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Beauty production at HERA

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Abstract. We present new and recent results on beauty production in electron proton collisions at 300-318 GeV centre-of-mass energy. The cross sections measured by the H1 and ZEUS experiments at HERA are compared with perturbative QCD calculations.

1 Introduction

It would be expected that beauty cross-sections in ep collisions at HERA can be accurately calculated using perturbative QCD (pQCD). In contrast, the first measurements at HERA [1,2,3] revealed significant excesses of data over pQCD predictions by factors of ~ 3, in line with similar findings in $p\bar{p}$ and $\gamma\gamma$ collisions at Tevatron [4] and LEP [5]. In this paper, we review recent HERA beauty measurements, all released after spring 2002. Two new results [6,7] have just become available for this conference. All results are based on the HERA I data from the years 1995-2000.

2 Theory

In the Standard Model the dominant mechanism for beauty production in ep collisions at HERA is the *direct* boson gluon fusion process as shown in Fig. 1a). Further contributions are expected from *resolved* photon processes as illustrated in Fig. 1b). All these processes are directly sensitive to the gluon density in the proton. The kinematics at HERA spans a large range in the photon virtuality Q^2 from photoproduction, where $Q^2 < 1$ GeV^2 to deep inelastic scattering (DIS), where Q^2 can reach values much higher than the squared b-quark mass. It is expected that resolved photon processes are suppressed towards larger Q^2.

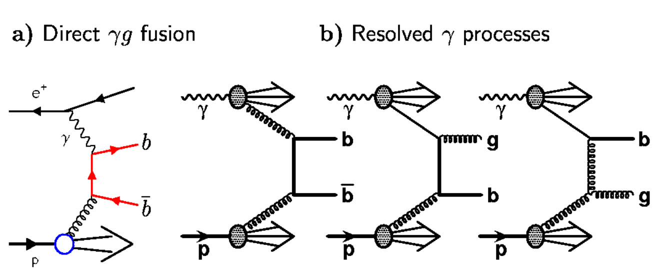

Fig. 1. Beauty production processes in leading order pQCD

The large mass of the beauty quark provides a hard scale, which renders a small coupling constant α_s in the hard subprocess. This facilitates the calculation of cross sections by means of pQCD. One distinguishes the following two approaches:

– In the so-called *massive* or *fixed order* scheme[8], u,d and s are the only active flavours in the proton, and charm and beauty are dynamically produced in the hard scattering. This approach should work well for the kinematic region $p_T \leq m_b$, where p_T is the transverse momentum of the outgoing b-quark. Calculation tools up to next-to-leading order (α_s^2) (NLO) are available in the form of Monte Carlo integration programs [9,10].
– At higher transverse momenta the so called *massless* or *resummed* approach [11] should be applicable, where charm and beauty are regarded as active flavours (massless partons) in the proton and in the photon and fragment only after the hard process into massive quarks. This ansatz incorporates excitation processes, such as the two right most diagrams shown in Fig. 1b).

3 Measurement technique

The total beauty production cross-section at HERA is two orders of magnitude smaller than that of charm. High p_T muons from semileptonic b-decays are used to identify the beauty events. In the **single track tag** analyses, the selected muon is required to be associated with a jet. To separate beauty events from charm and light quark background, two observables are used which exploit the large mass and the long lifetime of the b-quark, respectively:

1. The transverse momentum p_T^{rel} of the muon with respect to the axis of the associated jet: For muons from b-decays this exhibits a much harder spectrum than for the other sources.
2. The impact parameter δ of the muon track with respect to the primary event vertex: For muons from

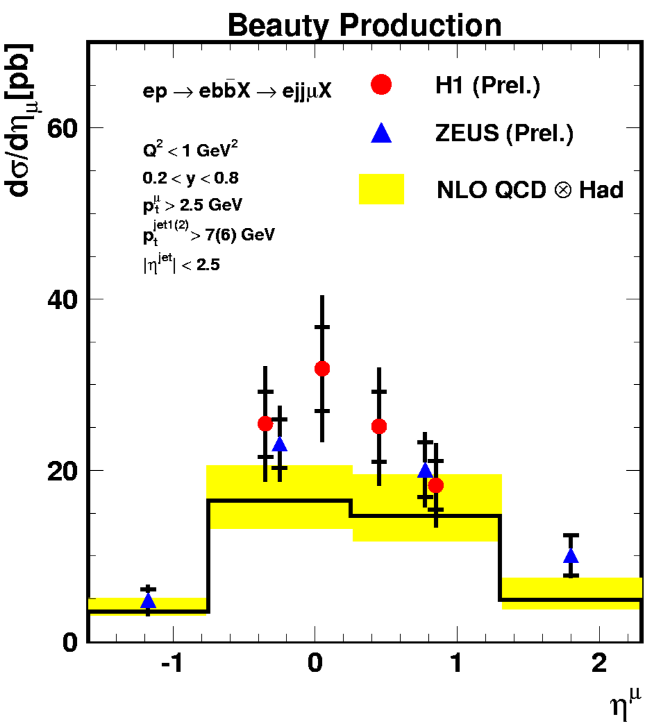

Fig. 2. Differential beauty cross sections as a function of pseudorapidity of the muon

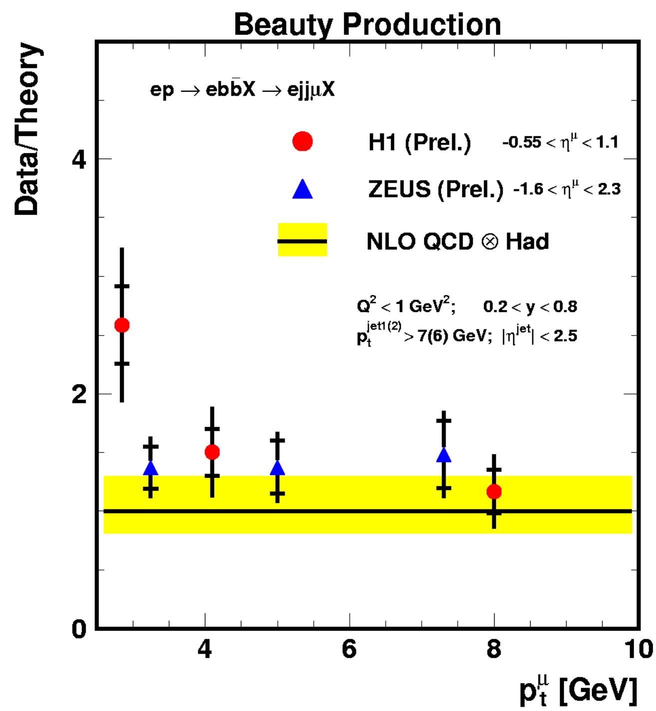

Fig. 3. Ratio of data and NLO calculation as a function of transverse momentum of the muon

b-decays this takes larger values as compared to the other sources.

Only the latter variable is used by the H1 experiment, where a central silicon vertex detector provides the necessary track resolution. Finally, the relative contributions of beauty and background in the data are determined from likelihood fits to the above observables.

In the **double track tag measurements** a D^{*+}-meson is required in addition to the muon. It is reconstructed in the decay channel $D^{*+} \to D^0\pi_s^+ \to \pi_s^+ K^-\pi^+$. The angular and charge correlation between the muon and the D^{*+}-meson are exploited to identify charm and beauty contributions.

4 Results

At this conference, new preliminary H1 results [6] have become available for beauty production in **photoproduction**, exploiting a three times larger data sample than for the first results [1]. The measurements are based on the muon single track tag technique described in the previous section. Fig. 2 shows the single differential cross-sections for $ep \to eb\bar{b}X \to e\,\text{jet}\,\text{jet}\,\mu$ as a function of the muon pseudorapidity. The kinematic cuts are listed in the figure legend. The new H1 data points are compared with measurements by ZEUS [12]. The H1 and ZEUS data agree well. The data points are also compared to a NLO calculation in the massive scheme based on [9]. For the calculation, fragmentation is performed using the Peterson function [13]. The errors of the prediction are dominated by the uncertainties of the renormalisation scale and the b-quark mass. *All* the data points in Fig. 2 lie above this theory calculation. However, data and calculation agree at the two sigma level. Figure 3 shows the ratio of the measured cross sections and the NLO calculation as a function of the muon transverse momentum. At the lowest momenta, the theory undershoot the data by a factor of two. The other data points are also above the theory but at a level of $\leq 50\%$. Figure 4 depicts the measured H1 cross-sections in bins of the muon transverse momentum compared to predictions from the leading order Monte Carlo programs PYTHIA [14] and CASCADE [15]. PYTHIA is run in the massless mode and simulates direct and resolved photon processes. Higher orders are approximated in PYTHIA and CASCADE by gluon showers generated using the DGLAP and CCFM evolution prescriptions, respectively. With the settings used, CASCADE and PYTHIA clearly fall below the data.

ZEUS presented last year the *first differential* cross-section measurements [16] in the **deep inelastic scattering** regime. Figure 5 shows the cross sections in bins of the photon virtuality Q^2, compared with a NLO calculation in the massive scheme based on [10]. In contrast to the photoproduction case discussed above, data and theory agree well.

ZEUS has presented at this conference a **first double track measurement [7] in the deep inelastic scattering regime** using D^{*+}-mesons and muons as described in Sect. 3. The measured cross-section is shown in Fig. 6 (right). It lies above a NLO calculation in the massive scheme based on [10]. Fig. 6 (left) shows the correspond-

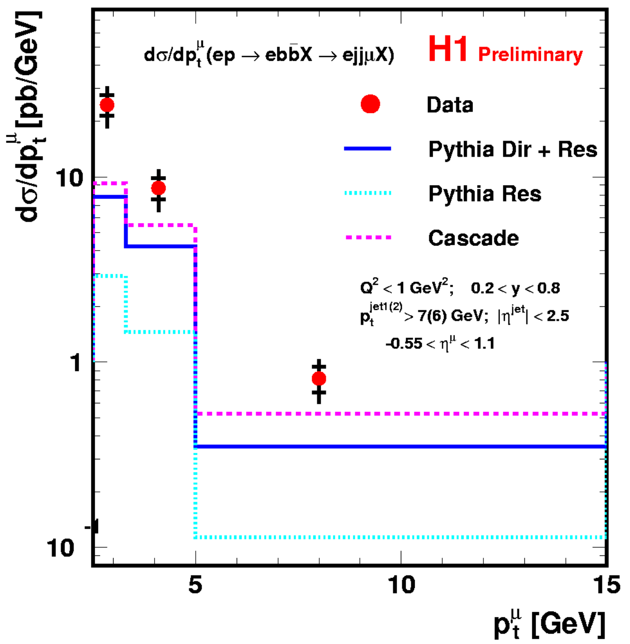

Fig. 4. Differential beauty cross-sections as a function of transverse momentum of the muon

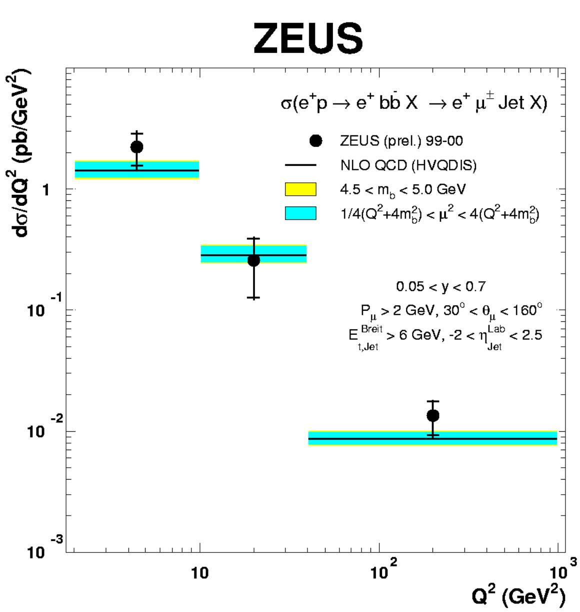

Fig. 5. Differential beauty cross sections in deep in elastic scattering as a function of the photon virtuality Q^2

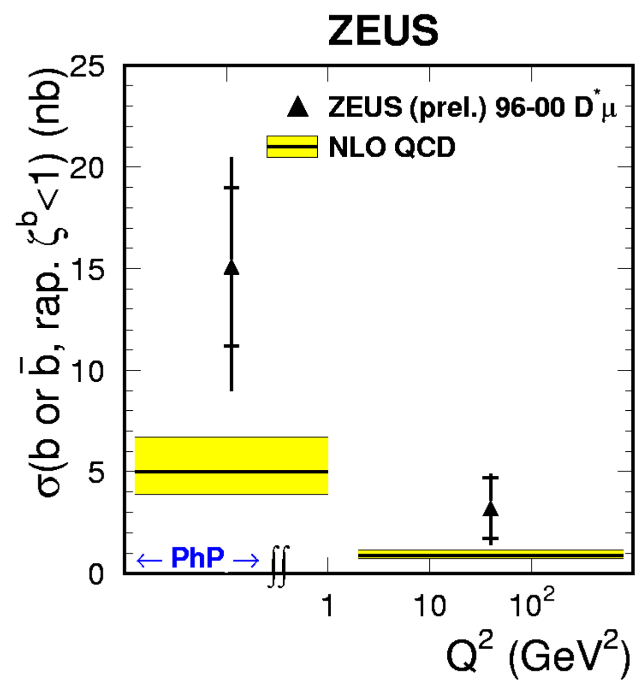

Fig. 6. $D^{*+}\mu$ cross-sections in photoproduction (*left*) and DIS (*right*)

ing ZEUS result in photoproduction [17]. This agrees with the H1 measurement [18] and is also above an NLO calculation based on [9].

5 Conclusions and outlook

New or recent measurements of beauty production in ep collisions have been presented at this conference. Almost all measured cross-sections are above QCD calculations performed in the massive scheme in NLO. However, in contrast to some of the earlier measurements, the excesses have now decreased to a level, at which the data are compatible with the theory predictions within errors. In the new H1 photoproduction measurement [6] it is recognized that a large part of the significant excess observed in the corresponding older measurements [1,2] was due to the fact that the data cross-sections were extrapolated outside their visible range using a leading order Monte Carlo simulation.

The upgraded HERA II collider with a factor of 5 larger luminosity and the improved H1 and ZEUS detectors will allow beauty measurements in ep collisions to be made with much higher precision and in an extended kinematic phase-space, further testing our understanding of the physics of heavy flavour production.

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