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Near threshold η-meson production in the dd $\to$ ^{4}He η reaction

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Investigation of the dd $\to^4$He η reaction has been a part of the experimental program at the ANKE facility of COSY-Jülich. It comprises measurements at four excess energies: 2.3 MeV, 7.7 MeV, 22 MeV, 42.7 MeV as well as an energy below threshold for background study. The results obtained so far as well as the employed experimental technique are presented.

Keywords: η-meson; mesic nuclei; meson production mechanism

1. Physics Motivation

Eta physics has drawn a lot of attention in recent years[1]. Of particular interest is the issue of η-nucleus quasi-bound states. Photoproduction data of the η meson off ^{3}He strongly support this idea[2]. Also the steep rise of the η-production amplitudes towards threshold in the pd $\to^3$He η and dd $\to^4$He η processes is believed to be an indication for such systems[3]. However, a refined analysis aiming at the extraction of the η-nucleus s-wave scattering length requires precise information on angular distributions, in particular on the contribution of the s-wave amplitude to the total cross-section. ^{4}He$-\eta$ quasi-bound states can exist in s-wave only, so that it is important to extract the value of the s-wave scattering length and not one contained by higher partial waves. For the pd $\to^3$He η reaction, though some differential cross-sections for higher Q values (Q>21 MeV) are available, there are still inconsistencies between various data sets on the total cross-section close to threshold (for a review see[6]). Angular distributions for the ^{4}He$-\eta$ system have never been successfully measured and the existing data on the total cross-section[7,8] cover the energy regime only up to Q=8 MeV.

The question of the η-meson production mechanism also remains ambiguous. Simple models where one or more nucleons remain spectators undershoot the cross-section due to the very large momentum transfer[5]. A contribution is required where

*on leave from the Institute of Physics, Jagiellonian University, Reymonta 4, 30-059 Cracow, Poland all nucleons are involved in the reaction mechanism. For the pd $\to {}^3\mathrm{He}\,\eta$ case Kilian and Nann showed that the final η momentum is essentially the same as that obtained from the sequential processes pp $\to$ dπ^+ followed by π^+n $\to$ pη, when the relative momentum between final proton and deuteron is zero, and thus the probability of ^{3}He formation is large (the so-called two-step model[4]). This model, however, also underpredicts the near-threshold amplitude by about a factor of 2.4. Moreover, it predicts enhancements in the cross-section for the intermediate pion being closest to its mass-shell, i.e. $\cos\theta_\eta = -0.3$, which is in conflict with the observation of enhancement at $\cos\theta_\eta = 0.5$ [9]. The problems mentioned here can result from neglecting the interference terms of the two mechanisms or a situation, where there is an intermediate d^* produced instead of a deuteron.

Although the existing dd $\to {}^4\mathrm{He}\,\eta$ data can be well described within the framework of the two-step model, it could be tested further, as in the ^{3}He$-\eta$ case, exploiting information on the differential cross-section. The latter would also be useful to better establish the parameters of ^{4}He$-\eta$ system.

2. Experiment with ANKE at COSY

In 2003 the investigation of the dd $\to {}^4\mathrm{He}\,\eta$ reaction was undertaken with the use of ANKE - an installation located at the internal target position at COSY-Jülich, Germany[10]. At its heart are three magnets, forming a chicane in the COSY ring, with the one in the middle being used as a spectrometer.

In the two measurements performed in 2003, data were taken at four excess energies above the reaction threshold ($Q = 2.3, 7.7, 22, 42.7$ MeV) and one data point below threshold ($Q = -2.7$ MeV) to study the background shape[11]. For this experiment, only the so-called forward detector system of ANKE was used, where reaction products with momenta comparable to the beam momentum are detected. The detector system is schematically depicted in Fig. 1. It comprises a set of wire chambers for tracking purposes and a three-layer scintillation hodoscope for triggering and energy loss measurement.

Selection of events with ^{4}He detection was done with the use of two-dimensional $\Delta\mathrm{E}-\mathrm{p}$ and $\mathrm{TOF}-\mathrm{p}$ cuts. The majority of events stemmed from two-pion

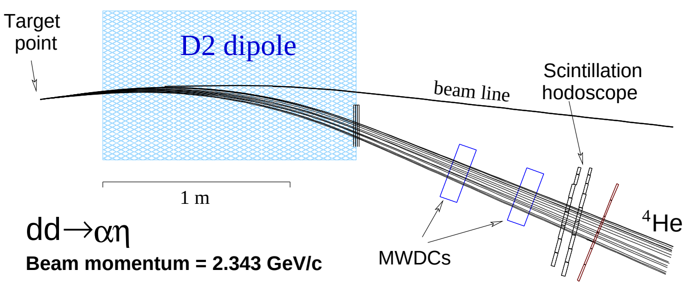

Fig. 1. Part of the ANKE detection system used in the measurement of the dd $\to {}^4\mathrm{He}\,\eta$.

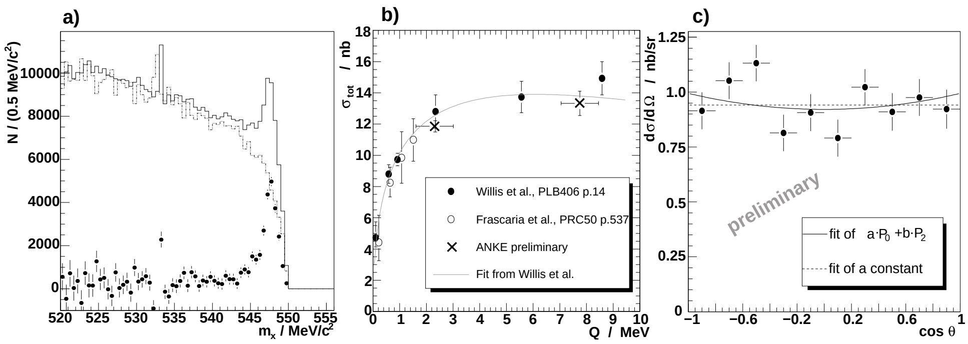

Fig. 2. *Preliminary* results of the dd $\rightarrow^4$He η measurement at ANKE: a) missing mass spectrum of the detected ^{4}He at $Q = 2.3$ MeV (solid) with the scaled subthreshold data (dotted) and extracted η-signal (points), b) total cross-section, c) angular distribution at $Q = 2.3$ MeV.

production[12]. The process of interest was then identified as a peak in the missing mass spectrum, see Fig.2a. It is also well seen in the transverse momentum distribution. Total cross-sections measured for $Q = 2.3$ MeV and 7.7 MeV, normalized to the inclusive measurement of Ref.[12] are in a good agreement with the existing data. The precision of the angular distribution measurement at $Q = 2.3$ MeV allows one to set an upper limit on the non-uniform contribution (i.e. higher partial waves). A fit of the formula $a\cdot P_0 + b\cdot P_2$ yields $b/a = 0.05 \pm 0.10$ (odd Legendre polynomials must vanish due to having two identical bosons in the entrance channel). However, a fit of a constant results in the same χ^2. Thus, the distribution for this excess energy is consistent with s-wave production.

Analysis of data taken at higher excess energies is in progress.

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