Determination of the Azimuthal Asymmetry of Deuteron Photodisintegration

in the Energy Region E_γ=1.1 – 2.3 GeV

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Introduction

The deuteron photodisintegration process is important for the investigation of the role of quarks and gluons in nuclear reactions. The main reason for conducting such an experiment is to identify the energy at which the transition from the hadronic picture of the deuteron (established in the reaction at low energies; usually below 1 GeV) to the quark-gluon picture (expected to hold for energies above several GeV) takes place.

Spin-dependent observables are crucial for identifying the underlying dynamics. The polarization observable Σ is predicted to have large sensitivity on the mechanism of deuteron photodisintegration. In an attempt to better understand this mechanism, we determined the azimuthal asymmetry of deuteron photodisintegration in the energy region E_γ=1.1 – 2.3 GeV.

Framework

The asymmetry Σ is related to the doubly-differential cross section for the reaction of deuteron photodisintegration

$$\frac{d^2\sigma}{dtd\phi}(s,t,\phi) = \frac{1}{2\pi}\frac{d\sigma_0}{dt}(s,t)[1+\mathcal{P}_\gamma\Sigma(s,t)\cos 2\phi]$$

where $d\sigma_0/dt$ is the unpolarized cross section for the reaction and ϕ is the azimuthal angle between the beam polarization and the observed nucleon transverse momentum.

For two different polarizations the above equation becomes

$$\frac{dN^{(\pm)}}{d\phi} = \frac{F_\gamma^{(\pm)}}{2\pi}[1\pm\mathcal{P}_\gamma\Sigma(s,t)\cos 2\phi]A(\phi)$$

with $dN^{(\pm)}/d\phi$ the azimuthal distributions of the events taken with the photon polarization perpendicular (+), and parallel (-) to the Hall-B floor, respectively.

The asymmetry is then determined by fitting the ratio

$$\frac{dN^{(-)}/d\phi - dN^{(+)}/d\phi}{dN^{(-)}/d\phi + dN^{(+)}/d\phi}$$

with the function

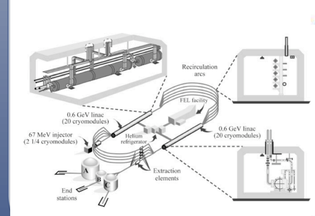
$$\frac{A-1+\frac{AB+1}{B+1}2C\cos[2(\phi-D)]}{A+1+\frac{AB-1}{B+1}2C\cos[2(\phi-D)]}$$

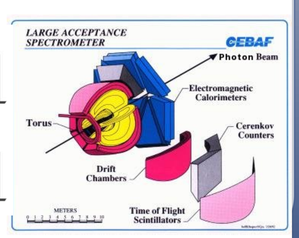
to determine the incident photon flux ratios, A= $F_\gamma^{(-)}/F_\gamma^{(+)}$, the photon polarization ratios, B= $\mathcal{P}_\gamma^{(-)}/\mathcal{P}_\gamma^{(+)}$, the product of the average photon polarization and the azimuthal asymmetry, C= $\bar{\mathcal{P}}_\gamma\Sigma$, and the photon polarization offset, D = ϕ_0.

Experiment

The data for this analysis were collected during the g13 experiment which was carried out in Hall-B of the Thomas Jefferson National Laboratory. The characteristics of this experiment are listed below:

- Liquid deuterium target (40 cm long)
- Linearly-polarized photon beam produced using the coherent bremsstrahlung technique (two orientations – *para* and *perp*)
- Collected data for six photon energy bins 200 MeV wide between 1.1 and 2.3 GeV
- Use of the tagger spectrometer to identify the energy of the photon that initiated the reaction
- Use of the CLAS to collect data over a large fraction of the full solid angle



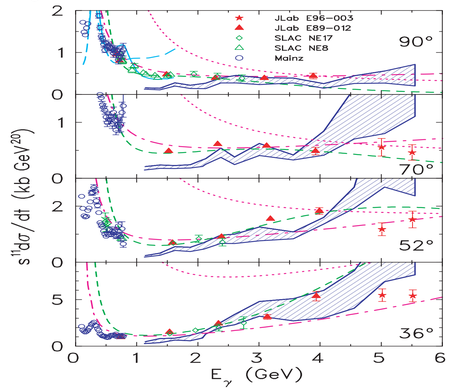


Previous Results

Main theoretical models

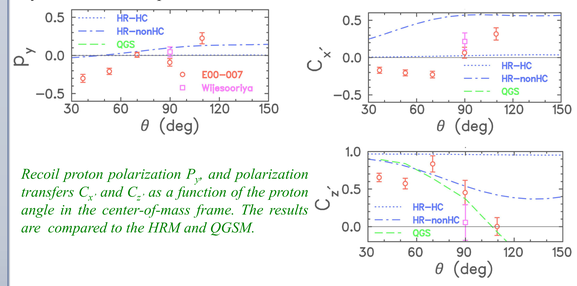
- Quark-Gluon String Model (QGSM)
- Hard Rescattering Mechanism (HRM).

These two models describe the reaction's differential cross section with the same degree of success.



Deuteron photodisintegration differential cross section multiplied by s^{11} as a function of photon energy. Experimental data are from Mainz (open squares), SLAC (green), and JLab Hall-C (red). The prediction of the QGSM is indicated with a red dashed-dotted line, and the HRM model by the hatched area.

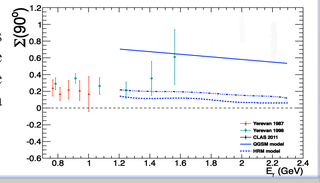
Additional information was needed to better understand the underlying dynamics. Several polarization observables were determined.



Recoil proton polarization P_y, and polarization transfers $C_{x'}$ and $C_{z'}$ as a function of the proton angle in the center-of-mass frame. The results are compared to the HRM and QGSM.

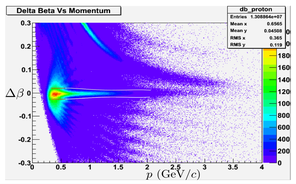
The QGSM predictions are very sensitive the the relative phase between different helicity amplitudes and thus do not provide predictions for P_y and $C_{x'}$. Both of these models predict with the same degree of success the data on the longitudinal polarization transfer.

There is currently only one data set available for the azimuthal asymmetry from Yerevan. These data are restricted to θ_p = 90°, and energies up to 1.6 GeV. These results are also associated with large uncertainties that do not allow a test of the theoretical predictions.

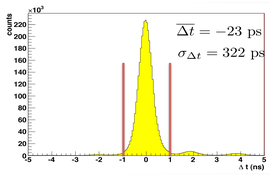


Reaction Reconstruction

Particle ID

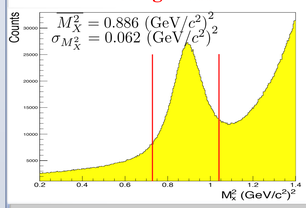


Photon Selection

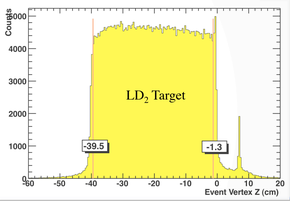


Reaction Reconstruction (continued)

Missing Mass

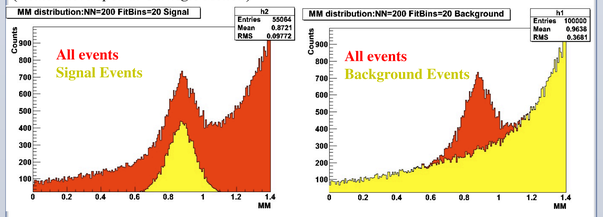


Z-Vertex cut



Background Subtraction

Performed on an event-by-event basis using probabilistic event weighting (*method developed at Carnegie Mellon*)



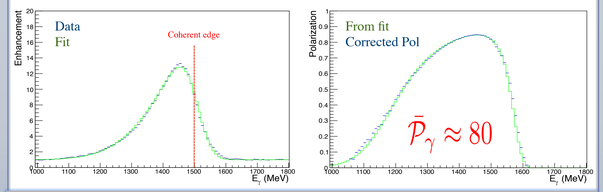
Photon Polarization

Determined using Analytic Bremsstrahlung Calculation. From fitting the enhancement distributions we were able to determine:

- Coherent-edge position
- Beam collimation
- Beam divergence

These parameters were then used to calculate the degree of photon polarization.

$$Enhancement = \frac{\text{Coh. Photon-energy spectrum}}{\text{Amo Photon-energy spectrum}} \qquad \frac{\Delta P}{P} = \frac{1}{Enh-1}\frac{\Delta Enh}{Enh}$$



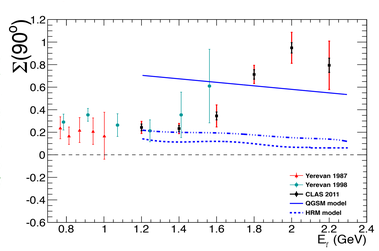
Systematic Studies

Source	Study	Value
Photon Polarization – P_γ	M. Dugger, Private Communication	∼ 5%
Offset – ϕ_0	$\phi_0 = -0.047°$ vs $\phi_0 = 0.297°$ *	< 0.2%
Flux ratio – F_R	F_R^{min} vs F_R^{max}	< 0.5%
ϕ-bin Width	$\Delta\phi = 12.5°$ vs $\Delta\phi = 25.0°$	∼ 7%
Particle ID cuts	3σ vs 2σ $\Delta\beta$ cuts	∼ 7%
Missing-mass cuts	3σ cut vs 2σ cut	∼ 5%
Fiducial Cuts	nominal vs ∼ 3° tighter cuts	∼ 3%
Background Subtraction	Probabilistic event weighting vs Bin scaling	∼ 7%

Results

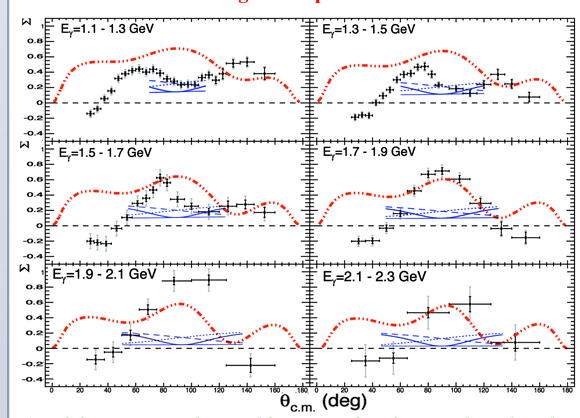
Comparison with previous measurements

Azimuthal asymmetry as a function of photon energy for proton angle in the center-of-mass frame θ=90°. Data from this work are indicated with the black circles. The solid and the dashed lines correspond to predictions of the QGSM and HRM respectively.



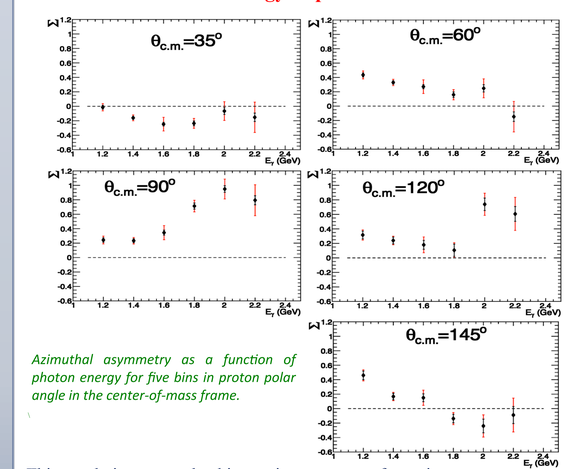
Results (continued)

Angular Dependence



Azimuthal asymmetry as a function of the proton angle in the center-of-mass frame for six different photon-energy bins. The red and blue curves correspond to predictions from the QGSM and HRM respectively.

Energy Dependence



Azimuthal asymmetry as a function of photon energy for five bins in proton polar angle in the center-of-mass frame.

This work increases the kinematic coverage of previous measurements to 2.3 GeV and to angles between 25° and 160°. This latter kinematic domain was completely unexplored in terms of polarization measurements. Our results compliments the previous measurements done on the differential cross section and polarization observables, providing additional information for the underlying dynamics.

Summary and Outlook

- We have determined the azimuthal asymmetry of deuteron photodisintegration between 1.1 and 2.3 GeV over a large fraction of the proton polar angle
- The available theoretical models, at their current state, fail to describe the results on the azimuthal asymmetry
- A collaboration with theorists is necessary to provide a better interpretation of the azimuthal asymmetry
- The results from this work can be used to place new constraints on the existing non-pQCD-based models or aid in the development of new theoretical models

Acknowledgements

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