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Neutrino Physics in a Tagged-Neutrino Beam*

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Neutrino Physics in a Tagged-Neutrino Beam

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Abstract

A new high-energy neutrino program is described. The experiment would tag and reconstruct semileptonic decays in an intense K_L beam. The species and energy of outgoing neutrinos would be identified event-by-event and the neutrino interactions recorded in a massive iron detector. Such a system could search new regions in $(\Delta m^2, sin^2 2\theta)$ space for neutrino oscillations with small mixing angles and measure ν_μ and ν_e cross-sections to ≈ 1%. The system could determine $\sin^2 \theta_W$ in deep-inelastic scattering off quarks to ±.002–.004, a significant improvement over existing measurements.

A. Introduction

Neutrino physics at high-energy has exclusively used charged beams to produce ν_μ from π and K decay. A vast amount of important and useful physics has resulted: measurements of structure functions, ν_μ cross-sections, determinations of $\sin^2 \theta_W$, and searches for neutrino oscillations have all been performed in the standard beams. However, the use of charged beams has disadvantages: the flux is difficult to measure and the beam content is difficult to model.

We propose [1] a new facility which produces ν from the semileptonic decays of the K_L, $K_L \to \pi\mu\nu_\mu$ and $K_L \to \pi e \nu_e$. This method will be free of the flux and beam content errors and will permit far more precise measurements of cross-sections and more sensitive searches for neutrino oscillations. Furthermore, it will provide the first copious, well-understood

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[†] Operated by Universities Research Association Inc. under contract with the United States Department of Energy.

source of high energy ν_e, providing precise checks of universality. Finally, we have begun to investigate the possibility of a 1–2% determination of $\sin^2\theta_W$, a factor of 4–5 better than previous deep-inelastic scattering experiments.

B. Oscillation Phenomenology

We quote the standard form for the probability of neutrino oscillations. In a two-component system one finds, for a neutrino of energy E_ν (GeV) traveling a distance L (km):

$$P(\nu_1 \rightarrow \nu_2) = sin^2 2\theta_{12} \;\; sin^2 1.27 \Delta m_{12}^2 \frac{L}{E_\nu}$$

where $\Delta m_{12}^2 = {m_1}^2 - {m_2}^2$ and m_1 and m_2 are the masses (eV/c^2) of the eigenstates ν_1 and ν_2. There are then two requirements for mixing:

1. the mixing angle must be non-zero;
2. at least one neutrino species must be massive.[1]

The present best limits from many sources are compiled [3] in Fig. 1.

C. Method and Advantages of Neutrino Tagging

We begin with a beam of K_L and the semileptonic decay modes $K_L \rightarrow \pi e \nu_e$ and $K_L \rightarrow \pi \mu \nu_\mu$. The apparatus first detects and analyzes the K_L decay with a tagging spectrometer, measuring the momenta and charges of the pion and lepton in order to reconstruct the K_L. We have then determined for each event the species and charge of the associated neutrino: ν_e, $\bar{\nu}_e$, ν_μ, or $\bar{\nu}_\mu$. A downstream neutrino detector detects and analyzes any neutrino interactions, searching for outgoing muons and separating ν_e interactions from ν_μ charged-current events. There is no flux uncertainty: once we predict that the neutrino passes through the neutrino detector, the cross-section is just the fraction of neutrinos which interact. Finally, for oscillation searches, we have a clean signal: a ν_e at birth followed by a ν_μ interaction in the neutrino detector. The arrangement is depicted in Fig. 2.

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[1] There are some models which allow mixing even if all neutrino masses are zero.[2]

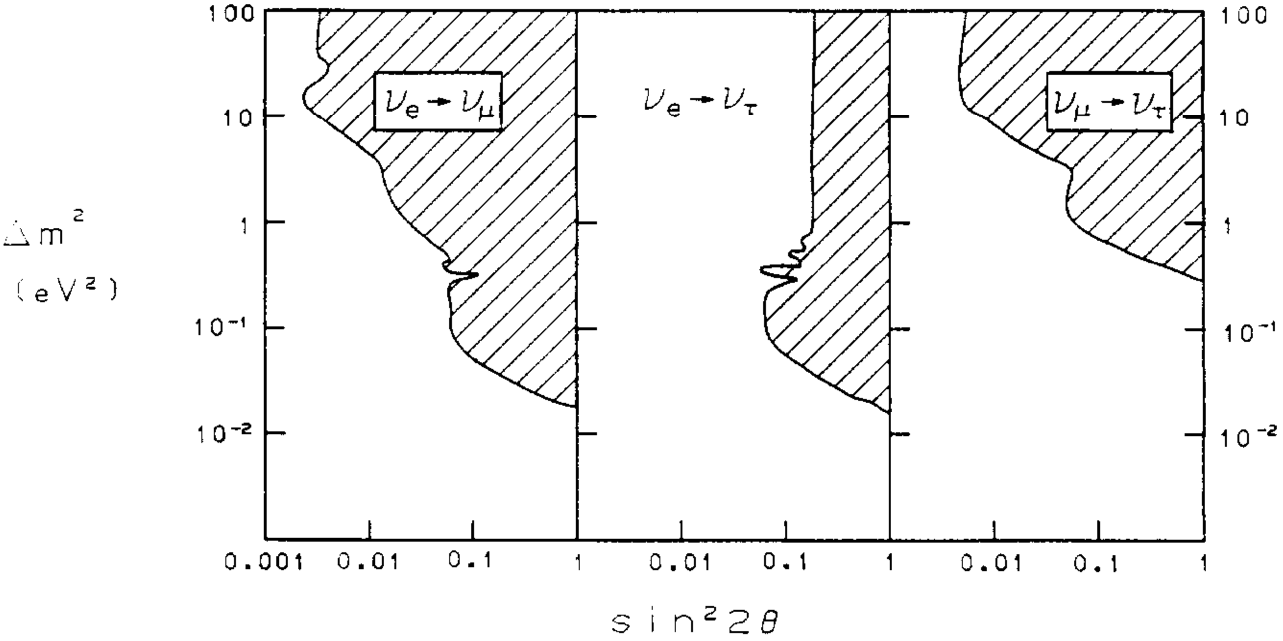

Figure 1: Existing Limits in the oscillation channels $\nu_\mu \rightarrow \nu_e$, $\nu_e \rightarrow \nu_\tau$, and $\nu_\mu \rightarrow \nu_\tau$.

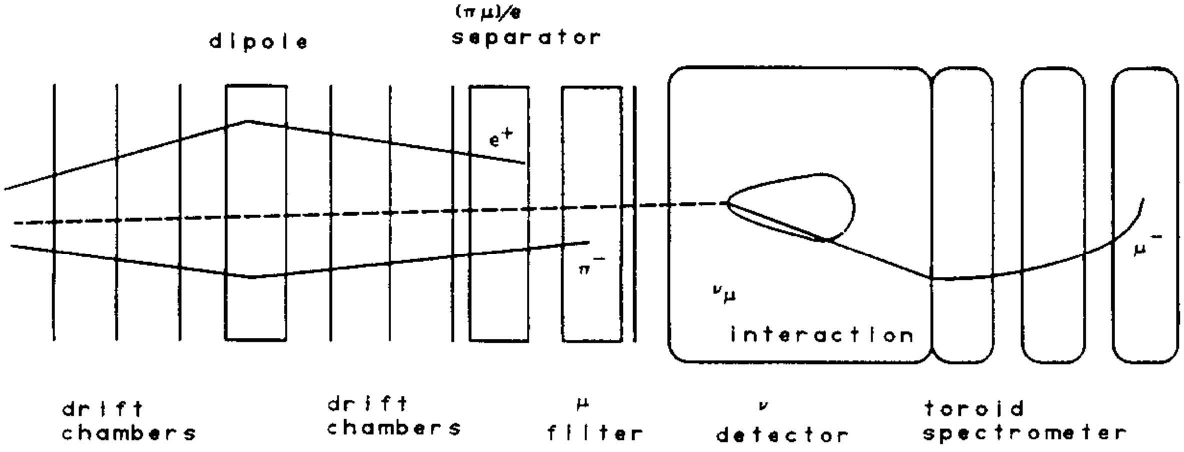

Figure 2: A schematic of a neutrino tagger. The beam direction is from the left; a $Ke3$ decay is pictured in the tagger, with the π and e identified and momentum analyzed. The neutrino detector downstream detected a ν_μ interaction, signaling an oscillation $\nu_e \rightarrow \nu_\mu$.

Let us concentrate on the advantages of the tagging scheme for oscillation searches. The K_L beam makes approximately equal numbers of ν_e and ν_μ (39% ν_e, 27% ν_μ). The large ν_e flux makes it possible to search for $\nu_e \rightarrow \nu_\mu$. Why is this an advantage? In previous searches using charged beams, we have been forced to look for $\nu_\mu \rightarrow \nu_e$. This is a difficult channel to detect: we are searching for a charged-current ν_e interaction, which has backgrounds from π^o production in the hadronic shower ($\pi^o \rightarrow 2\gamma,\ \gamma \rightarrow e^+e^-$) where resultant electrons may fake a signal. The detection and tracking of an electron is complicated and is easier in a low-density detector, limiting the rate. In addition, a search in any oscillation channel requires a precise simulation of the beam content. Since the standard charged beams are 99% ν_μ and only 1% ν_e, we require an accurate and detailed modeling of the small contamination of ν_e in the beam. These limitations have prevented oscillation searches from probing below $P(\nu_\mu \rightarrow \nu_e) \approx 0.5\%$.

The tagged line has neither limitation: the beam content is measured for each event and the signal is the presence of a high-energy muon, which has smaller backgrounds than those for electrons and is far easier to detect.

What are the backgrounds in the tagging scheme? The first set of backgrounds arise from muon-production in the shower, and has two sources. The first is "opposite-sign" dimuon production: an s or d quark is excited into charm, which then decays semileptonically into a μ. The cross-section for opposite-sign production is about 1% of the total charged-current cross-section at our energies. Fortunately, this background is eliminated by "charge-matching": the muon from charm decay will have the same charge as the electron in the tagger. This configuration does *not* signal an oscillation, as we can see by working out one case. Suppose an e^+ is tagged: then the outgoing neutrino at the K_L vertex is a ν_e. If the neutrino oscillates into a ν_μ, and the ν_μ interacts, the outgoing muon will be negative. The muon from charm decay will be a μ^+ and so the event is rejected.

The second μ-production background is called "same-sign" production and arises from π and K decay in the hadronic shower. This background has been extensively studied [4] in FNAL E-744/E-770. We use the name "same-sign" because it is the background for same-sign dimuon production in neutrino interactions. Using the E-744/E-770 results as a model, we predict 0.3 events in our final sample of 16K events (after all cuts).

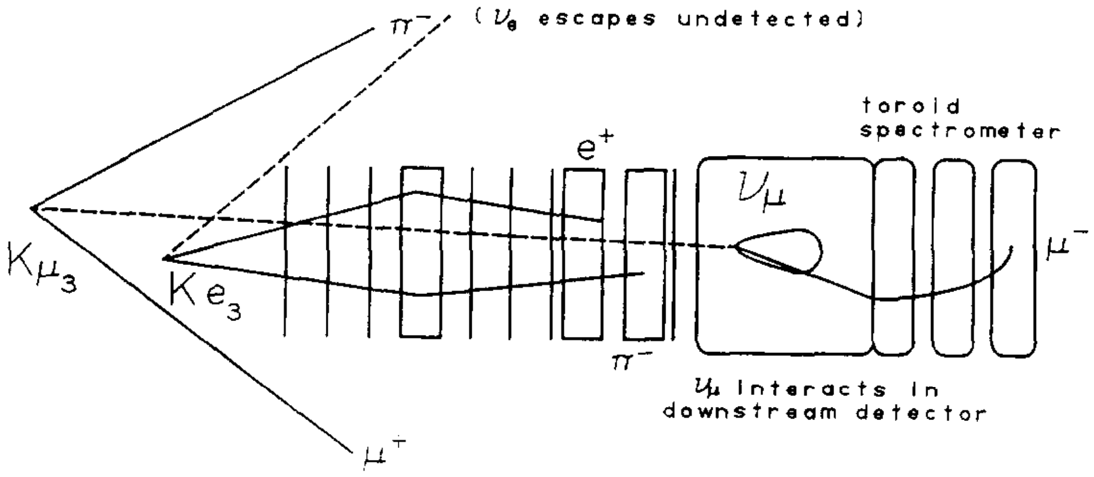

Figure 3: A schematic of a mistag. A $Ke3$ and a $K\mu3$ decay occur simultaneously. The ν_μ from the $K\mu3$ interacts, but the ν_e escapes or does not interact in the neutrino detector. With the (πe) pair tagged as shown, the combination appears to be an oscillation.

The second set of backgrounds arises from "mistags." Let us suppose that a Ke_3 and a $K\mu_3$ decay occur simultaneously, as shown in Fig. 3. Then the tagger sees the (πe) pair but the ν_μ interacts. The combination, $(\pi e)_{tagger}$ and ν_μ appears to be an oscillation. We reject this background by reconstructing the K_L from the tagger and predicting the energy, impact point, and species of the neutrino. The predicted impact point is then compared to the vertex measured by the neutrino detector. We do not compare the predicted and measured energies since there is too much energy carried off in "missing neutrinos" from the hadronic shower. The analysis then exclusively uses the prediction of the impact point in the neutrino detector; we cut at 10 cm and lose 1/3 of the data. After all cuts, we expect 0.3 events of background in a final sample of 16K tagged ν_e.

Finally, there is a small background from mistags from ν_μ produced in the primary production target. We have used data [5] from the FNAL beam-dump experiment E-613 to estimate ≤ 0.1 events from this source.

D. Physics Goals of the Tagged Line

The first phase of the experiment would concentrate on oscillations and cross-sections. Ultimately the experiment would attempt a 1% determination of $\sin^2\theta_W$, in deep-inelastic scattering. Such an experiment would require a completely new neutrino detector, optimized for that experiment. This paper uses the current CCFR detector as a "first-phase" model to study the oscillation searches and cross-section measurements that could be performed. The last Section explores the method and requirements of the $\sin^2\theta_W$ determination. We require 2.3 x 10^{18} protons on target, delivered in slow spill at 5 x 10^{12} *ppp* for 2 fixed-target runs (46 weeks). Table 1 shows what we will get: 51K charged-current events where the species of the neutrino is known and its energy well-determined. This will be the world's first sample of high-energy ν_e.

species	*number of events*		
	charged current	neutral current	Σ
ν_μ	14.5K	5K	20K
$\bar{\nu}_\mu$	6.5K	2.3K	9.3K
ν_e	20K	7K	27K
$\bar{\nu}_e$	10K	3.3K	13.3K

Table 1. Statistical Sample for Various Neutrino Interactions.

Table 2 summarizes the cross-section measurements. We see the ν_μ and $\bar{\nu}_\mu$ cross-section measurements will be improved by a factor of 3–5 over the systematics-limited measurements of the past. There are no accurate determinations of ν_e cross-sections at high-energy; hence this experiment would be the first to provide precise (1%) tests of ν_e/ν_μ universality at high-energy.

species	*proposed error*	*old error*
ν_μ	1–2 %	3–5 %
$\bar{\nu}_\mu$	1–2 %	3–5 %
ν_e	1–2 %	$\approx$ 10%
$\bar{\nu}_e$	1–2 %	$\approx$ 10%

Table 2. Expected Error in Cross-Section Measurements.

Fig. 4 shows the limits the experiment could obtain in oscillation searches. The simulations indicate that the experiment could explore new regions of mixing angle. We see in the $\nu_e \to \nu_\mu$ plot that the tagging experiment probes a factor of ten lower in mixing angle. If we were to observe a signal, we could also check particle/antiparticle rates, opening the possibility of CP-nonconservation studies in the neutrino sector.

The oscillation channel $\nu_e \rightarrow \nu_\tau$ has a poor limit in $\sin^2 2\theta_{e\tau}$, only 0.12 for large Δm^2. Here, we would use the reaction $\nu_\tau N \rightarrow \tau X$, $\tau \rightarrow \mu\nu_\mu\nu_\tau$ and observe the μ in the neutrino detector. The branching fraction $\tau \rightarrow \mu\nu_\mu\nu_\tau$ is only 17%, decreasing the statistical power relative to a $\nu_e \rightarrow \nu_\mu$ search (so the 16K $\nu_e \rightarrow \nu_\mu$ search has the statistical power of 2700 events for the $\nu_e \rightarrow \nu_\mu$ search). We have no way of distinguishing muons from ν_μ charged-current events from muons from τ decay. However, the region to which we are sensitive has already been excluded in $\nu_\mu \rightarrow \nu_e$ searches, so we would know the oscillation would be $\nu_e \rightarrow \nu_\tau$ and not $\nu_e \rightarrow \nu_\mu$. We see in the Figure approximately a factor of 70 improvement over previous limits in $\sin^2 2\theta_{e\tau}$ from $\sin^2 2\theta_{e\tau} < 0.1$ to $\sin^2 2\theta_{e\tau} < 0.0016$ (90% CL). A search at small mixing angle and large Δm^2 is certainly of great interest. Furthermore, astrophysical arguments constrain $m_{\nu_\tau} \leq 65$ eV/c^2; this mass range makes ν_τ a popular dark-matter candidate. Our search would be sensitive down to $m_\nu \geq 10\text{eV/c}^2$ for $\theta_{e\tau} \geq 0.017$, certainly an important region to cover.

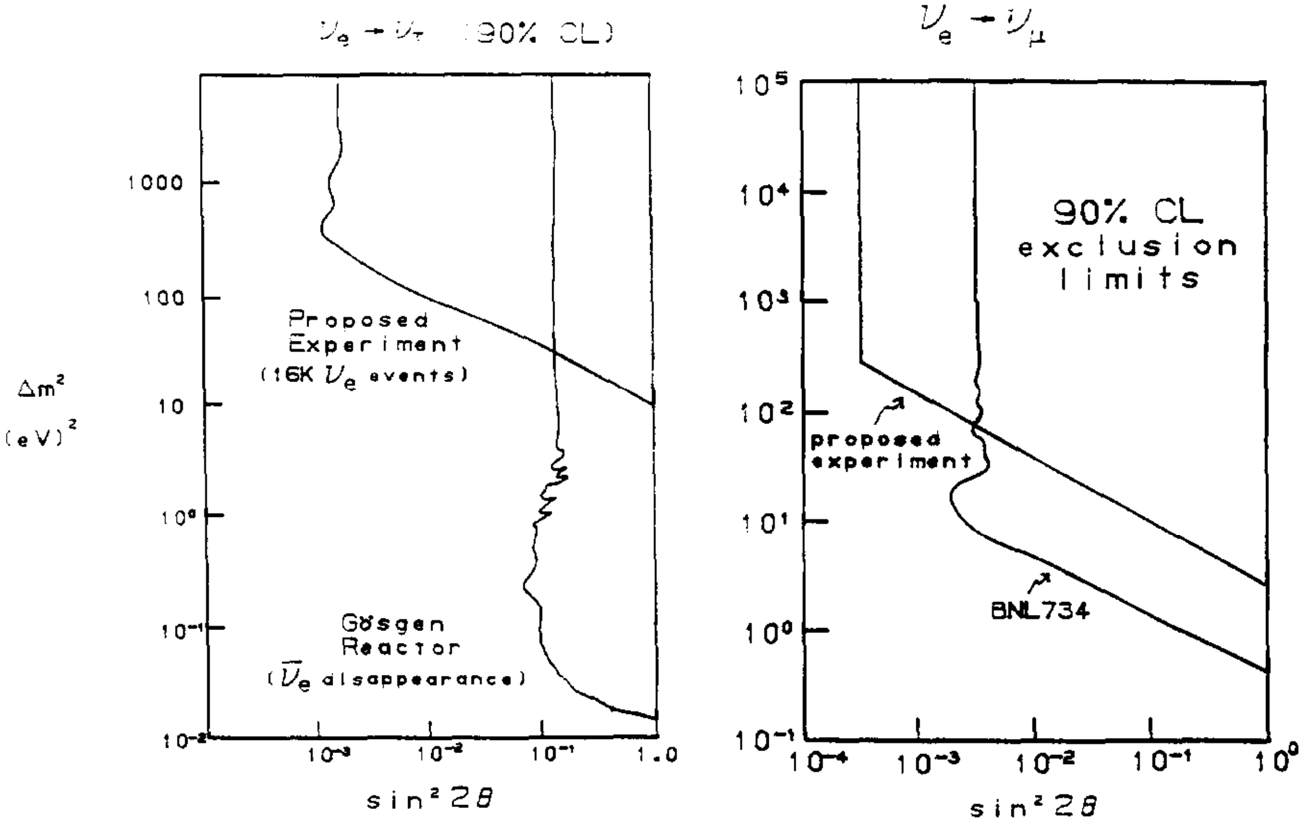

Figure 4. Oscillation limits achievable in the proposed experiment. The $\nu_e \rightarrow \nu_\mu$ limits are compared to BNL-734 and the $\nu_e \rightarrow \nu_\tau$ result is compared to the Gösgen result also shown in Figure 1.

E. Cross-Section Studies

There are no significant backgrounds in the cross-section determinations.[2] For each K_L tag, we predict whether the neutrino passes through the detector or not: for events with such a neutrino, the cross-section is just the ratio of those with an interaction to those without. The systematic error arises from the quality of the prediction and from the knowledge of the acceptance of the neutrino detector. If we make fiducial cuts within the detector, both errors decrease: the neutrino acceptance improves and small errors in the prediction do not move the neutrino in or out of the detector. The acceptance in the CCFR detector with "tight" fiducial cuts is 90% or more; from comparisons of data to Monte Carlo, we certainly know the acceptance to 5% of itself, leading to a 0.5% error. We are therefore confident that the prediction will have errors of 1% or less. The statistical errors for the charged-current and neutral-current channels vary; the statistical errors were given in Table 2.

We can also accurately study the energy dependence of the cross-section. The systematic errors are smaller because the tagged line has no errors from flux monitoring devices which must be calibrated and operated at different energies and we have an energy determination from the tagger which may be used instead of the value measured in the neutrino detector. Fig. 5 shows the determination of the ν_μ slope in this experiment plotted along with existing results; the slope is determined to approximately 1%. The ν_e total cross-section will be determined to similar accuracy; we do not separate charged-current from neutral-current ν_e events and hence only the total cross-section is measured. The CHARM collaboration [6] has measured $\sigma(\nu_e)/\sigma(\nu_\mu) = 1.20 \pm 0.11$ for charged-current events. A 1% measurement would reduce the errors by an order-of-magnitude and provide a precise test of universality.

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[2] The only background is a small contamination of ν_μ charged-current events in the ν_μ neutral-current sample; we estimate later a systematic error of 0.5% in the ratio.

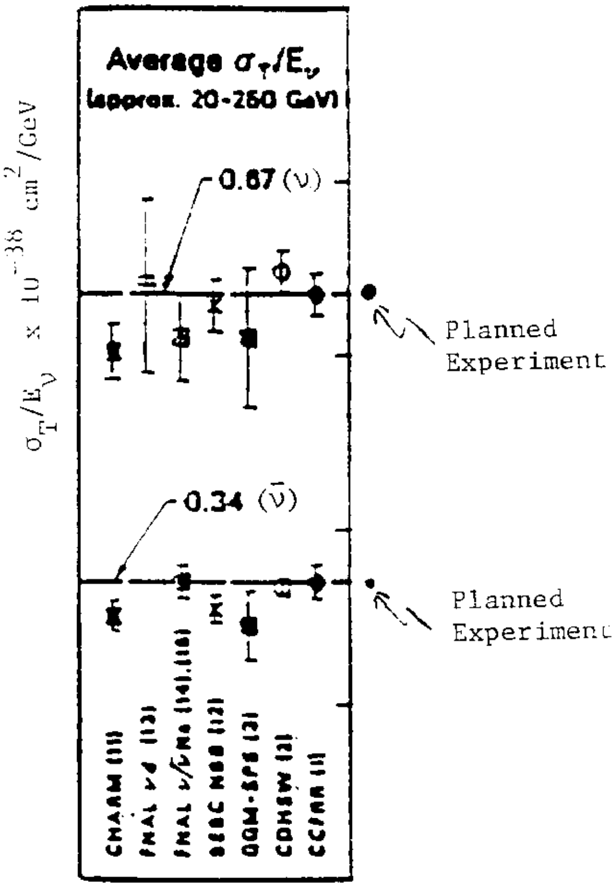

Figure 5. A comparison of the slope $\alpha = \sigma_\nu/E_\nu$ for the planned experiment to previous world data. The top plot is for neutrinos and the bottom is for antineutrinos from a total sample of 20K charged-current interactions. The dots outside the graph (from the Particle Data Book) represent the planned experiment; the size of the dots are the statistical errors, arbitrarily doubled to reflect the potential systematic errors.

F. Tagger Design

We need to reconstruct the momentum vectors of the pion and lepton and to identify the lepton. Hence we need tracking, magnetic analysis, and particle identification. We choose drift chambers and a dipole magnet for the tracking. For particle identification a TRD followed by a muon filter should be adequate (we will explore the rates, space charge, etc. in a later Section). The transverse size is large: 2.5 m by 2.5 m. The tagger itself is 15 m long, including a 3 m long muon filter. We explore the design of the tagger more fully in the following Section.

G. Neutral Beam and Rates

The neutral beam consists of K_L, n, Λ^o, K_S, and γ. We will sweep away the decay products of the Λ^o and K_S. A lead plug will convert the γ and the resultant e^+e^- pairs can be swept away. These are standard techniques used in K_L experiments (FNAL E-226, E-533, E-617, E-731). We are left with K_L and n. The targeting angle is a compromise: at larger targeting angles, the n/K_L ratio drops and so the number of hadronic interactions in the tagger drops. At small targeting angle, the number of decaying K_L increases but so does the number of interactions. We desire to keep space charge and total collected charge to manageable levels. We choose a targeting angle in θ_y from -2 to 2 mr and from 2 mr to 6 mr in θ_x and use a Be moderator to "fine-tune" the n/K_L ratio. The calculations use the Malensek parameterization of Atherton data [7] and have been checked by Fermilab E-731. [8] The agreement in shape is excellent and the normalization is good to 20%. We find a $< E_\nu >$ of 75 GeV for interacting ν.

The experiment uses a 200 m evacuated decay volume. We find that within our targeting there are 12.5 neutrons and 12.5 K_L per 20 nsec (1 RF bucket) and that 1.5 K_L decay every 20 nsec. The rates are then dominated by $\approx$ 75 MHz of K_L decay. We survive in this environment by making the beam large and finely segmenting the detector. The beam is 80 cm by 80 cm at the entrance to the tagger and we use 4 mm separation between sense wires. This leads to 375 KHz/wire in the hottest wires in the system. The number of interactions in the spectrometer were calculated assuming 1% λ_I for the detector (excluding the TRD) which then leads to 1 interaction every 4–5 buckets. The central wires see 500 KHz from all sources, with a space charge of 4 x 10^3 (minimum-ionizing particles)/mm^2/sec, and are 10% dead. The collected charge on the hottest wire over the course of the experiment, at a gain of 10^5, will be 10^{16} e/cm. These rates are high but manageable [9]; as we discuss later, we do not trigger on the tagger and so our problem is greatly simplified.

A TRD is chosen to separate $(\pi\mu)$ from $e^\pm$, since for good $e^\pm$ efficiency (90%) we can obtain 10^{-3} rejection of π and μ. The number of interaction lengths is small, about 2%, and so there will be one interaction every other bucket. We may use the information from the spectrometer to associate tracks with TRD hits offline, lessening the problems from the high interaction rate. The design of the TRD is just beginning, and much work remains.

The muon filter will be a Fe dump followed by scintillator. From CCFR data [10]we know that after 3 m of Fe a scintillator sees $\geq$(1 x minimum ionizing energy deposit) for about 1% of interacting hadrons. Most of these arise from soft hadronic punchthrough, which we could lessen by placing concrete or another low-Z material before the scintillator. At a rate of 10^{-2}, we expect 1 punchthrough every 160 nsec. However, the presence of a punchthrough does not produce background for the oscillation search! Since we are studying $\nu_e \rightarrow \nu_\mu$, a muon in the tagger *vetoes* an oscillation signal. The loss of data from punchthrough is small, and the background arises only if (1) the μ is misidentified in the TRD *and* (2) the μ misses the scintillators after the filter. The first factor is about 10^{-3} and the second factor has been measured in E-731 [11] for a similar dump to be 3 x 10^{-3}. Hence the background is ≤ 0.01 events.

A beam dump, consisting of toroids and Fe, follows the tagger. We have used HALO to simulate the number of muons from $K\mu3$ decay and from hadronic punchthrough passing though the beam dump for a given dump configuration. For 10 ft of toroidally magnetized steel (at 17 kG), followed by 20 m of Fe, we estimate a rate of 50 KHz entering the neutrino detector. This only presents a problem for muons passing through a typical ADC gate of 250 nsec. Muons which pass through the 2 μsec TDC gate used in the CCFR chambers do not provide a source of background: they must be in-time with the tagger and the neutrino interaction and must appear to come from the neutrino vertex. Muons are timed to within 10 nsec in the CCFR detector and after we demand the muon be in time with the neutrino interaction and pass through the neutrino detector, we expect zero background from this source. Muons which pass through within the ADC gate may require vetoing the event; we expect 625 out of the 51K charged-current events in the experiment, a negligible loss of data.

The experiment would trigger on hadronic energy deposit in the neutrino detector; the rate is dominated by cosmic-ray events. From E-744 data with a 20 GeV cut we expect a trigger rate of only 1-2 Hz. Hence the tagger can remain passive; whenever there is a trigger, the spectrometer would write out the times of all hits. The time for the neutrino to travel to the neutrino detector, to then form a trigger, and to send the trigger back, will be of order 1 μsec. At a maximum rate of 500 KHz only half the wires will have a hit and so we expect around 10K hits to be read out from the spectrometer system.

H. Determination of $\sin^2\theta_W$ in the Tagged Line

The Weinberg angle is a fundamental parameter of the standard model; R. Brock's and W. Marciano's contributions to this Conference made plain the great importance of measuring $\sin^2\theta_W$ in deep-inelastic νN scattering. The tagged line could ultimately perform a 1-2% measurement: $\sin^2\theta_W = 0.234 \pm 0.002$–$0.004$. This Section will describe the technique and what would be required.

Previous determinations of $\sin^2\theta_W$ in deep-inelastic scattering (DIS) have used dichromatic beams and the ratio

$$R_\nu = \frac{\sigma_\nu^{nc}}{\sigma_\nu^{cc}} = \rho^2(\frac{1}{2} + \sin^2\theta_W + \frac{5}{9}\sin^4\theta_W(1+r))$$

where

$$r = \frac{\sigma_{\bar\nu}^{cc}}{\sigma_\nu^{cc}}$$

This method has significant systematic errors, both experimental and theoretical, which we outline below.

The experimental errors arise from two sources. First, the determination of r requires accurate flux monitoring to determine the relative $\bar\nu/\nu$ flux, leading to an error of 0.5% or more. A second, more signficant error, arises from confusion between neutral- and charged-current events. If a μ from a charged-current interaction ranges out from dE/dx loss or leaves the detector before the end of the shower, the event will be misclassified as a neutral-current and affect the ratio R_ν accordingly. The typical size of the charged-current subtraction is 20% of the neutral-current events (for CDHS or CCFR). The errors from this large subtraction have been attacked by a variety of techniques [12] and can be held to (0.5–1.0)%.

The errors from the theory are equally large. The dominant error comes from the excitation of charm (a smaller error arises from the contribution of the strange sea to μ-production). The "slow-rescaling" hypothesis uses a parameter m_c as a phenomenological parameter in the replacement $x \to x + m_c^2/Q^2$. The errors in m_c are large and the total theoretical error is ≈ 0.007. [3]

Both these errors, charged-current to neutral-current confusion and m_c threshold effects, are lessened with higher energy. However, in a "best-conceivable" dichromatic run at the Tevatron with current detectors the error would be >3%.[4] We can greatly reduce these errors in the tagged line by using the Paschos-Wolfenstein relation:

$$R^- = \frac{\sigma_\nu^{nc} - \sigma_{\bar\nu}^{nc}}{\sigma_\nu^{cc} - \sigma_{\bar\nu}^{cc}}$$

Here we pay a price in the statistical error, since we are taking a ratio of differences; in R_ν we simply formed a ratio. However, there are significant advantages in the systematic errors. When the differences $\sigma_\nu - \sigma_{\bar\nu}$ are formed, the errors from the strange sea vanish and the error from the excitation of charm is reduced by a factor of four.[5] There are no errors from $\bar\nu/\nu$ flux and hence the only large systematic error is the charged-current to neutral-current crosstalk, which we have argued can be held to 0.5%.

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[3] Again, in either the CDHS or CCFR experiment with their typical Q^2.

[4] Scaling the E-649 proposal for FMMF to the fiducial mass of the CCFR detector.

[5] A more precise statement is that the errors in the R_ν test at $E_\nu = 200$ GeV are the same as the errors in the R^- test at 40 GeV. [13]

Hence the main error is statistical. We would need six to eight the fiducial mass of the CCFR detector to obtain a total error of 0.002–0.003 in $\sin^2\theta_W$. Such a detector, although massive (3000 tons) would not require as fine-grained instrumentation as the CCFR detector. That detector required muon momentum analysis for structure functions. The analysis of $\sin^2\theta_W$ uses only the *length* of the event as measured by scintillation counters in order to avoid errors from knowledge of the tracking efficiency.[6] As an example, we could then build a massive detector with frequent scintillation counter sampling (every 10 cm Fe) and infrequent tracking (Iarocci tubes every 30 cm Fe). A toroid system would follow, permitting measurements of cross-sections and oscillations as described in earlier Sections. It would also provide a wide variety of systematic checks between the tagging system and the neutrino detector. The price of such a detector (steel, scintillation, Iarocci tubes with a 6 ft radius) would be $4M. However, we believe that the CDHS detector is a better "model" than the CCFR apparatus, since we need muon momentum analysis for both the oscillation and cross-section measurements. With a toroid at the end of the target, as in CCFR, the acceptance for muons is only good near one end; with a magnetized target, we could increase the oscillation and cross-section statistics proportionately to the increase in mass. This would decrease the limits in the oscillation channels and increase the statistics of the cross-section measurements to where backgrounds and systematics would dominate, not statistics. We would open a factor of approximately 300 in the $\nu_e \rightarrow \nu_\tau$ channel and possibly be able to improve the limits on $\nu_\mu \rightarrow \nu_\tau$ by a factor of two.

Finally, there is a significant chance the Fermilab Fixed-Target program will be upgraded to an energy of 1.5 TeV from the current 900 GeV. [14] Such an improvement would only help the experiment. At our fixed targeting angle, the statistical power would increase by a factor of two; the neutrino energy would only increase by 10%. Hence we could make tighter cuts on neutrino energy, tagger/neutrino detector comparisons, etc. which would lower systematic errors. The tagger would suffer somewhat from the higher particle flux but a factor of two should be manageable. The oscillation searches will have higher background from "mistags" but again, with the larger event sample the cuts may be made more restrictive.

I. Conclusions

At a tagged-neutrino facility, we would have a precise measurement of $\sin^2\theta_W$ in DIS to contrast with the values which are being measured in $\nu_\mu e$ scattering at CHARM II and have been proposed by LCD. [15,16] As has been noted before, the value of $\sin^2\theta_W$ measured in DIS seems slightly higher than that measured in $\nu_\mu e$ scattering. [17] A precise, systematics-free measurement with errors $\leq \pm 0.004$ would be invaluable in understanding whether a discrepancy exists. The experiment would significantly improve cross-section measurements. It would probe new regions of neutrino oscillations critical for understanding the dark-matter problem. Finally, we will determine a fundamental parameter of the standard model to a new level of precision.

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[6] The length of the hadronic shower is typically 80 cm in Fe and defines a length for the event through the scintillation counters. Muons which exit the shower also deposit energy in the counters and make the event appear "longer."

References

[1] For details and a fuller explanation of many of the arguments in this paper, see R.H. Bernstein *et al.*, "A Proposal for a Neutrino Oscillation Experiment in a Tagged-Neutrino Line", Fermilab P-788.

[2] P. Langacker, this Conference.

[3] We have used data reviewed in W.Y. Lee, Neutrino '86 (proceedings), World Scientific Publishing Co., 1986, p. 157. The Figure is adapted from F. Vannucci, BNL Neutrino Workshop (Proceedings), BNL52079 UC-34-D.

[4] B.A. Schumm *et al.*, Phys. Rev. Lett. 60, 1618 (1988).

[5] M.E. Duffy *et al.*, Phys. Rev. D38, 2032 (1988).

[6] J.V. Allaby *et al.*, Phys. Lett. B179, 301 (1986).

[7] A. Malensek, FN-341.

[8] M. Woods & G. Bock, private communication.

[9] Proceedings on Radiation Damage Workshop, LBL-21170, UC34D, January 16-17, 1986.

[10] F.S. Merritt *et al.*, NIM A24, 27, (1986).

[11] G. Gollin, private communication.

[12] The CCFR and CDHS collaborations have applied different techniques: for CCFR, see P.G. Reutens *et al.*, Physics Letters 152B, 404 (1985) and for CDHS, H. Abramowicz *et al.*, Phys. Rev. Lett. 57, 298 (1986).

[13] R. Brock, private communication.

[14] F. Borcherding, this Conference.

[15] A. Capone, this Conference.

[16] D.H. White, this Conference.

[17] W. Marciano, this Conference. Also see U. Amaldi *et al.*, Phys. Rev. D36, 1385 (1987).