Studies of efficiency of the Kratta detectors in the deuteron breakup experiment.

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Abstract. An experiment focused on 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. Thirty Kratta modules have been arranged in a planar symmetric around beam axis configuration at few selected polar angles at which significant relativistic effects have been predicted. In front of each Kratta module 4 thin plastic scintillators were installed acting as a fast timing detectors to improve a trigger system. Determination of acceptance and efficiency of the detectors is discussed.

1. Introduction

Modern nuclear interaction models can be studied and tested in details using the deuteron breakup reaction, whose final state of three particles is complex enough to test different ingredients of few-nucleon system dynamics [1–3], which enter with varying strength in various phase-space regions. Recent years brought significant progress in the theory. The relativistic treatment of the breakup reaction in three-nucleon (3N) system was developed using nucleon-nucleon (NN) potential in [4]. Next, this approach has also been extended for calculations including three-nucleon force (3NF) in [5].

At relatively high energy of 200 MeV of the proton beam significant relativistic effects appear, according to the calculations, close to quasi free-scattering (QFS) condition. In such a configuration the undetected neutron has relatively low energy and momenta of the two breakup protons are coplanar on opposite sides of the beam ($\phi_{12} \approx 180°$). To search for proton-proton configurations with pronounced relativistic effects in the cross sections the authors of the calculations have performed systematic scan in the available reaction phase space. They have proposed a set of angular configurations defined with the fixed θ_{p1} angle of 37° of one of the breakup proton while for the coincident proton the θ_{p2} is in the range of 32° to 61°. For these configurations the Coulomb force as well as 3NF effects become negligible. Therefore only relativistic effects play a role and can be directly studied with the experimental data.

The experiment has been performed in February-March 2022 at Cyclotron Center Bronowice, Kraków, with the use of the 200 MeV proton beam and a solid CD_2 target. The reaction products have been detected with the Kratta detectors [8], arranged in configurations very close to ones proposed in [5].

2. Detection setup and trigger logic

In the experiment the proton-deuteron (pd) breakup and pd elastic scattering processes have been measured simultaneously. The main interest was the pd breakup reaction and the elastic scattering is used to check the detector performance as well as for the energy calibration and the data normalization.

To accomplish this task 30 Kratta modules have been arranged in 5 columns, each one consisting of 3 modules at following longitude angles: 37° , 43° , 49° , 55° , 61° in a planar left-right symmetric around the beam axis configuration (see Fig 1). Two additional modules were placed at 15° and used for a beam diagnostic. The left-right symmetry of the setup allowed one not only double acquired statistics, but also will allow for first order corrections of any geometrical misalignment connected to the beam direction and relative positioning of beam spot and the detectors. The detectors have been mounted inside the large-volume vacuum chamber.

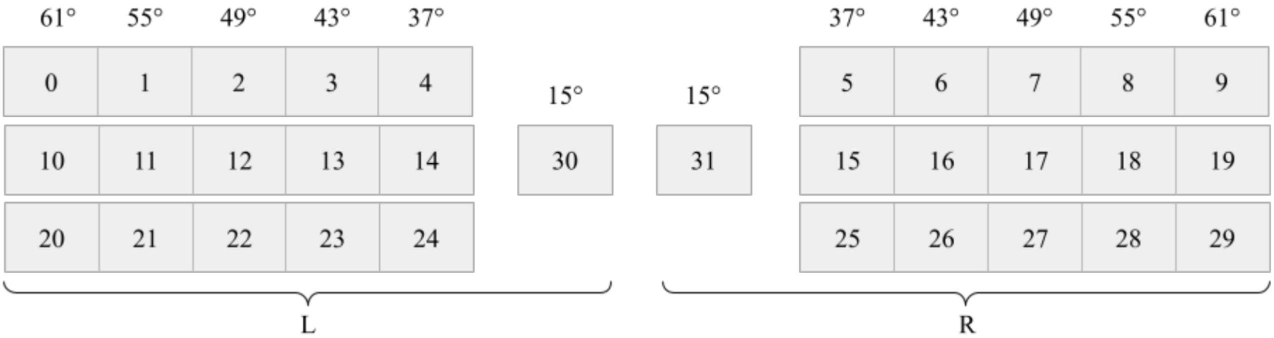

Figure 1. Schematic diagram of the used detection system with numbered modules. The left (L) and right (R) sides of the system are shown.

Kratta is a versatile, low energy, modular detector. Each module is an independent telescope and the modeles can be arranged in an arbitrary configuration. The modules are composed of three large area PIN photodiodes (Hamamatsu S5377-02) and of two CsI(Tl) crystals scintillators placed inside aluminum housing together with the charge preamplifiers. Fig. 2 presents the layout and dimensions of active elements in the module.

The detectors has been upgraded with four fast plastic scintillators (BC408) mounted in front of each module. Each scintillator is separately readout with SiPM (MICROFJ-30035-TSV-TR) and the signals are used in the data acquisition system for fast triggering. This improves time resolution and reduce accidental coincidences. The active solid angle of a module amounts to 4.5 msr. The detectors has been used successfully in the ASY-EOS experiment at GSI [10] and in proton-induced excitations experiment at the CCB [13, 14].

One of the key element of this measurement was the trigger based on fast time signals from the plastic detectors. The trigger logic is based on left-right coincidences (OR-Left AND OR-Right) between the Kratta modules arranged on both sides of the beam direction. To enhance number of the most important coincidences with the detectors placed at 37° (*37-Left*, *37-Right*), two dedicated trigger signals have been defined as (*37-Left* AND *OR-Right*) and (*37-Right* AND *OR-Left*). In the experiment also single trigger was used based on the plastic detectors or on the photodiode PD1. The latter one was utilized to measure plastic detectors efficiency.

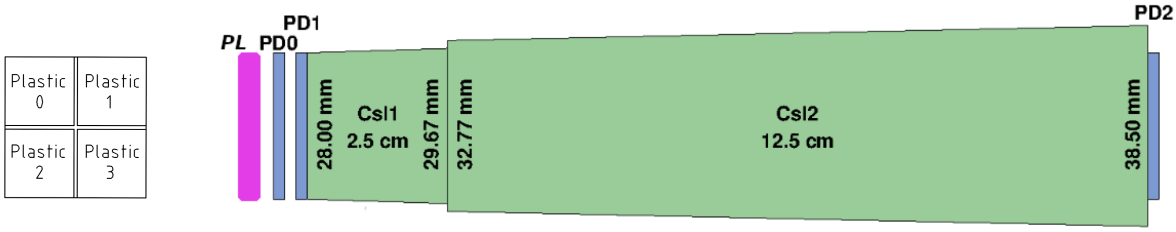

Figure 2. *Left panel:* Front view of Kratta module showing the arrangement of thin plastic detectors and their frame. *Right panel:* Schematic layout of the active elements in Kratta detector. **PL** stands for plastic, **PD0, PD1, PD2** are photodiodes, **CsI1, CsI2** are short and long Cesium Iodide scintillators respectively.

3. Efficiency estimation

The efficiency has been estimated for plastic detectors (PL), first (PD0) and second (PD1) photodiode. For the PD2 photodiode no reliable method to calculate efficiency has been developed so far. To study PD0 and PD1 efficiency the data collected with the regular trigger (based on the plastic detectors) have been used. In order to be sure that particles passed through a given element (PD0 or PD1), it was required that in a given Kratta module the signal was registered both in the plastic detector located in front of this module and in the photodiode located behind PD0 or PD1. In the case of the photothiode PD1 it was the PD2, while for the PD0 it was the PD1. In addition, both signals have to be closely correlated in time to avoid random events. The efficiency of a given element was calculated using the following formula:

$$\varepsilon_i(k) = \frac{N_i^{good}(k)}{N_i^{all}(k)}, \qquad (1)$$

where $\varepsilon_i(k)$ is the efficiency for k-th Kratta module, i is PD0 or PD1 photodiode, $N_i^{all}(k)$ is total number of events with a signal registered in at least the plastic and corresponding photodiode and $N_i^{good}(k)$ is number of registered events in all three detectors (plastic and two photodiods). The obtained efficiency of PD0 and PD1 are shown in Fig. 3.

In the next step, the plastic detectors efficiency has been estimated. The data collected with the single trigger based on the PD1 photodiode have been used. In addition, a signal in corresponding PD0 was required. To calculate the efficiency same formula like in the case of the photodiodes was applied, see Eq. 1. The obtained detection efficiency for plastics is shown in Fig. 3. This efficiency is the average over of all four plastics from the same module and includes also acceptance loss caused by passive elements in the system like e.g. holding frames.

4. Conclusions

The efficiency of two photodiodes and the plastic detectors of each Kratta modules used in the measurement have been estimated. In average the efficiency of the plastic detectors varies from 0.67 to 0.93 (mean value 0.83), for the PD0 photodiode is from 0.63 do 0.99 (mean 0.88) and the PD1 is from 0.9 to 0.99 (mean 0.96). The efficiency is crucial in the next steps of the analysis to obtain the differential cross sections.

Acknowledgments

This work was supported by the Polish National Science Center (NCN) from the 2019/35/N/ST2/03321 grant.

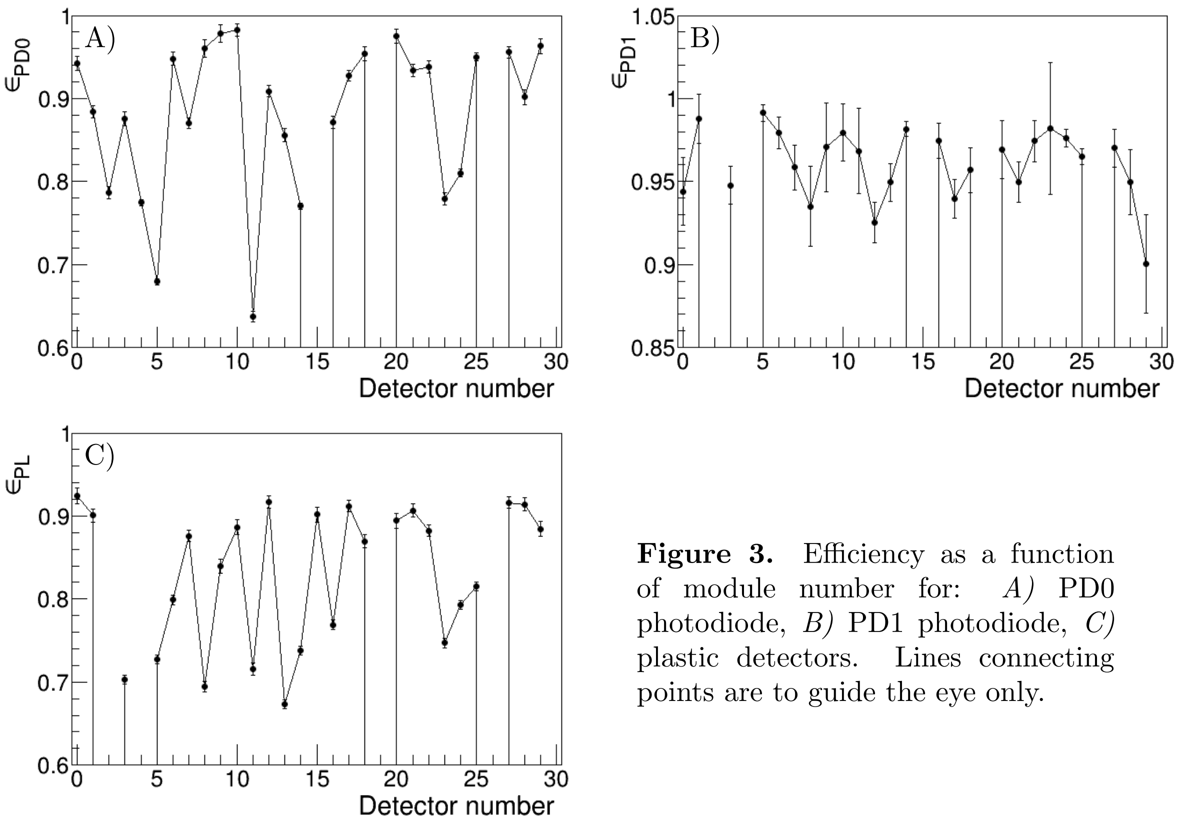

Figure 3. Efficiency as a function of module number for: *A)* PD0 photodiode, *B)* PD1 photodiode, *C)* plastic detectors. Lines connecting points are to guide the eye only.

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