Charm Physics at HERA

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Abstract. Recent results on charm physics from the HERA *ep* collider experiments H1 and ZEUS are described. Cross section measurements are made in photoproduction and deep-inelastic scattering (DIS) using a variety of techniques. The DIS results are used to extract the charm contribution to the proton structure function. The results are compared to QCD calculations.

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INTRODUCTION

The HERA electron-proton collider with a center of mass energy of 318 GeV operated until 2007 and provided each experiment, H1 and ZEUS, with approximately 500 pb^{-1} of data. Since charm comprises approximately 25% of the deep-inelastic scattering (DIS) cross section at HERA this provides a huge quantity of charm events enabling tests of charm production and fragmentation. In addition photoproduction events where the exchanged photon is almost on shell ($Q^2 \simeq 0$) provide tests in a regime which is similar to hadron-hadron collisions.

In perturbative QCD calculations, the production of heavy quarks at HERA proceeds dominantly via the direct photon-gluon fusion (PGF) process $\gamma g \to c\bar{c}$, where the photon interacts with a gluon from the proton to produce a pair of heavy quarks in the final state. Therefore, the measurement of processes involving heavy flavor production provides a test of the understanding of the QCD production mechanism and information on the gluon content of the proton. The presence of the heavy quark mass M provides an additional "hard" scale to the momentum transfer of the exchanged boson Q meaning the perturbative series has to be treated in different ways depending on the relative magnitude of M and Q. At small scales ($Q \sim M$) the mass of the heavy quark is taken into account via the "massive" PGF matrix element. This matrix element is implemented within the fixed flavor number scheme (FFNS). At high scales ($Q \gg M$) the quark's mass may be neglected and it is treated as a "massless" parton.

The latest sets of global parton density functions (PDFs) from the CTEQ and MSTW fitting groups (CTEQ6.6 [1], MSTW08 [2]) are based on the general mass variable flavor number scheme (GM VFNS) which aims to interpolate between the massive behavior at low Q^2 and massless behavior at high Q^2. The measurement of the charm contribution to the proton structure function $F_2^{c\bar{c}}$ allows the PDFs and the GM VFNS scheme to be tested directly. The understanding of the gluon and heavy quark distributions in the region of low Bjorken x has important implications for the measurement of Standard Model and new physics processes at hadron colliders such as the Tevatron and LHC.

CHARM TAGGING TECHNIQUES

At HERA there are 3 main ways of tagging charm events. The first is to fully reconstruct the charmed hadron (usually D^0, $D^{\pm}$ or D^*) from its decay products [3, 4, 5]. For D^0 and $D^{\pm}$ mesons combinatorial background is reduced by asking for a displacement of the D meson vertex from the primary vertex. The secondary vertex is reconstructed using the silicon vertex detectors. For D^* mesons by additionally constraining the D^*-D^0 mass difference the background is reduced to an acceptable level without the need for a secondary vertex requirement.

The second charm tagging method is to use all tracks which have a significant impact parameter to the primary vertex [6]. Light quark events and bottom are statistically separated from the charm due to their different track multiplicities and hadron lifetimes. This method is referred to as the ‘lifetime method’.

The other method is to tag charm via the semi-muonic decays of charm hadrons in jets [7]. Light quark events and bottom are statistically separated from the charm using the muon impact parameter and the relative muon transverse momentum relative to the jet axis.

CHARM MESON MEASUREMENTS IN PHOTOPRODUCTION AND DIS

The measurement of the D^* cross section in photoproduction [3] is shown in figure 1. The data are seen to be well described by the FFNS calculation, although the GMVFNS falls below the data at large P_T, showing there is still some theoretical work needed to understand the differences. In figure 2 (left) the DIS cross section for $D^{\pm}$ mesons is shown [4]. In general the FFNS calculations using the program HVQDIS show good agreement with the data, although as seen in figure 2 (right) the calculation tends to lie a little below the precise D^* cross section data from H1 at high $\eta(D^*)$ [5].

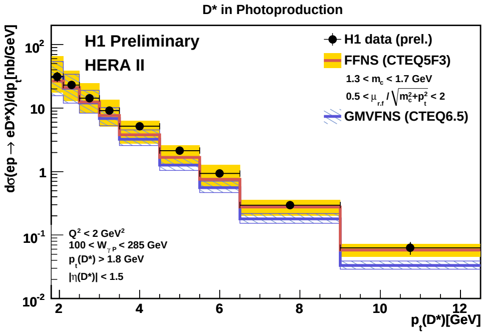

FIGURE 1. The D^* cross section measured in photoproduction as a function of $P_T(D^*)$.

ZEUS have also made measurements of the D^* fragmentation function using photoproduction events [8]. The data are found to be consistent with the symmetric Lund Bowler [9], Peterson [10] and Kartvelishvili [11] parameterisations. The extracted parameters are found to be consistent with those obtained from e^+e^- measurements within the context of PYTHIA.

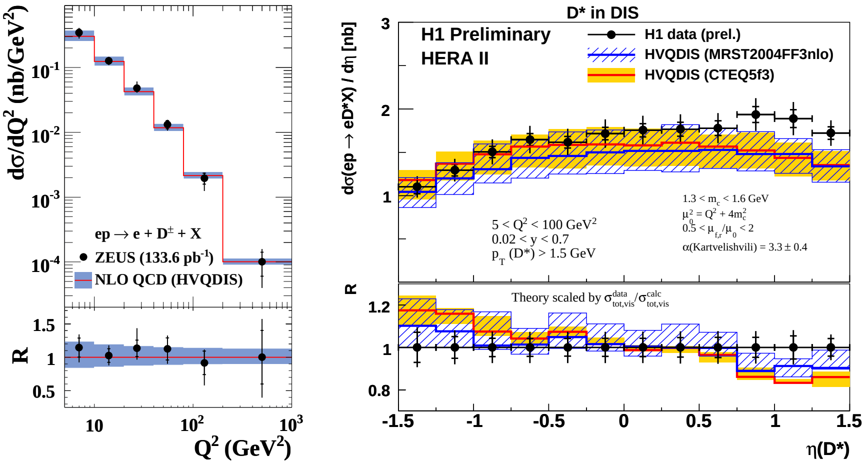

FIGURE 2. The cross section measured in DIS for $D^{\pm}$ as function of Q^2 (left) and the D^* as a function of $\eta(D^*)$ (right).

MEASUREMENT OF $F_2^{c\bar{c}}$

All three tagging techniques are used to make cross section measurements differentially in Q^2 and x and the QCD calculations are used to extrapolate over unmeasured phase space to determine the charm contribution to the proton structure function $F_2^{c\bar{c}}$. The data using all the methods are found to agree. Measurements using the lifetime [6] and muon techniques [7] are compared in figure 2 (left), which shows the data plotted as a function of Q^2. Scaling violations are clearly seen for the data at low x. A more precise determination of $F_2^{c\bar{c}}$ can be made by combining data extracted using different techniques. H1 combines the D^* [12] and lifetime measurements using a technique that takes into account the statistical and systematic errors including any correlations [13]. The resulting $F_2^{c\bar{c}}$ is shown figure 2 (right) plotted as a function of x. The data are seen to rise sharply at low x. The precision of this data is such that it is able to discriminate between the various theoretical predictions.

SUMMARY

Measurements of cross sections and related measurements in photoproduction and DIS made from HERA data have been presented. These measurements along with the extracted charm contribution to the proton structure function show agreement with QCD predictions. A combination of a selection of the data has been shown to improve the precision.

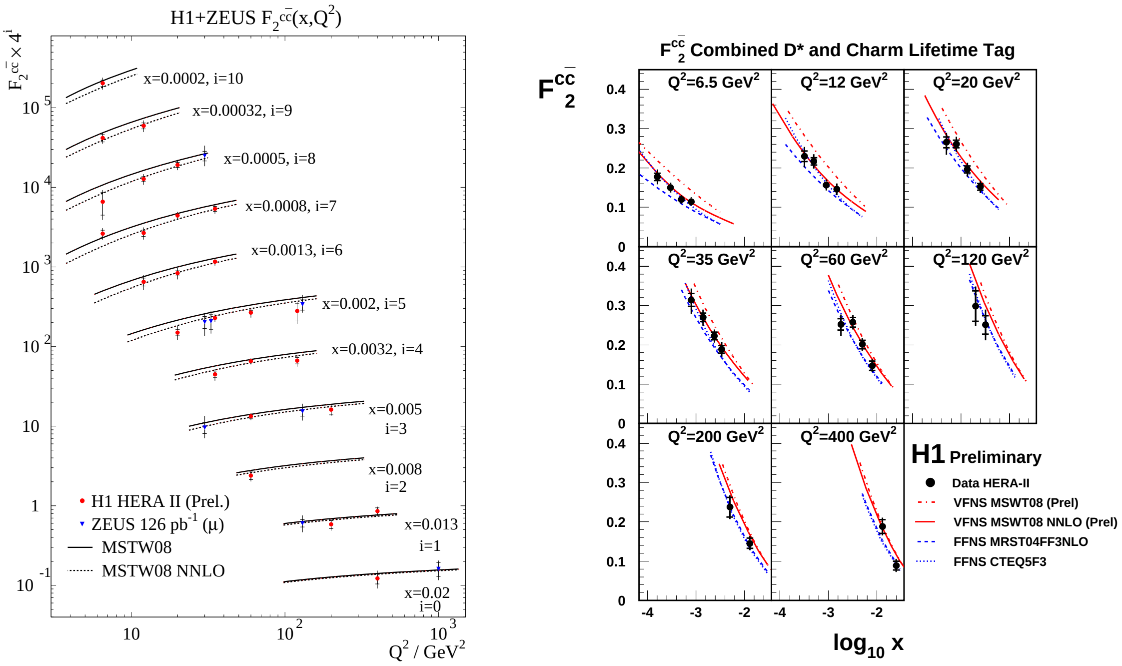

FIGURE 3. Measurement of the $F_2^{c\bar{c}}$ using the muon tag and lifetime methods, show as a function of Q^2 (left). Combined measurement of H1 data using the D^* and lifetime method show as a function of x (left).

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