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CHARM PRODUCTION AND F_2^c AT HERA*

Olaf Behnke

Physikalisches Institut, Universität Heidelberg
Philosophenweg 12, 69120 Heidelberg, Germany

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H1 and ZEUS results on open charm production in deep inelastic ep scattering at HERA are reviewed. The corresponding results for the proton structure function $F_2^c(x, Q^2)$ are discussed.

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1. Introduction

Open charm in deep inelastic ep collisions at HERA is mainly produced via the Boson Gluon Fusion (BGF) process shown in Fig. 1.

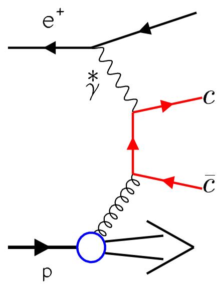

Fig. 1. Charm production from boson gluon fusion.

The study of such processes is of multifold interest:

- Measuring charm production in BGF gives direct access to the gluon distribution in the proton.

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- Charm production cross-sections are large and contribute in certain kinematical regions up to $\approx 30\%$ to the total event rate. Hence a precise knowledge is mandatory for the understanding of *inclusive* proton structure data.
- Charm production in DIS is an excellent testing ground for pQCD. In the kinematic region $Q^2 \leq m_c^2$ it is expected that NLO ($\mathcal{O}(\alpha_s^2)$) QCD calculations in the so-called *massive* scheme give reliable results. In this scheme u, d and s are the only active quark flavors in the proton and heavy quarks are dynamically produced via BGF. However, at larger virtualites a better description is expected from the so-called *massless* scheme, in which the heavy quarks are treated as sea quarks in the proton.
- Charm production is also important to look for deviations from the DGLAP QCD evolution scheme, which is used to relate the proton gluon densities at different Q^2 scales. The CCFM evolution scheme predicts different kinematics for the gluon entering the BGF process. This can be tested with the LO CASCADE MC [2], containing the CCFM evolution.

Open charm production in DIS is measured by reconstructing D^* meson decays or identifying electrons from charm decays. Table I summarizes the presented data sets (published in [3, 4, 6]).

TABLE I

Presented data sets

Collab.	ZEUS	H1	ZEUS
Channel	$D^* \to K2\pi(K4\pi)$	$D^* \to K2\pi$	$c \to ex$
Data	1996–1997	1997	1996–1997
Lumi $\mathcal{L}$	37 pb^{-1}	18 pb^{-1}	34 pb^{-1}
Kinematic cuts	$1 < Q^2 < 600$ GeV^2 $0.02 < y < 0.7$	$1 < Q^2 < 100$ GeV^2 $0.05 < y < 0.7$	$1 < Q^2 < 1000$ GeV^2 $0.03 < y < 0.7$
Selection cuts	$p_{\rm T}(D^*) > 1.5(2.5)$ GeV $\lvert\eta(D^*)\rvert < 1.5$	$p_{\rm T}(D^*) > 1.5$ GeV $\lvert\eta(D^*)\rvert < 1.5$	$1.2 < p_e < 5$ GeV $\lvert\eta_e\rvert < 1.1$

2. Results

Fig. 2 shows the measured ZEUS [4] and H1 [3] differential cross-sections of events with identified D^* mesons in the visible kinematical ranges as defined in Table I. The data are compared to *massive scheme* NLO calculations

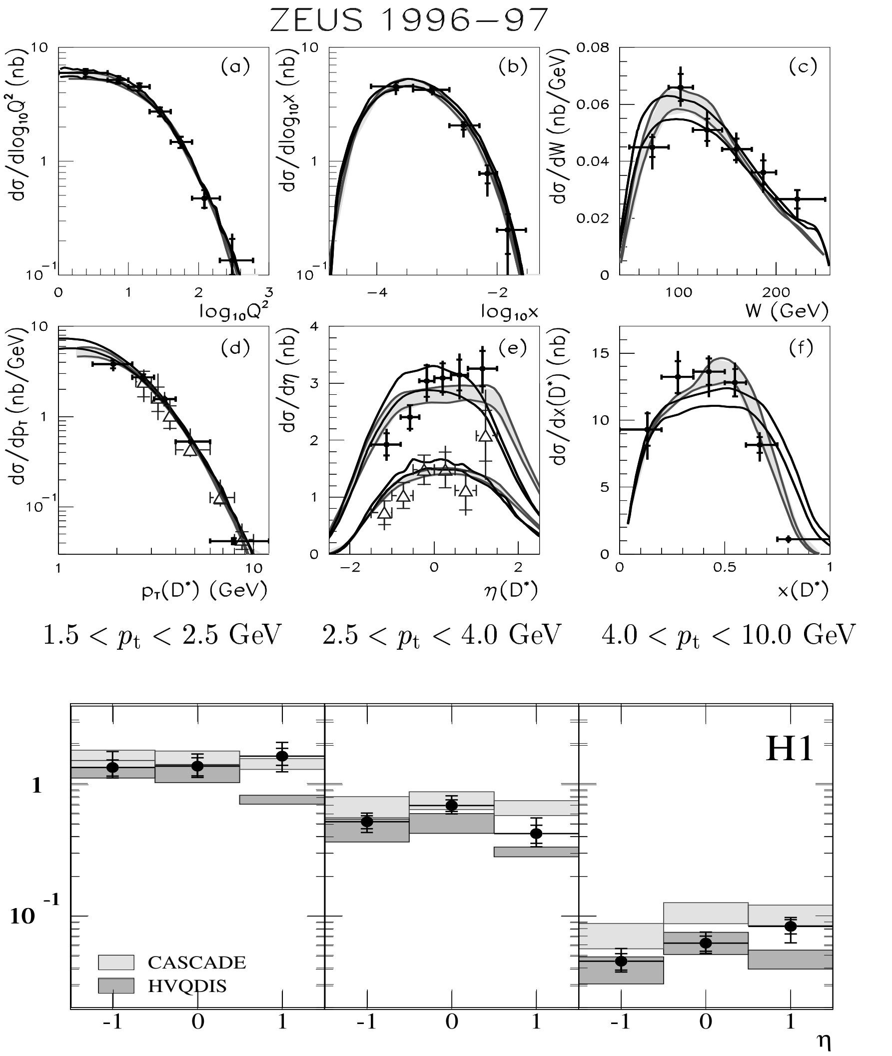

Fig. 2. ZEUS (top) and H1 (bottom) differential cross-section measurements of events with identified D^* mesons. The measured $D^{*+} \to K2\pi$ ($D^{*+} \to K4\pi$) results are shown as black dots (open triangles) with error bars. For the ZEUS results the black curves (shaded band) represent the prediction and errorband of HVQDIS with using Peterson (Lund) $c \to D^*$ fragmentation.

using the program HVQDIS [5] with input parameters listed in Table II. Upper and lower curves or error bands shown in Fig. 2 indicate the NLO calculation uncertainties as obtained from variations of the charm mass, renormalisation and factorisation scales μ_r, μ_f, strong coupling constant α_s and Peterson fragmentation parameters (see Table II).

TABLE II

Details of the NLO calculations.

Collaboration	ZEUS	H1
Programs	"HVQDIS" (Harris & Smith)	
PDFs	ZEUS F2 NLO Fit	GRV98-HO
Charm mass	$1.3 < m_c < 1.5$ GeV	
Scales	$\mu_r = \mu_f = k\sqrt{Q^2 + 4m_c^2}$;	$0.5 < k < 2$
Fragmentation $\parallel$	$\varepsilon_c = 0.035$	$0.035 < \varepsilon_c < 0.1$
Fragmentation $\perp$	—	$p_{\rm t} \exp(-\alpha p_{\rm t})$
$f(c \to D^*)$	0.222 (OPAL)	0.233 (ALEPH)

The distributions of the event kinematic quantities Q^2, Bjorken x and γp invariant mass W are well described by the NLO calculation both in shape and normalisation. While the $p_{\rm T}(D^*)$ distributions are also well predicted, both ZEUS and H1 observe more D^* mesons in the forward region (positive $\eta(D^*)$) compared to the HVQDIS calculations. It is important to note that H1 and ZEUS use different ingredients in their HVQDIS calculations. The main differences are the gluon densities in the proton and the $c \to D^*$ fragmentation, where H1 allows the D^* mesons to obtain a transversal momentum with respect to the charm quark direction, which is neglected by ZEUS. If the NLO calculation of ZEUS is reweighted with the LUND string fragmention, shown as shaded band in Fig. 2, a better description of the $\eta(D^*)$ spectrum is obtained. Fig. 2 shows also the comparison of the H1 D^* meson data with the CASCADE MC [2]. This model predicts more D^* mesons to be produced in the forward rapidity region which is in good agreement with the data.

In the following the measurements of the charm contribution to the total DIS cross-sections are discussed. Neglecting small contributions from the structure functions F_3 and $F_{\rm L}$, the inclusive DIS cross-section can be written as

$$\frac{d^2\sigma^{ep}}{dQ^2dx} = \frac{2\pi\alpha^2}{Q^4x}\, t\left(1 + (1-y)^2\right)\, F_2\left(x, Q^2\right) .$$

The structure function F_2^c is defined as the part of F_2 associated to events with charm production, *i.e.* where on the left side of the above equation σ^{ep} is replaced by $\sigma^{ep\to c\bar{c}}$ an on the right side F_2 by F_2^c . Note that this is a generic definition, independent of the production mechanism details. To determine F_2^c both H1 and ZEUS use the HVQDIS program [5] to extrapolate the measured D^* meson and electron cross-sections from the visible ranges as listed in the last row of table 1 to the full kinematic range. The extrapolation factors are large, typically varying from 1.5 to 10, depending strongly on Q^2 and on the analysed channel. Note that this introduces a large systematic model uncertainty. If one uses for the extrapolation the CASCADE MC instead of HVQDIS, results for F_2^c are obtained which differ up to 20%.

Fig. 3 shows the F_2^c results [3,4,6] in bins of Q^2 as function of Bjorken x. The measurements of H1 and ZEUS agree well with each other and also with the HVQDIS NLO calculation. A strong rise of F_2^c towards higher Q^2 and small x is observed, which reflects the kinematical behaviour of the proton gluon density. The ratio $F_2^c\ /F_2$, which is a measure for the contribution of charm to the total ep cross-section, approaches at the smallest x and highest Q^2 accessible regions values of ≈ 0.3. This shows that BGF is in this kinematic domain the dominant ep scattering process and that the "quark democratic" limit of 4/11 is almost reached. In this limit u, d, s, c and b quarks are expected to contribute to BGF with weights proportional to their electric charge squared.

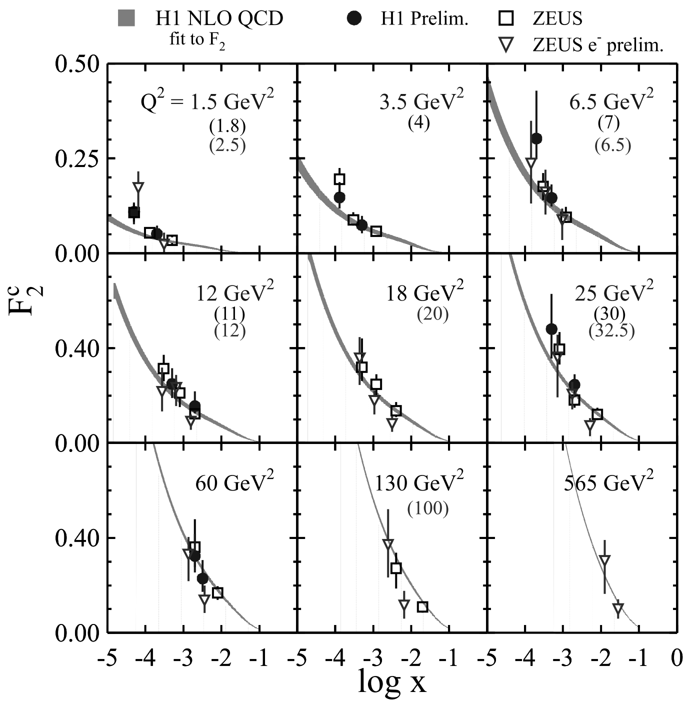

Fig. 3. F_2^c measurement results and comparisons with NLO QCD.

3. Conclusions

We have presented measurements of open charm production in deep inelastic ep scattering at HERA. The measured cross-section are generally in good agreement with the predictions from *massive scheme* NLO calculcations. Discrepancies are observed in the D^* meson rapidity shapes, which are sensitive to the charm quark fragmentation. The structure function F_2^c rises strongly towards small x and high Q^2, where the proton gluon densities are large and charm production from BGF contributes up to about 30% to the total ep scattering cross-section.

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