Extraction of $\mathbf{F_2^c(x, Q^2)}$ from $\mathbf{D^{*\pm}}$ cross sections at H1

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The charm contribution to the proton structure, $F_2^c\left(x, Q^2\right)$, is determined using the inclusive cross sections of $D^{*\pm}(2010)$ meson production in deep-inelastic scattering. The cross section measurement covers the region $5 < Q^2 < 1000$ GeV^2 in photon virtuality and $0.02 < y < 0.70$ in the inelasticity of the scattering process. The $D^{*\pm}$ meson is measured in transverse momentum and pseudo-rapidity down to $p_T > 1.5$ GeV and up to $|\eta| < 1.5$. The data were taken with the H1 detector corresponding to an integrated luminosity of 347 pb^{-1}. F_2^c is determined from the D^* production cross sections and compared to leading and next-to-leading order perturbative QCD predictions.

1   Introduction

The charm quark production in electron-proton (ep) scattering is dominated by the boson-gluon-fusion (BGF) process ($\gamma p \rightarrow c\bar{c}$). The charm contribution, $F_2^c(x, Q^2)$, to the proton structure is obtained by using the expression for the one photon exchange cross section for charm production:

$$\frac{d^2\sigma^c}{dxdQ^2} = \frac{2\pi\alpha_{em}^2}{Q^4 x}\left(1 + (1-y)^2\right) F_2^c(x, Q^2) . \tag{1}$$

The y range of the measurements is such that the contribution from the longitudinal structure function F_L^c is negligible. The current analysis [1] uses data taken with the H1 detector [2] during the HERA-II running period at a centre-of-mass energy of $\sqrt{s} = 318$ GeV. Preliminary results [3, 4] of the inclusive D^* cross section measurements at medium and high Q^2 are used. Compared to early results [5] by H1 a larger phase space and a significantly larger integrated luminosity of 347 pb^{-1} has been used. Hence, more precise tests of perturbative QCD (pQCD) become possible.

2   Theoretical Models of Open Charm Production

The description of heavy flavour production in ep collisions is based on pQCD at leading order (LO) or at next-to-leading order (NLO) for which calculations in several schemes are available [6, 7]. In this analysis, the $D^{*\pm}$ meson cross sections in the visible range, as well as the charm contribution to the proton structure function are calculated using two different models. On the one hand the HVQDIS program [6] is used. It is based on a NLO calculation in the fixed-flavor-number-scheme (FFNS) providing differential cross sections of massive charm quarks including mass effects at the production threshold. The parton evolution is performed according to the DGLAP evolution equations [8]. HVQDIS applies independent fragmentation. On the other hand the LO Monte Carlo program CASCADE [9], supplemented with parton showers, based on the CCFM evolution scheme is used. The CCFM evolution equations [10] are expected to be more appropriate to describe the parton

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evolution at small x. The hadronisation of partons is performed using the Lund String model as implemented in PYTHIA [11]. In case of HVQDIS the proton parton density function (PDF) MRST04FF3nlo [12] is used, while for CASCADE the proton PDF parametrisation A0 [13] is used. The renormalisation and factorisation scale for both pQCD calculations has been set to $\mu_{r,f}^2 = 4m_c^2 + Q^2$.

2.1 Fragmentation Model

Differential inclusive cross sections of charmed mesons are calculated using the HQVDIS program after fragmenting the charm quarks into $D^{*\pm}$ mesons. The Kartvelishvili fragmentation function [14] is used, which is controlled by a single parameter α. This is also used for CASCADE, where higher charm resonances as determined by ALEPH [15] are included. The charm fragmentation function was measured at H1 using inclusive $D^{*\pm}$ meson production associated with jet production, where a different behaviour of the fragmentation function close to the threshold of charm production and far above the threshold is reported [16]. This results in different values for α (see Table 1), which suggests a $\hat{s}$-dependent charm fragmentation function. $\hat{s}$ denotes the invariant mass of the produced $c\bar{c}$ pair. Since the fragmentation model influences the kinematic distributions of the D^* meson an additional uncertainty from the fragmentation model is assigned.

3 $D^{*\pm}$ Cross Section Data & Extraction of $F_2^c(x, Q^2)$

The cross section measurement covers the kinematic region of $5 < Q^2 < 1000$ GeV^2 and $0.02 < y < 0.70$ in the inelasticity of the scattering process. The visible range of the $D^{*\pm}$
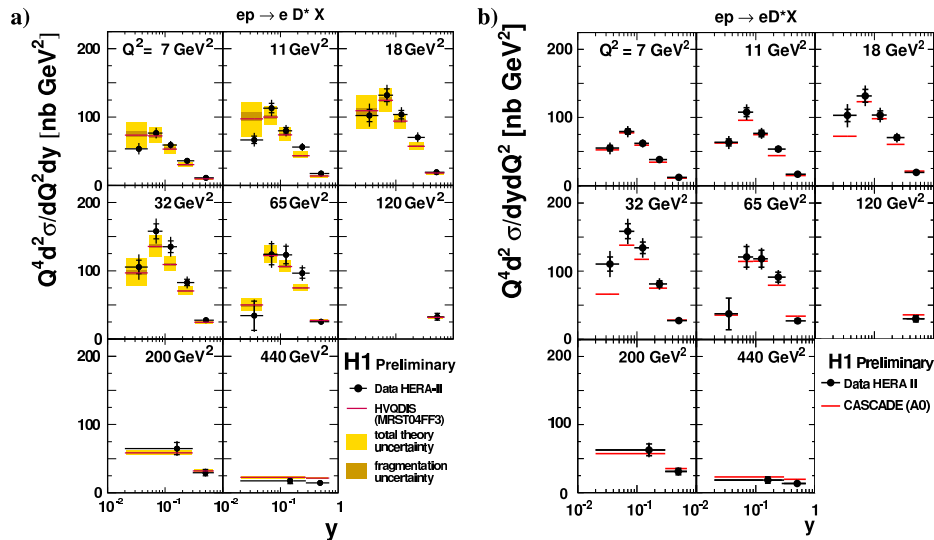

Figure 1: The double differential cross section in y and Q^2 compared to the prediction from HVQDIS a) and to the prediction provided by CASCADE b). The $\hat{s}$-dependent charm fragmentation function is used for both predictions. The shaded band in a) reflects the theoretical uncertainty estimated by parameter variations given in Table 1.

meson measurement is restricted to $p_T(D^*) > 1.5$ GeV and $|\eta(D^*)| < 1.5$. The double differential cross section as a function of Q^2 and y is shown in Figure 1a) compared to the prediction from HVQDIS and in b) for CASCADE. Both describe the data reasonably well. A total experimental error of 9% was achieved. These data are used for the extraction of F_2^c. The measured inclusive $D^{*\pm}$ cross sections $\sigma_{\text{vis}}^{\exp}(y, Q^2)$ in bins of y and Q^2 are converted to a bin centre corrected $F_2^{c\ \exp}(\langle x \rangle, \langle Q^2 \rangle)$ by the relation:

$$F_2^{c\ \exp}(\langle x \rangle, \langle Q^2 \rangle) = \frac{\sigma_{\text{vis}}^{\exp}(y, Q^2)}{\sigma_{\text{vis}}^{\text{theo}}(y, Q^2)} \cdot F_2^{c\ \text{theo}}(\langle x \rangle, \langle Q^2 \rangle) \ , \tag{2}$$

where $\sigma_{\text{vis}}^{\text{theo}}$ and $F_2^{c\ \text{theo}}$ are the theoretical predictions from the model under consideration. The Bjørken variable x is related to y via $x = Q^2/y \cdot s$. The contribution of open beauty production to the visible $D^{*\pm}$ meson cross sections is estimated to be of the order of 1-2% and is therefore neglected. The extraction of $F_2^{c\ \exp}$ is faced with an intrinsic problem as the measurement covers about 30% of the total phase space for charm production. The ratio $\sigma_{\text{full}}^{\text{theo}}/\sigma_{\text{vis}}^{\text{theo}}$ is the extrapolation factor to the full phase space which depends strongly on the underlying model. The ratio of the extrapolation factors from CASCADE normalised to HVQDIS is shown in Figure 2, where in general an agreement between the models at the level of 10% is observed. This is not the case for the highest x region, where differences in extrapolation of 80% are observed, which is known to depend strongly on the η region of the D^* cross section measurement. If extended to $|\eta(D^*)| < 1.9$ this differences go down to 20% [17].

Figure 2: The extrapolation factors from CASCADE are normalised to the ones obtained by HVQDIS.

3.1 Extrapolation Uncertainties

The extrapolation needed to determine $F_2^{c\ \exp}$ depends significantly on the underlying model and introduce extrapolation uncertainties. These are estimated by varying the model parameters like charm mass, renormalisation and factorisation scales, PDF set and fragmentation parameters. The parameter variations together with the average relative uncertainties are summarised in Table 1.

3.2 Results

F_2^c determined from the inclusive $D^{*\pm}$ cross sections as a function of x for different values of Q^2 is shown in Fig. 3a) or b) using either HVQDIS or CASCADE for the extrapolation
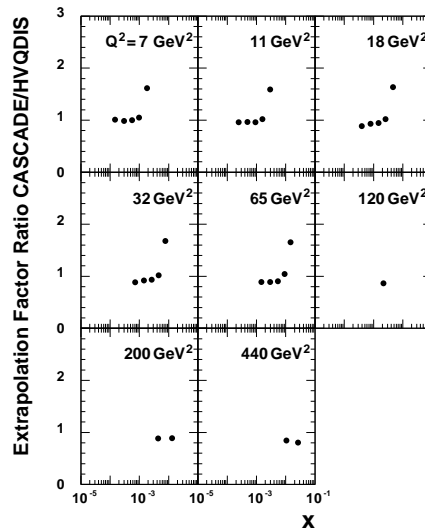
name	variation (HVQDIS)	rel. unc.	variation (CASCADE)	rel. unc.
charm mass	$1.3 < m_c < 1.6$ GeV	6%	$1.3 < m_c < 1.6$ GeV	7%
scale $\mu_0^2 = Q^2 + 4m_c^2$	$0.5 < \mu_{r,f}/\mu_0 < 2$	4%	$0.5 < \mu_{r,f}/\mu_0 < 2$	2%
PDF	CTEQ5f3 & MRST04ff3	13%	A0−, A0 , A0+	2%
$\hat{s}$ fragmentation:				
low $\hat{s}(< 70$ GeV^2)	$\alpha = 6.0^{+1.0}_{-0.8}$		$\alpha = 8.2 \pm 1.1$	
high $\hat{s}(> 70$ GeV^2)	$\alpha = 3.3 \pm 0.4$	5 %	$\alpha = 4.6 \pm 0.6$	8%
$\hat{s}$ threshold	70 ± 20 GeV^2	2 %	70 ± 20 GeV^2	2%

Table 1: Uncertainty of quantities which is utilised for the estimation of the extrapolation uncertainty calculated from HVQDIS and CASCADE. The relative uncertainties on the extrapolation factor are summarised.

to the full phase space. The inner error bar corresponds to the statistical error, whereas the outer is the systematic error added in quadrature. The relative uncertainties from the fragmentation model are added in quadrature to the systematic uncertainty of the data, whereas all other extrapolation uncertainties are indicated by a shaded band at the bottom of a certain Q^2 bin of F_2^c as shown in figure 3a) and b). The prediction of HVQDIS using the proton PDF CTEQ5f3 is shown in Fig. 3a) by the dark solid line and describes the data rather well. In addition also MRST04FF3 was used with HVQDIS, which underestimates the data slightly at low x and Q^2. In case of CASCADE the unintegrated gluon distribution A0 was used and is indicated in Fig. 3b) by the solid line, which describes the data nicely. A comparison of F_2^c using HVQDIS or CASCADE shows differences dominantly at high x and especially a steeper slope towards low x for the values extracted with HVQDIS.

4 Conclusions

The charm contribution, F_2^c, to the proton structure was determined using the measured cross sections of D^* production in y and Q^2. Two theoretical models, HVQDIS and CAS-CADE, were used for the extrapolation in $p_T(D^*)$ and $\eta(D^*)$ of the visible cross section to the full phase space. Differences between the extrapolation factors of these models are observed at high x. The uncertainty of the fragmentation model has been estimated from results of an H1 measurement. The total theory uncertainties are much larger than the experimental errors. Although especially at low x the predictions from HVQDIS with different proton PDFs differ slightly the discriminating power of the current analysis is not sufficient. Otherwise the comparison of the data to the predictions of HVQDIS and CASCADE shows a good agreement.

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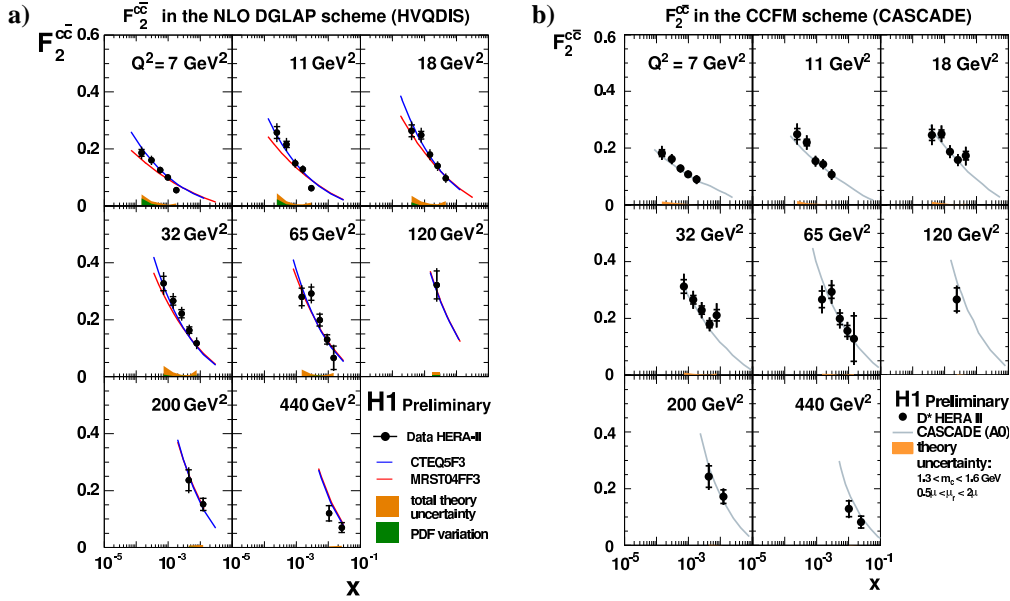
Figure 3: F_2^c as determined from the inclusive $D^{*\pm}$ meson cross sections using HVQDIS a) or CASCADE b). The error bars refer to the statistical (inner) and systematical error (outer) added in quadrature. The solid lines represent the predictions of F_2^c using appropriate parton densities for HVQDIS and CASCADE. The shaded band shows the relative change of the central value due to variation of the model parameters.

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