# MEASUREMENT OF THE INTERNAL SPIN STRUCTURE OF THE PROTON

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(Talk presented by R. Oppenheim)

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## ABSTRACT

Our final results of measurements at SLAC of the spin dependent asymmetry in the deep inelastic scattering of longitudinally polarized electrons by longitudinally polarized protons are presented. Data were obtained at a scattering angle of 10° and for incident energies of 16.2 and 22.7 GeV, which cover the kinematic range $0.18<x<0.70$ and $3.5<Q^2<10.0$ $(GeV/c)^2$. We compare our results with various models of proton spin structure and with the Bjorken and Ellis-Jaffe sum rules.

## EXPERIMENT

Inclusive deep inelastic electron proton (and electron neutron) scattering is described by four independent structure functions. Two of these are spin dependent and can be determined only from measurements of the scattering of polarized electrons by polarized nucleons; indeed thus far the only information about them comes from our SLAC experiments. Knowledge of these spin dependent structure functions is important[1,2,3] for tests of the parton model, of models of nucleon structure, of the Bjorken polarization sum rule, and of QCD, and also is essential for an understanding of spin effects in high energy hadron-hadron scattering.

The method of the experiment has been described.[4] The polarized electron source[5] (PEGGY I), which is based on photoionization of electron-spin-polarized $^6$Li atoms, provided $5\times10^8 e^-$/pulse at 120 pps with a polarization of $0.80\pm0.03$. The polarized target, which was based on the method of dynamic nuclear polarization[4,6], consisted of butanol doped with porphyrexide and provided an average proton polarization of 0.60. The spectrometer (Fig. 1) consisted of two dipole magnets, a Cerenkov counter, a PWC system, p and θ hodoscopes, and a 20 radiation length segmented lead glass shower counter. The momentum acceptance $\Delta p/p_0$ (overall $\Delta\Omega\Delta p/p_0$) was 0.4 (~0.4 msr), and the accuracy of the momentum determination was better than 1%. The spectrometer was designed to detect electrons scattered vertically by $\theta=10°$.

The basic quantity measured was the intrinsic electron-proton asymmetry $A=[d\sigma(\uparrow\downarrow) - d\sigma(\uparrow\uparrow)]/[d\sigma(\uparrow\downarrow) + d\sigma(\uparrow\uparrow)]$. From A we determine the virtual photon-proton helicity asymmetry $A_1=(\sigma_{1/2}-\sigma_{3/2})/(\sigma_{1/2}+\sigma_{3/2})$ using the relation $A=D(A_1+\eta A_2)$ where $A_2$ is an interference term, $\eta A_2$ is small, and $\eta$ and D are known kinematic expressions. Half a million events were collected at each of two spectrometer settings with E(E') = 22.66(11.5) GeV and E(E') = 16.19(10.0) GeV.

## RESULTS

Analysis of the data is complete, including radiative corrections. Fig. 2 shows values of $A/D \simeq A_1$ obtained from experiments E-80 and E-130 plotted vs. $Q^2$ in three intervals of x. The error bars include statistical and systematic errors. To test scaling of $A_1$ the values of A/D have been divided by $\sqrt{x}$ (which described well the x dependence of our $Q^2$-combined data) and least-squares straight lines have been fit in the region $Q^2>2$ GeV$^2$. The assumption of scaling (zero slope) gives $\chi^2$/DOF of 0.43/5, 2.4/5 and 5/3 and confidence levels of 99%, 80% and 18%, for the top, middle and bottom boxes, respectively. We therefore conclude that scaling of $A_1$ holds within our errors.

The $Q^2$-combined values of A/D are shown in Fig. 3. Our data are best described by $A/D=(0.94\pm0.08)\sqrt{x}$ (with $\chi^2$/DOF=9.5/11) and are consistent only with the Carlitz/Kaur, the Schwinger and possibly the Close models of $A_1$. Our confidence levels in these models are 70%, 70%, and 3%, respectively.

Our data permit a test of the Ellis-Jaffe sum rule[7] for the proton:

$$S^p_{EJ} = 2\int_0^1 g_1^p dx = \int_0^1 \frac{dx}{x}\,\frac{A_1^p F_2^p}{1+R^p} = \frac{(0.89)}{3}\left|\frac{g_A}{g_V}\right| = 0.372 \pm 0.002$$

and of the Bjorken sum rule:[8]

$$S_{Bj} = 2\int_0^1 (g_1^p - g_1^n)dx = \int_0^1 \frac{dx}{x}\left(\frac{A_1^p F_2^p}{1+R^p} - \frac{A_1^n F_2^n}{1+R^n}\right) = \frac{1}{3}\left|\frac{g_A}{g_V}\right| = 0.418 \pm 0.002$$

if $A_1^n$ is approximated by zero. The integrand $A_1^p F_2^p/(1+R^p)$ is plotted in Fig. 4 using $F_2^p(x,Q^2)$ from available data[9] and the value R=0.25±0.10 from the SLAC ep data.[10] The smooth curve in the region $0.1<x<0.64$ is obtained from our fit $A_1=0.94\sqrt{x}$ and $F_2^p$ evaluated at $Q^2=4$ (GeV/c)$^2$ (which is the mean $Q^2$ value of our data). The integral under this curve in the data region $0.1<x<0.64$ is 0.189±0.016, which saturates 45% of the Bjorken sum rule. The integral over the full x range using the Regge theory prediction $A_1 \alpha\, x^{1.14}$ for $x<0.01$ and our fit $A_1=0.94\sqrt{x}$ for $x>0.1$ gives

$$2\int_0^1 g_1^p(x)dx = 0.33 \pm 0.10$$

In conclusion, our result is consistent with the Ellis-Jaffe sum rule for the proton. This implies that our results are also consistent with the Bjorken sum rule provided that the neutron contribution is as small as suggested by the Ellis-Jaffe sum rule for the neutron.

It would clearly be valuable to measure $A_1^n$ for the neutron and also the other structure function $A_2$ for both the proton and the neutron. Use of a polarized deuteron target as well as a polarized

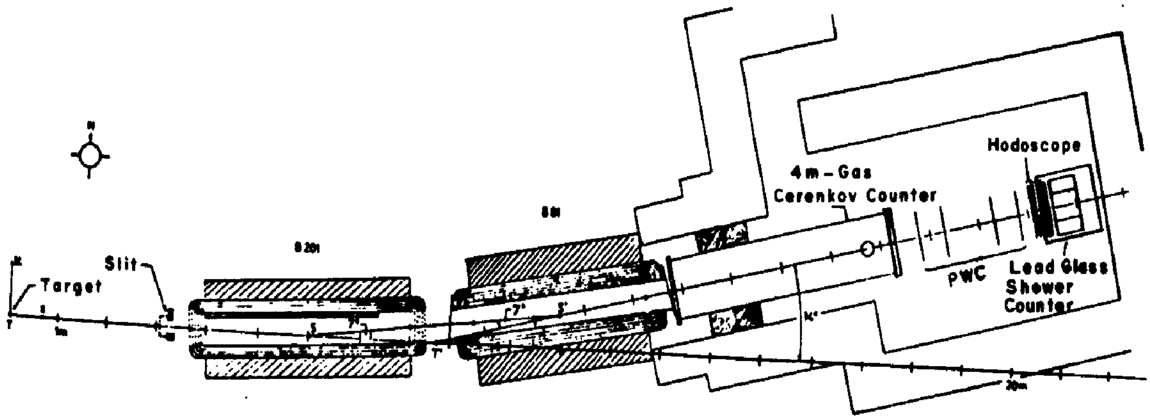

Fig. 1: E-130 Spectrometer (Plan View)

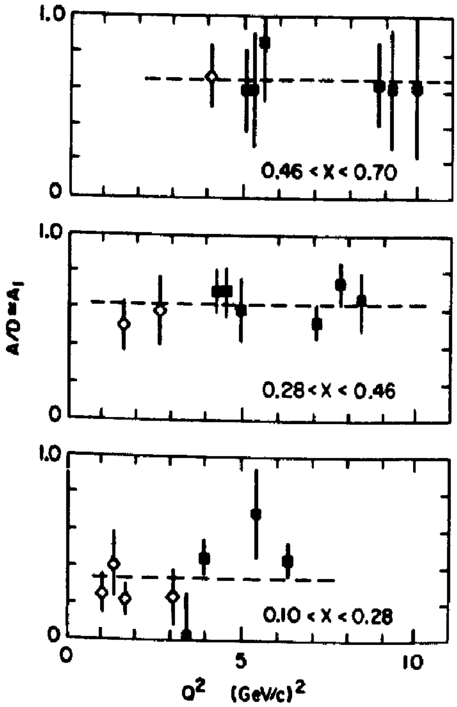

Fig. 2: Radiatively corrected values of $A/D \simeq A_1$ obtained in SLAC E80 (open diamonds) and SLAC E130 (closed squares)

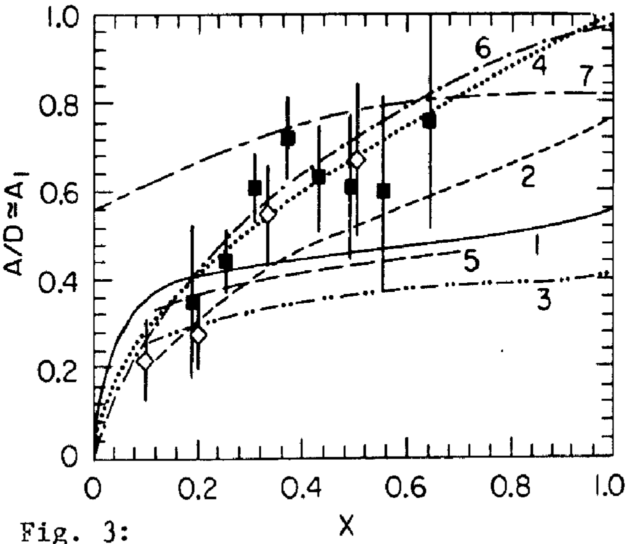

Fig. 3:
Experimental Values $A_1$ Compared with Theories.

1. Symmetrical Valence Quark Model (Kuti, Weisskopf, 1971).[11]
2. Current Quarks (Close, 1974).[12]
3. Orbital Angular Momentum, (Look, Fischbach, Sehgal, 1977).[13]
4. Unsymmetrical Model (Carlitz, Kaur, 1977).[14]
5. MIT Bag Model (Jaffe, Hughes, 1977).[15]
6. Source Theory (Schwinger, 1977).[16]
7. Quark-Geometrodynamics (Preparata, 1981).[17]

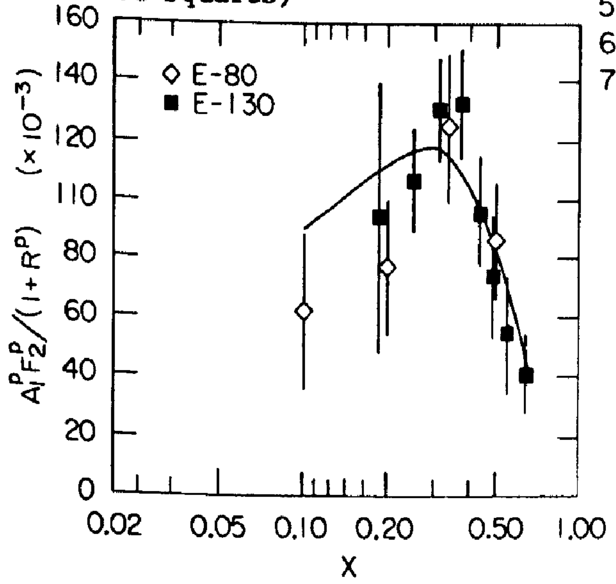

Fig. 4: Experimental values of $A_1^p F_2^p/(1+R^p)$. $F_2^p$ and R are from unpolarized data. The smooth curve is obtained using $A_1^p(x) = 0.94\sqrt{x}$.

proton target allows for the determination of the neutron structure functions. To determine $A_2$ the nucleon polarization must be transverse to the momentum and spin directions of the incident electron and lie in the scattering plane. We have designed an experiment for SLAC[18] using irradiated $NH_3$ and $ND_3$ targets as well as operation of our polarized target at 5T/0.6K, which is capable of determining $A_1^n$, $A_2^p$, and $A_2^n$ with accuracies about the same as those presented in this paper for $A_1^p$.

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## REFERENCES

†Deceased

1. V.W. Hughes in High Energy Physics with Polarized Beams and Polarized Targets, ed. by C. Joseph and J. Soffer (Birkhauser Verlag, 1981) p. 331.
2. V.W. Hughes in High Energy Physics with Polarized Beams and Polarized Targets, ed. by G.H. Thomas (AIP, New York, 1979), p. 171.
3. J. Kuti in High Energy Physics with Polarized Beams and Polarized Targets, ed. by C. Joseph and J. Soffer (Birkhauser Verlag, 1981) p. 344.
4. M.J. Alguard et al., Phys. Rev. Lett. 37, 1258 (1976); 37, 1261 (1976); 41, 70 (1978).
5. M.J. Alguard et al., Nucl. Inst. Meth. 163, 29 (1979).
6. W.W. Ash in High Energy Physics with Polarized Beams and Targets, ed. by M.L. Marshak (AIP, New York, 1976) p. 485.
7. J. Ellis and R. Jaffe, Phys. Rev. D9, 1444 (1974).
8. J.D. Bjorken, Phys. Rev. 148, 1467 (1966).
9. A.J. Buras and K.J.F. Gaemers, Nucl. Phys. B132, 249 (1978).
10. L.N. Hand, International Symposium on Lepton and Photon Interactions at High Energies, ed. F. Gutbrod (DESY, Hamburg, 1977) p. 417.
11. J. Kuti and V.W. Weisskopf, Phys. Rev. D4, 3418 (1971).
12. F.E. Close, Nucl. Phys. B80, 269 (1974).
13. G.W. Look and E. Fischbach, Phys. Rev. D16, 211 (1977); L.M. Sehgal, Phys. Rev. D10, 1663 (1974).
14. R. Carlitz and J. Kaur, Phys. Rev. Lett. 38, 673;1102 (E) (1977); J. Kaur, Nucl. Phys. B128, 219 (1977).
15. R.L. Jaffe, Phys. Rev. D11, 1953 (1975); R.J. Hughes, Phys. Rev. D16, 662 (1977).
16. J. Schwinger, Nucl. Phys. B123, 223 (1977).
17. G. Preparata in High Energy Physics with Polarized Beams and Polarized Targets, ed. by C. Joseph and J. Soffer (Birkhauser Verlag, 1981) p. 121.
18. SLAC E138 Proposal (1982).