SYSTEMATIC STUDIES OF THE THREE-NUCLEON SYSTEM DYNAMICS IN THE DEUTRON–PROTON BREAKUP REACTION*

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Precise and large sets of data for cross section, vector and tensor analyzing powers for the $^1\mathrm{H}(\vec{d},pp)n$ breakup reaction were obtained in experiments carried out at KVI Groningen and FZ-Jülich at deuteron beam energies of 100 MeV, 13 MeV and 160 MeV (cross sections only). These precise experimental data obtained in a wide phase-space region allowed to establish evidences for three-nucleon force contributions and to confirm predictions of sizable effect of the Coulomb force. The vector analyzing powers data are generally quite well described by theoretical predictions even with pure nucleon–nucleon interactions. Tensor analyzing powers can be also very well reproduced by calculations in most of the studied region but in some regions locally discrepancies are observed at energy of 130 MeV.

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1. Introduction

Few-nucleon system are ideal laboratories to study nuclear forces. Among them, the system composed of three nucleons ($3N$) is the simplest nontrivial environment, in which various models of the nucleon–nucleon (NN) interaction can be tested. Three-nucleon system dynamics can be investigated quantitatively by comparing observables calculated with the use of Faddeev equations with results of precise measurements. The breakup observables can be predicted using modern realistic pairwise nucleon–nucleon (NN) interactions, combined with model of $3N$ forces [1]. Moreover, the two- and three-nucleon interactions can be modeled within the coupled-channel (CC) framework by an explicit treatment of the Δ-isobar [2]. Alternatively, the dynamics is generated by the Chiral Perturbation Theory (ChPT), so far at the next-to-next-to-leading order with all relevant NN and $3N$ contributions taken into account [3]. The modern theoretical calculations include different pieces of nucleon–nucleon dynamics like the above-mentioned three-nucleon force but also the long-range Coulomb interaction or relativistic effects. Cross section observables in the region of medium energies are very sensitive to all these effects which reveal their influence in different regions of the phase space.

2. Experiments

The measurements of the breakup reaction were performed at KVI Groningen with the use of the SALAD and BINA detectors covering a large fraction of the reaction phase space [4–7]. Experiment at FZ-Jülich was devoted to studies of Coulomb effects in the breakup reaction at 130 MeV deuteron beam energy at very forward angles, making use of the Germanium Wall detection system [8]. The basic informations of these dp breakup experiments are shown in Table I.

TABLE I

Basic information of d–p experiments. The analysis of experimental data obtained for deuteron breakup reaction at 160 MeV is in progress.

Experiment	dp 130	dp 100	dp 130 GeWall	dp 160
Beam energy	130 MeV	100 MeV	130 MeV	160 MeV
Av. current	50 pA	8 pA	5 pA	10 pA
Polarization	vector & tensor (7 states)	vector & tensor (5 states)	vector (2 states)	No
Target	LH2	LH2	LH2	LH2, LD2
Thickness	($\sim$ 4 and 6 mm)	($\sim$ 6 mm)	($\sim$ 2 mm)	($\sim$ 6 mm)
Detector	SALAD	BINA	GeWall	BINA

3. Results

In order to search for subtle dynamical effects in few-body systems, a precise and systematic database is needed, what makes the measurements very demanding. Our new-generation experiments fulfilled these conditions and provided a very rich set of differential cross section data for the breakup reactions [5, 8]. The cross section data for 130 MeV compared with theoretical predictions showed both the significant influence of 3NF effects [4, 5], and also revealed new unexpectedly strong effects of Coulomb interaction. The calculations with the Coulomb interaction included were performed within coupled-channels (CDB+Δ+C) [9] and with realistic AV18 NN potential combined with the Urbana IX 3NF model (AV18+UIX+C) [10]. The role of that additional dynamics in the breakup cross section in the region of very forward angles is presented in Fig. 1 (dp 130 GeWall). The values of χ^2 per degree of freedom on the relative azimuthal angles ϕ_{12} of the two breakup protons were calculated for the individual configurations. The smallest value of χ^2/d.o.f. is obtained when the Coulomb force has been taken into account. In case of calculations which do not take into account the Coulomb force the obtained value of χ^2/d.o.f. is about 300.

The obtained results of the vector analyzing powers of the breakup reaction at 100 and 130 MeV are well reproduced by $2N$ calculations in the whole studied phase space. In case of the tensor analyzing powers certain discrepancies are observed. These problems remain, even if 3NF effects and Coulomb interactions are included in the calculations [7, 11].

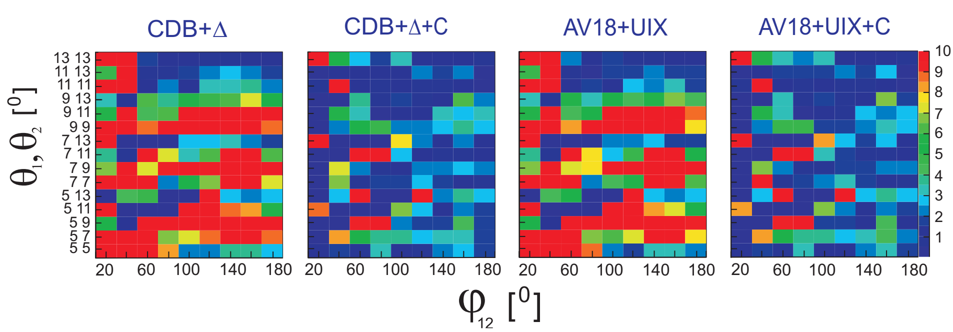

Fig. 1. Set χ^2/d.o.f. values obtained for the differentional cross sections and compared to various theoretical predictions. Cells of the map refer to individual configurations defined by the polar angles of two outgoing protons, θ_1, θ_2, and their relative azimuthal angle ϕ_{12}.

4. Summary and outlook

The obtained precise experimental data in a wide phase space region at different incident beam energies can serve as valid tool for verification of rigorous theoretical calculations which have been and are being developed.

The future studies of the $3N$ system dynamics in the breakup reaction with BINA detector in Cyclotron Center of Bronowice were proposed. Moreover, the experiment using the deuteron beam of 340, 360 and 400 MeV and the WASA detector is planned at FZ-Jülich with the aim to study the relativistic effects.

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