^0$

$\Xi_c \to \Xi^0 h^0$ Theoretical Predictions Refs

[5] J. G. Körner and M. Krämer, *Exclusive non-leptonic charm baryon decays*, Z. Phys. C **55** (1992) 659.

[6] M. A. Ivanov, J. G. Korner, V. E. Lyubovitskij, and A. G. Rusetsky, *Exclusive nonleptonic decays of bottom and charm baryons in a relativistic three-quark model: Evaluation of nonfactorizing diagrams*, Phys. Rev. D **57** (1998) 5632.

[7] Q. P. Xu and A. N. Kamal, *Cabibbo-favored nonleptonic decays of charmed baryons*, Phys. Rev. D **46** (1992) 270.

[8] H. Y. Cheng and B. Tseng, *Cabibbo-allowed nonleptonic weak decays of charmed baryons*, Phys. Rev. D **48** (1993) 4188.

[9] P. Żenczykowski, *Nonleptonic charmed-baryon decays: Symmetry properties of parity-violating amplitudes*, Phys. Rev. D **50** (1994) 5787.

[10] J. Q. Zou, F. R. Xu, G. B. Meng, and H. Y. Cheng, *Two-body hadronic weak decays of antitriplet charmed baryons*, Phys. Rev. D **101** (2020) 014011.

[11] K. K. Sharma and R. C. Verma, *A study of weak mesonic decays of Λ_c and Ξ_C baryons on the basis of HQET results*, Eur. Phys. J. C **7** (1999) 217.

[12] C. Q. Geng, Y. K. Hsiao, C. W. Liu, and T. H. Tsai, *Antitriplet charmed baryon decays with SU(3) flavor symmetry*, Phys. Rev. D **97** (2018) 073006.

[13] C. Q. Geng, C. W. Liu, and T. H. Tsai, *Asymmetries of anti-triplet charmed baryon decays*, Phys. Lett. B **794** (2019) 19.

[14] H. J. Zhao, Y. L. Wang, Y. K. Hsiao, and Y. Yu, *A Diagrammatic Analysis of Two-Body Charmed Baryon Decays with Flavor Symmetry*, JHEP **02** (2020) 165.

[15] F. Huang, Z. P. Xing, and X. Z. He, *A global analysis of charmless two body hadronic decays for anti-triplet charmed baryons*, JHEP **03** (2022) 143.

[16] Y. K. Hsiao, Y. L. Wang, and H. J. Zhao, *Equivalent* $SU(3)_f$ *approaches for two-body anti-triplet charmed baryon decays*, JHEP **09** (2022) 35.

[17] H. Zhong, F. Xu, Q. Wen and Y. Gu, *Weak decays of antitriplet charmed baryons from the perspective of flavor symmetry*, JHEP **02** (2023) 235.

[18] Z. P. Xing, *et al.*, *Global analysis of measured and unmeasured hadronic two-body weak decays of antitriplet charmed baryons*, Phys. Rev. D **108** (2023) 053004.