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Nuclear Studies with Intermediate Energy Probes

Annual Performance Report and Continuation Proposal

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1 Introduction

During the past year progress has been made on almost all projects for which support was received and one new project has been initiated. Data from our measurements at NIKHEF-K of the electro-production of neutral pions from the proton were completely analyzed and are about to be submitted for publication. These results represent the first precise measurement of this fundamental process in the threshold region. Inconsistencies in previously published results had led us to conclude that our results were in serious disagreement with previous calculations. However, when these inconsistencies were resolved it was seen that our results are completely consistent with these cxalculations as well as with new calculations based upon the Low Energy Theorems. Results from our studies of a gas jet target in the electron storage ring of the Saskatchewan Accelerator Laboratory (SAL) have been fully analyzed and are being prepared for publication. They are also serving as valuable input into our evaluation of possible future experiments. An Internal Target Development Facility (ITDF), established at NIKHEF-K in a collaborative effort involving NIKHEF-K, the University of Virginia, and the University of Bonn for the purpose of developing higher density gas jet targets suitable for use in electron rings, is operational. Diagnostic techniques are being evaluated in preparation for evaluating jet technology options. Our study of the calcium isotopes (^{42}C and ^{44}C) is nearing completion. Both the electron and proton scattering data have been completely analyzed. Consistent proton and neutron transition densities have been extracted and are being compared to corresponding results from pion scattering. Preparations for (γ, π^-) measurments at SAL have been completed and data taking is about to commence.

During the past year we have received approval for three new experiments. Proposals for measurements to complement our measurements of the reaction $^{14}C(\gamma, \pi^-)$ using the reactions $^{15}N(\gamma, \pi^-)$ and $^{13}C(\gamma, \pi^-)$ have been accepted at SAL and will be run concurrently with the ^{14}C measurements. A proposal to extend our measurements of the threshold electro-production of neutral pions from the proton has been accepted at NIKHEF-K. We now have two approved experiments, one at the Bates Linear Accelerator Center (BLAC) and one at NIKHEF-K, to extend our previous measurements of this fundamental process.

One disappointment during the year was our failure to produce new ^{14}C targets and to begin electron scattering and photon scattering measurements using them. This delay has resulted from the failure of the University to obtain an upgrading of its NRC license to enable us to accept the amount of ^{14}C required to construct the targets. The license upgrade is expected by the end of August and construction of targets will begin immediately. Measurements will begin as soon as possible thereafter.

During the coming year we plan to complete our (γ, π^-) measurements at SAL and complete our interpretation of the calcium electron and proton scattering data. We also plan to perform the photon scattering and low energy electron scattering measurements of ^{14}C at Technische Hochschule Darmstadt (THD). Work will continue on the development of gas jet targets at the ITDF at NIKHEF-K. Work on the storage of polarized electrons in the BLAC South Hall Ring will continue. Preparations for threshold pion production measurements at BLAC and NIKHEF-K will continue. Beam time has been requested for preliminary runs at NIKHEF-K.

2 Photo-Production of Charged Pions from p-Shell Nuclei

2.1 Pion Photo-Production from ^{14}C

A major goal of intermediate energy physics is the understanding of the role of sub-nucleonic degrees of freedom in the nucleus. One particularly illustrative means of studying these is the photo-production of pions. The presence of a pion in the final state is an unambiguous signature of a sub-nucleonic process. The interaction of the photon is among the best understood in nature. Many questions remain, however, about the reaction mechanism (the role of the Δ-resonance in particular) and about the sensitivity of the process to details of the nuclear wave functions.

Recent measurements of charged pion photo-production from p-shell nuclei using the reaction

$$^{13}C(\gamma, \pi^-)^{13}N_{gs} \tag{1}$$

at NIKHEF [1] and the reaction

$$^{15}N(\gamma, \pi^-)^{15}O_{gs} \tag{2}$$

at Mainz [2] have yielded seemingly contradictory results. Each involves a transition from a state of $(J^\pi, T) = (1/2^-, 1/2)$ to another of $(J^\pi, T) = (1/2^-, 1/2)$. Consequently, each transition involves both M1 and E0 isovector transition matrix elements. While the results from the former reaction suggested that the E0 contribution was seriously overestimated by current theoretical models [3], the results from the latter reaction agreed with predictions. However, it has been shown [4] that the apparent discrepancy between these results can be resolved if a more complicated wave function is used for the A=13 system.

The uncertainties are expected to lie in the description of the E0, rather than M1, matrix elements since the latter is dominated by a relatively well understood mechanism. This is by no means certain, however. The reaction

$$^{14}\mathrm{N}(\gamma, \pi^+)^{14}\mathrm{C}_{gs} \tag{3}$$

which involves a purely M1 transition has resisted attempts to describe it in a manner consistent with observations of elastic and inelastic electron scattering from ^{14}N and of ^{14}C β-decay [5]. Consequently, it would be desirable to observe a transition to which only the E0 amplitude contributes. The only such accessible case among p-shell nuclei (and given current experimental constraints, perhaps the only accessible such case in the entire periodic table) is the reaction

$$^{14}C_{gs}(\gamma, \pi^-)^{14}N^* \tag{4}$$

wherein the ^{14}N* state is the (0^+,T=1,2.313 MeV) isobaric analog of the ^{14}C ground state.

Measurements will commence in mid-July and will be completed by the end of August 1992.

2.2 Pion Photo-Production from ^{15}N

This measurement will complement directly our previously discussed measurements of the reaction $^{14}C(\gamma, \pi^-)^{14}N$. In both cases transitions between isobaric analog states will be studied. In the case of $^{15}N(\gamma, \pi^-)^{15}O$ the transition is between two states with $J^\pi = 1/2^-$; this implies contributions from both E0 and M1 amplitudes. At forward pion emission angles, $q^2 \leq 1$ fm^{-2}, the cross section is expected to be primarily due to the Δ dominated E0 amplitude; at backward angles, $q^2 \geq 1.3$ fm^{-2}, the cross section is expected to be primarily due to the spin flip dominated M1 amplitude. Consequently, a measurement of angular distributions of $^{15}N(\gamma, \pi^-)^{15}O$ for energies near threshold and near the expected peak in the Δ contribution will yield relatively clean information on both the E0 and M1 multipoles. Moreover, our measurements of $^{14}C(\gamma, \pi^-)^{14}N$ will further define the behaviour of the E0 multipole making our extraction of the M1 multipole from the $^{15}N(\gamma, \pi^-)^{15}O$ measurements even more reliable.

These measurements will use the same experimental configuration as will be used for the $^{14}C(\gamma, \pi^-)^{14}N$ studies and will be run concurrently with them during the summer of 1992.

2.3 Pion Photo-Production from ^{13}C

Much of the current uncertainty surrounding our understanding of pion photoproduction from p-shell nuclei has been generated by seeming inconsistencies between results from studies of the reactions $^{13}C(\gamma,\pi^-)^{13}N$ [1] and $^{15}N(\gamma,\pi^-)^{15}O$. [2] While the apparent discrepancy can be resolved by using a significantly more complicated wave function for the A=13 system, having to resort to such extremes for only one nucleus among a supposedly similar group suggests that our understanding of their structure is seriously deficient. Accordingly, it was noted that the quality of the $^{13}C(\gamma,\pi^-)^{13}N$ data which gave rise to the current uncertainty was less than optimal. Accordingly, it was decided to perform a more precise study using the same experimental configuration as will be used for the $^{14}C(\gamma,\pi^-)^{14}N$ studies.

These measurements will be run concurrently with the $^{14}C(\gamma,\pi^-)^{14}N$ measurements during the summer of 1992.

3 Threshold Electro-Production of Neutral Pions

For many years it was felt that the threshold electromagnetic production of pions from the proton was adequately described by the Low Energy Theorems (LET's) which were based upon very basic and essentially model independant properties of the electro-nuclear interaction. Then, Mazzucato *et al.* [6] measured precisely the reaction $p(\gamma,\pi^0)p$ and extracted a value for the E_{0+} amplitude, the sole surviving amplitude at threshold, of $(-0.5\pm0.3)\times10^3/m_{\pi^+}$, in sharp contrast with both the LET and previous experimental results; the new result was verified by Breitbach *et al.* [7] at Mainz. The interpretation of these data has been questioned [8], [9], [10] but questions remain.

3.1 p(e,e'p)π^0 near Threshold

The experiment was performed at NIKHEF-K using their pair of matched spectrometers, the high quality of which enabled us to determine W, the invariant energy of the final $p\pi^0$ state to within 500 keV. Cross sections were measured for two values of the virtual four-momentum, $-k_\mu^2 = 0.05$ (GeV/c)^2 and 0.10 (GeV/c)^2. The data have been fully analyzed and provide by far the best measurement to date of this fundamental process.

Near threshold one can expand the cross section in powers of q*, the magnitude of the 3-momentum of the produced pion in the center of mass frame, which is directly related to W:

$$\frac{d^3\sigma}{dE_f d\Omega_e} = \Gamma_t \frac{q^*}{4\pi k_L}\left(a_0 + \frac{a_2}{3}q^{*2} + a_5 q^{*2}\right) \tag{5}$$

where the five-fold differential cross section has been integrated over pion coordinates. This is possible since near threshold the reaction products all travel along the direction of the virtual photon so protons corresponding to pions emitted in all directions in the center of mass can be detected in a relatively small acceptance spectrometer. The a_0 term is related to the

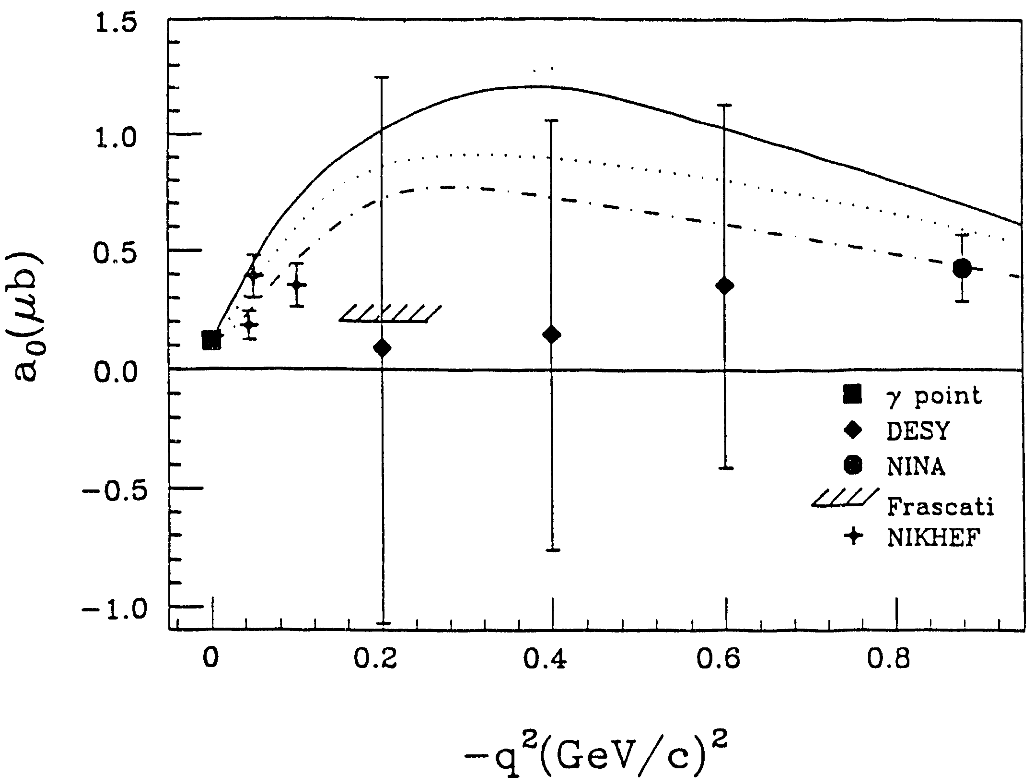

Figure 1: Threshold electro-production of neutral pions from hydrogen.

E_{0+} and L_{0+} amplitudes of interest by

$$a_0 = \lim_{q^* \to 0} (|E_{0+}|^2 - \epsilon k^2 |\frac{L_{0+}}{k_0}|^2). \tag{6}$$

The term "b" given by

$$b = \frac{1}{3} a_2 + a_5 \tag{7}$$

has been measured with sufficient accuracy that its contribution near threshold can be subtracted.

Figure 1 shows our preliminary results in terms of the parameter $a_0(k_\mu^2)$. The precision of our data is seen to be an order of magnitude better than that of previous data. As well, our data are seen to be consistent with all but the Frascati data and are seen to be in reasonable agreement with previous calculations, all of which give the LET value for E_{0+} at the photon point. Accordingly, our results suggest strongly that any violation of the LETs as indicated by the recent photo-production measurements [6, 7] is highly unlikely.

A paper describing our measurements is about to be submitted for publication.

3.2 p($\vec{e}$,e'p)π^0 near Threshold

We are collaborating with A. Bernstein (MIT) on a measurement of p($\vec{e}$,e'p)π^0 at BLAC. This measurement will focus directly on the threshold region using the polarization degree of freedom to permit extraction of isolated multipoles.

This experiment requires the full capabilities of the high duty factor beam to be provided by the South Hall Ring (SHR). Accordingly, it cannot run until the SHR has been commissioned. It will use existing spectrometers, albeit with new detectors. Their preparation is underway.

3.3 p(e,e'p)π^0 to π^+ Threshold

We are collaborating with H. Blok (VUA) on a measurement of p(e,e'p)π^0 at NIKHEF-K. This measurement will focus directly on the energy dependance of the amplitudes from π^0 threshold region through the π^+ region where a reanalysis of the Mainz [7] data by J. Bergstrom [8] suggested that an interesting interplay of amplitudes may be occurring.

These measurements, like those proposed for BLAC, will require a high duty factor beam such as will be available from the Amsterdam Pulse Stretcher (AmPS) currently being commissioned. Beam time has been requested in November 1992 for preliminary measurements. We anticipate that the full measurements will take place in 1993.

3.4 $p(e,e'p)\pi^0$ at Low k^2

The reanalyses [8, 9] of the recent photo-production data as well as our measurements at NIKHEF strongly indicate that there exists no order of magnitude error in the LETs of the neutral pion production process. However, as a result of the theoretical work stimulated by these experiments it has become clear that our understanding of this fundamental process is far from complete. This is true even in the model independant region of validity of the LETs. The reanalyzed Mainz and Saclay photo-production data and the data from soon to be performed photo-production experiments at SAL and Mainz will determine precisely the E_{0+} amplitude in this region. However, our knowledge of L_{0+} in this region is based solely on extrapolations from measurements at momentum transfers at which model dependant terms are significant. If we are to truly understand this fundamental process a direct determination of the L_{0+} amplitude in the model independant region is required.

The work of Scherer and Koch [11] indicates that for a measurement of L_{0+} to be model independant it must be at a momentum transfer ($-k^2$) of less than m_π^2. We have begun an analysis of such a measurement. First, obtaining a reasonable counting rate requires using an electron energy of the order of 300 MeV. This implies that the scattering angle for the electron AND the recoil direction of the proton are both less than or about 4 degrees. In this situation, both the recoiling proton and the scattered electron have momenta of about 150 MeV/c. Thus, placing the target directly in front of a dipole magnet will result in the magnet acting as a spectrometer for both protons and electrons. Clearly, backgrounds arising from Moller scattering, bremstrahlung followed by pair creation, etc. will be major problems. We are currently examining whether an internal target in an electron storage ring or a cell target and an extracted beam will give the best results.

To extract L_{0+} from the combination of L_{0+} and E_{0+} requires measuring the LT interference term in the cross section. Fortunately, the anticipated similarity in the magnitudes of L_{0+} and E_{0+} suggests that this term will be quite large, of the order of 40%. It does, however, imply that very accurate angular resolution be obtained in both the electron and proton trajectories.

Accordingly, the experiment promises to be technologically challenging, but well worth the effort.

4 Nuclear Physics with Internal Targets

4.1 Internal Target Physics with the BLAST

The BLAC South Hall Ring (SHR), when completed in 1992, will provide two new capabilities for nuclear physicists:

1. a high duty factor, polarized electron beam with energy up to 1 GeV and

2. a dedicated facility for internal target experiments.

We are proposing (see Table 4) to exploit these new capabilities in performing measurements of the electromagnetic response of the three-body system. An internal target of polarized ^{3}He will be used in conjunction with a large acceptance detector, the Bates Large Acceptance Spectrometer Toroid (BLAST). This utilization of both polarization and coincidence in the measurement of electron scattering from the three-body system is unprecedented. We are also collaborating (see Table 4) on two major proposals for experiments using unpolarized internal targets in the BLAC SHR.

Work during the past year towards these experiments has focussed on the preparation of the BLAST proposal, calculations related to the storage of polarized electrons in the South Hall Ring, evaluation of possible beam polarimeters, and the Internal Target Development Facility (ITDF) at NIKHEF-K. As the execution of these experiments is still some years away our focus during the coming year will continue to be on the technical developments required. We will continue our work related to the ITDF and intensify our work on the storage of polarized electrons. More detailed preparation for experiments must await determination of the construction schedule for the BLAST.

4.2 Internal Target Development Facility

The Internal Target Development Facility (ITDF) has been established to study the feasibility of using asymmetric nozzles in the construction of gas jet targets in order to obtain focusing of the jet. If successful it will enable us to use lower gas flows for a given thickness of target. This will make the target cheaper by reducing the number and/or size of the vacuum pumps required. It will also reduce the potential for undue interference with the stored beam.

The facility is currently operational and studies of profile monitors are underway. Despite the fact that the ideas upon which this facility is based were developed within our group our participation in this project has been less than we would like due to a shortage of personnel. During the coming year we plan to intensify significantly our efforts on the theoretical work related to the project and, if possible, to place a student at NIKHEF-K to work at the facility.

5 Nuclear Structure

5.1 Low-Lying Excitations of the Calcium Isotopes

Our study of the structure of the calcium isotopes ^{42}Ca and ^{44}Ca using a combination of electron and proton scattering is nearing completion. For each calcium isotope (^{42}Ca, ^{44}Ca) we have a full set of electron scattering data and three sets of proton scattering data corresponding to incident energies of 100 MeV, 200 MeV, and 318 MeV. The extraction of proton and neutron transition densities from the electron and 200 MeV and 318 MeV proton data has been completed. Extremely consistent results have been obtained for the neutron transition densities from the two sets of proton data. Comparison of our results to those obtained from pion scattering experiments is now underway.

We plan to complete these studies during the coming year.

5.2 Nuclear Structure of ^{14}C

The nuclear structure of the carbon isotopes has been extensively studied as part of a general attempt to understand nuclear excitations in the 1p shell. Transverse electron scattering experiments have been carried out for ^{12}C, [12, 13] ^{13}C, [14, 15] and ^{14}C, [16, 17] while high quality longitudinal electron scattering data are only available for ^{12}C [18] and ^{13}C. [19]

The principal goals of this work are (1) to determine the elastic scattering form factor in order to study the systematics of charge density differences, particularly in the nuclear interior, and of nuclear radii for the carbon isotopes ^{12,13,14}C; (2) to determine the longitudinal form factors of the low lying excited states, which together with the transverse form factors, will put severe constraints on the nuclear model parameters used to calculate wave functions; (3) to compare with pion and proton scattering data to develop a consistent set of proton-neutron matrix elements which in turn can be used to test our understanding of hadronic interactions; (4) and to determine the

B(E1↑) transition rate to the Ex = 6.094 MeV, 1^- state, from which we can calculate the B(E1↓) value for the analog transition in ^{14}O, an important parameter in astrophysical calculations of the hot or β-limited CNO cycle.

Elastic and inelastic electron scattering measurements have been approved by the Directorate of THD (low momentum transfer elastic and inelastic), by the NIKHEF-K PAC (moderate momentum transfer elastic and inelastic), and by the BLAC PAC (high momentum transfer elastic). In addition, photon scattering measurements have been approved by the Directorate of THD.

A proposal for changes in the UVa radioactive material handling licence has been submitted to the NRC. As soon as the changes are obtained assembly of targets suitable for these studies will begin. We anticipate completing the targets by mid fall and being ready to perform the electron scattering and photon scattering measurements at THD as soon as the accelerator schedule permits.

6 Operations and Budget

During the coming year experiments will be carried out at SAL (Saskatoon), NIKHEF-K, and THD (Darmstadt). Data acquisition will occur at the laboratories and data reduction will be done at UVa. First, we plan to complete the pion photo-production measurements from ^{13}C, ^{14}C, and ^{15}N at SAL. Second, we plan to perform preliminary measurements of the p(e,e'p)π^0 reaction at NIKHEF-K. Third, we plan to perform the photon scattering and low energy electron scattering measurements from ^{14}C at THD during the coming year.

The Internal Target Development Facility (ITDF) is located at NIKHEF-K and the bulk of the work is concentrated there. We are performing and will continue to perform theoretical work at UVa using the resources of the Florida State Supercomputer Center. We are hoping to locate a student at NIKHEF-K to work on this project.

The design of the lattice modifications required to maintain longitudinal polarization in the BLAC SHR will take place at UVa and CEBAF, as will investigations of polarimeter options. We have established a close collaboration with R. Rossmanith involving frequent visits by us to CEBAF and by him to UVa. This work and that on the gas jet targets is closely related to the development of the BLAST detector system. In order to facilitate coordination of these efforts the P.I. has been named a member of the BLAST Steering Committee, a position which will necessitate regular trips to BLAC.

The proposed budget is shown in Table 1.

Personnel – There are currently three graduate students working under my supervision on projects for which funding is sought. One will be supported by teaching assistantships during the coming academic year; two will be supported from the grant. Adding one new student brings to four the number of students to be supported during the summer of 1993.

Fringe benefits are computed at 8% of summer salary for the P.I.

Equipment – Equipment funds are requested for the purchase of computer

budget info removed. js

peripherals for the Intermediate Energy Physics Computer System which is currently supported primarily by the Institute for Nuclear and Particle Physics and the Commonwealth Center for Nuclear and High Energy Physics of UVa. Significant additional support comes from the DOE grant of J. S. McCarthy. It has been requested that we provide support for this system in view of our relatively high level of usage of it. The sum of $6,000 has been requested for this purpose.

During our test run of the range telescopes being used in the (γ, π^-) measurements at SAL an accident resulted in serious damage to the photomultiplier tubes of one telescope. The tubes must be replaced. Attempts to have the loss covered by the Commonwealth of Virginia insurance policy have so far been unsuccessful. Accordingly, we are requesting $8,000 for this purpose.

Travel – The funds requested are based on the following schedule of activities:

1. a one-month trip to SAL for one person to work on the reduction of data from the (γ, π^-) measurements;
2. a two-week trip for two people to NIKHEF-K to perform preliminary measurements of the p(e,e'p)π^0 reaction;
3. several trips to MIT and BLAC related to the development of an internal target capability in the South Hall Ring;
4. several trips to MIT and BLAC related to preparations for the p($\vec{e}$,e'p)π^0 measurements;
5. several trips to CEBAF related to electron polarization work;
6. a two-week trip for two people to THD for the $^{14}C(e,e')$ and $^{14}C(\gamma,\gamma')$ measurements;
7. two one-week trips to NIKHEF-K to work on the Internal Target Development Facility.

It is to be noted that funding is requested for travel to NIKHEF-K related to work on the Internal Target Development Facility. Such travel has been supported from a grant received in 1990 from NATO but those funds have been almost completely expended.

Miscellaneous – Included here are costs for shop, computer, and office supplies, charges for machine shop time at UVa, publication charges, etc. Specifically itemized are the costs of shipping the pion range telescopes from Saskatoon to Amsterdam.

Indirect Costs – In accordance with the policy of the University of Virginia Indirect Costs are applied to the Total Direct Costs (TDC) less Equipment (MTDC) at the following rates: on Grounds - 52%, off Grounds - 23.5%. The apportionment rate applied to the current application was computed from the distribution throughout the year of professional effort supported by this grant. For the purpose of computing this rate the P.I. contributes 0.25 FTE as he is paid by the University during the academic year. Peter Karen, a graduate student, is assumed to contribute 1.00 FTE, although he may graduate before the end of the budget period. Finally, graduate students K. Cromer and an as yet unnamed new student each contribute 0.25 FTE as they will be supported by this grant only during the three summer months. Table 2 shows the distribution of On Grounds and Off Grounds effort for each and the basis for the "Mixed" Indirect Cost rate of 41%.

Table 2: Indirect Cost Determination: Distribution of professional effort supported by this Grant.

Name	FTE		% on Grounds	% off Grounds
B. Norum	0.25		50	50
K. Cromer	0.25		0	100
T. Gresko	1.00		60	40
P. Karen	1.00		80	20
New Student	0.25		50	50
	2.75	FTE		
On Grounds Effort	1.65	FTE		
Off Grounds Effort	1.10	FTE		
Indirect Cost Rate	0.41			

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Appendices

A.1 Experimental Activities

The following tables list our current commitments to experiments. Table 3 lists the status of those experiments for which I have primary responsibility; that is, for which I am a spokesman. Table 4 lists the status of those experiments for which I have secondary responsibility, that is, for which I am not a spokesman.

Table 3: Experimental activities for which P.I. is spokesman. Experiments upon which I had, have, or plan to have students working towards Ph.D. dissertations are denoted by *. Running times at NIKHEF-K are computed on the basis of 70 hr ≡ 1 week although it is not uncommon to realize 90^+ hrs. The ^{14}C(e,e') experiment at THD has been approved for the time necessary to complete; beam time quoted is an estimate.

Experiment	Laboratory	Status	Beam Time	Comment
*Ca(e,e')	NIKHEF-K	Writing up	—	
*p(e,e'p)π°	NIKHEF-K	Writing up	—	
*^{14}C(γ,π^-)	SAL	1992	120 hrs	development
			280 hrs	experiment
^{15}N(γ, π^-)	SAL	1992	320 hrs	
^{13}C(γ, π^-)	SAL	1992	260 hrs	
*^{14}C(e,e$\prime$)	THD	1992-93	120 hrs	estimated
	NIKHEF-K	1993	140 hrs	≡ 2 weeks
	BLAC	1993^+	96 hrs	
*^{14}C($\gamma, \gamma\prime$)	THD	1992-93	60 hrs	estimated
Total			1,396 hrs	

Table 4: Experimental activities in which we are involved for which P.I. is not spokesman. Experiments upon which I currently have students working towards Ph.D. dissertations are denoted by *.

Experiment	Facility	Status/Time	Spokesman
Active or Approved:			
*Ca(p,p')	LAMPF	Writing up	J. Kelly (UMd)
	IUCF	Writing up	J.J. Kelly (UMd)
$^3\vec{He}$ ($\vec{e}$,eX)	BLAST	1000 hrs	R. Milner (MIT) J. van den Brand (UWisc)
NN,ΔN,ΔΔ	BLAST	1000 hrs	F.W. Hersman (UNH)
$^2\vec{d}$ ($\vec{e}$, e'X)	BLAST	1000 hrs	R. Alercon (ASU)
^{4}He,^{16}O(e,e'X)	BLAC	200 hrs	R. Redwine (MIT)
p($\vec{e}$,e'p)π^0	BLAC	200 hrs	A. Bernstein(MIT)
p(e,e'p)π^0	NIKHEF-K	200 hrs	H. Blok (VUA)
Total		3600 hrs	

A.2 Personnel

In addition to the Principal Investigator the following students have been working with me and have been supported in whole or in part by this grant.

Graduate Students

1. K. Cromer
2. T Gresko
3. P. H. Karen
4. T. P. Welcn

Undergraduate Students

1. C. Gaines
2. C. Harris
3. J. Phillips
4. W. Tompkins
5. E. Wulf

A.3 Publications

1. "Neutron and proton transition densities from $^{32,34}S(p,p')$ at $E_p = 318$ MeV. II. Neutron densities for ^{34}S," with M.A. Khandaker *et al.*, Phys. Rev. **C44** (1991) 1978.

2. "Neutron and proton transition densities from $^{32,34}S(p,p')$ at $E_p = 318$ MeV. I. Isoscalar densities for ^{32}S," with J.J. Kelly *et al.*, Phys. Rev. **C44** (1991) 1963.

3. "Effective interaction for $^{40}Ca(p,p')$ at $E_p = 318$ MeV," with J.J. Kelly *et al.*, Phys. Rev. **C44** (1991) 2602.

A.4 Seminars, Colloquia, and Conference Talks

1. "Electroproduction of π^0's at Threshold," T. P. Welch, Colloquium, University of Massachusetts, Amherst, Massachusetts, June 1992.
2. "Electroproduction of Neutral Pions near Threshold," B. E. Norum, Seminar, CEBAF, April 29, 1992.
3. "Laser Induced Extraction from the LHC or SSC," B. E. Norum, European Particle Accelerator Conference, Berlin, Germany, March 1992.
4. "Electroproduction of π^0's at Threshold," T. P. Welch, NIKHEF-K 7^{th} Mini-Conference, Amsterdam, Holland, December 1991.

OMB Burden Disclosure Statement

Public reporting burden for this collection of information is estimated to average 30 minutes per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Office of Information Resources Management Policy, Plans, and Oversight, AD-241.2 — GTN, Paperwork Reduction Project (1910-1400), U.S. Department of Energy, 1000 Independence Avenue, S.W., Washington, DC 20585; and to the Office of Management and Budget (OMB), Paperwork Reduction Project (1910-1400), Washington, DC 20503.

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