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

H1 Collaboration

Abstract

The first measurement of the cross section for the production of $D^{*\pm}$ mesons in deep-inelastic diffractive interactions at the ep collider HERA is presented. The data were taken during the 1994 running period and correspond to an integrated luminosity of $2.2\,\mathrm{pb}^{-1}$. Using the decay channel $D^{*+} \rightarrow D^0\pi^+_{slow} \rightarrow (K^-\pi^+)\pi^+_{slow}$, a cross section of $(380 \pm {}^{150}_{120}{}_{stat} \pm {}^{140}_{110}{}_{sys})$ pb is measured in the kinematic region $10\ \mathrm{GeV}^2 < \mathrm{Q}^2 < 100\ \mathrm{GeV}^2$, $0.06 < y < 0.6$, $x_{I\!P} < 0.05$, $M_Y < 1.6$ GeV, $|\eta(D^*)| < 1.25$ and $p_\perp(D^*) > 1$ GeV, where M_Y is the mass of the diffractively scattered proton-remnant system and η and $p_\perp$ are measured in the H1 laboratory frame. A predicted cross section is calculated using a partonic model of $eI\!P$ collisions in which the parton density functions for the $I\!P$ are taken from a QCD analysis of the diffractive structure function $F_2^{D(3)}$. In this model a "leading" gluon distribution carries about 80% of the momentum of the diffractive exchange. The result ($\sim$ 200 pb) is consistent with the measured value. A prediction (less than $\sim$ 10 pb) based on a quark-dominated $I\!P$ is inconsistent at the 2σ level with the measured value.

Introduction

The contribution of charm production to diffractive interactions is sensitive to the partonic structure of the diffractive exchange. Measurements of the diffractive structure function $F_2^{D(3)}$ suggest that this structure receives a substantial contribution from gluons, and a QCD analysis of $F_2^{D(3)}$ employing the DGLAP evolution equations yields a solution which tends towards a "leading" gluon distribution at the starting scale for the perturbative evolution $Q^2 = 2.5\,\mathrm{GeV}^2$ [1, 2, 3, 4]. Such a solution gives rise to the expectation of a large cross section for charm production through the boson-gluon fusion process. In this paper we present a search for the production of $D^{*\pm}$ mesons which subsequently decay via the channel[1] $D^{*+} \to D^0\pi^+_{slow} \to (K^-\pi^+)\pi^+_{slow}$. The first observation of $D^{*\pm}$ production in deep-inelastic diffractive interactions is reported and a measurement is made of the $D^{*\pm}$ production cross section in the kinematic region 10 GeV^2 $<$ Q^2 $<$ 100 GeV^2, $0.06 < y < 0.6$, $x_{\boldsymbol{P}} < 0.05$, $M_Y < 1.6$ GeV, $|\eta(D^*)| < 1.25$ and $p_\perp(D^*) > 1$ GeV. The measured cross section is compared with two predictions of a partonic model of diffractive scattering based on electron-pomeron interactions. In one case, the parton distributions ascribed to the pomeron are obtained from the QCD analysis of $F_2^{D(3)}$. In the other case, the pomeron is given an evolved quark-based structure [3]. This cross section measurement follows a comparison reported in [3] of the $D^{*\pm}$ yield in deep-inelastic diffraction with that expected based on the QCD analysis of $F_2^{D(3)}$.

Event Selection

The data used were collected at the H1 detector [5] in 1994, using 27.5 GeV positrons colliding with 820 GeV protons. After rejecting data taken when parts of the detector needed for this analysis were not operational, the integrated luminosity used is 2.24 pb^{-1}.

This analysis is restricted to events with a scattered positron detected in the backward electromagnetic calorimeter (BEMC). There must be a localized energy deposit of at least 10 GeV within the angular range $155° < \theta < 173°$ with respect to to the direction of the proton beam. The deposit must lie within the efficient region of the BEMC and be associated with a hit in the backward proportional chamber (BPC), which is immediately in front of the BEMC. These requirements restrict the accessible range in Q^2 and y. The requirement that a $D^{*\pm}$ be produced in the central region imposes an additional limit at the lower end of the y range. The region measured is 10 GeV^2 $<$ Q^2 $<$ 100 GeV^2 and $0.06 < y < 0.6$. The kinematic variables Q^2 and y are calculated using the "sigma" method [6], which minimises the QED radiative corrections to the Born cross section.

Diffractive events are recognized by their lack of energy flow in the region around the proton beam. Energy flow in this region is detected through charged particles produced in secondary scattering in the beam pipe and associated material as well as those coming directly from the ep interaction vertex [7]. An event is rejected if it has more than 7.5 GeV in the plug calorimeter, more than one hit pair in the first half of the forward muon detector, or any hits in the first three layers of the proton remnant tagger. The pseudorapidity of the most forward cluster with more than 400 MeV, η_{max}, must be less

[1]Charge conjugate states are implicitly included.

than 3.2. 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 M_X is reconstructed using tracks and calorimeter information. Only events with $x_{I\!P}$ less than 0.05 are accepted. The scattered proton is not detected, so it is not possible to distinguish an event in which the proton scatters elastically from one in which it dissociates into a low-mass state. The cross section is instead quoted for the range $M_Y < 1.6$ GeV, where M_Y is mass of the diffractively scattered proton remnant system. Models of proton dissociation [8, 9, 10] imply that the correction from the measured cross section ($M_Y < 1.6$ GeV) to one in which the proton vertex is truly elastic is about 5%.

Reconstruction of $D^{*\pm}$

The charmed meson D^{*+} is reconstructed in this analysis using its decay $D^{*+} \to D^0\pi^+_{slow} \to (K^-\pi^+)\pi^+_{slow}$. Because of the small mass difference $\Delta M = M_{D^{*+}} - M_{D^0}$, the pion from the D^{*+} decay (π^+_{slow}) has a momentum of only 40 MeV in the D^{*+} rest frame. Because of this kinematic constraint, ΔM is better resolved than the D^{*+} mass itself and is used in the cross-section measurement. The combinatorial background is also suppressed by the proximity to threshold, further improving the signal-to-background ratio.

The decay products are detected in the central tracker. To ensure a good detection efficiency, tracks are only used if they lie within the angular range $25° < \theta < 155°$ and have a $p_\perp$ of at least 200 MeV (K,π) or 100 MeV (π_{slow}). To protect further against badly reconstructed tracks, each track must also be at least 10 cm long in the projection perpendicular to the beam and must start in the inner section of the tracker.

All accepted tracks with $p_\perp > 200$ MeV are combined in oppositely charged pairs. No particle identification is used; each track is allowed to be either a kaon or a pion. If a pair has an invariant mass within 80 MeV of the D^0 mass, it is counted as a D^0 candidate. Each D^0 candidate is combined in turn with all remaining tracks with $p_\perp > 100$ MeV and the appropriate charge to reconstruct D^{*+} candidates. After cuts on the direction ($|\eta| < 1.25$) and transverse momentum ($p_\perp > 1$ GeV) of the $D^{*\pm}$, the mass difference ΔM is plotted as a histogram (fig. 1).

The number of $D^{*\pm}$ candidates is determined by fitting the histogram with a Gaussian peak plus a background function $a(\Delta M - M_{\pi^+})^b$, where a, b and the three parameters of the Gaussian are allowed to vary. The number of $D^{*\pm}$ detected is found to be $11.6 \pm 4.0_{stat}$.

The distribution of η_{max} for $D^{*\pm}$ candidates in the region of the peak is shown in fig. 2. It clearly shows the low-η plateau characteristic of diffractive events.

Acceptance and Background Corrections

The acceptance is calculated by running the H1 detector simulation program on a sample of $D^{*\pm}$ events from the diffractive Monte Carlo generator RAPGAP [11], which is based on a partonic model of $eI\!P$ interactions. The efficiency of the BEMC trigger is known to be better than 99% and is neglected.

The main sources of background are reflections (contributions from other D^0 decay modes), events outside the measured $x_{I\!P}$ range, and proton dissociation events (those

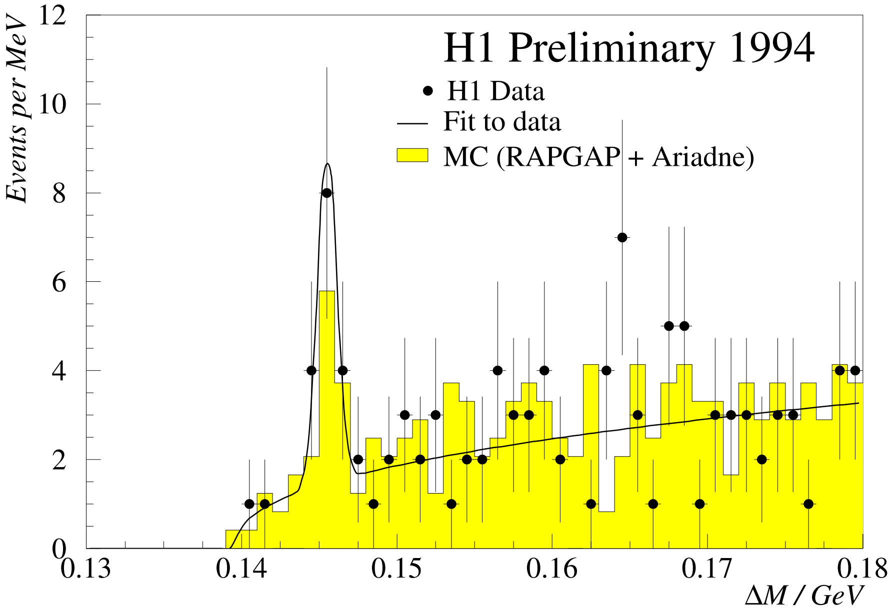

Figure 1: Distribution of the mass difference $\Delta M = M(K^-\pi^+\pi^+_{slow}) - M(K^-\pi^+)$, with a fitted curve of the form $a(\Delta M - M_{\pi^+})^b + Gaussian$ and a prediction from RAPGAP with the pomeron structure extracted from $F_2^{D(3)}$.

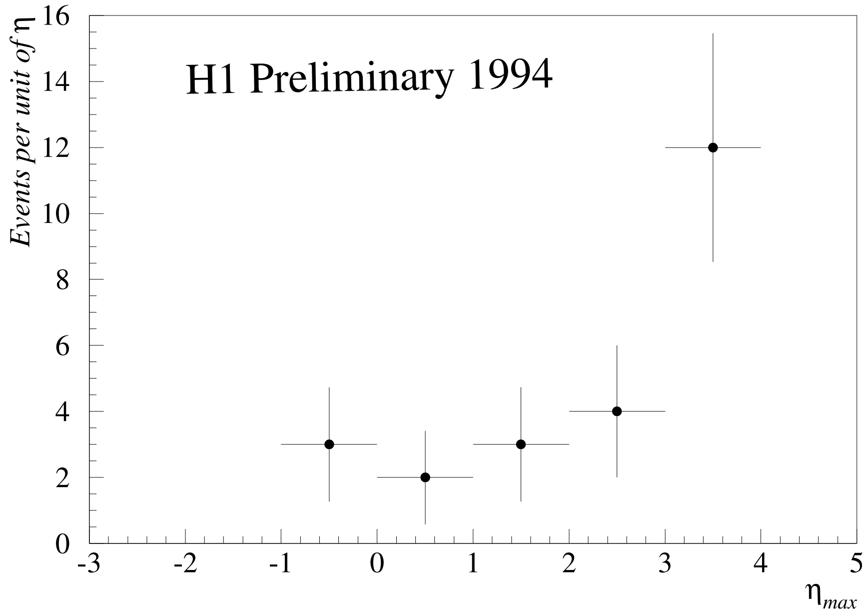

Figure 2: Distribution of η_{max} for $D^{*\pm}$ candidates in the region $|\Delta M - 145.4\ \mathrm{MeV}| < 2.0\ \mathrm{MeV}$.

with $M_Y > 1.6$ GeV). The contribution from reflections is estimated using RAPGAP. The contribution from high-$x_{\mathbb{P}}$ events is estimated using RAPGAP ($x_{\mathbb{P}} < 0.2$) and the heavy quark generator AROMA [12] ($x_{\mathbb{P}} > 0.2$). The fraction of events where the proton dissociates is estimated using the diffractive vector-meson dominance (VMD) generator, DIFFVM [8].

Systematic Errors

The largest systematic errors on the cross section are those due to the uncertainty in the $p_\perp$ distribution of the $D^{*\pm}$ ($\pm^{24}_{14}\%$) and the correction for reflections ($\pm 19\%$). The effect of varying the $p_\perp$ distribution is estimated by reweighting the Monte Carlo and recalculating the acceptance. There is also an error of $\pm 11\%$ from the fitting procedure, including uncertainty in the shape of the combinatorial background.

The other sources of systematic uncertainty taken into account, each responsible for an error of no more than 5%, are Monte Carlo statistics, the branching ratios for the D^{*+} and D^0 decays, the corrections for proton dissociation and high-$x_{\mathbb{P}}$ events, the effect of noise in the forward detectors, and the uncertainty in the distributions of t, $x_{\mathbb{P}}$ and β.

Result

The cross section[2] is calculated for the following kinematic region: $10\ \mathrm{GeV}^2 < \mathrm{Q}^2 < 100\ \mathrm{GeV}^2$, $0.06 < y < 0.6$, $x_{\mathbb{P}} < 0.05$, $M_Y < 1.6$ GeV, $|\eta(D^*)| < 1.25$ and $p_\perp(D^*) > 1.0$ GeV (η and $p_\perp$ in the H1 laboratory frame). The result is

$$\sigma(ep \to eD^{*\pm}XY) = (380 \pm {}^{150}_{120\,stat} \pm {}^{140}_{110\,sys})\ \mathrm{pb}.$$

The Monte Carlo generator RAPGAP, which models diffractive events as the interaction of the positron with a partonic pomeron, predicts a value of ~ 200 pb when the parton densities of the pomeron are taken from a QCD analysis [3, 4] of the diffractive structure function $F_2^{D(3)}$. When the parton densities are instead calculated on the assumption of a quark-based pomeron at 2.5 GeV^2, evolved to higher Q^2 [3], the predicted cross section is less than ~ 10 pb.

Conclusion

A first measurement of the cross section for $D^{*\pm}$ production in deep-inelastic diffractive interactions is reported. The result for the kinematic region covered is $(380 \pm {}^{150}_{120\,stat} \pm {}^{140}_{110\,sys})$ pb. The prediction (~ 200 pb) of a model in which charm is produced by boson-gluon fusion and the partonic structure of diffractive exchange is taken from a QCD analysis of diffractive interactions is consistent with the measured cross section. In this model, the structure of the pomeron receives a substantial contribution from a hard gluon

[2]The cross section is defined as $N/\mathcal{L}_{int}$, where N is the corrected number of $D^{*\pm}$ produced and $\mathcal{L}_{int}$ is the integrated luminosity.

distribution. The smaller prediction (less than ~ 10 pb) of a model in which the diffractive exchange is a quark-based pomeron is inconsistent at the 2σ level with the measured cross section.

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