PROPOSAL TO STUDY NEUTRAL CURRENT NEUTRINO AND ANTI-NEUTRINO
INTERACTIONS IN THE 15-FOOT BUBBLE CHAMBER
USING THE EXTERNAL MUON IDENTIFIER AND A DICHROMATIC BEAM

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SUMMARY

We propose to use dichromatic neutrino (antineutrino) beams to study neutral currents (NC), possible breakdown in scaling of charged currents (CC), evidence for lepton pairs and their suggestion of charm-particle production, and other phenomena that require "one-constraint" analysis. Backgrounds and systematic errors will be smaller for these events and we hope to use them to reexamine the "zero-constraint" analysis of the broad band beam events that we will have analyzed in earlier experiments, thereby, reducing the systematic errors of those previous analyses. Ne-H₂ mixtures (e.g. 1/3 ρ Ne to 2/3 ρ Ne) in the 15-foot bubble chamber are necessary in order to determine the hadronic final state four-momentum. An exposure of 200,000 (200,000)neutrino (antineutrino) pictures using a monohorn of the type that accepts 100 ± 5 GeV mesons between 2 and 8 milliradians, produced by 300 GeV protons (10¹³ per pulse) produces the following number of events:

<table>
<thead>
<tr>
<th>Eᵥ (GeV)</th>
<th>ν</th>
<th>(v)</th>
<th>Type Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>35</td>
<td>3900</td>
<td>(1500)</td>
<td>CC</td>
</tr>
<tr>
<td>35</td>
<td>860</td>
<td>(640)</td>
<td>NC</td>
</tr>
<tr>
<td>95</td>
<td>280</td>
<td>(40)</td>
<td>CC</td>
</tr>
<tr>
<td>95</td>
<td>60</td>
<td>(20)</td>
<td>NC</td>
</tr>
<tr>
<td>Total</td>
<td>5100</td>
<td>(.200)</td>
<td>CC and NC</td>
</tr>
</tbody>
</table>

Here we have recognized the possible need to run the antineutrinos at a higher density, ρ ~ 2/3 ρ Ne, because of event rate and other reasons. The use of other types of dichromatic beams is also considered.
INTRODUCTION

Many of the new and puzzling phenomena in neutrino physics, such as neutral currents (NC), possible existence of low mass neutral intermediate vector bosons (NIB), breakdown in scaling of charged currents (CC), evidence for lepton pairs and the suggestion of "charm-particle production" can best be studied with the 15-foot bubble chamber filled with a mixture of Ne-$\text{H}_2$ coupled with the External Muon Identifier (EMI).

By exposing this hybrid chamber to dichromatic neutrino and antineutrino beams one adds to the uniqueness of the apparatus and produces a natural follow-up to the wide-band beam experiments. In these latter experiments many of the phenomena depend heavily on "zero-constraint" analysis. A monoenergetic meson beam adds the additional constraint of "dichromaticity". It also confines the statistics into two energy channels while reducing the backgrounds and flux uncertainties that are likely to be the limiting systematic errors of the wide-band analyses. Proposal \(^{9B}\) described a modification of the Nezrick monohorn and gave the expected rates in hydrogen.

By using medium (heavy) mixtures of the Ne-$\text{H}_2$ one has a "target" mass of $\approx 5$ tons (10 tons) and with 200,000 neutrino (200,000 antineutrino) pictures one would obtain the following number of events.

<table>
<thead>
<tr>
<th>$&lt;E_{\nu(\bar{\nu})}&gt;$</th>
<th>CC</th>
<th>NC</th>
</tr>
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<tbody>
<tr>
<td>35 GeV $\nu_\pi$</td>
<td>3900 (1500)</td>
<td>860 (640)</td>
</tr>
<tr>
<td>92 GeV $\nu_K$</td>
<td>280 (40)</td>
<td>60 (20)</td>
</tr>
</tbody>
</table>

The total number of events here, 5100 (2200), is approximately the same as our original request of 5000 (5000). Our first priority is the neutrino exposure.
Physics Justification

A. Neutral Currents.

1. x and y distributions. The existence of neutral currents in $\Delta S = 0$ semi-leptonic interactions is now well established. Several experiments have measured the ratio of neutral current to charged-current events in high energy neutrino and antineutrino interactions with good agreement.\(^{(1)}\) The next step is to measure the distributions of the kinematic variables in neutral current events. In this experiment we propose to measure the distributions of $x = Q^2/(2M)\nu$ and $y = (E - E_\mu)/E_\nu$ in neutral current events. With these distributions we can test various theories and look for anomalies.

The Weinberg-Salam gauge-symmetry model is one that we can test. It contains a single free parameter, $Q_w^2$.\(^{(2)}\) If this parameter is specified and the parton distributions are known, the model predicts the $y$ distributions in neutrino and antineutrino interactions with hadrons.\(^{(3)}\) Figure 1 shows these $y$ distributions with the simplifying assumption that the hadron contains only valence quarks and that $\sin^2 Q_w = .39$. The value for $\sin^2 Q_w$ is chosen to fit the observed neutral to charged current ratios. Measurement of the $y$ distributions in neutral current events provides a significant test of this model. More generally these $y$ distributions provide a significant test of any model. We have merely used the Weinberg-Salam model as an example. It need hardly be mentioned that it is important to have good efficiency for the full range of $x$ and $y$.

2. Search for Scale Breakdown

a) The possible existence of a low mass neutral intermediate boson (NIB) will produce a distortion of the $x,y$ distribution by the propagator (called the distortion factor), $(1 + \frac{Q^2}{M^2})^{-2}$, which reduces the number of events above $Q^2 > M^2$. Here, $s$ is the square of the center of mass
energy and $M_0$ is the mass of the (NIB). Fig. 2a displays the distortion factor for $M_0 = 10$ GeV for the dichromatic neutrinos ($E_\nu = 35$ GeV, 95 GeV) from a pion and kaon beam of 100 GeV/c.

This factor causes the total cross section to saturate in a fashion that depends on the $x$ dependence of the structure function $W_Z$.

Fig. 2b shows how it would happen for two simple examples of $W_2^2(1-x)$ (solid lines) and $(1-x)^3$ (dashed lines) for $M_0 = 5$ GeV. Also shown is the $1-x$ case for $M_0 = 10$ GeV.

b. The production of new massive hadrons in (NC), although not expected in the charm quark scheme, will cause a different form of scale breakdown. Here, one expects an increase of NC events at high $y$ and low to medium values of $x$. The kinematics is summarized for 50 GeV neutrinos in an old figure from our NAL proposal-9 (June 1970) and is reproduced here as Fig. 3, and shows that hadrons as massive as 8 GeV can be produced. These events would be analogous to those in (CC) that may be producing departure from scaling as reported by Benvenuti et al\(^{(4)}\). The measurement of their mass would have to come from their non-leptonic decay modes because in the semi-leptonic ones there would be two neutrinos in the final state.

3. Reduction of Background Events.

The most difficult problem of (NC) physics is the irreducible background produced by the neutral hadrons from neutrino interactions in the surrounding material that produce stars in the bubble chamber. This background is substantially reduced by cleaning out the unwanted neutrinos from the beam. Here, our clearer understanding of the systematic errors of dichromatic events may allow us to reanalyze the broadband (NC) events and reduce the systematic errors of the earlier analysis that will have greater statistical accuracy.
B. Charged Currents.

1. \( x \) and \( y \) Distributions.

The hadronic structure as a function of \( x \) and \( y \) can be investigated as well with dichromatic beams as with broad-band ones. Figure 4 illustrates for the simple structure function \( W(x, 1-x) \) how 1000 events would distribute themselves. Figure 5 shows some typical hadronic configurations as a function of \( x \) and \( y \).

2. Total cross section measurements are more reliable with dichromatic beams because the meson fluxes can be measured and the neutrino-fluxes calculated from them.

3. Exclusive Channels.

a. Events in which particles such as \( \gamma, \pi^0, K_{L}^0, \Lambda, \Sigma^0, \) and \( \eta \) can be analyzed as 1-C events in the dichromatic beam.

b. Assurance that there are no missing neutrals in 4-C event candidates will give greater opportunity for particle identification using the technique described by Lynch(5). With this method it has been possible to make unique mass assignments of certain "3-C" broad band events.

4. Dilepton Events presumably arise from (CC) production of hadrons that decay leptonically. Although a neutrino is in the final state one can do "1-C" analysis on the decaying hadronic state, thereby sharpening the mass resolution. This in turn helps pull the signal out of the background for these presumably narrow resonances. Figures 6a-d show how some of the dimuons reported by Benvenuti et al(4) would strike the EMI. Parts (a) and (b) show the EMI system in plan and elevation views. Part (c) shows how the muons strike the absorber in front of the EMI if they were produced at the center of the bubble chamber and part (d) shows the same hit pattern if they were produced in the coils in front of the bubble chamber.
Unfortunately, we expect only 80 (40) or so dilepton events.

Apparatus Needed

A. 15-foot Neon-Hydrogen filled bubble chamber.

The specific mixture of Ne-H₂ that we request depends on what mixtures are used in the broad band exposures. For neutrinos, a light mixture of approximately 1/3 the density of pure Neon would be suitable if the bubble chamber is able to operate satisfactorily. Because the anti neutrino flux and cross sections are below those for neutrinos it might be necessary to run at a significantly higher density, say a factor of two, namely 2/3 the density of pure Neon.

B. The External Muon Identifier

By the time the hybrid 15-foot bubble system will be exposed to dichromatic beams we plan to have added more than 50 tons of Zinc absorber inside the bubble chamber vacuum tank between and behind the magnet coils. In the downstream equatorial direction there will be more than a meter of Zinc, constituting more than 8 collision lengths of absorber. This should be sufficient to reduce substantially hadronic "punch-through" there. Fig. 6a,b shows the EMI as it now exists (Apr. 1975).

C. Dichromatic Beams

Our group wishes to join others in building a new generation dichromatic beam system. We know of several schemes now being considered and for the purposes of this proposal have based our event rate calculations on a few of these. Table 1 summarizes the yields expected from a monohorn device similar to the Nezrick design(6) that focusses mesons between 2 and 8 milliradians and again uses the Clifford Risk multiperipheral model that
agrees well with experimental thin target data. Corrections have been made for thick target effects (7) and for absorption of mesons in the horn envelopes. Also considered are quadrupole beams of apertures that subtend 2 milliradians and 4 milliradians. These are the same systems that were considered in proposal 9B. (see its Table I). We are here choosing a smaller fiducial volume than previously, namely, $3\pi(\text{meter})^3$. Furthermore, in calculating antineutrino event rates we have set $\sigma_\nu = 1/3 \left( \sigma_\nu = 0.8 \ E \nu \times 10^{-38} \ \text{cm}^2 \right)$. The earlier calculations had assumed that $\sigma_\nu = \sigma_\nu = 0.8 \ E \nu \times 10^{-38} \ \text{cm}^2$. The neutrino and antineutrino event rates are summarized in tables I and II for 300 GeV and 400 GeV protons, respectively. Mesons of 100 GeV and 150 GeV with $\Delta p/p = \pm 0.05$ are focussed by the various devices. Rates are given for pure hydrogen, 1/3 Ne and 2/3 Ne. The numbers stated in the summary and the introduction are for the monohorn system for neutrino (antineutrino) interactions produced within one meter of the beam axis in the Ne-$H_2$ mixture of 1/3 (2/3) the density of pure Ne. No account has been taken in these rate calculations for the necessary fiducial volume cut in the downstream portion of the bubble chamber to provide sufficient track length for momentum measurement. Such a cut will reduce the event rates approximately 20 per cent.
<table>
<thead>
<tr>
<th>Device Type</th>
<th>Angular Acceptance</th>
<th>Meson</th>
<th>$E_0$</th>
<th>Meson Momentum</th>
<th>Neutrino Momentum</th>
<th>$\pi^+$</th>
<th>10$^9$ Interacting Protons</th>
<th>$\pi^-$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quad</td>
<td>$0&lt;\theta&lt;4$</td>
<td>$\pi^+$</td>
<td>300</td>
<td>100$\pm$5</td>
<td>28 to 43</td>
<td>12.7</td>
<td>9.5</td>
<td>6.45</td>
</tr>
<tr>
<td>Quad</td>
<td>$0&lt;\theta&lt;2$</td>
<td>$K^+$</td>
<td>300</td>
<td>100$\pm$5</td>
<td>91 to 95</td>
<td>0.85</td>
<td>0.55 $\pm$0.475</td>
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<td>Horn</td>
<td>$2&lt;\theta&lt;8$</td>
<td>$\pi^-$</td>
<td>300</td>
<td>100$\pm$5</td>
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| TABLE I |

300 GeV Protons

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<th>Device Type</th>
<th>Angular Acceptance</th>
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</table>

† Absorption in horn envelopes.
* $K^-$ yields calculated by using Aubert et al (8) $K^-/K^+$ ratio = 0.23 at 100 GeV, and assuming it does not change with angle.
‡ Full Neon density taken 20 times the liquid Hydrogen.
TABLE II

<table>
<thead>
<tr>
<th>Device Type</th>
<th>(mrad) Angular Acceptance</th>
<th>Meson</th>
<th>E_0</th>
<th>Meson Momentum</th>
<th>Neutrino Momentum</th>
<th>Neutrons per 10^3 Interacting Protons</th>
<th>Thousands of ν int in Hydrogen within 1 meter of axis per 10^19 inc prots on 1 mfp target</th>
<th>Density ± Percentage</th>
<th>Thousands of ν int in [1/3p] Neon within 1 meter of axis per 10^19 inc prots on 1 mfp</th>
<th>Density ± Percentage</th>
<th>Thousands of ν int in [2/3p] Neon within 1 meter of axis per 10^19 inc prots on 1 mfp</th>
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<tr>
<td>Quad</td>
<td>0&lt;θ&lt;4</td>
<td>π^+</td>
<td>400</td>
<td>150±7.5</td>
<td>35 to 64</td>
<td>15.0</td>
<td>19.2</td>
<td>20% ± 3</td>
<td>55.</td>
<td>110.</td>
<td>40% ± 3</td>
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<tr>
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<td>400</td>
<td>150±7.5</td>
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<td>1.23</td>
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<td>5.3</td>
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† Absorption in horn envelopes
* K^- yields calculated by using Aubert et al (8). K^-/K^+ ratio = 0.095 at 150 GeV, and assuming it does not change with angle (or proton momentum).
‡ Full Neon density taken 20 times the liquid Hydrogen.
References

1. For a recent summary of these experiments see D. Cundy, 17th International Conference of High Energy Physics, London, July 1974.


Figure Captions

1. y-distributions for neutrino and anti-neutrino charged and neutral current events.

2. a) Distortion factors of the x,y distribution caused by a (NIB) propagator of mass 10 GeV for the dichromatic neutrino energies of 35 GeV and 95 GeV.
   
   b) How (NIB) propagators of mass 5 GeV and 10 GeV cause the total neutral current to saturate as a function of s(= 2MEv) for simple structure function forms, VW, a 1-X, and (1-X)^3.

3. The kinematics of 50 GeV neutrino interaction on nucleons. The solid parallel lines are the loci showing the invariant hadron mass, W(GeV). Also shown is the expected meson multiplicity according to the Landau thermodynamic model.

4. How 1000 charged current neutrino events would populate the Q^2,\nu (or x,y) space if the structure VW were a 1-x.

5. The possible jet-like structure as a function of x,y.

6. a) Plan view of the bubble chamber, Zinc absorber, and the multiwire proportional chamber belts of the EMI system.

   b) Elevation view of the EMI system.

   c) How some of the muon pairs reported by Benvenuti et al would strike the Zinc absorber in front of the EMI modules if they were produced at the center of the bubble chamber.

   d) Ditto... if they were produced in the coils in front of the bubble chamber.
\( \nu \rightarrow \nu \), \( \bar{\nu} \rightarrow \bar{\nu} \), \( \bar{\nu} \rightarrow \mu^+ \)

\( \sin^2 \theta_w = 0.39 \)

Fig. 1
$M_0 = 10 \text{ GeV}$, DISTORTION FACTOR $(1 + \frac{S_{XY}}{M_0^2})^{-2}$

$E_x = 35 \text{ GeV}$  
$(S = 70 \text{ GeV}^2)$

$E_y = 95 \text{ GeV}$  
$(S = 190 \text{ GeV}^2)$

Fig 2a
$E_{\nu} = 50$ GeV

$\theta_{\mu} = 15^\circ$

$\gamma_{\omega} = 9$

$\langle n_{\pi} \rangle = 11$

$\langle n_{\pi} \rangle = 16$

$W = 10$

$W = 12.5$
Distribution of 1000 events

$Q^2 \ (\text{GeV}/c)^2$

$x=1$

$x=0.8$

$x=0.6$

$x=0.4$

$x=0.2$

$x=0$

$\nu = E - E'$

$E = 50 \ \text{GeV}$

for $\nu \beta = K(1-x)$

$\sigma^R = \sigma^S = 0$

Spin $\frac{1}{2}$ Partons

$M_W = \infty$

Fig 4
$E_y = 50$ GeV

$\langle n \pi \rangle = 0$

$\langle n \pi \rangle = 3.0$

$y = \nu/E$

Fig 5
μ particles produced
in the center of the
bubble chamber

Fig 6c
Pen events produced in the upstream portion of the tube.

Fig 6d