Reply to "Dual model form factors and pion photoproduction"

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In reply to the preceding Comment by Picciotto, it is argued that dual model factorization is not inconsistent with gauge invariance and that the $\pi\pi\gamma$ vertex function, with one pion being the only off-mass-shell particle, is expected to exhibit dynamical structure when embedded in the one-pion-exchange approximation to the four-point function $\gamma N \rightarrow \pi N$.

In the preceding Comment[1] it is argued that gauge invariance precludes any momentum dependence of the $\pi\pi\gamma$ form factor when one of the pions is the only particle off the mass shell. This result is then used to disprove dual model factorization[2] in the one-pion-exchange (OPE) approximation to π photoproduction on nucleons[3] according to which $F_{\pi\pi\gamma}(q^2)=F_{\pi NN}(q^2)$, provided the pion is the only off-mass-shell particle. The purpose of this Comment is to show that dual factorization is not incompatible with gauge invariance and that the $\pi\pi\gamma$ vertex, with only one pion off the mass shell, is expected to exhibit momentum dependence when embedded in the complete four-point function $\gamma N - \pi N$.

In the first place, the observation that gauge invariance leads to[1] $F_{\pi\pi\gamma}(q^2)=1$ is based on the Ward-Takahashi identity for an isolated $\pi\pi\gamma$ vertex. In the case of $\gamma N \rightarrow \pi N$ one is clearly not dealing with isolated vertices and thus gauge invariance constraints are not as simple. In fact, they result on certain constraint theorems in all the channels that have a Born term.[4] A specific model which satisfies these theorems is the electric Born approximation[5] which takes into account the t-channel pion pole (left-hand side diagram of Fig. 1) together with the s- and u-channel nucleon poles required by gauge invariance. In its original formulation both the πNN and the $\pi\pi\gamma$ vertex functions were taken as pointlike. As was shown in Ref. 3, dressing these vertices does not destroy gauge invariance provided $F_{\pi\pi\gamma}(q^2)=F_{\pi NN}(q^2)$, as it follows from dual factorization.

With the constraint theorems required by gauge invariance satisfied one can then proceed to examine the dynamical origin of the vertex structure and, in particular, how it arises in the Reggeized OPE model for $\gamma N \rightarrow \pi N$. Since the t-channel exchanged pion is off the mass shell it couples strongly to $J^P=0^-$ intermediate states of which the most important one is the three-pion state (Fig. 1) which resonates into π', π'', etc. These contributions dress up the pionic vertices which may be approximated by a series of $J^P=0^-$ radial excitations as in the dual model[2] or by an effective single pole as in the monopole form factor model. Apart from overall coupling constants the resulting vertex functions reflect pionic properties and thus should be universal, provided the other two particles in the vertex are on the mass shell. Concerning the pion pole itself, it is well known that bilinear unitarity precludes fixed poles in hadronic amplitudes and thus it should be properly Reggeized, i.e.,

$$g_\pi(s,t)=e g_{\pi NN}\frac{t}{\mu_\pi^2-t} \rightarrow e g_{\pi NN}\frac{t}{\mu_\pi^2-t}\{1+\exp[-i\pi\alpha_\pi(t)]\}\left(\frac{S}{S_0}\right)^{\alpha_\pi(t)}\beta^{(t)}_{\pi\pi\gamma}\beta_{\pi NN}(t)\ , \qquad (1)$$

where e is the electric charge, $g_{\pi NN}$ the on shell πNN coupling constant, $\alpha_\pi(t)=(1/2M_\rho^2)(t-\mu_\pi^2)$ the π-Regge trajectory, $S_0 \cong 1$ GeV^2, and $\beta(t)$ are the Regge residues assumed to have no energy dependence. According to the previous discussion the presence of these Regge residues does not contradict gauge invariance constraints if $\beta_{\pi\pi\gamma}(t)=\beta_{\pi NN}(t)$ and it is natural to identify them with the pionic form factor as done, e.g., in NN charge exchange[6] as well as in other hadronic reaction analyses.[2]

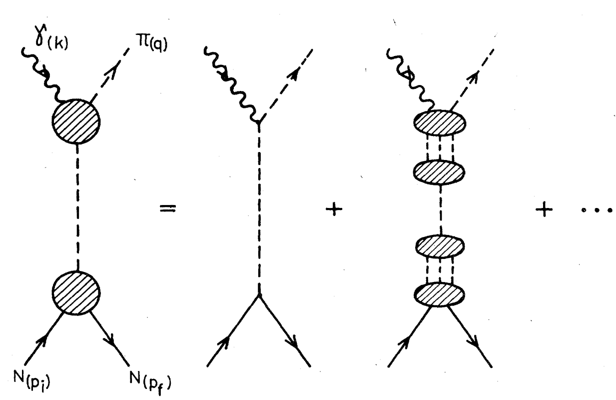

FIG. 1. One-pion exchange approximation in $\gamma N \rightarrow \pi N$ showing the dynamical origin of the vertex structure.

Reggeized OPE analyses of all these reactions consistently point to a somewhat soft πNN vertex structure, i.e., a monopole form factor range $\Lambda \cong 800-1000$ MeV, in line with recent independent dynamical calculations.[7] Concerning the deviation from the Goldberger-Treiman relation (GTR),[8] it has been shown recently[9] that Reggeized OPE analyses are not accurate enough to allow for an unambiguous extraction of the slope of the πNN form factor. In any case, rigorous results from the theory of chiral SU(2) $\times$ SU(2) symmetry breaking are now indicating[10,11] that the GT discrepancy cannot be more than 2%–3%. Adding to all this the state of flux of the experimental value of the nucleon axial vector coupling[11] $g_A(0)$, one may conclude that the deviation from the GTR does not provide, at the present time, a stringent constraint on the relative softness or hardness of the πNN vertex function.

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