Editors' Suggestion

Observation of New Ω_c^0 States Decaying to the $\Xi_c^+ K^-$ Final State

R. Aaij *et al.*[*]
(LHCb Collaboration)

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Two new excited states, $\Omega_c(3185)^0$ and $\Omega_c(3327)^0$, are observed in the $\Xi_c^+ K^-$ invariant-mass spectrum using proton-proton collision data collected by the LHCb experiment, corresponding to an integrated luminosity of 9 fb^{-1}. Five previously observed excited Ω_c^0 states are confirmed, namely $\Omega_c(3000)^0$, $\Omega_c(3050)^0$, $\Omega_c(3065)^0$, $\Omega_c(3090)^0$, and $\Omega_c(3119)^0$. The masses and widths of these seven states are measured with the highest precision to date.

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Singly charmed baryons consist of one charm quark and two lighter quarks. Owing to the large mass difference between the charm quark and the lighter quarks, the singly charmed baryon mass spectrum can be described systematically in heavy quark effective theory (HQET) [1]. Many excited states are expected because of the complex interplay of the three-quark system, which makes them an ideal testing ground for theories of the strong force. Studies of charmed baryon spectroscopy have the potential to reveal important insights into the fundamental nature of hadronic matter.

In 2017, the LHCb collaboration reported the observation of five new narrow Ω_c^0 states decaying to the $\Xi_c^+ K^-$ final state [2]. Four of them have been confirmed in e^+e^- collisions by the Belle Collaboration [3] and in the $\Xi_c^+ K^-$ invariant-mass projection of $\Omega_b^- \to \Xi_c^+ K^- \pi^-$ decays by the LHCb Collaboration [4]. The inclusion of charge-conjugate processes is implied throughout this Letter, unless stated otherwise.

The Ω_c^0 states have been studied extensively from the theoretical side. Most theoretical studies interpret these states as excited bound states [5–21]; however, the different schemes for matching their masses and quantum numbers have resulted in conflicting interpretations among different studies. In some studies [22–24], the $\Omega_c(3050)^0$ and $\Omega_c(3090)^0$ states are interpreted as baryon-meson molecular (quasibound) states. Some theoretical studies [25,26] also suggest the presence of three pentaquark states ($sscq\bar{q}$) with masses very close to the $\Omega_c(3065)^0$, $\Omega_c(3090)^0$, and $\Omega_c(3119)^0$ states, which may indicate the presence of a considerable $sscq\bar{q}$ component in these three states. In addition, another $sscq\bar{q}$ state is predicted with a mass of ∼2980 MeV (natural units are used throughout this Letter). The branching fractions of excited Ω_c^0 baryons to final states such as $\Xi_c\pi$, $\Omega_c\eta$, etc., may depend on the internal molecular or pentaquark structure of these baryons, and thus provide a way to elucidate their inner structure. Furthermore, the search for new excited states is also an essential way to experimentally study the charmed baryon spectrum. A lattice QCD calculation [27] presents a rich invariant-mass spectrum; dozens of D- or F-wave excited states were identified, expanding our understanding of the charmed baryon spectrum. Studying the excited states of Ω_c^0 baryons provides a unique opportunity to explore the properties of these intriguing particles, and to examine and verify a variety of theoretical predictions, including phenomenological models, thereby deepening our understanding of fundamental strong interaction effects.

This Letter presents an updated analysis of the $\Xi_c^+ K^-$ invariant-mass spectrum, using proton-proton (pp) collision data collected by the LHCb experiment from 2011 to 2018 at center-of-mass energies of 7, 8, and 13 TeV, corresponding to integrated luminosities of 1, 2, and 6 fb^{-1}, respectively. Grouped by trigger strategy, data recorded in 2011–2015 is referred to as dataset 1, and data collected in 2016–2018 is referred to as dataset 2. The increased charm production cross section at higher center-of-mass energy, the higher integrated luminosity, and the improvement in the trigger system [28,29] result in a 5 times larger sample size compared with the previous analysis [2]. The results presented in this Letter supersede the previous mass and width determinations [2].

The LHCb detector [30,31] is a single-arm forward spectrometer covering the pseudorapidity range $2 < \eta < 5$, designed for the study of particles containing b or c quarks. Simulated data samples are produced with the software packages described in Refs. [32–36] and are used to develop the event selection, estimate the invariant-mass resolution, and model physics processes that may constitute peaking backgrounds in the analysis.

[*]Full author list given at the end of the Letter.

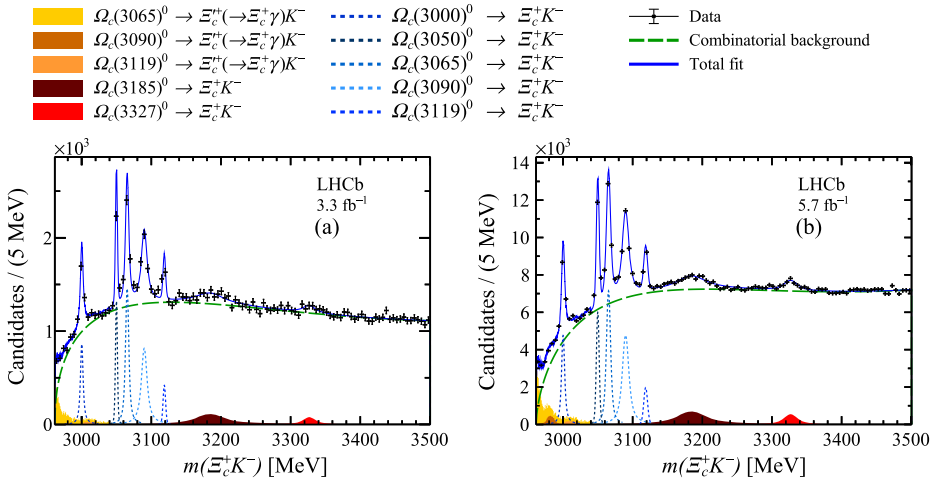

FIG. 1. Invariant-mass distribution of the $\Omega_c(X)^0$ candidates in (a) dataset 1 and (b) dataset 2, with the fit results overlaid. A bin width of 5 MeV is used for plotting. The previously observed excited Ω_c^0 states are shown in blue dashed lines. The $\Omega_c(3185)^0$ state is shown in the brown area, and the $\Omega_c(3327)^0$ state is shown in the red area. Three feed-down components are shown as the yellow areas, while the green long-dashed line corresponds to the combinatorial background.

The $\Xi_c^+(\to pK^-\pi^+)$ candidates are formed with three tracks that do not originate from any primary pp interaction vertex (PV) and have significant transverse momentum (p_T). Particle identification (PID) requirements are applied to all the final-state tracks in order to suppress combinatorial background. Additionally, PID vetoes are applied to suppress background from misidentified charm meson decays. These vetoes are formed by placing requirements on the invariant mass of the candidates recomputed with the relevant change in the particle mass hypothesis. The Ξ_c^+ candidates are required to have a large flight-distance significance from any PV and a small value of $\chi^2_{\rm IP}$, defined as the difference between the vertex fit χ^2 of the PV reconstructed with and without the particle in question. The reconstructed Ξ_c^+ candidates must have an invariant mass in the range of [2450, 2485] MeV, corresponding to about 3 times the invariant-mass resolution around the known Ξ_c^+ mass [37]. Each Ξ_c^+ candidate is combined with a K^- candidate that originates from the same PV and has p_T greater than 0.4 GeV. The $\Xi_c^+K^-$ combinations with good vertex quality and p_T greater than 4.5 GeV are retained as $\Omega_c(X)^0$ candidates, where X is the mass of the excited state.

A multivariate classifier based on a boosted decision tree (BDT) algorithm [38] and implemented in the TMVA [39] toolkit is used to further improve the signal purity. The variables used to train the BDT classifier are the χ^2 value of the Ξ_c^+ decay-vertex fit; the Ξ_c^+ flight distance; the angle between the Ξ_c^+ momentum vector and the line that connects the Ξ_c^+ decay vertex with its PV; the $\chi^2_{\rm IP}$ and p_T of Ξ_c^+ and $\Omega_c(X)^0$ candidates; and the $\chi^2_{\rm IP}$, p_T and particle-identification variables of all final state particles. Owing to the difference in trigger strategies, different BDT classifiers are used for datasets 1 and 2. The BDT classifier is trained with simulated signal decays generated with the 2012 (2016) configuration for dataset 1 (dataset 2), and background candidates taken from the Ξ_c^+ invariant-mass sideband region, defined as [2400, 2440] MeV and [2500, 2540] MeV. The working points are chosen such that the BDT classifier efficiency on the signal is 75%; no fine-tuned optimization is performed to avoid favoring any particular excited state.

To improve the mass resolution, the variable $m(\Xi_c^+K^-)$ is defined as the difference between the invariant mass of the $\Omega_c(X)^0$ and Ξ_c^+ candidates, to which the known Ξ_c^+ mass [37] is added. The $\Xi_c^+K^-$ invariant-mass distribution is shown in Fig. 1, where seven peaking structures are seen. Five of them have been observed in the previous analysis [2], while the $\Omega_c(3185)^0$ and $\Omega_c(3327)^0$ states are observed for the first time. There are no similar structures in the wrong-sign sample ($\Xi_c^+K^+$) or in the spectrum of Ξ_c^+ sideband candidates combined with a kaon.

To determine the masses and widths of these $\Omega_c(X)^0$ states, an extended maximum likelihood fit with bin widths of 1 MeV is performed to the $\Xi_c^+K^-$ invariant-mass distributions, simultaneously to datasets 1 and 2. The $\Omega_c(X)^0$ contributions are described by S-wave relativistic Breit–Wigner functions convolved with a Gaussian resolution function whose width is determined from simulated signal samples. The combinatorial background is parametrized by an empirical function,

$$B(\Delta m) = (\Delta m)^a \times \exp(b_1\Delta m + b_2\Delta m^2), \qquad (1)$$

where Δm is the difference between the invariant mass of the $\Xi_c^+K^-$ candidate and the $\Xi_c^+K^-$ mass threshold, and a, b_1, and b_2 are free parameters. In addition, three feed-down components from partially reconstructed decays of the $\Omega_c(3065)^0$, $\Omega_c(3090)^0$, and $\Omega_c(3119)^0$ resonances are

TABLE I. Fit results of the mass, width, and yield for each state, and for each data set. Uncertainties are statistical only.

Resonance	m (MeV)	Γ (MeV)	Yield (dataset 1)	Yield (dataset 2)
$\Omega_c(3000)^0$	3000.44 ± 0.07	3.83 ± 0.23	1225 ± 83	7533 ± 263
$\Omega_c(3050)^0$	3050.18 ± 0.04	0.67 ± 0.17	1139 ± 65	7379 ± 215
$\Omega_c(3065)^0$	3065.63 ± 0.06	3.79 ± 0.20	2180 ± 99	13046 ± 316
$\Omega_c(3090)^0$	3090.16 ± 0.11	8.48 ± 0.44	2234 ± 136	14434 ± 486
$\Omega_c(3119)^0$	3118.98 ± 0.12	0.60 ± 0.63	470 ± 66	3279 ± 234
$\Omega_c(3185)^0$	3185.1 ± 1.7	50 ± 7	1642 ± 367	10278 ± 1565
$\Omega_c(3327)^0$	3327.1 ± 1.2	20 ± 5	489 ± 173	3649 ± 723

included. These contributions are from $\Omega_c(X)^0 \to \Xi_c'^+(\to \Xi_c^+\gamma)K^-$ decays, where the photon is not reconstructed. Their shapes are determined from simulated samples and are fixed, while their yields are free to vary in the fit.

The fit results are shown in Fig. 1 and summarized in Table I. In addition to the five narrow states at lower invariant mass that were previously observed, two new states with masses of about 3185 MeV and 3327 MeV, denoted $\Omega_c(3185)^0$ and $\Omega_c(3327)^0$ are observed with high significance.

The enhancement around the $\Xi_c^+K^-$ mass threshold is described by the partially reconstructed decays of $\Omega_c(X)^0 \to \Xi_c'^+(\to \Xi_c^+\gamma)K^-$, as was done in the previous analysis [2]. In the exclusive analysis using the $\Omega_b^- \to \Omega_c(X)^0(\to \Xi_c^+K^-)\pi^-$ decay [4], these feed-down components are excluded by requiring an appropriate signal mass window of the Ω_b^- baryon, while the threshold enhancement is still present. This enhancement was modeled as an S-wave Breit-Wigner distribution, but the available data in Ref. [4] are not sufficient to declare an observation. To check if this resonance structure is present in this analysis, the enhancement is fitted using two alternative models: a Breit-Wigner component with and without the feed down coming from the $\Omega_c(3065)^0$ contribution. The yield of the $\Omega_c(3065)^0$ feed down is constrained to be 10% of the $\Omega_c(3065)^0$ signal yield for the former. This constraint is equivalent to fixing the ratio $\mathcal{B}[\Omega_c(3065)^0 \to \Xi_c'^+K^-] \times \mathcal{B}(\Xi_c'^+ \to \Xi_c^+\gamma)/\mathcal{B}[\Omega_c(3065)^0 \to \Xi_c^+K^-]$ to 0.1, which is chosen due to the small phase space of the $\Omega_c(3065)^0 \to \Xi_c'^+K^-$ decay. The yields of the other feed-down contributions are free to float. Unfortunately, the shape of the $\Omega_c(3065)^0$ feed down and the additional Breit-Wigner structure are too similar to be separated in this analysis. The relative contributions from these two components cannot be determined from data, and hence this is accounted for as a systematic uncertainty. The existence of another hidden state cannot be excluded.

The mass difference between the $\Omega_c(3185)^0$ and $\Omega_c(3327)^0$ baryons is approximately the mass of the pion. It is possible that partially reconstructed candidates from the $\Omega_c(3327)^0$ decay fall into the $\Omega_c(3185)^0$ region, such as $\Omega_c(3327)^0 \to \Xi_c(2645)^+(\to \Xi_c^+\pi^0)K^-$ and $\Omega_c(3327)^0 \to \Xi_c'^+(\to \Xi_c^+\gamma)K^-$ decays with the π^0 or γ not reconstructed. The $m(\Xi_c^+K^-)$ line shapes of such contributions are obtained using the fast simulation toolkit RapidSim [40]. The feed-down contributions have been studied under different spin structure hypotheses, and differences from phase-space simulation were found to be negligible. The fit favors the presence of the $\Omega_c(3327)^0$ feed down with the π^0 missing. The $\Omega_c(3327)^0$ feed down strongly affects the measured mass and width of the $\Omega_c(3185)^0$ baryon, and is assigned as a systematic uncertainty. None of the models for the $\Omega_c(3185)^0$ region can be ruled out. In addition, the effects of the three-body decay $\Omega_c(3327)^0 \to \Xi_c^+K^-\pi^0$ are checked with a uniform phase-space model, and found to be insignificant on any of the states when assuming the ratio $\mathcal{B}[\Omega_c(3327)^0 \to \Xi_c^+K^-\pi^0]/\mathcal{B}[\Omega_c(3327)^0 \to \Xi_c^+K^-]$ to be unity.

The effects of the $\Xi_c(3055)^0 \to \Xi_c'^+(\to \Xi_c^+\gamma)\pi^-$, $\Xi_c(3055)^0 \to \Xi_c(2645)^+(\to \Xi_c^+\pi^0)\pi^-$, and $\Xi_c(2923/2939/2965)^0 \to \Xi_c^+\pi^-$ decays, for which the pion is misidentified as a kaon and the π^0/γ from the $\Xi_c(2645)^+/\Xi_c'^+$ decays is missing, are studied and found to be negligible. The contribution from $\Omega_c(3327)^0 \to \Xi_c^+K^{*-}$ is kinematically suppressed.

Several checks are performed to confirm the existence of the observed states and the stability of the fitted parameters. Each dataset is divided into subsamples according to data-taking conditions, charge combination ($\Xi_c^+K^-$ or $\Xi_c^-K^+$), or different intervals of $p_T(K^-)$ and $p_T(\Xi_c^+)$. In all tests, the results are consistent with the default fit. A two-peak structure also describes the data well in the mass region around 3185 MeV; hence, the presence of two states in this region cannot be excluded. The bias from the fit model itself is estimated using pseudoexperiments. For each parameter, the mean differences between the fitted values and the input ones are included as systematic uncertainties.

The uncertainty related to the signal model is estimated by fitting the data with variations in the spin hypotheses and the Blatt-Weisskopf factor [41]. The systematic uncertainty from the combinatorial background model is estimated by using a fourth-order Chebyshev polynomial as an

TABLE II. Systematic uncertainties on the measured masses and natural widths.

Source (MeV, MeV)	$\Omega_c(3000)^0$ $[m, \Gamma]$	$\Omega_c(3050)^0$ $[m, \Gamma]$	$\Omega_c(3065)^0$ $[m, \Gamma]$	$\Omega_c(3090)^0$ $[m, \Gamma]$	$\Omega_c(3119)^0$ $[m, \Gamma]$	$\Omega_c(3185)^0$ $[m, \Gamma]$	$\Omega_c(3327)^0$ $[m, \Gamma]$
Threshold structure	$[^{+0.01}_{-0.07}, ^{+1.23}_{-0.19}]$	$[^{+0.00}_{-0.01}, ^{+0.00}_{-0.17}]$	$[^{+0.01}_{-0.00}, ^{+0.00}_{-0.11}]$	$[^{+0.01}_{-0.00}, ^{+0.12}_{-0.20}]$	$[^{+0.06}_{-0.00}, ^{+0.00}_{-0.16}]$	$[^{+0.32}_{-0.57}, ^{+8.05}_{-0.83}]$	$[^{+0.01}_{-0.15}, ^{+1.71}_{-0.04}]$
Feed down from $\Omega_c^0(3327)$	$[^{+0.04}_{-0.00}, ^{+0.04}_{-0.00}]$	$[^{+0.00}_{-0.00}, ^{+0.00}_{-0.01}]$	$[^{+0.01}_{-0.00}, ^{+0.03}_{-0.00}]$	$[^{+0.01}_{-0.00}, ^{+0.22}_{-0.00}]$	$[^{+0.01}_{-0.00}, ^{+0.07}_{-0.00}]$	$[^{+4.28}_{-0.00}, ^{+0.00}_{-10.81}]$	$[^{+0.00}_{-0.20}, ^{+0.98}_{-0.00}]$
Fit bias	$[^{+0.02}_{-0.00}, ^{+0.01}_{-0.00}]$	$[^{+0.02}_{-0.00}, ^{+0.12}_{-0.00}]$	$[^{+0.00}_{-0.00}, ^{+0.08}_{-0.00}]$	$[^{+0.01}_{-0.00}, ^{+0.20}_{-0.00}]$	$[^{+0.00}_{-0.02}, ^{+0.40}_{-0.00}]$	$[^{+0.00}_{-0.37}, ^{+4.84}_{-0.00}]$	$[^{+0.00}_{-0.18}, ^{+0.00}_{-0.70}]$
Spin and radius	$[^{+0.01}_{-0.01}, ^{+0.01}_{-0.01}]$	$[^{+0.01}_{-0.01}, ^{+0.01}_{-0.01}]$	$[^{+0.01}_{-0.01}, ^{+0.02}_{-0.01}]$	$[^{+0.01}_{-0.01}, ^{+0.05}_{-0.01}]$	$[^{+0.01}_{-0.01}, ^{+0.06}_{-0.01}]$	$[^{+0.01}_{-0.18}, ^{+0.56}_{-0.01}]$	$[^{+0.01}_{-0.02}, ^{+0.01}_{-0.60}]$
Background	$[^{+0.04}_{-0.00}, ^{+0.98}_{-0.00}]$	$[^{+0.00}_{-0.01}, ^{+0.00}_{-0.18}]$	$[^{+0.00}_{-0.00}, ^{+0.00}_{-0.29}]$	$[^{+0.00}_{-0.06}, ^{+0.00}_{-1.58}]$	$[^{+0.00}_{-0.21}, ^{+0.00}_{-0.60}]$	$[^{+5.98}_{-0.00}, ^{+0.00}_{-16.2}]$	$[^{+0.00}_{-1.24}, ^{+12.9}_{-0.00}]$
Bin size	$[^{+0.00}_{-0.10}, ^{+0.06}_{-0.04}]$	$[^{+0.00}_{-0.01}, ^{+0.40}_{-0.03}]$	$[^{+0.02}_{-0.03}, ^{+0.08}_{-0.07}]$	$[^{+0.01}_{-0.05}, ^{+0.37}_{-0.09}]$	$[^{+0.00}_{-0.06}, ^{+0.00}_{-0.60}]$	$[^{+0.14}_{-0.48}, ^{+2.75}_{-0.50}]$	$[^{+0.07}_{-0.00}, ^{+1.16}_{-0.00}]$
Momentum calibration	$[\pm 0.01, \ldots]$	$[\pm 0.03, \ldots]$	$[\pm 0.03, \ldots]$	$[\pm 0.04, \ldots]$	$[\pm 0.05, \ldots]$	$[\pm 0.07, \ldots]$	$[\pm 0.11, \ldots]$
Energy loss	$[\pm 0.04, \ldots]$	$[\pm 0.04, \ldots]$	$[\pm 0.04, \ldots]$	$[\pm 0.04, \ldots]$	$[\pm 0.04, \ldots]$	$[\pm 0.04, \ldots]$	$[\pm 0.04, \ldots]$
Simulation/Data difference	$[^{+0.00}_{-0.01}, ^{+0.20}_{-0.22}]$	$[^{+0.01}_{-0.04}, ^{+0.48}_{-0.67}]$	$[^{+0.01}_{-0.00}, ^{+0.36}_{-0.35}]$	$[^{+0.00}_{-0.02}, ^{+0.36}_{-0.29}]$	$[^{+0.03}_{-0.00}, ^{+0.80}_{-0.59}]$	$[^{+0.08}_{-0.34}, ^{+2.58}_{-0.67}]$	$[^{+0.02}_{-0.05}, ^{+0.27}_{-0.28}]$
Total	$[^{+0.07}_{-0.13}, ^{+1.59}_{-0.29}]$	$[^{+0.06}_{-0.07}, ^{+0.64}_{-0.72}]$	$[^{+0.06}_{-0.06}, ^{+0.38}_{-0.47}]$	$[^{+0.06}_{-0.10}, ^{+0.61}_{-1.62}]$	$[^{+0.09}_{-0.23}, ^{+0.90}_{-1.05}]$	$[^{+7.36}_{-0.92}, ^{+10.1}_{-19.5}]$	$[^{+0.14}_{-1.28}, ^{+13.1}_{-0.96}]$

alternative function. In addition, a systematic uncertainty is assigned based on the spread of results obtained by performing the fit with different bin widths.

Some sources of systematic uncertainty only contribute to the mass measurement, including the momentum calibration for charged particles, which has a relative accuracy of 0.03% [42,43], and the energy loss due to the imperfect modeling of the detector material, which results in a 0.04 MeV uncertainty. The differences between simulation and data mainly affect the measurement of the natural width of each state. It is calculated by varying the width of the resolution function by 10% [44]. Other assumptions for the $\Omega_c(3185)^0$ structure, such as the two-peak structure, additional feed-down components, or a combination of the two-peak structure and one more feed-down assumption cannot be excluded, and are included in the systematic uncertainties.

The systematic uncertainties are summarized in Table II. After considering the systematic uncertainty, the significance of the $\Omega_c(3185)^0$ and $\Omega_c(3327)^0$ states is larger than 12σ and 10σ, respectively. The significance for each state is determined from Wilk's theorem using the difference in log-likelihood with and without that signal component. The results of the measured mass and natural width of all seven states, shown in Table III, are the most precise to date, and supersede those in Ref. [2]. The correlations between these results and those in Ref. [4] are negligible, except for the systematic uncertainty due to the momentum calibration and energy loss, which are fully correlated. The natural widths of the $\Omega_c(3050)^0$ and $\Omega_c(3119)^0$ baryons are very close to zero; therefore upper limits on them are set at Bayesian 95% confidence level (CL), assuming Gaussian behavior for both statistical and systematic uncertainties.

TABLE III. Measured mass and natural width for each of the seven $\Omega_c(X)^0$ states. The first uncertainty is statistical, and the second is systematic; the third (mass only) arises from the uncertainty of the known Ξ_c^+ mass.

Resonance	m (MeV)	Γ (MeV)
$\Omega_c(3000)^0$	$3000.44 \pm 0.07^{+0.07}_{-0.13} \pm 0.23$	$3.83 \pm 0.23^{+1.59}_{-0.29}$
$\Omega_c(3050)^0$	$3050.18 \pm 0.04^{+0.06}_{-0.07} \pm 0.23$	$0.67 \pm 0.17^{+0.64}_{-0.72}$
		< 1.8 MeV, 95% CL
$\Omega_c(3065)^0$	$3065.63 \pm 0.06^{+0.06}_{-0.06} \pm 0.23$	$3.79 \pm 0.20^{+0.38}_{-0.47}$
$\Omega_c(3090)^0$	$3090.16 \pm 0.11^{+0.06}_{-0.10} \pm 0.23$	$8.48 \pm 0.44^{+0.61}_{-1.62}$
$\Omega_c(3119)^0$	$3118.98 \pm 0.12^{+0.09}_{-0.23} \pm 0.23$	$0.60 \pm 0.63^{+0.90}_{-1.05}$
		< 2.5 MeV, 95% CL
$\Omega_c(3185)^0$	$3185.1 \pm 1.7^{+7.4}_{-0.9} \pm 0.2$	$50 \pm 7^{+10}_{-20}$
$\Omega_c(3327)^0$	$3327.1 \pm 1.2^{+0.1}_{-1.3} \pm 0.2$	$20 \pm 5^{+13}_{-1}$

In conclusion, the $\Xi_c^+ K^-$ invariant-mass spectrum is investigated using pp collision data collected by the LHCb experiment. With a total integrated luminosity of 9 fb^{-1}, we were able to select a high-purity sample of Ξ_c^+ candidates and observe seven excited states, including two that had never been seen before: the $\Omega_c(3185)^0$ and $\Omega_c(3327)^0$ states, and also the $\Omega_c(3119)^0$ state that is not seen in the exclusive analysis using the $\Omega_b^- \to \Omega_c(X)^0(\to \Xi_c^+ K^-)\pi^-$ decay [4]. The $\Omega_c(3185)^0$ and $\Omega_c(3327)^0$ states have masses close to the threshold of the ΞD and ΞD^* final states. Referring to the lattice QCD result of Ref. [27], the $\Omega_c(3185)^0$ mass is in the predicted range for P-wave states, and the $\Omega_c(3327)^0$ mass is in the range for many possible states. While the quantum numbers of these states remain to be determined, their observations provide new information on the complex hadron spectroscopy in order to develop a deeper understanding of the strong interaction and its underlying principles.

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Mcconnell,[18] T. H. McGrath,[56] N. T. McHugh,[53] A. McNab,[56] R. McNulty,[18] B. Meadows,[59] G. Meier,[15] D. Melnychuk,[36] S. Meloni,[26,f] M. Merk,[32,74] A. Merli,[25,m] L. Meyer Garcia,[2] D. Miao,[4,6] M. Mikhasenko,[70,t] D. A. Milanes,[69] E. Millard,[50] M. Milovanovic,[42] M.-N. Minard,[8,a] A. Minotti,[26,f] T. Miralles,[9] S. E. Mitchell,[52] B. Mitreska,[15] D. S. Mitzel,[15] A. Modak,[51] A. Mödden,[15] R. A. Mohammed,[57] R. D. Moise,[14] S. Mokhnenko,[38] T. Mombächer,[40] M. Monk,[50,63] I. A. Monroy,[69] S. Monteil,[9] G. Morello,[23] M. J. Morello,[29,d] M. P. Morgenthaler,[17] J. Moron,[34] A. B. Morris,[42] A. G. Morris,[50] R. Mountain,[62] H. Mu,[3] E. Muhammad,[50] F. Muheim,[52] M. Mulder,[73] K. Müller,[44] C. H. Murphy,[57] D. Murray,[56] R. Murta,[55] P. Muzzetto,[27,k] P. Naik,[48] T. Nakada,[43] R. Nandakumar,[51] T. Nanut,[42] I. Nasteva,[2] M. Needham,[52] N. Neri,[25,m] S. Neubert,[70] N. Neufeld,[42] P. Neustroev,[38] R. Newcombe,[55] J. Nicolini,[15,11] D. Nicotra,[74] E. M. Niel,[43] S. Nieswand,[14] N. Nikitin,[38] N. S. Nolte,[58] C. Normand,[8,27,k] J. Novoa Fernandez,[40] G. N Nowak,[59] C. Nunez,[78] A. Oblakowska-Mucha,[34] V. Obraztsov,[38] T. Oeser,[14] S. Okamura,[21,e] R. Oldeman,[27,k] F. Oliva,[52] C. J. G. Onderwater,[73] R. H. O'Neil,[52] J. M. Otalora Goicochea,[2] T. Ovsiannikova,[38] P. Owen,[44] A. Oyanguren,[41] O. Ozcelik,[52] K. O. Padeken,[70] B. Pagare,[50] P. R. Pais,[42] T. Pajero,[57] A. Palano,[19] M. Palutan,[23] G. Panshin,[38] L. Paolucci,[50] A. Papanestis,[51] M. Pappagallo,[19,j] L. L. Pappalardo,[21,e] C. Pappenheimer,[59] W. Parker,[60] C. Parkes,[56] B. Passalacqua,[21,e] G. Passaleva,[22] A. Pastore,[19] M. Patel,[55] C. Patrignani,[20,g] C. J. Pawley,[74] A. Pellegrino,[32] M. Pepe Altarelli,[42] S. Perazzini,[20] D. Pereima,[38] A. Pereiro Castro,[40] P. Perret,[9] K. Petridis,[48] A. Petrolini,[24,h] S. Petrucci,[52] M. Petruzzo,[25] H. Pham,[62] A. Philippov,[38] R. Piandani,[6] L. Pica,[29,d] M. Piccini,[72] B. Pietrzyk,[8] G. Pietrzyk,[11] M. Pili,[57] D. Pinci,[30] F. Pisani,[42] M. Pizzichemi,[26,42,f] V. Placinta,[37] J. Plews,[47] M. Plo Casasus,[40] F. Polci,[13,42] M. Poli Lener,[23] A. Poluektov,[10] N. Polukhina,[38] I. Polyakov,[42] E. Polycarpo,[2] S. Ponce,[42] D. Popov,[6,42] S. Poslavskii,[38] K. Prasanth,[35] L. Promberger,[17] C. Prouve,[40] V. Pugatch,[46] V. Puill,[11] G. Punzi,[29,q] H. R. Qi,[3] W. Qian,[6] N. Qin,[3] S. Qu,[3] R. Quagliani,[43] N. V. Raab,[18] B. Rachwal,[34] J. H. Rademacker,[48] R. Rajagopalan,[62] M. Rama,[29] M. Ramos Pernas,[50] M. S. Rangel,[2] F. Ratnikov,[38] G. Raven,[33] M. Rebollo De Miguel,[41] F. Redi,[42] J. Reich,[48] F. Reiss,[56] C. Remon Alepuz,[41] Z. Ren,[3] P. K. Resmi,[57] R. Ribatti,[29,d] A. M. Ricci,[27] S. Ricciardi,[51] K. Richardson,[58] M. Richardson-Slipper,[52] K. Rinnert,[54] P. Robbe,[11] G. Robertson,[52] E. Rodrigues,[54,42] E. Rodriguez Fernandez,[40] J. A. Rodriguez Lopez,[69] E. Rodriguez Rodriguez,[40] D. L. Rolf,[42] A. Rollings,[57] P. Roloff,[42] V. Romanovskiy,[38] M. Romero Lamas,[40] A. Romero Vidal,[40] J. D. Roth,[78,a] M. Rotondo,[23] M. S. Rudolph,[62] T. Ruf,[42] R. A. Ruiz Fernandez,[40] J. Ruiz Vidal,[41] A. Ryzhikov,[38] J. Ryzka,[34] J. J. Saborido Silva,[40] N. Sagidova,[38] N. Sahoo,[47] B. Saitta,[27,k] M. Salomoni,[42] C. Sanchez Gras,[32] I. Sanderswood,[41] R. Santacesaria,[30] C. Santamarina Rios,[40] M. Santimaria,[23] E. Santovetti,[31,b] D. Saranin,[38] G. Sarpis,[14] M. Sarpis,[70] A. Sarti,[30] C. Satriano,[30,u] A. Satta,[31] M. Saur,[15] D. Savrina,[38] H. Sazak,[9] L. G. Scantlebury Smead,[57] A. Scarabotto,[13] S. Schael,[14] S. Scherl,[54] M. Schiller,[53] H. Schindler,[42] M. Schmelling,[16] B. Schmidt,[42] S. Schmitt,[14] O. Schneider,[43] A. Schopper,[42] M. Schubiger,[32] S. Schulte,[43] M. H. Schune,[11] R. Schwemmer,[42] B. Sciascia,[23] A. Sciuccati,[42] S. Sellam,[40] A. Semennikov,[38] M. Senghi Soares,[33] A. Sergi,[24,h] N. Serra,[44] L. Sestini,[28] A. Seuthe,[15] Y. Shang,[5] D. M. Shangase,[78] M. Shapkin,[38] I. Shchemerov,[38] L. Shchutska,[43] T. Shears,[54] L. Shekhtman,[38] Z. Shen,[5] S. Sheng,[4,6] V. Shevchenko,[38] B. Shi,[6] E. B. Shields,[26,f] Y. Shimizu,[11] E. Shmanin,[38] R. Shorkin,[38] J. D. Shupperd,[62] B. G. Siddi,[21,e] R. Silva Coutinho,[62] G. Simi,[28] S. Simone,[19,j] M. Singla,[63] N. Skidmore,[56] R. Skuza,[17] T. Skwarnicki,[62] M. W. Slater,[47] J. C. Smallwood,[57] J. G. Smeaton,[49] E. Smith,[44] K. Smith,[61] M. Smith,[55] A. Snoch,[32] L. Soares Lavra,[9] M. D. Sokoloff,[59] F. J. P. Soler,[53] A. Solomin,[38,48] A. Solovev,[38] I. Solovyev,[38] R. Song,[63] F. L. Souza De Almeida,[2] B. Souza De Paula,[2] B. Spaan,[15,a] E. Spadaro Norella,[25,m] E. Spedicato,[20]

E. Spiridenkov,[38] P. Spradlin,[53] V. Sriskaran,[42] F. Stagni,[42] M. Stahl,[42] S. Stahl,[42] S. Stanislaus,[57] E. N. Stein,[42] O. Steinkamp,[44] O. Stenyakin,[38] H. Stevens,[15] D. Strekalina,[38] Y. S Su,[6] F. Suljik,[57] J. Sun,[27] L. Sun,[68] Y. Sun,[60] P. N. Swallow,[47] K. Swientek,[34] A. Szabelski,[36] T. Szumlak,[34] M. Szymanski,[42] Y. Tan,[3] S. Taneja,[56] M. D. Tat,[57] A. Terentev,[44] F. Teubert,[42] E. Thomas,[42] D. J. D. Thompson,[47] K. A. Thomson,[54] H. Tilquin,[55] V. Tisserand,[9] S. T'Jampens,[8] M. Tobin,[4] L. Tomassetti,[21,e] G. Tonani,[25,m] X. Tong,[5] D. Torres Machado,[1] D. Y. Tou,[3] C. Trippl,[43] G. Tuci,[6] N. Tuning,[32] A. Ukleja,[36] D. J. Unverzagt,[17] A. Usachov,[33] A. Ustyuzhanin,[38] U. Uwer,[17] A. Vagner,[38] V. Vagnoni,[20] A. Valassi,[42] G. Valenti,[20] N. Valls Canudas,[76] M. Van Dijk,[43] H. Van Hecke,[61] E. van Herwijnen,[55] C. B. Van Hulse,[40,v] M. van Veghel,[32] R. Vazquez Gomez,[39] P. Vazquez Regueiro,[40] C. Vázquez Sierra,[42] S. Vecchi,[21] J. J. Velthuis,[48] M. Veltri,[22,w] A. Venkateswaran,[43] M. Veronesi,[32] M. Vesterinen,[50] D. Vieira,[59] M. Vieites Diaz,[43] X. Vilasis-Cardona,[76] E. Vilella Figueras,[54] A. Villa,[20] P. Vincent,[13] F. C. Volle,[11] D. vom Bruch,[10] A. Vorobyev,[38] V. Vorobyev,[38] N. Voropaev,[38] K. Vos,[74] C. Vrahas,[52] J. Walsh,[29] E. J. Walton,[63] G. Wan,[5] C. Wang,[17] G. Wang,[7] J. Wang,[5] J. Wang,[4] J. Wang,[3] J. Wang,[68] M. Wang,[25] R. Wang,[48] X. Wang,[66] Y. Wang,[7] Z. Wang,[44] Z. Wang,[3] Z. Wang,[6] J. A. Ward,[50,63] N. K. Watson,[47] D. Websdale,[55] Y. Wei,[5] B. D. C. Westhenry,[48] D. J. White,[56] M. Whitehead,[53] A. R. Wiederhold,[50] D. Wiedner,[15] G. Wilkinson,[57] M. K. Wilkinson,[59] I. Williams,[49] M. Williams,[58] M. R. J. Williams,[52] R. Williams,[49] F. F. Wilson,[51] W. Wislicki,[36] M. Witek,[35] L. Witola,[17] C. P. Wong,[61] G. Wormser,[11] S. A. Wotton,[49] H. Wu,[62] J. Wu,[7] K. Wyllie,[42] Z. Xiang,[6] Y. Xie,[7] A. Xu,[5] J. Xu,[6] L. Xu,[3] L. Xu,[3] M. Xu,[50] Q. Xu,[6] Z. Xu,[9] Z. Xu,[6] D. Yang,[3] S. Yang,[6] X. Yang,[5] Y. Yang,[6] Z. Yang,[5] Z. Yang,[60] L. E. Yeomans,[54] V. Yeroshenko,[11] H. Yeung,[56] H. Yin,[7] J. Yu,[65] X. Yuan,[62] E. Zaffaroni,[43] M. Zavertyaev,[16] M. Zdybal,[35] M. Zeng,[3] C. Zhang,[5] D. Zhang,[7] L. Zhang,[3] S. Zhang,[65] S. Zhang,[5] Y. Zhang,[5] Y. Zhang,[57] Y. Zhao,[17] A. Zharkova,[38] A. Zhelezov,[17] Y. Zheng,[6] T. Zhou,[5] X. Zhou,[7] Y. Zhou,[6] V. Zhovkovska,[11] X. Zhu,[3] X. Zhu,[7] Z. Zhu,[6] V. Zhukov,[14,38] Q. Zou,[4,6] S. Zucchelli,[20,g] D. Zuliani,[28] and G. Zunica[56]

(LHCb Collaboration)

[1]*Centro Brasileiro de Pesquisas Físicas (CBPF), Rio de Janeiro, Brazil*
[2]*Universidade Federal do Rio de Janeiro (UFRJ), Rio de Janeiro, Brazil*
[3]*Center for High Energy Physics, Tsinghua University, Beijing, China*
[4]*Institute Of High Energy Physics (IHEP), Beijing, China*
[5]*School of Physics State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing, China*
[6]*University of Chinese Academy of Sciences, Beijing, China*
[7]*Institute of Particle Physics, Central China Normal University, Wuhan, Hubei, China*
[8]*Université Savoie Mont Blanc, CNRS, IN2P3-LAPP, Annecy, France*
[9]*Université Clermont Auvergne, CNRS/IN2P3, LPC, Clermont-Ferrand, France*
[10]*Aix Marseille Univ, CNRS/IN2P3, CPPM, Marseille, France*
[11]*Université Paris-Saclay, CNRS/IN2P3, IJCLab, Orsay, France*
[12]*Laboratoire Leprince-Ringuet, CNRS/IN2P3, Ecole Polytechnique, Institut Polytechnique de Paris, Palaiseau, France*
[13]*LPNHE, Sorbonne Université, Paris Diderot Sorbonne Paris Cité, CNRS/IN2P3, Paris, France*
[14]*I. Physikalisches Institut, RWTH Aachen University, Aachen, Germany*
[15]*Fakultät Physik, Technische Universität Dortmund, Dortmund, Germany*
[16]*Max-Planck-Institut für Kernphysik (MPIK), Heidelberg, Germany*
[17]*Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Heidelberg, Germany*
[18]*School of Physics, University College Dublin, Dublin, Ireland*
[19]*INFN Sezione di Bari, Bari, Italy*
[20]*INFN Sezione di Bologna, Bologna, Italy*
[21]*INFN Sezione di Ferrara, Ferrara, Italy*
[22]*INFN Sezione di Firenze, Firenze, Italy*
[23]*INFN Laboratori Nazionali di Frascati, Frascati, Italy*
[24]*INFN Sezione di Genova, Genova, Italy*
[25]*INFN Sezione di Milano, Milano, Italy*
[26]*INFN Sezione di Milano-Bicocca, Milano, Italy*
[27]*INFN Sezione di Cagliari, Monserrato, Italy*

[28]Università degli Studi di Padova, Università e INFN, Padova, Padova, Italy
[29]INFN Sezione di Pisa, Pisa, Italy
[30]INFN Sezione di Roma La Sapienza, Roma, Italy
[31]INFN Sezione di Roma Tor Vergata, Roma, Italy
[32]Nikhef National Institute for Subatomic Physics, Amsterdam, Netherlands
[33]Nikhef National Institute for Subatomic Physics and VU University Amsterdam, Amsterdam, Netherlands
[34]AGH - University of Science and Technology, Faculty of Physics and Applied Computer Science, Kraków, Poland
[35]Henryk Niewodniczanski Institute of Nuclear Physics Polish Academy of Sciences, Kraków, Poland
[36]National Center for Nuclear Research (NCBJ), Warsaw, Poland
[37]Horia Hulubei National Institute of Physics and Nuclear Engineering, Bucharest-Magurele, Romania
[38]Affiliated with an institute covered by a cooperation agreement with CERN
[39]ICCUB, Universitat de Barcelona, Barcelona, Spain
[40]Instituto Galego de Física de Altas Enerxías (IGFAE), Universidade de Santiago de Compostela, Santiago de Compostela, Spain
[41]Instituto de Fisica Corpuscular, Centro Mixto Universidad de Valencia - CSIC, Valencia, Spain
[42]European Organization for Nuclear Research (CERN), Geneva, Switzerland
[43]Institute of Physics, Ecole Polytechnique Fédérale de Lausanne (EPFL), Lausanne, Switzerland
[44]Physik-Institut, Universität Zürich, Zürich, Switzerland
[45]NSC Kharkiv Institute of Physics and Technology (NSC KIPT), Kharkiv, Ukraine
[46]Institute for Nuclear Research of the National Academy of Sciences (KINR), Kyiv, Ukraine
[47]University of Birmingham, Birmingham, United Kingdom
[48]H.H. Wills Physics Laboratory, University of Bristol, Bristol, United Kingdom
[49]Cavendish Laboratory, University of Cambridge, Cambridge, United Kingdom
[50]Department of Physics, University of Warwick, Coventry, United Kingdom
[51]STFC Rutherford Appleton Laboratory, Didcot, United Kingdom
[52]School of Physics and Astronomy, University of Edinburgh, Edinburgh, United Kingdom
[53]School of Physics and Astronomy, University of Glasgow, Glasgow, United Kingdom
[54]Oliver Lodge Laboratory, University of Liverpool, Liverpool, United Kingdom
[55]Imperial College London, London, United Kingdom
[56]Department of Physics and Astronomy, University of Manchester, Manchester, United Kingdom
[57]Department of Physics, University of Oxford, Oxford, United Kingdom
[58]Massachusetts Institute of Technology, Cambridge, MA, United States
[59]University of Cincinnati, Cincinnati, OH, United States
[60]University of Maryland, College Park, MD, United States
[61]Los Alamos National Laboratory (LANL), Los Alamos, NM, United States
[62]Syracuse University, Syracuse, NY, United States
[63]School of Physics and Astronomy, Monash University, Melbourne, Australia
(associated with Department of Physics, University of Warwick, Coventry, United Kingdom)
[64]Pontifícia Universidade Católica do Rio de Janeiro (PUC-Rio), Rio de Janeiro, Brazil
(associated with Universidade Federal do Rio de Janeiro (UFRJ), Rio de Janeiro, Brazil)
[65]Physics and Micro Electronic College, Hunan University, Changsha City, China
(associated with Institute of Particle Physics, Central China Normal University, Wuhan, Hubei, China)
[66]Guangdong Provincial Key Laboratory of Nuclear Science, Guangdong-Hong Kong Joint Laboratory of Quantum Matter, Institute of Quantum Matter, South China Normal University, Guangzhou, China
(associated with Center for High Energy Physics, Tsinghua University, Beijing, China)
[67]Lanzhou University, Lanzhou, China
(associated with Institute Of High Energy Physics (IHEP), Beijing, China)
[68]School of Physics and Technology, Wuhan University, Wuhan, China
(associated with Center for High Energy Physics, Tsinghua University, Beijing, China)
[69]Departamento de Fisica, Universidad Nacional de Colombia, Bogota, Colombia
(associated with LPNHE, Sorbonne Université, Paris Diderot Sorbonne Paris Cité, CNRS/IN2P3, Paris, France)
[70]Universität Bonn - Helmholtz-Institut für Strahlen und Kernphysik, Bonn, Germany
(associated with Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Heidelberg, Germany)
[71]Eotvos Lorand University, Budapest, Hungary
(associated with European Organization for Nuclear Research (CERN), Geneva, Switzerland)
[72]INFN Sezione di Perugia, Perugia, Italy
(associated with INFN Sezione di Ferrara, Ferrara, Italy)
[73]Van Swinderen Institute, University of Groningen, Groningen, Netherlands
(associated with Nikhef National Institute for Subatomic Physics, Amsterdam, Netherlands)
[74]Universiteit Maastricht, Maastricht, Netherlands
(associated with Nikhef National Institute for Subatomic Physics, Amsterdam, Netherlands)

[75]Tadeusz Kosciuszko Cracow University of Technology, Cracow, Poland
(associated with Henryk Niewodniczanski Institute of Nuclear Physics Polish Academy of Sciences, Kraków, Poland)
[76]DS4DS, La Salle, Universitat Ramon Llull, Barcelona, Spain
(associated with ICCUB, Universitat de Barcelona, Barcelona, Spain)
[77]Department of Physics and Astronomy, Uppsala University, Uppsala, Sweden
(associated with School of Physics and Astronomy, University of Glasgow, Glasgow, United Kingdom)
[78]University of Michigan, Ann Arbor, MI, United States
(associated with Syracuse University, Syracuse, NY, United States)

[a]Deceased.
[b]Also at Università di Roma Tor Vergata, Roma, Italy.
[c]Also at Università di Firenze, Firenze, Italy.
[d]Also at Scuola Normale Superiore, Pisa, Italy.
[e]Also at Università di Ferrara, Ferrara, Italy.
[f]Also at Università di Milano Bicocca, Milano, Italy.
[g]Also at Università di Bologna, Bologna, Italy.
[h]Also at Università di Genova, Genova, Italy.
[i]Also at Universidad Nacional Autónoma de Honduras, Tegucigalpa, Honduras.
[j]Also at Università di Bari, Bari, Italy.
[k]Also at Università di Cagliari, Cagliari, Italy.
[l]Also at Università di Perugia, Perugia, Italy.
[m]Also at Università degli Studi di Milano, Milano, Italy.
[n]Also at Universidade Federal do Triângulo Mineiro (UFTM), Uberaba-MG, Brazil.
[o]Also at Universidade de Brasília, Brasília, Brazil.
[p]Also at Hangzhou Institute for Advanced Study, UCAS, Hangzhou, China.
[q]Also at Università di Pisa, Pisa, Italy.
[r]Also at Central South U., Changsha, China.
[s]Also at Università di Padova, Padova, Italy.
[t]Also at Excellence Cluster ORIGINS, Munich, Germany.
[u]Also at Università della Basilicata, Potenza, Italy.
[v]Also at Universidad de Alcalá, Alcalá de Henares, Spain.
[w]Also at Università di Urbino, Urbino, Italy.