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Charge Symmetry Breaking in $dd \rightarrow {}^4\mathrm{He}\,\pi^0$ with WASA-at-COSY

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Abstract. Charge symmetry breaking (CSB) observables are a suitable experimental tool to examine effects induced by quark masses on the nuclear level. Previous high precision data from TRIUMF and IUCF are currently used to develop a consistent description of CSB within the framework of chiral perturbation theory. In order to provide still missing data the physics program of WASA-at-COSY comprises two reaction channels. An exclusive measurement of the $dd \rightarrow {}^3\mathrm{He}n\,\pi^0$ reaction was carried out to obtain precise data on the total cross section as well as on the differential distributions. In addition, the studies on the reaction $dd \rightarrow {}^4\mathrm{He}\,\pi^0$ have been extended towards higher excess energies in order to provide information on the contribution of higher partial waves in the final state.

1 Introduction

Symmetries and symmetry breaking patterns in the non-perturbative regime of QCD is a key issue of the physics program of WASA-at-COSY. One objective is the determination of possible p-wave contributions to the charge symmetry breaking amplitude in the reaction $dd \rightarrow {}^4\mathrm{He}\pi^0$ at 1.2 GeV/c beam momentum (corresponding to an excess energy of $Q = 60\,\mathrm{MeV}$). Charge symmetry is a subgroup of isospin symmetry being broken by the different masses of the up and down quarks as well as by electromagnetic interaction [1]. In order to get access to quark mass effects on the hadron level it is favorable to look at charge symmetry breaking (CSB) observables as the relative pion mass difference, which is of electromagnetic origin, does not contribute. The reaction $dd \rightarrow {}^4\mathrm{He}\pi^0$ is forbidden by charge symmetry and, thus, the cross section is directly proportional to the square of the CSB amplitude. While the reaction has been measured close to threshold at IUCF [2] resulting in an energy dependence of the total cross section compatible with s-wave, data at higher excess energies sensitive to higher partial waves are missing. Such data are, however, crucial for calculations within the framework of Chiral Perturbation Theory currently under way. These calculations are a major theoretical effort and recent developments in this direction are reported in Refs. [3, 4].

2 Experiments

The experiments were carried out at the Institute for Nuclear Physics of the Forschungszentrum Jülich in Germany using the Cooler Synchrotron COSY [5] together with the WASA detection system. For

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the measurements of $dd \to {}^3\mathrm{He}n\pi^0$ and $dd \to {}^4\mathrm{He}\pi^0$ at excess energies of $Q \approx 40$ MeV and $Q \approx 60$ MeV, respectively, a deuteron beam with a momentum of 1.2 GeV/c was scattered on frozen deuterium pellets provided by an internal pellet target. The reaction products ^{3}He, ^{4}He and π^0 (the latter via the decay $\pi^0 \to \gamma\gamma$) were detected by the Forward Detector and the Central Detector of the WASA facility. The neutron remained undetected. The Forward Detector consists of several layers of plastic scintillators for particle identification and energy reconstruction and an array of straw tubes for precise tracking. The polar angular range between 3° and 18° fully covers the angular range of the outgoing ^{3}He and ^{4}He with the exception of very small scattering angles. At this beam momentum the helium ejectiles are already stopped in the first detector layers: in addition to the straw tube tracker only the two 3 mm thick layers of the Forward Window Counter and the first 5 mm thick layer of the Forward Trigger Hodoscope were used. The two photons from the π^0 decay were detected by the Scintillator Electromagnetic Calorimeter as part of the Central Detector. Photons were distinguished from charged particles using the Plastic Scintillator Barrel located inside the calorimeter. The experiment trigger was based on a coincidence between a high energy deposit in both layers of the Forward Window Counter and a low energy neutral cluster ($E > 20$ MeV) in the calorimeter to tag the decay of the pion. Further information on the WASA-at-COSY facility can be found in Ref. [6].

2.1 $dd \to {}^3\mathrm{He}n\pi^0$

For the first time an exclusive measurement of the $dd \to {}^3\mathrm{He}n\pi^0$ reaction has been performed. The data set amounts to about 3.4×10^6 fully reconstructed and background-free events. A total cross section of

$$\sigma_{tot} = (2.89 \pm 0.01_{stat} \pm 0.06_{sys} \pm 0.29_{norm})\,\mu\mathrm{b} \tag{1}$$

has been extracted. Differential distributions have been compared to the incoherent sum of a quasi-free reaction model and a partial-wave expansion limited to at most one p-wave in the final state. The contribution of the quasi-free processes accounts for about 1.1 μb of the total cross section matching the prediction of the quasi-free reaction model. The partial wave decomposition reveals the importance of p-wave contributions in the final state. The applied model shows a reasonable agreement for all differential distribution. For details the reader is referred to Ref. [7].

One goal of the measurement was to provide data for studying dd initial state interaction for small angular momenta, which is one missing information in the microscopic description of the charge symmetry breaking reaction $dd \to {}^4\mathrm{He}\pi^0$ within the framework of Chiral Perturbation Theory. In addition, this channel is used for absolute normalization for the reaction $dd \to {}^4\mathrm{He}\pi^0$.

2.2 $dd \to {}^4\mathrm{He}\pi^0$

While the previous measurements of $dd \to {}^4\mathrm{He}\pi^0$ close to reaction threshold were limited to the total cross section [8], in order to extract constraints on higher partial waves additional information on the differential cross section are essential. For this, an exclusive measurement detecting the ^{4}He ejectile as well as the two decay photons of the π^0 has been carried out. Separation between ^{3}He and ^{4}He has been done by means of a kinematic fit testing the final-state hypotheses ${}^3\mathrm{He}n\gamma\gamma$ and ${}^4\mathrm{He}\gamma\gamma$ requiring overall energy and momentum conservation. No constraint for the π^0 has been included in order not to introduce a fake π^0 signal. Thereby, the number of ^{3}He ejectiles falsely identified as ^{4}He was reduced by about four orders of magnitude.

Figure 1 shows the missing mass plot for the reaction $dd \to {}^4\mathrm{He}X$ after a the kinematic fit. The signal contains about 100 ${}^4\mathrm{He}\pi^0$ events. For the acceptance correction an isotropic angular distribution

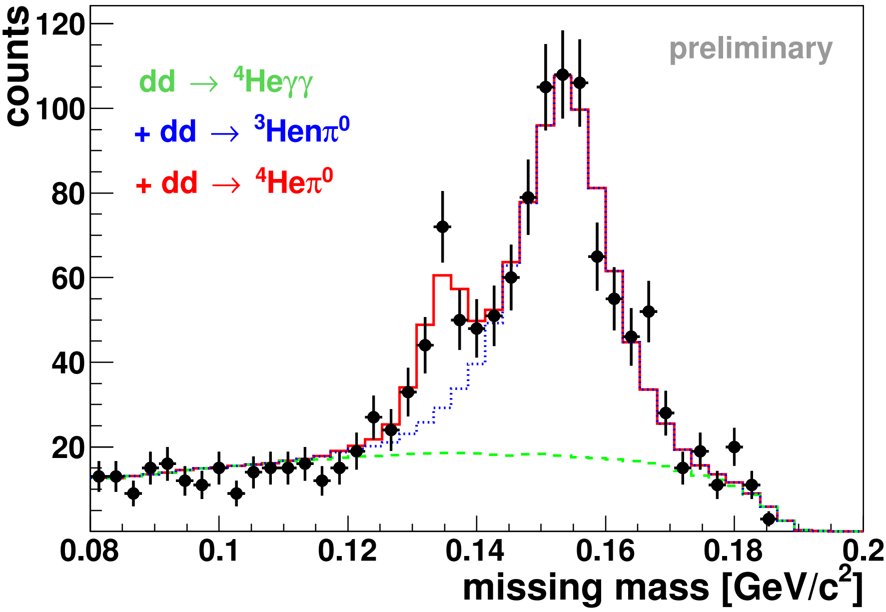

Figure 1. Missing mass plot for the reaction $dd \to {}^4\mathrm{He}X$. The different contributions fitted to the spectrum are double radiative capture $dd \to {}^4\mathrm{He}\gamma\gamma$ (green dashed), falsely assigned ${}^4\mathrm{He}\pi^0$ events from the reaction $dd \to {}^3\mathrm{He}n\pi^0$ (blue dotted, added) and the sum of all contributions including the signal (red solid).

has been assumed, for absolute normalization the reaction $dd \to {}^3\mathrm{He}n\pi^0$ has been used. A total cross section of

$$\sigma_{\mathrm{tot,prel.}} = (118 \pm 18_{\mathrm{stat}} \pm 13_{\mathrm{sys}} \pm 8_{\mathrm{norm}})\ \mathrm{pb}. \tag{2}$$

has been extracted. For the differential cross section the data have been divided into four angular bins within the detector acceptance ($-0.85 \leq \cos\theta^* \leq 0.75$). Here, a fit including the Legendre polynomials $P_0(\cos\theta^*)$ and $P_2(\cos\theta^*)$ does not show any evidence for contributions of higher partial waves — although not excluding either given the large statistical errors. For further details see Ref. [9].

3 Outlook

Based on the experiences gained during the two-weeks run on $dd \to {}^4\mathrm{He}\pi^0$ another eight-week measurement with a modified detector setup optimized for a time-of-flight measurement of the forward going ejectiles has been performed in spring 2014. In total, an increase of statistics by nearly a factor of 10 and significantly reduced systematic uncertainties are expected. In particular, the experiment has been designed to provide a better discrimination of background events from $dd \to {}^3\mathrm{He}n\pi^0$.

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