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Publication Date
1980-09-01

Peer reviewed

LBL-11510
CONF-800724--39

Lawrence Berkeley Laboratory
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Physics, Computer Science &
Mathematics Division

Presented at the XXth International Conference on High Energy
Physics, University of Wisconsin, Madison, WI, July 17-23, 1980

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G.H. Trilling

September 1980

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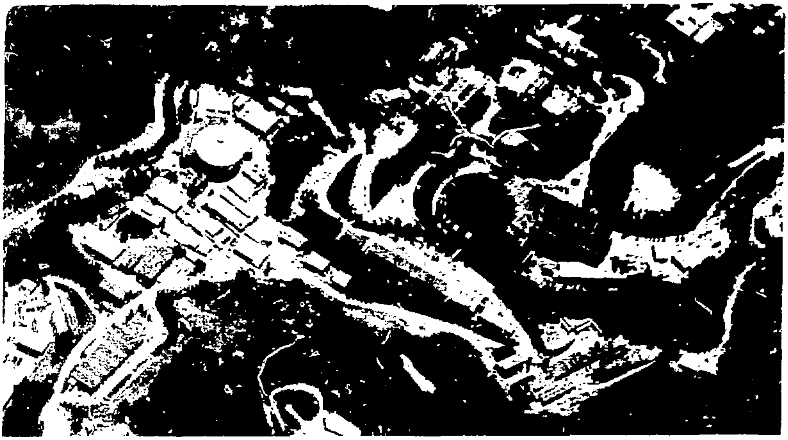

Prepared for the U.S. Department of Energy under Contract W-7405-ENG-48

LBL-11510

LOW ENERGY WEAK INTERACTIONS AND DECAYS

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I. INTRODUCTION

My task in this review is to discuss results presented to the Conference during Sessions B5 - 7 which cover various aspects of low energy weak interactions including recent work on neutrino oscillations. One topic whose subject matter might properly place it here, namely the weak decays of mesons containing b quarks, was not discussed in these sessions and will be reviewed in Professor Berkelman's paper. I shall try to summarize the results from essentially all of the material which was presented at Sessions B5 - 7.

II. CP-INVARIANCE VIOLATION

A Yale-BNL group has been engaged in an ambitious program to measure with high precision CP-invariance violation parameters in K-decay in the hope of distinguishing between milliweak and superweak violation effects.[1] An intermediate step in their program has been an accurate determination of the muon polarization P_n perpendicular to the decay plane in the decay $K_L^0 \rightarrow \pi^- + \mu^+ + \nu_\mu$. Their beautiful experimental work has already been published, and I will therefore only give the results presented at the Conference which differ just very slightly from those in the published article:

$$P_n = (1.6 \pm 5.3) \times 10^{-3}$$

$$\mathrm{Im}\ \xi = 0.009 \pm 0.028$$

where ξ is the usual ratio of form factors. These results are not yet precise enough to differentiate between milliweak and superweak, but the group is preparing further experiments at Brookhaven with substantially improved sensitivity.

III. HIGH STATISTICS STUDY OF Λ BETA DECAY

A University of Massachusetts-BNL collaboration[2,3] working at the AGS has been doing a high statistics study of the decay mode,

$$\Lambda^0 \rightarrow p + e^- + \bar{\nu}_e .$$

The rate measurement, based on a sample of 10,000 beta decays, has already been published,[2] and interested readers can look up the experimental details. We give here the result,

$$\frac{\Gamma(\Lambda^0 \rightarrow pe\bar{\nu})}{\Gamma(\Lambda^0 \rightarrow p\pi^-)} = (1.318 \pm 0.024) \times 10^{-3}$$

from which, using the Λ^0 lifetime and branching ratio into $p\pi^-$, one finds,

$$\Gamma(\Lambda^0 \rightarrow pe\bar{\nu}) = (3.215 \pm 0.068) \times 10^6\ s^{-1} .$$

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*Work partially supported by the U.S. Department of Energy, Contract No. W-7405-ENG-48.

In a paper submitted to the Conference the group has analyzed in its 10,000-event sample the e-$\bar{\nu}$ angular correlation, $dN/d(\cos\theta_{e\nu})$. One can write down the weak hadronic current for the Λ beta decay, dropping terms of order m_e/M, in the form

$$J^h_\mu = \bar{\psi}_p[f_1(q^2)\gamma_\mu + \frac{i}{M} f_2(q^2)\sigma_{\mu\nu}q_\nu + g_1(q^2)\gamma_\mu\gamma_5 + \frac{i}{M} g_2(q^2)\sigma_{\mu\nu}q_\nu\gamma^5]\psi_\Lambda$$

where f_1 is the vector coupling constant, g_1 is the axial-vector coupling constant, f_2 is the weak magnetism term, and g_2 is the second class current. In its analysis the Mass-BNL group focused on the precise determination of the ratio of axial vector to vector coupling constants $|g_1/f_1|$, assuming the theoretical value $g_2(0) = 0$. With appropriate radiative corrections, and use of the expected dipole q^2 dependence in the analysis, the group obtains from the angular correlation study,

$$|g_1(0)/f_1(0)| = 0.734 \pm 0.031 \ .$$

This result is relatively insensitive to the value of g_2, and is independent of any assumptions about the value of f_2/f_1.

From the absolute decay rate and the ratio $|g_1/f_1|$ one can calculate $|f_1(0)|$ and $|g_1(0)|$,

$$|f_1(0)| = 1.229 \pm 0.024$$

$$|g_1(0)| = 0.903 \pm 0.030 \ .$$

The result for $|f_1(0)|$ agrees well with the naive Cabibbo-model prediction of $\sqrt{3/2} = 1.22$.

It is worth noting that this experiment at its present state of analysis has statistics more than an order of magnitude larger than any previous experiment. Further information will be coming from analysis of the full data sample (~ 100,000 events) and from polarization information available in an appropriate subclass of the event sample.

IV. PARITY VIOLATION IN PROTON-NUCLEUS SCATTERING AT 6 GeV/c

Lockyer et al.,[4] a collaboration from six institutions, have presented final results from an experimental program carried on over several years to measure a parity-violating asymmetry in proton-nucleus scattering at 6 GeV/c. The experiment measures the asymmetry parameter,

$$A_L \equiv (\sigma_+ - \sigma_-)/(\sigma_+ + \sigma_-)$$

where $\sigma_+(\sigma_-)$ is the total cross section for positive (negative) helicity protons on a water target. A very rough estimate of the expected asymmetry is $A_L \sim \sqrt{\sigma_{weak}/\sigma_{strong}} \sim 10^{-6}$. Theoretical estimates by Henley and Krejs[5] suggest a much smaller value, $A_L \sim 10^{-7}$ with considerable quantitative uncertainty (because of unknown or inaccurately known parameters in the representation of both the strong and the weak amplitude in pp and pn scattering).

Needless to say, experiments to measure such extremely small asymmetries are exceedingly difficult. The experiment of Lockyer et al. used the ZGS polarized proton beam facility at Argonne; and, through a vertical magnetic deflection of the beam, produced the required longitudinal polarization. This longitudinal polarization was reversed each beam pulse. The transverse polarization prior to the rotation, plus any residual transverse polarization after rotation, can give rise to parity-allowed asymmetries which mask the real effect. The experimenters have made careful studies of such systematic effects by accentuating them to a known extent and thereby determining their impact on the measurements. They have also, through magnetic analysis, removed any contributions introduced by parity-violating hyperon decays.

The final result of the analysis is,

$$A_L = (3.38 \pm 0.65) \times 10^{-6} .$$

It is interesting to note that the raw asymmetry is $(5.90 \pm 0.58) \times 10^{-6}$, and that the removal of the various systematic effects leads to the final result which is nearly a factor of two smaller.

This result can be compared to lower energy measurements on p-p scattering, namely $A_L = (-3.2 \pm 1.1) \times 10^{-7}$ at 45 MeV (Ref. 6) and $(-1.7 \pm 0.8) \times 10^{-7}$ at 15 MeV.[7] These previous low energy measurements are in reasonable agreement with respect to both sign and magnitude with recent calculations by Desplanques et al.[8] Taken at face value, the new measurement suggests an increase of about 10 in the magnitude of A_L and a change in its sign as the incident proton momentum is increased to 6 GeV/c and the target is changed from protons to a mixture of protons and neutrons. While the theoretical work of Henley and Krejs does not allow sharp quantitative predictions, it does not suggest any large increase in $|A_L|$ due either to the much higher energy or to the presence of target neutrons.

Since the ZGS has been turned off, no further work with very high energy polarized proton beams is possible in the near future, but an experiment at 1.5 GeV/c is underway at LAMPF and should shed further light on this problem.

V. NEW RESULTS ON THE τ

The SLAC-LBL Group presented a branching ratio determination for the decay mode

$$\tau \rightarrow \rho\nu \qquad (1)$$

based on statistics larger than those used for its previously published results[9] and also reported the first observation of the Cabibbo-suppressed decay mode,[10]

$$\tau \rightarrow K^*(890)\nu . \qquad (2)$$

These measurements were made with the Mark II detector at SPEAR. The details of event selection and analysis procedure for the mode (1) have been discussed in Ref. 9, and I shall just give the final result

$$B(\tau \rightarrow \rho\nu) = (21.6 \pm 1.8 \pm 3.2)\%$$

where the two quoted uncertainties are the statistical and systematic errors respectively.

The decay mode (2) was identified by observation of the sequence,

$$e^+ + e^- \rightarrow \tau^+ + \tau^- \qquad (3a)$$

$$\tau^\pm \rightarrow e^\pm, \mu^\pm + 2\nu \qquad (3b)$$

$$\tau^\mp \rightarrow K_S^0 + \pi^\mp + \nu \qquad (3c)$$

$$K_S^0 \to \pi^+ + \pi^- \quad . \tag{3d}$$

The leptons in (3b) are identified in the liquid-argon calorimeters or muon identifiers, and the K_S^0 is reconstructed from its $\pi^+\pi^-$ decay. The $K_S^0\pi^\mp$ mass spectrum from events exhibiting the sequence (3), shown in *Fig. 1*, has a clear $K^*(890)$ peak. The corresponding branching ratio determined after appropriate background correction and Monte Carlo evaluation of efficiencies is

$$B(\tau \to K^*\nu) = (1.7 \pm 0.7)\% \ .$$

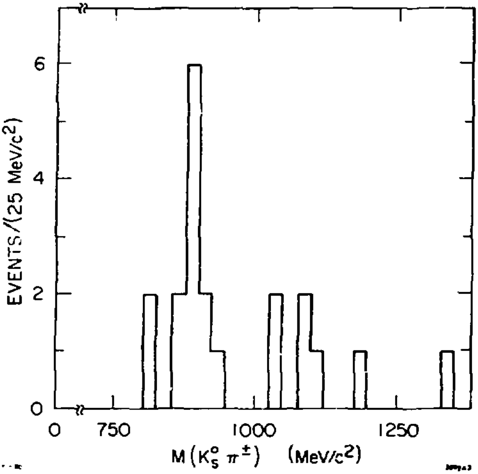

Fig. 1. $K_S\pi$ mass spectrum for $\tau \to K_S\pi\nu$ candidates.

The theoretical predictions based on the standard weak interaction model, as calculated by Tsai,[11] are

$$B(\tau \to \rho\nu) = (21.5 \pm 1.8)\% \ ,$$

$$B(\tau \to K^*\nu) = \tan^2\theta_c \, f_{ps} \, B(\tau \to \rho\nu) = (1.0 \pm 0.1)\% \ ,$$

where θ_c is the Cabibbo angle and $f_{ps} = 0.93$ is a phase space factor. Thus the experimental results continue to be in full agreement with the theoretical expectations based on the interpretation of the τ as a sequential lepton.

VI. CHARM PARTICLE DECAYS

A. Direct Lifetime Determinations

Over the last few years there have been several experiments designed to detect and measure the finite distances traveled by charm particles prior to their decay. The original intent of such experiments was to provide compelling evidence for the weak character of charm particle decay and rough estimates of lifetime.[12] The more recent experiments have been aimed at the identification of specific decay modes, and the quantitative determination of lifetimes of D^+, D^o, F^+, and Λ_c^+ particles.[13,14,15] Although the statistics are still almost as weak as the particle decays, the recent experiments have yielded some very interesting insights with respect to both lifetime and decay modes.

In Table I I have summarized the results from four emulsion-plus-downstream-detector experiments in which specific decay modes have been identified. I want to make a few explanatory comments about the Table and draw some conclusions:

(1) I have used the symbol τ to denote lifetime determinations based on a finite number of events with appropriate consideration of biases, efficiencies, potential paths, etc. I have used the symbol t to denote time-of-flight determinations of single events where these events have not been used in one of the τ measurements. It is important to note

Table I. Charm particle lifetime measurements.

Group	Accel-erator	Beam	Detectors	Results (in 10^{-13} s)	
WA-17[12]	SPS	ν	Emulsion BEBC	3 neutral (probably D^o)	$\tau = 0.53^{+0.57}_{-0.25}$
				4 charged (D^+, F^+, Λ_c^+)	$\tau = 2.5^{+2.2}_{-1.1}$ (assuming D^+)
				1 Λ_c^+	$t = 7.3$
WA-58[13]	SPS	γ	Emulsion spectrometer	2 D^o	$t = 0.84$ 0.45
				1 Λ_c^+	$t = 0.57$
				1 D^-	$t = 1.0$
E-531[14]	FNAL	$\nu,\bar{\nu}$	Emulsion spectrometer	10 D^o	$\tau = 1.01^{+0.43}_{-0.27}$
				5 $D^\pm$	$\tau = 10.3^{+10.5}_{-4.1}$
				5 Λ_c^+	$\tau = 1.36^{+0.84}_{-0.46}$
				2 $F^\pm$	$\tau = 2.2^{+2.8}_{-1.0}$
Ammar et al.[15]	FNAL	$\nu,\bar{\nu}$	Emulsion 15' chamber	1 F^+	$t = 1.4$

that the determination of a reliable value of τ goes well beyond the process of averaging a group of individual time-of-flight measurements. The efficiency for finding such events depends on their time-of-flight in a manner which is highly sensitive to the event search techniques used. Furthermore since such techniques obviously have to be different for neutral and charged particle decays, the ability to compare neutral and charged particle lifetimes depends on careful correction for detection biases. For these reasons, I have not attempted to incorporate data from single time-of-flight measurements into the lifetime determinations, with just one exception (see next paragraph).

(2) The three F events identified in emulsion are of great interest and I have therefore provided more detail on those events in Table II, including a best-fit lifetime for all three events. I shall discuss aspects of these events other than their lifetime in a later section.

Table II. F decays.

Decay mode	P (GeV/c)	Mass (MeV/c^2)	Proper time (10^{-13} s)	Group
$\pi^-\pi^-\pi^+\pi^0$	12.2	2026 ± 56	3.70	E-531[14]
$K^+\pi^-\pi^+\bar{K}^0$	9.7	2089 ± 121	0.91	E-531[14]
$\pi^+\pi^+\pi^-\pi^0$	2.37	2017 ± 25	1.4	Ammar et al.[15]
Overall $\tau = (2.0^{+1.8}_{-0.8}) \times 10^{-13}$ sec				

(3) Although obviously the statistics are still very limited, it appears that the $D^\pm$ lifetime is substantially larger than the D^0 lifetime. This point is particularly clear in the E-531 data but is also suggested by the WA-17 results. The same conclusion has been drawn from other inputs which will be discussed in the next section. On the basis of rather less statistical strength, it also appears that the F and Λ_c lifetimes may be intermediate between those of the D^0 and the $D^\pm$.

B. Semileptonic Branching Ratios

Pais and Treiman[16] pointed out several years ago that since Cabibbo-allowed semileptonic decay ($c \to s + e^+ + \nu_e$) satisfied the isospin rule $|\Delta\vec{I}| = 0$, the relation

$$\Gamma_{SL}(D^+) = \Gamma_{SL}(D^0) \qquad (4)$$

for any semileptonic decay mode (or for the totality of such modes) had to hold, subject only to small phase space corrections arising from mass differences between isospin multiplet members. It follows therefore that

$$\frac{\tau(D^+)}{\tau(D^0)} = \frac{B_{SL}(D^+)}{B_{SL}(D^0)} , \qquad (5)$$

where B_{SL} represents the semileptonic branching ratio. The DELCO and the Mark II Groups at SPEAR have both made measurements of the total semileptonic branching ratios by means of very different analysis procedures. The DELCO work has now been published[17] and I confine myself to quoting its main results:

DELCO:

$$\tau(D^+)/\tau(D^o) > 4.3 \quad (95\%\ \text{C.L.})$$

$$B_e(D^+) = 22^{+4.4}_{-2.2}\%$$

The Mark II analysis is based on the inclusive study[18] of D^+ and D^o decays tagged by the identification through a known exclusive channel of an accompanying D^- or $\bar{D}^o$ decay, the e^+e^- total energy being at the $\psi''(3770)$ where $D\bar{D}$ pair production is known to be the dominating process. The Mark II results are as follows:

$$\tau(D^+)/\tau(D^o) = 3.1^{+4.6}_{-1.4}$$

$$B_e(D^+) = 16.8 \pm 6.4\%\ .$$

Combining the DELCO and Mark II data to define a best estimate for $B_e(D^+)$, I obtain,

$$B_e(D^+) = 21^{+4}_{-2}\%\ .$$

I have not attempted to put together all the information on $\tau(D^+)/\tau(D^o)$ from both direct lifetime data and semileptonic branching ratio determinations, but it is clear that a numerical value in the range 4 - 20 would be consistent with all the experimental information.

C. Comparison of Semileptonic Rate with Theoretical Expectations

If one combines the measured value of $\tau(D^+)$ from Table I with the above determination of $B_e(D^+)$ one obtains,

$$\Gamma_e(D) = \frac{B_e(D^+)}{\tau(D^+)} = (2 \pm 1) \times 10^{11}\ \text{sec}^{-1}\ .$$

This result can be compared with the prediction given by Cabibbo and Maiani, and Cabibbo, Corbo and Maiani[19] based on analysis of the decay $c \to s + e^+ + \nu_e$,

$$\Gamma_{SL} = \frac{G^2}{192\,\pi^3} M_c^5\, g(\epsilon)[1 - \frac{2\alpha_s}{3\pi} f(\epsilon)]\ , \qquad (6)$$

where $g(\epsilon)$ is a phase space correction arising from the mass of the s quark, $\epsilon = M_s/M_c$, and the term in the brackets is a QCD correction. The charmed quark mass M_c to which Γ_{SL} is obviously very sensitive is determined to be 1.75 GeV/c^2 from a study of the D semileptonic decay electron spectrum, as measured by the DELCO group, and the corresponding prediction for Γ_{SL} is 2×10^{11} sec^{-1} in excellent agreement with the experimental value.

D. Further Study of Charm Meson Decays

The lifetime difference between D^+ and D^o decays provides an important clue on the mechanism for the Cabibbo-allowed hadronic decay process. Perhaps the most natural mechanism is the one shown in the diagram of Fig. 2a in which the light quark bound to the decaying c quark acts in a spectator role. Similar diagrams can be constructed

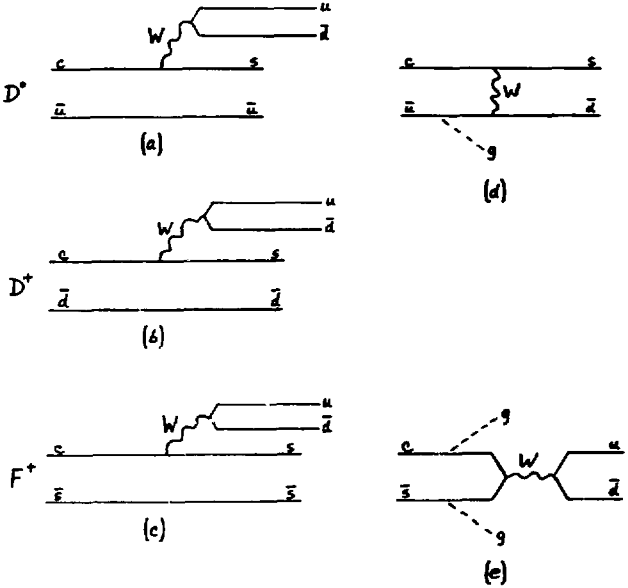

Fig. 2. Diagrams for D and F decay.

for D^+ and F^+ decays (Fig. 2b,c) and lead to the expectation of equal lifetimes for D^0, D^+ and F^+. The actual different lifetime values suggest a significant enhancement factor for the D^0 hadronic decays. Simple mechanisms for such enhancements (which would also help explain the $|\Delta \vec{I}| = 1/2$ enhancement in K decay) are the W annihilation mechanisms shown for D^0 decay in Fig. 2d and F^+ decay in Fig. 2e, but not possible for Cabibbo-allowed D^+ decay.[20] The presence of gluons is essential in these processes to remove helicity suppression factors which would otherwise strongly inhibit them. The enhancements provided by the annihilation diagrams plus perhaps the slight inhibitions induced by the Pauli principle in the D^+ decay of Fig. 2b, due to the two $\bar{d}$ in the final state,[21] can possibly account for a factor of perhaps 5 in $\tau(D^+)/\tau(D^0)$, although there might be theoretical difficulty if the experimental ratio turned out substantially larger.

The further experimental consequences of the dominance of diagrams such as those of Fig. 2d and 2e would be the following:

(1) D hadronic final states would be dominated by isospin 1/2. One would expect the rates of individual D^+ final state channels (which have to be $I = 3/2$) to be substantially less than the individual rates for the corresponding D^0 channels.

(2) The F^+ would have a shorter lifetime than the D^+ in view of diagram 2e. Furthermore a significant fraction of F^+ decays would not have $K\bar{K}$ contributions in the final state and could therefore go into multipion states ($\geq 3\pi$).

(3) There are Cabibbo-forbidden annihilation diagrams for D^+. Consequently one might expect a much larger fraction of Cabibbo-forbidden modes for D^+ than for D^0.

I shall postpone the discussion of F decays to the next section, and now confine myself to consideration of D^0 and D^+ decays. Consider first inclusive strange particle branching ratios obtained by the Mark II Collaboration[18] working at the ψ'' energy and studying D decays produced in association with well-established exclusive decay modes. These results are shown in Table III which also summarizes earlier results from the Lead Glass Wall (LGW) Collaboration.[22] To the extent that one neglects multikaon final states (and hence ignores multiple counting in the Table), the Mark II results suggest that 85 ± 15% of D^0 decays and 71 ± 19% D^+ decays are compatible with being Cabibbo-allowed, with corresponding numbers of 93 ± 28% and 49 ± 30% from the LGW experiment. The indicated $D^+ - D^0$ difference, while certainly not conclusive given the uncertainties, is nevertheless suggestive of the effect mentioned in item (3) above.

Table III. Strange particle branching ratios for D decays.

	D^0 (%)		D^+ (%)	
Mode	Mark II	LGW	Mark II	LGW
$D \rightarrow K^-X$	56 ± 11	36 ± 10	19 ± 5	10 ± 7
$D \rightarrow K^+X$	8 ± 3	--	6 ± 4	6 ± 6
$D \rightarrow \bar{K}^0X$	29 ± 11	57 ± 26	52 ± 18	39 ± 29
Total Cabibbo-favored	85 ± 15	93 ± 28	71 ± 19	49 ± 30

To test item (1), I consider briefly exclusive final states of D decay and their isospin character. The most recent branching ratio information from the Mark II experiment[18] is summarized in Table IV along with published results from the LGW experiment.[23] The agreement between the two sets of data is not overwhelmingly good, partly because of differences in the total cross section measurements at 3770 MeV, and in my further considerations I have just used the Mark II results.

In Table V, I have listed $K^*\pi$ and $K\rho$ branching ratios obtained from Dalitz plot fits to the $K\pi\pi$ final states.[18] The errors quoted in Table V combine quadratically systematic and statistical uncertainties, but do <u>not</u> include the errors in the $D\bar{D}$ cross sections which are common to all the measurements (and hence do not affect comparisons of the branching ratios). The Dalitz plots and interesting projections are shown in Fig. 3.

In interpreting the branching ratios for the $K\pi$, $K^*\pi$, $K\rho$, etc. final states one should keep in mind that the Cabibbo-allowed hadronic charm decay is expected to satisfy a $|\Delta\vec{I}| = 1$ selection rule (note

Table IV. $\sigma \cdot B$ and B for Cabibbo-favored D decays.

Mode	$\sigma \cdot B$ (nb)	B (%)	LGW B (%)
$K^- \pi^+$	0.24 ± 0.02	3.0 ± 0.6	2.2 ± 0.6
$\bar{K}^0 \pi^0$	0.18 ± 0.08	2.2 ± 1.1	--
$\bar{K}^0 \pi^+ \pi^-$	0.30 ± 0.08	3.8 ± 1.2	4.0 ± 1.3
$K^- \pi^0 \pi^+$	0.68 ± 0.23	8.5 ± 3.2	12.0 ± 6.0
$K^- \pi^+ \pi^- \pi^+$	0.68 ± 0.11	8.5 ± 2.1	3.2 ± 1.1
$\bar{K}^0 \pi^+$	0.14 ± 0.03	2.3 ± 0.7	1.5 ± 0.6
$K^- \pi^+ \pi^+$	0.38 ± 0.05	6.3 ± 1.5	3.9 ± 1.0
$\bar{K}^0 \pi^0 \pi^+$	0.78 ± 0.48	12.9 ± 8.4	--
$\bar{K}^0 \pi^+ \pi^- \pi^+$	0.51 ± 0.18	8.4 ± 3.5	--
$K^- \pi^+ \pi^- \pi^+ \pi^+$	< 0.23	< 4.1	--

Table V. B for quasi-two-body $K\pi\pi$ states.

Mode	B (%)
$K^- \rho^+$	7.2 ± 2.5
$\bar{K}^{*0} \pi^0$	$1.4^{+1.9}_{-1.4}$
$K^{*-} \pi^+$	3.2 ± 1.0
$\bar{K}^0 \rho^0$	$0.1^{+0.4}_{-0.1}$
$\bar{K}^{*0} \pi^+$	< 4

that $c \rightarrow s + u + \bar{d}$), from which one easily derives the triangular amplitude relations,

$$A(-+) + \sqrt{2}\, A(0\,0) = A(0+) \tag{7}$$

where $A(+-) \equiv$ decay amplitude for $D^0 \rightarrow K^-\pi^+$, $K^{*-}\pi^+$, $K^-\rho^+$
$A(0\,0) \equiv$ decay amplitude for $D^0 \rightarrow \bar{K}^0\pi^0$, $\bar{K}^{*0}\pi^0$, $\bar{K}^0\rho^0$
$A(0+) \equiv$ decay amplitude for $D^+ \rightarrow \bar{K}^0\pi^+$, $\bar{K}^{*0}\pi^+$, $\bar{K}^0\rho^+$.

The dominance of $I = 1, 2$ final states, appropriate to the annihilation diagram of 2d implies that $|A(0+)|^2$ is typically a few times smaller than $|A(-+)|^2 + |A(0\,0)|^2$, but since the enhancement factors involved seem to be at most of order 10, one can hardly argue that $A(0+)$ should be negligible in (7). It follows that relations like $|A(0\,0)|^2/|A(-+)|^2 = 1/2$ whose counterparts in strange particle decay are accurately obeyed should only show rough experimental agreement.

I have attempted to summarize the experimental situation in Table VI, using as my inputs the Mark II numbers of Tables IV and V. Since $\tau(D^0)/\tau(D^+) \sim 1/5 - 1/10$ both $K\pi$ and $K^*\pi$ final states satisfy the

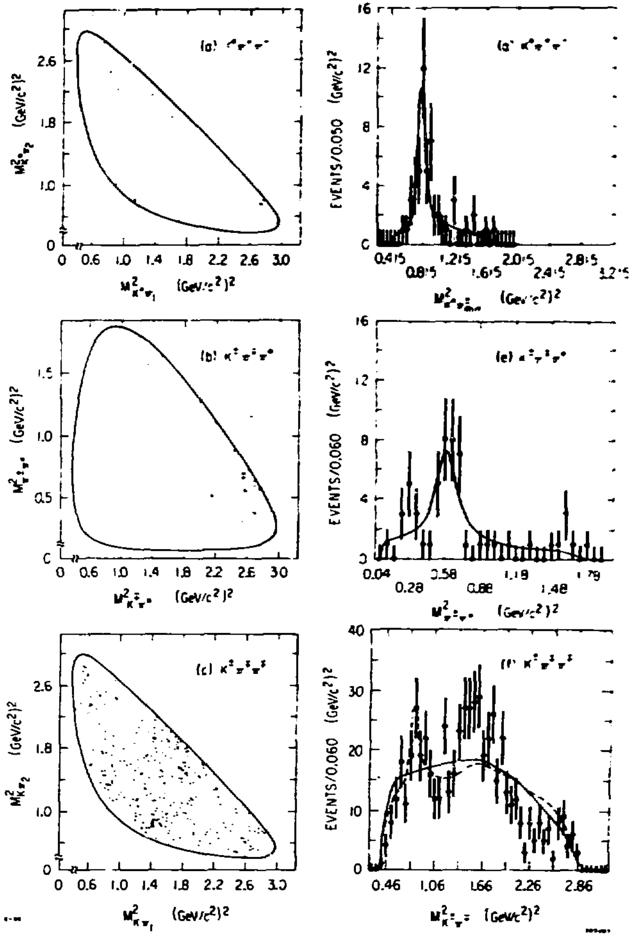

Fig. 3. Dalitz plots and projections for D → Kππ decay.[18]

Table VI. $I = 1/2$ final state tests.

Decay mode	$\frac{\Gamma(00)}{\Gamma(-+)}$	$\frac{\Gamma(0+)}{\Gamma(-+) + \Gamma(00)}$
$K\pi$	$0.7^{+0.5}_{-0.3}$	$(0.4 \pm 0.2)\,\frac{\tau(D^0)}{\tau(D^+)}$
$K^*\pi$	$0.4^{+0.7}_{-0.4}$	$< 0.8\,\frac{\tau(D^0)}{\tau(D^+)}$
$K\rho$	$0.01^{+0.06}_{-0.01}$	~ 1 (from Eq. 7)

expected $I = 1/2$ dominance, but the $K\rho$ state seems to pose a problem. Indeed the apparent absence of $\bar{K}^0\rho^0$ implies via (7) above that $\Gamma(\bar{K}^0\rho^+) \approx \Gamma(K^-\rho^+)$, hence that the $\bar{K}^0\rho^+$ final state should have a very large branching ratio. These indications are barely compatible with the rather poorly measured $\bar{K}^0\pi^+\pi^0$ branching ratio of 12.8 ± 8.4%. If confirmed, these $D \to K\rho$ results pose problems for both the annihilation diagram dominance and also for the so-called sextet dominance (based on analogy with octet dominance for $|\Delta\vec{I}| = 1/2$ in strange particle decay) according to which $\bar{K}^{*0}\pi^+$ and $\bar{K}^0\rho^+$ rates can be enhanced, but should be equal. Clearly much more extensive data on $K\pi\pi$ decay modes, hopefully to be obtained in the future from the Mark III detector, will be required to clear up this question.

E. F Decays

Cabibbo-allowed diagrams relevant to F decay have already been exhibited in Fig. 2c and 2e. The W-radiation diagram of Fig. 2c would lead dominantly to decay modes containing a $K\bar{K}$ component such as

$$F^+ \to K + \bar{K} + \pi\text{'s} \tag{8a}$$

$$\to \eta + \pi\text{'s} \tag{8b}$$

$$\to \eta' + \pi\text{'s} \tag{8c}$$

and would have a rate comparable to that for D^+ decay. Dominance of the annihilation diagram of Fig. 2e would lead to multipion final states and lifetimes perhaps more comparable to those of D^0.

Most of our past information on F decay has come from the DASP experiment[24] at DORIS which reported a substantial inclusive η cross section ($\sigma_\eta \approx 4$ nb) in the neighborhood of the 4.4 GeV e^+e^- annihilation cross-section bump. The DASP group claimed a threshold-like behavior for σ_η (see Fig. 4) in the region of 4.1 GeV which they ascribed to the onset of $F\bar{F}$ production accompanied by decay modes (8b). In addition, explicit observation of the exclusive mode

$$F^+ \to \eta + \pi^+ \tag{9}$$

was reported, with an F mass determination $M_F = 2.03 \pm 0.06$ GeV/c^2.

In my view, the most striking new results on F decay come from the three events observed in emulsion and described in Table II. The measurements on all these events appear to be very complete and represent the most compelling experimental evidence for the existence of F mesons.

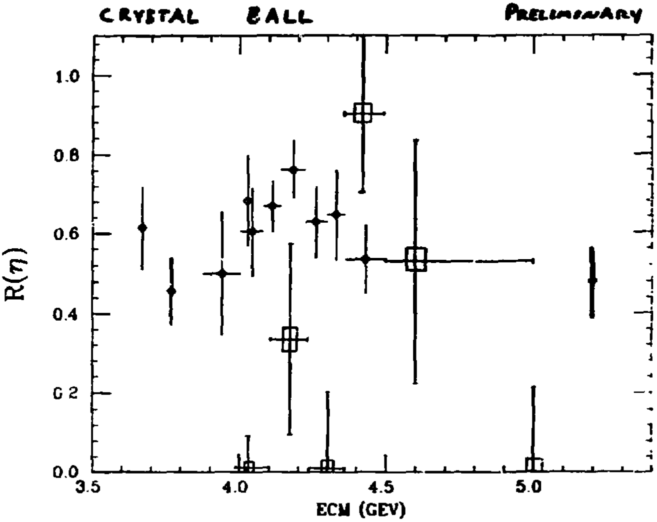

Fig. 4. Plot of ratio $R(\eta) \equiv \frac{\sigma(e^+e^- \to \eta X)}{\sigma(e^+e^- \to \mu^+\mu^-)}$ as a function of total energy. Diamonds are preliminary Crystal Ball data,[25] and squares are earlier DASP data.[24]

The lifetime, $\tau = (2.0^{+1.8}_{-0.8}) \times 10^{-13}$ sec, though in obvious need of statistical strengthening, appears intermediate between D^0 and D^+, and certainly compatible with the idea of W-annihilation dominance (where two gluons must here be emitted because of the W being a color singlet). Furthermore, out of three reconstructed decays, two are of the form $\pi^+\pi^-\pi^\pm\pi^0$ in which neither of the $\pi^+\pi^-\pi^0$ combinations fit the η mass.

There are also new results from the Crystal Ball Collaboration on the measurement of inclusive η production in e^+e^- annihilation between 3.6 and 4.5 GeV.[25] The Crystal Ball is a 4π sodium iodide detector plus inner tracking chambers for the detection of charged particles, with very good photon and electron energy resolution. The reconstruction of η's is based on detection of their 2γ decay mode. The major problem is the development of techniques to bring out the rather small η signal in the presence of a prodigious π^0 background. The preliminary Crystal Ball results are compared to the earlier DASP data in Fig. 4 which shows the ratio

$$R(\eta) \equiv \frac{\sigma(e^+e^- \to \eta X)}{\sigma(e^+e^- \to \mu^+\mu^-)}$$

as a function of total c.m. energy. The data in the Figure lead to the following conclusions:

1) The Crystal Ball measurements of $R(\eta)$ show no evidence of threshold behavior near 4.1 GeV and no indication of peaking at 4.4 GeV. These preliminary data thus do not confirm the DASP indications of large $B(F \rightarrow \eta X)$, although they say nothing about the exclusive $F^{\pm} \rightarrow \eta\pi^{\pm}$ decay mode.

2) There are about 0.15 η/hadronic event for all c.m. energies between 3.68 and 4.5 GeV.

3) From data at the ψ'', one can set a limit $B(D \rightarrow \eta X) < 0.1$.

Overall these various results on F decay are all remarkably consistent in supporting the interpretation of the $\tau(D^0)/\tau(D^+)$ ratio through enhancement from W annihilation diagrams. A few words of caution are however in order. Firstly, as often mentioned, the statistics on which these various results hang are still very limited -- for example, the lifetime results themselves are still in the state where one additional event can make a significant difference in the overall lifetime. Secondly, the photoproduction experiment on the Omega Spectrometer[26] at the SPS has reported evidence for (η + pions) bumps at masses near 2000 MeV, which they have rather naturally ascribed to F production and decay. My arguments above are not intended to suggest that such modes are not present, but only that they are perhaps not dominant in the same sense that modes involving K mesons overwhelmingly dominate D^0 decays. Incidentally I have not discussed here in any detail the F photoproduction results because they were not presented in those parallel sessions which it is here my task to summarize -- they will undoubtedly be described in Professor Wojcicki's summary paper.

VII. NEUTRINO OSCILLATIONS

The possibility of neutrino oscillations was suggested quite some time ago,[27] but a number of recent indications, including some evidence for nonzero neutrino masses, and new results from experiments with reactor-produced $\bar{\nu}_e$ have lately focused renewed interest on this subject. I shall not discuss here the evidence on nonzero neutrino masses -- it is both experimental (from a new study of the endpoint region of the tritium beta spectrum[28]) and theoretical (from astrophysics considerations[29]), and suggests mass values in the range of 10 - 40 eV. I do want however to discuss in some detail the reactor experiments.

To understand the interpretation of these experiments in terms of neutrino oscillations, it is useful to put down some very simple phenomenology. We assume two sets of neutrino eigenstates, the weak charged-current eigenstates ν_α (α = e, μ, τ, ...) and the mass eigenstates ν_j (j = 1, 2, 3, ...) related to each other through a unitary transformation U,

$$\nu_\alpha = \sum_j U_{\alpha j}\nu_j . \qquad (10)$$

Initially a single weak eigenstate ν_α is produced (for example, by beta decay); but, if U is not a unit matrix and the masses corresponding to the ν_j differ from each other, the various ν_j amplitudes will oscillate with different frequencies and change their phase relationships as time goes on. It is easy to show that after time t the probability that the initial neutrino ν_α manifests itself as a new weak eigenstate ν_β is given by

$$\begin{aligned} P_{\alpha\beta} &\equiv P(\nu_\alpha \rightarrow \nu_\beta) = \left|\sum_j U_{\alpha j} U^*_{\beta j} e^{-iE_j t}\right|^2 \\ P_{\bar\alpha\bar\beta} &\equiv P(\bar\nu_\alpha \rightarrow \bar\nu_\beta) = \left|\sum_j U^*_{\alpha j} U_{\beta j} e^{-iE_j t}\right|^2 \end{aligned} \qquad (11)$$

where E_j is the total energy of state ν_j.

As a simple example we consider the case in which only ν_e and ν_μ mix. Formula (11) then reduces to the relations

$$P_{ee} = P_{\mu\mu} = P_{\bar e\bar e} = P_{\bar\mu\bar\mu} = 1 - \sin^2 2\theta \sin^2 \Delta_{12}/2 \qquad (12a)$$

$$P_{e\mu} = P_{\mu e} = P_{\bar e\bar\mu} = P_{\bar\mu\bar e} = \sin^2 2\theta \sin^2 \Delta_{12}/2 \qquad (12b)$$

where θ is the two-dimensional rotation angle (similar to the Cabibbo angle) which parametrizes the 2×2 matrix U and

$$\frac{\Delta_{12}}{2} = \frac{m_1^2 - m_2^2}{4} \left(\frac{L}{E}\right) = 1.27\, \delta m^2 \left(\frac{L}{E}\right) \qquad (12c)$$

The right-hand expression in (12c) has the mass squared difference $\delta m^2 = |m_1^2 - m_2^2|$ in eV^2, the length L traveled between production and detection in meters, and the neutrino energy $E \gg m_1, m_2$ in MeV. For the purposes of discussing the reactor experiments, I shall assume the validity of (12). The consideration of complete three-dimensional mixing between ν_e, ν_μ and ν_τ does not significantly affect the interpretation of these experiments, which only measure $P_{\bar e\bar e}$ in a limited range of L/E, but does have important impact on attempts to make consistent fits in terms of neutrino oscillations to a wider variety of pheonomena. I shall come back to this very briefly at the end of this section.

It is clear from (12) that a necessary condition for the observation of oscillations is that Δ_{12} not be too small; i.e., $\delta m^2 (L/E) \gtrsim O(1)$. The δm^2 ranges probed by different kinds of experiments is illustrated[30] in Table VII. As shown in the Table, the reactor experiments for which $L \sim$ meters, $E \sim$ MeV probe values of δm^2 of the order of 1 eV^2 or higher.

We now move from these general remarks to a more specific discussion of reactor experiments, for which the experimentally determined values of $P_{\bar e\bar e}$ at distances L of the order of 6 - 11 meters from the core serve as the measure of possible oscillations. Although in principle any significant downward deviation of $P_{\bar e\bar e}$ from unity can be considered evidence for oscillations, it is clear that a really compelling demonstration of this phenomenon requires measurements at more than one value of L to establish the characteristic L/E dependence of (12).

The investigation of reactions induced by reactor-produced $\bar\nu_e$ has been largely pioneered by Reines and his collaborators ever since the first experiment which detected neutrino interactions.[31] In the search for neutrino oscillations, large reactors have the following nice features:

(i) Only $\bar\nu_e$ are initially produced;

(ii) The $\bar\nu_e$ have relatively low energies (a few MeV), and it is

Table VII. Sensitivity of various experiments to δm^2.

Experiment type	δm^2 range (eV^2)
High energy accelerator	$> 10^2$
Reactor, Meson Factory Low Energy accelerator	> 1
Deep Mine (present)	$> 10^{-2}$
Deep Mine (future)	$> 10^{-5}$
Solar neutrinos	$> 10^{-10}$

possible therefore to set up conveniently experiments for which $L/E \sim$ 1 m/MeV to study the $\delta m^2 \approx 1$ eV^2 region;

(iii) The flux of $\bar{\nu}_e$ can be very large ($\sim 2 \times 10^{13}$ $\bar{\nu}_e$ $cm^{-2}s^{-1}$ from the Savannah River Reactor).

Ideally if the spectrum (both shape and magnitude) of $\bar{\nu}_e$ produced by the reactor were known accurately, measurements of the corresponding spectrum at a well-defined distance from the reactor core would permit a direct test for the existence of oscillations. Such measurements have indeed been made through detection of the inverse beta reaction,

$$\bar{\nu}_e + p \rightarrow n + e^+ \qquad (13)$$

at 6 m by Nezrick and Reines,[32] at 11.2 m by Reines, Gurr and Sobel[33] and very recently at 8.7 m by the Caltech-Grenoble-Munich Collaboration.[34] Although comparison of experiments at various distances (for example, the 6 and 11.2 m experiments) can in principle provide information on oscillations independently of knowledge of the production spectrum, the three experiments listed are all somewhat different, and the systematic differences are perhaps too large to allow firm conclusions from such comparisons.

Alternatively, as mentioned above, one can search for oscillations by comparing any one of these measurements with the expected $\bar{\nu}_e$ spectrum produced by the reactor. The limitation here is that this spectrum is not well known, particularly in the upper end of the $\bar{\nu}_e$ energy range. The expected spectrum has been calculated independently by Avignone and Greenwood,[35] and by Davis et al.[36] The two calculated spectra differ by about 30% in the integrated rate predicted in the absence of oscillations for the reaction (13) and also differ slightly in shape, the Avignone spectrum predicting more rate particularly at the high $\bar{\nu}$ energies. Figure 5 summarizes both the Avignone and the Davis predictions for the inverse beta rate and shows the experimental results of Reines, Gurr and Sobel at 11.2 meters. From Fig. 5, one sees that the measurements, while in good agreement with the Davis spectrum over the lower part of the energy region, disagree with both spectra for positron energy > 5 MeV (or $\bar{\nu}_e$ energy > 6.8 MeV). Since the predicted spectrum is most unreliable at the high energy end, this theoretical uncertainty provides the natural interpretation of the discrepancy between expected and measured spectra in Fig. 5. However if one had strong confidence in one of the calculated spectra, the discrepancy could also be interpreted in terms of a neutrino oscilla-

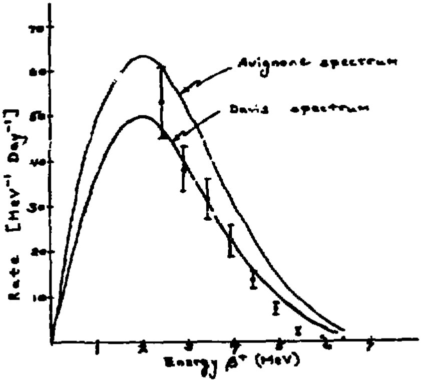

Fig. 5. Rate (at Savannah Reactor) for the process $\vec{\nu}_e + p \rightarrow n + e^+$ as a function of e^+ energy. The solid curves are from the calculations of Avignone and Greenwood[35] and Davis et al.[36] The data points are from the preliminary measurement at 11.2 m by Reines et al.[33]

tion between the production point and the detector at 11.2 m. As an example, Fig. 6 compares the ratio between the measured points and the Avignone spectrum with a plot of $P_{\bar{e}\bar{e}}$ calculated from (12) with $\delta m^2 = 1\ \mathrm{eV}^2$ and $\sin^2 2\theta = 1$. This plotted curve is not based on a fit, but simply illustrates the fact that if one literally believed the Avignone spectrum over the full $\bar{\nu}$ energy range, the neutrino oscillation hypothesis could provide a credible explanation for the discrepancy between experiment at 11.2 m and this spectrum seen in Fig. 5.

Unfortunately the calculated production spectrum is not sufficiently reliable to give much credence to the comparison in Fig. 6; and, therefore, Reines, Sobel and Pasierb (RSP) have searched for evidence of oscillations by an ingenious but very difficult experiment whose interpretation is rather insensitive to the spectrum.[37] Specifically they measure at 11.2 m the ratio,

$$r = \frac{S(\bar{\nu}e + d \rightarrow n + n + e^+)}{S(\bar{\nu} + d \rightarrow n + p + \bar{\nu})} \equiv \frac{\mathrm{CCD}}{\mathrm{NCD}} \qquad (14)$$

where S(X) is the rate for the reaction X integrated over all $\bar{\nu}$ energies and CCD, NCD are abbreviations for "charged current on deuterium," "neutral current on deuterium" (the notation CCP will be used for reaction (13)). No subscript was put on the $\bar{\nu}$ in the denominator of (14) because that process occurs independently of the $\bar{\nu}$ flavor and its rate is therefore unaffected by the existence or non-existence of oscillations (as long as the total number of $\bar{\nu}$ is conserved).

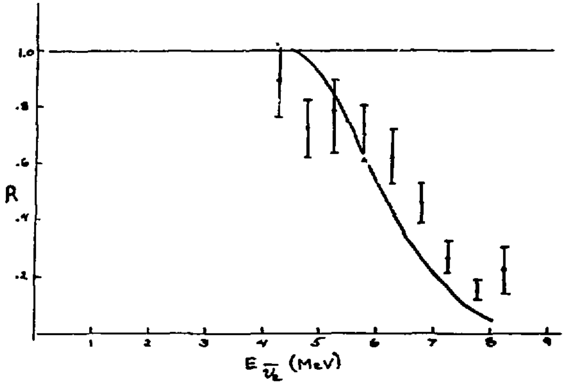

Fig. 6. Ratio of data in Fig. 5 to Avignone spectrum as a function of $\bar{\nu}_e$ energy. Curve corresponds to Eq. (12a) with $\sin^2 2\theta = 1$, $\delta m^2 = 1$ eV^2.

RSP measure the value of r, r_{exp}, by counting the relative numbers of events which give rise to two neutrons (CCD) and to a single neutron (NCD). They determine r_{exp} from the relation

$$r_{exp} = \frac{\overline{\eta'} S_{2N}}{\overline{\eta^2}(S_{1N} - S_{1N}^{BKGND}) - 2(\overline{\eta'} - \overline{\eta'^2})S_{2N}} \tag{15}$$

where S_{2N}, S_{1N} are two-neutron and one-neutron event rates, S_{1N}^{BKGND} is an experimentally measured reactor-associated one-neutron background and the η, η' terms are various efficiencies which I shall not discuss in detail here. Roughly $\overline{\eta^2}$ (let us neglect the differences between η and η' which involve subtle details) is the average two-neutron efficiency, $\bar{\eta}$ is the average one-neutron efficiency, and the second term in the denominator of (15) is the rate of one-neutron events arising from the CCD process because only one of the two produced neutrons is detected.

The advantages and disadvantages of using this type of experiment to get at neutrino oscillations are as follows:

(1) The theoretical value of r, r_{the} (calculated on the assumption of no oscillations, is independent of the absolute magnitude of the $\bar{\nu}$ flux and is insensitive to the shape of the spectrum. In particular, $r_{the} = 0.42$ (Davis spectrum), 0.44 (Avignone spectrum). However there is no assurance that the Avignone and Davis calculations span the full range of possibility; and indeed if one takes the CCP measurements shown in Fig. 5 as the best measure of the spectrum $r_{the} = 0.36$.

(2) The ratio

$$R \equiv r_{exp}/r_{the} \tag{16}$$

directly measures the quantity $\langle P_{\bar{e}\bar{e}} \rangle$ at 11.2 m where $\langle P_{\bar{e}\bar{e}} \rangle$ is an appropriate average over the $\bar{\nu}$ energy spectrum.

(3) The CCD and NCD cross sections are very small, about two orders of magnitude smaller than the free proton cross sections. One consequence is that the uncertainties in R are almost completely dominated by the statistics of the CCD measurement. This is perhaps good in that statistical errors are usually more reliably known than systematic ones, but bad in that in this case the statistical error is relatively large.

(4) Unlike the measurements shown in Fig. 5, the determination of S_{2N} gives a single global average which cannot be broken down into individual $\bar{\nu}_e$ energy bins. This obviously provides less redundancy in the interpretation of the results.

(5) Although the use of the ratio r diminishes those systematic uncertainties associated with the $\bar{\nu}_e$ spectrum and flux, other potential systematic uncertainties remain. In particular even though both CCD and NCD are measured in the same detectors their detection efficiencies are different (0.32 for NCD and 0.11 for CCD) and any systematic error in these efficiencies can directly affect r_{exp}.

The details of the experimental technique have been given in the paper of Pasierb et al.[37] It suffices to note here that the CCD and NCD signal rates are roughly 3 and 70 per day respectively, and the corresponding residual cosmic ray backgrounds (which must be removed by a reactor-on/reactor-off subtraction) are about 50 and 400 per day respectively. There is also a well understood and accurately known reactor-associated single neutron background of 10.2 ± 0.7 events per day which is subtracted from the single neutron rate.

The final result of RSP is as follows:

$$r_{exp} = 0.167 \pm 0.093$$

and $R \equiv (r_{exp})/(r_{the}) = 0.38 \pm 0.21$ (Avignone spectrum), 0.40 ± 0.22 (Davis spectrum). Thus $1 - R = 0.61 \pm 0.21$, and there seems to be a 3σ deviation from expectations in the absence of oscillations. This actually somewhat overstates the statistical significance of the effect, because of the coupling between the value of r_{exp} and its error, arising from the presence of S_{2N} in both numerator and denominator of (15). It turns out that an increase in the average CCD counting rate of close to a factor of 2 would take R from its measured value to the value of unity, and that this increase would actually represent a fluctuation of 2.3σ. Furthermore as noted by RSP, the possible range of r_{the} may not be bracketed by the Avignone and Davis spectra. If one uses the experimental spectrum of Fig. 5 as a measure of the shape of the production spectrum, the predicted r_{the} becomes 0.36, the value of R goes to 0.46 ± 0.26, and the overall statistical significance of the deviation from unity goes from 2.3σ to 1.8σ.

This factor of 1.8σ is based only on r_{exp} and on the shape of the measured CCP spectrum at 11.2 m but not on the absolute magnitude of the $\bar{\nu}_e$ flux which it also provides. We now move to consider the further information which this flux measurement gives by showing in Table VIII a set of ratios of measured to predicted rates for the various experiments at 11.2 and 6 m supplied by RSP. The numbers given for the 11.2 m CCP data for both Avignone and Davis spectra provide average numerical representations of the behavior already exhibited in Fig. 5.

Table VIII. Ratios of measured to predicted values.

Distance (meters)	Reaction	Neutrino threshold (MeV)	Spectra		
			Avignone	Davis	CCP measurement at 11.2 m
11.2	NCD	2.2	0.83 ± 0.13	1.1 ± 0.16	1.3 ± 0.22
11.2	CCD	4.0	0.32 ± 0.14	0.44 ± 0.19	0.61 ± 0.29
11.2	CCP	4.0	0.68 ± 0.12	0.88 ± 0.15	≡ 1.0
11.2	CCP	6.0	0.42 ± 0.09	0.58 ± 0.12	≡ 1.0
6	CCP	1.8	0.65 ± 0.09	0.84 ± 0.12	---
6	CCP	6.0	0.81 ± 0.11	1.02 ± 0.15	1.19 ± 0.27

I want to particularly emphasize the contents of the last column in which the $\bar{\nu}_e$ spectrum used for determining the predicted rates is the spectrum measured at 11.2 m by Reines, Gurr and Sobel via the CCP reaction and exhibited by the experimental points of Fig. 5. In the absence of measurement errors, the CCD entry for the last column should be unity, independently of the existence or non-existence of oscillations, since both CCD and CCP at 11.2 m are measurements of the $\bar{\nu}_e$ spectrum at that point.[38] The actual entry is 0.61 ± 0.29 where again the dominating contribution to the uncertainty is the CCD statistical error. It therefore seems likely that the difference between 0.61 and unity is at least in part due to a downward statistical fluctuation in the measured CCD rate. This evidence for such a fluctuation reduces the strength of the case for oscillations, based on the fact that R is well below unity.

This can be put in a more precise way as follows. Instead of using the ratio $r \equiv \mathrm{CCD}/\mathrm{NCD}$, we can instead use another ratio $r' \equiv \mathrm{CCP}/\mathrm{NCD}$, and form the quantity $R' \equiv r'_{exp}/r'_{the}$, which, in the absence of measurement errors, should differ from R defined in (16) only to the extent that the average over the $\bar{\nu}$ spectrum may be very slightly different. The ratio R' has the same advantages as R with respect to insensitivity to assumptions about $\bar{\nu}$ spectrum. With regard to other uncertainties it has one disadvantage and one advantage with respect to R: the disadvantage is that the CCP and NCD data were not obtained at the same time, hence there is a systematic normalization uncertainty (which is included in all the quoted errors); the advantage is that the dominating error in the R measurement, namely the statistical uncertainties of the CCD rate has been completely removed. The results for R' derived from the data of Table VIII and from the counting rate numbers of RSP are as follows,

$$R' = 0.77 \pm 0.20 \text{ (Avignone or Davis spectrum)}$$

$$R' = 0.90 \pm 0.23 \text{ (CCP spectrum)}$$

It may seem surprising that the ratio of R' to R is larger than 1/0.61, the factor needed to raise the low CCD entry in the last column of Table VIII to unity; this is a consequence of the fact that r_{exp} in (15) contains S_{2N} in both numerator and denominator positively correlated

-- if S_{2N} is increased by a factor $1/0.61 = 1.6$, r_{exp} is increased by almost a factor of 2.

The various values of R and R' which I have quoted are succinctly summarized in Table IX. In the last column of the Table, I have quoted probability levels corresponding to the fluctuations given in the adjacent column, account being taken of the fact that only in one direction could these fluctuations have simulated the existence of neutrino oscillations.

Table IX. Summary of rate-ratio measurements.

Ratio of rates used	Assumed $\bar{\nu}$ spectrum shape	$\mathcal{R} = \frac{r_{exp}}{r_{the}}$	Deviation from no oscillation expectation	Probability of one-sided fluctuation of equal or greater magnitude
$\frac{CCD}{NCD}$	Avignone Davis	0.39 ± 0.21	$2.3\ \sigma$	0.01
$\frac{CCD}{NCD}$	CCP data	0.46 ± 0.26	$1.8\ \sigma$	0.04
$\frac{CCP}{NCD}$	Avignone Davis	0.77 ± 0.20	$1.2\ \sigma$	0.11
$\frac{CCP}{NCD}$	CCP data	0.90 ± 0.23	$0.4\ \sigma$	0.34

What do I conclude from Table IX? I want to emphasize those inputs which help decide the case for or against the existence of oscillations rather than those inputs which, if one assumes that oscillations exist, give the best measurement of $\langle P_{\bar{e}\bar{e}}\rangle$. In my view this dictates particular consideration of the second and fourth rows of the Table since only these are really independent of assumptions about the $\bar{\nu}_e$ spectrum. If we give full weight to the deuterium experiment, the 4% probability level in the second row gives the right measure (on the assumption that none of the systematic uncertainties have been grossly underestimated) of the chance that normal non-oscillating behavior gave rise to the observations. The fourth row does not give full weight to the deuterium experiment -- it ignores the CCD rate measurement which is the weakest statistical piece and replaces it by the CCP rate measurement which supposedly is sensitive to the same input. In that case, the neutrino oscillation indication disappears completely; and, in my view, this fact weakens whatever positive conclusion one may have drawn from the smallness of the 4% in the second row of the Table.

Sobel, in his presentation to the Conference, has quoted preliminary results from the CIT-Grenoble-Munich Collaboration at $L = 8.7\,m$. The ratios of measured to predicted rates for the CCP reaction integrated over $\bar{\nu}$ energy above 3 MeV are 0.81 ± 0.18 (Davis spectrum) and 0.63 ± 0.14 (Avignone spectrum). One can as yet say little about the presence or absence of oscillations from these numbers given the spectrum uncertainties.

I complete this discussion by taking note of the fact that there exist other experiments whose results have a bearing on the absence or presence of neutrino oscillations and on the relevant parameters (mass differences, mixing matrix). These have been very usefully summarized in several papers by Barger and collaborators[30] who have also discussed possible sets of parameters (using the full three-dimensional mixing matrix). I shall not discuss these here. In my opinion as a perennial skeptic, those effects which are consistent with no oscillations (for example, the absence of $\nu_\mu \to \nu_e$ transitions in various accelerator experiments) seem better established than most of those whose interpretation could require oscillations.

My final conclusions on the present state of the subject of neutrino oscillations are then as follows:

1. There is no compelling evidence at the present time for the existence of neutrino oscillations.

2. The recent reactor experiment of Reines, Sobel and Pasierb hints at a possible anomaly, but even if this anomaly is indeed present, further proof is needed to connect it to oscillations. Furthermore from the totality of existing reactor data, it appears likely that even if there are oscillations, the magnitude of $\langle P_{\bar{e}\bar{e}} \rangle$ for the relevant L/E values is much closer to unity than the 0.39 ± 0.21 result of that experiment.

3. I understand that the CIT-Grenoble-Munich group is planning to continue and extend its measurements and that Reines, Sobel and collaborators are preparing a new detector capable of measuring the CCP reaction at various distances from the reactor core. Hopefully these experiments will resolve the interesting issues raised by the present set of experimental results.

DISCUSSION

Isgur: (Toronto) I would like to comment that it might be more useful to quote τ decay rates relative to $\tau \to e\nu\bar{\nu}$. Since the theoretical prediction of some of the hadronic modes like $\tau \to A_1\nu$ is uncertain, the real test of a mode like $\tau \to \rho\nu$ is its ratio to $\tau \to e\nu\bar{\nu}$ and not its branching ratio.

Trilling: The relevant experimental ratios from the Mark II Collaboration results are:

$$\frac{B(\tau \to \rho\nu)}{B(\tau \to e\nu\bar{\nu})} = 1.24 \pm 0.13 \pm 0.23$$

$$\frac{B(\tau \to K^*\nu)}{B(\tau \to e\nu\bar{\nu})} = 0.091 \pm 0.039 \ .$$

Rosner: (Minnesota) Can you comment on any of the present limits on the proton lifetime?

Trilling: I have no comment on this.

Kugler: (Weizmann Institute) Could you comment on the direct neutrino mass measurement in the tritium experiment?

Trilling: I am not sufficiently familiar with the details of that experiment to comment intelligently on it. As far as I know it was not presented at the Conference.

Petroff: (Orsay) Apparently the situation on the F decay in $\eta + X$ seems unclear, but I would like to remind you that we presented results at this Conference on photoproduction of F mesons. We observed the F decay in three independent modes: $\eta\pi$, $\eta 3\pi$, $\eta' 2\pi$ at a mass which favored the DORIS result (2.03 GeV/c^2). This experiment has been done at the Omega spectrometer at CERN.

Trilling: I apologize for not mentioning them. Due to the organization of the parallel sessions, your results were not presented in the sessions which I covered, and I did not hear your presentation nor see your paper. I presume that this will be covered by one of the other speakers. [Note: The Omega work is mentioned in this written version of the talk, but was not mentioned in the oral version.]

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31. Much of what I say concerning the reactor experiments is based on the talk by H. W. Sobel given at the Conference in Session B-5.
32. F. Nezrick and F. Reines, Phys. Rev. 142, 852 (1965).
33. The measurement of the e^+ spectrum was measured concurrently with the $\bar{\nu}_e$ - e scattering experiment reported in F. Reines, H. S. Gurr, and H. W. Sobel, Phys. Rev. Lett. 37, 315 (1976).
34. Preliminary results of the Caltech-Grenoble-Munich Collaboration reported by H. W. Sobel.
35. F. T. Avignone III and Z. D. Greenwood, University of South Carolina Preprint, February 1979.
36. B. R. Davis et al., Phys. Rev. D19, 2259 (1979).
37. Initial results of this experiment have been published in E. Pasierb et al., Phys. Rev. Lett. 43, 96 (1979).
38. This point has strongly been made in the unpublished note, "Comments on the Evidence for Neutrino Instability," by R. P. Feynman and P. Vogel.