**SOME PROPERTIES OF CHARMED PARTICLES
PRODUCED IN NUCLEUS INTERACTIONS**

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ABSTRACT

The azimuthal correlation distribution of 102 charmed-particle pairs observed in the hybrid emulsion experiment WA75 is compared with theoretical predictions. The various pairs — $(D^- D^0)$, $(D^- D^+)$, $(D^0 \overline{D}^0)$, and $(D^+ \overline{D}^0)$ —all show, within statistical error, the same azimuthal correlation distribution, demonstrating its independence from the specific nature of the production channel.

Among the decays of 150 charged charmed particles and 138 neutral ones seen, higher multiplicities are favoured for hadronic as opposed to semileptonic decays. The data are consistent with the muonic decays of charged D mesons proceeding through the channels $(\mu^\pm, \nu, K^0)$ and $[\mu^\pm, \nu, K^{*0}(892)]$, the fraction through K^0 being 0.76 ± 0.06 .

1. INTRODUCTION

The determination of many of the quantities relevant to charm physics—such as cross-sections and lifetimes—requires a complete analysis in order to evaluate all the various efficiencies of an experiment, whereas for other quantities this is not necessary.

This letter includes the angular correlations observed between pairs of D mesons, whose study provides a good test for the theoretical models of charm production [1]. Previously published data provide a sample of some hundred events [2, 3]. In addition, the determination of some branching fractions of decays of charmed particles may be realized since they are little influenced by scanning inefficiencies.

In this letter some such results are presented which pertain to 102 pairs and 84 single charmed particles produced by the interactions of 350 GeV/c π^- mesons with emulsion nuclei and seen during the beauty search in the WA75 hybrid emulsion experiment carried out at the CERN Super Proton Synchrotron (SPS) [4]. The experimental details, including the calibration, selection, and scanning procedures, will be described elsewhere [5]. The scanning and the study of events produced in a second exposure with a slightly different experimental set-up, in which the iron/tungsten dump was replaced by a uranium/iron calorimeter, is still in progress.

2. SELECTION OF EVENTS

The schematic layout of the apparatus is shown in fig. 1. The beam hodoscope (BH) and the vertex detector (VD) enabled a triggered interaction to be located within the emulsion, and established the time correlation between neutral topologies and primary vertex. Muons reconstructed in the magnetic spectrometer downstream from the dump were associated with one of the tracks seen in the VD.

The on-line trigger requirement for an event was an interaction in the emulsion target and at least a muon in the downstream magnetic spectrometer. The off-line analysis then selected the events to be searched for in the emulsion, by introducing a further requirement: the transverse momentum of the muon measured with respect to the beam direction had to be greater than 1.0 GeV/c (which was reduced to 0.6 GeV/c for a small subsample). This was done in order to enhance the signal of beauty decays—the principal aim of the experiment—at the expense of the background. However, since the transverse momentum was not specified with respect to the particle's line of flight, no absolute kinematic constraint against charmed-particle decays was imposed and many were observed in the sample.

Events where the muon track was not seen at the primary vertex were carefully analysed, and a search for both charged and neutral decays was performed over a distance of at least 3 mm. In this way, 326 secondary vertices showing decay-like topologies were found, originating from 212 π -nucleus interactions. These were analysed with a program that uses, as input, the line of flight of the charm candidate, the directions of the secondary particles, and, where applicable, the momentum of the muon. The compatibility of each event with known decay schemes of D mesons, consistent with the observed topology, was tested. This was done by allowing the identities of each decay particle (other than the detected muon) to be, in turn, π and K, and by letting the momenta of the particles involved vary between set limits. The minimum value of the momentum was made equal, in all cases, to the assigned rest mass (times c), as the particle tracks were observed to be of near-minimum ionization. The maximum value was defined by the limiting value of the transverse momentum, set at 1.3 times the charmed-particle mass (times c) for the decay candidate and at the maximum allowed by the decay kinematics for the secondary particles. The momentum assigned to the muon was the measured one. A further constraint, that the total momentum be less than 300 GeV/c, was also imposed.

Since the experiment did not detect neutral secondaries, this analysis cannot reject background decay-like topologies completely. However, such a background is expected to be negligible for events with an identified muon, and very small for events produced in association with another short-lived particle. Moreover, the presence of $\Lambda_c^\pm$ and D_s events in the sample has not been considered, but because of their small production cross-sections and muonic branching fractions, it is not expected to be significant.

After the above analysis there remain 102 examples of charmed-particle pairs (one of each pair decaying to a muon) and 84 single muonic charmed decays. These have been classified according to the sign of the charge of the observed muon, and the results are presented in table 1.

A Monte Carlo simulation was performed to determine the momentum spectra, at production, of all D mesons and of those decaying muonically, with the muon being accepted by the apparatus and satisfying the p_T requirement. As expected, charmed particles whose decays activate the trigger have a considerably harder and flatter momentum spectrum than do their partners. Thus the decay-length distributions are expected, and indeed observed, to be different not only between neutral and charged D mesons because of their lifetimes, but also between the triggered events and the others owing to their different momentum spectra.

3. CHARM-PAIR CORRELATIONS

The associated production of charmed particles was calculated by several authors [6] using perturbative QCD. At the present time, however, there are no predictions concerning the production rates of various pairs of charmed particles.

According to the models, the distribution of the azimuthal angle φ , i.e. the angle between the projections of the charmed particles' lines of flight in a plane normal to the beam direction, is strongly dependent upon the distribution of the intrinsic parton momentum K_T and is barely affected by any subsequent 'dressing' processes. The fact that some of the D mesons are produced from the decay of D^* has a negligible influence on the φ distribution, since the Q value of this decay, (5.7 ± 0.5) MeV, is so small.

Figure 2a shows the distribution of the angle φ found for the charmed-particle pairs in the experiment. Even though there are many inefficiencies in locating the decays of charmed particles and these depend on their natures and energies, they depend little on φ , so its distribution should be unbiased. The mean value $\langle\varphi\rangle = (115 \pm 12)^\circ$ agrees well with that found by experiment NA27, namely $\langle\varphi\rangle = (115 \pm 8)^\circ$, but whereas both distributions peak near 180° , no evidence is seen here for the subsidiary peak observed by NA27 around 120° . The events which were rejected as charmed decays by the kinematics have, on the other hand, values of φ spread evenly over the whole range from 0° to 180° . It is thus expected that any residual background in the sample will have little effect on the above conclusions.

The distributions of the angle φ are shown separately for the different charmed pairs ($D^- D^+$), ($D^0 \bar{D}^0$), ($D^- \bar{D}^0$), and ($D^+ \bar{D}^0$) in figs. 2b-e, respectively. Although the statistics are meagre, the distributions appear similar, all showing a strong 180° peaking and giving experimental confirmation of the expectation that the φ distribution is independent of whichever charm pairing is being considered.

The curves superimposed on fig. 2a have been computed according to various theoretical models, with the intrinsic parton momentum distribution given by

$$\frac{dN}{dK_T^2} = \frac{\exp(-K_T^2/\langle K_T^2 \rangle)}{\langle K_T^2 \rangle} .$$

The value $\langle K_T \rangle = 0.64 \text{ GeV}/c$ was taken from the results of lepton-pair hadroproduction experiments [7].

The curves which have been normalized to the total number of charmed pairs in the sample are based on two models.

– The fusion model [1]

Here the colliding partons, gg or qq , produce charmed–anticharmed quark pairs undergoing fragmentation and leading to the charmed mesons D , $\bar{D}$. The fragmentation function for the formation of the charmed mesons from the quarks depends on the variable z , $\bar{z}$, where

$$z = |p|/|P|, \quad \bar{z} = |\bar{p}|/|\bar{P}|,$$

where p ($\bar{p}$) is the meson momentum, and P ($\bar{P}$) is the momentum of the charmed (anticharmed) quark.

The fragmentation functions are

- i) $D(z) = \text{const} \times \{z[1 - (1/z) - 0.15/(1 - z)^2]\}^{-1}$, as suggested by e^+e^- experiments [8];
- ii) $D(z) = \delta(1 - z)$ (that is, the momentum of the charmed meson is taken equal to that of the charmed quark).

The predicted φ distributions are shown as curves A and B in fig. 2a.

– The cluster model [9].

Quark–quark scattering produces a hadronic cluster of fixed mass of $\sim 5 \text{ GeV}/c^2$, which decays in its rest frame with a fragmentation function of the Boltzmann type (curve C in fig. 2a).

Whilst it is seen that the experimental data are well reproduced by the fusion model, with the fragmentation function giving curve A, agreement with the cluster model is weaker. The strong asymmetry of the φ distribution shows that effects due to the Fermi motion of the nucleons that are struck, or to rescattering inside the nuclei, must be small.

4. TOPOLOGICAL BRANCHING RATIOS

Since the detection efficiencies within a given sample (neutral or charged particle, decay into muons or not) are comparable for different topologies, and since from Monte Carlo simulation there is no observable correlation between muon acceptance and event topology, it is possible to determine the topological branching ratios for various groups.

For this purpose, use will be made of the double charm events, and also of those for which only one muonic charmed decay was observed. The complete sample is then 188 charmed-particle decays in which a decay muon was observed in the spectrometer, and 100 in which it was not.

Table 2 shows the topological categories, where C and N refer to charged and neutral charmed particles, respectively, and the numbers are those of the charged decay particles.

It should be stressed that because of the trigger selection and different efficiencies, it is valid to compare only the frequencies of topologies within each box of Table 2.

The data, however, clearly show that the presence of a muon among the decay products is strongly correlated to low charged-particle multiplicities. This effect is seen for both neutral and charged charmed-particle decays.

The topologies of charged-particle decays with a muon have a ratio $R = C3/C1 = 0.19 \pm 0.06$, no topologies with higher multiplicities having been seen. If one disregards any contribution from the purely leptonic decays $D \rightarrow \mu + \nu$, as the branching ratio is expected to be very small [10, 11], then this sample arises from semileptonic decays, the Cabibbo-favoured ones being

$$D^{\pm} \rightarrow K^0 + \mu^{\pm} + \nu , \quad (1)$$

$$D^{\pm} \rightarrow K^{*0}(892) + \mu^{\pm} + \nu . \quad (2)$$

For K^0 production, in reaction (1) all events will appear as C1, whereas for reaction (2) two-thirds of $K^{*}(892)$ decay into $(K^{\pm} \pi^{\mp})$ pairs giving C3 topologies and one-third into $(K^0 \pi^0)$ giving C1. The branching fraction f of D 's decaying semileptonically through reaction (1) is then related to R , the C3/C1 ratio, by

$$f = \frac{2 - R}{2(R + 1)} = 0.76 \pm 0.06 .$$

This result should be compared with results reported by e^+e^- collider experiments in which this ratio was estimated by fitting the electronic decay spectrum. These are $f = 0.55 \pm 0.14$ (MARK III [12]) and $f = 0.35 \pm 0.12$ (DASP [13]).

For decays with no detected muon, the ratio $R = C3/C1$ has the value $R = 0.40 \pm 0.13$. If allowance is made for a contribution, to this sample, of $\sim 20\%$ semileptonic decays in which the lepton was not identified as such (mainly electronic decays), this result leads to a topological branching ratio for hadronic decays of charged D mesons of $R = 0.50 \pm 0.16$, to be compared with a result from SPEAR of 0.80 ± 0.23 (14).

The decays of neutral charmed mesons into a muon and three other charged particles has not been observed in the WA75 experiment, despite the fact that the simulation shows the acceptances of the apparatus to the muons from N2 and N4 topologies to be similar. For neutral charmed mesons, the dominant semileptonic modes are expected to be

$$D^0(\bar{D}^0) \rightarrow K^{\pm} + \mu^{\mp} + \nu ,$$

$$D^0(\bar{D}^0) \rightarrow K^{*\pm}(892) + \mu^{\mp} + \nu .$$

As the $K^{*}(892)$ is known to decay into more than one charged particle with a frequency of less than 10^{-3} [15], it is concluded that N4 topologies with a muon should be very rare, consistent with the fact that they have not been observed.

Making the small correction for unobserved electronic decays (expected to be N2 only), the topological ratio $R = N4/N2$ for hadronic decays of D^0 mesons becomes 0.24 ± 0.09 , in good agreement with the result from SPEAR, namely $R = 0.25 \pm 0.07$ [14].

In conclusion, the use of the emulsion technique in a hybrid apparatus allowed us not only to measure the line of flight of charmed particles with good accuracy and to observe the decay point directly with negligible biases, but even to determine their charge status without ambiguity (through the muon sign). Thus it was possible, without any hypothesis on the branching ratios and relative corrections, to explore the charm production and decay mechanism.

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Table 1

Observed decays of charmed particles (pairs and singles)
classified according to their charge status and to the sign of the muon

29 ^{a)}	$D^- D^+$	23	D^-
24	$D^+ \overline{D^0}$	19	D^+
26 ^{a)}	$D^0 D^-$	20	D^0
23	$D^0 \overline{D^0}$	22	$\overline{D^0}$

a) One pair has both charmed particles decaying muonically.

Table 2

Observed decays of charmed particles according to their topologies
and to the presence, or not, of the muon

	Topologies	With μ	Without μ
Charged charms	C1	84	35
	C3	16	14
	C5	–	1
Neutral charms	N2	88	40
	N4	–	10

Figure captions

Fig. 1 : Schematic layout of the apparatus.

Fig. 2 : Distributions of azimuthal angles between the lines of flight of charmed pairs: a) for all the pairs; b) to e) for the four different possible pairings. The curves, normalized to the number of observed events, refer to different theoretical models (see text).

Fig. 1

Fig. 2