BEAUTY PRODUCTION AT HERA

Martin Brinkmann

for the H1 and ZEUS Collaborations

Deutsches Elektronen-Synchroton (DESY),
Notkestrasse 85, 22607 Hamburg, Germany
E-mail: martin.brinkmann@desy.de

The study of beauty production in *ep* collisions at HERA provides an insight into QCD processes since the beauty quark mass automatically provides a hard scale for perturbative QCD calculations. A selection of new measurements of beauty production by the H1 and ZEUS collaborations in photoproduction and deep inelastic scattering is presented. Recent results on the beauty contribution $F_2^{b\bar{b}}$ to the proton structure function F_2 are shown. A detailed understanding of the beauty contribution is important for processes originating from b quarks at the LHC.

1 Introduction

For the description of beauty production processes the QCD factorisation theorem holds where the production cross section can be written as a convolution of the parton distribution functions (PDFs), the hard scattering matrix element and a hadronisation part. The hard scattering part can be treated within perturbative QCD (pQCD) in the presence of a hard scale which is for beauty production automatically given by the quark mass. Therefore the measurement of beauty quark production processes provides an ideal testing ground for pQCD. The so called "Multi scale problem" that arises in the presence of additional hard scales (e.g. large transverse momenta) is addressed in pQCD with different schemes. The dominant hard process for beauty production in *ep* collisions is the photon gluon fusion (PGF), which provides a direct sensitivity to the gluon density in the proton. The understanding of the beauty production mechanisms and measurement of the beauty contribution $F_2^{b\bar{b}}$ to the proton structure function F_2 are important for LHC measurements.

Heavy quark production measurements in ep collisions are made in two kinematic regions. In the photoproduction regime (PHP) the negative four-momentum transfer squared in the process is small, $Q^2 \approx 0\,\mathrm{GeV}^2$, whereas in deep inelastic scattering (DIS) the photon virtuality Q^2 is large compared to Λ_{QCD} and can be utilized as a hard scale.

The beauty contribution to the total ep cross section is only $O(10^{-3})$ to $O(10^{-2})$ and therefor most of the beauty measurements at HERA are statistically limited. Especially the cross section measurement via full reconstruction of B hadrons is not possible. For beauty measurements different tagging methods are used in various combinations: 1. Reconstruction of decay leptons from semileptonic decays 2. Usage of effects of the larger mass like high transverse momenta of the decay lepton with respect to the quark jet and 3. Usage of effects of the relatively long lifetime of the B hadrons, either by reconstruction of secondary vertices and calculating their decay length significance, or by calculating the impact parameter significance of displaced tracks.

To correct for the detector inefficiency and acceptance, Monte Carlo (MC) simulations based on leading order ($O(\alpha_s)$) matrix element using parton showers to approximate the higher orders are used. The RAPGAP program [1] for DIS and PYTHIA [2] for γp are based on collinear factorisation and DGLAP evolution of parton densities. CASCADE [3] uses a k_T unintegrated gluon density and is based on CCFM evolution.

The data are compared to next-to-leading order (NLO) QCD calculations. The NLO calculation FMNR [4] for γp and HVQDIS [5] for DIS are used, respectively. In these models the quark structure of the proton contains only 3 flavours, charm and beauty are produced dynamically as massive particles in a hard scattering (Fixed Flavour Number Scheme, FFNS). A NLO calculation in the generalized mass variable flavour number scheme GM-VFNS for heavy quarks [6] is also used for comparison to data. The GM-VFNS interpolates from the massive approach at low scales to the massless approach at high scales where also the heavy quarks are treated as active constituents in the proton.

2 Measurement of Beauty in PHP

Beauty cross sections have been measured by H1 in PHP down to the production threshold for the first time at HERA [7]. The measurement is based on data with an integrated luminosity of $L_{int} \sim 46\,\mathrm{pb}^{-1}$. Events are selected where both beauty quarks in the event decay semileptonic into low p_t electrons ($1\,\mathrm{GeV} < p_t^e < 5\,\mathrm{GeV}$). This analysis is possible due to a very good electron identification where the pion misidentification rate is only a few per mille. The measured cross sections are compared to predictions from NLO

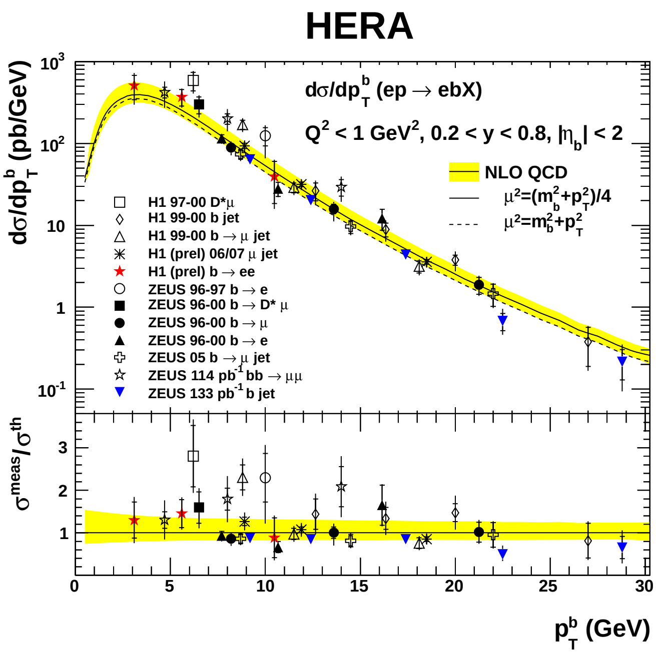

Figure 1: Summary plot for HERA beauty measurements in PHP. The cross sections are shown as a function of the transverse momentum of the b-quark together with the expectation from NLO QCD calculation (FMNR) for two different choices of the renormalisation scale.

pQCD calculations from FMNR. The NLO calculations describe the data well even at the lowest accessible transverse momentum of the b-quark.

A new measurement on beauty production at HERA in PHP accessing large transverse momenta has been performed by ZEUS [8] with an integrated luminosity of $L_{int} \sim 133\,\mathrm{pb}^{-1}$. Within this analysis two jets are required ($p_t^{jet} > 7(6)\,\mathrm{Ge}V$). For beauty tagging secondary vertices belonging to the jets are reconstructed and the decay length significance and invariant mass of each secondary vertex are used for flavour separation. The beauty cross sections are measured as a function of e.g. the jet kinematic variables (p_t^{jet},η^{jet}). The predicted cross sections from NLO QCD (FMNR) are in agreement with the data. The theoretical uncertainties ($\sim 30\,\%$) are larger than the experimental ones

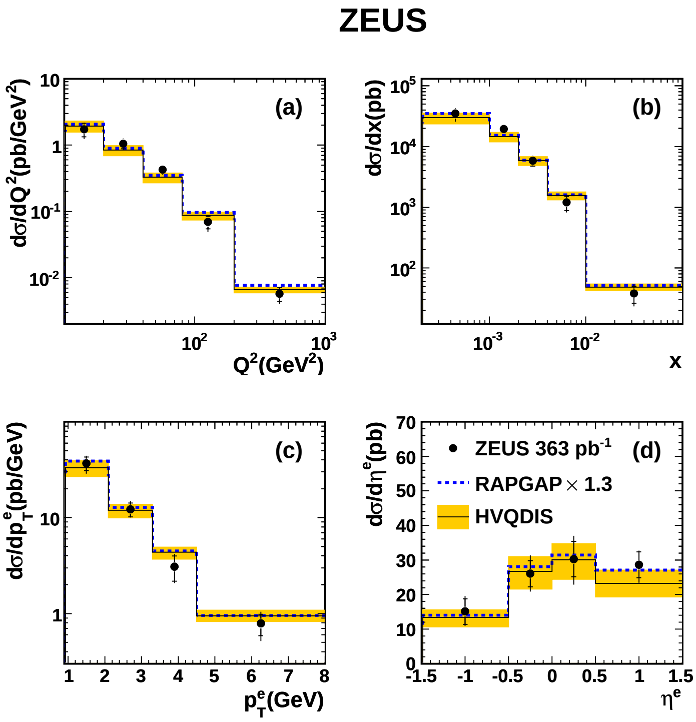

Figure 2: Measured beauty cross sections in DIS as a function of the photon virtuality Q^2, the Bjorken scale variable x and the kinematic variables of the electron p_t and η. Also shown the predictions from NLO QCD (HVQDIS) and LO plus parton shower MC (RAPGAP).

($\sim 20\,\%$) for most of the phase space.

In Fig. 1 the beauty cross sections in bins of p_t^b in PHP from various HERA measurements are summarized [7]. The measured cross sections are consistent with each other over a wide range of p_t^b. The measurements are compared with the prediction from the FMNR NLO pQCD calculation. In general a good agreement between data and the NLO calculation is observed.

3 Measurement of Beauty in DIS

In a recent beauty measurement in DIS by H1 ($L_{int} \sim 189\,\mathrm{pb}^{-1}$) for $Q^2 > 6\,\mathrm{GeV}^2$ jets are reconstructed with a transverse energy $E_t^{jet} > 6\,\mathrm{GeV}$ [9]. In order to tag beauty jets lifetime information is used in the form of the decay length significance of displaced tracks and secondary vertices. The measurements are performed in the laboratory frame as well as in the Breit frame. Differential cross sections has been measured e.g. in bins of E_t^{jet} and η^{jet}. Since in this phase space three scales of similar size are present (m_b, $\sqrt{Q^2}$, E_t^{jet}), this measurement is suitable to test the influence of different choices of the renormalisation and factorisation scale in the NLO pQCD calculation. The measured cross sections are compared to results from a NLO calculation (HVQDIS) which describes the data well for different choices of the renormalisation scale namely $\mu_r^2 = 0.5\,(Q^2+p_t^2+m^2)$ and $\mu_r^2 = Q^2+4m^2$. A beauty measurement performed by ZEUS for $5 < Q^2 < 1000\,\mathrm{GeV}^2$ based on the full HERA II data sample ($L_{int} \sim 354\,\mathrm{pb}^{-1}$) uses reconstructed jets ($E_t^{jet} > 5\,\mathrm{GeV}$) together with lifetime information via secondary vertices [10]. The measured cross sections are in reasonable agreement with results from NLO QCD predictions.

There are recent results of beauty measurements in DIS by ZEUS making use of semi leptonic decays. One of the measurements at $Q^2 > 10\,\mathrm{GeV}^2$ with $L_{int} \sim 363\,\mathrm{pb}^{-1}$ uses identified electrons in addition to secondary vertex reconstruction [11]. There is also a jet reconstructed with $p_t^{jet} > 2.5\,\mathrm{GeV}$ matching to the electron candidate. Due to the additional electron identification the cut on the transverse momentum of the jet needed for a reasonably large beauty fraction can be much lower than for the other analysis described above. The measured cross sections as a function of the kinematic variables of the event as well as the decay electron are shown in Fig. 2. The data are compared to results from a NLO QCD calculation and predictions from the LO plus parton shower Monte Carlo RAPGAP. The NLO calculations describes the data well and the Monte Carlo results agree with the data well in shape but not in the absolute normalisation. The other beauty measurement from ZEUS based on semi leptonic decays for $Q^2 > 2\,\mathrm{GeV}^2$ with $L_{int} \sim 114\,\mathrm{pb}^{-1}$ uses an identified muon matching to a reconstructed jet ($E_t^{jet} > 5\,GeV$) [12]. Cross sections are measured as a function of e.g. the kinematic variables of the muon as well as the jet. The NLO QCD prediction describes the measured cross sections reasonably well.

One way to summarize the beauty results in DIS is the extraction of $F_2^{b\bar{b}}$ for each measurement. The individual results are shown in Fig. 3 [10]. All measurements are

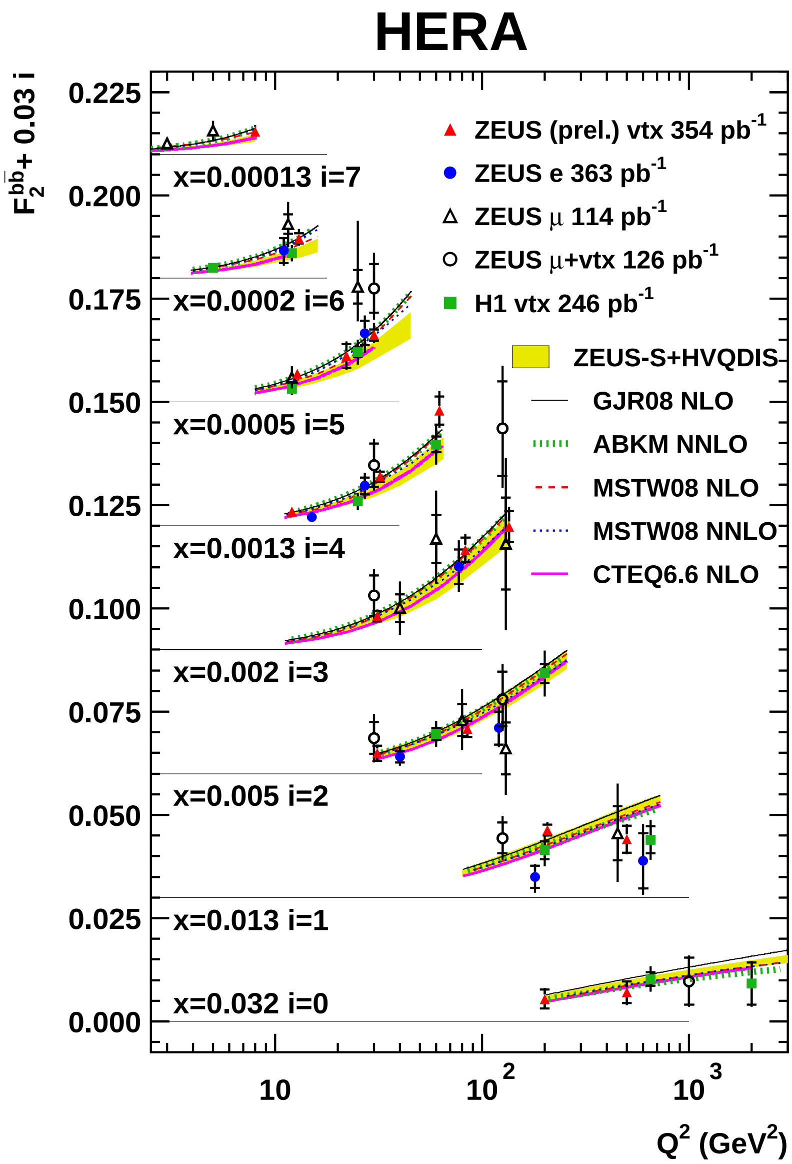

Figure 3: Results on $F_2^{b\bar{b}}$ from different H1 and ZEUS measurements compared to NLO and NNLO predictions.

consistent with each other. They are compared to NLO and NNLO models in a GM-VFNS as well with the NLO FFNS calculation. The different theory predictions are consistent with the data. The precision of the beauty measurements in DIS at HERA is not sufficient to discriminate between the different theory predictions.

4 Conclusions

Many new measurements on beauty production at HERA achieved by the H1 and ZEUS experiments in PHP and DIS were presented. Within these measurements different methods for beauty tagging like reconstruction of decay leptons and lifetime tagging are used in various combinations. The calculation in the NLO pQCD describes the beauty quark measurements in their particular phase spaces reasonably well in both PHP and DIS. Each beauty analysis in PHP provides cross sections as a function of the transverse momentum of the beauty quark extrapolated to a common phase space. This allows a comparison of the different measurements with each other which are consistent. Based on the measured beauty production cross sections in DIS the beauty contribution $F_2^{b\bar{b}}$ to the proton structure function F_2 has been extracted. Different beauty measurements provide consistent results of $F_2^{b\bar{b}}$ and predictions of $F_2^{b\bar{b}}$ from different NLO and NNLO pQCD models using different sets of parton density functions describe the measured $F_2^{b\bar{b}}$.

Acknowledgements

I would like to thank the organizers of the Low-x Meeting 2011 for giving me the opportunity to present results from HERA during the Meeting.

References

[1] H. Jung, Comput. Phys. Commun. **86** (1995) 147.

[2] T. Sjöstrand *et al.*, Comput.Phys Commun. **135** (2001) 238 [hep-ph/0010017].

[3] H. Jung and G.P. Salam, Eur. Phys. J. C **19** (2001) 351 [hep-ph/0012143]; H. Jung, Comput. Phys. Commun. **143** (2002) 100 [hep-ph/0109102].

[4] S. Frixione, M.L. Mangano, P. Nason and G. Ridolfi, Nucl. Phys. B **412** (1994) 225-259

[5] B. W. Harris and J. Smith, Phys. Rev. D **57** (1998), 2806 [hep-ph/9706334].

[6] G. Kramer and H. Spiesberger, Eur. Phys. J. C **38** (2004) 309 [arXiv:hep-ph/0311062].

[7] H1 Collaboration, H1prelim-11-071, https://www-h1.desy.de/publications/H1preliminary.short_list.html.

[8] H. Abramowicz *et al.* [ZEUS Collaboration], Eur. Phys. J. **C71** (2011) 1659.

[9] F. D. Aaron *et al.* [H1 Collaboration], Eur. Phys. J. **C71** (2011) 1509. [arXiv:1008.1731 [hep-ex]].

[10] ZEUS Collaboration, ZEUS-prel-10-004, http://www-zeus.desy.de/publications.php3.

[11] H. Abramowicz *et al.* [ZEUS Collaboration], Eur. Phys. J. **C71** (2011) 1573. [arXiv:1101.3692 [hep-ex]].

[12] H. Abramowicz *et al.* [ZEUS Collaboration], Eur. Phys. J. **C69** (2010) 347-360. [arXiv:1005.3396 [hep-ex]].