Vector partons?

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We consider an orthodox parton model in which the charged components of the hadrons have unity spin. We show that there is no scaling for the structure functions of deep electroproduction. An upper bound on the possible contribution of vector partons to the structure functions is obtained from data on deep electroproduction.

Recent results on e^+e^- annihilation into hadrons,[1] which indicate that the ratio of the cross section of this process to the cross section of annihilation into a muon pair increases with energy, have given rise to discussions of numerous models[2] that lead to a slower than the natural $\sim 1/q^2$ decrease of the cross section of the $e^+e^- \to$ hadrons process.

In particular, production of a pair of structureless charged vector mesons was discussed in[2] from this point of view. The possibility of the contribution of such mesons to the nonrenormalized electromagnetic current was discussed even earlier in[3].

It is clear, at the same time, that an appreciable contribution of such particles to the electromagnetic hadron current, or an appreciable presence of these particles among the charged partons, should alter radically the conclusions concerning scaling in deep electroproduction.

We consider in this paper the contribution of charged vector partons to the well-known structure functions $W_1(q^2, \nu)$ and $W_2(q^2, \nu)$ of this process on the basis of the orthodox parton model.[4,5]

These functions are easily expressed in terms of the corresponding contributions $W_{1(2)}(q^2, \nu)$ from the partons[5]

$$W_{1(2)}(q^2, \nu) = \sum_N P_N \sum_{i=1}^{N} \int f_i^N(x)\, W_{1(2)}^{(i)}(x, \nu, q^2)\, dx\,,$$

where P_N is the probability of a configuration of N partons in a hadron (parton), $f_i^N(x)$ gives the distribution of the longitudinal proton momentum of the ith parton with respect to the fraction x

$$(0 < |x| < 1, \quad \sum_N P_N = 1, \quad \int f_i^N(x)\, dx = 1).$$

The tensor $W_{\mu\nu}^{(i)}$, which describes the interaction of the virtual photon with a parton having unity spin, can be easily obtained by calculating the imaginary part of the forward Compton effect of a heavy photon on this parton

$$W_{\mu\nu}^{(i)} = -\frac{1}{2\pi}\,\mathrm{Im}\,\frac{1}{3}\,\epsilon^{\alpha}(p)\,\Gamma_{\alpha\beta}^{(i)\mu}\,\frac{g_{\beta\gamma} - \dfrac{p'_\beta p'_\gamma}{M_i^2}}{p'^2 - M_i^2 + i\epsilon}\,\Gamma_{\alpha'\gamma}^{(i)\nu}\,\epsilon^{\alpha'}(p)\,.$$

Here $\epsilon^{\alpha}(p)$ is the parton polarization vector, Q_i is its charge, M_i is its mass, $q-p=p'$, and $\Gamma_{\alpha\beta}^{(i)\mu}$ is the vertex of the interaction of a photon of polarization μ with a parton whose initial and final momenta and polarizations are (p, α) and (p', β), respectively:

$$\Gamma_{\alpha\beta}^{(i)\mu} = -Q_i\,[g_{\alpha\beta}(p+p')_\mu - g_{\alpha\mu}p_\beta - g_{\beta\mu}p'_\alpha]$$

(we are considering only the case of zero anomalous magnetic moment, in the spirit of the model in which partons are structureless hadron components; the conclusions concerning scaling violation remain, of course, unchanged in the general case).

Calculation leads to the following expression for $W_{\mu\nu}^{(i)}$: and with this taken into account we obtain

$$W_{\mu\nu}^{(i)}(p, q) = \frac{Q_i^2}{6}\,\delta(q^2 + 2pq)\left\{\left[3 + \frac{(pq)}{M_i^2}\right](p+p')_\mu (p+p')_\nu - \left[4(pq) + \frac{2(pq)^2}{M_i^2}\right]\left[g_{\mu\nu} + \frac{q_\mu q_\nu}{2(pq)}\right]\right\}$$

and with this taken into account we obtain $W_1(q^2, \nu)$ and $\nu W_2(q^2, \nu)$:

$$W_1(\nu, q^2) = \frac{1}{3m}\left(1 - \frac{\omega^2 q^2}{4m^2}\right)\sum_N P_N \sum_{i=1}^{N} Q_i^2 f_i^N\left(\frac{1}{\omega}\right),$$

$$\nu W_2(\nu, q^2) = \left(1 - \frac{q^2\omega^2}{6m^2}\right)\frac{1}{\omega}\sum_N P_N \sum_{i=1}^{N} Q_i^2 f_i^N\left(\frac{1}{\omega}\right),$$

where we have introduced the Bjorken variable $\omega = -2\nu m/q^2$ (m is the proton mass).

Thus, in the case considered here there is no scaling for the structure functions of deep electroproduction in the Bjorken limit ($-q^2$, $\nu \to \infty$, ω fixed). (We note the frequently encountered erroneous statement that in this limit the main terms of mW_1 and νW_2 are subject to scaling regardless of the parton spin.)

It follows from (1) that $R = (\sigma_L/\sigma_T) \to 0$ in this limit. This result can be easily understood by considering the interaction of a heavy photon with a parton in the Breit system: $p = (xP, 0, 0, xP)$, $p' = (xP, 0, 0, -xP)$, $q = (0, 0, 0, -2xP)$ (P is the proton momentum), in which $q_0 = 0$. As $\nu \to \infty$, transitions between longitudinal and transverse states of the vector particle predominate; in other words, the helicity amplitudes $\phi_{11;0}$ and $\phi_{0-1;1}$ predominate (λ_1 and λ_3 in $\phi_{\lambda_1\lambda_2;\lambda_3}$ are the helicities of the parton before and after the interaction with a photon of helicity λ_2), i.e., $R \to 0$ as $\nu \to \infty$.

Relation (1) enables us to estimate the upper limit of the possible contribution of charged vector partons (relative to the contribution of partons of spin 1/2) to νW_2.

If it is assumed that their distribution $f_i(x)$ with respect to x and the probability P_N have the same form as for spin-1/2 partons, then from (1) and from the data of[6], where a certain deviation from scaling can be observed [for $\omega = 6$ and $\omega = 12$ and for $q^2 = 1$–3.3 (GeV/c)^2] it follows that the contribution of the charged vector partons to νW_2 does not exceed 0.5% of the contribution of the partons that ensure scaling.

If this upper limit were to be the true value of the contribution of the vector partons to νW_2, then a significant violation of scaling in deep electroproduction is to be expected at $-q^2\omega^2 \approx 250$ (GeV/c)^2.

Experiments underway in Batavia on deep muon production can cast light, in principle, on this question in the nearest future.

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