Two Body Photodisintegration of the Deuteron up to 2.8 GeV

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Abstract

Measurements were performed for the photodisintegration cross section of the deuteron for photon energies from 1.6 GeV to 2.8 GeV and center-of-mass angles from 37° to 90°. The measured cross section at at $\theta_{cm} = 90°$ are in agreement with the constituent counting rules.

INTRODUCTION

The search for clear signatures of quarks in nuclei is of central importance in nuclear physics, and any experimental evidence of quarks in nuclei is vital to our understanding of nuclear physics in the intermediate energy region, that is at energies of roughly 1-5 GeV. Below 1 GeV, the description of nuclear reactions in terms the meson exchange model has been quite successful. At large energies ($E \gg 1$ GeV) and momentum transfers we expect a transition to asymptotic rules of perturbative QCD, in which hadrons are described in terms of constituent quarks. In the intermediate energy region, however, the role QCD is still unclear. Explicit calculations of cross sections for exclusive reactions have only recently become feasible, while meson exchange calculations in the few GeV region are difficult because of the large number of heavy resonances that can contribute and the need to include relativistic effects.

Intermediate energy data on exclusive reactions involving the deuteron have been available for some time. Measurements of the elastic electron scattering from a deuteron target were performed at SLAC at four momentum transfers up to $4\,(\mathrm{GeV/c})^2$[1]. The electric and magnetic form factor describing unpolarized scattering are well described out to the highest Q^2 by a fully relativistic calculations using a standard NN-interaction[1].

The success of the two nucleon description of elastic scattering from the deuteron, and the lack of any evidence for the quark substructure of the nucleons composing the deuteron even at momentum transfers as high as $4\,(\mathrm{GeV/c})^2$ is not surprising if one considers the square of the average momentum transfer to a nucleon in the deuteron[1], $\hat{t}_{\mathrm{N}}^{\mathrm{ed}} \equiv (P_{\mathrm{d}}'/2 - P_{\mathrm{d}}/2)^2 = -Q^2/4$, which always remains less the $1\,(\mathrm{GeV/c})^2$. The momentum transfer to a nucleon in the $^2\mathrm{H}(\gamma,\mathrm{p})\mathrm{n}$ reaction is given by $\hat{t}_{\mathrm{N}}^{\gamma\mathrm{d}} \equiv (P_{\mathrm{N}} - \frac{1}{2}P_{\mathrm{d}})^2$; for CM angles of 90 degrees, even at modest incident photon energies, there is relatively large momentum transfer to the nucleons in comparison with elastic electron scattering. With the assumption that large momentum transfers to nucleons in the nucleus is paramount to the observation of their quarks substructure, the importance of exclusive photoreactions is clear: The photon imparts all of its four momentum to the nucleons, and measurements at relatively large momentum transfers can be made before the cross section becomes prohibitively small, as it does in electron scattering studies.

If indeed the asymptotic region is reached, the $\gamma d \rightarrow np$ reaction should follow the dimensional scaling law[2]:

$$\frac{d\sigma}{dt} \propto s^{-11}. \tag{1}$$

Nonetheless, it is not yet known at what energy pQCD is strictly valid. In pion photoproduction, proton-proton elastic scattering and elastic electron-nucleon scattering, the scaling limit is apparently reached at energies of only a few times the mass of the hadrons involved.

Brodsky and Hiller[5] reported a variation of this scaling model, the reduced nuclear amplitude (RNA) approach, in which nucleon form factors are divided out of the amplitude, thereby factoring out the soft physics responsible for the binding of the quarks within the nucleons. The approach has been applied successfully to elastic *e-d* scattering, producing scaling at momentum transfers as low as $1\,(\mathrm{GeV/c})^2$[6].

EXPERIMENT

The present experiment was performed in end-station A at the Stanford Linear Accelerator Center, using a technique similar to that of earlier work [7]. Electron beams from the NPI injector were accelerated to energies from 1.6 to 2.8 GeV and passed through a removable copper radiator 0.086 cm thick to produce a beam of bremsstrahlung photons. The uncollimated photons and remaining electron beam then passed through a 15 cm long cryogenic liquid deuterium target. Charged particles from the target were detected in the spectrometer by an array of plastic scintillators and a set of ten wire chambers. Protons were identified with a time-of-flight system. Contributions from

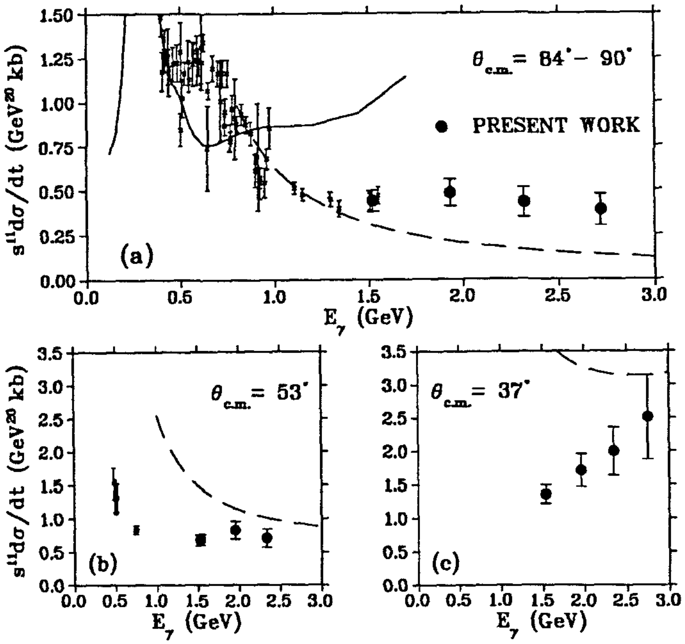

Figure 1: The measured $^2H(\gamma,p)n$ cross sections. The curves are discussed in the text.

the target windows were removed by subtracting the results obtained with a ^1H filled dummy target. The procedure was repeated without the radiator present, thereby measuring the yield from electrodisintegration. This subtraction of the electrodisintegration yield was done with an energy-dependent weighting function to account for the modification of the electron beam's flux and energy distribution by the radiator. Finally, events with pion production were removed by only accepting the photoprotons with the highest momenta.

RESULTS

It is convenient to discuss the results in terms of the quantity $s^{11}d\sigma/dt$, which should approach a constant value at fixed θ_{cm} according to the constituent counting rules. This quantity is plotted versus E_γ in fig. 1a for the $\theta_{cm} = 90°$ data, along with lower energy measurements[10]. The data are consistent with the scaling behavior suggested by the previous measurements [7] above $E_\gamma = 1.0\,\text{GeV}$. Fitting the available 90 degree data above $E_\gamma = 1.15\,\text{GeV}$ with the form $d\sigma/dt \propto 1/s^n$ yields $n = 11.2 \pm 0.2$, in good agreement with the counting rules. The dashed line in fig. 1a is the RNA analysis, normalized to a data point at $E_\gamma = 0.8\,\text{GeV}$. This curve falls below the high E_γ data, and does not reach an asymptotic limit at these energies. The solid line is a standard meson-exchange calculation[8] and disagrees with both the energy and angular dependence. At the other two angles the calculation is off-scale.

The data at $\theta_{cm} = 53°$, shown in fig. 1b, are also consistent with the asymptotic scaling law. With the NE8[7] data at $E_\gamma = 0.74\,\mathrm{GeV}$ included, a fit to the scaling behavior gives $n = 11.3 \pm 0.2$. The dashed line represents the RNA calculation with the same normalization as the 90 degree data.

At $\theta_{cm} = 37°$ the quantity $s^{11}d\sigma/dt$ is a rising function of energy (fig. 1c), and a fit to the scaling behavior gives $n = 9.5 \pm 0.4$. The 37° data all correspond to momentum transfers of less than 1 $(\mathrm{GeV/c})^2$ to the outgoing neutron. The lack of scaling behavior here is consistent with a threshold in the applicability of scaling behavior around momentum transfers of 1 $(\mathrm{GeV/c})^2$.

The results reported here demonstrate that at $\theta_{cm} = 90°$ the cross section for the process $\gamma d \rightarrow pn$ is in good agreement with the constituent counting rule predictions for incident photon energy greater than 1.5 GeV. This is qualitatively similar to measurements of other electromagnetic processes on elementary systems at energies of several GeV. Nevertheless, this observed agreement with the constituent counting rules may not be evidence of the onset of pQCD[11]. Further insight into this question may be obtained with cross section measurements at higher energy and from measurements of polarization observables in this reaction[12].

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