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A. Verganelakis: POSSIBLE DETERMINATION OF THE CHARACTER OF THE HIGHER RESONANCES IN PION PHOTOPRODUCTION AND PROTON COMPTON EFFECT BY USING POLARIZED γ-RAYS.

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LETTERE ALLA REDAZIONE

(La responsabilità scientifica degli scritti inseriti in questa rubrica è completamente lasciata dalla Direzione del periodico ai singoli autori).

Possible Determination of the Character of the Higher Resonances in Pion Photoproduction and Proton Compton Effect by Using Polarized γ-Rays.

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Many recent phenomenological analyses of experimental data on pion photoproduction and pion-nucleon scattering indicate that the structures, conventionally called second and third resonances, are more complicated than simple resonances in the $D_{\frac{3}{2}}$ and $F_{\frac{5}{2}}$, $T=\frac{1}{2}$ states respectively (1-5). However the experimental information is insufficient for a complete and unambiguous analysis in terms of angular-momentum states, and it turns out that different combinations of multipoles may fit equally well the existing experimental data (4). This uncertainty has led to some confusion in our understanding of these structures, and more restrictive experimental information is necessary for its clarification.

The purpose of the present letter is to point out that, in the case of photoproduction and proton Compton effect, experiments with polarized γ's (*) would be very helpful for the understanding of the above phenomena (7).

(*) At present polarized γ's are available only at low energies, but soon they will also be available for higher energies (6).

(1) M. BENEVENTANO, R. FINZI, L. MEZZETTI, L. PAOLUZI and S. TAZZARI: *Nuovo Cimento*, **28**, 1 (1963).

(2) G. HOHLER and K. DIETZ: *Analysis of photoproduction of pions* (to be published).

(3) C. PELLEGRINI and G. STOPPINI: *Nuovo Cimento*, **17**, 269 (1960).

(4) W. M. LAYSON: *Nuovo Cimento*, **27**, 724 (1963).

(5) C. D. WOOD, T. J. DEVLIN, J. A. HELLAND, M. J. LONGO, B. J. MOYER and V. PEREZ-MENDEZ: *Phys. Rev. Lett.*, **6**, 481 (1961).

(6) G. DIAMBRINI and R. F. MOZLEY: private communication.

(7) The use of polarized γ's for the study of the second resonance has been proposed by MORAVCSIK. His method requires the angular distribution of pions produced by perpendicularly polarized γ's and he shows that an isotropic distribution would be most probably caused by a mixture of $S_{\frac{1}{2}}$ and $D_{\frac{3}{2}}$ electric dipole states. *Phys. Rev. Lett.*, **2**, 171 (1959).

A) The form of the c.m. differential cross-section for pion photoproduction by polarized photons in terms of angular-momentum states, is well known [8]. With this form in mind let us consider the two cases of photon polarization — polarization perpendicular and parallel to the production plane — and let us study the corresponding differential cross-sections $d\sigma_\perp/d\Omega$ and $d\sigma_\parallel/d\Omega$ at $\theta_{c.m.}=90°$. We restrict ourselves up to D-wave contributions and, for the moment, make the unrealistic assumption that for a certain energy only one of the multipoles contributes. Then for each multipole we have the results given in Table I.

TABEL I. – *Values of* $d\sigma_\parallel/d\sigma_\perp$ *for pion photoproduction assuming that only one multipole term, indicated in the left-hand column, contributes. Nonzero and zero contributions to* $d\sigma_\parallel/d\Omega$ and $d\sigma_\perp/d\Omega$ *are indicated by « Yes » and « No » respectively.*

Multipoles (*)	j_γ	$d\sigma_\parallel/d\Omega$	$d\sigma_\perp/d\Omega$	$d\sigma_\parallel/d\sigma_\perp$
E_{01}	1	Yes	Yes	1
E_{13}	2	Yes	No	∞
E_{23}	1	Yes	Yes	4
E_{25}	3	Yes	Yes	9
M_{11}	1	Yes	Yes	1
M_{13}	1	Yes	Yes	$\frac{1}{4}$
M_{23}	2	No	Yes	0
M_{25}	2	No	Yes	0

(*) The notation is $E_{l_\pi 2J}$ for electric and $M_{l_\pi 2J}$ for magnetic multipoles; j_γ is total angular momentum of the photons.

From this table we see the following: *a*) in the ratio $d\sigma_\parallel/d\sigma_\perp$ the behaviour of magnetic multipoles is completely different from that of the corresponding electric ones (apart from E_{01} and M_{11}). *b*) At the region of energy where the state M_{13} or the state E_{23} is the only one present the ratio $d\sigma_\parallel/d\sigma_\perp$ is a constant.

Also $d\sigma_\parallel/d\sigma_\perp(M_{13}) = d\sigma_\perp/d\sigma_\parallel(E_{23})$.

Basing on this table we indicate in Fig. 1 the dashed lines (1) and (2) on which the experimental points for the ratio $d\sigma_\parallel/d\sigma_\perp$ should lie for pion photoproduction if it proceeds only through the state E_{23} or only through the state M_{13} respectively.

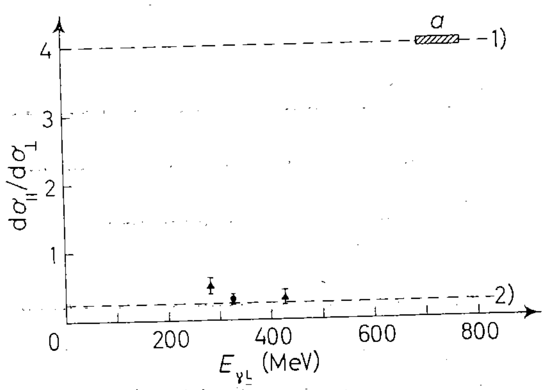

Fig. 1. – The ratio $d\sigma_\parallel/d\sigma_\perp$ *vs.* $E_{\gamma L}$ for pion-photoproduction for $\theta_{c.m.}=90°$. Experimental points should lie on the dashed line: 1) if the photoproduction proceeds through only the state E_{23}, or on the dashed line; 2) if it proceeds through only the state M_{13}. The experimental points at 750 MeV should lie on the cross-hatched area α if the second resonance is due to a pure E_{23} state. The reported experimental data at 285, 320 and 435 MeV are taken from refs. [13,9,12], respectively. ● Frascati, ▲ Stanford.

(8) See for example G. T. HOFF: *Phys. Rev.*, **122**, 665 (1961); and R. C. SMITH and R. F. MOZLEY: *Phys. Rev.*, **130**, 2429 (1963).

Now in what follows we will restrict ourselves to π^0 photoproduction for simplicity.

It has been pointed out that the resonance at 330 MeV is due to a magnetic dipole M_{13}. A recent experiment at Frascati (9) has measured the ratio $d\sigma_{\parallel}/d\sigma_{\perp}$ at $\theta_{c.m.}=90°$ and $E_{\gamma L}=330$ MeV for π^0 photoproduction and the results fit the table for M_{13} (see Fig. 1), which indicates clearly once more that at this energy all other partial waves are insignificant by comparison.

At the second resonance ($E_{\gamma L}\simeq 750$ MeV) experimental data for the ratio $d\sigma_{\parallel}/d\sigma_{\perp}$ do not exist. If this resonance is due to a pure E_{23} resonant state (*) (11) one would expect the experimental points for $d\sigma_{\parallel}/d\sigma_{\perp}$ to reach the cross-hatched area α. Now if this value of $d\sigma_{\parallel}/d\sigma_{\perp}$ is not confirmed by future experiments, but is found to be lower than 4, then it will suggest the existence of a background of states of magnetic type and possibly an E_{01} wave contribution. In that case, in order to clarify the situation, the angular distributions of $d\sigma_{\parallel}/d\Omega$, $d\sigma_{\perp}/d\Omega$, $d\sigma_{\parallel}/d\sigma_{\perp}$ and

$$(d\sigma_{\parallel}+d\sigma_{\perp})/2\,d\Omega = d\sigma/d\Omega\,,$$

at the energy of the second resonance will be very helpful.

To understand this, one has to take into account the fact that the states M_{23} and M_{25} do not contribute to $d\sigma_{\parallel}/d\Omega$ and the state E_{13} does not contribute to $d\sigma_{\perp}/d\Omega$ (see Table I). Furthermore it seems reasonable to assume that F-waves coming from the third resonance do not affect significantly the structure of the second (2), and that the E_{25} (electric octupole) gives insignificant contribution to the second resonance.

Bearing in mind these points, one may be able to discriminate between the various contributions by comparing the above-mentioned angular distributions. For example if a $D_{\frac{5}{2}}$ wave plays a certain role, as recent experimental data of Beneventano *et al.* indicate (1), then one can recognize it by the difference in behaviour of $d\sigma_{\parallel}/d\Omega$ and $d\sigma_{\perp}/d\Omega$. In the case that the multipole M_{25} predominates above all others, then $d\sigma_{\parallel}/d\Omega\to 0$ and the $d\sigma_{\perp}/d\Omega$ should be approximately twice the $d\sigma/d\Omega$ at ~ 750 MeV.

It should be pointed out that if future experiments confirm that the structure of the «second maximum» is due to only one multipole, this will indicate in principle, that contributions coming from the crossed channels are unimportant by comparison.

Similar considerations apply also to the third resonance.

B) For further confirmation of the nature of the resonances we consider now the case of the proton Compton effect. We take the form of the amplitude of the above process from ref. (14) and we calculate the c.m.differential cross-section using

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(9) G. Barbiellini, G. Bologna, G. Diambrini and G. P. Murtas: *Proc. of the 1963 Intern. Conference on Elementary Particles at Sienna* (to be published).

(*) This is not in disagreement with the observed polarization of the recoil proton in π^0 photoproduction (10).

(10) C. Mencuccini, R. Querzoli and G. Salvini: *Phys. Rev.*, **126**, 1181 (1962).

(11) R. F. Peierls: *Phys. Rev.*, **118**, 325 (1960).

(12) D. Drickey and R. F. Mozley: private communication (unpublished).

(13) D. Drickey and R. F. Mozley: *Phys. Rev. Lett.*, **8**, 291 (1962).

(14) L. I. Lapidus and Chon Kuang-Chao: *Žurn. Èksp. Teor. Fiz.*, **37**, 1714 (1959); translated *Sov. Phys. JETP*, **10**, 1213 (1960).

polarized photons. We have [15]

$$(1)\qquad \left(\frac{d\sigma}{d\Omega}\right)_{pol} = \left(\frac{d\sigma}{d\Omega}\right)_{unpol} - \frac{1}{2}\left(|R_1|^2 - |R_2|^2 - |R_3|^2 + |R_4|^2\right)\sin^2\theta\cos 2\varphi\,,$$

where φ is the angle between the photon polarization vector and the scattering plane.

The expression for R_i in terms of multipole amplitudes including those up to $J=\frac{3}{2}$ can be written

$$R_1 = \mathscr{E}_1 + 2\mathscr{E}_3 + 2\mathscr{E}_2\cos\theta - \mathscr{M}_2\,.$$

$$R_3 = \mathscr{E}_1 - \mathscr{E}_3 + 2\mathscr{E}_2\cos\theta + \tfrac{1}{2}\mathscr{M}_2 + \sqrt{6}\,C'(\mathscr{E}_3, \mathscr{M}_2)\,,$$

$$R_5 = -\mathscr{E}_2 - \sqrt{6}\,C'(\mathscr{M}_3, \mathscr{E}_2)\,.$$

The corresponding expressions for R_2, R_4, R_6 may be obtained from those for R_4, R_3, R_5, respectively, by the substitution $\mathscr{E}_i \rightleftarrows \mathscr{M}_i$. The notation is the same as in ref. [14].

If we again make the assumption that for a certain energy only one of the multipoles contributes then at $\theta_{c.m.}=90°$ eqs. (1) and (2) imply the results given in Table II.

TABLE II. (*) – *Values of* $d\sigma_{\parallel}/d\sigma_{\perp}$ *for proton Compton effect assuming that only one multipole term indicated in the left-hand column contributes. By « Yes » is indicated nonzero contributions to* $d\sigma_{\parallel}/d\Omega$ *and* $d\sigma_{\perp}/d\Omega$.

Multipoles	$d\sigma_{\parallel}/d\Omega$	$d\sigma_{\perp}/d\Omega$	$d\sigma_{\parallel}/d\sigma_{\perp}$
$\mathscr{E}_1$	Yes	Yes	1
$\mathscr{E}_2$	Yes	Yes	$\frac{5}{2}$
$\mathscr{E}_3$	Yes	Yes	$\frac{2}{5}$
$\mathscr{M}_1$	Yes	Yes	1
$\mathscr{M}_2$	Yes	Yes	$\frac{5}{2}$
$\mathscr{M}_3$	Yes	Yes	$\frac{2}{5}$

(*) Due to time-reversal invariance the above results for $d\sigma_{\parallel}/d\sigma_{\perp}$ are valid also if one uses an unpolarized beam but measures the final photon polarization.

These results are independent of the model that one may use to calculate these multipoles and are only a consequence of general properties of the amplitude. However, due to the connection of the proton Compton effect with the pion photoproduction through the unitary condition, when appropriate experimental data will be available from the first reaction one may extract supplementary information about the characrer of the latter, and viceversa.

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[15] A. P. CONTOGOURIS and A. VERGANELAKIS: *Phys. Lett.*, 6, 103 (1963).

In Fig. 2 we indicate the dashed lines (1) and (2) on which the experimental points for the ratio $\mathrm{d}\sigma_{\parallel}/\mathrm{d}\sigma_{\perp}$ should lie for the proton Compton effect if it proceeds through only the state $\mathscr{M}_3$ or through onlyt the state $\mathscr{E}_3$, respectively.

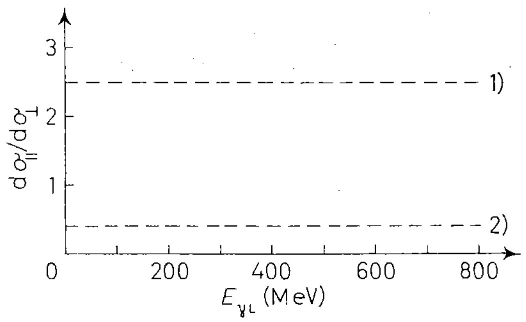

Fig. 2. – The ratio $\mathrm{d}\sigma_{\parallel}/\mathrm{d}\sigma_{\perp}$ *vs.* $E_{\gamma L}$ for proton Compton effect for $\theta_{\text{c.m.}} = 90°$. Experimental points should lie on the dashed line: 1) if the proton Compton effect proceeds through a pure $\mathscr{M}_3$ state, or on the dashed line; 2) if it proceeds through a pure $\mathscr{E}_3$ state.

It is to be noticed that if in the proton Compton effect essential divergences are observed different from the behaviour which the photoproduction implies, this will suggest that effects coming from the crossed channels are important (*).

Finally we want to stress that the remarks made here indicate only some of the possibilities to which the above analysis may be applied in the study of the structure of resonances occurring in the photoproduction and proton Compton effect.

* * *

A discussion with professors B. De Tollis, G. Salvini and Dr. D. Zwanziger is gratefully acknowledged.

(*) Quite recent experimental data in proton Compton effect with unpolarized γ's at energies that correspond to the second resonance in photoproduction, suggest that the scattering at $\theta = 90°$ proceeds largely through a (1, 3) isobar (16). But one is unable from the data to extract information regarding the details of this structure.

(16) R. F. Stiening, E. Loh and M. Deutsch: *Phys. Rev. Lett.*, **10**, 536 (1963).