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π^+-PHOTOPRODUCTION ABOVE $E_\gamma = 1$ GeV NEAR FORWARD DIRECTION*

by

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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 $2.5^\circ \leq \theta \leq 50^\circ$.* 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 note 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

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

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

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

In Eq. (2) $h_i^{M,E}(s',t)$ are known kinematical functions, s_c is a cut-off 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

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* Angle in the c.m. system.

** Notation as in Ref. 2.

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. 1,2,3):

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

II. Isobar approximation [Eq. (2)] with $\mathrm{Im}\, E_{1+}^{3/2} \equiv 0$

The calculations are extended to all angles. The results in Figs. 1,2,3 indicate:

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

b. This compensation is near forward direction achieved to a reasonable degree by the contribution of the dispersion integral arising from $\mathrm{Im}\, M_{1+}^{3/2}$. Since one can argue that near forward direction the dispersion contribution of each other imaginary part is smaller, we assume that the coupling of $\mathrm{Im}\, M_{1+}^{3/2}$ to the real parts of the amplitudes, particularly to the $J = 1/2$ 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 $\theta > 50^o$. The data from CEA[5] give for $E_\gamma > 2$ GeV and $\theta = 80^o$ a cross section $d\sigma/d\Omega < 5.10^{-2}$ μb/st. That is almost two orders of magnitude smaller than predicted by the isobar approximation.

d. The results show no dip in forward direction also at the highest energy $E = 2.6$ GeV in agreement with the present experimental data. A dip in forward direction is predicted by some peripheral one-particle exchange models.[7,8]

We applied to the isobar ansatz II the absorption correction according to Schilling[9] (Model 2). The result is partly a fairly good improvement at higher energies but for angles larger than $\theta = 50^{\circ}$ 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 $g_i^{M,E}(s',t)$ also for the other multipoles up to $J = 9/2$. 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 forward direction (at least for $J \leq 9/2$). We believe that one can only conclude from this that 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 would not appear, according to 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 Im $E_{0+}^{1/2,3/2}$ is small in π^+-production due 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 $I = 1/2$ resonances are suppressed. With increasing angle ($\theta > 50^{\circ}$) the situation changes completely: generally the kinematical factors $g_i^{M,E}(s',t)$ increase and some become very large in the kinematical region, where the partial amplitude expansion of Im $A_i(s,t)$ is not allowed. One has no longer one helicity amplitude dominating as near forward direction, but all four.

To see what would be the effect of taking into account the small multipoles, we calculated also the angular distributions in the isobar approximation II but with

$\mathrm{Im}\ E_{1+}^{3/2} \neq 0$, since it is one of the best known small imaginary parts. Near forward direction ($\theta < 50^{\circ}$) only small changes appear. But at backward 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

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

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 $E_{\ell\pm}$, $M_{\ell\pm}$ changed by the amount $\Delta\mathrm{Re}\ E_{\ell\pm}$, $\Delta\mathrm{Re}\ M_{\ell\pm}$. In Fig. 4 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 the resonance are shifted by $\Delta E \approx \Gamma/2$ from the resonance position. According to Fig. 4 the higher resonances should be observed most easily in forward direction, if they are not suppressed for kinematical reasons by the cancellation of the electric $E_{\ell\pm}$ and magnetic $M_{\ell\pm}$ 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 $\theta = 30^{\circ}$ excitation curve (Fig. 1) shows no resonant behavior at all in contrast to the $\theta = 2.5^{\circ}$ and 10° curves. According to Fig. 4, one would expect at $\theta = 30^{\circ}$ a resonance effect from $E_{3+}^{3/2}$. As shown in Ref. 10, 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 satisfy 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 $\theta = 45^{\circ}$.

The present phenomenological data in π^{+}- and π^{o}-photoproduction support the hypothesis that the $I = 3/2$ resonances $\Delta(1238)$, $\Delta(1920)$, and $\Delta(2420)$ combined together in a Δ-Regge trajectory, excite predominantly the magnetic multipoles $M^{3/2}_{\ell+}$.[11] Furthermore, the $I = 1/2$ resonances with $J^{P} = \frac{3^{-}}{2}, \frac{7^{-}}{2}$, combined together in a N-Regge trajectory, excite the electric and magnetic multipoles in such a way that they cannot contribute in forward or backward direction, i.e.,

$$E_{(\ell+1)-} / M_{(\ell+1)-} = \frac{\ell + 2}{\ell} \qquad \ell \geq 1 \qquad (4)$$

For the D_{13}-resonance N(1525) Eq. (4) is confirmed by experiment[10] 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.[10]

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

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FIGURE CAPTIONS

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

2. π^+-angular distributions at $E_\gamma = 1200$ MeV and 1480 MeV.

   Experimental data Refs. 1, 3, 4, 5.

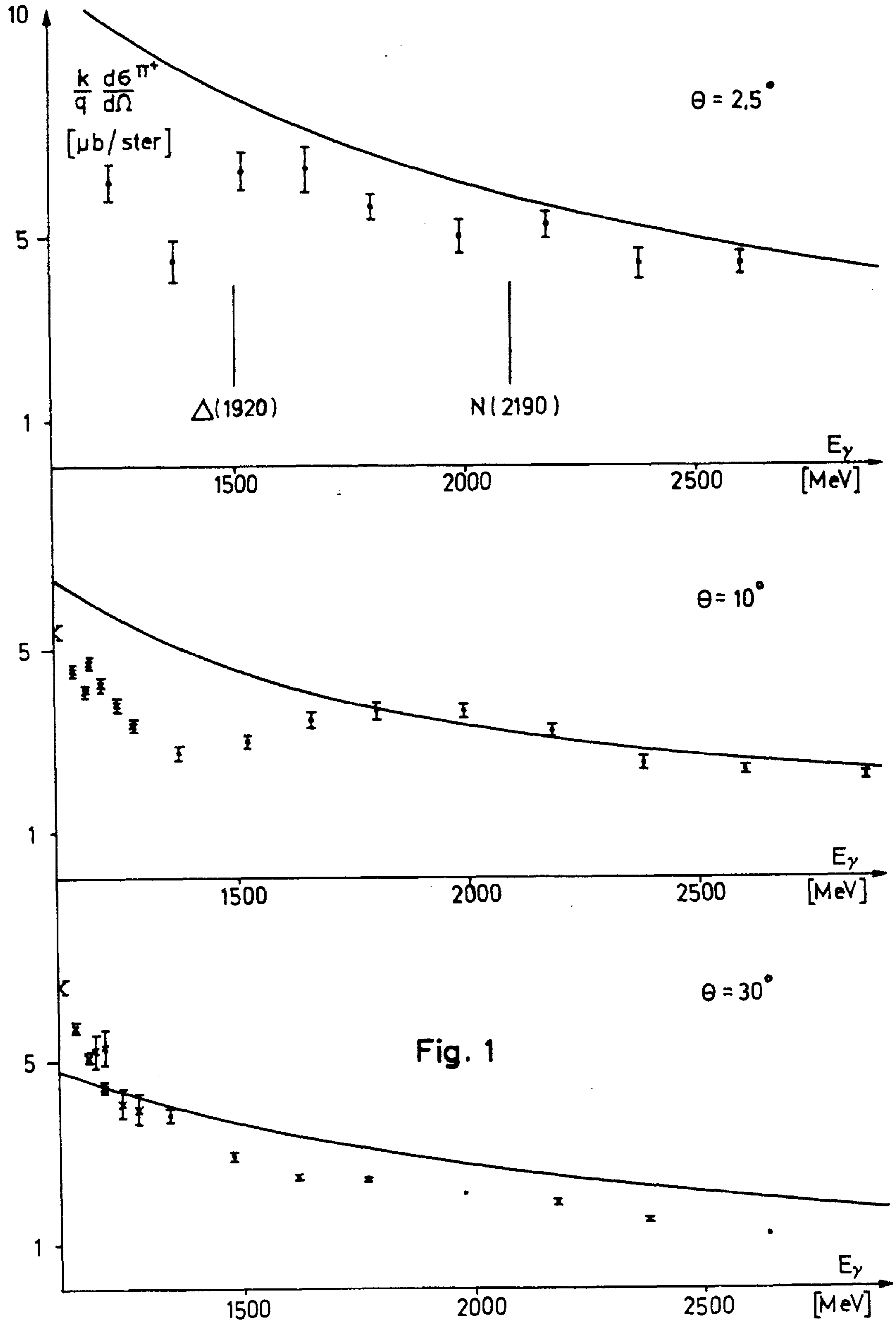
   ..... pole term; ———— II (with absorption, see text),

   —— · —— ansatz II but with $\mathrm{Im}\, E_{1+} \neq 0$.

3. π^+-angular distributions at $E_\gamma = 2180$ MeV and 2630 MeV.

   Experimental data.[1]

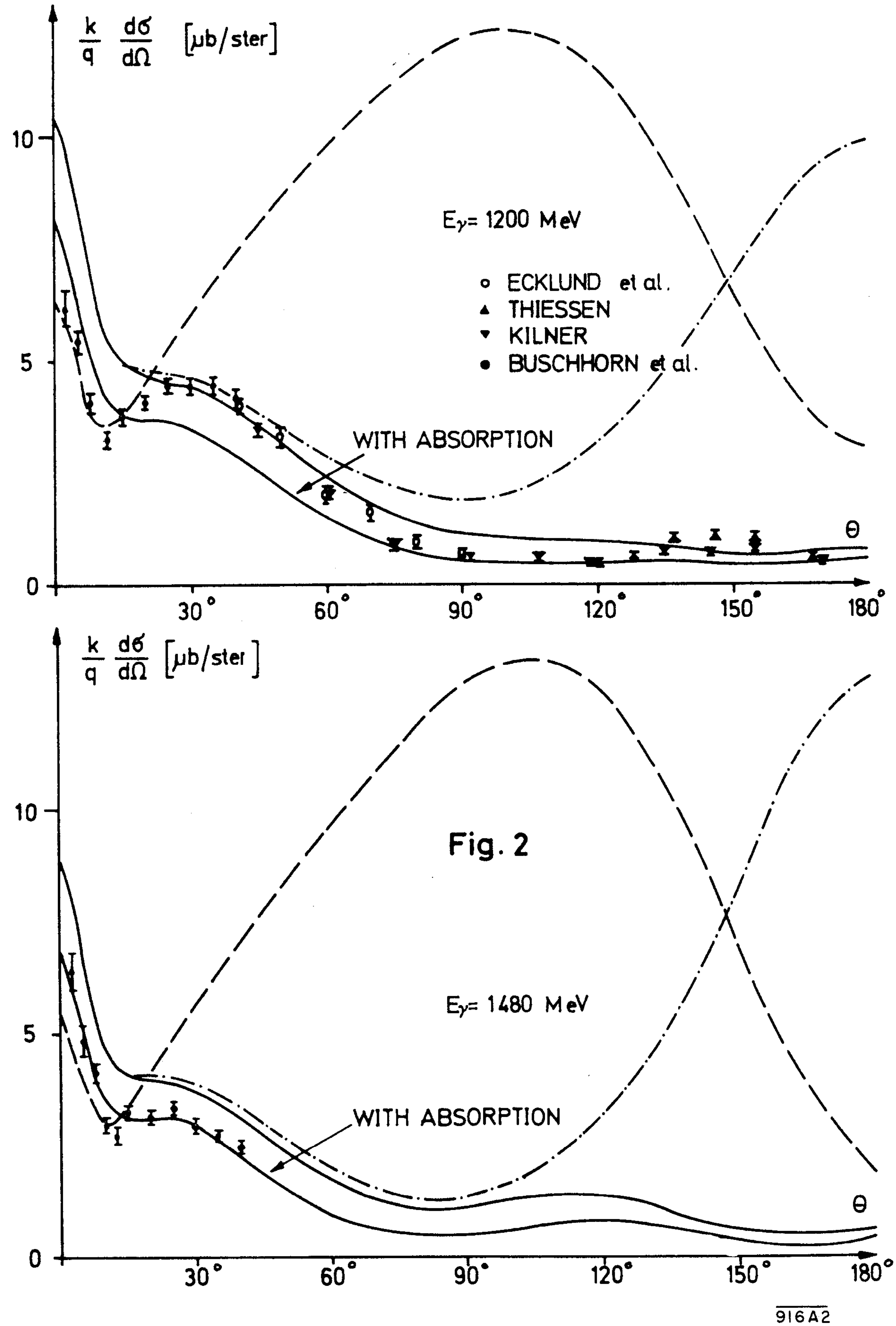
4. $\Delta\left(\frac{k}{q}\frac{d\sigma}{d\Omega}\right)$ [Eq. (3)] for $\Delta\mathrm{Re}\, E_{3+} = \Delta\mathrm{Re}\, M_{3+} = \Delta\mathrm{Re}\, E_{4-} = \Delta\mathrm{Re}\, M_{4-} = 0.05 \cdot 10^{-2} \lambda\!\!\!^{-}$.



10
5
1
$\frac{k}{q} \frac{d\sigma^{\pi^+}}{d\Omega}$
[μb/ster]
Θ = 2,5°
Δ(1920)
N(2190)
E_γ
1500
2000
2500
[MeV]
Θ = 10°
Θ = 30°

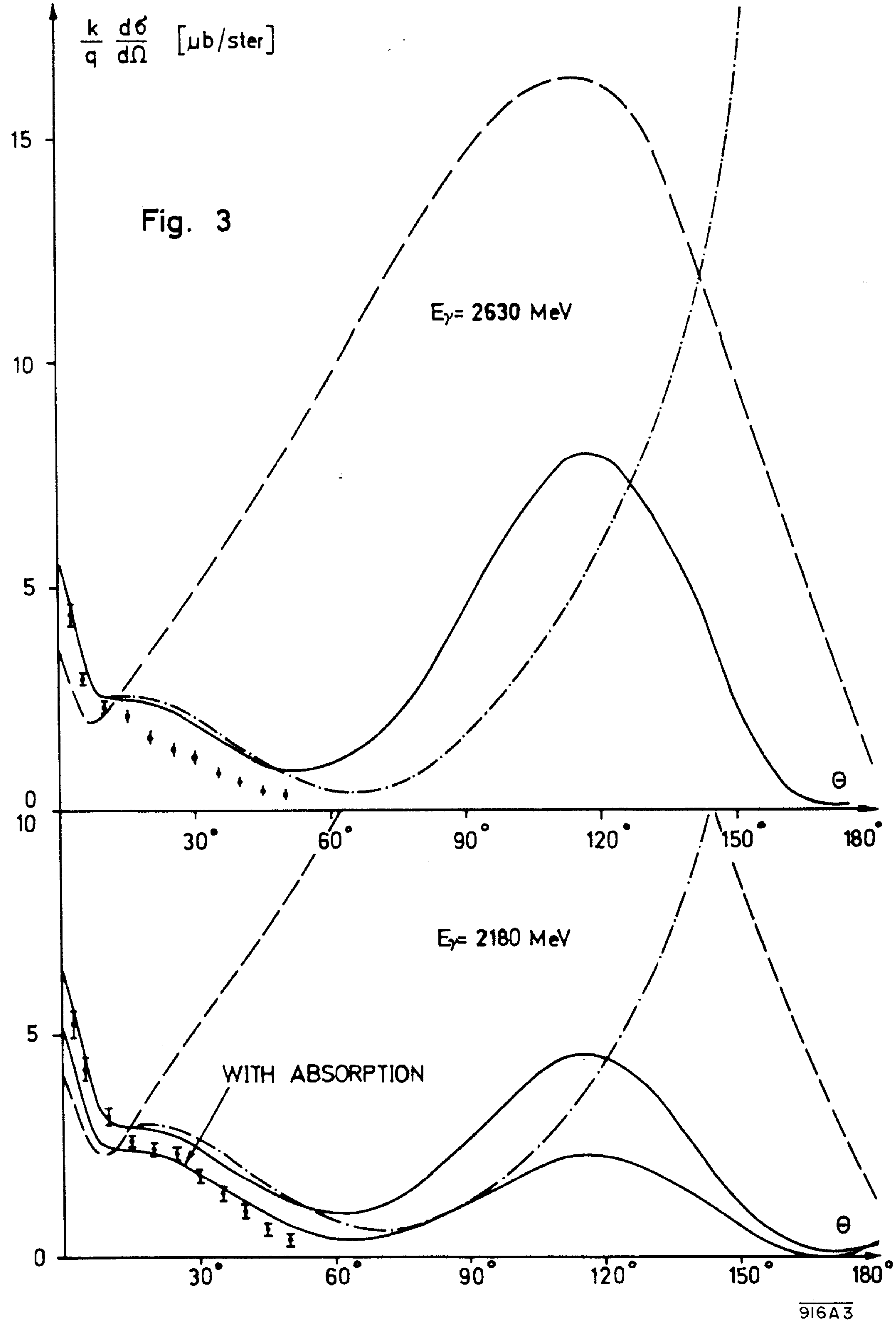
Fig. 1

916A1

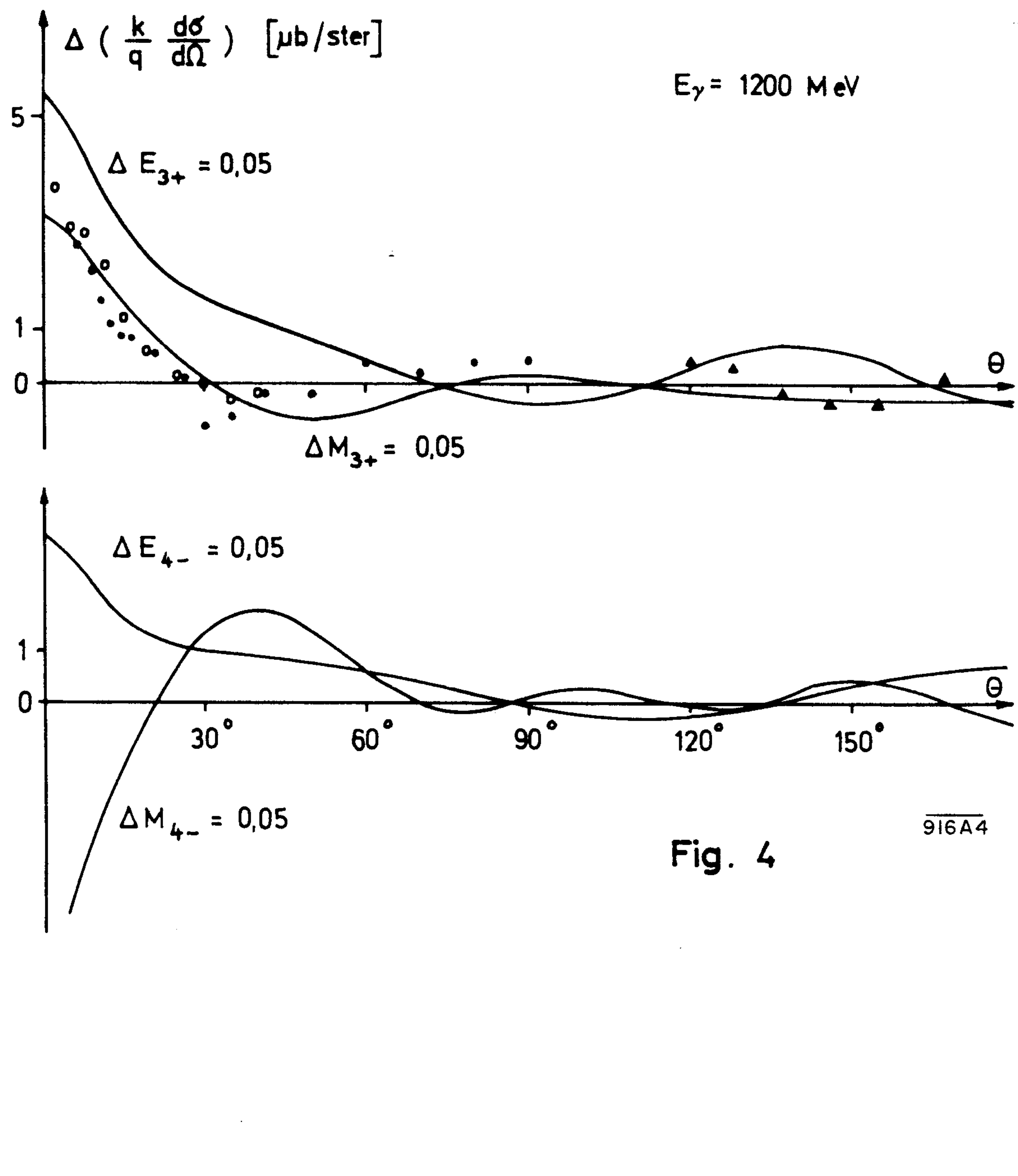


k/q dσ/dΩ [μb/ster]
10
5
0
Eγ= 1200 MeV
ECKLUND et al.
THIESSEN
KILNER
BUSCHHORN et al.
WITH ABSORPTION
Θ
30°
60°
90°
120°
150°
180°
k/q dσ/dΩ [μb/ster]
10
5
0
Eγ= 1480 MeV
WITH ABSORPTION
Θ
30°
60°
90°
120°
150°
180°
916A2

Fig. 2



k/q dσ/dΩ [μb/ster]
15
10
5
0
Fig. 3
Eγ= 2630 MeV
Θ
10
30°
60°
90°
120°
150°
180°
Eγ= 2180 MeV
5
WITH ABSORPTION
Θ
0
30°
60°
90°
120°
150°
180°
916A3



Δ (k/q dσ/dΩ) [μb/ster]
Eγ = 1200 MeV
5
1
0
ΔE3+ = 0,05
ΔM3+ = 0,05
Θ
ΔE4− = 0,05
ΔM4− = 0,05
30°
60°
90°
120°
150°
916A4

Fig. 4