Carbon related background estimation in the deuteron breakup reaction

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Abstract. An experiment devoted to studies of relativistic effects in the proton-deuteron breakup reaction has been performed at Cyclotron Center Bronowice in Kraków, Poland, with the use of the Kratta detectors and a deuterated polyethylene target (CD2). One of the main sources of background are reactions on carbon. They need to be subtracted from the measured spectra to obtain pure proton-deuteron breakup cross section. In order to determine this component, an additional measurement was carried out using a target made of natural graphite. A procedure of the background subtraction is discussed.

1 Introduction

The deuteron breakup reaction is often used as a tool to test theoretical approaches which describe the interaction between nucleons [1] in few-nucleon systems. The three-nucleon force (3NF) plays a fundamental role in the description of such processes. 3NF is an irreducible force which arises from the exchange of mesons between at least tree nucleons [2].

In recent years, there has been growing interest in the role of 3NF in the deuteron breakup reaction at higher energies, as it is believed that 3NFs may play an increasingly important role in this regime. As the energy increases, the relative contribution of the D-state to the deuteron wave function becomes more important, and the effects of 3NFs become more pronounced [3].

At higher energies the relativistic effects become also important, and it is crucial to include them in usually non-relativistic theoretical calculations. This has been demonstrated by a number of theoretical studies focused on the deuteron breakup reaction [4, 5]. Already in much simpler process, a proton-deuteron elastic scattering, the relativistic effects are important. However, the calculations that account for such effects [6] do not reproduce the experimental data in a proper way [7]. As it was also demonstrated in [8], the situation is even worse in the case of the deuteron breakup. This raises the question of whether the relativistic treatment of the few-nucleon interaction is correct or the 3NFs is underestimated, or we are still missing some important ingredients of the system dynamics.

To test the theoretical predictions [4], a dedicated measurement of the deuteron breakup using a 200 MeV proton beam was conducted in February and March 2022 at Cyclotron Center Bronowice in Krakow, Poland. 30 Kratta detectors [9] were used to measure deuteron-proton (dp) coincidences for specific dp angular configurations for which the calculations predict extremely large relativistic effects and practically negligible effects of 3NF. The main idea of this experiment is to answer the question whether the relativistic calculations performed by Skibiński et al. [4] are correct.

2 Target setup

The primary target used in this experiment was solid deuterated polyethylene (CD2) of the diameter of 9.5 mm and surface density of 62 mg/cm2. This target has been mounted on an aluminum frame using thin carbon threads, as shown in the Fig. 1. The second target was of the same diameter but made of pure natural graphite with the density of 50 mg/cm2. It was used mainly to estimate the contribution of reactions on carbon contained in the polyethylene target. In addition to the previously mentioned targets, a set of auxiliary targets made of polyethylene, thick carbon-13 and lead was used for the detector calibration purposes, and a luminescent target based on ZnS was used for beam spot observation. All these targets were placed on a remotely controlled target ladder.

3 Background estimation

When analyzing the data measured with the CD2 target, it is necessary to perform background subtraction to isolate the signal (proton-deuteron coincidences) from the reactions on carbon. Therefore, a dedicated measurement using the graphite target has been performed to establish background contribution originating from the carbon component in the CD2 target. By applying the same analysis conditions as for the CD2 data, one can determine
how much of the original signal came from carbon related events. However, due to the fact that the surface density of both targets was different and the overall dead time of the acquisition system was different, it was necessary to determine the relative scaling factor for both data sets. In this measurement proton-deuteron coincidences have been registered. The particle identification (PID) is based on the ∆E-E technique and the particles were selected by imposing the graphical cuts, see Fig. 2 as example. To determine the relative scalings and to fix the carbon component deuterons were selected in both data sets collected with CD₂ and carbon targets.

Our strategy was to investigate energy spectrum of the deuterons for carbon and CD₂ targets. In the case of CD₂ target we expect to have elastically scattered deuterons from proton-deuteron reactions as well as deuterons originating from the reactions on carbon inside the CD₂ target. Elastically scattered deuterons were mostly registered at backward angles while the corresponding protons were registered more in the forward detectors. Similarly, proton-deuteron coincidences are observed as a result of the reaction on carbon target. Deuterons originating from reaction on carbon form a continuous spectrum over the entire energy range as one can see in Fig. 3. The elastic proton-deuteron scattering contribution is visible as a peak in the CD₂ target spectrum. The scaling factor can be easily found by superimposing both data sets. The region to the left (lower energy) of the elastic deuteron peak may be contaminated with the breakup protons. Hence, only the region to the right of the elastic peak was chosen to find the scaling factor. It was determined by integrating the number of events obtained in the entire area of interest and making ratio of the result obtained for both targets.

4 Summary

In conclusion, the relativistic treatment of the calculations is essential for a complete understanding of the 3NF effects in the deuteron breakup reaction at higher energies and can significantly affect the predictions of theoretical models. Therefore, it is very important to precisely investigate these effects for phase-space regions where the impact of the other dynamical components (Coulomb force, 3NF) of the nucleon interaction is negligible. The key element needed for determination of the cross sections in this experiment is to estimate the background contribution originating from protons colliding with carbon nuclei in a solid CD₂ target. This was done by measuring the particles on a separate target made of natural carbon. It was shown how to determine the relative scaling factor of these two datasets using registered deuterons.

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References