Beauty production at HERA using the ZEUS experiment

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Abstract.
Beauty quark production in ep collisions is being studied with the ZEUS detector at HERA. The latest measurements of beauty production in deep inelastic scattering and photoproduction regime are presented. The first measurement exploits the potential of the ZEUS microvertex detector to identify beauty in photoproduction dijet events with a muon in the final state. The second is based on statistical methods to determine the fraction of beauty in photoproduction dijet events with an electron in the final state. Finally, the first measurement by ZEUS of the beauty contribution to the proton structure function, \(F_2^b\), in deep inelastic scattering is presented. The three measurements are compared with QCD predictions as well as with previous results. All the results presented here are preliminary.

1. Introduction
Since its discovery, the production of beauty quarks has been intensively studied. The measurement of its cross section is nowadays still a big challenge for physicists, beauty production being one of the few cases within the well established Standard Model in which experimental measurements and QCD theoretical predictions might still show some discrepancies. The ZEUS collaboration has contributed and continues to contribute considerably to the clarification of this issue providing measurements of beauty production in ep collisions at \(\sqrt{s} = 320\) GeV at HERA.

The two latest measurements of beauty production in the photoproduction regime \((Q^2 \approx 0)\) are presented here. Differential cross sections have been measured as a function of the muon transverse momentum \(p_T^\mu\) and muon pseudorapidity \(\eta^\mu\) in dijet events with a muon, and as a function of the electron transverse momentum \(p_T^e\) and electron pseudorapidity \(\eta^e\) in dijet events with an electron in the final state. In each analysis the beauty content in the sample has been determined using a different technique. In the first measurement a method based on the characteristic distribution of the transverse momentum of the muon with respect to the nearest jet, \(p_T^{rel}\), and the distribution of the muon impact parameter, \(\delta\), is used to separate the beauty signal from charm and light flavours. In the second analysis, the beauty fraction is extracted from a likelihood fit using variables sensitive to both the electron identification as well as semileptonic decays.

In the last analysis presented here the beauty contribution to the proton structure function \(F_2\) is measured for different \(Q^2\) values and compared to different theoretical predictions. The study is based on deep inelastic scattering events with a muon and a jet in the final state. The fraction of beauty quarks in the data was determined using the \(p_T^{rel}\) method.
2. Measurement of beauty photoproduction using semileptonic decays into muons.

The installation of the silicon vertex detector during the HERA luminosity upgrade period 2000/2001 provides high precision measurements that allows the use of identification techniques of beauty quarks based on their heavy mass and long lifetime.

The measurement presented here is based on a data sample collected during 2004 and 2005 corresponding to an integrated luminosity of $124 \, \text{pb}^{-1}$. Photoproduction ($Q^2 < 1 \, \text{GeV}^2$) events with two jets with $p_{T1,2} > 7.6$ GeV, $\eta_{1,2} < 2.5$ and a muon with $p_T > 2.5$ GeV and $-1.6 < \eta < 2.3$ were selected.

The beauty content was obtained by means of a simultaneous fit to the $p_{rel} T$ and $\delta$ distributions. Due to the large $b$ mass, $p_{rel} T$ is expected to be, on average, larger for muons coming from semileptonic $b$ decays than for muons from charm or light flavour decays. Similarly, $\delta$ is expected to be large for B hadrons due to their long lifetime. A positive sign is assigned to $\delta$ if the muon track intercepts the axis of the associated jet downstream of the beam position in the transverse plane, otherwise it is negative. The distributions of the two variables are shown in Fig. 1 and compared to the MC predictions.

To extract the $b$ fraction, a binned $\chi^2$ fit of two-dimensional distributions of the data in the plane $p_{Trel}^\mu$ versus $\delta$ was performed. Figure 2 shows the distributions of the differential cross sections as a function of the muon transverse momentum, $d\sigma/dp_T^\mu$, and muon pseudorapidity $d\sigma/d\eta^\mu$. The results are compared to the ZEUS HERA-I data[1] and to a NLO QCD prediction computed with the FMNR [2] program and corrected for hadronization effects. The results are compatible with previous measurements and with NLO QCD predictions.

![Figure 1](image1.png)

**Figure 1.** Distribution of $p_{Trel}^\mu$ (left) and muon impact parameter $\delta$ (right) of the data compared to the different MC distributions.

3. Beauty photoproduction using semileptonic decays into electrons.

Beauty photoproduction has been also measured using semileptonic decays to electrons as well as positrons. In this analysis based on a dataset of $L= 120 \, \text{pb}^{-1}$, events were selected in the photoproduction regimen ($Q^2 < 1 \, \text{GeV}^2$) with at least two jets with $p_{T1,2} > 7.6$ GeV, $\eta_{1,2} < 2.5$ and an electron associated to the closest jet coming from semileptonic decay with $E_T > 6$ GeV and $|\eta| < 2.5$. For the identification of the electrons and extraction of the $b$ fraction a likelihood ratio method was used combining five discriminating variables, three of them refer to calorimetric quantities while the other two are the momentum of the electron candidate transverse to the jet direction, $p_{Tperp}^e$ and the azimuthal angle between the electron and the missing transverse momentum vector corresponding to the neutrino from the semileptonic decay. A detailed description of this method can be found in [3]. Figure 3 shows the distributions

1 HERA-I refers to the data taken from 1996 to 2000 running period, previous to HERA luminosity upgrade.
Figure 2. Differential cross-sections as a function of the muon transverse momentum $p_T^\mu$ (left) and of the muon pseudorapidity $\eta^\mu$ (right) for beauty photoproduction in dijet events with a muon. The measurements are compared to previous results and to NLO QCD predictions corrected for hadronization effects.

Figure 3. Differential cross-sections as a function of the transverse momentum $p_T^e$ (left) and pseudorapidity $\eta^e$ (right) of the electrons for beauty photoproduction in dijet events with a semileptonic electron. The measurements are compared to the predictions from PYTHIA as well as to NLO QCD calculations with hadronization correction.

In Fig. 4 a summary of the differential cross sections for $b$-quark production as a function of $p_T^b$ measured by the ZEUS and H1 collaborations is shown. Though there is a light tendency of the data to lie above the theoretical predictions, especially for low $p_T^b$, all independent measurements are consistent and in agreement with the NLO QCD prediction.

4. Measurement of $F_2^{b\bar{b}}$

The beauty contribution to the proton structure function, $F_2^{b\bar{b}}$, has been measured for first time with the ZEUS experiment. The data used in this measurement has an integrated luminosity of 39 pb$^{-1}$ and was collected during the running period 2003/2004. Events were selected by requiring the presence of at least one muon in the final state and at least one jet. The kinematic
The measured values of $F_2^{bb}$ are found to be described by the theoretical predictions within the large uncertainties.

**Figure 5.** $F_2^{bb}$ as a function of $Q^2$. The results are compared to the measurements from H1, obtained using the impact parameter method, and to different perturbative QCD calculations. All the predictions were calculated using the VFNS scheme with different parameters [5], except HVQDIS which uses the FFNS scheme. The inner error bars are statistical uncertainties while the external bars show the statistical and systematic uncertainties added in quadrature.

**References**

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