Inclusive neutrino interactions in a six quark model*

Gordon J. Aubrecht, II, E. Takasugi, and K. Tanaka

Department of Physics
The Ohio State University
Columbus, Ohio 43210

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ABSTRACT

We examine the effects of non-diagonal terms in the neutral current of an $SU(2) \otimes U(1)$ gauge six-quark model with slow rescaling. The model reproduces the experimental charged current data with appropriate choice of heavy quark masses. The experimental neutral current data requires at least five quarks to explain it. In our context, the predictions for various heavy quark masses and quark mixings differ most for energies in the range 0-50 GeV. The various quantities are also calculated for proton and neutron targets.

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I. INTRODUCTION

The strong increase in the ratio of the inclusive charged current neutrino cross sections,¹ $\sigma^{\bar{\nu}N}/\sigma^{\nu N}$, and in the expectation value of the hadron energy for $\bar{\nu}$ inclusive cross section on isoscalar target,² $\langle y \rangle^{\bar{\nu}N}$, may suggest the appearance of heavy quarks³ in addition to the familiar SU(3) triplet quarks (u,d,s) and the charmed quark c. Despite the substantial increase in $\sigma^{\bar{\nu}N}$ with energy, the neutral to charged inclusive cross section ratio $R^{\bar{\nu}} = \sigma_{nc}^{\bar{\nu}N}/\sigma^{\bar{\nu}N}$ is seemingly constant.⁴ This appears to indicate that the neutral current cross section, $\sigma_{nc}^{\bar{\nu}N}$, also increases with energy. If $\sigma_{nc}^{\bar{\nu}N}$ does rise with energy, there is at least one new threshold. We study the contributions of the new threshold arising from the presence of a non-diagonal term in the neutral current: that involving a valence quark and a heavy quark.

We adopt an SU(2) $\otimes$ U(1) gauge model with six quarks grouped into left-handed doublets $\begin{pmatrix} u \\ d \end{pmatrix}_L$, $\begin{pmatrix} c \\ s_\theta \end{pmatrix}_L$, a right-handed doublet $\begin{pmatrix} u \cos\phi + t \sin\phi \\ b \end{pmatrix}_R$, and associated singlets.⁵ The Cabibbo-rotated quarks are given by $d_\theta = d \cos \theta_C + s \sin \theta_C$ and $s_\theta = s \cos \theta_C - d \sin \theta_C$, and the charges of the t and b quarks are 2/3 and -1/3, respectively.

A six-quark model is the simplest generalization of the four-quark GIM model⁶ and has the possible virtue of incorporating CP invariance in a natural manner.⁷ This model would be a five quark model, if the t quark were to be replaced by the c quark.⁸

In Sec. 2, the inclusive cross sections are obtained and the optimum values of m_b are determined for $\cos^2 \phi = \frac{1}{2}$ and 1 from fits for $\sigma^{\bar{\nu}N}/\sigma^{\nu N}$ and $\langle y \rangle^{\bar{\nu}N}$. We study in Sec. 3 the effect of the non-diagonal terms on $R^{\bar{\nu}} =$

$\sigma_{nc}^{\nu N}/\sigma^{\nu N}$ and $R^{\bar{\nu}} = \sigma_{nc}^{\bar{\nu} N}/\sigma^{\bar{\nu} N}$ with the choices $\cos^2 \phi = \frac{1}{2}$ and 1, which respectively maximize and minimize the effect. Quantities corresponding to those above are obtained for proton and neutron targets in Sec. 4, and conclusions are given in Sec. 5.

2. CHARGED AND NEUTRAL CURRENT CROSS SECTIONS

We begin by writing the charged and neutral currents in the present six-quark model

$$J_{\mu}^{+} = \bar{u} \gamma_{\mu} (1 + \gamma_5) d_{\theta} + \bar{c} \gamma_{\mu} (1 + \gamma_5) s_{\theta} + \cos \phi \bar{u} \gamma_{\mu} (1 - \gamma_5) b + \sin \phi \bar{t} \gamma_{\mu} (1 - \gamma_5) b, \quad (2.1)$$

$$J_{\mu}^Z = J_{\mu}^3 - 2 \sin^2 \theta_W J_{\mu}^{em}. \quad (2.2)$$

Here the expression

$$J_{\mu}^3 = \frac{1}{2} \left[\bar{u} \gamma_{\mu} (1 + \gamma_5) u - \bar{d} \gamma_{\mu} (1 + \gamma_5) d + \bar{c} \gamma_{\mu} (1 + \gamma_5) c - \bar{s} \gamma_{\mu} (1 + \gamma_5) s + \cos^2 \phi \bar{u} \gamma_{\mu} (1 - \gamma_5) u + \sin^2 \phi \bar{t} \gamma_{\mu} (1 - \gamma_5) t - \bar{b} \gamma_{\mu} (1 - \gamma_5) b + \sin \phi \cos \phi \{ \bar{u} \gamma_{\mu} (1 - \gamma_5) t + \bar{t} \gamma_{\mu} (1 - \gamma_5) u \} \right]. \quad (2.3)$$

is obtained from the charged current, and θ_W is the Weinberg angle.

The charged current cross sections on an isoscalar target with slow rescaling⁹ in the quark parton model are (in units of $G^2 M E / \pi$),

$$\begin{aligned} \frac{d\sigma^{\nu N}}{dx dy} = & \cos^2 \theta_c x \mathcal{V}(x) + 2 \{ 1 + (1-y)^2 \} x \mathcal{Z}(x) \\ & + \theta(W - W_c) \left(1 - y + \frac{yx}{x_c} \right) x_c \{ \sin^2 \theta_c \mathcal{V}(x_c) + 2 \mathcal{Z}(x_c) \} \\ & + \theta(W - W_b) \left(1 - y + \frac{yx}{x_b} \right) 2 \cos^2 \phi x_b \mathcal{Z}(x_b). \end{aligned} \quad (2.4)$$

$$\begin{aligned} \frac{d\sigma^{\bar{\nu}N}}{dx dy} = & (1-y)^2 x v(x) + 2\{1+(1-y)^2\} x \xi(x) \\ & + \theta(W-W_c)\left(1-y+\frac{yx}{x_c}\right) 2x_c \xi(x_c) \\ & + \theta(W-W_b)\left(1-y+\frac{yx}{x_b}\right) \cos^2\phi x_b \{v(x_b)+2\xi(x_b)\}, \end{aligned} \quad (2.5)$$

where

$$v(x) = u(x) + d(x) - \bar{u}(x) - \bar{d}(x), \quad (2.6)$$

$$\xi(x) = \bar{u}(x) = \bar{d}(x) = s(x) = \bar{s}(x), \quad (2.7)$$

with $x = Q^2/2Mv$, $y = v/E$, and

$$x_i = x + (m_i^2/2MEy) \quad (2.8)$$

The factor $\theta(W - W_i)$ [$W = 2MEy(1-x) + M^2$ is the invariant mass of the final hadron system, M is the nucleon mass, and W_i is $m_i + M$, the heavy i -quark threshold] is 0 below the threshold and 1 above the threshold.

The quark densities have been denoted $u(x)$, $d(x)$, $s(x)$, etc. We assume an SU(3) symmetric sea and neglect the c , b , and t sea contributions.

In a similar way, the neutral current cross sections can be parametrized using (2.2) as

$$\begin{aligned} \frac{d\sigma_{nc}^{(\nu, \bar{\nu})N}}{dx dy} = & \left(1-y+\frac{y^2}{2}\right) \left[\left\{ \frac{1}{2} + \frac{1}{4} \cos^4\phi - \left(1+\frac{2}{3} \cos^2\phi\right) X_W + \frac{10}{9} X_W^2 \right\} x v(x) \right. \\ & + \left. \left\{ 3 + \cos^4\phi - \frac{8}{3} (2 + \cos^2\phi) X_W + \frac{16}{3} X_W^2 \right\} x \xi(x) \right] \\ & \pm \left(y - \frac{y^2}{2}\right) \left\{ \frac{1}{2} - \frac{1}{4} \cos^4\phi - \left(1 - \frac{2}{3} \cos^2\phi\right) X_W \right\} x v(x) \\ & + \theta(W-W_t) \frac{1}{4} \sin^2\phi \cos^2\phi \left[\left(1-y+\frac{y^2 x}{2x_t}\right) x_t \{v(x_t)+4\xi(x_t)\} \right. \\ & \left. \mp \left(y - \frac{y^2}{2}\right) x v(x_t) \right] \end{aligned} \quad (2.9)$$

The neutrino and antineutrino neutral current cross sections correspond to the upper and lower signs in Eq. (2.9), and $X_W = \sin^2 \theta_W$.

The parameter m_b is determined by verifying that the quantities $\sigma^{\bar{\nu}N}/\sigma^{\nu N}$ and $\langle y \rangle^{\bar{\nu}N}$ give a reasonable description of the data for a given $\cos \phi$. In order to compare the models with the available data² for $\langle y \rangle^{\bar{\nu}N}$, it is necessary to incorporate the experimental cuts. The valence and sea distribution given by McElhaney and Tuan¹⁰ has been used. The values $\cos^2 \phi = \frac{1}{2}$ and 1 give the extremal contributions of the non-diagonal term to the neutral current cross sections. For these values of $\cos^2 \phi$ the plots on Figs. 1 and 2 show the two sets of optimum values $\cos^2 \phi = \frac{1}{2}$, $m_b = 4$, and $\cos^2 \phi = 1$, $m_b = 5$ for m_c fixed at 1.5 with all masses in GeV/c^2 .

3. EFFECT OF THE NON-DIAGONAL TERM

In order to isolate the essential features of the non-diagonal contribution, we estimate its effect when the sea contribution is neglected. Below the c, b, and t quark mass thresholds, we integrate Eqs. (2.4), (2.5), and (2.9);

$$\sigma_B^{\nu N} = V, \quad (3.1)$$

$$\sigma_B^{\bar{\nu}N} = \frac{1}{3}V, \quad (3.2)$$

$$R_B = (\sigma^{\bar{\nu}N}/\sigma^{\nu N})_B = \frac{1}{3}, \quad (3.3)$$

$$R_B^{\nu} = (\sigma_{nc}^{\nu N}/\sigma^{\nu N})_B = \frac{1}{2} - X_W + \frac{20}{27}X_W^2 + \frac{1}{12}\cos^4 \phi - \frac{2}{9}\cos^2 \phi X_W, \quad (3.4)$$

$$R_B^{\bar{\nu}} = (\sigma_{nc}^{\bar{\nu}N}/\sigma^{\bar{\nu}N})_B = 3\left(\frac{1}{6} - \frac{1}{3}X_W + \frac{20}{27}X_W^2 + \frac{1}{4}\cos^4 \phi - \frac{2}{3}\cos^2 \phi X_W\right), \quad (3.5)$$

where $V = \int v(x)xdx$, and $\cos^2 \theta_c = 1$ for simplicity. The subscript B indicates that the quantity is taken below the c, b, and t thresholds.

Far above the c, b, and t thresholds, where the effects of m_c , m_b , and m_t are negligible, (that is, at asymptotic energies),

$$\sigma_{\infty}^{\nu N} = V, \quad (3.6)$$

$$\sigma_{\infty}^{\bar{\nu} N} = \left(\frac{1}{3} + \cos^2 \phi\right) V, \quad (3.7)$$

$$R_{\infty} = \frac{1}{3} + \cos^2 \phi, \quad (3.8)$$

$$R_{\infty}^{\nu} = \frac{1}{2} - X_W + \frac{20}{27} X_W^2 + \frac{1}{12} \cos^2 \phi - \frac{2}{9} \cos^2 \phi X_W, \quad (3.9)$$

$$R_{\infty}^{\bar{\nu}} = 3 \left(\frac{1}{6} - \frac{1}{3} X_W + \frac{20}{27} X_W^2 + \frac{1}{4} \cos^2 \phi - \frac{2}{3} \cos^2 \phi X_W \right) / (1 + 3 \cos^2 \phi). \quad (3.10)$$

The subscript ∞ indicates that the quantity is taken far above all thresholds.

In order to relate the values of $R^{\nu, \bar{\nu}}$ far above the thresholds to those below thresholds, we use (3.4), (3.5), (3.9) and (3.10) to form the ratios

$$R_{\infty}^{\nu} / R_B^{\nu} = 1 + (\sin^2 \phi \cos^2 \phi / 12 R_B^{\nu}) , \quad (3.11)$$

$$R_{\infty}^{\bar{\nu}} / R_B^{\bar{\nu}} = \left[1 + \left(\frac{3}{4} \sin^2 \phi \cos^2 \phi / R_B^{\bar{\nu}} \right) \right] / (1 + 3 \cos^2 \phi). \quad (3.12)$$

Eqs. (3.11) and (3.12) give $R_{\infty}^{\nu} / R_B^{\nu} = 1$ and $R_{\infty}^{\bar{\nu}} / R_B^{\bar{\nu}} = 1/4$, respectively for $\cos^2 \phi = 1$. If we use the Gargamelle (GGM) data,¹¹ $R_B^{\nu} = 0.25 \pm 0.04$ and $R_B^{\bar{\nu}} = 0.39 \pm 0.06$ for $\langle E \rangle \sim 2$ GeV, we find $R_{\infty}^{\nu} / R_B^{\nu} = 1.08 \pm 0.01$ and $R_{\infty}^{\bar{\nu}} / R_B^{\bar{\nu}} = 0.59 \pm 0.03$, respectively, for $\cos^2 \phi = \frac{1}{2}$. The ratio $R_{\infty}^{\bar{\nu}} / R_B^{\bar{\nu}}$ is strongly dependent on the presence of the non-diagonal term while the ratio $R_{\infty}^{\nu} / R_B^{\nu}$ is almost independent of it.

We are interested in the energy dependence of R^V and $R^{\bar{V}}$. We shall compare the predictions from the slow rescaling model for m_c fixed at 1.5 GeV with the data for three cases:

- (i) $\cos^2 \phi = 1$, $m_b = 5$ GeV,
- (ii) $\cos^2 \phi = \frac{1}{2}$, $m_b = 4$ GeV; $m_t = 1.5$ GeV,
- (iii) $\cos^2 \phi = \frac{1}{2}$, $m_b = 4$ GeV; $m_t = 5$ GeV.

The combinations of ϕ and m_b provide reasonable fits for charged current cross section ratios and $\langle y \rangle^{\bar{V}N}$ as discussed in Sec. 2. The charged current cross sections do not depend on m_t because we disregard the sea from the t quark; the neutral current cross sections depend on m_t except for $\cos^2 \phi = 1$. For case (i), there are only diagonal neutral current contributions; for cases (ii) and (iii), the non-diagonal contributions are maximized.

The numerical calculation carried out with choice (i) gives essentially the same predictions for the cross sections as an alternative six-quark model.¹² Choice (ii) is not experimentally tenable; we therefore interpret this choice as a five-quark model by identifying the t -quark with the c -quark ($m_t = m_c$). Hereafter, the right handed doublet is taken as $\begin{pmatrix} (u+c)/\sqrt{2} \\ b \end{pmatrix}_R$ in model (ii).

The dependence of R^V and $R^{\bar{V}}$ on energy is presented in Figures 3 and 4. Here $\sin^2 \theta_w$ values of 0.3 and 0.4, representative of the range of leptonic neutral current experimental results,¹³ are used. The data we plot in our graphs are obtained from GGM, the Harvard-Penn-Wisconsin-Fermilab collaboration (HPWF),¹⁴ and the Caltech-Fermilab collaboration (CTF).¹⁵ The $R^{\bar{V}} - R^V$ curves for 10 GeV are plotted in Fig. 5. The GGM data are at low energy and are therefore most relevant here for comparisons. The HPWF and CTF data are to be compared with the 50 GeV $R^{\bar{V}} - R^V$ curve, shown in Fig. 6. All data are included in both plots to facilitate comparisons. In Fig. 7, the $R^{\bar{V}} - R^V$ curve is plotted for 150 GeV energy. While this

energy is not yet asymptotic, it is within the purview of current experimentation (which should provide further data for these comparisons), and high enough so that the quantities R^ν and $R^{\bar{\nu}}$ are rather slowly varying with increasing energy.

Figure 3 shows that R^ν has essentially no energy dependence regardless of the choice (i), (ii), or (iii), and the predictions are in reasonable agreement with the data for the choice $\sin^2 \theta_W = 0.3 - 0.4$. A general feature illustrated in Fig. 4 is the lower value of $R^{\bar{\nu}}$ for $\cos^2 \phi \neq 1$ (i.e. when there is a non-diagonal contribution) as compared to the case for $\cos^2 \phi = 1$ at low energy; note from Eqs. (3.5) and (3.10) that the effect of the change of $\cos^2 \phi$ from 1 to $\frac{1}{2}$ is that $R_B^{\bar{\nu}}(\cos^2 \phi = \frac{1}{2})/R_B^{\bar{\nu}}(\cos^2 \phi = 1) = 4/7$ increases with energy to $R_\infty^{\bar{\nu}}(\cos^2 \phi = \frac{1}{2})/R_\infty^{\bar{\nu}}(\cos^2 \phi = 1) = 8/5$ (for $\sin^2 \theta_W = 3/8$). The increase is not so obvious in R^ν . We see from Eqs. (3.4) and (3.9) (for $\sin^2 \theta_W = 3/8$) that $R_B^\nu(\cos^2 \phi = \frac{1}{2})/R_B^\nu(\cos^2 \phi = 1) = 10/11$ increases with energy merely to $R_\infty^\nu(\cos^2 \phi = \frac{1}{2})/R_\infty^\nu(\cos^2 \phi = 1) = 1$. As compared to a diagonal neutral current, the effect of the non-diagonality in this model is to decrease the low energy neutral current cross section. The shape of $R^{\bar{\nu}}$ with choice (i) differs from those with choices (ii) or (iii) because of the non-diagonal term in the neutral current; (ii) and (iii) differ because of their different quark mass thresholds. Fig. 4 indicates that choices (i) and (ii) are both reasonably descriptive of the data; choice (iii) is least favored. Figures 5 and 6 confirm that our choice for the range of $\sin^2 \theta_W$ (0.3-0.4 as taken from the leptonic data) is the best choice for the inclusive cross section data as well.

4. NEUTRINO PROTON CROSS SECTIONS

For this section we shall use the proton and neutron quark valence distribution functions as given by McElhaney and Tuan;¹⁰

$$u(x) = u_V(x) + \xi(x) , \quad (4.1)$$

$$d(x) = d_V(x) + \xi(x) . \quad (4.2)$$

The charged current cross sections on a proton target are

$$\begin{aligned} \frac{d\sigma^{\nu p}}{dx dy} = & 2 \cos^2 \theta_c x d_V(x) + 2(1+(1-y)^2) x \xi(x) \\ & + \theta(W-W_c)(1-y + \frac{y^2}{x_c}) 2 x_c \{ \sin^2 \theta_c d_V(x_c) + \xi(x_c) \} \\ & + \theta(W-W_b)(1-y + \frac{y^2}{x_b}) 2 \cos^2 \phi x_b \xi(x_b), \end{aligned} \quad (4.3)$$

$$\begin{aligned} \frac{d\sigma^{\bar{\nu} p}}{dx dy} = & 2(1-y)^2 x u_V(x) + 2(1+(1-y)^2) x \xi(x) \\ & + \theta(W-W_c)(1-y + \frac{y^2}{x_c}) 2 x_c \xi(x_c) \\ & + \theta(W-W_b)(1-y + \frac{y^2}{x_b}) 2 \cos^2 \phi x_b \{ u_V(x_b) + \xi(x_b) \} . \end{aligned} \quad (4.4)$$

In a similar way, the neutral current cross sections on a proton target can be parametrized as

$$\begin{aligned} \frac{d\sigma_{nc}^{(\nu, \bar{\nu}) p}}{dx dy} = & (1-y + \frac{y^2}{2}) \left[\left\{ \frac{1}{2} + \frac{\cos^4 \phi}{2} - \frac{4}{3}(1+\cos^2 \phi) X_W + \frac{16}{9} X_W^2 \right\} x u_V(x) \right. \\ & + \left(\frac{1}{2} - \frac{2}{3} X_W + \frac{4}{9} X_W^2 \right) x d_V(x) + \left. \left\{ 3 + \cos^4 \phi - \frac{8}{3}(2+\cos^2 \phi) X_W \right. \right. \\ & \left. \left. + \frac{16}{3} X_W^2 \right\} x \xi(x) \right] \\ & \pm (y - \frac{y^2}{2}) x \left[\left\{ \frac{1}{2} - \frac{\cos^4 \phi}{2} - \frac{4}{3}(1-\cos^2 \phi) X_W \right\} u_V(x) + \left(\frac{1}{2} - \frac{2}{3} X_W \right) d_V(x) \right] \\ & + \theta(W-W_t) \frac{\sin^2 \phi \cos^2 \phi}{2} \left[\left(1-y + \frac{y^2}{2x_t} \right) x_t \{ u_V(x_t) + 2 \xi(x_t) \} \right. \\ & \left. \mp (y - \frac{y^2}{2}) x u_V(x_t) \right] . \end{aligned} \quad (4.5)$$

The ν and $\bar{\nu}$ cross sections correspond to the upper and lower signs, respectively. We may obtain the results for a neutron target by exchanging $u_V(x)$ and $d_V(x)$. The ratios of neutron to proton charged current cross sections $\sigma^{\nu n}/\sigma^{\nu p}$ and $\sigma^{\bar{\nu} n}/\sigma^{\bar{\nu} p}$ are plotted in Figs. 8 and 9. The plot of Fig. 8 is compared to the recent data¹⁶ for $\sigma^{\nu n}/\sigma^{\nu p}$. The predictions for $\sigma^{\bar{\nu} p}/\sigma^{\nu p}$, $\langle y \rangle^{\bar{\nu} p}$, $R^{\nu p}$, $R^{\bar{\nu} p}$ (and the corresponding quantities for neutrons) are plotted in Figs. 10, 11, 12, and 13, respectively. Scattering on proton and neutron targets is of great interest. The forthcoming measurements in the hydrogen bubble chamber at ZGS and the 15-ft bubble chamber at FNAL should provide interesting information on the quark-parton model. In our model, $R^{\bar{\nu} p}$ and $R^{\bar{\nu} n}$ are most interesting for discriminating the existence of non-diagonality in the neutral current.

5. CONCLUSIONS

We have examined the effect of non-diagonality of the neutral current in a six-quark $SU(2) \otimes U(1)$ gauge model of the Weinberg-Salam type. We construct three cases of a six-quark model to be consistent with the charged current data. On the basis of Fig. 4, the appropriate place to look for the experimental effect of the non-diagonal term in the neutral current cross sections is at low energy (0-50 GeV). There are two theoretical characteristics of $R^{\bar{\nu}}$ to be examined: its magnitude (distinguishing diagonal from non-diagonal cases at energies of several GeV) and its shape at intermediate energies $\left\{ \text{distinguishing model (ii), with a term } (\bar{c}u)_R, \text{ from the others} \right\}$. At higher energies (~ 100 GeV) the three cases are not distinguishable.

On the basis of R^{ν} and $R^{\bar{\nu}}$, given in Figs. 3 and 4, we find that case (i) $[\cos^2 \phi = 1, (\bar{u}_b)_R]$, and case (ii) $[\cos^2 \phi = \frac{1}{2}, (\bar{u}+c)/\sqrt{2}_b)_R]$ are adequate to explain the neutral current data. Therefore, the minimum number of

quarks necessary to explain experimental data is five.

In Sec. 4, we present predictions (based on fits from electroproduction) of the neutron and proton target cross sections for our three cases, which will be checked with the forthcoming data.

It should be noted that we have made the conventional choice for the relative strength of the neutral and charged currents ($M_W/M_Z \cos \theta_W = 1$, where M_W and M_Z are the charged and neutral intermediate vector boson masses, respectively). It appears from Figs. 5 and 6 that $M_W/M_Z \cos \theta_W \sim 1$. We may note that the curves of $R^{\bar{\nu}}/R^{\nu}$ given in Fig. 14 are independent of the relative strengths of the neutral and charged currents and provide an alternative test of our choices in the wider sphere of allowed $SU(2) \otimes U(1)$ gauge models.¹⁷

In order to estimate the effects of the sea contributions in our result, we added a right-handed doublet $\begin{pmatrix} C \\ S \end{pmatrix}_R$ to the choices (i) and (iii) adopted above and repeated the calculation. We found that the effect was 5-8% for R^{ν} and $R^{\bar{\nu}}$ in the energy range we considered. This large an effect may indicate that the seas could be more important than heretofore thought.

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FIGURE CAPTIONS

- Fig. 1. Energy dependence of the charged current isoscalar target cross section ratio $\sigma^{\bar{\nu}N}/\sigma^{\nu N}$, demonstrating the fit with the parameters used. The data are taken from Ref. 1.
- Fig. 2 (a) Energy dependence of $\langle y \rangle^{\bar{\nu}N}$ for an isoscalar target. This curve is to be compared with corrected data.
 (b) Energy dependence of $\langle y \rangle^{\bar{\nu}N}$ for an isoscalar target showing the fit with the parameters using the experimental cuts on angle and muon energy. The data are taken from Ref. 2.
- Fig. 3 Energy dependence of R^{ν} compared with data of Refs. 13-15.
- Fig. 4 Energy dependence of $R^{\bar{\nu}}$ compared with data of Refs. 13-15.
- Fig. 5 $R^{\bar{\nu}}$ versus R^{ν} at 10 GeV. Data are from Refs. 13-15. Compare curves with data of Ref. 13 (GGM).
- Fig. 6 $R^{\bar{\nu}}$ versus R^{ν} at 50 GeV. Data are from Refs. 13-15. Compare curves with data of Refs. 14, 15 (HPWF, CTF).
- Fig. 7 $R^{\bar{\nu}}$ versus R^{ν} at 150 GeV.
- Fig. 8 Energy dependence of the ratio $\sigma^{\nu n}/\sigma^{\nu p}$. Data are taken from Ref. 16. At higher energies (~ 150 GeV) $\sigma^{\nu n}/\sigma^{\nu p} \approx 2.17$.
- Fig. 9 Energy dependence of the ratio $\sigma^{\bar{\nu}n}/\sigma^{\bar{\nu}p}$. At higher energies (~ 150 GeV) $\sigma^{\bar{\nu}n}/\sigma^{\bar{\nu}p} \approx 0.49$ for $\cos^2 \phi = 0.5$ and $\sigma^{\bar{\nu}n}/\sigma^{\bar{\nu}p} \approx 0.46$ for $\cos^2 \phi = 1$.
- Fig. 10 Energy dependence of charged current antineutrino to neutrino cross section ratio on proton and neutron targets.
- Fig. 11 Energy dependence of $\langle y \rangle^{\bar{\nu}p}$ and $\langle y \rangle^{\bar{\nu}n}$.

Fig. 12 Energy dependence of $R^{\nu p}$ and $R^{\nu n}$.

Fig. 13 Energy dependence of $\bar{R}^{\nu p}$ and $\bar{R}^{\nu n}$.

Fig. 14 Energy dependence of $\bar{R}^{\nu}/R^{\nu}$. This ratio is independent of the relative strengths of neutral and charged currents. Data are taken from Refs. 13-15.

Figure 1

Figure 2

Figure 3

Figure 4

Figure 5

Figure 6

Figure 7

Figure 8

Figure 9

Figure 10

Figure 11

Figure 12

Figure 13

Figure 14