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Measurement of Proton Polarization in the $d(\gamma, \vec{p})n$ Reaction
Update of TJNAF E89-019

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Why Updating?

- Scaling seen in E89-012 cross section data at $90^\circ_{\rm cm} \rightarrow$ motivation to examine the amplitudes in more detail through spin measurements
- Hall A and polarimeter commissioned
- request priority upgrade so that can schedule in timely manner

Goal

Simple view: search for quark effects in exclusive nuclear reactions

> At higher energies, there is already evidence that some behavior characteristic of hard QCD interactions sets in when photons are used to decompose a deuteron into a neutron and proton. Recent results from SLAC for this reaction ... reveal an energy dependence that agrees well with simple "counting rules" based on the total number of point-like constituents (here, valence quarks and the photon itself) participating in the interaction. **Future experiments at CEBAF will provide crucial information on whether this behavior persists in polarization measurements.** – DOE / NSF Nuclear Science Advisory Committee, in *Nuclear Science: A Long Range Plan* (February, 1996).

Summary of calculations

- solid line: Lee meson-exchange model
- dash dotted line: Laget meson-exchange model
- long dashed line: Brodsky and LePage reduced nuclear amplitudes
- short dashed line: Nagornyi asymptotic meson-exchange model
- dash dotted line: Kondratyuk *et al.* quark-gluon string model

Summary of data

- solid cicles: E89-012 preliminary
- open circles, diamonds: SLAC NE8, NE17
- x-es: older data

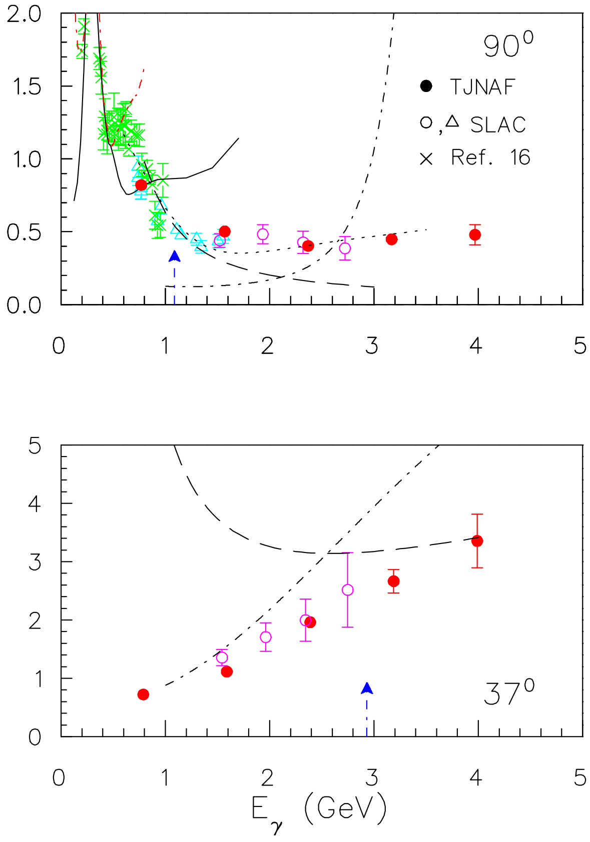

Figure 1: Cross sections $s^{11} d\sigma/dt$ for deuteron photodisintegration at center of mass angles of 90^o and 37^o, including preliminary data from E89-012.

Polarization Calculations

- Meson-exchange calculations show the general feature of negative spikes in the polarization, resulting from Born / resonance interference; all underpredict the measured data.

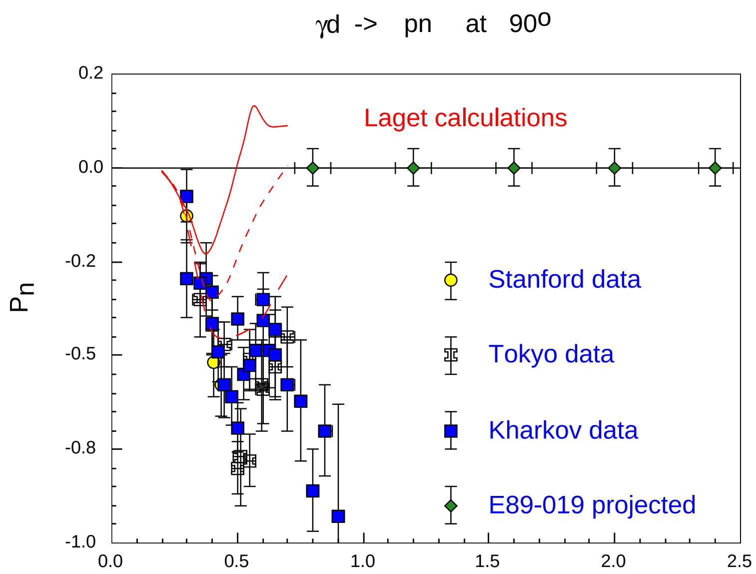

Figure 2: 90° induced polarization for deuteron photodisintegration, showing Laget calculations and projected uncertainties for this experiment. Each data point will shown will become 2 $\rightarrow$ 5 data points with the size uncertainty shown. In kinematic regimes where cross sections "scale", there is **no** data for polarizations / asymmetries in photoreactions.

CONTEXT

One of a series of experiments to investigate the reaction mechanism for deuteron photodisintegration for $E_\gamma \geq 0.8$ GeV.

Experiment	Status	Data
SLAC NE8	published	up to 1.8 GeV
SLAC NE17	published	up to 3 GeV
CEBAF E89-012	A- priority, run 1995, analyzing	up to 4 GeV, improved statistics
CEBAF E96-003	18 days approved, A- priority, was Hall C fall 1997	4 - 5.5 GeV
CEBAF E89-019	18 days approved, B priority, updating	0.8 - 2.4 GeV $\vec{p}$ at 90°_{cm}
CEBAF E93-017	*Hall B, approved, B+ priority*	*small momentum transfer*

- Extending the cross section measurements in E96-003 represents a *"natural extension of the work begun at SLAC"*.

Why Do We Want to Measure the Polarization?

- Cross sections at forward angles (E96-003) may tell us more about the onset of apparent scaling as a function of angle / momentum transfer, but...
- Cross sections at $90^\circ_{\rm cm}$ have been shown to scale starting at a surprisingly low energy / momentum transfer. Polarization measurements will help to determine what is actually happening.
- In particular, polarizations at $90^\circ_{\rm cm}$ provide a cleaner signal of small amplitudes, e.g., resonances, than do the cross section.
- Helicity conservation, expected in the quark picture, leads to vanishing induced polarization, P = 0.

In deuteron photodisintegration, the available proton polarization data are for E_γ up to 1.1 GeV at a c.m. scattering angle of 120° and show polarization that is large and negative. (For the perturbative QCD scaling rule falloff of $d\sigma/dt$, **deuteron photodisintegration stands out as a case that appears to work at a remarkably low energy**. The quantity $S^{11}d\sigma/dt$ for the 90° c.m. data looks constant in the higher energy region of E_γ, beginning at E_γ just 1.1 GeV, the same as the top energy for the polarization data, and a momentum transfer $-t = 1.2$ GeV^2, smaller than in any other known case...

However, none of the photoproduction experiments are at a high momentum transfer from the viewpoint of perturbative QCD. A sufficient momentum transfer for hadron helicity conservation to work is not known...

We shall close by emphasizing the value of polarization measurements at higher momentum transfer, *momentum transfers at least as large as the threshold for the perturbative QCD scaling law data to appear...* – Carl E. Carlson and M. Chachkhunashvili, Phys. Rev. D **45**, 2555 (1992).

> **It would also be interesting to test the prediction of QCD that the polarization of the nucleon emitted in this reaction goes to zero in the "true" perturbative scaling regime.** The polarization at energies below 0.75 GeV, where data do exist, is large. Measuring the polarization in the 1-4 GeV region should provide additional insights into the transition from nucleon to quark behavior. – L. Cardman, TJNAF, *Nuclear Physics News*, Vol. 6, No. 4, page 19, 1996.

Note: it is easy to argue why $P \neq 0$; it is similarly easy to argue why $s^{11} d\sigma/dt \neq$ constant.

Why pp Scattering May Be Difficult to Understand

However, as emphasized by Ralston and Pire, the possibility that long-distance, or Landshoff, processes are important in purely hadronic reactions can vitiate the hadron helicity conservation arguments. Hadron helicity conservation requires quark helicity conservation, plus neglect of the orbital angular momentum of a hadron's constituents projected along the momentum direction of that hadron. This is not justified if the interaction region is large. To the extent Landshoff processes are important one may see polarization in purely hadronic reactions even at high energy. **Thus, electromagnetic processes become of greater interest.** – Carl E. Carlson and M. Chachkhunashvili, Phys. Rev. D **45**, 2555 (1992).

Proposal: E89-019
Spokespersons: R. Gilman, R. Holt, and Z.E. Meziani
Title: Measurement of Proton Polarization in the $d(\gamma, p)n$ Reaction

Motivation:

It is proposed to measure proton polarization in the reaction $d(\gamma, p)n$ up to an energy of 2.8 GeV at four angles. The measurements wil improve upon the accuracy of existing low energy data and extend the range in energy by more than a factor of two.

The proposal addresses the issue of the scaling region where perturbative QCD predicts the polarization to vanish. Differential cross section measurements from SLAC experiments NE8 and NE17 indicate that the onset of scaling may occur in this kinematic region.

Measurement and Feasibility:

A Bremsstrahlung photon beam with maximum energies essentially equal to the electron kinetic energy is produced by a radiator some 20 cm upstream of the target. **The PAC was satisfied that the experimental technique had been addressed effectively.**

Issues:

The PAC views this as an interesting experiment, but notes that, given the abscense of a successful theory for photodisintegration experiments in the range below 2 GeV it is difficult to predict what precision is needed in P_n to differentiate among competing models. **The PAC suggests concentrating on one excitation function at $\theta = 90^\circ$ with a more extensive sample of energies than proposed and deferring angular distribution measurements.**

It seems unlikely that $P_n = 0$ over this energy range, therefore **precise data with small errors** could serve to stimulate both theoretical efforts to calculate polarizations and differential cross sections in a hadronic picture, and experimental efforts to focus on selective cases of angular distributions.

Manpower:

The manpower is considered adequate.

Recommendation:

The PAC recommends an initial beam time allocation of 18 days to permit measurement of an excitation function at 90° cm between 0.8 and 2.4 GeV.

TAC Comments

- *1. Two nonstandard energies:* Yes, perhaps. Would like, following PAC 7 comments, to run additional energies if schedulable.
- *2. Design and installation of bremsstrahlung radiator.* Have physicist conceptual design. Given higher priority and preliminary scheduling, should be able to get couple days of Hall A engineer/designer help. Rutgers will build. Two week down times should allow installation.
- *3. Assumes 0.06 X_0 Cu radiator, background has to be investigated.* Agree; we know this is okay in Hall C, but Hall A may be different. Will request 1 - 2 shifts development time in advance of experiment scheduling.

New Developments Since 1993

- *Experimental Data*
  - E89-012 preliminary data available; strong evidence now seen for scaling leads to a need for a closer look at the underlying reaction mechanism.
- *Polarimeter*
  - FPP now in Hall A, commissioned, measuring $^{1}H,^{16}O(\vec{e},e'\vec{p})$ in E89-033
  - E93-027, G_E^P, scheduled for 1998, will lead to significant improvement in capability
- *Interest*
  - Have quoted NSAC, Cardman, Carlson as examples of interest in the experiment.

What is needed Experimentally for $\gamma d \rightarrow \vec{p}n$?

- Beam line:
  - $\sim$ 20 μA unpolarized electrons
  - "6%" radiator, to be built by Rutgers
  - Cryotarget with deuterium (20 μA $\times$ 2 MeVcm^2/g $\times$ 2.5 g/cm^2 = 100 W) and empty cells, being built by Hall A
- Hadron arm:
  - $\sigma_{\mathrm{p}}/\mathrm{p} \sim 2 \times 10^{-3}$
  - $\sigma_\theta, \sigma_\phi \sim$ few mr
  - "Calibrated" FPP measures polarizations.
  - Background π^+ kinematically forbidden or near threshhold.
  - Do not see walls at 90°_{cm}.
  - Cross sections known; will try to improve statistics and systematics parasitically.
- On track for $\sim$1998 experiment, except for scheduling beamtime

Count rate estimate summary.

E GeV	θ deg.	p_p GeV/c	rate Hz	A_C	χ deg.	counts	data* time	days+
0.8	65.5	0.94	200	0.40	114	379,000	0.5	1
1.2	60.7	1.21	25	0.27	131	223,000	2.5	1
1.6	57.0	1.45	5	0.23	148	150,000	9	2
2.0	54.0	1.68	1	0.20	165	135,000	36	4
2.4	51.5	1.91	0.3	0.17	183	162,000	155	10
Total								18

* The time in hours to take the data *includes* background measurements. This time gives an uncertainty $\Delta P_n^{tg} = \pm 0.05$, integrating over the entire energy range of $\sim$140 MeV.

+ The time in days we will spend at each energy. The time allows for 2 to $\sim$5 energy bins to be measured, each to $\Delta P_n^{tg} = \pm 0.05$, including background subtractions, and allows for calibrations such as radiator linearity, BCMs, and the polarimeter through *ep* elastic scattering.

Effect of **worst case** unknown 1 % false asymmetry.

E(GeV)	$1/\cos(\chi)$	P_{tg}^{false}	$P_{tg}^{expected}$
0.8	2.46	0.06	-0.7, data
1.2	1.52	0.06	-0.9, “Bonn calc”
1.6	1.18	0.05	-0.3, “Bonn calc”
2.0	1.04	0.05	0 (?)
2.4	1.00	0.06	0 (?)

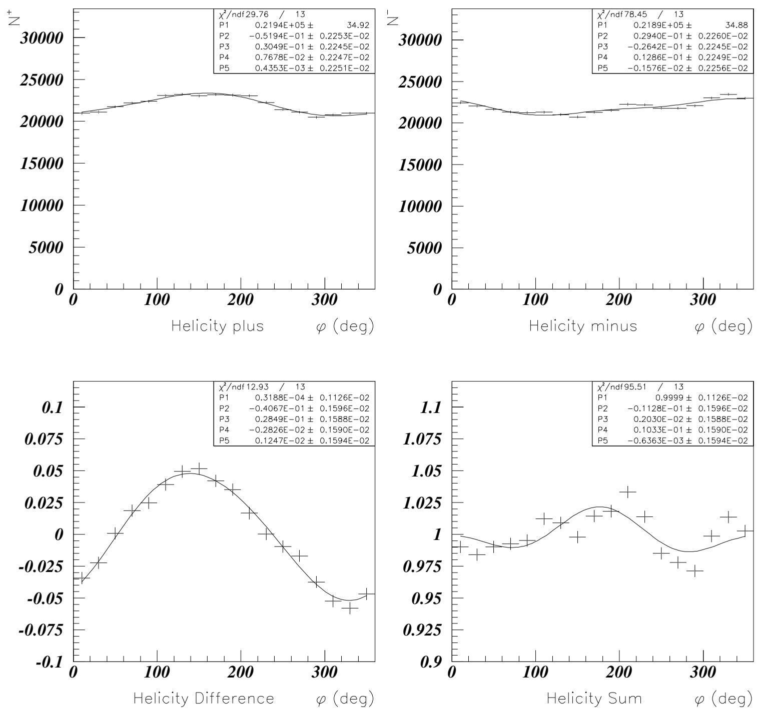

Figure 3: Azimuthal asymmetries from the polarimeter for elastic $\vec{e}p \rightarrow e'\vec{p}$. The summed spectrum in the lower right corner represents a measure of the **online** false asymmetry.

γd $\to$ pn

Monte Carlo Ingredients

- High energy Brem photons generated in Cu, Al, target.
- Generate proton in spectrometer angle acceptence. Two body kinematics give p_p.
- θ resolution from:
  - width of Brem cone
  - multiple scattering of proton in target
  - spectrometer – Ti window m.s. dominated, ~ 3 mr σ for 1 GeV/c electron
  - ϕ, vertical angle, corrections ignored
- Δp/p resolution from:
  - vertical width of photon spot at target, 10^{-3}/mm
  - straggling of proton in target - also leads to offset
  - intrinsic spectrometer resolution
- Recalculate photon energy from observed θ_p, p_p with two body kinematics, compare to correct energy.

Monte Carlo results

The energy separation of π^0 creation events from Brem threshhold is:

- 50 – 60 MeV in outgoing proton kinetic energy, or
- 3 – 10 % in proton momentum, or
- $\sim$140 MeV in reconstructed incident photon energy.

E_γ reconstruction for 0.8 GeV beam.
resolution (σ, in MeV)

Δp/p	$\Delta\theta_{\rm sp} = 0.01°$	$\Delta\theta_{\rm sp} = 0.2°$
10^{-5}	1.37	2.49
10^{-3}	1.95	2.86
2×10^{-3}	3.18	3.81
5×10^{-3}	7.08	7.39

E_γ reconstruction for 2.4 GeV beam.
resolution (σ, in MeV)

Δp/p	$\Delta\theta_{\rm sp} = 0.01°$	$\Delta\theta_{\rm sp} = 0.1°$
10^{-5}	2.42	6.65
10^{-3}	5.16	8.08
2×10^{-3}	9.45	11.33

Summary

Confirmation of apparent scaling at 90°
in E89-012 measurements
necessitates spin measurements
to provide direct test of underlying mechanisms
$+$
hall A + polarimeter commissioning
$\rightarrow$
request for priority upgrade
so E89-019 can be run in a timely manner