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REMARKS ON PROTON-COMPTON SCATTERING.

Nota interna n. 208

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It is well known that the main contribution to proton Compton scattering in the energy region of and below the peak corresponding to the 3 - 3 pion-nucleon resonance comes from the one-nucleon and the pion-nucleon intermediate states (diagrams (a) and (b) of fig. 1). However, in the range of photon lab. energy E_{γ} = 150 ÷ 230 MeV, the experimental results are in disagreement with the dispersion theoretical predictions, which are based on the above-mentioned intermediate states[1]. This indicates that certain contributions of the exchange type, the most important of which are given in the diagrams (c), (d) and (e) of fig. 1, may be of great significance. Now, Lapidus and Chou Kuang-chao[2] have given arguments in support of the fact that the one-pion exchange contribution (diagram (c)) makes the disagreement even stronger.[x] This being so, it is the purpose of the present letter to show that: (i) inclusion of the contributions (d) and (e) may account for the difference in a natural way; (ii) certain extreme values of the η^{o}-lifetime in its decay into two photons must definitely be excluded by the proton Compton scattering experimental

(x) - The acceptable value for the lifetime of $\pi^{o} \rightarrow 2\gamma$ is 2 x x 10^{-16} sec. With this value, the contribution (c) is rather insignificant, irrespective of its sign.

data, and (iii) experiments with polarized γ's (which now are reasonably easy[3]) can give information about the relative importance of the contributions (d) and (e) and therefore about the order of magnitude of the lifetime of $\eta^0 \to 2\gamma$.

Recent evidence concerning the quantum numbers of the η_0 particle[4] supports the assignment $J^{PG}=0^{-+}$; therefore, an η_0 can well be exchanged between a photon and a nucleon. If, therefore, we write the center-of-momentum amplitude for the scattering of photons by nucleons in the form[2]:

$$
\begin{aligned}
A = {} & R_1(\hat{e}_1,\hat{e}_2) + R_2(\hat{k}_1\times\hat{e}_1,\ \hat{k}_2\times\hat{e}_2) + iR_3(\vec{\sigma},\hat{e}_2\times\hat{e}_1) + \\
& + iR_4(\vec{\sigma}[\hat{k}_2\times\hat{e}_2]\times[\hat{k}_1\times\hat{e}_1]) + iR_5\big((\vec{\sigma}\hat{k}_1)(\hat{k}_2,\hat{e}_2\times\hat{e}_1) - \\
& - (\vec{\sigma}\hat{k}_2)(\hat{k}_1,\hat{e}_1\times\hat{e}_2)\big) + iR_6\big((\vec{\sigma}\hat{k}_2)(\hat{k}_2,\hat{e}_2\times\hat{e}_1) - (\vec{\sigma}\hat{k}_1)(\hat{k}_1,\hat{e}_1\times\hat{e}_2)\big)
\end{aligned}
\tag{1}
$$

we find that the π^0 and η^0 contributions to the scalar amplitudes R_i ($i = 1,2,\dots,6$) are as follows:

$$
R_1 = R_2 = R_3 = R_4 = 0 \qquad R_5 = R_6 = \pm\frac{\Lambda(k)}{x_0(k) - \cos\theta_{c.m.}} \tag{2}
$$

where

$$
\Lambda(k) = \frac{1}{e^2}\,\frac{M}{m}\,\frac{k}{E_k}\sqrt{\frac{\hbar}{m\tau}\,g^2} \tag{3}
$$

$$
x_0(k) = 1 + \frac{1}{2}\left(\frac{m}{k}\right)^2 \tag{4}
$$

and $\theta_{c.m.}$ = the c.m. scattering angle. In (3) and (4) M is the nucleon mass, k the c.m. photon momentum, E_k the c.m. proton energy, m the mass of the exchanged particle (η^0 or π^0), τ the lifetime of the exchanged particle in its decay into two γ-rays and g the coupling constant in the nucleon vertex. Now, in this phenomenological procedure the phases of the exchange contributions are not determined. Following reference (2), we will take the π^0 contribution with the lower sign in Eq. (2). However, due to the difference in the G-parity between π^0 and η^0, the sign of the η^0 contribution may well be different; in the calculations presented in figs.2 and 3 the upper sign has been used. We also take $\tau_\pi = 2 \times 10^{-16}$ sec, m = 550 MeV and, in agreement with the predictions of unitary symmetry[5],

(5) $$g^2_{\eta NN} \cong g^2_{\pi NN} = 15 .$$

Finally, comparison with the π^0-lifetime and phase-space considerations suggest that τ_η is of the order of 10^{-18}sec. At present there is no way, however, to exclude smaller values[6] and for this reason we shall treat τ_η as a free parameter.

The nucleon Compton effect also receives contributions from two-pion exchange processes (diagram (e) of fig. 1). If t is the energy variable in the crossed channel, these processes produce a branch cut $4m_\pi^2 \leq t < \infty$. Calculation of this contribution by means of the Mandelstam representation has already been considered[7,8]. Numerical results are not yet available, however, because the resulting expressions involve the T = 0 s-wave π-π phase shift and the total cross-section for $\gamma+\pi \rightarrow \pi+\pi$, on which the existing information is rather unreliable. In any case, there is some evidence[9] that the s-wave π-π amplitude exhibits a significant enhancement just above threshold[x]. In order, thus, to estimate the two-pion exchan

(x) - A pure resonance is unlikely since there is no centrifugal barrier to trap an s-wave.

ge effect we shall replace the corresponding cut by a pole at $t = t_{\rho} \cong 4m_{\pi}^2$ and simulate the whole contribution as exchange of another "particle" with quantum numbers 0^{++}, which subsequently will be denoted by σ. In this approximation and for $E_{\gamma} \lesssim 300$ MeV, the π-π exchange contribution to the amplitudes R_i is of the form(10):

$$(6)\qquad \begin{aligned} R_1 = -R_2 &\cong G e^2 \frac{1}{E_k + k}\left(1 + \frac{t_\rho}{2k^2} - x\right)^{-1} \\ R_j &\cong 0 \qquad (j = 3,4,5,6) \end{aligned}$$

Now, the over-all strength G which is a free parameter has been very roughly estimated as follows: First, for the coupling constant of the "particle" σ with the nucleon (vertex e_1 of the diagram (e), fig. 1) we have used the analysis of Scotti and Wong(11) which gives

$$(7)\qquad g^2_{\sigma NN} = 5.61$$

Second, to analyze the vertex e_2 (diagram (e) of fig. 1) we have assumed that the σ is coupled to the two photons by means of a π^+-π^- pair and we have subsequently applied lowest order perturbation theory. With a coupling constant $g^2_{\sigma NN}$ of the order of 1 and with $g^2{}_{NN}$ given by Eq. (7), the over-all strength G of Eq. (6) turns out to be

$$G \sim 1$$

This is expected on grounds of certain general arguments advanced in reference (8)(x).

(x) - Notice that an experimental value of $g^2_{\sigma\pi\pi}$ can be obtained by considering photoproduction of π^+-π^- pairs (in the very forward direction) in the field of a nucleus (Primakoff process for π^+-π^- production).

In this way we have added the diagrams (c), (d), (e) of fig. 1 to the dispersion theoretical predictions of reference 1 (Table IV) which take care of the contributions (a) and (b) to the amplitudes R_i. The values of the c.m. differential cross-section $\left(\frac{d\sigma}{d\Omega}\right)_{unpol.}$ for scattering of unpolarized photons on protons at $\theta_{c.m.} = 90°$ corresponding to a number of choices of τ_η and G are given in fig. 2. From this calculation it is clear that the η^0 and π-π exchange effects may well be responsible for the disagreement between the dispersion theoretical predictions and the experimental data in the region E_γ = 150-230 MeV. If $\tau_\eta \geq 10^{-20}$sec as is most probably the case, a significant amount of π-π exchange is necessary for a good agreement (curves III and V). It is also clear that values of $\tau_\eta < 10^{-21}$sec can be definitely excluded (curve VII) and in fact for either choice of the sign in Eq. (2) (the present experimental limit on the width of the η^0 resonance allows $\tau_\eta = 10^{-22}$sec [12]). Notice, finally, that if the η^0 contribution is significant ($\tau_\eta \leq 10^{-18}$sec) and is added with the lower sign in Eq. (2) no agreement with data can be obtained for any G.

We consider now the c.m. differential cross-section for scattering on nucleons of photons polarized perpendicular ($d\sigma_\perp$) or parallel ($d\sigma_\parallel$) to the plane of scattering. At $\theta_{c.m.} = 90°$, where the difference $d\sigma_\perp - d\sigma_\parallel$ takes its maximum value for given R_i, we find:

$$\frac{d\sigma_\perp}{d\Omega} = |R_1|^2 + |R_3|^2 + 2|R_4|^2 + |R_5|^2 + |R_6|^2 + 2\,\mathrm{Re}\,(R_4^* R_5 + R_3^* R_6)$$

$$\frac{d\sigma_\parallel}{d\Omega} = |R_2|^2 + 2|R_3|^2 + |R_4|^2 + |R_5|^2 + |R_6|^2 + 2\,\mathrm{Re}\,(R_4^* R_5 + R_3^* R_6)$$

Using these expressions and the values of R_i determined as before we have calculated the ratio $d\sigma_{\parallel}/d\sigma_{\perp}$ at $\theta_{c.m.} = 90^\circ$ for a number of values of τ_η and G (fig. 3).

We see now that from the curves of fig. 3 the following can be remarked(x): the two pion and the η^0 contributions act on $d\sigma_{\parallel}/d\sigma_{\perp}$ in opposite directions (curves 1 and 5 of fig. 3). Notice that this is contrary to what happens in the case of fig. 2 where the π-π and η^0 contribute in the same direction. Hence if the experiment gives data (with small errors) on the upper side of curve (3) (fig. 3) we conclude that the π-π exchange dominates over the η^0 contribution and therefore $\tau_\eta > 10^{-18}$ sec. On the contrary the η^0 will dominate and $\tau_\eta < 10^{-19}$ sec if the experimental data lie below curve (3).

We wish to emphasize finally that clearly observable differences between the values of $d\sigma_{\parallel}/d\sigma_{\perp}$ appear below the threshold for photopion production. This is very helpful because below this threshold the effect of the diagram (b) decreases and therefore the small uncertainties of the photoproduction analysis will be unimportant.

We would like to thank Prof. J.E. Bowcock and Dr. D.Zwanziger for a number of helpful discussions.

(x) - Due to time reversal invariance the same information for $d\sigma_{\parallel}/d\sigma_{\perp}$ could, in principle, be obtained if one uses an unpolarized beam but measures the final photon polarization.

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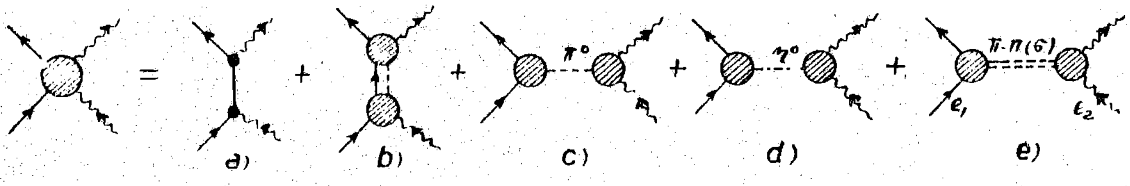


Fig. 1 - Contributions considered in the present analysis of proton-Compton scattering.

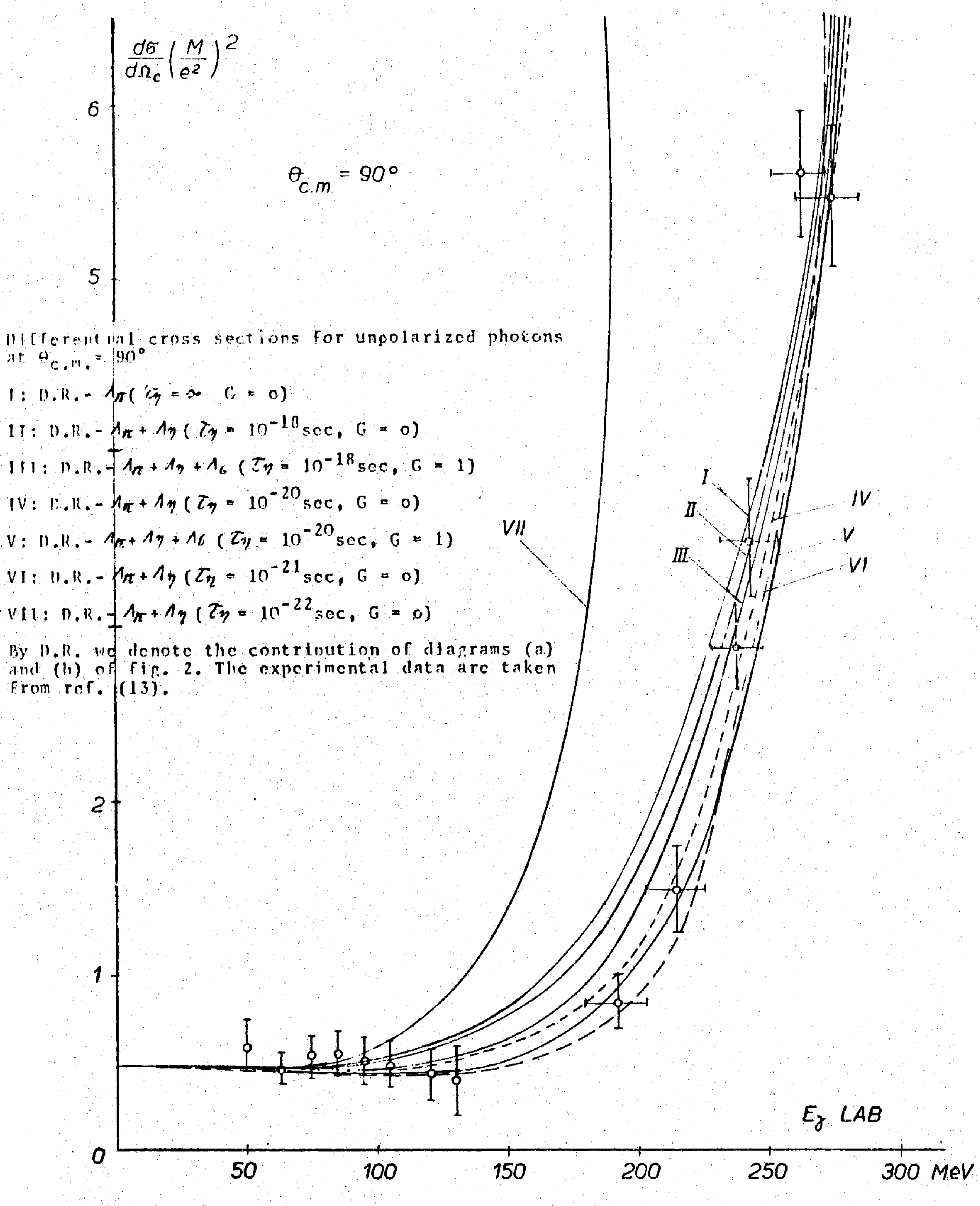


FIG. 2

Differential cross sections for unpolarized photons at $\theta_{c.m.} = 90°$

I: D.R. - Λ_π ($\tau_\eta = \infty$ G = o)

II: D.R. - $\Lambda_\pi + \Lambda_\eta$ ($\tau_\eta = 10^{-18}$sec, G = o)

III: D.R. - $\Lambda_\pi + \Lambda_\eta + \Lambda_\sigma$ ($\tau_\eta = 10^{-18}$sec, G = 1)

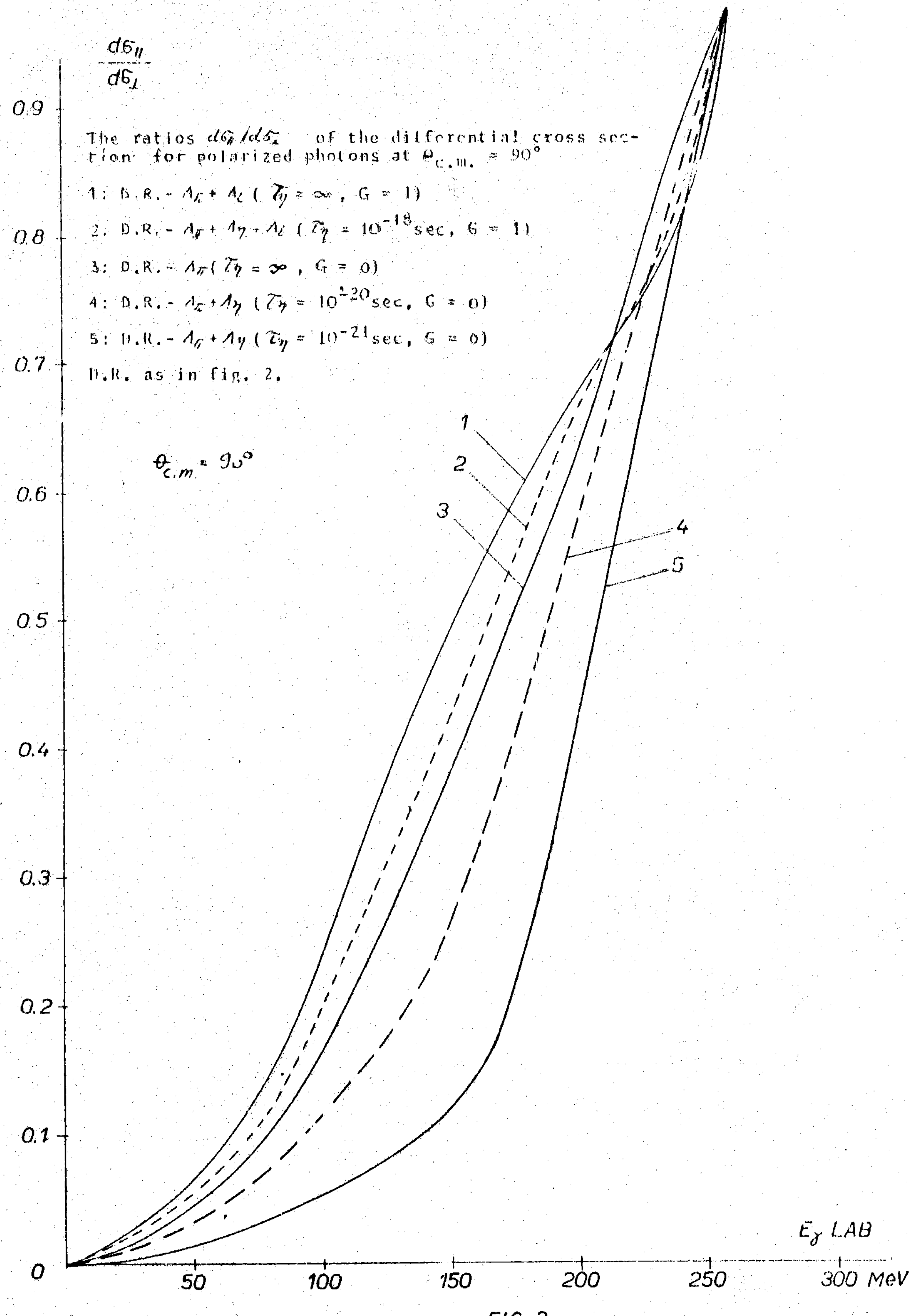
IV: D.R. - $\Lambda_\pi + \Lambda_\eta$ ($\tau_\eta = 10^{-20}$sec, G = o)

V: D.R. - $\Lambda_\pi + \Lambda_\eta + \Lambda_\sigma$ ($\tau_\eta = 10^{-20}$sec, G = 1)

VI: D.R. - $\Lambda_\pi + \Lambda_\eta$ ($\tau_\eta = 10^{-21}$sec, G = o)

VII: D.R. - $\Lambda_\pi + \Lambda_\eta$ ($\tau_\eta = 10^{-22}$sec, G = o)

By D.R. we denote the contribution of diagrams (a) and (b) of fig. 2. The experimental data are taken from ref. (13).



$d\sigma_{\parallel}/d\sigma_{\perp}$
The ratios $d\sigma_{\parallel}/d\sigma_{\perp}$ of the differential cross section for polarized photons at $\theta_{c.m.} = 90°$
1: D.R. - $A_\pi + A_\varepsilon$ ($\tau_\eta = \infty$, G = 1)
2. D.R. - $A_\pi + A_\eta + A_\varepsilon$ ($\tau_\eta = 10^{-18}$sec, G = 1)
3: D.R. - A_π($\tau_\eta = \infty$, G = 0)
4: D.R. - $A_\pi + A_\eta$ ($\tau_\eta = 10^{-20}$sec, G = 0)
5: D.R. - $A_\pi + A_\eta$ ($\tau_\eta = 10^{-21}$sec, G = 0)
D.R. as in fig. 2.
$\theta_{c.m.} = 90°$
1
2
3
4
5
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
50
100
150
200
250
300 MeV
E_γ LAB

FIG. 3