FERMILAB-PUB-77-170-E

E320

CALT 68-601
ENERGY RESEARCH AND
DEVELOPMENT REPORT

DETERMINATION OF THE V,A STRUCTURE OF THE NEUTRAL CURRENT COUPLING*

F. S. Merritt[†], B. C. Barish, J. F. Bartlett, A. Bodek[††], K. W. Brown,
D. Buchholz[†††], F. Jacquet[Φ], F. J. Sciulli, L. Stutte[ΦΦ], and H. Suter[ΦΦΦ]

California Institute of Technology, Pasadena, California 91125

and

H. E. Fisk and G. Krafczyk

Fermi National Accelerator Laboratory, Batavia, Illinois 60510

Abstract

We report the results of an analysis to determine the V,A structure of the neutral currents. We find a positive-helicity component ($P = 0.36 \pm .10$) which lies between pure V-A and pure V or A and a coupling strength $g_o = 0.31 \pm .03$ relative to the charged current interaction. These coupling parameters agree well with the prediction of the Weinberg-Salam model, with $\sin^2\theta_w = 0.33 \pm .07$.

---

* Work supported by the U.S. Energy Research and Development Administration. Prepared under Contract EY-76-C03-0068 for the San Francisco Operations Office.

† Now at Stanford University, Stanford, California.

†† Now at the University of Rochester, Rochester, New York.

††† Now at Northwestern University, Evanston, Illinois 60201.

Φ On leave of absence from Ecole´ Polytechnique, Paris, France.

ΦΦ Now at Fermi National Accelerator Laboratory, Batavia, Illinois 60510.

ΦΦΦ Swiss National Fund for Scientific Research Fellow.

In this letter we present an analysis of the data presented previously[1] to determine the coupling parameters relevant to the Lorentz structure of the neutral current interaction. In addition, we make some comparisons to specific models.

Our approach has been to simultaneously fit both the relative rates for ν and $\bar{\nu}$ neutral current reactions and the shapes of the measured differential distributions. The cross section ratio and the forms of the y-distributions are direct consequences of the structure of the coupling. For example, for the charged current reactions, the coupling is known to be very nearly exact V-A and the distributions, under the usual scaling assumptions, are written as

$$\frac{d\sigma^{\nu}}{dy}(CC) = \bar{E}\left[(1-\alpha) + \alpha(1-y)^2\right] \quad (1)$$

$$\frac{d\sigma^{\bar{\nu}}}{dy}(CC) = \bar{E}\left[\alpha + (1-\alpha)(1-y)^2\right] \quad (2)$$

where $\bar{E} = \frac{G^2ME}{\pi}\int_0^1 F_2(x)dx$. The shapes of the y-distributions and the relative magnitudes of the total cross-section are determined by the parameter α, often interpreted as the "antiquark" component in the nucleon. (In another common notation, $2\alpha = 1 - B$.) Dominantly flat distributions for ν events and $(1-y)^2$ distributions for $\bar{\nu}$ events are consequences of V-A coupling and the dominant negative helicities of the interacting nucleon constitutents (e.g. quarks). The charged current data reported previously from this experiment[2] yield a best value of $\alpha = 0.17$.

Predictions of gauge theories, as well as the analogy to charged and electromagnetic current couplings, suggest that the neutral current also couples through a combination of V and A. For most of the analysis reported in this paper, we have assumed a V,A type coupling and under this assumption, the neutral current distributions are similar in form to the charged current distributions:

$$\frac{d\sigma^{\nu}}{dy}(NC) = \bar{E}\, g_o \left[(1-P) + P(1-y)^2 \right] \tag{3}$$

$$\frac{d\sigma^{\bar{\nu}}}{dy}(NC) = \bar{E}\, g_o \left[P + (1-P)(1-y)^2 \right] \tag{4}$$

P, analogous to α in equations (1) and (2), is a "positive-helicity" parameter. In this case, however, it receives contributions from both a) V-A coupling to the antiquark component in the nucleon and b) V+A coupling to the quark component.

The structure of the neutral current coupling affects only P, while the strength of the coupling determines g_o (measured relative to the usual charged current coupling). In the event that neutral currents and charged currents scatter from the same nucleon components, we can make some direct predictions. If the neutral current coupling is pure V-A (like the charged current), $P = \alpha$; and if the coupling is pure V or pure A, $P = 1/2$. (The last statement is independent of the nucleon constituents.)

The data reported in the previous paper[1] can be used to determine these parameters. The measured E_h distributions reflect the y-distributions, since $E_h = E_{\nu} y$.

We first fit the CC distributions using equations 1 - 2 (see reference 2). This allowed a more precise (although model-dependent) determination of the relative flux normalizations and of the muon detection efficiency than did the general assumptionsof reference 1.

The neutral current distributions were then fitted with the form of equations 3-4, including the relative normalizations, to determine g_o and P. Figure 1 shows the results of this two parameter fit. The 1, 2, and 3 standard deviation contours for this fit are shown in the figure. The best values for the parameters are $g_o = 0.31 \pm .02$ and $P = 0.36 \pm .09$. This value for P is about three standard deviations from pure negative helicity scattering and about 1.5 standard deviations from pure V or pure A.

Using these fitted parameters, it is possible to extrapolate the hadron distributions[1] measured for $E_h \geq 12$ GeV to $E_h = 0$ in order to obtain the total cross section ratios. This extrapolation yields

$$\frac{\sigma^{\nu}(NC)}{\sigma^{\nu}(CC)} = 0.27 \pm 0.02$$

$$\frac{\sigma^{\bar{\nu}}(NC)}{\sigma^{\bar{\nu}}(CC)} = 0.40 \pm 0.08$$

and
$$\frac{\sigma^{\bar{\nu}}(NC)}{\sigma^{\nu}(NC)} = 0.75 \pm 0.15.$$

The cross sections $\sigma^{\bar{\nu}}$ (NC) and σ^{ν} (NC) are expected to be equal in some vector-like theories[3]. Our results, while not inconsistent, do not favor this possibility.

The physics of charged currents only affects the determination of the neutral current coupling parameters through 1) the calculated neutrino - antineutrino flux ratio, and 2) the calculated CC contamination in the neutral current signal. We have tested the sensitivity of the neutral current analysis to the assumed form of the charged-current distributions by allowing α to vary over the range (.11 - .29) allowed by the charged-current data, and have also used models incorporating an energy-dependent α, production of new heavy quarks, and varying x-distribution[4]. All models which were consistent with the charged-current data reproduced the values of g_o and P to within approximately one half of a statistical standard deviation. With all of these variations taken into account, the neutral current coupling parameters from this data are $g_o = (.31 \pm .02) \pm .02$

and $P = (.36 \pm .04) \pm .09$

where the inner errors are due to the systematic (model-dependent) variations and the outer errors are statistical.

A similar analysis using the less restrictive assumptions of reference 1 (which assumed no relation between the shape of the ν and $\bar{\nu}$ charged current distributions) gave the consistent results of $P = .38 \pm .13$ and $g_o = .32 \pm .05$.

Extracting the amount of V-A and V+A coupling for the neutral currents is by necessity more model dependent than the above analysis, since the separation depends on the antiquark fraction in neutral currents. We have determined these coupling parameters by using the neutral current parameters g_o and P determined above, with the value of α determined from the charged current data. The relations between these parameters are

$$g_n = (1-P)g_o = (1-\alpha)g^- + \alpha g^+$$

and

$$g_p = Pg_o = (1-\alpha)g^+ + \alpha g^-$$

where g^- and g^+ are the absolute magnitudes of the neutral current V-A and V+A coupling strengths, respectively. The Weinberg-Salam model[(5)] can be directly compared with results presented in this form since the positive helicity contribution from the antiquark component of the struck nucleon has been removed. In the Weinberg-Salam model, these couplings can be expressed in terms of a single parameter $\sin^2\theta_W$ as follows:

$$g^- = \frac{1}{2} - \sin^2\theta_W + \frac{5}{9}\sin^4\theta_W$$

and

$$g^+ = \frac{5}{9}\sin^4\theta_W$$

neglecting small effects of the Cabibbo angle, etc. Figure 2 shows this curve in the g^- vs. g^+ plane along with the results for the neutral current parameters from this experiment, using $\alpha = 0.17$. The data agree with the Weinberg-Salam model in magnitude and yield a best fit

$$\sin^2\theta_W = 0.33 \pm 0.07.$$

More generally, scalar, pseudo-scalar, and tensor couplings could, in principle, contribute to the neutral current signal. In an extreme case, pure scalar or pseudo-scalar coupling would produce a $d\sigma/dy \propto y^2$ distribution for both ν and $\bar{\nu}$. This is inconsistent with both the shapes and the relative magnitude of the measured hadron energy distributions, and is ruled out at the level of 5 standard deviations.

In the most general case, equations (3) and (4) may each contain an additional term of the form $C(1-y)$. The data from this experiment are not sufficiently accurate to support an additional parameter with reasonable precision. Therefore, even a large coefficient, C, cannot at this time be excluded.

Since the data involved two different energies, we can make a crude comparison to test for Z° propagator effects. We observe no such energy-dependent effects. Internally to this data we place a limit of $M_{Z^\circ} > 3$ GeV at the 90% confindence level. A better limit can be obtained by comparing with data at much lower energy.[4,6]

In conclusion, the neutral current hadron energy distributions are consistent with a combination of V and A couplings. The coupling appears to lie approximately midway between V or A and V-A, and about 1.5-2 standard deviations from each. These couplings agree quite well with the predictions of the Weinberg-Salam theory, and require a Weinberg angle consistent with the values obtained from other experiments.[(7)]

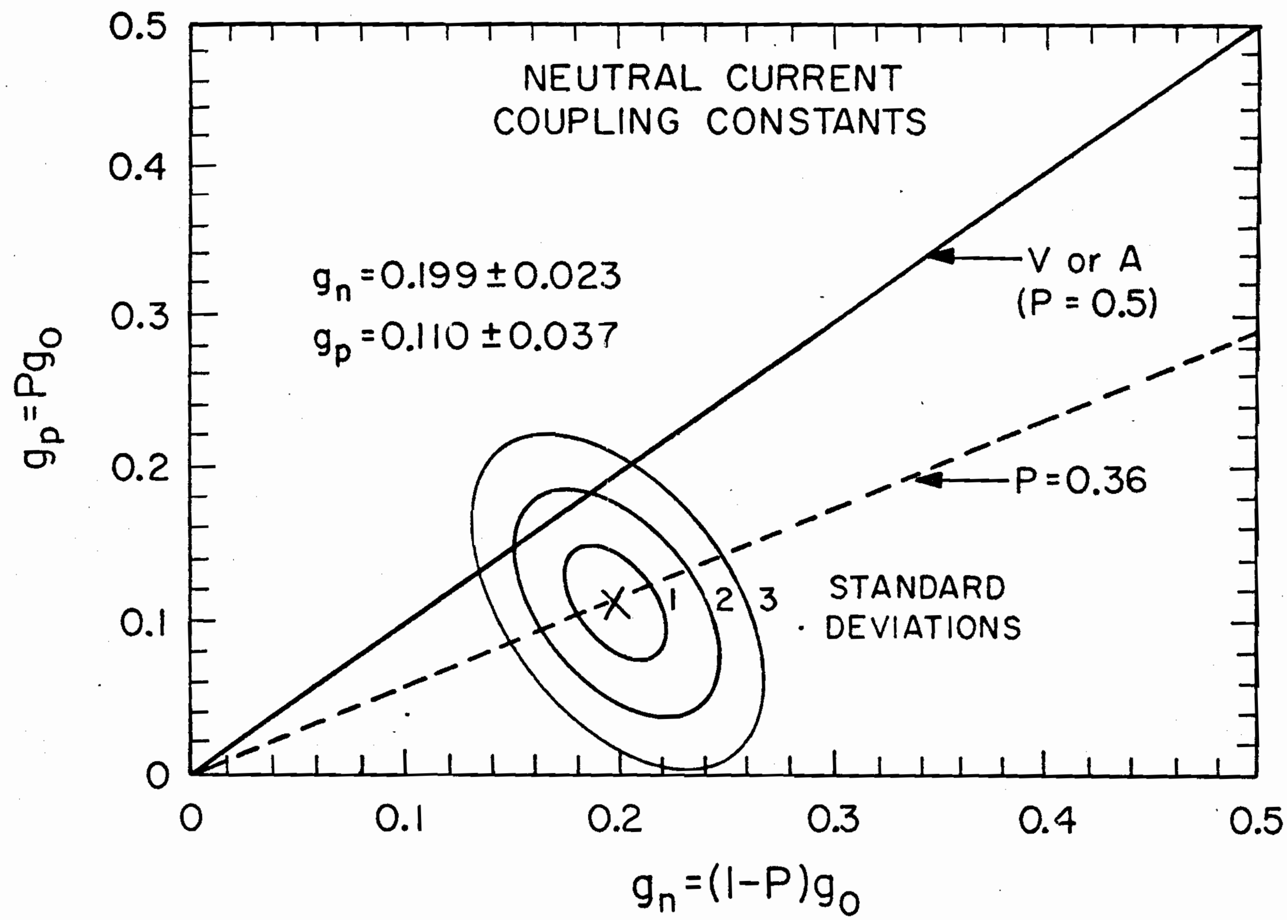
We wish to thank the Fermilab staff for their contributions to this experiment. In particular, we are indebted to Helen Edwards and the beam extraction group for developing the fast-spill resonant extraction used in this experiment, and to the Neutrino Lab for their continuing help and cooperation.

References

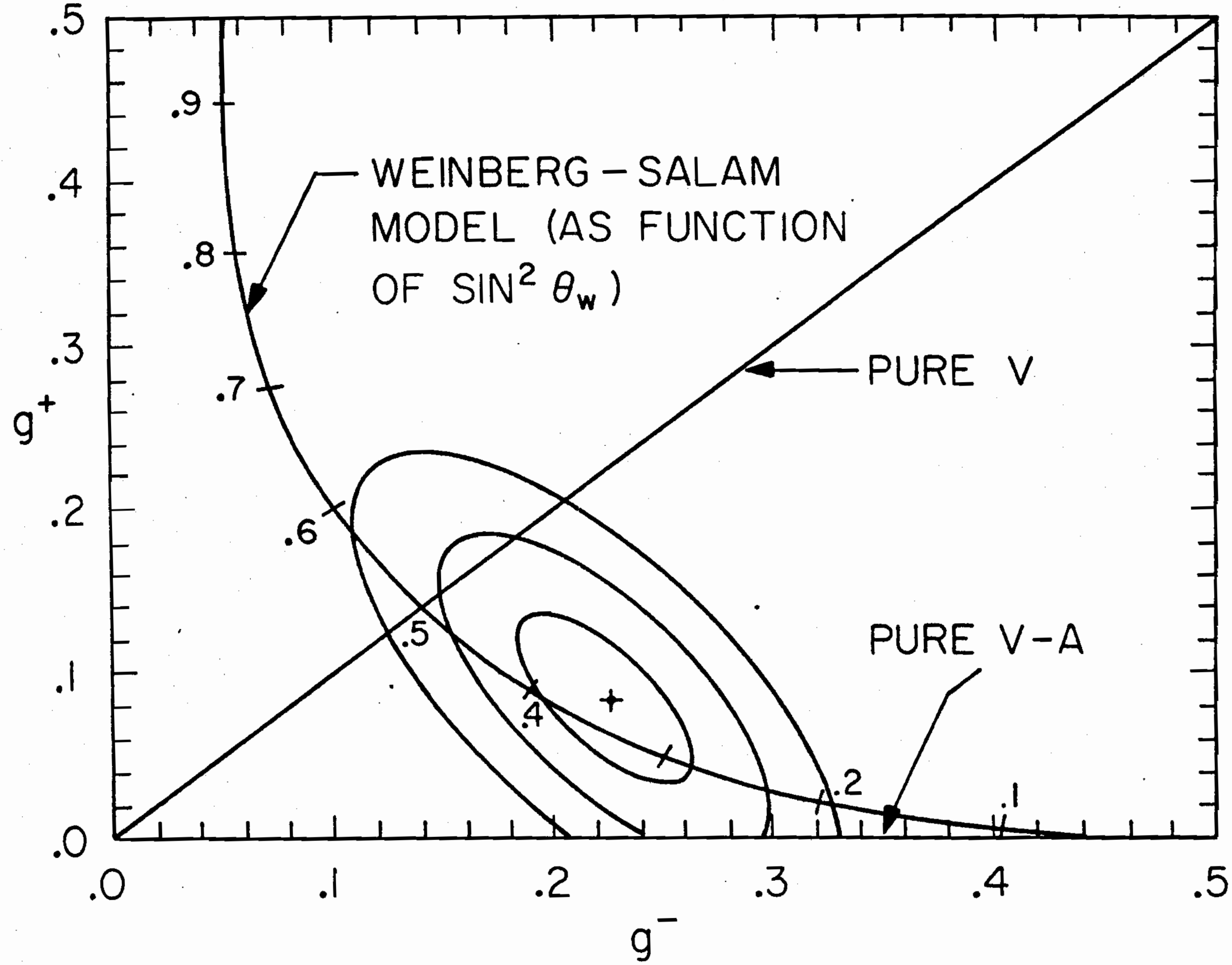
1. F. Merritt et al., CALT 68-600, "Differential Cross-Sections for Inclusive Neutral Current Interactions at High Energies", Preprint, preceding paper, (1977).
2. B. Barish et al., Phys. Rev. Lett. 38, 314 (1977).
3. A. De Rújula et al., Phys. Rev. D12, 3589 (1975), R. L. Kingsley et al., Phys. Rev. D12, 2768 (1975), H. Fritzsch et al., Phys. Lett. 59B, 256 (1975), S. Pakvasa et al., Phys. Rev. Lett. 35, 703 (1975).
4. F. Merritt, Caltech Ph.D. Thesis, 1977.
5. S. Weinberg, Phys. Rev. Lett. 19, 1264 (1967) and A. Salam, Elementary Particle Theory, ed. N. Svartholm (Almquist and Forlag, Stockhold, 1968).
6. F. J. Hasert et al., Phys. Lett. 46B, 138 (1973); and F. J. Hasert et al., Nucl. Phys. B73, 1 (1974).

Figure 1: The negative (g_n) and positive-helicity (g_p) coupling parameters, obtained by fitting the neutral current E_h distributions, define a point in the plot. The elliptical curves surrounding the point indicate the 1, 2, and 3 standard deviation limits due to statistical error. The result is about 3σ from pure negative helicity and 1.5σ from pure V or A.

Figure 2: A plot of the V-A and V+A coupling parameters g^- and g^+ is shown. A value of $\alpha = 0.17$ for the antiquark component has been used. For comparison, the prediction of the Weinberg-Salam model is shown with values of $\sin^2\theta_W$ as indicated.



NEUTRAL CURRENT
COUPLING CONSTANTS
$g_n = 0.199 \pm 0.023$
$g_p = 0.110 \pm 0.037$
V or A
(P = 0.5)
P = 0.36
1
2
3
STANDARD
DEVIATIONS
0.5
0.4
0.3
0.2
0.1
0
0
0.1
0.2
0.3
0.4
0.5
$g_p = P g_0$
$g_n = (1-P) g_0$



WEINBERG-SALAM MODEL (AS FUNCTION OF SIN² θw)
PURE V
PURE V-A
g+
g−
.0
.1
.2
.3
.4
.5
.9
.8
.7
.6
.5
.4
.2
.1