New charm results at LHCb

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(On behalf of the LHCb collaboration)

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Outline

- Observation of excited Ω_c^0 baryons in $\Omega_b^- \to \Xi_c^+ K^- \pi^-$ decays [LHCb-PAPER-2021-012, in preparation]

- Results on doubly charmed baryon searches
  - Search for the Ω_{cc}^+ baryon[arXiv:2105.06841]
  - Search for the Ξ_{cc}^+ baryon in the $\Xi_c^+ \pi^+ \pi^-$ final state [LHCb-PAPER-2021-019, in preparation]

- Measurement of the lifetimes of Ω_c^0 and Ξ_c^0 baryons with prompt production [LHCb-PAPER-2021-021, in preparation]

Observation of excited Ω_c^0 baryons in $\Omega_b^- \to \Xi_c^+ K^- \pi^-$ decays

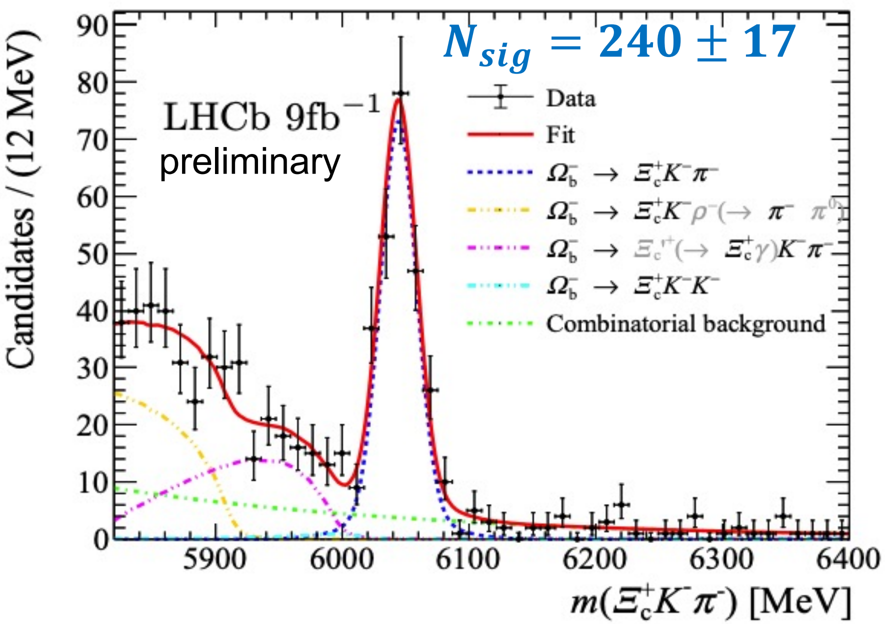
LHCb-PAPER-2021-012, in preparation

First observation of $\Omega_b^- \to \Xi_c^+ K^- \pi^-$

LHCb-PAPER-2021-012

- Potential for $\Omega_c^{**0} \to \Xi_c^+ K^-$ and the J^P analysis
- Dataset: Run1 + Run2; 9fb^{-1}
- Branching fraction ratio

$$\frac{\mathcal{B}(\Omega_b^- \to \Xi_c^+ K^- \pi^-)\mathcal{B}(\Xi_c^+ \to pK^-\pi^+)}{\mathcal{B}(\Omega_b^- \to \Omega_c^0 \pi^+)\mathcal{B}(\Omega_c^0 \to pK^-K^-\pi^+)} = 1.35 \pm 0.11(\text{stat}) \pm 0.05(\text{sys})$$



Ω_b^- mass

This analysis:

$m(\Omega_b^-) = 6044.3 \pm 1.2(\text{stat}) \pm 1.2(\text{sys})$ MeV

Averaging all LHCb measurements:

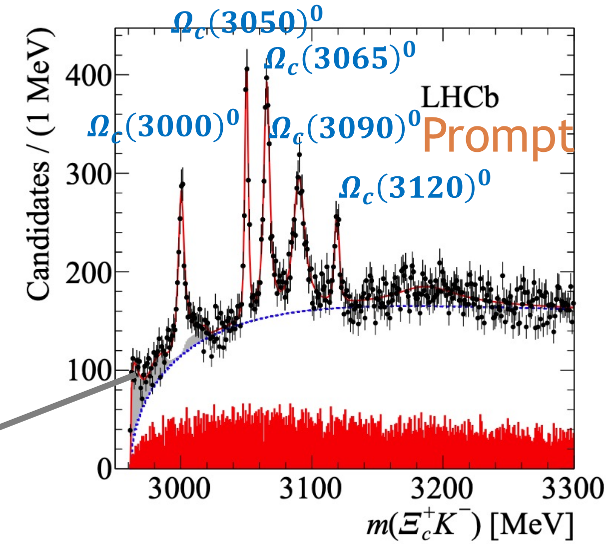
$m(\Omega_b^-) = 6044.8 \pm 1.3\text{MeV}$

Most precise to date

Ω_c^{**0} states in the $\Xi_c^+ K^-$ system

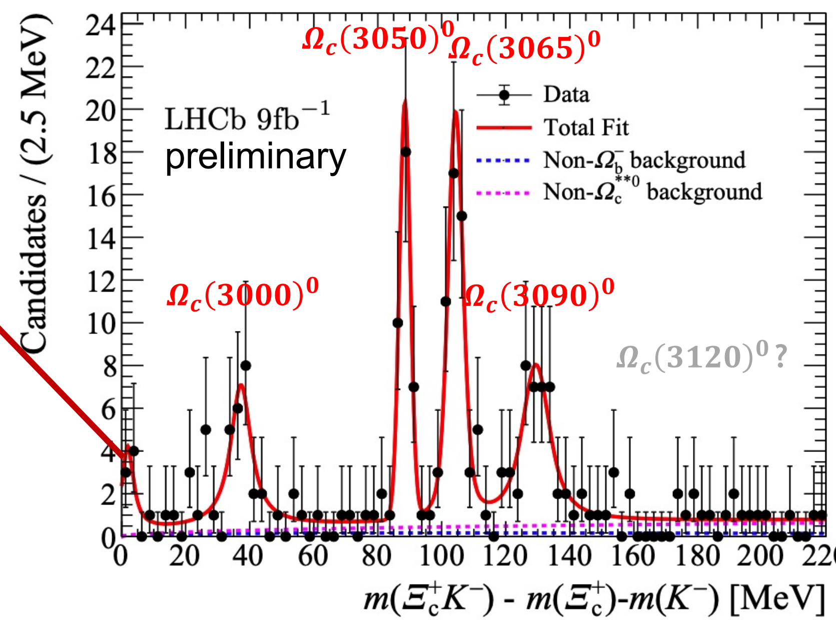
LHCb-PAPER-2021-012

[PRL 118 (2017) 182001]



- Re-observation of four Ω_c^{**0} previously discovered in prompt production $\Omega_c(3000)^0, \Omega_c(3050)^0, \Omega_c(3065)^0, \Omega_c(3090)^0$
  - $\Omega_c(3120)^0$ (not observed)
- Interpretation of the threshold structure
  - Feed down from partially reconstructed Ω_c^{**0} with higher mass
    - Will shift Ω_b^- mass outside its mass window in exclusive decays
  - Try to model it by S-wave RBW
- Unbinned maximum likelihood fit
  - All resonances modelled by S-wave relativistic BW function
  - Four states **>7σ**
  - Near-threshold structure **~5.6σ**
  - Mass, width and fit fraction of each state are measured

  (See next page)



Ω_b^- mass window: ~ ± 36 MeV

Measured properties

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$\mathcal{P}$: fit fraction

State	Observable	Measurement
Ω_b^-	m	$6044.3 \pm 1.2 \pm 1.2\,\mathrm{MeV}$
	$\frac{\mathcal{B}(\Omega_b^- \to \Xi_c^+ K^- \pi^-)}{\mathcal{B}(\Omega_b^- \to \Omega_c^0 \pi^-)}$	$1.35 \pm 0.11 \pm 0.05$
$\Omega_c(3000)^0$	ΔM	$37.4 \pm 1.0 \pm 0.6\,\mathrm{MeV}$
	m	$2999.0 \pm 1.0 \pm 0.6^{+0.17}_{-0.20}\,\mathrm{MeV}$
	Γ	$7.2 \pm 3.0 \pm 4.2\,\mathrm{MeV}$
	$\mathcal{P}$	$0.11 \pm 0.02 \pm 0.02$
$\Omega_c(3050)^0$	ΔM	$88.6 \pm 0.2 \pm 0.4\,\mathrm{MeV}$
	m	$3050.2 \pm 0.2 \pm 0.4^{+0.17}_{-0.20}\,\mathrm{MeV}$
	Γ	$0.0^{+0.5}_{-0.0} \pm 0.3\,\mathrm{MeV}$ ($< 1.1\,\mathrm{MeV}$, 95% CL)
	$\mathcal{P}$	$0.12 \pm 0.02 \pm 0.01$
$\Omega_c(3065)^0$	ΔM	$104.4 \pm 0.4 \pm 0.4\,\mathrm{MeV}$
	m	$3066.0 \pm 0.4 \pm 0.4^{+0.17}_{-0.20}\,\mathrm{MeV}$
	Γ	$1.7 \pm 1.0 \pm 0.7\,\mathrm{MeV}$
	$\mathcal{P}$	$0.19 \pm 0.02 \pm 0.02$
$\Omega_c(3090)^0$	ΔM	$129.5 \pm 1.1 \pm 1.0\,\mathrm{MeV}$
	m	$3091.1 \pm 1.1 \pm 1.0^{+0.17}_{-0.20}\,\mathrm{MeV}$
	Γ	$7.3 \pm 3.1 \pm 2.3\,\mathrm{MeV}$
	$\mathcal{P}$	$0.15 \pm 0.02 \pm 0.03$

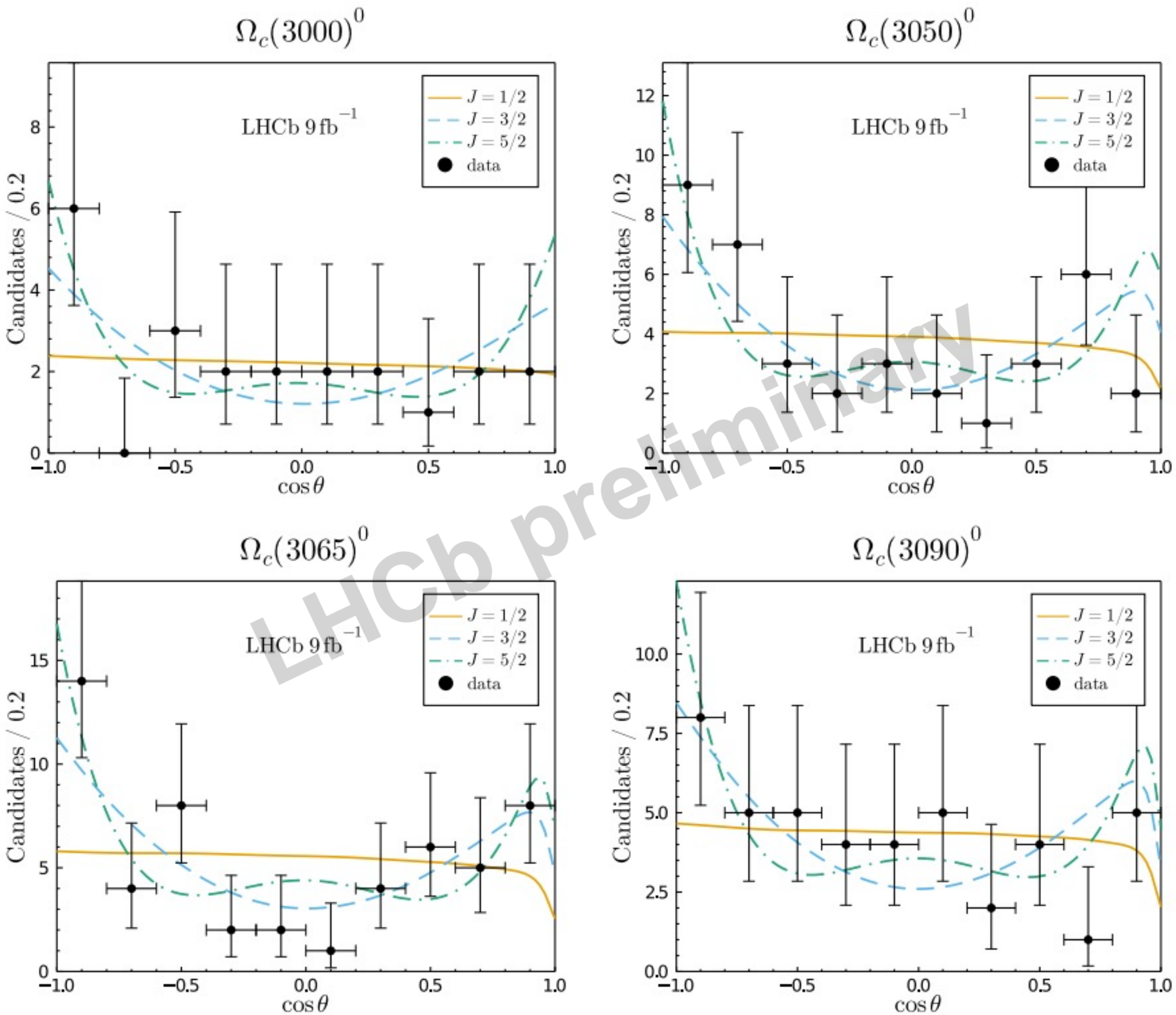
BW parameters of $\mathbf{\Omega_c^{**0}}$ states consistent with the previous results [PRL 118 (2017) 182001]

Spin test for the Ω_c^{**0} states

LHCb-PAPER-2021-012

Helicity angle

$$I_J(\cos\theta) = \frac{(2J+1)}{2}\left(\left|d^J_{1/2,-1/2}(\cos\theta)\right|^2 + \left|d^J_{1/2,+1/2}(\cos\theta)\right|^2\right)$$



- $\Omega_c(3050)^0 \quad J \neq \frac{1}{2}: 2.1\sigma$
- $\Omega_c(3065)^0 \quad J \neq \frac{1}{2}: 3.9\sigma$
- A combined spins hypothesis of the four states proposed by a model:
  - $(\frac{1}{2}, \frac{1}{2}, \frac{3}{2}, \frac{3}{2})$ rejected by 3.4σ

Phys. Rev. Lett. **119**, 042001

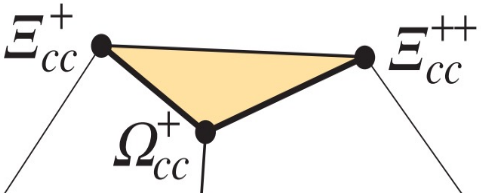
Phys. Rev. D 95, 114012

Eur. Phys. J. C 77 (2017) 325

Results on doubly charmed baryons

Doubly charmed baryons

- Isospin-doublet: $\Xi_{cc}^{+}(ccd)$ and $\Xi_{cc}^{++}(ccu)$
- Isospin-singlet: $\Omega_{cc}^{+}(ccs)$



- Ξ_{cc}^{++}:
  - Observed in $\Lambda_c^- K^- \pi^+ \pi^+$ final state [Phys.Rev.Lett. 119 (2017) 11, 112001]
  - Confirmed in $\Xi_c^+ \pi^+$ final state [Phys. Rev. Lett. 121 (2018) 162002]
  - Search for the decay $\Xi_{cc}^{++} \to D^+ p K^- \pi^+$ [JHEP 10 (2019) 124]
  - Lifetime measurement [Phys.Rev.Lett. 121 (2018) 5, 052002]
  - Production measurement [Chinese Physics C44 (2020) 022001]
  - Precise mass measurement [JHEP 02 (2020) 049]

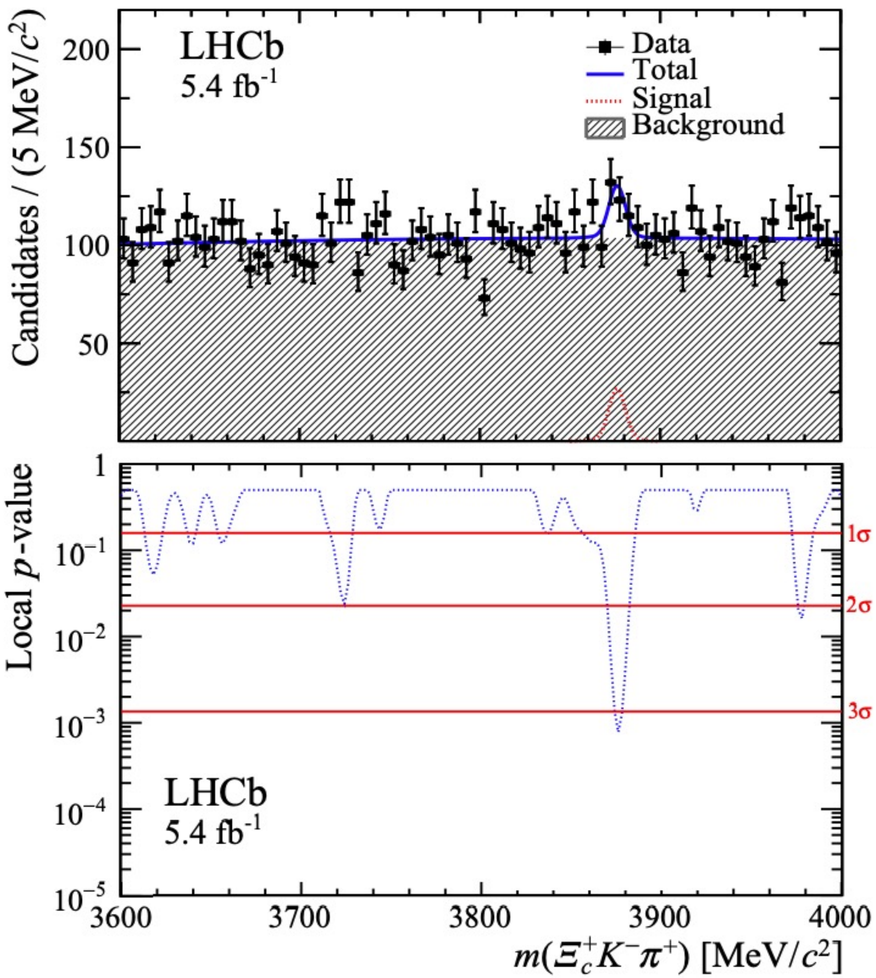
- Ξ_{cc}^{+} and Ω_{cc}^{+} not discovered yet
  - $\Xi_{cc}^{+} \to \Lambda_c^+ K^- \pi^+$ investigated by LHCb before, but no signal found [Sci.China Phys.Mech.Astron. (2020) 63 221062, JHEP 12 (2013) 90]
  - New results
    - Search for the doubly charmed baryon Ω_{cc}^{+} [arXiv:2105.06841]
    - Search for the doubly charmed baryon Ξ_{cc}^{+} in the $\Xi_c^+ \pi^+ \pi^-$ final state [LHCb-PAPER-2021-019, in preparation]

Search for $\Omega_{cc}^{+} \to \Xi_c^{+} K^{-} \pi^{+}$

arXiv:2105.06841

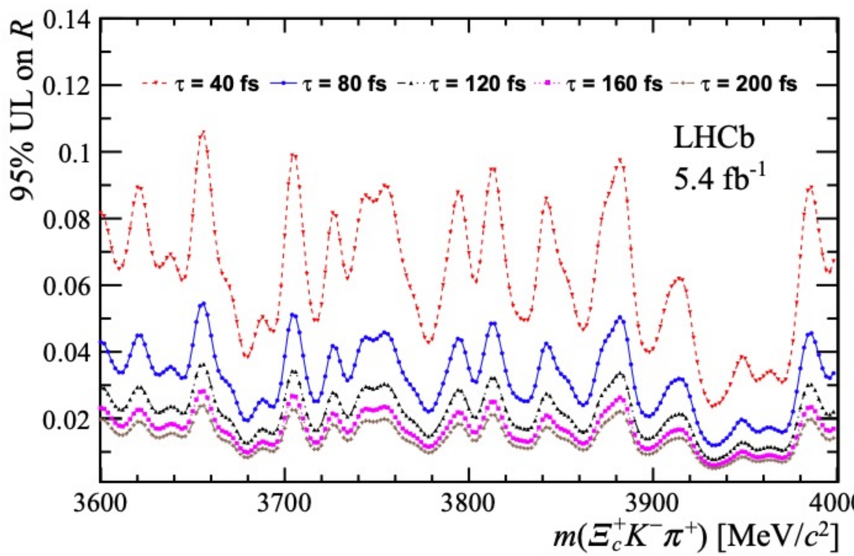
Dataset: 16-18, $5.4 \mathrm{fb}^{-1}$

- Local significance as a function of $m(\Omega_{cc}^{+})$
  - Largest: 3.2σ @3876MeV
- Global significance: $\mathbf{1.8\sigma}$



- Upper limit (UL) set under different mass and lifetime hypotheses
  - UL decreases when $\tau(\Omega_{cc}^{+})$ increases

$$R(\Omega_{cc}^{+}) = \frac{\epsilon(\Xi_{cc}^{++})}{\epsilon(\Omega_{cc}^{+})} \frac{N(\Omega_{cc}^{+} \to \Xi_c^{+} K^{-} \pi^{+})}{N(\Xi_{cc}^{++} \to \Lambda_c^{+} K^{-} \pi^{+} \pi^{+})}$$



Search for $\Xi_{cc}^{+} \to \Xi_c^{+}\pi^{-}\pi^{+}$

LHCb-PAPER-2021-019

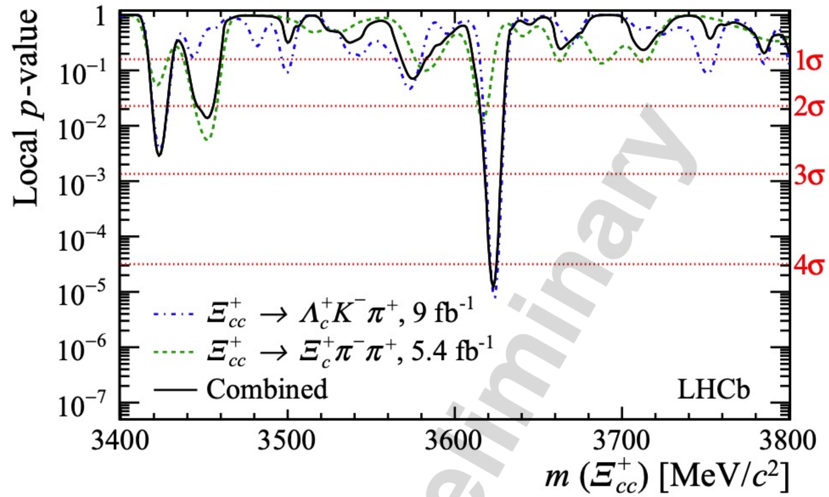
Dataset: 16-18, $5.4\mathrm{fb}^{-1}$

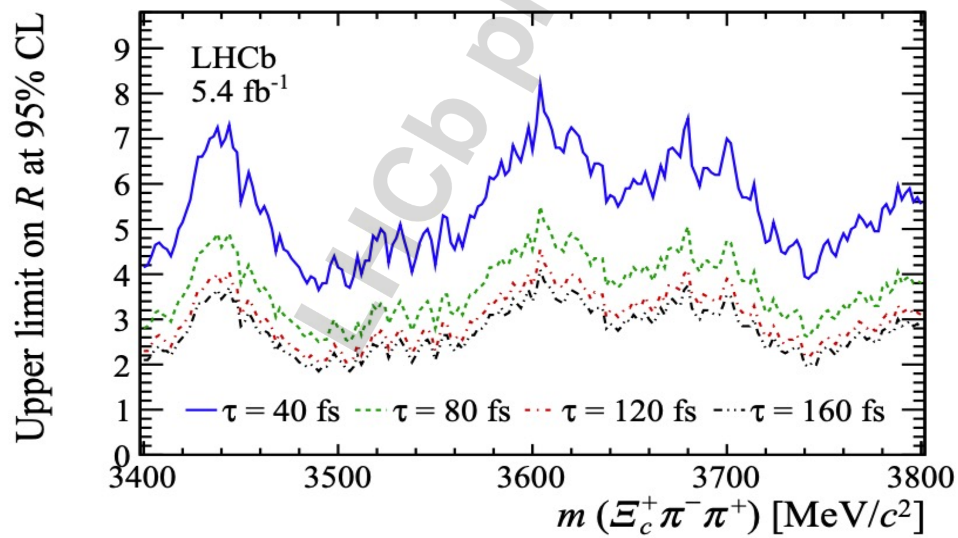
- Local significance as a function of $m(\Xi_{cc}^{+})$
  - Largest: 2.8σ @3617MeV

- Significance with the $\Xi_{cc}^{+} \to \Lambda_c^{+}K^{+}\pi^{-}$ result combined:
  - Largest local: 4.0σ @3623MeV
  - Global: 2.9σ

- Upper limit (UL) set under different mass and lifetime hypotheses

$$R(\Xi_{cc}^{+}) = \frac{\epsilon(\Xi_{cc}^{++})}{\epsilon(\Xi_{cc}^{+})}\frac{N(\Xi_{cc}^{+} \to \Xi_c^{+}\pi^{-}\pi^{+})}{N(\Xi_{cc}^{++} \to \Xi_c^{+}\pi^{+})}$$





Measurement of the lifetimes of Ω_c^0 and Ξ_c^0 baryons with prompt production

LHCb-PAPER-2021-021, in preparation

Lifetimes of singly charmed baryons

LHCb-PAPER-2021-021

- Before the LHCb measurements [PDG2018]

$$\tau_{\Xi_c^+}(442\text{fs}) > \tau_{\Lambda_c^+}(200\text{ fs}) > \tau_{\Xi_c^0}(112\text{fs}) > \tau_{\Omega_c^0}(69\text{fs})$$

  - Supported by the theoretical expectation

- LHCb measurements using exclusive b-hadron semi-leptonic decays
  - $\tau_{\Omega_c^0}$ is much larger than the previous result [Phys. Rev. Lett. **121**, 092003]
  - $\tau_{\Xi_c^0}$ has a tension with the previous result beyond 3σ [Phys. Rev. D **100**, 032001]

  PDG2020

$$\tau_{\Xi_c^+}(456\text{fs}) > \tau_{\Omega_c^0}(268\text{fs}) > \tau_{\Lambda_c^+}(202\text{fs}) > \tau_{\Xi_c^0}(153\text{fs})$$

$\tau_{\Omega_c^0}(268\text{fs})$ only takes the LHCb result

- Further measurements are essential to understand the puzzle

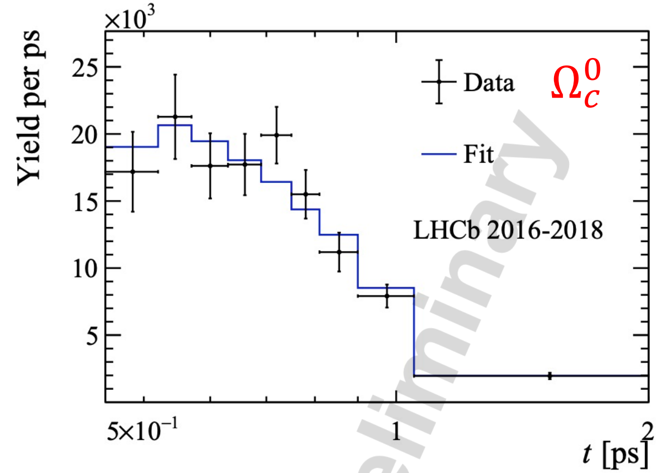
$\tau_{\Xi_c^0}$ and $\tau_{\Omega_c^0}$ measurement in prompt

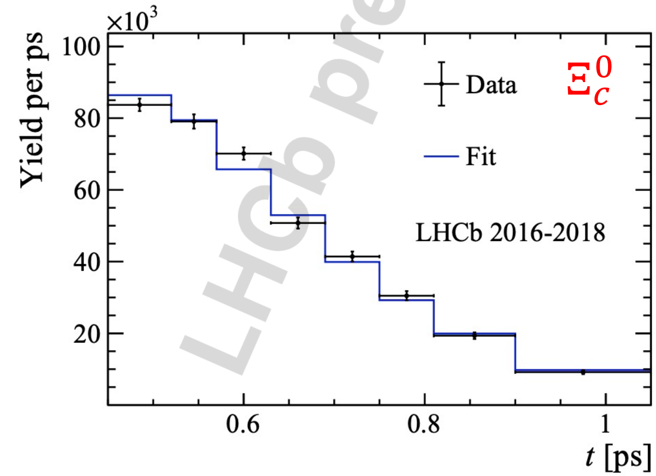
LHCb-PAPER-2021-021

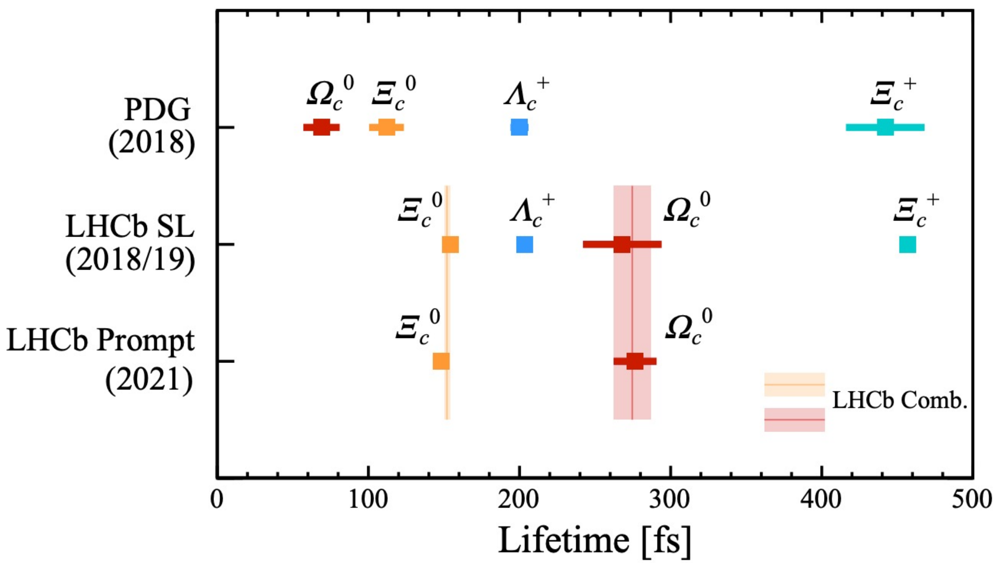
- Dataset: 2016-2018; $\Xi_c^0, \Omega_c^0 \rightarrow pK^-K^-\pi^+$
- Binned χ^2 fit to lifetime
  - Signals in each lifetime bin determined from a 2D fit on $(m, \log\chi^2_{IP})$

$$\tau_{\Omega_c^0} = (276.5 \pm 13.4 \pm 4.3 \pm 0.7)\text{fs}$$
$$\tau_{\Xi_c^0} = (148.0 \pm 2.3 \pm 2.2 \pm 0.2)\text{fs}$$

  - The precision of $\tau_{\Omega_c^0}$ improved by a factor of 2
  - Consistent with previous LHCb results







Combined with the previous LHCb results

$$\tau_{\Omega_c^0} = (274.6 \pm 12.4)\text{fs}$$
$$\tau_{\Xi_c^0} = (152.0 \pm 2.0)\text{fs}$$

Summary

- First observation of the $\Omega_b^- \to \Xi_c^+ K^- \pi^-$ decay
  - Precision Ω_b^- mass measurement: $m(\Omega_b^-) = 6044.8 \pm 1.3\text{MeV}$
  - Four Ω_c^{**0} states observed in the $\Xi_c^+ K^-$ system, $> 7\sigma$
  - Threshold structure: 5.6σ
  - Spin test
    - $\Omega_c(3050)^0 \;\; J \neq \frac{1}{2}: 2.1\sigma;$ $\Omega_c(3065)^0 \;\; J \neq \frac{1}{2}: 3.9\sigma$
    - $(\frac{1}{2}, \frac{1}{2}, \frac{3}{2}, \frac{3}{2})$ rejected by 3.4σ
- Searches for doubly charmed baryons Ξ_{cc}^+ and Ω_{cc}^+
  - Upper limit on the branching fraction ratio
- $\tau_{\Xi_c^0}$ and $\tau_{\Omega_c^0}$ measurement with prompt production

$$\tau_{\Omega_c^0} = (276.5 \pm 13.4 \pm 4.3 \pm 0.7)\text{fs}$$
$$\tau_{\Xi_c^0} = (148.0 \pm 2.3 \pm 2.2 \pm 0.2)\text{fs}$$

  - Consistent with previous LHCb results

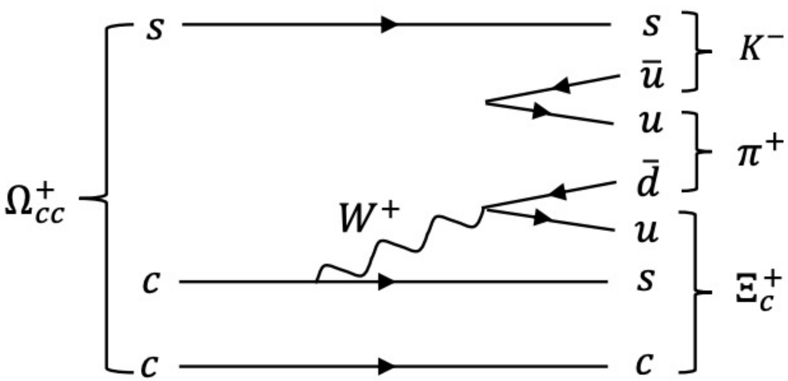
Thanks for your attention!

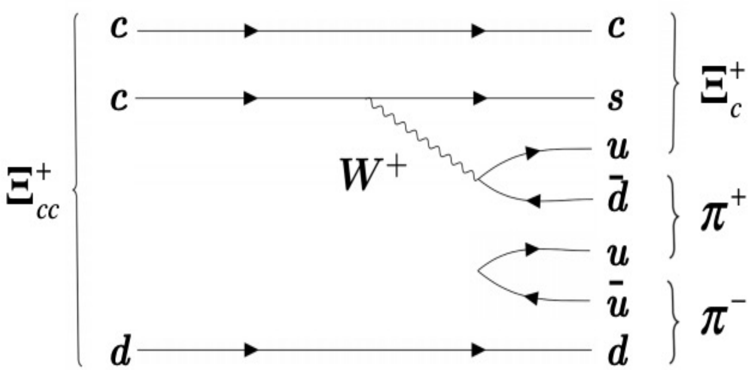
Any comments or questions?

Backup

Search for H_{cc}^{+} arXiv:2105.06841; LHCb-PAPER-2021-019

Example Feynman diagrams





- Ω_{cc}^+ predictions
  - $m = 3.6 - 3.9$ GeV
  - $\tau = 75 - 80$ fs
  - $\sigma(\Omega_{cc}^+) \sim 1/3\sigma(\Xi_{cc}^{+(+)})$
- Ξ_{cc}^+ predictions
  - $m(\Xi_{cc}^{+(+)}) = 3.5 - 3.7$ GeV
  - $|m(\Xi_{cc}^+) - m(\Xi_{cc}^{++})| \sim$ a few MeV
  - $\tau(\Xi_{cc}^+) = 60 - 120$ fs
  - $\tau(\Xi_{cc}^{++})/\tau(\Xi_{cc}^+) = 2 - 4$
- Shorter lifetime results in lower efficiency than that for Ξ_{cc}^{++}
  - One of the reasons why they are undiscovered