

Electroproduction at small Q^2 in the parton model

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It is shown that allowance for the coherent contribution to the cross section for the scattering of a virtual photon by partons leads to surprisingly good description of the electroproduction process also outside the scaling region (small Q^2), and that the recently observed violation of scaling^[5] can be attributed to the fact that the partons have a mass distribution.

According to the parton model, the hadron can be regarded at high energies as an aggregate of three pointlike partons. Incoherent scattering of virtual photons with large $Q^2 = -q^2$ by the partons (q is the photon momentum, $q^2 < 0$), yields gauge-invariant expressions for the functions W_1 and νW_2 (scaling). It is obvious that this representation of the hadron should remain true also when Q^2 is decreased without a change in the photon energy. Scaling will then be violated.

Violation of scaling is due primarily to the appearance of a contribution from the coherent scattering of the photons. Indeed, estimates show that at small Q^2 an important role is played by large distances (e.g., in the Feynman reference frame, where $q^2 = 0$, the dimensions of the photon are characterized by the quantity $\sim 1/\sqrt{Q^2}$). The resultant violation of scaling does not depend on the details of the parton interaction.

Another cause of violation of scaling as $Q^2 \rightarrow 0$ is the large interaction time τ_{int} of the photon in comparison with the lifetime τ of the system of interacting partons. In the Feynman system we have^[1]

$$\tau = \frac{|p|}{\sum_i \frac{E_{i\perp}^2}{2\xi_i} - \frac{M^2}{2}} = \frac{|p|Q^2}{\nu E_{1\perp}^2} = \frac{\sqrt{Q^2}}{E_{1\perp}^2}, \quad \tau_{int} \sim \frac{1}{\sqrt{Q^2}}, \quad (E_{1\perp}^2 = m_i^2 + p_{1\perp}^2) \quad (1)$$

i.e., the condition $\tau_{int}/\tau = E_{1\perp}^2/Q^2 \ll 1$ is violated at small Q^2 . Here $\nu = pq$, p and M are the momentum and mass of the proton, and $\xi = Q^2/2\nu$. In this case the violation of the scaling already depends on the peculiarities of the parton interaction. It turns out, however, that additional allowance for only the contribution from the coherent scattering of the photons describes well the inclusive ep scattering also at small Q^2 . This was first pointed out by Yoshii and Kitani.^[2] In their calculations it was necessary, besides the usual assumptions of the parton model, to postulate the amplitudes of the parton distributions with respect to the transverse coordinates

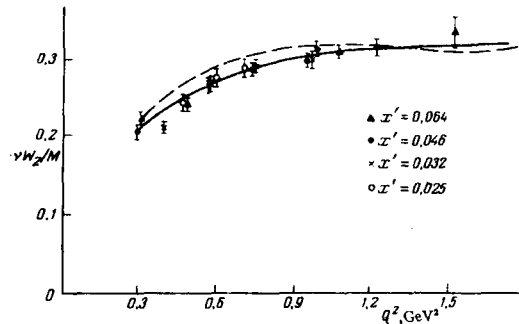


FIG. 1. Dependence of $\nu W_2/M$ on Q^2 as $x^1 = (W^2 - Q^2)/Q^2 \rightarrow 0$.

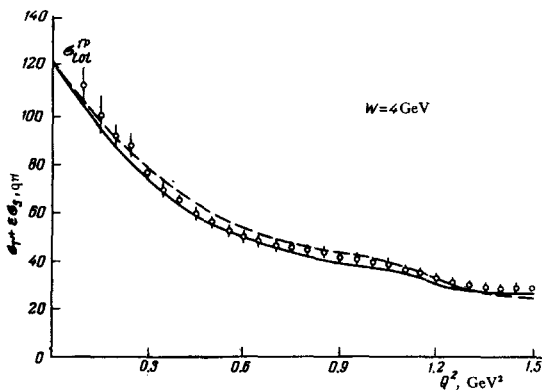


FIG. 2. Dependence of $\sigma_T + \epsilon\sigma_S$ on Q^2 , where σ_T and σ_S are respectively the total cross section for the scattering of a transverse and longitudinal photon by a proton.

(or, equivalently, with respect to p_\perp) in the lepton-photon c.m.s.

In the present paper, on the basis of the formula

$$\nu W_2(\xi, Q^2) = \nu W_2(\xi) \int_0^1 dY (1 - \cos \sqrt{Q^2} Y) F(Y), \quad (2)$$

which was obtained with allowance for the coherent contribution and under the natural assumption that none of the w ee partons are valent, we demonstrate, first, the weak dependence of νW_2 on the parton distribution $F(Y)$ with respect to the transverse distance Y between them, and compare, second, the results with the latest most accurate experimental data. In Fig. 1, the function

$$\frac{\nu W_2}{M^2} = F_2(\xi) (1 - e^{-a^2 Q^2}), \quad \xi = 0, \quad a^2 = 3.37 \text{ GeV}^{-2} \quad (3)$$

(solid line) is compared with the data extracted from^[3] by interpolation. Formula (3) was obtained assuming the distribution $F(Y)$ to be Gaussian.

In Fig. 2, the quantity $\sigma_T + \epsilon\sigma_S$, calculated from the formula

$$\sigma_T + \epsilon\sigma_S = \frac{4\pi^2\alpha}{W^2 - M^2} \frac{1}{\xi} \frac{\nu W_2}{M^2} \frac{1 + \epsilon R}{1 + R} \left(1 + \frac{M^2 Q^2}{\nu^2}\right) \quad (4)$$

is compared with the data of^[4]. Here σ_S and σ_T are the total cross sections for the scattering of longitudinal and transverse photons by a proton, $R = \sigma_S/\sigma_T$, $W^2 = (p + q)^2$, $\epsilon^{-1} = 1 + 2[\tan^2(\theta/2)] (1 + \nu^2/Q^2 M^2)$, and θ is the lepton scattering angle in the laboratory frame. The calculation was carried out for $\theta = 10^\circ$; it was assumed that $R = 0.18$ at $1.5 \lesssim Q^2 \lesssim 0.3 \text{ GeV}^2$ and $R = M^2 Q^2/\nu^2$ at $Q^2 \lesssim 0.3 \text{ GeV}^2$. The constant a^2 in formula (3) was determined from the condition $\sigma_T(Q^2 = 0) = \sigma_{tot}^p = 120 \text{ mb}$.^[4] The dashed lines in Figs. 1 and 2 show the corresponding functions assuming a trapezoidal distribution of the partons with respect to Y . The upper and lower bases of the trapezoid were assumed equal to $2r_0$ and $4r_0$, respectively; the quantity $r_0^2 = 40 \text{ GeV}^{-2}$ was also calculated from the condition $\sigma_T(Q^2 = 0) = 120 \text{ mb}$. It is seen from these figures that the results of the calculations are not sensitive to details of the parton distribution with respect to Y .

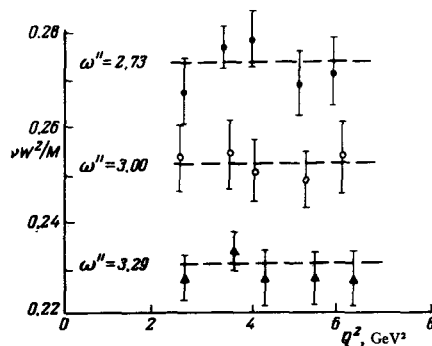


FIG. 3. Dependence of $\nu W_2/M$ on Q^2 at fixed ω'' .

Comparison of (4) with the experimental data shows that the agreement with the experiment is better than expected on the basis of the general estimates (1). Such an agreement can hardly be accidental. It must therefore be assumed that either the partons inside the hadron interact more weakly than is customarily assumed on the basis of their hadronic nature, or that the estimate (1) is too crude. The latter is more probable. In the case when the number of partons N is large (and it is precisely these states that are significant at small Q^2), it is important that the interaction take place without participation of that particular parton (or pair of partons) which absorbs the photon. Yet formula (1) yields an estimate only for the lifetime of the entire aggregate of the partons as a whole. If, e.g., the state of the system is changed as a result of the interaction of only some pair of partons, then the probability of the participation of a given parton in this act will be proportional to N^{-1} . In other words, if the number of partons is large, then the scaling-violating contribution from one or two partons will be small.

Third and final, we wish to call attention to the fact that the partons can have a certain mass distribution. The presence of such a distribution is significant at not too large values of ν and Q^2 . This may be precisely because of the recently observed violation of scaling.^[5] In fact, if the partons, absorbing or emitting a photon, can change their mass, then the functions $W_{1,2}$ for the partons will be proportional to $\delta(q^2 + 2x_i \nu + m_i^2 - m_i^2)$, i.e., the structure functions $F_{1,2}$ will depend on $x'' = \xi(1 - \Delta m^2/Q^2)$. This suggests that scaling will set in most rapidly if the variable $\omega'' = \omega/(1 - \Delta^2/Q^2)$ is used, where $\Delta^2 \approx 0.35 \text{ GeV}^2$. It is seen from Fig. 3 that if ω'' is fixed then scaling is well satisfied. The data were taken from^[3].

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