

Tensor analyzing power component T_{21} of a π^- -meson in the photoproduction on a deuteron

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Abstract. The preliminary results of measurement of the tensor analyzing power component, T_{21} of negative pion photoproduction on a polarized deuterons at photon energies of 280 MeV – 900 MeV, and in the pion emission angles of 0° – 180° are presented. The experimental results are compared with the theoretical predictions.

1. Introduction

The pion electro- and photoproduction on the deuteron will allow detailed studies of the nuclear structure as well as the dependence of the elementary amplitude on nuclear effects, on the reaction mechanism and the validity of the spectator model. The structure of the atomic nucleus at short distances ($r < 1$ fm), corresponding to large momenta ($p > 0.2$ GeV/c) of the internal nucleons, is investigated now by both hadron and electromagnetic probes very intensively. One expects a transition from the traditional meson and nucleon degrees of freedom of nuclear physics to the quark and gluon degrees of freedom of QCD at internucleon separations of a femtometer or less. New models should be based on some contribution of quark and meson degrees of freedom. The experimental and theoretical investigations of polarization observables of the processes may be very productive in the analysis of the non-nucleonic deuteron states.

Up to now we have obtained experimental data about T_{20} and T_{22} tensor analyzing power components for the reaction $\gamma + d \rightarrow p + p + \pi^-$, where the two outgoing protons were recorded in coincidence in the momentum range (340 – 700) MeV/c [1]. In the current paper we present the preliminary results of the measurement of the missing tensor analyzing power component, T_{21} for that reaction. The model using impulse approximation with re-scattering in final state fails to describe these three components. The adequate theoretical description of these experimental data requires the introduction of non-nucleon degrees of freedom and of exotic dibaryon states, allowing to study the deuteron structure at short distances as well as other problems.

2. Experimental setup

2.1. The internal polarized target of the VEPP-3

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The experiment was carried out at the VEPP-3 storage ring at an electron energy of 2 GeV and a beam current of ≈ 100 mA. The beam lifetime in the presence of an internal target was 3 h. The internal gas target of the storage ring consists of polarized deuterium atoms injected in the form of a jet with intensity of 8.2×10^{16} at/s into a thin-walled T-shaped storage cell with open edges. The cell was cooled by a liquid nitrogen. The jet of polarized atoms was produced by a polarized atomic beam source [2]. The vector polarization of the jet at the exit from the source was maintained close to zero ($P_z < 0.02$) while the tensor polarization of the jet atoms was close to the limit ($P_{zz} = +1$ or -2). The tensor polarization of the jet atoms was monitored by a Breit-Rabi polarimeter. To determine the experimental spin asymmetries of the reaction, the sign of the tensor polarization of the target was alternated and, in order to suppress the systematic errors, these alternations were performed frequently, once per 30 s. The degree of polarization of the deuterium atoms stored inside the cell is degraded due to various depolarizing processes. To determine the polarization of the target atoms, we used a target polarimeter (Low-Q polarimeter [3]) based on measurement of the elastic ed-scattering asymmetry in the range of low momentum transfer, for which the tensor analyzing power of the reaction is known. The average degree of target polarization during the experiment was determined with the LQ-polarimeter as $P_{zz} = 0.397 \pm 0.013[\text{stat.}] \pm 0.018[\text{syst.}]$. The direction of the deuteron polarization axis was fixed by a magnetic holding field H at $\theta_H = 120^\circ$ and $\varphi_H = 0^\circ$, where these angles are defined in a frame with the z axis is along the direction of the electron beam and the x axis is directed vertically.

2.2. Detector

The experiment was performed along with the concurrent measurement of the analyzing power components in elastic ed-scattering [4]. The total detector consisted of two identical two-arm systems, positioned symmetrically with respect to the electron beam and rotated relative to one another by 180° in the vertical plane. Each system consisted of an electron detector arm and a hadron hodoscope. We used the two hadron hodoscopes of both systems only. They measure the two protons of the $ed \rightarrow e'pp\pi^-$ - reaction in coincidence. Electron inducing this reaction was not detected. With the forward peaking approximation we relate the electron to photon induced cross section using the Dalitz-Yennie virtual photon spectrum. Since in this case a virtual photon is almost real, so we investigate the pion photoproduction. Each hadron hodoscope was composed of a vertex drift chamber, a drift chamber hodoscope and three layers of plastic scintillation counters. The particle trajectories were reconstructed by means of the tracking information from different sets of drift chambers. The first layer scintillator ($500 \times 235 \times 20$) mm³ was scanned by two photomultipliers. The second and the third layer were ($1000 \times 400 \times 126$) mm³ and ($1000 \times 400 \times 120$) mm³ in size, respectively, and were scanned by four photomultipliers. The scintillators were used for proton energy measurement and for particle identification. The absolute calibrations of the scintillation counters were performed periodically by measuring the proton energy loss of the $ep \rightarrow e'p'$ - reaction. The angular acceptance of the hadron hodoscope was $\theta_p = 44^\circ - 88^\circ$ in polar angle and $\varphi_p = -30^\circ - +30^\circ$ in azimuthal angle for one hodoscope and $\varphi_p = 150^\circ - 210^\circ$ for the other hodoscope. The measured range of the proton momentum is (340 – 700) MeV/c.

3. Extracting the T_{21} analyzing power

The cross section for π -meson photoproduction on tensor polarized deuterons in a condition that all three momenta of the final particles are in the same plane (in this case, all analyzing power components are real) has the form

$$\frac{d^5\sigma}{dp_1 d\Omega_1 d\Omega_2} = \frac{d^5\sigma_0}{dp_1 d\Omega_1 d\Omega_2} \left(1 + \sqrt{3} P_z T_{11} \sin \theta_H \sin \varphi_H + \frac{\sqrt{2}}{2} P_{zz} \left(T_{20} \frac{(3\cos^2 \theta_H - 1)}{2} + \sqrt{\frac{3}{2}} T_{21} \sin 2\theta_H \cos \varphi_H + \sqrt{\frac{3}{2}} T_{22} \sin^2 \theta_H \cos 2\varphi_H \right) \right), \quad (1)$$

where $\frac{d^5\sigma_0}{dp_1 d\Omega_1 d\Omega_2}$ is the cross section on unpolarized deuterons; T_{11} is the vector analyzing power; T_{20} , T_{21} and T_{22} are the components of the tensor analyzing power of the reaction; $P_z \approx 0$ and P_{zz} are the degrees of the vector and tensor target polarizations, respectively.

The experimental tensor asymmetry associated with the alternation of the sign of the target tensor polarization was determined as:

$$A^T = \sqrt{2} \frac{N^+ - N^-}{N^+ P_{zz}^+ - N^- P_{zz}^-}. \quad (2)$$

Here $N^+ (N^-)$ is number of the detected pp-events for the target polarization $P_{zz}^+ (P_{zz}^-)$ after corrections for the difference between the luminosity integrals. The tensor analyzing power component, T_{21} of the reaction is defined from equations (1) and (2) as:

$$T_{21} = \frac{k_\varphi}{2d_{21}} (A_0^T - A_{180}^T), \quad (3)$$

where $k_\varphi = 1.047$ is the correction for azimuthal angles, $d_{21} = \sqrt{\frac{3}{8}} \sin \theta_H$, $A_0^T (A_{180}^T)$ is the tensor asymmetry measured for pp-events in which the azimuthal angles of the slow protons are in the interval $0^\circ \pm 30^\circ$ ($180^\circ \pm 30^\circ$) accordingly.

4. Experimental data proceedings

The experimental data were processed in several stages. Events corresponding to the response of the two hadron hodoscopes in coincidence were selected, the polar and azimuthal angles of the particle were determined on the basis of the data from the drift chambers, and the pp-event vertex coordinates were reconstructed. The energy of the protons was found from the ratio of the energy loss in the scintillation layers. The energy losses were calculated from the Bethe-Bloch formula [5] and the specific light yield was determined using the modified Birks formula. For each pp-event, the energies and angles of both protons were used to reconstruct the kinematics of the reaction and to calculate all of the reaction kinematic parameters. Events, for which the polar angles of the proton fall into the interval $(44 - 88)^\circ$, the coordinates of the event vertex lie in the electron beam-target interaction region, the undetected mass is not less than the rest mass of a charged pion and the azimuthal angles of the final particle momenta fall in to interval $\pm 25^\circ$, were selected.

5. Theoretical description

Our theoretical description of π -meson photoproduction on deuterons is based on a diagrammatic approach. We consider diagrams corresponding to the pole mechanism of the reaction, along with one-loop diagrams that incorporate pion-nucleon and nucleon-nucleon rescattering. We also perform antisymmetrization that take into account the identity of the final-state nucleons [6]. The amplitude of π -meson photoproduction on nucleons is taken from [7]. This amplitude, written in the relativistically invariant form, involves a mixed version of πN interaction and takes into account the contributions of the Born diagrams in the s-, t- and u-channel; the s-channel contribution of the Δ -isobar; and the contribution of the t-channel exchange by ω - and ρ -mesons. Along with the Δ -isobar contribution, this amplitude also takes into account the contributions of higher nucleon resonances: $P_{11}(1440)$, $D_{13}(1520)$, $S_{11}(1535)$, $F_{15}(1680)$ and $D_{33}(1700)$. This makes it possible to extend the area of these amplitudes application up to γ -energies of 1 GeV. The results from calculations using this amplitude are in good agreement with the data of plural analyses for the resonant and nonresonant partial amplitudes and with the data on differential cross section and polarization observables of π -meson photoproduction on nucleons in the region of the Δ -isobar and higher nucleon resonances. The pion-nucleon scattering is described by a relativistically invariant amplitude [8] that involves a pseudovector version of πN interaction. The amplitude of nucleon-nucleon scattering is presented as a

multipole expansion up to partial waves with orbital momentum $L=2$. The partial phase shifts of nucleon scattering were taken from [9]. Deuteron wave functions derived from the Bonn potential were used in the calculations [10].

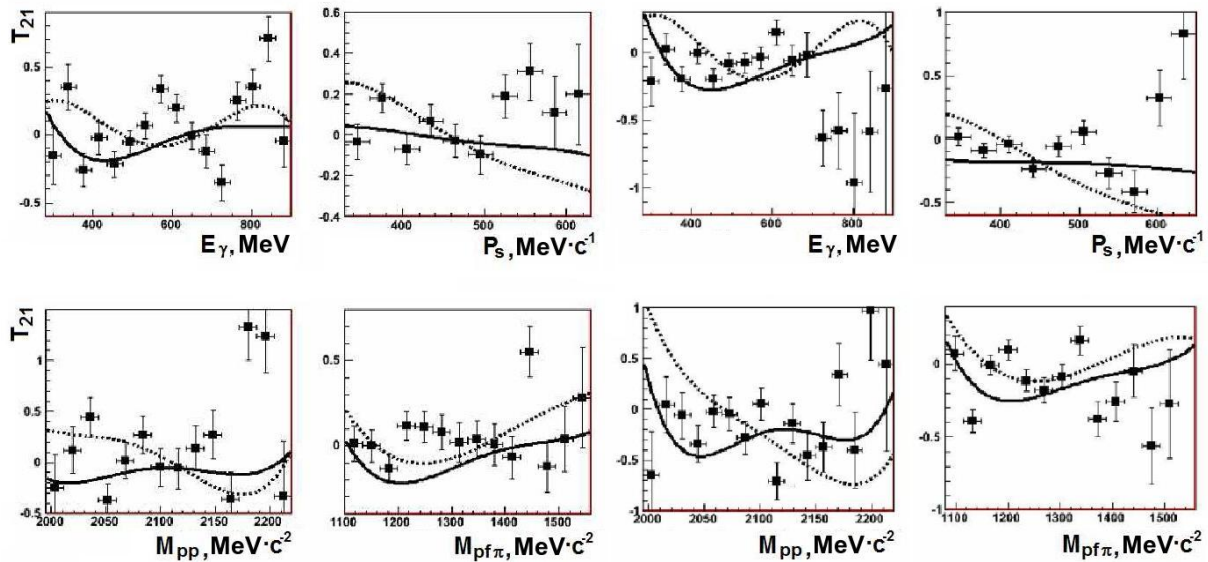


Figure 1. Tensor analyzing power component T_{21} versus kinematical variables: E_γ – the photon energy, P_s – the slow proton momentum, M_{pp} – the invariant mass of the two-proton subsystem. $M_{p\pi}$ – the invariant mass of the fast proton-meson subsystem. The solid and dashed lines show theoretical predictions with the FSI and PW model, respectively. The two left panels show T_{21} for the range of pion polar angle $(0 - 29)^\circ$, the two right panels are for $(30 - 59)^\circ$.

6. Results and discussion

The cross section and the analyzing power components of the reaction are functions of six kinematic variables. The range of variation of these variables is determined by the phase volume covered by the detector. The experimental dependences are presented as functions of one variable, and integration over other variables is performed within the phase volume element covered by the detector. To compare the experimental data with the predictions of the theory correctly, we performed a similar averaging of the theoretical data. A program was developed for simulating the tensor polarization observables of the reaction on the basis of a Monte-Carlo method.

We obtained the preliminary experimental and calculated dependences of the analyzing power component T_{21} of the reaction on the following reaction parameters: the momentum $p_f(p_s)$ - fast(slow) proton in the range of $(340 - 700)$ MeV/c, the photon energy in the range of $(280 - 900)$ MeV, the invariant masses of the $pp\pi$ -system in the range of $(2140 - 2740)$ MeV, the invariant masses of the $M_{p\pi}$ subsystem in range of $(1100 - 1600)$ MeV, and the invariant mass of the M_{pp} subsystem in the range of $(1990 - 2200)$ MeV. Some of these dependences are shown in figure 1 and figure 2. The experimental results, the results of the theoretical calculations within the plane-wave (PW) approximation, and the results of the calculation including the final state interaction (FSI) are shown by discrete points, dashed lines, and solid lines, respectively.

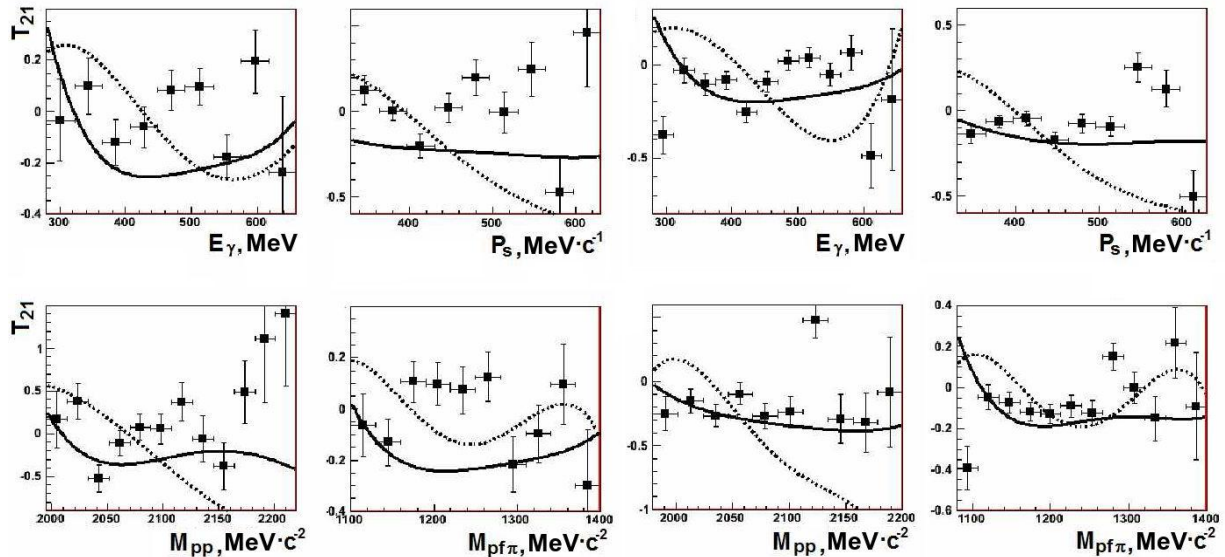


Figure 2. Tensor analyzing power component T_{21} versus kinematical variables. All symbols correspond to the one of Figure 1. The two left panels show T_{21} for the range of pion polar angle ($60 - 89^\circ$), and the two right panels show T_{21} for the range of pion polar angle ($90 - 180^\circ$).

The preliminary analysis shows that theoretical calculations with inclusion of πN and NN rescattering give only qualitative agreement with the experimental results. Differences (more than 3σ) of the theoretical and experimental results exist both in the broad intervals of the variables, and in the narrow intervals, comparable to the accuracy of the measurement.

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