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Mainz Microtron MAMI

Collaboration A2: "Real Photon Experiments"
Spokesperson: R. Beck

Proposal for an Experiment

Coherent Photoproduction of η-mesons from light nuclei - search for η-mesic nuclei

Collaborators :

CrystalBall@MAMI collaboration

Spokespersons for the Experiment : B. Krusche - Basel, M. Pfeiffer - Giessen

Abstract of Physics :

We propose to measure $\eta-$ and π^0-photoproduction from ^{3}He around the threshold for coherent η-production ($E_\gamma \sim 600$ MeV). The experiment is mainly motivated by search for light η-nucleus (quasi)bound states (η-mesic nuclei). In a previous experiment we have for the first time identified coherent η-photoproduction off ^{3}He. The energy dependence of cm back-to-back emission of $\pi^0 p$ pairs show a peak-like structure at threshold which could be indicative for the formation of a bound state. The present experiment aims at a large improvement of the statistical quality of the data. We further propose a similar experiment for ^{7}Li, which is the most promising candidate at somewhat larger mass.

Abstract of Equipment :

Unpolarized photon beam incident on a liquid ^{3}He target, respectively solid ^{7}Li target. High resolution of incident photon beam around the η-production threshold requires the use of the existing tagger microscope detector (only for ^{3}He). Crystal Ball in combination with the TAPS detector as forward wall.

MAMI–Specifications :

beam energy	880 MeV
beam current	< 100 nA
time structure	cw
polarization	unpolarized

Experiment–Specifications :

experimental hall/beam	A2
detector	Crystal Ball and TAPS as forward wall
target material	liquid ^{3}He, solid ^{7}Li
photon tagger	microscope in focal plane at $E_\gamma \sim 600$MeV

Beam Time Request :

set–up without beam	Installation of liquid ^{3}He target and tagger microscope ($\simeq$ 3weeks)
set–up/tests with beam	24 hours
data taking	300 hours (^{3}He) 200 hours (^{7}Li)

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1 Introduction and motivation

1.1 η-mesic nuclei

The study of the interaction of mesons with nucleons and nuclei has largely contributed to our understanding of the strong force. In the case of long-lived mesons like charged pions or kaons, secondary beams can be prepared which allow the detailed investigation of such interactions. Much less is known in the case of short-lived mesons like the η. Their interaction with nuclei is only accessible in indirect ways for example when the mesons are first produced in the nucleus from the interaction of some incident beam and then subsequently undergo final state interaction (FSI) in the same nucleus. The interaction of η-mesons with nuclei is of particular interest because the existence of bound η-nucleus systems has been discussed. It is well known, that the strong force does not generate bound pion-nucleus states since the pion-nucleon interaction is comparatively weak for small pion momenta. However, the situation is different for the η. The η-N interaction at small momenta is strongly influenced by the existence of an s-wave nucleon resonance ($S_{11}(1535)$), which lies close to the η production threshold and couples strongly to the Nη-channel [1].

In 1985 Bhalerao and Liu [2] performed coupled channel calculations for the $\pi N \rightarrow \pi N$, $\pi N \rightarrow \eta N$, and $\eta N \rightarrow \eta N$ reactions and found an attractive s-wave ηN-interaction. Shortly later, Liu and Haider [3] pointed out, that for nuclei with A $>$ 10 this interaction may lead to the formation of strongly bound η-nucleus systems which they termed η-*mesic* nuclei. Such a system would open interesting prospects in nuclear and particle physics and in particular offer an ideal laboratory for the study of the η-nucleon interaction.

Experimental evidence for 'heavy' η-mesic nuclei was e.g. searched for in $A(\pi^+,p)\eta(A-1)$ reactions [4], where it should manifest itself by a kinematical peak from the two-body $A(\pi^+,p)(A-1)_\eta$ [1] process and in double pionic charge exchange reactions [5]. However up to now no conclusive evidence for the existence of η-mesic nuclei was reported from such experiments.

A.I.Lebedev and V.A.Tryasuchev [6] have pointed out that photon induced reactions are advantageous for the search of η-mesic nuclei because they avoid initial state interaction effects. In contrast to hadronic induced reactions the photon can produce an η-meson with *any* of the nucleons. A proposal to search 'heavy' η-mesic nuclei from the reaction chain:

$$\gamma + A \rightarrow N_1 + (A-1)_\eta \rightarrow N_1 + (N_2 + \pi) + (A-2) \tag{1}$$

where the η-meson is produced on the nucleon N_1, captured in the rest nucleus $(A-1)$ which subsequently decays by emission of a nucleon-pion pair was put forward at the Lebedev Physics Institute in Moscow [7]. Recently, Sokol et al. [8] claimed evidence for the formation of η-mesic nuclei with mass number $A = 11$ (carbon, beryllium) in the $\gamma+^{12}$C reaction with the decay chain from eq. (1).

During the last few years, the data basis for the analysis of the ηN-interaction was supplemented by new precise data in particular for η-photoproduction from the proton and the deuteron [1, 9, 10, 11, 12, 13]. This has prompted several groups to carry out new analyses of the ηN-interaction. Most of them find a real part of the ηN-scattering length a, which is considerably larger than the original value from the work of Bhalerao and Liu [2] (a=0.27+i0.22). The more recent results for the real part of the scattering length span the entire range from 0.2 - 1. and most cluster between 0.5 - 0.8 (see e.g. [14] and ref. therein). The strength of the η-nucleus interaction, in particular the scattering length in this system and the position of possible quasi-bound states is very sensitive to the value of the η-nucleon scattering length [15]. The recent larger values of the ηN scattering length therefore have prompted speculations about the existence of much lighter η-mesic nuclei than originally considered by Liu and Haider [3].

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[1] We label η-mesic nuclei by the symbol A_η

Several authors theoretically studied the η-nucleus interaction for light nuclei, in particular ^{2}H, ^{3}H, ^{3}He, and ^{4}He (see e.g. [16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 14]). The existence of light η-mesic nuclei is controversely discussed in this literature, there is still controversy regarding the necessary strength of the ηN interaction. Ueda [16] predicted the existence of a quasibound ηNN state with I=0, $J^p=1^-$. He proposed [17] to search for evidence of this state in the $\gamma d \rightarrow np$ and $\gamma d \rightarrow \eta d$ reactions. In the first reaction one expects a peak in the total cross section just below η-production threshold, in the second a peak just above the threshold for coherent η-photoproduction. A quasibound η-^{4}He state was predicted by Scoccola and Riska [24] in the framework of a Skyrme model. Rakityanski and collaborators [19, 20, 26] calculated elastic η-nucleus scattering and found that within the uncertainty of the elementary ηN interaction ^{2}H, ^{3}H, ^{3}He and ^{4}He can all form quasibound η-nucleus states. In particular for the deuteron they predict [26] the existence of a quasibound state for real parts of the η-nucleon scattering length $\mathrm{Re}(a_{\eta N})$ larger than 0.7 - 0.8 fm. A very similar result was found in a calculation of the η-d scattering length by Green *et al.* [21]. On the other hand, very recently Grishina *et al.* [27] estimated $\mathrm{Re}(a_{\eta N}) \leq 0.3$ fm from an analysis of the threshold behavior of the $pn \rightarrow d\eta$ reaction and Garcilazo and Pena [28] found no binding of the ηNN system even for very large values of $a_{\eta N}$.

Light quasibound η-nucleus states have been sought in experiments investigating the threshold behavior of hadron induced η-production reactions. The idea is that quasibound states in the vicinity of the production threshold will give rise to an enhancement of the cross section relative to the expectation for phase space behavior. Such deviations can of course also arise from final state interaction effects (FSI) which do not necessarily involve the η-meson, as in np-FSI in case of η-production from the deuteron. During the last few years η-production near threshold was intensively investigated in the reactions: $pp \rightarrow pp\eta$ [29], $np \rightarrow d\eta$ [30, 31], $pd \rightarrow \eta^3$He [32], $\vec{d}d \rightarrow \eta^4$He [22], and $pd \rightarrow pd\eta$ [33]. All reactions show more or less pronounced threshold enhancements. Wilkin and collaborators (see e.g. [18, 22]) have argued that the results are best explained by quasibound states in the He-nuclei with a width that overlaps the production thresholds. However, so far there is no conclusive evidence that the final state interaction is strong enough to form quasibound states. If such states do exist, they should show up as threshold enhancements independently of the initial state of the reaction. Photoproduction of η-mesons from light nuclei is a very clean tool for the preparation of the η - nucleus final state with small relative momenta, but due to the much smaller electromagnetic cross sections sensitive threshold measurements are scarce until now.

2 Status of threshold η-photoproduction from the nucleon and light nuclei

During the last few years a strong effort both on the experimental and the theory side has advanced our understanding of η-photoproduction in the threshold region. Close to threshold the total $p(\gamma,\eta)p$ cross section shows an $(E_\gamma - E_{thr})^{1/2}$ behavior and the angular distributions are almost constant [1] which both is typical for s-wave production. In this way, the strong dominance of the $S_{11}(1535)$ resonance was finally established and resonance parameters like excitation energy, width and electromagnetic helicity amplitude were determined [1, 34].

Photoproduction from the proton alone is not enough to disclose the isospin structure of the S_{11}-excitation. A complete determination of the relevant amplitudes requires in addition the measurement of η-photoproduction from the neutron and coherent η-photoproduction from the deuteron making use of:

$$\sigma_p \propto |A^{IS} + A^{IV}|^2 \qquad \sigma_n \propto |A^{IS} - A^{IV}|^2 \qquad \sigma_d \propto |A^{IS}|^2 ,$$

where A^{IS} and A^{IV} are the isoscalar and isovector amplitudes of the electromagnetic excitation of the resonance. The combined result from the recent measurements of inclusive and exclusive quasifree η photoproduction from the deuteron and ^{4}He [9, 10, 35, 13] and coherent η photoproduction from the deuteron [10, 11] indicates the dominance of the isovector amplitude over the isoscalar amplitude by one order of magnitude [13]:

- $\langle\sigma_n/\sigma_p\rangle = (0.67 \pm 0.03)$
- $|A^n_{1/2}|/|A^p_{1/2}| = (0.819 \pm 0.018)$
- $A^{IV}_{1/2}/A^{IS}_{1/2} = (10.0 \pm 0.7)$
- $A^{IS}_{1/2}/A^p_{1/2} = (0.09 \pm 0.01)$

From the fact that the dominant S_{11}-excitation proceeds via a spin-flip amplitude with the above isospin structure and the quantum numbers of the nuclei we expect qualitatively for coherent η-photoproduction from light nuclei:

- ^{4}He: J=0, I=0, only non-spin-flip, isoscalar amplitude: very weak signal
- ^{2}H: J=1, I=0, isoscalar, spin-flip amplitude may contribute: small signal
- ^{3}He J=1/2, I=1/2, isovector, spin-flip amplitude may contribute: large signal

In case of ^{4}He this expectation was verified in so far, as in a dedicated experiment [35] no contributions from coherent production were identified and only an upper limit could be derived. The case of ^{3}He is thus of particular interest since here a substantial contribution from coherent η photoproduction is expected, which makes this nucleus the most promising candidate for the search of light η-mesic nuclei as far as the entrance channel is concerned.

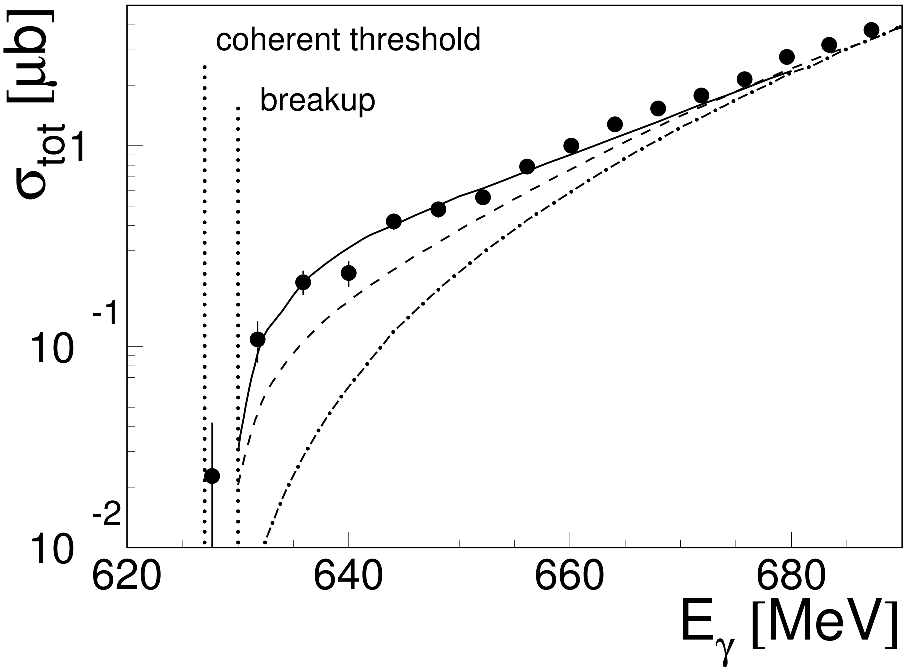

Figure 1: Threshold behavior of $d(\gamma,\eta)X$. Data from [13]. Model from Sibirtsev et al. [14]. Dotted: PWIA, dashed: PWIA and NN FSI, full: PWIA and NN FSI and $N\eta$ FSI.

Threshold enhancements for incoherent η photoproduction (resulting in the breakup of the target nuclei) have been reported both for the deuteron and ^{4}He [9, 35, 13, 12]. The interpretation of this effects is not simple since nucleon-nucleon FSI, η-nucleon FSI and interferences between them are involved. For ^{4}He the situation is further complicated since calculations must account for the various reaction channels involving pt, n^3He, dd, pnd, and $2p2n$ final states for the nucleons. Therefore calculations are so far only available for the deuteron. A typical result is shown in fig. 1 where the data are compared to model calculations from Sibirtsev et al. [14]. The data are in good agreement with PWIA calculations for high incident photon energies (more than roughly 50 MeV above the threshold). However, they are strongly underestimated close to threshold (dash-dotted curve). Nucleon-nucleon FSI (dashed curve) brings the calculation closer to the data but in addition nucleon-η FSI and the interference between both is needed to reproduce the threshold enhancement (solid curve). Calculations from other groups e.g. Fix and Arenhoevel [36]) give qualitatively the same result. Although FSI effects are thus substantial, there are no indications for (quasi)bound states for the deuteron.

2.1 Previous results for ^{3}He

Photoproduction of η-mesons from ^{3}He has been previously measured with the TAPS detector at the MAMI accelerator in 2000 [37]. The detector consists of hexagonally shaped BaF$_2$ crystals of 25 cm length with an inner diameter of 5.9 cm. It was set up for this experiment as shown in fig. 2. 6 blocks with 64 modules and a forward wall with 138 BaF$_2$ modules were used. The blocks were placed 55 cm away from the targets at polar angles of $\pm 54^o$, $\pm 103^o$, and $\pm 153^o$, the forward wall was placed 60 cm away from the target center. This setup covered roughly 37 % of the full solid angle. The analysis of η photoproduction was done in the same

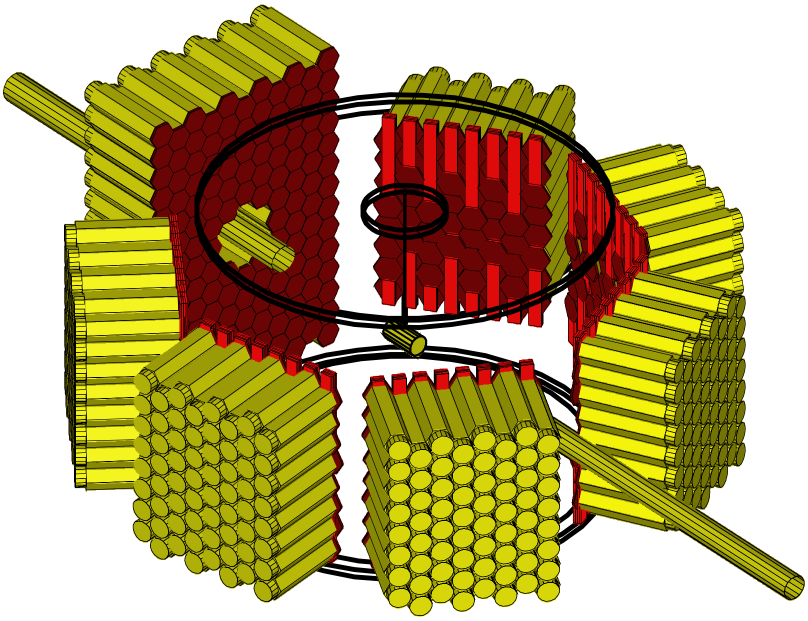

Figure 2: Setup of the TAPS-detector at the Mainz MAMI accelerator for the previous experiment. The beam entered the target chamber from the lower right edge.

way as in the previous experiments with TAPS at MAMI [1, 9, 35, 11, 12, 13] and is described in detail in [37]. Identification of photons and recoil nucleons was done with the aid of the charged particle veto detectors (individual plastic scintillators for each BaF$_2$ module), pulse shape analysis for the BaF$_2$ modules and a time-of-flight versus energy analysis. The η-mesons were identified with a standard invariant mass analysis. Absolute cross sections were obtained in the usual way from the measured photon flux, the target thickness and the detection efficiency of the detector which was determined with Monte Carlo simulations using the GEANT3 code. An important step of the analysis is the identification of coherent η photoproduction. Since the ^{3}He recoil nuclei do not reach the detectors, the identification must rely on the different reaction kinematics for coherent (final state η+^{3}He) and breakup (final states $\eta+pd$ or $\eta+ppn$) photoproduction. For this purpose missing energy spectra for the η mesons were constructed under the assumption of coherent kinematics. Missing energy spectra can be constructed from a comparison of the kinetic center-of-momentum (cm) energy $E^{\star}_{\eta}(E_b)$ of the η mesons derived from the incident photon energy E_b to the kinetic cm energy $E^{\star}_{\eta}(\gamma_1\gamma_2)$ reconstructed from the momenta of the η decay photons:

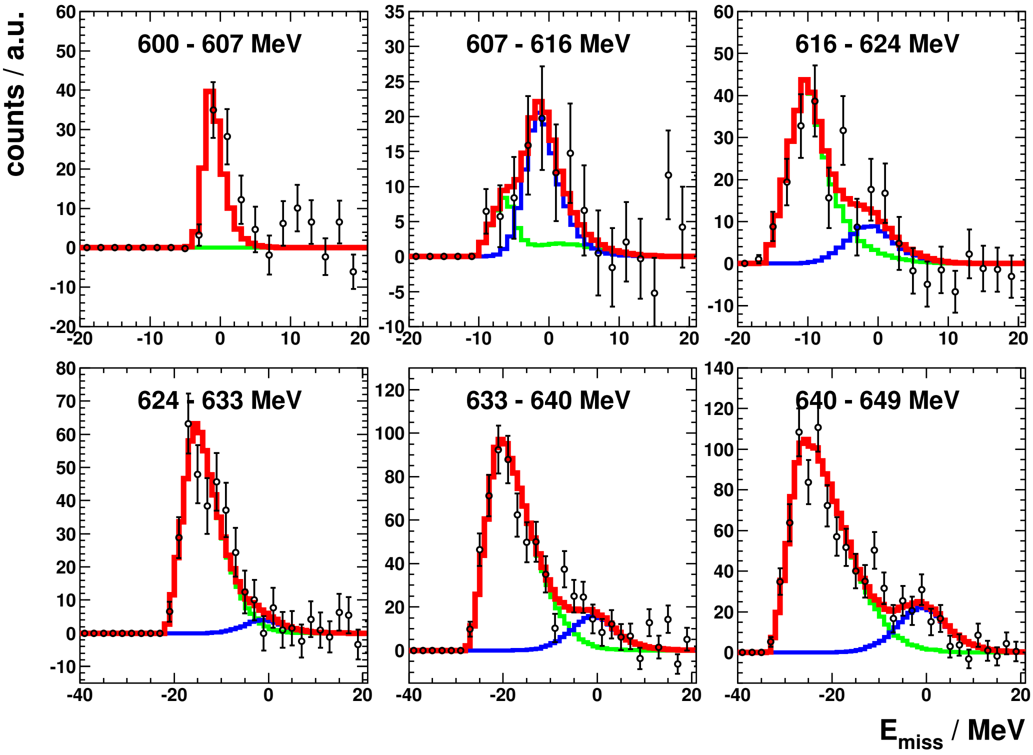

Figure 3: Missing energy spectra assuming coherent reaction kinematics for different ranges of incident photon energy. The simulated shapes for the coherent (black histograms) and breakup (light grey histograms) parts are fitted to the data. The dark grey histograms correspond to the sum of both.

$$\Delta E_{\eta} = E^{\star}_{\eta}(\gamma_1\gamma_2) - E^{\star}_{\eta}(E_b) \quad . \tag{2}$$

The reaction kinematic is assumed to be coherent, i.e. the η is produced off the ^{3}He nucleus which takes the recoil. In this spectra contributions from coherent production peak around zero while contributions from the breakup reactions where the recoil is mainly taken by one participant nucleon are shifted to negative values. Typical spectra for the most interesting low energy region are summarized in fig. 3. The experimental resolution was not good enough for a clean event-by-event separation of the coherent and breakup reactions. However, the spectra show clearly contributions from both reaction types. The data are compared in the figure to Monte Carlo simulations of the two processes which take into account the different reaction kinematics, the broadening of the breakup contributions due to nuclear Fermi smearing and the response of the TAPS detector. The cross sections for the coherent and breakup parts were determined by a fit of the two contributions to the data (see fig. 3). A clear peak around zero is already visible in the missing energy spectrum for incident photon energies between 600 and 607 MeV. This is the energy region between the coherent and breakup thresholds, where only the coherent part can contribute. The coherent part is still dominant in the range between 607 - 616 MeV, but at incident photon energies larger than 620 MeV the breakup reactions dominate, although even around 650 MeV coherent contributions are still clearly visible. This is the first clear identification of coherent η-photoproduction from a nucleus heavier than the deuteron.

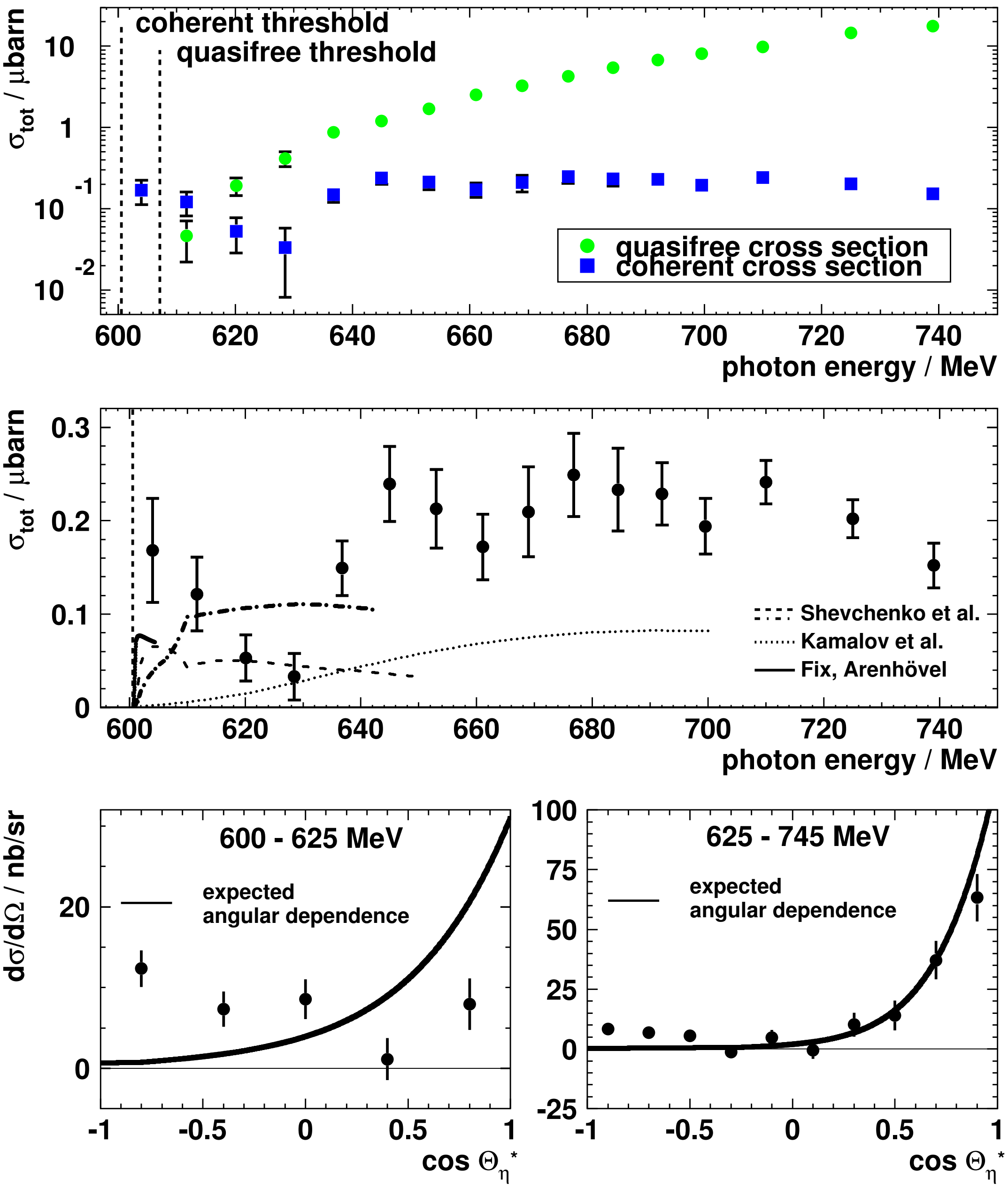

Figure 4: Photoproduction of η mesons from ^{3}He. Upper part: comparison of total cross sections for breakup and coherent part. Middle part: comparison of total cross section for coherent part to model predictions (dotted: Kamalov et al. PWIA ([38], dashed, dash-dotted: Shevchenko et al., [39], solid: Fix and Arenhoevel [36]. Lower part: selected angular distributions for the coherent part. Solid curves: angular dependence expected from ^{3}He form factor scaled to data.

Total cross sections for the coherent and breakup parts and selected angular distributions for the coherent part are summarized in fig. 4. The total cross section for the breakup part shows the expected smooth rise from the threshold to higher incident photon energies, similar to the observations for the deuteron and ^{4}He. In the threshold region there is again some enhancement of the breakup cross section in comparison to simple PWIA expectations [37], which points to significant FSI effects. However, more interesting is the coherent part, which after a minimum around incident photon energies around 630 MeV actually *rises* towards the threshold. This behavior is also clearly visible in the missing energy distributions (see fig. 3) it points to strong FSI effects and could be a first sign for the formation of a (quasi)bound state. PWIA calculations (see fig. 4, curve from Kamalov et al.) clearly underestimate the data. Calculations which take FSI effects into account [39, 36] predict larger cross sections in the vicinity of the threshold but are also not in quantitative agreement with the data, which suffers however from poor statistical quality. The simplest 'model' for the angular distributions assumes a strong forward peaking analogous to the ^{3}He form factor:

$$\frac{d\sigma}{d\Omega}(\Theta) \propto F^2(q^2(\Theta)) \tag{3}$$

Such an behavior is indeed found for incident photon energies larger than 625 MeV (see lower right corner of fig. 4). However, surprisingly, the angular behavior in the immediate threshold region (lower left corner of fig. 4) is very different. Here, the angular distribution is almost isotropic, although the form factor still predicts a significant forward peaking. This isotropy would however be consistent with the formation of an intermediate (quasi)bound state. In summary, we conclude that the data provide evidence for strong η-nucleus final state interaction and are qualitatively consistent with the formation of an η-mesic nucleus.

Further evidence for the possible formation of an η mesic nucleus can be searched for in a different possible decay channel of such an object. The principle, which is similar to the Sokol experiment [8] mentioned in the introduction, is sketched in fig. 5. When an η mesic nucleus is formed, the η meson can be absorbed on a nucleon which is excited into the $S_{11}(1535)$ resonance which can subsequently decay via pion emission (50% branching ratio). When the state is populated at incident photon energies below the coherent η production threshold this is basically the only possible decay mode of the system (the electromagnetic decay of the η meson itself is much slower). At energies above the coherent threshold this channel competes with the emission of η mesons. The signature of the additional decay channel are pion - nucleon pairs which are emitted back-to-back in the rest frame of the η mesic nucleus. Such pion - nucleon pairs have been searched for in the present experiment in the channel $\pi^o - p$, which is best suited for the TAPS detector. Their excitation function is shown in fig. 6. Pion nucleon

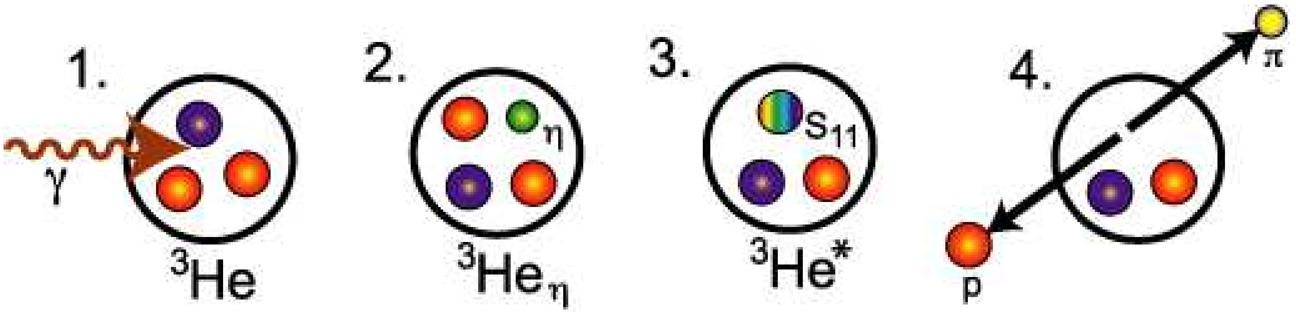

Figure 5: Formation of an η mesic nucleus and its decay via emission of back-to-back nucleon-pion pairs.

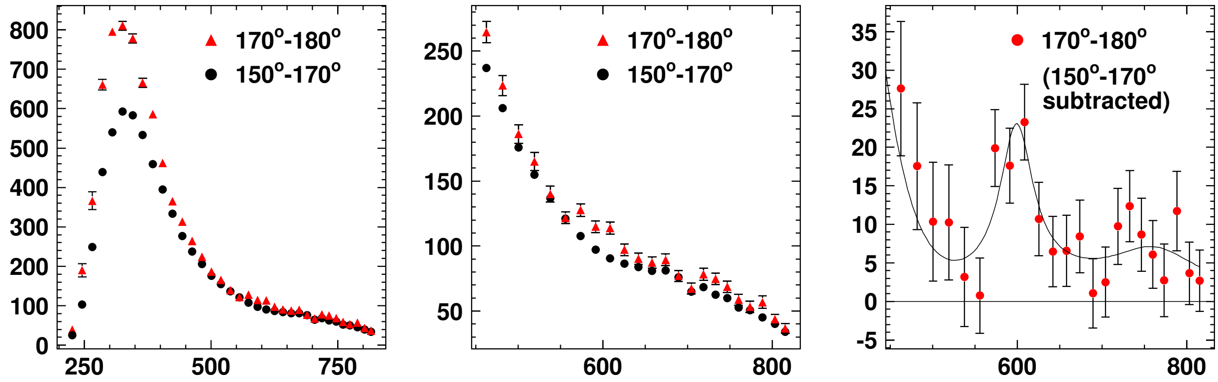

Figure 6: Left and center: excitation functions for the $\pi^o - p$ final state for opening angles between 170 - 180 ^{o} (triangles) compared to opening angles between 150 - 170 ^{o} in the incident photon - ^{3}He cm system (absolute normalization scaled for photon energies larger than 500 MeV). Right: difference of both distributions fitted with a Breit-Wigner curve.

pairs which large opening angles can be also produced in 'quasifree' pion production from the nucleus (depending on the contributing Fermi momenta of the bound nucleons). This 'quasifree' background dominates the reaction. It is estimated by a comparison of the yields for back-to-back production with opening angles larger than 170^o degrees to the yield at somewhat smaller opening angles (150 - 170^o) (see fig. 6). The two excitation functions are scaled to each other in the range of photon energies above 500 MeV. The excitation function for back-to-back emission shows a structure at the production threshold for η-mesons (600 MeV), which is particularly visible in the difference of the two excitation functions (see fig. 6, right side). Such a structure is expected for the formation of an η mesic nucleus. However, the statistical significance amounts only to 3.5σ.

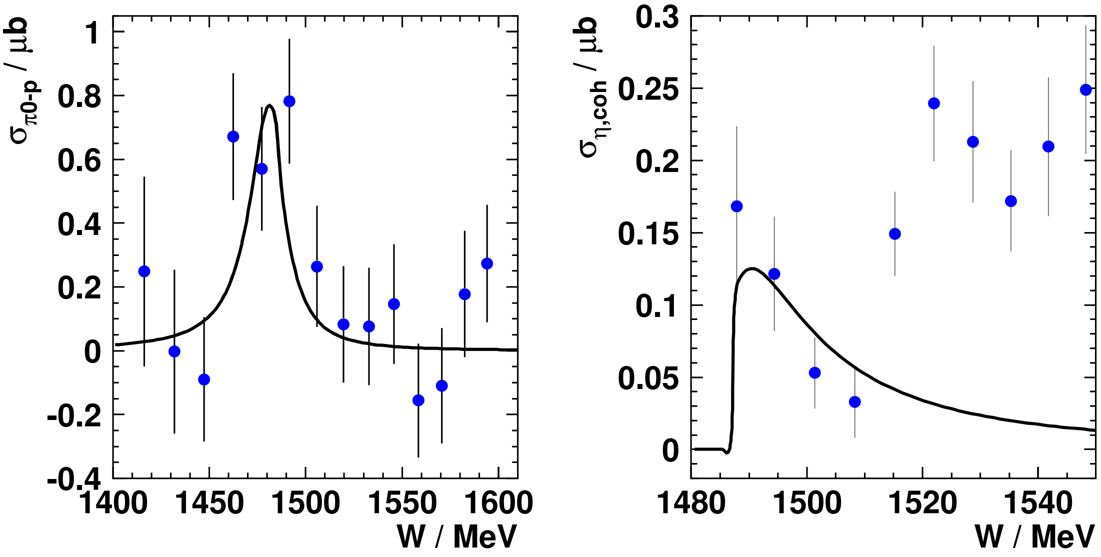

Figure 7: Comparison of the two possible decay channels of an η mesic nucleus. Left: background subtracted excitation function of pion-nucleon back-to-back pairs. Right: coherent η channel. Solid curves: best common fit of the hypothesis of the decay of an η-mesic nucleus to both data sets.

Finally it was analyzed if the observed effect in coherent η production and the structure in the excitation function of pion-nucleon back-to-back emission are roughly quantitatively consistent under the assumption that both are different decay channels of an η mesic nucleus. In the simple model it was assumed that the η - mesic (quasi)bound state can be described with a Breit-Wigner curve at position W with width Γ. For the decay only one single intermediate S_{11} resonance excitation is taken into account (multi-scattering processes are neglected). Proper phase space factors and the energy dependent branching ratio of the S_{11} resonance (50% pion, 50% η at resonance position W=1535 MeV, 100% pion below η production threshold) have been taken into account [37]. The result of the fit of this simplified model to the data is shown in fig. 7. A consistent description of the cross sections for both decay channels is possible for the following parameters of the Breit-Wigner resonance:

$$\begin{aligned} W &= (1481 \pm 4)\ \mathrm{MeV} \\ \Gamma &= (25 \pm 6)\ \mathrm{MeV} \end{aligned} \tag{4}$$

This corresponds to a (quasi)bound state of a width of ≈25 MeV, which is 'bound' by (4 ± 4) MeV.

In summary, we have found some indication for the formation of η mesic ^{3}He in coherent η photoproduction and in the production of back-to-back pion-nucleon pairs. The relative strength of the two signals is in fair agreement with the results of a simplified model for the decay of such an object. However, the statistical significance of both effects is still unsatisfactory and calls for an improved experiment.

2.2 Other possible cases for the formation of η-mesic nuclei via coherent η-photoproduction

It is evident from the discussion of the dominant amplitude for η-photoproduction (isovector spinflip via excitation of the S_{11} resonance) that coherent η-photoproduction has very different properties than the better known coherent pion production. Since the photon couplings of the S_{11} have different sign but comparable magnitude for proton and neutron, contributions from protons and neutrons cancel to a large extend. In combination with the required spin-flip only unpaired nucleons contribute significantly. Consequently, only odd-even or even-odd nuclei are promising candidates. For such nuclei, in the most simple PWIA approximation, the cross section $(d\sigma/d\Omega)_A$ is then given by:

$$\left.\frac{d\sigma}{d\Omega}\right|_A \approx F^2(q) \times \left.\frac{d\sigma}{d\Omega}\right|_N \tag{5}$$

where $(d\sigma/d\Omega)_N$ is the free nucleon cross section (proton for odd-even, neutron for even-odd nuclei) and $F^2(q)$ is the nuclear form factor. We can not expect that such a simple PWIA approximation provides an accurate estimate for the coherent cross sections. However, it yields e.g. ≈20nb/sr for the coherent cross section from ^{3}He for incident photon energies between 640 and 650 MeV and for forward angles around 40^o. This agrees with the experimental result ($\approx (50 \pm 25)$nb/sr [37]) within a factor of two. Here, we do not need predictions for absolute cross sections but only a reasonable estimate for the ratio of the cross section from other light nuclei compared to ^{3}He. According to eq. 5 this can be simply obtained from a comparison of the nuclear form factors. Tiator, Kamalov and Bennhold [40], following an argumentation along this lines, had previously suggested that a measurement of the coherent cross section ratio $d\sigma(^3He)/d\sigma(^3H)$ would be one of the best possibilities to measure the neutron/proton ratio for η-photoproduction. In the meantime, it is well established [13] that in the energy range of interest this ratio is close to 2/3. Consequently, the triton would be the most promising candidate (expected coherent cross section larger by 3/2 compared to ^{3}He), however the use of a liquid tritium target is difficult due to radioprotection safety aspects.

The next heavier possible targets are ^{7}Li, ^{9}Be and ^{11}B. The Li- and B-isotopes have an unpaired proton in the $p_{3/2}$ shell, ^{9}Be has an unpaired neutron in the same shell. Among those three ^{9}Be is disadvantageous since it has a larger rms radius (2.51 fm compared to 2.4 fm for ^{7}Li and ^{11}B [41]) which corresponds to a faster dropping form factor. The factor 2/3 from the neutron cross section leads to a further reduction of the cross section. The form factors for the two proton targets are very similar [42, 43]. Among those, ^{7}Li has the advantage that the expected background from quasifree meson production processes (η and π^o), which scales approximately with $A^{2/3}$ (A = atomic mass number), is smaller and the nuclear structure is simpler (only one unpaired proton in the $p_{3/2}$ shell). It is possible that a significant part of the strength leads to the excitation of the ^{7}Li nucleus to the $1/2^-$ state at 478 keV excitation energy (unpaired proton in $p_{1/2}$ shell), which however would not be resolved experimentally.

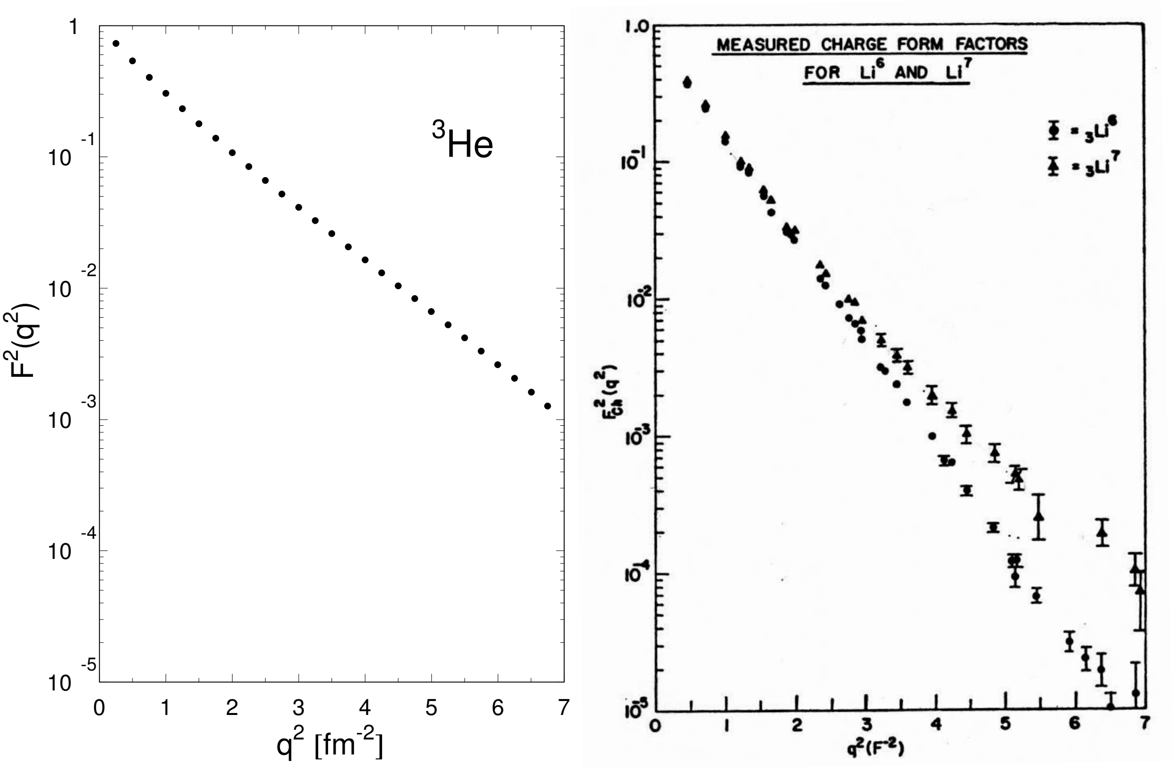

Figure 8: Form factors of ^{3}He [44] and ^{7}Li [42]

The form factors of ^{3}He [44] and ^{7}Li [42] are compared in fig. 8. In the range of interest (q^2 between 3 - 7 fm^2) the form factor of ^{7}Li is almost exactly one order of magnitude smaller than the ^{3}He form factor. This means, that the cross section for coherent η-photoproduction from ^{7}Li is expected to be suppressed roughly by one order of magnitude in comparison to ^{3}He. A factor of 3/2 is recovered since in ^{3}He the cross section comes from the unpaired neutron, while in ^{7}Li it comes from the proton. More specifically, using eq. 5 we find suppression factors between 10 and 16 for incident photon energies at the respective breakup thresholds (E_γ=606 MeV for ^{3}He, E_γ=578 MeV for ^{7}Li) and between 6 and 13 for incident photon energies 40 MeV above the coherent thresholds, both in the angular range 0^o - 45^o. It must be emphasized again, that this estimates come from the most simple PWIA approximation, which as has been shown for ^{3}He, is certainly not valid very close to threshold. Furthermore, they relate only to conventional coherent η-photoproduction. There are no reliable predictions for the influence of the formation of η-nucleus bound states on the threshold cross sections. However, the above estimates suggest that the search for similar effects as in ^{3}He in ^{7}Li will require an improvement of the statistical quality of data by at least one order of magnitude.

3 Proposed Experiments

We propose to remeasure η- and π^o-photoproduction from ^{3}He with much improved statistics and to do a first explorative mesurement of coherent η-photoproduction from ^{7}Li. For both measurements the reaction products will be measured with the combined setup of the Crystal Ball and the TAPS detector shown in fig. 9 which covers almost the complete solid angle.

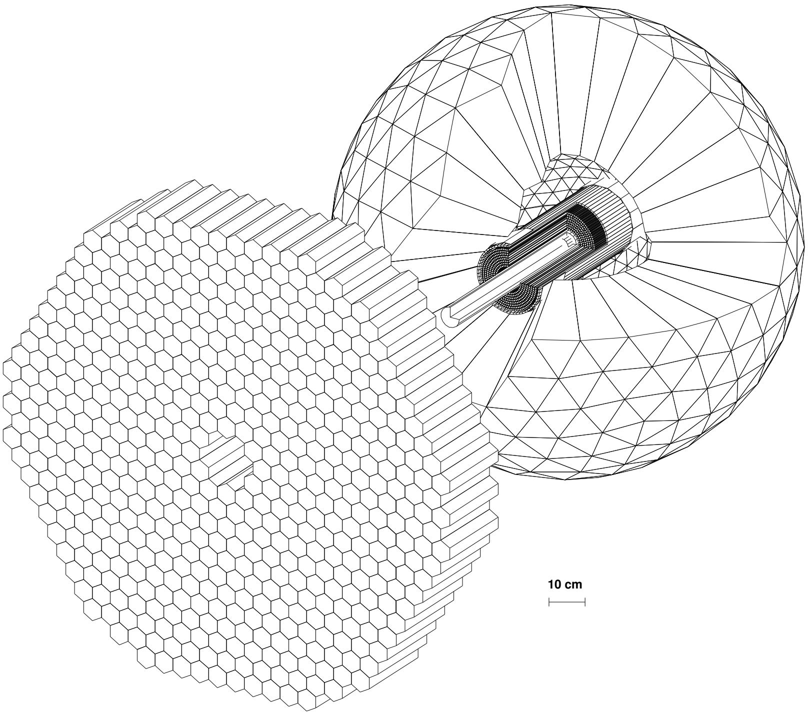

Figure 9: Combined setup of the Crystal Ball and TAPS-detector at the Mainz MAMI accelerator.

3.1 The ^{3}He experiment

We propose a high statistics measurement of η photoproduction and the reaction $^3\text{He}(\gamma, p\pi^o)X$ from ^{3}He for incident photon energies up to 800 MeV and in particular around the η photoproduction threshold at 600 MeV. The main improvement of this follow-up experiment compared to the experiment discussed above results from the much larger statistical quality of the data. Below we compare the expected statistical quality for the pilot and the follow-up experiment. The total beam time of the pilot experiment was 90 h.
For the estimate of the achievable statistical quality we assume that most parameters of the new experiment will be identical to the previous experiment, in particular:

- range of tagged photon energies: **536 - 820 MeV**
- tagging efficiency: ϵ_{tag} = **50 %**
- beam current: **100 nA**
- experiment dead time: **50 %**
- experiment trigger: $\geq$ **two photon cluster**

The new experiment will differ in the target length:

- target length: **previous experiment: 10 cm, new experiment: 5 cm**

The target must be shortened since the CB crystals are closer to the target so that the longer target would result in poor angular resolution . The main difference then arises from the detection efficiency of the improved experimental setup:

- coherent η-production: in the pilot experiment η mesons were only detected via their two-photon decay channel with a detection efficiency between 10 % (at threshold) and 7.5 % (at 800 MeV). In the suggested experiment we expect a detection efficiency for this channel on the order of 60 - 70 % and a detection efficiency of ≈30 % for the $\eta \rightarrow 3\pi^o \rightarrow 6\gamma$. The simultaneous measurement of both decay channels will also provide a check for systematic effects. All together, we thus expect an increase in detection efficiency for η photoproduction by one order of magnitude.
- photoproduction of π - proton pairs with large opening angles: the detection efficiency for π^o-proton pairs with opening angles larger than 170^o in the previous experiment was only 0.6 %. The present setup can reach detection probabilities for this three-prong final state of at least 40% (including the detection efficiency for the proton). We can therefore expect a gain in detection efficiency by a factor of 60.

Counterbalanced with the factor 1/2 from the target surface density we expect an increase in event rate by:

- **factor 5**: coherent η-photoproduction
- **factor 30**: π^o-proton pairs

For the coherent η-photoproduction we aim at a measurement of the shape of the threshold structure with the nominal tagger energy resolution of 2 MeV per bin with statistical uncertainties around 15 %. The previous experiment combined 4 tagger channels to energy bins of 8 MeV and achieved then statistical uncertainties around 30 %. Consequently, we need an improvement in statistics by a factor of 16. Together with the factor of 5 in event rate this requires a beame time of

300 h

Since the peak-to-background ratio for the signal in the excitation function of the π^o-proton pairs is small, the significance of the peak is approximately given by $S/\sqrt{B}$, where S are the signal and B the background counts. The significance will thus improve by one order of magnitude. The increase in counts by two orders of magnitude will allow to use the existing 'tagger microscope' for a precise measurement of the shape of the signal. This additional focal plane detector covers an energy rang of roughly 65 MeV with a resolution of the incident photon energy of ≈0.35 MeV.

3.2 The ^{7}Li experiment

This part of the experiment aims at a first investigation of coherent η photoproduction from heavier nuclei and will search for possible signs of the formation of η-nucleus (quasi)-bound states in such systems. Since we have only very rough estimates for the cross sections this experiment is meant as a feasibility study.

We have discussed above, that conventional coherent η production processes in ^{7}Li are probably suppressed in ^{7}Li by one order of magnitude compared to ^{3}He. For our estimates, we assume that all experimental conditions are identical to the ^{3}He experiment, except of the target density. The density of the ^{3}He target was 0.69 g/cm^2. The density of lithium is 0.534 g/cm^2. A five cm long target (corresponding to 3.3 % of radiation lengths) has a factor of 3.3 more nuclei/cm^2 than the helium target of same length (or a factor of 1.6 more than the target in the previous helium experiment).

Combined with the detection efficiency and the suppression of coherent η photoproduction in Li we thus expect a factor of:

$$\frac{\text{countrate}(^7\text{Li})}{\text{countrate}(^3\text{He,old experiment})} = \frac{N(\text{Li})}{N(\text{He})} \times \frac{\epsilon_{new}}{\epsilon_{old}} \times \frac{\sigma_{coh}(\text{Li})}{\sigma_{coh}(\text{He})} = 1.6 \times 10 \times \frac{1}{16} = 1. \quad (6)$$

between the count rates for the old ^{3}He and the proposed ^{7}Li experiment. Here, we have taken the most pessimistic value for the cross section ratio which corresponds to the kinematics at breakup threshold. In the energy range around 40 MeV above threshold it rises from 1/16 to 1/10. With a beam time of:

200 h

a signal from coherent η photoproduction should be seen.

We also estimate if with such a statistical quality it seems feasible to detect a peak-like-signal in the excitation function for π^o-proton pairs. We assume that the signal strength is suppressed by a factor of ten compared to He. At the same time the background from quasifree pion production will rise like $A^{2/3}$ with the mass number, which corresponds to a factor 1.75 from He to Li. Under this conditions the significance of the signal would be:

$$\frac{S}{\sqrt{B}}(\text{Li exp.}) = \frac{S}{\sqrt{B}}(\text{old He exp.}) \times \frac{60 \times 1.6 \times 0.1 \times 2.2}{\sqrt{60 \times 1.6 \times 1.75 \times 2.2}} = \frac{S}{\sqrt{B}}(\text{old He exp.}) \times 1.1 \quad (7)$$

which means that we can expect a comparable significance as in the He pilot experiment. Altogether, the results from the proposed experiment should allow to judge whether the search for η-mesic nuclei beyond ^{3}He is feasible.

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