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DIFFRACTIVE PRODUCTION AND THE LOW x PROTON STRUCTURE FUNCTION* **

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In the light of recent HERA data, we analyze the connection between F_2 at low x and diffractive production within a Generalized Vector Dominance picture.

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The motivations for this work are twofold:

(i) At HERA two interesting experimental results at low x were established since HERA started operating in 1992: first of all, the proton structure function $F_2(x, Q^2)$ rises steeply with decreasing $x \leq 10^{-2}$ and shows a considerable amount of scaling violations [1]. Secondly, when analysing the final hadronic state, the H1 and ZEUS collaborations found an appreciable fraction of final states (approximately 10 % of the total) of typically diffractive nature ("large rapidity gap events") with invariant masses of the diffractively produced hadronic state up to about 30 GeV [2].

(ii) With respect to DIS at small x, a longstanding theoretical question concerns the role of the variables x and Q^2. This question has been most succinctly posed and discussed by Sakurai and Bjorken, as recorded in the Proceedings of the '71 Electron Photon Symposium at Cornell University [3]. It concerns the transition to the hadronlike behavior of photoproduction, in particular, whether a behavior similar to photoproduction sets in the limit of $Q^2 \to 0$ only, or rather in the limit of $x \to 0$ at arbitrarily large fixed values of Q^2. Within the framework of QCD there is no unique answer to this question so far. We may hope that the HERA low-x data in conjunction with theoretical analyses will resolve this important issue.

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In a recent paper [4] and in the present work, we take the point of view that indeed x is the relevant variable, in the sense that $x \leq 10^{-2}$ defines the region in which those features of the *virtual* photoproduction cross section, $\sigma_{\gamma^* p}$, become important which show a close similarity to *real* photoproduction and hadron-induced processes (Generalized Vector Dominance). Work along these lines, accordingly, is to be considered as an attempt to quantitatively and directly combine the above-mentioned two experimental observations at HERA (low-x rise of F_2 and diffractive production) within a coherent picture. This work is still in progress, and the present report is to be considered as a fairly preliminary status report.

The hadronlike behavior of the photon in photon-nucleon reactions was experimentally established in the late sixties and early seventies [5]. The energy dependence of the total photoproduction cross section as well as the diffraction peaks observed in vector-meson production are typically hadronlike. Quantitatively, photoproduction and vector-meson production are related by the well-known sum rule [6]

$$\sigma_{\gamma p}(W^2) = \sum_{\mathrm{V}=\rho^0,\omega,\phi,J/\psi} \sqrt{16\pi} \sqrt{\frac{\alpha\pi}{\gamma_{\mathrm{V}}^2}} \left(\left. \frac{d\sigma}{dt} \right|_{t=0} (W^2) \right)^{1/2} . \qquad (1)$$

The vector-meson couplings have to be extracted from e^+e^- annihilation, *i.e.* from the integral over the peak in the cross section corresponding to the production of the vector meson V,

$$\frac{\alpha\pi}{\gamma_V^2} = \frac{1}{4\pi^2\alpha} \sum_F \int \sigma_{e^+e^- \to V \to F}(s) ds \, . \qquad (2)$$

Experimentally, from e^+e^- annihilation and photoproduction one knows that ρ^0, ω, and ϕ fail to saturate the sum rule (1) at the level of 22 %, which is one of the starting points of Generalized Vector Dominance [7]: Within the framework of a mass dispersion relation, the remaining 22 % are assumed to be due to more massive vector-state contributions to the forward Compton amplitude.

Qualitatively, the observation of a strong signal for the diffractive production of a high-mass continuum at low x at HERA, as well as the persistence of shadowing in electron (muon) scattering from complex nuclei [8], support the ansatz of Generalized Vector Dominance. Quantitatively, a recent analysis [4] of the HERA data showed reasonable agreement of the GVD picture with the data, provided the energy is restricted to the HERA energy region of W $\gtrsim$ 60GeV. An analysis in the same spirit, but different in detail, was presented in Ref. [9].

In the present note, we are concerned with the extension of the sum rule (1) to virtual photons and its application for the diffractive production of high-mass continuum states.

Applying GVD to the outgoing photon in the virtual forward Compton amplitude, the transverse virtual photon absorption cross section may be represented as

$$\begin{aligned}\sigma_T(W^2, Q^2) \; = \; & \sum_{V=\rho^0,\omega,\phi,J/\psi} \sqrt{16\pi}\sqrt{\frac{\alpha\pi}{\gamma_V^2}} \\ & \times \int\limits_{\overline{m}_V^2} dm^2 \frac{m^2}{Q^2+m^2} \cdot \frac{1}{m} \sqrt{\frac{d\sigma}{dtdm^2}(W^2, Q^2, m^2)\Big|_{t=0}} \, , \end{aligned} \tag{3}$$

which generalizes (1) to virtual photons. As in (1), we have neglected a possible real part in the forward production amplitude, $d\sigma/dtdm^2$ at $t=0$. Consistency of (3) with scaling of the proton structure function, F_2, or $\sigma_T \sim 1/Q^2$, requires the production cross section for spin 1 states, $d\sigma/dtdm^2$, of mass m at vanishing momentum transfer $t=0$ to behave as

$$\frac{d\sigma}{dtdm^2}\Big|_{t=0} \sim \frac{1}{m^2(Q^2+m^2)^2} \, . \tag{4}$$

The strong decrease with increasing m^2, as $1/m^6$ for small Q^2, is a consequence of the well-known fact [7, 10] that consistency of GVD, scaling of F_2 and scaling of e^+e^- annihilation implies a decrease of the vector-state nucleon forward amplitude with increasing mass as $1/m^2$. The corresponding factor of $1/m^4$ in the cross section, combined with the $1/m^2$ behavior of the photon coupling, results in the strong decrease with m^2 in (4).

A comparison with the diffractive production data [11] indicates a weak decrease in m^2 at fixed Q^2, in strong disagreement with (4). It should be noted, however, that relation (4) is to hold for that part of the diffractively produced states of mass m which are vector states and couple to the (virtual) photon in the forward Compton amplitude. Their production is required to show the strong decrease (4) with increasing mass, while the total diffractive production, including diffraction dissociation into states which do not couple to the photon, may well be, and in fact seems to be considerably larger. A direct test of sum rule (3) by inserting a measured cross section for diffractive production, in analogy to the procedure applied in testing (1), thus requires to determine the spin 1 part in the diffractive forward production amplitude. In Ref. [12] a thrust analysis of the final states was carried out which indeed indicates that the spin structure of the diffractively produced states is neither pure nor dominantly vector, thus containing hadronic states which do not contribute to the Compton forward amplitude.

The present situation of the GVD picture, diffraction and the rise of F_2 at low x, may consequently be summarized as follows: on the one hand the existence of diffractive production supports the GVD picture as a "*conditio sine qua non*". On the other hand, a satisfactory (*i.e.*, quantitative) solution to the suppression mechanism at work in the forward Compton amplitude (sometimes called the "Gribov paradox" [10]) is not yet achieved and will presumably require much theoretical and experimental effort in the years to come.

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REFERENCES

[1] S. Aid *et al.*, H1 Collaboration, *Nucl. Phys.* **B470**, 3 (1996); C. Adloff *et al.*, H1 Collaboration, *Nucl. Phys.* **B497**, 3 (1997); M. Derrick *et al.*, ZEUS Collaboration, *Z. Phys.* **C72**, 399 (1996); J. Breitweg *et al.*, ZEUS Collaboration, *Phys. Lett.* **B407**, 432 (1997).

[2] T. Ahmed *et al.*, H1 Collaboration, *Nucl. Phys.* **B429**, 477 (1994); M. Derrick *et al.*, ZEUS Collaboration, *Phys. Lett.* **B315**, 481 (1993).

[3] J.D. Bjorken, *Proc. of the 1971 International Symposium on Electron and Photon Interactions at High Energies*, ed. by N.B. Mistry, Cornell University 1972, p. 281.

[4] D. Schildknecht, H. Spiesberger, hep-ph/9707447; D. Schildknecht, *Acta Phys. Pol.* **B28**, 2453 (1997).

[5] G. Wolf, *Proc. of the 1971 International Symposium on Electron and Photon Interactions at High Energies*, ed. by N.B. Mistry, Cornell University 1972, p. 189; J.J. Sakurai, *International School of Subnuclear Physics, 8-26 July 1971*, ed. by A. Zichichi, Erice 1973, p. 242; T.H. Bauer, R.D. Spital, D.R. Yennie and F.M. Pipkin, *Rev. Mod. Phys.* **50**, 261 (1978).

[6] P.G.O. Freund, *Nuovo Cim.* **44A**, 411 (1966); L. Stodolsky, *Phys. Rev. Lett.* **18**, 135 (1967); K. Kajantie, J.S. Trefil, *Phys. Lett.* **24B**, 106 (1967).

[7] J.J. Sakurai, D. Schildknecht, *Phys. Lett.* **40B**, 121 (1972); B. Gorczyca, D. Schildknecht, *Phys. Lett.* **47B**, 71 (1973).

[8] J. Achman *et al.*, EM Collaboration, *Phys. Lett* **B202**, 603 (1988); M. Arneodo, *Phys. Rep.* **240**, 301 (1994).

[9] G. Shaw, *Phys. Lett.* **B318**, 221 (1993); P. Moseley, G. Shaw, *Phys. Rev.* **D52**, 4941 (1995); G. Kerley, G. Shaw, *Phys. Rev.* **D56**, 7291 (1997).

[10] J.D. Bjorken, Talk presented at the Conference of Nuclear Physics, Fundamental Interactions of Elementary Particles, October 23-27, 1995, ITEP, Moscow, hep-ph/9601363.

[11] M. Derrick *et al.*, ZEUS Collaboration, *Z. Phys.* **C70**, 391 (1996); C. Adloff et al., H1 Collaboration, *Z. Phys.* **C76**, 613 (1997).

[12] C. Adloff *et al.*, H1 Collaboration, DESY 97-210, subm. to *Z. Phys.* **C**.