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# Angular and energy dependence of $A_y$, $A_{yy}$ and $A_{xx}$ analyzing powers in dp elastic scattering and dp breakup reaction investigation

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Energy dependence of the vector $A_y$ and tensor $A_{yy}$ and $A_{xx}$ analyzing powers in deuteron-proton (dp) elastic scattering is investigated in the energy range from 400 - 2000 MeV at large scattering angles. The detection of the dp elastic scattering events has been done by the coincident measurement of deuteron and proton in the the angular range of 60°-135° in the cm. Preliminary results of differential cross sections and analyzing powers for dp elastic scattering are compared with theoretical predictions based on relativistic multi-scattering model which includes besides single and double scattering terms also delta isobar excitation. There are interesting parts of deuteron proton breakup reaction phase space in which three nucleon forces, relativistic or coulomb effects can be studied separately. Preliminary results of the cross section of the dp breakup reaction have been obtained in the energy range from 300 - 500 MeV of incoming deuteron for particular detector configurations in which the sensitivity to the nucleon-nucleon, three nucleon forces as well as relativistic effects are assumed. All measurements were performed at Nuclotron (JINR, Dubna).

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## 1. Introduction

The realistic nucleon-nucleon potentials are unable to describe e.g. binding energy of three [1] and four nucleon systems [2] and many scattering experiments. The cross section data of the pd elastic scattering obtained at 250 MeV cannot be reproduced by the Faddeev calculations [3]. The reason can be due to new type of short range correlations which is still not included in calculations. It has been found that in the vicinity of the Sagara discrepancy the currently known three nucleon force contribute up to 30% to the dp elastic scattering cross section at intermediate energies [4]. Situation is even worse in case of experiments with polarized beam and/or target. It has been found that the relativistic effects become very significant at relatively low energies in the fragmentation processes. Predicted behaviour of the tensor analyzing power of the $dp$ reaction within the framework of light-front dynamics using relativistic deuteron wave function [5] is in relatively good agreement with the data on the tensor analyzing power $A_{yy}$ of the $^9Be(d,p)X$ reaction at initial deuteron momenta of 5 $GeV/c$ and at proton emission angle of 178 $mr$ [6] and on the tensor analyzing power $A_{yy}$ obtained on hydrogen and carbon at initial deuteron momenta of 9 $GeV/c$ and at proton emission angle of 85 $mr$ [7].

The main goal of Deuteron Spin Structure program (DSS) is to obtain information about two and three nucleon forces, including their spin dependent parts. For this purpose, $dp$ elastic scattering and $dp$ breakup reaction are investigated in the energy ranges from 300 MeV - 2000 MeV and 300 MeV - 500 MeV of deuteron energy.

## 2. Polarization observables of $dp$ elastic and breakup reactions

Method of deuteron beam polarization estimation is based on measured of asymmetries at large scattering angles $\theta_{cm} \geq 60^\circ$ in $dp$-elastic scattering at 270 MeV [8] at the Internal Target Station (ITS) of Nuclotron. The internal beam polarimeter with a very thin target (tenths of $\mu m$) may have approximately the same efficiency as the extracted beam polarimeters. Efficiency can be achieved even at relatively low beam intensity with using a thin solid target inside the inner ring of the Nuclotron and multiple beam passage through the interaction point. Polarimeter uses high precision data on analyzing powers obtained at RIKEN [9]. The accuracy of the determination of the deuteron beam polarization is better than 2%. This uncertainty is propagated to the systematic error of analyzing power of $dp$ elastic scattering. Polarimeter has been used to measure polarization for six different spin modes. The long-term stability of the vector and tensor components of the beam polarization of SPI [10] has been demonstrated. Measured values of the beam polarization were $65\% - 75\%$ of the ideal values for all 6 spin modes of SPI.

The detection of the dp elastic scattering events has been done by the coincident measurement of deuteron and proton in the the angular range of 60° -135° in the cm. The $A_y$, $A_{yy}$ and $A_{xx}$ analyzing powers have been measured for the sixteen and fifteen angles defined by the position of the counters placed in the horizontal and vertical planes, respectively. ITS with targets inside is located inside particular part of the acceleration tube, scintillation counters are distributed in their vicinity. Then the angular placement are affected by the experimental condition and setup. The angular dependence of the cross section at deuteron energy of 1400 MeV is shown in Figure. 1. The statistical and systematic errors cover angular range between 3% and 20% and between 14%

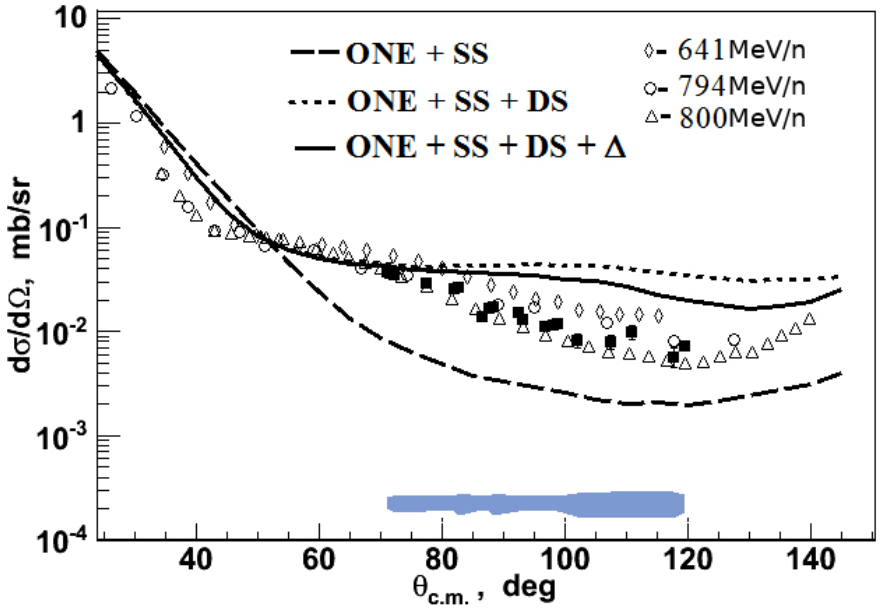


**Figure 1:** Angular dependence of the cross section at deuteron energy of 1400 MeV. Curves are predictions based on relativistic-multiple scattering model when one nucleon exchange and single scattering term (dashed curve), additional double scattering term (dotted curve) and Δ isobar (solid curve) are included. Nuclotron data are represented by closed symbols, world data at slightly different energies are shown by open symbols.

and 29%, respectively. Curves are predictions based on relativistic-multiple scattering model at deuteron energy of 1400 MeV, e.g. [11] when one nucleon exchange and single scattering term (dashed curve), additional double scattering term (dotted curve) and Δ isobar (solid curve) are included. Nuclotron data are represented by closed symbols, world data at slightly different energies are shown by open symbols. One can see large contribution which comes from double scattering term. It describes the data up to 70°. Δ isobar contribution comes at larger angles above 80° and rises with angle. However the data are described in this angular range only qualitatively. Δ isobar contribution improves the qualitative description of the cross section at 1400 MeV. In general, data at intermediate energies are reasonably described by the model at small and large angles, but not in the angles between. The reason of the discrepancy probably lay in the reaction mechanism which is not well understood.

Angular dependence of the vector $A_y$, tensor $A_{yy}$ and $A_{xx}$ at deuteron energy of 400, 700, 880 and 1000 MeV were compared with the predictions based on relativistic multiple scattering model. In general, large contribution which comes from double scattering term is observed, but it does not improve the description of analyzing powers in all cases, rather at small angles. Moderate contribution which comes from Δ isobar is found at higher energies. Strong sensitivity to the short range spin structure of the isoscalar nucleon-nucleon correlations is observed in deuteron analyzing powers.

Preliminary results of the five fold differential cross section of $dp$ breakup reaction investigated

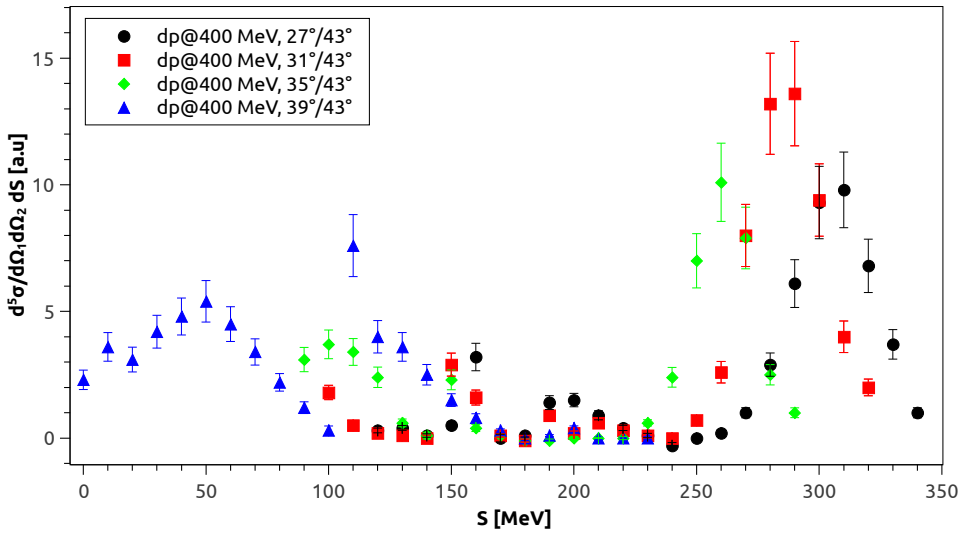


**Figure 2:** Preliminary results of the five fold differential cross section of $dp$ breakup reaction investigated at 400 MeV for the case of detector arms placed at the angles of 27° and 43° (black symbols), 31° and 43° (red symbols), 35° and 43° (green symbols), 39° and 43° (blue symbols), respectively. Only statistical errors are shown.

at 400 MeV for the case of detector arms placed at the angles of 27° and 43°, 31° and 43°, 35° and 43°, 39° and 43° are presented. The systematic error (under evaluation) is mainly affected by the procedure of Polyethylene - Carbon subtraction, the solid angle of the detectors and the normalization coefficient determinations. One can see some structures in kinematic $S-$ curve at the vicinity of $\approx$ 100 MeV and $\approx$ 260 MeV. The next step is to obtain results at other angles to investigate observed structure in recent data.

Possible measurements on extracted beam of Nuclotron include the measurements of the tensor $A_{yy}$ and vector $A_y$ analyzing powers (and, possibly, vector polarization transfer coefficient $C_y^y$) in inclusive deuteron breakup, $A(d,p)X$, at large transverse proton momenta [12] at the highest available energy at Nuclotron; of the tensor $A_{yy}$ and vector $A_y$ analyzing powers [13] (and, possibly, vector polarization transfer coefficient $C_y^y$ [14]) in the inelastic deuteron scattering, $A(d,d')X$, in the vicinity of the baryonic resonances excitation; of the tensor $A_{yy}$ and vector $A_y$ analyzing powers in the inclusive pion production, $A(d,\pi^-)X$, [15] also at the highest available energy at Nuclotron. The inclusive measurements of the analyzing powers in inclusive deuteron breakup and the inelastic deuteron scattering in the vicinity of the baryonic resonances excitation can be also performed. Future spin studies require also advanced deuteron beam polarimetry to more detailed studies of reaction mechanisms and structure of short nucleon correlations of deuteron induced reactions at intermediate energies.

## 3. Conclusion

Results of the cross section and analyzing powers of $dp$ elastic scattering along with predictions based on relativistic-multiple scattering model at intermediate energies were discussed.

Preliminary results of the five fold differential cross section of $dp$ breakup reaction investigated at 400 MeV for four detector configurations were presented. Further plans concerning few nucleon correlations investigation at short distances as well as polarimetry were briefly discussed.

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