First Measurement of the Left-Right Charge Asymmetry in Hadronic Z Boson Decays and a New Determination of $\sin^2\theta_W^{\rm eff}$

K. Abe,[19] K. Abe,[30] I. Abt,[13] T. Akagi,[28] N. J. Allen,[4] W. W. Ash,[28,*] D. Aston,[28] K. G. Baird,[16] C. Baltay,[34] H. R. Band,[33] M. B. Barakat,[34] G. Baranko,[9] O. Bardon,[15] T. L. Barklow,[28] G. L. Bashindzhagyan,[18] A. O. Bazarko,[10] R. Ben-David,[34] A. C. Benvenuti,[2] G. M. Bilei,[22] D. Bisello,[21] G. Blaylock,[16] J. R. Bogart,[28] B. Bolen,[17] T. Bolton,[10] G. R. Bower,[28] J. E. Brau,[20] M. Breidenbach,[28] W. M. Bugg,[29] D. Burke,[28] T. H. Burnett,[32] P. N. Burrows,[15] W. Busza,[15] A. Calcaterra,[12] D. O. Caldwell,[5] D. Calloway,[28] B. Camanzi,[11] M. Carpinelli,[23] R. Cassell,[28] R. Castaldi,[23,†] A. Castro,[21] M. Cavalli-Sforza,[6] A. Chou,[28] E. Church,[32] H. O. Cohn,[29] J. A. Coller,[3] V. Cook,[32] R. Cotton,[4] R. F. Cowan,[15] D. G. Coyne,[6] G. Crawford,[28] A. D'Oliveira,[7] C. J. S. Damerell,[25] M. Daoudi,[28] R. De Sangro,[12] R. Dell'Orso,[23] P. J. Dervan,[4] M. Dima,[8] D. N. Dong,[15] P. Y. C. Du,[29] R. Dubois,[28] B. I. Eisenstein,[13] R. Elia,[28] E. Etzion,[33] S. Fahey,[9] D. Falciai,[22] C. Fan,[9] M. J. Fero,[15] R. Frey,[20] K. Furuno,[20] T. Gillman,[25] G. Gladding,[13] S. Gonzalez,[15] G. D. Hallewell,[28] E. L. Hart,[29] J. L. Harton,[8] A. Hasan,[4] Y. Hasegawa,[30] K. Hasuko,[30] S. Hedges,[3] S. S. Hertzbach,[16] M. D. Hildreth,[28] J. Huber,[20] M. E. Huffer,[28] E. W. Hughes,[28] H. Hwang,[20] Y. Iwasaki,[30] D. J. Jackson,[25] P. Jacques,[24] J. A. Jaros,[28] A. S. Johnson,[3] J. R. Johnson,[33] R. A. Johnson,[7] T. Junk,[28] R. Kajikawa,[19] M. Kalelkar,[24] H. J. Kang,[26] I. Karliner,[13] H. Kawahara,[28] H. W. Kendall,[15] Y. D. Kim,[26] M. E. King,[28] R. King,[28] R. R. Kofler,[16] N. M. Krishna,[9] R. S. Kroeger,[17] J. F. Labs,[28] M. Langston,[20] A. Lath,[15] J. A. Lauber,[9] D. W. G. S. Leith,[28] V. Lia,[15] M. X. Liu,[34] X. Liu,[6] M. Loreti,[21] A. Lu,[5] H. L. Lynch,[28] J. Ma,[32] G. Mancinelli,[22] S. Manly,[34] G. Mantovani,[22] T. W. Markiewicz,[28] T. Maruyama,[28] H. Masuda,[28] E. Mazzucato,[11] A. K. McKemey,[4] B. T. Meadows,[7] R. Messner,[28] P. M. Mockett,[32] K. C. Moffeit,[28] T. B. Moore,[34] D. Muller,[28] T. Nagamine,[28] S. Narita,[30] U. Nauenberg,[9] H. Neal,[28] M. Nussbaum,[7] Y. Ohnishi,[19] L. S. Osborne,[15] R. S. Panvini,[31] C. H. Park,[27] H. Park,[20] T. J. Pavel,[28] I. Peruzzi,[12,‡] M. Piccolo,[12] L. Piemontese,[11] E. Pieroni,[23] K. T. Pitts,[20] R. J. Plano,[24] R. Prepost,[33] C. Y. Prescott,[28] G. D. Punkar,[28] J. Quigley,[15] B. N. Ratcliff,[28] T. W. Reeves,[31] J. Reidy,[17] P. L. Reinertsen,[6] P. E. Rensing,[28] L. S. Rochester,[28] P. C. Rowson,[10] J. J. Russell,[28] O. H. Saxton,[28] T. Schalk,[6] R. H. Schindler,[28] B. A. Schumm,[6] S. Sen,[34] V. V. Serbo,[33] M. H. Shaevitz,[10] J. T. Shank,[3] G. Shapiro,[14] D. J. Sherden,[28] K. D. Shmakov,[29] C. Simopoulos,[28] N. B. Sinev,[20] S. R. Smith,[28] M. B. Smy,[8] J. A. Snyder,[34] P. Stamer,[24] H. Steiner,[14] R. Steiner,[1] M. G. Strauss,[16] D. Su,[28] F. Suekane,[30] A. Sugiyama,[19] S. Suzuki,[19] M. Swartz,[28] A. Szumilo,[32] T. Takahashi,[28] F. E. Taylor,[15] E. Torrence,[15] A. I. Trandafir,[16] J. D. Turk,[34] T. Usher,[28] J. Va'vra,[28] C. Vannini,[23] E. Vella,[28] J. P. Venuti,[31] R. Verdier,[15] P. G. Verdini,[23] D. L. Wagner,[9] S. R. Wagner,[28] A. P. Waite,[28] S. J. Watts,[4] A. W. Weidemann,[29] E. R. Weiss,[32] J. S. Whitaker,[3] S. L. White,[29] F. J. Wickens,[25] D. A. Williams,[6] D. C. Williams,[15] S. H. Williams,[28] S. Willocq,[28] R. J. Wilson,[8] W. J. Wisniewski,[28] M. Woods,[28] G. B. Word,[24] J. Wyss,[21] R. K. Yamamoto,[15] J. M. Yamartino,[15] X. Yang,[20] S. J. Yellin,[5] C. C. Young,[28] H. Yuta,[30] G. Zapalac,[33] R. W. Zdarko,[28] and J. Zhou[20]

(SLD Collaboration)

[1]*Adelphi University, Garden City, New York 11530*
[2]*Istituto Nazionale di Fisica Nucleare Sezione di Bologna, I-40126 Bologna, Italy*
[3]*Boston University, Boston, Massachusetts 02215*
[4]*Brunel University, Uxbridge, Middlesex UB8 3PH, United Kingdom*
[5]*University of California at Santa Barbara, Santa Barbara, California 93106*
[6]*University of California at Santa Cruz, Santa Cruz, California 95064*
[7]*University of Cincinnati, Cincinnati, Ohio 45221*
[8]*Colorado State University, Fort Collins, Colorado 80523*
[9]*University of Colorado, Boulder, Colorado 80309*
[10]*Columbia University, New York, New York 10027*
[11]*Istituto Nazionale di Fisica Nucleare Sezione di Ferrara and Università di Ferrara, I-44100 Ferrara, Italy*
[12]*Istituto Nazionale di Fisica Nucleare Laboratorio Nazionali di Frascati, I-00044 Frascati, Italy*
[13]*University of Illinois, Urbana, Illinois 61801*
[14]*Lawrence Berkeley Laboratory, University of California, Berkeley, California 94720*
[15]*Massachusetts Institute of Technology, Cambridge, Massachusetts 02139*
[16]*University of Massachusetts, Amherst, Massachusetts 01003*
[17]*University of Mississippi, University, Mississippi 38677*
[18]*Moscow State University, Institute of Nuclear Physics, 119899 Moscow, Russia*
[19]*Nagoya University, Chikusa-ku, Nagoya 464 Japan*

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[20]*University of Oregon, Eugene, Oregon 97403*
[21]*Istituto Nazionale di Fisica Nucleare Sezione di Padova and Università di Padova, I-35100 Padova, Italy*
[22]*Istituto Nazionale di Fisica Nucleare Sezione di Perugia and Università di Perugia, I-06100 Perugia, Italy*
[23]*Istituto Nazionale di Fisica Nucleare Sezione di Pisa and Università di Pisa, I-56100 Pisa, Italy*
[24]*Rutgers University, Piscataway, New Jersey 08855*
[25]*Rutherford Appleton Laboratory, Chilton, Didcot, Oxon OX11 0QX, United Kingdom*
[26]*Sogang University, Seoul, Korea*
[27]*Soongsil University, Seoul, Korea 156-743*
[28]*Stanford Linear Accelerator Center, Stanford University, Stanford, California 94309*
[29]*University of Tennessee, Knoxville, Tennessee 37996*
[30]*Tohoku University, Sendai 980, Japan*
[31]*Vanderbilt University, Nashville, Tennessee 37235*
[32]*University of Washington, Seattle, Washington 98195*
[33]*University of Wisconsin, Madison, Wisconsin 53706*
[34]*Yale University, New Haven, Connecticut 06511*
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We present the first measurement of the left-right charge asymmetry A_Q^{obs} in hadronic Z boson decays. This was performed at $E_{\text{c.m.}} = 91.27$ GeV with the SLD at the SLAC Linear Collider with a polarized electron beam. Using 89 838 events we obtain $A_Q^{\text{obs}} = 0.225 \pm 0.056 \pm 0.019$, which leads to a measurement of the electron left-right asymmetry parameter, $A_e = 0.162 \pm 0.041 \pm 0.014$, and $\sin^2\theta_W^{\text{eff}} = 0.2297 \pm 0.0052 \pm 0.0018$. Also, the A_Q^{obs} measurement combined with the left-right cross section asymmetry determines A_e independent of the value of the electron-beam polarization. [S0031-9007(96)02072-8]

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The SLD Collaboration has performed measurements of the left-right cross section asymmetry $A_{LR} = (\sigma_L - \sigma_R)/(\sigma_L + \sigma_R)$ in the production of Z bosons by e^+e^- collisions [1–3]. In the standard mode of the electroweak interactions, to first order, this gives the electron left-right asymmetry factor $A_e = 2v_e a_e/(v_e^2 + a_e^2)$ from [4]

$$A_{LR}^{\text{obs}} = |\mathcal{P}_e| A_{LR} = |\mathcal{P}_e| A_e \,, \tag{1}$$

where $\mathcal{P}_e$ is the electron-beam longitudinal polarization, and v_e and a_e are the vector and axial vector coupling constants between the Z^0 and electron. The forward-backward fermion asymmetries in Z decays can also be used to provide independent information on the electron couplings to the Z. The forward-backward fermion asymmetry at the Z pole (excluding e^+e^- final states) can be easily determined from the differential cross section [5] and is given by

$$A_{FB,f}(\mathcal{P}_e) = -g(a)\,\frac{\mathcal{P}_e - A_e}{1 - \mathcal{P}_e A_e}\,A_f \,, \tag{2}$$

where $g(a) = a/(1 + \frac{1}{3}a^2)$, $0 < a \le 1$, $a = |\cos\theta|_{\max}$, $\cos\theta$ describes the angle between the outgoing fermion f and the direction of the incident electron, max refers to the aperture limit of the detector, and $A_f = 2v_f a_f/(v_f^2 + a_f^2)$. We can define $A_{FB,f}^L \equiv A_{FB,f}(-|\mathcal{P}_e|)$ and $A_{FB,f}^R \equiv A_{FB,f}(|\mathcal{P}_e|)$ as the forward-backward asymmetries for events produced with left- and right-handed beam polarization, respectively.

These asymmetries can be related to observable charge asymmetries [6–8]. At the parton level the fermion asymmetries for a quark-antiquark final state give the following average charges in the forward and backward hemispheres of left-handed events:

$$\begin{aligned} \langle Q_{F,f}^L \rangle &= q_f A_{FB,f}^L \,, \\ \langle Q_{B,f}^L \rangle &= -q_f A_{FB,f}^L \,, \end{aligned} \tag{3}$$

where q_f is the charge of the outgoing fermion. Similar expressions hold for right-handed events. These average charges can then be combined into the forward-backward charge flows, or asymmetries. For left-handed events

$$\langle Q_{FB,f}^L \rangle \equiv \langle Q_{F,f}^L \rangle - \langle Q_{B,f}^L \rangle = 2q_f A_{FB,f}^L \,, \tag{4}$$

with a similar expression for right-handed events.

The flavor-inclusive observables for the polarized $\langle \tilde{Q}_{FB} \rangle$ and unpolarized $\langle Q_{FB} \rangle$ forward-backward charge flows, which are measured at the final state hadron level, can be defined by summing over all flavors, weighting by the flavor production rate, and including dilution factors $0 < d_f < 1$ to account for a reduction in the measured charge magnitudes due to QCD corrections, hadronization effects, and $B\bar{B}$ mixing [9] as follows:

$$\begin{aligned} \langle \tilde{Q}_{FB} \rangle &\equiv \langle Q_{FB}^L \rangle f_L - \langle Q_{FB}^R \rangle f_R \\ &= 2g(a)|\mathcal{P}_e| \sum_f d_f q_f R_f A_f \,, \end{aligned} \tag{5}$$

$$\langle Q_{FB} \rangle \equiv \langle Q_{FB}^L \rangle f_L + \langle Q_{FB}^R \rangle f_R = 2g(a) A_e \sum_f d_f q_f R_f A_f \,, \tag{6}$$

where $f_L = \frac{1}{2}(1 + |\mathcal{P}_e| A_e)$ and $f_R = \frac{1}{2}(1 - |\mathcal{P}_e| A_e)$ are the fractions of left- and right-handed events, $R_f = \Gamma_f/\Gamma_{\text{had}}$, Γ_f is the partial width for the decay $Z \to f\bar{f}$, and Γ_{had} is the total hadronic width of the Z. The quantities $\langle Q_{FB}^{L}\rangle$ and $\langle Q_{FB}^{R}\rangle$ represent the mean, flavor-inclusive, forward-backward charge flows in left- and right-handed events. These quantities are measured using the momentum-weighted charge technique described below.

The ratio of these charge asymmetries has the simple form

$$A_{Q}^{\text{obs}} \equiv \frac{\langle Q_{FB}\rangle}{\langle \tilde{Q}_{FB}\rangle} = \frac{A_e}{|\mathcal{P}_e|}. \qquad (7)$$

The expression for A_Q^{obs} shows that uncertainties in the detector acceptance, charge measurement, and the dilution factors cancel out, thus effectively eliminating the dependence on Monte Carlo simulation for such corrections. By measuring the quantity $A_Q^{\text{obs}}|\mathcal{P}_e|$, A_e can be obtained in a manner largely independent of the A_{LR}^{obs} measurement [10]. Many systematic instrumental effects were investigated and are discussed below.

Furthermore, the two measurements can be combined to yield A_e without a measurement of the electron polarization, using the expression

$$A_e = \sqrt{A_{LR}^{\text{obs}} \times A_{Q}^{\text{obs}}}. \qquad (8)$$

This alternate determination of A_e is clearly not independent of the more precise measurement using A_{LR}^{obs} and the longitudinal polarization that has been published elsewhere [2,3].

In this paper, we present the first measurement of A_e from A_Q^{obs} and the electron-beam polarization. We also present an alternative measurement of A_e from A_{LR}^{obs} and A_Q^{obs} that does not require knowledge of the polarization magnitude.

Details of the SLAC Linear Collider (SLC), the polarized electron source, the measurement of the electron-beam polarization with the Compton polarimeter, and the SLD have been given elsewhere [1,2,11]. The results presented in this article are based upon a sample of data corresponding to an integrated luminosity of 5.1 pb^{-1}. The data were recorded at a mean center-of-mass energy of 91.27 $\pm$ 0.02 GeV during the 1993 and 1994–1995 runs of the SLC.

The momenta of charged particles were measured in the central drift chamber (CDC). Accepted particles were required to have (i) a minimum momentum transverse to the beam axis $>$0.15 GeV/c, (ii) a polar angle θ with respect to the beam axis satisfying $|\cos\theta| < 0.8$, and (iii) a point of closest approach to the beam axis within a cylinder of 5 cm radius and 10 cm half-length about the interaction point. If any remaining particle in an event had a total momentum $>$55 GeV/c the event was rejected.

Each event was divided into two hemispheres by a plane transverse to the thrust axis [12] which was determined using all accepted charged particles in the event. Hadronic events were selected by the following requirements: (i) the polar angle of the thrust axis satisfied $|\cos\theta_T| < 0.7$; (ii) there were at least three particles per hemisphere; (iii) the total energy of the particles in the event (assuming the particles to be pions) was greater than 20% of the center-of-mass energy; (iv) the scalar sum per hemisphere of particle momentum components parallel to the thrust axis was greater than 10% of the beam energy; and (v) the invariant mass of the particles in at least one hemisphere was greater than 2 GeV/c^2. A total of 49 850 hadronic Z decays produced by left-handed electrons and 39 988 produced by right-handed electrons were obtained with an estimated non-Z background of less than 0.05% [13]. The effect of the residual $\tau^+\tau^-$ events on the value of A_Q^{obs} was estimated to be (0.028 $\pm$ 0.012)% which is negligible. This is relevant because final-state polarization effects in this channel complicate its contribution to this quantity. The luminosity-weighted polarization for this sample of events was 0.730 $\pm$ 0.008, where the error is predominantly systematic [14].

The forward-backward charge asymmetries were determined in the following manner. A unit vector along the thrust axis, $\hat{\mathbf{T}}$, was chosen such that $\hat{\mathbf{T}} \cdot \mathbf{p}_{e^-} > 0$, where $\mathbf{p}_{e^-}$ is the electron beam direction. Tracks with momentum vector $\mathbf{p}$ were defined as forward if $\mathbf{p} \cdot \hat{\mathbf{T}} > 0$, and backward otherwise. The weighted charge in the forward hemisphere was then calculated for each event from

$$Q_F = \frac{\sum_{\mathbf{p}_i\cdot\hat{\mathbf{T}}>0} |\mathbf{p}_i \cdot \hat{\mathbf{T}}| q_i}{\sum_{\mathbf{p}_i\cdot\hat{\mathbf{T}}>0} |\mathbf{p}_i \cdot \hat{\mathbf{T}}|}, \qquad (9)$$

where q_i is the charge of particle i. The charge in the backward hemisphere, Q_B, was determined in a similar manner for tracks with $\mathbf{p} \cdot \hat{\mathbf{T}} < 0$. The quantity $Q_{FB} = Q_F - Q_B$ was then found for each event.

The distribution of Q_{FB} was formed separately for left- and right-handed events. The distributions for $\langle \tilde{Q}_{FB}\rangle$ and $\langle Q_{FB}\rangle$ were obtained in accordance with Eqs. (5) and (6) and are shown in Fig. 1. These distributions are Gaussian. The width of these curves are dominated by the physics of the process, not the detector resolution. The averages $\langle \tilde{Q}_{FB}\rangle$ and $\langle Q_{FB}\rangle$ and their errors were obtained from fits to their corresponding distributions [15]. Then A_Q^{obs} was determined using Eq. (7). A value for A_{LR}^{obs} was also obtained using the number of accepted left- and right-handed events. These results are summarized in Table I.

We investigated a number possible systematic errors due to biases in instrumentation, analysis misidentification, charge dependent nuclear interactions of low momentum hadrons, unphysical measured momenta, material asymmetries, and various backgrounds. We studied the possibility of a charge-dependent, forward-backward bias in the measured track sagitta, or momenta, by means of the dimuon and Bhabha events in the data sample. This can produce an artificial change in $\langle Q_{FB}\rangle$, while affecting

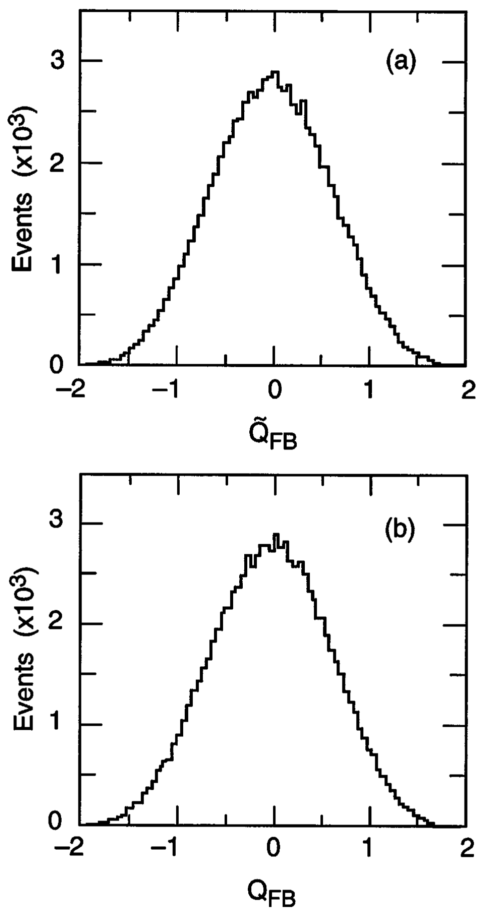

FIG. 1. Distributions of the polarized (a) and unpolarized (b) forward-backward charge flows.

$\langle \tilde{Q}_{FB} \rangle$ very little, thus biasing $A_Q^{\rm obs}$ [16]. This study led to a $(-1.6 \pm 6.5)\%$ change in $A_Q^{\rm obs}$. This error was the largest of the systematic errors studied. The systematic errors on the value of $A_Q^{\rm obs}$ resulting from these studies are presented in Table II.

The value for the left-right charge asymmetry, before radiative corrections and including the systematic error from Table II, is

$$A_Q^{\rm obs} = 0.225 \pm 0.056({\rm stat}) \pm 0.019({\rm syst}). \quad (10)$$

To obtain the relevant quantities A_e and $\sin^2\theta_W^{\rm eff}$ from $A_Q^{\rm obs}$ we must correct Eq. (7) for Z-γ interference, γ exchange, and radiative corrections. These were made to the measured asymmetries using the ZFITTER program [17]. The cancellation of the flavor sum in Eq. (7) is not preserved by these higher order processes, and Eqs. (5) and (6) must be used with ZFITTER to obtain $A_e/|P_e|$. The charge dilution factors d_f were varied by $\pm 20\%$ in a manner that maximizes the variation of the radiative correction to $A_Q^{\rm obs}$. This results in an uncertainty of $\pm 4\%$ in the corrected value of $A_Q^{\rm obs}$. After these corrections, the following values are obtained:

$$A_e = 0.162 \pm 0.041({\rm stat}) \pm 0.014({\rm syst}),$$
$$\sin^2\theta_W^{\rm eff} = 0.2297 \pm 0.0052({\rm stat}) \pm 0.0018({\rm syst}). \quad (11)$$

These results are largely independent of those previously obtained by SLD from A_{LR}, and are in good agreement with them.

We can also obtain A_e from $A_Q^{\rm obs}$ and $A_{LR}^{\rm obs}$ using Eq. (8), without the use of the Compton-measured polarization. After radiative corrections to the measured results, we obtain

$$A_e = 0.1574 \pm 0.0197({\rm stat}) \pm 0.0067({\rm syst}),$$
$$\sin^2\theta_W^{\rm eff} = 0.2302 \pm 0.0025({\rm stat}) \pm 0.0009({\rm syst}).$$

This result is not independent of those obtained from A_{LR} and $A_Q^{\rm obs}$ separately. Rather, it is an alternative measurement of A_e and $\sin^2\theta_W^{\rm eff}$ that does not use the measured polarization. This is a completely new technique in the determination of these quantities. These results can be compared with the latest value of $\sin^2\theta_W^{\rm eff} = 0.23049 \pm 0.00050$, obtained directly from a measurement of A_{LR} and the electron longitudinal polarization [3].

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TABLE I. Summary of results.

Quantity	Value
f_L, f_R	0.5549, 0.4451
$\langle Q_{FB}^L \rangle$	-0.0408 ± 0.0027
$\langle Q_{FB}^R \rangle$	0.0322 ± 0.0031
$\langle \tilde{Q}_{FB} \rangle$	-0.03697 ± 0.00204
$\langle Q_{FB} \rangle$	-0.00831 ± 0.00204
$A_Q^{\rm obs}$	0.2247 ± 0.0556
$A_{LR}^{\rm obs}$	0.1098 ± 0.0033

TABLE II. Summary of systematic errors.

Source of uncertainty	$\delta A_Q^{\rm obs}/A_Q^{\rm obs}$ (%)
q dependent, F-B sagitta bias	6.5
q independent, F-B sagitta bias	0.5
q independent, F-B track efficiency biases	0.2
Unphysical $p_{\rm tot}$ tracks	3.3
F-B asymmetry of SLD central material	1.5
e^+e^- final-state backgrounds	0.5
Two photon backgrounds	0.7
Radiative corrections	4.0
Polarization measurement [for result (10) only]	1.1
Residual $\tau^+\tau^-$ effect	0.03
SLC track backgrounds	0.02
Total	8.7

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*Deceased.

†Also at the Università di Genova, I-16146 Genova, Italy.

‡Also at the Università di Perugia, I-06100 Perugia, Italy.

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

[2] SLD Collaboration, K. Abe *et al.*, Phys. Rev. Lett. **73**, 25 (1994).

[3] SLD Collaboration, K. Abe *et al.*, Report No. SLAC PUB **96-7291**, 1996 (to be published).

[4] In Refs. [1,2] we use A_m instead of $A_{LR}^{\rm obs}$.

[5] The $q\bar{q}$ differential production cross section is presented in many places. See, for example, Morris Swartz, Report No. SLAC-PUB-4656.

[6] ALEPH Collaboration, D. Decamp *et al.*, Phys. Lett. B **259**, 377 (1991).

[7] DELPHI Collaboration, P. Abreu *et al.*, Phys. Lett. B **277**, 371 (1992).

[8] OPAL Collaboration, P. D. Acton *et al.*, Phys. Lett. B **294**, 436 (1992).

[9] It is assumed that the difference in the d_f factors for processes initiated by left- and right-handed electrons is negligible.

[10] The correlation between $A_{LR}^{\rm obs}$ and $A_Q^{\rm obs}$ is approximately -6%. Likewise, the correlation coefficient between A_{LR} and Q_{LR} is similar in value for the measurement presented in this Letter, since the error in the measured polarization is small compared to the statistical errors in $A_{LR}^{\rm obs}$ and $A_Q^{\rm obs}$.

[11] R. Alley *et al.*, Report No. NIM A365, 1995, p. 1; M. Woods, in *Proceedings of the 11th International Symposium on High Energy Spin Physics*, AIP Conf. Proc. No. 343 (AIP, New York, 1994), p. 230.

[12] E. Farhi, Phys. Rev. Lett. **39**, 1587 (1977).

[13] Our background is less than in previous studies of the SLD collaboration due to the more stringent cuts in our hadronic sample [18].

[14] This is the luminosity-weighted average polarization from two runs with polarizations of 0.63 and 0.78 [2,11].

[15] In computing the charge asymmetries for each event, a correction for a charge-dependent, forward-backward bias to the track sagitta was applied to each track's momentum as determined by our systematic error studies.

[16] This is because in $\langle \tilde{Q}_{FB} \rangle$ we measure the difference of the charge flow for left- and right-handed electrons, canceling these types of biases, while in $\langle Q_{FB} \rangle$ we measure the sum.

[17] We use the software ZFITTER 4.9 from D. Bardin *et al.*, Report No. CERN-TH. 6443/92, 1992 (unpublished).

[18] SLD Collaboration, K. Abe *et al.*, Phys. Rev. D **51**, 962 (1995).