Charm hadronisation
in $\gamma p$ collisions with ZEUS at HERA

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The measured $D^*\pm$, $D^0$, $D^\pm$, $D_s^\pm$ and $\Lambda^\pm_c$ photoproduction cross sections have been used to determine charm fragmentation ratios and fractions of $c$ quarks hadronising as a particular charm hadron, $f(c \rightarrow D, \Lambda_c)$. 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 $D^\pm_s$ 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 $\Lambda^\pm_c$ 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, $\gamma_s$, the fraction of $D$ mesons produced in a vector state, $P_v$, and the fractions of $c$ quarks hadronising as a particular charm hadron, $f(c \rightarrow D, \Lambda_c)$. Events with a $D^{*\pm}$ meson produced in association with an energetic jet have been used to measure the charm fragmentation function [2].

*On leave from Moscow State University, supported by the U.S.-Israel BSF
2 Measurement of charm fragmentation ratios and fractions

The production of $D^{\ast\pm}$, $D^0$, $D^\pm$, $D^{\pm}_s$ and $\Lambda_c^\pm$ charm hadrons was measured in the kinematic range $p_T(D, \Lambda_c) > 3.8$ GeV and $|\eta(D, \Lambda_c)| < 1.6$. The measurement was performed for photon-proton centre-of-mass energies in the range $130 < W < 300$ GeV using an integrated luminosity of $79 \text{ pb}^{-1}$. Figure 1 shows distributions of the reconstructed invariant mass for the $D^\pm$ and $\Lambda_c^\pm$ candidates reconstructed from the decay channels $D^+ \rightarrow K^- \pi^+ \pi^+$ (+c.c.) and $\Lambda_c^+ \rightarrow K^- p \pi^+$ (+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:

$$\text{Gauss}^{\text{mod}} \propto \exp\left[-0.5 \cdot x^{1+0.5 \cdot \tau}\right],$$
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.

\[
\begin{array}{|c|c|c|}
\hline
 & \text{ZEUS prel. ($\gamma p$)} & \text{Combined} \\
& \text{pt}(D, \Lambda_c) > 3.8 \text{ GeV} & e^+e^- \text{ data [3]} \\
& |\eta(D, \Lambda_c)| < 1.6 & \\
\hline
f(c \to D^+) & 0.249 \pm 0.014^{+0.004}_{-0.008} & 0.232 \pm 0.010 \\
f(c \to D^0) & 0.557 \pm 0.019^{+0.005}_{-0.013} & 0.549 \pm 0.023 \\
f(c \to D_s^+) & 0.107 \pm 0.009 \pm 0.005 & 0.101 \pm 0.009 \\
f(c \to \Lambda_c^+) & 0.076 \pm 0.020^{+0.014}_{-0.003} & 0.076 \pm 0.007 \\
f(c \to D^{++}) & 0.223 \pm 0.009^{+0.003}_{-0.005} & 0.235 \pm 0.007 \\
\hline
\end{array}
\]

where $x = |[M(K\pi) - M_0]/\sigma|$. The signal position, $M_0$, and width, $\sigma$, 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

\[
R_{u/d} = 1.014 \pm 0.068 \text{ (stat)}^{+0.024}_{-0.031} \text{ (syst)},
\]
\[
\gamma_s = 0.266 \pm 0.023 \text{ (stat)}^{+0.014}_{-0.012} \text{ (syst)},
\]
\[
P_v = 0.554 \pm 0.019 \text{ (stat)}^{+0.008}_{-0.004} \text{ (syst)}.
\]

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 $\approx 3.5$, as the measured $\gamma_s$ 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 $130 < W < 280$ 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

$$z = \frac{E + p_{||}}{E + p_{||}} \frac{D^{*\pm}}{2 E_{\text{jet}}}$$

where $p_{||}$ is the longitudinal momentum of the $D^{*\pm}$ meson relative to the axis of the associated jet of energy $E_{\text{jet}}$. 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 $p_T(D^{*\pm}) > 2$ GeV, $|\eta(D^{*\pm})| < 1.5$, $E_T^{\text{jet}} > 9$ 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 $\epsilon$. The MC was fit to the data via a $\chi^2$-minimisation procedure to determine the best value of $\epsilon$. 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 $\epsilon$ in the Peterson fragmentation function.

4 Summary

The measured $D^{*\pm}$, $D^0$, $D^\pm$, $D_s^\pm$ and $\Lambda^\pm$ 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 $\approx 3.5$, 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
dcharm fragmentation.

References

[1] ZEUS Collaboration, Measurement of charm fragmentation ratios and frac-
tions in $\gamma p$ collisions at HERA. Abstract 564, International Europhysics
Conference on High Energy Physics, Aachen, Germany (HEP 2003), July
2003; http://www-zeus.desy.de/physics/phch/conf/eps03_paper.html.

[2] ZEUS Collaboration, Measurement of charm fragmentation function in $D^*$
photoproduction at HERA. Abstract 778, International Conference on High
Energy Physics, Amsterdam, The Netherlands (ICHEP 2002), July 2002;
http://www-zeus.desy.de/physics/phch/conf/amsterdam_paper.html.

[3] L. Gladilin, Preprint hep-ex/9912064, 1999.

[4] F. Becattini, Z. Phys. C69 (1996) 485.

[5] Yi-Jin Pei, Z. Phys. C72 (1996) 39.

[6] H1 Collaboration, Measurement of Inclusive $D$-meson Production in Deep
Inelastic Scattering at HERA. Abstract 1015, International Conference on
High Energy Physics, Amsterdam, The Netherlands (ICHEP 2002), July
2002; available from http://www-h1.desy.de/.

[7] T. Sjöstrand, Comp. Phys. Comm. 82 (1994) 74.

[8] B. Anderson et al., Phys. Rep. 97 (1983) 31.

[9] M. G. Bowler, Z. Phys. C11 (1981) 169;
X. Artru and G. Mennesier, Nucl. Phys. B70 (1974) 93.

[10] C. Peterson et al., Phys. Rev. D27 (1983) 105.

[11] P. Nason and C. Oleari, Nucl. Phys. B565 (2000) 245.

[12] H. Albrecht et al., ARGUS Collaboration, Z. Phys. C52 (1991) 353.