

# Deuteron analyzing powers $A_y$ , $A_{yy}$ and $A_{xx}$ in $dp$ - elastic scattering at large transverse momenta

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The results on the the vector  $A_y$  and tensor  $A_{yy}$  and  $A_{xx}$  analyzing powers in deuteron-proton elastic scattering at large scattering angles are presented. These data were obtained at internal target at JINR Nuclotron in the energy range 400-1800 MeV using polarized deuteron beam from new polarized ion source. New data on the deuteron analyzing powers in the wide energy range demonstrate the sensitivity to the short-range spin structure of the isoscalar nucleon-nucleon correlations.

**KEYWORDS:** short-range correlations, spin structure, analyzing powers, polarization

## 1. Introduction

The short-range correlations (SRC) of nucleons in nuclei is the subject of intensive theoretical and experimental works during last years. Since SRC have densities comparable to the density in the center of a nucleon which is about  $\rho \sim 5\rho_0$  ( $\rho_0 \approx 0.17 \text{ fm}^{-3}$ ), they can be considered as the drops of cold dense nuclear matter [1]. The results obtained at BNL [2], SLAC [3] and JLAB [4, 5] clearly demonstrate that more than 90% all nucleons with momenta  $k \geq 300 \text{ MeV}/c$  belong to 2N SRC; the probability for a given proton with momenta  $300 \leq k \leq 600 \text{ MeV}/c$  to belong to  $pn$  correlation is  $\sim 18$  times larger than for  $pp$  correlations; the probability for a nucleon to have momentum  $\geq 300 \text{ MeV}/c$  in medium nuclei is  $\sim 25\%$ ; 3N SRC are present in nuclei with a significant probability [6]. However, still many open questions persist and further investigations are required both from the experimental and theoretical sides.

The main goal of the Deuteron Spin Structure (DSS) experimental program is to obtain the information on the spin - dependent parts of two-nucleon (2N) and three-nucleon (3N) forces from two processes:  $dp$ - elastic scattering in a wide energy range and  $dp$ - nonmesonic breakup with two protons detection at energies 300 – 500 MeV [7–10] using the Nuclotron internal target station (ITS) [11]. Such experimental program at Nuclotron was started by the measurements of the vector  $A_y$  and tensor  $A_{yy}$  and  $A_{xx}$  analyzing powers in  $dp$ - elastic scattering at  $T_d$  of 880 MeV [12] and 2000 MeV [13]. The systematic measurements of the differential cross section have been performed also in recent years [14–17].

In this paper we report new results of the energy scan of the vector  $A_y$  and tensor  $A_{yy}$  and  $A_{xx}$

analyzing powers in  $dp$ - elastic scattering obtained at the Nuclotron ITS [11] in the energy range of 400-1800 MeV.

## 2. Experiment at Nuclotron ITS

The ITS setup is well suited for study of the energy dependence of polarization observables for the deuteron-proton elastic scattering and deuteron breakup reaction with the detection of two protons at large scattering angles. For these purposes the  $\text{CH}_2$ -target of  $10\ \mu\text{m}$  thick is used for the measurements. The yield from carbon content of the  $\text{CH}_2$ -target is estimated in separate measurements using several twisted  $8\ \mu\text{m}$  carbon wires. The monitoring of the intensity is done from the detection of  $pp$ - quasielastic scattering at  $90^\circ$  in cms by the scintillation counters placed in the horizontal plane. The detection of the  $dp$ - elastic events is done by the coincidence measurements of the proton and deuteron. The detectors are placed in the both horizontal and vertical planes for the analyzing powers measurements. The selection of the  $dp$ - elastic events is done by the correlation of the energy losses in plastic scintillators for deuteron and proton and their time-of-flight difference. The use of large amount of the scintillation counters allowed to cover wide angular range [18]. Such a method has been used to obtain the polarization data in  $dp$ - elastic scattering at  $T_d$  of 880 MeV [12] and 2000 MeV [13].

The upgraded setup at ITS has been used to measure the vector  $A_y$  and tensor  $A_{yy}$  and  $A_{xx}$  analyzing powers in  $dp$ - elastic scattering between 400 MeV and 1800 MeV using polarized deuteron beam from new source of polarized ions (SPI) developed at LHEP-JINR [19]. These measurements were performed using internal target station at Nuclotron [11] with new control and data acquisition system [20]. The existing setup [18] has been upgraded by new VME based DAQ, [21], new MPod based high voltage system, [22], new system of the luminosity monitors etc. The same setup has been used as a polarimeter based on the use of  $dp$ - elastic scattering at large angles ( $\theta_{\text{cm}} \geq 60^\circ$ ) at 270 MeV [18].

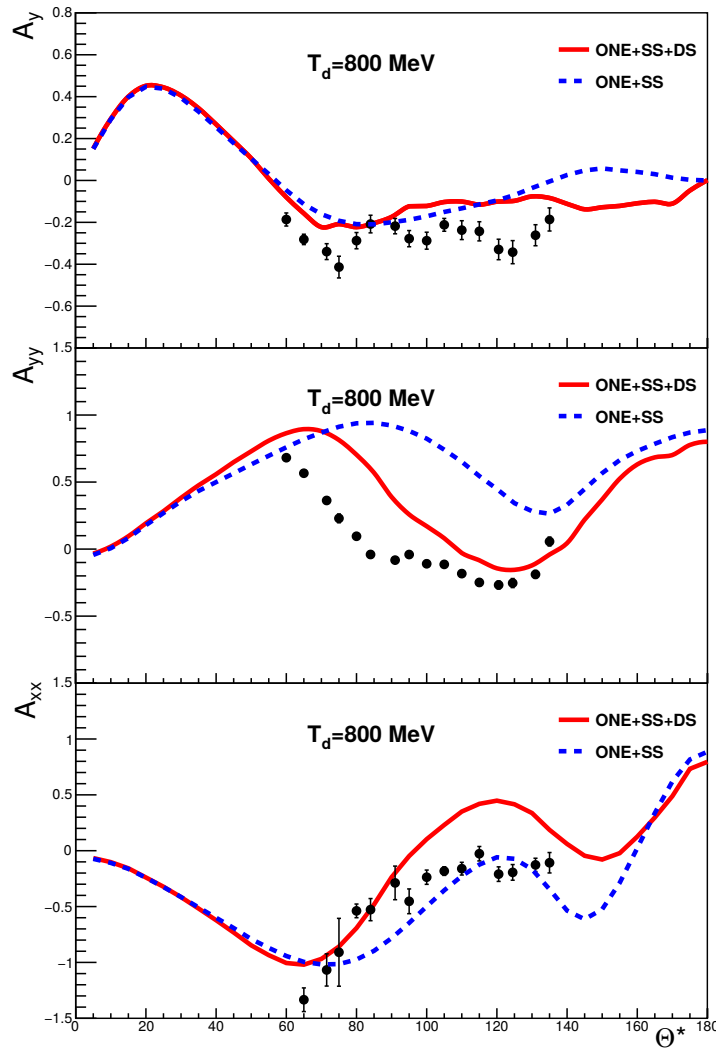
## 3. Measurements of the analyzing power in $dp$ - elastic scattering

New SPI [19] has been used to provide polarized deuteron beam. In the current experiment the spin modes with the maximal ideal values of  $(P_z, P_{zz}) = (0,0)$ ,  $(+1/3,+1)$  and  $(+1/3, +1)$  were used. The deuteron beam polarization has been measured at 270 MeV [18] where precise values of the deuteron analyzing powers exist [23]. The  $dp$ - elastic scattering events at 270 MeV were selected using correlation of the energy losses and time-of-flight difference for deuteron and proton detectors. The values of the beam polarization for different spin have been obtained as weighted averages for 8 scattering angles for  $dp$ - elastic scattering in the horizontal plane only. The typical values of the beam polarization were  $\sim 65\text{-}75\%$  from the ideal values.

After deuteron beam polarization measurements at 270 MeV, the beam has been accelerated up to the required energy  $T_d$  between 400 MeV and 1800 MeV. The scintillation detectors were positioned in the horizontal and vertical plane in accordance with the kinematic of  $dp$ - elastic scattering for the investigated energy. The main part of the measurements were performed using  $\text{CH}_2$  target. Carbon target was used to estimate the background. The selection of the  $dp$ - elastic events is done by the correlation of the energy losses in plastic scintillators for deuteron and proton and their time-of-flight (TOF) difference. The normalized numbers of  $dp$ -elastic scattering events for each spin mode were used to calculate the values of the analyzing powers  $A_y$ ,  $A_{yy}$  and  $A_{xx}$ .

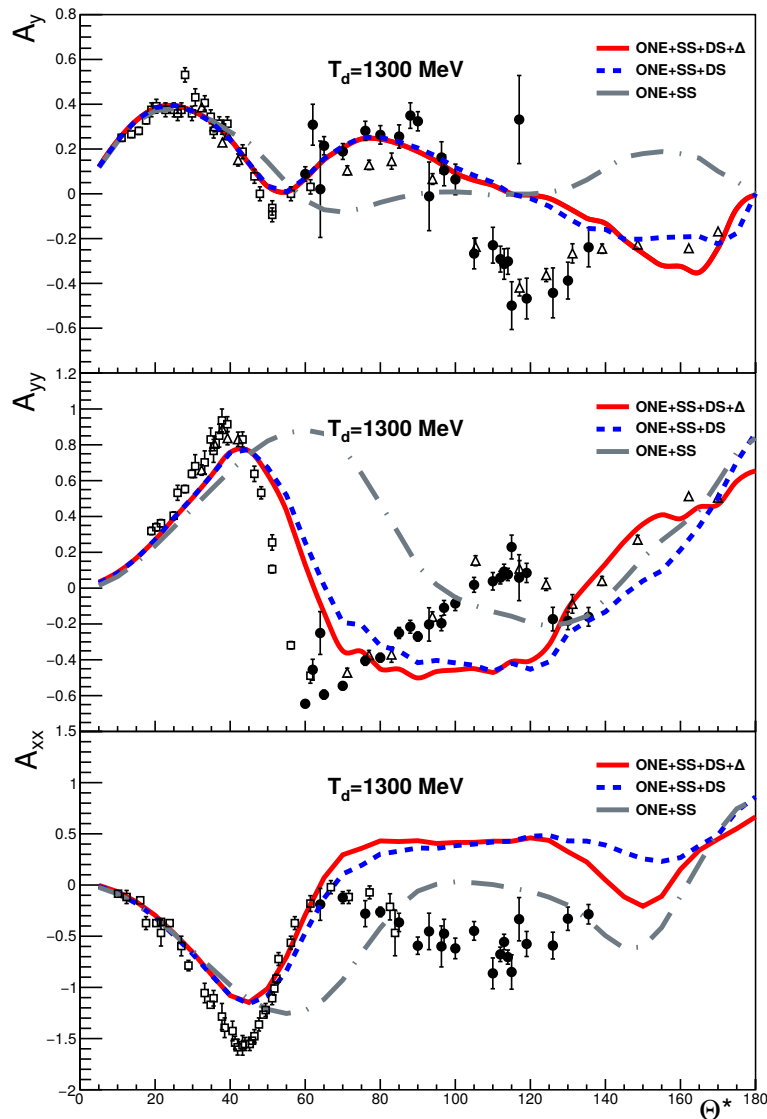
The preliminary results on the vector  $A_y$  and tensor  $A_{yy}$  and  $A_{xx}$  analyzing powers at the deuteron kinetic energy  $T_d$  of 800 MeV are presented in Fig. 1. Predictions of relativistic multiple scattering model [24, 25] with one nucleon exchange and single scattering (ONE+SS) terms are represented by dashed curves and with additional double scattering (DS) term by solid ones. Note that the contri-

bution of the  $\Delta$ - isobar mechanism is negligible at these energies [26, 27]. The relativistic multiple scattering model [24, 25] describes the  $A_y$  data satisfactorilly, while it fails to reproduce the tensor analyzing powers data. The considering of the DS term does not improve the agreement.



**Fig. 1.** The angular dependencies of the vector  $A_y$  and tensor  $A_{yy}$  and  $A_{xx}$  analyzing powers at the deuteron kinetic energy  $T_d$  of 800 MeV. The full circles are the results of the experiment performed at ITS at Nuclotron. Predictions of relativistic multiple scattering model with one nucleon exchange and single scattering (ONE+SS) terms are represented by dashed curves and with additional double scattering (DS) term by solid ones. The errors are statistical only.

The preliminary results on the vector  $A_y$  and tensor  $A_{yy}$  and  $A_{xx}$  analyzing powers at the deuteron kinetic energy  $T_d$  of 1300 MeV are presented in Fig. 2. Open triangles and squares are the data obtained at 1200 MeV at Saclay [28] and at ANL [29], respectively. One can see a good agreement of the data obtained at Nuclotron with the data from previous experiments [28, 29]. The lines are results of the theoretical calculations obtained in the relativistic multiple scattering expansion formalism [26, 27]. The four contributions are taken into account: one-nucleon-exchange (ONE), single- and double- scattering (SS and DS), and  $\Delta$ - isobar excitation. The presented approach was applied earlier to describe the differential cross sections at deuteron energies between 500 and 1300 MeV in a



**Fig. 2.** The angular dependencies of the vector  $A_y$  and tensor  $A_{yy}$  and  $A_{xx}$  analyzing powers at the deuteron kinetic energy  $T_d$  of 1300 MeV. The full circles are the results of the experiment performed at ITS at Nuclotron. Open triangles and squares are the data obtained at 1200 MeV at Saclay [28] and at ANL [29], respectively. Predictions of relativistic multiple scattering model with one nucleon exchange and single scattering (ONE+SS) terms are represented by dot dashed curves and with additional double scattering (DS) term by dashed ones. Solid curves represent calculations which include  $\Delta$ - isobar contribution [27]. The errors are statistical only.

whole angular range [26]. The dash-dotted, dashed and solid lines are the predictions obtained within relativistic multiple scattering model [26] considering ONE+SS terms only, with the DS contribution and with  $\Delta$ - isobar excitation term, respectively. One can see that the model describes the behavior of the vector analyzing power  $A_y$  up to  $\sim 100^\circ$  in cms, while the tensor analyzing powers  $A_{yy}$  and  $A_{xx}$  are not described over whole range of measurements. The  $\Delta$ - isobar excitation term gives a significant contribution at the angles larger than  $140^\circ$  in cms. Apparently, spin structure of the nucleon-nucleon interactions and deuteron at short distances is missed in the standard description used in the relativistic multiple scattering model [24–27].

The availability of the polarized proton beam at Nuclotron [30] allows to extend the DSS physics

program at ITS [10], namely, to perform the experiments on the measurements of the nucleon analyzing power  $A_y^p$  in  $pd$ - elastic scattering at 135-1000 MeV, in  $pd$ - nonmesonic breakup at the energies between 135-250 MeV for different kinematic configurations etc.

#### 4. Conclusions

The energy scan of the deuteron analyzing powers  $A_y$ ,  $A_{yy}$  and  $A_{xx}$  in  $dp$ - elastic scattering has been performed using polarized deuteron beam from new SPI [19] at upgraded JINR-Nuclotron. The data demonstrate the sensitivity to the short-range spin structure of the deuteron.

Next experiments using polarized deuterons and protons at ITS [11, 18] are in preparation.

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