Measurement of the Azimuthal Asymmetry in Deuteron Disintegration by Linearly Polarized Photons at $E_\gamma = 1.1 - 2.3$ GeV

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Motivation The process of deuteron photodisintegration,

$$\gamma + d \to n + p, \tag{1}$$

is especially important for the investigation of the role of quarks and gluons in nuclear interactions. This photonuclear reaction is: *i)* simplest ($A = 2$) and *ii)* well studied experimentally. During the last 15 years, about ten experiments have been performed for measuring its differential cross section over a broad range in energy and angle [1, 2, 3, 4, 5, 6, 7, 8]. There are also some data on the recoil proton polarization [9] and the single beam-spin asymmetry [10, 11].

The most remarkable property of the available data is the energy behavior of this photonuclear process. At $E_\gamma \geq 1$ GeV and large scattering angles, it was found that $\frac{d\sigma}{dt}(\theta_{cm} \approx 90^\circ) \sim s^{-11}$. On the one hand, just such a behavior is predicted by the constituent counting rules (CCR) based on the scaling law for the hadron wave functions [12, 13]. On the other hand, this scaling can be justified only in the high-energy limit, $t \sim s \gg m^2$, when one can neglect all the masses of the interacting particles. Therefore, it seems naive to expect that the CCR will hold in the few-GeV region. So, a natural question arises: what mechanism is really responsible for the observed energy behavior of this reaction?

To clarify this problem, several models for deuteron photodisintegration have been proposed [14, 15, 16, 17]. The most popular among them are: the asymptotic amplitudes model (AAM) [15], the hard-rescattering mechanism (HRM) [16], and the quark-gluon string model (QGSM) [17]. Summarizing the results presented in the above papers, one can conclude that the approaches based on these various physical principles describe with, practically the same success, the available data on the angular and energy dependence of the reaction. Thus, for a better understanding of the underlying mechanism, complementary information on the spin-dependent observables is necessary.

Concerning the polarization observables, data for the recoil-proton polarizations for energies above 1 GeV have been published recently [9]. Experimentally, the induced polarization P_y vanishes at $\theta_{cm} = 90°$, which can be easily explained by practically all of these models. The polarization transfers $C_{x'}$ and $C_{z'}$ for circularly polarized photons are also not large at $\theta_{cm} = 90°$ and can be described by both HRM [18] and QGSM [19].

The situation is completely unclear for the case of the azimuthal beam-spin asymmetry Σ, defined as

$$\Sigma = \frac{1}{\mathcal{P}_\gamma}\frac{N_{||} - N_\perp}{N_{||} + N_\perp}, \tag{2}$$

where $\mathcal{P}_\gamma$ is the degree of linear polarization of the incident photon beam and $N_{||}$ and $N_\perp$ are the numbers of events produced in the parallel and perpendicular (relative to the photon polarization) planes, respectively. For the asymmetry Σ, there are only Yerevan data in the energy range 0.8-1.6 GeV and at $\theta_{cm} = 90°$ [10, 11]. Unfortunately, the data at $E_\gamma \approx 1.6$ GeV have large uncertainties, which do not allow us to test these models. However, the Yerevan data indicate that $\Sigma(90°)$ might be large (about 50%) at these energies. This fact could be crucial for the determination of the mechanism mainly responsible for deuteron photodisintegration. For instance, the QGSM is able to describe a large ($\sim$ 50%) azimuthal asymmetry at $E_\gamma \approx 1.6$ GeV and $\theta_{cm} = 90°$ [19], while the HRM is not able to do so [18].

So, measurements of the azimuthal beam-spin asymmetry Σ for deuteron photodisintegration will give important complementary information on the underlying mechanism, and could thus provide a crucial test of nonperturbative calculations.

The Proposal We propose to measure the azimuthal asymmetry Σ for deuteron disintegration by linearly polarized photons for E_γ =1.1-2.3 GeV using the existing JLab equipment. It would be very useful (from both theoretical and experimental points of view) to have the asymmetry data obtained under the same conditions and in the same angular and energy range as the cross-section results reported recently by the CLAS collaboration [8]. Combining future data for Σ with the existing results for $d\sigma/dt$ [8] and recoil polarization (P_y, $C_{x'}$,$C_{z'}$) [9], we will obtain a practically complete experimental description of deuteron photodisintegration in the 1-2 GeV region that provides stringent constraints on the theory.

We should also emphasize the parasitic character of the proposed project. It will not require any new hardware or additional beam time, since all the expected data will be gathered (as a byproduct) during the proposed CLAS experiment [20] on kaon photoproduction. The reconstruction of relatively high energy neutrons at large angles, required for our proposed studies, was estimated to be $\sim$ 40-45%, and an additional trigger requiring one charged and one neutral particle in opposite sectors was tested for this application [22].

Experimental Setup The experiment will be performed with the the CLAS and the linearly polarized photon beam generated by the coherent bremsstrahlung of 5-GeV electrons passing through a 50 μm diamond target. This polarized photon beam has a well known peak spectrum and the peak-energy photons are highly polarized. The photon energy peak can be varied by changing (in the goniometer) the angle between the electron momentum and the plane of the crystal target. For an appropriate choice of the goniometer angle, we will have a photon spectrum with both the given peak energy and the chosen polarization direction.

The data will be taken for six photon-energy bins in the range 1.1-2.3 GeV with steps of 200 MeV. The linear polarization of the photons is practically constant over each 200-MeV region. The mean value of the beam polarization varies slowly from $\mathcal{P}_\gamma \approx 90\%$ at $E_\gamma = 1.2$ GeV to $\mathcal{P}_\gamma \approx 70\%$ at $E_\gamma = 2.2$ GeV [20, 21].

The photodisintegration events will be identified bycoincidence detection of both the photon (in the tagger) and the proton (in the CLAS). Kinematically allowed events will be reconstructed applying a missing-mass cut to the reaction $\gamma d \to pX$. The CLAS acceptance and reconstruction efficiency will be evaluated by Monte Carlo simulations of the photodisintegration process. Simulations will also be done for reactions like $\gamma d \to p\Delta^0$, $\gamma d \to pN\pi$ and $\gamma d \to pN\pi\pi$ to subtract the corresponding background contributions.

Beam-Time Request As emphasized above, the present proposal does not require any new hardware or additional beam time. All the statistics will be collected during the CLAS experiment [20] proposed for investigation of strange-particle photoproduction. It is proposed in [20] to use the six photon energy bins centered at $E_\gamma = (1.2, 1.4, 1.6, 1.8, 2.0,$ and $2.2)$ GeV. The linearly polarized photons will be used for 33 days with beam-time allocations $T = (5, 4, 5, 6, 6,$ and $7)$ days.

Statistical Uncertainties Our estimates of the number of the expected photodisintegration events N in a specific kinematic bin $(E_\gamma, \cos\theta_{cm})$ are based on the data [8] for $d\sigma/dt$. We also use the value 5×10^6 per second for the photon flux, 6.4 g/cm^2 for the thickness of the 40-cm LD_2 target and $9/4\pi$ for the CLAS acceptance. Having the total number of unpolarized events N, one can calculate the statistical uncertainty $\delta\Sigma = \frac{\pi}{2\mathcal{P}_\gamma}\frac{1}{\sqrt{N}}$ that determines the minimum value of $|\Sigma|$ that can be measured within the achieved statistics. In particular, at $\theta_{cm} = 90°$ the energy distribution of the expected statistical uncertainty is $\delta\Sigma(90°) = (0.8, 1.5, 2.1, 2.6, 3.7, 4.6)$ %. At smaller angles the uncertainties decrease because of the higher counting rate. Thus it will be possible to measure the asymmetry Σ with an absolute accuracy of a few percent.

Systematic Uncertainties Uncertainties in the linear polarization of the photon beam have been investigated for a JLab experiment [21]. A value of (3-4)% was found for the relative uncertainty $\delta\mathcal{P}_\gamma/\mathcal{P}_\gamma$ that should be taken into account in the determination of the systematic uncertainty.

In principle, incomplete azimuthal acceptance of the CLAS equipment can produce errors in measurements of the beam-spin asymmetries. To avoid this problem, half of the statistics will be collected with the photon beam polarization rotated by 90°. This should lead to cancellations of possible false asymmetries. Therefore, we do not anticipate any uncertainty due to the CLAS φ-acceptance.

In the unpolarized case, the remaining systematic uncertainties come from the total number of incident photons, the target length and density, the proton detection efficiency, and the background contributions. The resulting total systematic uncertainty for the disintegration cross section is less than 10% for all the kinematic bins $(E_\gamma, \cos\theta_{cm})$ under consideration. However, in the case of the beam-spin asymmetry Σ, the corresponding uncertainty should be significantly smaller because most of the above uncertainties cancel out in the ratio.

Conclusion We propose to measure the azimuthal beam-spin asymmetry, Σ, for deuteron disintegration by linearly polarized photons having eneries E_γ =1.1-2.3 GeV using the existing CLAS equipment. The present project has a completely parasitic character: it does not require any additional beam time since all the statistics should be collected during the CLAS experiment [20] proposed for investigation of strange-particle photoproduction. It is shown that the expected statistical and systematic uncertainties in the determination of the beam-spin asymmetry Σ are less than about 5%.

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