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RECENT RESULTS ON SPIN STRUCTURE OF LIGHT NUCLEI FROM THE R308n EXPERIMENT

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The high-momentum structure of the ^{3}He, ^{3}H and deuteron in the experiment with polarized deuteron beam performed at E_d=270 MeV at RIKEN, Japan in December 2000, was investigated. For this purpose the angular dependence of the tensor and vector analyzing powers were measured for the reactions d + d → ^{3}H + p and d + d → ^{3}He + n. In this report the results on the tensor A_{yy} and vector A_y analyzing powers are presented in the full angular range. The energy dependence of the tensor analyzing power T_{20} at a zero degree is also shown. First results on the A_y and A_{yy} in the d + d → p + X reaction near threshold are obtained.

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1 Introduction

The structure of light nuclei can be investigated by electromagnetic and hadronic probes. Simple reactions with large transfer momentum (short distances) and one-nucleon-exchange (ONE) mechanism are d + p → p + d [1]- [2], d + ^{3}He → p + ^{4}He [3]- [4] or d + ^{3}He → ^{3}He + d [5]. In the framework of ONE approximation the polarization observables of these reactions are expressed in terms of the D/S-waves ratios in these nuclei. However, polarization observables and calculation within ONE approximation with the standard deuteron and ^{3}He wave functions are strongly differ even at relatively small internal momenta ($\sim$ 200 MeV/c). This discrepancies may be due to a non-adequate description of the light nucleus spin structure at short distances, as well as by the importance of mechanism other than ONE.

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One of the next current interest for investigation of few-nucleon system is the study of three nucleon forces (3NF) in the three-nucleon continuum. They was predicted by Wigner in 1933 [6] and first calculation was made in 1934. If mesons mediate force between two nucleons, in three nucleon systems, they must raise its contribution.

2 Experiment

The experiment was performed at RIKEN Accelerator Research Facility (RARF) (see Fig. 1).

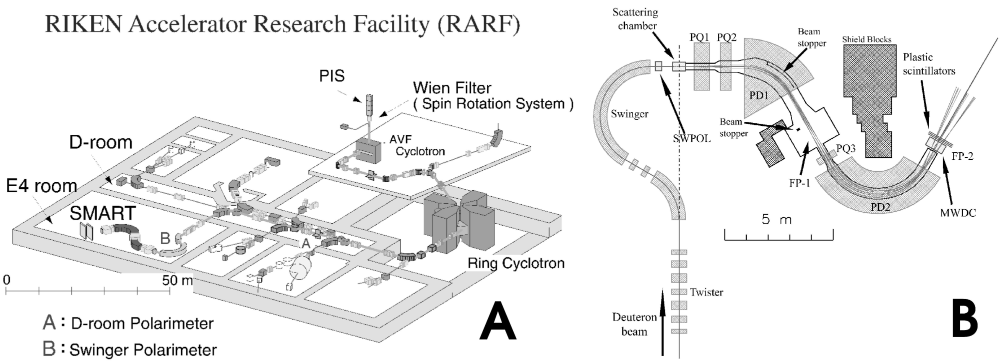

Fig. 1. A) RIKEN Accelerator Research Facility (RARF), B) SMART spectrograph

The direction of symmetric axis of the beam polarization was controlled with a Wien filter located at the exit of polarized ion source (PIS).

The deuteron vector (p_Z) and tensor (p_{ZZ}) beam polarization with respect to their cylindrically symmetric axis Z are defined by

$$p_Z = N_+ - N_-, \tag{1}$$
$$p_{ZZ} = N_+ + N_- - 2N_0, \tag{2}$$

where N_+, N_- and N_0 denotes the fractions of deuteron beam in magnetic substates +1, -1 and 0, respectively. In this experiment, four spin modes were used, whose ideal magnitudes of polarizations are

$$\text{mode 0: } (p_Z, p_{ZZ}) = (0, 0), \tag{3}$$
$$\text{mode 1: } (p_Z, p_{ZZ}) = (0, -2), \tag{4}$$
$$\text{mode 2: } (p_Z, p_{ZZ}) = (-2/3, 0), \tag{5}$$
$$\text{mode 3: } (p_Z, p_{ZZ}) = (1/3, 1). \tag{6}$$

The mode 0 - unpolarized mode, mode 1 - pure tensor mode, mode 2 - pure vector mode and mode 3 is mixed mode. The obtained polarization values were $\sim 75\%$ of the ideal values.

The polarized deuteron beam was accelerated up to 270 MeV by the combination of the AVF cyclotron and Ring cyclotron. The beam polarizations were measured with D-room polarimeter (DroomPOL) located at D-room and Swinger polarimeter (SWPOL) just before the target. Both polarimeters utilize d + p elastic scattering for polarimetry and value of polarization were derived using known analyzing powers A_y, A_{yy}, A_{xx} and A_{xz} [7] [8].

Deuterated polyethylene (CD_2) sheets with 0.72 and 0.32 mg/mm^2 were used as a target and carbon foil with 0.34 mg/mm^2 was used for measurement of background spectra.

The scattering angle of the polarized deuteron beam were controlled by rotating the Swinger. Scattered particles (^{3}H, ^{3}He or p) were momentum analyzed with quadrupole and dipole magnets (Q-Q-D-Q-D) and detected with MWDC followed by the three plastic scintillators at the second focal plane.

3 Detection and analysis

Criteria used for the identification of the scattered particles ^{3}H, ^{3}He or proton from the reaction d + d $\rightarrow$ ^{3}H + p (d + d $\rightarrow$ ^{3}He + n) are the following: particle must be registered in the all three scintillation detectors and it was selected by the correlation of the energy losses in the 1st and the 2nd and the 1st and the 3rd scintillation detectors; Radio frequency signal of the cyclotron was used as a reference of time-of-flight measurement.

The main source of the background was ^{3}He, ^{3}H and protons from the d + ^{12}C interaction. The number of useful events were obtained by the subtraction of the momenta spectra on the CD_2 and C foils. To obtain the analyzing powers A_y and A_{yy} for the d + d $\rightarrow$ ^{3}H + p (^{3}He + n) reactions we used the asymmetries and beam polarization values for the three different spin modes:

$$N^1_{exp}(\Theta_{cm}) = 1 + \frac{1}{2}p^1_{yy}A_{yy}(\Theta_{cm}), \tag{7}$$

$$N^2_{exp}(\Theta_{cm}) = 1 + \frac{3}{2}p^2_{y}A_{y}(\Theta_{cm}), \tag{8}$$

$$N^3_{exp}(\Theta_{cm}) = 1 + \frac{3}{2}p^3_{y}A_{y}(\Theta_{cm}) + \frac{1}{2}p^3_{yy}A_{yy}(\Theta_{cm}), \tag{9}$$

where N^1_{exp}, N^2_{exp} and N^3_{exp} are relative yields for 1st, 2nd and 3rd mode normalized by the yield for unpolarized mode.

4 Results and discussion

The tensor analyzing power T_{20} at $\Theta_{cm} = 0^\circ$ or 180°(see Fig. 2) is simple given by [10], [11]

$$T_{20} = \frac{1}{\sqrt{2}}\frac{2\sqrt{2}u(k)w(k) - w(k)^2}{u(k)^2 + w(k)^2}, \tag{10}$$

where $u(k)$ and $w(k)$ are the S- and D-wave functions for ^{3}He (^{3}H) or deuteron for $\Theta_{cm} = 0^\circ$ or 180°, respectively.

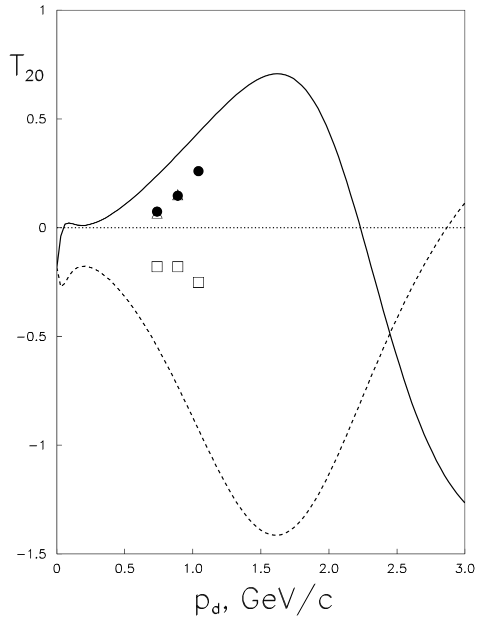

Fig. 2. Tensor analyzing power T_{20} at $\Theta_{cm} = 0°$ (upper five symbols) and $\Theta_{cm} = 180°$ (lower three symbols) at E_d= 270, 200 and 140 MeV. The ^{3}He + n (^{3}H + p) channel are presented by solid (open) symbols. The solid and dashed curves are calculated using Urbana ^{3}He wave function.

The ONE predictions reproduce incident energy dependence and the sign of the experimental data. Since the T_{20} at $0°$ and $180°$ is directly connected with D/S ratio of ^{3}He (^{3}H) or deuteron [10], the difference of signs of T_{20} at $0°$ and $180°$ reflects the difference in the relative sign of wave functions $u(k)$ and $w(k)$ for ^{3}He(^{3}H) or deuteron.

The results for the tensor A_{yy} and vector A_y analyzing power at energy E_d=270 MeV are presented in Fig. 3 [9].

In the ONE approximation the vector analyzing power A_y equals to zero, but some structures are observed in the experimental results. These results will be a clue to investigate the reaction mechanism beyond the ONE model.

ONE calculations predict that the tensor analyzing power at forward angles are sensitive to the structure ^{3}H (^{3}He) but they are deviate remarkably from the experimental results. These results may imply that there is a problem in the realistic ^{3}H (^{3}He) wave functions used in the ONE calculations.

The experimental data on A_{yy} for these reactions shows sensitivity to the spin structure of deuteron at backward angles.

The experimental results for the ^{3}H and ^{3}He at angles larger than $30°$ are in the agreement within statistical errors. At smaller angles the difference in the analyzing powers is observed, however these results require further investigation of the systematics. Therefore at the moment, we cannot conclude that the effect of charge symmetry breaking was observed (Fig. 4).

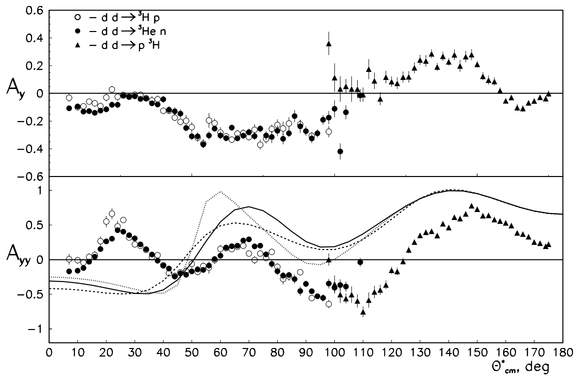

Fig. 3. The results for the tensor A_{yy} and the vector A_y analyzing powers in the centre-of-mass frame at energy E_d=270 MeV. The open and solid circles are for case of the ^{3}H + p and ^{3}He + n channels, respectively. The triangles are ^{3}H + p channels for the case of proton detection. The solid, dot-dashed and long-dashed curves are the results of ONE calculations [11] using Urbana [12], Paris [13] and Reid soft core [14] ^{3}He wave functions, respectively.

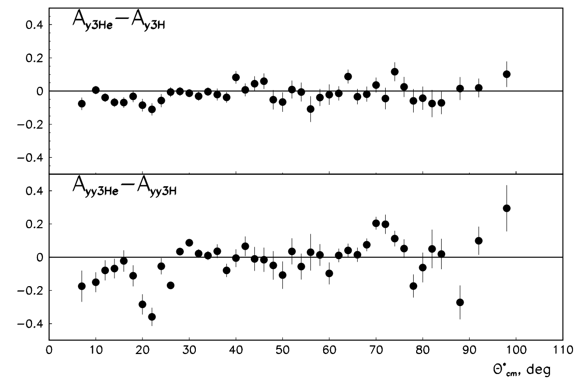

Fig. 4. $A_{y3He} - A_{y3H}$ and $A_{yy3He} - A_{yy3H}$ difference.

As a byproduct of the experiment the data on A_{yy} and A_y for the breakup reaction near threshold were obtained. Monte Carlo simulations has been performed at E_d=270 MeV of the initial energy and at small proton emission angles accordance with three and two particle phase space (Fig.5).

One can see that the two particle phase space (p dn - at the final state) well reproduces the experimental excitation energy near threshold. The three particles final state (p pnn) is quite

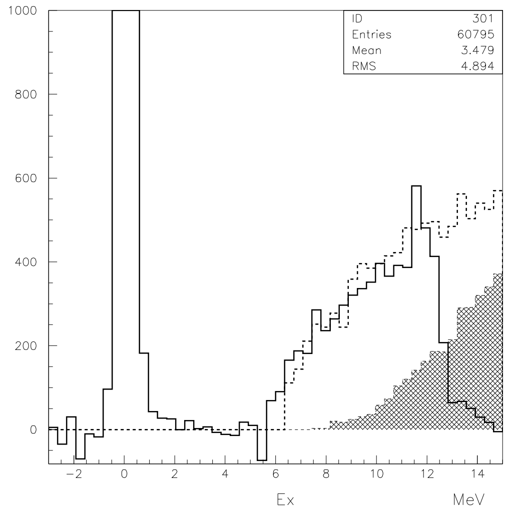

Fig. 5. Typical example of the obtained energy spectra of d + d → p + X reaction at emission angle $\Theta_{cm} = 8^{\circ}$. The histogram given by the solid line is the experimental data for d + d → p + X. The histogram given by the dot-dashed line and the shadowed one are events for d + d → p + dN and d + d → p + pnn reactions, respectively, generated by Monte-Carlo.

small within the acceptance of the spectrometer. One can say that the FSI is insignificant in this region for d + d → p + X breakup reaction.

The first experimental results of A_{yy} and A_y analyzing powers for d + d → p + X reaction at the small proton emission angles at E_d=270 MeV for different values of E_x=7 MeV and E_x=10 MeV are presented (Fig. 6). The comparison of the polarization observables of the breakup and the binary reactions give us the opportunity to conclude that they are in agreement within achieved errors.

5 Conclusions

The ONE predictions reproduced the incident energy dependence and the signs of the experimental data T_{20}.

The results for the tensor A_{yy} and vector A_y analyzing power for d + d → ^{3}H + p and d + d → ^{3}He + n at energy E_d=270 MeV are obtained.

ONE calculations predict that the tensor analyzing power at forward angles are sensitive to the structure ^{3}H (^{3}He) but they are deviate remarkably from the experimental results.

The experimental data on A_{yy} for these reactions shows sensitivity to the spin structure of deuteron at backward angles.

In the ONE approximation the vector analyzing power A_y equals to zero, but we see some structures in the experimental results.

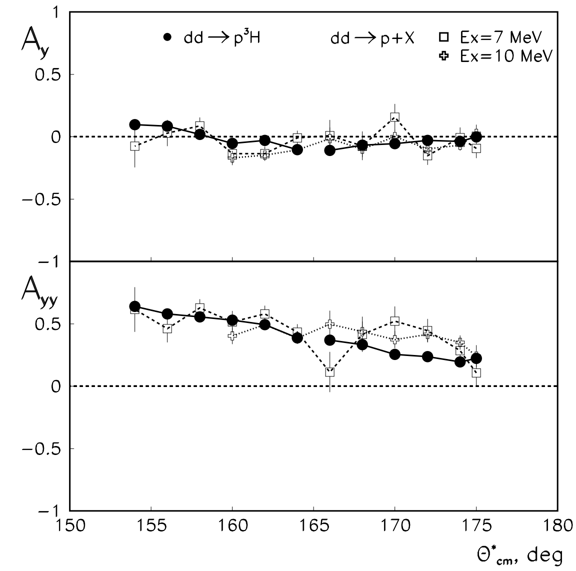

Fig. 6. The experimental results of A_{yy} and A_y analyzing powers for d + d → p + X reaction at E_d=270 MeV.

The experimental results for the ^{3}H and ^{3}He are in the agreement within achieved errors, therefore we cannot conclude that the effect of charge symmetry breaking was observed.

The experimental results of A_{yy} and A_y analyzing powers for d + d → p + X reaction at the small emission angles at E_d=270 MeV are presented.

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