Measurement of $D^{*\pm}$ Cross Sections and the Charm Contribution to the Structure Function of the Proton in Deep Inelastic Scattering at HERA

I. Redondo [a] *. On behalf of the ZEUS Collaboration

[a]Dept. de Física Teórica, Universidad Autónoma de Madrid, Cantoblanco, Madrid 28049, SPAIN.
e-mail: redondo@mail.desy.de

We present measurements on $D^{*\pm}$ production cross sections in deep inelastic e^+p scattering with $1 < Q^2 < 600\,\mathrm{GeV}^2$ and $0.02 < y < 0.7$ in two restricted kinematic regions in $p_T(D^{*\pm})$ and $\eta(D^{*\pm})$. The decay channels $D^{*+} \to D^0\pi^+$ with subsequent decay $D^0 \to K^-\pi^+$ or $D^0 \to K^-\pi^+\pi^+\pi^-(+\mathrm{c.c.})$ are used. The cross sections are extrapolated to the full kinematic region to determine the charm contribution to the proton structure function.

1. INTRODUCTION

The first HERA measurements of the charm contribution to the proton structure function, $F_2^{c\bar{c}}$ were reported by the H1 and ZEUS Collaborations from an analysis of $D^{*\pm}$ production in their 1994 data sets [1,2]. The results were consistent with Photon Gluon Fusion (PGF) being the dominant mechanism for $D^{*\pm}$ production in e^+p Deep Inelastic Scattering (DIS). If this is the case, this type of measurements are sensitive to the gluons in the proton. In addition, they can provide a test of the universality of the parton distribution functions (pdf's), namely, whether pdf's extracted from the inclusive measurement of the proton structure function, F_2, can be used as input for calculations of more exclusive processes as charm production.

Here we present a study of $D^{*\pm}$ production using the 1996 and 1997 data corresponding to an integrated luminosity of 37 pb^{-1}. More than tenfold larger data sample, together with the modifications of the ZEUS detector made for the 1996 and 1997 operation allow an extension of the kinematic range to both smaller and larger Q^2. The $D^{*\pm}$ is tagged via $D^{*+} \to (D^0 \to K^-\pi^+)\pi^+(+\mathrm{c.c.})$ and $D^{*+} \to (D^0 \to K^-\pi^+\pi^+\pi^-)\pi^+(+\mathrm{c.c.})$ decay channels, refered to as $K2\pi$ and $K4\pi$ respectively.

*Supported by the Comunidad Autónoma de Madrid.

2. $D^{*\pm}$ CROSS SECTIONS

The measured $D^{*\pm}$ cross section using the $K2\pi(K4\pi)$ final state, in the region $1.5(2.5) < p_T(D^*) < 15\ GeV$, $|\eta(D^*)| < 1.5$ is $\sigma(e^+p \to e^+D^{*\pm}X) = 8.31 \pm 0.31(stat)^{+0.30}_{-0.50}(sys)$ nb$(3.65 \pm 0.36(stat)^{+0.20}_{-0.41}(sys)$ nb$)$. Figure 1 shows the differential D^* cross sections in the restricted Q^2, y, $p_T(D^*)$ and $\eta(D^*)$ region as functions of $log_{10}(Q^2)$, $log_{10}(x)$, W, $p_T(D^*)$, $\eta(D^*)$ and $x(D^*) = 2p^*(D^*)/W$, where $p^*(D^*)$ is the momentum in the γ^*-proton CMS frame. The results using each decay channel can be directly compared in the $p_T(D^*)$ differential cross section. The agreement is satisfactory.

3. COMPARISON WITH NLO QCD

We compute NLO QCD calculations with a semi-inclusive Monte Carlo generator HVQDIS[3] for heavy quark production and subsequent fragmentation to $D^{*\pm}$ via a Peterson fragmentation function [4] . This generator is based on NLO calculations [5] in the three flavor number scheme (TFNS), in which only light quarks (u, d, s) are included in the initial state proton. Heavy quarks are produced exclusively by the convolution of the light flavours and the gluon with the massive matrix elements and coefficient functions calculated previously [6].

We use as input pdf ZEUS94 [7]. The QCD renormalization and factorization scales are set to $\sqrt{Q^2 + 4m_c{}^2}$. m_c is varied between 1.3 and

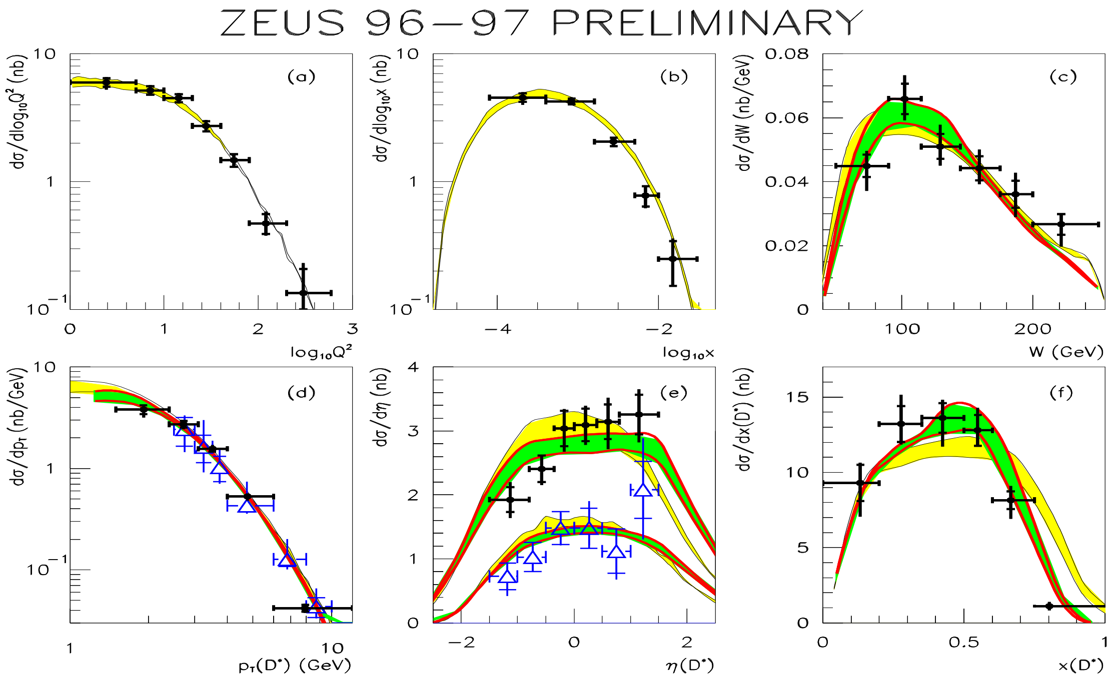

Figure 1. Differential cross sections for D^* production from the $K2\pi$ final state (solid dots) and from the $K4\pi$ channel (open triangles). The light shaded band corresponds to the standard Peterson fragmentation function. The dark shaded band show the NLO reweighted RAPGAP MC. The two sets of bands correspond to charm mass variations between 1.3 (upper curve) and 1.5 GeV (lower curve). In (a) and (b) the dark band is indistinguishable from the light one and is not shown.

1.5 GeV. $f(c \to D^*) = 0.222$ is taken from e^+e^- measurements [8]. The error on this quantity introduces a normalization uncertainty of $\sim 9\%$. Finally, the Peterson fragmentation parameter is set to $\epsilon = 0.035$. The NLO QCD predictions (figure 1) are in reasonable agreement with the data, except in the $\eta(D^*)$ distribution, where the measurements show a shift into the positive η region (proton direction) with respect to the prediction. Also a softer charm fragmentation is favored by the data.

3.1. Fragmentation Effects

In Monte Carlo fragmentation models like JETSET or HERWIG, a forward shift in the D^* direction w.r.t. that of the original charm quark is produced during the fragmentation due to the interaction of the charm quark with the proton remnant via either strings or soft gluon radiation.

To investigate how this affects the NLO QCD predictions we have reweighted a LO Monte Carlo for charm production, RAPGAP (it uses JETSET for the fragmentation) in a way such that at the stage of the hard interaction it will reproduce exactly the HVQDIS results for the $p_t(c)$ and $\eta(c)$ differential cross sections. The predictions from this NLO reweighted RAPGAP Monte Carlo are shown in figure 1. They provide a better description of the data, especially in the $\eta(D^*)$ and $x(D^*)$ differential cross sections. This result suggests that the small disagreement found with HVQDIS comes from the fact that the Peterson function can not account for all the charm quark fragmentation effects present at HERA, in particular the interaction with the remnant.

4. $F_2^{c\bar{c}}$ EXTRACTION

The procedure for extracting $F_2^{c\bar{c}}$ starts by measuring the $D^{*\pm}$ production cross section in the restricted $p_{\rm T}(D^*)$, $\eta(D^*)$ region in bins of Q^2 and y. The extrapolation to the full $p_{\rm T}(D^*)$, $\eta(D^*)$ region is done in the following way:

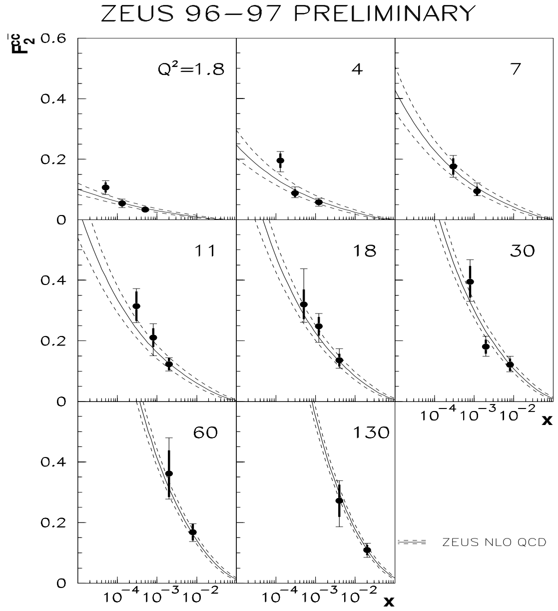

Figure 2. The measured $F_2^{c\bar{c}}$ at constant Q^2 as a function of x. The result of the NLO QCD ZEUS fit [7] is the solid curve. The dashed curves show the error from that fit.

$$F_2^{c\bar{c}\,\mathrm{m}}(x_i, Q_i^2) = \frac{\sigma_i^{\mathrm{m}}(e^+p \to D^*X)}{\sigma_i^{\mathrm{t}}(e^+p \to D^*X)} F_2^{c\bar{c}\,\mathrm{t}}(x_i, Q_i^2) \quad (1)$$

where x_i, Q_i^2 is the center of gravity of the bin i and 'm' and 't' denote 'measured' and 'theoretical' respectively. $F_2^{c\bar{c}t}$ is taken from ZEUS94 [7] fit. For σ_i^t we use the reweighted Monte Carlo. A number of assumptions are implicitly done in this procedure:

- The TFNS is valid,
- $F_L^{c\bar{c}}$ is negligible($< 1\%$ of F_2 in our Q^2, y region from calculations based on [6]),
- the value of $f(c \to D^*)$ measured in e^+e^- is valid also at HERA,
- the cross section outside the restricted region is well described by NLO QCD.

Figure 2 shows the measured $F_2^{c\bar{c}}$ after combining the results from both decay channels. Compared to our previous study we have extended the kinematic range to Q^2 as low as 1.8 GeV^2 and up to 130 GeV^2 and the errors are reduced substantially. $F_2^{c\bar{c}}$ exhibits a steep rise with decreasing x at constant Q^2. From a comparison with the ZEUS94 parametrization we determine that $F_2^{c\bar{c}}$ accounts for $< 10\%$ of F_2 at low Q^2 and $x \simeq 5 \cdot 10^{-4}$ and $\simeq 30\%$ of F_2 for $Q^2 >$ 11 GeV^2 at the lowest x measured.

5. SUMMARY

We have presented a charm analysis in DIS using the combined 1996 and 1997 data sample. Charm was tagged with D^* mesons decaying into two decays ($K2\pi$ and $K4\pi$). In the experimentally accessible region, differential $D^{*\pm}$ cross sections are in reasonable agreement with NLO QCD calculations of charm production in the TFNS using a pdf extracted from an inclusive measurement of F_2. This represents a successful test of the universality of the pdf's.

Small disagreements in the $\eta(D^*)$ and $x(D^*)$ distributions show that the fragmentation a la Peterson can not account for all the charm quark fragmentation effects present at HERA.

Using these calculations to extrapolate outside the measured $p_{\mathrm{T}}(D^*)$, $\eta(D^*)$ region, $F_2^{c\bar{c}}$ was extracted. $F_2^{c\bar{c}}$ is rising steeply with decreasing x at constant Q^2. It amounts to $\approx 25\%$ of F_2 at low x, $Q^2 > 10$.

REFERENCES

1. H1 Collab., C. Adloff *et al.*, Z. Phys. **C72**(1996)593
2. ZEUS Collab., J. Breitweg *et al.*, Phys. Lett. **B407** (1997) 402
3. B. W. Harris and J. Smith, hep-ph/9706334
4. C. Peterson *et al.*, Phys. Rev. **D27**, 105 (1983)
5. B. W. Harris and J. Smith, Nucl. Phys. **B452**(1995)109;
6. E. Laenen, S. Riemersma, J. Smith and W. L. Van Neerven, Nucl. Phys. **B392**(1995)162
7. ZEUS Collab., J. Breitweg *et al.*, The European Physical Journal **C7** (1999) 609-630
8. OPAL Collab., K. Ackerstaff *et al.*, Eur. Phys. J **C1**(1998)439