PRECISION MEASUREMENTS OF PARITY VIOLATION AND THE WEAK MIXING ANGLE IN MØLLER SCATTERING

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We report an observation of a parity-violating asymmetry in fixed target electron-electron (Møller) scattering at a four-momentum transfer $Q^2 = 0.03$ (GeV/c)^2. This is a most precise measurement of parity nonconservation to date, and leads to a determination of the electron's weak charge and of the value of the effective weak mixing angle $\sin^2\theta_W^{\rm eff} = 0.2403 \pm 0.0014$, which is consistent with the Standard Model expectation at the current level of precision. The comparison between the measurements of the weak mixing angle at $Q^2 = 0.03$ (GeV/c)^2 and at the Z^0 pole establishes the running of $\sin^2\theta_W$ with 6.5σ significance.

1. Physics Motivation

The weak mixing angle was previously measured by many experiments both on and off the Z-pole. The measurements at the Z-pole from the SLD and LEP experiments are in excellent agreement with the SM prediction. On the other hand, a measurement off the Z-pole, from the NuTeV experiment, is about 3σ above the SM prediction [1]. Here we report on a new measurement of $\sin^2\theta_W$, extracted from a measurement of parity-violation asymmetry in Møller scattering, by the E158 experiment. The E158 collaboration used the SLAC 48 GeV polarized electron beam, scattering it off unpolarized atomic electrons, to measure the right-left asymmetry. This asymmetry is given by [2]

$$A_{PV} \equiv \frac{d\sigma_R - d\sigma_L}{d\sigma_R + d\sigma_L} = \frac{G_F Q^2}{4\sqrt{2}\pi\alpha}\frac{1-y}{1+y^4+(1-y)^4}Q_W(e). \tag{1}$$

Here Q^2 is the momentum transfer, G_F is the Fermi coupling constant, and α is the fine structure constant. At the tree-level, the weak charge of the electron, $Q_W(e)$, is given by $Q_W(e) = 4\sin^2\theta_W - 1$. Equation 1 indicates that if the right-left asymmetry is measured with a fractional statistical error of 10%, the weak mixing angle can be then measured with a precession of 0.001, since the asymmetry is proportional to $(4\sin^2\theta_W - 1)$. The predicted asymmetry, at $Q^2 = 0.03$ (GeV/c)^2, is 1.8×10^{-7}, which is 40% below the tree level calculations due to one-loop radiative corrections [3,4].

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2. Experimental Technique

The main components of the experimental apparatus were a polarized electron beam, a liquid hydrogen target, a spectrometer, and detectors. Polarized electrons were produced by photoemission from a GaAs photocathode using a circularly polarized laser beam. The polarized electron source produced 5×10^{11} electrons per pulse with 85% beam polarization at a repetition rate of 120 Hz. Changing the beam energy from 45.0 GeV to 48.3 GeV flips the spin due to the $g-2$ precession as the beam traverses a 24.5° bend after acceleration. Therefore, the experiment was carried out at both energies in order to cancel the systematic effects. The electron beam was monitored by several devices along its path in order to correct the right-left asymmetry for the helicity-correlated differences in the beam characteristics.

The target in E158 was 1.5 m long aluminum pipe filled with liquid hydrogen, and kept at 20 K by a heat exchanger. The flux coming out from the target has Møller scatters, ep scatters, primary beam, and low energy particles. Therefore, E158 used a spectrometer consisting of several magnets and collimators to separate the scattered particles of interest from backgrounds. This magnetic spectrometer selects Møller scatters with very-forward scattering angles: $4 < \theta_{lab} < 7$ mrad. The Møller scatters are then focused on the detector face by a lens consisting of four quadrapole magnets.

The E158 detectors were designed to monitor the Møller asymmetry as well as the asymmetries of background processes. The Møller detector was designed to detect only Møller scatters at momentum range of 11-25 GeV. It consists of copper plates and quartz fibers oriented at 45^o w.r.t. the scattered particles for maximum Cherenkov radiation. The generated light was then integrated by the photomultiplier tubes (PMTs).

3. Systematics Uncertainties

To calculate the parity-violating asymmetry, the integrated responses of the PMTs were averaged to form the raw asymmetry, A_{raw}. Corrections ΔA_i and dilutions f_i to A_{raw} were then subtracted from A_{raw}

$$A_{PV} = \frac{1}{P_e \epsilon} \frac{A_{raw} - \sum_i \Delta A_i}{1 - \sum_i f_i} \tag{2}$$

where $P_e = 0.88 \pm 0.05$ and $\epsilon = 0.99 \pm 0.01$ are the beam polarization and detector linearity, respectively. ΔA_i andf_i are listed in Table 1. The *ep* flux within the Møller region was the dominant background.

4. Results

The results from the first of three E158 run periods have been already published [5]. Here we report the preliminary results from the full data set. The measured parity-violating asymmetry in the Møller scattering was found to be

Table 1. Corrections ΔA_i and dilutions f_i to A_{raw} and associated systematic uncertainties.

Source	ΔA (ppb)	f
Beam asymmetries	0 ± 4	-
Beam spotsize	0 ± 1	-
Transverse polarization	-4 ± 2	-
Elastic ep	-8 ± 2	0.058 ± 0.007
Inelastic ep	-22 ± 6	0.009 ± 0.003
High energy photons	3 ± 3	0.004 ± 0.002
Synchrotron photons	0 ± 2	0.002 ± 0.001
Neutrons	-1 ± 1	0.001 ± 0.001
Pions	1 ± 1	0.001 ± 0.001

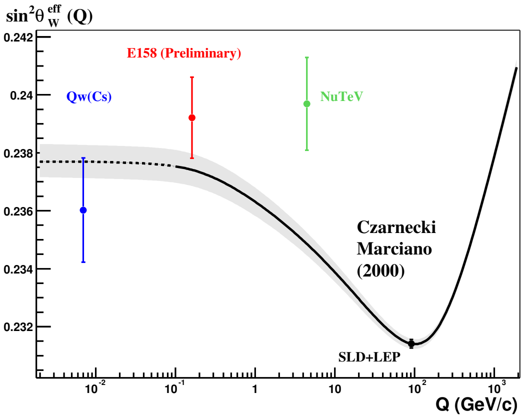

Fig. 1. Measurement of $\sin^2\theta_W^{eff}$ as a function of momentum transfer Q. The solid line and the dotted line are the theoretical prediction at high and low Q, respectively

$A_{PV} = -128 \pm 14$ (stat.) $\pm$ 12 (syst.) ppb. This is the most precise asymmetry ever measured in a parity-violating polarized-electron experiment. In the context of the Standard Model, A_{PV} result determines the weak mixing angle $\sin^2\theta_{W_{\overline{MS}}} = 0.2330 \pm 0.0011$ (stat.) $\pm\, 0.0010$ (syst.), which gives a Standard Model pull of 1.2σ. This result in turn provides new limits on the TeV scale physics. For example, a limit of 0.9 TeV was set on the mass of the extra Z' boson in the SO(10) Model.

References

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