JLAB USER GROUP

Jefferson Lab PAC15
Proposal Cover Sheet

This document must be received by close of business Thursday, Dec 17, 1998 at:

Jefferson Lab
User Liaison,
Mail Stop 12B
12000 Jefferson Ave.
Newport News, VA
23606

Experimental Hall: A
Days Requested for Approval: 3

Proposal Title:
Large Angle Two-Body Photodisintegration of the Deuteron at High Energy

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

Approved, Conditionally Approved, and/or Deferred Experiment(s) or proposals:
E93-017

Contact Person
Name: R. Gilman
Institution: Rutgers University
Address: P.O. Box 849
Address: Piscataway, NJ 08855-0849
City, State, ZIP/Country:
Phone: 757-269-7011 Fax: 757-269-5235
E-Mail: gilman@jlab.org

Jefferson Lab Use Only
Receipt Date: 12/17/98 PR-99-008
By: [redacted]

HAZARD IDENTIFICATION CHECKLIST

JLab Proposal No.: 99-08 (For CEBAF User Liaison Office use only.) Date: 12/17/98

Check all items for which there is an anticipated need.

Cryogenics
- ____ beamline magnets
- ____ analysis magnets
- ✓ target Hall A
  - type: Standard
  - flow rate: LH_2, LD_2
  - capacity: ____

Electrical Equipment
- ____ cryo/electrical devices
- ____ capacitor banks
- ____ high voltage
- ____ exposed equipment

Hall A standard

Radioactive/Hazardous Materials
List any radioactive or hazadorous/ toxic materials planned for use:

X

Pressure Vessels
- ____ inside diameter
- X operating pressure
- X window material
- X window thickness

Flammable Gas or Liquids
- type: ____
- flow rate: X
- capacity: ____

Drift Chambers Hall A standard
- type: ____
- flow rate: ____
- capacity: ____

Other Target Materials
- ____ Beryllium (Be)
- ____ Lithium (Li)
- ____ Mercury (Hg)
- ____ Lead (Pb)
- ____ Tungsten (W)
- ____ Uranium (U)
- X Other (list below)

Cu radiator

Vacuum Vessels
- ____ inside diameter
- ____ operating pressure
- ____ window material
- ____ window thickness

Hall A Standard

Radioactive Sources
- ____ permanent installation
- ____ temporary use
- type: ____
- strength: X

Large Mech. Structure/System
- ____ lifting devices
- ____ motion controllers
- ____ scaffolding or
- ____ elevated platforms

Hall A Standard

Lasers none
- type: ____
- wattage: ____
- class: ____

Installation:
- ____ permanent
- ____ temporary

Use:
- ____ calibration
- ____ alignment

Hazardous Materials
- ____ cyanide plating materials
- ____ scintillation oil (from)
- ____ PCBs
- ____ methane
- ____ TMAE
- ____ TEA
- ____ photographic developers
- ____ other (list below)

General:

Experiment Class:
- X Base Equipment
- ____ Temp. Mod. to Base Equip.
- ____ Permanent Mod. to Base Equipment
- ____ Major New Apparatus

Other: ____

LAB RESOURCES LIST

JLab Proposal No.: 99-08 Date 12/17/98
(For JLab ULO use only.)

List below significant resources — both equipment and human — that you are requesting from Jefferson Lab in support of mounting and executing the proposed experiment. Do not include items that will be routinely supplied to all running experiments such as the base equipment for the hall and technical support for routine operation, installation, and maintenance.

Major Installations *(either your equip. or new equip. requested from JLab)*

none

New Support Structures: none

Data Acquisition/Reduction

Computing Resources: Hall A DAQ standard, ~ few hundred Gb silo storage, standard farm usage

New Software: none

Major Equipment Hall A Standard

Magnets:

Power Supplies:

Targets:

Detectors:

Electronics:

Computer Hardware:

Other:

Other:

BEAM REQUIREMENTS LIST page 1

Lab Proposal No.: 99-08 Date: 12/17/98

Hall: A Anticipated Run Date: fall 1999 - parasitic later - dedicated PAC ~~Approved~~ Requested Days: 3

Spokesperson: Gilman, Holt, Meziani Hall Liaison:
Phone: 757-269-7011
E-mail: gilman@jlab.org

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

Condition No.	Beam Energy (MeV)	Mean Beam Current (μA)	Polarization and Other Special Requirements (e.g., time structure)	Target Material (use multiple rows for complex targets — e.g., w/windows)	Material Thickness (mg/cm²)	Est. Beam-On Time for Cond. No. (hours)
1	1.2	30	none	standard LD_2 + 6% Cu	2400 D_2 + 770 Cu	1
2	"	"	"	standard LD_2	2400 D_2	1
3	"	"	"	standard LH_2 + 6% Cu	1100 H_2 + 770 Cu	1
4	"	"	"	standard LH_2	1100 H_2	1
5	1.67	30	"	LD_2 + 6% Cu	see above	1
6	"	"	"	LD_2	"	1
7	"	"	"	LH_2 + 6% Cu	"	1
8	"	"	"	LH_2	"	1
9	1.95	"	"	LD_2 + 6% Cu	"	1
10	"	"	"	LD_2	"	1
11	"	"	"	LH_2 + 6% Cu	"	1
12	"	"	"	LH_2	"	1

all parasitic to 88-19, scheduled fall 1999

The beam energies, E_{Beam}, available are: $E_{Beam} = N \times E_{Linac}$ where N = 1, 2, 3, 4, or 5. E_{Linac} = 800 MeV, i.e., available E_{Beam} are 800, 1600, 2400, 3200, and 4000 MeV. Other energies should be arranged with the Hall Leader before listing.

BEAM REQUIREMENTS LIST page 2

Lab Proposal No.: 99-08 Date: 12/17/98

Hall: A Anticipated Run Date: fall 1999 parasitic later - dedicated PAC ~~Approved~~ Requested Days: 3

Spokesperson: Gilman, Holt, Meziani Hall Liaison:
Phone: 757-269-7017
E-mail: g.tman@jlab.org

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

Condition No.	Beam Energy (MeV)	Mean Beam Current (μA)	Polarization and Other Special Requirements (e.g., time structure)	Target Material (use multiple rows for complex targets — e.g., w/windows)	Material Thickness (mg/cm²)	Est. Beam-On Time for Cond. No. (hours)
13	2.48	30	none	standard LD_2 + 6% Cu	2400 D_2 + 770 Cu	3
14	"	"	"	Standard LD_2	2400 D_2	3
15	"	"	"	standard LH_2 + 6% Cu	1100 H_2 + 770 Cu	3
16	"	"	"	standard LH_2	1100 H_2	3
17	3.2	"	"	LD_2 + 6% Cu	see above	36
18	"	"	"	LD_2	"	12
19	"	"	"	LH_2 + 6% Cu	"	12
20	"	"	"	LH_2	"	12

parasitic to 99-19, scheduled fall 1999

dedicated

The beam energies, E_{Beam}, available are: $E_{Beam} = N \times E_{Linac}$ where N = 1, 2, 3, 4, or 5. E_{Linac} = 800 MeV, i.e., available E_{Beam} are 800, 1600, 2400, 3200, and 4000 MeV. Other energies should be arranged with the Hall Leader before listing.

Large-Angle Two-Body Photodisintegration of the Deuteron at High Energy

L. Auerbach[1], D. Beck[2], E. J. Beise[3], L. Bimbot[4], T. Black[5], M. Bouwhuis[2], E. Brash[6], R. V. Cadman[2], J. P. Chen[7], S. Choi[1], C. Crawford[5], S. Dardona[1], S. Dieterich[8], D. Dutta[5], B. W. Filippone[9], H. Gao[5], R. Gilman[8] (Spokesperson), C. Glashausser[8], R. J. Holt[2] (Spokesperson), S. Incerti[1], X. Jiang[8], C. E. Jones[9], M. Jones[10], E. Kinney[11], G. Kumbartzki[8], M. Kuss[7], J. LeRose[7], M. Liang[7], A. Lukhanin[1], S. Malov[8], P. Markowitz[12], R. D. McKeown[9], D. Meekins[13], Z.-E. Meziani[1] (Spokesperson), R. Michaels[7], M. A. Miller[2], A. M. Nathan[2], B. R. Owen[2], C. F. Perdrisat[10], D. Potterveld[14], V. Punjabi[15], A. Radyushkin[7,16], R. Ransome[8], A. Saha[7], A. Sarty[13], E. Schulte[2], K. Slifer[1], S. Strauch[8], B. Wojtsekhowski[7], S. Wood[7], F. Xiong[5], W. Xu[5]

[1] Temple University
[2] University of Illinois
[3] University of Maryland
[4] IPN Orsay
[5] Massachusetts Institute of Technology
[6] University of Regina
[7] Thomas Jefferson National Accelerator Facility
[8] Rutgers University
[9] California Institute of Technology
[10] College of William & Mary
[11] University of Colorado
[12] Florida International University
[13] Florida State University
[14] Argonne National Laboratory
[15] Norfolk State University
[16] Old Dominion University

Abstract

At present, high-energy deuteron photodisintegration data exist only at c.m. reaction angles of 90° or less. However, recent theoretical developments indicate that a comparison of the cross section at small and large angles would reveal new information about the dominant reaction process for the $D(\gamma, p)n$ reaction.

We propose to extend the existing differential cross section measurements for the exclusive $D(\gamma, p)n$ reaction to c.m. reaction angles as large as 145° in the energy region of 1.2 to 3.2 GeV. The proposed experiment must be performed in Hall A because of the need for spectrometer arms which can operate at large angles and which have a large target length acceptance as well as excellent target reconstruction properties. This experiment is compatible with E89-019, and much of it could run parasitically with E89-019 since E89-019 makes use of only one spectrometer arm. However, new beam time of three days is needed for the 3.2 GeV data.

1 INTRODUCTION

Recent measurements [1] of two-body photodisintegration of the deuteron at high energy have shown an energy dependence that is consistent with constituent counting rules [2, 3, 4] (CCR) at angles of $\theta_{cm} = 69°$ and $89°$. However, the data disagree with the constituent counting rules at smaller angles. Furthermore, the energy dependence at all angles disagrees with the reduced nuclear amplitude analysis [5, 6] (RNA). This is surprising since this analysis is expected to exhibit scaling before the onset of constituent counting and because the new $A(Q^2)$ for electron-deuteron elastic scattering [7] agree with RNA.

Nevertheless, two recent theoretical calculations can explain the energy and angular dependence of the $\mathrm{D}(\gamma,\mathrm{p})\mathrm{n}$ reaction. The asymptotic meson exchange model [8] and the quark-interchange model [9] can explain the energy and angular dependence of the high energy data. These two models disagree on the angular and energy dependence for the backward angles for which there are no measurements above a photon energy of 1.6 GeV.

Another theoretical calculation, the quark gluon string model [10] is in reasonable agreement with the forward angles. However, this calculation is based on Regge theory and is not expected to be valid at large angles.

The question that this proposal addresses is what power law energy dependence is exhibited at backward angles in the $\mathrm{D}(\gamma,\mathrm{p})\mathrm{n}$ reaction. Thus, we propose to measure the differential cross section for the exclusive $\mathrm{D}(\gamma,\mathrm{p})\mathrm{n}$ reaction for photon energies of 1.2, 1.6, 2.0, 2.4 and 3.2 GeV at center of mass angles of 115°, 130° and 145°. Also, several forward angle cross sections will be measured as a cross check on previous E89-012 data.

2 PHYSICS MOTIVATION

The traditional meson-exchange theory describes the $\mathrm{D}(\gamma,\mathrm{p})\mathrm{n}$ reaction rather well below a photon energy of 800 MeV as shown in Fig. 1. The data[1, 11, 12, 13] are from experiments NE8, NE17 and CEBAF E89-012. The solid curve is the calculation of Lee [14], the calculation of Laget [15] is not shown as it is limited to lower energies.

Above a photon energy of 1 GeV the traditional meson-exchange model deviates remarkably from the data. Moreover, the data appear to disagree

with the reduced nuclear amplitude calculation [5], given by the dashed curve in Fig. 1. This is especially surprising since this analysis works [6] very well for electron-deuteron elastic scattering above a momentum transfer of $Q^2 = -t = 2\ (GeV/c)^2$, which is reached by the photodisintegration data at all angles except 36°. More recent attempts to describe the data in terms of an asymptotic meson exchange model [8] have led to a reasonable agreement with the energy dependence at 90^0, as shown by the dotted curve. The model appears to have the correct angular distribution as well. This model agrees with the $1/s^n$ energy dependence observed in the data. Unfortunately, no data exist at center of mass angles larger than 90°, where the asymptotic meson exchange model predicts that the energy dependence should continue to scale as $1/s^{11}$.

The quark gluon string model [10], described above, is shown as the dot–dash curve.

More recently, Radyushkin has also predicted the correct energy dependence observed for the forward angle measurements in the $D(\gamma, p)n$ reaction. It is especially interesting in that he predicts that the angular distribution should be symmetric about $\theta_{cm} = 90°$. Such forward and backward peaking is typical of, for example, high-energy meson-photoproduction reactions.

Existing angular distribution data are shown in Fig. 2. Only in SLAC NE-8 at 1.6 GeV were data taken at angles larger than 90°_{cm}. At this lower energy, there is an indication of an increase in the large-angle cross sections, but the data are insufficient for a conclusive characterization.

The central point is that it is essential to measure a complete angular distribution for the $D(\gamma, p)n$ reaction in order to provide data to better understand the photodisintegration process at high photon energies, as well as provide a stringent test of the models. It now appears feasible to measure a complete angular distribution with the Hall A spectrometers up to a photon energy as high as 3.2 GeV.

3 PROPOSED MEASUREMENTS

We propose to measure the differential cross section for the exclusive $D(\gamma, p)n$ reaction for photon energies of 1.2, 1.6, 2.0, 2.4 and 3.2 GeV. We will measure at center of mass angles of 115°, 130° and 145°. These angles are chosen to be approximately symmetric about 90° with the existing forward-angle data

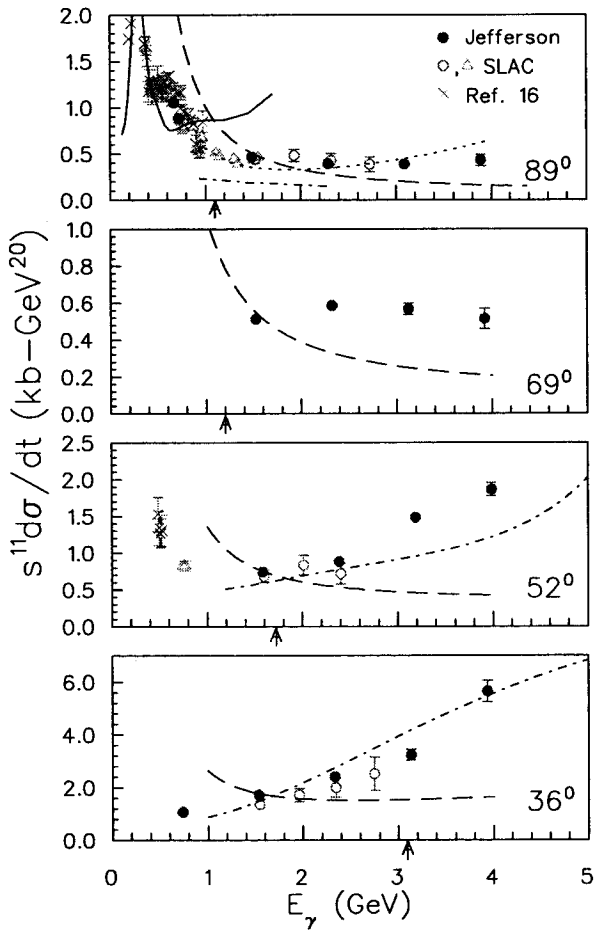

Figure 1: Deuteron photodisintegration data from Jefferson Lab E89-12, SLAC NE17, and SLAC NE8, as a function of the photon energy. Only statistical uncertainties are shown. The curves are described in the text.

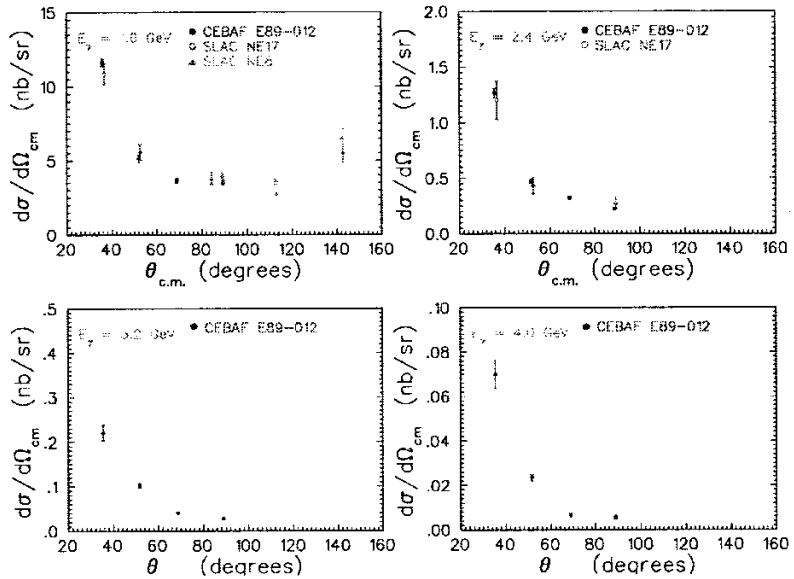

Figure 2: Angular distributions for deuteron photodisintegration at energies above 1 GeV. Large angle (> 90°) data were only taken at the lowest energy.

at 69°, 52° and 36°. We choose 115° rather than 110° to match on better to SLAC NE8 data.[12] In addition, as a cross check of previous measurements, E89-019 will measure cross sections during its polarization measurements at 90°, and we will further measure at 36°, where spectrometer-related background problems were largest in the Hall C E89-012 data. All angles will be measured for the 2.0 GeV energy setting only, since no previous data has been taken at that energy.

No additional beam time is requested for 1.2, 1.6, 2.0 and 2.4 GeV beam energies, only the approval to operate the second (electron) HRS arm during E89-019 for this experiment. We believe that these measurements can be done parasitically with essentially no impact on E89-019. An additional 3 days is requested to perform the measurements at 3.2 GeV.

4 EXPERIMENT

4.1 OVERVIEW

The experiment will employ the Hall A cryogenic liquid deuterium/hydrogen targets and the Bremsstrahlung photon beam produced by the electron beam striking the Hall A radiator. The maximum energy of the Bremsstrahlung beam is essentially equal to the electron kinetic energy. The target, located downstream of the radiator, is irradiated by the photons and the primary electron beam. The kinematics are chosen for the exclusive $D(\gamma, p)n$ reaction. The photo-produced protons will be detected in the Hall A HRS electron spectrometer, set for positively charged particles.

4.2 RADIATOR

The radiator is Cu with a 6% radiation length thickness. The Cu is approximately 72 cm upstream of the target so that the spectrometers do not view it directly. Energy loss in the Cu is about 75 watts for a beam current of $30\mu A$. The radiator assembly in Hall A is essentially a copy of the system used for Experiment E89-012 in Hall C.

4.3 TARGET

We plan to use the 15-cm Hall A liquid deuterium and hydrogen(2% r.l.) cryotargets. The cryotargets have been operated at currents above 100 μA with density fluctuations of only a few percent. At the requested 30 μA of this experiment, density fluctuations are negligible. The luminosity is about $\mathcal{L} = 1.4 \times 10^{38}$ /cm^2/s.

4.4 SPECTROMETER

We will use the Hall A HRS electron spectrometer with polarity reversed for the parasitic measurements, and both spectrometers for the 3.2 GeV measurements. Reversing polarity is a straightforward operation that should take only a few hours. For the large angle data, the spectrometer momentum range is 0.7 - 1.7 GeV/c and the angle range is 68 - 120°. The highest singles rate in the spectrometer is less than 1 kHz, to be compared with data acquisition capabilities of about 20% deadtime at 2 kHz (double this if the two spectrometers are read out independently).

4.5 BACKGROUND

At forward angles, for this energy regime, previous experiments have shown that real physics backgrounds are small, in agreement with simple kinematic expectations. For these low momenta, background pion rejection is allowed by a combination of an Aerogel Cerenkov detector and time-of-flight measurements between scintillators.

The main difficulty in this experiment is background protons in the large angle cross sections. At these angles, two-step processes involving scattering off two nuclei in the target lead to backgrounds above the bremsstrahlung endpoint. This phenomenon was both observed and simulated correctly during SLAC experiment NE8. Similar measurements were attempted in Hall C, but because of the background problem and the properties of the spectrometers, there are no good data above 1.6 GeV.

For these measurements in Hall A, we plan to use the y-target resolution of the Hall A HRS spectrometers to help subtract out this background. The technique is to divide the target into several regions of y-target. We plan to take about 1000 photodisintegration events, so that each target cut will have

about one hundred photodisintegration events. The two-step background should increase about linearly as one scans from upstream to downstream y-target cuts. Since the photodisintegration cross section is the same for each target bin - though the acceptance is different - one can extract from the comparison of these bins both the two-step background and the photodisintegration cross section. Since the two-step background is roughly of the same size as the photodisintegration events, subtraction of the background roughly increases the statistical uncertainties to about 5%. Uncertainties in acceptance in y-target will add an additional ~5% uncertainty in quadrature. Our estimate of the uncertainties in this procedure will be further quantified after analysis of recent y-target calibration data taken during E94-010.

4.6 SYSTEMATIC ERRORS

The main systematic uncertainties for this experiment are expected to be similar to those found in the Hall C experiment E89-012. We start from a consideration of recent work in Hall A. At this point, most cross sections measurements performed in Hall A are coincidence measurements. An example [7] is the *ed* coincidence measurements of experiment 91-026. These measurements agree with previous SLAC data to a few percent; *ep* measurements taken at the same time with spectrometer collimation agreed with previous world data to about 0.3%, with overall systematic uncertainties of about 5%.

As compared with these data, our experiment is easier in some respects. One example is target boiling effects, the uncertainties of which are reduced by our smaller beam current, of 30 vs. 100 μA. Another example is uncertainties related to the beam energy, which has only been known to $\approx 10^{-3}$. Both beam energy measurement systems in Hall A, using a specialized *ep* measurement system and an arc energy measurement system, are now operational and should be able to determine beam energy to better than an MeV. Recent measurments with these devices, as well as "spin-dance" measurements, appear to indicate that the accelerator is typically lower in energy than the nominal setting by about 10^{-3}; further studies of the absolute energy of the accelerator are in progress.

The uncertainty is increased by two major factors, the background subtraction which has been described above, and the calculation of real photon flux, which is good to ≈3%.[16, 17] The bremsstrahlung photon energy is

reconstructed from the measured momentum and scattering angle of the final state proton. The bremsstrahlung photon flux is calculated using the procedure developed by Matthews and Owens.

5 BEAM REQUEST

Table 1: Kinematics and Rates

E_e (GeV)	θ_{lab} (deg)	p_p (GeV/c)	$d\sigma/d\Omega_{lab}$ (pb/sr)	Rate (k/hr)	time (hours)
$\theta_{c.m.} =$	115°				
1.2	84.1	0.94	14500	99.	(1)
1.6	79.6	1.10	3100	16.	(1)
2.0	75.9	1.26	800	3.3	(1)
2.4	72.8	1.40	250	0.9	(2)
3.2	67.7	1.68	33	0.1	22
$\theta_{c.m.} =$	130°				
1.2	100.7	0.80	11000	73.	(1)
1.6	96.0	0.92	2200	11.	(1)
2.0	92.1	1.03	550	2.2	(1)
2.4	88.8	1.13	160	0.5	(4)
3.2	83.3	1.32	21	<0.1	36
$\theta_{c.m.} =$	145°				
1.2	120.3	0.68	7600	60.	(1)
1.6	115.9	0.76	1500	8.2	(1)
2.0	112.1	0.83	350	1.5	(1)
2.4	108.8	0.90	100	0.4	(5)
3.2	103.3	1.01	12	<0.1	64
				Data Time (days)	2.67
				checkout(days)	0.33
				Total (days)	3

Count rates have been calculated based on the following assumptions. The cross sections for D(γ, p)n reaction are extrapolated from the low energy

SLAC data using the $1/s^{11}$ scaling law. We assume a 15-cm target length which corresponds to a 2.2 gm/cm^2 target and a 30 μA electron beam. The bremsstrahlung photon flux is calculated for a thick (6%) copper radiator. A solid angle of 4.0 msr was assumed for the HRS spectrometer in calculating the rates; this is approximately the correct average for a target covering the full y-target acceptance of the spectrometer.

An overall detection efficiency of 80% is assumed for the rate estimates. The inefficiency results from inefficiencies in the spectrometer detectors, computer deadtime, and proton attenuation. The Hall A data acquisition system runs at 2 kHz with ~20% deadtime; using two independent DAQ systems for the two spectrometers allows each to be run at this rate and deadtime. Singles rates for this experiment are well below 1 kHz at the lowest beam energy, and decrease with energy.

The rate and beam time estimates for the large-angle data are given in Table 1. The lower energies, for which the times are marked by the parentheses, can be measured parasitically during E89-019, and do not require any new beam time. These times are, for each angle, of order a tenth as long as the time needed for the polarization measurement of E89-019. Since the time needed for this experiment is significantly shorter, and the two spectrometers can be operated essentially independently, we do not believe these parasitic measurements will have any significant impact on E89-019. The overhead time for changing spectrometer angle plus momentum is about 1 hour, and does not add significantly to the time needed. Not shown in the table are the angles at which cross checks will be made, 36° and 90°, and the additional two angles of 52° and 69° that will be measured only at 2.0 GeV.

Dedicated time is requested only for the 3.2 GeV measurements. For these data, we will measure the two forward angles with one spectrometer, and the largest angle with the second spectrometer, to minimize the beam time. The time given is sufficient to obtain roughly 1000 photodisintegration events both with and without the radiator, to enable an explicit subtraction of electrodisintegration events, and to enable the y-target dependence of the two-step background to be analyzed. An additional shift of beam time is requested for checkout, beam energy measurement, and current calibrations, as we anticipate that the 3.2 GeV measurements will run separately. No overhead is needed for spectrometer changes, since the largest angle setting takes several hours more than the two smaller angles combined. The total requested beam time with overhead, but without contingency for the facility

operation is 3 days.

6 COLLABORATION BACKGROUND AND RESPONSIBILITIES

This experiment requires the Hall A cryotarget, both HRS spectrometers and the bremsstrahlung radiator in Hall A. Many members of the current collaboration were involved in the SLAC deuteron photodisintegration experiments NE8, NE17, and the Jefferson Laboratory E89-012 experiment. Also, this collaboration has strong overlap with E89-019, during which the parasitic measurements are requested. The collaboration would provide the necessary personnel for operating the experiment and analyzing the data.

7 RELATED EXPERIMENTS

This proposal is similar to other $D(\gamma, p)n$ cross section measurements, as indicated in the proposal above. There is also some overlap with Hall B E93-017, which proposes measurement of angular distributions for photon energies from 0.8 to 1.5 GeV. Our 1.2 GeV measurements are intended to overlap these cross sections, as well as the 114° and 143° data of SLAC NE8, as a check on our two-step background rejection.

References

[1] C. Bochna *et al.* Phys. Rev. Lett. **65**, 1401 (1998)

[2] S. J. Brodsky and G. R. Farrar, Phys. Rev. Lett. **31**, 1153 (1973).

[3] V. Matveev *et al.*, Nuovo Cimento Lett.**7**, 719 (1973).

[4] G. P. LePage and S. J. Brodsky, Phys. Rev. Lett. **31**, 1153 (1973).

[5] S. J. Brodsky and J. R. Hiller, Phys. Rev. C **28**, 475 (1983).

[6] S. J. Brodsky and B. T. Chertok, Phys. Rev. Lett. **37**, 269 (1976).

[7] L. C. Alexa *et al.*, submitted to Phys. Rev. Lett.

[8] S.I. Nagornyi, YU. A. Kasatkin, and I.K. Kirichenko, Sov. J. Nucl. Phys. **55**, 189 (1992); S. I. Nagornyi and A. Dieperink, private communication, 1998.

[9] A. Radyushkin, private communication, 1998.

[10] L. A. Kondratyuk *et al.* Phys. Rev. C **48**, 2491 (1993).

[11] J. Napolitano *et al.*, Phys. Rev. Lett. **61**, 2530 (1988).

[12] S. J. Freedman *et al.*, Phys. Rev. C **48**, 1864 (1993).

[13] J. E. Belz *et al.*, Phys. Rev. Lett. **74**, 646 (1995).

[14] T.-S. H. Lee, Argonne National Laboratory Report No. PHY-5253-TH-88; T.-S.H. Lee, in *Proceedings of the International Conference on Medium and High Energy Nuclear Physics, Taipai, Taiwan, 1988* (World Scientific, Singapore, 1988), p.563.

[15] J. M. Laget, Nucl. Phys. **A312**, 265 (1978).

[16] J. L. Matthews and R. O. Owens, Nucl. Instrum. Methods **111**, 157 (1973).

[17] J. E. Belz, Ph.D. thesis, California Institute of Technology, 1994 (unpublished).