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CHARM PRODUCTION IN DEEP INELASTIC SCATTERING

MATTHEW WING
(ON BEHALF OF THE ZEUS COLLABORATION)
Bristol University, ZEUS, DESY
Notkestrasse 85, 22607 Hamburg, Germany
E-mail: wing@mail.desy.de

Precise measurements of charm production in deep inelastic scattering are presented and compared with next-to-leading-order QCD. The data show sensitivity to the choice of parametrisation of the gluon density in the proton and could be used in future global fits of the parton densities.

1 Introduction

Charm quarks are produced copiously in deep inelastic scattering (DIS) at HERA. At sufficiently high photon virtualities, Q^2, the production of charm quarks constitutes up to 30% of the total cross section [1,2]. Previous measurements of D^* cross sections [1,2,3,4] indicate that the production of charm quarks in DIS in the range $1 < Q^2 < 600$ GeV^2 is consistent with QCD calculations in which charm is produced through the boson-gluon-fusion mechanism. This implies that the charm cross section is directly sensitive to the gluon density in the proton.

In this paper, measurements of the D^* cross section [5] are presented with improved precision and in a kinematic region extending to higher Q^2 than the previous ZEUS results [1]. The cross sections are compared to a next-to-leading-order (NLO) QCD calculation using various parton density functions (PDFs) in the proton. In particular, the data are compared to calculations using the recent ZEUS NLO fit [6], in which the parton densities in the proton are parametrised by performing fits to inclusive DIS measurements from ZEUS and fixed-target experiments. The cross-section measurements are used to extract the charm contribution, $F_2^{c\bar{c}}$, to the proton structure function, F_2.

2 Results

An integrated luminosity of 82 pb^{-1} was used, more than double that of the previous ZEUS result [1]. Events were selected in a DIS regime defined by the kinematic region $1.5 < Q^2 < 1000$ GeV^2 and the inelasticity, y, restricted to $0.02 < y < 0.7$. Charm quarks were identified in these events by tagging a D^* meson in the decay channel $D^* \to D^0\pi_s \to K\pi\pi_s$. Transverse momentum, $p_T(D^*)$, and pseudorapidity, $\eta(D^*)$, requirements on the D^* meson, governed mainly by the acceptance of the tracking detector, were $1.5 < p_T(D^*) < 15$ GeV and $|\eta(D^*)| < 1.5$. After all cuts, 5545 ± 129 D^* mesons remained for cross-section measurements.

The D^* production rate, $r = N/\mathcal{L}$, in the e^-p data set is systematically higher than that in the e^+p data set. This difference increases with Q^2; for example, the ratio of the rates, r^{e^-p}/r^{e^+p}, is equal to 1.12 ± 0.06 for $1.5 < Q^2 < 1000$ GeV^2, while for $40 < Q^2 < 1000$ GeV^2 it is 1.67 ± 0.21 (only statistical errors are given). Such a difference in production cross sections is not expected from known physics processes. Many checks were performed to try and understand this observed difference; none gave an indication of its source. Therefore, the difference in rate is assumed to be a statistical fluctuation and the two sets of data were combined for the final results. An increased sample of e^-p data can resolve the issue.

The differential D^* cross sections as a function of Q^2, x, $p_T(D^*)$ and $\eta(D^*)$ are shown in Figure 1 compared with predictions from an NLO QCD calculation [7]. Predictions are shown for two PDFs: ZEUS NLO and CTEQ5F3 [8]; and two hadronisation schemes: the Peterson function and the Lund string fragmentation [9] as in Aroma [10]. For all cross sections, the NLO predictions give a reasonable description of the data. The NLO calculation does, however, exhibit a somewhat different shape, particularly for $d\sigma/dx$, where the NLO is below the data at low x and above the data at high x. The predictions using CTEQ5F3 instead of the ZEUS NLO fit, or using Aroma for the hadronisation instead of the Peterson function, give better agreement with the data. The prediction using the ZEUS NLO fit gives a better description than that using CTEQ5F3 (and also better than the prediction using GRV98-HO [11], not shown) for the cross-section $d\sigma/d\eta(D^*)$. A better description is also achieved by using Aroma for the hadronisation, although, in this case, $d\sigma/dp_T(D^*)$ is not so well described. Further refinement of NLO QCD fits and even the use of these data in future fits may achieve a better description.

The open-charm contribution, $F_2^{c\bar{c}}$, to the proton structure-function F_2 can be defined in terms of the inclusive double-differential $c\bar{c}$ cross section in x and Q^2 by

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

In this analysis, the $c\bar{c}$ cross section is obtained by measuring the D^* production cross section and employing the hadronisation fraction $f(c \to D^*)$ to derive the total charm cross section. Since only a limited kinematic region is accessible for the measurement of D^* mesons, a prescription for extrapolating to the full kinematic phase space is needed. The measured $F_2^{c\bar{c}}$ in a bin i is given by

$$F_{2,\text{meas}}^{c\bar{c}}(x_i,Q_i^2) = \frac{\sigma_{i,\text{meas}}(ep \to D^*X)}{\sigma_{i,\text{theo}}(ep \to D^*X)} F_{2,\text{theo}}^{c\bar{c}}(x_i,Q_i^2), \quad (2)$$

where σ_i are the cross sections in bin i in the measured region of $p_T(D^*)$ and $\eta(D^*)$. The value of $F_{2,\text{theo}}^{c\bar{c}}$ was calculated from the NLO coefficient functions [6]. In this calculation, the same parton densities, charm mass ($m_c = 1.35$ GeV), and factorisation and renormalisation scales ($\sqrt{4m_c^2 + Q^2}$) have been used as for the NLO QCD calculation of the differential cross sections. The hadronisation was performed using the Peterson fragmentation function. Typical extrapolation factors to the full phase space in $p_T(D^*)$ and $\eta(D^*)$ are 4.7 at low Q^2 and 1.5 at high Q^2.

The data for $F_2^{c\bar{c}}$ as a function of x for fixed Q^2 are compared in Figure 2 with previous measurements from H1 [2] and ZEUS [1] and with the ZEUS NLO fit. The three sets of data are consistent. The values of $F_2^{c\bar{c}}$ are also presented as a function of Q^2 at fixed values of x and compared with the ZEUS NLO fit in Figure 2. The data

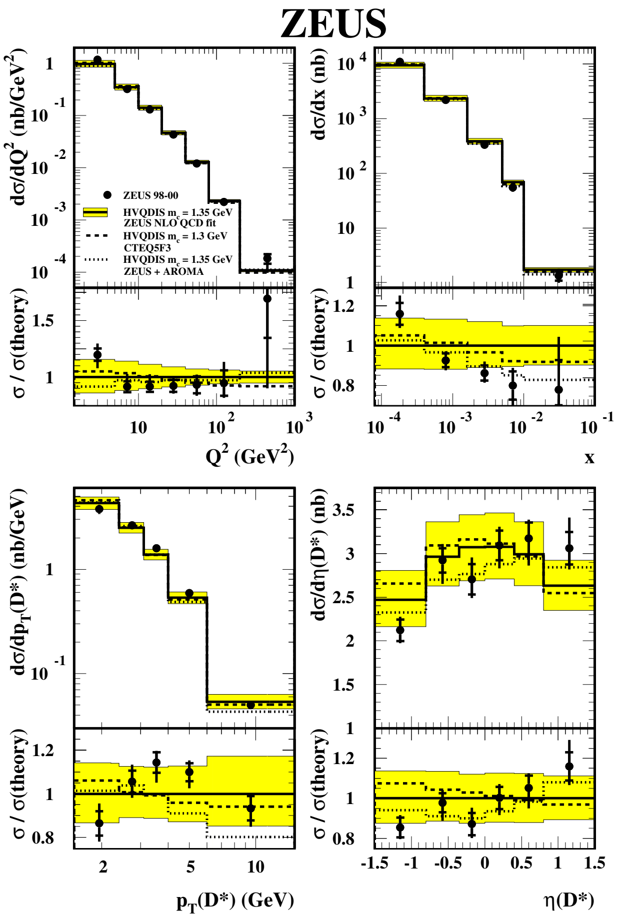

Figure 1. Differential cross sections compared to predictions from NLO QCD. The ratios of the cross sections to the central NLO QCD predictions are also shown beneath each plot.

rise with increasing Q^2, with the rise becoming steeper at lower x, demonstrating the property of scaling violation in charm production. The prediction describes the data well for all Q^2 and x. The uncertainty on the theoretical prediction is that from the PDF fit propagated from the experimental uncertainties of the fitted data. At the lowest Q^2, the uncertainty in the data is comparable to the PDF uncertainty shown. This implies that the double-differential cross sections could be used as an additional constraint on the gluon density in the proton.

3 Conclusions

The production of D^* mesons has been measured in DIS at HERA. Predictions from NLO QCD are in reasonable agreement with the measured cross sections, which show sensitivity to the choice of PDF and hence the gluon distribution in

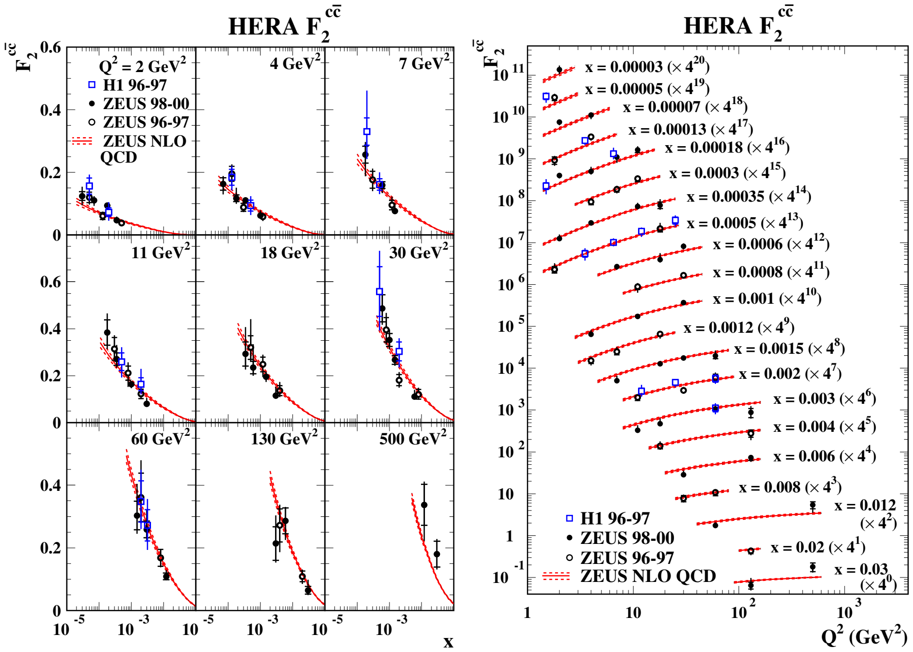

Figure 2. The measured $F_2^{c\bar{c}}$ as a function of x for fixed Q^2 and as a function of Q^2 for fixed x. The current data are compared with previous H1 and ZEUS measurements the predictions from the ZEUS NLO QCD fit.

the proton. The ZEUS NLO PDF, which was fit to recent inclusive DIS data, gives the best description of the D^* data. In particular, this is seen in the cross-section $d\sigma/d\eta(D^*)$. The double-differential cross section in y and Q^2 has been measured and used to extract the open-charm contribution to F_2. Since, at low Q^2, the uncertainties of the data are comparable to those from the PDF fit, the measured differential cross sections should be used in future fits to constrain the gluon density.

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