CEBAF Program Advisory Committee Eight Cover Sheet

This proposal must be received by close of business on Thursday, April 14, 1994 at:

CEBAF
User Liaison Office, Mail Stop 12 B
12000 Jefferson Avenue
Newport News, VA 23606

Proposal Title

Photoproduction of η and η' Mesons from Deuterium

Contact Person

Name: Barry G. Ritchie
Institution: Arizona State University
Address: Department of Physics and Astronomy
Address: Box 871504
City, State ZIP/Country: Tempe, AZ 85287-1504
Phone: (602) 965-4707 **FAX:** (602) 965-7954
E-Mail → Internet: barry.ritchie@asu.edu

Experimental Hall: B
Total Days Requested for Approval: 23
Minimum and Maximum Beam Energies (GeV): 1.6
Minimum and Maximum Beam Currents (μAmps): Photon tagger standard

CEBAF Use Only

Receipt Date: 4/14/94 PR 94-005

By: [illegible]

HAZARD IDENTIFICATION CHECKLIST

CEBAF Experiment: 94-008 **Date:** 5/25/94

Check all items for which there is an anticipated need—do not check items that are part of the CEBAF standard experiment (HRSE, HRSH, CLAS, HMS, SOS in standard configurations).

Cryogenics ___ beamline magnets ___ analysis magnets ✓ target ___ drift chambers ___ other	**Electrical Equipment** ___ cryo/electrical devices ___ capacitor banks ___ high voltage ___ exposed equipment	**Radioactive/Hazardous Materials** List any radioactive or hazadorous/toxic materials planned for use: ___ ___
Pressure Vessels ___ inside diameter ___ operating pressure ___ window material ___ window thickness	**Flammable Gas or Liquids** (incl. target) type: deuterium flow rate: < 1 liter/hr (est.) capacity: ~0.3 liter	**Other Target Materials** ___ Beryllium (Be) ___ Lithium (Li) ___ Mercury (Hg) ___ Lead (Pb) ___ Tungsten (W) ___ Uranium (U) ___ Other (list below)
Vacuum Vessels ___ inside diameter ___ operating pressure ___ window material ___ window thickness	**Radioactive Sources** ___ permanent installation ___ temporary use type: ___ strength: ___	**Large Mech. Structure/System** ___ lifting devices ___ motion controllers ___ scaffolding or elevated platforms ___ other
Lasers type: ___ wattage: ___ class: ___ **Installation** ___ permanent ___ temporary **Use** ___ calibration ___ alignment	**Hazardous Materials** ___ cyanide plating materials ___ scintillation oil (from) ___ PCBs ___ methane ___ TMAE ___ TEA ___ photographic developers ___ other (list below)	**Notes:** All items refer to CEBAF standard liquid deuterium target

CEBAF Research Proposal

Photoproduction of η and η' Mesons from Deuterium

Participants:

Arizona State University: B. G. Ritchie (Spokesman)
CEBAF: B. A. Mecking
Georgetown University: J. Lambert
University of Richmond: G. P. Gilfoyle, R. W. Major, M. F. Vineyard
University of South Carolina: G. Blanpied, C. Djalali, B. Preedom, and S. Whisnant
CEBAF Large Acceptance Spectrometer Collaboration

ABSTRACT

Differential cross sections for photoproduction on deuterium of η and η' mesons will be measured using the Hall B Bremsstrahlung Photon Tagger and the CEBAF Large Acceptance Spectrometer. Tagged photons of energies from 0.60 to 1.52 GeV will be incident on a liquid deuterium target. For coherent photoproduction, identification of the η and η' will be made by detection of the recoil deuteron in the CLAS. Cross sections for incoherent η photoproduction will be made by detecting one of the nucleons and the two photons arising from the meson decay, while incoherent η' photoproduction will be measured by detecting one of the nucleons and the pions and photon arising from η' decay into a ρ. The measurements will provide important information on the behavior of these mesons in a lightly bound two-nucleon system, give insight into the structure of the $S_{11}(1535)$ and $P_{11}(1710)$ nucleon resonances, extend knowledge of the properties of the mesons themselves, and form a firm basis for future experiments studying η and η' interactions with heavier nuclei.

April 14, 1994

I. Scientific Motivation

A. Introduction

This research proposal seeks beam time in Hall B using the CLAS and the CEBAF Bremsstrahlung Photon Tagging Spectrometer to measure differential cross sections for coherent and incoherent (breakup) photoproduction of $\eta(547)$ *and* $\eta'(958)$ *mesons on the deuteron for photon energies from 0.63 to 1.52 GeV.* These measurements are of great interest for many reasons, among which are:

1. Existing data on coherent and incoherent photoproduction from deuterium are limited to a few non-zero data points near threshold with large uncertainties.

2. Existing theories of the mechanisms believed responsible for photoproduction of η mesons on deuterium are grossly inconsistent with the sparse measured cross sections.

3. Data on the photoproduction of η' mesons from the deuteron are non-existent.

4. Deuterium η and η' photoproduction measurements are a critically needed complement to studies of the photoproduction of these mesons on the proton and on heavier nuclei.

5. Models of isoscalar nucleon resonances can be subjected to stringent tests by data obtained from coherent and incoherent photoproduction of η and η' mesons from deuterium.

The present lack of high quality data for photoproduction of these mesons is primarily due to the unavailability of appropriate experimental facilities to make such measurements. The combination of resources to be available at CEBAF in Hall B, however, will be well-suited to making such measurements. As indicated in the Conceptual Design Report(CDR) [1], the Bremsstrahlung Photon Tagging Spectrometer will provide good photon energy resolution ($dE/E_0 = 0.3\%$) over a wide energy range (0.20-0.95E_0) at high photon flux ($> 10^7$/s), essential to obtaining cross sections for both mesons with useful precision in reasonable beam times. The CDR also notes that a substantial effort will be devoted to photon beam monitoring to permit precision measurements of absolute cross sections. Within the capabilities specified in the CDR and presently being implemented by the Tagger Working Group, our investigations of the design of this experiment indicate the tagger capabilities will be very suitable for these measurements.

The experiment design studies described below also indicate that the CEBAF Large Acceptance Spectrometer (CLAS) is more than adequate to perform measurements of kinematical variables with the firm particle identification required to isolate the meson production process from other background processes. Our preliminary simulations of the CLAS acceptance indicate that coverage of most of the center-of-mass angle range for the coherent photoproduction process can be obtained, as well as usable coverage of much of the forward hemisphere for incoherent photoproduction. The overall acceptance is sufficient, based on cross sections estimates, to permit the measurements desired to be made within a reasonable period of beam time. Finally, the CEBAF electron accelerator will provide high quality continuous electron beams with energies considerably greater than the 1.202 GeV η' photon energy threshold, making possible measurements at and beyond threshold for the photoproduction of that particle.

Using this combination of unique resources, the cross sections provided by this experiment for η photoproduction will be of much greater precision than existing measurements and will greatly extend coverage to regions presently unmeasured and inaccessible at other facilities. At the same time, the first extensive cross sections for η' photoproduction will be measured. The simultaneous measurement of both coherent and incoherent processes for η and η' photoproduction will help elucidate the isospin structure of the electromagnetic transition densities, and, as a complement to a previously approved study of photoproduction on the proton, will facilitate specific determination of the amplitudes for photoproduction on the neutron.

The proposed experiment meshes closely in terms of experimental requirements with several of the approved experiments using the tagger, supplements the present generation of photoproduction experiments elsewhere, and also complements the CEBAF electroproduction measurements presently under consideration by the Nucleon Resonance collaboration. It will also provide a foundation for subsequent studies by the collaboration of the photoproduction of these mesons by heavier targets and with polarized photons and/or polarized targets.

B. Photoproduction of η mesons from deuterium

Because the η and η' mesons are members of the fundamental meson nonet, the study of η photoproduction shares many of the motivations of the extensive study of pion photoproduction over the past fifteen years or so. Those studies have provided considerable data for investigations of the properties of nucleon resonances and their dynamics within the nuclear medium. The isoscalar nature of the η meson, however, adds the possibility of an "isospin" filter for aiding the deconvolution of the series of broad and overlapping nucleon resonances. Thus, with the advent of facilities such as CEBAF, the possibility of systematic precision studies of η photoproduction over a broad range of center-of-mass energies, momentum transfers, and nuclei offers a powerful tool for studying intensively the response of nucleon resonances in the nuclear medium and the quark model properties of the nucleon itself.

However, before these tools can be exploited, a sound understanding of the interactions of these mesons with nucleons is needed. The lightly-bound deuteron provides the simplest nucleus for studying these interactions via coherent and incoherent photoproduction. Analyses of the deuterium measurements, in concert with studies of the results of proton η and η' meson photoproduction experiments, should provide information on the neutron photoproduction amplitudes, yield data on the properties of the specific $I = 1/2$ nucleon resonances associated with η and η' photoproduction, and determine the role of meson rescattering in the photoproduction process.

Coherent η photoproduction must proceed through the isoscalar part of the electromagnetic transition amplitude due to the isoscalar nature of the η and the deuteron.

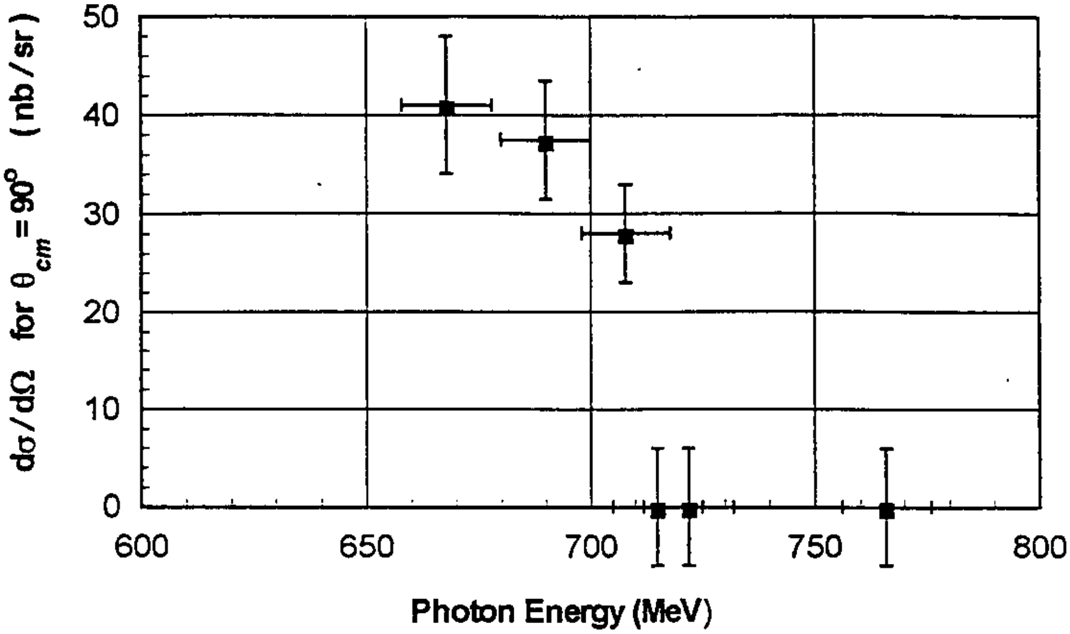

Figure 1: Existing differential cross section data for coherent η photoproduction on deuterium from Ref. [5].

At threshold, the reaction should proceed through coupling to the $S_{11}(1535)$ resonance. Photopion results [2] indicate that the electromagnetic transition amplitude for that resonance is primarily isovector ($T^1 \gg T^0$). These photopion results for the transition amplitude are consistent with quark models of the $S_{11}(1535)$ resonance [3, 4]. In the impulse approximation, then, coherent photoproduction would proceed through the small T^0 amplitude. Since the isoscalar amplitude would be given by $T^0 = T^p + T^n$, where $T^p(T^n)$ is the proton (neutron) amplitude, and photopion results and quark models agree that $T^p \approx -T^n$, in the impulse approximation the coherent photoproduction cross sections should be essentially zero.

The existing coherent photoproduction differential cross section data set comes from a single experiment by Anderson and Prepost [5]. The cross section measurements were made by detecting the recoiling deuteron in a magnetic spectrometer following the bremsstrahlung photoproduction of η mesons in a liquid deuterium target. All measurements were made at scattering angles of 90^o in the center-of-mass. Particle identification in the spectrometer was performed using range, energy loss, and time-of-flight measurements. Yields were determined as the electron beam energy was raised to give a corresponding increase in the bremstrahlung endpoint energy. Without photon energy definition, the experiment had to extrapolate multipion background below η threshold to regions at and above threshold. The resulting coherent photoproduction cross sections are shown in Figure 1. Far from being small, the measured cross sections are comparable to coherent photopion cross sections on deuterium in the same energy region (e.g: refs. [6]-[8]).

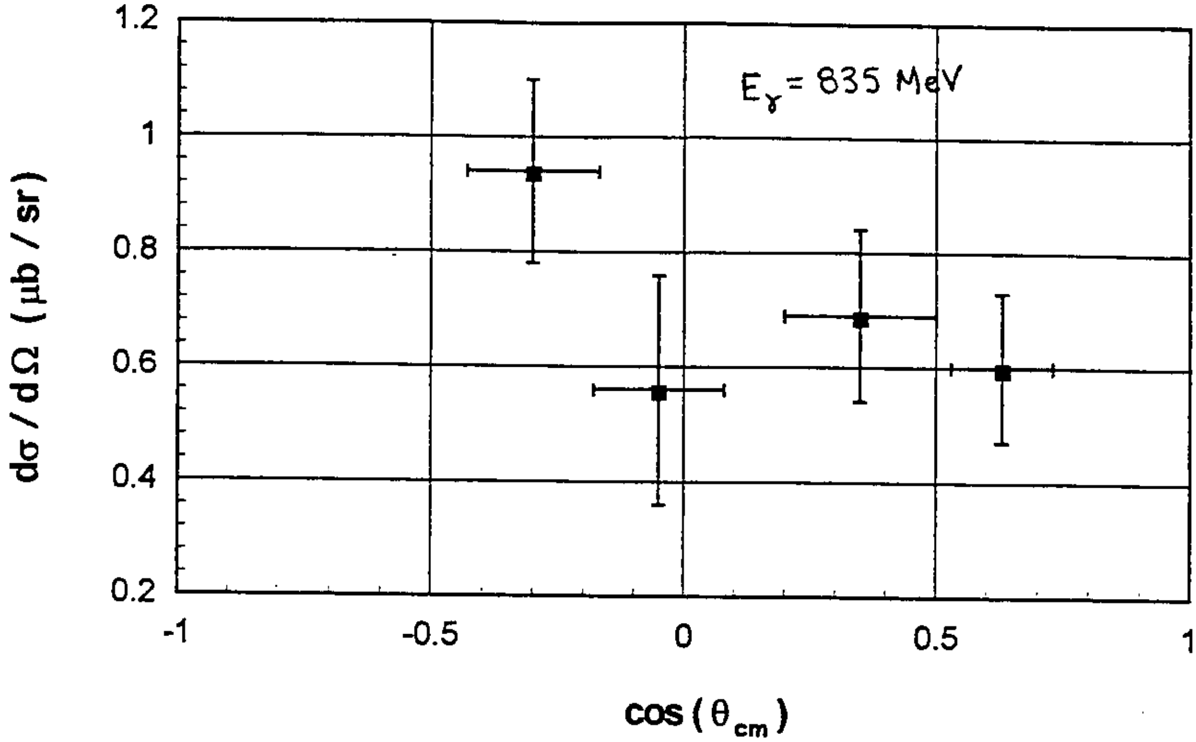

Figure 2: Existing data on incoherent η photoproduction on deuterium from Ref. [9].

Incoherent photoproduction cross sections for deuterium were made at about the same time by Bacci, *et al.* [9]. In this case, the detection technique observed the two photons arising from the decay of the η meson. The same bremstrahlung tail technique employed by Anderson and Prepost was used to determine the yields for the incoherent process, and the same background interpolation for multipion photoproduction had to be performed. The data are shown in Figure 2. In comparison with their $\gamma + p \rightarrow \eta + p$ data [10, 11], Bacci *et al.* found the cross sections for the incoherent process to be approximately a factor of two greater than the proton photoproduction cross sections, and that the proton and deuteron angular distributions were similar. This led them to the conclusion that the proton and neutron amplitudes added incoherently and were about equal.

By combining the coherent and incoherent cross sections and assuming the validity of the impulse approximation, Ref. [5] determined that $T^0/T^1 \approx 1$, which is clearly in disagreement with the photopion and quark model results discussed above. Subsequent analyses [12, 13, 14] have obtained agreement with the cross sections, as seen in the example in Fig. 3, for values of this ratio from 0.6-0.8, but those ratios are also at variance with the photopion and quark model results. Using the accepted value for the isoscalar $S_{11}(1535)$ electromagnetic transition amplitude, the best theoretical predictions are from 2 to 5 times lower in magnitude than the measurements of Ref. [5], even when rescattering is included. (While rescattering, and even double rescattering, effects are suggested to be important in understanding coherent photopion production, as in, for example [15], the most recent analyses indicate such contributions to coherent η photoproduction are of little help in resolving this discrepancy, partially due to the isoscalar nature of the η meson.)

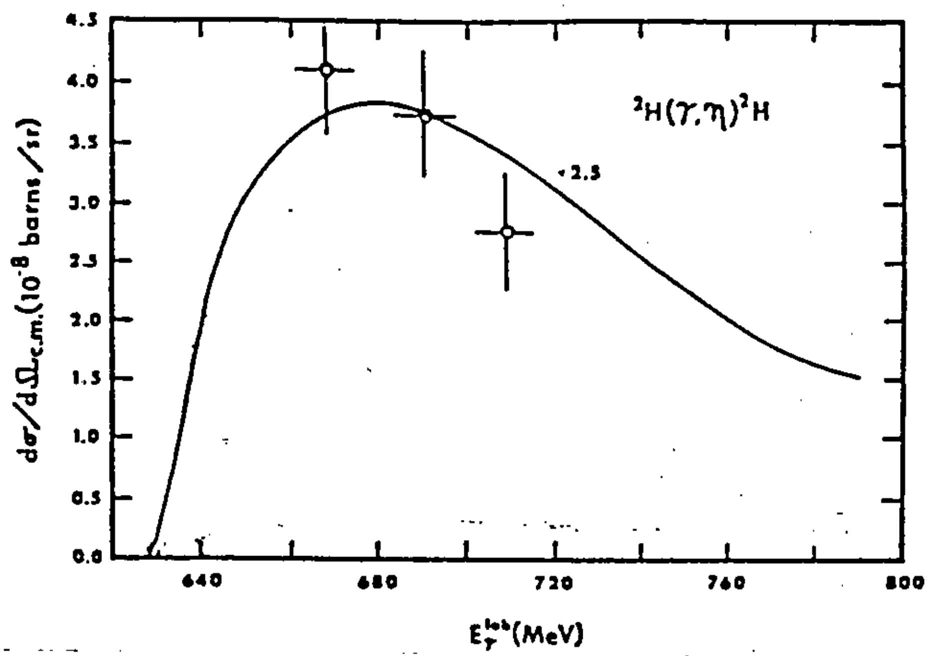

Figure 3: Existing data on coherent η photoproduction cross sections on deuterium, compared with an impulse approximation calculation with rescattering included from Ref. [13]. The calculation has been multiplied by a factor of 2.5.

While it is true that, as pointed out in [12], this discrepancy rests on three assumptions (the reaction occurs principally through the $S_{11}(1535)$ resonance, the impulse approximation gives the dominant contribution to the amplitude, and the isoscalar transition amplitude is small), these assumptions are believed to be on sound grounds and are generally well-accepted. An implicit fourth assumption, the validity of the data, can only be tested by new measurements. Further, tests of the importance of rescattering can be obtained from reasonably complete angular distributions, with particular emphasis on large scattering angles.

With accurate coherent and incoherent cross sections, and with the results of the next generation of $\gamma + p \rightarrow \eta + p$ measurements, stringent tests of the details of the reaction mechanism and nucleon models can be applied. If rescattering is important, the incoherent cross sections provide an avenue to get at the neutron and proton amplitudes more directly. Recently, Zhang and Anderson [16] have noted that the angular dependences of the T^0 and T^1 components of the incoherent reaction mechanism are quite different, and that the ratio of coherent to incoherent cross sections can provide a signature for the isospin components of the $S_{11}(1535)$ electromagnetic transition amplitudes.

The above discussion has focussed on coherent and incoherent η photoproduction measurements at the threshold and an understanding of the nature of the $S_{11}(1535)$ resonance. Of course, other resonances have strong ηN couplings (e.g.: the $P_{11}(1710)$), but *no data at all exists except at threshold.* Questions concerning the behavior of other resonances, as well as the η photoproduction background, cannot be addressed at all at present due to lack of data and the faciltities to obtain that data. Thus, there is a profound need for coherent and incoherent η photoproduction data on deuterium which span a broad angular range and stretch well above the present energy coverage in order to address these issues.

C. Photoproduction of η' mesons on deuterium

As noted in the CEBAF proposal to study η' photoproduction on the proton [17], simultaneous measurements on deuterium photoproduction of that meson should provide insight on the structure of those resonances to which the η' couples. Further, due to the differing wave functions for the η and η' , coherent and incoherent photoproduction cross section measurements on deuterium for both mesons should also provide additional insight into resolving questions concerning the structure of the η and η' mesons themselves when coupled with the proton measurments [17, 18].

The availability of η' cross sections would provide a very challenging new arena for probing the quark model understanding of light mesons and nucleons. At present, however, *no data exist* for η' photoproduction on deuterium, and essentially none exists for the proton [19]. Thus, an initial study such as that proposed here and in Ref. [17] are essential to open up the field of η' -nucleon physics.

D. Relation to present and future directions

This experiment represents an important component of a series of related initial studies of the photoproduction of eta mesons and their interactions with nucleons. The measurement of photoproduction of η and η' mesons on deuterium represents a logical complementary study for an approved CEBAF experiment which will measure the photoproduction cross sections for these mesons on the proton [17]. The data obtained in that experiment and experiments elsewhere should greatly improve our knowledge of the dynamics of η and η' photoproduction on the proton.

However, it should be clear from the above discussion that, based on the present failure to understand the existing deuterium photoproduction cross sections, it is doubtful whether a sound understanding of the neutron amplitudes exists. These deuterium measurements would provide a useful "theoretical laboratory" for probing those issues and the coherent and incoherent measurements should yield information specific to the neutron. As noted above, the large angle data should be useful in resolving the rescattering question.

A better understanding of the neutron amplitudes and the role of rescattering will provide a firm footing for further ventures in eta-nucleus physics. For instance, the use of polarized beams and targets for both the proton and deuteron experiments, is essential for a helicity amplitude analysis. Such studies are an obvious future direction to complement these first studies. Such analyses can provide a tightly constrained interpretation of the observables based on the pertinent multipole transition components, which in turn provide stringent tests for models of nucleon resonances.

The shortcomings in interpreting the existing coherent photoproduction data on deuterium also reflect to a degree the limits of our understanding of the propagation of the

$S_{11}(1535)$ and $P_{11}(1710)$ nucleon resonances within nuclei, the subject of an η electroproduction proposal on the nucleon [20] and the subject of a η photoproduction proposal for heavy nuclei [21]. Further steps towards a microscopic understanding of the phenomena associated with the propagation of these resonances in nuclear matter can be made with the improvement in the database for the fundamental photon-nucleon meson production process that this experiment will provide. Follow-up experiments with polarized targets for heavier nuclei and polarized photons, as well as attempts at photoproduction leading to excitation of discrete states in the target nucleus, are obvious subsequent steps to the initial experiments planned on heavy nuclei. These will certainly exploit the information gained on the fundamental photo-nucleon meson production in this experiment.

While this brief list does not exhaust all possibilities for future η and η' experiments, the discussion underscores the importance of the measurements to be made in this experiment and their relation to further progress in the field of eta-nucleus interactions.

II. Experimental Method

A. General information

The coherent measurements will use the CLAS and photon tagger in standard configuration as described in the CEBAF Conceptual Design Report. The incoherent measurements will require calorimeter instrumentation out to 75 degrees in two opposing sectors in addition to the standard 8 to 45 degree coverage on all sectors. Using an incident electron beam energy of 1.6 GeV, the photon tagger focal plane energy acceptance will be binned in energy bins of 75 MeV. The full acceptance of the tagger focal plane would provide photon energies from 0.32 GeV (well below threshold for coherent η photoproduction) to 1.52 GeV. For this experiment, a tagged photon flux of 1×10^7 photons/sec in the energy range from 0.6 to 1.52 GeV will be used. Instrumentation of all sectors of the CLAS will be necessary for kinematical reconstruction of events.

The kinematics to be explored by photon energies from 0.60 to 1.52 GeV will span a center-of-mass energy range of from 2.40 GeV (corresponding to η threshold) to 3.04 GeV. As noted in Table 1, the threshold for coherent η photoproduction on deuterium is 0.629 GeV, while that for η' is 1.202 GeV.

The target to be used for this and other approved first round experiments [21, 22, 23] is presently under design. Based on recent discussions of that design, we have assumed that the target geometry is a liquid-deuterium-filled cylinder 6.4 cm in diameter, about 8 cm long with 0.17 mm walls, and a density of approximately 1.2 g/cm^2.

B. Measurement techniques and simulations

1. Coherent photoproduction

The photoproduction cross sections for coherent η and η' photoproduction will be measured by detecting the recoiling deuteron following photoproduction.

a. Spectrometer acceptance

The scattering angles and kinematics for recoil deuterons following η production are

Reaction	E_{thr} (MeV)	Meson Mass (MeV/c^2)	Meson Decay Mode	Branching Ratio
$\gamma + d \rightarrow \eta + d$	629.2	547.45 ± 0.19	$\pi^+\pi^-\gamma$	5%
			neutrals	71%
			$\pi^+\pi^-\pi^0$	24%
$\gamma + d \rightarrow \eta' + d$	1201.9	957.8 ± 0.1	$\pi^+\pi^-\eta$	44%
			$\rho\gamma$	30%
			$\pi^0\pi^0\eta$	21%
$\gamma + d \rightarrow \pi^0 + d$	139.82	134.9734 ± 0.0008	2γ	99%
$\gamma + d \rightarrow \rho + d$	928.05	768.1 ± 0.5	$\pi^+\pi^-$	100%
$\gamma + d \rightarrow \omega + d$	945.02	781.95 ± 0.14	$\pi^+\pi^-\pi^0$	89%

Table 1: Reaction information pertinent to this proposal. [24]

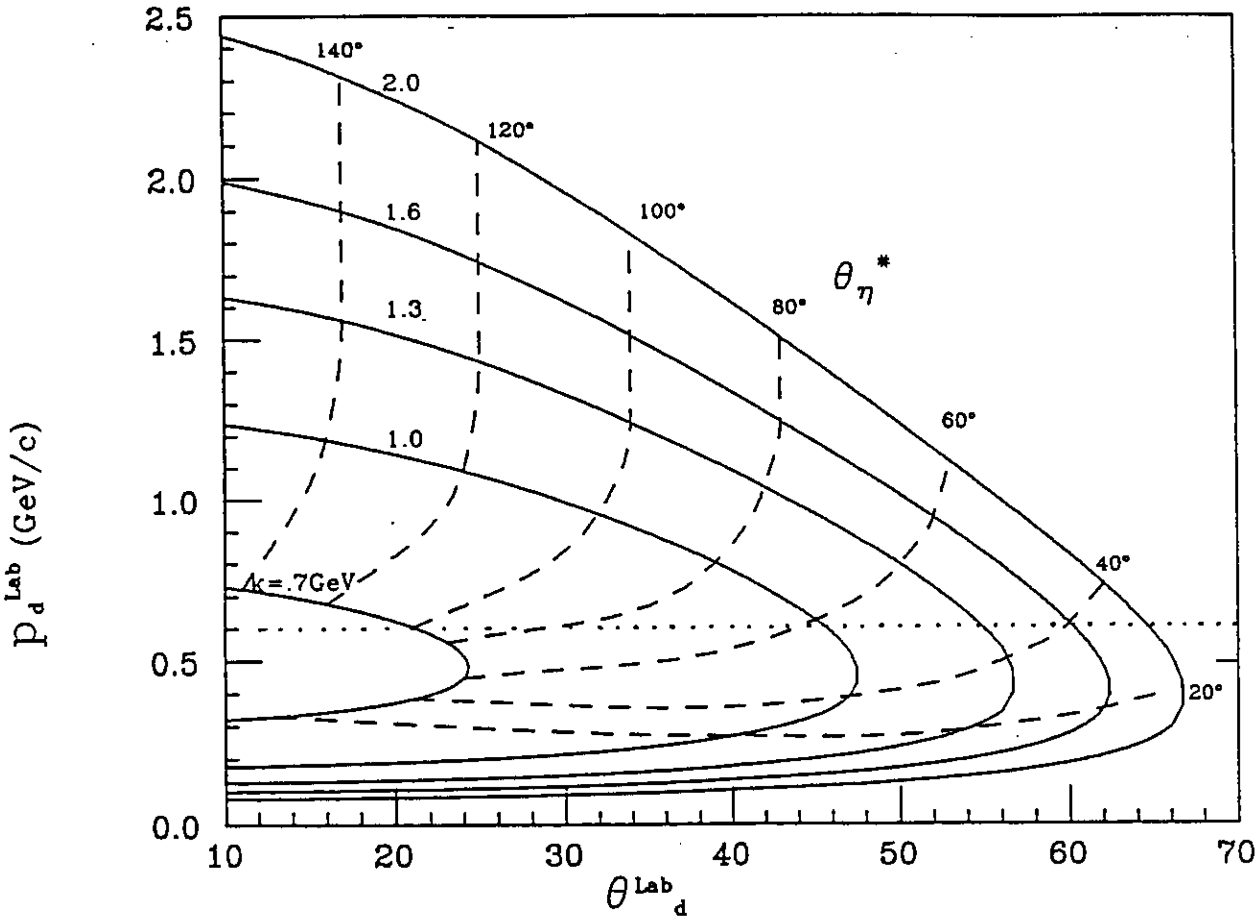

Figure 4: Kinematics for coherent η photoproduction on the deuteron for various photon energies.

shown in Fig. 4 for photon energies of 0.7 to 2.0 GeV. From that figure, it is seen that all of the recoil deuterons have laboratory scattering angles of about 66 degrees or less. Since the CLAS detection solid angle begins at about 8 degrees (which corresponds to an η meson scattering angle of about 20 degrees in the center-of-mass system for the lowest photon energies), the acceptance for smaller recoil angles is affected most by the uninstrumented downstream exit hole in the CLAS. To minimize the effects of this exit hole, the polarity of the magnetic field of the CLAS will be chosen to bend the deuterons outward so as to increase the acceptance for the protons with the lowest scattering angles. ϕ acceptance lowers the overall event rate but does not otherwise affect the differential cross section measurement.

Another limitation to be considered is a momentum threshold below which multiple Coulomb scattering in the target material and target walls compromise missing mass resolution to an unacceptable degree or result in markedly poorer angle resolution. For our simulations, we assumed a simple "worst case" scenario in which any deuterons with recoiling laboratory momenta of less than 600 MeV/c (corresponding to an energy of about 94 MeV) were excluded from analysis. Recoiling deuterons with momenta at this cutoff momentum would lose about 4% of their momentum in the target and surrounding material.

The overall impact of this momentum cut on acceptance can best be seen in Fig. 4, where a dotted line denotes the low momentum cutoff. These cuts obviously restrict the angular coverage and were incorporated in our simulations of the CLAS acceptance.

We have performed simulations of the CLAS acceptance for coherent η photoproduction with subsequent detection of the recoiling deuteron for incident photon energies of 0.7, 1.0, 1.3, and 1.6 GeV. We have for completeness also performed some simulations at 2.0 GeV to indicate the feasibility of higher energy studies in the future. We have investigated an experimental design assuming the use of the standard liquid deuterium target as presently contemplated for the CLAS, the standard CLAS geometry with a magnetic field which bends deuteron trajectories outward, and the low momentum cutoff discussed above.

The angular acceptance results for coherent η photoproduction are shown in Fig. 5. In general, the acceptance is relatively smooth and rapidly extends with increasing photon energy to cover η center-of-mass scattering angles from about 60 degrees to about 150 degrees. The overall detection acceptance, summed over all angles, is generally above 40% for deuterons resulting from coherent η photoproduction over nearly the entire energy range to be studied, as seen in Table 2.

Using this recoil deuteron detection technique for coherent η' photoproduction, the minimum lab scattering angle is similarly restricted by the CLAS layout. Because of the differing kinematics, however, the angular range subtended by the uninstrumented forward gap in the CLAS results in a somewhat smaller loss of solid angle coverage for η' photoproduction, as seen in the scattering angle kinematics shown in Fig. 6. The angular range subtended for the recoiling deuteron by CLAS instrumentation corresponds to η' angles from about 20 to 140 degrees in the center-of-mass at threshold. The use of a field polarity which bends the recoiling deuterons outward will be beneficial to the η' studies as well. The recoil deuteron lower momentum cut imposes an additional restriction, limiting small angle coverage for the η' to about 35 degrees for the produced η' in this case, as shown in Fig. 6.

Our simulations of the spectrometer acceptance under these conditions for η' photoproduction are summarized in Fig. 7 and Table 2. Again, the acceptance is seen to be relatively smooth, and the acceptance summed over all angles goes from about 40% near η' threshold to about 50% at 1.52 GeV.

GeV	η	η'	ω	ρ	2π	π
0.7	15%	*	*	*	*	44%
1.0	48%	*	25%	21%	5%	55%
1.3	56%	37%	51%	44%	27%	59%
1.6	60%	53%	57%	54%	31%	62%
2.0	62%	59%	61%	58%	42%	63%

Table 2: Angle-summed spectrometer acceptance for meson detection following coherent photoproduction on deuterium.

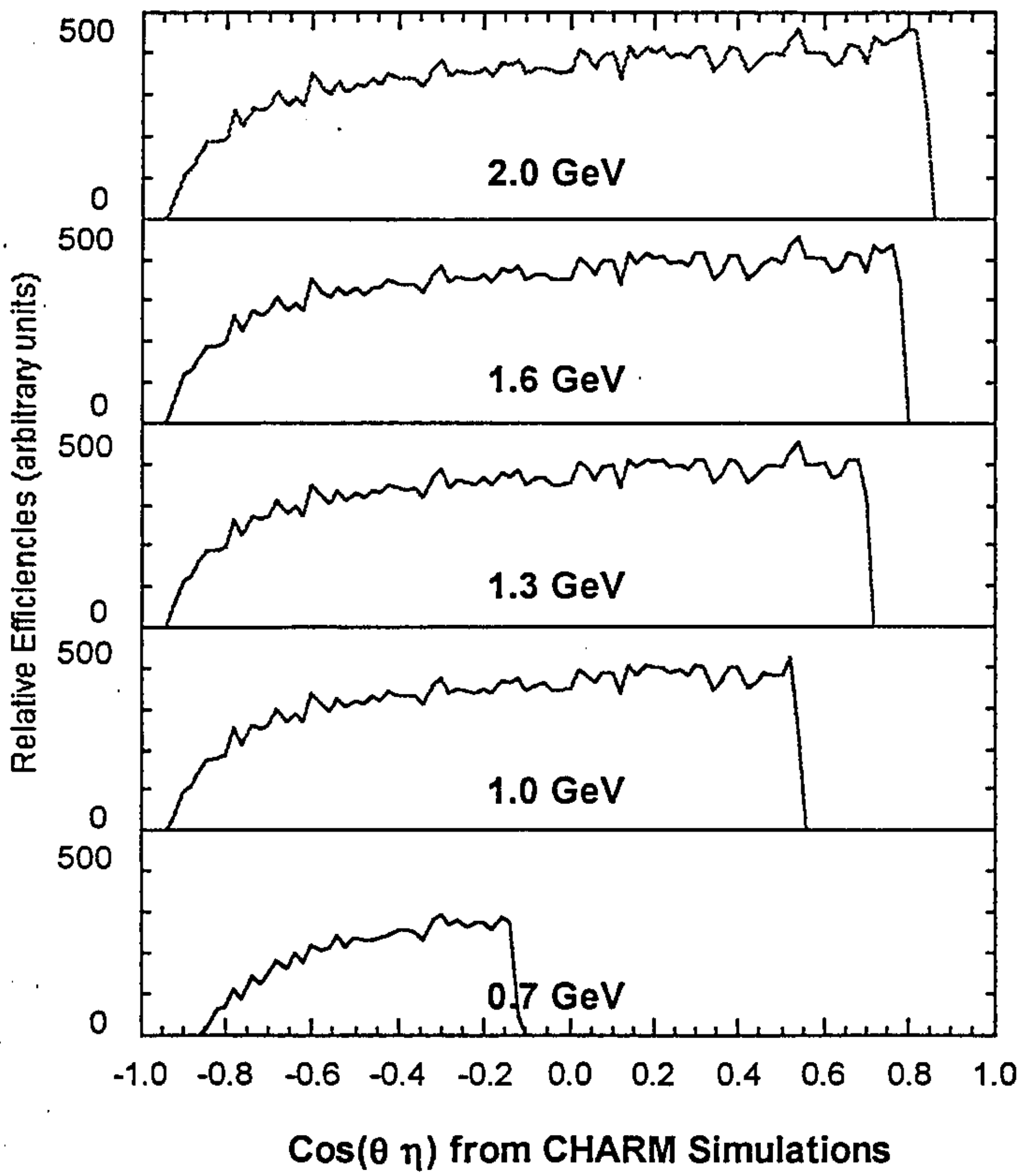

Figure 5: CLAS detection acceptance at various incident photon energies for coherent η photoproduction on deuterium, assuming CLAS detection of the recoil deuteron only.

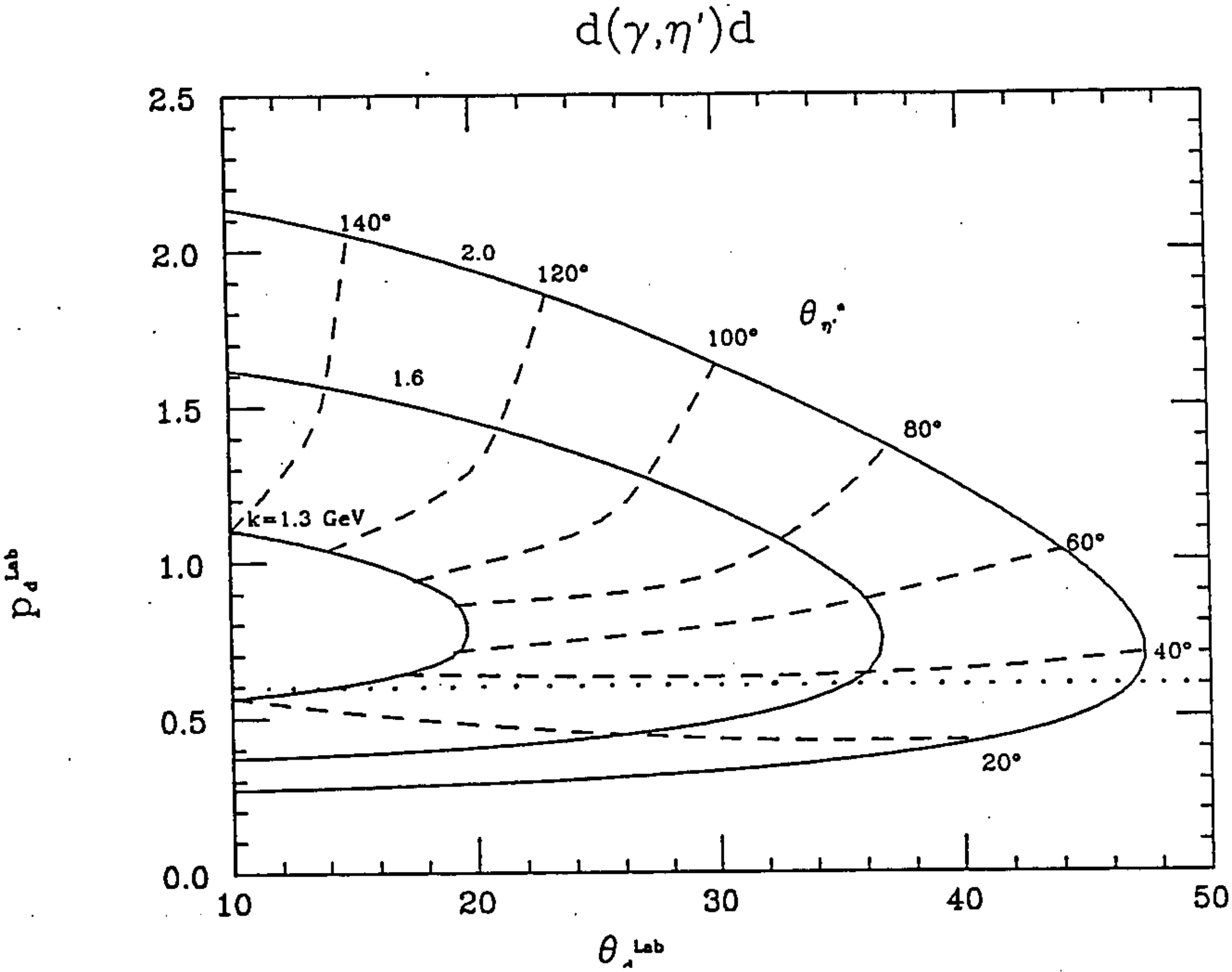

Figure 6: Kinematics for coherent η' photoproduction on the deuteron at various incident photon energies.

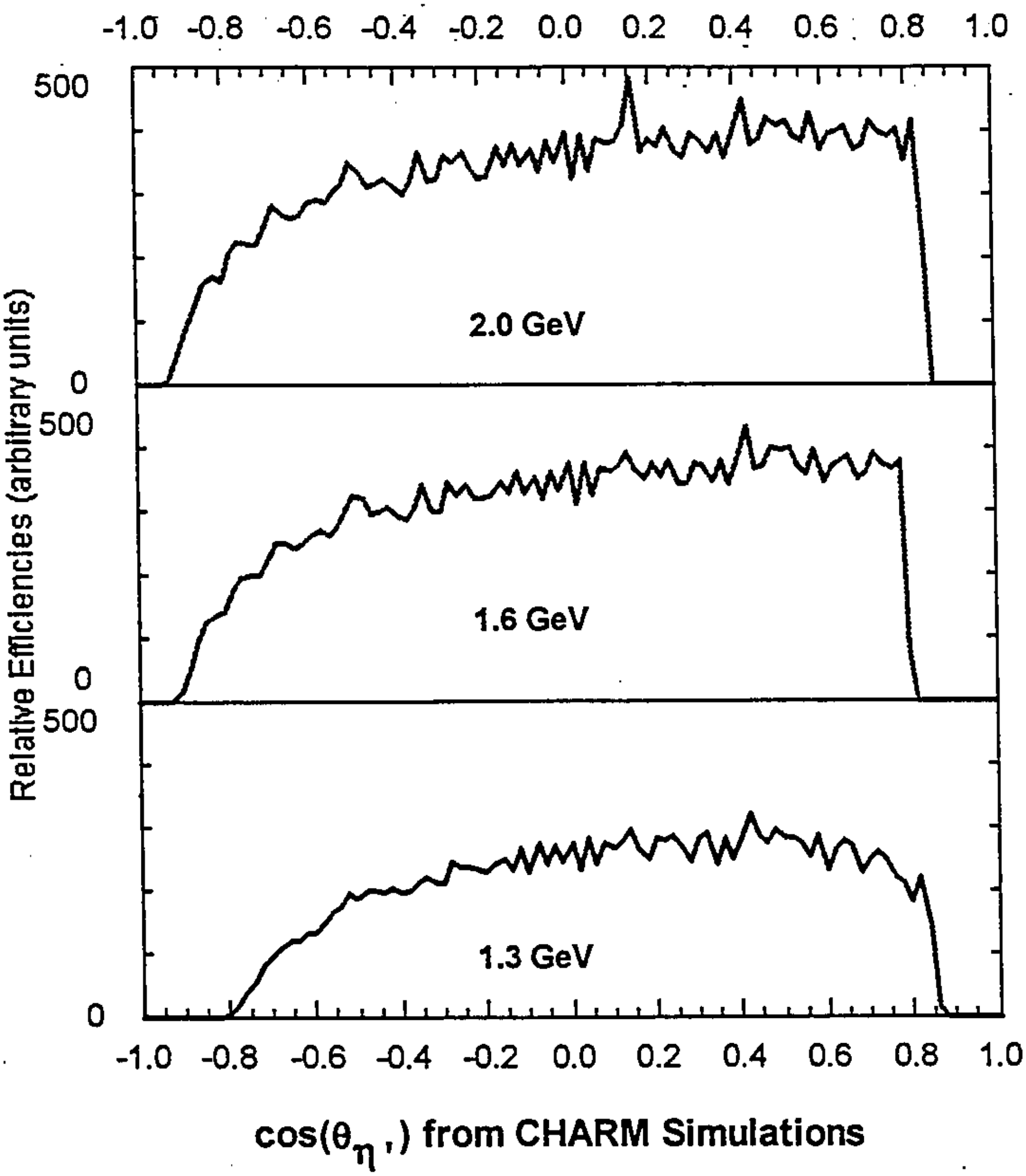

Figure 7: CLAS detection acceptance at various incident photon energies for coherent η' photoproduction on deuterium assuming CLAS detection of the recoil deuteron only.

b. Missing mass spectra

We have simulated missing mass spectra under the conditions mentioned above. To be complete, we have performed simulations for π, multi-π, η, η', ω, and ρ photoproduction using the masses and widths from the Particle Data Group [24]. The spectra were generated by simulating the CLAS acceptance for each particle, incorporating the appropriate angle and momentum resolution of the CLAS, applying the low momentum cutoff described in the preceeding section, and performing the missing mass reconstruction based solely on the kinematical information provided by the recoil deuteron.

Since the magnitudes and shapes of the differential cross sections for most of these processes are either unknown or poorly known, for the purposes of these simulations we have assumed uniform photoproduction angular distributions for all particles, and used weights for the cross sections at each energy that are guesses in most cases as to what these cross sections might be in order to generate full missing mass spectra. These weights, expressed as cross sections in nb, are given in Table 3.

As the target design is still somewhat uncertain, we have not explicitly included the multiple Coulomb scattering contributions to missing mass resolution in our simulations. An estimate of the worst effect of multiple Coulomb scattering on missing mass resolution can be made based on η coherent photoproduction near threshold. At an incident photon energy of 700 MeV, based on the deuterium target design noted above, the multiple Coulomb scattering contributions for deuterons at this cutoff momentum (from both the energy spread of the deuterons leaving the target and the effect on reconstructed missing mass due to altered scattering angle) would result in a spread in the reconstructed missing mass of about 3 MeV for the η meson. This degradation is tolerable for the smallest scattering angles where the cross sections are expected to be larger, and the effect on missing mass reconstruction for higher recoil momenta and higher incident photon energies will be much less.

An additional concern is the background resulting from photodeuteron production on the windows of the target. We have simulated the contribution from the windows by using the results of the parametrization of the inclusive ^{12}C photodeuteron production by Baba, *et al.* [25] for incident photon energies from 360 to 600 MeV. We are unaware of appropriate data for photon energies in our region of interest, but the cross sections appear to be slowly varying in energy, so we have used simple linear extrapolations of the published cross sections. These cross section values are listed in Table 3.

It is also unclear what fraction of inclusive photodeuteron production events will be

GeV	η	η'	ω	ρ	2π	π	^{12}C
0.7	250	*	*	*	*	500	58 μb
1.0	60	*	100	100	100	125	82 μb
1.3	50	10	30	30	50	100	106 μb
1.6	30	10	30	30	30	75	129 μb

Table 3: Arbitrary weights for different photoproduction channels assigned for simulated missing mass spectra (in nb, unless otherwise noted).

accompanied by other nucleons or nucleon clusters; photodeuteron production resulting in a deuteron and more than one nucleon being detected in the final state would be excluded from events for coherent photoproduction analysis, which requires only a deuteron be detected in the CLAS. As a worst case estimate, we have assumed that *none* of those photodeuteron events are accompanied by any hadron. Hence, our simulations of the target window backgrounds are based on the very conservative assumption that the inclusive photodeuteron cross sections predict the exclusive cross sections for having only a deuteron emitted in the final state. We have applied the low momentum cut to those backgrounds events.

Additional angle dependent momentum cuts can be inferred from the meson photoproduction reaction kinematics shown in Figs. 4 and 6. These cuts could be applied to the simulated missing mass spectra in order to estimate the resulting reduction of target window related backgrounds, but the spectra shown here include no such cut.

The results of these missing mass simulations are shown in Fig. 8 for photon energies of 0.7, 1.0, 1.3, and 1.6 GeV. In general, the η and η' peaks appear on a relatively smooth background dominated by the sum of the multi-pion and photodeuteron distributions.

Backgrounds arising from accidental coincidences between tagged photons and detected deuterons are estimated to be insignificant since the overall event rate, detailed below, is expected to be substantially less than 100/bin/s and the tagger timing resolution should be better than 2 ns. Coincidences arising from events produced by untagged photons coincident with tagged photons at the target should be minimized by appropriate collimation and, of course, form an experimental consideration to be handled by all other experiments which will use the tagger.

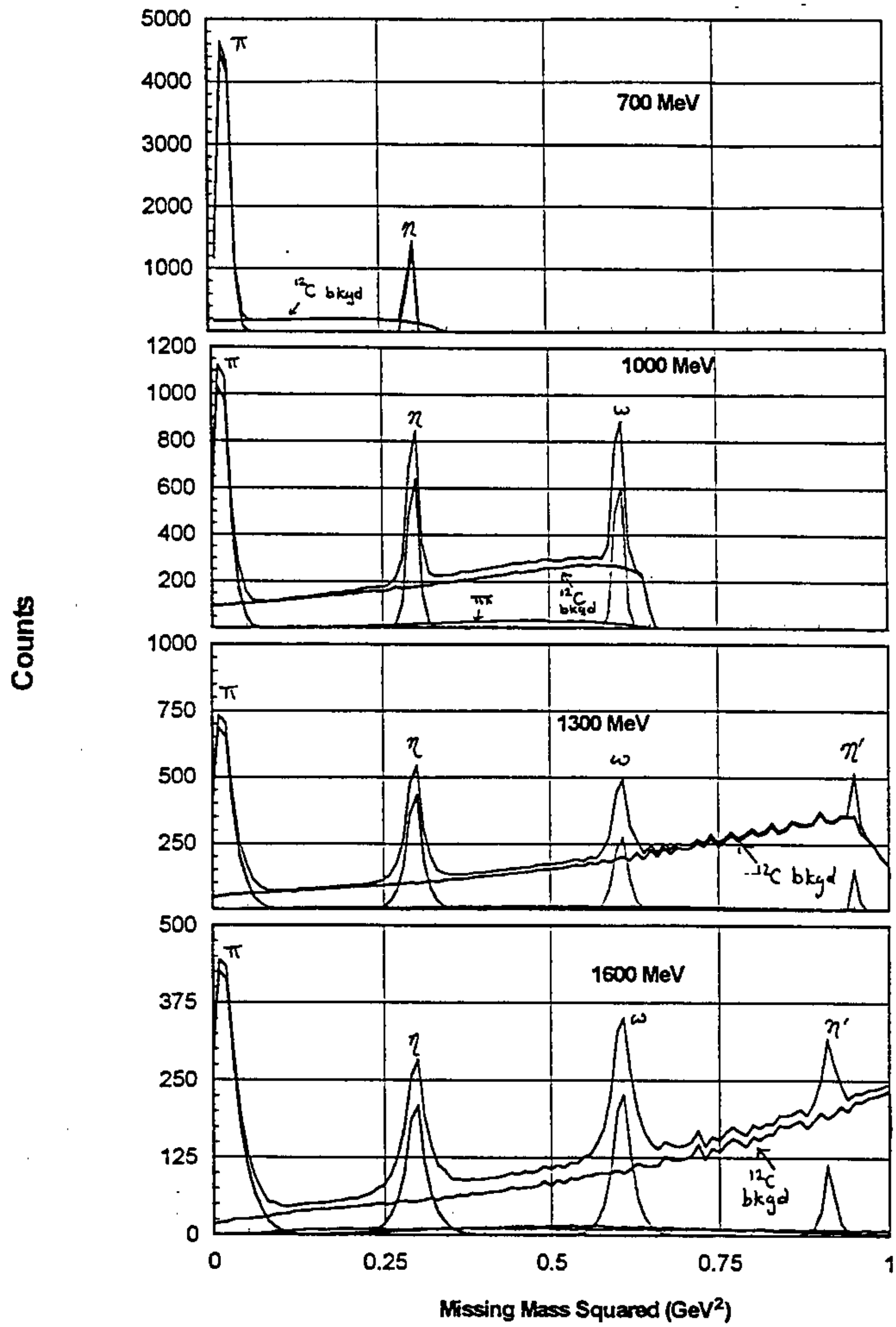

Figure 8: Simulated missing mass spectra for coherent photoproduction using the CLAS at incident photon energies of 0.7, 1.0, 1.3, and 1.6 GeV. Momentum cuts have been applied as described in the text. Weights have been assigned as indicated in Table 3 for the different processes, and target window backgrounds have been included as described in the text.

c. Alternate reaction signatures

In order to provide additional improvement in the signal to noise ratio should it be necessary, it is possible to detect decay products arising from the decay of the η and η' and couple that information with the recoil deuteron kinematical information. While such additional information will reduce the background markedly, the overall angle summed acceptance is lowered by such additional cuts.

As an example we have simulated the detection of pions from η meson decay coupled with detection of the recoil deuteron as above. In all cases, we have found that, due to the high efficiency for pion detection, the overall acceptance is given essentially by multiplying the appropriate branching ratio, given in Table 1, by the overall acceptance of the recoil deuteron. Thus, for η detection using both pion and deuteron detection, the detection efficiency is essentially about 17% (29% branching ratio sum for charged pions [24] multiplied by the overall deuteron acceptance of about 50% - 60%). A similar result would be achieved for η' detection looking for the $\rho\gamma$ decay branch. The acceptance was observed to be qualitatively identical to the results for just deuteron recoil detection, again due to the high efficiency for detecting pions in the CLAS.

2. Incoherent photoproduction

The photoproduction cross sections for incoherent η photoproduction will be measured by detecting either the neutron or the proton following photoproduction and the two photons arising from η decay. The cross sections for incoherent η' photoproduction can be determined by detecting either the neutron or the proton and the pions and photon arising from the $\rho\gamma$ decay branch. Though the overall detection efficiency will be lower as a result of the relatively lower efficiency for neutral particle and photon detection compared with charged particle detection for the CLAS, as can be seen from a comparison of Figs. 1 and 2, the incoherent cross sections could be considerably higher than the coherent cross sections. Thus, one might expect comparable rates.

a. Spectrometer performance for η incoherent photoproduction

In order to perform cross section measurements for the breakup photoproduction of η mesons, detection of the η meson will be accomplished by looking at the 2γ η decay branch, which has a branching ratio of about 39% [24]. For this experiment, we have assumed that the CLAS will be instrumented in six sectors from 8 to 45 degrees with electromagnetic shower calorimeters for photon detection, with additional coverage in two opposing sectors out to 75 degrees. We have performed simulations at several energies with the assumption that the reaction will be dominantly quasifree η -nucleon photoproduction.

Based on this CLAS layout and the assumption of quasi-free photoproduction, the detection solid angle coverage for the incoherent photoproduction cross sections for η photoproduction is shown for an incident photon energy of 1 GeV in Fig. 9; other energies are similar. It is clear that measurements will be restricted to cross sections for forward η scattering angles, as would be expected based on the instrumentation of the CLAS. Nonetheless, this solid angle coverage should be usable. In general, the angle-summed acceptance at 0.7 GeV is 2% for either (proton + 2γ) or (neutron + 2γ) coincidences, rising to 7% and 4% at around 1.5 GeV for (proton + 2γ) and (neutron + γ detection,

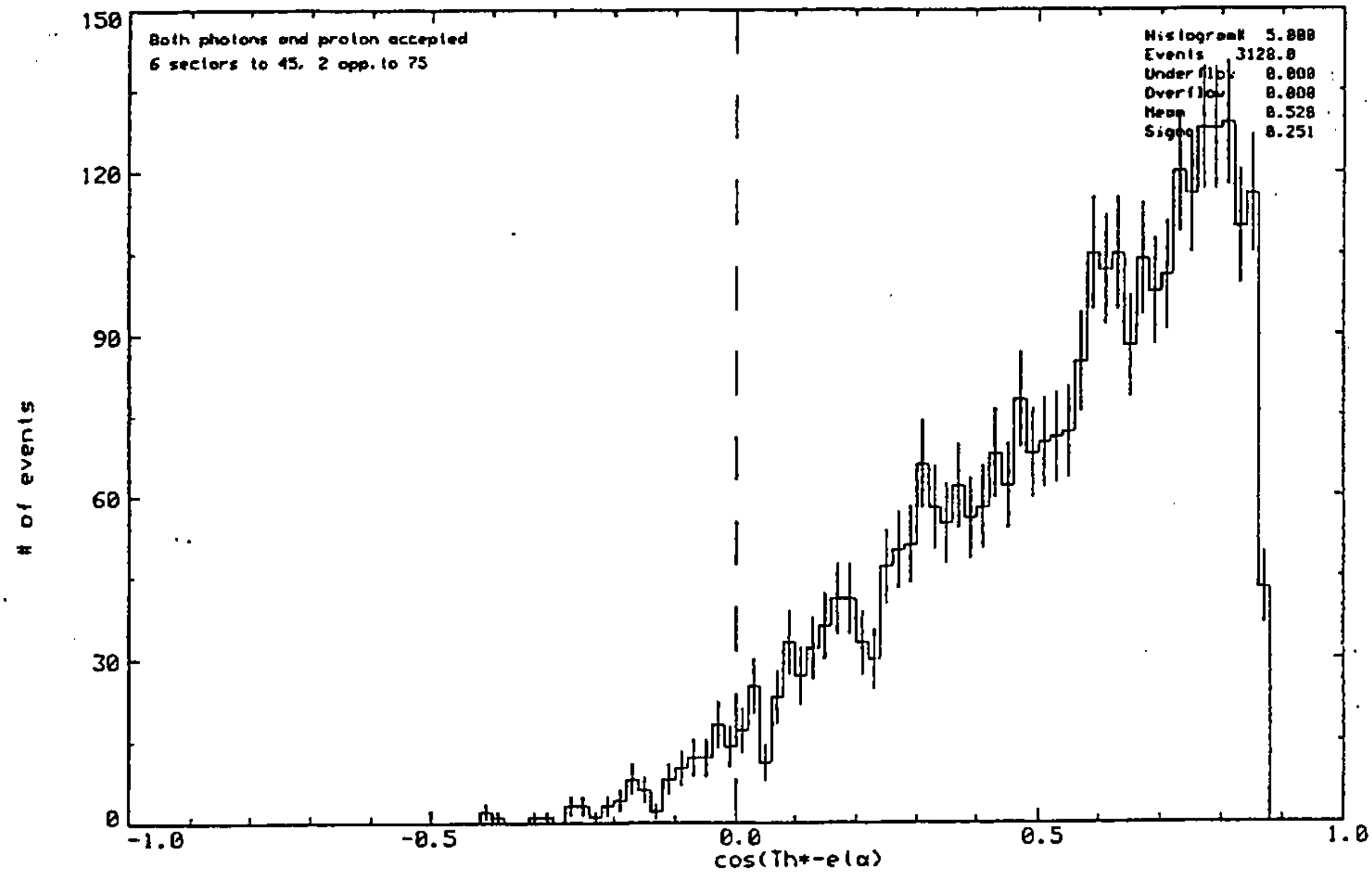

Figure 9: CLAS detector acceptance for incoherent η photoproduction on deuterium with a detection signature of $(proton + 2\gamma)$ as a function of η center-of-mass scattering angle. The incident photon energy is 1 GeV.

respectively. Simulations of the missing mass resolution indicate that the resolution is more than adequate for the purposes of this experiment.

Since these cross sections, though previously unmeasured, could be perhaps 10 times greater than the coherent photoproduction cross sections, the detection acceptances for incoherent photoproduction via the detection signatures simulated are probably at least comparable to those for the coherent channel.

b. Spectrometer performance for η' incoherent photoproduction

In order to perform cross section measurements for the breakup photoproduction of η' mesons, detection of the meson will be accomplished by looking at the $\rho\gamma$ η decay branch, which has a branching ratio of about 30%, detecting the photon and the two pions emitted in the ρ decay. The reaction signature, thus, is $(nucleon + 2\pi + \gamma)$. In this case, we again assume that the CLAS will be instrumented in six sectors from 8 to 45 degrees with electromagnetic shower calorimeters for photon detection, with additional coverage in two opposing sectors out to 75 degrees.

We are investigating this detection mode at the present time and will have performed simulations at energies of 1.3 and 1.6 GeV by the time of the Program Advisory Committee meeting. Presentation of those results will be made then, but due to the high pion detection efficiency of the CLAS, the overall acceptance will likely be on the order of a few percent.

3. Count rates and relative uncertainties

In order to make an initial prediction of the count rates for the differential cross sections to be measured in this experiment, with corresponding estimates on the accuracy to be achieved, we have used estimates of the total cross sections along with the detector acceptance figures noted above for the deuteron recoil events for coherent production and the various event signatures noted above for incoherent production.

In estimating count rates, we have assumed a tagged photon flux of 10^7 photons/sec over an energy range from 0.60 to 1.52 GeV. The energy distribution of the tagged photons is assumed to drop as $1/E_\gamma$. Based on previous simulations for other experiments using the CLAS and a deuterium target [21, 22, 23], an incident tagged photon intensity of about 10^7 photons/sec over this energy range should result in a total CLAS event rate from all sources of about 1 kHz, a "safe" rate for toleration by the data acquisition system. Using energy bins of approximately 75 MeV results in 12 energy bins going from 0.60 to 1.52 GeV for the 1.6 GeV incident electron energy. This bin size is appropriate to the 100-150 FWHM values of the nucleon resonances in the energy excitation region of interest, and it can be further subdivided for those regions of the focal plane corresponding to high photon flux or larger cross section. Using the 75 MeV bin size, we arrive at about 9.1×10^5 (3.6×10^5) photons/sec in the 75 MeV wide bin at 0.60 GeV (1.50 GeV).

The η and η' photoproduction cross sections are essentially unknown; indeed, that is one of the motivations for the experiment. A conservative estimate for coherent η production at threshold can be made by assuming that the total cross section is approximately given by half of the differential cross section for η photoproduction at 90 degrees as determined by Ref. [5] integrated over the detector acceptance. (Such an estimate would be consistent with the assumption that the best calculations at present are reasonably accurate.) With this assumption, a total cross section of about 250 nb near threshold would be predicted. Above threshold, a conservative assumption can be made that the coherent η yield falls off to about 40 nb at 1.5 GeV since the underlying nucleon cross sections are believed to diminish with increasing photon energy.

With these assumptions, for the liquid deuterium target described above, about 5 coherent η photoproduction events per minute should be detected in the 75 MeV bin at 0.70 GeV. Similar estimates for the 75 MeV wide bin at 1.5 GeV would give a rate of 0.4/min for coherent η photoproduction events. Assuming the η' photoproduction rate is half that for η photoproduction at 1.5 GeV, we would get an η' rate of 0.2/min. Assuming an isotropic angular distribution with well-determined background, a 10 point angular distribution with 3% statistical uncertainty in the 1.5 GeV bin for coherent η photoproduction would require about 18 days, with a similar 10-point angular distribution for η' photoproduction with perhaps 5% statistics. (A different shape for the angular distribution would be binned appropriately to achieve similar relative uncertainty.) Because of the larger cross sections and photon fluxes involved, the threshold η photoproduction region could be subdivided into either smaller energy bins with 3% statistical accuracy or finer angular bins.

The overall detection acceptances for incoherent cross section detection, coupled with the perhaps ten times larger cross sections and the appropriate branching ratios, should give rates perhaps one-third of the coherent rates. Thus, the same amount of beam time could probably yield incoherent cross sections (over the accesible angular range) of about 5-7 % accuracy.

4. Absolute normalization

Absolute normalization of the cross sections will be based on the relative photon flux monitors in place for the tagger and the estimated density of the liquid deuterium target under operating conditions. It is estimated that the uncertainties in these separate contributions should result in an overall normalization uncertainty of about 3-5%, though a final estimate cannot be made until the designs of the beam monitoring equipment and the deuterium target are more complete.

If a multi-particle detection signature is used for coherent photoproduction as described above, the absolute normalization will depend on the knowledge of the particular branching ratio. Those branching ratios have uncertainties on the order of 1-3% [24]; those uncertainties would have to be factored into the normalization uncertainties described in the preceeding paragraph if an alternate reaction signature were used, resulting in a maximum absolute normalization uncertainty of about 6%.

Since the incoherent photoproduction η and η' detection modes to be used in this experiment rely on a knowledge of decay branching ratios, their absolute normalizations must incorporate the uncertainties in the associated branching modes; these would be 1.3% and 4.7% for the η and η' incoherent cross sections, respectively [24]. (We note that the uncertainty for the η' decay mode may be improved by, for instance, the measurements of an already approved CEBAF experiment [17].) This branching ratio uncertainty, coupled with the combined estimated photon flux and deuterium density normalization uncertainties of 3-5%, would yield a total absolute uncertainty of about 3-6% and 6-7% for the η and η' incoherent cross sections, respectively.

C. Beam time requirements

1. Development time

Since this experiment could be one of the first round of Hall B experiments, we expect that development time will be allocated to perform general tests for commissioning the Hall B instrumentation. This commissioning time will include time to calibrate the photon flux monitors and the tagger itself, all of which will be required for any experiment using the tagger. That time is not included in the specific time request for this experiment. Since the particular group of scientists proposing this experiment is made up in large part of persons building the photon tagger, we will be participating in all such development activities in any event.

Assuming commissioned Hall B instrumentation, the initial set-up, target operation, and trigger studies for this experiment should take about 5 days of beam time. These test activities, however, can be made in conjunction with those planned for Refs. [21, 22, 23].

2. Data acquisition time

Based on the count rates discussed above, we anticipate that about 18 days will be needed for data acquisition to perform the measurements proposed with the uncertainties noted above.

3. Total time requested

Total time required for these measurements, including set-up, trigger tests and data acquisition time is approximately 23 d. *No contingency time is included in this estimate.*

D. Accelerator requirements

1. Beam quality requirements

Anticipated accelerator performance for the first cycle of experiments as indicated in the CEBAF equipment plan is acceptable. With the use of the tagger, the required beam current is well within the stated expectations, and the 1.6 GeV beam energy required is also within the anticipated capabilities of the machine during the first Hall B experiments.

2. Special requirements

This experiment does not require a polarized electron beam, use of a polarized target, or polarized photons for the measurements described above.

E. Data acquisition requirements

We anticipate that the standard CEBAF data acquisition system for the CLAS and the photon tagger will be sufficient for this experiment, with a CLAS event handling rate of about 1 kHz. Several of the principal participants on this experiment are also active in the Hall B software development effort, and their expertise will be extremely valuable should this experiment be approved as one of the first Hall B experiments.

III. Relation to other experiments

This proposal can be placed in context with other experiments planned at CEBAF in terms of experimental design and physics interests. As noted above, this proposal is one of a set of CEBAF proposals which are aimed at making initial studies of η and η' meson-nucleon [17] and -nucleus [21] reactions. The physics motivations for this proposal are also complementary in nature to the η electroproduction measurements proposed by Steve Dytman and the CEBAF nucleon resonance collaboration [20]. Finally, we note that the measurements and set-up proposed here are for the most part compatible with three other approved CEBAF experiment proposals [21, 22, 23], though the physics emphases are different for Ref. [22] and [23].

Because of its intrinsic interest, η and η' meson photoproduction are also being studied or planned for study at laboratories other than CEBAF. The PHOENICS facility at Bonn has recently been used for a series of measurements targeted on determining inclusive cross sections for η photoproduction on deuterium as a follow-up to an earlier experiment on hydrogen [26]. (Some measurements were also made on nitrogen.) The detection acceptance for coherent photoproduction events was probably too small to permit measurements of those cross sections. Those inclusive measurements are presently under analysis at Bonn; several of the collaborators on this proposal are participants in that endeavor. However, that experiment was limited to photon energies of about 1 GeV, which lies below threshold for η' photoproduction and is at the lower range of energies for the measurements proposed here. The results of this experiment should supplement the Bonn results with measurement of the coherent cross sections. The experiment proposed here will also complement the inclusive measurements made at Bonn by extending them to considerably higher energies, and, where they overlap, provide considerably better statistics and angular resolution.

Coherent photoproduction measurements which will overlap the energy range of this proposal are also being contemplated for the GRAAL facility when it is completed. Several of the collaborators on this proposal are participants in the GRAAL collaboration. Depending on the capabilities realized for that facility, the measurements there could be comparable to the coherent measurements to be obtained here. The use of a magnetic spectrometer (CLAS) in this proposal, however, will greatly assist the handling of the background reactions described above for both the coherent and incoherent reactions.

IV. Theoretical support

We have begun initial assessment of theoretical interest in the development of the research goals for this experiment. Profs. R. J. Jacob and W. B. Kaufmann at Arizona State, with backgrounds in pion production via hadrons and photons, have already assisted in the development of this proposal and will continue to work closely with the group. Prof. Nimai Mukhopadhyay of Rensselaer Polytechnic Institute, whose theory interests greatly overlap the topics described above, has also expressed interest in working with this group during the planning stages of our measurements. Prof. Mukhopadhyay and his collaborators have developed and applied the effective Lagrangian approach to the existing photoproduction data on the proton, and the extension of that approach to the data to be obtained here is of great interest to them.

V. Equipment contribution

The CLAS and photon tagger devices operating in standard configuration, along with the cryogenic liquid deuterium target, provide all equipment necessary for this experiment. Though no specific additional equipment will be provided, we note again that a significant portion of the collaboration is involved in the design and construction of the tagger.

VI. Required CEBAF support

Standard operational support for the CLAS will be required, along with cryogenic support for operation of the liquid deuterium target.

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