Fermilab Proposal 544

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PROPOSAL TO STUDY ANTINEUTRINO INTERACTIONS IN HYDROGEN AND NUCLEI WITH AN INTERNAL TARGET AND CONVERTER SYSTEM IN THE 15-FT. BUBBLE CHAMBER

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PROPOSAL TO STUDY ANTINEUTRINO INTERACTIONS IN HYDROGEN AND NUCLEI WITH AN INTERNAL TARGET AND CONVERTER SYSTEM IN THE 15-Ft. BUBBLE CHAMBER

ABSTRACT

We propose to investigate antineutrino interactions on free protons and simultaneously on nuclei with 90% gamma conversion and 95% electron and muon identification by using an Internal Target and Converter (ITC) system in the 15-Ft. bubble chamber.

We request an exposure of 500,000 pictures in a broad-band antineutrino beam with two horns. We request a primary proton intensity of $1.3 \cdot 10^{13}$ ppp at 400 GeV/c. Based on the yields of antineutrino events in E-180 and E31 we expect to obtain between 20,000 and 30,000 antineutrino interactions in this exposure.

The following physics topics will be investigated:

I. New particle production: the detection of two leptons and/or strange particles in the final state will be a signature for new particle production.

II. Deep inelastic scattering: investigation of inclusive distribution (x and y distributions,

multiplicities, σ_n/σ_p ratio and resonance production) for both charged and neutral currents.

III. Nuclear effects: A-dependence of total cross sections and nuclear scaling.

INTRODUCTION

Neutrino and antineutrino experiments in the last few years have provided many new results which have significantly advanced our understanding the characteristics of the weak interaction. In addition to the discovery of neutral currents several entirely new phenomena associated with charged current reactions have been revealed:

1) Dimuon events in both neutrino and anti-neutrino interactions.
2) μ-e events in neutrino interactions.
3) The high y-anomaly in antineutrino interactions and the rise of the $\sigma_{\bar{\nu}}/\sigma_{\nu}$ ratio as a function of energy.

It is clear that continued experimental effort in this field is extremely important.

We propose to investigate antineutrino interactions in the Fermilab 15-Ft. bubble chamber filled with hydrogen supplemented by the Internal Target and Converter system (ITC)[1] and the External Muon Identifier (EMI).[2]

Our request is for an exposure of 500,000 pictures in a broad-band antineutrino beam with two horns. We request a primary proton intensity of 1.3×10^{13} ppp and a primary proton energy of 400 GeV. Based on the yields obtained in Experiments E-180 and E-31 we expect to obtain approximately 25,000 antineutrino events.

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The unique features of the proposed experiment are:

1) The experimental arrangement combines the advantages of free proton target characteristic of the hydrogen bubble chamber with the improved detection efficiency for neutral particles usually associated with a heavy liquid filling. This feature provides the ability to make 3-C fits, in the case of the CC events and meaningful 0-C fits, in the case of NC events for a very much larger class of reactions than would be possible using the bare bubble chamber alone. The hydrogen fiducial volume for the ITC system is 16 m^3 which is comparable to the fiducial volume for the bare chamber (20 m^3). This is approximately four times larger than the hydrogen fiducial volume for a typical TST design ($\sim$4 m^3).

2) The thickness of the plates and the material of the plates can both be changed. This means that the effective number of nuclear interaction lengths and the effective number of radiation lengths can be varied independently for the ITC system. Furthermore by using plates of different materials it is possible to investigate the A-dependence of the antineutrino cross section. In the bare bubble chamber filled with a neon-hydrogen mixture the fraction of neon is the only free parameter.

A corresponding neutrino experiment with the ITC system has been proposed. We anticipate that important conclusion will be drawn from comparisons made between the results of the two experiments.

ITC SYSTEM

The ITC system has been described in detail in [1]. We will not repeat these details here. Instead we simply enumerate the principle features and advantages of the ITC system which are relevant to this proposal.

The ITC system consists of a series of 9 stainless non-magnetic steel each one 0.9 cms (0.5 radiation lengths) thick. The average gap between the plates in the middle plane of chamber is 30 cm. Each plate is tilted to provide maximum fiducial volume for cameras #5 and #6. Only parts of each track segment are visible on the third view. The ITC system provides a total of 4.8 radiation lengths of material (4.5 r.l. of steel and 0.3 r.l of hydrogen). The average γ conversion efficiency is approximately 90% for a fiducial volume of 16 m^3.

The momentum uncertainties for γ-rays and π^0's are given by $\Delta p/p \sim 0.31$ and $\Delta p/p \sim 0.17$ respectively. By measuring converted bremstrahlung γ-rays these uncertainties can be reduced to $\Delta p/p \sim 0.1$ and $\Delta p/p \sim 0.06$ respectively. The momentum resolution for charged hadrons is expected to be better than 2%.

Electrons will radiate in the plates and are expected to be identified with 95% efficiency. While the EMI will be very important for identification of fast forward muons it is less useful for slow muons produced at wide angles. For slow muons the only method of identification will be a study of interactions in the plates. The overall muon detection efficiency will be approximatley 95%.

Using the EMI data, plate penetration and transverse momentum balance we can identify >95% of charged current events. The hadron energy resolution is ~8% and the resolution in antineutrino energy $E_{\bar{\nu}}$ is ~3%. Using the method of transverse momentum balance we can reduce the error on $E_{\bar{\nu}}$ to ~1.5%. In this experiment the resolution in W, Q^2, ν, x and y will be much better than in bare hydrogen bubble chamber experiments (see Table II). Neutral current events are identified with ~95% efficiency by the non-observation of a muon and by transverse momentum balance.

The spatial separation of the hydrogen and the nuclear target in this experiment makes it easy to identify the target for each event in contrast with experiments using a hydrogen-neon mixture. This makes it possible to study both nuclear events and hydrogen events separately and to determine with high accuracy the cross-section ratio $\sigma_{\bar{\nu}n}/\sigma_{\bar{\nu}p}$ in both charged and neutral currents.

In addition to its physics advantages, the ITC system has some technical advantages over the bare chamber. The fact that the entrance and exit points to the plates are corresponding points supplies additional information. This may, for example, help to solve the track match problem for event with high multiplicity.

In conclusion we emphasize again that the unique feature of the ITC is the excellent neutral detection efficiency for a hydrogen fiducial volume comparable to the bare chamber.

PHYSICS

Several recent experimental results very likely indicate that new particles are being produced in both ν and $\bar{\nu}$ interactions. The discovery of neutrino induced dimuon events (HPWF[3], CTF[4] and ITEP-IHEP[5]) and observation of $\mu^- e^+$ pairs accompanied by strange particles (GGM[6], BCHW[7], CB[8]) is strong evidence for new particle production by neutrinos. There is also evidence for new phenomena in antineutrino reactions. The HPWF collaboration has reported the observation of antineutrino induced dimuon events, an anomaly in the antineutrino y-distribution, a rise in the mean value of y $\langle y \rangle$ and a rise in the cross-section ratio $\sigma_{\bar{\nu}}/\sigma_{\nu}$ with increasing energy. However, so far there is no evidence for antineutrino induced $\mu^+ e^-$ events in experiments E-180 and E-172.

It is difficult to explain all this experimental data using only one model. The existing theoretical models each predict very different levels for new particle production by antineutrinos. For example, using the simple quark-parton model one predicts charmed particle production only from the quark-antiquark sea in antineutrino reactions which seems to be in contradiction to experimental data on $\sigma_{\bar{\nu}}/\sigma_{\nu}$ and $\langle y \rangle$ as functions of energy. Alternatively one can consider models in which there is new particle production off valence quarks. In these models one expects a larger effect and a strong energy dependence. Some models predict new particle production only in antineutrino reactions. It is clear that new experimental information on antineutrino reaction is urgently needed.

I. New Particles

The intrinsic advantages of the ITC system discussed above are particularly important in this experiment because they make it possible to detect charmed particles with high efficiency. The free proton target coupled with good neutral detection make it possible to use the 0-C fits for some charmed particle production channels. In particular 0-C fits will provide good mass resolution (50-100 MeV) in the case of semileptonic decays.

The easiest way to detect charmed particles is to find evidence for semileptonic decays by searching for events with two charged leptons in the case of charged current reaction and for event with a single lepton in the case of the neutral current reactions.

Hadronic decay modes can be detected by analying events with strange particles. In this experiment we can detect with high efficiency not only neutral strange particles, which can be detected by practically any bubble chamber, but also charged strange particles ($K^{\pm}$, $\Sigma^{\pm}$, etc). For charged strange particles hydrogen is to be preferred because of the large nuclear interaction length (~7m).

Effective $\Delta S = \Delta Q$ violations are characteristic of charm particle decays and can serve as a distinctive signature for charmed particle production, for example:

$$\bar{\nu}_\mu p \to \mu^+ D^- p \qquad \Delta S = -\Delta Q$$
$$D^- \to K^+ \pi^- \pi^-$$

In general strange particles are expected to be produced preferentially in charmed particle decays by a factor $ctg^2\theta_c$ and the detection of a strange particle in an event will be an useful signature of possible charmed particle production in the proposed experiment.

1) Leptonic Pair Production

The bubble chamber used in conjunction with the ITC and the EMI provides efficient and reliable identification of muons and electrons.

μe pairs

Possible reactions with a muon and an electron in the final state are:

$$\bar{\nu}_\mu p \rightarrow \mu^+ e^- X \qquad (1)$$

$$\bar{\nu}_\mu Nuc \rightarrow \mu^+ e^- X \qquad (2)$$

For the reaction (1) we expect to be able to set an upper limit as low as 10^{-3} (for the yield relative to the single muon events) and for the reaction (2) we expect to be set an upper limit as low as $\sim 3 \cdot 10^{-4}$. If the relative yield of $\mu^+ e^-$ events in antineutrino interactions is the same as the relative yield of $\mu^- e^+$ events in neutrino interactions we expect ~15 events for reaction (1) and ~50 events for reaction (2) respectively.

The main background for the reaction (1) is due to electron neutrino interactions, for example:

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$$\nu_e p \rightarrow e^- \pi^+ X$$

where the fast π^+ is incorrectly identified as a muon by the EMI. Based on the calculated ν_e contamination in the beam and the "punch-through" probability we expect ~1 background event from this source.

For the reaction (2) in addition to the ν_e induced background there are backgrounds due to Dalitz pairs, and due to assymetric pairs and Compton electrons produced by gamma-rays which convert in the plate where the interaction occurred. By requiring that the electron momentum be greater than 1 GeV/c and by eliminating events where the invariant mass of the e^- and any primary gamma ray is consistent with a π^o, this background can be reduced to a reasonable level ~10 events.

The observation of a few tens of $\mu^+ e^-$ events will enable us to study the accompanying hadrons in these events and in particular to measure the yield of strange particle production. The excellent energy resolution in this experiment enables us to investigate the detailed production mechanism for these events and to check for example the hypothesis that the μe events are produced by the decay of a new particle:

$$\bar{\nu}_\mu N \rightarrow \mu^+ Y X$$
$$\quad\quad \hookrightarrow e^- \nu_e X'$$

and also to investigate other possible production mechanisms.

<u>$\mu\mu$ pairs</u>

Possible reactions with two mesons in the final state are:

$$\bar{\nu}_\mu p \rightarrow \mu^+ \mu^- X \tag{4}$$

$$\bar{\nu}_\mu Nuc \rightarrow \mu^+ \mu^- X \tag{5}$$

Based on the CTF data we expect to obtain ~16 events for reaction (4) and 50 events for reaction (5). The main backgrouond is due to EMI "punch-through". Based on the E-180 data we conclude that the "punch-through" probability is 6.5% for hadrons with momentum greater than 6 GeV/c. The background will be comparable to the expected signal. Using various kinematic cuts we expect to be able to reduce this background further. An analysis of $\mu^+\mu^+$ events will be useful to check the background estimates. An analysis of the associated hadrons in the dimuon events, particularly a measurement of the yield strange particles, will

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help to understand the production mechanism of the dimuon events and inparticular will help to check the hypothesis that the dimuon events are produced by the decay of a new hadron:

$$\bar{\nu}_\mu N \to \mu^+ Y X$$
$$Y \to \mu^- \bar{\nu}_\mu X'$$

2) Search for Direct Leptons in the Neutral Currents

If the direct lepton yield for the neutral currents is approximately the same as dilepton yield for the charged currents, we can expect ~5-10 neutral current events with a charged single lepton generated in pure hydrogen.

The background in this case comes from two sources:

i) Ordinary charged current $\bar{\nu}_\mu$, $\bar{\nu}_e$ and ν_e interactions and

ii) neutral current events where a hadron is misidentified as a muon by the EMI.

3-C fits for the charged current events will help to eliminate background (i). Events with large transverse momentum imbalance will be good candidates for direct lepton production by neutral currents. By eliminating events in which the momentum of the charged lepton is very high we can reduce the background from both sources (i) and (ii).

3) Effective Mass Inclusive Distributions

We will search for new narrow resonance production by plotting the invariant mass combinations for events with strange particles (e.g., $K^o n\pi$, $\Lambda^o n\pi$, where n = 1, 2 .... charged or neutral pions).

4) Analysis of Exclusive Channels with Strange Particle Production

As is shown in Table I we expect ~300-500 strange particle events in pure hydrogen. Therefore a total kinematic analysis of exclusive channels with strange particle production will be possible. The following are possible reactions involving associated production of strange particles.

$$\bar{\nu}_p \rightarrow \mu^+\Lambda K^o M^{*)}$$
$$\rightarrow \mu^+\Sigma^o K^o M$$
$$\rightarrow \mu^+\Sigma^- K^+ M$$
$$\rightarrow \mu^+\Sigma^+ K^o \pi^- M$$
$$\rightarrow \mu^+\Xi^- K^o K^+ M$$
$$\rightarrow \mu^+\Xi^o K^o K^o M$$
$$\rightarrow \mu^+ p K^- K^o M$$

The cross section for strangeness changing processes $\Delta S = \Delta Q$ in charged current reactions is directly proportional to the Cabibbo angle - squared.

$$\bar{\nu}_p \rightarrow \mu^+\Lambda M$$
$$\rightarrow \mu^+\Sigma^o M$$
$$\rightarrow \mu^+\Sigma^- \pi^+ M$$
$$\rightarrow \mu^+\Sigma^+ \pi^- M$$

*) M means either nothing or $\pi^+\pi^-$ pairs with (without) π^o mesons.

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The most interesting possibility is the detection of $\Delta S = -\Delta Q$ reactions which are characteristic of charmed particle production. Possible examples of $\Delta S = -\Delta Q$ reactions in $\bar{\nu}p$ interactions are:

$$\bar{\nu}p \rightarrow \mu^+ p \bar{K}^o \pi^- M$$
$$\rightarrow \mu^+ p K^- \pi^+ M$$

One possible example for a $\Delta S = - \Delta Q$ reaction

$$\nu p \rightarrow \mu^- \Lambda \pi^+ \pi^+ \pi^+ \pi^-$$

was found in a neutirno exposure. No evidence has yet been found for antineutrino induced $\Delta S = -\Delta Q$ events.

Very little information exists on strange particle production by neutral currents. We will be able to observe strange particle production by neutral currents in this experiment. Possible associated production reactions are:

$$\bar{\nu}p \rightarrow \bar{\nu}\Lambda K^+ M$$
$$\rightarrow \bar{\nu}\Sigma^+ K^o M \qquad \Delta S = 0$$
$$\rightarrow \bar{\nu}\Sigma^o K^+ M$$
$$\rightarrow \bar{\nu}\Sigma^- K^+ \pi^+ M$$

We will be able to place upper limits on strangeness changing neutral currents reactions, for example:

$$\bar{\nu}p \rightarrow \bar{\nu}K^{o}pM$$
$$\rightarrow \bar{\nu}\Lambda^{o}\pi^{+}M$$
$$\rightarrow \bar{\nu}\Sigma^{+}M \qquad \Delta S = 1$$
$$\rightarrow \bar{\nu}\Sigma^{o}\pi^{+}M$$
$$\rightarrow \bar{\nu}\Sigma^{-}\pi^{+}\pi^{+}M$$

It will be possible to make useful 0-C fits and to investigate in detail the production mechanism for strange particles in neutral currents.

II. DEEP INELASTIC SCATTERING

1) Charged Currents

There are several reasons why it is important and interesting to study deep inelastic scattering of neutrinos and antineutrinos. We can extract very fundamental information from this data about constituents of the nucleons. Additional information is obtained by comparing this data with data from eN and μN scattering experiments. Observations of deviations from Bjorken scaling are very important theoretically.

In the bare hydrogen bubble chamber neutral particles are detected with very low efficiency and it is not possible to estimate the energy of the incoming antineutrino (or the inclusive variables x, y, Q^2, W^2, etc.) very accurately. In this experiment it will be possible to do 3-C fits for the charged current events. This feature will very much improve the accuracy of the inclusive variables. This will permit a detailed study of scaling violations and will lead to a better understanding of the high y-anomaly.

By comparing our results with the result from the corresponding neutrino experiment we will be able to obtain good estimates for the weak structure functions and to test some theoretical relations and sum rules, for example the Adler sum rule.[9]

2) Neutral Currents

The excellent energy resolution in the proposed experiment is particularly advantageous for the investigation of neutral current events. In previous experiments the only measured variable was and the other variables E, x, y, Q^2, etc., were not precisely determined. In this experiment there is good neutral detection efficiency and good energy resolution and the energy of incoming antineutrinos can be obtained from a 0-C fits. Up to the present time that the distributions in the scaling variables (x, y, Q^2, W^2, etc.) have not been measured for the neutral currents. Measurements of inclusive distributions for understanding the nature of the weak neutral current. We expect to obtain approximately 1,500 antineutrino-proton and 5,000 antineutrino-nucleus neutral current interactions:

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$$\bar{\nu}_\mu p \rightarrow \bar{\nu}_\mu X \quad (7)$$

$$\bar{\nu}_\mu Nuc \rightarrow \bar{\nu}_\mu X \quad (8)$$

The most important background for the reactions (7) and (8) is due to neutrino induced neutral current events. The use of the plug to suppress neutrino contamination in the beam will help to decrease these backgrounds.

3) Measurement of $R = \sigma_{\bar{\nu}p}/\sigma_{\bar{\nu}n}$ in Charged and Neutral Currents

Some models predict that the ratio $R = \sigma_{\bar{\nu}p}/\sigma_{\bar{\nu}n}$ will be energy dependent and a good measurement of R as a function of energy will be a sensitive test of these models.[10]

The hydrogen bubble chamber together with the ITC system will provide a very simple method for measuring R in both charged and neutral currents. The spatial separation of the hydrogen target from the nuclear target and the large hydrogen fiducial volume make it possible to measure R to an accuracy of ~4%. A measurement of R in the bare bubble chamber with a hydrogen-neon mixture is considerably more complicated and uncertain due to the problem of identifying the target for each event.

4) Multiplicity Distributions

It is important to obtain information about the neutral multiplicity in neutrino and antineutrino interactions. In this experiment it will be possible to investigate multiplicity distributions for both charged and neutral particles as functions of W^2 and Q^2 in both charged and neutral

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current antineutrino interactions in pure hydrogen. These measurements can be compared with corresponding data from electroproduction and photoproduction experiment.

5) Exclusive Channels

A comparison of ρ-meson production in the neutral and charged current reactions

$$\bar{\nu}p \rightarrow \mu^+\rho^- p$$
$$\bar{\nu}p \rightarrow \bar{\nu}\rho^o p$$

will provide important information about the isotopic spin structure of the weak interaction. Using the vector dominance model the coupling constants for $W^+\rho^+$ and $Z^o\rho^o$ can be obtained.

We can also study other meson resonance production, for example ω^o, η, η', θ, A_2, f, etc.

Baryon resonances could be studied in the following reactions

$$\bar{\nu}p \rightarrow \mu^+\Delta^o,\ N^o$$
$$\rightarrow \bar{\nu}\Delta^+,\ N^{+*},\ \text{etc.}$$

The high neutral detection efficiency in this experiment will enable us to study the simultaneous production of meson and baryon resonances in the same reaction by both charged and neutral currents.

$\bar{\nu} p \to \mu^+ \rho^o \Delta^o, N^o$ $\quad$ $\bar{\nu} p \to \bar{\nu} \rho^o \Delta^+, N^+$

$\to \mu^+ \rho^- \Delta^+, N^+$ $\quad$ $\to \bar{\nu} \rho^+ \Delta^o, N^o$

$\to \mu^+ \rho^+ \Delta^-, N^-$

$\to \mu^+ \omega^o \Delta^o, N^o$

6) Electron Antineutrino Interactions

There is a small admixture ~2-3% of $\bar{\nu}_e$ in the $\bar{\nu}_\mu$ beam. We expect ~100-200 $\bar{\nu}_e$ p events and 300-600 $\bar{\nu}_e$ Nuc events. These events can be identified at the scanning stage with very high efficiency. The statistics will be good enough to enable us to study some characteristics of electron antineutrino interactions.

III. STUDY OF NUCLEAR INTERACTIONS

We propose to investigate the possibility of using an ITC with plates of different materials. This would enable us to investigate the A-dependence of the total cross section and to study nuclear effects as a function of A.

We propose to install nine plates in the chamber made from different materials: Al, Fe, Sn, Ta. The proposed modification would allow us to measure the cross section for different values of A in one experiment with the same systematics. The atomic weight changes from 1 (in the hydrogen) through 181 (in the tantalum). The arrangement of the plates would be basically similar to the arrangement described in proposal #489 and the effective number of radiation lengths would be approximately the same.

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We would also like to investigate a specific nuclear effect referred to as nuclear scaling.[11] The invariant function f = $\frac{E}{p^2}\frac{d^2\sigma}{dpd\Omega}$ for protons produced in the backward hemisphere in the laboratory system has an exponential form $f = c\, e^{-Bp^2}$. Experiments made in recent years show that the parameter B is independent of the initial energy, the type of incident particle and the atomic weight of the target. The parameter C is independent of the energy and type of incident particle. It will be interesting to check nuclear scaling for neutrinos and antineutrinos. We estimate that we will obtain approximately 800 events with protons in the backward directions.

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TABLE I

EXPECTED YIELD OF $\bar{\nu}$ EVENTS in 15-Ft. CHAMBER WITH ITC

Reaction	Number of Events		
	E-180	E-28	This Experiment
$\bar{\nu}_p \rightarrow \mu^+ X$	3500	6000	4000
$\rightarrow \bar{\nu} X$	1300	2200	1500
$\rightarrow \Lambda/K_s^o X$	300	500	300
$\rightarrow \mu^+ e^- X$	10	15	10
$\rightarrow \mu^+ \mu^- X$	10	15	10
$\bar{\nu}_p \rightarrow$ anything	5000	9000	6000
$\bar{\nu}$Nuc $\rightarrow \mu^+ X$	13000	21500	14500
$\rightarrow \bar{\nu} X$	5000	8000	6000
$\rightarrow \mu^+ e^- X$	40	60	40
$\rightarrow \mu^+ \mu^- X$	40	60	40
$\bar{\nu}$Nuc $\rightarrow$ anything	18000	30000	20000

The calculations were done for $5 \cdot 10^5$ p photos, $1.3 \cdot 10^{13}$ ppp, 400 GeV protons, 2 horns with a plug, $16 m^3$ hydrogen, $\Sigma P_x > 8.5$ GeV/c.

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TABLE II

A COMPARISON OF THE RESOLUTION FOR SOME KINEMATIC VARIABLES IN THE BARE CHAMBER AND THE CHAMBER WITH THE ITC SYSTEM (FROM P-489)

Variables	Charged Currents		Neutral Currents	
	H_2	H_2 + ITC	H_2	H_2 + ITC
$E_{\bar{\nu}}$	8%	2%	Not measureable	20%
X	0.03	0.007	" "	0.1
Y	0.04	0.01	" "	0.1
Q^2	8%	1.5%	" "	20%
ν	16%	4%	" "	5%
W	8%	2%	" "	7%

Fermilab Proposal 544-A

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PROPOSAL TO STUDY ANTINEUTRINO INTERACTIONS IN HYDROGEN WITH GAMMA RAY CONVERTER SYSTEM IN THE 15-FT BUBBLE CHAMBER

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PROPOSAL TO STUDY ANTINEUTRINO INTERACTIONS IN HYDROGEN WITH A GAMMA RAY CONVERTER SYSTEM IN THE 15-FT BUBBLE CHAMBER

ABSTRACT

We propose to investigate antineutrino interactions on free protons with 90% gamma conversion and 95% electron and muon identification by using a downstream converter (DC) system in the 15-ft bubble chamber.

We request an exposure to 500,000 pictures in a broad-band antineutrino horn beam. We request a primary proton intensity of $\gtrsim 1.3 \cdot 10^{13}$ protons per pulse at 400 GeV/c. Based on the yields of antineutrino events in E-180 and E-31 we expect to obtain 6,000 antineutrino interactions from this exposure.

The following physics topics will be investigated:

I. New Particle Production

The detection of two leptons and/or strange particles in the final state will be studied as a signature for new particle production.

II. Inclusive Reactions

Investigation of the neutral current structure and parity nonconservation using free protons as isovector targets.

III. Exclusive Reactions

IV. Nuclear Interactions

A-dependence of total cross sections and nuclear scaling.

V. Electron Antineutrino Interactions

INTRODUCTION

Neutrino and antineutrino experiments in the last few years have provided many new results which have significantly advanced our understanding of the characteristics of the weak interaction. In addition to the discovery of neutral currents, several entirely new phenomena associated with charged current reactions have been revealed:

1. Dimuon events in both neutrino and antineutrino interactions.
2. μ-e events in neutrino interactions.
3. Trimuon events in neutrino interactions.

It is clear that continued experimental effort in this field is extremely important.

We propose to investigate antineutrino interactions in the Fermilab 15-ft bubble chamber filled with hydrogen, and supplemented by the downstream converter (DC) and the External Muon Identifier (EMI).

Our request is for an exposure of 500,000 pictures in a broad-band antineutrino horn beam. We request a primary proton intensity of $\gtrsim 1.3 \times 10^{13}$ protons per pulse and a primary proton energy of 400 GeV. Based on the yields obtained in experiments E-180 and E-31 we expect to obtain approximately 6,000 antineutrino-hydrogen events.

The unique features of the proposed experiment are:

1. The experimental arrangement combines the advantages of the free proton target characteristic of the hydrogen

bubble chamber with the improved detection efficiency for neutral particles usually associated with a heavy liquid filling. This feature provides the ability to make 3-C fits, in the case of the CC events and meaningful 0-C fits, in the case of the NC events for a very much larger class of reactions than would be possible using the bare bubble chamber alone.

2. The introduction of the DC system allows the identification of electrons with high efficiency while keeping unbiased accurate measurements of the electron energy.
3. 90% of the gamma-rays produced in antineutrino interactions would be detected. Their energy will be measured with reasonable precision (20%-30% for energies above 3 GeV). Therefore, a major part (70%) of energy going into neutrals which is lost in bare chamber experiments, is detected. In addition, the reconstruction of neutral pions which is possible with the proposed DC system allows the study of exclusive channels containing one final state pi-zero. Observation of gamma-rays can be used also as a veto signal for exclusive channels which do not contain a pi-zero.

PHYSICS

I. New Particles

The intrinsic advantages of the DC system are particularly important in this experiment because they make it possible to detect charmed particles with high efficiency and low background. The free proton target coupled with good neutral detection make it possible to use the 0-C fits for some charmed particle production channels. In particular, 0-C fits will provide good mass resolution (50-100 MeV) in the case of semileptonic decays.

The easiest way to detect charmed particles is to find evidence for semileptonic decays by searching for events with two charged leptons, in the case of charged current reaction, and for events with a single lepton in the case of the neutral current reactions.

Hadronic decay modes can be detected by analyzing events with strange particles. In this experiment we can detect with high efficiency not only neutral strange particles, but also charged strange particles ($K^{\pm}$, $\Sigma^{\pm}$, etc.). For charged strange particles hydrogen is to be preferred because of the large nuclear interaction length (~ 7m).

In general, charmed particles are expected to decay preferentially into strange particle final state by a factor $ctg^2\theta_C$ and the detection of a strange particle in an event will be a useful signature of possible charmed particle production in the proposed experiment.

A. Leptonic Pair Production

The bubble chamber used in conjunction with the DC and the EMI provides efficient and reliable identification of muons and electrons.

μ-e Pairs

The reaction with a muon and an electron in the final state is:

$$\bar{\nu}_\mu p \rightarrow \mu^+ e^- X \qquad (1)$$

Based on the preliminary results of E-180, we expect ~ 15 events for reaction (1).

The main background for the reaction (1) is due to electron neutrino interactions, for example:

$$\nu_e p \rightarrow e^- \pi^+ X$$

where a fast π^+ is incorrectly identified as a muon by the EMI. Based on the calculated ν_e contamination in the beam and the "punch-through" probability we expect ~ 1 background event from this source.

The observation of μ^+e^- events will enable us to study the accompanying hadrons in these events and in particular to measure the yield of strange particle production. The excellent energy resolution in this experiment enables us to investigate the detailed production mechanism for these events and to check for example the hypothesis that the μe events are produced by the decay of a charmed particle such as:

$$\bar{\nu}_\mu p \rightarrow \mu^+ F^- p M^* \qquad F^- \rightarrow e^- \bar{\nu}_e \pi^+ \pi^- \tag{2}$$

$$\bar{\nu}_\mu p \rightarrow \mu^+ \bar{D}^o \Lambda M \qquad \bar{D}^o \rightarrow e^- \bar{\nu}_e K^+ \tag{3}$$

$$\bar{\nu}_\mu p \rightarrow \mu^+ D^- \Sigma^- M \qquad D^- \rightarrow e^- \bar{\nu}_e K^o \tag{4}$$

and also to investigate other possible production mechanisms.

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*M means either nothing or $\pi^+\pi^-$ pairs with or without π^o mesons.

$\mu\mu$ Pairs

The reaction with two opposite-sign muons in the final state is

$$\bar{\nu}_\mu p \rightarrow \mu^+\mu^- X \quad (5)$$

This reaction can be studied if the EMI is improved to reduce the "punch through" background from hadrons. An analysis of the associated hadrons in the dilepton events, particularly a measurement of the yield of strange particles, will help us to understand the production mechanism and in particular will help to check the hypothesis that the dilepton events are produced by the decay of a new hadron:

$$\bar{\nu}_\mu N \rightarrow \mu^+ Y X, \quad Y \rightarrow \mu^- \bar{\nu}_\mu X'$$

B. Search for Direct Leptons in the Neutral Currents

If the direct lepton yield for the neutral currents is approximately the same as dilepton yield for the charged currents, we can expect ~ 5-10 neutral current events with a charged single lepton generated in pure hydrogen.

The background in this case comes from two sources:

i) Ordinary charged current $\bar{\nu}_\mu$, $\bar{\nu}_e$ and ν_e interactions, and
ii) Neutral current events where a hadron is misidentified as a muon by the EMI.

3-C fits for the charged current events will help to eliminate background (i). Events with large transverse momentum imbalance will be good candidates for direct lepton production by neutral currents. By eliminating events in which the momentum of the charged lepton is very high we can reduce the background.

C. Search for Hadronic Modes of New Particle Decays

Using the excellent resolution of the hydrogen filling we will search for production of new narrow resonances by studying invariant mass combinations. The reactions which we can study are, for example:

$$\bar{\nu}_\mu p \rightarrow \mu^+ \bar{D}^o \Lambda M$$
$$\hookrightarrow K^+\pi^- \; (K^o\pi^+\pi^-)$$

$$\bar{\nu}_\mu p \rightarrow \mu^+ D^- \Sigma^+ M$$
$$\hookrightarrow K^o\pi^- \; (K^+\pi^-\pi^-)$$

$$\bar{\nu}_\mu p \rightarrow \mu^+ F^- P M$$
$$\hookrightarrow K^+K^-\pi^-$$

Exclusive channels with new particles produced can be extracted with low background from the sample of events with 3-constraint fits. A direct comparison in the same experiment of hadronic and semi-leptonic decays of new particles opens the possibility to determine branching ratios for these decays.

II. Inelastic Scattering. Inclusive Reactions

A. Charged Currents

In the bare hydrogen bubble chamber neutral particles are detected with very low efficiency causing difficulties in estimating the energy of the incoming antineutrino. In this experiment it will be possible to do 3-C fits for a wide class of charged current events. This will improve the accuracy in determining the inclusive variables allowing scaling violations to be studied. Kinematic separation of protons and the reconstruction of π^o's allows one to determine the three quark fragmentation functions which can then be compared with QPM predictions.

By comparing our results with those of the corresponding neutrino experiment we will be able to obtain good estimates for the weak structure functions and to test theoretical relations among them and the sum rules.

B. Neutral Currents

At the present time our knowledge of the NC structure is very poor. Therefore the direct measurement of parity nonconservation and the measurement of NC total cross section on protons in antineutrino interactions at high energy are very important for the theory of weak interaction.

We propose to study the parity nonconservation by measuring the longitudinal polarization of the Λ-particles in the reaction

$$\bar{\nu}_\mu p \rightarrow \bar{\nu}_\mu \Lambda X$$

or determining the density matrix of ρ or Δ in the reaction

$$\bar{\nu}_\mu p \rightarrow \bar{\nu}_\mu \rho(\Delta) X.$$

We expect to obtain approximately 1500 antineutrino-proton neutral current interactions. The absence of nuclear effects, the high neutral detection efficiency and good energy resolution are of primary importance here. The proposed DC system allows the measurement of distributions of x, y, Q2 and specifically U = X (1-Y) which is associated with hadron characteristics only. The CC background can be decreased by a combination of EMI data and an improved kinematic procedure for muon identification. The neutron background can be estimated from fits to the reaction

$$(np \rightarrow pp\pi^-).$$

The weak neutral current is described by four parameters α, β, γ and δ:

$$j_{NC} = \frac{\alpha}{2}\,(\bar{U}\gamma_\mu U - \bar{d}\gamma_\mu d) + \frac{\beta}{2}\,(\bar{U}\gamma_\mu\gamma_s U - \bar{d}\gamma_\mu\gamma_s U) + \frac{\gamma}{2}\,(\bar{U}\gamma_\mu U + \bar{d}\gamma_\mu d) + \frac{\delta}{2}\,(\bar{U}\gamma_\mu\gamma_s U + \bar{d}\gamma_\mu\gamma_s U).$$

The NC total cross section data in ν and $\bar{\nu}$ beams on nuclei with I =0 (including the deuteron) allow the determination of only two combinations of these parameters, $\alpha^2 + \beta^2 + \gamma^2 + \delta^2$ and $\alpha\beta + \gamma\delta$.

In the proposed experiment using free proton targets with I = 1/2 we will be able to find independent combination of the same parameters:

$$2(\alpha\gamma + \delta\beta) + (\alpha\beta + \beta\gamma).$$

C. Multiplicity Distributions

It is important to obtain information about the neutral multiplicity in neutrino and antineutrino interactions. In this experiment it will be possible to investigate multiplicity distributions for both charged and neutral particles as functions of W^2 and Q^2 in both charged and neutral current antineutrino interactions in pure hydrogen. These measurements can be compared with corresponding data from electroproduction and photoproduction experiments.

III. Exclusive Reactions

A. Two Body and Quasi-Two Body Reactions

This experiment opens attractive possibilities for the study of the simplest exclusive channels, for example:

$$\bar{\nu}_\mu p \rightarrow \bar{\nu}_\mu p \qquad (6)$$

$$\bar{\nu}_\mu p \rightarrow \mu^+ n \qquad (7)$$

$$\bar{\nu}_\mu p \rightarrow \mu^+ \Lambda \qquad (8)$$

$$\bar{\nu}_\mu p \rightarrow \mu^+ \Sigma^o \qquad (9)$$

$$\bar{\nu}_\mu p \rightarrow \mu^+ \pi^- p \qquad (10)$$

$$\bar{\nu}_\mu p \rightarrow \mu^+ \pi^o n \qquad (11)$$

$$\bar{\nu}_\mu p \rightarrow \mu^+ K^o \Lambda \qquad (12)$$

The use of the DC system as a veto signal for additional neutral pions cleans the sample of events for reactions 6-12. Further rejection of background can be done by kinematic analysis. The fraction of events of each of these reactions is about 1% of the total yield. Reaction 6 is extremely important for understanding the nature of neutral currents. Previous experiments studying this reaction have been done with nuclear targets. Production of single strange particles in Reactions 8 and 9 provides a good check of the Cabbibo theory. By selecting events of reactions 10-12 with a very low energy baryon in the lab system, we can study the scattering of antineutrinos on pions and kaons, which have not yet been measured.

B. Strange Particle Production

As is shown in Table I, we expect ~ 300-500 strange particle events in pure hydrogen. Therefore a kinematic analysis of exclusive channels with strange particle production will be possible.

The most interesting possibility is the detection of $\Delta S = -\Delta Q$ reactions which are characteristic of charmed particle production. Possible examples of $\Delta S = -\Delta Q$ reactions in $\bar{\nu}p$ interactions are:

$$\bar{\nu}p \rightarrow \mu^+ p \bar{K}^o \pi^- M$$
$$\rightarrow \mu^+ p K^- \pi^+ M$$

Very little information exists on strange particle production by neutral currents. We will be able to observe strange particle production by neutral currents in this experiment. Possible associated production reactions are:

$$\bar{\nu}p \rightarrow \bar{\nu}\Lambda K^+ M$$
$$\rightarrow \bar{\nu}\Sigma^+ K^o M$$
$$\rightarrow \bar{\nu}\Sigma^o K^+ M \qquad \Delta S = 0$$
$$\rightarrow \bar{\nu}\Sigma^- K^+ \pi^+ M$$

We will be able to place upper limits on strangeness changing neutral current reactions, for example:

$$\bar{\nu}p \rightarrow \bar{\nu}K^o p M$$
$$\rightarrow \bar{\nu}\Lambda^o \pi^+ M$$
$$\rightarrow \bar{\nu}\Sigma^+ M \qquad \Delta S = 1$$
$$\rightarrow \bar{\nu}\Sigma^o \pi^+ M$$
$$\rightarrow \bar{\nu}\Sigma^- \pi^+ \pi^+ M$$

It will be possible to make useful 0-C fits and to investigate in detail the production mechanism for strange particles in neutral currents.

C. Resonance Production

A comparison of ρ-meson production in the neutral and charged current reactions

$$\bar{\nu}p \rightarrow \mu^+ \rho^- p$$
$$\bar{\nu}p \rightarrow \bar{\nu}\rho^o p$$

will provide important information about the isotopic spin structure of the weak interaction. Using the vector dominance model the coupling constants for $W^+\rho^+$ and $Z^o\rho^o$ can be obtained.

We can also study other meson resonance production, for example ω^o, η, η', ϕ, A_2, f, etc.

Baryon resonances could be studied in the following reactions

$$\bar{\nu}p \to \mu^+\Delta^o,\ N^o$$
$$\to \bar{\nu}\Delta^+,\ N^{+*},\ \text{etc.}$$

The high neutral detection efficiency in this experiment will enable us to study the simultaneous production of meson and baryon resonances in the same reaction by both charged and neutral currents.

$$\bar{\nu}p \to \mu^+\ \rho^o\ \Delta^o,\ N^o \qquad \bar{\nu}p \to \bar{\nu}\ \rho^o\ \Delta^+,\ N^+$$
$$\to \mu^+\ \rho^-\ \Delta^+,\ N^+ \qquad \to \bar{\nu}\ \rho^+\ \Delta^o,\ N^o$$
$$\to \mu^+\ \rho^+\ \Delta^-,\ N^-$$
$$\to \mu^+\ \omega^o\ \Delta^o,\ N^o$$

IV. Study of Nuclear Interactions

We propose to investigate the possibility of using in the DC system the plates with different materials; for example, to replace one steel plate with a plate made from Ta. This would enable us to investigate the A-dependence of the total cross section and to study nuclear effects such as nuclear scaling.

The essence of this phenomenon is as follows: The invariant function $f = \frac{E}{p^2}\frac{d^2\sigma}{dpd\Omega}$ for particles produced in the backward hemisphere in the laboratory system has an exponential form $f = C\, e^{-Bp^2}$. Experiments made in recent years show that the parameter B is independent of the initial energy, the type of incident particle and the atomic weight of the target. The parameter C is independent of the energy and type of incident particle. The preliminary results from E-180 show the same features of the invariant function in antineutrino interactions. We expect to have about 100 events with protons produced in the backward hemisphere and to study this process in more detail.

V. Electron Antineutrino Interactions

We expect 50-100 $\overline{\nu}_e p$ events from the 1-2% of ν_e and $\overline{\nu}_e$ in the $\overline{\nu}_\mu$ beam. These events can be reliably identified at the scanning stage because of showering in the plates. The electron energy can be measured with high precision allowing the characteristics of electron antineutrino interactions to be studied such as the x, y and Q2 dependence.

TABLE I

EXPECTED YIELD OF $\bar{\nu}$ EVENTS IN 15-FT. CHAMBER WITH DC

REACTION	NUMBER OF EVENTS BASED ON:		
	E-180	E-31	P-489
$\bar{\nu}_p \to \mu^+ X$	3500	6000	4000
$\to \bar{\nu} X$	1300	2200	1500
$\to \Lambda/K_s^o X$	300	500	300
$\to \mu^+ e^- X$	10	15	10
$\to \mu^+ \mu^- X$	10	15	10
$\bar{\nu}_p \to$ anything	5000	9000	6000

The calculations were done for $5 \cdot 10^5$ photos, $1.3 \cdot 10^{13}$ ppp, 400 GeV protons, 2 horns with a plug, $\Sigma Px > 8.5$ GeV/c.