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A.M. Cnops, P.L. Connolly, S.A. Kahn, H.G. Kirk,
M.J. Murtagh, R.B. Palmer, N.P. Samios and M. Tanaka

Brookhaven National Laboratory, Upton, New York 11973

and

C. Baltay, M. Bregman, L.D. Chen, H. French, M. Hibbs, R. Hylton,
M. Kalelkar[a)], J.-T. Liu, C. Murphy, J. Okamitsu, E. Schmidt[b)], K. Shastri, and
A. Vogel

Columbia University, New York, N.Y. 10027

presented by

H.G. Kirk

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[a)] Present address: Rutgers University, New Brunswick, N.J. 08903

[b)] Present address: Fermilab, Batavia, Ill. 60510

OBSERVATION OF A VISIBLE CHARMED PARTICLE DECAY IN NEUTRINO INTERACTIONS

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In a sample of 250 semileptonic charmed particle decays (ν_μ + Neon $\to \mu^- + e^+ + \ldots$ events), we find one clear event where the e^+ does not come directly from the ν interaction vertex but from a decay point 1.1 cm downstream of the vertex. We interpret this event as a visible charmed particle decay: into an e^+ and a positive and a negative charged track. The observation of a visible charm decay in our sample is consistent with what we would expect if the charm lifetime were of the order of 5×10^{-13} sec.

We have accumulated a final sample of 250 events of the type,

$$\nu_\mu + \text{Neon} \to \mu^- + e^+ + \text{hadrons},$$

in a neutrino experiment at Fermilab. Considerable evidence has been obtained in this and other experiments[1] indicating that the origin of the e^+ in these opposite sign dilepton events is the semileptonic decay of charmed particles produced in the neutrino interactions. If the lifetime of these charmed particles were short, in the range of 10^{-13} to 10^{-12} seconds, then in most of these events the decay would occur so close to the neutrino interaction vertex that the e^+ would seem to come directly from the interaction point. However in a small fraction of the events the charmed particle might live long enough for the decay point to be distinguishable from the interaction vertex where the charmed particle was produced.

In this note we report that in one of the events in this $\mu^- e^+$ sample, the e^+ appears not to originate at the neutrino interaction vertex but at a point 1.1 cm distant from the interaction vertex. A charged track produced at the interaction vertex decays into three charged tracks, an e^+ and a positive and a negative hadron.

The experiment was carried out at the Fermi National Accelerator Laboratory using the double-horn focused wideband muon-neutrino beam and the 15-ft bubble chamber filled with a heavy neon-hydrogen mixture (64 atomic % neon). Details of the $\mu^- e^+$ sample such as selection criteria, rate, backgrounds, etc. have been given in previous publications.[2] Our

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[a] Present address: Rutgers University, New Brunswick, N.J. 08903

[b] Present address: Fermilab, Batavia, Ill. 60510

final sample consists of 250 μ^-e^+ events in a total of ∿ 100,000 charged current ν_μ interactions.

Our confidence in the origin of the e^+ comes from a careful examination of the vertex region of the event under very high magnification. A photograph and sketch of the event is shown in Fig. 1. The event has been measured and geometrically reconstructed, and the e^+ track has been extrapolated back to the interaction vertex. The distance of closest approach of the e^+ (i.e. the perpendicular distance from the extrapolated e^+ track to the interaction vertex) is 2100 ± 280 microns. The decay angle (i.e. the angle between the e^+ and the parent track) is $8.9 \pm 1^\circ$ and the distance from the interaction vertex to the decay point is 1.1 ± 0.2 cm. Thus it is very clear that the e^+ does not come from the interaction point but from a distinct decay point.

The event consists of a 5.7 GeV/c μ^-, two slow positive tracks that are most likely protons (possibly from breakup of the neon nucleus), a decaying positive track, an interacting negative track, and the short (1.1 cm) track that splits into an e^+, a leaving positive track, and a very energetic interacting negative track. The total visible energy of the event is 43 GeV. We unfortunately cannot tell whether the positive decay product is a μ^+, π^+, K^+ or p, or whether the negative decay product is a π^- or K^-. In the spirit of showing consistency of interpreting this event as charm decay, we can call the positive a π^+ and the negative a K^-, in which case the decay could be $D^+ \rightarrow K^-\pi^+e^+(\nu_e)$. The $K^-\pi^+e^+$ effective mass is 1676 MeV, consistent with this interpretation with a missing ν_e. The decay cannot be interpreted as the decay of a charmed baryon since the effective masses with the proper mass assignments exceed the $\Lambda_c^+(2260)$ mass (the K^-pe^+ mass is 3889 MeV, and the $\pi^+\pi^-\ e^+$ mass with a missing Λ^0 is larger than 2700 MeV). The positive decay product is within errors at 0° to the short 1.1 cm track. This allows another possible interpretation of this event as the decay of a neutral particle, for example $D^0 \rightarrow K^-e^+(\nu_e)$ at 1.1 cm from the interaction vertex, with the positive track coming directly from the vertex, unrelated to the decay, but accidentally falling on top of the decay point in all three stereoscopic views. The K^-e^+ mass is 1493 MeV. (The errors on all of the effective masses given are of the order of ± 25 MeV.)

We have considered a variety of backgrounds, i.e. interpretations other than charm decay for this event. The e^+ has a transverse momentum of 450 ± 60 MeV/c with respect to the line of flight of the parent particle. This is significantly larger than the transverse momentum allowed in the decay of any known strange particle; thus the event cannot be interpreted as a strange particle decay. Other possibilities considered were a) a positive hadron produced at the interaction vertex interacting in 1.1 cm, producing hadrons including a π^0, which then Dalitz decays so asymmetrically that only the e^+ is visible; b) an e^+ from the interaction vertex scattering inelastically or elastically at 1.1 cm producing the observed e^+; c) a hadron produced at the interaction vertex interacting at 1.1 cm from the vertex producing a K^+ which then decays into $\pi^0e^+\nu$ in flight producing the e^+ observed. The total background from all of the above sources was estimated to be less than 0.1 events. Thus it is not likely that the observed event is due to the backgrounds discussed, and we interpret it as an example of visible charm decay.

In order to estimate the proper time at which the decay occurred, we need to know the momentum of the parent particle. We cannot reconstruct this momentum because there is a missing ν_e in the decay. We have calculated the minimum and maximum energy that the ν_e could have carried off by requiring that the effective mass of the decay products including the ν_e be consistent with the D meson mass. This gives a range for the momentum of the D before decay to be 35 to 63 GeV/c with a corresponding range of proper times of 9×10^{-13} to 2×10^{-12} sec. This number, however, is not very meaningful since our efficiency for seeing a decay drops drastically at shorter lifetimes (we cannot see decay distances under 0.5 cm in this experiment), and thus the visible decay is likely to be way out on the tail of the lifetime distribution.

A more fruitful approach is to consider that we have a sample of 250 semileptonic charm decays ($\mu^- e^+$ events) and to ask how many of these decays do we expect to occur at distances longer than 0.5 cm as a function of the charmed particle lifetime. We can actually carry out such a calculation since we know the momentum distribution of the parent D mesons from our previous observation$^{3)}$ of ∿ 60 events of the hadronic decays, $D^o \rightarrow K^o\pi^+\pi^-$, where there are no missing particles and thus the momentum of the D^o can be measured. Figure 2 shows the momentum distribution of this sample after background subtraction. Assuming that the charmed particles whose semileptonic decays we see in the $\mu^- e^+$ events have the same momentum distribution and that a single lifetime is involved (which is not strictly true since we probably have some mixture of D^o, D^+, Λ_c^+, etc. decays), we obtain the number of charm decays into an e^+ + hadrons that we expect in the whole experiment as a function of charm lifetime, shown in Fig. 3. The curve shown in this figure also includes an estimate of our efficiency of finding such decays with decay distances over 0.5 cm. Based on this calculation, we expect to see an event if the charm lifetime is of the order of 5×10^{-13} sec.

Charmed lifetimes of this order of magnitude are consistent with the events observed in emulsions$^{4)}$ and the events with visible charmed decays seen in another neutrino experiment$^{5)}$ in the 15-ft chamber at Fermilab.

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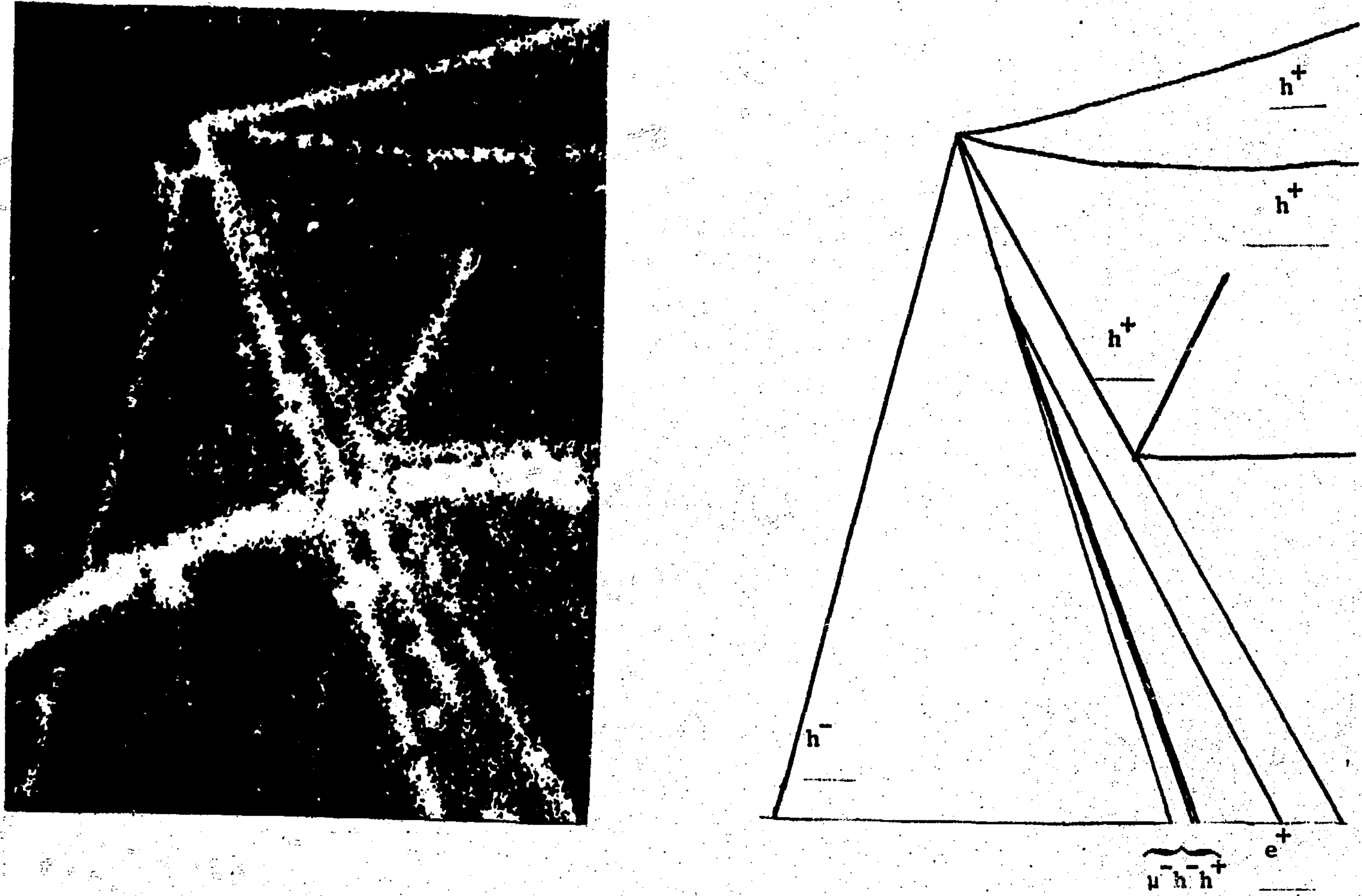

FIG. 1. Photograph and sketch of the neutrino interaction. The symbol h is used for tracks with hadron interpretations.

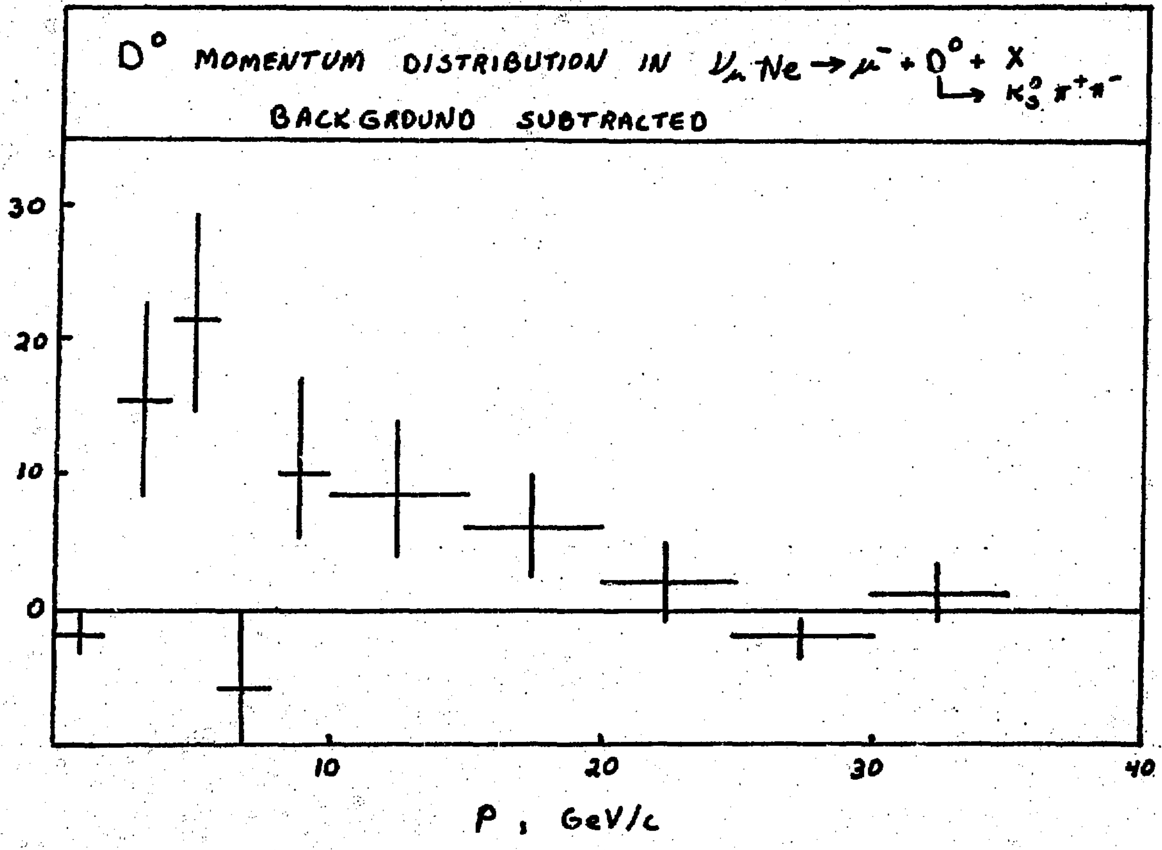

FIG. 2. The measured D^0 momentum distribution.

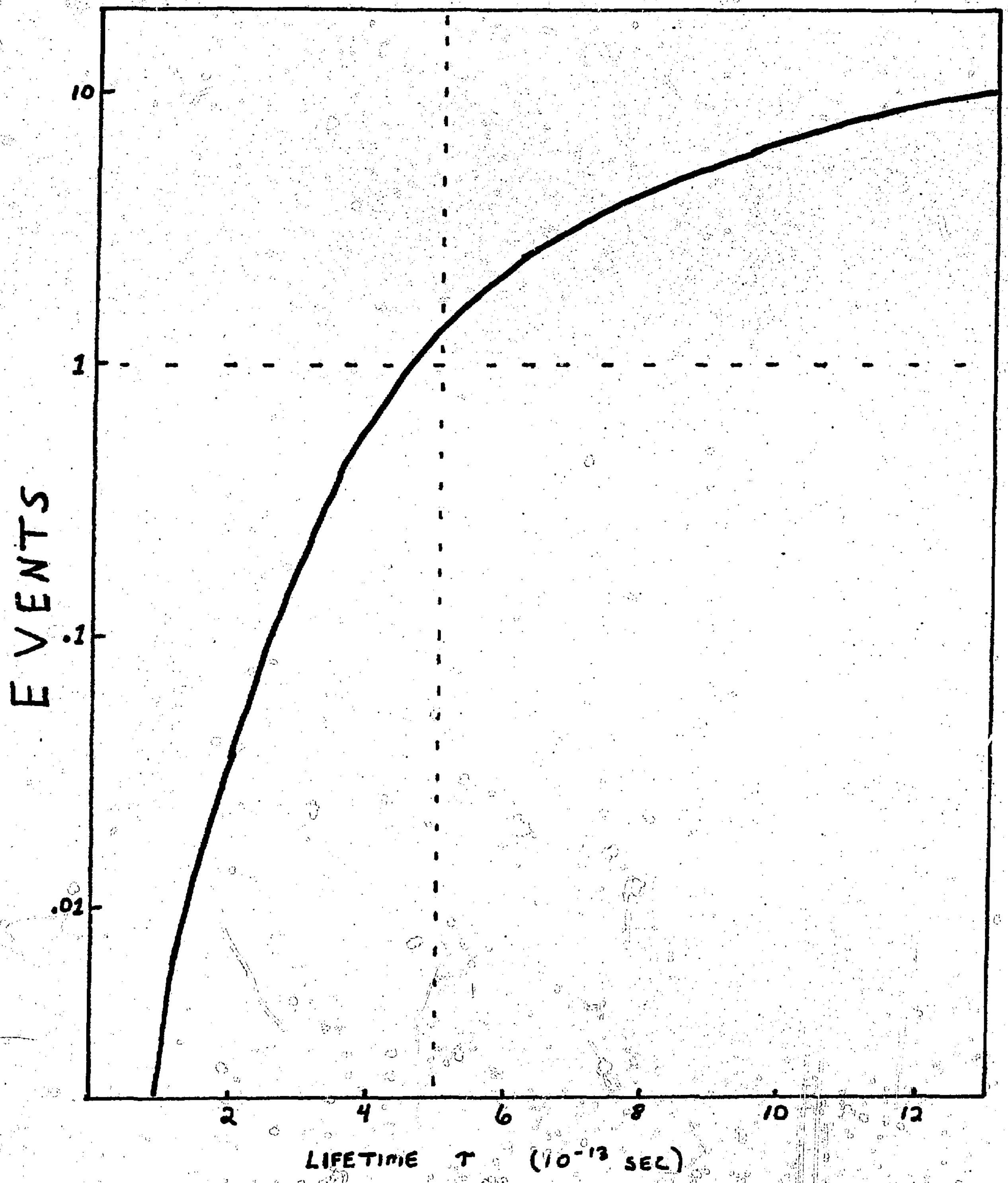

FIG. 3. Expected number of visible charm decays as a function of the charm lifetime.