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CHARM PHOTOPRODUCTION AT 20 GeV INCLUDING PRELIMINARY LIFETIME RESULTS WITH IMPROVED OPTICAL RESOLUTION*

SLAC Hybrid Facility Photon Collaboration

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ABSTRACT

Sixty five charm events have been observed in an exposure, during 1983, of the SLAC Hybrid Facility (SHF) to a backward scattered laser beam. Preliminary results for the charmed meson lifetimes have been obtained based on 19 neutral and 22 charged decays thereby doubling our earlier data. These lifetimes are consistent with our published results and the two data samples have been combined. From the resulting 42 neutral, 45 charged and 13 topologically ambiguous decays the charmed meson lifetimes are measured to be

$$\tau_{D^0} = (6.4^{+1.1}_{-0.9} \pm 0.5) \times 10^{-13} s$$

$$\tau_{D^\pm} = (8.2^{+1.3}_{-1.1} \pm 0.6) \times 10^{-13} s$$

and their ratio $\tau_D^{\pm}/\tau_{D^0} = 1.3^{+0.5}_{-0.3}$

The inclusive charm cross-section at a photon energy of 20 GeV has been measured to be (60 $\pm 8 \pm 21$) nb.

1. INTRODUCTION

The SHF photon collaboration has previously published results from an experiment to study the production and decay of charmed particles[1]. This paper reports the data from a new experiment with approximately the same number of charm events and with an improved apparatus.

A 20 GeV backward scattered photon beam passed through the SLAC one meter bubble chamber where the normal 3- view stereo cameras were supplemented with a high resolution camera to allow the decays of charmed particles to be efficiently detected. Downstream detectors were used to trigger the cameras on the total hadronic cross-section. Approximately 1.2 million pictures were taken, containing 300,000 usable hadronic interactions. After scanning and measuring, 65 events were found containing direct visual evidence for the production and multiprong decay of at least one charmed particle. After imposing rigorous cuts to the data 47 charm decays remained.

The experiment uses a photon beam energy sufficiently far above threshold to yield a useful number of events, but which is low enough to give a small average charged multiplicity so that the pictures are clean. The low incident energy also allows close limits to be put on the proper flight times of decays with missing neutral particles. The equipment, data acquisition and analysis are first described and then the analysis and results on the lifetimes of charged and neutral D mesons are presented and discussed.

2. EXPERIMENTAL DETAILS

The experiment was performed at the SLAC Hybrid Facility (Figure 1). The beam, bubble chamber, downstream detectors, data acquisition and trigger are described in detail in reference 1.

The 20 GeV photon beam was produced by backscattering laser light from 30 GeV electrons provided by the SLAC linear accelerator. The photon beam spectrum has a FWHM of 2 GeV. The cross section of the beam was a circle of 3mm diameter and the intensity was 20-30 gammas per pulse at a rate of 10-12 Hz.

The downstream detector system consisted of four sets of proportional wire chambers (PWCs), two atmospheric pressure Cerenkov counters and an array of lead-glass blocks. Each of these detectors was made insensitive to tracks in a vertical plane which contained most of the background e^+e^- pairs and the beam.

The chamber flash lamps were triggered if sufficient energy was deposited in the lead-glass blocks and/or a track originating in the fiducial volume of the bubble chamber was detected in the PWCs.

This basic system has been in use at the SHF since data taking began for the previous experiment in 1980. However during four years of operation with about four months of data taking per year, several changes have been made, primarily aimed at improving the resolution achieved with the high resolution camera. The most significant of these are described below.

2.1 The Bubble Chamber

Towards the end of the previous experiment the glass window through which the events were photographed was replaced. The new window had a 100 mm extension, replacing hydrogen in the chamber, which forced spurious bubbles to flow around the window and not across the field of vision. The resulting smaller volume of H_2 also allowed for better control of the chamber operating conditions. This was further improved later in this present experiment by the installation of a deuterium cooling loop. The chamber was operated at 29K and with a high expansion ratio to give a high bubble density (60 per cm) but a slow bubble growth to allow sufficient time for the camera trigger.

2.2 The High Resolution Camera.

For this present exposure a new high resolution camera was installed which would resolve bubbles of 40 μm diameter.[2] The single lens used previously was replaced by a pair of Nikon Apo-Nikkor 610 mm lenses to give a resolvable point separation which was found to be close to the ideal diffraction limit of about 30 μm for a depth of field of $\pm$ 2mm. The two lenses each record about half the usable beam path, with a small overlap between the images.

2.3 The Camera Trigger.

In this new exposure the time available to make the camera trigger decision was reduced by about 30 μs, since 40 μm bubbles were to be recorded. In order to still use the track information from the PWCs, as part of the trigger, a dedicated hardware processor was built and installed. This reconstructed lines from PWC hits in the non-bend plane, rejecting those which could not come from the fiducial volume.

2.4 The Cerenkov Counters.

The large counter was filled with Freon 114 for this latest experiment. This reduces the pion threshold to about 2.6 GeV/c.

3. THE DATA

The results presented here are based on 1.2 million photographs containing 300,000 hadronic interactions in the fiducial volume. The high resolution film was scanned for hadronic events and each was closely examined at high magnification for decays within 1.5 cm in space of the production vertex. 76 % of the film was scanned more than once.

The requirement for a decay candidate was that either the decay point was visible or that any of the decay tracks, projected back, missed the production vertex by an impact distance of more than a track width.

To produce a pure sample of charm decays the following were rejected:

(i) decays with fewer than two charged products

(ii) two prong decays consistent with photon conversions or strange particle decays

(iii) three prong decays consistent with charged strange particle decays or neutral strange particle decays superimposed on a track from the production vertex.

Within a fiducial volume 75 cm long, a total of 65 events remained containing 76 visible multiprong charm decays. 13 of these are topologically ambiguous between charged and neutral decays.

To ensure that events were detected with high and uniform efficiency and to reduce topological ambiguity it was further required for each decay that (see Figure 2):

(iv) the projected decay length (ℓ) be greater than 500 μm

(v) at least one track have a projected impact distance (d_{max}) greater than 110μm (2-3 track widths)

(vi) the projected impact distance for at least one other track (d_2) be greater than 40 μm.

The 44 events which remained contain 47 charm decays, 19 neutral, 22 charged and six topologically ambiguous. Seven neutral and four charged decays are compatible with Cabibbo-allowed D decays with no undetected neutrals.

Figure 3 shows a scatterplot of decay length (ℓ) against d_{max} for all decays. [Data from this and the previous experiment have been included to allow more sensitive investigation of possible losses]. The region of the plot excluded by the cuts is also indicated. There is no evidence of a loss of events in the region accepted by the cuts. Comparison with a Monte Carlo simulation shows that appreciable losses of events occur only for regions excluded from our data sample.

Various backgrounds to the charm decays have been considered and found to contribute less than one event to the sample(1).

4. RESULTS

4.1 Lifetimes

The lifetimes of the charmed particles were determined by comparing a set of parameters describing each decay to those of Monte Carlo events to which the same cuts had been applied. The parameters, which were derived from measurements of distances projected onto the high resolution film, were:-

(i) d_{max}

(ii) ℓ

(iii) l_{eff}, the projected distance travelled by the particle minus the length from the production vertex to the first point along its path where its decay would have satisfied all of the cuts. Note that this first detection point is uncorrelated with the decay distance. Thus l_{eff} is the path length over which a charmed particle would have been accepted as such.

(iv) T_{eff}, the average effective lifetime calculated by using upper (P_{max}) and lower (P_{min}) limits on the momentum for each decay. P_{min} is the momentum for the visible particles in the decay and P_{max} is obtained by assuming that all of the neutral momentum in the event comes from the charm decay vertex. The beam energy was sufficiently low that the limits are normally close together.

$$\text{Then} \qquad T_{eff} = \frac{l_{eff}M}{cP'}$$

where $\frac{1}{P'} = \frac{1}{2}[\frac{1}{P_{max}} + \frac{1}{P_{min}}]$ and where M was taken to be the D mass.

The likelihood that the actual and Monte Carlo events have similarly distributed decay parameters is then maximised by varying the lifetimes. The Monte Carlo model used was of the form $\gamma P \rightarrow D\bar{D}N^*$. Using this model, the probability distribution for each event is characterised by a most likely lifetime τ_{ml}. We have used other production models and find a systematic error in the dependence of the lifetime on the model assumed which is smaller than the statistical error.

After correcting for ambiguous decays the charged lifetime is

$$\tau^{\pm} = (9.7^{+2.5}_{-1.9} \pm 0.6) \times 10^{-13} s$$

The contribution of $F^{\pm}$ and $\Lambda_c^{\pm}$ production to the charged lifetime is estimated to be small, on the order of 3%. After correcting for this we find the charged D lifetime to be

$$\tau_{D^\pm} = (10.0^{+2.5}_{-1.9} \pm 0.6) \times 10^{-13} s$$

The D^0 lifetime is

$$\tau_{D^0} = (5.9^{+1.4}_{-1.2} \pm 0.5) \times 10^{-13} s$$

The systematic error takes account of the treatment of ambiguous decays in the lifetime determination and uncertainty in the production mechanism and decay characteristics. These results are consistent with those obtained in our previous experiment at the SHF[1], which yielded

$$\tau_{D^\pm} = (7.4^{+2.3}_{-2.0}) \times 10^{-13} s$$

$$\tau_{D^0} = (6.8^{+2.3}_{-1.8}) \times 10^{-13} s$$

The two data samples have been combined, together with one D^0 and two $D^\pm$ decays additional to the published data sample of the previous experiment to yield the results

$$\tau_{D^\pm} = (8.2^{+1.3}_{-1.1} \pm 0.6) \times 10^{-13} s \quad (45\ decays)$$

$$\tau_{D^0} = (6.4^{+1.1}_{-0.9} \pm 0.5) \times 10^{-13} s \quad (42\ decays)$$

Figure 4 shows the distributions in τ_{ml} for these samples. The agreement with the fitted lines using the above parameters is excellent. The sample of neutral decays to four charged particles yields

$$\tau_{D^0(4pr)} = (6.7^{+1.8}_{-1.4} \pm 0.5) \quad \text{(22 decays)}$$

consistent with that of the total sample.

The lifetimes have been computed for a range of values of the cut parameters and the results show no bias against short decay lengths. For example, Figure 5 shows the result of changing all three cuts by the same factor F (e.g. F=2 refers to $d_{max} > 220\mu m, d_2 > 80\mu m$ and $\ell > 1.0mm$). For F ranging between 0.5 and 2.0 the computed values of the lifetime are consistent with those for F = 1.

In the combined sample there are 15 of each of $D^{\pm}$ and D^0 decays which have no undetected neutrals. These fully reconstructed decays are not subject to the systematic errors in the lifetimes which are discussed above, and only statistical errors are quoted here. The results are:

$$\tau_{D^0} = (9.9 \pm 2.5) \times 10^{-13} s$$

$$\tau_{D^{\pm}} = (8.8 \pm 2.2) \times 10^{-13} s.$$

Both experiments give values for τ_{D^0} which are more than one standard deviation above the value presently quoted as the world average. The τ_{ml} distribution for D^0 decays shows one decay with a value of $52 \times 10^{-13} s$. This event, which is shown in Figure 6, contains two charm decays, one of which is a four prong decay 9.0mm from the production vertex. The decay products are identified as $K^+\pi^+\pi^-\pi^-$, either by information from the Cerenkov counter or ionization in the bubble chamber and the effective mass is 1861$\pm$ 8 MeV, consistent with the accepted value of the D^0 mass. The proper flight time (which is model independent) is $55 \times 10^{-13} s$. In a distribution characterised by τ_{D^0} above, the probability of observing such an event in our experiment is about 2 percent. On the other hand, the probability of observing this or a longer decay in this experiment is about 4×10^{-4} if the lifetime is the world average[3] of $4.4 \times 10^{-13} s$

K^0 and neutron interactions on both hydrogen and deuterium (the latter as a contamination in the chamber) have been investigated as a possible explanation for this decay. The probability of this event being a background event (i.e. with identified products giving the D^0 mass and whose resultant momentum lies closely along the line between the production and decay vertex), with a second close decay, is negligibly small.

4.2 Charm Production Cross-Section.

The determination of the cross-section for the previous experiment is described in Ref. 1. The estimate of the number of charm events, including those undetected, depends on the relative production of D and Λ_c^+, the ratio of one prong to multiprong decays of the $D^{\pm}$, and on the properties of the Λ_c^+, all of which are poorly known. It also uses Monte Carlo calculations of the probability for either of the charm decays in an event to survive the cuts. For this present preliminary calculation of the cross-section, the ingredients are the same as those used in reference 1. Using the charm event scanning efficiency of 90 ±10% and the charm triggering efficiency of 84 ±6%, the sensitivity of the experiment was found to be 2.18 ± 0.34 events/nb.

The calculation of the cross section is dominated by systematic errors, principally due to the lifetimes and the 1-prong branching ratio. Using the lifetimes from this new experiment,

$$\sigma_{charm} = (63 \pm 12 \pm 22) nb.$$

This agrees with the result from our previous experiment of $\sigma_{charm} = 56 nb$. Combining these two results, using the combined lifetimes, $\sigma_{charm} = (60 \pm 8 \pm 21) nb$.

5. DISCUSSION AND CONCLUSIONS

From a new exposure of the SHF to a 20 GeV photon beam, a sample of 65 events has been selected, which show clear evidence for the decay of charmed particles.

Results on the lifetimes of the charged and neutral D mesons have been obtained which are consistent with those published by this collaboration from a previous experiment. The two data sets have been combined to yield the preliminary results:

$$\tau_{D^{\pm}} = (8.2^{+1.3}_{-1.1} \pm 0.6) \times 10^{-13} s$$

$$\tau_{D^0} = (6.4^{+1.1}_{-0.9} \pm 0.5) \times 10^{-13} s.$$

The charged D lifetime is in good agreement with, and the D^0 result is significantly larger than, the world average values[3]. The observation of a very long lived D^0 meson supports this result. The measured value of the ratio $\tau_{D^\pm}/\tau_{D^0} = 1.3\pm^{+0.5}_{-0.3}$ is consistent with the dominance of 'spectator' decay mechanisms, where the charmed quark decays without affecting the other quark in the meson, over other, non-spectator, mechanisms.

No direct evidence for $\Lambda_c^+ or F^\pm$ decays has been found, although the new data confirms the indirect evidence previously published[1] that some Λ_c^+ production is present. We also find that the small amount of $D^{*\pm}$ production previously reported has been confirmed.

A preliminary new measurement, using the new lifetimes, of the cross section for the photoproduction of charm of 63 nb is in agreement with that previously published and the combined result using the combined lifetimes, is $\sigma_{charm} = (60 \pm 8 \pm 21)nb$.

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REFERENCES

1. K. Abe et al. (SLAC Hybrid Facility Photon Collaboration) Phys. Rev. D30, 1, 1984.

2. J. D. Ferrie and R.C. Field, Nucl. Instr. and Methods 221, 330 (1984).

3. Review of Particle Properties Rev. Mod. Phys. 56, No.2, Part II, (April 1984).

FIGURE CAPTIONS

1 The SLAC Hybrid Facility with bubble chamber, proportional wire chambers, Čerenkov counters, lead glass columns and beam stop counter.

2. Sketch showing the decay parameters used in the analysis; maximum projected impact distance (d_{max}), second largest projected impact distance (d_2) and projected decay length (ℓ).

3. Scatterplot of decay length (ℓ) against d_{max} for all decays. The region of the plot excluded by the cuts is also indicated. Events denoted by ⋄ are from this experiment and those by x are from the previous one.

4. Distributions of τ_{ml} (defined in the text) for charged and neutral decays. The curves are exponentials corresponding to the quoted lifetimes.

5. Dependence of the lifetimes, determined by the maximum likelihood method, on the cut parameters. The cuts are $d_{max} > F \times 110\mu m, d_2 > F \times 40\mu m$ and $\ell > F \times 500\mu m$. The numbers of decays surviving the cuts are shown in brackets.

6. Photograph of an event taken by the high resolution camera. A fully reconstructed $\overline{D}^0 \rightarrow K^+\pi^+\pi^-\pi^-$ is clearly visible at the second vertex. The decay length is the longest in our sample of charm events. Details of the event are discussed in the text.

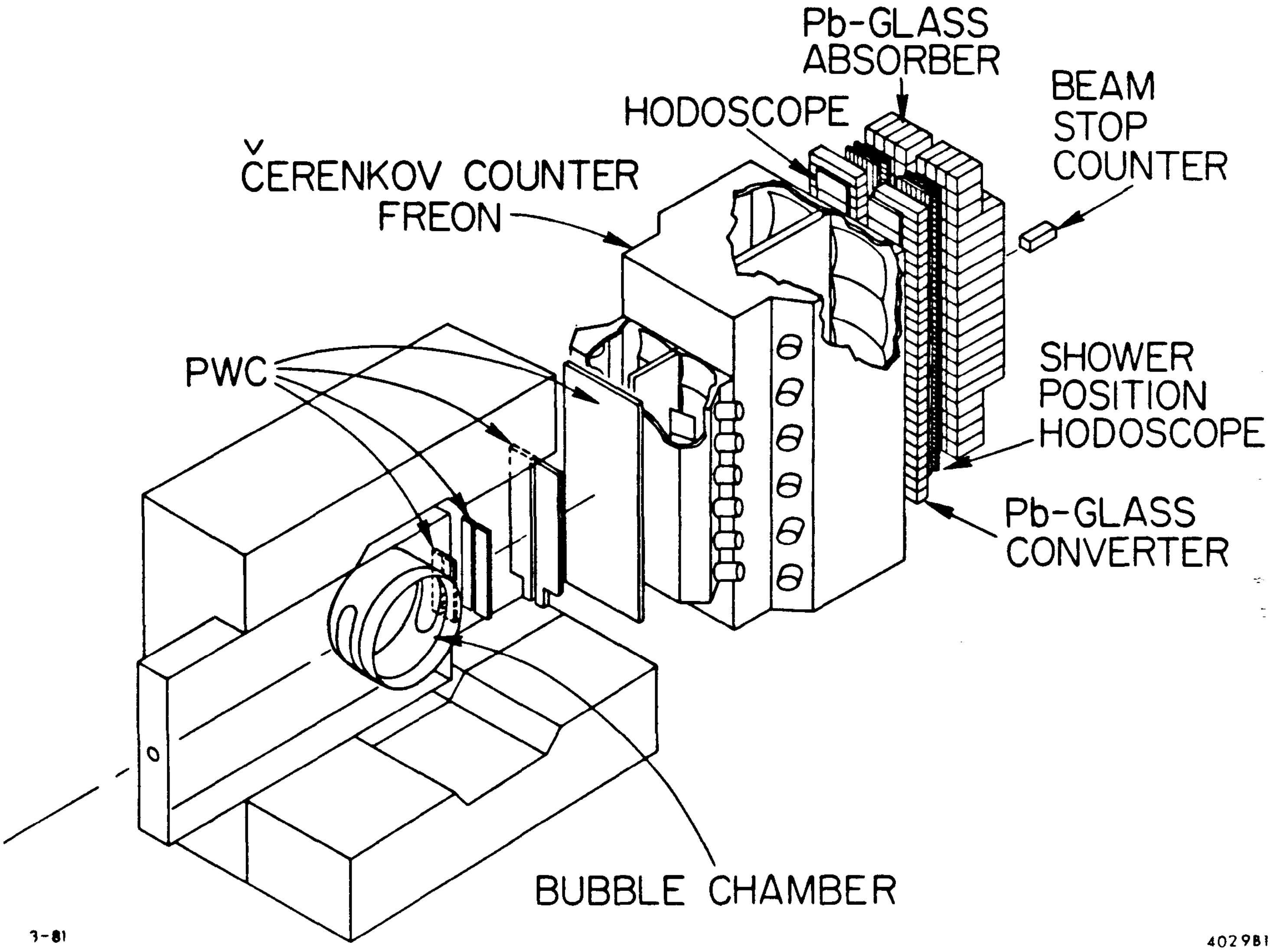

Pb-GLASS
ABSORBER
BEAM
STOP
COUNTER
HODOSCOPE
ČERENKOV COUNTER
FREON
PWC
SHOWER
POSITION
HODOSCOPE
Pb-GLASS
CONVERTER
BUBBLE CHAMBER
3-81
4029B1

FIGURE 1

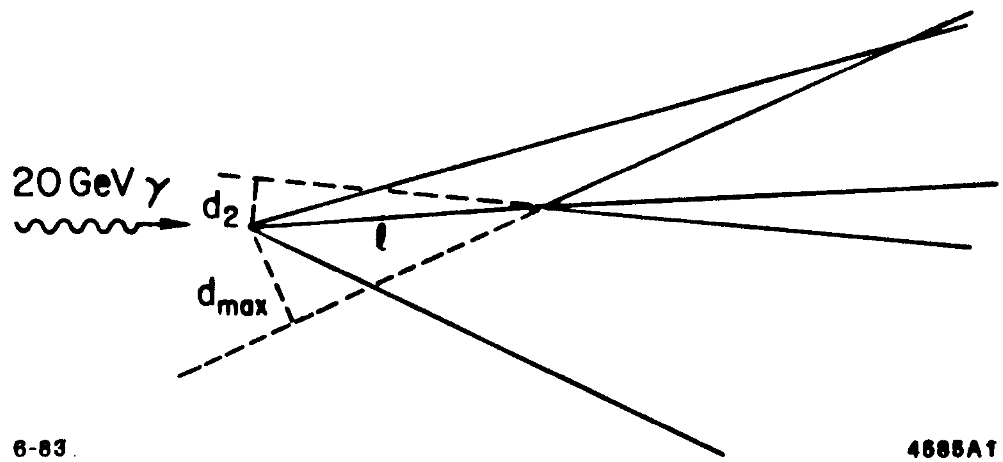


FIGURE 2

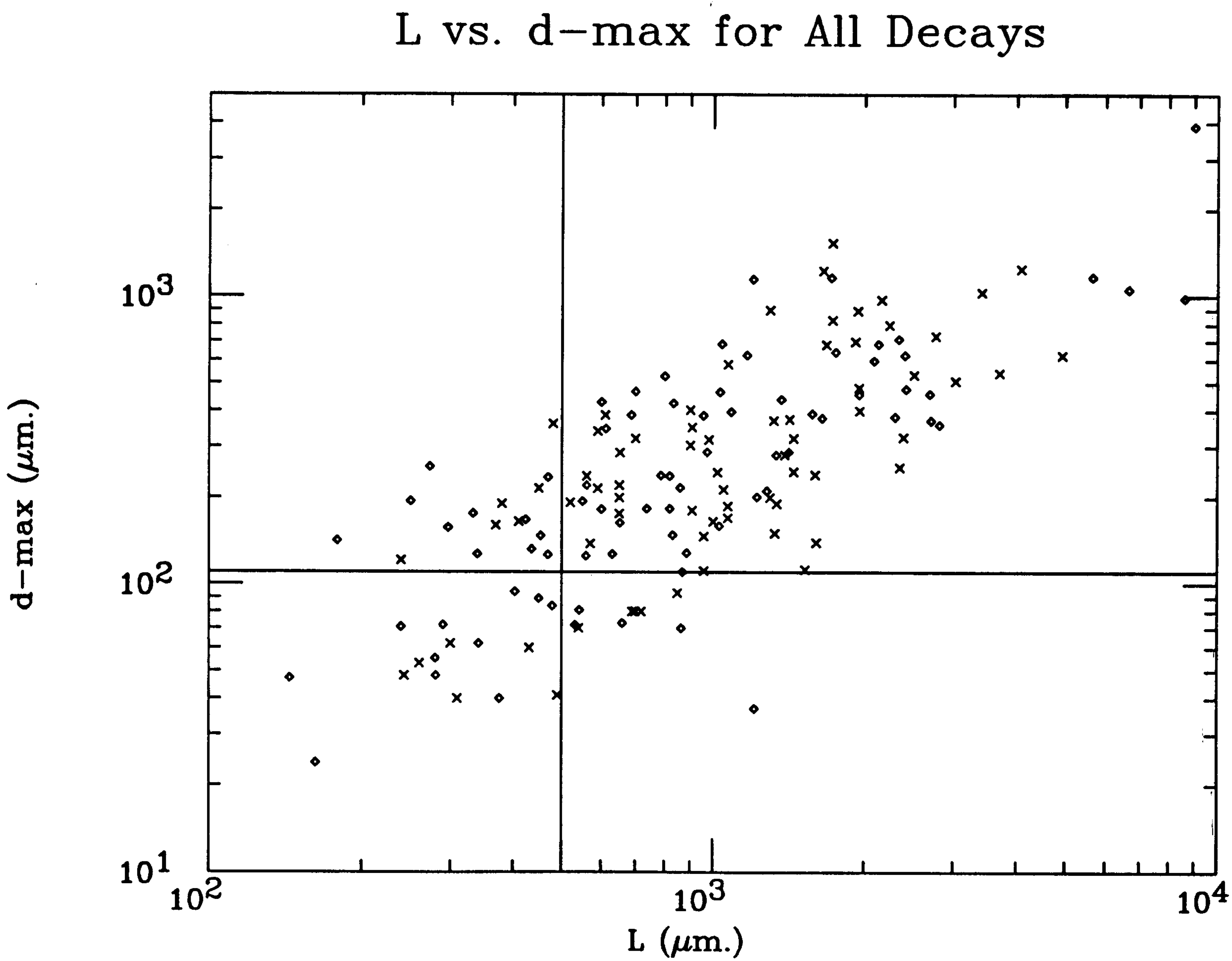


FIGURE 3

Charged Decays

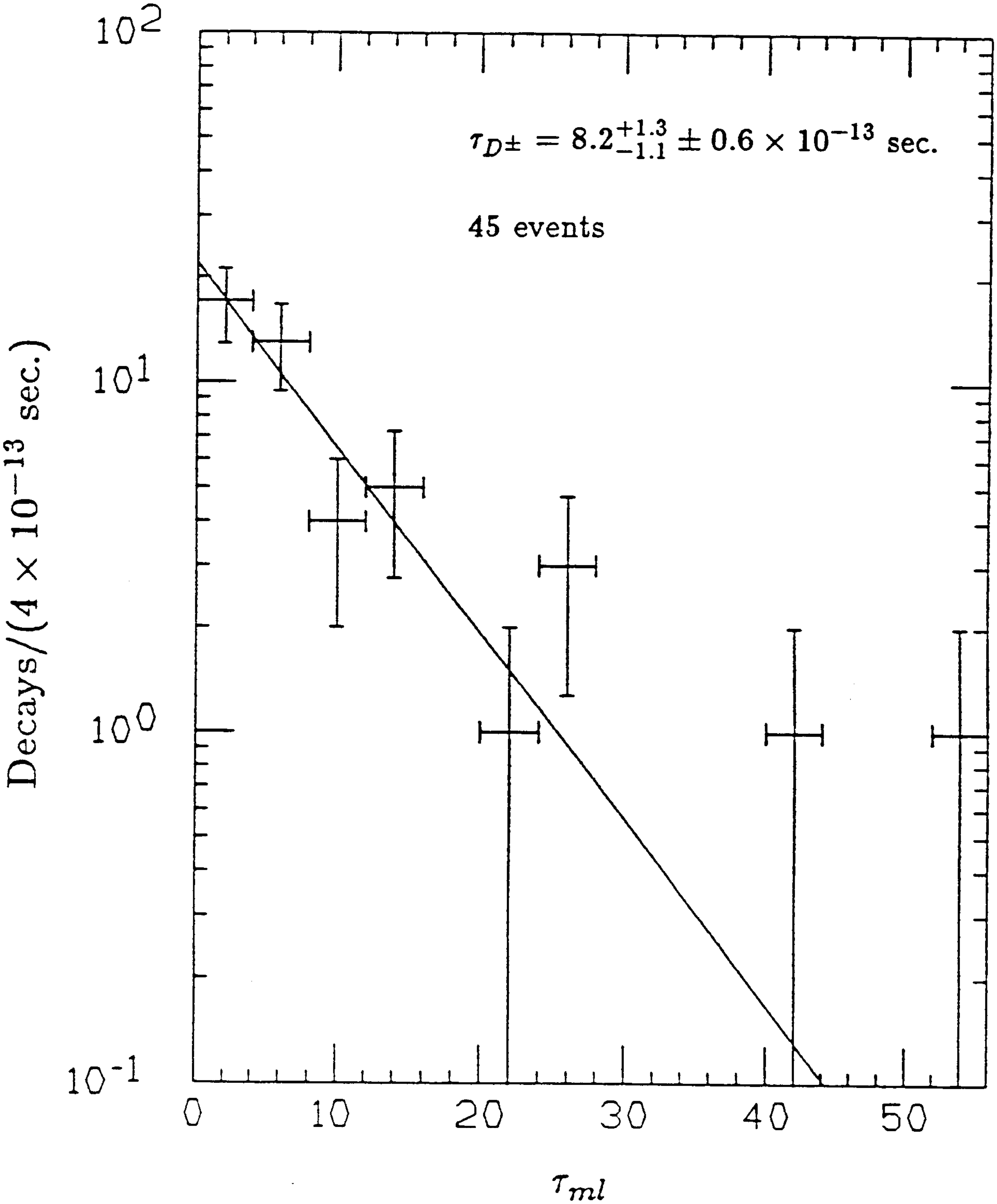


FIGURE 4A

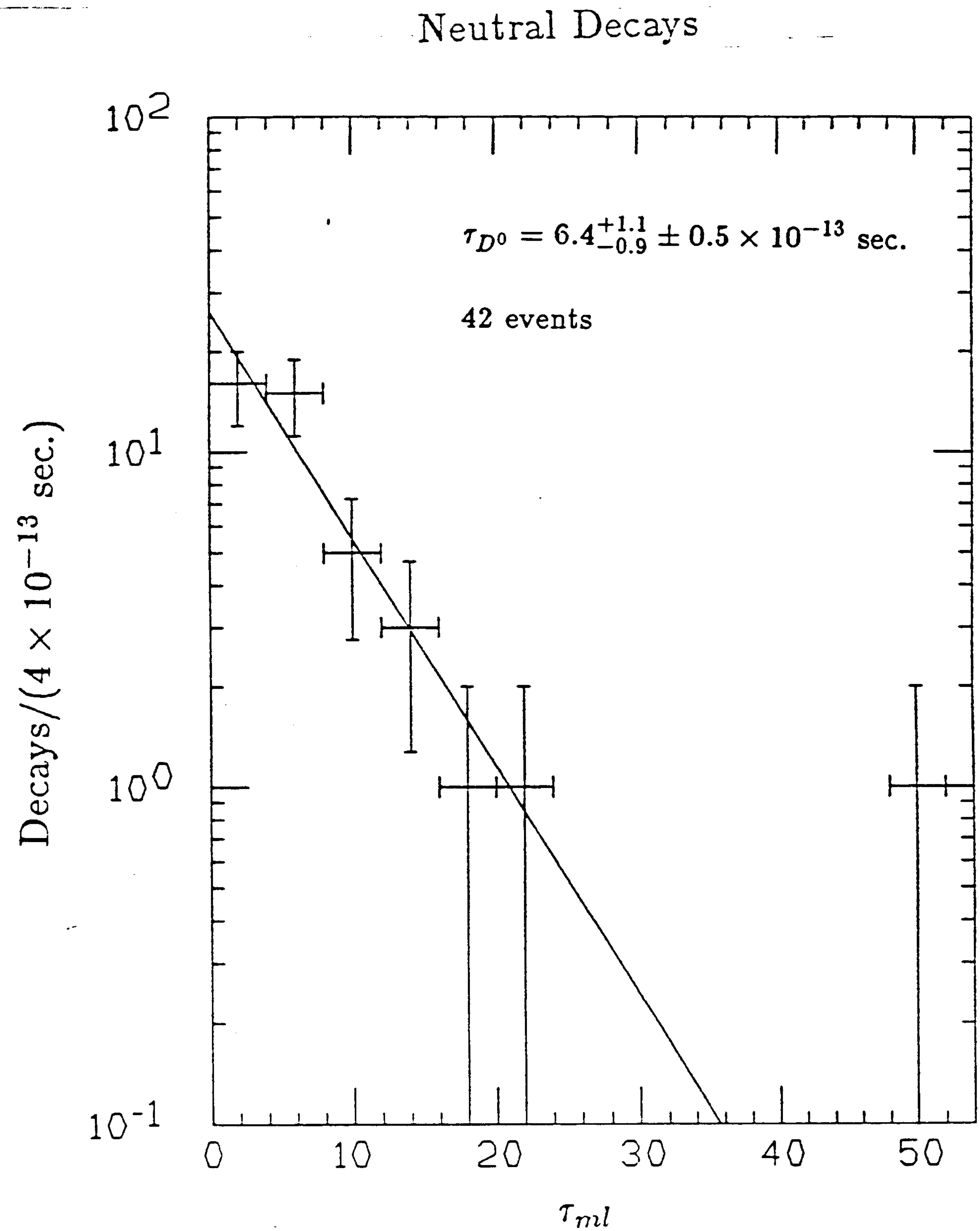
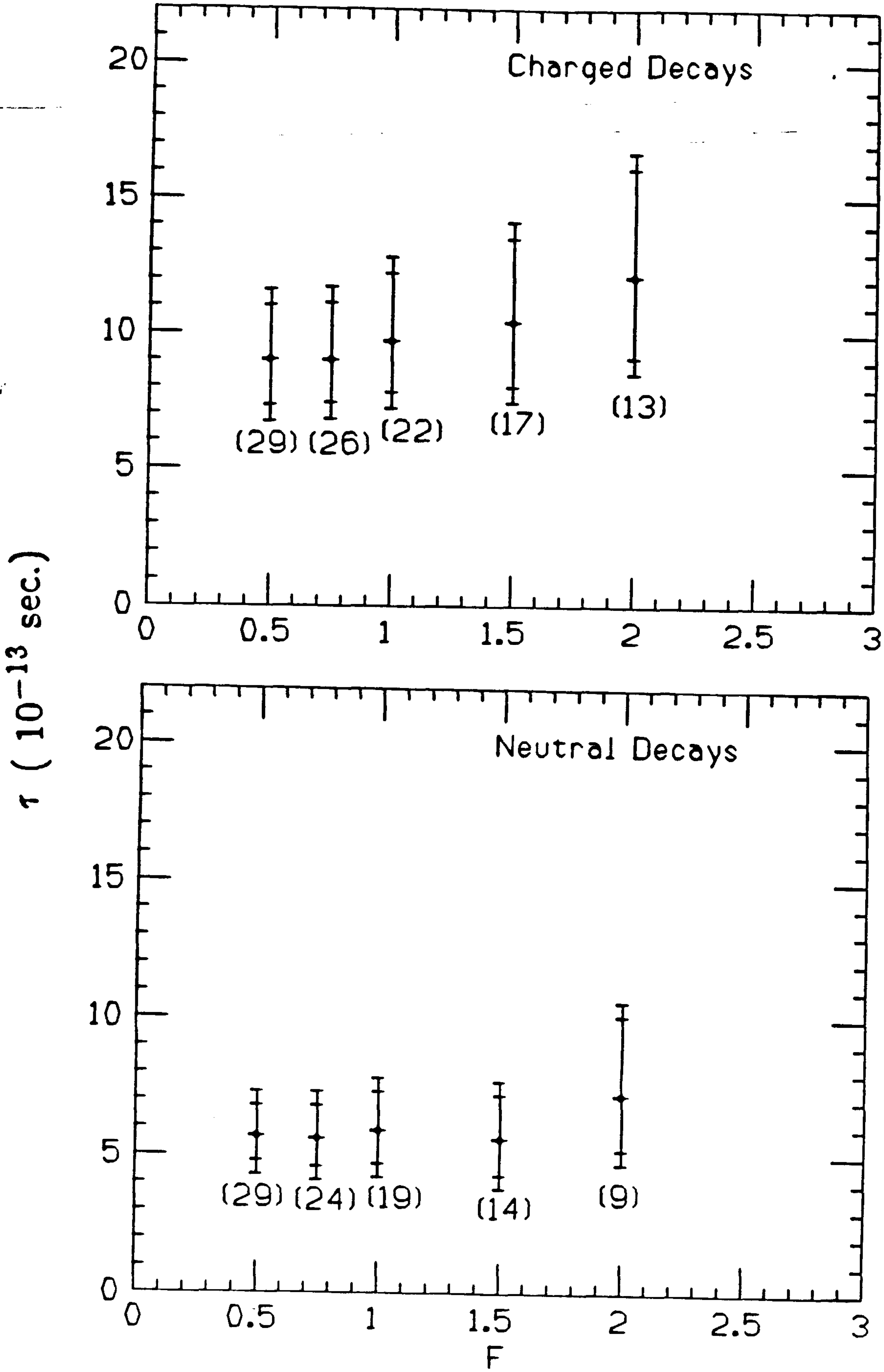

Neutral Decays
$\tau_{D^0} = 6.4^{+1.1}_{-0.9} \pm 0.5 \times 10^{-13}$ sec.
42 events
Decays/$(4 \times 10^{-13}$ sec.)
10^2
10^1
10^0
10^{-1}
0
10
20
30
40
50
τ_{ml}

FIGURE 4B



Charged Decays
(29)
(26)
(22)
(17)
(13)
Neutral Decays
(29)
(24)
(19)
(14)
(9)
τ (10⁻¹³ sec.)
F

FIGURE 5

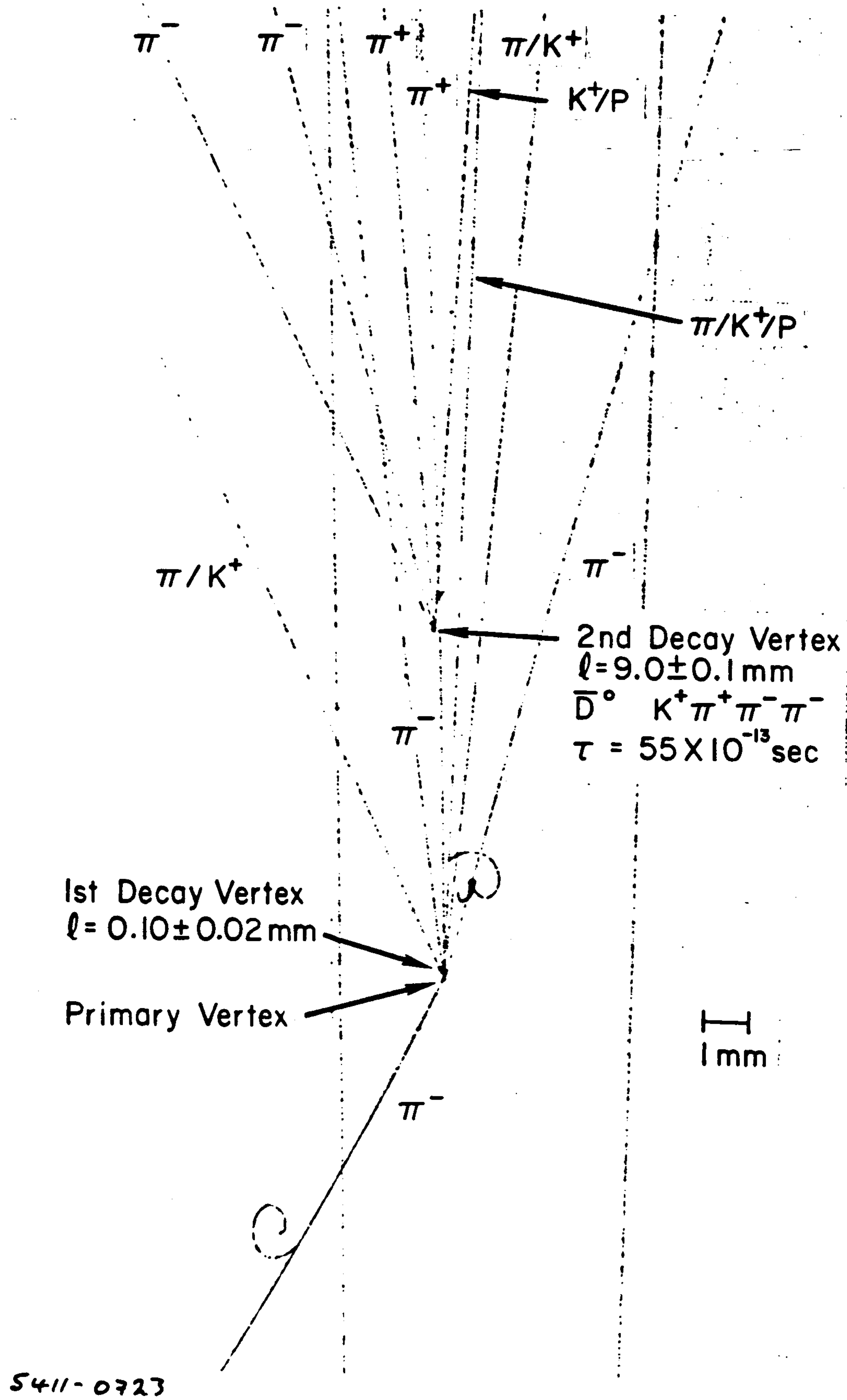

π⁻
π⁻
π⁺
π/K⁺
π⁺
K⁺/P
π/K⁺/P
π/K⁺
π⁻
2nd Decay Vertex
ℓ=9.0±0.1mm
D̄° K⁺π⁺π⁻π⁻
τ = 55X10⁻¹³sec
π⁻
Ist Decay Vertex
ℓ= 0.10±0.02mm
Primary Vertex
1mm
π⁻
5411-0723

FIGURE 6