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RESULTS ON NEUTRINO-ELECTRON ELASTIC SCATTERING
AT AGS ENERGIES

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Abstract

In an experiment designed to study elastic scattering of ν (and $\bar{\nu}$) from electrons and protons via the weak neutral current, we have recently completed several extensive data taking runs. Results for the cross section of $\nu + e \rightarrow \nu + e$ are presented based upon the first third of the available sample. Preliminary analysis of $\nu + e \rightarrow \nu + e$ is in progress and evidence for the signal is presented.

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The purely leptonic, weak neutral current reactions:

$$\nu_{\mu} + e^{-} \rightarrow \nu_{\mu} + e^{-} \quad (1)$$

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

are prescribed completely by the $SU(2)_L \times U(1)$ "Standard Model". The cross sections are small, being the order of 10^{-42} cm^2 at $E = 1 \text{ GeV}$, and are given by

$$\sigma(\frac{\nu}{\bar{\nu}}) = \frac{G_F^2 m_e^2}{2\pi} E_{\nu} \rho^2 [(g_V^e \pm g_A^e)^2 + \frac{1}{3} (g_V^e \pm g_A^e)^2]$$

Where g_V^e and g_A^e are the vector and axial vector coupling of the electron to the neutral, intermediate vector boson (Z^0), ρ can be taken as the neutrino's coupling to the Z^0 and G_F is the Fermi constant. In the "Standard Model", the expectation is that $g_A^e = -1/2$, $g_V^e = -1/2 + 2\sin^2\theta_w$, and $\rho = 1$ if the Higgs' boson is in an iso-doublet.

A precision measurement of the parameter, $\sin^2\theta_w$, in purely leptonic reactions is important because it is relatively free from the uncertainties due to QCD radiative corrections.¹⁾

The precision achievable in experiments utilizing reaction (1) and (2) is emphasized by forming the ratio of their cross sections written explicitly in terms of $\sin^2\theta_w$:

$$R = \frac{\sigma(\nu_{\mu} - e^{-})}{\sigma(\bar{\nu}_{\mu} - e^{-})} = 3 \left\{ \frac{(1 - 4 \sin^2\theta_w + \frac{16}{3} \sin^4\theta_w)}{(1 - 4 \sin^2\theta_w + 16 \sin^4\theta_w)} \right\}$$

The error in $\sin^2\theta_w$ depends upon the value of $\sin^2\theta_w$ and is approximately one eighth the error in R when $\sin^2\theta_w = 1/4$ -- a condition apparently nearly satisfied in nature.

The aim in the experiment under discussion here is to measure the $\sin^2\theta_w$ as precisely as possible at low neutrino energy ($\sim 1 \text{ GeV}$). The fundamental limit to the precision is expected to arise from systematic uncertainties principally due to relative flux normalization.

The experiment is being performed at the Alternating Gradient Synchrotron of the Brookhaven National Laboratory. The detector consists of an active material (liquid scintillator) which also serves as a calorimeter ($\Delta E/E = 0.15/(E)^{1/2}$) and to provide fast timing. Figure 1 and Table I contain the details of the detector parameters. The

TABLE I

BROOKHAVEN NEUTRINO DETECTOR

LOCATION Brookhaven National Laboratory, Upton, NY 11973 USA

INCIDENT BEAM Neutrino, Horn Focussed from 28 GeV Protons 110m from proton target

ASSEMBLY Modular construction; each module consisting of a plane of calorimeter and two planes (x,y) of tracking proportional drift tubes 112 Modules + γ -Catcher + Spectrometer
Weight 172 + 30 metric tons

MODULE PROPERTIES

CALORIMETER (LIQUID SCINTILLATOR)

Active Area $4.22 \times 4.09 \text{ m}^2$ Thickness 7.9 cm
Weight (Liquid and Acrylic) 1.35 metric tons
16 cells/module 2 Amperex 2212A phototubes/cell
1 Pulse Height Measurement/2 Time Measurements per Tube Readout

PROPORTIONAL DRIFT TUBES (PDT)

Active Area $4.2 \times 4.2 \text{ m}^2$
Thickness (x and y) 7.6 cm 54 x wires 54 y wires
1 Pulse Height Measurement/2 Time Measurements per Wire Readout

GAMMA CATCHER 10 standard calorimeter modules with 2 radiation length of lead between each module
30 metric tons target mass.

MUON SPECTROMETER

2m x 2m Aperture Muon Spectrometer
 $\langle f \text{ Bd} \rangle = 70 \text{ MeV/c}$
 $(\Delta p/p)^2 = (.10^2 + (.067p))^2 p \text{ in GeV/c}$

TABLE II

Data Runs Accumulated

Protons on Target

Run No.	ν	$\bar{\nu}$	Fid. Vol.
I	6.3×10^{18}	5×10^{17}	1/2
II	8.8×10^{18}	9.1×10^{18}	1
III	1.4×10^{19}	2.7×10^{19}	1

construction is modular with each calorimeter plane matched with a proportional drift tube plane pair (X,Y) which provides precision measurements of angle ($\Delta\theta = 0.022 \text{ rad}/(E)^{1/2}$ for electrons) as well as additional pulse height and timing information. A magnetic spectrometer (air gap) follows the detector and is used to aid in establishing the properties of the neutrino (anti-neutrino) flux.

The detector is operated in a trigger-less mode via a pre-beam initiated 10 μsec gate during which the beam is extracted in 12 R.F.-buckets of 30nsec duration separated by 224 nsec. The beam pulse repetition rate is approximately 40 per minute. The average beam energy is approximately 1.5 GeV for ν_μ and 1.3 GeV for $\bar{\nu}_\mu$. This beam structure permits continuous monitoring of possible out-of-time backgrounds ($< 1\%$) and initial event selection by time-clustering of hits.

The kinematics of the reactions (1) and (2) provide a distinctive signal. In particular, the relation $E_e \theta_e^2 = 2 m_e (1 - E_e/E)$ restricts events to very small laboratory angles.

Here θ_e and E_e are the laboratory angle and energy, respectively, of the recoil electron. From this relation it can be seen that all of the signal is contained at $E_e \theta_e^2 < 2 m_e$ exclusive of resolution. At AGS energies the mean energy of the recoil electron is roughly 500 MeV thus the corresponding r.m.s. angles are less than 0.045 radians. The signal is consequently very strongly forward peaked.

Details of the analysis procedure can be found elsewhere;²⁾ however a brief discussion is given here.

The event sample to be studied is initially selected from the raw data tapes by loose software filters designed to select forward-going ($< 20^\circ$) events which do not contain muons or extra hadrons. The resulting sample is then cut to contain only events with shower angles less than 180 mr; this sample contains more than 90% of the reaction (1) and (2) events.

The principal backgrounds arise from the quasi-elastic reactions involving the small contamination of ν_e and $\bar{\nu}_e$ ($< 0.5\%$) in the respective beams and from the neutral current production of π^0 mesons in which some fragments in the final state are not detected and only an electromagnetic shower remains. However, the angular and energy correlations of the background showers are quite different from those of the signal. At AGS energies θ^2 distributions are relatively flat and the electron energies from the ν_e reactions are large. To aid in suppression of these

backgrounds cuts are made on θ_e^2 ($0 - 0.01 \text{ rad}^2$) and E_e ($210 - 2100 \text{ MeV}$) after an initial selection has been made to separate electromagnetic showers predominantly photon initiated.

This selection is carried out by using the ionization energy deposits in the early part of the shower where photon-initiated showers tend to have more than minimum ionization deposit. The algorithm to achieve this uses the pulse height information from the first calorimeter plane after the vertex and the average of minimum (of X and Y) pulse heights for the first two proportional drift tube pairs. The acceptable pulse height levels are set by comparison to several reference samples: beam muons, electrons from $\nu_e + n \rightarrow e^- + p$, and photons derived from events seen in the detector with electromagnetic showers pointing back to a disconnected vertex. Figures 2 and 3 illustrate the pulse height distributions for these samples as well as those of the signal plus background candidates (Fig. 2d, 3d). Over a wide range of pulse height cuts the size of the signal is quite insensitive. A typical choice is made such that 90% of the electrons are accepted as minimum ionizing.

Table II lists the data samples accumulated so far. The data presented here from our analysis to date, are contained in II(ν) and one-half of (II($\bar{\nu}$) plus III($\bar{\nu}$)).

In Fig. 4a are shown the θ^2 distribution for the ν_μ sample of those events classified as consistent with minimum ionization at the vertex. Figure 4b are those identified as more than minimum ionizing. The distribution in θ^2 of this latter sample is flat with no evidence of a peak at small angles. A signal of 51 ± 9 electrons from reaction (1) is extracted from the θ^2 distribution utilizing the region $\theta^2 > 0.01$ to establish the flat background level. Figure 5a and 5b show the preliminary θ^2 distributions for a subset of the $\bar{\nu}_\mu$ data. A clear signal of 44 ± 12 events of reaction (2) is derived from this subset under the same procedure used for the ν_μ .

Our intended procedure for extracting a final value of $\sin^2\theta_w$ is to first normalize each reaction (1) and (2) separately to the corresponding neutrino and anti-neutrino flux by reference to the low- Q^2 quasi-elastic cross sections and then form the ratio, R.

Samples of reactions (4) and (5) are filtered from the raw data

$$\nu_\mu + n \rightarrow \mu^- + p \quad (4)$$

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

tapes simultaneously with those of reactions (1) and (2). Normalization candidates are selected by requiring a single track at the vertex with an angle of $< 15^\circ$ with respect to the beam axis and for which the single track has a range of at least 20 calorimeter modules. Subtractions from the normalization sample must be made for inelastic backgrounds: reactions (6), (7), and (8) for ν_μ and reactions (9), (10), and (11) for $\bar{\nu}_\mu$.

$$\nu_\mu + p \rightarrow \mu^- + p + \pi^+ \quad (6) \qquad \bar{\nu}_\mu + n \rightarrow \mu^+ + n + \pi^- \quad (9)$$

$$\nu_\mu + n \rightarrow \mu^- + p + \pi^0 \quad (7) \qquad \bar{\nu}_\mu + p \rightarrow \mu^+ + n + \pi^0 \quad (10)$$

$$\nu_\mu + n \rightarrow \mu^- + n + \pi^+ \quad (8) \qquad \bar{\nu}_\mu + p \rightarrow \mu^+ + p + \pi^- \quad (11)$$

Corrections must also be made to both signal and normalization channels for efficiencies and acceptance within cuts. This procedure has been completed for the data II(ν). For the sample II($\bar{\nu}$) and III($\bar{\nu}$), the analysis has recently started. Consequently, a result for only reaction (1) is presented together with preliminary progress on reaction (2).

Corrections to the reaction (1) signal of 51 ± 9 are made for losses (pulse height, 5%; $\theta^2 < 0.01 \text{ rad}^2$, 13%; $210 < E < 3200 \text{ MeV}$, 24%; angle reconstruction, scanning, and filtering, 21%). Corrections to the reaction (4) normalization sample include background subtractions of 13% for reactions (6) plus (8), 4% for reaction (7), 16% for acceptance, and 24% for inefficiencies.

This analysis yields the result for reaction (1):

$$\sigma(\nu_\mu + e^- \rightarrow \nu_\mu + e^-) = [1.60 \pm 0.29(\text{stat.}) \pm 0.26(\text{sys.})] \times E_\nu (\text{GeV}) \times 10^{-42} \text{ cm}^2$$

Data analysis has recently begun for finding $\sigma(\bar{\nu}_\mu + e^- \rightarrow \bar{\nu}_\mu + e^-)$. Studies have begun on internal consistency checks for the more difficult background ($\sim 25\%$) reactions (9), (10) and (11) which do not contain decaying π^+ . Several corrections made to establish $\sigma(\nu_\mu + e^- \rightarrow \nu_\mu + e^-)$ and $\sigma(\bar{\nu}_\mu + e^- \rightarrow \bar{\nu}_\mu + e^-)$ are common to both numerator and denominator in R; studies are underway to establish the level of compensation (or cancellation) thus provided and hence the limit of systematic error.

As can be seen from Table II and Figs. 4,5, we expect to obtain from our present data a total of approximately 150 events for reaction (1) and 90 events for reaction (2). Recently, the collaboration has been approved for additional extensive data-taking runs. With the presently increased average intensity of the AGS a doubling of the data sample is to be expected. Preliminary indications are that a final precision of $0.01 - 0.015$ on $\sin^2 \theta_w$ would then be possible from this experiment.

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BNL NEUTRINO DETECTOR

Figure 1. Elevation and detail of BNL/Brown/KEK/Osaka/Pennsylvania/Stony Brook neutrino detector (E-734).

FIG. 2

Figure 2: Pulse height distributions for neutrino data. Left column is for first calorimeter after vertex; right column is for $(X + Y)$ of first and second planes of proportional drift tubes. (a) beam muons, (b) $e^- + n$ $e^- + p$, (c) photon initiated, (d) signal plus background sample prior to separation by ionization.

FIG. 3

Figure 3. Same as Figure 2 but for anti-neutrino sample.

FIG. 4

Figure 4. θ^2 distribution for neutrino data. (a) events satisfying minimum ionizing cut, (b) events failing minimum ionizing cut, (c) photon induced sample.

$$\bar{\nu}_{\mu}$$

Figure 5. Same as Figure 4 but for anti-neutrino sample.