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Measurement of charm production and $F_2^{c\bar{c}}$ with ZEUS

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Three measurements of charm production in deep inelastic scattering performed with the ZEUS detector at HERA are presented: the production of D^+ and of D^{*+} mesons and a preliminary measurement of charm jets. Results are used to extract the charm reduced cross section $\sigma_{\rm red}^{c\bar{c}}$ and compared to previous results and QCD calculations.

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1. Introduction

Charm production corresponds to a sizable fraction of the deep inelastic scattering (DIS) cross section at HERA, up to $\sim 40\%$ at large Q^2 and low x. In order to make an optimal use of HERA DIS data it is therefore necessary to have a precise understanding of charm production and of the interplay of the different scales (m_c, Q^2) involved in the process. Two different theoretical approaches to heavy flavour production have been used in parton density fits: the fixed-flavour-number scheme (FFNS) [1] in which the heavy quarks are produced in the hard scattering, and the general-mass variable-flavour-number schemes (GMVFNS) [2] that interpolate between FFNS at low Q^2 and the high-Q^2 limit in which charm and beauty are treated as massless quarks and included in the proton parton density functions (PDFs). The GMVFNS exists in different variants, which treat differently the intermediate Q^2 region. Charm production measurements provide then a direct test to these approaches.

In the FFNS, at leading order, charm is produced through the boson–gluon fusion process $\gamma^* g \to c\bar{c}$. Therefore, charm cross section measurements provide a direct constraint to the gluon content of the proton which is independent from that obtained from the scaling violation of the structure functions as measured in inclusive DIS.

The two HERA collaborations, ZEUS and H1, have been improving their measurement of charm production over the past years, using different methods to tag charm production: the reconstruction of charmed hadrons [3], semileptonic decays [4] and inclusive secondary vertex tagging [5]. To further improve the overall precision, H1 and ZEUS measurements have been combined together [6].

Three new measurements performed with the ZEUS detector at HERA are presented in this contribution, based on different experimental methods: the final measurement of the production of D^+ [7] and of D^{*+} [8] mesons, and a preliminary measurement of the production of charm jets [9]. They are based on the data collected in the HERA II running period and on an integrated luminosity of approximately 0.35 fb^{-1}. They were not included in the H1-ZEUS combination [6].

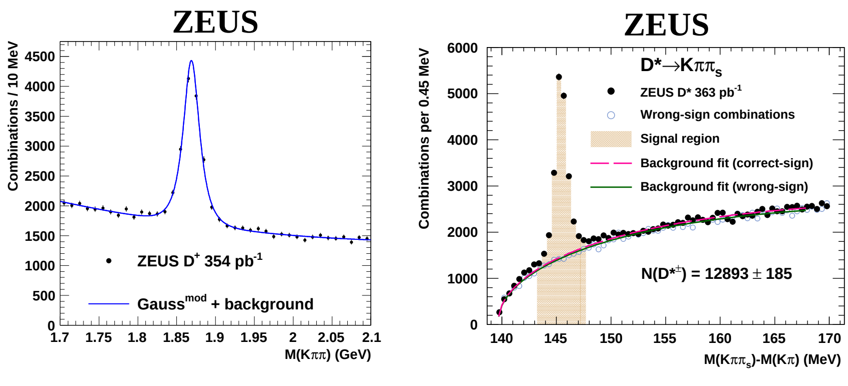

Figure 1: Left: $K\pi\pi$ invariant mass for the D^+ candidates. Right: mass difference $M(K\pi\pi_s) - M(K\pi)$ for D^{*+} candidates.

2. Measurement of D^+ and D^{*+} production in DIS

The D^+ mesons have been reconstructed from the decay $D^+ \to K^-\pi^+\pi^+$ (charge conjugation is implied hereafter). For each D^+ candidate the transverse decay length significance S_l is defined as $S_l = L_{XY}/\sigma(L_{XY})$, with L_{XY} being the distance between the decay vertex and the interaction point in the transverse plane and $\sigma(L_{XY})$ its error. A cut at $S_l > 4$ has been used to obtain a clean D^+ signal, shown in Fig. 1 (left). The D^{+*} candidates have been selected from the decay $D^{*+} \to D^0\pi_s^+$ followed by the decay $D^0 \to K^-\pi^+$. The distribution of the mass difference $\Delta M = (M_{K\pi\pi_s} - M_{K\pi})$ is shown in Fig. 1 (right) for correct $(K^-\pi^+\pi_s^+)$ and for wrong $(K^-\pi^-\pi_s^+)$ charge combinations. A simultaneous fit to the two distributions was used to estimate the background in the signal mass window.

Differential D^+ and D^{*+} cross sections have been measured in the "visible" kinematic range defined by the inclusive DIS variables $5 < Q^2 < 1000$ GeV^2 and $0.02 < y < 0.7$ and by the meson in the range $1.5 < p_T < 15$ GeV, $|\eta| < 1.6$ for the D^+ and $1.5 < p_T < 20$ GeV, $|\eta| < 1.5$ for the D^{+*}. Examples of measured differential cross sections are shown in Figure 2, compared to FFNS next-to-leading order (NLO) QCD predictions obtained with the HVQDIS program [10]. The data are in good agreement with the theoretical prediction.

The D^{*+} differential cross sections have been combined with H1 data to provide a preliminary combined HERA D^* cross section measurement [11]. The combination is illustrated in Figure 3. The ZEUS and H1 data sets have similar precision, the improvement in the uncertainty after the combination demonstrates the potential of the new ZEUS data to further improve the final HERA measurement.

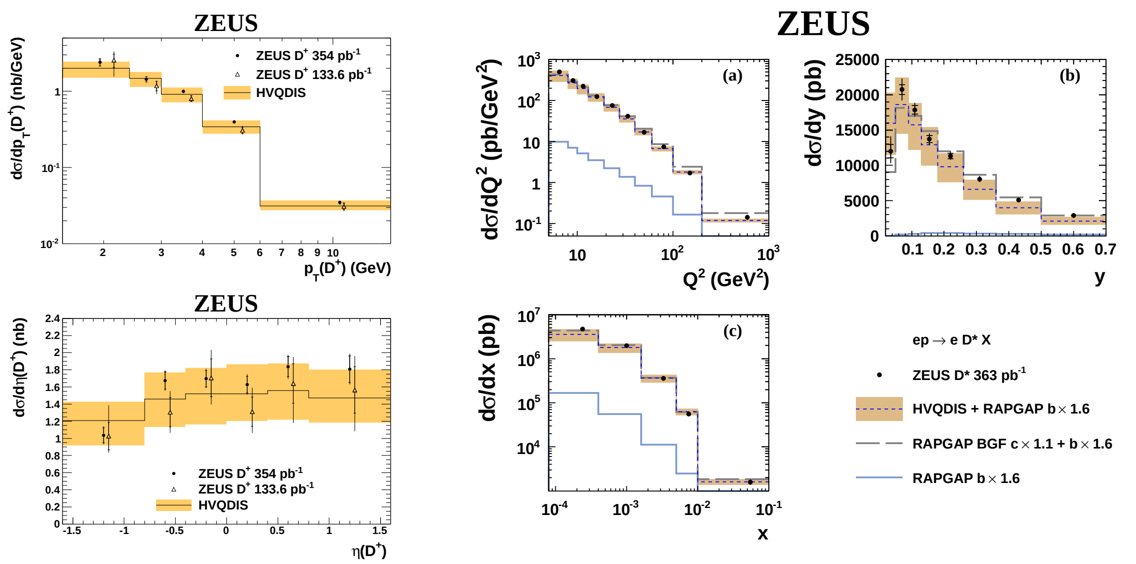

Figure 2: Differential D-meson cross sections compared with NLO QCD calculations based on the FFNS HVQDIS program: Left: D^+ cross section as a function of p_T and η. Right: D^{*+} cross sections as a function of (a) Q^2, (b) y, (c) x. The bands represent the theoretical uncertainty.

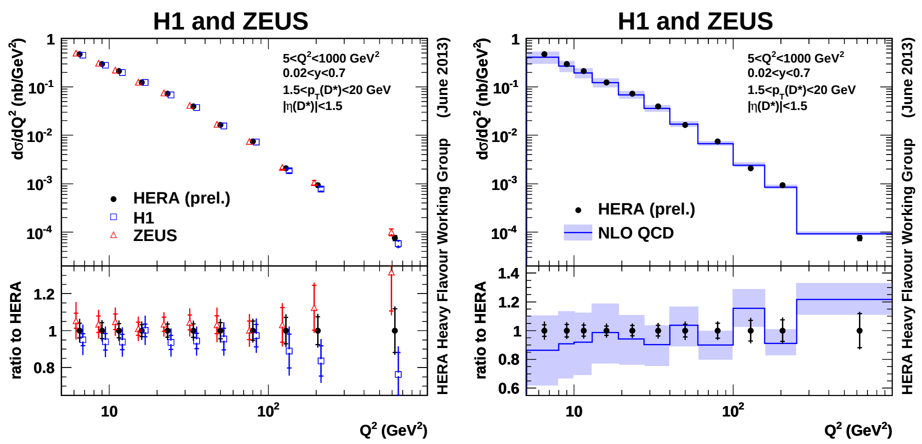

Figure 3: Visible D^{*+} cross section differential in Q^2. Left: measurements from the ZEUS (blue) and H1 (red) collaborations and the preliminary HERA combination (black). Right: the latter compared to FFNS NLO QCD calculations.

3. Extraction of $\sigma_{\rm red}^{c\bar{c}}$

The charm reduced cross section $\sigma_{\rm red}^{c\bar{c}}$ and the charmed structure functions $F_2^{c\bar{c}}$ and $F_L^{c\bar{c}}$ are defined in analogy to the corresponding quantities of inclusive DIS, from the $c\bar{c}$ double differential cross section $\frac{d^2\sigma^{c\bar{c}}}{dx\,dQ^2}$ corrected for QED/EW effects:

$$\sigma_{\rm red}^{c\bar{c}}(x,Q^2,s) \;=\; F_2^{c\bar{c}}(x,Q^2) - \frac{y^2}{Y_+}F_L^{c\bar{c}}(x,Q^2) \;=\; \frac{d^2\sigma^{c\bar{c}}}{dx\,dQ^2}\left(\frac{2\pi\alpha_{em}^2}{xQ^4}\,Y_+\right)^{-1}$$

where $Y_+ = 1+(1-y)^2$.

The double-differential cross sections for D^+ and D^{*+} production in the "visible" kinematic range have been corrected to $\frac{d^2\sigma^{c\bar{c}}}{dx\,dQ^2}$ by subtracting the beauty contribution, estimated using MC samples normalized to independent measurements, and by extrapolating to the full D meson η and p_T range using NLO FFNS calculations and charm fragmentation fraction based on ep and e^+e^- measurements.

The extracted reduced cross sections are presented in Figure 4 (left), in which the D^+ and D^{*+} measurements are compared to the combination of all the previous H1 and ZEUS measurements. The results are in good agreement with each other. The present measurements, in some cases, have similar precision as the combined result. The D^{*+} results are compared in Figure 4 (right) to a theoretical calculation based on the GMVFN scheme and on the HERAPDF1.5 parton densities, extracted from inclusive HERA data only [12]. The good agreement supports the validity of the GMVFN scheme used in the parton density fit.

4. Measurement of Charm jet production

The preliminary ZEUS measurement of charm jet production in DIS is based on the selection of jets with transverse energy $E_T > 4.2$ GeV and $-1.6 < \eta < 2.2$ and the reconstruction of a vertex

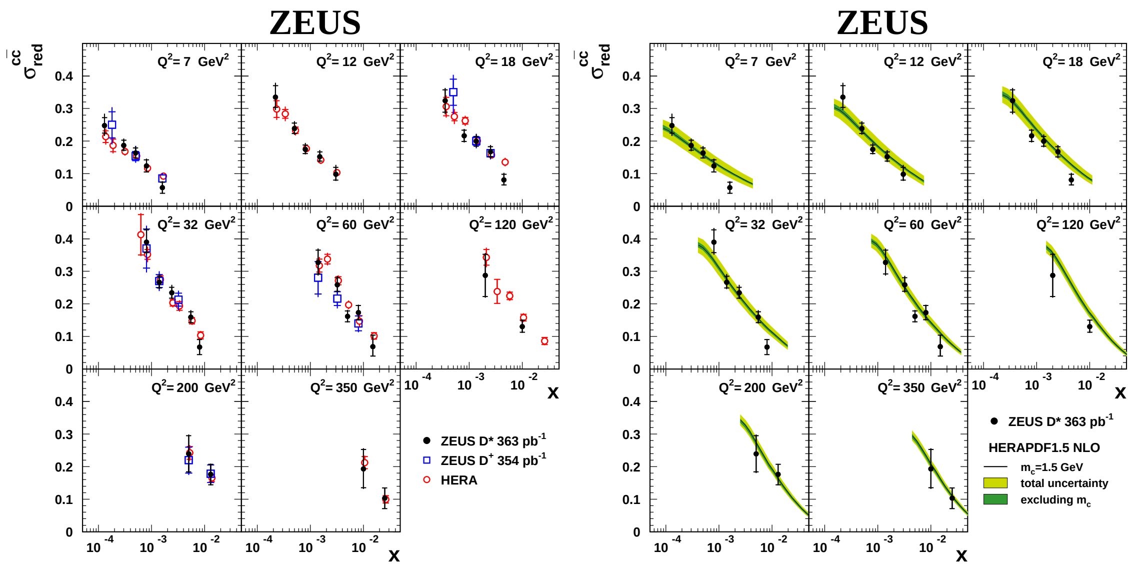

Figure 4: Left: reduced charm cross section $\sigma_{\rm red}^{c\bar{c}}$ extracted from the D^{*+} (filled points) and the D^{+} (squares) measurements compared to the combination of all previous HERA data (empty circles). Right: the D^{*+} data compared to a GMVFNS calculation based on the HERAPDF1.5 parton densities. The external band shows the theoretical uncertainty associated to the charm mass and the internal band shows the other theoretical uncertainties.

from the charged tracks associated to the jet. The decay length significance S_l and the vertex mass $m_{\rm vtx}$ have been used to separate light flavours, charm and beauty, using a Monte Carlo-template fitting technique. Figure 5 (left) shows the S_l distribution in the mass bin $1.4 < m_{\rm vtx} < 2$ GeV and the corresponding fitted components. The negative side of the S_l distribution, dominated by resolution effects, has been used to estimate and subtract the light flavour background.

The charm components extracted from the fit have been used to measure the charm jet cross section. An example of the results is shown in Figure 5 (right). Thanks to the large size of the jet sample, this measurement allows to improve the charm production measurement at high p_T and high Q^2, where the D meson data are statistically limited. For $Q^2 \leq 100$ GeV^2 the jet data are less precise than the D-meson measurements due to larger systematic uncertainties.

5. Conclusions

The ZEUS collaboration is completing its programme of charm measurements in DIS. The final results from D^+ and D^{*+} are among the most precise available charm measurements in DIS. The analysis of charm jets will shortly be finalized; it will provide a complementary measurement with very different systematic uncertainty and improves the precision at large Q^2 and large charm p_T. The combination of these measurements with those from H1 and the previous ZEUS data should provide the ultimate measurement of the charm reduced cross section at HERA and provide a stringent test for the heavy flavour calculations.

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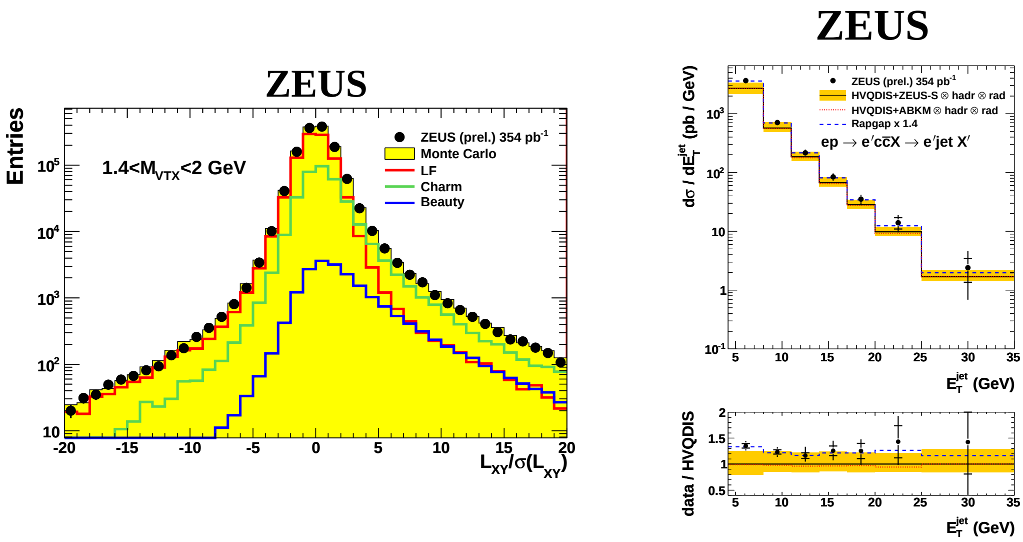

Figure 5: Left:distribution of the transverse lifetime significance for vertices associated to jets, showing the data (points) and the light flavour (LF), charm and beauty components. Right: charm jet cross section as a function of the jet E_T compared to NLO QCD calculation (HVQDIS) with two different PDF sets.

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