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Search for the doubly heavy Ξ_{bc}^0 baryon via decays to D^0pK^-

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Abstract: A search for the doubly heavy Ξ_{bc}^0 baryon using its decay to the D^0pK^- final state is performed using proton-proton collision data at a centre-of-mass energy of 13 TeV collected by the LHCb experiment between 2016 and 2018, corresponding to an integrated luminosity of 5.4 fb^{-1}. No significant signal is found in the invariant mass range from 6.7 to 7.2 GeV/c^2. Upper limits are set at 95% credibility level on the ratio of the Ξ_{bc}^0 production cross-section times its branching fraction to D^0pK^- relative to that of the $\Lambda_b^0 \to D^0pK^-$ decay. The limits are set as a function of the Ξ_{bc}^0 mass and lifetime hypotheses, in the rapidity range from 2.0 to 4.5 and in the transverse momentum region from 5 to 25 GeV/c. Upper limits range from 1.7×10^{-2} to 3.0×10^{-1} for the considered Ξ_{bc}^0 mass and lifetime hypotheses.

Keywords: B physics, Hadron-Hadron scattering (experiments), Heavy quark production, QCD, Spectroscopy

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Contents

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1 Introduction

In the constituent quark model [1–3], two heavy quarks (b or c) can be bound together with a light quark to form doubly heavy baryons [4]. Studies of these particles are of great interest for the understanding of hadron spectroscopy and QCD at low energies. The Ξ_{cc}^{++} baryon (valence quark content ccu)[1] was first observed in 2017 by the LHCb collaboration [5]. The Ξ_{bc}^{0} baryon (bcd) containing two different heavy quarks is expected to have a mass in the range of 6.8–7.1 GeV/c^2 [6–22]. The Ξ_{bc}^{0} production cross-section is predicted to be about 16 nb at a centre-of-mass energy of $\sqrt{s} = 13$ TeV in the pseudorapidity range $1.9 < \eta < 4.9$ and for a transverse momentum $p_{\mathrm{T}} > 4\,\mathrm{GeV}/c$ [23].

The Ξ_{bc}^{0} baryon has not been observed to date. Five categories of Ξ_{bc}^{0} decays have been studied theoretically: (i) semileptonic decays induced by $c \to d(s)\ell^+\nu_\ell$ or $b \to u(c)\ell^-\overline{\nu}_\ell$ transitions, with branching fractions estimated to be within the range 10^{-6}–10^{-2} [24–29]; (ii) non-leptonic decays mediated by weak scattering of the b-quark and c-quark [13, 30]; (iii) non-leptonic decays occurring through c-quark charged current interaction, whose branching fractions are predicted to be 10^{-5}–10^{-1} [25–29]; (iv) non-leptonic decays produced by b-quark charged current, with branching fractions ranging 10^{-9}–10^{-3} [25–28, 31]; and (v) flavour-changing neutral current processes $b \to d(s)\ell^+\ell^-$, with branching fractions highly suppressed and within the range 10^{-10}–10^{-8} [24, 32].

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[1] The inclusion of charge-conjugate modes is implied throughout this paper.

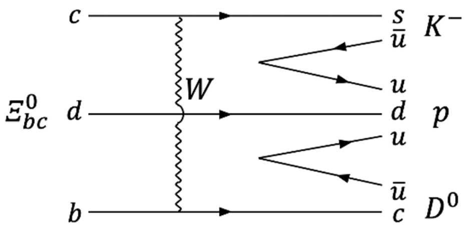

Figure 1. The $\Xi^0_{bc} \to D^0pK^-$ decay induced by the weak W-scattering of constituent b and c quarks.

The Ξ^0_{bc} lifetime is estimated by calculating full decay width which is expected to consist of four major contributions, due to $b \to cW^-$ and $c \to sW^+$ transitions, Pauli interference between the products of heavy quark decays and the quarks in the initial state, and weak scattering effects between the constituents, e.g. $bc \to cs$, $cd \to su$. The Ξ^0_{bc} lifetime is predicted to be in the range of 90–280 fs [13, 20, 33–35]. By contrast, ref. [36] advocates that the Ξ^0_{bc} lifetime is similar to that of the B_c^+ meson, i.e. (510 ± 9) fs [37].

This paper presents the first search for the Ξ^0_{bc} baryon in the mass range from 6.7 to $7.2\,\text{GeV}/c^2$, using proton-proton (pp) collision data collected by the LHCb experiment at a centre-of-mass energy of $\sqrt{s} = 13\,\text{TeV}$ between 2016 and 2018, corresponding to an integrated luminosity of $5.4\,\text{fb}^{-1}$. The Ξ^0_{bc} baryon is searched for through the $\Xi^0_{bc} \to D^0pK^-$, $D^0 \to K^-\pi^+$ decay chain, which is preferred for its ease of reconstruction at LHCb. A leading-order Feynman diagram contributing to this decay is shown in figure 1. The branching fraction $\mathcal{B}(\Xi^0_{bc} \to D^0pK^-)$ is expected to be similar to that of the $\Xi^+_{bc} \to D^0pK^0$ decay, about 0.1% [13]. Considering the value of $\mathcal{B}(D^0 \to K^-\pi^+) = (3.89 \pm 0.04)\%$ [37], the total branching fraction of the $\Xi^0_{bc} \to D^0(\to K^-\pi^+)pK^-$ decay chain is expected to be in the range of 10^{-5}–10^{-4}.

To reduce systematic uncertainties, the Ξ^0_{bc} production cross-section is measured relative to that of the normalisation mode corresponding to a Λ^0_b baryon decaying to the same final state. Both the Ξ^0_{bc} and Λ^0_b baryons are reconstructed in the rapidity range from 2.0 to 4.5 and in the transverse momentum region from 5 to $25\,\text{GeV}/c$. The search is performed with the analysis procedure entirely defined before inspecting the data across the considered mass range.

2 Detector and simulation

The LHCb detector [38, 39] is a single-arm forward spectrometer covering the pseudorapidity range $2 < \eta < 5$, designed for the study of particles containing b or c quarks. The detector includes a high-precision tracking system consisting of a silicon-strip vertex detector surrounding the pp interaction region [40], a large-area silicon-strip detector located upstream of a dipole magnet with a bending power of about 4 Tm, and three stations of silicon-strip detectors and straw drift tubes [41] placed downstream of the magnet. The polarity of the dipole magnet is reversed periodically throughout data taking. The tracking system provides a measurement of the momentum, p, of charged particles with a relative uncertainty that varies from 0.5% at low momentum to 1.0% at 200 GeV/c. The minimum distance of a track to a primary pp interaction vertex (PV), the impact parameter (IP), is measured with a resolution of $(15 + 29/p_{\mathrm{T}})\,\mu\mathrm{m}$, where p_{T} is expressed in GeV/c. Different types of charged hadrons are distinguished using information from two ring-imaging Cherenkov detectors [42]. Photons, electrons and hadrons are identified by a calorimeter system consisting of scintillating-pad and preshower detectors, an electromagnetic and a hadronic calorimeter. Muons are identified by a system composed of alternating layers of iron and multiwire proportional chambers [43]. The online event selection is performed by a trigger [44], which consists of a hardware stage, based on information from the calorimeters and muon systems [45], followed by a software stage, at which all tracks with $p_{\mathrm{T}} > 300\,\mathrm{MeV}/c$ are reconstructed for data collected at $\sqrt{s} = 13\,\mathrm{TeV}$ [46]. The software trigger used in this analysis requires a two-, three- or four-track vertex with significant displacement from any PV. At least one charged particle must have $p_{\mathrm{T}} > 1.7\,\mathrm{GeV}/c$ and be inconsistent with originating from any PV. A multivariate algorithm [47] is used for the identification of displaced vertices consistent with the decay of a b hadron.

Simulated samples are used to develop the candidate selection and to estimate the corresponding efficiency as well as that of the detector acceptance. Simulated pp collisions are generated using Pythia [48, 49] with a specific LHCb configuration [50]. A dedicated package, GenXicc2.0 [51], is used to simulate the Ξ_{bc}^0 baryon production. Decays of unstable particles are described by EvtGen [52], in which final-state radiation is generated using Photos [53]. The interaction of the generated particles with the detector, and its response, are simulated using the Geant4 toolkit [54, 55] as described in ref. [56]. The simulated Ξ_{bc}^0 events are generated with a mass of $6.9\,\mathrm{GeV}/c^2$ and a lifetime of 400 fs, and samples with different mass and lifetime hypotheses are obtained using a weighting technique. The Ξ_{bc}^0 baryon decay is assumed to follow a uniform phase-space model.

3 Reconstruction and selection

For both the Ξ_{bc}^0 signal and the Λ_b^0 normalisation modes, D^0 candidates are reconstructed in the $K^-\pi^+$ final state. Two oppositely charged tracks identified as a kaon and a pion with an invariant mass in the range of $1.84 < m(K^-\pi^+) < 1.89\,\mathrm{GeV}/c^2$ are requested to form a common vertex that is significantly displaced from any PV. The D^0 candidate is then combined with two oppositely charged tracks identified as a proton and as a kaon to form a Ξ_{bc}^0 or a Λ_b^0 candidate. The two tracks are required to have a high transverse momentum and to be inconsistent with originating from any PV. The D^0, p and K candidates are required to form a common vertex with a good fit quality. The Ξ_{bc}^0 and Λ_b^0 candidates have to point back to the PV and have an invariant mass larger than $5.0\,\mathrm{GeV}/c^2$.

A multivariate analysis is applied to both the signal and the normalisation candidates to further improve the purity of the samples. The selection algorithm is a Boosted Decision Tree (BDT) algorithm implemented in the TMVA package [57]. To train this classifier, simulated Ξ_{bc}^0 baryon decays are used as the signal proxy and candidates lying in the upper D^0pK^- mass sideband (8.0–$8.5\,\mathrm{GeV}/c^2$) adjacent to the signal region for the background proxy. The BDT algorithm uses kinematic and vertex-topology variables that show good

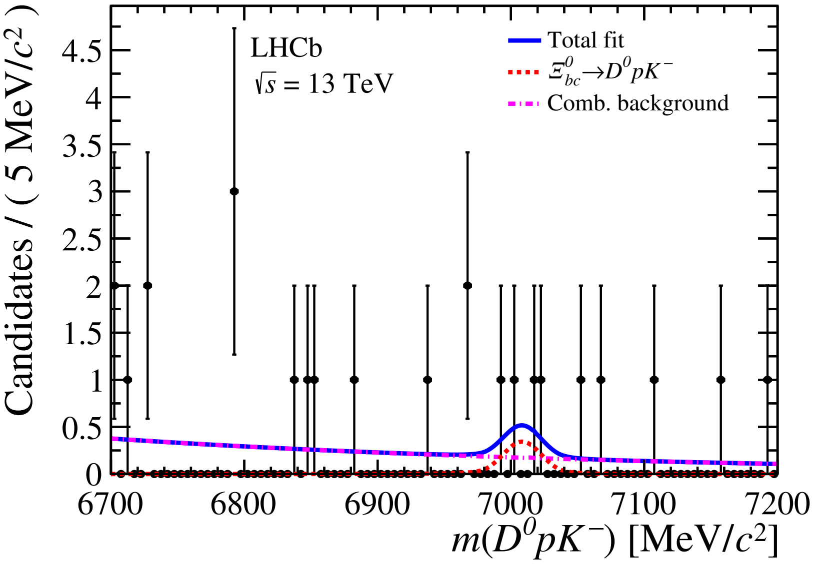

Figure 2. Invariant mass $m(D^0pK^-)$ distribution of selected Ξ^0_{bc} candidates (black points) together with the projection of the fit (blue solid line) for the full data sample. The $\Xi^0_{bc} \to D^0pK^-$ signal component, with the central mass value varying freely (red dashed line), and combinatorial background (purple dotted line) are also shown.

discrimination power between signal and background. The variables include: the χ^2_{IP} and transverse momentum of all particles; particle identification (PID) variables for the final state particles; the flight-distance χ^2 between the PV and the decay vertex; the vertex quality of the D^0 and Ξ^0_{bc} candidates; and the angle between the momentum and the flight direction of the Ξ^0_{bc} candidate. The χ^2_{IP} is defined as the difference in χ^2 of the PV fit with and without the particle in question. The flight-distance χ^2 is defined as the χ^2 of the hypothesis that the decay vertex of the candidate coincides with its associated PV, defined as the PV with the smallest χ^2_{IP}. It has been verified that this BDT classifier does not shape the background invariant mass distribution.

A selection requirement is applied on the BDT response. It is determined by maximizing the value of the Punzi figure of merit $\varepsilon / \left(\frac{a}{2} + \sqrt{N_B}\right)$ [58], where ε is the estimated signal efficiency, a corresponds to the number of standard deviations in a Gaussian significance test, which is taken as 5, and N_B is the number of background candidates determined in the upper sideband and extrapolated to the signal region. The performance of the BDT classifier is tested and found to be stable against the Ξ^0_{bc} lifetime in the range from 100 to 500 fs.

4 Yield measurements

The invariant mass distribution of the selected candidates within the range 6.7–7.2 GeV/c^2 for the full data sample is shown in figure 2. The Ξ^0_{bc} signal yield is determined from an unbinned maximum-likelihood fit to the invariant mass $m(D^0pK^-)$ distribution. The signal is described by a double-sided Crystal Ball (DSCB) function [59] comprising a Gaussian

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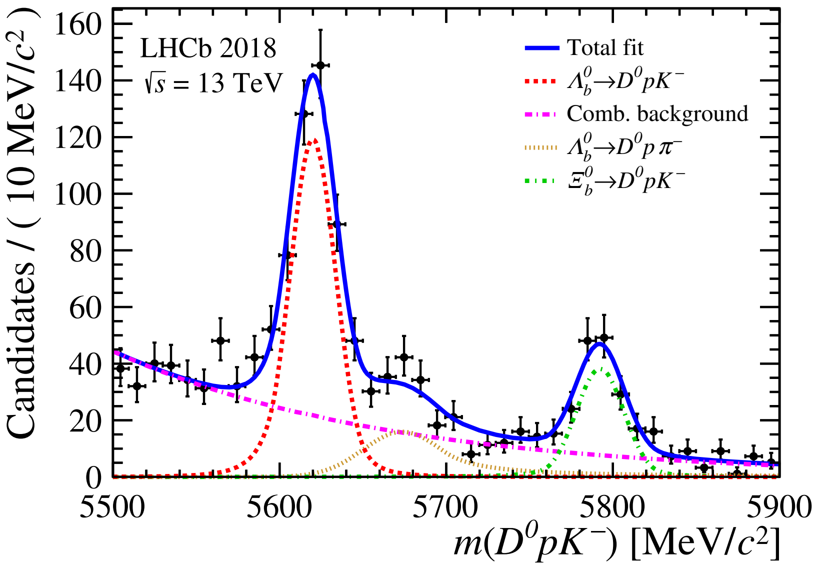

Figure 3. Invariant mass distribution for $\Lambda_b^0 \to D^0 p K^-$ candidates in the 2018 data sample (black points). The fit projection (blue solid line) is superimposed. The normalisation component (red dashed line), the misidentified background (brown dashed line), the combinatorial background (purple dotted line), and the $\Xi_b^0 \to D^0 p K^-$ (green dotted line) components are also shown. Similar distributions are obtained for the 2016 and 2017 data samples.

core with power-law tails on both sides, while the background is described by an exponential function. The parameters of the signal model are fixed from simulation except for the peak position that is allowed to vary in the fit. The mass resolution of the signal decay is $14.2 \pm 0.4\,\text{MeV}/c^2$ for all mass hypotheses, as determined from simulation. The projection of the fit to the mass distribution, with the Ξ_{bc}^0 mass parameter varying freely, is also shown in figure 2. No excess is observed in the full Ξ_{bc}^0 mass range, therefore upper limits are set on the production ratios.

As the selection efficiency varies with the data-taking conditions, the yield of the normalisation mode is determined for each year separately. The Λ_b^0 signal yield, N_{norm}, is obtained from an extended unbinned maximum-likelihood fit to the invariant mass $m(D^0 p K^-)$ distribution in the 2016, 2017 and 2018 data samples. The fit model includes a DSCB function to describe the $\Lambda_b^0 \to D^0 p K^-$ decay and three separate background components: random combinations of tracks or genuine D^0 decays combined with random tracks (combinatorial background); the Cabibbo-favoured decay $\Lambda_b^0 \to D^0 p \pi^-$ where the pion is incorrectly identified as a kaon (misidentified background); and the $\Xi_b^0 \to D^0 p K^-$ decay component. The shape of the normalisation mode and the misidentified background are taken from simulation. The latter is parameterised with a Crystal Ball (CB) function. The $\Xi_b^0 \to D^0 p K^-$ decay component is described by a DSCB function and the combinatorial background by an exponential function. As an illustration, the $m(D^0 p K^-)$ distribution for the 2018 data sample is shown in figure 3 along with the projection of the associated fit result. A total of about 1200 Λ_b^0 candidates are obtained.

Period	$\epsilon_{\text{norm}}/\epsilon_{\text{sig}}$	N_{norm}	α $[\times 10^{-3}]$
2016	3.66 ± 0.17	376 ± 26	9.7 ± 0.8
2017	3.50 ± 0.13	371 ± 26	9.4 ± 0.7
2018	3.22 ± 0.13	425 ± 28	7.6 ± 0.6

Table 1. Efficiency ratios between the normalisation and signal modes and the single-event sensitivity, α, for the nominal Ξ^0_{bc} hypothesis, $m(\Xi^0_{bc}) = 6.9\,\text{GeV}/c^2$ and $\tau(\Xi^0_{bc}) = 400\,\text{fs}$. The uncertainties are statistical only.

5 Production cross-section ratio

The production cross-section ratio, R, is defined as

$$R \equiv \frac{\sigma(\Xi^0_{bc})\mathcal{B}(\Xi^0_{bc} \to D^0 p K^-)}{\sigma(\Lambda^0_b)\mathcal{B}(\Lambda^0_b \to D^0 p K^-)} = \frac{\epsilon_{\text{norm}}}{\epsilon_{\text{sig}}}\frac{N_{\text{sig}}}{N_{\text{norm}}} \equiv \alpha N_{\text{sig}}, \tag{5.1}$$

where σ is the production cross-section and $\mathcal{B}$ is the decay branching fraction, ϵ_{sig} and ϵ_{norm} are the selection efficiencies of the signal and normalisation decay modes, respectively, N_{sig} and N_{norm} are the corresponding yields, and $\alpha = \epsilon_{\text{norm}}/(\epsilon_{\text{sig}} N_{\text{norm}})$ is the single-event sensitivity.

The signal efficiency depends upon the assumed mass and lifetime of the Ξ^0_{bc}. Simulated events are generated with $m(\Xi^0_{bc}) = 6.9\,\text{GeV}/c^2$ and $\tau(\Xi^0_{bc}) = 400\,\text{fs}$, from here on referred to as nominal, and used to evaluate the efficiency ratio. The variation of the efficiency ratio as a function of $m(\Xi^0_{bc})$ and $\tau(\Xi^0_{bc})$ relative to the nominal point is then determined with a weighting technique discussed in section 7. The kinematic distribution of Ξ^0_{bc} baryons produced at the LHC is also unknown and is assumed to be the same as for the Λ^0_b baryon. Transverse momentum and rapidity distributions of simulated Ξ^0_{bc} are therefore corrected to match that of Λ^0_b decays observed in data.

The efficiencies can be factorised into that of the geometrical acceptance, track reconstruction, trigger, offline pre-selection, PID, and multivariate selection. The individual efficiencies are evaluated with simulated events of $\Xi^0_{bc} \to D^0 p K^-$ and $\Lambda^0_b \to D^0 p K^-$ decays, except for tracking and PID where the efficiencies are determined using calibration data samples, namely the $J/\psi \to \mu^+\mu^-$ decay [60] for tracking and $D^{*+} \to D^0(\to K^-\pi^+)\pi^+$ and $\Lambda \to p\pi^-$ decays for PID [61, 62].

The track multiplicity distribution is taken from $\Lambda^0_b \to D^0 p K^-$ data for both signal and normalisation samples. The simulated Dalitz plot of these decays are corrected to match the distribution observed in background-subtracted data, obtained using the *sPlot* technique [63]. The efficiency ratio and the single-event sensitivity at the nominal Ξ^0_{bc} mass and lifetime are summarised in table 1. The single-event sensitivity is determined according to eq. (5.1) using the obtained efficiency ratios and the normalisation yields reported in table 1.

The analysis is performed assuming a uniform phase-space model for the signal decay $\Xi^0_{bc} \to D^0 p K^-$. Efficiency maps in bins of the invariant masses $m(D^0 p)$ and $m(pK^-)$ are provided in figure 4 to allow for the interpretation of the result in different theoretical model scenarios.

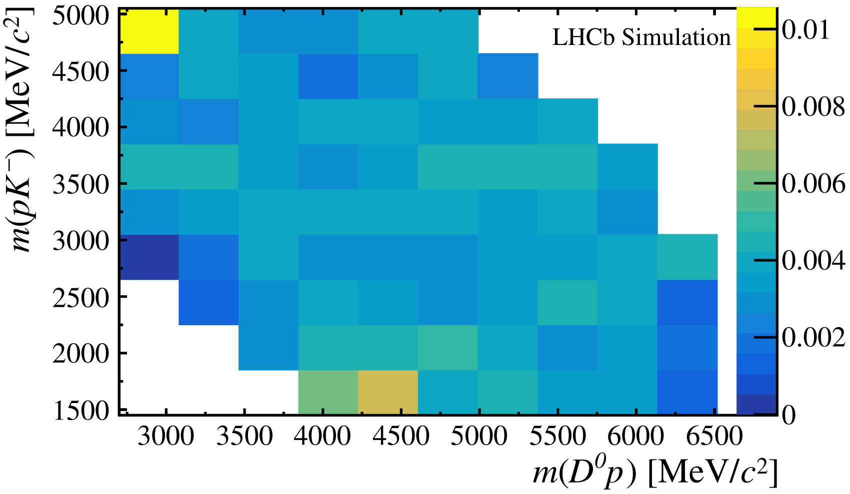

Figure 4. Efficiency of selected $\Xi_{bc}^0 \to D^0pK^-$ decays as a function of the invariant masses $m(D^0p)$ and $m(pK^-)$ in the simulation. The variation of efficiency across the Dalitz plot reflects the specific phase-space dependent requirements of the selection.

Source	R [%]
Fit model	3.6
Hardware trigger	6.8
PID	5.4
$\Lambda_b^0 \to D^0pK^-$ Dalitz plot weight	1.5
Simulation/data difference	5.0
Total	10.7

Table 2. Summary of the systematic uncertainties on measurement of the production ratio, R.

6 Systematic uncertainties

Systematic uncertainties on the production ratio arise from the fit model, the trigger efficiency, the PID efficiency, the Dalitz plot weighting, and the simulation and data difference. The total systematic uncertainty is calculated as the quadratic sum of the individual uncertainties, presented in table 2, assuming all the sources are uncorrelated.

The uncertainty on the signal yield may arise from the shape of the signal, the combinatorial background, and the misidentified background. This is quantified by choosing alternative functions. A Gaussian function is used for the signal and a second-order polynomial for the combinatorial background. The effect due to the misidentified background is estimated by fixing the ratio of the $\Lambda_b^0 \to D^0p\pi^-$ yield to that of the $\Lambda_b^0 \to D^0pK^-$ decay with their measured branching fractions [64], taking into account their selection efficiencies. The sum in quadrature of these uncertainty estimates, yielding 3.6%, is taken as systematic uncertainty due to the fit model.

The cancellation of the hardware-trigger efficiencies in the ratio between the signal and the normalisation modes is studied with $B^0 \to \bar{D}^0\pi^+\pi^-$ control samples, using a tag-and-

Period	$\tau = 100\,\text{fs}$	$\tau = 200\,\text{fs}$	$\tau = 300\,\text{fs}$	$\tau = 400\,\text{fs}$	$\tau = 500\,\text{fs}$
2016	141 ± 14	27.5 ± 2.4	14.1 ± 1.2	9.7 ± 0.8	7.7 ± 0.7
2017	134 ± 12	25.9 ± 2.1	13.5 ± 1.1	9.5 ± 0.8	7.6 ± 0.6
2018	102 ± 9	20.8 ± 1.6	10.8 ± 0.8	7.6 ± 0.6	6.1 ± 0.5

Table 3. Single-event sensitivity α in units of 10^{-3} for different lifetime hypotheses of the Ξ_{bc}^0 baryon for different data-taking periods. The uncertainties are due to the limited size of the simulated samples and the statistical uncertainties on the measured Λ_b^0 baryon yields.

probe method [65]. The data and simulation difference between the efficiency ratio in the normalisation mode $\Lambda_b^0 \to D^0 p K^-$ and the $B^0 \to \bar{D}^0 \pi^+ \pi^-$ control sample is assigned as a systematic uncertainty, and amounts to 6.8%.

The PID efficiency is determined in bins of particle momentum and pseudorapidity using calibration data samples. There are several associated sources of systematic uncertainty, namely due to the limited size of the control samples, notably for high-p_{T} protons from the Λ sample, the assumption that kinematic correlations between tracks are neglected, and limitations in the method (e.g. the finite kinematic binning used). The total systematic uncertainty associated with the PID efficiency, calculated as the sum in quadrature of individual contributions, amounts to 5.4%.

The Dalitz plot of the simulated $\Lambda_b^0 \to D^0 p K^-$ decays is weighted to match that observed in data. Several binning schemes of the Dalitz plot have been considered and the maximal difference in R of 1.5% is taken as the corresponding systematic uncertainty.

The simulation and data agreement is checked with control modes, and a difference of 5.0% is found between different years of data-taking, which is taken as systematic uncertainty.

7 Variation of efficiency with mass and lifetime

The trigger, reconstruction and selection efficiencies for Ξ_{bc}^0 candidates have a strong dependence upon the Ξ_{bc}^0 lifetime. The simulated Ξ_{bc}^0 events are generated with a lifetime value of 400 fs as described in section 2. To test other lifetime hypotheses, the simulated events are weighted to reproduce other lifetime hypotheses and the efficiency is recalculated. A discrete set of hypotheses (100, 200, 300, 400 and 500 fs) is considered. The total efficiency is found to have a linear dependence on the Ξ_{bc}^0 lifetime. The value and uncertainty on the single-event sensitivity α are provided for each lifetime hypothesis in table 3.

The efficiency could also depend on the Ξ_{bc}^0 baryon mass hypothesis in the simulation, since it affects the kinematic distributions of the decay products. To assess its effect, large samples of simulated events are generated with alternative mass hypotheses, namely 6.7 and 7.1 GeV/c^2. The efficiencies for other mass values are interpolated between the nominal and these two hypotheses. Two tests are carried out with these samples. Firstly, the detector acceptance efficiency is recomputed. Secondly, the p_{T} distributions of the Ξ_{bc}^0 baryon daughters are weighted to match those of the alternative mass hypothesis and the remaining efficiency is recalculated. The total efficiency is found to have negligible dependence on the Ξ_{bc}^0 mass, thus it is ignored in the evaluation of the single-event sensitivities.

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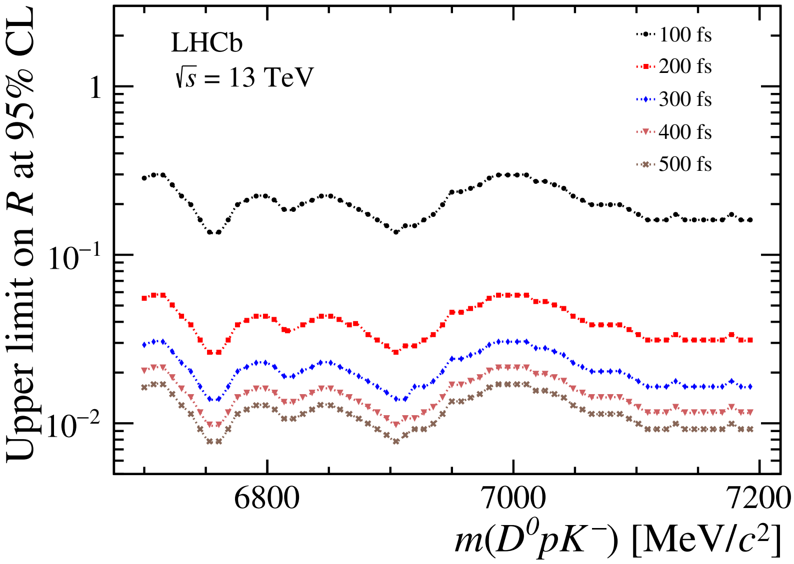

Figure 5. Values of upper limits on R at 95% CL as a function of $m(D^0pK^-)$ for five Ξ_{bc}^0 lifetime hypotheses. The curves from top to bottom correspond to lifetime hypotheses from 100 fs to 500 fs, respectively.

8 Results

The upper limits on the Ξ_{bc}^0 decay ratio R are obtained by performing again a fit to the data invariant mass distribution assuming different Ξ_{bc}^0 mass hypotheses in the range from 6.7 to 7.2 GeV/c^2, and in steps of 7.5 MeV/c^2, for five lifetime hypotheses, in the fiducial region of rapidity $2.0 < y < 4.5$ and transverse momentum $5 < p_{\mathrm{T}} < 25$ GeV/c. For each Ξ_{bc}^0 baryon mass and lifetime hypothesis, the likelihood profile $\mathcal{L}(R)$ is determined as a function of R with simultaneous fits to the $m(D^0pK^-)$ invariant mass distributions. Then it is convoluted with a Gaussian distribution whose width is a quadratic sum of the statistical and systematic uncertainty on the single-event sensitivity. The upper limit at 95% credibility level (CL) is defined as the value of R at which the integral of the profile likelihood equals 95% of its total area. Upper limits on R at 95% CL for different lifetime hypotheses are shown in figure 5.

9 Conclusion

A first search for the $\Xi_{bc}^0 \to D^0pK^-$ decay is performed at LHCb with a data sample of pp collisions, corresponding to an integrated luminosity of 5.4 fb^{-1}, recorded at a centre-of-mass energy of 13 TeV. No evidence for a signal is found. Upper limits at 95% CL on the Ξ_{bc}^0 baryon production cross-section times its branching fraction to the D^0pK^- final state relative to the $\Lambda_b^0 \to D^0pK^-$ decay are obtained in the fiducial region of rapidity $2.0 < y < 4.5$ and transverse momentum $5 < p_{\mathrm{T}} < 25$ GeV/c, and for various Ξ_{bc}^0 mass and lifetime hypotheses. The upper limits are set assuming that the kinematic distributions of the Ξ_{bc}^0 baryon follow those of the GENXICC2.0 model [51] and that the decay of the

Ξ_{bc}^0 baryon proceeds according to a uniform phase-space model. The values of the upper limits depend strongly on the lifetime, varying from 3.0×10^{-1} to 1.7×10^{-2} for 100 fs and 500 fs, respectively. Future searches at LHCb with improved trigger conditions, additional Ξ_{bc}^0 decay modes, and larger data samples will further improve the Ξ_{bc}^0 signal sensitivity.

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