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EXPERIMENTAL STUDY OF THE NUCLEON LONGITUDINAL STRUCTURE FUNCTION IN CHARGED-CURRENT NEUTRINO AND ANTINEUTRINO INTERACTIONS

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- Abstract -

The x dependence of the longitudinal structure function F_L was determined with the CHARM neutrino detector exposed to neutrino and antineutrino Wide Band Beams of the CERN 400 GeV SPS. The results show a clear deviation from the Callan-Gross relation. The amount and the x-dependence of this deviation are in agreement with the contribution coming from a finite transverse momentum of the partons in the nucleon if both the intrinsic and perturbative QCD terms are taken into account.

We report on a study of the absorption of longitudinally and transversally polarized virtual vector bosons W by nucleons, and on the related longitudinal structure function. This study is based on neutrino and antineutrino scattering on an isoscalar target. The data presented here were obtained using the CHARM fine grain calorimeter exposed to the CERN 400 GeV SPS wide-band neutrino and antineutrino beams. Details of the apparatus and of its performance may be found in Ref. /1/. This analysis uses the same sample of events from which we already determined the nucleon structure functions /2/. The event selection criteria are the same as those discussed in Ref. /2/.

The data are directly related to the differential cross sections for ν and $\bar{\nu}$ which can be expressed, introducing the structure functions F_1, F_2 and F_3, as

$$\frac{d^2\sigma^{\nu,\bar{\nu}}}{dxdy} = \frac{G^2 s}{2\pi}\left[(1-y-\frac{Mxy}{2E_\nu})\ F_2 + xy^2F_1 \pm (y-y^2/2)\ xF_3\right] \qquad (1)$$

while the cross sections σ_L, σ_+, σ_- for absorption of vector bosons W with polarization of 0, +1, -1, respectively are related to the same F_1, F_2 and F_3 by the relations

$$\sigma_L = \sqrt{2}\,\frac{G\pi}{K}\left[(\frac{2Mx}{Q^2} + \frac{1}{2Mx})\ F_2 - \frac{1}{M}\,F_1\right]$$

$$\sigma_\pm = \sqrt{2}\,\frac{G\pi}{K}\,\frac{1}{M}\left[F_1 \pm \frac{1}{2}\,(1 + \frac{Q^2}{2\nu^2})\ F_3\right] \quad ;$$

the constant K represents an overall W flux factor.

Defining the transversal cross section $\sigma_T = 1/2\ (\sigma_+ + \sigma_-)$ and the ratio $R = \sigma_L/\sigma_T$ we can write

$$R = \frac{F_2(x,Q^2) - 2xF_1(x,Q^2)}{2xF_1(x,Q^2)} + \frac{Q^2}{\nu^2}\ \frac{F_2(x,Q^2)}{2xF_1(x,Q^2)}$$

or, introducing $F_L = F_2 - 2xF_1 + \frac{Q^2}{\nu^2}\frac{F_2}{2xF_1}$

$$R = \frac{\sigma_L}{\sigma_T} = \frac{F_L}{2xF_1} \qquad (2)$$

The simple quark-parton model with spin 1/2 partons yields $F_2 = 2xF_1$ (the Callan-Gross relation) /3/ and hence R essentially equal to zero. Finite contribution to σ_L can come from partons with finite transversal momentum $P_T \neq 0$. Transverse momentum can be generated by gluon emission and reabsorption, as described by perturbative QCD, giving contributions to R of the order $\alpha_s(Q^2)$. A more substantial contribution to R would come from W-absorption by integer spin constituents of the nucleon.

Rewriting the cross sections in terms of F_2, F_3 and F_L using relation (2), and neglecting for simplicity the term $MxyF_2/2E_\nu$. we obtain

$$\frac{d^2\sigma^{\nu,\bar{\nu}}}{dxdy} = \frac{G^2S}{2\pi}\left[\frac{1}{2}\,(1 + (1-y)^2)F_2 \pm \frac{1}{2}\,(1 - (1-y)^2)xF_3 - y^2/2\; F_L\right] \quad . \qquad (3)$$

F_L can be then extracted from the data using the different y dependence of the coefficients of different structure functions.

The data are classified in bins of (x,Q^2) using the unfolding B-spline technique described in Ref. /2/. The content of each bin is related to the structure functions by the following expressions:

$$N(x,Q^2) = W_2F_2(x,Q^2) + W_3F_3(x,Q^2) - W_LF_L(x,Q^2)$$

$$\bar{N}(x,Q^2) = \bar{W}_2F_2(x,Q^2) - \bar{W}_3F_3(x,Q^2) - \bar{W}_LF_L(x,Q^2) \qquad (4)$$

where W_1, W_2, W_3 are the integrals of the y-dependent coefficients of equation (3) over the ν ($\bar{\nu}$) spectrum and the (x, Q^2) bin.

To disentangle F_L using the y dependence we integrate Eq. (4) in two different y intervals, chosen such as to have sufficient statistics in the number of events appearing on the left-hand side and sensitive differences in the W coefficients on the right-hand side of Eq. (4). These intervals were chosen as $0. \leq y \leq 0.5$ and $0.6 \leq y \leq 1$, giving 31056 and 13334 events, respectively, from the neutrino sample (88795 and 11065 events from the antineutrino sample) out of total samples of 50270 neutrino events, 108730 antineutrino events.

Eliminating F_3 from the two couples of Eq. (4) we obtain the equations

$$\left(\frac{N}{W_3} + \frac{\bar{N}}{\bar{W}_2}\right)_{H,L} = \left(\frac{W_2}{W_3} + \frac{\bar{W}_2}{\bar{W}_3}\right)_{H,L} F_2 - \left(\frac{W_L}{W_3} + \frac{\bar{W}_L}{\bar{W}_3}\right)_{H,L} F_L \quad ,$$

where H, L stand for the high and low y intervals. From the two equations we can extract F_L and F_2 for 5 x-bins integrated over Q^2. The range of Q^2 depends on x. In Table 1 we summarize the F_L values together with the x binning and the corresponding central Q^2 values.

The results for F_L and R are presented in Fig. 1 and 2, after applying radiative corrections /4/ and taking into account the effect of Fermi-motion /5/. In Fig. 1 we also show an estimate of the systematic errors on F_L coming from the uncertainty in our knowledge of the neutrino energy spectra. These uncertainties are assumed, as in Ref. /2/, to be 4% on the neutrino to antineutrino flux ratio and 5% maximum on the shape of each beam energy spectrum.

The results show at low values of x a clear deviation from the expectation of Callan-Gross relation confirming previous experiments /6/. This deviation can be interpreted as the contribution of finite transverse momenta of partons in the nucleon. The perturbative QCD prediction for this contribution /7/, obtained by integrating the structure functions determined in the same experiment /2/, is shown as a continuous line for $Q^2 > 3$ GeV^2 in Fig.1. Non-perturbative QCD contributions are expected to be non-negligible at the Q^2 values involved in this analysis. An attempt to calculate corrections for the first power of $(1/Q^2)$ is given in Ref. /8/ in terms of the parameter K_T, which represents the dynamically generated average transverse momentum. The application of this model for two different values of K_T (300 and 500 MeV/c) leads to the global theoretical prediction for the longitudinal structure function, also shown in Fig. 1.

We can then conclude that the amount and the x-dependence of the deviation from the Callan-Gross relation determined in this experiment are in good agreement with present QCD theoretical description of the nucleon structure.

We wish to thank R.Petronzio for many useful and stimulating discussions.

- References -

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- Figure Captions -

Fig. 1 Observed x - dependence of the longitudinal structure function F_L. The central Q^2 values for each x bin is indicated on the top of the figure. Both statistical and systematic error bars are shown. The continuous line is the perturbative QCD prediction, the dotted (dashed) lines represent the predictions including non-perturbative effects of K_T = 300 MeV/c (500 MeV/c), respectively.

Fig. 2 The ratio $R = \sigma_L / \sigma_T$ determined by the structure functions F_L and F_2, as a function of x.

TABLE 1

Summary of the longitudinal structure function F_L in five bins of x and the corresponding central values of Q^2.

x	Q^2	F_L
0. - 0.05	0.76 GeV^2	0.24 ± 0.22
0.05 - 0.1	3.0 GeV^2	0.24 ± 0.09
0.1 - 0.2	9.3 GeV^2	0.13 ± 0.06
0.2 - 0.3	16.6 GeV^2	0.06 ± 0.07
0.3 - 0.5	18.9 GeV^2	0.06 ± 0.13

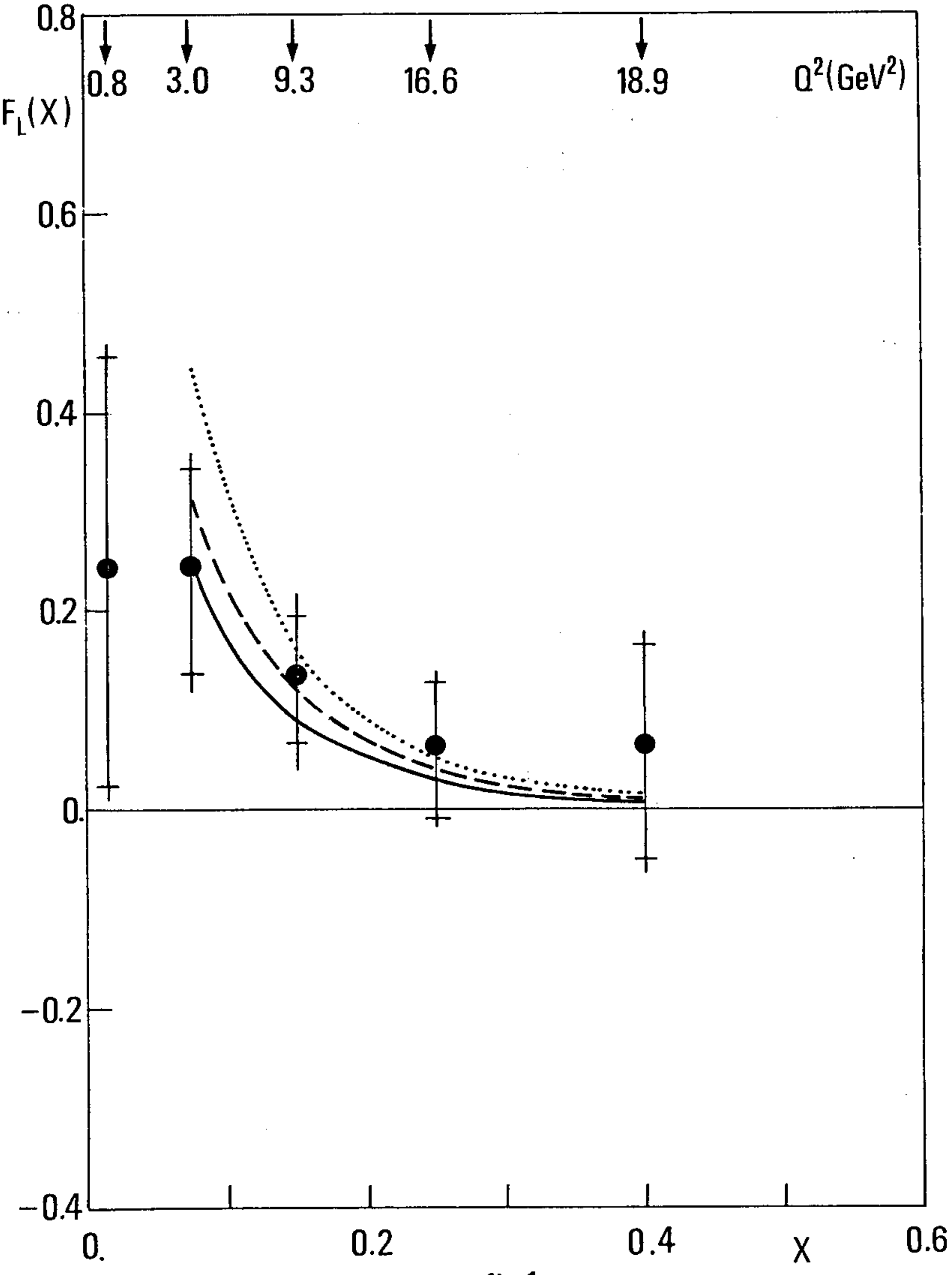

fig.1

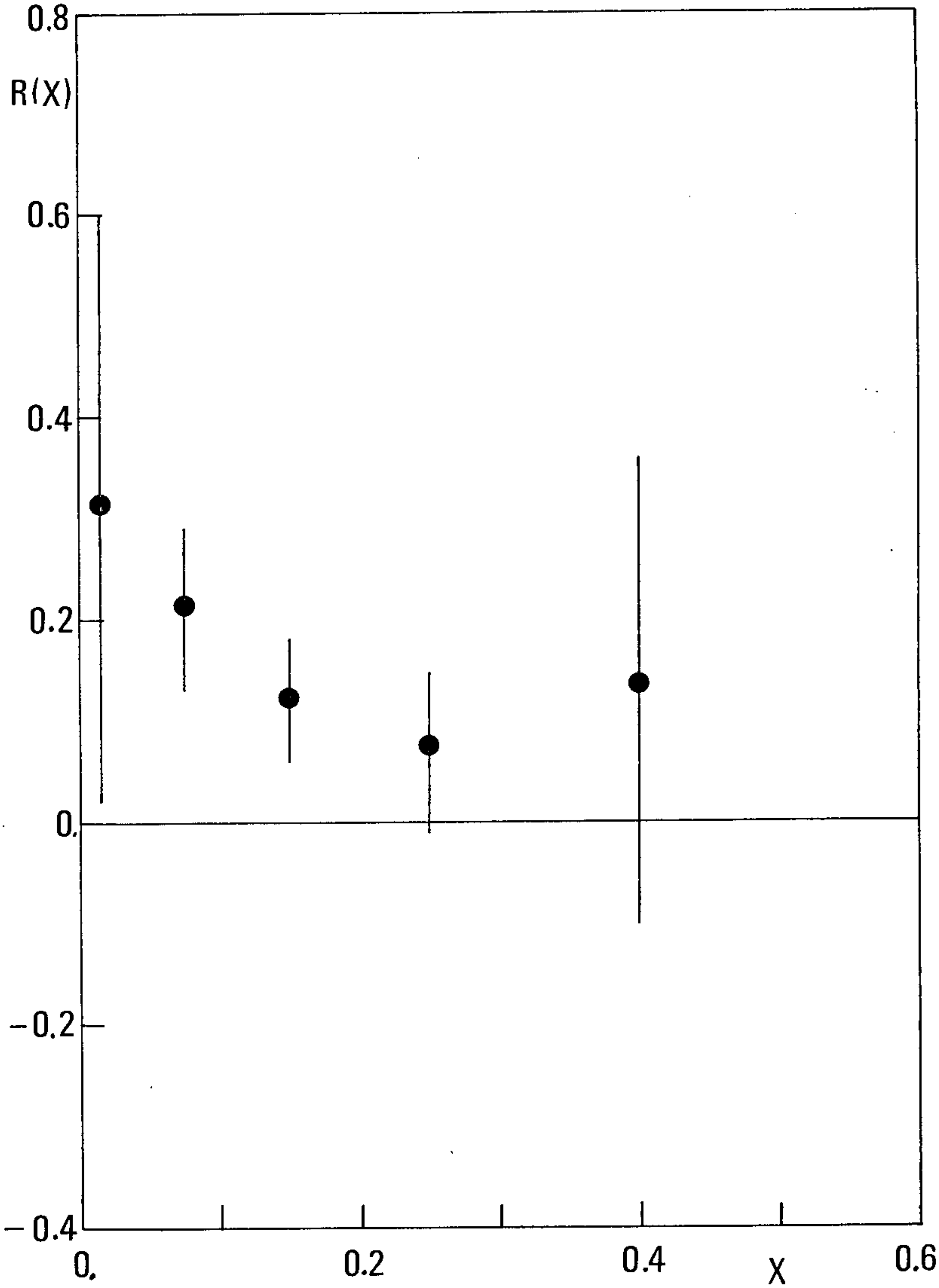

fig. 2