The Reaction $D(e, pp)e'\pi^-$ on Polarized Deuteron at High Proton Momenta

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Abstract

The differential cross section and target asymmetry components of the reaction $D(e, pp)e'\pi^-$ on polarized deuteron were measured. The kinetic energies of the protons were measured within 55-180 MeV and 46-265 MeV and the acceptance angles in lab. frame are $\Theta_{1,2} = 64^0 - 82^0$, $\Delta\phi_{1,2} = 32^0$. The sharp peak of the tensor $a_{20}$-component of the target asymmetry is found near the invariant mass of the $pp\pi$-system $M_{pp\pi} = 2300 \, \text{MeV}/c^2$. The performed calculations of the differential yield and the tensor target asymmetry do not describe the obtained experimental results.

The interest to study of the $\pi^-$-meson production on a deuteron for high polar angles and large momenta of both protons proceeds from an opportunity to acquire a new information on the dynamics of NN-interaction at short internucleon distances. In the region of proton momenta larger than the Fermi-momentum the quasifree mechanism of the $\pi^-$-meson production appears to be suppressed. The relative contribution of more complex reaction mechanisms grows in this kinematic area and these reactions require new models to describe the nucleon systems and hadron interactions. It is for
these reasons the previous experiments in Hamburg [1], Saclay [2] and Bonn [3, 4] chose the search for dibarion states and observation of the (ΔΔ)-states as their main subject.

Our experiment was focused on the region of an even higher opening angles and larger values of the invariant mass than before. Also, the use of a polarized deuteron target enabled us to consider a number of polarization observables.

The measurements reported here were conducted simultaneously with the experiments performed [5, 6], which used an internal tensor-polarized deuterium target in the VEPP-3 storage ring at 2 GeV electron energy. The particle-detection system consisted of two identical two-arm apparatus to detect the protons in coincidence [7, 8]. Each arm of the detector was placed symmetrically around the electron-beam axis at a polar angle of 75° with respect to the beam line. The proton telescope included a drift chamber and the thin and thick scintillator counters. Each proton arm detected particles within the range of angles $\theta = 68^\circ - 82^\circ$ and $\Delta \varphi = 32^\circ$. The kinetic energy of the protons which deposit all their energy was reconstructed combining the values of the energy deposition in the detector layers. In these measurements the direction and sign of the target polarization were changed periodically during the data acquisition [6]. The integrated luminosity and the average value of the tensor target polarization were determined from electron-deuteron elastic scattering [5].

The collected data were processed in a few consecutive stages [8, 9], which resulted in momentum vectors for both protons and reconstructed the vertex coordinates for the events. Computation of the pion momentum and photon energy was done on an assumption of a zero angle of electron scattering. The selected events were used to determine the yield of the reaction to each detector for two signs and two directions of the guide magnetic field.

The components of the experimental target asymmetry are defined as the counting rate combinations [8]:

\[
\begin{align*}
    a_{11} &= \frac{\sum_{i=1,2}(-1)^{i}\delta_{ij}[N^{i}_{1+} + N^{i}_{2-}]}{N}, \\
    a_{20} &= \frac{\sum_{i,j=1,2}(N^{i}_{j+} - N^{i}_{j-})}{N}, \\
    a_{22} &= \frac{\sum_{i,j=1,2}(-1)^{i}\delta_{ij}[N^{i}_{j-} - N^{i}_{j+}]}{N},
\end{align*}
\]

(1)

where $N_{ijk}$ is the counting rate in the detector system $i$ with the magnetic guide field index $j$, and the sign of deuteron tensor polarization degree $P_{zz}$ given by $k$ and $N$ is the total counting rate.

In order to obtain the distributions of We used (see ref. [8]) the connection between the yield of the reaction summed over $i$, $j$ and $k$ into a 6-D
phase space volume of the momenta, $V_6$ and differential cross section of the reaction

$$Y(V_6) = \int_{V_6} \epsilon L \frac{d^6 \sigma}{d^3 p_1 d^3 p_2} d^3 p_1 d^3 p_2,$$  \hspace{1cm} (2)

where $p_1$ and $p_2$ are the momenta of the protons, $\epsilon$ is the total detection and selection efficiency of the $pp$-events, $L$ is the integral luminosity obtained from the measured elastic $ed$-scattering.

The dependences of the cross section and the analyzing power components of the reaction on the invariant mass $pp$-system that we obtained at this experiment were presented in ref. \[8, 9\]. Here we present the first results as a function of the $pp\pi^-$-system mass, $M_{pp\pi}$. The differential yield of the reaction is shown in Fig.1. and tensor $a_{20}$-component of the target asymmetry is shown in Fig.2.

The calculations of the cross section of the investigated process were made in a few theoretical models. The cross section of the process initiated by electrons was expressed in the terms of the cross section of a reaction induced by the virtual photons. We used Dalitz-Yennie’s virtual photon spectrum. For NEWGAM-code \[8\] one nucleon pion photoproduction operator has been taken from the phenomenological analysis \[10\] and the deuteron wave function was obtained using the Paris N-N potential. Also we used the ENIGMA-code which was developed for the exclusive pion electroproduction on nuclei \[11\]. The calculations of the polarization observables and cross section of the reaction were made within the spectator model using the elementary pion photoproduction amplitude discussed in ref. \[12\]. The Born terms of this amplitude are determined in pseudovector $\pi N$-coupling, the $\Delta$-resonance is considered both in the $s$- and the $u$-channels and the $\rho$ and $\omega$-mesons exchange are considered in the $t$-channel. This amplitude is useful for the studies of the $\Delta$-resonance. In addition, we studied the role of the various dynamic effects in photoproduction of $\Delta(1232)$-isobar on a polarized deuteron using the relativistic impulse approximation in the nucleon-spectator model \[13\].

The experimental and some calculated dependences of the differential yield of the reaction on the mass of the $pp\pi$-system can be see in Fig. 1. The solid curve shows the result of the ENIGMA-code, the result of the NEWGAM-code is slightly different from this result. The dashed line corresponds to the calculation based on the total one-nucleon amplitude of the $\pi$-mesons photoproduction \[12\], whereas the dot-dashed line shows the result of the calculation based on the one-nucleon amplitude including the $\Delta$-isobar in the $s$-channel only. One can see that the experimental spectrum is peaked
at $M_{pp\pi^-} = 2300\ MeV/c^2$. It is clear from this figure that the experimental yield of the reaction are much higher than their calculated counterparts.

Figure 2. plots the behavior of the tensor target $a_{20}$ -asymmetry versus the invariant mass of the $pp\pi^-$-system. Here one can see a peculiar feature - an sharp rise in the range of masses $M_{pp\pi^-}=2300\ MeV/c^2$. Note that events from this range correspond to production $\Delta^0(1232)$-isobar. This could be seen from the distribution of the invariant mass pion and one the fastest of two protons, $M_{p\pi^-}$ - which excibe a clean peak at 1232 MeV/c$^2$. The calculated values of the $a_{20}$-component of the target asymmetry is below 0.6 in the mass region near 2300 MeV/c$^2$.

We keep on working on further analysis of obtained results. These results allow us to make two conclusions. The behavior of the differential yield and $a_{20}$ -component of the target asymmetry near $M_{pp\pi^-}=2300\ MeV/c^2$ is associated with the excitation of $\Delta^0(1232)$-isobar on the deuteron. The noticeable difference near $M_{pp\pi^-}=2300\ MeV/c^2$ between the experimental values and the calculated tensor target $a_{20}$ asymmetry and the reaction yield may be related with an excitation of a dibarion resonance state and its following decay into proton and $\Delta^0(1232)$-isobar.
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