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Observation of a polarization structure in inelastic ^{40}Ca(p, p')X reaction at 1 GeV

O. V. Miklukho[1], A. Yu. Kisselev, G. M. Amalsky, V. A. Andreev, G. E. Gavrilov, A. A. Izotov, N. G. Kozlenko, P. V. Kravchenko, M. P. Levchenko, D. V. Novinskiy, A. N. Prokofiev[1], A. V. Shvedchikov, S. I. Trush, A. A. Zhdanov

Konstantinov Petersburg Nuclear Physics Institute, National Research Centre "Kurchatov Institute", 188300 Gatchina, Russia

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The polarization of the secondary protons in the inelastic (p, p') reaction on the ^{40}Ca nucleus at the initial proton energy 1 GeV was measured in a wide range of the scattered proton momenta at a laboratory angle $\Theta = 21°$. The final protons from the reaction were detected using the magnetic spectrometer equipped with multiwire-proportional chambers polarimeter. A structure of the polarization data, related probably to scattering off the nucleon correlations in the nucleus, was observed.

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Introduction. This work was motivated by a result of experiments in which the medium-induced modification of nucleon-nucleon scattering amplitude was studied at PNPI synchrocyclotron with 1 GeV proton beam energy [1–4]. In the exclusive $(p, 2p)$ experiments with different nuclei the polarization of both secondary protons and spin-correlation parameters have been measured. These measurements were performed using a two-arm magnetic spectrometer with an overal energy resolution sufficient to clearly distinguish a shell structure of the nuclei. Both arms of the spectrometer were equipped with multiwire-proportional chamber polarimeters. An analysis of the experimental data indicated the existing of an additional interaction of the recoil protons with the nucleon correlations (NC) [5, 6] in the residual nucleus [3, 4]. In the first inclusive experiment (in the year 2006) the scattered proton polarization in the reaction ^{40}Ca(p, p')X at $\Theta = 21°$ was measured using the high-energy arm of the magnetic spectrometer [7]. At a proper secondary proton momentum, when scattering off the ^{4}He-like nucleon correlations in the ^{40}Ca nucleus could dominate, the measured polarization was found to be close to that in free elastic proton–^{4}He scattering.

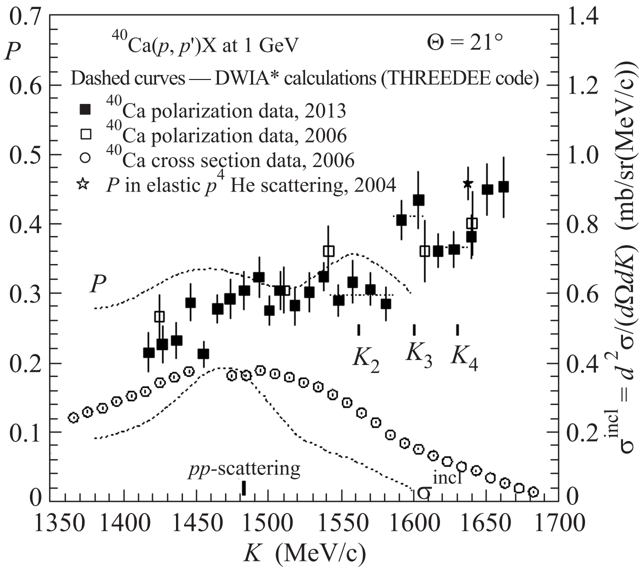
We present the results of the second inclusive experiment performed in the year 2013. A main goal of this experiment was to study in details the polarization (P) in the reaction ^{40}Ca(p, p')X at $\Theta = 21°$ in a wide range of the scattered proton momentum K ($K = (1410-1670)$ MeV/c) with a better statistic accuracy than was made earlier. The polarization was measured in narrow momentum intervals ($\simeq 10$ MeV/c) and with a small step on the K ($\simeq 10$ MeV/c). A special interest was to make the measurements at the $K > 1500$ MeV/c. In this region, since the NC are more massive than the nucleon, the quasielastic $(p, p'\mathrm{NC})$ reactions (the elastic scattering off the NC in nuclear medium) are kinematically not forbidden. So, if the NC would exist in the nucleus, the effects from the scattering off them could appear in the K region.

The momentum resolution of the high-energy magnetic spectrometer [3] in these measurements was ± 2.5 MeV/c. This value was estimated by measuring a width of the clearly separated 2^+ excited level in the (p, p') reaction with the ^{12}C nucleus at the same angle. A calibration of the analyzing power of the polarimeter with a carbon analyzer was carried out using the *pp*-elastic scattering polarization data obtained in this experiment. For the calibration in a wide range of the secondary proton energy we performed polarization measurements with the polyethylene (CH_2) and carbon (^{12}C) targets at different angular and momentum settings of the spectrometer. An uncertainty of the calibration was included in a total error of the polarization measurement.

Results and analysis. In Figure the measured polarizations P in the reaction ^{40}Ca(p, p')X (black squares) are plotted versus the scattered proton momentum K.

The old data on the polarization P (empty squares) and on the differential cross sections (empty circles) obtained in the year 2006 [7] are also shown. The black star corresponds to the polarization in the elastic p-^{4}He scattering [2]. The dashed curves in the figure present the polarization and differential cross section for the

[1] e-mail: miklukho@pnpi.spb.ru; prokan@pnpi.spb.ru



Polarization P of the protons scattered at angle $\Theta = 21°$ (black squares) in the inclusive reaction ^{40}Ca(p, p')X as a function of the secondary proton momentum K. The old data on the polarization (empty squares) and the differential cross section $\frac{d^2\sigma}{d\Omega d\mathbf{K}}$ (empty circles) in the reaction was obtained in the year 2006 [7]. Dashed curves are the DWIA* predictions of the polarization and the cross section. The experimental cross section data are normalized to the DWIA* prediction near the centroid of the quasielastic peak. The black star corresponds to the polarization in the elastic p-^{4}He scattering [2]. The dotted lines are one-parameter linear fits to experimental data for the K intervals II, III, and IV, defined in the text

reaction on the ^{40}Ca nucleus calculated in the framework of a spin-dependent Distorted Wave Impulse Approximation (DWIA) taking into account the relativistic distortion of the nucleon spinor in nuclear medium (DWIA*) [1, 3, 8]. In this approach the proton scattering off the uncorrelated nuclear nucleons was only taken into account. The calculations were performed with the THREEDEE code [9].

As seen from Figure in the momentum interval 1480 MeV/c $< K <$ 1545 MeV/c (I) the DWIA* predictions are in a good consent with the experimental data. This consent is broken in the interval 1545 MeV/c $<$ $< K <$ 1585 MeV/c (II). At $K >$ 1585 MeV/c a polarization jump is clearly distinguished within the interval 1585 MeV/c $< K <$ 1615 MeV/c (III). In the interval 1615 MeV/c $< K <$ 1645 MeV/c (IV) the polarization is noticeably less than that in the III. At $K >$ 1645 MeV/c the polarization increases again.

It is possibly that an essential change of the polarization in the momentum ranges II, III, and IV can be related to a proton qualielastic scattering off the two-nucleon, three-nucleon, and four-nucleon correlations. A value of the polarization in the proton interaction with a NC can depend on number and isospin properties of nucleons in the correlation.

The calculated final proton momenta K_2, K_3, and K_4 corresponding to maximum of the quasielastic peaks in the ^{40}Ca$(p, p'$NC)X reaction on the stationary NC consisting of two, three, and four nucleons are shown in Figure. In these calculations the masses of free nuclei ^{2}H, ^{3}He, and ^{4}He were used as the NC masses. The residual nuclei (X) in the reactions were assumed to be in a ground state. As seen in the figure the momenta K_2 (1562 MeV/c), K_3 (1601 MeV/c), and K_4 (1631 MeV/c) are within the momentum intervals II, III, and IV.

The DWIA* calculations show that a contrubtion in the momentum interval II from the quasielastic scattering on the uncorrelated nucleons (with momenta less than the Fermi momentum $k_{\mathrm{F}} \approx 250$ MeV/c) is rather large. This contribution at the $K >$ 1585 MeV/c, including the momentum intervals III and IV, is essentially suppressed. The measured polarization in the momentum interval IV is less than that in the free elastic p-^{4}He scattering [2]. This can be related to a modification of proton interaction with the four-nucleon system in nuclear medium. The relative difference of these polarizations is close to that of the polarizations calculated in the DWIA* and DWIA for the quasielastic scattering off the uncorrelated nuclear nucleons.

The widths (ΔK) of the momentum intervals II–IV are not only determined by a horizontal angular acceptance of the spectrometer ($\Delta\Theta_h \simeq 1^0$). A main contribution in the ΔK can come from a motion of the NC in nucleus. For instance, if the two-nucleon correlation was immovable then a ΔK value of the momentum interval II would be equal to about of 10 MeV/c. This value is about four times less than that estimated from this experiment. So, due to a motion of the NC, the effective angular acceptance essentially increases. This enables us to observe the polarization angular distribution in scattering from the NC within the momentum interval ΔK.

We would like to make some remarks about results of the investigations at the $K <$ 1480 MeV/c. As seen from Figure the DWIA* does not described the experimental polarization data in this region. This can be due to an essential contribution in the region from the multistep processes of knocking out nucleons from the nucleus [7], which are not taken into account in the framework of the DWIA*. A polarization jump in the K region is possibly a combined effect of these multistep reactions and a discrete energy-shell structure of the nucleus. This was clearly confirmed in the similar experiment (recently performed) with the ^{12}C nucleus having only two energy-shells.

In present $^{40}\mathrm{Ca}(p,p')\mathrm{X}$ experiment performed at the initial proton energy $E_p = 1\,\mathrm{GeV}$ and transferred four-momentum $Q \approx 0.6\,\mathrm{GeV/c}$ the momentum intervals II, III, and IV were estimated on the final proton polarization data. These intervals can be converted to the x_B intervals II*, III*, and IV*, where x_B is the Bjorken kinematical variable ($x_\mathrm{B} = Q^2/(2m\nu)$, where Q, ν, and m are the four-momentum transfer, the energy transfer, and nucleon mass). The obtained x_B intervals are $1.5 < x_\mathrm{B} < 2$ (II*), $2 < x_\mathrm{B} < 3$ (III*), $3 < x_\mathrm{B} < 4$ (IV*). It is interesting to note that in the JLAB unpolarized (e,e') experiment at $E_e \sim 4.6\,\mathrm{GeV}$ and $Q^2 > 1.4\,\mathrm{GeV}^2/\mathrm{c}^2$ the effects from the two-nucleon and three-nucleon correlations in a cross section were found in the x_B ranges $1.5 < x_\mathrm{B} < 2$ and $2.25 < x_\mathrm{B} < 2.8$ [6].

Conclusion. The secondary proton polarization in the reaction $^{40}\mathrm{Ca}(p,p')\mathrm{X}$ at 1 GeV was measured in a wide range of the scattered proton momenta at laboratory angle $\Theta = 21°$. A structure in the polarization data was observed. This structure at the $K > 1480\,\mathrm{MeV/c}$ may be related to the scattering off the nucleon correlations in the nucleus.

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