JLAB
USER GROUP

Jefferson Lab PAC17
Proposal Cover Sheet

This document must be received by close of business Thursday,
Dec. 14, 1999 at:

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

Experimental Hall: A
Days Requested for Approval: 10

☐ **Proposal Title:**
Proton Polarization Angular Distribution in Deuteron Photo-Disintegration

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

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

none

Contact Person
Name: Ron Gilman
Institution: Rutgers University,
Address:
Address: MS 12H, JLab, 12000 Jefferson Ave.
City, State, ZIP/Country: Newport News, VA 23606
Phone: 757 269 7011 **Fax:** 757 269 5703
E-Mail: gilman@jlab.org

Jefferson Lab Use Only
Receipt Date: 12/14/99
By: [redacted]
PR 00-007

HAZARD IDENTIFICATION CHECKLIST

JLab Proposal No.: ____________________ Date: ____________
(For CEBAF User Liaison Office use only.)

Check all items for which there is an anticipated need.

Cryogenics
____ beamline magnets
____ analysis magnets
____ target
type: ____________
flow rate: ____________
capacity: ____________
Standard Hall A

Electrical Equipment
____ cryo/electrical devices
____ capacitor banks
____ high voltage
____ exposed equipment
Standard Hall A

Radioactive/Hazardous Materials
List any radioactive or hazadorous/ toxic materials planned for use:
____
____
____
____
none

Pressure Vessels
____ inside diameter
____ operating pressure
____ window material
____ window thickness
[redacted]
Standard Hall A

Flammable Gas or Liquids
type: ____________
flow rate: ____________
capacity: ____________

Drift Chambers
type: ____________
flow rate: ____________
capacity: ____________
Standard Hall A

Other Target Materials
____ Beryllium (Be)
____ Lithium (Li)
____ Mercury (Hg)
____ Lead (Pb)
____ Tungsten (W)
____ Uranium (U)
____ Other (list below)
Standard Hall A cryotarget
+ carbon foil

Vacuum Vessels
____ inside diameter
____ operating pressure
____ window material
____ window thickness
Standard Hall A

Radioactive Sources
____ permanent installation
____ temporary use
type: ____________
strength: ____________
none

Large Mech. Structure/System
____ lifting devices
____ motion controllers
____ scaffolding or elevated platforms
none

Lasers
type: ____________
wattage: ____________
class: ____________

Installation:
____ permanent
____ temporary

Use:
____ calibration
____ alignment

None

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

none

General:

Experiment Class:

✓ Base Equipment
____ Temp. Mod. to Base Equip.
____ Permanent Mod. to Base Equipment
____ Major New Apparatus

Other: ____________
____

BEAM REQUIREMENTS LIST

JLab Proposal No.:
Date:

Hall: A
Anticipated Run Date: 2001
PAC Approved Days:

Spokesperson: R. Gilman
Phone: 757-269-7011
E-mail: gilman@jlab.org

Hall Liaison:

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)	~2000	30	70-80% polarized	Cu	774	120
				Al	50	
				D	2430	
(2)	~2000	30	〃	Cu	774	50
				Al	50	
				H	1050	
(3)	~2000	30	〃	Al	50	50
				D	2430	
(4)	~2000	30	〃	Al	50	20
				H	1050	

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.

LAB RESOURCES LIST

JLab Proposal No.: ____________ Date ____________
(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 Standard

New Software: None

Major Equipment

Magnets: standard

Power Supplies:

Targets: H_2, D_2 Liquid target.
Hall-A standard

Detectors: Hall-A standard,
FPP as it is in Hall-A.

Electronics: Hall-A standard.

Computer Hardware: Hall-A standard

Other: None.

Other: Hall-A radiator, as already installed and used in the beam line.

COMPUTING REQUIREMENTS

- Amount of raw data expected: The average trigger rate is estimated to be about 500 Hz. The total amount of data for a 10-day run is about 500-700 GB.

- Computer power required for reconstruction and analysis: for online analysis, the standard Hall-A online Linux computer, which has two P-333 cpus, is considered to be good enough. For offline analysis after the experiment is done, we need roughly 100-200 cpu-day computing power.

- Computer power required for simulations: none.

- Amount of on-line disk storage: 20 GB, or standard Hall-A configuration.

- Amount of data to be imported and exported to outside institutions: none.

- Other special requirements: none.

PROTON POLARIZATION ANGULAR DISTRIBUTION IN DEUTERON PHOTO-DISINTEGRATION

P. Bosted
American University, Washington, DC, USA

B. Fox, E. Kinney
University of Colorado, Boulder, CO, USA

K. Aniol, M. Epstein, D. Margaziotis
California State University, Los Angeles, CA, USA

J. Gao
California Institute of Technology, Pasadena, CA, USA

S. Churchwell
Duke University, Durham, NC, USA

P. Markowitz
Florida International University, Miami, FL, USA

D. Meekins, R. Roche, A. Sarty
Florida State University, Tallahassee, FL, USA

M. Amarian, S. Frullani, F. Garibaldi, G.M. Urciuoli
INFN/Sanita, Roma, Italy

J.P. Chen, E. Chudakov, J. Gomez, O. Hansen, K. de Jager, M. Kuss, J. LeRose,
M. Liang, N. Liyanage, R. Michaels, J. Mitchell, A. Saha, B. Wojtsekhowski
Jefferson Laboratory, Newport News, VA, USA

R. Gilman (Contact Person)
Jefferson Laboratory, Newport News, VA, USA, and
Rutgers University, New Brunswick, NJ, USA

S. Glamazdin, V. Gorbenko, R. Pomatsalyuk
Kharkov Institute of Physics and Technology, Kharkov, Ukraine

K. Fissum
Department of Physics, University of Lund, P.O. Box 118, S-221 00 Lund, Sweden

Z. Chai, D. Dutta, H. Gao, D. W. Higinbotham, M. Rvachev, R. Suleiman,
F. Xiong, W. Xu
Massachusetts Institute of Technology, Cambridge, USA

V. Punjabi
Norfolk State University, Norfolk, VA, USA

L. Todor, P. Ulmer
Old Dominion University, Norfolk, VA, USA

L. Bimbot
Institut de Physique Nucleaire, Orsay, France

K. Benslama, E. Brash, G. Huber
University of Regina, Regina, SK, Canada

S. Dieterich, C. Glashausser, X. Jiang, G. Kumbartzki, S. Malov, R. Ransome,
S. Strauch
Rutgers University, New Brunswick, NJ, USA

K. McCormick
DAPNIA, Saclay, France

S. Choi, Z.-E. Meziani (Spokesperson)
Temple University, Philadelphia, PA, USA

T. Chang, R.J. Holt (Spokesperson), E.C. Schulte, K. Wijesooriya
University of Illinois at Urbana-Champaign, Urbana, IL, USA

C.C. Chang, M. Jones, J. Kelly
University of Maryland, College Park, MD, USA

J. Calarco
University of New Hampshire, Durham, NH, USA

R. Lindgren
University of Virginia, Charlottesville, VA, USA

C. Perdrisat
College of William and Mary, Williamsburg, VA, USA

O. Gayou
College of William and Mary, Williamsburg, VA, USA, and
Universite Blaise Pascal, Aubiere, France

and The Hall A Collaboration

The apparent scaling in 90°_{cm} deuteron photodisintegration, first observed several years ago at SLAC, has led to several related experiments and a number of theoretical calculations. We have in the past year measured in Hall A, with up to 2.5-GeV photons, cross sections at large angles and the proton polarization at 90°_{cm}. Very preliminary online analysis of the induced polarizations yields the very surprising result that the induced polarizations apparently vanish starting at about the same energy at which the existing cross section data start to scale, to follow the constituent counting rules. Given this result, we propose further measurements to see if this observation holds at other angles. We request 10 days to measure an angular distribution at $E_\gamma \sim 2$ GeV.

1 Introduction

At beam energies above a few GeV and four-momentum transfers $-t > 1$ $(\mathrm{GeV/c})^2$, cross sections for several exclusive photoreactions demonstrate the approximate validity of the constituent counting rules. [1] These rules can be derived from perturbative QCD [2], but pQCD is generally considered to be inapplicable to these data[3]. The apparent onset of scaling[4,5] comes at particularly low energies, near 1 GeV, for deuteron photodisintegration; in contrast photo-nucleon reactions at this energy exhibit pronounced resonance effects. These observations, and the theoretical approaches discussed below, demonstrate that photodisintegration, with its high momentum transfer, may be amenable to description in terms of quark degrees of freedom. A successful approach of this type would be an important step in trying to understand the transition between QCD and meson-baryon degrees of freedom in describing nuclei, one of the major goals for research at the Thomas Jefferson National Accelerator Facility (JLab).

We have recently extended the photodisintegration studies by measuring the recoil proton polarization at 90°_{cm}. We discuss below the surprising result that we have obtained: the measured proton polarization is consistent with vanishing above about 1 GeV, as would be expected from hadron helicity conservation. Meson-baryon models predict large polarizations, and quark models do not generally require hadron helicity conservation. It might be considered troubling that pQCD, which cannot be right for this reaction in these kinematics, does require both helicity conservation and scaling of cross sections. Thus, pQCD is the model in best agreement with all the data at 90°_{cm} and photon energies above 1 GeV.

Here we propose to measure an angular distribution for the proton polarization at a photon energy of about 2 GeV. These data, along with ongoing theoretical work, will provide an improved determination of the photodisintegration reaction mechanism.

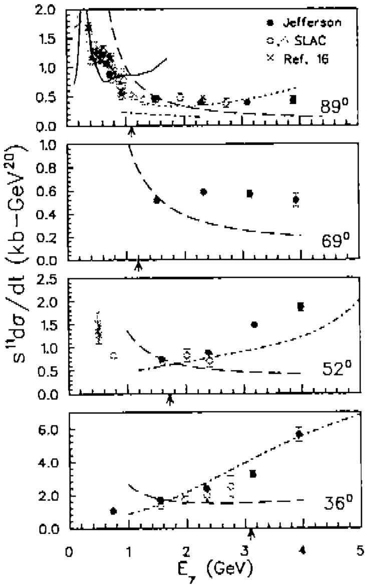

Figure 1: Deuteron photodisintegration data compared to several theories, mentioned in the text. The cross sections are multiplied by s^{11}, so that quark-scaling behavior results in a constant value.

2 Existing Data and Theories

In the past few years, we have performed several experiments [5,6,7,8] to study photodisintegration, to attempt to determine the onset of apparent scaling, and thus lead to an understanding of the reaction mechanism. The published results of Hall C experiment 89-012 [5], and previous data[4], are shown in Fig. 1, taken from reference [5]. Scaling is seen from quite low energies at 69 and 89°_{cm}, but there is a much slower fall off of the cross sections with energy at the more forward angles of 36 and 52°_{cm}. The curves shown include the reduced nuclear amplitudes (RNA) model [9] (long dash), quark-gluon string (QGS) theory [10] (dot dash), and conventional nuclear physics calculations [11,12] (dot and solid).

Our understanding of these data from these models is not satisfactory. Scaling is seen and expected at high momentum transfers, but almost certainly much higher than the kinematics of these data. The QGS calculations are expected to work best at low momentum transfer, consistent with the good agreement at 36°_{cm}, and poor agreement at larger angles. The Nagornyi nuclear calculations [12] agree well at 90°_{cm}. The RNA approach does not agree well at any angle. It is necessary to understand if the good agreement for some

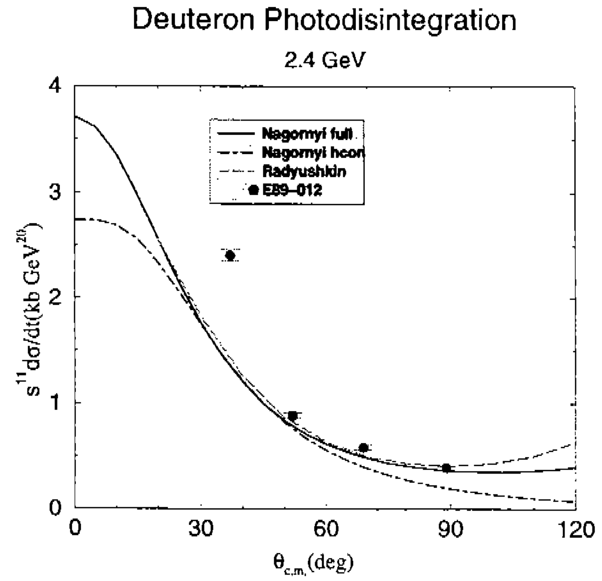

Figure 2: Deuteron photodisintegration angular distribution at 2.4 GeV, compared to the calculations, described in the text.

calculations at some angles is fortuitous, or whether the calculations are correct and why the disagreement arises for other angles.

In Fig. 2, we compare the angular distribution data at 2.4 GeV, taken from Fig. 1, with the asymptotic meson-exchange model[12] of Nagornyi and Dieperink, and with a quark-model calculation[13] of Radyushkin. The quark-model calculation was normalized to the photodisintegration data point at 1.6 GeV and 90°_{cm}, so the agreement with the data at this energy indicates that the large-angle energy dependence is satisfactory. Both show good quantitative agreement with the data, except for under predicting the forward-angle rise. Nagornyi also estimates the effects of helicity conservation on the cross sections by turning off anomalous magnetic moments of the nucleons, in the "hcon" calculation. Similar quality of agreement has also been shown in another quark model calculation[14].

We have recently completed Hall A experiment 89-019[8], measuring proton polarization at 90°_{cm} as a function of beam energy. Because the experiment was just completed, we show in Fig. 3 the online data, set to 0, and the online statistical uncertainties, to indicate the quality of the measurements. (We are unwilling at this point to present the online values, but they are described be-

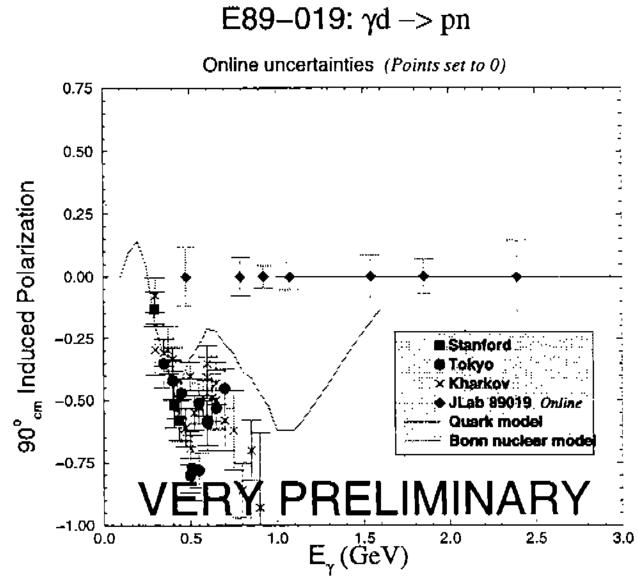

Figure 3: Deuteron photodisintegration induced polarization uncertainties from Jefferson Lab E89-019, along with previous data and two theoretical estimates.

low and will be presented at the PAC meeting.) Systematic uncertainties have not yet been precisely evaluated, but for the online analysis are about 0.1. (We expect to obtain systematic uncertainties of ~0.05 in the final analysis, in line with the statistical uncertainties.) We also show older data[15], a conventional meson / baryon calculation from the Bonn group [16], and vanishing induced polarization, as would result from helicity conservation, expected in simpler quark models.

Preliminary analysis shows that the data are of good quality. The low-energy data points are consistent with most of the earlier measurements from Tokyo and Kharkov. However, they contradict the increase in induced polarization with energy seen in the highest energy Kharkov experiment, from about 700 - 900 MeV. At these energies, the magnitudes of our measured polarizations are much smaller than those of Kharkov.

To calibrate the polarimeter analyzing power and false asymmetries, measurements of *ep* elastic scattering were taken at the same proton spectrometer and FPP analyzer setting as for each of our data points. For this reaction, the proton polarization depends on the beam helicity; the two polarization-transfer components determine both the proton electromagnetic form factor ratio $\mu G_E/G_M$ and the polarimeter analyzing power A_C, as the beam polarization was measured by the Hall A Møller polarimeter. The induced polarization vanishes in *ep* elastic scattering, in the one-photon exchange approximation, so summing data from the two beam helicity states measures the false asymmetries of the polarimeter. Given this calibration and the data overlap at the lowest energies, we have confidence in our preliminary results, despite the disagreement with the higher-energy Kharkov experiment.

We find the induced polarization steadily dropping above 500 MeV beam energy. In particular, ***the induced polarization is consistent with vanishing above about 1 GeV.*** This observation can be explained as resulting from hadron helicity conservation (HHC). HHC requires that the sum of all hadron helicities is the same in the initial state as in the final state.

For point particles, helicity conservation is a direct result of the electromagnetic coupling, which violates helicity conservation only at the level of m/E. Thus, helicity conservation for quarks is not unreasonable. However, in coupling the quarks to form a nucleon, orbital angular momentum may contribute, leading to the initial and final state hadrons having different helicity. Large momentum transfer elastic *pp* scattering is known to have non-vanishing polarizations, and thus hadron helicity non-conservation. One explanation for these data is the contribution of the independent scattering mechanism.[17]

We consider the observed vanishing photodisintegration induced polarization to be highly surprising for several reasons.

- Our new data disagree with the old higher-energy Kharkov data, and the trend implied by these data.

- The calculations by the Bonn group indicate that the D_{13} and D_{15} resonances should contribute to the reaction, leading to large induced polarizations up to 1.5 GeV, peaking near 1 GeV.

- A measurement was performed during the past year at Yerevan[18] of the Σ asymmetry, the cross section asymmetry between linearly-polarized photons polarized parallel and perpendicular to the scattering plane. These unpublished data at $90^\circ_{\rm cm}$ show large asymmetries, as the photon energy increases up to 1.5 GeV, tending towards 1 with increasing energy. If there is HHC, Σ is generally nonzero and results from a combination of amplitudes that, with typical assumptions about the relative phases, requires $\Sigma(90^\circ) \to -1$. The inference is that HHC most likely does not hold.

- In the hadronic sector, proton-proton elastic scattering and Λ production are well known for their HHC-violating polarization effects at large

> energy and momentum transfer. It has been speculated that these large polarizations can result from independent scattering (Landshoff) mechanisms.[17]

At this point, we can only speculate as to why helicity conservation appears valid in deuteron photodisintegration. In the framework of meson-baryon theory, Lee[11] has indicated that photodisintegration proceeds largely via absorption of the photon on one of the nucleons. The intermediate nucleon may be excited to some baryon resonance. The energy of this particle is shared with the second nucleon though a meson-exchange / final state interaction. Naively, since the nucleon-nucleon interaction has significant polarization effects at these center of mass energies, one should see non-vanishing polarizations in photodisintegration as well. However, calculations[16] indicate small polarization effects from final state interactions at higher energies.

Most of the polarization generated in the meson-baryon calculations results from interference between the resonances and the Born term. If the polarization is to vanish in these models, either that the resonance contributions are vastly overestimated, or somehow the combination of *all* resonances acts to wash out the induced polarization at all energies.

Helicity conservation is not generally a fundamental symmetry in quark calculations, but it is often assumed in simpler calculations. Since the nucleon Pauli form factor directly measures helicity non-conservation, it is clear that one does not generally expect helicity conservation in JLab kinematics. One possibility is that for these large momentum transfer photoreactions, the photon interaction becomes point-like, suppressing the Landshoff mechanism and allowing helicity conservation.[19]

An alternate explanation comes from the framework of non-forward parton distributions, in which one expects the amplitudes to be largely real. This would cause the induced polarization, the imaginary part of an interference of amplitudes, to vanish, naturally leading to our experimental result. Too, it could potentially explain the recent Yerevan Σ asymmetry data, which result from the real part of an interference of amplitudes.

The induced polarization is perpendicular to the scattering plane. For a polarized photon beam, there are two additional proton polarization components, in the scattering plane. The polarization transfers C_x and C_z lead to the proton spin being polarized perpendicular and parallel to the proton momentum direction, respectively. The polarization transfer C_x is the real part of essentially the same interference of amplitudes as the induced polarization P, so it should not generally vanish with non-forward parton distributions. However, the interference contains products of helicity-conserving amplitudes times helicity-violating amplitudes, so in the limit of HHC, both observables will vanish. C_z is generally nonzero, and model dependent. It does not have any direct implications for HHC, and we will not discuss it further.

From this discussion, it is clear that the vanishing of P we have presented above is not sufficient to claim HHC in deuteron photodisintegration; it may instead indicate that the amplitudes are nearly real. We did however measure the photodisintegration with polarized beam, except for the point at 1.15 GeV, and thus C_x can also be determined. Only two of the four other points above 1 GeV have been analyzed so far.[20] The polarizations appear to be small; when all the points are analyzed will it be clearer if the vanishing induced polarizations reflect HHC, rather than real amplitudes.

Given these results, we have been in contact with several theorists concerning the data and polarization calculations. Polarization calculations are now underway in the QCD rescattering model[14] and in the quark-gluon string model[10]. There is also interest from Nagornyi[12], Radyushkin[13], Ralston, Carlson, Afanasev, and Jeschonnek.

Given our recent experimental results, and the current status of theory, we have concluded that it is important to measure an angular distribution for the proton polarization. The vanishing polarization could be a general phenomena, at all angles. The polarization could decrease monotonically with angle, as has been seen in Regge-theory calculations for several photoreactions at beam energies of several GeV.[21] The vanishing polarization could be correlated with the apparent scaling of the cross sections. It is possible that the polarizations are not generally 0, except at 90°_{cm}. Resonance contributions could be large, as in the Bonn calculations, but unlike these calculations actually have a node near 90°_{cm}. To summarize, characterizing the angular distribution allows comparison to expected theoretical calculations, in addition to directly providing clues about the underlying physical processes. By measuring at the highest feasible energy, near ~ 2 GeV, we ensure that we are in the region at which the 70°_{cm} cross sections scale, and improve the applicability of the quark models.

3 The Experiment

We propose to measure an angular distribution for deuteron photodisintegration at a beam energy of about 2 GeV. This energy is the highest feasible energy for an angular distribution; this can be demonstrated by noting that the 1.95 GeV point in Fig. 3 was taken in four days, compared to the ten days of data for the 2.5 GeV point, with its poorer uncertainty. This proposal represents an improvement over the previous proposal[8], in line with our actual measurements during fall 1999, by requesting measurements of both the induced polarization P and the polarization transfer C_x, as well as C_z. The physics arguments were presented above.

We plan to take advantage of technical improvements to increase the figure of merit, and reduce the beam time, for the experiment. Experiment 99-007, which extends G_E^p measurements[22] to higher Q^2, is tentatively scheduled for late fall 2000. It will install a thicker analyzer with higher figure of merit in the polarimeter. This allows an estimated factor of 2 reduction in the beam time needed. This analyzer is appropriate only for higher proton momenta, which we will be running in this experiment. Installation and removal of the thicker analyzer are difficult tasks; we assume that this experiment will be approved and scheduled for immediately after E99-007. As a result, we will be able to take advantage of the modified analyzer, and reduce the beam time request accordingly.

The experimental techniques are identical to those of our recently completed experiment, E89-019. We use a 30 μA, $\sim$70% polarized electron beam impinging on a 6% Cu radiator to generate the polarized photon beam. The mixed electron + photon beam then strikes the Hall A 15-cm cryogenic deuterium target. The hadron spectrometer is used to detect protons corresponding to photon energies near the end point, for the chosen center-of-mass angles. Reconstructed target quantities are used to eliminate background events, and scattering of the protons in the polarimeter is used to determine the proton polarization.

During E89-019, we obtained uncertainties of $\Delta P \approx 0.05$ for the induced polarization at the target for our 1.95 GeV data point; the uncertainty was about 0.07 for C_x due to the beam polarization, and about 0.23 for C_z due to the beam polarization and the unfavorable spin transport for this spin component. The measurement took 4 days. Thus, 2 days are required for this measurement with the improved analyzer. For the forward angles at this energy, larger cross sections lead to higher count rates that approximately compensate for the decrease in polarimeter figure of merit with higher proton momentum. As a result, similar times are required at each angle.

We do not propose to improve upon the statistical uncertainty of our recent measurements, as systematic uncertainties on the induced polarization will be about 0.05 (absolute). This results mainly from the false asymmetry. For the polarization transfer, the false asymmetry is small. The uncertainties from spin transport, analyzing power, and beam polarization are about 5 % (relative), becoming quite small for small polarizations. However, checks of helicity conservation require both P and C_x to vanish, so we believe it is not reasonable to measure one of these two components to much greater precision than the other.

Table 1 shows the proposed kinematic points, uncertainties, and times.

The large increase in the uncertainty for C_z near 70°_{cm} results from the 180° rotation in this spin component at ≈ 1.9 GeV/c. The times shown in Table 1 total 9 days for photodisintegration measurements.

An additional one day is needed for elastic *ep* scattering to calibrate the polarimeter. This is optimally done with a higher beam energy than that of the measurements, in the range ≈ 3.5 to 4.0 GeV. Each of the 5 *ep* measurements requires about 4 hours.

Table 1: Proposed data points, uncertainties, and times for $E_\gamma \approx 2$ GeV angular distribution.

θ_{cm} (deg)	θ_{lab} (deg)	p_p (GeV/c)	p_T (GeV/c)	$-t$ $(\mathrm{GeV/c})^2$	ΔP / ΔC_x / ΔC_z (absolute)	time (days)
37	20.1	2.35	0.8	0.4	0.05 / 0.06 / 0.09	2.
53	29.4	2.19	1.1	1.0	0.05 / 0.07 / 0.16	1.5
70	40.1	1.96	1.3	1.7	0.05 / 0.07 / 0.62	1.5
90	54.3	1.65	1.3	2.7	0.05 / 0.07 / 0.24	2.
110	71.2	1.34	1.3	3.8	0.06 / 0.05 / 0.09	2.

4 Summary

During fall 1999, this collaboration measured recoil proton polarization in deuteron photodisintegration. We obtained the result that the induced polarization is consistent with vanishing, inconsistent with meson-baryon model calculations. The data indicate that hadron helicity is conserved and / or the reaction amplitudes are real. Polarization calculations are expected to be available in several quark models in the near future.

Our understanding of the implications of the data, and testing of the new calculations, can be greatly improved by measuring an angular distribution at the highest feasible energy. We request ten days to perform such a measurement at 2 GeV.

References

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