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SPIN-ISOSPIN RESPONSE OF A NUCLEON AT HIGH EXCITATION ENERGY

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ABSTRACT

The tensor analyzing power for $p(d, {}^2\mathrm{He})\Delta^0$ reaction with polarized deuterons is discussed. General expressions for T_{20} and T_{22} for this reaction are derived. The models of π-exchange and $\pi+\rho$-exchange does not reproduce the measured combination of T_{20} and T_{22}.

The charge-exchange reactions have been used recently for excitation of internal degrees of freedom of a nucleon inside nuclei. The simplest example is the excitation of a delta-isobar in nuclei seen in the reactions (^{3}He, t) [1, 2] and (d, $2p$) [3]. An important feature of the last reaction is the possibility to use polarized deuterons in order to study the spin structure of the reaction amplitude.

It was shown in [4] that the delta-isobar excitation in (^{3}He, t) reaction on a proton is well described in one pion exchange model. This approximation well reproduces both absolute value of the cross-section and shape of tritium spectrum. The same is valid for the ^{2}He spectrum in (d, ^{2}He) reaction (see Fig. 1).

If the reaction takes place on a nucleus a virtual pion can propagate inside nuclear medium changing thus the position and the width of a delta [5]. These effects are, however, very sensitive to distortion of an incoming and outgoing waves. It is therefore difficult to estimate the degree of pion renormalization. In addition, all the estimates were carried out assuming the dominant contribution of pion exchange. This hypotheses must be the subject of a study as well.

Using the (d, ^{2}He) reaction with polarized deuterons one can separate the contribution of others than pion exchange mechanisms contributing to isobar production.

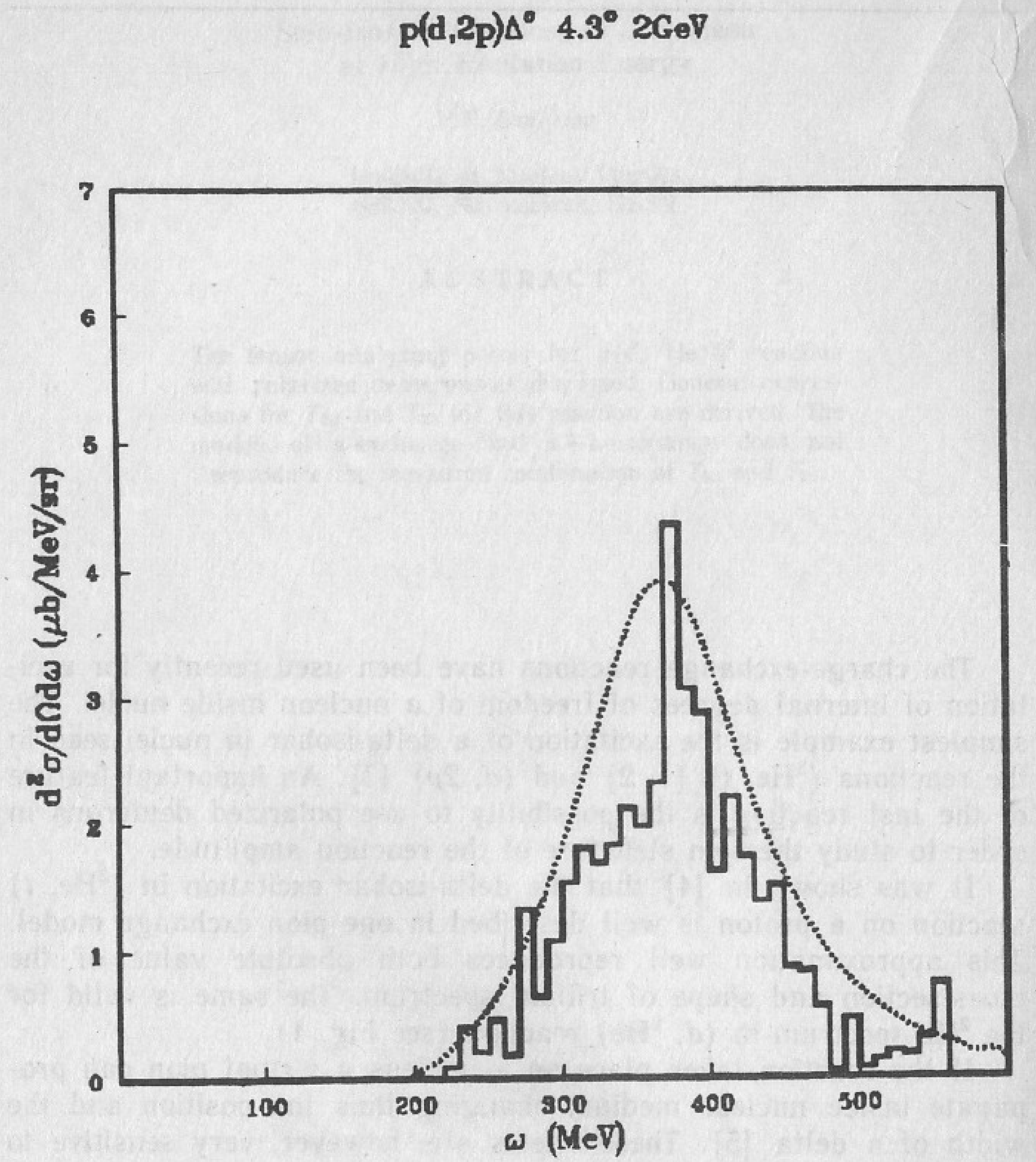

Fig. 1. The ^{2}He spectrum in the Δ-isobar region. Calculated curve—OPE.

THE TENSOR ANALYZING POWER OF THE $(d,\,^2\mathrm{He})$ REACTION IN OPE APPROXIMATION

In the experiment [3] two protons with good accuracy were in $^1S_0$ state. According to authors admixture of higher angular momentum was only few percents. With this accuracy we shall consider below the reaction as transformation of a particle with spin 1 and positive parity into a particle with spin 0 and positive parity in final state. A particle with spin 1 can be described by a polarization vector with the following components $\varepsilon_\lambda^\mu(p)$:

$$\varepsilon_+^\mu = \left(0,\ -\frac{1}{\sqrt{2}},\ \frac{i}{\sqrt{2}},\ 0\right),$$
$$\varepsilon_-^\mu = \left(0,\ \frac{1}{\sqrt{2}},\ \frac{i}{\sqrt{2}},\ 0\right), \qquad (1)$$
$$\varepsilon_0^\mu = \left(\frac{p}{M},\ 0,\ 0,\ \frac{E}{M}\right)$$

and satisfying the condition $p_\mu \varepsilon_\lambda^\mu(p) = 0$. Here M is the deuteron mass and p_μ is its momentum.

The reaction amplitude in one pion exchange approximation is factorized

$$T_\lambda = -\sqrt{\frac{2}{3}}\, F(q^2)\, \frac{f_\pi}{m_\pi}\, (\varepsilon_\lambda^\mu q_\mu)\, \frac{1}{q^2 - m_\pi^2}\, \Gamma_{\pi N\Delta}\,, \qquad (2)$$

where $F(q^2)$ is the transition formfactor and $\Gamma_{\pi N\Delta}$ is the $\pi N\Delta$-vertex. Due to this factorization the tensor analyzing power does not depend on the structure of the $\pi N\Delta$-vertex. By definitions of T_{20} and T_{22} we have

$$T_{20} = \frac{1}{\sqrt{2}}\, \frac{\overline{T_+T_+^*} + \overline{T_-T_-^*} - 2\overline{T_0T_0^*}}{\sum_\lambda |T_\lambda|^2}. \qquad (3)$$

After simple calculation we obtain

$$T_{20} = -\sqrt{2}\left(1 + \frac{3}{2}\, \frac{q_\perp^2}{q^2\left(1 - \frac{q^2}{4M^2}\right)}\right); \qquad (4)$$

$$T_{22}=\frac{\sqrt{3}}{2}\,\frac{q_{\perp}^{2}}{q^{2}\left(1-\frac{q^{2}}{4M^{2}}\right)}. \qquad (5)$$

For $A_y=\frac{1}{2}T_{20}+\sqrt{\frac{3}{2}}\,T_{22}\cos 2\varphi$ we find

$$A_{y,}=-\frac{1}{\sqrt{2}}+\frac{3}{2\sqrt{2}}\,(1-\cos 2\varphi)\,\frac{q_{\perp}^{2}}{-q^{2}\left(1-\frac{q^{2}}{4M^{2}}\right)}; \qquad (6)$$

where φ is the angle between spin quantization axes and normal to scattering plane.

The polarization response (6) does not depend on a target and must be the same both for proton and for carbon. In Figs 2 and 3 the measured response for these targets is shown with account of polarization of the deuteron beam $\rho_{20}=0.61$ [6]. One can see the difference of the responses of carbon and of proton and even for proton the response is almost twice smaller than prediction of OPE model.

PHENOMENOLOGICAL ANALYSIS OF THE POLARIZATION RESPONSE

Big difference of the proton and carbon responses indicates the importance of distortion effects. At the moment we shall not discuss these effects but try to analyze the elementary amplitude of the reaction on a proton.

Deviation of the measured proton response from the OPE predictions indicates the presence of transversal spin components in the amplitude which are absent in OPE contribution. To estimate the contribution of these components let us discuss the general structure of the polarization response for spin transition $1^{+}\rightarrow 0^{+}$. The amplitude of the reaction is

$$T_{\lambda}=-\varepsilon_{\lambda}^{\mu}(p)\,\Gamma_{\mu}. \qquad (7)$$

The spin density matrix is proportional to the amplitude (7) squared and summed over all final states:

$$\overline{T_{\lambda}T_{\lambda'}^{*}}=\varepsilon_{\lambda}^{\mu}(p)\,\varepsilon_{\lambda'}^{\nu *}(p)\,\Lambda_{\mu\nu}. \qquad (8)$$

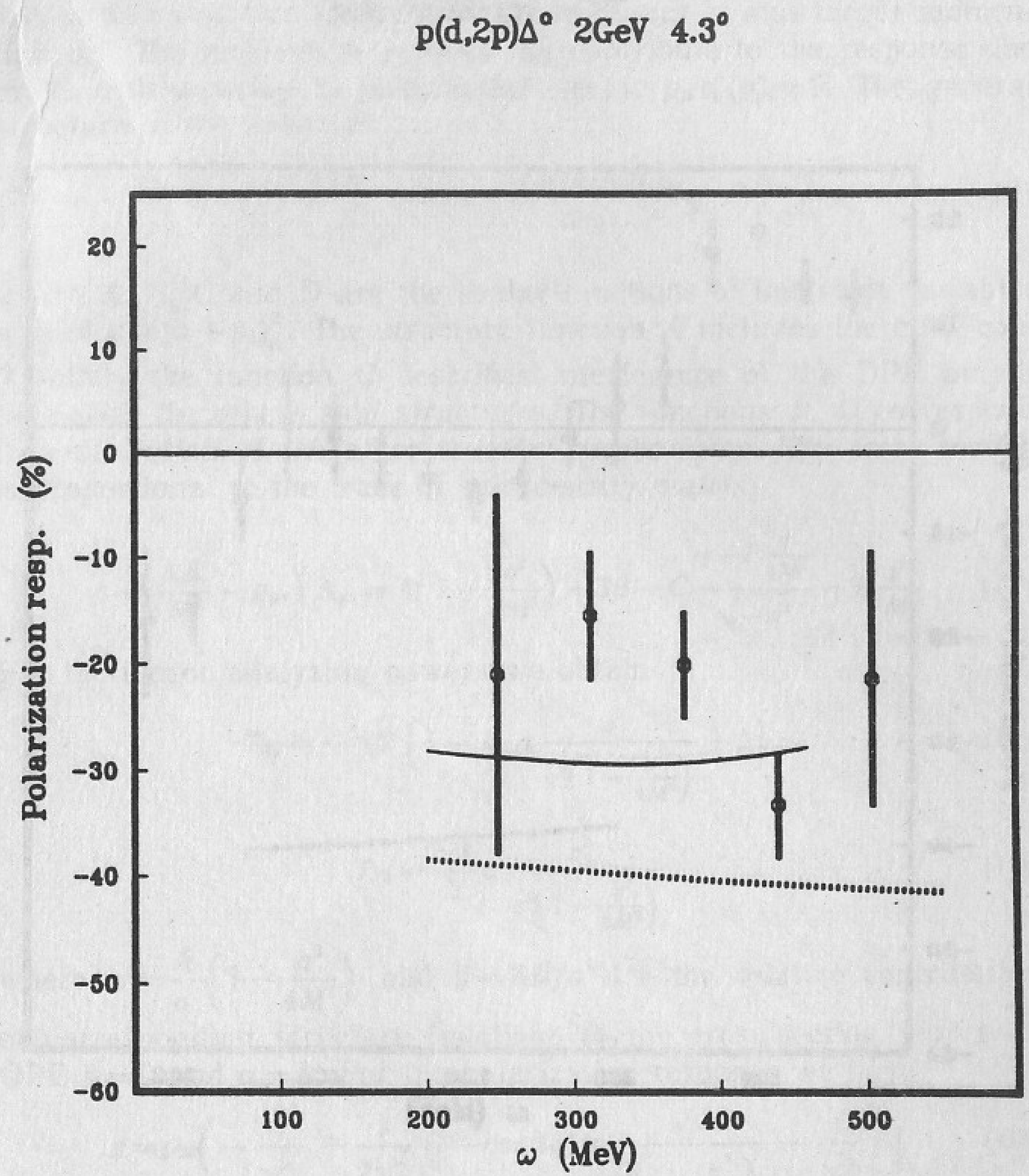

Fig. 2. Polarization response in reaction $p(d,\,^{2}\mathrm{He})\Delta^{0}$ at scattering angle $\theta=4.3°$, $\cos 2\varphi=0.909$: full line — $\pi+\rho$ model, dotted line — OPE.

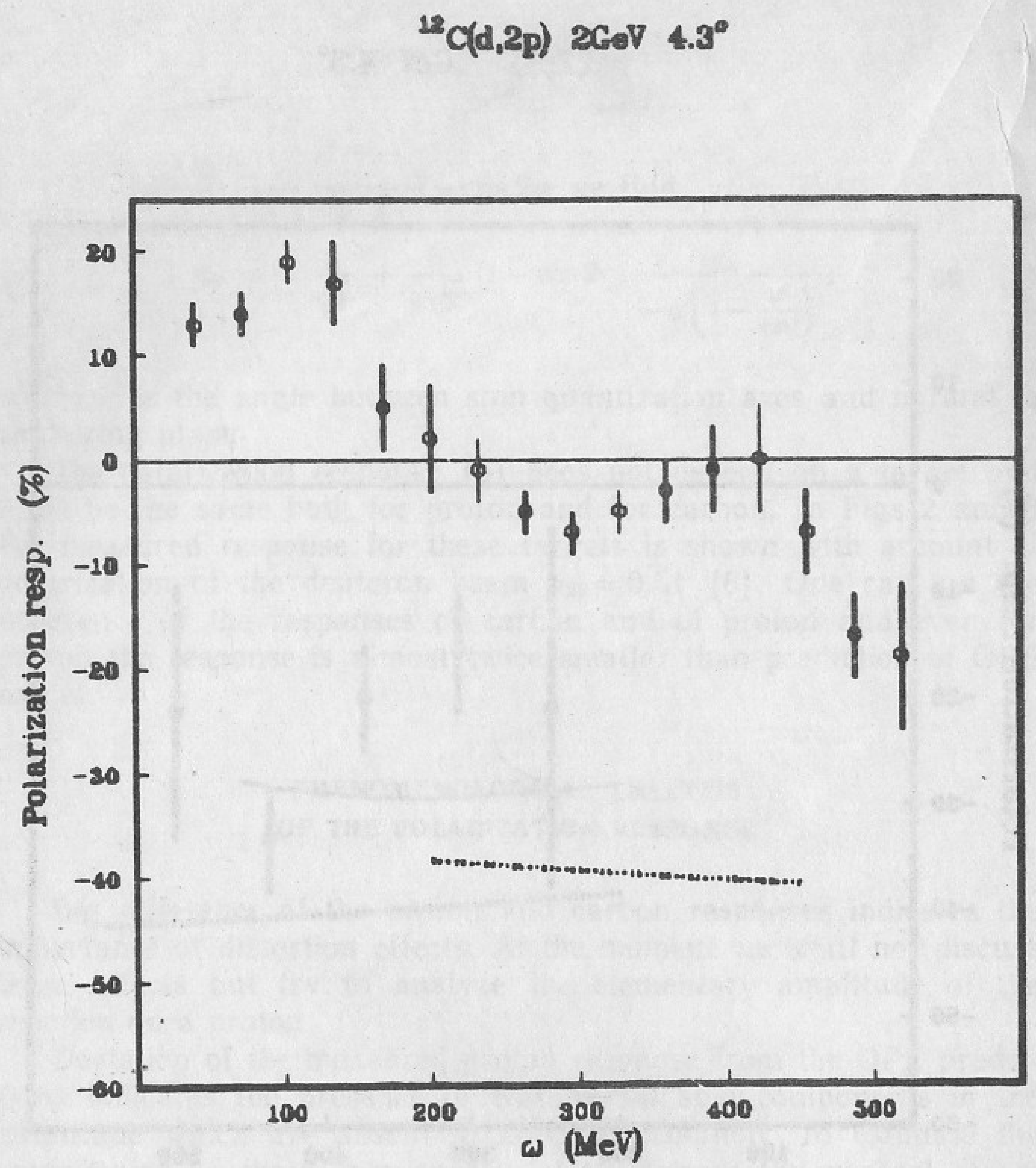

Fig. 3. Polarization response in reaction $^{12}C(d, {}^2He)$ at scattering angle $\theta = 4.3°$, $\cos 2\varphi = 0.909$.

The tensor $\Lambda_{\mu\nu}$ is symmetrical second rank tensor. It can be expressed in terms of two independent momentums q_μ and target momentum $p_{1\mu}$. The momentum p_μ does not contribute to the response due to its orthogonality to polarization vector $p_\mu \varepsilon^\mu_\lambda(p) = 0$. The general structure of the tensor is

$$\Lambda_{\mu\nu} = -A\frac{q_\mu q_\nu}{q^2} - Bg_{\mu\nu} + C\frac{p_{1\mu}q_\nu + p_{1\nu}q_\mu}{m\sqrt{-q^2}} + D\frac{p_{1\mu}p_{1\nu}}{m^2}, \tag{9}$$

where A, B, C and D are the scalar functions of invariant variables q^2 and $s = (p+p_1)^2_\mu$. The structure function A includes the OPE contribution, the function C describes interference of the OPE amplitude with the others spin structures. The functions B, D correspond to contribution of the other reaction mechanisms. The cross-section is proportional to the trace of spin density matrix

$$\sigma \sim \left(\frac{p_\mu p_\nu}{M^2} - g_{\mu\nu}\right)\Lambda_{\mu\nu} = A\left(1 - \frac{q^2}{4M^2}\right) + 3B - C\frac{\omega - E\frac{q^2}{4M^2}}{\sqrt{-q^2}} + D\frac{\vec{p}^2}{M^2}. \tag{10}$$

For the tensor analyzing powers we obtain

$$T_{20} = -\sqrt{2}\left(1 + \frac{3}{2}\alpha\frac{q_\perp^2}{q^2\left(1 - \frac{q^2}{4M^2}\right)} - \beta\right), \tag{11}$$

$$T_{22} = \frac{\sqrt{3}}{2}\alpha\frac{q_\perp^2}{q^2\left(1 - \frac{q^2}{4M^2}\right)}, \tag{12}$$

where $\alpha = \frac{A}{\sigma}\left(1 - \frac{q^2}{4M^2}\right)$ and $\beta = 3B/\sigma$ are the relative contribution of corresponding structure functions to the cross-section. For pure OPE $\beta = 0$ and $\alpha = 1$. For the polarization response we have:

$$p = \rho_{20}\left(-\frac{1}{\sqrt{2}} + \frac{3}{2\sqrt{2}}(1 - \cos 2\varphi)\,\alpha\frac{q_\perp^2}{q^2\left(1 - \frac{q^2}{4M^2}\right)} + \frac{1}{\sqrt{2}}\beta\right). \tag{13}$$

From (13) one can estimate contribution of nonOPE part of the cross-section. From Fig. 2 we see that for Δ-isobar region $p \approx -0.2$. Taking into account value of $\langle\cos 2\varphi\rangle = 0.909$ for $\theta = 4.3°$, we obtain $\beta \approx 0.5$. Therefore, the results of measurement [6] give for contribution of other than OPE spin structures the same order as for the OPE.

THE MODEL OF $\pi+\rho$ EXCHANGE

As possible generalization of the OPE model let us discuss the contribution of two pion exchange. Since the main contribution in two pion channel comes from rho-resonance, we shall restrict ourselves by rho-meson exchange. Similar to what has been done for the OPE amplitude (2), it is convenient to introduce a relativistic vertex of $\rho d\,{}^2$He-interaction. The only combination satisfying all conditions of invariance and at small deuteron momentum equal to matrix element of $\vec{\sigma}\times\vec{q}$ caculated with wave functions of d and ^{2}He ($\vec{\sigma}$ is the nucleon spin matrix) is

$$V_\lambda^\mu = \frac{f_{\rho*}}{m_\rho} e_{\mu\nu\gamma\sigma}\,\varepsilon_\lambda^\nu(p)\, q_\gamma \frac{p_\sigma}{M} F(q^2)\,, \qquad (14)$$

where M is the deuteron mass and $F(q^2)$ — the same transition formfactor as in (2). The Δ-isobar created in lab. system is nonrelativistic, therefore for vertexes $\pi N\Delta$ and $\rho N\Delta$ we can use their nonrelativistic expressions. Let $p_{1\mu}=(m, 0)$ be the momentum of target the $\rho N\Delta$ vertex can be written as follows:

$$\Gamma^\mu_{\rho N\Delta} = \frac{f_{\rho N\Delta}}{m_\rho}\, e_{\mu\nu\gamma\sigma}\, S_\nu\, q_\gamma \frac{p_{1\sigma}}{m}. \qquad (15)$$

Since $p_{1\mu}$ has only zero's component the $\Gamma_{\rho N\Delta}$ eventually coincides with its nonrelativistic expression. In (15) S_ν is usual matrix of $N\Delta$-transition. For the $\pi N\Delta$ vertex we have $\Gamma_{\pi N\Delta} = \frac{f_{\pi N\Delta}}{m_\pi}(\vec{S}\cdot\vec{q})$.

Combining (14), (15) and (2) and calculating product of two antisymmetric tensors we find

$$T_\lambda = -\sqrt{\frac{2}{3}} F(q^2)\,(\varepsilon_\lambda^\mu q_\mu) \left[\frac{f_\pi f_{\pi N\Delta}}{m_\pi^2}\,\frac{(\vec{S}\cdot\vec{q})}{q^2-m_\pi^2} - \frac{f_\rho f_{\rho N\Delta}}{m_\rho^2}\,\frac{\frac{E}{M}(\vec{S}\cdot\vec{q}) - \frac{\omega}{M}(\vec{S}\cdot\vec{p})}{q^2-m_\rho^2}\right] +$$

$$+(\varepsilon_\lambda^\mu \tilde{S}_\mu)\,\frac{q^2(E+E')}{2M}\,\frac{f_\rho f_{\rho N\Delta}}{m_\rho^2}\,\frac{1}{q^2-m_\rho^2}\sqrt{\frac{2}{3}}\,F(q^2)\,, \qquad (16)$$

here p'_μ is the momentum of ^{2}He and the vector $\tilde{S}_\mu$ is $\tilde{S}_\mu = \left(\frac{(\vec{p}+\vec{p}')\cdot\vec{S}}{E+E'}, \vec{S}\right)$.

From (16) we see that like in nonrelativistic case the rho-meson

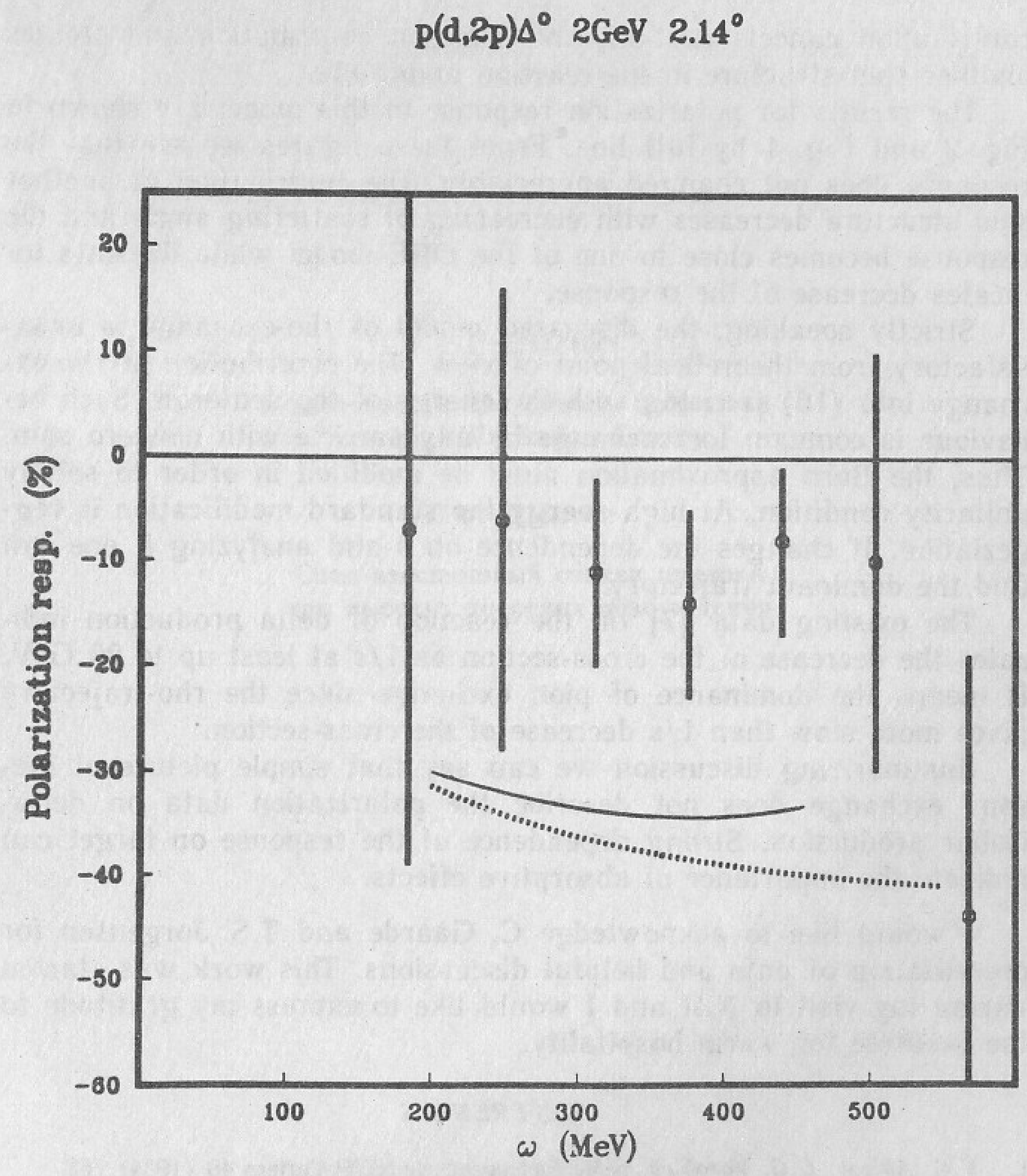

Fig. 4. Polarization response in reaction $p(d, {}^2\mathrm{He})\Delta^0$ at scattering angle $\theta=2.14°$, $\cos 2\varphi=0.68$: full line — $\pi+\rho$ model, dotted line — OPE.

contribution cancels partially the π-meson contribution and creates another spin structure in the reaction amplitude.

The results for polarization response in this model are shown in Fig. 2 and Fig. 4 by full line. From these figures we see that the response does not changed appreciably. The contribution of another spin structure decreases with decreasing of scattering angle and the response becomes close to one of the OPE model while the data indicates decrease of the response.

Strictly speaking, the discussed model of rho-exchange is unsatisfactory from theoretical point of view. The contribution of rho-exchange into (16) is rising with the energy of the deuteron. Such behaviour is common for exchange by any particle with nonzero spin. Thus, the Born approximation must be modified in order to satisfy unitarity condition. At high energy the standard modification is reggeziation. It changes the dependence on s and analyzing it one can find the dominant trajectory.

The existing data [7] on the reaction of delta production indicates the decrease of the cross-section as $1/s$ at least up to 20 GeV. It means the dominance of pion exchange since the rho-trajectory gives more slow than $1/s$ decrease of the cross-section.

Summarizing discussion we can say that simple picture of meson exchange does not describe the polarization data on delta-isobar production. Strong dependence of the response on target can indicate the importance of absorptive effects.

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