POSSIBILITY OF MEASUREMENT OF CROSS SECTION AND VECTOR ANALYZING POWERS OF p–^{3}He SCATTERING AT THE BRONOWICE CYCLOTRON CENTER

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A new possibility of continuation of few-nucleon dynamics studies at medium energies has appeared together with a new facility at the Institute of Nuclear Physics PAN in Kraków — The Bronowice Cyclotron Center (CCB). The new cyclotron PROTEUS provides a proton beam in an energy range of 70–230 MeV. Current progress in the theoretical calculations for four-nucleon ($4N$) systems is a main motivation to investigate p–^{3}He scattering. Due to the fact that the beam cannot be polarized, the only possibility to study spin observables is to build a polarized ^{3}He target system. A planned experiment assumes the construction of a cylindrical double Pyrex cell with separated pumping and target chambers with an additional polyamide film covering apertures for the passing beam and the reaction products. To polarize ^{3}He gas, the spin-exchange optical pumping method will be used.

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1. Introduction

Experiments with polarized targets or beams give an access to a large number of observables, which are sensitive to the dynamical ingredients, hidden in the unpolarized case, when one averages over spin states. The polarization observables, *e.g.* the analyzing powers, are sensitive to spin-dependent part of the interaction, that makes them interesting for testing theoretical calculations based on various approaches to model the interaction in few-nucleon systems.

In a low and medium energy domain, the properties of few-nucleon systems are successfully modeled with the realistic two-nucleon ($2N$) potentials, coupled-channel (CC) method with explicit Δ-isobar excitation or Chiral Perturbation Theory (ChPT). At a certain level of experimental precision, subtle effects can be studied, for example the three nucleon force ($3N$F). The calculations, in order to correctly describe the system dynamics, include the model of $3N$F (*e.g.* Tucson Melbourne TM force [1]) and/or the Coulomb force [2]. Systems composed of three nucleons ($3N$) have been investigated more vividly since 1998, when 2π-$3N$F was discovered [3]. Currently, there exists quite extensive database of observables for $3N$ systems, however it is still insufficient to unambiguously fix a relevance of $3N$F.

The natural extension of the experimental and theoretical investigations is turning to $4N$ systems. Such ensemble reveals the complexity of heavier systems, *e.g.* variety of entrance and exit channels, various total isospin states and appears as a perfect tool for testing the existing $3N$F models. Theoretical calculations of the bound states show very week influence of the $4N$ force so they are assumed to be negligible [4, 5]. Nevertheless, one should, in principle, verify this claim also in the case of nuclear reactions.

Recent years have brought serious progress in precise calculations of the cross section and polarization observables. The very first $4N$ scattering results with the realistic $2N$ forces were obtained for single channel n–^{3}H, p–^{3}He [6–8] and p–^{3}H [9] reactions below inelastic threshold. Then, the observables were calculated at energies below three-body breakup threshold, for n–^{3}H [10], p–^{3}He [11], n–^{3}He, p–^{3}H and $d-d$ [12]. So far, the rigorous predictions have been limited to a domain of the lowest energies. Recently, the calculations were extended for higher energies, above the four-cluster breakup threshold. The predictions have been performed for p–^{3}He [13], n–^{3}He [14] elastic and transfer reactions up to an energy of 35 MeV. The 3 and $4N$ dynamical components were modeled separately via the explicit treatment of a single Δ-isobar for p–^{3}He elastic scattering at 30 MeV. For this reaction, the observables were also calculated for energy of 70 MeV [15]. In the case of the $d+d$ system, recent progress is presented in [16, 17].

The calculations at higher energies are currently feasible and studies of the $2N$, $3N$ and $4N$ force effects are possible [5, 13]. One expects a progress in this field, which would result in predictions for observables at medium energies. Experimental basis, which could be used for testing these forthcoming theoretical findings, is nowadays very poor, especially for spin observables at medium energies [18–27]. Therefore, the idea of the construction of a polarized ^{3}He target at the new CCB facility has come up.

2. A planned detection system

A schematic overview of the experimental setup for the planned measurements with a polarized ^{3}He target is shown in Fig. 1.

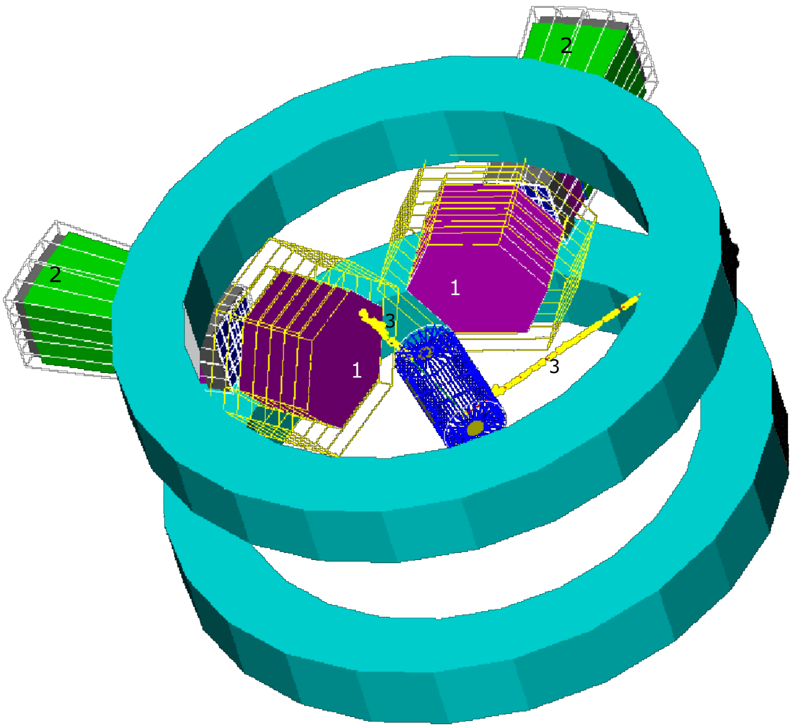

Fig. 1. A sketch of the planned detection system performed with Geant4. The target cell is visible in the center, the pumping chamber is not seen in the picture. The vertex MWDC detectors (marked with 1 (magenta)) are situated next to the target and before the Kratta modules (marked with 2 (light green)). The cyan rings are the Helmholtz coils. A selected particle trajectories are seen as light gray/yellow (marked with 3) paths.

The planned detection system will include two cylindrical chambers, two Helmholtz coils, two Multi-Wired Drift Chambers (MWDC) and two sets of the Kratta detectors [28]. MWDCs as well as the Kratta modules will be placed in front of the target exit windows to reconstruct the tracks of the emerging particles.

The system of the two connected cells (*e.g.* [29, 30]) will be made of commercial grade Pyrex glass in a shape of a cylinder with two end caps. One cylinder, with a diameter of 50 mm and the same length, will be used as an optical pumping cell. The other, with a diameter of 50 mm and length of 100 mm, will serve as a target cell for the polarized ^{3}He gas. The target cell and the optical pumping cell will be connected together with Pyrex tubes.

The polarized ^{3}He will be produced with SEOP (Spin-Exchange Optical Pumping) [31]. With this method, typical optical pumping cell pressures are 1–8 bar, therefore, a high target density is ensured. The main disadvantages are the long polarization build-up time and the depolarization effect from wall relaxation [32]. In this experiment, the target will posses thin polyamide windows covering apertures for the passing beam and the scattered particles. Optimal measurement conditions have to be found to ensure pressure high enough to obtain acceptable luminosity and still the mechanically stable target cell construction. Serious problems are expected due to ^{3}He depolarization on the windows foil as well as the diffusion of ^{3}He through this foil. Dedicated material tests are being carried out.

The target and pumping cells will be placed between the two Helmholtz coils of about 500 mm diameter. They will provide a magnetic field of a few mT in a sphere of about 200 mm diameter with accuracy of 10%.

The optical pumping cell will be placed inside an oven cavity to maintain the 150–190°C required to obtain the proper Rb vapor density. It will be uniformly illuminated with the laser light tuned to rubidium D1 line at 795 nm. The polarization will be transfered from the optically pumped Rb to the ^{3}He in binary collisions. Then, the polarized gas will be transported to the target place where collisions with the proton beam will occur. The emerging particles will be detected with the MWDCs and the Kratta modules. MWDCs will be used to reconstruct the trajectory of the charged particles, ^{3}He ions and protons from the elastic scattering reactions. For applied cylindrical drift cell geometry, with maximum drift length of 5 mm, we assume conservatively the position resolution of a single plane to be around 200 μm. This precision allows one to reconstruct reaction vertex with accuracy below 1 mm, which is extremely important for possibility of efficient background reduction. Having in mind very large stopping power of helium ions as compared to protons, also application of pulse height information from MWDC is considered for a particle identification (PID). Two techniques are possible: *(i)* approximate, but simple in realization, *time-over-threshold* method, and *(ii)* dedicated pulse-height measurement performed in parallel to drift time measurement. Successful implementation of either of these method would considerable lower the detection threshold of the experiment.

The energy detectors are modular and can be easily arranged around the target. They will also serve as the PID detectors [28]. Due to the fact that the detector granularity is rather poor ($\Delta\theta \sim 8°$ at the distance of 200 mm from the target), the construction of a dedicated energy detector is planned.

Currently, the experimental setup is tested and optimized with the Geant4 simulation.

3. Summary and conclusions

Precise measurements of the vector analyzing powers for the p–^{3}He elastic scattering is planned at CCB. In further future investigations of the $^3\mathrm{He}(p,dp)p$ channel are also considered. Such studies are important for understanding of the interaction between nucleons in heavier systems. The experiments will also allow one to investigate the $3N$F in the four-body environment. Currently developed theoretical models for $4N$ systems need an experimental verification. Within these predictions different pieces of the dynamics can be studied separately and also their mutual interplay can be investigated. The experimental apparatus which will be used in the experiment with the polarized ^{3}He target is under construction.

Such studies will allow one to fill a data-deficient sector of $4N$ systems.

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