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

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Abstract

Antineutrino-proton interactions have been studied in BEBC filled with hydrogen and equipped with the Internal Picket Fence (IPF) and the three plane External Muon Identifier (EMI). The beam was the CERN SPS wideband beam. A total of 80.000 pictures containing more than 5400 events was analysed.
The IPF was used to apply a 'pattern recognition' procedure which turns out to be very effective in terms of event separation and background reduction. In the framework of the present analysis a preliminary value for the neutral to charged current cross section is found of $R_p^{\bar{\nu}} = 0.332 \pm 0.032$. With the help of additional data from isoscalar targets the left and right handed quark couplings are determined. The Weinberg angle and the ρ parameter are found to be $\sin^2\Theta_\omega = 0.228 \pm 0.022$; $\rho = 1.01 \pm 0.06$.

1. The experiment WA21

The experimental set-up can be subdivided into three parts (fig.1):

I. The bubble chamber BEBC filled with liquid hydrogen (H_2) at a temperature of approximately 3o K (1).
The fiducial volume was chosen to be 17 m^3 corresponding to 1t target mass. A superconduction magnet delivered inside the bubble chamber a homogenous and constant field of 3.5 T.

II. The external muon identifier (EMI) with two downstream (inner and outer) planes and one upstream plane (2).
Between the EMI inner and outer plane an iron shield of five to ten hadronic interaction lengths is situated to separate outgoing muons from strongly interacting particles, e.g. pions. The EMI geometrical efficiency is almost 1oo % for muons with momentum greater than 1o GeV/c and drops to about 5o % for muons of 3 GeV/c momentum. Muons below 3 GeV/c can not be detected.

III. The internal picket fence IPF (3).
It consists of 288o proportional tubes of 1.5 cm diameter and 2oo cm height each, surrounding the pressure vessel of BEBC in two layers. In addition with special software (4), unique features with respect to event separation and background reduction are gained:

a) The majority of event vertices can be reconstructed as space-time points.
b) Almost all hadronic induced events, originating from neutrino interactions upstream the bubble chamber, can be detected on an event-by-event basis by means of their upstream(veto) picket activity (fig.2).
c) The geometrical efficiency of the EMI is extended.
d) Charged current events with no charged hadrons produced (one prongs) can be found with an efficiency of about 75 %.
e) Throughgoing muons, the main systematic background for the pattern recognition to fake CC events, can be electronically measured and excluded.

The data were taken in summer 1981. On about 80.000 frames, 5437 interactions in the bubble chamber were visible. The beam was the CERN wideband beam (WBB). The SPS delivered protons with 4oo GeV/c momentum on a beryllium target ($1o^{13}$ protons/spill). Parent pions and kaons were produced decaying tonto (anti)neutrinos with an average energy of 4o GeV. The neutrino background in the antineutrino beam was about 25 %. Contributions from $\bar{\nu}_e$ can be estimated to be less than 1.5 %.

2. Event classification and cuts

We obtain in the bubble chamber

(i) Charged current (CC) events with an EMI identified μ^+,

(ii) CC events with an EMI identified μ^-,

(iii) Hadronic induced (N*) events vetoed by the IPF or in addition by through-going muons,

(iv) all other events consisting of

- genuine $\bar{\nu}$ - neutral current (NC) events
- genuine ν - NC events,
- CC events without detected muon due to geometrical and electronical losses of the EMI,
- N* events without specific features,
- $\bar{\nu}$ background events (CC and NC).

In general a cut on the hadronic (visible) energy was applied at 5 GeV. In our ananlysis we have recalculated the true hadronic energy by means of a Monte Carlo simulation separatly for NC and CC events. The results given refer to a total hadronic energy above 7.5 GeV. In addition the charged multiplicity was required to be greater/equal three.

Muons from charged current interactions were accepted down to 3 GeV/c momentum for $\bar{\nu}$ CC events and down to 5 GeV/c momentum for ν CC events.

In order to be comparable with previous calculations (5) and to minimize our systematic error we have introduced an additional cut on the hadronic transverse momentum p_t^H (fig.4).

3. Results on NC/CC calculation

	NC	$CC(\mu^+)$
raw data	800 ± 23	1061 ± 33
wrong timing	3 ± 2	
vetoed NC	60 ± 12	
silent N*	- 7 ± 2	
false CC	5 ± 3	- 1 ± 1
Pion decay	7 ± 3	- 4 ± 2
EMI elec. ineff.	- 92 ± 20	42 ± 11
EMI geom. ineff.	- 76 ± 5	23 ± 2
P_μ cut	- 155 ± 5	71 ± 4
ν NC	- 130 ± 14	
$\bar{\nu}_e$	- 20 ± 3	
$E_{tot}^H \geq 7.5$	- 4 ± 1	11 ± 1
total	392 ± 41	1203 ± 35

The ν NC background was calculated assuming $R_p^{\nu} = 0.39 \pm 0.04$ for neutrino-proton interactions (6). The contributions from $\bar{\nu}_e$ events were estimated via a WBB simulation program (7) under the assumption of muon/electron universality.
The results obtained read as follows:

NC/CC = 0.325 ± 0.035

0.025 (stat) ± 0.024 (syst)

And for $p_t^H > 0.75$:

NC/CC = 0.332 ± 0.032

4. Interpretation of our result in terms of the Standard Model

Since we are working on a proton target it is not possible to give a model independent interpretation of the NC/CC ratio or the value of $\sin^2\theta_\omega$ respectively. Thus the NC/CC ratio is related to the quark couplings q_i weighted be some coefficients a_i (8):

$$NC/CC = a_i\, u_L^2 + a_2\, u_R^2 + a_3 d_L^2 + a_4 d_R^2$$

The coefficients a_i are sensitive to the beam and the cuts applied to the data and have been determined by Monte Carlo integration. For example:

$$a_1 = \frac{\iiint \phi(E)E\,(1-y)^2\{x\,u(x,Q^2) + x\,c(x,Q^2)\} + \{x\,\bar{u}(x,Q^2) + x\,\bar{c}(x,Q^2)\}\,dEdxdy}{\iiint \phi(E)E\,(1-y)^2\{x\,u(x,Q^2) + x\,c(x,Q^2)\} + \{x\,\bar{d}(x,Q^2) + x\,\bar{s}(x,Q^2)\}\,dEdxdy}$$

The input for a_1 is:

a) $x\ q_i(x,Q^2)$ parametrization of the quark densities by Buras & Gaemers(9)

b) $\phi(E_\nu)$ known WA21 $\bar{\nu}$ flux

c) cuts on the data $E_{tot}^H > 7.5$ GeV, p_t^H .

The remaining coefficients a_2, a_3 and a_4 have been calculated accordingly. The dependence of the coefficients on p_t^H is given in fig.3. With the $\bar{\nu}$ beam we are especially sensitive to the right handed quark couplings. In the Standard Model without radiative corrections and neglecting heavier than charm quark contributions the NC/CC ratio without p_t^H cut has to match

$$NC/CC = 1.017u_L^2 + 0.663d_L^2 + 3.338u_R^2 + 1.83d_R^2$$

$$= 0.223 \pm 0.032$$

Since we have four unknowns but only one equation we have to use boundary conditions in order to determine the quark couplings. In this analysis we have applied measurements from isoscalar targets, namely from CDHS and from the BEBC D_2 Collaboration (WA25).

$$u_L^2 + d_L^2 = 0.30 \pm 0.01$$

$$u_R^2 + d_R^2 = 0.03 \pm 0.01$$

$$-1.06u_L^2 + 1.06d_L^2 - 0.25u_R^2 + 0.25d_R^2 = 0.06 \pm 0.06$$

$$0.49u_L^2 - 0.49d_L^2 + 2.85u_R^2 - 2.85d_R^2 = 0.02 \pm 0.09$$

Solving the five equations simultanously one obtains:

$$u_L^2 = 0.14 \pm 0.03 \qquad u_R^2 = 0.019 \pm 0.014$$

$$d_L^2 = 0.16 \pm 0.03 \qquad d_R^2 = 0.011 \pm 0.017$$

The quark couplings are directly related to the weak mixing angel Θ_ω (11):

$$u_L = 1/2 - 2/3 \sin^2\Theta_\omega \qquad d_L = -1/2 + 1/3 \sin^2\Theta_\omega$$

$$u_R = -2/3 \sin^2\Theta_\omega \qquad d_R = 1/3 \sin^2\Theta_\omega$$

Fixing $p = 1$ yields $\sin^2\Theta_\omega = 0.224 \pm 0.012$.

Leaving p as a free parameter the result is:

$p = 1.01 \pm 0.06$ and $\sin^2\Theta_\omega = 0.228 \pm 0.022$.

5. Conclusions

We have measured the cross section for neutral to charged currents in antineutrino-proton interactions. A new technique for the event separation by means of the Internal Picket Fence leads to a considerable improvement in our analysis with respect to background reduction and systematic errors.
The obtained value of the weak missing angle $\sin^2\Theta_\omega = 0.228 \pm 0.022$ and $p = 1.01 \pm 0.06$ is in good agreement with the Standard Model. Since we have used only 1/3 of our total statistic, the errors on the right (and left) handed quark couplings are still large, compared to what we aimed for.
A complete analysis of all our statistics covering neutrino and antineutrino data is expected in the near future.

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Figure Captions

Fig.1 : Lay-out of the system BEBC/IPF/EMI

Fig.2 : N* event obtained in BEBC.
A ν makes a primary CC interaction in the coils upstream BEBC.
A μ, charged and neutral hadrons are produced.
One neutron enters the chamber, interacts and is visible as a "N*" event.
The crosses are marking hits, which can be measured simultaneously by the system EMI/IPF.

Fig.3: The curves show the development of the quark coupling coefficients a_i as a function of a p_t^H cut.

Fig.4: The raw and corrected NC/CC ratio is shown in dependence of p_t^h.
The solid line represents the theoretical expectations taken from fig.3.

Schematic lay-out of EMI picket fence in BEBC

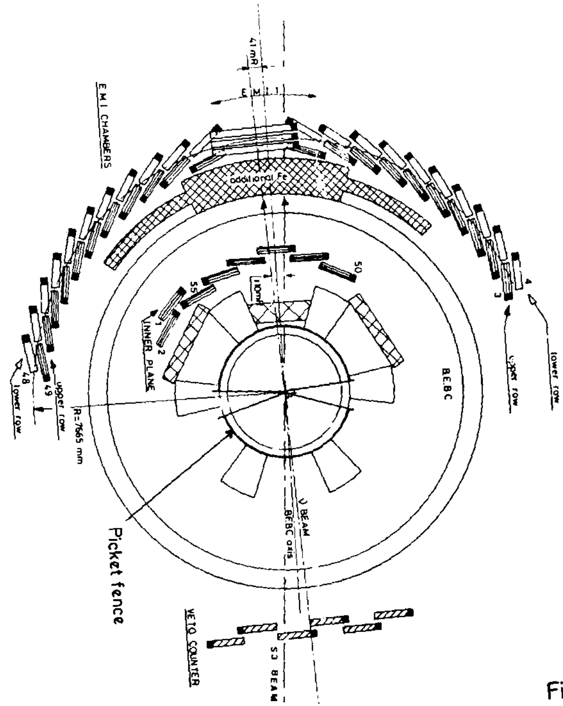

Fig. 1

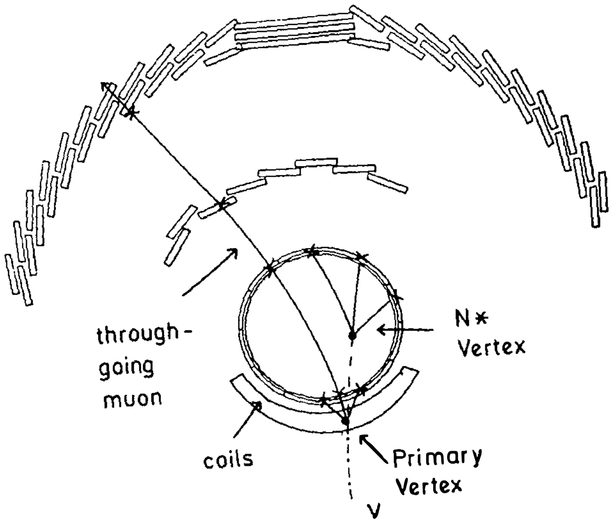

Fig. 2

Evolution of Coefficients of Neutral Current Couplings with P_t^H - cut.

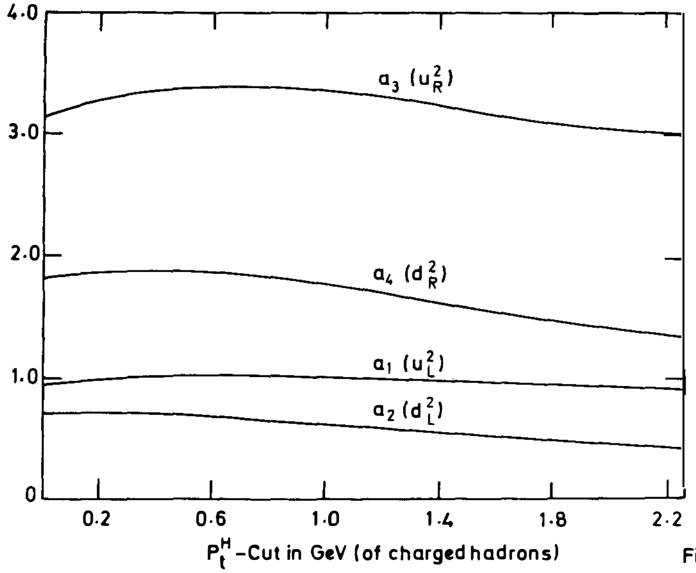

Fig. 3

NC/CC - ratio as a function of P_t^H

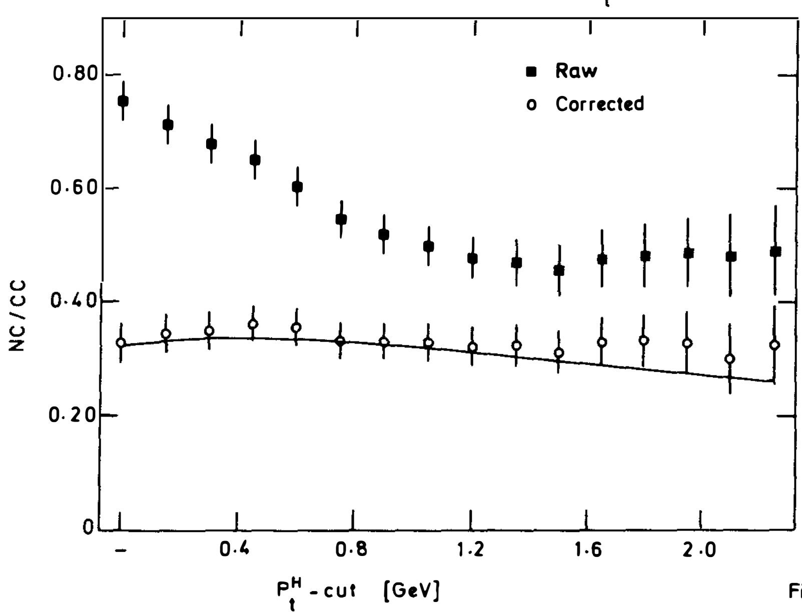

Fig. 4