Precise Analysis of the HERA Data on Deep Inelastic Scattering

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Abstract

Thermodynamical approach is employed for the precise analysis of the ndata on deep inelastic scattering in the whole Q^2 range covered by experiments at HERA, including the real photoproduction data ($Q^2 = 0$). A new interpretation of the sea-quark contribution in view of Regge phenomenology is elaborated.

Recent experiments on Deep Inelastic Scattering (DIS) at HERA [1, 2] cover a range in the squared four-momentum transfer near $Q^2 = 0$ that corresponds to the real photoproduction [3–5]. However, photoproduction and DIS regions are described presently by different theoretical approaches, non of which gives a satisfactory description of the transition between these regions. Our model elaborated in the framework of supernonequilibrium thermodynamics [6, 7] describes two regions in the same way and provides simple analytical expressions for the structure function $F_2^p(x, Q^2)$ and the total cross section $\sigma_{\gamma p}^{tot}(W)$ convenient for the precise analysis of the data in the whole Q^2 range covered by measurements, including fixed target data (BCDMS, NMC, E665).

As in our previous work [7] the structure function of the nucleon contains three terms:

$$F_2^{(p,n)} = F^{(sea)} + \frac{1}{2}(F^{(S)} \pm F^{(V)}) . \tag{1}$$

The functions $F^{(sea)}$, $F^{(S)}$ and $F^{(V)}$ are the sea-quark, isoscalar and isovector valence-quark contributions. The first term corresponds to an interaction of the proton with a rotating and vibrating string-like constituent v ejected in the virtual transition $\gamma^* + p \to v + R$, where the mass ratio m_v/M_R can be neglected.

To describe the limit $Q^2 \to 0,\ W \to \infty$ in view of Regge-based model [8] we have somewhat modified the sea–quark term assuming

$$F^{(sea)} = N^{(sea)} x(1+z)e^{-z}/z^3 , \quad z = \sqrt{a^2 + \Delta x/(1-x)} , \tag{2}$$

$$\Delta = A \ln(1.0032 + \omega Q^2) \tag{3}$$

$$\Delta/a^2 = \frac{(s - M_N^2)^\alpha}{3\, s^\alpha} \left[Cf + \frac{D\,(f_0 + \Lambda f s^{\alpha/3})\, s^{2\alpha/3}}{\Lambda\, \Delta\, (1 + \Lambda\, s^{\alpha/3})} \right] \tag{4}$$

$$f = \left[1 + 6/\Delta^{0.8}\right]^{-1} + \left[\left(0.23\Delta^{2/3}\right)^{-1} + \Delta^{0.8}/6 \right]^{-1} \tag{5}$$

$$N^{(sea)} = \frac{5\,\Delta^2}{168} \left[1 - \frac{0.75}{1 + k\,\Delta^2} \right] , \quad k = 3 \cdot 10^{-5}. \tag{6}$$

Here $\alpha \equiv \alpha_P(0) = 1.08$ is the Pomeron intercept, $\Lambda = 0.3$ when the cms energy $W = \sqrt{s}$ is given in GeV, M_N is the nucleon mass, $f_0 = f(Q^2 = 0)$. Four parameters $C,\ D,\ A$ and ω are determined by fitting procedure with the valence-quark terms in eq.(1) obtained in our previous work [7].

In the photoproduction limit the valence-quark contribution vanishes, and we obtain for the photon–proton cross section in the region $0 \le Q^2 \le 10^{-5}\ GeV^2$ a two-parameter formula

$$\sigma_{\gamma^* p}^{tot} \approx \sigma_0 \frac{(s - M_N^2)^{3\alpha/2 - 1}}{s^{\alpha/2}} \left(1 + b\, s^{-2\alpha/3}\right)^{3/2} \underset{s \to \infty}{\longrightarrow} \sigma_0\, s^{\alpha - 1} , \tag{7}$$

where

$$\sigma_0 = \frac{5\,\pi^2 \alpha_f}{168\,\Delta_0} \left(\frac{D f_0}{3\,\Lambda}\right)^{3/2} , \tag{8}$$

$$b = C\Lambda\, \Delta_0/D , \quad \Delta_0 = \Delta(Q^2 = 0) ,$$

α_f is the fine structure constant.

Fitting is performed with the whole bulk of the HERA data [1–4,9–11] and fixed-target data [5,12–14] with statistical and systematical errors added quadratically. Data for the real photoproduction [5] in a resonance region $W \leq 4\ GeV$ are not included in the fitting procedure. The ZEUS–95 [1], H1–95 [2], ZEUS–94 [9,10], and E665 [12] data are renormalized by adjustable factors which turn out to be 1.020 ± 0.013, 0.944 ± 0.012, 0.962 ± 0.020, 1.027 ± 0.006 and 1.016 ± 0.010 respectively, the value of χ^2 being 583 for 663 points. We suppose that at least two sets, from refs.[2] and [10], have to be renormalized by the factors of 0.97 and 1.027. In this case we have got

$$\begin{aligned} &C = 6098 \pm 119\,, \\ &D = (51.55 \pm 0.09)\ GeV^{-2\alpha}\,, \\ &A = 16.28 \pm 0.25\,, \\ &\omega = (0.466 \pm 0.014)\ GeV^{-2}\,, \\ &\chi^2 = 597 \text{ for } 663 \text{ points}\,, \end{aligned} \tag{9}$$

contribution of the ZEUS–94 data [10] to χ^2 being 235 for 188 points. Thus, ZEUS–94 data exhibit a worse fitting compared with H1–94 data [11]. This fact was revealed earlier in ref.[15] where the ZEUS data were raised above the H1 data by 3% just as in our work.

Figures 1–28 show $F_2^p(x, Q^2)$ for some values of Q^2 quoted in refs. [1, 2, 11, 12]. Figure 29 shows the total photon-proton cross section $\sigma^{tot}_{\gamma^* p}(Q^2, W)$ defined in refs. [16, 17] in the most interesting region where a unified description of the data has not been obtained in previous investigations. In the interval $0 \leq Q^2 \leq 10^{-5}\ GeV^2$ $\sigma^{tot}_{\gamma^* p}$ varies within 0.2% and can be described by formula (7) where

$$\sigma_0 = 71.91\,, \quad b = 1.846 \tag{10}$$

where the energy is in GeV and the cross section in μb. The function $\sigma^{tot}_{\gamma p}(W)$ has the minimum equal to 113.5 μb and the value of $(169.4 \pm 0.4)\ \mu b$ at $W = 210\ GeV$. It is worth noting that formula (7) gives only a non-resonance part of the cross section with the maximum of 163.7 μb at $W = 1.41\ GeV$. In addition, the direct production of $\Delta(1232)$, $N(1470)$ and other resonances should be taken into account that is indicated by experimental data (see fig.29). Figure 30 shows the photon–proton cross section in the intermediate region $2 \leq Q^2 \leq 25\ GeV^2$.

Thus, our model gives a precise description of the HERA data throughout the full kinematic range in Q^2 and W. Uncertainties in calculated values of F_2^p and $\sigma^{tot}_{\gamma^* p}$ do not exceed 1% in this range. The intercept is extracted with a high accuracy, $\alpha_P(0) = 1.080 \pm 0.003$ that excludes large values $\alpha_P(0) \geq 1.10$ quoted in ref.[18]. In this context, we stress that in our model $\alpha_P(0)$ stands for a parameter determining the large–Q^2 behaviour of the cross section. Thus, we suggest an alternative representation of Regge phenomenology without using the concept of the pomeron trajectory. It is of interest that there is a range in Q^2, W where $\sigma^{tot}_{\gamma^* p}(Q^2, W) > \sigma^{tot}_{\gamma^* p}(0, W) \equiv \sigma^{tot}_{\gamma p}(W)$, i.e. our approach indicates a nonmonotonic behaviour of $\sigma^{tot}_{\gamma^* p}$ when $Q^2 \to 0$ contrary to common models quoted, for example, in refs.[2,18]

In conclusion we note that $\sigma^{tot}_{\gamma^* p}(W)$ in the range $0.1 \leq Q^2 < 1\ GeV^2$, $s \leq 10\ GeV^2$ essentially depends on the valence-quark contribution which has not such a high accuracy in our fit as the sea-quark part. We hope to obtain a more reliable parameterization for this range in a further work.

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Figure Captions

Fig1. Calculated function F_2^p versus x for $Q^2 = 0.11,\ 0.15,\ 0.20,\ 0.25,\ 0.4,\ 0.5\ GeV^2$. Data are from refs.[1,2,12].
Fig.2 Structure function for $Q^2 = 0.85$ and $1.2\ GeV^2$. Data are from refs.[2,12].
Figs.3–28. Calculated function F_2^p versus x for Q^2 quoted in ref.[11]. Data are from refs.[2,9–13].
Fig.29 and 30. Calculated photon–proton cross section versus W^2 for some values of Q^2 (in GeV^2). Data are from refs.[1–5,9–13].
In all the figures H1–95 [2] and ZEUS–94 [10] data are renormalized by the factors 0.97 and 1.027. Solid lines are presented with experimental points and dashed lines without the experimental points.