HEAVY FLAVOUR PRODUCTION AT THE ELECTRON-PROTON COLLIDER HERA

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Recent measurements of the H1 and ZEUS experiments based on the HERA II data set and exploiting various heavy flavour tagging techniques for both photoproduction and Deep Inelastic Scattering are presented. The results are in agreement with theoretical NLO predictions. The DIS data are used to extract the charm and the beauty contribution to the proton structure function F_2 which are compared to perturbative QCD calculations.

1 Introduction

Heavy quark production in lepton-proton scattering is a powerful tool to test perturbative quantum chromodynamics (pQCD) and has been extensively studied at the HERA collider. Within pQCD, the production of charm and bottom quarks proceeds in neutral (NC) or charged current (CC) reactions via lepton-parton scattering and the exchange of a virtual boson γ^*/Z_0 or $W^\pm$ with space-like momentum in the so-called boson gluon fusion process. A detailed understanding of the production mechanism sheds light on the underlying parton dynamics in QCD. Results on deep-inelastic scattering (DIS) heavy-quark production provide important constraints in global fits on the parton distribution functions (PDFs) of the proton. This makes these measurements not only highly relevant for the interpretation of LHC data but also for other results like for example the correct prediction of the high energy neutrino background for cosmic ray physics [1].

Heavy flavour analyses at HERA are based on a large variety of tagging techniques that exploit specific properties of charm and beauty hadrons like their long lifetime and large mass leading to displaced vertices or to decay leptons with high transverse momentum. In the case of charm also fully reconstructed decay modes like the so-called "golden decay channel" $D^{*\pm} \to D^0\pi^\pm_{\rm slow} \to K^\mp\pi^\pm\pi^\pm_{\rm slow}$ are being used. The results presented here are largely based on the HERA II data and, depending on the analysis, thus correspond to an integrated luminosity of up to 360 $\rm pb^{-1}$.

2 Heavy Flavour Production in Photoproduction

As an example photoproduction (i.e. negligible photon virtuality $Q^2 < 1$ GeV^2) of beauty and charm quarks in events with at least two jets has recently been measured with the ZEUS detector. The fractions of jets containing b and c quarks were extracted using the invariant mass of charged tracks associated with secondary vertices and the decay-length significance of these vertices [2]. Fig. 1(a,b) shows differential cross sections as a function of jet transverse momentum in comparison with scaled leading order (LO) Monte Carlo (MC) and with next-to-leading-order (NLO) QCD predictions. Generally good agreement is observed. The theory prediction only weakly depends on the proton PDF being used for the calculation. This measurement together with a recent H1 measurement [3] at the b-quark production threshold considerably extends the accessible p_T range in both directions as is displayed in fig. 1(c) which is a summary of differential cross section measurements at HERA for b-quark production as a function of p_T^b demonstrating the good description of the measurements by a massive NLO calculation (FMNR) over the entire p_T^b range.

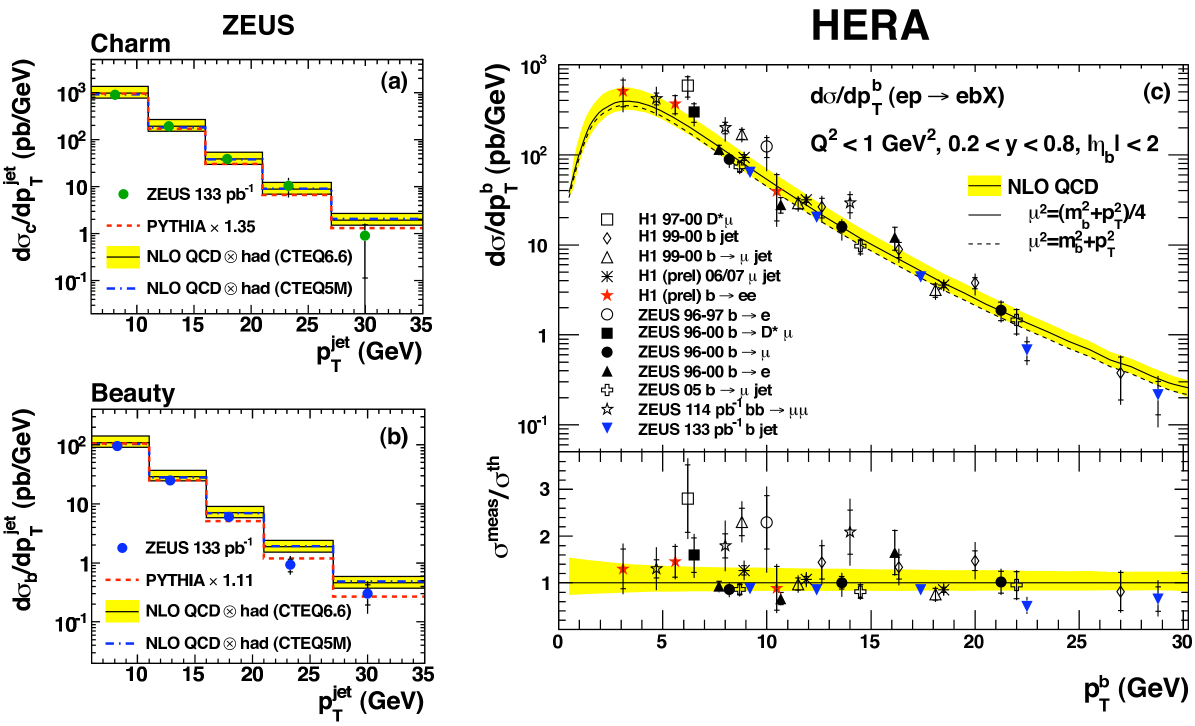

Figure 1: Differential charm-jet (a) and beauty-jet (b) photoproduction cross sections as a function of p_T^{jet}. The data are compared to a scaled LO MC prediction and a NLO QCD calculation (FMNR) using two different proton PDFs. Summary of H1 and ZEUS measurements of beauty production as a function of p_T^b (c). The data (symbols) are compared to a massive NLO QCD prediction (FMNR).

3 Heavy Flavour Production in DIS

The large HERA II data sample enables very detailed studies of heavy flavour production also in DIS. Inclusive D^* meson production in DIS has been thoroughly studied by H1 in the range $5 < Q^2 < 100$ GeV^2 of the photon virtuality using the "golden decay channel" [4]. While in general the data are reasonably well described by a massive NLO calculation (HVQDIS) the predictions slightly undershoot the data in the forward direction as can be seen in fig. 2(a) which presents the measured differential D^* cross section as a function of pseudorapidity $\eta(D^*)$. Double differential distributions show that the excess mainly occurs at low $p_T(D^*)$.

Fig. 2(b) shows a measurement where events with beauty jets of transverse energy $E_T^{jet} >$ 6 GeV are selected based on variables reconstructed using the H1 vertex detector with which the impact parameters of the tracks to the primary vertex and the position of secondary vertices are measured [5]. The differential crosss section as a function of Q^2 is well described by the NLO

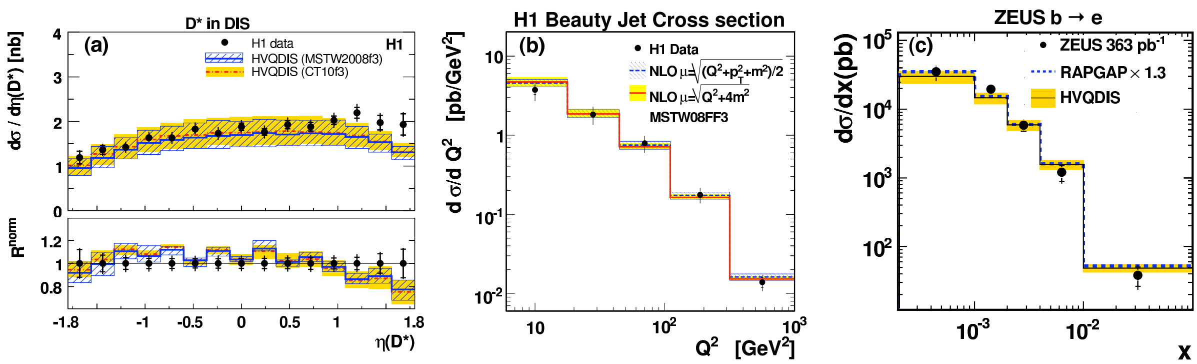

Figure 2: Differential D^* cross section as a function of pseudorapidity $\eta(D^*)$ (a). Differential beauty-jet cross section as function of Q^2 (b). Differential cross section for electrons from b-quark decays as a function of Bjorken-x (c). In all distributions the data are compared with NLO QCD predictions (HVQDIS).

prediction.

In a recent ZEUS measurement [6] beauty events were identified using electrons from semileptonic b decays with a transverse momentum $0.9 < p_T^e < 8$ GeV. Both the predictions from the NLO QCD calculations as well as the scaled RAPGAP cross sections describe the measured dependence of the differential cross section on the Bjorken-variable x well as can be seen from fig. 2(c).

4 Charm and Beauty Contributions to Proton Structure

A number of inclusive measurements based on different techniques have allowed extraction of the charm (beauty) contribution $F_2^{c\bar{c}}$ ($F_2^{b\bar{b}}$) to the proton structure function F_2 which is related to the double differential cross section as a function of Bjorken-x and Q^2 as (likewise for beauty):

$$\frac{d^2\sigma^{c\bar{c}}}{dx\, dQ^2} = \frac{2\pi\alpha^2}{Q^4 x}[(1+(1-y)^2)\cdot F_2^{c\bar{c}}(x,Q^2) - y^2 F_L^{c\bar{c}}]. \qquad (1)$$

The different individual $F_2^{c\bar{c}}$ results have lately been combined by the H1 and ZEUS collaborations. Besides improved statistical accuracy the averaging procedure leads to a significant reduction of cross correlated systematic uncertainties resulting in a precision of about 5-10%. Fig. 3 (left) presents the combined results in comparison with different pQCD predictions. The precision of the data is higher than the variation between the predictions of the different models. The combined $F_2^{c\bar{c}}$ measurement thus can be used to study differences in the available flavour number schemes and it can be included in global PDF fits, which allows to further constrain the fit parameters [8].

Fig. 3 (right) shows a summary of a large variety of different experimental methods to extract the beauty contribution $F_2^{b\bar{b}}$ to the structure function F_2. The measurements are well compatible with each other within their uncertainties. Also shown is a NLO QCD prediction based on the program HVQDIS which describes the data well.

5 Summary

Recent measurements of the H1 and the ZEUS experiments on charm and beauty production in both photoproduction and DIS are presented. Exploiting the full HERA statistics in many

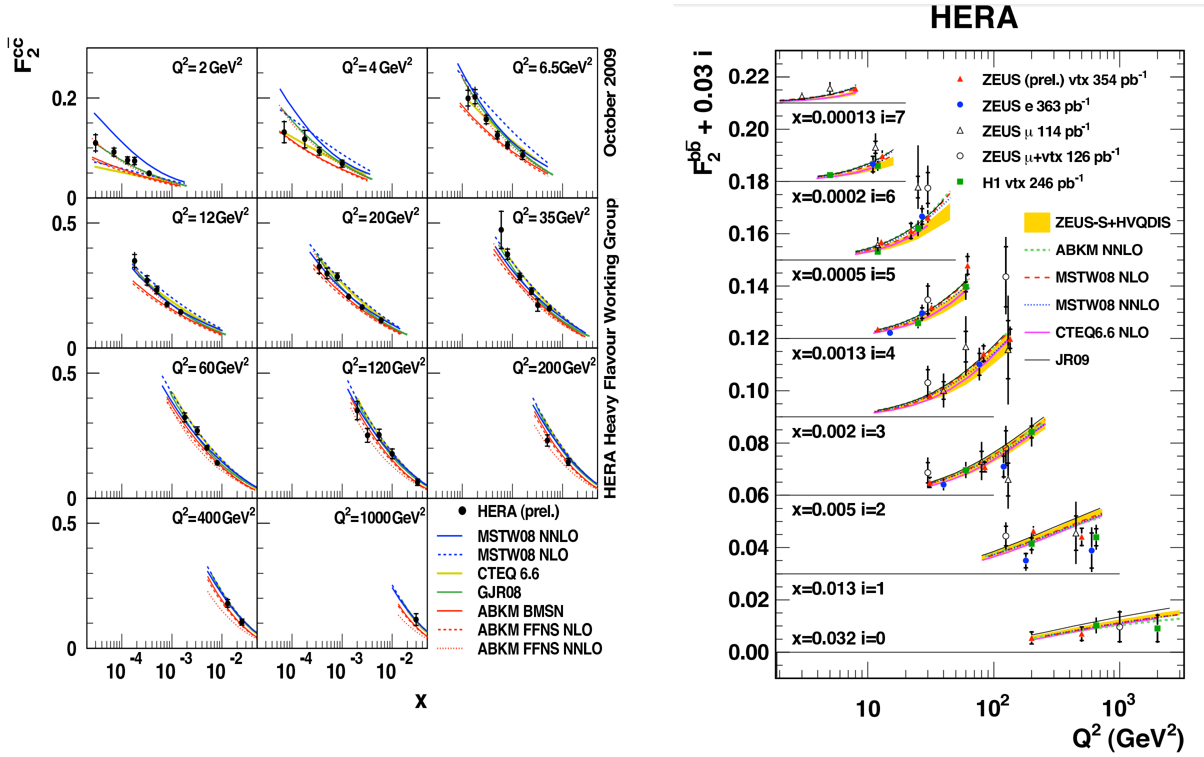

Figure 3: HERA-averaged $F_2^{c\bar{c}}$ (left) and recent determinations of $F_2^{b\bar{b}}$ (right) as a function of x in bins of Q^2 based on different heavy flavour tagging methods compared to QCD predictions in GMVFNS and FFNS from different global fit analyses at NLO and NNLO.

cases leads to increased precision and to the extension of the measured phase space. The large variety of different experimental techniques allow non-trivial cross checks to be made. In general the measurements are very well consistent with each other. The current data exhibit some sensitivity to different approaches in pQCD calculations of heavy flavour production. In general the measurements can be reasonably well described by up-to-date NLO QCD predictions.

References

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