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MEASUREMENTS OF THE DEUTERON ELASTIC STRUCTURE FUNCTION $A(Q^2)$ AT THE JEFFERSON LABORATORY

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FOR THE JEFFERSON LAB HALL A COLLABORATION*

Results from experiment E91-026 In Hall A at the Jefferson Laboratory are reported. The aim of this experiment was to extract the deuteron structure function $A(Q^2)$ from coincidence elastic electron-deuteron cross-section measurements. A squared four-momentum transfer (Q^2) range of 0.7 to 6.0 $(\mathrm{GeV/c})^2$ was covered. Data from this experiment improve the quality of existing data at the low end as well as significantly extend the Q^2 range. The results are compared to conventional meson-nucleon calculations based on both the non-relativistic and relativistic impulse approximation. They are also compared to predictions of dimensional scaling and perturbative quantum chromodynamics.

1 Introduction

Electron scattering from the deuteron is an ideal testing ground to study the nucleon-nucleon (NN) interaction at short distances. It also allows the study of the role of meson exchange currents (MEC). Models based on the non-relativistic impulse approximation[1] (IA) augmented by MEC[2] and isobar contributions[3] (IC) are expected to describe the low momentum transfer data[4,5,6,7]. As the momentum transfer increases, relativistic calculations[8,9,10] (RIA) might become necessary giving way to quantum chromodynamics[11] (QCD) at very large momentum transfers. There are problems in this simple picture: in the case of the IA and RIA calculations, the coupling constants and form factors of MEC like the $\gamma\pi\rho$ are poorly determined. In the case of QCD or the calculationally simpler perturbative QCD (pQCD), the momentum transfer at which these calculations are expected to be applicable is highly controversial. Several authors have argued[12,13] that pQCD is not applicable at the squared momentum transfer reached by this experiment. Finally,

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there are hybrid models[14,15] which incorporate both descriptions: at large NN separations, the nucleus is treated in terms of nucleons and mesons while for internucleon distance of ≤ 1 fm, the deuteron is described as a six-quark object.

Here we present a brief decription of experiment E91-026 in Hall A at the Jefferson Laboratory (JLab) and report results on $A(Q^2)$. The final results have been submitted for publication[16]. Although values for $B(Q^2)$ in the range of 0.7 to 1.4 $(\mathrm{GeV/c})^2$ were also extracted, these will be presented elsewhere.

2 Form Factors

The cross section for unpolarized elastic electron scattering of the deuteron is given by

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega} = \sigma_{\mathrm{M}} \left[A(Q^2) + B(Q^2) \tan^2\left(\frac{\theta}{2}\right) \right], \tag{1}$$

with σ_{M} the Mott cross section, Q^2 the squared four-momentum transfer and θ the electron scattering angle. The electric and magnetic structure functions $A(Q^2)$ and $B(Q^2)$ can be expressed in terms of the charge monopole, magnetic dipole and charge quadrupole form factors F_{C}, F_{M} and F_{Q}

$$A(Q^2) = F_{\mathrm{C}}^2 + \frac{2}{3}\tau F_{\mathrm{M}}^2 + \frac{8}{9}\tau^2 F_{\mathrm{Q}}^2 \tag{2}$$

$$B(Q^2) = \frac{4}{3}\tau(1+\tau) F_{\mathrm{M}}^2, \tag{3}$$

with τ being a kinematical factor. $A(Q^2)$ and $B(Q^2)$ can be extracted by means of a Rosenbluth separation where the differential cross section $\mathrm{d}\sigma/\mathrm{d}\Omega$ is measured at different electron scattering angles keeping Q^2 constant. F_{M}^2 is given directly by $B(Q^2)$. F_{C} and F_{Q} can only be separated by measuring additional polarization observables, e.g. the deuteron tensor polarization t_{20} (JLab experiment E94-018[17]).

The Rosenbluth technique is, however, limited to small Q^2 due to $B(Q^2)$ becoming much smaller than $A(Q^2)$. Backward electron scattering (180° scattering) at higher Q^2 values allows us to extend the knowledge of $B(Q^2)$, because the contributions from F_{C} and F_{Q} vanish at 180°. Similarily, the separation of F_{C} and F_{Q} is restricted to small Q^2, for experimental reasons. It will be difficult to extend the Q^2 range of 0.65-1.85 $(\mathrm{GeV/c})^2$ spanned by E94-018 to higher Q^2.

3 Experimental Setup

The measurements used the Continuous Electron Beam Accelerator (CEBA) and the Hall A facilities of JLab. Electrons with energies of 3.2 to 4.4 GeV and beam currents of 5 to 120 μA were scattered off a high power (700 W) cryogenic deuterium/hydrogen target. Scattered electrons and recoiling deuterons were detected in coincidence using the two 4 GeV/c High Resolution Spectrometers (HRS) in Hall A. Both HRS's used two planes of scintillators for triggering and timing and a drift chamber system for particle tracking. The electron HRS was also equipped with a gas Čerenkov counter and a lead-glass calorimeter for electron identification. Elastic electron-proton scattering in coincidence was used to check the double-arm system acceptance. Incomplete triggers (one of the two scintillator planes missing) were prescaled and recorded, for detector efficiency studies.

4 Discussion of the Results

Figure 1 shows the $A(Q^2)$ data of this experiment as filled circles. The left

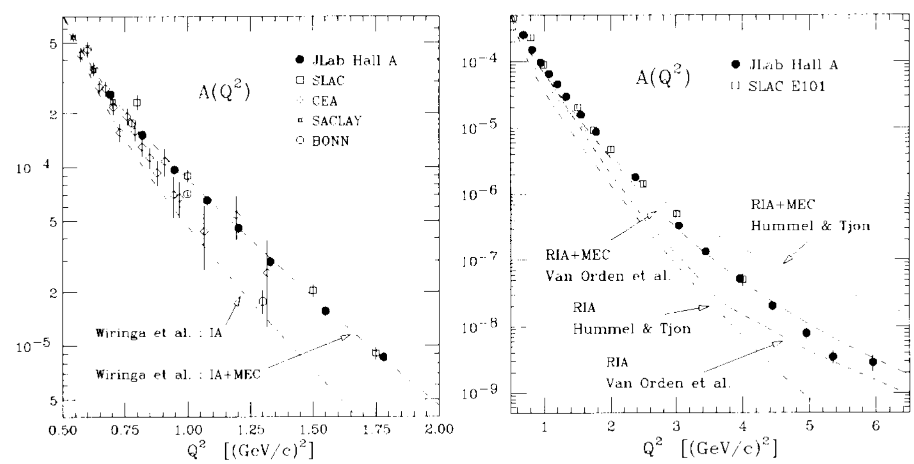

Figure 1. $A(Q^2)$ data from this experiment (filled circles), compared to previous data taken at SLAC[5] (open squares), CEA[4] (open diamonds), Saclay[7] (crossed squares) and Bonn[6] (open circles), as function of squared four-momentum transfer. In the left half $[Q^2 \leq 2\,(\mathrm{GeV/c})^2]$ they are compared to IA predictions[1], without (dash-dot) and with inclusion of MEC (dashed curve), in the right $[Q^2 \leq 6.5\,(\mathrm{GeV/c})^2]$ to RIA models[8,9], with and without MEC.

panel focuses on the low Q^2 region. One of the long-standing issues is, despite large experimental errors, an apparent discrepancy between the SLAC[5] and the CEA[4] and Bonn[6] data sets. The E91-026 data show excellent agreement with the SLAC results. The IA predictions[1], after inclusion of MEC, seem to provide a good description of the data.

The right side of Fig. 1 shows $A(Q^2)$ over the entire Q^2 range studied. Again, there is excellent agreement between our results and the SLAC[5] data in the range of overlap. Our results continue with a smooth fall-off to larger Q^2. RIA calculations[8,9] are able to describe this behaviour. The agreement, however, depends on the $\gamma\pi\rho$ MEC coupling constants and form factors chosen: those of Hummel and Tjon[9] are based on a vector dominance model (VDM) while those of Van Orden *et al.*[8] are based on a quark model.

Dimensional scaling[18] and pQCD[11] predict $\sqrt{A(Q^2)}$ (the deuteron form factor F_d) to fall off as $(Q^2)^{-5}$ at large Q^2. In this case, the product $F_d \cdot (Q^2)^5$ should be independent of Q^2 (scaling). Figure 2 shows this product as function

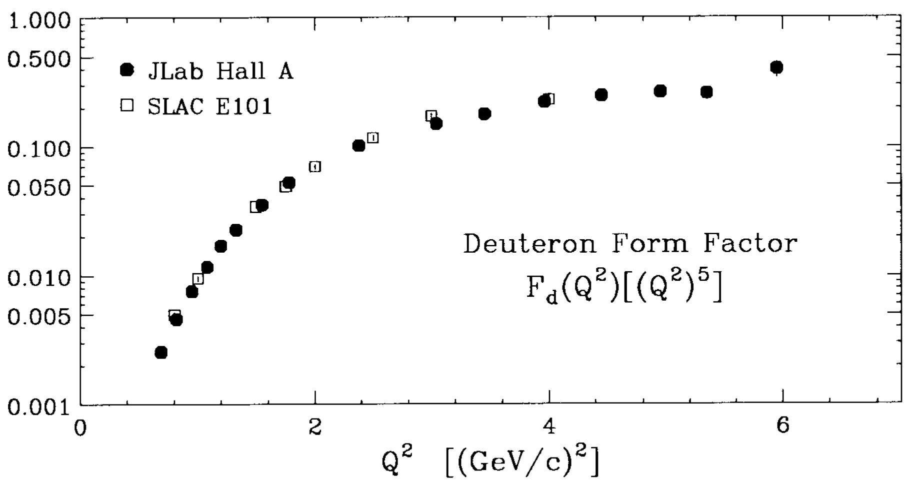

Figure 2. (F_d) (i.e. $\sqrt{A(Q^2)}$), multiplied by $(Q^2)^5$, as function of Q^2. The filled circles represent data from this experiment, the open squares those taken at SLAC[5].

of Q^2. Our data indicate an approach to scaling. Despite the validity of pQCD being questioned[12,13] at moderate values of Q^2, such a scaling behaviour has been also reported from deuteron photo-disintegration experiments[19].

5 Summary

The elastic structure function $A(Q^2)$ has been measured for squared four-momentum transfers up to $6\,(\mathrm{GeV/c})^2$. The results have clarified inconsistencies in previous data sets for $Q^2 \leq 1.4\,(\mathrm{GeV/c})^2$. The data are consistent with calculations based on RIA including MEC, with specific choices for the MEC form factors. At large Q^2 the data seem to approach scaling, as predicted by pQCD. However, $A(Q^2)$ and $B(Q^2)$ data as well as measurements of the form factors of the Helium isotopes at larger Q^2 will be crucial in verifying this above mentioned scaling behaviour.

References

1. R. Schiavilla and D. O. Riska, *Phys. Rev.* C **43**, 437 (1991), and references therein.
2. V.V. Burov, V.N. Dostovalov and S.E. Suskov, *Sov. J. Part. Nucl.* **23**, 317 (1992), and references therein.
3. R. Dymarz and F.C. Khanna, *Nucl. Phys.* A **516**, 549 (1990), and references therein.
4. J.E. Elias *et al.*, *Phys. Rev.* **177**, 2075 (1969).
5. R.G. Arnold *et al.*, *Phys. Rev. Lett.* **35**, 776 (1975).
6. R. Kramer *et al.*, *Z. Phys.* C **29**, 513 (1985).
7. S. Platchkov *et al.*, *Nucl. Phys.* A **510**, 740 (1990).
8. J.W. Van Orden, N. Devine and F. Gross, *Phys. Rev. Lett.* **75**, 4369 (1995), and references therein.
9. E. Hummel and J.A. Tjon, *Phys. Rev.* C **42**, 423 (1990).
10. P.L. Chung *et al.*, *Phys. Rev.* C **37**, 2000 (1988).
11. S.J. Brodsky *et al.*, *Phys. Rev. Lett.* **51**, 83 (1983).
12. N. Isgur and C.H. Llewellyn-Smith, *Phys. Lett.* B **217**, 535 (1989).
13. G.R. Farrar, K. Huleihel, and H. Zhang, *Phys. Rev. Lett.* **74**, 650 (1995).
14. T.-S. Cheng and L.S. Kisslinger, *Phys. Rev.* **35**, 1432 (1987).
15. H. Dijk and B.L.G. Bakker, *Nucl. Phys.* A **494**, 438 (1989).
16. L.C. Alexa *et al.*, submitted to *Phys. Rev. Lett.*, preprint available at http://www.jlab.org/Hall-A/publications/papers/e91026_prl.ps.gz
17. S. Kox *et al.*, JLab Proposal 94-018.
18. S.J. Brodsky and G.R. Farrar, *Phys. Rev. Lett.* **31**, 1153 (1973).
19. C. Bochna *et al.*, submitted to *Phys. Rev. Lett.*, preprint available at http://xxx.lanl.gov/ps/nucl-ex/9808001