Measurement of beauty production at HERA using events with muons and jets

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Abstract. Several new measurements of beauty production at HERA have been presented at this conference. In this talk we report about the H1 measurement using events with a muon associated to a jet. This is the first beauty analysis at HERA, where both the long lifetime and the large mass of *b*-flavoured hadrons are exploited to identify the beauty events, leading to an improved signal separation. 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 to next-to-leading order. A significant excess is observed in certain corners of the kinematic phase space. At the end of this report new and recent beauty measurements are summarised.

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INTRODUCTION

The dominant beauty production mechanism at HERA is the process $\gamma g \to b\bar{b}$, where the photon is emitted from the electron and the gluon from the proton. Since the large b mass provides a hard scale, rendering a small α_s, it would be expected that beauty production can be accurately calculated using perturbative QCD (pQCD). In contrast, the first measurements at HERA [1, 2] revealed significant excesses of data over pQCD calculations performed to next-to-leading order (NLO). Similar observations were made in hadron-hadron collisions [3] and also in two-photon interactions [4]. Newer beauty production measurements from the H1 [5] and ZEUS Collaborations [6] are in better agreement with QCD predictions or again somewhat higher [7]. In the recent article [8] by Matteo Cacciari with the title 'Rise and Fall of the Bottom Quark Production Excess' it is argued, that improvements both in the theoretical models and in the way the data to theory comparisons are handled, have lead to a much better data description, especially for new measurements from hadron-hadron collisions, as discussed in [9].

At this conference several new measurements are reported on beauty production at HERA. In this paper the H1 measurement [10] is described, where events are used with a muon in the central pseudo rapidity range, which is associated to a jet. Differential cross sections are measured both in photoproduction with photon virtualities $Q^2 < 1$ GeV^2 and in deep inelastic scattering with $2 < Q^2 < 100$ GeV^2. The data were collected in the years 1999-2000. 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 the p_T^{rel} spectrum extends to much larger values than for the other sources.
2. The signed impact parameter δ of the muon track with respect to the primary event vertex: For muons from b-decays this takes larger values as compared to the other sources.

Finally, the relative contribution of beauty and background in the data is determined from a likelihood fit to the two-dimensional distribution of p_T^{rel} and δ . The ZEUS measurements [6, 7], which are also discussed in the following, rely on the p_T^{rel} observable alone.

RESULTS

Photoproduction. For the photoproduction analysis at least two jets are required in the final state with transverse momenta $p_t^{jet_{1(2)}} > 7(6)$ GeV. Figure 1 shows the differential cross-sections as function of the muon pseudorapidity (left) and transverse momentum (right). The

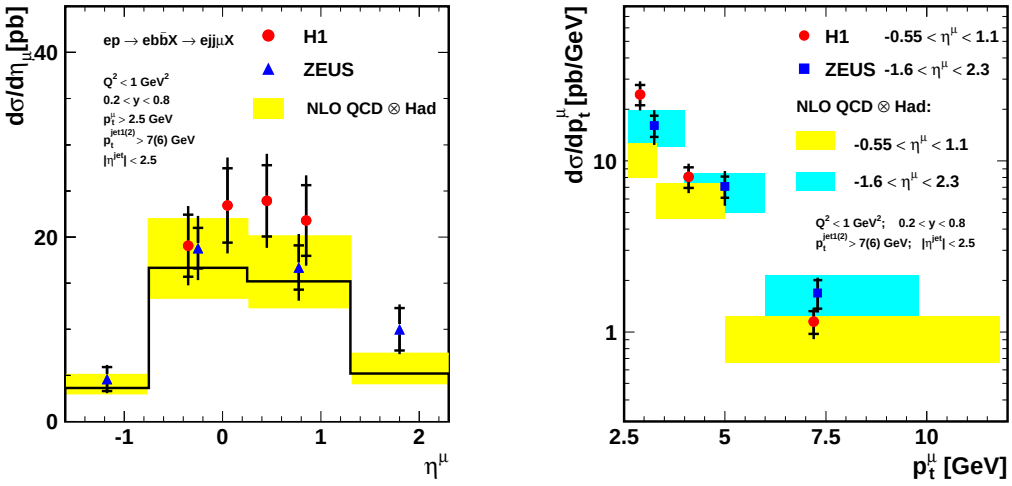


FIGURE 1. Differential beauty cross sections in photoproduction as a function of (left) muon pseudo-rapidity and (right) muon transverse momentum. Shown are the new H1 measurement [10] and the ZEUS measurement [6].

figure also shows the ZEUS measurement [6], which covers a wider muon pseudorapidity range. The H1 and ZEUS measurements agree well in the overlapping region. The data are also compared to an NLO calculation, using the program [11]. For the calculation, fragmentation is performed using the Peterson function [13]. The errors of the theory prediction are dominated by the uncertainties of the renormalisation scale and the b-quark mass. The data tend to lie slightly above this calculation, however, within the errors the calculation describes all the H1 and ZEUS data points. The measured cross sections as function of the muon transverse momentum are compared in figure 1 (right) to the NLO predictions in the respective kinematic ranges of the H1 and ZEUS measurements. In the lowest bin from 2.5 GeV to 3.3 GeV the H1 measurement exceeds the prediction by a factor of ~ 2.5, while at higher transverse momenta a better agreement is observed. Such an excess is not seen in the ZEUS data. This discrepancy needs to be clarified in the future.

Deep inelastic scattering. For the DIS analysis the jet algorithm is applied in the Breit frame and at least one jet with transverse momentum $p_{t,jet}^{Breit} > 6$ GeV is required. Figure 2 shows the differential cross sections of the new H1 measurement (top) and the ZEUS measurement [7] (bottom) as function of muon transverse momentum (left) and pseudo-rapidity (right). The data are compared to an NLO calculation using the program [12]. The H1 and ZEUS measurements are made in similar kinematic regions and also the observations and conclusions are very similar:

1. An excess of data over NLO prediction is observed towards smaller muon transverse momenta below 4 GeV.
2. A rise of the differential cross sections is observed towards more positive muon pseudorapidities, (i.e. more close to the proton direction) which is not reproduced by the NLO calculation.

SUMMARY

Figure 3 presents a summary of the very new and recent HERA beauty cross section measurements as a function of the photon virtuality Q^2. The figure shows the ratios of the measured cross

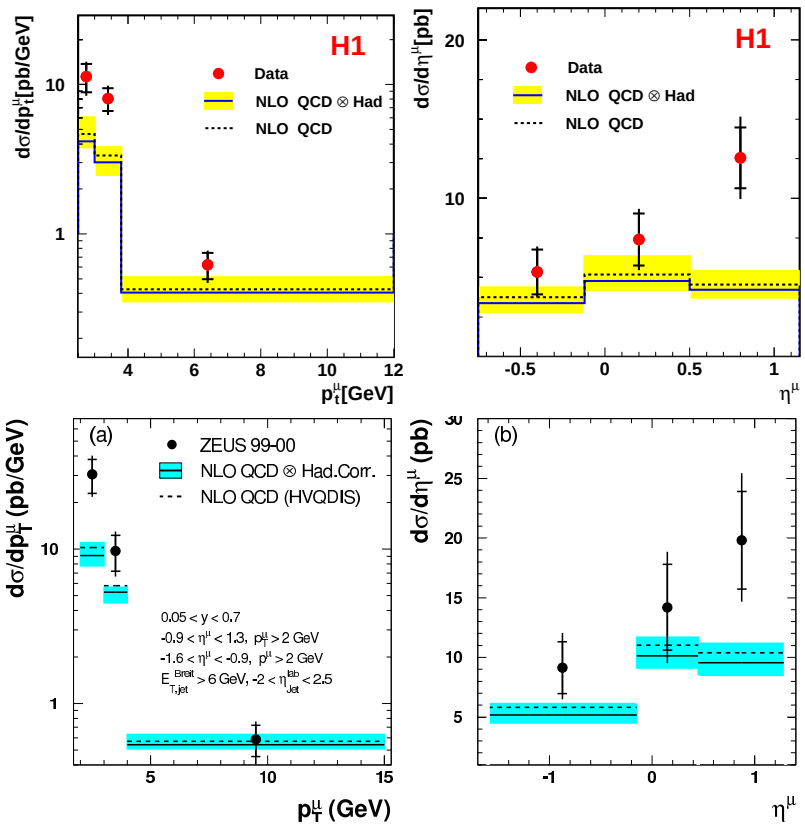
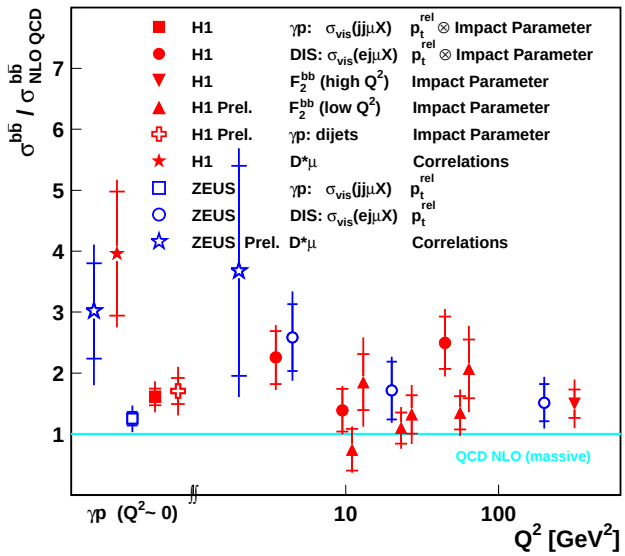


FIGURE 2. Differential beauty cross sections in DIS as a function of (left) muon transverse momentum and (right) muon pseudorapidity for the H1 measurement [10] (top) and the ZEUS measurement [7] (bottom).

sections and the corresponding NLO predictions based on the programs [11, 12]. Uncertainties of the NLO calculations are not taken into account. The new H1 measurement presented in this paper enters the plot as the full square point (photoproduction) and the full circle points (DIS). The following observations are made from all the different measurements:

- Most of the data points are above the predictions.
- There is no clear trend visible for the ratio as function of Q^2.
- There are indications that the data exceed the predictions more significantly towards small b-quark transverse momenta, i.e. closer to the threshold region. This is seen in the new H1 measurement presented here (figures 1 and 2) and also in the H1 and ZEUS $D^*\mu$ measurements [16, 17]. Further evidence comes from another new beauty measurement [18] by ZEUS which is not shown in figure 3. This measurement uses pairs of muons with applying very low momentum cuts and determines the total beauty production cross-section, integrating over photoproduction and DIS, to be higher than the NLO prediction by a factor ~ 2.4. On the contrary, the new inclusive beauty measurements [14, 5] by H1 in the DIS regime, using a vertex tagging method, are in reasonable or good agreement with the NLO predictions as can be seen in figure 3.
- There are indications for an excess of beauty production in the more forward (i.e. proton) direction as can be seen for the DIS measurements in figure 2 and also in the ZEUS photoproduction measurement [6] for muons identified in the forward muon detector (not included in figure 3).



Key	Ref.	Signature	p_T cuts
Photoproduction			
☆	[17]	$D^*\mu$	low
★	[16]	$D^*\mu$	low
□	[6]	2 jets+μ	medium
■	[10]	2 jets+μ	medium
✚	[15]	tracks	high
DIS			
☆	[17]	$D^*\mu$	low
▲	[14]	tracks	low
▼	[5]	tracks	low
●	[10]	1 jet+μ	medium
○	[7]	1 jet+μ	medium

FIGURE 3. Ratio of beauty production cross section measurements at HERA to NLO QCD predictions using the programs [11, 12].

It will be quite interesting to see how this picture develops in the future with the new HERA II data, which will allow to make measurements with much higher precision. It would be very desirable if the theory model improvements reported in [8], which are available for hadron-hadron collisions, would be also made available for the HERA processes.

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