

Recent results of beauty-charm hadrons at LHCb

Shiyang Li

Central China Normal University

On behalf of the LHCb collaboration

第十三届全国粒子物理学术会议（2021）

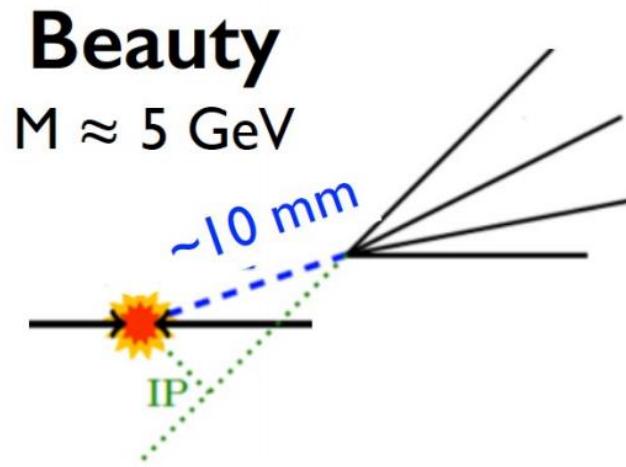
18 Aug. 2021

Outline

- Motivation
- LHCb detector
- B_c^- meson production fraction and asymmetry
- Precision B_c^+ meson mass
- Search for Ξ_{bc}^0 and Ω_{bc}^0 baryons
- Summary

Motivation

- ❑ **Beauty-charm hadrons** composed of at least **two heavy quarks (b and c quark)** are interesting objects, investigation of which can help us better understand the nonperturbative nature of QCD
- ❑ Compared to minimum bias (background)
 - Relatively high mass -> high transverse momentum
 - Relatively long lifetime -> large impact parameter (IP)
- ❑ Requires excellent vertexing, tracking, particle identification



LHCb detector

□ Advantages

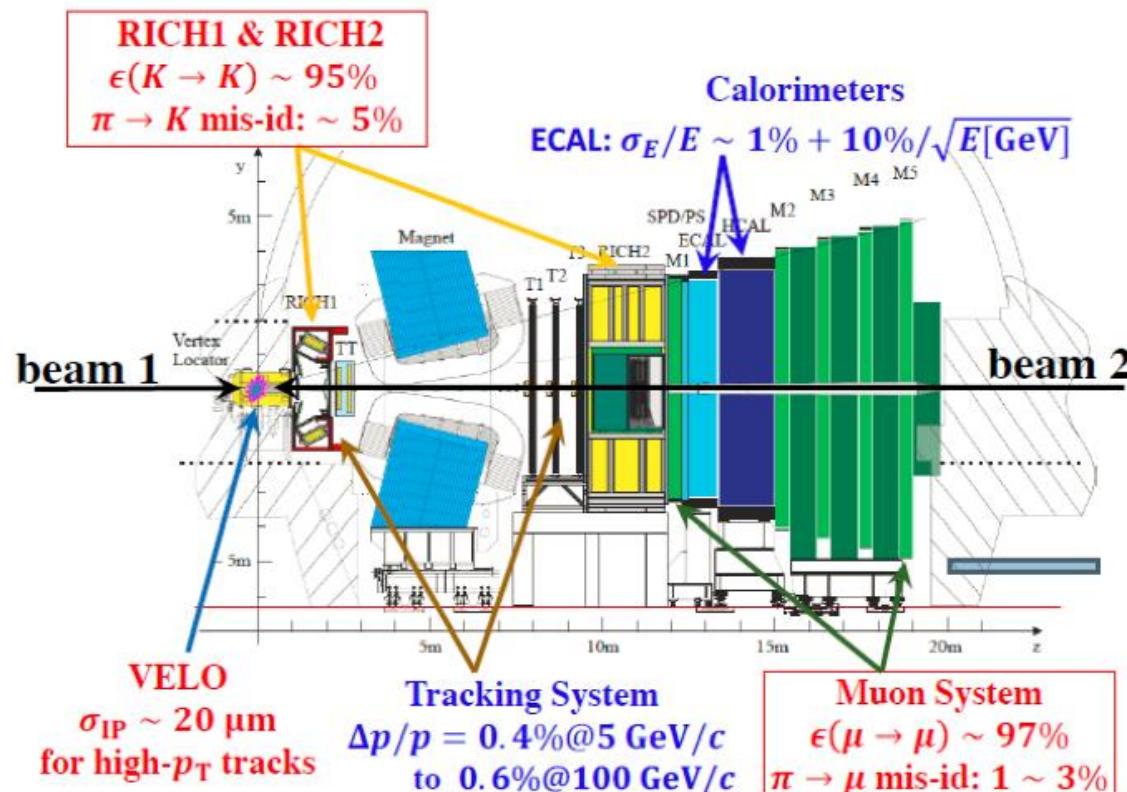
Good particle identification (Muon station & RICHes)

Excellent vertex resolution

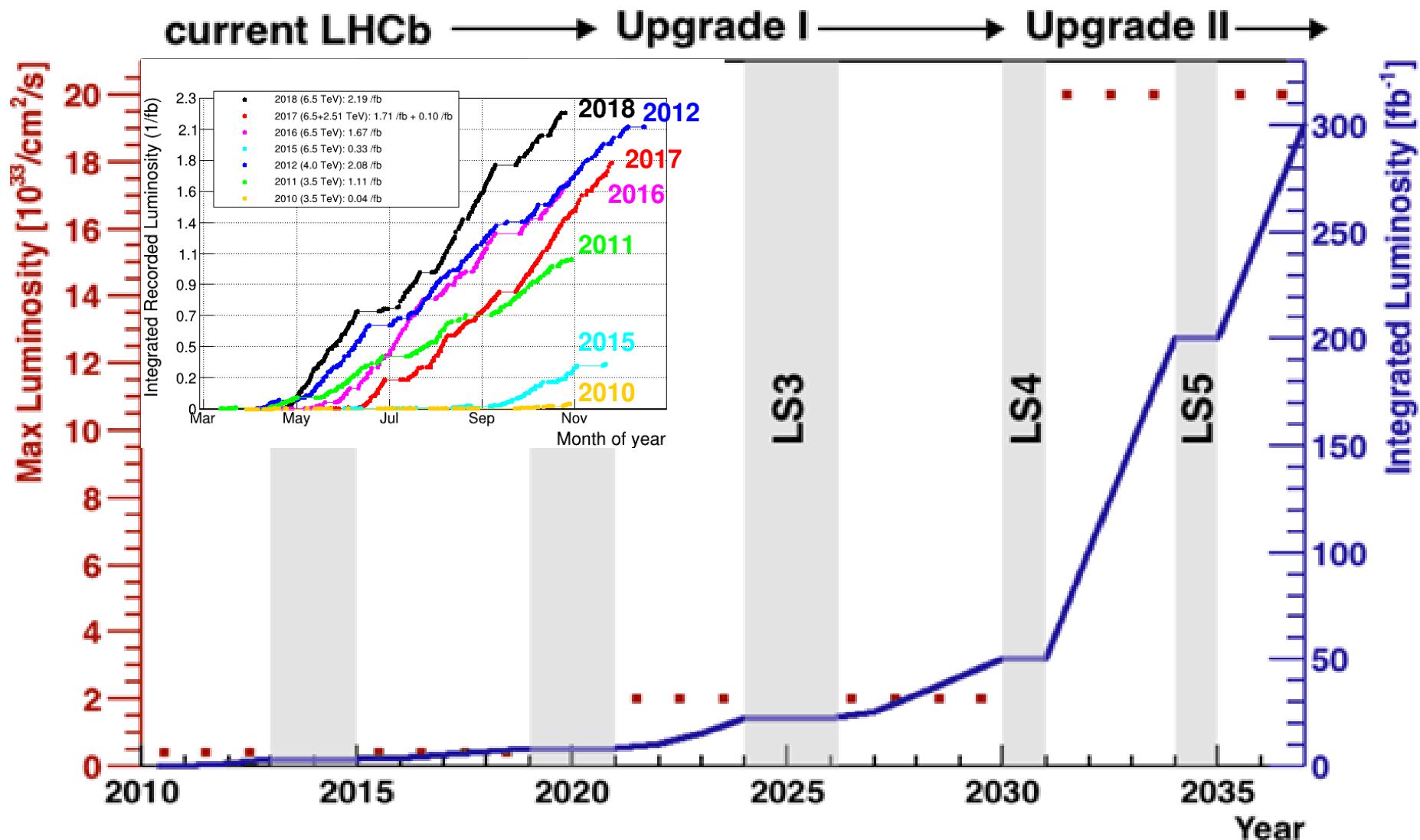
Dedicated to precision study of b/c-hadrons

[JINST 3 (2008) S08005]

[Int. J. Mod. Phys. A30(2015) 1530022]

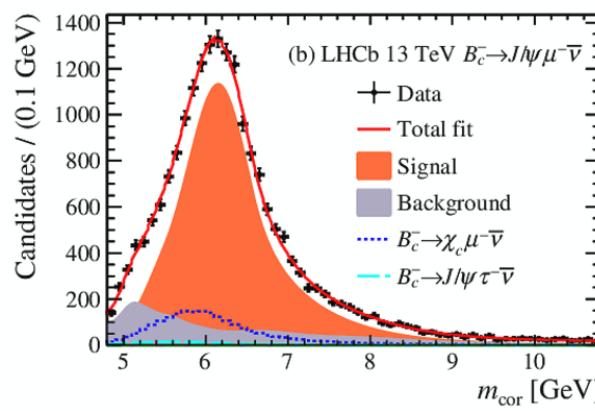
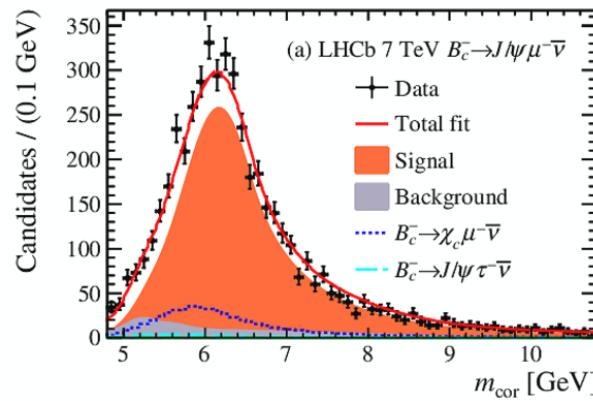


LHCb integrated luminosity

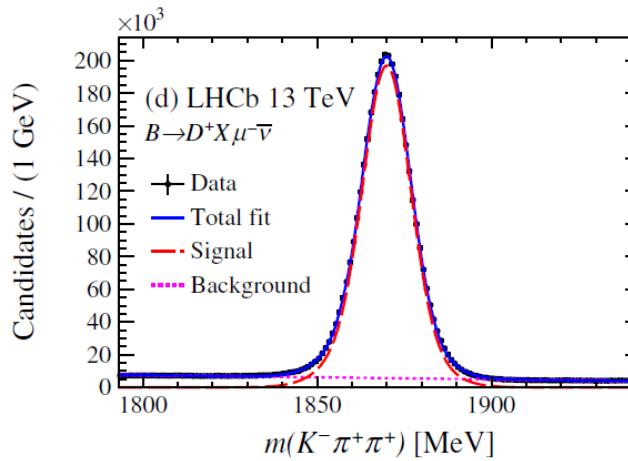
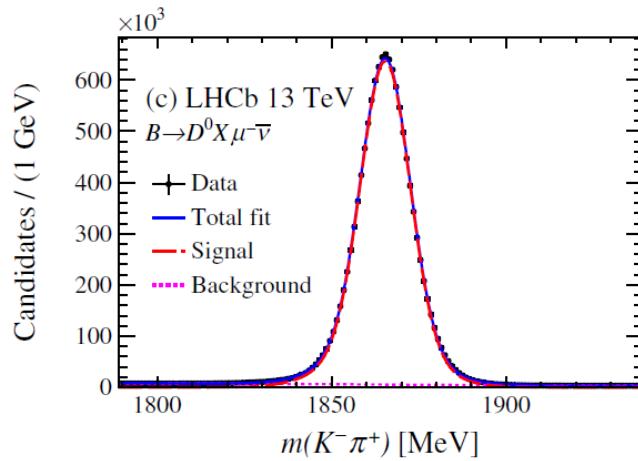


B_c^- meson production fraction and asymmetry

□ Signal channel $B_c^- \rightarrow J/\psi \mu^-\bar{\nu}$



□ Normalized to $B \rightarrow D^{0/+} X \mu^-\bar{\nu}$



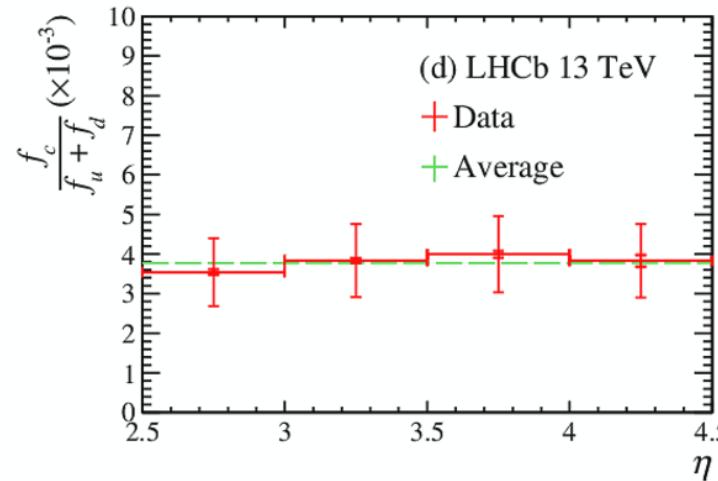
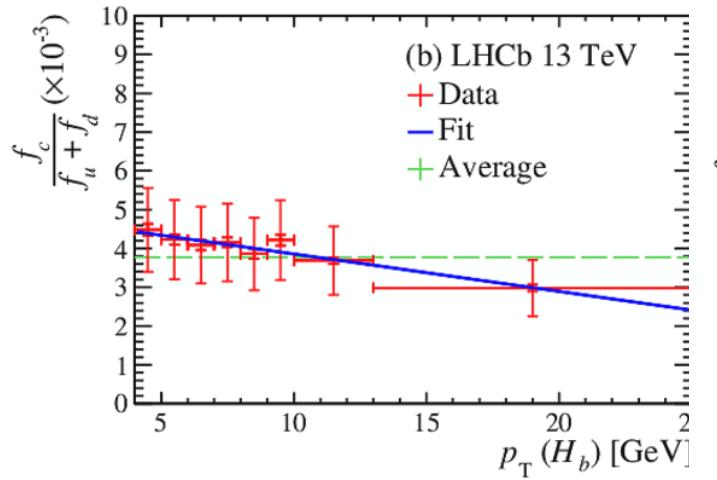
[PHYS. REV. D100 \(2019\) 112006](#)

B_c^- meson production fraction and asymmetry

□ Fraction results

$$R_c = \frac{f_c}{f_u + f_d} \equiv \frac{n_{corr}(B_c^- \rightarrow J/\psi \mu^- \bar{\nu})}{n_{corr}(B \rightarrow D^0 X \mu^- \bar{\nu}) + n_{corr}(B \rightarrow D^+ X \mu^- \bar{\nu})} \cdot \frac{\langle \mathcal{B}_{sl} \rangle}{\mathcal{B}(B_c^- \rightarrow J/\psi \mu^- \bar{\nu})}$$

Use $\langle \mathcal{B}_{sl} \rangle = 10.70 \pm 0.19 \%$, $\mathcal{B}(B_c^- \rightarrow J/\psi \mu^- \bar{\nu}) = 1.95 \pm 0.46 \%$



$$\frac{f_c}{f_u + f_d} = (3.63 \pm 0.08 \pm 0.12 \pm 0.86) \times 10^{-3} \text{ for } 7 \text{ TeV}$$

$$\frac{f_c}{f_u + f_d} = (3.78 \pm 0.04 \pm 0.15 \pm 0.89) \times 10^{-3} \text{ for } 13 \text{ TeV}$$

[PHYS. REV. D100 \(2019\) 112006](#)

B_c^- meson production fraction and asymmetry

□ Production asymmetry

7 TeV production asymmetry		
p_T (GeV) \ η	2.5 – 3.5	3.5 – 4.5
4 – 6	$7.91 \pm 7.00 \pm 1.03$	$-6.44 \pm 6.44 \pm 2.10$
6 – 8	$-4.34 \pm 5.43 \pm 1.62$	$-6.66 \pm 6.65 \pm 2.03$
8 – 10	$-1.13 \pm 6.31 \pm 1.56$	$-9.63 \pm 7.23 \pm 0.81$
10 – 25	$0.24 \pm 4.13 \pm 0.98$	$-4.87 \pm 8.63 \pm 1.44$

13 TeV production asymmetry		
p_T (GeV) \ η	2.5 – 3.5	3.5 – 4.5
4 – 6	$3.13 \pm 3.33 \pm 1.16$	$1.76 \pm 3.23 \pm 0.91$
6 – 8	$-0.34 \pm 2.79 \pm 1.26$	$-5.03 \pm 3.61 \pm 1.06$
8 – 10	$2.03 \pm 2.73 \pm 0.94$	$-2.48 \pm 4.29 \pm 1.78$
10 – 25	$1.50 \pm 2.05 \pm 0.73$	$-1.47 \pm 4.20 \pm 2.18$

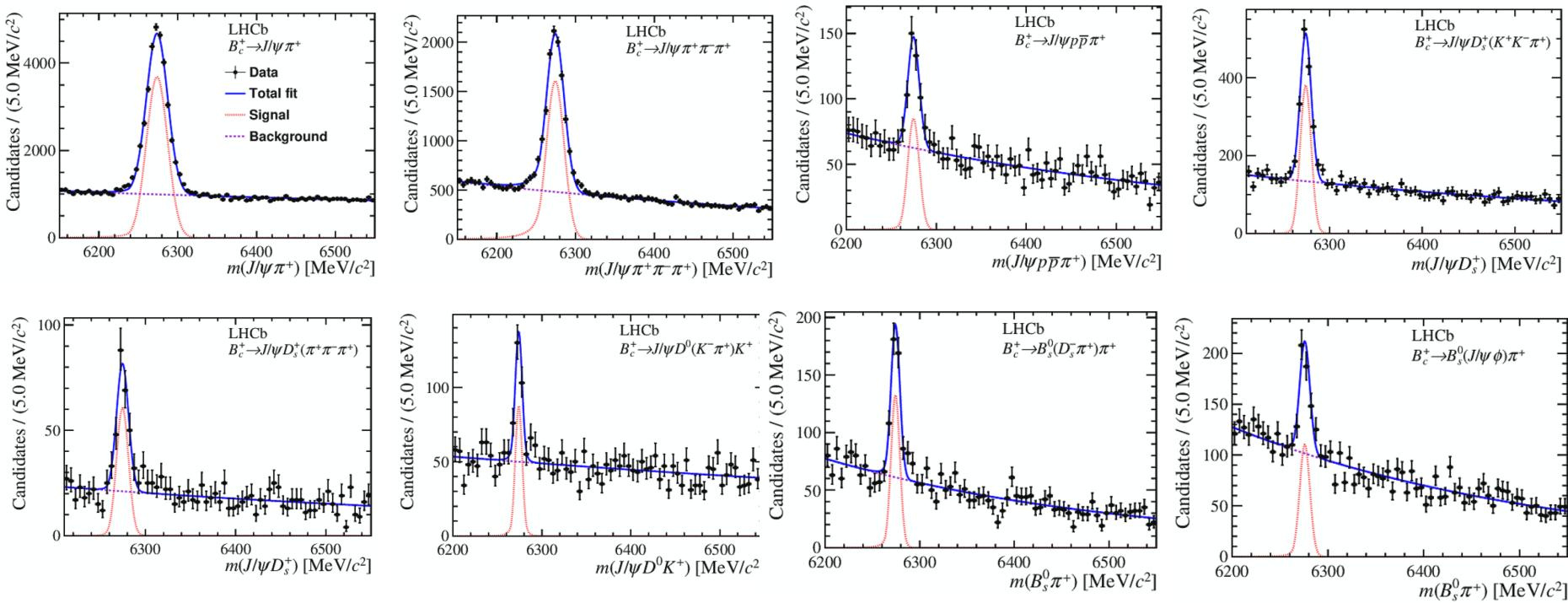
□ Averaging the $B_c^- - B_c^+$ production asymmetries over $p_T(H_b)$ and η

($-2.5 \pm 2.1 \pm 0.5$)% for 7 TeV

($-0.5 \pm 1.1 \pm 0.4$)% for 13 TeV

Precision B_c^+ meson mass

- The B_c^+ mesons are reconstructed via the decays $B_c^+ \rightarrow J/\psi\pi^+$, $B_c^+ \rightarrow J/\psi\pi^+\pi^-\pi^+$, $B_c^+ \rightarrow J/\psi p\bar{p}\pi^+$, $B_c^+ \rightarrow J/\psi D_s^+(D_s^+ \rightarrow K^+K^-\pi^+, \pi^+\pi^-\pi^+)$, $B_c^+ \rightarrow J/\psi D^0K^+$ ($D^0 \rightarrow K^-\pi^+$) and $B_c^+ \rightarrow B_s^0\pi^+$ ($B_s^0 \rightarrow J/\psi(\rightarrow \mu^+\mu^-)\phi(\rightarrow K^+K^-)$, $\rightarrow D_s^-(K^+K^-\pi^+)\pi^+$)

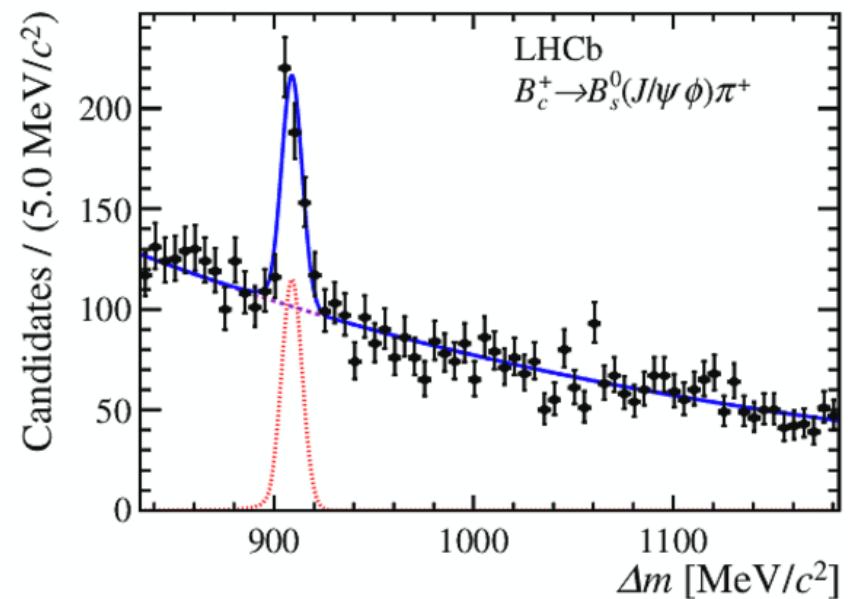
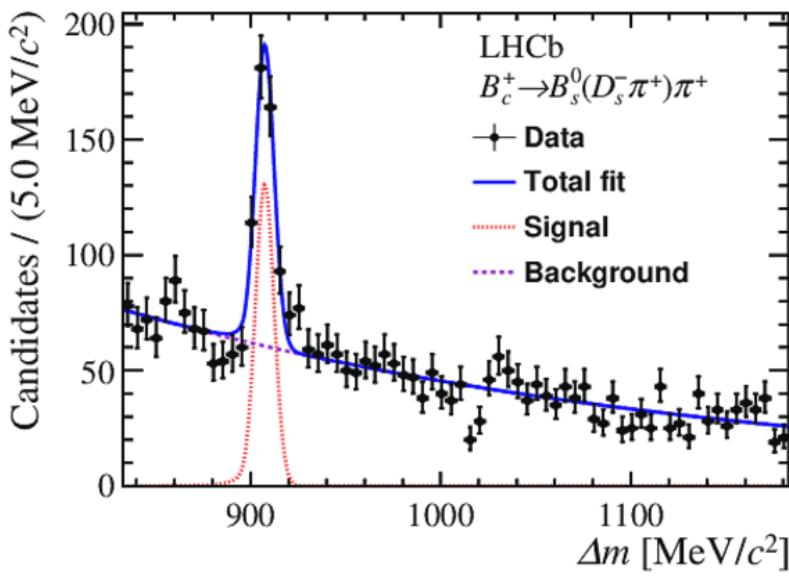


Precision B_c^+ meson mass

- The difference between the B_c^+ and B_s^0 meson masses

$$\Delta M = M(B_c^+) - M(B_s^0)$$

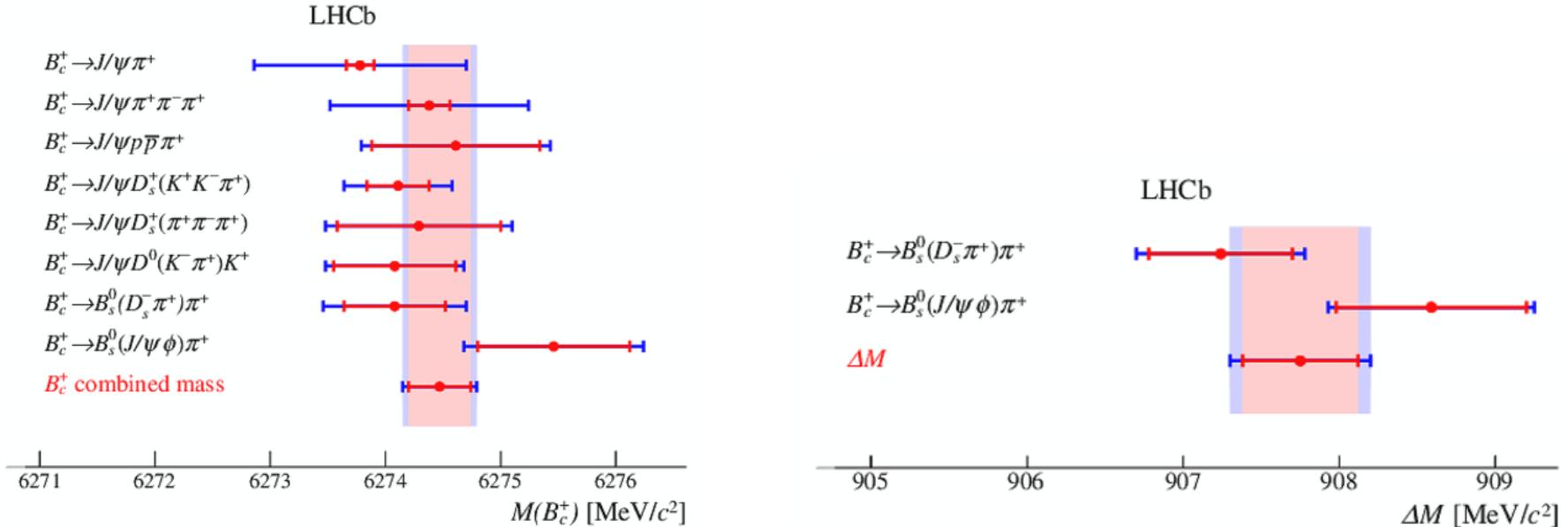
- Decay channels: $B_c^+ \rightarrow B_s^0 \pi^+$ ($B_s^0 \rightarrow J/\psi (\rightarrow \mu^+ \mu^-) \phi (\rightarrow K^+ K^-)$, $\rightarrow D_s^- (K^+ K^- \pi^+) \pi^+$)



[JHEP 07 \(2020\) 123](#)

Precision B_c^+ meson mass

□ Combination of the B_c^+ mass and mass difference measurements



The red (inner) cross-bars show the **statistical uncertainties**, and the blue (outer) cross-bars show the **total uncertainties**

□ Result

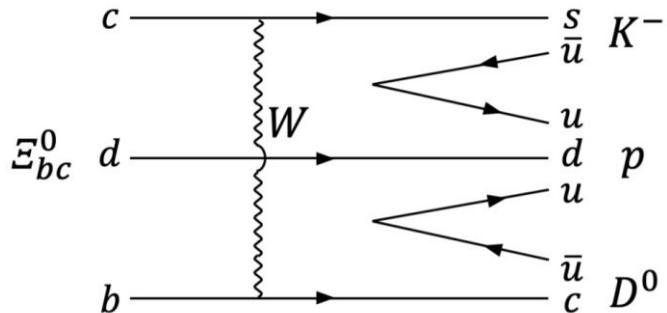
$$M(B_c^+) = 6274.47 \pm 0.27(\text{stat}) \pm 0.17(\text{syst}) \text{ MeV}/c^2$$

$$\Delta M = 907.75 \pm 0.37(\text{stat}) \pm 0.27(\text{syst}) \text{ MeV}/c^2$$

[JHEP 07 \(2020\) 123](#)

Searching for Ξ_{bc}^0

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



Motivation

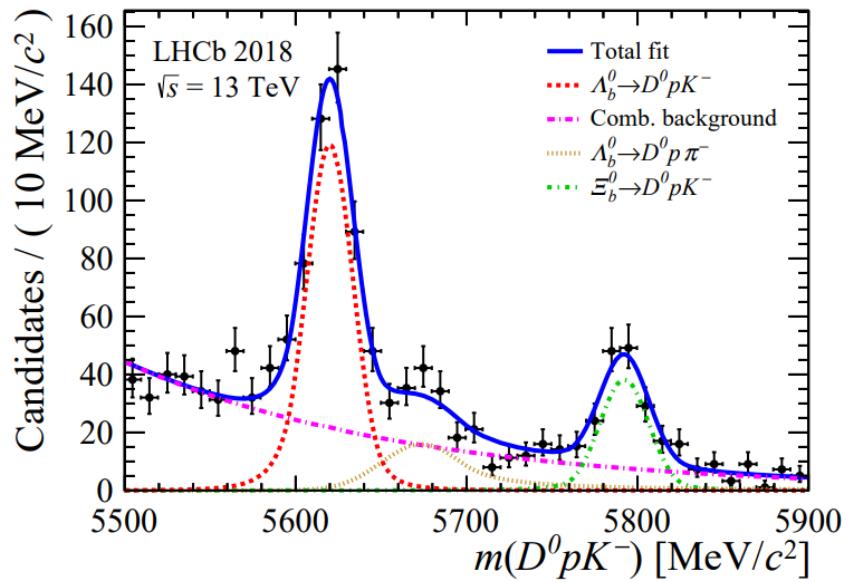
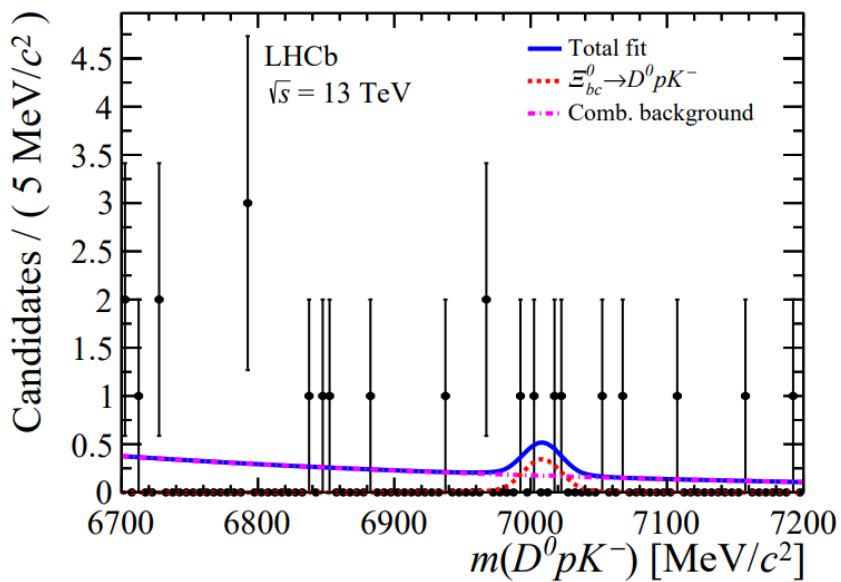
- Ξ_{cc}^{++} has been observed, but the other double heavy baryons (contains at least one b quark) has not been found yet
- The total branching fraction of the $\Xi_{bc}^0 \rightarrow D^0 p K^-$ decay chain is expected to be in the range of $10^{-5} - 10^{-4}$ [JHEP 11 (2020) 095]

Theory predictions for Ξ_{bc}^0

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

Searching for Ξ_b^0

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



[JHEP 11 \(2020\) 095](#)

Searching for Ξ_{bc}^0

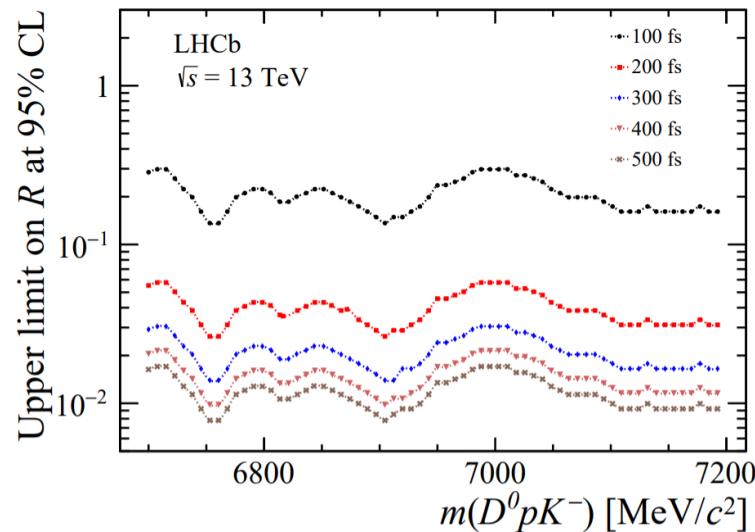
Result

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

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

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

fiducial region: $2.0 < y < 4.5$ & $5 < p_T < 25 \text{ GeV}/c$



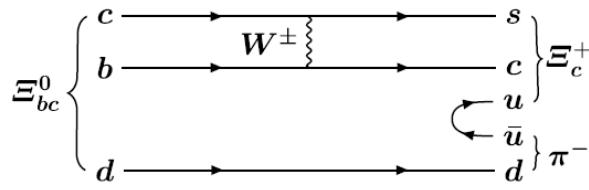
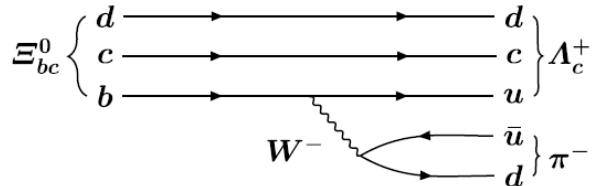
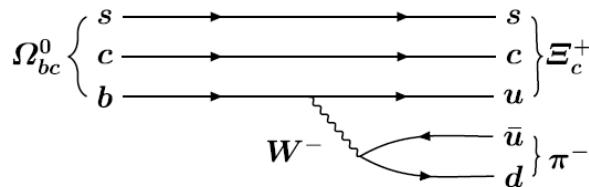
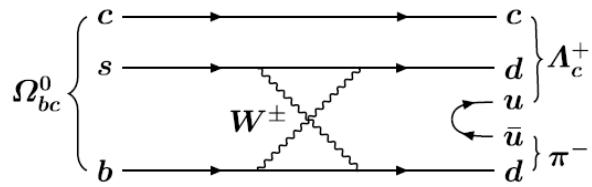
[JHEP 11 \(2020\) 095](#)

Searching for Ω_{bc}^0 and Ξ_{bc}^0

- Search for Ω_{bc}^0 and Ξ_{bc}^0 decaying to $\Lambda_c^+\pi^-$ and $\Xi_c^+\pi^-$ in run2 (2016+2017+2018) data [LHCb-PAPER-2021-002]
- Theory predictions for Ω_{bc}^0 and Ξ_{bc}^0

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

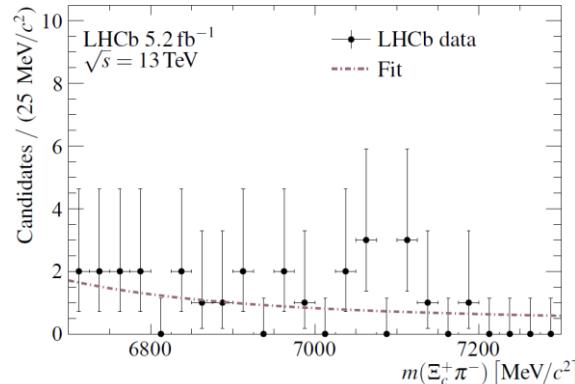
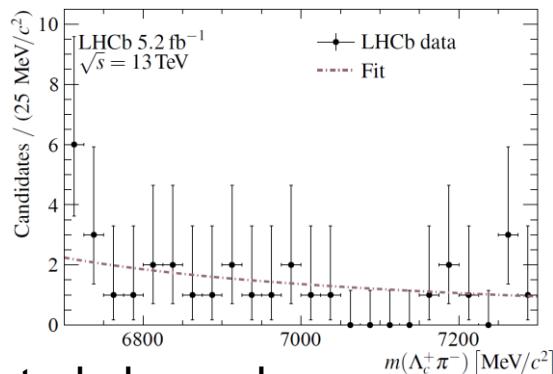
- Examples Feynman diagram



Searching for Ω_{bc}^0 and Ξ_{bc}^0

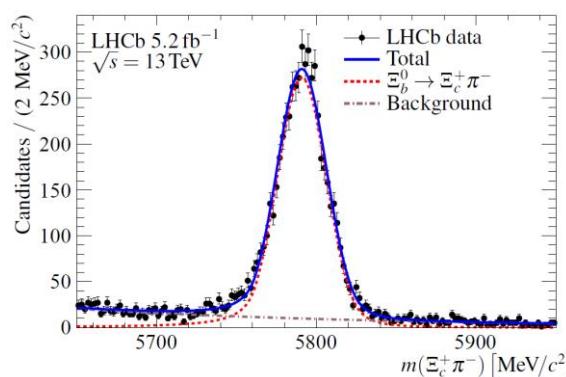
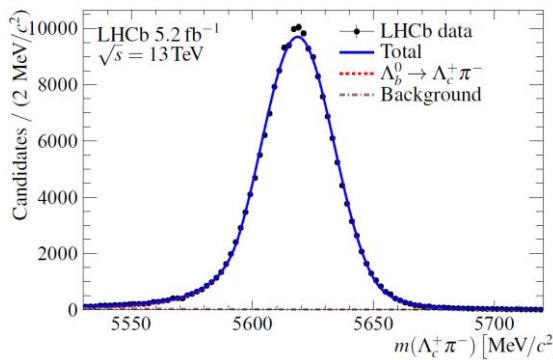
□ Signal channels

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



□ Control channels

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



[LHCb-PAPER-2021-002]

Searching for Ω_{bc}^0 and Ξ_{bc}^0

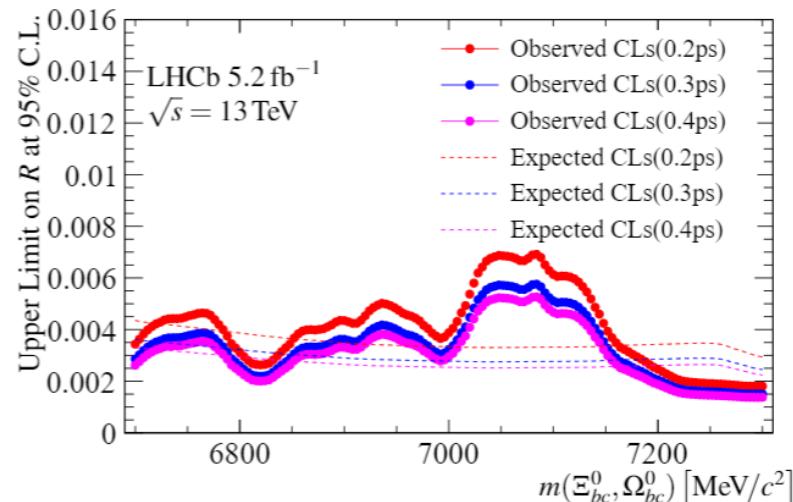
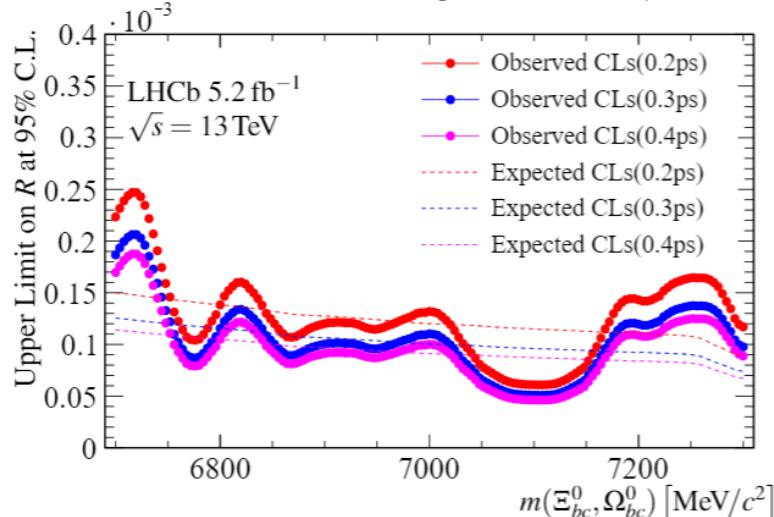
Result

- The first search for the doubly heavy Ω_{bc}^0 baryon
- No Ω_{bc}^0 and Ξ_{bc}^0 signal in run2(2016+2017+2018) data
- Using CLs method to set upper limits on:

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

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

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]

Accepted by Chinese Physics C

Summary

□ World-leading works on beauty-charm hadrons spectroscopy

- Production fraction and asymmetry of B_c^- meson
- Precision mass of B_c^+ meson
- No signal for $\Xi_{bc}^0 \rightarrow D^0 p K^-$ 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

□ With LHCb upgrade ($50\ fb^{-1}$) & upgrade-II ($300\ fb^{-1}$), more exciting results are coming.

- $\Xi_{bc}^+ \rightarrow J/\psi \Xi^+ ?$

Thanks for your attention!