PROCEEDINGS OF SCIENCE

Recent LHCb results in charm spectroscopy

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

LHCb continues to expand its world-leading sample of charmed hadrons collected during LHC's Run 1 and Run 2. With this data set, LHCb is discovering many previously unobserved charmed states and making the most precise determinations of the properties of these states. This paper presents the recent LHCb results in charm spectroscopy, including the observation of five new excited Ω_c^0 states, the study of excited Λ_c^+ states using the $\Lambda_b^0 \to D^0 p \pi^-$ decay, and the observation of the doubly charmed baryon Ξ_{cc}^{++} in its decays to $\Lambda_c^+ K^- \pi^+ \pi^+$ and $\Xi_c^+ \pi^+$.

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)211

1. Introduction

The LHCb detector [1] is a single-arm forward spectrometer dedicated to precision study of beauty and charm hadrons. It has excellent vertexing, tracking and particle-identification performance, which makes it an ideal experiment to study charm spectroscopy. This paper presents the recent LHCb results in charm spectroscopy, including the observation of five new excited Ω_c^0 states, the study of excited Λ_c^+ states using the $\Lambda_b^0 \to D^0 p \pi^-$ decay, and the observation of the doubly charmed baryon Ξ_{cc}^{++} in its decays to $\Lambda_c^+ K^- \pi^+ \pi^+$ and $\Xi_c^+ \pi^+$.

2. Spectroscopy of charmed baryon

The $\Xi_c^+ (\to pK^- \pi^+) K^-$ mass spectrum is studied with LHCb data, and five new and narrow excited Ω_c^0 states are observed [2], as shown in Fig. 1, in which there is also a broad structure around 3188 MeV/c^2 that is fitted as a single resonance now. The results of the fit to $m(\Xi_c^+ K^-)$ for the mass, width, yield and significance of each resonance are summarized in Table 1.

An amplitude analysis of the decay $\Lambda_b^0 \to D^0 p \pi^-$ is performed in the part of the phase space containing resonances in the $D^0 p$ channel, which enable studying the spectrum of excited Λ_c^+ states that decay into $D^0 p$. The projection of $m(D^0 p)$ of the fit to the $\Lambda_b^0 \to D^0 p \pi^-$ data in the $D^0 p$ mass range of 2.8-3 GeV/c^2 is shown in Fig. 2. A near-threshold enhancement in the $D^0 p$ amplitude is found to be consistent with a new resonance, denoted the $\Lambda_c(2860)^+$. The masses, widths and favored quantum numbers of the $\Lambda_c(2860)^+$, $\Lambda_c(2880)^+$ and $\Lambda_c(2940)^+$ are measured, and the results are summarized in Table 2.

3. Doubly charmed baryon

The doubly charmed baryons are composed of two charm quarks and one light quark, and are providing a unique system to test quantum chromodynamics (QCD).

Table 1: Results of the fit to $m(\Xi_c^+ K^-)$ for the mass, width, yield and significance for each resonance [2]. For each fitted parameter, the first uncertainty is statistical and the second systematic. The asymmetric uncertainty on the $\Omega_c(X)^0$ arising from the Ξ_c^+ mass is given separately. Upper limits are also given for the resonances $\Omega_c(3050)^0$ and $\Omega_c(3119)^0$ for which the width is not significant.

Resonance	Mass (MeV/c^2)	Γ (MeV/c^2)	Yield	N_σ
$\Omega_c(3000)^0$	$3000.4 \pm 0.2 \pm 0.1^{+0.3}_{-0.5}$	$4.5 \pm 0.6 \pm 0.3$	$1300 \pm 100 \pm 80$	20.4
$\Omega_c(3050)^0$	$3050.2 \pm 0.1 \pm 0.1^{+0.3}_{-0.5}$	$0.8 \pm 0.2 \pm 0.1$	$970 \pm 60 \pm 20$	20.4
		$< 1.2\,\text{MeV}/c^2, 95\%$ CL		
$\Omega_c(3066)^0$	$3065.6 \pm 0.1 \pm 0.3^{+0.3}_{-0.5}$	$3.5 \pm 0.4 \pm 0.2$	$1740 \pm 100 \pm 50$	23.9
$\Omega_c(3090)^0$	$3090.2 \pm 0.3 \pm 0.5^{+0.3}_{-0.5}$	$8.7 \pm 1.0 \pm 0.8$	$2000 \pm 140 \pm 130$	21.1
$\Omega_c(3119)^0$	$3119.1 \pm 0.3 \pm 0.9^{+0.3}_{-0.5}$	$1.1 \pm 0.8 \pm 0.4$	$480 \pm 70 \pm 30$	10.4
		$< 2.6\,\text{MeV}/c^2, 95\%$ CL		
$\Omega_c(3188)^0$	$3188 \pm 5 \pm 13$	$60 \pm 15 \pm 11$	$1670 \pm 450 \pm 360$	

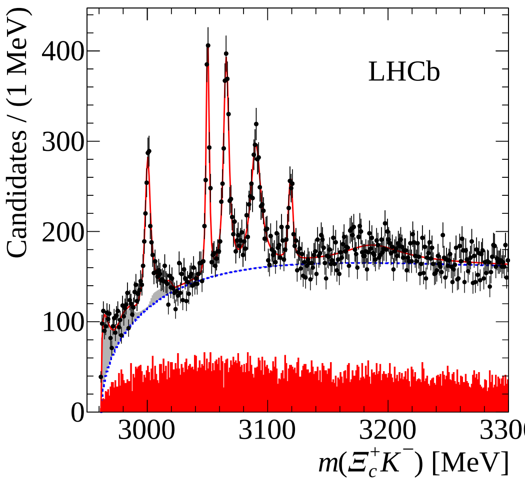

Figure 1: Invariant mass distribution of $\Xi_c^+ K^-$ candidates with fit projections overlaid [2]. The shaded (red) histogram shows the corresponding mass spectrum from the Ξ_c^+ sidebands and the shaded (light gray) distributions indicate the feed-down from partially reconstructed $\Omega_c(X)^0$ resonances.

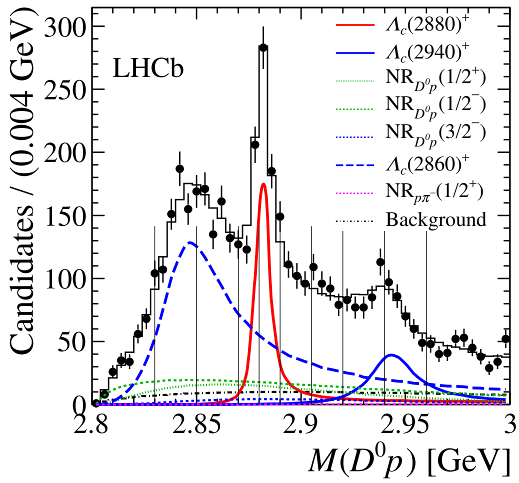

Figure 2: Projection of $m(D^0 p)$ of the fit to the $\Lambda_b^0 \to D^0 p \pi^-$ data in the $D^0 p$ mass range including the $\Lambda_c(2880)^+$ and $\Lambda_c(2940)^+$ resonances [3]. An exponential model is used for the nonresonant partial waves, and the $J^P = 3/2^-$ hypothesis is used for the $\Lambda_c(2940)^+$ state.

Table 2: Results of the mass, width and favored quantum number for each excited Λ_c^+ state [3]. For each fitted parameter, the first uncertainty is statistical, the second systematic, and the third due to the amplitude model.

Resonance	Mass (MeV/c^2)	Γ (MeV/c^2)	J^{PC}
$\Lambda_c(2860)^+$	$2856.1^{+2.0}_{-1.7} \pm 0.5^{+1.1}_{-5.6}$	$67.6^{+10.1}_{-8.1} \pm 1.4^{+5.9}_{-20.0}$	$3/2^+$
$\Lambda_c(2880)^+$	$2881.75 \pm 0.29 \pm 0.07^{+0.14}_{-0.20}$	$5.43^{+0.77}_{-0.71} \pm 0.29^{+0.75}_{-0.00}$	$5/2^+$
$\Lambda_c(2940)^+$	$2944.8^{+3.5}_{-2.5} \pm 0.4^{+0.1}_{-4.6}$	$27.7^{+8.2}_{-6.0} \pm 0.9^{+5.2}_{-10.4}$	$3/2^-$

The doubly charmed baryon Ξ_{cc}^{++} is searched [4] using its decay to $\Lambda_c^+ K^- \pi^+ \pi^+$, which, as pointed out in Ref. [5], has a branching fraction of $\mathcal{O}(10\%)$. A highly significant structure is observed in the $\Lambda_c^+ K^- \pi^+ \pi^+$ invariant mass distribution shown in Fig. 3. The Ξ_{cc}^{++} mass is measured to be $3621.40 \pm 0.72\,(\text{stat}) \pm 0.27\,(\text{syst}) \pm 0.14\,(\Lambda_c^+)$ MeV$/c^2$, and is consistent with theoretical predictions (*e.g.* Ref. [6]). Such peak still remains highly significant ($> 12\sigma$) in a subsample of candidates for which the reconstructed decay time exceeds five times its uncertainty. The Ξ_{cc}^{++} lifetime is measured to be $0.256\,^{+0.024}_{-0.022}\,(\text{stat}) \pm 0.014\,(\text{syst})$ ps [7], and the weakly decay nature of the doubly charmed baryon Ξ_{cc}^{++} is established.

The Ξ_{cc}^{++} baryon is also searched [8] with its decay to $\Xi_c^+ \pi^+$, which has sizable branching fraction [5]. A signal is observed with a local significance of 5.9σ in the vicinity of the previous LHCb observation [4], as shown in Fig. 4. The Ξ_{cc}^{++} mass is measured to be $3620.6 \pm 1.5\,(\text{stat}) \pm 0.4\,(\text{syst}) \pm 0.3\,(\Xi_c^+)$ MeV$/c^2$. Averaging over the two measurements [4, 8], the Ξ_{cc}^{++} mass is determined to be $3621.24 \pm 0.65\,(\text{stat}) \pm 0.31\,(\text{syst})$ MeV$/c^2$. The ratio of the total branching fraction between the $\Xi_{cc}^{++} \to \Xi_c^+ \pi^+$ and $\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^+$ decays is measured to be,

$$\frac{\mathcal{B}(\Xi_{cc}^{++} \to \Xi_c^+ \pi^+)}{\mathcal{B}(\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^+)} \times \frac{\mathcal{B}(\Xi_c^+ \to p K^- \pi^+)}{\mathcal{B}(\Lambda_c^+ \to p K^- \pi^+)} = 0.035 \pm 0.009\,(\text{stat}) \pm 0.003\,(\text{syst}).$$

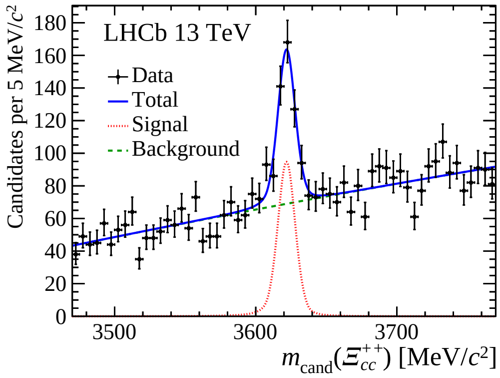

Figure 3: Invariant mass distribution of $\Lambda_c^+ K^- \pi^+ \pi^+$ candidates with fit projections overlaid [4].

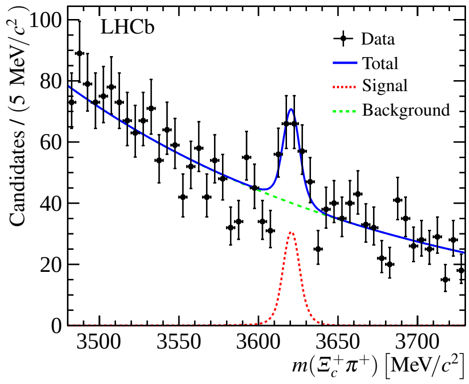

Figure 4: Invariant mass distribution of $\Xi_c^+ \pi^+$ with fit projections overlaid [8].

This is consistent with the prediction of Ref. [5], which, however, has big uncertainties. This measurement provides important information to improve our understanding of the doubly charmed baryon decays.

4. Summary

LHCb has done world-leading works on singly and doubly charmed baryons spectroscopy. Five new excited Ω_c^0 states and one broad structure are observed in the $\Xi_c^+ \pi^+$ mass spectrum, and their masses and widths are measured. In an amplitude analysis of the $\Lambda_b^0 \to D^0 p \pi^-$ decay, a new resonance denoted $\Lambda_c(2860)^+$ is observed, whose mass, width, favored quantum numbers are measured together with those of the $\Lambda_c(2880)^+$ and $\Lambda_c(2940)^+$ states. The doubly charmed baron Ξ_{cc}^{++} is observed in its decays to $\Lambda_c^+ K^- \pi^+ \pi^+$ and $\Xi_c^+ \pi^+$, the Ξ_{cc}^{++} mass and lifetime, and the ratio of the total branching fraction between these two decays are measured.

References

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

[2] LHCb collaboration, R. Aaij *et al.*, *Observation of five new narrow Ω_c^0 states decaying to $\Xi_c^+ K^-$*, Phys. Rev. Lett. **118** (2017) 182001, arXiv:1703.04639.

[3] LHCb collaboration, R. Aaij *et al.*, *Study of the $D^0 p$ amplitude in $\Lambda_b^0 \to D^0 p \pi^-$ decays*, JHEP **05** (2017) 030, arXiv:1701.07873.

[4] LHCb collaboration, R. Aaij *et al.*, *Observation of the doubly charmed baryon Ξ_{cc}^{++}*, Phys. Rev. Lett. **119** (2017) 112001, arXiv:1707.01621.

[5] F.-S. Yu *et al.*, *Discovery potentials of doubly charmed baryons*, Chin. Phys. **C42** (2018) 051001, arXiv:1703.09086.

[6] Z. S. Brown, W. Detmold, S. Meinel, and K. Orginos, *Charmed bottom baryon spectroscopy from lattice QCD*, Phys. Rev. **D90** (2014) 094507, arXiv:1409.0497.

[7] LHCb collaboration, R. Aaij *et al.*, *Measurement of the lifetime of the doubly charmed baryon Ξ_{cc}^{++}*, Phys. Rev. Lett. **121** (2018) 052002, arXiv:1806.02744.

[8] LHCb collaboration, R. Aaij *et al.*, *First observation of the doubly charmed baryon decay $\Xi_{cc}^{++} \to \Xi_c^+ \pi^+$*, Phys. Rev. Lett. **121** (2018) 162002, arXiv:1807.01919.