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The Longitudinal Structure Functions in High Energy Lepton-Hadron Scattering*

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ABSTRACT

The ratio of longitudinal to transverse structure funcations at high energies, hitherto unmeasured, can be determined from present generation of muon-hadron scattering experiments. This quantity has an important bearing on the viability of the quark-parton picture and the correct interpretation of the 'anomalies' of high energy neutrino and anti-neutrino scattering experiments.

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The important role played by high energy lepton-hadron scattering in the present framework of particle physics stems in part from two key observations made at SLAC on deep inelastic electron-hadron scattering: (i) scaling of the structure functions, and (ii) smallness of the ratio, R, of longitudinal to transverse cross-section. The former suggested the parton picture, whereas the latter indicated that these (charged) constituents are fermions. The quark-parton model[1] has been widely adopted as the common language to describe lepton-hadron scattering following its initial successes[2] in providing a simple picture for the striking early results of neutrino and anti-neutrino experiments. Lately, however, several energy dependent 'anomalies' have been observed at high energies.[3] The interpretation of these new effects are not clear at present. It is of vital importance, therefore, to check the experimental foundations of the quark-parton picture mentioned above.

The scaling behavior of the structure functions has been observed in the high energy domain by the FNAL muon-hadron scattering experiments to hold within 20 - 30%.[4] (There are also indirect evidence for its validity in the neutrino experiments.[2]) The mild deviation from strict scaling can be understood from the framework of asymptotically free gauge theories which also provide the theoretical basis for the parton model.[5] <u>In contrast, there has been no experimental confirmation of the smallness of R at high energies, although it is always</u>

invoked as a key ingredient in the interpretation of data in the new energy domain.

The traditional and certainly most unambiguous method of determining R is based on the use of the Rosenbluth formula. Employing this method requires measuring the cross-section at many energies and scattering angles with fairly high statistics. This is not practicable at present for the high energy μN experiments. However, an alternative way of determining R exists and is already feasible with current experiments. This involves the study of the distribution of the measured cross-section in the variable $y (= \nu / E)$. It is applicable to experiments at a single incident energy provided the scaling behavior of the structure functions holds. This method is similar to that used the neutrino experiments to measure the relative contributions of left- and right-handed structure functions.[2,3] Although relatively straightforward, its applicability to virtual photon-hadron scattering for the determination of R has been completely overlooked.

The cross-section for deep inelastic eN and μN scattering at high energies can be written,

$$ME \frac{d\sigma}{dxdy} = \frac{\pi\alpha^2}{x^2 y^2} F_2 \left[\frac{y^2}{1+R} + 2(1-y) \right] , \qquad (1)$$

where all notations are standard;[1] in particular, $x = q^2/2M\nu$, $y = \nu / E$ are the scaling variables and $F_2 = \nu W_2$ is the most commonly referred to (scaling) structure function. Assuming R to be small, the recent high energy μN scattering experiments[4] observed approximate scaling behavior of F_2. We point out the obvious alternative procedure: assuming F_2 to be a function of x only, one can determine R from the y-distribution of the observed cross-sections. To make maximal use of the limited statistics available in present experiments, equation (1) can be integrated in the x-variable over any range appropriate for a given situation regarding experimental acceptance provided R remains fairly constant in that range. On the other hand, of course, by studying the y-distribution in various x-ranges, one will be able to measure any possible dependence of R on x.

For neutrino- and anti-neutrino-scattering one can write:

$$\frac{d\sigma^{\nu}}{dxdy} = \frac{G^2ME}{\pi}\, x \left[W_L + (1-y)^2\, W_R + 2(1-y)\, W_S \right], \tag{2}$$

$$\frac{d\sigma^{\bar{\nu}}}{dxdy} = \frac{G^2ME}{\pi}\, x \left[\overline{W}_R + (1-y)^2\, \overline{W}_L + 2(1-y)\, \overline{W}_S \right], \tag{3}$$

where $W_{L,R}$ ($\overline{W}_{L,R}$) are the left- and right-handed structure functions for neutrino-(antineutrino) scattering respectively. We also use W_S and $\overline{W}_S$ to denote the longitudinal (or scalar) structure functions for these processes. (The subscript S rather than L is chosen, obviously, to avoid confusion with left-handedness.) The striking results $\sigma^{\nu}/\sigma^{\bar{\nu}} \simeq 3$,

$d\sigma^{\nu}/dy \sim 1$ and $d\sigma^{\bar{\nu}}/dy \sim (1-y)^2$ observed at $E \lesssim 10$ GeV[2] for nuclear targets[2] suggest strongly

$$W_i = \overline{W}_i \qquad , \; i = L, R, S \tag{4}$$

$$W_R, W_S << W_L. \tag{5}$$

These results have a very simple interpretation in the quark-parton picture.[2] However, recent experiments at high energies have detected significant changes in $\sigma^{\nu}/\sigma^{\bar{\nu}}$ and the y-distributions, especially for anti-neutrino scattering.[3] Most contemporary attempts to interprete these "anomalies" focus on extra contributions to W_R and $\overline{W}_R$ due to new currents and/or quarks (with or without scaling violation). It is almost universally assumed that $W_S \simeq \overline{W}_S \simeq 0$. From the phenomenological point of view, however, the observed anomalies could also be attributed to an increasing contribution of W_S and/or $\overline{W}_S$ to Eqs. (2) and (3) at high energies. Although such a feature is not expected from the quark-parton picture, it seems wise to keep an open mind since the validity of this simple model is by no means a foregone conclusion. It is in this context that determination of longitudinal (scalar) to transverse ratio R in μN scattering experiments described above acquires added relevancy.

If the longitudinal structure function is found to be sizable in μN scattering, the current interpretation of the νN scattering data and, for that matter, the very basis of the quark-parton picture have to be reconsidered. (Within the framework of the parton language, a large longitudinal (scalar) structure function can come from charged spin zero or spin one partons or perhaps from "diquarks" acting like partons which reveal themselves at very short distances.) On the other hand, if R is found to remain small at high energies, the credibility of this intuitively appealing picture will be strengthened. Even in that case, however, the possibility that W_S and/or $\overline{W}_S$ are (at least partially) responsible for the observed anomalies in νN and $\bar{\nu} N$ scattering can not be ruled out. This is because the weak processes involve axial currents as well as vector currents which are not related to the electromagnetic current by strict internal symmetry operations (like CVC).

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[3] The latest developments and references to earlier results can be found in T. Y. Ling, contribution to International Conference on the Production of Particles with New Quantum Numbers, University of Wisconsin, Madison (1976) (to be published).

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