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Combined $F_2^{c\bar{c}}$ measurement at HERA

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On behalf of the H1 and ZEUS collaborations

A combination is presented of deep inelastic cross sections of charm production measured by the H1 and ZEUS Collaborations. The charm contribution $F_2^{c\bar{c}}$ to the proton structure F_2 is determined by combining the results of D meson production cross section measurements with measurements using semi-muonic decays into muons as well as with those based on inclusive track measurements with lifetime information. The combination method used takes the correlations of systematic uncertainties into account, resulting in an improved accuracy. The data cover the kinematic range of photon virtuality $2 < Q^2 < 1000\,\mathrm{GeV}^2$ and of the Bjorken scaling variable $10^{-5} < x < 10^{-1}$.

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1. Introduction

Several results on the measurement of the $F_2^{c\bar{c}}$ at HERA have been published by the H1 [1, 2] and the ZEUS [3, 4] collaborations. These data have shown clear evidence that charm production in deep inelastic ep scattering is dominated by the photon gluon fusion process. The mass m_c of the charm quark implies a sufficiently high scale to apply perturbative QCD for calculating this process. However, this process is a multi-scale problem since additional scales are involved, e.g. the virtuality Q^2 of the exchanged photon and the transverse momenta $p_\perp$ of the outgoing quarks. Depending on the relative magnitude of m_c, Q and $p_\perp$ different approaches in pQCD have been formulated. In this paper the massive fixed flavour number scheme (*FFNS*) [5] and the general mass variable flavour number scheme (*GM-VFNS*) [6] will be considered.

The preliminary results presented here are based on published and preliminary data from the HERA-I and HERA-II running periods. The averaged $F_2^{c\bar{c}}$ is obtained combining the D meson measurements [2, 3] and the results of the displaced track [1] and semi-muonic decay [4] analyses. The results are compared to different approaches in next-to-leading order (*NLO*) and next-to-next-to-leading order (*NNLO*) QCD.

2. Analysis Procedure

Details on the analysis procedure can be found elsewhere [7]. The different steps are only briefly summarised below.

2.1 Extraction of $F_2^{c\bar{c}}$ from visible cross sections

The D meson and muon production cross sections $\sigma_{\rm vis,i}^{\rm meas}$ measured in a given bin i of x, Q^2 and in the visible phase space in η and p_T of the D meson or of the muon, respectively. These cross sections are transformed to $F_2^{\rm c\bar{c},meas}(x,Q^2)$ at a reference point in x, Q^2 by

$$F_2^{\rm c\bar{c},meas}(x,Q^2) = \sigma_{\rm vis,i}^{\rm meas} \frac{F_2^{\rm c\bar{c},model}(x,Q^2)}{\sigma_{\rm vis,i}^{\rm model}}. \tag{2.1}$$

using the NLO calculation at FFNS [5, 8]. Charm tagging with D mesons or muons benefits from a clean signature at the expense of a restrictive visible phase space. These restrictions result in significant extrapolation factors for transforming the visible cross section $\sigma_{\rm vis,i}^{\rm meas}$ to $F_2^{c\bar{c}}$ which then introduces sizable extrapolation uncertainties.

In the inclusive displaced track analysis the reduced charm cross section $\tilde{\sigma}^{c\bar{c}}$ defined as

$$\tilde{\sigma}^{c\bar{c}}(x,Q^2) = \frac{{\rm d}^2\sigma^{c\bar{c}}}{{\rm d}x\,{\rm d}Q^2}\frac{xQ^4}{2\pi\alpha^2(1+(1-y)^2)}, \tag{2.2}$$

is extracted by

$$\tilde{\sigma}^{c\bar{c}}(x,Q^2) = \tilde{\sigma}(x,Q^2)\frac{\rho_c N_c^{\rm MCgen}}{\rho_l N_l^{\rm MCgen} + \rho_c N_c^{\rm MCgen} + \rho_b N_b^{\rm MCgen}}\delta_{\rm BCC}, \tag{2.3}$$

where α is the fine structure constant evaluated with scale Q^2, and $N_l^{\rm MCgen}$, $N_c^{\rm MCgen}$, and $N_b^{\rm MCgen}$ are the number of light, c, and b quark events generated from the Monte Carlo simulation in each bin. The inclusive reduced cross section $\tilde{\sigma}(x,Q^2)$ is taken from [9]. A bin centre correction $\delta_{\rm BCC}$ is applied using a NLO QCD expectation for $\tilde{\sigma}^{c\bar{c}}$ and $\tilde{\sigma}$ to convert the bin averaged measurement into a measurement at a given x–Q^2 point. $F_2^{c\bar{c}}$ is obtained from the reduced cross section $\tilde{\sigma}^{c\bar{c}}$ by

$$F_2^{c\bar{c}} = \tilde{\sigma}^{c\bar{c}} + \frac{y^2}{1+(1-y)^2} F_L^{c\bar{c}}. \tag{2.4}$$

Extracting $F_2^{c\bar{c}}$ from inclusive displaced tracks profits from moderate extrapolation uncertainties but is hampered by considerable uncertainties form light flavour initiated background.

2.2 Combination Method

The combination of the data sets uses the χ^2 minimization method as described in [10]. The χ^2 function takes into account the correlated systematic uncertainties for the H1 and ZEUS cross section measurements. The χ^2 is defined as

$$\chi^2\,(m,b) = \sum_i \frac{\left(m^i - \sum_j \gamma_j^i m^i b_j - \mu^i\right)^2}{\left(\delta_{i,\rm stat}\,\mu^i\right)^2 + \left(\delta_{i,\rm uncor}\,m^i\right)^2} + \sum_j b_j^2\,, \tag{2.5}$$

where $\mu^i \equiv F_{2,i}^{c\bar{c}}(x_i,Q_i^2)$ is the value of a particular measurement i and γ_j^i, $\delta_{i,\rm stat}$ and $\delta_{i,\rm uncor}$ are the relative correlated systematic, relative statistical and relative uncorrelated systematic uncertainties, respectively. The χ^2 function depends on the predictions m^i for the measurements and on the shifts of the correlated systematic error sources b_j.The summation runs over all correlated systematic sources. The predictions m^i are given by the assumption that the true value for a given (x,Q^2) point is the same for all the measurements at that particular point.

The combined data are obtained as the set of m^i corresponding to the χ^2 minimum with respect to m and b. Assuming the statistical uncertainties being constant and the systematic uncertainties being proportional to m^i, the minimum of Eq. 2.5 provides an unbiased estimator of m.

The original double differential cross section measurements are published with their statistical and systematic uncertainties. The statistical uncertainties correspond to $\delta_{i,\rm stat}$ in Eq. 2.5. The systematic uncertainties are classified as either point-to-point correlated or point-to-point uncorrelated, corresponding to γ_i^j and $\delta_{i,\rm uncor}$, respectively. Asymmetric systematic uncertainties are symmetrised before performing the averaging. The resulting average is found to be insensitive to the details of the symmetrisation procedure. Experimental systematic uncertainties are treated as independent between the H1 and ZEUS data sets. Model uncertainties are treated as correlated. All the $F_2^{c\bar{c}}$ data from H1 and ZEUS are combined in one single minimisation.

3. Results

In total 9 different $F_2^{c\bar{c}}$ measurements with 54 different sources of systematic uncertainties have been combined to obtain the averaged $F_2^{c\bar{c}}(x,Q^2)$ from HERA. The individual measurements were transformed to a common grid of (x,Q^2) points prior to the combination with help of the NLO FFNS QCD program [5]. These data are shown in Figure 1 together with the result of the averaging procedure. The different measurements on $F_2^{c\bar{c}}$ are found to be very consistent with each other resulting in a total χ^2/N_{dof} of the averaging procedure of $88/110$. The cross-correlated uncertainties

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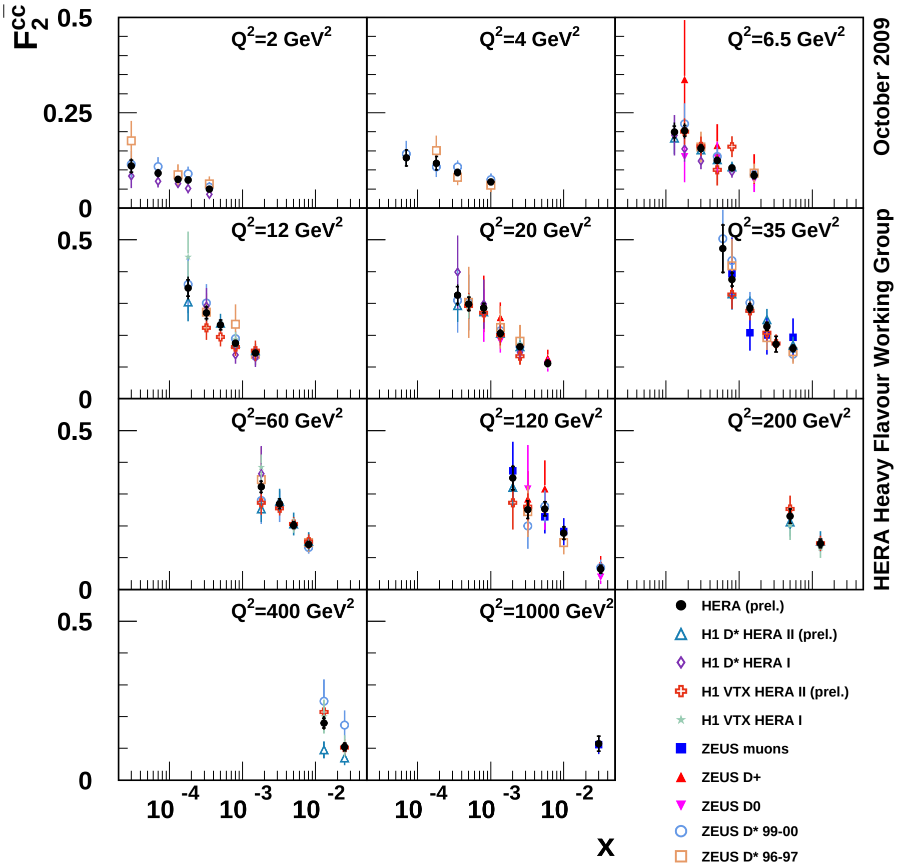

Figure 1: Charm contribution to the proton structure function $F_2^{c\bar{c}}$ as a function of x in bins of Q^2. The averaged HERA $F_2^{c\bar{c}}$ (black) is compared to the data sets of the H1 and ZEUS measurement used for the combination. The inner (full) error bars of the averaged value represent the uncorrelated (total) uncertainties.

between H1 and ZEUS are significantly reduced and the improvement of the combined result is clearly visible. On average a precision on $F_2^{c\bar{c}}$ of better than 10% has been achieved.

In Figure 2 the combined values of $F_2^{c\bar{c}}$ are compared to predictions based on recent QCD fit [11, 12, 13, 14] to global scattering data. In most of the (x, Q^2) phase space the data are more precise than the spread observed in the theoretical predictions. Therefore the combined HERA $F_2^{c\bar{c}}$ data provides valuable constraints on the theory of heavy flavour production in DIS.

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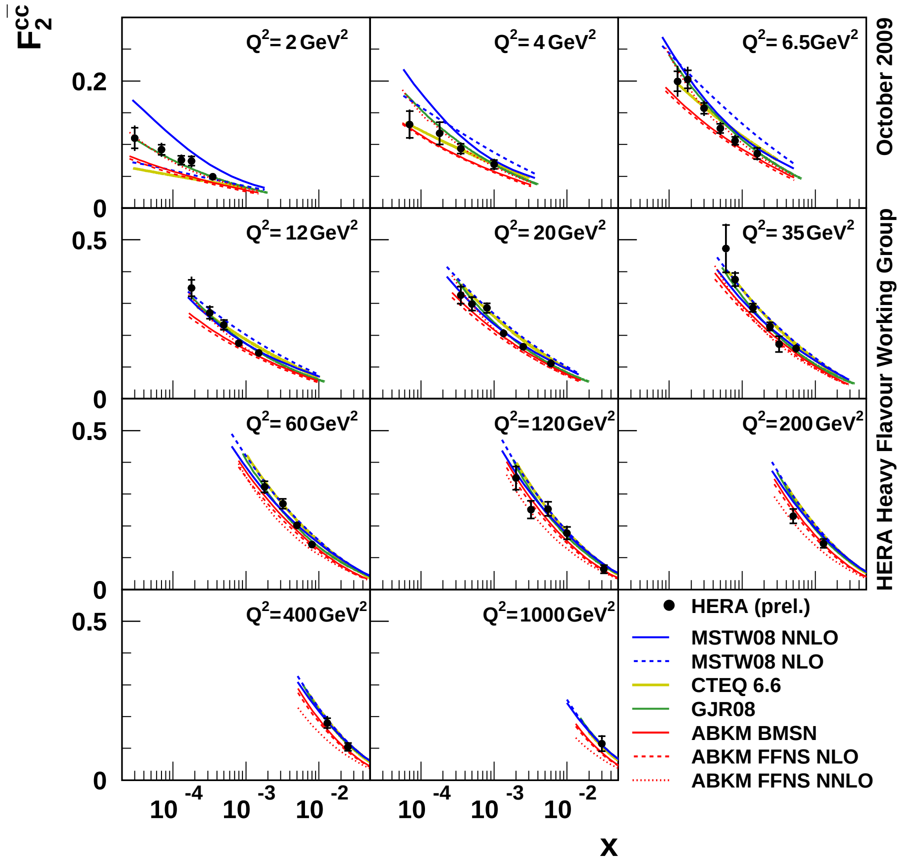

Figure 2: HERA averaged $F_2^{c\bar{c}}$ as a function of x in bins of Q^2. The data (closed symbols) are shown with the uncorrelated (inner error bars) and the total (full error bars) uncertainties. Predictions from the global QCD analyses of ABKM, MSTW08 at NLO and NNLO and CTEQ 6.6 as well as GJR08 are shown.

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