(Submitted to the London Conference, June 1974)

CONF-74-121-E
E 2221

A New Measurement of High Energy Neutrino and Antineutrino Total Cross Sections*

B. Aubert[†], A. Benvenuti, D. Cline, W. T. Ford, R. Imlay,
T. Y. Ling, A. K. Mann, F. Messing, J. Pilcher[§],
D. D. Reeder, C. Rubbia, R. Stefanski and L. Sulak

Department of Physics
Harvard University
Cambridge, Massachusetts 02138

Department of Physics
University of Pennsylvania
Philadelphia, Pennsylvania 19104

Department of Physics
University of Wisconsin
Madison, Wisconsin 53706

FERMILAB
Batavia, Illinois 60510

Abstract

The slope of the energy dependence of the neutrino cross section has been measured up to 45 GeV using a flux measurement obtained from quasielastic events giving the value $\alpha^{\nu} = .67 \pm .15$. The ratio of antineutrino to neutrino cross section up to 30 GeV has been measured using a similar technique and is found to be .41 ± .11 at a mean energy of 21 GeV. The relative energy dependence of the neutrino cross section is also measured up to 230 GeV and 100 GeV for the neutrino and antineutrino cross sections. In the former case excellent agreement is found with a linear rising cross section over the full energy range.

We have previously reported high energy neutrino and antineutrino total cross section measurements based on experimental data obtained with an unfocussed neutrino-antineutrino beam at FNAL.[1] New data which have been taken with magnetic horn focussing and with an improved experimental setup are reported here. We address three aspects of these data: 1) the value of α^{ν} obtained by a flux independent method which uses quasielastic events for normalization; 2) the relative energy dependence of the neutrino and antineutrino cross sections up to ∿230 GeV and 100 GeV respectively; and 3) the value of $\alpha^{\bar{\nu}}/\alpha^{\nu}$ obtained in a flux independent manner.

The new detector arrangement is described in more detail elsewhere and consists of a liquid scintillator ionization calorimeter which serves as the target for neutrino and antineutrino interaction and a magnetic muon spectrometer.[2] Both calorimeter and muon spectrometer have been calibrated with hadron and muon beams. We note that the bulk of the neutrino and antineutrino interactions occur on C^{12} which is an I = 0 nucleus (equal number of neutrons and protons) and for which Glauber shielding corrections are expected to be small providing a nearly ideal target for neutrino interactions.

The events were recorded during a run with proton energy of 300 GeV and the magnetic horn set to focus negative particles (enriched antineutrino beam) and at 400 GeV proton energy with positive particles focussing. Neutrino and antineutrino interactions are identified by the sign of the muon charge. For each event the hadronic energy and muon momentum were measured and in turn the Q^2

and invariant mass W of the hadronic system obtained.

The exclusive neutrino and antineutrino scattering channels such as the quasielastic process $\nu_\mu + n \to \mu^- + p$ and Δ production; $\nu_\mu + p \to \Delta^{++} + \mu^-$ are observed to have two interesting properties: 1) the cross sections become energy independent at high energy and 2) the cross sections for neutrino and antineutrino scattering become equal at high energy. These properties have been directly verified at somewhat lower energies and form the basis for our method to measure absolute cross sections.[3,4] Because of the excellent energy response of a large liquid scintillation detector to low energy hadrons quasielastic and Δ production events are directly recognized in this experiment. The W distribution is shown in Fig. 1a combining neutrinos and antineutrinos. Figures 1b and 1c show the same distribution for events with $Q^2 < 1$ and $Q^2 < .5\ (\text{GeV/c})^2$, respectively. A clustering of events at low W centered on the N and Δ mass is observed. The continum contribution at higher W is observed to diminish as Q^2 is reduced as expected for deep inelastic scattering thus reducing the background under the quasielastic and Δ production events. In Fig. 2 is shown the Q^2 distribution for the W cuts centered on the N and Δ mass of $W < 1.2$ GeV and $1.45 > W > 1.2$ GeV, respectively. For comparison we show in Fig. 2 the theoretically expected distribution which is know to fit the low energy quasielastic scattering data.[4] Below Q^2 of 0.6 GeV^2 there is excellent agreement with the data, and the quasielastic and Δ production signal is essentially free of background.

In the neutrino energy interval 10-30 GeV there are 19 quasielastic events and 468.4 neutrino events corrected for detection efficiency. Using the low energy determination of the quasielastic cross section[4] a value of $\alpha^{\nu} = 0.56 \pm .15$ is obtained. Similarly, the combined quasielastic and Δ production events give a value of $\alpha^{\nu} = 0.67 \pm .15$. These values of α^{ν} are in very good agreement with our previous measurement[1] as shown in Fig. 3. As can also be seen in Fig. 3 there is excellent agreement between the value of α^{ν} obtained from the neutrino data and that expected on the basis of CVC, chiral symmetry and electroproduction data.[1] Our results are also in agreement with the measurement of α^{ν} at lower energies.[5]

The energy dependence of the total neutrino cross section was obtained by comparing the experimental energy distribution with the prediction of a monte carlo program using the method described in our previous work.[1] A further correction to this formula was introduced using recent particle production data obtained at 300 GeV.[6] The resulting relative neutrino cross section is shown in Fig. 4. It is seen that the cross section rise is consistent with linear in energy over the energy range of 10-250 GeV in remarkable agreement with the expectations of Bjorken scaling.[7] Using the absolute value of the cross section obtained at low energy from quasielastic and Δ production data an absolute cross section scale is obtained as shown in Fig. 4. However, it should be noted that this scale has an uncertainty of approximately 20% due to the uncertainty in α^{ν} at low energy. In a similar way the antineutrino relative cross section is obtained and reported in Fig. 5. Again the data are consistent with a linear rise up to $\sim$100 GeV.

Combining the measurement of α^{ν} at low energy and the linear rise of the cross section, limits on the energy variation of α^{ν} are obtained and reported in Fig. 6.

The ratio $\alpha^{\bar{\nu}}/\alpha^{\nu}$ was calculated using the quasielastic and Δ production events for both neutrino and antineutrinos and assuming the equality of these cross sections. From the sample of 30 antineutrino and 30 neutrino quasielastic and Δ production events we obtain a value of $\alpha^{\bar{\nu}}/\alpha^{\nu} = .41 \pm .11$ at a mean energy of 21 GeV, in good agreement with our previous measurement. It should be noted that although the statistical error on the value of $\alpha^{\bar{\nu}}/\alpha^{\nu}$ is large, the present measurement does not depend on the relative neutrino and antineutrino fluxes. The measured value of $\alpha^{\bar{\nu}}/\alpha^{\nu}$ is close to the value measured at low energy of $0.38 \pm .02$[5] and is in good agreement with the expected value obtained for the neutrino and antineutrino interactions on relativistic spin 1/2 fermion constituents such as for the parton model.[8]

We have repeated the measurement of the neutrino and antineutrino total cross sections and obtained a good agreement with our previous experiment.[1] The linear rise of the total neutrino cross section is shown to extend above 150 GeV and the measured values of α^{ν} and $\alpha^{\bar{\nu}}/\alpha^{\nu}$ are in excellent agreement with the twin hypothesis of CVC and chiral symmetry. Conversely, these results can be viewed as strengthening the evidence for spin 1/2 relativistic fermions in the nucleon.

References

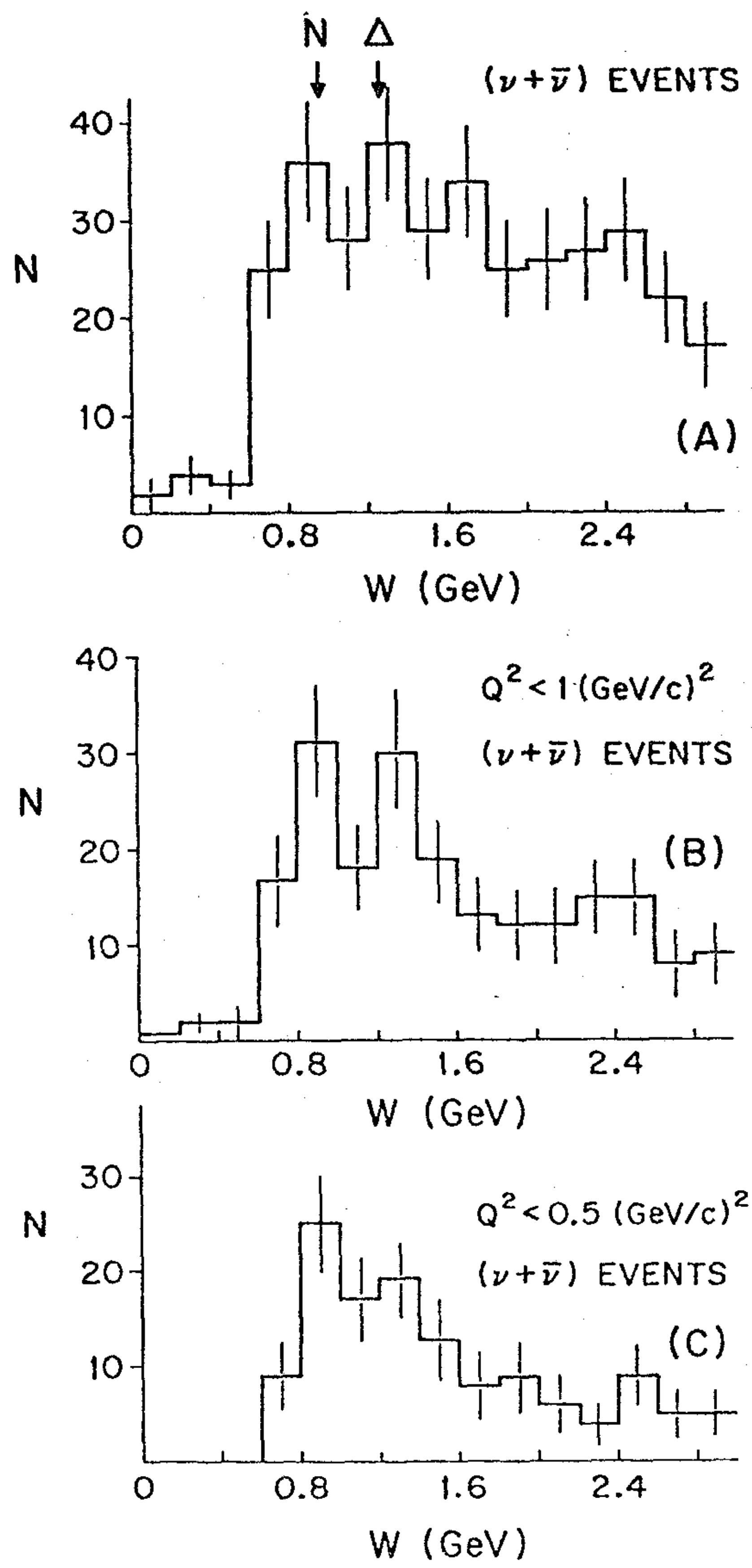
*Work supported in part by the U. S. Atomic Energy Commission under contract AT(11-1)-881-414.

†On leave of absence from Laboratoire de L'Accelerateur Lineaire, Orsay, France.

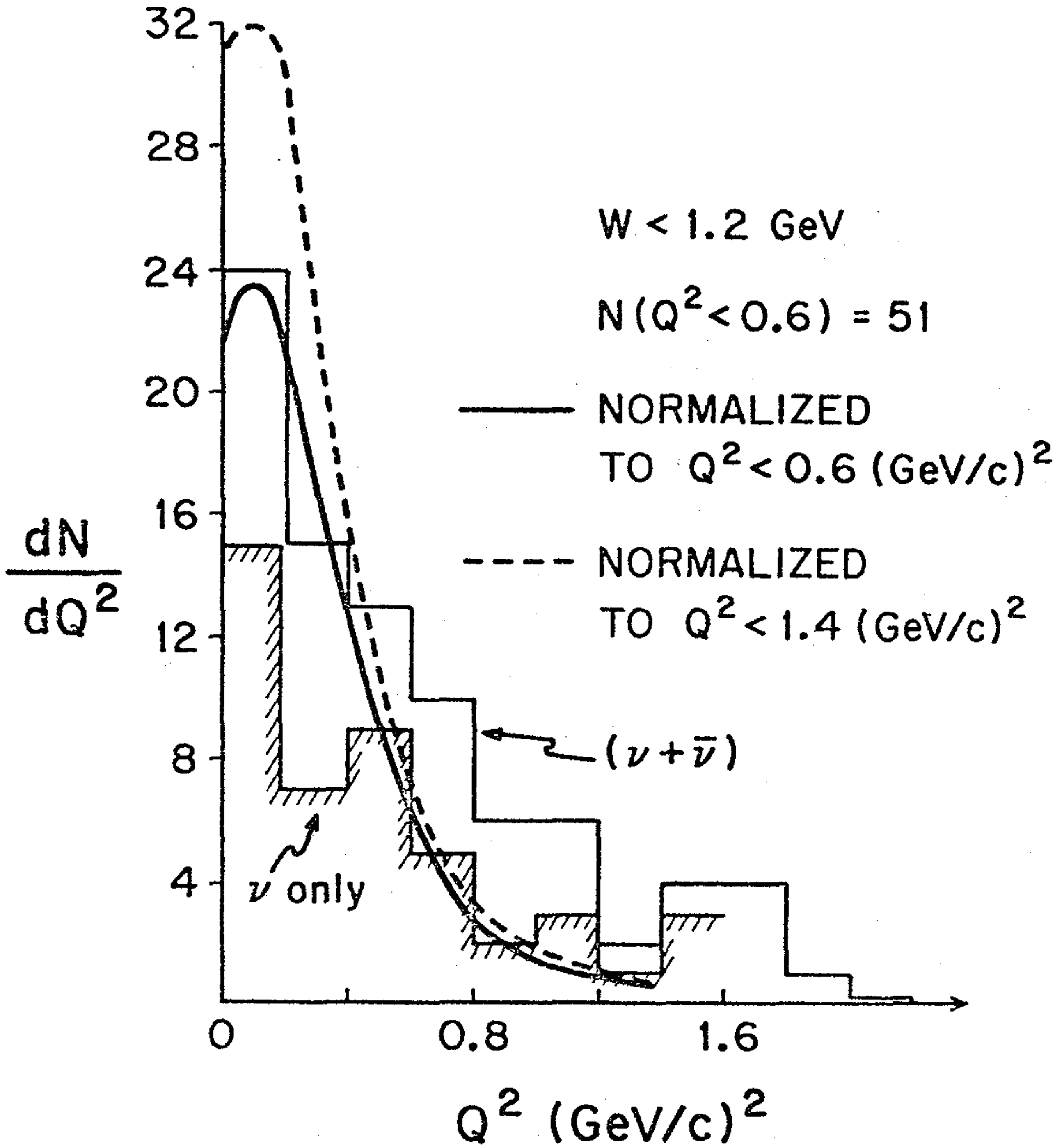
§Alfred P. Sloan Foundation Fellow, now at the University of Chicago, Chicago, Illinois 60637.

1. A. Benvenuti et al., Phys. Rev. Letters 32, 125 (1974) and Phys. Rev. Letters 31, 1018 (1973).
2. B. Aubert et al., Phys. Rev. Letters 32, 1454 (1974).
3. For quasielastic scattering and low mass resonances: I. Budagov et al., Lettere Nuovo Cimento 2, 686 (1969); W. A. Mann et al., Proceedings of the XVI International Conference on High Energy Physics, Chicago-Batavia (1972); T. Eichten et al., Phys. Letters B46, 274 (1973); B46, 281 (1973). J. Campbell et al., Phys. Rev. Letters 30, 335 (1973).
4. See, for example, P. Schreiner and F. Von Hippel, Phys. Rev. Letters 30, 339 (1973); P. Schreiner et al., Phys. Rev. Letters 8, 339 (1973). M. Derrick, Quasielastic Neutrino Reactions: Form Factors, ANL Report 7350 (1973).
5. D. H. Perkins, Proceedings of the XVI International Conference on High Energy Physics, Chicago-Batavia 4, 189 (1972); T. Eichten et al., Phys. Letters B46, 274 (1973); B46, 281 (1973).
6. W. Baker et al., NAL PUB74/13/EXP.
7. J. D. Bjorken, Phys. Rev. 179, 1547 (1969); J. D. Bjorken and E. A. Paschos, Phys. Rev. D1, 3151 (1970).

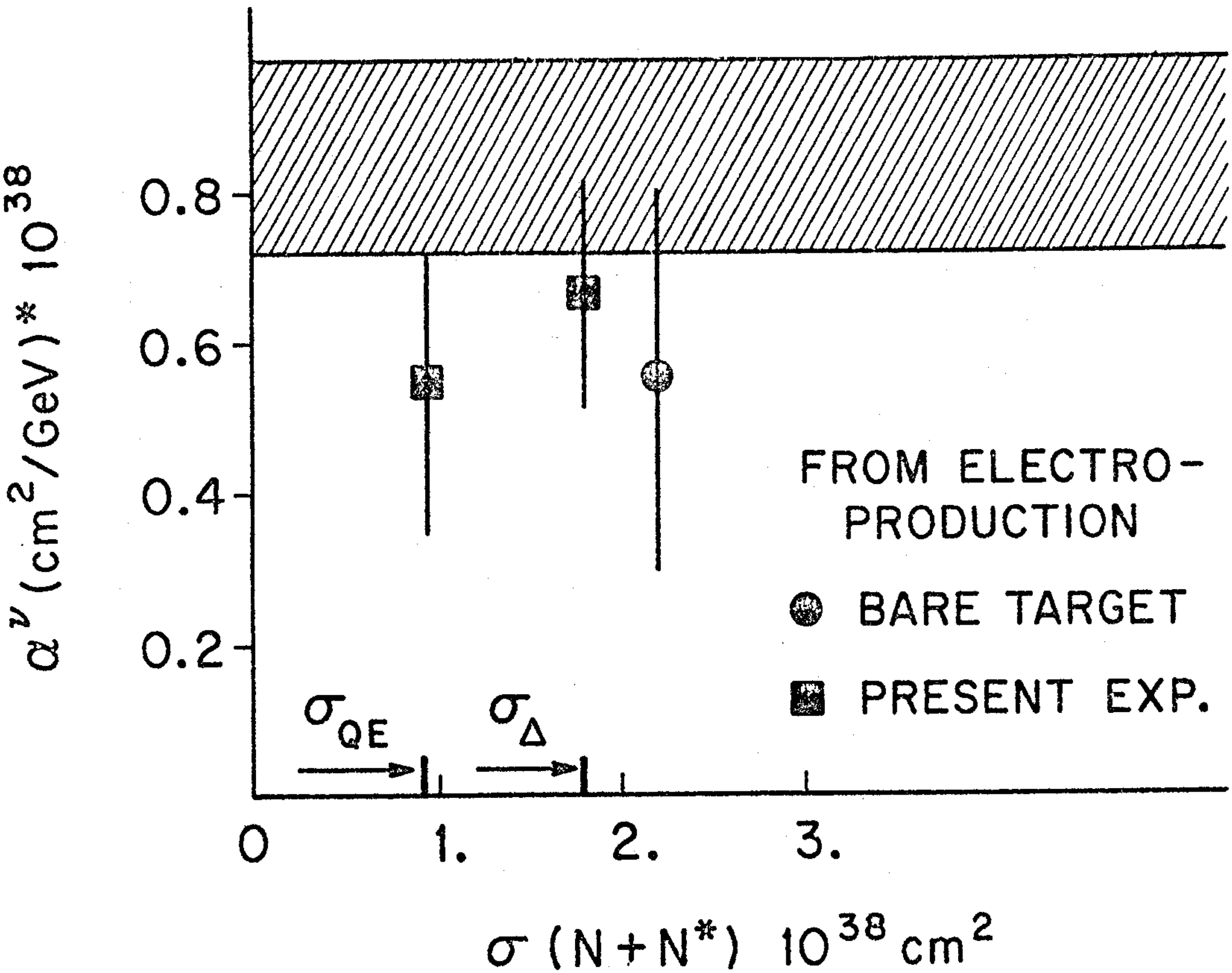
8. R. P. Feynman, Phys. Rev. Letters 23, 1415 (1969) and in the Proceedings of the Third Topical Conference on High Energy Collisions, Stony Brook, New York (1969); J. D. Bjorken and E. A. Paschos, Phys. Rev. 185, 1975 (1969).



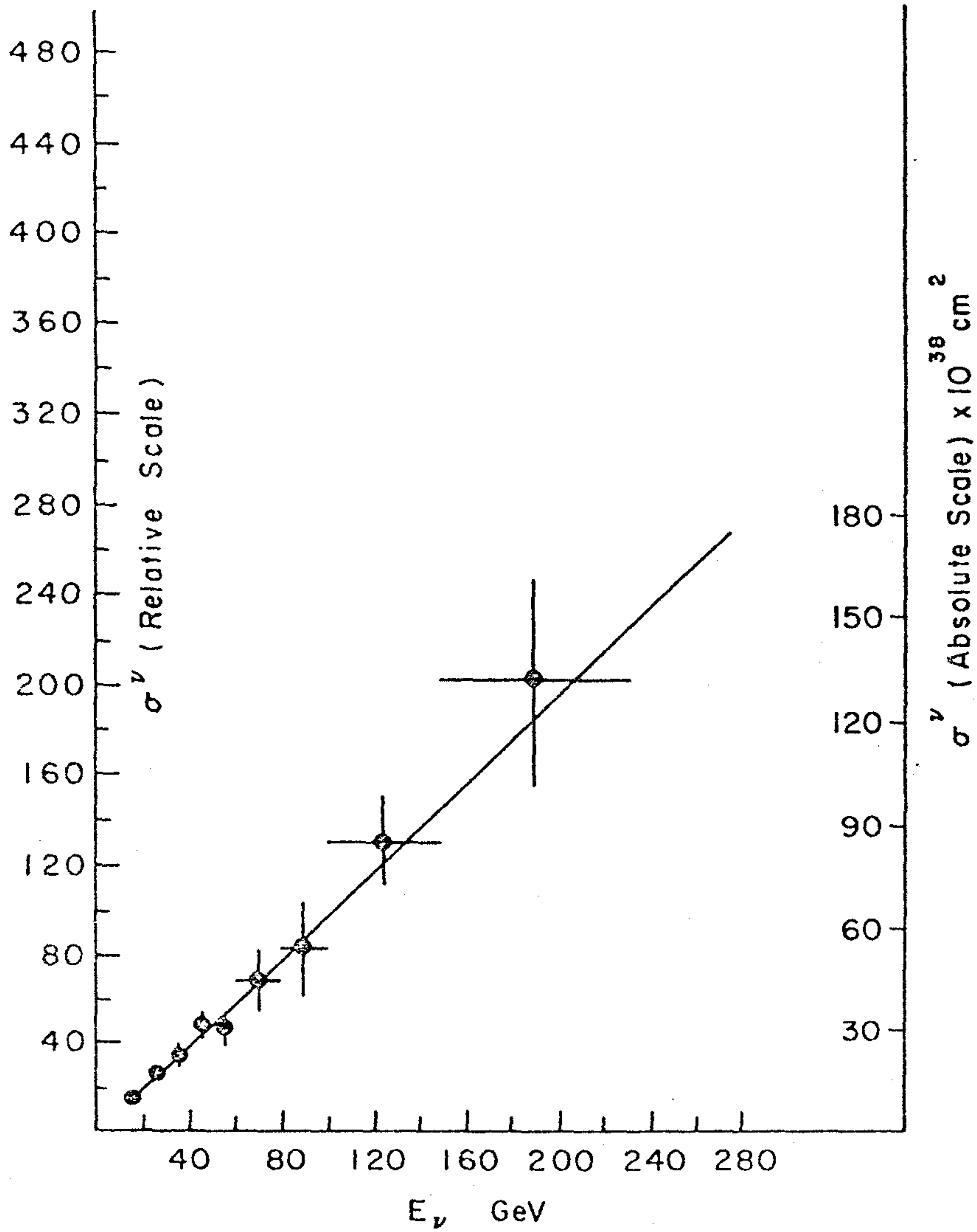
N
Δ
(ν+ν̄) EVENTS
40
30
20
10
(A)
0
0.8
1.6
2.4
W (GeV)
Q² < 1 (GeV/c)²
(ν+ν̄) EVENTS
(B)
W (GeV)
Q² < 0.5 (GeV/c)²
(ν+ν̄) EVENTS
(C)
W (GeV)



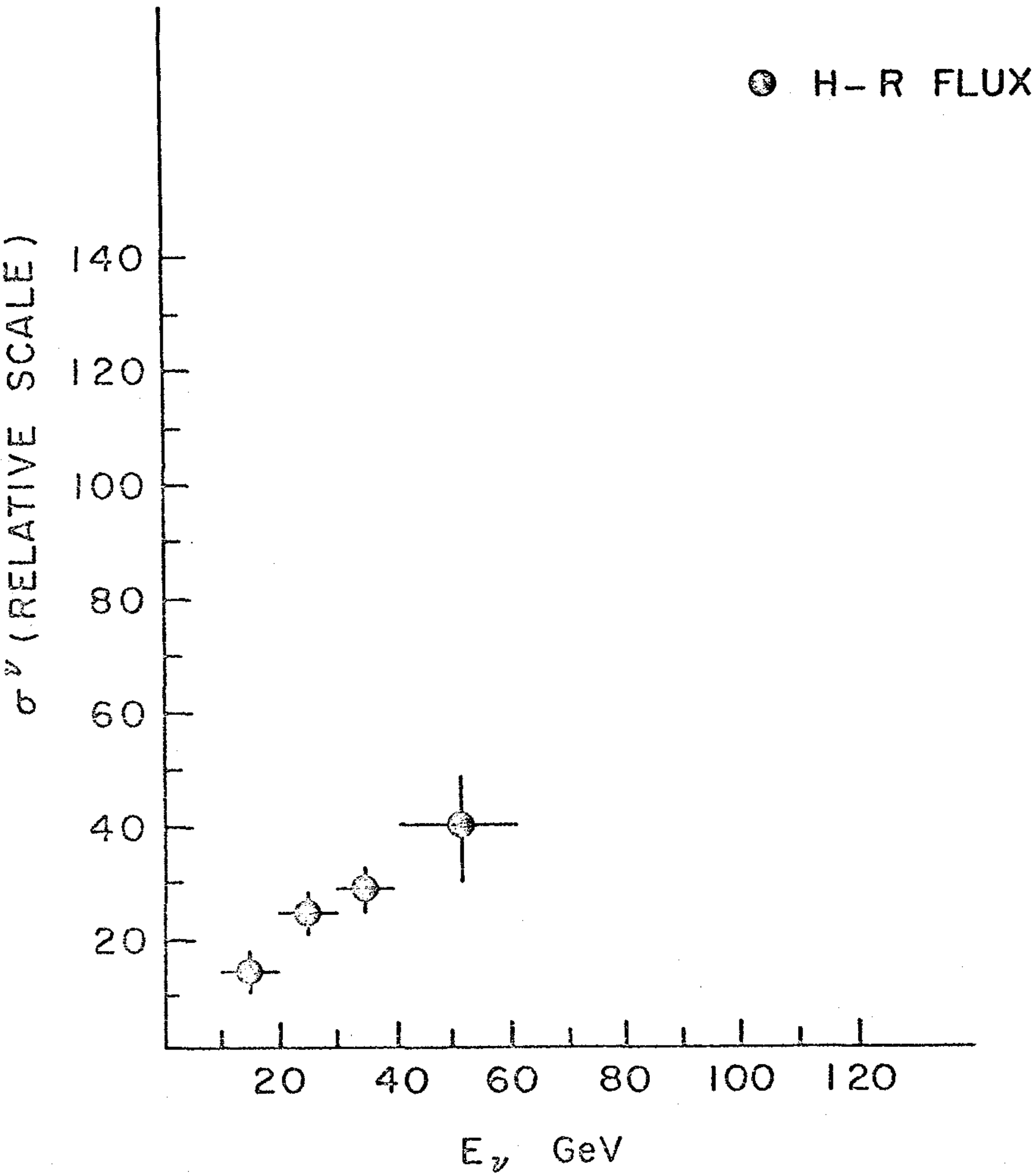
32
28
24
20
16
12
8
4
dN/dQ²
0
0.8
1.6
Q² (GeV/c)²
W < 1.2 GeV
N(Q²<0.6) = 51
NORMALIZED
TO Q²<0.6 (GeV/c)²
NORMALIZED
TO Q²<1.4 (GeV/c)²
(ν+ν̄)
ν only



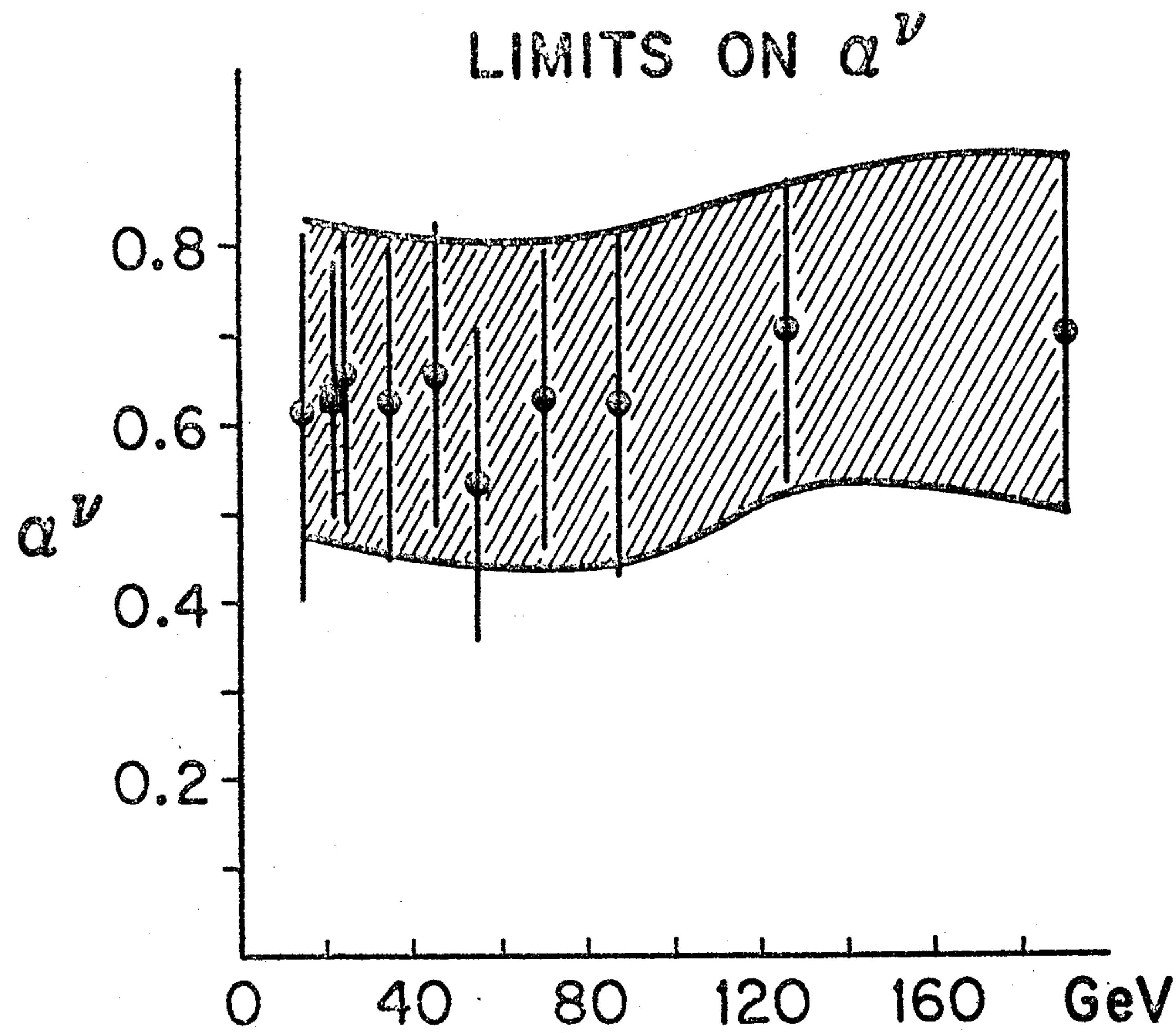
α^ν (cm²/GeV)* 10^38
0.8
0.6
0.4
0.2
0
1.
2.
3.
σ_QE
σ_Δ
FROM ELECTRO-
PRODUCTION
BARE TARGET
PRESENT EXP.
σ (N+N*) 10^38 cm²



480
440
400
360
320
280
240
200
160
120
80
40
σ^{ν} (Relative Scale)
180
150
120
90
60
30
σ^{ν} (Absolute Scale) x 10^{38} cm^2
40
80
120
160
200
240
280
E_{ν} GeV



H-R FLUX
$\sigma^{\bar{\nu}}$ (RELATIVE SCALE)
140
120
100
80
60
40
20
20
40
60
80
100
120
E_ν GeV


LIMITS ON a^{ν}
a^{ν}
0.8
0.6
0.4
0.2
0
40
80
120
160
GeV