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Comments

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Dual model form factors and pion photoproduction

Charles Picciotto
Physics Department, University of Victoria, Victoria, British Columbia, Canada V8W 2Y2
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It is shown that a recent analysis of pion photoproduction is inconsistent with the fundamental requirements of current conservation. For a monopole vertex function, the analysis should lead to a value $\Lambda \simeq 680$ MeV rather than 1000 MeV as claimed.

In recent years there has been significant progress in developing a parametrization of the off-mass-shell structure of pionic form factors. In particular, the dual unitarizable model has been used extensively in detailed analyses of various processes.[1] In this model, the general expression of the form factor for a three-point vertex is

$$F_{123}(p_1^2,p_2^2,p_3^2)=\prod_{i=1}^{3}\Gamma(\beta_i-s_i)\frac{\Gamma(1-\alpha'(p_i^2-m_i^2))}{\Gamma(\beta_i-s_i-\alpha'(p_i^2-m_i^2))}\ , \tag{1}$$

where s_i and p_i are the spin and four-momentum of the particle of mass m_i, $\alpha' \simeq 0.83$ GeV^{-2} the universal Regge slope, and β_i free parameters that govern asymptotic behavior. One of the consequences of the factorization of this expression is that the contribution from any given hadron should be the same for every vertex, regardless of what the other two particles are. For example, the form factors $F_{\pi NN}, F_{\pi\pi\gamma}, F_{\pi N\Delta}$ should all be identical to each other if the only off-shell particle is the pion, except for an overall normalization constant determined at the on-shell point. In the regions of p^2 tested so far, if the pion is the only virtual particle Eq. (1) can be approximated with the standard monopole expression

$$F_\pi(q^2)=\frac{\Lambda^2-m_\pi^2}{\Lambda^2-q^2}\ , \tag{2}$$

where q^2 is the pion's four-momentum squared and $F_\pi(q^2)$ has been normalized to unity on shell. Comparisons with the data in all cases studied by the group of Ref. 1 have led to $\Lambda \simeq 800$–1000 MeV and $\beta \simeq 2.5$–3.

The purpose of this paper is to point out that, at least in one case, the assumptions made in this dual model for three-point functions is inconsistent with the fundamental requirement of differential current conservation. In the analysis of pion photoproduction[2] the OPE amplitude was written in terms of the product $F_{\pi NN}(q^2)F_{\pi\pi\gamma}(q^2)$ and, as prescribed by the model, the two form factors were made equal. In fact, however, current conservation dictates that $F_{\pi\pi\gamma}$ has no q^2 dependence when only the pion is off shell. Perhaps the most direct way to see this is by use of the generalized Ward identity.[3] The vertex function has the form

$$\Gamma_\mu(p,q,k)=(p+q)_\mu F_\pi(p^2,q^2,k^2)+(p-q)_\mu G_\pi(p^2,q^2,k^2)\ . \tag{3}$$

Here, we have assumed that all particles are off shell, and $p,q,k,$ are the four-momenta of the incoming and outgoing pions and of the photon, respectively. In this case, the Ward-Takahashi identity takes the form

$$(p^2-q^2)F_\pi(p^2,q^2,k^2)+k^2G_\pi(p^2,q^2,k^2)=(p^2-m_\pi^2)-(q^2-m_\pi^2)\ . \tag{4}$$

Putting one pion and the photon on shell leads to

$$(q^2-m_\pi^2)F_\pi(g^2)=(q^2-m_\pi^2)\ , \tag{5}$$

or $F_\pi(q^2)=1$. This approach does not yield an expression for $G_\pi(q^2)$. However, the Lorentz condition keeps the last term of Eq. (3) from contributing for real photons.

We see then that the assumption $F_{\pi\pi\gamma}(q^2)=F_{\pi NN}(q^2)$ is not allowed by these fundamental considerations. This result can be looked at in the context of the detailed analysis of pion photoproduction carried out in Ref. 2. There, it was assumed that the one-pion-exchange amplitude would be proportional to

$$F_{\pi\pi\gamma}(q^2)F_{\pi NN}(q^2)=F_{\pi NN}^2(q^2)\ .$$

However, our conclusion dictates that it should be proportional to $F_{\pi NN}(q^2)$. The range of $-q^2$ in this case was $0-0.3$ (Gev/c)^2. The value $\Lambda \simeq 1000$ MeV in Eq. (2) gave the best fit to the data. The question is whether a different value of Λ would give a comparable fit to the cross sections and polarization asymmetries if we use $F_{\pi NN}$ instead of $F_{\pi NN}^2$. It turns out that in this range of $-q^2$, the value of $F_{\pi NN}(q^2)$ for $\Lambda=680$ MeV never differs by more than 1% from the value of $F_{\pi NN}^2(q^2)$ for $\Lambda=1000$ MeV. Of course, this means that the analysis of Ref. 2 points to a value of $\Lambda \simeq 680$ MeV rather than 1000 MeV as claimed.

To add to the controversy, note that an earlier analysis[4] of cross sections for $\bar{p}p \rightarrow \bar{n}n$ and $np \rightarrow pn$ at $P_{lab}=8$ GeV/c

was consistent with $\Lambda = 600$ MeV and[5] $\beta \simeq 6.5$. Also, this lower value of Λ gives a much better agreement with the Goldberger-Treiman discrepancy.[6] Finally, an analysis of the existing data for $\pi^- p \rightarrow \pi^- p \gamma$ appears to favor a value $\Lambda \simeq 680$ MeV for $F_{\pi N \Delta}$, although more data are needed for a meaningful conclusion. The result of that study will be published elsewhere.

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