JLab Program Advisory Committee Eleven Proposal Cover Sheet

This document must be received by close of business on Wednesday, December 18, 1996 at:

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

(Choose one)

☒ **New Proposal Title:** Two-Body Photodisintegration of the Deuteron at High Energy

☐ **Update Experiment Number:**

☐ **Letter-of-Intent Title:**

Contact Person

Name: Roy Holt
Institution: University of Illinois
Address: Loomis Laboratory of Physics
Address: 1110 W. Green St.
City, State ZIP/Country: Urbana, IL 61801
Phone: 217-244-6039 **FAX:** 217-333-1215
E-Mail › Internet: r-holt@uiuc.edu

Experimental Hall: C **Days Requested for Approval:** 10.6

Jefferson Lab Use Only

Receipt Date: 17 DEC 96 PR 96-003

By: [signature]

LAB RESOURCES REQUIREMENTS LIST

CEBAF Proposal No.: ______________________ Date: ______________
(For CEBAF User Liaison Office use only.)

List below significant resources — both equipment and human — that you are requesting *from CEBAF* 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 CEBAF)*

New Support Structures:

Data Acquisition/Reduction

Computing Resources:

New Software:

Major Equipment

Magnets

Power Supplies

Targets: Hall C cryotarget
LD_2, LH_2

Detectors: C_4F_{10} gas in
HMS Cerenkov

Electronics

Computer Hardware

Other

Other

HAZARD IDENTIFICATION CHECKLIST

CEBAF Experiment: ______________________ Date: ______________

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

Cryogenics	Electrical Equipment	Radioactive/Hazardous Materials
____ beamline magnets ____ analysis magnets ✓ target ____ drift chambers ____ other	____ cryo/electrical devices ____ capacitor banks ____ high voltage ____ exposed equipment	List any radioactive or hazadorous/toxic materials planned for use: ____________ ____________
Pressure Vessels ____ inside diameter ____ operating pressure ____ window material ____ window thickness	**Flammable Gas or Liquids** (incl. target) type: LH_2, LD_2 flow rate: ____________ capacity: ____________	**Other Target Materials** ___ Beryllium (Be) ___ Lithium (Li) ___ Mercury (Hg) ___ Lead (Pb) ___ Tungsten (W) ___ Uranium (U) ___ Other (list below) ____________ ____________
Vacuum Vessels ____ inside diameter ____ operating pressure ____ window material ____ window thickness	**Radioactive Sources** ____ permanent installation ____ temporary use type: ____________ strength: ____________	**Large Mech. Structure/System** ____ lifting devices ____ motion controllers ____ scaffolding or elevated platforms ____ other
Lasers type: ____________ wattage: ____________ class: ____________ **Installation** ____ permanent ____ temporary **Use** ____ calibration ____ alignment	**Hazardous Materials** ____ cyanide plating materials ____ scintillation oil (from) ____ PCBs ____ methane ____ TMAE ____ TEA ____ photographic developers ____ other (list below) ____________ ____________ ____________	**Notes:** standard Hall C cryotarget or t_{20} target will be used.

BEAM REQUIREMENTS LIST

TLab Proposal No.: ______________________ Date: ______________

Hall: ________ Anticipated Run Date: ______________ PAC Approved Days: __________

Spokesperson: Roy Holt
Phone: 217-244-6039
E-mail: r-holt@uiuc.edu

Hall Liaison: R. Carlini

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.)

(1/3)

Condition No.	Beam Energy (~~M~~eV) G	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	3.0	30	cw	6% Cu radiator	770	} 5
				LD_2	2040	}
2	3.0	30	cw	6% Cu	770	} 3
				LH_2	1020	}
3	4.0	30	cw	6% Cu	770	} 46
				LD_2	2040	}
4	4.0	30	cw	LD_2	2040	15
5	4.0	30	cw	LH_2	1020	5
6	4.0	30	cw	6% Cu	770	} 15
				LH_2	1020	}
7	5.0	30	cw	6% Cu	770	} 135
				LD_2	2040	}
8	5.0	30	cw	LD_2	2040	45

(Continued on next page)

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

JLab Proposal No.: ____________ Date: ____________

Hall: ______ Anticipated Run Date: ____________ PAC Approved Days: ________

Spokesperson: R. Holt Hall Liaison: ____________
Phone: ____________
E-mail: ____________

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.)

(2/3)

Condition No.	Beam Energy (~~MeV~~) (GeV)	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)
9	5.0	30	cw	6% Cu	.770	46
				LH_2	1020	
10	5.0	30	cw	LH_2	1020	16
11	5.5	30	cw	6% Cu	770	33
				LD_2	2040	
12	5.5	30	cw	LD_2	2040	11
13	5.5	30	cw	6% Cu	770	13
				LH_2	1020	
14	5.5	30	cw	LH_2	1020	4
15	4.4	30	cw	6% Cu	770	45
				LD_2	2040	
16	4.4	30	cw	LD_2	2040	15
		continued on next page				

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

Lab Proposal No.: ______________________ Date: ____________

Hall: ________ Anticipated Run Date: ____________ PAC Approved Days: ____________

Spokesperson: R. HOLT Hall Liaison: ____________

Phone: ____________

E-mail: ____________

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.)

3/3

Condition No.	Beam Energy (~~MeV~~) GeV	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)
17	4.4	30	cw	6% Cu	770	} 16
				LH_2	1020	
18	4.4	30	cw	LH_2	1020	5

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.

Two-Body Photodisintegration of the Deuteron at High Energy

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Abstract

The cross section for the $d(\gamma,p)n$ reaction was measured up to a photon energy of 4.0 GeV at the Thomas Jefferson National Accelerator Facility (TJNAF, formerly CEBAF). The cross section at a photoproton center-of-mass angle of 90° exhibits a scaling behavior consistent with the constituent counting rule in the photon energy range from 1 to 4 GeV. The results at a proton center-of-mass angle of 37° are suggestive but inconclusive about the onset of the same scaling behavior at photon energies above 3.0 GeV.

We propose to extend the forward angle differential cross section measurements for the exclusive $d(\gamma,p)n$ reaction up to a photon energy of 5.5 GeV. This work will provide the first data for this reaction above 4 GeV, and permit a test of a threshold effect in the observed scaling at angles smaller than 90°. The proposed experiment must be performed in Hall C because of the need for the HMS, a spectrometer which can exceed a momentum of 4 GeV/c. This experiment is compatible with the t_{20} apparatus and could run during breaks in the t_{20} schedule.

1 INTRODUCTION

One of the interesting questions in nuclear physics is whether nuclear reactions exhibit any quark effects at high energies. Traditionally, quarks in particle physics have manifested themselves as a rather abrupt change in the momentum transfer dependence of the cross section, eg. Bjorken scaling. A possible method to search for a scale change in photonuclear reactions is to search for such a change in the cross section as a function of the incident photon energy.

Deuteron photo-disintegration at high energies is an excellent process for addressing the question of whether the onset of quark effects can be observed in nuclear reactions because the photon is a relatively well understood probe and because the deuteron is the best understood nucleus theoretically. In addition, a relatively large momentum transfer [1] to the constituents can be obtained in exclusive photonuclear reactions at photon energies of a few GeV, because the absorbed photon delivers all of its energy to the constituents.

Interestingly, high energy exclusive photoreactions from the nucleon [2] as well as other reactions involving the nucleon [3] have exhibited an energy dependence consistent with the constituent counting rule. Although the quark counting rule behavior has been observed in the exclusive reactions, the underlying reaction mechanism governing the onset of scaling behavior is not understood.

The question that this proposal addresses is whether a nuclear reaction adheres to the quark counting rules or exhibits some scaling feature at high energies. In particular, we propose to measure the differential cross section for the exclusive $d(\gamma,p)n$ reaction for photon energies of 4.0, 4.4, and 5.0 GeV at center of mass angles of 37° and 53°. Further, we propose to measure the cross section at 37° at 5.5 GeV. The 4.4, 5.0 and 5.5 GeV data will be completely new and the 4 GeV data will provide a cross check with the previous E89-012 data.

2 PHYSICS MOTIVATION

The traditional meson-exchange theory describes the $\gamma d \rightarrow pn$ rather well below a photon energy of 800 MeV as shown in Fig. 1. The data[4,5,6,7] from experiments NE8, NE17 and CEBAF E89-012 are summarized at $\theta_{cm} = 90^0$ in Fig. 1. Here, the solid curve is the calculation of Lee[8] and the short dashed curve is from Laget[9]. However, 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[11], given by the long dashed curve, in Fig. 1. This is especially surprising since this analysis works[12] very well for electron-deuteron elastic scattering above a momentum transfer of 1 $(GeV/c)^2$. More recent attempts to describe the data in terms of an asymptotic meson exchange model[10] have led to a reasonable agreement with the energy dependence at 90^0, although this model is arbitrarily normalized to the data at 1 GeV.

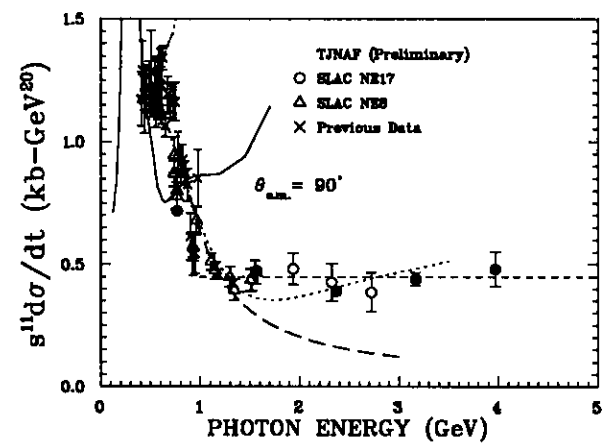

Figure 1: The preliminary TJNAF data together with the existing data as a function of the photon energy at $\theta_{c.m.} = 90°$. The solid circles are the TJNAF data with statistical uncertainties only. The curves are described in the text.

Exclusive scattering processes at high energy and large transverse momentum, can be described by the quark counting rule [13,14,15]. This rule predicts the following scaling law for the differential cross section:

$$(d\sigma/dt)_{AB\to CD} \sim s^{2-n} f(cos\theta^*) \quad (1)$$

Here n is the total number of elementary fields, θ^* is the center of mass angle, and t and s are the Mandelstam variables. For the $\gamma d \to \ p\ n$, the total number of elementary fields are 13. So the quark counting rule gives:

$$(d\sigma/dt)_{AB\to CD} \sim s^{-11} f(cos\theta^*) \quad (2)$$

The recent results from TJNAF at $\theta_{cm} = 90°$ are consistent with this scaling behavior. (See Fig. 1.) The TJNAF results are shown as the closed circles in the figure. The results are in excellent agreement with the SLAC experiments below 3 GeV and continue to show the $1/s^{11}$ behavior up to the maximum energy of experiment E89-012, 4 GeV.

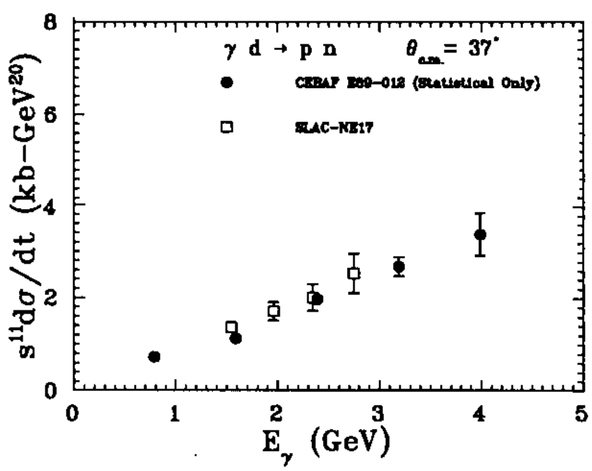

Figure 2: The preliminary TJNAF data together with the SLAC NE17 data as a function of the photon energy at $\theta_{c.m.} = 37°$. The solid circles are the TJNAF data with statistical uncertainties only.

On the other hand, there is no clear evidence for the same scaling behavior at $\theta_{cm} = 37°$ as shown in Fig. 2. The data are in excellent agreement with the SLAC data below 3 GeV, but do not exhibit a $1/s^{11}$ scaling behavior. One reason might be that there is a threshold effect in the transverse momentum.

In that case, one would not expect to see the scaling below a photon energy of 3 GeV. The existing data between 3 and 4 GeV would not be sufficient to show up such a threshold effect. Data over a larger "lever arm" would be necessary to show up such a scaling behavior.

Another issue is whether the scaling effect seen at 90^0 for the $\gamma d \rightarrow pn$ reaction is independent of the c.m. reaction angle. There is some indication that the scaling should be independent over a large range of reaction angles. For example, data[2] for the $\gamma p \rightarrow \pi^+ n$ show that the cross section follows the quark counting rule prediction above a photon beam energy of 3.0 GeV and the scaling behavior does not depend on the measured reaction angles.

3 PROPOSED MEASUREMENTS

We propose to measure the differential cross section for the exclusive $d(\gamma, p)n$ reaction for photon energies of 4.0, 4.4, and 5 GeV at center of mass angles of 37° and 53°. Also, the cross section at 5.5 GeV will be measured at 37°. The measurement at 4 GeV will provide a cross check with previous data.

4 EXPERIMENT

4.1 OVERVIEW

The experiment will employ the Hall C cryogenic liquid deuterium/hydrogen targets and the Bremsstrahlung photon beam produced by the electron beam striking the Hall C 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 C HMS spectrometer.

4.2 RADIATOR

The radiator is Cu with a 6% radiation length. The Cu will be placed approximately 1.2 m upstream of the target so that the spectrometer does not view it directly at the smallest scattering angle. Energy loss in the Cu is about 75 watts for a beam current of $30\mu A$. The radiator assembly will be the same as that used for Experiment E89-012.

4.3 TARGET

We plan to use the Hall C liquid deuterium and hydrogen(2% r.l.) cryotargets. The design heat load for Hall C cryotarget is up to 0.5 kW, much greater than the 144 W load for this experiment. For a 12 cm long target cell, at an incident electron beam current of 30 μA, the luminosity is $\mathcal{L} = 1.1 \times 10^{38}$ /cm^2/s for liquid deuterium at 20 K and operating pressure of 2 atm. The density fluctuations were found to be negligible operating at these beam currents.

4.4 SPECTROMETER

We will use the Hall C HMS spectrometer in its standard configuration. The highest momentum setting required for the spectrometer is 5.6 GeV/c and the most forward angle is 14.0°. The highest singles rate in the spectrometer is less than 1 kHz. As in experiment E89-012, the gas Cerenkov detector will be loaded with an atmosphere of C_4F_{10} so that the relatively small pion contamination can be eliminated above 2.5 GeV/c.

4.5 BACKGROUND

The dominant background process from this experiment is believed to be due to two-step processes which produce protons which appear to have nearly the same momentum as the photoprotons from deuterium. In this process, particles produced in the target scatter in the spectrometer magnet and show up in the high momentum side of the detector. This background is most severe at the highest energies and forward angles. Thus, the worst case is expected to occur at 5.5 GeV and an angle of 37°. Based on experience from E89-012, we expect the background to be approximately 40% of the signal in this worst case. This background was taken into account in estimating the beam time request. Measurements of the shape of the background will be made by running the LH2 target.

4.6 SYSTEMATIC ERRORS

The main systematic uncertainties for this experiment are expected to be similar to those found in E89-012. The main sources of systematic error for E89-012 are given in Table 1 for the HMS data at 4 GeV in the first column. The estimated systematic errors for the 5 pass runs in the right column are based on the E89-012 experience.

One of the important systematic error comes from the uncertainty in the spectrometer acceptance. Presently, the HMS acceptance for a 15 cm target is known to 5%. This acceptance is likely to be better known next year, but it is not the limiting uncertainty.

Table 1: Major contributions to the overall systematic uncertainty for experiment E89-012 given in relative percentage of the quantity, $s^{11}\frac{d\sigma}{dt}$ for the $d(\gamma,p)n$ reaction.

sources	4-pass actual(E89-012) 4.045 GeV	5-pass projected
acceptance	5.0%	5.0%
proton absorption	1.0	1.0
background subtraction	8.0	10.0
beam current	2.0	1.0
beam energy	0.8	1.0
photon flux	3.0	3.0
tracking	3.0	3.0
target thickness	3.0	3.0
particle id.	1.0	1.0
Total	11.1	12.1

The bremsstrahlung photon energy is reconstructed from the measured momentum and scattering angle of the final state proton. The bremsstrahlung photon flux can be calculated from the reconstructed photon energy using the procedure developed by Matthews and Owens. The uncertainty [16,17] in calculating the bremsstrahlung flux is on the order of 3%.

We plan to run at an electron beam energy of 30 μA. The uncertainty in the electron beam current should be 1%. The main uncertainty in target thickness is due to cuts placed on the target to eliminate background from the windows, which give a target thickness uncertainty of 3% in the worst case. The main uncertainty of background subtraction should be of order 10% in the worst case based on previous studies of the background for E89-012.

5 BEAM REQUEST

Count rates have been calculated based on the following assumptions. The cross sections for $d(\gamma,p)n$ reaction are extrapolated from the 4 GeV data from E89-012 using the $1/s^{11}$ scaling law. We assume a 12-cm target length which corresponds to a 2.0 (gm/cm^2) target and a $30\mu A$ electron beam. The bremsstrahlung photon flux is calculated for a thick (6%) copper radiator. A solid angle of 6.0 msr was assumed for the HMS spectrometer in calculating the rates. A tracking efficiency of 95%, a proton attenuation factor of 0.9, and a computer dead time of 20% were assumed in estimating the counting rates. The aim is for an overall statistical accuracy of 10% except at 5 GeV and 53^0 where the goal is 15%.

Table 2: Kinematics and Rates

θ_{cm} (deg)	θ_{lab} (deg)	p_p (GeV/c)	$d\sigma/d\Omega_{lab}$ (pb/sr)	Rate (in) (min^{-1})	Rate (out) (min^{-1})	time (days)
$E_\gamma =$	4.0 GeV					
37	15.8	4.27	210	8.1	2.4	0.4
53	23.3	3.91	56	2.2	0.7	1.2
70	32.1	3.43	32	1.2	0.4	1.8
$E_\gamma =$	4.4 GeV					
37	15.3	4.64	106	3.6	1.2	0.9
53	22.5	4.24	28	1.0	0.3	2.6
$E_\gamma =$	5.0 GeV					
37	14.6	5.18	41	1.3	0.4	2.6
53	21.5	4.72	11	0.3	0.1	3.3
$E_\gamma =$	5.5 GeV					
37	14.0	5.64	20	0.6	0.2	2.6
					Data Time	15.4
					Overhead	0.9
					checkout	0.3
					Energy meas.	0.3
					Total	16.9

The rate and beam time estimates are given in Table 2. The rates (in/out) refer to the proton rates with the radiator in/out. In addition to the 15.4 days of beam time necessary for the measurements, there is an additional 9 hours for target, radiator changes, 12 hours for energy changes, an additional 8 hours for the beam energy measurement, and 8 hours for checkout at 3 GeV. The total requested beam time with overhead, but without contingency for the facility operation is 16.9 days.

6 COLLABORATION BACKGROUND AND RESPONSIBILITIES

This experiment requires the Hall C cryotarget, HMS and bremsstrahlung radiator which have already been commissioned in Hall C. Many members of the current collaboration were involved in the SLAC deuteron photodisintegration experiments NE8, NE17, and the Jefferson Laboratory E89-012 experiment which includes commissioning of the Hall C equipment, particularly the cryotarget. The collaboration would provide the necessary personnel for operating the experiment and analyzing the data.

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