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NEUTRAL CURRENT CONSTRAINTS ON GAUGE MODELS OF
WEAK AND ELECTROMAGNETIC INTERACTIONS

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Recent studies by Sehgal and Hung and Sakurai suggest that neutrino hadron neutral current couplings must lie in one of two allowed regions in coupling parameter space. We extend their analyses using realistic BNL ν_μ and $\bar{\nu}_\mu$ spectra in the elastic $\nu_\mu p$ ($\bar{\nu}_\mu p$) calculations and also study constraints imposed by the q^2 -distributions. We also compare these results with a variety of gauge models. The Weinberg-Salam and $SU(2)_L \times SU(2)_R \times U(1)$ models fall within one allowed region, while a vectorlike $SU(3) \times U(1)$ model and a hybrid $SU(2) \times U(1)$ model with a $(u,b)_R$ doublet fall in the other region.

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Schgal¹ has recently analyzed the Gargamelle semi-inclusive² and inclusive³ neutral current data to determine the magnitudes of the left and right chiral couplings of the u and d quarks which contribute to neutrino-hadron neutral current scattering. He found $|\epsilon_L(u)|^2 = 0.082 \pm 0.035$, $|\epsilon_R(u)|^2 = 0.055 \pm 0.025$, $|\epsilon_L(d)|^2 = 0.158 \pm 0.035$, and $|\epsilon_R(d)|^2 = 0.001 \pm 0.025$.

Hung and Sakurai⁴ subsequently attempted to determine the signs of the chiral couplings by using the elastic $\nu_\mu p$ and $\bar{\nu}_\mu p$ H₂O data⁵ from BNL. They defined eight possible solutions corresponding to different signs for $\epsilon_L(u)$, $\epsilon_R(u)$, and $\epsilon_L(d)$ ($\epsilon_R(d)$ is nearly zero). They labeled four of these solutions A, B, C, and D. The other four (A', B', C', D') differ only by an overall sign. (The two sets of solutions are displayed in Figures 2 and 3). Hung and Sakurai then used the calculation by Albright et. al.⁶ of the $\nu_\mu p$ and $\bar{\nu}_\mu p$ elastic cross sections to argue that only solutions A and B are in agreement with the elastic data.

We have compared the four solutions (A, B, C, D) with the elastic $\nu_\mu p$ and $\bar{\nu}_\mu p$ H₂O data. Our analysis extends that of Hung and Sakurai in that we fold in the most reliable ν_μ and $\bar{\nu}_\mu$ BNL spectra⁷. In addition, we have studied the dependence of the results on the poorly known mass parameters that appear in the dipole form factors for the axial isovector and isoscalar currents and on the axial vector SU(3) parameter $D/(F + D)$ that is used to relate the axial isovector and isoscalar matrix elements. We have found that the results are insensitive to $D/(F + D)$, so we fix its value at 0.66 (as found from hyperon decay). The results of our calculation for $R_{\bar{\nu}p}^{e2} = \sigma(\nu p - \nu p) / \sigma(\bar{\nu} n - \bar{\nu} p)$ and $R_{\nu p}^{e2} = \sigma(\bar{\nu} p - \bar{\nu} p) / \sigma(\nu p - \nu p)$ are shown in Fig. 1 for $M_V = 0.84$ GeV and $M_A = 0.84$ and 0.90 GeV. It can be seen that regions C and D are clearly ruled out, which agrees with the conclusion of Hung and Sakurai⁴. We have also compared the q^2 distributions predicted by each region with the H₂O data. Solutions A and B are in better agreement with the data than C and D, but none can be conclusively ruled out by the q^2 distributions. These calculations will be presented in more detail elsewhere⁸.

We have also compared the predictions of several popular gauge models with solutions A and B. The multiplet assignments of the u and d quarks are given in Table I. The SU(2) X U(1) models include the Weinberg-Salam model⁹ (WS) two hybrid models¹⁰, and a general model which interpolates between all the others. The predictions of the models are shown in Figures 2a and 3a. The W-S and first hybrid model (with a $(ub)_R$ doublet) pass through corners of

regions A and B, respectively, for $x = \sin^2 \theta_w$ in the ranges 0.3-0.4 and 0.35-0.4. The allowed mixing angles for the right handed fields in the general model are shown in Fig. 3a. All of the models are made worse if Higgs triplets are added.

The predictions of an $SU(2)_L \times SU(2)_R \times U(1)$ model¹¹ are shown in Figs. 2a and 3b. The model falls in region A for ϵ (a ratio of Higgs VEV's) small and values of $x = \sin^2 \theta$ as shown.

The predictions of two vectorlike $SU(3) \times U(1)$ models are displayed on Figs. 2b and 3b. The LW and LS¹¹ models assign leptons to 3 and 3^* , respectively, and differ in quark assignments (Table I). w and z are Weinberg like angles; q , r , and r' are ratios of VEV's, and $r'' = rz^2$. The L-W model falls well outside the allowed regions while the L-S model intersects region B.

In conclusion, there are models that correspond to each allowed region. It is important for Sehgal's analysis to be verified by higher energy semi-inclusive experiments, and that experiments which distinguish between regions A and B be performed.

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Table I

The multiplet assignment of the u- and d-quarks in various models.

Model	Assignments	
<u>SU(2) X U(1)</u>	<u>doublets</u>	<u>singlets</u>
Weinberg-Salam (W-S)	$\begin{pmatrix} u \\ d \end{pmatrix}_L$	u_R, d_R
Hybrid Model I (HM-I) (Gürsey-Sikivie (GS-B))	$\begin{pmatrix} u \\ d \end{pmatrix}_L \begin{pmatrix} u \\ b \end{pmatrix}_R$	d_R
Hybrid Model II (HM-II)	$\begin{pmatrix} u \\ d \end{pmatrix}_L \begin{pmatrix} t \\ d \end{pmatrix}_R$	u_R
General Model (GM)	$\begin{pmatrix} u \\ d \end{pmatrix}_L \begin{pmatrix} u \\ b \end{pmatrix}_R \begin{pmatrix} t \\ d \end{pmatrix}_R$	$\begin{pmatrix} t \\ c \end{pmatrix}_R \begin{pmatrix} b \\ s \end{pmatrix}_R \dots$
<u>SU(2) X SU(2) X U(1)</u>	<u>SU(2)_L</u>	<u>SU(2)_R</u>
Mohapatra-Sidhu (M-S)	$\begin{pmatrix} u \\ d \end{pmatrix}_L$	$\begin{pmatrix} u \\ d \end{pmatrix}_R$
<u>SU(3) X U(1)</u>	<u>Triplets</u>	<u>Singlets</u>
Lee-Weinberg (L-W)	$\begin{pmatrix} u \\ d \\ b \end{pmatrix}_L \begin{pmatrix} t \\ b \\ d \end{pmatrix}_R$	u_R
Langacker-Segre (L-S)	$\begin{pmatrix} u \\ d \\ b \end{pmatrix}_L \begin{pmatrix} u \\ b \\ d \end{pmatrix}_R$

Fig. 1. Predictions for $R_{\nu p}^{e\ell}$ and $R_{\bar{\nu} p}^{e\ell}$ for regions A, B, C, and D. The box corresponds to the HPW measurement. The q^2 cut and the ν_n and $\bar{\nu}_n$ spectra are folded in.

Fig. 2a) Predictions of $\tilde{SU}(2) \times U(1)$ and $SU(2)_L \times SU(2)_R \times U(1)$ for the left chiral couplings, plotted against X (M-S for $\epsilon = 0$ is plotted against $X/2$). The M-S predictions for $\epsilon = \pm .1$ are displaced downward for clarity.
 b) Predictions of $SU(3) \times SU(1)$.

Fig. 3a) Predictions of $SU(2)_L \otimes U(1)$ for the right chiral couplings. The interior of the dashed box represents the general model for $x = \sin^2 \theta_W = 0.3$.

b) Predictions of $SU(2)_L \otimes SU(2)_L \otimes U(1)$ and $SU(3) \otimes U(1)$.