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Deuteron analyzing powers in dp - elastic scattering at large transverse momenta

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Abstract. The results on the vector A_y and tensor A_{yy} and A_{xx} analyzing powers in deuteron-proton elastic scattering at large transverse momenta 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.

1. Introduction

The short range correlations (SRCs) of nucleons in nuclei is the subject of intensive theoretical and experimental works during last years [1]. The results obtained at BNL [2], SLAC [3] and JLAB [4, 5] clearly demonstrate that more than 90% all nucleons with momenta $k \geq 300$ MeV/ c belong to the two-nucleon (2N) SRCs; the probability for a given proton with momenta $300 \leq k \leq 600$ MeV/ c to belong to pn correlation is ~ 18 times larger than for pp correlations; the probability for a nucleon to have momentum ≥ 300 MeV/ c in medium nuclei is $\sim 25\%$; three-nucleon (3N) SRCs 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. For instance, the experimental data on the spin structure of 2N and 3N SRCs are almost absent.

The main goal of the Deuteron Spin Structure (DSS) experimental program is to obtain the information on the spin - dependent parts of 2N and 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, 8, 9] using the Nuclotron internal target station (ITS) [10]. The motivation of this program at low and intermediate energies is based on theoretical analysis of the experimental results obtained for the deuteron induced reactions (see recent reviews [11, 12] and references therein).



Importance of the dp - elastic scattering studies at high energy is discussed in [13]. 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 [14] and 2000 MeV [15]. The systematic measurements of the differential cross section have been performed also in recent years [16, 17, 18].

In this paper we report new results on the vector A_y and tensor A_{yy} and A_{xx} analyzing powers in dp - elastic scattering obtained at the Nuclotron ITS [10] in the energy range of 400-1800 MeV.

2. Experimental setup at 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 CH_2 -target of 10 μm thick is used for the measurements. The yield from carbon content of the CH_2 -target is estimated in separate measurements using several twisted 8 μm carbon wires. The monitoring of the intensity is done from the detection of pp - quasielastic scattering at 90° 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 [19]. Such a method has been used to obtain the polarization data in dp - elastic scattering at T_d of 880 MeV [14] and 2000 MeV [15].

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 [20]. These measurements were performed using internal target station at Nuclotron [10] with new control and data acquisition system [21]. The existing setup [19] has been upgraded by new VME based DAQ [22], new MPod based high voltage system [23], new system of 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 [19], where precise data on analyzing powers [24, 25, 26] exist, has been developed at internal target station (ITS) at Nuclotron [10]. The accuracy of the determination of the deuteron beam polarization achieved with this method is better than 2% because of the values of the analyzing powers were obtained for the polarized deuteron beam, which absolute polarization had been calibrated via the $^{12}\text{C}(d, \alpha)^{10}\text{B}^*[2^+]$ reaction [26].

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

New SPI [20] 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 [19]. 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 ~ 65 -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 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 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} .

4. Discussion of the dp - elastic scattering results

Here the results on the angular dependencies of the deuteron analyzing powers A_y , A_{yy} and A_{xx} obtained at the deuteron energies of 400, 700, 1000 and 1300 MeV are presented. The results of the analysis for $T_d=800$ MeV are discussed in the dedicated talk at this conference [27].

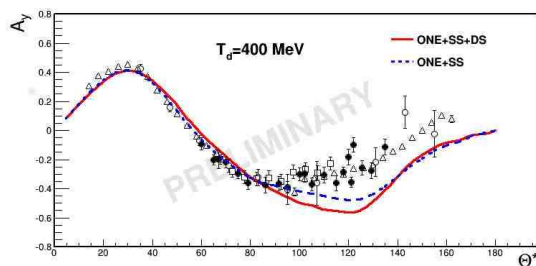


Figure 1. The vector analyzing power A_y at the deuteron kinetic energy T_d of 400 MeV. The full circles are the preliminary results of the DSS experiment at ITS at Nuclotron. Open symbols are the world data [31, 32, 33].

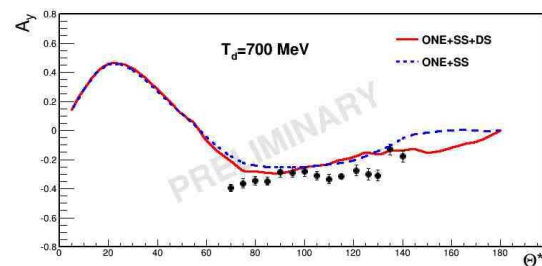


Figure 2. The vector analyzing power A_y at the deuteron kinetic energy T_d of 700 MeV. The full circles are the preliminary results of the DSS experiment at ITS at Nuclotron.

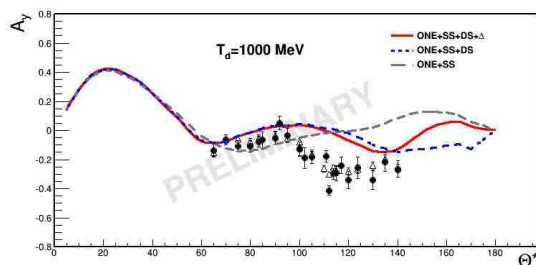


Figure 3. The vector analyzing power A_y at the deuteron kinetic energy T_d of 1000 MeV. The full circles and open triangles are the preliminary results of the DSS experiment at ITS at Nuclotron for hydrogen and polyethelene, respectively.

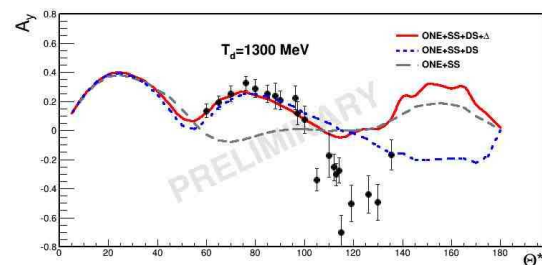


Figure 4. The vector analyzing power A_y at the deuteron kinetic energy T_d of 1300 MeV. The full circles are the preliminary results of the DSS experiment at ITS at Nuclotron.

The angular dependencies of the deuteron vector analyzing power A_y in dp - elastic scattering at the deuteron kinetic energy T_d of 400 MeV, 700 MeV, 1000 MeV and 1300 MeV are presented in Figs 1,2,3 and 4, respectively. The full circles are the results of the present experiment at ITS at Nuclotron. Open circles, squares and triangles in Fig. 1 are the data obtained at Saclay [31] and IUCF [32], [33], respectively. The full circles and open triangles in Fig. 3 are the preliminary results obtained at 1000 MeV within the DSS experiment for hydrogen and polyethelene, respectively. The theoretical calculations were performed in the relativistic multiple scattering expansion formalism [28, 29, 30]. The four contributions are taken into

account: one-nucleon-exchange (ONE), single- and double- scattering (SS and DS), and Δ -isobar excitation. Dashed and solid lines in Figs. 1 and 2 are the calculations performed within relativistic multiple scattering model [28, 29] considering ONE+SS terms only and with the DS contribution added, respectively. Note that the contribution of the Δ - isobar mechanism is negligible at these energies [30]. One can see good agreement of new data obtained at Nuclotron with the data from earlier experiments [31, 32, 33]. The relativistic multiple scattering model [28, 29] describes the data up to $\sim 90^\circ$ - 100° only, while it fails to reproduce the data at larger angles. The considering of the DS term does not improve the agreement. The dash-dotted, dashed and solid lines in Figs 3 and 4 are the predictions obtained within relativistic multiple scattering model [30] considering ONE+SS terms only, with the DS contribution and with Δ -isobar excitation term, respectively. One can see, that the DS- term consideration allows to improve the agreement with the data on A_{yy} analyzing power at the angles up to $\sim 100^\circ$. The Δ - isobar excitation term gives a significant contribution only at the angles larger than 140° in cms.

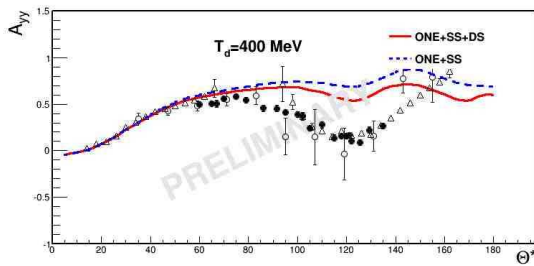


Figure 5. The tensor analyzing power A_{yy} at the deuteron kinetic energy T_d of 400 MeV. The full circles are the preliminary results of the present experiment at ITS at Nuclotron. Open symbols are the world data [31, 33]. Lines are the same as in Fig. 1.

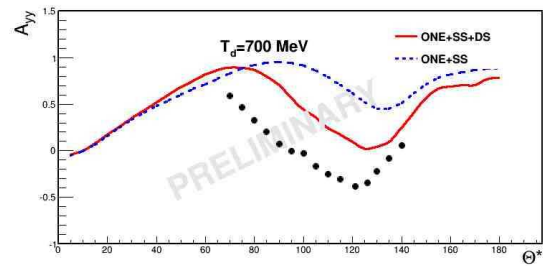


Figure 6. The tensor analyzing power A_{yy} at the deuteron kinetic energy T_d of 700 MeV. The full circles are the preliminary results of the DSS experiment at ITS at Nuclotron. Lines are the same as in Fig. 2.

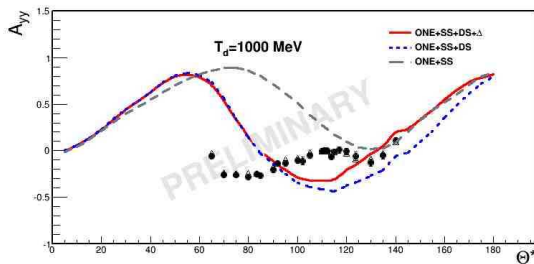


Figure 7. The tensor analyzing power A_{yy} at the deuteron kinetic energy T_d of 1000 MeV. The full circles and open triangles are the preliminary results of the DSS experiment at ITS at Nuclotron for hydrogen and polyethylene, respectively. Lines are the same as in Fig. 3.

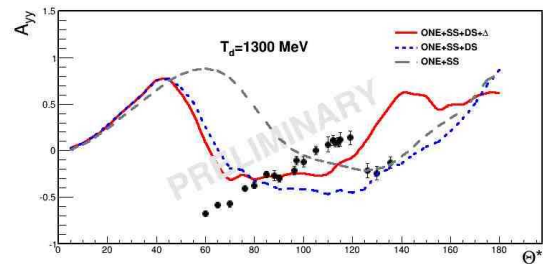


Figure 8. The tensor analyzing power A_{yy} at the deuteron kinetic energy T_d of 1300 MeV. The full circles are the preliminary results of the DSS experiment at ITS at Nuclotron. Lines are the same as in Fig. 4.

The angular dependencies of the tensor analyzing power A_{yy} in dp - elastic scattering at the

deuteron kinetic energy T_d of 400 MeV, 700 MeV, 1000 MeV and 1300 MeV are presented in Figs 5,6,7 and 8, respectively. The symbols and lines are the same as in Figs 1-4. The consideration of the ONE+SS terms allows to describe the behaviour of the A_{yy} analyzing power at 400 MeV up to $\sim 80^\circ$ only. The DS term gives a significant contribution at larger angles, however, its taking into account does not remove the discrepancy of the calculation with the data. The contribution of the Δ - isobar excitation [30] is small within angular range of the experiment.

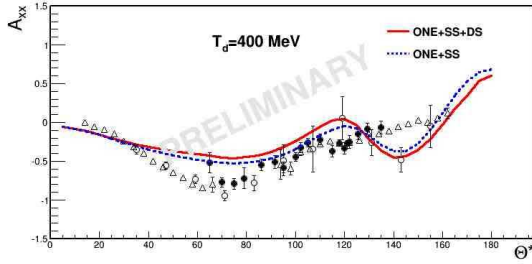


Figure 9. The tensor analyzing power A_{xx} at the deuteron kinetic energy T_d of 400 MeV. The full circles are the preliminary results of the present experiment at ITS at Nuclotron. Open symbols are the world data [31, 33]. Lines are the same as in Fig. 1.

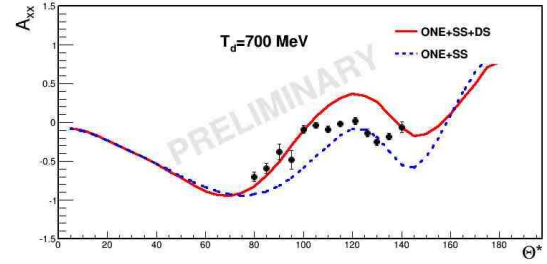


Figure 10. The tensor analyzing power A_{xx} at the deuteron kinetic energy T_d of 700 MeV. The full circles are the preliminary results of the DSS experiment at ITS at Nuclotron. Lines are the same as in Fig. 2.

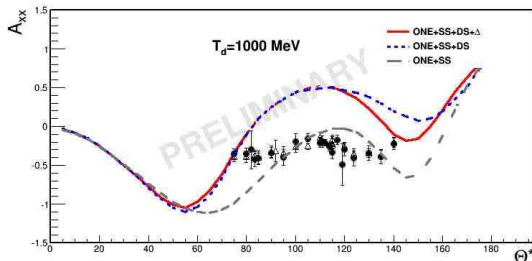


Figure 11. The tensor analyzing power A_{xx} at the deuteron kinetic energy T_d of 1000 MeV. The full circles and open triangles are the preliminary results of the DSS experiment at ITS at Nuclotron for hydrogen and polyethylene, respectively. Lines are the same as in Fig. 3.

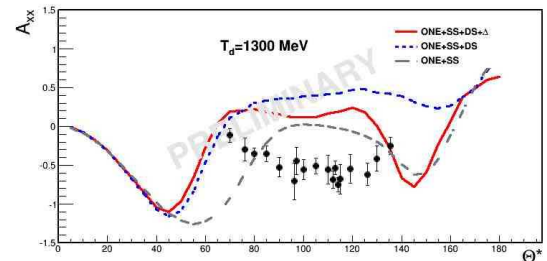


Figure 12. The tensor analyzing power A_{xx} at the deuteron kinetic energy T_d of 1300 MeV. The full circles are the preliminary results of the DSS experiment at ITS at Nuclotron. Lines are the same as in Fig. 4.

The angular dependencies of the tensor analyzing power A_{xx} in dp - elastic scattering at the deuteron kinetic energy T_d of 400 MeV, 700 MeV, 1000 MeV and 1300 MeV are presented in Figs 9,10,11 and 12, respectively. The symbols and lines are the same as in Figs 1-4. The A_{xx} behaviour is not described by the model [28, 29] over the whole angular range. The considering of the contribution of the three-nucleon forces or N^4 LO calculations performed within chiral effective field theory (χ EFT) [34] do not allow to get an agreement with the data on the tensor analyzing powers at 400 MeV. The reason of the deviation can be the neglecting by the 3N SRCs.

5. Conclusions

The systematic measurements of the analyzing powers A_y , A_{yy} and A_{xx} in dp - elastic scattering at 400-1800 MeV have been performed at the upgraded Nuclotron with new SPI [20]. The data demonstrate the sensitivity to the short-range spin structure of the isoscalar 2N correlations.

The availability of the polarized proton beam at Nuclotron [35] allows to extend the DSS physics program at ITS [13], 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, in the $pA \rightarrow ppX$ reactions etc.

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