Vector and tensor analyzing powers in deuteron-proton breakup

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Vector and tensor analyzing powers in deuteron-proton breakup

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Abstract. Vector and tensor analyzing powers of the ^{1}H($\vec{\rm d}$,pp)n breakup reaction at 130 and 100 MeV deuteron beam energies have been measured at KVI Groningen with the use of the detection systems covering large fractions of the phase space. The high precision data 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. The 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 (3NFs), TM99 or Urbana IX, are included. Problems of all theoretical approaches with describing A_{xx} and A_{yy} are limited to very small regions of the phase space, usually characterized with the lowest relative energies of the two protons. Predicted effects of 3NFs are much lower at 100 MeV, therefore at this energy equally good consistency between the data and the calculations is obtained with or without 3NFs.

1. Introduction

Observables for three-nucleon (3N) systems constitute important basis for testing modern approaches to describe interactions between nucleons. At present, experimental data available for such tests span: binding energies of $A = 3$ nuclei, rich sets of observables determined for the elastic nucleon-deuteron scattering, recently growing data base for the breakup of a deuteron in collision with a nucleon and observables measured for electromagnetic processes. 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 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.

In the theoretical calculations the full dynamics of the three-nucleon system is obtained in different ways: Realistic nucleon-nucleon (NN) potentials (CD Bonn, AV18, Nijm I and Nijm II) are combined with model 3N forces [1] or with an effective 3N interaction resulting from the explicit treatment of the Δ-isobar excitation in the coupled channel approach, without and with Coulomb interaction included [2]. Alternatively, the chiral perturbation theory approach is used: at the next-to-next-to-leading order with all relevant NN and 3N contributions taken into account, while at the next order (N3LO) so far without taking into account the corresponding 3NF contributions [3, 4].

2. Experimental results

Experimental studies of the ^{1}H($\vec{\mathrm{d}}$,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 [5] and BINA [6], both characterized with a large angular acceptance. 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 [7, 8, 9]. 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($\vec{\mathrm{d}}$,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 the variable S, denoting the arc-length along the kinematical curve.

The experimental results confronted with the theoretical predictions show 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 [10]. Similar conclusions emerge from the analysis of the vector analyzing power of the d-p elastic scattering at 130 MeV [11]. 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

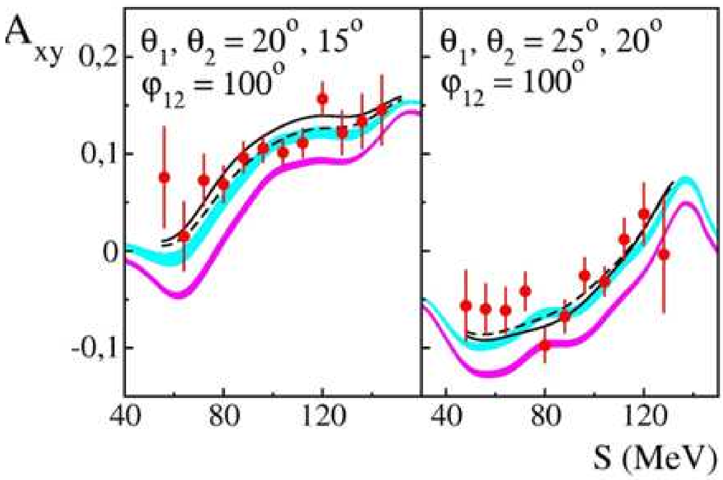

Figure 1. Examples of tensor analyzing power A_{xy} distributions obtained for the d-p breakup at 130 MeV. Two geometries, for which large 3NF effects were predicted, are shown. The error bars represent statistical uncertainties. The data are compared to calculations performed with the realistic potentials 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.

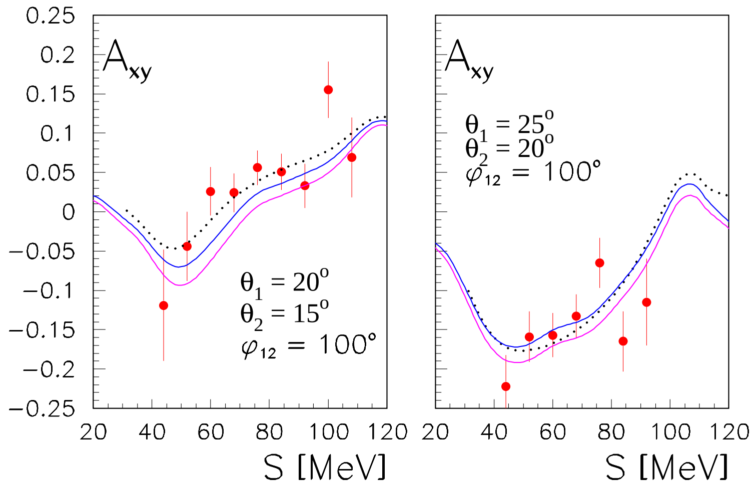

Figure 2. Examples of tensor analyzing power A_{xy} distributions obtained for the d-p breakup at 100 MeV. The same geometries as in Fig. 1 are presented. The data are compared to calculations performed with the CD-Bonn realistic potential without (blue/dark gray line) and with (magenta/light gray line) TM99 3N force, as well as with predictions obtained within the coupled-channel framework with the CD Bonn+Δ potential and with inclusion of the Coulomb force (dotted line).

these observables even when including model 3NF [11]. 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 [10, 12]. 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} were observed for a few geometries of outgoing protons. When the data were sorted according to the energy E_{rel} of the relative motion of the two protons, it turned out that the discrepancies between the calculations and the data, observed in A_{xx} and A_{yy}, are localized in kinematical regions characterized with the lowest E_{rel}. At 100 MeV no sizable 3NF effect is predicted for A_{xy}, as it is shown in sample distributions in Fig. 2: The data are equally well described with or without the model force. In certain regions, Coulomb interaction between protons starts to play the role for this observable: the calculations taking into account that dynamical ingredient reproduce all details of the measured distributions.

3. Summary

As compared to cross section, analyzing powers of the breakup reaction at 100 and 130 MeV are less sensitive to dynamics beyond the pure nucleon-nucleon interaction. In particular, the vector analyzing powers are very well described by the NN interaction alone and 3NF effects are neither predicted nor observed. This behavior is very similar to the one observed for the elastic scattering data. The tensor analyzing powers reveal certain sensitivity to additional dynamics, though not in agreement with the model 3NFs. High precision of the large data sets and good control over the systematic effects lead to unveiling local discrepancies between the data and theory for these observables. Such discrepancies, clearly depending on a beam energy, must be considered as indications of deficiencies in the spin part of the assumed models of the 3N system dynamics.

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