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VECTOR DOMINANCE, REGGE POLES AND π^{o} PHOTOPRODUCTION†

Haim Harari

Weizmann Institute of Science, Rehovot, Israel

and

Stanford Linear Accelerator Center, Stanford University, Stanford, California

ABSTRACT

The presently accepted Regge parametrization of π^{o} photoproduction claims that the $t \sim -0.5\ \mathrm{BeV}^2$ cross section is completely provided by B-exchange. We show that this statement disagrees with vector dominance by a factor of at least 4 and probably 10 or more. Additional I=0 poles or cuts are needed both in this process and in the I=0 t-channel combination of $\pi N \rightarrow \rho N$ cross-sections.

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The vector-meson dominance hypothesis relates pion photoproduction processes to the production of transversely polarized vector mesons in pion-initiated reactions[1]. Recent applications[1] of this idea to π^+, π^- and π^0 photoproduction indicate that such relations are at least consistent with experiment and in some cases one can even detect significant agreement.

Regge-pole theory can be applied to $\gamma + N \rightarrow \pi + N$ as well as to $\pi + N \rightarrow V + N$ reactions. Many experimental features of these processes require the introduction[2] of significant contributions of "exotic" poles and cuts such as the π', B and ω' poles, the $\pi - P$ cut, etc.

The purpose of this note is to suggest that once we accept the vector-dominance hypothesis as a valid principle, we may use it in order to test specific Regge "explanations" of the data. In particular, we point out that the currently accepted parametrization[3] of $\gamma + p \rightarrow \pi^0 + p$ in terms of ω and B exchange is in violent disagreement with vector dominance and that an extra $1^{CG} = 0^{--}$ exchange term such as an ω' pole or an ω-P cut is necessary in order to "explain" this process within the framework of Regge theory. We further show that between these two possibilities the ω-P cut is favored.

The usual Regge description of high energy π^0 -photoproduction runs as follows[3]:

(1) Only C = - 1 neutral mesons can be exchanged in the t-channel. The only established ones are ω, ρ, ϕ and B.

(2) The $\phi\pi\gamma$ coupling is vanishing or extremely small[4]; the $\rho\pi\gamma$ coupling is smaller than the $\omega\pi\gamma$ one; the B trajectory is lower than the ω. Hence, ω-exchange should dominate.

(3) A pure Reggeized ω-exchange predicts a forward dip in $d\sigma/dt$ (in agreement with experiment) and a zero in $d\sigma/dt$ at the point where $\alpha_\omega(t) = 0$.

(4) Since experimentally[5] there is a dip or a "break" but not a zero in the angular distribution around $t \sim -0.5$ BeV^2, there should be another contribution present. Since ρ-exchange would also yield a zero at the same t-value, the only candidate for contributing to $d\sigma/dt$ at $t = -0.5$ is B-exchange[6]. An adequate fit of all angular distributions between $E_\gamma = 2$ BeV and 5.8 BeV can be achieved with ω and B exchange[3].

The simple point that we would like to make here is the following: In the ω + B exchange model, the entire contribution to $\frac{d\sigma}{dt}(\gamma + p \rightarrow \pi^o + p)$ at the $\alpha_\omega(t) = 0$ point must come from B exchange and therefore from π^o-photoproduction by isoscalar photons. This means that at $t \sim -0.5$ BeV^2 vector dominance gives:

$$\frac{d\sigma}{dt}(\gamma + p \rightarrow \pi^o + p)_{t=-0.5} = \tfrac{1}{2}\, g^2_{\gamma\omega}\, \rho^H_{11} \frac{d\sigma}{dt}(\pi^+ + n \rightarrow \omega + p)_{t=-0.5} \qquad (1)$$

where ρ^H_{11} is the helicity-frame density matrix element for ω-production ($\rho^H_{11} \leq \frac{1}{2}$), $g_{\gamma\omega}$ is the direct $\omega \longleftrightarrow \gamma$ coupling constant and the factor $\frac{1}{2}$ comes from the isospin relation between the $\pi^o + p \rightarrow \omega + p$ and the $\pi^+ + n \rightarrow \omega + p$ cross sections. We have neglected the ϕ contribution in view of the extremely small $\pi + N \rightarrow \phi + N$ cross section.

Using the measured $\rho^o \rightarrow \ell^+ + \ell^-$ decay rate and SU(3), or the vector dominance predictions, we get for $g^2_{\gamma\omega}$:[7]

$$g^2_{\gamma\omega} = (4 \pm 2)\, 10^{-4} \qquad (2)$$

where the 50% error is probably an overestimate of the actual ambiguities. Using $\rho^H_{11} \leq \frac{1}{2}$ we therefore predict:

$$\frac{d\sigma}{dt}(\gamma + p \to \pi^{o} + p)_{t=-0.5} \leq 1.5 \times 10^{-4} \frac{d\sigma}{dt}(\pi^{+} + n \to \omega + p)_{t=-0.5} \tag{3}$$

where we have used the upper error limit of Eq. (2). A survey of all existing data on $\pi^{+}+n \to \omega+p$ indicates that at $p_{lab} = 6$ BeV/c: [8]

$$40 \frac{\mu b}{BeV^2} \leq \frac{d\sigma}{dt}(\pi^{+} + n \to \omega + p)_{t=-0.5} \leq 120 \frac{\mu b}{BeV^2} \tag{4}$$

where, again, the error estimate is very liberal. Inserting this value in Eq. (3) we therefore find that vector-dominance and the ω+B Regge pole model for π^{o} photoproduction predict:

$$\frac{d\sigma}{dt}(\gamma + p \to \pi^{o} + p)_{t=-0.5,\ p_{lab}=6} \leq 0.02 \frac{\mu b}{BeV^2} \tag{5}$$

where the right-hand-side of the inequality represents an extremely high estimate of the relevant quantity, the actual value being probably around $0.01 \frac{\mu b}{BeV^2}$ or less[9]. The experimental values for the left-hand-side of Eq. (5) are around $0.1 \frac{\mu b}{BeV^2}$ with 20% errors[5], indicating a discrepancy of at least a factor 4 and probably a factor 10-20 with the ω+B model.

The moral is that at least 30%-50% of the $t = -0.5$ BeV^2 value of $\frac{d\sigma}{dt}(\gamma+p \to \pi^{o}+p)$ comes from π^{o}-production by isovector photons, namely from pure I=0 exchange, while the rest could come from interference between I=0 and I=1 exchanges, but probably not from I=1 exchange alone. The obvious candidates for the extra I=0 exchange term are the elusive ω'-meson (if it exists) or the ω-P cut[10]. In the first case ω' will have to contribute 75%-95% of the $t = -0.5$ BeV^2 cross section (unless it finds a ρ'

to interfere with; there cannot be ω'-B interference). In the second case the ω-P cut could interfere with anything (B, ρ', ρ-P cut, etc.). The experimental energy dependence of $\frac{d\sigma}{dt}$ at $t = -0.5$ indicates[5] that $\alpha_{eff}(-0.5) \approx 0$, thus slightly preferring the ω-P cut possibility.

Another interesting consequence of our analysis is the following:

$$\frac{d\sigma}{dt}(\pi^o + p \to \rho^o + p)^{p_{lab}=6}_{t=-0.5} \geq \frac{0.3}{g^2_{\gamma\rho}\,\rho^H_{11}} \frac{d\sigma}{dt}(\gamma + p \to \pi^o + p)^{p_{lab}=6}_{t=-0.5} \tag{6}$$

where the factor 0.3 on the right-hand-side follows from the necessity of producing <u>at least</u> 30% of the $t = -0.5$ cross-section by isovector photons alone. Using $\rho^H_{11} \leq \frac{1}{2}$ and $g^2_{\rho\gamma} = (3.5 \pm 1)\,10^{-3}$ we predict:

$$\frac{d\sigma}{dt}(\pi^o + p \to \rho^o + p)^{p_{lab}=6}_{t=-0.5} \geq 15\,\frac{\mu b}{BeV^2} \tag{7}$$

At $p_{lab} = 4$ BeV/c the same considerations lead to a lower limit of about 30 $\frac{\mu b}{BeV^2}$. In terms[11] of measurable cross-sections we predict:

$$\frac{d\sigma}{dt}(\pi^- + p \to \rho^- + p) + \frac{d\sigma}{dt}(\pi^+ + p \to \rho^+ + p) - \frac{d\sigma}{dt}(\pi^- + p \to \rho^o + n)\ {}^{p_{lab}=4}_{t=0.5} \geq 60\,\frac{\mu b}{BeV^2} \tag{8}$$

where the right-hand-side is an extremely low estimate. The most probable value for the right-hand-side is 100-150 $\frac{\mu b}{GeV^2}$. This is on the border of disagreement with the data collected by Contogouris et al.[11], but we cannot claim a real inconsistency before better data on all the relevant quantities are known. Since pure Reggeized ω exchange predicts a vanishing right-hand-side for Eq. (8), our calculation gives a <u>lower</u> limit based on vector-dominance for

The <u>non-ω contribution</u> to $I=0$ exchange in $\pi N \to \rho N$. Again, an ω' or an ω-P cut are necessary.

We conclude with a few additional remarks:

(a) If the $t = -0.5$ $\gamma p \to \pi^0 p$ cross section comes only from ω' and B exchange, we have seen that the ω' contributes at least 75% of the cross-section. This would lead in Eq. (8) to a right-hand-side of at least $150 \frac{\mu b}{BeV^2}$ in contradiction with experiment[11]. <u>This strongly favors the ω-P cut over the ω'</u>.

(b) A good measurement of $\frac{d\sigma}{dt}(\gamma + n \to \pi^0 + n)$ will enable us to determine the size and sign of the isovector-isoscalar interference term in π^0-photoproduction. If $\rho + \omega + \omega' + B$ exchange is the correct model, $\frac{d\sigma}{dt}(\gamma + n \to \pi^0 + n) = \frac{d\sigma}{dt}(\gamma + p \to \pi^0 + p)$, at least at $t = -0.5$ BeV^2 (at other points there could be $\rho - \omega$ interference). If the ω-P cut version is favored, $\frac{d\sigma}{dt}(\gamma + n \to \pi^0 + n)$ at $t = -0.5$ could be anything between zero and $2\frac{d\sigma}{dt}(\gamma + p \to \pi^0 + p)$. The larger the $\gamma + n \to \pi^0 + n$ cross section is, the stronger our Eq. (8) becomes, and if we want to minimize the danger of disagreement with the data we must predict an extremely small and possibly vanishing[12] $\gamma + n \to \pi^0 + n$ cross section at $t = -0.5$.

(c) Polarized photon experiments may, in principle, distinguish between ω'-exchange and an ω-P cut contribution to π^0-photoproduction. The ω' involves only natural parity exchange while the ω-P cut could apriori contribute to the exchange of natural <u>and</u> unnatural parity[13].

(d) The small isoscalar photon contribution to π-photoproduction at $t = -0.5$ <u>is</u> sufficient to induce the large observed π^+/π^- ratio in $\gamma d \to NN\pi$, <u>if</u> it interferes strongly with the isovector contribution to charged π photoproduction. This can happen through π-B interference or through any number of cut-pole interference effects.

(e) Vector dominance and the measured π^+/π^- photoproduction ratio predict a sharp forward peak in $\rho_{11}^H \frac{d\sigma}{dt}(\pi N \rightarrow \rho N)$ in all possible charge states except $\pi^0 \rightarrow \rho^0$, and a forward dip in $\rho_{11}^H \frac{d\sigma}{dt}(\pi N \rightarrow \omega N)$. No significant data are available.

FOOTNOTES AND REFERENCES

1. D. S. Beder, Phys. Rev. 149, 1203 (1966); H. Joos, Acta Physica Austriaca, 1967, to be published; H. Fraas and D. Schildknecht, DESY 68/4 report (1968); A. Dar, V. F. Weisskopf, C. A. Levinson and H. J. Lipkin, Phys. Rev. Letters 20, 1261 (1968); M. Krammer, Phys. Letters 26B, 633 (1968); R. Diebold and J. A. Poirier, Phys. Rev. Letters 20, 1532 (1968); G. Buschhorn et al., contributed paper to the 1967 International Symposium on Electron and Photon Interaction at High Energies (Stanford, California, 1967); I. Derado and Z. G. T. Guiragossian, SLAC-PUB-460, to be published.

2. The forward peak in $\gamma p \to \pi^+ n$ requires at least a π-π' conspiracy (J. S. Ball, W. R. Frazer and M. Jacob, Phys. Rev. Letters 20, 518 (1968)) or a π-P cut (D. Amati et al., Phys. Letters 26B, 510 (1968)). The π^+/π^- photoproduction on deutron leads to π-B or π'-ρ or cut-pole interference. The non-vanishing ρ_{00} density matrix element in $\pi N \to \omega N$ leads to a significant B-exchange (M. Barmawi, Phys. Rev. 142, 1088 (1966)).

3. J. P. Ader, M. Capdeville and Ph. Salin, Nuclear Physics B3, 407 (1967). See also the discussion by H. Harari, Proceedings of the 1967 International Symposium on Electron and Photon Interactions at High Energies (Stanford, California, 1967) p. 347.

4. A detailed discussion of the $\phi\pi\gamma$ coupling is given e.g. by H. Harari, Phys. Rev. 155, 1565 (1967).

5. M. Braunschweig et al., Phys. Letters 26B, 405 (1968); R. Anderson et al., SLAC-PUB-431, submitted to Phys. Rev. Letters.

6. M. P. Locher and H. Rolnik, Phys. Letters 22, 996 (1966), have suggested that s-channel resonances are "filling" the zero. This is hard to reconcile with the 11 and 17.8 BeV data. Moreover, the s-channel resonances are not necessarily different than B or ω' or ω–P cut exchange at low energy.

7. $\Gamma(\rho \to \ell^+\ell^-)/\Gamma(\rho \to \pi^+\pi^-) = (5 \pm 1.5)\,10^{-5}$ is a reasonable average of present data. (See e.g. S. C. C. Ting, Proceedings of the 1967 International Symposium on Electron and Photon Interactions at High Energies (Stanford, California, 1967).) It leads to $g^2_{\gamma\rho} = (3.5 \pm 1)\,10^{-3}$. SU(3) predicts $g^2_{\gamma\omega} = \frac{1}{9} g^2_{\rho\gamma} \sim 4 \times 10^{-4}$. Vector dominance and the experimental $\Gamma(\omega \to \pi^o\gamma)/\Gamma(\pi^o \to 2\gamma)$ give values around $g^2_{\gamma\omega} = 5 \times 10^{-4}$.

8. M. Barrier et al., Proceedings of the CERN conference on high energy hadron collisions, January 1968, Vol. II, p. 135, find at $p_L = 5.1$ BeV/c $\sigma(\pi^+ + n \to \omega + p) \times \frac{\Gamma(\omega \to \pi^+\pi^-\pi^o)}{\Gamma(\omega \to \text{all})} = 128 \pm 3\,\mu b$, with a t dependence e^{Bt}, $B = 3.08 \pm 0.7$. Using the known $\omega \to \pi^+\pi^-\pi^o$ branching ratio we estimate $\frac{d\sigma}{dt}(\pi^+ + n \to \omega + p)^{p=5.1}_{t=-0.5} = 110 \pm 50 \frac{\mu b}{GeV^2}$. Assuming an $S^{2\alpha-2}$ energy dependence with $-\frac{1}{2} < \alpha < \frac{1}{2}$ we find at $p_L = 6$ BeV, $t = -0.5$ a value of $80 \pm 40 \frac{\mu b}{GeV^2}$. M. Barmawi (Ref. 2) quotes experiments of W. Bugg, et al. and G. Benson et al. giving $\frac{d\sigma}{dt} \sim 0.25 \frac{mb}{GeV^2}$ at $t = -0.5$, $p_L = 3.25$– 3.65 BeV/c. Assuming the same energy dependence as above we find for $p_{lab} = 6$ GeV/c, $t = -0.5$, $\frac{d\sigma}{dt} \sim 80 \pm 30 \frac{\mu b}{GeV^2}$. E. Shibata and M. Wahlig, Phys. Letters 22, 354 (1966) find at $p_L = 10$ BeV/c $\sigma(\pi^- + p \to \omega^o + n) \times \frac{\Gamma(\omega \to \pi + \gamma)}{\Gamma(\omega \to \text{all})} = 5 \pm 2\,\mu b$ with an e^{4t} t-dependence. This gives at $t = -0.5$, $\frac{d\sigma}{dt} = 20 \pm 10 \frac{\mu b}{GeV^2}$. The same energy correction gives at $p_{lab} = 6$, $t = -0.5$ $\frac{d\sigma}{dt} = 60 \pm 45$ ($\mu b/GeV^2$). The consistency among these evaluations encourages us in believing that our Eq. (4) is realistic.

9. In addition to taking the extreme limits of Eqs. (2) and (4), we have also used the $\rho_{11} = \frac{1}{2}$ limit in the absence of concrete information. The average values of Eqs. (2) and (4) and a $\rho_{11} \sim \frac{1}{4}$ would give $0.004 \frac{\mu b}{GeV^2}$ as the limit in Eq. (5).

10. The ω' may be needed elsewhere in order to avoid the difficulty with factorization pointed out by V. Barger and L. Durand, Phys. Rev. Letters 19, 1295 (1967).

11. A. P. Contogouris, J. Tran Thanh Van and H. J. Lubatti, Phys. Rev. Letters 19, 1352 (1967).

12. This agrees with the prediction of A. Dar et al., Ref. 1, who derived it using different assumptions.

13. One could also consider the exchange of the I = 0 component of the B-meson octet. Such a contribution would interfere with B-exchange but not with ω'. Polarized photon experiments can distinguish between such a contribution and ω' exchange. Another possibility is the introduction of a fixed pole, either in photoproduction only or in photoproduction and and $\pi N \rightarrow VN$.