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ELECTROMAGNETIC INTERACTIONS WITH NUCLEI AND NUCLEONS

Progress Report
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I. INTRODUCTION

In this document we report the progress for DOE Grant No. DE-FG05-89ER40501, A000. The grant began March, 1990, and we are reporting on the progress at this time for the past year. Our primary research effort continues to be at the LEGS project at Brookhaven National Laboratory. We are extremely pleased to report that data taking has started at LEGS, and the first experiment is almost completed.

This report will summarize our present research effort at LEGS. In addition we will report on the extensive instrumentation program that we have undertaken as part of our research effort at LEGS and CEBAF. We will also report on the continuing effort to digest the data taken in various experiments at SLAC. Those efforts continue to result in the production of research publications.

In addition the principal investigators are heavily involved in the CLAS collaboration in Hall B at CEBAF. We are part of several experiments that have been approved for beam time at CEBAF and have made commitments to construct experimental equipment for CEBAF. We will report on the approved experiments and on instrumentation efforts. We expect our primary experimental effort to continue at LEGS until CEBAF becomes operational.

During the past year we also completed the testing of the University of Virginia Nucleon Detector System, and it was used in a first experiment at LAMPF. We collaborated on this experiment which will be described.

This report will be divided into separate sections describing our progress at LEGS, in Instrumentation, SLAC, CEBAF, and LAMPF. We will also discuss our significant efforts in the education and training of both undergraduate and graduate students. Finally the publications and abstracts are appended.

II. LEGS

A. General LEGS Work

The Laser Electron Gamma Source (LEGS) is designed¹ to provide intense beams of monochromatic and polarized gamma rays with energies up to 500 MeV. Backward angle Compton scattering of laser light from high energy electrons is used to produce the intense photon beams. The energies of the gamma rays in the LEGS beam are defined by detecting the appropriate scattered electrons over the photon energy range from 175 to 300 MeV. The entire spectrum of photon energies is provided simultaneously.

Some 250 days of running have occurred since LEGS first turned on in May, 1988. A typical gamma ray spectrum is shown in Figure 1 with both untagged (top) and tagged (below) photons. The position of the high energy Compton edge (227 MeV) can be changed by using different laser wavelengths. Beams up to 300 MeV can currently be used. The tagging spectrometer tags all photons between 180 MeV and the high energy Compton edge. In addition a small secondary tagging interval that uses only part of the spectrometer tags the interval from 90 to 120 MeV. The spectrum at the bottom of Figure 1 indicates the lower energy gamma rays.

B. Photodisintegration of the Deuteron

The most important progress of the recent year at LEGS was the beginning of the first experiment, the photodisintegration of deuterium. The first data were taken in December 1989 after the liquid D_2 target was filled and tested. Preliminary data, presented at both the Spring meeting of the APS in Washington and the PANIC meeting in Boston, were taken before the end of the year. Although we were able to extract cross sections and asymmetries from this data, it also provided us with a much needed check of our entire data collection and analysis

Figure 1. LEGS gamma-ray spectra for 488 nm light backscattered from 2.5 GeV electrons. In this case the Compton edge is at 227 MeV. Top) all gamma rays. Middle) gamma rays tagged with a single element of the tagging focal plane detector array. Bottom) gamma rays tagged with low energy tagger.

procedure. A much larger set of data was taken in the energy range between 180 and 210 MeV during the summer of 1990. This data is currently being analyzed as we begin to acquire data in the higher energy range up to 300 MeV.

Polarization observables reflect interference terms that are sensitive to effects that are not easily accessible through unpolarized cross section measurements. Recent calculations for the photo-disintegration of deuterium² suggest that meson-exchange (MEC) and delta-isobar (IC) currents should strongly affect the photon polarization asymmetry, Σ , the difference between cross sections measured with the photon's electric vector in the reaction plane and perpendicular to it, divided by the sum. The predicted effects are so large as to completely flip the sign of the asymmetry above pion threshold. Some asymmetry data has been published³, but most are limited to angles near 90 degrees.

A new measurement of the $d(\gamma, p)n$ reaction is presently underway at LEGS. Protons are detected at eight angles simultaneously in an array of 24 CaF_2 -plastic-scintillator phoswich detectors, and in a silicon-microstrip array with raytracing capabilities. Data up to 300 MeV are currently being analyzed. A preliminary analysis of a portion of the data between 202 and 210 MeV beam energy is shown in the accompanying figures. For this data set, the gamma-ray polarization was flipped between directions parallel and perpendicular to the reaction plane at a frequency averaging once every 60 sec. To minimize bias to the data and average out systematic errors, the length of time spent in any one polarization state was randomly chosen between 30 and 90 sec. Protons were selected by imposing cuts in energy-loss vs total energy and in time-of-flight. The energy spectrum in each detector was dominated by the two-body $d(\gamma, p)n$ peak, with a small background coming from reactions within the mylar of the target walls and of the vacuum chamber window. This background contribution was confirmed by raytracing in the micro-strip detector system which easily separated events produced in target windows from those associated with deuterium.

The unpolarized cross section, the average of the parallel and perpendicular reactions, is shown as the solid circles in Figure 2. The error bars reflect statistical uncertainties only. The

Figure 2. Unpolarized cross section for $d(\gamma, p)n$. Solid circles: data from LEGS for $E_\gamma = 206 \pm 4$ MeV. Open squares: data from Bonn⁴. Open diamonds) data from Frascati⁵. The solid and dashed lines show calculations by Arenhoeval² using Paris and Bonn potentials, respectively.

systematic errors are still being evaluated. For comparison, the Bonn measurements⁴ are shown as open squares and the recent Frascati measurements⁵ are shown as open diamonds. The solid⁶ and dashed curves⁷ are recent calculations by Arenhoevel and collaborators using the Paris and the Bonn r-space potentials for the nucleon-nucleon interaction, respectively. These calculations include meson-exchange and delta-isobar currents.

The photon asymmetry for this data set is shown as the full circles in Figure 3, and is in excellent agreement with the limited range of published data (open squares - Gorbenko, et. al.³; open triangle - Liu³). The solid and dashed curves are the corresponding calculations using the Paris and Bonn potentials, respectively.

Since the $d(\gamma, p)n$ reaction is entirely contained within a plane, one can write the cross section in terms of the reaction angle (θ) within the plane and the angle (ϕ) made by the gamma ray polarization vector with the reaction plane, $\phi = 0^\circ$ or 90° known as parallel and perpendicular reactions. The cross section for arbitrary θ and ϕ can quite generally be written as

$$\frac{d\sigma}{d\Omega}(\theta, \phi) = \frac{1}{2} \left[\left. \frac{d\sigma}{d\Omega} \right|(\theta) + \left. \frac{d\sigma}{d\Omega} \right|_{\perp}(\theta) \right] + \frac{1}{2} P \left[\left. \frac{d\sigma}{d\Omega} \right|(\theta) - \left. \frac{d\sigma}{d\Omega} \right|_{\perp}(\theta) \right] \cos(2\phi)$$

Thus, the polarization sensitive effects are isolated, not in the asymmetry, but in the parallel - perpendicular difference cross section. This is shown in Figure 4 for this data set. (There are no other reported measurements here since the asymmetry and the unpolarized cross sections have not previously been measured at the same laboratory.) The solid and dashed curves are again the calculations of Arenhoevel² using Paris and Bonn potentials, and now show considerable sensitivity to the Nucleon-Nucleon potential. These curves differ by a factor of two in Figure 4 while the predicted differences in the unpolarized cross section (Figure 2) are at most 15%.

Figure 3. Photon asymmetry for $d(\vec{\gamma}, p)n$. Solid circles: LEGS data for $E_\gamma = 206 \pm 4$ MeV. Open squares: data from Kharkov. Open diamonds: data from Stanford. The solid and dashed lines are calculations by Arenhoeval².

Figure 4. Difference between parallel and perpendicular cross sections. The calculated curves are by Arenhoeval² using the Paris and Bonn potentials.

The predicted effects of MEC and IC upon the polarized cross sections increases dramatically with energy. Tracking these effects, as well as the dependence upon the Nucleon-Nucleon potential, with complete angular distributions will provide an interesting test of such theories. The full data set is expected to have statistical errors at least a factor of two smaller than those of figs.2-4 for each 8 MeV interval from 180 MeV to 300 MeV. This analysis is ongoing.

C. Progress Towards Other Experiments

Much progress has been made in preparing for future experiments at LEGS. The next experiment, scheduled to begin in early 1991, is the photodisintegration of ^3He . This experiment will use the current array of phoswich detectors in coincidence with a large array of plastic scintillator bars which will be capable of particle identification. The bars and their stand are currently at BNL awaiting the completion of the deuterium experiment. The target for the liquid ^3He is nearing completion as well, and is hoped to be approved for use in the NSLS building before the end of the year. An RPI graduate student has written and performed preliminary tests of the data acquisition software to be used for this experiment by using a small number of detectors parasitically during the present experiment. A completely separate and parallel data acquisition system has been assembled.

The experiment following the ^3He experiment is planned to be a measurement of the ratio of the E2 and M1 multipoles for the delta resonance. This will be a photon scattering experiment where the incoming polarized photons are scattered and detected in a large 19" x 19" NaI crystal described below.

III. Instrumentation

A. LEGS Instrumentation

LEGS Beam Properties. The properties of the gamma-ray beam are now quite well known, and various improvements have resulted in properties that are reproducible from fill to fill of the ring, and even over much longer periods. The profile of the beam is roughly Lorentzian, with a full width at half maximum of 9 mm vertically by 22 mm horizontally at a target position 41 meters from the center of the interaction straight section. The use of a new system of skew quadrupoles in the x-ray ring to correct transverse coupling and an orbit control feedback system to stabilize the electron beam position in the interaction region are both necessary to achieve a beam size this small. The orbit feedback system maintains the beam centroid to within less than 1 mm at the target.

The LEGS tagging spectrometer has been in routine use for the past year. The focal plane has been accurately calibrated from 185 to 240 MeV in gamma-ray energy. The measured energy resolution over this range is 4.8 to 6.2 MeV (FWHM). This resolution is dominated by the x-ray ring energy spread: subtracting the nominal value for this spread from the observed resolution gives an intrinsic resolution of the spectrometer of 3.8 MeV. The corresponding resolving power is 1 part in 600 of the electron energy. Measured properties of the spectrometer (resolution, dispersion, and acceptance) are in excellent agreement with those calculated from ray tracing.

The bremsstrahlung component of the gamma-ray beam has been reduced by replacing the vacuum pipe of the storage ring in the central part of the interaction straight section with a new pipe with integral vacuum pumps and electrostatic ion clearing electrodes. This has resulted in a reduction of the bremsstrahlung rate by a factor of 5 to 10 to about 5×10^4 at 220 MeV, or about 1% of the total beam. This is important because the bremsstrahlung is not polarized, and it therefore dilutes the polarization of the gamma-ray beam.

Electron Orbit Stabilization by Feedback. Because the nuclear targets are located so far

from the laser-electron interaction region in the storage ring, very small changes in the angle of the beam in the ring can result in large motions of the gamma-ray beam on the target. These motions are accompanied by changes in the flux and in the beam shape since the electron-laser beam overlap is changed. To prevent these variations in the beam a control system was built and installed last year to stabilize the electron orbit in the interaction straight section of the ring.

The first of the two LEGS feedback systems was commissioned during dedicated studies shifts in the summer and fall of 1989. (The second will be used to maintain the calibration of the tagging spectrometer.) By the end of November this first system was sufficiently reliable to begin using it during normal NSLS operations. During the spring of 1990, the system was tested and found to successfully maintain the position and size of the photon beam on target within the amount expected from the divergence of the electron beam. It was also necessary to minimize the strength of any steering magnet within the laser interaction region, as any small change in the beam direction will result in a separate photon beam direction. Much study time was spent to determine a consistent orbit of the ring which minimized these fields in our straight section and did not effect the other users groups at the NSLS. In total, the feedback system now consists of 6 local bumps of the ring for both horizontal and vertical motions.

The increased position stability of the beam in turn made it possible to begin using the deuterium target. Because of various cooling elements and insulation, the clear area of this target is only about twice the FWHM of the beam. Slits, followed by a sweeping magnet, collimate the beam to prevent any scattering by support structures in the target. The high beam stability achieved with the feedback system allows 85% of the beam to be transported to the target. In the fall of 1990 the feedback system receiver cards were replaced with permanent circuit boards rather than the prototype wire wrap version initially installed.

Tagging Focal Plane Detectors and Electronics. The complete focal plane detector is now in operation. It is a 128 element plastic scintillator hodoscope, 50 cm long, made from two

overlapping but offset planes, each containing 64 elements. It spans the entire range of the tagging spectrometer, from 180 to 320 MeV. Each half-element, defined by a coincidence between front and back planes, represents about 1 MeV in photon energy, so that the detector makes negligible contribution to the total energy resolution. The measured time resolution of this detector and its associated electronics is about 600 ps, and it is capable of counting at rates of several megahertz per element with negligible losses (less than 1%).

The electronics for distributing and processing the tagger signals have been improved. The repeater modules, which transmit the tagger "hit" pattern to the two experimental areas, have been rebuilt to eliminate a source of dead time. The previous version could not transmit pulses from events in two consecutive RF bunches of the beam (separated by 19 ns). Now the repeaters clear in less than 15 ns, so they can transmit events from consecutive bunches. To restrict the event trigger to more useful events, a trigger generator has been constructed for the focal plane detector. This module produces a trigger only when there is a signal in at least one detector in the front plane and at least one detector in the back plane. A prescaler module has also been built to reduce the rate of each of the tagger elements, so they can be monitored by CAMAC scalars without overflow.

Beam Flux Monitoring. Crucial to any determination of a scattering cross section is an accurate measure of the incident flux. For photon scattering measurements using tagged photons, this is typically done by scaling the number of counts from the tagger. The scaling ratio is usually determined by putting a highly efficient detector in the photon beam which can then be used to determine the efficiency of the tagging counters.

We chose to instead monitor the beam flux as the data are taken. During the spring of 1990 we assembled various detectors consisting mainly of plastic scintillators sandwiched between sheets of Pb. Charged particles resulting from interactions in the target are vetoed by a thin plastic scintillator. Pairs are then produced in Pb which are subsequently detected in the following plastic scintillators. In addition, two pairs of scintillators were positioned downstream

to detect electron-positron pairs that resulted from interactions in the Pb. Various logical combinations of the signals are then scaled as a measure of the photon flux. A given combination is then normalized to the actual beam flux by positioning a large NaI crystal in the photon beam to measure the absolute flux. This is done during special conditions of the ring when the current is much reduced to avoid gain drop at very high rates. For various intensities of photon flux, the beam monitors have been shown to be accurate to within 2%.

Beryllium Mirrors. Originally, the laser light entered the ring vacuum cavity through a quartz window on the axis of the straight interaction section. This became a problem when the synchrotron radiation from the ring damaged the quartz window, which then would absorb laser energy. This process heated the window, which would then act as a lens and deform the laser beam, reducing the backscattered photon flux. The first step in a solution to this problem was to take the entrance window of the laser off the axis of the interaction straight section. The laser light was then reflected up to pass through the window and then reflected back down and into the straight section. This resulted in less damage to the quartz window, but the damage was not removed altogether, since the quartz reflecting mirrors used to reflect the laser light also tend to reflect the synchrotron radiation. This problem was much improved by replacing the quartz reflecting mirrors with beryllium mirrors, which because of their low-Z, are much less efficient at reflecting the damaging synchrotron radiation, resulting in a much longer usable life for the quartz windows and improved beam flux.

B. Major LEGS Software Projects

The data acquisition system used at LEGS is the LAMPF based "Q" system. This has proven to be well matched to typical event rates we experience during the taking of actual experimental data; however, it is sometimes useful for diagnostic purposes to have a set of dedicated camac and data acquisition routines available. For this reason, a set of routines were

written during the past year for communications with a LeCroy 1440 high voltage power supply, to acquire data from a large NaI crystal in coincidence with various tagging signals, and to drive and acquire data from our beam monitoring apparatus. The high voltage routines allow a user interface to inspect and/or change high voltage settings, as well as provide a fortran library for user programs, such as one used to gain match a set of detectors. The NaI pulse height acquisition program, appropriately called MCA, digitizes the analog signal using a LeCroy 3511 adc and a 12-bit register and can maintain acquisition rates up to 50 kHz. The beam monitor program controls movements of the beam monitor and collects data at each of the positions at a maximum rate of 100 kHz. Both have proved very useful in understanding and monitoring the photon beam.

C. NaI Detector System

The 19 inch x 19 inch NaI crystal for the high-resolution NaI gamma-ray spectrometer has been delivered to Brookhaven. This crystal was tested for energy resolution during and after the manufacturing process with a system that uses cosmic ray muons to measure the uniformity of response throughout the crystal volume (muon CAT scanning). The muon-CAT scan data has been analyzed to yield a map of the crystal as a function of light collection efficiency, which, when used in conjunction with a Monte-Carlo simulation of high energy gamma rays, is hoped to predict the measured response. The remaining components of the spectrometer have been designed and a large goniometer to hold the detector with its shielding is presently under construction. A temporary goniometer has been completed which supports the crystal and a 2 inch anticoincidence front plastic for initial measurements of the detector response. A set of high performance bases for the Hamamatsu 1911 phototubes on the NaI have been constructed. The use of 3 high voltage inputs and bridging each capacitor in the base to ground should reduce sensitivities to the gamma flux rate.

D. Nucleon Detector System

Two years ago one of the principal investigators was primarily responsible for obtaining \$200,000 from the state of Virginia for the construction of a nucleon detector system. During the past year the detector system was assembled and tested. A detector stand was designed and constructed to contain the system, and the entire system was used in a first experiment at LAMPF. We plan to use the same detector system in two more experiments during the coming year at LEGS. After initial experiments on the photodisintegration of the deuteron, the second experiment at LEGS will be a measurement of the interactions of photons with ^3He in which an existing detector will be used as a proton detector, and the nucleon detector system will be used to detect both neutrons and protons. Thus coincident measurements of n+p and p+p will allow correlation studies of ^3He .

One of the most important experiments to be done at LEGS will be a measurement of the E2/M1 ratio for the delta in both the proton and neutron. Polarized gammas will be scattered from both the proton and the deuteron to excite the delta. In the case of the proton, a coincidence will be made between the outgoing gamma ray in a large NaI detector and the proton in the large solid angle nucleon detector described here. For the neutron delta, the coincidence between the gamma ray and neutron will be used to limit scattering from the deuteron target to the kinematic cases where the proton is merely a spectator. Such an experiment will require the large solid angle, good timing characteristics, and particle identification of the nucleon detector. An additional long term (2-3 years) experiment at LEGS will measure the polarizability of both the neutron and proton. This experiment will also require the use of the nucleon detector system.

University of Virginia nuclear physicists have long been interested in the few nucleon systems. During the past summer the UVa nucleon detector system was used at LAMPF in a coincidence experiment $^4\text{He}(\pi^+, pp)$ and $^4\text{He}(\pi^+, pn)$. This experiment will be discussed elsewhere. Previous data suffered from limited phase space caused by the lack of complete

kinematic coverage. The nucleon detector system allowed these experiments to be performed more efficiently and with less systematic error. Both neutrons and protons were detected in the nucleon detector system in coincidence with protons detected in a large acceptance magnetic spectrometer at LAMPF. Such experiments probe the three body continuum and aid in understanding the role of final-state interactions in electrodisintegration of the three-nucleon system.

The nucleon detector system will eventually consist of 48 scintillator bars, each 10 cm x 10 cm x 160 cm. Light pipes and 2 inch photomultiplier tubes are placed at both of the 10 cm x 10 cm ends in order to collect sufficient light, but also to enable position determination along the 160 cm length. Neutrons (or protons) pass through the 10 cm depth giving approximately 10% neutron detection efficiency for 100 MeV neutrons. The scintillator bars allow flexibility in several different orientations including 30 cm depth (3 bars deep by 16 bars wide; $\approx 30\%$ efficiency), 20 cm depth (2 bars deep by 24 bars wide; $\approx 20\%$ efficiency) or 10 cm depth (1 bar deep by 48 bars wide; $\approx 10\%$ efficiency). The objective is to create a flexible system allowing a large solid angle detector system with sufficiently large detector efficiency for neutrons.

Many of the design parameters are determined by the requirements for detecting neutrons. However, the detector system is also an excellent system for detecting low mass charged particles, especially protons. No plans currently exist for detecting deuterons, but the possibility certainly exists. In order to detect protons, and to eliminate charged particles by anticoincidences when detecting neutrons, we have included 24 scintillator paddles which are each 0.6 cm x 11 cm x 160 cm. The paddles are thin enough so the neutrons will have little probability of being detected, but the protons will produce a large signal - allowing particle identification. The number of paddles allow them to be used in either the 2 x 24 or 3 x 16 configurations. Light pipes and photomultiplier tubes are placed at each 0.6 cm x 11 cm end of the paddles.

We decided on the LeCroy high density, high voltage power supply distribution CAMAC based system and on ECLine electronics. Thus far our experience has been very favorable. We

have not been able to obtain enough funds to complete the entire detector electronics. In particular, we do not have enough coincidence registers or scalars and almost none of the trigger electronics. At LAMPF we had to rely on borrowed electronics from the pool and other groups. We hope to eventually acquire a complete set of electronics, so that it can be transported as a unit to various laboratories. Our group has previously acquired a microVax data acquisition system that will be used for testing and can be taken to the accelerator site if needed.

We presently have 32 bars and 24 paddles of the planned 48 bars and 24 paddles. Andrew Sandorfi of the LEGS group of Brookhaven has purchased an additional 16 bars for which we are providing the phototubes and bases. This will complete our 48 bar system, although the Brookhaven bars may not be mobile for Virginia use at other installations. For neutron detection these will primarily be used in one of two configurations: (1) Four element sets, each set consisting of 1 paddle followed by 3 bars, providing 16 neutron detectors each 10 cm wide for a total detector area $1.6 \text{ m} \times 1.6 \text{ m}$ (2.56 m^2), 30 cm thick and 1.6 m long. The neutron detection efficiency for this arrangement is about 30% for each set. (2) The other possibility for a set consists of two bars rather than three, giving a total number of 24 sets for a total detector area of $2.4 \text{ m} \times 1.6 \text{ m}$ (3.84 m^2). The neutron detector efficiency is reduced to 20% in this case.

At the present time the funds provided by the state of Virginia have been expended, and attempts to obtain the remaining \$135,000 needed to complete the system from the DOE have been unsuccessful.

For the ^3He experiment at LEGS, the nucleon detector system will be mounted such that the bars and paddles are horizontal above the liquid ^3He target. Richard Lindgren of the University of Virginia has designed and constructed a detector holder for this application that is presently at Brookhaven. Obviously, a system as large and unwieldy as 48 scintillator bars, 24 scintillator paddles, 144 photomultiplier tubes and bases represents a problem in mounting for an experiment.

The entire system is now at Brookhaven, having been shipped there from LAMPF in August, 1990. Special crates for shipment of the system have been constructed. The scintillators and phototubes seem to have arrived at Brookhaven in good shape. The LeCroy high voltage power supply was damaged, and some components are now being repaired in the Brookhaven electronics shop. Complete testing will be required of all components before being used in the ^3He experiment at LEGS.

We originally expected that the normal positioning of the bars and paddles would be in the vertical direction. We designed and constructed a unique system to hold the nucleon detector system vertically that would be used at LAMPF and LEGS. The system worked well at LAMPF, but after its initial use, we have decided that the timing from the scintillators is so good that better angular definition can be obtained if the scintillators are mounted horizontally. Timing from the phototubes at each end of the bars allows determination of the position of the incident particle. When mounted vertically, this position resolution is 10 cm, the width of the bars. When mounted horizontally, the position resolution is determined by the timing resolution. Brookhaven has designed a detector stand to hold the scintillators horizontally for the E2/M1 experiment that uses many of the same components from the vertical stand. We hope that this arrangement will give us better angular definition and help discriminate between the nucleons sought for and background events.

E. Waveshifting Fibers

A new instrumentation project has been started in the last year involving waveshifting optical fibers. RMS in collaboration with Dr. Oscar Rondon-Aramayo of the University of Virginia has been studying the coupling of scintillators to small diameter, waveshifting fibers. By this coupling the light from scintillators can be read out via small, flexible light pipes. The amount of light can then be measured by a light detection device capable of handling a large number of channels such as a photodiode array or a charge coupled device (CCD) and image

intensifiers. We are interested in applying these techniques to the construction of polarimeters for medium energy neutrons to be used to measure the electric form factor of the neutron at CEBAF. A volume of scintillator consisting of many small scintillators arranged in hodoscope layers and using fiber readout would allow tracking the protons recoiling from neutron proton elastic scattering. The neutron polarization would be inferred from asymmetries in the direction of the recoil protons. Monte Carlo studies indicate that the efficiency of this polarimeter would be many times higher than the efficiencies of present devices. We are constructing a 100 channel prototype recoil particle tracking detector to test the basic ideas and to develop techniques. We hope to evaluate both photodiode array and CCD light detection methods. Funds to buy equipment for this work have been obtained from the National Science Foundation's Small Grants for Exploratory Research program.

If successful, we expect that similar techniques could be used in detectors for experiments at LEGS. For example, a 4π steradian detector for neutrons and neutral pions could be constructed. This detector could be used to measure the E0 multipole for threshold neutral pion production from the neutron. For the proton there is an anomalous suppression of the E0 multipole that casts doubt on low energy theorems. There are no data for the neutron to check the findings from the proton. It is easy to imagine many other applications of the basic methods. For example, one could incorporate thin lead sheets and construct a position sensitive shower counter with 1 cm spatial resolution that could be used at LEGS to study photon scattering at small angles (Delbruck scattering).

F. EGN Prototype Detector for CEBAF

The forward shower counter for the CLAS detector to be installed in Hall B at CEBAF is known as the Electron Gamma Neutron detector (EGN). A prototype of this detector has been constructed at the University of Virginia and tested at the AGS test beam facility at Brookhaven National Laboratory. Construction of this detector is one of the major commitments of UVA faculty members to CEBAF.

The prototype constructed was a lead/scintillator sandwich that used alternating 2 mm thick lead sheets and 1 cm thick scintillators with 39 layers each. It was divided into a front and a rear section with 5 and 9 radiation lengths thickness, respectively, for improved pion rejection. The EGN detector must consist of 6 segments each with a triangular shape so it is natural to use triangulation to determine the position of the incident particle. Thus layers were arranged in three orientations that differed by 60 degree rotations. Each layer of scintillator consisted of 10 cm wide bars with varying lengths. There were 11 bars in a layer giving a 127 cm length to each side of the triangle. At one end of each scintillator the light was coupled to a waveshifting bar at a right angle to the scintillator. Separate waveshifters were used for the front and rear sections so that a front (rear) waveshifter was coupled to 15 (24) scintillators. There were a total of 66 waveshifters, light pipes and photomultipliers. The electronics used in these tests were borrowed from the University of Virginia nucleon detector. Details of the construction and performance of the prototype are given in the paper submitted to IEEE Transactions in Nuclear Physics which is appended.

The AGS test beam provided a low flux of pions and electrons with energies up to 4 GeV. We studied the energy resolution, position resolution, pion rejection efficiency and electron efficiency. The average energy resolution for electrons was $9.3\% / \sqrt{E(\text{GeV})}$. Because an electron shower spreads to a width greater than the 10 cm bars we were able to use centroid measurements from each of the three views to locate showers to within a few cm. The pion rejection efficiency was determined to be greater than 98%. The prototype is being transferred from Brookhaven to CEBAF for further testing with cosmic rays. Knowledge gained will be used to finalize the shower counter design for CLAS.

G. Photon Beam Facility at CEBAF

As part of our efforts towards establishing a research program at CEBAF, we have agreed in a Memorandum of Understanding with CEBAF to do the following for the tagged photon

beam system in Hall B:

- 1) Design, build, and install a pair spectrometer capable of beam intensity monitoring at high and low photon rates.
- 2) Construct a total absorption counter, for example a lead-glass scintillator, useful for measurement of low beam intensity.
- 3) Construction of a photon beam profile monitor.

The method of determining absolute cross sections would depend on normalizing the electrons detected in the photon beam tagger magnetic spectrometer with actual photons in the beam. This can be done at low beam intensities with a lead-glass scintillator with reasonable energy resolution. A coincidence between the photon tagger and lead-glass scintillator determines the correct normalization, if the scintillator is placed directly in the photon beam. Such a technique doesn't work at higher beam intensities, because the scintillator could not handle the higher count rate.

Our technique would consist of also using a pair magnetic spectrometer. A thin target placed about one meter in front of an H-type magnetic spectrometer would be used to produce e^+e^- pairs when the photons pass through. These e^+e^- pairs enter the magnetic field and are bent in opposite directions. They are momentum analyzed by the magnetic field, exit the field, and are detected on either side of the beam axis by scintillators in coincidence.

In the simplest system, a coincidence formed between the two scintillators establishes that a pair was produced, and a normalization is determined. In a more advanced system the momentum determination performed by the magnetic field results in particles exiting at different directions. If a position sensitive detector is used, the energy of the incoming photon can also be determined and compared with the corresponding electron energy determined in the photon tagger spectrometer. This method allows better determination of the normalization by also giving an energy dependence. The count rate in the pair spectrometer is determined by the thickness of the foil placed in front of it. At low beam intensities a thicker foil is used than at higher beam intensities. A normalization determined at low beam intensities between

the lead-glass scintillator, pair spectrometer, and photon tagging magnet can be extended to high beam intensities by using the pair spectrometer.

We have designed a system shown in Figure 5 that initially will allow absolute normalization, but by requiring vertical focussing of the e^+ and e^- will also give momentum determination. A position sensitive detector can easily be added now, if funds are available, or later.

The H-type magnet needed has the following properties:

Field strength: 1.5 Tesla

Field gap: 15 cm

Field width: 70 cm

Field depth: 2.5 m

The alcove at the back of Hall B has a width of 16 feet, height of 10 feet, and depth of 20 feet. The beam dump is another 90 feet past the alcove. This space should be adequate to place the magnetic spectrometer and associated equipment.

At the present time a search is being made for an adequate magnet.

We expect to be able to build the total absorption counter from lead-glass scintillators available from other labs. A search has been underway by CEBAF staffers to locate such material. We will need to purchase light pipes, phototubes, phototube bases, and associated electronics.

Another project for Hall B is a live time, γ beam position monitor using scintillating fibers. One of us (RMS) has investigated the feasibility of using short lengths of scintillating fibers coupled to optical fibers. Tests were made at LEGS in August 1990 as part of a research project for an REU student. A thin radiator and a scintillator coincidence paddle were placed in front of a 15 mm long, 2 mm diameter scintillating fiber. Light from the fiber was coupled to a photomultiplier tube by an optical fiber. When this assembly was placed in the LEGS gamma-ray beam with the axis of the fiber parallel to the beam, coincidences were observed. Phototube pulse heights were consistent with the passage of one or two minimum ionizing

Figure 5. Photon beam intensity monitoring system.

particles down the length of the scintillating fiber. Thus we believe that a bundle of fibers can be used as a gamma-ray beam profile monitor. A practical device would have too many fibers to use photomultipliers but if the light were directed to an image intensifier a solid state camera could be used to record the image. Both live images and digitized and stored images of the beam profile would be available. An image intensifier and solid state camera are being purchased as part of the waveshifting fiber instrumentation project discussed above.

IV. SLAC

A. Delta Electroproduction in Nuclei

SLAC NPAS experiment NE5 measured inclusive electron scattering cross sections for electroproduction of the delta in nuclei. These cross sections have been reported in Physical Review Letters. A complete writeup of this experiment is in progress. During the last year quantum hadrodynamics calculations by K. Wehrberger, C. Bedan and F. Beck⁸ have become available. Wehrberger has calculated the NE5 carbon cross sections and an example is shown in Figure 6. The dashed curve is calculated for the free nucleon. The solid curve is calculated for "universal" coupling of the Δ to the scalar and vector mean fields (that is, the Δ and nucleon couplings are equal). Since the calculation did not include contributions from quasideuteron scattering or higher lying resonances, the agreement is quite good.

B. Quasielastic Scattering and Excitation of the Delta by ${}^4\text{He}(e,e')$.

The nucleus ${}^4\text{He}$ is interesting because it is a few body system where microscopic calculations are available, but its density is comparable to nuclei like carbon. It therefore can exhibit properties similar to medium weight nuclei. Recently momentum distributions up to 350 MeV/c have been determined at NIKHEF in a ${}^4\text{He}(e,e'){}^3\text{H}$ experiment⁹. Longitudinal and transverse separations have been performed in a ${}^4\text{He}(e,e')$ measurement¹⁰ and in a ${}^4\text{He}(e,e'){}^3\text{H}$ experiment¹¹. In this last experiment it was found that the transverse response agrees with the momentum distribution calculated by Schiavilla et al.¹² and that the q dependence of the transverse response agrees with that for the free nucleon up to the 830 MeV/c limit of this experiment. A damping of ~20% was observed for the longitudinal response, but the accuracy was not good enough to draw as accurate a conclusion for the slope of the q dependence as for the transverse response.

^{12}C , $E = 1108 \text{ MeV}$, $\Theta = 37.5^\circ$

Figure 6. Inclusive electron scattering cross section vs. invariant mass for carbon from SLAC NPAS experiment NE5. The curves indicate calculations by K. Wehrberger. Solid curve: universal coupling for the delta. Dashed curve: free delta.

We have performed an experiment at SLAC where we were able to study the ${}^4\text{He}(e,e')$ reaction at high momentum transfers up to 1.1 GeV/c without separation. In this momentum transfer domain, the cross-section is dominated by the transverse response and so it is a good check of transverse response.

The experimental data were obtained at the NPAS facility of the Stanford Linear Accelerator Center (SLAC). The electrons, of energies 0.96, 1.1, 1.3, 1.5, and 3.8 GeV, were obtained using the nuclear physics injector. The data for the three lowest beam energies were obtained using the 1.6 GeV/c magnetic spectrometer, while for 1.5 and 3.8 GeV, the 8 GeV/c magnetic spectrometer was utilized. The energies and scattering angles are given in Table 1. The ${}^4\text{He}$ target was a 25-cm long, high-pressure, recirculating gas target used at a pressure of 25 atm. In addition, an empty target cell was used to determine background. A 15 cm long liquid H target using recirculating liquid and a similar empty target cell was also used for absolute cross section calibration purposes. A carbon target used for normalization of the two spectrometers was 0.019 radiation lengths thick.

We were primarily responsible for constructing a new detector package for the 1.6 GeV/c spectrometer. It consisted of (a) three multiwire drift chambers each with four planes of wires, (b) an isobutane-filled Cherenkov detector at atmospheric pressure, (c) two planes of scintillator hodoscope, and (d) a 35 segment lead-glass shower counter. The drift chambers were used to obtain position information for the electron trajectories, and the Cherenkov and shower counters provided pion discrimination. The event trigger was determined by coincidence between the scintillator hodoscopes and either the Cherenkov detector or the shower counter.

The detector package for the 8 GeV/c magnetic spectrometer has been well tested and calibrated by previous users, including ourselves (J. P. Chen, *et. al.*¹³). The electron trajectories were determined by ten planes of wire chambers. Electron identification was provided by a lead-glass shower counter and a nitrogen-filled Cherenkov detector.

After converting the raw data to absolute cross sections, a correction was made for the elastic radiative tail. The maximum elastic radiative corrections at the minimum scattered

electron energy were negligible for 3.8 GeV beam energy, but range from 3% for 1.3 GeV to 22% for the 0.96 GeV beam energy. Continuum radiative corrections were applied using the prescriptions of Mo and Tsai¹⁴ and Stein *et al*¹⁵. The continuum radiative corrections were as large as 40% for the quasielastic peak for ^4He at 3.8 GeV and 15° , but decreased to only about 20% at the delta peak. Corresponding corrections for the lower energy beam energies at 37.5° were 20-35% for the quasielastic peak and 3-12% for the delta region.

Data taken with the 1.6 GeV/c spectrometer were converted to absolute cross sections using a spectrometer acceptance function calculated by a Monte Carlo code. This code gave a calculated acceptance function for the shorter H target that was within 1% of the measured acceptance function. Data taken with the 8 GeV/c spectrometer at 3.8 GeV incident beam energy were corrected by a normalization factor of 1.027 determined by measurements of electron elastic scattering from H. The data taken with the 8 GeV/c spectrometer for a beam energy of 1.5 GeV were normalized with the ^4He elastic peak and are believed to be accurate to within 3%. In order to compare measurements taken with the two spectrometers, the cross sections were compared for a carbon target for a beam energy of 2.5 GeV and scattering angle of 40° for both spectrometers. The results agreed to within 1%, well within the expected absolute cross section uncertainties.

The overall uncertainty for the absolute ^4He cross sections measured with the 1.6 GeV/c spectrometer is estimated to be 6% with the largest contribution coming from the spectrometer acceptance function (5%). For the 8 GeV/c spectrometer data the uncertainty is estimated to be about 5% with the largest contribution being the radiative corrections.

Table 2. Experimental Parameters

Target	Incident Energy (GeV)	Angle (degrees)	Q ² Quasielastic (GeV/c) ²	Q ² Delta (GeV/c) ²
Data:				
He	0.961	37.5	0.308	0.206
He	1.108	37.5	0.400	0.275
He	1.299	37.5	0.533	0.392
He	1.501	15.0	0.144	0.115
He	3.804	15.0	0.856	0.772
Normalization:				
H	0.96-1.3	37.5		
H	3.804	15.0		
C	1.501	40.0 (1.6 GeV/c spectrometer)		
C	1.501	40.0 (8 GeV/c spectrometer)		

The experimental results in the form of cross section per nucleon are shown in Figures 7-9. In order to compare the data for the different kinematic regions, the data are shown as a function of the invariant mass W , where

$$W^2 = M^2 + 2M\omega - Q^2$$

The other values are the mass M , the energy loss $\omega = E_0 - E'$, and the four momentum transfer, $Q^2 = 4E_0E'\sin^2(\theta/2)$, where E_0 is the incident electron beam energy, E' is the outgoing electron energy, and θ is the laboratory scattering angle. The use of the invariant mass allows us to indicate the quasielastic scattering peak at approximately the nucleon mass and the delta peak at approximately the delta resonance energy.

The model used for calculations to understand the results is the straightforward extension of the model which has been tailored for the analysis of the ${}^3\text{He}(e,e')X$ reaction^{16,17}. It takes into account all the possible one-body and two-body interactions of the virtual photon. Besides trivial changes in the kinematics and the spin and isospin coupling coefficients, the only major modification concerns the various overlap integral which enter the calculation. They are computed numerically, starting from the four and three body variational wave-functions which have been obtained by the Urbanna group¹⁸ for the Argonne V14 potential¹⁹.

The kinematics and the phase-space are relativistic. The various elementary currents and matrix elements include relativistic corrections up to terms of the order $(1/m)^3$. The wave functions are non relativistic.

The cross-section of the two-body break-up channel, ${}^4\text{He}(e,e'p){}^3\text{H}$, reproduces nicely, within 20% (ref. 20, 21, 22), the exclusive experiments recently performed at Amsterdam²³ and Saclay²⁴. The direct proton knock-out (a) is basically the product of the nucleon current matrix element and the overlap integral between the ${}^4\text{He}$ and T ground state wave functions. The two nucleon matrix elements involve a numerical six-fold integral, which is performed according to Laget¹⁷. It runs over the internal relative momentum of the two nucleons in the active pair and the momentum of their center of mass. The two other nucleons are assumed to be spectators and the integral over their relative momentum leads to the various overlap

Figure 7. Cross sections for the ${}^4\text{He}(e,e')$ reaction for $E_0 = 1.5 \text{ GeV}$ and scattering angle of 15° . Both the quasielastic and delta peak are seen.

Figure 8. Cross sections for the ${}^4\text{He}(e,e')$ reaction for incident energies of 0.96, 1.1, and 1.5 GeV for a scattering angle of 37.5° .

Figure 9. Cross sections for the ${}^4\text{He}(e,e')$ reaction for $E_0 = 3.8 \text{ GeV}$ and scattering angle of 15° .

integrals, between ${}^4\text{He}$ or ${}^3\text{He}$ and the states of a nucleon pair (${}^2\text{H}$, np pair in $T=0$ or $T=1$, and pp pair), which enter the calculation.

The cross-section of the two body break-up channel ${}^4\text{He}(e, e'n) {}^3\text{He}$ is computed in the same way by exchanging the role of the neutron and the proton.

The cross-section of the three body break-up channel, ${}^4\text{He}(e, e'p)n{}^2\text{H}$, is computed along the same lines and reproduces nicely²¹ the shape and the magnitude of the structure which have been observed in the continuum²⁴.

The cross-section of the pion production channel, ${}^4\text{He}(e, e'){}^4\text{N}+\pi$ is approximated, as by Laget¹⁶, by the convolution of the nucleon momentum distribution and the $N(e, e'\pi)N$ cross-section²⁵.

Below $Q^2 = 1 \text{ (GeV/c)}^2$, this model is expected to be reasonable: the various electromagnetic form factors are known, and the expansion of the matrix elements, which includes the terms of order $(1/m)^3$, is expected to be good. Above $Q^2 = 1 \text{ (GeV/c)}^2$, the $N-\Delta$ transition electromagnetic form factor is not known, and relativistic corrections are expected to be more severe. This might be the reason why the model fails to produce the delta peak at the highest momentum transfers.

C. Quasielastic Scattering at High Q^2

Analysis of SLAC NPAS experiment NE9 has continued. The object of this experiment was to investigate the quenching of the longitudinal response function for quasielastic scattering that had been observed at Saclay and Bates. It has also been observed that the experimental Coulomb sum is suppressed. These results have been explained by assuming that a nucleon swells when in the nuclear medium and therefore that a modified form factor must be used. A variety of other explanations have also been proposed such as final state interactions, relativistic effects, two body correlations and off-shell effects. None of these have been successful at describing both the longitudinal and transverse response functions. The predictions of these

models differ at high Q^2 which motivated the experiment.

Cross sections were measured for inclusive electron scattering from nuclei at $Q^2=0.9$ (GeV/c)². Data were taken at forward and backward angles so that a Rosenbluth separation could be performed. Targets used were ^{3,4}He and Fe. The data for Fe have been completely analyzed and a letter has been submitted to Physical Review Letters. A copy of the manuscript is appended to this report. The He data are currently being analyzed. An abstract, regarding the He analysis was submitted to the 1990 Fall meeting of the Division of Nuclear Physics of the APS.

Results from the Fe data are summarized in Figures 10 and 11. Figure 10 shows the longitudinal and transverse response functions at $Q^2 = 0.9$ (GeV/c)² and $Q^2_{\text{eff}} = 0.9$ (GeV/c)² which accounts for Coulomb effects. The longitudinal response is in agreement with a Fermi gas calculation on the low energy loss side of the quasielastic peak but below the calculation on the high energy loss side of the peak. Figure 11 shows the Coulomb sum calculated from the Saclay and Bates data as well as from the present data. Although the uncertainties are large it appears that the Coulomb sum is below that calculated from Fermi gas models.

V. CEBAF

The two principal investigators have been involved with the Hall B Large Acceptance Spectrometer project at CEBAF for several years. From the very beginning we decided that the Large Acceptance Spectrometer provided the detector system that would best support our proposed physics research at CEBAF. First, we want to continue our efforts in photon induced reactions that we have begun at LEGS. We have been able to successfully argue that a photon tagger be constructed in Hall B. Request for bids for the main photon tagger magnet are now being prepared. Second, we want to continue our work in nucleon resonances that began with the delta experiment at SLAC. We are both members of the nucleon resonance group at CEBAF, the largest and most highly organized collaboration at CEBAF. Several of our

Figure 10. (a) Longitudinal and (b) transverse response functions for ^{56}Fe at $Q^2 = 0.9 \text{ (GeV/c)}^2$ (crosses) and at $Q^2_{\text{eff}} = 0.9 \text{ (GeV/c)}^2$ (circles). Only statistical errors are shown. The solid curves are the PWBA calculation, which should be compared to the data at constant Q^2_{eff} .

Figure 11. Coulomb sum for ^{56}Fe . The circle is the data of this experiment at $q_{\text{eff}}=1.14$ GeV/c. Total error is shown. The squares are the Saclay⁶ and Bates⁷ data. The solid curve is from the Fermi gas calculation.

colleagues from the University of Virginia are also members of this collaboration. Third, we believe that the CEBAF Large Acceptance Spectrometer (CLAS) provides the most unique and flexible instrument to perform coincidence measurements in experiments producing multiple particles. As energies go higher, this multiple detection capability will be increasingly important.

We regularly attend CLAS meetings and CEBAF meetings. We are collaborators on a number of beam proposals. Our efforts in instrumentation for CEBAF have been detailed in Section III on Instrumentation. Even though beam will not be available at CEBAF until 1994, we expect to be prepared to participate in the earliest experiments performed at CEBAF.

The Program Advisory Committee of CEBAF held its fourth meeting in two sessions, December '89 and March '90. The purpose of this meeting was to hear oral presentations of proposals for beam and to award beamtime for the first round of experiments at CEBAF. At this meeting RMS presented a proposal to measure the A and Q^2 dependence of electroexcitation of the Δ in nuclei (proposal number PR-89-017). This proposal was given conditional approval to be run in Hall B with the CEBAF Large Acceptance Spectrometer (CLAS). Because of the large solid angle, high data rate and good particle identification properties of the CLAS it is possible to perform several experiments at once provided the same target and beam conditions are required. Approval of PR-89-017 was conditional on a run plan to be used in common with four other experiments. These five experiments address somewhat overlapping physics, all involving one or more hadrons and an electron in the final state. A group known as the multihadron working group is preparing a common run plan and will present it to the next PAC meeting.

In addition we were coauthors on 6 other proposals which were approved. These are listed below. Four of these (37, 38, 39, 42) are part of the nucleon resonance program.

Proposal No.Title

ACCEPTED PROPOSALS:

PR-89-017	Electroexcitation of the $\Delta(1232)$ in Nuclei.
PR-89-037	Electroproduction of the P_{33} (1232).
PR-89-038	Measurements of $p(e,e'\pi^+)n$, $p(e,e'p)\pi^0$ and $n(e,e'\pi^-)p$ in the Second and Third Resonance Regions.
PR-89-039	Amplitudes for the $S_{11}(1535)$ and $P_{11}(1710)$ Resonances from an $ep \rightarrow e'p\eta$ experiment.
PR-89-042	A Measurement of the Electron Asymmetry in $p(e,e'p)\pi^0$ and $p(e,e'\pi^+)n$ in the Mass Region of the $P_{33}(1232)$ for $Q^2 < 2$ (GeV/c) ² .
PR-89-043	Measurements of the Electroproduction of the $\Lambda(\text{gnd})$, $\Lambda(1520)$ and $f_0(975)$ via the $K^+ K^- p$ and $K^+ \pi^- p$ final states.
PR-89-045	Study of Kaon Photoproduction on Deuterium.

VI. LAMPF

In August of 1990 we participated in experiment 1126 at LAMPF to measure cross sections for the $^4\text{He}(\pi^+, pp)$ and $^4\text{He}(\pi^-, pn)$ reactions. The object of this experiment was to study isoscalar and isovector two-nucleon pion absorption in ^4He compared to that in the more

weakly bound nuclei ^3He and ^2He . A relatively high beam energy, 500 MeV, was chosen to enhance sensitivity to the short range components of the two-nucleon system. Since the pn final state can be produced either by $\pi^- + pp$ or by $\pi^+ + nn$ a comparison may give some indication of the Coulomb repulsion between the two protons of the pp pair.

Both positive and negative pion beams were provided by the P³E beam line. A liquid ^4He target and calibration targets of CH_2 and CD_2 were used. Protons were detected by the Large Acceptance Spectrometer in coincidence with either a proton or a neutron detected by the University of Virginia nucleon detector which has been described above. This experiment was the first use of the UVA nucleon detector and therefore provided valuable experience for future experiments at LEGS, Bates and CEBAF.

These data are being analyzed primarily by the experiment spokesman, L. C. Smith. This work will include detailed analysis of the nucleon detector's performance in actual experimental conditions. Of particular interest are the efficiency for detection of neutrons, the timing resolution (and the neutron interaction position resolution derived from it) and the efficiency for identification of pions, protons and neutrons.

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VII. EDUCATION AND TRAINING OF STUDENTS

We continue to treat the education and training of both undergraduate and graduate students as a high priority. At most times we have had two-three graduate students and two undergraduate students working with us part time. Brian Milbrath, a third-year graduate student, is completing his course work this semester. He has completed the Ph.D. qualifying exam and has begun work on his doctoral thesis. In January, 1991 he will move to Brookhaven National Laboratory where he will remain until his doctoral thesis data are complete. The E2/M1 experiment on the delta is his project.

The undergraduate students at Virginia are very bright. We encourage our students to become involved in research, and, invariably, we find that our graduates remember their research participation as a highlight of their experience at Virginia. We normally have two undergraduate students each working 5-10 hours a week. An undergraduate student, Aaron Gillespie, worked for us since January, 1989 on various aspects of the nucleon detector. Initially he assembled phototube bases and other nucleon detector parts. He graduated last May and went to graduate school at Cal Tech. We have also employed several other University of Virginia undergraduates. During the summer of 1990 we participated in a Research Experiences for Undergraduates program and supervised 4 students, one of whom was stationed at LEGS.

Undergraduate students with whom we have worked in the last year and their projects are listed below:

University of Virginia Hourly Research Assistants:

Aaron Gillespie, Studies of Properties of Scintillating Fibers.

Sung Jung, Construction of a Prototype Tracking Detector.

David Jones, Construction of the EGN Prototype Detector for CLAS at CEBAF.

Rose Finn, Construction of the EGN Prototype Detector for CLAS at CEBAF;

Construction of a Prototype Tracking Detector.

REU Program:

Rose Finn, University of Virginia, Construction of Photomultiplier Bases for the LEGS NaI Gamma-ray Detector.

Girish Gvalani, Davidson College, Feasibility Study of a Scintillating Fiber Gamma-ray Beam Profile Monitor.

Jennifer Granata, Fairfield University, Development of Scintillation Detectors for Proton and Neutron Detection.

Karl Gordon, Wittenberg University, Simulation of a Cellular Scintillation Neutron Detector.

VIII. PUBLICATIONS

A. Journals and Proceedings

1. "Computed Tomography of Scintillators with Muons: Understanding the Response to High Energy Gamma Rays", D.H. Dowell, A.M. Sandorfi, A.Q.R. Baron, B.J. Fineman, O.C. Kistner, G. Matone, C.E. Thorn, and R.M. Sealock, Nucl. Instr. and Meth. **A286**, 183 (1990).
2. "Phenomenological Δ -Nucleus Potential From Inclusive Electron-Nucleus Scattering Data", J. S. O'Connell and R. M. Sealock, to be published in Physical Review C
3. "Longitudinal and Transverse Response Function in $^{56}\text{Fe}(e,e')$ at Momentum Transfer Near 1 GeV/c", J.P. Chen, Z.E. Meziani, D. Beck, G. Boyd, L.M. Chinitz, D.B. Day, L.C. Dennis, G. Dodge, B.W. Filippone, K.L. Giovanetti, J. Jourdan, K.W. Kemper, T. Koh, W. Lorenzon, J.S. McCarthy, R.D. McKeown, R.G. Milner, R.C. Minehart, J. Morgenstern, J. Mougey, D.H. Potterveld, O.A. Rondon-Aramayo, R.M. Sealock, L.C. Smith, S.T. Thornton, R.C. Walker, C. Woodward, submitted to Physical Review Letters.
4. "Photon-Beam Polarization Asymmetries in $d(\gamma,p)n$ " S. Hoblit, G. Blanpied, M. Blecher, A. Caracappa, C. Djalali, M.A. Duval, G. Giordano, O.C. Kistner, G. Matone, K. Mize, L. Miceli, B.M. Preedon, A.M. Sandorfi, C. Schaerf, R.M. Sealock, C.E. Thorn, S.T. Thornton, K. Vaziri, C.S. Whisnant, to be published in the proceeding of the PANIC 90 Conference.
5. "Lead-scintillator Electromagnetic Calorimeter with Stereo Readout", R. Minehart, M. Amaryan, K. Beard, S.K. Bowling, V. Burket, R. Demirchyan, Y. Efremenko, H.O. Funsten, K. Giovanetti, D. Joyce, L. Kramer, J. Lieb, R.M. Marshall, R. Sealock, L.C. Smith, P.K. Teng, S. Thornton, H. Weller, to be published IEEE Transactions in Nuclear Science.

B. Abstracts

1. "The Photodisintegration of the Deuteron with Polarized Photons", K. Mize, G. Blanpied, M. Blecher, C. Djalali, M. A. Duval, G. Giordano, S. Hoblit, O. Kistner, G. Matone, R. Sealock, C. Thorn, S. Thornton, K. Vaziri, C.S. Whisnant, Bull. Am. Phys. Soc. 35, 928 (1990).

2. "Quasielastic $R_{L,T}$ Response Functions of ^3He and ^4He at $Q^2 = 1 \text{ (GeV/c)}^2$ ", Z. Meziani, G. Dodge, T. Koh, J. Chen, L. Chinitz, D. Day, K. Giovanetti, J. McCarthy, R. Minehart, O. Rondon-Aramayo, R. Sealock, C. Smith, S. Thornton, D. Beck, G. Boyd, B. Fillipone, J. Jourdan, R. McKeown, R. Milner, D. Potterveld, R. Walker, C. Woodward, L. Dennis, K. Kemper, H. Morgenstern, I. Sick, W. Lorenzon, Bull Am. Phys. Soc. 35, 1679 (1990).

C. Invited Talk: "Computed Tomography of Large Scintillators", R.M. Sealock, Physics Department Colloquium at James Madison University, April, 1990.

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