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Observation of a Very Long-Lived $\bar{D}^0$ Decay to $K^+\pi^+\pi^-\pi^-$ With a Proper Flight Time of 55 $\times 10^{-13}$ seconds*

SLAC Hybrid Facility Photon Collaboration

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ABSTRACT

The characteristics of a very interesting event recently found in an exposure of the SLAC Hybrid Facility to 20 GeV photons are discussed. This event contains two decays and is consistent with the production and decay of two charmed particles. The longer decay, of length 9mm, fits the hypothesis $\bar{D}^0 \rightarrow K^+\pi^+\pi^-\pi^-$ and has a proper flight time of $55 \times 10^{-13}s$. Possible background sources for this event are investigated and found to be extremely small.

We wish to call attention to an event found in the most recent (BC75) exposure of the SLAC Hybrid Facility to a 20 GeV backward scattered photon beam. This exposure was taken under very similar conditions (but with somewhat improved resolution) to those described in reference 1 (BC72/73) and the criteria for accepting events were exactly the same in both experiments.

The event is shown in Figure 1 and some specifics of the event are given in Table I. It contains two decays; a short decay at (0.10 ± 0.02) mm into at least two charged tracks and a long neutral decay into four charged particles at a distance of (9.0 ± 0.1) mm from the production vertex.

After close inspection of the high resolution film, we conclude that tracks 5^+ and 8^- definitely come from the short decay vertex and track 2^+ is likely to come from it. Tracks $(3^+, 4^+, 7^-)$ are ambiguous between the primary vertex and the short decay vertex, while track 6^- clearly comes from the primary vertex. Track 2^+ undergoes a 1-prong decay after 3.1 cm (off the photograph of Fig. 1) and is identified as a K^+ or Σ^+. There is no indication of a recoil proton stub at the short decay vertex. For those tracks definitely coming from the short decay, track 5 can be e^+, μ^+, π^+, or K^+ while track 8^- is identified as a pion by range. The minimum mass of this decaying particle is $M(e^+\pi^-) = (652 \pm 5)$ MeV/c^2 and therefore, all strange particle decay interpretations are ruled out. On the other hand, the short decay is fully compatible with a charmed particle decay.

The long decay at 9 mm from the production vertex has four charged tracks and its vertex is clearly separated from all other tracks. The identities of the charged tracks are given in Table I. The invariant mass $M_{(K^+\pi^+\pi^-\pi^-)} = (1862 \pm 8)$ MeV/c^2 is consistent with the accepted $\bar{D}^0$ mass. Also, the decay shows no transverse momentum imbalance, the resulting momentum vector of the four decay particles projected onto the film plane having a component transverse to its line of flight of (65 ± 100) MeV/c. Thus all the evidence is fully consistent with the decay of a (10.10 ± 0.06) GeV/c $\bar{D}^0$ into $K^+\pi^+\pi^-\pi^-$.

The proper flight time is calculated to be $(55.4 \pm 0.7) \times 10^{-13}$s.

To our knowledge the event contains the longest lived neutral D meson ever reported and clearly has an important bearing on the D^0 mean lifetime. Figure 2a shows the probability that an experiment of the size of the combined BC72/73 and BC75 ones would contain an acceptable $D^0/\bar{D}^0$ with proper flight time $> 55 \times 10^{-13}$ seconds as a function of D^0 lifetime. The calculation of the probability takes into account the fact that the total number of $D^0/\bar{D}^0$ produced, estimated from the observed number of $D^0/\bar{D}^0$, depends on the lifetime. The shaded region indicates the uncertainty in this number ($\pm 1\sigma$). For the published lifetime from our first experiment [(1)] of $6.8^{+2.3}_{-1.8} \times 10^{-13}s$, this probability is 3.3 percent. The probability decreases rapidly with decreasing lifetime and is 6×10^{-4} for the Particle Data Group[2] value of $4.4^{+0.8}_{-0.6} \times 10^{-13}s$.

The above conclusions are clearly totally dependent on the long decay really being a $\bar{D}^0$ and not some form of background. We have therefore examined all possible sources of background which could simulate a constrained 4-prong $\bar{D}^0$ decay (within 5σ of the D^0 mass and within 15 mm of the production vertex which is the maximum scanning length in our experiments). Table II lists conceivable sources of background. As can be seen, some are in fact not possible for the various reasons listed. In particular it should be noted that the 4-prong decay cannot come from the interaction of any neutral particle on a proton, since the minimum range of the recoil proton is 1.3 cm and would not be missed. The only possibilities left are background sources due to interactions of two independent beam $\gamma's$ or of a secondary K^0 (or neutron) on a deuteron present in the liquid hydrogen. In this latter type of background the spectator proton is not seen and the mass of the 4-body system is within 5σ of the $\bar{D}^0$ mass (in the case of a neutron interaction, within 5σ of the $p\pi^+\pi^-\pi^-$ mass which would be obtained if a p were substituted for the K^+, see Table Ib).

Background source 7 has the highest probability in this experiment. Here the long 4-prong decay is simulated by a secondary K^0 (from the production and subsequent decay of either of two charmed particles) interacting with a deuteron in the liquid hydrogen. In this hypothesis the short visible decay at 0.1 mm is then from the decay of one of the charmed particles produced and the other charm decay vertex is not visible. The expression used to obtain the probability that our experiment contains a secondary interaction on a deuteron simulating a $\bar{D}^0$ of this type within 15 mm of the production vertex is:

$$P = N_{charm} f_1 f_2 f_3 f_4 (\tfrac{15}{l})\ f_5$$

N_{Charm}	=	Number of charm/anticharm particle pairs in the whole film. From the measured charm cross section (Ref.1), 56^{+24}_{-23} nb, and a sensitivity of 5.0 events/ nb for the combined exposures we estimate N_{charm} = 280. (This estimate is only weakly dependent on the charm lifetime.)
f_1	=	Number of K^0s per interaction with momentum larger than the minimum necessary to generate the required mass (=0.4).
f_2	=	Fraction of interactions on deuterons in which the spectator proton is not seen on the high resolution photograph (=1/3).
f_3	=	Fraction of deuteron molecules in the liquid hydrogen ($= \frac{1.5}{10000}$) (measurements within our experiment are consistent with this natural frequency).
f_4	=	Fraction of the $(K^+\pi^+\pi^-\pi^-)$ invariant mass plot within $5\sigma(\pm$ 40 MeV) of the D^0 mass. (=1/10, this being averaged over the K^0 momentum spectrum above threshold).
l/f_3	=	Mean free path in millimetres for a K^0 to interact on a

neutron giving a $K^+\pi^+\pi^-\pi^-n(\pi^0)$ final state, averaged over the K^0 momentum spectrum. The cross section for the above reactions was estimated to be < 2 mb. From this $l/f_3 > 130{,}000 \times \frac{10{,}000}{1.5} (= 0.87 \times 10^9)$.

f_5 = Fraction of the cross section for the above reactions for which the p_T imbalance would not have been clearly observed $(=\frac{1}{4})$.

The probability, P, that in our experiment the long decay comes from this background source is less than 1.6×10^{-8}.

We have examined the possibilities that the event can be explained by two secondary interactions (sources 4 and 5, Table II) or two separate photon interactions which happen within 15 mm of each other (source 6b, Table II) and find that they are even less probable than the above explanation.

The upper limit to the relative probability that the event is due to background compared to the charm interpretation is shown in Fig. 2b. In this calculation we required that the $D^0/\bar{D}^0$ decayed into $K^\mp\pi^\pm\pi^+\pi^-$ (with a 7.5% branching ratio) and decayed after 55×10^{-13}s. It can be seen that this ratio is very small for our published lifetime and is small even for considerably shorter lifetimes.

In conclusion, we have found a γp interaction containing 2 decays. We have shown that these are fully compatible with the decays of two charmed particles, the longer lived being a $\bar{D}^0 \rightarrow K^+\pi^+\pi^-\pi^-$ with a proper flight time of $55.4 \times 10^{-13}s$. We have also shown that the probability for an event having these characteristics coming from background sources is extremely small (less than 1 in 6×10^7 experiments of our size). Figure 2a shows the probability that in an experiment of our size we would see a $\bar{D}^0$ surviving 55×10^{-13}s as a function of $\bar{D}^0$ mean lifetime. Using our published lifetime of 6.8×10^{-13}s from experiment BC72/73, the probability for our experiment to contain a $\bar{D}^0$ decay living at least this long is 3.3 percent. This probability decreases with decreasing mean lifetime.

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REFERENCE

1. K. Abe, et al., Phys. Rev D30 (1984) 1.

2. Particle Data Group, Reviews of Modern Physics 56 (1984).

Table 1: General Characteristics of the event.
For track numbering, see Fig. 1.

a) Track Identification

Track No.	Charge	Momentum MeV/C	Identity	Identified by	Vertex
6	−	489±6	$e/\mu/\pi$	ionization	Primary
3	+	4017±48	—	———	Primary or Short Decay
4	+	382±4	$e/\mu/\pi$	ionization	
7	−	431±4	$e/\mu/\pi$	ionization	
2	+	3030±330	K^+/Σ^+	Decay	
5	+	1072±12	not proton	ionization	Short Decay
8	−	65±2	π	range	
10	+	5452±56	K/P	Čerenkov	Long Decay
11	−	599±6	$e/\mu/\pi$	ionization	
13	+	3694±33	$e/\mu/\pi$	Čerenkov	
14	−	466±4	$e/\mu/\pi$	ionization	
15	0	574±53	γ	Lead Glass	All

b) Invariant Masses

Mass (Track Number)	Effective Mass (MeV/c^2)
$e^+(13)\ e^-(11)$	387±5
$e^+(13)\ e^-(14)$	531±5
$K^+(10)\ \pi^-(11)\ \pi^+(13)\ \pi^-(14)$	1862±8
$P(10)\ \pi^-(11)\ \pi^+(13)\ \pi^-(14)$	2159±8

Table 2: Possible background sources for event. For a detailed discussion see text.

Background Source	Comment	Could it simulate long decay
1. $K^0_L \rightarrow \pi^+\pi^-\pi^0$ $\rightarrow e^+e^-\gamma$	a) There is no possible e^+e^- mass less than 135 MeV, see Table 1b. b) $M(\pi^+\pi^-e^+e^-) >> M_K$ c) One track (10^+) is not an e or a π	No
2. $K^0 p \rightarrow K^+\pi^-\pi^-\pi^+p(\pi^0)$ ie: Secondary interaction of a K^0 from the production vertex	With $M_{K^+\pi^-\pi^-\pi^+}$=1862 MeV, the minumum range of the recoil proton is 2.2cm and would be easily seen.	No
3. np $\rightarrow p\pi^-\pi^-\pi^+(\pi^0)p$ ie: Secondary interaction of a neutron from the production vertex	With $M_{p\pi^-\pi^-\pi^+}$=2159 MeV, the minimum range of the recoil proton is 4 cm and would be easily seen.	No
4. $K^0 d \rightarrow K^+\pi^+\pi^-\pi^-(\pi^0)n(p_s)$ ie: Secondary interaction of a K^0 from the production vertex with a deuteron in the liquid hydrogen	Deuterium contamination of hydrogen is very low (see text)	Yes
5. nd $\rightarrow p\pi^+\pi^-\pi^-(\pi^0)n(p_s)$ ie: Secondary interaction of a neutron from the production vertex with a deuteron in the liquid hydrogen	See 4. above	Yes
6. The event is due to two independent beam γ interactions, one of which gives the production and short decay vertex and the other gives the 4-prong vertex 9mm downstream.	a) The 4-prong cannot be due to a secondary interaction on hydrogen since the minimum range of the proton in $\gamma p \rightarrow K^+\pi^+\pi^-\pi^-p(K^0\pi^0)$ or $K^+K^-\pi^+\pi^-(\pi^0)p$ is 1.3 cm and would be seen. b) The 4-prong could be due to a beam γ interaction on a deuteron in the liquid hydrogen $\gamma d \rightarrow p\pi^+\pi^-\pi^-(p_s)(\pi^0)$	a) No b) Yes
7. The event is due to the production of a charm anti-charm pair with a visible decay at 0.1mm. The long decay is simulated by a secondary K^0 from the charm decays interacting with a deuteron.	See 4. above	Yes

FIGURE CAPTIONS

1. Photograph of the event taken by the high resolution camera. Insert shows enlargement of region around primary vertex and short decay vertex. The position of the primary and short decay vertices were determined by measurement. The event is fully compatible with the decays of two charmed particles, the decay at 9 mm being a $\bar{D}^0 \rightarrow K^+\pi^+\pi^-\pi^-$ with a proper flight time of 55.4×10^{-13}s. Details of the event are discussed in the text.

2. a) Probability that an experiment of the size of the combined BC72/73 and BC75 exposures would contain an acceptable $D^0/\bar{D}^0$ with proper flight time $> 55 \times 10^{-13}$ seconds as a function of D^0 lifetime. Shaded area represents the uncertainty ($\pm1\sigma$) in the calculated number of $D^0/\bar{D}^0$ produced.

   b) Upper limit to the relative probability that the event is due to background compared to the charm particle decay interpretation as a function of D^0 lifetime.

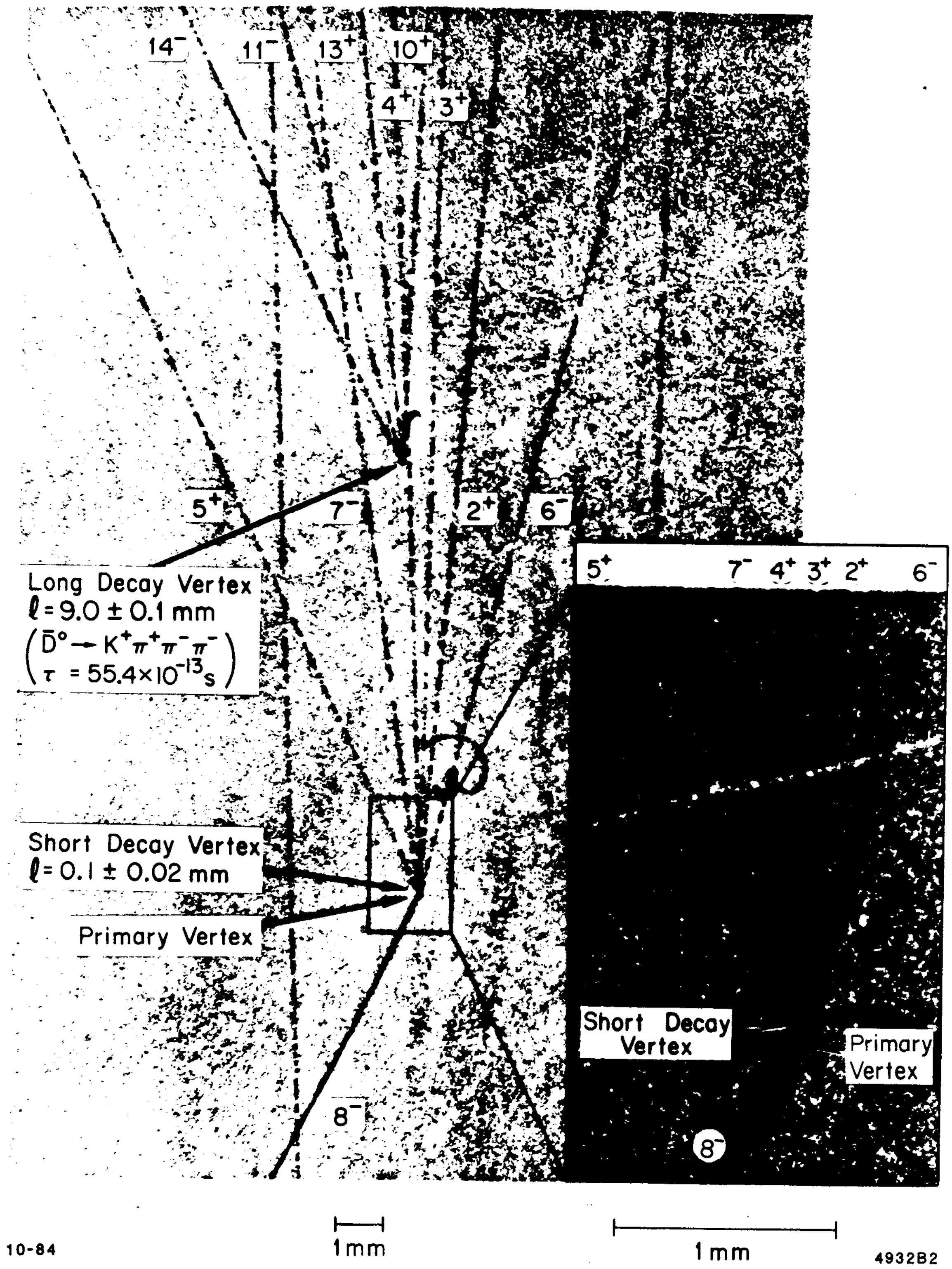
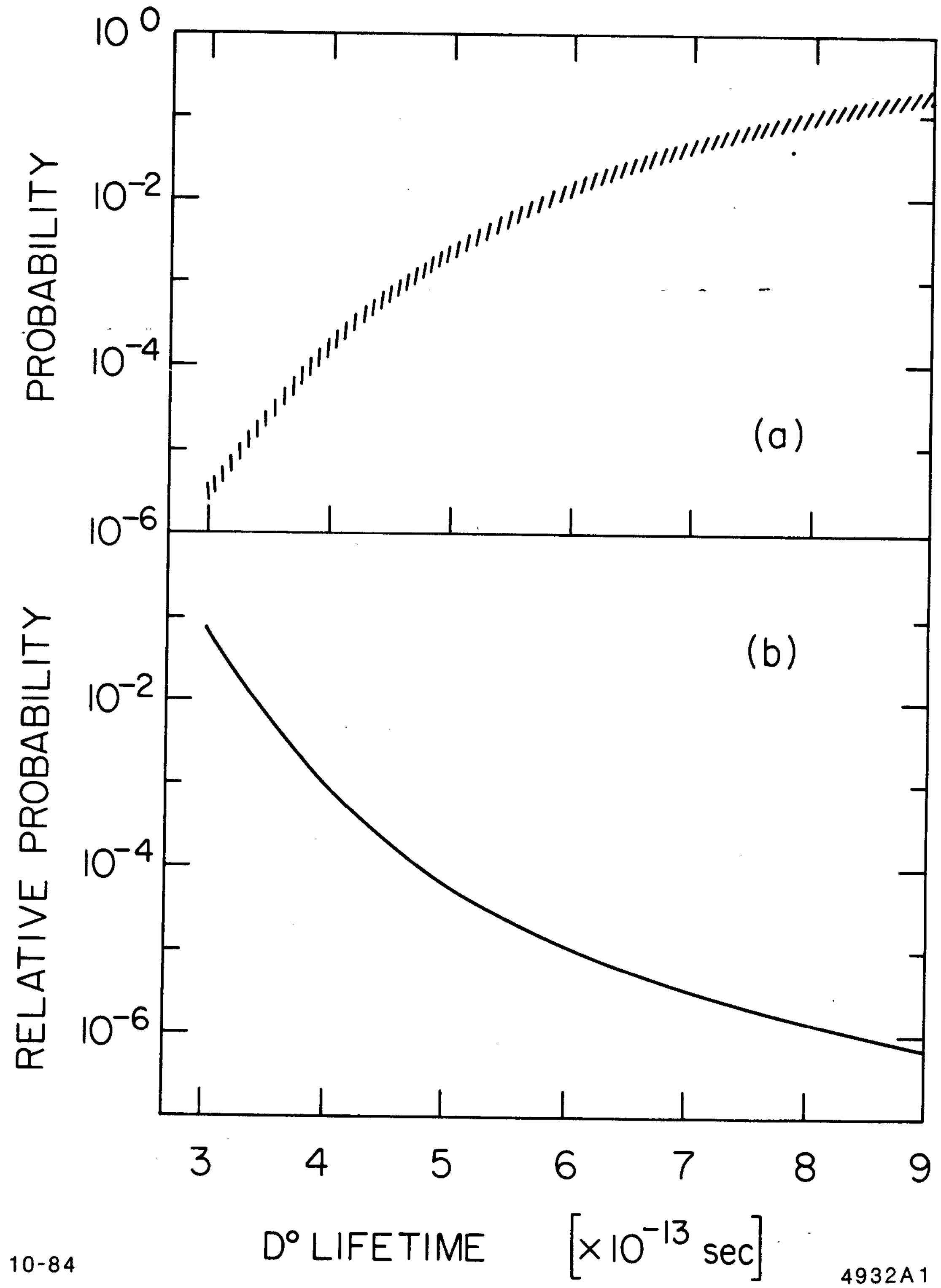

14⁻
11⁻
13⁺
10⁺
4⁺
3⁺
5⁺
7⁻
2⁺
6⁻
Long Decay Vertex
ℓ = 9.0 ± 0.1 mm
(D̄° → K⁺π⁺π⁻π⁻
τ = 55.4×10⁻¹³ s)
Short Decay Vertex
ℓ = 0.1 ± 0.02 mm
Primary Vertex
8⁻
5⁺ 7⁻ 4⁺ 3⁺ 2⁺ 6⁻
Short Decay Vertex
Primary Vertex
8⁻
10-84
1mm
1mm
4932B2

FIGURE 1



PROBABILITY
RELATIVE PROBABILITY
(a)
(b)
10^0
10^-2
10^-4
10^-6
3
4
5
6
7
8
9
D° LIFETIME [× 10^-13 sec]
10-84
4932A1

FIGURE 2