PROCEEDINGS OF SCIENCE

Studies of B_c mesons at LHCb

Jibo He[*†]
University of Chinese Academy of Sciences (UCAS), Beijing, China
E-mail: jibo.he@cern.ch

The B_c meson is formed by two heavy quarks of different flavor, which makes it an interesting laboratory for test of effective theories of the strong interaction with a unique setting for production, decay and spectroscopy studies. This paper presents recent results on the B_c meson from LHCb, including the B_c^+ mass, lifetime and production measurements, search for excited B_c^+ states, observation of the $B_c^+ \to D^0 K^+$ decay, and search for B_c^+ decays to two charm mesons.

ICHEP 2018, XXXIX International Conference on High Energy Physics
4-11 July 2018
COEX, Seoul, Korea

[*]Speaker.
[†]on behalf of the LHCb collaboration.

PoS(ICHEP2018)146

1. Introduction

The B_c meson is formed by two heavy quarks of different flavor, which makes it an interesting laboratory for test of effective theories of the strong interaction with a unique setting for production, decay and spectroscopy studies. The LHCb experiment [1] is one of the four large experiments at the LHC. It has excellent vertexing, tracking and particle identification performance, which makes it an ideal experiment to study the B_c meson. This paper presents recent results on the B_c meson from LHCb, including the B_c^+ mass, lifetime and production measurements, search for excited B_c^+ states, observation of the $B_c^+ \to D^0 K^+$ decay, and search for B_c^+ decays to two charm mesons.

2. B_c^+ mass, lifetime and production measurements

LHCb has performed the most precise measurements of the B_c^+ mass with the $B_c^+ \to J/\psi\pi^+$ [2], $B_c^+ \to J/\psi D_s^+$ [3], $B_c^+ \to J/\psi p\bar{p}\pi^+$ [4], and $B_c^+ \to J/\psi D^0 K^+$ [5] decays. Averaging over all these measurements, the B_c^+ mass is determined to be $6274.6 \pm 1.0\,\text{MeV}/c^2$.

LHCb has measured the B_c^+ lifetime using the $B_c^+ \to J/\psi\mu^+\nu_\mu X$ [6], $B_c^+ \to J/\psi\pi^+$ [7] decays. The B_c^+ lifetime is measured to be $509 \pm 8\,(\text{stat}) \pm 12\,(\text{syst})$ fs and $513 \pm 11\,(\text{stat}) \pm 6\,(\text{syst})$ fs, respectively. These are the most precise measurements to date.

LHCb has performed the first measurement of the double differential production cross-section of the B_c^+ meson as a function of the B_c^+ transverse momentum and rapidity [8]. The B_c^+ production cross-section times branching fraction of $B_c^+ \to J/\psi\pi^+$ relative to that of the $B^+ \to J/\psi K^+$ decay is measured to be, $[\sigma(B_c^+)\cdot\mathcal{B}(B_c^+ \to J/\psi\pi^+)]\,/\,[\sigma(B^+)\cdot\mathcal{B}(B^+ \to J/\psi K^+)] = (0.683 \pm 0.018\,(\text{stat}) \pm 0.009\,(\text{syst}))\%$ in the fiducial region $p_\text{T}(B) < 20$ GeV/c and $2 < y(B) < 4.5$, where $p_\text{T}(B)$ and $y(B)$ are the transverse momenta and rapidity of the B_c^+ and B^+ mesons.

3. Search for excited B_c^+ states

The B_c meson family has a rich spectrum. There are two $B_c(2S)$ states, $B_c(2^1S_0)^+$ and $B_c(2^3S_1)^+$. The $B_c(2^1S_0)^+$ decays to $B_c^+\pi^+\pi^-$, and $B_c(2^3S_1)^+$ decays to $B_c^{*+}(\to B_c^+\gamma)\pi^+\pi^-$. The photon from the B_c^{*+} decay is very soft and is difficult to reconstruct in LHCb. According to studies in Ref. [9], when the photon is missing, the reconstructed $B_c(2^3S_1)^+$ mass is shifted down by the mass difference between the B_c^{*+} and B_c^+ states, and the mass resolution is only slightly degraded. The $B_c(2S)$ states are searched for with $2\,\text{fb}^{-1}$ of proton-proton collision data at 8 TeV taken by the LHCb experiment [10]. There are 3325 ± 73 $B_c^+ \to J/\psi\pi^+$ signal, however, there is no obvious signal peak in the $B_c^+\pi^+\pi^-$ invariant mass distribution, as shown in Fig. 1. Upper limits on the ratios of the production cross-sections of the $B_c(2^1S_0)^+$ and $B_c(2^3S_1)^+$ states times the branching fractions of $B_c(2^1S_0)^+ \to B_c^+\pi^+\pi^-$ and $B_c(2^3S_1)^+ \to B_c^{*+}\pi^+\pi^-$ over the production cross-section of the B_c^+ state are given as a function of their masses. They are found to be between 0.02 and 0.14 at 95% confidence level for $B_c(2^1S_0)^+$ and $B_c(2^3S_1)^+$ in the mass ranges $[6830, 6890]\,\text{MeV}/c^2$ and $[6795, 6890]\,\text{MeV}/c^2$, respectively.

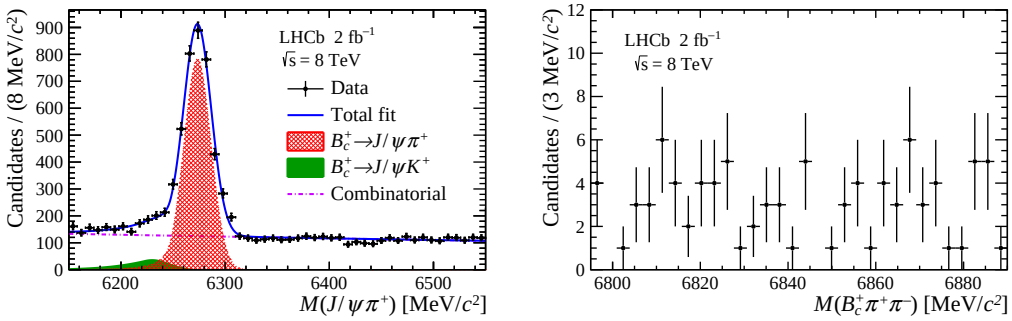

Figure 1: Invariant mass distribution of $J/\psi\pi^+$ with fit projection overlaid (left) and invariant mass distribution of $B_c^+\pi^+\pi^-$ (right) [10].

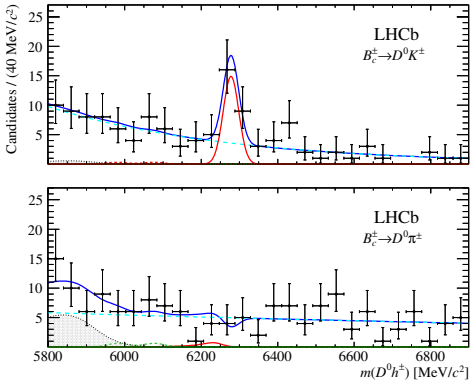

Figure 2: Results of the simultaneous fit to the D^0K^+ (top plot) and $D^0\pi^+$ (bottom plot) invariant mass distributions in the B_c^+ mass region, including the $D^0 \to K^-\pi^+$ and $D^0 \to K^-\pi^+\pi^-\pi^+$ final states [11].

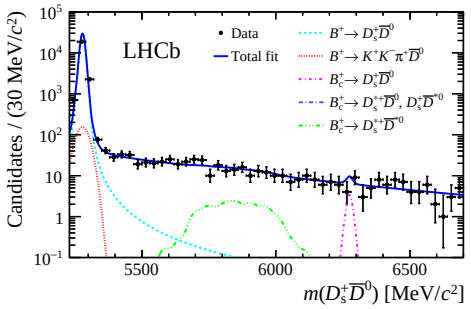

Figure 3: Invariant mass distribution of $D_s^+\overline{D}^0$ with fit projections overlaid [12]. The D_s^+ is reconstructed in the $K^+K^-\pi^+$ final state, and the $\overline{D}^0$ is reconstructed in the $K^+\pi^-$ final state.

4. B_c^+ decays

LHCb has performed a search for $B_c^+ \to D^0\pi^+$ and $B_c^+ \to D^0K^+$ decays [11]. The former is cabibbo-favored in the tree level $b \to u$ transition, while the latter is cabibbo-suppressed in the tree level $b \to u$ transition but can be enhanced in the $b \to su\bar{u}$ penguin decays or weak annihilation $\bar{b}c \to W^+$. Figure 2 shows the D^0K^+ and $D^0\pi^+$ invariant mass distributions in the B_c^+ mass region, including the $D^0 \to K^-\pi^+$ and $D^0 \to K^-\pi^+\pi^-\pi^+$ final states [11], together with the simultaneous fit results. The $B_c^+ \to D^0K^+$ mode is observed with a statistical significance of 5.1σ, while there is no $B_c^+ \to D^0\pi^+$ signal yet, which shows that the $B_c^+ \to D^0K^+$ is not dominated by the tree level $b \to u$ transition, but rather by the $b \to su\bar{u}$ penguin or weak annihilation $\bar{b}c \to W^+$ diagrams. The branching fraction multiplied by the production rates for B_c^+ relative to B^+ mesons in the LHCb acceptance is measured to be $(f_c/f_u)\cdot\mathcal{B}(B_c^+ \to D^0K^+) = (9.3^{+2.8}_{-2.5}\,(\text{stat}) \pm 0.6\,(\text{syst})) \times 10^{-7}$.

A search for decays of B_c^+ to two charm mesons, including $B_c^+ \to D_{(s)}^{(*)+}\overline{D}^{(*)0}, D_{(s)}^{(*)+}D^{(*)0}$, is performed by LHCb [12]. Such decays can be used to measure the CKM-angle γ. Compared to the $B^+ \to \overline{D}^{(*)0}K^-$ decay, which has an amplitude ratio $r(B) \equiv |A(B^+ \to D^0K^+)/A(B^+ \to \overline{D}^0K^+)| \approx 0.1$, the $B_c^+ \to D_s^+\overline{D}^{(*)0}$ decay has a large amplitude ratio $r(B_c^+) \equiv |A(B_c^+ \to D^0D_s^+)/A(B_c^+ \to \overline{D}^0D_s^+)| \approx 1$, resulting in larger CP asymmetry, therefore has better sensitivity to the CKM-angle γ. However,

the B_c^+ production is small, and the B_c^+ lifetime is short. No evidence for a signal is found in the $3\,\text{fb}^{-1}$ of data taken by the LHCb experiment during 2011-2012, and upper limits are set on the branching fractions of these twelve B_c^+ decay modes. Take $B_c^+ \to D_s^+ \bar{D}^0$ as an example, the invariant mass distribution of $D_s^+ \bar{D}^0$ is shown in Fig. 3, and the branching fraction multiplied by the production rates for B_c^+ relative to B^+ mesons in the LHCb acceptance is measured to be $(f_c/f_u) \cdot [\mathcal{B}(B_c^+ \to D_s^+ \bar{D}^0)/\mathcal{B}(B^+ \to D_s^+ \bar{D}^0)] = (3.0 \pm 3.7) \times 10^{-4}$, or the corresponding upper limit is $< 0.9(1.1) \times 10^{-3}$ at 90% (95%) confidence level.

5. Summary

LHCb has done world-leading works on the B_c physics. The most precise measurements of the B_c^+ mass and lifetime have been performed with several B_c^+ decay modes. The first measurement of the double differential production cross-section of the B_c^+ meson as a function of the B_c^+ transverse momentum and rapidity is performed using the $B_c^+ \to J/\psi \pi^+$ decay. The excited B_c^+ states are searched for with the largest B_c^+ (low p_T) sample but there is no obvious signal yet. The $B_c^+ \to D^0 K^+$ is observed for the first time. A first search for the B_c^+ decays to two charm mesons is performed, and no signal is found yet.

References

[1] LHCb collaboration, A. A. Alves *et al.*, *The LHCb Detector at the LHC*, JINST **3** (2008) S08005.

[2] LHCb collaboration, R. Aaij *et al.*, *Measurements of B_c^+ production and mass with the $B_c^+ \to J/\psi \pi^+$ decay*, Phys. Rev. Lett. **109** (2012) 232001, arXiv:1209.5634.

[3] LHCb collaboration, R. Aaij *et al.*, *Observation of $B_c^+ \to J/\psi D_s^+$ and $B_c^+ \to J/\psi D_s^{*+}$ decays*, Phys. Rev. **D87** (2013) 112012, arXiv:1304.4530.

[4] LHCb collaboration, R. Aaij *et al.*, *First observation of a baryonic B_c^+ decay*, Phys. Rev. Lett. **113** (2014) 152003, arXiv:1408.0971.

[5] LHCb collaboration, R. Aaij *et al.*, *Observation of $B_c^+ \to J/\psi D^{(*)} K^{(*)}$ decays*, Phys. Rev. **D95** (2017) 032005, arXiv:1612.07421.

[6] LHCb collaboration, R. Aaij *et al.*, *Measurement of the B_c^+ meson lifetime using $B_c^+ \to J/\psi \mu^+ \nu_\mu X$ decays*, Eur. Phys. J. **C74** (2014) 2839, arXiv:1401.6932.

[7] LHCb collaboration, R. Aaij *et al.*, *Measurement of the lifetime of the B_c^+ meson using the $B_c^+ \to J/\psi \pi^+$ decay mode*, Phys. Lett. **B742** (2015) 29, arXiv:1411.6899.

[8] LHCb collaboration, R. Aaij *et al.*, *Measurement of B_c^+ production in proton-proton collisions at $\sqrt{s} = 8\ TeV$*, Phys. Rev. Lett. **114** (2015) 132001, arXiv:1411.2943.

[9] Y.-N. Gao *et al.*, *Experimental prospects of the B_c studies of the LHCb experiment*, Chin. Phys. Lett. **27** (2010) 061302.

[10] LHCb collaboration, R. Aaij *et al.*, *Search for excited B_c^+ states*, JHEP **01** (2018) 138, arXiv:1712.04094.

[11] LHCb collaboration, R. Aaij *et al.*, *Observation of $B_c^+ \to D^0 K^+$ decays*, Phys. Rev. Lett. **118** (2017) 111803, arXiv:1701.01856.

[12] LHCb collaboration, R. Aaij *et al.*, *Search for B_c^+ decays to two charm mesons*, Nucl. Phys. **B930** (2018) 563, arXiv:1712.04702.