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Mainz Microtron MAMI

Collaboration A2: "Real Photons"
Spokesperson: A. Thomas

Proposal for an Experiment

"Photoproduction of Neutral Pseudoscalar Mesons on the Neutron"

Collaborators :

The CrystalBall@MAMI Collaboration.

Spokespersons for the Experiment :

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Abstract of Physics :

The main objective of this proposal is to measure $d\sigma/d\Omega, \Sigma$, and the double polarizations G and E for the reaction $\gamma n \rightarrow \pi^0 n$ within a deuteron target. Simultaneously, we will measure $\gamma n \rightarrow \pi^- p$, $\gamma n \rightarrow \pi^0 \pi^0 n$, $\gamma n \rightarrow \pi^0 \eta n$, and $\gamma n \rightarrow K^0 \Lambda$. These measurements will provide both the GW Data Analysis Center (SAID) and the Mainz MAID Group with new data to be included in their analyses.

Abstract of Equipment :

We will make use of the almost 4π coverage of the Crystal Ball and TAPS for photons and neutrons, the tracker and PID for charged particle detection, the upgraded Glasgow photon tagger, polarized and unpolarized photon beams, and LD_2 and polarized frozen spin targets that will be available with MAMI C.

MAMI–Specifications:

beam energy	1500 MeV
beam current	< 100nA
time structure	cw
polarization	unpolarized/linearly/circularly polarized photons

Experiment–Specifications:

experimental hall/beam	A2
detector	Crystal Ball, TAPS, MWPC, PID
target material	CD2, liquid deuterium, polarized deuterium

Beam Time Request:

set–up without beam	200 (200 parallel with proposal A2/ XXX)
set–up/tests with beam	200 hours (200 parallel with proposal A2/ XXX)
data taking	600 hours in 2006 (400 parallel with proposal A2/ XXX)
	600 hours in 2007 (400 hours parallel with proposal A2/ XXX)
	600 hours in 2008 (400 hours parallel with proposal A2/ XXX)

1 Overview

1.1 The Structure of the Nucleon

What is the structure of the nucleon? is a key scientific question in nuclear physics. In order to address this question it is essential to have a clear understanding of the spectrum of excited states of the nucleon. One measure that can be proposed to better understand the baryon spectrum is that the community perform a combined analysis of the π, η and K photo-production data and incorporate two-pion final states into a coupled channel analysis. All hadronic channels that have significant coupling strength need to be included in the analysis. Experiments that are thus far missing in the existing data base - the production of mesons off the neutron - cross sections, beam asymmetry and target polarization measurements in particular - must be performed to be included in this combined analysis.

According to Quantum Chromodynamics, QCD, nucleons are complicated systems of quarks and gluons held together by strong interactions. The field theoretic approach to the problem is based on QCD. Perturbative solutions, that are applicable at high energies, fail in the resonance region. Connecting the observed properties of baryons with the underlying theoretical framework provided by QCD is one of the central challenges of modern science. Effective Field methods, such as Chiral Perturbation Theory (ChPT), have been successful at low energies, but an extension to the resonance region is difficult. The lattice technique holds promise as it is a direct solution to QCD, but extraction of resonance properties becomes progressively more difficult for higher excited states having a given set of quantum numbers [*i.e.* the nucleon, Roper, and N(1710)]. For this reason, and in order to facilitate comparisons with more phenomenological models, it is important to: a) determine to the few percent level the properties of low-lying resonances, and b) determine the set of (higher) resonances which can be unambiguously extracted from fits to experimental data. Efforts are being made to study these problems at GW, ITEP, JLab, Mainz and other nuclear theory centers. These theoretical efforts need measurements to test their models. Experimentalists need theorists for guidance in selecting the most crucial experiments. The program outlined in this proposal is a result of ongoing discussions between the theoretical and experimental communities.

The focus of this proposal is the production of pseudoscalar mesons and the study of their interactions with the neutron. Our program centers on the use of real polarized and unpolarized photons to produce short-lived mesons on polarized and unpolarized nucleon targets. With the upgrade of MAMI-C to 1.5 GeV, we can produce the complete nonet of pseudoscalar mesons. The results of our program will be used to test theoretical predictions based on ChPT, which links meson-nucleon dynamics and QCD, lattice QCD, and dynamical models. They will also be used to expand the GW SAID and MAMI MAID analyses and data bases[Ar02],[Dr99].

The particular measurements proposed herein are:

- $\gamma\, d \to \pi^0 n(p_s)$ & $\vec{\gamma}\, \vec{d} \to \pi^0 n(p_s)$;
- $\gamma\, d \to \pi^0 \pi^0 n(p_s)$ & $\vec{\gamma}\, \vec{d} \to \pi^0 \pi^0 n(p_s)$;
- $\gamma\, d \to \pi^0 \eta n(p_s)$ & $\vec{\gamma}\, \vec{d} \to \pi^0 \eta n(p_s)$;

- $\gamma\, d \rightarrow K^0\Lambda(p_s)$ & $\vec{\gamma}\, \vec{d} \rightarrow K^0\Lambda(p_s)$.

Our program emphasizes the use of polarized beams and targets allowing us to measure independent amplitude combinations contributing to the scattering processes and thus resolve the ambiguities in partial-wave analyses.

1.2 Extracting Resonance Information

Pion photoproduction has long been analyzed in order to extract the photo-decay amplitudes associated with the N^* and Δ^* resonances. Extensive fits to elastic pion-nucleon scattering have provided mass and width values for the contributing resonances. Multipole phases are also linked to corresponding pion-nucleon phase shifts, through Watson's theorem, up to the onset of inelasticity.

Above the two-pion production threshold, multipole analysis becomes increasingly model-dependent. The GW DAC (SAID) and Mainz (MAID) fits to this region attempt to describe the available data, within the constraints obtained from pion-nucleon scattering from the SAID analysis [Ar03], employing different phenomenology. In the MAID approach, resonance parameters are varied in fitting the data. The SAID approach is to first obtain multipole amplitudes in a manner as "model-independent" as possible. The extracted multipoles are then refitted to functional forms having both resonance and background contributions.

Differences between these approaches are most evident in predictions for observables not yet measured. Each new experiment provides further constraints related to a different bi-linear combination of helicity amplitudes. We need to consider what types of data are currently available in the database, and consider which measurements are both necessary and best suited to the Crystal Ball and TAPS at MAMI.

1.3 Spin Observables

In the reaction $\gamma N \rightarrow N\pi$, three particles carry polarization: the photon beam, target nucleon, and recoil nucleon. There are three possible double-polarization experiments: beam/target, beam/recoil, and target/recoil. The total number of observables is 16, though not all are independent. The formalism and definitions of observables commonly used to describe pseudoscalar meson photoproduction is found in Ref. [Ba75]. Without a recoil polarimeter we cannot measure recoil polarization with either the Crystal Ball or TAPS and are left with the beam/target combinations given in Table 1.

At present, only $d\sigma/d\Omega$ and Σ can be measured with either setup. With polarized targets, all the observables from Table 1 are measurable in an energy region where SAID and MAID give different predictions and no data are available for the $\gamma n \rightarrow n\pi^0$ reaction [Fig. 1]. The further possibility of nucleon polarimetry at MAMI further expands the scope of this project in future years.

The differential cross section for reactions of the type $\vec{\gamma} + \vec{p} \rightarrow p + X$, where X is a pseudoscalar meson, with linearly polarized (P_γ^{L}) or circularly polarized (P_γ^{c}) photons and

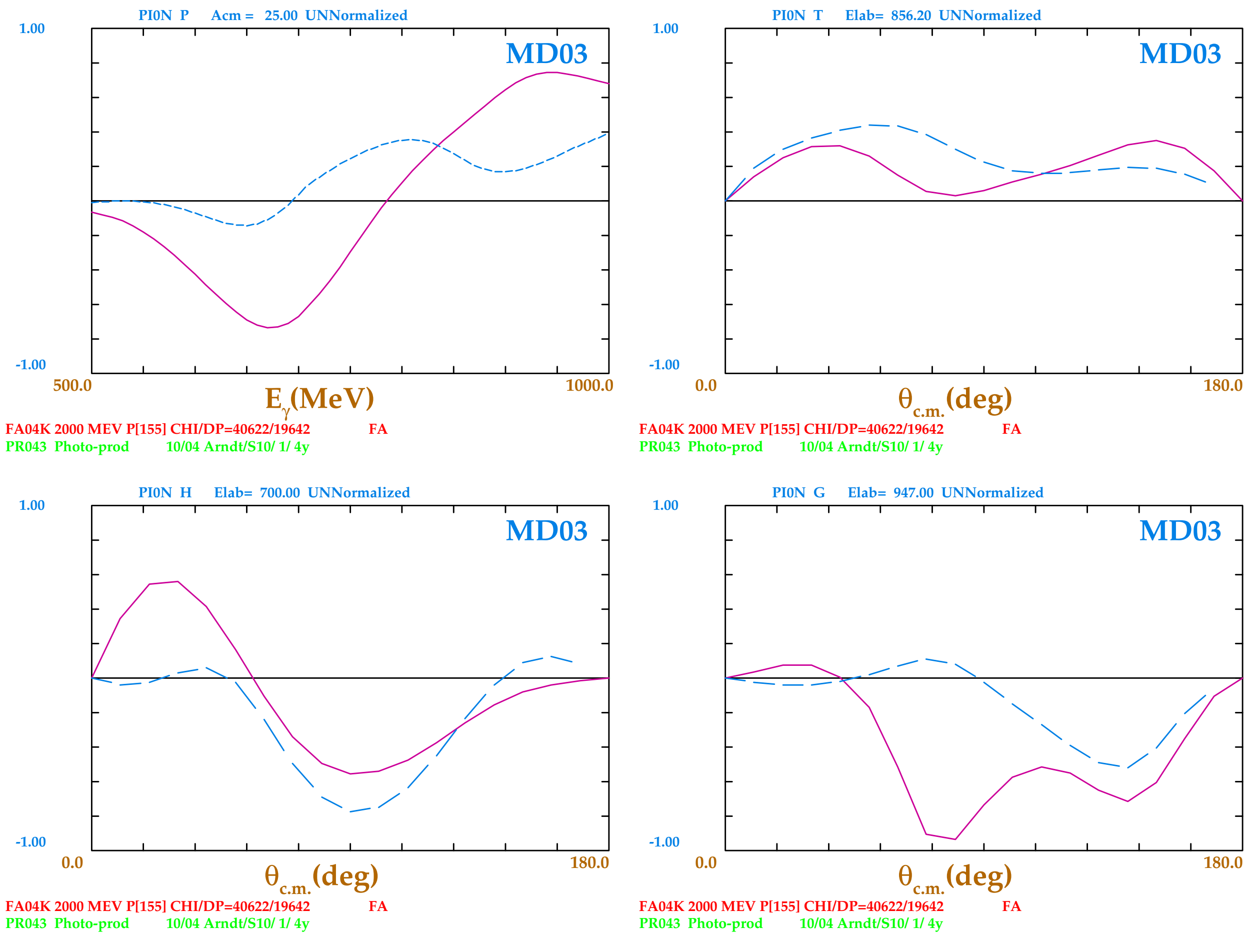

Figure 1: Plots comparing the SAID [SAID] (solid line) and MAID [Dr99] (dashed line) predictions for the $\gamma n \to n\pi^0$ observables P, T, H, and G.

Table 1: Observables in single-pion photoproduction with polarized target and/or polarized photons. See also Ref. [Ba75].

	Photon beam		
Target	unpolarized	circularly polarized	linearly polarized
unpolarized	$d\sigma/d\Omega$	—	Σ
longitudinally	—	E	G
transversely	T	F	H, P

with longitudinally polarized targets $[P_T = (P_x, P_y, P_z)]$, can be written

$$\begin{aligned} \frac{d\sigma}{d\Omega}(\theta,\phi) &= \frac{d\sigma}{d\Omega}(\theta)\left[\,1 - P_\gamma^{\rm L}\,\Sigma\,\cos 2\phi \right. \\ &+ \left. P_x(-P_\gamma^{\rm L}\,H\,\sin 2\phi + P_\gamma^{\rm c}\,F) + P_y(T - P_\gamma^{\rm L}\,P\,\cos 2\phi) + P_z(P_\gamma^{\rm L}\,G\,\sin 2\phi - P_\gamma^{\rm c}\,E)\,\right], \end{aligned} \tag{1}$$

where θ is the polar angle and ϕ is the azimuthal angle. The factors Σ (photon asymmetry), H, F, T (target asymmetry), P, G, and E are the observables. The dominant multipole amplitudes for excitation of the low-lying baryon resonances are: $M_{1+} \Leftrightarrow \Delta(1232)\frac{3}{2}^+$; $M_{1-} \Leftrightarrow N(1440)\frac{1}{2}^+$; $E_{2-} \Leftrightarrow N(1520)\frac{3}{2}^-$; and $E_{0+} \Leftrightarrow N(1535)\frac{1}{2}^-$. The above observables can be related to the interference of the multipole amplitudes as: $G \sim \Im(M_{1+}M_{1-})$; $\Sigma \sim \Re(M_{1+}E_{2-})$; and $T \sim \Im(M_{1+}E_{0+})$. We can also obtain G and Σ together in a single experiment with linearly polarized photons and a longitudinally polarized target. The advantage of the 4π Crystal Ball and TAPS detectors at MAMI for obtaining the ϕ dependence is clearly evident. A transversely polarized target is planned at MAMI; we would encourage its development and will plan to incorporate it into our program as soon as it is available.

2 The Photoproduction of Neutral Pseudoscalar Mesons on the Neutron.

2.1 The Photoproduction of Neutral Pions

The photoproduction of pions has been the most important process used in the determination of baryon-resonance photo-decay amplitudes. This process is defined by three independent isospin amplitudes (the isospin 3/2 amplitude and independent isospin 1/2 amplitudes for proton and neutron targets). Of these, the isospin 3/2 and isospin 1/2 (proton) amplitudes are most reliably determined from experiments measuring polarized and unpolarized observables for $\gamma p \to p\pi^0$ and $\gamma p \to n\pi^+$. Assuming a good determination of the isospin 3/2 amplitude, measurements of $\gamma n \to p\pi^-$ are sufficient to give the remaining isospin 1/2 amplitude for neutrons. However, fits much above the $\Delta(1232)$ region are generally model-dependent and this model-dependence is greatest for the extraction of $n\gamma$ photo-decay amplitudes.

The measurement of $\gamma n \rightarrow n\pi^0$ allows a valuable check of the $n\gamma$ photo-decay amplitudes and the models used in analyzing both proton and neutron target data. Given a model for the background and photo-decay amplitudes, determined from reactions excluding $n\pi^0$ photoproduction, one should be able to predict the $n\pi^0$ observables. However, at higher energies there is little justification for the most commonly used background parameterizations. Simple Born-term (point coupling) calculations of the background give very large contributions which must either be damped with phenomenological form-factors or cancel with resonance contributions[Wo01]. The Born-term contribution to $n\pi^0$ photoproduction is much simpler due to the lack of charged particles. This should also be an advantage for the separation of resonance and background effects. The availability of $n\pi^0$ observables would allow a determination of resonance contributions from four possible sets of the required three charge channels [($p\pi^0$, $n\pi^+$, $p\pi^-$), ($p\pi^0$, $n\pi^+$, $n\pi^0$), ($n\pi^0$, $p\pi^-$, $n\pi^+$), or ($n\pi^0$, $p\pi^-$, $p\pi^0$)], which would tightly constrain the analysis methods. The present neutron target data is quite

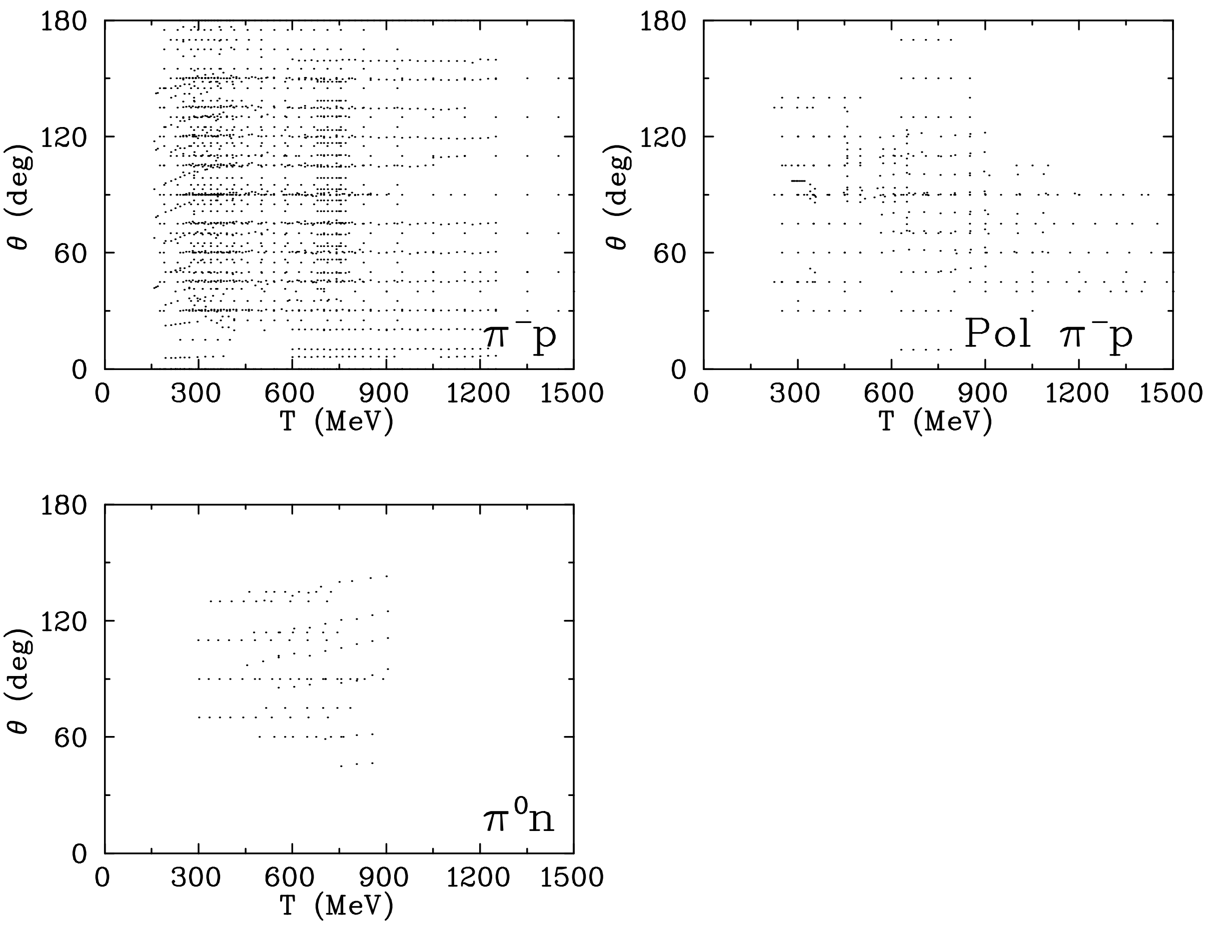

Figure 2: Energy-angle distribution of available neutron target photoproduction data: unpolarized and polarized $\pi^- p$ and unpolarized $\pi^0 n$. No polarization observable data exist for the $\gamma n \rightarrow \pi^0 n$ reaction. Data are from the SAID database [SAID].

sparse. Only differential cross sections exist for $n\pi^0$ - with no measurements beyond 905

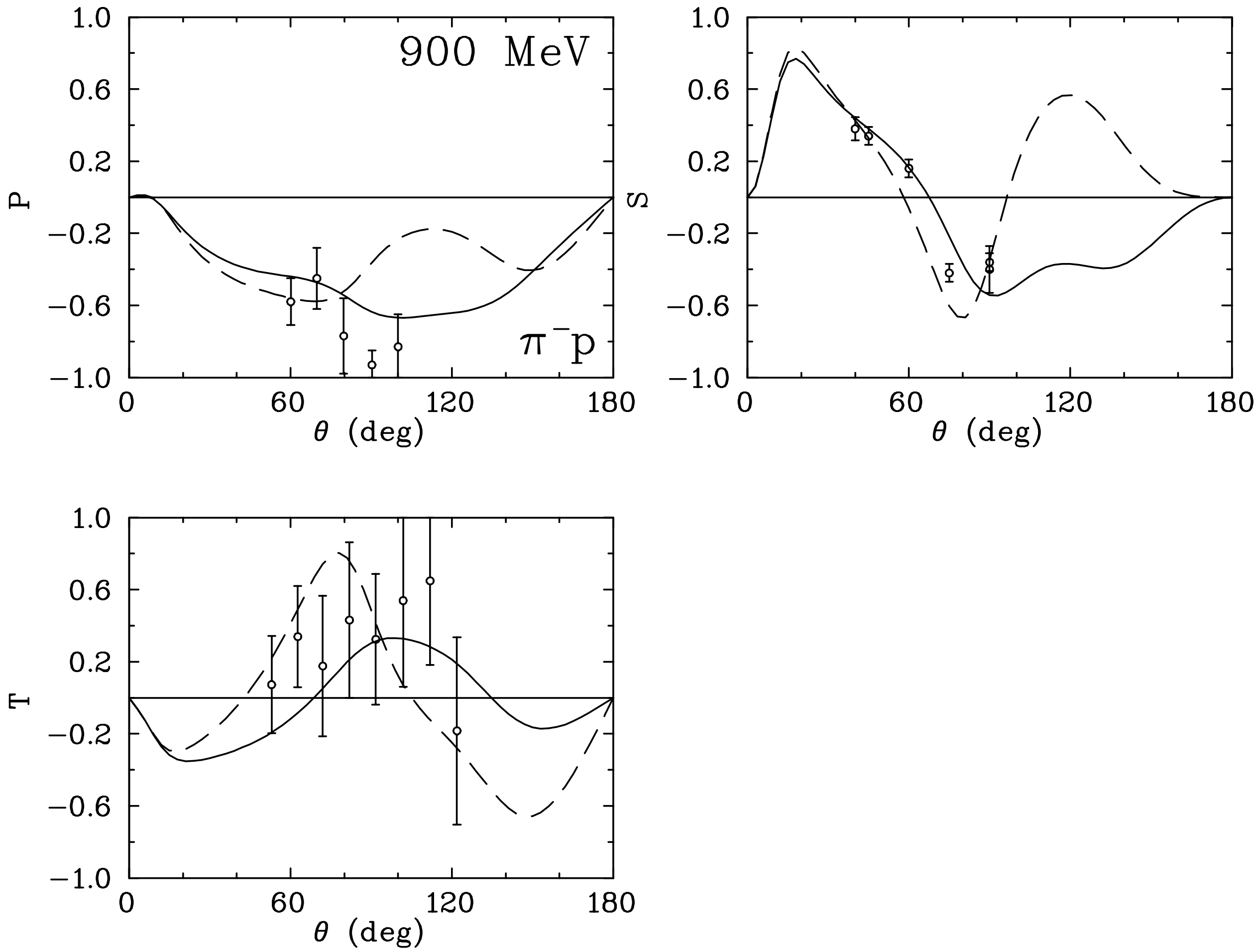

Figure 3: Polarized measurements S, P, and T in negative pion photoproduction on the neutron at 900 MeV. Solid (dashed) line gives the GW SM02 [Ar03] (MAID) [Dr99] solution. Data are from the SAID database [SAID].

MeV (corresponding to a center-of-mass energy of about 1600 MeV). Differential cross sections for $p\pi^-$ are more numerous, but few polarized measurements exist above 1 GeV, and these give almost no coverage of the backward angles [Fig. 2]. As one should expect, predictions for backward angle observables show large differences between the existing SAID and MAID analyses [Figs. 1 and 3]. However, as both SAID and MAID use similar background parametrizations, deviations could easily arise in unexpected kinematic regions. Only a precise set of neutron-target measurements can settle these issues. We are currently discussing the problem of corrections for the fact that the neutron is bound in a nucleus with our theoretical collaborators.

2.1.1 The Photoproduction of $\pi^0\pi^0$ and $\pi^0\eta$ on the Neutron

In order to extract reliable N^* resonance parameters from the meson photoproduction data which are now coming out of JLab, GRAAL, ELSA, and MAMI, partial-wave analyses must be extended to include additional channels and reactions. It has become increasingly evident that single-channel πN analyses alone do not provide the necessary constraints needed for a full and unambiguous determination of resonance properties. This is particularly true for resonances which have only a weak coupling to the πN state.

We will exploit the photon and neutron detection properties of the Crystal Ball and TAPS at MAMI by measuring the fundamental photoproduction reaction $\gamma n \to \pi^0 n$. (The reaction $\gamma n \to \eta n$ is treated in another proposal) from threshold to 1400 MeV. In this same energy region we shall study the production of the strange neutral pseudoscalar meson in the reactions $\gamma n \to K^0\Lambda$, and the two-step decays $\gamma n \to \pi^0\pi^0 n$ and $\gamma n \to \pi^0\eta n$. In addition, from these same data, we will be able to explore the details of the electromagnetic properties of resonances by searching for the radiative decay chains that result in a $\pi^0\gamma$ or $\eta\gamma$ final state such as $N^* \to \gamma\Delta$ or $N^* \to \gamma N(1535)$.

These measurements will first be carried out using a LD_2 target to provide the target neutrons in determinations of total and differential cross sections as well as beam asymmetry. Then we will use a polarized deuterium target to make double polarization measurements. These experiments are complementary to the charged final-state measurements at JLab [E94-103, E04-102, E02-112, E03-105, E05-012]; they will further the investigation of low-lying resonances and will contribute to the search for the "missing" resonances.

2.2 Photoproduction at Neutral Kaons on the Neutron

Strangeness photoproduction is a fundamental process and an important tool for gaining insight into nucleon resonances. There are six elementary strangeness photoproduction reactions: (1) $\gamma + p \to K^+ + \Lambda$; (2) $\gamma + p \to K^+ + \Sigma^0$; (3) $\gamma + p \to K^0 + \Sigma^+$; (4) $\gamma + n \to K^0 + \Lambda$; (5) $\gamma + n \to K^+ + \Sigma^-$; (6) $\gamma + n \to K^0 + \Sigma^0$. Among these reactions, (1) and (2) have received intensive experimental attention [Mc04], [Ze03], [Go99], [Tr98]. Our proposal will focus on reaction (4), which has an all-neutral final state and has received little or no experimental attention. This reaction is ideally suited to a detailed study with the Crystal Ball-TAPS set-up at MAMI-C. The reaction mechanism will be identified by the sequential decays:

$$\begin{array}{rll} \gamma + n \rightarrow & K^0 & + \Lambda \\ & K^0 & \rightarrow K^0_S \rightarrow \pi^0\pi^0 \rightarrow 4\gamma \\ & \Lambda & \rightarrow \pi^0 n \rightarrow 2\gamma + n \ ; \end{array}$$

thus, the reaction chain for events of reaction (4) is

$$\gamma + n \rightarrow K^0 + \Lambda \rightarrow 3\pi^0 + n \rightarrow 6\gamma + n \ .$$

Not only is this reaction of interest in itself, but also it is required to understand hypernuclear production by the electromagnetic interaction. This process is isospin-1/2 selective and may provide essentially new information about the spectrum of N^* resonances. We should also be able to determine the final-state Λ polarization, since the Λ is self-analyzing.

A variety of reasons leads us to believe that the photoproduction of the $K^0\Lambda$ system should have significant contributions from N^* production in the near-threshold region. This expectation is in accord with a unitary coupled-channels analysis of hadronic and electromagnetic $K\Lambda$ production [Fe98] that found appreciable branching ratios of 10-20% of the $S_{11}(1650)$ and $P_{11}(1710)$ states into the $K\Lambda$ channel. Significant $K\Lambda$ couplings for these states are also predicted by a relativized quark-model calculation [Ca98]. Furthermore, a relativized quark-model calculation [Ca92] predicts $P_{11}(1710)$ to have helicity photocouplings that are about equal in magnitude but opposite in sign for γn and γp.

The total cross section for $\pi^- p \rightarrow K^0\Lambda$ is shown in Fig. 4. A strong peak occurs at a c.m. energy W of about 1.7 GeV, which is arguably associated with the $P_{11}(1710)$ resonance. The data of Jones *et al.* [Jo71] (filled diamonds) suggest that this peak might have a relatively narrow width (about 70 MeV), but better data are needed at energies above the peak to confirm this. The quality of the data shown in this figure make it clear why little is known experimentally about resonances that decay to $K\Lambda$. The $P_{11}(1710)$ is of special interest. This resonance, although given a rating of 3 stars by the Particle Data Group (PDG) [Ei04], is little understood. It is known to have a small πN branching ratio, which makes it very difficult to study in traditional elastic πN scattering experiments. Even the total decay width of this state is not well known (the PDG estimate is 50 to 250 MeV). It is commonly believed that the $P_{11}(1710)$ has a significant branching ratio to $K\Lambda$; thus, $K\Lambda$ photoproduction at MAMI-C might shine new light on the properties of this state.

Interestly, two entirely different experiments recently revealed evidence for narrow structures at a c.m. energy of about 1.7 GeV. (1) In an experiment at JLab, the CLAS Collaboration measured the cross section for $ep \rightarrow e'p\pi^+\pi^-$ and observed a narrow resonant structure with a mass of about 1.7 GeV, which was best described as a P_{13} state [Ri04]. (2) In an experiment at GRAAL, a narrow resonance-like structure was seen for the reaction $\gamma n \rightarrow \eta n$ at about 1.7 GeV, which was not observed in measurements on the proton [Re05]. Clearly, further study of other resonance reactions in the vicinity of 1.7 GeV is warranted.

Figure 5 shows recent isobar-model results for the angular distributions and cross sections of reactions (1) and (4) at $E_\gamma = 1.05$ GeV. Solid and dashed curves show predictions for two different parameter sets. Both parameter sets give similar results for $\gamma p \rightarrow K^+\Lambda$ but the predicted angular distributions are very different for $\gamma n \to K^0\Lambda$. Figure 6 similarly shows different isobar-model predictions for the $\gamma n \to K^0\Lambda$ reaction. The particular models referred to in the figure are Saclay-Lyon (SLA) [Da96], Kaon-MAID (K-MAID) [Ma00], and M2 and H2 [By04]. These models also reveal more different results for $\gamma n \to K^0\Lambda$ reaction than for $\gamma p \to K^+\Lambda$. Figure 6 demonstrates that the K-MAID and SLA models are much more sensitive to a contribution from K_1 exchange than the M2 or H2 models. This phenomenon is valid for photon energies up to 1.5 GeV and kaon lab energies up to 50° [By04]. Measurement of the $K^0\Lambda$ channel is therefore very important to give new information on strangeness production by the electromagnetic interaction.

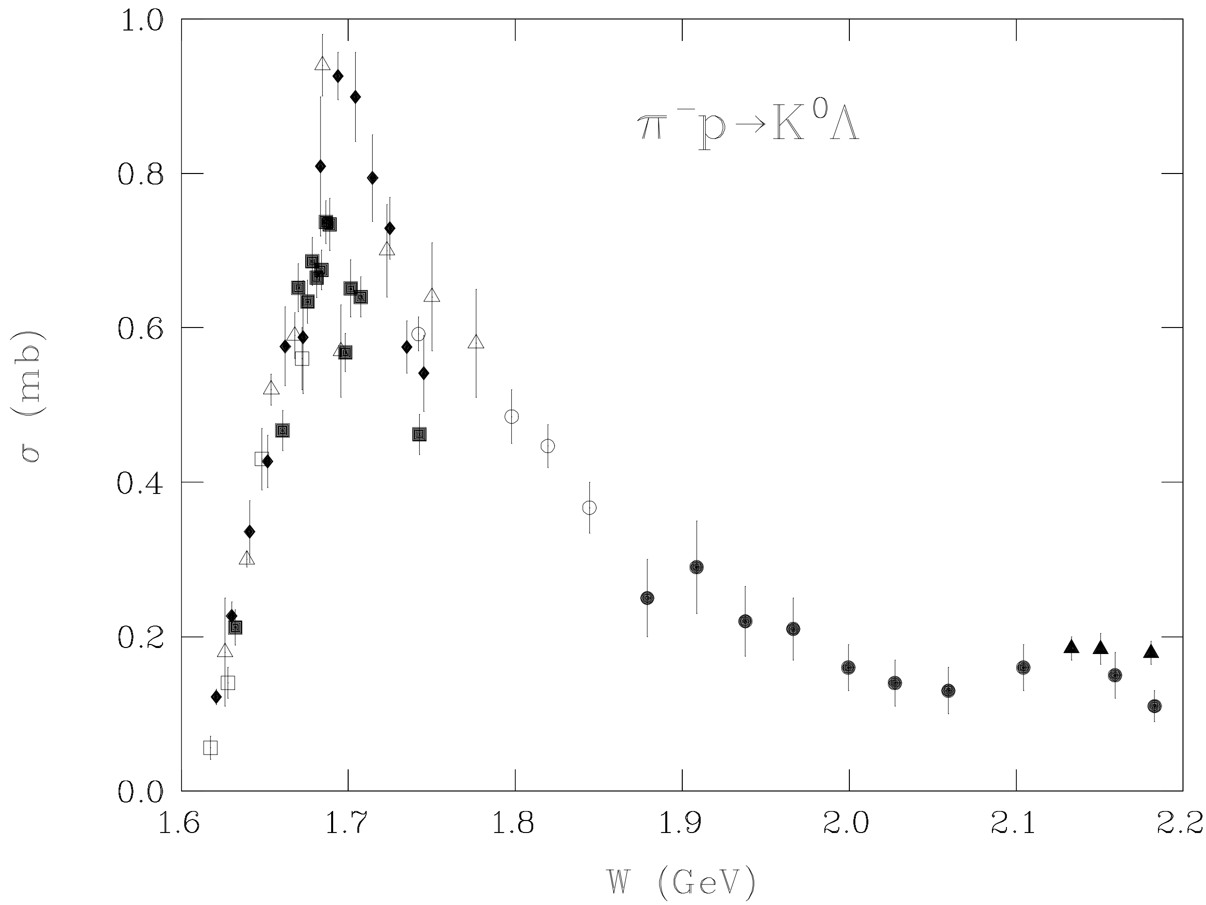

Figure 4: Total cross section for $\pi^- p \rightarrow K^0\Lambda$ as a function of laboratory momentum $p_{\rm lab}$. Data from Bertanza *et al.* [Be62] are shown as open squares, from Knasel *et al.* [Kn75] as filled squares, from Binford *et al.* [Bi69] as open circles, from Saxon *et al.* [Sa80] as filled circles, from Van Dyke *et al.* [Va69] as open triangles, from Dahl *et al.* [Da67] as filled triangles, and from Jones *et al.* [Jo71] as filled diamonds.

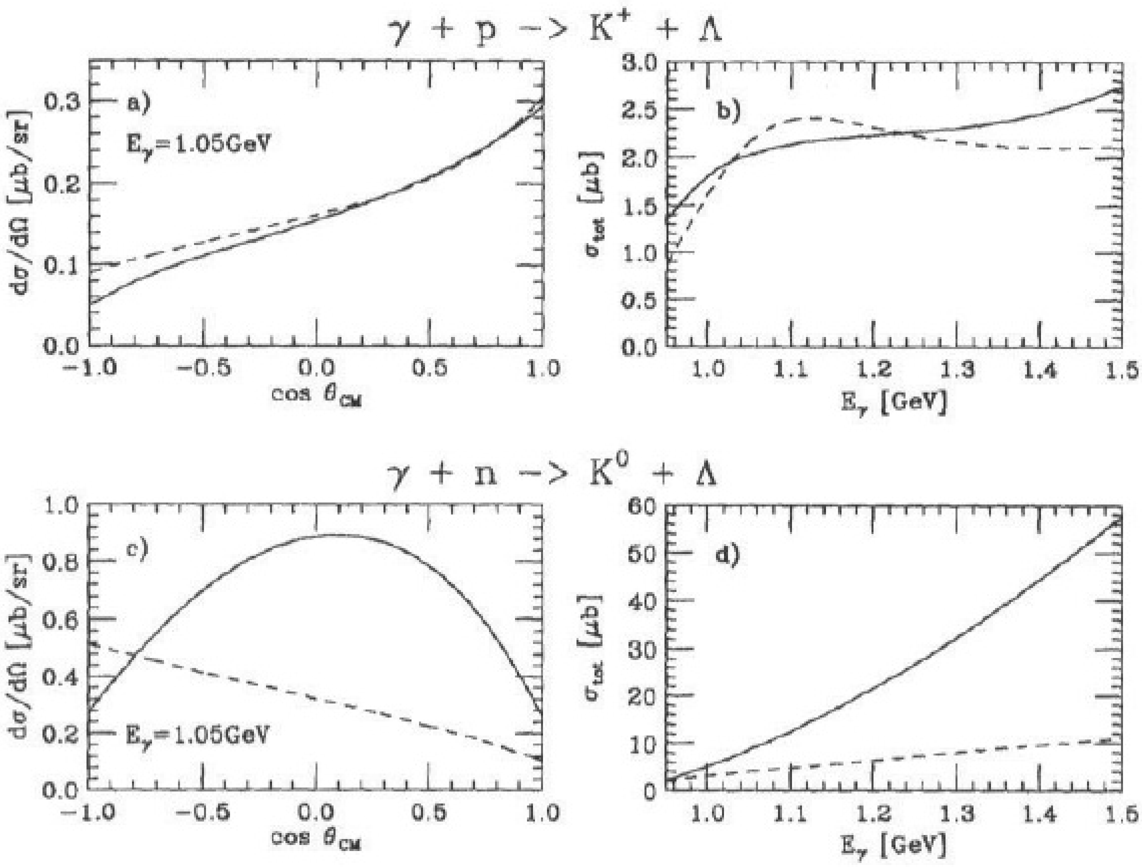

Figure 5: The angular distribution of K^+ (K^0) Λ photoproduction process on the nucleon at $E_\gamma = 1.05$ GeV (a) and c)). Solid and dashed curves show the results from the parameters sets of Ref. [Ad90] and [Wi92], respectively. Figures b) and d) show total cross sections for each production channel.

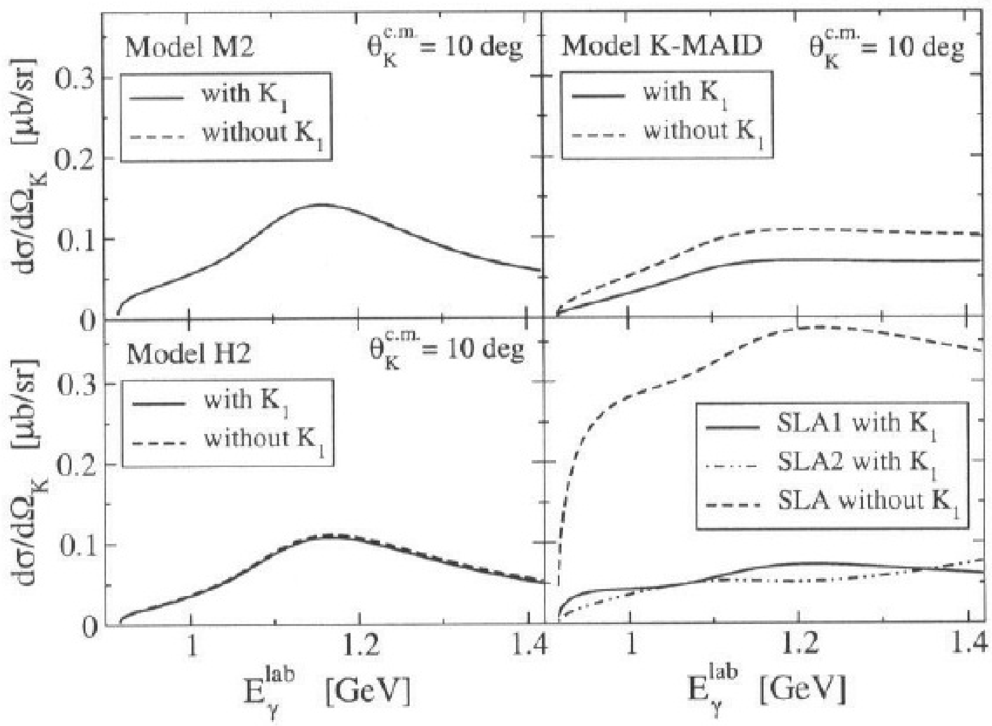

Figure 6: Contribution of the K_1 exchange to the differential cross section in $\gamma n \to K^0\Lambda$ is shown as a function of energy at kaon angle of $10°$.

3 Experimental Considerations

3.1 The Crystal Ball and TAPS at MAMI

A unique and extensive program of photonuclear physics is possible with the combination of the 4π Crystal Ball (CB) multi-photon and neutron spectrometer with the TAPS detector [Fig. 7] at MAMI. The facilities at MAMI include tagged, polarized photons and polarized p, d, and ^3He targets. Such a facility allows us to measure meson photoproduction and a variety of double polarization observables.

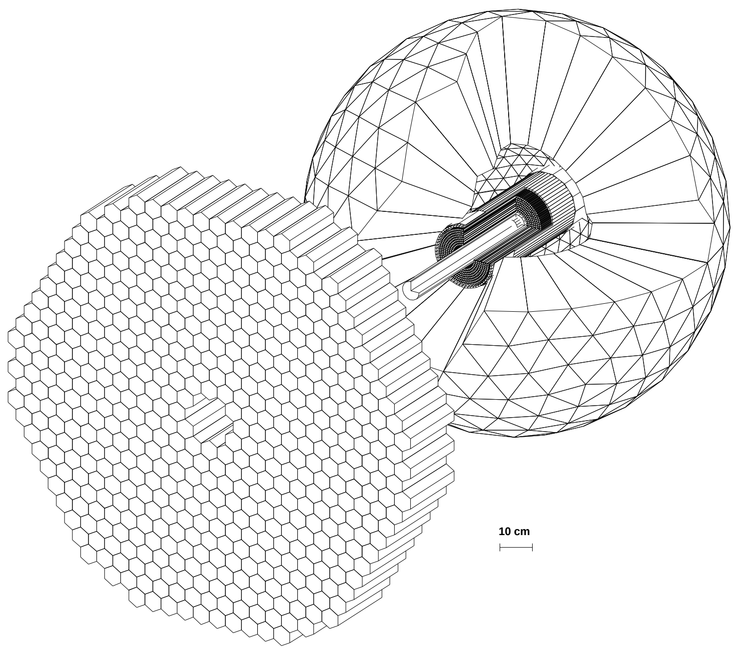

Figure 7: The experimental apparatus proposed for our measurements at MAMI. To show the position of the cylindrical wire chamber and the target inside the Crystal Ball some of the Crystal Ball crystals have been omitted.

The combination of the MAMI tagged photon beam and the Crystal Ball with TAPS provides an excellent opportunity for outstanding physics. The frozen-spin polarized target that allows almost 4π particle detection and provides longitudinally polarized nucleons is been developed; we are pushing for the construction of a transversely polarized target within the next two to three years. A section of the TAPS detector has become the forward detection array (end cap) of the CB, substantially improving the acceptance at forward angles. The tagged photon flux at MAMI is 10-100 times larger than at other facilities. The combination of high photon flux, both linearly and circularly polarized beams, a polarized target, and a 4π detector with a forward wall presents an excellent opportunity for experiments in the first and second baryon resonance region of high interest and quality.

While the Crystal Ball is an almost-4π photon spectrometer, including the TAPS detector as an end cap increases that coverage in the all-important forward direction. While this in itself provides a unique opportunity to measure reactions in which one or more of the

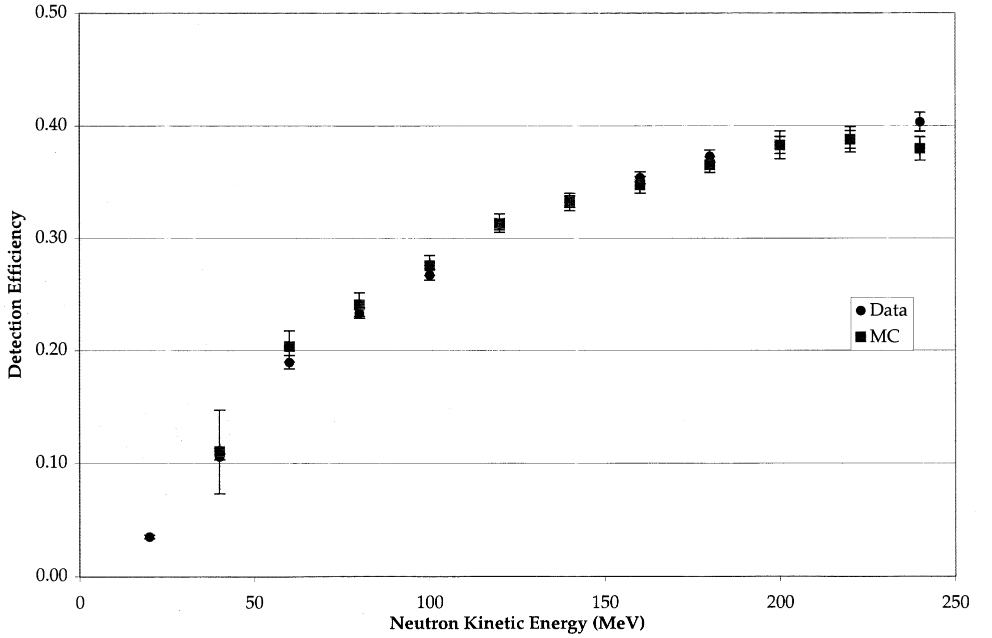

Figure 8: The neutron detection efficiency obtained with the Crystal Ball using the reaction $\pi^- p \to \pi^0 n$ measured for four π^- beam momenta [St01].

final-state particles decay into photons, the fact is that both the Crystal Ball [Fig. 8] and TAPS also have a high detection efficiency for neutrons. This, coupled with the excellent energy resolution of the MAMI tagged photon beam, provides an opportunity to make precision measurements of the heretofore sparsely measured [Fig. 2] neutral photoproduction channel $\gamma n \to \pi^0 n$, providing high-quality input to the new SAID and MAID analyses. This channel has never been measured by detecting both photons and the neutron (except for one exploratory measurement at Daresbury [Cl74]). There are also some older measurements that were made with bremsstrahlung beams [An77],[He75],[Ba72]. It should be noted that even in the case where there seems to be sufficient existing data for the $\gamma n \to \pi^- p$, the angular coverage is insufficient to help decide between competing analyses due to a lack of data in the backward angles [Fig. 3].

While only the position information of the neutron (θ, ϕ) is measured in the Crystal Ball, in the forward direction a measure of neutron energy is given by the TAPS detector. This information provides a way of extracting a measure of the recoil of the "spectator" proton, p_s. Thus, it is expected that the measurements made at MAMI will not only have lower background, but also a better handle on the problem of using a neutron bound in the deuteron as a target. In all cases, the neutron detection efficiency is known to about 3% [St01].

3.2 Physics Plan for Year One

3.2.1 Cross Section Measurements

We will carry out this experiment using the upgraded A2 tagged photon facility. During the initial running we will measure differential cross sections using a LD2 target. We plan to run with two photon beam settings. The first setting would include the entire range of tagged photon beam energies and would be primarily to obtain complete angular distributions below E_γ = 900 MeV which overlaps existing data for the reaction $\gamma n \to \pi^0 n$, but fills in the angular range of the existing measurements. The second setting would only look at events with tagged photons above E_γ = 900 MeV and would measure this reaction in a region in which no present data exist with higher statistics than if the entire tagger were on. Data on our other reactions of interest for this proposal, as well as data for other measurements being proposed, will be obtained in the process. We estimate that 100 hours of full tagger energy range and 250 hours of high-energy running should be sufficient to obtain differential cross sections with 5% statistics in bins of 20 MeV and cos θ of 0.1. While having circularly polarized photons is not a requirement for this stage of running, it would not interfere with the cross-section measurements and would provide the opportunity to measure say a double polarization in the $K\Lambda$ production. Our beam request overlaps with the request of other proposals and can run well in coordination with them.

3.2.2 Linearly Polarized Beam Measurements

Linearly polarized photons will be produced by the coherent bremsstrahlung facility and would provide photons of differing degrees of polarization that are most useful between approximately 1/4 to 1/2 E_0. Linear polarization over this range varies with fraction of the electron beam energy from about 0.4 to 0.7 [Fig. 9]. Tuning the position of the polarization maximum is done by adjusting the goniometer.

Since no present data exist for these reactions, and since for the $\gamma n \to \pi^0 n$ differences in SAID and MAID predictions are fairly large, especially at back angles, we estimate that 600 hours of linearly polarized beam, while not providing the same uncertainties at all angles and energies, would provide data of sufficient quality to make a significant contribution to the present PWA. Several settings for the goniometer will be required to position the intensity/polarization maximum at different energies [Fig. 9].

We are not concerned here with exact energies during the first round of data taking and the exact positions of the polarization maxima will be discussed with the spokespersons of the experiments with compatible running conditions. Again here, we see very little need for dedicated beam time, however, after consideration of initial analysis we will approach the director and/or PAC for additional time if the physics warrants further investigations in a specific energy region.

Circularly polarized photons will be provided by bremsstrahlung of longitudinally polarized beam electrons and have higher polarization closer to the end-point energy. For single-pion photoproduction, only linearly polarized photons are of interest or even useful. However, there is merit in making measurements with circularly polarized photons for the double meson production and the $K\Lambda$ production reactions. Here we would anticipate approximately 600 hours of circularly polarized beam. Again we are compatible with other

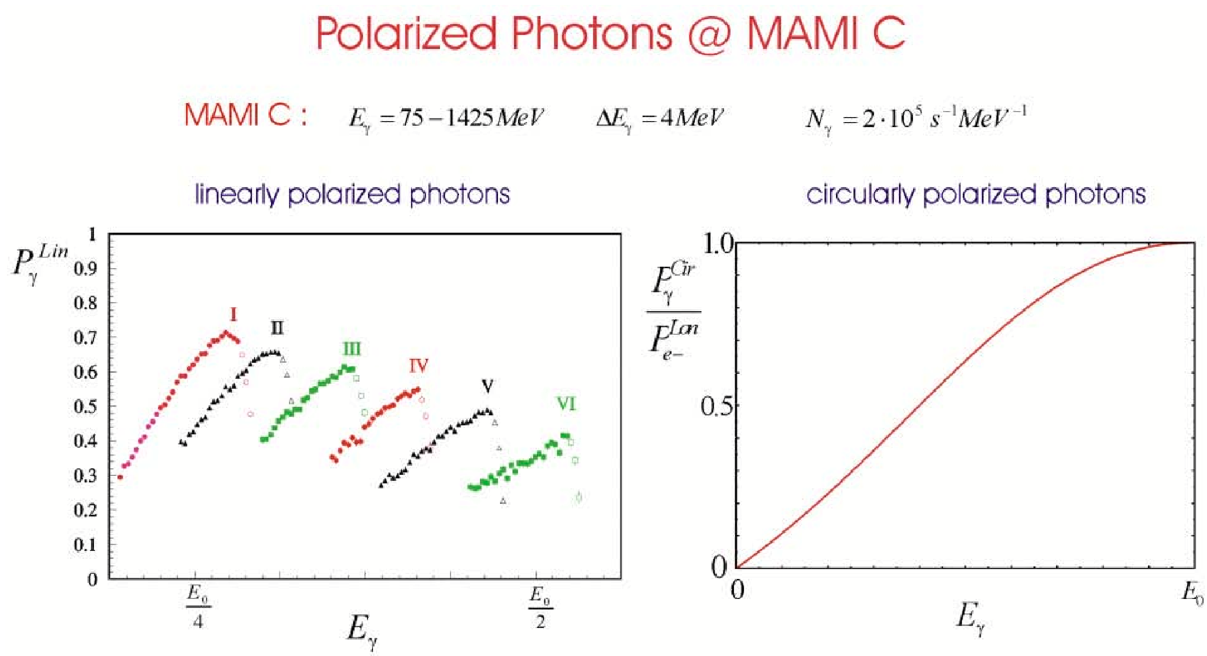

Figure 9: Energy distribution of linearly polarized photon beam at several goniometer settings.

experiments, however, we may request special running conditions after preliminary analysis. This might occur in the case of the $K\Lambda$ production where the Λ is self analyzing and may require measurements with special beam conditions and a high-multiplicity trigger to gain more statistics.

3.3 Physics Plan for Years Two and Three

3.3.1 Double-Polarization Measurements

The new Mainz frozen-spin target will be used to provide polarized neutrons (deuterons) for this and other A2 experiments. The target material is deuterated butanol (C_4H_9OH). This target is expected to be operational early in 2007. The system consists of a horizontal dilution refrigerator that is now being built at Dubna, and a 5 Tesla superconducting magnet which is used during the polarization process. The dynamic nuclear polarization is driven by a microwave system. In frozen-spin mode the target is cooled and maintained at 50 mK. An internal superconducting coil “holds” the polarization with a magnetic field of ~ 0.4 Tesla. In similar systems a maximum polarization for deuterons of near to 0.7 has been reached with a relaxation time of better than 100 hours. We expect to re-polarize every other day - this process takes about 6 hours. The target is 2.5 cm long ($\phi \sim 2.5$ cm) so that the number of polarized nucleons is of the order of 0.5×10^{22}. This estimate includes a dilution factor that takes into account unpolarized deuterons and a “filling factor”.

Except for the $K\Lambda$ reaction, no double-polarization measurements can be taken without the availability of a polarized target. While, because of the significant contributions possible to the field, we would request the acceleration of the development of a transversely polarized target, it is recognized that for the near future we will only have a longitudinally polarized target. Thus, in this request we will only address time for measurements using a longitudinally polarized target. Additionally, we recognize that one of our colleagues is developing a recoil hadron polarimeter, which would be most welcome and expand the range of our measurements. However, since it is in a very preliminary stage of development, we will await further news before assuming its availability.

Here again our beam-time request is based on the reaction $\gamma n \to \pi^0 n$. To obtain measurements of G and E of the order of 10% uncertainty, we would need approximately 600 hours of linearly polarized beam on target. The dominant consideration is that the longitudinal beam polarization in one region of interest near the $S_{11}(1535)$ only reaches about 40% even though lower intensity and polarization maxima are higher.

We will obtain data with circularly polarized beam for the $K\Lambda$ and the two-meson final states simultaneous with the experiment of Pedroni *et al.*. The time requested by that experiment provides sufficient beam to fulfill those goals which would utilize circularly polarized beam.

4 Personnel Contributing to this Proposal

The contact spokesperson, William Briscoe of the George Washington University, and the co-spokespersons, Mark Manley from Kent State University and John Price from California State University, Dominguez Hills, are contributing members to the Crystal Ball and TAPS Collaboration at MAMI. They provide expertise to this program in data acquisition and analysis. All have undergraduate and/or graduate student support from their institutions for these experiments.

William Briscoe, Igor Strakovsky, and Ronald Workman, together with Richard A. Arndt, are members of the GW DAC (SAID) group and together with additional George Washington University collaborators Cornelius Bennhold, Harald Griesshammer, Helmut Haberzettl, and Yordanka Ilieva, represent many decades of experience in phenomenological, experimental and theoretical nuclear physics at GW.

Prof. Hartmuth Arenhoevel, Dr. Michael Schwamb, and Dr. Alexander Fix are working with us in the area of the corrections necessary to extract pion photoproduction cross sections on the neutron using deuterium and ^3He targets. Dr. Fix visited GW this year to discuss with this and other topics such as the coherent photoproduction neutral pions from the deuteron of with our experimenters and theorists.

Dr Viatcheslav Kouznetsov of the Institute for Nuclear Research, Moscow was recently a visiting guest scientist working in Hall B at JLab. We have previously collaborated him at GRAAL on the analysis of a beam asymmetry measurement [Ba02] and he will join for this proposal to assist us with analysis.

Professor Alexander Kudryatsev, Dr. V.E. Tarasov, both of ITEP, have worked very closely with us on several projects. They, with Prof Maxim Polyakov, Ruhr-Universitaet, Bochum, and Prof Yakov Azimov, PNPI, Gatchina, will provide theoretical support of the analysis and interpretation of our data.

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