VECTOR DOMINANCE AND FORWARD PHOTOPRODUCTION OF CHARGED PIONS BY POLARIZED PHOTONS*

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Received 8 May 1969

Vector-dominance predicts a relation between the combined asymmetry in π^+ and π^- photoproduction by polarized photons and the cross section for producing transversely polarized vector mesons. We predict that at high energies and $t = -m_\pi^2$ this relation will be violated by the data. We explain this expected failure by a strong mass dependence of the mechanism which governs the forward amplitudes for these processes.

The vector meson dominance hypothesis relates the cross sections for charged pion photoproduction to those for the production of transversely polarized vector mesons in pion-nucleon collisions. Specific cross sections for photoproduction of pions by polarized photons can be related to the appropriate density matrix elements of the produced vector mesons. Recent experiments at DESY have indicated a strong disagreement between the data and the vector meson dominance prediction [1-3]:

$$\frac{\Sigma_\perp - \Sigma_\parallel}{\Sigma_\perp + \Sigma_\parallel} = \frac{g^2_{\gamma\rho}\sigma^\rho_{1,-1} + g^2_{\gamma\omega}\sigma^\omega_{1,-1}}{g^2_{\gamma\rho}\sigma^\rho_{1,1} + g^2_{\gamma\omega}\sigma^\omega_{1,1}} \approx \frac{\rho^\rho_{1,-1}}{\rho^\rho_{1,-1}} \qquad (1)$$

where

$$\Sigma_\perp = \frac{d\sigma}{dt}(\gamma_\perp p \to \pi^+ n) + \frac{d\sigma}{dt}(\gamma_\perp n \to \pi^- p) \qquad (2)$$

$$\Sigma_\parallel = \frac{d\sigma}{dt}(\gamma_\parallel p \to \pi^+ n) + \frac{d\sigma}{dt}(\gamma_\parallel n \to \pi^- p) \qquad (3)$$

$\gamma_\perp$, $\gamma_\parallel$ are linearly polarized photons with polarization vectors perpendicular and parallel to the scattering plane, respectively; $g_{\gamma V}$ are the direct photon-vector meson couplings; $\sigma^V_{ij} = \rho^V_{ij}\, d\sigma^V/dt$; $d\sigma^V/dt$ and ρ^V_{ij} are the differential cross sections and the helicity-frame density matrix elements for $\pi^- p \to V^0 n$.

Białas and Zalewski [4] have recently raised doubts concerning the application of eq. (1) in the helicity frame. They correctly point out that other frames could be chosen for computing the ρ^V_{ij} values mentioned in eq. (1) and that a priori we do not have any convincing reasons to prefer one frame over another. They also show that in a particular frame for which $\mathrm{Re}\,\rho_{10} = 0$, the right hand side of eq. (1) is maximal and better agreement is obtained between the available photoproduction data and eq. (1).

In this note we draw attention to the possibility that the vector meson dominance relation (1) is badly violated for any frame of reference* for t-values around $t = -m_\pi^2$. Although complete data for the four cross sections appearing in the left hand side of eq. (1) are not available for $t = -m_\pi^2$, we claim that our understanding of the forward peak in $(d\sigma/dt)\,(\gamma N \to \pi^\pm N)$ is sufficient to predict with confidence that the left hand side of eq. (1) at high energies and $t = -m_\pi^2$ will be close to 1 (within 10% or so). The data for $\pi^- p \to V^0 n$ indicate [1-4] (not conclusively, in our opinion) that the right hand side of eq. (1) at the same s and t-values, for any frame, is much smaller (around 0-0.5).

In the near forward region (say, $|t| < 0.1\ \mathrm{GeV}^2$) accurate data exist for π^+ and π^- photoproduction by unpolarized photons [5] and for π^+ production by polarized photons [6]. Data for π^- production by polarized photons exist [1] only for $|t| \geq 0.2\ \mathrm{GeV}^2$ and only at one energy. We claim that the missing data for $|t| \leq m_\pi^2$ can be pre-

* This research has been supported in part by the Air Force Office of Scientific Research through the European Office of Aerospace Research, OAR, United States Air Force under Contract F-61052-68-C-0070.

* The vector meson states having helicity ±1 have to be defined with respect to a specific Lorentz frame. Starting from the rest frame of the vector meson, we can apply a Lorentz transformation in any given direction and evaluate the $\rho_{1,1}$ and ρ_{1-1} density matrix elements with respect to this direction. Among all frames in which this direction is in the scattering plane, the one in which $\mathrm{Re}\,\rho_{10} = 0$ possesses the largest value of $(\rho_{1,-1}/\rho_{11})$. If $(\Sigma_\perp - \Sigma_\parallel)/(\Sigma_\perp + \Sigma_\parallel)$ exceeds this maximal value, we have a frame-independent violation of eq. (1).

dicted on the basis of our understanding of the nature of the forward peak in $\pi^{\pm}$-photoproduction, and that at $t \approx -m_{\pi}^2$:

$$\frac{d\sigma}{dt}(\gamma_{\perp} n \to \pi^- p) \approx \frac{d\sigma}{dt}(\gamma_{\perp} p \to \pi^+ n) \quad (4)$$

$$\frac{d\sigma}{dt}(\gamma_{\parallel} n \to \pi^- p) \approx 0 . \quad (5)$$

These predictions, together with the available data for the other reactions [5,6] give, at $t \approx -m_{\pi}^2$:

$$(\Sigma_{\perp} - \Sigma_{\parallel})/(\Sigma_{\perp} + \Sigma_{\parallel}) \approx 1 . \quad (6)$$

Our predictions (4)-(6) are based on the following description of the forward peak in charged pion photoproduction:

In the extreme forward direction (say, $t = -10^{-3}$ GeV^2) the conspiracy relation for $\gamma p \to \pi^+ n$ teaches us that the contributions of natural and unnatural parity exchanges must be essentially equal. Consequently, $\sigma(\gamma_{\perp} p \to \pi^+ n) = \sigma(\gamma_{\parallel} p \to \pi^+ n)$. The sharp decrease of $d\sigma/dt$ between $t \approx t_{min}$ and $t = -m_{\pi}^2$ is caused by $\sigma_{\parallel}$ alone while $\sigma_{\perp}$ stays constant in this range of t. At $t = -m_{\pi}^2$, $\sigma_{\parallel}$ almost vanishes and is much smaller than $\sigma_{\perp}$. This prediction is supported by the polarized photon data [6] as well as by two (related) theoretical arguments:

(i) Dispersion relations as well as finite energy sum rule analysis of $\gamma N \to \pi^{\pm} N$ show [7] that at $0 \leq |t| \leq m_{\pi}^2$ the s-channel Born term is the main contribution which builds the forward peak. The Born term contribution to the dispersion relation or the finite energy sum rules has a rapidly varying t-dependence for $\sigma_{\parallel}$ but an almost constant t-dependence for $\sigma_{\perp}$. This is primarily caused by the gauge invariance relation between the t-channel pion and the s-channel nucleon pole.

(ii) The only reason for a strong variation of the cross section over the narrow forward region $0 < |t| \leq m_{\pi}^2$ could be the influence of the pion pole. As an unnatural parity object, the pion pole affects $\sigma_{\parallel}$ but does not produce any strong t-dependence in $\sigma_{\perp}$.

The same description applies to $\sigma(\gamma n \to \pi^- p)$ and the t-variation of $\sigma_{\perp}$ and $\sigma_{\parallel}$ is expected to follow a similar pattern for this process at $0 < |t| \leq m_{\pi}^2$. Furthermore, the cross sections for π^+ and π^- photoproduction at $|t| \leq m_{\pi}^2$ are dominated by the exchange of negative G-parity only and are therefore equal to each other at any given energy. This is supported by the experimental data for the π^+/π^- photoproduction ratio [5] as well as by the Born-term dominated finite energy sum rules analysis mentioned above [7]. We therefore conclude that in $\gamma n \to \pi^- p$: (i) $\sigma_{\perp} = \sigma_{\parallel}$ in the extreme forward direction (ii). Around $t = -m_{\pi}^2$ $\sigma_{\parallel} \approx 0$ while $\sigma_{\perp}$ retains its forward value. (iii) the absolute magnitudes of $\sigma_{\perp}$ and $\sigma_{\parallel}$ for $\gamma n \to \pi^- p$ at $|t| \leq m_{\pi}^2$ are equal to those for $\gamma p \to \pi^+ n$. These are the results claimed in eqs. (4)-(6).

The numerical value of the left hand side of eq. (1) is therefore predicted by our analysis to be around 1 at $t = m_{\pi}^2$. The right hand side was extracted from the data by various authors [1-4], all of which found values ranging between 0 and 0.5 depending on the frame. If these values are to be trusted we should immediately conclude that the vector meson dominance prediction, eq. (1), fails at $t = -m_{\pi}^2$ independent of the specific frame chosen. We must add, however, that the data for ρ_{ij}^V (in this t-region) represent averages over a range of t-values and it is not clear that more precise measurements at $|t| \leq m_{\pi}^2$ will not change the situation. We therefore have to wait for further data for ρ_{ij}^V as well as for a confirmation of our predictions for polarized photoproduction of π^-, before we can be absolutely convinced that we face here a basic discrepancy.

If we assume, however, that this discrepancy will actually materialize, we must ask ourselves what causes it. It seems to us that we are dealing here with a reaction mechanism whose details must depend in a crucial way on the photon-vector meson mass difference. In fact, good arguments exist [8] for predicting that $(d\sigma/dt)(\pi^- p \to \rho_{tr}^0 n)$, in contrast to $\gamma N \to \pi^{\pm} N$, will not show a sharp forward peak with a break at $t = -m_{\pi}^2$. If the responsible mechanism really depends here on m_V in such a crucial way we should actually expect the vector meson dominance hypothesis to fail precisely in those regions in t, for which the V^0-γ mass difference strongly affects the behavior of $d\sigma/dt$. In this case, the failure of the vector meson dominance hypothesis at $t = -m_{\pi}^2$ should not surprise us.

If this is the situation, at what t-values should we expect the γ-V^0 mass difference to become a minor factor in the reaction mechanism, so that the vector meson dominance hypothesis should and could be expected to work? Our qualitative answer to this question is that the vector meson dominance hypothesis should start working (for $\gamma N \to \pi^{\pm} N$ and $\pi N \to V_{tr}^0 N$) at those t-values in which the pion-exchange contribution becomes small relative to other exchanges. It is the π-exchange mechanism which is responsible for the behavior at small t and which (presumably) depends strongly on the mass of the vector particle. Experimentally it seems that somewhere around $t = -0.6$ GeV^2 the vector meson dominance hypothesis starts working properly [3,9]. It would be interesting to see whether the π-exchange contribution indeed loses its importance at these t-values*.

Summarizing, we expect that the vector meson dominance prediction for polarized photoproduction of charged pions will fail at $t = -m_{\pi}^2$. This failure should be expected on theoretical grounds, in view of the crucial role played by the mass of the vector particle in the mechanism which is responsible for the near forward cross section.

* The "importance of the π-exchange contribution" is a model dependent concept. The π'-trajectory in the π-π' conspiracy model plays part of the role of the absorption term in an absorprive π-exchange model. Hence, the "π'-contribution" may or may not be considered as a part of the π-exchange term, depending on the particular model used.

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