Experimental data on the $dp \rightarrow ppn$ reaction at the deuteron energy of 300–500 MeV obtained at ITS at Nuclotron

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The experiment on dp non-mesonic breakup at Internal Target Station at Nuclotron is presented. Recent results on the study of the dp -breakup reaction with 300–500 MeV unpolarized deuteron beam at Internal Target Station at Nuclotron are discussed. Selection procedure of useful events for the $dp \rightarrow ppn$ reaction with the registration of two protons is shown. Further scientific program with polarized and unpolarized deuterons is discussed.

Keywords: $dp \rightarrow ppn$; deuteron; breakup.

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1. Introduction

The successes of meson-exchange theories in the description of two-nucleon observables directed the research towards systems composed of three nucleons ($3N$), where

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nucleon-nucleon (NN) interaction models can be tested in a non-trivial environment and, moreover, additional dynamics related to the presence of the third nucleon can be investigated. The deuteron breakup process, with its variety of final states and rich information contained in the observables of the 3N continuum, is ideally suited for such tests.¹

Properties of few-nucleon system at moderate energies are determined mainly by pairwise nucleon-nucleon interactions. Models of NN forces describe the long range interaction part according to the meson-exchange, while the short range is based on phenomenology, adjusted by fitting a certain number of parameters to the NN scattering data. Nowadays a new generation of the NN potentials (AV-18,² CD-Bonn,³ Nijmegen⁴ etc.) was obtained. They reproduce data on the nucleon scattering up to 350 MeV with very good accuracy. However, these modern $2N$ forces fail to provide the experimental binding energies of few-nucleon systems. Moreover, the data on the dp -elastic scattering and deuteron breakup are not described properly.

Precise predictions for observables in the $3N$ system can be obtained via exact solutions of the $3N$ Faddeev equations for any nucleon-nucleon (NN) interaction, even with the inclusion of a $3NF$ model.⁵ Incorporation of the $3N$ forces makes it possible to reproduce the binding energy of the three-nucleon bound systems and also data on unpolarized dp -interaction. Nevertheless, polarization data for the reactions with participation of three and more nucleons are not described even with inclusion of $3NF$. Therefore, the obtaining of the additional polarization data in the dp -interaction in the wide energy range more is very desirable for the study of the spin structure of $2N$ and $3N$ forces.⁶ To investigate the details of the dynamics of the $3N$ system, in addition to elastic Nd scattering data, reliable deuteron breakup data sets, covering large regions of the available phase space, are needed.

The experimental data on the deuteron analyzing powers for dp -breakup for large phase space were obtained at 130 MeV at KVI.⁷ The predictions for analyzing powers and differential cross section in the selected dp -breakup configurations at 400 MeV were obtained in Ref. 8. It was shown large sensitivity of these observables to the model of $3NF$.

The purpose of Deuteron Spin Structure experimental program is to obtain the information on the spin-dependent parts of 2-nucleon and 3-nucleon forces from two processes^{9,10}: dp -elastic scattering in a wide energy range^{11–14} and dp non-mesonic breakup with two protons detection at energies 200–500 MeV.¹⁵ In particular, it is planned to measure A_y , A_{yy} and A_{xx} analyzing powers in dp -breakup at Internal Target Station at 200–500 MeV.

In this report the status of the experiment at internal target station (ITS) at Nuclotron preparation and first beam results are presented.

2. The Experimental Setup

The first stage of the DSS experimental program^{10,16,17} is the beam energy scan of dp -elastic scattering cross section at the deuteron energies from 400 up to 2000 MeV

and measurements of dp -non-mesonic breakup at 300, 400 and 500 MeV in different kinematic configurations. These measurements will be performed using ITS¹⁸ with new control and data acquisition system.¹⁹

The dp breakup reaction will be investigated using $\Delta E - E$ techniques for the detection of protons. 8 detectors of this kind are planned to use in the experiment. The details of the $\Delta E - E$ detector construction are presented in Refs. 15 and 20.

Each detector consists of two scintillators ΔE and E . The first scintillator has the cylindrical form with the height 10 mm and the diameter 80 mm. Two PMTs-85 view through given scintillator and they are located the friend opposite to the friend. Two planes have been made on the scintillator to increase the area of the optical contact between the scintillator and photocatode of the PMT-85. These planes have been polished. ΔE scintillator is covered by a white paper. Digital dividers of the high voltage are used for PMT-85.

E scintillator also has the cylindrical form with height 200 mm and diameter 100 mm. PMT-63 view through this scintillator. Given PMT has been chosen because of the suitable size of the cathode (100 mm) with both good time and amplitude properties. E scintillator has been wrapped by a white paper. The part which is located to ΔE scintillator has been covered by a black paper. It is made to exclude possibility of hit the light from one plastic scintillator to another. The calibration for $\Delta E - E$ counters were performed with cosmic muons and pp -quasi elastic scattering.

3. The Simulation Results

The simulation results on the energy losses of the protons which passes through the scintillators are presented in Fig. 1. In (b) figure the energy losses of the proton in thin scintillator are plotted versus ones of the thick scintillator. The events were selected in the region of approximate linear dependence of the energy losses in the scintillator versus the incident proton energy.²¹ Therefore the following conditions

Fig. 1. (a) Simulation results of the energy losses of the protons passed through ΔE and E scintillators when the length of a scintillator is 21 cm ($\Delta E + E$) (b) Simulation results of the energy losses of the protons passed through ΔE and E scintillators in thin scintillator versus thick.

on the ΔE and E information were imposed:

$$5 \text{ MeV} < \Delta E < 35 \text{ MeV} \quad \text{and} \quad 0 \text{ MeV} < E < 180 \text{ MeV}.$$

4. Results Obtained at Nuclotron

Breakup events collected for an unpolarized beam were analyzed at a set of kinematical points, defined by polar emission angles of the two protons, Θ_1 , Θ_2 , their relative azimuthal angle Φ_{12} and their energies, expressed by a variable S . Using the measured variables and considering momentum and energy conservation, all the other kinematical variables of the reaction can be obtained unambiguously. Definitions of coordinate systems and angles are given in Ref. 22. For each configuration Θ_1 , Θ_2 , Φ_{12} of the two outgoing protons, the kinematical spectra E_2 versus E_1 were built (see an example in Fig. 6). The kinematical energy relations are perfectly reproduced by the data, which confirms the reliability of the whole calibration procedure. The variable S corresponds to the arc-length along the kinematical curve, with 0 chosen at the minimal value of E_2 . The S -curves for several kinematical configurations are shown in Fig. 2.

The first step in the event selection for the three-body break-up channel is to find the energy correlation between the final-state protons for a particular kinematical configuration (Θ_1 , Θ_2 , Φ_{12}), where Θ_1 , Θ_2 are the polar angles of the two protons, respectively, and Φ_{12} is the difference between their azimuthal angles. The number of break-up events in an interval $S - \Delta S/2$, and $S + \Delta S/2$ was obtained by projecting the events on a line perpendicular to the S -curve.

Next step is the selection procedure of useful events. Experimental data were obtained on polyethylene (CH_2) target and carbon (^{12}C) target for assessment

Fig. 2. The energy correlation between two protons in coincidence for the three-body deuteron break-up reaction is shown as S-curves for several kinematical configurations (left figure). Right figure presented the energy correlation between two protons coincidence as S-curve for two different configuration and for 300 MeV, 400 MeV, 500 MeV energy of deuteron. The kinematics are defined by (Θ_1 , Θ_2 , Φ_{12}), the polar scattering angles of the two protons, respectively, and the relative azimuthal angle.

background. To remove the carbon contribution $CH_2-^{12}C$ normalized spectra subtraction is needed. Polyethylene and carbon spectra of S-curve after normalization are presented in Fig. 3. The normalization coefficient of the data on ^{12}C target were obtained using the time difference, the amplitudes and the missing mass histograms. The result of the $CH_2-^{12}C$ subtraction is shown in the right panel in Fig. 3.

The statistical error associated with the background subtraction is roughly given by $\delta N_{dp} = \sqrt{N_{CH_2} + \Lambda^2 N_C}$ where the Λ is normalization coefficient of the data on ^{12}C target, $\Delta S = 10$ MeV. Preliminary results are presented in Fig. 4.

Fig. 3. Left picture presented experimental data obtained on CH_2 target (light grey color) and data obtained on carbon target (dark grey color). Right histogram were obtained after delet background for $\Theta_1 = 25^\circ$, $\Theta_2 = 34^\circ$, $\Phi_{12} = 135^\circ$ and at 300 MeV energy of deuteron.

Fig. 4. Preliminary result of the experimental data for S-curve (MeV) obtained after background subtraction for $\Theta_1 = 25^\circ$, $\Theta_2 = 34^\circ$, $\Phi_{12} = 135^\circ$ and of 300 MeV energy of deuteron.

5. Conclusion

The preliminary results for $dp \rightarrow ppn$ reaction at 300–500 MeV for different geometry at Internal Target Station at Nuclotron are obtained. The procedure of selection of events relating to the dp-breakup reaction is established. The setup for the studies of deuteron non-mesonic breakup reaction was put into operation.

The future plans are to continue to process the obtained data and to estimate a contribution of background events to these results for the study of dp-breakup reaction. We are going to take the data on dp-breakup using with polarized deuteron beams at Nuclotron. New source will provide up to $2 \cdot 10^{10}$ ppp and higher values of polarization than POLARIS. Part of the IUCF source is used for the construction. The putting into operation of new PIS is planned in 2016.

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