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MEASUREMENT OF CHARMED PARTICLE LIFETIMES AND DECAY BRANCHING RATIOS

Photon Emulsion Collaboration

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ABSTRACT

The lifetimes of charmed hadrons photo-produced in nuclear emulsion have been computed from a practically background-free sample of 44 neutral particle decays and 42 charged particle decays including 27 $D^{\pm}$, 11 Λ_c^+, 1 F^+ and 3 ambiguous decays.

The values obtained are:

$$\tau(D^o, \bar{D}^o) = (3.6 {}^{+1.2}_{-0.8} \pm 0.7)\ 10^{-13} s,$$

$$\tau(D^{\pm}) = (5.0 {}^{+1.5}_{-1.0} \pm 1.9)\ 10^{-13} s,$$

$$\tau(\Lambda_c^+) = (2.3 {}^{+0.9}_{-0.6} \pm 0.4)\ 10^{-13} s.$$

Branching ratios of various decay topologies were also obtained.

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† The authors wish to dedicate this work to the memory of their two friends and colleagues deceased recently.

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1. INTRODUCTION

The weak decays of heavy quarks are described by relatively simple schemes based on the coupling of quarks and leptons to the charged weak bosons $W^{\pm}$. Therefore in recent years, several experiments have been performed to study the weak decay features of heavy flavours.

In this paper we present a measurement of the lifetime and of the decay branching ratios of the $D^{o}/\bar{D}^{o}$, $D^{\pm}$ and Λ_c^{+} charmed hadrons photoproduced in nuclear emulsion.

It is an updating of previous results [1-3] based on about twice more events. The experiments (WA45 and WA58) have been performed at the CERN SPS exposing NIKFI BR2 emulsion, coupled with the Ω' spectrometer, to a tagged photon beam from 20 to 70 GeV [4].

2. EXPERIMENTAL METHOD

A detailed description of our experimental method and instrumental set up can be found elsewhere [5], but we wish to mention here some of the main features of the experiment:

The two usual scanning methods for particle decays in emulsion were used:

(a) for charged particle decays, tracks at minimum ionization from selected primary interactions emitted in a forward cone of ± 15° were followed until they left the emulsion or led to a decay or a secondary interaction;

(b) for neutral particle decays, a volume scanning was performed in a forward cone of ± 15°, starting from the primary interaction.

The scanning efficiency was determined for charged and neutral decays. In the charged case an efficiency of 0.94 was found, independently of the distance from the primary interaction. In the neutral case each laboratory has determined its own efficiency as a function of the distance from the primary interaction up to the maximum distance in which the scanning volume was performed [2, 3]. In Table 1, we give the breakdown of our charmed particle sample. It shows that most of these were observed in pairs, which reduces drastically the possibility of background events.

In the cases where only one charged decay-like secondary vertex was found, in order to avoid the contamination of the expected background, only 3C fit events were accepted. In view of the geometry of the emulsion target and of the presumed fraction of decays into all neutral particles, we roughly expected some 30% of single decays in our sample.

3. LIFETIME OF CHARMED HADRONS

We should like to point out that since our last publications on charmed particle lifetime [2, 3] our statistic of events has been roughly doubled.

In order to evaluate the lifetime, the scanning efficiency $\varepsilon(t)$ is folded in the likelihood function as follows:

$$L = \prod_{i=1}^{n} \left\{ \varepsilon_i(t) \exp(-t_i/\tau) \Big/ \int_{t_i^{min}}^{t_i^{max}} \varepsilon_i(t) \exp(-ti/\tau)\, dt \right\} \qquad (1)$$

where t_i^{min} and t_i^{max} stand for the times of flight corresponding respectively to the minimum and maximum measurable path lengths in the emulsion for the ith particle [3].

When two different hypotheses are allowed for the decaying particle (ambiguous decays), a weight is associated to each hypothesis according to a Monte Carlo calculation or kinematic fit [2].

4. LIFETIME RESULTS

The mean lifetime is obtained by maximizing the likelihood function (1). For the neutral D mesons we obtain:

$$\tau(D^o, \bar{D}^o) = (3.6 \, {}^{+1.2}_{-0.8} \pm 0.7)\ 10^{-13}\ s \qquad (2)$$

where the systematic error 0.7 results from the two extreme values of t_i obtained by the maximum or the minimum solutions for the momentum in the OC fit events. If we use only the 39 neutral D from the double events of our sample, the value obtained is $(3.8 \, {}^{+1.4}_{-0.9} \pm 0.8)\ 10^{-13}$s.

For the charged D mesons, using all the 27 events, the lifetime is:

$$\tau(D^{\pm}) = (5.0 \,^{+1.5}_{-1.0} \pm 1.9)\ 10^{-13}\ s \ , \tag{3}$$

a value which remains stable when the lifetime is computed including the ambiguous events, or using only the 23 double events. If we use only the 15 negatively charged D mesons, we get:

$$\tau(D^{-}) = (6.1 \,^{+2.6}_{-1.6}) \times 10^{-13} s \tag{4}$$

which is fully compatible with the former one.

The lifetime ratio between the lifetimes of charged and neutral D mesons turns out to be

$$R = \frac{\tau(D^{\pm})}{\tau(D^{o},\ \bar{D}^{o})} = 1.4 \,^{+0.6}_{-0.4} \pm 0.6 \ . \tag{5}$$

The computed lifetime for the Λ_c^+ baryons, using the unambiguous events only, is

$$\tau(\Lambda_c^+) = (2.3 \,^{+0.9}_{-0.6} \pm 0.4)\ 10^{-13}\ s \ . \tag{6}$$

Again this value does not change significantly when adding the two ambiguous events.

The fully reconstructed F^+ event decays through the channel $F^+ \rightarrow \pi^+\pi^+\pi^-\pi^o$. None of the $\pi^+\pi^-\pi^o$ combinations gives the ϕ mass, which could be a signal of the contribution of an annihilation mechanism.

The neutral D and Λ_c^+ lifetimes agree with the reported values obtained with comparable statistics [6]. The charged D lifetime is lower than the world average but it is compatible with it within the statistical and systematic errors.

5. MASSES CALCULATION

The values of the hadron masses computed from the 3C fit events mentioned in Table 1 are shown in Table 2.

6. DECAY BRANCHING RATIOS

We have computed the branching ratios for the different channels observed in our experiments, taking into account the proper weights for the ambiguous events. For the neutral D, the branching ratios are computed assuming that 8% of the particles decay in all neutral secondaries [7]. The results are given in Table 3.

In the case of Λ_c^+ baryons, we computed the relative decay width of each channel with respect to the total hadronic width in the following way

$$\frac{Q(\Lambda_c^+ \rightarrow \text{channel})}{Q(\Lambda_c^+ \rightarrow \text{hadrons})}$$

the results are listed in Table 4.

There are not many results to compare these data with. However, Abe et al. [8] published recently some Λ_c^+ branching fractions which are compatible with those presented here.

On the other hand, it is usual to define a C_n fraction of topological decay as the fraction of decays giving n charged secondaries [9]. In that respect, we obtain C_4 topology/C_2 topology = 0.33 ± 0.12; C_2 topology $\rightarrow K^\pm$ + anything/C_2 = 0.60 ± 0.17 and $C_4 \rightarrow K^\pm$ + anything/C_4 = 0.79 ± 0.36.

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TABLE CAPTIONS

Table 1 Breackdown of the charmed particle sample used in this paper.

Table 2 Charmed particle masses computed from 3C fit events.

Table 3 Weighted branching ratios for different decay channels of neutral and charged D mesons.

Table 4 Relative decay width for different decay channels of Λ_c^+ baryons.

Table 1

Particle	No. of decays	Fit (contraints)			Single events
		0C	2C	3C	
D^o, $\bar{D}^o$	44	28	–	16	5
D^+	12	6	1	5	3
D^-	15	10	1	4	1
Λ_c^+	11	7	–	4	–
F^+	1	–	–	1	–
D^+/Λ_c^+	2	1	–	1	1
D^-/F^-	1	1	–	–	–
Total	86	53	2	31	10

Table 2

Hadron	$D^o/\bar{D}^o$	$D^{\pm}$	Λ_c^+	F^+
3C fit evts.	16	9	4	1
Mass (GeV/c^2)	1852 ± 7	1875 ± 10	2301 ± 17	1965 ± 60

Table 3

Channel	Branching Ratio (Relative numbers)
$D^o \to K^- \pi^+$	6 ± 4
$D^o \to K^- \pi^+ n\pi^o$	35 ± 10
$D^o \to \bar{K}^o \pi^+ \pi^-$; $D^o \to \bar{K}^o \pi^+ \pi^- n\pi^o$	25 ± 8
$D^o \to K^- \pi^+ \pi^- \pi^+ n\pi^o$	8 ± 4
$D^o \to \bar{K}^o \pi^+ \pi^- \pi^+ \pi^-$	2.7 ± 2.4
$D^+ \to \bar{K}^o \pi^+$; $D^+ \to \bar{K}^o \pi^+ n\pi^o$	20 ± 9
$D^+ \to \bar{K}^o \pi^+ \pi^- \pi^+$	18 ± 9
$D^+ \to K^- \pi^+ \pi^+$	27 ± 11
$D^+ \to K^- \pi^+ \pi^+ n\pi^o$	18 ± 9

Table 4

Decay Channel	Relative width (%)
$\Lambda_c^+ \to \Lambda^o$ + hadrons (Σ^o included)	49 ± 24
$\Lambda_c^+ \to p$ + hadrons	41 ± 24
[$\Lambda_c^+ \to \Sigma^o \pi^+ \pi^o$]	[16 ± 8]
$\Lambda_c^+ \to \Sigma^+ \pi^+ \pi^-$	10 ± 8