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POSSIBLE DEVIATIONS FROM SIMPLE QUARK-PARTON MODELS IN HIGH ENERGY ANTINEUTRINO DIFFERENTIAL DISTRIBUTIONS*

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Abstract

We have analyzed differential distributions for a sample of high energy ν and $\bar{\nu}$- interactions. The antineutrino data require more anti-quark component than expected from low energy results. Also, some indications of energy dependent effects have been observed in these distributions.

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Charged current neutrino interactions ($\nu + N \rightarrow \mu^- +$ hadrons) have long been recognized as providing fundamental information about nucleon structure. From a combination of deep inelastic electron scattering experiments at SLAC[1] and studies of neutrino interactions at CERN[2] a rather simple description of this structure has emerged. In this model, scattering dominantly occurs from point-like, spin 1/2, fractionally charged constituents.

Basically, the low energy data are quite consistent with an interpretation when incorporating a scaling hypothesis for the structure functions and the quantitative predictions of a quark-parton model. Further, early studies of neutrino and antineutrino interactions at the higher energies of Fermilab have also shown striking <u>qualitative</u> agreement with this same picture.[3]

In this model the forms of the differential cross sections for an isoscalar target are given by the following:

$$\frac{d^2\sigma^{\nu}}{dxdy} = \frac{G^2 M E_{\nu}}{4\pi} \left[q(x) + (1-y)^2 \bar{q}(x) \right] \qquad (1)$$

and

$$\frac{d^2\sigma^{\bar{\nu}}}{dxdy} = \frac{G^2 M E_{\bar{\nu}}}{4\pi} \left[\bar{q}(x) + (1-y)^2 q(x) \right]$$

where $x = Q^2/2ME_h$, $y = E_h/E_\nu$, M is the nucleon mass and E_h is the energy transfer to hadrons in the laboratory system. The incident neutrino energy is $E_\nu = E_h + E_\mu$ and $Q^2 = 4\, E_\nu\, E_\mu\, \sin^2\theta/2$ is the square of the 4-momentum transfer. Here E_μ and θ_μ are the laboratory final state energy and scattering angle of the muon. The structure functions $q(x)$ and $\bar{q}(x)$ are related to the quark and antiquark momentum distributions in the nucleon. At low energies the antiquark component has been determined to be small and confined to small x.[2] This leads to the qualitative predictions that (1) $\frac{d\sigma^{\nu}}{dy} \sim$ flat and $\frac{d\sigma^{\bar{\nu}}}{dy} \sim (1-y)^2$, (2) the total cross section σ_ν and $\sigma_{\bar{\nu}}$ grow linearly with energy, and (3) $\sigma^{\bar{\nu}}/\sigma^{\nu} \sim 1/3$.

There are theoretical conjectures which would complicate this picture. For example, the function $q(x)$ and $\bar{q}(x)$ could also depend on Q^2, and there could also be finite non-spin 1/2 contributions of the form $K(x, Q^2)$ (1-y). Such effects are expected in asymptotic freedom[3] models and could lead to an apparent energy dependence of the antiquark fraction $\bar{q} / (q+\bar{q})$. Some Q^2 dependence of the electromagnetic structure functions has been seen in high energy inelastic muon scattering experiments.[4] Energy dependent effects could also come from the production (beyond some threshold) of particles composed of new quarks. Recently, it has been suggested[5] that there may be V+A (right handed) charged currents coupling to new massive quarks.

In this letter we report on the observation of deviations from predictions of the simple quark parton model. The data were taken in Sept.-Oct. 1974 using the Caltech-Fermilab apparatus[6] and a narrow-band neutrino beam.[7] The neutrino interacted in a target composed of 140 tons of steel-scintillation counters and measured the E_h using calorimetry techniques.[8] The muon energy E_μ was determined for events where the muon traversed a steel toroidal spectrometer located downstream of the target.

The experiment was run using short spill (~1msec) extraction from the accelerator (in order to simultaneously do a neutral current experiment). The use of this short spill obviated our ability to directly monitor either the neutrino or antineutrino flux. This represents a serious limitation in the data since no absolute cross sections can be determined and even the relative normalization of ν and $\bar{\nu}$ data requires physics assumptions.

Our total sample of charged current events within the fiducial volume consists of ν-events and $\bar{\nu}$-events. The muon traversed the toroidal μ-spectrometer in 875 of the ν-events and 185 of the $\bar{\nu}$-events. For these events θ_μ, E_μ, and E_{had} are measured and therefore the neutrino energy ($E_\nu = E_\mu + E_{had}$) and scaling variables are determined. For the remainder, only θ_μ and E_{had} were measured. These events have also been included in our analysis.

Figure 1 shows the measured energy distributions for neutrino and anti-neutrino events with a final-state muon traversing the magnet. The characteristic two-peak spectrum from the dichromatic beam is apparent in the neutrino data. For antineutrinos, the relatively lower production of high energy K^-'s is reflected by the smaller fraction of high energy $\bar{\nu}$ events.

In order to test whether our data is consistent with the expectations of the quark-parton model we have used the forms of equations (1) and (2) and assumed a form for the structure function, wherein the shape of $q(x) + \bar{q}(x) = F_2(x)$ is the same as $F_2^{ed}(x)$ and $\bar{q}(x) = \frac{F_2(x)}{2} e^{-\lambda x}$. In this parameterization, the value of λ determines the fraction of anti-quark in the nucleon. We define this fraction as $\alpha = \bar{Q}/(Q + \bar{Q})$, where $Q = \int_0^1 q(x)dx$, etc.

We have simultaneously fit the y-distribution for events through the magnet and the E_{had} distribution for events missing the magnet (see Fig. 2). The fit to the antineutrino data requires a finite α (see Table I). The best value determined from a fit to all the data is $\alpha = 0.24^{+.08}_{-.13}$. The overall fit to the data is acceptable, however, the amount of anti-quark is substantially larger than the usual expectations of a quark-parton model.

In the context of this scaling model the ratio $\frac{\sigma_{\bar{\nu}}}{\sigma_\nu} = \frac{2\alpha + 1}{3 - 2\alpha}$. For our best fit, the value of this ratio predicted is $\frac{\sigma_{\bar{\nu}}}{\sigma_\nu} \sim 0.6$. This indicates that the ratio, integrated over our energy spectrum, would have changed significantly compared to low energies.[9]

In order to further explore this high energy behavior we have analyzed the data in two energy bins (π-decay antineutrinos, $E_{\bar{\nu}} < 90$ GeV, and K-decay anti-neutrinos, $E_{\bar{\nu}} > 90$ GeV) allowing an energy dependent (or scale-breaking) term. As can be seen in Table I, the analysis indicates a larger value for α at high energies. This general behavior is expected in asymptotically-free field theories and leads to a rising $\sigma_{\bar{\nu}}/\sigma_\nu$ ratio.

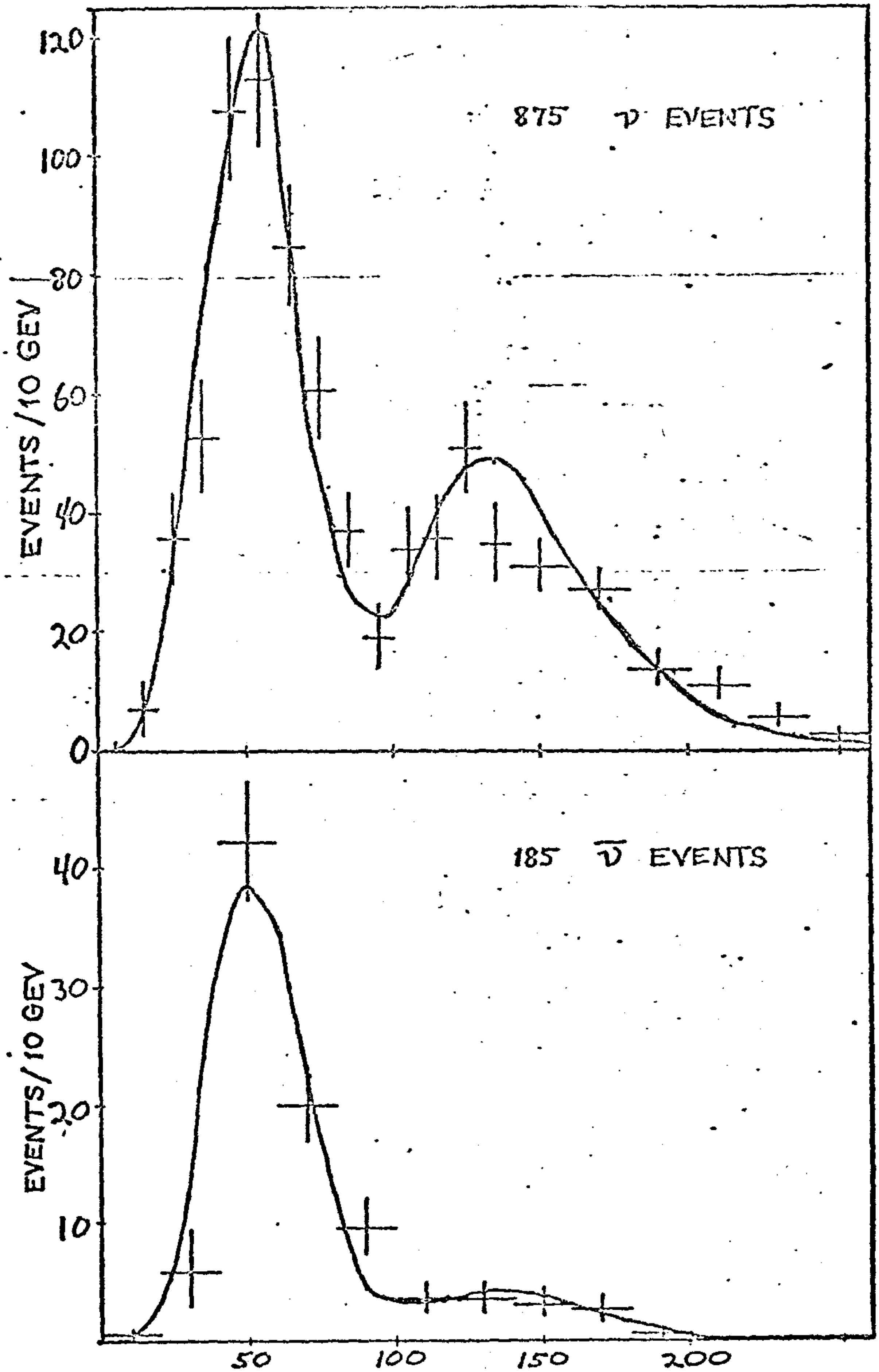
875 ν EVENTS
185 ν̄ EVENTS
EVENTS/10 GEV
EVENTS/10 GEV
120
100
80
60
40
20
0
40
30
20
10
50
100
150
200
$E_\nu^{(H)}$ (GEV)

Fig 1

ANTI-NEUTRINO CHARGED-CURRENT EVENTS

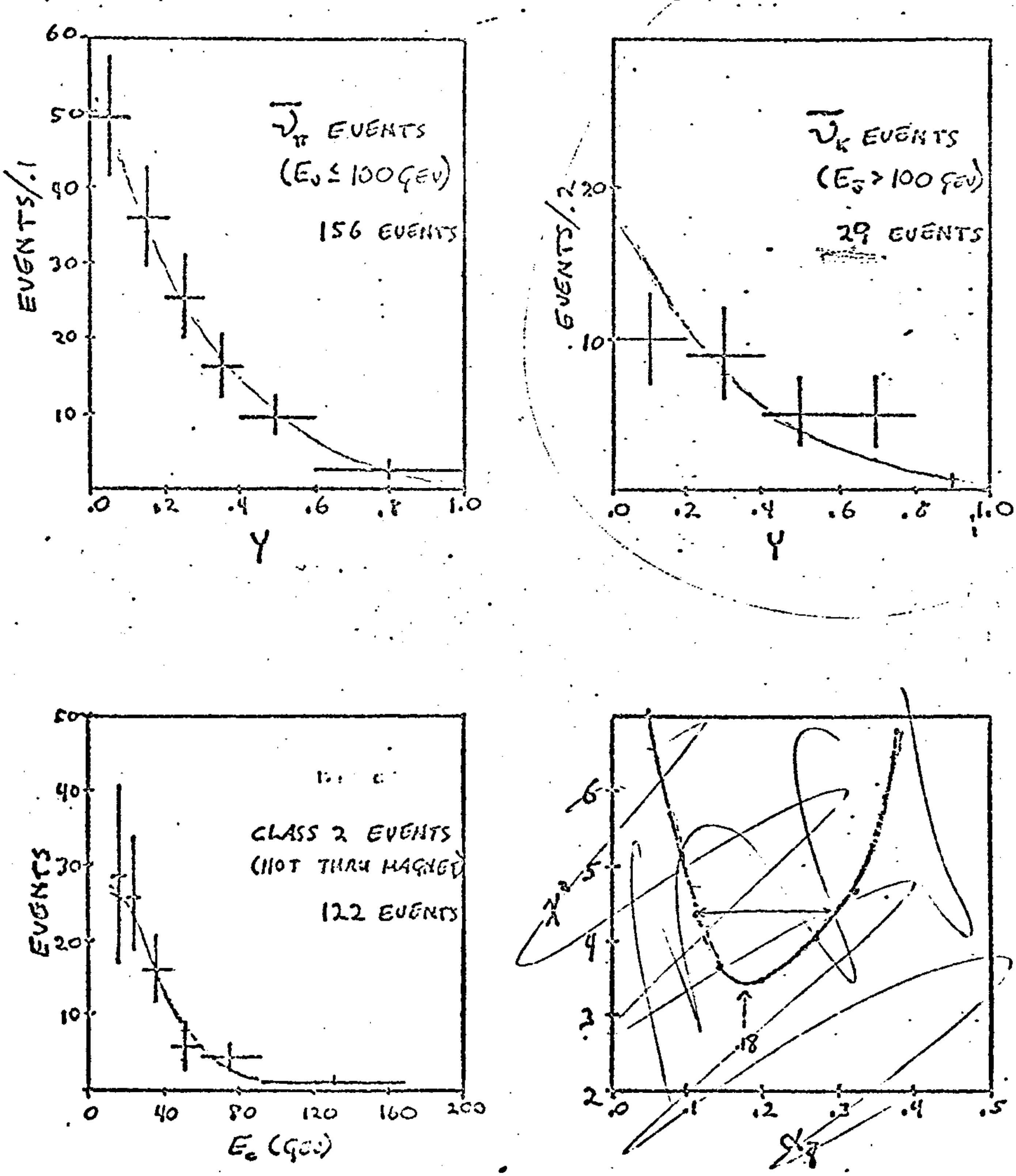

Fig 2

phase curves { α = 0 ? α = 0.27 ? m = 5 GeV ?

TABLE I:

Model	Free Parameters	χ^2	Calculated $\sigma_{\bar{\nu}} / \sigma_{\nu}$	$\bar{E}_{\bar{\nu}}$
Scaling	$\alpha = 0.24^{+.08}_{-.13}$	19	$0.59^{+.10}_{-.15}$	all E_{ν}
Non-Scaling	$\alpha_{\pi} = 0.17^{+.13}_{-.11}$	16	$0.52^{+.15}_{-.11}$	50 GeV
	$\alpha_{k} = 0.32^{+.18}_{-.15}$		$.69^{+.31}_{-.19}$	150 GeV
b - Quark Right-handed Currents $\alpha = 0.06$	$M_b = 5.1^{+0.9}_{-0.5}$	20	$0.44^{+.03}_{-.04}$	50 GeV
			$0.68^{+.07}_{-.09}$	150 GeV

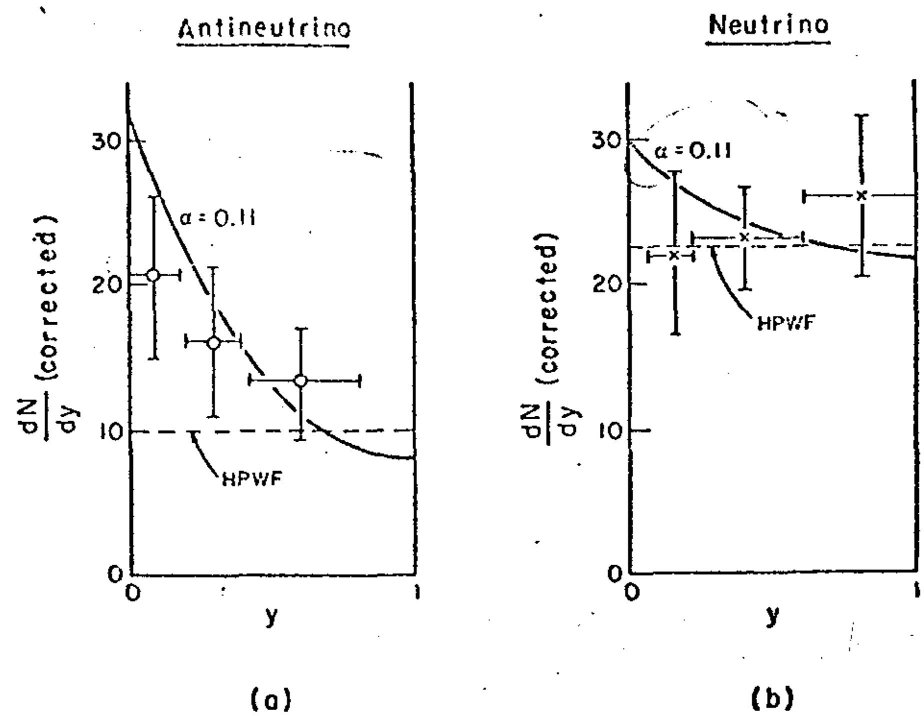

Fig 3 - $\bar{\nu}_\pi$, ν_π data [show fit for α = 0.17].

We have also fit the data using a radically different model with right-handed currents and production of b-quarks.[10] In this model, the amount of $\bar{Q}$ is fixed at the best low energy value $\alpha \sim 0.06$ and the free parameter is the b-quark mass. As shown in Table I, a good fit is obtained with $M_b = 5.1$ GeV/c^2. This model for the charged currents also implies a growing $\sigma_{\bar{\nu}} / \sigma_{\nu}$ ratio above b-quark threshold.

From our data, it is not possible to distinguish between these explanations or others which could affect antineutrino distributions. All we can conclude with any certainty is that the antineutrino y-distributions have apparently changed character and are flatter at high energies. It is not valid without further assumptions to conclude that the data necessarily imply a growing $\sigma_{\bar{\nu}} / \sigma_{\nu}$ ratio. All our fits have in common an assumption that charge symmetry is valid as $y \to 0$. (That is, $\frac{d\sigma^{\nu}}{dy}\Big|_{y=0} = \frac{d\sigma^{\bar{\nu}}}{dy}\Big|_{y=0}$). This would be approximately true in the theories mentioned above. Since our data is not normalized, however, we cannot check this hypothesis.

Various reports of a breakdown of charge symmetry have been previously reported[11] by the Harvard-Pennsylvania-Wisconsin-Fermilab group. They have reported (also for unnormalized data) that if the data is cut for $x > 0.1$ the antineutrino distribution is close to $\frac{d\sigma^{\bar{\nu}}}{dy} \sim (1-y)^2$. That data was normalized by assuming that for $x > 0.1$ ν and $\bar{\nu}$ cross sections are equal at $y = 0$. The conclusion of that analysis was that $\bar{\nu}$-distributions for $x < 0.1$ are almost flat and that the ν and $\bar{\nu}$ normalization differ by about a factor of three at <u>all</u> y. This would imply a substantial breakdown of charge symmetry at $y = 0$.

We have performed a similar analysis on our data which is shown in Fig. 3. Although statistics are limited our data shows no obvious violation of charge symmetry at small y and $x < 0.1$.

Again, we emphasize that our data show strong indications that the antineutrino distributions have changed shape at high energies. However, to verify this apparent change and to unambiguously resolve the question of whether this observation represents an excess of antineutrino events at large y, a redistribution of events in y, or, indeed, a lack of antineutrino events at small y, will require good statistics distributions normalized to independently measured incident flux. We have recently taken such data and results should be forthcoming soon.