Off-diagonal generalized vector dominance: A comparison with recent *ep* deep-inelastic data

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The predictions of a recently suggested generalized vector-dominance model which includes off-diagonal terms are compared with 4° deep-inelastic *ep* scattering data.

The approach to the scaling limit of the proton structure function $\nu W_2(\omega', q^2)$ when q^2 increases at fixed $\omega' \equiv W^2/q^2+1$ from $q^2 \approx 0$ to the scaling regime $q^2 \gtrsim 2$ to 3 GeV^2, has repeatedly been discussed[1] within the framework of generalized vector dominance (GVD). Quite recently a large amount of deep-inelastic *ep* scattering data taken at a 4° electron scattering angle by the Stanford Linear Accelerator Center group A has become avaliable.[2] This note is devoted to a comparison of the GVD prediction with these data.[3]

In order to make our presentation self-contained, let us briefly summarize the basic assumptions and results of GVD[1] as applied to deep-inelastic scattering. The starting point is the observation that the total photoabsorption cross section from nucleons (or equivalently the imaginary part of the forward Compton amplitude) at sufficiently high energies is dominated by the contributions of the low-lying vector mesons, ρ^0, ω, and ϕ, which may thus be considered as the most important virtual constituents of the photon. Quantitatively,[1] about 78% of the total photoabsorption cross section is due to the ρ^0, ω, ϕ component of the incoming photon: Photons show hadronlike behavior. The missing part of the total $q^2=0$ cross section, about 22%, is attributed in GVD to the coupling of the photon to higher-mass vector states [e.g., $\rho'(1250)$, $\rho''(1600)$, . . ., if GVD is formulated in terms of a discreet series] as revealed by e^+e^- annihilation beyond the ρ^0, ω, ϕ region. Because of the propagation factor $(1+q^2/m_V^2)$, with increasing spacelike $q^2>0$, in inelastic electron-nucleon scattering these more massive vector states become relatively more important compared with $q^2=0$ photoproduction. However, no change in the "hadronlike" production mechanism is expected for the total virtual-photoabsorption cross section at $q^2>0$ compared with $q^2=0$, if the total photon-nucleon center-of-mass energy W is large enough also for the higher-mass states to be able to scatter diffractively. We thus obtain the obvious condition $\omega' \equiv W^2/q^2+1$ large, e.g., $\omega' \gtrsim 10$, for hadronlike behavior, diffractive-type scattering, and validity of the simple GVD.[4]

More specifically, in GVD in obvious generalization of ρ^0, ω, ϕ dominance, one starts from a double dispersion relation for σ_T (or equivalently the imaginary part of the forward Compton amplitude), given by

$$\sigma_T(W,q^2) = \int \frac{m^2\rho(W,m^2,m'^2)m'^2}{(q^2+m^2)(q^2+m'^2)}\, dm^2 dm'^2. \qquad (1)$$

The spectral weight function ρ is related to the product of the vector-state–photon coupling measured in e^+e^- annihilation and the absorptive part of the vector-meson–nucleon forward-scattering amplitude. Explicit model calculations have often been based[1,5] on the diagonal approximation of (1), in which the off-diagonal diffraction-dissociation-type transitions $V(m)p \to V(m')p$ with $m \neq m'$ are assumed to be negligible. Once the diagonal approximation is adopted in (1), the rather large coupling of the photon to high-mass hadrons (as evidenced by the $1/s$ scaling behavior of the total $e^+e^- \to$ hadrons cross section) forces one into assumptions on the underlying hadron physics which are at variance with our ideas on hadron-hadron interactions. Thus it seemed natural[6] to drop the diagonal approximation and rather to include diffraction-dissociation-type transitions within what has been called "off-diagonal generalized vector dominance."

The specific model which will be confronted with the new data in what follows, is the model[6] developed by Fraas, Read, and Schildknecht (FRS). The model has been formulated in terms of a discrete Veneziano-type spectrum of vector mesons with vector-meson–photon couplings appropriately chosen such that on the average $\sigma(e^+e^- \to \text{hadrons}) \propto 1/s$. As for the hadron physics input, the vector-meson–proton cross sections σ_{Vp} are assumed to be independent of the mass of the vector mesons V. The diffraction-dissociation-type amplitudes $V(m)p \to V(m')p$ for $m' \neq m$, are for simplicity restricted to effective transitions between next neighbors, i.e., adjacent states in the Veneziano spectrum of states. Their magnitude has been

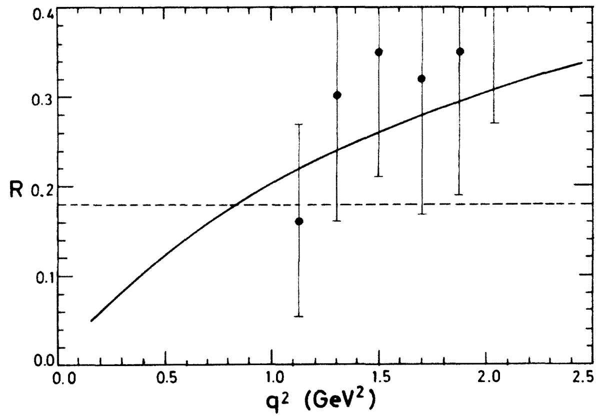

FIG. 1. $R \equiv \sigma_s/\sigma_T$ as a function of q^2 according to (3), (4) with separation data (Ref. 2) for $\omega' \gtrsim 10$. The dotted curve shows the value (Ref. 2) $R = 0.18$.

taken to be consistent with what is known about diffraction dissociation in hadron-hadron interactions. The off-diagonal terms through destructive interference ensure the convergence of the infinite sum of vector mesons contributing to σ_T and $\sigma_{\gamma p}$ in the limit of large photon-nucleon center-of-mass energy $W \to \infty$. There is one parameter in the model, δ, which is related to the strength of hadronic diffraction dissociation compared with the corresponding elastic amplitude. It is fixed to be $\delta = 0.28$ in the model by requiring σ_T to reduce to the correct magnitude of photoproduction $\sigma_T(W, q^2 = 0) = \sigma_{\gamma p}$ at $q^2 = 0$. The diagonal and off-diagonal transitions then sum up to a simple pole in q^2:

$$\sigma_T(W, q^2) = \frac{\bar{m}^2}{(q^2 + \bar{m}^2)} \sigma_{\gamma p}(W), \tag{2}$$

where the mass scale $\bar{m}$ quite naturally depends on the strength of the off-diagonal transitions, i.e., again on δ. With $\delta = 0.28$, as determined from photoproduction, the mass m^{-2} is predicted to be

$$\bar{m}^2 = \frac{1 + 2\delta}{2(1 + \delta)} m_\rho{}^2 \cong 0.61 m_\rho{}^2 \cong 0.36 \text{ GeV}^2. \tag{3}$$

Thus, the q^2 dependence of σ_T in (2) is predicted without an adjustable parameter. The longitudinal-to-transverse ratio $R \equiv \sigma_s/\sigma_T$ in GVD shows a characteristic logarithmic increase[1] and is given by

$$R = \xi \left[\left(1 + \frac{\bar{m}^2}{q^2}\right) \ln\left(1 + \frac{q^2}{\bar{m}^2}\right) - 1 \right]. \tag{4}$$

The parameter ξ is the ratio of longitudinal to transverse vector-meson forward scattering and has been measured[7] in ρ^0 electroproduction.

With the expressions (2) and (4) for σ_T and R we now can discuss the proton structure function νW_2. Specifically, we can first of all look at the

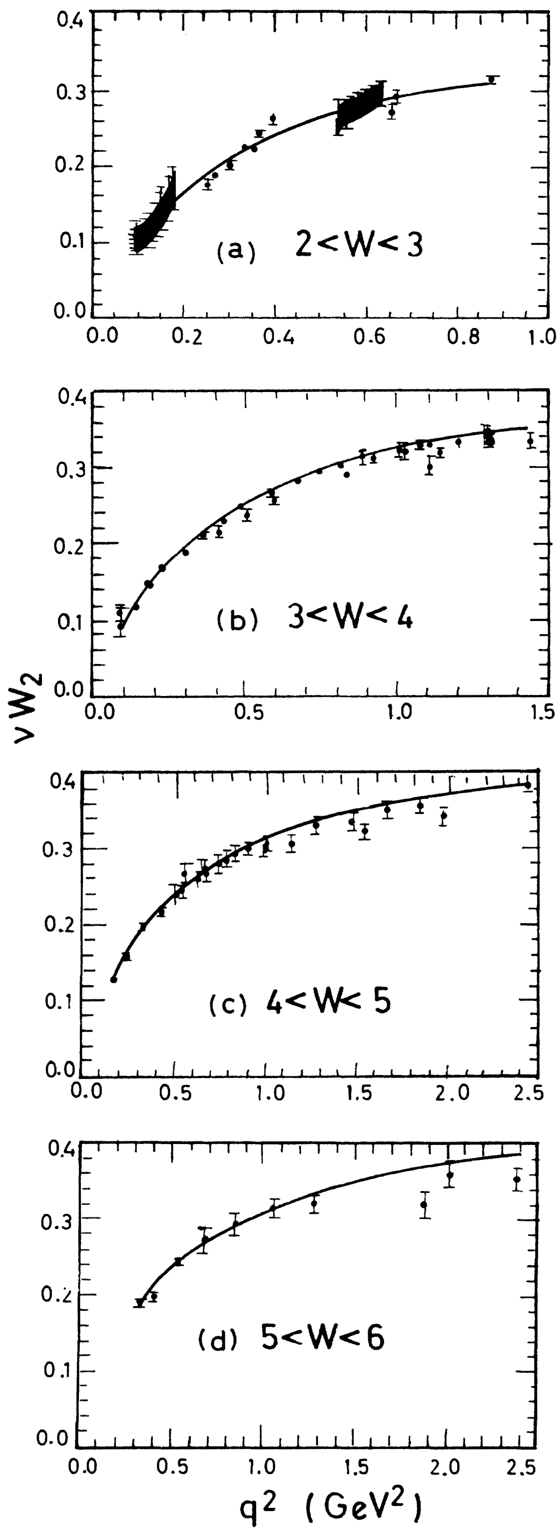

FIG. 2. νW_2 as a function of q^2 for different ranges of W (GeV) compared with the FRS off-diagonal GVD prediction. (a) $2 < W < 3$ GeV; (b) $3 < W < 4$ GeV; (c) $4 < W < 5$ GeV; (d) $5 < W < 6$ GeV.

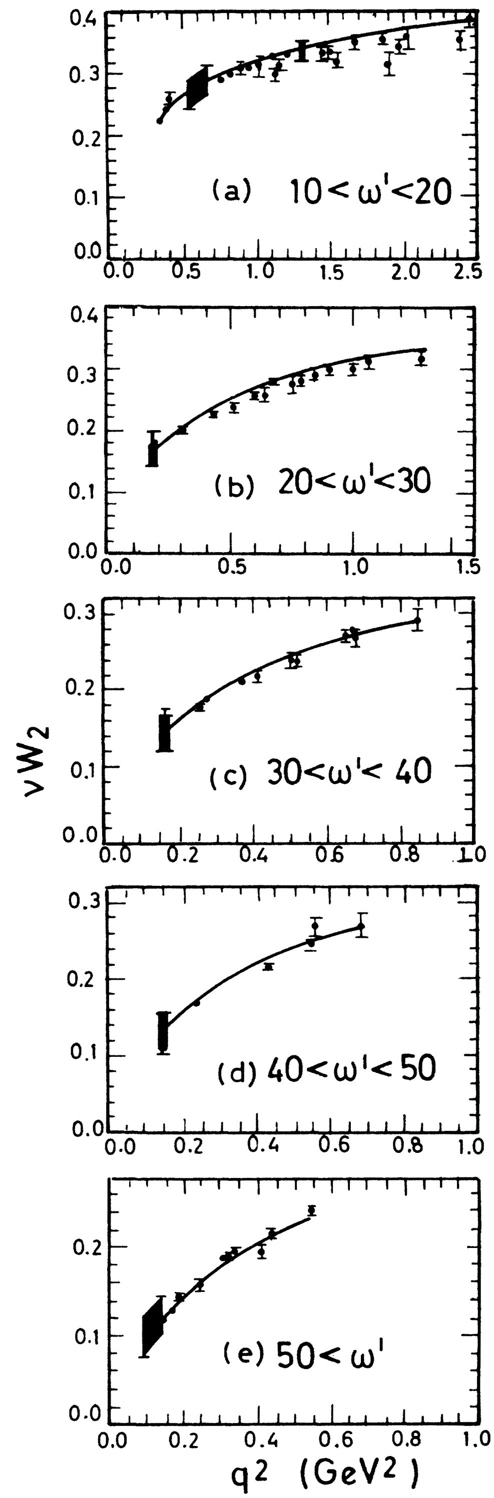

FIG. 3. νW_2 as a function of q^2 for different ranges of ω' compared with the FRS off-diagonal GVD prediction. (a) $10<\omega'<20$; (b) $20<\omega'<30$; (c) $30<\omega'<40$; (d) $40<\omega'<50$; (e) $\omega'>50$.

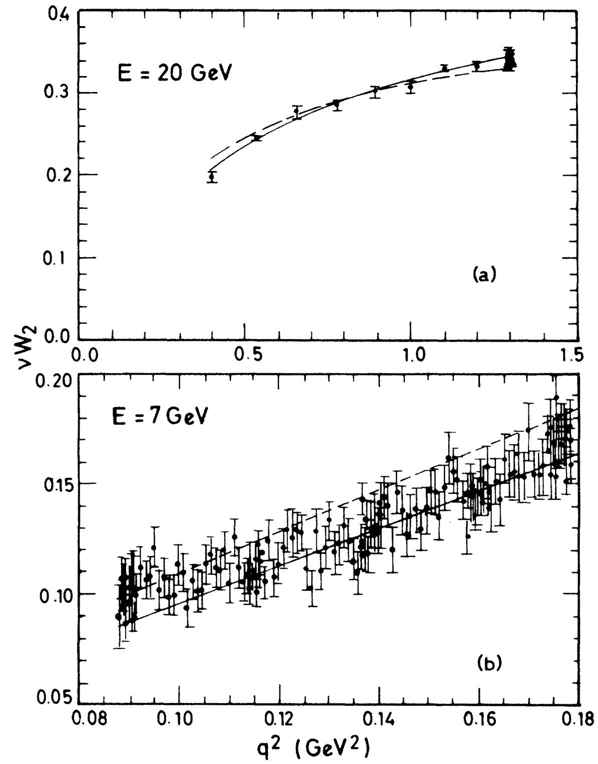

FIG. 4. νW_2 as a function of q^2 at 4° scattering angle for incident electron energies of 20 and 7 GeV, respectively. The curves are obtained with $R=0.18$ (---) and R according to GVD (——) from (4), respectively.

q^2 dependence of νW_2 in the limit of photoproduction, $q^2\to 0$ at fixed W (i.e., the q^2 dependence for $q^2 \ll W^2$ or $\omega' \gtrsim 10$). With (2) and (4) and $K\equiv (W^2-M^2)/2M$, the structure function νW_2 is given by

$$\nu W_2(W,q^2)=\frac{K}{4\pi^2\alpha}\frac{(K+q^2/2M)q^2\overline{m}^2}{[q^2+(K+q^2/2M)^2](q^2+\overline{m}^2)}\times\sigma_{\gamma p}(W)(1+R)$$

$$\cong\frac{1}{4\pi^2\alpha}\frac{q^2\overline{m}^2}{(\overline{m}^2+q^2)}\sigma_{\gamma p}(W)(1+R). \qquad (5)$$

Secondly, we can look at the approach to scaling by examining νW_2 as a function of q^2 in the limit $q^2\to\infty$ for fixed $\omega'(\omega'\gtrsim 10)$. The scaling limit for $q^2\to\infty$ with ω' fixed is given by

$$\nu W_2(\omega'\gtrsim 10, q^2\to\infty)=\frac{1}{4\pi^2\alpha}\overline{m}^2\sigma_{\gamma p}(1+R). \qquad (6)$$

To a good approximation the limiting behavior of νW_2 is seen already by $q^2 \gtrsim 1$ GeV^2 (apart from the logarithmic increase of R).

The comparison of the above predictions with the available data is presented in Figs. 1 to 4. Figure 1 shows R from (4) with $\overline{m}^2$ from (3) as a function of q^2. The parameter ξ has been chosen to be ξ

$=0.25$, which value is somewhat low compared with ρ^0 electroproduction.[7] Separation data for $\omega' \gtrsim 10$[8] are seen to be consistent with the predicted rise of R, which is linear for small q^2 and logarithmic for $q^2 \to \infty$. For the predictions of νW_2 on Figs. 2 to 4, according to (2), (3), and (4), $\sigma_{\gamma p}$ has been parametrized[9] by

$$\sigma_{\gamma p} = 89 + 93.2/\sqrt{E_\gamma}\,,$$

where $\sigma_{\gamma p}$ is in μb and E_γ is in GeV. Figure 2 shows the behavior of νW_2 as q^2 approaches the limit of photoproduction $q^2 \to 0$ at fixed W (or equivalently $\omega' \to \infty$ at fixed W). Figure 3 shows the approach to scaling νW_2 as a function of q^2 at fixed ω'. Both Figs. 2 and 3 show excellent agreement[10] between the FRS off-diagonal GVD prediction and the deep-inelastic data. Moreover, a search for the best value of $\bar{m}^2$ amusingly agrees with the calculated value of $\bar{m}^2 = 0.61 m_\rho{}^2$. If R is replaced by a constant, or if a slightly different parametrization[9] of $\sigma_{\gamma p}$ is used, the change in $\bar{m}^2$ is less than 3%. Finally, Fig. 4 illustrates the importance of including the q^2 variation of R by comparing with the result obtained for $R = 0.18$, the favored value[2] of the SLAC-MIT collaboration. The agreement with the data is improved with R varying with q^2 as in Fig. 1.

Thus in summary, the GVD model recently proposed[6] for large ω' agrees remarkably well with the new data on deep-inelastic ep scattering. In particular, GVD accounts *quantitatively* for the approach to scaling and quantitatively predicts the large ω' value of the scaling structure function νW_2 in terms of the photoproduction cross section. Apart from quantitative details it is *qualitatively* satisfying to have a unified description of photoproduction and large-ω' deep-inelastic scattering. Finally, let us add the remark that GVD allows one to *quantitatively* predict[11] what to expect in deep-inelastic scattering at large ω' as a reflection of the production of $J(3.1)$ and $\psi(3.7)$ and the associated rise in $\sigma_h/\sigma_{\mu^+\mu^-}$ in e^+e^- annihilation.

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[2] S. Stein *et al.*, Phys. Rev. D 12, 1884 (1975); J. S. Poucher *et al.*, Phys. Rev. Lett. 32, 118 (1974); and Stanford Linear Accelerator Center Report No. SLAC-PUB-1309 (unpublished).

[3] As in Stein *et al*. (Ref. 2) data for $\omega' \gtrsim 10$ at 6° and 10° (Poucher *et al.*, Ref. 2) has also been included in the comparison.

[4] In Ref. 1 the model has been extended to small ω' by introducing a physically motivated $t_{\min}$ correction factor.

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[7] E.g., K. C. Moffeit, in *Proceedings of the Sixth International Symposium on Electron and Photon Interactions at High Energy, Bonn, 1973,* edited by H. Rollnik and W. Pfeil (North-Holland, Amsterdam, 1974).

[8] E. M. Riordan *et al.*, Phys. Rev. Lett. 33, 561 (1974).

[9] E.g., E. Gabathuler, in *Proceedings of the Sixth International Symposium on Electron and Photon Interactions at High Energy, Bonn, 1973* (see Ref. 7).

[10] In fact $\chi^2/N = 1.7$ on 380 data points for the curves shown. Using the 5-parameter fit for $F_2(\omega')$ determined by Stein *et al*. (Ref. 2) and their factorization ansatz gives $\chi^2/N = 2.3$ on the same data set.

[11] D. Schildknecht and F. Steiner, Phys. Lett. 56B, 36 (1975).