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ABSTRACT

A neutrino proton scattering experiment has been performed using a wide band horn focussed neutrino beam at Fermilab and the 15 Ft. bubble chamber filled with hydrogen. Results of a study of approximately 450 charged current neutrino events in the energy range 15 - 200 GeV are presented and are found to be generally consistent with expectations based on scaling and the quark-parton model.

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I. INTRODUCTION

A neutrino proton scattering experiment[1] has been performed using a wide band horn focussed neutrino beam at Fermilab and the 15-Ft. bubble chamber filled with hydrogen. The data presented here are based on a study of approximately 450 charged current neutrino events in the energy range 15-200 GeV which are examples of the reaction

$$\nu_\mu p \to \mu^- + \text{hadrons} \tag{1}$$

The events occurred in an exposure of approximately 62000 pictures and the mean proton intensity on the target was approximately 0.5×10^{13} protons per pulse. The muon flux in the shielding was monitored throughout the exposure and an external muon identifier[2] (EMI) was operated in conjunction with the experiment. The beam monitoring data and the data from the EMI are not yet fully analyzed and the results presented here are based on analysis of information from the bare bubble chamber only.

II. THE ANALYSIS

A. Muon Selection

The analysis of reaction 1 requires the identification of the muon amongst the charged secondaries. For this analysis we select from the non-interacting negative tracks in each event the track with the highest transverse momentum relative to the neutrino direction. The probability that the muon in a charged current event is correctly chosen using this procedure has been estimated by a Monte Carlo study and the results are shown in Table I. In a charged current event the probability that the muon is correctly chosen is believed to better than 95%.

B. Estimation of Neutrino Energy

The neutrino energy is estimated using the method of transverse momentum balance. The method depends on the assumption that the momentum véctor of the charged hadrons defines the direction of the neutral hadron momentum. The energy resolution obtained using this method has been estimated with the Monte Carlo and the results are shown in Table I.

For those events in which the track chosen as the muon lies on the same side of the neutrino direction as the momentum vector of the charged hadrons, it is not possible to use the method of transverse momentum balance to obtain an estimate of the neutrino energy. On the basis of a Monte Carlo study it is expected that approximately 65% of neutral current events will behave in this way. In this analysis all the events in this class are classified as neutral current events and are eliminated from the sample. An estimate for the fraction of genuine charged current events which are misclassified as neutral current events based on the results of the Monte Carlo study is shown in Table I.

TABLE I

Energy	Events with muon correction selected	FWHM error in estimate of neutrino energy	Events classified as NC.
10-20	97%	20%	5%
20-40	96%	14%	5%
40-100	97%	9%	5%
100-200	98%	6%	4%

The procedure used to select the muon and the method used to estimate the neutrino energy were suggested by studies of the behavior of neutrino interactions at energies of a few GeV.[3,4] Details of the application of these methods in this experiment are discussed in Ref. 1.

Incorrect muon selection, loss of events incorrectly classified as neutral current events and errors in the estimate of the neutrino energy lead to systematic biases in the experimental distributions. For the distributions presented here an attempt has been made to correct for these effects by computing a correction factor for each bin based on the results of the Monte Carlo study. The corrections applied to the data after the background subtractions are typically of order 5% and never more than 20%. The errors shown in the figures are statistical only.

III. BACKGROUNDS

For the distributions presented here the following cuts have been applied to the data.

a) The total visible momentum along the beam direction p_x must be greater than 10 GeV.

b) The incident neutrino energy E must lie in the range 15 - 200 GeV.

Within these cuts the number of events due to the interactions of incoming charged tracks or due to neutrons and neutral kaons is believed to be negligible.[1] The raw event rate is shown in Table II.

Neutral current events which have been misclassified as charged current events constitute a background in the charged current sample. The probability for a neutral current event to be classified as a charged current event is estimated using the charged current events. The muon is ignored and the remaining hadron shower is classified as a neutral current or charged current event. The ratio of the neutral current to charge current cross-sections on protons is unknown and has been assumed to be equal to 0.30 as is predicted by Weinberg theory.[5] The estimated background from this source is included in Table II.

The contamination of antineutrinos in the neutrino beam is believed to be approximately 10%. The estimated background due to antineutrino events misclassified as neutrino events is also shown in Table II based on the results of a Monte Carlo study. The ratio of the antineutrino to the neutrino cross-section on protons has been assumed to be ~ 2/3.

TABLE II

Energy GeV	Raw Events	NC Background	Antineutrino Background	Corrected Events
15-20	57	2.4	3.9	60.4
20-25	64	3.0	3.6	68.3
25-30	62	0.9	2.4	76.2
30-40	81	3.0	3.1	86.1
40-50	51	2.1	1.3	53.5
50-60	27	0.6	0.7	25.2
60-80	40	2.4	0.8	32.6
80-100	30	1.5	0.4	28.4
100-150	25	0.9	0.3	22.8
150-200	12	0.3	0.2	9.1

IV. RESULTS AND CONCLUSIONS

Bjorken scaling predicts that the total neutrino cross-section should be linear with neutrino energy. The shape of neutrino spectrum with energy has been estimated using π and K production spectra based on the Hagedorn-Ranft model.[6] Figure 1 shows (Event rate)/(Hagedorn-Ranft flux) in arbitrary units. If the shape of the neutrino flux computed using the Hagedorn-Ranft model is correct, we can conclude that the total cross-section is consistent with a linear increase with energy for energies in the range 15 - 200 GeV.

Figure 2 shows the mean value of Q^2, the square of the 4-momentum transfer, as a function of neutrino energy. The data are consistent with a linear increase as is expected from Bjorken scaling. A straight line fit through the origin gives

$$< Q^2 > = (0.18 \pm 0.01)E$$

This result for the slope is a little lower than the result 0.21 ± 0.02 obtained using a nuclear target.[7]

The variable y is defined by $y = \nu/E$ where ν is the energy transfer to the hadrons in the lab. The y-distribution is shown in Fig. 3 and is consistent with being flat. There is no strong energy dependence.

In Fig. 4 we show the distribution in $x = Q^2/2m\nu$. In the quark parton model the x-distribution measures the contribution of d and $\bar{u}$ quarks in the proton. Neglecting the contribution of strange quarks and antiquarks we expect

$$F_2^{\nu p} = 24/5\ F_2^{ed} - 6F_2^{ep} \qquad (2)$$

The curve which has been normalized to the data for $x > 0.2$ is the quantity (2) computed from fits to the SLAC electron scattering data.[8] While the general shape of the x-distribution is compatable with the prediction (2) there is some indication of an excess of events at small x in the neutrino data. Within the statistical errors this effect shows no strong energy dependence.

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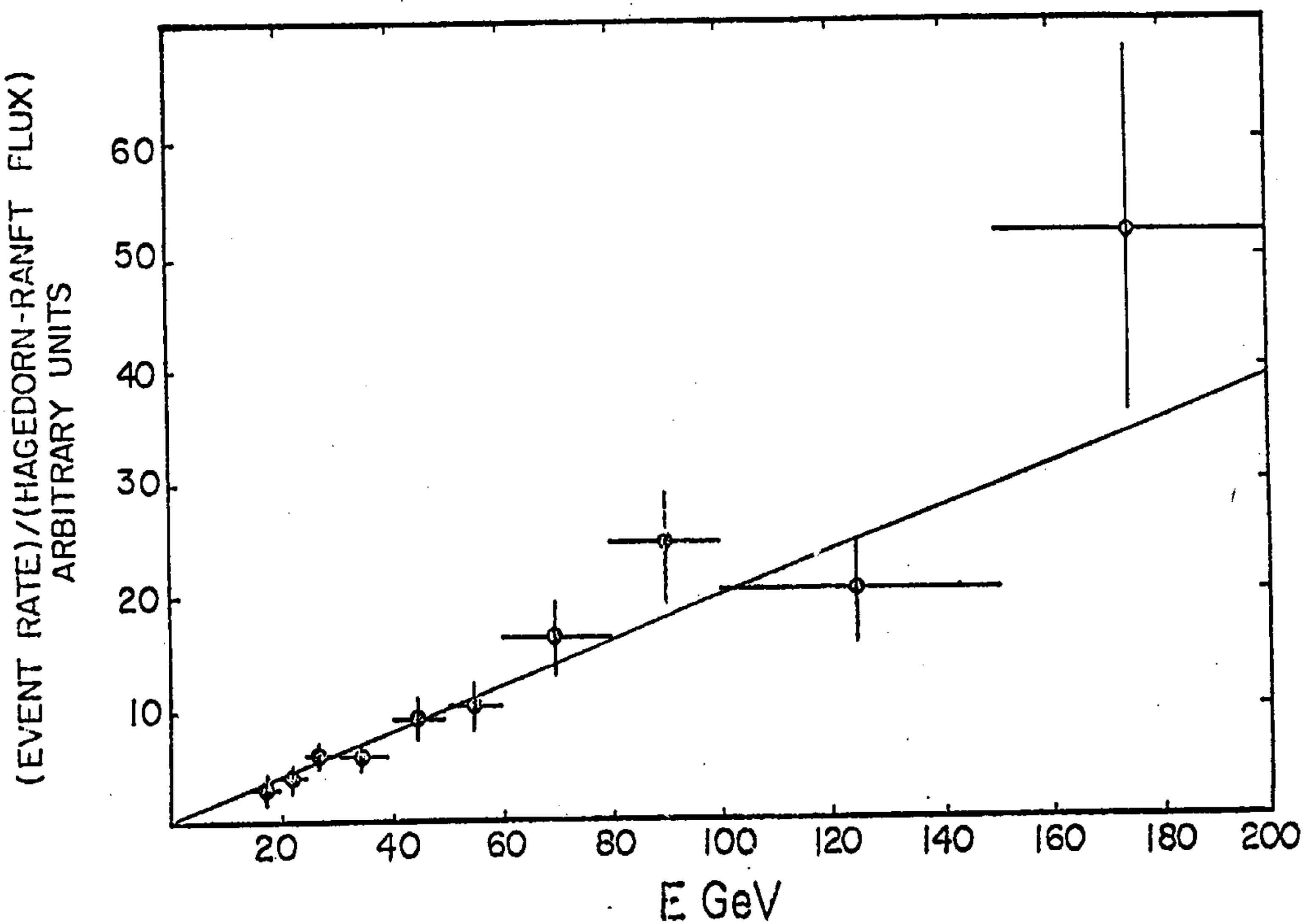

Fig. 1: (Event rate)/(Flux from Hagedorn-Ranft) in arbitrary units plotted as a function of E. The straight line is a fit to the data points.

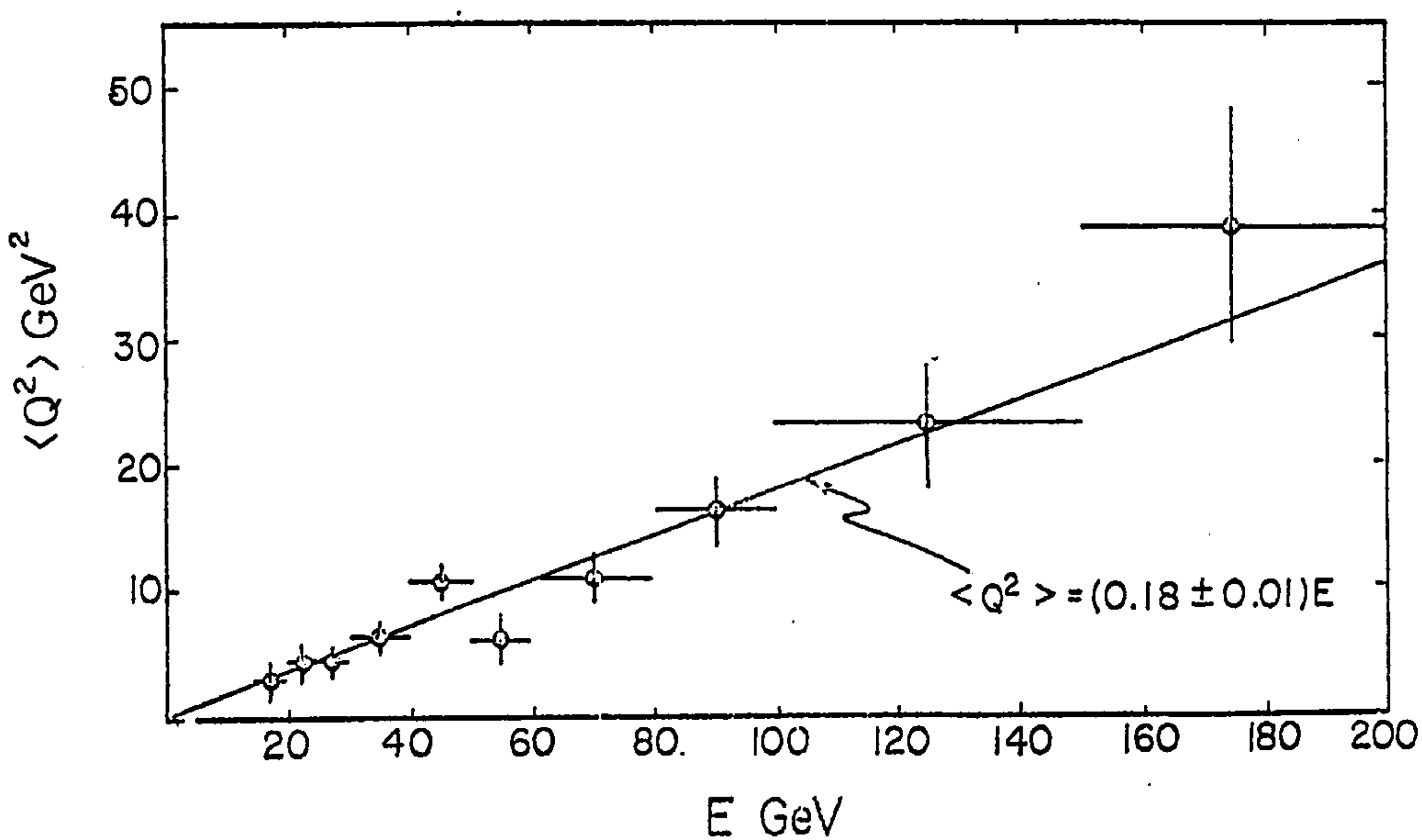

Fig. 2: $< Q^2 >$ plotted as a function of E. The straight line is a fit to the data points.

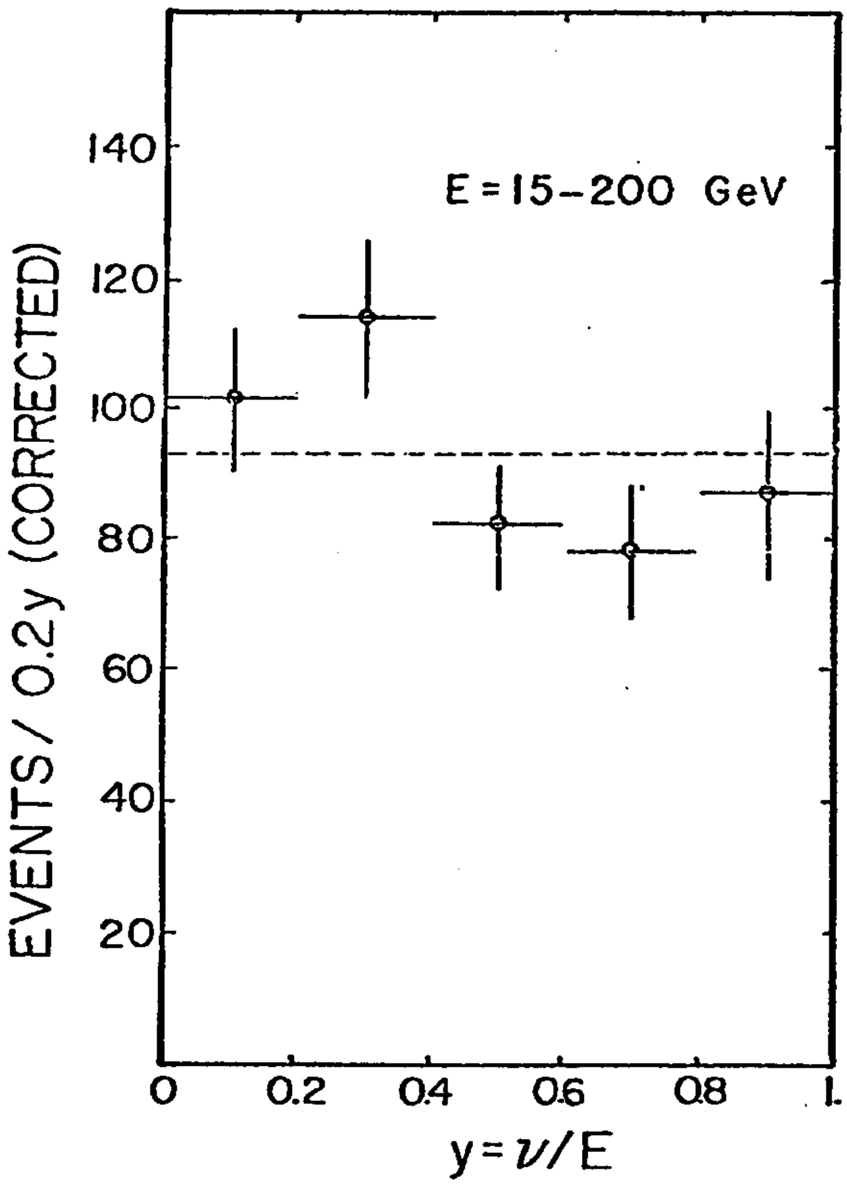

Fig. 3: The distribution in y = ν/E. The straight line shows a flat distribution.

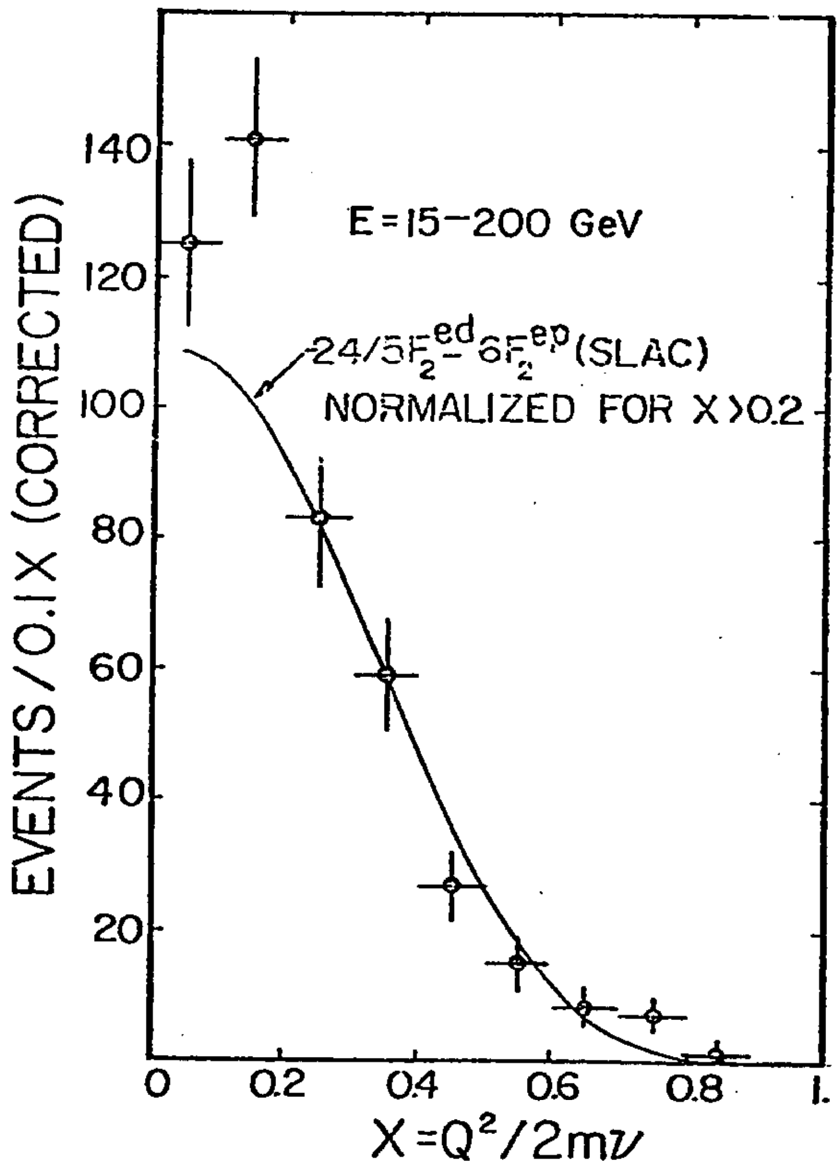

Fig. 4: The distribution is $x = Q^2/2m\nu$. The curve which has been normalized to the data for $x > 0.2$ is a prediction from electron scattering data. (See text).