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HIGH ENERGY NEUTRINO NEUTRAL-CURRENT INTERACTIONS[$]

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Abstract

We have extracted a sample of neutral-current events from an exposure of the FERMILAB 15 ft. bubble chamber to the Quadrupole Triplet neutrino beam, for which the average energies are 90 GeV for neutrino and 60 GeV for antineutrino events. For visible hadronic longitudinal momentum above 10 GeV/c, we observe a neutral-current (NC) to charged-current (CC) event ratio of 0.301 ± 0.026. The K production rate in NC events agrees with that in CC events but the Λ rate is significantly lower. The distribution of K^{o}'s in fractional energy variable z is obtained and compared, for the first time, with those from high energy CC events.

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I. Introduction

Studies of neutral-current (NC) neutrino interactions have focussed primarily on testing the Glashow-Salam-Weinberg (GSW) model and determining the important parameter $\sin^2\theta_W$. The most precise determinations of this parameter come from measurements of the ratio of NC to charged-current (CC) events by experiments[1-3] in narrowband beams. Narrowband beams offer the advantages of smaller backgrounds from the wrong-sign neutrino and improved knowledge (for individual events) of the neutrino energy but have smaller neutrino fluxes than wideband beams. The knowledge of the neutrino energy has allowed the determination of the distributions of the scaling variables x and y by counter experiments[1,4] and by two bubble chamber experiments.[5,6]

More detailed tests of the GSW model have been done by determining the left-handed (u_L, d_L) and right-handed (u_R, d_R) couplings of the light quarks to the neutral current. These couplings have been determined[7,8] from measurements of NC/CC for νp, νn, $\bar{\nu}p$, and $\bar{\nu}n$ using wideband beams plus hydrogen,[9-12] deuterium,[8,13] or light Ne-H_2 mixtures[14,15]. Wideband beams are necessary for these studies to increase event rates. Detailed studies of the hadron system require visual detectors and high statistics. Unfortunately, experiments in wideband beams have significant backgrounds from the wrong-sign neutrino and usually have average event energies of 25 GeV or below, resulting in substantial contamination of the NC sample by CC events with unidentified muons.

One important property of the hadron system is the rate and characteristics of strange particle production. The GSW model requires that the couplings (s_L, s_R) of the strange quark to the neutral current be the same as those of the down (d) quark. One possible test of this feature

of the model is to compare the observed strange particle production with what is expected due to direct production of strange quarks from an NC interaction with an s or $\bar{s}$ quark plus indirect production of strange quarks as part of the hadronization process for u and d quarks. It is, of course, also important to look for evidence of strangeness-changing neutral currents, which are required to be absent in the GSW model. The only published limit[16] on strangeness-changing neutral currents is based on a limit on non-associated Λ and Σ^o production in neutrino interactions at energies of a few GeV. The only report on strange particle production at higher energies is from an antineutrino experiment[17] at FERMILAB. The only determination of the NC couplings of strange quarks comes from the measurements of the y distributions for both NC and CC events by the CHARM collaboration[1]. The result is

$$(s_L^2 + s_R^2)/(d_L^2 + d_R^2) = 1.39 \pm .43$$

In this paper, we present preliminary results on a sample of high-energy NC events. Section II discusses general experimental details and efficiencies for detecting muon neutrino and electron neutrino CC events. Section III gives the criteria used to select the NC event sample, the backgrounds and losses, and the resulting value of NC/CC. In section IV, we discuss the rate and characteristics of K^o and Λ production. Finally, the results are summarized in section V.

II. Experimental details

The data used in this analysis comprise about 15% of the total for experiment E546, a 326,000 picture exposure of the FERMILAB 15 ft. bubble chamber to the Quadrupole Triplet neutrino beam. The complete exposure corresponds to 3.4×10^{18} protons on target. An important feature of the

Quadrupole Triplet beam is that lower energy neutrinos are suppressed. In fact, the average observed event energies for ν_μ and $\bar{\nu}_\mu$ CC events are 90 GeV and 60 GeV respectively. The bubble chamber liquid was a neon (47% atomic) - hydrogen mixture with a density, radiation length, and absorption length of 0.56 g/cm^3, 53 cm, and 193 cm respectively. More details of the experimental conditions, scanning, muon identification, electron identification, and other cuts are given in previous publications on dimuons[18] and dilepton events.[19] For the present analysis, we use the same fiducial volume (14.5 m^3) as that used for the latter study.

The 2-plane EMI and prototype IPF available for this experiment are described in detail elsewhere.[20,21] For this experiment, the IPF consisted of 16 picket chambers each with an active area of 0.1m by 1.0m and constructed electrically as though it were a drift chamber with all the sense wires ganged together. The pickets were placed inside the bubble chamber vacuum tank between the one-inch thick steel chamber body and the superconducting coil. The active area of the pickets comprised 30% of the area spanned by them. For the present analysis, as for the search for tau neutrino interactions already reported,[22] it is important to reject muon neutrino CC events with high efficiency. Therefore, we use the IPF and employ criteria that allow us to identify muons using only a single EMI plane in addition to two-plane identification. In order to have high electronic efficiencies for the EMI and IPF, we use only data from the latter 3/4 of the experiment. The numbers of ν_μ and $\bar{\nu}_\mu$ CC events with the muon identified (two-plane muon) in both EMI planes for the 15% of the film used for this study are 1052 and 195 respectively. The average EMI electronic efficiency is 0.93 for each plane. The EMI geometric acceptances for μ^- tracks to hit both planes, only the first plane, and

neither plane are 0.87, 0.10 and 0.03 respectively for muon momenta above 4 GeV/c. The corresponding μ^+ acceptances are 0.92, 0.06, and 0.02 respectively. For μ^- of momenta below 4 GeV/c, these acceptances are 0.04, 0.18, and 0.78 respectively; the corresponding μ^+ acceptances are 0.10, 0.29 and 0.61.

The overall efficiency of the IPF is determined from the fraction of events with 2-plane muons that also have at least one hit in the IPF that is in-time with the EMI. An IPF hit is defined to be in-time with the EMI if the IPF time is within 10 clock counts before or 50 clock counts after the EMI time. (One clock count is about 30 nanoseconds.) This fraction is 0.75 ± 0.01 for ν_μ and 0.62 ± 0.03 for $\bar{\nu}_\mu$ CC events. The IPF efficiency is nearly independent of the total visible longitudinal (i.e., along the incident neutrino direction) momentum but increases with the visible hadronic longitudinal momentum and the number of primary tracks that leave the bubble chamber without interacting. The IPF efficiencies as functions of total and hadronic visible longitudinal momenta are given in Tables 1 and 2 respectively. The probability of accidental time-coincident hits in the IPF and EMI was determined to be 0.056 ± 0.006 by looking for IPF hits at a time 100 clock counts before the EMI time for a 2-plane muon.

In order to find events with muons, we originally measured all non-interacting tracks leaving the bubble chamber within 60° of the neutrino beam direction. Since then we have systematically made complete measurements of all events containing a 2-plane muon and of all events with an identified primary electron found in a special scan. In order to select a relatively clean sample of NC candidate events for complete measurement, we have again used the leaving track measurements. To eliminate a larger fraction of muon neutrino CC events, we identify muons using single-plane

as well as two-plane criteria. For tracks hitting both EMI planes, either time-coincident matches of confidence levels above 10^{-4} in both planes or a match of confidence level above 0.1 in either plane that is in-time with a hit in the IPF is required to identify the track as a muon. For tracks hitting the first but not the second EMI plane, only a match of confidence level above 0.01 was required if the track's momentum exceeded 4 GeV/c. For tracks of momenta below 4 GeV/c, the EMI match was required to be in-time with the IPF. These criteria correctly identify the muon in 85% of all ν_μ CC events and 89% of all $\bar{\nu}_\mu$ CC events. (These fractions of identified muons are higher than those in previous analyses[18,19] primarily due to the use of single-plane in addition to two-plane criteria for muon identification.) The fractions of unidentified CC events depend on the event's total visible longitudinal momentum primarily due to EMI acceptance. These fractions are given in Table 1 along with the fractions of CC events having that visible longitudinal momentum.

The other leaving tracks in events with two-plane muons can be used to determine how often hadrons will be misidentified as muons using these criteria. The result is that 0.11 of all events will have a hadron misidentified as a muon. The probability that an event will have a hadron misidentified as a muon is nearly independent of the total visible longitudinal momentum (above 10 GeV/c) for CC events (see Table 1) but increases significantly with visible hadronic longitudinal momentum (see Table 2).

The overall detection efficiency for electron neutrino CC events was estimated to be 0.75 based on a scanning efficiency of 0.95 and an average electron identification efficiency of 0.79. The overall efficiency was assumed to be independent of the event's total energy. Also the energy

spectra for ν_e and $\bar{\nu}_e$ events were taken to be the same[23] as those for ν_μ and $\bar{\nu}_\mu$ events respectively.

III. Determination of NC/CC

The events recorded in the original scan of the film include muon and electron neutrino CC events and neutral-hadron-induced events as well as NC events. Events that had a muon (2-plane or single-plane) identified in the leaving track measurements or had a single primary electron that satisfied our electron identification criteria[19] were eliminated from consideration for the NC sample. Also eliminated were events known to be outside the fiducial volume from the leaving track measurements. The remaining events were all examined by scanners and were selected for full measurements if they had sufficiently high visible energy and were not associated with other upstream events (either in the bubble chamber walls or in the liquid). Specifically, events were required to have at least 2 primary tracks (excluding short, stopping tracks) and to have a visible momentum vector (estimated from track curvatures) with magnitude above about 5 GeV/c and with direction within about 30° of the neutrino beam direction. Cosmic ray events are removed very effectively by the requirement on the direction of the visible momentum vector. The criteria were sufficiently loose to accept all neutrino-induced events with visible longitudinal momentum above 5 GeV/c; and, in fact, many events with visible momenta below 5 GeV/c were selected and measured. The non-association criterion was designed to further reduce contamination from neutral-hadron-induced events where the neutral hadron was produced in an upstream interaction. Specifically, events were rejected from the NC sample if there was another interaction within 10° of the direction exactly opposite to the estimated visible momentum vector of the event. The loss of NC events that are accidentally

associated with upstream events was estimated to be 4/125 by applying the same criteria to 125 known CC events. (Note here that CC events were identified from the leaving track measurements of all neutral-induced events, including those apparently associated with upstream events.) This loss is assumed to be independent of event energy.

The losses of 0-prong and 1-prong NC events as a function of visible momentum are estimated using Monte Carlo generated[24] CC events with the appropriate cut on the visible hadronic momentum. The 0-prong final state $\nu n x^{o}$ (x^{o} denotes all neutral hadrons) is assumed to have the same fractional rate as the CC final state $\mu^{-} p x^{o}$. The 1-prong final states $\nu p x^{o}$ and $\nu n x^{+}$ are assumed to have the same fractional rates as $\mu^{-} p x^{o}$ and $\mu^{-} n x^{+}$ respectively. The fractional contributions of these final states (all of which are lost from the NC sample) are given in Table 2.

The same muon identification criteria were applied to the full measurements of NC candidates. Three 2-plane μ^{+} and 32 2-plane μ^{-} were found giving a total of 195 2-plane μ^{+} and 1052 2-plane μ^{-} events. The 35 new events are consistent with the scanning and measuring inefficiencies in the leaving track measurements estimated for the dimuon study[18]. There are 804 events with visible longitudinal momentum above 2.5 GeV/c and no identified muons or single primary electrons. The distributions of visible longitudinal momentum and missing transverse momentum for these events are shown in Figs. 1 and 2 respectively.

In order to estimate the backgrounds from unidentified CC events, we first calculate the total number of CC events using the observed numbers of 2-plane μ^{+} and μ^{-} and correcting for EMI acceptance and electronic efficiency, EMI dead time (1.2%), hadron misidentification (2%), and events with muon momenta below 4 GeV/c. The result is 1490 ν_{μ} and 248 $\bar{\nu}_{\mu}$ CC

events. The corrected numbers of electron neutrino CC events are 43 and 10 for ν_e and $\bar{\nu}_e$ respectively. Multiplying the corrected numbers of CC events by the fractions for a given total visible longitudinal momentum and the unidentified fractions for that momentum (see Table 1) gives the CC backgrounds in Table 3. These CC backgrounds must be multiplied by a factor 0.89 for total visible longitudinal momenta above 10 GeV/c to correct for events in which the true muon is not identified but some hadron is misidentified as a muon. The total CC backgrounds in Table 3 include this correction.

The remaining background to be estimated is that due to neutral-hadron-induced events. The shape of the visible momentum spectrum of this background is assumed to be the same as that of neutral-induced events associated with measured neutrino events with 2-plane muons. The ratios of the numbers of events with momenta above 10 GeV/c and above 25 GeV/c to that in the 5-10 GeV/c region are 0.705 ± 0.073 and 0.156 ± 0.028 respectively. The normalization of this background shape is obtained from the estimated number of neutral-hadron-induced events in the 5-10 GeV/c region. This number is estimated from the 113 observed candidates by subtracting the CC backgrounds (5.9 events) and the estimated number of true NC events in this region. The estimated number of true NC events detected in this region comes from multiplying the total number of CC events (with visible hadronic longitudinal momenta in this same region) by an NC/CC ratio of 0.30 ± 0.05 and by the appropriate factors for losses of NC events. The result is that 52.0 ± 8.8 NC events are estimated resulting in 55.1 ± 13.8 events induced by neutral hadrons. Use of an NC/CC ratio of 0.30 is justified for this calculation by the observation that a comparable value would be obtained for events with visible hadronic longitudinal

momenta above 25 GeV/c, where one can safely ignore the neutral-hadron-induced background. The uncertainty in this input NC/CC ratio was increased to 0.05 to include some of the systematic uncertainties. Note that the extreme limits that all or none of the events in the 5-10 GeV/c region are neutral-hadron-induced would result in estimates of the NC signal for momenta above 10 GeV/c that are about 12% lower or higher respectively than that given in Table 3.

The backgrounds from CC and neutral-hadron-induced events and the resulting observed and corrected (for losses) NC events are given for two momentum regions in Table 3. Also given are the corrected numbers of CC events with visible hadronic longitudinal momenta in these regions. The values we obtain for NC/CC for momenta above 10 GeV/c and above 25 GeV/c are 0.301 ± 0.026 and 0.293 ± 0.032 respectively. These values are consistent between themselves and with what would be expected for our mixture of neutrino and antineutrino events from previous measurements[1-3] of the NC/CC ratios. The distribution of the visible hadronic longitudinal momentum for the net NC signal (i.e., after subtraction of the backgrounds from unidentified CC and neutral-hadron-induced events) is compared with that from CC events in Fig. 3.

IV. Strange particle production

Kinematic fits are done to all V's associated to NC candidates to try to identify K^o and Λ decays. We require a 3-C fit with $\chi^2<16$ (i.e. confidence level above about .1%) in order to associate the K^o or Λ with the primary vertex. Ambiguities between K^o and γ or Λ and γ fits are rare because the electrons from the γ conversion are usually identified in the bubble chamber. Ambiguities between K^o and Λ fits are resolved by choosing the Λ hypothesis unless the confidence level for the K^o hypothesis is

greater than 4% and that for the Λ hypothesis is below 4%. Ambiguities between K^o and $\bar{\Lambda}$ fits are resolved by choosing the K^o hypothesis unless the confidence level for the $\bar{\Lambda}$ hypothesis is above 4% and that for the K^o hypothesis is below 4%. In order to calculate rates and obtain distributions, we reject decays within 1 cm of the primary vertex and within 20 cm of the bubble chamber wall. The decays that remain are weighted to correct for these losses plus that due to interactions before decay.

In the 587 NC candidates with visible longitudinal momentum above 10 GeV/c, we observe 29 K^o_S, 6 Λ, and 1 $\bar{\Lambda}$ with unique fits. In addition, the 2 K/γ ambiguities are resolved as 1 K^o and 1 γ, the 3 K/Λ ambiguities are all resolved as Λ's, and the 6 $K/\bar{\Lambda}$ ambiguities are all resolved as K^o's. The totals are 36 K^o_S, 9 Λ, and 1 $\bar{\Lambda}$. The weighted numbers are 52.4, 11.7, and 1.3 respectively. Correcting for branching ratios gives rates of

$$0.26 \pm 0.04 \quad K^o \text{ per event}$$

$$0.03 \pm 0.01 \quad \Lambda \text{ per event}$$

$$0.003 \pm 0.003 \quad \bar{\Lambda} \text{ per event}$$

In order to extract rates for NC events, one must subtract the contributions from unidentified CC events. There are an estimated 193.5 neutrino plus 26.1 antineutrino CC events in this NC sample. The K^o and Λ rates observed in all events with 2-plane μ^- and μ^+ are given in the first two lines of Table 4. Using these rates and subtracting the contributions due to the unidentified CC events gives the following rates for the remaining 328.6 NC events plus 38.8 neutral-hadron-induced events:

$$0.25 \pm 0.07 \quad K^o \text{ per event}$$

$$0.001 \pm 0.017 \ \Lambda \text{ per event}$$

These rates should be compared to those in CC events with the same requirement on the visible hadronic longitudinal momentum (see Table 4). The result is that the NC K^o rate is about one standard deviation lower than that seen in CC events but the Λ rate is over 4 standard deviations lower. The only other reported comparison of K^o and Λ rates is from an antineutrino experiment[17]. Explicit rates were not given but, based on the stated numbers of K^o's and Λ's, it appears that their K^o rate in NC events is somewhat higher and their Λ rate somewhat lower respectively than those in CC events but that neither is inconsistent with the CC values.

It is hard to understand why Λ production would be different in NC and CC interactions. Studies[25,26] of CC events on isoscalar targets indicate that most Λ's are associated with the spectator diquark, which is expected to fragment into hadrons in the same way whether the interaction with the struck quark is NC or CC. There is a possible bias that affects Λ detection more than K^o detection. The tracks from a Λ decay typically have a smaller opening angle than those from a K^o_S decay and therefore Λ decays close to the primary event vertex are more likely to be missed by measurers. In order to check for this loss, about 35% of the NC events have been carefully examined to look for missed K^o or Λ decays. No new decays associated with the primary event vertex were found. Therefore, there is no evidence to indicate that our low Λ rate in NC events is due to a systematic loss.

The distribution of K^o's in the fractional energy variable z (defined to be the K^o momentum divided by the corrected total hadronic momentum) is compared to those from CC events in Fig. 4. This is the first comparison of K^o production in NC and CC events at high energies. One might expect

differences in K^o production between NC and CC events due to different production mechanisms. In CC events, K^o's can result from the decays of charmed particles. Charm production is greatly suppressed in NC interactions, but NC interactions with strange quarks are a possible source of K^o's not present in CC interactions. In Fig. 4, the z distribution for K^o's produced in NC events is somewhat flatter but not inconsistent with those from CC events. Note that the distributions in Fig. 4 are not directly comparable to those from CC events in other experiments because of our requirement that the visible hadronic longitudinal momentum be above 10 GeV/c.

V. Summary

For a sample of neutrino events with average energy of about 100 GeV, we observe an NC/CC ratio of 0.301 ± 0.026 for visible hadronic longitudinal momentum above 10 GeV/c. The observation is in good agreement with previous measurements. The K^o production rate in NC events agrees with that in CC events but the Λ rate is significantly lower. The K^o z distribution in NC events is consistent with those from CC events.

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TABLE CAPTIONS

1. Event fractions, IPF efficiencies, and hadron misidentification probabilities for three regions of total visible longitudinal momentum. The longitudinal momentum is the projection of the momentum vector onto the incident neutrino direction.

2. Event fractions, IPF efficiencies, and NC event losses for three regions of visible hadronic longitudinal momentum. As in table 1, quantities given with errors are determined from real data; quantities without errors are determined from Monte Carlo events.

3. NC candidates and estimated backgrounds due to unidentified CC and neutral-hadron-induced events for three regions of visible longitudinal momentum. Also given are the corrected numbers of CC events with visible hadronic longitudinal momentum in these same three regions. The NC/CC value for the 5-10 GeV/c region is assumed in order to calculate the number of neutral-hadron events in this region.

4. Neutral strange particle production rates for NC and CC events.

FIGURE CAPTIONS

1. Visible longitudinal momentum distribution for 804 NC candidates with longitudinal momentum above 2.5 GeV/c (solid line). The dashed line shows the expected background from unidentified CC events; the dotted line shows that from neutral-hadron-induced events.

2. Missing transverse (relative to the incident neutrino direction) momentum for the same NC candidates as in fig. 1.

3. Visible hadronic longitudinal momentum distributions for the net NC signal (solid line) and for combined ν and $\bar{\nu}$ CC events (circles) normalized to the NC signal in the region above 5 GeV/c.

4. Distribution K^{o}'s in various intervals of the fractional energy variable Z. The CC data is based on events with visible hadronic longitudinal momentum above 10 GeV/c.

TABLE 1

	TOTAL VISIBLE LONGITUDINAL MOMENTUM		
	5-10 GeV/c	>10 GeV/c	>25 GeV/c
Fraction of ν_μ CC Events	.0041	.9955	.9359
Fraction of unidentified ν_μ CC Ev.	.634	.139	.127
Fraction of unidentified ν_e CC Ev.	.25	.25	.25
Fraction of $\bar{\nu}_\mu$ CC Events	.0123	.9863	.8846
Fraction of unidentified $\bar{\nu}_\mu$ CC Ev.	.634	.110	.110
Fraction of unidentified $\bar{\nu}_e$ CC Ev.	.25	.25	.25
IPF efficiency for ν_μ Ev.	.22±.14	.76±.01	.77±.01
IPF efficiency for $\bar{\nu}_\mu$ Ev.	.22±.14	.62±.03	.64±.04
Hadron misidentification probability	0.	.106±.008	.111±.009

TABLE 2

	HADRONIC VISIBLE LONGITUDINAL MOMENTUM		
	5-10 GeV/c	>10 GeV/c	>25 GeV/c
Fraction of ν_μ CC Events	.1116	.7968	.5193
Fraction of $\bar{\nu}_\mu$ CC Ev.	.1801	.5846	.2574
IPF efficiency for ν_μ Ev.	.54±.04	.86±.01	.93±.01
IPF efficiency for $\bar{\nu}_\mu$ Ev.	.44±.09	.76±.04	.94±.03
NC event loss fractions			
Hadron misidentification	.011±.005	.140±.011	.178±.015
0-prong & 1-prong Ev.	.167	.044	.026
Accidental association	.032±.016	.032±.016	.032±.016

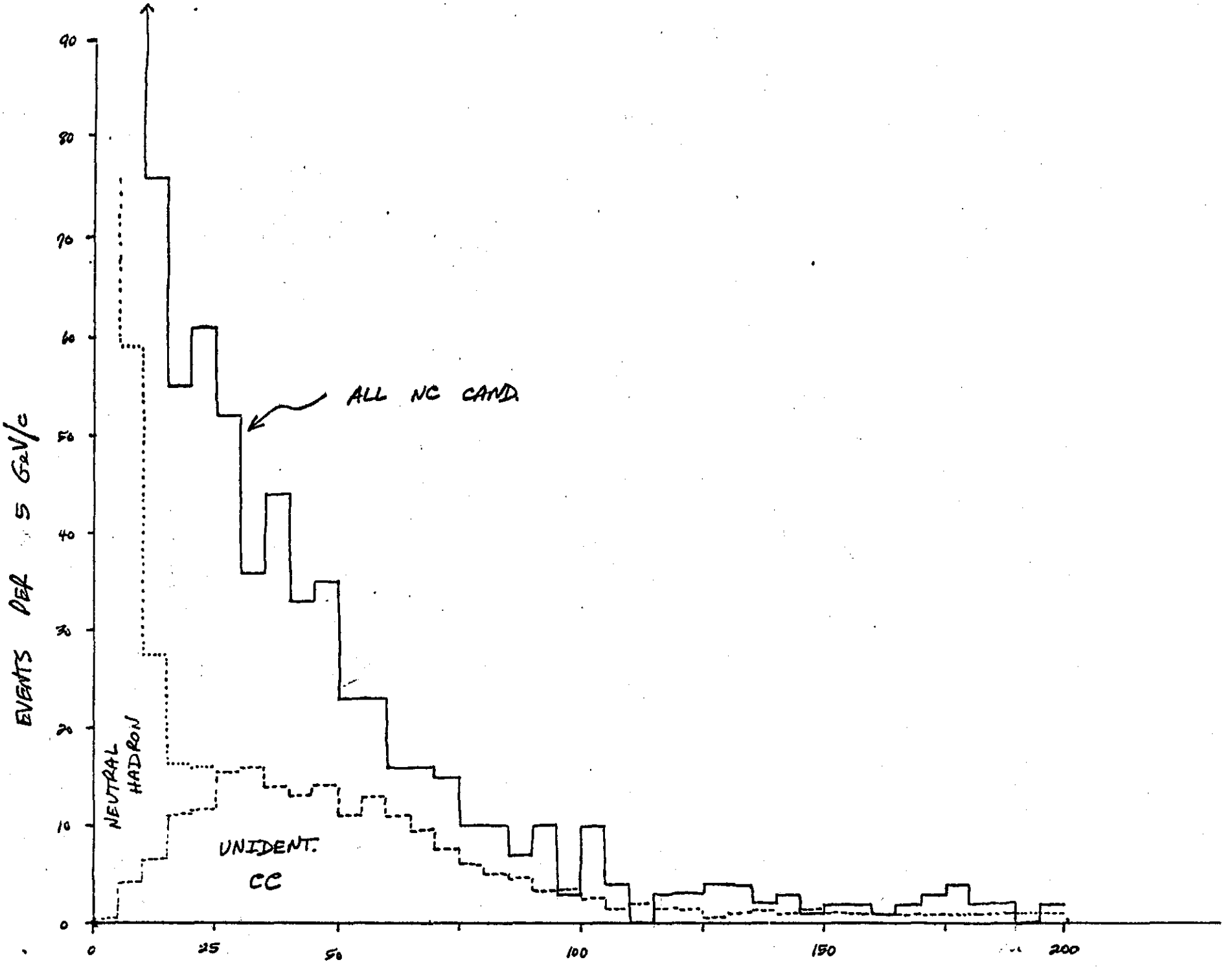
TABLE 3

	VISIBLE LONGITUDINAL MOMENTUM		
	5-10 GeV/c	>10 GeV/c	>25 GeV/c
Observed NC candidates	113	587	395
Unidentified μ^-	3.9±0.1	206.8±6.4	177.6±5.5
Unidentified μ^+	1.9±0.1	26.9±1.9	24.1±1.7
Unidentified e^-	0.04±0.003	10.6±0.7	10.0±0.6
Unidentified e^+	0.03±0.004	2.4±0.3	2.2±0.3
Total CC Background	5.9±0.2	219.6±6.0	190.3±5.2
Neutral-Hadron Background	55.1±13.8	38.8±10.5	8.6±2.7
Net Observed NC Signal	52.0±8.8	328.6±27.1	196.1±20.7
Corrected NC Events	65.3±11.0	413.0±34.1	253.0±26.8
Corrected ν_μ CC Ev.	166.3±5.1	1187.2±36.6	773.8±23.9
Corrected $\bar{\nu}_\mu$ CC Ev.	44.7±3.2	145.0±10.4	63.8±4.6
Corrected ν_e CC Ev.	4.8±0.3	34.0±2.1	22.2±1.3
Corrected $\bar{\nu}_e$ CC Ev.	1.8±0.2	5.7±0.8	2.5±0.3
Total Corrected CC Ev.	217.6±6.0	1371.9±38.1	862.3±24.4
NC/CC	Assumed 0.30±0.05	0.301±0.026	0.293±0.032

TABLE 4

NEUTRAL STRANGE PARTICLE PRODUCTION RATES

	K^o per event	Λ per event
ν_μ CC	0.278±0.011	0.081±0.0044
$\bar{\nu}_\mu$ CC	0.239±0.023	0.083±0.0097
HADRONIC LONGITUDINAL MOMENTUM > 10 GeV/c		
ν_μ CC	0.334±0.014	0.091±0.0054
$\bar{\nu}_\mu$ CC	0.358±0.038	0.086±0.013
NC Candidates	0.26±0.04	0.03±0.01
NC (CC Background removed)	0.25±0.07	0.001±0.017


EVENTS PER 5 GeV/c
90
80
70
60
50
40
30
20
10
0
ALL NC CAND.
NEUTRAL HADRON
UNIDENT. CC
0
25
50
100
150
200
VISIBLE LONGITUDINAL MOMENTUM (GeV/c)

F. 1

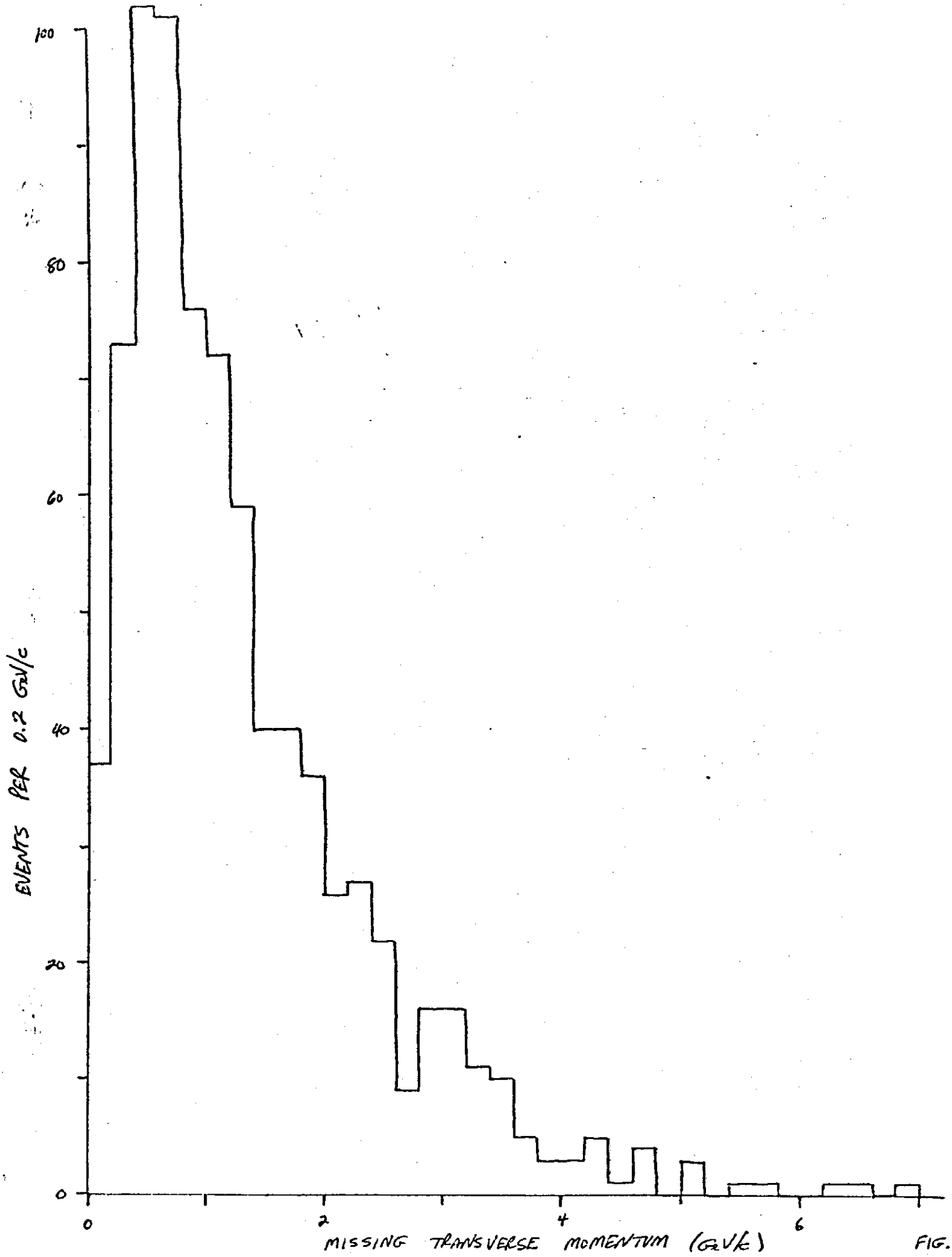

100
80
60
40
20
0
EVENTS PER 0.2 GeV/c
0
2
4
6
MISSING TRANSVERSE MOMENTUM (GeV/c)

FIG.

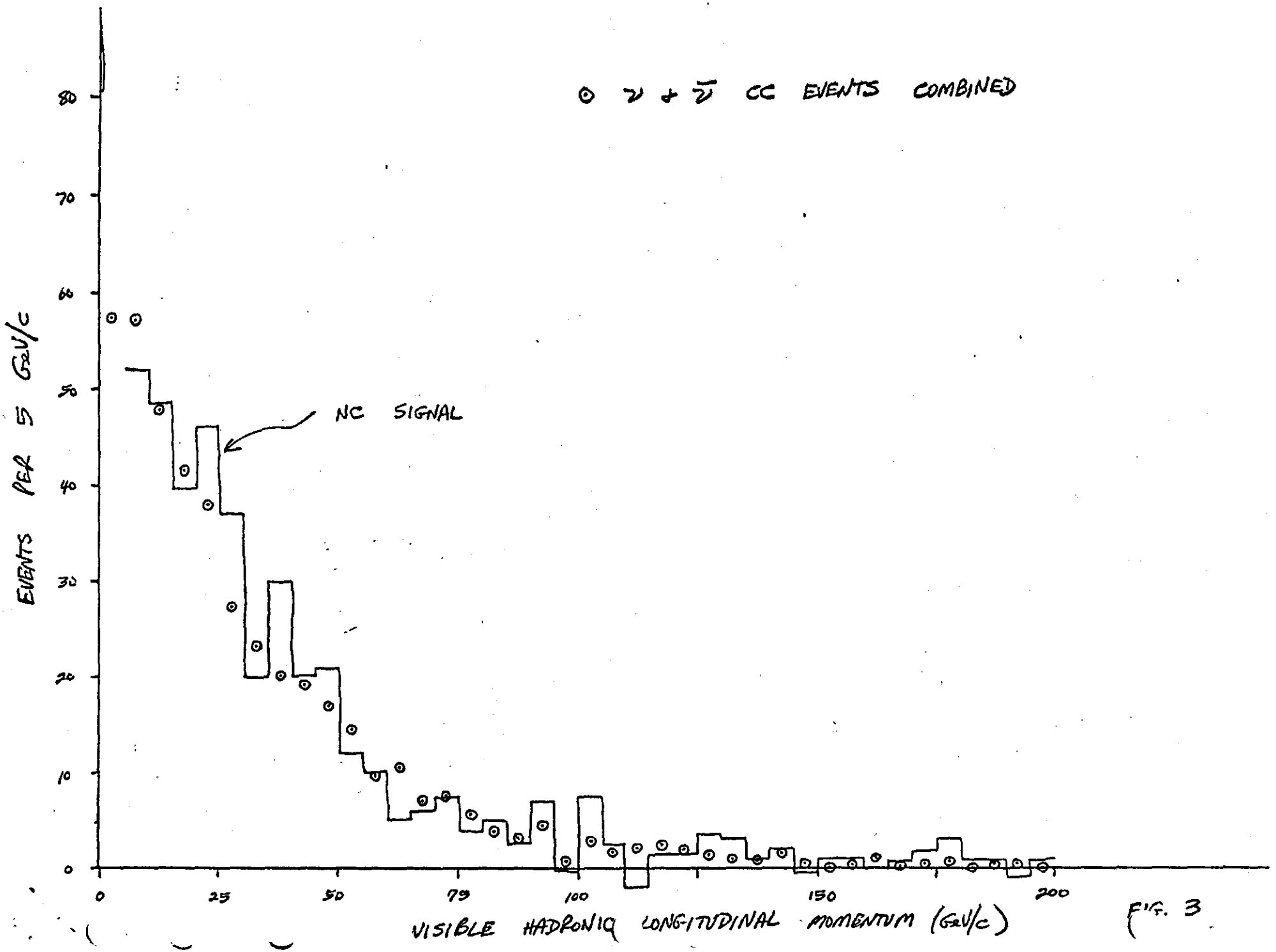

⊙ ν + ν̄ CC EVENTS COMBINED
NC SIGNAL
EVENTS PER 5 GeV/c
0
10
20
30
40
50
60
70
80
0
25
50
75
100
150
200
VISIBLE HADRONIC LONGITUDINAL MOMENTUM (GeV/c)

FIG. 3

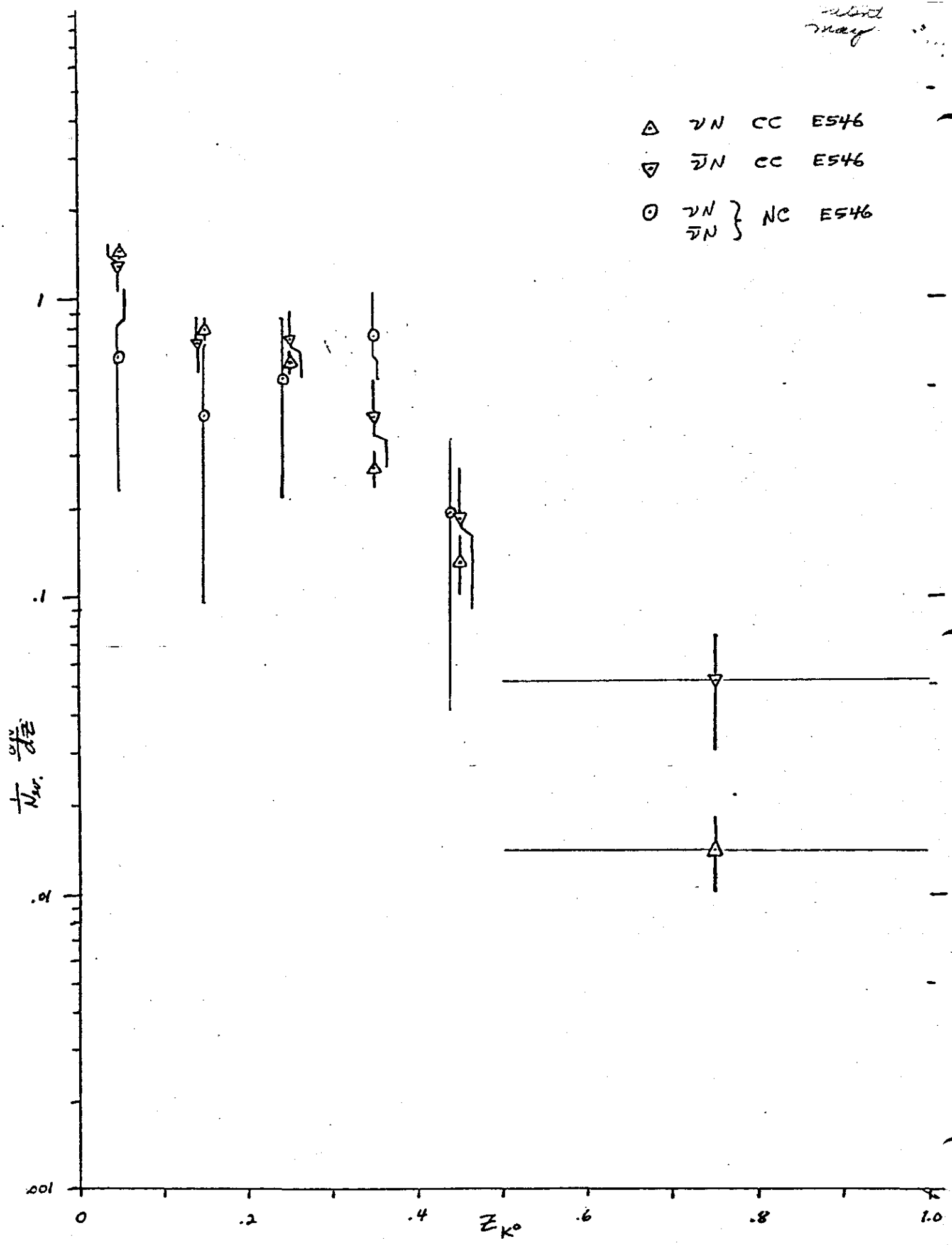

νN CC E546
ν̄N CC E546
νN ν̄N NC E546
1
.1
.01
.001
0
.2
.4
.6
.8
1.0
Z_{K^0}
$\frac{1}{N_{\nu}}\frac{dN}{dZ}$

FIG. 4