# Diffractive $D^{*\pm}$ Meson Production in Deep-Inelastic Scattering at HERA

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**Abstract.** A new measurement is presented of $D^{*\pm}$ meson production in deep-inelastic scattering at HERA. Cross sections are measured for the process $ep \to eXY$, where the system $X$ contains at least one $D^{*\pm}$ meson and is separated by a large rapidity gap from a low mass proton remnant system $Y$. The cross sections are measured in the kinematic region $2 < Q^2 < 100$ GeV$^2$, $0.05 < y < 0.7$, $x_{I\!P} < 0.04$, $M_Y < 1.6$ GeV and $|t| < 1$ GeV$^2$. The $D^{*\pm}$ mesons are restricted to the range $p_T(D^*) > 2$ GeV and $|\eta(D^*)| < 1.5$. The data are compared with NLO QCD calculations using recent H1 diffractive PDFs as well as with a model of two gluon exchange.

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## INTRODUCTION

This paper presents a new measurement of diffractive $D^{*\pm}$ production in deep inelastic scattering at HERA. This process is characterised by two distinct hadronic systems $X$ and $Y$ separated by a large rapidity gap. The system $X$ contains at least one $D^{*\pm}$ meson. The system $Y$ consists of the elastically scattered proton or a low mass diffractive state. In addition to the hard scale from the large photon virtuality, the hard scale from the charm mass means diffractive charm production is an interesting process to test different perturbative QCD approaches to diffraction. More details of this analysis can be found in [1].

Hard diffractive processes may be described theoretically using the collinear factorisation or perturbative two gluon approaches. The collinear approach [2] uses diffractive parton densities obtained from next-to-leading order (NLO) fits to the reduced diffractive cross section. Charm production then proceedes dominantly via the Boson Gluon Fusion process, where the factorisation theorem states that the hard scattering matrix elements are the same as for inclusive heavy flavour production. Hence diffractive charm production is directly sensitive to the diffractive gluon density, which is only indirectly constrained in inclusive diffraction through scaling violations. The pertubative two gluon approach [3] uses non-diffractive un-integrated gluon densities of the proton to combine two gluons into a colourless exchange. This exchange can then couple directly to a $c\bar{c}$ pair ($\gamma^* p \to c\bar{c}\ p$) or to a $c\bar{c}g$ system ($\gamma^* p \to c\bar{c}g\ p$).

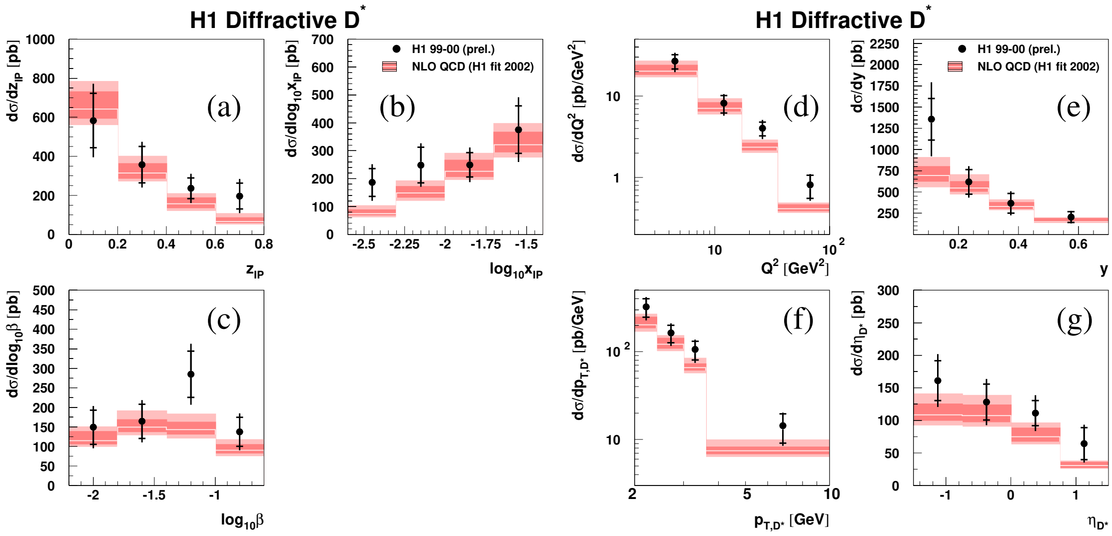


**FIGURE 1.** Differential cross sections for $D^{*\pm}$ meson production in diffractive DIS as a function of (a) $z_{\mathbb{P}}$, (b) $x_{\mathbb{P}}$, (c) $\beta$, (d) $Q^2$, (e) $y$, (f) $p_T(D^*)$ and (g) $\eta(D^*)$. The inner error bars show the statistical error and the outer error bars the total error. The data are compared to a NLO QCD prediction from the diffractive version of HVQDIS using NLO diffractive PDFs. The inner error band represents the renormalisation scale uncertainty and the outer error band the total uncertainty.

## EVENT SELECTION AND KINEMATIC RECONSTRUCTION

This analysis is based on an integrated luminosity of 42.6 pb$^{-1}$ collected in the years 1999 and 2000 by the H1 detector [4], from collisions of 27.5 GeV positrons with 920 GeV protons at HERA. DIS events are selected in the kinematic range $2 < Q^2 < 100$ GeV$^2$ and $0.05 < y < 0.7$. Diffractive events are selected by requiring no activity above noise thresholds in the forward detectors, thus limiting the $X$ system to $\eta_{max} < 3.2$. Monte Carlo simulations are then used to correct to the range of the proton remnant system mass $M_Y < 1.6$ GeV and the squared four-momentum transfer at the proton vertex to $|t| < 1$ GeV$^2$. The kinematic range is restricted to $x_{\mathbb{P}} < 0.04$ to supress contributions from non-diffractive scattering and secondary reggeon exchanges. Further diffractive kinematic quantites are $\beta$, the fractional longitudinal momentum of the colourless exchange carried by the struck quark, and $z_{\mathbb{P}}$, the fraction of of the colour singlet exchange that enters the hard scattering.

The $D^{*\pm}$ mesons are reconstructed through the decay channel $D^{*+} \to D^0\pi^+_{slow} \to (K^-\pi^+)\pi^+_{slow}(+c.c.)$, with the decay products within the CTD acceptence ($20^\circ < \theta < 160^\circ$) and with transverse momentum $p_T$ of at least 120 MeV for the $\pi_{slow}$, 300 MeV for the other pion and 500 MeV for the $K$ meson. The invariant mass of the $K\pi$ combination must be within $\pm 80$ MeV of the $D^0$ mass. Additionally the $D^{*\pm}$ must be in the pseudorapidity range $|\eta(D^{*\pm})| < 1.5$ and have a transverse momentum $p_T(D^{*\pm}) > 2$ GeV. The number of reconstructed $D^{*\pm}$ mesons is determined by fitting the mass difference $\Delta M = M(K^{\mp}\pi^{\pm}\pi^{\pm}_{slow}) - M(K^{\mp}\pi^{\pm})$ for all selected events and track combinations. A total of $140 \pm 16$ diffractive $D^{*\pm}$ mesons are found.

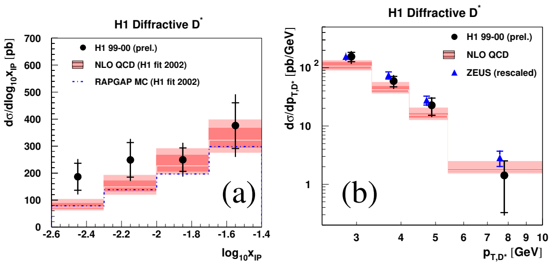


**FIGURE 2.** Differential cross sections for $D^{*\pm}$ meson production in diffractive DIS as a function of (a) $x_{I\!P}$ and $p_T(D^*)$. The data are compared to a NLO QCD prediction (see Fig.1). In (a) the data are also compared to the LO hadron level from RAPGAP (dot-dashed curve). In (b) the data are compared to the measurement from ZEUS (see text).

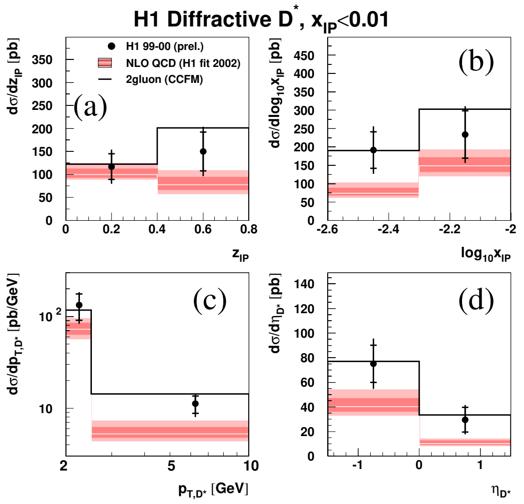


**FIGURE 3.** Differential cross sections for $D^{*\pm}$ meson production in diffractive DIS, in the kinematic region $x_{I\!P} < 0.01$, as a function of (a) $z_{I\!P}$, (b) $x_{I\!P}$ (c) $p_T(D^*)$ and (d) $\eta(D^*)$. The data are compared to predictions from NLO QCD (see Fig.1) and from the perturbative two gluon approach of BJKLW.

## RESULTS AND COMPARISONS WITH CALCULATIONS

The differential cross sections are obtained from fits to the $\Delta M$ distribution in each kinematic bin. The data are then corrected for detector effects using the RAPGAP Monte Carlo generator [5], using diffractive parton densities. The visible cross sections are measured in the kinematic region $2 < Q^2 < 100$ GeV$^2$, $0.05 < y < 0.7$, $x_{I\!P} < 0.04$, $M_Y < 1.6$ GeV$^2$, $|t| < 1$ GeV$^2$, $p_T(D^*) > 2$ GeV and $|\eta(D^*)| < 1.5$.

The diffractive $D^{*\pm}$ cross sections are compared to two models based on NLO (LO) diffractive parton distributions from H1 [6]. For all models the charm mass was set to $m_c = 1.5$ GeV, $\Lambda_{QCD} = 0.2$ and the number of quarks set to $N_f = 4$. For the NLO calculation the diffractive version of the HVQDIS [7, 8] program with NLO diffractive parton densities (PDFs) was used. The renormalisation, $\mu_r$, and fragmentation, $\mu_f$, scales were set to $\mu_f^2 = \mu_r^2 = Q^2 + 4m_c^2$ and the Peterson fragmentation function was set to $\varepsilon = 0.078$. Uncertainties were evaluated by varying $\mu_r$ by factors of $1/4$ and 4, $m_c$ within 1.35-1.65 GeV and $\varepsilon$ between 0.035 and 0.1. For the LO calculation $O(\alpha_s)$ matrix elements and LO diffractive PDFs [6] were used in the RAPGAP Monte Carlo event generator. The $D^*$ meson was fragmented using the Lund string model [9] and $\mu_f$ and $\mu_r$ were set to $\mu_f^2 = \mu_r^2 = Q^2 + p_T^2 + 4m_c^2$. The data are also compared to a prediction from the perturbative two gluon approach 'BJKLW' [3, 10, 11] using unintegrated inclusive gluon PDFs [12] evolved using the CCFM evolution equations. The comparison is made only for small $x_{I\!P} < 0.01$, so quark exchange may be neglected, and with a cut on the gluon $p_T$ in the $c\bar{c}g$ system of $p_T > 1.5$ GeV, to ensure perturbative QCD is applicable.

Figure 1 shows the diffractive $D^{*\pm}$ cross sections differentially as a function of $z_{I\!P}$, $x_{I\!P}$, $\beta$, $Q^2$, $y$, $p_T(D^*)$ and $\eta(D^*)$. The differential cross sections are reproduced within the errors by the NLO HVQDIS calculation. Figure 2 (a) shows the differential $x_{I\!P}$ cross section again, compared to the predictions from the NLO HVQDIS calculation and to the LO calculation as implemented in RAPGAP. The prediction from RAPGAP is in agreement with the full NLO calculation. Figure 2 (b) shows the differential $p_T(D^*)$ cross section, compared to the measurement from the ZEUS [13] collaboration, rescaled to the phase space of this measurement using RAPGAP and with an additional 10% correction for different $M_Y$ ranges. Both measurements are in good agreement. The description of the shapes of the differential cross sections by the LO and NLO calculations supports the validity of hard scattering factorisation.

Figure 3 shows the diffractive $D^{*\pm}$ cross sections for $x_{I\!P} < 0.01$ differentially as a function of $z_{I\!P}$, $x_{I\!P}$, $p_T(D^*)$ and $\eta(D^*)$ compared to both the NLO HVQDIS calculation and the prediction from the perturbative two gluon calculation of BJKLW. The NLO HVQDIS calculation falls below the data in all differential bins, however is still able to describe the data within errors. The data are also described in all differential bins by the two gluon prediction.

## SUMMARY

A new measurement of diffractive $D^{*\pm}$ production in DIS at HERA has been presented, based on an integrated luminosity of 42.6pb$^{-1}$. Cross sections have been measured differentially as a function of various kinematic variables. LO and NLO QCD calculations using the colinear factorisation approach with diffractive PDFs are able to describe the shapes of the differential cross sections within errors. This agreement supports the validity of hard scattering factorisation. In the range $x_{I\!P} < 0.01$, the data are described by both a prediction from the perturbative two gluon model and the NLO colinear factorisation prediction for all differential cross sections.

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