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BEAUTY PHOTOPRODUCTION WITH ZEUS

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The photoproduction of beauty quarks has been measured using $\mathcal{L} = 110$ pb^{-1} of data collected by the ZEUS detector at HERA. Beauty quarks are identified in events containing two jets and a muon in the final state by using the transverse momentum distribution of the muon relative to the direction of the closest jet. Differential cross sections have been measured and compared with different Monte Carlo models and with next–to–leading order QCD predictions; good agreement between data and theory has been found.

1 Introduction

Beauty production is a stringent testing ground for perturbative QCD, since the large b–quark mass sets a hard scale at which theoretical calculations at next–to–leading order (NLO) are expected to give reliable results.

At the lepton–proton collider, HERA, operating at a centre–of–mass energy of ~ 300 GeV, beauty is mainly produced in events where a photon interacts with a parton from the proton, generating a $b\bar{b}$ pair. The photoproduction regime, the main contribution to the cross section, is defined when the photon virtuality Q^2 is lower than 1 GeV^2 (with a mean value of $\sim 10^{-3}$ GeV^2 for $b\bar{b}$ events).

In γp interactions, the photon can couple directly with a parton from the proton (direct photon processes) or it can fluctuate into a hadronic state, where one of the partons takes part in the hard interaction (resolved photon processes).

Here, a measurement of beauty photoproduction in events with two jets and a muon [1], is reported. The data sample used amounts to $\mathcal{L} = 110$ pb^{-1} collected by the ZEUS experiment during the 1996–2000 data–taking period, at a centre–of–mass energy of 300 (318) GeV in 1996–97 (1998–2000). The measured cross sections are compared with the predictions of perturbative QCD at next–to–leading order and different Monte Carlo models. The obtained results are compared with those of a previous ZEUS measurement [2] based on beauty tagging via its semi–leptonic decay into electrons.

2 Data selection and signal extraction

Events were selected having at least one muon and two jets in the final state. Both the ZEUS central tracking detector and the muon detectors were used for muon position and momentum reconstruction. A matching in position and momentum between the track in the central chamber and the segment found in the muon detectors was performed. In this way the backgrounds from non–primary muons and in–flight decays, together with background from fake muons, were significantly reduced.

Jets were reconstructed by running the k_T algorithm [3] in the longitudinally invariant mode, using the E recombination scheme, which gives as output massive jets. Background from deep inelastic scattering was rejected by requiring no scattered electron candidate in the ZEUS calorimeter.

In order to discriminate between the beauty signal and the background from charm and lighter quarks, the distribution of the transverse momentum of the muon with respect to the axis of the closest jet, $p_T^{\rm rel}$, was used. The $p_T^{\rm rel}$ distribution of the data was fitted with the sum of beauty and charm–plus–light–flavour component to extract the b fraction in the data. The beauty $p_T^{\rm rel}$ shape was taken from the PYTHIA [4] Monte Carlo. The $p_T^{\rm rel}$ distribution of charm–plus–light–flavour background from PYTHIA was corrected in order to reproduce the $p_T^{\rm rel}$ distribution as measured in the data, using a sample of dijet events without any muon requirement.

3 Results

The extracted b fraction was converted into a beauty cross section. The reference Monte Carlo used for the acceptance determination was PYTHIA, while HERWIG [5] was used as a systematic check.

The measured cross sections are compared with the predictions of perturbative QCD at next–to–leading order based on the program from Frixione et al. [6]. The b–quark mass was set to $m_b = 4.75$ GeV and the renormalisation and factorisation scales to $\mu_R = \mu_F = \mu = m_T = \sqrt{{p_T^b}^2 + m_b^2}$. The b–quark fragmentation into a B hadron was performed according to the Peterson [7] fragmentation function ($\epsilon = 0.0035$). The uncertainties on the NLO predictions due to the choice of the theoretical parameters are obtained by varying at the same time the b–quark mass and the scale to $m_b = 5.0$ GeV ($m_b = 4.5$ GeV) and $\mu = 2m_T$ ($\mu = m_T/2$).

The cross sections are also compared with the predictions of the PYTHIA and CASCADE Monte Carlo programs. The PYTHIA Monte Carlo is based on the DGLAP evolution equations, and includes both direct and resolved photon processes. The CASCADE [8] Monte Carlo implements k_T factorization; the gluon density, unintegrated in the gluon transverse momentum, is obtained by analysing the proton structure functions using the CCFM evolution equations [9].

The kinematic region where the cross sections described below were determined is defined by: $Q^2 < 1$ GeV^2, $0.2 < y < 0.8$, where y is the fraction of the electron energy transferred to the proton in its rest frame, $p_T^{\rm jet1,2} > 7, 6$ GeV, $\eta^{\rm jet1,2} < 2.5$, plus some cuts on the muon p or p_T depending on the angular region where the muon was detected: $p^\mu > 4$ GeV, $p_T^\mu > 1$ GeV for muons in the forward region ($1.5 < \eta^\mu < 2.3$), $p_T^\mu > 2.5$ GeV for muons in the barrel region ($-0.9 < \eta^\mu < 1.3$), $p^\mu > 2.5$ GeV for muons in the rear region ($-1.6 < \eta^\mu < -0.9$).

The cross section was determined in each of the three angular regions where the muon was detected, defined by the cuts listed above: the results are shown in Fig. 1(a). Good agreement is found between the data and the NLO QCD and Monte Carlo predictions.

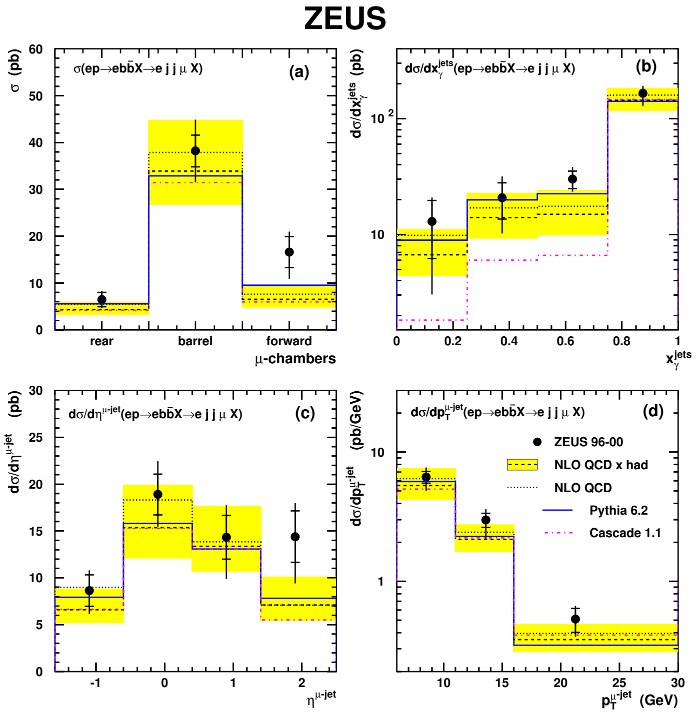

Figure 1. (a) The cross section in the forward, barrel and rear regions defined in the text, and the differential cross sections as a function (b) of $x_\gamma^{\rm jets}$, (c) of the pseudorapidity $\eta^{\mu-\rm jet}$ and (d) of the transverse momentum $p_T^{\mu-\rm jet}$ of the jet containing the muon, in the kinematic region defined in the text. The full error bars are the quadratic sum of the statistical (inner part) and systematic uncertainties. The data (points) are compared with the predictions of NLO QCD (dotted line: parton level, dashed line: corrected to the hadron level), with the shaded band showing the theoretical uncertainty, and with the PYTHIA and CASCADE Monte Carlo models.

The $x_\gamma^{\rm jets}$ variable, the fraction of the total hadronic $E - p_Z$ carried by the two highest–p_T jets, defined as

$$x_\gamma^{\rm jets} = \frac{\sum_{i=1,2}(E^{\rm jet_i} - p_Z^{\rm jet_i})}{E - p_Z} \qquad (1)$$

corresponds at leading order to the fraction of the exchanged–photon momentum involved in the hard scattering. It is therefore a tool to distinguish between direct photon processes, which give a peak at $x_\gamma^{\rm jets} \sim 1$, and resolved photon processes, populating the whole $x_\gamma^{\rm jets}$ region. The differential cross section as a function of $x_\gamma^{\rm jets}$ is shown in Fig. 1(b): the sample is dominated by the high–$x_\gamma^{\rm jets}$ peak, but a low–$x_\gamma^{\rm jets}$ component is also visible. The NLO QCD and the PYTHIA Monte Carlo describe the data well, while CASCADE tends to underestimate the cross section at low $x_\gamma^{\rm jets}$.

The differential cross sections as a function of the pseudorapidity $\eta^{\mu-\rm jet}$ and transverse momentum $p_T^{\mu-\rm jet}$ of the jet containing the muon were also determined

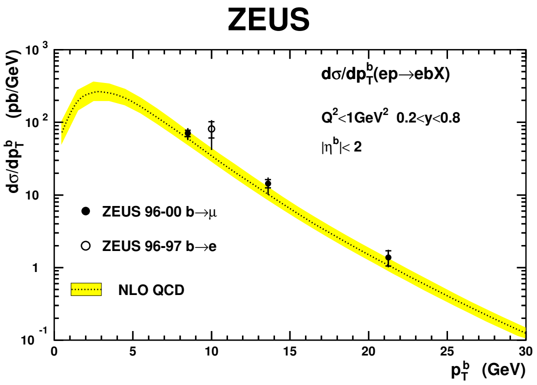

Figure 2. Differential cross section for b–quark production as a function of the b–quark transverse momentum p_T^b for b–quark pseudorapidity $|\eta^b| < 2$, $Q^2 < 1$ GeV^2, $0.2 < y < 0.8$. The filled points are the ZEUS results reported in [1] and the open point is the previous ZEUS measurement in the electron channel [2]. The full error bars are the quadratic sum of the statistical (inner part) and systematic uncertainties. The dashed line shows NLO QCD prediction with the theoretical uncertainty shown as the shaded band.

and are shown in Fig. 1(c) and (d). The μ-jet variables description by the NLO QCD and the MC models is good.

The cross section in Fig. 1(d) was extrapolated at the b–quark level, using the NLO QCD predictions. A b–quark cross section was determined in the kinematic region $Q^2 < 1$ GeV^2, $0.2 < y < 0.8$, $|\eta^b| < 2$. This cross section was compared with a previous similar ZEUS measurement where beauty was tagged via its semi–leptonic decay into electrons [2]. The results are shown in Fig. 2. Nice agreement is found between the two measurements and with the NLO calculation.

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