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Photoproduction of D^* Mesons in e-p Collisions at HERA

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Abstract

A measurement of the charm photoproduction cross section at $W_{\gamma p} \approx 100$ GeV is presented. It utilizes a new device for tagging scattered electrons at low y-values installed in the H1 detector at HERA in the winter 1994/1995. Charm production is identified through the reaction $D^\star \rightarrow K\pi\pi$. Applying the Weizsäcker Williams Approximation and extrapolating from the visible to the total kinematical range, the γp-cross section is measured to be $\sigma_{\gamma p \rightarrow c\bar{c}X} = (6.42 \pm 1.15_{stat} \pm^{1.08}_{0.91}{}_{syst} \pm 2.15_{theor})\,\mu b$ at a γ-p centre-of-mass energy $W_{\gamma p} = 95$ GeV for $Q^2 < 0.01$ GeV^2.

Adding to this new result the three previous measurements obtained in 1994 at higher $W_{\gamma p}$, a fit is performed to calculate the $W_{\gamma p}$-dependence of the γp-cross section for the particular choice of the form $\sigma = \sigma_0 \cdot W_{\gamma p}^{2\lambda}$. A slope parameter $\lambda = 0.61 \pm^{0.28}_{0.24}$ is determined, which can be compared to values seen in other processes.

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1 Introduction

The study of heavy quark production in lepton-proton scattering provides an important testing ground for the standard model [1]. At the electron-proton collider HERA with an $e-p$ centre-of-mass energy $\sqrt{s} = 300$ GeV, heavy quarks are produced predominantly by the *photon gluon fusion* process $\gamma g \rightarrow c\bar{c}$, where a photon emitted by the electron and a gluon from the proton generate a $c\bar{c}$ pair. The major contribution is due to the exchange of an almost real photon *(photoproduction)*, where the negative squared four-momentum transfer carried by the photon is $Q^2 \approx 0$. In photoproduction the kinematics of the process can be described by s, Q^2 and the scaling variable $y \approx 1 - E_e/E_{e'}$, where E_e and $E_{e'}$ denote the energies of the incoming and scattered electron, respectively. For $Q^2 \approx 0$ the $\gamma - p$ centre-of-mass energy is given by $W_{\gamma p}^2 = W^2 = y \cdot s$.

In a previous publication measurements of the charm photoproduction cross sections at $\gamma - p$ center of mass energies, $W_{\gamma p}$, of 142, 200 and 230 GeV are described [2]. In this paper a new measurement at a lower energy $W_{\gamma p} \approx 100\,GeV$ is presented. In combination with the published measurements the $W_{\gamma p}$ dependence of the cross section is investigated.

To enlargen the $W_{\gamma p}$ acceptance, a new electron calorimeter at $z = -44\,m$ (ET44) was installed in the winter shutdown 1994/1995. It is very similar in construction to the electron tagger at 33 m (ET33), which is part of the H1 luminosity system [3], and provides a means to detect, or tag, electrons scattered under very small angles, less than 3.5 mrad with respect to the beam axis. This corresponds to an upper limit in Q^2 of $0.01\,GeV^2$. The kinematical coverage of the ET44 in y extends from 0.04 up to 0.24. The analysis presented here is based on the 1995 data sample, which corresponds to an integrated luminosity of $L = (1.223 \pm 0.012) pb^{-1}$. A detailed description of the H1 detector, including the ET33 can be found elsewhere [4].

2 The γp-cross section

In order to measure charm production at $W_{\gamma p} \approx 100\,GeV$, events with a detected positron in the electron tagger at 44 m are selected. This selection determines the kinematically accepted y range to $0.04 < y < 0.24$. The integrated photon flux in this range, $Fl = 5.09 \cdot 10^{-2}$, was calculated [5] using the Weizsäcker Williams Approximation [6].

Events containing charm are selected through the reconstruction of the decay $D^{\star +} \rightarrow D^0 \pi_s^+$ with subsequently $D^0 \rightarrow K^- \pi^+$, (+ charged conjugate states). The analysis very closely follows the previous one [2], apart from a lower cut on the transverse momentum p_t of the D^* candidate of $p_t > 1.8$ GeV/c to increase the number of signal events, compared to the previous value of 2.5 GeV/c. The selection also is restricted to the central detector region by requesting a D^* rapidity of $-1.5 < \eta < 1.5$. The total number of $D^\star$ decays is obtained from a fit of the well known $\Delta m = m_{K\pi\pi} - m_{K\pi}$ distribution [7] of the $D^\star$ candidate decays for an 80 MeV/c^2 mass window around the $K\pi$ invariant mass (selecting D^0 decays), a $p_t(\pi_{slow}) > 120$ MeV/c and $p_t(\pi, K) > 350$ MeV/c. The background shape is estimated by means of wrong sign combinations, as described in [2]. Fig.1 shows the measured Δm-distribution for $D^\star$ candidates (points). Also shown are the wrong sign combinations (histogram) and the fit (solid line).

The cross section for the production of $D^\star$ mesons is determined in the visible kinematic region, defined by $p_t(D^\star) > 1.8\,GeV$, $|\eta(D^\star)| < 1.5$, $Q^2 < 0.01\ GeV^2$ and $0.04 < y < 0.24$, which corresponds to $60\,GeV < W_{\gamma p} < 147\,GeV$. It is given by

$$\sigma_{vis}(ep \rightarrow D^* X) = \frac{N(D^* \rightarrow K\pi\pi)_{measured}}{Br(D^* \rightarrow K\pi\pi) \cdot L \cdot \epsilon_{etag44} \cdot \epsilon_{rec}} \tag{1}$$

where :

- $N(D^* \to K\pi\pi)_{measured} = 56 \pm 10$: number of D^* candidates from the fit.
- $Br(D^* \to K\pi\pi) = 0.0262$: branching ratio [8]
- $\epsilon_{rec} = 0.5$: reconstruction efficiency for events with at least one D^* in the visible range
- $\epsilon_{etag44} = 0.6$: efficiency of the electron tagger ET44 within the accepted region; value 0.6 is averaged over given y-range.

Evaluating eq. 1 yields a charm production cross section of

$$\sigma_{vis}(ep \to D^\star X) = (30.55 \pm 5.46_{stat} \pm^{4.82}_{3.96\,syst})\ nb$$

in the visible range, The systematic error is dominated by the uncertainty on the number of $D^\star$ candidates ($\pm 9\%$) and on the $D^* \to K\pi\pi$ decay fraction.

The visible cross section is extrapolated to the full (p_t, η) range and converted to the γp charm cross section $\sigma(\gamma p \to c\bar{c}X)$ using the integrated photon flux as mentioned above, and assuming a constant γp cross section over the given y range.

The γp cross section thus is approximated by:

$$\sigma_{\gamma p}(\gamma p \to c\bar{c}X) = \frac{\sigma_{vis} \cdot EF \cdot Br(D^\star \to K\pi\pi)}{2 \cdot B_{DF}(c \to K\pi\pi) \cdot Fl}, \tag{2}$$

where EF is the extrapolation factor from the visible (p_t, η) range to the full range, and $B_{DF}(c \to K\pi\pi) = 0.0071$ [9] the total decay fraction. Inserting the numbers yields

$$\sigma(\gamma p \to c\bar{c}X) = (6.42 \pm 1.15_{stat} \pm^{1.08}_{0.91\,syst} \pm 2.15_{theor})\ \mu b$$

for $0.04 < y < 0.24$, corresponding to a mean value $\bar{y} = 0.1$ or a $\bar{W} = 95\,GeV$, and $Q^2 < 0.01$ GeV^2. Here the first (second) error denotes the statistical (systematic) error, respectively, and the third indicates the error resulting from theoretical uncertainties (30 % from m_c and 15 % due to the choice of proton structure functions). Figure 1 shows the γp cross section for various $W_{\gamma p}$-values as measured recently by the H1 and ZEUS collaborations using data at higher center of mass energies, and earlier results from several fixed target experiments at lower $W_{\gamma p}$-values. The measurements agree well with theoretical predictions based on NLO perturbative QCD calculations [10], using the parametrisations MRS-G [11] or MRS-H [12] for the proton structure function and GRV-G-HO [13] for the photon structure function. The lower and upper curve represent calculations, where the renormalisation scale was varied between $\mu_R = m_c/2$ and $\mu_R = 2m_c$. The NLO calculations with one single set of parameters can describe well the the shape of the $W_{\gamma p}$-dependence over the large range, although the absolute normalisation appears a bit low. Due to the large errors the measurements are not sensitive enough to unambiguosly distinguish different gluon densities. However the general trend of increasing cross section with $W_{\gamma p}$ is nicely confirmed.

3 The $W_{\gamma p}$ Dependence

The $W_{\gamma p}$ dependence of the γp-cross section at high $W_{\gamma p}$ may be parametrized ad hoc by the following Ansatz:

$$\sigma_{\gamma p}(y) = \sigma_0 \cdot W_{\gamma p}^{2\lambda} = \sigma_0 \cdot \left(\frac{s}{s_0}\right)^\lambda \cdot y^\lambda. \tag{3}$$

Using the H1 measurements at four different $W_{\gamma p}$ values, the slope parameter λ and the normalisation factor σ_0 are determined by a χ^2 minimisation procedure. To cover exactly the same kinematical regime the analysis of the 1995 data is repeated with identical cuts as applied in [2]. Table 1 gives a compilation of the various numbers. All the $y-independent$ parts of the efficiency and the acceptance are absorbed into the variable

$$x_i = \frac{N_{rec}^{D^\star}}{\epsilon \cdot L \cdot Br} \tag{4}$$

All y dependencies on the other hand are moved into the function

$$F_i(\sigma_0, \lambda) = \sigma_0 \cdot \left(\frac{s}{s_0}\right)^\lambda \cdot \int_{y_l^i}^{y_h^i} Fl_{\gamma/e}(y) \cdot \epsilon^i(y) \cdot y^\lambda \cdot dy.$$

Here the index i denotes the four different measurements, i= 1 (ET33), 2 (ET44), 3 (untagged sample at lower W (UT1)), 4 (untagged sample at higher W (UT2)) (see table 1). Here untagged refers to the measurements where the positron was not detected explicitely in a tagger or the main detector. To extract an estimator for (λ, σ_0) the function to be minimized, $\chi^2(\sigma_0, \lambda)$, is given by

$$\chi^2(\sigma_0, \lambda) = (\mathbf{x} - \mathbf{F}(\sigma_0, \lambda))^T \ \mathbf{M} \ (\mathbf{x} - \mathbf{F}(\sigma_0, \lambda)). \tag{5}$$

Here, $\mathbf{M}$ denotes the inverse of the covariance matrix, which includes the correlations between the four different measurements. For the minimisation, only statistical errors are included because all systematic errors except the one on the acceptance are 100 % correlated. To estimate the contribution of the latter, the x_i are varied by ± 1 standard deviation of the systematic error of the acceptance. The resulting difference in λ at the minimum of χ^2 is less than 6.5 %. This uncertainty has been added in quadrature to the error of λ. The result of the minimisation yields a value of $\lambda = 0.61 \pm^{0.28}_{0.24}$ at a normalisation value of $\sigma_0 = (\, 0.65 \pm^{7.05}_{0.615})$ nb. The value for λ is nearly independent on the value of the normalisation σ_0. The function $\sigma(W_{\gamma p})$ as defined in equation 3 is shown in fig.2 with this value of λ as the dotted line.

Within certain models such values of λ may be compared to W-dependencies seen in other processes. The total cross section of all hadron-hadron, gamma-hadron and gamma-gamma interactions is found to increase proportional $\sim s^{0.08} \sim (W^2)^\lambda$. In a previous publication [14] it was observed that the photoproduction cross section grows with $W^{2\lambda}$ with λ being proportional to $\log(p^2_{t,max})$. Here $p_{t,max}$ is the largest transverse momentum measured in the detector. If in charm photoproduction instead of $p^2_{t,max}$ the scale $m_c^2 + p^2_{t(c)}$ is considered, then a similar slope in both processes is observed.

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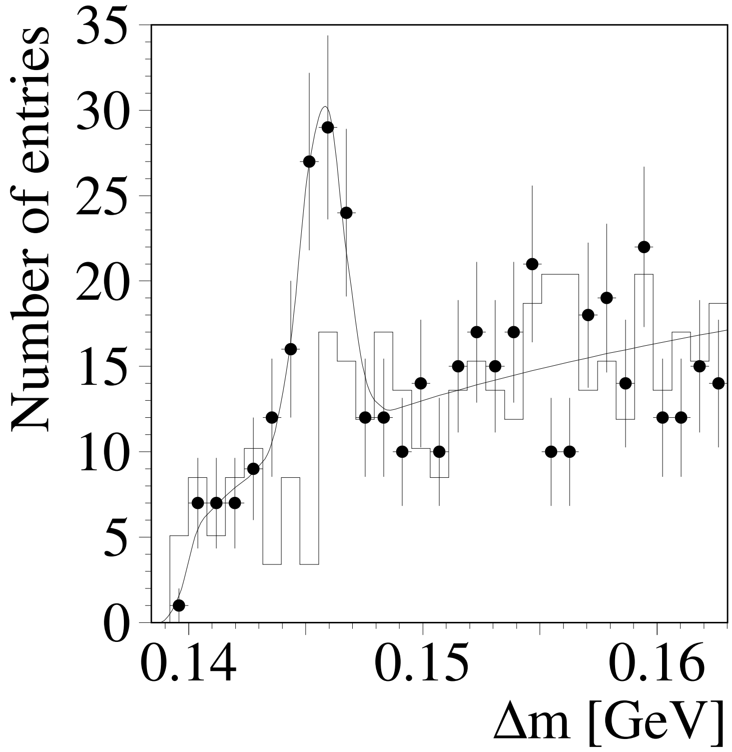

Figure 1: Δm *distribution, for events with a positron detected in the electron tagger at 44 m (solid dots). The solid line represents a fit (see text) to a signal and a wrong sign combinatorial background (solid histogram).*

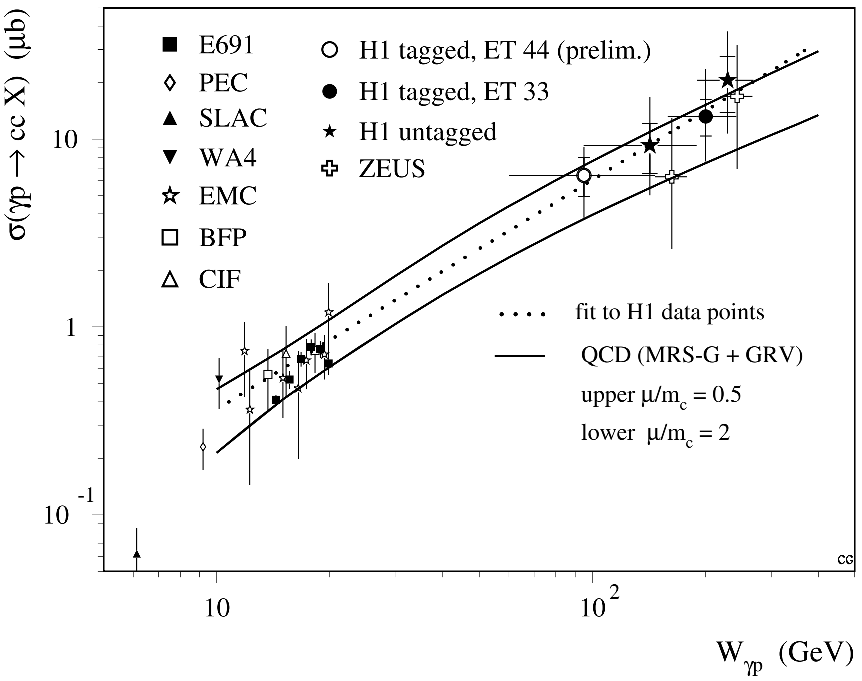

Figure 2: *The total γp cross section as a function of $W_{\gamma p}$. Shown are results from H1 and ZEUS in the higher W region and results from fixed target experiments covering the low W range. The dotted line represents the parametrisation as described in the text with a slope as obtained from the fit to the H1 data. The solid and dash-dotted lines indicate predictions of pQCD calculations assuming different scales and proton structure functions.*

Quantity	ET 44	ET 33	UT 1	UT 2
Range in y	$0.04 < y < 0.24$	$0.28 < y < 0.65$	$0.1 < y < 0.4$	$0.4 < y < 0.8$
Range in Q^2 $[GeV^2]$	< 0.006	< 0.01	< 4	< 4
$N_{rec}^{D^\star}$	21 ± 8	119 ± 16	46 ± 9	51 ± 12
ϵ, not y dependent	0.5	0.48	0.52	0.31
Luminosity $[pb^{-1}]$	1.223	2.77	1.29	1.29
mean Acceptance	0.11	0.6	0.21	0.56
Photon flux	0.0509	0.0141	0.0486	0.0155

Table 1: *Compilation of data necessary to calculate the visible ep and γp cross sections. The efficiency given in the table includes the trigger efficiency in the case of ET 33. For ET 44 the trigger efficiency is included in the number given for the luminosity. The numbers for $N_{rec}^{D^\star}$ have been obtained for the visible range: $-1.5 < \eta < 1.0$ and $p_t(D^\star) > 2.5\,GeV$, and are not corrected for the acceptances of the electron taggers. The value for acceptance is the average value.*