

Some Highlights in Few-Body Nuclear Physics

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1. INTRODUCTION

During the past five years, there have been tremendous advances in both experiments and theoretical calculations in few-body nuclear systems. Advances in technology have permitted experiments of unprecedented accuracy. Jefferson Laboratory has begun operation and the first round of experimental results have become available. New polarization techniques have been exploited at a number of laboratories, in particular, at Jefferson Lab, IUCF, RIKEN, NIKHEF, Mainz, MIT-Bates and HERMES. Some of these results will be shown here. In addition, there have been tremendous advances in few-body theory. Five modern two-nucleon potentials have which describe the nucleon-nucleon data extremely well have become available. A standard model of nuclear physics based on these two nucleon potentials as well as modern three-nucleon forces has emerged. This standard model has enjoyed tremendous success in the few body systems. Exact three-body calculations have been extended into the continuum in order to take full advantage of scattering data in advancing our understanding of the the few-nucleon system. In addition, the application of chiral symmetry has become an important constraint on nucleon-nucleon as well as three-nucleon forces. As a result of all these efforts, we have seen rapid developments in the three-body force.

Despite these advances, there remain some extremely important open issues:

- (1) What is the role of quarks and gluons in nuclear structure ?
- (2) Can we distinguish meson exchange from quark interchange ?
- (3) Is few-body theory sufficient to describe simultaneously the mass 2, 3 and 4 form factors ?
- (4) What is the isospin and spin dependence of the three-body force ?
- (5) Are there medium modifications for nucleons and mesons in nuclei ?
- (6) Is there an enhancement of antiquarks or pions in nuclei related to the binding ?
- (7) Are short range correlations observable in nuclei ?

In this talk, I will summarize the status of our understanding of these issues.

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2. ELECTROMAGNETIC INTERACTIONS IN THE DEUTERON

Although QCD is accepted as the theory of the strong interaction, there have been no unambiguous signatures for QCD effects in nuclear reactions. One of the primary goals of nuclear physics is to identify whether the traditional effective nucleon-nucleon theory or QCD-inspired models best describe the observations. Electro- and photo-reactions in the deuteron are an extremely promising avenue for investigating QCD effects in nuclei because the deuteron is the simplest nucleus and the electromagnetic interaction is well understood. In particular, it is especially interesting to probe the deuteron at the highest momentum transfer that is practicable in electron-deuteron elastic scattering and at the highest possible photon energy in deuteron photodisintegration.

2.1. Electron-Deuteron Elastic Scattering

The deuteron has three electromagnetic form factors: the monopole, G_C , the quadrupole, G_Q , and the magnetic, G_M form factors. The Rosenbluth formula for elastic electron scattering from the deuteron is given by

$$d\sigma/d\Omega = \sigma_{Mott}[A(Q^2) + B(Q^2)\tan^2(\theta/2)] \quad (1)$$

where the quantities $A(Q^2)$ and $B(Q^2)$ are the longitudinal and transverse structure functions of the deuteron and are related to the three form factors: $G_C(Q^2)$, $G_Q(Q^2)$, and $G_M(Q^2)$; and σ_{Mott} is the Mott cross section which includes the nuclear kinematic recoil factor. By measuring only the cross section, $G_M(Q^2)$ can be determined from a measurement of $B(Q^2)$. Clearly, to isolate the monopole and quadrupole form factors, a third measurement is necessary. The preferred observable is tensor polarization t_{20} since it depends sensitively on $G_C(Q^2)$ and $G_Q(Q^2)$.

2.1.1. Cross Section Measurements for e-d Scattering

Recently, the quantity $A(Q^2)$ was measured [1,2] in experiment E91-026 (spokespersons: J. Gomez, G. Petratos), and experiment E94-018 (spokespersons: E. Beise, S. Kox). In order to perform E91-026, both high resolution spectrometers (HRS) in Hall A were used. One of the spectrometers was used to detect the scattered electrons while the other served as a hadron arm and detected the recoil deuterons in coincidence with the scattered electron. The new results for $A(Q^2)$ extend up to a Q^2 of 6 GeV² and are shown in Fig. 1, where the E91-026 data are represented by the solid circles. The data [2] from experiment E94-018 extend up to 2 GeV² and were collected in Hall C during the t_{20} experiment [3].

The theoretical calculations by Van Orden *et al* [4] and Carbonell *et al* [5] agree well with the data, but meson exchange currents (MEC) appear to be essential to describe the data. Tjon [6] also has recently used a form factor for the $\rho\pi\gamma$ MEC and achieves much better agreement with the data than in the original Hummel & Tjon [7] calculation. Also, calculations by Wiringa *et al* [8] describe the data well up to 2 GeV².

The situation with $B(Q^2)$ is less clear. Here the calculation by Van Orden *et al* with MEC does not agree with the data, but the RIA calculation is in much better agreement with the data, particularly at the higher values of momentum transfer. In the near future, the $B(Q^2)$ data could be extended up to a momentum transfer of 6 GeV², whereas in the longer term, the $A(Q^2)$ data could be extended up to nearly 10 GeV² with the 12-GeV upgrade and the MAD spectrometer.

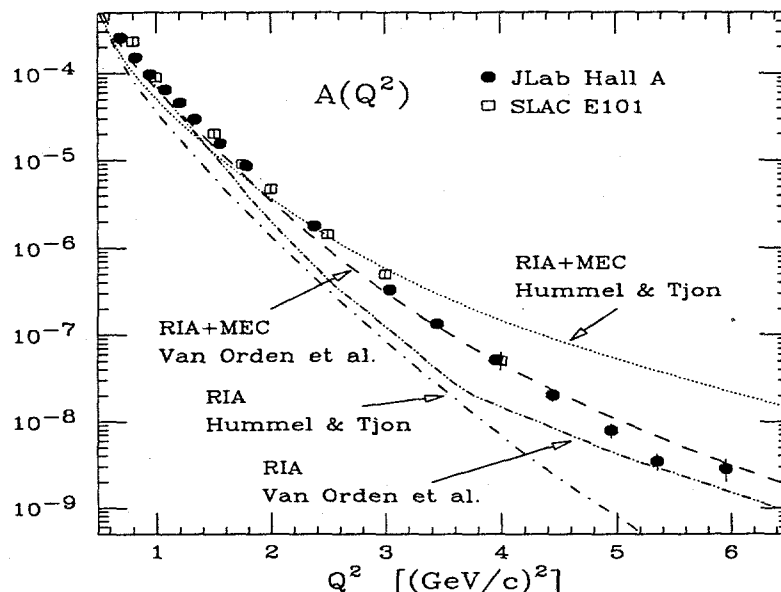


Figure 1. Data for $A(Q^2)$ in electron-deuteron elastic scattering as a function of Q^2 . The solid circles represent the E91-026 data and the open boxes are SLAC E101 data. The curves represent either relativistic impulse calculations (RIA) or RIA and meson exchange currents (RIA + MEC).

One may conclude from this work that the data are in good agreement with traditional meson exchange models. However, the data are also in agreement with constituent counting rules and the reduced form factor analysis [9]. The agreement with constituent counting rules is a signature for QCD effects in the reaction. Apparently, a measurement of the cross section alone in e-d scattering is not sufficient to conclude that quark effects have been observed. We must turn to polarization phenomenon where perturbative QCD (pQCD) would predict [10] that hadron helicity should be conserved. This leads to unique predictions [11,12] of the polarization in e-d scattering.

2.1.2. Polarization Measurements for e-d Scattering

The tensor polarization in electron deuteron scattering was measured in recent experiments. The tensor analyzing power, T_{20} was measured [13] in a polarized internal target experiment at the VEPP-3 storage ring at the Budker Institute of Nuclear Physics in Novosibirsk. The data are in the momentum transfer region from 0.33 to 0.61 GeV^2 . These data demonstrate that the minimum in T_{20} occur at a smaller value of momentum transfer than indicated by the earlier MIT-Bates data [14]. This means that the two lobes of the "dumbbell" feature of the deuteron structure are further apart.

The tensor polarization, t_{20} , was measured [3] in the momentum transfer range 0.65 to 1.7 GeV^2 in electron-deuteron elastic scattering (Experiment E94-018 spokespersons: E. Beise, S. Kox) in Hall C at JLab. In this experiment, the scattered electrons were measured in the high momentum spectrometer (HMS) and the recoil deuterons were

detected in a special hadron arm and a tensor polarimeter that was previously calibrated at SATURNE II.

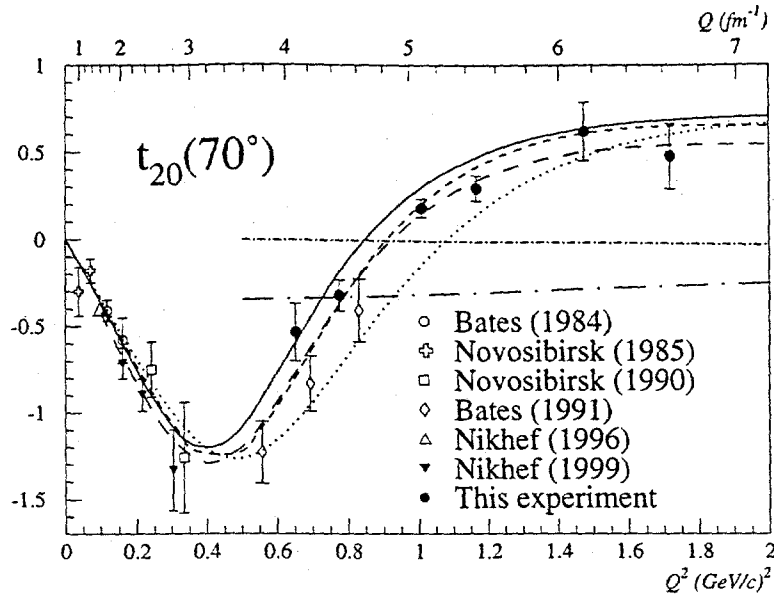


Figure 2. The JLab measurements of t_{20} are represented by the dark circles. The traditional meson exchange calculations described in the text agree best with the data, while the QCD calculations disagree with the data.

The JLab results are shown as the dark circles in Fig. 2. The results are in good agreement with a nonrelativistic impulse calculation which includes MEC (solid curve) [8] as well as relativistic impulse calculations [15,16]. However, the results disagree with QCD calculations [11,12]. We can conclude that there is no evidence for pQCD effects in e-d scattering up to 1.7 GeV^2 . The lower momentum transfer data shown in the figure are from a series of previous experiments at MIT-Bates [14,17], NIKHEF [18,19] and Novosibirsk [20,21]. The measurement of the tensor polarization permits G_C and G_Q to be determined. The JLab measurement is well above the first minimum in G_C and extraction of this minimum gives much better agreement with the Sauer line [22] than the previous MIT-Bates data [14]. It is not clear that the measurements of t_{20} can be extended to higher momentum transfer. However, more accurate measurements are possible at MIT-Bates with the new BLAST facility up to approximately a GeV^2 .

Sensitivity to the short-range part of the tensor interaction is expected in photodisintegration of the deuteron where the asymmetry from linear polarized photons is measured [23]. The new high-accuracy data for photon energies between 110-315 MeV illustrate the need for nucleon-nucleon calculations that consistently treat the nucleon-nucleon

and nucleon-delta part of the interaction.

2.2. Two-Body Photodisintegration of the Deuteron

Relatively large momentum transfer [24] to the constituents can be obtained in exclusive photonuclear reactions at photon energies of a few GeV, because the absorbed photon delivers all of its energy to the constituents.

2.2.1. Differential Cross Section Measurements

One obvious signature of a QCD effect in the $d(\gamma, p)n$ reaction is a scaling behavior, for example, the constituent counting rule behavior. For deuteron photo-disintegration $\gamma d \rightarrow pn$ process, the constituent counting rule [25-27] predicts:

$$\frac{d\sigma}{dt} \propto s^{-11}. \quad (2)$$

This behavior has been observed at large angles, $\theta_{cm} = 70$ and 90° as shown in Fig. 3. Here, $s^{11}d\sigma/dt$ is plotted as a function of E_γ .

In order to test whether the onset of scaling occurs at higher energies for the forward angles, the measurements at the forward angles were extended up to 5.5 GeV in experiment E96-003 at JLab.

Experiments E89-012 and E96-003 were performed in Hall C at JLab. The experimental technique is very similar to the one used at SLAC which has been described in detail [30]. **It now appears that the onset of scaling is observed[29] at the smaller angles at large photon energies, consistent with a $p_T^2 \approx 2\text{GeV}^2$** This is a very exciting result which should be confirmed.

Lee's meson-exchange calculation [35], which is a traditional calculation that reproduces the measured NN phase shifts up to 2.0 GeV and is also constrained by photo-meson production data gives a reasonable description of the data below 500 MeV, but above 1.0 GeV the calculation disagrees with the data. Asymptotic meson-exchange calculations also cannot describe the differential cross section data for this reaction[37]. Although the results at $\theta_{cm} = 90^\circ$ are consistent with the s^{-11} dependence expected from the constituent counting rule, this does not mean that pQCD is valid in this energy region. Polarization data would be necessary to test for the onset of pQCD in this reaction. However, a new quark rescattering model[39] is in reasonable agreement with the present differential cross section data. This suggests that the GeV region could be a "transition region" between meson-exchange models and pQCD.

With the use of MAD[40] and the energy upgrade, the cross section measurements could be extended up to 6 GeV at 90° and 7 GeV at 37° . Note that at a photon energy of 6 GeV, there is 1 GeV per constituent quark in the deuteron, and thus, measurements at this energy should be approaching the traditional Bjorken scaling regime.

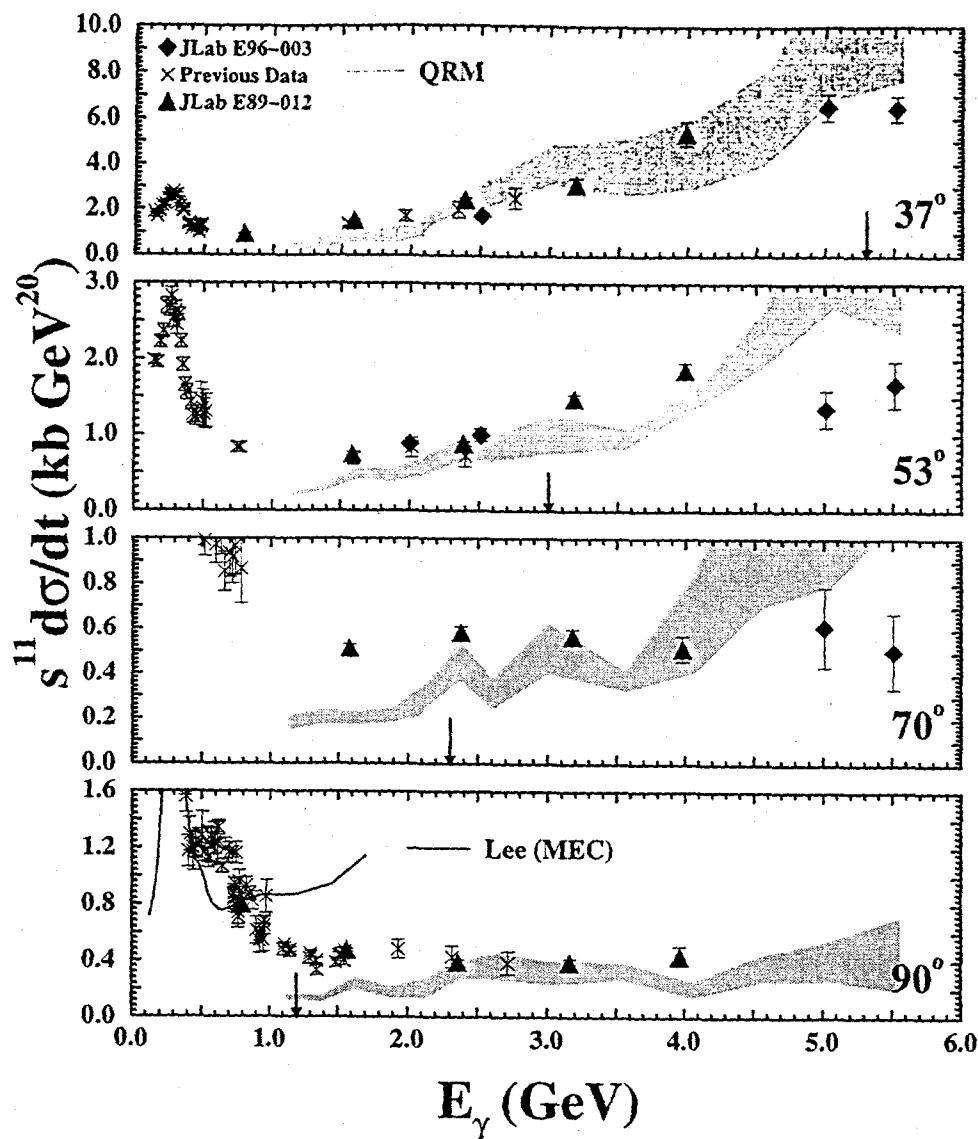


Figure 3. Data for deuteron photodisintegration as a function of the photon energy at four reaction angles. The darkened triangles represent the JLab E89-012 data [28], while the darkened diamonds represent the JLab E96-003 data[29]. The crosses are all the other existing data [30–34]. The solid line is a traditional meson-exchange calculation [35], and the shaded area is the quark rescattering model[39]. These models have an absolute normalization. The arrows in the figure denote the photon energy where $p_T^2 = 1.8 \text{ GeV}^2$, a possible threshold for scaling. The cross section at the forward angles is consistent with the constituent counting rule at high energy.

2.2.2. Photoproton Polarization Measurements

The onset of hadron helicity conservation is a signature for pQCD effects in nuclear reactions. Although previous searches for hadron helicity conservation have been performed, this is the first attempt in a photoreaction where Landshoff terms are absent.

The photoproton polarization for the $d(\gamma, p)n$ reaction was measured in Hall A at JLab (Experiment E89-019; spokespersons, R. Gilman, R. J. Holt, Z.-E. Meziani). This experiment made use of the focal plane proton polarimeter that is available in one of the HRS spectrometers. The measurements were performed for photon energies ranging from 0.5 to 2.5 GeV and at $\theta_{cm} = 90^\circ$. The results for the outgoing proton polarization, p_y , are shown as the dark triangles in Fig. 4. in good agreement with previous data [41,42] at the lower energies, but in disagreement with the high energy Kharkov data [43]. At a photon energy of 1 GeV, the polarization vanishes and is at or near zero up to 2.5 GeV. This is consistent with the behavior predicted by pQCD [10,44], but inconsistent with a meson-exchange calculation [45]. Coincidentally, the value of 1 GeV is where the cross section at $\theta_{cm} = 90^\circ$ begins to obey the constituent counting rule.

Since the electron beam was circularly polarized, it was possible to measure the polarization transfers C_x and C_z as well. These results are also shown in Fig. 4. **Because the polarization transfer C_x does not vanish in this energy region, we must conclude that hadron helicity is not conserved, and consequently that pQCD is not valid in this energy region.** Since a state-of-the-art MEC model and pQCD fail in this energy region, there is the strong suggestion that a transition-region model, such as the quark re-scattering model, is important in this energy region. A preliminary calculation [46] with this model is consistent with both the absolute magnitude of the cross section and the polarization. With the use of MAD these polarization measurements could be extended up to 4 GeV.

3. Nuclear Binding and Pion Excess

One of the most important issues in nuclear physics is whether there is a pion or light antiquark excess related to the binding of nucleons into a nucleus. Traditional theory[47, 48] of the nuclear interactions predicts a net increase in the distribution of virtual pions in nuclei relative to that of free nucleons. **The absence of this excess would shake the very foundations of our understanding of nuclear physics.** Nevertheless, this pion excess has yet to be observed. Drell-Yan experiments[49] have thus far failed to observe an excess of antiquarks in nuclei. More recently, preliminary results[50] from Jefferson Lab indicate that there is no observable pion excess in the $A(e, e'\pi)$ experiments. Fig. 5 shows the present status of the preliminary JLab experiment[51] (E91-003).

Recent theoretical analyses[52] have suggested that the pion excess in nuclei is more difficult to observe than previously believed. It is suggested that the pion strength occurs in the tail of the response function where the experiments performed to date have little or no sensitivity. This is an open question and the resolution of this issue is extremely important.

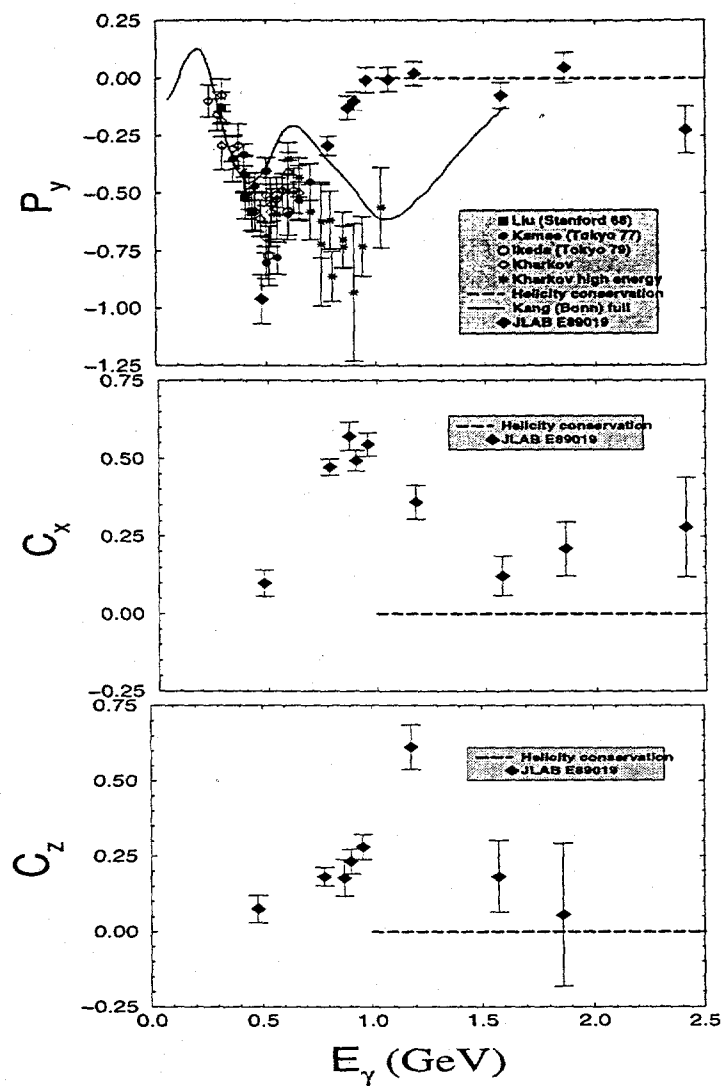


Figure 4. Induced proton polarization (top panel) and polarization transfer (lower panels) for the $\gamma d \rightarrow pn$ reaction as a function of the photon energy at a center-of-mass angle of 90° . Hadron helicity conservation would imply that these three polarization observables should vanish.

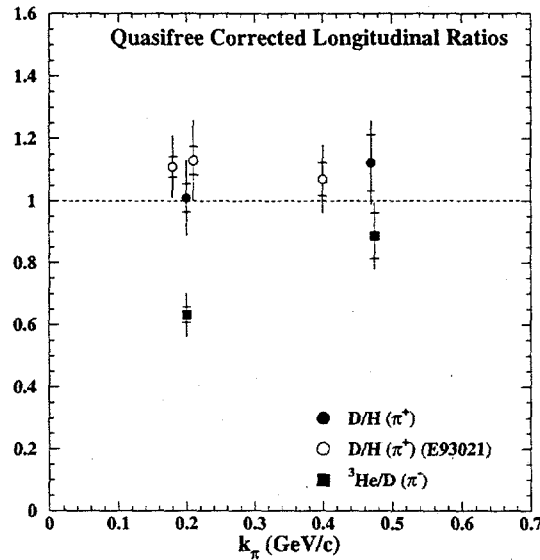


Figure 5. Preliminary ratios of the longitudinal electropion production in ${}^3\text{He}$ to D and of D to H. No significant enhancement of pion yield is observed in nuclei

4. The Three-Body Force

The standard model of nuclear physics uses an effective two-body theory in the form of potentials, such as the CD-Bonn or Argonne V18, in which isobar (or QCD) degrees of freedom are absent. Absence of these degrees of freedom induce more complicated forces in the effective theory, such as three-body forces. Modern examples of three-body forces are the Tucson-Melbourne, Urbana-IX, Illinois-2, or the Texas-Los Alamos force. All of these forces have a long range two-pion exchange component, the Fujita-Miyazawa mechanism. Without these three-nucleon forces, the binding energy of light nuclei are too small and the binding energy of nuclear matter is too large at high densities. The most recent three-body force includes a three-pion exchange part and mostly affects the isospin $3/2$ part of the force. This part of the force is especially interesting since it is the part that is important in neutron star calculations. This part of the force is presently best constrained by the binding energies and charge radii of neutron rich light nuclei.

An important question is not only the isospin dependence of the three-body force, but also the spin-dependent part of the force. For this part, one would expect polarization measurements in nuclear reactions to be essential. However, there was no progress until recently when H. Witala *et al*[53] demonstrated the importance of the three-body force at large reaction angles for nucleon-deuteron elastic scattering. The importance of this work is that it extended Faddeev theory into the continuum so that scattering calculations involving three nucleons could be performed exactly for the first time. Another very interesting and potentially powerful approach is the use of chiral perturbation theory[54]

to constrain the terms that can appear in a three-body interaction.

Polarization experiments in proton-deuteron scattering have been performed at IUCF[55], RIKEN[56], and KVI[57]. Some results from an experiment at IUCF are shown in the Fig. 6. The important finding is that the calculations of polarization observables are significantly modified by the three-body force. Generally, the corrections are in the right direction, but the magnitudes of the correction are not correct, especially for the condition where the proton beam is polarized and the deuteron target is unpolarized. This condition gives a measurement of the beam polarization or A_y . Problems in describing A_y persist even at low energies and may be an indication[58] of a tensor part to the three-body force. Clearly, high-quality data of this kind are essential in determining the spin-dependence of the three-body force. Further experiments are planned at IUCF and RIKEN in the near future.

5. FORM FACTORS of ^3He and ^4He

One of the main goals of few-body physics is to have a consistent theoretical description of the form factors of the light nuclei. There has been recent experimental work[59] at MIT-Bates to extend the magnetic form factor of ^3He up to a momentum transfer of approximately 46 fm^{-2} . In the high momentum transfer range, the MEC dominate the cross section. The MEC shifts the first minimum in the form factor from about 7 fm^{-2} to about 15 fm^{-2} . Surprisingly, the calculations by Marcucci *et al*[60] show rather poor agreement with the location of the first minimum in the magnetic form factor data. This calculation does extremely well for the deuteron in this momentum transfer range. The earlier calculations by Hadjimichael *et al*[61] and Struve *et al*[62] are in better agreement with the data. However, if one compares with the charge form factor of ^3He , then the Marcucci *et al* calculation gives a good description of the low momentum transfer region. The isoscalar and isovector form factors can be formed from the form factors of ^3He and ^3H . A comparison with these indicates that the isovector part of the magnetic form factor is not adequately explained by the theoretical calculations of Marcucci *et al*. This difficulty also persists in the capture reactions in light nuclei for example the $p(n,\gamma)d$ reaction is mostly described by the impulse approximation and calculation agree with the data. However, for the $^3\text{He}(n,\gamma)^4\text{He}$ the MEC part accounts for approximately 90% of the cross section and the calculation disagrees[64] with the data. It is important to "calibrate" the meson-exchange currents with these low energy data. With the energy upgrade and MAD, the ^3He form factor measurement can be extended[63] up to 145 fm^{-2} .

Very little data exist for the form factors of ^3H . It is planned to develop a tritium target in order to measure the elastic form factors of tritium. In addition, it is planned to use this target to measure the proton form factor in the nucleus. With the upgrade it is planned to measure the quark u/d ratio by comparing inclusive electron scattering from ^3H and ^3He targets.

For ^4He , the agreement is better with the VMC method than the GFMC method for calculating the He wave function. This surprising result likely indicates again that the MEC part of the calculation must be improved.

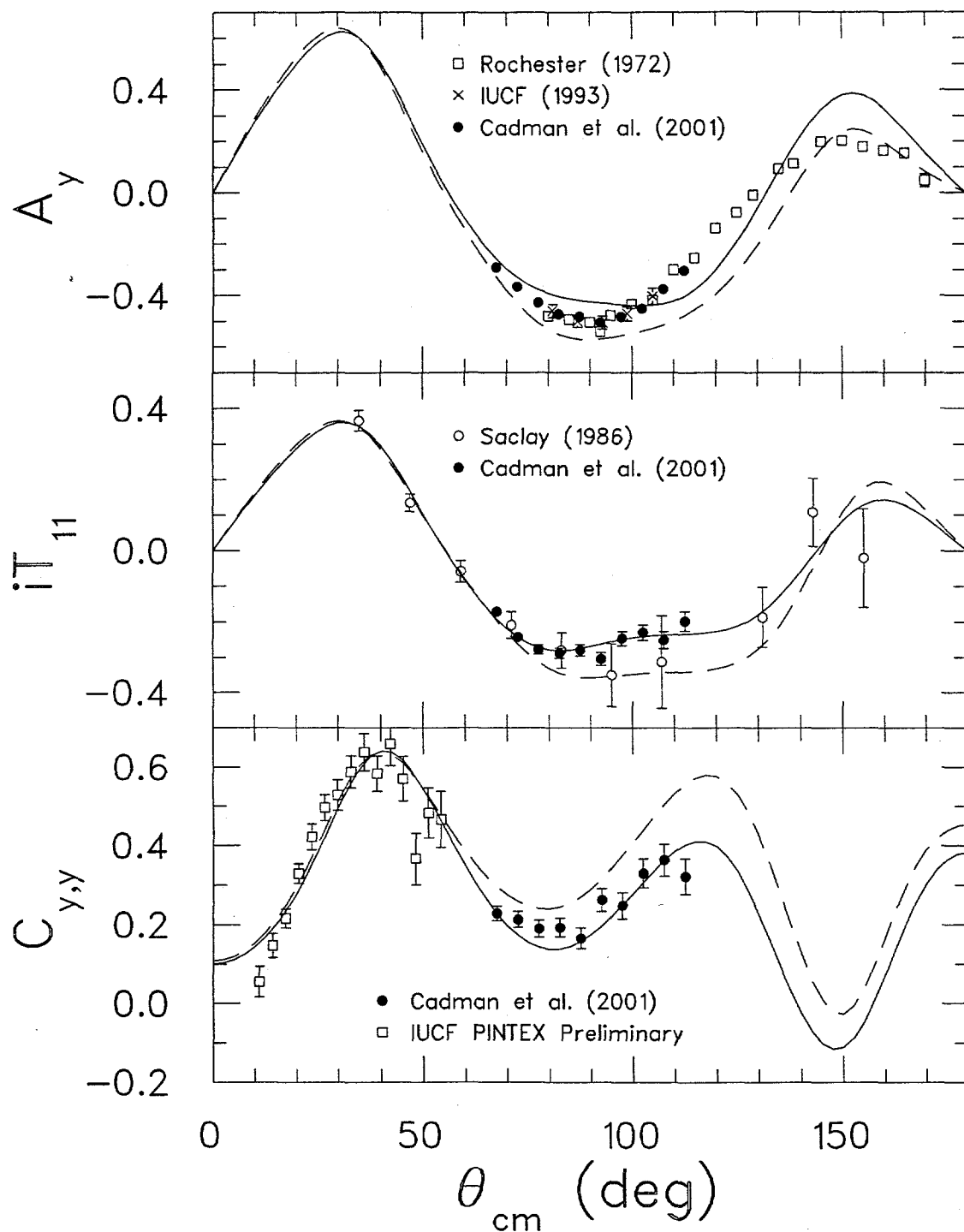


Figure 6. Polarization data for proton-deuteron elastic scattering at IUCF. The dashed curve represents only the two-nucleon force, CD-Bonn, while the solid curve also includes the three-body force, Tucson-Melbourne. There is substantial sensitivity to the three-body force at large scattering angles. The solid points were taken[55] with a laser-driven polarized deuterium target at IUCF.

6. FEW BODY NUCLEI as a "LABORATORY"

The advance in our understanding of few body nuclei over the past five years permits us to use the few body nuclei as a "test bed" for a deeper understanding of the strong interaction. For example, the question of whether the nuclear medium modifies the properties of the nucleons and mesons, whether short range nuclear correlations can be observed, and whether we can observe charge symmetry violation due to the light quark mass difference.

6.1. Nuclear Medium Effects

6.1.1. The EMC Effect

The most celebrated medium modification effect is the EMC effect in nuclei where deep inelastic scattering from nuclei exhibits a different parton distribution from that of just A free nucleons. This effect is well-documented in heavy nuclei. Although many models exist to explain the effect, none are well accepted. **Light nuclei offer a more rigorous study of the EMC effect since exact few body calculations can be performed.** A noted example are recent calculations by Benhar et al [66]. Benhar can explain many of the features of the EMC effect above $x = 0.2$ for nuclear matter, and has predictions for light nuclei. It is found that nuclear pions improve the agreement with the data in the intermediate x range. These calculations can be tested in ^3He , but little data [65] exist. The EMC effect in these light nuclei will be studied [67] at JLab.

6.1.2. The HERMES Effect

In addition to the EMC effect, there exists a HERMES effect [65] at low x in nuclei. **Surprisingly, the ratio of the longitudinal to transverse cross section appears to be enhanced in ^3He and ^{14}N relative to that in the deuteron at low values of x as shown in Fig. 7. This effect is not understood.**

However, this effect has been explained [68] in terms of a $\sigma - \omega$ model. Studies of light nuclei might reveal further interesting features of the effect. Experiment E99-118 at JLab as well as data for ^{41}Kr from HERMES should provide further information about this novel effect. **Clearly, the EMC and HERMES effect show that the nucleus cannot be taken as just a collection of nucleons.**

6.1.3. Pion in the Nuclear Medium

The pion is believed to have an important role in the nuclear and nucleon structure. It would be interesting to determine whether the pion structure function is modified in the nuclear medium. From a straightforward application [70] of the Nambu Jona-Lasinio model, it appears that there would be no medium modification. However, the NJL model does not explicitly include binding. If instead, Brown-Rho scaling [71] is valid, then one would expect a significant medium modification. It appears possible to measure the pion structure function in a light nucleus, for example, ^3He . This question is being explored [72] for both a JLab experiment and a possible electron-ion collider facility.

6.1.4. $A(e,e'p)$ and $A(p,2p)$

A search for medium modifications was performed [73] at Mainz. Here the ratio of the electric to magnetic form factor of the proton in ^4He was measured by measuring the normal polarization transfer in the $^4\text{He}(e,e'p)^3\text{H}$ reaction. While the measurement indicates that the ratio of these form factors to the free ratio is only about 90%, it

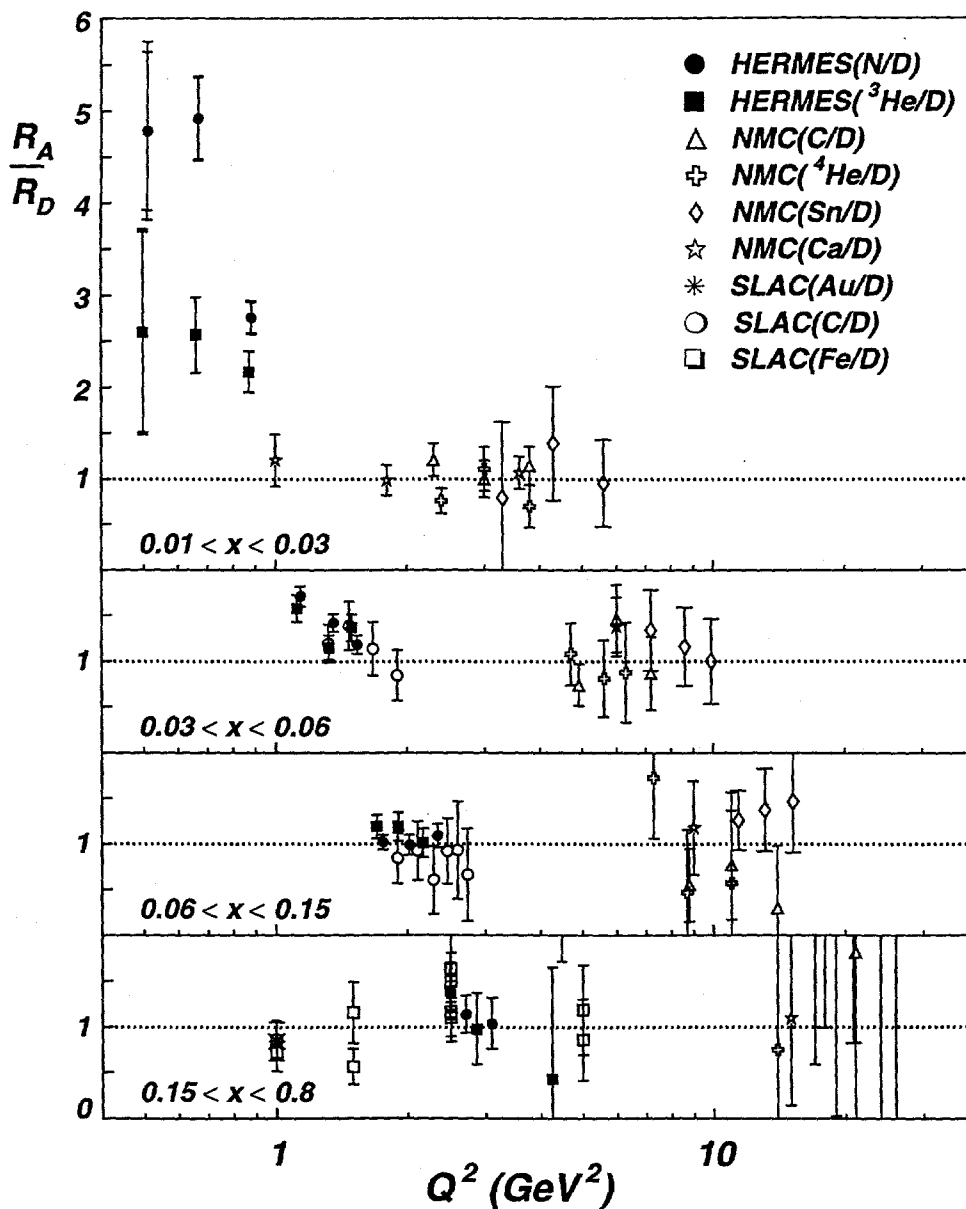


Figure 7. The HERMES effect in ³He and ¹⁴N. The ratio of the longitudinal to transverse deep inelastic scattering cross section in ³He and ¹⁴N compared to that in the deuteron.

appears that the theoretical calculations that are fully relativistic can explain the data without medium modification.

The first polarized internal target experiment[74] at IUCF was $^3\text{He}(p, p'n)p$. It was found that at relatively low missing momentum, the results are in surprisingly good agreement with PWIA, but deviate from PWIA above a missing momentum of about 300 MeV/c.

This deviation from PWIA at high missing momentum is perhaps related to the fact that the minimum expected in $^4\text{He}(e, e'p)$ has not been observed. The first search for the minimum in this reaction was performed[75] at NIKHEF. However, for this search it was believed that the final state interactions could readily fill the minimum since to reach large p_m , a relatively large angle between the incident photon and the outgoing proton was necessary. In addition, I. Sick[76] has pointed out that multi-step final state interactions could be important at high missing energy.

Recently, preliminary data[77,78] from JLab at a more favorable kinematics, a small θ_{pq} aimed at minimizing the effects of final state interactions also do not reveal a minimum in the cross section. While this remains a mystery, it is likely that further experimental work[76], planned for the near future at JLab, will shed more light onto the missing minimum problem and the role of multi-step final state interactions. A further possibility is that short-range correlations fill this minimum.

6.2. Short-Range Correlations

A long-standing goal of nuclear physics is to study short-range correlations in nuclei. Until recently the search for short-range correlations has eluded all efforts. Direct evidence for short range correlations has emerged[79] from a recent $^3\text{He}(e, e'2p)$ experiment in Hall B. The signature for short-range correlations is (1) a fast proton which has absorbed essentially all of the virtual photons four momentum, (2) the back-to-back emission of a pn pair, (3) a large relative pn pair momentum, and (4) essentially no average pair momentum along the direction of the virtual photon. An enhancement in the yield in these kinematic conditions has been observed in the preliminary data from Hall B. If these data stand further scrutiny, then further experimental and theoretical work will be necessary to obtain quantitative information from this very promising beginning.

6.3. Charge Symmetry Breaking

Charge symmetry breaking continues to be of extremely high interest because of recent advances in chiral perturbation theory[80]. For example, the $dd \rightarrow \alpha\pi^0$ reaction is particularly interesting for the study of charge symmetry breaking. Recently, this reaction was proposed[81] to be carried out at IUCF. This reaction is most sensitive to the light quark mass difference because odd partial waves are excluded from the pion channel. This means that the usual $\pi - \eta$ mixing terms that usually enter other reactions such as $np \rightarrow d\pi^0$ are strongly suppressed in this reaction. The light quark mass difference is usually found from the neutron-proton mass difference, however coulomb self energy terms can complicate this interpretation. A calculation of this difference from lattice gauge theory is still somewhat distant. Thus, a result from this experiment[82] in the near future would be most interesting as a further test of the chiral effective field theory.

7. Summary and Outlook

Few body physics has entered a Renaissance. With the advent of new facilities and experimental techniques, the quantity and quality of interesting data has burgeoned in the past few years. Similarly, there have been rapid advances in few-body nuclear theory. In the past few years, we have seen the rise in the nuclear standard model, relativistic calculations, application of chiral perturbation theory, and Faddeev calculations extended into the continuum. Thus, during the past five years, significant experimental and theoretical "tools" have become available. The prospect for improving these methods and applying them to the central questions in our field represents a tremendous opportunity for the next five years.

There remains a substantial amount of work to significantly increase our understanding of the strong interaction in nuclei. One can identify several high-priority areas for further study:

(1) Map out the "transition region", the region between where meson-exchange models are valid and where pQCD is valid. More data are needed to understand this region. Elastic scattering as well as high-energy photodisintegration experiments will be essential. In addition, more theoretical effort will be necessary in this region.

(2) Simultaneously describe the mass 2, 3 and 4 body form factors. For this, more data for the triton as well as higher accuracy data for T_{20} will be needed. A dedicated theoretical effort will be necessary as well

(3) Determine the spin-dependence and isospin dependence of the three-body force. High accuracy polarization data in p-d elastic scattering and the break-up channel will be necessary. Measurements of the masses and charge radii of neutron rich light nuclei will be necessary.

(4) Find the enhancement of antiquarks or pions in nuclei. This is an absolute priority since our whole understanding of the nuclear standard model is based on the existence of this pion excess. For this, further Drell-Yan as well as $A(e,e'\pi)$ experiments likely will be essential.

(5) Study the effects of the nuclear medium in light nuclei. In particular, map out the EMC and HERMES effects in light nuclei where "exact" nuclear calculations can be performed. In addition, determine the effect of the nuclear medium on the meson structure functions. Determine the reason for the "missing" minimum in the proton distribution in ${}^4\text{He}$.

(6) Pursue and quantify short range correlations in nuclei.

(7) Measure the charge symmetry breaking effect in few-body nuclear reactions.

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