SLAC – PUB – 4326
April 1987
(T/E)

Status of the SLC*

KENNETH C. MOFFEIT

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

ABSTRACT

A brief report on the status of the SLAC Linear Collider (SLC) program is presented.

Talk presented at the XXIIth Rencontres De Moriond
Les Arcs, France, March 8–15, 1987

⋆ Work supported by the Department of Energy, contract DE – AC03 – 76SF00515.

I. Introduction

Collisions at the SLAC Linear Collider (SLC) are imminent. The construction is complete and the beam transport systems in the arcs and final focus are being commissioned. A large part of the SLC has had extensive checkout and has met the specification for initial operation. The upgrade of the Mark II was completed more than a year ago and a large data sample was obtained at PEP with the new detector components. The Mark II is now located in the SLC interaction hall and is taking cosmic ray data. It is ready to move onto the beam line at the SLC interaction region.

The goals of the SLC are to develop the techniques of linear colliders and to do physics at and slightly above the energy necessary to produce the Z°. 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 millimeters 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 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° via its coupling to e^+e^- pairs. At the design luminosity of the SLC, Z°'s will be produced in excess of one million per year.

Since my talk in early March, considerable progress has been made on commissioning the SLC. The acceptance of the south damping ring is now understood. The beam enters and leaves with high efficiency similar to that of the electron ring. On March 25 positrons were transported to the interaction region and a few days later electrons and positrons were simultaneously accelerated to the end of the accelerator, launched into the arcs and passed through the interaction point.

The outline of this paper will be as follows. A short review of the physics goals and the status of the SLC will be followed by a discussion of the energy spectrometer with center-of-mass energy resolution on a pulse-to-pulse basis of $\pm$ 50 MeV/c^2. The status of the SLC polarization experiment will be discussed. Finally, in the last section, the expected physics program of the Mark II will be given.

II. Physics at the SLC

The physics program of the SLC concentrates on production of Z°'s and their decay. Measurements of the Z° 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° mass will be determined to an accuracy of 50 MeV/c^2. Once the Z° 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° width is both a test of the standard model and a measure of the particle content of Z° decays. For example, a fourth neutrino species contributes about 180 MeV/c^2 to the Z° 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

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

In the standard model, A_{LR} is uniquely predicted once M_Z is known and is independent of the final fermion type. Thus, all visible Z° decays can be used for the precision test 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 1 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, experimental halls and detectors. The SLC works as follows: two bunches of 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 a few microns in diameter 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.

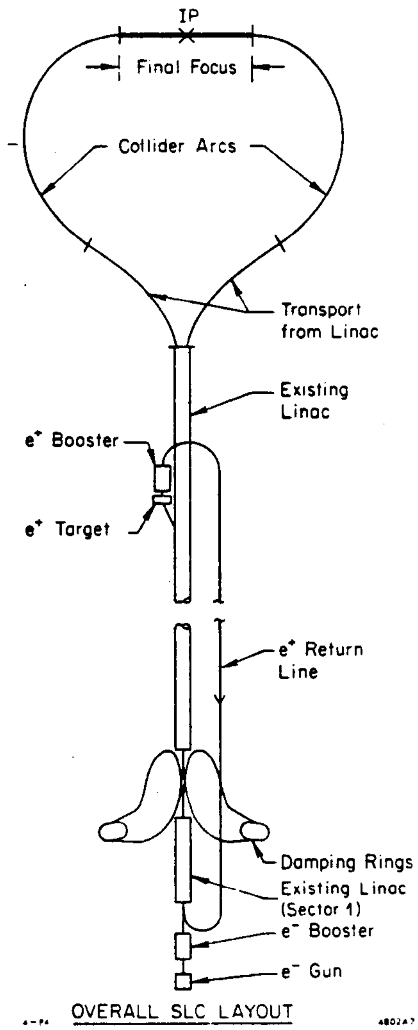

Figure 1. Schematic layout of the SLC systems.

The electron source and injector is required to deliver to the damping ring two bunches of greater than 5×10^{10} electrons 59 ns apart at 180 hertz. Tests 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. Their emittances are too high for this after the electrons are collected into a single bunch and the positrons return from the e^+ source. 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 have been made. The north ring was built with these changes and was commissioned by February 1986. Both rings have now been commissioned. The electron ring requires double pulse kickers to handle the two bunches. These will be ready for installation in May 1987.

The SLC requires a short bunch length of 1 to 2 mm after reinjection into the Linac. This is accomplished by taking the $\sigma_L \approx 6$ mm long beam as it emerges from the damping ring through a bunch length compressor which shortens the bunch length and broadens the energy spread. In our commissioning studies, we have learned that with increasing beam current the bunch length in the damping ring grows (at 3×10^{10} e^-, a bunch length of $\sigma_L \approx$ 15mm is observed). Such long beams cannot be compressed to the required 1~2 mm. The problem is believed to be due to discontinuities in the vacuum beam pipe where bellows, transitions from round to rectangular geometry and instrumentation ports exist. Initial operation at the SLC will be at currents of $(1-2)\times 10^{10}$ where the broadening is not severe. However, the problem will have to be solved in order to reach design luminosity.

The main improvements to the Linac were upgrading for higher energy by replacing the 38–megawatt klystrons with 67 megawatt ones and addition of beam focusing and position monitoring every 40 feet. The RF control and monitoring was also upgraded. To reach the Z° mass, an energy of about 47 GeV is required at the end of the linac. With only 200 of the 67–megawatt klystrons added, an energy of 53 GeV/c^2 has been reached. The remaining 40 38–megawatt klystrons will not be replaced with the high-powered ones until the physics program shows they are necessary. Commissioning of the automatic steering and energy stabilization has been accomplished. Work is in progress on operation with both electrons and positrons simultaneously.

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 2. 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.

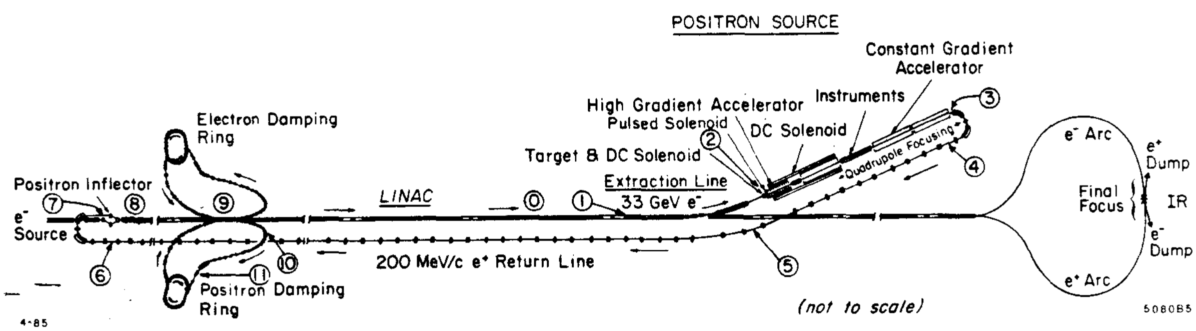

Figure 2. Schematic diagram of the SLC positron source system (not to scale). The source from target to end of constant gradient accelerator is about 15 m.

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 m high gradient accelerator section followed by standard accelerator sections. They are then transported back to the beginning of the Linac for further acceleration to 1.21 GeV, whereupon they are sent to the positron damping ring. Positrons are now routinely produced and sent to the positron damping ring and extracted.

The collider arcs transport the electrons (north arc) and positrons (south arc) from the linac to the final focus. 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. Mechanical stability of the arc magnets must be held to tolerances of 100 μm. Automatic alignment mechanisms are used to adjust for thermal effects and earth movement. Commissioning of the arcs is in progress.

The final focus system takes the linac e^+ and e^- beams as they emerge from the arcs with elliptical size of 250 μm $\times$ 30 μ m to round spots with sigma less than a few micros at the IR. All of this 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 profile monitors. The vacuum is 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 is complete and commissioning is now in progress.

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 time that these could be installed is in Summer 1989.

The experimental hall has 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 were completed last summer. The Mark II detector is parked in the east area and is ready to move onto the beam line. The SLD detector has already begun assembly in the west area.

While the ultimate goal of the SLC calls for a luminosity of 6×10^{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. For the initial operation, a luminosity of 6×10^{27} cm^{-2} sec^{-1} is therefore a reasonable goal. This corresponds to about 15 Z°'s per day.

IV. Energy Spectrometer

Two spectrometers, one in each extraction line, are being built for installation in Fall 1987.[1] These will enable SLC to achieve an absolute center-of-mass energy resolution of 45 MeV/c^2. After the spent beams are ejected from the final focus beam line by kicker and septum magnets, they will be momentum-analyzed in a spectrometer system. The spectrometer magnet produces a precisely known deflection of $\approx$ 18 mrad of the beam. Two smaller bend magnets are located before and after the spectrometer magnet with their bends orthogonal to the spectrometer bend plane. These small bends produce two bands of synchrotron radiation separated by $\approx$ 25 cm which can be simultaneously observed on one optical plane located just before the dump for the beam. The relative displacement of the two bands of synchrotron light is proportional to the beam momentum. This arrangement is shown in Figure 3.

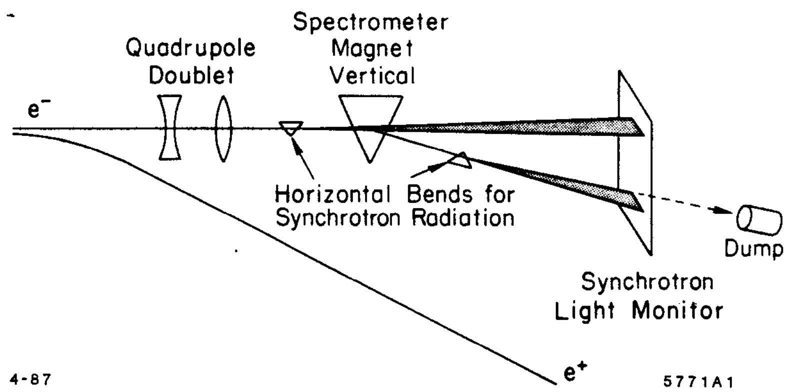

Figure 3. Arrangment of the components of the energy spectrometers. Electrons exiting the septum magnet enter a quadrupole doublet followed by horizontal, vertical and another horizontal bend magnet. Two beams of synchrotron light are emitted by the horizontal bends which are detected by an X–ray monitor.

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 and Wisconsin is preparing the systems for the polarization capability at the SLC.[2]

The electrons are produced longitudinally polarized by irradiating a GaAs crystal with circularly polarized light. The source will be capable of producing beams of the required intensity and pulse structure for SLC. Polarization of 45% is 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 precessed 90^0 by the guide field. Compton and Møller polarimeters will be used to monitor and measure the polarization near the interaction point. Full polarization capability is expected to be ready following Summer 1988.

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 Figure 4 as a function of the number, N, of observed Z decays. The three curves correspond to different levels of precision when 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°'s, the accurate measurements of M_Z and A_{LR} at the SLC will make very high precision tests of the standard model.

VI. Status of the Detectors

Two detectors have been approved for SLC. The first detector for the SLC is 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 5, a sectional view of the detector is shown. The upgraded Mark II, with the exception of the vertex detectors and small angle monitors, was completed in Summer 1985 and data acquisition occurred at PEP with the new components until the end of February 1986. The move of the Mark II from PEP to SLC started in March 1986 and first cosmic ray data in the east area of the experimental hall occurred in November 1986. It will take about four weeks to move the Mark II onto the beam line.

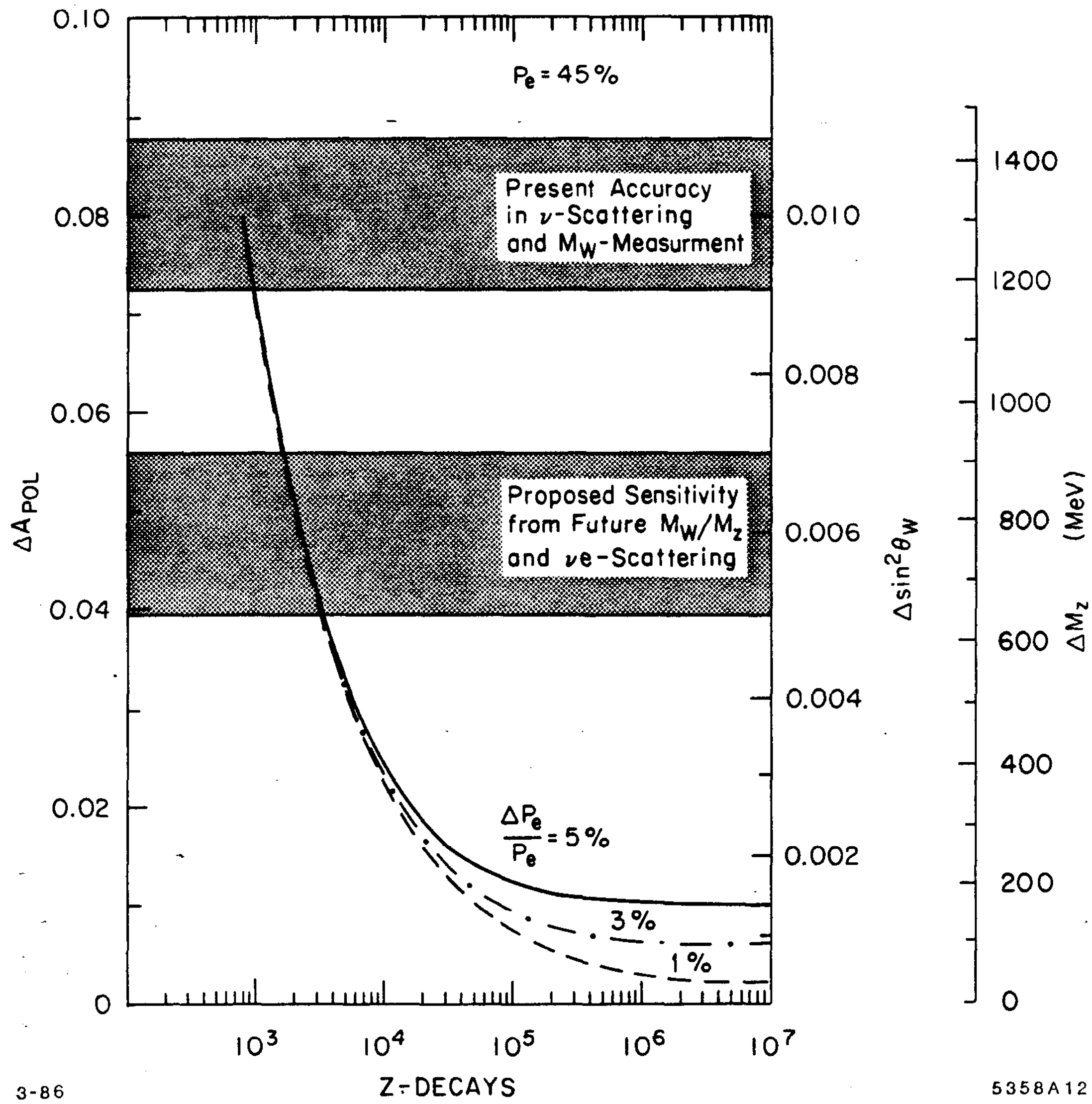

Figure 4. The uncertainty in the left-right asymmetry, ΔA_{LR}, as a function of the number, N, of observed Z decays. The three curves correspond to $\Delta P/P =$ 5%, 3%, 1%. The scales on the right give the corresponding uncertainty in $\sin^2\theta_W$ and M_Z. The shaded regions indicate present accuracy and proposed sensitivity from M_W/M_Z measurements and ν-scattering experiments.

The Mark II 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 consists 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

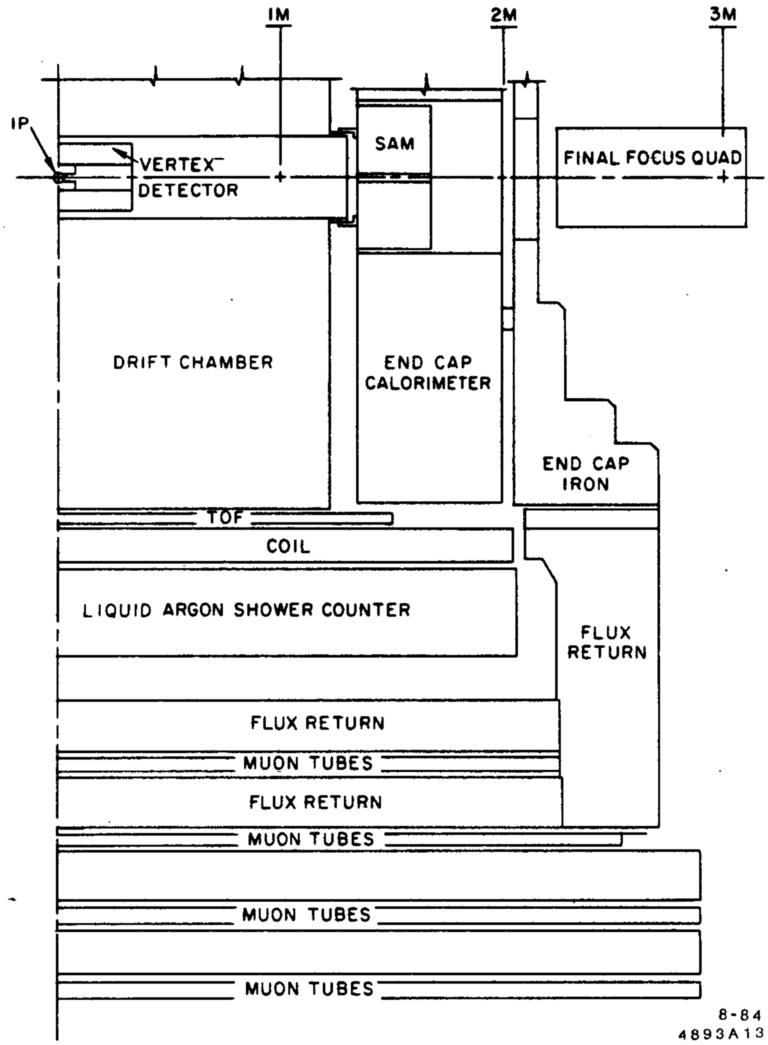

Figure 5. A sectional view of a quadrant of the Mark II detector.

active length is 2.3 m. The magnetic field of the new coil is 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 6 shows a plot of dE/dx versus momentum from data taken at PEP with the upgraded detector.

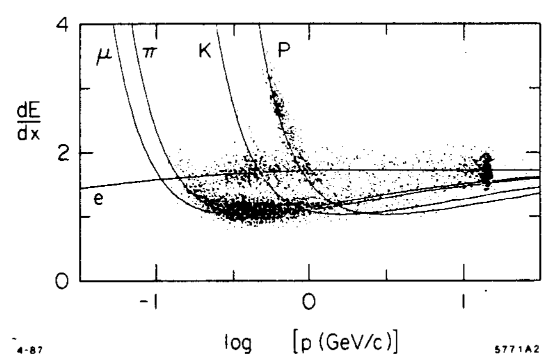

Figure 6. Plot of dE/dx versus momentum from data taken at PEP with the upgraded Mark II detector.

A comparison of the inclusive distributions for sphericity and thrust are shown in Figure 7 for the data taken with the Mark II before (PEPV) and after (upgrade) the upgrade for SLC.[3] The good agreement of the two data sets shows that already the new detector components are well understood.

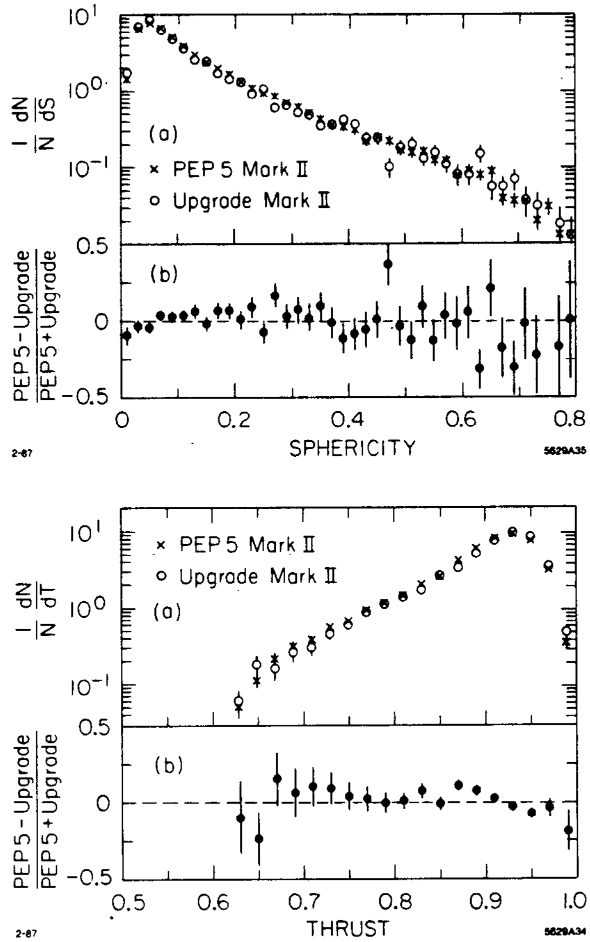

Figure 7. Comparison of the inclusive distributions for sphericity and thrust for the data taken before (PEPV) and after (upgrade) of the Mark II detector.

The Mark II exposure is expected to last about two years. During this period, three sets of data will be taken:

i) First look during the Summer and Fall of 1987 where 1000 to 2000 Z° events are expected.

ii) An exploration phase in the first half of 1988 with 10 to 20 thousand Z°. The precision energy spectrometer is expected for this data sample.

iii) A measurement data set where some 100 to 200 thousand Z° events can be expected. Polarized electrons are expected to be available for part of this data set.

Table 1 gives the precision we can expect for physics at the Z° with these data samples.

Table 1. Expected Physics Program with the Mark II.

Topic	*First Look*	*Exploration*	*Measurement*
Number Z°	1–2 K	10–20 K	100–200K
Z mass*	$\Delta M = 70$ MeV/c^2	$\Delta M = 50$ MeV/c^2	
Z width*	$\Delta\Gamma = 120$ MeV/c^2	$\Delta\Gamma = 50$ MeV/c^2	
ν Counting			
$\Gamma_{tot} - \Gamma_{vis}$		$\Delta\Gamma_{invis} \approx 80$MeV/c^2	$\Delta\Gamma_{invis} \approx 50$ MeV/c^2
$\gamma\nu\nu$ on peak		$\Delta\Gamma_{invis} \approx 150$MeV/c^2	$\Delta\Gamma_{invis} \approx 50$ MeV/c^2
Electroweak**			
A^{μ}_{FB}	$\delta^2_s \approx .06$	$\delta^2_s \approx .02$	$\delta^2_s \approx .006$
A^{b}_{FB}	$\delta^2_s \approx .08$	$\delta^2_s \approx .025$	$\delta^2_s \approx .008$
A^{τ}_{pol}	$\delta^2_s \approx .12$	$\delta^2_s \approx .04$	$\delta^2_s \approx .012$
A_{LR}			$\delta^2_s \approx .001$
QCD	Some topics	Detailed	Precise
b lifetime		10%	3%
Top	See an indication	Mass	Couplings
Suzy	Indication of easy signals	Measurement of easy signals; indication of harder signals	Detailed measurements
Higgs Minimal		$M < 4$ GeV	$M < 10$ GeV

* with extraction line spectrometers

** $\delta^2_s = \Delta \sin^2 \theta_w$

A new SLD detector is being built to replace the Mark II. The Collaboration consists of institutions from the United States (California Institute of Technology, Boston, California State Northridge, Cincinnati, 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 in having hadron calorimetry and full particle identification over nearly 4π solid angle. The schedule for building the detector shows completion in 1989. The construction of the magnet is underway with the iron core already at SLAC and delivery of the 0.6T conventional coil will occur in Spring 1987.

VII. Conclusions

Colliding beams at the Z° mass will occur this summer at the SLC. The progress on commissioning the systems of the SLC is proceeding. The upgrade Mark II detector had extensive checkout at PEP before its move to the SLC experimental hall and is ready to take data at SLC. The physics experiments will soon start to study Z° properties and look for new physics. The energy spectrometers will be installed in Fall 1987 and provide pulse-to-pulse center of mass energy measurement with an accuracy of $\pm$ 50 MeV/c^2. Longitudinally polarized electrons are expected in late 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 my colleagues on the SLC, Mark II and Polarization for their help in preparing this report, and my particular appreciation to Bill Atwood and Witold Kozanecki.

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