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Probing nuclei with antineutrinos

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From a sample of charged-current antineutrino events in a Ne-H mixture we have obtained a subsample of events having a backward proton in the laboratory. The systematics of these backward-proton events are found to be in agreement with previous results from backward-proton events obtained using hadron and γ beams.

In recent years a number of experiments have investigated backward-proton production from inclusive reactions of the type

$$a+A \to p+X ,$$

where A is a target nucleus, a is a hadron or γ, and p is a proton emitted into the backward hemisphere in the laboratory. Backward protons cannot originate from interactions on free nucleons; therefore backward-proton events permit investigation of the structure of the nucleus. Systematic investigations of experimental inclusive backward-proton spectra obtained using hadron and γ beams, as summarized by Leksin[1] and Frankel *et al.*[2] have shown that the backward-proton spectra are insensitive to either the nature of the incident particle or its energy. Many different theoretical interpretations of this phenomenon have been published (see, for example, Ref. 3). We report here backward-proton production in antineutrino-neon charged-current interactions. These are the first published results on backward-proton production obtained from neutrino- or antineutrino-initiated interactions.[4]

The data come from a 74 400-picture exposure of the Fermilab 15-ft. bubble chamber filled with a 21% atomic Ne-H mixture. The exposure was 6×10^{17} protons on target at 300 GeV using the horn-focussed broad-band antineutrino beam. The charged-current (cc) sample was obtained by identifying the muon either by using the external muon identifier (EMI) or by applying a kinematic method based on the muon having a high transverse momentum relative to the other particles in the event.[5] Consideration of various efficiencies and backgrounds leads to the further cc-event-selection requirements that the muon have momentum $P_\mu > 4$ GeV/c and that the antineutrino have energy $E_{\bar{\nu}} > 10$ GeV.[6] A total of 837 antineutrino charged-current events were obtained.

Tracks were identified as backward protons if all of the following criteria were satisfied:

(1) The track emerged into the backward hemisphere in the laboratory.

(2) The proton momentum was between 0.2 and 0.7 GeV/c.

(3) The proton momentum from curvature was not inconsistent with the measured range for a proton.

(4) There was no evidence for particle decay.

The selected sample contains 36 events. The momentum spectrum for the protons from this sample is shown in Fig. 1. The invariant momentum spectrum was fitted for the entire backward hemisphere ($90° < \theta \leq 180°$) to the form

$$\frac{E}{P^2}\frac{dN}{dP} = Ce^{-BP^2} \qquad (1)$$

to obtain the slope parameter $B = 9.5 \pm 1.9$ (GeV/c)$^{-2}$. In Eq. (1), E and P are the proton energy and momentum, respectively, and C is related to the rate of backward-proton production. In gener-

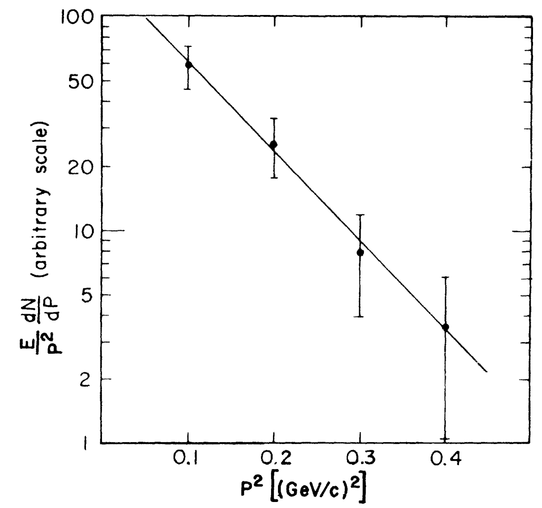

FIG. 1. Distribution of proton laboratory momentum (P) for the 36 backward-proton events. The solid line is a fit to $(E/P^2)dN/dP = Ce^{-BP^2}$.

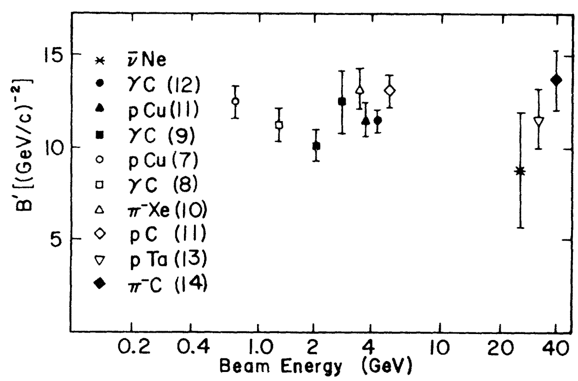

FIG. 2. Comparison of the parameter B' obtained in this experiment to values obtained in other experiments at various energies using hadron and γ beams incident on various targets.

al the slope parameter B depends on θ. Most of the existing data are in the angular region $120° < \theta < 150°$. For this restricted angular range we obtain a slope parameter $B' = 8.9 \pm 3.1$ $(\mathrm{GeV}/c)^{-2}$. Figure 2 shows a comparison of our value of B' to values obtained in other experiments at various energies using hadron and γ beams incident on various targets.[7-14] Within the rather large errors our data are consistent with the conclusion that B' is independent of the type of incident particle even for an interaction initiated by a weakly interacting point-like probe.

The rate $f_{\bar{\nu}\mathrm{Ne}}$ of backward- ($\theta \geq 90°$) proton charged-current events relative to all antineutrino-Ne charged-current events can be obtained from these data. The observed non-backward-proton events are apportioned between H and Ne interactions by using the known bubble-chamber mixture and the ratio $\sigma_{\bar{\nu}p}/\sigma_{\bar{\nu}n} \approx 2.25$ obtained in this experiment.[15] We obtain $f_{\bar{\nu}\mathrm{Ne}} = 0.07 \pm 0.01$.

The relative rate of backward-proton events has been shown in hadron and γ-ray experiments to depend only on the target mass number for backward protons in a fixed angle interval.[1] Using the backward production rates measured in p-Cu and p-C reactions,[11] we interpolate the rate for p-Ne reactions to be $f_{p\mathrm{Ne}} = 0.08 \pm 0.03$ for the backward protons satisfying our selection criteria. We find $f_{\bar{\nu}\mathrm{Ne}} \approx f_{p\mathrm{Ne}}$, which extends the observation that the rate of backward-proton production is not

TABLE I. Mean-value comparison of backward-proton events and charged-current events.

Variable[a]	Backward-proton events	Charged-current events
Number of events	36	837
$\langle E_{\bar{\nu}} \rangle$ (GeV)	25.48 ± 2.82	28.78 ± 0.71
$\langle P_\mu \rangle$ (GeV/c)	18.10 ± 2.36	19.02 ± 0.53
$(1 - \cos\theta_\mu)$	$(2.87 \pm 0.60) \times 10^{-3}$	$(5.96 \pm 0.31) \times 10^{-3}$
$\langle \nu \rangle$ (GeV)	7.38 ± 1.47	9.71 ± 0.44
$\langle Q^2 \rangle$ [(GeV/c)^2]	1.43 ± 0.25	3.58 ± 0.15
$\langle x \rangle$	0.17 ± 0.02	0.23 ± 0.01
$\langle y \rangle$	0.26 ± 0.03	0.33 ± 0.01
$\langle n \rangle$	7.42 ± 0.64	6.20 ± 0.11
$\langle C \rangle$	2.14 ± 0.17	1.25 ± 0.04
$\langle C_1 \rangle$	0.81 ± 0.28	0.98 ± 0.04

[a] $x = Q^2/2M_p\nu$, $y = \nu/E_{\bar{\nu}}$, $\nu = E_{\bar{\nu}} - E_\mu$, $E_{\bar{\nu}}$ is the antineutrino energy; E_μ, P_μ, and θ_μ are the muon laboratory energy, momentum and scattering angle; Q^2 is the absolute value of the momentum transfer between the $\bar{\nu}$ and muon; n = number of prongs (including identified neutrals); C = total charge (sum of identified positive tracks minus identified negative tracks); C_1 = total charge as above minus protons with momentum <1 GeV/c.

dependent on the type of incident particle to include reactions initiated by a weakly interacting pointlike probe.

We summarize the deep-inelastic characteristics of the 36 backward-proton events by comparing in Table I the mean values of their kinematic variables with those of the total antineutrino charged-current event sample. There are large differences between the backward-proton sample and total sample for $\langle n\rangle$, $\langle C\rangle$, $\langle Q^2\rangle$, and $\langle 1-\cos\theta_\mu\rangle$. The differences in $\langle n\rangle$ and $\langle C\rangle$ show that the backward-proton events have on the average one more proton than the nonbackward events. We note that the average $\langle Q^2\rangle$ and $\langle 1-\cos\theta_\mu\rangle$ are closely correlated. In a previous report[16] on antineutrino charged-current interactions it was shown that $\langle Q^2\rangle$ is a function of $E_{\bar{\nu}}$. The large difference in $\langle Q^2\rangle$ cannot be attributed to the spread in center-of-mass energy caused by the Fermi motion of the nucleons in the nucleus.

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[5]This kinematic method permits recovery of events otherwise lost due to EMI geometric acceptance or technical inefficiency. For a discussion of the effectiveness of this method in supplementing the EMI see J. P. Berge *et al.*, in Proceedings of the International Neutrino Converence, Elbrus, USSR, 1977 (unpublished).

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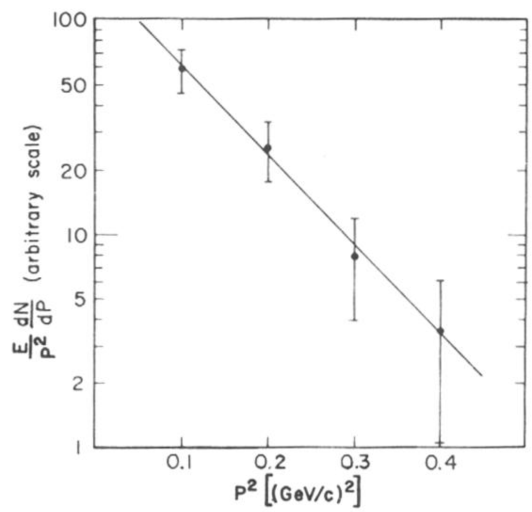

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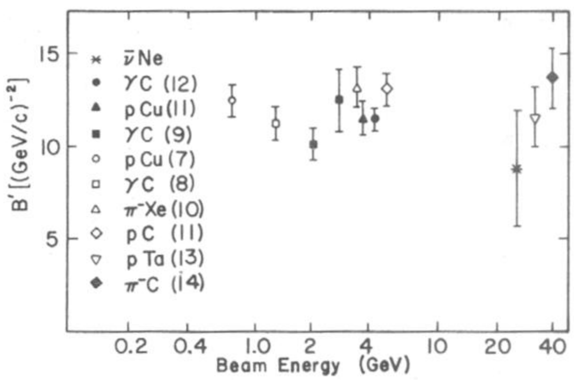

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