Photoproduction of $\eta$-mesons from light nuclei

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Abstract

In a series of experiments coherent and quasifree $\eta$-photoproduction from light nuclei ($^4\text{He}$, $^3\text{He}$, $^2\text{H}$) was investigated with the TAPS-detector at the Mainz MAMI-accelerator. The experiments were motivated by two different subjects: the determination of the isospin structure of the electromagnetic excitation of the $S_{11}(1535)$ resonance and the study of the $\eta$-nucleon and $\eta$-nucleus interaction at small momenta. The results for the deuteron and $^4\text{He}$ are summarized and first preliminary results for $^3\text{He}$ are presented.

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1. Introduction

Photoproduction of mesons from light nuclei can serve two purposes: the investigation of the isospin structure of the electromagnetic excitation of nucleon resonances and the study of the meson - nucleon interaction via final state interaction effects. In principle, there are two possibilities to learn about the isospin structure of the photoexcitation amplitudes. Coherent photoproduction from light nuclei may be used as an isospin filter, while photoproduction from bound nucleons in quasifree kinematics can be used to extract the neutron cross section. The small binding energy and the comparatively well understood nuclear structure single out the deuteron as exceptionally important target nucleus. However, as a cross check for nuclear effects, it is desirable to use also a nucleus with a different momentum distribution of the bound nucleons as target. In this respect $^4\text{He}$ is an extreme case due to the strong binding of the nucleus.

During the last few years we have intensively studied quasifree, and coherent $\eta$-photoproduction from the deuteron and from He-nuclei [1-5].
The electromagnetic excitation of $I = 1/2$ $N^*$ resonances involves two isospin components, the isoscalar and the isovector amplitudes. The complete determination of the amplitudes is possible from the measurement of $\eta$-photoproduction from the proton, the neutron and coherent photoproduction from the $I = 0, J = 1$ deuteron making use of:

$$\sigma_p \sim |A^{IS}_{1/2} + A^{IV}_{1/2}|^2, \quad \sigma_n \sim |A^{IS}_{1/2} - A^{IV}_{1/2}|^2, \quad \sigma_d \sim |A^{IS}_{1/2}|^2$$

(1)

where $A^{IS}_{1/2}$ denotes the isoscalar and $A^{IV}_{1/2}$ the isovector part of the helicity amplitude. It is of course clear that the extraction of the amplitudes from the cross sections requires a careful separation of the contributions from overlapping resonances and background terms like Born terms or vector meson exchange. The situation is simplest close to threshold where only a few partial waves contribute. In this sense $\eta$-photoproduction in the threshold region is a special case, since the reaction is completely dominated by the excitation of the $S_{11}(1535)$ resonance.

2. Experiments

The experiments were done at the Mainz MAMI accelerator with the TAPS-detector [6, 7], experimental details can be found in [1]-[4]. The extraction of the cross section ratio $\sigma_n/\sigma_p$ for the reaction on the neutron and the proton can be done with different experimental concepts, which have all been exploited.

- Measurement of the inclusive $d(\gamma, \eta)X$ reaction and comparison of the sum of Fermi smeared proton cross section and Fermi smeared ansatz for the neutron cross section to the inclusive nuclear cross section in PWIA. Variation of $\sigma_n$ until agreement is achieved.

- Coincident measurement of $\eta$-mesons and recoil nucleons. Extraction of the ratio of $\sigma_n/\sigma_p$ as function of the incident photon energy $E_\gamma$.

- Coincident measurement of $\eta$-mesons and recoil nucleons and reconstruction of the effective $\sqrt{s^*}$ and effective incident photon energy $E^*_\gamma$ from the final state kinematics, extraction of $\sigma_n/\sigma_p$ as function of $E^*_\gamma$:

$$s^* = (E_\eta + E_p)^2 - (\vec{p}_\eta + \vec{p}_R)^2$$

(2)

$$E^*_\gamma = \frac{s^* - m_R^2}{2m_R}.$$  

(3)
3. Results

3.1. Inclusive quasifree $\eta$-production

The total cross sections for the reactions $d(\gamma, \eta)X$ and $^4He(\gamma, \eta)X$ are summarized in fig. 1. The result of the PWIA analysis in the $S_{11}(1535)$ range was a constant ratio $\sigma_n/\sigma_p=2/3$ [1, 4]. Only very close to the thresh-
old the agreement between PWIA and experimental results is not good (see inserts in fig. 1). This is due to final state interaction (FSI) effects which have been understood in the meantime [8]. Note that the influence of the different nuclear momentum distributions is quite severe. The total cross sections from $^4He$ and from the deuteron are almost equal at an incident photon energy of 800 MeV although twice the number of nucleons is involved in the He case. The good agreement of both data sets with impulse approximations using the same neutron proton ratio is therefore quite reassuring for the application of this method.

3.2. Exclusive quasifree $\eta$-production

The data for the neutron - proton cross section ratio obtained with the exclusive measurements for different targets are summarized in fig. 2 and compared to model predictions. The observed rise of the cross section ratio

![Fig. 1. Inclusive $\eta$ photoproduction cross section. Left side: from the deuteron. Circles: ref. 5, triangles: ref. 1. Right side: from $^4He$ 2. For both pictures the dashed lines indicate the coherent, the breakup and the free nucleon production thresholds. The solid curves are the result of the impulse approximation model under the assumption of a constant $\sigma_n/\sigma_p=2/3$ ratio (see text). Inserts: threshold region.](image-url)
to unity at the breakup threshold for incident photon energies, respectively at the free nucleon threshold for equivalent photon energies, is understood and a pure nuclear effect due to rescattering contributions etc. The ratios are almost constant for higher incident photon energies and within their systematical uncertainties consistent with $\sigma_n/\sigma_p=2/3$. A comparison of the energy dependence in the $S_{11}$-range to model predictions clearly disfavors the interpretation of the resonance as a $K\Sigma$ bound state [9].

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\begin{align*}
\sigma_n/\sigma_p &
\end{align*}
\]

Fig. 2. Ratio of exclusive proton and neutron cross sections in the TAPS acceptance. The deuteron data are compared to the $^4$He-data [2] and to model predictions from Sauermann et al. [10] and Kaiser et al. [9]. The curves labeled MAID are the predictions from the MAID model [11] for the full model (MAID1) and restricted to the contributions from the $S_{11}(1535)$-resonance, Born terms and vector meson exchange (MAID2).

3.3. Coherent $\eta$-production

The results from the quasifree $\eta$-photoproduction in combination with coherent production from the deuteron [3] have been interpreted as evidence for a dominant isovector contribution in the photoexcitation of the $S_{11}$-resonance. Since in addition the relevant multipole ($E_{o^+}$) is a spin-flip multipole it is expected that the coherent reaction on $^4$He ($I = 0, J = 0$) is almost completely suppressed, that it is weak on the deuteron ($I = 0, J = 1$) and not suppressed on $^3$He ($I = 1/2, J = 1/2$). In agreement with this expectation, only upper limits could be derived for the coherent reaction on $^3$He [2], while a small contribution was seen for the deuteron [3]. However, in case of the deuteron the results for the quasifree and coherent
reaction are not yet completely understood since the first seem to indicate an isoscalar admixture of \( \approx 9\% \) while the latter require a larger isoscalar contribution of \( \approx 20\% \) \[3\]. The problem could be due to nuclear effects in the coherent reaction which are not yet well enough under control. Additional information will be gained from the coherent reaction on \(^3\)He, where due to the quantum numbers of the nucleus the dominant isovector, spin-flip part of the amplitude contributes. First preliminary results for the the cross section of this reaction indicate indeed a substantial contribution from the coherent part (see fig. 3).

Fig. 3. Preliminary results for the \(^3\)He\((\gamma, \eta)X\) reaction (full symbols) and the \(^3\)He\((\gamma, \eta)^3\)He reaction (open symbols) \[12\].

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