π^+ Photoproduction above $E_\gamma=1$ GeV near the Forward Direction*

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π^+ photoproduction is considered near the forward direction and at medium high energies $1<E_\gamma<3$ GeV. It is shown that with a simple isobar ansatz in fixed-t dispersion relations one is able to predict the main features of the angular distributions in the region which is covered by recent measurements at DESY. The results indicate the importance of certain contact contributions of the resonances which are not taken into account by the peripheral models presented up to now.

RECENT measurements of π^+ photoproduction at DESY[1] yielded the systematic behavior of the angular distributions for $1.2\leq E_\gamma\leq 2.6$ GeV and $2.5°\leq\theta\leq 50°$.[2] The main task of the theory in this energy region is to determine (a) the predominantly real background amplitude, and (b) the effects of the resonances in the direct channel. The physical effects which are important for the background amplitude have not been known up to now, although they yield the largest contribution in the angular distributions. In this paper we should like to point out that some insight into the mechanism, which is responsible for the important background effects, follows from fixed-t dispersion relations[3,4]

$$\mathrm{Re}A_i(s,t)=A_i(s,t)_{\mathrm{pole}}+\frac{1}{\pi}P\int_{(M+1)^2}^{\infty}ds'\,\mathrm{Im}A_i(s',t)\times\left\{\frac{1}{s'-s}\pm\frac{1}{s'-u}\right\}. \quad (1)$$

For the kinematical region considered, an expansion of $\mathrm{Im}A_i(s',t)$ into partial amplitudes is still allowed. The dominant term in this expansion comes, of course, from the $\Delta(1236)$ pion nucleon isobar. Retaining, therefore, in this expansion only this resonance yields

$$\mathrm{Re}A_i(s,t)=A_i(s,t)_{\mathrm{pole}}+\frac{1}{\pi}P\int_{(M+1)^2}^{s_c}ds'\left\{\frac{1}{s'-s}\pm\frac{1}{s'-u}\right\}\times\{h_i^M(s',t)\,\mathrm{Im}M_{1+}^{3/2}(W')+h_i^E(s',t)\,\mathrm{Im}E_{1+}^{3/2}(W')\}. \quad (2)$$

In Eq. (2), $h_i^{M,E}(s',t)$ are known kinematical functions, and s_c is a cutoff energy which in practice will correspond to a photon energy E_γ around 800 MeV.

At the resonance, $\mathrm{Im}E_{1+}^{3/2}/\mathrm{Im}M_{1+}^{3/2}$ is of the order of -10%. Therefore it is consistent to neglect $\mathrm{Im}E_{1+}^{3/2}$ also in (2), since it is of the same order as some other neglected imaginary parts. That these are not taken into account in the background amplitude will be justified later on.

First we compare the experimental data with the following two theoretical absolute predictions (Figs.

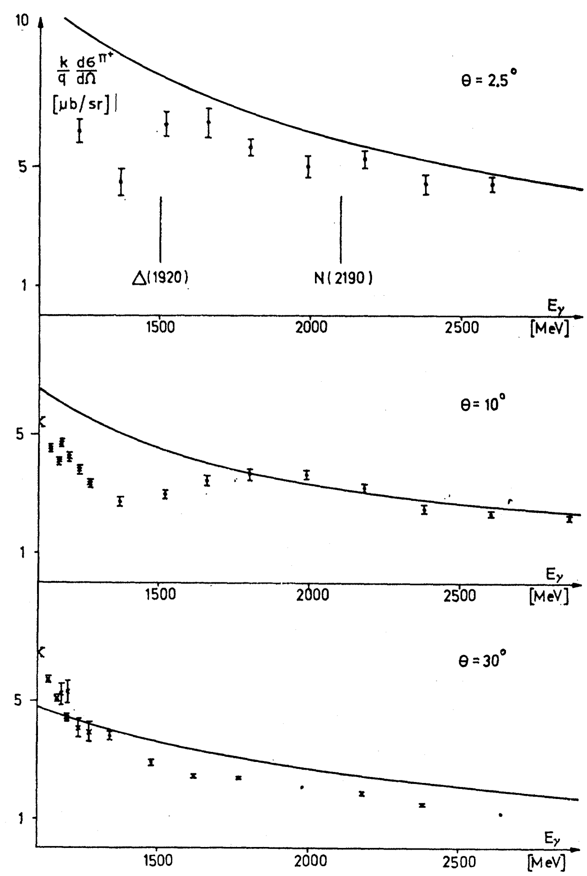

FIG. 1. π^+ excitation curves at $\theta=2.5°$, 10°, and 30°—ansatz II.

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[1] G. Buschhorn, J. Carroll, R. D. Eandi, P. Heide, R. Hübner, W. Kern, U. Kötz, P. Schmüser, and H. J. Skronn, Phys. Rev. Letters **17**, 1027 (1966); **18**, 571 (1967); G. Buschhorn, P. Heide, U. Kötz, R. A. Lewis, P. Schmüser, and H. J. Skronn, DESY Report No. 67/36 (unpublished).
[2] Angle in the c.m. system.
[3] Notation as in Ref. 4.
[4] W. Schmidt, Z. Physik **182**, 76 (1964).

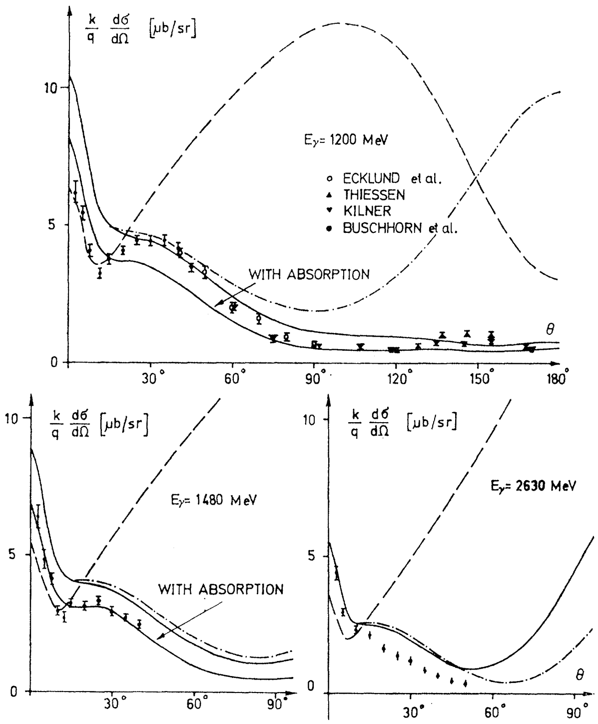

FIG. 2. π^+ angular distributions at $E_\gamma=1200$, 1480, and 2630 MeV. Experimental data of Refs. 1, 5, 6, and 7. Dashed line, pole term; solid line, ansatz II (with and without absorption, see text); dot-dash, ansatz II but with $\text{Im}E_{1^+}\neq 0$.

1 and 2):

I. $A_i(s,t)\approx A_i(s,t)_{\text{pole}}$.

II. Isobar approximation [Eq. (2)] with $\text{Im}E_{1+}^{3/2}\equiv 0$. The calculations are extended to all angles. The results in Figs. 1 and 2 indicate:

(a) The pole term of (1) has to be appreciably compensated for $\theta\geq 20°$ by effects coming from the dispersion integral to get the right order of magnitude for the background amplitude.

(b) This compensation is achieved to a reasonable degree near the forward direction by the contribution of the dispersion integral arising from $\text{Im}M_{1+}^{3/2}$. Since one can argue that near the forward direction the dispersion contribution of each other imaginary part is smaller, we assume that the coupling of $\text{Im}M_{1+}^{3/2}$ to the real parts of the amplitudes, particularly to the $J=\frac{1}{2}$ multipoles, is responsible for the necessary damping of the pole term in the considered kinematical region. One should note that for low energies $E_\gamma\sim 1.2$ GeV (Fig. 2) the cancellation works astonishingly well over the whole angular interval.

(c) Above $E_\gamma=1.5$ GeV, the isobar approximation II of the background amplitude breaks down for $\theta>50°$. The data from CEA[8] give for $E_\gamma>2$ GeV and $\theta=80°$ a cross section $d\sigma/d\Omega<5.10^{-2}$ μb/sr. That is, almost two orders of magnitude smaller than predicted by the isobar approximation.

(d) The results also show no dip in forward direction at the highest energy $E=2.6$ GeV, in agreement with the present experimental data. A dip in the forward direction is predicted by some peripheral one-particle-exchange models.[9,10]

We applied to the isobar ansatz II the absorption correction according to Schilling[11] (model 2). The result is partly a fairly good improvement at higher energies, but for angles larger than $\theta=50°$ the damping effect is again orders of magnitude too small.

We tried to look systematically for the limits of the present model of the background amplitude. In order to do this, we calculated the kinematical functions $h_i^{M,E}(s',t)$ also for the other multipoles up to $J=\frac{9}{2}$. From these results, one sees that the strength with which the imaginary parts of the different multipoles are kinematically coupled to the real part of the total amplitudes is always of the same order near the forward direction (at least for $J\leq\frac{9}{2}$). We believe that one can only conclude from this that $\text{Im}M_{1+}^{3/2}$ yields the largest dispersion contribution in the forward direction. The effect of all other imaginary parts in the dispersion contribution would be more pronounced if a cancellation in π^+ photoproduction did not appear, as a result of which these smaller contributions yield a rather small net effect. We mention in this respect the fact that at lower energies the effect of the s-wave multipoles $\text{Im}E_{0+}^{1/2,3/2}$ is small in π^+ production owing to a cancellation, which seems to predominate also at higher energies. Further, the leading order in the kinematical factors appears for a special helicity combination of multipoles, in which at least some of the isospin $I=\frac{1}{2}$ resonances are suppressed. With increasing angle ($\theta>50°$), the situation changes completely: generally the kinematical factors $h_i^{M,E}(s',t)$ increase, and some become very large in the kinematical region, where the partial-amplitude expansion of $\text{Im}A_i(s,t)$ is not allowed. One no longer has one helicity amplitude dominating, as one has near the forward direction, but all four contribute significantly.

To see what would be the effect of taking into account the small multipoles, we also calculated the angular distributions in the isobar approximation II but with $\text{Im}E_{1+}^{3/2}\neq 0$, since it is one of the best known small imaginary parts. Near the forward direction ($\theta<50°$) only small changes appear. But near the background

[5] S. D. Ecklund and R. L. Walker, Phys. Rev. **159**, 1195 (1967).

[6] J. Kilner, thesis, California Institute of Technology, 1966 (unpublished).

[7] H. A. Thiessen, thesis, California Institute of Technology, 1966 (unpublished).

[8] V. B. Elings, K. J. Cohen, D. A. Garelick, S. Homma, R. A. Lewis, P. D. Luckey, and L. S. Osborne, Phys. Rev. Letters **16**, 474 (1966).

[9] S. D. Drell and J. D. Sullivan, Phys. Rev. Letters **19**, 268 (1967).

[10] J. P. Ader, M. Capdeville, and P. Salin, CERN Report, No. TH803, 1967 (unpublished).

[11] K. Schilling, DESY Report No. 66/9, Hamburg, 1966 (unpublished).

direction, the inclusion of $\mathrm{Im}E_{1+}{}^{3/2}$ leads to drastic effects even at lower energies, where it destroys the reasonable agreement which was achieved with the ansatz II (Fig. 2). Further refinement of the theory may therefore show that the agreement with ansatz II found near the backward direction was only fortuitous.

To study the influence of the higher resonances in the direct channel we calculated the differences

$$\Delta\left(\frac{k}{q}\frac{d\sigma}{d\Omega}\right)=\left(\frac{k}{q}\frac{d\sigma'}{d\Omega}(E,\theta)-\frac{d\sigma}{d\Omega}(E,\theta)\right), \tag{3}$$

where $d\sigma/d\Omega$ is calculated according to Eq. (2) and $d\sigma'/d\Omega$ is calculated according to Eq. (2) with one real part of the multipoles $E_{l\pm}$, $M_{l\pm}$ changed by the amount $\Delta\,\mathrm{Re}E_{l\pm}$, $\Delta\,\mathrm{Re}M_{l\pm}$. In Fig. 3, the result is plotted for $E_\gamma=1200$ MeV.

Since the background amplitude is almost real, only the real parts of the resonant multipoles affect the angular distributions appreciably. Therefore, the possible large effects of a resonance are shifted by $\Delta E\approx\frac{1}{2}\Gamma$ from the resonance position. According to Fig. 3, the higher resonances should be observed most easily in the forward direction, if they are not suppressed for kinematical reasons by the cancellation of the electric $E_{l\pm}$ and magnetic $M_{l\pm}$ multipoles. The experimental results for the excitation curves in Fig. 1 show a clear resonant structure in the region of the F_{37} resonance $\Delta(1920)$, whereas indications of the G_{17} resonance $N(2190)$ are very small. A detailed analysis shows:

(1) The F_{37} resonance is predominantly excited by the multipole $M_{3+}{}^{3/2}$. This follows from the fact that the $\theta=30°$ excitation curve (Fig. 1) shows no resonant behavior at all in contrast to the $\theta=2.5°$ and $10°$ curves. According to Fig. 3, one would expect at $\theta=30°$ a resonance effect from $E_{3+}{}^{3/2}$. As shown in Ref. 12, the influence of the F_{37} resonance starts at rather low energies around 1 GeV.

(2) Since in the region of the G_{17} resonance no pronounced resonant behavior is seen (Fig. 1), we expect either that the excitation of the G_{17} resonance is very small for both multipoles or that the resonant electric and magnetic multipoles have the ratio $\mathrm{Re}E_{4-}/\mathrm{Re}M_{4-}=5/3$. For the second alternative, we expect that the G_{17} resonance produces a peak (or dip) around $\theta=45°$.

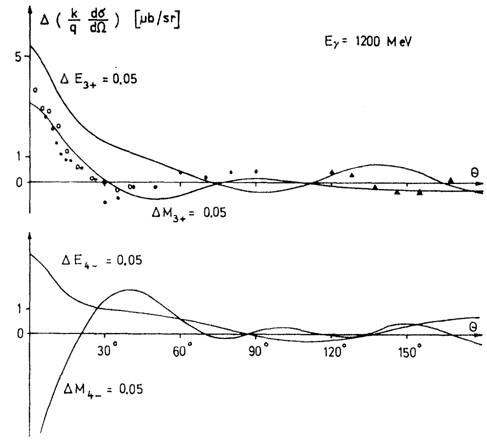

FIG. 3. $\Delta[(k/q)d\sigma/d\Omega]$ [Eq. (3)] for $\Delta\,\mathrm{Re}E_{3+}=\Delta\,\mathrm{Re}M_{3+}=\Delta\,\mathrm{Re}E_{4-}=\Delta\,\mathrm{Re}M_{4-}=0.05\times10^{-2}\lambda\!\!\!^{-}$.

The present phenomenological data in π^+ and π^0 photoproduction support the hypothesis that the $I=\frac{3}{2}$ resonances $\Delta(1238)$, $\Delta(1920)$, and $\Delta(2420)$, combined together in a Δ Regge trajectory, excite predominantly the magnetic multipoles $M_{l+}{}^{3/2}$.[13] Furthermore, the $I=\frac{1}{2}$ resonances with $J^P=\frac{3}{2}^-$, $\frac{7}{2}^-$, combined together in an N Regge trajectory, excite the electric and magnetic multipoles in such a way that they cannot contribute in the forward or the backward direction, i.e.,

$$E_{(l+1)-}/M_{(l+1)-}=(l+2)/l,\quad l\geq1. \tag{4}$$

For the D_{13} resonance $N(1525)$, Eq. (4) is confirmed by experiment,[12] and for the G_{17} resonance $N(2190)$, it is consistent with the present data. The same ratio (4) would also apply for the N trajectory, to which the F_{15} resonance $N(1688)$ belongs.[12]

According to this hypothesis only the resonances of the Δ trajectory should be observable in pion photoproduction in the forward and backward directions. The recent results at DESY[1] for π^0 production in the backward direction seem to exhibit such behavior.

[12] G. Schwiderski, thesis, Karlsruhe, 1967 (unpublished).

[13] P. G. O. Freund, A. N. Maheswari, and E. Schonberg, Phys. Rev. 159, 1232 (1967).