

The E158 Experiment

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Abstract. We have carried out a precision of the parity-violating asymmetry A_{PV} in the scattering of longitudinally polarized electrons off electrons in a liquid hydrogen target. The measurement was performed with the 50 GeV beam line at SLAC. The final result with the full data set collected in three production runs is $A_{PV} = -131 \pm 14$ (stat) ± 10 (syst) parts per billion. The result leads to new limits on possible contact interactions at the TeV scale. We discuss future prospects for more precise measurements.

PACS. 12.15.Mm Neutral Currents – 11.30.Er C, P, T and other discrete symmetries

1 Introduction

Precision measurements of weak neutral current (WNC) interactions, mediated by the Z boson, play a central role in tests of the electroweak theory and in the search for new dynamics at very high energy scales. One class of WNC experiments involves measurements of the fractional difference in the cross-section for longitudinally polarized electrons scattering off unpolarized nuclear targets. A non-zero asymmetry (A_{PV}) is a signature of parity violation and arises from the interference between the WNC and electromagnetic amplitudes [1].

WNC measurements can test the standard model by comparing the extracted value of the weak mixing angle $\sin^2 \theta_W$ in each case (evolved to the same energy scale) to the precise value obtained in high energy collider measurements. A deviation would be a signature of new contact interactions at the TeV scale. Since fixed target WNC measurements are carried out at $Q^2 \ll M_Z^2$, such new physics amplitudes can interfere with the electromagnetic amplitude, unlike the case of WNC measurements at the Z resonance [2]. It is necessary, however, to measure $\sin^2 \theta_W$ to fractional accuracy better than 1% [3].

Prior to the E158 experiment, two published measurements achieved such sensitivity: the weak charge measurement in ^{133}Cs [4] and the NuTeV neutrino deep-inelastic scattering measurement [5]. Here, we discuss a measurement of A_{PV} in electron-electron (Møller) scattering [6], a purely leptonic reaction with little theoretical uncertainty [7, 8]. The E158 experiment at the Stanford Linear Accelerator Center (SLAC) was designed to use the longitudinally polarized 50 GeV electron beam to measure A_{PV} to a relative accuracy of about 10%.

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2 Experimental Overview

Target electrons, in a 1.54 m long cell of liquid hydrogen (10.5 gm/cm^2), were bombarded by a 48 GeV electron beam, the longitudinal polarization of which was changed pseudo-randomly. Møller electrons (beam electrons scattering off target electrons), were isolated by a forward magnetic spectrometer consisting of a 3-dipole "chicane" and 4 quadrupole magnets. Møller electrons of interest in the full range of the azimuth (spanning the polar angular range $4.5 \text{ mrad} < \theta_{lab} < 8 \text{ mrad}$) traversed through the bores of the quadrupoles and were brought to a ring focus on a calorimeter 60 m downstream of the target.

The experimental asymmetry was measured by averaging the fractional difference in the cross-section over complementary pairs of beam pulses of opposite helicity. In order to achieve the desired statistical precision of 10 parts per billion (ppb) in a reasonable length of time, the integrated signal of more than 20 million electrons were detected each beam pulse. The calorimeter provided both radial and azimuthal segmentation. The bulk of the electron-proton (ep) scattered flux was intercepted by the outermost ring. The radiative tail of the ep flux was the main background in the inner Møller rings, totalling $\approx 8\%$. Other background was less than 1%.

Data were collected over 3 run periods in 2002 and 2003. Rapid reversal of the polarization of the electron beam, generated via photoemission on a GaAs photocathode by circularly polarized laser light, suppressed spurious asymmetries. Additional suppression was achieved by passively reversing the sign of the asymmetry by two independent methods. First, the state of a half-wave plate in the laser line was toggled each day. Second, spin precession in the 24.5° bend after beam acceleration created opposite helicity orientation at 45 GeV and 48 GeV beam energies. Roughly equal statistics were accumulated with opposite signs of the measured asymmetry.

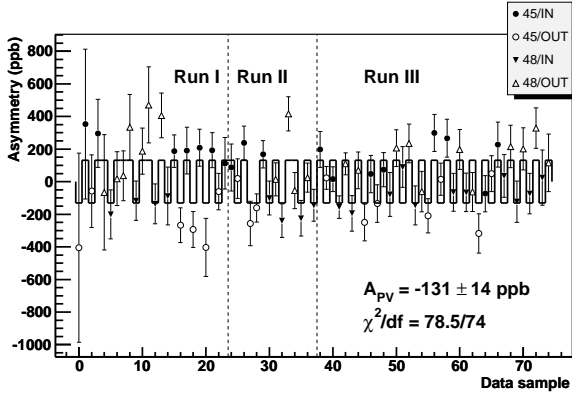


Fig. 1. A_{PV} for 75 data samples

3 Results and Implications

Figure 1 shows the parity-violating asymmetry as a function of data-set number. Each data-set constitutes about two days of data, after which either the beam energy or the state of the half-wave plate were changed to flip the sign of the measured asymmetry. The grand average result for the parity-violating asymmetry in Møller scattering at $Q^2 = 0.03 \text{ GeV}^2$ was found to be:

$$A_{PV} = -131 \pm 14(\text{stat}) \pm 10(\text{syst}) \quad (\text{ppb}). \quad (1)$$

From this measurement, the value of $\sin^2 \theta_W$ can be extracted within the context of the Standard Model. Using a definition which reproduces the effective leptonic couplings at the Z pole, we determine:

$$\sin^2 \theta_W^{\text{eff}} = 0.2397 \pm 0.0010(\text{stat}) \pm 0.0008(\text{syst}). \quad (2)$$

Figure 2 shows the E158 result, which establishes the "running" of $\sin^2 \theta_W$ [9] by more than 6 standard deviations. Also shown are the two other precise low energy $\sin^2 \theta_W$ determinations mentioned earlier. It can be seen that the ^{133}Cs result and the E158 result are consistent with the standard model expectation. The deviation of the NuTeV result thus implies that either there are new contact interactions specific to neutrino interactions or that there are additional strong interaction effects that are unaccounted for. One leading candidate is charge symmetry violation in the parton distribution functions [10].

The E158 measurement can be used to set limits on the size of possible new contributions beyond the standard model. Assuming a new contact interaction scale [11] characterized by A_{LL} , the 95% C.L. limit is 7 TeV or 16 TeV depending on the sign of the contact interaction term.

4 Future Prospects

The figure of merit to measure the WNC amplitude in Møller scattering rises with incident beam energy. It is therefore possible to contemplate improved new measurements of A_{PV} at future facilities [12]. One possibility is to carry out a new measurement at Jefferson Laboratory

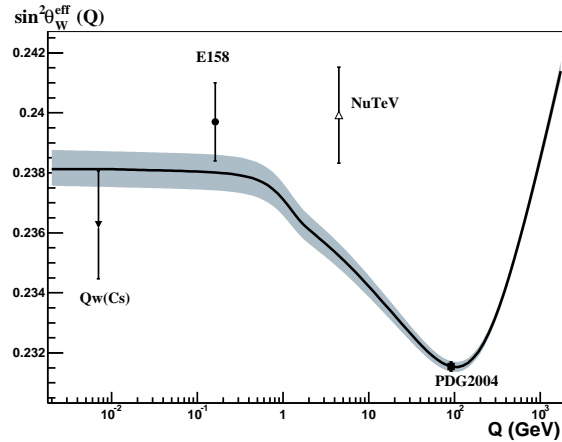


Fig. 2. $\sin^2 \theta_W$ as a function of Q^2

after it is upgraded to 12 GeV, where it is potentially possible to achieve a factor of 5 improvement over the reported measurement. The ultimate measurement could be carried out at the proposed International Linear Collider, using the electron beam downstream of the primary collider interaction region. More than an order of magnitude improvement is possible [13], which competes very favorably with future collider determinations of the weak mixing angle and measurements of the W boson mass.

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