Recent results of the doubly charmed baryon at LHCb

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On behalf of the LHCb collaboration

CLHCP 2019

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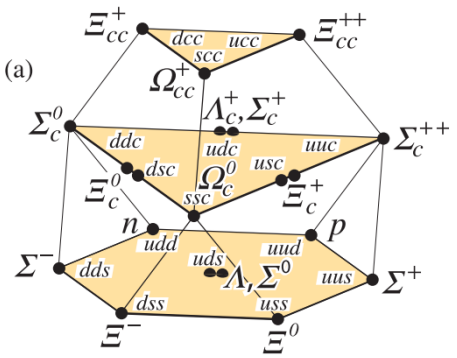
Outline

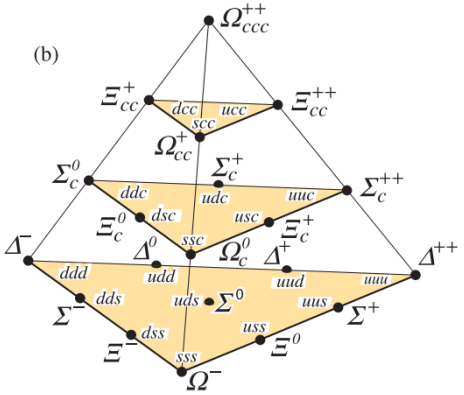
- Introduction
- LHCb detector
- $\Xi_{cc}^{++} \to \Xi_c^+ \pi^+$ — PRL 121 (2018) 162002
- $\Xi_{cc}^{++} \to D^+ p K^- \pi^+$ — arXiv:1905.02421 (JHEP)
- $\Xi_{cc}^{+} \to \Lambda_c^+ K^- \pi^+$ — arXiv:1909.12273 (SCI CHINA PHYS MECH)
- Ξ_{cc}^{++} production measurement — LHCb-PAPER-2019-035
- Summary

Introduction

- Quark model predictions for doubly charmed baryons ground states [$\Xi_{cc}^{+}(ccd)$、$\Xi_{cc}^{++}(ccu)$ *and* $\Omega_{cc}^{+}(ccs)$].

$J^P = \frac{1^+}{2}$





$J^P = \frac{3^+}{2}$

- SELEX reported the first observation of Ξ_{cc}^{+} with $\Xi_{cc}^{+} \to \Lambda_c^+ K^- \pi^+$ and $\Xi_{cc}^{+} \to D^+ p K^-$:
  - ✓ Short lifetime: $\tau(\Xi_{cc}^{+}) < 33$ fs @90% CL
  - ✓ High production: $R = \frac{\sigma(\Xi_{cc}^{+}) \times \mathcal{B}(\Xi_{cc}^{+} \to \Lambda_c^+ K^- \pi^+)}{\sigma(\Lambda_c^+)} \sim 20\%$
  - ✓ Mass： $3518.7 \pm 1.7\ \mathrm{MeV}/c^2$

- Not confirmed by FOCUS, Babar, Belle and LHCb.

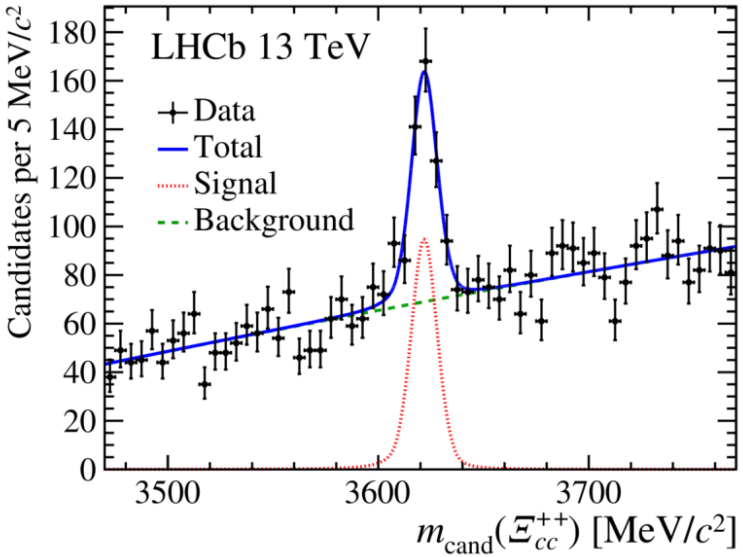
Ξ_{cc}^{++} observation

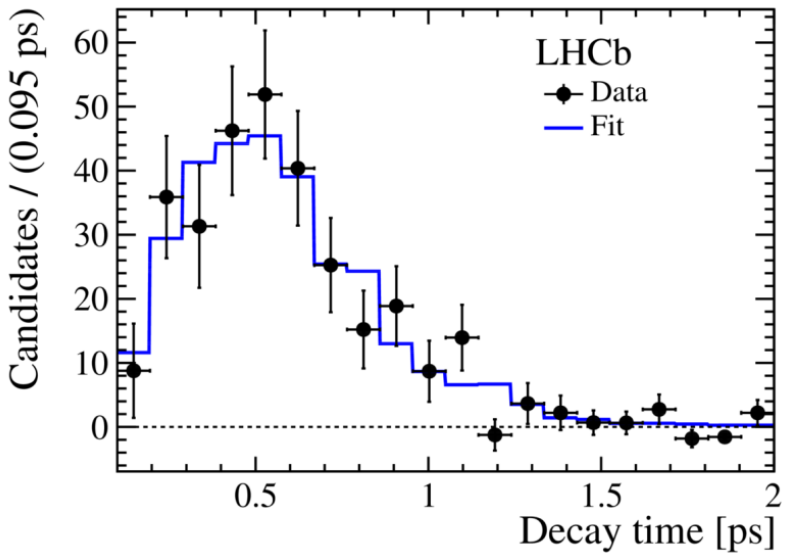
- Ξ_{cc}^{++} first observed in LHCb with $\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^+$ in 2017:
  - ✓ M: $3621.40 \pm 0.72 \pm 0.31\ \mathrm{MeV}/c^2$
  - ✓ τ: $0.256^{+0.024}_{-0.022} \pm 0.014\ ps$

PRL 119 (2017) 112001

PRL 121 (2018) 052002

- Mass seems splitting too large to be SELEX's isospin partner.
- Consistent with most theoretical expectations.
- Lifetime shows it's a weak decay.





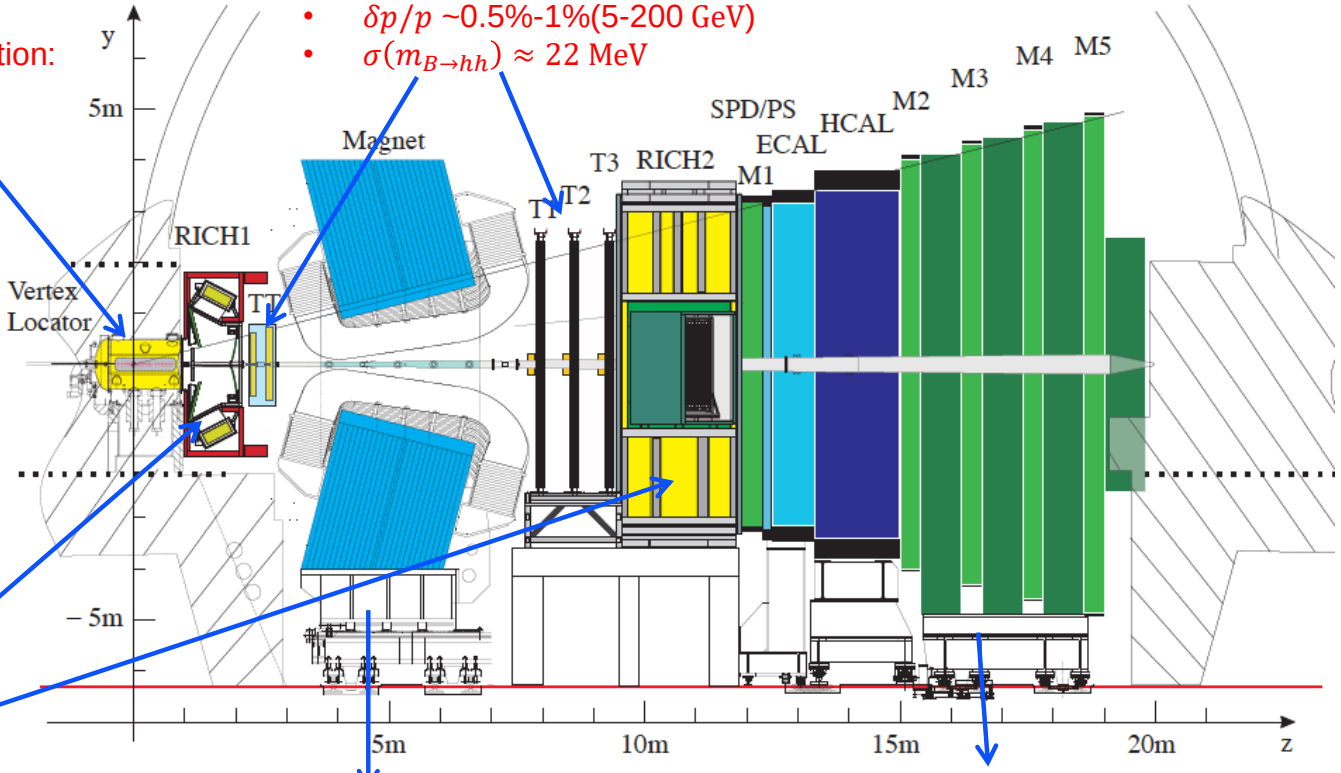
LHCb detector

- Aiming for precision measurements in b, c flavor sectors.
- Fully instrument covering $2 < \eta < 5$.

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

Vertex Locator(vertex reconstruction)
- Impact parameter resolution: 20 μm
- Decay time resolution: 45 fs (τ_B~1.5 ps)

Tracking system(particle reconstruction)
- ϵ(Tracking) ~96%
- $\delta p/p$ ~0.5%-1%(5-200 GeV)
- $\sigma(m_{B\to hh}) \approx 22$ MeV



RICH: particle ID
- $\varepsilon(K \to K)$ ~95%
- Mis-ID: $\varepsilon(\pi \to K)$ ~5%

Magnet
Bending power: 4 Tm

Muon system
- μ ID: $\varepsilon(\mu \to \mu)$ ~97%
- Mis-ID: $\varepsilon(\pi \to \mu)$ ~1-3%

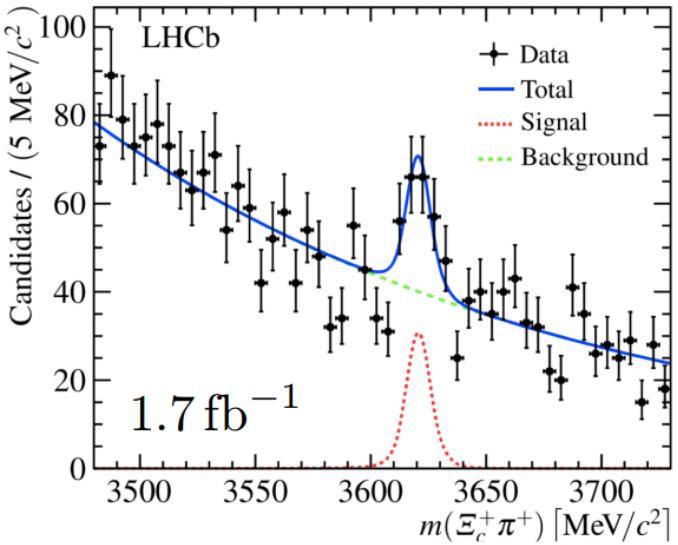
$\Xi_{cc}^{++} \to \Xi_c^+ \pi^+$

PRL 121 (2018) 162002

- Confirmed with $\Xi_c^+\pi^+$ ($\Xi_c^+ \to p^+K^-\pi^+$) using 2016 data.

- Combined mass

  M: $3621.24 \pm 0.65 \pm 0.31\ \mathrm{MeV}/c^2$



- $\mathcal{R} \equiv \frac{\mathcal{B}(\Xi_{cc}^{++} \to \Xi_c^+\pi^+;\Xi_c^+ \to p^+K^-\pi^+)}{\mathcal{B}(\Xi_{cc}^{++} \to \Lambda_c^+K^-\pi^+\pi^+;\Lambda_c^+ \to p^+K^-\pi^+)}$
  $= (3.5 \pm 0.9 \pm 0.3) \times 10^{-2}$

With recent Belle measurement:

$\mathcal{B}(\Xi_c^+ \to p^+K^-\pi^+) = (0.45 \pm 0.21 \pm 0.07)\%$ Phys. Rev. D100 031101

$$\mathcal{R} = \frac{\mathcal{B}(\Xi_{cc}^{++} \to \Xi_c^+\pi^+)}{\mathcal{B}(\Xi_{cc}^{++} \to \Lambda_c^+K^-\pi^+\pi^+)} \approx 0.5$$

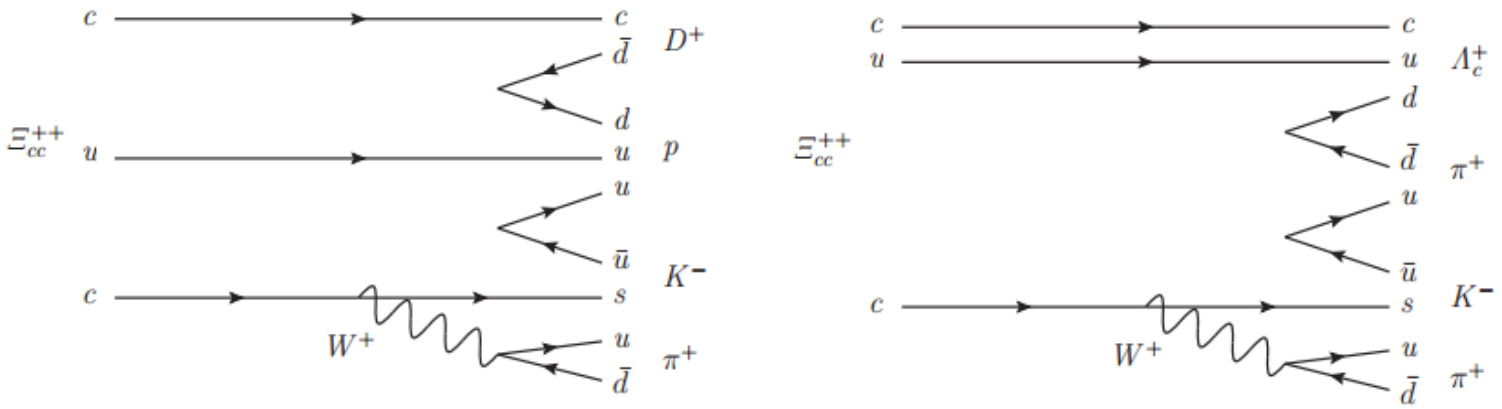
Consistent with one theoretical prediction.

Yu, *et al.* Chin. Phys.C42(2018) 051001

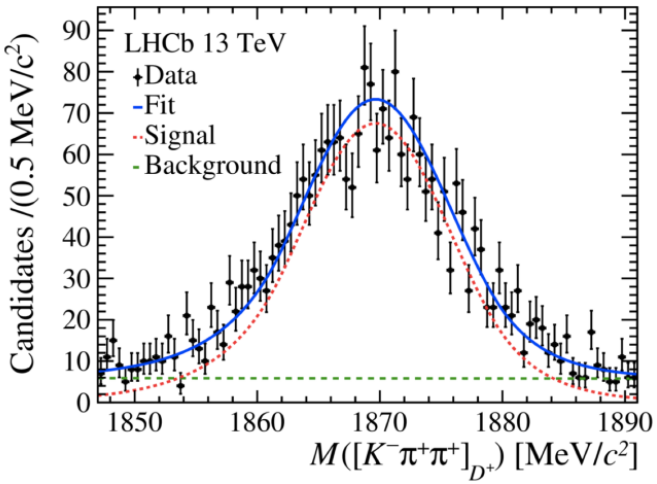
$\Xi_{cc}^{++} \to D^+ p K^- \pi^+$

arXiv:1905.02421 (JHEP)

- Smaller *Q* value, relative smaller branching fraction.



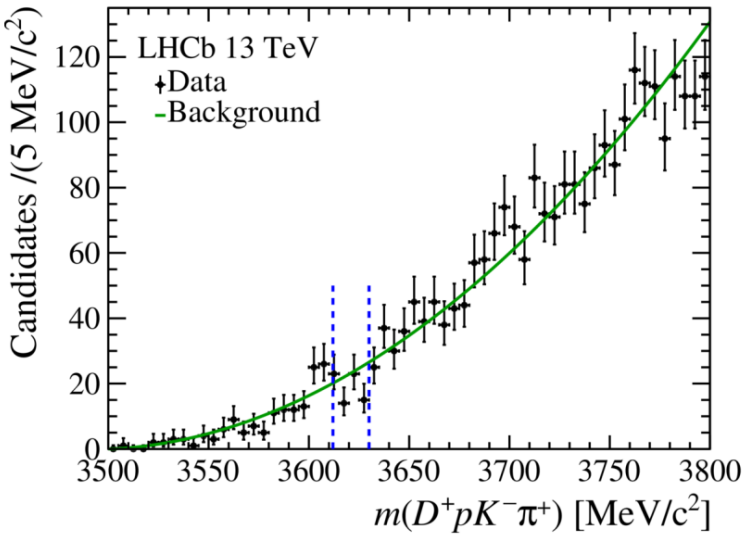
- Search with $D^+ p K^- \pi^+$ ($D^+ \to K^- \pi^+ \pi^+$) using 2016 data.



$\Xi_{cc}^{++} \to D^+ p K^- \pi^+$ result

arXiv:1905.02421 (JHEP)

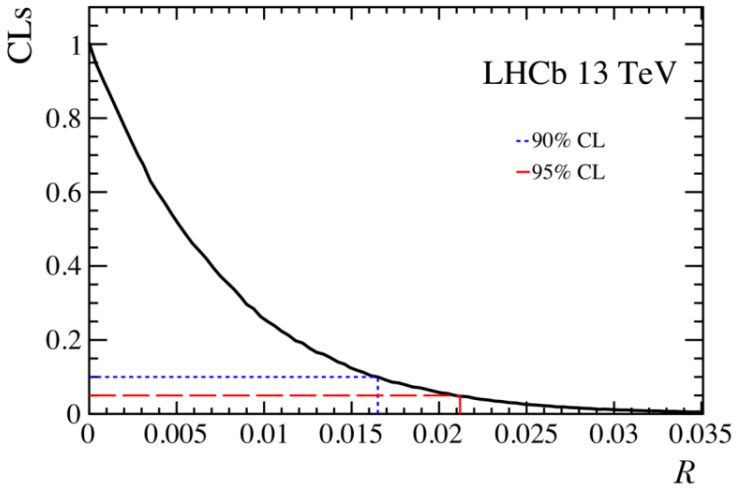
- Mass fit with 2^{nd} order Chebeychev.



- No significant signal.

- Set upper limit on $\mathcal{R} \equiv \frac{\mathcal{B}(\Xi_{cc}^{++} \to D^+ p K^- \pi^+)}{\mathcal{B}(\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^+)}$.

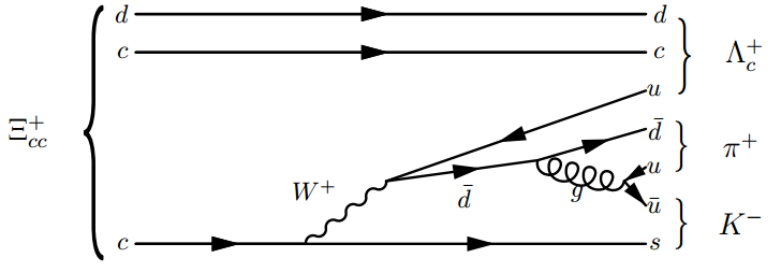
- $\mathcal{R}$ < 1.7% (2.1%) @ 90% (95%) confidence level.



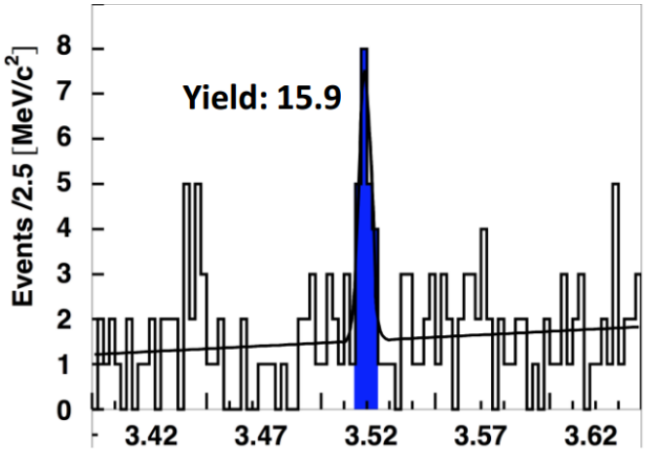
$\Xi_{cc}^{+} \to \Lambda_c^{+} K^{-} \pi^{+}$

- Predicted to have similar mass and cross-section to Ξ_{cc}^{++}, but much shorter lifetime.
- Most promising channel $\Xi_{cc}^{+} \to \Lambda_c^{+} K^{-} \pi^{+}$ $\mathcal{B}\sim O(10\%)$.
- First observed by SELEX at 2002, with mass 3518.7 MeV/c^2.
- No signal from LHCb using 0.65 fb^{-1} Run 1 data.
- Further search with full Run 1+2 dataset.

arXiv:1909.12273
(SCI CHINA PHYS MECH)



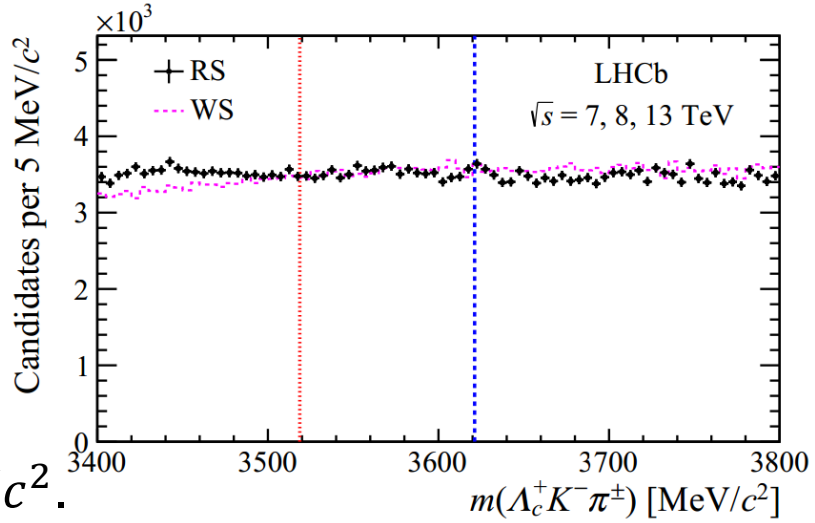
PRL 89 (2002) 112001



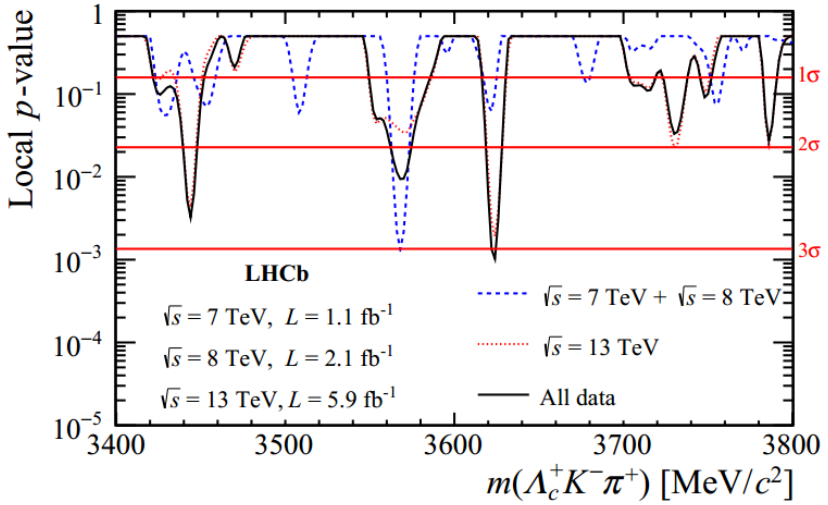
$\Xi_{cc}^{+} \to \Lambda_c^{+} K^{-} \pi^{+}$ mass spectrum

arXiv:1909.12273
(SCI CHINA PHYS MECH)

- Compare right sign and wrong sign mass distributions.



- Largest local significance 3.1σ (statistical) around 3620 MeV/c^2.



- Global significance 1.7σ.

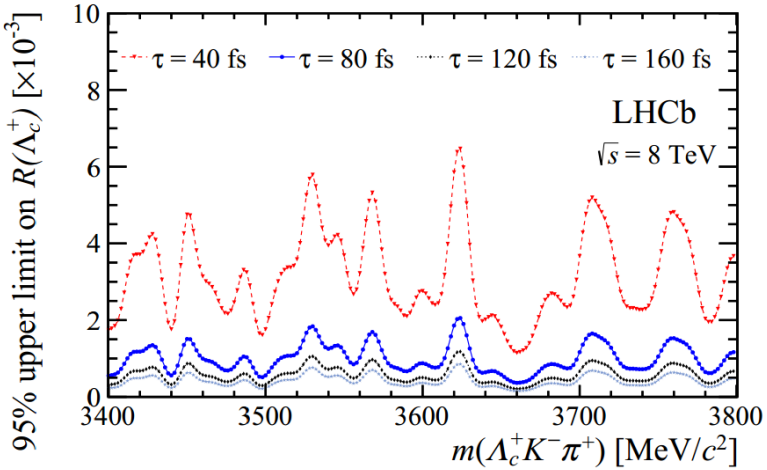
- Upper limits set.

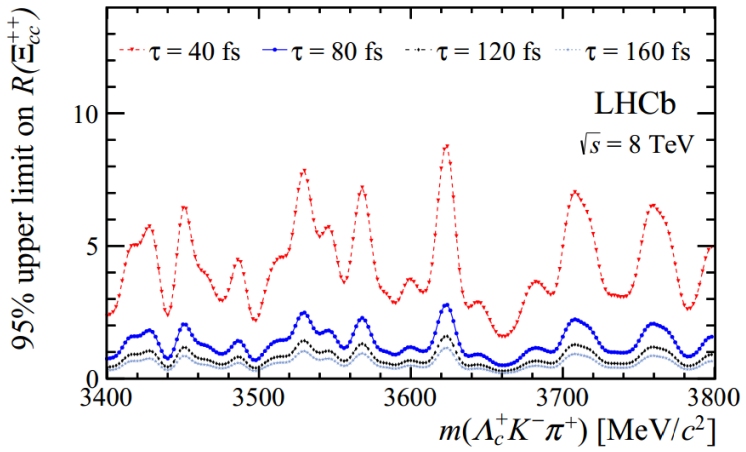
$\Xi_{cc}^{+} \to \Lambda_c^{+} K^{-} \pi^{+}$ upper limits

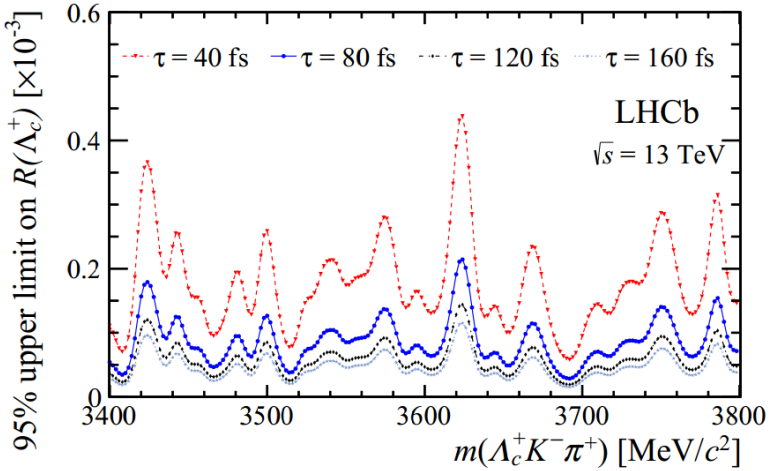
- Set limits on $\mathcal{R}(\Lambda_c^+) \equiv \dfrac{\sigma(\Xi_{cc}^+)\mathcal{B}(\Xi_{cc}^+ \to \Lambda_c^+ K^- \pi^+)}{\sigma(\Lambda_c^+)}$

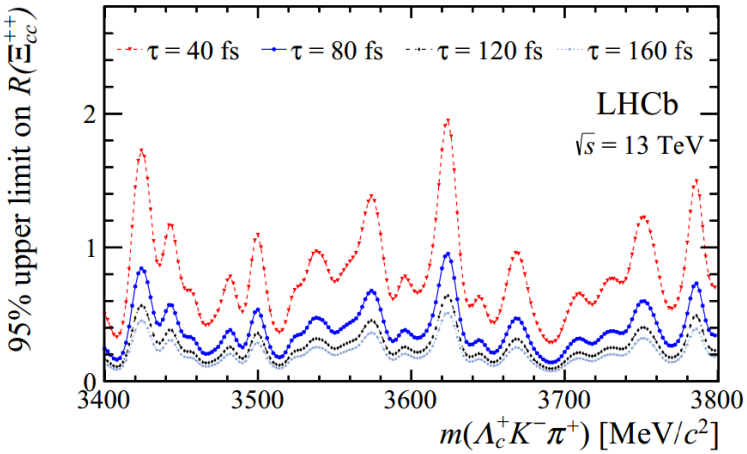
  and $\mathcal{R}(\Xi_{cc}^{++}) \equiv \dfrac{\sigma(\Xi_{cc}^+)\mathcal{B}(\Xi_{cc}^+ \to \Lambda_c^+ K^- \pi^+)}{\sigma(\Xi_{cc}^{++})\mathcal{B}(\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^+)}$.

arXiv:1909.12273
(SCI CHINA PHYS MECH)









$\Xi_{cc}^{+} \to \Lambda_c^{+} K^{-} \pi^{+}$ upper limits

- Largest production ratios of masses @ 95% credibility level. arXiv:1909.12273 (SCI CHINA PHYS MECH)

Lifetime	$\sqrt{s} = 8\,\text{TeV}$		$\sqrt{s} = 13\,\text{TeV}$	
	$\mathcal{R}(\Lambda_c^+)$ $[\times 10^{-3}]$	$\mathcal{R}(\Xi_{cc}^{++})$	$\mathcal{R}(\Lambda_c^+)$ $[\times 10^{-3}]$	$\mathcal{R}(\Xi_{cc}^{++})$
40 fs	6.5	8.8	0.45	2.0
80 fs	2.1	2.8	0.22	1.0
120 fs	1.2	1.6	0.15	0.6
160 fs	0.9	1.2	0.12	0.5

- Depends strongly on mass and lifetime.
- Improved by one order of magnitude than LHCb Run 1 analysis.
- Significantly below expectations from SELEX.

Ξ_{cc}^{++} production measurement

LHCb-PAPER-2019-035

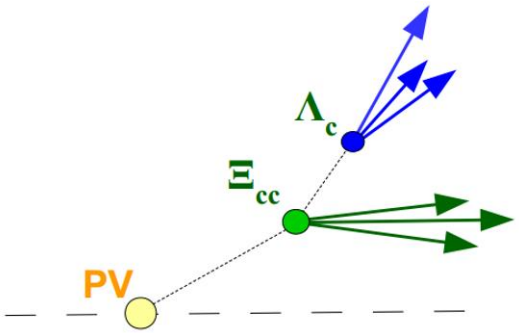
- Study the hadron production rate ratio between doubly charmed baryon to singly charmed baryon.

- Production rate ratio *R:* (2.0 < y < 4.5 && 4 < p_{T} < 15 GeV/c)

$$R \equiv \frac{\sigma(\Xi_{cc}^{++})\mathcal{B}(\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^+)}{\sigma(\Lambda_c^+)} = \frac{N_{sig}}{N_{con}} \frac{\varepsilon_{con}}{\varepsilon_{sig}}$$

  - Signal channel $\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^+$;
    Prompt Λ_c^+ as control channel.
  - 2016 data with two different trigger categories.
  - Selection for Λ_c^+, as close as possible.

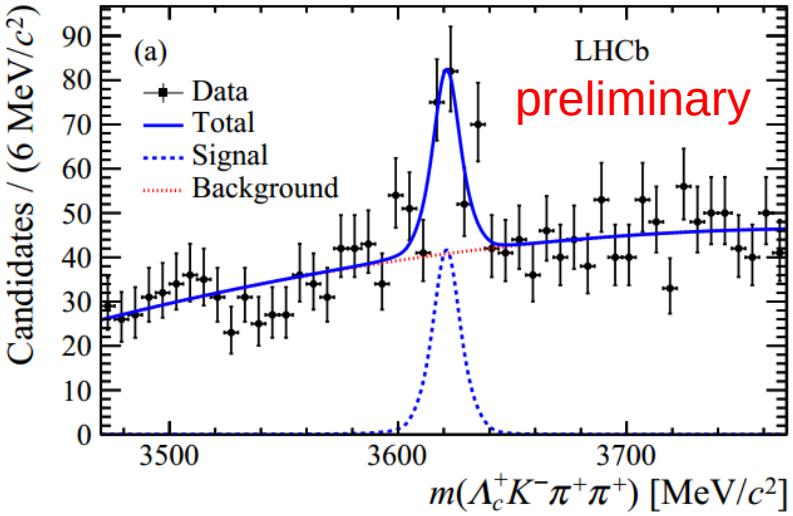
- Results at three different lifetime hypothes.

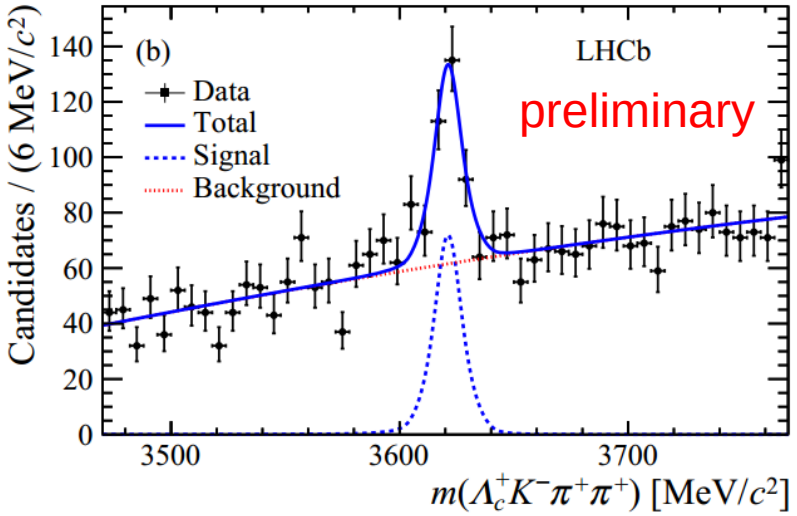


Ξ_{cc}^{++} signal yields

LHCb-PAPER-2019-035

- Simultaneous fit to Ξ_{cc}^{++} two trigger categories.
  - Signal: Double-sided crystalball (DSCB) + Gaussian (parameters fixed from simulation)
  - Bkg: 2^{nd} order Chebychev polynomial.

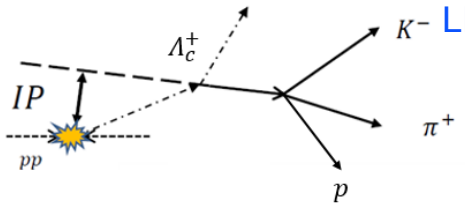




- Left (TOS): triggered by at least one of the Λ_c^+ decay products.
- Right (eXTIS): triggered by event not being the signal.

Prompt Λ_c^+ signal yields

- Two steps fit to Λ_c^+ two trigger categories.
- Mass fit:



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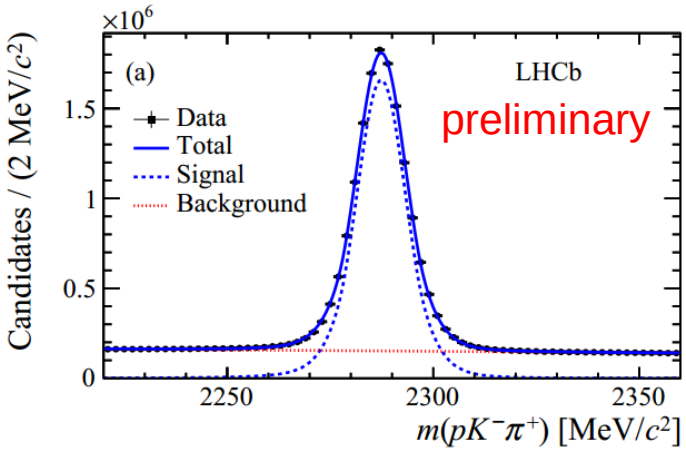
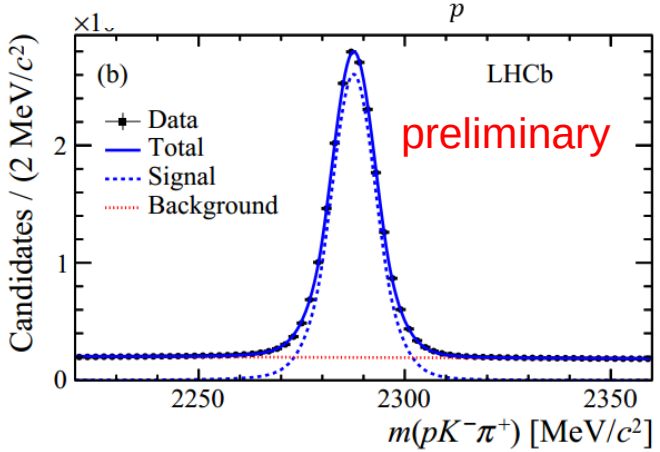
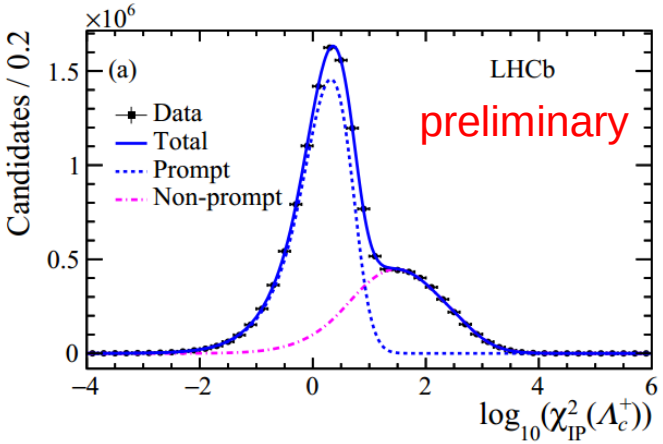
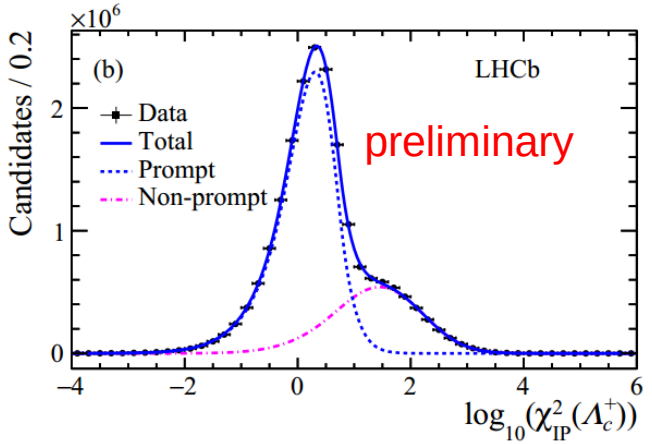




- $\mathrm{Log}_{10}(\chi^2_{\mathrm{IP}}(\Lambda_c^+))$ fit separate prompt and non-prompt components:





Ξ_{cc}^{++} production rate ratio results

LHCb-PAPER-2019-035

- Results at three different lifetimes.
- Combine two trigger categories with BLUE method.

preliminary

Categories	$R\ [\times 10^{-4}]$		
	0.230 ps	0.256 ps	0.284 ps
TOS	$2.90 \pm 0.57 \pm 0.49$	$2.57 \pm 0.51 \pm 0.43$	$2.31 \pm 0.46 \pm 0.39$
exTIS	$2.41 \pm 0.35 \pm 0.34$	$2.11 \pm 0.31 \pm 0.30$	$1.88 \pm 0.27 \pm 0.27$
Combined	$2.53 \pm 0.30 \pm 0.33$	$2.22 \pm 0.27 \pm 0.29$	$1.98 \pm 0.23 \pm 0.26$

- Could be improved in the future with more data and more precise lifetime measurement.
- More precise predictions could help our understanding.

Summary

- LHCb has performed the world-leading studies of doubly charmed baryons.
- Ξ_{cc}^{++} has been confirmed with $\Xi_c^+\pi^+$, set upper limits on $\mathcal{R}(\mathcal{B})(\approx 0.5)$.
- Search with $D^+pK^-\pi^+$, but no observation, upper limits set on $\mathcal{R}(\mathcal{B})$ < 2.1% at 95% CL.
- Search $\Xi_{cc}^+ \to \Lambda_c^+K^-\pi^+$, but no observation, upper limits set on $\mathcal{R}(\Lambda_c^+)$ and $\mathcal{R}(\Xi_{cc}^{++})$, significantly below expectations from SELEX.
- First production rate ratio of Ξ_{cc}^{++} w.r.t. prompt Λ_c^+ is measured~$O(10^{-4})$.
- Much more will be released in the future…

Thanks!

Backup