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HIGH-ENERGY PHOTOPRODUCTION OF π^0 AND η MESONSAND THE DIP PROBLEM

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A B S T R A C T

The high-energy photoproduction of π^0 and η mesons is investigated in a model involving Regge poles plus Regge cuts, with particular attention devoted to the problem whether sense-nonsense α factors have to be explicitly included or not in the parametrization of scattering amplitudes.

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It is well known that a striking difference is present between the π^0 and η differential cross-sections. In fact, whereas the π^0 cross-section shows a dip around $t \sim -0.5(\text{GeV}/c)^2$ followed by a secondary maximum, the t dependence of the η cross-section shows no structure in the same region ¹⁾.

Since both π^0 and η photoproduction should possibly be dominated by Reggeized vector meson exchange, the different shape of the differential cross-sections is rather puzzling.

On the other hand, the question whether sense-nonsense α factors should be included or not in the parametrization of scattering amplitudes has not yet been clarified. In fact, equivalent descriptions of πN scattering, for example, can be obtained in both cases.

We find that only the class of theory ²⁾ which explains the dip in the differential cross-sections as due to interference between the pole terms and the cut terms leads to a natural explanation of both π^0 and η photoproduction, whereas no agreement can be found in η photoproduction if the sense-nonsense factors are explicitly included in the amplitudes. We recall that Regge poles are definitely incapable of providing a reasonable picture of photoproduction processes and that Regge cuts or absorption or more complicated singularities are definitely needed ³⁾.

We shall first formulate a very simple model ⁴⁾ for calculating cut corrections to Regge pole exchanges directly in terms of s channel helicity amplitudes. For simplicity we shall limit to pseudoscalar meson photoproduction off nucleons, since the generalization to other processes is completely straightforward.

We start from parity-conserving s channel Reggeized helicity amplitudes (SHA) in the form

$$s f_{\lambda_1 \lambda_2 \lambda_3 \lambda_4}^{(\pm)}(s, t) = \sqrt{-\frac{t}{s_0}}^{|M-1\lambda|+|M-1\mu|} G_{\lambda\mu}^{(\alpha)} \gamma_{\lambda\mu}^{\pm}(t) \frac{1 + s e^{-i\pi\alpha(t)}}{\sin \pi \alpha(t)} \left(\frac{s}{s_0}\right)^{\alpha(t)} \quad (1)$$

where $\lambda = \lambda_3 - \lambda_1$, $\mu = \lambda_4 - \lambda_2$; M is the Toller quantum number and

$$s f_{\lambda_1 \lambda_2 \lambda_3 \lambda_4}^{(\pm)}(s, t) = s f_{\lambda_1 \lambda_2 \lambda_3 \lambda_4}(s, t) \pm \eta_4 \eta_2 (-1)^{s_4 - s_2} (-1)^{\lambda_4 - \lambda_2} s f_{\lambda_1 - \lambda_2 \lambda_3 - \lambda_4}(s, t) \quad (2)$$

The factor $G_{\lambda\mu}(\alpha)$ depends only on the choosing mechanism of the trajectory at the sense-nonsense points; we shall try both $G_{\lambda\mu}(\alpha) = 1$ (no α factors in the amplitudes); $G_{\lambda\mu} = \alpha(t)$ (nonsense choosing of the vector meson trajectory). More complicated mechanisms are easily incorporated.

Only four amplitudes are independent, we choose those corresponding to the helicity configurations:

$$[\lambda_1, \lambda_2, \lambda_3, \lambda_4] = [1, \frac{1}{2}, 0, \pm \frac{1}{2}] \equiv [f_{10}^{(\pm)} \text{ and } f_{11}^{(\pm)}]$$

The differential cross-section is then

$$\frac{d\sigma}{dt} = \frac{1}{(s-m^2)^2} \left\{ |f_{10}^{(+)}|^2 + |f_{10}^{(-)}|^2 + |f_{11}^{(+)}|^2 + |f_{11}^{(-)}|^2 \right\}$$

The kinematics of the reaction tells us that only one amplitude of each parity survives at $t \sim 0$ [$f_{11}^{(+)}$ and $f_{11}^{(-)}$ in our notations] and their contributions to $d\sigma/dt$ must be equal at $t=0$. We must therefore add the condition:

$$f_{11}^{(+)}(s, t=0) = f_{11}^{(-)}(s, t=0) \quad (3)$$

We shall restrict the Regge pole exchanges to the ρ and ω trajectories for both π^0 and η photoproduction. In fact, the experimental data for the ratio

$$\frac{\sigma(\gamma p \rightarrow \pi^0 p)}{\sigma(\gamma n \rightarrow \pi^0 n)}$$

imply a non-negligible contribution of the isovector exchange in the t channel of π^0 photoproduction in addition to the dominant isoscalar exchange; in η photoproduction, $SU(3)$ symmetry for the meson couplings suggests a contribution of the same order of magnitude from both isoscalar and isovector exchanges in the t channel.

We have for SHA:

$$f_{10}^{(\pm)}(s,t) = f_{1\frac{1}{2}0\frac{1}{2}}(s,t) \pm f_{1-\frac{1}{2}0-\frac{1}{2}}(s,t)$$

$$f_{11}^{(\pm)}(s,t) = f_{1\frac{1}{2}0-\frac{1}{2}}(s,t) \mp f_{1-\frac{1}{2}0\frac{1}{2}}(s,t)$$

(4)

and from parity and G parity conservation for ρ and ω exchanges

$$f_{10}^{(+)}(s,t) = 2 f_{1\frac{1}{2}0\frac{1}{2}}(s,t)$$

$$f_{11}^{(+)}(s,t) = 2 f_{1\frac{1}{2}0-\frac{1}{2}}(s,t)$$

(5)

We define the Pomeron-Regge pole cut contribution to be in the impact representation

$$f_{\lambda\mu}^{\text{cut}}(s,t) = \int_0^\infty F_{\lambda\mu}^R(b,s) \psi(x) J_{|\lambda-\mu|}(bq) b db$$

(6)

where

$$F_{\lambda\mu}^R(b,s) = \int_0^\infty f_{\lambda\mu}^R(st) J_{|\lambda-\mu|}(bq) q dq \quad (7)$$

and

$$\psi(x) = \sum_{n=1}^{\infty} c_n x^n \quad (8)$$

with

$$x = \frac{\beta}{\xi} e^{-b^2/4\xi\tau} ; \quad \xi = \ln(s/s_0) - i\pi/2 ; \quad q = \sqrt{-t} \quad (9)$$

In (9) β is a real constant representing the Pomeron coupling to the particular channel considered and τ is the Pomeron slope.

The coefficients in (8) depend on the discontinuity across the cut; we shall try the two cases:

i) Glauber-type multiple scattering ⁵⁾:

$$c_n = 1/n!$$

ii) Amati-Fubini-Stanghellini type of discontinuity ⁶⁾:

$$c_n = \frac{1}{n!} (-1)^n 2^{2n-2}$$

Furthermore, in order to reduce the number of unknown parameters we shall assume the ρ NN coupling to be purely magnetic and the w NN coupling purely electric. We shall then fix the trajectory functions as

$$\alpha_{\rho,w}(t) = 1 + \alpha'_{\rho,w} (t - m_{\rho,w}^2)$$

with 7)

$$m_\rho^2 = 0.585 \text{ (GeV)}^2, \quad m_\omega^2 = 0.614 \text{ (GeV)}^2$$

$$\alpha'_\rho = 0.89 \text{ (GeV)}^{-2}, \quad \alpha'_\omega = 1. \text{ (GeV)}^{-2}$$

and $\tau = 0.42$ from the new Serpukhov data ⁸⁾. No t dependence is allowed in the residue functions $\gamma_{\lambda\mu}^\pm$ ⁹⁾.

The model is then completely specified by the final parametrization:

for ω exchange:

$$f_{10}^{(+)\omega}(s, t) = 2i \sqrt{-t/s_0} \gamma_{10}^\omega \left(e^{-i\pi/2} s/s_0 \right)^{\alpha_\omega(t)} G^\omega(\alpha) \quad (10)$$

$$f_{1\frac{1}{2}0\frac{1}{2}}^{(\omega-P)cut}(s, t) = \int_0^\infty F_{1\frac{1}{2}0\frac{1}{2}}^\omega(b, s) \psi(x) J_1(bq) b db$$

$$F_{1\frac{1}{2}0\frac{1}{2}}^\omega(b, s) = \int_0^\infty f_{1\frac{1}{2}0\frac{1}{2}}^\omega(s, t) J_1(bq) q dq \quad (10')$$

for ρ exchange:

$$f_{11}^{(+)\rho}(s, t) = 2i \left(-t/s_0 \right) \gamma_{11}^\rho \left(e^{-i\pi/2} s/s_0 \right)^{\alpha_\rho(t)} G^\rho(\alpha) \quad (11)$$

$$f_{1\frac{1}{2}0-\frac{1}{2}}^{(\rho-P)cut} = \int_0^\infty F_{1\frac{1}{2}0-\frac{1}{2}}^\rho(b, s) \psi(x) J_0(bq) b db$$

$$F_{1\frac{1}{2}0-\frac{1}{2}}^\rho(b, s) = \int_0^\infty f_{1\frac{1}{2}0-\frac{1}{2}}^\rho(s, t) J_0(bq) q dq \quad (11')$$

Note that in (10) and (11) we have neglected slowly varying functions of t in the signature factors.

By simple calculations we get explicitly for the Regge pole-n Pomeron cut:

$$i) \quad G^{\omega}(\alpha) = G^{\rho}(\alpha) = 1.$$

$$\begin{aligned} f_{10}^{(\pm)(\omega-P)cut}(s,t) &= \sqrt{-\frac{t}{s_0}} i \gamma_{10}^{\omega} (1 \pm \gamma_{10}^{cut}) \left(e^{-i\frac{\pi}{2}} s/s_0 \right)^{\alpha_{\omega}(0)} \times \\ &\times \frac{1}{(2R_{\omega}^2)^2} \sum_{n=1}^{\infty} c_n \left(\frac{\beta}{\xi} \right)^n \frac{1}{(2T_{\omega,n}^2)^2} e^{t/4T_{\omega,n}^2} \end{aligned} \quad (12)$$

$$\begin{aligned} f_{11}^{(+)(\rho-P)cut}(s,t) &\equiv f_{11}^{(-)(\rho-P)cut}(s,t) = i/s_0 \gamma_{11}^{\rho} \left(e^{-i\frac{\pi}{2}} s/s_0 \right)^{\alpha_{\rho}(0)} \cdot \frac{1}{2R_{\rho}^4} \times \\ &\times \sum_{n=1}^{\infty} c_n \left(\frac{\beta}{\xi} \right)^n \frac{1}{2T_{\rho,n}^2} e^{t/4T_{\rho,n}^2} \left\{ 1 - \frac{T_{\rho,n}^{-2}}{4R_{\rho}^2} \left(1 + \frac{t}{4T_{\rho,n}^2} \right) \right\} \end{aligned} \quad (13)$$

where

$$R_{\omega}^2 = \alpha'_{\omega} \xi \quad ; \quad R_{\rho}^2 = \alpha'_{\rho} \xi$$

$$R_n^2 = \frac{\xi T}{n}$$

$$T_{\rho,n}^2 = \frac{1}{4R_{\rho}^2} + \frac{1}{4R_n^2} \quad ; \quad T_{\omega,n}^2 = \frac{1}{4R_{\omega}^2} + \frac{1}{4R_n^2}$$

ii) $G^w(\alpha) = G^l(\alpha) = \alpha(t)$.

$$\begin{aligned} f_{10}^{(+)(w-p)wt}(s,t) &= \sqrt{-\frac{t}{s_0}} i \gamma_{10}^w (1 \pm \gamma^{cut}) \left(e^{-i\frac{\pi}{2}} s_{s_0} \right)^{\alpha_w(0)} \times \\ &\times \left\{ \frac{\alpha_0}{(2R_w^2)^2} \sum_{n=1}^{\infty} C_n \left(\frac{\beta}{\xi} \right)^n \frac{1}{(2T_{w,n}^2)^2} e^{t/4T_{w,n}^2} - \frac{\alpha'_w}{2R_w^6} \times \right. \\ &\times \left. \sum_{n=1}^{\infty} C_n \left(\frac{\beta}{\xi} \right)^n e^{t/4T_{w,n}^2} \left[\frac{1}{(2T_{w,n}^2)^2} - \frac{1}{16T_{w,n}^6 R_w^2} \left(1 + \frac{t}{8T_{w,n}^2} \right) \right] \right\} \end{aligned} \quad (15)$$

$$\begin{aligned} f_{11}^{(+)(p-p)wt}(s,t) &\equiv f_{11}^{(-)(p-p)wt}(s,t) = i \gamma_{11}^p \left(e^{-i\frac{\pi}{2}} s_{s_0} \right)^{\alpha_p(0)} \times \\ &\times \left\{ \frac{\alpha_0}{2R_p^4} \sum_{n=1}^{\infty} C_n \left(\frac{\beta}{\xi} \right)^n \frac{e^{t/4T_{p,n}^2}}{2T_{p,n}^2} \times \left[1 - \frac{T_{p,n}^{-2}}{4R_p^2} \left(1 + \frac{t}{4T_{p,n}^2} \right) \right] - \right. \\ &- \frac{\alpha'_p}{R_p^6} \sum_{n=1}^{\infty} C_n \left(\frac{\beta}{\xi} \right)^n \frac{e^{t/4T_{p,n}^2}}{2T_{p,n}^2} \times \left[1 - \frac{T_{p,n}^{-2}}{2R_p^2} \left(1 + \frac{t}{4T_{p,n}^2} \right) + \right. \\ &\left. \left. + \frac{T_{p,n}^{-4}}{16R_p^4} \left(1 + \frac{t}{2T_{p,n}^2} + \frac{t^2}{32T_{p,n}^4} \right) \right] \right\} \end{aligned} \quad (16)$$

We are thus left with four unknown parameters γ_{10}^w , γ_{11}^l , γ^{cut} and β ; in fact, we expect β to be of order 10 in our notations from factorization considerations.

We have fitted the four parameters to the differential cross-sections for π^0 photoproduction in the energy range $4 \text{ GeV} \leq E_\gamma \leq 15 \text{ GeV}$ and for momentum transfers up to $|t| \sim 1.6(\text{GeV})^2$.

We have found a very good fit for $n=1$, $C_n = 1/n!$, $G^p(\alpha) = G^w(\alpha) = 1$ and destructive interference between the pole and cut contributions ($X^2 = 64$ for 66 experimental points). Furthermore, the predictions for lower energies extrapolate very well down to 3 GeV for both differential cross-sections and asymmetry ratio for polarized incident γ rays. The parameters of the fit correspond to

$$\gamma_{10}^w = 2.47 \sqrt{\mu b} \text{ GeV} ; \gamma_{11}^p = 0.48 \sqrt{\mu b} \text{ GeV}$$

$$\gamma^{\text{cut}} = 1.96 ; \beta = 7.72 -$$

The contributions of the cuts corresponding to $n > 1$ turn out to be small. Of course in our model the cut contributions turn out to be rather large as the momentum transfers increase; in fact, the ratio $(d\sigma/dt)_{\text{pole}} / (d\sigma/dt)_{\text{cut}}$, which is of order 5 at $E_\gamma = 6 \text{ GeV}$ and $t = -0.2(\text{GeV}/c)^2$ drops to about 1 for $t = -0.6(\text{GeV}/c)^2$ and finally to 0.1 for $t = -1(\text{GeV}/c)^2$. A ratio of this kind for the pole over cut contributions was also found by the Michigan group ²⁾ in the processes they have analyzed. Moreover, we have found that a fit of about the same quality (even if a little bit worse) can be obtained also for $G(\alpha) = \alpha(t)$, but only if the Pomeron slope is allowed to be much smaller than the Serpukhov value; in this case no strong ρ contribution was found. In fact we end up with a model rather similar to the one proposed by Capella and Tran Thanh Van ¹⁰⁾.

No good fits were obtained for

$$C_n = \frac{1}{n!} (-1)^n 2^{2n-2}$$

and destructive interference between pole and first cut; the new feature was that the bigger was n , the better was the model but never satisfactory.

We have then tried to predict η photoproduction from SU(3) symmetry at the meson couplings.

We assume ¹¹⁾

$$g_{\omega\eta\gamma} = -\frac{1}{3\sqrt{3}} g_{\omega\pi\gamma} \quad ; \quad g_{\rho\eta\gamma} = -\frac{1}{\sqrt{3}} g_{\omega\pi\gamma}$$

$$g_{\rho\pi\gamma} = \frac{1}{3} g_{\omega\pi\gamma} \quad ; \quad \frac{g_{\omega\pi\gamma}^2}{4\pi} = 0.038 -$$

We found that only in the case where no α factors are included in the amplitude a correct description of the experimental cross-sections can be obtained. In fact, we fixed the ω coupling at the SU(3) value and allowed a small SU(3) breaking at the ρ coupling from the symmetry value $\gamma_{11}^0(\gamma p \rightarrow \eta^0 p) = -0.92$. We get a good agreement with the experimental data for $\gamma_{11}^0 \sim -0.6$. The predictions of the model are given in Fig. 4. We also give the prediction of the model for the asymmetry ratio R in Fig. 5. The model predicts no sensible energy dependence for R and strong unnatural parity contributions for momentum transfers bigger than $0.6(\text{GeV}/c)^2$, contrary to π^0 photoproduction. We think that it would be very interesting to have some experimental information on the asymmetry ratio for η photoproduction at large momentum transfers.

On the other hand, we could not find any possibility of washing out the dip in η differential cross-sections if the α factors are explicitly included in the amplitudes.

We think that the model we described works rather well; in fact, both π^0 and η photoproduction data are reproduced very nicely in a large range of energies and momentum transfers. Moreover, we find that the dip problem seems to have an easy explanation if one takes Harari's point of view ³⁾. We should perhaps stress again that, in our model, the dip mechanism is due to pole-cut destructive interference.

R E F E R E N C E S

- 1) R. Anderson et al., SLAC-PUB-644 (1969).
- 2) F. Henyey et al., Phys.Rev.Letters 21, 946 (1968).
- 3) See, e.g., H. Harari, Review talk presented at the Fourth International Symposium on Electron and Photon Interactions, Liverpool, England (Sept. 1969).
- 4) The model we present here is very similar to the one proposed by A.P. Contogouris and J.P. Lebrun, Nuovo Cimento 64, 627 (1969).
- 5) R. Glauber, Lectures in Theoretical Physics, New York (1958).
- 6) See, e.g., L. Van Hove, CERN lectures 65-22 (1965).
- 7) We take $\alpha'_0 = 0.89(\text{GeV})^{-2}$ from G. Lovelace, Nuclear Phys. B12, 253 (1969). For α'_ω we assume the "universal" value of $1(\text{GeV})^{-2}$.
- 8) G.G. Beznogikh et al., Dubna preprint EI-4628 (1969).
- 9) In fact, we assumed $s_0 = m_\pi m_N$; with this choice the residues turn out to be very slowly varying functions of t .
- 10) A. Capella and J. Tran Thanh Van, Nuovo Cimento Letters 1, 321 (1969).
- 11) See, e.g., A. Dar and V.F. Weisskopf, Phys.Letters 26B, 670 (1969).
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- 13) R.L. Anderson et al., private communication (1969).
- 14) D. Bellenger et al., Contribution to the XIV Conference on High Energy Physics, Vienna (1968).
- 15) W. Braunschweig et al., (Bonn-DESY group), preliminary results.
- 16) R.L. Anderson et al., private communication (1969).

FIGURE CAPTIONS

- Figure 1 : Differential cross-sections for $\gamma p \rightarrow \pi^0 p$ at $E_\gamma = 3, 4, 5$, and 5.8 GeV. The data are from Ref. 12); the full lines correspond to the present fit.
- Figure 2 : Differential cross-sections for $\gamma p \rightarrow \pi^0 p$ at $E_\gamma = 6, 9, 12$ and 15 GeV. The data are from Ref. 13); the full lines correspond to the present fit.
- Figure 3 : Asymmetry ratio for $\gamma p \rightarrow \pi^0 p$ at $E_\gamma = 3$ GeV. The data are from Ref. 14); the full line is the prediction of the model.
- Figure 4 : Differential cross-sections for $\gamma p \rightarrow \eta p$ at $E_\gamma = 4, 5.5$ and 6.5 GeV. The data at 4 GeV are from Ref. 15); the data at 5.5 and 6.5 GeV are from Ref. 16); the full lines correspond to the present model.
- Figure 5 : Prediction for the asymmetry ratio of $\gamma p \rightarrow \eta p$ at $E_\gamma = 4$ GeV. No sensible energy dependence of the asymmetry ratio is predicted by the model.

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5