NAL PROPOSAL No. 42

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Neutrino Interactions in the Deuterium-Neon 14 Foot Double Bubble Chamber

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June 10, 1970

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Abstract: We propose to study the interactions of high energy neutrinos in the 14 foot bubble chamber. The target chamber to be filled with Deuterium and the surrounding region filled with nearly pure Neon. An exposure of one million pictures is requested, in order to map out the s and t dependences of the basic interactions in which neutrinos participate.

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II. Physics Justification.

Introduction:

Neutrino physics is one of the current frontiers of elementary particle physics. The neutrino being the natural probe of the weak interactions of leptons and hadrons. Two obvious problems in a complete understanding of the weak interactions remain.[7] The problem of finding the proper modification of the Fermi Theory at high energy and the problem of understanding the origin of CP non conservation. With the availability of high intensity accelerators and large bubble chambers, neutrino physics will return to the domain of experiment. Perhaps the known problems of the weak interactions will be solved and perhaps new ones will develop as we explore reactions never before systematically observed.

1) Quasi Elastic Reaction

$$\nu + n \rightarrow \mu^- + p \qquad (1)$$

$$p + Ne \rightarrow p + Ne \qquad (2)$$

1a. Physics

The quasi elastic reaction (1) is one of the basic elementary particle reactions. There is great interest in measuring it, both as a function of s and of t. Due to the shape of the neutrino energy spectrum[1] and the apparent flatness of the cross section[2] for reaction (1), most of the information will be collected in the neighborhood of 8 GeV where the spectrum peaks. Reaction (2) describes the use of scattering off neon as an analyzer of the polarization of the recoil proton. Such an analysis, while of great intrinsic interest, might require either substantially larger flux or exposure size than that envisioned here, to make it practical.

1b. Equipment and Rates

The 14 foot bubble chamber should be very adequate for the analysis of the bulk of the events due to reaction (1), since they give a three constraint fit and have momenta in the order of 8 GeV/c.

Assuming a flux of 10^{10} ν/pulse/m^2, a deuterium target volume of 3 cubic meters, and an energy-independent cross section of $0.4 \times 10^{-38} cm^2$, we obtain a total rate of 500 events in 10^6 pictures.

2) Single Pion Production

$$\nu + p \rightarrow \mu^- + \pi^+ + p \qquad (3)$$

$$\nu + n \rightarrow \mu^- + \pi^+ + n \qquad (4)$$

$$\nu + n \rightarrow \mu^- + \pi^0 + p \qquad (5)$$

2a.) Physics

One expects some or all of the processes in Fig. 1 to contribute. The CERN heavy liquid bubble chamber data[2] appears to be dominated by production of the $N^*(1236)$. One is interested in the relative strengths of the processes as well as their s and t dependences. Of ultimate interest are the weak form factors of the nucleon, N^* and pion.

2b.) Rates for Single Pion Production

The CERN heavy liquid bubble chamber results[5] indicate a cross section of approximately $1.0 \times 10^{-38} cm^2$ for reaction 3. This would give a rate of 1250 events in 10^6 pictures. If the $N^*(1236)$ continues to dominate, there will be an additional 400 events from reactions 4 and 5. Large $I = \frac{1}{2}$ contributions would increase these numbers.

2c.) Event Separation

Reaction 3 is analyzable, in spite of the fact that the spectator neutron is invisible, without the need to observe secondary interactions. Reactions 4 and 5 are unconstrained if one does not obtain additional information. In reaction 4 we would do the zero constraint calculation and then look for a neutron interaction along the calculated neutron's flight path in the Deuterium and Neon. In reaction 5 we would attempt to reconstruct the π^0 from the γ rays converted in the D_2 and Neon.

3) Low Momentum Transfer q^2 Inelastic Processes

3a.) Physics

$$\nu + n \rightarrow \mu^- + \text{Hadron Complex} \qquad (6)$$

An interesting subclass of inelastic processes is those for which the momentum transfer q^2 between the leptons is small (see Fig. 2).

Adler Tests:

Adler has proposed tests[3] of both CVC and PCAC. For the events with $\overline{p}_{\mu^-}$ parallel to $\overline{p}_{\nu}$, he shows that the cross section (e.g. for N^* production)[4] is

$$\sigma \propto (\langle N^* \mid \partial (V_\alpha + A_\alpha) / \partial X_\alpha \mid N \rangle)^2 \qquad (7)$$

CVC:

Since CVC states that $\partial V_\alpha / \partial X_\alpha$ is zero, there can be no terms which give rise to parity violating effects. (V-A interference terms). The reaction

$$\nu + n \rightarrow \mu^- \, p \, \pi^+ \pi^- \qquad (8)$$

offers such a test by measurement of the expectation value of the quantity

$$\overline{p}_\mu \cdot (\overline{p}_{\pi^+} + x \, \overline{p}_{\pi^-}) \qquad (9)$$

PCAC

Here one looks for dominance of pion exchange and for a verification of the relation that the matrix element

$$| M(\nu + N \rightarrow \mu^- + N^*) |^2 \propto | M(\pi^+ + N \rightarrow N^*) |^2 \qquad (10)$$

4) Highly Inelastic Reactions

4a.) Physics

Electroproduction experiments have shown that there is a region of energy transfer to the hadrons where the momentum transfer dependence becomes essentially flat. This is an exciting discovery and can be interpreted as indicating the existance of localized substructure in the nucleon. The CERN neutrino experiments[5] give similar indications. We propose to study these inelastic neutrino reactions over the wide range of energy and momentum transfer available at NAL. The reaction

$$\nu + n \rightarrow \mu^- \, p \, \pi^+ \pi^- \qquad (11)$$

would seem to be especially suitable, since it gives the neutrino energy directly. Other reactions of the form

$$\nu + n \rightarrow \mu^- + p + n\pi^0 \qquad (12)$$

would also be susceptible to analysis on detection of the γ conversions in the neon.

Total Cross Section and Partons

There are various models for the apparent subnucleon objects. K. Gottfried[6] has a model which makes the apparently simple prediction

$$\sigma^{TOT}(\nu n) = 2\sigma^{TOT}(\nu p) \qquad (13)$$

$$(E_\nu \rightarrow \infty, q^2 \rightarrow \infty)$$

Information on total n and p cross sections will be obtainable from this experiment. The total cross sections are of great interest in and of themselves. Several models[5] predict cross sections that use linearly with neutrino energy. The CERN HLBC data show such a rise[5] within the energy range spanned by their data.

4b.) Rates for Inelastic Reactions

The total cross sections have risen to approximately 5 x $10^{-38} cm^2$ per nucleon[5] at 8 GeV and is dominantly inelastic. It corresponds to an inelastic event rate of approximately 10,000 inelastic events per nucleon in 10^6 pictures.

5) Intermediate Vector Boson

5a.) Physics

As is well known, the description of the weak interactions in terms of currents coupling at the same space time point cannot be valid at high energies.[7] For example, the reaction

$$\nu_\mu + e^- \rightarrow \nu_e + \mu^- \qquad (14)$$

cannot be so described above 300 GeV, where that form violates unitarity. To solve this problem, it has been suggested that the currents interact by exchange of a vertical vector meson W. Detailed properties of the W are discussed by Lee.[8]

The interactions of the W with a pair of leptons would be semi weak. One would expect to produce the W most copiously with an electromagnetic coupling to the target (see Fig. 3).

Previous experiments[9] put the mass M_W at greater than 2 GeV.

5b.) Production and Detection of the W

Since the production involves a virtual photon, a high Z target is required. In particular, the Neon region of the bubble chamber would serve as the principle target for the W search. The signature of the W decay would be the presence of a wide angle μ^+, μ^- from a single event. The reaction chain being

$$\nu + N_e \rightarrow \text{Hadrons} + W^+ + \mu^- \quad (15)$$

$$W^+ \rightarrow \mu^+ + \nu$$

$$W^+ \rightarrow \pi^+\pi^o$$

$$W^+ \rightarrow ?$$

5c.) Rates for W Production

We assume the cross section for W production on Iron quoted by Meyer,[10] the 10% branching of W to $\mu\nu$ and 25% detection efficiency as he does. Scaling N_e to F_e by Z^2 and assuming 0.5 m^3 as the useful Neon volume in the bubble chamber, we would expect to detect a total of 5 events per 10^6 pictures for a 5 GeV mass W. It is possible that this experiment would be able to increase this rate by detecting a larger fraction of the W decays (e.g. $\pi^+\pi^o$) The deuterium is relatively useless as a target for W production. It may, in addition, be possible to detect at least the high momentum μ^+ from W^+ produced at the end of the shielding. The rates for a lower mass W are, of course, higher and vary rapidly with M_W.

6) Tests of Selection Rules

One can search for reactions which violate the "rules" of weak interactions such as $\Delta S \doteq \Delta Q$. One such reaction is

$$\nu + n \rightarrow \Sigma^+ + \mu^- \quad (16)$$

III Experimental Configuration

1. Bubble Chamber

We propose to run the 14 foot bubble chamber in the sensative target mode. The inner target to be filled with deuterium and the surrounding chamber with as pure a neon mixture as is compatible with operating conditions (past experience has shown this to be approximately 95% Neon for smaller chambers). Fig. 4 shows an attempt at a compromise configuration. It has nearly 2 radiation lengths of Neon in any but the backward direction. It affords nearly a 50% collision probability for neutron at large angles, the collision probability is even greater for forward going hadrons.

2. <u>Geometrical Reconstruction</u>

The Purdue group, in particular R. S. Christian, has been devoting considerable effort in studies concerned with the geometrical reconstruction of events in target chambers. A modified TVGP code exists which should be suitable for use in the 14 foot configuration.

3. <u>Muon Detector</u>

Since it is not practical to fill the Bubble Chamber with enough Neon to insure the identification by interaction of all Hadrons, we propose to place behind the bubble chamber a hadron absorber followed by a set of spark chambers to definitely identify the bulk of the muons.

4. <u>Neutrino Flux</u>

We would anticipate taking part in experiments to survey the muon flux in the shielding to deduce the neutrino spectrum.

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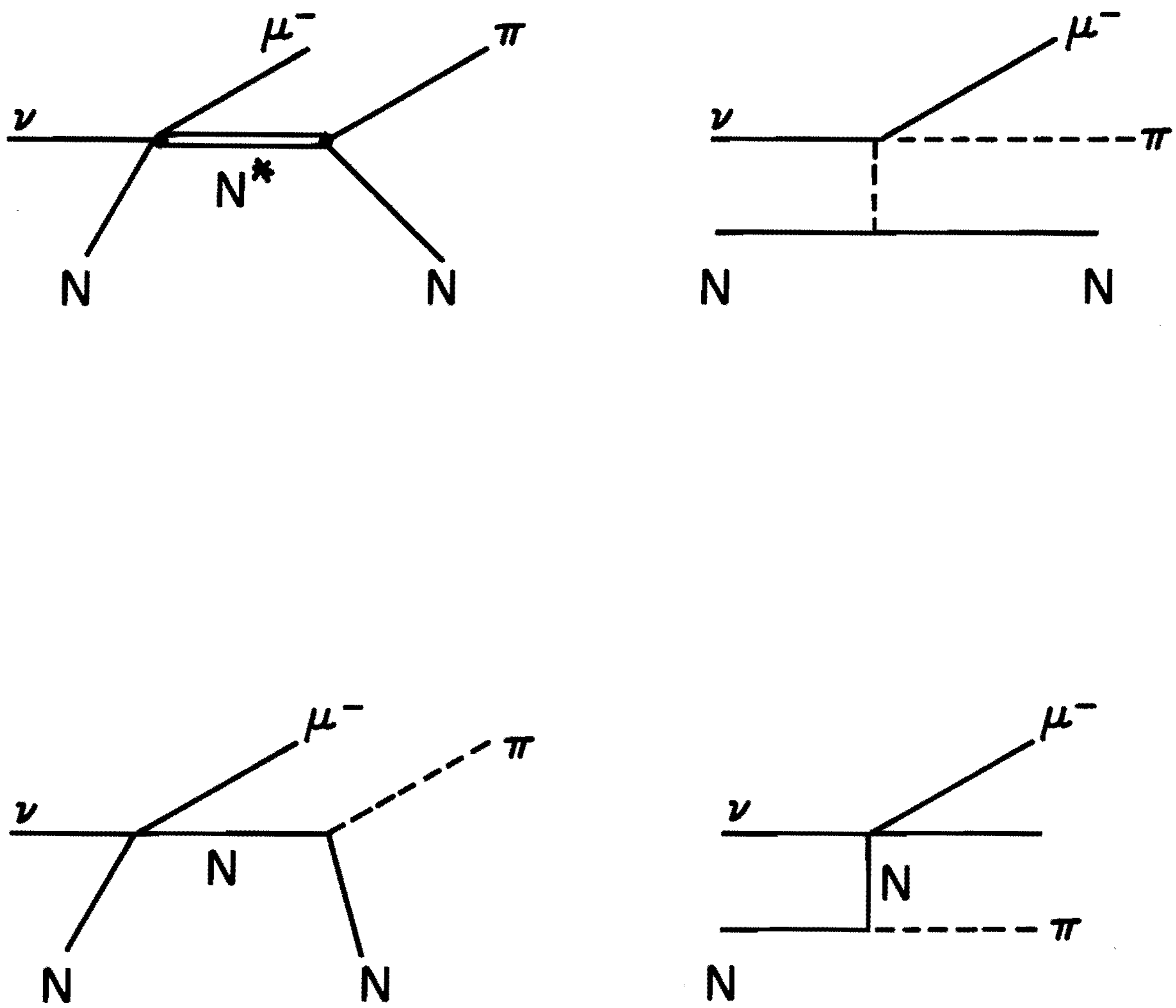

Fig 1 Single Pion Production

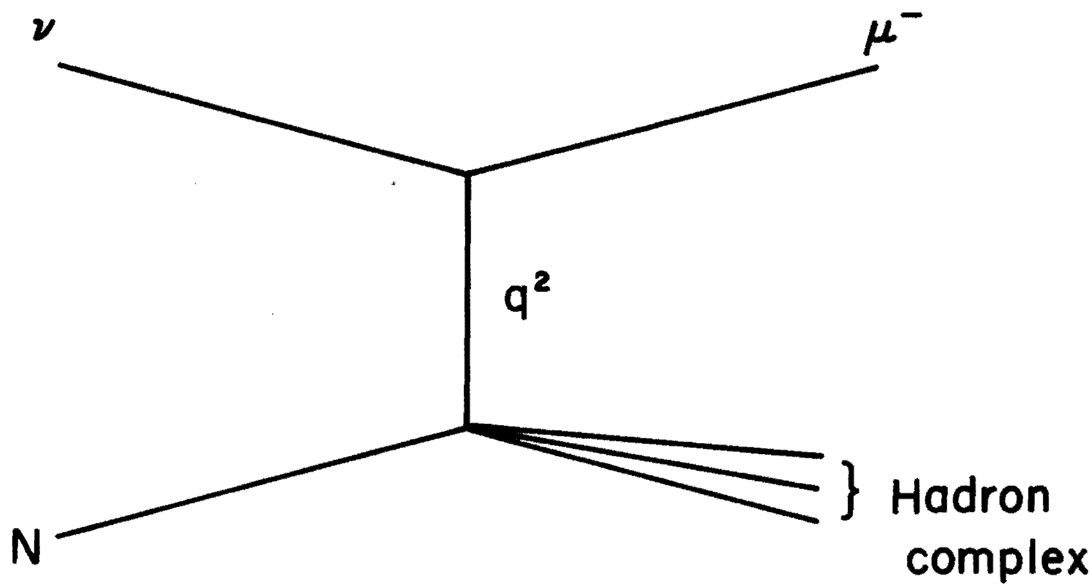

Fig 2 Inelastic Processes

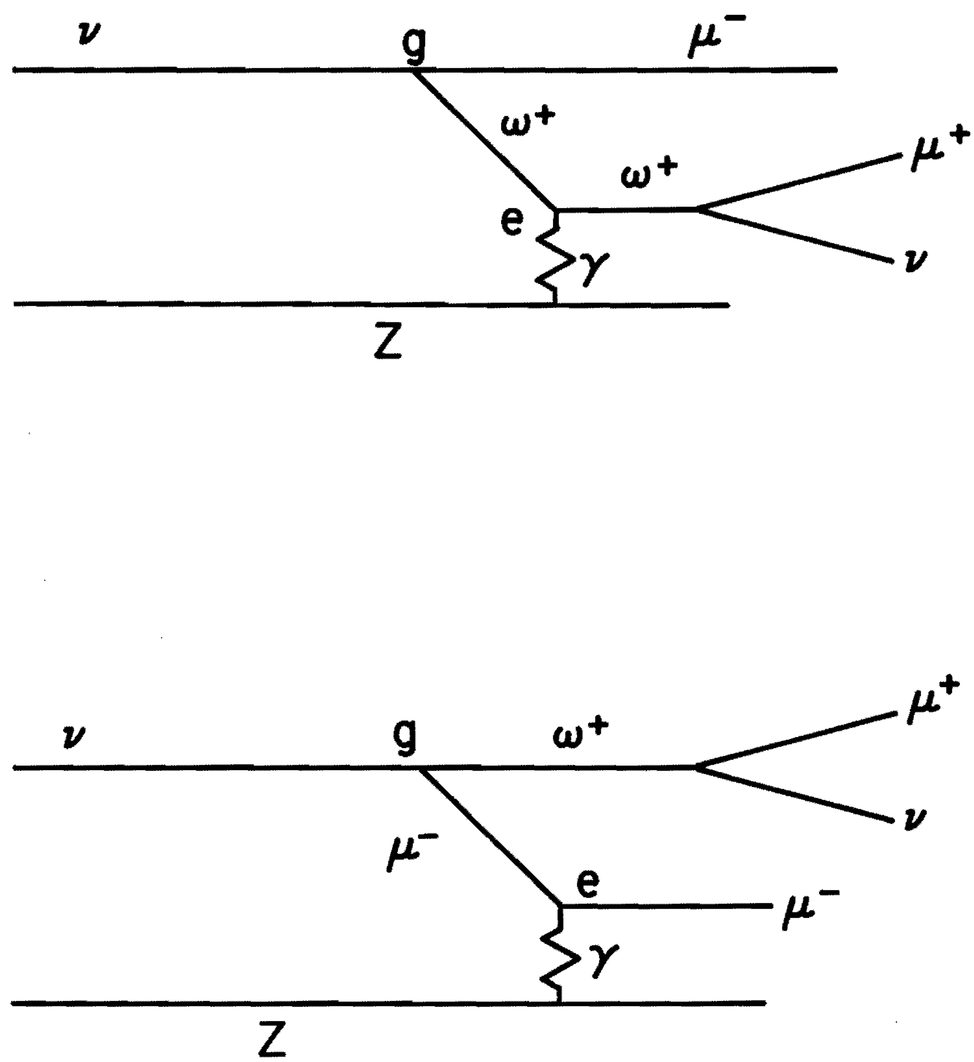

Fig 3   W Production

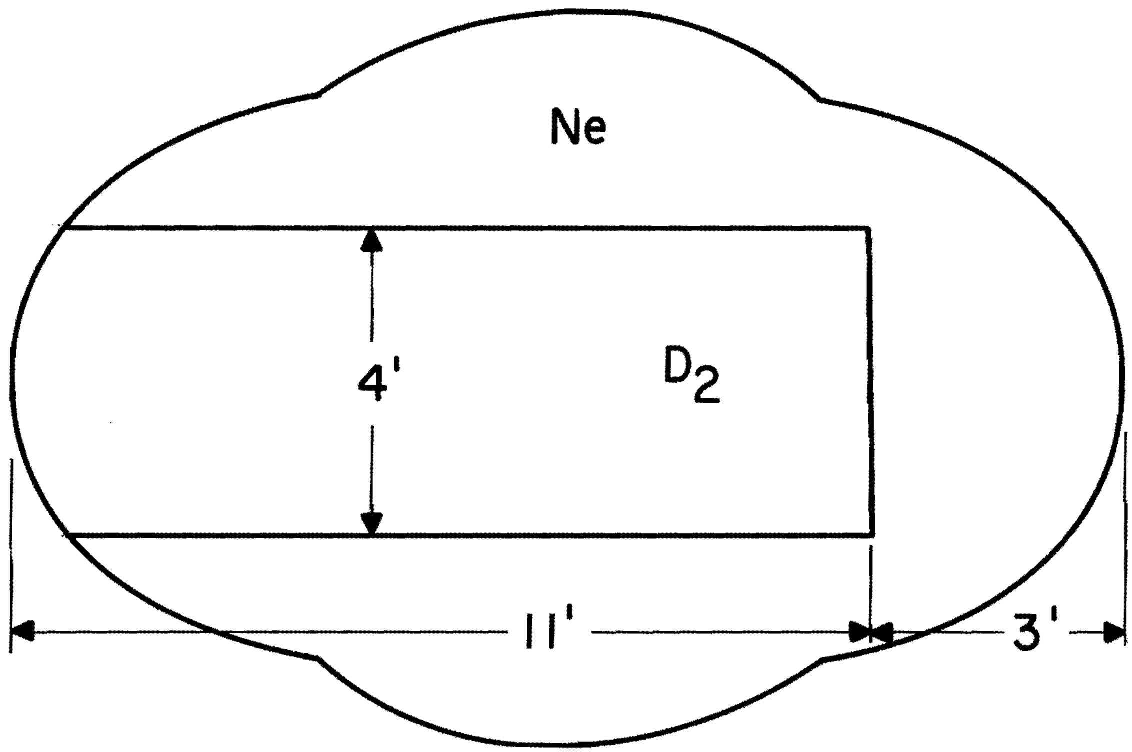

Fig 4 Possible Target Chamber Configuration