Photoproduction of D^* Mesons at HERA

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A measurement of cross sections for $D^{*\pm}$ meson photoproduction at HERA is presented. The measurement uses data taken with the H1 detector during the years 1999 to 2000. The cross sections are determined in the kinematic region $171 < W < 256$ GeV, $Q^2 < 0.01$ GeV^2, $p_t(D^*) > 2.5$ GeV and $|\eta(D^*)| < 1.5$, where W is the photon-proton centre of mass energy and Q^2 is the photon virtuality. In addition to the total cross section, the data are presented as a function of $p_t(D^*)$, $\eta(D^*)$ and W. The results are compared to QCD predictions.

1 Introduction

In electron proton interactions heavy quarks are produced predominantly in photon gluon fusion processes, where a photon emitted by the incoming electron interacts with a gluon in the proton forming a quark antiquark pair. The cross section is dominated by processes where the virtuality Q^2 of the exchanged photon is very small. As the heavy quark mass provides a hard scale, heavy quark photoproduction is a good testing ground for QCD calculations.

Charm quark photoproduction has previously been studied at HERA [1, 2]. In this paper differential cross sections for D^* photoproduction obtained from a larger data set are presented. The results are compared with several leading and next-to-leading order QCD calculations.

2 Cross Sections

The analysis was performed with data taken in 1999 and 2000, when HERA collided positrons[1] with energy $E_e = 27.5$ GeV and protons with $E_p = 920$ GeV. The data set corresponds to an integrated luminosity of 49.2 pb^{-1}.

[1] Positrons are generally referred to as electrons in the following.

Photoproduction events are selected by detection of the scattered electron in an electron tagger close to the beam line 33 m away from the interaction point. The small scattering angle leads to a photon virtuality $Q^2 < 0.01$ GeV^2. The acceptance of the tagger is restricted to $171 < W < 256$ GeV.

The D^* meson is reconstructed via the decay channel[2] $D^{*+} \to D^0\pi_s^+ \to K^-\pi^+\pi_s^+$. In each event, tracks with opposite charges are combined in pairs, one assigned the pion, one the kaon mass. If the kaon (pion) assigned track fulfills $p_t(K) > 0.5$ GeV ($p_t(\pi) > 0.3$ GeV), the invariant mass, $m(K\pi)$, is calculated. If the result is consistent with the D^0 mass, $|m(K\pi) - m(D^0)| < 80$ MeV, the remaining tracks with $p_t(\pi_s) > 0.12$ GeV and an opposite charge to that taken as a kaon are added to form a D^* candidate. It is required to satisfy $p_t(D^*) > 2.5$ GeV and $|\eta(D^*)| < 1.5$. The number of D^* mesons is determined by a fit of a gaussian signal and a three parameter background function, resulting in 1117 ± 76 D^* mesons.

Cross sections are presented for inclusive D^* production via the process $ep \to e' D^{*\pm} X$. They are corrected for the efficiency of the selection criteria and the triggering as well as the product of the branching ratios $D^{*+} \to D^0\pi_s^+$ and $D^0 \to K^-\pi^+$ ($2.57 \pm 0.06\%$ [3]). The total inclusive D^* production cross section in the kinematic range specified above amounts to $\sigma(D^*) = (4.74 \pm 0.32 \pm 0.64)$ nb. The first error represents the statistical, the second the systematic uncertainty. The differential cross sections $d\sigma/dp_t$, $d\sigma/d\eta$ and $d\sigma/dW$ are shown in figure 1. The H1 data are shown as points with error bars (inner: statistical, outer: statistical and systematic added in quadrature). A common normalisation uncertainty of 4.4% is not included.

3 Comparison with QCD Calculations

The data are compared with next-to-leading order (NLO) calculations in the "3-flavour massive" [4], the "4-flavour massless" [5] and the "matched" (FONLL) [6] scheme and with leading order Monte Carlo models, PYTHIA [7] and CASCADE [8]. The charm mass is always set to $m_c = 1.5$ GeV. The settings of the NLO calculations are detailed in the following table, where $m_t = \sqrt{m_c^2 + p_{t,c}^2}$ is the transverse mass and $f(c \to D^{*+})$ means the fraction of c-quarks hadronising as D^{*+}-mesons:

[2] Charge conjugate states are always implicitly included.

	3-flavour	4-flavour	FONLL
Fragmentation	Peterson [9], ($\epsilon = 0.035$)	BKK O[10]	Kartvelishvili [11]
Renor. scale μ_f	m_t	$2 \cdot m_t$	m_t
Fact. scale μ_r	$2 \cdot m_t$	$2 \cdot m_t$	m_t
Proton density	CTEQ5D	CTEQ6M	CTEQ5M
Photon density	GRV-G	AFG	GRV-G
$f(c \to D^{*+})$	0.235		0.235

To estimate the uncertainty of the calculation, μ_r has been varied by a factor 0.5 (2.0) as an upper (lower) limit for the cross section in the "3-flavour massive" and the FONLL scheme. For "4-flavour massless" both μ_r and μ_f have been varied independently by 0.5 and 2.0 and the maximal (minimal) value is taken as upper (lower) limit. The "3-flavour massive" calculation provides a prediction of the total cross section in the visible range, $\sigma(D^*) = \left(3.06^{+1.01}_{-0.57}\right)$ nb, which lies slightly below the measured value, but is compatible with the data within errors for the extreme value of μ_r.

Figure 1a) and g) compare the $d\sigma/dp_t$-calculations of all three NLO schemes to the data. The "3-flavour massive" prediction lies below the data in the low p_t region, where FONLL is closer to the data and "4-flavour massless" fits best. The $d\sigma/d\eta$-calculations for "3-flavour massive" and "4-flavour massless" are shown in figure 1b). Neither calculation can describe the shape of the measured cross section, which shows an enhancement compared with the theory in the forward direction. Both NLO predictions for $d\sigma/dW$ in figure 1c) can describe the shape of the data.

PYTHIA implements DGLAP evolution and contains contributions from both resolved and direct photon interactions. The resolved component is dominated by the charm excitation process. It is calculated from a matrix element with a massless charm quark originating in the photon. The CTEQ5L and GRV-G parametrisations are used for the proton and photon parton densities, respectively. CASCADE applies k_t-factorisation with off-mass-shell matrix elements supplemented with CCFM parton evolution. Both models have in common the Peterson fragmentation with $\epsilon = 0.078$.

The total cross section in the visible range, $\sigma(D^*)$, amounts to 5.9 nb for PYTHIA and 6.2 nb for CASCADE. Both lie slightly above the data. PYTHIA reasonably describes the shape of $d\sigma/dp_t$ while CASCADE is too hard

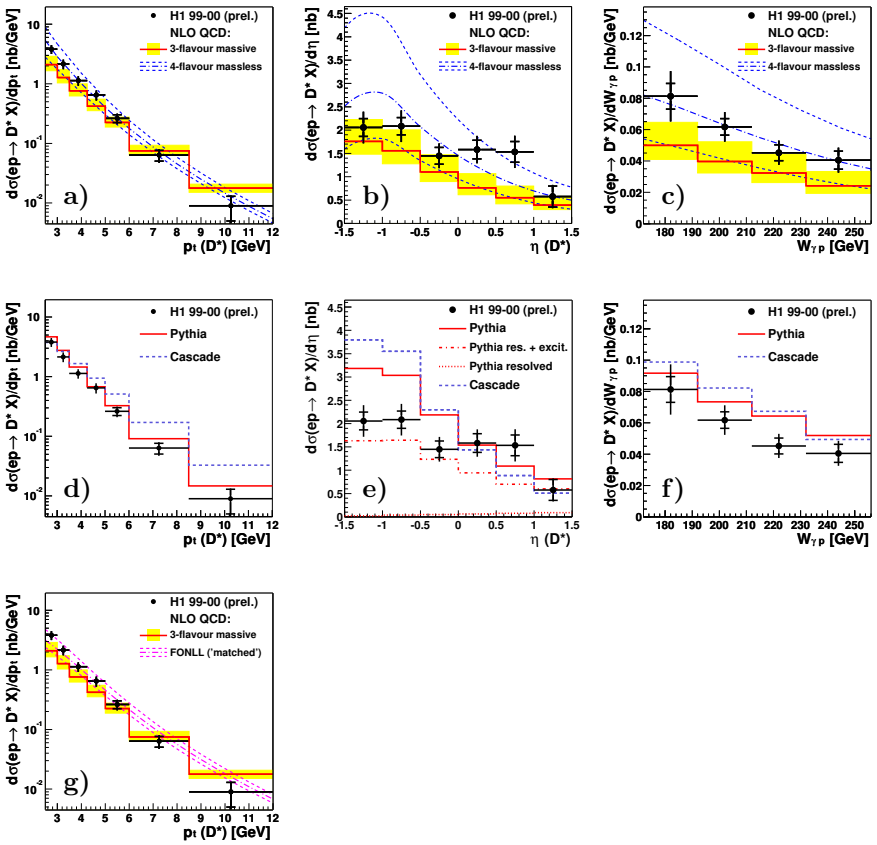

Figure 1: Differential D^*-photoproduction cross section $d\sigma/dp_t$, $d\sigma/d\eta$ and $d\sigma/dW$ compared to QCD predictions from different calculations. See text.

(figure 1d). Neither calculation can reproduce the shape of $d\sigma/d\eta$ (figure 1e). Therefore the PYTHIA prediction is split up into its different production mechanisms: direct, resolved with a light parton from the photon and charm excitation. The charm excitation process is dominant in the forward region ($\eta \approx 0.5$). However, changing normalisation of this sub-process does not lead to a better overall description. Both PYTHIA and CASCADE describe the shape of

$d\sigma/dW$ quite well within the uncertainties (figure 1f).

4 Summary

Cross sections for inclusive $D^{*\pm}$ photoproduction have been presented in the kinematic region $Q^2 < 0.01$ GeV^2, $171 < W < 256$ GeV, $p_t(D^*) > 2.5$ GeV and $|\eta(D^*)| < 1.5$ as a function of $p_t(D^*)$, $\eta(D^*)$ and W. They have been compared to NLO QCD calculations in the "3-flavour massive", in the "4-flavour massless" and – in the case of $d\sigma/dp_t$ – in the "matched" FONLL scheme as well as to two Monte Carlo models, PYTHIA and CASCADE.

The total cross section calculation lies below the data in the "3-flavour massive" NLO calculation and slightly above the data for both PYTHIA and CASCADE, which yields a p_t spectrum harder than measured. The same is true for the "3-flavour massive" NLO calculation which underestimates the low p_t region, while FONLL and "4-flavour massless" are closer to the data. None of the calculations is able to predict adequately the shape of $d\sigma/d\eta$, but the shape of $d\sigma/dW$ is described by all.

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