MEASUREMENT OF THE RATIO OF NEUTRAL TO CHARGED CURRENT CROSS SECTIONS OF NEUTRINO INTERACTIONS IN HYDROGEN

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presented by

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1. INTRODUCTION

We present a measurement of the ratio R_p of Neutral Current (NC) to harged urrent (CC) cross sections from neutrino interactions or protons. Similar measurements exist for the interactions of ν and $\bar{\nu}$ on isoscalar targets [1,2], from which the magnitude of the left- and right-handed couplings of the neutral current to quarks have been determined [3]. But, because of of the isospin symmetry of the target, the contributions of the up and down quarks to the couplings cannot be separated. Used together with the measurement of NC/CC on protons, the magnitude of the couplings to u and d quarks can be determined separately. However, the only published measurement of neutrinos on protons $R_p = 0.48 \pm 0.17$ [4] does not reach the precision required to put significant constraints on the couplings. In the present experiment, we determine R_p to a precision which is better than 10%.

2. EXPERIMENTAL CONDITIONS

The experiment was carried out in the CERN SPS wideband neutrino beam, obtained from 350 GeV protons. A total of about 285 000 pictures were taken in the bubble chamber BEBC filled with hydrogen. The pictures were double-scanned for events with ≥ 3 charged tracks. The chamber was equipped with a two-plane External Muon Identifier (EMI) [5]. The subsample used for this analysis consists of 2750 events with an EMI identified muon with $p_\mu > 3$ GeV/c (CC events) and 3900 events where no muon is detected (NC candidates), both with measured hadronic energy $E_H \geq 5$ GeV and in a fiducial volume of 18 m^3 corresponding to $\sim$ 1 t of H_2.

3. SELECTION OF NEUTRAL CURRENT EVENTS

The sample of events without a detected muon contains, in addition to the real neutral current events, a considerable number of background events. The main sources contributing to this background are: (a) CC events where the muon is not identified because of the limited EMI geometrical acceptance; from a Monte-Carlo simulation it is estimated that the geometrical acceptance is 98% for $p_\mu > 10$ GeV/c, but that it decreases rapidly for smaller p_μ and is essentially zero below 3 GeV/c. The corresponding contamination in the NC candidates is approximately 70% of the true number of NC events. (b) Interactions in the liquid produced by incoming neutral hadrons (K^0's and neutrons) originating from neutrino interactions in the material in front of the chamber. A Monte-Carlo program was used to simulate the production of the neutral hadrons in the material surrounding the bubble chamber, to follow their cascade and to determine the number of neutral hadron interactions in the bubble chamber. The contamination from neutral hadron interactions was found to be approximately 40% of the true number of NC events.

The uncertainties in these corrections are large, and do not allow to reach the accuracy mentioned above. An efficient way of reducing this background is to select events with large transverse momentum p_T^H of the hadronic system with respect to the neutrino beam direction. This is illustrated by the examples given in fig. 1, and can qualitatively be understood as follows: as the neutrals are in general not detected in this experiment, p_T^H corresponds, in the case of true CC or NC events (fig. 1(a)), to $\sim 2/3$ of the true hadronic p_T (or the p_T of the muon). When the muon is not identified and hence counted with the hadrons, p_T^H measures the unbalance in p_T, which is $\sim 1/3$ of the true hadronic p_T. Fig. 1(b) shows that the p_T^H of misclassified CC events is indeed about half of the p_T^H of the identified events. Finally, the total hadronic p_T is shared by several hadrons, which have each a small p_T component with respect to the direction of the hadronic system. It is therefore expected that the p_T of any individual hadron, with respect to the neutrino direction, is on the average small compared to the total hadronic p_T. This is supported by the p_T distribution of V^0's, given in fig. 1(c). In conclusion, the events coming from the main sources of background in the NC candicates are concentrated in the region of small p_T^H.

4. NEUTRAL CURRENT TO CHARGED CURRENT RATIO

The raw ratio R_p for events with p_T^H, greater than a given value p_T^{MIN} is shown as a function of p_T^{MIN} in fig. 2. The fast drop of the ratio as p_T^{MIN} increases reflects the presence of contaminations in the NC sample, together with the loss of CC events due to inefficiencies in muon identification. In addition to the two dominant corrections discussed above, corrections have been applied for:

- The "electronic" inefficiency of the EMI and accidental association of hadrons to hits on the EMI due to background.
- Background due to $\bar{\nu}_\mu$, $\bar{\nu}_e$ and ν_e events.
- One-prong events, which are not recorded at the scanning.
- The value of the hadronic p_T^H is determined from the measured particles only, hence the contribution due to neutral hadrons is in general missing. A calibration of the measured p_T^H was obtained from CC events by comparing p_T^H to the p_T^μ of the muon. It was found that the measured p_T^H corresponds on average to 0.8 of p_T, with a spread of 0.3. The calibration of p_T^H in NC events could be different if the p_T carried by neutral hadrons were different in NC and CC events. From a Monte-Carlo calculation differences in the π^0 and neutron production are estimated to lead to a systematic loss of $\sim$ 4% of the NC events.

The NC to CC ratio R_p, after all corrections have been applied, is shown in fig. 2 as a function of p_T^{MIN}. The value of p_T^{MIN} which makes the systematic errors due to uncertainties in the correction procedure about equal to the statistical errors corresponds to 1.5 GeV/c (measured transverse momentum). It can be clearly seen that the corrections are drastically reduced by the cut in p_T. The best estimate of R_p is therefore

$$R_p = 0.52 \pm 0.04 \text{ for } p_T^H > 1.5\ (1.9)\ \text{GeV/c}, \qquad (1)$$

where the statistical and the systematic errors each contribute $\pm$ 0.03. The cut $p_T^H > 1.5$ GeV/c measured p_T corresponds to a cut on the true $p_T^H > 1.9$ GeV/c. As seen from fig. 2, the value of R_p is not very sensitive to the exact value of p_T used.

5. STRUCTURE OF THE NEUTRAL CURRENT

The analysis of the inclusive scattering of ν and $\bar{\nu}$ on isoscalar targets has given an accurate measurement of the left and right-handed couplings of neutral currents. The chiral couplings, as used in the analysis of Sehgal [3], are u_L, u_R, d_L, d_R, where u and d refer to the up and down quarks and L and R refer to left- and right-handed couplings respectively. The ABCLOS Collaboration [2] used the ratios of total cross sections to determine the combinations $(u_L^2 + d_L^2)$ and $(u_R^2 + d_R^2)$ and their best estimate is

$$u_L^2 + d_L^2 = 0.32 \pm 0.03\ ,\ u_R^2 + d_R^2 = 0.04 \pm 0.03\ . \qquad (2)$$

The coupling constants u_L^2 and d_L^2 can be determined individually by combining the above result with the NC to CC cross section ratio on protons.

In the quark parton model the differential cross sections for ν-proton inclusive scattering are

$$\frac{d^2\sigma}{dxdy}(CC) = \frac{2G^2ME}{\pi} \times \left[(d_V + d_S + s_S) + (u_S + c_S)(1-y)^2\right]$$

$$\frac{d^2\sigma}{dxdy}(NC) = \frac{2G^2ME}{\pi} \times \left\{u_V\left[u_L^2 + u_R(1-y)^2\right] + d_V\left[d_L^2 + d_R(1-y)^2\right] + \left[(u_S + c_S)(u_L^2 + u_R^2) + (d_S + s_S)(d_L^2 + d_R^2)\right]\left[1 + (1-y)^2\right]\right\} \quad (3)$$

where u_V, u_S, d_V and d_S are the quark density distributions for u and d valence or sea quarks, s_S (c_S) are the density distribution of strange (charmed) quarks, these quark densities being functions of x and Q^2 [6]. In the above expression, it has been assumed that the sea quark and anti-quark density distributions are identical and that the couplings are the same for quarks with the same charge.

Integrating the differential cross sections over x and y gives for the ratio R_p of NC to CC total cross sections

$$R_p = f_1\, u_L^2 + f_2\, d_L^2 + f_3\, u_R^2 + f_4\, d_R^2, \quad (4)$$

where the f_i are ratios of integrals over the known quark density distributions.

For the evaluation of the integrals f_i, we have used the Q^2 dependent parametrization of the quark density distributions proposed by Buras and Gaemers [7], with a non SU(3) symmetric contribution of strange quarks in order to reproduce the dimuon production in ν and $\bar{\nu}$ interactions [8]. The quark density distributions were used as input in a Monte-Carlo program which takes into account the energy distribution of the neutrino wideband beam and the effect of the cut on p_T^H. The values obtained for the integrals f_i with a cut $p_T^H > 1.5$ GeV/c and $E_H > 5$ GeV are:

$$f_1 = 2.1 \qquad f_2 = 1.0 \qquad f_3 = 0.70 \qquad f_4 = 0.36\ . \quad (5)$$

These values are not sensitive to the detailed shape of the beam, the neutrino energy entering only via the Q^2 dependence of the quark density functions. This dependence is known to be small and it is partially absorbed as the f_i are ratios of quark densities.

Using the above value of $u_R^2 + d_R^2$ and the values for f_3 and f_4, the right-handed contribution R_p^{RH} to the NC/CC ratio R_p is bound to lie inside the limits $R_p^{RH} = 0.03 \pm 0.02$ and $R_p^{RH} = 0.02 \pm 0.01$ corresponding to $d_R = 0$ and $u_R = 0$ respectively. As this difference is small compared to the errors of the experiment, we have assumed that $R_p^{RH} = 0.025 \pm 0.02$. Taking the value of $u_L^2 + d_L^2$ from eq. (2) and the estimate of eq. (1) for R_p, we get

$$u_L^2 = 0.15 \pm 0.05$$

$$d_L^2 = 0.16 \pm 0.07.$$

Fig. 3 displays the constraints on u_L^2 and d_L^2 coming from the measurement on isoscalar targets and from this experiment. It also shows that the results agree with the standard SU(2) × U(1) model [9]. The value of $\sin^2\theta_W$ determined from the R_p value obtained in this experiment is

$$\sin^2\theta_W = 0.18 \pm 0.03$$

in good agreement with other determinations.

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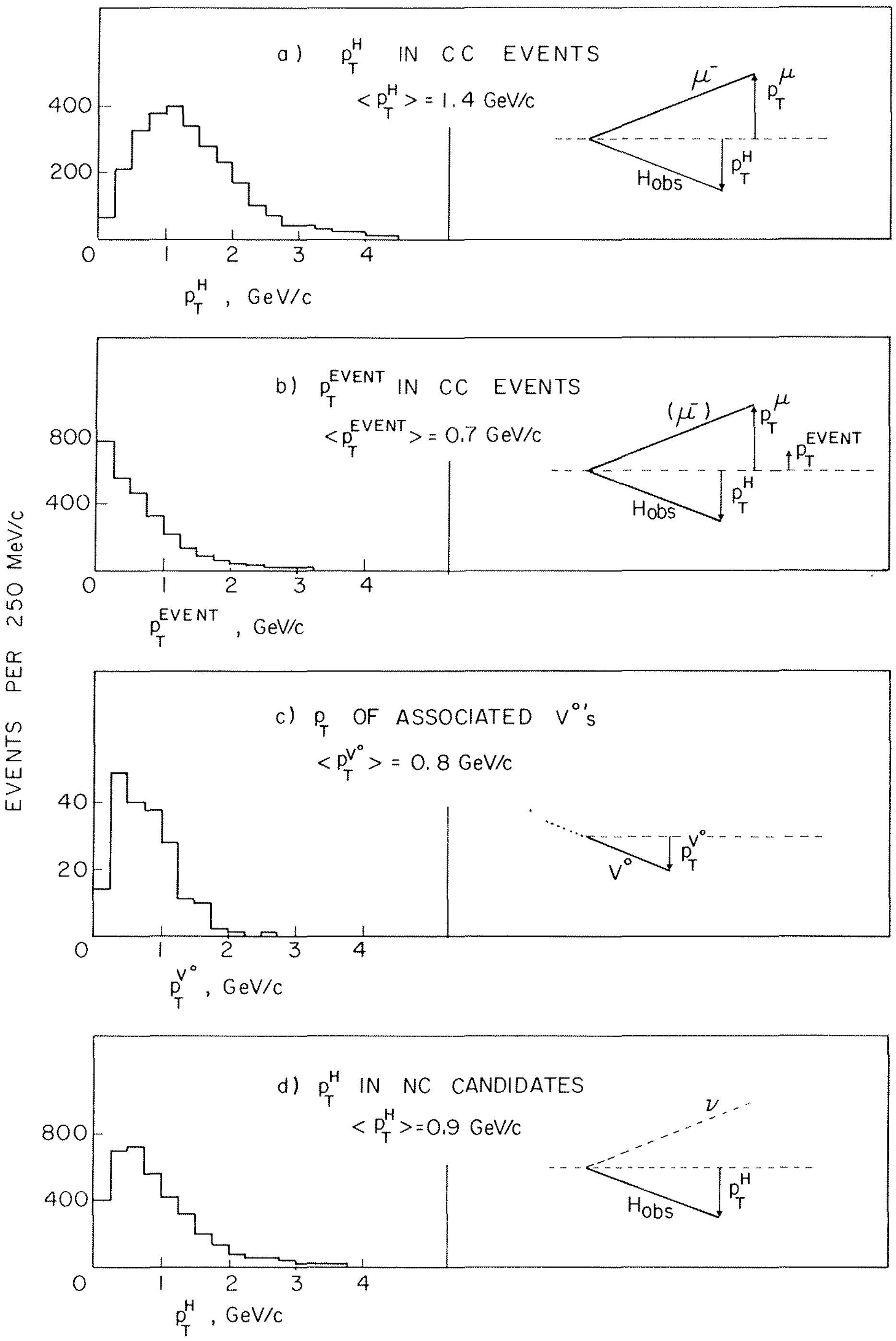

Fig. 1

Event distributions as functions of the transverse momentum p_T with respect to the ν-direction:

(a) the p_T of the detected hadronic system p_T^H in CC events;

(b) the p_T of all tracks, including the muons, in CC events;

(c) the p_T of neutral hadrons, obtained from V^0's associated to neutrino interactions;

(d) the p_T of the detected hadrons p_T^H in NC candidates, including background.

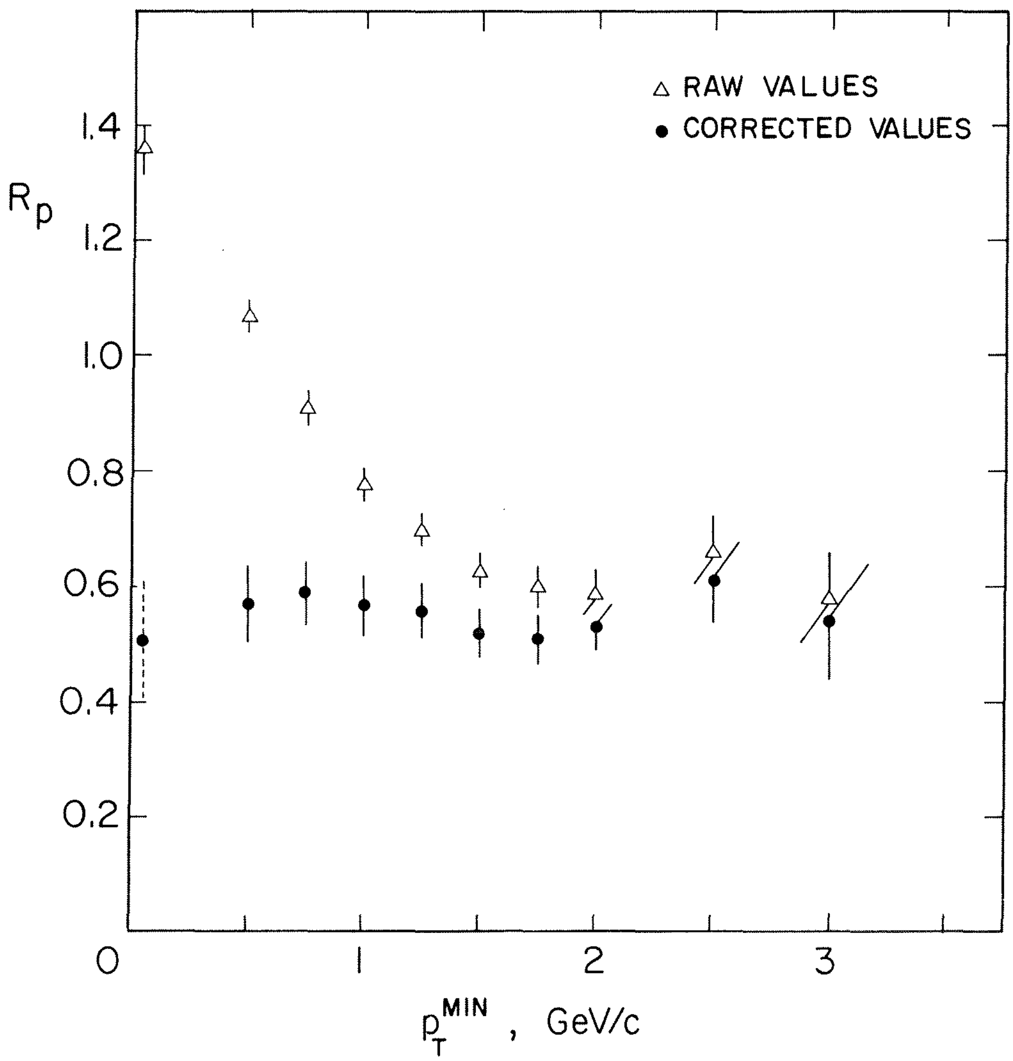

Fig. 2

Ratio R_p of NC to CC events with p_T^H above a given p_T^{MIN} and plotted as a function of p_T^{MIN}. Only events with $E_H \geq 5$ GeV are included. The values of R_p are displayed before corrections (Δ) and after all corrections have been applied (dots).

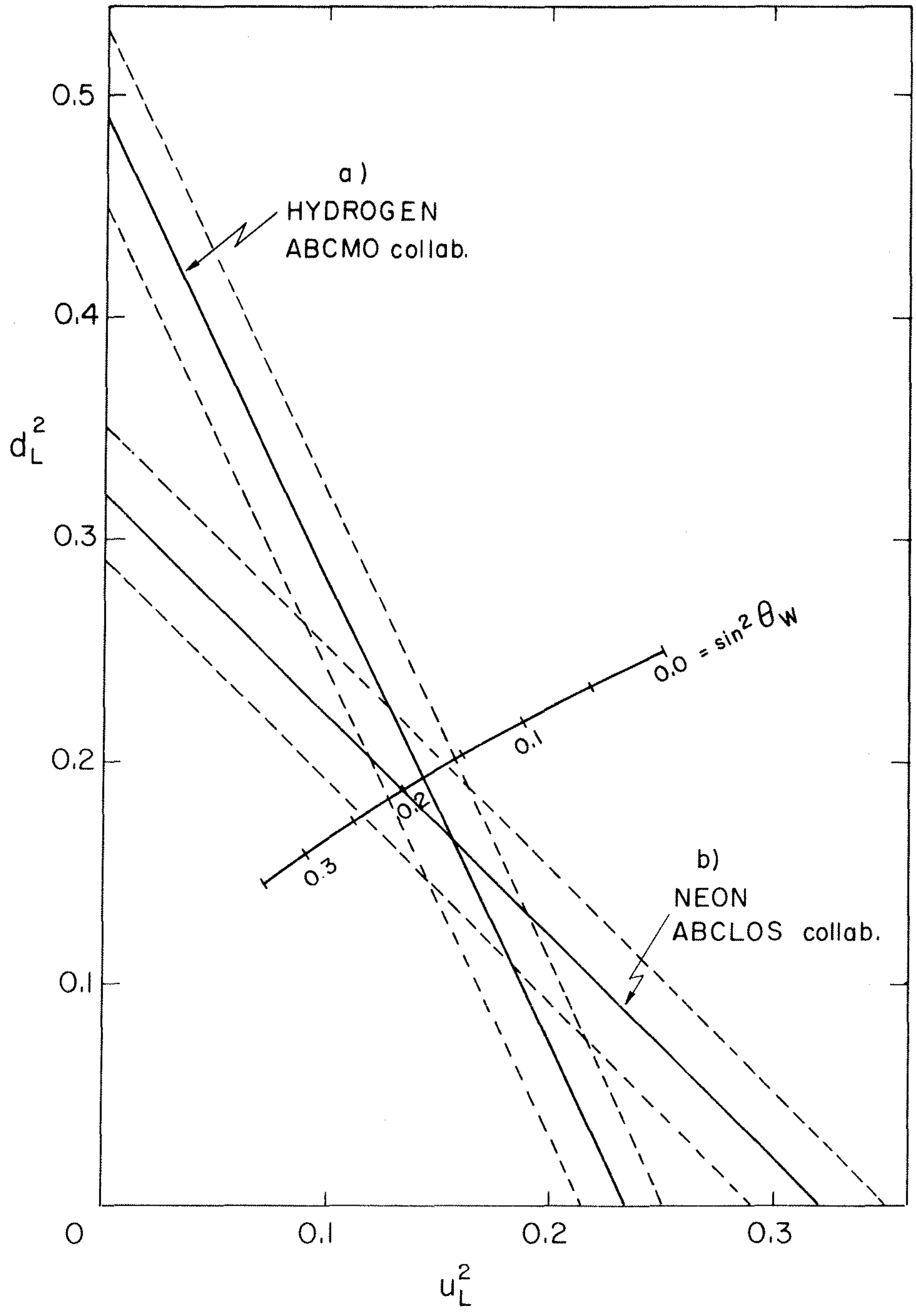

Fig. 3

The relations between the coupling constants u_L^2 and d_L^2 obtained from isoscalar data (line a) [2] and from νp interactions in this experiment (line b). The errors indicated by dotted lines correspond to 1 standard deviation. Also shown is the prediction of the standard SU(2) × U(1) model as a function of the single parameter $\sin^2\theta_W$ (curve c).