E-531

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CHARMED PARTICLE PRODUCTION AND DECAY LIFETIMES AND A NEUTRINO OSCILLATION TEST

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ABSTRACT

This paper reports Fermilab Experiment 531, "A study of Weak Decay Lifetimes of Neutrino Produced Particles in a Tagged Emulsion Spectrometer". Lifetimes deduced from 81% of the materials scanned so far are presented for D^0, $D^{\pm}$, and $F^{\pm}$ charmed mesons, and $\Lambda_c^{\mp}$ charmed baryons. Some of physical speculations are made basing on those observed lifetimes. Upperlimit of ν_μ-ν_τ oscillation rate is also estimated depending to the present statistics.

INTRODUCTION

A large collaboration of United States, Canadian, Korean and Japanese scientists in the list[1] attached to the end of this report, constructed and operated Fermilab Experiment 531, in which a hybrid emulsion spectrometer shown in Fig. 1. was exposed to a wide-band neutrino beam to study lifetimes of charmed particles.

While many of the first generation experiments with a hybrid emulsion counter apparatus[2] have suffered grievously lacking the efficient cooperation of emulsion with counter, we have obtained a large sample of charm decays applying a new emulsion technology developed for the purpose in addition to a complete counter effort.

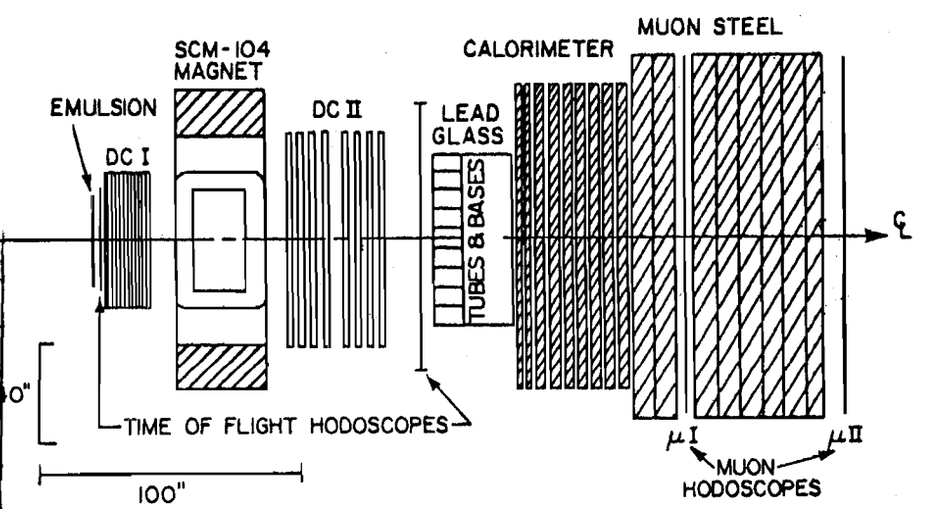

Fig. 1. Plan view of the experiment

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(To be published in a Conference Proceedings of the American Institute of Physics)

EXPERIMENTAL PROCEDURE

As we wished to measure lifetimes of charmed particles, we used neutrinos for producing charm, emulsions to see the topology of the resulting decay with short flight length, and an electronic detector to specify event location and identify decay products. A magnet surrounded by drift chambers provides momentum analysis and aids in finding events within the emulsion. A time-of-flight system separates pions and kaons to 2.5 GeV and protons to 5 GeV. A wall of lead glass detectors is used to identify electromagnetic showers, and muons are identified by passage through 1.6 and/or 3 GeV equivalent of steel. Non-electromagnetic hadronic energy was recorded in a conventional iron calorimeter. Information on resolution of spectrometer elements is shown in Table I.

Table I Resolution of spectrometer elements

Quantity measured	Error (σ)
Drift chamber position resolution	120 microns
Charged particle momenta for Tracks passing through magnet	$\frac{\delta P}{P} = 0.13 + .005P$
Tracks analyzed only by fringe field	$\frac{\delta P}{P} \simeq 0.3P$
Gamma ray energy	$\frac{\delta E}{E} = \frac{0.3}{\sqrt{E(GeV)}}$
Gamma ray position	5 cm
Time-of-flight	120 picoseconds
Calorimeter	$\frac{\delta E}{E} = \frac{1.0}{\sqrt{E(GeV)}}$

This apparatus was exposed to the single horn focussed neutrino beam at Fermilab. A total of 7×10^{18} protons of 350 GeV/c momentum were incident on the production target. A simple neutrino trigger required only no charged particle be incident and that two or more charged particles exit the emulsion and pass through the magnet. Charged and neutral current events were accepted equally.

As for the performance of the counter system of our apparatus, it has been reported repeatedly in each symposium and conference[3]. Using counter data only, E-531 exhibits features typical of most bulk neutrino experiments in terms of the variables such as E_{vis}, x, and y. However, description of these distributions is skipped because of space-limitation.

NEW EMULSION TECHNIQUES

Before designing emulsion target which will be combined with counter spectrometer, our Nagoya Group has analysed the cause of low locating rate of tagged events in emulsion in the preceeding experiments with hybrid system[2]. The conclusion was that the deficit was inevitably connected with the use of volume scanning method to search events in a conventional pellicle stack. To overcome the deficit, we

have developed new method as an extension of the emulsion chamber technique which has been successfully applied to the study of charmed particles in cosmic ray and accelerator energies since 1971[4]. There are 4 points in this new method.

The first is, adoption of thick emulsion films which are fablicated by coating both sides of a 70 micron polystyrene sheet with 330 micron of emulsion. Modules of 68 layers of such films stacked on four lucite posts are exposed perpendicularly to the beam as is shown in Fig. 2. Unlikely to the case of pure pellicle stack, doubly coated emulsion films are used as a position detector of tracks traversing the film base as well as analyser of 3 dimensional topology of the events in thick emulsion layers. By analogical expression, this is compared with a supermulti-layer counter assembly with spatial resolving power of submicron. This type of detector could have a better matching with counter array than a pellicle stack does.

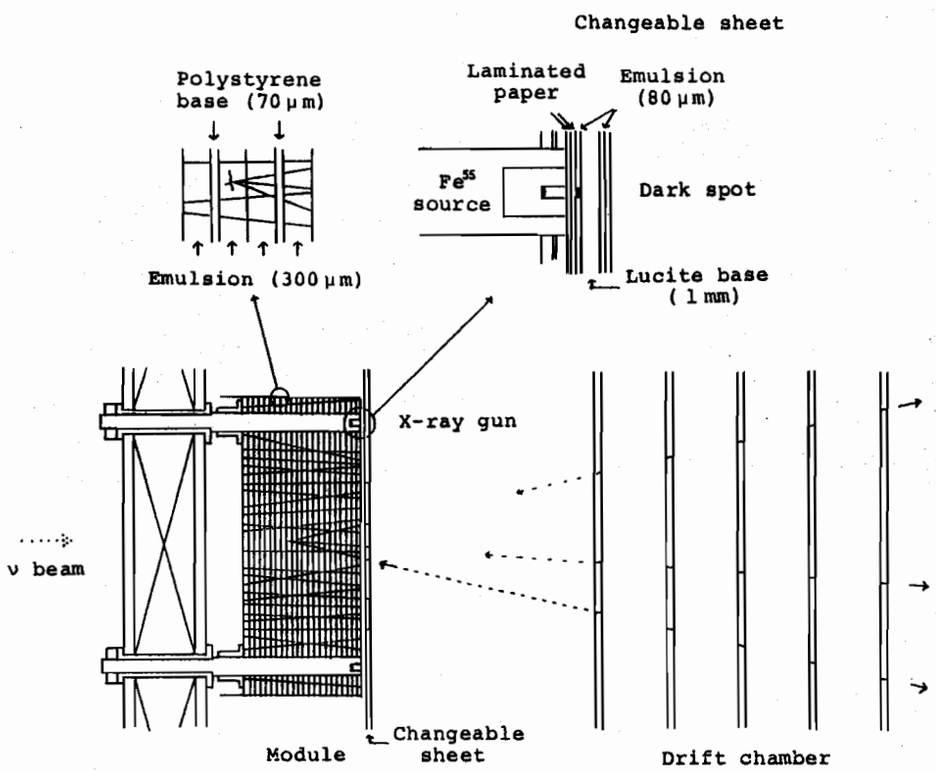

Fig. 2. Emulsion film chamber with changeable sheet

The second one is the tracing back method of secondary tracks predicted by the counters. The idea of the method is shown in Fig.2. Once an individual track from an event is found at the down stream surface of a module, it could be extrapolated to the interaction vertex employing doubly coated emulsion films. Such a technique is highly efficient because it doesn't rely on the existence of a large number of black tracks from nuclear breakup as does the volume scanning method.

This trace back method is also applicable for search of neutral decay away from original interaction vertex. Picking up at the downstream face of a module such a track that not seen at interaction vertex but tracked in a drift chamber spectrometer, one can easily trace back it to a neutral decay vertex no matter how far is it from the interaction point. This method is, however, could not be successfull without suppressing background density in the emulsion.

To realize the tracing back method under actual condition with high muon background, so called changeable sheet is introduced as the third new technique. That is an 800 micron sheet of lucite coated on both sides with a thin layer of emulsion placed immediately downstream of the emulsion target. An important function of this fiducial sheet is to serve as a low background interface to couple the drift chamber tracks to those seen in the emulsion module. As is shown in Fig. 2, the marks left on this sheet by the Fe^{55} sources imbedded in each mounting post record the relative positions of all modules. By changing this sheet many times during the experiment, muon and other backgrounds are kept sufficiently low to pick up a single minimum track predicted by drift chambers on this sheet.

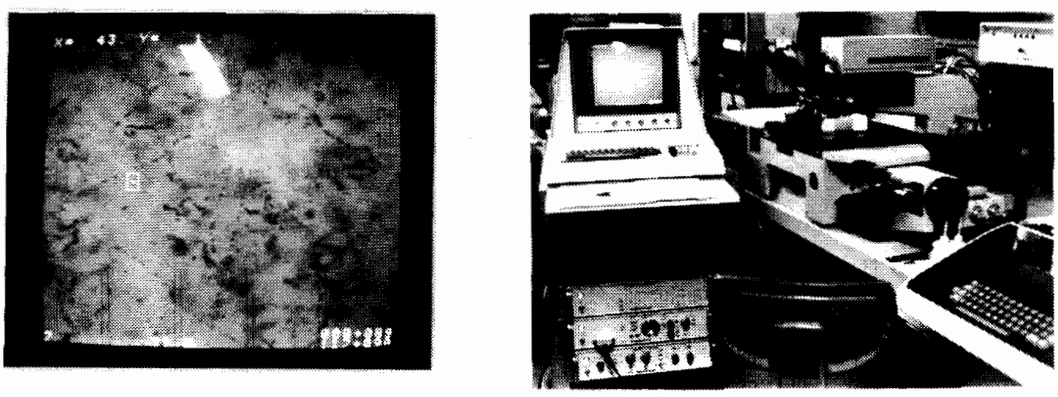

Fig. 3. Measuring microscope

The fourth one is using an epoch-making computer-controlled semiautomatic scanning technique to speed up location time of an event. It consists of CPU and several peripheral units. Among them there is a measuring microscope. This unit consists of a microscope, moving stage driven by a signal from CPU, ITV camera and console with CRT. This CRT plays a role of a video monitor of emulsion image as well as a character display as shown in Fig. 3. Measurement of a track co-ordinate is carried out on the CRT screen adjusting a measuring window by a joy stick. Relative co-ordinate of the most dark point inside the window to one of the corner of the TV image is measured electrically and the absolute co-ordinate is calculated by the CPU. Accuracy of this measurement is 0.1 μm or 1 μm over the working range of 10 cm × 10 cm.

X and Y coordinates of a grain spot is measured in a few seconds. Measuring coordinates of a track at 4 different depth, one can get x, y, θ and ϕ of a track in about 10 seconds, and those values are displayed on the TV screen to be compared with the predicted ones. Using this system, scanning of a track on a fiducial sheet is carried out in an area of 2.4 mm × 2.4 mm around the point predicted by the drift chambers. It takes less than 10 minutes per one predicted track. Efficiency of this scanning method is very high and about 96%. The found track is then followed into the most down-stream emulsion plane in the module using same measuring stage. It also takes 10 minutes. Then the track is extrapolated back to the interaction vertex employing highly precise emulsion techniques on ordinary microscope. It takes only each one minute to trace a track plate by plate. Mean location time of one neutrino event is about one hour. This machine has changed completely the image of emulsion work. Style of new emulsion work is more or less likened to the bubble chamber film analysis.

SCANNING SUMMARY

In the first run of the E-531, 23 liters of emulsion was organized into 27 modules of perpendicular type and 12 modules of pellicle stacks mounted on posts edge on to the beam. Up dated event finding summary is shown in Table II, disposing the data according to the finding method.

853 located events have been searched for charm decay candidates. Neutral decays were looked for by following back tracks into the emulsion as well as by volume scan in a cylinder, 1 mm long with a radius of 300 μm. For charged decays, all minimum-ionizing tracks were followed down to 6 mm.

In Table II, number of found multi-prong decays are also disposed according to the method of searching. Location efficiency, ratio of charms over found events and also charms over searched events by track follow back method are much higher than that by volume scanning method. To see the situation clearer, N_h distribution of the found events by the track follow method is shown in Fig. 4. Content of white stars is rather high about 27%, and in this part, 50% of charm decays were found associated. The white star is very hard to find by the volume scanning method. Now the cause

Table II Event finding summary

Group		I	II	III
Method		Track follow	Mix	Volume scan
Predicted		952	199	1046
After cut		750	161	832
Searched	A	548	151	718
Found	B	449	102	302
Multi-prong charm	C	22	1	7
B/A		0.82	0.68	0.42
C/B		0.049	0.010	0.023
C/A		0.040	0.007	0.010

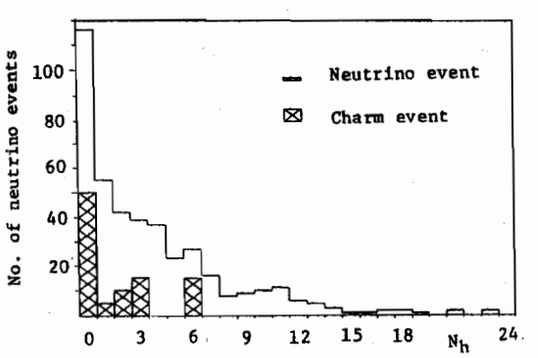

Fig. 4. N_h distribution

of very low locating efficiency of the neutrino events and low charm content in conventional pellicle stacks is made clearer.

MASS FITTING OF CHARMED PARTICLES

We have found so far 29 multiprong charm decay and about 30 kinks. These candidates have been fit to various decay hypothesis. Uniquely fitted results are listed in the following Table III. When a daughter has been identified by one of the particle identification systems with a confidence level of 95%, it appears in the Table underlined. Unseen particles added to balance momentum transverse to the direction of the parent particle are indicated in brackets.

Table III-a D^0 Fits

Event	Decay length (μm)	P_μ (GeV/c)	Hypothesis	P (GeV/c)	Mass (MeV)	Decay time ($\times 10^{-13}$ sec)
493- 177	326	-18.7	$D^0 \to \pi^+ \underline{\pi^-} (k^0)$	19.27		1.05
478-2638	126	- 4.8	$D^0 \to \underline{\pi^-} \pi^- \underline{\pi^+} \underline{\pi^+} \pi^- \pi^+ (\pi^0)$	9.1		0.86
486*-6857	256	not seen	$D^0 \to k^- \underline{\pi^+} \pi^- \pi^+ (\pi^0)$	12.8		1.24
513-8010	27.2	+11	$D^0 \to k^+ \pi^+ \underline{\pi^-} \underline{\pi^-} \underline{\pi^0}$	9.2	1766± 48	0.18
518-4935	116	- 4	$D^0 \to \pi^+ k^- \underline{\pi^0} \underline{\pi^0}$	30.1	1935±132	0.24
556*-152	41	-10	$D^0 \to \pi^- k^- \underline{\pi^+} \underline{\pi^+} \underline{\pi^0}$	15.4	1855± 43	0.17
577*-5409	67	-30	$D^0 \to \pi^+ \underline{\pi^-} (k^0)$	11.3		0.37
654-3711	6.5	- 4	$D^0 \to \pi^+ \underline{\pi^+} k^- \underline{\pi^-} \underline{\pi^-} \underline{\pi^+}$	19.2	1923± 46	0.021
661-6517	2647	-26	$D^0 \to k^- \underline{\mu^+} (\nu)$	22.8 32.7		7.20 4.24
670*-7870	187	+34	$D^0 \to k^+ \underline{\pi^-} (\pi^0)$	6.8 9.5		1.71 1.22

* These events have a D* with mass ∿ 2008 ± 3 MeV.

For the neutral decays, 10 events among 12 are consistent with D^0 decays. One of the remaining 2 decays took place when the magnet was off and could not be fitted now. The last one has a proton as a daughter of a neutral parent which decayed at 4.4 mm down, and a neutral charmed baryon hypothesis has been examining.

Results of fitting for 19 charged multiprong decays and 2 of kinks are as follows.

Two events are consistent only with F decays. Three semileptonic decays are consistent only with the $D^\pm$ hypothesis. Two events are somewhat ambignous in interpretation. One of these two fits both D and F with similar likelihood, but the event is used in the fit for the $D^\pm$ lifetime on the basis that F decay is Cabibbo Unfavored. For another event a Λ_c^+ hypothesis is possible but the confidence level is only 3%, and this decay is also used in the $D^\pm$ lifetime fit.

Five events have an identified baryon, either by time of flight or by reconstructions of a Λ^0, and fit a Λ_c^+ decay hypothesis. The remaining 9 events are not listed yet. Among them 5 are ambiguous between $F^+/D^+/\Lambda^+$ and are not used in the lifetime fit. Three events

are not yet fully analysed. The last one event with a possible charge 2 baryon decay is also recorded during magnet was off and is still on the way of detailed analysis.

Table III-b F± Fits

Event	Decay length (μm)	P_μ (GeV/c)	Hypothesis	P (GeV/c)	Mass (MeV)	Decay time ($\times 10^{-13}$ sec)
527-3682	670	+30	$F^- \to \pi^- \pi^- \pi^+ \pi^0$	12.25	2026± 56	3.70
597-1851	130	not seen	$F^+ \to \underline{k}^+ \underline{\pi}^- \underline{\pi}^+ k^0$	9.70	2089±121	0.91

Table III-c D± Fits

Event	Decay length (μm)	P_μ (GeV/c)	Hypothesis	P (GeV/c)	Mass (MeV)	Decay time ($\times 10^{-13}$ sec)
512-5761	457	>150	$D^+ \to k^- \pi^+ \underline{\pi}^+ \underline{\pi}^0$	10.1	1829± 35	2.82
546-1339	2145	- 7	$D^+ \to k^- \underline{\pi}^+ \underline{\mu}^+ (\nu)$	16.1		8.33
580-4508	2307	+ 7	$D^- \to \pi^- \underline{k}^+ \underline{e}^- (\nu)$	9.4		15.3
598-1759	1802	-11	$D^+ \to k^- k^+ \pi^+ \pi^0$	17.0	1860± 25	6.60
663-7758	13000	>150	$D^+ \to k^- \pi^+ \underline{e}^+ (\nu)$	118		6.86

Table III-d Λ_c^+ Fits

Event	Decay length (μm)	P_μ (GeV/c)	Hypothesis	P (GeV/c)	Mass (MeV)	Decay time ($\times 10^{-13}$ sec)
476-4449	27.7	-59	$\Lambda_c^+ \to \underline{p}\, \pi^+ \pi^- (k^0)$	2.9 5.0		0.73 0.42
549-4068	20.6	-11	$\Lambda_c^+ \to k^- \underline{p}\, \underline{\pi}^+ (\pi^0)$	2.2		0.70
567-2596	175	- 5.4	$\Lambda_c^+ \to \underline{p}\, (k^0)$	6.5		2.10
610-4088	221	- 8	$\Lambda_c^+ \to \underline{\pi}^+ \pi^- \pi^+ \underline{\Lambda}^0$	4.7	2382 ± 90	3.58
650-6003	40.6	-15	$\Lambda_c^+ \to \underline{\pi}^+ \pi^- \pi^+ \underline{\Lambda}^0$	5.7	2192 ± 92	0.54

LIFE TIME

The lifetime for each charmed particle is obtained by maximizing a likelyhood function which is weighted by the finding efficiency dependent to the decay length. Fig. 5 shows finding efficiencies for neutral and charged particles. For decays which occur at distances less than 16 micron, tracks from the primary vertex obscure the decay point,

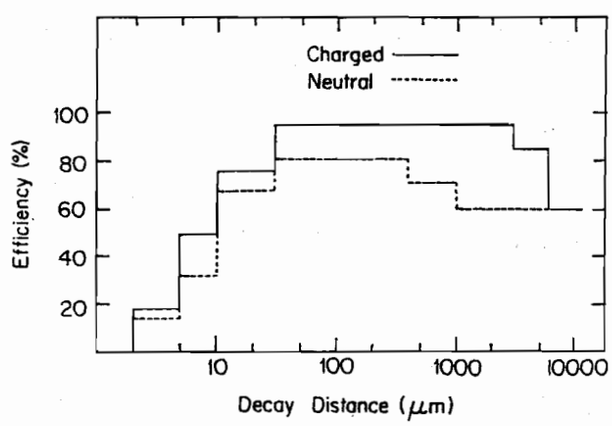

Fig. 5. Charm finding efficiency

thus reducing the efficiency. For neutral decays the finding efficiency inside the scan volume is approximately 80%. This is based on comparing found γ-conversions inside the scan volume to a Monte-Carlo prediction, and by a rescan of 420 events which had a track in the drift chambers not seen at the primary vertex. The latter method yielded 3 neutral events. Since all decay candidate could have been found by this technique, the finding efficiency outside the scan volume is 60%.

Table IV Lifetime summary

Particle	Lifetime ($\times 10^{-13}$ sec)	Events
D^0	$1.01^{+0.43}_{-0.27}$	10
$D^{\pm}$	$10.3^{+10.5}_{-4.1}$	5
$F^{\pm}$	$2.2^{+2.8}_{-1.0}$	2
Λ_c^+	$1.36^{+0.84}_{-0.46}$	5

The results of the lifetime fit are presented in Table IV, with $\pm 1\ \sigma$ limit. These values are still preliminary but are not expected to change beyond the $1\ \sigma$ limit. For D^0 statistic has increased and one lifetime has become assured. From the table we note that D^0, $F^{\pm}$ and Λ_c^+ are significantly shorter-lived than $D^{\pm}$. This suggests that process other than the simple radiative decay of the free charmed quark may be important in the calculation of decay rates for these particles.

SPECULATIONS AND A NEUTRINO OSCILLATION TEST

Basing on those lifetimes, we can make some of interesting estimations. For example, using lifetime of charged D meson obtained by our experiment and branching ratio of $D^+ \to X^0 e^+ \nu_e$ obtained at SLAC [5], one can estimate partial decay width of $D^+ \to X^0 e^+ \nu_e$ as $1.9^{+1.4}_{-1.0} \times 10^{11}$ /sec. Assuming that the D^+ and D^0 have the same semileptonic partial widths, and using the D^0 lifetime, we obtain the branching ratio of $D^0 \to X^- e^+ \nu_e$ as about 2%. If we relate pure loptonic width of $F \to \tau\nu$ to $\pi \to \mu\nu$, we can estimate branching ratio of $F \to \tau\nu$ as 1.6%.

Finally, depending of our statistics, we can estimate upperlimit of $\nu_\mu - \nu_\tau$ oscillation rate. So far we have observed 600 charged current events but no tau decays. As a signature of τ decays, we take events with no muon from vertex, and with charged trident decay or kink with P_T higher than 50 MeV/c and not with identified daughter as a proton. We observed no such signal. Correcting scanning efficiency (0.55) and considering cross-section ratio of ν_τ and ν_μ (0.6 for our beam energy), we obtain rate of $(\nu_\mu \to \nu_\tau)$ as less than 1.1% with 90% C.L. Taking average pass length (790m) and average neutrino energy (24GeV), we obtain the upper limit of $\delta m^2_{\mu\tau} = (m^2_{\nu_\tau} - m^2_{\nu_\mu})$ as a function of mixing angle $\theta_{\mu\tau}$ as shown in the Fig. 5. Any topology of τ decay could be observed in our experiment. So, this is the first result based on direct observation, and this indicates that the mixing of ν_μ and ν_τ may be very small.

In concluding, we will finish the analysis of the material from the first run in a few months, and are expecting still more 10 - 20

decays at that time. A second run will start in Dec. of this year and expect to find 70~100 more decays with improved particle identification. Therefore, new data expected before the next conference should further elucidate these questions and have promise of producing many interesting surprise.

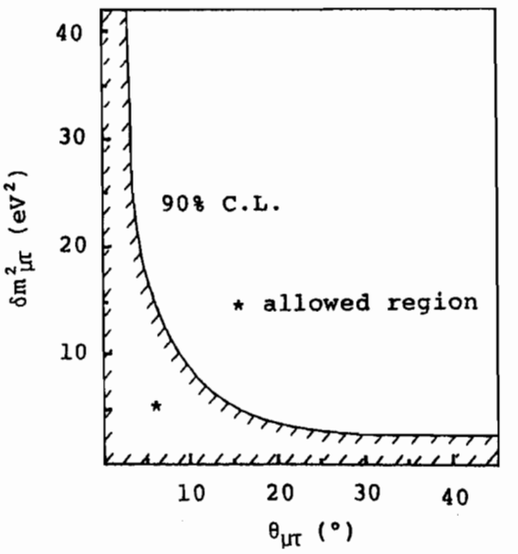

Fig. 6. Upper limit of $\delta m^2_{\mu\tau}$

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REFERENCES

1. The list of E531 collaborators is as follows:
N.Ushida, T.Kondo, G.Fujioka, H.Fukushima, Y.Takahashi, S.Tatsumi, C.Yokoyama, Y.Homma, Y.Tsuzuki, S.Bahk, C.Kim, J.Park, J.Song, D.Bailey, S.Conetti, J.Fischer, J.Trischuk, H.Fuchi, K.Hoshino, M.Miyanishi, K.Niu, K.Niwa, H.Shibuya, Y.Yanagisawa, S.Errede, M.Gutzwiller, S.Kuramata, N.Reay, K.Reibel, T.Romanowski, R.Sidwell, N.Stanton, K.Moriyama, H.Shibata, T.Hara, O.Kusumoto, Y.Noguchi, M.Teranaka, H.Okabe, J.Yokota, J.Harnois, C.Hebert, J.Herbert, S.Lokanathan, B.McLeod, S.Tasaka, P.Davis, J.Martin, D.Pitman, J.Prentice, P.Sinervo, T.Yoon, H.Kimura, Y.Maeda.
2. L. Hand et al., Nucl. Inst. and Method 167, 261 (1979).
A. L. Read et al., Phys. Rev. 19, 1287 (1979).
D. Allasia et al., to be published in Nucl. Phys. (1980).
3. N. W. Reay, XXth Int. Cosmic Ray Conf, (Kyoto, 1979).
J. Prentice, Lepton Photon Symp, (Fermilab, 1979), 563.
N. W. Reay, Montreal Meeting of the APS (Div. of Particle and Field, 1979).
J. Trischuk, XVth Recontre de Moriond, Les Arcs, France (1980) and else where.
4. H. Fuchi et al., AIP conf. Proc. No49, Particles and Fields No.16 Cosmic Rays and Particle Physics-1978 (Bartol Conf.) 49 (1979).
K. Niu, ibid, 181.
5. $BR(D^+ \to X^0 e^+ \nu_e) = 22^{+4.4}_{-2.2}\%$ (DELCO), 16.8±6.4% (MARK II).