Charm Fragmentation Fractions and the Charm Fragmentation Function

Zuzana Rúriková
for the H1 collaboration

Max-Planck-Institut für Physik, München, Germany
E-mail: rurikova@mail.desy.de

Abstract.
The fragmentation of a charm quark to charmed hadrons in deep-inelastic scattering has been studied using the H1 detector at HERA.

The visible cross sections for inclusive D^+, D^0, D_s^+ and D^{*+} meson production were determined making use of the secondary vertex displacement measured by the central silicon detector of H1 and fragmentation fractions and fragmentation ratios were extracted.

To investigate the fraction of the charm quark's momentum transferred to a charmed hadron, the differential cross section of D^*-meson has been measured as a function of two scaling observables.

The parameters of the Peterson and Kartvelishvili fragmentation functions, as implemented in a model with leading-order matrix elements, parton showers, string fragmentation and particle decays, were extracted from a fit to the measured distributions. The fits, using both observables, lead to the following ranges for the fragmentation parameters: $0.014 < \varepsilon < 0.036$ (Peterson) and $4 < \alpha < 6.8$ (Kartvelishvili).

Keywords: Charm, Fragmentation Fractions, Fragmentation Function
PACS: 12.39.St,13.87.Fh,14.40.Lb,14.65.Dw

INTRODUCTION

The production of a charm quarks is expected to be well described by perturbative QCD (pQCD) calculations due to the hard scale provided by the charm mass. However, the hadronization of a charm quark into a cluster of hadrons involves non-perturbative processes. Therefore, a theoretical description of the production of charmed hadrons contains a phenomenological, non-perturbative part, which, if used consistently, is expected to be process independent. In this article, we investigate the probability of a charm quark to hadronize to various charmed mesons and to transfer a fraction of its momentum to a D^{*+}-meson (charge conjugated states are always included). The analyses cover kinematic regions of photon virtuality $2 < \mathrm{Q}^2 < 100\ \mathrm{GeV}^2$ and inelasticity $0.05 < \mathrm{y} < 0.7$.

MEASUREMENT OF FRAGMENTATION FRACTIONS

The visible cross sections of D^+, D^0, D_s^+ and D^{*+} mesons were measured by the H1 collaboration [1] making use of the following decay channels: $D^+ \to K^-\pi^+\pi^+$, $D^0 \to K^-\pi^+$, $D_s^+ \to \Phi\pi^+ \to (K^+K^-)\pi^+$ and $D^{*+} \to D^0\pi^+ \to K^-\pi^+\pi^+$.

The relative large life time of weakly decaying D-mesons makes it possible to reconstruct the displacement of their decay point with respect to the primary vertex, using the

H1 central silicon tracker [3].

After cuts on secondary vertex quantities, the number of signal events is determined for each D-meson individually, by fitting the invariant mass distributions with a Gaussian to describe the signal and an appropriate background shape.

The fragmentation fractions $f(c \to D)$ are defined as the ratio of the total cross section of a given charmed meson to the one for a charm quark. Monte Carlo (MC) model was used to perform the extrapolation from visible to the total cross section for the charmed meson and to predict the cross section for charm production. The resulting values for $f(c \to D)$ are listed in Table 1. They agree well within errors with the world average values.

TABLE 1. Fragmentation fractions

Frag. fractions	D^+	D^0	D_s^+	D^{*+}
H1: $f(c \to D)$	0.203 ± 0.026	0.560 ± 0.046	0.151 ± 0.055	0.263 ± 0.032
World Average: $f(c \to D)$	0.232 ± 0.018	0.549 ± 0.026	0.101 ± 0.027	0.235 ± 0.010

The fragmentation fractions include in addition to the directly produced D-mesons all possible decay chains resulting in a particular charmed meson. The fragmentation ratios are used to characterize distinct aspects of fragmentation, such as the proportions of light quark flavours u,d and s created in the fragmentation process and the formation of different angular momentum states. The definition of these include only directly produced mesons. The measured ratios are summarized in Table 2. The detailed information about the definition of these parameters and their experimental determination can be found in [1].

TABLE 2. Fragmentation ratios

Ratio	**H1 measurement**				e^+e^- **experiments**	
	value	**stat.err.**	**syst.err.**	**theo.err.**	**value**	**err.**
P_V^d	0.693	$\pm$ 0.045	$\pm$ 0.004	$\pm$ 0.009	0.595	$\pm$ 0.045
P_V^{u+d}	0.613	$\pm$ 0.061	$\pm$ 0.033	$\pm$ 0.008	0.620	$\pm$ 0.014
$R_{u/d}$	1.26	$\pm$ 0.20	$\pm$ 0.11	$\pm$ 0.04	1.02	$\pm$ 0.12
γ_s	0.36	$\pm$ 0.10	$\pm$ 0.01	$\pm$ 0.08	0.31	$\pm$ 0.07

The ratio P_V of cross sections for a given combination of quarks to be produced in various spin states has been evaluated separately for the $c\bar{d}$ quark combination and the sum of $c\bar{u}$ and $c\bar{d}$ quark combinations. The ratio $R_{u/d}$ of probabilities for a charm quark to hadronize together with a u or d quark agrees well with the value of unity (isospin invariance). The suppression of s-quarks with respect to u and d quarks is measured by the factor γ_s and is found to be almost three.

These observations agree well with the values measured in e^+e^- and thus support the assumption of a universal fragmentation.

MEASUREMENT OF FRAGMENTATION FUNCTION

The momentum transfer from a charmed quark to a charmed hadron is usually described by a phenomenological fragmentation function. Widely used parametrizations are the

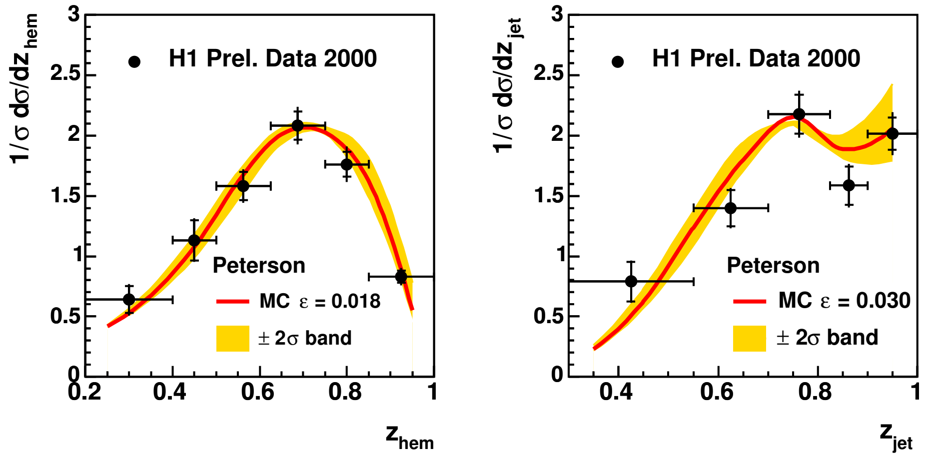

FIGURE 1. Measured D^{*+} z-distributions for the hemisphere method (left) and jet method (right) compared with a QCD model prediction (RAPGAP/PYTHIA), using the Peterson parametrization for the non-perturbative fragmentation function.

ones by Peterson et al. [4]. and by Kartvelishvili et al. [6], Their free parameters ε and α determine the "hardness" of the respective fragmentation function.

The H1 collaboration has measured the fragmentation function of charm to the D^{*+}-meson, reconstructing a D^{*+}-meson close to the kinematic threshold ($p_t(D^{*+}) > 1.5$ GeV) from the decay into $K^-\pi^+\pi_s^+$, with the $K^-\pi^+$ originating from the decay of the D^0-meson [2]. The definition of the variable z describing the fragmentation of a charm quark into a D^{*+}-meson in DIS is more ambiguous than for example in e^+e^- annihilation, where typically it is defined as $z = E_{D^*}/(\sqrt{s}/2)$. In this analysis we investigate two definitions based on different approaches.

In the first approach, the *jet method*, the charm quark momentum is approximated by the momentum of the jet which contains the reconstructed D^{*+}-meson. For this purpose the inclusive k_t-cluster algorithm [7] was applied in the γp-frame. The observable z is defined as $z = (E+p_{\rm L})_{D^*}/(E+p)_{\rm D^*jet}$, where p_L is the D^{*+}-momentum parallel to the jet direction. The $p_t(D^{*+}\,jet)$ is required to be greater than 3 GeV.

The second approach, the *hemisphere method*, is analogous to the method used in e^+e^- measurements. The event is divided into two hemispheres using the thrust axis calculated in a plane perpendicular to the photon direction in the γp-frame. The energy and the momentum of particles which are found in the hemisphere which contains the D^{*+}-meson is in first order a good approximation of that of the charm quark. Thus one defines $z = (E+p_{\rm L})_{D^*}/(E+p)_{\rm D^*hem}$.

The data were corrected to hadron level using the RAPGAP 3.1 MC interfaced with PYTHIA 6.2 and the full detector simulation and reconstruction package of H1. Radiative corrections were calculated using HERACLES 4.63.

The normalized D^{*+} fragmentation distributions $\frac{1}{\sigma}\frac{d\sigma}{dz}$ are used to extract the parameters of the Peterson and Kartvelishvili non-perturbative fragmentation functions, using the RAPGAP/PYTHIA MC. For steering the production of excited heavy states and other hadronization parameters, a set tuned [5] by ALEPH to their data has been used.

The fraction of resolved photon interactions contributing to D^{*+} production in our range of Q^2 was taken to be 33 % as predicted by RAPGAP.

The normalized cross section as a function of z_{hem} and z_{jet} on hadron level was generated for various values of the respective fragmentation parameter, and the resulting χ^2, comparing data and model predictions as a function of the fragmentation parameter, was calculated. The full correlation matrix was used, taking statistical and uncorrelated systematic errors as well as correlations into account.

TABLE 3. The extracted fragmentation parameters for Peterson and Kartvelishvili parametrizations.

Parametrization		Hemisphere Method	Jet Method	Range
Peterson	ε	$0.018^{+0.004}_{-0.004}$	$0.030^{+0.006}_{-0.005}$	$0.014 < \varepsilon < 0.036$
Kartvelishvili	α	$5.9^{+0.9}_{-0.6}$	$4.5^{+0.5}_{-0.5}$	$4 < \alpha < 6.8$

If the QCD based Monte Carlo model provides a correct description of all aspects of D^{*+}-production, then the jet and hemisphere methods should lead to the same extracted fragmentation parameter. The discrepancy ($< 3\sigma$) between the parameters may signal inadequacies in one or more aspects of the model. Therefore, at this stage of the analysis H1 prefers to suggest the following ranges for the fragmentation parameters: $0.014 < \varepsilon < 0.036$ (Peterson) and $4 < \alpha < 6.8$ (Kartvelishvili).

CONCLUSION

The production of a charm quarks is expected to be well described by perturbative QCD calculations. However, the hadronization of a charm quark involves a non-perturbative process which is not described by pQCD. The H1 collaboration has measured cross sections of D^+, D^0, D_s^+ and D^{*+}-mesons and used them to extract fragmentation fractions and ratios. The results of the measurement are in agreement with the world averages. The differential cross section for D^{*+}-mesons as a function of two scaling variables has been measured and used to extract parameters for the Peterson and Kartvelishvili parametrizations of fragmentation function.

REFERENCES

1. A. Aktas et al. [H1 collaboration], Eur.Phys.J. C38 (2005) 447-459.
2. A. Aktas et al. [H1 collaboration], H1prelim-05-074.
3. D. Pitzl et al., Nucl. Instrum. Meth. A **454** (2000)334. [arXiv:hep-ex/0002044]
4. C. Peterson, D. Schlatter, I. Schmitt and P. M. Zerwas, Phys. Rev. D **27** (1983) 105.
5. G. Rudolph [ALEPH collaboration], private communication.
6. V. G. Kartvelishvili, A. K. Likhoded and V. A. Petrov, Phys. Lett. B **78** (1978) 615.
7. S. D. Ellis and D. E. Soper, Phys. Rev. D **48**, 3160 (1993) [arXiv:hep-ph/9305266]; S. Catani, Y. L. Dokshitzer, M. H. Seymour and B. R. Webber, Nucl. Phys. B **406**, 187 (1993).