RESULTS ON CHARMED MESON DECAY FROM THE WA82 EXPERIMENT AT THE CERN OMEGA SPECTROMETER

WA82 Collaboration*

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Summary

The WA82 experiment has collected data with the Ω' spectrometer at the CERN SPS. Its aim was a high statistics study of charm hadroproduction, using a silicon microstrip vertex detector and a trigger on impact parameter. WA82 is also studying rare decay modes for charm. Latest results on non-leptonic charmed meson decay branching ratios are presented here, including the study of doubly Cabibbo-suppressed modes for D^+. This analysis, using the particle identification provided by a Ring Imaging CHerenkov detector (RICH), gives an indication for a new decay mode, $D^+ \rightarrow K^-K^+K^+$. An upper limit for the $D^+ \rightarrow K^+\pi^-\pi^+$ mode branching ratio is also obtained.

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Much work has been carried out in trying to understand the so-called charm-decay puzzle ([1]): 1° the difference between the lifetime of the D^+ meson and the lifetimes of the D^0 and D_S^+ mesons; 2° disagreements between experimental data and theoretical expectations for D^0 decays. It has been shown early ([2]) that the origin of this puzzle was in the non-leptonic sector. Effects of possible relevance include non-leptonic decays occurring via processes not described by spectator diagrams, final-state interactions and the destructive interference that may arise in the Cabibbo-favoured decays of the D^+ but not in the decays of the D^0. It is noted that doubly Cabibbo-suppressed decays (hereafter referred to as DCSD) of D^+ are not subject to destructive interference, therefore their relative branching fractions might be enhanced ([3]). It has been also pointed out ([4]) that, for a $D^0\overline{D^0}$ mixing search, the DCSD of D^0 represent a background with a strength which needs to be measured and treated theoretically in a detailed way.

WA82 has measured relative branching fractions for the semileptonic decay $D^+ \rightarrow \overline{K}^{*0} e^+ \nu_e$ ([5]) (the charge conjugate states will be implicitly included throughout this paper) and for several charmed meson non-leptonic decay modes ([6]): 1° Cabibbo-suppressed decays $D^0 \rightarrow K^- K^+$, $D^0 \rightarrow \pi^- \pi^+$ and $D^0 \rightarrow \pi^- \pi^- \pi^+ \pi^+$; 2° $D^\pm$ and $D_S^\pm$ 3-body decays, in particular $D_S^+ \rightarrow \pi^-\pi^+\pi^+$ and $D^+ \rightarrow K^-K^+K^+$ (DCSD) which cannot be described by simple spectator diagrams, but must involve annihilation sub-processes or final-state rescattering. The E691 collaboration has observed the decay $D_S^+ \rightarrow \pi^- \pi^+ \pi^+$ ([7]) in addition to the decay $D^+ \rightarrow \pi^- \pi^+ \pi^+$ previously reported by Mark III ([8]). The decay $D^+ \rightarrow K^- K^+ K^+$ has been studied by E691 ([9]) in the ϕ-resonant mode only. A measurement for the other DCSD considered here, $D^+ \rightarrow K^+ \pi^- \pi^+$, has been performed by Mark III ([10]), showing an excess of events above background corresponding to a 2.5 σ significance.

In the WA82 experiment the CERN Omega Spectrometer, supplemented with a silicon microstrip detector, was used to study charmed hadrons produced by interactions of 340 GeV/c π^- mesons on a 2 mm thick target. Some 5×10^7 events were recorded and are used in the present analysis. For 60 % of the data, particle identification was provided by a Ring Imaging CHerenkov detector (RICH). The experimental set-up, the trigger requirements, the data processing and the event selection and simulation have been described in previous publications ([6,11,12]). Kaon identification with the RICH was performed by cutting on x_K, the ratio between the conditional and the *a priori* probability for the kaon mass hypothesis. Its efficiency has been determined experimentally as a function of momentum by considering the signals for D^0 and D^+ Cabibbo-favoured decays ([12]). The signal over noise ratio can be further improved by cutting on the proper lifetime of the decay candidate.

Fig. 1 shows the invariant mass distributions for the full data sample, for the D^0 Cabibbo-suppressed decays; $\pi^-\pi^+\pi^+$ modes for $D^\pm$ and $D_S^\pm$ are given by fig. 2 (a-b). In the distributions for pure pionic (resp. kaonic) modes, extra peaks appear, due to the reflection of the corresponding Cabibbo-favoured mode in which the kaon (resp. pion) is wrongly assumed to be a pion (resp. kaon). The fits give 103 ± 27 events for K^-K^+, 51 ± 13 events for $\pi^-\pi^+$ and 64 ± 12 events in $\pi^-\pi^-\pi^+\pi^+$. For $D^\pm$ and $D_S^\pm$, we have also asked that the calculated proper lifetime, τ, of a decay candidate should be greater than some specified value. The cut $\tau > 0.8$ ps eliminates a substantial part of the D_S^+ signal, while the D^+ signal is little affected, as is to be expected from the D^+ and D_S^+ lifetimes. For the calculation of relative branching fractions we obtain a reduced background, with no significant loss of statistics, by requiring $\tau > 0.8$ ps when considering D^+ and $\tau > 0.5$ ps when considering D_S^+. The fits give then 19.7 ± 7.0 events for D^+ and 28.6 ± 8.4 events for D_S^+. Fig. 2 (c) shows the $K^-K^+K^+$ invariant mass distribution for the data sample for which RICH information was available. In order to optimise background reduction, while keeping evidence of a signal, we request $x_K > 0.5$ for both K^+ candidates. The RICH cut approximately halves, to 13.1 ± 4.5, the number of events in the peak at the D^+ mass. This is consistent with the RICH efficiency for the mode considered (0.40 ± 0.03). By contrast, the background is reduced by more than a factor of 5. To further reduce the background and check the compatibility of the observed peak with a D^+ signal, we have also applied cuts on proper lifetime, obtaining the invariant mass distribution shown in fig. 2 (d) for $\tau > 1.3$ ps. There is then a peak of 5.7 ± 2.8 events at the D^+ mass, in agreement with the numbers expected from simulated data and from the observed reduction of the $D^+ \to K^- \pi^+ \pi^+$ signal. Fig. 2 (e) shows a $D^+ \to K^+ \pi^- \pi^+$ distribution ($x_K > 0.5$ for the kaon candidate and $\tau > 1.3$ ps), for which no signal is visible. The $D^+ \to K^- \pi^+ \pi^+$ distribution with the same selection criteria and practically no background is given by fig. 2 (f). We obtain an upper limit for $D^+ \to K^+ \pi^- \pi^+$ of 6.5 events at a confidence level of 90%.

The number of events in the various decay modes was determined by maximum likelihood fits to the invariant mass distributions. Signal peaks are fitted with gaussians. Linear functions are used to describe the structureless backgrounds except in the case of $D^+ \to K^- K^+ K^+$ (and $D^0 \to K^- \pi^- \pi^+ \pi^+$, not shown), where a quadratic function is adopted. The tails of the reflection peaks are modelled as Breit-Wigner curves, as given by simulated data for the Cabibbo-favoured modes. When considering signals other than $K^-\pi^+$, $K^-\pi^+\pi^+$ or $K^-\pi^-\pi^+\pi^+$, the meson masses are fixed to the PDG values ([13]) and peak widths are those determined from simulated events.

Relative detection efficiencies for the decay modes considered have been determined from the simulated data. The effect on the $\pi^-\pi^+\pi^+$ and $K^-K^+K^+$ invariant mass distributions of the proper lifetime cuts used in our analysis is compatible with the expectations both from simulation and from the observed reduction of the $D^+ \to K^- \pi^+ \pi^+$ signal. Our results are summarized and compared with the current PDG data ([13]) in table 1. For each of our measurements the first error quoted is statistical and the second is systematic, taking into account uncertainties in the calculated detection efficiencies and different parameterisations of the background. Our results for previously established modes are in agreement with the PDG values. We find also, using the value of $\Gamma(D^+ \to K^-\pi^+\pi^+)$ from the PDG,

$$B(D^+ \to K^-K^+K^+) = (4.6 \pm 1.6 \pm 0.7) \times 10^{-3}.$$

We find no evidence either for $D_S^+ \to K^- K^+ K^+$ nor for a significant $D^+ \to \phi K^+$ resonant contribution in $D^+ \to K^- K^+ K^+$. The latter is not incompatible with the E691 result ([9]) of $B(D^+ \to \phi K^+) = (3.3^{+1.8}_{-1.5} \pm 0.8) \times 10^{-4}$, which in our data would yield a signal of 1.3 events. Similarly, we obtain

$$B(D^+ \to K^+\pi^+\pi^-) < 3.3 \times 10^{-3} \text{ (90\% CL)},$$

to be compared to the Mark III result [10] of $B(D^+ \to K^+\pi^+\pi^-) = (3.9^{+0.9+0.9}_{-0.8-0.8}) \times 10^{-3}$.

In conclusion, we have measured relative branching fractions for some D^0, D^+ and D_S^+ decays. Our measurements for the D^0 are in good agreement with the other recent measurements, in particular for $D^0 \to \pi^- \pi^- \pi^+ \pi^+$ for which a relative branching ratio of the double of the naïve $\tan^2\theta_c$ expectation has been obtained with a good precision. This paper focuses on DCSD and, in particular, on the study of a new decay $D^+ \to K^- K^+ K^+$ in the non-resonant mode, the identification of which was possible using RICH information and reinforced by lifetime cuts.

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Table 1. - Comparison between WA82 results and PDG data.

	WA82	PDG
$\frac{\Gamma(D^0\to K^-K^+)}{\Gamma(D^0\to K^-\pi^+)}$	$.107 \pm .029 \pm .015$	0.113 ± 0.007
$\frac{\Gamma(D^0\to \pi^-\pi^+)}{\Gamma(D^0\to K^-\pi^+)}$	$.048 \pm .013 \pm .008$	0.045 ± 0.005
$\frac{\Gamma(D^0\to K^-K^+)}{\Gamma(D^0\to \pi^-\pi^+)}$	$2.23 \pm 0.81 \pm 0.46$	≈ 2.5
$\frac{\Gamma(D^0\to \pi^-\pi^-\pi^+\pi^+)}{\Gamma(D^0\to K^-\pi^-\pi^+\pi^+)}$	$.115 \pm .023 \pm .016$	0.100 ± 0.011
$\frac{\Gamma(D^+\to \pi^-\pi^+\pi^+)}{\Gamma(D^+\to K^-\pi^+\pi^+)}$	$0.032 \pm 0.011 \pm 0.003$	0.035 ± 0.007
$\frac{\Gamma(D^+\to \phi\pi^+)}{\Gamma(D^+\to K^-\pi^+\pi^+)}$	$0.062 \pm 0.017 \pm 0.006$	0.075 ± 0.007
$\frac{\Gamma(D^+\to \pi^-\pi^+\pi^+)}{\Gamma(D^+\to \phi\pi^+)}$	$0.52 \pm 0.23 \pm 0.05$	
$\frac{\Gamma(D_s^+\to \pi^-\pi^+\pi^+)}{\Gamma(D_s^+\to \phi\pi^+)}$	$0.33 \pm 0.10 \pm 0.04$	$0.44 \pm 0.10 \pm 0.04$
$\frac{\Gamma(D^+\to K^-K^+K^+)}{\Gamma(D^+\to K^-\pi^+\pi^+)}$	$0.057 \pm 0.020 \pm 0.007$	
$\frac{\Gamma(D^+\to K^-K^+K^+)}{\Gamma(D^+\to \phi\pi^+)}$	$0.49 \pm 0.23 \pm 0.06$	
$\Gamma(D^+ \to K^-K^+K^+)/\Gamma_{total}$	$(4.6 \pm 1.6 \pm 0.7) \times 10^{-3}$	
$\frac{\Gamma(D^+\to K^+\pi^+\pi^-)}{\Gamma(D^+\to K^-\pi^+\pi^+)}$	< 0.042 90% CL	< 0.05 90% CL
$\Gamma(D^+ \to K^+\pi^+\pi^-)/\Gamma_{total}$	$< 3.3 \times 10^{-3}$ 90% CL	$< 4 \times 10^{-3}$ 90% CL

Fig. 1.

(a) K^-K^+ invariant mass distribution for the full data sample.
(b) $\pi^-\pi^+$ invariant mass distribution.
(c) $\pi^-\pi^-\pi^+\pi^+$ invariant mass distribution.

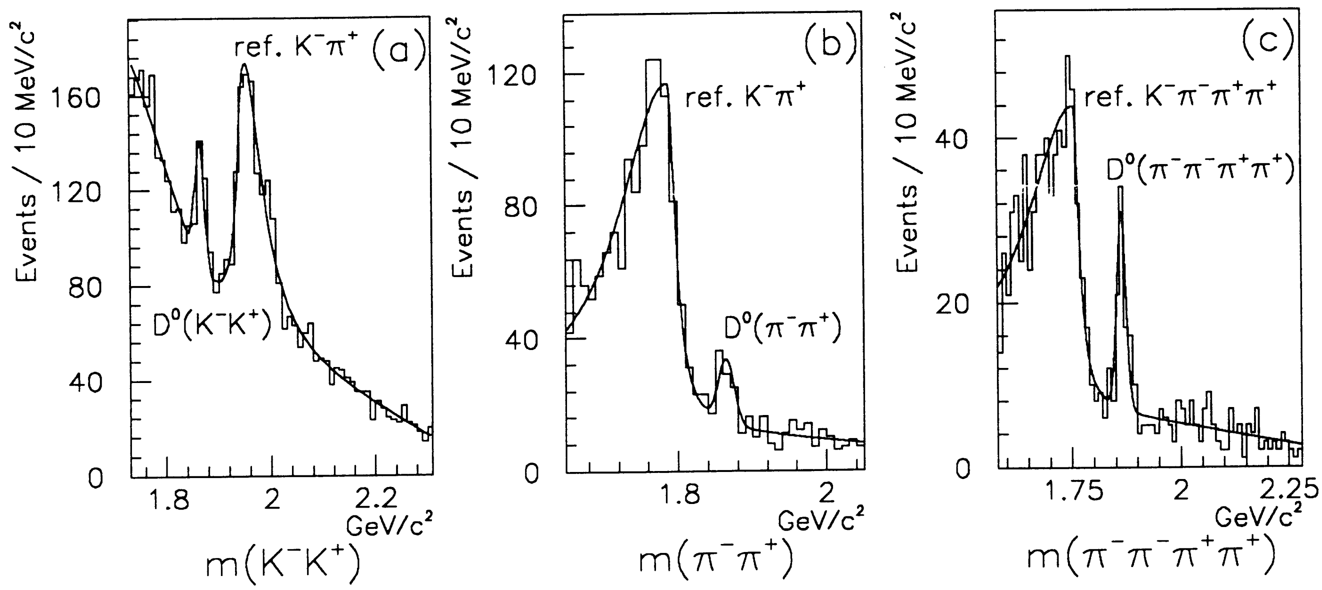

Fig. 2.

(a-b) $\pi^-\pi^+\pi^+$ invariant mass distribution for the full data sample, cuts on proper lifetime as indicated.

(c) $K^-K^+K^+$ invariant mass distribution for the 60 % of data for which RICH information is available, with no RICH identification (dotted line) and with $x_K > 0.5$ for both K^+ candidates (solid line).

(d) Upper curve as solid line of (c); shaded area with additional requirement $\tau > 1.3$ ps.

(e-f) $K^+\pi^-\pi^+$ and $K^-\pi^+\pi^+$ invariant mass distributions with $x_K > 0.5$ for the K candidate and $\tau > 1.3$ ps.