Jefferson Lab
Proposal Cover Sheet (Generic)

Experimental Hall: B
Days Requested for Approval: ____________

Submission Date: 12/15/95
Other: PAC 10

☐ **New Proposal Title:**
☒ **Update Experiment Number:** 89-004, 89-024, 91-008, 93-033, 94-015, 94-103
☐ **Letter-of-Intent Title:**
(Choose one)

Proposal Physics Goals
Indicate any experiments that have physics goals similar to those in your proposal.

Approved, Conditionally Approved, and/or Deferred Experiment(s) or proposals:

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By: ____________

The $\gamma 1$ Running Period at CLAS

December, 1995

The CLAS running period entitled $\gamma 1$ (Gamma 1) presently consists of those experiments which use a liquid hydrogen target and the real photon tagger. The running requirements of the experiments are overlapping and will be outlined here. The experiments are:

- 89-004 Electromagnetic Production of Hyperons (Schumacher *et al*)
- 89-024 Radiative Decays of the Low-Lying Hyperons (Mutchler *et al*)
- 91-008 Photoproduction of η and η' Mesons (Ritchie *et al*)
- 93-033 Search for Missing Baryons Formed in $\gamma p \rightarrow p\pi^+\pi^-$ Using the CLAS at CEBAF (Napolitano *et al*)
- 94-015 Study of the Axial Anomaly Using the $\gamma\pi^+ \rightarrow \pi^+\pi^o$ Reaction Near Threshold (Miskimen, Wang, Yegneswaran *et al*)
- 94-103 The Photoproduction of Pions (Briscoe, Ficenec, Jenkins *et al*)

As can be seen from the titles, the range of physics addressed by these experiments is broad. Two involve the production and decay of strange particles, one seeks to determine the presently unknown eta photoproduction cross sections, one systematically explores the nucleon resonance region using single pion photoproduction, while the others exploit the relative simplicity of photoproduction to probe poorly known sectors of hadronic physics. E89-004 will explore the photoproduction of the ground state hyperons Λ, Σ^o and Σ^+, adding abundant polarization data available for the first time. This will make it possible to extract several hadronic couplings and definitively describe the resonance structure of these reactions. E89-024 will use CLAS as a copious source of excited hyperons, such as the $\Lambda(1405)$, and extract the small radiative decay branching ratios by reconstruction of the hadronic decay products. These provide particularly sensitive tests of quark model structure of the hyperons. E91-008 plans to measure the differential cross sections for η and η' photoproduction using detection of the recoil protons in CLAS. These measurements are viewed as providing a foundation for later eta production measurements in nuclei, and for studying baryon resonances which couple to etas. E93-033 will search for firmly predicted yet undiscovered baryon states which decay to, for example, $\Delta\pi$ instead of the better-studied Nπ. This experiment will undertake the analysis of $p\pi^+\pi^-$ final states and do the necessary partial wave analysis to extract new intermediate states. E94-015 seeks to measure an amplitude strictly forbidden by the full QCD Lagrangian, but which is present as an "anomaly" in the simplest effective Lagrangian which is solvable. The experiment will actually use the reaction $\gamma p \rightarrow \pi^+\pi^o n$, and hinges on extraction of the t-channel pole term corresponding to the anomalous reaction. E94-103 is a survey of the single pion photoproduction reaction on hydrogen and deuterium, and seeks to minimize systmatic errors to provide high accuracy data for a full amplitude analysis of the nucleon resonance region.

For several years there has been an understanding within the collaboration that several of the real photon experiments would gather data in parallel. The plan is for all of the Gamma 1 experiments to accumulate data within the same 65 day running period. This concept was first endorsed by PAC6. Compromises in running conditions mean that no single experiment will collect data at its optimal rate, but all participants have expressed agreement with the proposed running scenario. In late 1995, a discussion among all six spokespersons reviewed and refined the proposal for joint running. There is substantial agreement among the spokespersons on the main parameters. Uncertainties which remain are due to open issues in CLAS's actual performance, which will not be settled until the first year of running.

The six spokespersons are in agreement that a consensus-building approach to determining running conditions for this set of experiments will work. When appropriate, a representative of the six will be designated within the group to interact with the CEBAF-appointed COP who oversees operations of the detector system.

This run scenario pre-supposes that the trigger for the CLAS will work as planned, that is, up to a full 1,500/sec single-particle event rate will be recorded with acceptably small deadtime. In other words, the trigger can be "minimum bias," with no on-line selection of rare types of events necessary. Because the tagged photon spectrum goes as 1/E, data taking will be prescaled at the trigger level to roughly equalize the recorded rate as a function of energy. The two breakpoints for pre-scaling are set first below the eta threshold, and also at a higher energy away from known thresholds. The proposed running scenario which emerged from the discussions is as follows:

Beam endpoint energy: $E_o = 2.4$ GeV 5 days setup, 52 days running

- Liquid hydrogen target, 1.0 gm/cm^2
- Tagging range: 20% to 95% of E_o for 0.48 to 2.28 GeV
- Total tagging rate of 1×10^7 photons/second
- Prescale factors:

  4 - from 0.48 to 0.65 GeV (10% of all tagged photons)

  2 - from 0.65 to 1.40 GeV (53%)

  1 - from 1.40 to 2.28 GeV (37%)
- Trigger: the estimated single-charged particle rate under these running conditions is 640/sec, without correcting for acceptances. The estimated deadtime is then 43%. The total hadronic rate in the spectrometer will be about 3000 /sec.
- Magnetic field setting: 20% to 50% of nominal field with positive particles bending out. In the first year of running data will be accumulated at several settings in order to test momentum resolution and acceptance estimates. Appropriate compromise settings will be selected for subsequent running.

Beam Endpoint energy: 3.2 GeV 1 day setup, 7 days running

- Tagging range: 71% to 95% of E_o for 2.28 to 3.04 GeV
- Total tagging rate of 1×10^7 photons/second
- Prescale factors: unity
- Trigger: One charged particle
- Magnetic field setting: 50% of nominal field with positive particles bending out.

The present plan is for this data set to be accumulated over a period of three calendar years. It must be expected that some addition setup time will be needed in each year to reestablish and continue the run from previous years.

It should be noted that each of the groups involved in these experiments is playing a substantial role in developing the hardware for the CLAS spectrometer or the photon tagger.

BEAM REQUIREMENTS LIST

CEBAF Proposal No.: 89-004, 89-024, 91-008, 93-033, 94-015 Date: 12-94

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List all combinations of anticipated targets and beam conditions required to execute the experiment. (This list will form the primary basis for the Radiation Safety Assesment Document (RSAD) calculations that must be performed for each experiment.)

Condition #	Beam Energy (MeV)	Beam Current (μA)	Polarization and Other Special Requirements (e.g., time structure)	Target Material (use multiple rows for complex targets — e.g., w/windows)	Target Material Thickness (mg/cm²)
1	2400	0.1	Circular Polarization	LH2	1 gm/cm^2
			(if available)		
2	3200	0.1	Circular Polarization	LH2	1 gm/cm^2
			(if available)		

The beam energies, E_{Beam}, available are: $E_{Beam} = N \times E_{Linac}$ where N = 1, 2, 3, 4, or 5. For 1995, E_{Linac} = 800 MeV, i.e., available E_{Beam} are 800, 1600, 2400, 3200, and 4000 MeV. Starting in 1996, in an evolutionary way (and not necessarily in the order given) the following additional values of E_{Linac} will become available: E_{Linac} = 400, 500, 600, 700, 900, 1000, 1100, and 1200 MeV. The sequence and timing of the available resultant energies, E_{Beam}, will be determined by physics priorities and technical capabilities.

HAZARD IDENTIFICATION CHECKLIST

CEBAF Proposal No.: 89-004, 89-024, 91-008, 93-033, 94-015 (For CEBAF User Liaison Office use only.)

Date: 12-94

Check all items for which there is an anticipated need.

Cryogenics X beamline magnets X analysis magnets X target type: LH2 flow rate: ____ capacity: ____	**Electrical Equipment** X cryo/electrical devices ___ capacitor banks X high voltage ___ exposed equipment	**Radioactive/Hazardous Materials** List any radioactive or hazadorous/ toxic materials planned for use: NONE
Pressure Vessels ___ inside diameter ___ operating pressure ___ window material ___ window thickness	**Flammable Gas or Liquids** type: LH2 flow rate: ____ capacity: ____ **Drift Chambers** type: CLAS flow rate: ____ capacity: ____	**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
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)	**General:** Experiment Class: X Base Equipment ___ Temp. Mod. to Base Equip. ___ Permanent Mod. to Base Equipment ___ Major New Apparatus Other: ____

CEBAF Program Advisory Committee Nine
Extension and Update Cover Sheet

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Experiment: E 89 - 004

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- [ ] Extension
- [ ] Update
- [x] Hall B Update

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By: 9

PAC10 UPDATE FOR CEBAF EXPERIMENT 89-004

Electromagnetic Production of Hyperons

R. A. Schumacher, Spokesperson

This experiment will obtain the world's most complete data set for real photon induced strangeness production, and use it to resolve problems in understanding this reaction process. Since the approval of this proposal in 1989 the intended scope of this experiment has evolved somewhat. Partly spurred by this proposal, there has been considerable theoretical work in this area. Unlike pion photoproduction, the elementary production of kaons is not dominated by a single strong resonance, while the quark pair which is produced is distinguishable, which leads to new and interesting problems in pseudoscalar meson production. The interest at CEBAF in elementary strangeness production is also underscored by the approval of two electro-production experiments, which will complement the results of this experiment.

There are three isospin channels on the proton which are of equal interest: $\gamma + p \rightarrow K^+ + \Lambda$; $\gamma + p \rightarrow K^+ + \Sigma^o$; and $\gamma + p \rightarrow K^o + \Sigma^+$. The contribution of CEBAF and CLAS to this field will be to provide data for all three elementary channels (the third one is essentially unmeasured), and to emphasize the hyperon polarization variables which show large sensitivity to typical model parameters. Experiment E89-004 will exploit CLAS to obtain these data, using the large detector acceptance to examine the self-analyzing weak decays of the hyperons. In the original written proposal the Λ and Σ^o reactions were emphasized, though already in the '89 PAC presentation the Σ^+ channel was shown to have appreciable acceptance in CLAS and hence would form part of the measurement program.

As a natural extension, circular polarization of the tagged photons in CLAS would enable significant beam-recoil double polarization measurements, one of the few instances where such highly selective measurements could be made relatively easily. Within the group involved in E89-004 there has been considerable discussion about this topic, and we expect that an appropriate extension will be requested of a future PAC. If circularly polarized beams are routinely available by the time this experiment runs, we will take our data in this mode.

Recent theoretical work includes a re-analysis of the existing data by Adelseck and Saghai [1], which revealed possible systematic inconsistencies in the old data. They tried to find reaction models with hadronic Born couplings consistent with the SU(3) values. Their pruning of the data set and other procedures were later criticized [2], but the analysis remains the best recent discussion of the existing data set. Photoproduction data were again analyzed by Williams,Ji,and Cotanch [3], in an approach that emphasized consistency with the crossed-channel radiative capture reaction $p(\gamma, K^+)\Lambda$. The same group then extended their model [4] to include all the strangeness electroproduction data as well. The result was the most comprehensive theoretical treatment to date within the framework of the hadrodynamic models, including constraints both from crossing symmetry and the notions of duality of s and t channel processes. Further work by Bennhold [5] on the incorporation of hadronic form factors to enforce unitarity is in progress. In a study of all possible spin observables in near-threshold strangeness production, Fasano, Tabakin and Saghai [6] explored sensitivity of the "nodal structure" of the multipoles to resonances in the elementary amplitudes. Their need for more and better data is clear. Pioneering work to relate these data to underlying QCD-inspired theory has recently appeared, as in the Chiral Quark Model approach of Z.

Li [7], and others [8]. The significance of data in the presently-unmeasured $K^o\Sigma^+$ channel in understanding the structure of S_{11} resonances has recently been recognized [9].

On the experimental front, the Bonn group working with their Saphir detector has started measurements [10] of hyperon photoproduction. The intrinsically low intensity of that machine, the inability to do circularly polarized measurements, and the poor quality of the first data appearing in preprint form, indicates that CLAS will be competitive when we start our program. There are also plans at Grenoble/GRAAL, using a non-magnetic tracking and calorimetric device, to examine hyperon photoproduction. With a low top energy (1.5 GeV) and no charge identification it is clear that CLAS retains significant advantages for these studies.

Carnegie Mellon University is deeply involved in the construction of the CLAS detector with which these measurements will be made. The Region I tracking drift chamber, which sits inside the main toroid of the CLAS, is being designed and built jointly at CMU and the University of Pittsburgh. Carnegie Mellon is responsible for all the mechanical components of the drift chamber structure, including the 'endplates', the detector assembly components, the wire stringing structure, and the structure for installing the detector in the spectrometer. We developed the detailed design for the wire layout, as well as the strategy for integrating sectors of the chamber into one unit. Jointly with Pitt we will manage the stringing of the wires, and the final stages of assembly, testing, and commissioning. This detector is of importance to the experiment discussed here because reconstruction of the hyperons will ultimately always be limited the tracking capabilities of this detector. Applying vertex and distance-of-closest-approach cuts will place great demands on this drift chamber. Carnegie Mellon physicists are also active on several physics and technical working group committees within the CLAS collaboration.

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[1] R. A. Adelseck and B. Saghai, Phys. Rev. **C42** (1990) 108.

[2] Ron L. Workman Phys. Rev. **C44** (1991) 552.

[3] R. A. Williams, C-R Ji, and S. R. Cotanch, Phys. Rev. **C43** (1991) 452; ibid. Phys. Rev. **D41** (1990) 1449.

[4] R. A. Williams, C-R Ji, and S. R. Cotanch, Phys. Rev.**C46** (1992) 1617.

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[10] M. Bockhorst *et al*, Z. Phys. **C63** (1994) 37.

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Extension and Update Cover Sheet

This update must be received by close of business on Thursday, December 1, 1994 at:

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Experiment: E 89 - 024

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☐ Extension ☐ Update ☒ Hall B Update

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PAC10 UPDATE FOR CEBAF EXPERIMENT 89-024

Radiative Decays of Low-Lying Hyperons

Rice University, College of William and Mary and the CLAS Collaboration
G.S. Mutchler, Spokesperson

The goal of E89-024 is to make a model-independent measurement of the electromagnetic branching ratios of the $\Lambda(1520)$, $\Lambda(1405)$ and $\Sigma(1385)$ hyperons, free of any hadronic initial state interactions. Such data will provide a stringent test of the various quark models of the hyperons. This document updates some of the now obsolete information in the original proposal. Specifically, only the measurement of the reaction $\gamma p \rightarrow K^+Y^*$, $K^+Y^* \rightarrow \gamma\Lambda$ has been approved, due to the limited shower counter coverage. Also since several experiments will be grouped for simultaneous running, much of the discussion on various running configurations and triggering options is no longer valid.

In the proposal, Table I listed the radiative widths, Γ_γ(keV), calculated from various models, and Table II listed the existing data. New calculations of Γ_γ(keV) and further analysis of the existing data have since been published. Updated values of theory and data are given in Table I. All of the existing data were derived from $K^-p \rightarrow \Lambda\gamma, \Sigma^0\gamma$ data, so that the Γ_γ experimental values quoted are model dependent. For example, the $\Lambda(1405)$ lies below the K^-p threshold and hence can be excited only via the high energy tail of the resonance. In the table, NRQM refers to the nonrelativistic quark model of Isgur and Karl, RELQM refers to a relativised constituent quark model calculation due to Warns *et al* and the bag models are calculations using the static-cavity approximation to the MIT bag model of Jaffe and DeGrand.

Table I Radiative Decays Widths (keV)

Transition $Y^* \rightarrow \Lambda\gamma$	NRQM (3,4)	MIT BAG(3)	Chiral BAG(1)	RELQM (2)	Experiment K - P
$\Lambda(1520)$	156	46	32	215	150±30 (5) 30±11 (6)
$\Lambda(1405)$	200	17	75	118	27±8 (7,8)
$\Sigma(1385)$	273	152		267	
$Y^* \rightarrow \Sigma\gamma$					
$\Lambda(1520)$	55	17	51	293	47±17 (6)
$\Lambda(1405)$	72	2.7	1.9	46	10±4 (7,8) 23±7 (7,8)
$\Sigma(1385)$	22	15		23	

Table II shows the updated count rates for the approved measurement, $Y^* \rightarrow \Lambda\gamma$, using the proposed 52 days of running at $E_0 = 2.4$ GeV, and 7 days at $E_0 = 3.2$ GeV, as outlined in the covering pages. The assumed running conditions are $10^7\gamma/sec$ tagged and prescaled, $B = 0.5B_{max}$ with positives bending out, 1.0 gm/cm^2 LH_2 target and the forward shower counter. (The 2.4 GeV count rates given in the PAC9 update assumed negatives bending out, a more favorable prescaling and $B = 0.2B_{max}$.) The count rates were estimated using the FASTMC program distributed by CEBAF, agumented to give a better measure of multiple scattering in the target flask and vacuum vessel. A range of values of the radiative widths, as suggested by the data in Table I were assumed and are listed in column 2 of the table.

The radiative widths for the $Y^* \rightarrow \Sigma\gamma$ background were also given a range; specifically 70 and 20 keV for the $\Lambda(1405)$, 22 and 15 keV for the $\Sigma(1385)$ and 45 and 15 keV for the $\Lambda(1520)$. Column 3 of the table lists the count rate for $K^+p\pi^-$ detected and column 5 for $K^+p\pi^-\gamma$. Columns 4 and 6 list the corresponding backgrounds due to the reaction $Y^* \rightarrow \Sigma\gamma$. Detecting the gamma ray greatly reduces this background at the cost of a factor of 3 in the count rate. Both types of data will be available. Any running done with $B = 0.2_{max}$ will increase the total counts. As can be seen from the table, the proposed joint running should yield an adequate measurement of the electromagnetic branching ratios.

Table II Count Rate Estimates

$E_0 = 3.2$ GeV		$K^+p\pi^-$ Detected		$K^+p\pi^-\gamma$ Detected	
Transition	Γ_γ keV	Counts/ 160 hrs	Bkgd ($\gamma\Sigma$)	Counts/ 160 hrs	Bkgd ($\gamma\Sigma$)
$\Lambda(1520) \rightarrow \Lambda\gamma$	150	530	10	165	2
	30	106	3	33	0
$E_0 = 2.4$ GeV		$K^+p\pi^-$ Detected		$K^+p\pi^-\gamma$ Detected	
Transition	Γ_γ keV	Counts/ 1200 hrs	Bkgd ($\gamma\Sigma$)	Counts/ 1200 hrs	Bkgd ($\gamma\Sigma$)
$\Lambda(1520) \rightarrow \Lambda\gamma$	150	970	20	320	6
	30	194	7	64	2
$\Lambda(1405) \rightarrow \Lambda\gamma$	200	700	34	225	3
	30	105	10	35	1
$\Sigma(1385) \rightarrow \Lambda\gamma$	270	1310	15	420	0
	150	730	8	235	0

The main background will be from the reaction $\gamma p \rightarrow \pi^+ p \pi^-$ with the π^+ miss-identified as a K^+. This will be most likely to occur due to accidental events from an adjacent beam bucket, see figures 13 and 14 in the proposal. Not only will the kaon be miss-identified, but an incorrect photon energy will be assigned to the event. To solve this problem, the Rice group is designing a "start counter". This consists of six thin, 3mm thick, scintillation counters that surround the LH_2 target and covers $7^0 < \Theta < 150^0$. The design goal is a time resolution of $\sigma = 300ps$. This coupled with the $\sigma = 300ps$ time resolution of the Tagger scintillators will greatly reduce accidentals due to the 2 ns time structure of the beam. The William and Mary group is constructing the TOF laser calibration system. Their shop has constructed over 70 light guides for the forward angle TOF counters and several prototypes for the large angle TOF counters. They are also involved in software development for the CLAS data acquisition system.

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Experiment: **Check Applicable Boxes:**

E 91 - 008 ☐ Extension ☐ Update ☒ Hall B Update

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Update for Approved Experiment 91-008

Photoproduction of η and η' Mesons

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CEBAF Large Acceptance Spectrometer Collaboration

ABSTRACT

Differential cross sections for the photoproduction on the proton of $\eta(549)$ and $\eta'(958)$ mesons will be measured using the CEBAF Hall B bremsstrahlung photon tagger and the CEBAF Large Acceptance Spectrometer in Hall B. Tagged photons of energies from 0.65 to 2.25 GeV will be incident on a liquid hydrogen target. Identification of the η and η' will be made by detection of the recoil proton in the CLAS. The measurements will provide important information on properties of the mesons themselves and on the $S_{11}(1535)$ and $P_{11}(1710)$ nucleon resonances and form a firm basis for future experiments studying η and η' interactions with nuclei.

Collaboration Activities

As noted in the proposal, the collaboration responsible for this experiment has been active in the development of the Hall B Photon Tagger through participation in the Photon Tagger Working group. Several members of the collaboration have also worked on design and construction activities on other components of Hall B instrumentation and support. The spokesman, working within the Photon Tagger Working Group, is responsible for the focal plane electronics for the tagger. His group has led efforts in determining the electronics logic for the tagger, and has designed and prototyped modularized electronics for the focal plane. Presently, the group has a contract with CEBAF to assemble the full complement of modularized electronics specific to the tagger. Other members of this collaboration are playing critical roles in the design and construction of Hall B instrumentation crucial to this and all approved experiments using the CLAS and photon tagger.

Current Physics Issues

As noted in the original proposal, the measurements to be undertaken for this experiment are of significant interest, with the following being only a partial list of the motivations:

1. Existing data are too sparse in kinematical coverage or are too limited in precision to provide accurate determination of the amplitudes involved in the elementary process $\gamma p \rightarrow \eta p$.
2. Data on the photoproduction of η' mesons from the nucleon are practically non-existent.
3. η photoproduction cross sections on the nucleon provide an isospin selectivity which will be extremely valuable in unraveling the spectrum of baryon resonances.
4. Significant questions about the structure of the mesons themselves, particularly the η', exist.
5. It may be possible that the strange content of the mesons can be exploited to help probe the strange quark content, if any, of the nucleon.
6. Investigations of η and η' interactions with the neutron and with nuclei require a detailed understanding of η and η' interactions with the proton.

The physics underpinnings of these motivations have not changed significantly since the approval of the proposal in 1991. In particular, it is still true that practically nothing is known concerning η' photoproduction on the nucleon, and that situation is unlikely to change until CEBAF and GRAAL are operating with sufficiently energetic photon beams.

The database with respect to η photoproduction on the proton will soon be expanded. Recently, the spokesman and collaborators at Bonn have extended η photoproduction measurements on the proton and the deuteron to 1.2 GeV. However, these measurements, while extremely important, still lie in a region where previous measurements have provided some insight already. The opportunity to more fully investigate the baryon resonance spectrum via η photoproduction must await the capabilities of Hall B.

In the original proposal, the relationship of this experiment to other CEBAF experiments was discussed. Since this proposal was approved, additional η and η' photoproduction experiments on the deuteron (94-008) and in heavy nuclei (93-008) have been approved. While each of those experiments will focus on somewhat different important physics issues, each will rely heavily on the results to be obtained in this experiment on the proton in order to obtain reasonable interpretations of the phenomena observed.

Thus, the motivations and interests in the photoproduction of these mesons remain. These measurements will be critical to resolving important questions related to our understanding of the structure of the nucleons, the structure of the mesons themselves, and the interactions of nucleons and these mesons with each other. They also provide a foundation for understanding the results of other approved experiments.

CEBAF Program Advisory Committee Nine
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Experiment: **Check Applicable Boxes:**

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PAC10 UPDATE FOR CEBAF EXPERIMENT 93-033

A Search for Missing Baryons Formed in $\gamma p \to p\pi^+\pi^-$ Using the CLAS at CEBAF

J. Napolitano, Spokesperson

This experiment attempts to solve a long outstanding problem in baryon structure. This "missing baryons" problem is as crucial today as it was when this experiment was approved by PAC6 in 1993.

Briefly stated, the missing baryons problem represents a mismatch between the number of states predicted by the quark model and the number that are observed experimentally. The predicted states and their quantum numbers follow rigorously from the underlying $SU(6) \times O(3)$ symmetry for quarks with spin and orbital angular momentum. An intriguing solution to this problem was originally put forth by Lichtenberg[1] who suggested that pairs of quarks bind tightly into "diquarks" with a particular set of quantum numbers. Baryons, then, would be *quark-diquark* systems, and the reduced symmetry nicely accounts for the missing states, including their quantum numbers.

However, nearly all data on non-strange baryons is from s-channel formation experiments with $N\pi$ in the initial or final state, or both. If the missing baryons do not couple to $N\pi$, they would not have been discovered. This was first suggested many years ago, and modern dynamical quark model calculations support this hypothesis [2]. On the other hand, these states do not have anomalously small couplings to photons [3], or to $N\pi\pi$ final states such as $\Delta\pi$ or $N\rho$ [4]. This experiment will search for the missing states using the reaction $\gamma p \to p\pi^+\pi^-$, which therefore includes various final states including $\Delta^{++}\pi^-$, $\Delta^0\pi^+$, and $N\rho^0$, as well as those with the $\pi^+\pi^-$ in a relative S-state or with excited baryons such $N\frac{1}{2}^+(1440)$ and $\Delta\frac{3}{2}^+(1600)$. Dynamical models predict the masses of these states to be ~ 2 GeV, and therefore $\sqrt{s}$ is very nicely covered by the 2.4 GeV beam energy which dominates the $\gamma1$ running period.

Some of the recent progress on this experiment has been theoretical. The number of possible quasi-twobody states which can end up as $p\pi^+\pi^-$ is quite large, and it is very useful to have some idea where to look. Capstick and Roberts [4] have calculated these branches in the framework of the relativized quark model, with this and other experiments in mind, and we will use these results to help direct the data analysis.

A different observation has been made which allows this experiment to confront the diquark model directly. In the Lichtenberg diquark model, there can be no $\frac{7}{2}^+$ nucleon although this is a perfectly reasonable state in the quark model. In fact, weak evidence [5] exists for such a state at 1980 MeV in elastic πN scattering, and the extracted elastic amplitude is consistent with calculations [2]. In fact Capstick and Roberts [4] predict this state decays predominantly to $\Delta\pi$. The relative amounts of $\Delta^{++}\pi^-$ and $\Delta^0\pi^+$ in the photoproduction analysis will be used to separate an intermediate nucleon state from the nearby well known $\Delta\frac{7}{2}^+(1950)$, following a partial wave analysis.

The partial wave analysis is in fact nontrivial, especially because of the various overlapping final states in $p\pi^+\pi^-$. We have started to study the problem in some detail. Good examples exist for s-channel formation in πN scattering [5] and in photoproduction [6], and we are of course studying this work. We have also embarked on an analysis of $p\pi^+\pi^-$ final states produced in $K^\pm$ inelastic scattering, using data acquired at SLAC by the LASS/E135 collaboration. We are guided by previous analyses [7, 8] of this system, albeit with far poorer statistics than what we now have on hand.

This experiment will accumulate an enormous number (several $\times 10^8$) of events, and we must be prepared to deal with them. We have converted our data analysis facility at Rensselaer from a VAX/VMS system to an IBM/RS6000 UNIX system, compatible with the data analysis setups for the CLAS. In particular, we have learned to simultaneously use available CPU cycles on up to 24 RS6000/390 computers on the RPI campus, using resources of the campus Numerically Intensive Computing system and our own upgraded network. We are now using the system to analyze the E135 data, as well as the massive data set ($\sim 10^9$ triggers) from experiment E852 at Brookhaven National Laboratory. We intend to be fully prepared to analyze the data for missing baryons soon after it is acquired.

Finally, of course, Rensselaer has a large instrumental commitment to the CLAS in the gas Čerenkov detector system. The design for this detector is virtually complete, and nearly all the outside orders have been placed. The first of six mechanical structures has been machined and assembled, including mirrors, Winston cones, magnetic shields, and support hardware. The photomultipliers are being tested and calibrated. All this work is going on at Rensselaer, and all six sectors will be ready for installation in the CLAS in the summer of 1996. For the energies encountered in E93-033, however, it is unlikely that the Čerenkov detector would be sensitive to $\pi^\pm$, but as demonstrated to PAC6, this experiment has no difficulty with particle identification.

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CEBAF Program Advisory Committee Nine
Extension and Update Cover Sheet

This update must be received by close of business on Thursday, December 1, 1994 at:

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

Experiment: E 94 - 015

Check Applicable Boxes:

- [ ] Extension
- [ ] Update
- [X] Hall B Update

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By: gp

PAC10 UPDATE FOR CEBAF EXPERIMENT 94-015

Study of the Axial Anomaly using the $\gamma\pi^+ \to \pi^+\pi^0$ Reaction Near Threshold

Contact person: R. A. Miskimen

In quantum mechanics an anomaly occurs when a symmetry of the classical action is not shared by the full quantum theory. The anomaly in chiral quantum field theory was first discovered in theoretical studies of π^0 decay through the partially conserved axial current, where it was found that an anomalous axial current is needed to explain the π^0 decay rate[1]. In chiral perturbation theory the anomalous fourth order Lagrangian was first systematically constructed by Wess, Zumino, and Witten (WZW) [2]. Because the chiral anomaly is a short range phenomena and is unaffected by hadronization problems, the WZW Lagrangian has no free parameters and depends only on the pion decay constant and the number of QCD colors, N_c. Although the chiral anomaly is well understood theoretically, this important aspect of modern particle physics has not been well tested experimentally. While the prediction for $\pi^0 \to 2\gamma$ is in good agreement with $N_c = 3$, the situation for the $\gamma\pi \to \pi\pi$ amplitude, $F^{3\pi}$, is not yet clear. The goal of this experiment is to measure $F^{3\pi}$ in the $\gamma p \to \pi^+\pi^0 n$ reaction.

Since this proposal was approved at PAC 8, there have been several theoretical developments. Recently, d'Hoker and Weinberg proved the uniqueness of the WZW term and the model independence of calculations that use the WZW Lagrangian [3]. There are also new calculations available for the momentum transfer dependence of $F^{3\pi}$. Holstein [4] has noted that at low momentum transfers chiral perturbation theory calculations for $F^{3\pi}$ should be equivalent to calculations that include vector meson dominance and the anomaly term, provided final state interactions are included in the latter calculation. The form proposed by Holstein for $F^{3\pi}(s,t,u)$ includes rescattering in each of the three $\pi\pi$ channels and satisifies unitarity. Alkofer and Roberts[5] have used the QCD Dyson-Schwinger equations to calculate $F^{3\pi}(s,t,u)$. In their calculation $F^{3\pi}(0)$ is reproduced independent of the gluon and quark functions, which were choosen to provide a good description of observables such as $\pi\pi$ scattering and the pion electromagnetic form factor. Ivanov and Mizutani[6] have calculated $F^{3\pi}(s,t,u)$ in a confined quark model that is unconstrained by the chiral anomaly. In their model the contact amplitude is somewhat less than 1/4 of the chiral anomaly prediction. We plan to test these calculations with experimental data and then use the models to extrapolate $F^{3\pi}$ to zero momentum transfer.

In extracting $F^{3\pi}$ from $\gamma p \to \pi^+\pi^0 n$ data, background reactions such as $\gamma p \to \pi\Delta$ and $\gamma p \to \rho^+ n$ may limit the accuracy of the analysis. For this reason we are working with W. Roberts at Old Dominion University on calculations of $\gamma p \to \pi\Delta$ and $\gamma p \to \rho^+ n$ reactions. In these studies we use density matrix elements derived by Roberts [7] to calculate differential cross sections for $\pi^+\pi^0 n$ final states. A physics paper detailing our studies of the sensitivity of $\gamma p \to \pi^+\pi^0 n$ to the chiral anomaly and background reactions is being prepared for submission to the *Physical Review*.

Linearly polarized photons can aid in the identification of pseudo-scalar exchange mechanisms through the $(1 - cos2\phi)$ azimuthal dependence of the cross section. Other reaction mechanisms, such as $\gamma p \rightarrow \pi\Delta$, will not have this angular distribution. A letter of intent to extend this experiment to the use of linearly polarized photons was submitted to PAC 9[8] and was very favorably received; *"The PAC endorses the physics case and recommends that the collaboration produce a full proposal in conjunction with the development of the physics case for the CBF"*. We plan to submit a physics proposal for the use of linearly polarized photons to PAC 11.

Regarding experimental preparations, the three co-spokespersons for the experiment (R. Miskimen, K. Wang, and A. Yegneswaran) are actively involved in the development and construction of CLAS. R. Miskimen recently spent a sabbatical year at CEBAF where he spent much of his time working on the design of the chamber mounted electronics for the CLAS region 1 drift chamber. With the fabrication and testing of the electronics nearly complete, he is now working on a technique for laser calibration of the CLAS drift chambers. K. Wang is at the University of Virginia where he is working on the development of a linearly polarized photon source for CLAS using Compton backscattered laser light. A. Yegneswaran, as a CEBAF staff member, is on site 100% of the time and is responsible for the CLAS drift chamber electronics. A UMass graduate student, B. Asavapibhop, has been working on tests of drift chamber electronics and calculations of the chiral anomaly. We expect that Asavapibhop will do a Ph.D. thesis on this experiment if the schedule for CLAS operations remains favorable.

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[1] S. L. Adler, Phys. Rev. **177**, 2426 (1969); J. S. Bell and R. Jackiw, Nuovo Cimento **60A**, 47 (1969).

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[5] R. Alkofer and C. Roberts, *Calculation of the anomalous* $\gamma\pi^* \rightarrow \pi\pi$ *form factor*, Argonne preprint ANL-PHY-8214-TH-95, to be published.

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[8] LOI-94-108, R. A. Miskimen and K. Wang, spokespersons.

CEBAF Program Advisory Committee Nine Proposal Cover Sheet

This proposal must be received by close of business on Thursday, December 1, 1994 at:

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

Proposal Title

The Photoproduction of Pions

Contact Person

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Experimental Hall: B Days Requested for Approval: 92 (82 concurrent)

Hall B proposals only, list any experiments and days for concurrent running:

"Gamma 1" 52(2400 MeV), 7(3200 MeV) with hydrogen
"Gamma 2" 23(1600 MeV), with deuterium
G.1: 89-004, 89-024, 91-008, 93-033, 94-015; G.2: 89-045, 93-008, 93-017, 94-008

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Receipt Date: ______________________

By: ______________________

BEAM REQUIREMENTS LIST

CEBAF Proposal No.: PR-94-103 Date: ____________

(For CEBAF User Liaison Office use only)

List all combinations of anticipated targets and beam conditions required to execute the experiment. (This list will form the primary basis for the Radiation Safety Assesment Document (RSAD) calculations that must be performed for each experiment.)

*Represents Concurrent Runs with CLAS in Hall B: "Gamma 1" and "Gamma 2"

Condition #	Beam Energy (MeV)	Beam Current (μA)	Polarization and Other Special Requirements (e.g., time structure)	Target Material (use multiple rows for complex targets — e.g., w/windows)	Target Material Thickness (mg/cm²)
1*	2400	10^7	tagged photons/second (480–2280)	liquid hydrogen	1000
2*	3200	10^7	tagged photons/second (2280–3040)	liquid hydrogen	1000
3*	1600	10^7	tagged photons/second (900–1520)	liquid deuterium	2000
4	3200	10^7	tagged photons/second (1520–3040)	liquid deuterium	2000
*****	LAB RESOURCES REQUIREMENTS LIST – Standard and ordinary for CLAS with single charge trigger				
*****	HAZARD IDENTIFICATION CHECKLIST – Standard and ordinary for CLAS with liquid hydrogen and deuterium				

The beam energies, E_{Beam}, available are: $E_{Beam} = N \times E_{Linac}$ where N = 1, 2, 3, 4, or 5. For 1995, E_{Linac} = 800 MeV, i.e., available E_{Bea} 800, 1600, 2400, 3200, and 4000 MeV. Starting in 1996, in an evolutionary way (and not necessarily in the order given) the follo additional values of E_{Linac} will become available: E_{Linac} = 400, 500, 600, 700, 900, 1000, 1100, and 1200 MeV. The sequence timing of the available resultant energies, E_{Beam}, will be determined by physics priorities and technical capabilities.

The Photoproduction of Pions
CEBAF Experiment 94-103
Update

The γN interaction is one of the most powerful ways of investigating hadron structure. In reactions with the nucleon, one may study the radiative-decay amplitudes of the N(I=1/2) and Δ(I=3/2) resonances without the complexities involved in heavier nuclei. These amplitudes are essential in testing theories of the strong interaction, especially those based on the quark model. In particular, pion photoproduction provides a means by which intermediate resonance states can be scrutinized in a straightforward manner, given the well-known nature of the electromagnetic interaction. The radiative decay of a resonance is sensitive to the dynamics of quarks within the hadron. However, the radiative amplitudes for many resonances are not well-known, e.g. $S_{11}(1535)$, $P_{13}(1720)$, and $F_{17}(1990)$ to name a few; thus, current checks on the validity of some models are often difficult and inconclusive The lack of good data, as well as other factors, such as the reliance on pion-nucleon elastic-scattering analyses, often precludes extraction of accurate decay amplitudes.

We will measure single-pion photoproduction using CLAS and the Tagger Facility in Hall B at CEBAF with tagged photons having energies between 400 and 3040 MeV. Differential cross sections for the reactions $\gamma p \rightarrow \pi^o p$ and $\gamma p \rightarrow \pi^+ n$, and for $\gamma n \rightarrow \pi^- p$ will be measured to an accuracy better than 4% in hydrogen and 6% in deuterium, for center of mass angular increments of 3° to 6° between 20° and 140°, and for energy increments of 4.9 to 12.5 MeV. These measurements will provide unique and coherent results from tagged photons over a broad range of angle and energy; and with a few exceptions, represent the only pion photoproduction data above 1800 MeV. The differential cross sections extracted from this data will be analyzed to determine the partial-wave amplitudes and the photocouplings for some 25 baryon resonances in the energy range of the experiment.

Many of the resonances which are predicted by the quark model between threshold and our energy cutoff are not observed in analyses of the current pion-photoproduction data. Our new results, which in some cases will yield partial-wave amplitudes with uncertainties a factor of five smaller than current results, will determine current photocouplings more accurately, and can reveal currently unidentified weakly-produced resonance states. The photocouplings of baryon resonances are a crucial test of our understanding of nonperturbative quantum chromodynamics (QCD). The results will be compared with quark-model predictions; with predictions from multichannel analyses, e.g. $\gamma N \rightarrow \pi N$, $\gamma N \rightarrow \pi\pi N$, $\gamma N \rightarrow \eta N$, $\pi N \rightarrow \pi N$, $\pi N \rightarrow \pi\pi N$ and $\pi N \rightarrow \eta N$; and with other timely physics models. The establishment of the Q^2 =0 electroproduction point in the more fundamental photoproduction processes will provide an important constraint on any results obtained in electroproduction experiments.

The beam-time request presented in the proposal did not include calibration runs which will be performed for all experiments during the commissioning phase of CLAS. Phase I of this experimet has been approved to run concurrently in CLAS with the other approved experiments that have been allocated time in running periods "Gamma 1" and "Gamma 2". These include experiments 89-004, 89-024, 91-008, 93-033, 94-015, and 89-045, 93-008, 93-017, 94-008, respectively. Some conditions for running period "Gamma 1" are listed in the first two rows of Table 1; and some conditions for running period "Gamma 2" are listed in the third row of Table1. Assuming the running time, tagger, and trigger conditions that are currently envisioned by the approved experiments, we will measure single pion differential cross sections of 1 μb/sr in energy bins, ΔE, and angular bins, $\Delta[\cos(\theta_{CM})]$, with the statistical uncertainties shown in the last column of the first three rows (Phase I) in Table 1. Of course, at photon energies below the largest tagged energy, in an energy region of constant trigger prescaling, the uncertainties will be less than they are at the highest tagged energy. We will adjust the angular bins continuously and energy bins in fixed increments as a function of photon energy to best match the systematic uncertainties.

Table 1. Statistical Uncertainties in Differential Cross Section for 1μb/sr

Target	E_e (GeV)	E_γ (GeV)	Time (days)	ΔE (MeV)	$\Delta[\cos(\theta_{CM})]$	Error (%)
Phase I -- Beam Time Allocated for Running Periods Gamma 1 and Gamma 2						
hydrogen	**2.4**	**2.28**	**52**	**4.9**	**0.05**	**2.0**
hydrogen	**3.2**	**3.04**	**7**	**12.5**	**0.10**	**2.5**
deuterium	**1.6**	**1.52**	**23**	**6.2**	**0.05**	**2.0**
Phase II -- Beam Time Allocation Deferred by the PAC						
deuterium	**3.2**	**3.04**	**10**	**12.5**	**0.10**	**2.4**

Phase II of this experiment, which requires new beam time(1 day of setup and 10 days of running with 3.2 GeV electrons and a deuterium target), has had its allocation of beam time deferred to a later date by the PAC. The tagging range would be 47% to 95%, or 1.52 to 3.04 GeV, at a rate of 0.63×10^7 photons/second. The magnetic field setting would be 100% of nominal with negative particles bending out. The uncertainty listed in the last row and column of Table 1 assumes a 50% accidentals rate, a 40% dead time, a 80% azimuthal acceptance over the polar angular range of interest, a 80% trigger and reconstruction efficiency, and a 75% tagger and spectrometer operating efficiency. These assumptions are comparable to those used in the 3.2 GeV run with hydrogen.