Vector and Tensor Analyzing Powers in Deuteron-Proton Breakup

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Abstract High precision data for vector and tensor analyzing powers of the $^1H(\vec{d}, pp)n$ breakup reaction at 130 and 100 MeV deuteron beam energies have been measured in a large fraction of the phase space. They are compared to the theoretical predictions based on various approaches to describe the three nucleon (3N) system dynamics. Theoretical predictions describe very well the vector analyzing power data, with no need to include any three-nucleon force effects for these observables. Tensor analyzing powers can be also very well reproduced by calculations in most of the studied region, but locally certain discrepancies are observed. At 130 MeV for A_{xy} such discrepancies usually appear, or are enhanced, when model 3N forces are included. Predicted effects of 3NFs are much lower at 100 MeV and at this energy equally good consistency between the data and the calculations is obtained with or without 3NFs.

Observables for three-nucleon (3N) systems constitute important basis for testing modern approaches to describe interactions between nucleons. The deuteron–nucleon breakup reaction leads to a final state with three free particles, thus providing possibility to study observables for continuous set of kinematical configurations

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of the outgoing nucleons. In order to fully exploit the research potential of this process, experiments covering significant part of its phase space are indispensable.

Experimental studies of the ^{1}H(d, pp)n breakup reaction were performed at KVI Groningen, The Netherlands, with the use of polarized deuteron beams with energies of 130 and 100 MeV, and two detection systems, respectively SALAD [1] and BINA [2]. High precision cross section data for the breakup reaction at 130 MeV provided an important information on significant impact of 3N and Coulomb forces on this observable [3–5]. In the next step, a complete set of vector (A_x, A_y) and tensor (A_{xx}, A_{xy}, A_{yy}) analyzing powers attainable with the transversally polarized deuteron beam was determined for about 800 kinematical points (for each observable), covering large part of the phase space of the ^{1}H($\vec{\text{d}}$, pp)n breakup reaction at 130 MeV. The set of data for the same reaction at 100 MeV comprises so far A_x, A_y and A_{xy} analyzing powers, each determined at over 400 kinematical points. All the results were obtained on a systematic grid of kinematical variables, for polar angles, θ_1, θ_2, of the outgoing protons between 15° and 30° and for the full range of their azimuthal angles. At each geometry, defined by θ_1, θ_2 and the relative azimuthal angle φ_{12}, the energy dependence of studied observables was described by means of variable S, denoting the arc-length along the kinematical curve.

The experimentally determined observables were compared to the results of rigorous Faddeev calculations [6] performed with the use of modern realistic nucleon-nucleon potentials (CD Bonn, AV18, Nijm I and Nijm II) only, referred to in the following by 2N, as well as including the Tucson-Melbourne three nucleon force model (2N+TM99). The experimental data were also confronted with the results of the coupled channel approach with the CD-Bonn+Δ potential, without and with Coulomb interaction included [7].

Confronting the calculated observables with the experimental data shows no sensitivity of the deuteron vector analyzing powers of the breakup reaction at 100 and 130 MeV to any additional dynamics beyond the pure NN interactions. The calculations based on NN forces alone are sufficient to provide a very good description of the whole data sets. Similar conclusions emerge from the analysis of the vector analyzing power of the d–p elastic scattering at 130 MeV [8]. On the other hand, the tensor analyzing powers of the elastic scattering do show the need of including additional dynamics and also reveal the problem of describing these observables even when including model 3NF [8]. Tensor analyzing powers of the breakup reaction at the same beam energies are very well reproduced by calculations in the majority of the studied region, but locally certain discrepancies are observed [9]. For A_{xy} such discrepancies usually appear, or are enhanced, when model 3N forces, TM99 or UIX, are included, see examples in Fig. 1. Problems of all theoretical approaches with describing A_{xx} and A_{yy} are localized in kinematical regions characterized with the lowest relative momenta of the two protons. At 100 MeV no sizable 3NF effect is predicted for A_{xy}. In certain regions, Coulomb interaction between protons starts to play the role for this observable.

As compared to cross section, analyzing powers of the breakup reaction reveal smaller sensitivity to dynamics beyond the pure nucleon-nucleon interaction. Nevertheless, high precision of the large data sets and good control over the systematic effects lead to unveiling, in the case of tensor analyzing powers, local discrepancies between data and theory. Such discrepancies, clearly depending on beam energy, must be considered as indications of deficiencies in the spin part of the assumed models of the 3N system dynamics.

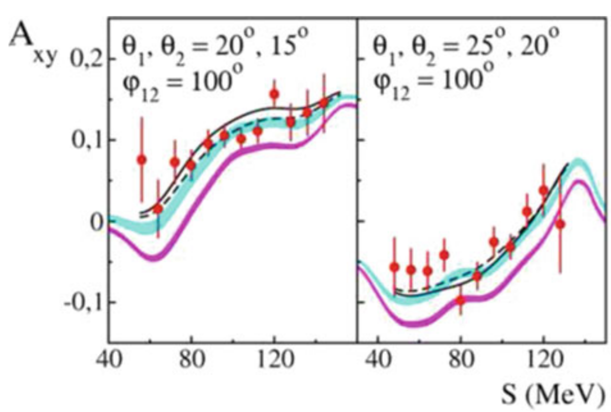

Fig. 1 Examples of tensor analyzing power A_{xy} distributions obtained for the d–p breakup at 130 MeV. Two geometries, for which large 3NF effects were predicted, are shown. The data are compared to calculations performed with the realistic potentials without (*cyan/light gray band*) and with (*magenta/dark gray band*) TM99 3N force, as well as with predictions obtained within the coupled-channel framework with the CD Bonn+Δ potential without (*dashed line*) and with (*solid line*) inclusion of the Coulomb force

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