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D-MESON LIFETIMES

LEBC-EHS Collaboration

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ABSTRACT

We present the final results on the D-meson lifetime measurements obtained by the NA27 experiment. From a sample of 145 $D^o/\bar{D}^o$ and 149 $D^{\pm}$ decays, we have measured $\tau(D^o) = 4.6\ ^{+0.6}_{-0.5} \times 10^{-13}$s, $\tau(D^{\pm}) = 11.2\ ^{+1.4}_{-1.1} \times 10^{-13}$s, with a ratio $R = \tau(D^{\pm})/\tau(D^o) = 2.4 \pm 0.4$.

In this paper we present the results of an analysis of D-meson lifetimes using the full data sample from the NA27 $\pi^- p$ and pp exposures. Previous results have been given [1] based on only part of the statistics now available.

Data were collected using the high resolution hydrogen bubble chamber LEBC in association with the European Hybrid Spectrometer (EHS) exposed at the CERN SPS to a 360 GeV π^- beam (15.8 events/μb) and a 400 GeV proton beam (38.5 events/μb). No on-line charm selecting trigger was employed in the data taking. A simple interaction trigger that requires at least two charged particles from the interaction region has an estimated efficiency for charm decays of $(98\ ^{+2}_{-3})\%$. Details of the spectrometer are given in [2]. Here we emphasize the properties of the vertex detection technique which are particularly important for an unbiased determination of charm particle lifetimes.

The high resolution bubble chamber was 12 cm long in the beam direction with an optical depth of 3 mm. Two views of each event were photographically recorded. The optical quality of the film was extremely high, a typical track (5 cm long) having ~ 400 precisely aligned bubbles with optically resolved bubble images less than 20 μm in diameter. The bubble density was 80 cm^{-1} so that, for example, charged particles produced at $x_F = 0$ with lifetimes in the range $(10^{-13} - 10^{-12})$s have typically (4 - 40) bubbles.

The film was subjected to two independent scans followed by a comparison check scan, each controlled by a physicist. Evidence for secondary decay activity at the scanning stage was usually the observation of one or more tracks which did not point back to the main vertex i.e. had a detectable impact parameter (fig. 1). Events were passed for measurement as charm candidates if the transverse decay length, defined in fig. 1, was less than 2 mm. A first measurement removed strange particle decays by fitting to two-body channels. Charm decay candidates were required to have at least one decay track with p_T > 250 MeV/c with respect to the parent or to have a charm topology (four or more charged prongs from a neutral decay, three or more from a charged decay). Events satisfying these conditions were passed to the HPD machine for precise measurement. The HPD measurement of a typical event containing a pair of charm decay vertices is shown in fig. 2. The centre of each bubble is measured with a precision of ~ 5 μm resulting in r.m.s. residuals, after fitting to a straight line, of 1.8 μm for approximately 25 master points used to reconstruct the track. The impact parameter precision is ~ 2.5 μm at the main vertex. In fig. 3 we show the impact parameter distribution for all tracks arising from charm particle decays. The hatched region represents those tracks added to the decays after the HPD measurement and not correctly assigned or detected at the scanning stage. The initial scanning is clearly efficient at finding decays with at least one track having an impact parameter larger than 50 μm (2 1/2 bubble diameters). The HPD is efficient in finding all tracks with impact parameter larger than 7 μm (3σ, where σ is the HPD precision on the impact parameter).

The event sample is shown in table 1. It consists of 664 detected charm decays, 212 of them coming from interactions with only one charm detected, the remaining 452 being observed as charm pairs from 226 interactions. The charged and neutral decays are classified as C_n and V_n respectively, where n denotes the number of charged decay products. To avoid the possibility of background contamination in unconstrained decays we require:

(a) A V2 decay must have one decay track with p_T > 250 MeV/c <u>and</u> be paired with a second charm decay.

(b) A C3 decay must have one decay track with p_T > 250 MeV/c <u>or</u> be paired with a second charm decay.

V4, C5 and V6 decays are accepted as charm on the basis of topology alone. C1 decays are not used in the analysis; however, if the decay track has p_T > 250 MeV/c a C1 can complete a charm pair.

Details of the analysis techniques available for determining lifetimes from a sample of decays without kinematic fits are given in [1] where it is shown that all techniques give consistent results. It is however critical that the event sample is free from background and we therefore emphasize the clean nature of the experiment:

- The hydrogen bubble chamber ensures negligible background from secondary interactions.
- The absence of a charm trigger removes any possible bias in the data taking.

- The high resolution optical system ensures efficient detection of charm decays at the scanning stage.
- The precision of the HPD measurement ensures that tracks and vertices are correctly related.
- The cuts applied to the data sample remove all background arising from strange particle decays and ensure lifetime independent detection efficiency.

For the proton exposure, to speed up the data processing, the charm box cut described in [1] has been reduced to ± 200 μm for V2, which are exposed to a large strange particle background contamination. This cut is such that the ℓ_{max} correction will begin to play an important role for the V2 topology.

In table 1 the first two columns give the numbers of decays with a clean charm signature divided by topology and found in the π^- and proton exposures respectively. The third column gives the total. The fourth column gives the number of good kinematic fits and the fifth column the samples available for the transverse length analysis (see below) after all cuts. Note that the fit and L_T samples overlap since many decays with kinematic fits can also be used in the L_T method. The final column gives the number of decays used for the final lifetime determinations.

In ref. (1), four methods of lifetime analysis were presented and compared using the data from the π^- exposure. A technique based on the distribution in transverse decay length

$$L_T = \frac{ctp_T}{m}$$

was introduced and preferred over other analyses using unfitted decays. In ref. [1], the transverse length function was simply expressed in an approximated form and the resulting lifetimes were properly corrected by applying a small correction factor determined by Monte-Carlo. We have extended our analysis taking into account the correct normalization implied by the fact of keeping the event production angle fixed [3]. The lifetime results obtained incorporating into the likelihood function the kinematic correlations are in good agreement with those given by the approximated function mentioned above, giving confidence in our results.

To be consistent with [1] and to allow a useful comparison between the lifetimes obtained with the π^- exposure to those reported here, we give in table 2 the results of the analysis obtained with the approximated function used in [1]. We also give in table 2 the values found using the subsample giving kinematic fits. The lifetimes for kinematically constrained decays are obtained using the standard likelihood function whose parameters are extensively described in [1] and [2].

All four determinations give compatible results for D^o as well as for D^+ (see table 2). We can therefore combine the π^- and proton data. Finally, combining the results from the standard likelihood applied to kinematically constrained decays with the results from the transverse length method applied to the unconstrained ones, we find as our best results:

$$\tau(D^o) = 4.6\,^{+0.6}_{-0.5} \,.\, 10^{-13}\mathrm{s} \quad \text{(145 decays)}$$

$$\tau(D^\pm) = 11.2\,^{+1.4}_{-1.1} \,.\, 10^{-13}\mathrm{s} \quad \text{(149 decays)}$$

$$R = \tau(D^\pm)/\tau(D^o) = 2.4 \pm 0.4 \;.$$

Detailed comparisons of all techniques based on the full data sample are given in refs [3] and [4]. The stability of the results against variations in the parameters used to define ℓ_{min} show that (a) no significant contamination exists from particles of different lifetime to $D^\pm$ and (b) that the values chosen for the cuts to derive the final lifetimes are correct. Fig. 4 shows the $(L_T - L_{Tmin})$ distributions for the D^o and $D^\pm$ samples. A clear difference is observed for the mean values of the two distributions, reflecting the fact that $\tau(D^+) = 2.4\ \tau(D^o)$.

We note that our results are in excellent agreement with all the values obtained previously with partial statistics from the same experiment [1], [2] and [5] and therefore supersede them.

We also note that an earlier LEBC-EHS Experiment, NA16 [6] had produced results in good agreement with the more accurate values presented here.

Finally, one may note that the current world average values established by the PDG [7] agree with our results and are affected by errors comparable to ours.

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TABLE CAPTIONS

Table 1 Event sample.

Table 2 Results of the two methods used to measure the lifetimes and applied separately to the π^- and to the proton data.

TABLE 1

Topology	π^- Exposure	p Exposure	Total	Fits	L_T analysis	Fit + L_T
C1	28	82	110	–	–	–
C3/C5	55	151	206	64	138	149
V2	78	190	268	10	70	145
V4/V6	22	58	80	43	59	

TABLE 2

$\times 10^{-13}$s	π Data [1] L_T	π Data [1] Fits	Proton data L_T	Proton data Fits
$\tau\ (D^o)$	$4.5^{+0.8}_{-0.7}$	$3.6^{+1.0}_{-0.7}$	$5.0^{+0.8}_{-0.7}$	$5.6^{+1.2}_{-0.9}$
$\tau\ (D^{\pm})$	$10.4^{+2.8}_{-2.0}$	$9.8^{+3.4}_{-2.2}$	$11.3^{+1.6}_{-1.3}$	$11.1^{+2.3}_{-1.8}$

FIGURE CAPTIONS

Fig. 1 (a) Definition of the impact parameter y.

(b) Definition of the transverse decay length L_T.

Fig. 2 HPD digitization of an event. The event has two V4 decays. Note the different scales along and across the beam direction.

Fig. 3 Impact parameter distribution for all tracks from charm decays. The dashed part of the histogram represents tracks added to the decay at the measurement stage.

Fig. 4 Distributions of $(L_T - L_{Tmin})$ for $D^o(\bar{D}^o)$ and $D^{\pm}$ charm particles.

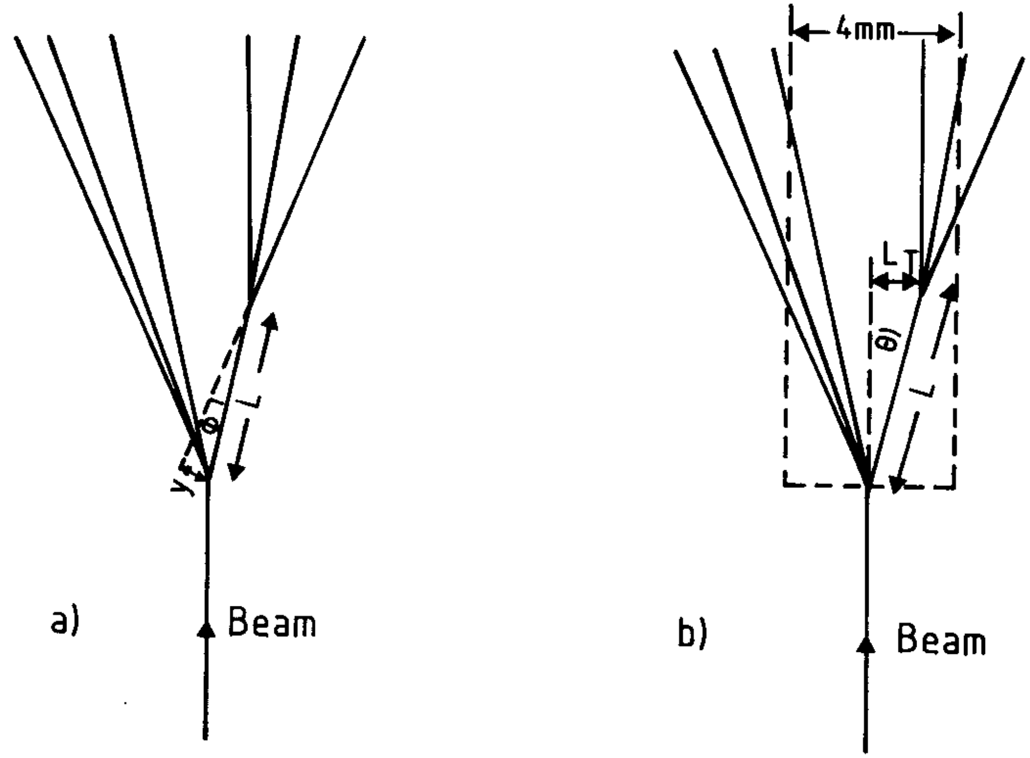


Fig. 1

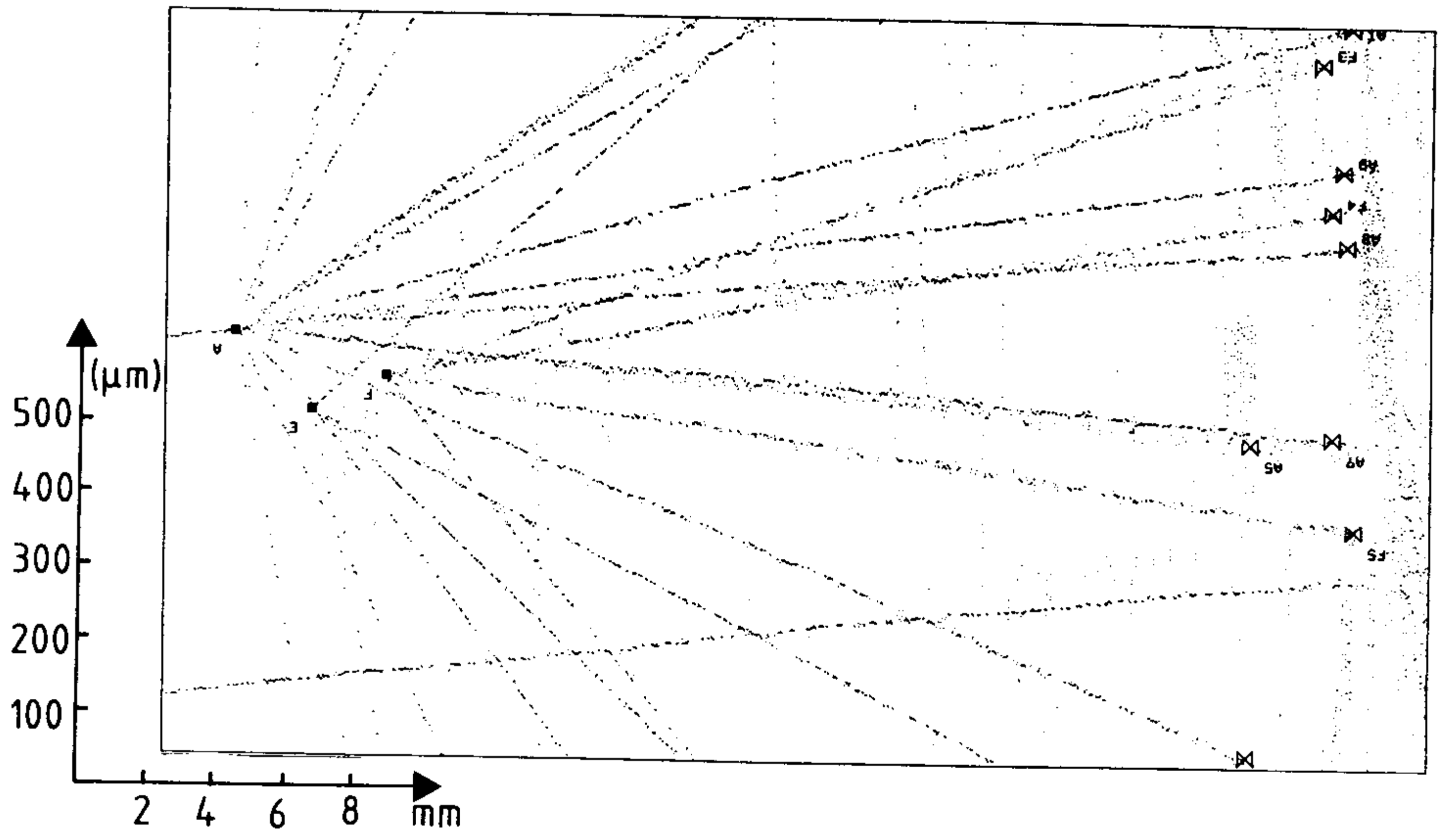


Fig. 2

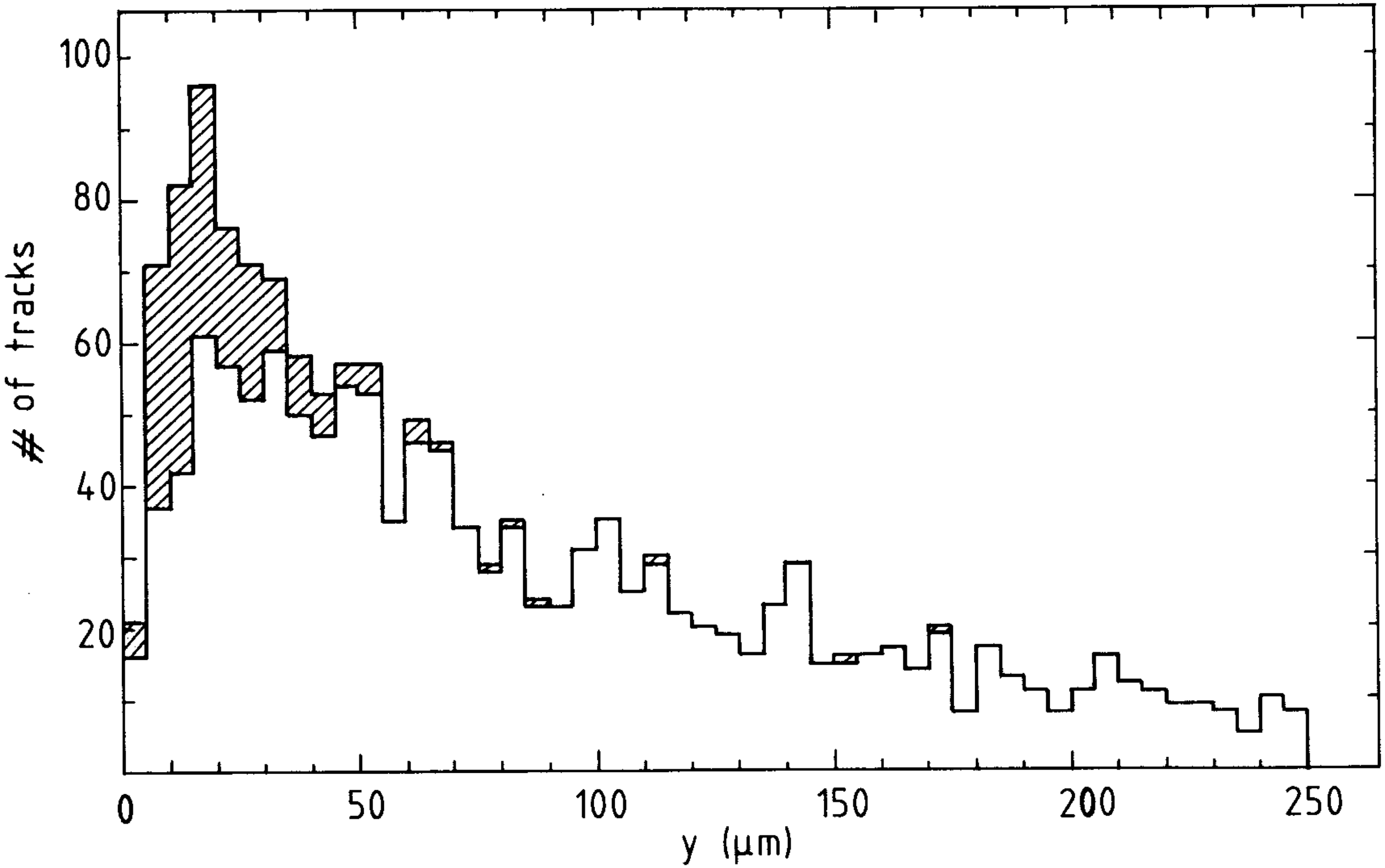
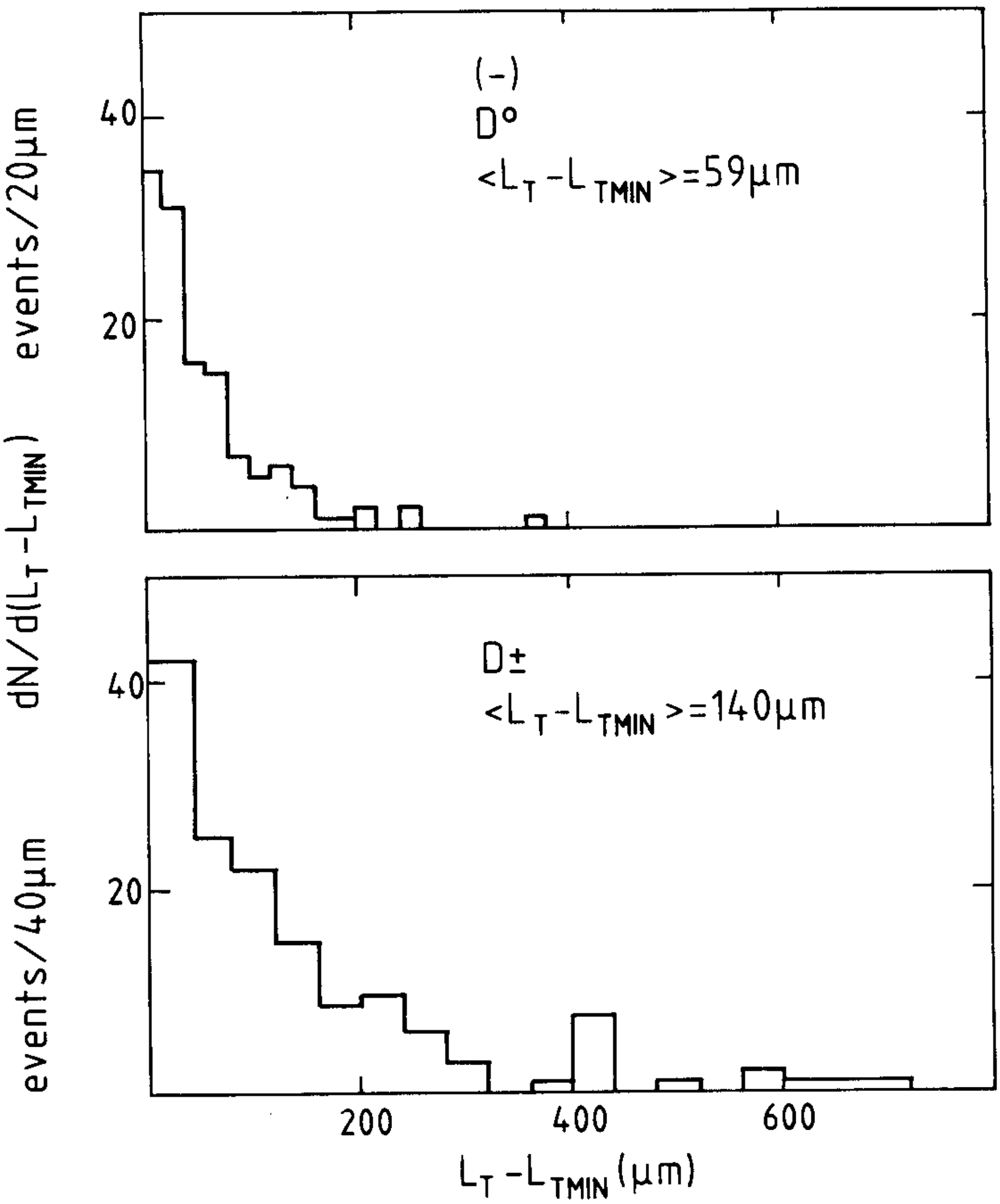


Fig. 3



(-)
D°
<L_T - L_TMIN>=59μm
D±
<L_T - L_TMIN>=140μm
events/20μm
dN/d(L_T - L_TMIN)
events/40μm
40
20
200
400
600
L_T - L_TMIN (μm)

Fig. 4