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ABOUT ω^0-EXCHANGE IN (γ,π^0) REACTIONS ON PROTON AND CARBON NEAR THRESHOLD

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Recently, the unique experimental data for π^0 -photoproduction on proton in the threshold region ($E_\gamma < 160$ MeV) have been obtained [1] . The results of this experimental investigation contradict the predictions of the effective Lagrangian method and the low-energy theorems. This circumstance can change drastically the available interpretation of the experimental data for π^0 -photoproduction off nuclei.

The aim of this letter is twofold. On the one hand, we are going to investigate the threshold behaviour of the elementary (γ , π^0) process amplitude. We limit ourselves to two elementary amplitudes that are widely used in modern nuclear calculations: i) BL amplitude [2] obtained in the effective Lagrangian method and ii) BDW - amplitude [3] obtained in the dispersion method. Much attention will be paid to the role of ω^0 - meson exchange, particularly, to the tensor contribution of the ωNN vertex.

On the other hand, we are going to investigate the coherent $^{12}C(\gamma,\pi^0)^{12}C$ reaction with the help of the new versions of the BL and BDW amplitudes obtained by taking into account the new experimental data [1] .

The general structure of the pion photoproduction amplitude in πN c.m. frame is the following:

$$\mathcal{F} = i\mathcal{F}_1\, \sigma\cdot\epsilon + \mathcal{F}_2\, \sigma\cdot\eta\, \sigma\cdot[\varkappa\times\epsilon] + i\mathcal{F}_3\, \sigma\cdot\varkappa\, \eta\cdot\epsilon + i\mathcal{F}_4\, \sigma\cdot\eta\, \eta\cdot\epsilon, \qquad (1)$$

where $\varkappa = k/|k|$ and $\eta = q/|q|$ are the unit vectors of photon and pion momenta: ϵ is the photon polarization vector.

In the case of the BL amplitude the functions $\mathcal{F}_\alpha$ are represented as a sum over the Born diagram t_α^B and contributions from Δ - isobar excitation $\mathcal{F}_\alpha^\Delta$ and ω^0 exchange $\mathcal{F}_\alpha^\omega$.

$$\mathcal{F}_\alpha^{BL}(\omega, x) = -\frac{m}{4\pi\omega} t_\alpha^B + \mathcal{F}_\alpha^\Delta + \mathcal{F}_\alpha^\omega, \tag{2}$$

where m is the nucleon mass, $\omega = E_\pi(q) + E_N(q)$ and $x = \underset{\sim}{\varkappa} \cdot \underset{\sim}{\eta}$ in πN c.m. frame. For further discussion we need only the expressions for $\mathcal{F}_\alpha^\Delta$ and $\mathcal{F}_\alpha^\omega$. The unitary version of BL amplitude gives the following expressions:

a) Δ - term:

$$\mathcal{F}_1^\Delta = 3x M_{1+}^\Delta \; ; \; \mathcal{F}_2^\Delta = 2M_{1+}^\Delta \; ; \; \mathcal{F}_3^\Delta = -3M_{1+}^\Delta \; ; \; \mathcal{F}_4^\Delta = 0, \tag{3}$$

where

$$M_{1+}^\Delta(\omega) = -\frac{M(M+\omega)\,g_1\,g_3}{18\pi\omega(\omega^2 - M^2 + iM\Gamma)} \cdot \frac{|\underset{\sim}{k}||\underset{\sim}{q}|}{m_{\pi+}^2} e^{i\Psi_1} \tag{4}$$

$$\Gamma = 110\left(\frac{|\underset{\sim}{q}|}{|\underset{\sim}{q}_\Delta|}\right)^3 \frac{M}{\omega} \frac{1 + (R|q_\Delta|)^2}{1 + (R|q|)^2} \text{ MeV}. \tag{5}$$

The constants in (4) and (5) have the following values:

$$M = 1225 \text{ MeV}; \; g_1 = 0.282\sqrt{4\pi/137}, \; g_3 = 2.18$$

$$R = 0.007 \text{ MeV}^{-1}, \; q_\Delta = 222.9 \text{ MeV}. \tag{6}$$

The phase Ψ_1 is determined by exp.(30) from Ref. [2] .

b) ω - term: in contrast with Ref.[2] we use the full expression for ω^0 exchange contribution including both the vector and tensor components of the ωNN vertex. The corresponding coupling constants G_ω^V and G_ω^T are defined so that the ωNN-vertex has the form

$$\bar{u}(p_f)\left\{G_\omega^V \gamma_\mu + \frac{G_\omega^T}{2m}\sigma_{\mu\nu}(p_f - p_i)_\nu\right\} u(p_i). \tag{7}$$

Then using the results obtained in Ref. [3] with the dispersion method (neglecting the terms of an order of $(\underset{\sim}{p}/m)^2$) one has

$$\begin{aligned}\mathcal{F}_1^\omega &= \left[(\omega-m)^2 - |\underset{\sim}{k}|(E_\pi - |q|x) - R_\omega m_\omega^2(\omega-m)/2m\right]D \\ \mathcal{F}_2^\omega &= |\underset{\sim}{q}||\underset{\sim}{k}|\left[1 + R_\omega m_\omega^2/(\omega+m)/2m\right]\omega D/m\end{aligned} \tag{8}$$

$$\begin{aligned}\mathcal{F}_3^\omega &= -(\omega-m)|\underset{\sim}{q}|\left[1 - R_\omega(\omega-m)/2m\right]D \\ \mathcal{F}_4^\omega &= -(\omega-m)|\underset{\sim}{q}|^2\left[1 + R_\omega(\omega+m)/2m\right]D/2m,\end{aligned} \tag{9}$$

where $R_\omega = G_\omega^T / G_\omega^V$, G_ω^V = 10 and

$$D = \frac{m}{4\pi\omega}\frac{1}{m_{\pi^0}}\frac{G_\omega^V \; 0.374\sqrt{4\pi/137}}{m_\omega^2 - m_\pi^2 - 2|\underset{\sim}{k}|(E_\pi - |\underset{\sim}{q}|x)}. \tag{10}$$

Note that the value of the vector coupling constant is close to that given by the quark model G_ω^V = 11.5 [2] and to the results of analyses of NN-potential [4] where G_ω^V = 9.96 (see also the compilation [5]).

The amplitude determined above in (2-10) will be called by us the BL - amplitude in the case R_ω = 0 and when the Born term with **pseudovector** πNN coupling is used.

In the case of the BDW amplitude the functions $\mathcal{F}_\alpha(\omega, x)$ are decomposed over the multipoles $f_{\ell\pm}^{(I)}(\omega) \equiv \{E_{\ell\pm}^{(2I)}, M_{\ell\pm}^{(2I)}\}$, where ℓ = 0,1,2,3 is the pion orbital momentum, I = 1/2 and 3/2 is the total isospin of πN system. The electric $E_{\ell\pm}$ and magnetic $M_{\ell\pm}$ multipoles tabulated in Ref. [3] are calculated by interpolation over $|\underset{\sim}{q}|$ with the help of cubic splines. In the threshold region they are approximated by

$$f_{\ell\pm}(\omega(|\underset{\sim}{q}|)) = |\underset{\sim}{q}|^\ell \left(A_{\ell\pm} + B_{\ell\pm}|\underset{\sim}{q}|^2\right), \tag{11}$$

where the coefficients $A_{\ell\pm}$ and $B_{\ell\pm}$ are determined from the equivalence of the logarithmic derivatives at the point

T a b l e.

Electric $E_{\ell\pm}^{(2I)}$ and magnetic $M_{\ell\pm}^{(2I)}$ multipoles (in units $10^{-3}/m_{\pi^+}$) at threshold region, calculated by extrapolation of the BDW - amplitude [3]. E_γ^L and $q_\pi^{c.m.}$ - photon energy and momentum (in MeV), respectively.

E_γ^L	145	146	148	150	152	155
$q_{\pi^0}^{c.m.}$	8.30	16.6	26.3	32.3	39.2	46.7
$E_{0+}^{(0)}$	1.26	1.26	1.26	1.26	1.25	1.25
$E_{0+}^{(1)}$	46.4	46.1	45.7	45.2	44.7	44.0
$E_{0+}^{(3)}$	-21.5	-21.4	-21.2	-21.0	-20.9	-20.6
$E_{1+}^{(1)}$	.595	1.15	1.71	2.02	2.20	2.30
$E_{1+}^{(3)}$	-.112	-.229	-.379	-.502	-.615	-.778
$M_{1+}^{(1)}$	-.342	-.694	-.1.13	-1.47	-1.78	-2.20
$M_{1+}^{(3)}$	.425	.876	1.47	1.96	2.43	3.11
$M_{1-}^{(1)}$	.250	.506	.823	1.07	1.29	1.59
$M_{1-}^{(3)}$	-.337	-.683	-1.11	-1.45	-1.75	-2.17

E_γ^{LAB} = 160 MeV. The values of the most important multipoles, obtained in such way, are represented in the Table. In Fig.1 the cross-sections of the $\gamma p \to \pi^0 p$ reaction, calculated with the given above amplitudes, are compared with the experimental data in the threshold region. It is clearly seen that in this region the BL - results are 2 times higher and the BDW - results are 3 times lower than the experimental points.

If we take into account the tensor component of the ωNN vertex in the case of the BL amplitude, having R_ω as a free parameter, the best agreement with experimental data will be achieved when $R_\omega(BL)$ = - 0.28 . The negative sign of $R_\omega(BL)$ is in agreement with the results of the vector dominance model in its simple interpretation in which one has

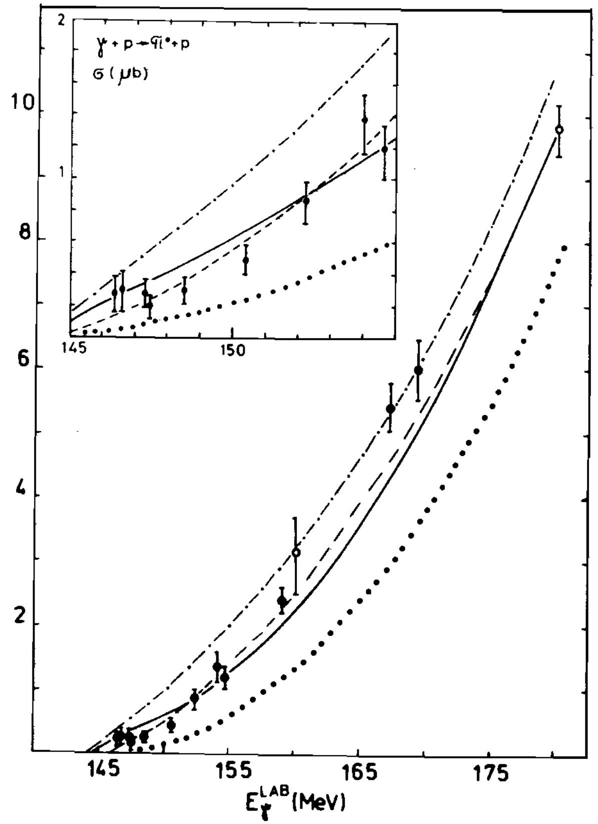

Fig. 1. The π^0 - photoproduction cross-section on the proton calculated using BL - amplitude with R_ω = 0 (dash-dotted line), R_ω = -0.28 (dashed line) and using BDW - amplitude with G_ω^V = 0, R_ω = 0 (dotted line) and G_ω^V = 10, R_ω = 0.43 (full line). Data are from ref. [1] (ɸ) and [12] (ϕ).

$R_\omega = (\mu_p + \mu_n) = -0.12$ (μ_p and μ_n are the anomalous magnetic momenta of a proton and a neutron respectively) but the absolute value of $R_\omega(BL)$ is approximately two times larger. Note that an analogous situation takes place for the ρ -meson exchange [6] .

However, the value of $R_\omega(BL)$ contradicts the results of other analyses. For example, from the description of the pp-scattering in the framework of the OBEP-model it follows that $R_\omega = 0.43$ [4].

Adding the ω°-meson exchange contribution at $G_\omega^V = 10$ and $R_\omega = 0.43$ with the help of exps (8-10) leads to a good agreement of the BDW- results in the threshold region with experimental data. The description for higher photon energies (see fig.2) and for the Δ_{33}- resonance region is improved as well.

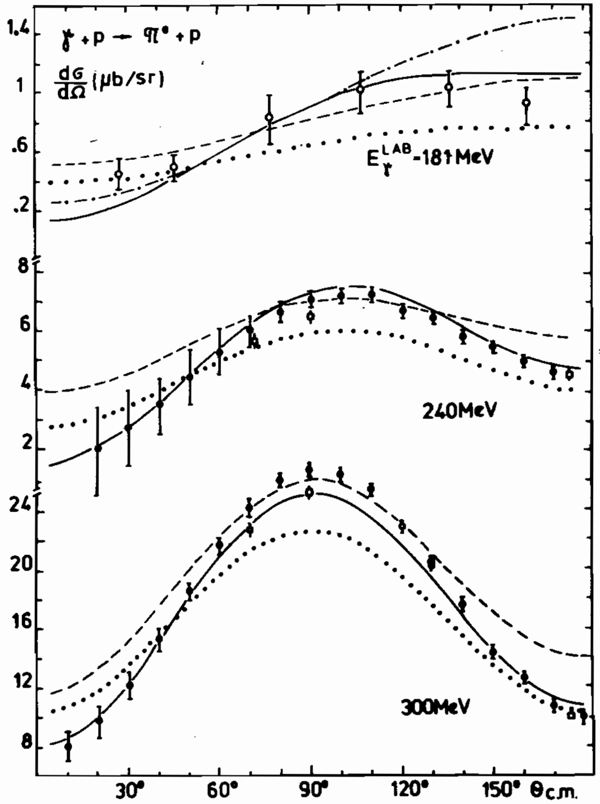

Fig. 2. The same as in fig. 1 for angular distributions. Data are from ref. [13] (ϕ), [14](ɸ) and [15] (ϕ).

The results of calculations with old and extended versions of the BL and BDW amplitudes for the $^{12}C(\gamma,\pi^\circ)^{12}C$ reaction are represented in Fig. 3. The cross-sections were calculated within the DWIA in the momentum space [7] with half-off--shell extrapolation of the elementary amplitude [8]. One can note a much better agreement with experimental data in the threshold region for the extended BDW amplitude when the ω°-exchange is included. However, the discrepancy with the experimental points from Ref.[9] appears when $E_\gamma^L > 170$ MEV. The difference between the theoretical and experimental results will increase if one considers not only the dominant coherent process but the transitions to the low-lying excited states $J^\pi T = 2^+0$ ($E^* = 4.44$ MeV) and 3^-0 ($E^* = 9.64$ MeV) keeping in mind

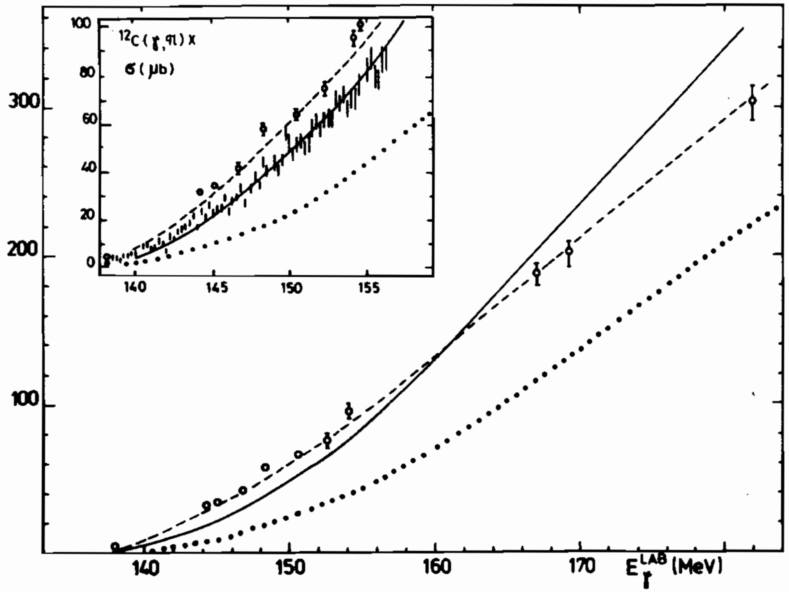

Fig. 3. The π°-coherent photoproduction cross-section on carbon. The meaning of the curves is the same as in fig. 1. experimental points from ref.[9], I - preliminary data from the Mainz-Giessen collaboration.

that such transitions are presented in experimental data. For example, at E_γ^L = 180 MeV both for the BDW and BL - amplitudes we have

$$\sigma_{coh.} : \sigma(2^+0) : \sigma(3^-0) = 1 : 0.07 : 0.01 . \qquad (12)$$

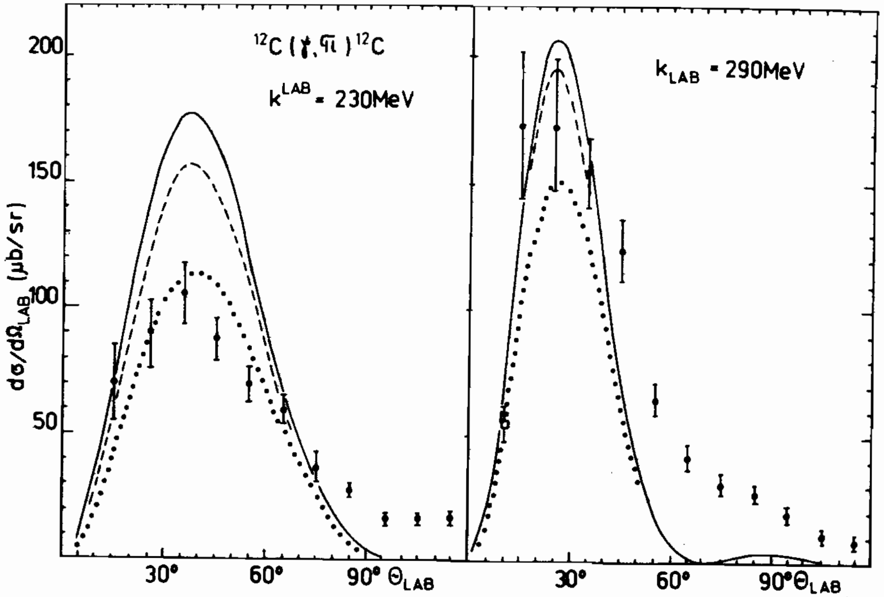

Fig. 4. The same as in fig. 3 for angular distribution. Experimental points are taken from ref. [16].

To our mind it is now impossible to make any particular conclusion from the analysis of the experimental data for π^0 -photoproduction off nuclei. Numerous experimental investigations are needed. For the forthcoming experiments we want to emphasize two circumstances. Firstly, the extended BL and BDW amplitudes give 1.5 times higher results than the experimental ones for E_γ^L = 230 MeV (see Fig. 4). According to Ref. [10, 11], in this region one can expect large effects from

medium modification of the elementary amplitude. At the same time, for E_γ^L = 290 MeV, when these modifications are evaluated to be small, we obtain a good description of experimental data. Secondly, adding the tensor component of the ωNN - vertex does not change the results for coherent pion photoproduction significantly both for the BL and BDW amplitudes because this adding slightly modifies the spin independent $\mathcal{F}_2$ component of the elementary amplitude. Larger effects should manifest themselves in the transitions to the excited states where the contribution of the spin-flip components $\mathcal{F}_1$, $\mathcal{F}_3$, $\mathcal{F}_4$ is dominant.

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Чумбалов А.А., Камалов С.С., Тетерева Т.В. E4-88-123
О роли обмена ω^o-мезоном в (γ,π^o) реакции на протоне и углероде в околопороговой области

С помощью амплитуд, полученных методом эффективных лагранжианов (BL) и дисперсионным методом (BDW) проведен анализ новых данных для (γ,π^o) реакции на протоне в околопороговой области. Показано, что BL-амплитуда дает отношение констант связи G^T_ω/G^V_ω для ωNN-вершины в два раза больше, чем простая модель векторной доминантности. Значение этого отношения в случае BDW-амплитуды имеет противоположный знак и совпадает с результатами других анализов. Новые версии BL и BDW-амплитуд приводят к завышенным DWIA результатам для (γ,π^o) реакции на ядре ^{12}C в области $E_\gamma \sim 230$ МэВ и к хорошему согласию с экспериментом в околопороговой и Δ_{33}-резонансной областях.

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Chumbalov A.A., Kamalov S.S., Tetereva T.V. E4-88-123
About ω^o-Exchange in (γ,π^o) Reactions on Proton and Carbon near Threshold

With the amplitudes obtained in the effective Lagrangian (BL) and the dispersion (BWD) methods the new data for the (γ,π^o) reaction on proton near the threshold are analysed. It has been found that the BL-amplitude gives the tensor to vector ratio of the ωNN coupling two times larger than the simple vector dominance model. The value of this ratio in the case of the BDW-amplitude has an opposite sign and is consistent with the results of other analyses. The new versions of the BL- and BDW-amplitudes lead to overestimated DWIA results for the (γ,π^o) process on carbon at $E_\gamma \sim 230$ MeV and to good agreement with the data in the threshold and Δ_{33} resonance region.

The investigation has been performed at the Laboratory of Theoretical Physics, JINR.

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