NAL Proposal No. 315

Scientific Spokesman: F. A. Nezrick

Fermi National Accelerator Laboratory
P. O. Box 500
Batavia, Illinois 60510

FTS/Commercial: 312/840-4094

PROPOSAL TO TEST THE $\nu_\mu - \nu_e$ UNIVERSALITY IN THE 15-FOOT BUBBLE CHAMBER AND MAKE A PRELIMINARY INVESTIGATION OF THE FOUR FERMION INTERACTION

B. A. Arbuzov, A. F. Dunaitsev, P. F. Ermolov,
S. S. Gerstein, I. I. Karpov, A. I. Mukhin,
Ju. G. Stroganov, A. A. Volkov
Institute of High Energy Physics, Serpukhov

S. K. Ereschenko, V. D. Hovansky, V. S. Kaftanov, G. K. Kliger,
V. A. Kolganov, M. A. Kubantsev, V. I. Zakharov
Institute of Theoretical and Experimental Physics, Moscow

F. DiBianca, M. Johnson, P. Limon, T. Murphy,
F. Nezrick, R. Orr, and R. Stefanski
Fermi National Accelerator Laboratory, Batavia, Illinois

May 1974

ABSTRACT

We propose a study of ν_e, $\bar{\nu}_e$, ν_μ and $\bar{\nu}_\mu$ interactions in the neon filled 15-foot bubble chamber using the EMI. We intend to (1) make a universality test of $\nu_e - \nu_\mu$ and $\bar{\nu}_e - \bar{\nu}_\mu$ in the charged current interactions with about a 5% sensitivity to a violation at a neutrino energy of 100 GeV, (2) make a universality test in the neutral current interactions to check for example the existence of a restricted universality,[13] (3) use the four fermion interactions to make a test of the additive versus multiplicative lepton conservation law. In addition, a preliminary study of the specific four fermion interactions will be undertaken.

To accomplish this study we propose a new beam in which the relative energy spectra of ν_e, $\bar{\nu}_e$, ν_μ and $\bar{\nu}_\mu$ can be precisely determined and in which all four types of neutrinos are produced simultaneously. We request about 30,000 interactions resulting from an exposure of about 500,000 pictures using 2.5 x 10^{13} interacting protons per pulse at 500 GeV on our target. If approved, we will undertake the detailed design of the special beam requested.

Table of Contents

		Page
I.	INTRODUCTION	1
II.	PHYSICS CONTENT OF EXPOSURE	
	A. Universality Tests of the Charged Current Interactions	5
	1. Universality Tests Using Total Cross Sections	5
	2. Universality Tests for Specific Final States	6
	B. Universality Tests of the Neutral Current Interactions	8
	C. Four Fermion Interactions on Electrons	11
	1. Tests of the Additive vs. Multiplicative Lepton Conservation Law	11
	2. Preliminary Observation of the Four Fermion Individual Channels	13
III.	EXPERIMENTAL ARRANGEMENT	
	A. Beam Design	15
	B. Absolute Normalization Spectrometer	20
	C. Detector	22
IV.	EVENT RATE DETERMINATIONS	
	A. Flux Calculation	25
	B. Cross Sections and Event Rates	26
V.	CONCLUSION	28
	REFERENCES	30

I. INTRODUCTION

The operation of the FERMILAB at energies approaching 500 GeV and intensities exceeding 10^{13} protons per pulse opens a new era of neutrino physics research only two decades after the first discovery of the free neutrino.[1] A vigorous electronic and bubble chamber research program[2] is underway to investigate the properties and nature of the muon neutrino and its interactions. With the prospects of the FERMILAB operating at 500 GeV and even possibly higher if the energy doubler project is successful and with a new intensity goal of 10^{14} protons per pulse,[3] it is reasonable to consider second generation neutrino experiments. Second generation experiments can study rare processes unobservable with present operating conditions or they can study the more copious processes in a more controlled way, i.e. where the experiment is not based on maximizing the event rate but is based on optimizing the quality of the eventual physics result.

This experiment incorporates both of the second generation goals. As we outlined in our letter of intent,[4] we propose to study muon-neutrino and electron-neutrino interactions simultaneously in an experiment where the two event rates are comparable and where their relative energy distribution can be accurately determined. Furthermore, the experiment will be carried out in a detector which has high detection efficiency for identifying both electrons and muons.

Specifically, we propose constructing a new beam (Section III.A) in the present neutrino area where the neutrinos originate

primarily from the $K_{\ell 3}$ decays of the K_L^o rather than from the charged meson decays of conventional neutrino beams. This type of beam has the advantage of nearly equal fluxes of ν_e, $\bar{\nu}_e$, ν_μ and $\bar{\nu}_\mu$ with comparable energy distributions. Since all four types of neutrinos come from decays of the same parent, the K_L^o, their relative energy spectra are determined solely by the decay branching ratios of K_{e+3}, K_{e-3}, $K_{\mu+3}$ and $K_{\mu-3}$ and their decay kinematics. Therefore, the relative energy spectra can be accurately determined. In the conventional horn focused ν_μ beam the other three neutrino components are considerably suppressed, e.g. $\frac{\bar{\nu}_\mu}{\nu_\mu} < 0.1$, $\frac{\nu_e}{\nu_\mu} < 0.005$, $\frac{\bar{\nu}_e}{\nu_\mu} < 0.0005$.

The K_L^o type of neutrino beam was to our knowledge first proposed at the FERMILAB 1969 Aspen Summer Study.[5] It was proposed in more detail in the winter of 1969 at the FERMILAB TACOS (Toward a Choice of Secondary Beams) committee.[6] This type of beam was then studied in much more detail at the 1972 ECFA Study[7] and at the FERMILAB 1973 Aspen Summer Study.[8]

The new beam for this experiment would be a simple sweeping magnet front end to the bare target neutrino beam. If the quality and properties of the beam are determined to be as anticipated, we would propose a new optimized beam be built to increase the flux by at least a factor of 4.

A spectrometer (Section III.B) installed at the downstream end of the decay tunnel would be used to measure absolutely the ν_e, $\bar{\nu}_e$, ν_μ and $\bar{\nu}_\mu$ energy spectra and to help determine the backgrounds in the beam.

The detector in this experiment (Section III.C) is the 15-foot bubble chamber filled with pure neon followed by the external muon identifier (EMI).[9] Electrons should be uniquely identified since the average potential length in the chamber, about 1.8 m, is more than 6 radiation lengths. Muon identification would be deduced by observing the hadrons interacting in the chamber; an individual hadron has an interaction probability of about 91% in the chamber. For events where more than one track leaves the chamber without interacting, the EMI will be used to help identify them. The 15-foot chamber with magnetic field is unique in being able to pick out background due to π^o production, followed by Dalitz decay which might look like a $\nu_e \rightarrow e$ event.

The physics program of this experiment depends greatly on the neutrino fluxes achieved. Since no K_L^o fluxes have been measured above CERN-BNL energies it is difficult to determine with certainty the neutrino fluxes. We present a range of fluxes (Section IV.A) from different calculations and expect the real situation to be bounded by these calculations. It is clear that a good test of ν_μ-ν_e universality can be made using the inclusive channels (Section II.A.1) and exclusive channels (Section II.A.2) of the interactions on neon. These tests will be precision tests since they do not suffer from the flux shape and normalization problem encountered in neutrino experiments using conventional neutrino beams. A test of ν_e-ν_μ universality of the neutral current interactions (Section II.B) can be made by summing over all the neutral channels produced by the four types of neutrinos in

this experiment and comparing with the ν_μ and $\bar{\nu}_\mu$ results from other experiments, or by varying the amount of ν_μ contamination in the beam which can be done quite easily.

The extent to which the four fermion interaction can be studied (Section II.C) depends on whether our flux estimates are optimistic or pessimistic and on which theory if any describes the four fermion interaction. For example, the total rate for $\nu_e + e \rightarrow e + \nu_e$ in this experiment ranges from 20 events to 4.5 events for the conventional V-A theory depending on the different fluxes used. Assuming the minimum value of the four fermion cross sections allowed in the Weinberg-Salam theory,[10] at most several events are expected in each of the four fermion channels assuming the modest flux calculations.

Summing over all the four fermion channels it is possible to make a test of the additive vs. multiplicative lepton conservation law (Section II.C.1). This is accomplished by determining the e^-/μ^- ratio for the sum of all the four fermion events. This ratio is sensitive to the mixture of multiplicative law and additive law.

Because of the special nature of the beam in this experiment a class of other tests and searches is possible. However, their value would depend on the quality of the status of these tests from other bubble chamber and counter experiments performed in broad band and narrow band beams run before us. Two examples in this class are the study of the V-A interference term F_3[26] in neutrino and antineutrino interactions, and the search for possible muon and electron heavy leptons.[39]

II. PHYSICS CONTENT OF EXPOSURE

A. UNIVERSALITY TESTS OF THE CHARGED CURRENT INTERACTIONS

All experimental evidence at present is in agreement with the hypothesis that muons and electrons behave identically except for mass differences, in charged current interactions. Possible discrepancies in μ/e scattering have been reported[11] but do not appear to lie outside the possible systematic uncertainties of these experiments. In this experiment an accurate universality test can be made between ν_μ/ν_e and $\bar{\nu}_\mu/\bar{\nu}_e$ since the neutrino spectra relative to one another are precisely known.

1. Universality Tests Using Total Cross Sections.

Using the reactions

$$\nu_e + N \rightarrow e^- + \Gamma \qquad (1)$$

$$\bar{\nu}_e + N \rightarrow e^+ + \Gamma \qquad (2)$$

$$\nu_\mu + N \rightarrow \mu^- + \Gamma \qquad (3)$$

$$\bar{\nu}_\mu + N \rightarrow \mu^+ + \Gamma \qquad (4)$$

where Γ is any hadronic final state, a universality test can be made as a function of energy from the energy dependence of the ratio of cross sections. ν_μ/ν_e universality is tested from the cross section ratio of reaction 3 and reaction 1 while the $\bar{\nu}_\mu/\bar{\nu}_e$ universality is tested from the cross section ratio of reaction 4 and reaction 2. Using the modest flux estimates and reasonable cross sections (see Section IV), the event rate for this experiment as a function of energy for these channels is determined and is given in Table I. If we call the event rate of reaction 1 at energy E, $R_1(E)$ and likewise for the other

reactions then we can define the breakdown of universality as a function of energy for neutrinos as

$$U(E) = \frac{\left[\frac{R_3(E)}{R_1(E)}\right]_{exp} - \left[\frac{R_3(E)}{R_1(E)}\right]_{th}}{\left[\frac{R_3(E)}{R_1(E)}\right]_{th}}$$

and similarily for antineutrinos,

$$\overline{U}(E) = \frac{\left[\frac{R_4(E)}{R_2(E)}\right]_{exp} - \left[\frac{R_4(E)}{R_2(E)}\right]_{th}}{\left[\frac{R_4(E)}{R_2(E)}\right]_{th}}$$

where the subscripts exp and th refer to the experimental and theoretical values. The level of U(E) and $\overline{U}(E)$ which we can determine in this experiment based on statistics alone is given in Table II. The quantities U(E) and $\overline{U}(E)$ can be related to the more conventional way of presenting universality breakdown by assuming a particular model for the breakdown, i.e. $\frac{1}{1 + q^2/\Lambda^2}$, where $\frac{1}{\Lambda^2}$ is a measure of universality.

2. Universality Tests for Specific Final States.

Universality tests are also possible by making comparisons for individual final states. These tests will however be somewhat weaker because of limited statistics. For example, consider the reactions

$$\nu_\mu + n \rightarrow \mu^- \; P \; \pi^+ \qquad (5)$$

$$\nu_e + n \rightarrow e^- \; P \; \pi^+ \qquad (6)$$

Using the modest flux estimates and the most recent single pion cross section measurement,[12] $\sigma(\nu_\mu + n \rightarrow \mu^- \; P \; \pi^+) = 0.7 \times 10^{-38}$ cm^2/nucleon, the total event rate as a function of energy for reactions 5 and 6 for this experiment is calculated and given in Table III. Defining a neutrino universality violation parameter for the single pion channels to be U'(E) as U(E) was previously defined for the total cross section, the level of violation that we can determine in this experiment based on statistics alone is given in Table III.

E. UNIVERSALITY TESTS OF THE NEUTRAL CURRENT INTERACTIONS

All experimental information on μ/e universality tests to date come from semileptonic charge-changing processes; i.e. charged current interactions. Recently Georgi and Pais addressed themselves to the following questions.[13] Is it possible to construct models where universality is obeyed in charged current processes but violated in neutral current processes? They conclude that this type of "restricted universality" is possible. In general, they point out that, "In the context of a gauge theory, we can evidently have restricted universality if and only if inequivalent representations are involved for muon and for electron type leptons, that is, if heavy leptons exist and/or if there is more than one neutral current."[13]

The Weinberg theory for example is a natural theory where the conventional μ/e universality law holds. However, Georgi and Pais have constructed a model with restricted universality and explicitly calculate the breakdown of universality in the neutral current interactions.[13]

Consider the reactions:

$$\nu_\mu + N \rightarrow \nu_\mu + \Gamma \tag{7}$$

$$\nu_e + N \rightarrow \nu_e + \Gamma \tag{8}$$

This particular model with restricted universality predicts

that the cross section ratio of reactions 1 and 3 are the same while the cross section ratio reaction 7 to reaction 8 is 16 to 1. Other models can give even larger universality violations in the neutral current interactions. How small a universality violation can we see in the neutral current interactions? Assume that the neutral current to charge current ratio for muon neutrinos is energy independent and is given by the CERN experiment[14] i.e. 23% for neutrinos and 46% for antineutrinos. We can now estimate the total muon-neutrino plus electron-neutrino neutral current to charged current ratio under two assumptions:

(1) that universality holds for the neutral and charged currents i.e.

$$\frac{\nu_\mu + N \to \nu_\mu + \Gamma}{\nu_\mu + N \to \mu^- + \Gamma} = \frac{\nu_e + N \to \nu_e + \Gamma}{\nu_e + N \to e^- + \Gamma} = 0.23$$

and

$$\frac{\bar{\nu}_\mu + N \to \bar{\nu}_\mu + \Gamma}{\bar{\nu}_\mu + N \to \mu^+ + \Gamma} = \frac{\bar{\nu}_e + N \to \bar{\nu}_e + \Gamma}{\bar{\nu}_e + N \to e^+ + \Gamma} = 0.46.$$

(2) that restricted universality holds at the values explicitly calculated by Georgi and Pais i.e.,

$$\frac{\nu_\mu + N \to \nu_\mu + \Gamma}{\nu_\mu + N \to \mu^- + \Gamma} = 0.23, \quad \frac{\nu_e + N \to \nu_e + \Gamma}{\nu_e + N \to e^- + \Gamma} = 0.14$$

and

$$\frac{\bar{\nu}_\mu + N \to \bar{\nu}_\mu + \Gamma}{\bar{\nu}_\mu + N \to \mu^+ + \Gamma} = 0.46, \quad \frac{\bar{\nu}_e + N \to \bar{\nu}_e + \Gamma}{\bar{\nu}_e + N \to e^+ + \Gamma} = .028.$$

Using the modest flux estimate and rates from Table VII we find the TOTAL neutral current to charged current event ratio to be $\frac{8,400}{29,000} = 0.29$ for assumption 1 and $\frac{3,100}{29,000} = 0.11$ for assumption 2. Even including the absolute normalization problem and lepton identification errors this type of test is possible.

The misidentification errors that we have considered all appear to be small. For example to move events from the neutral current class to the charged current class one could have;

(1) Dalitz pairs with unmeasured curvature simulating ν_e charged current events.

(2) Asymmetric Dalitz pairs simulating ν_e charged current event.

This can be corrected two ways. First by making fits to the $e^{\pm}$ and correlated γ in the chamber to a π^o and second by observing anomalously large numbers of the forbidden e^+ four fermion type events. Moving events from the charged current class to the neutral class is the most probable for the muon neutrino events where the muon in the final state is not identified. In this case the EMI is very important. If one considers only those events where all final state particles pass through the EMI then the useful event rate is reduced by a factor of 2.5 but the muon identification per track is about 99%. This subset of events can be used to correct all the events. The total of the above corrections is small compared to

the magnitude of the effect.

C. FOUR FERMION INTERACTIONS ON ELECTRONS

Historically the detection of the neutrino-lepton elastic scattering has proved to be the most elusive of all the neutrino interactions. First searched for in 1935[15], it is still under active pursuit.[16]. In this experiment it appears possible to observe for the first time the diagonal four fermion interaction $\nu_e + e \rightarrow e + \nu_e$. Moreover, integrating over all the four fermion interactions, a test of the additive vs. multiplicative lepton conservation law is possible.

1. Test of the Additive vs. Multiplicative Lepton Conservation Law

The additive lepton conservation law has been sufficient to explain the lepton conservation in the observed reactions and the suppression of reactions such as $\mu \rightarrow e + \gamma$.[17] In this scheme the lepton quantum numbers are additively conserved for μ and ν_μ ($N_\mu + N_{\nu_\mu} = L_\mu$) and for e and ν_e ($N_e + N_{\nu_e} = L_e$) individually. Present experimental evidence does not rule out the possibility of an alternate conservation law - the multiplicative conservation law.[18] In the multiplicative scheme, $L_\mu + L_e$ is conserved as well as $(-1)^{L_e}$. All reactions allowed by the additive scheme are allowed by the multiplicative scheme. However, new reactions are allowed using the multiplicative scheme.

A selection between these two schemes may be possible

by measuring the e^-/μ^- ratio summed over all the four fermion reactions. The reason why this test in practice can be a precision test lies in being able to accurately determine the relative shapes of the various neutrino spectra. Table IV lists the four fermion reactions allowed by the additive conservation law and those additional reactions allowed by the multiplicative conservation law. These additional reactions are $\nu_e + e^- \rightarrow \mu^- + \nu_\mu$ and $\bar{\nu}_\mu + e^- \rightarrow \bar{\nu}_e + \mu^-$. Table V lists the cross sections for these reactions. The cross sections for reactions 1a), 2a), 3a), and 4a) were calculated using the Weinberg model with $\sin^2 \Theta_W = 0.3$ (See Fig. 1). The cross sections for reactions 2b) and 3b) were calculated assuming V-A with no Z^o contribution. The cross sections for reactions 1b) and 4b) were calculated assuming pure additive law then pure multiplicative law. Table VI gives the total event rate for the four fermion reactions in this experiment allowed under the additive and multiplicative laws using the modest flux estimates of Table VII. Summing over all the channels the e^-/μ^- ratio is sensitive to the type of conservation law being $e^-/\mu^- = 0.93$ for the additive law reactions and $e^-/\mu^- = 0.57$ for the pure multiplicative law.

Using the optimistic flux estimates the statistical errors on e^-/μ^- are such that if the additive law were true we could not rule out the pure multiplicative law. However, if the pure multiplicative law were true we would have a 2.6 standard deviation departure from the pure additive law estimate. Tests based on the absolute μ^- rate alone are possible.

For this test it is essential to identify the sign and type of lepton in the final state. The identification procedure for electrons and muons has been described in Sections II. B and II. C. The probability of muon identification for these events is extremely high (approaching 100%) because first, there is only a single track to identify and second, the final state lepton in these reactions is in the extremely forward direction; well within the acceptance of the external muon identifier.

2. Preliminary Observation of the Four Fermion Individual Channels

The theoretical literature on the four fermion interaction is indeed rich. If sufficient statistics were available in these channels tests could be made of the V and A nature of the interaction,[20] the Weinberg model,[10] the Gell-Mann approach to renormalization,[21] the two component neutrino theory,[22] the hypothesis of conservation of lepton number,[23] the Universal Fermi Model and general tests of <u>any</u> intermediate vector boson theory with and without μ-e universality.[24] However, with this experiment the number of events expected per channel is low. See Tables VI and VII. It is clear we will be able to see events even at the minimum Weinberg cross section. From Table VI we see that in total there will be about 35 four fermion interactions in this experiment assuming the additive conservation law, natural universality and $\sin^2 \Theta_W = 0.3$.

Let us now consider the background problems and what conclusions can be drawn with these statistics. In general,

the four fermion events are characterized by an energetic forward going lepton whose angle to the neutrino direction is proportional to $\sqrt{M_\ell/E_\nu}$. The main background to the four fermion interactions is from $\nu_e + n \rightarrow e^- +$ (proton with length less than 1.5mm).[25] This background has been studied in the CERN heavy liquid bubble chamber neutrino experiment[26] by the analogous pseudo-elastic reaction $\nu_\mu + n \rightarrow \mu^- +$ (invisible proton) and was found to be about 3% of the total ν_μ interactions. The cross sections for the pseudo-elastic reaction and the single pion reaction are about equal.[27] Therefore, from Table III the total number of pseudo-elastic events expected is about 10 giving a background of about 2 events. In addition by using the requirement of a fast forward going electron and the fact that the four fermion cross section is proportional to energy while the pseudo-elastic cross section is constant should make this background negligible. In summary we can do the following:

(1) We will for the first time be able to see a diagonal four fermion interaction.

(2) From the total event rate we can put preliminary bounds on the Weinberg angle i.e., observe deviations from the V-A cross sections (See Fig. 1)

(3) From the absolute rate of single μ^- events we can put bounds on the amount V-A vs. V+A.[28]

(4) If we have an optimistic event rate then the lepton recoil spectrum can be used to better test the V-A, Weinberg and other theories.[29]

III. EXPERIMENTAL ARRANGEMENT

In this experiment we intend to utilize the maximum amount of the existing neutrino beam installation. We therefore, intend to use the existing proton transport to the target, target tube, decay tube, shield, 15' bubble chamber and the EMI. Our new beam would consist of a new target train load to produce a neutral beam at zero degrees. There are special problems encountered in this beam design related to suppressing unacceptable backgrounds which are solvable but a detailed design is not yet complete. Upon approval of this proposal we will carry out a detailed study and design of the complete beam. To study the four fermion interations in greater detail a special high flux beam may have to be constructed. To make an accurate determination of the neutrino spectra and to evaluate the neutrino backgrounds, a special spectrometer will be installed at the end of the decay tube.

A. BEAM DESIGN

All existing accelerator neutrino beams are produced by focussing charged mesons toward a detector and allowing a fraction of the mesons to decay producing neutrinos.[30] Focussing the mesons toward the detector can be done over a large energy range (e.g. horn system) producing a broad band beam, over a small energy range (e.g. the narrow band system) producing a dichromatic energy beam or the focussing can be done by only the Lorentz transformation producing a bare target beam. The ν_μ and $\bar{\nu}_\mu$ fluxes dominantly come from the $\pi_{\mu 2}$ and $K_{\mu 2}$ decays while the ν_e and $\bar{\nu}_e$ fluxes

dominantly come from the K_{e3} decays. Because of the small K/π ratio, the small $K_{e3}/K_{\pi 2}$ ratio and the three body vs. two body decay kinematics, the electron-neutrino flux is suppressed relative to the muon-neutrino flux by several hundred. Therefore accurate ν_μ and ν_e comparisons are difficult. Also, if weak neutral currents exist at the ~20% level then the ν_e events will be masked by backgrounds from the ν_μ neutral current interactions.

A new type of beam is therefore proposed which produces simultaneously ν_e, $\bar{\nu}_e$, ν_μ and $\bar{\nu}_\mu$ with accurately determined relative energy spectra. Because of these properties this beam could be called the universal neutrino beam. This beam originates from the three body leptonic decay modes of the K_L^o. The relative neutrino energy spectra can be accurately determined since they depend solely on the relative branching ratios, decay energies and decay kinematics. The absolute normalization can be obtained by measuring the K_L^o energy spectrum and also by measuring the energy spectra of the decay particles ($e^\pm$, $\pi^\pm$, $\mu^\pm$) as a function of radial position at the end of the decay pipe using a special spectrometer.

This type of beam was originally proposed in 1969 and more fully developed at the 1972 ECFA Study and at the 1973 FERMILAB Aspen Summer Study. The summer study beam represents the present state of the evolution of this beam. We will not present a beam layout different from the summer study beam because to do so requires information which is not

yet available These items will be gone into in detail below.

Schematically the universal beam is shown on Fig. 2. The standard proton transport is used to direct and focus the proton beam onto the neutrino target. The solid angle acceptance of the beam is defined by collimators C1 and C2. Following the target is a magnetic field region which sweeps the charged particles produced at the target and the remaining proton beam into a dump, the face of collimator C1. Short lived neutral particles in the beam, e.g. K_S^o and Λ^o, have mean decay lengths of about 13m and 17m respectively at 250 GeV/c momentum. The decay of these particles produce $\pi^{\pm}$ which then decay giving a ν_μ contamination to the universal beam. The second sweeping region is therefore necessary to reduce this contamination by deflecting the charged secondaries onto the face of collimator C2. The decay tunnel, muon shield and detector area are essentially the same as in the conventional neutrino beam. Collimators C1 and C2 could possibly be the aperatures of the two magnetic field regions.

A detailed beam design study will answer the following questions:

(1) What should be the solid angle acceptance of the beam? Until the K_L^o spectrum at FERMILAB is measured it is impossible to know how hard one must work for a bigger acceptance to enhance the flux. The K_L^o spectrum should be measured within the next

few months by Experiment 87 for 300 GeV interacting protons in the energy range 20 GeV < $E_{K_L^o}$ < 200 GeV.[31] An absolute normalization of 10% may be possible. Once this spectrum is known a realistic beam design can be initiated.

(2) How should the proton beam be dumped to minimize the contamination to the universal beam? The proton beam should be dumped cleanly to minimize scattering down the beam line which can result in charged meson producing a ν_μ contamination. Also the proton beam must be dumped at a large angle to the neutrino beam line to minimize the neutrino contamination resulting from meson decays in the first few interaction lengths of the dump. Possibly a reentrant dump in C1 where the protons are at a large angle to the neutrino beam line will be acceptable.

(3) Should the charged secondaries be deflected onto the side walls of magnet M1 or should they be absorbed by collimator C1 or several collimators distributed within M1? To minimize the neutrino contamination from the decay of charged mesons produced at the target it is necessary to deflect the mesons out of the neutral beam in as short a distance as possible (to minimze their decay probability) and to absorb them cleanly. This requires high magnetic fields in M1 and a detailed study of the scattering from the collimator lips.

(4) How should the charged decay products of the K_s^o and Λ^o be removed from the beam so that the neutrino contamination from these sources are minimized? This depends on the strength and aperature of M2 and whether C2 is a single collimator, multiple collimators in M2 or just the aperature of M2.

(5) How can the thin vacuum window of the decay tunnel be eliminated as well as any other mass between the target and the neutron dump? Because of the high flux of high energy neutrons produce in this beam, any mass in the beam acts as a secondary target. The backgrounds from these sources are substantial unless special precautions are taken. For example the target tube may have to be operated in vacuum[38] in order to eliminate the vacuum window between it and the decay tunnel. For our running conditions, the vacuum window (1/8" Al.) gives a neutrino contamination comparable to an unfocussed beam operating at 10^{11} ppp.

(6) How can the neutron dump be designed to minimize the neutrino contamination? As in item 5, neutrons interacting in the dump produce mesons which can decay before being absorbed producing a contamination to the universal beam. To minimize this effect a tungsten dump may be adequate. If not, a series of converter and sweeping fields may be necessary.

B. ABSOLUTE NORMALIZATION SPECTROMETER

Even though the ν_μ and ν_e spectra from K_L^o decay are very similar, they are not identical. In fact the ν_e yield at high energies is significantly higher than the ν_μ yield, and since the cross section is proportional to E_ν, there are many more ν_e events than ν_μ events at high energies. See Fig.VII. If one includes the yield of neutrinos from Λ^o decay, which gives very high energy ν_e fluxes, the problem is even worse. It is very important, then, to measure the spectra of secondaries from the target. We intend to do this by measuring the electron, muon and pion spectra in the decay pipe. This can be done, since the number of charged particles in the decay pipe is the same order as the number of neutrinos, about 10^8 to 10^9 per square meter. In addition, the number of muons, pions, and electrons are similar, so that the rejection in the detectors does not have to be so good. That is, we can allow some of the pions to look like electrons or muons, without much error in the measurement.

There are many possible ways to make this measurement, and details have not been worked out. The simplest would be to put a very small spectrometer at the end of the decay region, and detect charged particles in a very small solid angle, using detectors that distinquish between electrons, pions, and muons. A spectrometer is used to bend the particles out of the decay pipe to decrease the background from neutrons and γ-rays. The spectrometer should be small enough so that the rate is not too high, and so that it

can be moved about the decay region to sample the radial distribution.

The ν_μ flux due to pion decay can be measured by turning off some of the sweeping magnets, giving pions a longer effective decay path, and then extrapolating to the normal configuration. The contribution due to Λ^o decay can also be measured in this way, since most of the Λ^o will decay in the sweeping region, but only a small percentage of the $K_L{}^o$ decay there. The measured spectra would be used as input to a Monte-Carlo to reconstruct the neutrino spectra.

This sampling of the beam will have to be done using slow spill, but this spill usually exists in the neutrino lab at low intensity, even if only fast spill is used for data taking. Hence, the spectrum could be measured simultaneously when we are running. We expect that the zero degree yield of $K_L{}^o$ and Λ^o will be measured soon. Since we can use this information to make accurate calculations of the <u>differences</u> in the ν_μ and ν_e yields, a crude measurement of the e, μ, and π fluxes in the decay pipe will give us good measurements of the absolute fluxes, and excellent measurements of the differences in the ν_e and ν_μ spectra.

C. DETECTOR

The detector used in this experiment is the 15-foot bubble chamber filled with neon followed by the external muon identifier (EMI). To maximize the total event rate and to provide the maximum detection efficiency for electrons and hadrons a pure neon filling was selected. For an average interaction, i.e. with its vertex at the center of the chamber the potential length to the chamber wall is 1.9 m. This represents about 2.5 collision lengths and about 7 radiation lengths. Using the total track length method[32] to determine the electron energy should give an energy resolution of about ±30%. The electron identification from radiation loss in the chamber should be unique.

An individual hadron will have about 10% probability of leaving the detector without interacting. It is therefore essential in the high multiplicity deep inelastic events to use the EMI to help identify the muon. This is particularily true in our case since with a mixed beam of ν_μ and $\bar{\nu}_\mu$ even the sign of the muon is not known a priori. Also if only one charged track leaves the chamber without interacting it cannot be assumed to be a muon since the neutral current event will have no charged lepton in the final state.

The useful fiducial volume of the bubble chamber in this experiment is about 20 m^3 which represents a target mass of about 24 tons. This mass of target compares favorably with most conceivable counter experiments. It should be noted that if the EMI is not used for muon identification it will be necessary to

reduce the fiducial volume in order to increase the potential length available for muon identification. Reducing the fiducial volume is obviously undesirable because it reduces the useful event rate.

The bubble chamber is also ideal for our research because in addition to the large mass, the magnetic field allows the essential separation of e^+, e^-, μ^+ and μ^-. The good visual resolution at the event vertex is likewise essential for the four fermion interaction studies since it allows a distinction to be made between $\nu_e + e \rightarrow \nu_e + e$ and the "quiet events" such as $\nu_e + n \rightarrow p + e^-$ where the proton energy is low. Vertex resolution in conjunction with a high magnetic field allows identification of π^o which could simulate directly produced electrons. It appears in general that for the four fermion studies, the neon filled 15-foot chamber is greatly superior to conceivable counter experiments.

There is one possible feature of the neon-filled bubble chamber that, to our knowledge, has not been explored. If the chamber is filled with pure neon, it can be used as a scintillation calorimeter. This procedure would require significant development work, but pure neon, if the chamber can use it, is a very good scintillator with a light output that is a significant fraction of NaI(Tl).[33] The light collection could be done from the extra camera ports and would be assisted by the Scotchlite in the chamber. The phototubes would have to be on long light pipes to remove them far enough so that they could be shielded from the magnetic field. There is sufficient time before the flashtubes are fired to close a shutter or otherwise protect the tube.

A technique of this sort could be used to significantly decrease the number of pictures that have to be scanned, and the biases are easily measured by recording the pulse heights but not using the tubes in the trigger.

IV. EVENT RATE DETERMINATION

A. FLUX CALCULATION

Since the K_L^o flux has not yet been measured at energies above the CERN and BNL energies we felt it was necessary to use several different reasonable particle production models to estimate the flux of $K_L^o \rightarrow \pi \ell \nu_\ell$. All calculations assume that the decay, shield and detector parameters are as built: A 400 m long decay path, a 1000 m shield and the 15-foot bubble chamber. The fluxes are all given for a proton energy of 500 GeV in units of ν/GeV-m^2 - 10^{13} interacting protons for a flux averaged over the detector area of 5.7 m^2.

The most recent flux estimates of Baltay and Roe presented at the FERMILAB Workshop on Second Generation Neutrino Experiments, May 18, 1974, are based on Monte-Carlo calculations using two different particle production models fit to high energy data. No additional details were given. These fluxes are presented in Fig. 3 labeled 1 and 3 for ν_e and ν_μ spectrum respectively. It is assumed in all of these calculations that the ν_e and $\bar{\nu}_e$ spectra are identical and the ν_μ and $\bar{\nu}_\mu$ spectra are identical.

Monte Carlo calculations were performed at FERMILAB using the Trilling production model[34] and $K_L^o/\pi^+ = 0.15$. We felt this model was reasonable since in the forward direction, useful for the neutral beam, the flux agrees with the Hagedorn-Ranft model.[35] The $K/\pi = 0.15$ also roughly agrees with the Hagedorn-Ranft predictions. The fluxes based on these calculations are labeled 2 and 5 for ν_e and ν_μ respectively. A third estimate

using the intuitive scaling of Kalbfleish[36] was also made. This estimate is based on taking the ν_μ spectrum from K^+ and scaling by 1) the ratio of mean decay energies of $K^+_{\ell 2}$ and $K^o_{\ell 3}$, 2) the differences in branching ratios for $K^+_{\mu\nu}$ and $K^o_{\pi\mu\nu}$, 3) the difference in mean decay lengths between the K^+ and $K_L{}^o$ and 4) possible differences in production yields of K^+ and $K_L{}^o$. Assuming no differences in production yields and using the Hagedorn-Ranft K^+ yields the flux labeled 4 was estimated.

Looking at the spectra of Fig. 3 one first concludes that they agree within a factor of 10. However, this is based on the K^+ and $K_L{}^o$ spectra being the same. Also recent measurements at FERMILAB at 300 GeV indicate that the Hagedorn-Ranft K^+ yields could be high by a factor of 3. The situation could be somewhat worse than Fig. 3 indicates. To be safe we consider respectively the ν_e ($\bar{\nu}_e$) and ν_μ ($\bar{\nu}_\mu$) fluxes from curves 1 and 3 to be optimistic estimates, the fluxes from curves 2 and 5 to be modest estimates, and the flux from 4 to be a pessimistic estimate.

B. CROSS SECTIONS AND EVENT RATES

In determining the total cross sections for ν and $\bar{\nu}$ on nuclei the recent CERN electron-neutrino data[3] has been used, i.e.

$$\sigma_{\nu_e} = (0.93 \pm 0.17) \times 10^{-38}\ E_{\nu_e}\ \text{cm}^2/\text{nucleon}$$

$$\sigma_{\bar{\nu}_e} = (0.37 \pm 0.09) \times 10^{-38}\ E_{\bar{\nu}_e}\ \text{cm}^2/\text{nucleon}$$

in good agreement with σ_{ν_μ} and $\sigma_{\bar{\nu}_\mu}$. Therefore using the CERN muon-neutrino cross sections we use,

$$\left.\begin{array}{l}\sigma_{\nu_\mu} = \sigma_{\nu_e} \\ \\ 3\sigma_{\bar{\nu}_\mu} = 3\sigma_{\bar{\nu}_e}\end{array}\right\} = 0.8 \times 10^{-38}\ E_\nu\ \mathrm{cm}^2/\mathrm{nucleon}.$$

Since the theoretical four fermion cross sections are strongly model dependent we illustrate the range of event rates expected by first assuming the conventional V-A theory, then assuming the cross section is the minimum allowed by the Weinberg model. These cross sections are illustrated in Fig. 1.

The event rates are calculated assuming the flux and cross section estimates above for a 500,000 picture exposure of the neon filled 15-foot bubble chamber. A proton intensity of 2.5 x 10^{13} per pulse at 500 GeV interacting in the target has been assumed. A fiducial volume of 20 m^3, radius of 1.35 m, gives a total target of 1.4 x 10^{31} nucleons and a 7.2 x 10^{30} electrons. The total event rates for this experiment under the above assumptions are given on Table VII. We do not explicitly give the event rates available if the accelerator operates at 1000 GeV but for a linearly rising cross section the importance of a higher energy beam is clear. Enhancements in event rates of a factor of 3 or 4 per interacting proton can be expected if the accelerator operated at 1000 GeV.

V. CONCLUSION

This experiment is unique in being able to:

(1) Test for universality violations of 10% or better in the charged current interactions,

(2) Make a good test of universality in the neutral current interactions,

(3) Test whether the lepton conservation law is additive or multiplicative,

(4) Detect four fermion interactions with the best conceivable signal-to-background ratio.

The key to this experiment is a new type of neutrino beam which to the best of our knowledge was first described[5,6] by one of the participants of this proposal. This new beam produces the four types of neutrinos with approximately equal fluxes but with relative energy spectra which can be precisely determined.

To accomplish the above physics goals we propose an exposure of the neon-filled 15-foot bubble chamber followed by the EMI to the new neutrino beam. We request 30,000 total neutrino interaction in the $20m^3$ (24 ton) fiducial volume of the bubble chamber which could result from 500,000 pictures using 2.5×10^{13} interacting protons per pusle at 500 GeV on the target of the new beam. The beam design is not complete; however, if approved we will undertake the detailed design of the requested beam.

Regarding the collaboration of this experiment we wish to point out:

(1) The collaboration is organized under the present USA-USSR Protocol Annex II. No new annex is necessary.

(2) This collaboration will have the experience of working together since 1972 and through two neutrino experiments with the 15-foot bubble chamber.

(3) Our approved experiments of neutrinos in hydrogen and antineutinos in hydrogen-neon will allow us to make comparisons with these data in as systematic a manner as possible.

(4) This collaboration has sufficient strength to adequately and promptly carry out the beam design, spectrometer design and analysis of the experiment.

REFERENCES

[1]F. Reines et. al., Phys. Rev. 117, 159 (1960).

[2]NALREP, January, 1974 pg. 18-20

[3]R. R. Wilson, announcement at the 1974 FERMI Annual Users Meeting.

[4]Letter of intent to study ν_e and ν_μ interactions in the neon filled 15-foot bubble chamber submitted Nov. 9, 1973.

[5]F. A. Nezrick, Seminar on Possible Neutrino Beams for FERMILAB Summer Study, June 1969.

[6]F. A. Nezrick, Neutrino Beam Study Report to TACOS, Dec. 30, 1969.

[7]R. Turley et. al., CERN/ECFA/72/4 Vol. 1 pg. 167-169 (1972).

[8]C. Baltay and B. Roe, 1973 FERMILAB Summer Study Report, Vol. 1 pg. 233 (1973).

[9]M. L. Stevenson et. al., FERMILAB Proposal No. 155.

[10]S. Weinberg, Phys. Rev. Letters 19, 1264 (1967).
A. Salam and J. C. Ward, Phys. Letters 13, 169 (1964).

[11]T. J. Braunstein et. al., Phys. Rev. D 6, 106 (1972).

[12]J. Campbell, Phys. Rev. Letters 30, 335 (1973).

[13]H. Georgi and A. Pais, Rockefeller Report Number C00-2232B-44.

[14]F. J. Hasert et. al. To be published in Nuc. Phys. B.
F. J. Hasert et. al. TC-L/Int 74-1 7.1.74.

[15]M. E. Nahmias. Proc. Comb. Phil. Soc. 31, 99 (1935).

[16]F. Reines, International Neutrino Conference, Downington, Pa. April 26-28, 1974.

[17]T. D. Lee and C. S. Wu, Ann. Rev. of Nucl. Science 15, 381, 1966 and 16, 471, 1967. C. H. Llewellyn-Smith, Physics Reports 3C, No. 5 (1972).

[18] For experimental consequences see for example G. R. Kalbfleisch, Nucl. Phys. B25, 197, 1971.

[20] E. C. Sudarshan and R. E. Marshak, Phys. Rev. 109, 1860 (1958). R. P. Feynman and M. Gell-Mann Phys. Rev., 109, 193 (1958).

[21] M. Gell-Mann et al., Phys. Rev. 179, 1518 (1969).

[22] H. Weyl, Z. Phys. 56, 330 (1929). T. D. Lee and C. N. Yang, Phys. Rev. 105, 1671 (1957) and many others.

[23] W. Pauli, Nuovo Cimento 6, 204 (1957).

[24] L.M. Sehgal, Phys. Letters, 48B, 60 (1974).

[25] F. A. Nezrick, 1969 FERMILAB Summer Study Vol. 1, 113 (1969).

[26] See for example, D. H. Perkins, "Neutrino Interactions," in Proceedings of the XVI International Conference on High Energy Physics, Chicago-Batavia September 1972.

[27] See Reference 26.

[28] C. Jarlskog, "Tests of the V-A Theory in Neutrino-Lepton Interactions," to be published.

[29] See for example S. L. Adler, NAL-Conf-74/39-THY.

[30] Y. Kang and F. A. Nezrick 1969 FERMILAB Summer Study Vol. 1, 217 (1969).

[31] W. Lee et al., FERMILAB Proposal No. 87.

[32] R. Arnold et. al., NPA/Int. 68-9.

[33] "Theory and Practice of Scintillation Counting," J. B. Birks, Pergamon Press (1967), p. 609 ff.

[34] G. Trilling, LRL UCID-16000, Vol. 1, XIII-1, 1965.

[35] F. A. Nezrick, 1969 FERMILAB Summer Study Vol. 1, 403 (1969).

[36] G. R. Kalbfleisch, 1969 FERMILAB Summer Study Vol. 1, 343 (1969).

[37] H. Deden et. al., Phys. Letters (1974).

[38] The provision to provide a vacuum in the target region already existed at FERMILAB but has not been implemented.

[39] J. D. Bjorken and C. H. Llewellyn Smith, Phys. Rev. D 7, 887 (1973).

TABLE I

Energy Dependence of Total Event Rate

for ν_e, $\bar{\nu}_e$, ν_μ, $\bar{\nu}_\mu$ on Neon

Neutrino Energy GeV	Reaction			
	1	2	3	4
0 - 25	490	160	875	290
25 - 50	3300	1100	2450	820
50 - 75	3300	1100	2000	670
75 - 100	2800	900	1100	370
100 - 125	1900	635	500	170
125 - 150	1200	400	225	75
150 - 175	650	220	90	30
175 - 300	750	250	5	2

TABLE II

AMOUNT OF UNIVERSALITY VIOLATION DETECTABLE IN THIS EXPERIMENT FROM REACTIONS 1, 2, 3 and 4 AS A FUNCTION OF ENERGY. BASED ON STATISTICS ONLY

Neutrino Energy (GeV)	U(E)	$\bar{U}$(E)
0 - 25	13%	10%
25 - 50	3	5
50 - 75	3	5
75 - 100	4	6
100 - 125	5	9
125 - 150	7	13
150 - 175	11	-

TABLE III

Energy Distribution of Single Pion Events

for ν_μ and ν_e and Value of U'(E)

Neutrino Energy (GeV)	Event Rate		Amount of Universality Violation Detectable
	Reaction 5	Reaction 6	
0 - 25	20	11	14%
25 - 50	23	31	27%
50 - 75	11	18	23%
75 - 100	4.3	11	45%
100 - 125	1.6	6	-
125 - 150	0.58	3	-
150 - 175	0.20	1.5	-
175 - 300	0.005	0.8	-

TABLE IV

Four Fermion Reactions Allowed by

Lepton Conservation Laws

Allowed by Additive Law	Allowed in Addition by Multiplicative Law
1. a) $\nu_e + e^- \rightarrow e^- + \nu_e$	b) $\nu_e + e^- \rightarrow \mu^- + \nu_\mu$
2. a) $\bar{\nu}_e + e^- \rightarrow \bar{\nu}_e + e^-$	(NONE)
b) $\bar{\nu}_e + e^- \rightarrow \bar{\nu}_\mu + \mu^-$	
3. a) $\nu_\mu + e^- \rightarrow \nu_\mu + e^-$	(NONE)
b) $\nu_\mu + e^- \rightarrow \nu_e + \mu^-$	
4. a) $\bar{\nu}_\mu + e^- \rightarrow \bar{\nu}_\mu + e^-$	b) $\bar{\nu}_\mu + e^- \rightarrow \bar{\nu}_e + \mu^-$

TABLE V

The Cross Sections for the Reactions of Table IV

Reaction	Cross Section (cm^2/electron)	
	Pure Additive	Pure Multiplicative
1. a) $\nu_e + e^- \rightarrow e^- + \nu_e$	$1.12 \times 10^{-41} E_\nu$	$1.12 \times 10^{-41} E_\nu$
b) $\nu_e + e^- \rightarrow \mu^- + \nu_\mu$	--	$1.12 \times 10^{-41} E_\nu$
2. a) $\bar{\nu}_e + e^- \rightarrow \bar{\nu}_e + e^-$	$0.54 \times 10^{-41} E_\nu$	$0.54 \times 10^{-41} E_\nu$
b) $\bar{\nu}_e + e^- \rightarrow \bar{\nu}_\mu + \mu^-$	$0.54 \times 10^{-41} E_\nu$	$0.54 \times 10^{-41} E_\nu$
3. a) $\nu_\mu + e^- \rightarrow \nu_\mu + e^-$	$0.12 \times 10^{-41} E_\nu$	$0.12 \times 10^{-41} E_\nu$
b) $\nu_\mu + e^- \rightarrow \nu_e + \mu^-$	$1.62 \times 10^{-41} E_\nu$	$1.62 \times 10^{-41} E_\nu$
4. a) $\bar{\nu}_\mu + e^- \rightarrow \bar{\nu}_\mu + e^-$	$0.2 \times 10^{-41} E_\nu$	$0.2 \times 10^{-41} E_\nu$
$\bar{\nu}_\mu + e^- \rightarrow \bar{\nu}_e + \mu^-$	--	$0.2 \times 10^{-41} E_\nu$

TABLE VI

Four Fermion Rates in This Experiment

Reaction	100% Additive Law		100% Multiplicative Law	
	e^-	μ^-	e^-	μ^-
1. a) $\nu_e + e^- \rightarrow e^- + \nu_e$	9.5		9.5	
b) $\nu_e + e^- \rightarrow \mu^- + \nu_\mu$				9.5
2. a) $\bar{\nu}_e + e^- \rightarrow \bar{\nu}_e + e^-$	4.5		4.5	
b) $\bar{\nu}_e + e^- \rightarrow \bar{\nu}_\mu + \mu^-$		4.5		4.5
3. a) $\nu_\mu + e^- \rightarrow \nu_\mu + e^-$	1.0		1.0	
b) $\nu_\mu + e^- \rightarrow \nu_e + \mu^-$		13.5		13.5
4. a) $\bar{\nu}_\mu + e^- \rightarrow \bar{\nu}_\mu + e^-$	1.7			
b) $\bar{\nu}_\mu + e^- \rightarrow \bar{\nu}_e + \mu^-$			1.7	1.7
	16.7	18.0	16.7	29.2
$\frac{e^-}{\mu^-}$ (Using the modest flux estimates) =	0.93 ± 0.31		0.57 ± 0.17	
$\frac{e^-}{\mu^-}$ (Using the optimistic flux estimates) =	0.93 ± .26		0.57 ± 0.14	

TABLE VII

Event Rate

Reaction	Pessimistic Flux Estimate (Curve 4)*	Modest Flux Estimate (Curves 2 and 5)*	Optimistic Flux Estimate (Curves 1 and 3)*	
1. $\nu_e + N \rightarrow e^- + \Gamma$	4,500	14,500	20,000	
2. $\bar{\nu}_e + N \rightarrow e^+ + \Gamma$	1,500	4,500	6,500	
3. $\nu_\mu + N \rightarrow \mu^- + \Gamma$	2,800	7,200	12,500	
4. $\bar{\nu}_\mu + N \rightarrow \mu^+ + \Gamma$	1,000	2,500	4,000	
5. $\nu_e + e \rightarrow e + \nu_e$	4.5	13.5	20	Assuming V-A
6. $\bar{\nu}_e + e \rightarrow e + \bar{\nu}_e$	1.5	4.5	6.5	
7. $\nu_\mu + e \rightarrow \nu_e + \mu$	4.5	13.5	20	
8. $\nu_e + e \rightarrow e + \nu_e$	1.1	3.4	5	Using minimum Weinberg value
9. $\bar{\nu}_e + e \rightarrow e + \bar{\nu}_e$	0.3	1.0	1.5	
10. $\nu_\mu + e \rightarrow e + \nu_\mu$	0.2	0.6	0.8	
11. $\bar{\nu}_\mu + e \rightarrow e + \bar{\nu}_\mu$	0.2	0.6	0.8	

*Curve numbers refer to Figure 3.

Assuming: Conventional Beam Layout, K_L^o Source Only

$20 m^3$ neon
2.5×10^{13} int. protons/pulse
500,000 pulses

NEUTRINO ELECTRON SCATTERING CROSS-SECTIONS IN WEINBERG AND V-A MODEL

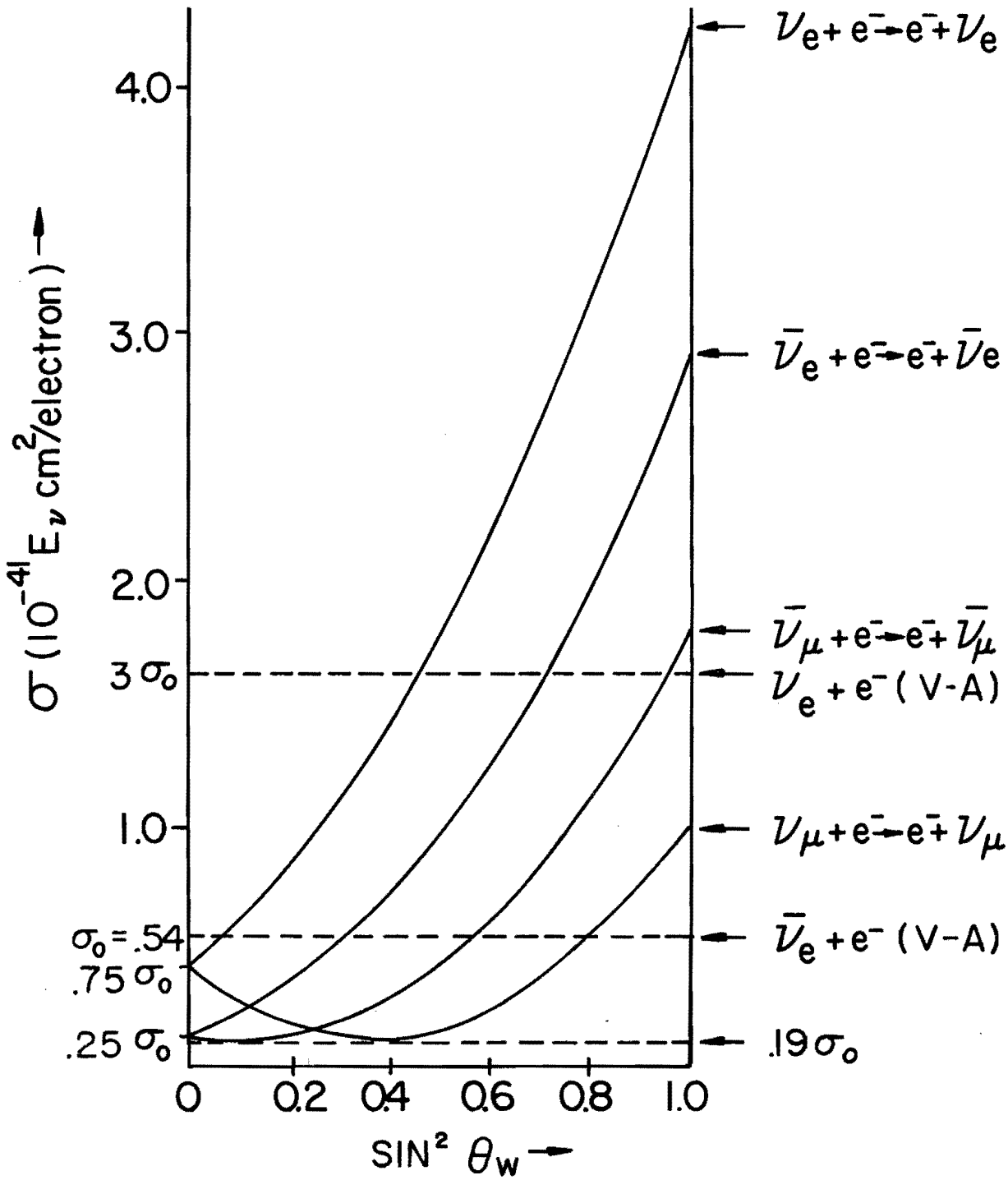
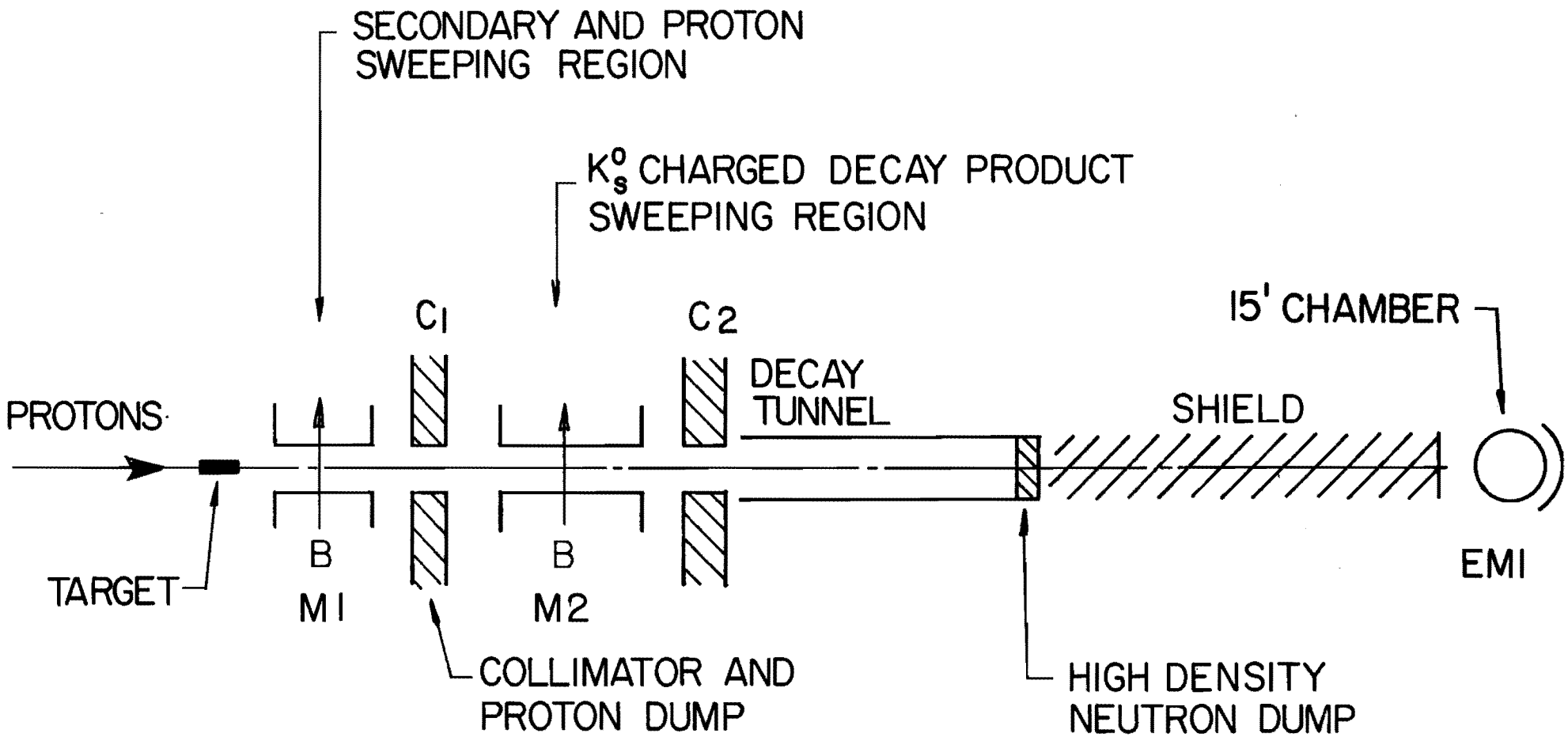


FIGURE 1



SCHEMATIC LAYOUT OF THE UNIVERSAL $\nu_e, \bar{\nu}_e, \nu_\mu, \bar{\nu}_\mu$ BEAM

FIGURE 2

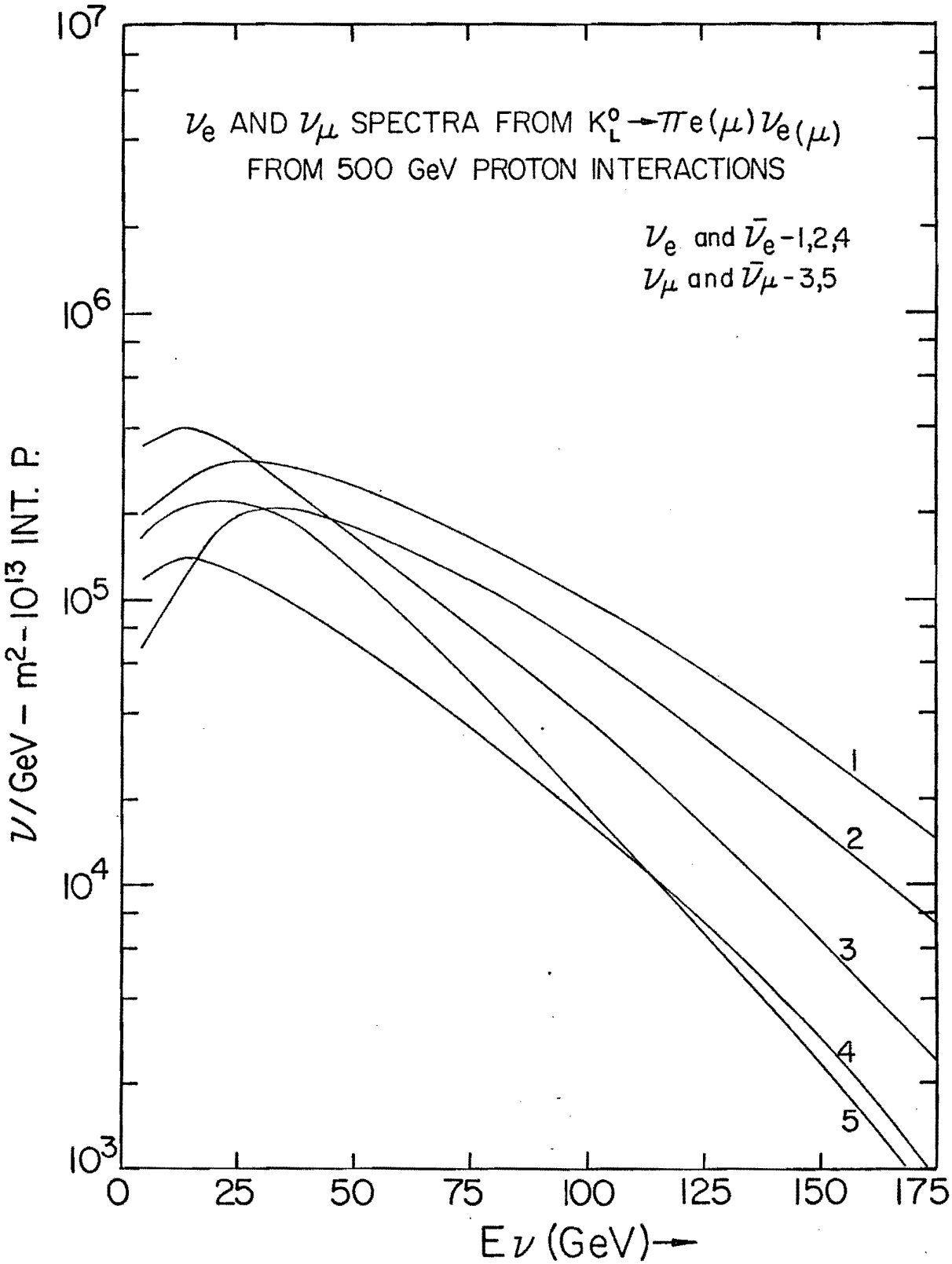

ν_e AND ν_μ SPECTRA FROM $K_L^0 \rightarrow \pi e(\mu) \nu_{e(\mu)}$
FROM 500 GeV PROTON INTERACTIONS
ν_e and $\bar{\nu}_e$ - 1,2,4
ν_μ and $\bar{\nu}_\mu$ - 3,5
ν/GeV - m^2 - 10^{13} INT. P.
10^7
10^6
10^5
10^4
10^3
0
25
50
75
100
125
150
175
$E\nu$ (GeV)
1
2
3
4
5

FIGURE 3