Beauty photoproduction at ZEUS

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Recent results on beauty photoproduction in *ep* collisions at a center-of-mass energy of 318 GeV at the ZEUS experiment at HERA are presented. The analyses are based on HERA II data and make use of the Micro Vertex Detector (MVD). The measured cross sections are compared with perturbative NLO QCD calculations.

1 Introduction

Heavy quark production processes provide a powerful insight into our understanding of Quantum Chromodynamics (QCD). QCD calculations for the beauty production at HERA have relatively small uncertainties, thanks to the large b quark mass, m_b. Moreover the production cross section for heavy quarks (HQ) is roughly proportional to the gluon content of the proton and can provide a stringent constraint to the gluon parton density function (PDF).

The beauty measurement at HERA is not simple due to its small production cross section. A big effort has been devoted in the last years by the ZEUS collaboration to improve the precision of the measurements. A brief summary of the most recent b photoproduction results at ZEUS will be given here, starting with the summary of the theoretical framework from an experimental point of view (Sec. 2) and a short description of the experimental methods (Sec. 3). The results are summarized in Sec. 4.

2 Theoretical framework

Boson-gluon fusion (BGF) is, at leading order in α_s, the process responsible for the production of b quarks in *ep* collisions. Due to the photon propagator, the cross section is dominated by the region with small four-momentum transfer $Q^2 \sim 0$. In this region the *ep* collision can be seen as an interaction between a real photon emitted from the electron and the photon (photoproduction) and can be calculated in the *Weizsäcker-Williams* (WW) approximation [2]. A significant contribution to the photoproduction cross section comes from resolved photon processes, in which the photon behaves as a source of partons.

Next-to-leading order (NLO) corrections ($\mathcal{O}(\alpha_s^2)$) for HQ production in *ep* collisions are known since the '90s and are available, for photoproduction, through the FMNR program [3] that allows the calculation of cross sections with arbitrary cuts on the final state (it uses the WW approximation and includes resolved photon processes). The contribution of NLO corrections is significant, with k factors $\sigma^{NLO}/\sigma^{LO} \sim 1.4$.

The theoretical uncertainties on the NLO predictions can be evaluated by varying the parameters used in the calculation. The variations of the photoproduction cross section, evaluated using FMNR [4], are $\sim 30\%$ from the variation of m_b in the range $m_b = 4.75 \pm 0.25$ GeV and $\sim 20\%$ from the variation of the renormalization and factorization scales in the

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range $\mu_r = \mu_f = 2^{0\pm1} m_T$, where $m_T^2 = m_b^2 + \frac{1}{2}[(P_T^b)^2 + (P_T^{\bar{b}})^2]$. The uncertainty coming from the PDFs (mainly gluon in the proton) is $\sim 3\%$. In particular corners of the phase space, dominated by three jets configurations, the $\mathcal{O}(\alpha_s^2)$ calculations are effectively leading order and therefore less precise. These corners include the region of small azimuthal separation between the two highest-p_T jets $\Delta\Phi^{jj}$ and the region of small $x_\gamma = \Sigma E - P_Z/2yE_0$, where y is the inelasticity and E_0 the lepton beam energy. The observable x_γ is (in the leading order QCD picture) an estimator of the fraction of the photon energy entering the hard interaction.

Experiments do not measure b quarks directly but rather B hadrons, leptons from B decays or jets containing B hadrons. The perturbative calculations should therefore be interfaced with models of hadronization (and decay) to be compared with the experimental data. Observables that involve the presence of jets require an additional correction for jet hadronization effects. This is typically obtained using MC models. Overall the non pertubative uncertainties for beauty are significantly smaller than the perturbative uncertainties.

3 Experimental methods

Beauty production is a small fraction of the total cross section at HERA: $\sigma_{b\bar{b}}/\sigma_{tot} \sim 0.1\%$ wich increases to $\sim 6\%$ for events with high-p_T jets. This makes the measurement of beauty production quite difficult. However, beauty and charm decays are the main sources of high-p_T leptons originating in the proximity of the interaction region. Therefore many analyses concentrated on leptonic tags. Selecting events with two jets and a high-p_T lepton, a b fraction larger than 20% can be reached. In a sample of events with jets and leptons the beauty contribution can be extracted exploiting the transverse momentum of the lepton with respect to the associated jet axis, p_T^{rel}, which is harder for beauty than for charm and light flavours (LF) due to the large B mass. Technically, the p_T^{rel} distribution of the data is fitted with MC templates for b, c and LF to determine the b fraction (Fig. 1(a)). Control samples of data are used to check these MC templates and correct them if needed. When data from

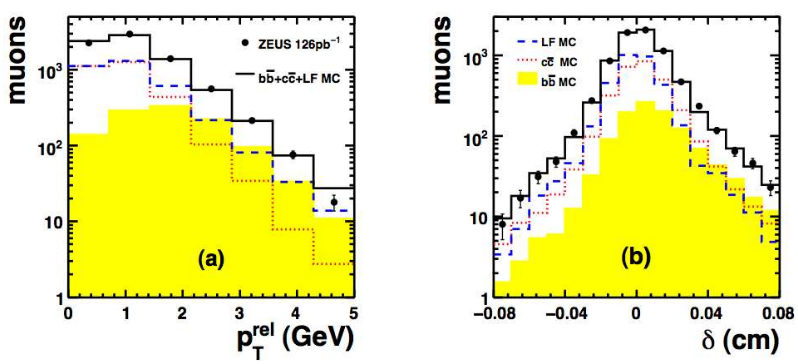

Figure 1: Distribution of discriminant variables used to extract the b and c content of the muon photoproduction sample: (a) p_T^{rel} and (b) δ.

a precise vertex detector are available, the impact parameter of the lepton with respect to the interaction vertex in the transverse plane, δ, can be used to tag leptons originating from a displaced vertex due to a heavy hadron decay. A negative (positive) sign is assigned to

δ if the lepton trajectory crossed the axis of the associated jet upstream (downstream) of the event vertex, such that leptons from true secondary vertices are shifted to positive δ, whilst tracks from the primary vertex have a symmetric δ distribution around zero reflecting the resolution (Fig. 1(b)). The first results presented (see Sec. 4) used a combination of δ and p_T^{rel} to extract the b content. While δ gives a good separation between light and heavy flavours, p_T^{rel} has the best discriminating power between b and c plus LF.

The information from the silicon vertex detector can be further exploited to tag beauty in inclusive events, without the need of lepton requirements as in the second result presented in Sec. 4. A way to extract the b and c content of the sample is to reconstruct the decay vertices of the B hadrons and use the resulting decay length which, due to the long lifetime of the B hadron, is enhanced at high values for beauty and charm compared to the light flavour background. Furthermore, the invariant mass of the tracks associated with the decay vertex, m_{vtx}, can be used to distinguish between the beauty- and charm-enriched regions.

4 Results

4.1 Semi-leptonic tagging

Both of the photoproduction results reported here are based on the first data collected with the ZEUS Micro Vertex Detector [5] during the HERA II running period. The first

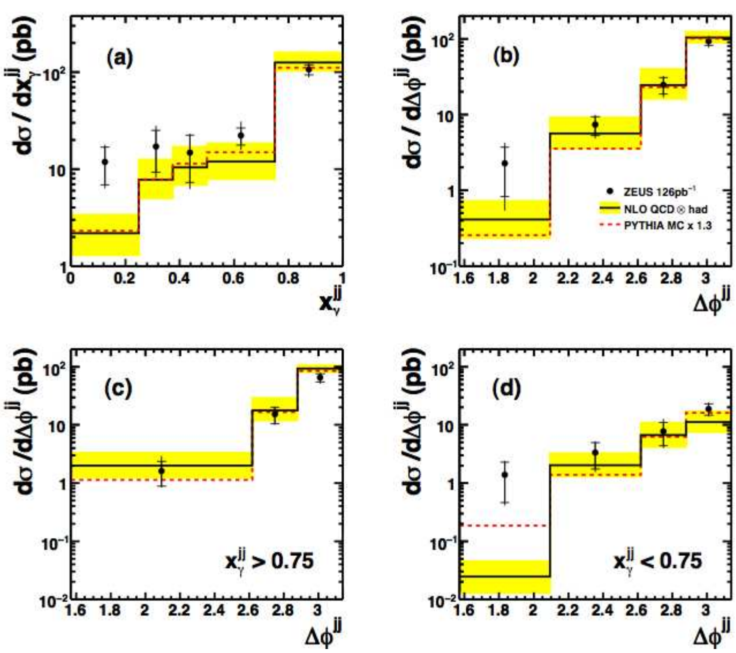

Figure 2: Differential cross section as a function of (a) x_γ^{jets} and (b) $\Delta\Phi^{jj}$. In (c) the differential cross sections are shown as a function of $\Delta\Phi^{jj}$ for a resolved-enriched sample and in (d) the same for a direct-enriched sample. The measurements (black dots) are compared with the NLO QCD predictions.

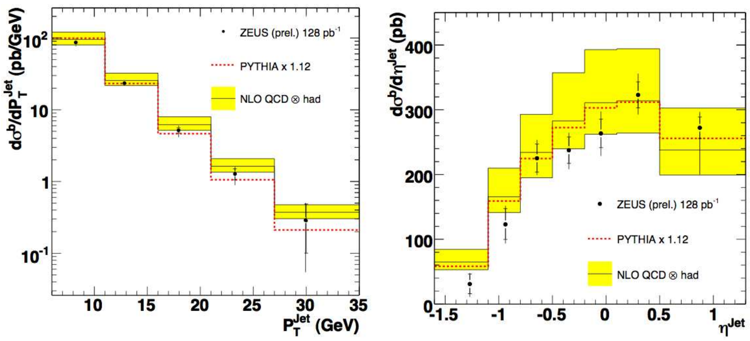

Figure 3: Differential cross sections as a function of: (left) p_T^{Jet} and (right) η^{Jet}. The measurements (black dots) are compared with the NLO QCD predictions.

measurement analyses a sample of 126 pb^{-1} looking at final states with at least one muon and two jets in the kinematic region $Q^2 < 1$ GeV^2 and $0.2 < y < 0.8$ [6]. The jets, defined at hadron-level using the k_T algorithm, are required to have $p_T^{j1,j2} > 6, 7$ GeV and $|\eta| < 2.5$. The transverse momentum cut for the selected muons goes down to $p_T > 1.5$ GeV, a lower threshold with respect to the previous paper which used 2.5 GeV. The beauty fraction is extracted using a combination of δ and p_T^{rel} and confirms the previous results obtained in HERA I based on p_T^{rel}-only tagging. In general the results are in good agreement with the NLO prediction within the uncertainties and do not confirm the excess observed in H1 at low muon p_T [7]. While the overall agreement of dijet measurements with NLO QCD is quite satisfactory, it is interesting to look at particular regions of the phase space where the theoretical description may be problematic as in the low x_γ^{jets} region. Fig. 2 (a) shows the measured x_γ^{jets} distribution. The description of the low x_γ^{jets} tail, dominated by resolved-photon interactions and multijet topologies, is reasonably good given the large uncertainties involved. For the $\Delta\Phi^{jj}$ distribution(Fig. 2 (b,c,d)), which is sensitive to additional radiation effects, similar conclusions can be drawn.

4.2 Lifetime tagging

Photoproduction of beauty quarks in two-jets events has also been measured using an integrated luminosity of 128 pb^{-1}. The beauty content has been extracted using the decay length significance of the B hadrons and the invariant mass of the decay vertices. Differential cross sections in P_T^{Jet} and η^{Jet} (Fig. 3) are measured in the kinematic range defined by $Q^2 < 1$ GeV^2, $0.2 < y < 0.8$, $P_T^{Jet1(2)} > 7, 6$ GeV and $|\eta^{Jet1(2)}| < 2.5$. The new measurements extend results from leptonic tags to higher P_T and are in agreement with NLO QCD.

5 Summary

For a more direct comparison, cross sections obtained with different experimental techniques in different visible kinematic regions, σ_{vis}^{exp}, have been transformed into differential cross

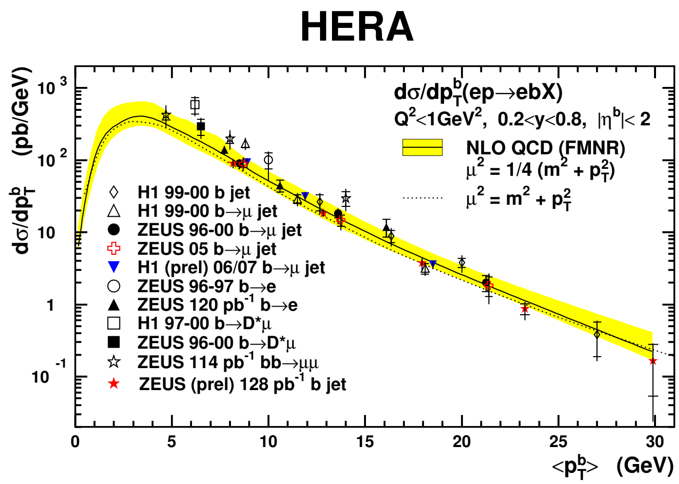

Figure 4: Differential cross section as a function of p_T of the b quark extracted from all the HERA photoproduction measurements of beauty production. The new results presented here are indicated with the empty crosses (semi-leptonic channel) and full stars (lifetime tagging).

sections in the transverse momentum of the b quark, p_T^b, using the NLO theory:

$$\frac{d\sigma}{dp_T^b} = \sigma_{vis}^{exp} \times \frac{d\sigma^{NLO}/p_T^b}{\sigma_{vis}^{NLO}}.$$

All the HERA photoproduction results are shown in Fig. 4. The data obtained with different methods and in different kinematic regions are in good agreement among each other and with the NLO QCD. The central value of the NLO QCD prediction shown in Fig. 4 was calculated, as suggested in [8], with $\mu_r = \mu_f = \frac{1}{2}m_T$ instead of the previously used $\mu_r = \mu_f = m_T$.

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