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Charm production in deep inelastic scattering using HERA II data

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Abstract

The production of charmed mesons in deep inelastic scattering has been measured with the ZEUS detector at HERA II using 73 pb^{-1} $e^{\pm}p$ data taken in the 2003-5 running period. The relative rate of $D^{*}(2010)$ meson production between the $e^{+}p$ and the $e^{-}p$ data sets is also measured and compared to previous results.

1 Introduction

Charm quarks are copiously produced in deep inelastic scattering (DIS) at HERA. At sufficiently high photon virtualities, Q^2, the production of charm quarks constitutes up to 30% of the total cross section [1, 2]. Previous measurements of D^* cross sections [1–5] indicate that the production of charm quarks in DIS in the range of $1 < Q^2 < 1000\,\mathrm{GeV}^2$ is consistent with calculations in Quantum Chromodynamics (QCD) in which charm is produced through the boson-gluon-fusion (BGF) mechanism. This implies that the charm cross section is directly sensitive to the gluon density in the proton.

In the most recently published ZEUS measurement [5], made using 65 pb^{-1} e^+p data and 17 pb^{-1} e^-p data, it was observed that the D^* production rate, $r = N/\mathcal{L}$, for e^-p was systematically higher than in the e^+ data set, and rising with Q^2. The ratio r^{e^-p}/r^{e^+p} was equal to 1.67 ± 0.21 (only statistical errors are given) for $40 < Q^2 < 1000\,\mathrm{GeV}^2$. Such a difference was not expected from any physics process, and so the phenomenon was treated as a statistical fluctuation.

This paper presents a measurement r^{e^-p}/r^{e^+p} in the range $5 < Q^2 < 1000\,\mathrm{GeV}^2$ for 40 pb^{-1} e^+p data and 33 pb^{-1} e^-p data, collected during the HERA II 2003-5 running period. The ratio is compared to the HERA I ZEUS results from 1998-2000. A virtue of this analysis is that many of the systematic effects cancel.

2 The ZEUS detector

A detailed description of the ZEUS detector can be found elsewhere [6]. The main components used in this analysis were the compensating uranium-scintillator calorimeter, the central tracking detector and the microvertex detector.

The high-resolution uranium–scintillator calorimeter (CAL) [7] consists of three parts: the forward (FCAL), the barrel (BCAL) and the rear (RCAL) calorimeters. Each part is subdivided transversely into towers and longitudinally into one electromagnetic section (EMC) and either one (in RCAL) or two (in BCAL and FCAL) hadronic sections (HAC). The smallest subdivision of the calorimeter is called a cell. The CAL energy resolutions, as measured under test-beam conditions, are $\sigma(E)/E = 0.18/\sqrt{E}$ for electrons and $\sigma(E)/E = 0.35/\sqrt{E}$ for hadrons (E in GeV).

Charged particles are tracked in the central tracking detector (CTD) [8], which operates in a magnetic field of 1.43 T provided by a thin superconducting coil. The CTD consists of 72 cylindrical drift chamber layers, organised in 9 superlayers covering the polar-angle[1] region $15° < \theta < 164°$.

In 2001 a silicon microvertex detector (MVD) [9] was installed inside the CTD. The MVD is organised into a barrel with 3 cylindrical layers and a forward section with four planar layers perpendicular to the HERA beam direction. The barrel contains 600 single-sided silicon strip sensors each having 512 strips with a readout pitch of 120 μm; the forward section contains 113 sensors, each of which has 480 strips with a readout pitch of 120 μm. Currently, without final corrections for alignment, the hit resolution of the MVD is 40 μm in the $R-Z$ and 65 μm in the $R-\phi$ plane. The resulting resolution of the primary vertex is around 100 μm both in the transverse and the longitudinal planes.

A three-level trigger was used online to select neutral current DIS events inclusively [10].

3 DIS Selection

An inclusive selection of neutral current DIS events was made; this was chosen to be directly comparable to the previous measurement [5]. The electron method was used to reconstruct Q^2 and y in terms of the electron energy E'_e and the angle θ_e of the scattered electron:

$$Q^2_e = 2E'_e E_e(1 + \cos\theta_e)$$

and

$$y_e = 1 - \tfrac{E'_e}{2E_e}(1 - \cos\theta_e),$$

where E_e is the electron beam energy. The value of y reconstructed from the hadronic system using the Jaquet-Blondel method, y_{JB}, was also used.

In addition the quantity δ $(E - p_z)$,

$$\delta = \textstyle\sum_i E_i(1 - \cos\theta_i),$$

calculated using the energies, E_i, of individual calorimeter cells that are above noise thresholds of 80 MeV (EMC) and 140 MeV (HAC) was used.

Events were selected with $5 < Q^2_e < 1000\,\mathrm{GeV}^2$, $y_e < 0.95$, $40 < \delta < 60\,\mathrm{GeV}$ and $y_{\mathrm{JB}} > 0.02$. A vertex within 30 cm of the nominal interaction point in Z was also required.

[1] The ZEUS co ordinate system is a right-handed Cartesian system, with the Z axis pointing in the proton beam direction, referred to as the “forward direction”, and the X axis pointing left towards the centre of HERA. The nominal interaction point is shifted by +1.75 cm in X with respect to the coordinate origin.

4 Selection of D^* candidates

The selection of D^* mesons also followed the strategy used in the previous publication [5]. The D^* mesons were identified using the decay channel $D^{*+} \rightarrow D^0\pi_s$ with the subsequent decay $D^0 \rightarrow K^-\pi^+$ and the corresponding antiparticle decay, where π_s^+ refers to a low momentum ("slow") pion accompanying the D^0.

Charged tracks measured by the CTD and MVD and assigned to the primary event vertex were selected. The transverse momentum was required to be greater than 0.12 GeV and the absolute value of the track pseudorapidity, $|\eta|$, was required to be less than 1.75. These restrictions ensured that the track acceptance and momentum resolution were high. Tracks with opposite charges and transverse momenta $p_T > 0.4$ GeV were combined in pairs to form D^0 candidates. The tracks were alternately assigned the masses of the kaon and a pion and the invariant mass of the pair, $M_{K\pi}$, was found. Each additional track, with charge opposite to that of the kaon track, was assigned the pion mass and combined with the D^0-meson candidate to form a D^* candidate.

The signal regions for the reconstructed masses, $M(D^0)$ and $\Delta M = (M_{K\pi\pi_s} - M_{K\pi})$, were $1.80 < M(D^0) < 1.92$ GeV and $0.143 < \Delta M < 0.148$ GeV, respectively. To allow the background to be determined, D^0 candidates with wrong-sign combinations, in which both tracks forming the D^0 candidates have the same charge and the third track has the opposite charge, were also retained. The kinematic restrictions were applied as for those D^0 candiates with correct-charge combinations.

The kinematic region for D^* candidates was $1.5 < p_T(D^*) < 15$ GeV and $|\eta(D^*)| < 1.5$. Figures 1 and 2 show the ΔM distribution for the D^* candidates, in e^+p and e^-p scattering respectively, together with background from the wrong-charge combinations. The fit to the distribution, shown in in the figure, has the form:

$$F = p_1 \times \exp\left(-0.5x^{1+\frac{1}{1+0.5x}}\right) + p_4(\Delta M - m_\pi)^{p_5},$$

where $x = |(\Delta M - p_2)/p_3|$, the p_i are free parameters and m_π is the pion mass.

The number of D^* candidates was determined in the signal regions by subtracting the wrong-charge background from the correct-charge candidates in the region $0.143 < \Delta M < 0.148$ GeV. The normalisation of the wrong-charge background sample was determined as the ratio of events with correct-charge combinations to wrong-charge combinations in the region $0.150 < \Delta M < 165$ GeV. This factor is compatible with unity for both e^-p and e^+p data. The normalisation factors were determined separately for each bin when calculating rates and ratios in Q^2 bins.

5 Systematics and Cross Checks

The systematic effects considered in the evaluation of r^{e^-p}/r^{e^+p} were:

- an uncertainty of $\pm 7.5\%$ on the ratio of the integrated luminosities. Part of this uncertainty arises from the fact that final offline corrections to data luminosity have not yet been applied;
- relaxing the η cut on tracks used to reconstruct the D^* to $|\eta| < 2.0$;
- strengthening the cut on the p_T of the track accepted as the slow pion candidate to $p_T > 0.15\,\text{GeV}$;
- varying the cut on the p_T of tracks accepted as K candidates by ± 50 MeV;
- varying the cut on the p_T of tracks accepted as π candidates by ± 50 MeV;
- tightening, to $0.182 < M(D^0) < 0.192\,\text{GeV}$, the D^0 mass window used to select D^* candidates;
- employing the double angle method rather than the electron method to reconstruct the kinematic quantities y and Q^2.

Cross checks of the result were made with further raising of the p_T cut on the track accepted as the slow pion candidate to 0.2 and 0.25 GeV. In addition it was checked that extracting the signal in each bin using the fit described in Section 4 gave consistent values of r^{e^-p}/r^{e^+p}. Studies of the rate of inclusive NC DIS events in the same kinematic region as the D^* candidate events were made to ensure there was no bias introduced between the 2003-4 e^+p and 2004-5 e^-p running periods.

6 Results

In total 1240 ± 64 (1118 ± 60) D^* candidates in the kinematic region $5 < Q^2 < 1000\,\text{GeV}^2$, $0.02 < y < 0.7$, $1.5 < p_T(D^*) < 15$ GeV and $|\eta(D^*)| < 1.5$ were found in e^+p (e^-p) data corresponding to a rate of $30.7 \pm 1.8/\text{pb}^{-1}$ $(33.5 \pm 1.8/\text{pb}^{-1})$. The rate for events with $Q^2 > 40\,\text{GeV}^2$ was $6.4/\text{pb}^{-1}$ $(6.3/\text{pb}^{-1})$ for e^+p (e^-p) data. The ratio r^{e^-p}/r^{e^+p} in bins of Q^2 is shown in Fig.3, compared to the ZEUS HERA I values and the theoretical expectation of unity. At all values of Q^2 the value of the ratio is consistent with unity. The observation of the increase of this ratio with increasing Q^2, found previously [5], is not confirmed.

7 Summary

A study of the ratio, r^{e^-p}/r^{e^+p}, of the production rate of D^* mesons in neutral current DIS in e^-p and e^+p collisions was made using data taken by ZEUS during the 2003-5 running period. The sample used was directly comparable to that used by ZEUS in a 1998-2000 result. The ratio was observed to be consistent with unity at all values of Q^2, as would be expected within the Standard Model. The results support the assertion that the higher value of the ratio observed previously was due to a statistical fluctuation.

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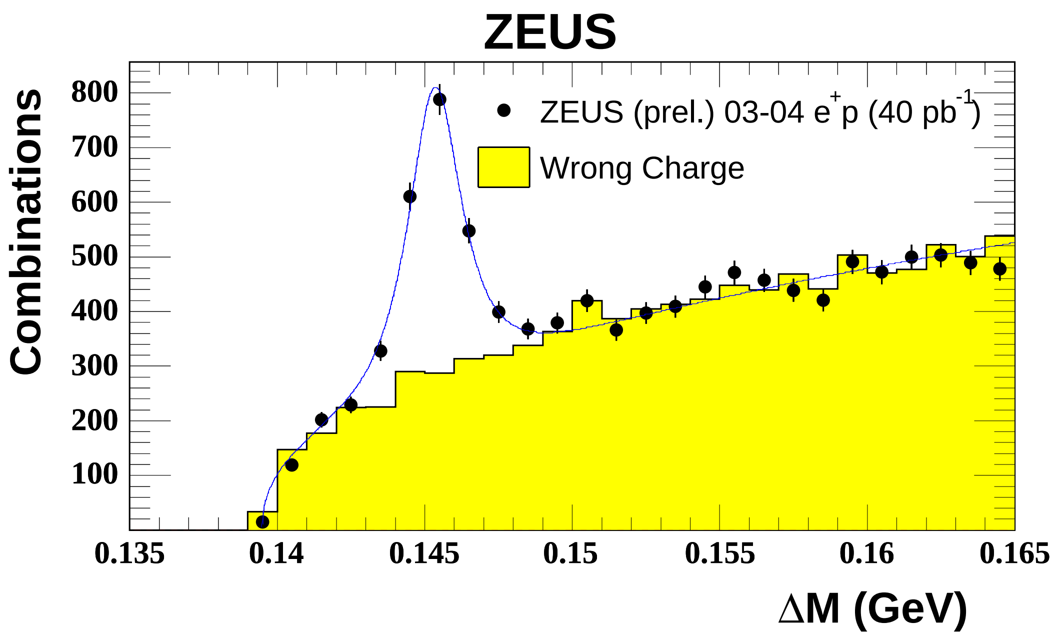

Figure 1: *The distribution of the mass difference, $\Delta M = (M_{k\pi\pi_s} - M_{k\pi})$, for D^* candidates in e^+p scattering (solid dots). The ΔM distribution from wrong-chrage combinations, normalised in the region $0.150 < \Delta M < 0.165$ GeV, is shown as the histogram. The solid line shows the result of the fit described in the text.*

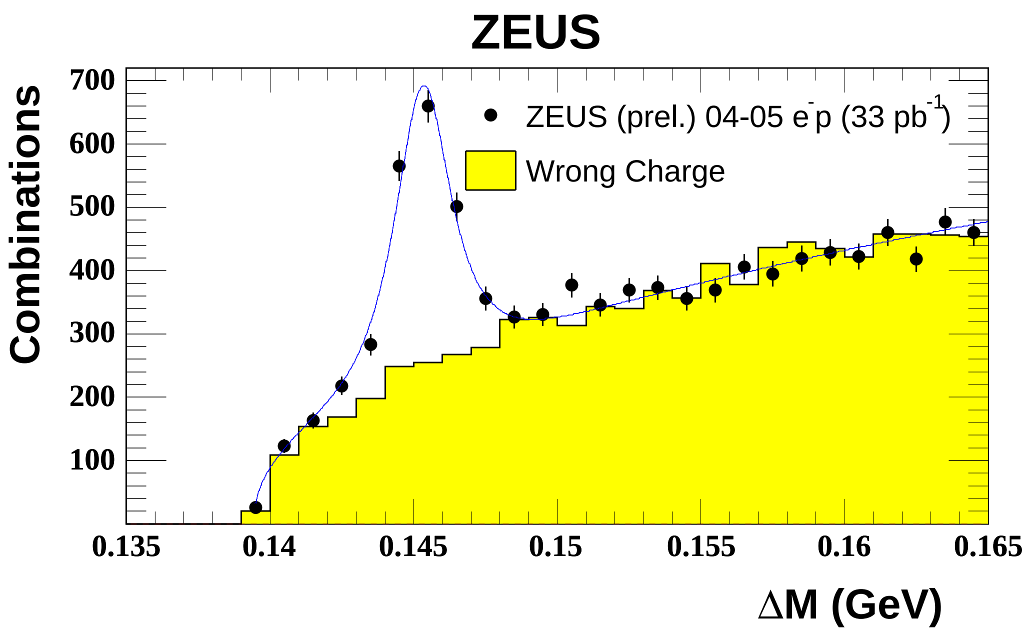

Figure 2: *The distribution of the mass difference, $\Delta M = (M_{k\pi\pi_s} - M_{k\pi})$, for D^* candidates in e^-p scattering (solid dots). Other details as in Figure 1*

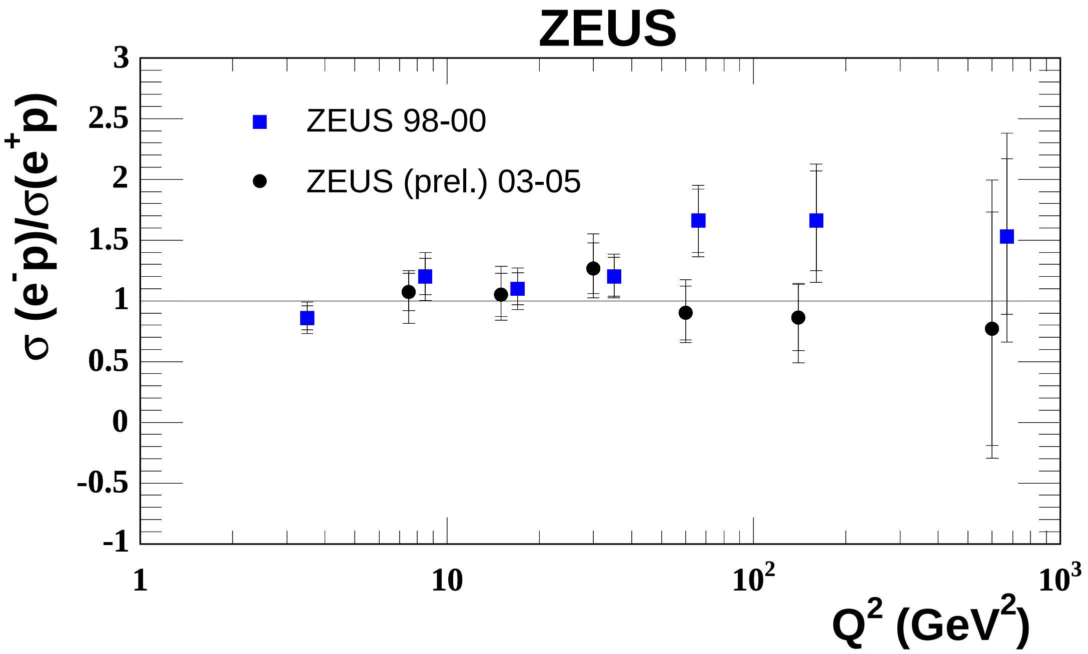

Figure 3: *The ratio r^{e^-p}/r^{e^+p} for the 2004-2005 running period (solid dots) compared to the ZEUS measurement for the 1998-2000 running period (solid squares).*