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ADDENDUM TO

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PROPOSAL FOR STUDYING ANTI-NEUTRINO INTERACTIONS IN NEON WITH A NARROW BAND BEAM IN THE 15-FOOT BUBBLE CHAMBER

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VII. Experimental Effort.

The physicists proposing this experiment have worked extensively with bubble chambers, and several of us (S.F., A.K., R.P., W.S., S.H., V.H.) have considerable experience with heavy liquid chambers. One of us (R.D.) is currently involved in a study of ν interactions in the 15-foot chamber.

Scanning and measuring will be carried out at UCLA, (3 FTE), UCR, (4 FTE), and FSU, (4 FTE). The UCR group will use three micrometric image plane digitizers for this purpose, of which two are currently being fitted with a 15x-50x dual magnification system specifically designed for 15-foot film. At FSU three micrometric type scanning measuring machines with single magnification of 20x in two views and dual magnification - 15x and 50x - in the third view will be available for scanning and measuring. At UCLA micrometric type scanning tables will be used. The collaboration will also have access to the semi-automatic POLLY type measuring machine at the UCI-UCLA-UCR Data Processing Center - utilization of this device will depend on film quality.

We expect to be able to scan all of the 200,000 photographs in one year. The estimated scanning rate is about 10 frames per hour which corresponds to about 10 man-years of scanning effort. The measuring needs about one man-year effort. These rates are based on our experience with the 250 GeV/c π^-p experiment and on other neutrino experiments using the Fermilab 15' bubble chamber.

The CERN chain of geometry and kinematic programs, HYDRA, especially written for large bubble chambers with long track lengths and non-uniform magnetic field, will be used for event reconstruction.

Summary of Proposal

This proposal is for the study of anti-neutrino interactions with a dichromatic anti-neutrino beam in the 15 ft. bubble chamber filled with neon or a heavy neon-hydrogen mix. A total of 200,000 pictures is requested. For 400 GeV protons at intensity 10^{13} protons per pulse we expect approximately 4000 anti-neutrino interactions, of which about 1000 are neutral current interactions. The primary purpose of the proposed experiment is to make a detailed study of neutral current phenomena.

I. Introduction

The study of neutrino interactions with calorimeter - iron core magnet setups at FNAL has uncovered two phenomena of major interest: neutral currents, and dimuon production.[1] It has been pointed out in several proposals[2-4] that the structure of neutral currents can be determined with a narrow band neutrino beam in the FNAL 15 ft. bubble chamber filled with a neon or a heavy neon-hydrogen mix. This arrangement also has some unique advantages for the investigation of possible new (charmed?) hadronic states which may be associated with the dilepton production referred to above.[5]

We are requesting here a total of at least $4x10^3$ anti-neutrino interactions with a narrow band beam in the FNAL 15 ft. chamber filled with neon or with a heavy neon-hydrogen mixture. The actual number of pictures will depend on the incident proton energy and intensity, and will be $\approx 2x10^5$ for 400 GeV protons at $1x10^{13}$ protons per pulse. We are aware of three approved proposals for ν, $\bar{\nu}$ exposures in the 15 ft. bubble chamber with dichromatic beam and a heavy filling.[2-4] Consequently we do not request here a specific anti-neutrino energy, but rather one which is in consonance with the aims of the program of bubble chamber neutrino studies at FNAL.

The primary purpose of the proposed experiment is to make a definitive study of the neutral current interaction. The exposure should yield $\gtrsim 1000$ such interactions. On a realistic time scale it seems likely that the production of new hadrons in weak interactions may be fairly well understood before this experiment could be completed. Nevertheless the elucidation of certain aspects of this phenomenon may still require the unique capabilities of the neon bubble chamber.

II. Neutral Currents

The importance of studying this fundamental phenomenon hardly needs to be stressed. The experimental arrangement of a dichromatic beam in the 15 ft. bubble chamber filled with neon is optimized for neutral current studies. Thus for the inclusive reaction:

$$\bar{\nu} + N \rightarrow \bar{\nu} + \text{hadrons},$$

the total energy, E_h, and the momentum of the hadronic shower can be measured, and the scaling variables: $x = q^2/2M(E - E_h)$ and $y = E_h/E_\nu$ can be determined; (q^2 is the four-momentum transfer between incoming and outgoing neutrino, and M is the target nucleon mass). Although there will be some nuclear reabsorption it should also be possible to look at neutral current interactions in some exclusive channels.

Below we outline aspects of the neutral current interaction which can be studied in such an exposure.

1. Analysis of x and y distributions:

These distributions will allow us to investigate the following questions:

(i) Does the neutral current see the same point-like quark structure within the nucleon as the charged current?

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(ii) What is the space-time structure of the neutral currents - V, A, S, P, T or some combination thereof?

(iii) What are the scaling properties of neutral current interactions?

These topics are strongly interrelated. If the space-time structure of the neutral currents is known then question (i) can be answered by studying the x distribution. In the following we will assume that, as with charged currents, the nucleon behaves like a set of point-like valence quarks. Then, for a current which is a linear combination of vector and axial vector covariants, the y distribution, $\frac{d\sigma}{dy}$, has the form given in Table I.

TABLE I

current structure	$\left(\frac{d\sigma}{dy}\right)_\nu$	$\left(\frac{d\sigma}{dy}\right)_\nu$	$R_\nu/R_{\bar{\nu}}$
V - A	1	$(1-y)^2$	1
Pure V or pure A	$\frac{1}{2}[1 + (1 - y)^2]$		0.33
V + A	$(1-y)^2$	1	0.11

Results to date are inconsistent with a V-A structure for neutral currents.[6]

The more extreme possibility that muonless neutrino interactions involve S, P and/or T covariants can be examined to some degree. It is relatively easy to test the S and/or P case since a y distribution going like y^2 is characteristic of S and/or P. In general however "for any admixture of V and A interactions there is a corresponding admixture of S, P and T interaction which yields the same ν and the same $\bar{\nu}$ cross section".[7]

The scaling properties of neutral current interactions are of great interest. A possible scaling violation in charged current $\bar{\nu}$ interactions has been reported at small x, large y, for $E_{\bar{\nu}} \gtrsim 30$ GeV.[8] It has been conjectured that this breakdown is associated with a new particle production threshold. In the conventional GIM charm model such a scaling breakdown is not expected for neutral currents.[9]

2. Measurement of $R_{\bar{\nu}}$: Counter experiments at FNAL give values of 0.32 ± 0.08 and 0.033 for[1]

$$R_{\bar{\nu}} = \frac{\sigma(\bar{\nu}+N\to\bar{\nu}+\text{hadrons})}{\sigma(\nu+N\to\mu^{+}+\text{hadrons})}$$

We can measure this ratio at the two widely separated energies of $\bar{\nu}_{\pi}$ and $\bar{\nu}_{k}$, and more precisely than above because of the improved measurement of $d^2\sigma/dxdy$ in the bubble chamber experiment.

For the one-parameter, (Θ_w), Weinberg-Salam model we have the prediction:

$$R_{\bar{\nu}} = \frac{1}{2} - \sin^2\Theta_w + \frac{20}{9}\sin^4\Theta_w$$

3. Combined ν, $\bar{\nu}$ distributions: As seen in Table I, $R_{\nu}/R_{\bar{\nu}}$ is a sensitive function of the vector-axial vector mix in the neutral current. The coimbined ν, $\bar{\nu}$ distributions allow a determination of the coupling constants for semi-leptonic neutral current processes. Thus for a V, A mixture which is pure isovector we have:

$$\frac{1}{4}(v_3{}^2+a_3{}^2) = \frac{\sigma(\nu\to\nu)+\sigma(\bar{\nu}\to\bar{\nu})}{\sigma(\nu\to\mu^-)-\sigma(\bar{\nu}\to\mu^+)}$$

$$\frac{1}{2}v_3a_3 = \frac{\sigma(\nu\to\nu)-\sigma(\bar{\nu}\to\bar{\nu})}{\sigma(\nu\to\mu^-)-\sigma(\bar{\nu}\to\mu^+)}$$

Current tests of these formulae suggest that the neutral current interaction is predominantly (if not purely) vector or predominantly axial vector;[10,11] the two possibilities cannot be distinguished because of the symmetry of the above expressions between v_3 and a_3. Analogous relationships exist for the coupling constants in the pure isoscalar case. And for the Weinberg-Salam model which contains both isoscalar and isovector components we have the constraints:

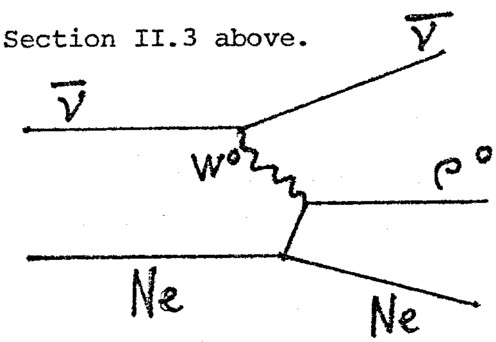
$$R_\nu = \frac{1}{2} - \sin^2\Theta_W + \frac{20}{27}\sin^4\Theta_W$$

$$R_{\bar{\nu}} = \frac{1}{2} - \sin^2\Theta_W + \frac{20}{9}\sin^4\Theta_W$$

4. Isospin Properties: It will be interesting to look for diffractive processes:

$$\bar{\nu} + \text{Ne (or N)} \rightarrow \bar{\nu} + \text{meson} + \text{Ne (or N)}$$

Sakurai[11] and others have pointed out that in low q^2 neutral current reactions we may expect diffractive production of vector and/or axial vector mesons of the same quantum number as the current: ρ^o for isovector, ω and ϕ for isoscalar, A_1 for isovector axial vector etc. The diffractive process may be crucial in determining whether V or A dominates in semileptonic neutral current interactions, because of the ambiguity between V and A discussed in Section II.3 above.



These processes can be readily identified in the bubble chamber.

III. Production of Hadrons with a New Quantum Number

Current studies on dimuon production in ν, $\bar{\nu}$ interactions at FNAL give:[12,13]

$$\frac{\sigma(\nu,\bar{\nu} \to \mu^+\mu^-)}{\sigma(\nu,\bar{\nu} \to \mu^{\mp})} \simeq 10^{-2}$$

Analysis of these dimuon interactions gives strong evidence for the production of new hadrons, ("Y particles"), with the following properties:

(i) these hadrons are produced in both ν and $\bar{\nu}$ interactions at $E_\nu \gtrsim 30$ GeV.

(ii) the mass of at least one of them lies between 2 and 4 GeV.

(iii) they decay weakly, with muonic processes accounting for approximately 10% of decays.

Thus in 3000 charged current events we expect ~300 events*

$$\bar{\nu} + N \to \mu^+ + \bar{Y} \text{ (+ hadrons)}$$

$\xrightarrow{80\%}$ hadrons ..... (1)

$\xrightarrow{10\%}$ $\mu^- + \bar{\nu}$ (+ hadrons) ..... (2)

$\xrightarrow{10\%}$ $e^- + \bar{\nu}$ (+ hadrons) ..... (3)

Because the purely hadronic decays of y particles are expected to have high multiplicity: $n \geq 3$, the π^o measurement capability of the neon chamber may be quite important in determining the mass of these particles.

Electrons are readily identified by bremstrahlung in neon, thus

*Since $\sigma_{\mu\mu}(\bar{\nu})/\sigma_{\mu}(\bar{\nu}) = (2\pm1)\text{x}10^{-2}$ the number of Y production events could be considerably larger than 300.

permitting us in reaction (3) to observe the ($\mu^- e^+$) signal, characteristic of charmed particle production. Because the incident $\bar{\nu}$ momentum is known, $\bar{Y}$ can be observed as peaks in invariant mass spectra in all three reactions. Comparison of (1), (2) and (3) would enable us to study the ratio of hadronic to leptonic decays for Y particles.

It will be extremely interesting to compare Y, $\bar{Y}$ production in ν, $\bar{\nu}$ interactions. In the GIM scheme charm production in neutrino interactions can occur off valence quarks, (x large), or off sea quarks ($x \simeq 0$); for antineutrinos only the latter process can occur.[9] Furthermore, while production of both charmed mesons and charmed baryons is predicted in ν interactions, only charmed mesons are expected in $\bar{\nu}$ interactions. The most likely configuration in $\bar{\nu}$ interactions is a $C = -1$ meson accompanied by an $S = +1$ particle.

Diffractive production of charmed vector mesons can, in principle, occur for both ν and $\bar{\nu}$ interactions.

The combined ν, $\bar{\nu}$ data on Y production will be needed to elucidate the Y production mechanism.

With the narrow band beam we can also look for production of new hadrons in neutral current reactions:

$$\bar{\nu} + N \rightarrow \bar{\nu} + \bar{Y} \text{ (+ hadrons)}$$
$$\qquad\qquad\qquad\quad \llcorner\!\!\longrightarrow \text{hadrons}$$

This process would also be evidenced by e^- production or the occurrence of "wrong sign" muons arising from leptonic decay of $\bar{Y}$ in the above reaction. Although Y production is not expected in neutral current reactions in the GIM scheme we shall not be limited in our investigations by current theoretical models.

IV. Exclusive Reactions

Bubble chambers complement counter experiments in making possible the study of exclusive neutrino interactions. The interest of neutral current diffractive channels has already been mentioned, (section II.4). In charged current interactions we can study exclusive channels involving π^o production, as for example diffractive ρ^- production:

$$\bar{\nu} + Ne \rightarrow \mu^+ + \rho^- + Ne$$
$$\rho^- \rightarrow \pi^- + \pi^o.$$

V. Equipment

Running conditions are dictated by the requirements for a definitive study of $\bar{\nu}$ neutral current interactions: i.e. (i) a narrow band beam, (ii) measurement of the total outgoing hadronic energy and momentum, and (iii) muon identification capability.

1. The Beam: The two-horn narrow band beam described in P-380 would be suitable for this experiment.[14] The p-380 setup uses a momentum selected beam of π and K mesons, (momentum P_o), and relies on two-body decay kinematics to obtain a dichromatic beam with the two momenta 0.4 Po, (pion neutrinos), and 0.95 P_o, (kaon neutrinos). For 400 GeV incident protons the meson beam is optimized for momentum around 150 GeV/c, which corresponds to $E_{\nu\pi} \simeq 60$ GeV and $E_{\nu K} \simeq 135$ GeV. The yield is fairly

constant over the range $130 < P_o < 170$ GeV/c. With a momentum resolution of $\Delta P_o/P_o = \pm 5\%$ for the meson beam, the neutrino energy resolution is $\simeq\pm 5\%$ at the center of the chamber and roughly twice that near the edge of the chamber. The ratio of $\nu/\bar{\nu}$ fluxes is $\simeq 2$. As discussed in Section VI below, an acceptable $\bar{\nu}$ flux can be obtained with the two-horn beam for incident intensity of 10^{13} protons/pulse and $\Delta P_o/P_o = \pm 10\%$.

The new dipole-quadrupole narrow band beam now being designed by the Cal Tech-FNAL group would also be very suitable. This beam would be superior to the two-horn beam in regard to maximum attainable neutrino energy, wideband background and spill time.

3. The Bubble Chamber: We assume that the 15 ft. bubble chamber can be operated with a pure neon or heavy neon-hydrogen mixture (from 80% to 95% neon).[15] The total target mass is around 40 tons. The radiation length for pure neon is 25 cm, and the effective interaction length is about 80 cm. If the fiducial volume is restricted to 20 tons, most of the hadrons will give visible interactions or decays in the chamber. For π^o's the detection efficiency, based on conversion of both decay photons to electron pairs, is estimated at around 95%. Thus the hadronic shower from a neutrino interaction is essentially contained within the bubble chamber, and it will be possible to estimate the energy and momentum of the shower. Muons can be identified by their failure to interact and electrons by bremstrahlung.

We expect a uniform efficiency for the entire y range in neutral current interactions, unlike counter experiments which have serious holes at large and small y. This fact is crucial to the measurement of $R_{\bar{\nu}}$.

3. The External Muon Identifier: We would like to use the external muon identifier built by the Hawaii-LBL group to assist in muon identification.

IV. Event Rates

Event rates are estimated for the two-horn beam,[14] and the following experimental conditions:

10^{13} incident protons per pulse at 400 GeV

$130 < P_o < 170$ GeV/c with $\Delta P_o/P_o = 10\%$

target mass = 20 tons

number of pictures = 2×10^5

This gives:

$\approx$3000 charged current interactions

$\approx$1000-1600 neutral current interactions*

VII. Experimental Effort

This experiment is to be performed as a collaboration between the University of California at Riverside, Fermilab, and Florida State University. Both UCR and FSU have conventional scanning and measuring machines. At UCR, there are three Micrometrics image-plane digitizing tables, one Vanguard scan table and one NRI film-plane measuring machine. These machines have been successfully used to scan and measure film from a 250 GeV/c $\pi^- p$ 15' bubble chamber experiment. In addition, the semi-automatic measuring device MOLLY at the UCI - UCLA - UCR Data Processing Center will be used to measure events with minimal manual guidance.

*current estimates of $R_\nu/R_{\bar{\nu}}$ range from 0.33 to 0.55.

The CERN chain of geometry and kinematic programs, HYDRA, especially written for large bubble chambers with long track lengths and non-uniform magnetic field, will be used.

From the collaborating institutions there will be at least 6 physicists working on this experiment. Several of us are experienced in working with heavy liquid bubble chambers. We expect to be able to scan all of the 200,000 photographs in one year. The estimated scanning rate is about 10-20 frames per hour. This corresponds to about 10 man-years of scanning effort. The measuring needs about 1 (one) man-year effort. These rates are based on our experience with the 250 GeV/c $\pi^- p$ experiment and on other neutrino experiments using the Fermilab 15' bubble chamber.

We would be glad to assist in the construction of the dichromatic beam required for this experiment.

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