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Production of D^+ and Λ_c^+ in DIS and F_2^c measurement at ZEUS

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Two recent measurements of charm production in deep inelastic *ep* scattering at HERA are presented. One analysis reconstructed D^+ and Λ_c^+ decays with a neutral strange hadron in the final state using 120 pb^{-1} of data. The kinematic region of this measurement is $0 < p_T(D^+,\Lambda_c^+) < 10$ GeV, $|\eta(D^+,\Lambda_c^+)| < 1.6$, $1.5 < \mathrm{Q}^2 < 1000$ GeV^2 and $0.02 < \mathrm{y} < 0.7$. Inclusive and single differential cross sections have been measured in this unique kinematic region. The fraction of c quarks hadronising into Λ_c^+ baryons has been measured for the first time in DIS regime.

In another analysis a lifetime tag was used for the reconstruction of $D^+ \to K^-\pi^+\pi^+$ decays based on an integrated luminosity of 323 pb^{-1}. The kinematic region of this measurement is $1.5 < p_T(D^+) < 15$ GeV, $|\eta(D^+)| < 1.6$, $5 < \mathrm{Q}^2 < 1000$ GeV^2 and $0.02 < \mathrm{y} < 0.7$. Differential cross sections of D^+ production have been measured and compared to previous results and pertubative QCD predictions. The charm contribution to the structure function, F_2^c, has been extracted.

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1. Introduction

Charm production in deep inelastic scattering (DIS) at HERA provides a test of perturbative QCD in the presence of multiple hard scales such as the photon virtuality Q^2 and the charm quark mass m_c. Heavy quark production is directly sensitive to the gluon parton density function of the proton since it predominantly occures through boson-gluon fusion (BGF). Charm events at HERA have been tagged by the presence of D mesons, lifetime tags or leptons from semileptonic decays. Two analyses of D^+ and Λ_c^+ production are reported here.

On one hand D^+ and Λ_c^+ hadrons were reconstructed in 120 pb^{-1} of HERA I data. The combinatorial background was suppressed by the usage of decay channels with a neutral strange hadron in the final state. This allowed to explore very low $p_T(D^+)$ region for the first time at HERA. Measurements of the D^+ and Λ_c^+ cross sections provide information about both c quark production and fragmentation.

On the other hand D^+ mesons were reconstructed in 323 pb^{-1} of HERA II data. A lifetime tag based on micro-vertex detector information was used to suppress the light-flavour background significantly. The current analysis uses higher integrated luminosity and improved tracking compared to the previously published ZEUS results [2].

2. Measurement of D^+ and Λ_c^+ production in deep inelastic scattering at HERA

The production of D^+ and Λ_c^+ hadrons has been studied using 120 pb^{-1} of HERA I data collected with the ZEUS detector. The kinematic region of this measurement was $0 < p_T(D^+, \Lambda_c^+) < 10$ GeV, $|\eta(D^+, \Lambda_c^+)| < 1.6$, $1.5 < Q^2 < 1000$ GeV^2 and $0.02 < y < 0.7$. The hadronic decays $D^+ \to K_S^O \pi^+$, $\Lambda_c^+ \to K_S^O p$ and $\Lambda_c^+ \to \Lambda \pi^+$ (+c.c.) were reconstructed. The presence of a neutral strange hadron in the final state significantly reduced the combinatorial background. This allowed a measurement without an explicit cut on the transverse momentum of the reconstructed charmed hadrons. It is particularly important at low Q^2, where charm quarks are prediminantly produced with low transverse momentum. Figure 1 shows the invariant mass spectrum of the reconstructed D^+ mesons in the region $0 < p_T(D^+) < 1.5$ GeV, that was not accessible in previous measurements at HERA, as well as invariant mass spectra for the two Λ_c^+ decay channels. After all cuts 691 ± 107 D^+ mesons, 79 ± 25 $\Lambda_c^+ \to K_S^O p$ baryons and 84 ± 34 $\Lambda_c^+ \to \Lambda \pi^+$ baryons were reconstructed.

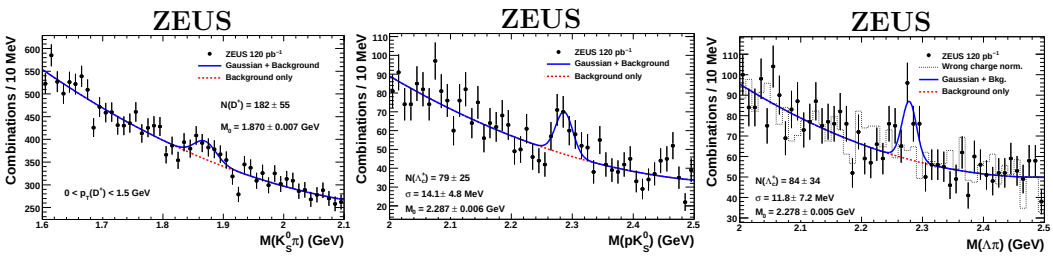

Figure 1: *The invariant mass $M(K_S^O \pi^+)$ distribution of D^+ candidates in the region $0 < p_T(D^+) < 1.5$ GeV (left) together with $M(K_S^O p)$ (center) and $M(\Lambda \pi^+)$ (right) distributions of Λ_c^+ candidates.*

The following total visible cross section of D^+ production in the kinematic region of the measurement has been obtained:

$$\sigma(D^+) = 25.7 \pm 4.1\,(\text{stat.})\ ^{+3.8}_{-5.2}\,(\text{syst.})\ \pm 0.8\,(\text{br.})\ \text{nb}.$$

A small contribution from beauty quark production was subtracted. The NLO QCD prediction for D^+ production in the massive fixed flavour number scheme (FFNS) by HVQDIS [3] was $\sigma(D^+) = 12.7\ ^{+3.8}_{-4.1}$ nb. The measured and predicted cross sections are in agreement within two standard deviations. The central value for the theoretical prediction was calculated using the charm mass of 1.5 GeV and setting the renormalisation and factorisation scales to $\mu_r = \mu_f = \sqrt{Q^2 + 4m_c^2}$. The charm quark fragmentation was modelled by the Peterson fragmentation function [4] with the parameter ε set to 0.079. Upper and lower bounds were estimated by variation of the model parameters [1]. The resulting deviations from the central value were then added in quadrature to obtain the total theoretical uncertainty.

The differential cross sections as a function of Q^2, x, $p_T^2(D^+)$ and $\eta(D^+)$ are shown in Figure 2. The HVQDIS predictions describe the shape of all measured differential cross sections reasonably well. The differential cross section in $p_T^2(D^+)$ is compared to a previous ZEUS result [5] for $p_T^2(D^+) > 9$ GeV^2. The two measurements are in good agreement.

The following total visible cross section of Λ_c^+ production were measured:

- using the decay channel $\Lambda_c^+ \to K_S^0 p$: $\sigma(\Lambda_c^+) = 14.9 \pm 4.9\,(\text{stat.})\ ^{+2.2}_{-2.6}\,(\text{syst.})\ \pm 3.9\,(\text{br.})$ nb;

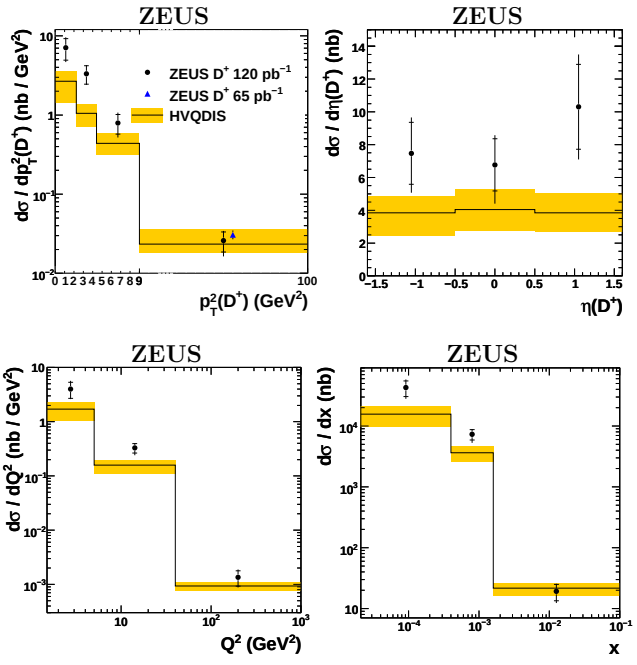

Figure 2: *Differential D^+ cross sections as a function of $p_T^2(D^+)$, $\eta(D^+)$, Q^2 and x. The data (black circles) are compared to the previous ZEUS result (blue triangle) and to the NLO QCD calculations by HVQDIS (central value together with an uncertainty band). Inner error bars show the statistical uncertainties and outer error bars show the statistical and systematic uncertainties added in quardature.*

- using the decay channel $\Lambda_c^+ \to \Lambda\pi^+$: $\sigma(\Lambda_c^+) = 14.0 \pm 5.8\,(\text{stat.})\ ^{+3.8}_{-3.3}\,(\text{syst.})\ \pm 3.7\,(\text{br.})$ nb.

The measurements in the two decay channels were combined taking into account correlations between the systematic uncertainties. This combined cross section together with the total cross section for D^+ were combined with the previous ZEUS D^0, D^+ and D_s^+ measurements in DIS in a slightly different kinematic region [5] to extract the Λ_c^+ fragmentation fraction:

$$f(c \to \Lambda_c^+) = 0.117 \pm 0.033\,(\text{stat.})\ ^{+0.026}_{-0.022}\,(\text{syst.})\ \pm 0.027\,(\text{br.}).$$

The fragmentation fraction f$(c \to \Lambda_c)$ has already been measured in photoproduction (PHP) regime [6] and at e^+e^- colliders [7]. Hence a measurement in DIS is a useful test of fragmentation universality. All measurements are in agreement within the errors.

3. Measurement of D^+ production production and F_2^c extraction in deep inelastic scattering at ZEUS

HERA II data with an integrated luminosity of 323 pb^{-1} collected from 2005 to 2007, were used to measure D^+ meson production in DIS. The D^+ mesons were reconstructed in $D^+ \to K^-\pi^+\pi^+$ (+c.c.) decay mode. The measurement covered a kinematic region of $1.5 < p_T(D^+) < 15$ GeV, $|\eta(D^+)| < 1.6$, $5 < \text{Q}^2 < 1000$ GeV^2 and $0.02 < \text{y} < 0.7$.

The purity of the D meson signal was increased through the use of the signed two dimensional decay length significance (S_l). It is defined as a two dimensional projection of the distance from the secondary vertex to the primary point of interaction, projected onto D^+ momentum vector divided by the error of this projection. Selected D^+ candidates were required to have χ^2 of the decay vertex less than 9 (for 3 degrees of freedom) and S_l higher than 4.

Figure 3 shows an invariant mass spectra of D^+ candidates before and after the S_l cut was applied. The statistical uncertainty on the number of reconstructed D^+ mesons was reduced from 6.3% to 2.3%. After all cuts 7206 ± 168 D^+ candidates were collected.

Differential cross sections of D^+ production were measured as a function of Q^2, y, $p_T(D^+)$, $\eta(D^+)$ and double differentially in Q^2 and y. The single differential cross sections of D^+ production are shown in Figure 4. A small contribution from beauty quark production was subtracted using Monte Carlo. The data have not been corrected to QED Born level yet. The measured cross

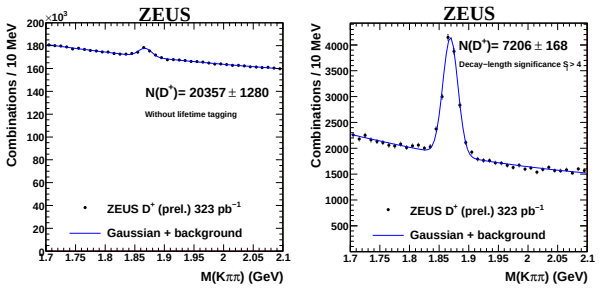

Figure 3: *The effect of the S_l cut on the statistical precision of the reconstructed D^+ signal. The invariant mass $M(K\pi\pi)$ distribution before (left) and after (right) cut on S_l.*

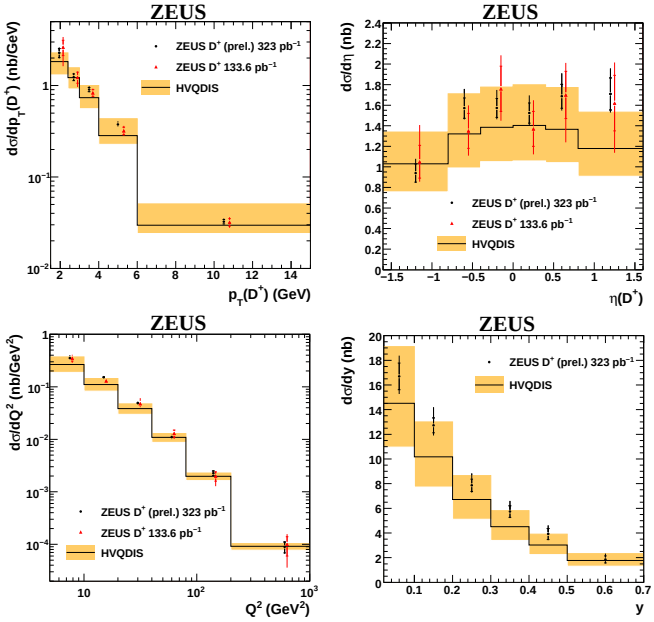

Figure 4: *The measured cross sections for D^+ production as a function of $p_T(D^+)$, $\eta(D^+)$, Q^2 and y. The data(black circles) are compared to the previous ZEUS measurements (red triangles) and to the NLO QCD predictions by HVQDIS (central value together with an uncertainty band).*

sections are compared to the previously published ZEUS measurement [2] and the NLO QCD predictions by HVQDIS . This analysis is significantly improved in both statistical and systematic precision compared to the previous ZEUS results. The current measurement agrees with the NLO QCD predictions within uncertainties. The setup for NLO QCD calculations was similar to the one described in Section 2 of this review.

The cross sections of D^+ production, measured double differentially in bins of Q^2 and y, were used to extract the charm contribution to the proton structure function F_2: F_2^c. The inclusive double differential cross sections of charm quark production at low y, neglecting small F_L contribution, can be parametrized as:

$$\frac{d^2\sigma^{c\bar{c}}}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4}[1+(1-y)^2]F_2^c(x,Q^2).$$

The extraction of F_2^c requires some model assumptions to extrapolate the measured cross sections to the full phase-space in $p_T(D^+)$ and $\eta(D^+)$ and to model the fragmentation of a c quark into a D^+ meson. The uncertainty related to the model assumptions was estimated from the variation of model parameters [1].

Figure 5 shows the extracted values of F_2^c compared to H1 and ZEUS combined results [8] and HERAPDF1.0 predictions [9]. The inner error bars represent experimental statistical and systematic uncertainties added in quadrature. Outer bars show statistical, systematic and estimated theoretical uncertainties summed in quadrature. The theoretical uncertainty is dominant at low and medium Q^2. Current measurement agrees with the combination of all previous measurements of the H1 and ZEUS collaborations using different techniques and with the theoretical predictions.

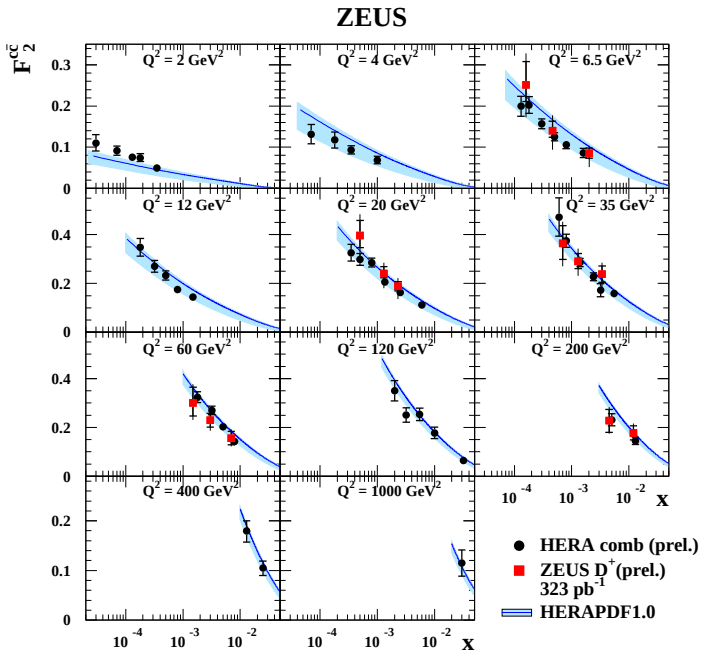

Figure 5: *The measured F_2^c as a funtion of x for the fixed values of Q^2. Results of the current analysis (red squares) are compared to the ZEUS and H1 combined F_2^c results and predictions by HERAPDF1.0.*

4. Conclusions

Charm production in DIS has been measured through the reconstruction of D^+ and Λ_c^+ hadrons. The D^+ cross sections are in agreement with NLO QCD predictions and previously published ZEUS results. F_2^c has been extracted, and is in agreement with the combination of all previous measurements. The Λ_c^+ fragmentation fraction has been measured for the first time in DIS.

References

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