Charm hadronisation in γp collisions with ZEUS at HERA

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The measured $D^{*\pm}$, D^0, $D^\pm$, $D_s^\pm$ and $\Lambda_c^\pm$ photoproduction cross sections have been used to determine charm fragmentation ratios and fractions of c quarks hadronising as a particular charm hadron, $f(c \to D, \Lambda_c)$. Events with a $D^{*\pm}$ meson produced in association with an energetic jet have been used to measure the charm fragmentation function. The results are compared with different models and with previous measurements.

1 Introduction

Charm quark production has been extensively studied at HERA using $D^{*\pm}$ and $D_s^\pm$ mesons. The data have been compared with the theoretical predictions by assuming the universality of charm fragmentation. This assumption allows the charm fragmentation characteristics, obtained in e^+e^- annihilations, to be used in calculations of charm production in ep scattering. Measuring the charm fragmentation characteristics at HERA permits the verification of the charm-fragmentation universality and contributes to the knowledge of charm fragmentation.

The production of $D^{*\pm}$, D^0, $D^\pm$, $D_s^\pm$ and $\Lambda_c^\pm$ charm hadrons have been measured in ep scattering at HERA in the photoproduction regime ($Q^2 \approx 0$) [1]. The measured production cross sections have been used to determine the ratio of neutral and charged D meson production rates, $R_{u/d}$, the strangeness suppression factor, γ_s, the fraction of D mesons produced in a vector state, $P_{\rm v}$, and the fractions of c quarks hadronising as a particular charm hadron, $f(c \to D, \Lambda_c)$. Events with a $D^{*\pm}$ meson produced in association with an energetic jet have been used to measure the charm fragmentation function [2].

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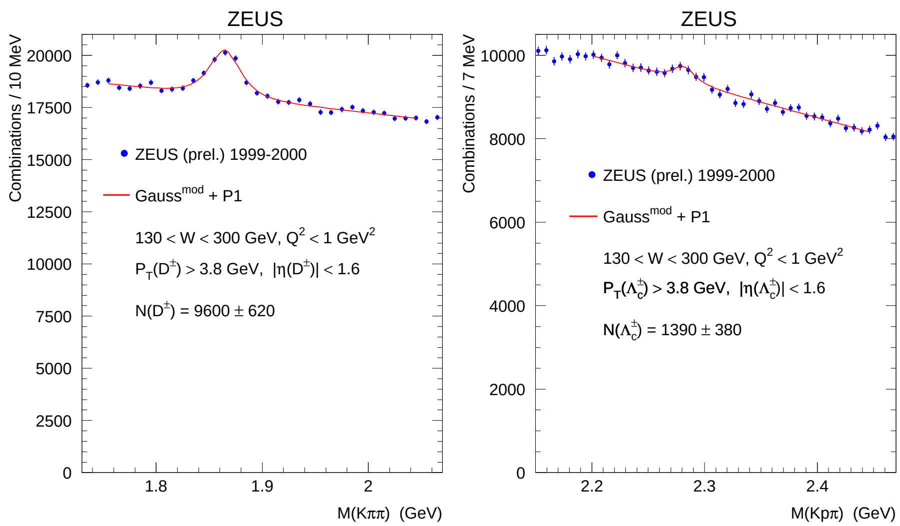

Figure 1: Distributions of the reconstructed invariant mass for the $D^{\pm}$ candidates (left) and for the $\Lambda_c^{\pm}$ candidates (right). The solid curves represent fits to a sum of a modified Gaussian function and a linear background function.

2 Measurement of charm fragmentation ratios and fractions

The production of $D^{*\pm}$, D^0, $D^{\pm}$, $D_s^{\pm}$ and $\Lambda_c^{\pm}$ charm hadrons was measured in the kinematic range $p_T(D,\Lambda_c) > 3.8\,\mathrm{GeV}$ and $|\eta(D,\Lambda_c)| < 1.6$. The measurement was performed for photon-proton centre-of-mass energies in the range $130 < W < 300\,\mathrm{GeV}$ using an integrated luminosity of $79\,\mathrm{pb}^{-1}$. Figure 1 shows distributions of the reconstructed invariant mass for the $D^{\pm}$ and $\Lambda_c^{\pm}$ candidates reconstructed from the decay channels $D^+ \to K^-\pi^+\pi^+$ (+c.c.) and $\Lambda_c^+ \to K^- p \pi^+$ (+c.c.), respectively. The mass distributions were fitted to a sum of a "modified" Gaussian function and a linear background function. The modified Gaussian function, which was designed for the best description of the reconstructed signals, took the form:

$$\mathrm{Gauss}^{\mathrm{mod}} \propto \exp[-0.5 \cdot x^{1+\frac{1}{1+0.5\cdot x}}],$$

	ZEUS prel. (γp) $p_T(D, \Lambda_c) > 3.8\,\mathrm{GeV}$ $|\eta(D, \Lambda_c)| < 1.6$	Combined e^+e^- data [3]
$f(c \to D^+)$	$0.249 \pm 0.014^{+0.004}_{-0.008}$	0.232 ± 0.010
$f(c \to D^0)$	$0.557 \pm 0.019^{+0.005}_{-0.013}$	0.549 ± 0.023
$f(c \to D_s^+)$	$0.107 \pm 0.009 \pm 0.005$	0.101 ± 0.009
$f(c \to \Lambda_c^+)$	$0.076 \pm 0.020^{+0.017}_{-0.001}$	0.076 ± 0.007
$f(c \to D^{*+})$	$0.223 \pm 0.009^{+0.003}_{-0.005}$	0.235 ± 0.007

Table 1: The fractions of c quarks hadronising as a particular charm hadron. The first and second uncertainties represent statistical and systematic uncertainties, respectively. For the values obtained for charm production in e^+e^- annihilations, the combined statistical and systematic uncertainties are quoted.

where $x = |[M(K\pi) - M_0]/\sigma|$. The signal position, M_0, and width, σ, as well as the numbers of charm hadrons in each signal were free parameters of the fit. Other details of the charm-hadron reconstruction are discussed in [1].

Using the measured cross sections, the charm fragmentation ratios are

$$R_{u/d} = 1.014 \pm 0.068\,(\mathrm{stat})^{+0.024}_{-0.031}\,(\mathrm{syst}),$$

$$\gamma_s = 0.266 \pm 0.023\,(\mathrm{stat})^{+0.014}_{-0.012}\,(\mathrm{syst}),$$

$$P_{\mathrm{v}} = 0.554 \pm 0.019\,(\mathrm{stat})^{+0.008}_{-0.004}\,(\mathrm{syst}).$$

The measured $R_{u/d}$ value agrees with one. This confirms isospin invariance which suggests u and d quarks are produced equally in charm fragmentation. The s quark production is suppressed by a factor ≈ 3.5, as the measured γ_s value shows. The measured P_{v} fraction is sizeably smaller than the naive spin counting prediction of 0.75. The predictions of the thermodynamical approach [4] and the string fragmentation approach [5], which both predict 2/3 for the fraction, are closer to, but still above, the measured value.

The fraction of c quarks hadronising as a particular charm hadron, $f(c \to D, \Lambda_c)$, is given by the ratio of the production cross section for the hadron to the sum of the production cross sections for all charm weakly-decaying ground states. The measured fragmentation fractions are compared in Table 1 with the values obtained for charm production in e^+e^- annihilations [3]. These measurements, as well as the values obtained in deep inelastic scattering (DIS) [6], agree within experimental uncertainties. This confirms the universality of charm fragmentation.

3 Measurement of charm fragmentation function

Fragmentation fractions are used to parameterise the transfer of the quark's energy to a given meson. The measurement of the charm fragmentation function in the transition from a charm quark to a $D^{*\pm}$ meson was performed for photon-proton centre-of-mass energies in the range $130 < W < 280\,\text{GeV}$ using an integrated luminosity of $120\,\text{pb}^{-1}$. Using events with a $D^{*\pm}$ meson produced in association with an energetic jet, the fragmentation variable, z, was defined as

$$z = (E + p_{||})^{D^{*\pm}} / (E + p_{||})^{\text{jet}} \equiv (E + p_{||})^{D^{*\pm}} / 2\,E^{\text{jet}},$$

where $p_{||}$ is the longitudinal momentum of the $D^{*\pm}$ meson relative to the axis of the associated jet of energy E^{jet}. The equivalence of $(E + p_{||})^{\text{jet}}$ and $2\,E^{\text{jet}}$ arises because the jets are reconstructed as massless objects. The $D^{*\pm}$ meson was included in the jet-finding procedure and was thereby uniquely associated with one jet only.

Figure 2 shows the normalised differential cross section, $1/\sigma(d\sigma/dz)$, measured in the kinematic range $p_T(D^{*\pm}) > 2\,\text{GeV}$, $|\eta(D^{*\pm})| < 1.5$, $E_T^{\text{jet}} > 9\,\text{GeV}$ and $|\eta^{\text{jet}}| < 2.4$. The data were compared with various fragmentation models implemented in the leading-logarithmic Monte Carlo (MC) program PYTHIA [7]. The LUND string fragmentation model [8] modified for heavy quarks [9] gives a reasonable description of the data [2]. In Fig. 2, the measurement is compared with PYTHIA predictions obtained using the Peterson fragmentation function [10] with different values of the parameter ϵ. The MC was fit to the data via a χ^2-minimisation procedure to determine the best value of ϵ. The result of the fit is $\epsilon = 0.064 \pm 0.006^{+0.011}_{-0.008}$. The result is in reasonable agreement with the default value used in PYTHIA (0.05), and with the value 0.053 obtained in the leading-logarithmic fit [11] to the ARGUS data [12].

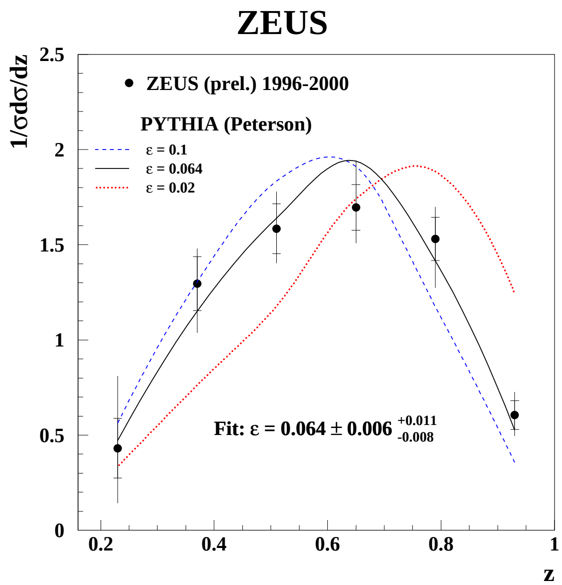

Figure 2: Relative cross section $1/\sigma(d\sigma/dz)$, for the data compared with PYTHIA predictions for different values of the parameter ϵ in the Peterson fragmentation function.

4 Summary

The measured $D^{*\pm}$, D^0, $D^\pm$, $D_s^\pm$ and $\Lambda_c^\pm$ photoproduction cross sections have been used to determine charm fragmentation ratios and fractions of c quarks hadronising as a particular charm hadron. The measured ratio of neutral and charged production rates agrees with one. This confirms isospin invariance which suggests u and d quarks are produced equally in charm fragmentation. The s quark production is suppressed by a factor ≈ 3.5, as the measured value of the strangeness suppression factor shows. The measured fraction of D mesons produced in a vector state is sizeably smaller than the naive spin counting prediction of 0.75.

The fragmentation function for $D^{*\pm}$ mesons has been measured by requiring a jet to be associated with the $D^{*\pm}$ meson. The LUND string fragmentation model gives a reasonable description of the data, as does the Peterson function with $\epsilon = 0.064 \pm 0.006^{+0.011}_{-0.008}$ as determined from a fit to the data.

All measured fragmentation characteristics agree with those obtained for charm production in e^+e^- annihilations, thus confirming the universality of charm fragmentation.

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