

# SPIN MEASUREMENTS IN HIGH $-t$ EXCLUSIVE PHOTOREACTIONS

R. GILMAN

*Rutgers University Dept. Physics & Astronomy,  
Piscataway, NJ 08855, USA*

*and*

*Thomas Jefferson National Accelerator Facility,  
Newport News, VA 23606, USA*

*E-mail: gilman@jlab.org*

The approximate validity of the constituent counting rules to few GeV photoreactions has been known for many years. It is now generally accepted that perturbative QCD, which leads to these rules, cannot be applicable in this low energy and momentum transfer regime. Cross section and polarization measurements now underway show promise to lead to the underlying physics. Initial experiments on deuteron photodisintegration and pion photoproduction are now in progress, and are expected to be followed by several other measurements.

## 1 Introduction

At beam energies above a few GeV and four momentum transfers  $-t > 1$  (GeV/c)<sup>2</sup>, cross sections<sup>1</sup> for several exclusive photoreactions demonstrate the approximate validity of the constituent counting rules (CCR). These rules can be derived from perturbative QCD<sup>2</sup>, but this explanation is not generally accepted<sup>3</sup>. One can identify two shortcomings with the existing data set.<sup>a</sup> First, the relatively poor precision of the cross section data are not sufficient to distinguish between the CCR and more recent quark-based models<sup>6,7</sup> that predict modest scaling violations. Second, no polarization data exist at high  $-t$ , and thus the related prediction of hadron helicity conservation is untested in these reactions.

More precise cross-section measurements, now possible at Jefferson Lab, can determine the power law scaling of the cross sections systematically as a function of angle. Polarization measurements are possible with the focal plane proton polarimeter in Hall A. The induced polarization  $P$  and the polarization transfer  $C_x$  measure the imaginary and real parts of interferences between helicity violating and helicity conserving amplitudes. If hadron helicity violation measures orbital angular momentum<sup>8</sup>, these data relate to the nucleon spin

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<sup>a</sup>Two recent high-quality Jefferson Lab measurements of the proton electric<sup>4</sup> and deuteron<sup>5</sup> form factors do not lead to an unambiguous interpretation, as the deuteron form factor follows asymptotic predictions, while the proton form factor does not, at similar momentum transfer.

problem. Spin measurements are generally helpful to determine the reaction mechanism, as they are sensitive to small reaction amplitudes.

In the following sections, we will review the experiments underway and some of the expected future experimental efforts.

## 2 Deuteron Photodisintegration

Several experimental measurements of deuteron photodisintegration at SLAC and at Jefferson Lab have shown the applicability of the CCR at large scattering angles. These data<sup>9,10</sup> are compared in Fig. 1, taken from<sup>9</sup>, to several theories. Multiplying the cross sections by  $s^{11}$  removes the asymptotic energy dependence expected from pQCD. The agreement at  $90_{cm}^\circ$  is better than one would expect, given that phase space factors should not be negligible in this kinematic regime. The reduced nuclear amplitude analysis<sup>11,12</sup> (RNA), given by Eq. (1), is shown as the long dashed line.

$$\frac{d\sigma}{d\Omega_{cm}} \propto \frac{1}{s - m_d^2} F_p^2(\hat{t}_p) F_n^2(\hat{t}_n) \frac{1}{p_T^2} f^2(\theta_{cm}) \quad (1)$$

This approach can be viewed as an attempt to extend the validity of the CCR to lower energies and momentum transfers by including various expected kinematic and form factors.

The quark gluon string model<sup>13</sup>, given as the dashed - dotted line, is in reasonable agreement with the forward angles. However, this calculation is based on Regge theory and is not expected to be valid at large angles.

Earlier meson-exchange calculations<sup>14</sup>, shown as a solid line, do not fall as fast as the data at high energies. More recent asymptotic meson-exchange calculations<sup>15</sup>, shown as the dotted line, do agree reasonably with the  $90_{cm}^\circ$  data, as well as at other angles (not shown).

More recently, Radyushkin<sup>16</sup> has proposed a quark model which naturally explains the energy and angle dependence of the existing data. He proposes that the reaction proceeds largely via quark exchange between the two nucleons, with the photon coupling to one of the exchanged quarks, and the photon's momentum shared between the two by some short-distance mechanism, such as gluon exchange. Coupling to a quark within the nucleon is suppressed because high-momentum components of the wave function are small. Preferentially the two quarks are different, e.g., one u and one d quark, since quarks of the same charge would lead to cancellations. In this picture, the energy and angle dependence of the amplitude arise largely from the transition form factors of  $p \leftrightarrow n$ , as the hard short-distance process should have a relatively slow angle and energy dependence. Assuming these transition form factors are like

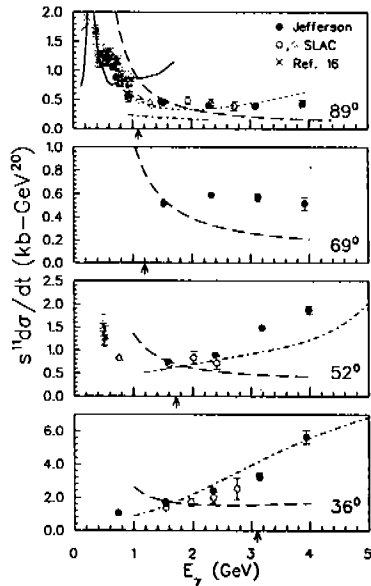


Figure 1: Deuteron photodisintegration data compared to several theories, as described in the text.

the nucleon dipole form factor, and including phase space factors, the result obtained is similar to the RNA result, Eq. (1).

Three measurements are being performed at Jefferson Lab this year to further stress the predictions. Cross sections at energies above 4 GeV and at forward angles are being measured in Hall C<sup>17</sup>, while large angle cross sections at lower energies are being measured in Hall A<sup>18</sup>.

Fig. 2 compares existing data<sup>9</sup> to calculations. Radyushkin<sup>16</sup> predicts that the angular distribution is largely symmetric about  $90^\circ_{cm}$ . The curve was generated from an expression similar to that of Eq. (1), in which the  $1/p_T^2$  factor does not appear, the angle dependence was taken to be unity, and the absolute normalization was fit to the 1.6 GeV,  $90^\circ_{cm}$  data point. These slight differences reduce the energy and angle dependence, and allow the data to be well fitted, unlike in the RNA approach.

The asymptotic meson-exchange model<sup>15</sup> predicts an asymmetric angular distribution, as preferentially the photon couples to the proton, ejecting it in the forward direction. In the high-energy limit, assuming helicity conservation (hcon), coupling to the neutron is reduced, suppressing back-angle cross sections.

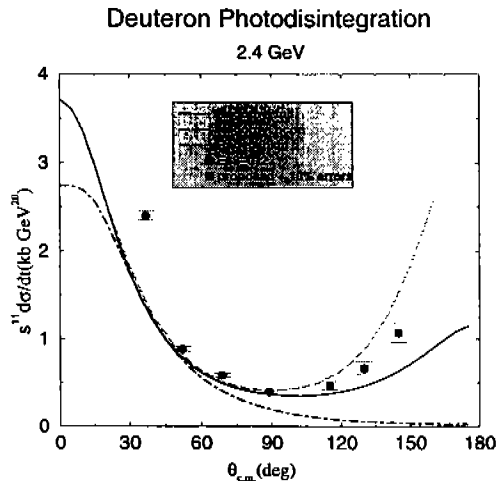


Figure 2: Comparison at one energy of cross-section predictions to existing data and planned measurements of E99-008; the curves are described in the text.

Further constraints on theories, including the first tests of helicity conservation, will be provided by experiment 89-019<sup>19</sup>. This experiment measures recoil proton polarizations for energies up to  $E_\gamma = 2.4$  GeV; the induced polarization  $P$  and the transverse polarization transfer  $C_x$  test helicity conservation, which requires both to vanish. In the case that one or both are nonzero, they provide a measure of whether the reaction amplitudes are largely real, as expected in most quark models, or have large imaginary parts, as one expects if there are resonance contributions. Lower-energy induced-polarization data<sup>20</sup> exist, and are shown in Fig. 3 compared to a Bonn calculation<sup>21</sup> and to the helicity conserving prediction,  $P = 0$ , generally assumed in quark models. In the Bonn meson-exchange calculations, the structures in the polarization result from the interference of the Born amplitude with the  $\Delta$  resonance, and with the  $D_{13}$  and  $D_{15}$  resonances near 1 GeV.

### 3 Pion Photoproduction

While deuteron photodisintegration provides a large momentum transfer at modest energy<sup>22</sup>, one naively expects that quark physics should be more evident in a simpler reaction involving fewer quarks, such as pion photoproduction. Cross sections in such reactions are known to approximately scale, but polarization data are sparse above 1 GeV and do not exist above the resonance

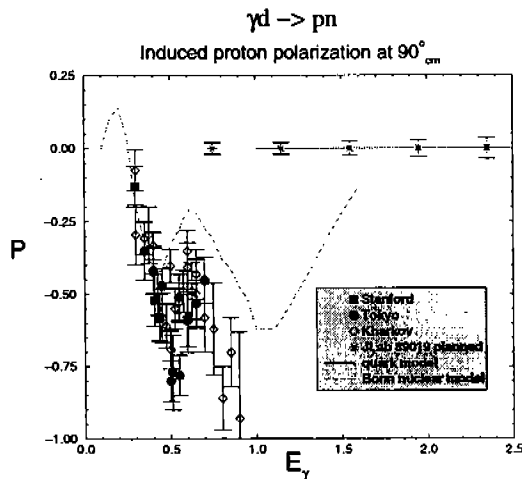


Figure 3: Induced polarization data for deuteron photodisintegration; the curves are described in the text.

region.

An example of this is shown in Fig. 4. The good agreement of the several data sets is evident, and the data are well fit up to about 1 GeV by the phase shift analysis of SAID<sup>23</sup>. Resonance structures are evident in the data. There is no indication in these data that the induced polarization vanishes at higher energies. While some high-energy induced polarization data exist, there are no polarization transfer data.

An experiment<sup>24</sup> will run this fall at Jefferson Lab to investigate the spin observables. The Hall A focal plane polarimeter will measure induced proton polarization and polarization transfer in neutral pion photoproduction from the proton. The experiment uses a circularly-polarized photon beam generated from the longitudinally-polarized electron beam. Measurements are planned for several energies, from near 1 GeV to over 4 GeV, and for a range of angles.

Various quark-model calculations, including pQCD<sup>25</sup> and non-forward parton distributions<sup>26</sup> (NFPD), have been compared to the cross section data. The pQCD calculations sum all leading-order diagrams, while the NFPD calculations assume the meson is produced by hard scattering from a quark. These cross section estimates tend to fall below the experimental values, indicating the need for additional soft physics. The experiment<sup>24</sup> will provide high quality cross sections, so that small scaling violations expected<sup>26</sup> may be detectable. Spin observables are also calculated within these models.

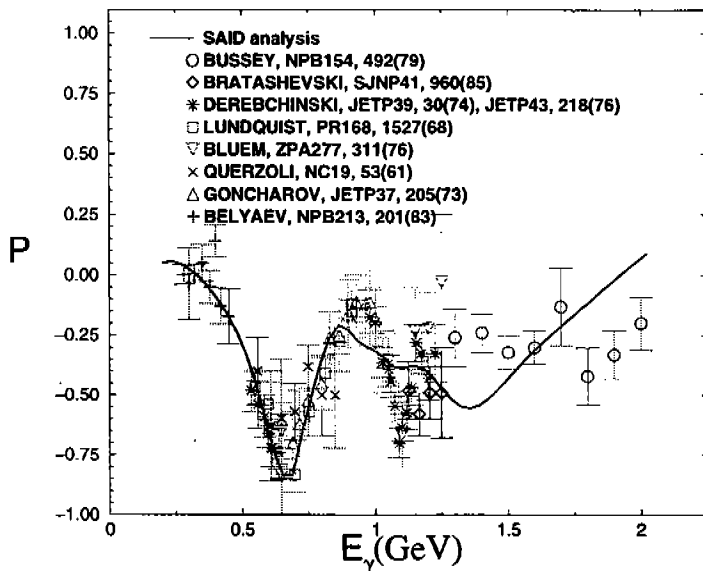


Figure 4: Induced polarization data for pion photoproduction from the proton, compared to the SAID phase shift analysis.

#### 4 Future Experiments

The experiments described above become more difficult at higher energies, due to the decrease in cross section with energy, and to the decrease in polarimetry figure of merit with proton momentum. There is no simple solution to extending deuteron photodisintegration recoil-polarization measurements to higher energies. Pion photoproduction with untagged Bremsstrahlung suffers in addition from an increasing  $ep$  elastic scattering background. One can either measure a photon from the neutral pion decay in coincidence, as will be done to investigate real Compton scattering<sup>27</sup>, or one can attempt an alternative pseudo-scalar meson production reaction.

Photoproduction of  $K^+\Lambda^0$  final states<sup>28</sup> is particularly attractive. From a theoretical viewpoint, the  $\Lambda^0$  wave function is particularly simple, as its spin is carried entirely by the strange quark, within the constituent quark model. From an experimental viewpoint, the self-analyzing decay of the  $\Lambda^0$  allows accurate polarimetry with only a few thousand events. Thus, it is possible to extend precise measurements to energies well above 4 GeV, and to high momentum transfers.

## 5 Summary

It has for many years been a puzzle why reaction cross sections and form factors have tended to follow the simple, pQCD inspired, constituent counting rules. Recent theoretical efforts in quark models more appropriate for this kinematic regime indicate subtle scaling violations may be detected. A new generation of experiments, including those described above, should be able to detect scaling violations, and to provide spin observables that test theoretical assumptions.

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