Scaling-Variable Distributions for Antineutrino-Nucleon Interactions

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New data are reported on high-energy antineutrino interactions obtained using the Fermilab 15-ft bubble chamber filled with a light neon-hydrogen mixture. The new data support a gentle energy dependence for the y distribution consistent with the trend of the existing data, but show no evidence for a marked energy threshold. The data for $\langle x\rangle$ and $\langle\psi\rangle = \langle xy\rangle$ show some decrease with increasing energy which may be related to scaling deviations measured in electron and muon experiments.

Evidence has been reported from experiments using calorimeter-spectrometer techniques for a large change in the character of the antineutrino muon inelasticity distributions at high energies.[1,2] These data have generated extensive theoretical discussions.[3,4] Interest centers on the behavior at high y where in these experiments the muon-acceptance losses are particularly large. (See Ref. 5 for definition of variables.) We report here the results of an experiment on high-energy charged-current antineutrino scattering performed using the Fermilab 15-ft bubble chamber. The bubble chamber used with the external muon identifier[6] (EMI) has the important advantage of good muon angular acceptance out to relatively high values of y.

The data come from an exposure of the bubble chamber (21% atomic neon-hydrogen) to the double-horn-focused antineutrino beam with plug[7] for 4.7×10^{17} 300-GeV protons. The EMI arrangement and utilization in this experiment have been previously described.[7] The efficiency of the film scan was measured in a partial double scan, and the data were corrected by weighting the events as a function of the total multiplicity. Events consisting of only a single charged track (predominately quasielastic events) were not included in the scan; the resulting bias was eliminated by accepting only events with $\nu > 2$ GeV. For accepted events the scan efficiency as a function of y varies from 0.90 to 0.98 and is largest for events at high y.

The charged-current event sample considered in this Letter includes only events with a positive muon identified by the EMI. To reduce backgrounds and to ensure good EMI acceptance, we require that the total measured momentum along the beam direction, P_x, be greater than 7.5 GeV/c and that the momentum of the muon, P^μ, be greater than 4 GeV/c. The events have been weighted by the calculated EMI geometric acceptance. For positive muons averaged over the fiducial volume, the EMI acceptance is 0.96 for muons along the beam direction and falls to 0.60 for muons at 0.5 rad. At fixed angle, the EMI acceptance is nearly independent of muon momentum above 4 GeV/c. The requirement that $P^\mu > 4$ GeV/c and $\nu > 2$ GeV restricts the data to regions in y bounded by $y_{\min} = 2/E$ and $y_{\max} = 1 - 4/E$ (E in GeV). Within this y region the data cover the full kinematic range in x $(0 < x < 1)$. In this experiment, 611 events pass the selection criteria.

E is estimated by summing the momentum of the muon and the momentum of the hadrons along the beam direction. An average correction to account for neutrals which leave the chamber undetected was applied to the longitudinal momentum P_x^h of the visible hadrons. This correction[8] was determined from the imbalance of the mean transverse momentum of the visible hadrons and the mean transverse momentum of the muons as a function of P_x^h and is well parametrized by $P_x^h(\text{corrected}) = 1.20(P_x^h + 1.0)$.

By assuming the validity of the Callan-Gross relation,[9] the differential cross section in y for charged-current antineutrino scattering integrated over any range of x is

$$\frac{d\sigma}{dy} = \frac{G^2 mE}{\pi}\int F_2\,dx\left[\left(1 - y + \tfrac{1}{2}y^2\right) - By\left(1 - \tfrac{1}{2}y\right)\right], \quad (1)$$

where B is the ratio of the integrated structure functions xF_3 and F_2: $B = \int xF_3\,dx/\int F_2\,dx$. In the quark parton model, B is related to the relative antiquark content of the nucleon by $\overline{Q}/(Q + \overline{Q}) = \frac{1}{2}(1 - B)$, where Q and $\overline{Q}$ represent the relative contribution of quarks and antiquarks for the same x range.

Figures 1(a)–1(c) show the x distributions for the restricted regions of y for the energy intervals 10–30, 30–50, and 50–200 GeV. In each case, the curve which has been normalized to the data is a prediction computed from the quark dis-

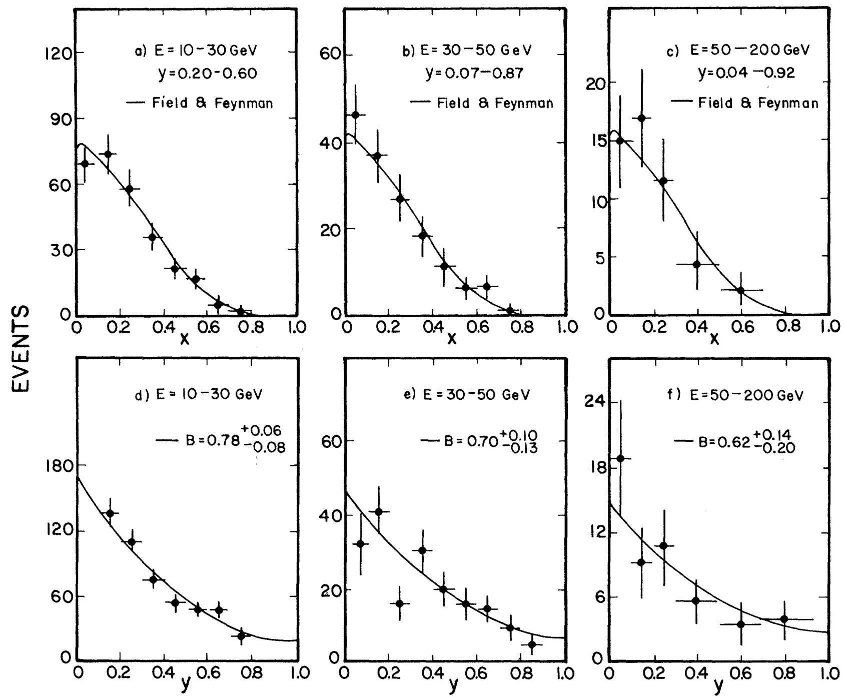

FIG. 1. (a)–(c): the x distributions for the energy ranges 10–30, 30–50, and 50–200 GeV. The curve is computed from the quark distributions of Ref. 10. (d)–(f): the y distributions for the three energy ranges. The curve is for the best fit for B in each case.

tributions of Field and Feynman,[10] which are based on electron and neutrino data from experiments at lower energies. Figures 1(d)–1(f) show the y distributions for the three energy intervals for $0<x<1$. The distributions are inconsistent with no $\bar{Q}$ contribution, i.e., inconsistent with a pure $(1-y)^2$ form. The curve is the best fit using Eq. (1) for each energy interval. Table I shows the fitted value of B from the y distributions for various ranges of x for the three energy intervals. The trend of the data suggests that the antiquark contribution at small x is increasing with increasing energy. Figure 2(a) shows the

TABLE I. Fitted values of B as functions of energy for various x ranges.

E (GeV) / x range	10–30	30–50	50–200	10–200
0–0.1	$0.56^{+0.18}_{-0.24}$	$0.32^{+0.30}_{-0.50}$	$-0.50^{+0.81}_{-2.38}$	$0.38^{+0.17}_{-0.21}$
0.1–0.2	$0.90^{+0.08}_{-0.12}$	$0.68^{+0.20}_{-0.34}$	$0.52^{+0.32}_{-0.66}$	$0.80^{+0.09}_{-0.11}$
0.2–0.4	$0.72^{+0.12}_{-0.18}$	$0.76^{+0.13}_{-0.22}$	$0.76^{+0.17}_{-0.34}$	$0.74^{+0.09}_{-0.12}$
0.4–1.0	$0.88^{+0.10}_{-0.12}$	$1.00^{+0.00}_{-0.10}$	$1.00^{+0.00}_{-0.08}$	$0.96^{+0.004}_{-0.008}$
0–1.0	$0.78^{+0.06}_{-0.08}$	$0.70^{+0.10}_{-0.13}$	$0.62^{+0.14}_{-0.20}$	$0.73^{+0.05}_{-0.06}$

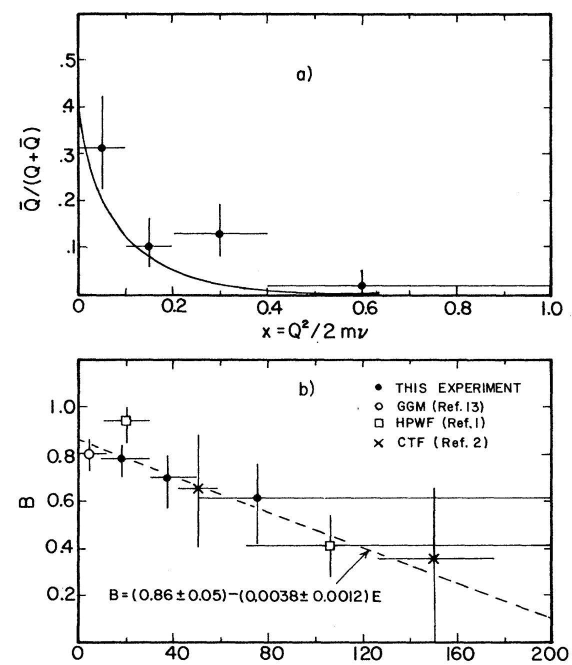

FIG. 2. (a) The relative antiquark contribution as a function of x computed using all the data in the energy range 10–200 GeV. The curve is computed from the quark distributions of Ref. 10. (b) The world data for B for the maximum x range as a function of energy. A linear fit is made to the the total world data.

relative antiquark contribution as a function of x computed using all the data in the energy range 10–200 GeV. For the whole x range the data give $\overline{Q}/(Q+\overline{Q}) = 0.14 \pm 0.03$, while the prediction from Ref. 10 is 0.08. At these energies the antiquark contribution is larger than would be expected based on the lower-energy data.

Figure 2(b) shows the value of B for the maximum x range plotted as a function of energy.[11] Also shown in Fig. 2(b) are the values of B from the Harvard-Pennsylvania-Wisconsin-Fermilab (HPWF)[1] and the Caltech-Fermilab (CTF) collaborations,[2] and from a fit to events in the scaling region in the Gargamelle (GGM) collaboration.[12] Our data taken together with the data from the other experiments support a gentle energy dependence for B. The combined world data for B are well fitted by a linear energy dependence. The best fit [$\chi^2 = 3.86$ for six degrees of freedom (D.O.F.)] gives

$$B = (0.86 \pm 0.05) - (0.0038 \pm 0.0012)E. \qquad (2)$$

Figure 3(a) shows $\langle y \rangle$ as a function of energy for $0.2 < y < 0.6$ and $E > 10$ GeV, and for $0.05 < y < 0.9$ and $E > 40$ GeV. Our data show no evidence for a sharp rise in $\langle y \rangle$ in the vicinity of 30 GeV. The curves in Fig. 3(a) show the expected energy dependence computed using values of B from Eq. (2); our data are well represented by these curves.

Deviations from exact Bjorken scaling have been observed in electron and muon experiments.[13] In neutrino experiments, scaling deviations would appear as a decrease in $\langle x \rangle$ as a function of energy. Figure 3(b) shows $\langle x \rangle$ as a function of energy. From empirical fits[14] to electron and muon data we predict $\langle x \rangle \propto E^{-b}$, with $b = 0.15$. The best fit to the data over the whole energy range for $0.2 < y < 0.6$ gives $b = 0.14 \pm 0.06$ ($\chi^2 = 14.0$ for ten D.O.F.), compatible with the scaling deviation expected from electron and muon data. Figure 3(c) shows the energy dependence of $\langle v \rangle$ ($v = xy$) for the same restricted y ranges. If the x and y dependence factorize, we expect the same energy dependence for $\langle v \rangle$ and $\langle x \rangle$ since the energy dependence of $\langle y \rangle$ is small. The best fit to the form $\langle v \rangle \propto E^{-b}$ for $0.2 < y < 0.6$ over the full energy range gives $b = 0.09 \pm 0.09$ ($\chi^2 = 8.8$ for ten D.O.F.). In Figs. 3(b) and 3(c) the curves are normalized to the data in the two y ranges assuming $b = 0.15$. For $0.05 < y < 0.9$ the data for $\langle v \rangle$ show a more rapid falloff with energy above 40 GeV than is indicated by the fit; for this y range the data give $\langle v \rangle = 0.086 \pm 0.010$ for $40 < E < 60$ GeV and $\langle v \rangle = 0.048 \pm 0.007$ for $60 < E < 200$ GeV.

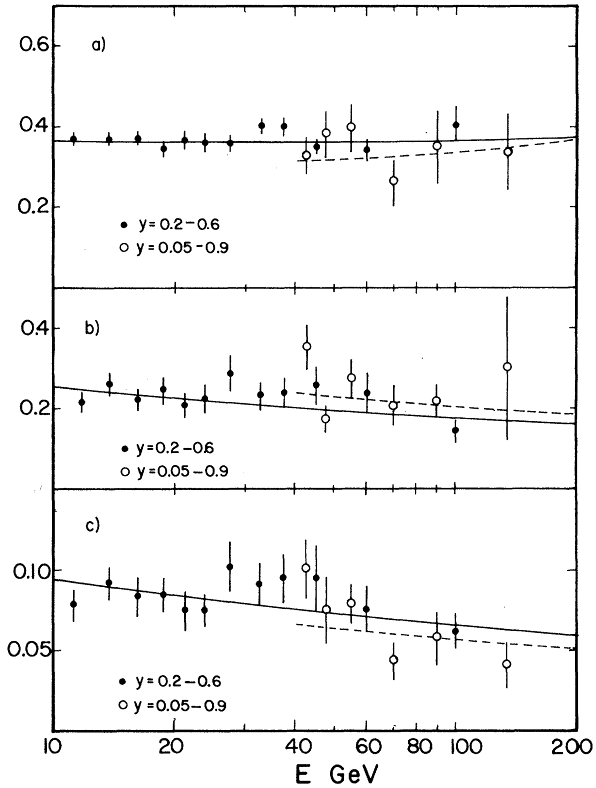

FIG. 3. (a) $\langle y \rangle$ as a function of energy. The curves are computed from Eq. (1) for the two y ranges. (b) $\langle x \rangle$ as a function of energy. The solid curve is $\langle x \rangle \propto E^{-b}$ with $b = 0.15$ normalized to the data for $0.2 < y < 0.6$, $E > 10$ GeV. The broken curve is for $0.05 < y < 0.9$ and $E > 40$ GeV. (c) $\langle v \rangle$ as a function of energy. The curves are for $b = 0.15$.

We conclude that the y distribution for charged-current antineutrino scattering is inconsistent with a pure $(1-y)^2$ form over the energy range explored in this experiment. In terms of the quark parton model the relative antiquark contribution is larger than would be expected based on the low-energy data. When combined with the world data, our data support a gentle energy dependence for the y distribution. While the x distributions are in reasonable agreement with predictions based on the quark parton model and electron scattering data, $\langle x \rangle$ and $\langle v \rangle$ show a decrease with increasing energy consistent with scaling deviations observed in electron and muon scattering experiments.

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R. Endorf (visitor from University of Cincinnati, Cincinnati, O. 45221), R. Hanft, C. Kochowski (visitor from Centre d'Etudes Nucléaires de Saclay, France), J. A. Malko, F. A. Nezrick, W. G. Scott, W. Smart, W. Venus (visitor from Rutherford Laboratory, Chilton, England), and J. Wolfson, Fermi National Accelerator Laboratory, Batavia, Ill. 60510; V. V. Ammosov, A. G. Denisov, P. F. Ermolov, V. A. Gapienko, V. I. Klyukhin, V. I. Koreshev, S. P. Kruchinin, A. I. Mukhin, P. V. Pitukhin, Y. G. Rjabov, V. I. Sirotenko, and E. A. Slobodyuk, Institute for High Energy Physics, Serpukhov, U. S. S. R.; V. I. Efremenko, P. A. Gorichev, V. S. Kaftanov, V. D. Khovansky, G. K. Kliger, V. Z. Kolganov, M. A. Kubantsev, A. N. Rosanov, and V. G. Shevchenko, Institute for Theoretical and Experimental Physics, Moscow, U. S. S. R.; C. T. Coffin, R. N. Diamond (present address, Florida State University, Tallahassee, Fla. 32306; and H. French, W. Louis, B. P. Roe, R. T. Ross, A. A. Seidl, and D. Sinclair, University of Michigan, Ann Arbor, Mich. 48104.

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[5]The scaling variables are defined by $x = Q^2/2m\nu$ and $y = \nu/E$, where Q^2 is the square of the four-momentum transfer, ν is the energy transfer to the hadrons in the laboratory, and E is the energy of the incoming antineutrino.

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[10]R. D. Field and R. P. Feynman, California Institute of Technology Report No. CALT-68-565 (to be published).

[11]The data are plotted for the maximum x range in each case: $x < 0.4$ for GGM; $x < 0.6$ for HPWF; and $0 < x < 1.0$ for CTF and this experiment. Because of the rapidly falling x distribution, the effect of the different cuts in x is not expected to be important.

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Search for Superheavy Elements in the Bombardment of ^{248}Cm with ^{48}Ca

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We have searched for superheavy elements 110 to 116 with half-lives between 10^4 and 10^8 s in fractions chemically separated after each of a series of bombardments of ^{248}Cm made with 267-MeV ^{48}Ca ions. After 6 months of α and spontaneous-fission counting, our results provide no persuasive evidence for the presence for the presence of superheavy elements. The most plausible explanation for not finding the superheavy elements is that they have either short half-lives or very small formation cross sections.

Numerous searches have been made for superheavy elements (SHE's) located in the "island of stability" believed to be centered at $Z = 114$, $N = 184$. Although these searches have failed to find any convincing evidence for SHE's,[1] the quest continues. This is the first reporting of experiments in which ^{248}Cm has been bombarded with ^{48}Ca ions in the expectation of producing SHE's.