Fermi National Accelerator Laboratory

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A REVIEW OF RECENT MEASUREMENTS OF CHARMED PARTICLE LIFETIMES USING EMULSIONS

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I. Introduction

This talk is a review of results which have been reported during the past year on charmed particle decays in emulsions. Reviews of earlier results were covered by Diebold[1] at the Tokyo Conference last August and discussed at the Bartol Conference last October by Niu[2], Yamanouchi[3], and Rosner[4].

The status of the experimental study of charmed particle lifetimes was described[4] last year as still being in its infancy. The observations available from emulsion techniques did indicate, however, the existence of short lived particles, with lifetimes in the region of 10^{-13} seconds. Some of the data also suggested[1,2,3] that several charmed particle species may have been observed, with lifetimes $\sim 1.2 \times 10^{-12}$ sec., $\sim 4 \times 10^{-13}$ sec. and $\sim 2 \times 10^{-14}$ sec.

Experimentally, lifetimes may be established by direct observations of individual events, with proper decay times deduced from

$$\tau = \left(\frac{\ell_{dec}}{c}\right)\left(\frac{M_c}{P_c}\right) \quad (1)$$
$$= 3.3 \times 10^{-15}\, \ell_{dec}\, (M_c/P_c) \text{ sec.}$$

where ℓ_{dec} is the observed decay length (in microns), M_c and P_c are the mass and momentum of the charmed particle undergoing decay. Technical interest also needs to focus on decay detection efficiency, identification of secondary particles, decay modes, kinematic fipting procedures, as well as on experimental conditions with good event statistics.

Theoretical aspects of interest here in charmed particle average lifetimes[4,5,6] can be summarized in the form:

$$\tau_c \simeq 5.0 \times 10^{-12} \left(\frac{1.75}{M_c^q}\right)^5 \cdot B_{SL} \text{ sec} \quad (2)$$

where M_c^q is the mass of the charmed quark and $B_{SL} = \Gamma_{SL}/(\Gamma_{SL} + \Gamma_h)$ is the semi-leptonic branching ratio for a charmed particle species, with Γ_{SL} the decay width for semi-leptonic and Γ_h the width for hadronic decay modes. Precise lifetime measurements should, therefore, shed light on the charmed quark mass M_c^q, but particularly on the degree of non-leptonic enhancements (Γ_h) for the main charmed particles which are believed to decay by weak interactions, i.e. the D^0, D^+, F^+, and C_0^+ particles and their antiparticles[4,5].

An overview of typical expectation values is sketched in Figure 1 for parameters in the production and decay of charmed particles ($M_c \sim 2$ GeV/c^2) in hadronic collisions at Fermilab and CERN SPS energies. Decay lengths are shown as ranging from microns to centimeters, depending on the collision dynamics and kinematic regions, as well as on particle lifetimes. For neutrino interactions in the experiments to be reviewed, charmed particle characteristics are expected to be similar to those in hadronic collisions for the target fragmentation region; current fragmentation characteristics are anticipated to be similar to those illustrated for the hadronic central region in Figure 1. Theoretical biases and estimates, as reviewed by Rosner[4], would suggest the 10^{-13} second region in Figure 1 for D^0, F^+, C_0^+, and the 10^{-12} seconds region for D^+ particles. Observable yields are expected to show $\sigma(D^0) \sim 3/2\, \sigma(F^+) \sim 3\sigma(D^+)$, with expected total charm production cross sections, normalized to inelastic cross sections, $\sigma_c/\sigma_{in} \sim 10^{-3}$, $\sim 10^{-2}$, $\sim 10^{-1}$ for incident hadrons, photons and neutrinos in current experiments at Fermilab and CERN SPS.

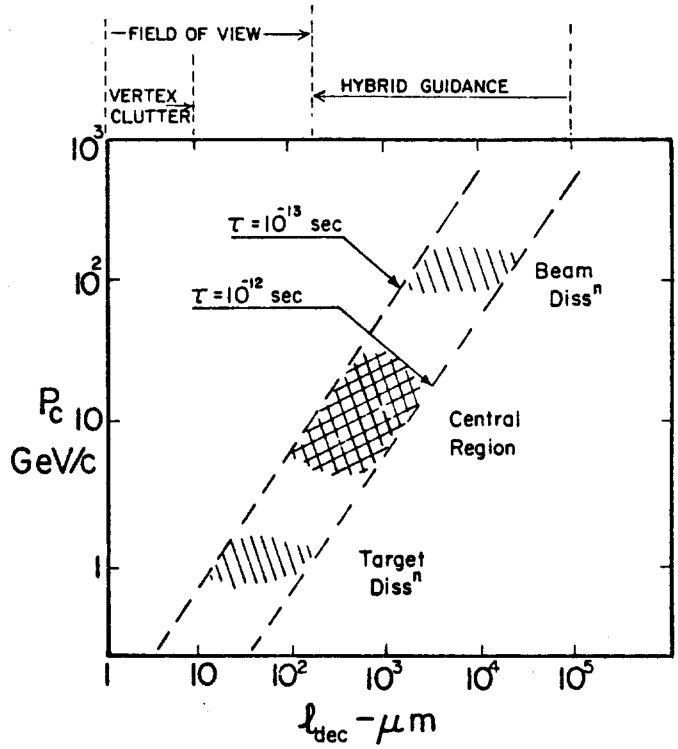

Fig. 1 Estimates of typical momenta and decay lengths expected for charmed particles produced at Fermilab and CERN SPS energies.

At the top of Figure 1 are shown some features which bear on the capabilities of emulsion methods for dectecing charmed decays:

a) Typically, emulsion microscopy allows efficient recognition of decaying charged or neutral particles in a field of view of about 150 μm when using ~ 1,000 X magnification.

b) For the first 10 μm or so near the primary interaction vertex, direct recognition of decays is difficult. By track coordinate measurements and vertex fitting[7,8], decaying particles may be detected in this cluttered region if at least one of the secondary tracks from a decay shows an impact parameter, or distance of closest approach to the vertex, to exceed $3\sigma \gtrsim 0.15$ μm[7].

c) At decay distances larger than a field of view, $\ell_{dec} \gtrsim 150$μm, direct scanning can be carried out over successive downstream fields of view, with corresponding increases in the required scanning time. For events selected for close scrutiny, particle decays are now typically searched by following tracks out to ~ 5mm from the vertex. Direct scanning for neutral decays with $\ell_{dec} \gtrsim$ 1mm tends to become very laborious.

d) Increasingly, emulsion experiments are making use of hybrid arrangements with external track chambers. Much of the new experimental data reviewed here has depended on such hybrid guidance, not only for helping to locate the primary interaction vertices in the emulsion and for secondary particle spectroscopy, but also in improving the detection efficiency for locating decay particles with large values of ℓ_{dec}, as indicated at the top of Figure 1. This kind of guidance is especially useful for searching in the emulsions for those tracks which appear to be either extras or missing, in the downstream detectors. The hybrid technique of back-following individual tracks from the downstream detector to their origins in an emulsion-stack, first developed[9] for short lived particle searches in neutrino interactions in 1965, has been made particularly effective in Fermilab neutrino experiment E531 as just described by Prentice[10].

II. Recent Experimental Results

New charm decay data from emulsion experiments, as reported since the Tokyo Conference, are summarized in Figure 2 and include:

a) 2 sets of associated $D\bar{D}$ candidates from proton collisions in emulsion chambers, by Niu and his associates[11,12],

b) a $\bar{D}^0$ event from photon collision[13], using emulsion-Omega spectrometer hybrid system in the CERN SPS experiment WA4,

c) 17 analyzable neutrino-induced charm candidates; 10 from Fermilab experiment E-531 with emulsion - drift chamber spectrometer, as just reported to this Conference by Prentice[10], 6 from CERN experiment WA17 using emulsions in front of the Big European Bubble Chamber BEBC[14,15,16] and an initial event from Fermilab experiment E-564 using emulsions inside the 15-foot bubble chamber[17].

Each of these charmed particle decay candidates is represented in Figure 2 by its decay topology (N_{ch} = 2 or 4 for neutrals, N_{ch} = 3 for all the reported charged events), the decay length ℓ_{dec}, and estimated momentum P_c. The dashed lines for various proper decay times τ are from equation (1), assuming $M_c \sim 2$ GeV/c^2.

A. D^+D^- Candidate Pair from 25 TeV Proton Collision

The highest momentum candidates in Figure 2 are from observations[11] on a pair of charged decay candidates in an emulsion chamber exposed to cosmic rays at balloon altitudes. From angular distribution and relative scattering measurements on the 56 observed shower particles, and on gamma ray showers in the downstream analyzer portion of their chamber, the incident proton energy was estimated to be about 25 TeV. Table I gives a summary of observations and fitted values for tracks 27 and 32 which were analyzed as D^+, D^- candidates; decay angles and momentum estimates are also shown for the three secondary particles observed from each decay vertex.

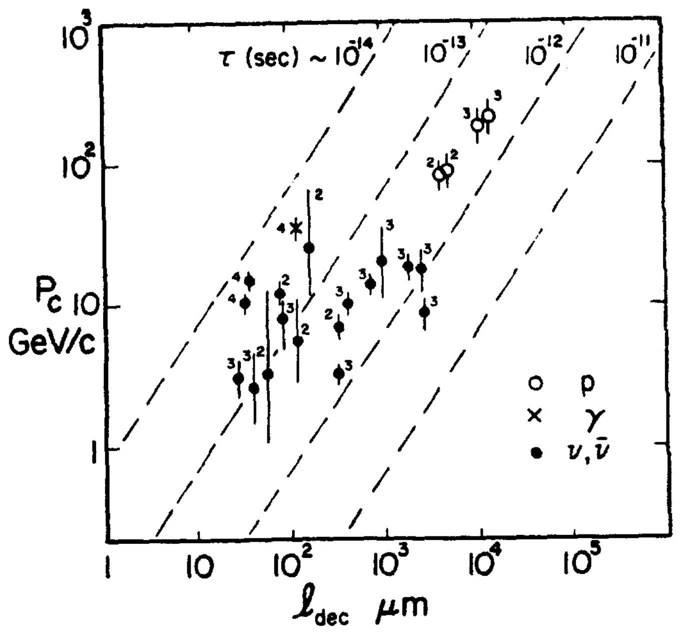

Fig. 2 Summary of observed characteristics for the 22 recently reported charmed particle decay candidates in emulsions which are discussed in this review.

Qualitatively, this event shows the expected characteristics for central region production of associated charmed particle pairs, similar to those in Figure 1. (For 25 TeV incident protons, central region particles may be expected to show $P_c/M_c \sim \gamma_{cm} \sim 110$, $\theta_{prod} \sim 1/\gamma_{cm} \sim 9$ mrads, and if $\tau_c \sim 3 \times 10^{-13}$ sec, $\ell_{dec} \sim$ 10mm.) In addition to the $D^{\mp}$, D^- hypothesis shown in Table I, various other charmed (charged) meson and baryon combinations are also possible interpretations for these two particles, with decay times in the region 2-5 x 10^{-13} seconds.

TABLE I

Associated Decay Candidates in 25 TeV Proton Interaction

(Assuming Decays to be $D^{\pm} \to (\pi\pi\pi)^{\pm} K^0$)

Track	Topology (n_{ch})	ℓ_{dec} (mm)	θ (mrad)	P (GeV/c)	P_c (GeV/c)	Decay Time (x 10^{-13} sec)
27	3	12.9	7.94		217-430	1.9 - 3.7
27-1			8.50	86^{+43}_{-22}		
27-2			1.61	69^{+33}_{-17}		
27-3			6.25	38^{+18}_{-9}		
32	3	12.8	5.63		176-352	2.3 - 4.6
32-1			8.34	94 ± 45		
32-2			5.05	36^{+14}_{-8}		
32-3			5.82	27^{+9}_{-6}		

B. D^0, $\bar{D}^0$ Candidates in 400 GeV Proton Collision

Associated neutral charmed particles from a 400 GeV proton collision has been reported[12] from an emulsion chamber exposed at Fermilab. Table II gives a summary of the results on the two neutral decay particles, including their deduced momenta and lifetimes, on the assumption that they represent three-body decays of D^0, $\bar{D}^0$ mesons. The resultant decay times are deduced to lie between 2.8 and 4.2 x 10^{-13} seconds.

In contrast to the cosmic ray event discussed above, which appeared to be central region produced, the neutral particles in this case have momenta, decay lengths and production angles which are more consistent, from Figure 1, with production by beam particle diffraction disassociation.

TABLE II

Associated Neutral Candidates V's in 400 GeV-Proton Collisions
(Assuming D^0, $\bar{D}^0$ decays)

	V-I	V-II
Flight Length (μm)	4700 ± 20	4250 ± 30
Emitting Angle (mrad)	17.0 ± 0.1	29.5 ± 0.2
Opening Angle (mrad)	40.0 ± 0.2	20.8 ± 0.2
Daughter angle (mrad)	m 24.9 ± 0.2	a 14.3 ± 0.2
	n 16.1 ± 0.2	b 11.8 ± 0.3
	π^0 9.6 ± 0.1	
Daughter Momentum (GeV/c)	m $20.6^{+3.7}_{-2.7}$	a $38.4^{+8.9}_{-6.1}$
	n $22.9^{+4.3}_{-3.1}$	b $17.0^{+3.5}_{-2.5}$
	π^0 $24.6^{+9.3}_{-4.0}$	
Transverse Momentum of missing neutral (GeV/c)	$0.234^{+0.098}_{-0.082}$	$0.537^{+0.0118}_{-0.082}$
Possible decay mode	$\pi^\pm\pi^\mp\pi^0K^0$	$\pi^\pm\pi^\mp K^0$
	$K^\mp\mu^\pm\pi^0\nu_\mu$	$K^\pm\mu^\mp\nu_\mu$
	$\mu^\pm K^\mp\pi^0\nu_\mu$	$\mu^\mp K^\pm\nu_\mu$
Mass (GeV/c^2)	1.863	1.863
	if P_{K^0} = 11.0-37 GeV/c	if P_{K^0} = 9.2-27.9 GeV/c
	P_{ν_μ} = 1.4-37 GeV/c	P_{ν_μ} = 4.3-16.5 GeV/c
	P_{ν_μ} = 1.2-37 GeV/c	P_{ν_μ} = 5.2-37 GeV/c
Momentum (GeV/c)	69.3-105	59.7-92
Transverse momentum (GeV/c)	1.18-1.8	1.76-2.7
Life time(s)	2.8-4.2 x 10^{-13}	2.9-4.4 x 10^{-13}

C. $\bar{D}^0$ from Photon Collision

A contributed paper[13] to this Conference describes the production and decay of a $\bar{D}^0$ in emulsion exposed to a tagged photon beam at the CERN SPS. All the $\bar{D}^0$ decay products were detected and identified in the downstream Omega Spectrometer.

The spectrometer trigger and predictions for this event showed 10 charged prongs and 2 gamma rays associated with the vertex, and 3 extra tracks, not associated with the reconstructed vertex. The appearance of the found event in emulsion is shown in Figure 3. A summary of the track characteristics and event analysis is listed in Table III.

Tracks 1d, 2d, 3d and 4d in Figure 3 and Table III were found to give a good fit for the decay of a $\bar{D}^0$ meson into $\pi^+\pi^-\pi^-K^+$, with a proper decay time of (2.26 ± 0.05) x 10^{-14} sec.

For the expected associated charmed particle in this electromagnetic interaction, the situation is not yet clear. There is sufficient missing mass and momentum, as shown in Table III, for a D^0 which could decay into undetected neutrals. This explanation would then suggest a near-threshold[5] production mechanism in which the $\bar{D}^0$ is produced at the beam disassociation vertex while the D^0 would come from the target vertex. Another explanation could consider the possible high momentum K^- (track 9) as rising from D decay very near the vertex. Coordinate measurements and impact parameter tests, as discussed above, have not yet been reported for this event.

Approximately 100 photon interactions have been examined so far and a major new exposure is planned.

D. Neutrino-induced charm in Experiment E-531.

This major new experiment and its preliminary results are described in the preceding report by Prentice[10]. Highlights on the decay characteristics of 10 charmed particle candidates in the events analyzed so far are summarized in Table IV. (The events are also included in Figure 2.)

It may be noted that the four neutral D^0, $\bar{D}^0$ candidates, one charmed baryon, Λ_c^+, and one storage charmed meson, F^-, in Table IV are regarded as fitting unique kinematic hypotheses. The baryon candidate is further strengthened by a proton signature in time of flight counters. The remaining four charged decays have ambiguous interpretations. In addition, one candidate was also described as a possible short-lived doubly charged particle. This raises the exciting possibility of observing weak decay of the C_1^{++} member of the C_1 isotriplet as discussed by Korner et al.[18]

E. Neutrino-induced Charm in Experiment WA17.

A description of this experiment, as well as other experiments using emulsions in neutrino exposures, was given at the Tokyo Conference by Sacton[19]. Since that time 5 charm decay candidates were reported this summer[14,15], and data on an additional neutral event was communicated to this Conference[16]. A summary of the results on the 6 decay events is seen in Table V.

It may be noted that only event 4 in Table V shows a unique decay hypothesis, without involving missing particles, and gives a decay time of 7.3 ± 0.1 x 10^{-13} seconds for this example of charmed baryon (Λ_c^+ or C_0^+) decay. The other charged candidates have missing neutrals and allow ambiguous fits for charmed meson or baryon hypotheses. The neutral events are all taken as examples of D^0 decay, but require missing neutrals from tests from coplanarity and momentum balance.

For the charmed baryon candidate, event 4 in Table V, results of measurements on bubble chamber and emulsion tracks are summarized in Table VI. As in the Omega Spectrometer example in Figure 3 and Table II, there is good matching in Table VI between particle directions as found in the emulsion and as predicted from bubble chamber reconstruction. Identification of secondary (decay) particles was aided in this event by analysis of interactions in the hydrogen bubble chamber (track 33 gave an excellent 4C fit for a pp elastic scatter), and by ionization measurements in the emulsion which supported the K^- assignment for track 32 and π^+ for track 31. It is also interesting to note that the $(K^-\pi^+)$ system in this event is found to be 0.866 ± 0.10 GeV/c^2, suggesting the decay scheme $\Lambda_c^+ \rightarrow p\bar{K}^{*0} \rightarrow pK^-\pi^+$.

For the most recent D^0 candidate, event 3 in Table IV, the primary neutrino interaction contains a negative muon candidate of 5.9 GeV/c and three additional minimum ionizing particles all seen in BEBC. The neutral charmed candidate decays after 181 μm into two charged particles, both seen in BEBC: a positive particle of 8.6 GeV/c and a negative one of 2.4 GeV/c. The angle between the vector sum of the secondary momenta and the V^0 line of flight is 0.035 ± 0.010 radians. No acceptable two-body decays are found (all lead to wrong invariant masses). Different three-body decay modes are found to be compatible as in Table VII.

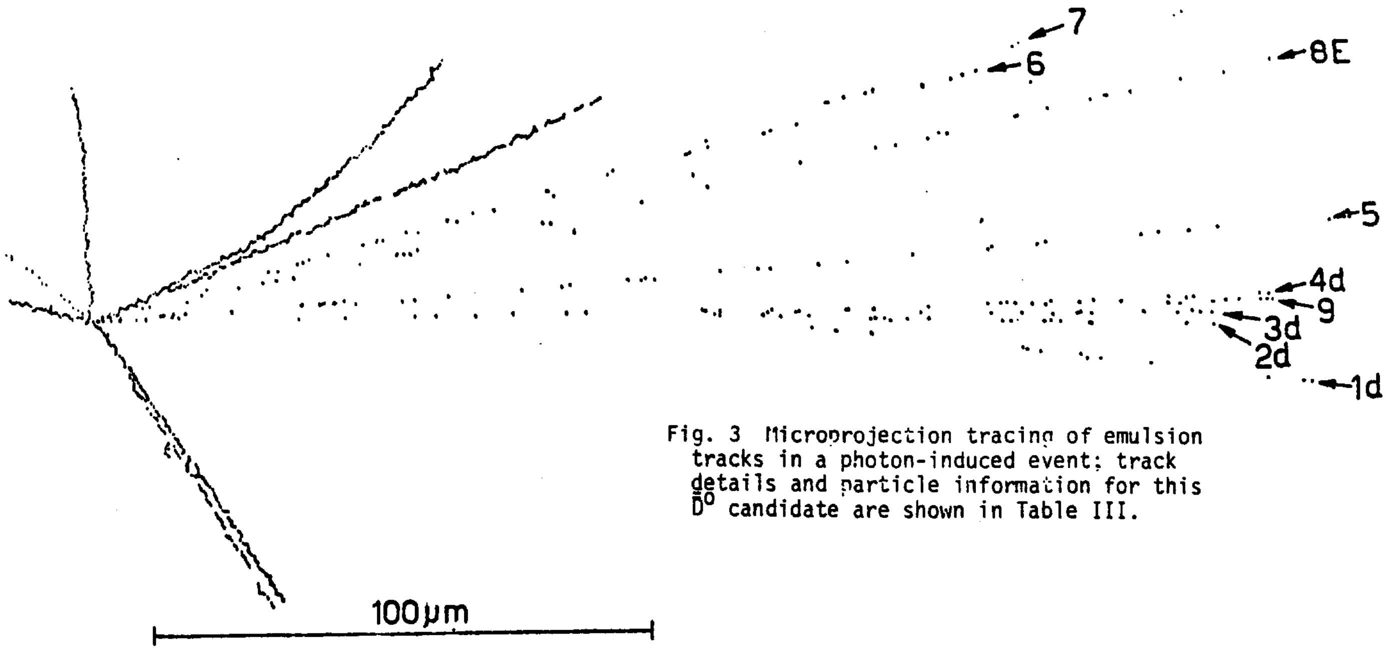

Fig. 3 Microprojection tracing of emulsion tracks in a photon-induced event; track details and particle information for this D^0 candidate are shown in Table III.

TABLE III

Predicted and measured values of the event and computed values of the decaying particle

SPECTROMETER PREDICTED VALUES								EMULSION MEASURED VALUES			
N	P	ΔP	THETA	ΔTHETA	PHI	ΔPHI		THETA	ΔTHETA	PHI	ΔPHI
1d	3.369	.012	.0266	.0002	-.1292	.0008	+	.024	.010	-.1279	.0020
2d	1.083	.006	.0905	.0014	-.0376	.0022	-	.103	.007	-.0447	.0006
3d	10.590	.123	.0120	.0002	-.0212	.0006	-	.007	.006	-.0218	.0004
4d	18.769	.132	-.0024	.0002	.0069	.0003	K^+	-.003	.005	.0069	.0005
5	3.113	.011	-.0378	.0002	.0504	.0008	-	-.033	.040	.053	.007
6	1.921	.060	.0348	.0042	.2597	.0039	+	-.017	.053	.257	.032
7	.271	.061	-.4510	.0259	.4147	.1970	+	-.444	.053	.262	.025
8E	1.469	.020	.2870	.0024	.2095	.0027	-	.271	.073	.178	.022
9	14.505	.229	-.0003	.0001	-.0095	.0006	K^-?	.004	.021	-.0091	.0020
10	.245	.003	-.1174	.0162	-.0287	.0104	-	NOT SEEN			
11	2.973	.006	-.0949	.0002	-.0345	.0006	e^+	NOT SEEN			
G1	.790		.0114		-.0257						
G2	.374		-.0991		-.0205						

INCIDENT MOMENTUM = 64.3 GeV/c; MISSING MOMENTUM = 5.1 GeV/c; MISSING MASS ≈ 2 GeV

DECAYING PARTICLE

MASS (1.866 ± .008) GeV

MOMENTUM: PX' = 33.8 ± .12; PY' = -.045 ± .057; PZ' = -.220 ± .260 GeV/c

DECAY PATH: (122.7 ± 2.2) μ; DECAY TIME (2.26 ± .05) x 10^{-14} sec.

TABLE IV

Charmed Particle Fitted Decay Values from Neutrino Experiment E-531 (Preliminary)

Event	Topology N_{ch}	Decay Length ℓ_{dec} (μm)	Decay Hypothesis	P_c GeV/c	Decay Time τ (10^{-13} sec.)
1	4	34	$\bar{D}^0 \to \pi^+\pi^-\pi^+\pi^-\pi^0$	10	0.21
2	4	40	$D^0 \to K^-\pi^+\pi^-\pi^+\pi^0$	15.5	0.16
3	2	74	$D^0 \to \bar{K}^0 \pi^+\pi^-$	12.4	0.37
4	2	210	$\bar{D}^0 \to K^+\pi^-$	6.8	1.9
5	3	27	$\Lambda_c^+ \to p\pi^+\pi^-\pi^0$	3.2	0.63
6	3	670	$F^- \to \pi^-\pi^+\pi^-\pi^0$	12.8	3.6
7	3	457	$D^+ \to K^-\pi^+\pi^+\pi^0$	10	2.8
			$F^+ \to K^-K^+\pi^+\pi^0$	10	3.1
8	3	1802	$\Lambda_c^+ \to K^-K^+p\pi^+\pi^0$	17.7	7.7
			$D^+ \to K^-K^+\pi^+\pi^0$	17.7	6.3
9	3	2145	$D^+ \to K^-\pi^+\mu^+(\nu)$	13.0 24.8	10.4 5.4
			$F^+ \to K^-K^+\mu^+(\nu)$	13.0 19.5	11.2 7.5
10	3	2307	$D^- \to K^+\pi^-e^-(\nu)$	6.7 10.7	18.3 15.4
			$F^- \to K^+K^-e^-(\nu)$	6.7 7.7	23.4 20.4

TABLE V

Charm Decays in Neutrino Experiment WA17

Event	Topology (N_{ch})	ℓ_{dec} (μm)	Decay Particle (Hypothesis)	P_c (GeV/c)	Decay Time τ (10^{-13} sec)
1	2	54	D^0	1-15	0.2 - 4.2
2	2	115	D^0	3-17	0.4 - 2.5
3	2	181	D^0	12-64	0.2 - 1.0
4	3	354	$\Lambda_c^+ \to p\pi^+K^-$	3.72±.04	7.3 ± 0.1
5	3	96	D^+, F^+, Λ_c^+	5-12	0.5 - 1.2
6	3	906	D^+, F^+, Λ_c^+	12-38	1.6 - 5.3

TABLE VI

Charmed Baryon Candidate in Experiment WA17

	x(mm)	y(mm)	plate
Predicted vertex in emulsion reference frame:	141.3±31	77.2±0.5	147.7±1.2
Located vertex in emulsion reference frame:	117.3	75.9	145.6

Track parameters measured in emulsion			Predicted parameters at vertex from measurements in BEBC			
Track	Dip Deg.	Azimuth Deg.	Dip Deg.	Azimuth Deg.	Momentum (GeV/c)	Particle
1	-16.8±0.5	-49.9±0.5				
2	+ 2.8±0.3	- 2.3±0.2	2.8±0.1	-2.3±0.1	31.805±0.090	μ^-
3	- 2.2±0.3	- 2.3±0.2				
31	+11.6±0.4	- 6.8±0.2	10.1±1.2	-6.7±1.2	1.628±0.005	π^+
32	+17.4±0.5	- 1.1±0.2	14.4±4.4(+)	7.1±4.4(+)	0.815±0.040(+)	K^-
33	-26.4±0.6	+ 2.6±0.2	-26.9±2.1	2.8±2.1	1.538±0.008	p

Track 3 shows ℓ_{dec} = 354 microns

Decay hypothesis $\Lambda_c^+ \to p\pi^+K^-$

$M_c = 2.29 \pm 0.015$ GeV/c^2

$P_c = 3.72 \pm 0.04$ GeV/c

$\tau = 7.3 \pm 0.1 \times 10^{-13}$ sec.

TABLE VII

Possible Decay Solutions for a D^0 Candidate with N_{ch} = 2, ℓ_{dec} = 181 μm, in Experiment WA17

Decay Modes	Solution 1		Solution 2	
	P_c	τ(10^{-13}s)	P_c	τ(10^{-13}s)
$D^0 \to \pi^+\pi^-K^0$	12.6	0.90	64.2	0.18
$\pi^+K^-\pi^0$	11.9	0.95	22.7	0.50
$\mu^+K^-\nu$	11.9	0.95	22.8	0.49
$e^+K^-\nu$	12.2	0.92	18.4	0.61

F. Neutrino-induced Charm in Experiment E-564.

In this experiment cryogenic sensitized nuclear emulsions were mounted inside the Fermilab 15-foot bubble chamber. Only 6mm of steel separate the emulsions from the beginning of bubble tracks in the liquid. Thus the acceptance for secondary particles is very nearly 4π, and the lever arm for projecting bubble tracks back to neutrino primary interactions in the emulsions is very short.

Data analysis by the Poland-US-USSR collaboration on this experiment is still in a preliminary stage. One charm decay candidate has been observed[17] in the first twelve interactions located in the emulsion from bubble chamber predictions. Emulsion and bubble chamber observations for this event are shown in Table VIII.

TABLE VIII

Charm Candidate Event in Neutrino Experiment E-564

	Emulsion Data		Predictions form 15-ft. Bubble Chamber			
Track	Azimuth deg.	Dip deg.	Azimuth deg.	Dip deg.	P GeV/c	Particle
1	2.7	-4.6	2.4	-5.5	12.76	(μ^-)
2	8.3	-18.1	8.3	-17.9	1.36	(+)
3	29.7	-27.1	29.8	-25.3	0.31	(-)
4	-29.1	4.1				
4.1	-45.6	10.2	-44.3	10.5	1.99	(+)
4.2	-1.9	40.1	-1.4	38.7	0.29	(+)
4.3	85.6	-60.0				
5			35.0	-16.7	0.24	(-)
6			34.8	-21.6	0.17	(+)
7			-6.0	40.7	0.07	(+)

Decay Length for track 4: ℓ_{dec} = 50 ± 1μm

Possible charm hypotheses F^+ (2030), Λ_c^+ (2260)

Favored hypothesis (preliminary)

$F^+ (2030) \to \pi^+\pi^+\pi^-\pi^-$

$P_c \sim 2.5$ GeV/c

$\tau \sim 1.3 \times 10^{-13}$ sec.

III. Summary

At the Tokyo Conference last year there were positive indications from search experiments that short-lived particles were indeed observed in emulsions, with decay properties similar to those predicted for charmed particle decays.

At this Conference we have the beginning of results from second generation experiments using nuclear emulsions, which provide more quantitative estimates of individual particle lifetimes and particle species identification. While the data is not sufficient yet to do exponential lifetime determinations, some assessments of average decay times for several species can be made:

a) D^0, $\bar{D}^0$ - From the 10 neutral decay candidates in Figure 2 and in the Tables, arithmetic mean values $\bar{\tau}$ $(D^0) \simeq 0.6 \times 10^{-13}$ seconds are found if one takes only the 5 well-fitted events, $\bar{\tau}$ $(D^0) \simeq 1.0 \times 10^{-13}$ seconds if one adds the lower estimates from the other 5 candidates, and $\bar{\tau}$ $(D^0) \simeq 2.0 \times 10^{-13}$ seconds if one adds the upper estimates from the other 5 candidates. The overall estimate of $\bar{\tau}$ $(D^0) \simeq 1 \times 10^{-13}$ from these experiments is in general agreement with the predictions[4].

b) $\Lambda_c^{\pm}$ or $C_0^{\pm}$ charmed baryon - Two candidates have been reported (see Tables IV and V) with apparently identified protons and unique kinematic fits. Both have momenta near 3 GeV/c but differ by an order of magnitude in their decay lengths of 27 μm and 354 μm. The proper decay times are 0.63 and 7.3×10^{-13} seconds. Five other events have possible charmed baryon decay hypotheses; their mean lifetimes are also near 4×10^{-13} seconds. Except for the one candidate from experiment WA17 with $\tau \sim 0.63 \times 10^{-13}$ seconds, there is poor agreement with theoretical estimates[4,18] and expectations of leptonic branching ratio and lifetime equalities for D^0 and C_0^{+} (Λ_c^{+}) particles.

c) $F^{\pm}$ - Table IV lists one uniquely fit F^- candidate with $\tau = 3.6 \times 10^{-13}$ seconds, and Table VIII lists a favored F^+ fit with $\tau = 1.3 \times 10^{-13}$ seconds. Five other $F^{\pm}$ candidates are listed among the ambiguous fits, with decay times ranging from 1 to 23 $\times 10^{-13}$ seconds. As for the C_0^{+} (Λ_c^{+}), the present data suggests a longer average lifetime for the $F^{\pm}$ than for the D^0, in contrast to expectations[4].

d) $D^{\pm}$ - No uniquely fitted $D^{\pm}$ candidates are listed among the recently reported events. Tables IV and V list 6 ambiguous candidates, which would give an average lifetime $\bar{\tau}$ $(D^{\pm}) \sim 6 \times 10^{-13}$ sec. Such a longer apparent lifetime than for the D^0 would be fully consistent with larger semi-leptonic branching ratios and with theoretical predictions.

e) In addition to providing the principal new data on charmed particle decays in emulsions, Experiment 531 also appears to have evidence for a doubly charged short-lived particle. It is tempting to ask whether this may be the C_1^{++} particle, whose mass may turn out to be sufficiently low to allow weak decays[18], with similar possibilities for the C_1^{0} and C_1^{+} charmed baryons.

References

1. R.Diebold, Proc. 19th Int. Conf. High Energy Physics, Tokyo (1978).
2. K.Niu, AIP Conf. Proc. No. 49, Bartol Conf. ed. T.Gaisser, (1979).
3. T.Yamanouchi, see reference 2.
4. J.L.Rosner, see reference 2.
5. M.K.Gaillard, B.W.Lee and J.L.Rosner, Rev. Mod. Phys. 47, 277 (1975).
6. N.Cabibbo, G.Corbo and L.Maiani, Nuc. Phys. B155, 93 (1979).
7. S.Baroni et al., Lett. Nuovo Cimento 24, 45 (1979).
8. H.Shiwe et al., Phys. Rev. 125, 1024 (1962).
9. EHS Burhop et al., Nuovo Cimento 39, 1037 (1965).
10. J.Prentice, preceding presentation at this Conference.
11. H.Fuchi et al., contributed paper HE2-19, XVI Int. Cosmic Ray Conference, Kyoto (1979).
12. H.Fuchi et al., Phys. Lett. 85B, 135 (1979).
13. A.Conti et al., contributed paper, Bologna-CERN-Florence-Geneva-Moscow LPI-Paris VI-Santander-Valencia-Emulsion Collaboration and Bonn-CERN-EP Paris-Glasgow-Lancaster-Manchester-Orsay-Paris VI-Paris VII-Rutherford-Sheffield Omega Collaboration. Also discussed in presentation by F.Richard to this Conference.
14. R.Sever et al., contributed paper to Neutrino '79 Bergen Conference by the WA17 Collaboration; Ankara-Brussels-CERN-Dublin-UC London-Open Univ.-Pisa-Roma-Torino.
15. M.Conversi, CERN-EP/79-85.
16. J.Sacton, communication to this Conference.
17. L.Voyvodic, et al., communication from Fermilab, IEHP, ITEP, JINR, Krakow, Univ. Kansas, Univ. Washington collaboration.
18. J.G.Korner, et al. Z.Physik C 2, 119 (1979).
19. J.Sacton, see reference 1.

Discussion

Q. (Peoples, Fermilab) Could you tell me what the fitted values of Λ_c or charmed baryon masses are for those two events that were reported?

A. I'm afraid I don't know whether 2260 MeV/c^2 was used as input or not for the one that Dr. Prentice showed where the proton was identified by time of flight. The CERN WA17 event was reported to yield a mass of 2295 ± 15 MeV/c^2.

Q. (Prentice, Univ. of Toronto) In answer to John Peoples' question, the masses for the $\Lambda_c^{\pm}$ fits in E-531 are preliminary, with values 2250 ± 50 and 2225 ± 26 MeV/c^2 respectively.

A. I might just comment on the second event in E531, with apparent momentum of 18 GeV/c. I find it rather difficult to picture this as a struck baryon picking up so much momentum. It seems much more plausible as a current fragmentation meson rather than a struck baryon from the production mechanism point of view, and the kinematics do not exclude a charmed meson interpretation.

Q. (Cautis, SLAC) Are there any plans to take more data with emulsion in front of the 15' or the BEBC.

A. Experiment E564 with emulsions inside the 15' chamber is being scheduled for another exposure next summer, with wide band neutrino beam and neon-hydrogen in the chamber. We also hope to improve the resolution of the extra cameras to be used for this experiment. As far as BEBC is concerned and the WA17 experiment, my impression from Dr. Sacton is that it's not clear if they will run again.