Eur. Phys. J. A **18**, 409–411 (2003)
DOI 10.1140/epja/i2002-10246-x

THE EUROPEAN PHYSICAL JOURNAL A

Deuteron photodisintegration at high energy

F. Ronchetti[a]

INFN, Laboratori Nazionali di Frascati, Via E. Fermi 40, 00044 Frascati, Roma, and Università di Roma Tre, Dipartimento di Fisica, Via della Vasca Navale 84, 00146 Roma, Italy

Received: 30 September 2002 /
Published online: 22 October 2003 –

Abstract. The high-energy two-body deuteron break-up is a very well-suited process to identify quark effects in nuclei. In particular, its study in the few GeV region can clarify the transition from the nucleonic to the QCD picture of hadrons. The CEBAF Large Angle Spectrometer (CLAS) at JLab allowed for the first time the complete measurement of the angular distributions of the two-body deuteron photodisintegration differential cross-section at photon energies from 0.5 to 2.95 GeV. First results from the analysis of 30% of the total collected data show persistent forward-backward asymmetry and are well described by a calculation derived in the non-perturbative framework of the Quark Gluon String Model (QGSM).

PACS. 21.45.+v Few-body systems – 25.20.-x Photonuclear reactions

1 Introduction

A fundamental issue in nuclear physics concerns the study of the interplay between hadronic and partonic degrees of freedom in nuclei.

To this purpose, the deuteron photodisintegration is well suited for studying nuclear reactions in the intermediate-energy regime where neither the traditional meson exchange models nor perturbative QCD (pQCD) describe the data well. It is an exclusive reaction in which a large momentum is imparted to the constituents [1].

At high incident-photon energy and intermediate angles, conventionally 90°, where both the t-dominance and u-dominance are suppressed, the $\gamma d \rightarrow pn$ differential cross-section is well described by the Constituents Counting Rule (CCR) [2]:

$$\frac{\mathrm{d}\sigma}{\mathrm{d}t} = \frac{1}{s^{N-2}} f(\theta_{\mathrm{CM}}),$$

where N is the minimum number of microscopic fields involved in the reaction, s is the square of the total energy, and θ_{CM} is the proton scattering angle. In this case, with $N = 13$, the CCR predicts $\mathrm{d}\sigma/\mathrm{d}t \propto s^{-11}$.

Before the present experiment, the deuteron photodisintegration differential cross-section for $E_\gamma > 1\,\mathrm{GeV}$ was measured only at few proton angles ([3–5]) as can be seen in fig. 1. These data show s^{-11} scaling only at large angles: $\theta_{\mathrm{CM}} = 69°$ and 89°.

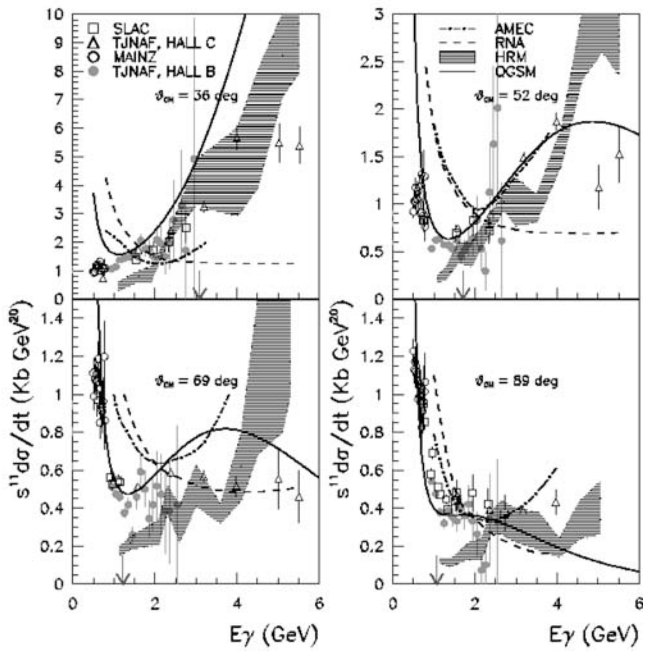

Fig. 1. Deuteron photodisintegration cross-section multiplied by s^{11}. Experimental data are from Mainz [3], JLab Hall C [4], SLAC [5] and CLAS. Points are multiplied by s^{11}, and arrows indicate the expected threshold for the onset of the scaling, where $t > 1\,\mathrm{GeV}$ [2]. For the theoretical curves, see [6–9].

For intermediate energies, the cross-section data indicate a deviation from the predictions of the simple CCR and more sophisticated models have been developed.

In the Reduced Nuclear Amplitude (RNA) model [10, 6] the binding of the quarks inside the nucleons and the

[a] *Present address*: Laboratori Nazionali di Frascati, CP 13, Via E. Fermi 40, 00044 Frascati, Roma, Italy; e-mail: ronchetti@lnf.infn.it

deuteron is taken into account with empirical form factors and the elementary cross-section is computed assuming CCR scaling. This approach is able to describe the $\gamma d \to pn$ cross-section with an appropriate normalization factor for $\theta_{\rm CM} = 89°$ and $69°$ with $E_\gamma > 2\,\rm GeV$.

In the Hard quark Rescattering Model (HRM) [7], the elementary interaction consists of a quark exchange between the two nucleons. The incoming photon is absorbed by a quark of one nucleon which then gives up its momentum via a hard gluon exchange with a quark of the other nucleon. The model assumes that this rescattering mechanism is analogous, with some approximation, to the wide-angle p-n scattering which is also dominated by quark exchange. The limits for the applicability of the model are $E_\gamma > 2.5\,\rm GeV$ and momentum transfer $t > 2\,\rm GeV^2$, but, under particular assumptions for the short-distance p-n interaction, they can be extended. However, the agreement with the data is poor, especially at higher energies where the uncertainty is large, due to the limited knowledge of the pn cross-section for the actual kinematic conditions.

A non-pQCD calculation has been done in the framework of the Quark Gluon String Model (QGSM) [8]. It assumes that the scattering amplitude at high energy is dominated by the exchange of three quarks in the t-channel, and the duality property allows its extension at lower energies. The intermediate three-quarks state can be identified with the nucleon Regge trajectory.

A short overview of the QGSM and the comparison with data are given in sect. 3.

Traditional models based on the N-π picture fail to reproduce data at $E_\gamma > 1\,\rm GeV$. However, this approach was extended in the few GeV region in the Asymptotic Meson Exchange Current (AMEC) model [9], using form factors to describe the d-NN interaction vertex and an overall normalization factor fixed by fitting the experimental data at 1 GeV. The results reproduce the energy dependence of the cross-section only for $\theta_{\rm CM} = 89°$. It is worth noticing that also this non–QCD-based model provides a scaling law for the cross-section, with an exponent depending on the scattering angle.

Complementary information to the differential cross-section is provided by polarization observables. At high energies, a signature of pQCD effects is the Hadron Helicity Conservation (HHC) [11–14].

The proton polarization was measured in the $\boldsymbol{\gamma d \to pn}$ reaction only for proton angle $\theta_{\rm CM} = 90°$ [15]. Above 1 GeV, data show that the induced polarization is small, consistent with HHC. However, the transverse and longitudinal, in-plane, polarizations are non-zero, and indicate that helicity is not conserved at least up to 2 GeV. Thus, it can be concluded that experimental data at $\theta_{\rm CM} = 90°$ on cross-section and polarization give results that cannot be consistently interpreted in a perturbative picture.

2 The JLab experiment E93-017

A new dataset for the $\gamma d \to pn$ cross-section was obtained using the CLAS detector [16]. A *bremsstrahlung* photon beam is produced from a continuous electron beam by hitting a thin radiator, and then tagged [17] using a spectrometer operating in the range between 0.20 and 0.95 of the electron energy with a resolution about 0.1%. Scattered hadrons are detected with the CLAS [18], a nearly 4π spectrometer based on a toroidal magnetic field generated by 6 superconducting coils which define 6 independent modules. Each module is implemented with 3 regions of drift chambers [19] to track charged particles, and time-of-flight (TOF) scintillators [20] for charged-hadron identification.

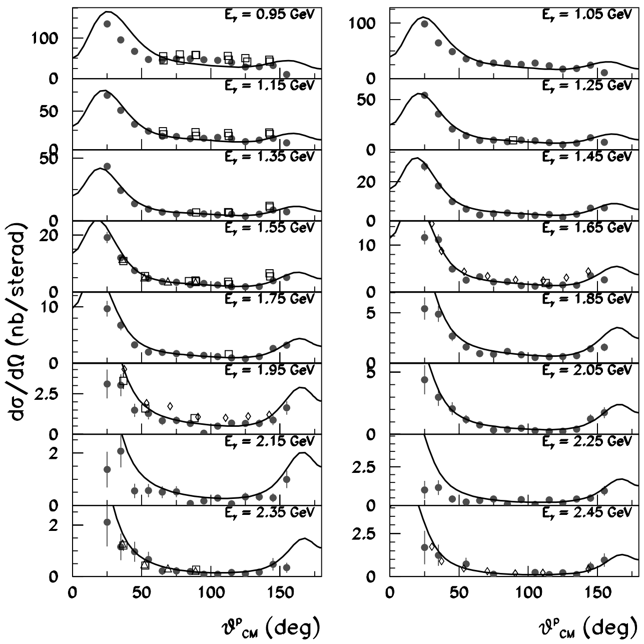

Fig. 2. First results of the deuteron photodisintegration differential cross-section measured with the CLAS (full dots), compared with the published data from JLab Hall C of [4] (open triangles) and SLAC [5] (open squares). The curve is the QGSM calculation [8].

The resolution of the proton momentum is of the order of a few percent, while the proton efficiency is better than 90% in the fiducial region of the detector.

Data were taken with photon energy ranging from 0.5 to 2.95 GeV with a trigger given by the coincidence between the tagger and the CLAS detector (TOF) signals. The total number of recorded triggers is about $2.5 \cdot 10^9$.

Photodisintegration events are selected requiring the identification of a photon in the tagger and a charged hadron in the CLAS, and then applying a missing-mass cut to the reaction $\gamma d \to pX$. The detector acceptance and proton efficiency have been evaluated by Monte Carlo simulations of the photodisintegration reaction, and the background contribution has been computed fitting the experimental missing-mass distributions.

In fig. 2 the differential cross-section $d\sigma/d\Omega$ is reported as a function of the proton angle in the CM frame, for fixed photon energy above 0.9 GeV. The present preliminary results are obtained from the analysis of about 30% of the accumulated statistic. Moreover, an additional cut $\theta_{\rm CM} > 20°$ has been applied, that will be removed in the final analysis. The agreement with the other available data from SLAC [5] and JLab Hall C [4] is good at all energies and angles. Notice that, in spite of the limited data set, the statistical error is lower than 5% for $E_\gamma < 1.5$ GeV. The statistical error will be improved by a factor 3 or more for photon energies up to 2.5 GeV when the whole CLAS dataset will be analyzed.

3 The Quark Gluon String Model

The QGSM is a non-pQCD approach [21,22], used in the description of hadronic reactions at high energies [23]. Due to the duality property of amplitudes, it can be applied at intermediate energies for reactions without explicit resonances in the direct channel [24]. This approach has also been used for the description of heavy-ion collisions at high energy [25].

In particular, the reaction $\gamma d \to pn$ is described by the exchange of three valence quarks in the t-channel plus any number of gluons: this corresponds to the formation and break-up of a quark-gluon string in the intermediate state, leading to the factorization of the amplitudes. Such a string can also be identified with the nucleon Regge trajectory since the QGSM can be considered as a microscopic model for the Regge phenomenology, and can be used for the calculation of different quantities that have been considered before only at a phenomenological level [23].

In ref. [8], the QGSM has been applied for the description of the deuteron photodisintegration reaction, using QCD-motivated non-linear nucleon Regge trajectories [26] and including the photon spin variables with the assumptions of the dominance of the amplitudes that conserve s-channel helicity. The interference between the isoscalar and isovectorial components of the photon has been taken into account, leading to forward-backward asymmetry in the cross-section.

The result of this model is shown in fig. 2 as full line. The agreement between data and QGSM calculations is very good and the angular dependence of the cross-section at fixed photon energy is reproduced together with the forward-backward asymmetry showed by the data.

From fig. 2 it is clear the importance of the CLAS datum at very forward angles, in order to check the QGSM prediction of a decreasing cross-section at 10°–20°.

The QGSM model accounts for the decrease of $\mathrm{d}\sigma/\mathrm{d}t$ at fixed angle as a function of the photon energy, as shown in fig. 1 for four CM proton angles.

4 Conclusions

For its simplicity, the deuteron is very suitable to study the quark structure of nuclear matter and the $\gamma d \to pn$ is an ideal reaction, since γ-quark interactions are well known and momentum transfers are large. The experimental data for the cross-section at 90° are consistent with the CCR scaling, while the proton polarizations show that HHC is not conserved at least up 2 GeV giving the indication that a plain pQCD interpretation of the process may not be correct.

New measurements of the cross-section have been performed using the CLAS, with tagged-photon energy between 0.5 and 2.95 GeV, covering for the first time almost all proton angles in the CM frame. The preliminary results of about 30% of the total CLAS statistics are in good agreement with the already published data.

The CLAS data have been interpreted in the framework of the QGSM, a non-perturbative approach used for the description of binary hadronic reactions. This model works well for all proton angles and photon energy above 1 GeV.

References

1. R.J. Holt, Nucl. Phys. A **684**, 148c (2001).
2. S.L. Brodsky, G.L. Farrar, Phys. Rev. Lett. **31**, 1153 (1973); V. Matveev *et al.*, Lett. Nuovo Cimento **7**, 719 (1973).
3. R. Crawford *et al.*, Nucl. Phys. A **603**, 303 (1996).
4. C. Bochna *et al.*, Phys. Rev. C **41**, 4576 (1998); E.C. Shulte *et al.*, Phys. Rev. Lett. **87**, 102302-1 (2001).
5. S.J. Freedman *et al.*, Phys. Rev. C **48**, 1864 (1993); J.E. Beltz *et al.*, Phys. Rev. Lett. **74**, 646 (1995).
6. S.J. Brodsky, B.T. Chertok, Phys. Rev. D **14**, 3003 (1976); Phys. Rev. Lett. **37**, 269 (1976); S.J. Brodsky, C.-R. Ji, G.P. Lepage, Phys. Rev. Lett. **51** 83 (1983); L.C. Alexa *et al.*, Phys. Rev. Lett. **82**, 1374 (1999); D. Abbott *et al.*, Phys. Rev. Lett. **82**, 1879 (1999).
7. L.L. Frankfurt *et al.*, Phys. Rev. Lett. **84**, 3045 (2000); Nucl. Phys. A **663** & **664**, 349 (2000).
8. V.Yu. Grishina *et al.*, Eur. Phys. J. A **10**, 355 (2001).
9. A.E.L. Dieperink, S.I. Nagorny, Phys. Lett. B **456**, 9 (1999).
10. S.L. Brodsky, J.R. Hiller, Phys. Rev. C **28**, 475 (1983).
11. G.P. Lepage, S.J. Brodsky, Phys. Rev. D **22**, 2157 (1980); S.J. Brodsky, G.P. Lepage, Phys. Rev. D **24**, 2848 (1981).
12. D.G. Grabb *et al.*, Phys. Rev. Lett. **65**, 3241 (1990).
13. T. Gousset *et al.*, Phys. Rev. D **53**, 1202 (1996); C. Carlson, M. Chachkhunashvili, Phys. Rev. D **45**, 2555 (1992).
14. A. Afanasev *et al.*, Phys. Rev. D **61**, 034014 (2000).
15. K. Wijesooriya *et al.*, Phys. Rev. Lett. **86**, 2975 (2001), and references therein.
16. N. Bianchi *et al.*, CEBAF proposal E-93-017.
17. D.I. Sober *et al.*, Nucl. Instrum. Methods A **440**, 263 (2000).
18. W. Brooks, Nucl. Phys. A **663** & **664**, 1077c (2000).
19. D. Carman *et al.*, Nucl. Instrum. Methods A **449**, 81 (2000).
20. E.S. Smith *et al.*, Nucl. Instrum. Methods A **432**, 265 (2000).
21. G. 't Hooft, Nucl. Phys. B **72**, 461 (1974).
22. G. Veneziano, Phys. Lett. B **52**, 220 (1974); Nucl. Phys. Lett. B **117**, 519 (1976).
23. A.B. Kaidalov, Z. Phys. C **12**, 63 (1982); Surv. High Energy Phys. **13**, 265 (1999).
24. A.B. Kaidalov, Sov. J. Nucl. Phys. **53**, 872 (1991); C. Guaraldo *et al.*, Yad. Fiz. **59**, 1896 (2000); Phys. At. Nucl. **63**, 1395 (2000).
25. E.E. Zabrodin *et al.*, Phys. Lett. B **508**, 184 (2001).
26. M.M. Brisudova *et al.*, Phys. Rev. D **61**, 054013 (2000).