METHOD OF PROTON POLARIZATION MEASUREMENTS IN INVESTIGATIONS OF PHOTON INTERACTION WITH NUCLEONS AND NUCLEI AT 2 GeV LINAC (NSC KIPT)

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The method used for proton polarization measurements and the equipment for investigations of the photon interaction with nucleons and nuclei of intermediate energies at the 2 GeV linear electron accelerator (NSC KIPT) is described. The characteristics of key elements of the equipment (magnetic spectrometer, carbon polarimeter with the track registration of pC-scattering) are given. The main results of the proton polarization measurements in the reactions $\gamma p \to p\pi^0$, $\gamma D \to pn$, $\gamma A \to pX$ are presented.

PACS: 24.70. + s, 25.20. · x

1. INTRODUCTION

The investigations of physical processes of particle-nuclei interactions are closely connected with polarization measurements. The polarization experiments feature a considerable informative about process dynamic, nucleus structure, properties of particles and resonances etc. The fundamental problem is studying a role of meson-nucleon and quark-gluon degrees of freedom (d.o.f.) in the mechanisms of particle-nuclei interactions at intermediate energies and in certain cases polarization experiments can give a unique information on this problem.

It is known that polarization experiments are referred to a group of the most complex ones as far as besides registration of the reaction itself it is necessary to measure a pC-scattering. Especially this concerns double polarization experiments with using the beams of polarized particles (nucleons, electrons, photons), polarized targets (nucleon, nuclei) and nucleon polarimeters. A realisation of such experiments also requires to develop and employ a unique physical arrangement (sources of polarized particles, goniometers, low-temperature targets, magnetic spectrometer, complicated detector systems with a powerful computer support).

In the early 1960th the physical program of investigations of the photon interaction with nucleon and nuclei at the 2 GeV linear electron accelerator has been formed in KIPT. This program planed also proton polarization measurements. For realization of these measurements we have developed the method and suitable equipment. This equipment includes a carbon polarimeter with track registration of the pC-scattering and a magnetic spectrometer with particle focusing into the carbon polarimeter. In comparison with other methods where only the polarimeters were used [1,2] this method has the following advantages:

-the use of a magnetic spectrometer with particle focusing in the polarimeter provides a wide angular and photon energy ranges of proton polarization measurements in the reaction with a high angular and energy resolution being investigated;

-the layout of a polarimeter with track proton registration in the focal plane of the spectrometer provides proton momentum measurements in front of the carbon polarimeter with a resolution $\Delta p/p \sim 1\%$.

2. EXPERIMENTAL ARRANGEMENT

A layout of experimental arrangement used for polarization measurements at the 2 GeV linear electron accelerator (NSC KIPT) is shown in Fig. 1.

After passing the deflecting magnets, the electron beam was focused by magnetic lenses (1) into a photon radiator (3). The dimensions and position of the beam on the radiator were regulated by a secondary-emission monitor (2). Upon leaving the radiator a photon beam was formed on a target (6) by means of lead collimators (5) and was purified out from the charged component with magnets (4). The intensity of the photon beam was under continuous control using a Wilson quantometer (7). After interaction of photon beam with the target, the emitting protons were momentum-analyzed by means of a magnetic spectrometer (8) mounted at an angle θ_p according to kinematics of the reaction under investigation. Upon passing the spectrometer, charged particles fall into a polarimeter (9) where after appropriate selection by the electron logic they were detected using the spark chambers.

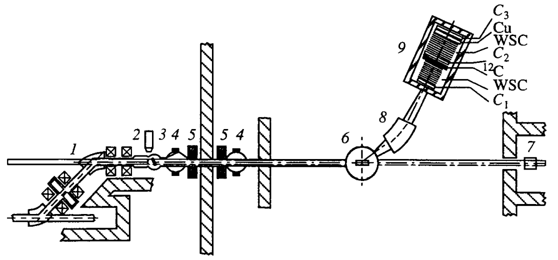

***Fig. 1**. Layout of the experimental setup: 1-magnetic lenses; 2-secondary emission monitor; 3-photon radiator; 4-deflecting magnet; 5-lead collimators; 6-^{3}He target; 7-Wilson's quantometer; 8-magnetic spectrometer; 9-telescope of wire chambers; WSC-wire spark*

chambers; C_1, C_2 and C_3-scintillation counters; ^{12}C-carbon scatter; Cu-copper absorber

MAGNETIC SPECTROMETER

The magnetic spectrometer used for polarization measurements [3] is a sector-type magnet having a homogeneous field with the horizontal focusing close to ideal one and the vertical focusing of the second order taking into account the scattering fields on its boundaries. The main characteristics of the spectrometer are: maximum momentum-2.3 GeV/c; angle of bend in the horizontal plane-30°; radius of deflection-535.8 cm; solid angle-1.74×10^{-3} sr; momentum resolution Δp/p for the target of 5 mm-0.2%; input angular acceptance-0.6°, 1.3 °, 4°; dispersion-14,5 mm/%; angular range of spectrometer location-from 12° to 100°; momentum acceptance-from -5% to +10%.

POLARIMETER

The first polarimeter used for polarization measurements at the 2 GeV electron accelerator was composed of telescopic optical spark chambers with 42 graphite electrodes with dimensions 350×350×7 mm³ [4]. Fig. 2 shows the arrangement of this telescope and the magnetic spectrometer.

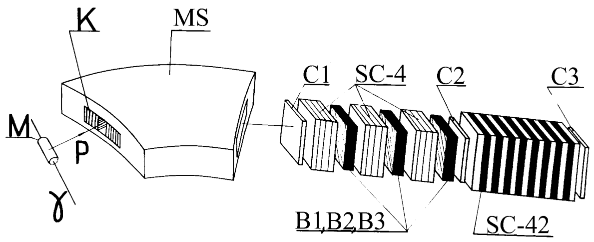

Fig. 2. *Experimental arrangements: M-target; K-collimator; MS-magnetic spectrometer; C1, C2, C3-scintillation counters; SC-4, SC-42-optical spark chambers; B1, B2, B3-carbon plates*

Such a distributed carbon system of the analyser of proton polarization has the following advantages in comparison with a carbon block system [1]:

- employment of the distributed carbon polarimeter gives a possibility to exclude the events of double and more pC-scattering in the process of "useful" events selection for polarization calculations;

- measurement of the proton energy by a number of graphit electrodes (through which electrons passed) in the spark chambers SC-42 (Fig. 2) before and after scattering makes it possible to perform comparison with the results of proton energy measurements on a coordinate of proton passing through the horizontal focal plane of the spectrometer. Such a comparison allows one to select the events with small energy losses of inelastic pC-scattering (ΔE<10 MeV) and to use the carbon analyzing power close to maximal values for an elastic scattering only [5] and thereby to decrease errors of proton polarization measurements. The proton polarization was measured with the given polarimeter in the proton energy range 100…350 MeV. The polarimeter efficiency reaches only few percents in the angular interval of pC-scattering from 5° to 20°. The use of the film technique provides a documentary of the registration of pC-scattering but requires a large amount of the film and special measuring automatic-manual devices for survey and selection of the events of pC-scattering. All this demanded much time for handling the polarization experiments.

The following stage was the development of an automatic polarimeter without film registration of events. Such a polarimeter was manufactured with using the spark wire magnetostrictive chamber [6]. The schematic diagram of this polarimeter is shown in Fig. 3.

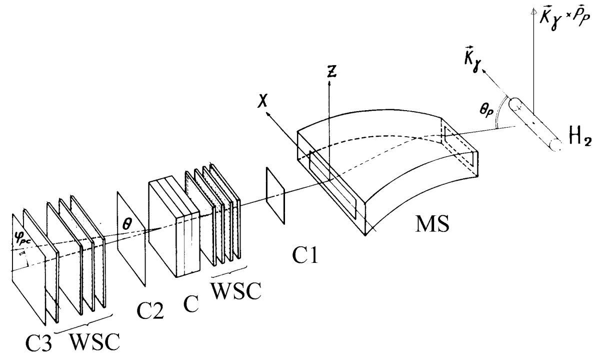

Fig. 3. *H_2-target; MS-magnetic spectrometer; C1, C2, C3-scintillation counters; C-carbon block; WSC-wire spark chambres*

The polarimeter consists of two blocks every of which comprises ten wire spark chambers with an effective area 180×180 mm² and 380×380 mm² respectively. The carbon scatterer was arranged between the blocks of spark chambers. The detailed description of the polarimeter, the electron system of track information reception and the computer software for data processing is given in paper [7]. This polarimeter is also arranged in the focal plane of the spectrometer and moves together with it in the course of the experiment. This polarimeter was used for measurements of the proton polarization in the proton energy range from 100 to 800 MeV.

3. RESULTS OF PROTON POLARIZATION MEASUREMENTS

The reaction $\gamma p \to p\pi^0$. In this reaction the proton polarization measurements were carried at the 2 GeV linear electron accelerator with using the non-polarized and linearly polarized photons. The proton polarization was measured with the non-polarized photon beam in the energy range from 360 to 1300 MeV. This is the range of nucleon resonances excited in an intermediate state of the given reaction. A study of properties of the resonances, their systematic, mechanisms of their excitation in the framework of meson-nucleon and quark-gluon theories, their contribution in the reaction cross-sections is a main direction of fundamental and experimental investigations in this region. A proton polarization measurements play an important role since its value is sensitive even to "weak" resonances unlike the cross-sections.

The energetic dependencies of the proton polarization was measured with the interval E_γ=25-40 MeV in the angular range θ_π=60°-150° cm with the interval 10°. The angular resolution of measurements is ~1.5°. Fig. 4

shows the results of the proton polarization measurements at NSC KIPT in the reaction $\gamma p \to p\pi^0$ for the angle θ_π=110° cm together with other data [8,9].

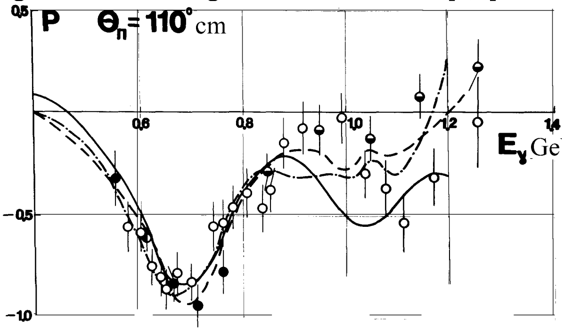

Fig. 4. Proton polarization in the reaction $\gamma p \to p\pi^0$ at Θ_π=110° cm as a function of the photon energy. The open circles-Kharkov [8,9]; the solid circles-Stanford; the left solid circles-Bonn; the down solid circles-Daresburg

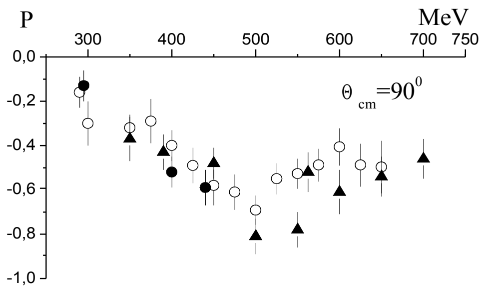

Fig. 5. Proton polarization in the reaction $\gamma D \to pn$ at Θ_p=90° cm as a function of the photon energy. The open circles-Kharkov; the solid circles-Stanford [15]; the solid triangles-Tokyo [16]

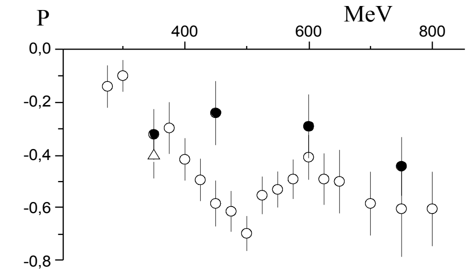

Fig. 6. Proton polarization in the reaction $\gamma^{3,4}He \to pX$ and $\gamma D \to pn$ as a function of the photon energy. The open circles-$\gamma D \to pn$ [13]; the solid circles-$\gamma^3 He \to pX$ [18]; the open triangles-$\gamma^4 He \to pX$ [18]

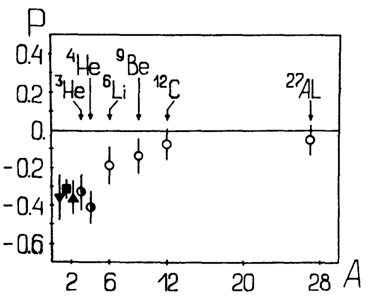

Fig. 7. Proton polarization in the reaction $\gamma A \to pX$ as a function of atomic number [19]

The proton polarization data of NSC KIPT are presently the most full in a resonance range of the reaction $\gamma p \to p\pi^0$. These data amount to more half of all world data [8,9]. The including of these data in the phenomenological analysis of the reaction $\gamma p \to p\pi^0$ [10] allowed one to get the most precise values of radiation decay amplitudes for a majority of nucleon resonances in the given region and thereby provided a safe testing of electromagnetic characteristics of resonances calculated in the framework of various versions of a quark model.

The proton polarization measurements were first conducted in the reaction $\gamma p \to p\pi^0$ with using linearly polarized photons and allowed one to get the first data about P_x and P_z-components of proton polarization. These measurements were performed in the region of Δ (1232)-isobar and ensured a more unambiguous selection of solutions in energy-independent analysis of this reaction [11].

The reaction $\gamma D \to pn$. Investigations of the two-body deuteron photodisintegration are connected with a study of a deuteron structure, nucleon-nucleon interactions, mechanisms of the reaction for various energies, role of meson-exchange currents (MEC), isobar configuration (IC), final state interactions (FSI), non-nucleon degree of freedom (d.o.f.), structure of the deuteron wave function (DWF) etc. The proton polarization measurements give an important contribution in these investigations due to the high sensitivity to some interaction effects in this reaction. The excitation of resonances (baryon and dibaryon resonances, FSI, MEC, IC, a contribution of deuteron D-state etc.) should be included to them. At NSC KIPT systematical proton polarization measurements were carried out in the reaction $\gamma D \to pn$ at photon energies from 200 to 1000 MeV and proton emission angles between 25° and 120° cm [12-14]. Fig. 5 shows the energy dependence of the proton polarization for the angle 90° cm together with other data [15,16].

These measurements confirm appreciable contributions of MEC, IC, FSI in the reaction mechanism at photon energies from 200 to 400 MeV and a hypothesis about excitation of dibaryon resonances at photon energies from 400 to 700 MeV. A manifestation of these resonances is connected with a quark mechanism of nucleon interactions at small distances (r<1 fm) in deuteron. At NSC KIPT the proton polarization was first measured with using the linearly polarized photon beam. Execution of such experiments extended significantly a set of measured polarization observables ($P_y^{\perp\perp}$, $P_y^{||}$, Σ, T_y, P_y, T_1) in one experiment, where (⊥, ||) is the direction of the photon polarization vector with respect to the plane of the reaction, Σ-asymmetry cross-section for the linearly polarized photons, T_y-asymmetry on a polarized target, P_y-proton polarization on the non-polarized photon beam, T_1-asymmetry of nucleon polarization due to the linearly polarized photons. The measurements of such a set of the observables was first performed in the reaction $\gamma D \to pn$ at energies from 200 to 600 MeV [17]. These data were included in the phenomenological multipole analysis with using the dibaryon resonanses (DR) [17]. The results of this analysis evidence about an important contribution of DR into the description of the experimental data in the given reaction at these photon energies.

The reaction $\gamma^{3,4}He \rightarrow pX$. The proton polarization was first measured in the inclusive reactions (γ,pn) on the lightest nuclei at NSC KIPT [18]. These measurements were connected with a study of quasi-deuteron mechanism of interactions in nuclei, properties of nucleon-nucleon correlations on various relative distances, a peculiarity of behaviour of their wave functions (WF) in comparison with WF of a free deuteron. The proton polarization was measured in the kinematics of the reaction of free deuteron photodisintegration for nuclei ^{3}He (E_γ=350-750 MeV), ^{4}He (E_γ=350 MeV) and the proton emission angle $\theta_p \sim 70°$ lab**.** The results of these measurements for nuclei ^{3,4}He are presented in Fig. 6 and compared with the similar measurements on the free deuteron [14,17].

A comparison shows some agreement between these measurements. It can evidence about an identical meson-exchange mechanisms of np-pair for these nuclei and the free deuteron. However, the proton polarization measurements for the more heavy nuclei (^{6}Li, ^{9}Be, ^{12}C, ^{27}Al) [19] in the same kinematics of the free deuteron turned out close to their zero values (Fig. 7). This can be caused either by the essential difference of properties of np-pair and its wave function for more heavy nuclei and a deuteron or by the effect of a presence of a nuclear "medium", i.e. by the secondary proton interactions in nuclei.

In such a way the method of the proton polarization measurements developed at NSC KIPT allowed one to carry out at the 2 GeV linear electron accelerator the systematical investigations of the photon interaction with nucleons and nuclei and to get new data on the proton polarization in the reactions $\gamma p \rightarrow p\pi^0$, $\gamma D \rightarrow pn$, $\gamma A \rightarrow pX$. The data have an important significance for astudy of reaction mechanisms and development of new theoretical approaches in their description.

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