Charge asymmetry in neutrino experiments above the threshold of charmed-particle production

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It was indicated that the charge asymmetry in the $\nu_\mu N(\bar{\nu}_\mu N)$ scattering observed at high energies can be attributed to production of charmed particles if the angular momentum of the sea quarks increases with increasing energy.

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According to the experimental data on $\nu N(\tilde{\nu}N)$ scattering at energies above 50 GeV, the parameters $B^{\nu(\tilde{\nu})}$, which characterized the wide distributions, have the following values:

$$B^{\nu} = 0.75^{+0.2}_{-0.1}; \quad B^{\tilde{\nu}} = 0.45^{+0.15}_{-0.10} \ [1], \quad B^{\tilde{\nu}} = 0.36^{+0.30}_{-0.36} \ [2].$$

The quantities $B^{\nu(\tilde{\nu})}$ are expressed in terms of the well known structure functions

$$B^{\nu(\tilde{\nu})} = \int x F_3^{\nu(\tilde{\nu})}\,dx / \int 2x F_1^{\nu(\tilde{\nu})}\,dx.$$

The results point to a possible violation of charge symmetry, according to which for an isoscalar target we have $B^{\nu}=B^{\tilde{\nu}}$. The difference between the presented values and the CERN data[3] ($B^{\nu}=B^{\tilde{\nu}}=0.92\pm 0.04$ at energies below 10 GeV) also indicates that the transition to higher energies was accompanied by violation of scaling.

We shall not discuss here the causes of scaling violation,1) and wish only to indicate that the deviations of B^{ν} from unity can explain in simple fashion the observed violation of the charge symmetry on the basis of the GIM model,[4] at energies above the threshold for the production of charmed particles.

In the spirit of the naive quark-parton model,[5–7] we assume that the nucleon contains valent quarks u_v and d_v and a sea of quarks and antiquarks, the distribution of the $u(d)$ quarks in the proton being the same as the distribution of the $d(u)$ quarks in the neutron.

Taking into account the scattering of neutrinos and antineutrinos by quarks and antiquarks of the nucleon, we obtain in the standard GIM scheme for the structure functions F_1 and F_3 above the threshold of production of the charmed particles the expressions:

$$\begin{aligned}
&F_1^{\nu p} = \bar{u} + d + s + \bar{c}; && F_1^{\tilde{\nu} n} = \bar{u} + d + \bar{s} + c, && \text{(a)}\\
&F_1^{\nu n} = u + \bar{d} + s + \bar{c}; && F_1^{\tilde{\nu} p} = u + \bar{d} + \bar{s} + c, && \text{(b)}\\
&\tfrac{1}{2} F_3^{\nu p} = -\bar{u} + d + s - \bar{c}; && \tfrac{1}{2} F_3^{\tilde{\nu} n} = -\bar{u} + d - \bar{s} + c, && \text{(c)}\\
&\tfrac{1}{2} F_3^{\nu n} = u - \bar{d} + s - \bar{c}; && \tfrac{1}{2} F_3^{\tilde{\nu} p} = u - \bar{d} - \bar{s} + c, && \text{(d)}
\end{aligned} \qquad (1)$$

where u and d are the distribution functions of the corresponding quarks in the proton.

It follows from (1a) and (1b) that $F_1^{\nu p} = F_1^{\tilde{\nu} n}; F_1^{\nu n} = F_1^{\tilde{\nu} p}$.

As to the functions F_3, they turn out to be charge-symmetrical only in the limit of exact $SU(4)$ symmetry, when $s = \bar{s} = c = \bar{c}$. In the real case of broken $SU(4)$ symmetry, however, there are many grounds for assuming that the sea of the C quarks is suppressed by at least one order of magnitude with the sea of the s quarks. (The suppression of the sea of heavy quarks can naturally be expected, if for no other reason than by analogy with electromagnetic pair production, the cross section of which is inversely proportional to the square of the mass of the produced particles).

It is seen from (1c) and (1d) that the suppression of the sea of C quarks in comparison with the sea of the s quarks makes the functions F_3 patently charge-asymmetrical: $F_3^{\nu p} \neq F_3^{\tilde{\nu} n}$; $F_3^{\nu n} \neq F_3^{\tilde{\nu} p}$. This fact was noted already in[9], but it acquires practical significance once B^ν becomes much smaller than unity. It must be emphasized that violation of charge symmetry takes place only in the interference structure functions F_3 and only above the threshold of the production of the charmed particles. Up to this threshold, the functions F_1 satisfy the charge-symmetry relations accurate to terms $\sin^2\theta_c$.

The parameters B^ν and $B^{\tilde{\nu}}$ can be represented in the form

$$B^\nu = \frac{1 + \epsilon\lambda}{1 + \epsilon(2 + \lambda)}; \qquad B^{\tilde{\nu}} = \frac{1 - \epsilon\lambda}{1 + \epsilon(2 + \lambda)}, \tag{2}$$

$$\epsilon = \langle u + d\rangle_S / \langle u + d\rangle_V \qquad \lambda = 2\langle S\rangle_S / \langle u + d\rangle_S, \tag{3}$$

where ϵ and λ are equal to the ratio of the first moments of the sea (S) and valence (V) quarks respectively (for example, $\langle u\rangle_S = \int x u_S dx$). Eliminating ϵ from (2), we obtain

$$B^{\tilde{\nu}} = B^\nu(1 + \lambda) - \lambda \qquad (B^{\tilde{\nu}} \leqslant B^\nu \leqslant 1). \tag{4}$$

If we take by way of estimate $\lambda = 1$, then, substituting in (4) the value $B^\nu = 0.75$, we get $B^{\bar{\nu}} = 0.5$, which agrees with the experimental values given above. For λ, however, one should more readily assume the value $\lambda \approx 0.6$ (which follows from the relations between the πN and kN scattering cross sections, and also from data on the yields of ordinary and strange particles[8]). At $\lambda = 0.6$, relation (4) is also satisfied within the limits of experimental errors. It is clear, however, that at the present experimental accuracy one can speak only of qualitative agreement.

It should be noted that violation of charge symmetry in the functions F_3 does not violate the equality of the cross sections for scattering by an isoscalar target $d\sigma^{\nu N}/dxdy(y = 0) = d\sigma^{\bar{\nu} N}/dxdy(y = 0)$, inasmuch as at $y = 0$ these cross sections are proportional to the functions $F_2 = 2xF_1$.[10]

The quantity ϵ, which characterizes the fraction of the sea quarks, is expressed in terms of the measured quantities B^ν and $B^{\bar{\nu}}$: $\epsilon = (1 - B^\nu)/(B^\nu + B^{\bar{\nu}})$. At $\lambda = 0.6$ and at the values $B^\nu = 0.7$ and $B^{\bar{\nu}} = 0.52$ which correspond to this value of λ, the parameter ϵ amounts to ~ 0.25. An estimate of ϵ independent of the foregoing analysis can be obtained by comparing the x-distributions in neutrino reactions at high energies with the structure functions obtained in electroproduction processes at $E \leq 20$ GeV. The experimental data on both neutrino[11] and antineutrino[12] reactions point to the presence of a noticeable excess of the differential cross sections $x < 0.2$ over the data taken from electroproduction at low energies. If we interpret this excess at an increase of the fraction of the sea quarks, then we obtain for ϵ the value 0.2—0.3, which coincides with that calculated from charge asymmetry. The ratio of the total cross sections for the scattering $\sigma^{\bar{\nu}}/\sigma^{\nu} = (2 - B^{\bar{\nu}})/(2 + B^{\nu})$ at the chosen values of the parameters increases to $\sigma^{\nu}/\sigma^{\bar{\nu}} = 0.55$, and the average value $\langle y_{\bar{\nu}} \rangle = \frac{1}{4} + 3\epsilon(1+\lambda)/[4 + 4\epsilon(4+3\lambda)]$ becomes equal to 0.38. Both indicated values agree with the experimental data.

The cross sections for the production of charmed particles can be expressed in terms of the y-distribution parameters B^{ν} and $B^{\bar{\nu}}$. The use of the experimental values of B^{ν} and $B^{\bar{\nu}}$ in the GIM scheme yields for the lepton-pair production cross section and for the lepton kinematic characteristics values that agree with experiment.[13]

Thus, the entire aggregate of experimental data on $\nu N(\bar{\nu}N)$ interactions fits splendidly in the GIM scheme (assuming that the fraction of the sea quarks increases with increasing energy) and does not call for multiquark schemes and right-hand hadron currents.

1)It is possible that early scaling is analogous to the nuclear scaling observed in the scattering of hadrons with energy of several GeV by nuclei (Yu. Leksin *et al.*), and reflecting only the fact that the nuclei consist of nucleons. In this sense, early scaling corresponds to the fact that the nucleons consist of valent quarks, and the quark-antiquark sea has not managed to develop as yet at these energies.

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