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Measurement of the Production of $D^{*\pm}$ Mesons in Deep-Inelastic Diffractive Interactions at HERA

H1 Collaboration

Abstract

A measurement is presented of $D^{*\pm}$ meson production in diffractive interactions at HERA. The data correspond to an integrated luminosity of 20.8 pb^{-1}. Using the decay channel $D^{*+} \rightarrow D^0\ \pi^+_{slow} \rightarrow (K^-\ \pi^+)\ \pi^+_{slow}$, a cross section of 154 $\pm$ 40 (stat.) ± 35 (syst.) pb is measured in the kinematic range $2 < Q^2 < 100\ \mathrm{GeV}^2$, $0.05 < y < 0.7$, $x_{I\!P} < 0.04$, $M_Y < 1.6$ GeV, $|t| < 1\ \mathrm{GeV}^2$, $p_T(D^*) > 2$ GeV and $|\eta(D^*)| < 1.5$, where $x_{I\!P}$ is the fraction of the proton's momentum carried by the diffractive exchange, M_Y is the mass of the diffractively scattered proton-remnant system and η and p_T are measured in the H1 laboratory frame.

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1 Introduction

The first observations of $D^{*\pm}$ charmed meson production in deep-inelastic diffractive interactions at HERA have been reported [1]. In this paper, we present results based on approximately a factor 10 increase in luminosity on the previous H1 analysis, allowing a more accurate measurement over a wider kinematic range.

2 Event Selection

The data were collected using the H1 detector [2] over the three years 1995, 1996 and 1997, where HERA collided 27.6 GeV positrons with 820 GeV protons. After rejecting data when parts of the detector essential for the analysis were not operational, the integrated luminosity used is 20.8 pb^{-1}.

The analysis is restricted to events in which the scattered positron is detected and identified in the SpaCal [3], a lead – scintillating fibre spaghetti calorimeter situated in the backward region of the H1 detector [1]. 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 positrons are identified as clusters with energy $E_e > 9$ GeV, radius < 3.5 cm (consistent with electromagnetic energy deposition), and with the cluster matching within 2.5 cm to a charged track segment in the backward drift chamber BDC [4], located immediately in front of the SpaCal. The scattering angle of the electron was required to be $\theta < 177^o$. These requirements restrict the accessible range in Q^2, the negative of the four-momentum squared of the exchanged photon, and the inelasticity y, defined as $y = p \cdot q / p \cdot k$, where p, k and q are, respectively, the four-momenta of the incident proton, of the incident positron and of the exchanged photon. The kinematic region measured is thus $2 < Q^2 < 100~\mathrm{GeV}^2$ and $0.05 < y < 0.7$, where Q^2 and y are calculated from the scattered electron energy and angle.

As with measurements of the diffractive structure function $F_2^{D(3)}$ [5], the hadronic final state is separated into two distinct systems X and Y, respectively of mass M_X and M_Y, lying either side of the largest gap in rapidity between hadrons in the photon–proton centre of mass frame, the system Y being closest to the outgoing proton direction. Diffractive events are recognised by the absence of any signal in detectors situated in the forward part of the H1 apparatus, that have sensitivity at large pseudorapidities [2]. An event is rejected if it has more than one hit pair in the forward muon detector or a hit in any of the scintillators of the proton remnant tagger situated at $z = +24$ m. Additionally, the pseudorapidity of the most forward energy deposit with energy greater than 300 MeV in the H1 liquid argon calorimeter is required to be less than 3.3.

Although the scattered proton is not detected directly, the fact that no part of the system Y is detected in the forward detectors restricts $M_Y \lesssim 1.6$ GeV and $|t| \lesssim 1~\mathrm{GeV}^2$, t being the square of the four-momentum transfer to the system Y. The cross section measurement is corrected to these values. The fraction of the proton's momentum carried by the diffractive exchange, $x_{I\!P}$, is calculated using the formula $x_{I\!P} = (Q^2 + M_X^2)/(Q^2 + W^2)$, where W is the $\gamma^* p$ centre of mass energy. The mass M_X is reconstructed using combined track and calorimeter information whilst avoiding double counting [5], and W is reconstructed using the energy and angle of the scattered electron. The event sample is restricted to $x_{I\!P} < 0.04$.

[1] In the following, the polar z axis is taken along the beam direction, the $+z$ or "forward" direction being that of the outgoing proton beam.

[2] The pseudorapidity η of an object detected with polar angle θ is defined as $\eta = -\log\ \tan(\theta/2)$.

3 Reconstruction of $D^{*\pm}$ Mesons

The D^{*+} mesons are reconstructed using the decay channel

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

which has a branching ratio of 2.62% [6] (the charge conjugate is always implied).

The decay products are detected in the central tracker. To ensure good detection efficiency and to reduce the combinatorial background, the tracks are required to lie in the angular range $20^{\mathrm{o}} < \theta < 160^{\mathrm{o}}$ and to have a transverse momentum p_T, defined with respect to the beam axis, of at least 140 MeV (π_{slow}) and 250 MeV (K, π). To protect further against badly reconstructed tracks, each track is required to be at least 10 cm long in the projection perpendicular to the beam and to start in the inner section of the tracker.

The invariant mass of the $K\pi$ combination has to be consistent with the D^0 mass within ± 80 MeV. After cuts on the direction ($|\eta| < 1.5$) and transverse momentum ($p_T > 2$ GeV) of the $D^{*\pm}$, the mass difference distribution $\Delta M = M(K^-\pi^+\pi^+_{slow}) - M(K^-\pi^+)$ is plotted in fig 1.

The number of $D^{*\pm}$ candidates is determined by fitting the histogram in fig. 1 with a Gaussian distribution for the signal plus a background function $a(\Delta M - M_\pi)^b$, where M_π is the mass of the pion. The position of the Gaussian is fixed to a value taken from a higher statistics sample of events without the diffractive conditions [7]. The width and normalisation of the Gaussian and the background parameters a and b are allowed to vary. The number of D^* candidates detected is found to be $38 \pm 10\ (\mathrm{stat.}) \pm 4\ (\mathrm{syst.})$, where the systematic error is estimated by varying the details of the fit procedure.

4 Cross Section Calculation

Monte Carlo simulations are used to correct the data for the effects of losses and migrations. The acceptance is calculated by running the H1 detector simulation program on a sample of D^* events from the diffractive Monte Carlo generator RAPGAP [8], which is based on a partonic model of $e\mathbb{P}$ interactions. To study any dependence of the acceptance corrections on the underlying physics model of the simulation, the data are also corrected using a simulation based on a calculation of Bartels et al. [9]. This approach models diffractive charm production by the interaction of two gluons from the proton with an exclusive $c\bar{c}$ final state.

The trigger efficiency for diffractive events is obtained from the detector simulation, and is verified in the data using a larger sample of D^* candidates without the diffractive conditions. The loss of diffractive events due to noise fluctuations in the forward detectors is estimated directly from the data, using a sample of random read-outs of the detector, not correlated with a physics trigger.

A background to the selected sample of events arises from interactions with high $x_{\mathbb{P}}$ ($x_{\mathbb{P}} > 0.1$) or large M_Y ($M_Y > 5$ GeV) values. The contribution of this background is estimated using the heavy quark generator AROMA [10]. Another significant source of background is due to contributions to the signal of events with D^0 decay modes other than that defined in (1), with wrongly identified charged particles or lost neutral particles. Simulations using the AROMA Monte Carlo show that this background contributes ($7 \pm 4\%$) of the signal. The DIFFVM [11] generator, which contains both elastic and proton dissociation events, is used to obtain the correction to the measured region $M_Y < 1.6$ GeV. The contribution from photoproduction background is found to be negligible.

5 Systematic Errors

Systematic uncertainties in the cross section determination have been estimated by varying the measurement conditions, in particular using the Monte Carlo simulations.

- The largest systematic error is due to the uncertainties in the physics model for D^* production, used to compute the acceptance corrections. This error is 12%, as estimated from the difference in the cross sections calculated using the two different Monte Carlo generators introduced in section 4.
- An error of 10% is found for the uncertainty in the fitting procedure used to obtain the number of D^* mesons.
- The uncertainty in the reconstruction efficiency of the central tracker for the three tracks is estimated as 7%.
- The uncertainty in the trigger efficiency gives a contribution of 6% to the systematic error.
- The uncertainty in the measured energy and angle of the scattered electron leads to a systematic error of 6%.
- The uncertainty in the correction due to the smearing of events across the boundary $M_Y = 1.6$ GeV is estimated by varying in the DIFFVM simulation the efficiency of the proton remnant tagger and by varying between 0.5 and 2 the ratio of double to single dissociation. This contributes 6% to the error.
- The uncertainty in the fraction of events lost due to noise in the forward detectors is 6%.
- Other sources of systematic error are the uncertainties in the hadronic energy scale of the liquid argon and SpaCal calorimeters, the uncertainty in the branching ratio for the measured decay channel, and the uncertainties in the $x_{I\!P}$ and t distributions used in the Monte Carlo simulations to compute acceptances and losses. Each of them is responsible for an error of no more than 5%.

The combined total systematic error on the cross section measurement is 22%.

6 Result and Conclusion

An improved measurement of the cross section for $D^{*\pm}$ meson production in deep-inelastic diffractive interactions is reported. It is performed on combined 1995, 1996 and 1997 data, which represents an order of magnitude increase in luminosity over the previous H1 analysis.

The number of D^* events detected in the decay channel $D^{*+} \to D^0\, \pi^+_{slow} \to (K^-\, \pi^+)\, \pi^+_{slow}$ and in the charge conjugate channel is $38 \pm 10\ (\mathrm{stat.}) \pm 4\ (\mathrm{syst.})$ events.

The cross section for the kinematic region $2 < Q^2 < 100\ \mathrm{GeV}^2$, $0.05 < y < 0.7$, $x_{I\!P} < 0.04$, $M_Y < 1.6\ \mathrm{GeV}$, $|t| < 1\ \mathrm{GeV}^2$, $p_T(D^*) > 2\ \mathrm{GeV}$ and $|\eta(D^*)| < 1.5$ (η and p_T in the H1 laboratory frame) is

$$\sigma(ep \to (D^{*\pm}X)Y) = 154 \pm 40\ (\mathrm{stat.}) \pm 35\ (\mathrm{syst.})\ \mathrm{pb}\ . \qquad (2)$$

With this increased data set, further investigations should be possible. The study of the differential distributions is expected to provide useful information concerning the dynamics of diffractive DIS and, in particular, the role of gluons in the production mechanism.

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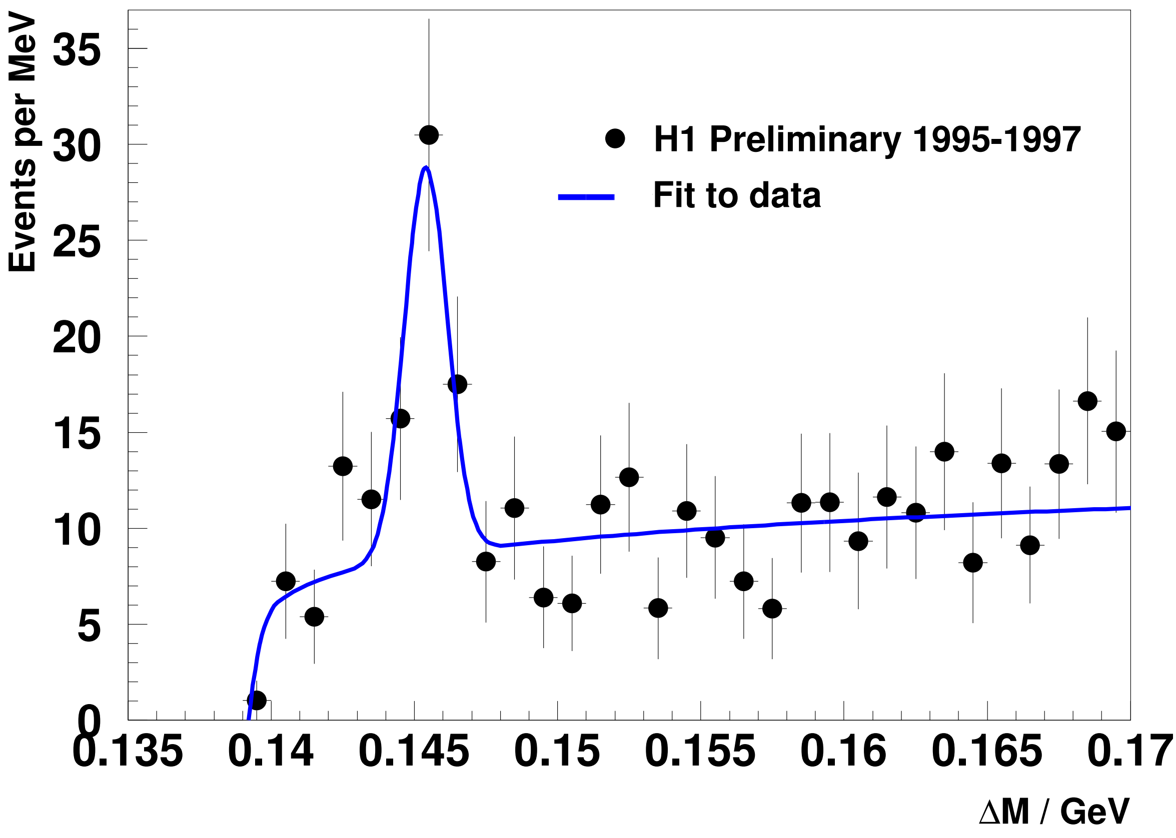

Figure 1: *Distribution of the mass difference* $\Delta M = M(K^-\pi^+\pi^+_{slow}) - M(K^-\pi^+)$*, with a curve fitted to the form* $a(\Delta M - M_{\pi^+})^b + Gaussian$*. The number of* $D^{*\pm}$ *mesons in the Gaussian part of the fit is* $38 \pm 10\ (\mathrm{stat.}) \pm 4\ (\mathrm{syst.})$.