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PHOTODISINTEGRATION OF THE DEUTERON AT HIGH ENERGY

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R. J. Holt
Physics Division, Argonne National Laboratory
Argonne, IL 60439-4843 USA

ABSTRACT

Measurements of the angular distribution for the $\gamma d \to pn$ reaction were performed at SLAC for photon energies between 0.7 and 1.8 GeV (experiment NE8) and between 1.6 and 4.4 GeV (experiment NE17). The final results for experiment NE8 will be presented, but only preliminary results for NE17 will be discussed. The data at $\theta_{cm} = 90°$ appear to follow the constituent counting rules. The angular distribution at high photon energies exhibit large values of the cross section at forward angles. There is evidence that the cross section may also be large at backward angles and high energies.

1. Introduction

Measurements of two-body photodisintegration of the deuteron were extended into the multi-GeV range in order to test the conventional as well as the QCD-based models of the process. Two calculations[1,2] based on the meson-exchange model were performed in the GeV region: Y. Kang *et al.*[1] included all of the $J \lesssim 5/2$ nucleon resonances, and T.-S. H. Lee[2] included only several of the resonances. In addition, both the constituent counting rules[3] and the reduced nuclear amplitude analysis[4] may apply to this exclusive process in this energy region. The results will be discussed within the framework of these models.

The results above a photon energy of 2 GeV are particularly interesting, since exclusive photo-processes on the proton appear[5] to scale according to the constituent counting rules. While these rules appear to work for the nucleon and for nucleon-nucleon scattering[6], there is not a good test[7] of the constituent counting rules for processes involving nuclei. Further, the reduced amplitude analysis has been sufficiently tested[8] only for electron-deuteron elastic scattering and there is no information for other reaction processes. While the meson-exchange models[2,9] describe the data rather well for the $\gamma d \to pn$ reaction below 1 GeV, the success of these models above 1 GeV has met with mixed results. The new data will not only provide a stringent test of these models, but give us a better understanding of nuclear photodisintegration processes in the GeV region.

2. Experiment

The Nuclear Physics Injector at SLAC was employed to perform both experiments NE8 and NE17. A schematic diagram of the experiment is illustrated in Fig. 1. The electron beam from SLAC in the energy range from 0.8 to 1.8 GeV for experiment NE8, and 1.6 to 4.2 GeV for NE17, was directed into a Cu radiator (4 or 6% radiation length). The bremsstrahlung photons from this process then irradiated a 15-cm long LD_2 target. The photoprotons from the $\gamma d \to pn$ reaction were analyzed and detected in the 1.6-GeV spectrometer in NE8 and the 8-GeV spectrometer in experiment NE17.

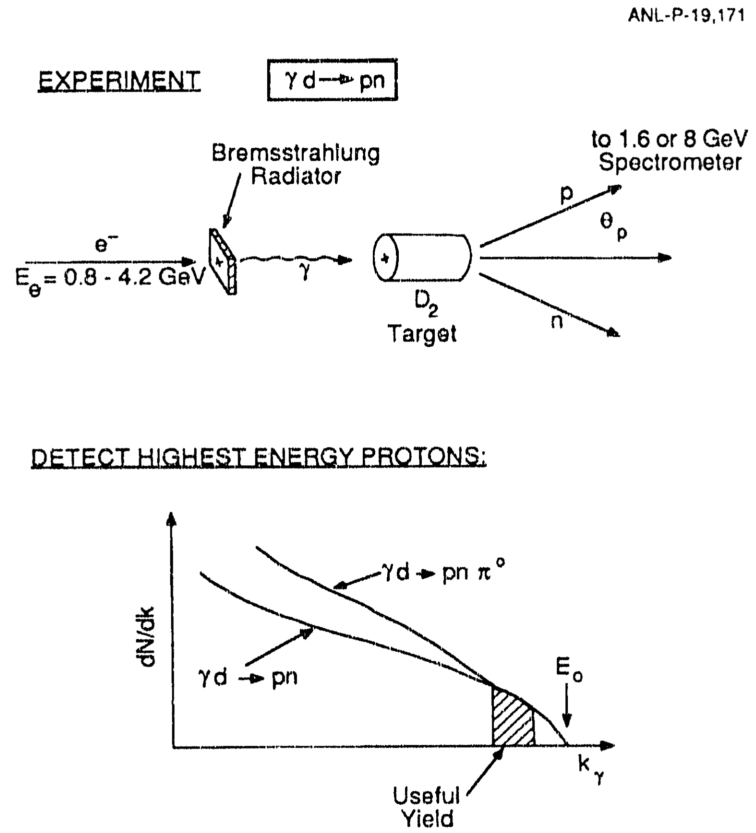

Fig. 1. Schematic diagram of the $\gamma d \to pn$ experiment performed at SLAC.

The key to the method was to observe only the highest energy photoprotons in the spectrometer so that protons produced in other reaction processes, *e.g.* $\gamma d \to pn\pi^0$, were eliminated. This procedure ensured that only the two-nucleon process was observed. The acceptances of the spectrometers were calibrated with respect to the well-known electron-proton elastic cross section. This analysis procedure is still in progress for the NE17 data which used the 8-GeV spectrometer in the large solid angle tune. For this reason, only the NE8 data will be recorded here.

The results from experiment NE8 at a reaction angle of 90°, 114°, and 143° are shown as the darkened points in Fig. 2 and compared with previous data as well as a meson-exchange calculation by T.-S. H. Lee[2]. The disagreement with the meson-exchange model prompted us to consider other energy dependences, for example that expected from constituent counting rules and the reduced nuclear amplitude analysis.

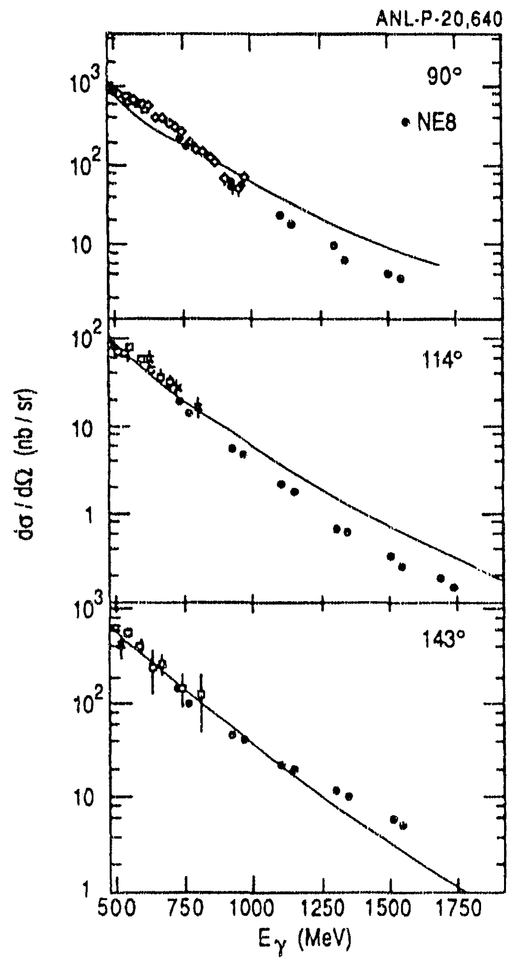

Fig. 2. Cross sections from experiment NE8 at SLAC for the $\gamma d \to pn$ reaction are given by the solid points, the remaining data are from Ref. 10. The solid curves are predictions of T.-S. H. Lee.

A meson-exchange calculation by the Bonn group was presented at the PANIC 90 meeting and these results are shown in Fig. 3 for 90°. In this calculation, Y. Kang *et al.*[1] included all nucleon resonances with spin $\lesssim$ 5/2. This very ambitious approach agrees better with the data as shown in the figure. One concern regarding this calculation is that the πNN cutoff was changed arbitrarily by 40% for photon energies above 700 MeV. This procedure can change the energy dependence remarkably and most likely accounts for the improved agreement with the energy dependence of the data. No present meson-exchange calculation can simultaneously explain the energy dependence of the cross section both above and below 1.0 GeV with a constant πNN cutoff.

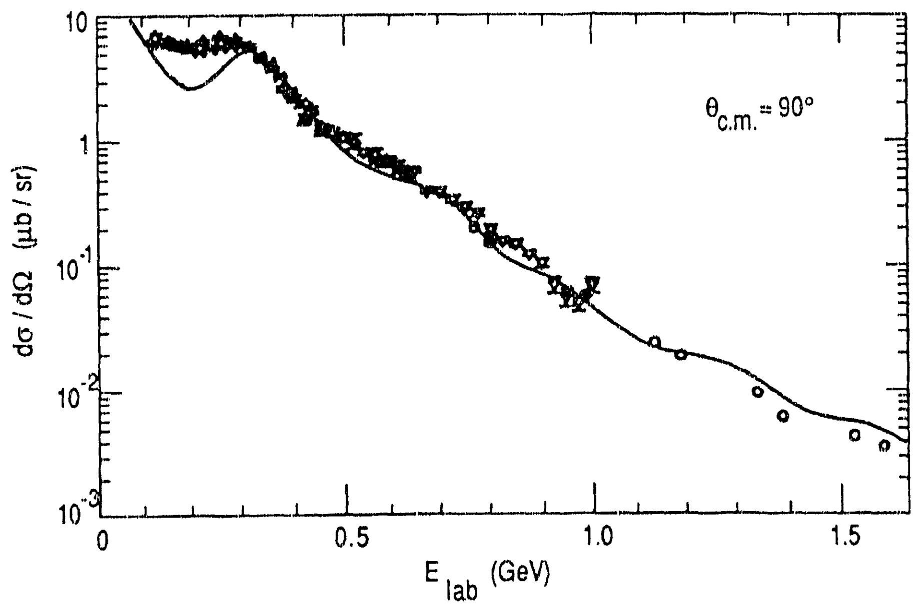

Fig. 3. The cross section for the $\gamma d \to pn$ reaction at $\theta_{cm} = 90°$. The open circles are from experiment NE8 at SLAC. The solid curves represents the meson-exchange calculation of Y. Kang *et al.* and it includes nucleon resonances up to J$\lesssim$5/2.

The application of the constituent counting rules has been very successful[11] in describing the high-momentum transfer results for electron elastic scattering from the pion and the nucleons. These results are well known and lend support to the claim that asymptotic scaling has been achieved. Although it is generally believed that the constituent counting rules can successfully describe the high momentum transfer results, there is disagreement regarding the underlying reason for their success. While S. Brodsky *et al.*[11] argue that asymptotic scaling has been observed, N. Isgur[12] contends that this apparent scaling behavior is not founded in perturbative QCD.

The constituent counting rules have met with great success in describing exclusive photoreactions for the proton at high photon energy. The most celebrated case[5] is found in the $\gamma p \to \pi^+ n$ reaction at $\theta_{cm} = 90°$. According to the constituent counting rules the differential cross section at a fixed center of mass angle is given by

$$\frac{d\sigma}{dt} \sim \frac{1}{s^{n-2}}$$

where s and t are the usual Mandelstam variables and n is the total number of constituents in the initial and final states.

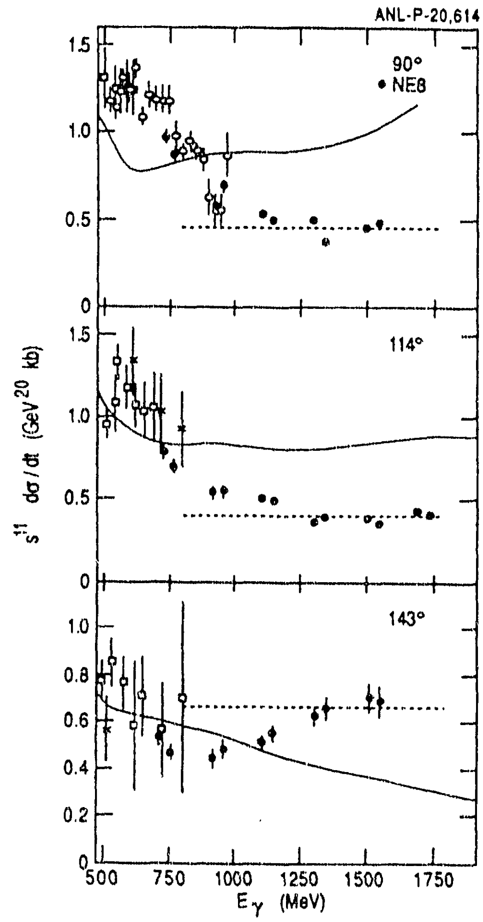

Fig. 4. $s^{11}d\sigma/dt$ for the $\gamma d \to pn$ reaction at $\theta_{cm} = 90°$, 114° and 143° as a function of photon energy. The energy dependence of the data at the highest energies is remarkably consistent with the s^{-11} dependence expected from the constituent counting rules (dotted curve). The solid curves are the meson-exchange calculations of T.-S. H. Lee.

It is not surprising that reactions involving only a single nucleon in the initial state can be described by quark degrees of freedom. However, for an initial state involving a nucleus it would be very surprising, since the quarks are believed to be confined to the hadrons and it would be very unlikely for all the quarks in the nucleus to occur in a very small region of the nucleus as implied by the constituent counting rules. Thus, it is very interesting to compare a photonuclear reaction to the asymptotic scaling prediction. These results for 90°, 114°, and 143° are plotted as $s^{11}\, d\sigma/dt$ as a function of E_γ in Fig. 4. At the highest energies the results are consistent with the expected $1/s^{11}$ dependence.

This is a very surprising result and at first appears to be at variance with the elastic electron-deuteron scattering data. After all, if we have not seen evidence for the onset of asymptotic scaling at $Q^2 = 4$ GeV^2 in e-d scattering, why do the data near a photon energy of 1.5 GeV appear to be consistent with asymptotic scaling? The main problem is how to compare the two experiments on the same scale. The important scale is the momentum transferred to the individual quarks in the two reactions. For a matter of simplicity we will consider only the momentum transferred to the nucleons in the deuteron in the two cases. In the case of e-d scattering the average momentum transfer to a nucleon in the deuteron is just $(Q/2)^2$. It turns out that the magnitude of the momentum transfer[13] to a nucleon in the deuteron in the photo-disintegration process is approximately $2m_dT_d$. For the same momentum transfer to a nucleon in e-d scattering at $Q^2 = 4$ (GeV/c)^2, the corresponding photon energy is 1.1 GeV in the photodisintegration process. Thus, the fact that the photodisintegration data are consistent with asymptotic scaling above a photon energy of 1.3 GeV is not inconsistent with existing electron-deuteron scattering data.

The main problem with making a strong conclusion regarding a consistency with the constituent counting rules is that the s-range of the consistency with the rules is rather small and one of the main motivations for experiment NE17. Preliminary results from experiment NE17 go up to $E_\gamma = 2.8$ GeV at $\theta_{cm} = 90°$ and appear to follow the s^{-11} dependence.

Brodsky and Chertok[8] proposed that one could better see the onset of scaling in electron scattering from nuclei if the nucleon form factors were first removed from the cross section data. This approach represents a significant departure from conventional models of electron scattering. In the conventional picture the scattering amplitude for the impulse approximation depends on the product of the nucleon form factor and the body form factor of the nucleus. However, in the reduced nuclear amplitude model the scattering amplitude depends on the product of the nucleon form factors for each nucleon in the nucleus. This factorization has been shown to be valid in the limit that the nucleons are unbound, and it is argued that at very high momentum and energy transfers that binding effects are small.

Brodsky and Hiller[4] first applied the reduced nuclear amplitude analysis to two-body photodisintegration of the deuteron. At that time the highest energy data were at a photon energy of 1 GeV. The prediction for the differential cross section from this model is given by

$$\frac{d\sigma}{d\Omega} = \frac{1}{[s(s-M_d^2)]^{1/2}} F_p^2(t_p)\, F_n^2(t_n)\, f^2(\theta_{cm}) / p_T^2 \qquad (1)$$

where the F_i are the nucleon form factors, $t_i = (p_i - p_d)^2$, and p_T is the transverse momentum.

Here $f(\theta)$ is the reduced nuclear amplitude that is expected to have no energy dependence where this model is valid. The results for $f^2(\theta)$ from experiment NE8 are given in Fig. 5. At an angle of 90° and 114° the data do not show a strong energy dependence for $f(\theta)$ at photon

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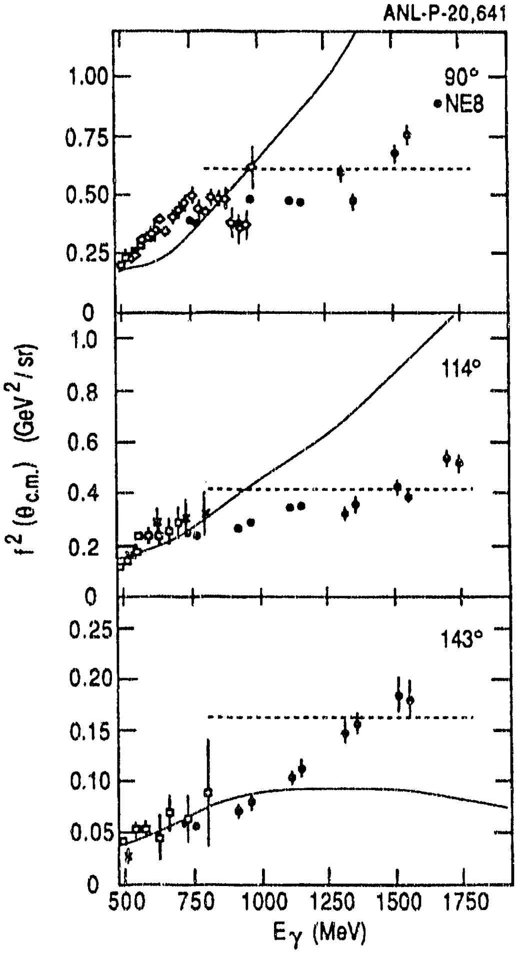

Fig. 5. The reduced nuclear amplitude $f^2(\theta)$ for the $\gamma d \rightarrow pn$ reaction at angles of θ_{cm} = 90°, 114° and 143° as a function of photon energy. The energy dependence appears to be in reasonable agreement with that expected by Brodsky and Hiller. The solid curves are the same calculations as those of Fig. 4.

energies above 1 GeV. However, the results at 143° are in worse agreement with the model. Again, it is essential to extend these measurements to higher energy as a more stringent test of the model.

A new meson-exchange calculation by Lee and Coester[14] is based on light-front dynamics. This calculation can explain some of the backward enhancement, however, an arbitrary inelasticity must be added to the final state interaction for this purpose.

3. Summary

Presently, it appears that the energy dependence of the cross section, $d\sigma/dt$, follows the constituent counting rules at $\theta_{cm} = 90°$, but at smaller angles falls off more slowly than constituent counting. The angular distribution is very forward peaked at high energy, but there is almost no data for large angles. The complete angular distribution at high energy should be measured[15] at SLAC or CEBAF to confirm the suggestion of forward and backward enhancement of the cross section.

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