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Combination and QCD analysis of the HERA $F_2^{c\bar{c}}$ results

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Different measurements of charm production in DIS by the H1 and ZEUS experiments were combined into a preliminary common HERA measurement of the charmed structure function $F_2^{c\bar{c}}$. The combined measurement reaches a precision of $7-10\%$ for $6.5 \leq Q^2 \leq 60$ GeV^2. The data are compared to different theoretical predictions and are included in a PDF fit with inclusive DIS data.

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1. Introduction

The production of charm in deep inelastic scattering (DIS) provides an interesting testing ground for perturbative QCD in the presence of multiple hard scales, such as the squared four momentum exchange, Q^2, and the heavy-quark mass, m_c. Moreover, charm production provides a tool to access the gluon parton density function (PDF) in the proton since it occurs, at leading order, through the boson-gluon fusion process $\gamma^* g \to c\bar{c}$. Several measurements of charm production in DIS have been published by the H1 and ZEUS collaborations. These measurements were combined to produce a preliminary common HERA measurement of the charmed structure function $F_2^{c\bar{c}}(x,Q^2)$ defined as the component of the proton structure function $F_2(x,Q^2)$ with a $c\bar{c}$ pair in the final state [1]. The combined data are presented and compared to theoretical predictions in Section 2; their impact on a PDF fit to HERA DIS data is discussed in Section 3.

2. Combination of charm DIS data

Different measurements of charm production in DIS, based on different methods to identify charm production, were included in the combination: reconstructed D mesons such as $D^{*\pm}$ [2], $D^{\pm}$ and D^0 [3]; muons from semileptonic decays [4]; and inclusive lifetime tag measurements based on the analysis of tracks with large impact parameter [5] [1]. Each measurement is sensitive to charm production in a different kinematic range and has different sources of systematic uncertainties.

The cross sections for D mesons and muons, measured in experimentally-accessible η and p_T ranges, were extrapolated to the full phase space using the HVQDIS [7] program to extract $F_2^{c\bar{c}}(x,Q^2)$. The combination method is similar to that described in [8]: a minimum χ^2 analysis was performed to find the best set of true $F_2^{c\bar{c}}(x,Q^2)$ values to fit the measurements. A total of 146 measurements were combined into 46 $F_2^{c\bar{c}}(x,Q^2)$ points, taking into account 54 correlated systematic parameters. The fit gave $\chi^2/\mathrm{ndf} = 81/110$, showing the good agreement among the different data sets. The correlated systematics include experimental uncertainties for sets of similar measurements and common theoretical uncertainties related to the model used for the extrapolation of visible cross sections to the full phase space.

Figure 1 shows the individual measurements used as input to the combination and the results of the combination. The combined measurement reaches a precision of 7-10% in the range $6.5 \leq Q^2 \leq 60\ \mathrm{GeV}^2$.

The combined data are compared to theoretical predictions based on next-to-leading order (NLO) or next-to-NLO (NNLO) calculations in Figure 2. Different predictions used different PDF sets, different values of the charm mass, and different schemes for the treatment of the heavy quarks. In particular, the predictions labeled ABKM FFNS [9] and GJR08 [10] are obtained in the fixed-flavour-number scheme (FFNS) in which charm is never treated as a massless parton but is only produced in the hard scattering. The other predictions in the left panel of Fig. 2 , MSTW08 [11], CTEQ 6.6 [12] and ABKM BMSN [13], are calculated using generalised mass variable-flavour-number schemes (GMVFNS) that correspond to the FFNS for $Q^2 \leq m_c^2$ while treat charm as a massless parton at large Q^2. The precision of the combined data is sufficient to discriminate among different models.

[1] The H1 lifetime tag data included in preliminary form in the combination have been published recently [6].

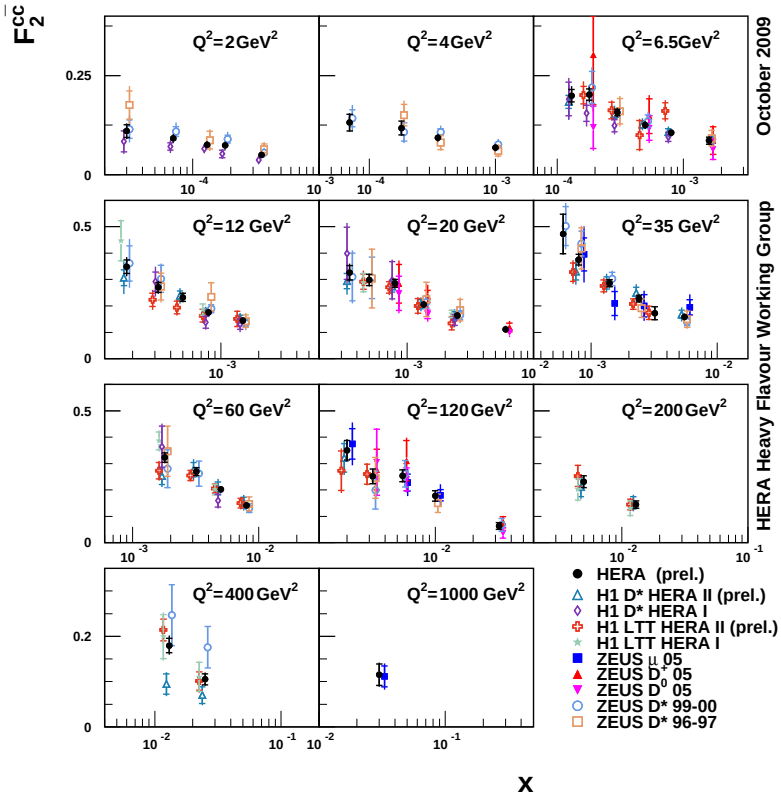

Figure 1: Individual H1 and ZEUS $F_2^{c\bar{c}}$ measurements compared to the results of the combination (filled circles). The inner (outer) error bars show the uncorrelated (total) uncertainties.

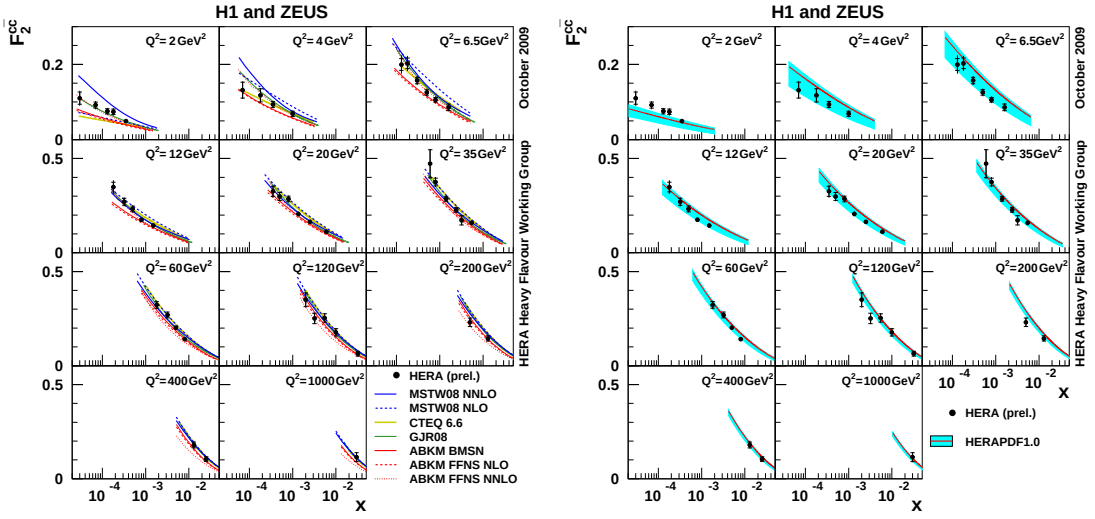

Figure 2: Combined $F_2^{c\bar{c}}$ compared to recent QCD predictions: (left) from the global fit analyses of ABKM [9, 13], MSTW [11], CTEQ [12], GJR [10]; and (right) a NLO calculation based on the HERAPDF1.0 fit to HERA data [8]. The band in the right panel represents the variation of $1.35 < m_c < 1.65$ GeV while the red line corresponds to $m_c = 1.4$ GeV.

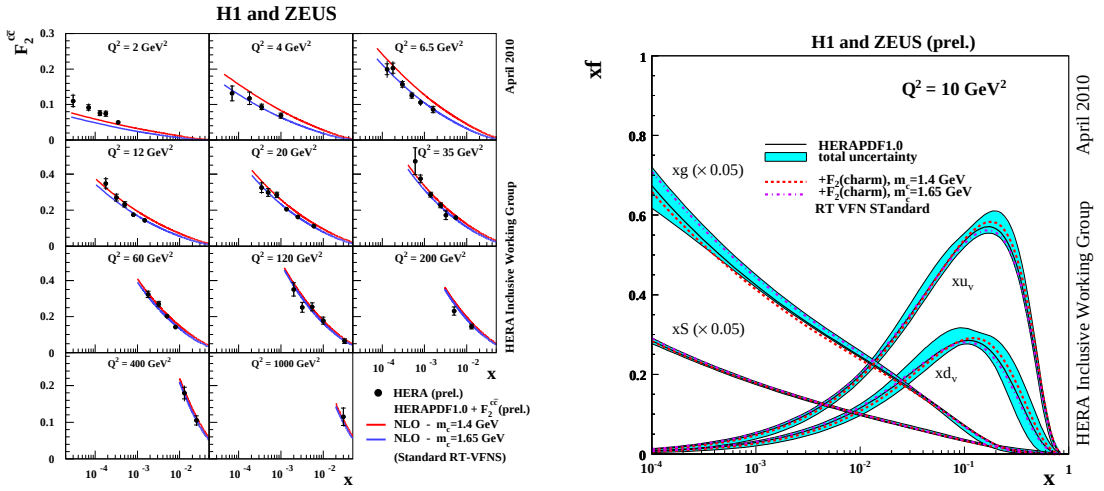

Figure 3: The results of the PDF fit to inclusive HERA I and $F_2^{c\bar{c}}$ data (HERAPDF1.0+$F_2^{c\bar{c}}$) compared to: (left) the combined $F_2^{c\bar{c}}$ data and (right) the PDFs from the fit to inclusive HERA I data only (HERAPDF1.0) evaluated at $Q^2 = 10$ GeV^2. The results are presented for two different charm masses.

In the right panel of Fig. 2 the data are compared with a prediction based on the HERAPDF1.0 PDF set [8], obtained from a fit to inclusive HERA I data. The NLO calculation was performed in the Thorne-Roberts variant of the GMVFNS, similar to that used in [11]. The band corresponds to a variation of the charm mass from 1.35 to 1.6 GeV in the $F_2^{c\bar{c}}$ calculation and in the PDF fit. The agreement between the charm data, which are directly sensitive to the gluon PDF, and the calculation based on the gluon PDF obtained from scaling violation in inclusive DIS is a nice consistency check of our understanding of the proton content.

3. QCD fit including charm data

The HERAPDF1.0 NLO fit to inclusive DIS data was extended by including the combined $F_2^{c\bar{c}}$ measurement. Only inclusive and $F_2^{c\bar{c}}$ data with $Q^2 \geq 3.5$ GeV^2 were included in the fit. Two different charm masses were used: 1.4 and 1.65 GeV. The total χ^2 for 633 data points was $\chi^2_{\rm tot} = 730.7$ for $m_c = 1.4$ GeV and $\chi^2_{\rm tot} = 627.5$ for $m_c = 1.65$ GeV, showing the consistency between charm and inclusive data when using the higher charm mass. The contribution to the total χ^2 from the 41 $F_2^{c\bar{c}}$ points was $\chi^2_{\rm charm} = 134.5$ and $\chi^2_{\rm charm} = 43.5$ for $m_c = 1.4$ GeV and $m_c = 1.65$ GeV respectively. The fits are compared to the $F_2^{c\bar{c}}$ data in Fig. 3(left).

The impact of the $F_2^{c\bar{c}}$ data on the PDFs extracted from the fit is shown in Fig. 3 (right). For $m_c = 1.65$ GeV, the gluon PDF increases with respect to the HERAPDF1.0 result, still remaining within the uncertainties of the original PDF set. The effect on the quark PDFs is negligible. The fit was repeated using different theoretical schemes for the treatment of the heavy quark masses. The variation of the heavy quark scheme and of the charm mass introduced significant variations in the fit result. A more detailed study of this aspect was presented after this conference [14].

4. Conclusions

Different measurements of charm production in DIS were combined into a preliminary HERA measurement of the charmed structure function $F_2^{c\bar{c}}$. A precision of $7-10\%$ is reached for $6.5 \leq Q^2 \leq 60$ GeV^2, which is sufficient to distinguish between different theoretical predictions. The combined $F_2^{c\bar{c}}$ and inclusive DIS measurements were used as input to the HERA1.0+$F_2^{c\bar{c}}$ NLO PDF fit. A good χ^2 was obtained using $m_c = 1.65$ GeV, demonstrating the consistency of charm and inclusive measurements within the NLO QCD framework.

References

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