High-Precision Measurement of the Left-Right Z Boson Cross-Section Asymmetry

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We present a measurement of the left-right cross-section asymmetry (A_{LR}) for Z boson production by e^+e^- collisions. The measurement includes the final data taken with the SLD detector at the SLAC Linear Collider during the period 1996–1998. Using a sample of 383 487 Z decays collected during the 1996–1998 runs we measure the pole value of the asymmetry, A_{LR}^0, to be $0.150\,56 \pm 0.002\,39$ which is equivalent to an effective weak mixing angle of $\sin^2\theta_W^{\rm eff} = 0.231\,07 \pm 0.000\,30$. Our result for the complete 1992–1998 data set comprising approximately 537 000 Z decays is $\sin^2\theta_W^{\rm eff} = 0.230\,97 \pm 0.000\,27$.

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The SLD Collaboration has performed a series of increasingly precise measurements of the left-right cross-section asymmetry in the production of Z bosons by e^+e^- collisions [1–3]. In this Letter, we present a measurement based upon data recorded during the 1996 and 1997–1998 runs of the SLAC Linear Collider (SLC), which represents about three quarters of our total sample and leads to improved statistical precision and reduced systematic uncertainty. The overall average given at the end of this Letter is based upon all the data from the completed SLD experimental program [4].

The left-right asymmetry is defined as $A_{LR}^0 \equiv (\sigma_L - \sigma_R)/(\sigma_L + \sigma_R)$, where σ_L and σ_R are the e^+e^- production cross sections for Z bosons at the Z pole energy with left-handed and right-handed electrons, respectively. The standard model (SM) predicts that this quantity depends upon the effective vector (v_e) and axial-vector (a_e) couplings of the Z boson to the electron current,

$$A_{LR}^0 = \frac{2v_e a_e}{v_e^2 + a_e^2} \equiv \frac{2[1 - 4\sin^2\theta_W^{\rm eff}]}{1 + [1 - 4\sin^2\theta_W^{\rm eff}]^2}, \qquad (1)$$

where the effective electroweak mixing parameter is defined [5] as $\sin^2\theta_W^{\rm eff} \equiv (1 - v_e/a_e)/4$. The quantity A_{LR}^0 is a sensitive function of $\sin^2\theta_W^{\rm eff}$ and depends upon virtual electroweak radiative corrections including those which involve the Higgs boson and those arising from new phenomena outside of the scope of the SM. Presently, the most stringent upper bounds on the SM Higgs mass are provided by measurements of $\sin^2\theta_W^{\rm eff}$.

We measured the left-right asymmetry by counting hadronic and (with low efficiency) $\tau^+\tau^-$ final states produced in e^+e^- collisions near the Z pole energy for each of the two longitudinal polarization states of the electron beam. The asymmetry formed from these rates, A_{LR}, was then corrected for residual effects arising from pure photon exchange and Z photon interference to extract A_{LR}^0. The measurement required knowledge of the absolute beam polarization, but did not require knowledge of the absolute luminosity, detector acceptance, or efficiency [6].

The operation of the SLC with a polarized electron beam has been described previously [7]. The maximum luminosity of the collider was approximately 3×10^{30} cm^{-2} sec^{-1}, and the longitudinal electron polarization at the e^+e^- collision point was typically $\sim$75%. The luminosity-weighted mean e^+e^- center-of-mass energy ($E_{\rm cm}$) was measured with precision energy spectrometers [8] and was found to be 91.26 ± 0.03 GeV for the 1996 run. During the 1997–1998 period, the energy spectrometers were (for the first time) calibrated to the well-measured Z boson mass [9] by performing a three-point scan of the resonance [10], with the result $E_{\rm cm} = 91.237 \pm 0.029$ GeV for the 1997–1998 run.

The longitudinal electron beam polarization ($\mathcal{P}_e$) was measured by a Compton-scattering polarimeter [1–3,11]. The primary device was a magnetic spectrometer and multichannel Cherenkov detector that observed Compton-scattered electrons in the energy range 17 to 30 GeV. The analyzing powers of the detector channels incorporated resolution and spectrometer effects, and differed by typically $\sim$1% from the theoretical Compton polarization asymmetry function [12] at the mean accepted energy for each channel. The minimum energy of a Compton-scattered electron for the initial electron and photon energies was 17.36 GeV. The location of this kinematic end point at the detector (in the dispersive plane of the spectrometer) was monitored by frequent scans of the detector's horizontal position during polarimeter operation. This technique determined and monitored the analyzing powers of each detector channel. Polarimeter data were acquired continually during the operation of the SLC.

Beginning in 1996, two additional detectors were operated in order to assist in the calibration of the primary spectrometer-based polarimeter. Both devices detected Compton-scattered photons and hence were independent of the spectrometer calibration and its systematic uncertainties. Because of their inherent sensitivity to beamstrahlung background, these two devices, the polarized gamma counter (PGC) [13] and the quartz fiber calorimeter (QFC) [14], were operated only when the electron and positron beams were not in collision. However, when compared with concurrent results from the primary detector they achieved comparable precision and provided a useful cross-check of our calibration procedure.

The systematic uncertainties that affect the polarization measurement are summarized in Table I. The largest contribution, due to analyzing power calibration, was estimated by a comparison of our reference polarization measurement provided by the Cherenkov detector channel located at the kinematic end point (and Compton asymmetry maximum) to the results from a neighboring channel and from the PGC and QFC devices. A $\sim$0.6% systematic error on the PGC calibration was dominated by the difference in the photon energy response function as determined from test beam data, and from EGS [15] Monte Carlo simulations. For the QFC device, uncertainties on the linearity of the response function, also deduced from test beam data, dominated the total systematic error of $\sim$0.6%. The weighted mean residual of all analyzing power cross-checks is $0.30\% \pm 0.39\%$ ($\chi^2 = 1.9$ for 2 degrees of freedom), from which we quote a calibration uncertainty of 0.4%.

Interspersed high and low background polarimeter operation in 1997–1998, achieved by periodic removal of the positron beam, permitted improved studies of the

TABLE I. Systematic uncertainties that affect the A_{LR} measurement. The uncertainty on the electroweak interference correction is caused by the uncertainty on the SLC energy scale. Where they differ from the errors for the 1997–1998 data, the errors for 1996 are given in parentheses.

Uncertainty	$\delta\mathcal{P}_e/\mathcal{P}_e$ (%)	$\delta A_{LR}/A_{LR}$ (%)	$\delta A^0_{LR}/A^0_{LR}$ (%)
Laser polarization	0.10		
Detector linearity	0.20		
Analyzing power calibration	0.40		
Electronic noise	0.20		
Total polarimeter uncertainty	0.50	0.50	
Chromaticity and IP corrections (ξ)		0.15(0.16)	
Corrections in Eq. (2)		0.07(0.05)	
A_{LR} Systematic uncertainty		0.52(0.52)	0.52(0.52)
Electroweak interference correction			0.39(0.37)
A^0_{LR} Systematic uncertainty			0.64(0.63)

Cherenkov detector linearity and significantly reduced the associated uncertainty, previously our largest effect, to 0.2% [16]. The total relative systematic uncertainty is estimated to be $\delta\mathcal{P}_e/\mathcal{P}_e = 0.50\%$ (down from 0.65% [3]).

In our previous Letters [2,3], we examined an effect that causes the beam polarization measured by the Compton polarimeter, $\mathcal{P}_e$, to differ from the luminosity-weighted beam polarization, $\mathcal{P}_e(1+\xi)$, at the SLC interaction point (IP), where ξ is a small fractional correction. A number of measures in the operation of the SLC and in monitoring procedures reduced the size of this *chromaticity* correction and its associated error to below 0.2% [17]. From beam energy spread, polarization transport, and luminosity energy dependence measurements, we determined a contribution to ξ of $+0.001\,24 \pm 0.0012$ (1996) and $+0.001\,17 \pm 0.0008$ (1997–1998) due to the chromaticity effect. The results for both runs are smaller than for previous years [3].

A similar effect of comparable magnitude arises due to the small precession of the electron spin in the final focusing elements between the SLC IP and the polarimeter. We estimated this effect contributed -0.0011 ± 0.0005 to ξ in 1996, and -0.0024 ± 0.0008 to ξ in 1997–1998, where the larger value in the recent data reflects the larger focusing angles used at the time.

The depolarization of the electron beam by the e^+e^- collision process is expected to be negligible [18]. The contribution of depolarization to ξ was determined to be 0.000 ± 0.001 by comparing polarimeter data taken with and without beams in collision. Combining the three effects described above, the overall correction factors were determined to be $\xi = 0.0002 \pm 0.0016$ (1996) and $\xi = -0.0012 \pm 0.0015$ (1997–1998).

The e^+e^- collisions were measured by the SLD detector which has been described elsewhere [19]. For Z decays the detector trigger and the event selection relied on the liquid argon calorimeter (LAC) [20] and the central drift chamber tracker (CDC) [21]. For each event candidate, energy clusters were reconstructed in the LAC. Selected events were required to contain at least 22 GeV of energy observed in the clusters and to manifest a normalized energy imbalance of less than 0.6 [22]. The left-right asymmetry associated with final state e^+e^- events is expected to be diluted by the t-channel photon exchange subprocess. Therefore, we excluded e^+e^- final states by requiring that each event candidate contain at least four selected CDC tracks, with at least two tracks in each hemisphere (defined with respect to the beam axis), or at least four tracks in either hemisphere. This track topology requirement excludes Bhabha events which contain a reconstructed gamma conversion. The selected CDC tracks were required to extrapolate to the IP within 5 (10) cm radially (along the beam direction), to have a minimum momentum transverse to the beam direction of 100 MeV/c, and to form a minimum angle of 30° with the beam direction.

We estimate that the combined efficiency of the trigger and selection criteria was $(91 \pm 1)\%$ for hadronic Z decays. Tau pairs constituted $(0.3 \pm 0.1)\%$ of the sample. Because muon pair events deposited little energy in the calorimeter, they were not included in the sample. A residual background in the sample was due to e^+e^- final state events. We use our data and a Monte Carlo simulation to estimate this background fraction to be $(0.013 \pm 0.013)\%$. The background fraction due to cosmic rays, two-photon events, and beam related processes was estimated to be $(0.029 \pm 0.029)\%$ for 1997–1998, and $(0.016 \pm 0.016)\%$ for 1996.

For the 1997–1998 (1996) data sets, respectively, a total of 331 614 (51 873) Z events satisfied the selection criteria. We found that 183 355 (29 016) of the events were produced with the left-handed electron beam (N_L) and 148 259 (22 857) were produced with the right-handed beam (N_R). The measured left-right cross-section asymmetry is [23]

$$A_m \equiv \frac{N_L - N_R}{N_L + N_R} = \begin{cases} 0.105\,83 \pm 0.001\,73, & 97/8\,, \\ 0.118\,73 \pm 0.004\,36, & 96\,. \end{cases}$$

We verified that the measured asymmetry A_m did not vary significantly as more restrictive criteria (calorimetric and tracking based) were applied to the sample and that A_m

was uniform when binned by the azimuth and polar angle of the thrust axis.

The measured asymmetry A_m is related to A_{LR} by the following expression which incorporates a number of small correction terms in lowest-order approximation,

$$A_{LR} = \frac{A_m}{\langle \mathcal{P}_e \rangle} + \frac{1}{\langle \mathcal{P}_e \rangle}\Big[f_b(A_m - A_b) - A_{\mathcal{L}} + A_m^2 A_{\mathcal{P}} - E_{\rm cm}\frac{\sigma'(E_{\rm cm})}{\sigma(E_{\rm cm})}A_E - A_\varepsilon + \langle \mathcal{P}_e \rangle \mathcal{P}_p \Big], \quad (2)$$

where $\langle \mathcal{P}_e \rangle$ is the mean luminosity-weighted polarization; f_b is the background fraction; $\sigma(E)$ is the unpolarized Z cross section at energy E; $\sigma'(E)$ is the derivative of the cross section with respect to E; A_b, $A_{\mathcal{L}}$, $A_{\mathcal{P}}$, A_E, and A_ε are the left-right asymmetries [24] of the residual background, the integrated luminosity, the beam polarization, the center-of-mass energy, and the product of detector acceptance and efficiency, respectively; and $\mathcal{P}_p$ is any longitudinal positron polarization which is assumed to have constant helicity [25].

In the past, we have taken $\mathcal{P}_p$ to be negligible, based on calculations of transverse polarization buildup in the SLC positron damping ring (ignoring efficiencies in positron polarization transport to the beam collision point) that indicate the effect cannot be larger than a few parts in 10^5. Nevertheless, we determined that we could address this issue experimentally, and directly measured $\mathcal{P}_p$ in 1998. The SLC positron beam was delivered to the fixed target Møller polarimeter in SLAC's End Station A [26] in a one week dedicated experiment, and the result ($\mathcal{P}_p = -0.02\% \pm 0.07\%$) was consistent with zero [27].

The luminosity-weighted average polarization $\langle \mathcal{P}_e \rangle$ for the 1997–1998 (1996) data was estimated from measurements of $\mathcal{P}_e$ made when Z events were recorded,

$$\langle \mathcal{P}_e \rangle = (1 + \xi)\frac{1}{N_Z}\sum_{i=1}^{N_Z}\mathcal{P}_i = \begin{cases} 72.92\% \pm 0.38\%, & 97/8, \\ 76.16\% \pm 0.40\%, & 96, \end{cases} \quad (3)$$

where N_Z is the total number of Z events, and $\mathcal{P}_i$ is the polarization measurement associated in time with the ith event. The error on $\langle \mathcal{P}_e \rangle$ was dominated by the systematic uncertainties on the polarization measurement. The different values for $\langle \mathcal{P}_e \rangle$ seen during different SLC running periods are due to different GaAs photocathodes used at the SLC polarized source.

The corrections defined in Eq. (2) were found to be small. The results for 1997–1998 (1996) are detailed below. The correction for residual background contamination was moderated by a nonzero left-right background asymmetry [$A_b = 0.023 \pm 0.022$ (0.033 ± 0.026)] arising from e^+e^- final states which remained in the sample. Residual electron current asymmetry ($\lesssim 10^{-3}$) from the SLC polarized source was reduced by periodically reversing a spin rotation solenoid at the entrance to the SLC damping ring. The net luminosity asymmetry was estimated from the measured asymmetry of the rate of radiative Bhabha scattering events observed with a monitor located in the North Final Focus region of the SLC to be $A_{\mathcal{L}} = [-1.3 \pm 0.7] \times 10^{-4}$($[+0.03 \pm 0.5] \times 10^{-4}$). A statistically less precise cross-check was performed by examining the left-right asymmetry of the sample of approximately 800 000 small-angle Bhabha scattering events detected by the luminosity monitoring system (LUM) [28]. Since the theoretical left-right asymmetry for small-angle Bhabha scattering is very small [$\mathcal{O}(10^{-4})\mathcal{P}_e$ within the LUM acceptance], the measured asymmetry of $[-10 \pm 10] \times 10^{-4}$ was a direct determination of $A_{\mathcal{L}}$ and was consistent with the more precisely determined one. The polarization asymmetry was directly measured to be $A_{\mathcal{P}} = [+2.8 \pm 6.9] \times 10^{-3}$($[+2.9 \pm 4.3] \times 10^{-3}$). The left-right beam energy asymmetry arises from the small residual left-right beam current asymmetry due to beam loading of the accelerator and was measured to be $[+2.8 \pm 1.4] \times 10^{-7}$($[-0.1 \pm 3.5] \times 10^{-7}$). The coefficient of the energy asymmetry in Eq. (2) is a very sensitive function of the center-of-mass energy and was found to be 4.3 ± 2.9 for $E_{\rm cm} = 91.237 \pm 0.029$ GeV (2.0 ± 3.0 for $E_{\rm cm} = 91.26 \pm 0.03$ GeV). The SLD had a symmetric acceptance in polar angle [6] which implied that the efficiency asymmetry A_ε is negligible. The corrections listed in Eq. (2) change A_{LR} by $[+0.16 \pm 0.07]\%$ ($[+0.02 \pm 0.05]\%$) of the uncorrected value.

From Eq. (2), we found the left-right asymmetry to be $A_{LR}(91.237\ \text{GeV}) = 0.1454 \pm 0.002\,37(\text{stat}) \pm 0.000\,77(\text{syst})$, for 1997–1998 and $A_{LR}(91.26\ \text{GeV}) = 0.1559 \pm 0.005\,72(\text{stat}) \pm 0.000\,84(\text{syst})$ for 1996.

We found the pole asymmetry A_{LR}^0 for 1997–1998 to be $A_{LR}^0 = 0.149\,06 \pm 0.002\,37(\text{stat}) \pm 0.000\,96(\text{syst})$, and $A_{LR}^0 = 0.159\,29 \pm 0.005\,73(\text{stat}) \pm 0.001\,01(\text{syst})$, for 1996, where the systematic uncertainty includes the uncertainty on the electroweak interference correction (see Table I) which arose from the uncertainty on the center-of-mass energy scale. Combining the value of A_{LR}^0 and $\sin^2\theta_W^{\rm eff}$ [29] provided by the 1996–1998 data of $A_{LR}^0 = 0.150\,56 \pm 0.002\,39$ and $\sin^2\theta_W^{\rm eff} = 0.231\,07 \pm 0.000\,30$ with our previous measurements [1–3] (systematic errors are conservatively taken to be fully correlated between measurements) we obtain the value,

$$A_{LR}^0 = 0.151\,38 \pm 0.002\,16\,,$$
$$\sin^2\theta_W^{\rm eff} = 0.230\,97 \pm 0.000\,27\,.$$

This $\sin^2\theta_W^{\rm eff}$ determination is the most precise presently available, and is smaller by 2.7 standard deviations than the recent average of measurements performed by the LEP Collaborations [9].

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[1] K. Abe *et al.*, Phys. Rev. Lett. **70**, 2515 (1993).

[2] K. Abe *et al.*, Phys. Rev. Lett. **73**, 25 (1994) [hep-ex/9404001].

[3] K. Abe *et al.*, Phys. Rev. Lett. **78**, 2075 (1997) [hep-ex/96011011].

[4] A complete description of the SLD A_{LR} and polarimetry experimental programs will be available in a long article, now in preparation. We provide theses and SLD internal memos where appropriate.

[5] We follow the convention used by the LEP Collaborations in Phys. Lett. B **276**, 247 (1992).

[6] The value of A_{LR} is unaffected by decay-mode-dependent variations in detector acceptance and efficiency provided that the efficiency for detecting a fermion at some polar angle (with respect to the electron direction) is equal to the efficiency for detecting an antifermion at the same polar angle.

[7] M. Woods, in *Proceedings of the 12th International Symposium on High Energy Spin Physics (SPIN96)*, edited by C. W. Jager *et al.* (World Scientific, Singapore, 1997), p. 621.

[8] J. Kent *et al.*, Report No. SLAC-PUB-4922, 1989.

[9] The LEP Collaborations, the LEP Electroweak Working Group, The SLD Heavy Flavour and Electroweak Working Groups, Report No. CERN-EP/2000-016, 2000.

[10] All line shape parameters excepting the Z mass were fixed at their measured values. The ZFITTER 6.22 program of D. Bardin *et al.*, Report No. DESY 99-070, 1999 (hep-ph/9908433) was used. For details on this work, internal SLD-note-264, July, 1999, is available from the authors.

[11] R. King, SLAC-Report-452, 1994; A. Lath, SLAC-Report-454, 1994; E. Torrence, SLAC-Report-509, 1997; D. Onoprienko, SLAC-Report-556, 2000.

[12] See S. B. Gunst and L. A. Page, Phys. Rev. **92**, 970 (1953).

[13] R. C. Field *et al.*, IEEE Trans. Nucl. Sci. **45**, 670 (1998), and internal SLD-note-266, February 2000.

[14] S. C. Berridge *et al.*, in *Calorimetry in High Energy Physics Proceedings*, edited by E. Cheu *et al.* (World Scientific, Singapore, 1998), p. 170, and internal SLD-note-267, October, 1999.

[15] W. R. Nelson, H. Hirayama, and D. W. O. Rogers, The EGS4 Code System, SLAC-Report-265, 1985.

[16] The assumption that collisional depolarization was negligible was implicit in our comparison of high and low background running used to constrain nonlinearities in our polarimeter response. Our experimental test of this assumption is described later in this Letter.

[17] For details on this work, see internal SLD-note-258, June, 1999.

[18] P. Chen and K. Yokoya, in *Proceedings of the Eighth International Symposium on High-Energy Spin Physics, Minneapolis, MN, 1988* (American Institute of Physics, New York, 1998), p. 938.

[19] The SLD Design Report, SLAC Report No. 273, 1984.

[20] D. Axen *et al.*, Nucl. Instrum. Methods Phys. Res., Sect. A **328**, 472 (1993).

[21] M. Fero *et al.*, Nucl. Instrum. Methods Phys. Res., Sect. A **367**, 111 (1995).

[22] The energy imbalance is defined as a normalized vector sum of the energy clusters as follows: $E_{\rm imb} = |\sum \vec{E}_{\rm cluster}|/\sum |E_{\rm cluster}|$.

[23] The absolute sign of A_m is inferred from the sign of the measured Compton-scattering asymmetry, the measured helicity of the polarimeter laser, and the theoretical sign of the Compton-scattering asymmetry.

[24] The left-right asymmetry for a quantity Q is defined as $A_Q \equiv (Q_L - Q_R)/(Q_L + Q_R)$ where the subscripts L,R refer to the left- and right-handed beams, respectively.

[25] Since the colliding electron and positron bunches were produced on different machine cycles and since the electron helicity of each cycle was chosen randomly, any positron helicity arising from the polarization of the production electrons was uncorrelated with electron helicity at the IP. The net positron polarization from this process vanished rigorously. However, positron polarization of constant helicity would affect the measurement.

[26] H. R. Band *et al.*, Nucl. Instrum. Methods Phys. Res., Sect. A **400**, 24 (1997).

[27] Internal SLD-Note-268, May, 2000.

[28] S. C. Berridge *et al.*, IEEE Trans. Nucl. Sci. **39**, 242 (1992).

[29] The quantities A_{LR}^0 and $\sin^2\theta_W^{\rm eff}$ are related by Eq. (1) and are completely equivalent. The correction for pure photon exchange and for electroweak interference (which arises from the deviation of the effective e^+e^- center-of-mass energy from the Z pole energy), including the effect of initial-state radiation, $A_{LR}^0 - A_{LR}(E_{\rm cm})$, is determined with the ZFITTER 6.22 program (see Ref. [10]) and is found to be $0.003\,58 \pm 0.000\,58$ ($0.003\,37 \pm 0.000\,59$).