CHARMED QUARK FRAGMENTATION FUNCTIONS IN A MONTE CARLO QUARK RECOMBINATION MODEL

By V. Černý

CERN, Geneva*

and P. Lichard, J. Pišút

Department of Theoretical Physics, Comenius University, Bratislava, Czechoslovakia

(Received January 24, 1979)

Charmed quark fragmentation functions are calculated in a Monte Carlo quark-paron recombination model. It is shown that the shape of the fragmentation functions is rather sensitive to the leading behaviour of the charmed quark during the fragmentation process. We argue that the data on charmed meson production can provide useful information about the dynamics of this process.

Charmed quark fragmentation functions are relevent for the description of the charmed hadron production in e^+e^- annihilation via $e^+e^- \rightarrow c\bar{c}$ or in the deep inelastic neutrino scattering $\nu d \rightarrow \mu^- c$, $\nu s \rightarrow \mu^- c$ with a subsequent "fragmentation" of the charmed quark into final state hadrons. However, one need not take the word "fragmentation" too literally. The dynamics of the process may be quite different. The confinement forces play an essential rôle here. In the case of the e^+e^- annihilation the colour separation in the state of the c and $\bar{c}$ moving with large opposite velocities can lead to a copious quark-antiquark pair production in the central region. The final hadrons are then expected to be produced by the recombination of the initial leading quarks and the central $q\bar{q}$ pairs [1]. Thus the process may look like an inside-outside cascade rather than an outside-inside one. In Ref. [2], it was shown that a model based on such a recombination picture can give a reasonable description of the fragmentation functions of the light (u, d, s) quarks.

In this note we extend this model calculation to the case of the charmed quark fragmentation functions. These functions are interesting to study in detail, because one expects that only one charmed particle is produced. Because of the large c quark mass,

* Address: CERN, CH 1211 Genève 23, Switzerland.

the $c\bar{c}$ pairs do not appear in the central region (if the energies are not extremely high). Therefore the charmed mesons are produced by a recombination of the leading (initial) c quark with an antiquark from the polarization cloud. Since the recombination process is expected to be of a short range in rapidity, the observed D meson spectrum is closely related to the c quark distribution just prior to the recombination. We show that the shape of the fragmentation functions is very sensitive to the assumed behaviour of the leading quark during the "fragmentation" process. This fact is rather important. It suggests that the data on charmed hadron production can provide substantial information about the dynamics of this process.

In the calculations we model the multiproduction of hadrons in the situation where c and $\bar{c}$ quarks are (in the initial stage) moving fast in the opposite directions as it is expected in the e^+e^- annihilation. Particle spectra (densities) on the side of the leading c quark

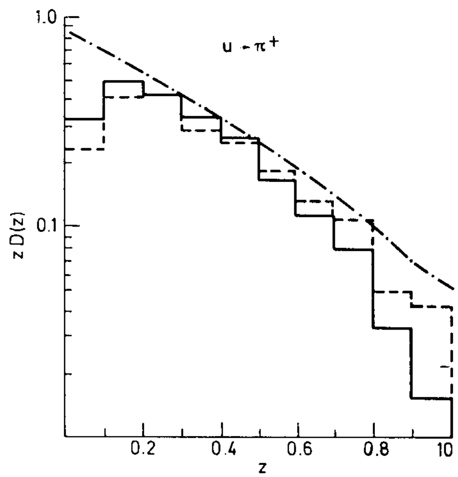

Fig. 1. The model calculations for u quark fragmentation into π^+ (histogram) corresponding to the energies (in the $e^+e^- \to u\bar{u}$) 4.8 GeV (dashed) and 7.4 GeV (solid). The dotted curve represents the analytic approximation of the Field and Feynman calculation [7]

then give directly the c quark fragmentation functions. The light quark fragmentation functions calculated in this model [2] appeared to be in good agreement with the recent data analyses (Fig. 1). We therefore assume that this approach can also give reasonable predictions for the charmed quark fragmentation functions.

For the computation we have used the Monte Carlo program simulating the multiparticle production in hadron-hadron collisions which is described in detail in Ref. [3]. Briefly speaking the program generates explicit parton configurations consisting of the leading (c and $\bar{c}$) quarks and of the central quarks and antiquarks. A weight is assigned to a generated configuration according to the formula

$$dP_N(\vec{p}_1, \dots \vec{p}_N) \sim G^{2N} W_{\text{id}} \sqrt{|x_1|}\sqrt{|x_2|} \exp\left(-\sum p_{Ti}^2/R^2\right)\delta\left(\sum \vec{p}_i\right)\delta\left(\sqrt{s}-\sum E_i\right)\prod d^3\vec{p}_i/2E_i, \tag{1}$$

which is basically given by the cylindrical phase space. W_{id} is a factor for identical particles, $\sqrt{|x_1|}\sqrt{|x_2|}$ are the Kuti and Weisskopf factors [4] assigned to the leading c, $\bar{c}$ quarks.

Because of the large c quark mass we assume that only light quarks are created in the central region. The $u\bar{u}$ and $d\bar{d}$ pairs are generated with equal probabilities, $s\bar{s}$ pairs are suppressed by a phenomenological factor $\lambda = P(s\bar{s})/P(u\bar{u})$.

The program then simulates the recombination of nearby (in rapidity) $Q\bar{Q}$, QQQ and $\bar{Q}\bar{Q}\bar{Q}$ into mesons, baryons and antibaryons. For example a D^{*+} meson can be created by a $c\bar{d}$ recombination, which, however, can also give a "direct" D^+. We fix the relative probabilities (by the spin counting arguments) of these two possibilities to 3 : 1. Similarly we proceed in the case of other mesons and baryons. The resonances created in the recombination process are then let to decay according to the experimental branching ratios.

Having fixed the model parameters to $G = 1.15$, $R^2 = 0.20\,(\text{GeV/c})^2$, $\lambda = 0.32$ by comparison of the model calculation with the data for the case of hadron-hadron collisions at corresponding energies [3], we obtained the charmed quark fragmentation functions presented in Fig. 2.

The fragmentation functions have rather different shapes from those of the light quarks which behave like $D(z) \sim 1/z$ for small z values and decrease at large z. The difference

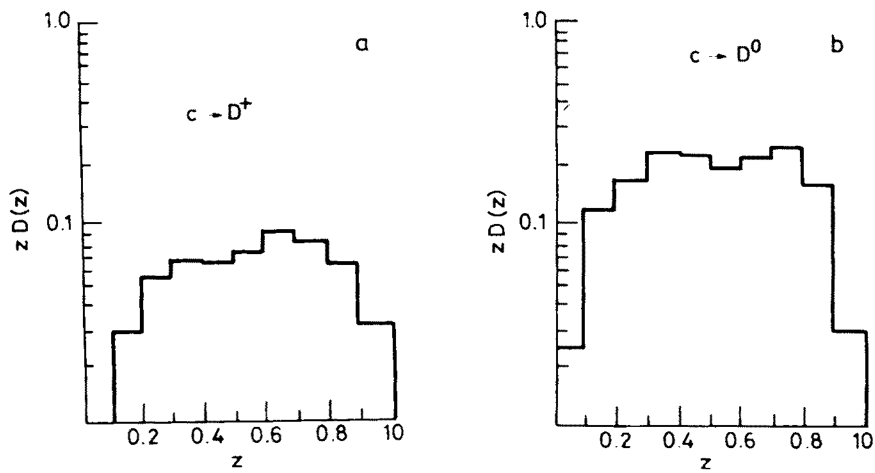

Fig. 2. The model calculations for the c quark fragmentation functions into D^+ (a) and D^0 (b) corresponding to the energy 20 GeV in the $c\bar{c}$ "initial state"

is due to the fact that "central" quarks alone cannot give rise to a charmed hadron, the recombination of the leading c quark is necessary.

In the fragmentation of quarks to non-charmed hadrons, resonance decays such as $\varrho \to \pi\pi$ are rather important. The final shape of the fragmentation is steeper than the one corresponding to the directly produced hadrons (resonances) since the kinematics of the $\varrho \to \pi\pi$ is such that the π's tend to have smaller longitudinal momenta than the parent ϱ's. In the case of charmed hadrons the situation is different. The D meson produced in the decay $D^* \to D\pi$ has almost the same momentum as the parent D^* since their mass difference is very small.

The experimental information about the charmed quark fragmentation functions is not yet quite conclusive. The D meson production has been observed in νN interactions [5] but the statistics is not large, and the energies in e^+e^- annihilation experiments have not been high enough up to now. Therefore the best information about the $D_c^D(z)$ functions still seems to be that coming from the analysis of the dimuon production in νN collisions [6]. This analysis suggests that the fragmentation functions are rather flat; our results are consistent with such a behaviour.

However, as we already pointed out, the c quark fragmentation functions are rather sensitive to the behaviour of the leading quark during the process. This is opposite to the case of the light quark fragmentation, where different models [7, 8] use slightly different assumptions about the leading quark behaviour, but the results are only weakly dependent on these details because of the copious "central" production and because of the resonance decays.

In our approach the leading rôle of the c quark (in contradistinction to the "central" quarks) is described by the Kuti–Weisskopf factor $\sqrt{x}$ in Eq. (1). For comparison we did a different calculation for the extreme case where the leading quark is always the fastest.

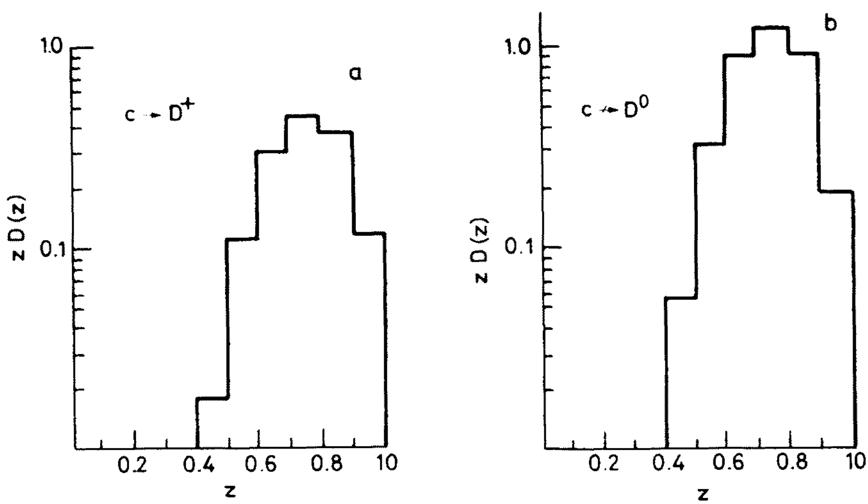

Fig. 3. c quark fragmentation functions obtained in the case when the c quark is always the fastest one in the recombination chain

We used Eq. (1) without the $\sqrt{x}$ factors but we kept the c quark and the $\bar{c}$ quark at the ends of the generated parton sequence (in the rapidity space). With parameters having the same values as in the previous case, we obtained fragmentation functions with a rather different shape (Fig. 3), peaked at large z values.

This is an important point, since it suggests that when higher statistics data on charmed meson production become available, one will be able to obtain information about the leading quark behaviour, in particular about its momentum distribution prior to the recombination. Such information may be useful for a better understanding of the rôle of the confinement forces. For example, in the models [9] where the central production is due to a (soft) bremsstrahlung-like process the leading quark spectrum is given as $(1-z)^{\alpha}$ where the power α is determined by the particle density in the central region.

The calculation with the leading quark kept at the end of the (rapidity) parton sequence gives a quantitative estimate of the kinematical effects due to the large mass of the leading quark as it was qualitatively discussed by Bjorken [10]. If one assumes that the dynamics of the (soft) "hadronization" process is such that the leading quark has always a larger rapidity (or velocity) than central partons, then its momentum distribution is strongly peaked at large z values since the transformation from the rapidity into momentum space reads $p = m_{\perp} \cosh y$. Although the effect is expected to be more pronounced for the case of very heavy quarks (top, bottom), our results suggest that it could be observed also in the c quark fragmentation.

However, in discussing these effects one has to keep in mind that in addition to soft hadronization processes the leading quark spectrum can also be modified by higher order hard processes (short-distance effects) [11]. A simple estimate can be done easily for the leading quark deceleration due to hard (collinear) gluon bremsstrahlung. These effects are in fact responsible for the scaling violations at high energies.

The gluon bremsstrahlung contribution to the Q^2 dependence of the first moment of the fragmentation function is given as [12]

$$^1D(Q^2) = \exp\left(-\tfrac{16}{9}\, Y\right) {}^1D(Q_0^2),$$

where

$$Y = \frac{1}{2\pi b} \log\left(1 + \alpha_s(Q_0^2) b \log\frac{Q^2}{Q_0^2}\right), \quad b = \frac{1}{12\pi}(33 - 2N_f).$$

Taking the reference value $Q_0 = 5$ GeV, one obtains for $Q = 20$ GeV

$$^1D(Q^2) \approx 0.8\, {}^1D(Q_0^2).$$

Since the Q_0 value is rather arbitrary, one can only roughly estimate that the hard (short--distance) processes take away about 10 to 20% of the leading quark momentum at PETRA energies. This has to be taken into account if one wants to discuss the soft (confinement) effects.

To conclude: we have presented predictions for the charmed quark fragmentation functions at higher energies based on a Monte Carlo quark-parton recombination model. An alternative calculation has shown that the shapes of the fragmentation functions are rather sensitive to the behaviour of the leading quark during the fragmentation process. It suggests that the data on charmed meson production can provide substantial information about the dynamics of this process.

One of the authors (V.Č.) is indebted to R. Odorico and C. Sachrajda for useful discussions.

REFERENCES

[1] J. D. Bjorken, Proceedings of the Summer Institute on Particle Physics, Ed. M. Zipf, SLAC-167 (1973); A. Kasher, J. Kogut, L. Susskind, *Phys. Rev. Lett.* **31**, 792 (1973).
[2] V. Černý, P. Lichard, P. Pišút, J. Boháčik, A. Nogová, to be published in *Phys. Rev.* D.
[3] V. Černý, P. Lichard, J. Pišút, *Phys. Rev.* **D16**, 2822 (1978); *Phys. Rev.* **D18**, 2409 (1978).
[4] J. Kuti, V. F. Weisskopf, *Phys. Rev.* **D4**, 3418 (1970).
[5] C. Baltay et al., *Phys. Rev. Lett.* **41**, 73 (1978).
[6] R. Odorico, V. Roberto, *Nucl. Phys.* **B136**, 333 (1978).
[7] R. D. Field, R. P. Feynman, *Nucl. Phys.* **B136**, 1 (1978).
[8] B. Anderson, G. Gustafson, C. Peterson, *Nucl. Phys.* **B135**, 273 (1978).
[9] S. Pokorski, Warsaw Preprint IFT 77-16 (1977).
[10] J. D. Bjorken, *Phys. Rev.* **D17**, 171 (1978).
[11] B. L. Ioffe, *Phys. Lett.* **78B**, 277 (1978).
[12] K. Konishi, A. Ukawa, G. Veneziano, CERN Preprint TH. 2509 (1978).