LIFETIMES OF CHARMED MESONS

ARGUS Collaboration

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DESY, D-2000 Hamburg 52, Fed. Rep. Germany

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Received 22 May 1988

Using the ARGUS detector at the e^+e^- storage ring DORIS II at DESY, we have measured the lifetimes of the D^0, D^+ and D_s^+ mesons. We find $\tau_{D^0} = (4.8 \pm 0.4 \pm 0.3) \times 10^{-13}$ s, $\tau_{D^+} = (10.5 \pm 0.8 \pm 0.7) \times 10^{-13}$ s and $\tau_{D_s^+} = (5.6^{+1.3}_{-1.2} \pm 0.8) \times 10^{-13}$ s.

For footnotes see next page.

In the spectator model of heavy flavour decays, light quarks play a minor role and it is expected that the lifetimes of all charmed hadrons are approximately equal. Initial experiments measuring the lifetimes [1] of charmed particles and the ratio of the D^+ to D^0 semileptonic branching fractions [2] indicated that this was not the case. Several mechanisms have been proposed to account for this difference [#1], but agreement with experiment is still unsatisfactory. Accurate measurements provide a check of previous results and constrain models which attempt to explain lifetime differences.

We report here measurements of the D^0, D^+, and D_s^+ lifetimes [#2] using data collected by the ARGUS detector. The detector has been described in detail elsewhere [4]. This analysis relies primarily on the good spatial resolution of the vertex drift chamber [5] and the particle identification capabilities of the detector. The vertex drift chamber provides excellent resolution of less than 100 μm in the r–ϕ plane at the interaction point for high momentum tracks. The method of particle identification is described in ref. [6]. For charged tracks, dE/dx and time-of-flight measurements yield a χ^2 for the possible particle mass hypotheses e, μ, π, K and p. A likelihood ratio, l_i, for each of these hypotheses is then calculated:

$$l_i=\frac{w_i\cdot\exp(-\chi_i^2/2)}{\sum_j w_j\cdot\exp(-\chi_j^2/2)},\quad i,j=\mathrm{e},\mu,\pi,\mathrm{K},\mathrm{p}\ ,$$

where the w_i are relative particle production weights. These are set to five for the pion hypothesis and unity for all others, in approximate agreement with observation. A track is used as particle i if l_i exceeds 0.05.

The data sample corresponds to an integrated luminosity of 166 pb^{-1} at centre-of-mass energies around 10 GeV. From our sample of multi-hadron events, we have reconstructed D mesons decaying via the following channels:

(1) $D^{*+}\to D^0\pi^+$, $D^0\to K^-\pi^+$,

(2) $D^{*+}\to D^0\pi^+$, $D^0\to K^-\pi^+\pi^+\pi^-$,

(3) $D^+\to K^-\pi^+\pi^+$,

(4) $D_s^+\to\phi\pi^+$, $\phi\to K^+K^-$.

For each measurement, events containing candidates consistent with the appropriate decay mode were chosen. Each of the tracks forming a candidate was required to have at least four hits in the vertex chamber and belong to the main event vertex within seven standard deviations. Those systems which passed our kinematic selection criteria (tables 1 and 2) were then fitted to a separate vertex using a three-dimensional parametric vertex fit [7]. Only systems which had a vertex χ^2 per degree-of-freedom less than five were accepted as charm decay candidates.

Since the events contain, in general, the decay products of charm quarks and other long-lived particles, it is not possible to measure the beam interaction point on an event-by-event basis. for this reason, the beam position and beam widths were measured using tracks from the Bhabha events in each run (typically equivalent to about 25 nb^{-1} of integrated luminosity), which gave about 500 tracks in the barrel region of the detector. The beam center was determined to an accuracy of approximately 30 μm in the

Table 1
Summary of D^0 data selection criteria. Momenta are in units of GeV/c, masses in GeV/c^2. ΔM refers to the D^{*+}–D^0 invariant mass difference.

$D^{*+}\to D^0\pi^+$	
$D^0\to K^-\pi^+$	$D^0\to K^-\pi^+\pi^+\pi^-$
$\sigma_l\leq 0.1$ cm	$\sigma_l\leq 0.07$ cm
$P_{K\pi}>2.5$	$P_{K3\pi}>2.5$
$1.818<M_{K\pi}<1.898$	$1.830<M_{K3\pi}<1.886$
$0.1435<\Delta M<0.1475$	$0.1435<\Delta M<0.1475$
	$\lvert M_{\pi^+\pi^-}-M_{K_S^0}\rvert>0.03$

[1] Supported by the German Bundesministerium für Forschung und Technologie, under contract number 054DO51P.
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[9] Supported by Raziskovalna skupnost Slovenije and the Internationales Büro KfA, Jülich.
[10] Supported by the Swedish Research Council.
[11] Supported by the US Department of Energy, under contract DE-AS09-80ER10690.
[#1] For a discussion of these mechanisms, see ref. [3].
[#2] References in this paper to a specific charged state are to be interpreted as implying the charge-conjugate state also.

Table 2
Summary of D^+ and D_S^+ data selection criteria. $\theta^*_{\phi D_S}$ is the angle between the ϕ and the D_S^+ boost direction in the rest frame of the $\phi\pi$ system. $\theta^*_{K\pi}$ is the helicity angle between the K^- and the π^+ in the rest frame of the ϕ system.

$D^+ \to K^-\pi^+\pi^+$	$D_S^+ \to \phi\pi^+$, $\phi \to K^+K^-$
$\sigma_l \leq 0.08$ cm	$\sigma_l \leq 0.1$ cm
$P_{K\pi\pi} > 3.5$	$P_{KK\pi} > 2.4$
$1.835 < M_{K\pi\pi} < 1.895$	$1.930 < M_{KK\pi} < 1.995$
$P_K > 0.4$, $P_\pi > 0.4$	$1.0115 < M_{KK} < 1.0275$
	$\cos\theta^*_{\phi D_S} < 0.9$, $\lvert\cos\theta^*_{K\pi}\rvert > 0.5$

horizontal direction and 20 μm in the vertical direction. The corresponding beam widths were found by studying impact parameter distributions of Bhabha tracks with respect to the beam center and were determined to be about 480 μm and 85 μm, respectively.

The decay length of each candidate was determined by measuring the most probable path length in the r–ϕ plane,

$$l_{xy} = \frac{x_v t_x B_{xx} + y_v t_y B_{yy} + B_{xy}(t_x y_v + t_y x_v)}{t_x^2 B_{xx} + t_y^2 B_{yy} + 2 t_x t_y B_{xy}},$$

where (x_v, y_v) is the displacement from the beam center of the fitted secondary vertex, t_x and t_y are the direction cosines of the decaying particle and the matrix B is the inverse of the sum of the beam and vertex covariance matrices. The corresponding error is

$$\sigma_{lxy} = (B_{yy} t_x^2 + B_{xx} t_y^2 + 2 B_{xy} t_x t_y)^{-1/2}.$$

The proper decay length and error are then

$$l \equiv c\tau = \frac{l_{xy}}{\beta\gamma \sin\theta}, \quad \sigma_l = \frac{\sigma_{lxy}}{\beta\gamma \sin\theta},$$

where θ is the polar angle of the particle with respect to the beam axis.

To extract the proper decay length, l_0, we used a maximum likelihood fit where the single-event likelihood function is described by an exponential convoluted with a gaussian resolution function,

$$g(l) = (1/\sqrt{2\pi}\sigma_l l_0) \times \int_0^\infty \exp(-\xi/l_0) \exp[-(l-\xi)^2/\sigma_l^2] \, d\xi.$$

In addition, the effect of background events in the sample was accounted for by adding a gaussian, $b(l)$, of width σ_l and mean background decay length, l_b. This gives the complete single-event likelihood function as

$$L(l) = (1 - f_b) g(l) + f_b b(l),$$

where f_b is the fraction of background contamination in the event sample.

The method was checked by a Monte Carlo simulation of each of the decay channels, including a detailed simulation of the ARGUS detector [8]. The decay length analysis reproduced the Monte Carlo input decay length within errors for all channels. We conclude that there is no bias in the method.

The background fractions were found for each of channels (1)–(4) by fitting the appropriate invariant mass distributions (figs. 1a–4a, respectively) with a gaussian for the signal and a polynomial parametrization for the background. the background proper decay lengths were measured by choosing events from the sidebands and passing them through the same cuts [9].

Table 3 summarizes the decay length analysis for all channels, including the results of the sideband analysis. The maximum likelihood fits to the proper decay lengths are shown in figs. 1b–4b for the four channels, respectively. The systematic error on the decay length measurement for the $D^0 \to K^-\pi^+$ candidates was obtained by adding in quadrature the following contributions: ±2 μm from varying the background fraction within errors, ±1 μm by changing the background lifetime within errors, $^{+4}_{-5}$ μm from allowing the beam sizes to vary by ±100 μm in x and ±50 μm in y, ±0.6 μm by allowing the beam positions to vary within errors, $^{+3}_{-6}$ μm from changing the quality cuts on the vertex χ^2 and σ_l within reasonable limits, and an additional ±4.5 μm from uncertainties in the error matrix B. In the case of the D^+ mea-

Table 3
Summary of decay length analysis. The number of events quoted (N) includes the background fraction f_b.

Decay	N	f_b(%)	l_b(μm)	l_0(μm)
$D^0 \to K^-\pi^+$	431	8±2	19±17	146^{+16+9}_{-15-7}
$D^0 \to K^-\pi^+\pi^+\pi^-$	452	16±2	34±10	142^{+18+9}_{-17-5}
$D^+ \to K^-\pi^+\pi^+$	825	56±4	25±5	315^{+25+19}_{-23-16}
$D_S^+ \to \phi\pi^+$	168	32±4	2±37	167^{+39+24}_{-36-23}

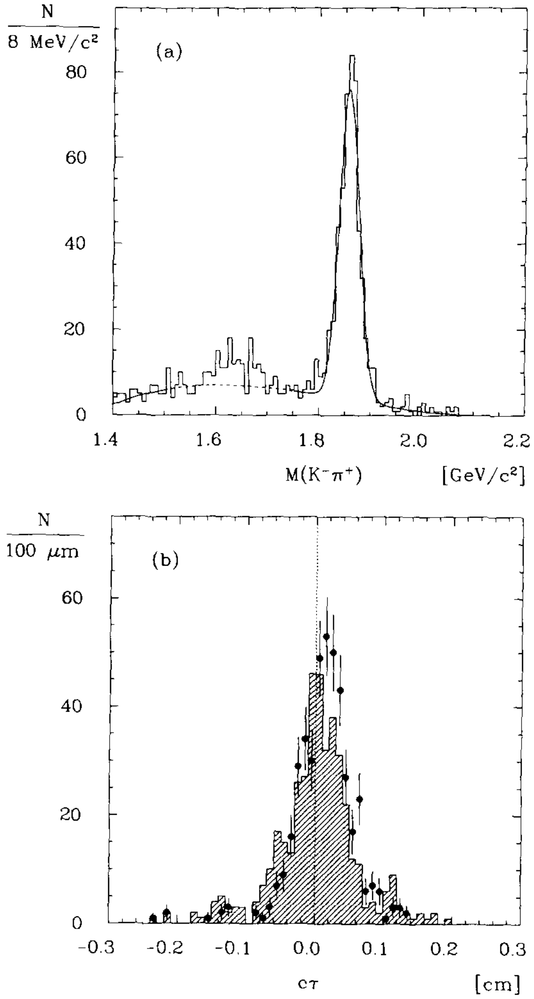

Fig. 1. (a) $K^-\pi^+$ invariant mass distribution. The region between 1.5 and 1.7 GeV/c^2, containing D^0 decays into $K^-\pi^+\pi^0$ where the π^0 is missed, is excluded from the fit. (b) Proper decay length distribution for $D^0 \to K^-\pi^+$ candidates. The hatched distribution shows the sideband decay lengths in relation to the D^0 sample.

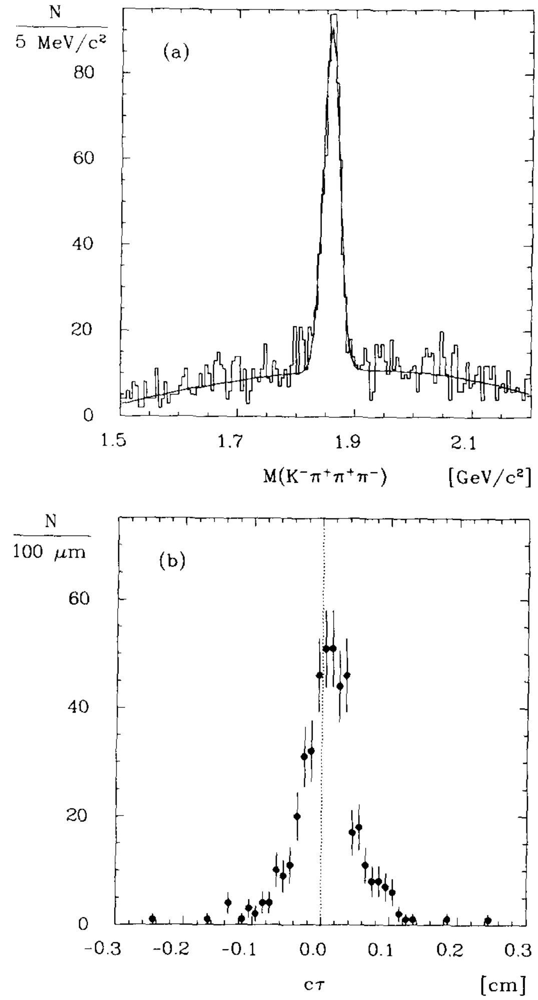

Fig. 2. (a) $K^-\pi^+\pi^+\pi^-$ invariant mass distribution. (b) $D^0 \to K^-\pi^+\pi^+\pi^-$ proper decay length distribution.

surement, although the same sources were considered, the background uncertainty is the dominant component, contributing $^{+14}_{-17}$ μm. For the D_S^+, the error matrix (± 16 μm) and beam width ($^{+10}_{-14}$ μm) dominate.

Combining the two available channels, the lifetime of the D^0 meson is determined to be

$$\tau_{D^0} = (4.8 \pm 0.4 \pm 0.3) \times 10^{-13}\ \mathrm{s}\,.$$

The corresponding results for the D^+ and D_S^+ mesons are

$$\tau_{D^+} = (10.5 \pm 0.8 \pm 0.7) \times 10^{-13}\ \mathrm{s}\,,$$

$$\tau_{D_S^+} = (5.6^{+1.3}_{-1.2} \pm 0.8) \times 10^{-13}\ \mathrm{s}\,.$$

For the ratio of charged to neutral D lifetimes, we find $\tau_{D^+}/\tau_{D^0} = 2.2 \pm 0.3 \pm 0.2$ which should be equal to the ratio of semileptonic branching fractions, $\mathrm{Br}(D^+ \to e^+X)/\mathrm{Br}(D^0 \to e^+X)$. This ratio has been measured by the MARK III collaboration to be $2.3^{+0.5}_{-0.4} \pm 0.1$ [10]. From the D_S^+ and D^0 measurements we calculate $\tau_{D_S^+}/\tau_{D^0} = 1.2 \pm 0.3 \pm 0.2$. These results represent the most precise charmed meson lifetime measurements from e^+e^- annihilation data,

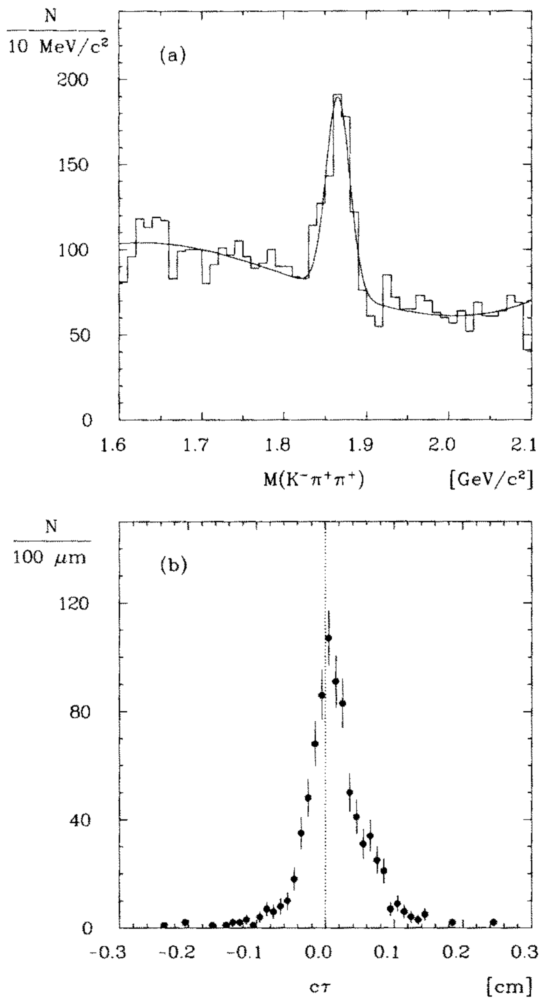

Fig. 3. (a) $K^-\pi^+\pi^+$ invariant mass distribution. (b) $D^+ \to K^-\pi^+\pi^+$ proper decay length distribution.

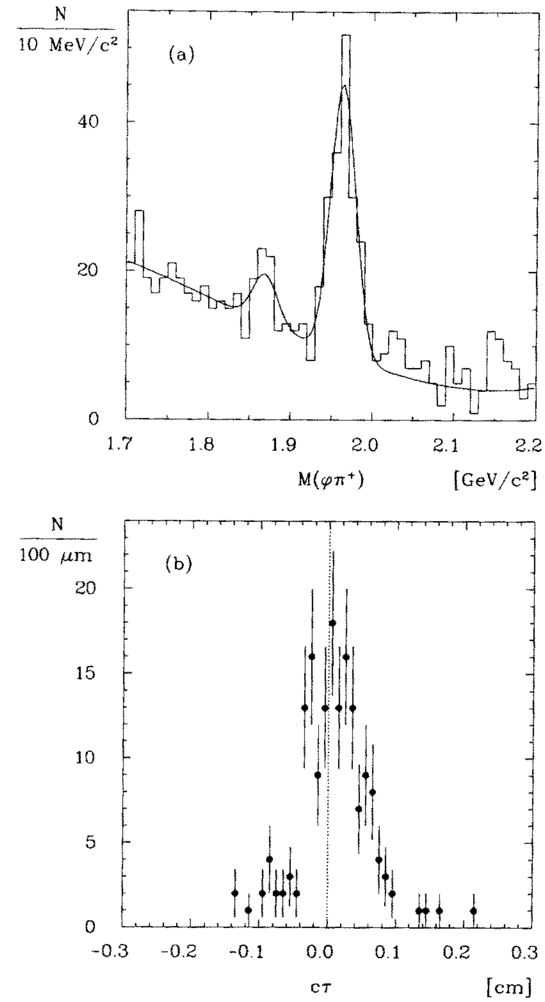

Fig. 4. (a) $\phi\pi^+$ invariant mass distribution. The peak at a mass of 1.869 MeV/c^2 is from the decay $D^+ \to \phi\pi^+$. (b) $D_s^+ \to \phi\pi^+$ proper decay length distribution.

are in good agreement with recent results from other experiments [#3].

It is a pleasure to thank U. Djuanda, E. Konrad, E. Michel and W. Reinsch for their competent technical help in running the experiment and processing the data. We thank Dr. H. Nesemann, B. Sarau, and the DORIS group for the excellent operation of the storage ring. The visiting groups wish to thank the DESY directorate for the support and kind hospitality extended to them.

[#3] For a review of recent results, including results only presented at conferences see ref. [11]. Results since then can be found in ref. [12].

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