Semi-leptonic Decays of Heavy Quarks in Dijet Photoproduction at HERA

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The production of heavy quarks has been studied in photoproduction processes with the ZEUS detector at HERA using an integrated luminosity of 36.9 pb^{-1}. Events with a photon virtuality, $Q^2 < 1$ GeV^2, were selected with two jets of high transverse energy and an electron in the final state. Consideration of the distribution in $p_T^{\rm rel}$ – the momentum of the electron transverse to the axis of the jet to which the electron is closest – allows a measurement of the beauty cross-section in a restricted region of phase space.

1. INTRODUCTION

Two important motivations for the study of heavy quarks are the possibility of providing stringent tests of perturbative QCD and yielding knowledge of the structure of the photon. In this paper, the emphasis is to make a measurement of beauty production, which, with its larger mass should allow perturbative QCD calculations to be more reliable. The treatment of heavy quarks is one of the uncertain inputs to parametrisations of the photon structure function. Consideration of $x_\gamma^{\rm obs}$, where $x_\gamma^{\rm obs}$ is the fraction of the photon energy contributing to the two highest transverse energy jets, may give us some insight into the structure of the photon. We define $x_\gamma^{\rm obs}$ in terms of the transverse energy, $E_T^{\rm jet}$, and pseudorapidity, $\eta^{\rm jet}$, of the two highest transverse energy jets;

$$x_\gamma^{\rm obs} = \frac{\sum_{jet1,2} E_T^{\rm jet} e^{-\eta^{\rm jet}}}{2yE_e}, \qquad (1)$$

where yE_e is the initial photon energy. Results from the production of $D^*(2010)$ mesons in dijet photoproduction [1] show a significant cross-section at low $x_\gamma^{\rm obs}$ consistent with approximately 45% resolved photon processes on comparison with HERWIG Leading Order (LO) Monte Carlo (MC) [2] predictions. This demonstrates that at LO, we should consider charm production not just as a boson gluon fusion process, but also as a result of the photon fluctuating into a source of partons. It is then natural to pose the question of the dominant mechanisms in beauty production.

2. CROSS-SECTION DEFINITION

For the process,

$$e^+ + p \rightarrow \text{dijets} + e^- + X, \qquad (2)$$

two differential cross-sections, $d\sigma/dx_\gamma^{\rm obs}$ and $d\sigma/dp_T^{\rm rel}$ were measured, inclusive of quark flavour. The quantity $x_\gamma^{\rm obs}$ is defined in Equation (1) and $p_T^{\rm rel}$ is the momentum of the electron transverse to the axis of the jet to which the electron is closest. A data sample with a total luminosity of 36.9 pb^{-1} collected during the years 1996 and 1997 was analysed.

The virtuality of the photon was required to be $Q^2 < 1$ GeV^2 which allied to $0.2 < y < 0.8$, where y is the fraction of the the electron's energy carried by the photon, defines the events to be in the photoproduction region. Each event was required to have two high transverse energy jets (reconstructed using the k_T clustering algorithm [3]) with $E_T^{\rm jet1,2} > 7, 6$ GeV and $|\eta^{\rm jet}| < 2.4$. An electron in the final state was selected in the event with $p_T(e^-) > 1.6$ GeV and $|\eta(e^-)| < 1.1$.

3. METHOD

The electrons were identified using their rate of energy loss, dE/dx, traversing the Central Tracking Detector (CTD). With the knowledge that for

electrons, $dE/dx \sim 1.4$ mips (minimum ionising particles) and hadrons, with $p_T(e^-) > 1.6$ GeV, $dE/dx \sim 1$ mip, a separation of the two can be realised. The resolution of dE/dx is not such that direct identification can be performed, so we require additional information.

If a cluster of cells in the calorimeter has more than 90% of the energy deposited in the electromagnetic calorimeter, we call it *electron enriched*. If a cluster has more than 60% of the energy deposited in the hadronic calorimeter, we call it *hadron enriched*. These clusters are then matched to tracks and the dE/dx considered. Although, the electron enriched sample contains mostly hadrons, the hadron enriched sample is an efficient rejector of electrons. Therefore a statistical subtraction of the two yields the number of electrons.

Before using the electron sample to extract physics results, we have to eliminate any remaining background. The significant, background arises from photons converting to an e^+e^- pair in dead material. The pairs are identified with a topological finder, which considers the distance of closest approach, vertex and invariant mass of all combinations of two tracks. Using a a calculation for pair production [4], the number of pairs missed is estimated when the e^+ has low momentum (below 200 MeV) such that the CTD reconstruction efficiency is poor. A second step relies on MC, but at a reduced level as a consequence of the model independent first step.

In Fig. 1, we see the dE/dx distribution for electron and hadron enriched samples (top) and the electron signal with the background from converting photons (bottom). The hadron enriched sample is normalised to the electron enriched sample in the shaded region shown. In this region a good description of the hadronic background in the electron enriched sample by the hadronic enriched sample is seen. An excess of the electron enriched sample over the hadron enriched sample at larger values of dE/dx is also seen, consistent with the presence of electrons, which is then clearly shown in the subtracted plot. In Fig. 1 (bottom) a clear electron signal is seen which allied to the background estimation can then be used to extract physics results.

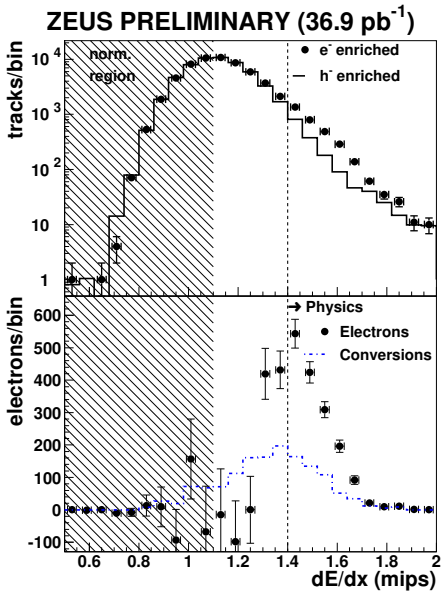

Figure 1. Distribution in dE/dx for electron and hadron enriched samples (top) and electron signal with the conversion background (bottom).

4. RESULTS

The measured cross-sections, for the process (2), as a function of $x_\gamma^{\rm obs}$ and $p_T^{\rm rel}$ are shown in Figs. 2 and 3 respectively, compared to HERWIG MC expectations. The ZEUS data points have statistical errors (inner bars) and statistical plus systematical errors added in quadrature (outer bars). The uncertainty due to the ZEUS calorimeter energy scale is shown as the shaded band. Fig. 2 shows the MC separately as 60% direct photon processes (vertically hatched histogram) and 40% resolved photon processes (diagonally hatched histogram) and the two combined (open histogram). In Fig. 3 the MC is shown separately as 83% charm and light quark processes (diagonally hatched histogram) and 17% beauty processes (horizontally hatched histogram) and again the two combined (open histogram). The percentages are the prediction from the MC, which requires a normalisation factor of 3.7 in order to describe the data. The HERWIG MC used has the default heavy quark masses; $m_c = 1.55$ GeV and $m_b = 4.95$ GeV and the CTEQ-4D [5] and GRV-LO [6] structure functions for the proton and photon respectively.

In Fig. 2, we see a peak at high $x_\gamma^{\rm obs}$ consistent with direct photon processes, but with a tail at low $x_\gamma^{\rm obs}$ which cannot be explained by direct processes alone. The HERWIG MC predicts a significant component of resolved photon processes, which when added to the direct component shows good agreement in shape with the measured data. Fitting the ratio of direct and resolved to the data gives a resolved component of $35\pm6(stat)\%$, in good agreement with the prediction and consistent with the aforementioned D^* result [1].

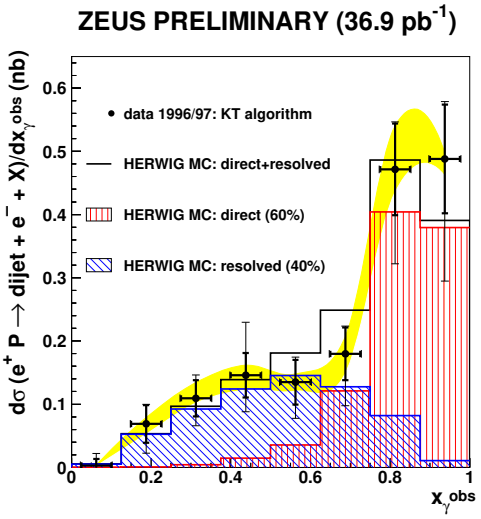

Figure 2. Cross-section $d\sigma/dx_\gamma^{\rm obs}$ compared to MC expectations.

In Fig. 3, we see the cross-section peaked at low $p_T^{\rm rel}$, consistent with decays from predominantly charm quarks and light mesons. At high $p_T^{\rm rel}$, we also see a significant cross-section consistent with decays predominantly from beauty quarks. The total MC sample shows good agreement with the measured data. Allowing the contributions of beauty and charm plus light flavours to vary, a percentage of $20\pm6(stat.)^{+12}_{-\ 7}(syst.)$ % for beauty production (χ^2/ d.o.f. ~ 1.2) was determined, in good agreement with the prediction. Using this value, we can then extract a beauty cross-section in our restricted kinematic region;

$$\sigma_{b\bar{b}}^{\rm vis}(e^+ + p \to {\rm dijet} + e^- + X) = 39 \pm 11^{+23}_{-16}\ {\rm pb}.$$

(ZEUS Preliminary)

The cross-section has been compared to HERWIG MC predictions with the masses and structure functions specified previously. The measured value was found to lie a factor of about 4 above the MC prediction.

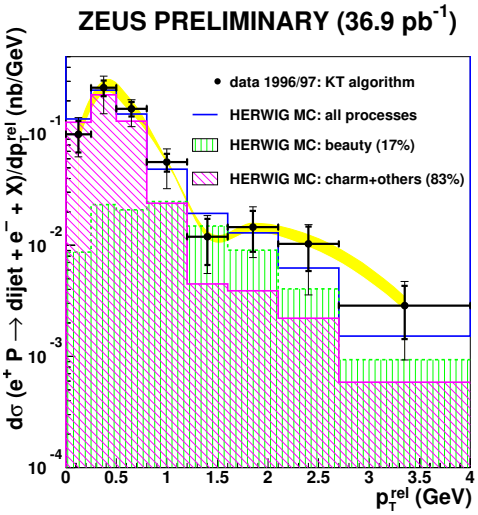

Figure 3. Cross-section $d\sigma/dp_T^{\rm rel}$ compared to MC expectations.

5. CONCLUSIONS

The first measurement of open beauty production from the ZEUS collaboration has been performed in dijet photoproduction events with an electron in the final state. The measured cross-section lies a factor of 4 above a LO MC prediction. Although the measurement is interesting in itself, the opportunity to study the production mechanisms is the obvious goal.

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