Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA

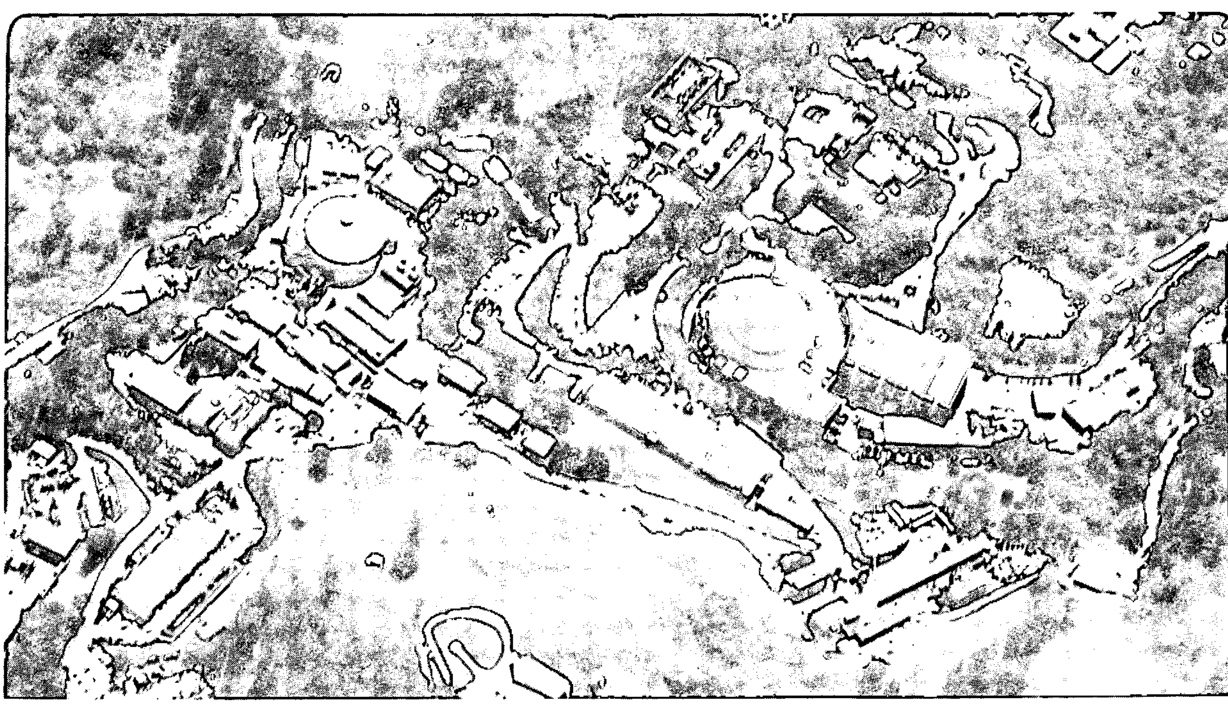
Physics Division

Presented at Particles and Fields 92, Batavia, IL,
November 10–17, 1992, and to be published
in the Proceedings

A Preliminary Measurement of $R_b = \frac{\Gamma(Z^\circ \rightarrow b\bar{b})}{\Gamma(Z^\circ \rightarrow \text{hadrons})}$ at SLD

The SLD Collaboration

November 1992



Prepared for the U.S. Department of Energy under Contract Number DE-AC03-76SF00098

LBL-34448

A Preliminary Measurement of $R_b = \frac{\Gamma(Z^\circ \to b\bar{b})}{\Gamma(Z^\circ \to \text{hadrons})}$ at SLD

THE SLD COLLABORATION
Stanford Linear Accelerator Center, Stanford University
Stanford, CA 94309, USA

November 1992

This work was supported by the Director, Office of Energy Research, Office of High Energy and Nuclear Physics, High Energy Physics Division, of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

SLAC-PUB-5972
November 1992
(T/E)

A PRELIMINARY MEASUREMENT OF $R_b = \frac{\Gamma(Z^\circ \to b\bar{b})}{\Gamma(Z^\circ \to \text{hadrons})}$ AT SLD[(a)]

THE SLD COLLABORATION[(b)]
Stanford Linear Accelerator Center, Stanford University, Stanford CA 94309, USA
Represented by
D. SU
Rutherford Appleton Laboratory, Chilton, Didcot, Oxon, England

ABSTRACT

We present a preliminary measurement of R_b, the ratio of $\Gamma(Z^\circ \to b\bar{b})$ relative to $\Gamma(Z^\circ \to \text{hadrons})$ using the silicon CCD–pixel vertex detector of the SLD at the SLAC Linear Collider (SLC). An impact parameter method and a displaced vertex method are applied to all charged tracks, to efficiently tag $Z^\circ \to b\bar{b}$ events. From the impact (displaced vertex) approach we find $R_b = 0.214 \pm 0.010 \pm 0.025$ ($R_b = 0.204 \pm 0.010 \pm 0.030$), consistent with the standard model value.

1. Introduction

The branching fraction ratio R_b measures the sum of the squares of the vector and axial vector couplings of the b-quark to the Z°. As the CKM parameter $V_{tb} \approx 1$ one anticipates large vertex and external radiative corrections $[\Delta V \propto (M_t/M_Z)^2]$ for $M_t \gg M_Z$. R_b isolates the vertex corrections, as oblique corrections largely cancel in the ratio, being common to all fermions.[1] This is further accompanied by a very weak dependence of R_b on QCD corrections with a change of $R_b < 0.1\%$ for a 10% variation in α_s. These insensitivities to conventional radiative corrections make R_b an excellent variable in the search for new physics once M_t is known, and if $\delta R_b \sim 1\%$ can be obtained. We present herein preliminary results on the measurement of R_b from a sample of 11.8 K Z° events ($\langle$ e-polarization $\rangle \approx 22\%$) collected at $\sqrt{s} = 91.55$ GeV in the SLD at the SLC, using a CCD vertex detector. Z° events containing b-decays are tagged by two techniques; one similar to that used by Mark II,[2] namely the counting of all tracks with large impact parameters (b) to the interaction point (IP), and one that counts displaced vertices from b and c-quark decays directly. High efficiencies and purities are achieved as both hadrons and leptons are included in the tagging procedures.

2. Detector Description and Tracking Performance

For this analysis, only a subset of the elements of SLD are utilized; the central drift chamber (CDC)[3] covering 85% 4π sr, the CCD vertex detector (VXD)[4] covering 75% 4π sr, and the liquid argon calorimeter (LAC) covering 95% 4π sr.[5] The LAC is used in the SLD trigger. Charged tracks are reconstructed in the CDC and linked with pixel-clusters in the VXD. A combined fit using the Billior method[6] is performed, to properly account for multiple scattering as the track is extrapolated through the VXD material and the 25 mm radius beryllium beam pipe, into the IP. The angular errors of the CDC combined with local $\langle \delta R\phi \rangle$ and $\langle \delta z \rangle$ of VXD clusters of 5 μm and 8 μm, respectively, lead to XY (plane perpendicular to the e^+e^- beams) and Rz (plane containing the beam axis) impact resolutions of $(\alpha, \beta)_\phi = (13\ \mu\text{m},\ 70\ \mu\text{m})$, and $(\alpha, \beta)_{Rz} = (52\ \mu\text{m},\ 70\ \mu\text{m})$, respectively.[b]

[b] We parametrize the impact resolution function as $\alpha \oplus \beta / P\sqrt{(\sin^3\theta)}$, where the sum is taken in quadrature.

Presented at Particles & Fields 92: Meeting of Division of Particles & Fields of the APS (DPF92), Batavia, Illinois, November 10–17, 1992

3. Beam Position

The beams of the SLC have RMS profiles averaged over our sample of $2 \otimes 2\ \mu m^2$ in X and Y; while the luminous region in Z is $\sim 650\ \mu$m. Frequent beam-beam scans coupled with a feedback utilizing the pulse to pulse beamstrahlung monitor information is used to maintain the beams in collision and stabilize the IP position. The IP is *tracked* in SLD utilizing Z° events. A fit is performed for the X, Y IP position and error (σ_x, σ_y) using ~ 50 time-ordered tracks of small b, from $\sim 10\ Z^\circ$ events. Each sample spans approximately half an hour to three hours for stability. The 447 measurements for the 1992 data run have σ_x, $\sigma_y \simeq 10$ to 15 μm. The impact parameter of $\mu^+\mu^-$ and e^+e^- to the IP (Fig. 1) gives $\langle\sigma_{\mathrm{IP}}\rangle \approx 11\ \mu$m after unfolding the single track impact resolution.

4. Detector and Event Selection

The SLD trigger is based on loose calorimetric criteria to eliminate primary beam related backgrounds; conventional $e^\pm$ and γ scattered from the beam pipe and masks, and upstream electroproduced muons, unique to SLC. The former are reduced by total energy and asymmetry cuts, while the latter are reduced utilizing the fine grained tower structure of the LAC and the pattern of energy deposition of the muons.

Hadronic Z° events are selected off-line for analysis from the sample of triggers. We require visible energy in tracks $E_{vis} > 18$ GeV and that the thrust axis lie within $|\cos(\theta_T)| < 0.71$ where tracking is optimal. We require the number of tracks $N_{\mathrm{chrg}} \geq 7$, eliminating 2γ and τ-pair events. Bad running periods and events with the number of CDC/VXD linked tracks < 3 are rejected. We retain 4857 Z° events with an estimated background contamination $< 1\%$. Flavor dependence of the selection for b-quarks relative to all hadronic Z° events is found by Monte Carlo to be negligible within 1.000 ± 0.007.

5. The Determination of R_b

5.1. The Impact Technique

After event selection the set of CDC tracks having a VXD fit is further refined: We require that CDC tracks start at a radius $r < 0.4$ m, have $N_{\mathrm{hit}} > 40$ and have good fit quality ($\chi^2/df < 5$). Tracks originating from identified long lived V's and γ-conversions are eliminated. Tracks are extrapolated to the XY point of closest approach to the IP, and the 2–D impact parameter (b) and error (σ_b) are calculated. We require $|b| < 0.3$ cm and $\sigma_b < 250\ \mu$m for tracks, equivalent to requiring momentum $p >\sim 0.5$ GeV/c. All tracks are required to extrapolate to within 1 cm of the average beam position in Z.

The JADE algorithm with parameter YCUT = 0.02 was applied to charged tracks to reconstruct jets. A sign is attached to $|b|$ for each track with the $+(-)$ convention chosen for tracks crossing its assigned jet axis in front(back) of the IP. A nonzero lifetime preferentially populates $+|b|$, while $-|b|$ tracks reflects uncertainty in the jet direction and the tracking resolution. The normalized impact parameter (b_{norm}) is formed from the signed b divided by σ_b in quadrature with σ_{IP} along the $\hat{b}$ direction.

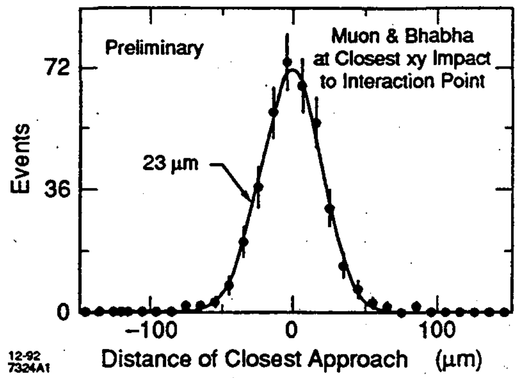


Figure 1. The XY impact parameter to the IP for tracks from muon-pair and Bhabha events.

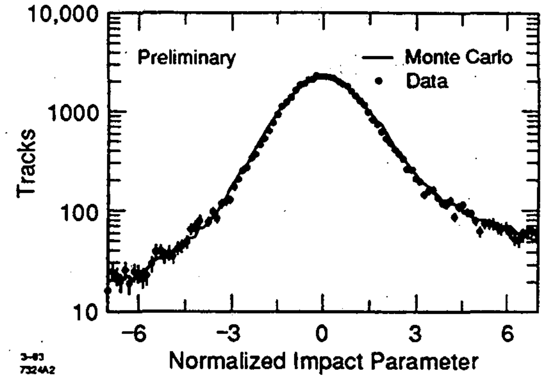


Figure 2. The signed and normalized impact parameter b_{norm} for tracks in all Z° candidate events.

The Monte Carlo (MC) simulation contains knowledge of resolution, geometry, efficiency and backgrounds, but unmodeled effects remain. These are associated with detailed CDC waveforms, models of drift velocity variation and residual misalignments and distortions. The MC is adjusted (as a function of p) to match tracking efficiency and resolution by removing 6% of the tracks and adding small additional fluctuations to b, thereby putting b_{norm} in both data and MC into agreement, for values of $b_{\text{norm}} < 0$. Since $-|b|$ tracks reflect resolution and not the lifetime effects of b- and c-quarks, this is an unbiased procedure for correcting the simulation of $b_{\text{norm}} \geq 0$ tracks. A similar correction is applied for Z impact in Sec. 5.2.

The impact parameter tagging technique for $b\bar{b}$ events utilizes the property that b-hadrons have a large decay length (~ 0.2 cm) resulting in many large P_t tracks having large $+|b|$. We cut on the number of tracks ($\geq N_{\text{sign}}$) in an event having $b_{\text{norm}} > 3$. Figure 2 shows b_{norm} for MC and data, while Fig. 3 shows the tagging efficiency (ϵ_b) and purity (Π_b) versus N_{sign}. The standard model values for $\Gamma(Z^\circ \rightarrow q\bar{q})$ are used to estimate the Π_b; however, only the ϵ values actually alter R_b. Choosing $N_{\text{sign}} = 3$, we tag 996 of 4857 events (Fig. 5), resulting in $\epsilon_b = 0.71$, $\epsilon_c = 0.18$, $\epsilon_{uds} = 0.04$, $\Pi_b = 0.74$, and $R_b = 0.214 \pm 0.010$ (statistical error only).

5.2. The Displaced Vertex Technique

The displaced vertex technique is based on the observation that b-hadron decays results in more 2–prong vertices displaced from the IP, than decays in uds or c events. Pairs of tracks, each with $p > 0.3$ GeV, $|b| < 0.3$ cm, and $|Z_0| < 1$ cm are combined to find candidate 2–prong vertices. The cut on $|b|$ is effective in V and $\gamma \rightarrow e^+e^-$ rejection. To reduce combinatorics of tracks from opposing jets, the opening angle of a pair must be less than 90° in the lab. A 3–D fit on each vertex must satisfy $\chi^2 < 5$. The decay length $L(= \mathbf{l} \bullet \mathbf{P_V}/|\mathbf{P_V}|)$ from the IP to the fitted vertex must be < 2 cm and $> 6\sigma_L$ ($\sigma_L = \sigma_V \oplus \sigma_{\text{IP}}$, where σ_V is the flight distance fit error). The tag requires a minimum of vertices N_V to satisfy this cut. Fig. 4 shows ϵ_b, Π_b and ϵ_c, ϵ_{uds} versus N_V. For $N_V \geq 4$, (Fig. 6) we retain 749 of 4857 events with $\epsilon_b = 0.58$, $\Pi_b = 0.77$, $\epsilon_c = 0.11$, and $\epsilon_{uds} = 0.03$. An overlap of 610 events with the impact technique is observed. This analysis yields $R_b = 0.204 \pm 0.011$ (statistical error only).

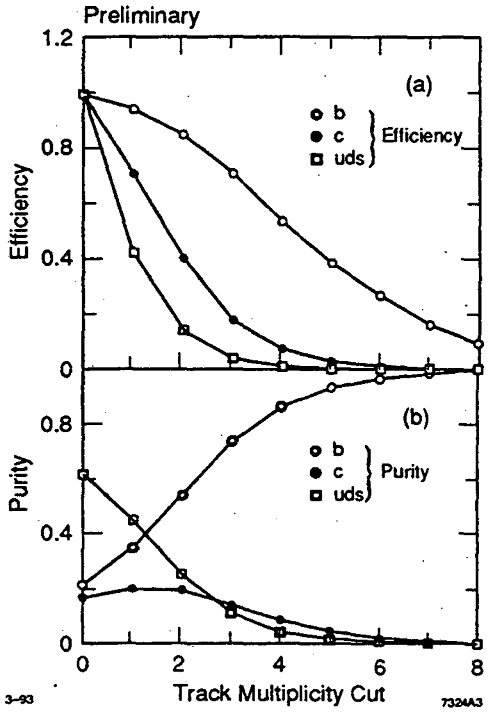


Figure 3. The impact tagging efficiency and purity as a function of the track multiplicity cut ($N_{\rm sign}$) for $b_{\rm norm} > 3$ from MC.

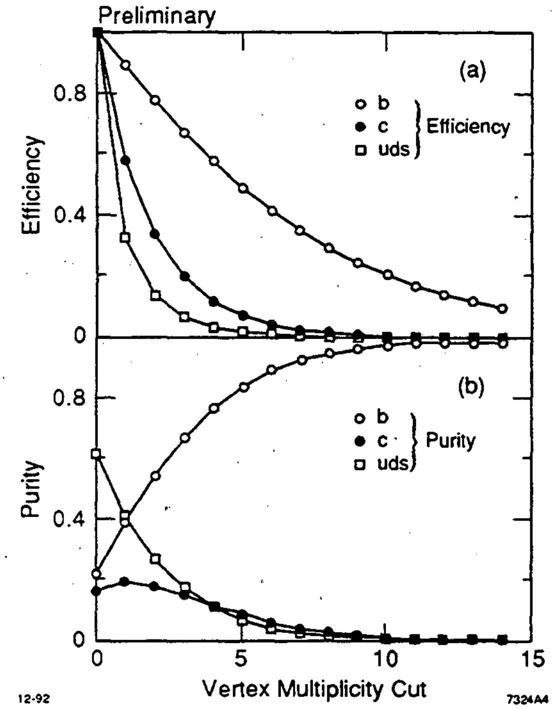


Figure 4. The vertex tagging efficiency and purity as a function of the vertex multiplicity cut (N_V) for $L/\sigma_L > 6$ from MC.

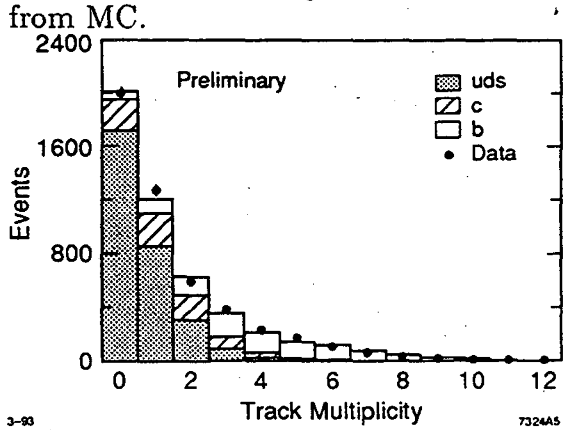


Figure 5. The distribution of track multiplicity ($N_{\rm sign}$) for $b_{\rm norm} > 3$ over the Z° sample.

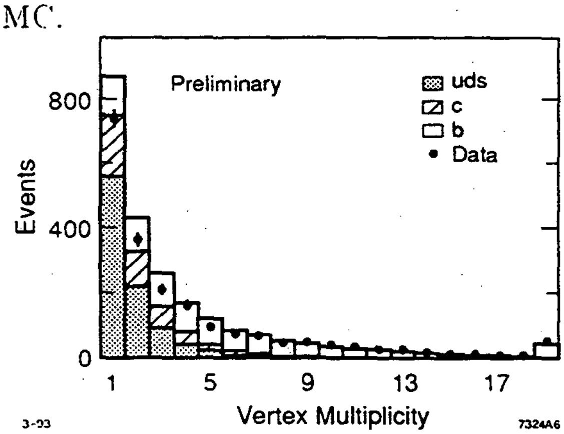


Figure 6. The distribution of vertex multiplicity (N_V) for $L/\sigma_L > 6$ over the Z° sample.

6. Systematic Errors

Our preliminary estimates of systematic errors for the impact parameter and vertex techniques are shown in Table I. Detector errors are conservative estimates. The b-lifetime is varied from 1.2 to 1.5 ps. The fragmentation has been studied with JETSET 6.3, using Peterson functions with $(\langle x_\epsilon\rangle, \epsilon) = (0.494 \pm 0.025, 0.06)$ and $(0.700 \pm 0.021, 0.006)$ for c- and b-quarks, respectively. Exclusive models of the decays of b and c hadrons have been adjusted to reflect present knowledge of their decays.[3] The $\Gamma(B \to D^\circ)/\Gamma(B \to D^+)$ ratio error was found to have a negligible effect. The value[7] of $\Gamma(Z^\circ \to c\bar{c})/\Gamma(Z^\circ \to \text{hadrons}) = 0.17 \pm 0.03$ is varied about its error, as was the D^+ fraction ($\pm 10\%$), therein. The charged track multiplicity of B decays $= 5.52 \pm 0.25$ was varied about its error. The measured values for R_b without radiative corrections are $R_b = 0.214 \pm 0.010 \pm 0.025$ (impact method) and $R_b = 0.204 \pm 0.011 \pm 0.030$ (vertex method), where the first error is statistical and the second systematic. These results are consistent with the prediction of $R_b \approx 0.22$ in the standard model.[8]

Table I. Systematic errors (%)

Source	Impact	Vertex
Tracking resolution	9.0	6.8
Tracking efficiency	5.0	11.2
Beam position	2.1	1.9
Subtotal	10.5	13.2
b-lifetime	2.8	3.0
b-fragmentation	2.3	0.7
b-decay Properties	2.7	5.7
c-fragmentation	1.0	1.6
$\Gamma(Z^\circ \to c\bar{c})$	1.6	2.2
Subtotal	4.9	7.0
Total	11.6	15.0

7. Conclusions

Tagging methods that exploit the small and stable SLC IP and the 3–D information of the CCD–pixel vertex detector are found to be highly efficient for b-decays and to provide excellent background rejection against lighter quarks. These approaches systematically differ from conventional lepton tagging both in physics bias and the level required for detector modelling. The large systematic errors at present reflect our preliminary detector simulation and do not represent fundamental limits to the methods.

8. References

[a]Work supported by Department of Energy contracts DE–FG02–91ER40676 (BU), DE–FG03–92ER40701 (CIT), DE–FG03–91ER40618 (UCSB), DE–FG02–91ER40672 (Colorado), DE–FG02–91ER40677 (Illinois), DE–FG02–91ER40661 (Indiana), DE–AC03–76SF00098 (LBL), DE–FG02–92ER40715 (Massachusetts), DE–AC02–76ER03069 (MIT), DE–FG06–85ER40224 (Oregon), DE–AC03–76SF00515 (SLAC), DE–FG05–91ER40627 (Tennessee), DE–AC02–76ER00881 (Wisconsin), DE–FG02–92ER40704 (Yale); by National Science Foundation grants PHY–91–13428 (UCSC), PHY–89–21320 (Columbia), PHY–92–04239 (Cincinnati), PHY–88–17930 (Rutgers), PHY–88–19316 (Vanderbilt), PHY–92–03212 (Washington); and by the Istituto Nazionale di Fisica Nucleare of Italy (Bologna, Ferrara, Frascati, Pisa, Padova, and Perugia); the Japan-US Cooperative Research Project on High Energy Physics (KEK, Nagoya, and Tohoku); the Natural Sciences and Engineering Research Council of Canada (British Columbia, Victoria, and TRIUMF); and the Science and Engineering Research Council of the United Kingdom (Brunel and RAL).

[3]Models have been adjusted to reflect recent data presented from LEP, on fragmentation, CLEO, Argus on exclusive beauty decays and multiplicity, MARK III and the Particle Data Group on charm decays and multiplicities. See J. Snyder, D. Su, R. Schindler, G. Punkar SLD B-Physics Internal Memo (10-15-92).

[b]The SLD Collaboration:[◇] K. Abe,[28] I. Abt,[14] P. D. Acton,[4] G. Agnew,[4] C. Alber,[9] C. Arroyo,[10] W. W. Ash,[26] D. Aston,[26] N. Bacchetta,[21] K. G. Baird,[24] C. Baltay,[32] H. R. Band,[31] G. J. Baranko,[9] O. Bardon,[17] R. Battiston,[22] A. O. Bazarko,[10] A. Bean,[6] R. J. Belcinski,[18] R. Ben-David,[32] A. C. Benvenuti,[2] S. Bethke,[16] M. Biasini,[22] T. Bienz,[26] G. M. Bilei,[22] D. Bisello,[21] G. Blaylock,[7] T. Bolton,[10] J. E. Brau,[20] M. Breidenbach,[26] W. M. Bugg,[27] D. Burke,[26] T. H. Burnett,[30] P. N. Burrows,[17] W. Busza,[17] A. Calcaterra,[12] D. O. Caldwell,[6] D. Calloway,[26] B. Camanzi,[11] M. Carpinelli,[23] J. Carr,[9] R. Cassell,[26] R. Castaldi,[*,23] A. Castro,[21] M. Cavalli-Sforza,[7] G. B. Chadwick,[26] O. Chamberlain,[16] L. Chen,[29] P. E. L. Clarke,[4] R. Claus,[26] H. O. Cohn,[27] J. A. Coller,[3] V. Cook,[30] R. Cotton,[4] R. F. Cowan,[17] P. A. Coyle,[7] D. G. Coyne,[7] A. D'Oliveira,[8] C. J. S. Damerell,[25] S. Dasu,[26] R. De Sangro,[12] P. De Simone,[12] S. De Simone,[12] R. Dell'Orso,[23] P. Y. C. Du,[27] R. Dubois,[26] W. Dunwoodie,[26] D. D. Durrett,[9] G. Eigen,[5] B. I. Eisenstein,[14] R. Elia,[26] E. Erdos,[9] C. Fan,[9] M. J. Fero,[17] T. Fieguth,[26] K. M. Fortune,[14] R. Frey,[20] J. I. Friedman,[17] J. Fujimoto,[15] K. Furuno,[20] M. Gallinaro,[12] A. Gillman,[25] G. Gladding,[14] S. Gonzalez,[17] G. D. Hallewell,[26] T. Hansl-Kozanecka,[17] E. L. Hart,[27] K. Hasegawa,[28] Y. Hasegawa,[28] S. Hedges,[4] S. S. Hertzbach,[18] M. D. Hildreth,[26] D. G. Hitlin,[5] J. Huber,[20] E. W. Hughes,[26] H. Hwang,[20] E. Hyatt,[10] Y. Iwasaki,[28] J. M. Izen,[14] P. Jacques,[24] A. S. Johnson,[3] J. R. Johnson,[31] R. A. Johnson,[8] T. Junk,[26] S. Kaiser,[26] R. Kajikawa,[19] M. Kalelkar,[24] I. Karliner,[14] H. Kawahara,[26] M. H. Kelsey,[5] H. W. Kendall,[17] H. Y. Kim,[30] P. C. Kim,[26] R. King,[26] M. Klein,[5] R. R. Kofler,[18] M. Kowitt,[16] N. M. Krishna,[9] R. S. Kroeger,[27] P. F. Kunz,[26] Y. Kwon,[26] J. F. Labs,[26] M. Langston,[20] A. Lath,[17] J. A. Lauber,[9] D. W. G. Leith,[26] X. Liu,[7] M. Loreti,[21] A. Lu,[6] H. L. Lynch,[26] J. Ma,[30] W. A. Majid ,[14] G. Mancinelli,[22] S. Manly,[32] G. Mantovani,[22] T. W. Markiewicz,[26] T. Maruyama,[26] H. Masuda,[26] A. Mazzucato,[†,21] E. Mazzucato,[11] J. F. McGowan,[14] A. K. McKemey,[4] B. T. Meadows,[8] D. J. Mellor,[14] R. Messner,[26] A. I. Mincer,[5] P. M. Mockett,[30] K. C. Moffeit,[26] R. J. Morrison,[6] B. Mours,[26] G. Mueller,[26] D. Muller,[26] T. Nagamine,[26] U. Nauenberg,[9] H. Neal,[26] M. Nussbaum,[8] L. S. Osborne,[17] R. S. Panvini,[29] H. Park,[20] M. Pauluzzi,[22] T. J. Pavel,[26] F. Perrier,[26] I. Peruzzi,[*,12] L. Pescara,[21] M. Petradza,[26] M. Piccolo,[12] L. Piemontese,[11] E. Pieroni,[23] K. T. Pitts,[20] R. J. Plano,[24] R. Prepost,[31] C. Y. Prescott,[26] D. Pripstein,[16] G. D. Punkar,[26] B. N. Ratcliff,[26] T. W. Reeves,[29] P. E. Rensing,[26] J. D. Richman,[6] L. S. Rochester,[26] L. Rosenson,[17] J. E. Rothberg,[30] P. C. Rowson,[10] J. J. Russell,[26] D. Rust,[13] P. Saez,[26] B. Saitta,[11] A K. Santha,[8] A. Santocchia,[22] T. Schalk,[7] R. H. Schindler,[26] U. Schneekloth,[17] D. Schultz ,[26] B. A. Schumm,[16] A. Seiden,[7] L. Servoli,[22] M. H. Shaevitz,[10] J. T. Shank,[3] G. Shapiro,[16] S. L. Shapiro,[26] D. J. Sherden,[26] A. Shoup,[8] C. Simopoulos,[26] S. R. Smith,[26] J. A. Snyder,[32] M. D. Sokoloff,[8] P. Stamer,[24] H. Steiner,[16] R. Steiner,[1] I. E. Stockdale,[8] M.G. Strauss,[18] D. Su,[25] F. Suekane,[28] A. Sugiyama,[19] S. Suzuki,[19] M. Swartz,[26] A. Szumilo,[30] T. Takahashi,[26] F. E. Taylor,[17] M. Tecchio,[21] J. J. Thaler,[14] N. Toge,[26] J. D. Turk,[32] T. Usher,[26] J. Va'Vra,[26] C. Vannini,[23] E. Vella,[26] J. P. Venuti,[29] R. Verdier,[17] P. G. Verdini,[23] A. P. Waite,[26] S. J. Watts,[4] A. W. Weidemann,[27] J. S. Whitaker,[3] S. L. White,[27] F. J. Wickens,[25] D. A. Williams,[7] D. C. Williams,[17]

R. W. Williams,[30] S. H. Williams,[26] R. J. Wilson,[3] W. J. Wisniewski,[5] M. S. Witherell,[6] M. Woods,[26] G. B. Word,[24] J. Wyss,[21] R. K. Yamamoto,[17] J. M. Yamartino,[17] S. J. Yellin,[6] C. C. Young,[26] H. Yuta,[28] G. Zapalac,[31] R. W. Zdarko,[26] C. Zeitlin,[20] J. Zhou,[20] M. Zolotorev,[26] and P. Zucchelli[11]

†Deceased
*Also at the Università di Genova
*Also at the Università di Perugia
[1]Adelphi University, Garden City, NY 11530
[2]INFN Sezione di Bologna, I-40126 Bologna, Italy
[3]Boston University, Boston, MA 02215
[4]Brunel University, Uxbridge, Middlesex UB8 3PH, UK
[5]California Institute of Technology, Pasadena, CA 91125
[6]University of California at Santa Barbara, Santa Barbara, CA 93106
[7]University of California at Santa Cruz, Santa Cruz, CA 95064
[8]University of Cincinnati, Cincinnati, OH 45221
[9]University of Colorado, Boulder, CO 80309
[10]Columbia University, New York, NY 10027
[11]INFN Sezione di Ferrara and Università di Ferrara, I-44100 Ferrara, Italy
[12]INFN Lab. Nazionali di Frascati, I-00044 Frascati, Italy
[13]Indiana University, Bloomington IN 47405
[14]University of Illinois, Urbana, IL 61801
[15]KEK National Laboratory, Tsukuba-shi, Ibaraki-ken 305 Japan
[16]Lawrence Berkeley Laboratory, University of California, Berkeley, CA 94720
[17]Massachusetts Institute of Technology, Cambridge, MA 02139
[18]University of Massachusetts, Amherst, MA 01003
[19]Nagoya University, Chikusa-ku, Nagoya 464 Japan
[20]University of Oregon, Eugene, OR 97403
[21]INFN Sezione di Padova and Università di Padova, I-35100 Padova, Italy
[22]INFN Sezione di Perugia and Università di Perugia, I-06100 Perugia, Italy
[23]INFN Sezione di Pisa and Università di Pisa, I-56100 Pisa, Italy
[24]Rutgers University, Piscataway, NJ 08855
[25]Rutherford Appleton Laboratory, Chilton, Didcot, Oxon OX11 0QX UK
[26]Stanford Linear Accelerator Center, Stanford University, Stanford, CA 94309
[27]University of Tennessee, Knoxville, TN 37996
[28]Tohoku University, Sendai 980 Japan
[29]Vanderbilt University, Nashville, TN 37235
[30]University of Washington, Seattle, WA 98195
[31]University of Wisconsin, Madison, WI 53706
[32]Yale University, New Haven, CT 06511

1. Boulware and Finnell, *Phys. Rev.* **D44** (1991) 2054, and references therein.
2. R. G. Jacobsen et al., *Phys. Rev. Lett.* **67** (1991) 3347.
3. *SLD Design Report, SLAC–REPORT–273* (1984);
   W .B. Atwood et al., *Nucl. Inst. Methods* **A252** (1986) 295.
4. For details of the performance of the silicon CCD vertex detector in the SLD, see M. Strauss (SLD Collaboration), in these proceedings; SLAC–PUB–5906.
5. D. Axen et al., *SLAC–PUB–5354* (1992), to be published in *Nucl. Inst. Methods*.
6. P. Billior, *Nucl. Inst. Methods* **225** (1984) 352.
7. P. Kluit, *Heavy Flavor Physics at LEP,* lecture presented at the Stanford Linear Accelerator Center Summer Institute, 1992.
8. W. Hollik, *Fortschrift Phys.* **38** (1990) 165, and references therein.

LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
TECHNICAL INFORMATION DEPARTMENT
BERKELEY, CALIFORNIA 94720