

Investigation of the light nuclei spin structure from hadronic channels at NUCLOTRON

P.K.Kurilkin^{*1}, I.Dobrin², V.V.Fimushkin¹, D.A.Finogenov³, S.G.Genchev⁴,
Yu.V.Gurchin¹, A.P.Ierusalimov¹, A.Yu.Isupov¹, K.Itoh⁵, M.Janek⁶, E.V.Karpechev³,
J.-T.Karachuk^{1,2}, S.V.Khabarov¹, T.Kawabata⁷, A.N.Khrenov¹, V.A.Krasnov¹,
A.B.Kurepin³, A.K.Kurilkin¹, V.P.Ladygin¹, N.B.Ladygina¹, D.Lipchinski²,
A.N.Livanov¹, Y.Maeda⁸, A.I.Malakhov¹, G.Martinska⁹, S.M.Piyadin¹, J.Popovich²,
A.N.Prokofichev¹, V.L.Rapatsky¹, A.I.Reshetin³, S.G.Reznikov¹, P.A.Rukoyatkin¹,
S.Sakaguchi¹⁰, H.Sakai^{11,12}, Y.Sasamoto¹³, K.Sekiguchi¹⁴, Ya.G.Skhomenko¹⁵,
K.Suda¹², V.V.Syschenko¹⁵, G.Tarjániová⁶, A.A.Terekhin¹, T.Uesaka¹², J.Urban⁹,
T.A.Vasiliev¹, I.E.Vnukov¹⁵, N.I.Zamiatin¹, E.V.Zubarev¹

(DSS collaboration)

¹Joint Institute for Nuclear Research, Dubna 141980, Russian Federation

²Advanced Research Institute for Electrical Engineering, Bucharest 030138, Romania

³Institute for Nuclear Research of RAS, Moscow 117312, Russian Federation

⁴Laboratory for Technical Developments and Applications, BAS, Sofia 1784, Bulgaria

⁵Department of Physics, Saitama University, Saitama 338-8570, Japan

⁶Physics Department, University of Žilina, Žilina 010 26, Slovak Republic

⁷Department of Physics, Kyoto University, Kyoto 606-8502, Japan

⁸Department of Applied Physics, University of Miyazaki, Miyazaki 889-2192, Japan

⁹P.J.Šafarik University, Košice 041 80, Slovak Republic

¹⁰Department of Physics, Kyushu University, Fukuoka 812-8581, Japan

¹¹Department of Physics, University of Tokyo, Tokyo 113-8654, Japan

¹²RIKEN Nishina Center, Saitama 351-0198, Japan

¹³Center for Nuclear Study, University of Tokyo, Tokyo 113-0033, Japan

¹⁴Department of Physics, Tohoku University, Sendai 980-8578, Japan

¹⁵Belgorog National Research University, Belgorod 308015, Russian Federation

E-mail: pkurilkin@jinr.ru

The wide experimental program of the DSS project devoted to the investigation of the spin structure of light nuclei using internal and extracted deuteron beam at Nuclotron(JINR, Dubna) is discussed. Recent data on the deuteron analyzing powers in dp - elastic scattering obtained at Nuclotron demonstrate strong deviation from the relativistic multiple scattering model predictions at large scattering angle in the cms. The scheme of the deuteron beam polarimetry at Nuclotron at intermediate and low energies is discussed.

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1. Introduction

The data of light nuclei interaction in the reactions induced by unpolarized and polarized deuterons are very important to describe the nature of $2N$ and $3N$ correlation, the relativistic effects and nonnucleon degrees of freedom. During last several decades the investigation of the cross section and polarization observables in Nd interaction have been performed at different experiments all over the world at RIKEN[1]-[4], KVI[5]-[11], IUCF[12]-[14] and RCNP[15, 16] at intermediate ($E/A \sim 100 - 300$ MeV) energies.

The cross section and polarization observables data in Nd - elastic scattering have been accumulated at the energy range $130 - 270$ MeV [1]-[14]. Such activities were stimulated by the observed discrepancy of 30% between the differential cross section data[1, 17] and Faddeev calculation results[18] using modern high-quality nucleon-nucleon (NN) potentials CD-Bonn [19], Argonne-V18 (AV18) [20], Nijmegen-I and Nijmegen-II[21]. It was found that the discrepancies between the Faddeev calculations and experimental data on the cross section and polarization observables increase with the energy at large scattering angles. The inclusion of the 2π - exchange three-nucleon forces (3NF) such as TM-3NF [22], TM99[23] or UrbanaIX -3NF [24] does not help remove these discrepancies at the energies higher than 250 MeV[15, 16, 25, 26] at backward angles around $\Theta_{cm} \sim 140^\circ$. The authors stated that the reason of this discrepancy can be neglecting by new type of short-range 3NF. The relativistic effects can also play a role at these energies. The inclusion of the relativistic effects into the calculation leads to improve of the description of experimental data only at very backward scattering angles [27, 28]. So the further investigations of light nuclei interaction processes at higher energies are very desirable to get additional information about internal structure of a nucleon and relativistic effects.

The experimental program of DSS project[29]-[32] includes several parts. First one is to obtain the information on the spin-dependent parts of 2-nucleon and 3-nucleon forces from two processes: dp -elastic scattering in a wide energy range from 300 MeV up to 2000 MeV and dp non-mesonic breakup with two protons detection at energies 200 - 500 MeV. The second goal is the measurement of the T_{20} and C_{yy} for the ${}^3\text{He}(d, p){}^4\text{He}$ reaction[33]-[35] at the energy range of 1000-2000 MeV using extracted polarized deuteron beam from new polarized ion source [36] and polarized ${}^3\text{He}$ target[37]. The development of the high precision deuteron beam polarimetry at low and moderate high energies is important for these investigations.

2. Recent result obtained at Nuclotron

The experimental program on the deuteron structure investigation 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 [38, 39] and 2000 MeV [40]. The details of the experiment can be found in [41]. The detection system (see Fig.1) was designed for analyzing powers measurements in a wide range of initial deuteron energies. The detector support with mounted 46 plastic scintillation counters was placed downstream the ITS spherical chamber. Each plastic scintillation counter was coupled to a photo-multiplier tube Hamamatsu H7416MOD. Nine proton detectors were installed for left, right and up, but due to space limitation - only four for down directions. Four deuteron detectors were placed at scattering angles of deuterons coinciding kinematically with the protons for left, right and

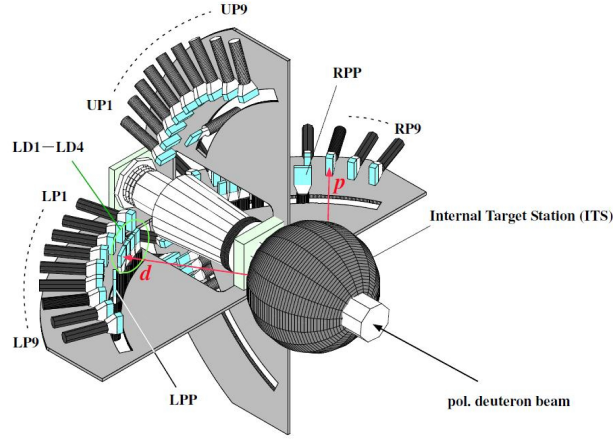


Figure 1: A schematic view of the experimental setup installed downstream the ITS spherical chamber for analyzing powers measurements. Plastic scintillation counters coupled to PMTs are placed to the left, right, up, and down the beam axis.

up scattering. Only one deuteron detector was used to cover the solid angle corresponding to down scattering. In addition, one pair of detectors was placed to register two protons from quasi-elastic pp - scattering at $\theta_{pp}=90^\circ$ in the c.m. in the horizontal plane to monitor the beam luminosity. Selection of the dp - elastic scattering events was based on the kinematical coincidence of the scattered deuterons and recoil protons by the scintillation counters. The energy loss correlation and time-of-flight difference for the signals from the corresponding proton-deuteron detector pairs were used in the analysis.

The beam polarization has been measured before the data taking using the asymmetry of the dp - elastic scattering yields at $T_d^{lab}=270$ MeV with the same detection system [42] and the high precision data on analyzing powers for the reaction obtained at RIKEN[3, 43].

The angular dependencies of the vector A_y and tensor analyzing powers A_{yy} and A_{xx} obtained at $T_d^{lab}=880$ MeV are presented in Fig. 2 by the solid symbols. The error bars are the statistical only. The solid lines in Fig. 2 are the results of the nonrelativistic Faddeev calculations[44] using the CD-Bonn nucleon-nucleon potential[19]. The dashed lines correspond to a relativistic calculation in the multiple scattering expansion formalism [45] up to the second-order terms of the nucleon-nucleon t -matrix [46] with the use of the CD-Bonn [19] DWF. The model [45] takes into account the off-energy-shell effects. The dot-dashed curves correspond to the relativistic calculation of the optical potential framework [47] up to the total angular momentum $J = 39/2$. The results are obtained with the use of DWF derived from the dressed bag model of the Moscow-Tübingen group [48] and the on-shell nucleon-nucleon t -matrix based on the phase-shift analysis solution SP07 [49]. One can see that the results of Faddeev calculations based on CD-Bonn potential even without involving 3NFs are in good agreement with all the analyzing powers within the achieved experimental accuracy while the approach [45] describes reasonably well the angular dependencies of A_y over the whole angular range of measurements and A_{yy} at backward angles only. The calculations [47] reproduce only the behavior of tensor analyzing powers A_{yy} at the angles larger than 100° in the c.m., while they fail to describe the analyzing powers A_y and A_{xx} . It can be noted, that the relativis-

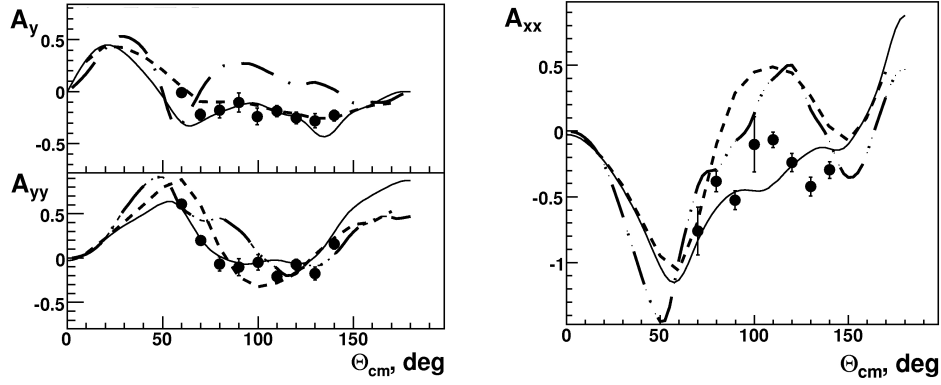


Figure 2: The angular dependencies of the vector A_y and tensor analyzing powers A_{yy} and A_{xx} for dp - elastic scattering at $T_d^{lab}=880$ MeV. The lines are explained in the text.

tic multiple scattering model calculations [45, 50] give the better agreement with the differential cross section data in the vicinity of its minimum than the nonrelativistic Faddeev calculations at this energy[39].

The results on the angular dependence of the vector A_y and tensor A_{yy} analyzing powers in dp - elastic scattering at 2000 MeV are shown in Figures 3 and 4, respectively. The data obtained at Argonne National Laboratory(ANL) are presented by the solid symbols[51]. Open squares and circles are the data obtained at the ITS[40] and at hydrogen bubble chamber at JINR[54], respectively. The dashed and solid lines are the results of the relativistic multiple scattering model calculations[45] with and without of the double scattering term. The full calculations are in a reasonable agreement with the data.

The dependence of the vector A_y and tensor A_{yy} analyzing powers at fixed angles in c.m.s are plotted as function of transverse momentum p_T in the Fig.5 and Fig.6, respectively. The open and solid symbols represent the data obtained at RIKEN [1, 3, 4], Saclay [55, 56], ANL [51]-[53] and at Nuclotron [39, 40], respectively. The values of A_{yy} are change the sign at $p_T \sim 600$ -650 MeV/c as in the case of deuteron inclusive breakup. The negative sign of A_{yy} is observed at large p_T . Vector

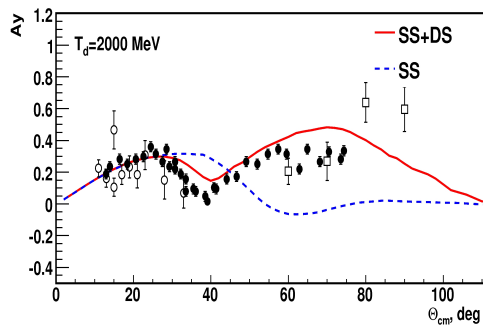


Figure 3: Vector A_y analyzing power in dp - elastic scattering at 2000 MeV. The symbols and curves are explained in the text.

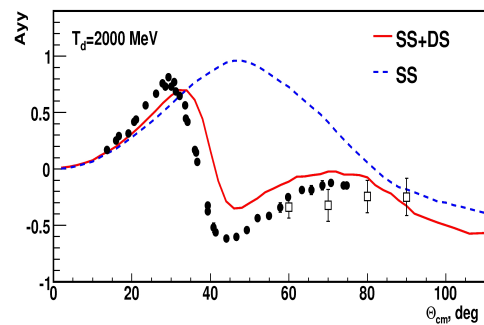


Figure 4: Tensor A_{yy} analyzing power in dp - elastic scattering at 2000 MeV. The symbols and curves are the same as in Figure 3

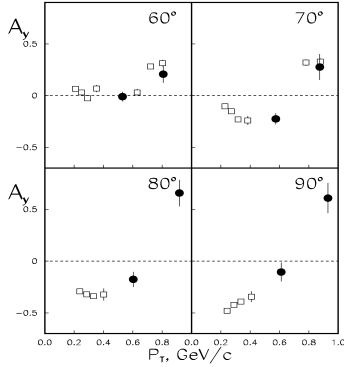


Figure 5: Vector A_y analyzing power in dp -elastic scattering obtained at fixed angles of 60° , 70° , 80° and 90° in the c.m. as a function of transverse momentum p_T . The open and solid symbols are the data obtained at RIKEN [1, 3, 4], Saclay [55, 56], ANL [51]-[53] and at Nuclotron [39, 40], respectively.

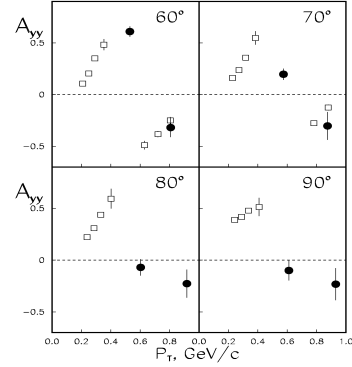


Figure 6: Tensor $A_{y,y}$ analyzing power in dp -elastic scattering obtained at fixed angles of 60° , 70° , 80° and 90° in the c.m. as a function of transverse momentum p_T . The open and solid symbols are the data obtained at RIKEN [1, 3, 4], Saclay [55, 56], ANL [51]-[53] and at Nuclotron [39, 40], respectively.

analyzing power A_y has small negative values at low p_T , but it achieves large positive values at p_T higher ~ 700 MeV/c. The change of the sign is also observed for A_y at $p_T \sim 600$ -700 MeV/c at large scattering angles in the c.m. The large positive values of the single spin asymmetry is also observed in pp - elastic scattering at high energies and large p_T (so called Krish-effect[57]). It would be interesting to perform the further precise measurement to understand the reason of such behavior.

3. Deuteron beam polarimetry at Nuclotron

The main part of experimental program of DSS project is related with the use of polarized deuteron beam. For these investigations the high precision deuteron beam polarimetry at Nuclotron accelerator complex is necessary to obtain reliable values of beam polarization.

The polarimeter based on the spin asymmetry measurement in dp - elastic scattering at large angles ($\theta_{\text{cm}} \geq 60^\circ$) at 270 MeV [42], where precise data on analyzing powers [3, 4] exist, and placed at internal target station (ITS) at Nuclotron is proposed as the reference deuteron polarimeter at Nuclotron-NICA. 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 [43]. This polarimeter is planned to use in the counting mode for permanent monitoring of the beam polarization at the energies of 270 – 2000 MeV[41, 58].

We propose to design new low energy deuteron polarimeter based on the detection of the charged particles from the $dd \rightarrow {}^3\text{H}p$ reaction at 10 MeV. Both deuteron vector and tensor analyzing powers at the scattering angle of $\sim 130^\circ$ in the c.m. [59, 60] are large enough to provide the efficient polarimetry. The thin solid CD_2 and carbon targets will be used to obtain the effect

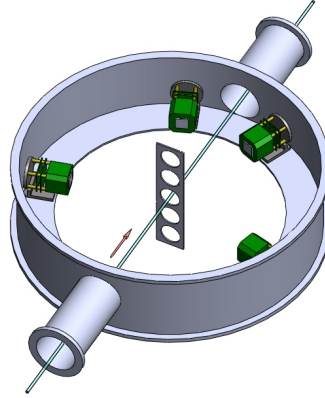


Figure 7: A schematic view of the deuteron beam polarimeter at 10 MeV.

on deuterium via $CD_2 - C$ subtraction procedure. This will avoid the use of the gaseous targets. However, the problem of the carbon background elimination appears.

The scheme of the low energy deuteron polarimeter with solid target and 4 silicon strip detectors for the detection of the scattering on the left and right is shown in Fig.7.

The proton and triton will be detected by the two silicon microstrip detectors developed at LHEP JINR [61]. The strip size is $500 \mu m$ with the number of strips 64 in the both X and Y directions. The selection events of the $dd \rightarrow p^3H$ reaction will be done using the proton and triton scattering angles correlation and coplanarity condition. These selection criteria will significantly reduce the the contribution from the carbon content of the CD_2 target. The additional selection can be the energy depositions of the proton and triton in the silicon detector. The simulation of the $dd \rightarrow p^3H$ events selection using the relation between scattering angles of protons and tritons and at 130° in the c.m. at 10 MeV and distance of 20 cm from the target has been performed using Pluto event generator and ROOT package. The background coming from $dd \rightarrow dd$, $dd \rightarrow pnpn$ and $dd \rightarrow dpn$ channels has been taken into account. The correlations of the X and Y coordinates for the proton and triton detectors are presented in Figs. 8 and 9, respectively. One can see the clean selection of the $dd \rightarrow ^3H p$ events. The energy loss information will be also used in the analysis to reduce the background.

4. Future plans of DSS experiment at Nuclotron

The first stage of the DSS experimental program[30, 31, 32] 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 were performed using ITS[62] with new control and data acquisition system[63]. The details and preliminary results of the experiments on the study of the energy dependence of dp - elastic scattering cross section and investigation of $dp \rightarrow ppn$ reaction can be found in [64, 65] and [67, 68], respectively.

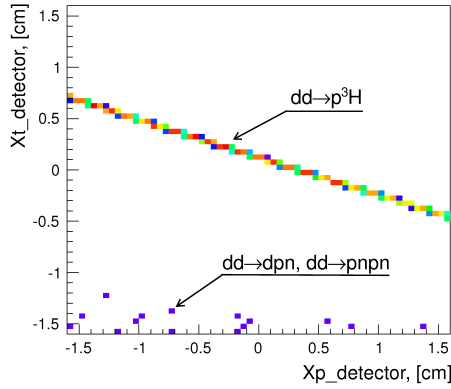


Figure 8: The correlation of the X-coordinates for protons and tritons registered by the silicon strip detector.

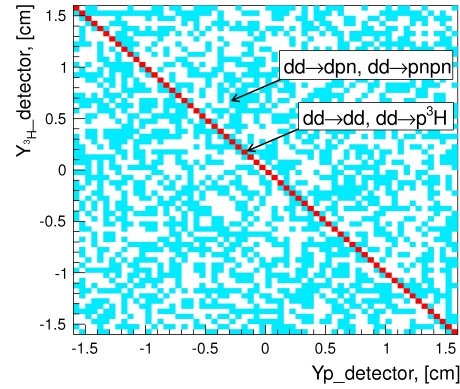


Figure 9: The correlation of the Y-coordinates for protons and tritons registered by the silicon strip detector.

Future plans of DSS collaborations in spin studies are related with the construction of new polarized deuteron source[36]. In our experiments we are planning to use the spin modes with the following ideal values of (p_z, p_{zz}) : $(0,0)$, $(0,-2)$, $(2/3,0)$ and $(-1/3,+1)$.

The analyzing powers measurements in dp - elastic scattering at large angles in cms at various energies up to 2000 MeV and in dp - non-mesonic breakup at the energies below 500 MeV will be done using internal target and polarized deuteron beam from new PIS.

The main goal of the DSS experiment is to obtain the data on $C_{//}$ in the energy region of 1.0 – 1.75 GeV, where the contribution from the deuteron D-state is expected to reach a maximum in one-nucleon exchange approximation. It is necessary to obtain new information on the strange structure observed in the behaviour of T_{20} in the dp - backward elastic scattering and to realize experiment on the full determination of the matrix element of the ${}^3\text{He}(d,p){}^4\text{He}$ reaction in the model independent way. These data will help us also to understand the short-range spin structure of deuteron and effects of non-nucleonic degrees of freedom. For these purposes the extracted polarized deuteron beam from new PIS[36] and spin-exchange-type polarized ${}^3\text{He}$ target developed at CNS of Tokyo University[37] and modified for the experiment at Nuclotron can be used.

For these investigation it is planned to perform the calibration of the ITS polarimeter at the energies 270-2000 MeV [41, 69, 70, 71] with the expected error bars for analyzing powers ± 0.02 and the calibration of the high energy polarimeters based on the dp - elastic scattering at forward angles where both tensor and vector analyzing powers have large values [52, 56]. The possibility of the dp - elastic scattering events selection using timing and amplitude information from the scintillation counters detected deuterons and protons in the kinematic coincidence has been demonstrated at 1600 MeV and 2000 MeV [72].

5. Conclusion

The data on the analyzing powers A_y , A_{yy} and A_{xx} in dp - elastic scattering have been measured at ITS at the Nuclotron at the energies of 880 and 2000 MeV. The results on the tensor analyzing powers at 880 MeV indicate strong deviations from the predictions of the relativistic

phenomenological approaches [45, 47] based on the use of the nucleon-nucleon forces only. The non-relativistic Faddeev calculations [44] using CD-Bonn 2NF [19] describe only the angular behavior of the analyzing powers data, however, they fail to reproduce the differential cross section data obtained in earlier experiments [73, 74].

Future studies of the deuteron-induced reactions like $dp \rightarrow pd$, dp - breakup, $dd \rightarrow {}^3Hp$ (3Hen) and $d^3He \rightarrow p^4He$ at Nuclotron are related with new PIS developed at LHEP-JINR. For these investigations it is necessary to develop the scheme of the deuteron beam polarization measurements. The polarimeter at ITS [42] should play an important role being the reference deuteron polarimeter at Nuclotron. It will provide the precision in the deuteron beam polarization $\sim 3\%$ at the energy range of 270-2000 MeV. The new low energy deuteron beam polarimeter based on the detection of the charged particles from the $dd \rightarrow {}^3Hp$ reaction at 10 MeV is proposed to measurement of the tensor and vector polarization component of the deuteron beam simultaneously.

Acknowledgments

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