SLAC – PUB – 3798
October 1985
(E/I)

OVERVIEW OF THE SLD*

M. BREIDENBACH

Stanford Linear Accelerator Center
Stanford University, Stanford, California, 94305

ABSTRACT

The SLD is a second generation detector for the SLAC Linear Collider (SLC). It is optimized for Z^o physics and exploration of new physics in the Z^o energy region. The SLD will have a CCD vertex detector, high resolution drift chambers for momentum measurement, a Čerenkov Ring Imaging Detector for particle identification, and calorimetry based on lead/liquid argon followed by an iron/gas system. The detector covers the full solid angle.

INTRODUCTION

The SLD is a detector designed to study e^+e^- interactions at energies up to 100 GeV in the center-of-mass at the Stanford Linear Collider (SLC). It is being designed and built by an international collaboration of approximately 125 physicists and 30 engineers.[1]

The SLC is expected to begin operations in late 1986 or early 1987 using the SLAC/LBL Mark II detector; the SLD will replace the Mark II in 1989, somewhat before the turnon of LEP.

This paper is a general introduction to the SLD, which is more completely described in the SLD Design Report.[2] Other contributions to this conference cover particular aspects of the detector in more detail.

The SLD is designed around the following major themes:

- good electromagnetic and hadronic calorimetry covering the complete solid angle with projective geometry, fine segmentation, and good energy resolution;
- full instrumental capability over the complete solid angle, not only in the 'standard' central region;
- powerful and robust particle identification over a wide range of momentum;
- uniform technology throughout the full solid angle.

The detector is shown schematically in Figs. 1, 2 and 3, and the expected performance parameters are summarized in Table I. Particle tracking and momentum measurement are provided by a CCD vertex detector, a high-precision central drift chamber, and pairs of endcap drift chambers, all in a 0.6 Tesla magnetic field produced by a conventional aluminum solenoid. Particle identification is provided by Čerenkov Ring Imaging Detectors (CRIDs). The calorimeter consists of two sections: a liquid argon calorimeter (LAC) with lead radiator is located inside the coil; and the laminated iron of the flux return is instrumented with limited-streamer-mode tubes to complete the energy measurement. The streamer tubes of this warm-iron calorimeter (WIC) are instrumented with strip readout to provide muon tracking in addition to calorimetry. The same technology is used in the endcaps and central region, thus providing uniform response.

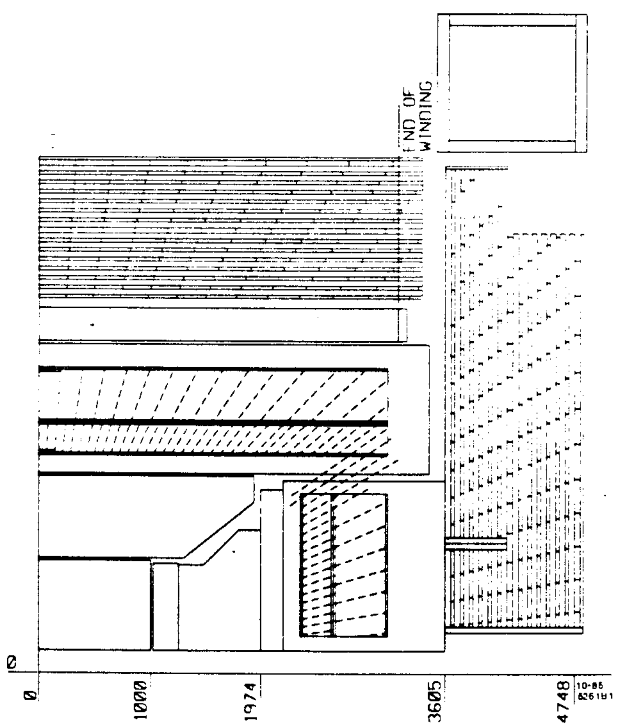

Fig. 1. Vertical section in the plane including the $e^{\pm}$ beams of one quadrant of the detector.

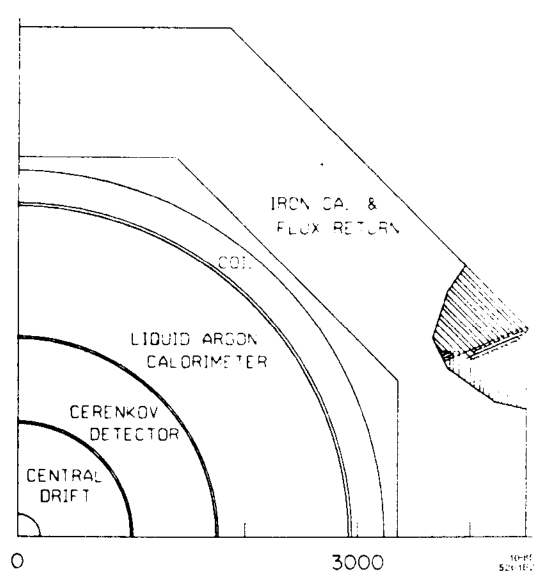

Fig. 2. Vertical section in the plane perpendicular to the $e^{\pm}$ beams of one quadrant of the detector.

* Work supported by the Department of Energy, contract DE-AC03-76SF00515.

Presented at the Nuclear Science Symposium, San Francisco, California, October 23-25, 1985

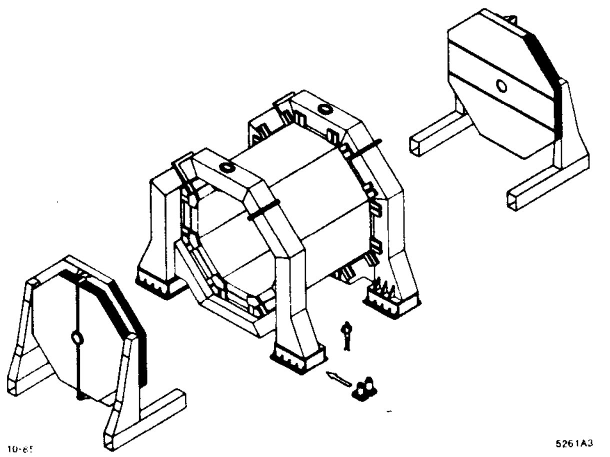

Fig. 3. Isometric view of the detector.

Table I. Summary of Proposed Performance Parameters

Drift Chamber System	
Spatial Resolution (σ)	$\leq$ 100 μm
Magnetic Field	0.6 Tesla
Momentum Resolution	
$\sigma(1/p)$ measurement limit	1.3×10^{-3} (GeV/c)$^{-1}$
$\sigma(p)/p$ Coulomb scattering limit	$(1-2) \times 10^{-2}$
Two-Track Separation	1 mm
Calorimetry	
Electromagnetic	
Energy Resolution σ_E/E	$8\% / \sqrt{E\,(\text{GeV})}$
Segmentation	~ 33 mrad × 36 mrad
Angular Resolution	~ 5 mrad
Hadronic	
Energy Resolution σ_E/E	$\leq 55\% / \sqrt{E\,(\text{GeV})}$
Segmentation	~ 66 mrad × 72 mrad
Angular Resolution	~ 10 mrad
Vertex Detector	
Segmentation	22 μm ×22 μm
Precision Transverse to Line of Flight	4 – 20 μm
Two-Track separation	40 μm
Particle Identification	
e/π	1×10^{-3}
μ/π (above 1 GeV)	2×10^{-3}
K/π (up to 30 GeV)	1×10^{-3}
K/p (up to 50 GeV)	1×10^{-3}
Solid Angle Coverage	
Tracking	97%
Particle Identification	97%
EM Calorimeter	$\geq$ 99%
Hadron Calorimeter	97%

VERTEX DETECTION - CCDs

The vertex detector[3] consists of two cylindrical mosaics of CCDs, 14 and 25 mm in radius on a ceramic frame, as shown in Fig. 4. The CCDs offer spatial resolution of ~ 5 μm as unambiguous space points with very high efficiency. The use of CCDs is practical at the SLC because of the very small beam pipe and the machine properties which permit resetting of the devices during the 5.6 ms interpulse period along with suppression of the beam during readout. The resolution in the distance of closest approach of a track to the vertex varies between 4 and 20 μm, depending upon the momentum of the particle.

The 22-μm-square pixels are found to be >98% efficient for minimum ionizing particles. A 40-μm double-track resolution has been achieved in beam tests.

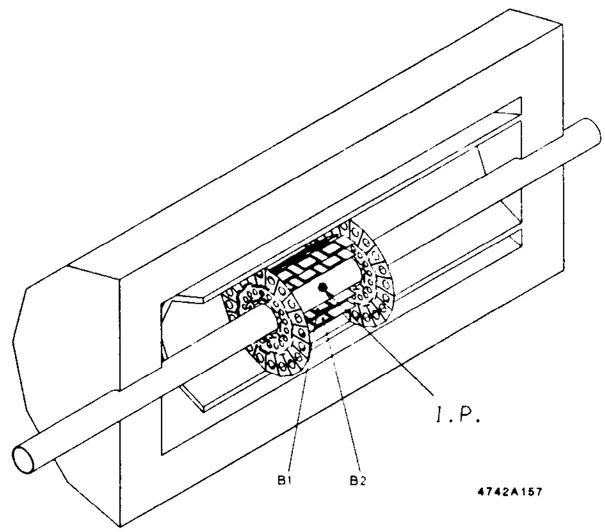

Fig. 4. General arrangement of the vertex detector.

TRACKING

The central drift chamber has 80 layers of sense wires arranged in a vector cell geometry. The cell design is shown in Fig. 5. Guard wire doublets between the sense wires serve to equalize drift time paths. Prototype tests[4] using this cell structure with a slow gas (CO_2 + 8% isobutane) give a spatial resolution of about 55 μm. In the full-size drift chamber, it is expected that the resolution will be degraded by systematic uncertainties, and an overall resolution of ~ 100 μm is expected. This translates into a momentum resolution of $\sigma(1/p) \leq 1.3 \times 10^{-3}$ (GeV/c)$^{-1}$ over most of the solid angle. Charge division and 50 mrad stereo provide z resolution of 2 mm at the vertex and 2×10^{-3} in the tangent of the dip angle. Planar endcap drift chambers extend the tracking coverage to 97% of 4π.

PARTICLE DETECTION - THE CRIDs

The CRID principle is illustrated in Fig. 6. The CRIDs have both a liquid freon radiator, whose light is 'proximity focused' on the photon detector, and a gas radiator whose light is focused by mirrors on the opposite side of the photon detector. The photon detector itself is a quartz box containing TMAE to convert the photons. The photoelectrons then drift towards a set of proportional readout wires. The Čerenkov circles will be sought in locations determined using information from the drift chambers to simplify the pattern recognition problem. This system provides essentially complete particle identification for momenta from 0.2 to 30 GeV/c.

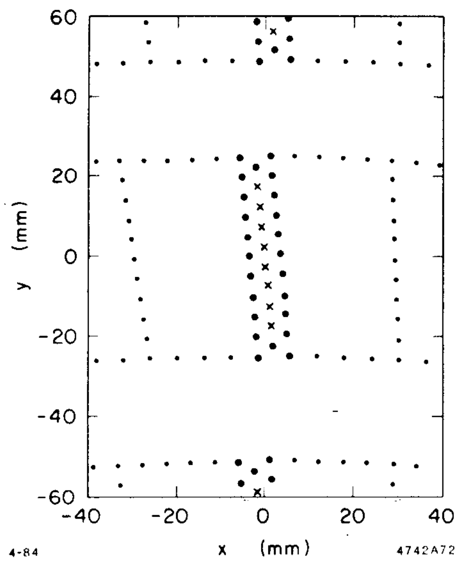

Fig. 5. The basic drift chamber cell design. Sense wires are shown as X, guard wires as •, and field wires as · .

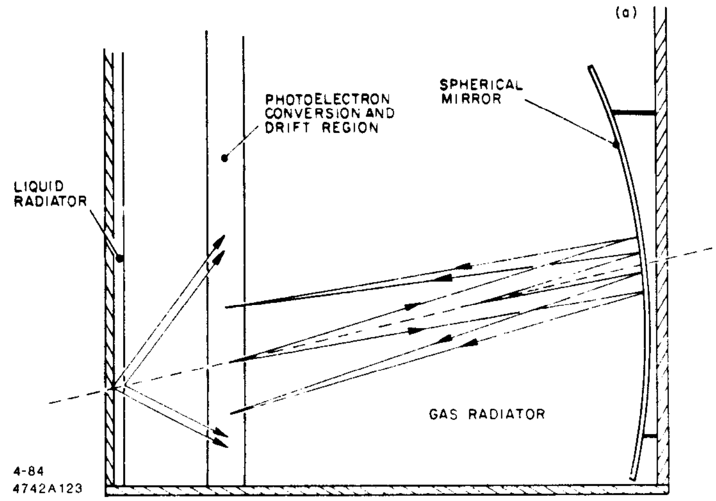

Fig. 6. The CRID principle for a two radiator system.

Figure 7 shows the mechanical design of the CRID, which, like the other detector systems, has a barrel and endcaps to maximize solid angle coverage. In the barrel, the liquid radiator, photon detectors, and focusing mirrors form concentric cylinders with the photoelectrons drifting parallel to the collinear E and B fields. In the endcaps, the corresponding components are coaxial disks with the E field transverse to the solenoidal magnetic field.

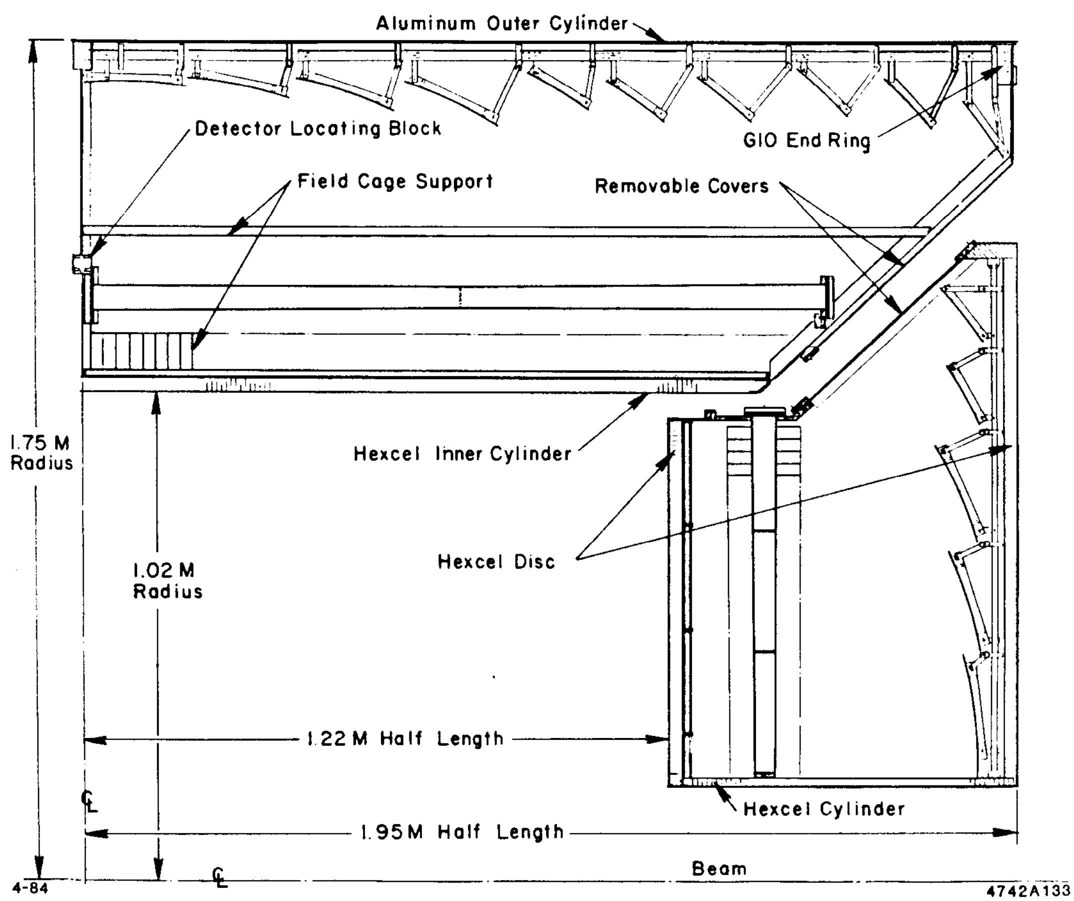

Fig. 7. Engineering layout of the CRID in a plane including the $e^{\pm}$ beams.

The liquid freon radiator is contained in quartz-faced cells approximately 1-cm thick. The gas radiator (gas candidates include isobutane and FC87) fills the entire volume of the vessels. The same photon detector is used for the two radiators. High voltage is fed from the center of the structure to limit the potential to $\sim$ 35 kV, and to limit the maximum electron drift to 80 cm. Electron detectors at the end of the drift sections amplify the single electrons while geometrically restricting photons from the amplification avalanche from feeding back to the drift region. The proportional wires also have charge division readout[5] to measure the conversion depth in the TMAE, permitting the correction of certain parallax errors.

The CRID prototype program[6] has already demonstrated the generation of electron rings from liquid and gas radiators with excellent quantum efficiency. Improvement of the electron attenuation in the drift gas and the further suppression of photon feedback are under investigation.

CALORIMETRY

The LAC consists of a lead radiator structure in liquid argon with a thickness of 22 radiation lengths for electromagnetic showers followed by 2.2 interaction lengths for hadronic showers. Each of the projective towers covers approximately 33 mrad on a side at $\theta = 90°$ in the electromagnetic section and 66 mrad in the hadronic section. The electromagnetic energy resolution is $\sigma(E)/E = 0.08/\sqrt{E(\mathrm{GeV})}$. The 5-interaction-length WIC serves as a 'tail catcher' for the hadron showers which escape the LAC.

The presence of substantial calorimetry inside the coil relaxes the constraints on the thickness of the coil, as only about 15% of the energy of a 50 GeV jet is expected to escape the cryogenic calorimeter. The expected hadronic energy resolution of the combined LAC and WIC is about $\sigma(E)/E = 0.55/\sqrt{E(\mathrm{GeV})}$. The liquid argon calorimeter is segmented 4 times in depth, and the warm iron calorimeter provides 2 additional samples. The WIC uses planes of Frascati Plastic Tubes operating in limited streamer mode, with cathode pickup electrodes on both surfaces for readout. Cathode pads are arranged in projective towers which match those in the LAC, and cathode strips are used for muon tracking, so that the iron also serves as a muon detector.

The LAC is built in vacuum insulated cryostats arranged as barrel and endcaps with radiator stack thicknesses of 75 cm. The total liquid argon volume is 40,000 liters. The stacks are built as electromagnetic and hadronic modules on aluminum strongbacks. The barrel is constructed from 144 electromagnetic and 144 hadronic modules arranged in 48 groups azimuthally in each of 3 sections parallel to the beam. Two small liquid argon calorimeters serve as a luminosity monitor, extending the electromagnetic calorimetry to polar angles below 50 mrad.

Measurements[7] were made on LAC prototype stacks of lead, uranium, and a lead-uranium mix backed up with a WIC prototype in a configuration simulating that of the SLD. At a beam energy of 11 GeV, the pure uranium radiator, combined with the WIC, had a hadronic resolution $\sigma_h/E = 18.2 \pm 2\%$ and an relative e/π response ratio of 1.17 ± 0.1. The lead LAC prototype plus WIC had a resolution $\sigma_h/E = 18.7 \pm 2\%$ and $e/\pi = 1.24 \pm 0.1$. The similarity of these results and other considerations led to the decision to use lead for the LAC, rather than a mixture of uranium and stainless steel as was originally proposed. These measurements and much other work related to uranium calorimetry were discussed at the Caltech Conference on Compensated Calorimetry.[8]

MAGNET COIL

A 0.6 Tesla magnetic field will be provided by a room temperature aluminum solenoidal coil. The coil will be approximately 6 meters in diameter, 6.5-meters long, and about 30-cm thick. Since there are about 3 absorption lengths of hadron calorimeter before the coil, the thickness has been largely governed by considerations of power consumption. It will consist of 508 turns carrying a current of 6600 amperes. The total power consumption will be about 5 MW.

DATA ACQUISITION

The very large number of readout channels needed to cope with the complicated Z^o event topologies requires a new generation of readout electronics.[9] The SLD will use about 50,000 waveform recording channels for the drift chambers and CRIDs, permitting time and charge division measurements with good multihit capability; about 50,000 sample and hold channels for calorimetry with wide dynamic range; and about 100,000 simple 1-bit channels for the strip detectors of the muon system. These systems, with appropriate preamplification and shaping, will be mounted on the detector subsystems and will communicate with Fastbus processing modules on the outside of the detector over analog optical fibers. The very low e^+e^- annihilation cross section (relative to hadronic cross sections) allows extensive multiplexing. The 180 Hz repetition rate of SLC allows 5.6 milliseconds for 'lowest level' trigger processing with no deadtime

New VLSI circuits for the waveform recording (Analog Memory Units – AMUs) and the calorimetry (Calorimetry Data Units – CDUs) have been developed in collaboration with the Stanford Electronics Laboratory. The AMU[10] has 256 sample-and-hold units which can sample at up to 200 MHz with an 11 bit dynamic range. Sixteen AMUs will be packaged in a hybrid with their clock drivers. Calibration circuitry will be packaged with the preamplifier hybrids.

The CDU[11] has 32 data channels; each data channel has 4 time cells with a 13 bit dynamic range. The CDUs are used in a dual range scheme with two data channels per calorimeter channel. The hybrid LAC preamplifier uses a low noise FET preamp without transformer coupling. Both the preamplifier and CDU hybrids will be mounted on the calorimeter bulkheads.

Both the AMU and CDU have internally controlled 1-MHz serial outputs. The outputs will be further multiplexed and received by Fastbus modules which correct, compact, and format data before passing it to programmable processors (SSPs)[12] in each crate. Data is passed over Fastbus to central trigger processors which will 'compute' a trigger decision in about 2 ms. Subsequent data flow is to secondary trigger processors expected to be 'Fastbus VAXes'[13] and finally to the on-line host computer for data storage, monitoring and control.

CONCLUSION

The SLD is a second generation detector for SLC, optimized for physics in the Z^o energy range. It is now in the later stages of R&D and the early stages of construction. It will be completed in 1989.

REFERENCES

1. **SLD Collaboration:** D. Axen, University of British Columbia; A. Benvenuti, *INFN* Sezione di Bologna; F. DeJongh, G. Eigen, H. Grau, D. Hitlin, J. Hanson, S. Sondergaard, K. Warfield, California Institute of Technology; R. Kennett, California State University Northridge; D. Bauer, D.O. Caldwell, D. Hale, A. Lu, R. Morrison, M. Witherell, S. Yellin, University of California, Santa Barbara; D. Coyne, M. Cavalli-Sforza, University of California, Santa Cruz; R. Endorf, R. Johnson, B. Meadows, M. Nussbaum, University of Cincinnati; J. Carr, L. Cremaldi, U. Nauenberg, University of Colorado; E. Anderson, Y. Au, C. Baltay, R. Barbee, R. Gardner E. Hyatt, S. Manly, M. Shaevitz, S. Smith, R. Steiner, A. Tiho, Columbia University; G. Callegari, L. Piemontese, Università di Ferrara and *INFN* Sezione di Bologna; R. DeSangro, I. Peruzzi, M. Piccolo, Laboratori Nazionali di Frascati dell' *INFN*; J.S. Brown, D. Lesny, G. Gladding, L. Pregernig, J.J. Thaler, University of Illinois; W. Busza, J. Friedman, S. Fuess, A. Johnson, H. Kendall, V. Kistiakowsky, T.F. Lyons, L.S. Osborne, L. Rosenson, D. Ross, F. Taylor, R. Verdier, B. Wadsworth, J.S. Whitaker, R.K. Yamamoto, Massachusetts Institute of Technology; H.R. Band, Northeastern University; D. Bisello, M. Loreti, L. Pescara, Universitá di Padova and *INFN* Sezione di Padova; S. Alpat, R. Battiston, G.M. Bilei, P. Cenci, G. Mantovani, M. Pauluzi, Universitá di Perugia and *INFN* Gruppo di Perugia; R. Castaldi, C. Vannini, P.G. Verdini, Sezione di Pisa, *INFN*; C. Damerell, R. English, A. Gillman, L. Lintern, R. Stephenson, C. Uden, S. Watts (Brunel University), F. Wickens, Rutherford Appleton Laboratory; C. Hodges, G. Mundy, S. Salomon, K. Simpson, A. Steiner, San Francisco State University; W.W. Ash, V. Ashford, D. Aston, W. Atwood, W. Baker, F. Barrera, G. Bauer, T. Bienz, F. Bird, R. Boyce, M. Breidenbach, B. Bricaud, G. Burgueno, E. Cisneros, W.M. Dunwoodie, R. Early, S. Ecklund, J. Flynn, D. Freytag, D. Fryberger, R. Gearhart, M. Gravina, G. Haller, G. Hallewell, T. Hansl-Kozanecki, H. Kang, P.F. Kunz, D.W.G.S. Leith, H.L. Lynch, D. McShurley, R.L. Messner, D. Nelson, B. Nielsen, M. Nordby, J.A. Nuttall, G. Oxoby, L. Paffrath, H. Peterson, D. Porat, C.Y. Prescott, B.N. Ratcliff, R. Reif, L. Rochester, A. Rothenberg, J. Russell, O. Saxton, R. Schindler, G. Schultz, D. Schultz, P. Seward, S.L. Shapiro, R.H. Shaw, D. Sherden, K. Skarpaas, R. Stiening, N. Toge, R. Watt, T. Weber, D.E. Wiser, C. Young, Stanford Linear Accelerator Center; J. Brau, W. Bugg, A. Weidemann, University of Tennessee; G. Ludgate, A. Olin, C. Oram, *TRIUMF*; A.V. Barnes, S.E. Csorna, R.S. Panvini, D. Prindle, T. Reeves, Vanderbilt University; A. Astbury, G.A. Beer, R. Dubois, R. Keeler, G.R. Mason, L.P. Robertson, E. Young, University of Victoria; V. Cook, R.J. Davisson, P.M. Mockett, J. Rothberg, J. Rutherfoord, R.W. Williams, E. Vella, K. Young, University of Washington; J.R. Johnson, T. Maruyama, R. Prepost, University of Wisconsin.
2. SLD Design Report. SLAC-Report-273, May 1984.
3. C.J.S. Damerell *et al.*, "Use of CCDs as High Precision Tracking Detectors," these proceedings.
4. C. Hodges *et al.*, "Analysis of Digitized Waveforms in a Prototype of the SLD Central Drift Chamber," these proceedings; C. Young *et al.*, "Performance of the SLD Central Drift Chamber Prototype," these proceedings.
5. F. Bird *et al.*, "Charge Division using Carbon Filaments for Obtaining Coordinate Information from the Detection of Single Electrons." these proceedings.
6. V. Ashford *et al.*, "Development of Čerenkov Ring Imaging Detectors for the SLD," these proceedings.
7. R. Dubois *et al.*, "SLD Liquid Argon Calorimeter Prototype Beam Test Results," these proceedings; A. S. Johnson *et al.*, "Performance of the SLD Warm Iron Calorimeter Pre-Prototype," these proceedings; L. Piemontese *et al.*, "Performance of the SLD Warm Iron Calorimeter Prototype," these proceedings.
8. Proceedings of the Workshop on Compensated Calorimetry, ed. D. Hitlin (Pasadena, 1985).
9. R. S. Larsen, "Overview of the Data Acquisition System Design of the SLAC SLD Detector," these proceedings.
10. D. Freytag *et al.*, "Waveform Sampler Camac Module," these proceedings.
11. G. M. Haller *et al.*, "Performance Report for Stanford-SLAC Multichannel Sample and Hold Device," these proceedings.
12. H. Brafman *et al.*, IEEE Trans. Nucl. Sci. NS-32, 336 (1985).
13. E. J. Siskind, NYCB Real Time Computing; "Development of 32-Bit Single Board Computer Systems in Fastbus Packaging," DOE Small Business Innovation Research Program (Private Communication).