Beauty Production at HERA *

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on behalf of the H1 and ZEUS collaborations

An overview of new measurements of beauty production in $e-p$ collisions done by the H1 and ZEUS experiments at HERA is presented. Various techniques are used to efficiently tag the beauty flavour in the events, thereby exploring different regions of phase space. Differential cross sections are measured both in photoproduction and in deep inelastic scattering. The measured data are found to be somewhat higher then perturbative QCD calculations done at next-to-leading order.

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1. Introduction

Measuring beauty production in ep collisions at HERA is ideally suited to study the strong force. The dominant production mechanism is the photon-gluon-fusion process, directly driven by the gluon density in the proton. The large mass of the beauty quark, m_b, provides a hard kinematical scale, which allows calculations by means of perturbative QCD. Additional hard scales, such as the virtuality Q^2 of the exchanged photon or the transverse momenta of the outgoing b-quarks, complicate the picture. The measurements are performed both in the region of photoproduction ($Q^2 \approx 0$ GeV^2) and in deep inelastic scattering (DIS with $2 < Q^2 < 100$ GeV^2). At the scales O(m_b) considered here, pQCD calculations performed in the "massive scheme" at Next-to-Leading Order (NLO) are expected to give reliable results. Consequently, the data are compared with NLO predictions in the "massive scheme" ([7, 8]).

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2. The measurements

To separate b from c and light quark background, the large mass and the long lifetime of the b-quark are exploited. In practice, the following variables are used: 1. p_T^{rel}: The relative transverse momentum of the muon with respect to the axis of an associated jet in semileptonic decays; 2. the impact parameter δ: the distance of a track in the transverse plane with respect to the ep collision vertex. δ can be precisely measured with the silicon track detectors. 3. $S = \delta/\sigma_\delta$, S_1, S_2: the impact parameter significances of tracks (ordered according to size) in the event.

The fractions of b-quark events in the data samples are then determined from fits to distributions of p_T^{rel}, δ, S_i and/or 2-dimensional combinations thereof. Properly normalising the fractions yields directly the b-production cross sections, using the different tagging techniques as described below.

(i) Tagging beauty with muons and jets: In these analyses b-events are identified using muons from semileptonic b-decays, which provide a clean experimental signature. In addition to the muon the presence of at least one jet (two jets) in the DIS (photoproduction) sample is required. Figure 1 shows the differential cross-sections measured by H1 [1] and ZEUS [2] in photoproduction as a function of the muon pseudorapidity (left) and transverse momentum (right). Both measurements agree well in the overlapping region. Also shown are NLO pQCD predictions[7], in which the fragmentation is performed using the Peterson function. The errors of the theory prediction (bands) are dominated by the scale uncertainties. With a tendency to lie below the data, this calculation describes the H1 and ZEUS data points within the uncertainties. In the lowest p_T bin the H1 measurement somewhat exceeds the prediction while at higher transverse momenta a better agreement is observed. Such an excess is not seen in the ZEUS data. Their new silicon microvertex detector (MVD) allowed ZEUS to complement previous measurements using the latest HERA-II data. The results are found to be compatible with their previous ZEUS measurements and with NLO QCD. In the DIS regime, the H1 and ZEUS measurements are done in similar kinematic regions. The observations lead to conclusions very similar to the photoproduction case.

(ii) Tagging beauty by lifetime information: The method, applied in photoproduction, exploits explicitly the large lifetime information and it relies only on the significances S_i ([4]). Without requiring a detected muon it thus extends the phase space of b transverse momenta. While the charm data are reasonably well described in both normalization and shape, the beauty data are again found to be somewhat higher than the NLO prediction.

(iii) Double tagging beauty by D^* and muons: Further measurements by H1 ([9]) and ZEUS ([10]) are based on the simultaneous detection of a

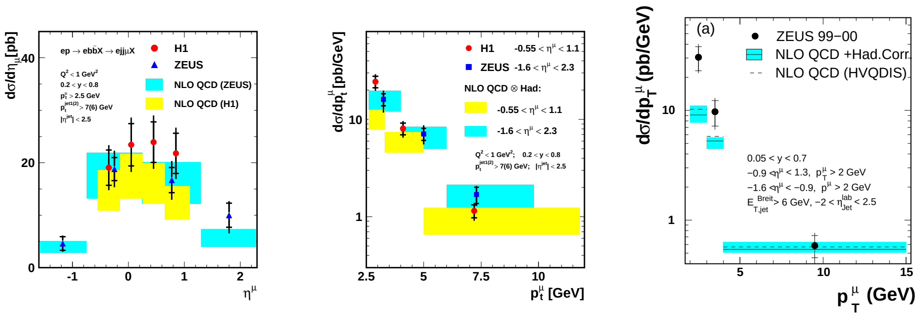

Fig. 1. *Differential cross section for the process* $ep \to eb\bar{b}X \to ejj\mu X'$ *as functions of the muon variables pseudo-rapidity* η_{mu} *and transverse momentum* p_t^{μ}*. a) and b) show the H1 and ZEUS results and the NLO predictions in photoproduction, c) shows the ones in the DIS-regime.*

$D^{*\pm}$ meson and a muon. The charge and angular correlation between the two serves to separate the b and c contributions. The kinematic region for $b\bar{b}$ is characterised by lower $b\bar{b}$ centre-of-mass energies than in most previous analyses, which require high momentum jets. A shape comparison of the measured differential distributions with QCD calculations at LO and NLO clearly indicate that effects beyond the LO approximation are directly observed. Again, charm is better described by NLO QCD than is beauty, where the differences are largest at low $p_t(\mu)$ and for more forward $\eta_t(\mu)$.
(iv) Double tagging beauty by two muons: A conceptually very similar analysis by ZEUS measures events in which two muons are observed in the final state. A low $p_t(\mu)$ threshold in combination with a large rapidity coverage accesses essentially the full phase space for b-production. The differential cross sections are shown in Figure 2a) and b). The LO QCD predictions, based on the Pythia and Rapgap Monte Carlo programs, describe the shapes pretty well, but are a factor of two low in normalisation.

When comparing the total inclusive cross sections, which covers the b-phase space down to $p_t(b) \approx 0$, it is found, that the NLO pQCD predictions are a factor of roughly 2.4 below the measurements, although they are still compatible within the very large uncertainties.

3. Summary

The recent inclusive beauty production cross section measurements at HERA are summarised in figure 2, which shows the ratio of measured cross sections to the NLO QCD prediction as a function of Q^2. Most of the data points lie above the predictions and there is no clear Q^2-dependence visible.

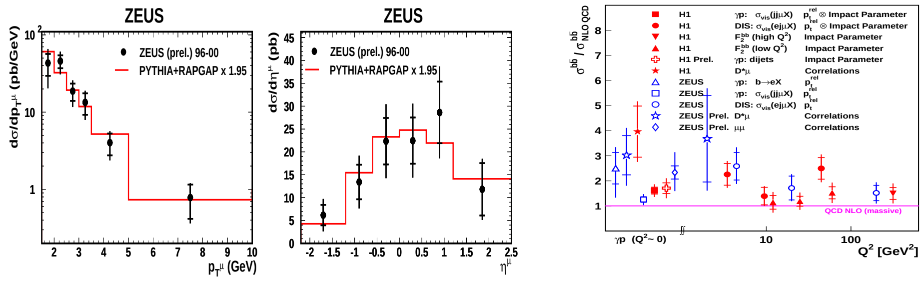

Fig. 2. *a) and b) show the differential cross sections for* $ep \to eb\bar{b}X \to e\mu\mu X'$ *measured by ZEUS in double muon tagging in photoproduction. Overlaid are the LO predictions scaled up by a factor of 1.95. c) depicts the ratio of measurement to NLO prediction for the different methods as a function of* Q^2

The differential spectra indicate that the data tend to lie above the predictions more significantly towards small b-quark transverse momenta, i.e. closer to the threshold region and in the more forward (i.e. proton) direction. The single significances are not that large, however they are observed in different regions with differing measuring methods. Results in the DIS regime show somewhat better agreement with the NLO predictions. Thus, differences between QCD predictions and data still prevail. It is expected that the new HERA II data will provide higher precision. But to resolve the issues completely, improvements are needed also on the theoretical side.

REFERENCES

[1] A. Aktas *et al.* [H1 Collab.], Eur. Phys. J. C **41**, 453 (2005)

[2] S. Chekanov *et al.* [ZEUS Collab.], Phys. Rev. D **70** (2004) 012008.

[3] S. Chekanov *et al.* [ZEUS Collab.], Phys. Lett. B **599**, 173 (2004)

[4] A. Aktas *et al.* [H1 Collab.], [arXiv:hep-ex/0507081].

[5] D. Pitzl *et al.*, Nucl. Instrum. Meth. A **454** (2000) 334.

[6] E. N. Koffeman [ZEUS Collab.], Nucl. Instrum. Meth. A **473**, 26 (2001).

[7] S. Frixione, P. Nason and G. Ridolfi, Nucl. Phys. B **454**, 3 (1995).

[8] B.W.Harris and J.Smith, Nucl. Phys. B **452**, 109 (1995).

[9] A. Aktas *et al.* [H1 Collab.], Phys. Lett. B **621**, 56 (2005).

[10] S. Chekanov *et al.* [ZEUS Collab.], Contributed paper 575 to Int. Conf. on High Energy Physics, 2003, Aachen.

[11] S. Chekanov *et al.* [ZEUS Collab.], Contributed paper 269 to Int. Conf. on Lepton-Photon interactions, 2005, Uppsala.