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STATUS OF THE SLC*

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ABSTRACT

A brief report on the goals and progress of the SLAC Linear Collider program is presented.

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I. Introduction

The goals of the SLAC Linear Collider, SLC, are to develop the techniques of linear colliders and to do physics at and slightly above the energy necessary to produce the Z^0. In a linear collider the electrons and positrons collide once and are then discarded. This is in contrast to a storage ring where the beams are stored for many hours and collide many thousands of times a second. In order to obtain a luminosity large enough to do interesting physics, the beams are focused to a small spot of a few microns and they are only a few millimeter in length. Using the repetition rate of 180 hertz at SLAC, luminosities of 6×10^{30} cm^{-2} sec^{-1} can be reached. A genuine linear collider would require two accelerators directed at one another. The SLC prototype will use only the existing linear accelerator upgraded to reach 50 GeV. The positrons and electrons are accelerated simultaneously to the desired energy, then they enter separate arcs which transmit them to an intersecting region where they collide head on. In this way the SLC machine can reach center of mass energies high enough to produce the Z^0 via its coupling to e^+e^- pairs. At the design luminosity of the SLC, Z^0's will be produced in the excess of one million per year.

The outline of this paper will be as follows. A short review of the physics goals will be followed by the status of the SLC and the detectors. Finally, in the last section the plans for polarized electrons will be given.

II. Physics at the SLC

The physics program of the SLC concentrates on production of Z^0's and their decay. Measurements of the Z^0 mass and width will be among the first and most important physics results from the SLC. Using spectrometers in the extraction lines of the SLC the Z^0 mass will be determined to an accuracy of around 50 MeV/c^2. Once the Z^0 mass is known to this accuracy, all of the couplings of the standard model of electroweak interactions are completely determined by three fundamental constants: α, G_F, and M_Z. The Z^0 width is both a test of the standard model and a measure of the particle content of Z^0 decays. For example, a fourth neutrino species contributes 160 MeV/c^2 to the Z^0 width.

The SLC is unique among existing or planned colliding - beam facilities in its potential to accelerate longitudinally polarized electrons. The polarization sense is reversible from pulse to pulse at the operator's control, and thereby allows precise tests of the couplings of the fermion through the measurement of the left-right asymmetry.

$$A_{LR} = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R} .$$

In the standard model, A_{LR} is uniquely predicted once M_Z is known. In lowest order, for $e^+ e^- \rightarrow f\bar{f}$, independent of the final fermion type,

$$A_{LR}\ (M_Z) = \frac{{g_L^e}^2 - {g_R^e}^2}{{g_L^e}^2 + {g_R^e}^2} = \frac{2a_e v_e}{a_e^2 + v_e^2}$$

The accuracy of the measurement of A_{LR} depends on the uncertainty in the polarization measurement and statistics. The precision anticipated at the SLC is displayed in Fig. 1 as a function of the number, N, of observed Z decays. The three curves correspond to different levels of precision of measuring the electron polarization. The scales on the right show the resulting precision of the A_{LR} measurement to those of $\sin^2\theta_W$ and M_Z . The left-right asymmetry will replace the ratio of neutral to charged currents for neutrino scattering as the best test of the standard model when the number of Z's is between 10^3 and 10^4. With the more precise measurement of the beam polarization at the 1% level and with 10^6 Z^0's, the accurate measurements of M_Z and A_{LR} at the SLC will make very high precision tests of the standard model.

Searches for Z-decays to the predicted top and Higgs particles will be made as well as searches for new or unexpected phenomena beyond the standard model.

III. The Status of the SLC

Figure 2 shows the layout of the systems of the SLC. These include a new injector and booster, two damping rings to provide the small beam emittance, a new positron source, the existing linac structure upgraded for higher energy and better control of the beams, beam transport arcs, a final focus section, and experimental halls and detectors. The SLC works as follows: two bunches of 5×10^{10} electrons separated by 59 ns are accelerated to 1.2 GeV and stored in the north damping ring on opposite sides of the ring for the time between accelerator cycles (5.6 msec at 180 hertz). The two e^- bunches are extracted 59 ns behind the positron bunch from the south damping ring and accelerated. The e^+ bunch and the first e^- bunch are sent around the colliding arcs to be focused to less than 2 micron size for collision at the interaction region. The second e^- bunch generates new positrons for a later e^+ bunch. A brief status report of these systems is given below.

The electron source and injector is required to deliver to the damping ring two bunches of greater than 5×10^{10} electrons 59 nanosecond apart at 180 hertz. Test in 1984 showed that the new thermionic gun and first linac section upgraded with 80 focusing quadrupoles passed these specifications.

The damping rings are used to reduce the beam emittance to values low enough to be focused to the small sizes needed at the e^+ e^- interaction region. After the electrons are collected into a single bunch and the positrons return from the e^+ source their emittances are too high for this. The south ring was built a few years ago and the experience showed the need for stronger sextupoles, better and more position monitors, and septum cooling. These improvements are in progress. The north ring was built with these changes and was commissioned in February 1986. Both rings will be running in the summer. The maximum single bunch beam stored is 4×10^{10} e^- and this was limited only by the time available for tuning. The electron ring requires a double pulse kicker to handle the two bunches.

The main improvements to the Linac are upgrading for higher energy and addition of beam focusing and position monitoring every 40 feet. The RF control and monitoring is also being upgraded. The first third of the accelerator is complete and the rest is scheduled to be finished by summer. Replacement of the 38 megawatt klystrons with 67 megawatts ones are in progress. About 75% of the 232 units are made and it is expected that the complete complement will be on the machine by January 1987. Twenty sectors have the new high powered klystrons installed. Experience was made in the January and February 1986 running period with four of these sectors.

The SLC requires a positron source with a yield large enough to give equal numbers of positrons and electrons at the interaction point. The colliding positrons must have an emittance and bunch length similar to the electron beam. A schematic diagram of the positron source is shown in Figure 3. A single bunch of electrons trailing the primary bunch by about 59 ns is extracted from the Linac at the two-thirds point. These 33 GeV electrons are transported to the positron vault where they strike a tantalum - 10% tungsten target. Positrons are collected in a focusing solenoid system using an iron shaped solenoidal field of 1 Tesla at the target and a pulsed solenoidal field of 5 Tesla. The positron beam is accelerated to 200 MeV in a 1.5 meter accelerator section of 50 MeV/meter followed by standard accelerator sections. They are then transported back to the beginning of the Linac for further acceleration to 1.21 GeV, where upon they are sent to the positron damping ring. The extraction and return beam lines are finished and the other components are scheduled to be completed by summer. The goal of the positron group is to have the entire positron system commissioned by the end of the summer 1986.

Magnets for the collider arcs are fabricated and installation is in progress. The 950 magnets combine bending, quadrupole and sextupole fields into one element. The very strong focusing uses second order achromatic optics to transport a $\frac{\Delta E}{E} = \pm 0.5\%$ beam to the final focus. Commissioning of the arcs is planned for late Fall 1986.

The final focus system takes the linac e^+ and e^- beams as they emerge from the arcs with elliptical size of $250\mu m \times 30\mu m$ to round spots with sigma less than 2 μm at the IR. This all has to be done with $\pm 0.5\%$ momentum spread and without background from off axis $e^\pm$ and synchrotron radiation. The control of the beams occurs within 500 feet of the IR using a set of 8 bending magnets, 27 quadrupoles, 8 sextupoles and numerous correctors and profiles monitors. The vacuum is to be 2×10^{-9} torr within ± 30 meters of the IR. After the beams collide they are transported through the final focus to a kicker magnet where they are extracted and directed toward a dump. The installation of these components is in progress and the commissioning is planned for the end of 1986.

Initially the quadrupole triplet near the interaction region will be conventional magnets. There are plans to replace these with superconducting magnets so the beams can be focused to a smaller spot size at the IR. The earliest these could be installed is in the summer of 1988.

Mechanical stability of the arc magnets and final focus magnets must be held to tolerances of $100\mu m$. Automatic alignment mechanisms are used to adjust for thermal effects and earth movement.

The experimental hall has also beam support and assembly areas. To minimize beam downtime, there are two staging areas for two detectors and either can move onto the beam line. The facilities are nearing completion. Experimental equipment is being moved into the East assembly area. The contractor is expected to finish in June 1986.

While the ultimate goal of the SLC calls for a luminosity of $6 \times 10^{30} cm^{-2} sec^{-1}$, at turn on the machine will be unable to deliver that luminosity. For the first couple of years of data taking the maximum luminosity will be 6×10^{29} cm^{-2} sec^{-1} due to the limitation of the 120 pps operation and the conventional quadrupole triplet in the final focus. In addition, $e^\pm$ beams with 7.5 $\times 10^{10}$ particles per bunch will be required to reach the design luminosity. Undoubtedly, it will take time to learn how to achieve high luminosity so for the Spring 1987 a luminosity of 6×10^{28} cm^2 sec^{-1} is a reasonable goal.

IV. Status of the Detectors

Two detectors have been approved for SLC. The first detector for the SLC will be an upgrade of the Mark II which was used at PEP. The upgrade involved replacing the main tracking chamber and associated electronics, the endcap chambers, the time-of-flight counters and the coil. In addition, new vertex detectors of silicon strips and a precision drift chamber are being made for installation at the SLC. In Figure 4 a sectional view of the Mark II/SLC detector is shown. The upgraded Mark II with the exception of the vertex detectors and small angle monitors was completed last summer and data acquisition occurred at PEP with the new components until the end of the February 1986. The move of the Mark II from PEP to SLC started in March. After checking out the detector with cosmic rays in the staging area at the SLC experimental hall it is planned that it move on to the beam line in February 1987. Data taking is scheduled to start in March.

The MARK II/SLC collaboration has nine institutions and some 120 physicists. The original Mark II collaboration of SLAC and LBL has been joined by groups from California Institute of Technology, University of Colorado, University of Hawaii, Indiana University, John Hopkins University, University of Michigan, University of California at Santa Cruz, and two other SLAC groups.

The Mark II central drift chamber consist of 12 layers of cells each containing 6 sense wires. Alternate layers have their wires parallel to the axis or at $\sim \pm 3.5^0$ to the axis to provide stereo information. The inner radius is 19 cm, the outer radius is 148 cm, and the active length is 2.3 m. The magnetic field of the new coil will be at 5 Kg. Readout of the data is by Fastbus. Both TDC and FADC data is accumulated. The dE/dx information will provide e/π separation for particles with energy less than 10 GeV. Figure 5 shows an event taken at PEP during the checkout. Preliminary analysis shows that the resolution from tracking averages to about 175 μm which corresponds to $\sigma(p)/p = 0.1p$ (Gev/c).

The SLD Collaboration consist of institutions from the United States (California Institute of Technology, Boston, California State Northridge, Cincinatti, Colorado, Columbia, Illinois, MIT, Northeastern, San Francisco State, SLAC, Santa Barbara, Santa Cruz, Tennessee, Vanderbilt, Washington, Wisconsin), Canada (British Columbia, Triumf, Victoria) and Europe (Frascatti, Ferrara, Padona, Perugia, Pisa, Rutherford). This large detector goes beyond the Mark II/SLC in having hadron calorimetry and full particle identification over nearly 4π solid angle. Figure 6 shows a cross section of a quadrant of the SLD.

The schedule for building the detector shows completion in 1989. The research and development projects will conclude by the end of 1986. The construction of the magnet is underway with delivery of the iron core and the 0.6T conventional coil in the Spring 1987.

Tracking in the SLD consists of a CCD vertex detector and central and endcap drift chambers. The resolution from the 200 CCD cylindrical vertex detector is expected to be 5 μm and a double track separation of 40 μm. The central tracker is 2 meters long and has inner and outer radius of 20 cm and 100 cm, respectively. The resolution for a single track is expected to be 100 μm and a double track separation of 2 mm. Tests with a prototype using the cell configuration and gas of the design chamber have shown resolutions to be considerably better.

Cerenkov ring imaging detectors (CRID) will provide the particle separation in the SLD. Liquid freon and gaseous freon provide the radiators and the Cerenkov rings are detected by photon detection in a quartz box filled with a carrier gas which is doped with tetrakis-dimethyl-amino-ethylene (TMAE). The photoelectrons are drifted toward a detector of sense wires at the ends of the CRID volume. Prototype tests look promising with performance at the expected level.

Calorimetry in SLD is achieved with liquid Argon and lead as a radiator. The electromagnetic shower is measured in the first 22 radiation lengths in towers of 33 milliradians followed by 2.2 collisions lengths in 66 milliradians towers for the hadronic section. Instrumented warm iron calorimetry outside the aluminum coil completes the hadron calorimeter and muon tracking. The resolutions expected are $\sigma(E) = 8\% \sqrt{E}$ (electromagnetic) and about $55\% \sqrt{E}$ (hadronic).

V. Polarization at the SLC

The SLC has the capability of accelerating polarized electrons and transporting these through the damping ring to the interaction region with small depolarization of the beam. A collaboration of physicists from Indiana, LBL, SLAC, Rome, Genoa and Wisconsin was recently approved to provide a polarization capability at the SLC.

The electrons are produced longitudinally polarized by irradiating a GaAs crystal with circularly polarized light. A source capable of reliably producing beams of the required intensity and pulse structure for SLC has been built and is presently being installed at the SLC. Polarization of 45% are expected with this source. To preserve the polarization while the electrons are in the damping ring the spin direction must be transverse to the plane of the damping ring. In addition, the spin direction must be reestablished after leaving the damping ring so that it points in the desired direction for acceleration to the end of the linac and transportation around the electron arc to the interaction point where longitudinal polarization is required. Three spin rotating solenoids of 6.34 T-m each are needed to rotate the spin. These superconducting solenoids are located at positions in the transfer lines to and from the damping ring where the spin direction has processed 90^0 by the guide field. Compton and Møller Polarimeters will be used to monitor and measure the polarization.

Full polarization capability is expected to be ready in the summer of 1988. The polarized electron source will be available for use at the beginning of the SLC program. It is also expected that implementation of systems of the polarization will occur in the summer 1987.

VI. Conclusions

Colliding beams at the Z^0 mass will occur in the next year at the SLC. The progress on the accelerator and the other systems of the SLC is proceeding according to schedule. The Mark II/SLC detector is on its way from checkout at PEP to the SLC experimental hall. The physics experiments will start in 1987 to study Z^0 properties and look for new physics. Longitudinally polarized electrons will be available in 1988 and will allow more precise tests of the standard model. The SLD detector to fully exploit the potential physics is under construction and expected to be ready in 1989.

Acknowledgements

A great number of people are working on the SLC. I would like to thank some of those for their assistance in preparing this report: R. Stiening, R. Erickson, John Seeman, S. Ecklund, and G. Fisher on the SLC status and schedules and M. Breidenbach, D. Hitlin and G. Hanson provided information on the detectors. In addition, the report on the SLC program at the 1985 Aspen Winter Physics Conference by C. Prescott was very helpful.

Figures Captions

1. The uncertainty in the left-right asymmetry, ΔA_{LR}, as a function of the number, N, of observed Z decays. The three curves correspond to $\Delta P/P =$ 5%, 3%, 1%. The scales on the right give the corresponding uncertainty in $\sin^2\theta_W$ and M_Z. The shaded regions indicate present accuracy and proposed sensitivity from M_W/M_Z measurements and ν-scattering experiments.
2. Schematic layout of the SLC systems.
3. Schematic diagram of the SLC positron source system (not to scale). The source from target to end of constant gradient accelerator is about 15 meters.
4. A sectional view of a quadrant of the Mark II/SLC detector.
5. Drift chamber tracks in a multihadronic event from the Mark II/SLC detector. The short lines represent the six hit sense wires in a cell.
6. A cross section of a quadrant of the SLD.

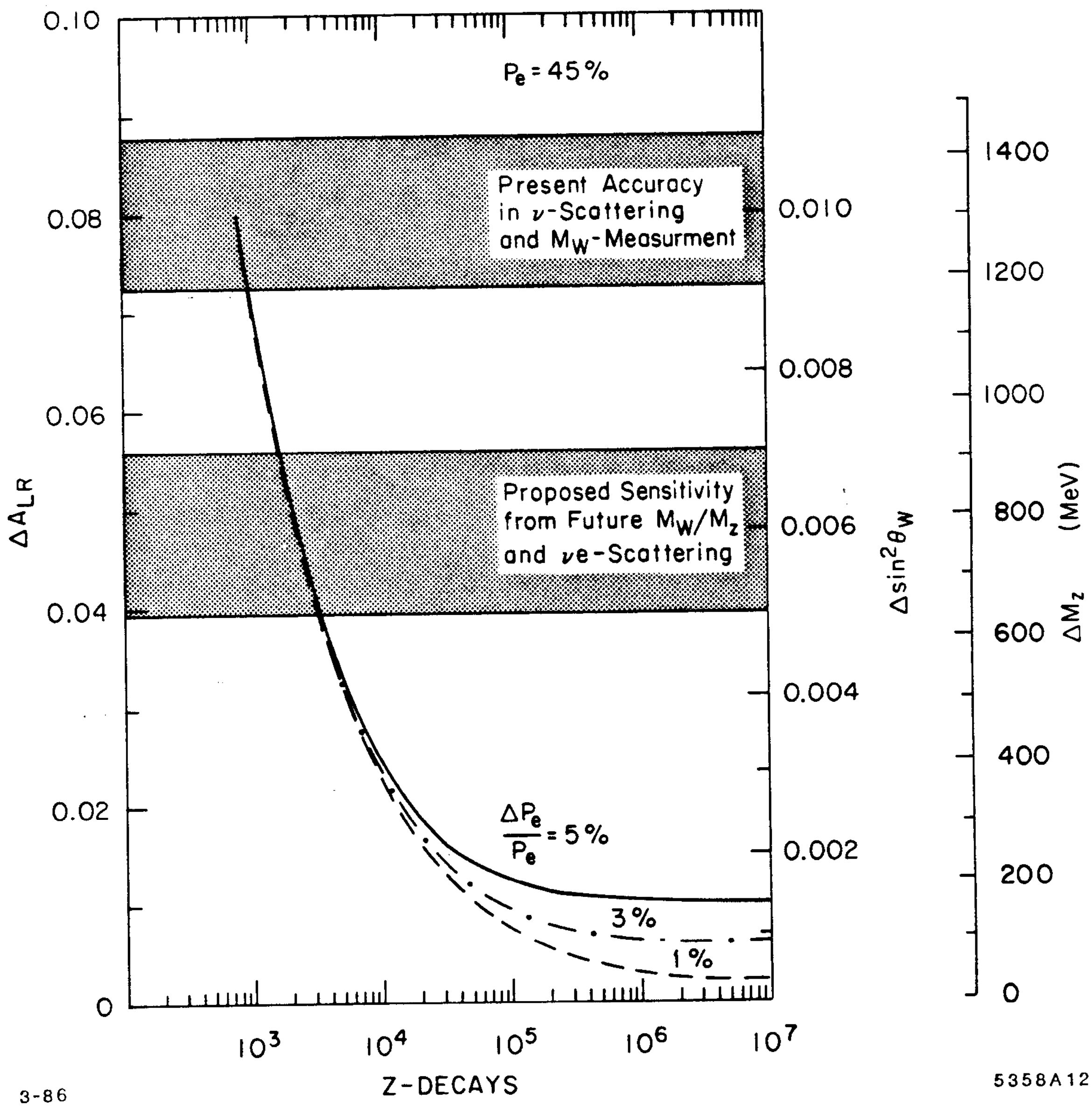

0.10
0.08
0.06
0.04
0.02
0
$P_e = 45\%$
Present Accuracy
in ν-Scattering
and M_W-Measurment
Proposed Sensitivity
from Future M_W/M_z
and νe-Scattering
$\frac{\Delta P_e}{P_e} = 5\%$
3%
1%
ΔA_{LR}
0.010
0.008
0.006
0.004
0.002
$\Delta \sin^2\theta_W$
1400
1200
1000
800
600
400
200
0
ΔM_z (MeV)
10^3
10^4
10^5
10^6
10^7
Z-DECAYS
3-86
5358A12

Figure 1

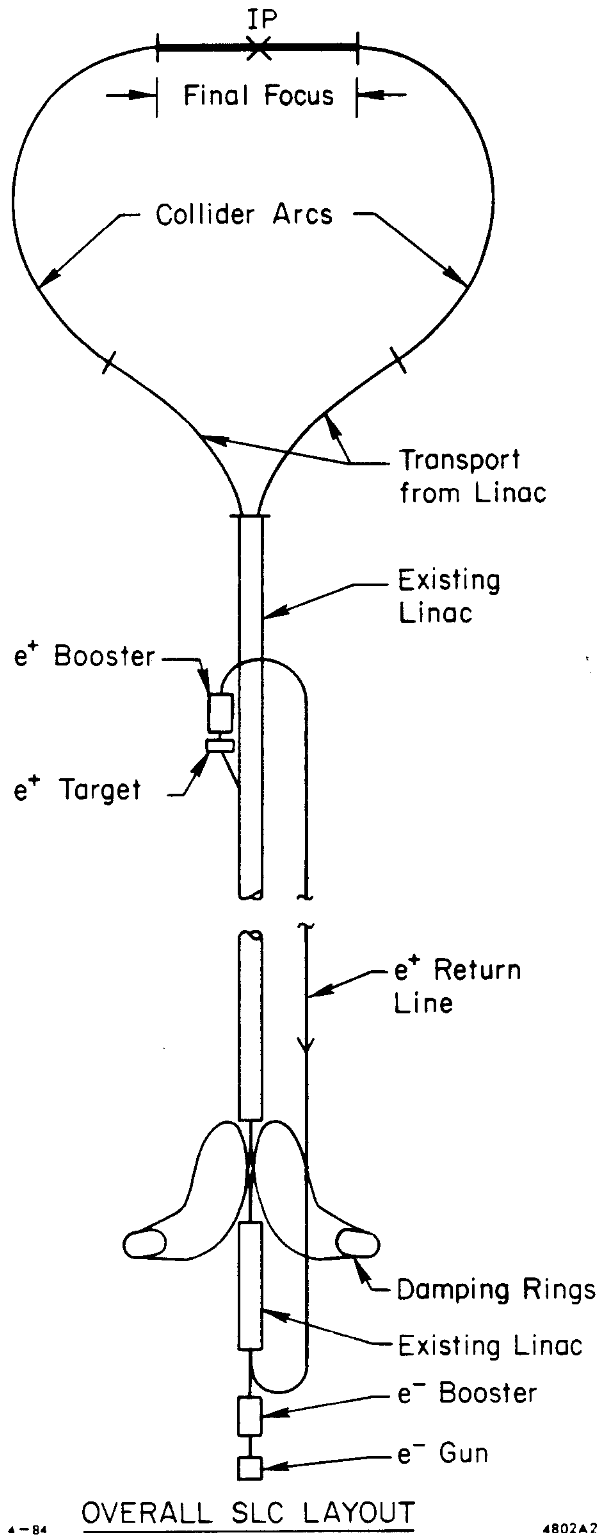
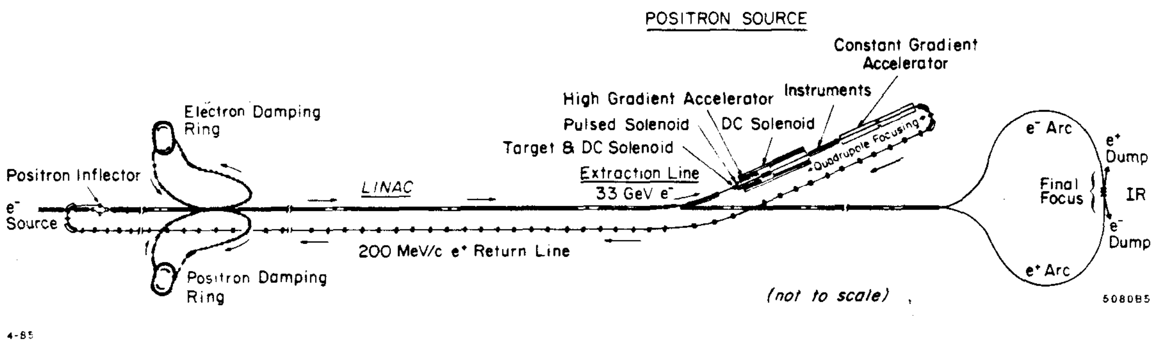

IP
Final Focus
Collider Arcs
Transport from Linac
Existing Linac
e+ Booster
e+ Target
e+ Return Line
Damping Rings
Existing Linac
e− Booster
e− Gun
OVERALL SLC LAYOUT
4−84
4802A2

Figure 2



POSITRON SOURCE
Constant Gradient Accelerator
High Gradient Accelerator
Instruments
Pulsed Solenoid
DC Solenoid
Target & DC Solenoid
Extraction Line
33 GeV e⁻
Quadrupole Focusing
Electron Damping Ring
Positron Inflector
e⁻ Source
LINAC
200 MeV/c e⁺ Return Line
Positron Damping Ring
e⁻ Arc
e⁺ Dump
Final Focus
IR
e⁻ Dump
e⁺ Arc
(not to scale)
4-85
5080B5

Figure 3

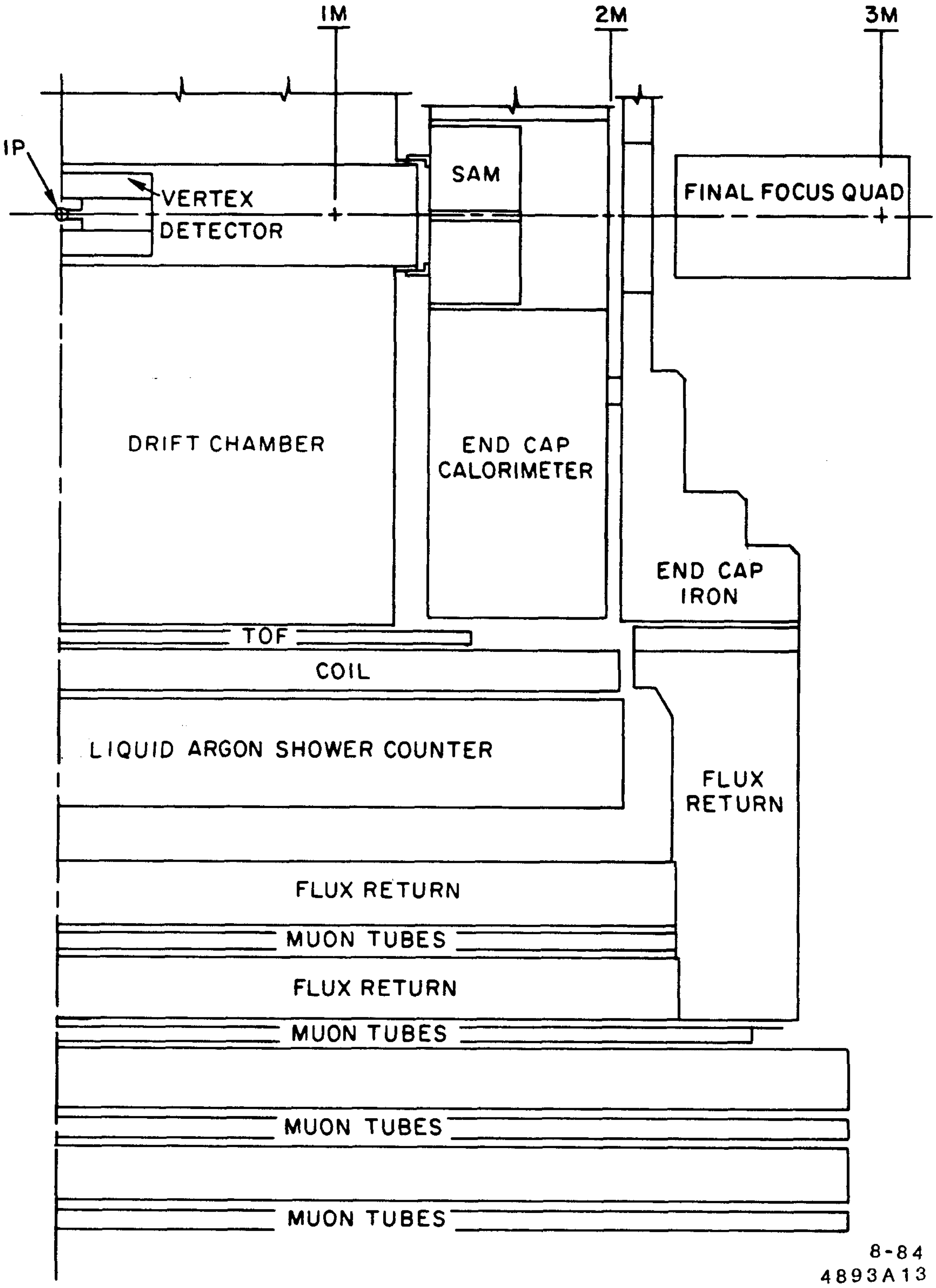
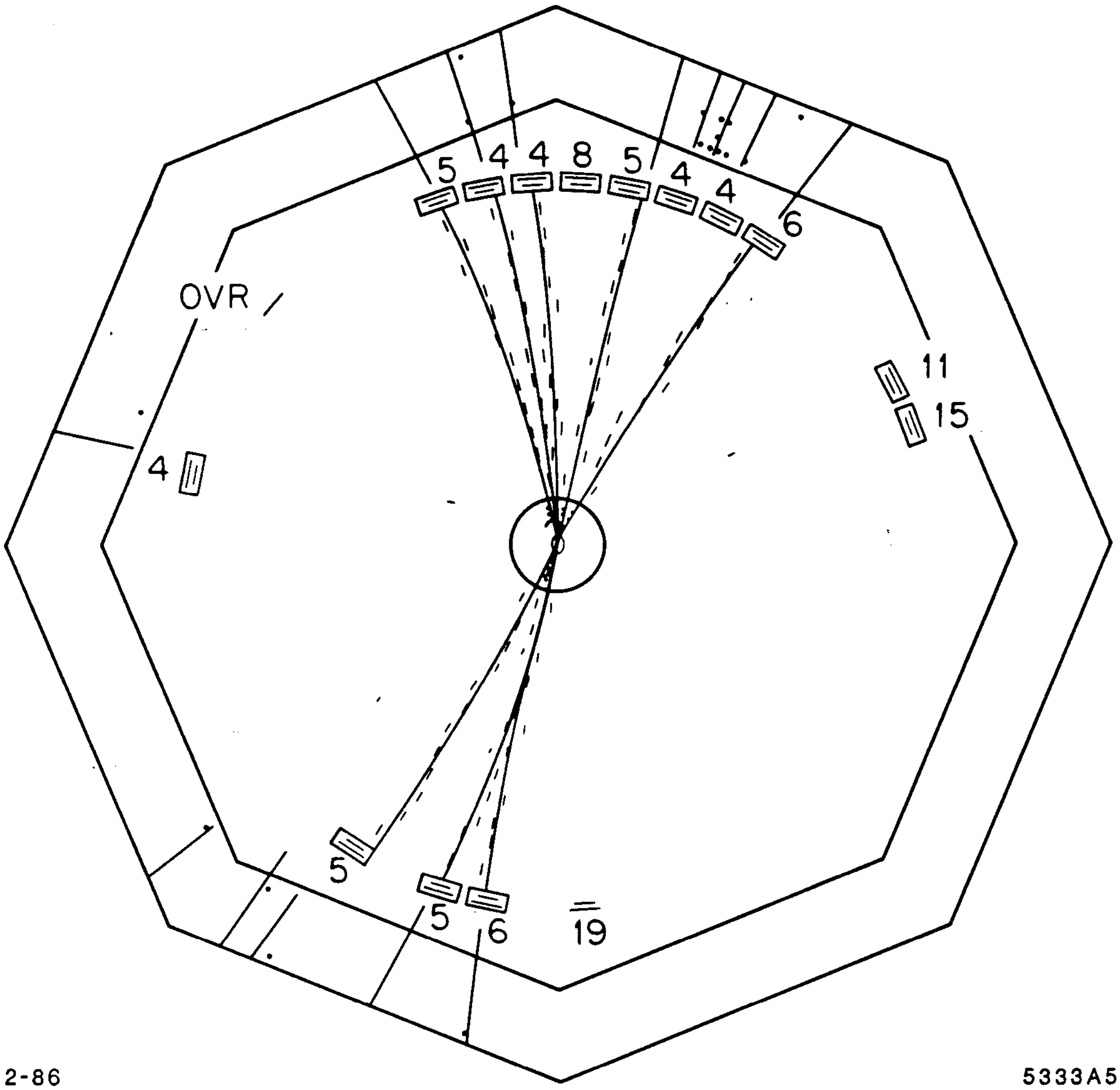

1M
2M
3M
IP
VERTEX
DETECTOR
SAM
FINAL FOCUS QUAD
DRIFT CHAMBER
END CAP
CALORIMETER
END CAP
IRON
TOF
COIL
LIQUID ARGON SHOWER COUNTER
FLUX
RETURN
FLUX RETURN
MUON TUBES
FLUX RETURN
MUON TUBES
MUON TUBES
MUON TUBES
8-84
4893A13

Figure 4



2-86

5333A5

Figure 5

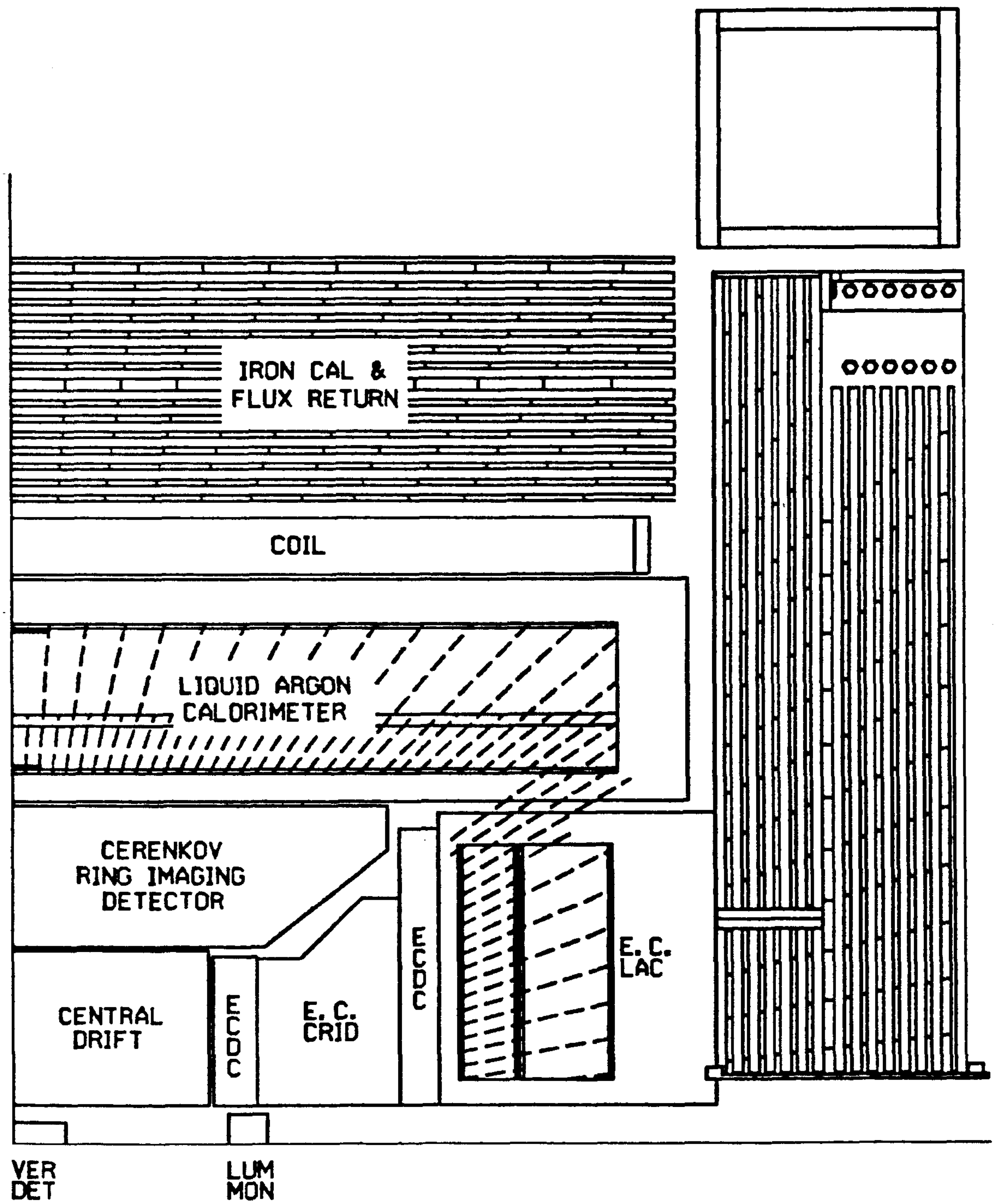

IRON CAL &
FLUX RETURN
COIL
LIQUID ARGON
CALORIMETER
CERENKOV
RING IMAGING
DETECTOR
CENTRAL
DRIFT
ECDC
E. C.
CRID
ECDC
E. C.
LAC
VER
DET
LUM
MON

Figure 6