Photoproduction of \(\eta\) Mesons: Recent Results and Planned Experiments

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Abstract

In a series of experiments carried out at the Mainz MAMI accelerator with the TAPS detector we have measured \(\eta\)-photoproduction on nucleons and nuclei which provides a very selective tool for the study of \(N^*\) resonances. The \(p(\gamma,\eta)p\) reaction was used to study the excitation of the \(S_{11}(1535)\), \(P_{11}(1440)\) and \(D_{13}(1520)\) resonances and to fix the \(\eta\)NN-coupling in the nuclear Born terms. Quasifree \(\eta\)-photoproduction on deuterium was explored for a comparison of the \(p(\gamma,\eta)p\) and \(n(\gamma,\eta)n\) cross sections. First results of the recent experiments are presented and planned experiments on coherent \(\eta\)-photoproduction and exclusive quasifree \(\eta\)-photoproduction are discussed.

1. Introduction

Excitation energies and quantum numbers of the prominent low lying resonances of the free nucleon are well known. However, properties like mass, spin and parity alone do not offer stringent tests of hadron models. The situation is much like in nuclear physics where in many cases different models can reproduce approximately the low energy excitation spectrum of a nucleus. Much more crucial tests come from the investigation of transitions between the states which reflect their internal structure and are therefore more sensitive to the model wave functions.

The dominant decay channel of nucleon resonances is the hadronic decay via meson emission to the nucleon ground state. The photoproduction of mesons carries information on both, electromagnetic and strong decay properties of the baryons. The photoproduction of pions e.g. was vastly employed to study the properties of nucleon resonances like the \(\Delta(1232)\) on the free nucleon and in nuclear matter. However, due to their hadronic decay modes all resonances have large width and are thus overlapping already at moderate excitation energies. Furthermore all low lying resonances are decaying into the pion channel, which makes it difficult to study the properties of resonances that are only weakly excited. This difficulty can be partly overcome by looking at decay channels that due to selection rules are specific for certain classes
of resonances. The isoscalar $\eta$-meson is such a selective probe because due to isospin conservation only the $I=1/2$ $N^*$ resonances can decay into the $\eta N$ channel but not the $I=3/2$ $\Delta$-resonances, which are only seen in the $\pi N$ channel. The situation is illustrated in figure 1, where the low energy excitation scheme of isospin $1/2$ and $3/2$ resonances is shown.\(^1\)

![Diagram of resonances](image)

Fig. 1. Decay scheme of low lying nucleon resonances. Shown are isospin $1/2$ and $3/2$ resonances. The arrows indicate decays via pion or $\eta$-meson emission. For the $\eta$-decays the respective branching ratios of the resonances are quoted.

Three resonances may contribute to $\eta$-production on the proton from threshold ($\sqrt{s} \approx 1485$ MeV) to the maximum energy available at the MAMI accelerator (790MeV corresponding to $\sqrt{s} \approx 1537$ MeV). These are the $S_{11}(1535)$, the $D_{13}(1520)$ and the
$P_{11}(1440)$ resonances. The $P_{11}(1440)$ resonance is subthreshold for the production on the proton, however as shown in figure 2 it may contribute due to its large width.

![Graph showing resonances and multipole strengths](image)

Fig. 2. Shown are the position and width of the low lying $N^*$-resonances. The dashed line indicates the production threshold for the $p(\gamma,\eta)p$ reaction and the dashed dotted line the maximum energy available at the MAMI accelerator. The multipoles corresponding to the resonances are indicated on top of the figure.

In an early attempt to analyse $\eta$-photoproduction on the proton Hicks et al.\textsuperscript{2} parametrized the electric and magnetic transition amplitudes in terms of this low lying resonances by energy dependent Breit-Wigner forms. The most prominent result of their isobar analysis (and a reanalysis by Tabakin et al.\textsuperscript{3}), was a strong dominance of the $S_{11}(1535)$-resonance close to threshold. The decay branching ratio of this resonance into $\eta N$ is much larger than for the other resonances. This situation is very different from pion photoproduction in this energy range where all resonances have comparable decay branching ratios. This feature of $\eta$-photoproduction is especially surprising because the second $S_{11}$-resonance decays only very weakly into the $\eta$-channel. The then existing data did not allow to extract much information about the contribution of the other resonances. The most promising way to look for such contributions is to measure precise differential cross sections and to identify the respective multipoles by their angular distribution. This is in principle even possible for the $P_{11}$ (Roper) resonance although the angular distribution of the $M_{1-}$ multipole is isotropic like the
$E_{\eta^+}$ from the $S_{11}$. However, if both multipoles contribute an additional interference term with a $\cos(\Theta)$ dependence will arise.

The photoproduction of $\eta$-mesons does of course not only proceed via nucleon resonances. Contributions from vector meson exchange and nucleon Born terms complicate the picture (see fig. 3).

![Tree level diagrams contributing to $\eta$-photoproduction in the threshold region](image)

In the isobar analysis mentioned above\textsuperscript{2,3} these diagrams were only included in a smoothly varying background fitted to the data. More recently Mukhopadhyay et al.\textsuperscript{4} have explicitly included this terms. They treated the process in an effective Lagrangian approach and expressed the Lagrangians $L_{\gamma NN^*}$, $L_{\eta NN^*}$, $L_{\gamma V\eta}$, $L_{VNN}$, $L_{\eta NN}$, $L_{\eta NN}$ in 8 parameters that have to be fitted to data.

In a different approach Bennhold and Tanabe\textsuperscript{5} have tried to predict the cross section of $\eta$ photoproduction on nucleons and nuclei from a coupled channel analysis of related processes. They used data from the $\pi N \rightarrow \pi N$, $\pi N \rightarrow \pi \pi N$ and $\pi^- p \rightarrow \eta n$ reactions to fix the hadronic vertex and the isobar propagators and pion photoproduction to constrain the electromagnetic vertex. The original analysis included only the production via $N^*$ resonances. More recently\textsuperscript{6,7} the contributions from t-channel vector meson exchange and s,u-channel nucleon Born terms have been included in the way suggested by Mukhopadhyay et al.\textsuperscript{4} However, only very little is known about the $\eta NN$ vertex. In the case of pion production the coupling structure in the Born terms is preferred to be pseudovector, but due to the large mass of the $\eta$ and the SU(3)$\otimes$SU(3) chiral symmetry breaking there are no low energy theorems for $\eta$-photoproduction. Consequently as already pointed out in\textsuperscript{4} there is no reason to prefer pseudovector (PV) over pseudoscalar (PS) coupling. Furthermore values for the coupling constant derived from other reactions are varying over a wide range.\textsuperscript{7} In this sense the coupled channel analysis no longer predicts the $\eta$-photoproduction cross sections, at least the elementary cross section must be fitted to data to fix the $\eta NN$ vertex. However, again the existing data (for a compilation see\textsuperscript{3}) is not precise enough to solve this ambiguity.\textsuperscript{7}

Photoproduction from the proton alone cannot completely determine the elementary production operators, e.g. no information about the isospin composition is obtained.
In principle such information may be obtained by studying photoproduction on the
neutron and/or using coherent $\eta$-photoproduction on light nuclei as spin - isospin filter. However, even for the excitation of the dominant $S_{11}$-resonance, the few available experimental results are strongly at variance with theoretical predictions. Coupled channel analysis of related reactions in accordance with quark models predict a predominantly isovector excitation of the $S_{11}$-resonance with $E_{0^+}^{(0)} / E_{0^+}^{(1)} = 0.29.6$ This means that the cross section for the $n(\gamma, \eta)n$ reaction should be roughly one third of the $p(\gamma, \eta)p$ reaction and the cross section for coherent $\eta$-production on deuterium should be very small because only isoscalar components may contribute.

On the other hand Bacci et al.\textsuperscript{9} report a cross section for $\gamma+d \rightarrow \eta+(p,n)$ that is approximately twice as large as for $p(\gamma, \eta)p$ and conclude that the cross sections for $\eta$-photoproduction on free protons and free neutrons are essentially equal. The only experimental result\textsuperscript{10} for $d(\gamma, \eta)d$ adds to this puzzle. The measured cross section is approximately one order of magnitude larger than predicted. The authors conclude that after taking into account form factors etc. the cross sections on the proton and deuteron are equal as well. Halderson and Rosenthal\textsuperscript{8} have tried to solve this problem by taking into account rescattering effects, which were responsible for a similar situation in pion photoproduction. However, this contributions turned out to be too small to account for the observed cross section. The experimental results taken together mean, that the isovector component must almost vanish.

Apart from studying the elementary production process on the nucleon $\eta$-photoproduction may be also applied to investigate $N^*$ resonances in nuclear matter. Quasifree $\eta$-production from complex nuclei allows to elucite such questions as the mean free path of the $\eta$ in nuclear matter and medium modifications of the $N^*$-resonances. This part of the $\eta$-photoproduction experiments at MAMI is covered by the contribution of M. Röbig-Landau to this workshop.

Giving the many interesting physical questions involved, it is not astonishing that during the last few years considerable efforts have been put into the development of theoretical models. However, in general the situation is such, that attempts of getting a better understanding of $\eta$-photoproduction in the threshold region were severely hampered by the lack of precise experimental data. With the advent of high duty electron accelerators like MAMI in Mainz, providing tagged photons beams of excellent quality, and the development of powerful detector systems, the opportunity for a new generation of very precise experiments has emerged. It is therefore expected that due to the experiments carried out, under way or planned at the Mainz and Bonn\textsuperscript{11} accelerators this situation will improve significantly during the next few months.
2. Experiments and Analysis

The $\gamma$-photoproduction experiments discussed in this contribution have been carried out at the Mainz Microtron (MAMI).\textsuperscript{12} The 855 MeV cw electron beam was used to produce quasimonochromatic photons by means of bremsstrahlung tagging. Typical beam intensities of $5 \times 10^5$ photons/MeV$\times$s and an energy resolution of 1-2 MeV were achieved with the tagging spectrometer\textsuperscript{13} for photon energies up to 790 MeV. The collimated beam was impinging on the production targets located approximately 12 m downstream of the radiator. Data was taken from liquid hydrogen, liquid deuterium and some nuclear targets. The neutral mesons were detected via their $\gamma$-decay channels with the TAPS detector system.\textsuperscript{14} Five TAPS blocks were arranged in one plane around the target in order to cover the full range of the $\eta$ polar angle in one setup (see contribution of M. Röbig-Landau).

![Diagram](image)

Fig. 4. On the left hand side scatter plots of the fast light component versus the total light output for neutral and charged particles are shown. The BaF$_2$-module was placed at forward angles. On the right hand side the TOF difference between coincident hits in TAPS and the absolute TOF measured versus the tagging spectrometer are shown. Both with and without PSA cut.
In a separate experiment one block of the TAPS detector was moved into the direct photon beam in order to study the response of the spectrometer to monochromatic photons. Details of the energy calibration and the energy resolution of TAPS can be found in the contribution of A. Gabler to this workshop and in ref.15.

The discrimination of photons and particles was done in the usual way with the aid of the veto detectors, pulse shape analysis (PSA) and time-of-flight analysis (TOF). The obtained results are displayed in figure 4. Shown is the pulse shape analysis for a detector at very forward angles. For neutral events, i.e. events with no signal from the corresponding veto detector, clearly too bands appear that may be attributed to photons and neutrons. The latter ones produce a signal similar to protons due to the production of recoil protons. If a veto signal is required a third band from charged pions shows up. Entries in the 'photon band' for charged events originate mainly from high energy conversion electrons created in the target and target chamber.

The importance of the PSA-cut is demonstrated by the TOF spectra in figure 4. Plotted is the $\gamma\gamma$-coincidence timing in TAPS and the $e\gamma$-coincidence timing between TAPS and the tagging spectrometer. The background due to particles is completely removed by the PSA cut. Consequently after applying PSA and TOF cuts only true coincidences between decay photons from neutral mesons survive. The accidental background in the time-of-flight measured versus the tagger is mainly due to pions from the delta resonance region, which were not tagged.

![Graph](image_url)

**Fig. 5.** Intensity of detected $2\gamma$-events versus the incident photon energy measured with a liquid hydrogen target.

The resulting data is so clean, that an excitation function of events with at least
two coincident photons clearly shows the $\eta$-signal as displayed in figure 5. This spectrum includes events from the three dominant decay channels of the eta namely $\eta \rightarrow 3\pi^0$, $\eta \rightarrow 2\gamma$ and $\eta \rightarrow \pi^+\pi^-\pi^-$. A rough estimate from branching ratios and detection efficiencies shows, that the three channels contribute with relative intensities of 0.7:0.28:0.02. For our purpose the most important channel is the 2$\gamma$-decay which allows to measure differential cross sections. However, one can use the 3$\pi^0$-decay for an independent measurement of the total cross section. This is extremely useful for the tracking of systematic errors because cut efficiencies for the identification of photons will enter in a different way and the detection efficiency, which must be obtained from Monte Carlo simulations, is very different from the 2$\gamma$-decay.

Events from the $\eta \rightarrow 3\pi^0$ channel can be discriminated by multiplicity cuts as demonstrated in figure 6 where the excitation functions of events with $\gamma$-multiplicity 3, 4 and 5 are shown. No background was subtracted, not even background from random coincidences between TAPS and the tagger. In the 5$\gamma$ channel the intensity is too low, whereas significant background is present in the 3$\gamma$-channel.

Fig. 6. Identification of $\eta$-mesons in the $\eta \rightarrow 3\pi^0$ channel by multiplicity and missing mass cuts (see text for explanation)
Most useful for a determination of the total cross section from the $3\pi^-$-decay of the $\eta$-meson is the $4\gamma$-channel. In this channel only one source of physical background is left over, namely the $p(\gamma,2\pi^0)p$-reaction. Events from this reaction are complete in the sense that energies and momenta from all particles in the final state, with the exception of the recoil proton are measured. The mass of the recoil particle can be extracted from the energies and momenta of the four photons and the $p(\gamma,2\pi^0)p$-reaction is identified by comparing the measured recoil mass to the proton mass as shown in figure 6, where these events show up at a missing mass of zero. The broad peak at positive missing mass stems from the $\eta$-decays. This can be nicely demonstrated by restricting the energy range to tagger channels below the $\eta$-threshold where this structure disappears (not shown). By applying a cut on the missing mass most of the background is suppressed and only random background is left over. Of course, this method can be turned around and used to uniquely identify $2\pi^0$ production which is in itself very interesting.

Identification of the $2\gamma$-decays of the $\eta$-meson proceeds via standard invariant mass analysis using $m_{\eta\eta}=(2E_{\gamma_1}E_{\gamma_2}(1-\cos\theta_{\gamma_1\gamma_2}))^{1/2}$. The result of this analysis for the measurement with the proton target is shown in figure 7. The upper part displays the complete spectrum which shows a very prominent peak from $\pi^0$ production and the $\eta$-peak at higher energies. Random background was subtracted. The region covering the $\eta$-peak is shown in more detail in the lower part of the figure. It is very important for the main purpose of the experiment to understand this spectrum in detail. First one must be sure that all background can be removed by applying cuts on invariant mass (and missing energy, see below), because any background component could completely obscure the small effects of anisotropy in the differential cross section which are awaited from the contribution of the $P_{11}$ or $D_{13}$ resonances. On the other hand one must understand very well the shape of the invariant mass peak in order to find the correct normalisation of the total cross section which depends on the intensity of the peak below the indicated threshold. Some physical question like e.g. the distinction between pseudoscalar and pseudovector coupling in the nucleon Born terms depend sensitively on the absolute value of the total cross section (see contribution of L.Tiator to this workshop). A first indication of the background level can be obtained by looking at the invariant mass spectrum just below the $\eta$-production threshold. As can be seen from figure 7, this background is almost negligible for invariant masses above 485 MeV. In the next step a full GEANT\textsuperscript{15} simulation including tracking through target, target chamber, veto detectors and BaF\textsubscript{2}-modules was performed. The result agrees perfectly with the measured spectrum. This agreement again signals that no significant background components are present. The intensity of the simulated peak at energies below the applied cut amounts to 15\% of the total intensity. The excellent agreement of the line shapes allows to establish this fraction with an uncertainty of less than 10\%. Consequently the systematic error of the normalisation caused by the invariant mass cut is on the order of 1\%. 
The measurement on the proton is kinematically overdetermined because the momenta of the incident proton and photon and the momenta of the decay photons are known. This feature was exploited for a missing energy analysis of the detected mesons which offers an independent method of background control and elimination. For this purpose the cm energy of the mesons derived from the incident photon energy was compared to the energy computed from the measured decay photons. The result for five tagger channels close to the \( \eta \)-production threshold is shown in figure 8. These spectra again underline the very low background level of the experiments. The count rate for the two tagger channels below threshold is statistically consistent with zero over the full displayed range. The same holds for the spectra from tagger channels just above threshold in the range excluding the \( \eta \)-peak. This result is important because it implies that background from the \( \eta \rightarrow 3\pi^o \) decay does not extent under the \( \eta \) invariant mass peak.

3. Results

The absolute normalisation of the cross sections is obtained from the target thickness (0.39 g/cm\(^2\) for the liquid hydrogen target), the intensity of the photon beam and the detection efficiency of the detector setup. The photon intensity produced in the radiator was measured by counting the deflected electrons in the tagging spectrometer. The beam intensity at the target site is the product of the measured electron intensity and the tagging efficiency \( \epsilon \) which was controlled a few times per day by moving a lead glass detector into the direct photon beam at a reduced beam intensity. Typical values of \( \epsilon = 0.5 \) were obtained with variations of a few per cent over a period of two weeks. The energy and angle dependent detection efficiency of the TAPS detector was modelled with Monte-Carlo simulations. So far complete simulations with the GEANT3 code\(^\text{16}\) were only carried out for the 2\(\gamma\)-decay channel of the \( \eta \)-meson. Typical values of the efficiency are 10 % close to threshold and 5 % at 790 MeV.

The absolute normalisation of the cross sections is not yet final because systematic effects of some analysis cuts (probably in the 10% range) still have to be included. Therefore preliminary results for the total cross sections from the \( \eta \rightarrow 2\gamma \) channel are shown in figure 9 in arbitrary units. Background from random coincidences between TAPS and the tagger (< 10%) and a very small background component (< 1%) from the target windows, which was measured with an empty target, are subtracted. No indication of additional background sources was found.

The sharp s-wave like rise of the p(\( \gamma, \eta \))p cross section at threshold, which is characteristic for the dominant E_{0+} multipole, is clearly visible. The position of the threshold can be determined very precisely. Hence an independent value for the mass of the \( \eta \)-meson may be extracted. The most precise determination of the \( \eta \)-mass (\( m_\eta = 547.3 \pm 0.15 \text{ MeV} \)) was only recently obtained by spectroscopy of the dp\( \rightarrow \)\(^3\)He\( \eta \) reaction.\(^\text{17}\) This result deviated significantly from the value quoted by the Particle
Data Group\textsuperscript{1} which was subsequently revised. The $\eta$-mass can be extracted from the data displayed in figure 9 with a statistical error of less than 100 keV. Therefore the total error is dominated by the energy calibration of the tagger, which is not yet completed. A final precision of the mass better than 250 keV is expected.

The total cross section for quasifree $\eta$-production on the deuteron is also shown in figure 9. The absolute normalisation, though arbitrary, should be more or less the same for both reactions. The shape of this cross section is strongly influenced by effects of nuclear Fermi motion. The tail of the cross section extends far beyond the free production threshold all the way down to the coherent threshold at 628 MeV. In a first attempt to compare the two cross sections in order to get information about the $n(\gamma, \eta)n$ reaction we have tried to incorporate these effects in a very simple fashion. The measured $p(\gamma, \eta)p$ cross section was used to calculate the cross section for quasifree photoproduction on the deuteron in impulse approximation under the assumptions $\sigma_n=\sigma_p$ and $\sigma_n=1/3\sigma_p$. The momentum distribution of the bound nucleons was taken from the deuteron wave function.\textsuperscript{18} The results are shown by the lines in figure 9. It is evident, that the data is not very well reproduced by this simplistic model, more elaborate calculations are certainly necessary. However, the data seems to favour a neutron cross section not much lower than the proton cross section.

Preliminary results for differential cross section in arbitrary units are shown in figure 10 in order to demonstrate the quality of the data. The angular resolution of the TAPS detector is not yet completely defolded, which may still cause systematic effects especially close to threshold.

Under the assumption of the strong dominance of the $S_{11}$ resonance, in a first approximation only the $E_{o+}$-multipole and its interference terms with other multipoles must be included. In this limit the differential cross section may be written as:\textsuperscript{7}

$$\frac{k}{q} \frac{d\sigma}{d\Omega} = E_{o+}^2 - Re(E_{o+}^* (E_{2-} - 3M_{2-})) - 2 Re(E_{o+}^* (3E_{1+} + M_{1+} - M_{1-})) cos(\Theta_\eta^*) +$$

$$+ 3 Re(E_{o+}^* (E_{2-} - 3M_{2-})) cos^2(\Theta_\eta^*)$$

where $k, q$ are the cm momenta of the photon and the $\eta$-meson. Consequently, by fitting the cross section in the usual way by:

$$\frac{k}{q} \frac{d\sigma}{d\Omega} = A + B \cdot cos(\Theta_\eta^*) + C \cdot cos^2(\Theta_\eta^*)$$

the strength of the $E_{o+}$-multipole may be directly obtained by $E_{o+}^2 = A + B/3$. Contributions from the $P_{11}$ and $D_{13}$ resonances should show up in the $B$ and $C$
coefficients. In case of the $P_{11}$ resonance the situation is rather complicated because Born terms and vector mesons contribute significantly to the $\cos(\Theta_{\eta}^*)$-term.\textsuperscript{7} The situation is much clearer for the $D_{13}$ resonance which is expected to give the dominant contribution to the $\cos^2(\Theta_{\eta}^*)$-term via the $E_2$- and $M_2$- multipoles. Numerical values of the coefficients cannot yet be given pending the final analysis of detection efficiency and angular resolution. It is evident however, that nonisotropic components from resonances other than the $S_{11}$ or from nucleon Born terms and vector mesons are present. Such contributions have been detected for the first time.

4. Summary and Future Experiments

The $\eta$-photoproduction experiments carried out during the first two years of the TAPS detector at the Mainz accelerator will provide very precise total and differential cross sections for the $p(\gamma,\eta)p$ and $d(\gamma,\eta)X$ reactions. In case of the proton, the quality of the data allows for the first time to identify contributions beyond the strongly dominating $E_{\eta^+}$ multipole.

As already mentioned, photoproduction on the proton alone cannot completely determine the structure of the production operator. Additional information about the isospin structure may be obtained from the $n(\gamma,\eta)n$ cross section which is in principle accessible by comparison of the proton and deuteron cross sections. However, this comparison is largely complicated by the effects of Fermi smearing on the quasifree cross section. A very good understanding of the details of the quasifree production process is necessary in order to deduce quantitative results for the $n(\gamma,\eta)n$. Furthermore this comparison might be obscured by final state interaction effects like e.g. pion rescattering, which may enhance the quasifree cross section on deuteron.

Therefore a much cleaner approach is to measure quasifree production on light nuclei with identification of the recoil proton or neutron. Comparison of this exclusive quasifree cross sections will directly probe the isospin structure, eliminating most effects of Fermi motion and final state interactions. Ideally this experiment should be carried out for different light nuclei. It is therefore planned to equip the TAPS spectrometer with a forward detector system that is capable to identify recoil protons, neutrons and deuterium (see below), and to measure exclusive quasifree $\eta$-photoproduction on $^4\text{He}$ and possibly deuterium.

Another approach to study $\eta$-photoproduction in more detail lies in the investigation of coherent $\eta$-production on light nuclei. The nuclei may be used as spin-isospin filters depending on their ground state properties. Two obvious candidates are the $d(\gamma,\eta)d$ and the $^3\text{He}(\gamma,\eta)^4\text{He}$ reactions. In case of the deuteron the ground state is characterized by $I=0$, $J=1$. Consequently only isoscalar components contribute. The restriction of possible amplitudes is even much more severe for $^4\text{He}$ with an $I=0$, $J=0$ groundstate. Again only isoscalar components may contribute. In addition, the
excitation of the $S_{11}$ resonance is completely suppressed because the $E_{\gamma}^+$ multipole is a spin-flip amplitude that may not contribute in a $J=0 \rightarrow J=0$ transition. This makes the $^4\text{He}(\gamma,\eta)^4\text{He}$ reaction an ideal complement to the photoproduction on proton, neutron and deuteron, that are all dominated by the $S_{11}$ resonance. Only small magnetic non-spin flip multipoles ($M_{1-},M_{2-}$), which arise from the Born terms and the $P_{11}$ and $D_{13}$ resonances are present. Furthermore, due to the lowering of the threshold ($706$ MeV on the proton, $628$ MeV on the deuteron and $587$ MeV on $^4\text{He}$) the $P_{11}$ resonance is no longer subthreshold.

The coherent reactions are very hard to come by experimentally. First of all the cross sections are expected to be very small due to nuclear form factors. Coupled channel predictions for the $d(\gamma,\eta)d$ cross section are almost two orders of magnitude lower than the $p(\gamma,\eta)p$ cross section. On the other hand, the only experimental result on coherent $\eta$-photoproduction is almost an order of magnitude larger than the coupled channel predictions. The situation is even more severe for the $^4\text{He}(\gamma,\eta)^4\text{He}$ reaction, where the suppression of the dominant reaction channel further reduces the expected cross section. The main experimental problem lies in the identification of the coherent process in the presence of a much more intense background from quasifree production processes, which as demonstrated by the deuterium data, extends down to the coherent threshold due to Fermi motion effects. However, also in this respect deuterium and $^4\text{He}$ are ideal cases. Close to threshold deuterium nuclei gain enough momentum to recoil out of the target. Hence they can be identified in a forward detector. Helium recoil nuclei cannot be identified because they are stopped in a liquid Helium target. Fortunately, the separation energy of protons and neutrons from $^4\text{He}$ is $\approx 20$ MeV. This means that quasifree production is kinematically completely forbidden for the first $20$ MeV above the coherent threshold. At higher energies, quasifree events are shifted in the missing energy spectra by at least $20$ MeV with respect to coherent events. This shift can be resolved with the TAPS spectrometer.

An experiment proposal to measure exclusive quasifree $\eta$-photoproduction and coherent $\eta$-photoproduction on $^4\text{He}$ with the TAPS spectrometer is approved for the Mainz accelerator and will be carried out during the next stay of TAPS at Mainz.
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Fig. 7. Invariant mass spectrum measured with the hydrogen target. In the lower expanded part the full line shows the measured spectrum above \( \eta \)-production threshold, the dotted line the measured spectrum below \( \eta \)-production threshold and the dashed line a GEANT simulation of the line shape.
incident photon: \[ E'_{\eta} = \sqrt{\frac{s + m_{\eta}^2 - m_p^2}{s}} \]
decay photons: \[ E'_{\eta} = \gamma(E_{\gamma 1} + E_{\gamma 2} \gamma \beta (E_{\gamma 1} \cos(\Theta_1) + E_{\gamma 1} \cos(\Theta_2))) \]

Fig. 8. Missing energy spectra measured with the hydrogen target. Shown are spectra for the two tagger channels just below the \( \eta \)-production threshold, the channel at threshold and the two channels above threshold. Random background was subtracted, all spectra are in the same arbitrary units.
Fig. 9. Preliminary results for the total cross section of $\eta$-photoproduction on the proton and deuteron in arbitrary units. The dashed curve is an extrapolation of the deuteron cross section from the measured proton cross section under the assumption of $\sigma_n = \sigma_p$. It was obtained in the most simple approximation by Fermi smearing of the proton cross section. The dashed dotted curve gives the result of the same calculation for $\sigma_n = 1/3\sigma_p$. 
Fig. 10. Preliminary results for the differential cross section from the reaction $p(\gamma, \eta)p$. The angular distributions are given in the same arbitrary units. Note that finite resolution effects have not yet been fully accounted for. The full lines are fits to the data including $s, p$- and $d$-wave components.