Diffractive neutrino- and photon-hadron scattering: Rising cross sections*

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We speculate on the possible connections between the nonscaling behavior of the e^+e^--annihilation cross section observed at SPEAR and the results of a recent Fermilab neutrino experiment. We also conjecture that the total photoproduction cross section will begin to rise when the photon energy reaches 40 or 50 GeV.

The SPEAR e^+e^--annihilation experiment[1] reveals that the hadron to lepton ratio

$$\sigma(e^+ + e^- \to \text{hadrons})/\sigma(e^+ + e^- \to \mu^+ + \mu^-) \tag{1}$$

increases with energy when the center-of-mass energy increases from 3 to 5 GeV. This unexpected nonscaling behavior has motivated many theoretical considerations. Rather than speculating on its origin, we shall in this note speculate on its possible consequences and its possible connection with a recently observed phenomenon in an inelastic neutrino scattering experiment[2] performed at the Fermi National Accelerator Laboratory.

In the Fermilab neutrino experiment[2] a significant change is observed in the invariant hadron mass distribution in $\bar{\nu}$-nucleon inelastic scattering as the incident energy exceeds 30 GeV. We suggest that this phenomenon is related, though indirectly, to the nonscaling behavior of the e^+e^--annihilation cross section observed in the SPEAR experiment. The line of thought runs as follows.

There is no doubt that the electromagnetic and weak currents are related, although the detailed relationship is still not completely clear. Then, the nonscaling behavior in the e^+e^- channel would imply a corresponding behavior in the $\nu_\mu\mu^+$, $\bar{\nu}_\mu\mu^-$, $\nu_e e^+$, and $\bar{\nu}_e e^-$ channels. We should expect, for example, the ratio

$$\sigma(\nu_\mu + \mu^+ \to \text{hadrons})/\sigma(\nu_\mu + \mu^+ \to \nu_\mu + \mu^+) \tag{2}$$

in a hypothetical $\nu_\mu\mu^+$-annihilation experiment to increase with the incident energy starting at a center-of-mass energy equal to some mass value m. This mass value m, in principle, can be related to the corresponding mass value, which is roughly 3 GeV, in e^+e^- annihilation. Without committing ourselves to any particular dynamical symmetry scheme, we take m to be a parameter, which we will estimate from the results of the Fermilab neutrino experiment.

We adopt the point of view that the hadronic states in the annihilation channel also participate and are diffractively produced in the corresponding inelastic lepton scattering. This viewpoint has been labeled generalized vector dominance.[3,4] However, we believe that it is correct only in a certain kinematical region, as has been previously emphasized,[4] and which will be specified below.

Suppose that the ratio (2) indeed starts to increase with energy at a center-of-mass energy equal to m. The hadronic states in that nonscaling region should then be able to be diffractively produced in ν_μ-nucleon inelastic scattering. The condition for a state with mass m to be diffractively produced is roughly estimated to be[4]

$$2\nu/(m^2 + Q^2) \gtrsim D, \tag{3}$$

where D is the dimension of the target. For a nucleon target, D is roughly $2/m_\pi$. We know that this is indeed in general agreement with the deep-inelastic electron scattering data[5]; the electron-proton and electron-neutron scattering cross sections are roughly the same for $x \lesssim 0.1$ or $\omega \gtrsim 10$. Therefore, we take

$$2M\nu/(m^2 + Q^2) \geq 10 \quad (M,\ \text{nucleon mass}) \tag{4}$$

to be the condition for diffractive production of a state of mass m. We apply this condition to the inelastic neutrino scattering.

For large ν and $Q^2 \leq 1\ \text{GeV}^2$ the invariant hadronic mass W is given by

$$W^2 \simeq 2M\nu. \tag{5}$$

A state of mass m can be diffractively produced, then, according to the condition (4), neglecting Q^2 in it when Q^2 is small, if

$$W^2 \gtrsim 10m^2. \tag{6}$$

According to the results of the Fermilab neutrino experiment,[2] the $\bar{\nu}_\mu$-nucleon scattering shows an unexpected large cross section starting at $W \sim 5$ or 6 GeV when the incident energy $E_{\bar{\nu}}$ exceeds 30 GeV.[6] It seems plausible to interpret it to be the onset of diffractive production of those physical states that we expect to exist in the "nonscaling" region in $\bar{\nu}_\mu\mu^-$ annihilation. This interpretation is supported by the fact that the phenomenon observed in the Fermilab experiment occurs at small x. With $W^2 \simeq 30\ \text{GeV}^2$ we then obtain, according to (6), the estimate

$$m \sim 1.7 \text{ GeV}. \tag{7}$$

This indicates that the center-of-mass energy at which the ratio (2) will start to show nonscaling behavior should be somewhere between 1.5 and 2 GeV. We recall that the corresponding value in the electromagnetic case (1) is about 3 GeV. This information is useful for determining the relationship between the electromagnetic and weak currents.

From the diffractive point of view, which we believe is correct for $2M\nu/(m^2+Q^2)\geq 10$, there are other expectations concerning inelastic neutrino scattering:

(i) The V-A interference term F_3 in both ν-nucleon and $\bar{\nu}$-nucleon scattering should vanish in the diffractive region,[7] i.e., the small-x region. This reflects the strong interaction phenomenology of vacuum-quantum-number exchange at high energy.

(ii) As a consequence of (i), ν- and $\bar{\nu}$-nucleon scattering cross sections should be equal in the small-x region. It is therefore essential that the phenomenon observed in $\bar{\nu}$-nucleon scattering should also take place in ν-nucleon scattering when x is small. In particular, the y dependence should be the same there, and is given by[8]

$$\frac{d^2\sigma}{dx\,dy}=\frac{G^2ME}{\pi}\left[(1-y)+\frac{y^2}{2(1+R)}\right]F_2(x,Q^2), \tag{8}$$

where

$$R\equiv \sigma_S/\sigma_T .$$

We note that the y dependence for electroproduction is of the same form.

(iii) The expected nonscaling behavior in $\nu_\mu\mu^+$ and $\bar{\nu}_\mu\mu^-$ annihilations could also lead to *a large violation of Bjorken scaling in the small-x region in deep-inelastic neutrino scattering. Such a violation has been previously conjectured for electroproduction.*[9]

We now turn to electromagnetic processes and make the following conjectures:

(a) Corresponding to the phenomenon observed in the Fermilab neutrino experiment, there should be a similar behavior in high-energy electroproduction. A rise in cross section is expected, for small Q^2, to start at roughly

$$W^2 \geq 10\times(3\text{ GeV})^2 = 90\text{ GeV}^2. \tag{9}$$

The excessive events corresponding to this rise should be at the 10% level, as is indicated by the neutrino experiment.[2]

(b) The nonscaling behavior of e^+e^- annihilation should also be reflected in the total photoproduction cross section. As the photon energy increases, such that

$$2M\nu/(3\text{ GeV})^2 \geq 10 \tag{10}$$

or $\nu \geq 45$ GeV, the states in the nonscaling region in the e^+e^--annihilation channel will start to participate and be diffractively produced in photon-nucleon scattering, resulting in an increase of the cross section. It seems to us that if the viewpoint of the generalized vector dominance is indeed qualitatively correct, the cross section will have to rise, although the exact behavior of the energy dependence is difficult to predict. Again, the rise is expected to be at the 10% level. *We therefore conjecture that the total photoproduction cross section will begin to increase with energy when the photon energy reaches* 40 *to* 50 GeV, *according to (10). The rise will continue, at least, into the energy region* $\nu\sim 125$ GeV. This prediction can be soon checked by the photon-production experiment, now being planned at Fermilab.

We emphasize that it is the cumulative effects of the continuum states, in both electromagnetic and weak channels, we have explored in this note. These effects are independent of the existence of the recently observed narrow resonances. They are essentially phenomenological, and independent of any specific interpretation of the new resonances and the rise of the ratio (1). The estimate (7) refers to the onset of a new scale in the weak channel, and is not necessarily connected with the mass value of any new particles.

Added note. After the submission of this paper for publication, the results of the deep-inelastic muon scattering experiment performed at the Fermi National Accelerator Laboratory became known.[10] They seem to confirm our prediction of a positive scaling violation at large ω (Ref. 9), and lend further support to the general viewpoint presented in this paper.

We should also like to remark that our speculation concerning the rise of the photoproduction cross section is suggested by (a) the approximate constant photoproduction cross section at the present SLAC energies, and (b) the rise of inelastic cross sections in neutrino scatterings (and, of course, the implicit assumption of close similarity between electromagnetic and weak currents). The aforementioned results of the muon inelastic scattering experiment seem to further support our speculation of a rising photoproduction cross section. However, since the proton-proton cross section also shows a rise at high energy, a rising photoproduction cross section can only be considered as another support for the general viewpoint we have adopted.

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[6]The absence of this phenomenon for $E_{\bar{\nu}} < 30$ GeV is presumably related to the y dependence of the cross section, where $y \equiv \nu/E_{\bar{\nu}}$.

[7]This point has already been made by C. A. Piketty and L. Stodolsky, Nucl. Phys. B15, 571 (1970).

[8]In order to measure the y dependence unambiguously, the values of x and Q^2 should be kept fixed so that the result will not depend upon the scaling or nonscaling behavior of the structure functions. Since $yE^2 = Q^2/2Mx$ this can be achieved by varying the incoming lepton energy E.

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