

# Heavy Quark Electroproduction and the Heavy Quark Contribution to the Proton Structure

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New results on charm and beauty electroproduction from the H1 and ZEUS Collaborations at the  $ep$  collider HERA are presented. Differential cross sections are compared to a next-to-leading order QCD calculation. The heavy quark contributions,  $F_2^{c\bar{c}}$  and  $F_2^{b\bar{b}}$ , to the proton structure function  $F_2$  are compared using different experimental techniques. Also, results are shown on the charm fragmentation function, thereby testing the universality of fragmentation.

## 1. INTRODUCTION

At HERA, 27.5 GeV electrons (or positrons) were collided with 920 GeV protons providing a center-of-mass energy of  $\sqrt{s} = 318$  GeV. The H1 and ZEUS experiments each collected data corresponding to an integrated luminosity of about  $500 \text{ pb}^{-1}$ , split into two running phases: HERAI and HERAII. The dominant production process for heavy quarks at HERA is photon gluon fusion, in which a photon emitted from the electron fuses with a gluon in the proton producing a quark anti-quark pair. Thus the production of heavy quarks is directly sensitive to the gluon density in the proton. In the case of electroproduction or deep-inelastic scattering (DIS), the virtuality of the exchanged photon is large ( $Q^2 \gtrsim 2 \text{ GeV}^2$ ) and provides a hard scale for reliable calculations in perturbative Quantum Chromodynamics (pQCD). The available pQCD calculations are performed in a scheme ("massive") which assumes no heavy quark content of the proton and are based on collinear or  $k_T$  factorisation.

## 2. CROSS SECTION MEASUREMENTS

### 2.1. Charm Measurements

Many experimental results for charm production at HERA use charm mesons to identify the presence of charm quarks, especially the  $D^{*\pm}$  meson exploiting the well known mass difference method. The H1 Collaboration presented new preliminary measurements of the electroproduction of  $D^{*\pm}$  mesons in two regions of the photon virtuality:  $5 < Q^2 < 100 \text{ GeV}^2$  [1] and  $100 < Q^2 < 1000 \text{ GeV}^2$  [2]. The visible phase space of the  $D^{*\pm}$  meson is restricted to  $|\eta(D^*)| < 1.5$  and  $p_T(D^*) > 1.5 \text{ GeV}$ . The results are based on the full HERAII statistics corresponding to an integrated luminosity of about  $350 \text{ pb}^{-1}$ . The next-to-leading order (NLO) massive QCD calculation HVQDIS [3] (using collinear factorisation) agrees with the measurement up to the largest  $Q^2$  (fig. 1 (a)) where the massive approach is not expected to be appropriate. The single and double differential cross sections as a function of the transverse momentum  $p_T$  and the pseudorapidity  $\eta$  (fig. 1 (b)) of the  $D^*$  meson are reasonably well described by HVQDIS and show a sensitivity to the gluon density in the proton. Unfortunately, the theoretical uncertainties due to a variation of the charm mass, the renormalisation and factorisation scales and the fragmentation parameter  $\alpha$  are larger than the experimental uncertainties.

The ZEUS Collaboration has measured differential cross sections for  $D^{*\pm}$  [4],  $D^0$  and  $D^\pm$  [5] mesons in the range  $5 < Q^2 < 1000 \text{ GeV}^2$  based on part of the HERAII luminosity. For the  $D^0$  and the  $D^\pm$  analysis the signal-to-background ratio has been improved by using lifetime information from the Micro Vertex Detector. The HVQDIS prediction describes the  $Q^2$ ,  $p_T$  and  $\eta$  distributions for all charm mesons reasonably well.

In order to study the charm production process further the angular correlation of dijets in events with  $D^*$  mesons was measured by the H1 experiment [6]. At small azimuthal differences between the two jets, where higher order processes are expected to contribute, the HVQDIS calculation as well as the leading order (LO) Monte Carlo program CASCADE [7], based on  $k_T$  factorisation and including parton showers, have problems to describe the data.

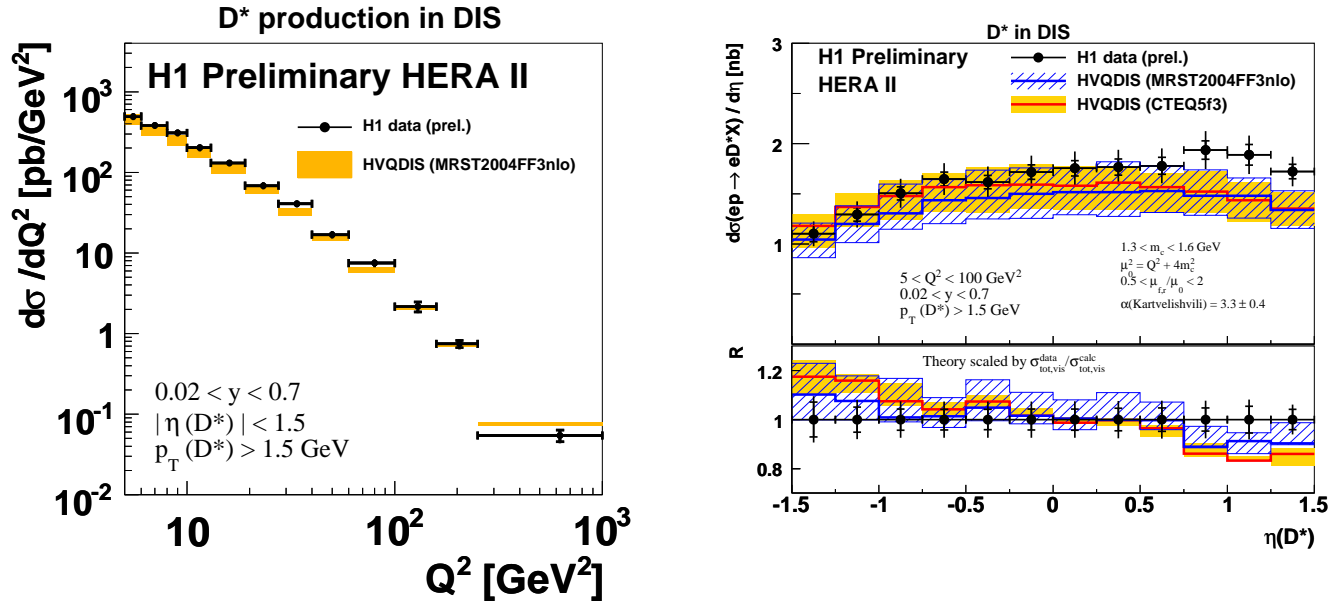


Figure 1:  $D^{*\pm}$  cross section as a function of (a) the photon virtuality  $Q^2$  and (b) the pseudorapidity of the  $D^{*\pm}$  meson  $\eta(D^*)$  compared to the NLO QCD calculation HVQDIS with the proton parton densities MRST2004FF3nlo [8] and CTEQ5F3 [9].

## 2.2. Beauty Measurements

Since the beauty cross section at HERA is very small, the reconstruction of exclusive hadron decays is difficult. Therefore, more efficient tagging methods which exploit either the long lifetime of  $B$  hadrons using precise silicon vertex detectors (displaced track method) or the large  $b$  quark mass using the transverse momentum of leptons with respect to jets ( $p_T^{rel}$  method), are used instead. A new preliminary measurement [10] combining the methods in events with a muon and a jet was presented by the ZEUS experiment. The kinematic range was restricted to  $Q^2 > 20$  GeV<sup>2</sup>,  $p_T^\mu > 1.5$  GeV and  $-1.6 < \eta^\mu < 2.3$ . As the jet was used only for tagging purposes, a loose jet selection of  $p_T^{jet} > 3$  GeV and  $-3 < \eta^{jet} < 3$  was applied. The cross sections were extracted by a three-dimensional fit to the impact parameter, the momentum of the muon transverse to the jet and the missing transverse momentum parallel to the muon direction. The measured differential beauty and charm cross sections are reasonably well described by HVQDIS (fig. 2).

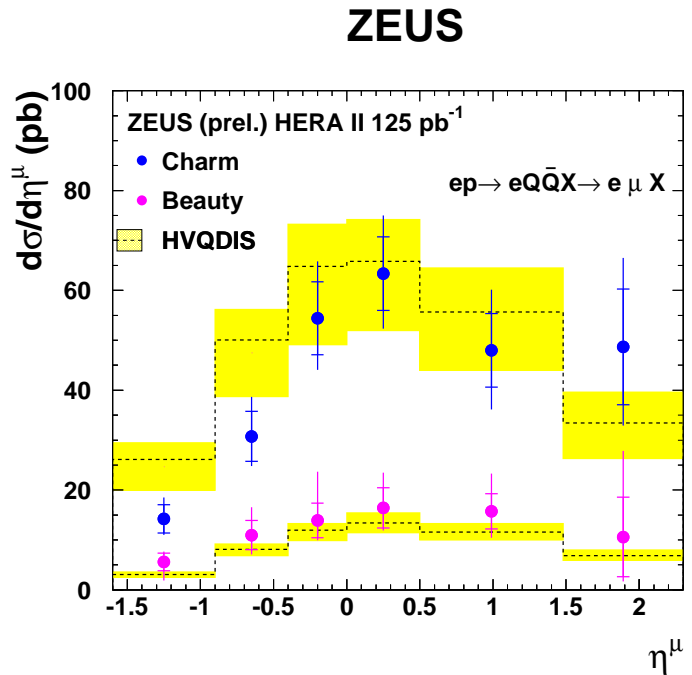
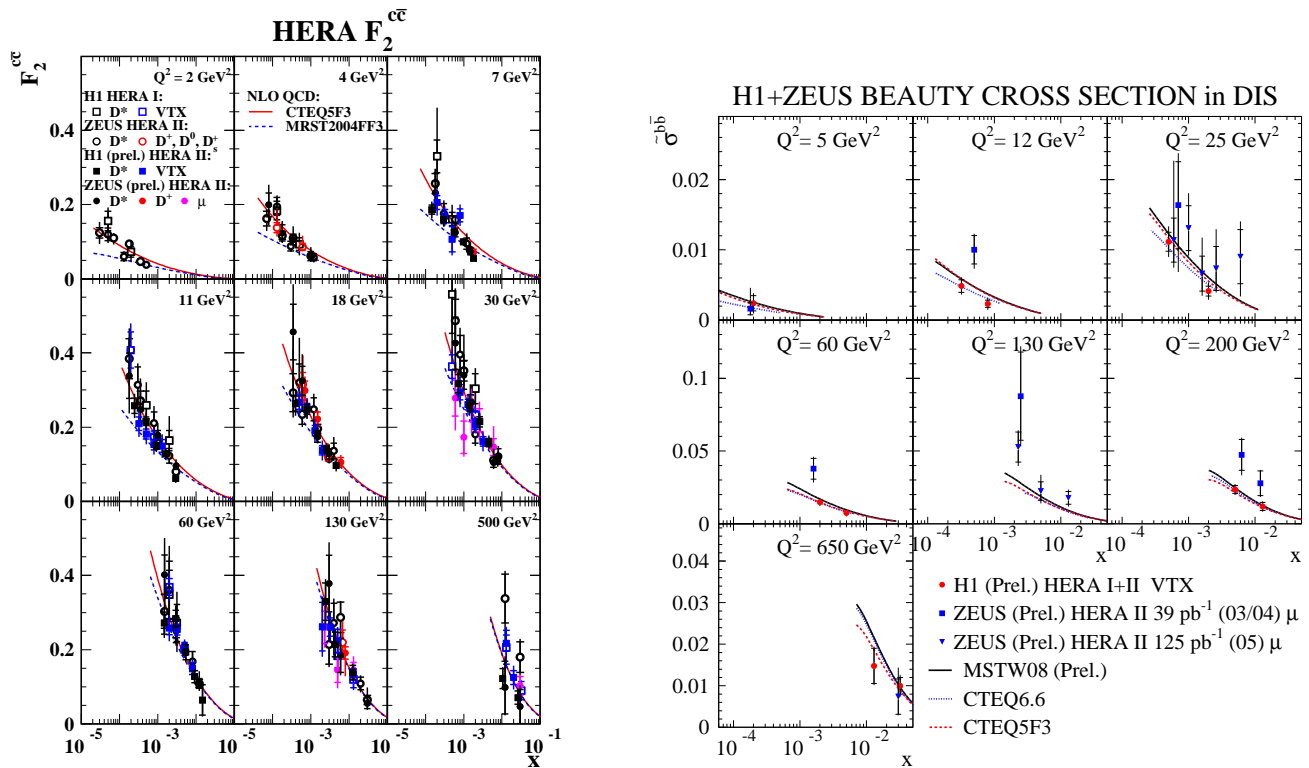


Figure 2: Cross section for the production of a muon and a jet from the decay of beauty and charm quarks as a function of the pseudorapidity of the muon  $\eta_\mu$ .

Figure 3: Charm (left) and beauty (right) contribution to the proton structure function  $F_2$ .

### 3. CONTRIBUTION TO THE PROTON STRUCTURE FUNCTION $F_2$

The charm and beauty contributions,  $F_2^{c\bar{c}}$  and  $F_2^{b\bar{b}}$ , to the inclusive proton structure function  $F_2$  can be extracted from the cross section measurements by extrapolating to the full phase space of the studied final state. A different approach is employed in the inclusive lifetime analysis, where all tracks with lifetime information from precise measurements in the central silicon detector are used. The H1 Collaboration presented a preliminary analysis [11] based on this approach using a neural net to improve the separation power. A comparison of the different measurements of  $F_2^{c\bar{c}}$  and  $F_2^{b\bar{b}}$  is shown in fig. 3. The experimental results agree well with each other. NLO QCD predictions with different proton parton distributions can describe the data and show the sensitivity of the data to the gluon density.

### 4. CHARM FRAGMENTATION

One important ingredient to the extraction of the charm production cross section and the charm contribution  $F_2^{c\bar{c}}$  to the proton structure function from measured  $D$  meson cross sections is the fragmentation that describes the transition of a charm quark into a charm hadron. The spectrum of the momentum fraction  $z$  transferred from the heavy quark to the hadron influences strongly the transverse momentum distribution of the heavy hadron and thus the extrapolation from differential cross sections to  $F_2^{c\bar{c}}$ . Both ZEUS [12] and H1 [13] have studied the fragmentation of charm quarks. In the presence of a jet both experiments find results consistent with fragmentation functions determined from  $e^+e^-$  data indicating that fragmentation is universal. For events with no jets, corresponding to low photon gluon centre-of-mass energies, H1 finds a harder fragmentation which can be interpreted as an inadequacy of the QCD models to provide a consistent description of the full phase space down to the kinematic threshold.

## 5. SUMMARY

Several new measurements of the electroproduction of charm and beauty quarks at HERA from the H1 and ZEUS Collaborations were presented. In general the measurements are reasonably well described by the next-to-leading order perturbative QCD calculation HVQDIS. The charm and beauty contributions,  $F_2^{c\bar{c}}$  and  $F_2^{b\bar{b}}$ , to the inclusive proton structure function  $F_2$  extracted with different methods agree with each other and show sensitivity to the gluon density in the proton. Measurements of the charm fragmentation function are an important input to the extrapolation of charm meson cross sections to  $F_2^{c\bar{c}}$  and provide information on the universality of fragmentation.

## Acknowledgments

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