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Deep Inelastic Data as a Test of Hadron Symmetries*

William F. Palmer and Walter W. Wada

Department of Physics
The Ohio State University
Columbus, Ohio 43210

It is proposed that the deep inelastic electron and neutrino scattering data near $x = 0$ provide a way of distinguishing between SU(3) and SU(4) as the fundamental underlying hadron symmetry.

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DISCLAIMER

A possible implication of the new resonances discovered at SLAC and BNL[1] is that the underlying fundamental hadron symmetry is not SU(3), but SU(4), as had already been suggested by the neutral weak strangeness-changing current suppression[2].

In this letter we would like to point out how deep inelastic neutrino scattering and electroproduction data can be used as a probe of the fundamental hadron symmetry, if a t-channel point of view is taken[3]. In that case, the transformation properties of the exchanged objects, Pomeron (P) and Reggeon (P'), and of the currents determine the ratio of the asymptotic charged weak and electromagnetic structure functions. Beyond the basic scale of the two structure functions, set by the CVC hypothesis, their ratio depends essentially on the hadron symmetry group which classifies the currents and governs the number of ways and the relative strength with which the currents couple to hadrons.

Given this point of view, we calculate below the ratio of the deep inelastic neutrino scattering to the electroproduction structure functions, in SU(3) and SU(4), and argue that accurate data near $x=0$, which will shortly become available, should clearly distinguish between the two symmetry schemes.

We assume Bjorken scaling of the structure functions for deep inelastic electron and neutrino scattering[4]. We further assume that the structure functions have the Regge asymptotic behavior in the scaling variable $x = Q^2/2M\nu$ in the Regge region (away from $x=1$, the elastic limit). With nucleon as the target $[N=\frac{1}{2}(p+n)]$ in terms of the dominant t-channel exchanges we have

$$F_2^{\nu N}(x) = F_{2P}^{\nu N}(x) + F_{2P'}^{\nu N}(x) = \beta_P^{\nu N}(x) + \beta_{P'}^{\nu N}(x) \; x^{\frac{1}{2}} \qquad (1)$$

$$F_2^{eN}(x) = F_{2P}^{eN}(x) + F_{2P'}^{eN}(x) = \beta_P^{eN}(x) + \beta_{P'}^{eN}(x)\ x^{\frac{1}{2}}\ , \tag{2}$$

where $\beta_P^{\nu N}(x)$ and $\beta_P^{eN}(x)$ are the residue functions corresponding to Pomeron (P) exchange, and $\beta_{P'}^{\nu N}(x)$ and $\beta_{P'}^{eN}(x)$ those corresponding to Reggeon (P') exchange.

From the high energy behavior of the quark-nucleon scattering, it has been deduced that both $\beta_P^{eN}(x)$ and $\beta_{P'}^{eN}(x)$ should be proportional to $(1-x)^7$[5,6]. The same dependence on x is expected for $\beta_P^{\nu N}(x)$ and $\beta_{P'}^{\nu N}(x)$ under CVC and the assumption $|V| = |A|$. It is this damping near $x=1$ which requires, as we shall see, small x data to support our conclusions.

From (1) and (2) we get

$$F_2^{\nu N}(x) - F_{2P}^{\nu N}(x) = \frac{\beta_{P'}^{\nu N}(x)}{\beta_{P'}^{eN}(x)} \left(F_2^{eN}(x) - F_{2P}^{eN}(x)\right). \tag{3}$$

Since $F_2^{\nu N}(x) - F_{2P}^{\nu N}(x)$ and $F_2^{eN}(x) - F_{2P}^{eN}(x)$ are each dominated by the Reggeon (P') exchange in the t-channel, according to the two component hypothesis of duality[7], each must be made up solely of resonances in the direct channel. Thus it should be possible to obtain the ratio $\beta_{P'}^{\nu N}(x)/\beta_{P'}^{eN}(x)$ by summing up the resonance contributions to $F_2^{\nu N}(x) - F_{2P}^{\nu N}(x)$ and $F_2^{eN}(x) - F_{2P}^{eN}(x)$ in various symmetry schemes.

Alternatively, we may go back to the t-channel exchange picture, and calculate the ratio $\beta_{P'}^{\nu N}(x)/\beta_{P'}^{eN}(x)$ from the transformation properties of the currents and the Reggeon (P'). In terms of the fundamental representation of SU(4)[2], the electromagnetic current is given by

$$J_{em}^{\sigma} = \tfrac{2}{3}\bar{p}\gamma^{\sigma}p - \tfrac{1}{3}\bar{n}\gamma^{\sigma}n - \tfrac{1}{3}\bar{\lambda}\gamma^{\sigma}\lambda + \tfrac{2}{3}\bar{p}'\gamma^{\sigma}p'\ , \tag{4}$$

where p, n, λ are the fractionally charged quarks of the SU(3) subgroup and p' the charmed quark. The quark-antiquark content of the P' exchanged in the t-channel is

$$P' = \frac{1}{\sqrt{2}} (\bar{p}\,p + \bar{n}\,n) \quad . \tag{5}$$

Designating the $J_{em} - P' - J_{em}$ vertex by (J_{em}, P', J_{em}) from (4) and (5) we have

$$(J_{em}, P', J_{em}) = (\tfrac{2}{3})^2 \langle \bar{p}\,p | P' | \bar{p}\,p \rangle + (\tfrac{1}{3})^2 \langle \bar{n}\,n | P' | \bar{n}\,n \rangle = \frac{5}{9} C_1 \ , \tag{6}$$

where C_1 is an unknown reduced matrix element. The weak charged current in the SU(4) symmetry group is given by[2],

$$J_W^{\sigma} = \bar{n}\,\gamma^{\sigma}(1-\gamma_5)p + \bar{\lambda}\,\gamma^{\sigma}(1-\gamma_5)p' \ , \tag{7}$$

where we make the approximation $\theta_c = 0$. Designating the vector part of J_W^{σ} by V_W^{σ}, the $V_W - P' - V_W$ vertex is given by

$$(V_W, P', V_W) = \langle p\,n | P' | p\,n \rangle = C_1 .$$

Doubling this value to include the axial vector contribution, we have

$$\frac{\beta_{P'}^{\nu N}(x)}{\beta_{P'}^{eN}(x)} = \frac{(J_W, P', J_W)}{(J_{em}, P', J_{em})} = \frac{18}{5} \ . \tag{9}$$

Since P' does not contain λ and p' quarks, <u>the same ratio</u> also results in the SU(3) symmetry scheme. For the $J_{em} - P - J_{em}$ vertex, from (4) we get

$$(J_{em}, P, J_{em}) = (\tfrac{2}{3})^2 \langle \bar{p}\,p | P | \bar{p}\,p \rangle + (\tfrac{1}{3})^2 \langle \bar{n}\,n | P | \bar{n}\,n \rangle$$

$$+ (\tfrac{1}{3})^2 \langle \bar{\lambda}\,\lambda | P | \bar{\lambda}\,\lambda \rangle + (\tfrac{2}{3})^2 \langle \bar{p}'p | P | \bar{p}'p \rangle = \frac{10}{9} C_2 \ , \tag{10}$$

where C_2 is an unknown reduced matrix element. Similarly, from (7), we obtain for the $V_w - P - V_w$ vertex $(P \sim \bar{p}'p' + \bar{p}p + \bar{n}n + \bar{\lambda}\lambda)$

$$(V_w, P, V_w) = \langle \bar{p}\, n | P | \bar{p}\, n \rangle + \langle \bar{p}'\lambda | P | \bar{p}'\lambda \rangle = 2C_2. \tag{11}$$

Doubling this value to include the axial vector contributions, we have

$$\frac{F_{2P}^{\nu N}(x)}{F_{2P}^{eN}(x)} = \frac{(J_w, P, J_w)}{(J_{em}, P, J_{em})} = \frac{18}{5} \quad \text{in SU(4)}. \tag{12}$$

From (9) and (12) we find the Pomeron-dominated terms in (3) cancel, giving

$$F_2^{\nu N}(x) = \frac{18}{5} F_2^{eN}(x) \qquad \text{in SU(4)}. \tag{13}$$

Dropping the p' contribution in (10) and (11), that is, reverting to an SU(3) symmetry scheme, we find that the above cancelation does not take place, leading to

$$F_2^{\nu N}(x) = \frac{18}{5} F_2^{eN}(x) - \frac{3}{5} F_{2P}^{eN}(x) \qquad \text{in SU(3)}. \tag{14}$$

The relation (13) has been previously obtained in several ways, for example by Close and Gilman[8] by summing the direct channel resonances in an SU(6) [SU(3) internal symmetry] scheme. Their results are not in conflict with ours; the direct channel sum is dual to the Reggeon (P') exchange which, as remarked after Eq. (9) yields the same ratio in SU(3) and SU(4). It is the Pomeron (P) contribution or "background" or "sea" which distinguishes between the SU(3) or SU(4) schemes.

To compare (13) and (14) with available $x \neq 0$ data we must take into account the known sharp fall-off of the P contribution away from $x = 0$. [At $x = 0$, where the P' contribution vanishes, the effect is most striking,

$F_2^{\nu N}(0) = \frac{18}{5} F_2^{eN}(0)$ in SU(4) compared to $F_2^{\nu N}(0) = \frac{15}{5} F_2^{eN}(0)$ in SU(3).] Taking the parton model estimate[5,6] that the P contribution falls off like $(1-x)^7$, the SU(3) prediction is

$$F_2^{\nu N}(x) \approx \frac{18}{5} F_2^{eN}(x) - \frac{3}{5}(1-x)^7 F_2^{eN}(0). \tag{14'}$$

The analysis of Ref.6 indicates that $F_2^{eN}(0) \approx 0.8/3$, yielding

$$F_2^{\nu N}(x) \approx \frac{18}{5} F_2^{eN}(x) - (0.16)(1-x)^7. \tag{14''}$$

In Fig.(1) we show the neutrino data as compared with $\frac{18}{5} F_2^{eN}(x)$ from Ref.9 (data points and solid curve) and the SU(3) prediction, Eq.(14"), as the dashed curve. The solid curve, the SU(4) prediction in our framework, has been extended to x = 0 using the estimate of Ref.6. It is clear that more accurate low x data will clearly distinguish between the two schemes.

Figure 1

The extension of the present method to the deep inelastic neutrino reaction arising from the neutral current is straightforward, leading to the result previously obtained[10],

$$\frac{F_2^{\nu\to\nu}(x)}{F_2^{\nu\to\mu}(x)} = \frac{1}{18}\left(9 - 18\sin^2\theta_W + 20\sin^4\theta_W\right).$$

This result is, of course, based on an SU(4) underlying hadron symmetry.

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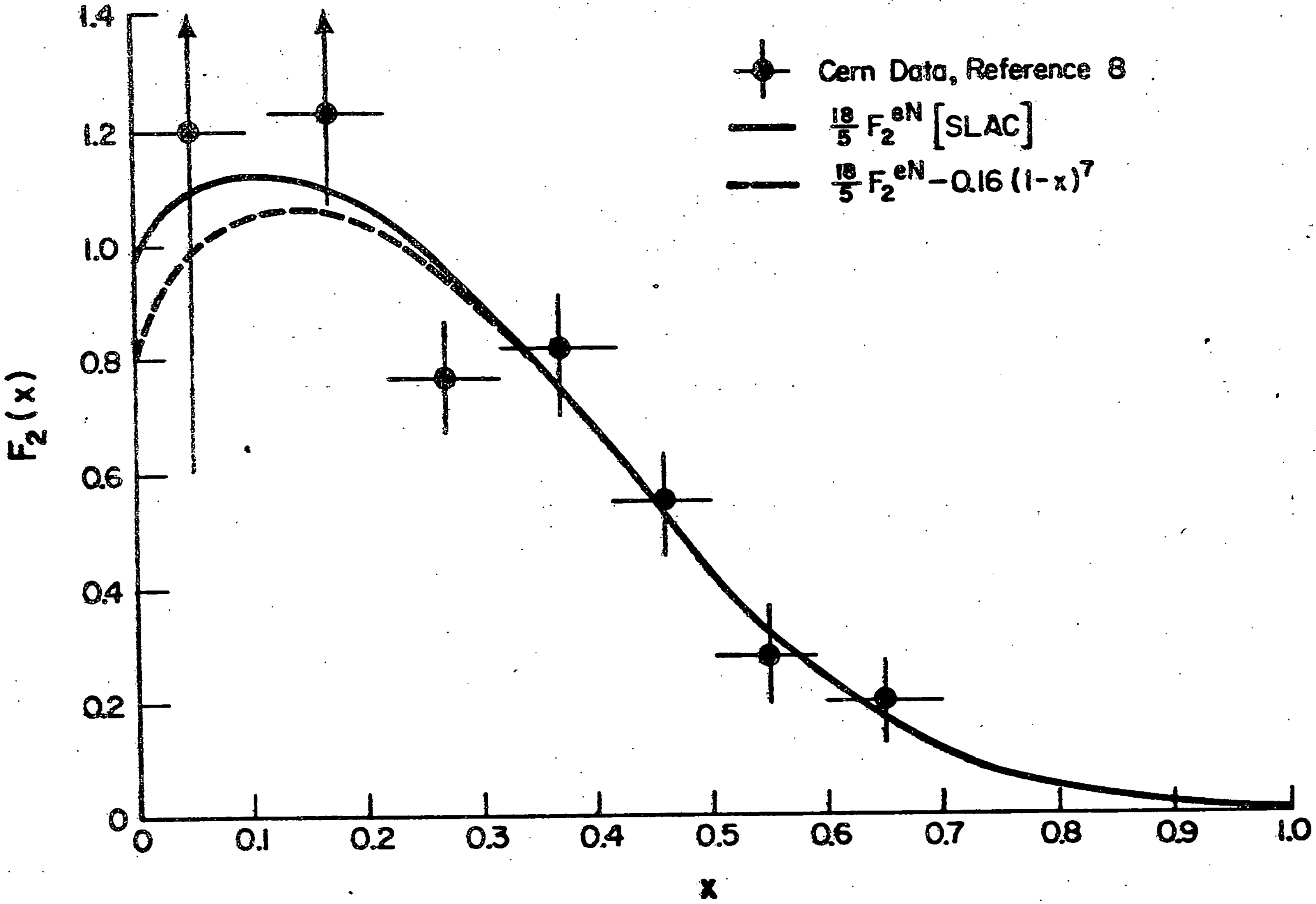
Figure Caption

Figure 1. Comparison of the SU(3) prediction (dashed curve) and the SU(4) prediction (solid curve) with the CERN deep inelastic neutrino scattering data.



Cern Data, Reference 8
$\frac{18}{5} F_2^{eN}$ [SLAC]
$\frac{18}{5} F_2^{eN} - 0.16(1-x)^7$
$F_2^{\nu N}(x)$
x
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
0.1
0.3
0.5
0.7
0.9