CHARM AND BEAUTY OF HERA

K. LIPKA
for the H1 and ZEUS Collaborations

Deutsches Elektronen Synchrotron (DESY)
Notkestrasse 85, 22607 Hamburg, Germany

Recent results on charm and beauty production in *ep* scattering at HERA are presented. Different methods of charm and beauty tagging are discussed. Measurements of the charm fragmentation function and D-meson cross sections in deep inelastic scattering and photoproduction are shown. The extracted charm (beauty) contributions, $F_2^{c\bar{c}}$ ($F_2^{b\bar{b}}$), to the inclusive proton structure function F_2 in deep inelastic scattering (DIS) as measured by the H1 and ZEUS experiments are compared to perturbative QCD calculations.

1 Introduction

The study of charm and beauty quark production at high energies is a powerful tool to test perturbative quantum chromodynamics (pQCD). In *ep* collisions at HERA charm and beauty quarks are produced predominantly in photon-gluon fusion [1,2,3,4]. Charm (beauty) production contributes to the total deep inelastic scattering (DIS) cross section by at most 30% (1%) at HERA. Charm and beauty quarks are tagged via semi-leptonic decays, by making use of the long lifetime of heavy flavoured hadrons and/or the large mass of heavy quarks. Charm quarks are also tagged by reconstructing charmed hadrons e.g. $D^{*\pm}$, $D^{\pm}$ and D^0 mesons. From the measured visible charm/beauty cross section their contribution $F_2^{c\bar{c}}$ and $F_2^{b\bar{b}}$ to the proton structure function F_2 is extracted. When using the lifetime information, the charm and the beauty contributions $F_2^{c\bar{c}}$ and $F_2^{b\bar{b}}$ to the proton structure function F_2 are extracted simultaneously. By combination of different analysis techniques, more precise tests of perturbative pQCD become possible.

Heavy quark production in *ep* collisions can be described in pQCD using different schemes. At energy scales larger than the heavy quark mass calculations can be performed in the zero mass variable flavour number scheme (ZMVFNS), where the heavy quarks are treated as massless partons in the proton. The fixed flavour number scheme (FFNS [5,6,7]) applies close to the heavy quark production threshold and takes into account the heavy quark mass effects properly. In the latter scheme all quark flavours lighter than a particular heavy quark are treated as massless with massive charm (beauty) being produced dynamically in boson-gluon fusion. A consistent treatment of heavy quarks in pQCD over the full energy range should be provided through the calculation in the generalised mass variable flavour number scheme (GMVFNS [8,9,10]).

2 Charm and beauty in photoproduction

HERA measurements [11,12,13] of charm and beauty production at low photon virtualities ($Q^2 \approx 0$) are shown in Fig. 1. The cross section for $D^{*\pm}$ meson production measured by the H1 experiment as a function of transverse momentum $p_T(D^*)$ is compared with the pQCD calculations at next-to-leading order (NLO) in FFNS [7] and GMVFNS [8]. Large theoretical uncertainties are caused by a variation of the renormalisation and factorisation scales in the calculations. In general, both NLO predictions describe the data well, however the GMVFNS underestimates the cross section at high $p_T(D^*)$. In Fig. 1 (right) a compilation of beauty production measurements is shown.

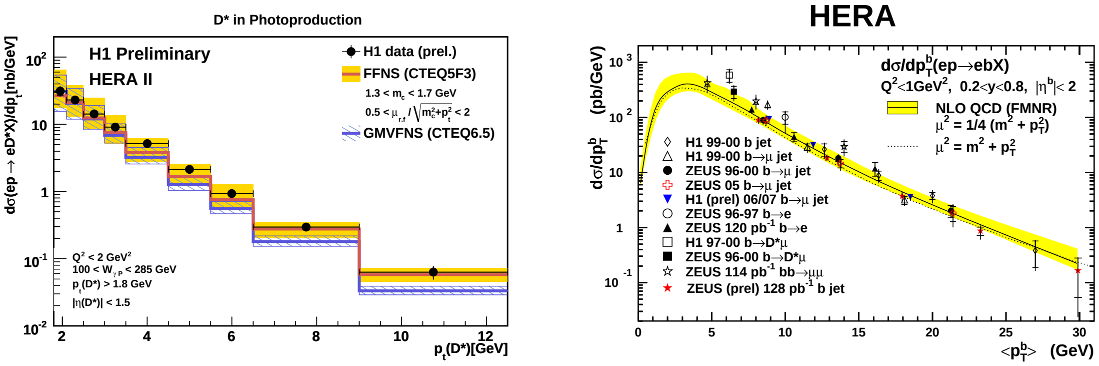

Figure 1: Measurements of charm and beauty in photoproduction. Left panel: $D^{*\pm}$ cross section as a function of $p_T(D^*)$. The data (closed symbols) are compared to the FFNS (shaded band) and GMVFNS (hatched area) predictions. Right panel: H1 and ZEUS measurements of beauty production as a function of $<p_T^b>$. The data (symbols) are compared to the QCD prediction in FFNS (shaded band).

Several measurement techniques of both the H1 and the ZEUS experiments are presented as a function of average transverse b-quark momentum $<p_T^b>$. The results of different measurements agree well and the data are described by the pQCD prediction at NLO in FFNS [7].

3 Charm and beauty in DIS

Charm and beauty production is studied also at larger photon virtualities ($Q^2 > 5$ GeV^2) at H1 [4,13,14] and ZEUS [15]. Results of these measurements are presented in Fig. 2. The cross section

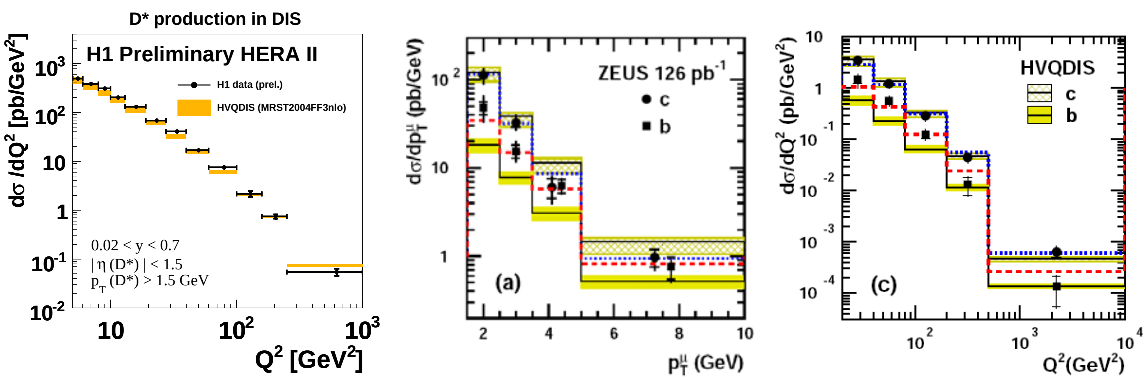

Figure 2: Measurements of charm and beauty production in DIS. Left: Cross section for $D^{*\pm}$ production as a function of Q^2. The data (symbols) are compared to the NLO calculation (shaded band). Middle, right: cross sections of charm (upper symbols) and beauty (lower symbols) as a function of muon transverse momentum p_T^μ and Q^2, respectively. The NLO prediction for charm (beauty) is shown by shaded (hatched) band.

of $D^{*\pm}$ meson production in DIS is measured in a wide range of Q^2, as shown in Fig. 2 (left). The data agree well with the NLO calculation in FFNS [6]. In Fig. 2 (middle, right) the production of charm and beauty quarks in DIS as measured [15] by the ZEUS experiment using semi-leptonic decays into muons is shown. In this case charm and beauty quarks are measured simultaneously. The charm cross sections are described well by the NLO calculation in FFNS [6], while the beauty cross section is underestimated.

4 Charm and beauty structure functions

The charm (beauty) contribution $F_2^{c\bar{c}}$ ($F_2^{b\bar{b}}$) to the inclusive proton structure function F_2 is obtained by using the expression for the one photon exchange cross section for charm production

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

The values of $F_2^{c\bar{c}}$ and $F_2^{b\bar{b}}$ are determined using the measured cross sections of charm- and beauty-tagged DIS events. The visible phase space accessible by the detectors H1 and ZEUS via reconstruction of charmed mesons covers only about 30% of the full phase space. Therefore the determination of $F_2^{c\bar{c}}$ via e.g. $D^{*\pm}$ strongly depends on the model used for the extrapolation. $F_2^{c\bar{c}}$ and $F_2^{b\bar{b}}$ are also measured at H1 [4] and ZEUS [15] via semi-leptonic decays and using the vertex detector information. In Fig. 3 the measured $F_2^{c\bar{c}}$ and $F_2^{b\bar{b}}$ are shown at various Q^2as a function of the Bjorken scaling variable x, which is the proton momentum fraction carried by a struck quark. The measurements of $F_2^{c\bar{c}}$ and $F_2^{b\bar{b}}$ cover the kinematic range of $5<Q^2<1000$

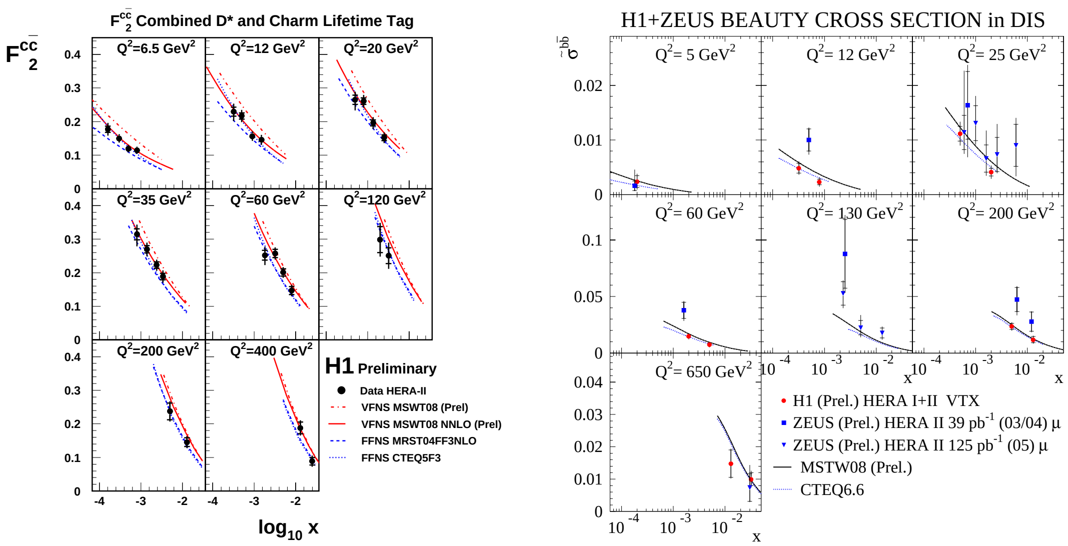

Figure 3: Charm and beauty contributions to the proton structure function

GeV^2 and 10^{-4} $<x<$ 10^{-1}. The structure function $F_2^{c\bar{c}}$ from H1 is obtained by combining the measurements of $D^{*\pm}$ meson production with the results obtained by using the vertex information. This combination [16] takes into account the correlations of systematic uncertainties. The experimental values of $F_2^{c\bar{c}}$ are compared to predictions of calculation in FFNS [5] and the results of the global QCD fits in GMVFNS [9,10] at NLO and NNLO. FFNS describes the data best, while the predictions in GMVFNS tend to overestimate $F_2^{c\bar{c}}$ over a wide range of Q^2. Measurements of $F_2^{b\bar{b}}$ by the H1 and ZEUS collaborations are also compared to the predictions in GMVFNS [9,17]. Within the uncertainties the data are well described by the theory.

5 Summary

Recent measurements of the H1 and the ZEUS experiments on charm and beauty production in both photoproduction and DIS are presented. The charm and beauty contributions $F_2^{c\bar{c}}$ and $F_2^{b\bar{b}}$ to the inclusive proton structure function F_2 are shown. These measurements cover the kinematic range $10^{-4}<x<10^{-1}$ in the Bjorken scaling variable. The charm tagging methods can be combined to obtain higher precision of the measurement. The current data are sensitive to different approaches in pQCD calculations of charm production. In general, different pQCD calculations describe the data on both charm and beauty production well. The pQCD calculations at NLO in FFNS agree with the measurements better than the GMVFNS models.

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