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First measurement of Ξ_c^0 production in pp collisions at $\sqrt{s} = 7$ TeV

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ABSTRACT

The production of the charm-strange baryon Ξ_c^0 is measured for the first time at the LHC via its semileptonic decay into $e^+\Xi^-\nu_e$ in pp collisions at $\sqrt{s} = 7$ TeV with the ALICE detector. The transverse momentum (p_T) differential cross section multiplied by the branching ratio is presented in the interval $1 < p_T < 8$ GeV/c at mid-rapidity, $|y| < 0.5$. The transverse momentum dependence of the Ξ_c^0 baryon production relative to the D^0 meson production is compared to predictions of event generators with various tunes of the hadronisation mechanism, which are found to underestimate the measured cross-section ratio.

Quantum Chromodynamics (QCD) as the theory of the strong interaction has been a cornerstone of the Standard Model for several decades. It has been tested through measurements in e^+e^-, pp, $p\bar{p}$ and ep collisions at momentum-transfer scales where perturbative techniques are applicable [1]. In particular, measurements of charm hadrons have provided important tests of the theory because perturbative techniques are applicable down to low transverse momentum (p_T) thanks to the large mass of the charm quark compared to the QCD scale parameter ($\Lambda_{QCD} \sim 200$ MeV). The production cross sections of charm hadrons can be calculated using the factorisation approach as a convolution of three factors [2]: the parton distribution functions of the incoming protons, the hard-scattering cross section at partonic level and the fragmentation functions of charm quarks into charm hadrons. There are several state-of-the-art calculations adopting different factorisation schemes. The collinear factorisation scheme is used by calculations at next-to-leading order in α_s, such as the general-mass variable flavour number scheme (GM-VFNS) [3–5] and the fixed order with next-to-leading-log resummation (FONLL) [6,7] approaches, while the k_T factorisation scheme is employed at leading order in Refs. [8–10]. However, some of these calculations do not provide predictions for heavy-baryon production due to the lack of knowledge about the fragmentation function of charm quarks into baryonic states. Measurements of the production of charm baryons, such as Λ_c^+ and Ξ_c^0, are essential to develop and test models of the hadronisation process.

While a variety of new charm-baryon resonances, such as Ω_c^0 [11], Ξ_{cc}^{++} [12], have recently been found, charm-hadron cross-section measurements at the Large Hadron Collider (LHC) are mainly limited to mesons [13–21], apart from a few measurements of the Λ_c^+ cross section in pp and p–Pb collisions [16,22]. In the case of Ξ_c^0, the existing measurements are currently limited to e^+e^- collisions [23–27]. New measurements of charm-baryon production are therefore needed to provide further insights into the hadronisation processes in pp collisions. For example, interactions at the partonic level among the produced quarks and gluons, such as colour reconnection, could be stronger in pp collisions than in e^+e^- collisions, resulting in an enhanced production of baryons relative to mesons [28]. The measurements of charm-baryon production in pp collisions also serve as a reference for heavy-ion collisions, where a modification of the baryon-to-meson ratio is expected if a substantial fraction of charm quarks hadronises via recombination with other quarks from the deconfined medium created in the collision [29–33]. Measurements of charm-strange baryons, e.g. Ξ_c^0, could also provide additional input to better understand the hadronisation mechanism of strange quarks in pp collisions because of their valence quark composition.

In this paper, we report the first measurement of the p_T-differential production cross section of Ξ_c^0 multiplied by the branching ratio (BR) into the semileptonic decay mode, $\Xi_c^0 \rightarrow e^+\Xi^-\nu_e$, and its ratio to the measured production cross section of D^0 mesons [21] as a function of p_T, up to 8 GeV/c. The absolute branching ratio of this Ξ_c^0 decay is currently unknown [34]. Using a data sample of pp collisions at $\sqrt{s} = 7$ TeV recorded with the ALICE detector in 2010, the measurement is performed by analysing $e^+\Xi^-$ pairs formed by combining positrons and Ξ^- baryons reconstructed with the detectors of the ALICE central barrel, covering the pseudorapidity interval $|\eta| < 0.9$. The missing momentum of the neutrino is corrected using unfolding techniques. Charge conjugate modes are implied everywhere, unless otherwise stated. Only the sub-detectors relevant for this data analysis are described below. A more complete and detailed description of the ALICE detector and its performance can be found in Refs. [35,36].

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The detectors used in this analysis include the Inner Tracking System (ITS), the Time Projection Chamber (TPC) and the Time-Of-Flight detector (TOF). These detectors are located in a large solenoid magnet producing a magnetic field of 0.5 T parallel to the LHC beam axis. The ITS consists of six cylindrical layers of silicon detectors, placed at radial distances ranging from 3.9 cm to 43 cm from the nominal beam axis and covering the full azimuth. The two innermost layers consist of Silicon Pixel Detectors (SPD), the two intermediate layers of Silicon Drift Detectors (SDD) and the two outermost layers of Silicon Strip Detectors (SSD). The total material budget of the ITS is on average 7.7% of a radiation length, for particles with $\eta = 0$ [37]. The ITS spatial resolution enables the measurement of the distance of closest approach (d_0) of tracks to the primary vertex with a resolution better than 75 μm in the transverse plane for $p_{\mathrm{T}} > 1$ GeV/c in pp collisions [38]. The TPC is a cylindrical gaseous detector with a volume of about 90 m^3. The TPC provides track reconstruction with up to 159 space points at radial distances from the beam axis ranging between 85 cm and 247 cm, within the full azimuth. The TPC cluster-position resolution is about 500 μm along the beam direction and in the transverse direction for tracks with $\eta = 0$ [39]. The TPC also provides particle identification capabilities via the measurement of the specific ionisation energy loss, dE/dx, with a resolution of approximately 5.2% in pp collisions [36]. The TOF detector consists of multi-gap resistive plate chambers placed at a radial distance of 3.7 m from the beam axis and also covers the full azimuth. The TOF detector, with a timing resolution of about 80 ps, measures the time-of-flight of particles relative to the time of the collision, which is determined by the arrival time of the particles at the TOF detector and by the T0 detector, an array of Cherenkov counters placed at +370 cm and −70 cm from the nominal interaction point along the beam axis [40].

The analysed data sample consists of pp collisions at $\sqrt{s} =$ 7 TeV recorded during the 2010 LHC data taking period with a minimum bias trigger that requires at least one hit in either the SPD or the V0 detectors. The two layers of the SPD detector cover $|\eta| < 2.0$. The two V0 detectors, each comprising 32 scintillator tiles, are installed on both sides of the interaction point and cover $-3.7 < \eta < -1.7$ and $2.8 < \eta < 5.1$. The trigger condition captures 87% of the pp inelastic cross section [41]. The collision vertex is reconstructed with an efficiency of 88% and only events with a reconstructed vertex within 10 cm from the nominal interaction point along the beam direction are used in this analysis. Pile-up events are identified by searching for a second interaction vertex, reconstructed with at least three SPD tracklets (that are two-point track segments connecting hits in the two SPD layers) pointing to a common vertex, which is separated from the first vertex by at least 8 mm. After the selections, the analysed sample corresponds to an integrated luminosity $L_{\mathrm{int}} = 5.9 \pm 0.2$ nb^{-1}.

The Ξ_{c}^0 candidates are defined from $\mathrm{e}^+\Xi^-$ pairs by combining a track originating from the primary vertex (denoted by "electron track" in the following) and a reconstructed Ξ^- baryon. Electron tracks satisfying $|\eta| < 0.8$ and $p_{\mathrm{T}} > 0.5$ GeV/c are required to have at least 100 associated clusters in the TPC (out of which at least 80 are used for the calculation of the dE/dx signal), a χ^2 normalised to the number of TPC clusters smaller than 4 and at least 4 hits in the ITS. It is also required that the electron track has associated hits in the two innermost layers of the ITS, in order to reject electrons from photon conversions occurring in the detector material outside the innermost SPD layer [13]. Electrons are identified using the dE/dx measurement in the TPC and the time-of-flight measurement of the TOF detector. In both cases, the selection is applied on the n_σ^{TPC} and n_σ^{TOF} variables defined as the difference between the measured dE/dx or time-of-flight values and the one expected for electrons, divided by the corresponding detector resolution. The following selection criteria are applied: $|n_\sigma^{\mathrm{TOF}}| < 3$ and $-3.9 + 1.2p_{\mathrm{T}} - 0.094p_{\mathrm{T}}^2 < n_\sigma^{\mathrm{TPC}}(p_{\mathrm{T}}) < 3$. The p_{T}-dependent lower limit on n_σ^{TPC} was optimised to reject hadrons. Thus, an electron purity of 98% is achieved over the whole p_{T} range.

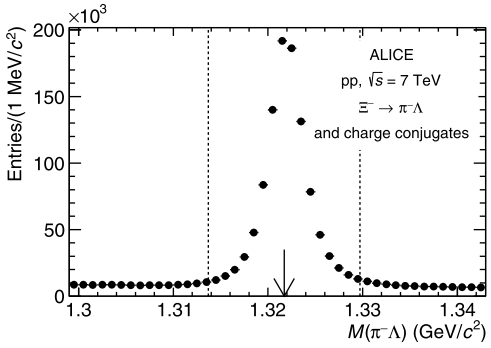

Fig. 1. Invariant-mass distribution of $\Xi^- \to \pi^-\Lambda$ (and charge conjugate) candidates integrated over p_{T}. The arrow indicates the world average Ξ^- mass from Ref. [34] and the dashed lines indicate the selected interval for the Ξ^- candidates.

The background from "photonic" electrons (originating from Dalitz decays of neutral mesons and photon conversions in the detector material) remaining in the electron sample are identified using a technique based on the invariant mass of $\mathrm{e}^+\mathrm{e}^-$ pairs [42]. The electron tracks are paired with opposite-sign tracks from the same event passing loose selection criteria ($|n_\sigma^{\mathrm{TPC}}| < 5$ without TOF requirement) and are identified as photonic electrons if there is at least one pair with an invariant mass smaller than 50 MeV/c^2. Setting such loose electron identification criteria is meant to increase the efficiency of finding the partners. This improves the signal-to-background ratio for Ξ_{c}^0 by about 50%, while the fraction of the signal lost due to misidentifications is less than 2%.

The Ξ^- baryons are reconstructed from the decay chain $\Xi^- \to \pi^-\Lambda$, followed by $\Lambda \to \mathrm{p}\pi^-$. Tracks used to define Ξ^- candidates are required to have at least 80 clusters in the TPC and a dE/dx signal in the TPC consistent with the expected values for protons (pions) within 4σ. The Ξ^- and Λ baryons have long lifetimes ($c\tau$ of about 4.91 cm and 7.89 cm, respectively [34]), and thus they can be identified using their characteristic cascade-like or V-shaped decay topologies [43–45]. Pions originating directly from Ξ^- decays are selected by requiring $d_0 > 0.02$ cm; protons and pions originating from Λ decays are required to have $d_0 > 0.07$ cm. The d_0 of the Λ trajectory to the primary vertex is required to be larger than 0.03 cm, while its cosine of the pointing angle, which is the angle between the reconstructed Λ momentum and the line connecting the Λ and Ξ^- decay vertices, is required to be larger than 0.98. The distances of the Ξ^- and Λ decay vertices from the beam line are required to be larger than 0.4 and 2.7 cm, respectively. These selection criteria are tuned to reduce the background, while keeping a high efficiency for the signal. Fig. 1 shows the Ξ^- peak in the $\pi^-\Lambda$ invariant-mass distribution integrated over p_{T}. Only Ξ^- candidates with invariant masses within 8 MeV/c^2 from the Ξ^- mass (1321.71 ± 0.07 MeV/c^2 [34]) indicated by an arrow in Fig. 1 are kept for further analysis. In this interval, the signal-to-background ratio is about 8.

The $\mathrm{e}^+\Xi^-$ pairs are formed from selected positrons and Ξ^- candidates. Only pairs with an opening angle smaller than 90 degrees are used for the analysis. The background in the $\mathrm{e}^+\Xi^-$ pair distribution is estimated by exploiting the fact that Ξ_{c}^0 baryons decay into $\mathrm{e}^+\Xi^-\nu_{\mathrm{e}}$ (right-sign, RS), but not into $\mathrm{e}^-\Xi^-\overline{\nu}_{\mathrm{e}}$ (wrong-sign, WS), while most of the background sources contribute equally to RS and WS pairs. The yield of WS pairs is therefore used to estimate the background and is subtracted from the yield of RS pairs to obtain the Ξ_{c}^0 raw yield. The procedure is verified with

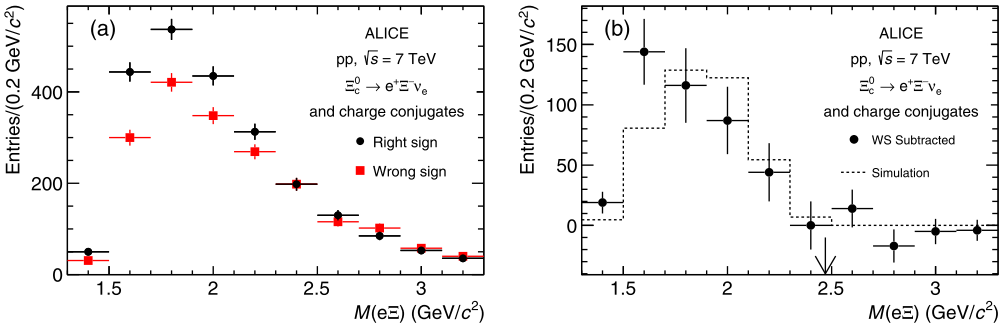

Fig. 2. (a) Invariant-mass distributions of right-sign and wrong-sign (and charge conjugate) pairs integrated over the whole p_T interval. (b) Invariant-mass distribution of Ξ_c^0 candidates obtained by subtracting the wrong-sign pair yield from the right-sign one compared with the signal distribution from the simulation, which is normalised to the measured RS−WS yield. The arrow indicates the Ξ_c^0 mass [34].

PYTHIA 6.4.21 [46] simulations using the Perugia-0 tune [47] and the GEANT3 transport code [48], including a realistic description of the detector response and alignment during the data taking period. A similar procedure was adopted by the ARGUS and CLEO collaborations studying e^+e^- collisions [24,25].

Fig. 2(a) shows the invariant-mass distributions of RS and WS pairs, integrated over the whole p_T interval. The invariant-mass distribution of Ξ_c^0 candidates obtained by subtracting the WS pair yield from the RS one is shown in Fig. 2(b) together with the signal distribution from the simulation, which is normalised to the measured RS−WS yield. The shapes of the two distributions are found to be consistent with each other. Due to the missing momentum of the neutrino, the invariant-mass distribution of the $e^+\Xi^-$ pair does not peak at the Ξ_c^0 mass ($2470.85^{+0.28}_{-0.40}$ MeV/c^2 [34]) indicated by an arrow in Fig. 2(b). The invariant mass of $e^+\Xi^-$ pairs from Ξ_c^0 decays is bounded by the Ξ_c^0 mass due to the missing momentum of the neutrino. Thus only $e^+\Xi^-$ pairs satisfying $m_{e\Xi} < 2.5$ GeV/c^2 are selected for further analysis.

In order to obtain the p_T-differential production cross section of Ξ_c^0 baryons, the background-subtracted (WS-subtracted) yield needs to be corrected for: the signal loss due to misidentification of photonic electrons, the Ξ_b contribution in the WS pairs, the missing neutrino momentum, the detector acceptance and the track-reconstruction and the candidate-selection efficiencies. No correction is applied for possible differences in the acceptance of RS and WS pairs, which are found to be negligible for the current analysis based on a study with the mixed-event technique (i.e. by pairing electrons and Ξ^- from different events).

The first correction accounts for the signal loss caused by the misidentification of photonic electrons. The misidentification occurs when electrons from Ξ_c^0 decays accidentally have opposite-sign partners giving rise to a very small invariant mass of the e^+e^- pair. The misidentification probability is estimated to be less than 2% by applying the tagging algorithm to e^+e^+ and e^-e^- pairs. The correction is applied as a function of the p_T of the $e^+\Xi^-$ pair.

The second correction accounts for the overestimation of the background caused by $\Xi_b \to e^-\Xi^-\bar{\nu}_e X$ decays, which produce WS pairs. Since the branching ratio of Ξ_b into $e^-\Xi^-\bar{\nu}_e X$ and the Ξ_b cross section in pp collisions at LHC energies have not been measured yet, two assumptions are made to estimate this contribution. First, the shape of the transverse momentum distribution of the Ξ_b baryon is assumed to be the same as that of Λ_b^0, which was measured for $p_T > 10$ GeV/c and $|y| < 2$ by the CMS collaboration [49]. This measurement is extrapolated to $p_T = 0$ using the Tsallis function,

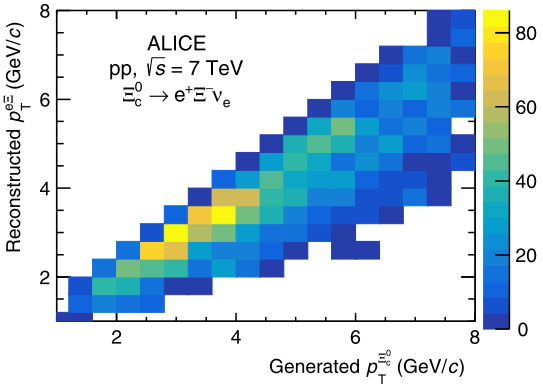

Fig. 3. Correlation between the generated Ξ_c^0-baryon p_T and the reconstructed $e^+\Xi^-$ pair p_T, obtained from the simulation based on PYTHIA 6 described in the text. (For interpretation of the colours in the figure(s), the reader is referred to the web version of this article.)

$$Cp_T\left[1+\frac{\sqrt{p_T^2+m^2}-m}{nT}\right] \quad (1)$$

whose parameters were also determined by the CMS collaboration by fitting the measured distribution. The fit parameters are consistent with those determined by the LHCb collaboration for the measurement of Λ_b^0 down to $p_T = 0$ at forward rapidity ($2 < y < 4.5$) [50]. The second hypothesis is made for the total yield of $\Xi_b \to e^-\Xi^-\bar{\nu}_e X$, which is determined by using the measurements of $BR(b \to \Xi_b) \cdot BR(\Xi_b \to \Xi^- l^- \bar{\nu} X)$ [51] and $BR(b \to \Lambda_b^0) \cdot BR(\Lambda_b^0 \to \Lambda l^- \bar{\nu} X)$ [52] in e^+e^- collisions and by assuming that the fraction of beauty quarks that hadronise into Λ_b^0 and Ξ_b baryons are the same as those in e^+e^- collisions. This assumption is supported by B-meson measurements, which show that the yield of B_s^0 mesons relative to non-strange B mesons is consistent in e^+e^- and $p\bar{p}$ collisions [53]. The Ξ_b distribution obtained with these assumptions is further processed to take into account the detector acceptance, efficiency and the momentum carried by non-reconstructed decay particles. This is done with the PYTHIA 6 simulation using GEANT3 for particle transport through the detector. The correction increases with p_T and reaches 2% at the highest p_T interval.

The transverse momentum distribution of $e^+\Xi^-$ pairs is corrected for the missing momentum of the neutrino using unfolding techniques. The response matrix to correct for the missing neutrino momentum is generated based on the correlation between the p_T of the Ξ_c^0 baryon and that of the reconstructed $e^+\Xi^-$ pair, which is obtained from the simulation described above and is shown in Fig. 3. The response matrix includes both the decay kinematics and

Table 1
Summary of systematic uncertainties on the p_T-differential cross section of $\Xi_c^0 \rightarrow e^+\Xi^-\nu_e$ for 5 p_T intervals. The uncertainty on the missing neutrino momentum is denoted as p_T^{ν} in the table.

Source	Relative systematic uncertainty (%) in the measured p_T intervals (GeV/c)				
	1–2	2–3.2	3.2–4.4	4.4–6	6–8
Raw yield	5	5	5	5	5
$(A \times \varepsilon)$	30	22	16	13	14
p_T^{ν}	29	8	6	7	10
Normalisation			3.5		

the instrumental effects, such as energy loss and bremsstrahlung in the detector material. The response matrix needs to be determined using a realistic Ξ_c^0-baryon p_T distribution. However, the distribution is not known *a priori*. Therefore, the response matrix is prepared in two steps. In the first step, the response matrix is obtained with the p_T distribution generated with PYTHIA 6. The resulting Ξ_c^0 momentum distribution is used to produce the response matrix for the second iteration. The unfolding is performed with the RooUnfold [54] implementation of the Bayesian unfolding technique [55], which is an iterative method based on Bayes' theorem. Convergence of the Bayesian method is achieved after three iterations.

The p_T-differential production cross section of Ξ_c^0 baryons multiplied by the branching ratio into the considered semileptonic decay channel is calculated from the yields obtained by the unfolding approach as follows:

$$\mathrm{BR}\cdot\frac{\mathrm{d}^2\sigma^{\Xi_c^0}}{\mathrm{d}p_T\mathrm{d}y} = \frac{N_{\Xi_c^0}}{2\cdot\Delta p_T\Delta y\cdot(A\times\varepsilon)\cdot L_{\mathrm{int}}\cdot\mathrm{BR}_{\Xi^-}}, \quad (2)$$

where $N_{\Xi_c^0}$ is the yield in a given p_T interval with width Δp_T. The yield is divided by the integrated luminosity L_{int} of the analysed sample and by the product of the branching ratios of the decays $\Xi^- \rightarrow \pi^-\Lambda$ (99.887 ± 0.035% [34]) and $\Lambda \rightarrow p\pi^-$ (63.9 ± 0.5% [34]), which is indicated as BR_{Ξ^-}. The factor 1/2 is needed because the cross section is computed for the average of Ξ_c^0 and $\overline{\Xi}_c^0$, while the raw yield includes both contributions. The factor $(A \times \varepsilon)$ is the product of the geometrical acceptance (A) and the reconstruction and selection efficiency (ε) for $\Xi_c^0 \rightarrow e^+\Xi^-\nu_e$ decays determined for Ξ_c^0 generated in $|y| < 0.8$. Finally, the yield is normalised to one unit of rapidity by dividing it by $\Delta y = 1.6$ under the assumption that the rapidity distribution of Ξ_c^0 is uniform in the range $|y| < 0.8$. This assumption is verified with an accuracy of 1% using PYTHIA 6. Note that the flatness of the rapidity distribution in $|y| < 0.8$ is also relevant for the comparison to the D^0 meson cross section, which was determined in $|y| < 0.5$ [21].

The acceptance and the efficiency are calculated from the simulations with an additional correction to take into account the fact that the elastic cross section of anti-protons is not accurate in GEANT3 [56]. The correction is calculated using the GEANT4 transport code [57], which has a more accurate description of the cross section, and found to be less than 2%. Since the acceptance and the efficiency depend on the Ξ_c^0-baryon p_T, the Ξ_c^0 should be generated with a realistic momentum distribution. This was obtained via a two-step procedure similar to that used for the response matrix. Fig. 4 shows the product of the geometrical acceptance and the reconstruction and selection efficiency $(A \times \varepsilon)$ of Ξ_c^0 as a function of p_T.

The systematic uncertainty on the Ξ_c^0 cross section has different contributions, which are the uncertainties on the raw yield (owing to the procedure of background estimation), on the $(A \times \varepsilon)$ factor (due to imperfections in the simulated samples), on the correction of the missing neutrino momentum (related to the unfolding procedure) and on the normalisation. Table 1 summarises

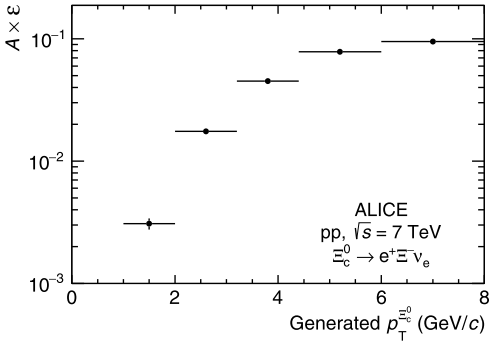

Fig. 4. Product of acceptance and efficiency $(A \times \varepsilon)$ of Ξ_c^0 baryons generated in $|y| < 0.8$ decaying into $e^+\Xi^-\nu_e$ as a function of p_T, determined from simulations PYTHIA 6 (see text).

the estimated systematic uncertainties, reporting their values in all the p_T intervals. The total systematic uncertainty is determined by adding the individual contributions in quadrature in each p_T interval.

The systematic uncertainty on the raw yield includes the uncertainties due to the WS subtraction procedure and to the estimation of the Ξ_b contribution. In the WS subtraction procedure described above, it was assumed that all the background sources contribute equally to RS and WS pairs. This is true as long as the background comprises uncorrelated pairs of electrons and Ξ^-. A systematic uncertainty of 4% on the Ξ_c^0 signal yield due to possible differences between RS and WS is estimated from simulations with the PYTHIA 6 event generator by checking the remaining contamination of background pairs in the RS yield after the subtraction of the WS pairs. The WS subtraction could also be affected by the amount of hadron contamination in the electron sample and the signal-to-background ratio of the Ξ_c^0 signal. This effect is studied by repeating the analysis with different electron identification criteria. The results obtained with these modified criteria are found to be consistent with the ones from the default selections and therefore no systematic uncertainty is assigned. The systematic uncertainty due to the Ξ_b contribution to the WS pairs is estimated by varying the Ξ_b momentum distribution within the quoted uncertainty of about 50% on the cross section of Λ_b^0 in pp collisions [49] and the quoted uncertainty of about 50% on the ratio of the fragmentation fractions of beauty quarks into Λ_b^0 and Ξ_b in e^+e^- collisions [51, 52]. The effect on the final results is found to be about 1% because the contribution from Ξ_b is small. These systematic uncertainties add up to a total uncertainty of 5% for the raw yield extraction.

The systematic uncertainties arising from the reconstruction and selection efficiencies are estimated by repeating the analysis with different selection criteria for electrons, Ξ^- and $e^+\Xi^-$ pairs and by comparing the corrected yields. Due to the statistical limitations of the Ξ_c^0 sample, the electron efficiencies are studied via variations of the track-quality criteria and of the n_σ values for the electron identification with TPC and TOF in the $\Lambda_c^+ \rightarrow e^+\Lambda\nu_e$ decays, which are analysed with the same procedure and have higher statistical significance. The RMS of the deviations of the corrected

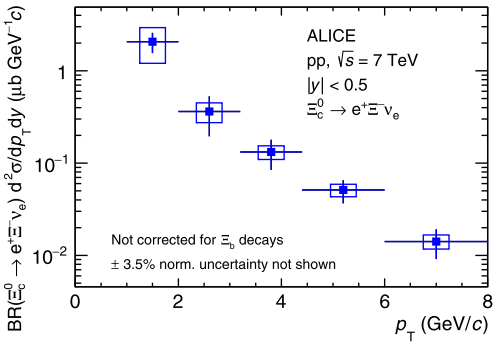

Fig. 5. Inclusive Ξ_c^0-baryon p_T-differential production cross section multiplied by the branching ratio into $e^+\Xi^-\nu_e$, as a function of p_T for $|y| < 0.5$, in pp collisions at $\sqrt{s} = 7$ TeV. The error bars and boxes represent the statistical and systematic uncertainties, respectively. The contribution from Ξ_b decays is not subtracted.

yields relative to the value obtained with the standard selection criteria, which amounts to 4% and 3%, is then assigned as a systematic uncertainty on the reconstruction and selection efficiency. Similarly, a systematic uncertainty of 1% on both the Ξ^- reconstruction and selection efficiency is estimated from the RMS deviation of the inclusive Ξ^- corrected yield against variations of the criteria applied to select the Ξ^- decay tracks and its cascade decay topology. In addition, a systematic uncertainty of 4% on the Ξ^- efficiency due to possible imperfections in the description of the detector material in the simulations [44] is considered and summed in quadrature with that estimated from the variation of the selection criteria. The uncertainties on the electron and Ξ^- track-quality criteria are considered as correlated and combined linearly. The uncertainty on the $e^+\Xi^-$ pair selection efficiency is estimated by varying the selection criteria on the opening angle and the invariant mass of the pair and a systematic uncertainty of 3–27% is assigned depending on p_T. Finally, a systematic uncertainty may also arise from an imperfect description of the acceptance of $e^+\Xi^-$ pairs in the simulation. It is estimated to be 11% by comparing the azimuthal distributions of inclusive electrons and Ξ^- baryons in the data and in the simulation. The uncertainty on the $e^+\Xi^-$ pair acceptance is summed in quadrature with that on the electron and Ξ^- selection efficiencies, resulting in a systematic uncertainty on the $(A \times \varepsilon)$ correction factor ranging from 13% to 30% depending on p_T.

The systematic uncertainty on the missing neutrino momentum correction with the unfolding procedure is evaluated by varying the prior distribution to the Bayesian unfolding and by using different unfolding techniques, such as the χ^2 minimisation method [58, 59] and the Singular Value Decomposition (SVD) method [60]. The RMS deviation of the results, ranging between 4% and 29% depending on p_T, is assigned as a systematic uncertainty. A systematic uncertainty of 3% is also assigned due to the imperfect knowledge of the Ξ_c^0-baryon p_T distributions used as input for the efficiency calculation and the unfolding procedure from the simulation. It is estimated from the difference induced in the result by adding an additional step in the iterative procedure described above to obtain the input p_T distributions. These systematic uncertainties add up to an uncertainty ranging between 6% and 29% depending on p_T.

Finally, the results have a 3.5% normalisation systematic uncertainty arising from the uncertainty in the determination of the minimum-bias trigger cross section in pp collisions at $\sqrt{s} =$ 7 TeV [41].

The p_T-differential cross section of Ξ_c^0 baryons multiplied by the branching ratio into $e^+\Xi^-\nu_e$ is shown in Fig. 5 for the p_T interval $1 < p_T < 8$ GeV/c at mid-rapidity, $|y| < 0.5$. The error bars and boxes represent the statistical and systematic uncertainties, respectively. The feed down contribution from Ξ_b, e.g.

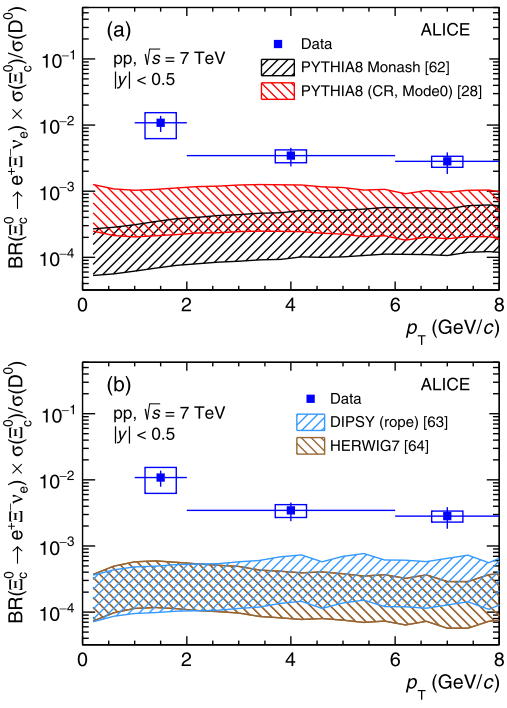

Fig. 6. Ratio of the p_T-differential cross sections of Ξ_c^0 baryons (multiplied by the branching ratio into $e^+\Xi^-\nu_e$) and D^0 mesons [21] as a function of p_T for $|y| < 0.5$, in pp collisions at $\sqrt{s} = 7$ TeV. The error bars and boxes represent the statistical and systematic uncertainties, respectively. Predictions from theoretical models, (a) PYTHIA 8 with different tunes [28,62]. (b) DIPSY [63] and HERWIG 7 [64], are shown as shaded bands representing the range of the currently available theoretical predictions for the branching ratio of the considered Ξ_c^0 decay mode.

$\Xi_b^- \to \Xi_c^0\pi^-$ [61], is not subtracted due to the lack of knowledge of the absolute branching ratios of $\Xi_b \to \Xi_c^0 + X$.

The ratio of the p_T-differential cross section of Ξ_c^0 baryons to that of D^0 mesons [21] is shown in Fig. 6. The p_T intervals of the cross-section measurements are combined to have the same p_T bin boundaries for Ξ_c^0 and D^0. The systematic uncertainty in a merged p_T interval is defined by propagating the yield extraction uncertainties of the D^0 measurement as uncorrelated among p_T intervals and all the other uncertainties of the D^0 and Ξ_c^0 measurements as correlated. The systematic uncertainty on the Ξ_c^0/D^0 ratio is calculated treating all the uncertainties on the Ξ_c^0 and D^0 cross sections as uncorrelated, except for the normalisation uncertainty that cancels out in the ratio. The ratio integrated in the transverse momentum interval $1 < p_T < 8$ GeV/c is found to be $(7.0 \pm 1.5(\mathrm{stat}) \pm 2.6(\mathrm{syst})) \times 10^{-3}$.

In Fig. 6(a), the measured transverse momentum dependence of the Ξ_c^0/D^0 ratio is compared with predictions from the PYTHIA 8.211 event generator [46,65]. PYTHIA 8 uses $2 \to 2$ processes followed by a leading-logarithmic p_T-ordered parton shower for the charm quark pair production and the hadronisation is treated with the Lund string model [66]. The figure shows the results obtained with different tunes of hadronisation: the Monash 2013 tune [62] and the Mode 0 tune from [28]. The latter is based on a model for the hadronisation of multi-parton systems, which includes string formation beyond the leading-colour approximation and is implemented in PYTHIA 8 with specific tuning of the colour reconnection parameters. As compared to the Monash 2013 tune, this model provides a better description of the measured baryon-to-meson ratios in the light-flavour sector. Two other tunes (Mode 2 and Mode 3) provided in Ref. [28] give similar Ξ_c^0/D^0 ratios as Mode 0. In Fig. 6(b), the measured ratio is also compared to other models implementing different hadronisation mechanisms: DIPSY [63]

with the rope hadronisation [67] and HERWIG 7.0.4 [64] with the cluster hadronisation [68]. To compare the data with these models, theoretical calculations of the branching ratio, which range between 0.83% and 4.2% [69–71], are used. This range defines the width of the bands shown for the model calculations represented in Fig. 6. Although the predictions of the Mode 0 tune of PYTHIA 8 are the closest to the data compared to the other models, all calculations underestimate the measured ratio significantly. Thus, this new measurement can provide an important constraint to the models of charm quark hadronisation in pp collisions, once a measurement of the absolute branching ratio of the Ξ_c^0 will become available.

In summary, we reported on the first LHC measurement of the inclusive p_T-differential production cross section of the charm-strange baryon Ξ_c^0 multiplied by the branching ratio into $e^+\Xi^-\nu_e$ in pp collisions at $\sqrt{s} = 7$ TeV. The ratio of this measurement integrated over $1 < p_T < 8$ GeV/c to the production cross section of the D^0 meson integrated over the same p_T interval was found to be $(7.0 \pm 1.5(\text{stat}) \pm 2.6(\text{syst})) \times 10^{-3}$. Several event generators with various models and tunes for the hadronisation mechanism underestimate the measured ratio.

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