νN: STRUCTURE OF WEAK INTERACTION

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1. INTRODUCTION

Electroweak interaction processes have been investigated over an energy range from a few electronvolts (the parity violation in atomic physics) to a few tens of GeV ($E \approx 37$ GeV) (the asymmetry on the reaction $e\bar{e} \to \mu\bar{\mu}$ at the electron positron storage rings PETRA and PEP). This energy range, if measured in terms of the expected masses of the weak vector bosons, is quite small, and in reality we have until now only investigated the low-energy behaviour. In this domain the physics is described by a low-energy effective Lagrangian not very different from that proposed by Fermi in 1934.

A large number of experimental results collected in different reactions are today in agreement within experimental errors with the standard model incorporating $SU(2)_L \times U(1)$ and the GIM mechanism. At Q^2, $s \ll M^2_{Z^0}$, neglecting the propagator effects, the standard model reduces to an effective Lagrangian

$$L_{eff} = \frac{G}{\sqrt{2}} [J^+_\lambda J^-_\lambda + \rho J^0_\lambda J^0_\lambda] ,$$

where $J^{\pm}_\lambda$ are the charged currents (CC) of the weak isospin doublets:

$$\begin{pmatrix} \nu_e \\ e \end{pmatrix}_L , \begin{pmatrix} u \\ d_c \end{pmatrix}_L , \ldots$$

and J^0_λ is the weak neutral current (NC) described in the unifying $SU(2)_L \times U(1)$ model by

$$J^0_\lambda = J^3_\lambda - \sin^2\theta \, J^{em}_\lambda .$$

$\rho = M^2_W/M^2_Z \cos^2\theta$ is the relative strength of the CC and NC, predicted by the simplest version of the model to be one, and $\sin^2\theta$ is the single parameter of the theory that describes the relative strength of the SU(2) and U(1) coupling constants. The electric charge, the weak isospin, and the weak hypercharge of the particles satisfy the relation

$$Q = T_3 + Y .$$

Experimental efforts today are concentrated on the verification, with increasing accuracy, of the validity of the standard model, which is the most economic one in terms of the number of parameters. More accurate experiments can also constrain other models which are variants of the standard model containing more parameters.

The high-energy neutrino beams at present available at the CERN SPS and at Fermilab give the possibility to extend into the Q^2 region 10-200 GeV^2 the tests of the space-time structure of the weak current, previously only possible in the low-energy region. The data on NC interpreted in terms of the standard model give an accurate measurement of $\sin^2\theta$.

The most recent experimental results on the Lorentz structure of the weak current in CC induced reactions at high Q^2 are:

i) The μ^+ polarization in the experiment $\bar{\nu}_\mu Fe \to \mu^+ X$ (test of helicity conservation in CC).

ii) The purely leptonic reaction $\nu_\mu e^- \to \mu^- \nu_e$.

iii) The inelasticity distribution of opposite-sign dimuon events (test of the generation universality of CC in neutrino interactions).

2. POLARIZATION OF μ^+ FROM THE INCLUSIVE REACTION $\bar{\nu}_\mu Fe \rightarrow \mu^+X$

The most general Lagrangian, which is bilinear in the fields of the reaction, gives the following inelasticity distribution for the process[1] $\bar{\nu}_\mu N \rightarrow \mu^+X$

$$\frac{d\sigma}{dy} \propto 2(g_V - g_A)^2 + 2(g_V + g_A)^2(1 - y)^2 + (|g_S|^2 + |g_P|^2)y^2$$
$$+ 32|g_T|^2(1 - 1/2y)^2 + 8 \text{ Re } [g_T(g_S^* + g_P^*)]y(1 - y/2) .$$

g_i are the coupling constants of the different Lorentz invariant combinations of the spinors participating in the reaction. The quantity

$$y = (E_\nu - E_\mu)/E_\nu$$

is proportional to the energy of the hadronic system X. The study of the y distribution[2] at high energy is consistent with V-A structure, but the same y distribution could be obtained with a mixture of scalar (S), pseudoscalar (P), and tensor (T) (confusion theorem). The measurement of the μ^+ helicity can resolve this ambiguity. Helicity conservation is a general property of a gauge interaction, since V and A interactions conserve the helicity, whereas S and P interactions do not conserve helicity (Fig. 1).

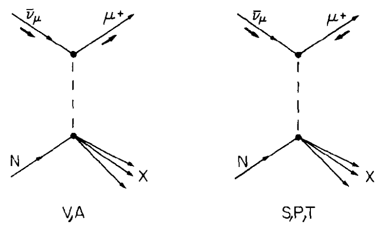

Fig. 1

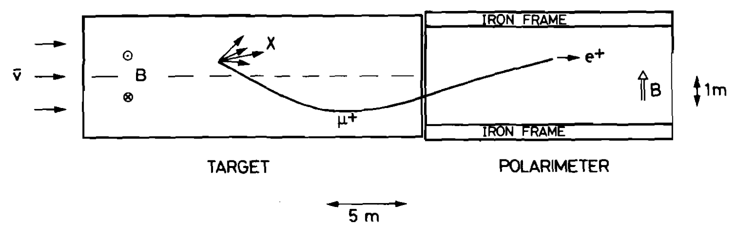

Fig. 2

The experiment was carried out at the CERN SPS wide-band beam (WBB) using the CDHS detector[3] as an instrumented target where the antineutrino interaction took place, and the CHARM[4] detector as polarimeter of the stopped μ^+ (Fig. 2). The polarization is derived from the measured asymmetry of the decay positron. The quantity

$$R(t) = \frac{N_B(t) - N_F(t)}{N_B(t) + N_F(t)} = R_0 \cos(\omega t + \Phi) + \text{const.}$$

is shown in Fig. 3 and is determined from $\sim$ 17,000 detected $\mu^+ \rightarrow e^+$ decays in the CHARM polarimeter. $N_{B,F}(t)$ are the number of decay positrons in the backward and forward regions measured at a time t after the μ^+ has stopped. The best fit to the data is obtained for

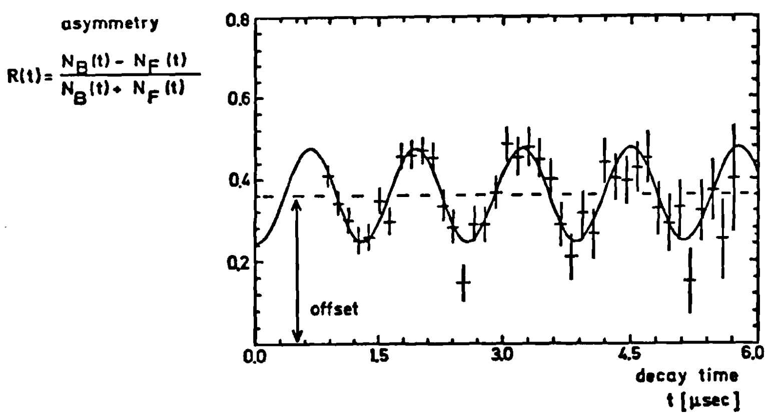

Fig. 3

$$R_0 = 0.11 \pm 0.01 \;, \quad \Phi = -3.03 \pm 0.09 \;,$$

from which is derived

$$P = 0.80 \pm 0.07\ (\text{stat}) \pm 0.14\ (\text{syst})\ .$$

This polarization value sets an upper limit to the possible S, P, and T contribution to the CC reaction at $\langle Q^2 \rangle = 4.5\ \text{GeV}^2$ of $\sigma_{SPT}/\sigma_{all} \leq 0.25$ at 95% confidence level (c.l.).

The μ^+ polarization is shown in Fig. 4a versus the inelasticity y. The data show a constant P value over the explored range of y. Since the S and P interactions that contribute to the lepton spin-flip amplitude are zero at y = 0 (Fig. 4b) the value of the polarization at small y can be treated as a normalization and the value at large y (y ≥ 0.2) can be used to derive a limit on S and P contributions which are unaffected by the systematic errors of the integrated polarization value

$$\frac{\sigma_{SP}}{\sigma_{all}} \leq 0.15 \text{ at } 95\% \text{ c.l.}$$

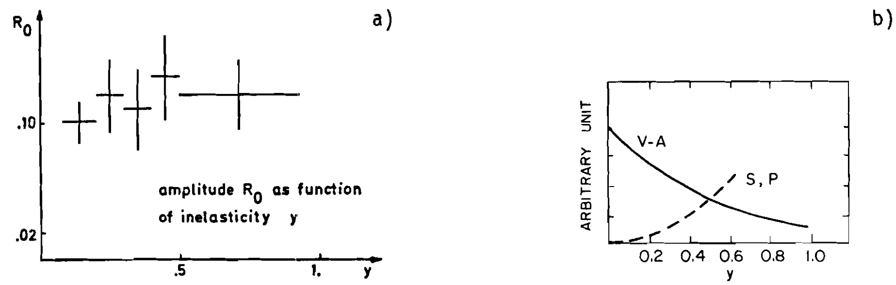

Fig. 4

3. NEUTRINO CHARGED CURRENT REACTIONS ON AN ELECTRON TARGET

The investigation of the reaction

$$\nu_\mu e^- \rightarrow \mu^- \nu_e$$

has been suggested by Jarlskog[5] to complement the information on purely leptonic CC reactions until recently only studied in muon decay: $\mu \rightarrow e\nu_\mu\bar{\nu}_e$. The centre-of-mass energy of the reaction is low because of the small target mass, but the energy threshold in the laboratory system is 10.9 GeV. The cross-section for $s > m_\mu^2$ and in the hypothesis of V and A interactions is

$$\frac{d\sigma}{dy} = \frac{G^2 s}{8\pi}\left[(1 + P)(1 - \lambda)y^2 + (1 - P)(1 + \lambda)\right]$$

$$P = \frac{N(\nu_R) - N(\nu_L)}{N(\nu_R) + N(\nu_L)}$$

$$\lambda = \frac{C_L^2 - C_R^2}{C_L^2 + C_R^2}$$

$$y = E_\mu/E_\nu \;,$$

where $C_{L,R}$ are the helicity couplings. Figure 5 shows the results from two CERN experiments, the first from Gargamelle[6] and the more recent one from the CERN-Hamburg-Amsterdam-Rome-Moscow (CHARM) Collaboration[7]. The data are in agreement with left-handed incoming neutrinos interacting on electrons through a V-A interaction or left-handed current. These data can be used to constrain the strength of the coupling of a charged Higgs particle to the lepton-neutrino system, but **the limits** are not very stringent.

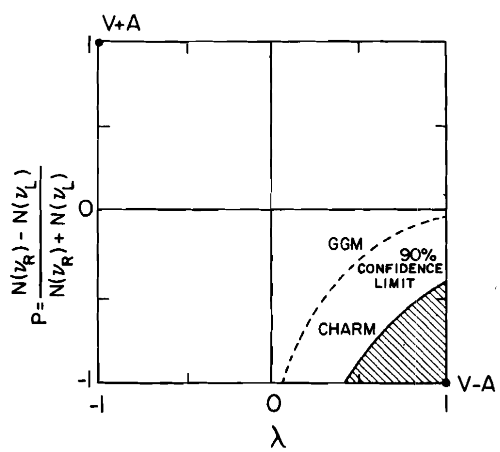

Fig. 5

For massless neutrinos the coupling of $\mu\nu$ and $e\nu$ to the charged Higgs particle -- expressed in the notation of McWilliam and Li[8] -- can be limited by the relation

$$|\alpha^L_{\mu\nu}\alpha^L_{e\mu}| \le 0.6 \ .$$

4. GENERATION UNIVERSALITY IN THE CHARGED CURRENT

Opposite-sign dimuon events in neutrino interactions are interpreted as due to the following production mechanism

$$\nu N \to \mu^- D X$$
$$\quad\quad \hookrightarrow \mu^+ Y \ .$$

The relative frequency of dimuon events compared to that of single muon events is in agreement with the quark-parton model and the GIM mechanism, together with the known Cabibbo mixing angle θ_C ($tg^2\ \theta_C = 0.057$)

$$\nu d \to \mu^- C \propto \sin^2\theta_c$$
$$\nu s \to \mu^- C \propto \cos^2\theta_c$$
$$\bar\nu \bar d \to \mu^+ \bar C \propto \sin^2\theta_c$$
$$\bar\nu \bar s \to \mu^+ \bar C \propto \cos^2\theta_c \ .$$

These processes are described by the Lagrangian of the CC in the standard model and expressed in terms of the following current

$$J^+ = \frac{G}{\sqrt{2}} (\bar u, \bar c)\gamma_\mu(1 - \gamma_5)\begin{vmatrix} \cos\theta_c & \sin\theta_c \\ -\sin\theta_c & \cos\theta_c \end{vmatrix}\begin{pmatrix} d \\ s \end{pmatrix} .$$

The y distributions are

$$\frac{d\sigma^\nu}{dy} = \frac{G^2 M E_\nu}{\pi}\left[2\cos^2\theta_c\ s + 2\sin^2\theta_c\ d\right]$$

$$\frac{d\sigma^{\bar\nu}}{dy} = \frac{G^2 M E_\nu}{\pi}\left[2\cos^2\theta_c\ \bar s + 2\sin^2\theta_c\ \bar d\right]$$

and are flat for both neutrinos and antineutrinos.

The amount of strange quarks in the sea s [9] is derived from the integrated cross-sections for single and dimuon production from ν and $\bar\nu$

$$R_2 = \frac{\sigma_{\bar\nu 2\mu}/\sigma_{\bar\nu 1\mu}}{\sigma_{\nu 2\mu}/\sigma_{\nu 1\mu}} \ .$$

The results are[9]

$$\xi_2 = \frac{s}{d} = tg^2\ \theta_c \frac{R_1 R_2 - \xi_1}{1 - R_1 R_2} = 5.6 \times 10^{-2}$$

with

$$\xi_1 = \frac{\bar u + \bar d}{u + d} = 0.12 \qquad R_1 = \frac{\sigma_{\bar\nu 1\mu}}{\sigma_{\nu 1\mu}} = 0.48 \ .$$

The y distribution of the dimuon events in the more general hypothesis of V and A interactions gives information on the left- and right-handed coupling of the s, c doublet. The y distribution can be written

$$\frac{d\sigma}{dy} \propto \{\alpha + (1 - \alpha)(1 - y)^2\}\ f(y) \ ,$$

where the term proportional to α is due to the left-handed coupling V-A and that proportional to $(1 - \alpha)$ is induced by a right-handed coupling V + A; f(y) represents the threshold behaviour.

The results from the CERN-Dortmund-Heidelberg-Saclay (CDHS)[9] and CHARM[10] Collaborations on α are

CDHS: neutrinos $(1 - \alpha) < 0.10$ 95% c.l.

antineutrinos $(1 - \alpha) < 0.30$ 95% c.l.

CHARM: antineutrinos $\alpha = 0.85 \pm 0.10$.

Figures 6 show the y distributions for ν_μ from the CDHS experiment. In conclusion, the new experimental results on the space-time structure of the CC weak interaction at $Q^2 \approx$ (10-100) GeV^2 point to a Lagrangian which is well described by V and A currents combined to give dominantly left-handed coupling.

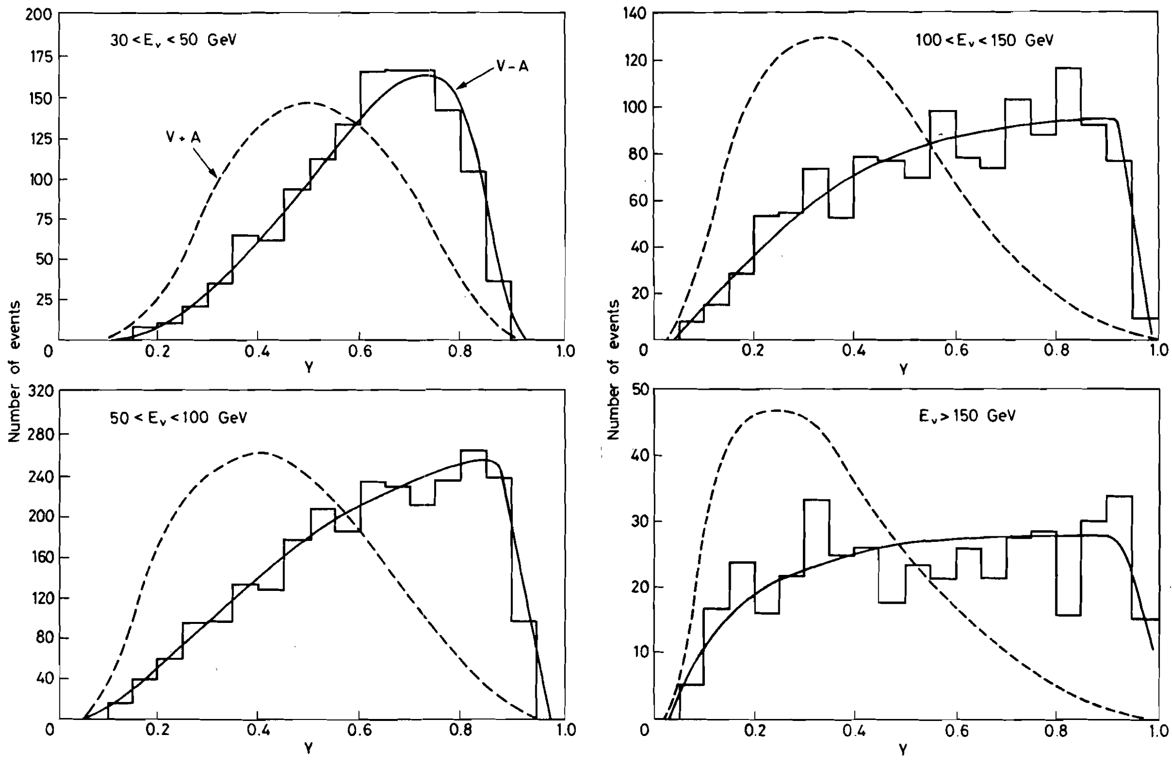

Fig. 6

5. SPACE-TIME STRUCTURE OF THE WEAK NEUTRAL CURRENT INDUCED BY NEUTRINOS

The NC phenomena induced by ν at $Q^2 << M^2_{Z^0}$ on a fermion f are represented by a current-current interaction which, with the quite general hypothesis of V and A interactions, assuming a quark-parton model, can be written

$$\mathcal{L}_{eff}(\nu f) = - \frac{G}{\sqrt{2}} \bar{\nu}\gamma_\lambda(1 + \gamma_5)\nu\left\{\bar{f}\gamma_\lambda[f_L(1 + \gamma_5) + f_R(1 - \gamma_5)]f\right\} .$$

In the standard model the left- and right-handed couplings, f_L and f_R, are functions of the single parameter $\sin^2 \theta$, and are related to the weak isospin and the electric charge. The relations among these quantities are

$$f_{L,R} \propto T_{3_{L,R}} - Q_f \sin^2 \theta$$

$$Q_f \propto T_3 + Y .$$

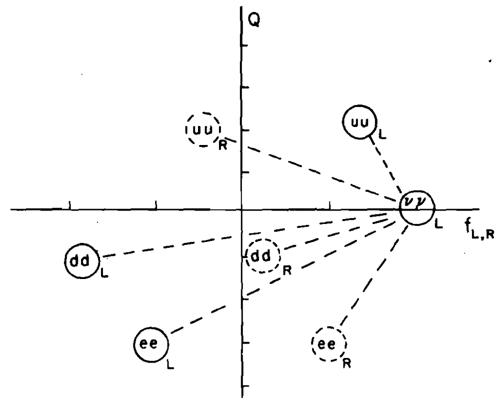

Fig. 7

The particles are assigned to an isodoublet if their helicity is left-handed, and to an isosinglet if they are right-handed.

The particles belonging to the first lepton-quark generation (ν_e, e, u, d) are shown in the plane of the electric charge Q and the weak coupling $f_{L,R}$ in Fig. 7 for $\sin^2\theta = \frac{1}{4}$.

The NC interactions induced by neutrinos are represented by all the lines connecting the $\nu\nu$ box with all the other boxes. The interactions of the first generation planes are described by six, *a priori* independent, coupling constants.

The new experimental results on the NC coupling defined by Fig. 7 are, however, obtained using ν_μ beams. We have to assume μe universality in order to verify the lepton-quark universality in one generation.

6. NEUTRINO-ELECTRON SCATTERING

Neutrino-electron scattering is the simplest reaction in which to study the weak NC coupling of Fig. 7. The electron is the only free point-like target existing in nature, and the main corrections to the zero-order diagram of the weak interaction are the well-known electromagnetic higher-order corrections.

The measured quantity in the neutrino electron reaction is, for the moment, the total cross-section, measured, for example, in a high-intensity wide-band neutrino beam. The cross-section value is very low, owing to the small electron rest mass m_e = 0.5 MeV, which produces a low centre-of-mass energy for the reaction.

The total ν_μe and $\bar{\nu}_\mu$e cross-sections for the V,A interactions are, in the case of $E_\nu \gg m_e$,

$$\sigma = \frac{2G^2 m_e E_\nu}{\pi}\left[c_L^2 + \frac{c_R^2}{3}\right]$$

$$\bar{\sigma} = \frac{2G^2 m_e E_\nu}{\pi}\left[c_R^2 + \frac{c_L^2}{3}\right] .$$

In the standard model

$$c_L = -\frac{1}{2} + \sin^2\theta , \quad g_V = c_L + c_R = -\frac{1}{2} + 2\sin^2\theta$$

$$c_R = \sin^2\theta , \quad g_A = c_L - c_R = -\frac{1}{2} .$$

Recently two relatively high-mass and fine-grained calorimetric experiments have obtained statistically significant results on the reactions

$$\nu_\mu e \rightarrow \nu_\mu e \tag{1}$$

$$\bar{\nu}_\mu e \rightarrow \bar{\nu}_\mu e . \tag{2}$$

Table 1

Reaction	σ/E ($\times 10^{-42}$ cm^2/GeV)	Collaboration
$\nu_\mu e \to \nu_\mu e$	1.4 ± 0.3	VMWOP 1980
$\bar\nu_\mu e \to \bar\nu_\mu e$	1.7 ± 0.33 (stat) ± 0.37 (syst)	CHARM 1981

Table 2

Reaction	σ/E ($\times 10^{-42}$ cm^2/GeV)	$\sin^2\theta$
$\nu_\mu e \to \nu_\mu e$	1.5 ± 0.3	$0.24 {+0.06 \atop -0.04}$
$\bar\nu_\mu e \to \bar\nu_\mu e$	1.6 ± 0.3	0.27 ± 0.05

Table 3

Collaboration	$\sin^2\theta$	Measured quantities
CELLO	0.25 ± 0.15	R_{ee}
JADE	0.25 ± 0.15	$R_{ee}, R_{\mu\mu}, A_{\mu\mu}$
Mark J	0.24 ± 0.12	$R_{ee}, R_{\mu\mu}, R_{\tau\tau}, A_{\mu\mu}$
PLUTO	0.22 ± 0.22	R_{ee}
TASSO	0.24 ± 0.11	$R_{ee}, A_{\mu\mu}$

In Table 1 are given the results on reaction (1) from the Virginia-Maryland-Washington-Oxford-Pekin (VMWOP) Collaboration[11] and on reaction (2) from the CHARM Collaboration[12].

In Table 2 are presented the world average values of these reactions and the $\sin^2\theta$ value derived from these cross-sections.

In Table 3 is given for comparison the value of $\sin^2\theta$ measured in purely leptonic reactions as known before the Bonn Conference from measurements at the PETRA e^+e^- storage ring at $s \simeq 10^3$ GeV^2. The recent progress in this field is reviewed by Branson at this conference[13].

The quantity $R_{f\bar f}$ gives the ratio of the measured number of fermion ($f\bar f$) pairs produced in $e\bar e$ annihilation to that computed from the one-photon annihilation. $A_{\mu\mu}$ is the forward-backward asymmetry in muon-pair production that measures the electroweak interference.

Figure 8 presents the status of our knowledge of the pure leptonic weak NC interaction, in terms of the coupling constants g_A, g_V of the V and A currents. The neutrino-electron scattering experiments select two solutions: one corresponds to that expected from the standard model.

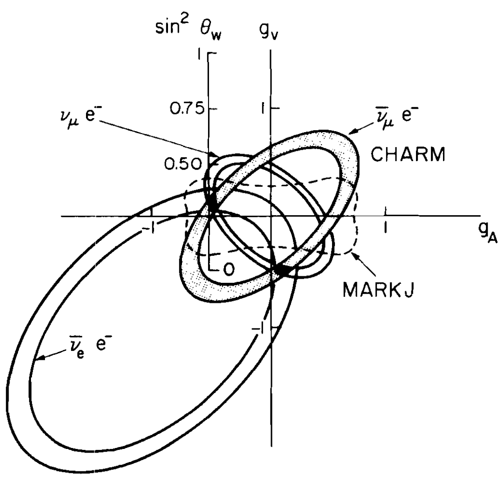

Fig. 8

The PETRA data favour one of the two solutions and exactly the one which is in agreement with the standard model with $\sin^2\theta \approx \frac{1}{4}$. From the neutrino and antineutrino scattering data and the PETRA limit one derives the following values of coupling strength:

$$c_L = -0.25 \pm 0.014 \text{ (stat)} \pm 0.014 \text{ (syst)}, \quad g_V = -0.02 \pm 0.02 \text{ (stat)} \pm 0.02 \text{ (syst)}$$

$$c_R = 0.27 \pm 0.014 \text{ (stat)} \pm 0.014 \text{ (syst)}, \quad g_A = -0.52 \pm 0.02 \text{ (stat)} \pm 0.02 \text{ (syst)} .$$

7. INCLUSIVE NEUTRINO-NUCLEON SCATTERING ON ISOSCALAR TARGETS

The deep inelastic reactions of neutrinos on isoscalar nuclear targets are described, in terms of the quark-parton model and with the hypothesis of a V-A interaction, by the following y distribution (neglecting the contribution of the s and c quarks):

$$\frac{d\sigma^{\nu\mu^-}}{dy} = \frac{G^2 M E_\nu}{\pi}\left[Q + \bar{Q}(1-y)^2\right]$$

$$\frac{d\sigma^{\bar{\nu}\mu^+}}{dy} = \frac{G^2 M E_{\bar{\nu}}}{\pi}\left[\bar{Q} + Q(1-y)^2\right]$$

$$\frac{d\sigma^{\nu\nu}}{dy} = \frac{G^2 M E_\nu}{\pi}\left\{\rho^2(u_L^2 + d_L^2)\left[Q + \bar{Q}(1-y)^2\right] + \rho^2(u_R^2 + d_R^2)\left[\bar{Q} + Q(1-y)^2\right]\right\}$$

$$\frac{d\sigma^{\bar{\nu}\bar{\nu}}}{dy} = \frac{G^2 M E_{\bar{\nu}}}{\pi}\left\{\rho^2(u_R^2 + d_R^2)\left[Q + \bar{Q}(1-y)^2\right] + \rho^2(u_L^2 + d_L^2)\left[\bar{Q} + Q(1-y)^2\right]\right\} ,$$

where Q and $\bar{Q}$ represent the fraction momenta carried by the quark and the antiquark, respectively, in the nucleon ($Q = \int x[u(x) + d(x)]dx$).

The values of the NC neutrino-quark coupling can be extracted from a simultaneous fit of the four y distributions or from the integrated quantities

$$R = \frac{\sigma^{\nu\nu}}{\sigma^{\nu\mu^-}} , \quad \bar{R} = \frac{\sigma^{\bar{\nu}\bar{\nu}}}{\sigma^{\bar{\nu}\mu^+}} , \quad r = \frac{\sigma^{\bar{\nu}\mu^+}}{\sigma^{\nu\mu^-}}$$

through the relations

$$\rho^2(u_L^2 + d_L^2) = \frac{R - r^2\bar{R}}{1 - r^2}$$

$$\rho^2(u_R^2 + d_R^2) = \frac{\bar{R} - R}{r^{-1} - r} .$$

A recent analysis of this type done by the CHARM Collaboration[14]) gives

$$\rho^2(u_L^2 + d_L^2) = 0.305 \pm 0.013$$

$$\rho^2(u_R^2 + d_R^2) = 0.036 \pm 0.013 .$$

In terms of the weak angle we have

$$\rho^2 = 1.027 \pm 0.023 \quad \text{and} \quad \sin^2\theta = 0.247 \pm 0.038 ,$$

in good agreement with the value from the analysis of the world data on weak interactions recently published by Kim et al.[15]). These data can also be interpreted in terms of the standard model where $\rho = 1$ and

$$u_L = \frac{1}{2} - \frac{2}{3}\sin^2\theta , \quad u_R = -\frac{2}{3}\sin^2\theta$$

$$d_L = -\frac{1}{2} + \frac{1}{3}\sin^2\theta , \quad d_R = \frac{1}{3}\sin^2\theta .$$

The two recent sets of data from the CHARM and the CalTech-Fermilab-Rochester-Rockefeller (CITFRR)[16] Collaborations, analysed in terms of the standard model, give

$$\sin^2\theta = 0.220 \pm 0.014\text{: CHARM: } E_H > 2\text{ GeV}$$

$$\sin^2\theta = 0.230 \pm 0.010\text{: CITFRR: } E_H > 20\text{ GeV}\ .$$

The NC interaction on proton and neutron targets gives information on the separate values of the coupling constants for u and d quarks. The most recent experimental results from bubble-chamber exposures to neutrino beams at Fermilab and CERN give results on $u^2_{L,R}$ and $d^2_{L,R}$ in agreement with the standard model within experimental errors that are by now becoming rather small.

Experiments with the 15 ft Fermilab bubble chamber[17] filled with NeH have yielded new results, presented at this conference:

$$u^2_R = 0.038 \pm 0.028$$

$$d^2_R = 0.007 \pm 0.026\ .$$

The Illinois-Maryland-Stony Brook-Tohoku-Tufts (IMSTT) Collaboration[18], studying the neutrino-deuteron interaction in a bubble chamber, has measured the following quantities

$$R_p = \frac{\sigma(\nu p \to \nu X)}{\sigma(\nu p \to \mu^- X)} \approx 2u^2_L + d^2_L = 0.47 \pm 0.05$$

$$R_n = \frac{\sigma(\nu n \to \nu X)}{\sigma(\nu n \to \mu^- X)} \approx 2d^2_L + u^2_L = 0.22 \pm 0.02$$

$$R_{I=0} = \left.\frac{NC}{CC}\right|_{I=0} = 0.30 \pm 0.02$$

and derived

$$u^2_L = 0.19 \pm 0.07\ , \quad d^2_L = 0.11 \pm 0.03$$

in reasonable agreement with the previous results.

8. LIMIT ON THE LEFT-RIGHT SYMMETRIC MODEL FROM THE NEUTRAL CURRENT EXPERIMENTS

The left-right symmetric model is one of the most popular extensions of the standard model for electroweak interactions[19]. Some attractive features of this model are: the restoration of a left-right symmetry in the electroweak interaction at high energies, and an interesting relation between the electric charge and other important quantum numbers of the particles

$$Q = T_{3_L} + T_{3_R} + \frac{B - L}{2}\ ,$$

where T_{3_L} and T_{3_R} are the weak isospin for the left and right isodoublets, and B and L are the baryonic and leptonic numbers, respectively.

The weak NC Lagrangian of the neutrino-fermion interaction in the left-right symmetric model is[20]

$$\mathcal{L}^{NC} = \frac{4G}{\sqrt{2}}\left[\eta_L(J^3_{\mu_L} - \sin^2\theta\ J^{em})^2 - 2\eta_{LR}(J^3_{\mu_L} - \sin^2\theta\ J^{em}_\mu)(J^3_{\mu_R} - \sin^2\theta\ J^{em})\right]\ .$$

The quantities η_L, η_R, and η_{LR} are defined as follows:

$$\eta_L = \frac{1}{2}(\rho_A + \rho_V), \quad \eta_{LR} = \frac{1}{2}(\rho_A - \rho_V), \quad \eta_R = \eta_L - f_{pV}\ .$$

Table 4

Reaction	Parameter	$SU(2)_L \times (1)$	$SU(2)_R \times SU(2)_L \times U(1)$
νe	$g_V = c_L + c_R$	$-\frac{1}{2} + 2\sin^2\theta$	$\rho_A\left(-\frac{1}{2} + 2\sin^2\theta\right)$
	$g_A = c_L - c_R$	$-\frac{1}{2}$	ρ_A
ν"q"	α	$1 - 2\sin^2\theta$	$\rho_V\,(1 - 2\sin^2\theta)$
	β	1	ρ_A
	γ	$-\frac{2}{3}\sin^2\theta$	$\rho_V\left(-\frac{2}{3}\sin^2\theta\right)$
	δ	0	0
e"q"	$\tilde{\alpha}$	$-1 + 2\sin^2\theta$	$f_{pV}\,(-1 + 2\sin^2\theta)$
	$\tilde{\beta}$	$-1 + 4\sin^2\theta$	$f_{pV}\,(-1 + 4\sin^2\theta)$
	$\tilde{\gamma}$	$\frac{2}{3}\sin^2\theta$	$f_{pV}\left(\frac{2}{3}\sin^2\theta\right)$
	$\tilde{\delta}$	0	0
$e^+e^- \to \mu^+\mu^-$	h_{VV}	$\frac{1}{4}(1 - 4\sin^2\theta)^2$	$\frac{1}{4}(2\rho_V - f_{pV})(1 - 4\sin^2\theta)^2$
	h_{AA}	$\frac{1}{4}$	$\frac{1}{4}(2\rho_A - f_{pV})$
	h_{VA}	$\frac{1}{4}(1 - 4\sin^2\theta)$	$\frac{1}{4}f_{pV}(1 - 4\sin^2\theta)$

Table 4 shows the relations between the parameters ρ_A, ρ_V, and f_{pV} of the left-right symmetric model with the value predicted by the standard model for different reactions between lepton-lepton and lepton-quark. The new data on neutrino-electron and neutrino-quark scattering plus the results on the asymmetry of polarized electron-deuteron scattering allow the determination of the upper limit on the mass of the second neutral vector boson predicted by the left-right symmetric model without the use of the very low energy data from the parity violation in the atomic transition. The relation [taken from Sehgal[21]] is

$$\frac{M_1^2}{M_2^2} \simeq \frac{(1 - 2\sin^2\theta)(\eta_R/\eta_L - \eta_{LR}^2/\eta_L^2)}{[(1 - \sin^2\theta)[1 + (\eta_R/\eta_L)] + 2\sin^2\theta\,\eta_{LR}/\eta_L]^2} \leq 0.1$$

and

$$M_2 > 3M_1 .$$

9. UNIVERSALITY OF THE WEAK COUPLING CONSTANT FOR THE DIFFERENT FERMION GENERATIONS

In the standard model the coupling constant of the fermions to the weak vector bosons is the same for all generations. There are new experimental results that confirm this hypothesis.

i) The τ lifetime measured by Mark 2 at PEP is[22]

$$t_\tau = (4.9 \pm 1.8) \times 10^{-13}\ \text{s} .$$

This value agrees, within the errors, with the expected value of 2.8×10^{-13} s computed from the μ lifetime.

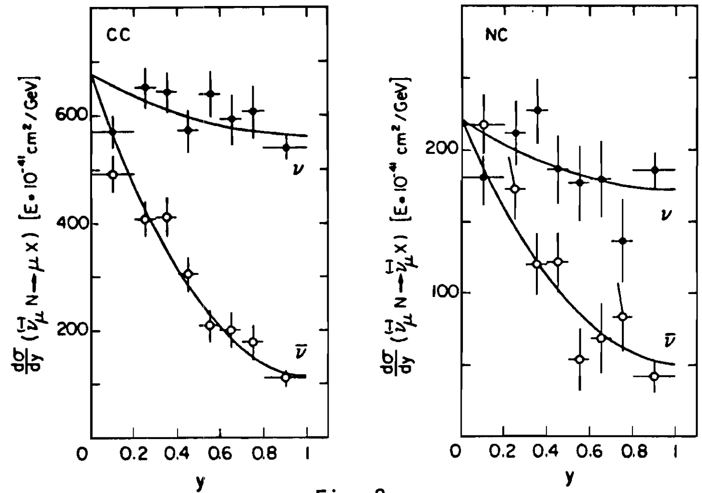

Fig. 9

ii) The CHARM Collaboration[14]) has derived, from a simultaneous fit to the y distribution for neutrino and antineutrino interactions on nucleons for both CC and NC (Fig. 9), the coupling constant of the strange quark to the neutral vector boson compared with the coupling constant to the down quark.

$$\frac{g_s^2}{g_d^2} = \frac{s_L^2 + s_R^2}{d_L^2 + d_R^2} = 1.39 \pm 0.43$$

in agreement with that expected from universality.

iii) The mass spectrum of the neutrino-induced dimuon events, as measured by the CDHS Collaboration[9]) is shown in Fig. 10. The peak at 3.1 GeV is interpreted as the creation of the $C\bar{C}$ bound state J/ψ produced through the Z^0 and gluon fusion.

From the comparison of the NC cross-section from CDHS for J/ψ production with that for J/ψ production by muons from the European Muon Collaboration (EMC) (Fig. 11), in the context of the gluon fusion model applied to both the photon gluon and the Z^0 gluon vertex, can be derived a connection between the $u\bar{u}Z^0$ coupling and the $c\bar{c}Z^0$ coupling giving

$$\frac{g_c^2}{g_u^2} = 1.6 \pm 0.5 \ .$$

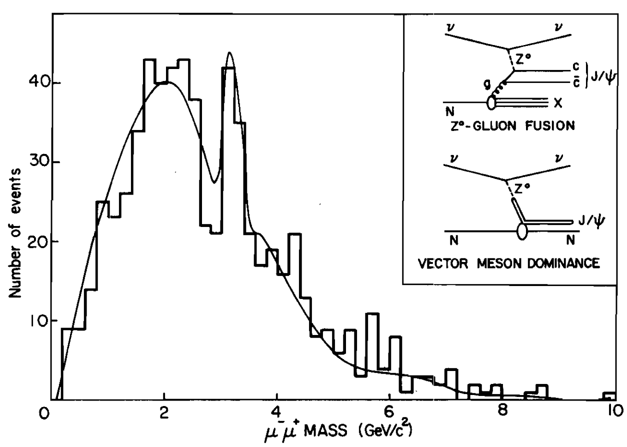

Fig. 10

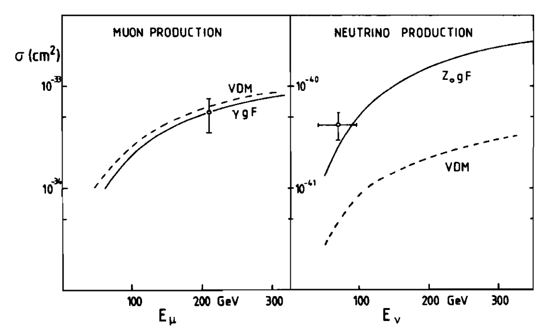

Fig. 11

10. CONCLUSIONS

i) The experimental data on electroweak interactions in the range $10^{-16} \le Q^2 \le 10^3$ GeV^2 agree with the standard model $SU(2)_L \times U(1)$ + GIM within the errors, provided $\sin^2\theta = 0.225 \pm 0.01$.

ii) In the explored energy region $Q^2 < M^2_{Z^0}$ the electroweak interactions are still left-handed, at least for 80-90% of the cross-section. This means that lepton and quarks appear in left-handed doublets and right-handed singlets.

iii) The weak angle has been measured with an accuracy of $\sim$ 5% in the neutrino-quark interaction. Future improvement will come but will be finally limited by the uncertainty in the corrections to the quark parton model. The new data on the weak angle from $e\bar{e} \to f\bar{f}$ and from $\overset{(-)}{\nu}_\mu e \to \overset{(-)}{\nu}_\mu e$ scattering, show that the knowledge of the weak angle in the purely leptonic sector could reach, in the future, an accuracy not very far from that of the intrinsically more complex neutrino-quark sector. At this level of accuracy the computation of the radiative corrections becomes important[23].

iv) The generation universality of the weak coupling is compatible for the μ and τ leptons and for the s, c quarks in the CC, and for d, s and u, c in the NC in the four quarks scheme.

v) The most definitive test of the standard model may come with the discovery of the Z^0 at a mass consistent with the measured value of $\sin^2\theta$. With the hope that future experiments will produce the Z^0, the measurement of $\sin^2\theta$ has to improve in accuracy, keeping in mind that the mass of the Z^0 (still to be discovered!) will be measured at (1-2)%. Figure 12 shows the value of $\sin^2\theta$ measured by different experiments in the Q^2 range accessible at present.

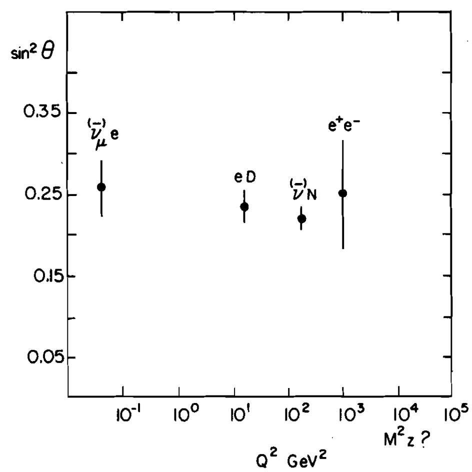

Fig. 12

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DISCUSSION

R. MARSHAK, Virginia Polyt. Institute:

Comment: The speaker is right that the weak hypercharge in the standard electroweak model has no clear physical meaning and that the limit on the mass of W_R is not that stringent. One good way to study the weak boson masses (without producing the particles) and to distinguish between the standard model and the left-right symmetry model (with B-L the weak hypercharge) is to do more accurate measurements of backward-forward asymmetry in $e^+e^- \to \mu^+\mu^-$ and similar processes. For example, the left-right model permits "left-handed" weak bosons of substantially lower mass than the standard model.

B. KAYSER, SLAC & US-NSF:

The value 1.4 ± 0.4 for g_s^2/g_d^2 is about in the middle between the value you would have if the right-handed strange quark were in a singlet and that if it were in a doublet (which is the most seriously considered alternative). Are there plans or possibilities of reducing the present error?

M. ROOS, University of Helsinki:

You concluded that the world is L-handed still, and not R-handed. There are, however, GUTs which mix some R-handed interactions into the dominant L-handed interactions. The interesting way to use data is therefore not to test R against L, but to give the upper limits to possible R-admixture. This, from μ decay, is today still as large as 10-15%.

I would like to comment on the fits of $\sin^2 \theta_W$ and ρ to NC data, that the error of 1.5% on ρ, quoted from Kim et al., should in my opinion be 4.5%.

P. LANGACKER, Pennsylvania University:

A new experiment to study the low-energy neutral-current interaction is beginning at Brookhaven by a US-Japan Collaboration. The detector has 100 T fiducial volume which is 80% liquid scintillator.

Expected rates after analysis are 150 $\nu p \to \nu p$ per day and $2 \nu_\mu e^- \to \nu_\mu e$ per day.