EPJ Web of Conferences **37**, 03008 (2012)
DOI: 10.1051/epjconf/20123703008

Investigation of the Charge Symmetry conserving reaction $\mathrm{dd} \rightarrow {}^3\mathrm{Hen}\pi^0$ with WASA-at-COSY

P. Podkopał[1,2,a], V. Hejny[1], A. Magiera[2], and A. Wrońska[2] for the WASA-at-COSY Collaboration

[1] Institut für Kernphysik and Jülich Center for Hadron Physics, Forschungszentrum Jülich, Germany
[2] Institute of Physics, Jagiellonian University, Cracow, Poland

Abstract. The reaction $dd \rightarrow {}^3Hen\pi^0$ has been measured at a beam momentum of p_d = 1.2 GeV/c using the WASA-at-COSY facility. For the first time data on the total cross section as well as differential distributions were obtained. The data are described with a phenomenological approach based on the combination of a quasi-free model and a partial wave expansion model for the three-body reaction.

1 Introduction

Investigation on charge symmetry breaking (CSB) in strong interaction is one of the most challenging topics in hadron physics [1]. Charge symmetry is the invariance of a system under rotation by 180° around the second axis in isospin space. In quantum chromodynamics (QCD) charge symmetry requires the invariance under exchange of up and down quarks. However, these quarks have different masses and charges, therefore charge symmetry is not a strict symmetry of the QCD Lagrangian. The elementary sources of CSB will show up also on the hadronic level. In this way, CSB studies help to connect quark-gluon dynamics to hadronic degrees of freedom, allowing in particular to access the impact of mass difference of up and down quarks.

The first observation of the $dd \rightarrow {}^4He\pi^0$ reaction was reported for beam energies very close to the reaction threshold [2]. At the same time information on CSB in $np \rightarrow d\pi^0$ manifesting as a forward-backward asymmetry became available [3]. These data triggered advanced theoretical calculations within effective field theory, providing the opportunity to investigate the influence of the quark masses in nuclear physics [4]. This is done using Chiral Perturbation Theory (ChPT) which has been extended to pion production reactions [5]. First steps towards a theoretical understanding of the $dd \rightarrow {}^4He\pi^0$ reaction have been taken [6,7]. It was found that the existing data are not sufficient for a precise determination of all parameters and new data are required. These data should comprise the measurement of the charge symmetry forbidden $dd \rightarrow {}^4He\pi^0$ reaction and the charge symmetry conserving $dd \rightarrow {}^3Hen\pi^0$ channel. The measurement of first reaction should be performed at a beam energy higher than used in Ref. [2] in order to study the contribution of the higher partial waves. The measurement of the second reaction is necessary to study the relevance of the initial state interactions, which strongly influence the results for $dd \rightarrow {}^4He\pi^0$ reaction.

2 Experiment

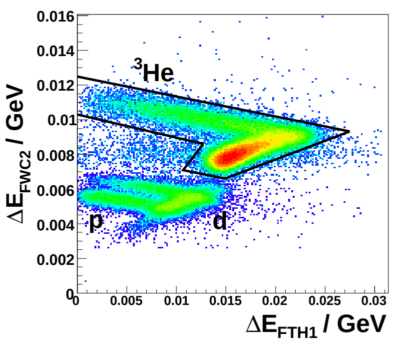
The experiment was carried out at the Institute for Nuclear Physics of Forschungszentrum Jülich in Germany. For the measurement the Cooler Synchrotron COSY [8] together with the WASA detection system was used. A deuteron beam with a momentum of 1.2 GeV/c, corresponding to an excess energy of about 40 MeV, has been scattered on deuteron pellets provided by an internal pellet target. The

[a] e-mail: podkopal@googlemail.com

average luminosity during the experiment was in the order of 10^{30} cm^{-2} s^{-1}. The reaction products were detected by the two main components of the WASA facility, namely the Forward Detector and the Central Detector. The reaction was measured close to threshold, therefore the angular range for the outgoing ^3He was limited to a maximum polar angle of about 17° and thus, the ^3He were detected in the Forward Detector only. The two photons from the π^0 decay were registered within 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.

3 Data Analysis and Results

The first step in the analysis was the identification of helium in the forward detector. This has been done by checking the energy loss in the Forward Window Counter versus the energy loss in the first layer of the Forward Trigger Hodoscope (see left panel of Fig. 1). After helium selection two neutral hits (photons) in the central detector were requested and the corresponding invariant mass was reconstructed. As a result a nearly background free pion peak was obtained (see right panel of Fig. 1). Finally, the data were refined by applying a kinematic fit.



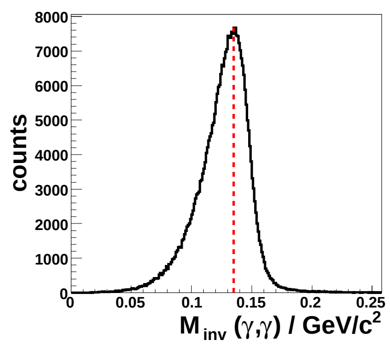


Fig. 1. Energy loss in the Forward Window Counter versus energy loss in the first layer of the Forward Trigger Hodoscope. The obtained energy pattern allows to distinguish between different particles types. The graphical cut indicated in black represents the region used to select ^3He candidates (left). Two photon invariant mass distribution corresponding to the $\pi^0 \to \gamma\gamma$ decay (right).

For luminosity determination $dd \to {}^3Hen$ was used. This reaction was measured simultaneously with a different, prescaled trigger. Therefore, it was possible to extract the angular distribution for the outgoing ^3He integrated over the whole run. Data for $dd \to {}^3Hen$ and $dd \to {}^3Hp$ are available for similar beam momenta as used in the present experiment [9]. It was assumed that the cross section for these two reaction channels are equal, as it was shown by authors for beam momentum of 1.65 Gev/c. The angular distributions for the $dd \to {}^3Hp$ reaction for a beam momenta of 1.109 GeV/c, 1.387 GeV/c and 1.493 GeV/c were parametrized. Then, for each polar angle, the differential cross section was calculated according to this parametrization for every beam momentum. The dependence of the differential cross section on the beam momentum was fitted and then interpolated to the present beam momentum of 1.2 GeV/c. The resulting distributions were used as an input for the simulations of the $dd \to {}^3Hen$ reaction. The whole procedure allowed the determination of the integrated luminosity necessary to calculate the cross section of the $dd \to {}^3Hen\pi^0$ reaction.

Presently, no theoretical models exist for a microscopic description of the investigated reaction. However, in order to have a sufficiently precise acceptance correction a model which reproduces the experimental data reasonably well is required. The data have been compared to a quasi-free reaction model based on existing data for the two-body reaction $dp \to {}^3He\pi^0$ and a partial-wave expansion for the three-body reaction, both added incoherently. For the investigated reaction $dd \to {}^3Hen\pi^0$ with

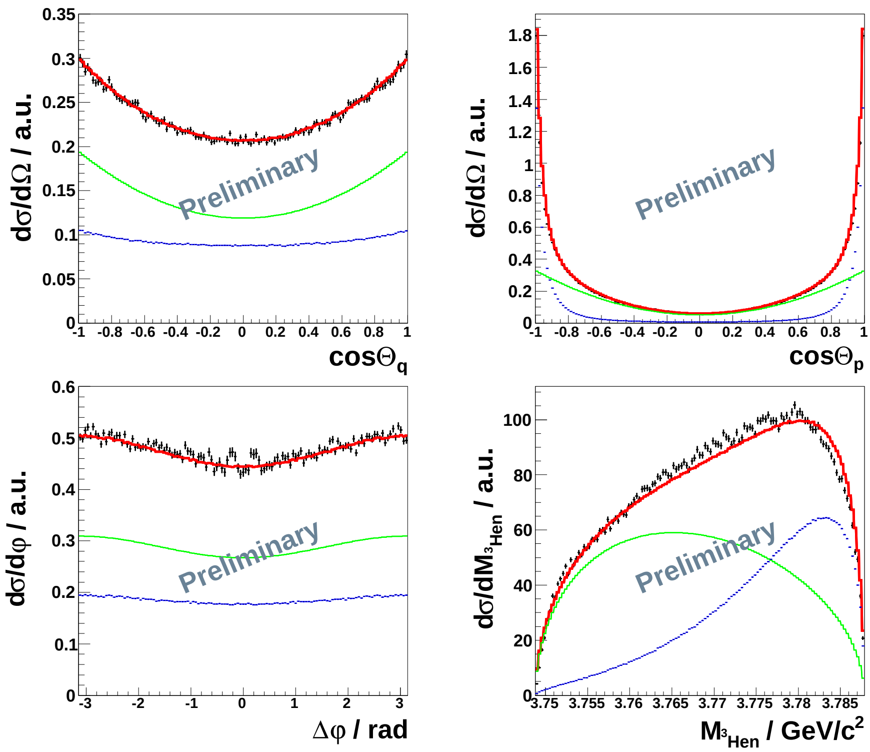


Fig. 2. The acceptance corrected, experimental differential cross sections (black points) presented as a function of $M_{^3Hen}$, $cos\theta_q$, $cos\theta_p$ and φ are compared to model calculations (red line) based on an incoherent sum of the quasi-free reaction (blue line) and a partial wave model (green line).

unpolarised particles in the initial state and three particles in the final state four independent variables fully describe the reaction kinematics. In the present analysis the choice of these independent variables is based on the Jacobi momenta **q** and **p**, where **q** is the π^0 momentum in the overall c.m. frame and **p** is the relative momentum in the ^3Hen subsystem. Using the Jacobi momenta following variables were constructed: $cos\theta_q$, $cos\theta_p$ (the polar angles of **q** and **p**), $M_{^3Hen}$ and φ (the angle between the projections of **q** and **p** onto the xy-plane). The relative angular momenta for the partial wave expansion were defined accordingly: one in the global π^0 - (^3Hen) system and one within the ^3Hen subsystem (in the following described by a lower and a upper case letter, respectively). The analysis has been limited to $l + L \leq 1$. Taking into account all possible spin configurations this results in 18 possible amplitudes. After combining the amplitudes with the same signature in the final state four possible contributions can be identified: *sS*, *sP*, *pS* and *sP* - *pS* interferences. They can be described by seven real coefficients (four complex numbers minus one overall phase). All four distributions of the independent variables were fitted simultaneously. The contribution from the quasi-free reaction mechanism is about 1/3 of the total cross section and is consistent with the value one gets from folding the cross section for $dp \to {}^3He\pi^0$ with the deuteron wave function. Contributions from higher partial waves are illustrated in Fig. 2: while the effect of *p*-waves in the angular distributions is significant, the restriction to at most one *p*-wave is already sufficient to provide a consistent description of the data. The probability of a *p*-wave in the overall c.m. system and in the ^3Hen subsystem is of similar size. For the partial wave analysis the standard approximation for the momentum dependence of $|M|^2 \propto q^{2l+1}p^{2L+1}$ was used. Deviations from this assumption were studied by repeating the fit for various subranges in $M_{^3Hen}$ (corresponding to intervals in **q** and **p**). All but one coefficient remained constant. Only the *p*-wave contribution in the ^3Hen system showed a significant momentum dependence: compared to the default scaling it has larger values for small relative momenta. A quantitative analysis of this effect is in progress.

In a subsequent run first data for the charge-symmetry breaking reaction $dd \rightarrow {}^4He\pi^0$ at pd = 1.2 GeV/c have already been taken. A preliminary analysis indicates a cross section lower than estimated from extrapolation of the results of Ref. [2]. For a high-statistics run aiming at contributions from higher partial waves various options are currently being discussed like exploiting the reaction $dd \rightarrow dd\pi^0$ or going higher in energy closer to the pole of the Δ resonance and the $2\pi^0$ threshold.

4 Acknowledgements

We acknowledge valuable discussions with C. Hanhart on this issue. We also want to thank the technical and administrative staff at the Forschungszentrum Jülich, especially at the COoler SYnchrotron COSY and at the participating institutes. This work has been supported by German Federal Ministry of Education and Research, the Polish Ministry of Science and Higher Education and COSY-FFE (Forschungszentrum Jülich).

References

1. G. Miller *et al.*, Phys. Rept. **194**, (1990) 1
2. E. Stephenson etal., Phys. Rev. Lett. **91**, (2003) 142302
3. A. Opper *et al.*, Phys. Rev. Lett. **91**, (2003) 212302
4. G.A. Miller *et al.*, Ann. Rev. Nucl. Part. Sci. **56** (2006) 253
5. C. Hanhart *et al.*, Phys. Rept. **397**, (2004) 155
6. A. Gårdestig *et al.*, Phys. Rev. **C 69**, (2004) 044606
7. A. Nogga *et al.*, Phys. Lett. **B 639**, (2006) 465
8. R. Maier *et al.*, Nucl. Phys. **A 626**, (1997) 395c-403c
9. G. Bizard *et al.*, Phys. Rev.**C 22**, (1980) 1632