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ABSTRACT. -

Neutrino- and antineutrino-nucleon scattering into hadrons is analyzed and related to electron-nucleon scattering according to a scaling model which has been recently proposed. The electromagnetic and weak structure functions are determined and explicitly given in terms of the πN total cross sections. Predictions are made in good agreement with experiments.

2.

The observed scaling behaviour of the structure functions in deep inelastic scattering of leptons off nucleons has suggested an intuitive picture of hadrons as composite systems of point-like con stituents with simple properties[1,2]. The further identification of partons with quarks allows one to deduce[3,4] certain selection rules, inequalities and sum rules between different structure functions and gives a consistent theoretical framework whose predictions are remar kably consistent with the experimental data, with the possible exception of the results for $\sigma (e^+e^- \to$ hadrons$)$[4]. In particular the pre dictions of the absolute values and the relative ratio of neutrino and antineutrinos cross sections from electron scattering are considered one of the biggest successes of the quark parton model.

On the other hand parton models do not provide enough con-straints on the actual magnitude and the explicit ω dependence of the structure functions and we are left with a complete arbitrariness of the parton distribution functions inside the nucleon, which have to be suitably chosen in order to fit the data. Furthermore most of the inequalities and sum rules of the quark parton model can be re produced[5] by imposing hadron-like duality arguments on the struc-ture functions without having to deal explicitly with quarks as partons. Besides, since in parton models we have to face the problem of why the quarks do not show up in the final states, the question ari-ses naturally as to whether we really need point like quarks to un derstand deep inelastic phenomena.

Recently we have proposed[6] a scaling model of electromagne tic interactions in which the photon is coupled to a continuum of ha-dronic states of dual type whose properties are established consi-stently. With the exception of recent high energy results for $\sigma (e^+e^- \to$ hadrons$)$[4] (which is a source of embarrassment to any scaling model - we predict $R \equiv \sigma (e^+e^- \to$ hadrons$)/\sigma (e^+e^- \to \mu^+ \mu^-) =$

$= 8\pi^2/f_\rho^2 \simeq 2.5$), the model proposed gives a unified description of the electromagnetic properties of hadrons as the photon mass is continuously varied from the $q^2 \simeq 0$ region, with manifest hadron-like behaviour of the photon, to the large q^2 deep inelastic region, where the point-like behaviour is also clearly indicated. In particular, in the framework of two component duality, we have been able to construct the structure functions explicitly in excellent agreement with experiments, starting only with a knowledge of the photoproduction data for the ρ, ω and φ mesons. The scaling properties of the structure functions, and the consequent point like behaviour of the cross sections, do not follow however in this framework from the existence of any elementary constituents, but rather from common properties of scaling shared by strong and electromagnetic interactions.

The aim of the present paper is to extend our picture to deep inelastic neutrino- and antineutrino - nucleon scattering. We first compare $F_2^V(\infty)$ as predicted in our model with $F_2^A(\infty)$, obtained by Langacker and Suzuki[7] using the partially conserved axial vector current hypothesis (PCAC). This allows us to prove the validity of the SKFR relation[8] and to show the consistency of our approach with current algebra. Then from the t channel analysis of the neutrino- and antineutrino-nucleon scattering, and using the explicit form of the electron-nucleon structure functions, derived in our previous work, we are able to determine the weak structure functions, by means of the usual tools of hadron physics. In particular we derive a whole set of relations which hold also in the quark parton model and corresponding sum rules starting from the Adler sum rule as input. The absolute values and the relative ratios of neutrino and antineutrino cross sections are also predicted, in good agreement with experiments.

Let us consider first the results previously derived for pho-

4.

toproduction total cross sections and deep inelastic eN scattering, in the framework of two-component duality. We obtained[6]:

(1a)
$$\sigma_{\gamma N}^{D} = \frac{11}{9} \frac{4\pi\alpha}{f_\varrho^2} \ \sigma_{\varrho N}^{D} (\frac{1}{2})^2 \zeta(2, \frac{1}{2}),$$

(1b)
$$\sigma_{\gamma N}^{R}(\nu) = \frac{11}{9} \frac{4\pi\alpha}{f_\varrho^2} \ \sigma_{\varrho N}^{R}(\nu)(\frac{1}{2})^{3/2} \zeta(\frac{3}{2}, \frac{1}{2}),$$

and

(2a)
$$F_2^{\gamma D}(\omega) \xrightarrow[\omega \to \infty]{} \frac{11}{9} \frac{1}{\pi} \frac{m_\varrho^2}{2f_\varrho^2} \ \sigma_{\varrho N}^{D},$$

(2b)
$$F_2^{R}(\omega) \xrightarrow[\omega \to \infty]{} \frac{11}{9} \frac{m_\varrho}{4f_\varrho^2} \sqrt{q^2} \ \sigma_{\varrho N}^{R}(\nu),$$

where the factor $11/9 = 1+2/9$ accounts for isovector and isoscalar production ($\sigma_{\varrho N} = \sigma_{\omega N} \simeq 2 \ \sigma_{\varphi N}$). The ϱN cross section $\sigma_{\varrho N} = \sigma_{\varrho N}^{D} + \sigma_{\varrho N}^{R}(\nu)$ is measured in ϱ-photoproduction and agrees pretty well both in ma gnitude and ν dependence with the average of the $\pi^{\pm} N$ cross sections[9]. This identification, as well known, is a nice prediction of the simple quark model[10]. Using this fact, we have a first simple connection among quite different processes as πN scattering, ϱ and total photopro duction and deep inelastic eN scattering. A similar relation was deri ved by Langacker and Suzuki[7] and Fujikawa and O'Donnell[11]. More in detail, the total cross section for πN scattering is related through PCAC to the structure function F_2^{A} for the axial vector current:

(3)
$$\sigma_{\pi N}(\nu) = \frac{\pi}{f_\pi^2} \ F_2^{A}(\nu, q^2=0),$$

where f_π is the pion decay constant. Furthermore, from the Deser-
-Gilbert-Sudarshan representation Langacker and Suzuki also sho
wed that the Pomeron residue of F_2^A is indepedent of q^2, whence

$$(4) \qquad \sigma_{\pi N}(\infty) = \frac{\pi}{f_\pi^2} \; F_2^A(\infty),$$

having assumed Bjorken scaling[12] for $F_2^A(\nu, q^2)$. On the other hand,
taking into account only the isovector contribution in eq. (2a) we have

$$(5) \qquad \sigma_{\pi N}(\infty) = \pi \; \frac{2f_\varrho^2}{m_\varrho^2} \; F_2^V(\infty).$$

By comparing (4) and (5), and using the chiral relation $F_2^A = F_2^V$,
we derive

$$(6) \qquad 2 \, f_\varrho^2 \, f_\pi^2 = m_\varrho^2,$$

the well known SKFR relation[8], which is experimentally verified
with very good accuracy. This result strongly supports our picture
of deep inelastic eN scattering which leads to eqs. (1) and (2). It
also reinforces Pagels's conjecture[13] of the fundamental role played
by f_π as the dimensional constant in strong interactions.

It has to be noted however that eq. (2) is stricly correct only
for the transverse contribution to $F_2^\gamma(\omega)$. A factor (1+R), with $R \equiv$
$\equiv \sigma_L / \sigma_T$, should appear in the r.h.s. of (2). It follows therefore
that the exact fulfillment of (6) implies $R = 0$ as $\omega \to \infty$, in agreement
with the quark parton model, with only spin 1/2 constituents.

Let us consider now inelastic neutrino- and antineutrino-nucleon
scattering. The main idea is to relate, in the framework of a simple
Regge model, the structure functions for $\bar\nu$ N and ν N scattering to
those for eN scattering, explicitly given by eqs. (2), both for protons

and neutrons. Most of our results hold more generally than in a simple Regge picture, and can be obtained applying general constraints of hadrons duality to the structure functions[5].

The t channel quantum numbers and the corresponding Regge trajectories for the structure functions are shown in Table I[14].

TABLE I

t channel quantum numbers for Regge contributions to the structure functions[14].

Structure Functions	$(-1)^J P$	$(-1)^J C$	I^G	Regge Trajectories
$F_{1,2}^{\gamma p} + F_{1,2}^{\gamma n}$	+	+	0^+	P, f, f'
$F_{1,2}^{\gamma p} - F_{1,2}^{\gamma n}$	+	+	1^-	A_2
$F_{1,2}^{\nu p} - F_{1,2}^{\nu n}$	+	+	0^+	P, f, f'
$F_{1,2}^{\nu p} - F_{1,2}^{\nu n}$	+	+	1^+	ϱ
$F_3^{\nu p} + F_3^{\nu n}$	+	+	0^-	ω, φ
$F_3^{\nu p} - F_3^{\nu n}$	+	+	1^-	A_2

Assuming SU(3) symmetry for the factorized residues with the additional constraints of the quark model, and the equality of the vector and axial vector couplings we can express all the structure functions as follows (we neglect strangeness changing interactions, i.e. $\sin^2\theta_c \simeq 0$):

(7a)
$$F_2^{\gamma p} + F_2^{\gamma n} = 2 (a_p^V + a_p^S) + 2(a_{p'}^V + a_{p'}^S) \, \omega^{-1/2},$$

(7b)
$$F_2^{\gamma p} - F_2^{\gamma n} = 2 \, a_{A_2} \, \omega^{-1/2},$$

(7c) $$F_2^{\nu p} + F_2^{\nu n} = 8\, a_p^V + 8\, a_{p'}^V\, \omega^{-1/2},$$

(7d) $$F_2^{\nu n} - F_2^{\nu p} = 12\, a_{A_2}\, \omega^{-1/2},$$

(7e) $$F_3^{\nu p} + F_3^{\nu n} = -36\, a_{A_2}\, \omega^{1/2},$$

(7f) $$F_3^{\nu p} - F_3^{\nu n} = 12\, a_{A_2}\, \omega^{1/2}.$$

Here a_i^V and a_i^S refer to the couplings of isovector and isoscalar photons respectively, $\alpha_p(0) = 1$ and $\alpha_i(0) = 1/2$ for all other trajectories. We have decoupled the nucleons from the pure strange φ and f' trajectories and assumed pure F couplings of the vector and tensor trajectories at the nucleon vertex. The D/F ratio obtained from analysis of hadronic reaction data is ~ -0.2, although it may be nearer to zero for V exchange than for T exchange[15]. Similar arguments give $a_{p'}^V / a_{A_2} = 5$ which agrees, through eqs. (7a-b), (1) and (2), with total photoproduction data on protons and neutrons[9].

Finally, using the fact that $a_i^S \cong 2/9\, a_i^V$, we are left with only two unknowns a_P^V and $a_{P'}^V$ which are determined through eqs. (2):

(8)
$$a_P^V \equiv F_2^V(\infty) = \frac{f_\pi^2}{\pi}\, \sigma_{\pi N}(\infty),$$

$$a_{P'}^V = \frac{5\, f_\pi^2\, \sqrt{2M_p}}{12\, m_\varrho}\, \beta_{\pi p},$$

where $\sigma_{\pi p}(\nu) \equiv \sigma_{\pi p}(\infty) + \beta_{\pi p}/\sqrt{\nu}$. The whole set of structure functions for both weak and electromagnetic inelastic processes is therefore determined and predicted from the knowledge of πp total cross sec

tions or, equivalently, from photoproduction data.

Furthermore, from eqs. (7) we can derive a large set of relations among different structure functions which, although strictly true in the Regge region, are expected to hold, by duality, also in the small ω region. They also reproduce the results derived in the framework of the quark parton model[3]. Explicitly, from eqs. (7a) and (7c) we have:

$$(9) \qquad F_2^{\nu N} \equiv \frac{1}{2}(F_2^{\nu p} + F_2^{\nu n}) = \frac{1}{2}(F_2^{\nu N} + F_2^{\bar{\nu} N}) = \frac{18}{5.5}\,\frac{1}{2}(F_2^{\gamma p} + F_2^{\gamma n}),$$

where the factor 5.5 in the denominator of the r.h.s. becomes 5 if we neglect the φ contribution to a_i^S in eq. (7a) $(a_i^S = \frac{1}{9}\,a_i^V)$.

From eqs. (7b) and (7c) we have[16]

$$(10) \qquad F_2^{\nu n} - F_2^{\nu p} = 6\,(F_2^{\gamma p} - F_2^{\gamma n}),$$

which allows one to derive the Gottfried sum rule[17] from the Adler sum rule[18].

From eqs. (7b) and (7f) we get the Llewellyn-Smith relation[19]

$$(11) \qquad F_3^{\nu p} - F_3^{\nu n} = 6\,\omega\,(F_2^{\gamma p} - F_2^{\gamma n}) = 12\,(F_1^{\gamma p} - F_1^{\gamma n}),$$

where the last equality assumes $R = 0$.

From eqs. (7b), (7d) and (7a) we have:

$$(12) \qquad \frac{F_3^{\nu p} + F_3^{\nu n}}{\omega} = -3(F_2^{\nu n} - F_3^{\nu p}) = -18(F_2^{\gamma p} - F_2^{\gamma n}),$$

which again relates the Gross-Llewellyn-Smith[20] sum rule to the Adler sum rule.

We can test these relations locally by comparison with the elec‑ tron and neutrino data. The ratio of total neutrino and antineutrino cross sections is given by[3]:

(13)
$$\frac{\sigma_{TOT}^{\bar{\nu}N}}{\sigma_{TOT}^{\nu N}} = \frac{2-B}{2+B} \quad,$$

with

(14)
$$B \equiv -\int_0^1 dx\, x\, F_3(x) \Big/ \int_0^1 dx\, F_2(x) .$$

Using eqs. (9) and (12) we get:

(15)
$$B = 5.5\, \frac{\int dx (F_2^{\gamma p} - F_2^{\gamma n})}{\int dx (F_2^{\gamma p} + F_2^{\gamma n})} \underset{\sim}{} 5.5\, \frac{(0.16-0.12)^{(21)}}{(0.16+0.12)} = 0.85,$$

to be compared with $B_{exp} = 0.90 \pm 0.04^{(22)}$ and $B = 1$ in the quark par‑ ton model with purely fermion partons.

Similarly, from (9), we get for the total cross section summed over neutrino and antineutrino beams:

$$\sigma_{TOT}^{\nu N}(E) + {}_{TOT}^{\bar{\nu}N}(E) = \frac{G^2 M_N E}{\pi}\, \frac{4}{3} \left[\frac{1}{2} \int_0^1 dx (F_2^{\nu N} + F_2^{\bar{\nu}N}) \right] =$$

$$\cong \frac{G^2 M_N E}{\pi}\, \frac{4}{3} \left[0.46 \right],$$

to be compared with the experimental value $(0.47 \pm 0.07)^{(22)}$.

It follows therefore that, within the present accuracy, the data support the approximate validity of the above relations also in the

low ω region, where the integrals are experimentally evaluated.

To conclude, we have been able to reproduce all the results of the quark parton model without invoking point constituents but ra ther accomodating scaling in a fairly natural way by imposing on the current induced processes the regularities one observes in purely ha dronic reactions. Furthermore, we have found consistent links among different processes as e^+e^- annihilation, photoproduction of vector mesons and total photoproduction on nucleons, πN scattering and deep inelastic electron and neutrino scattering, in agreement with experiments.

REFERENCES. -

(1) - R. P. Feynman, Phys. Rev. Letters 23, 1415 (1969).

(2) - J. D. Bjorken and E. A. Paschos, Phys. Rev. 185, 1975 (1969).

(3) - For a review see for example C. H. Llewellyn-Smith, Phys. Reports 3C, 261 (1972); F. J. Gilman, lectures at the Summer Institute on Particle International at Very High Energies, Louvain, Belgium (1973); SLAC-PUB-1338 (1973).

(4) - G. Tarnopolsky, J. Eshelman, M. E. Law, J. Leong, H. Newman, R. Little, K. Stranch and R. Wilson, Phys. Rev. Letters 32, 432 (1974); B. Richter, Invited talk presented to the Irvine Conference on Lepton Induced Reactions, Irvine, Cal. (1973).

(5) - See for example M. Chaichian, S. Kitakado, S. Pallua, B. Renner and J. De Azcarraga, Nuclear Phys. 51B, 221 (1973).

(6) - E. Etim, M. Greco and Y. Srivastava, Phys. Letters 41B, 507 (1972); A. Bramon, E. Etim and M. Greco, Phys. Letters 41B, 609 (1972); M. Greco, Nuclear Phys. 63B, 398 (1973).

(7) - P. Langacker and M. Suzuki, Phys. Letters 40B, 561 (1972); Phys. Rev. D7, 273 (1973).

(8) - K. Kawarabayashi and M. Suzuki, Phys. Rev. Letters 16, 255 (1966); Fayazaddin and Riazuddin, Phys. Rev. 147, 1071 (1966).

(9) - G. Wolf, Proceedings of the 1971 Intern. Conf. on Electron and Photon Interactions at High Energies, Ithaca (Cornell University, 1972).

(10) - See for example H. Joos, Hadronic Interactions of Electrons and Photons (edited by J. Cumming and H. Osborn) (Academic Press, 1971).

(11) - K. Fujikawa and P. J. O'Donnell, Phys. Rev. D8, 3200 (1973).

(12) - J. D. Bjorken, Phys. Rev. 179, 1547 (1969).

(13) - H. Pagels, Rockefeller University preprint (1972) (unpublished).

12.

(14) - H. Pagels, Phys. Rev. D3, 1217 (1971); see also C. H. Llewellyn-
-Smith, ref. (3).

(15) - C. Michael, Springer Tracts in Modern Physics, (edited by G.
Höhler), Vol. 55 (Berlin, 1970).

(16) - P. M. Fishbane and D. Z. Freedman, Phys. Rev. D5, 2582 (1972).

(17) - K. Gottfried, Phys. Rev. Letters 18, 1174 (1967).

(18) - S. L. Adler, Phys. Rev. 143, 144 (1966).

(19) - C. H. Llewellyn-Smith, Nuclear Phys. B17, 277 (1970).

(20) - D. J. Gross and C. H. Llewellyn-Smith, Nuclear Phys. B14, 337
(1969).

(21) - J. S. Poucher, M. Breidenbach, R. Ditzler, J. I. Friedman, H. W.
Kendall, E. D. Bloom, R. L. A. Cottrell, D. H. Coward, H. De Stae
bler, C. L. Jordan, H. Piel and R. E. Taylor, Phys. Rev. Letters
32, 110 (1974).

(22) - P. Musset, Proceedings of the II Intern. Conf. on Elementary
Particles, Aix-en-Provence (1973), and references therein. See
also F. J. Gilman, ref. (3).