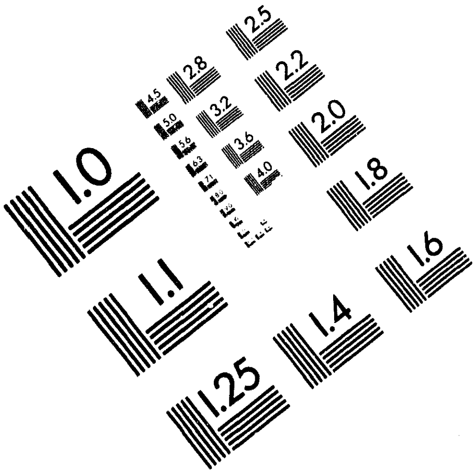


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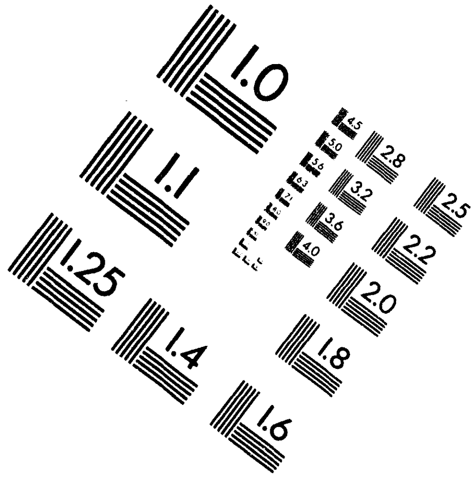


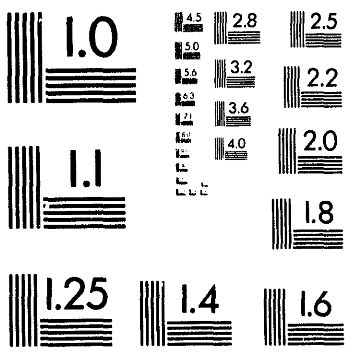

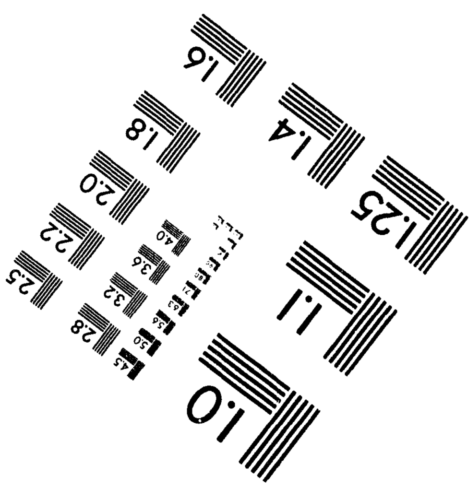

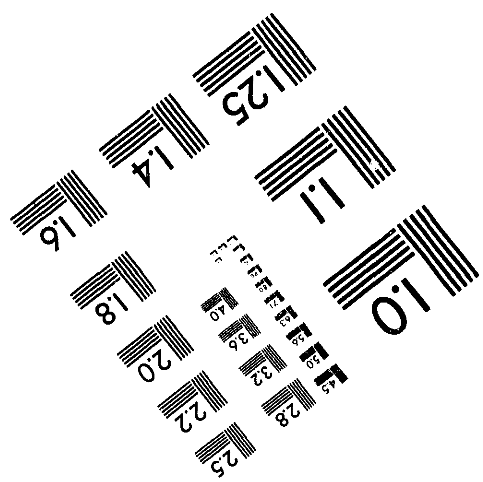

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# DEUTERON PHOTO-DISINTEGRATION AT LARGE ENERGIES

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ABSTRACT

Current proposals at CEBAF include the measurement of cross sections and polarization observables of exclusive photo-reactions such as deuteron photo-disintegration and pion photo-production from nucleons. At issue is the applicability of traditional meson-exchange models versus quark models of these reactions at photon energies of several GeV. Beam energies above 4 GeV at CEBAF could make possible the measurement of these reactions over a kinematic range sufficiently broad to distinguish between the models. Estimates of counting rates for a Hall-C experiment to measure the $\gamma d \rightarrow pn$ cross section are presented.

## 1. Introduction

One of the current issues in nuclear physics is whether quark degrees of freedom become apparent in high energy nuclear reactions. Evidence for such degrees of freedom would be the onset of asymptotic scaling[1,2] in the cross section, and the conservation of hadron helicity[3]. To date, studies have focused on photo-reactions in the few-body systems, where stringent tests of our understanding of short-range nuclear dynamics should be possible[4]. Currently, no polarization data for high energy photo-reactions exist—experiments at high energy have been confined to cross section measurements.

Asymptotic scaling predicts that the differential cross section $d\sigma/dt$ should obey the constituent counting rule[5], in which $d\sigma/dt$ scales with energy as $1/s^{n-2}$, in which $s$ is the square of the center-of-mass energy and n is the total number of point-like constituents involved in both the initial and final states of the reaction. Such scaling has been observed in reactions such as high-energy nucleon-nucleon scattering[6], pion photo-production from protons, and the electromagnetic form factors of the pion, proton and nucleon, but little data exist for photo-reactions involving nuclei. Recently, cross sections were measured at SLAC for the $\gamma d \rightarrow pn$ reaction for photon energies from $1.5 - 2.8$ GeV and center-of-mass scattering angles from $37 - 90°$. The counting rule predicts that the cross section will have the form:

$$\frac{d\sigma}{dt} = \frac{h(\theta_{cm})}{s^{11}} \tag{1}$$

where $h(\theta_{cm})$ can only be determined through more detailed modeling of the dynamics. The data shown in figure 1 seem to agree with this prediction at $\theta_{cm} = 90°$ and $53°$, but disagree at $37°$.

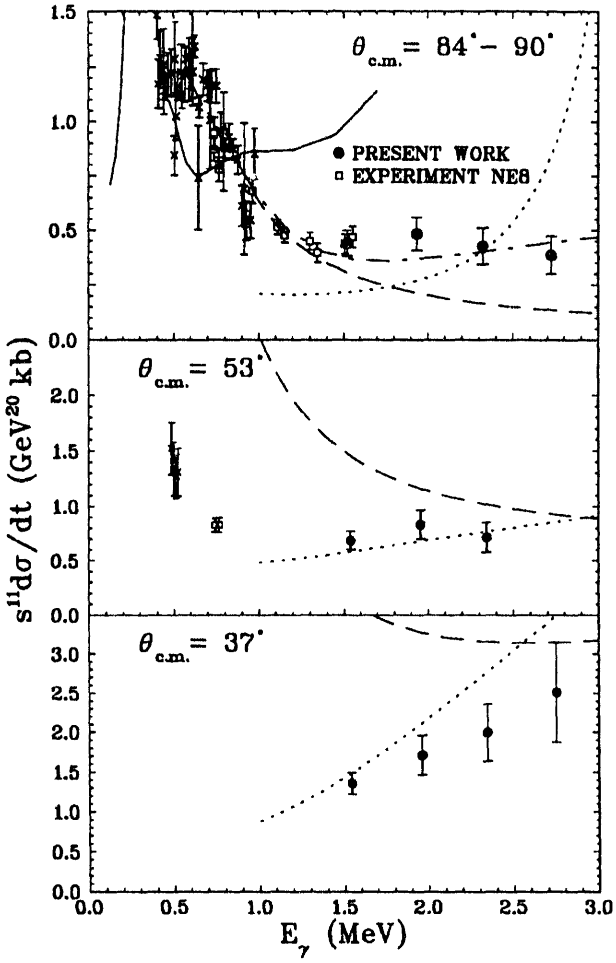


Figure 1: $s^{11}d\sigma/dt$ vs. $s$, for: (a) $\theta_{\rm cm} = 90°$, (b) $\theta_{\rm cm} = 53°$, (c) $\theta_{\rm cm} = 37°$. Results from SLAC experiment NE17 are plotted as diamonds, and earlier data are plotted as open circles. The dashed curves represent the reduced nuclear amplitudes analysis, as discussed in the text.

In general, it is expected that asymptotic scaling requires large values for all the Mandelstam variables $s$, $t$, and $u$. The 37° data correspond to momentum transfers of less that 1 GeV$^2$ to the outgoing neutron, and this may be too low to be in the scaling regime. The data at all angles is consistent with a threshold in the observance of scaling around momentum transfers of 1 GeV$^2$. In this case, scaling at $\theta_{cm} = 37°$ would have an onset at photon energies of around 3 GeV.

Besides the constituent counting rule, the reduced nuclear amplitude analysis[7] (RNA) may apply to deuteron photo-disintegration. This analysis, based on perturbative QCD (pQCD), successfully describes elastic $e-d$ scattering[8] at small $s$ where the counting rule breaks down. The RNA analysis factors out the proton and neutron form factors to describe the reaction in terms of a simpler, 'reduced' reaction involving point-like objects. When applied to deuteron photo-disintegration, one has:

$$\frac{d\sigma}{d\Omega_{\rm cm}} = \frac{1}{[s(s-m_d{}^2)]^{1/2}} F_p^2(t_p) F_n^2(t_n) \frac{1}{p_T^2} f^2(\theta_{cm}) \tag{2}$$

where the $F_N(t)$ are the nucleon form factors, $t_i = (p_i - p_d/2)^2$ is the momentum transfer to the nucleon, $p_T$ is the transverse momentum in the center-of-mass, and $f(\theta_{cm})$ is the 'reduced nuclear amplitude.' This formulation is expected to work better than constituent counting at small $s$ since soft components are removed by dividing out the nucleon form factors.

The dashed curves in figure 1 represent the RNA prediction for the energy dependence of the cross section. The reduced amplitude $f(\theta_{cm})$ is difficult to calculate[7]; a value was chosen for $\theta_{cm} = 90°$ that agrees with a data point at $E_\gamma = 800$ MeV. This curve falls below the data at higher energies, and does not reach an asymptotic limit. For purposes of comparison, we have plotted the RNA curve for $\theta = 53°$ and $37°$, using the same value of $f$. These curves show a more rapid decrease in the cross section with photon energy than is consistent with the data, and additionally lie above the data in the energy range studied. This conflicts with the expected forward and backward peaking expected of the reduced nuclear amplitude[7].

The solid curve in figure 1a represents the meson-exchange based calculation of Lee, *et al.*[9] The calculation agrees well with data below 500 MeV, but disagrees with the data above $E_\gamma = 1$ GeV in both energy and angular dependence. (At the forward angles the calculation is off scale.) Y. Kang, *et al.*[10] have calculated the cross section for $\theta_{cm} = 90°$ and $E_\gamma < 1.5$ GeV using a meson-exchange model with a larger number of resonances to achieve better agreement with the data over this energy range. The large number of nucleon resonances makes the extension of these models to higher energies problematic.

The agreement at 90° with the counting rule is not conclusive evidence of the onset of pQCD. The energy dependence is also consistent with the asymptotic amplitude calculations of Nagornyĭ *et al.*[11], (shown in figure 1 as a dot-dashed curve), which are based only on meson and baryon degrees of freedom. Kondratyuk *et al.*[12] have applied a quark-gluon string model and Regge phenomenology to obtain scaling-like behavior over a limited range of $s$, (shown if figure 1 as a dotted curve), although there is strong disagreement with the highest energy data.

## 2. CEBAF Experiments

Further insight into this matter can be achieved at CEBAF through measurements of these cross sections at higher energies and with better statistics than were possible at SLAC. The experimental technique is substantially the same. A bremsstrahlung photon beam is created by passing the CEBAF electron beam through a removable copper radiator immediately upstream of a cryogenic deuterium target, as shown in figure 2. Protons from the $\gamma d \to pn$ reactions are detected in one of the hall-C spectrometers. The photon's energy and center-of-mass scattering angle can be calculated from the proton's energy and angle, assuming the proton originated in the $\gamma d \to pn$

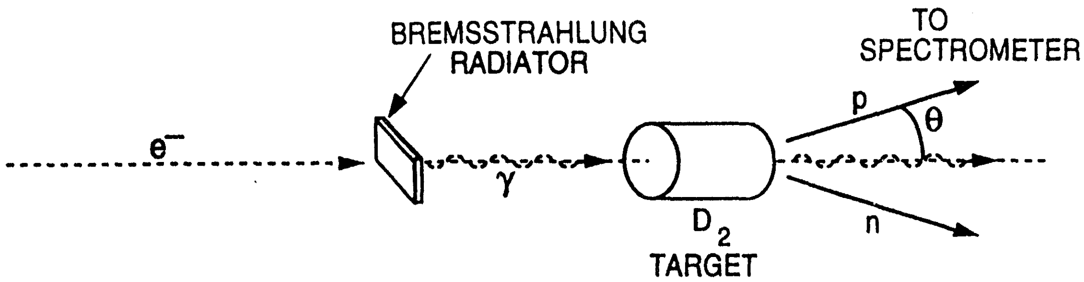


Figure 2: Experimental method for measuring the $\gamma d \rightarrow pn$ cross section.

reaction. Only protons near the bremsstrahlung endpoint are accepted, to remain above the pion-production threshold. Background from the aluminum target walls is eliminated by subtracting measurements with an identical target cell filled with hydrogen. Electro-disintegration background from the electron beam passing through the target is eliminated by subtracting measurements with the radiator removed from measurements with it inserted. Absolute cross sections are obtained from the scattering rate using the bremsstrahlung yield calculated by numerically integrating the thick-target equations of Matthews and Owens.

Estimates for the running time of an experiment in hall-C can be extrapolated from the experience of NE17. In the following, we use a cross section model with $s^{-11}$ energy dependence, and calculate the time needed for a cross section measurement with 10% statistical accuracy. The calculation assumes a 15 cm long target, a 6% radiation lengths thick Cu radiator, and a 6.5 msr solid angle for the HMS spectrometer. The beam current is limited to 30$\mu$A by the allowable radiation level in hall-C. Two hours are allowed for changing beam energies, and a 50% efficiency is assumed for running the experiment. Table 1 lists the kinematic settings, and time required for measurements for $\theta_{cm} = 37°$, 53°, and 90°, and photon energies from 2 – 6 GeV in 1 GeV steps. The total time is the sum of the beam times plus the time for energy change, all divided by the efficiency.

## 3. Conclusions

The time estimates show that measurements to 6 GeV at all three angles would be possible with the existing hall-C equipment, but would require a very large time to complete. However, the forward angle measurements take substantially less time because the cross section is larger—for example, the total time for the 6 GeV, 37° point is only 176 hours. Experiment 89-012 is approved to make cross-section measurements to 4 GeV at these angles. It thus appears feasible to extend these measurements to

Table 1: Running time estimates for $\gamma d \to pn$ cross section measurement.

| $E_{beam}$ (GeV) | $\theta_{cm}$ (deg) | $\theta_{lab}$ (deg) | $P_{spec}$ (GeV) | Beam time (min) | Total time (hr) |
|---|---|---|---|---|---|
| 2.0 | 37 | 19.9 | 2.41 | 1.3 | |
| | 53 | 29.2 | 2.24 | 1.5 | |
| | 90 | 53.9 | 1.70 | 5.0 | 4.3 |
| 3.0 | 37 | 17.5 | 3.35 | 26.2 | |
| | 53 | 25.8 | 3.09 | 30.7 | |
| | 90 | 48.2 | 2.26 | 107.4 | 10 |
| 4.0 | 37 | 15.8 | 4.27 | 165.4 | |
| | 53 | 23.4 | 3.92 | 190.7 | |
| | 90 | 44.1 | 2.81 | 710.1 | 40 |
| 5.0 | 37 | 14.5 | 5.19 | 1044 | |
| | 53 | 21.5 | 4.74 | 1219 | |
| | 90 | 40.9 | 3.34 | 4962 | 245 |
| 6.0 | 37 | 13.6 | 6.11 | 5148 | |
| | 53 | 20.1 | 5.57 | 6183 | |
| | 90 | 38.3 | 3.87 | 24045 | 1183 |

5 GeV at all angles, and 6 GeV at $\theta_{cm} = 37°$, using a higher energy beam at CEBAF. Such measurements should extend well into the scaling regime at all angles, and provide a sensitive test of our understanding of short-range forces and quark degrees of freedom in few-body systems.

## 4. Acknowlegements

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## 5. References

1. V. A. Matveev, R. M. Muradyan, A. N. Tavkhelidze, *Lett. Nuovo Cimento* **7** (1973) 719.
2. S. Brodsky and G. Farrar, *Phys. Rev. Lett.* **31** (1973) 1153.
3. S. J. Brodsky and G. P. Lepage, *Nucl. Phys.* **A353** (1981) 247c.
4. R. J. Holt, *Phys. Rev.* **C41** (1990) 2400.
5. R. L. Anderson *et al.*, *Phys. Rev.* **D14** (1976) 679.
6. J. Ralston and B. Pire, *Phys. Rev. Lett.* **49** (1982) 1605.
7. S. J. Brodsky and J. R. Hiller, *Phys. Rev.* **C28** (1983) 475.
8. S. J. Brodsky and B. T. Chertok, *Phys. Rev.* **D14** (1976) 3003.

9. T.-S. H. Lee, Argonne National Laboratory report PHY-5253-TH-88; T.-S. H. Lee, in *Proceedings of the International Conference on Medium and High Energy Nuclear Physics, May 23-27, 1988, Taipei, Taiwan* (World Scientific, 1988) 563.
10. Y. Kang, P. Erbs, W. Pfeil, H. Rollnik, *Abstracts of the Particle and Nuclear Intersections Conference, MIT* (Cambridge MA, 1990) I-40; W. Pfeil, private communication.
11. S. I. Nagornyĭ, Yu. A. Kasatkin, and I. K. Kirichenko, *Sov. J. Nucl. Phys.* **55** (1992) 189.
12. L. A. Kondratyuk *et al.*, *Phys. Rev.* **C48** (1993) 2491.

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