Doubly heavy baryons at LHCb

Shiyang Li

Central China Normal University

On behalf of the LHCb collaboration

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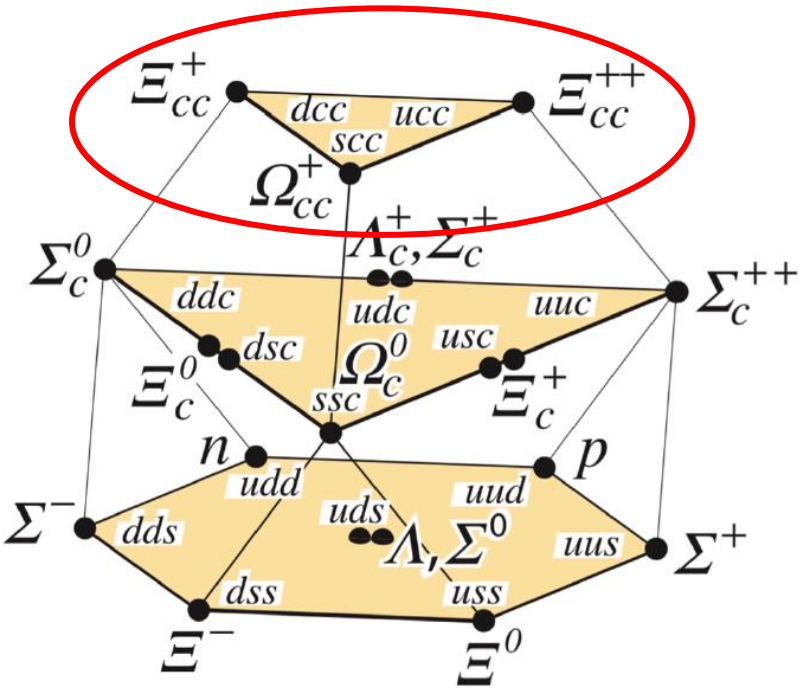
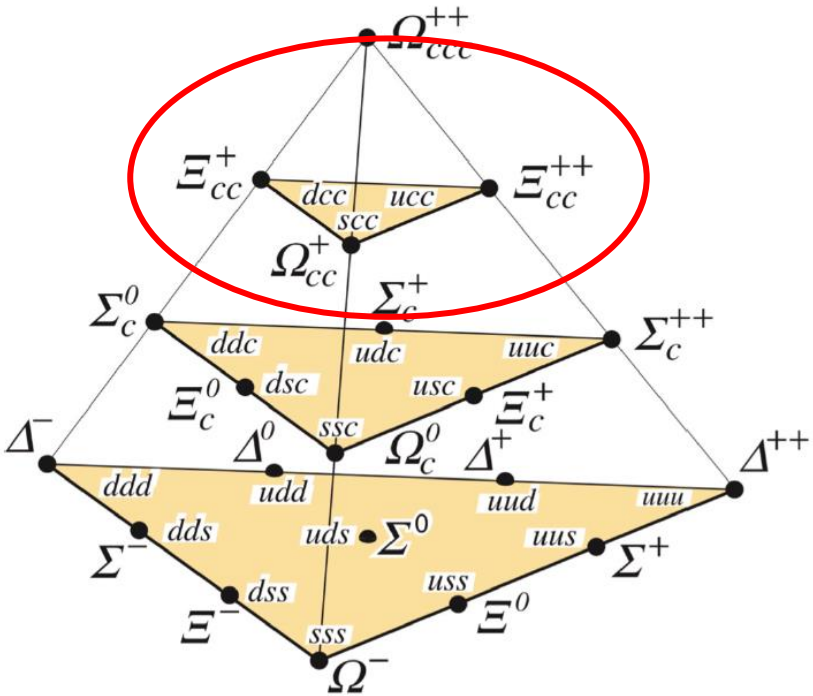
Outline

- Motivation
- LHCb detector
- Observation of Ξ_{cc}^{++} bayron
- Precision Ξ_{cc}^{++} mass and lifetime measurements
- Search for Ξ_{cc}^{+} bayron
- Search for Ξ_{bc}^{0} and Ω_{bc}^{0} bayrons
- Summary

Motivation

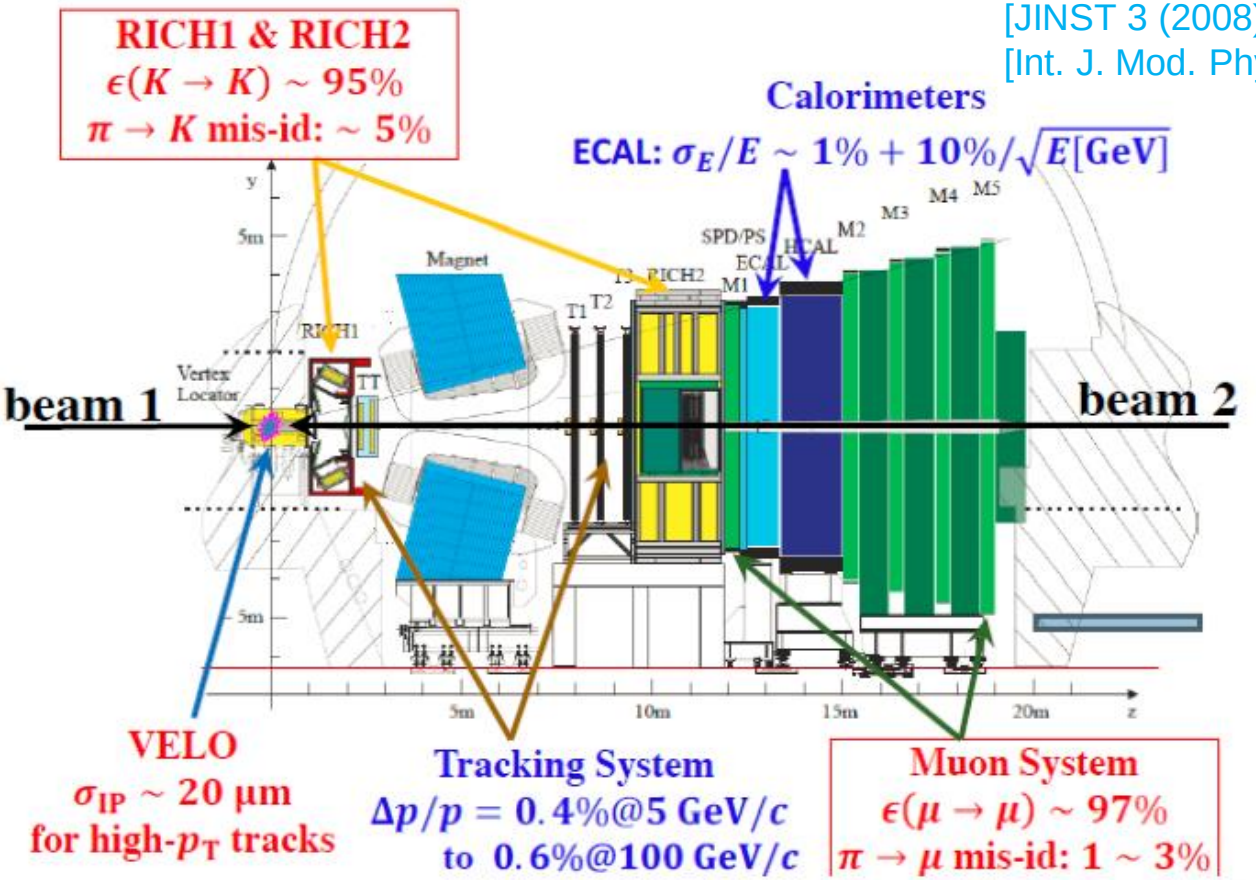
- Doubly heavy baryons composed of two heavy quarks (b or c quark) and a single light quark (u, d or s quark) are interesting objects, investigation of which can help us better understand the nonperturbative nature of QCD





LHCb detector

[JINST 3 (2008) S08005]
[Int. J. Mod. Phys. A30(2015) 1530022]

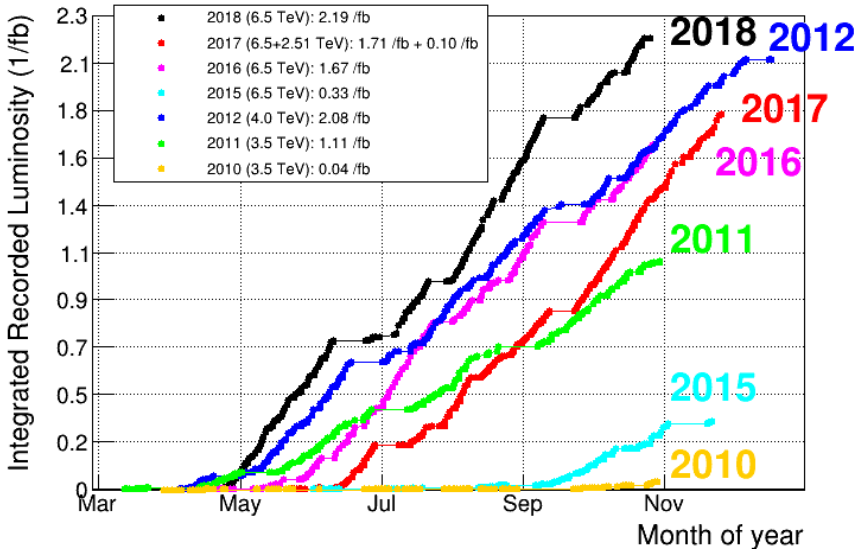


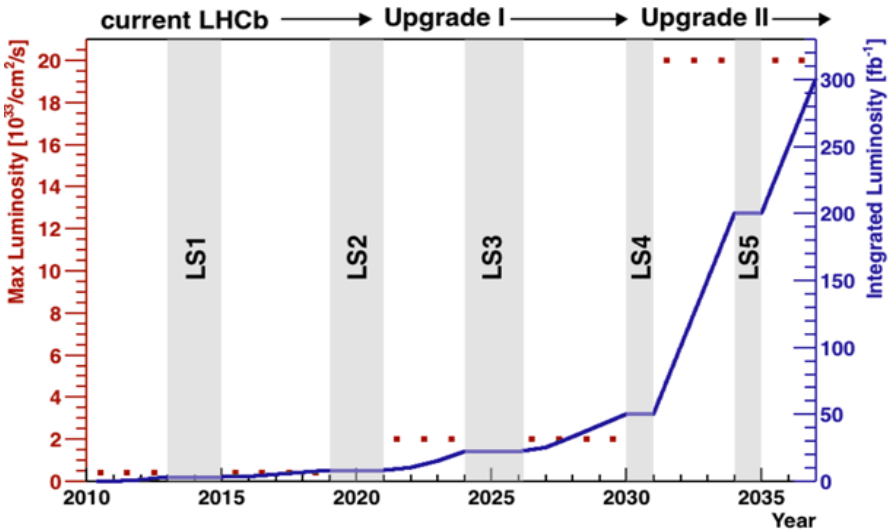
- Advantages

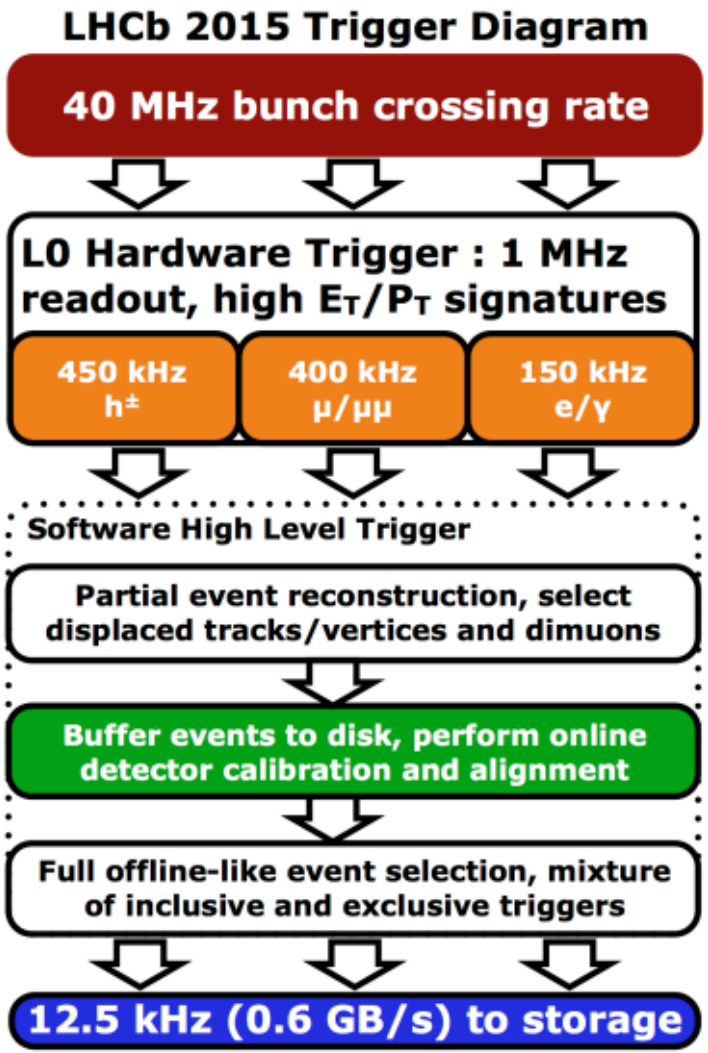
Good particle identification (Muon station & RICHes)

Excellent vertex resolution to isolate doubly heavy baryons from lighter hadrons (VELO)

LHCb integrated luminosity







Discovery of the double charm baryon Ξ_{cc}^{++}

Jibo's talk on Ξ_{cc}^{++} production

- Observation

Observed by the LHCb experiment in 2017 using $\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^+$ (a) [PRL 119 (2017) 112001]

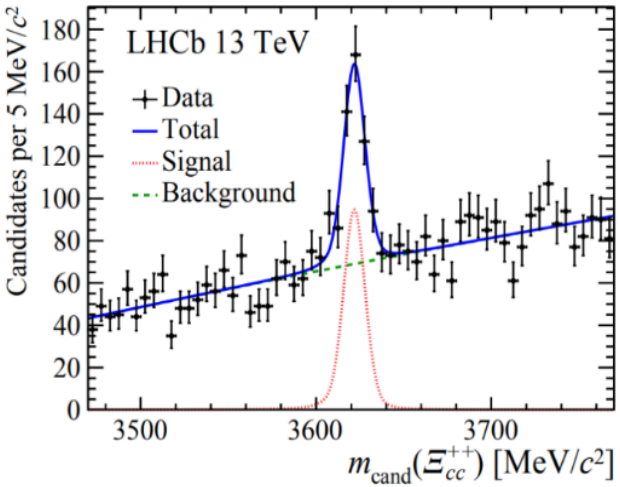
- Re-discovery

Re-discovery by LHCb experiment using $\Xi_{cc}^{++} \to \Xi_c^+ \pi^+$ (b) [PRL 121 (2018) 162002]

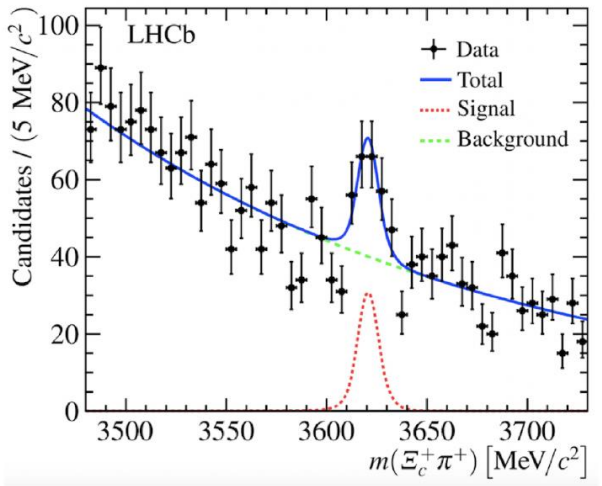
- Others

No $\Xi_{cc}^{++} \to D^+ p K^- \pi^+$ signal in 2016 data (c) [JHEP 10 (2019) 124]

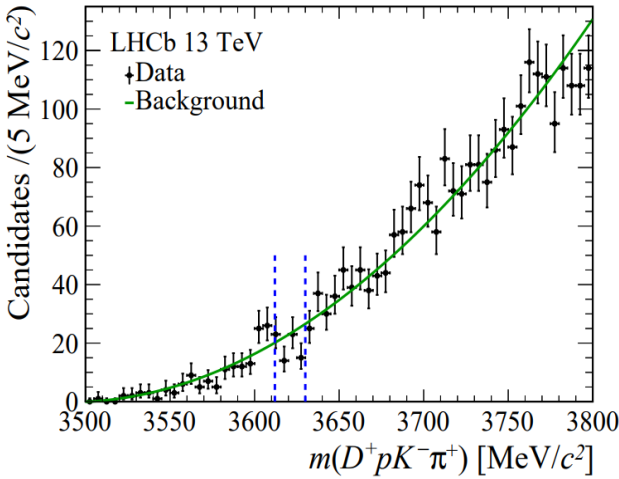
Likely suppression from low Q-value of decay



(a)



(b)

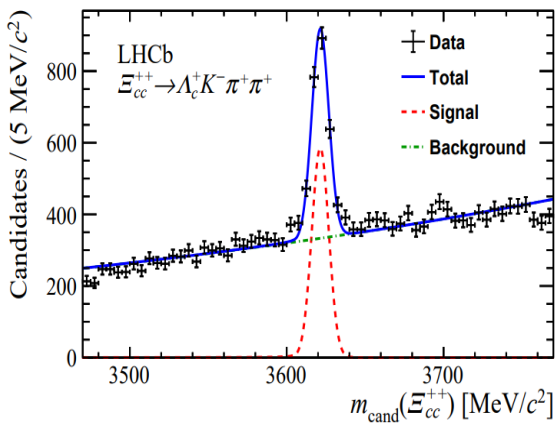


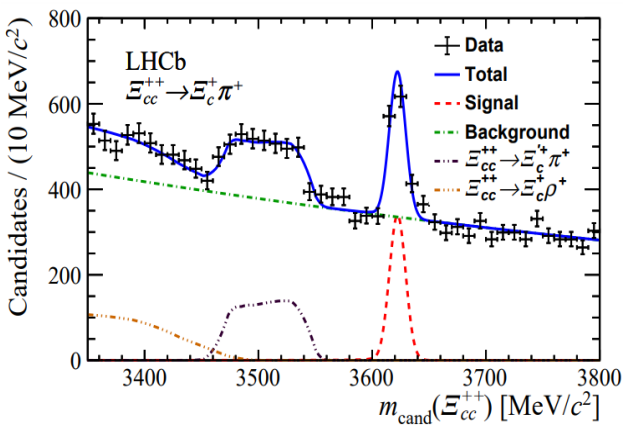
(c)

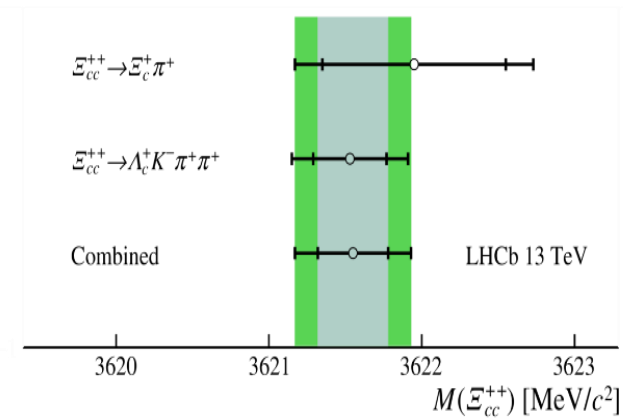
Precision Ξ_{cc}^{++} mass

Precision Ξ_{cc}^{++} mass

The Ξ_{cc}^{++} candidates are reconstructed via the decay modes $\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^+$ and $\Xi_{cc}^{++} \to \Xi_c^+ \pi^+$ using 2016-2018 data







Combined result:

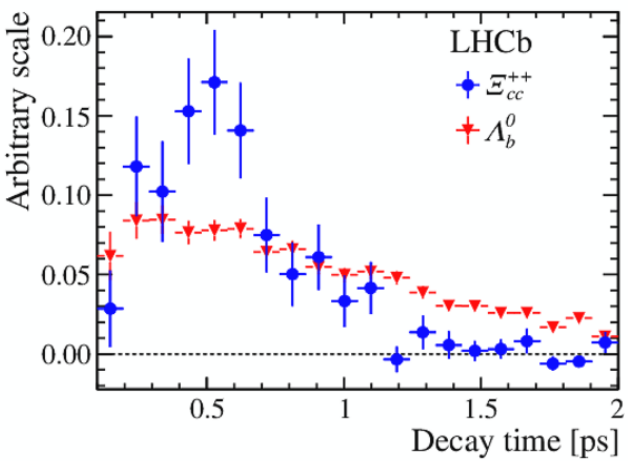
$$m(\Xi_{cc}^{++}) = 3621.55 \pm 0.23(stat) \pm 0.30(syst) MeV/c^2$$

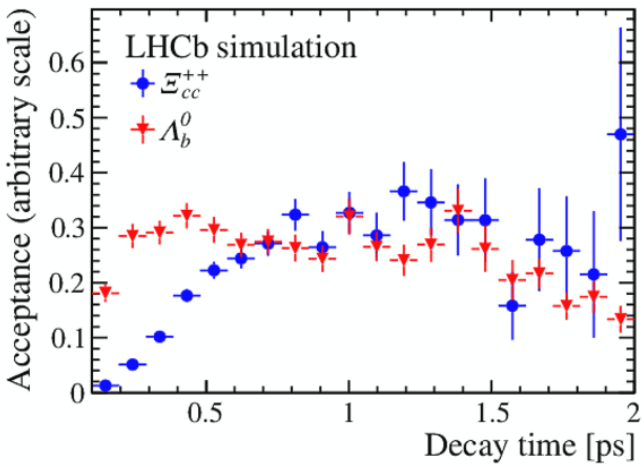
JHEP 02 (2020) 049

Ξ_{cc}^{++} lifetime

Ξ_{cc}^{++} lifetime

- The signal reconstructed in the final state $\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^+$
- Decay-time distribution measured relative to $\Lambda_b^0 \to \Lambda_c^+ \pi^- \pi^+ \pi^-$
  - ✓ Same selection requirements applied to both decays and common systematic effects largely cancel
  - ✓ Lifetime acceptances taken from simulation





$$\tau(\Xi_{cc}^{++}) = 0.256^{+0.024}_{-0.022}(stat) \pm 0.014(syst)ps$$

PRL 121 (2018) 052002

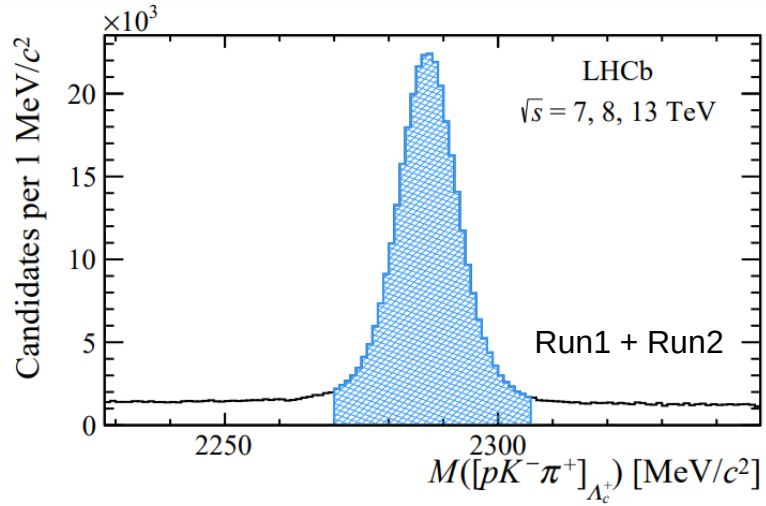
Searching for Ξ_{cc}^{+}

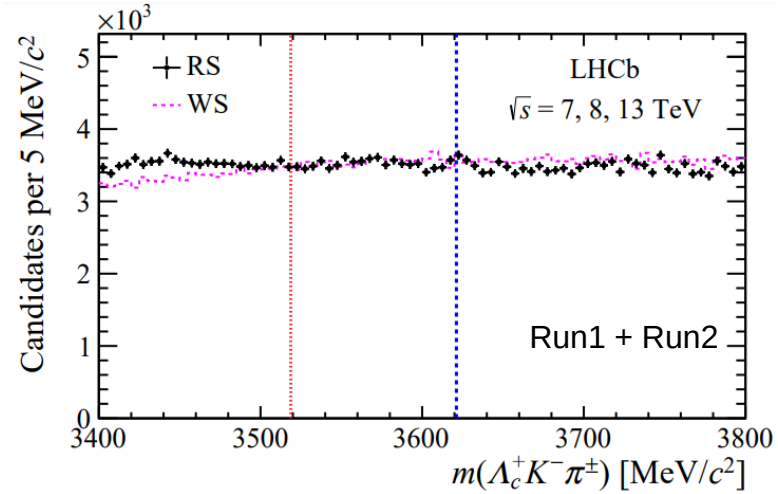
- Searched for $\Xi_{cc}^{+} \to \Lambda_c^{+} K^{-} \pi^{+}$ in run1&run2 data

- Motivation

The SELEX collaboration reported the observation of the Ξ_{cc}^{+} baryon decaying into $\Lambda_c^{+} K^{-} \pi^{+}$ and $pD^{+}K^{-}$ final states [PRL.89:112001,2002, PLB, 2005, 628(1–2):18-24.]

- Mass distributions of the (left) intermediate Λ_c^{+} and (right) Ξ_{cc}^{+} candidates





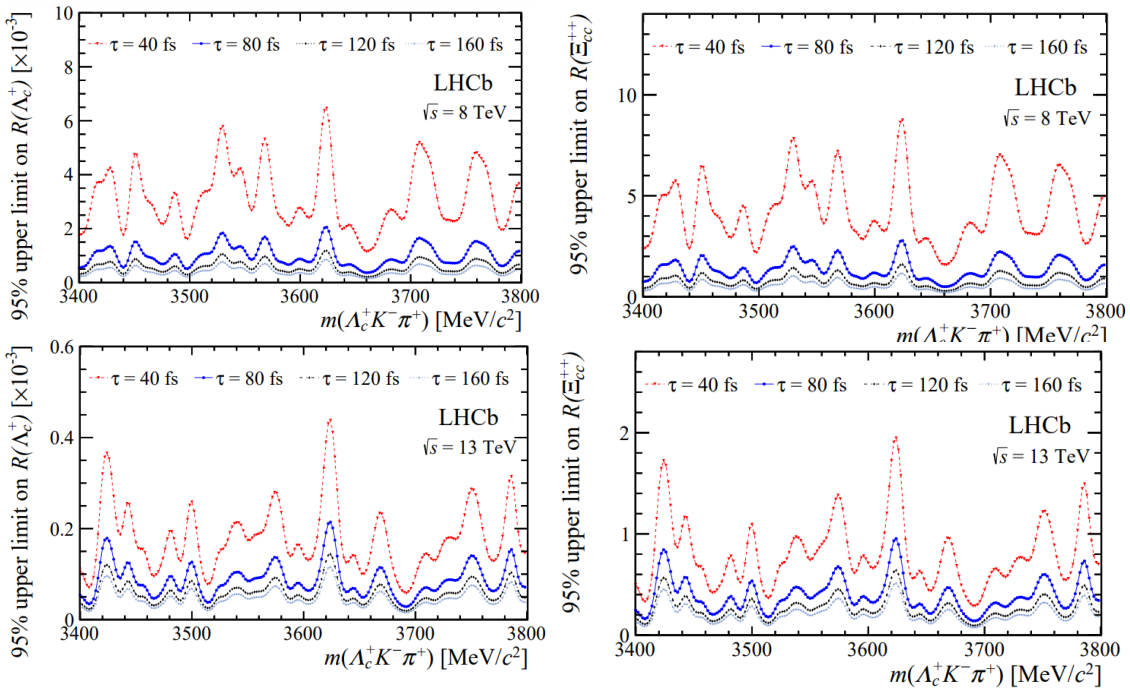
Sci.China Phys.Mech.Astron. (2020) 63 221062

Searching for Ξ_{cc}^{+}

- Result
- No $\Xi_{cc}^{+} \to \Lambda_c^{+} K^{-} \pi^{+}$ signal in run1&run2 data
- Using CLs method to set upper limits on:

$$\mathcal{R}(\Lambda_c^{+}) \equiv \frac{\sigma(\Xi_{cc}^{+}) \times \mathcal{B}(\Xi_{cc}^{+} \to \Lambda_c^{+} K^{-} \pi^{+})}{\sigma(\Lambda_c^{+})} \qquad \mathcal{R}(\Xi_{cc}^{++}) \equiv \frac{\sigma(\Xi_{cc}^{+}) \times \mathcal{B}(\Xi_{cc}^{+} \to \Lambda_c^{+} K^{-} \pi^{+})}{\sigma(\Xi_{cc}^{++}) \times \mathcal{B}(\Xi_{cc}^{++} \to \Lambda_c^{+} K^{-} \pi^{+} \pi^{+})}$$

fiducial region: 2.0<y<4.5 & 4<p_T<15GeV/c



Upper limit range: $0.12 \times 10^{-3} - 0.45 \times 10^{-3}$ $[\mathcal{R}(\Lambda_c^{+})]$
$0.5 \times 10^{-3} - 2.0 \times 10^{-3}$ $[\mathcal{R}(\Xi_{cc}^{++})]$ @95% C.L.

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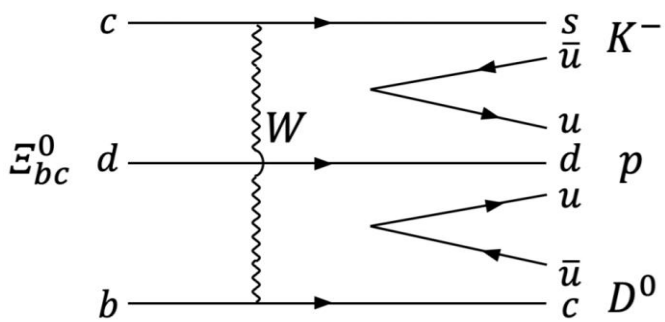
Searching for Ξ_{bc}^0

- First search for $\Xi_{bc}^0 \to D^0 p K^-$ in run2 (2016+2017+2018) data



- Motivation

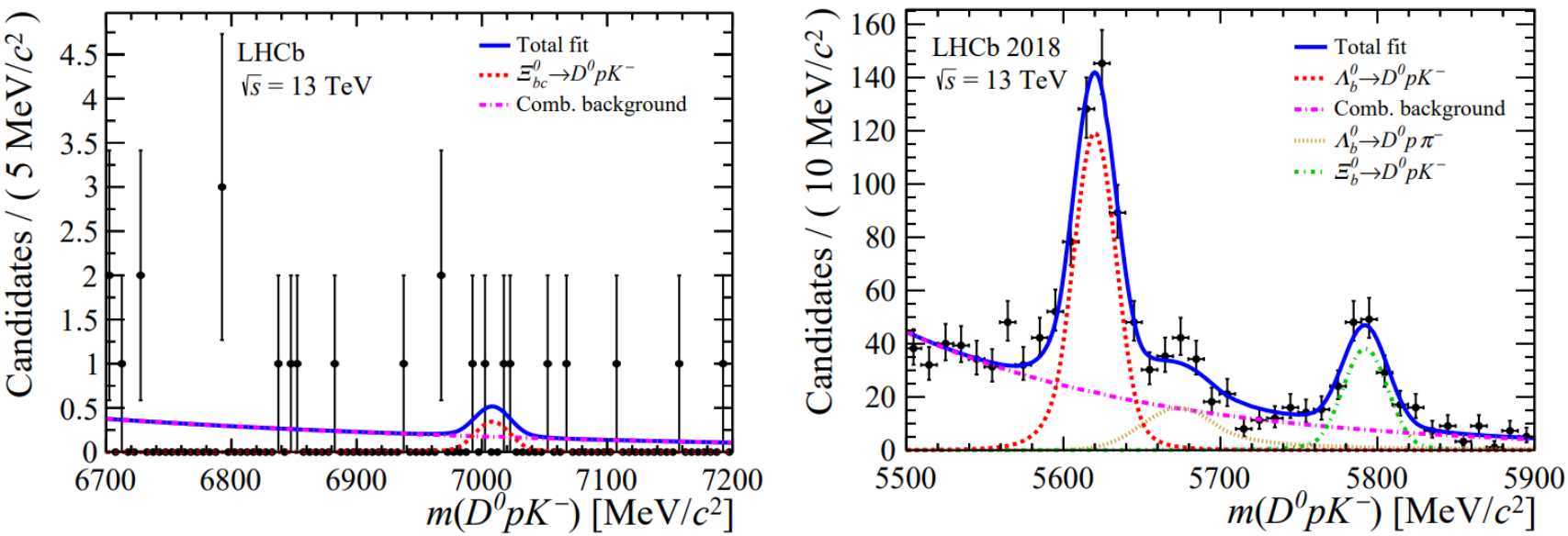
  - Ξ_{cc}^{++} has been observed, but the other double heavy baryons (contains at least one b quark) has not been found yet
  - The total branching fraction of the $\Xi_{bc}^0 \to D^0 p K^-$ decay chain is expected to be in the range of $10^{-5} - 10^{-4}$ [JHEP 11 (2020) 095]

- Theory predicts for Ξ_{bc}^0

	Mass	Lifetime
Ξ_{bc}^0	$[6700,7200]\mathrm{MeV/c^2}$	$0.20 - 0.33\mathrm{ps}$

Searching for Ξ_{bc}^0

- Same selection requirements applied to both decays
- Invariant mass m(D^0pK^-) distribution of selected Ξ_{bc}^0 candidates (black points) together with the projection of the fit (blue solid line) for the full data sample.
- Fitting invariant mass distribution for $\Lambda_b^0 \to D^0pK^-$ candidates in the 2018 data sample



JHEP 11 (2020) 095

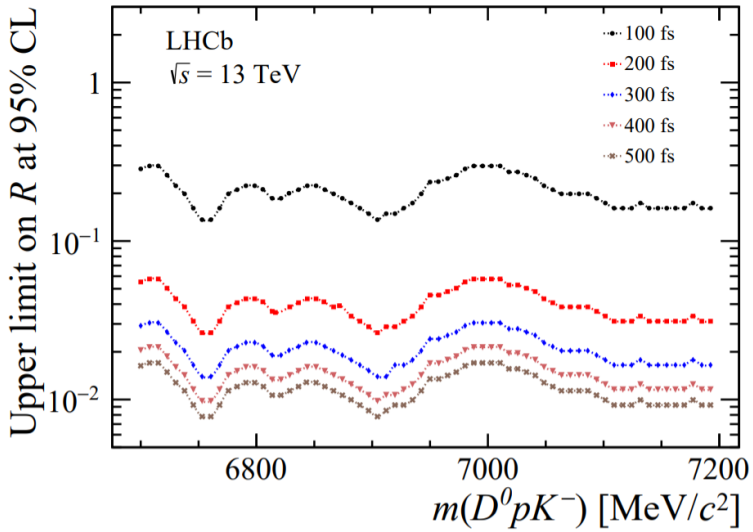
Searching for Ξ_{bc}^0

- Result
- No $\Xi_{bc}^0 \to D^0 p K^-$ signal in run2(2016+2017+2018) data
- Using CLs method to set upper limits on:

$$\mathcal{R} = \frac{\sigma(\Xi_{bc}^0)\mathcal{B}(\Xi_{bc}^0 \to D^0 p K^-)}{\sigma(\Lambda_b^0)\mathcal{B}(\Lambda_b^0 \to D^0 p K^-)}$$

Upper limit range: $1.7 \times 10^{-2} - 3.0 \times 10^{-1}$ @95% C.L.

fiducial region: 2.0<y<4.5 & 5<p_T<25GeV/c



JHEP 11 (2020) 095

Searching for Ξ_{bc}^0 and Ω_{bc}^0(Preliminary)

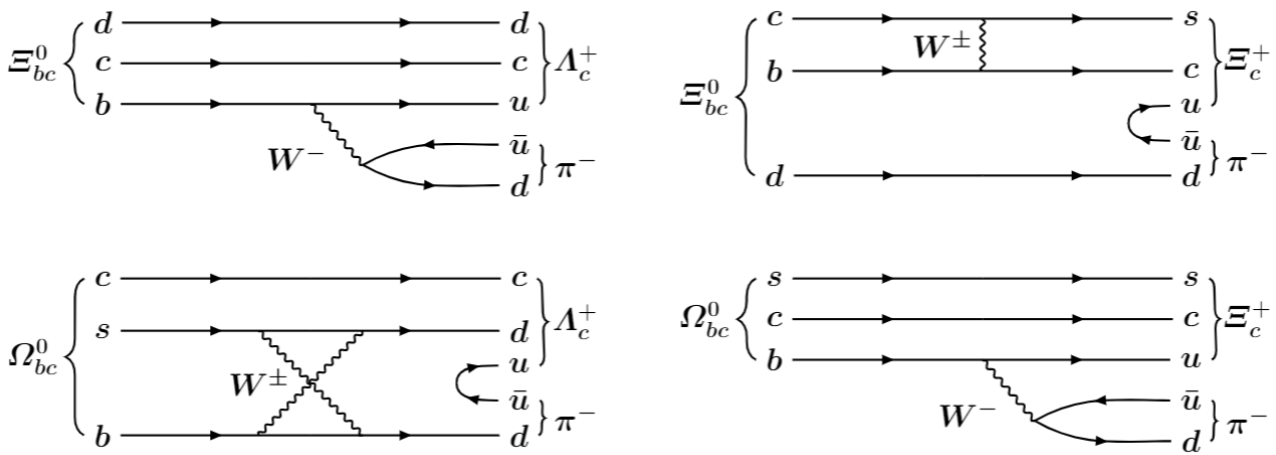
- Search for Ξ_{bc}^0 and Ω_{bc}^0 decaying to $\Lambda_c^+\pi^-$ and $\Xi_c^+\pi^-$ in run2 (2016+2017+2018) data

[LHCb-PAPER-2021-002]

- Theory predicts for Ξ_{bc}^0 and Ω_{bc}^0

	Mass	Lifetime
Ξ_{bc}^0	[6700,7200]$\mathrm{MeV/c^2}$	$0.20-0.33\mathrm{ps}$
Ω_{bc}^0	about 100 MeV heavier than Ξ_{bc}^0	$0.22\mathrm{ps}$

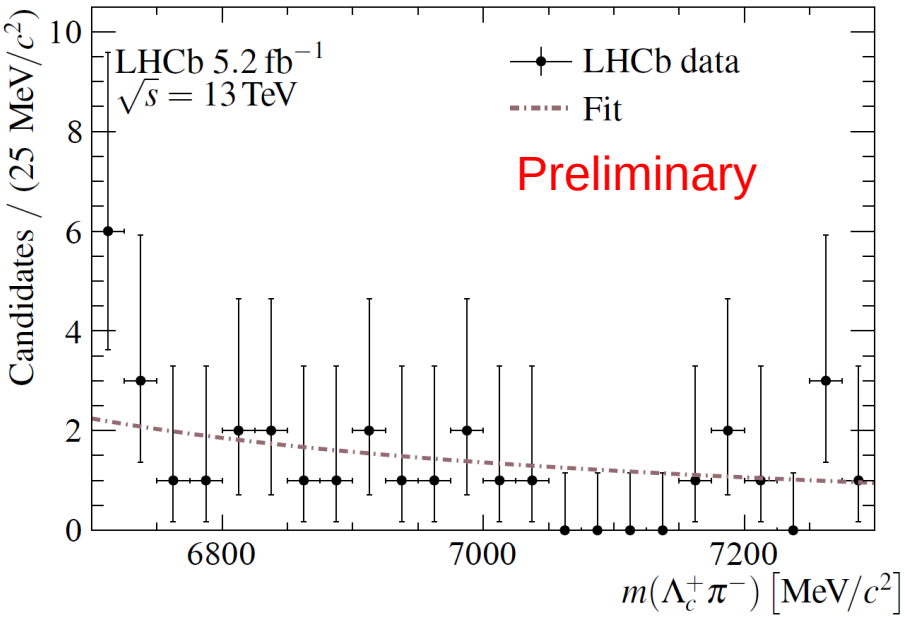
- Examples Feynman diagram

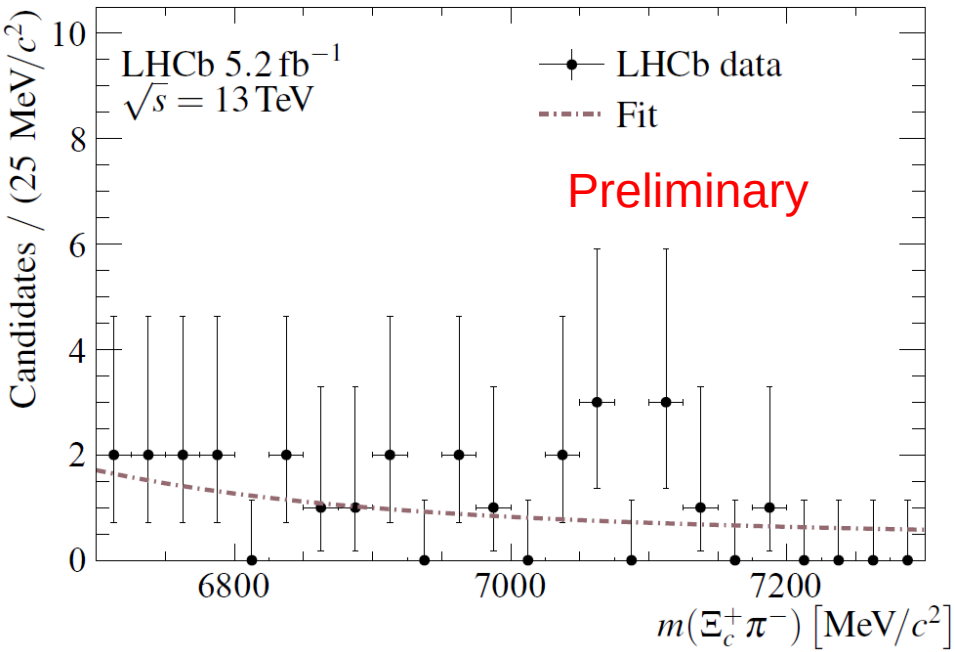


Searching for Ξ_{bc}^0 and Ω_{bc}^0(Preliminary)

- Signal channels

  Invariant mass distributions of selected (left) $\Xi_{bc}^0(\Omega_{bc}^0) \to \Lambda_c^+\pi^-$ and (right) $\Xi_{bc}^0(\Omega_{bc}^0) \to \Xi_c^+\pi^-$ candidates with results of the background only fit (blue solid line)



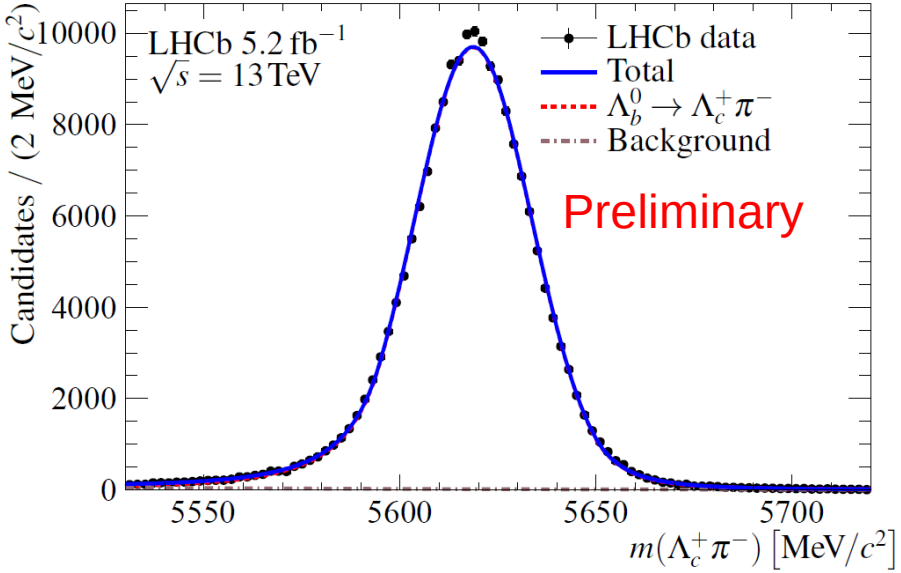


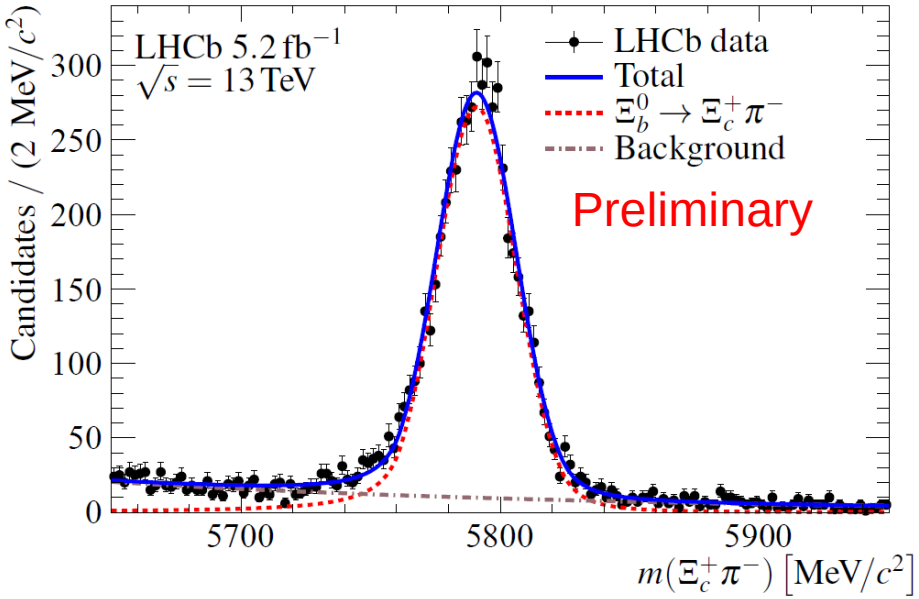
[LHCb-PAPER-2021-002]

Searching for Ξ_{bc}^0 and Ω_{bc}^0(Preliminary)

- Control channels

  Invariant mass distributions of (left) $\Lambda_b^0 \to \Lambda_c^+(\to pK^-\pi^+)\pi^-$ and (right) $\Xi_b^0 \to \Xi_c^+(\to pK^-\pi^+)\pi^-$ candidates with the fit results overlaid (blue solid line)





[LHCb-PAPER-2021-002]

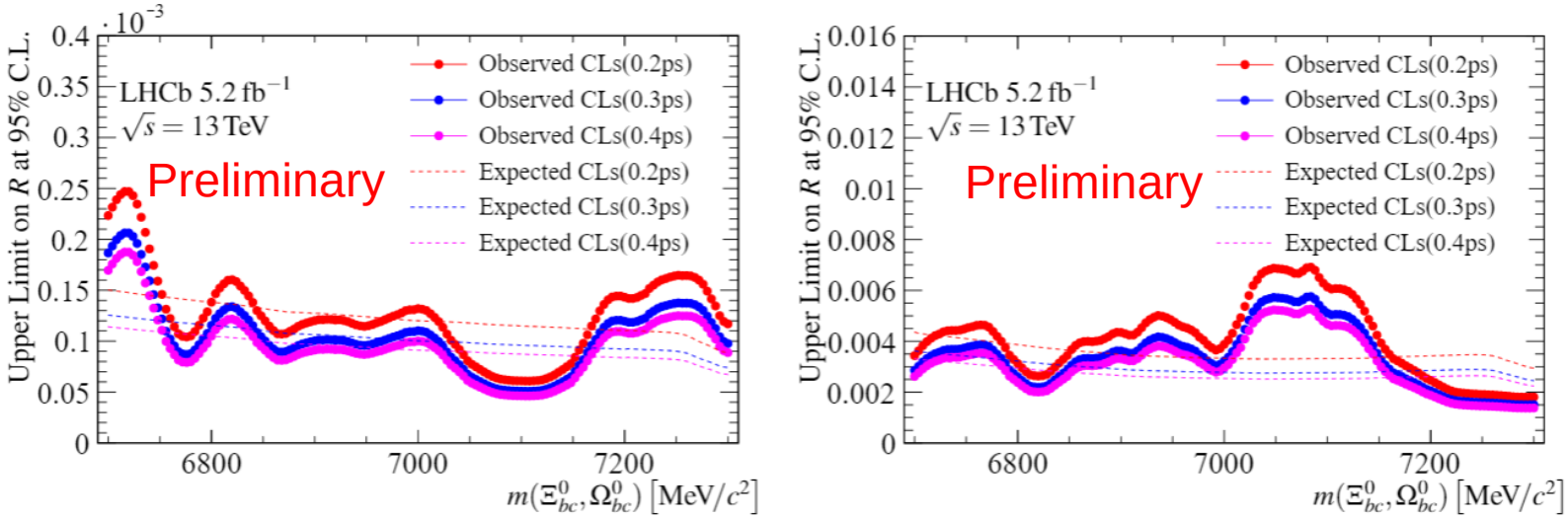
Searching for Ξ_{bc}^0 and Ω_{bc}^0(Preliminary)

◻ Result

- No Ξ_{bc}^0 and Ω_{bc}^0 signal in run2(2016+2017+2018) data
- Using CLs method to set upper limits on:

$$\mathcal{R}(\Lambda_c^+\pi^-) = \frac{\sigma(pp \to H_{bc}^0 X)\mathcal{B}(H_{bc}^0 \to \Lambda_c^+\pi^-)}{\sigma(pp \to \Lambda_b^0 X)\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+\pi^-)} \qquad \mathcal{R}(\Xi_c^+\pi^-) = \frac{\sigma(pp \to H_{bc}^0 X)\mathcal{B}(H_{bc}^0 \to \Xi_c^+\pi^-)}{\sigma(pp \to \Xi_b^0 X)\mathcal{B}(\Xi_b^0 \to \Xi_c^+\pi^-)}$$

fiducial region: 2.0<y<4.5 & 2<p_T<20 GeV/c



Upper limit range: $0.5 \times 10^{-4} - 2.5 \times 10^{-4}$ $[\mathcal{R}(\Lambda_c^+\pi^-)]$
$1.4 \times 10^{-3} - 6.9 \times 10^{-3}$ $[\mathcal{R}(\Xi_c^+\pi^-)]$ @95% C.L.

[LHCb-PAPER-2021-002]

Summary

- World-leading works on doubly heavy baryons spectroscopy

- Observed Ξ_{cc}^{++}(ccu) state decaying to $\Lambda_c^+ K^- \pi^+ \pi^+$ and $\Xi_{cc}^{++} \to \Xi_c^+ \pi^+$ final states
- No evidence of $\Xi_{cc}^{++} \to D^+ p K^- \pi^+$ decay

  Implications for dynamics of weakly decaying doubly charmed baryons

- Precision mass and lifetime of state
- No signal for $\Xi_{cc}^{+} \to \Lambda_c^+ K^- \pi^+$ in run1 &run2 data
- No signal for $\Xi_{bc}^{0} \to D^0 p K^-$ in run2 (2016+2017+2018) data
- No signal for Ξ_{bc}^{0} and Ω_{bc}^{0} decaying to $\Lambda_c^+ \pi^-$ and $\Xi_c^+ \pi^-$ in run2 (2016+2017+2018) data

- Expect more of doubly heavy baryons

- Diverse programmed of double heavy baryons studies currently in progress

  Search for the doubly charmed baryon Ω_{cc}^{+} with the $\Xi_c^+ K^- \pi^+$ decay

Hopefully more doubly heavy baryons results coming soon

Thanks for your attention!

Thanks!