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Photodisintegration of Light Nuclei with CLAS

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We report preliminary results of photodisintegration of deuteron and ^{3}He measured with CLAS at Jefferson Lab. We have extracted the beam-spin asymmetry for the $\vec{\gamma}d \to pn$ reaction at photon energies from 1.1 GeV to 2.3 GeV and proton center-of-mass (c.m.) angles between 35° and 135°. Our data show interesting evolution of the angular dependence of the observable as the photon energy increases. The energy dependence of the beam-spin asymmetry at 90° shows a change of slope at photon energy of 1.6 GeV. A comparison of our data with model calculations suggests that a fully non-perturbative treatment of the underlying dynamics may be able to describe the data better than a model based on hard scattering. We have observed onset of dimensional scaling in the cross section of two-body photodisintegration of ^{3}He at remarkably low energy and momentum transfer, which suggests that partonic degrees of freedom may be relevant for the description of nuclei at energies lower than previously considered.

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The understanding of baryon structure and interactions from Quantum Chromodynamics is one of the main objectives of contemporary nuclear physics. Of particular interest is the regime of confinement where models using effective degrees of freedom have been used to interpret experimental data and to gain insight into baryon properties and dynamics. The complexity of the strong interaction and the phenomenology involved in the models have left many open questions. The nature of the transition from hadronic to partonic degrees of freedom, and understanding nuclei in terms of quarks and gluons are some of the key problems that need to be addressed. A common method to study the transition between hadronic and partonic descriptions of strong dynamics is to search for the onset of some experimentally accessible phenomena which are predicted by QCD by mapping experimental observables over a broad kinematic range. One such phenomenon is dimensional scaling.

Dimensional scaling laws, or Constituent Counting Rules (CCR), have been first derived in the framework of perturbative QCD (pQCD) and state that at asymptotically large center-of-mass (c.m.) energy squared, s, and four-momentum transfer squared, t, the invariant cross section of an exclusive reaction at fixed c.m. angle should scale as $d\sigma/dt \propto s^{-n+2}$, where n is the total number of point-like particles and gauge fields in the initial and final states [1]. The scaling laws have been also derived non-perturbatively, using the AdS/CFT correspondence between string theories in Anti-de Sitter space-time and conformal field theories in physical space-time [2]. The fundamental origin of scaling is the scale invariance of the interactions among hadron constituents. Thus, the laws naturally reflect the property of asymptotic freedom of QCD at small distances. In the AdS/CFT approach, however, the interactions among hadron constituents are also scale invariant at very large distance scales (so-called regime of “conformal window") where the effective strong coupling is large but constant.

Dimensional scaling laws have been extensively tested experimentally in a vast number of processes. The interest in the laws stems from the fact that they directly relate an experimental observable to the underlying structure of the hadrons participating in the process. The studies have been primarily done on the nucleon and the two-nucleon bound system. The majority of experimental data show consistency with dimensional scaling at energies as low as 1 GeV. Despite significant theoretical and experimental effort, it is still unclear what is the origin of dimensional scaling at such a low energy scale. The question about the onset of quark-gluon dynamics in nuclei is particularly interesting not only because some predictions of QCD, such as color transparency and hidden color, can only be tested in nuclei but also because it is relevant for understanding how to describe nuclei from QCD.

Here we report measurements of the beam-spin asymmetry of deuteron photodisintegration, $\vec{\gamma}d \to pn$, and of differential cross sections of two-body breakup of ^{3}He, $\gamma^3\text{He} \to pd$. The data were taken with the CEBAF Large Acceptance Spectrometer (CLAS) [3] in Hall B at Jefferson Lab during the experiments E06-103 [4] and E93-044 [5], respectively. E06-103 made use of the coherent bremsstrahlung facility located in Hall-B to produce a linearly polarized photon beam with polarizations of the order of 75%. The polarized photons were incident on a 40-cm long cryogenic LD_2 target. E93-044 collected data with circularly polarized photon beam incident on a 18-cm long cryogenic liquid ^{3}He target. CLAS provided an efficient detection of the final-state charged particles over a large fraction of the full solid angle.

The transition between hadronic and partonic degrees of freedom via dimensional scaling in reactions involving light nuclei has been most extensively studied in deuteron photodisintegration. At medium energies the process is characterized by a large momentum transfer, which provides access to the underlying quark-gluon dynamics. The cross section data [6, 7, 8, 9, 10, 11, 12, 13] determined that the onset of dimensional scaling happens at $p_\perp > 1.1$ GeV/c, where $p_\perp$ is the transverse momentum of the outgoing nucleon. The data on the induced polarization, p_y, and the polarization transfers C_x and C_z [14, 15], indicated that pQCD alone does not provide a valid description of the reaction below 2.4 GeV. Thus, previous studies of this process established that if dimensional scaling can be interpreted as an evidence for the onset of parton dynamics, this dynamics is non-perturbative.

As neither QCD nor chiral effective field theories are able to predict the available data at these intermediate energies, the interpretation of the observed dimensional scaling relies on phenomenological models. The main QCD based models for deuteron photodisintegration are the reduced nuclear amplitudes (RNA) model [16, 17], the hard-rescattering mechanism (HRM) [18, 19, 20], and the quark-gluon string model (QGSM) [21, 22]. The HRM studies the absorption of the photon by a quark of one nucleon followed by a high-momentum transfer interaction with a quark in the other nuclean. The scattering amplitude is expressed as convolution of the large-angle pn scattering amplitude, the hard photon-quark interaction vertex (calculated from pQCD), and the low momentum nuclear wave function. On the other hand, the reaction in the QGSM proceeds through three-quark exchange with an arbitrary number of gluon exchanges. The free parameters of the model are fixed by other processes, with two parameters fixed using the deuteron photodisintegration cross-section data. The QGSM model is, thus, a fully non-perturbative partonic model.

Since neither the cross section data nor the measurements of p_y and C_x and C_z for deuteron photodisintegration could resolve the question wether a fully non-perturbative treatment or a phenomenological extension of pQCD provides a better description of the process, another polarization observable, the beam spin asymmetry, Σ, has attracted attention [23, 24]. Predictions of the angular dependence of the beam-spin asymmetry from the HRM [25] and QGSM [26] show differences of up to 40%. For this reason, a precise measurement of Σ over a large range of proton angles is expected to give insight in the details of the underlying mechanisms and to test nonperturbative calculations. An earlier measurement of Σ was carried out at Yerevan [27, 28], however, these data were restricted only to proton angle $\theta_p^{c.m.} = 90^\circ$, and cover the photon-energy range between 0.8 and 1.6 GeV. In addition, the higher photon-energy data of Σ ($E_\gamma = 1.4 - 1.6$ GeV) are characterized by large uncertainties that do not allow to discriminate between the models under consideration.

Our data for the beam-spin asymmetry of deuteron photodisintegration cover photon energies from 1.1 GeV to 2.3 GeV and proton c.m. scattering angles between 35° and 145°. We determined Σ using a binned method, taking the ratio of polarized yields obtained with different orientation of the photon polarization [29]. This method simplifies significantly the determination of the observable reducing, at the same time, systematic effects associated with the detector acceptance. Our preliminary results of the beam-spin asymmetry are shown in Figs. 1 and 2.

The angular dependences of Σ show rich structures at lower energies, which evolve into a single peak at higher energies. While none of the two models reproduces exactly the shape of the data, the QGSM calculation seems to better desribe the general features of the angular distributions. The energy dependence (Fig. 2) of Σ at $\theta_p^{c.m.} = 90^\circ$ shows a transition from lower to higher asymmetries at photon energies between 1.6 and 2.0 GeV, which is not predicted by either of the models. Such

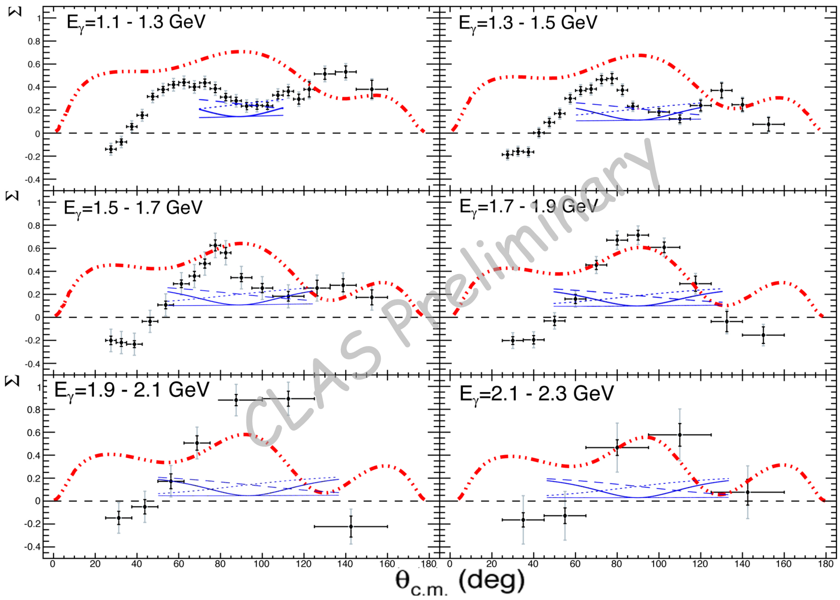

Figure 1: Beam-spin asymmetry for six photon energy bins 200-MeV wide between 1.1 and 2.3 GeV as a function of the proton angle $\theta_p^{c.m.}$. Data shown are from CLAS (preliminary). Theoretical predictions of the QGSM and HRM are shown with red and blue lines respectively. Systematic uncertainties are indicated with grey error bars and statistical with black.

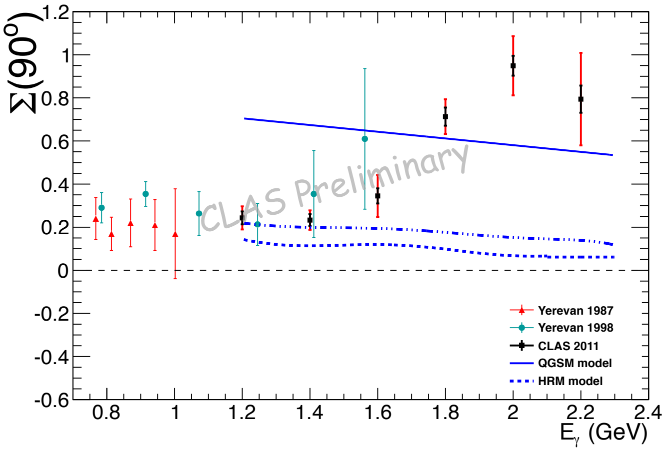

Figure 2: Beam-spin asymmetry for proton angles $\theta_p^{c.m.} = 90°$ as a function of photon energy. Data shown are from CLAS (preliminary) and Yerevan [27, 28]. Theoretical predictions of the QGSM and HRM are shown with solid and dashed lines respectively. The black error bars indicate statistical uncertainties were the red the systematic uncertainties.

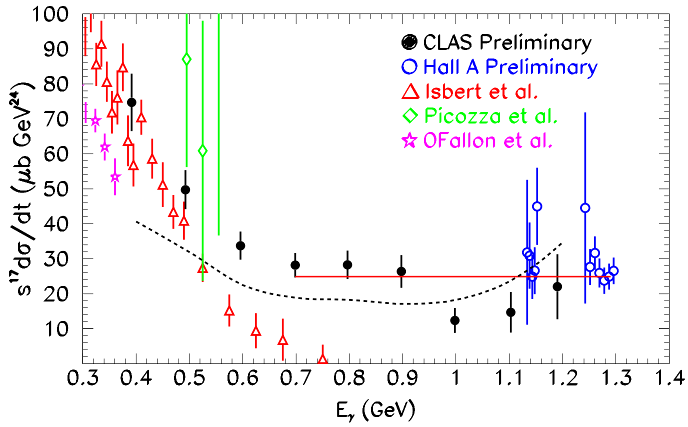

Figure 3: Differential cross sections of the reaction $\gamma^3\text{He} \to pd$, at c.m. angle of 90°, scaled by s^{-17} as predicted by dimensional scaling laws. Shown are preliminary CLAS (solid circles), preliminary Hall-A [30] (open circles), [31] (open triangles), [32] (open diamonds), and [33] (open stars) data. The solid line is a linear fit to the data at $E_\gamma \leq 0.7$ GeV. The dashed line is a hadronic-model calculation [34].

a transition might be an indication of a change in the production mechanism.

In order to study dimensional scaling when the three-bound nucleon system is involved, we have extracted differential cross sections of the reaction $\gamma^3\text{He} \to pd$ at proton center-of-mass (c.m.) angles of 40° – 140° and photon beam energies of 0.4 – 1.5 GeV. Since the onset of dimensional scaling has been most extensively studied using cross sections of exclusive processes at c.m. angle of 90°, we first focus on data at this c.m. angle. The reason for this choice is that at this kinematics the momentum transfers to both final state particles are reasonably large. In Fig. 3 we show our scaled invariant cross sections, together with other data, as a function of photon energy. At beam energies smaller than ~ 0.7 GeV, the cross sections decrease smoothly as E_γ increases. Above 0.7 GeV, the scaled invariant cross section seems to be consistent with the scale invariance predicted by dimensional scaling. The scaling power was extracted by fits of the dependence of $d\sigma/dt$ on s to the function $d\sigma/dt = As^{-N}$, where A is a constant. CLAS and preliminary Hall-A data [30] data were included in the fits. The extracted value of the scaling power is $N = 17 \pm 1$ that is well in agreement with the prediction of dimensional scaling. A comparison of the data with the hadronic-model calculation of Laget [34] shows that while the model reproduces well the magnitude of the data, the latter are in a better agreement with dimensional scaling than with the model prediction.

At the other c.m. angles, where no other measurements besides the CLAS results exist at beam energies above 1 GeV, we could not evaluate the value of the scaling power from the data. Instead, we fitted the energy dependence of each scaled invariant cross section with the function $d\sigma/dt = As^{-17}$ and evaluated the quality of the fits. Figure 4 shows the results of these fits. At each proton c.m. angle, we first include all the data in the fit, then remove the lowest-energy point and re-fit, and so on. We do not perform fits on less than four data points. Overall, the χ^2/ndf, where ndf labels the number of degrees of freedom in the fit, improves significantly as we exclude the lowest-energy data points. Above some value of s, the quality of the fits does not improve much as more data points are being excluded. Our interpretation of the results of the fits is that at this value of s our data suggest the onset of dimensional scaling for that c.m. angle. Figure 4 shows

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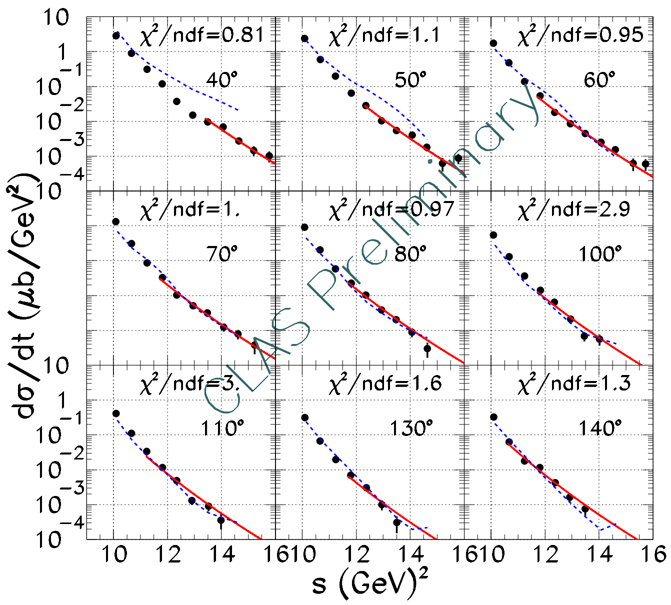

Figure 4: Preliminary CLAS differential cross sections of the reaction $\gamma^3\mathrm{He} \to pd$ as a function of s for different proton c.m. angles (shown in each plot). The solid lines show fits of the cross sections to the function $d\sigma/dt = As^{-17}$, where A is a fit parameter. The quality of the fits is shown through the χ^2/ndf, where ndf labels the number of degrees of freedom in the fit, shown at the top of each plot. The dashed curves show the model calculation of [34].

that the fits quality is overall fairly good. It also shows, that at all angles, dimensional scaling sets on at photon energies between 0.6 GeV and 0.8 GeV, which suggests that the threshold value of s is mostly energy independent for this reaction. An exception of the general trend is the cross section at c.m. angle of 40° where our data suggest that dimensional scaling sets on at E_γ of about 1 GeV. The magnitude of the minimum momentum transfer squared to the deuteron, t, at which we observe the onset of scaling at proton c.m. angle of 90° is 0.64 (GeV/c)^2, whereas the minimum c.m. transverse momentum is 0.95 GeV/c. These values are remarkably lower than the minimum values at which the onset of dimensional scaling was observed for other leptoproduction processes involving light nuclei. For example, the deuteron form factor scales at t of about 2 (GeV/c)^2 [35], whereas the cross section of the two-body breakup of deuteron scales at $p_\perp > 1.1$ GeV/c [13]. Since the conformal window covers the range of momentum transfer to a quark up to ~ 0.5 GeV/c, we can naively compare this value to the average minimum momentum transfer to a deuteron or a proton constituent at which we observe onset of scaling. For our data, the minimum average momentum transfer to a deuteron constituent at which scaling sets on is 0.35 GeV/c, whereas the minimum average momentum transfer to a proton constituent at which scaling sets on is 0.6 GeV/c. If indeed the overall momentum transfer in the reaction is equally shared among the constituents of the final state hadron, then the scaling we observe in two-body photodisintegration of ^{3}He seems to qualitatively support the hypothesis of conformal window at very low momentum transfer.

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References

[1] S. J. Brodsky and G. Farrar, Phys. Rev. Lett. **31**, 1153 (1973).

[2] Phys. Rev. Lett. **88**, 031601 (2002).

[3] B. A. Mecking et al., Nucl. Instrum. Meth. A 503, 513 (2003).

[4] P. N.-Turonski et al., Jefferson Lab Experiment E06-103, 2006.

[5] B.L. Berman, G. Audit, and P. Corvisiero, Jefferson Lab Experiment E93-044, 1993.

[6] J. Napolitano et al., Phys. Rev. Lett. **61**, 2530 (1988).

[7] S. Freedman et al., Phys. Rev. C **48**, 1864 (1993).

[8] J. E. Belz et al., Phys. Rev. Lett. **74**, 646 (1995).

[9] C. Bochna et al., Phys. Rev. Lett. **81**, 4576 (1998).

[10] E. C. Schulte et al., Phys. Rev. Lett. **87**, 102302 (2001).

[11] E. C. Schulte et al., Phys. Rev. C **66**, 042201R (2002).

[12] M. Mirazita et al., Phys. Rev. C **70**, 014005 (2004).

[13] P.Rossi et al., Phys. Rev. Lett. **94**, 012301 (2005).

[14] K. Wijesooriya et al., Phys. Rev. Lett. **86**, 2975 (2001).

[15] X. Jiang et al., Phys. Rev. Lett. **98**, 182302 (2007).

[16] S. Brodsky and J. Hiller, Phys. Rev. C **28**, 475 (1983).

[17] S. Brodsky, J. Hiller, C.-R. Ji, and G. A. Miller, Phys. Rev. C **64**, 055204 (2001).

[18] L. Frankfurt, G. Miller, M. Sargsian, and M. Strikman, Phys. Rev. Lett. **84**, 3045 (2000).

[19] L. Frankfurt, G. Miller, M. Sargsian, and M. Strikman, Nucl. Phys. A **663**, 349 (2000).

[20] B. Julia-DIaz and T.-S. H. Lee, Mod. Phys. Lett. A **18**, 200 (2003).

[21] L. Kondratyuk et al., Phys. Rev. C **48**, 2491 (1993).

[22] V. Y. Grishina et al., Eur. Phys. J. A 10, 355 (2001).

[23] R. Avakian et al., Jefferson Lab Letter of Intent LOI-06-101, 2006.

[24] R. Avakian et al., CLAS Approved Analsysi CAA-NP07-01, 2008.

[25] M. Sargsian, Phys. Lett. B 587, 41 (2004).

[26] V. Y. Grishina et al., Eur. Phys. J. A 19, 117 (2004).

[27] F. Adamian et al., J. Phys. G 17, 1189 (1991).

[28] F. Adamian et al., Eur. Phys. J. A 8, 423 (2000).

[29] N. Zachariou, Ph.D. Dissertation, The George Washington University, 2012.

[30] I. Pomerantz et al., arXiv:1303.5049 [nucl-ex] (2013).

[31] V. Isbert et al., Nucl. Phys. A 578, 525 (1994).

[32] P. Picozza et al., Nucl Phys. A 157, 190 (1970).

[33] N.M. O'Fallon et. al. Phys. Rev. C **5**, 1926 (1972).

[34] J.M. Laget, Phys. Rev. C **38**, 2993 (1988).

[35] L.C. Alexa et al., Phys. Rev. Lett. **82**, 1374 (1999)