Measurement of charm production in DIS with inclusive secondary vertices and determination of $F_2^{c\bar{c}}$ with the ZEUS detector at HERA

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Charm production in deep inelastic scattering has been measured with the ZEUS detector using the full HERA II data set. The charm content in events with a jet has been extracted using the decay length significance and invariant mass of secondary vertices. Differential cross sections as a function of the photon virtuality Q^2, Bjorken x, jet transverse energy E_T^{jet} and jet pseudorapidity η^{jet} were measured and compared to theoretical predictions. The open charm contribution to the proton structure function F_2 was extracted from double differential cross sections.

1 Introduction

The production of charm quarks at HERA, an electron-proton collider with a center-of-mass energy of 318 GeV, is interesting in several aspects. In the lowest order, heavy quarks are produced via boson-gluon fusion, hence this process is sensitive to the gluon content of the proton and provides means to check the validity of the gluon density determined from scaling violations of the inclusive F_2 structure function. Charm production allows studies of the multiple-hard-scale problem in QCD which arises because the charm mass is not the only hard scale in the process: at very high photon virtuality Q^2 or charm quark momentum the perturbative expansion can diverge due to presence of large logarithmic terms. Several schemes exist to perform perturbative calculations, such as massive, massless or mixed schemes. They treat differently heavy quark mass and hence the multi-scale problem. Charm data are also sensitive to the value of the charm quark mass.

This work reports a preliminary measurement [1] of charm jet production differential cross-sections in DIS and the determination of the charm contribution to the F_2 proton structure function, $F_2^{c\bar{c}}$.

2 Experimental procedure

After production in the hard interaction, charm quarks hadronize into charm hadrons, which due to their long lifetime travel detectable distances before they decay. This feature allows the usage of lifetime-tagging techniques in order to distinguish charm quark production from background processes. The measurement reported here employs a method where the charm quarks are tagged by a secondary vertex associated with a jet.

The kinematic region considered was:

- $5 < Q^2 < 1000$ GeV^2, where Q^2 is the negative 4-momentum squared of the virtual photon;
- $0.02 < y < 0.7$, where y is the fraction of the electron energy lost in the interaction in the proton rest frame (inelasticity);
- jets were required to have $E_T > 4.2$ GeV and $-1.6 < \eta < 2.2$.

Tracks belonging to each jet were considered. If at least two tracks with $p_T > 0.5$ GeV were found within the cone of $\Delta R = \sqrt{\Delta\phi^2 + \Delta\eta^2} < 1$ w.r.t. to the jet axis, a secondary vertex was fitted, otherwise the jet was discarded. For each fitted secondary vertex, its decay length significance was calculated using the formula: $S = L_{xy}/\sigma(L_{xy})$, where L_{xy} is the decay length projected onto the jet axis in the plane perpendicular to the beam, and $\sigma(L_{xy})$ is its uncertainty. The decay length signifance was used as a discriminating variable. The distributions for data and charm, beauty and light flavor (LF) Monte Carlo are shown in Fig. 1. The dominant contribution comes from LF production. This background was reduced by mirroring, that is subtraction of the negative significance part from the positive part. After the mirroring, template fits were performed to obtain the charm fraction in the data. The secondary vertex mass was used in addition for separation: the fits were done simultaneously in three vertex mass bins (1-1.4 GeV, 1.4-2 GeV, 2-6 GeV). This is done mainly to enhance the sensitivity to beauty, since the mass is larger for b-quarks than for charm or LF. The procedure was repeated for each bin in the differential cross-sections. $F_2^{c\bar{c}}$ was determined by extrapolation of $Q^2 - x$ double-differential cross-sections to the full phase space using NLO QCD calculations described below.

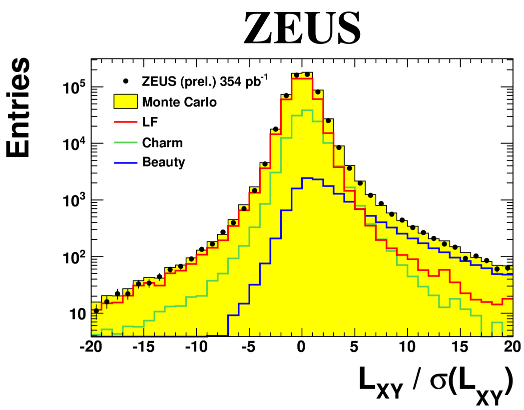

Figure 1: Decay length significance for data, charm, beauty and light flavors Monte Carlo for vertex mass in range [2, 6] GeV. The Monte Carlo distributions were scaled according to the fit results.

3 Theory predictions

NLO QCD calculations were performed with the HVQDIS [2] program (fixed-flavor number scheme). The ZEUS-S [3] and ABKM NLO [4] parton density functions (PDF) were used. The renormalization and factorization scales were set to $\mu_R = \mu_F = \sqrt{Q^2 + 4m_c^2}$. The charm quark mass was set to $m_c = 1.5$ GeV. As HVQDIS provides parton cross-sections at QED Born level, hadronization and QED corrections were applied as determined from the RAPGAP [5] Monte Carlo (LO+parton shower). Uncertainties on the theory predictions were estimated by variation of HVQDIS settings: μ_R and μ_F independently by factors 0.5 and 2; m_c to 1.3 and 1.7 GeV and by variation of the PDFs within uncertainties.

4 Results

Fig. 2 shows measured differential cross sections as a function of E_T^{jet} and η^{jet} together with NLO QCD calculations. Predictions from RAPGAP Monte Carlo, scaled according to the fit are also shown. The overall agreement between data and theoretical predictions is reasonable, although the data tend to lie above the NLO predictions. Predictions with ZEUS-S and ABKM PDF sets are practically the same. Conclusions for differential cross sections as a function of Q^2 and x (not shown) are very similar.

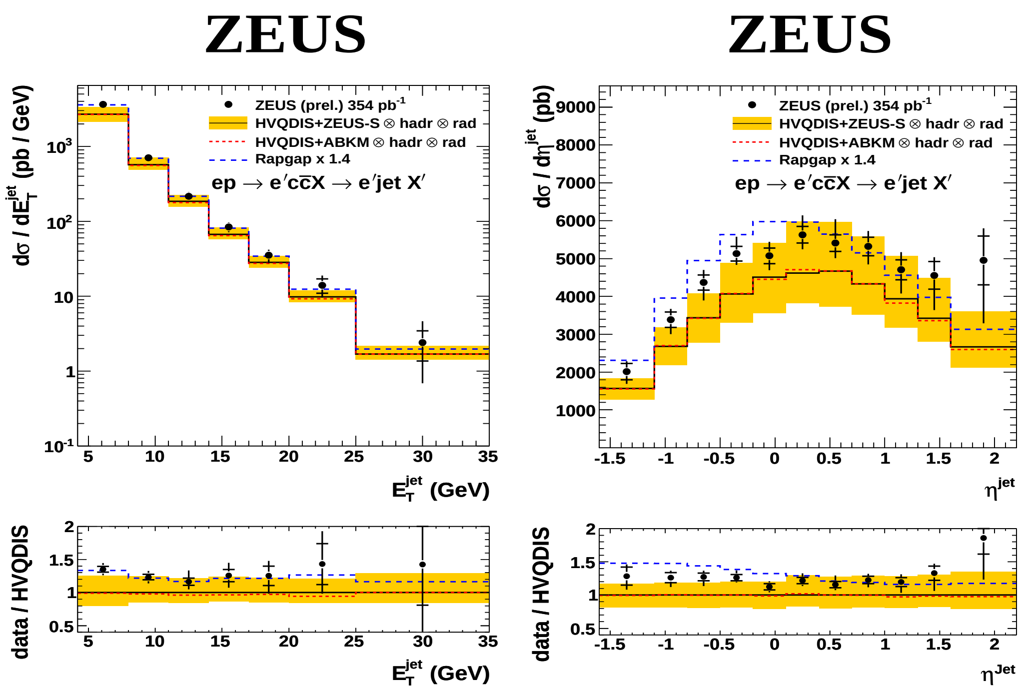

Figure 2: Measured differential cross-sections as a function of E_T^{jet} and η^{jet}.

Fig. 3 shows the contribution to the proton structure function $F_2^{c\bar{c}}$ as a function of x for different values of Q^2. Data are compared to recent ZEUS preliminary measurements [6] with D^* and D^+ tags and also to the preliminary combination [7] of H1 and ZEUS data. All results are consistent, albeit using different techniques. The precision of the new measurement is competitive at moderate and high Q^2. The precision at low Q^2 can still be improved by extending the phase space to lower jet energies. The prediction from HERAPDF 1.0 [8] is also shown. The uncertainty band is determined by the charm mass variation. Charm data are not included in the HERAPDF 1.0 fit hence the nice agreement confirms the QCD factorization theorem.

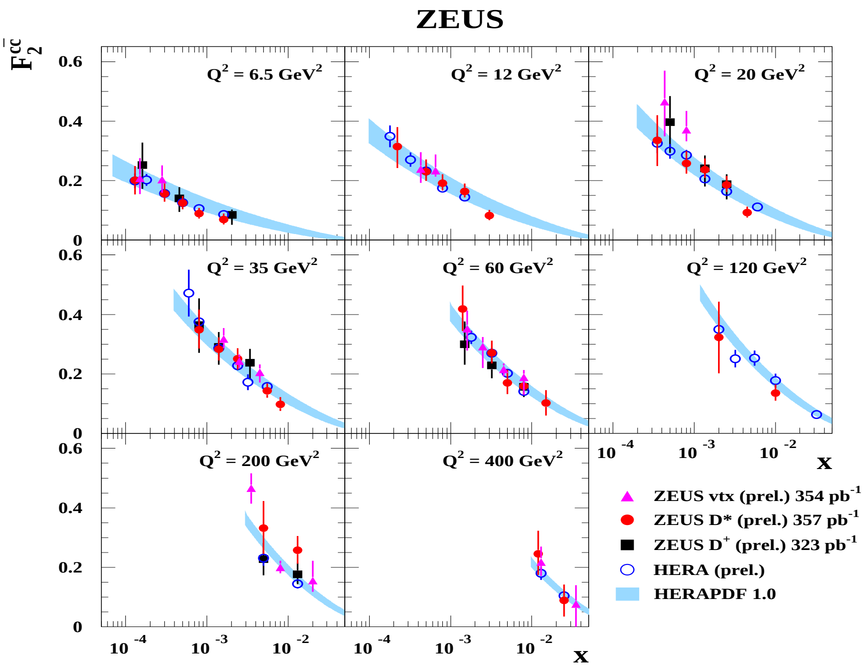

Figure 3: $F_2^{c\bar{c}}$ results compared to previous measurements and QCD predictions based on HERAPDF 1.0

5 Conclusions

The measurement of charm production differential cross-sections in deep inelastic scattering and charm contribution to the proton structure function $F_2^{c\bar{c}}$ with inclusive secondary vertices at ZEUS has been reported. The overall agreement between data and QCD calculations is reasonable, with the theory lying slightly below the data. The precision of $F_2^{c\bar{c}}$ is competitive compared to previous measurements. There are ongoing studies to reduce the extrapolation uncertainty at low Q^2.

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