Photoproduction of η-Mesons off ^{3}He

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Photoproduction of η-mesons off ^{3}He has been studied at the MAMI accelerator using the Crystal Ball/TAPS detector setup. The total cross section for the coherent η-photoproduction was measured with improved statistical quality. Both, the total and differential cross sections show evidence for dominant final state interaction. Additionally, the photoproduction of η-mesons off quasi-free protons and neutrons was studied. The preliminary cross section on the neutron confirms the narrow bump-like structure at $W \simeq 1.7$ GeV, which was already seen in different experiments on the deuterium target [1–3, 10, 11].

1 Introduction

Photoproduction of mesons is an ideal tool to investigate the meson-nucleon (-nucleus) interactions. An important question is whether the properties of the strong interaction allow the formation of meson-nucleus bound states. The best candidate for such a bound state is the η-meson. Already in the 1980s Bhalerao, Liu and Haider [4,5] found that an attractive ηN s-wave interaction might lead to the formation of quasi-bound η-nucleus states, the so-called η-mesic nuclei. Such quasi-bound states should give rise to an enhancement at the threshold of the cross section relative to the expectation for phase space behavior. Such threshold behaviours have been previously studied in hadron and photon induced reactions for η-^{3}He [6,7] and η-^{4}He [8,9] systems. With the 4π-detector in Mainz, this experiment was able to improve the statistical quality of the coherent η-photoproduction off ^{3}He drastically. The results will be discussed below.
Besides the investigation of η-mesic nuclei, this experiment was used to study the excitation spectrum of the nucleon. In particular, total cross sections of η-photoproduction off quasi-free protons and neutrons have been measured. Previous experiments [1–3, 10, 11] have reported a narrow structure at $W \simeq 1.7$ GeV with a width of ~ 25 MeV in the cross section on the neutron which is not visible for the proton.
The experiment was carried out at the MAMI acceleration facility in Mainz. A circularly polarised tagged photon beam with energies up to 1.4 GeV and a typical energy resolution

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of 4 MeV was used. For a geometrical acceptance close to 4π steradian several detectors are needed. The Crystal Ball detector (CB) surrounds the target and is made of 720 NaI crystals. Inside the CB the Particle Identification Detector (PID) is placed. The PID is made of 24 plastic scintillators and is used to identify charged particles. The opening angle to the forward direction of the CB is covered using the photon spectrometer TAPS. The TAPS detector is made of BaF_2 and $PbWO_4$ crystals and is placed 1.475 m in front of the target. A plastic veto is mounted in front of every BaF_2 crystal. The cryogenic ^{3}He target is centered in CB and has a length of 5.3 cm and a density of 0.069 g/cm^3.

2 Results

To investigate the formation of a η-nucleus bound states, the cross section of the coherent η-photoproduction was measured. An invariant mass analysis for each energy and meson center-of-mass polar angle has been performed to identify the $\eta \rightarrow 2\gamma$ and $\eta \rightarrow 6\gamma$ decay. Due to the overdetermined kinematics the missing energy was used to separate the coherent from breakup reactions. The total cross section of the two decay channels are shown in Fig.1

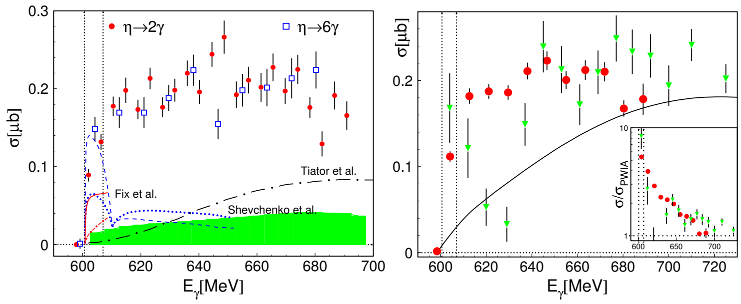

Figure 1: Left: Coherent η cross section for $\eta \rightarrow 2\gamma$ (red) and $\eta \rightarrow 6\gamma$ (blue). Several models are indicated. Right: The average of $\eta \rightarrow 2\gamma$ and $\eta \rightarrow 6\gamma$ is compared to a previous measurement by M. Pfeiffer et al. [6].

(left). Both results are in good agreement and show a steep increase between the coherent and the breakup threshold. All indicated models do not reproduce the data. On the right side the average of the two cross sections is compared to an earlier experiment [6]. The two measurements are in agreement if one takes into account the lower statistical quality of the older results.

The η-photoproduction off quasi-free protons and neutrons has been identified with an invariant mass analysis. The competing background, which mainly comes from $\eta\pi^0$ reactions, was eliminated by cutting on the missing mass and on the coplanarity of the η-nucleon pair. Additionally, the background was reduced by coincidence cuts and a random background subtraction. Monte-Carlo simulations with Geant4 were used for the angle and energy dependent detection efficiency correction. On the one hand the cross section was calculated

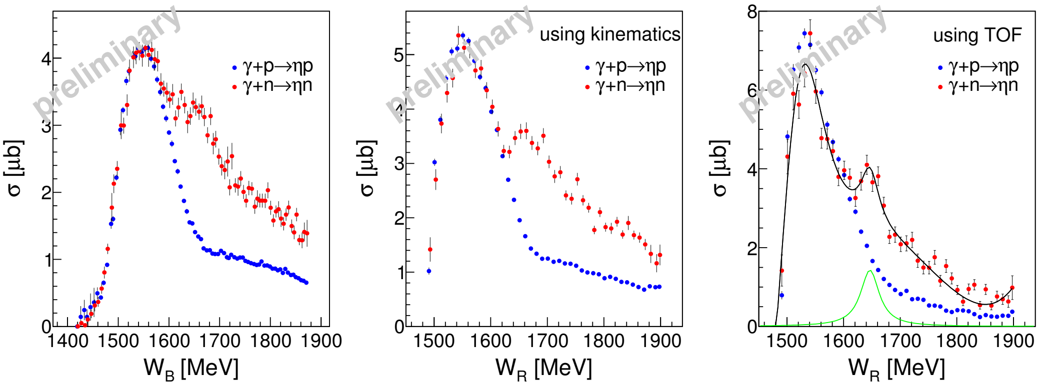

Figure 2: Total cross sections of quasi-free η-photoproduction on the proton (blue) and on the neutron (red). The proton cross section is scaled to the neutron. The cross section on the right-hand side is fitted with two Breit-Wigner functions and a background polynomial. The fit yields a width of 45 MeV for the structure, which is comparable to the experimental resolution.

as a function of the center of mass energy with the initial state particles:

$$W_B^2 = (P_\gamma + P_{N,i})^2 = 2E_\gamma m_N + m_N^2$$

Since the momentum of the initial state nucleon is not exactly known, the structures are smeared out due to the Fermi motion. On the other hand the center-of-mass energy has been calculated with the final state particles:

$$W_R^2 = (P_\eta + P_{N,f})^2$$

In this case no effects of Fermi motion are visible but the experimental resultion of the recoil nucleon is the limiting factor. The resulting cross sections as a function of W_B (left) and W_R (middle) are visible in Fig.2. In the central picture the structure around $W \simeq 1675$ MeV is quite narrow, whereas the structure on the left side is broadened by Fermi motion. The position of this structure is consistent with the deuterium data by I. Jaeglé et al. [1,2] but is somewhat broader. This is caused by the fact that the kinematical reconstruction of the recoil nucleon momentum is more approximate in ^{3}He than in deuterium. Since one has a three-body final state instead of a two-body final state one has to assume that the two spectator nucleons have no relative momentum. To overcome this problem the recoil nucleon momentum has been calculated for nucleons detected in TAPS using time-of-flight instead of kinematics, which results in the cross sections in Fig.2 (right). In this case the structure has a width of 45 MeV which is comparable to the experimental resolution.

3 Conclusions

The coherent η-photoproduction off ^{3}He was measured with improved statistical quality. The resulting total cross section rises extremely between the coherent and breakup threshold. The angular distributions at threshold (not shown) are almost isotropic or have even an angular dependence opposite to the expectation from the form factor behavior. All these effects are strong evidence for dominant final state interaction, which could be related to a resonant state at η-photoproduction threshold.
The cross section of quasi-free η-photoproduction on the neutron shows a bump-like structure. The position and width of this structure is consistent with the deuteron data. The existence of this structure in the cross section on ^{3}He, which has a different neutron-to-proton ratio and a bigger Fermi motion than deuterium, makes it very unlikely that this structure is caused by rescattering of mesons or final state interaction. Currently further experiments are running at MAMI in Mainz and ELSA in Bonn to measure single and double polarisation observables which then can be used to identify the responsible partial waves.

Acknowledgments

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