Observation of the Production of Short-Lived Particles in a High-Resolution Streamer-Chamber Experiment

J. Sandweiss, T. Cardello, P. Cooper, S. Dhawan, R. Kellogg,(a) D. Ljung,(b)
T. Ludlam,(c) R. Majka,(d) P. McBride, P. Némethy,(d) L. Rosselet,(e)
A. J. Slaughter, H. D. Taft, L. Teig, and L. Tzeng
Yale University, New Haven, Connecticut 06520

and

S. Ecklund(f) and M. Johnson
Fermi National Accelerator Laboratory, Batavia, Illinois 60510

(Received 22 January 1980)

Short-lived particles produced in association with muons have been observed in the interactions of 350-GeV/c protons with neon in a high-resolution streamer chamber. The characteristics of these events are consistent with the expected properties of charmed particles if the average lifetime lies between 10^{-13} and 2×10^{-12} sec. With the assumption that the observed events are mainly $D^{\pm}$ mesons with lifetimes of approximately 10^{-12} sec, the production cross section is estimated to lie between 20 and 50 μb per nucleon.

PACS numbers: 13.20.Jf, 14.40.Pe

The discovery of particles with the theoretically predicted attributes of charm as well as the theoretical prediction[1-3] that charmed particles should have lifetimes of the order of 10^{-13} sec have motivated a number of experiments to observe directly the decays of such particles.[4-6] Several of these experiments, in particular those using bubble-chamber and emulsion techniques,[7,8] have observed such decays associated with neutrino interactions. The experiment reported here was designed to detect the production and decay of charmed particles in hadronically induced events where the production rate is perhaps as low as 0.1% of the total interaction rate. For hadronic production of charm, therefore, it is advantageous to employ a device which is triggerable with fast electronics yet retains the capability of recording short decay lengths.

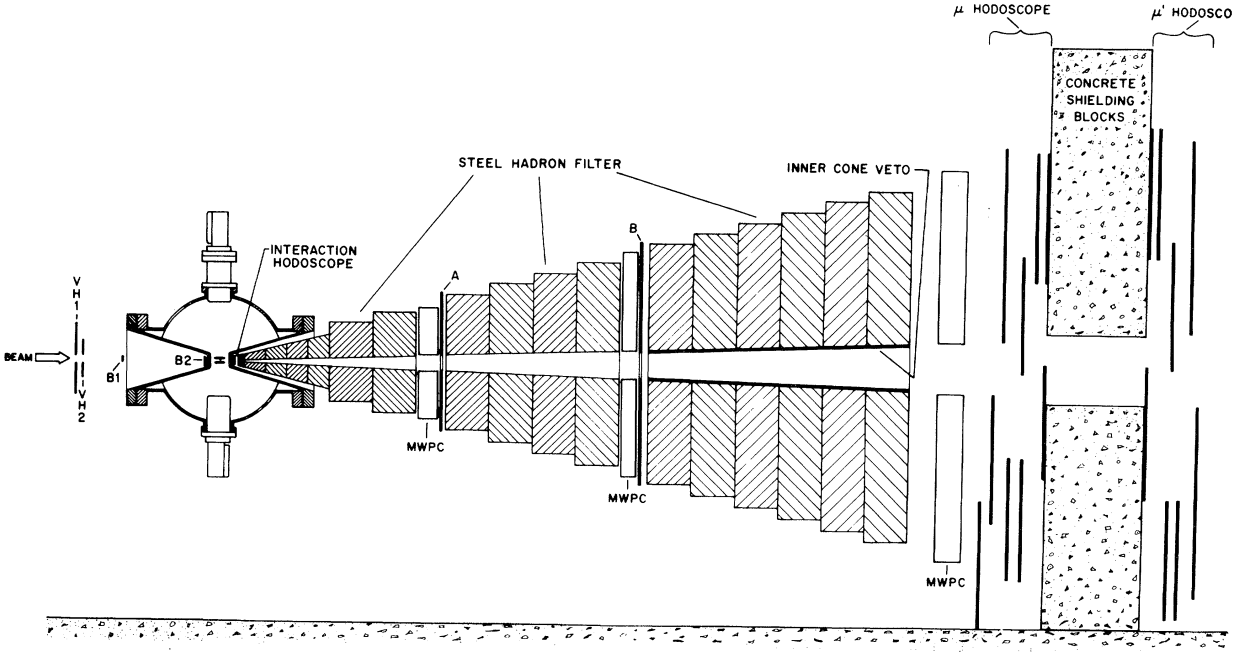

FIG. 1. The experimental arrangement, including the streamer chamber, beam-defining counters, interaction hodoscope, and muon filter.

TABLE I. Data sample.

Incident beam	350-GeV protons
Incident flux per pulse	$(0.5-0.8)\times 10^6$
Average number of triggers per pulse	~1
Number of fiducial interactions with full muon trigger	1062
Ratio of nonfiducial to fiducial triggers	10/1

A high-resolution streamer chamber has been developed and used to study production of charmed particles by incident 350-GeV protons interacting with the nuclei of the chamber gas consisting of 90% Ne and 10% He at a pressure of 24 atm. In this experiment, the width of track images was 150–200 μm (in space) and the experimental resolution was 40 μm. Other properties of the chamber have been described elsewhere.[9]

The position of the chamber and the associated muon filter is shown in Fig. 1. The beam was defined by the small counter *B*1. Upstream interactions were vetoed by requiring that the hole counters *VH*1 and *VH*2 not count for a good beam particle.

Interactions of the incident beam particles in the chamber gas (or windows) were detected by requiring two or more counts in a small eight-counter hodoscope located just behind the exit beam window. The trigger was designed to select events with prompt muons by requiring, in addition to a beam particle and interaction signal, a count in one or more of the counters behind the muon filter and the absence of a count in the inner-cone veto counter. Some data were also taken with an interaction trigger which required only a beam particle, an interaction, and no inner-cone veto. Table I summarizes the data sample obtained.

The scaled, ungated rates for beam, interaction, and muon triggers imply that the muon requirement rejects all but 1 in 2200 hadronic interactions. If we assume that the hadrons accompanying charmed particles are produced with distributions similar to those in ordinary hadronic events then approximately 27% of charm-production events survive the cone veto requirement. Using these rates, a Monte Carlo analysis discussed below with different assumptions for charmed-particle semileptonic branching ratios and lifetimes indicates that the muon trigger events obtained are between 15 and 50 times richer in charm production than a similar sample of "raw" interaction-trigger events. The small sample of interaction triggers obtained confirms the Monte Carlo analysis within limited statistics.

The data sample has been analyzed in terms of an l, θ_D plot where l is the distance in space (neglecting dip angles) which the charmed particle traveled before decaying and θ_D is the projected angle of the decay track. When the line of flight of the charmed particle cannot be observed it is assumed to be along the beam direction. These definitions are illustrated in Fig. 2. The bound-

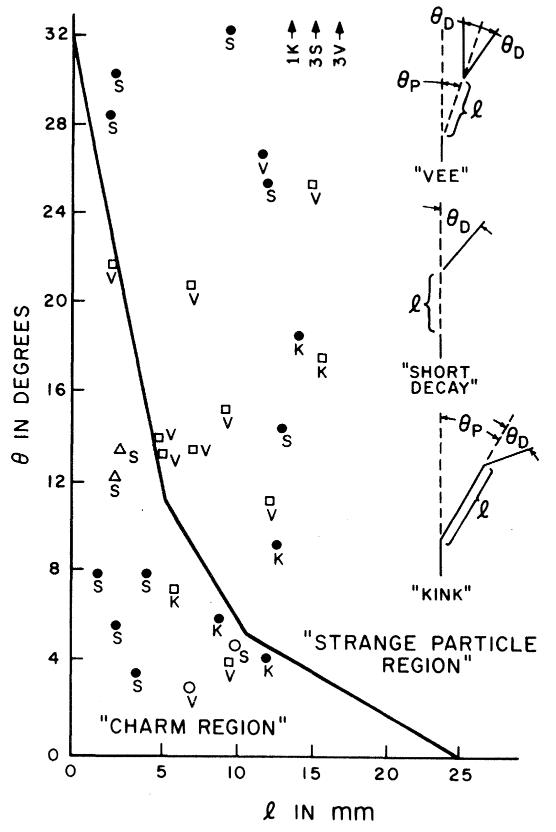

FIG. 2. Definitions of event categories and data from the muon trigger sample displayed on a plot of length vs laboratory angle. The squares represent all events having projected angle $\theta_p \geq 13°$. Open circles represent events for which the track not associated with the primary vertex is possibly, but not uniquely, a muon. The two triangles represent events for which this "decay track" is a uniquely identified muon. Note that seven strange-particle events lie off scale.

ary separating the "charm" region and the "strange-particle" region was chosen so that for charmed-particle lifetimes of 10^{-12} sec or less there should be a negligible number of charmed-particle decays in the strange-particle region. It is important to note that this boundary is determined solely by kinematics and does not depend on assumptions about the dynamics of hadronic charm production. Finally, a requirement is imposed on all but the "short decay" events that the projected production angle of the decaying track, θ_p, be within 13° of the incident beam direction if the event is to be considered a charm candidate.

Figure 2 presents the data from the muon-trigger sample and shows that there are 10 charm candidate events with production angle $\theta_p < 13°$ and 26 strange-particle events (3 in the charm region with production angle $\theta_p \geq 13°$). The sources of background in this sample include δ rays, secondary interactions, and strange-particle decays. While δ rays can be shown to give a negligible contribution and secondary interactions amount to less than 0.2 background event, strange-particle decays are a potentially serious source of background. From the events observed in the strange-particle region, the strange-particle decay contributions for those strange particles with momenta less than about 2 GeV/c can be directly estimated. Above 2 GeV/c, where at typical decay angles the potential path for decay of these particles is largely inside the charm region, the background has been estimated with use of data from a bubble chamber study of 205-GeV/c π on hydrogen.[10] A summary of the charm signal statistics is given in Table II.

A Monte Carlo sample was generated using the observed events and a charm-production model which assumed that D-$\bar{D}$ pairs were produced in an uncorrelated fashion with the following Feynman X (X_F) and transverse momentum ($P_\perp$) dependence:

$$d^2\sigma/d(P_\perp^2)\,dX_V = A\exp(-9.94X_F^2 - 2P_\perp).$$

TABLE II. Charm signal summary.

Strange-particle events	26
Charm candidates	10
Backgrounds to charm candidates	
(a) "Slow" strange particles	1.07 ± 0.38
(b) Fast strange particles	0.85
(c) Secondary interactions	0.18
Total background	2.1 ± 0.4

The results are essentially unchanged if an X_F distribution of the form $(1-X_F)^{2.9}$ is used as suggested by studies of prompt single muons.[11] It is also assumed that the states D^+D^-, D^+D^0, $D^0\bar{D}^0$, and D^0D^- are produced with equal probability and that the purely hadronic decays of the D mesons proceed via phase space with the multiplicities adjusted so that the average number of charged decay particles from both charged and neutral D mesons is 2.3. Finally, the following two models have been used for the semileptonic branching ratios and the ratio of D^0 to $D^\pm$ lifetimes[12]: model 1,

$$R(D^0) = R(D^\pm) = 10\%, \quad \tau(D^0) = \tau(D^+);$$

model 2,

$$R(D^\pm) = 23\%, \quad R(D^0) = 0\%, \quad \tau(D^0) = \tau(D^\pm)/5.8.$$

An integrated scanning efficiency was determined by overlaying representations of the Monte Carlo events on actual photographs, and the results of this analysis are shown in Fig. 3. Limits on the lifetime may be deduced by noting that if the lifetime were less than 10^{-3} sec the observed events would have clustered at the lowest values of l and θ_D permitted by the scanning efficiency. On the other hand, if the lifetime were greater than 2×10^{-12} sec the method of background determination used would have eliminated the signal in the charm region. We note that our results agree with the measurements of hadronic production of charm deduced from prompt-muon observation[11] if we use a value for the $D^\pm$ lifetime of

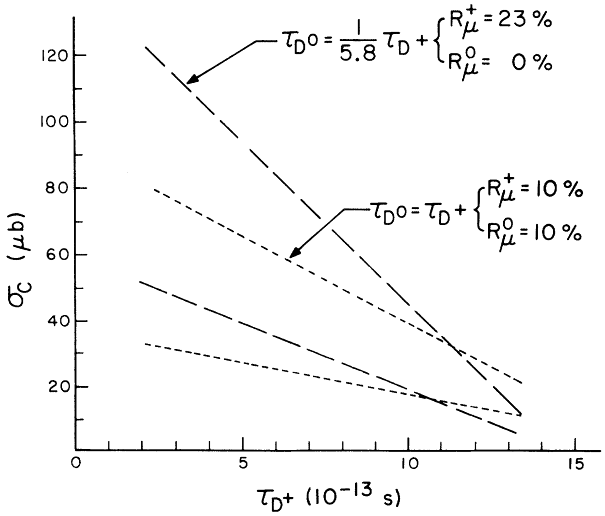

FIG. 3. The relationship between the charm-production cross section and the lifetime of the $D^\pm$ implied by this experiment, for the two models discussed in the text.

approximately 10^{-12} sec as is also indicated by neutrino emulsion experiments.[7,8]

In conclusion, short-lived particles produced in association with muons in hadronic interactions have been observed in this experiment. The most reasonable interpretation is that of charmed-particle production. The average lifetime of the particles observed above the strange-particle background must lie between 10^{-13} and 2×10^{-12} sec. If, as suggested by Refs. 11 and 12, the lifetime of the $D^{\pm}$ is approximately 10^{-12} sec, the production cross section is estimated to lie between 20 and 50 μb per nucleon for 350-GeV incident protons.

This work was supported in part by the U. S. Department of Energy. We are especially appreciative of the support and assistance of the research division and meson laboratory division of Fermi National Accelerator Laboratory.

---

[a] Present address: University of Maryland, College Park, Md. 20742.

[b] Present address: Fermi National Accelerator Laboratory, Batavia, Ill. 60510.

[c] Present address: Brookhaven National Laboratory, Upton, N. Y. 11973.

[d] Present address: Lawrence Berkeley Laboratory, Berkeley, Cal. 94720.

[e] Present address: CERN, Geneva 23, Switzerland.

[f] Present address: Stanford Linear Accelerator Center, Stanford, Cal. 94305.

[1] M. K. Gaillard, B. W. Lee, and J. L. Rosner, Rev. Mod. Phys. 47, 277 (1975).

[2] J. D. Jackson, C. Quigg, and J. L. Rosner, in *Proceedings of the Nineteenth International Conference on High Energy Physics, Tokyo, Japan, August 1978*, edited by S. Homma, M. Kawaguchi, and H. Mayazawa (Physical Society of Japan, Tokyo, 1979), p. 391.

[3] N. Cabibbo, G. Corbo, and L. Maiani, Nucl. Phys. B155, 93 (1979).

[4] K. Niu, E. Mikumo, and Y. Maeda, Prog. Theor. Phys. 46, 1644 (1971).

[5] G. Goldhaber *et al.*, Phys. Rev. Lett. 37, 255 (1976).

[6] H. Fuchi *et al.*, Phys. Lett. 85B, 135 (1979).

[7] R. Diebold, in *Proceedings of the Nineteenth International Conference on High Energy Physics, Tokyo, Japan, August 1978*, edited by S. Homma, M. Kawaguchi, and H. Miyazawa (Physical Society of Japan, Tokyo, 1979), p. 666.

[8] N. W. Reay, in Proceedings of the Annual Meeting of the Division of Particles and Fields of the American Physical Society, McGill University, Montreal, 25–27 October 1979 (to be published).

[9] J. Sandweiss, Phys. Today 31, No. 10, 40 (1978); R. Majka *et al.*, to be published.

[10] D. Ljung, private communication.

[11] K. W. Brown *et al.*, Phys. Rev. Lett. 43, 410 (1979).

[12] J. Kirby, in Proceedings of the International Symposium on Lepton and Photon Interactions at High Energies, Fermilab, Batavia, Illinois, 23–29 August 1979 (to be published).