Neutral current with allowance for the growth of the sea of quarks and antiquarks

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It is shown that allowance for the contribution of the sea of quarks-antiquarks above the threshold of the production of charmed particles has a substantial effect in neutrino processes with neutral currents.

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Experiments at high energy point to violation of scaling in reactions of neutrino and antineutrino scattering by nucleons,[1–4] and also in μp scattering.[5] It was indicated in earlier papers[6] that if this violation is interpreted as a consequence of an increase in the role of the sea quarks, then the GIM scheme explains in natural fashion the observed violation of charge symmetry[1,2] and all the characteristics of dilepton events.[8–10] We show in this article that the same increase of the sea has a substantial effect in neutrino processes with neutral currents.

For processes with neutral currents the neutrino interaction Langrangian in the GIM scheme takes the form

$$L = \frac{G}{\sqrt{2}}[\bar{\nu}\gamma_\alpha(1+\gamma_5)\nu]\{\alpha[\bar{\psi}_u O_\alpha^+\psi_u + \bar{\psi}_c O_\alpha^+\psi_c] + \beta[\bar{\psi}_d O_\alpha^+\psi_d + \bar{\psi}_s O_\alpha^+\psi_s]$$

$$+\gamma[\bar{\psi}_u O_\alpha^-\psi_u + \bar{\psi}_c O_\alpha^-\psi_c] + \delta[\bar{\psi}_d O_\alpha^-\psi_d + \bar{\psi}_s O_\alpha^-\psi_s]\}; \qquad O_\alpha^\pm = \gamma_\alpha(1\pm\gamma_5).$$

In the Weinberg—Salam model we have

$$\alpha = \frac{1}{2} - \frac{2}{3}\sin^2\theta_W, \quad \beta = -\frac{1}{2} + \frac{1}{3}\sin^2\theta_W, \quad \gamma = -\frac{2}{3}\sin^2\theta_W, \quad \delta = \frac{1}{3}\sin^2\theta_W \quad .$$

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For an isoscalar target, neglecting the sea of charmed quarks and under the standard assumptions concerning the properties of the sea and valent quarks ($u=u_V+u_S$, $d=d_V+d_S$, $u_S=\bar{u}_S$, $d_S=\bar{d}_S$, $S=S_s=\bar{S}_s$) we have the following expressions for the scattering cross sections:

$$\frac{d^2\sigma(\nu N\to\nu X)}{dx\,dy} = \sigma_0 x\{[\alpha^2+\beta^2+(\gamma^2+\delta^2)(1-y)^2](u+d)_V$$

$$+(2-2y+y^2)[(\alpha^2+\beta^2+\gamma^2+\delta^2)(u+d)_S+2(\beta^2+\delta^2)s]\};$$

$$\frac{d^2\sigma(\tilde{\nu}N\to\nu X)}{dx\,dy} = \sigma_0 x\{[\gamma^2+\delta^2+(\alpha^2+\beta^2)(1-y)^2](u+d)_V$$

$$+(2-2y+y^2)[(\alpha^2+\beta^2+\gamma^2+\delta^2)(u+d)_S+2(\beta^2+\delta^2)s]\}.$$

Here x and y are the usual scaling variables; u, d, s, and c are the distribution functions of the quarks in the proton, and $\sigma_0=G^2ME/\pi$.

Under the same assumptions, for processes with charged currents, at energy above the threshold of charmed-particle production, the cross sections take the form

$$\frac{d^2\sigma(\nu N\to\mu X)}{dx\,dy} = \sigma_0 x[(u+d)\cos^2\theta+2s\sin^2\theta+(\bar{u}+\bar{d})(1-y^2)+\underline{(u+d)\sin^2\theta+2s\cos^2\theta}];$$

$$\frac{d^2\sigma(\tilde{\nu}N\to\tilde{\mu}X)}{dx\,dy} = \sigma_0 x[(u+d)(1-y)^2+(\bar{u}+\bar{d})\cos^2\theta+2\bar{s}\sin^2\theta+\underline{(\bar{u}+\bar{d})\sin^2\theta+2\bar{s}\cos^2\theta}].$$

The underscored terms correspond to production of charmed particles, and θ is the Cabibbo angle. The total cross sections of the reactions are

$$\sigma(\nu\to\nu) = \sigma_0 <u+d>_V[\alpha^2+\beta^2+\frac{1}{3}(\gamma^2+\delta^2)+\frac{4}{3}(\alpha^2+\beta^2+\gamma^2+\delta^2)\epsilon+\frac{4}{3}(\beta^2+\delta^2)\lambda\epsilon];$$

$$\sigma(\tilde{\nu}\to\tilde{\nu}) = \sigma_0 <u+d>_V[\gamma^2+\delta^2+\frac{1}{3}(\alpha^2+\beta^2)+\frac{4}{3}(\alpha^2+\beta^2+\gamma^2+\delta^2)\epsilon+\frac{4}{3}(\beta^2+\delta^2)\lambda\epsilon];$$

$$\sigma(\nu\to\mu) = \sigma_0 <u+d>_V[(1+\epsilon)\cos^2\theta+\lambda\epsilon\sin^2\theta+\frac{\epsilon}{3}+\underline{(1+\epsilon)\sin^2\theta+\lambda\epsilon\cos^2\theta}];$$

$$\sigma(\tilde{\nu}\to\tilde{\mu}) = \sigma_0 <u+d>_V\left[\frac{1}{3}(1+\epsilon)+\epsilon\cos^2\theta+\lambda\epsilon\sin^2\theta+\underline{\epsilon\sin^2\theta+\lambda\epsilon\cos^2\theta}\right];$$

$$\epsilon=<u+d>_S/<u+d>_V,\quad \lambda=2<s>/<u+d>_S,\quad <u>=\int xu\,dx.$$

In the usual quark-parton model, the distribution functions u, d, s and c are assumed to depend only on the variable x. Violation of scaling means that these functions can depend also on q^2. We assume that the dependence on q^2 is weak (for example, in gauge theories with asymptotic freedom this dependence is logarithmic). Therefore, when integrating the expression for $d^2\sigma/dxdy$ we can assume that the distribution functions are taken at a certain effective q^2 that depends on the energy.

In the absence of a sea of quarks and below the threshold of charmed-particle production we have $R_\nu = R_\nu^0 = [\alpha^2+\beta^2+\frac{1}{3}(\gamma^2+\delta^2)]/\cos^2\theta$, $R_{\tilde{\nu}} = R_{\tilde{\nu}}^0 = 3(\gamma^2+\delta^2)+\alpha^2+\beta^2$. In the Weinberg—Salam model at $\sin^2\theta_W = 3/8$,

$$R_\nu^\circ = 11/(48\cos^2\theta) \approx 0.24; \quad R_{\tilde{\nu}}^\circ = 7/16 \approx 0.44 \quad .$$

In the region above the threshold of charmed-particle production and at $\epsilon(E) \neq 0$ we have

$$R_\nu = [\alpha^2+\beta^2+\frac{1}{3}(\gamma^2+\delta^2)+\frac{4}{3}(\alpha^2+\beta^2+\gamma^2+\delta^2)\epsilon+\frac{4}{3}(\beta^2+\delta^2)\lambda\epsilon]/(1+\frac{4}{3}\epsilon+\lambda\epsilon);$$

$$R_{\tilde{\nu}} = [\gamma^2+\delta^2+\frac{1}{3}(\alpha^2+\beta^2)+\frac{4}{3}(\alpha^2+\beta^2+\gamma^2+\delta^2)\epsilon+\frac{4}{3}(\beta^2+\delta^2)\lambda\epsilon]/\left(\frac{1}{3}+\frac{4}{3}\epsilon+\lambda\epsilon\right).$$

At $\sin^2\theta_W = 3/8$

$$R_\nu = \frac{1}{16}(11+18\epsilon+10\lambda\epsilon)/[3+\epsilon(4+3\lambda)];$$

$$R_{\tilde{\nu}} = \frac{1}{16}(7+18\epsilon+10\lambda\epsilon)/[3+\epsilon(4+3\lambda)].$$

At the parameter values $=0.6$ and $=0.25$[6] we get

$$R_\nu = 0.24; \quad R_{\tilde{\nu}} \approx 0.32.$$

In the limit as $\epsilon \to \infty$,

$$R_\nu = R_\nu = R^\infty = \frac{1}{4} + \frac{1}{8}(1-\lambda)/(4+3\lambda).$$

At $\lambda = 0.6$ the quantity R^∞ is equal to $R^\infty \approx 0.26$.

Thus, the increase of the parameter ϵ with energy, obtained from processes with charged currents,[1–4] leads to a substantial change in the value of $R_{\tilde{\nu}}$ with increasing energy (the value of R_ν remains practically unchanged in this case).

The ratio of the cross sections for the neutral currents in the Weinberg—Salam model is equal to (at $\sin^2\theta_W = 3/8$)

$$\sigma^{\tilde{\nu}\to\tilde{\nu}}/\sigma^{\nu\to\nu} = [7+2\epsilon(9+5\lambda)]/[11+2\epsilon(9+5\lambda)].$$

With increasing energy, this ratio can range between $7/11 \approx 0.64$ and unity.

We note also the following circumstance. When processes with charged and neutral currents are separated in experiment, a kinematic cutoff in the hadron energy is usually employed. The true values R_ν and $R_{\tilde{\nu}}$ are then reconstructed by using a definite model-dependence expression for $d^2\sigma/dx\,dy$. It is clear that at high energies such a correction must be carried out with allowance for the increase in the fraction of the sea quarks (see the formulas for $d^2\sigma/dx\,dy$).

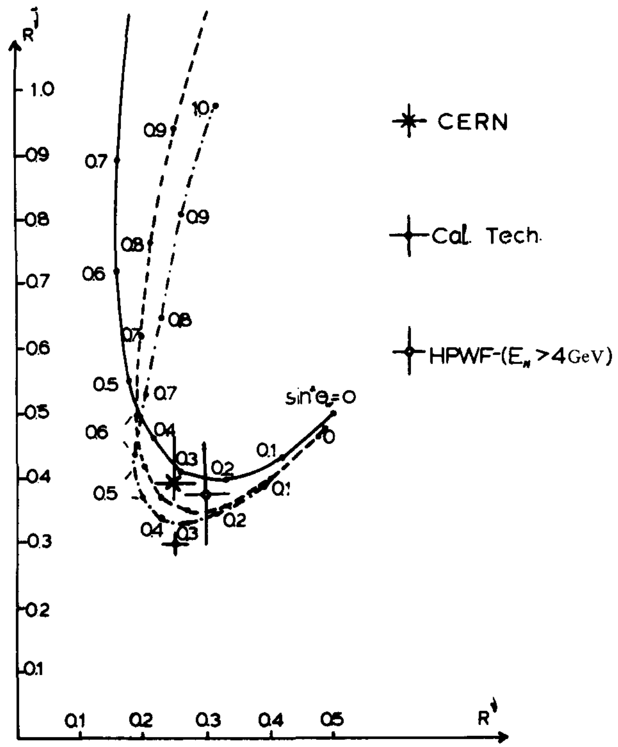

FIG. 1.

Figure 1 shows the results of a comparison of the experimental data with the Weinberg—Salam model. It is seen that allowance for the sea of quarks and antiquarks improves the agreement.

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