CHARM PRODUCTION IN EP-COLLISIONS

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Recent results on the production of open charm in electron proton scattering at HERA are reviewed. Results on the fragmentation of charm are presented and compared to the measurements at e^+e^- colliders. Recent results on the charm contribution to the proton structure function F_2 are shown. Furthermore, measurements of inclusive D^* meson, D^* + jet and D^* + muon production are presented. These results are compared with perturbative QCD calculations at next-to-leading order as well as with Monte Carlo predictions.

1 Introduction

At HERA, electrons (or positrons) of energy 27.5 GeV are collided with 920 GeV protons, providing a center-of-mass energy of $\sqrt{s} \approx 318$ GeV. During the HERA-I run, the experiments H1 and ZEUS each collected data corresponding to an integrated luminosity of about 110 pb^{-1}, thus allowing significant tests of perturbative QCD for heavy quark production.
In electron proton collisions, heavy quarks are predominantly produced via the photon gluon fusion (PGF) mechanism, in which a photon emitted by the incoming electron interacts with a gluon in the proton forming a quark anti-quark pair. The cross section is largest in photoproduction, in which the exchanged photon is almost real $Q^2 \sim 0$, and decreases towards the region of deep inelastic scattering (DIS) which is at larger values of Q^2 ($Q^2 \gtrsim 2\,\mathrm{GeV}^2$).
Heavy quark production can be described by factorising the process into three parts: the proton structure, the hard partonic interaction and the fragmentation of the final state quarks into hadrons. The structure function $F_2^{c\bar{c}}$ denotes the contribution from events with charm to the inclusive proton structure function F_2. The hard interaction process is calculable in perturbative QCD as the heavy quark mass provides a hard scale.
The HERA data are compared with next-to-leading order (NLO) calculations in the massive (see [1] for photoproduction and [2] for DIS), massless [3] and matched [4] schemes, which are expected to

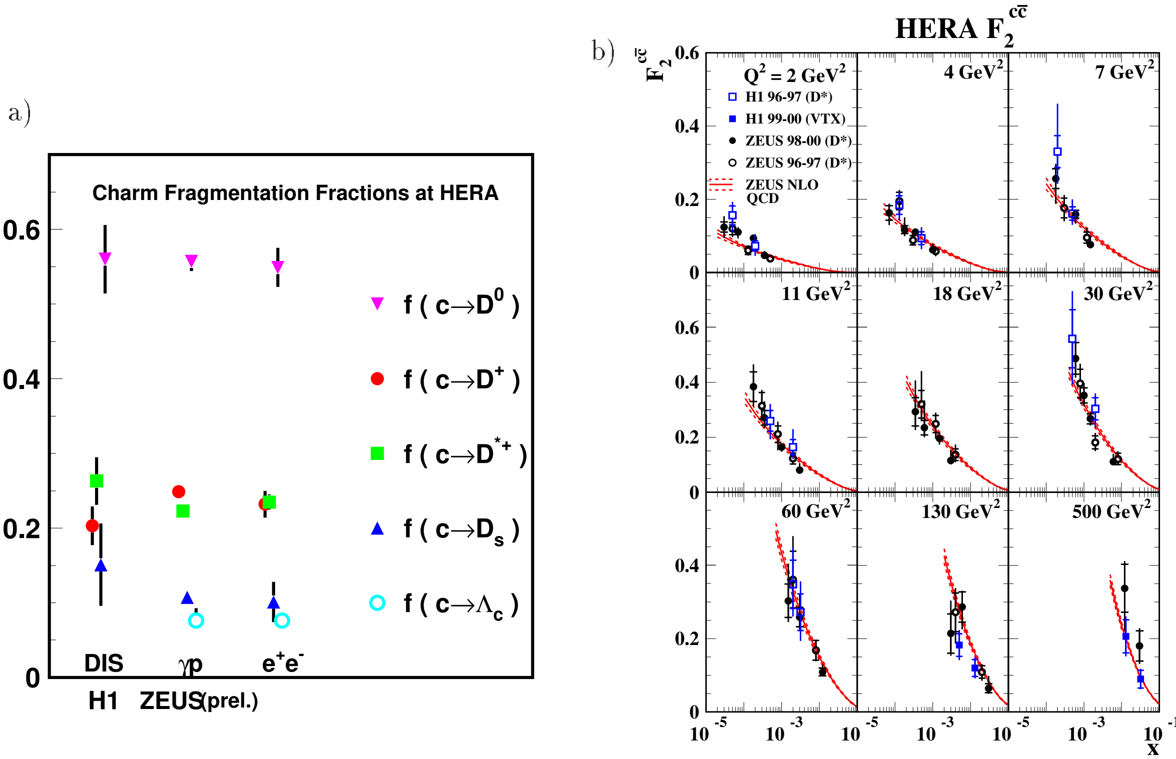

Figure 1: a) Fragmentation fractions obtained at HERA and compared with e^+e^- measurements. b) Charm contribution to the structure function F_2, $F_2^{c\bar{c}}$, compared with the NLO QCD fit.

hold in different limits of the scale μ used for the calculation of the hard cross section. In addition the data are compared with the Monte Carlo generators PYTHIA[5], which implements the DGLAP evolution equation[6] and CASCADE[7] which is based on the CCFM evolution equation[8].

2 Fragmentation

In most measurements of charm production at HERA, D^* mesons are used to identify the presence of charm quarks, exploiting the well known mass difference method. The charm quark cross section is then determined from the measured D^* cross section by using the fragmentation fraction $f(c \to D^*)$, as measured by other experiments. These measurements are based on the assumption of universality of charm fragmentation.

In recent measurements the H1 and ZEUS experiments have determined the fragmentation fractions $f(c \to D)$ for the various charmed hadrons (D^+, D^0, D_s, D^{*+} and Λ_c (ZEUS)) in DIS or photoproduction respectively[9,10]. In figure 1a), the fragmentation fractions obtained in ep collisions at HERA are presented. The results are compared with measurements at e^+e^- colliders and good agreement is observed indicating that fragmentation is universal.

In the H1 measurement the shape of the differential D meson cross sections was found to be very similar for different D meson species. Also the fragmentation ratios, the ratio of u to d quarks $R_{u/d}$, the strangeness suppression factor γ_s and the fraction of D mesons produced as vector mesons P_v, obtained by ZEUS and H1 are in good agreement with those from the LEP experiments. The uncertainties in particular on the ZEUS measurement are competitive with those from LEP.

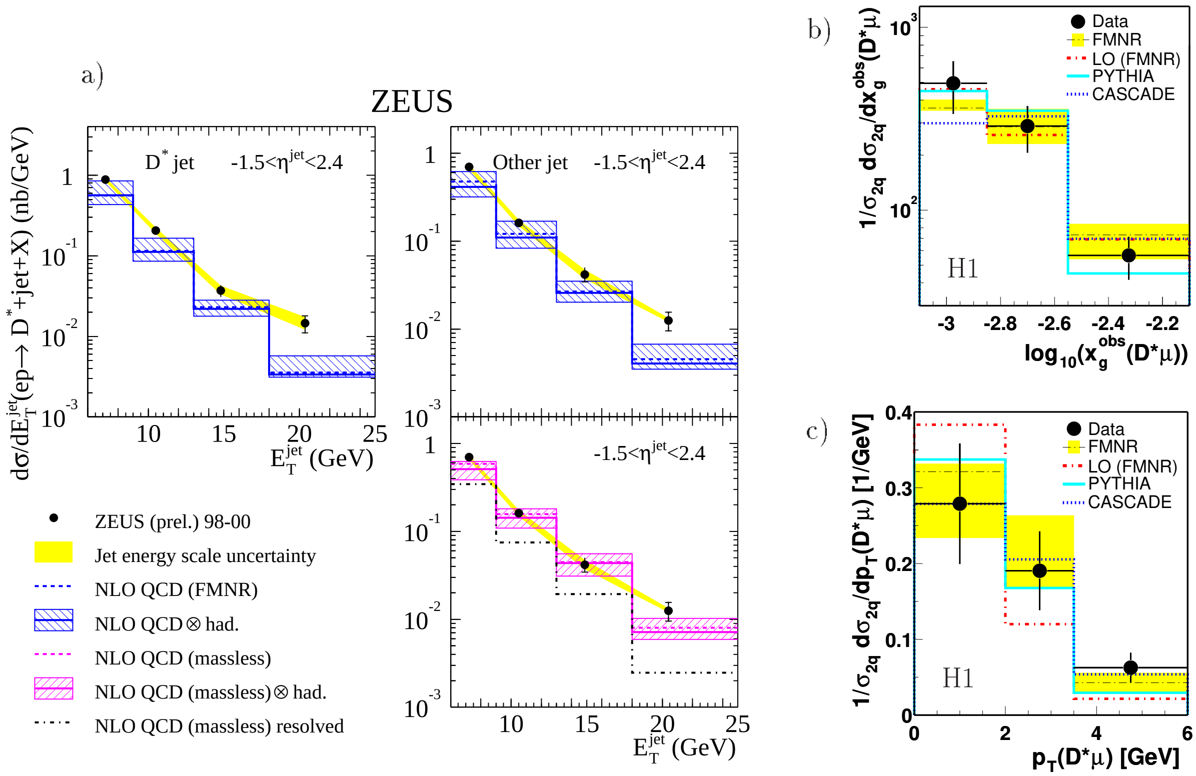

Figure 2: a) D^* + jet cross section as a function of E_T^{jet}. b+c) Normalised D^* + muon cross section as a function of x_g^{obs} (b) and $p_T(D^*\mu)$ (c). The $b\bar{b}$ quark contamination is approximately 10%.

3 Proton Structure

Both H1 and ZEUS have determined the charm contribution $F_2^{c\bar{c}}$ to the structure function F_2 of the proton [11,12]. $F_2^{c\bar{c}}$ is shown as a function of Bjorken x in several bins of Q^2 in figure 1b). In the past $F_2^{c\bar{c}}$ was always determined by extrapolation of the measured visible D^* cross section into the full phase space. In a recent measurement the H1 collaboration made use of the H1 silicon vertex detector to measure the fraction of charm events from the lifetime distribution in an inclusive event sample. In this measurement the size of the extrapolation is substantially reduced. The results of this measurement are indicated in figure 1b) as filled squares in the last two Q^2 bins. Generally, good agreement between the ZEUS and H1 data and the NLO QCD prediction is obtained. This means that the prediction of the charm contribution to F_2 from scaling violations is consistent with the $F_2^{c\bar{c}}$ measurement.

4 Production Mechanism

The measurement of the D^* production cross section as a function of Q^2 for $1.5 < Q^2 < 1000\,\mathrm{GeV}^2$ was extended towards low Q^2 ($0.05 < Q^2 < 0.7$ GeV^2) by the ZEUS collaboration using the beam pipe calorimeter [13]. It was found that the NLO calculation using the ZEUS NLO fit for the parameterisation of the parton densities is consistent with the data over the whole Q^2 range. However, a more detailed look at the pure photoproduction data set shows some deviations between the data and both the massive and the matched NLO calculations [14]. Particularly in the intermediate transverse momentum range and in the forward direction, both theoretical predictions are below the data.

If at least one jet is required in addition to the D^* meson, the transverse energy of the jet, E_T^{jet}, provides an additional hard scale. In an analysis of the ZEUS collaboration, carried out in the photoproduction regime, the D^* + jet cross section as a function of E_T^{jet} was determined [15] and compared to the massive and massless NLO calculations (figure 2a)). At high jet transverse energies the data are above the massive calculation, while the massless NLO calculation describes the data better, at least in this regime.

In a very recent and even more exclusive analysis in the photoproduction regime, performed by the H1 collaboration, a muon is required in addition to the D^* meson [16]. The charge and angle correlations between the D^* and the muon are used to select double tagged events. Due to the double tagging, details of the production mechanism can be studied. The normalised D^* + muon cross sections as a function of x_g^{obs} and $p_T(D^*\mu)$ are shown in figure 2b+c). The quantity x_g^{obs} is a good estimate of the relative momentum fraction of the gluon x_g, whereas the correlation is worse for $p_T(D^*\mu)$ and the transverse momentum of the gluon k_T. The data are compared to the NLO calculation and the LO calculation (indicated as FMNR in the figure) as well as to the Monte Carlo generators PYTHIA and CASCADE. All calculations give a reasonable description of the shape of the x_g^{obs} distribution. In the case of the $p_T(D^*\mu)$ distribution, the pure LO calculation is too soft to describe the data, while the NLO calculation and the Monte Carlo generators describe the data well.

5 Summary

Charm production at HERA has been extensively studied. Comparisons of HERA data with measurements at e^+e^- colliders support the assumption that the fragmentation of charm is independent of the underlying hard physics process. The measurements of the charm contribution $F_2^{c\bar{c}}$ to the proton structure are consistent with the expectations from the scaling violations of F_2. NLO QCD effects are essential to predict charm photoproduction as shown for D^* + muon events. The general description is reasonable although some details of the D^* cross sections are poorly described.

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