# H1 AND ZEUS RESULTS ON BEAUTY PRODUCTION

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The H1 and ZEUS experiments are measuring beauty production in ep collisions at HERA. The $b$ quark mass provides a hard scale which allows a dedicated test of perturbative QCD. The latest results in photoproduction and deep inelastic scattering are presented and compared to the NLO QCD predictions as well as to LO + parton shower Monte Carlo simulations.

## 1 Introduction

At HERA a center of mass energy of $\sqrt{s} = 318$ GeV is achieved by colliding positrons (or electrons) of 27.5 GeV and protons of 920 GeV. In the years 1996-2000 the experiments H1 and ZEUS collected an integrated luminosity of more than 100 pb$^{-1}$ each, yielding a good opportunity to study perturbative QCD calculations for beauty production.

Photon gluon fusion is the main mechanism for beauty production at HERA, where a photon emitted by the initial positron [a] interacts with a gluon in the proton, resulting in a quark antiquark pair. With at least one hard scale, due to the large $b$ quark mass, perturbative QCD calculations are applicable. Nevertheless, a hard scale is also given by the transverse jet energy and, in DIS events, by the photon virtuality $Q^2$. The presence of more than one hard scale can lead to large logarithms in the calculation, which can spoil the reliability of the perturbative expansion. Hence, precise differential cross section measurements are needed to test the theoretical understanding of beauty production.

The measurement techniques rely on signatures that are characteristic for $b$ production and decay. Due to the large $b$ mass, the transverse momentum of the muon with respect to the axis of the closest jet, $p_T^{rel,\mu}$, is larger in a $b$ decay to a jet and a muon than in decays of lighter quarks. A different method to extract $b$ decays is the measurement of the lifetime provided by

[a] Electrons and positrons will not be distinguished in the following sections and are both referred to as positrons.

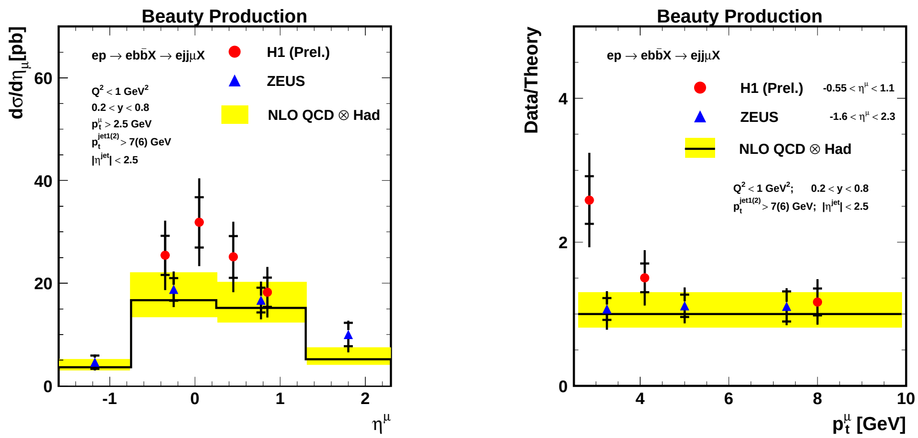


Figure 1: Differential cross sections of beauty photoproduction as a function of the muon pseudorapidity in comparison to NLO QCD (left) and the data/theory ratio of the muon transverse momentum (right).

silicon vertex detectors. Because of the large $b$ lifetime, the impact parameter of the muon is larger for $b$ than for light flavour decays.

## 2 Beauty in Photoproduction

If the negative squared four-momentum exchanged at the positron vertex is small ($Q^2 < 1$ GeV$^2$), the exchanged photon emitted by the positron is quasi-real, and the reaction $ep \to e'b\bar{b}X$ can be considered as a photoproduction process.

ZEUS has measured beauty photoproduction [1] in events with two jets and a muon in the final state, using the data collected in the years 1996-1997 and 1999-2000, which correspond to an integrated luminosity of $\mathcal{L} = 110.4 \pm 2.2$ pb$^{-1}$. The visible cross sections are obtained for events with $p_T^{jet_{1(2)}} > 7(6)$ GeV, $\eta^{jet_{1,2}} < 2.5$, $0.2 < y < 0.8$ and $Q^2 < 1$ GeV$^2$. The angular acceptance of the three muon chambers and of the central tracking detector define three regions of good acceptance, in which the cross section is measured and compared to the NLO QCD prediction based on the FMNR program [2] with Peterson fragmentation [3] (see Tab. 1):

Table 1: ZEUS kinematic ranges and cross sections for each muon chamber in comparison to the NLO QCD prediction corrected to the hadron level with the theoretical uncertainty and the hadronisation corrections $C_{had}$.

| $\mu$-chambers | kinematic range | $\sigma\pm$ stat. $\pm$ sys. | $\sigma^{NLO} \times C_{had}$ | $C_{had}$ |
|---|---|---|---|---|
| rear | $-1.6 < \eta^\mu < -0.9$, $p^\mu > 2.5$ GeV | $6.5 \pm 1.5^{+1.0}_{-1.1}$ | $4.3^{+1.6}_{-1.0}$ | 0.80 |
| barrel | $-0.9 < \eta^\mu < 1.3$, $p_T^\mu > 2.5$ GeV | $38.2 \pm 3.4^{+5.7}_{-5.8}$ | $33.9^{+11.0}_{-7.0}$ | 0.89 |
| forward | $1.48 < \eta^\mu < 2.3$, $p^\mu > 4$ GeV, $p_T^\mu > 1$ GeV | $16.6 \pm 3.3^{+2.9}_{-4.6}$ | $6.5^{+2.8}_{-1.6}$ | 0.86 |

H1 has used data collected in the years 1999-2000 corresponding to an integrated luminosity of $\mathcal{L} = 48$ pb$^{-1}$ to measure beauty photoproduction [4]. The visible cross section for events with at least two high transverse momentum jets with $p_T^{jet_{1(2)}} > 7(6)$ GeV, $\eta^{jet_{1,2}} < 2.5$, $0.2 < y < 0.8$, $Q^2 < 1$ GeV$^2$, and a muon in the final state with $-0.55 < \eta^\mu < 1.1$ and $p_T^\mu > 2.5$ GeV is measured to be $\sigma_{vis}(ep \to eb\bar{b}X \to ejj\mu X) = 42.5 \pm 3.4_{stat} \pm 8.9_{sys}$.
The prediction from the NLO QCD calculation [2] including fragmentation [3] and hadronisation corrections is $\sigma^{NLO} \times C_{had} = 24.1^{+7.2}_{-5.1}$.

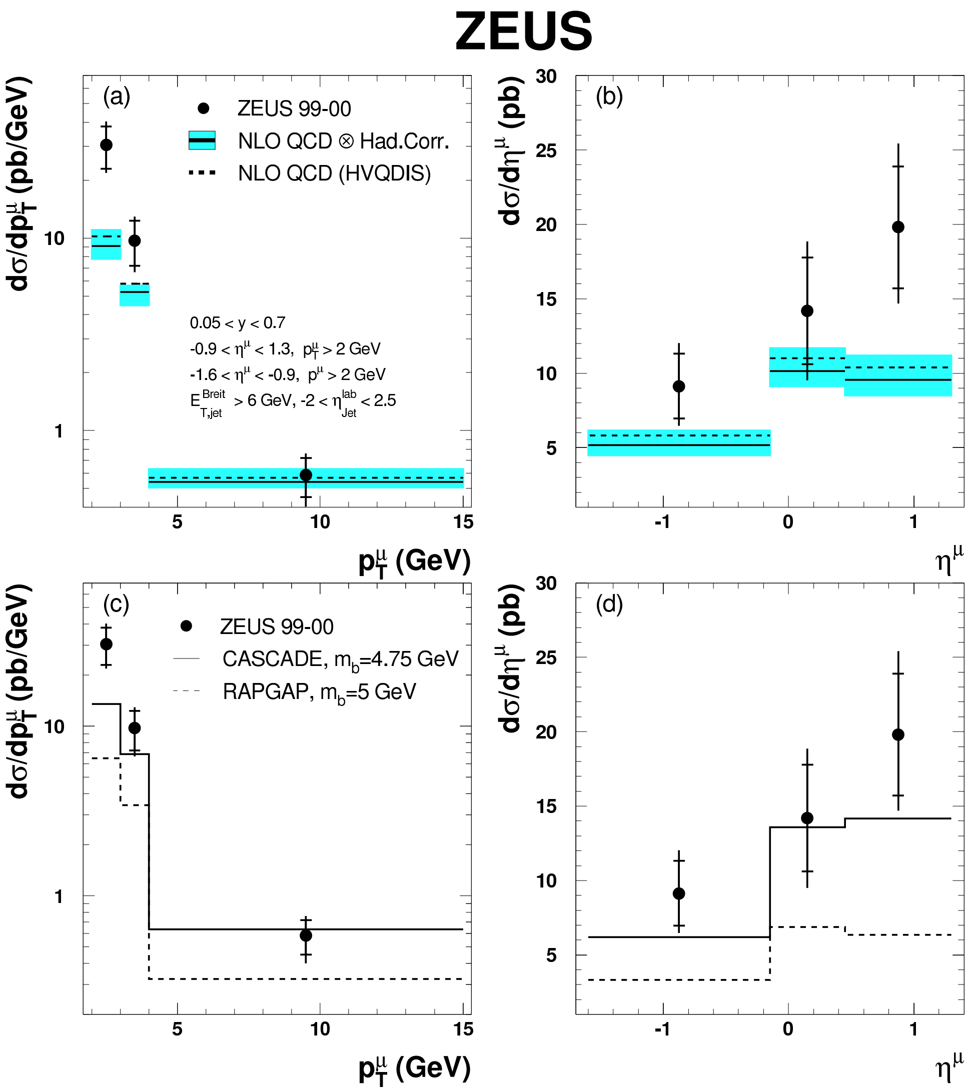


Figure 2: Differential cross sections of beauty in DIS measured by ZEUS as a function of the muon transverse momentum (left) and of its pseudorapidity (right) in comparison to NLO QCD calculations (a,b) and to the LO QCD MC programs (c,d) Cascade (solid line) and Rapgap (dashed line).

The differential cross section in $\eta^\mu$ and the data/theory ratio as a function of $p_T^\mu$ measured by ZEUS and H1 are shown in Fig. 1.

## 3 Beauty in Deep Inelatic Scattering

ZEUS has measured beauty production in DIS [5] using the data taken in 1999-2000, which corresponds to an integrated luminosity of $\mathcal{L} = 72.4 \pm 1.6$ pb$^{-1}$. The total visible cross section was determined in the kinematic range $Q^2 > 2$ GeV$^2$ and $0.05 < y < 0.7$ with at least one hadron-level jet in the Breit frame[b] with $E_{T,jet}^{Breit} > 6$ GeV and $-2 < \eta_{jet}^{lab} < 2.5$, and with a muon fulfilling: $-1.6 < \eta^\mu < -0.9$ and $p^\mu > 2$ GeV or $-0.9 < \eta^\mu < 1.3$ and $p_T^\mu > 2$ GeV. The result is $\sigma_{vis}(ep \to eb\bar{b}X \to ej\mu X) = 40.9 \pm 5.7_{stat}\,{}^{+6.0}_{-4.4}{}_{sys}$.
The NLO QCD calculation using the Hvqdis program[6] with hadronisation corrections modeled

[b] The Breit frame is defined by $\vec{\gamma} + 2x\vec{P} = \vec{0}$, where $\vec{\gamma}$ is the momentum of the exchanged photon, $x$ the Bjorken scaling variable and $\vec{P}$ is the proton momentum. A space-like photon and a proton collide head-on.

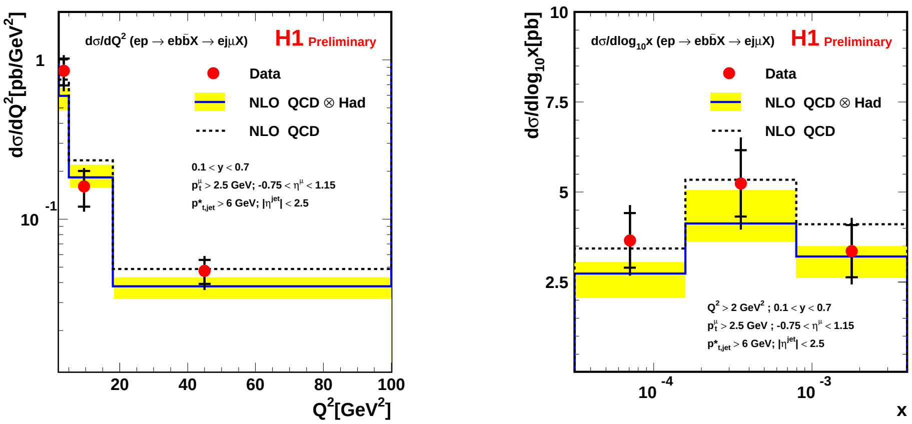


Figure 3: Differential cross sections of beauty production in DIS measured by H1 as a function of $Q^2$ (left) and of $x$ (right) in comparison to NLO QCD.

by the Kartvelishvili [7] parametrisation predicts $20.6^{+3.1}_{-2.2}$ pb, while the CASCADE Monte Carlo program gives 28 pb and the RAPGAP Monte Carlo gives 14 pb. Fig. 2 shows that the data are well described by NLO QCD and by the MC except in the region of low $p_T^{\mu}$.

H1 has also measured beauty production in DIS [8], using the data collected in the years 1999-2000, which correspond to an integrated luminosity of $\mathcal{L} = 50$ pb$^{-1}$. The events are selected by requiring at least one high transverse momentum jet in the Breit frame with $p_{T,jet}^{Breit} > 6$ GeV, $|\eta_{jet}| < 2.5$ and a muon associated to the jet with $-0.75 < \eta^{\mu} < 1.15$ and $p_T^{\mu} > 2.5$ GeV. The visible cross section in the range $2 < Q^2 < 100$ GeV$^2$ and $0.1 < y < 0.7$ is measured as $\sigma_{vis}(ep \to eb\bar{b}X \to ej\mu X) = 8.8 \pm 1.0_{stat} \pm 1.5_{sys}$.
In comparison, the NLO QCD calculation, including corrections from fragmentation and hadronisation, is $7.3^{+1.0}_{-1.5}$ pb. The Monte Carlo programs RAPGAP and CASCADE give a good description of the shapes of the distributions observed in the data, though the RAPGAP prediction is too low in normalization.

## 4 Summary and Outlook

Recent HERA beauty measurements show improved agreement between data and NLO QCD calculations. The Monte Carlo simulations describe the shape very well, though sometimes the predictions are too low in normalisation. The higher statistics which will be collected in the HERA II running period in the next years will allow more precise differential measurements.

## References


1. S. Chekanov *et al*, hep-ex/0312057, accepted by Physical Review D, 2003.
2. S. Frixione *et al*, *Nucl. Phys.* B **412**, 225 (1994).
3. C. Peterson *et al*, *Phys. Rev.* D **27**, 105 (1983).
4. H1 Coll., contr. paper (abstract 117) to EPS03, Aachen 2003, and LP03, Fermilab 2003.
5. S. Chekanov *et al*, DESY-04-070, 2004.
6. B. W. Harris and J. Smith, *Phys. Rev.* D **57**, 2806 (1998); *Nucl. Phys.* B **452**, 109 (1995); *Phys. Lett.* B **353**, 535 (1995).
7. V. G. Kartvelishvili, A. K. Likhoded, V. A. Petrov, *Phys. Lett.* B **78**, 615 (1978).
8. H1 Coll., contr. paper to DIS 2004, Slovakia 2004