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THE RATIO σ_L/σ_T FROM DEEP INELASTIC ELECTRON SCATTERING*

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ABSTRACT

Values of $R = \sigma_L/\sigma_T$ for deep inelastic electron-nucleon scattering have been derived from several experiments with incident electron energies up to 20 Gev. Included are previously unpublished measurements at intermediate angles (largely at 15° and 18°). An average value of $R = 0.22 \pm 0.1$ is obtained for the kinematic region covered by the experiments. No significant kinematic dependence of R is observed. A table of extracted values of the structure functions, νW_2 and $2MW_1$, is also presented.

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We report on a deep inelastic electron scattering experiment performed using the 20-GeV spectrometer facility at the Stanford Linear Accelerator Center. The experiment is one in a series of similar experiments performed by groups from MIT and SLAC.[1-8] All of these experiments provide data on the inclusive scattering from hydrogen and deuterium in the deep inelastic region, ($Q^2 > 2$ (GeV/c)^2, $W^2 > 4$ GeV^2). Combining data from this experiment with that from previous experiments, we have determined values of the structure functions for the nucleons and also values of $R \equiv \sigma_L/\sigma_T$, the ratio of longitudinal to transverse cross sections for the absorption of virtual photons.

The experimental set-up for these measurements was similar to that described in Ref. 5. Measurements of the cross sections were made in various kinematic ranges. For each value of beam energy, which ranged from 6.5 to 19.5 GeV, data runs were made for scattered momenta ranging from 2 GeV/c up to the momentum corresponding to elastic scattering. In the deep inelastic region there were measurements taken at approximately 8 separate (Q^2,W^2) points for each beam energy and angle.

The beam intensity was measured with two toroidally wound monitors which were calibrated against a Faraday cup to an absolute accuracy of ±1%. The average energy of the electrons was known to ±0.1% with a spread of ±0.375%. The size of the electron beam was about 2 mm with an angular spread of 0.1 mrad.

The targets for this experiment were similar to those used in previous experiments. The hydrogen and deuterium cells were each 7 in. long and had stainless steel walls 0.0017 in. thick. A third empty cell was used to simulate the scattering from the walls of the first two cells so that an appropriate empty target subtraction of about 5% could be made.

Multiwire proportional chambers (PWC's) measured the trajectories of scattered electrons which passed through the 20-GeV spectrometer. From these trajectories the momenta and scattering angles of those electrons were reconstructed with an angular resolution of ±0.1 mrad and a momentum resolution of ±0.1%. Signals from scintillation counters in coincidence with a shower counter signal provided the basic trigger. The shower counter and a Čerenkov counter were used to identify electrons. The trigger efficiency was measured to be greater than 99.5% for electrons. Track reconstruction efficiency in the PWC's was 94% (with about one half of the loss due to the presence of multiple tracks in the chambers).

The major systematic error in the measured cross section arose from the uncertainty in our determination of the optical properties of the spectrometer. The acceptance, $\Delta\Omega\Delta p/p$, depends primarily on the dispersion in momentum, the dispersion in scattering angle θ, and the accepted range in angle perpendicular to the scattering plane, ϕ. Various special measurements were made to determine the parameters of a mathematical model of the spectrometer. Variations in the model that were consistent with the measurements determined the systematic errors assigned to the acceptance. The p dispersion was measured by changing the momentum setting of the spectrometer in small increments and correlating the observed positions of the elastic peak in the focal plane with the computed momenta. The θ dispersion was measured by placing a grating of brass bars in front of the spectrometer and correlating the observed positions of the transmitted particles with the computed angles. Both of these dispersions showed a small but definite dependence on the spec-

trometer momentum setting, which had not been seen in the optics measurements using an electron beam made at the time of the initial commissioning of the spectrometer. The estimated systematic error in the spectrometer acceptance is ±4% based on these dispersion measurements. The ϕ acceptance was limited to ±8 mrad by slits in front of the spectrometer; however, this acceptance decreased slightly as θ increased because of finite target length effects. Uncertainties in the ϕ acceptance led to a final systematic error in the spectrometer acceptance of ±5% (see Table I).

The errors in the cross section are mainly systematic since the statistical accuracy of our measurements varied between 1-3%. Table I lists the sources and sizes of our systematic errors and leads to our estimate of ±7.5% as the average systematic error for this experiment. Reference 5 contains a detailed discussion of the error analysis.

The measured cross sections were corrected for radiative processes.[5,6] We first subtracted the contribution of radiation from elastic scattering processes. The remaining cross section was corrected for radiation between states in the inelastic continuum.

The radiative corrections were large, averaging about 20%, and there were differences as large as 25% between corrections for different scattering angles (e.g. 18°-60°) at the same (Q^2,W^2). Possible errors due to various approximations in the radiative corrections procedure, coupled with the large size of the corrections, led us to an estimate of a 5% systematic uncertainty in the final cross sections from this source.

The measured cross sections are consistent with previous measurements with this spectrometer, and with the overlapping measurements obtained with the 8-GeV spectrometer at 15° and 18°. In the latter case the present cross sections appear to be 4.5% higher than those in Ref. 4, well within the estimated relative systematic error of 8%. Tables of the measured cross sections are available[7] but are not reproduced here.

The differential cross section can be written as the product of a flux factor of virtual photon intensity, Γ, times the weighted sum of absorption cross sections for the virtual photons incident upon a nucleon,[9]

$$d^2\sigma/d\Omega dp = \Gamma(Q^2,W^2,\theta)[\sigma_T(Q^2,W^2) + \epsilon(Q^2,W^2,\theta)\sigma_L(Q^2,W^2)],$$

where σ_T is the photoabsorption cross section for transversely polarized photons, σ_L is that for longitudinally polarized photons, Q is the 4-momentum of the virtual photon, W the mass of the unobserved final hadronic state, Γ is the flux of virtual photons and ϵ is the polarization parameter for the photon. In order to determine σ_T and σ_L separately, we require cross sections at the same values of Q^2 and W^2 but at different angles (i.e., different ϵ).

We have determined the structure functions using the present data and those from the previous experiments. Small interpolations were necessary in order to obtain cross sections from different angles at precisely the same Q^2 and W^2. A grid of (Q^2,W^2) values was chosen with roughly the same spacing as the measured data points so that the correlation between the cross sections at neighboring grid points be small, and so that each grid point could be treated as an independent measurement of the structure functions.

For each grid point and scattering angle we determined $d^2\sigma/d\Omega dp$ divided by Γ. Figure 1 shows an example of the data at the grid-point $Q^2 = 9$ $(GeV/c)^2$, $W^2 = 7$ GeV^2. The data are from different angles (i.e., ϵ) and different experiments, and are seen to be consistent within systematic errors where they overlap. σ_L and σ_T are extracted by making a least squares fit to the data points which is linear in ϵ. The errors used in the fits are the quadratic sums of the statistical and systematic errors. In the present experiment the average systematic error was about 7.5%. The systematic errors assigned to the 50° and 60° data varied between 6% and 14%. The errors on the MIT-SLAC data[8] are a complicated function of kinematics, but the variation in error is not large and we adopted a systematic error of 5.5% for all kinematic points. The errors assigned to each data point were treated as uncorrelated errors in the fit. This is not rigorously true since some part of the systematic error represents a normalization error and would therefore be the same for all points from a given experiment. We estimate, however, that more than half of the systematic errors are not due to normalization, so that the assumption of independent errors seems reasonable. We have extracted σ_L/σ_T from all (Q^2,W^2) points having data which span at least 0.3 units in ϵ. Table II gives values of R, νW_2 and $2MW_1$, for each of the grid points chosen for both hydrogen and deuterium. The errors given are the cross section errors propagated through the fitting routine and so include our estimates of the systematic errors.

For hydrogen the average value of σ_L/σ_T over the entire (Q^2,W^2) range, using the combined data set is 0.22. The systematic error on the average value is estimated as ±0.1. This error in the average is

approximately the same size as the minimum error in R from a single grid point since combining individual measurements does not reduce the error when systematic errors dominate. If, for example, we allow the 1.6 GeV spectrometer data to increase by their systematic error everywhere, the average value of R decreases from 0.22 to 0.14. The values of R we report are consistent with earlier measurements.[1,3,4,8]

The quantity $R \equiv \sigma_L/\sigma_T$ is a measure of the spin of the constituents of the proton. In naive parton models, spin 1/2 partons give rise to small values of R,[10] which decrease as $1/Q^2$ with increasing Q^2 for fixed x ($\equiv Q^2/2M\nu$). Early predictions for R based upon QCD[11] were smaller in size than parton model calculations and were smaller than the measurements. In Figure 2 we present our data for hydrogen and deuterium by plotting the values of R versus Q^2 for different W^2 bins. We note that although early QCD calculations were somewhat lower than the data, higher-twist effects have been included in later calculations[12-14] and bring theory and data closer to agreement. Our data indicate the presence of higher-twist effects but we cannot distinguish among the various models.

Our conclusions on the experimental value for σ_L/σ_T are the following: 1. R is not consistent with zero; our best estimate for the average value is $R = 0.22 \pm 0.1$. These results are somewhat higher than theory, although higher-order corrections have substantially reduced the disagreement. 2. There is no evidence for a fall-off of R with Q^2, although the data are not inconsistent with this. 3. Our deuterium data are consistent with $R = 0.24 \pm 0.1$ and also show no kinematic trends.

REFERENCES

1. G. Miller et al., Phys. Rev. D 5, 528 (1972).
2. J.S. Poucher et al., Phys. Rev. Lett. 32, 118 (1974).
3. E.M. Riordan et al., Phys. Rev. Lett. 33, 561 (1974). See also E.M. Riordan, MIT Ph.D. thesis, MIT Report No. LNS-C00-3069-176 (1973).
4. E.M. Riordan et al., Report No. SLAC-PUB-1634 (1975). Paper contributed to 1975 International Symposium on Lepton and Photon Interactions at High Energies, Stanford, California.
5. S. Stein et al., Phys. Rev. D 12, 1884 (1975).
6. W.B. Atwood et al., Phys. Lett. 64B, 497 (1976). See also W.B. Atwood, Stanford University Ph.D. thesis, SLAC Report No. 185 (1975).
7. M.D. Mestayer, Stanford University Ph.D. thesis, SLAC Report No. 214 (1978).
8. A. Bodek et al., Phys. Rev. D 20, 1471 (1979).
9. L.N. Hand, Phys. Rev. 129, 1834 (1963).
10. C.G. Callen and D.J. Gross, Phys. Rev. Lett. 22, 156 (1969).
11. A. De Rújula, H. Georgi and N.D. Politzer, Ann. Phys. (N.Y.) 103, 315 (1977).
12. L.F. Abbott, W.B. Atwood, and R.M. Barnett, Phys. Rev. D 22, 582 (1980).
13. K.J. Kim, Phys. Lett. 76B, 95 (1978).
14. T. Kobayashi and N. Yamazaki, Prog. Theor. Phys. 65, 282 (1981).

Table 1. Systematic Errors

Source of Error	Size
Spectrometer Acceptance	5.0%
Electron Detection Efficiency	3.75%
Background Subtraction	3.0%
Interpolation	2.5%
Beam Intensity	1.6%
Target Thickness	1.0%
Average (rms) Systematic Error	7.5%

TABLE II. Values of R, νW_2, and $2MW_1$ for hydrogen and deuterium.
(Q^2 in $(GeV/c)^2$, W^2 in GeV^2)

		Hydrogen Target			Deuterium Target		
Q^2	W^2	R	νW_2	$2MW_1$	R	νW_2	$2MW_1$
3	4	0.186±0.152	0.1836±0.0059	0.4046±0.0423	0.274±0.16	0.2910±0.0091	0.5969±0.0642
	7	0.195±0.110	0.2906±0.0095	0.8328±0.0567	0.287±0.11	0.4870±0.0158	1.296 ±0.0897
	10	0.319±0.226	0.3412±0.0242	1.120 ±0.1214	0.185±0.22	0.5771±0.0439	2.108 ±0.2537
	13	0.174±0.217	0.3533±0.0319	1.587 ±0.1674	0.122±0.19	0.6133±0.0548	2.880 ±0.2790
6	4	0.120±0.186	0.0685±0.0035	0.1165±0.0142	0.158±0.18	0.1026±0.0050	0.1688±0.0201
	7	0.157±0.095	0.1593±0.0062	0.3179±0.0163	0.254±0.12	0.2490±0.0101	0.4586±0.0301
	10	0.203±0.116	0.2361±0.0108	0.5402±0.0318	0.354±0.13	0.3907±0.0172	0.7941±0.0521
9	4	0.209±0.119	0.0315±0.0013	0.0426±0.0028	0.217±0.11	0.0445±0.0018	0.0612±0.0040
	7	0.220±0.103	0.0905±0.0034	0.1419±0.0077	0.268±0.13	0.1342±0.0056	0.2023±0.0141
	10	0.208±0.131	0.1516±0.0076	0.2769±0.0180	0.194±0.14	0.2284±0.0118	0.4223±0.0304
	13	0.458±0.188	0.2230±0.0143	0.3842±0.0276	0.374±0.18	0.3436±0.0232	0.6286±0.0486
12	4	0.260±0.145	0.0161±0.0007	0.0191±0.0016	0.271±0.13	0.0236±0.0010	0.0277±0.0021
	7	0.202±0.116	0.0526±0.0024	0.0745±0.0044	0.358±0.13	0.0779±0.0033	0.0977±0.0059
	10	0.167±0.149	0.0975±0.0070	0.1609±0.0102	0.179±0.15	0.1462±0.0107	0.2387±0.0156
	13	0.422±0.300	0.1555±0.0157	0.2357±0.0277	0.185±0.25	0.2182±0.0244	0.3968±0.0439
	16	0.908±0.619	0.2439±0.0392	0.3055±0.0520			
15	4	0.204±0.186	0.0086±0.0006	0.0100±0.0010	0.298±0.18	0.0138±0.0009	0.0149±0.0013
	7	0.263±0.150	0.0332±0.0020	0.0414±0.0027	0.249±0.14	0.0470±0.0029	0.0593±0.0038
	10	0.281±0.201	0.0687±0.0057	0.0940±0.0078	0.005±0.17	0.0860±0.0091	0.1499±0.0115
	13	0.565±0.454	0.1200±0.0163	0.1485±0.0232			
18	4	0.166±0.170	0.0050±0.0004	0.0056±0.0005	0.262±0.17	0.0088±0.0006	0.0093±0.0008
	7	0.376±0.221	0.0218±0.0190	0.0236±0.0020	0.126±0.17	0.0296±0.0027	0.0390±0.0030

FIGURE CAPTIONS

Figure 1.

Virtual photoabsorption cross sections, $(d^2\sigma/d\Omega dp)/\Gamma = \sigma_T + \epsilon\sigma_L$, plotted against the polarization parameter, ϵ, for $Q^2 = 9$ $(GeV/c)^2$, $W^2 = 7$ GeV^2. Data from several experiments are shown. Overplotted is the result of a linear fit. σ_T is the $\epsilon = 0$ intercept and $\sigma_T + \sigma_L$ the $\epsilon = 1$ intercept; therefore the slope gives the value of $R = \sigma_L/\sigma_T$, which is 0.22 ± 0.10 for this plot.

Figure 2.

Values of σ_L/σ_T from Table II for hydrogen and deuterium are plotted versus Q^2 for various W^2. No striking kinematic variation is apparent. For clarity, only the errors for hydrogen are shown. The errors for deuterium are similar. The errors include systematic errors (see text). The solid line is the function $R = Q^2/\nu^2$; The dashed line is $R = 0.22$.

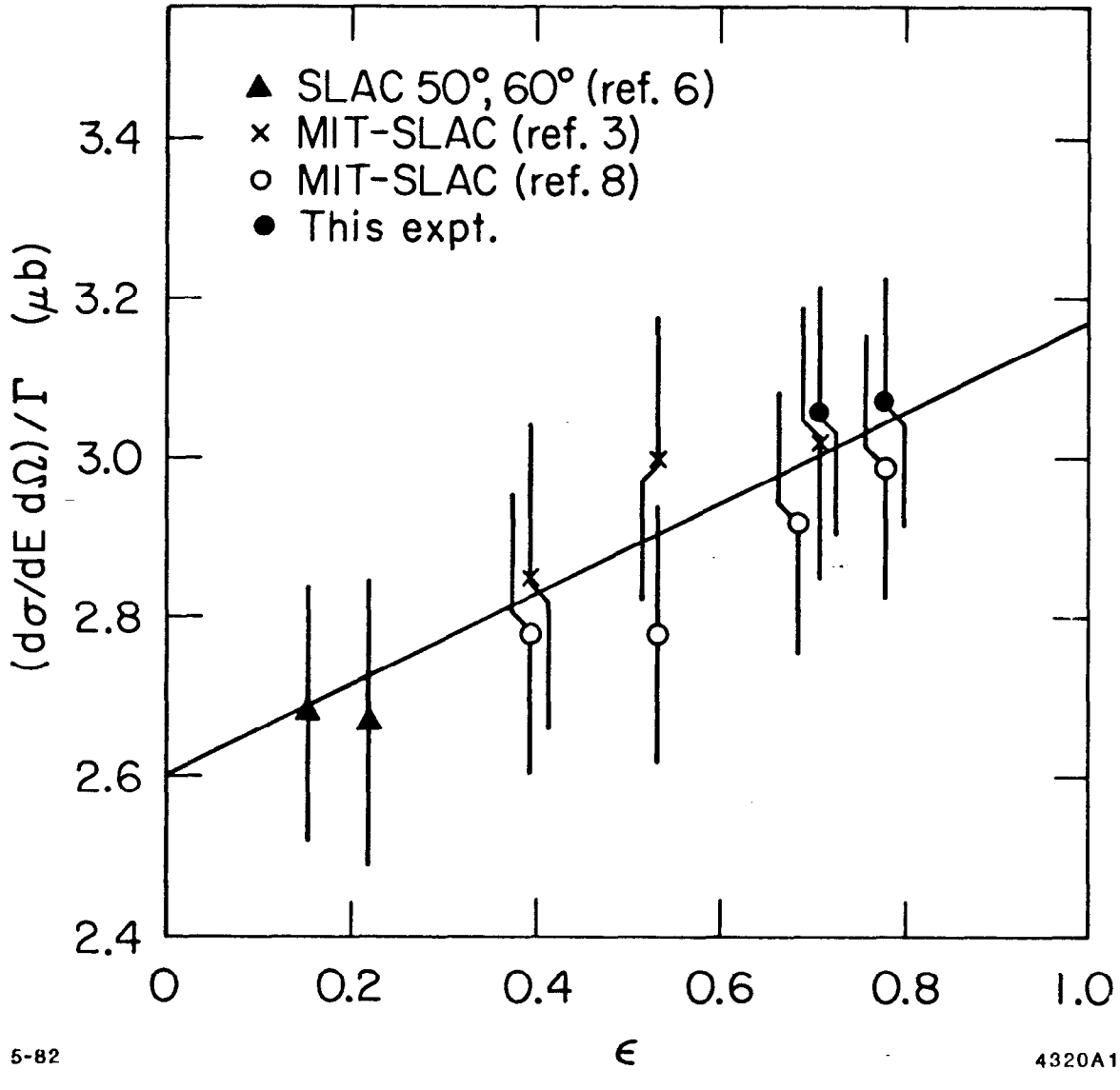
▲ SLAC 50°, 60° (ref. 6)
× MIT-SLAC (ref. 3)
○ MIT-SLAC (ref. 8)
● This expt.
3.4
3.2
3.0
2.8
2.6
2.4
(dσ/dE dΩ)/Γ (μb)
0
0.2
0.4
0.6
0.8
1.0
ε
5-82
4320A1

Fig. 1

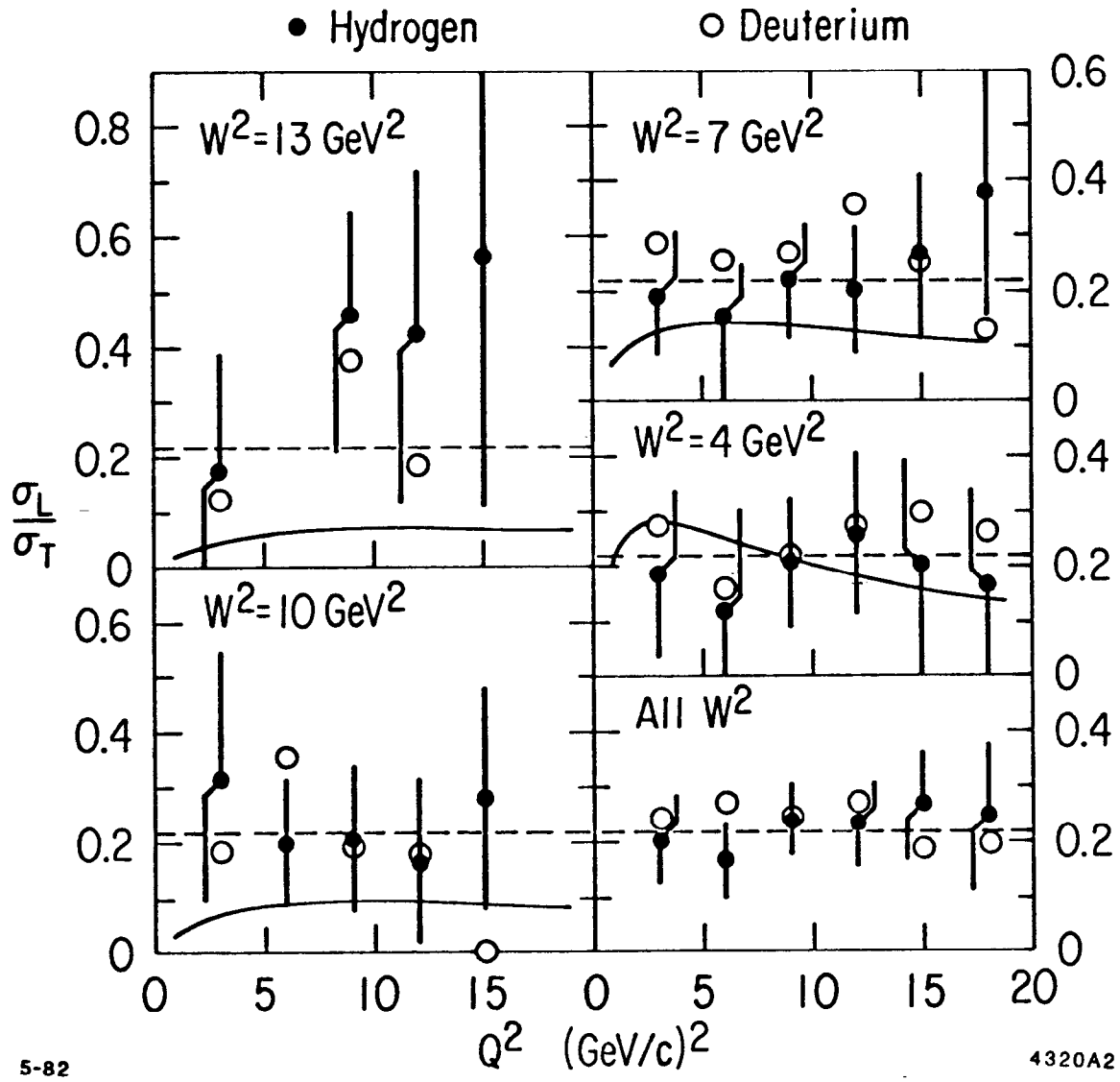
● Hydrogen
○ Deuterium
W^2=13 GeV^2
W^2=7 GeV^2
W^2=4 GeV^2
W^2=10 GeV^2
All W^2
$\frac{\sigma_L}{\sigma_T}$
Q^2 (GeV/c)^2
5-82
4320A2

Fig. 2