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I.G.AZNAURYAN, A.S.BAGDASARYAN

ANALYSIS OF PION PHOTOPRODUCTION ON PROTONS IN II AND III RESONANCE REGIONS

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ANALYSIS OF PION PHOTOPRODUCTION ON PROTONS IN II AND III RESONANCE REGIONS

It is shown that one may single out a sufficiently large group of amplitudes $\mathcal{A}(\overset{*}{N}{}^{+} \longrightarrow P\gamma)$ whose values are independent of ambiguities available in different analyses. Estimates for these amplitudes are obtained.

Yerevan Physics Institute

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АНАЛИЗ ФОТОРОЖДЕНИЯ ПИОНОВ НА ПРОТОНАХ ВО II И III РЕЗОНАНСНЫХ ОБЛАСТЯХ

Показано, что может быть выделена довольно большая группа амплитуд $A(\overset{*}{N}{}^{+} \to p\gamma)$, значения которых не зависят от неоднозначностей, присутствующих в различных анализах. Получены оценки на эти амплитуды.

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It is well known that the pion photoproduction on nucleons in the resonance region gives information on $\overset{*}{N} \to N\gamma$ -couplings which are important to test the quark models predictions and obtain a more reliable classification on nucleon resonances. This information is of particular interest because contrary to πN -scattering, where the absolute values of amplitude $\overset{*}{N} \to N\pi$ are determined, in the pion photoproduction on nucleons not only the absolute values, but also the relative signs of the $\overset{*}{N} \to N\gamma$ and $\overset{*}{N} \to N\pi$ amplitudes products are determined.

A few analyses of data on pion photoproduction on nucleons [1-9] using different phenomenological approaches are at present performed. However it is difficult to establish from these analyses which of the obtained values of $\overset{*}{N} \to N\gamma$ couplings are model-independent and follow from the qualitative characteristics of data available. Therefore it is complicated to single out amplitudes whose values are of particular importance to verify the quark models predictions.

All the analyses [1-3] are carried out under assumption that one may neglect the non-resonance contributions in imaginary parts of the phase-shift amplitudes except for A_{0+} and A_{1-} . Such an assumption in the II and III resonance regions may be justified from the analogy with the results of πN -scattering phase-shift analyses (see, e.g. [10]). In this work we want to single out a group of amplitudes $A(N^{*+} \to P\gamma)$ whose values under this assumption are independent of ambiguities in different analyses. Specific features of resonance behaviour of experimental data can directly be put in correspondence with these amplitudes and they are well determined in order of magnitude and sign from the data qualitative analysis being independent of the models used. Here are related, as is well known, all the amplitudes $A^{P}_{1/2}$, $A^{P}_{3/2}$ in the II resonance region (see, e.g. [17]) and practically all the amplitudes $A^{P}_{3/2}$ in the III resonance region. From the data on $\Sigma(\gamma p \to \pi^{\circ} p)$ one can conclude on the positiveness of expressions $A^{\pi^{\circ}}_{0+}(S_{11}) + A^{\pi^{\circ}}_{0+}(S_{31})$ and $A^{\pi^{\circ}}_{2-}(D_{13}) + A^{\pi^{\circ}}_{2-}(D_{33})$ in the III resonance region.

II Resonance Region

This region is determined by the resonances $P_{11}(1470)$, $S_{11}(1535)$ and $D_{13}(1535)$. The $S_{11}(1535)$ and $D_{13}(1520)$ resonance masses are known sufficiently well and define a centre of the II resonance region at $E_{\gamma} = 0.73 \div 0.80$ GeV. The $P_{11}(1470)$ resonance mass is determined more poorly, there are given [10] the values $1.39 \div 1.47$ GeV for it, its width being $180 \div 240$ MeV. For convenience we give the expressions for the observables $\frac{d\sigma}{d\Omega}$, Σ, P and T through the multipoles A_1, A_{0+}, A_{2-} and B_{2-} which correspond to the resonances under question. We take into account in P and T the contribution of interferences of these multipoles with A_{1-} and B_{1-} ones of resonance $P_{33}(1232)$ which are essential between the I and II resonance regions.

$$\frac{\kappa}{q}\frac{d\sigma}{d\Omega} = \frac{9}{4}\sin^2\theta\,|B_{2-}|^2 + |A_{1-}|^2 + |A_{0+} - 2A_2|^2 - 2\cos\theta\cdot\mathrm{Re}[A_{1-}(A^*_{0+} - 2A^*_{2-})] + 3\sin^2\theta\cdot\mathrm{Re}[A_{2-}(2A^*_{0+} - A^*_{2-})], \tag{1}$$

$$\frac{d\sigma}{d\Omega}\frac{\kappa}{q}\Sigma = 3\sin^2\theta\cdot\mathrm{Re}[B_{2-}(A^*_{0+} + A^*_{2-})], \tag{2}$$

$$\frac{d\sigma}{d\Omega}\frac{\kappa}{q}P = \sin\theta\cdot\mathrm{Im}\Big\{-2(A_{1+} + A_{1-}) + \frac{9}{2}\sin^2\theta\,B_{1+}B^*_{2-} + 6\cos\theta\cdot A_{1+}A^*_{1-} + 18\cos^2\theta\,A_{1+}A^*_{2-}\Big\}, \tag{3}$$

$$\frac{d\sigma}{d\Omega}\frac{\kappa}{q}T = \sin\theta\cdot\mathrm{Im}\Big\{3[B_{1+}(A^*_{0+} + A^*_{2-}) - B^*_{2-}(A_{1+} + A_{1-})] - 3\cos\theta\cdot B_{1+}A^*_{1-} - 9\cos^2\theta(B_{1+}A^*_{2-} + B_{2-}A^*_{1+})\Big\}, \tag{4}$$

where κ and q are the photon and pion c.m. momenta, θ is the pion production c.m. angle.

1. To determine the value of amplitude $A^p_{1/2}$ of resonance $S_{11}(1535)$ it is convenient to make use of data on η -meson photoproduction near threshold. The cross section of this process is of strongly pronounced resonance nature (Fig.1). Its isotropic character and the absence of forward-backward asymmetry (Fig.2) are unambiguously interpreted as manifestation of resonance $S_{11}(1535)$ [11]. Note that this resonance is feebly marked in

$\gamma N \to N\pi$, owing to which it is difficult to separate it from the non-resonance background. Because of this there is a great difference in the values of amplitude $A^{p}_{1/2}(S_{11})$ obtained from the data analysis on $\gamma N \to N\pi$ alone: $30 \div 100 \quad 10^{-3}\sqrt{\mathrm{GeV}}$ [1-9].

The absolute values of amplitude $A^{p}_{1/2}(S_{11})$ obtained from the $\gamma p \to p\eta$ [11] data analysis are in a narrower interval: $80 \div 100 \ 10^{-3}\sqrt{\mathrm{GeV}}$, which gives for the multipole $A^{\pi^0}_{0+}(S_{11})$ in reaction $\gamma p \to p\pi^{0}$ the values $0.54 \div 0.67\ \sqrt{\mu b}$. This amplitude sign is discussed in what follows.

2. A characteristic feature of $\frac{d\sigma}{d\Omega}(\gamma p \to p\pi^{0})$ in the II resonance region is a distinctly pronounced angular dependence with a maximum at $\theta = 90^{0}$ (Fig.3) which has a resonance character (Fig.4). This dependence is less marked in $\gamma p \to n\pi^{+}$ (Fig.5) due to a large background connected with the electric Born amplitudes. Taking into account the values of multipole $A^{\pi^0}_{0+}(S_{11})$ obtained from the $\gamma p \to p\eta$ data, one can readily see that the resonance behaviour $\frac{d\sigma}{d\Omega}(\gamma N \to N\pi)$ in the II resonance region is unambiguously determined by multipole $B_{2-}(D_{13})$.

3. P and T observables in $\gamma p \to p\pi^{0}$ are of explicit resonance character (Figs. 6 , 7). Their behaviour at $\theta = 90^{0}$ is determined by the interference with multipoles $A^{\pi^0}_{1+}(P_{33}(1233)) = 1,7\sqrt{\mu b}$ and $B^{\pi^0}_{1+}(P_{33}(1232)) = -3,6\sqrt{\mu b}$ and unambiguously determines the positiveness of multipoles $A^{\pi^0}_{0+}(S_{11})$ and $B^{\pi^0}_{2-}(D_{13})$. This fixes the positiveness of signs of $A^{p}_{1/2}(S_{11})$ and $A^{p}_{3/2}(D_{13})$, and hence we obtain:

$$A^{p}_{1/2}(S_{11}) = 80 \div 100 \cdot 10^{-3}\sqrt{\mathrm{GeV}}; \qquad (5)$$
$$A^{p}_{3/2}(D_{13}) = 130 \div 180 \cdot 10^{-3}\sqrt{\mathrm{GeV}}.$$

The obtained conclusions on signs are confirmed by the data on $\Sigma(\gamma p \to p\pi^\circ)$ (Fig.8).

4. The behaviour of $\frac{d\sigma}{d\Omega}(\gamma p \to p\pi^\circ$ at $\theta = 0^0$ and 180^0 in the I and II resonance regions is determined by multipoles A_{0+}, A_{1-}, A_{1+} and A_2 :

$$\frac{d\sigma}{d\Omega}(0^\circ, 180^\circ) = \left|(A_{1-} - 2A_{1+}) \mp (A_{0+} - 2A_{2-})\right|^2. \tag{6}$$

In the first and above-resonance region we have $\frac{d\sigma^{\pi^\circ}}{d\Omega}(0^\circ) > \frac{d\sigma^{\pi^\circ}}{d\Omega}(180^\circ)$, which is connected with the interference of $A^{\pi^\circ}_{1+}(P_{33})$ with positive background contribution to $A^{\pi^\circ}_{0+}$. In the $P_{11}(1470)$ resonance region at $E_\gamma = 0.6 \div 0.7$ GeV (Fig.9) $\frac{d\sigma^{\pi^\circ}}{d\Omega}(180^\circ)$ begins increasing, which can be naturally explained by the interference of $A^{\pi^\circ}_{0+}$ (background) with the amplitude $A^{\pi^\circ}_{1-}(P_{11}(1470))$ if this amplitude is both positive and not small ($\sim 0.3 \div 0.55\sqrt{\mu b}$). The contribution of amplitude $A^{\pi^\circ}_{1+}(P_{33})$ in this region is already not of significance. Further on as the energy increases the contribution of amplitude $A^{\pi^\circ}_{0+}(S_{11}(1535))$ begins manifesting itself, which results in further increasing $\frac{d\sigma^{\pi^\circ}}{d\Omega}(180^\circ)$ and decreasing $\frac{d\sigma^{\pi^\circ}}{d\cdot}(0^\circ)$. Here the amplitude $A^{\pi^\circ}_{2-}(D_{13}(1520))$ must be small and not distort the contribution of amplitude $A^{\pi^\circ}_{0+}(S_{11}(1535))$.

Thus, following the behaviour of $\frac{d\sigma}{d\Omega}(\gamma p \to p\pi^\circ)$ at $\theta = 0^0$ and 180^0 one can conclude unambiguously on the suppression of amplitude $A^p_{1/2}(D_{13})$ as well as on the value and sign of amplitude $A^p_{1/2}(P_{11})$

$$A^p_{1/2}(D_{13}) \approx 0, \tag{7}$$

$$A^{p}_{1/2}\,(P_{11}) = -(50 \div 90)\cdot 10^{-3}\,\sqrt{GeV}$$

The III Resonance Region

This region is determined by resonances $S_{31}(1650)$, $S_{11}(1700)$, $D_{13}(1700)$, $D_{33}(1670)$, $D_{15}(1670)$ and $F_{15}(1690)$, whose masses are well determined. In the centre of the III resonance region ($E_\gamma = 1 \div 1.05$ GeV) only imaginary parts of the corresponding multipoles contribute. Apparently the III resonance region involves also resonances $P_{33}(1690)$, $P_{11}(1780)$ and $P_{13}(1810)$, whose masses are determined with large errors. Multipoles A_{0+}, A_{1-}, A_{1+}, B_{1+}, A_{2-}, B_{2-}, A_{2+}, B_{2+}, A_{3-}, B_{3-} with $I = \frac{1}{2}$, and A_{0+}, A_{1+}, B_{1+}, A_{2-}, B_{2-} with $I = \frac{3}{2}$ respectively correspond to these resonances. Let us give the expressions for the helicity amplitudes using these multipoles:

$$N = \sqrt{2}\cos\frac{\theta}{2}\left\{A_{1-} - A_{0+} + (1-3x)(A_{1+} - A_{2-}) + \left(3x + \frac{3}{2} - \frac{15}{2}x^2\right)(A_{2+} - A_{3-})\right\}, \tag{8}$$

$$S_1 = \frac{\sin\theta}{\sqrt{2}}\cos\frac{\theta}{2}\left\{-3(B_{1+} - B_{2-}) + 3(1-5x)(B_{2+} - B_{3-})\right\},$$

$$S_2 = \sqrt{2}\sin\frac{\theta}{2}\left\{A_{1-} + A_{0+} + (1+3x)(A_{1+} + A_{2-}) + \left(3x - \frac{3}{2} + \frac{15}{2}x^2\right)(A_{2+} + A_{3-})\right\},$$

$$D = \frac{\sin\theta}{\sqrt{2}}\sin\frac{\theta}{2}\left\{3(B_{1+} + B_{2-}) + 3(1+5x)(B_{2+} + B_{3-})\right\}.$$

1. A characteristic feature of differential cross sections of $\gamma p \to p\pi^0$ and $\gamma p \to n\pi^+$ in the III resonance region is the structure with maxima at $\theta = 45^0$ and 135^0 which is of strongly pronounced resonance character (Figs.10-13). At the same time at $\theta = 0$, 90 and 180^0 the resonance structure of these cross sections is feebly pronounced. These features of the resonance behaviour of $\frac{d\sigma}{d\Omega}$ are most naturally described by the term $|S_1|^2 + |D|^2$ [illegible]. Its contribution to $\frac{d\sigma}{d\Omega}$ is

$$\frac{d\sigma_{res}}{d\Omega} \equiv \frac{1}{2}\left(|S_1|^2 + |D|^2\right) = \frac{9}{4}\sin^2\theta \; Re\Big\{|B_{2-} + B_{2+}|^2 + \tag{9}$$

$$+ |B_{1+} + B_{3-}|^2 + 2\cos\theta\big[B_{2+} B^*_{3-}(9 - 25\cos^2\theta) + 4B_{2-} B^*_{3-} +$$

$$+ 4B_{1+} B^*_{2+} - B_{2-} B^*_{1+}\big] + 15\cos^2\theta\big[|B_{2+}|^2 + |B_{3-}|^2 -$$

$$- \frac{2}{3}\left(B_{2-} B^*_{2+} + B_{1+} B^*_{3-}\right)\big]\Big\}.$$

2. It is seen from (9) that the structure of $\frac{d\sigma}{d\Omega}$ with two maxima can arise only in the case when multipoles $B_2(D_{15}(1650))$ and $B_{3-}(F_{15}(1690))$ are nonzero. However from the symmetricity of $\frac{d\sigma}{d\Omega}(\gamma p \to p\pi^0)$ in the centre of the III resonance region at $E_\gamma = 1 \div 1.05$ GeV (Fig.10) one can unambiguously conclude that one of these multipoles must be suppressed. Indeed, at these energies we have

$$\frac{d\sigma^{\pi^0}_{res}}{d\Omega}(45^\circ) - \frac{d\sigma^{\pi^0}}{d\Omega}(135^\circ) = \frac{9}{4\sqrt{2}}\Big\{8X_{\pi^0} - 7\,Re\big[B^{\pi^0}_{2+}(D_{15})\cdot \tag{10}$$

$$B^{\pi^0 *}_{3-}(F_{15})\big]\Big\} \approx 0,$$

where

$$X_{\pi^0} \equiv \mathrm{Re}\Big\{\big[B_{2-}^{\pi^0}(\mathcal{D}_{13}) + B_{2-}^{\pi^0}(\mathcal{D}_{33})\big]\, B_{3-}^{\pi^0 *}(F_{15}) + \big[B_{1+}^{\pi^0}(P_{13}) + B_{1+}^{\pi^0}(P_{33})\big]\, B_{2+}^{\pi^0 *}(\mathcal{D}_{15})\Big\} \qquad (11)$$

Making use of this relation we obtain for the cross sections differences

$$\Delta_1 \equiv \frac{d\sigma_{res}^{\pi^0}}{d\Omega}(45^\circ) - \frac{d\sigma_{res}^{\pi^0}}{d\Omega}(60^\circ), \qquad (12)$$

$$\Delta_2 \equiv \frac{d\sigma_{res}^{\pi^0}}{d\Omega}(135^\circ) - \frac{d\sigma_{res}^{\pi^0}}{d\Omega}(120^\circ),$$

the following

$$\Delta_1(\Delta_2) = \frac{99}{64}\Big\{|B_{3-}^{\pi^0}(F_{15})|^2 + |B_{2+}^{\pi^0}(\mathcal{D}_{15})|^2 - \frac{18}{11}\,y \mp \frac{75}{11}\,\mathrm{Re}\big[B_{2+}^{\pi^0}(\mathcal{D}_{15})\, B_{3-}^{\pi^0 *}(F_{15})\big]\Big\}, \qquad (13)$$

where

$$y \equiv \mathrm{Re}\Big\{\big[B_{2-}^{\pi^0}(\mathcal{D}_{13}) + B_{2-}^{\pi^0}(\mathcal{D}_{33})\big]\, B_{2+}^{\pi^0}(\mathcal{D}_{15}) + \big[B_{1+}^{\pi^0}(P_{13}) + B_{1+}^{\pi^0}(P_{33})\big]\, B_{3-}^{\pi^0 *}(F_{15})\Big\} \qquad (14)$$

One can see from (13) that even not large in value interference of amplitudes $B_{2+}^{\pi^0}(\mathcal{D}_{15})$ and $B_{3-}^{\pi^0}(F_{15})$ breaks substantially the symmetricity of $\frac{d\sigma}{d\Omega}(\gamma p \rightarrow p\pi^0)$ in the III resonance region, hence we have the following two solutions:

$$(\mathrm{I}) \quad |B_{3-}^{\pi^0}(F_{15})| \approx 0{,}3 \div 0{,}4\sqrt{\mu b}\,, \quad B_{2+}^{\pi^0}(\mathcal{D}_{15}) \approx 0, \qquad (15)$$

$$(\mathrm{II}) \quad |B_{2+}^{\pi^0}(\mathcal{D}_{15})| \approx 0{,}3 \div 0{,}4\sqrt{\mu b}\,, \quad B_{3-}^{\pi^0}(F_{15}) \approx 0. \qquad (16)$$

For the both solutions from (10) we have

$$X_{\pi^0} \approx 0. \qquad (17)$$

All the analyses available [1-8] are based on solution (I). As the argument in favour of this solution is, to our mind, the behaviour of $\frac{d\sigma}{d\Omega}(\gamma p \to p\pi^\circ)$ between II and III resonance regions, where $\frac{d\sigma^{\pi^\circ}_{res}}{d\Omega}(45^\circ)$, as the energy decreases, falls more rapidly than $\frac{d\sigma^{\pi^\circ}_{res}}{d\Omega}(135^\circ)$ (Fig.14). Such a behaviour of $\frac{d\sigma}{d\Omega}(\gamma p \to p\pi^\circ)$ is most naturally accounted for by the increase of the interference with the positive amplitude $B_{2-}(\mathcal{D}_{13}(1520))$ which takes place for the solution (I) alone (see (10, 11)). This interference increasing most essentially affects the real parts of the amplitudes and this determines the positiveness of the amplitude $B^{\pi^\circ}_{3-}(F_{15})$ in solution (I).

3. In the centre of the III resonance region the relation between the sums of $\frac{d\sigma_{res}}{d\Omega}(45^\circ)$ and $\frac{d\sigma_{res}}{d\Omega}(135^\circ)$ for $\gamma p \to p\pi^\circ$ and $\gamma p \to n\pi^+$ is determined by the interference of amplitudes $B^{3/2}_{1+}$ and $B^{1/2}_{3-}$ for solution (I) and $B^{3/2}_{2-}$ and $B^{1/2}_{2+}$ for solution (II):

$$\Delta = \frac{1}{2}\left[\frac{d\sigma^{\pi^+}_{res}(45^\circ)}{d\Omega} + \frac{d\sigma^{\pi^+}_{res}(135^\circ)}{d\Omega}\right] - \left[\frac{d\sigma^{\pi^\circ}_{res}(45^\circ)}{d\Omega} + \frac{d\sigma^{\pi^\circ}_{res}(135^\circ)}{d\Omega}\right] = \frac{g'}{8}\,\mathrm{Re}\left\{B^{\pi^\circ}_{1+}(P_{33})B^{\pi^\circ *}_{3-}(F_{15}) + B^{\pi^\circ}_{2-}(\mathcal{D}_{33})B^{\pi^\circ *}_{2+}(\mathcal{D}_{15})\right\}, \qquad (12)$$

$$|\Delta| < 0{,}5\,\mu b.$$

This relation permits to find out the values of amplitudes $B^{\pi^\circ}_{1+}(P_{33})$ and $B^{\pi^\circ}_{2-}(\mathcal{D}_{33})$ respectively for solutions (I) and (II).

4. For the further analysis let us use the fact that in the centre of the III resonance region $\frac{d\sigma^{\exp}}{d\Omega}(\gamma p \to n\pi^{+})$ at $\theta = 45^{0}$ is approximately by 3-4 μb as higher as at $= 135^{0}$. Taking into account (15, 16) we obtain

$$X_{\pi^{+}} = 2\,\mathrm{Re}\left\{\left[B_{2-}^{\pi^{0}}(\mathcal{D}_{13}) - \frac{1}{2}B_{2-}^{\pi^{0}}(\mathcal{D}_{33})\right]B_{3-}^{\pi^{0}*}(F_{15}) + \right. \tag{19}$$

$$\left. + \left[B_{1+}^{\pi^{0}}(P_{13}) - \frac{1}{2}B_{1+}^{\pi^{0}}(P_{33})\right]B_{2+}^{\pi^{0}*}(\mathcal{D}_{15})\right\} \approx 0{,}24 \div 0{,}32\,\mu b.$$

For solution (I) from the comparison of relations (11, 15, 19) we find unambiguously that amplitude $B_{2-}^{\pi^{0}}(\mathcal{D}_{33})$ is nonzero and its sign is opposite to that of $B_{3-}^{\pi^{0}}(F_{15})$, i.e. negative. Note also that in the III resonance region the contribution of a large positive amplitude $B_{2-}^{\pi^{0}}(\mathcal{D}_{13}(1520))$ noticeably affects, then relations (11, 17) confirm our conclusion on the negative sign of amplitude $B_{2-}^{\pi^{0}}(\mathcal{D}_{33})$ Finally, for solution (I) from relations (11, 15, 17-19) we obtain

$$(\bar{\mathrm{I}})\quad \begin{cases} B_{3-}^{\pi^{0}}(F_{15}(1690)) = 0{,}3 \div 0{,}4\sqrt{\mu b}, \quad A_{3/2}^{p}(F_{15}) = 97 \div 130\cdot 10^{-3}\sqrt{\mathrm{GeV}}; \\ B_{2-}^{\pi^{0}}(\mathcal{D}_{33}(1670)) = -(0{,}2 \div 0{,}3)\sqrt{\mu b}, \quad A_{3/2}^{p}(\mathcal{D}_{33}) = 59 \div 88\cdot 10^{-3}\sqrt{\mathrm{GeV}}; \\ \left[B_{2-}^{\pi^{0}}(\mathcal{D}_{13}(1520))\right]_{\underline{\mathrm{III}}} + B_{2-}^{\pi^{0}}(\mathcal{D}_{13}(1700)) = 0{,}2 \div 0{,}3\sqrt{\mu b}; \\ \left|B_{1+}^{\pi^{0}}(P_{33}(1690))\right|_{\underline{\mathrm{II}}} < 0{,}15\sqrt{\mu b}; \\ B_{2+}^{\pi^{0}}(\mathcal{D}_{15}(1670)) \approx 0. \end{cases} \tag{20}$$

In [20] $[B_{2-}^{\pi^0}(D_{13}(1520))]_{\underline{III}}$ is the contribution of resonance $D_{13}(1520)$ to the multipole $B_{2-}^{\pi^0}$ in the III resonance region. The value of this contribution is model-dependent and we cannot find out unambiguously on its background the value of amplitude $B_{2-}^{\pi^0}(D_{13}(1700))$. The expression $[B_{1+}^{\pi^0}(P_{33}(1690))]_{\underline{III}}$ is the contribution of resonance $P_{33}(1690)$ to the multipole B_{1+} in the III resonance region. The value of amplitude $B_{1+}^{\pi^0}(P_{33}(1690))$, proceeding from its quality, depends upon the resonance $P_{33}(1690)$ mass. The value of amplitude $B_{1+}^{\pi^0}(P_{13}(18$ from the differential cross section data in solution (I) cannot be determined.

For solution (II) the relations (11, 17, 19) are compatible only in the case when the contributions of the both resonances $P_{13}(1810)$ and $P_{33}(1690)$ are essential in the III resonance region:

$$B_{2+}^{\pi^0}(D_{15}(1670)) = \xi \cdot 0,3 \div 0.4\sqrt{\mu b}\,; \qquad (21)$$

$$[B_{1+}^{\pi^0}(P_{33}(1690))]_{\underline{III}} = -\xi \cdot 0,2 \div 0,3\sqrt{\mu b}\,;$$

$$[B^{\pi^0}(P_{13}(1810))]_{\underline{III}} = \xi \cdot 0,2 \div 0,3\sqrt{\mu b}\,;$$

$$|E_{2-}^{\pi^0}(D_{33}(1670))| < 0,15\sqrt{\mu b}$$

$$B_{3-}^{\pi^0}(F_{15}(1690)) \approx 0.$$

The sign ξ of amplitude $B_{2+}^{\pi^0}(D_{15}(1670)$ as well as the value of amplitude $B_{2-}(D_{13}(1700))$ from the differential cross sections data in solution (II) are out of determination.

Thus, from the analysis of the resonance behaviour of differential cross sections in the III resonance region one can obtain the two solutions for amplitudes $A^p_{3/2}$, the results (20) obtained for solution (I) agreeing well with the results of all the analyses [1-8]. The discrepancies with [8] are accounted for by the fact that in [8] only the data on $\gamma p \to p\pi^0$ are considered. We emphasize that all these conclusions are under assumption that the non-resonance contributions to the imaginary parts of the partial amplitudes under question are negligible.

5. For the further analysis and obtaining information on amplitudes $A^p_{1/2}$ it is convenient to consider data on $\Sigma(\gamma p \to p\pi^0)$ and $\Sigma(\gamma p \to n\pi^+)$ in the III resonance region, for these quantities different signs at small and large angles (Figs.15, 16) are typical. Such a behaviour of Σ is of resonance character (Figs.17, 18) (which is most pronounced in data on $\Sigma(\gamma p \to p\pi^0)$) and indicates to the contribution and resonance character of those terms in Σ that are proportional to $\cos\theta$ and $\cos^3\theta$

Let us write out these terms:

$$\Sigma^{(+)} = \frac{3\cos\theta\sin^2\theta}{d\sigma/d\Omega} Z , \qquad (22)$$

where

$$Z = \mathrm{Re}\Big\{(5A_{0+} + 2A_{2-})B^*_{3-} - 3(A_{2-} + A_{2+})B^*_{1+} + 3(A_{1+} + A_{3-})B^*_{2-} -$$

$$- (5A_{1-} + 3A_{3-})B^*_{2+}\Big\}.$$

The further analysis we shall make for solution (I) where $\mathrm{Im}\, B_{2+} = 0$ For this solution we also have $\mathrm{Im}\, B_{2-}(\gamma p \to p\pi^0) = 0$ and $B^{\pi^0}_{1+}(P_{33}(1690)$ is suppressed. Hence, the expression (22) for

$\gamma p \to p\pi^{\circ}$ is essentially simplified and we obtain in the centre of the III resonance region the following:

$$Z(\gamma p \to p\pi^{\circ}) = \Big\{\big[5\big(A_{0+}^{\pi^{\circ}}(S_{11}) + A_{0+}^{\pi^{\circ}}(S_{31})\big) + 2\big(A_{2-}^{\pi^{\circ}}(D_{13}) + A_{2-}^{\pi^{\circ}}(D_{33})\big)\big] B_{3-}^{\pi^{\circ}}(F_{15}) - 3\big[A_{2-}^{\pi^{\circ}}(D_{13}) + A_{2-}^{\pi^{\circ}}(D_{33}) + A_{2+}^{\pi^{\circ}}(D_{15})\big] \cdot B_{1+}^{\pi^{\circ}}(P_{13})\Big\} \approx 2. \tag{23}$$

As far as amplitude $B_{3-}^{\pi^{\circ}}(F_{15})$ is large and positive, it follows from (23) that

$$A_{0+}^{\pi^{\circ}}(S_{11}) + A_{0+}^{\pi^{\circ}}(S_{31}) > 0, \tag{24}$$

$$A_{2-}^{\pi^{\circ}}(D_{13}) + A_{2-}^{\pi^{\circ}}(D_{33}) > 0. \tag{25}$$

If expressions (24) and (25) are saturated by contributions of resonances alone, then expression (25) agrees with predictions of a quark model, whil expression (24) contradicts it. This indicates either to a large positive contribution of the non-resonance background to (24) (which is in accord with Ref. [8]), or to the violation of predictions of the quark model (which is in accord with Ref. [7]). For a final solution of this question a detailed phase-shift analysis of the experimental data is necessary.

Since for $\gamma p \to n\pi^{+}$ two amplitudes $B_{3-}^{\pi^{+}}$ and $B_{2-}^{\pi^{+}}$ are large, the analysis of expression (22) for $\gamma p \to \pi^{+}n$ is ambiguous.

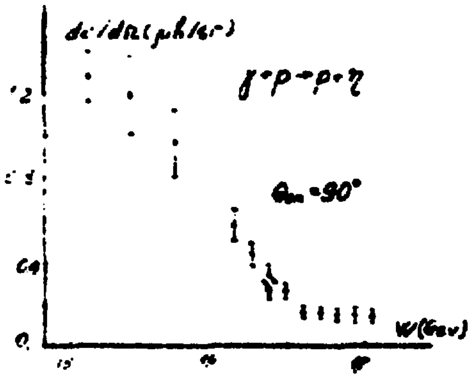

Fig. 1

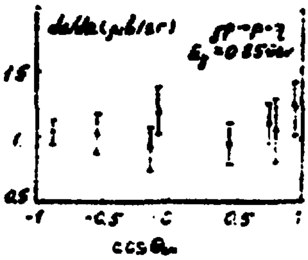

Fig.2

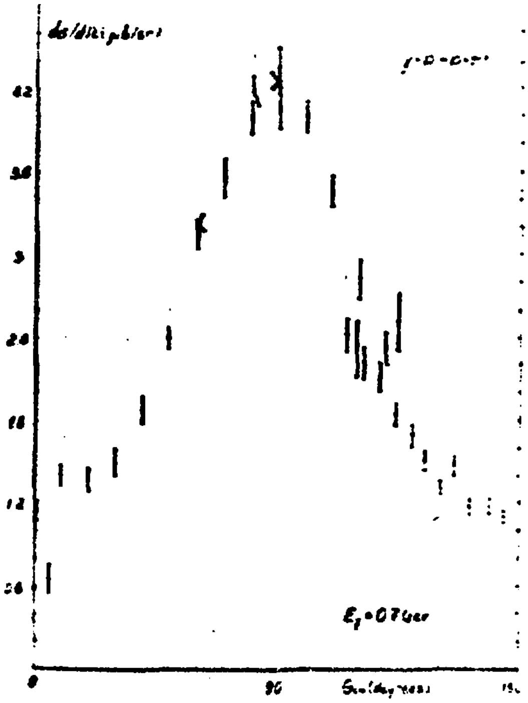

Fig.3

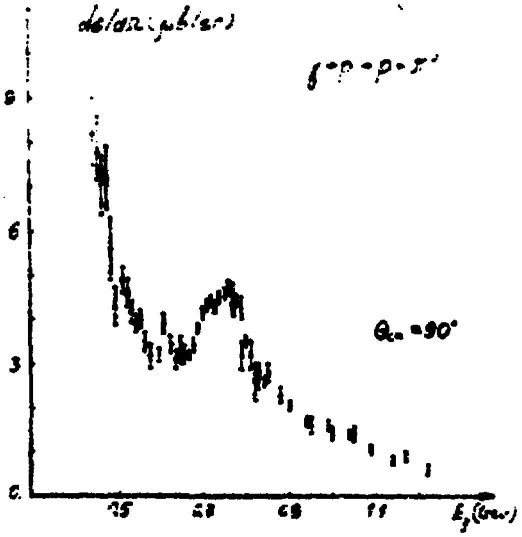

Fig.4

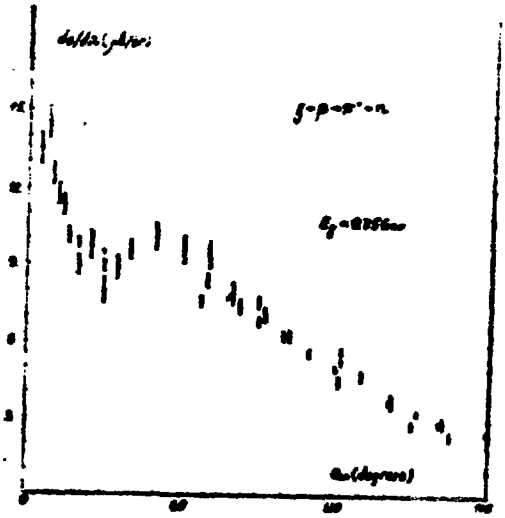

Fig.5

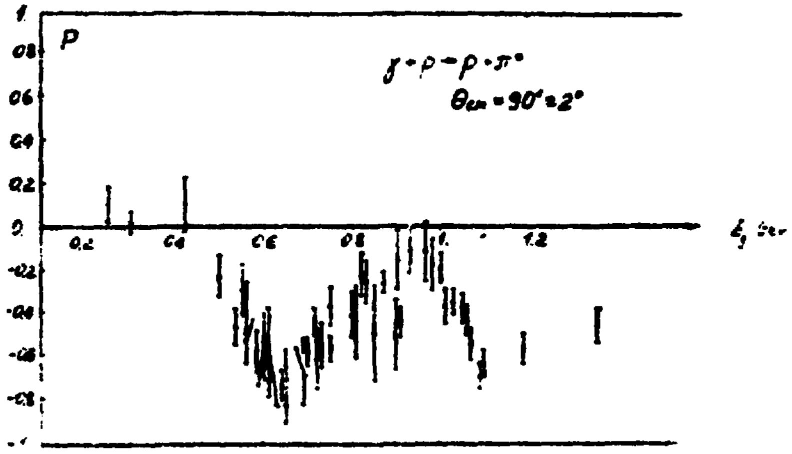
P
$\gamma + p \to p + \pi^0$
$\theta_{cm} = 90° \pm 2°$
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
0.2
0.4
0.6
0.8
1.
1.2
E_γ GeV

Fig.6

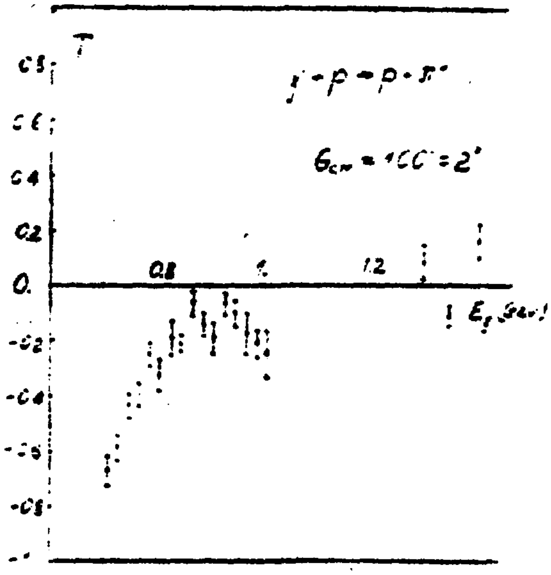
T
$\gamma + p \to p + \pi^0$
$\theta_{cm} = 100° \pm 2°$
0.8
0.6
0.4
0.2
0.
-0.2
-0.4
-0.6
-0.8
-1
0.8
1.
1.2
E_γ GeV

Fig.7

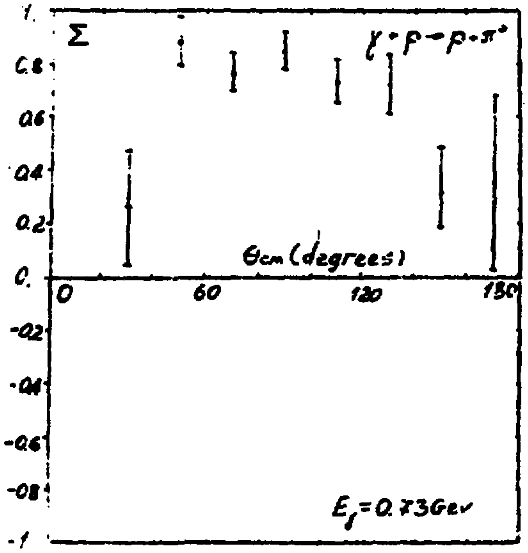
Σ
γ+p→p+π°
1.
0.8
0.6
0.4
0.2
0.
-0.2
-0.4
-0.6
-0.8
-1
0
60
120
180
θcm (degrees)
Eγ=0.73GeV

Fig.8

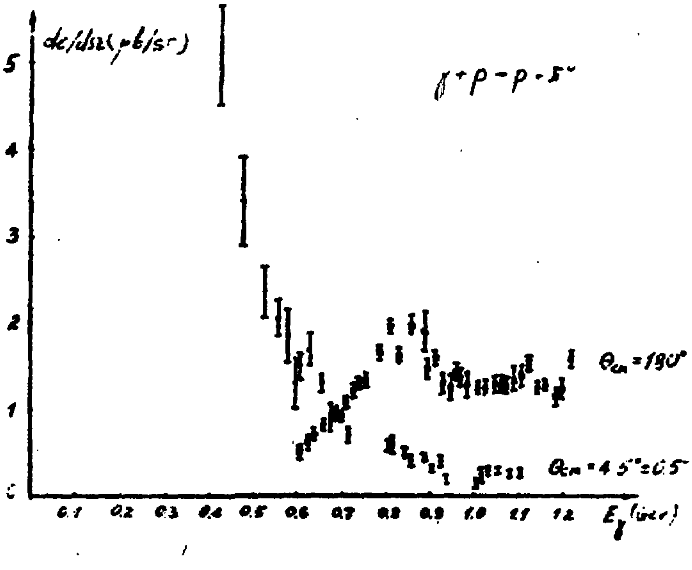
dσ/dΩ(μb/sr)
γ+p→p+π°
5
4
3
2
1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
Eγ(GeV)
θcm=180°
θcm=45°±0.5°

Fig.9

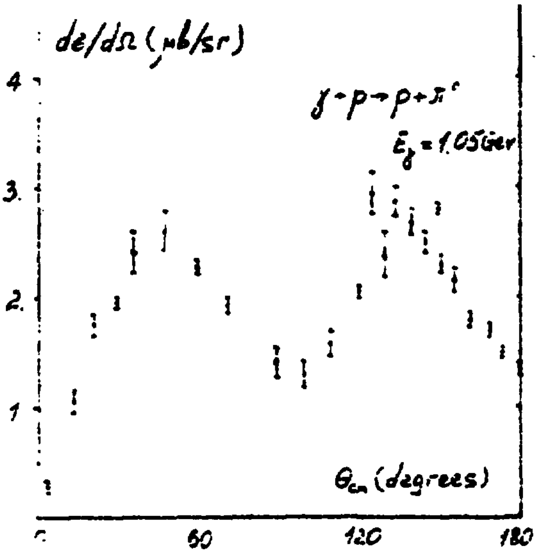
dσ/dΩ (μb/sr)
4
3.
2.
1
γ+p→p+π°
E_γ = 1.05 GeV
θ_{cm} (degrees)
0
60
120
180

Fig.10

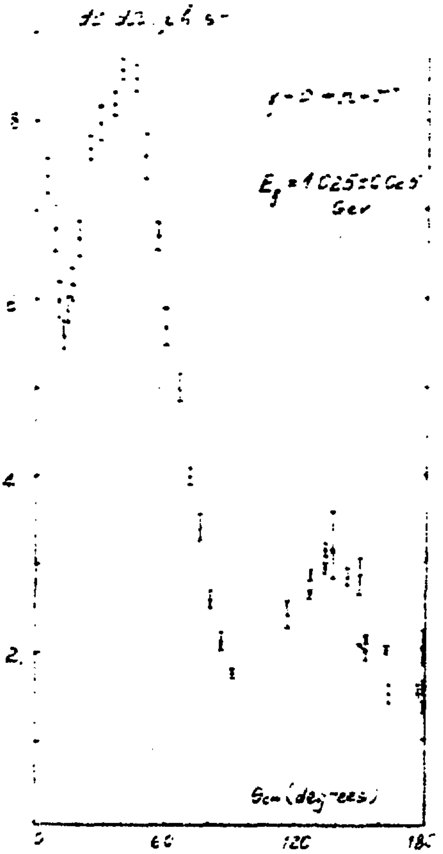
dσ/dΩ (μb/sr)
8
6
4
2.
γ+p→n+π+
E_γ = 1.025±0.05 GeV
θ_{cm} (degrees)
0
60
120
180

Fig.11

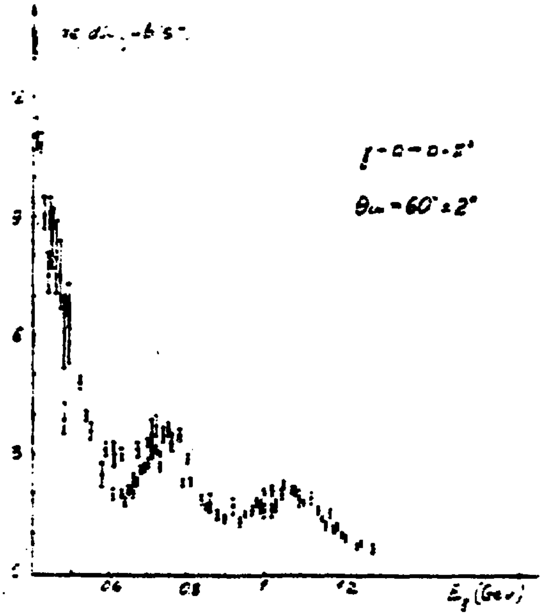
dσ/dΩ(μb/sr)
12
9
6
3
0
γ+p→p+π°
θcm=60°±2°
0.6
0.8
1
1.2
Eγ(Gev)

Fig.12

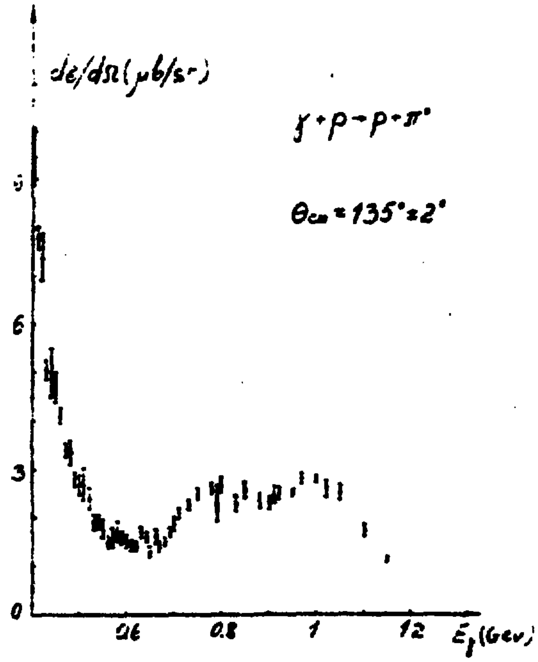
dσ/dΩ(μb/sr)
γ+p→p+π°
θcm=135°±2°
9
6
3
0
0.6
0.8
1
1.2
Eγ(Gev)

Fig.13

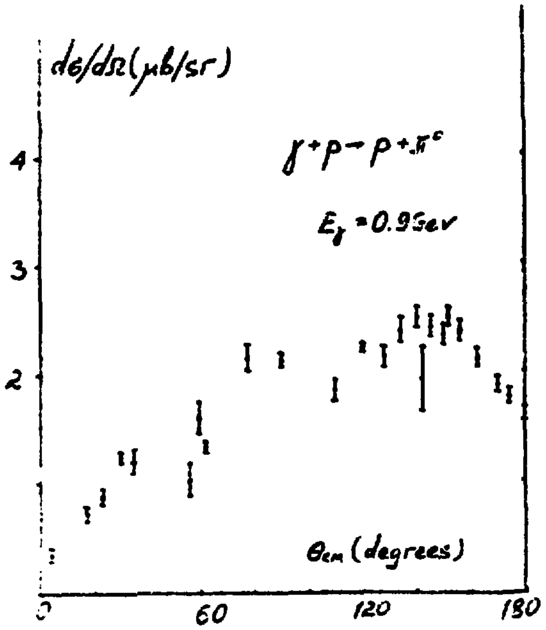
dσ/dΩ(μb/sr)
γ+p→p+π°
Eγ=0.9Gev
4
3
2
θcm (degrees)
0
60
120
180

Fig.14

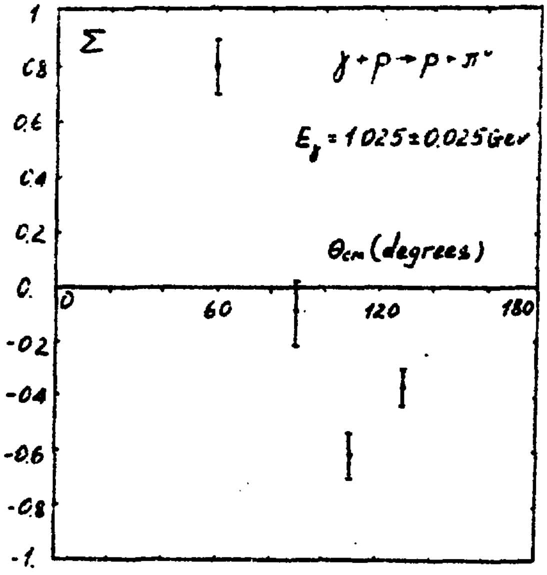
Σ
γ+p→p+π°
Eγ=1025±0.025Gev
θcm (degrees)
1
0.8
0.6
0.4
0.2
0.
-0.2
-0.4
-0.6
-0.8
-1.
0
60
120
180

Fig.15

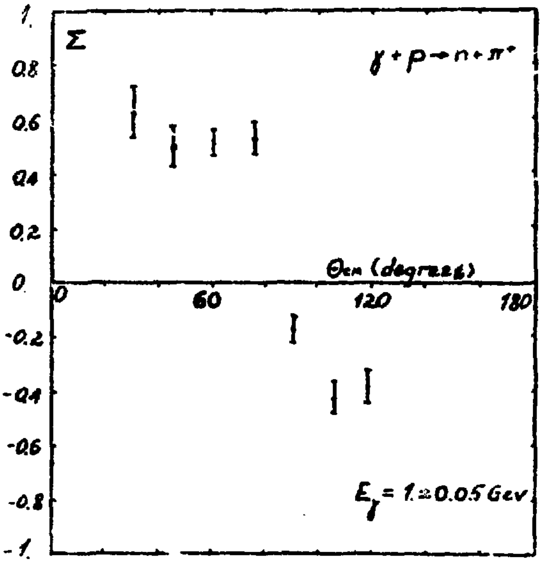
Σ
γ + p → n + π⁺
1.
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1.
θcm (degrees)
0
60
120
180
Eγ = 1.±0.05 Gev

Fig.16

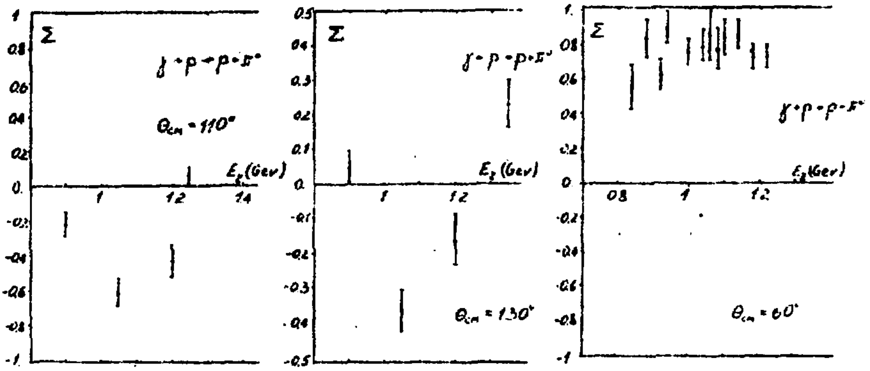
Σ
γ + p → p + π⁰
θcm = 110°
Eγ (Gev)
1
0.8
0.6
0.4
0.2
0.
-0.2
-0.4
-0.6
-0.8
-1.
1
1.2
1.4
Σ
γ + p → p + π⁰
Eγ (Gev)
θcm = 130°
0.5
0.4
0.3
0.2
0.1
0.
-0.1
-0.2
-0.3
-0.4
-0.5
1
1.2
Σ
γ + p → p + π⁰
Eγ (Gev)
θcm = 60°
1.
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
0.8
1
1.2

Fig.17

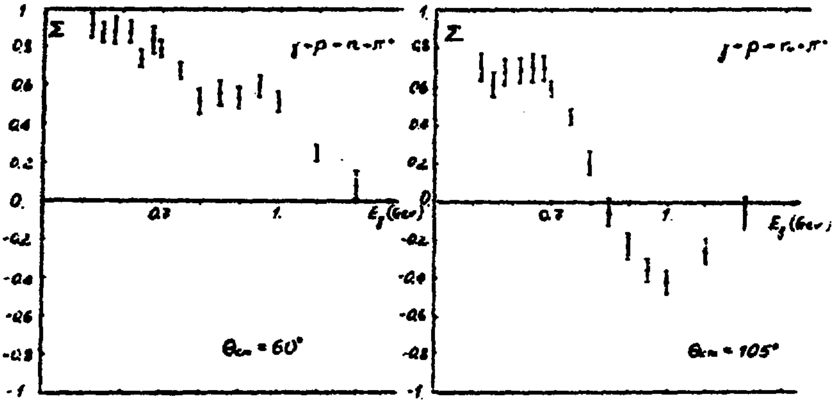
Σ
γ+p→n+π⁺
1
0.8
0.6
0.4
0.2
0.
-0.2
-0.4
-0.6
-0.8
-1
0.7
1.
E_γ (GeV)
θ_cm = 60°
Σ
γ+p→n+π⁺
1.
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1.
0.7
1.
E_γ (GeV)
θ_cm = 105°

Fig.18

REFERENCES

1. W.J.Metcalf, R.L.Walker. Nucl.Phys. B76, 253, 1974.
2. R.G.Moorhouse, H.Oberlack, A.H.Rosenfeld. Phys.Rev. D9, 1, 1974.
3. G.Knies, R.G.Moorhouse, H.Oberlack. Phys.Rev. D9, 2680, 1974.
4. R.C.E.Devenish, D.H.Lyth, W.Rankin. Phys.Lett. 52B, 227, 1974.
5. R.L.Crawford. Nucl.Phys. B97, 125, 1975.
6. I.M.Barbour, R.L.Crawford. Nucl.Phys. B111, 358, 1976.
7. P.Feller et al. Nucl.Phys. B104, 219, 1976.
8. I.G.Aznauryan, N.Z.Akopov, A.S.Bagdasaryan. EPI-264(57)-77.
9. F.A.Berends, A.Donnachie. Preprint HC/T/77/17.
10. Review of Particle Properties. Phys.Lett. 75B, 1, 1978.
11. D.Menze, W.Pfeil, R.Wilcke. Compilation of Pion Photoproduction Data. Bonn Univ., 7-1, 1977.
12. L.O.Abrahamian, R.O.Avakian, A.O.Aganiants et al. Phys.Lett. 48B, 463(1974).
13. J.Alspector, D.Fox, D.Luckey et al. Phys.Rev.Lett. 28, 1403, 1972.
14. H.R.Hicks, S.R.Deans, D.T.Jacobs et al. Phys.Rev. D7, 2614, 1973.
15. R.O.Avakian, E.O.Avakian, A.E.Avetisian et al. Yad.Fiz. 26, 1014, 1977
16. P.J.Bussey, C.Raine, J.G.Rutherglen et al. Nucl.Phys. B154, 205, 1979.
17. R.L.Walker. P.R. 182, 1729, 1969.

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ВО II И III -РЕЗОНАНСНЫХ ОБЛАСТЯХ

(на английском языке, перевод З.Н.Асланян)

Ереванский физический институт

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