PROCEEDINGS OF SCIENCE

The differential cross section in the dp-elastic scattering at the energies from 500 to 1000 MeV/n

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The results of study of dp-elastic scattering at the energies from 500 to 1000 MeV/nucleon at Nuclotron JINR are reported. The differential cross section data were obtained for angles range of 70-120 deg. in the c.m.s. The results are compared with existing experimental data.

XXII International Baldin Seminar on High Energy Physics Problems
Dubna, Russia
September,15-20 2014

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PoS(Baldin ISHEPP XXII)099

Contents

1. Introduction

The study of dp-elastic scattering at various energies at large angles is one of the directions of DSS (Deuteron Spin Structure) project program [1]. This reaction is the longtime subject of the theoretical and experimental investigations. Now the different theoretical models are developed: Faddeev calculations in the momentum space [2] and configuration space [3], and variational calculations based on the solution of the three-particle Schroedinger equation [4, 5, 6]. The momentum-space Faddeev equations for three-nucleon scattering can now be solved with high accuracy for the most modern two- and three- nucleon forces below 200 MeV/n of the projectile energy [7, 8]. The discrepancy between the theory and experiment is increasing with increasing energy indicating the possibility of relativistic effects. The theoretical calculations using not only 2N forces but also different 3N forces [9, 10] give the best agreement with experimental data.

The experimental material for dp-elastic scattering covers the energy range from tens to thousands MeV/n. The precise data were obtained at RIKEN at the energies of 70, 100 and 135 MeV/n [11] for the angular range of $10^\circ < \theta^* < 180^\circ$. The analogous experiment was performed in RCNP at the energy of 250 MeV/n [12], where the data on the cross section and complete set of proton spin observables were obtained.

The transition to higher energies will allow one to understand the mechanism of manifestation of the fundamental degrees of freedom at distances of the order of the nucleon size. Glauber scattering theory which takes both single and double interactions in this case is a classic approach [13, 14]. The experimental data for dp-elastic scattering at energies from 425 to 1250 MeV/n are presented in [15]-[25]. The differential cross section data for center-of-mass angles between 91^o and 164^o at energies 470 and 590 MeV/n were obtained at the National Aeronautics and Administration Space Radiation Effects Laboratory [16]. The data at 580 and 582 MeV/n were presented in [17] and [18], respectively. The absolute differential cross section was measured at 641.3 and 792.7 MeV/n in the angular range of $35^\circ - 115^\circ$ and $35^\circ - 140^\circ$, respectively [19]. The data for forward angles at 796 and 1000 Mev/n were presented in [21] and [22], respectively. The experiment to obtain of the data at 1 GeV/n for the angles of $10^\circ < \theta^* < 170^\circ$ at the Brookhaven National Laboratory (BNL) was performed [24]. The new data on the differential cross section of the dp-elastic scattering at 1.25 GeV/n were obtained with HADES detector [25]. The experimental data are described by the relativistic multiple scattering theory which takes both single and double interactions into account [26].

The experimental setup at Internal Target Station (ITS) [27] at Nuclotron allows to obtain the different observables from 60^o to 140^o in the c.m.s. The measurements of differential cross section were performed at ITS Nuclotron at the energies from 200 to 440 MeV/n [28]. Here the preliminary data at the energies between 500 and 1000 MeV/n are presented.

2. Experiment

The measurements were performed at ITS [27] at Nuclotron JINR. New ITS DAQ system was used during data taking [29]. The elastically-scattered deuterons and protons were counted by two pairs of detectors placed symmetrically with respect to the beam direction. This allows to improve the quality of the experiment. All deuteron- and proton-counters are based on the Hamamatsu H7416MOD. Another two detectors based on the FEU-85 and FEU-63 were used to count of the quasi-elastically-scattered protons [30]. The layout of the counters with respect to the beam direction for energy 1000 MeV/n is shown in Fig.1. The $D_{1,2}$, $P_{1,2}$ and $PP_{1,2}$ are deuteron-,proton- and pp-detectors,respectively. All counters were placed in horizontal plane. The DP-detectors were rotated to give an angular range of the $\theta_{lab} = 19^o$ to 50^o ($\theta_{c.m.} = 70^o$ to 120^o). The PP-detectors were mounted at the angle corresponding to quasi-elastic scattering at $\theta_{c.m.} = 90^o$ and remained stationary throughout the experiment for each energy. The size of the D-,P- and PP-counters are 50x50x20 mm^3, 20x60x20 mm^3 and ϕ100x200 mm^3, respectively. The distances between $P_{1,2}$- $D_{1,2}$- and $PP_{1,2}$- counters and point the beam interaction with the target are 63, 60 and 100 cm, respectively. The angular spans of $P_{1,2}$-, $D_{1,2}$- and $PP_{1,2}$- detectors were 2^o, 5^o, 10^o in the laboratory system, which corresponds to 4^o, 10^o and 20^o in the c.m.s., respectively.

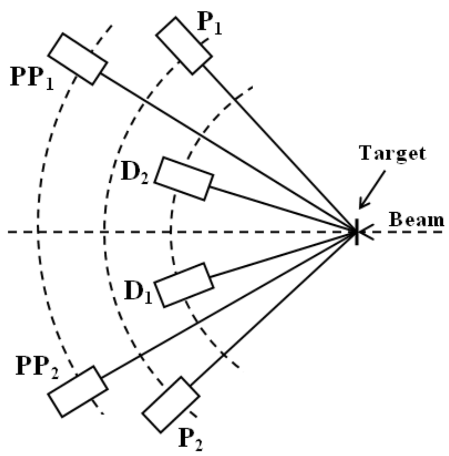

Figure 1: Layout of the counters with respect to the beam direction.$D_{1,2}$, $P_{1,2}$- deuteron and proton detectors, $PP_{1,2}$-detectors to registered of the pp-quasi-elastic scattering.

In the case measurements at lower energies the minor change was made in the scheme of detectors. The size of the D-,P- and PP- counters are 10x40x24 mm^3, 20x60x20 mm^3 and 50x50x20 mm^3, respectively. All detectors are based on the Hamamatsu H7416MOD. The PP-counters were mounted at the distance 60 cm.

The VME based data acquisition system was used for the data taking from scintillation detectors [31]. TQDC16 module allows to measure the amplitude and time appearance of the signal. Each module is separated on the two parts with 8 input channels having own first level trigger logics. In the current experiment the first level trigger signal was appeared when the signal from one module part coincides with the signal from any channel of other part.

3. Data analysis

The data processing at 1000 MeV/n is shown below as an example. The procedure to obtain differential cross section data begins by analysis of the amplitude spectra. The signal amplitudes correlation for D- and P- detectors was made. Then the graphical cut was imposed to select dp-elastic scattering particles (Fig. 2).

The next stage is the application of the temporary gates on the deuteron and proton time difference spectra to estimate the background in the amplitude data. The subtraction of the timing signal from D- and P- counters was made by using the cut for signal amplitudes correlation (Fig 3). In this distribution the dp-elastic scattering events (I domain) and the background (II and III domains) are selected so that the width of both domains are equal.

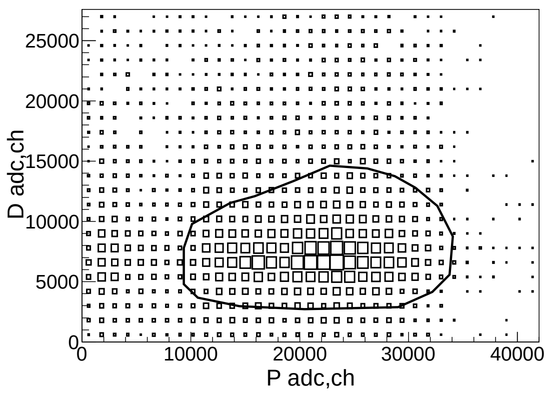

Figure 2: The signal amplitudes correlation for D and P detectors at 1000 MeV/n. The solid line is the graphical cut to select dp-elastic scattering events.

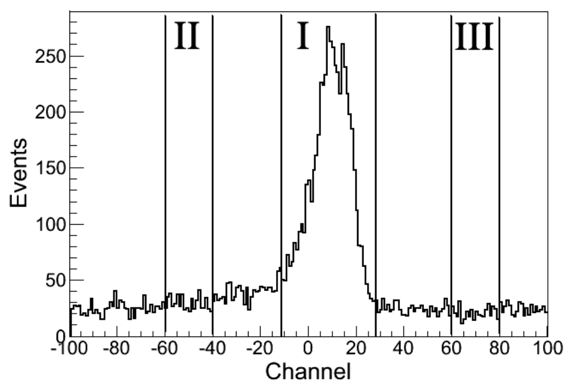

Figure 3: The subtraction of the timing signal from D- and P- counters for $\theta^* = 70^o$ in the c.m.s. at 1000 MeV/n.

The amplitude distribution for proton counter by using these timing gates is shown in Fig. 4 A. The subtraction of the resulting spectra allows to reduce of the background (Fig 4 B).

Analogous procedure was performed for data by using CH_2-target as well as C-target.

The next stage is the CH_2-C subtraction procedure. The carbon background subtraction normalization coefficient k is deduced from the interval $a_{min} < a < a_{max}$, where a - channels of CH_2-

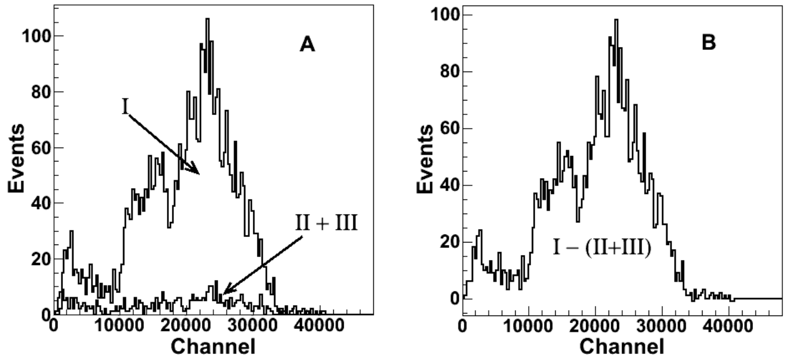

Figure 4: The cleaning procedure of the amplitude spectrum by using of the timing gates.

and C-amplitude distributions:

$$k = \frac{N_{CH_2}|_{a_{min}<a<a_{max}}}{N_C|_{a_{min}<a<a_{max}}}. \tag{3.1}$$

Here N_{CH_2} and N_C - CH_2- and C-amplitude distributions integrals in a-interval. The carbon background can be subtracted as:

$$N_{dp} = N_{CH_2} - kN_C,$$

were N_{dp} - resulting dp-elastic scattering distribution, N_{CH_2} - total CH_2-distribution,kN_C - normalized C-distribution. The subtraction resulting spectra allows to obtain the dp-elastic scattering events.

4. The differential cross section

In Fig.5 the data for differential cross section at 1000 MeV/n are compared with world data and with the theoretical predictions.

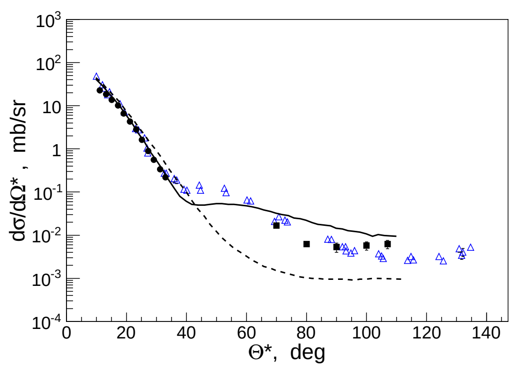

Figure 5: The differential cross section for dp-elastic scattering at 1000 MeV/n. Squares - the results of this work, circles - data from [22], triangles - data from [24], line - the theoretical calculations without DS term.

New data are shown by the solid squares. The errors are the statistical only. The systematic error due to normalization and $CH_2 - C$ subtraction procedure $\approx$ 30 %. The data obtained earlier for forward angles [22] are shown by the solid circles. The open triangles are world data from [24] obtained with a monochromatic protons beam at the Brookhaven Cosmotron by using a liquid-deuterium target. The data at Nuclotron are normalized to data from [24] at the 70^o in the c.m.s. The shape of the angular dependence of new data agrees with the behaviour of the world data. The dashed and solid lines are the calculations without and with double scattering term, respectively. One can see that the single scattering mechanism does not reproduce the experimental data at the scattering angles θ^* larger than 45°. The inclusion of the double scattering term in the calculations provides better agreement with the experimental results. However, some discrepance remains. Probably, taking into account new reaction mechanisms like explicit Δ-isobar excitation will improve the description of the data. The preliminary data for differential cross section at 500,650 and 750 MeV/n are shown in Fig. 6, Fig 7 and Fig.8, respectively. One can see, the

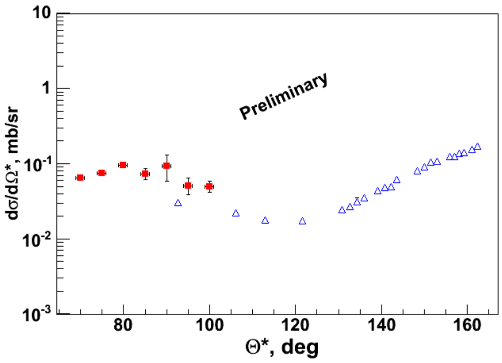

Figure 6: The differential cross section for dp-elastic scattering at 500 MeV/n. Squares - the results of this work, triangles - data from [16].

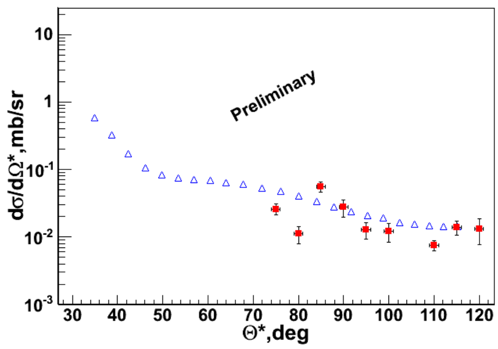

Figure 7: The differential cross section for dp-elastic scattering at 650 MeV/n. Squares - the results of this work, triangles - data from [19].

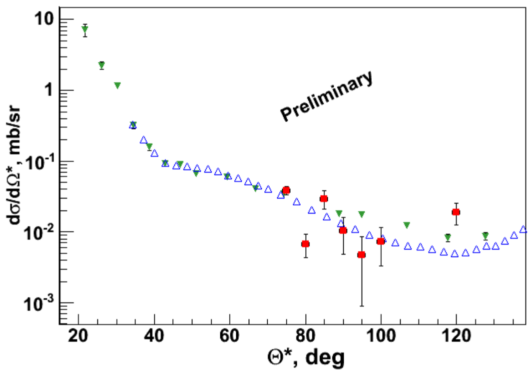

Figure 8: The differential cross section for dp-elastic scattering at 750 MeV/n. Squares - the results of this work, open triangles - data from [19], solid triangles - data from [23].

shapes of the angular dependence of data obtained at Nuclotron are in the reasonable agreement with the behavior of the world data [23, 24, 19, 16].

5. Conclusion

The procedure on the dp-elastic scattering differential cross section at high energies at ITS at Nuclotron using $CH_2 - C$ subtraction is established.

The preliminary differential cross section data for dp-elastic scattering at 500,650,750 and 1000 MeV/n are obtained. The results are compared with existing data for similar values of energies.

The data obtained at 1000 MeV/n are compared with the calculations performed within the framework of the relativistic multiple scattering theory [26]. It is shown that taking into account the double scattering term improves the description of the obtained experimental results.

The work has been supported in part by the RFBR grant 13-02-00101a.

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