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

H1 Collaboration

Abstract

Preliminary results on the inclusive $D^{*\pm}$ production in deep inelastic ep scattering are presented for momentum transfers squared 2 GeV^2 $< Q^2 <$ 100 GeV^2 using the data collected by the H1 experiment at HERA in 1996. The differential $D^{*\pm}$ cross sections are found to agree well with the Next-to-Leading Order QCD predictions, both in shape and normalization. From this data the charm contribution $F_2^c\left(x, Q^2\right)$ to the proton structure function has been extracted.

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1 Introduction

First results on the charm contribution to the proton structure F_2^c in deep inelastic ep scattering (DIS) at HERA have been published on basis of the data taken in 1994 [1, 2]. In this paper preliminary results on inclusive D^{*+}[1] production in DIS and F_2^c in an extended kinematic range are presented using the data taken in 1996 at HERA by the H1 experiment.

2 Event Selection

The data collected with the H1 detector [3] at HERA during the 1996 running period have been used. HERA has been operated with 27.5 GeV positrons colliding with 820 GeV protons at a center of mass energy of $\sqrt{s} = 300$ GeV. The data amount to an integrated luminosity of $\mathcal{L}_{int} = 7.18$ pb^{-1}.

The analysis is restricted to events in which the scattered electron is detected and identified in the SpaCal [4], a lead-scintillating fibre spaghetti type calorimeter situated in the backward region of the H1 detector. The events were triggered by an electromagnetic cluster in the Spacal in coincidence with a charged track signal from the central drift chambers of the detector. The positron is identified to be the most energetic cluster of $E > 6$ GeV. Its cluster radius has to be less than 3.5 cm, consistent with an electro-magnetic energy deposition, and the position of the cluster has to match within 2.5 cm with a charged track segment in the backward drift chamber BDC [5], situated directlysee Katerinas answer in front of the SpaCal. The scattering angle of the electron is required to be $\Theta < 177°$ where Θ is defined with respect to the incoming proton direction.

These requirements restrict the accessible range of the negative four momentum squared of the photon to 2 GeV^2 $< Q^2 <$ 100 GeV^2 and the inelasticity to $0.05 < y < 0.7$. Here Q^2 and y are calculated from the scattered positron energy and angle.

$D^{*\pm}$ mesons are reconstructed using the decay

$$D^{*+} \rightarrow D^0\pi^+_{slow} \rightarrow (K^-\pi+)\pi^+_{slow}, \tag{1}$$

which has a branching ratio of 2.62% [6]. The decay products are detected in the central tracker. To ensure good detection efficiency, the tracks have to lie in the angular range of $20° < \Theta < 160°$. The combinatorial background is suppressed by requiring transverse momenta p_T of at least 300 MeV for K, π and 120 MeV for π_{slow}. Since no particle identification has been applied in the current analysis tracks fulfilling the quality requirements described in ref. [1] were considered as K and π candidates in turn. The invariant mass $m_{K\pi}$ of the $K\pi$ combinations is required to be consistent with the D^0 mass within $\pm$70 MeV/c^2. The combinatorial background is further suppressed by demanding $p_{T\ D^*} > 3$ GeV or $x_{D*} > 0.2$. Here x_{D*} is defined as $x_{D*} = 2 \cdot p^*_{D^*}/W$ where $p^*_{D^*}$ denotes the momentum of the D^* in the hadronic center of mass frame.

The distribution of the mass difference $\Delta m = m_{K\pi\pi} - m_{K\pi}$ is shown in fig. 1 for the $K\pi\pi$ combinations in the acceptance range $|\eta| < 1.5$ and $p_t > 1.5$ GeV. A distinct enhancement is visible around the nominal $D^{*+} - D^0$ mass difference of 145.4 MeV. No enhancement is observed in the Δm distribution for the $K\pi$ mass range 2.05 GeV$< m_{K\pi} <$ 2.3 GeV. The number of D^* mesons N_{D^*} is extracted from Likelihood fits to the Δm distributions with a function taken to be the superposition of a Gaussian for the signal and a term $N_B(m - m_\pi)^\alpha$ for the background. A total of 407 ± 28 D^{*+} mesons is observed.

[1]The charge conjugate is always implied.

3 Inclusive Cross Sections

The data are subsequently used to extract differential cross sections for the process $ep \to D^{*+}X$ in the visible range 2 GeV^2 $< Q^2 <$ 100 GeV^2, $0.05 < y < 0.7$, $|\eta_{D^*}| < 1.5$ and $p_{T\,D^*} > 1.5$ GeV.

The efficiency for the reconstruction, the selection cuts and the acceptance of the apparatus is evaluated from Monte Carlo simulations by using the leading order AROMA generator [7]. The generated events are fed into the H1 detector simulation program and are subjected to the same reconstruction and analysis chain asd the data. The observed differential distributions of the D^* mesons are acceptably reproduced.

In fig. 2 the inclusive differential D^{*+} cross sections are shown as a function of $p_{T\,D^*}$, η_{D^*}, W, x_{D^*}, x_{Bj}, and Q^2. The errors account for the statistical error (inner error bars) and the total error (outer error bars) obtained by adding the statistical and the systematic errors in quadrature. A bin by bin correction due to QED radiation has been applied using the HECTOR program [8]. It ammounts to 7% for the full kinematic range. The data is compared with the expectation from the NLO QCD calculations using the HVQDIS program [9] using the GRV 94 HO parton density parameterization [10]. The inclusive visible D^{*+} cross section is obtained in this calculation by convoluting the charm quark production cross section with the Peterson fragmentation function using $\epsilon = 0.078$(histograms). The uncertainties in the calculation due to a variation of the charm quark mass between 1.3 GeV and 1.7 GeV is indicated by the shaded area. This calculation is found to be in good agreement with the measured cross section. Slight excesses over the theoretical prediction are observed in the data for $\eta_{D*} > 0$ and $x_{D^*} < 0.2$ which are highly correlated. Taking into account the uncertainties due to model parameters not covered by the shaded area of the histograms, e.g. fragmentation, factorization and renormalization scale, in all distributions the significance of the current analysis the data is in agreement with the NLO calculations on the basis of the HVQDIS program with the precision achieved in the current analysis.

The systematic error includes all uncertainties due to analysis and detector effects as well as various sources of uncertainties due to the AROMA model used for the efficiency calculation. Being explicit, it covers the uncertainties in the determination of the signal events in each individual bin coming from the mass resolution, the shape of the combinatorial background as well as the contribution due to reflections in the D^0 mass window. Furthermore the errors on the knowledge of the trigger efficiency, the luminosity determination, the track reconstruction efficiency, and the energy and angular resolution of the scattered positron are included. The contribution of photoproduction events in the selected sample is estimated using Monte Carlo simulations and found to be negligible.

The raw data distribution of x_{D^*} shows a larger production rate of D^{*+} mesons for $x_{D^*} < 0.2$ compared to the expectation of the AROMA model. To account for this discrepancy the effect of removing the cut in x_{D^*} on the differential cross sections by properly reweighting the efficiency has been investigated and a separate systematic error is attributed to this effect. This is the dominant source of systematic error in all distributions except for $d\sigma/dx_{D^*}$.

The effect on the efficiency of the model parameters for D^* from charm production in the AROMA simulation, e.g. parton densities, charm quark mass and fragmentation [11], has been studied by different Monte Carlo simulations and has been included in the systematic error.

Finally, following the observation in photoproduction of a much higher cross section for beauty production than predicted by the LO Monte Carlo, for the systematic error estimate a beauty contribution of 5$\times$ the AROMA Monte Carlo expectation has been considered to our data sample [12]. The latter uncertainty has been added linearly to the systematic error.

4 Charm Contribution to the Proton Structure F_2^c

The charm contribution $F_2^c(x, Q^2)$ to the proton structure function is obtained by using the expression for the one photon exchange cross section for charm production

$$\frac{d^2\sigma^c}{dx dQ^2} = \frac{2\pi\alpha^2}{Q^4 x}\left(1 + (1-y)^2\right)\ F_2^c(x, Q^2)\ . \tag{2}$$

Since the NLO QCD calculation [13] predicts a contribution of F_L^c to the charm production cross section below 2% everywhere in the kinematic range of this analysis, the simplification $R = F_2/2xF_1 - 1 = 0$ is used.

The visible inclusive D^{*+} cross sections in bins of x and Q^2, $\sigma_{\rm vis}^{\rm exp}(x, Q^2)$ are converted to a bin center corrected $F^c_{2,exp}(\langle x\rangle, \langle Q^2\rangle)$ by the relation:

$$F_2^{c\ \rm exp}(\langle x\rangle, \langle Q^2\rangle) = \frac{\sigma_{\rm vis}^{\rm exp}(x, Q^2)}{\sigma_{\rm vis}^{\rm theo}(x, Q^2)} \cdot F_2^{c\ \rm theo}(\langle x\rangle, \langle Q^2\rangle)\ , \tag{3}$$

where the theoretical predictions for the inclusive cross section $\sigma_{\rm vis}^{\rm theo}$ and $F_2^{c\ \rm theo}$ are obtained from the HVQDIS program and the program of ref. [14], respectively.

In fig. 3 the charm contribution to the proton structure function F_2^c from this inclusive D^{*+} analysis is shown together with the results of the previous D^{*+} and D^0 analyses from H1. Due to the enlarged acceptance for the detection of the scattered positron with the new backward calorimeter the accessible kinematic range could be extended down to $Q^2 = 2.5$ GeV^2. Good agreement is observed between the two data sets in the region of overlap. For the current analysis statistical (inner error bars) and total errors (outer error bars) are shown separately, where the latter hasve been obtained by adding statistical and systematic errors in quadrature. The outermost asymmetric error shows the effect of a possible beauty contribution of five times the predicted LO cross section on reducing F_2^c.

Apart from the sources of systematic error included in the differential $\sigma(ep \to D^{*+}X)$ distributions, the changes of F_2^c due to a variation of m_c between 1.3 and 1.7 GeV, due to the scale, the parton density parameterization in the HVQDIS program and in the theoretical calculation of $F_2^{c\ \rm theo}$ have been considered. The effect of the hardness of the fragmentation on $\sigma_{\rm vis}^{\rm theo}$ has also been investigated. The dominant uncertainties contributing to the systematic error of F_2^c are due to the extrapolation in x_{D^*}, the track efficiency and the charm fragmentation.

Fig. 3 also includes the prediction for F_2^c from the determination of the gluon density from a NLO QCD fit to the H1 inclusive F_2 data. The band indicates the uncertainty in this extraction introduced by varying the charm quark mass between 1.3 GeV/c^2 and 1.7 GeV/c^2. This expectation is found to be in good agreement with the direct measurement of F_2^c. The same conclusion has been obtained from the direct determination of the gluon density based on the analysis of D^* production in DIS and photoproduction [15].

5 Conclusions

New results on differential inclusive D^{*+} cross sections and on the charm contribution to the proton structure F_2^c from the 1996 H1 data have been presented. The differential inclusive D^{*+} cross sections are found to be in reasonable agreement with the NLO expectation, both in shape and absolute value. The kinematic range of the measurement of F_2^c could be extended down to $Q^2 = 2.5$ GeV^2. Good agreement is observed with respect to our previous measurement as well as with the extraction of F_2^c from the NLO QCD fit to the H1 inclusive F_2 data.

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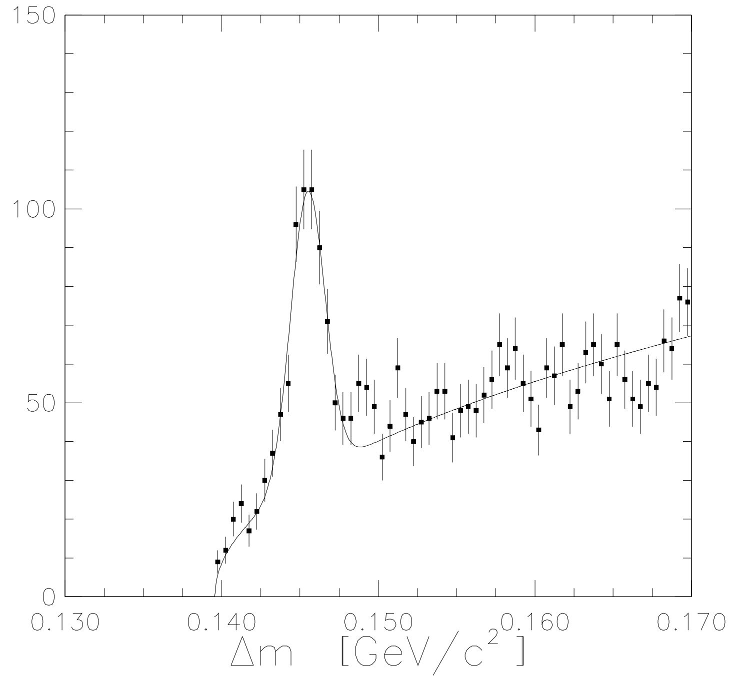

Figure 1: Distribution of the mass difference $\Delta m = m(K^-\pi^+\pi_s^+) - m(K^-\pi^+)$ for DIS events with D^* candidates. The data points are obtained from the $K^-\pi^+$ mass combinations fulfilling $|m(K^-\pi^+) - m_{D^0}| < 70$ MeV. The solid line represents the result of the fit described in the text.

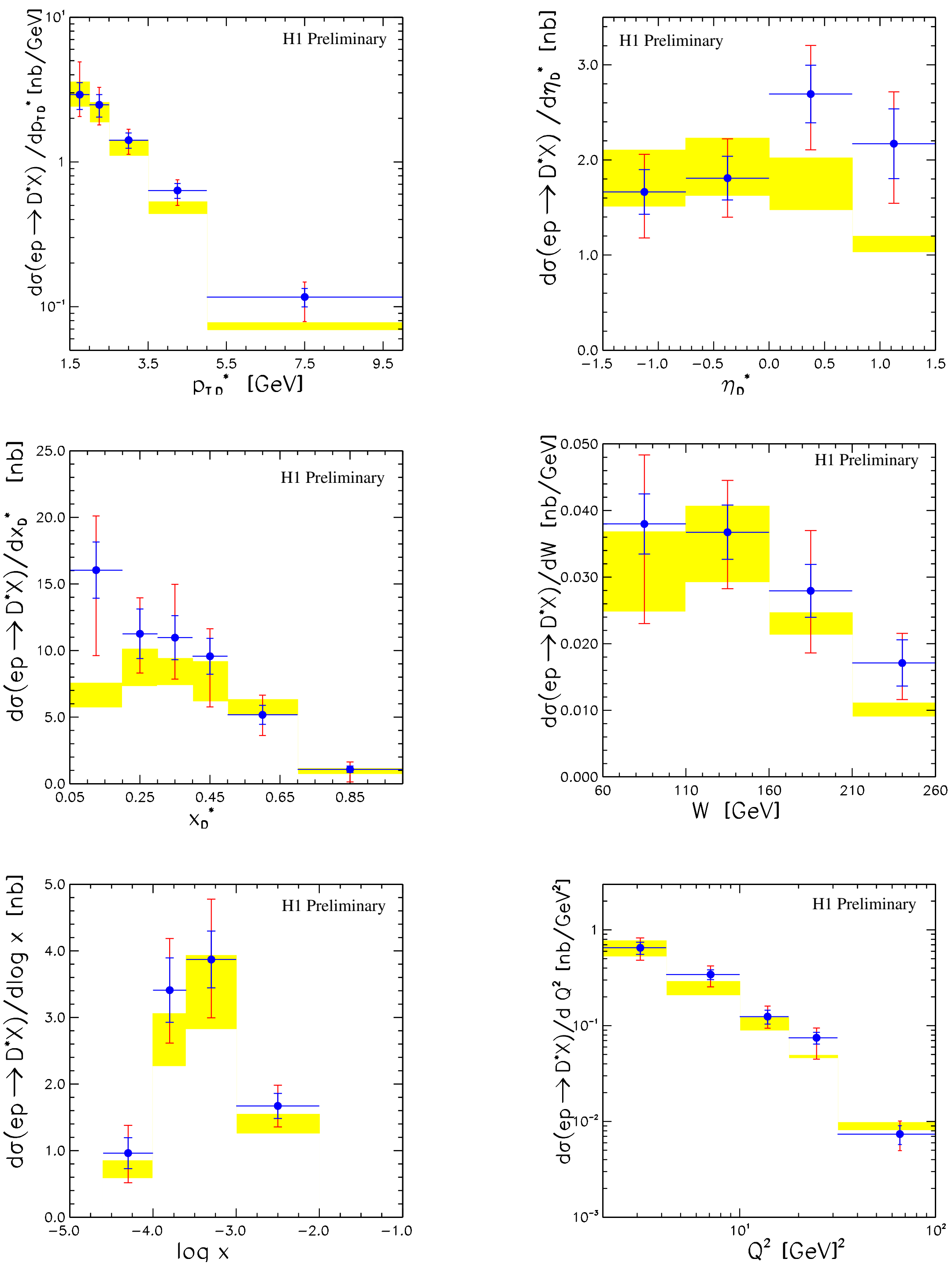

Figure 2: Differential inclusive cross section $\sigma(ep \rightarrow eD^{*+}X)$ versus $p_{T\ D^*}$, η_{D^*}, x_{D^*}, W, x_{Bj}, Q^2. The inner and outer error bars correspond to the statistical and the total error, respectively. The NLO QCD calculation using the HVQDIS program is also presented. The shaded band indicates the variation of the expected cross section due to a variation of m_c between 1.3 (upper bound) and 1.7 GeV/c^2(lower bound).

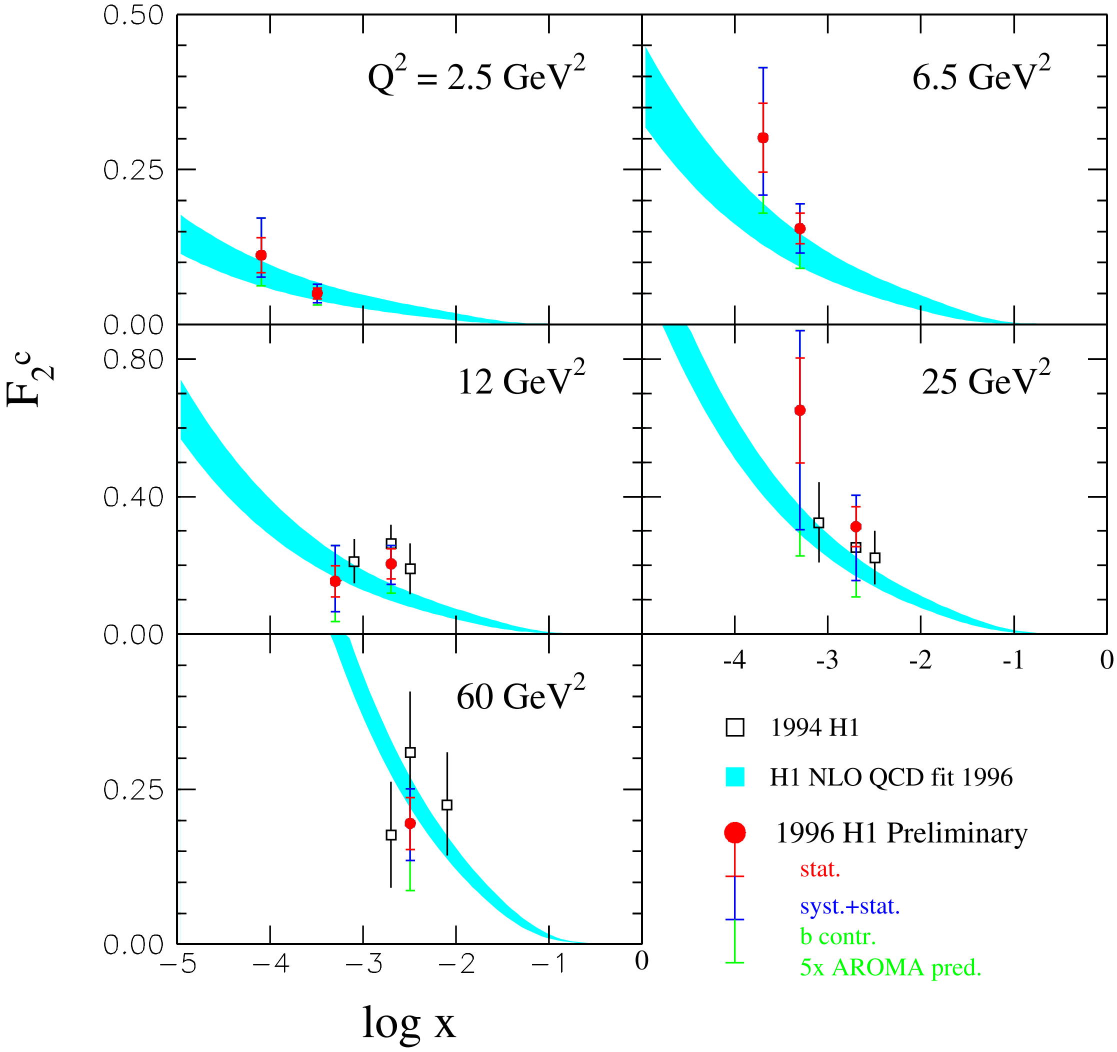

Figure 3: The charm contribution to the proton structure function F_2^c as derived from the inclusive D^{*+} meson analysis of the 96 data (full dots) in comparison with the results from the inclusive D^{*+} and D^0 meson analysis of the 94 data sample (open boxes). The error bars refer to the statistical and the total errors; the outermost lower error bar indicates the uncertainty introduced due to the uncertainty of the beauty contribution and is obtained as described in the text. The shaded band represents the predictions from the H1 NLO fit to the F_2 measurements.