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Investigations of the charge symmetry breaking reaction $dd \longrightarrow \alpha\pi^0$ with the WASA-at-COSY experiment

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Abstract. The charge symmetry breaking reaction $dd \longrightarrow {}^4\text{He}\pi^0$ has been measured with the WASA-at-COSY experimental setup at a beam momentum of $p_d = 1.2$ GeV/c (Q = 60 MeV). For the first time a signal for this reaction has been observed at an excess energy well above threshold. The determined preliminary total cross section is $\sigma_{\text{tot}}^{\text{prel}} = (120 \pm 20_{\text{stat.}})$ pb.

1 Introduction

In the framework of the Standard Model, isospin symmetry is broken by the mass and charge difference of quarks [1, 2]. From isospin symmetry breaking observables it is difficult to access these individual terms, because on the hadronic level, isospin symmetry breaking is dominated by the pion mass difference ($\Delta\pi$), which is almost a pure electromagnetic effect. Only the reactions, where these two sources of isospin symmetry breaking can be disentangled, open an experimental window to probe the u and d quark mass difference effects in hadronic processes [3]. This can be achieved by using charge symmetry breaking (CSB) observables where $\Delta\pi$ does not contribute. Charge symmetry is a special case of isospin symmetry, corresponding to a rotation of 180° in isospin space interchanging the up and down quarks.

Up to now, there were two successful measurements of CSB observables: one is the forward-backward asymmetry (A_{fb}) in the $np \longrightarrow d\pi^0$ reaction [4], the other is the π^0 production in the $dd \longrightarrow {}^4\text{He}\pi^0$ reaction near threshold [5]. Advanced theoretical calculations based on Chiral Perturabtion Theory (χ_{PT}) show that CSB effects manifest themselves in many different physical phenomena on the hadronic level [6, 7]. A consistent theoretical analysis of both measurements is currently in progress [8–13]. It is shown within a plane wave calculation, that when all parameters are fixed the p-waves in the $dd \longrightarrow {}^4\text{He}\pi^0$ reaction may be predicted parameter free to leading and next-to-leading order [11]. Therefore, experimental input of p-wave contributions at higher excess energies is needed.

2 Experimental setup

The measurement of the CSB reaction $dd \longrightarrow {}^4\text{He}\pi^0$ is the one of the primary objectives of the WASA-at-COSY experiment [16], which is located at the COoler SYnchortron COSY [15] at the

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Institute for Nuclear Physics of Forschungszentrum Jülich, Germany. The CSB program started with an analysis of the charge symmetry conserving reaction $dd \longrightarrow {}^3\mathrm{He}n\pi^0$ at p_d = 1.2 GeV/c [14]. The goal of this analysis was to get information about the main source of background for the signal reaction $dd \longrightarrow {}^4\mathrm{He}\pi^0$ and to provide experimental constraints for theoretical calculations of the dd initial state interactions.

The second step of the program is the investigation of the $dd \longrightarrow {}^4\mathrm{He}\pi^0$ reaction at p_d = 1.2 GeV/c (E_d = 350 MeV). In June 2008, in a high-luminosity two-weeks run the first data were collected. The main goal of this experiment was to obtain the total cross section and to extract a first angular distribution.

3 Data analysis and results

During the run a total integrated luminosity of about $L \approx 5$ pb^{-1} was achieved. The reaction was tagged by two neutral clusters from the π^0 decay in the electromagnetic calorimeter of the Central Detector and a ^{4}He in the Forward Detector (a set of plastics scintillator layers and a tracking detector).

The identification of helium is based on the energy losses patterns dE – dE in the first layers of the Forward Detector - two layers of the Forward Window Counter and the first layer of the Forward Trigger Hodoscope. Because of the small kinetic energy, ^{4}He particles do not reach further layers of the Forwad Detector. The main sources of background are the charge symmetry conserving reaction $dd \longrightarrow {}^3\mathrm{He}n\pi^0$ and the double radiative capture $dd \longrightarrow {}^4\mathrm{He}\gamma\gamma$. In order to suppress the background deriving from the ^{3}He isotopes and to ensure energy and momentum conservation, an overall kinematic fit was used. Two hypotheses were tested: $dd \longrightarrow {}^4\mathrm{He}\gamma\gamma$ and $dd \longrightarrow {}^3\mathrm{He}n\gamma\gamma$. No constraint on the $\gamma\gamma$ invariant mass was included to avoid the production of an artificial π^0 peak. Finally, a combined χ^2 cut was used to suppress background from the misidentified ^{3}He. Detector acceptance and all applied cuts efficiency for the signal reaction is about 20%.

4 Results

In Fig. 4 the ^{4}He missing mass spectrum is shown. On top of a flat background from the double radiative capture $dd \longrightarrow {}^4\mathrm{He}\gamma\gamma$, two distinct peaks are visible. One is linked to the signal, the second is caused by remaining misidentified ^{3}He from the $dd \longrightarrow {}^3\mathrm{He}n\pi^0$ reaction. The background was fitted with distributions from event generators filtered by Monte-Carlo simulations. For $dd \longrightarrow {}^4\mathrm{He}\gamma\gamma$ a homogeneous 3-body phase-space distribution was assumed, for the $dd \longrightarrow {}^3\mathrm{He}n\pi^0$ channel the model obtained from the previous measurement [14] was used. The difference between data and fitted background is presented in the inset plot, which was fitted with a Gaussian function. The preliminary result for the total cross section of the $dd \longrightarrow {}^4\mathrm{He}\pi^0$ reaction is $\sigma_{\mathrm{tot}}^{\mathrm{prel}}$ = (120±20(stat.)) pb, assuming a 2-body phase space. For the double radiative capture reaction $dd \longrightarrow {}^4\mathrm{He}\gamma\gamma$ it is $\sigma_{\mathrm{tot}}^{\mathrm{prel}}$ = (960 ± 45(stat.)) pb, based on the assumption of a 3-body phase space.

In addition, a first angular distribution for $dd \longrightarrow {}^4\mathrm{He}\pi^0$ at Q = 60 MeV was obtained, which is consistent with s-wave pion production. However, the limited statistics introduces large statistical and systematical uncertainties, which are currently under investagtion.

5 Future strategy

One of the challenges that made the $dd \longrightarrow {}^4\mathrm{He}\pi^0$ reaction analysis difficult was a poor ^{3}He – ^{4}He separation, solely based on the energy loss pattern from the first three layers of the Forward Detector. In order to improve that, a modified version of the WASA detector will be used for the next run

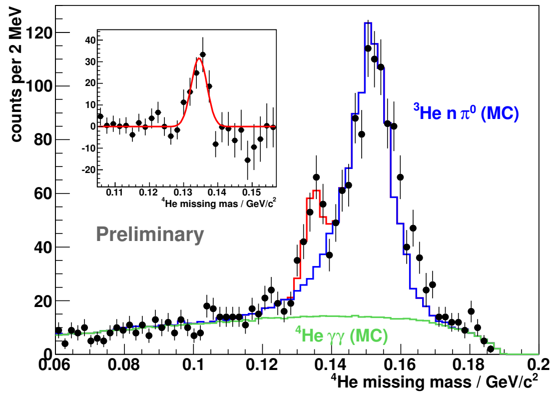

Figure 1. ^{4}He missing mass distribution. Background fitted with Monte-Carlo simulation templates: double radiative capture (green) and $dd \longrightarrow {}^3\text{He}n\pi^0$ (blue). The background subtracted data are fitted with a Gaussian function (inset, red). Only statistical uncertainties are presented.

(see Fig. 2). All layers of the Forward Detector between the Forward Proportional Chamber and the Forward Veto Hodoscope will be removed, which will provide time of flight as a new independent observable. In the new setup the Forward Veto Hodoscope will take over the role of the Forward Trigger Hodoscope as stopping layer. The simulation of the new setup verifies that this replacement does not affect the performance of the current detector. In addition, when time of flight is introduced, the ^{3}He – ^{4}He separation significantly improves. A high statistics data sample will be taken in a eight-weeks long run using this modified detector setup in spring 2014. The experimental goal is to reach about 20% statistical uncertainty for the anisotropy parameter of the angular distribution. This precision will allow a reasonable comparison with the theoretical calculations which are currently in progress.

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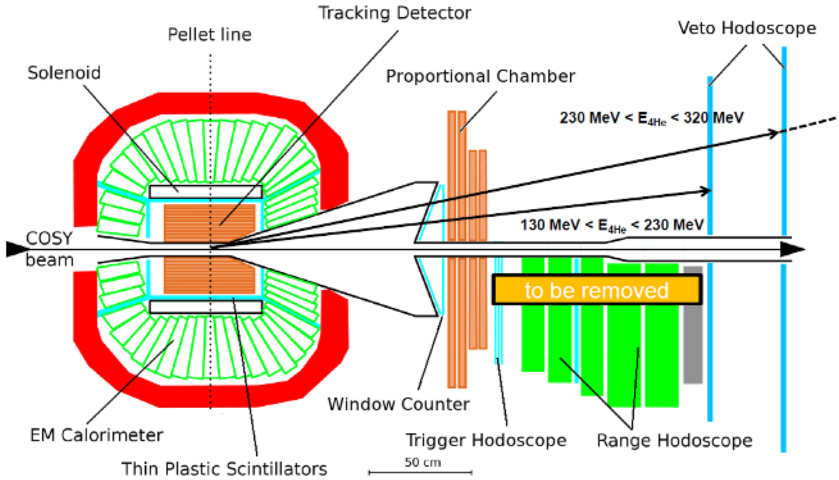

Figure 2. The planned modification of the WASA-at-COSY detector setup. The upper part shows the removed Forward Detector layers between Forward Proportional Chamber and Forward Veto Hodoscope. The lower part presents the current WASA detector setup. The kinetic energy of ^{4}He needed to reach and stop in first or second layer of Forward Veto Hodoscope is indicated.

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