FURTHER MEASUREMENTS OF PARITY NON-CONSERVATION IN INELASTIC ELECTRON SCATTERING ☆

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We have extended our earlier measurements of parity violating asymmetries in the inelastic scattering of longitudinally polarized electrons from deuterium to cover the range $0.15 \leqslant y \leqslant 0.36$. The observed asymmetry shows only slight y dependence over this range. Our results are consistent with the expectations of the Weinberg–Salam model for a value of $\sin^2\theta_W = 0.224 \pm 0.020$.

Parity nonconservation in the deep-inelastic scattering of longitudinally polarized electrons from unpolarized deuterons has been reported in an earlier publication [1]. Parity nonconservation at these levels is predicted in many unified gauge theories where there is interference between the weak (neutral current) and electromagnetic scattering amplitudes. In our previous publication we observed the helicity dependence of the cross section and reported a value for the asymmetry at a single value of the fractional energy loss of the electron, $y = (E_0 - E')/E_0$. We report here additional measurements covering a range of y values in the reaction

$$e(\text{polarized}) + d(\text{unpolarized}) \to e' + X\,, \qquad (1)$$

taken with a beam energy of 19.4 GeV and at scattered electron energies from 10.2 to 16.3 GeV. Taken together with the measurements reported in ref. [1], the results provide more stringent tests for specific gauge theory models.

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Making a quark–parton model assumption that the electrons scatter from spin $\frac{1}{2}$ constituents of the target, it can be shown that the parity-violating asymmetry,

$$A \equiv (\sigma_R - \sigma_L)/(\sigma_R + \sigma_L) , \quad (2)$$

has the general form

$$A/Q^2 = a_1 + a_2 [1 - (1-y)^2]/[1 + (1-y)^2] , \quad (3)$$

where σ_R (σ_L) is the inelastic scattering cross section, $d^2\sigma/d\Omega\, dE'$, for positive (negative) helicity electrons, Q^2 is the magnitude of the four-momentum transfer squared, $y \equiv (E_0 - E')/E_0$, and E_0 (E') is the incident (scattered) electron energy [2–5]. In general, a_1 and a_2 may depend on kinematic parameters but for an isoscalar target such as deuterium they are expected to be constants. Measurement of the asymmetry for a range of y values permits separation of the coefficients a_1 and a_2. These coefficients are related to the neutral current couplings of the electron and the quarks and have specified values within a given gauge theory. In particular, the Weinberg–Salam model predicts a small value for a_2, while the so-called "hybrid" model, which incorporates a heavy neutral lepton, predicts $a_1 = 0$ and a large value for a_2. The latter model could accommodate the reported absence of parity violation in certain atomic physics experiments [6,7]. The possibility of an independent measurement of a_1 was an important motivation for extending our measurements.

The experimental arrangement was identical to that employed in ref. [1]. Longitudinally polarized electrons were obtained by photoemission from a gallium arsenide crystal optically pumped by circularly polarized laser light from a flash lamp pumped dye laser pulsed in synchronism with the linac (1.5 μs long, 120 pulses per second). The polarization was reversed randomly on a pulse-to-pulse basis. Electrons were accelerated with negligible loss of polarization. Electrons, inelastically scattered at 4° from a 30 cm long liquid deuterium target, were momentum analyzed and focussed by a three-element magnet spectrometer and detected in lead-glass shower counters. The signals from these counters were integrated during the entire beam pulse, thereby measuring the scattered electron flux (typically 1000 electrons) for each pulse. Studies were made to assure that the integrated signals from the counters were directly proportional to the incident beam flux, and that the widths of the distributions were consistent with the expected statistical widths based on the number of scattered electrons detected by that counter. Each of these important characteristics was checked regularly during the course of the experiment. Studies using movable slits within the spectrometer established that scattering from the magnet pole tips contributed little to the measured yields. Wire orbit measurements made at the end of the experiment verified the spectrometer central momentum and dispersion at each operating point.

The lead-glass counters were composed of two optically isolated pieces each viewed by separate photomultipliers. For the measurements of ref. [1] the spectrometer quadrupole current was set to maximize the acceptance of the counters, while for the new measurements the quadrupole current was increased to give a momentum focus in the plane of these counters. For each of these conditions the two lead-glass counters provided two separate momentum channels, though for the latter runs this division was considerably sharper, at the cost of a small fraction of the total acceptance. For all of the data presented here, the yields from each lead-glass counter have been treated separately.

Experimentally measured asymmetries, A_{exp}, are related to the parity-violating physics asymmetries, A, by

$$A_{exp} = P_e A , \quad (4)$$

where P_e is the magnitude of the beam polarization. Both the sign and magnitude of the polarization were determined by observing the asymmetry in the scattering of polarized beam electrons from polarized target electrons in a magnetized iron foil [8] [‡1]. Periodically we measured the polarization of the accelerated beam under the same conditions as for our data. The average polarization was 0.37; each measurement had a statistical error less than 0.01 and we estimate the overall systematic uncertainty to be 0.02.

The pion contamination in the scattered electron yield increases as the scattered electron energy decreases. Using counters placed behind a 27 radiation length lead absorber located behind the main lead-glass counters, it was established that there was a negligible asymmetry in the pion yields, and thus that the principal effect of pion contamination in the scattered

‡1 The present P_e measurements used the same target, but a different spectrometer and detector.

electron yields was to dilute the measured electron asymmetries. Corrections for pion contamination have been made using separately measured pion/electron ratios along with the measured values of the pion asymmetries.

The beam position, angle, and energy parameters were monitored with high precision on a pulse-to-pulse basis using a system of resonant microwave cavities [9,10]. Two cavities placed two meters upstream of our target measured horizontal and vertical position. Two more cavities placed 50 meters upstream permitted measurement of horizontal and vertical angles. A fifth cavity was located in the beam transport system where the beam was dispersed horizontally in energy. The beam charge delivered in each pulse was measured using standard toroid monitors [11]. The resolutions per pulse were 10 μm in position, 0.3 μrad in angle, 0.01% in energy, and 0.07% in beam intensity. A microcomputer driven feedback system used the position and energy signals to stabilize the average position, angle, and energy. Possible systematic asymmetries due to imbalance of any of these quantities between the two beam helicities contribute to the systematic uncertainties. The size of these effects can be determined from the measurements, and small corrections to the measured asymmetries were applied separately to each point. The systematic uncertainties for these corrections are estimated to be equal to the corrections themselves, and are included in the overall systematic errors.

We corrected for electromagnetic radiative effects by assuming that the asymmetry had a kinematic dependence given by eq. (3) and by using previously measured cross sections [12] and customary radiative correction formulae [13]. We ignored the effects of higher-order weak processes [14]. Radiative corrections do not generate asymmetries but for a given spectrometer setting give rise to effective values of Q^2 and y that differ from those calculated for the central orbit in the spectrometer. For our data radiative corrections reduced Q^2 by 1% to 3% and lowered the average y by 3% (at the lowest y) to 25% (at the highest y). We incorporated radiative effects into our data by shifting the Q^2 and y values to the average after corrections were included.

Table 1 gives the kinematic variables, fraction of pion contamination, and asymmetries measured for the eleven data points reported here. Five of these points are from the earlier data of ref. [1], reanalyzed in the separate momentum bins from the two halves of the shower counter. Three of these five points were taken at incident beam energies different from 19.4 GeV.

The errors assigned to the data come mainly from counting statistics; in addition there are point-to-point systematics and an overall uncertainty in the scale.

Table 1
Asymmetries and kinematic parameters. $x \equiv Q^2/2M(E_0 - E')$ and $y \equiv (E_0 - E')/E_0$. An overall error of ±5% in scale, due to uncertainty in P_e, is not included in these errors.

E_0 (GeV)	Q^2 $(\mathrm{GeV}/c)^2$	x	y	π/e fraction (%)	$10^5\ A/Q^2$ asymmetry $(\mathrm{GeV}/c)^{-2}$	total error $(\mathrm{GeV}/c)^{-2}$	statistical error only $(\mathrm{GeV}/c)^{-2}$
16.2	0.92	0.14	0.22	2.1	−11.8	±4.5	±3.4
19.4	1.53	0.28	0.15	0.8	− 8.9	±1.3	±1.1
19.4	1.52	0.26	0.16	0.9	− 9.2	±1.7	±1.2
19.4	1.33	0.16	0.23	2.1	− 6.3	±1.7	±1.4
19.4	1.28	0.14	0.25	2.8	−13.4	±2.8	±1.6
19.4	1.25	0.13	0.26	3.3	− 8.6	±2.0	±1.6
19.4	1.16	0.11	0.29	6.0	−10.4	±1.8	±1.4
19.4	1.07	0.09	0.32	10.8	− 4.6	±2.9	±2.2
19.4	0.93	0.07	0.36	25.0	− 5.3	±3.0	±2.0
22.2	1.96	0.28	0.17	1.0	− 7.0	±2.1	±1.9
22.2	1.66	0.15	0.26	2.9	− 8.9	±2.8	±2.2

The point-to-point systematic error consists of three terms: imbalance in beam parameters (average 2.5% of A), uncertainty in background subtractions (average 2.8% of A), and uncertainty in P_e (estimated 2.5% of P_e). We combine these point-to-point errors in quadrature and add them linearly to the statistical error. For the analysis that follows, we take these combined errors to be gaussian standard deviations. Finally, uncertainties in the measurements of P_e give a 5% uncertainty in the scale common to all asymmetries.

Fig. 1 displays our asymmetries as a function of y.. The errors are combined from statistical and systematic contributions; the inner error bar on each point shows the statistical error alone. The best fit y-dependencies of two gauge theory model predictions based on the SU(2) × U(1) gauge group are also shown. These two models differ in the assumed assignment of the right-handed electron. The original Weinberg–Salam model (W–S) [15], extended to include quarks [16], assumes that left-handed leptons and quarks are placed in weak isospin doublets and the right-handed leptons and quarks are in singlets. To describe inelastic scattering from the nucleon, we use the simple quark–parton model [5]. The predicted asymmetry at each y-value depends on the mixing parameter $\sin^2\theta_W$. For the W–S model fit we obtain $\sin^2\theta_W = 0.224 \pm 0.020$ and a χ^2 probability of 40%. The error given on $\sin^2\theta_W$ comes from a fit error of 0.012 added linearly to a contribution of 0.008 arising from the 5% systematic uncertainty in P_e. This value is consistent with our earlier result and with values obtained from a number of different neutrino neutral current experiments [17]. The hybrid model assumes the same isospin assignment for the quarks, but places the right-handed electron in a doublet with a hypothesized heavy neutral lepton [5]. For this model the best fit has a low value for $\sin^2\theta_W$ (= 0.015) and a χ^2 probability of 6×10^{-4}, which appears to rule out this model.

The determination of a value for $\sin^2\theta_W$ depends in part on the validity of the quark–parton model which, in fact, may not accurately describe inelastic

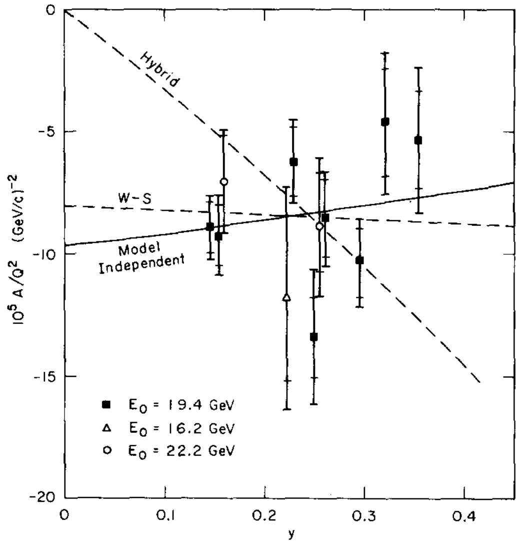

Fig. 1. Asymmetries measured at three incident energies are plotted against $y \equiv (E_0 - E')/E_0$. The total error bar gives the combined statistical and systematic error. The inner error corresponds to the statistical part only. The data are compared with two SU(2) × U(1) model predictions, the Weinberg–Salam model and the hybrid model. In each case $\sin^2\theta_W$ has been adjusted to minimize χ^2. See text. A two-parameter model-independent fit (eq. (3)), based only on simple parton model assumptions, is also shown. The Weinberg–Salam model is an acceptable fit to the data; the hybrid model appears to be ruled out.

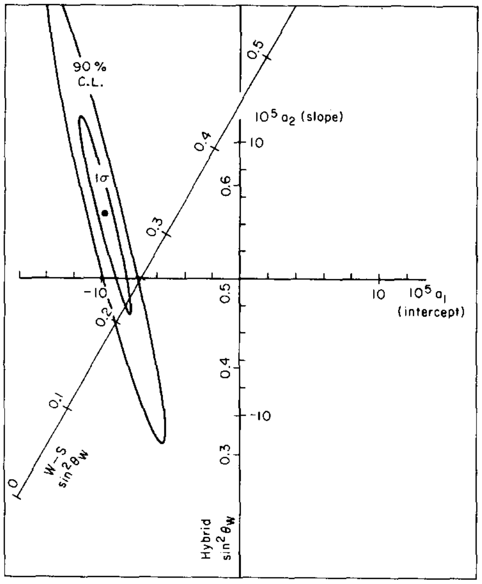

Fig. 2. The solid dot and the associated ellipses represent the fit to eq. (3). The contours correspond to 1σ and to the 90% confidence level, based on combined systematic and statistical errors assumed to be gaussian standard deviations. Also shown are the predictions of the Weinberg–Salam model (W–S) for various values of $\sin^2\theta_W$, and the predictions of the hybrid model which has $a_1 = 0$.

scattering in our kinematic range. To investigate the sensitivity of our quoted value for $\sin^2\theta_W$ to reasonable changes in the simple quark–parton model for our kinematic region, we modify the form of eq. (3) according to parameterizations suggested in refs. [2–4]. For the range of variation suggested for a_1, a_2 and the form of the y dependence, we find values of $\sin^2\theta_W$ between 0.207 and 0.227 for the W–S model. These values lie within our quoted errors, but the uncertainty on the "theory" may be comparable to our present experimental uncertainties.

We can also analyze our results independent of gauge theory assumptions. If we parameterize our results according to eq. (3), we obtain an intercept parameter $a_1 = (-9.7 \pm 2.6) \times 10^{-5}$ and a slope parameter $a_2 = (4.9 \pm 8.1) \times 10^{-5}$. This fit is also shown in fig. 1. Since these parameters are correlated, the χ^2 contours for values of a_1 and a_2 are shown in fig. 2. In this figure the W–S model is a straight line which passes through the region allowed by these results; the hybrid model coincides with the a_2 axis which is outside the allowed region. Within the W–S model the coefficients a_1 and a_2 are related and for a given value of $\sin^2\theta_W$ have definite values. We conclude that within experimental errors our results are consistent with the W–S model, and furthermore our best value of $\sin^2\theta_W$ is in good agreement with the weighted average for the parameter obtained from neutrino experiments.

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