Beauty photoproduction using decays into electrons at HERA

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Photoproduction of beauty quarks in events with two jets and an electron associated with one of the jets has been studied with the ZEUS detector at HERA using an integrated luminosity of 120 pb^{-1}. The fractions of events containing b quarks, and also of events containing c quarks, were extracted from a likelihood fit using variables sensitive to electron identification as well as to semileptonic decays. Total and differential cross sections for beauty and charm production were measured and compared with next-to-leading-order QCD calculations and Monte Carlo models.

1. INTRODUCTION

The production of heavy quarks in ep collisions at HERA is an important testing ground for perturbative Quantum Chromodynamics (pQCD) since the large b-quark and c-quark masses provide a hard scale that allows perturbative calculations. When Q^2, the negative squared four-momentum exchanged at the electron or positron is small, the reactions $ep \to e\, b\bar{b}\, X$ and $ep \to e\, c\bar{c}\, X$ can be considered as a photoproduction process in which a quasi-real photon, emitted by the incoming electron interacts with the proton. For heavy-quark transverse momenta comparable to the quark mass, next-to-leading-order (NLO) QCD calculations in which the massive quark is generated dynamically are expected to provide reliable predictions for the photoproduction cross sections. This analysis [1] was performed with data taken by the ZEUS [2] detector from 1996 to 2000, when HERA collided electrons or positrons with energy $E_e = 27.5\,\mathrm{GeV}$ with protons of energy $E_p = 820\,\mathrm{GeV}$ (1996–1997) or $920\,\mathrm{GeV}$ (1998–2000). The corresponding integrated luminosities are $38.6 \pm 0.6\,\mathrm{pb}^{-1}$ at centre-of-mass energy $\sqrt{s} = 300\,\mathrm{GeV}$, and $81.6 \pm 1.8\,\mathrm{pb}^{-1}$ at $\sqrt{s} = 318\,\mathrm{GeV}$.

2. THEORY

The measurements are compared to a leading-order plus parton-shower Monte Carlo (PYTHIA) as well as QCD predictions at next-to-leading order (NLO), based on the FMNR programme [3]. This NLO programme separately generates processes containing point-like and hadron-like photon contributions, which have to be combined to obtain the total cross section. The main uncertainties of the NLO calculations originate from the uncertainties of the heavy-quark masses (pole masses) and the renormalisation and factorisation scales. The central values for the masses were set to $m_b = 4.75\,\mathrm{GeV}$ and $m_c = 1.6\,\mathrm{GeV}$ where both masses were varied by $\pm 0.25\,\mathrm{GeV}$. The renormalisation, μ_R, and factorisation, μ_F, scales were chosen to be equal and set to $\mu_R = \mu_F = \sqrt{\hat{p}_T^2 + m_{b(c)}^2}$, and varied by a factor two for the uncertainty.

3. SIGNAL EXTRACTION

Electron candidates were selected by requiring tracks fitted to the primary vertex and having a transverse momentum, p_T^e, of at least $0.9\,\mathrm{GeV}$ in the pseudorapidity range $|\eta^e| < 1.5$. For the identification of electrons from semileptonic heavy-quark decays, variables for particle identification were combined with event-based information characteristic of heavy-quark production.

3.1. Electron identification

A central tool for this analysis was the dE/dx measurement from the Central Tracking Detector (CTD). The pulse height of the signals on the sense wires was used as a measure of the specific ionisation. This pulse height was corrected for a number of effects [4]. After all corrections, the measured dE/dx depended only on the particle velocity, $\beta\gamma$. This is illustrated in Fig. 1. It shows the specific energy loss as a function of $\beta\gamma$, for the different samples of identified particles, $e^{\pm}, \mu^{\pm}, \pi^{\pm}, K^{\pm}, p, \bar{p}$. Additional variables for the electron identification are the fraction of energy in the calorimeter which is deposited in the electromagnetic part of the calorimeter and the ratio of this energy to the track momentum measured by the CTD. These two variables use the differences in shower and cluster topologies of electrons, hadrons and muons.

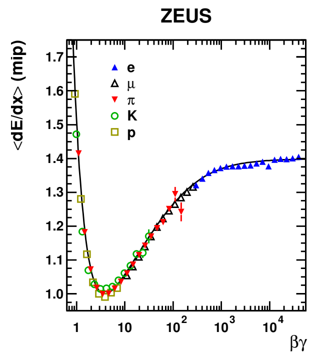

Figure 1: The mean dE/dx measured in the CTD as a function of $\beta\gamma$.

3.2. Decay identification

To identify electrons from semileptonic decays, the event signature of a lepton from a heavy quark and missing transverse momentum from the neutrino was used. The size of the transverse-momentum component of the electron candidate relative to the direction of the jet axis reflects the mass of the decaying hadron and gives a good separation of the semileptonic b-quark decays from other sources. To distinguish semileptonic c-quark as well as b-quark decays from the light flavour background the difference of azimuthal angles between the electron candidate and the missing transverse momentum vector was used.

3.3. Test function

The discriminating input variables were combined in a likelihood hypothesis test in order to calculate the heavy quark contributions in the data set. For a given hypothesis of particle, i, and source j, the likelihood, $\mathcal{L}_{ij}$, is given by

$$\mathcal{L}_{ij} = \prod_{l} \mathcal{P}_{ij}(d_l)\,, \tag{1}$$

where $\mathcal{P}_{ij}(d_l)$ is the probability to observe particle i from source j with value d_l of a discriminant variable. The particle hypotheses $i \in \{e, \mu, \pi, K, p\}$ and sources, j, for electrons from semileptonic beauty, charm decays and background, $j \in \{b, c, \mathrm{Bkg}\}$, were considered. For the likelihood ratio test, the test function, T_{ij} was defined as

$$T_{ij} = \frac{\alpha_i \alpha'_j \mathcal{L}_{ij}}{\sum\limits_{m,n} \alpha_m \alpha'_n \mathcal{L}_{mn}}. \tag{2}$$

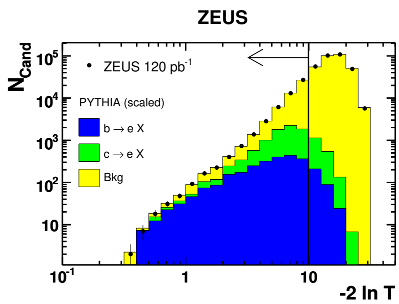

Figure 2: The distribution of the likelihood ratio.

Test functions were calculated separately for the three samples.
The fractions of the three samples in the data, $f^{\mathrm{DATA}}_{e,b}$, $f^{\mathrm{DATA}}_{e,c}$, $f^{\mathrm{DATA}}_{\mathrm{Bkg}}$, were obtained from a three-component maximum likelihood fit to the T distributions. The fit (Fig. 2) range of the test function was restricted to $-2\ln T < 10$.

4. RESULTS

The visible ep cross sections for b-quark and c-quark production and the subsequent semileptonic decay to an electron with $p_T^e > 0.9$ GeV in the range $|\eta^e| < 1.5$ in photoproduction events with $Q^2 < 1\,\mathrm{GeV}^2$ and $0.2 < y < 0.8$ and at least two jets with $E_T > 7(6)$ GeV, $|\eta| < 2.5$ were determined separately for $\sqrt{s} = 300$ GeV and $\sqrt{s} = 318$ GeV.

The cross sections at the two different centre-of-mass energies are consistent with each other; combining the results leads to a reduced statistical uncertainty. For the complete data set (96 − 00) the cross sections and the NLO predictions evaluated at $\sqrt{s} = 318$ GeV are:

$$\sigma_b^{vis} = (125 \pm 11(stat.)^{+10}_{-11}(syst.))\ \text{pb},$$
$$\sigma_c^{vis} = (278 \pm 33(stat.)^{+48}_{-24}(syst.))\ \text{pb}.$$

$$\sigma_b^{NLO} = 88^{+22}_{-13}\ \ \text{pb},$$
$$\sigma_c^{NLO} = 380^{+170}_{-110}\ \text{pb}.$$

Differential cross sections as a function of p_T^e and η_e are shown in Fig 3. The figure also shows the NLO QCD and the scaled PYTHIA predictions. The scale factors have been calculated from the total visible $b\bar{b}$ and $c\bar{c}$ cross section, which are a factors of 1.75 and 1.28 higher than the corresponding PYTHIA predictions. Both the predictions from the NLO QCD calculations as well as the scaled PYTHIA cross sections describe the data well.

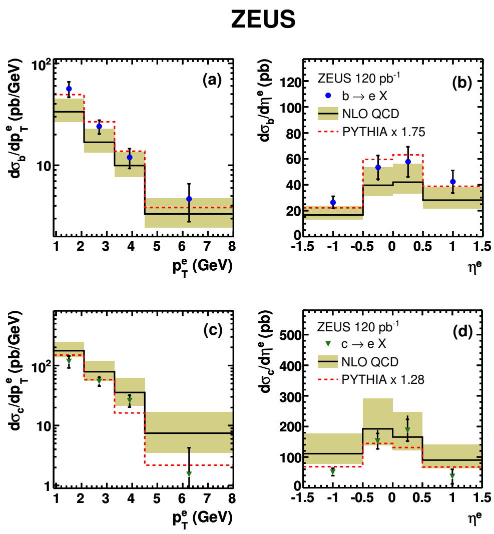

Figure 3: Differential cross sections as a function of the a),c) transverse momentum and the b),d) pseudorapidity of the electrons for a),b) $b\bar{b}$ and c),d) $c\bar{c}$ production.

5. CONCLUSIONS

Beauty and charm production have been measured in dijet photoproduction using semileptonic decays into electrons. The results were compared to both NLO QCD calculations as well as predictions from a Monte Carlo model. The NLO QCD predictions are consistent with the data.

The Monte Carlo models describe well the shape of the differential distributions in the data. The good agreement with the NLO QCD prediction allows the cross section as a function of p_T^b to be extracted. The resulting cross section is shown in Fig 4 and is also compared with previous measurements by both the H1 and ZEUS collaborations. The measurements agree well with the previous values, giving a consistent picture of b-quark production in ep collisions in the photoproduction regime, and are well reproduced by the NLO QCD calculations.

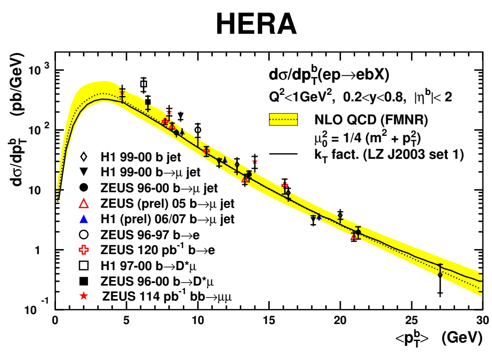

Figure 4: Cross sections for beauty production as a function of p_T^b for various decay channels.

References

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