OPEN HEAVY FLAVOUR PRODUCTION AT HERA

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Selected recent ZEUS and H1 results on open charm and beauty production in high energy *ep* collisions are reviewed. Measurements of differential D^* cross sections, charm meson production ratios and semi–leptonic beauty decays are discussed and compared with QCD predictions.

1 Introduction

Measurements of charm and beauty production at HERA probe proton and photon structure as well as the mechanisms of the hard subprocesses underlying *ep* interactions. In particular, they are considered an excellent testing ground for perturbative QCD calculations as the heavy quark mass provides a hard scale. Here, heavy quark production is predominantly gluon induced, the leading–order (LO) process being *boson–gluon fusion*, where a photon emitted by the electron and a gluon coming from the proton form a quark-antiquark-pair. The exchange of a quasi–real photon (*photoproduction*, γp) dominates over large photon virtualities (*deep inelastic scattering*, DIS).

Perturbative QCD calculations are available in next–to–leading order (NLO) and yield charm and beauty production cross sections one and three orders of magnitude smaller than the total cross section respectively. Monte Carlo (MC) simulations used in present analyses are based on LO matrix elements, which, except for the CCFM–based CASCADE program, are combined with a DGLAP–like parton evolution and leading–log parton showers.

The experimental results presented below are based on sub–samples of the data recorded by the H1 and ZEUS experiments between 1996 and 2000 at *ep* centre–of–mass energies of 300 and 318 GeV, with corresponding integrated luminosities $\mathcal{L}$ ranging from about 10 to 100 pb^{-1}.

2 Open charm production

Although recently analyses using other channels have become available, most of the HERA results on open charm production are based on the selection of $D^*(2010)$ mesons via the decay chain $D^* \to D^0\pi \to K\pi\pi$.

2.1 *The charm proton structure function F_2^c*

D^* production in DIS has been studied by both H1[1] and ZEUS[2]. The charm proton structure function F_2^c, which is defined in analogy to the inclusive structure function F_2, has been extracted as a function of the Bjørken scaling variable x and the photon virtuality Q^2. The charm contribution to DIS is significant, the ratio of F_2^c to F_2 being largest at low x and high Q^2, where the gluon component in the proton is dominant, cf. figure 1(a). The picture of charm production as a gluon driven process is also reflected in the scaling violations of F_2^c itself which are more pronounced than in the inclusive case. As shown in figure 1(b), a NLO DGLAP QCD fit to inclusive H1 data provides a good description of the F_2^c data from both experiments with a tendency, however, to underestimate the rise towards higher Q^2 at very small x.

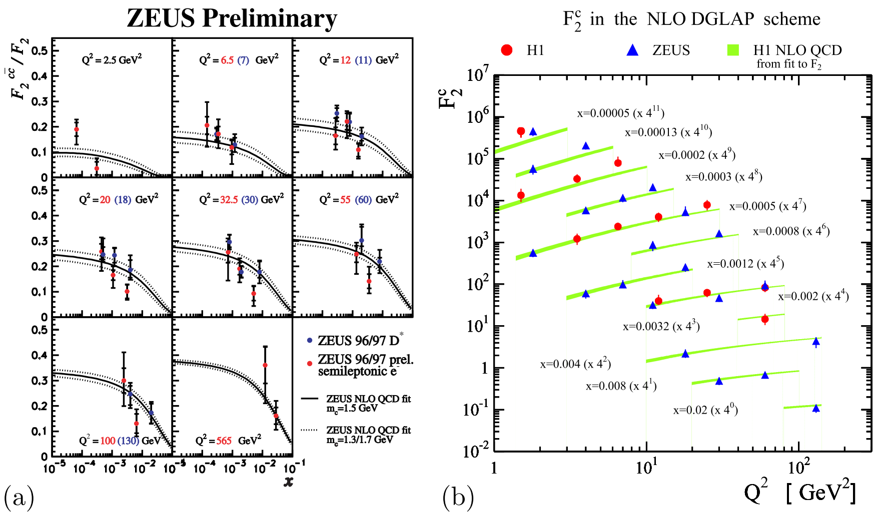

Figure 1. Measured charm contribution to the proton structure function as a function of x and Q^2, compared with NLO QCD: (a) ratio F_2^c/F_2 and (b) F_2^c.

2.2 *Differential D^* γp cross sections*

In photoproduction, double differential cross sections in terms of the D^* transverse momentum and (pseudo)rapidity are derived by H1[3] and ZEUS[4] and compared to QCD predictions. Due to differences in observables and visible regions used by the experiments the data cannot be compared together directly. It has been shown recently, however, that an FONLL calculation[5] is able to provide an acceptable description of the cross sections of both exper-

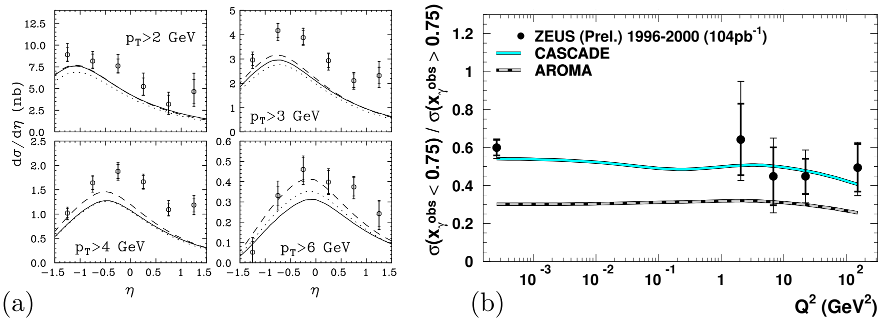

Figure 2. (a) D^* cross sections as measured by ZEUS, compared with QCD predictions. (b) Ratio of resolved to direct D^* production as a function of Q^2, compared with LO MC.

iments. For the H1 results consistency within errors is found in all measured regions while the ZEUS data hint at a possibly harder transverse momentum spectrum and an excess in the positive pseudorapidity region, cf. figure 2(a).

2.3 Resolved photon processes

Based on a sample of events with at least two jets and an identified D^* meson, ZEUS has studied[6] the role of resolved photon processes, where, in contrast to direct processes, only a fraction $x_\gamma < 1$ of the photon momentum enters the hard interaction. Experimentally, the fraction x_γ^{obs} of the incoming electron momentum going into the production of the two highest-E_t jets is used, which, however, is sensitive to any radiation not collinear to the heavy quarks. Defining a cut at $x_\gamma^{obs} = 0.75$, the ratio of resolved to direct processes in D^* photoproduction is found to be about 60%. A non–perturbative interpretation of this result in terms of a charm–containing hadronic photon structure, however, is compromised by the fact that the measured ratio is independent of Q^2 within errors and that the CASCADE MC gives a good description without an explicit resolved photon component, see figure 2(b).

2.4 D Meson production ratios

ZEUS reports results on charm meson production ratios. Fragmentation fractions for excited meson states have been determined[7] and the relative strangeness production rate has been studied[8] as well as the ratio of vector meson to pseudoscalar meson production.[9] The results can directly be compared to measurements at e^+e^- colliders and good agreement is found in all cases. In this sense charm fragmentation appears universal.

3 Open beauty production

HERA results on open beauty production are based on semileptonic b hadron decays within jets. The first measurement[10], obtained from an inclusive muon analysis on γp data recorded by H1 in 1996, yielded a cross section exceeding the QCD expectation significantly. Since then, new data and improved experimental tools have become available.

3.1 Photoproduction

ZEUS has measured b photoproduction in inclusive muon[11] and electron[12] analyses. As in the first measurement at HERA, the transverse lepton momentum p_t^{rel} relative to an associated jet is used as observable thus exploiting the large b mass. Figure 3(a) shows the measured differential cross section, $d\sigma/dp_t^{rel}$ for a sample of 943 electron candidates ($p_t > 1.6$ GeV, $|\eta| < 1.1$) from data collected during 1996 and 1997 corresponding to an integrated luminosity of $\mathcal{L} = 38.5$ pb^{-1}. Using MC simulations to model the beauty signal and charm background, a fit (taking the normalisation from the data) results in a beauty fraction f_b of 15% with the signal dominating the high p_t^{rel} region.

A recent H1 analysis[13] uses not only the b mass signature but detects beauty hadrons also via their long lifetimes by reconstructing the signed impact parameter δ. The δ distribution for 1415 muon candidates with $p_t > 2$ GeV and polar angles between 35° and 130° selected from 1997 data ($\mathcal{L} = 14.7$ pb^{-1}) is shown in figure 3(b) together with the result of a fit for the decomposition of the sample into contributions from beauty production, charm production and misidentified light hadrons (*fake muons*). f_b is deter-

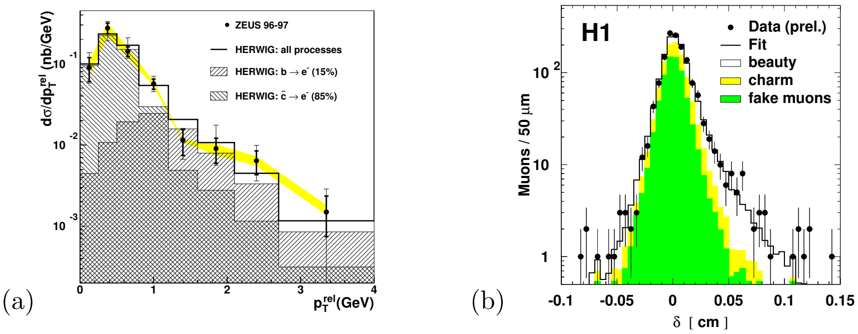

Figure 3. (a) $d\sigma/dp_t^{rel}$ for ZEUS electron γp data and MC (normalised and fitted to the data). (b) Muon δ spectrum (H1 γp sample) with the decomposition from the δ fit. δ is positive if the track intersects the jet downstream of the primary event vertex.

mined to be 26%, the signal being enriched at high positive δ. An improved measurement yielding a consistent result is obtained by combining both observables in a fit to the two–dimensional (δ, p_t^{rel}) distribution.

Translating f_b into visible cross sections, all results are consistently above corresponding NLO QCD predictions obtained from the FMNR program,[14] see figure 4(a). The excess is significant for the H1 measurements.

In the search for the source of the discrepancies between data and theory valuable information might be gained from differential cross section measurements. First results in the muon channel have recently been presented by ZEUS. Within errors, a LO MC gives an acceptable description with a tendency to underestimate the cross section for large muon pseudorapidities, see figure 4(b). Clearly, more statistics is needed to draw any firm conclusions.

3.2 DIS

Having established the impact parameter method in the γp regime, H1 performs a combined (δ,p_t^{rel}) analysis[15] to measure for the first time open b production in DIS. Based on 171 muon candidates selected from 1997 data ($\mathcal{L}$ = 10.5 pb^{-1}), the cross section in the visible range, defined by $p_t(\mu) > 2$ GeV, $35° < \theta(\mu) < 130°$, $Q^2 < 1$ GeV^2 and $0.1 < y < 0.8$, is determined to [39 $\pm$ 8 ($stat.$) $\pm$ 10 ($syst.$)] pb. This again exceeds significantly the NLO QCD prediction of (11 ± 2) pb, which is obtained from the HVQDIS program,[16] cf. figure 4(a).

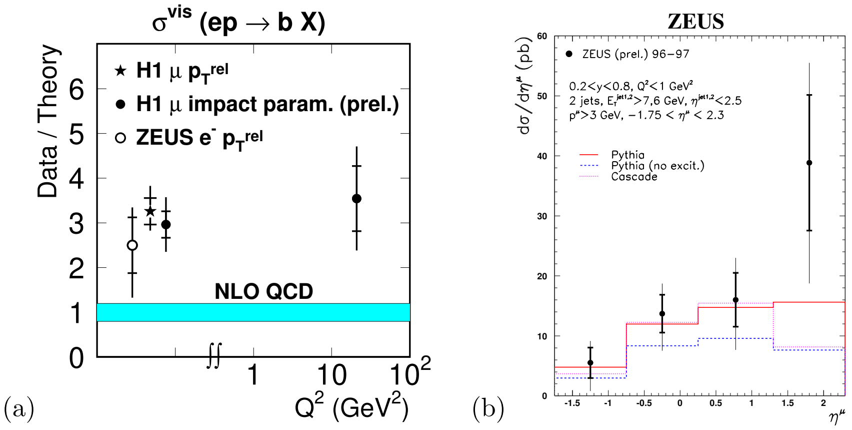

Figure 4. (a) Ratio of measured b production cross sections to theoretical predictions, as a function of Q^2. (b) b cross section as a function of $\eta(\mu)$, compared with LO MC predictions.

4 Summary

The study of open charm production at HERA is rapidly becoming a precision tool to test QCD in the presence of two hard scales. In the overall picture, pQCD gives a reasonable description of the data thus confirming the concept of charm production as a dominantly hard, gluon–induced process accounting for a significant part of the proton structure. Differential cross section measurements using several channels and including jet–based observables provide a starting point to investigate the details of the production mechanism.

Open beauty production is measured in inclusive lepton analyses including the b lifetime signature. Previous photoproduction results are confirmed and improved, and the DIS cross section is measured for the first time. All measured cross sections are found to be above the NLO QCD predictions, similar to the observations in $p\bar{p}$[17] and $\gamma\gamma$[18] interactions.

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