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Electroweak Coupling Measurements from Polarized Bhabha Scattering at the Z^0 Resonance*

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ABSTRACT

The cross section for Bhabha scattering ($e^+e^- \to e^+e^-$) with polarized electrons at the center of mass energy of the Z^0 resonance has been measured with the SLD experiment at the SLAC Linear Collider (SLC) during the 1992 and 1993 runs. The first measurement of the left-right asymmetry in Bhabha scattering ($A_{LR}^{e^+e^-}(\theta)$) is presented. From $A_{LR}^{e^+e^-}(\theta)$ the effective weak mixing angle is measured to be $sin^2\theta_W^{\rm eff} = 0.2245 \pm 0.0049 \pm 0.0010$. The effective electron vector and axial vector couplings to the Z^0 are extracted from a combined analysis of the polarized Bhabha scattering data and and the left-right asymmetry (A_{LR}) previously published by this collaboration. From the combined 1992 and 1993 data the effective electron couplings are measured to be $v_e = -0.0414 \pm 0.0020$ and $a_e = -0.4977 \pm 0.0045$.

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The SLD Collaboration has recently performed the most precise single measurement of the effective electroweak mixing angle, $sin^2\theta_W^{\rm eff}$, by measuring the left-right cross section asymmetry (A_{LR}) in Z boson production at the Z^0 resonance.[1] The left-right cross section asymmetry is a measure of the initial state electron coupling to the Z^0, which allows all visble fermion final states to be included in the measurement. For simplicity, the e^+e^- final state (Bhabha scattering) is omitted in the A_{LR} measurement due to the dilution of the asymmetry from the large QED contribution of the t-channel photon exchange. Here we present two new results: the first measurement of the left-right cross section asymmetry in polarized Bhabha scattering ($A_{LR}^{e^+e^-}(\theta)$), and measurements of the effective electron coupling constants based on a combined analysis of the A_{LR} measurement[1] and the Bhabha cross section and angular distributions. The vector coupling measurement is the most precise yet presented.

In the Standard Model, measuring the left-right asymmetry yields a value for the quantity A_e, a measure of the degree of parity violation in the neutral current, since:

$$A_{LR} = A_e = \frac{2v_e a_e}{{v_e}^2 + {a_e}^2} = \frac{2[1-4sin^2\theta_W^{\rm eff}]}{1+[1-4sin^2\theta_W^{\rm eff}]^2}, \tag{1}$$

where the effective electroweak mixing parameter is defined[2] as $sin^2\theta_W^{\rm eff} = \frac{1}{4}(1-v_e/a_e)$, and v_e and a_e are the effective vector and axial vector electroweak coupling parameters of the electron. The partial width for Z^0 decaying into e^+e^- is dependent on the coupling parameters:

$$\Gamma_{ee} = \frac{G_F M_Z^3}{6\sqrt{2}\pi}({v_e}^2 + {a_e}^2)(1+\delta_e), \tag{2}$$

where $\delta_e = \frac{3\alpha}{4\pi}$ is the correction for final state radiation. G_F is the Fermi coupling constant and M_Z is the Z^0 boson mass. By measuring A_e and Γ_{ee}, the above equations can be utilized to extract v_e and a_e.

The data presented at this meeting were collected during the 1992 and 1993 runs of the SLAC Linear Collider (SLC), which collides unpolarized positrons with longitudinally polarized electrons at a center of mass energy near the Z^0 resonance.[3] The luminosity-weighted electron beam polarization ($<\mathcal{P}_e>$) was measured to be $(22.4 \pm 0.7)\%$ for the 1992 run and $(63.0 \pm 1.1)\%$ for the 1993 run.[1,4]

The analysis presented here utilizes the calorimetry systems of the SLD detector.[5] Small angle coverage (28-65 mrad from the beamline) is provided by the finely-segmented silicon-diode/tungsten-radiator luminosity calorimeters (LUM).[6] The LUM measures small angle Bhabha scattering, thereby providing both the absolute luminosity and a measure of the left-right luminosity asymmetry. Events at larger angles from the beamline are measured with the liquid argon calorimeter (LAC).[7]

A detailed description of the systematic error analysis for the luminosity measurement is given elsewhere.[8] The total systematic uncertainty is 0.93%, which is composed of 0.88% experimental and 0.3% theoretical uncertainty. The integrated luminosity is $\mathcal{L} = 385.37 \pm 2.47$ (stat) $\pm$ 3.58 (sys) nb^{-1} for the 1992 polarized SLC run and $\mathcal{L} = 1781.1 \pm 5.1$ (stat) $\pm$ 16.6 (sys) nb^{-1} for the 1993 SLC run.

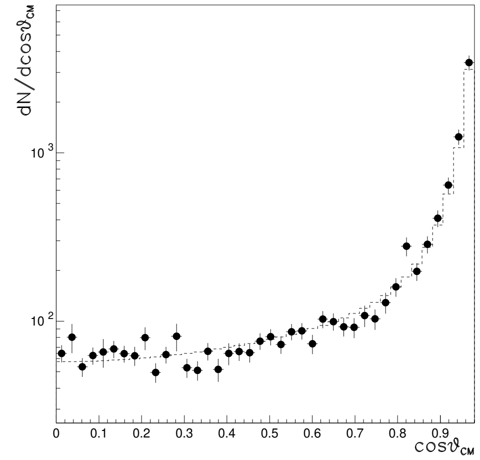

Fig. 1. Fit to the corrected wide angle Bhabha distribution. The points are the corrected data, the curve is the fit.

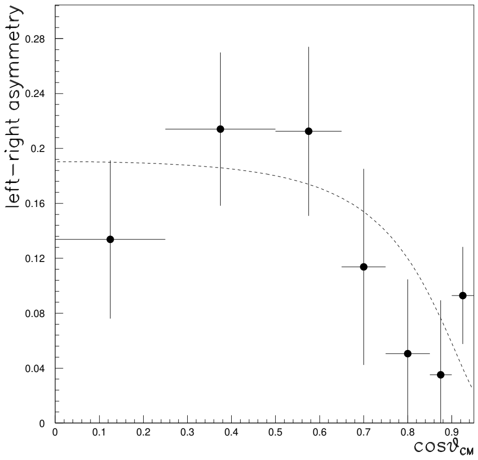

Fig. 2. EXPOSTAR fit to the wide angle Bhabha left-right asymmetry. The points are the corrected data, the curve is the fit.

The wide angle Bhabha selection algorithm makes use of the distinct topology of the e^+e^- final state. Selected events are required to possess two clusters which contain at least 70% of the center of mass energy and manifest a normalized energy imbalance of less than 0.6. The two largest energy clusters are also required to deposit less than 3.8 GeV of energy in the hadronic calorimeter. The total number of reconstructed clusters found in the event must be less than 9. Collinearity in the final state is controlled by requiring the absolute value of the rapidity sum of the two main clusters to be less than 0.30. The angle-dependent efficiency and contamination is calculated from Monte Carlo simulations. Two small sources of contamination are $e^+e^- \to \gamma\gamma$ (1.25%) and $e^+e^- \to \tau^+\tau^-$ (0.28%). Other sources of contamination were all found to give negligible contributions.

To extract Γ_{ee} and A_e, the data are fit to a calculated differential e^+e^- cross section using the maximum likelihood method. Two programs are used to calculate the differential e^+e^- cross section: EXPOSTAR[9] and DMIBA.[10] To extract the maximal amount of information from the differential polarized Bhabha scattering distribution, the fit is performed over the entire angular region accepted by the LAC ($|cos\theta| < 0.98$). No t-channel subtraction is performed.

The partial width Γ_{ee} is extracted from the data in two ways: (1) using the full fit to the differential cross section to $|cos\ \theta|$=0.98, and (2) measuring the cross section in the central region ($|cos\ \theta| < 0.6$) where the systematic errors are smaller, yielding a more precise measurement. Figure 1 shows the fit to the full $e^+e^- \to e^+e^-$ distribution, which yields $\Gamma_{ee} = 83.14 \pm 1.03$ (stat) $\pm$ 1.95 (sys) MeV. The 2.4% systematic error is dominated (2.1%) by the uncertainty in the efficiency correction factors in the angular region $0.6 < |cos\theta| < 0.98$, where the LAC response is difficult to model due to materials from interior detector elements.[8,11]

A more precise determination of Γ_{ee} was performed using only the central region of the LAC and the small angle region in the LUM.[12] The program MIBA[13] is then used to calculate Γ_{ee} based on the total measured cross section within the defined fiducial region. From this method, we find: $\Gamma_{ee} = 82.89 \pm 1.20$ (stat) ± 0.89 (sys) MeV. The loss in statistical precision of the limited fiducial region is more than compensated by the improvement in the systematic uncertainty. The 1.1% systematic uncertainty is dominated by a 1.0% uncertainty in the e^+e^- cross section into the fiducial region arising from the uncertainty in the absolute luminosity and the accuracy of the simulation.

To extract A_e from the Bhabha events, the right- and left-handed differential $e^+e^- \rightarrow e^+e^-$ cross sections are fit directly to v_e and a_e using EXPOSTAR, yielding:

$$A_e = 0.202 \pm 0.038 \text{ (stat)} \pm 0.008 \text{ (sys)}.$$

Figure 2 shows the measured left-right cross section asymmetry for $e^+e^- \rightarrow e^+e^-$ ($A_{LR}^{e^+e^-}(\theta)$) compared to the fit. The measurement of A_e is limited by the statistical uncertainty. The 3.8% systematic is dominated by a 3.2% uncertainty in the angle-dependent response correction factors. The polarization uncertainty contributes 1.7% with other factors contributing less than 1%.[1,8,11]

The results for Γ_{ee} and A_e from above may now be used in equations 1 and 2 to extract the effective vector and axial vector couplings to the Z^0: $v_e = -0.0507 \pm 0.0096$ (stat) ± 0.0020 (sys), and $a_e = -0.4968 \pm 0.0039$ (stat) ± 0.0027 (sys), where e^+e^- annihilation data have been utilized to assign $|v_e| < |a_e|$, and $\nu_e e$ scattering data have been utilized to establish $v_e < 0$ and $a_e < 0$.[14] Figure 3 shows the one-sigma (68%) contour for these electron vector and axial vector coupling measurements. Most of the sensitivity to the electron vector coupling and, hence, $sin^2\theta_W^{\text{eff}}$ arises from the measurement of A_e, while the sensitivity to the axial vector coupling arises from Γ_{ee}. Also shown are standard model calculations using the program ZFITTER.[15] The effective electroweak mixing angle represented by these vector and axial vector couplings is:

$$sin^2\theta_W^{\text{eff}} = 0.2245 \pm 0.0049 \ \pm 0.0010,$$

where the first error is statistical, the second systematic.

Combining the Bhabha results with the SLD measurement of A_{LR}[1] gives:

$$v_e = -0.0414 \pm 0.0020 \qquad\qquad a_e = -0.4977 \pm 0.0045,$$

the most precise measurement of the electron vector coupling to the Z^0 published to date.[11] The v_e, a_e contour including the A_{LR} measurement is also shown in Figure 3, demonstrating the increased sensitivity in v_e from A_{LR}.

In summary, the effective electron coupling constants have been determined with a new method which combines the left-right cross section asymmetry (A_{LR}) with the polarized Bhabha scattering angular distribution. The effective electron vector coupling to the Z^0 is determined with the best precision to date.

We thank the personnel of the SLAC accelerator department and the technical staffs of our collaborating institutions for their outstanding efforts on our behalf.

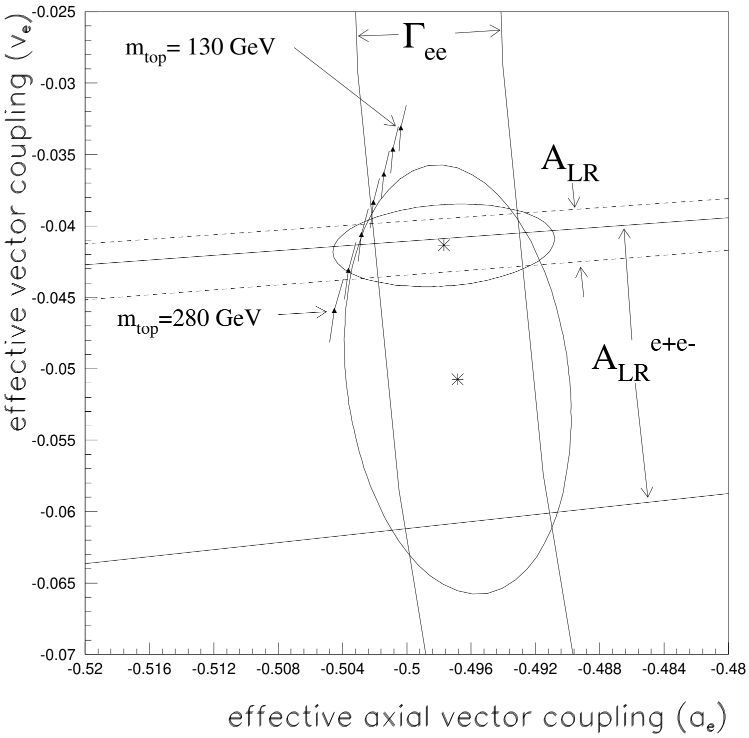

Fig. 3. One standard deviation (68%) contour for v_e and a_e. The points indicate the Standard Model calculation as a function of the mass of the top quark and the Higgs boson.

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