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ANALYZING POWERS iT_{11} AND T_{20} OF dp → ppn REACTION AT 400 MeV INVESTIGATED AT NUCLOTRON

One of the tools to study spin structure of short range correlations (SRCs) and three nucleon forces is the measurement of the polarization observables. Deuteron induced reactions at intermediate energies are investigated at Internal Target Station (ITS) of Nuclotron through the dp elastic and dp → ppn reactions. Analyzing powers iT11 and T20 analyzing powers of dp → ppn reaction at 400 MeV are presented.

Keywords: *iT11 and T20 analyzing powers, dp → ppn reaction, few nucleon correlations.*

1. Introduction

Reactions with few nucleons have a rich phase space. Polarization observables can be measured under various kinematic conditions. Intermediate energy region is of a special interest. In the region of few hundreds MeV QCD cannot be applied. Many experimental and theoretic studies are aimed in the region below the pion threshold where the exact calculations can be done. The most used contribution in theoretical models which include three nucleon forces (3NFs) is two pion exchange, e.g. Urbana IX [1] and Tucson-Melbourne [2]. These models properly describe binding energies of three and four nucleon systems. Generally, cross section of reactions with few nucleons in which the nucleon is unpolarized is better described than for the polarized case. Much worst situation is when the beam or target is polarized, especially in the case of polarization observables measurement. The simplest reactions in which three nucleon forces can be investigated are dp elastic scattering and dp → ppn reactions. Spin structure of the np SRCs has been investigated at JINR via the measurements of the tensor analyzing power A_{yy} in deuteron inclusive breakup at different energies in the wide regions of the x_F and transverse proton momentum p_T [3]. The A_{yy} data demonstrate the dependence on two internal variables, x_F and p_T or their combinations. However, none of used approaches [4, 5] describe the data. In the vicinity of the Sagara discrepancy the currently known 3NF contribute by up to 30 % to the dp elastic scattering cross section at intermediate energies [6]. The investigation of dp → ppn reaction at deuteron energy of 270 MeV at RIKEN [7] and IUCF [8] reveals that vector analyzing power A_y can be described using only NN forces. But other polarization observables need 3NFs to describe the data. The investigation of dp → ppn reaction at energy of 130 MeV measured at KVI [9] shows similar behavior. Inclusion of 3NF improves the description of a part of the data but breaks the other.

Reactions dp elastic and dp → ppn are studied in intermediate energy region from 300 - 2000 MeV and 300 - 500 MeV with unpolarized and polarized beam at Nuclotron with the aim of the study of a few nucleon correlations.

2. Experiment and results

The goal of the Deuteron Spin Structure (DSS) experimental program is to obtain the information about two and three nucleon forces including their spin dependent parts from dp elastic scattering at the energies between 300 – 2000 MeV and dp → ppn reactions with registration of two protons at deuteron energies of 300 – 500 MeV [10]. Deuteron beam is accelerated up to the required energy with Nuclotron. Polarization of deuteron beam is provided by new polarization ion source (PIS). The new PIS can provide unique opportunity for the studies of the spin effects and polarization phenomena in a few body systems at internal target

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station (ITS) and also on extracted beam with the BM@N setup. Commissioning of the upgraded DSS setup has been performed at 270 MeV using unpolarized and polarized deuteron beam in June-July 2016. Good values of vector and tensor polarizations [11] were obtained at low energy polarimeter.

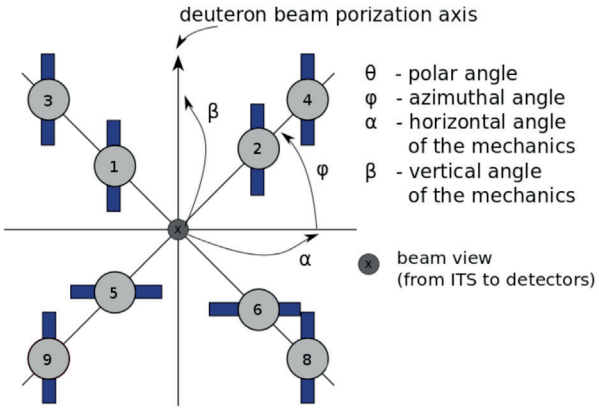

Fig. 1 Placement of ΔE-E detectors in case of dp → ppn reaction measurement at 400 MeV; detectors are placed in the vicinity of the ITS; position of each detector is defined by physical angles θ (not shown) and φ; angles of mechanics are used to adjust detector position related to beam direction

The transversely polarized deuteron beam interacting with the polyethylene and carbon targets. The effect on hydrogen is obtained by subtracting of carbon spectra from spectra on polyethylene. The polarization was flipped each spill between "spin-up" and "spin-down" (perpendicular to the plane of the accelerator) and no polarization. Ideal values of polarization were (*pz, pzz*) = (-1/3, 1) and (-1/3, -1), respectively. The polarization of deuteron beam was monitored continuously during the whole experiment. Vector and tensor polarizations are obtained from the asymmetries and known values of analyzing powers of dp elastic reaction at energy of 270 MeV. These values were used in determination of analyzing powers of dp → ppn reaction at 400 MeV. The measured values of polarization for "mode +" when tensor component is positive are: *pz* = -0.190 ± 0.009, *pzz* = 0.533 ± 0.017 and for "mode -": *pz* = -0.230 ± 0.007, *pzz* = - 0.705 ± 0.013. Statistical and systematical errors are taken into account. Statistical error comes from the ratio of dp elastic to pp quasi elastic events. Eight Δ*E* - *E* detectors are used in dp → ppn experiment to obtain the asymmetries. The details of the Δ*E* − *E* detector construction can be found in [12]. Each detector lays on the plane which is rotated by the angle of 45° or -45° related to the beam orbit one, see Fig. 1. The detector placement is determined by polar θ and azimuthal φ angles, see Table 1. Azimuthal angle φ have anticlockwise direction and is related to the detector closest to beam direction.

Detectors layout - polar (θ) and azimuthal (φ) angles; α and β - angles of mechanics Table 1

Detector No.	θ [°]	φ [°]	α[°]	β[°]
1	34.8	45.0	24.1	24.1
2	36.8	315.0	-25.0	25.0
3	50.4	45.0	38.6	38.6
4	52.5	315.0	-39.6	39.6
5	34.8	135.0	24.1	-24.1
6	36.8	225.0	-25.0	-25.0
8	52.5	225.0	-39.6	-39.6
9	50.4	135.0	38.6	-38.6

Monte Carlo simulation has been performed to confirm the suitability of the experiment and to find the criteria for selection of the useful events [13]. The cross section σ of the investigated reaction can be expressed through the cross section of unpolarized one σ_0, deuteron beam polarizations p_Z and p_{ZZ}, angles θ, φ, β and analyzing powers in spherical representation iT_{11}, T_{20}, T_{21} and T_{22} by following:

$$\sigma = \sigma_0 \Big(1 + \sqrt{3}\, iT_{11}(\theta) p_z \sin\beta \cos\phi + \frac{T_{20}(\theta)}{\sqrt{8}} p_{zz} (3\cos^2\beta - 1) + \sqrt{3}\, T_{21}(\theta) p_{zz} \cos\beta \sin\phi - \frac{\sqrt{3}}{2} T_{22}(\theta) p_{zz} \sin^2\beta \cos 2\phi \Big) \quad (1)$$

The last two terms vanish because of the polarization of deuteron beam is perpendicular to the accelerator orbit and slope of detectors plane is 45° or -45°, respectively. The obtained counts for two polarized modes and one unpolarized have been normalized on the beam luminosity. Tensor analyzing powers are vanishing in a case of registration of two protons under pp quasi condition. Therefore only vector analyzing powers A_y have non zero value. Vector analyzing power A_y is related to iT_{11} through the following equation:

$$A_y = \frac{\sqrt{3}}{2} iT_{11} \quad (2)$$

The obtained vector analyzing powers A_y for two angles at 72.3° and 76.5° in the pp centre of mass system (CMS) are shown In Fig. 2 along with the world data at 200 MeV/N [14, 15]. One can see agreement between data at the obtained experimental level of accuracy. The measured values of iT_{11} and T_{20} analyzing powers for four detector configurations are shown in Table 2. The configurations which contain detectors 8 and 9 were not taken into account due to some interference between them and accelerator device support mainly rails. Each detector configuration is determined by polar (θ_1, θ_2) and azimuthal φ angles. The azimuthal angle φ is related to the angle of detector closest to the beam direction, see Fig. 1. Analyzing power T_{20} is equal to zero in case of pp quasi elastic scattering at 90°. Values of iT_{11} and T_{20} analyzing powers should be equal for the detector configuration 1, 6 and 5, 2 in case that angles θ_1, θ_2 and ϕ and

vector and tensor polarization are the same for both cases. One can see agreement between the obtained data at the experimental level of accuracy. In the last column, iT_{11} and T_{20} analyzing powers for 1, 6 and 5, 2 configurations are combined. A low yield has been observed in other detector configurations.

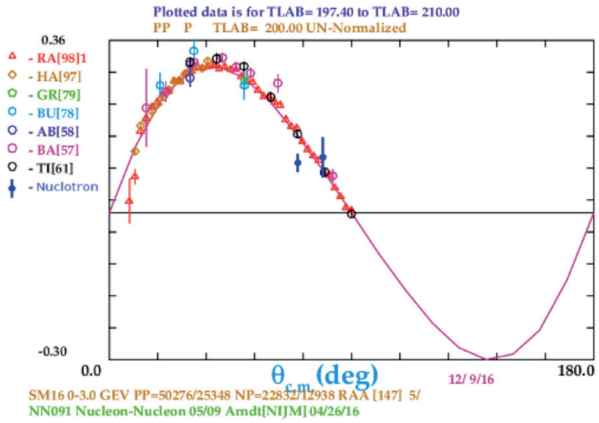

Fig. 2 Angular dependence of the vector analyzing power at energy of 200 MeV/N; data obtained at Nuclotron JINR are represented by full blue symbols (72.3° and 76.5° in CMS); other symbols represent world data [14, 15] and references therein

3. Conclusion

Values of the vector analyzing powers iT_{11} at 72.3° and 76.5° in CMS are 0.10 ± 0.02 and 0.11 ± 0.06, respectively. They are in agreement with world pp- elastic scattering data within experimental errors. Values of the vector iT_{11} and tensor T_{20} analyzing powers are 0.47 ± 0.10 and 0.02 ± 0.20.To substantially decrease the errors of analyzing powers the beam luminosity needs to be increased at about factor of 10. The future plans are connected with the measurements of tensor and vector analyzing powers in interesting regions of phase space where the contributions of three nucleon forces is expected to be large enough to observe. The sufficient statistics will allow obtaining kinematic (S curve) dependence of analyzing powers.

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Spherical analyzing powers iT_{11} and T_{20} for different detector configuration - polar (θ_1, θ_2) and azimuthal φ angles Table 2

Conf.	θ_1 [°]	θ_2 [°]	ϕ [°]	iT_{11}	T_{20}	iT_{11} combined	T_{20} combined
detectors – 5, 4	34.8	52.5	135	0.10 ± 0.02	0	-	-
detectors – 6, 3	36.8	50.4	45	0.11 ± 0.06	0	-	-
detectors – 1, 6	34.8	36.8	135	0.55 ± 0.15	0.13 ± 0.30	0.47 ± 0.10	0.02 ± 0.20
detectors – 5, 2	34.8	36.8	135	0.39 ± 0.13	-0.09 ± 0.27		

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