"$D^{*\pm}(2010)$ IN DIFFRACTION AND WITH A LEADING NEUTRON"

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The ZEUS measurements of $D^{*\pm}(2010)$ meson production in diffractive DIS and associated with a leading neutron in photoproduction regime are compared with predictions of different models.

1 Introduction

The diffractive process at HERA, characterized by a large rapidity gap in the distribution of the final-state hadrons, is considered to proceed via the exchange of an object carrying the quantum numbers of the vacuum, known as the Pomeron ($I\!P$). In the resolved-Pomeron model [1], the exchanged Pomeron acts as a source of partons, one of which interacts with the virtual photon. Measurements of inclusive diffractive Deep Inelastic Scattering (DIS) at HERA have been used to extract the diffractive parton distributions (diffractive pdfs) of the proton. A combined fit of the Pomeron parton densities to the H1 and ZEUS inclusive diffractive DIS measurements and to the ZEUS data on diffractive dijet photoproduction has been made by Alvero et al. (ACTW) [2]. The fit results have been interfaced to the program HVQDIS [3] to calculate cross sections for diffractive charm production in DIS [4], both to leading and next-to-leading order (NLO) in QCD. If QCD factorisation [16] holds in diffractive DIS, these diffractive pdfs are universal and may be used to predict the cross sections for exclusive hard diffractive DIS process such as heavy flavour production.

In an alternative view, the diffractive process at HERA can be described by the dissociation of the virtual photon into a $q\bar{q}$ or $q\bar{q}g$ state which interacts with the proton by the exchange of two gluons or, more generally, a gluon ladder with the quantum numbers of the vacuum [5,6,7]. In the "saturation" model [8,9], the calculation of the $q\bar{q}g$ cross section is performed under the assumption of strong k_T ordering of the final-state partons, which corresponds to $k_T^{(g)} \ll k_T^{(q,\bar{q})}$. Alternatively, in the model of Bartels et al. [6,10,11], configurations without strong k_T ordering are included in the $q\bar{q}g$ cross-section calculation and the minimum value for the final-state-gluon transverse momentum, $k_{T,g}^{\mathrm{cut}}$, is a free parameter. The sum of the $q\bar{q}$ and $q\bar{q}g$ contributions in the saturation model and the model of Bartels et al. are hereafter referred to as SATRAP and BJLW, respectively.

Events containing a leading neutron have been studied in ep collisions at HERA [12,13,14,15]. The neutrons carry a large fraction of the incoming proton beam energy, $x_L > 0.2$, and are produced at very small scattering angles, $\theta_n < 0.8$ mrad, indicative of a peripheral process. The mechanism for leading neutron production is not well understood. Particle-exchange models within Regge theory [16], in particular the one-pion-exchange model (OPE) [17,18,19], are often applied to describe leading neutron production.

Charm production in diffractive DIS, which has been measured by the H1 and ZEUS collaborations [20,21,22], and in reactions associated with a leading neutron in photoproduction [23] allow quantitative tests of the models due to the sensitivity of charm production to gluon-initiated processes. Final states containing heavy quarks are of particular interest, since the additional hard scale ensures the applicability of perturbative QCD.

2 Diffractive D^* in DIS

The ZEUS Collaboration has measured charm production in diffractive DIS [21]. The process studied in the paper was $ep \to eXp \to e(D^{*\pm}X')p$, in which the system X includes at least one $D^{*\pm}(2010)$ meson. The latter was reconstructed using the mass-difference method [24] in the decay channel $D^{*+} \to D^0\pi_s^+$ followed by $D^0 \to K^-\pi^+(+c.c.)$, where π_s indicates the "slow" pion.

Figure 1 shows the differential cross sections measured in the kinematic range $1.5 < Q^2 < 200$ GeV^2, $0.02 < y < 0.7$, $\beta < 0.8$, $p_T(D^*) > 1.5$ GeV and $|\eta(D^*)| < 1.5$ as functions of β, $\log(\beta)$, $\log(Q^2)$ and W for $x_{I\!P} < 0.035$ and as functions of $p_T(D^*)$, $\eta(D^*)$, $\log(M_X^2)$ and β for $x_{I\!P} < 0.01$. The data are compared with the ACTW NLO predictions, calculated with the gluon-dominated fit B, the SATRAP predictions and the BJLW predictions (only for $x_{I\!P} < 0.01$).

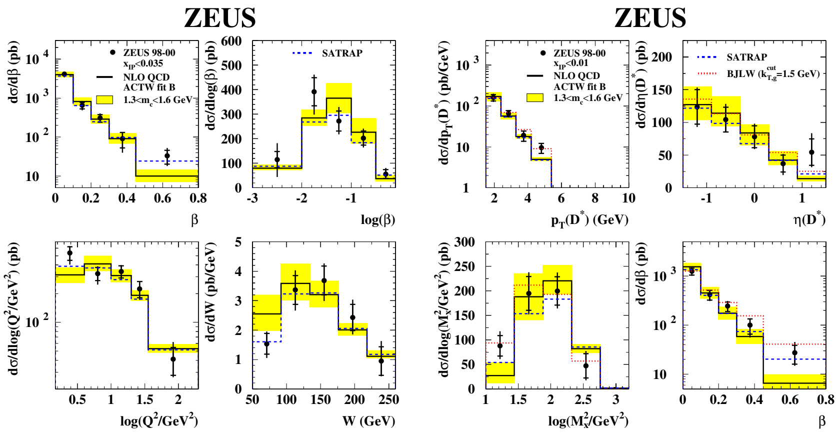

Figure 1. Differential cross sections for diffractive D^* production (dots) compared with different models (see text). The inner error bars indicate the statistical uncertainties, while the outer ones correspond to the statistical and systematic uncertainties added in quadrature. The shaded area shows the effect of varying the charm-quark mass in the ACTW NLO prediction.

The BJLW model predictions, obtained with the requirement that value $k_{T,g}^{\rm cut} = 1.5$ GeV, describe the differential cross sections in the range $x_{I\!P} < 0.01$ both in shape and normalisation. The SATRAP predictions reproduce the shapes and the normalisations of the differential cross sections measured in both $x_{I\!P}$ ranges. The ACTW NLO predictions, obtained with the gluon-dominated fit B, describe the data reasonably well in both $x_{I\!P}$ ranges.

Fig. 2 shows the quantity $x_{I\!P} F_2^{D(3),c\bar{c}}$ measured by the ZEUS Collaboration [21] where $F_2^{D(3),c\bar{c}}$ is the open-charm contribution to the diffractive proton structure function. It is shown as a function of $\log(\beta)$ for different values of Q^2 and $x_{I\!P}$. In all cases, $x_{I\!P} F_2^{D(3),c\bar{c}}$ rises as β decreases. The curves show the predictions obtained from the ACTW NLO calculations based on gluon-dominated fits B, D and SG [2]. The fit B prediction generally agrees with the data. The fit D (SG) prediction overestimates (underestimates) the measured $x_{I\!P} F_2^{D(3),c\bar{c}}$ at low β.

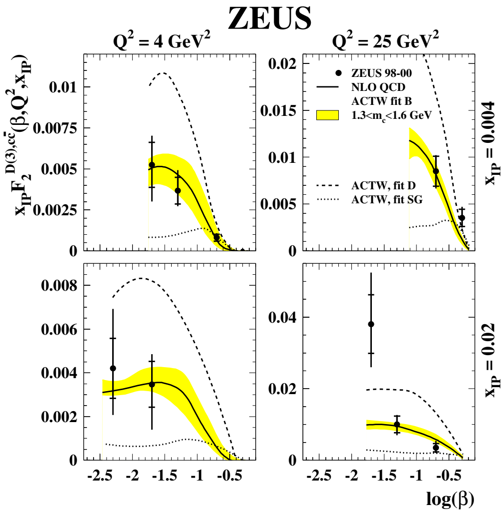

Figure 2. The measured charm contribution to the diffractive structure function of the proton multiplied by $x_{I\!P}$, $x_{I\!P} F_2^{D(3),c\bar{c}}$, as a function of β for different values of Q^2 and $x_{I\!P}$ (dots). The inner error bars indicate the statistical uncertainties, while the outer ones correspond to the statistical and systematic uncertainties added in quadrature. The shaded area shows the effect of varying the charm-quark mass in the ACTW NLO prediction.

3 Photoproduction of $D^{*\pm}$ mesons associated with a leading neutron

The photoproduction of $D^{*\pm}$ mesons associated with a leading neutron has been measured in ep interactions at HERA by the ZEUS Collaboration in the kinematic region $Q^2 < 1$ GeV^2, $130 < W < 280$ GeV, $|\eta(D^*)| < 1.5$, $p_T(D^*) > 1.9$ GeV, $\theta_n < 0.8$ mrad and $x_L > 0.2$ [23]. The measured differential cross section as a function of x_L is shown in Fig. 3 and compared to the predictions, normalised to the data, of the MC models RAPGAP with OPE for leading-neutron production, HERWIG, PYTHIA and inclusive RAPGAP. Fig. 3a shows that only RAPGAP with OPE describes the measured neutron energy distribution seen in the data.

Figure 3b shows the differential cross section in x_L compared to the predicted cross sections from RAPGAP with OPE, based on different parametrizations for the pion structure function: GRV set 1 and Owens sets 1 and 2 [25]. The data have little sensitivity to the choice of the pion structure function. Even with an extreme choice of a pion structure function, e.g. a completely flat gluon distribution, or a parametrization identical to the proton structure function, little variation is seen in the predictions.

Figure 3c shows the data compared to the predictions from RAPGAP with OPE for four different pion flux factor parametrisations: f_1, the light-cone form-factor [26]; f_2, form-factor equal to one [19]; f_3, the exponential form factor [27] and f_4, the monopole form factor [28]. All RAPGAP distributions are normalized to the data and the resulting normalization factors are given in the figure. Fluxes f_1 and f_3 give similar results, being compatible with the data both in shape and normalization. Fluxes f_2 and f_4 are disfavored by the data.

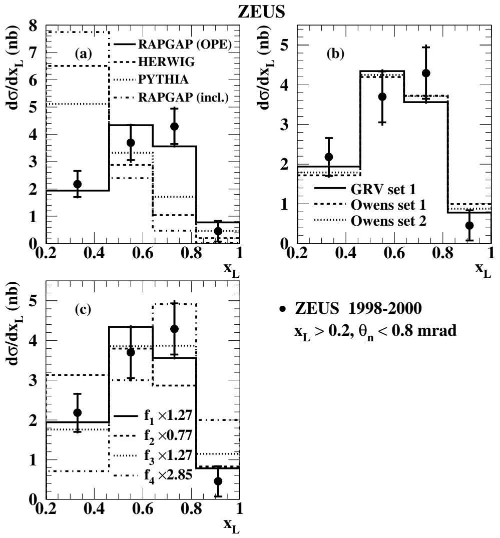

Figure 3. The points show the differential cross sections for neutron-tagged D^* production as a function of x_L. The histograms show the predictions of different models (see text). The error bars displayed on the plots denote the statistical uncertainty (inner) and the quadratic sum of the statistical and the systematic uncertainties (outer). All distributions are normalized to the data. The numbers in (c) are the normalisation factors.

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