SLC Upgrades for the SLD Extension

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Introduction

In the 1997/98 run, the luminosity of the SLC was increased by a factor of four. This improvement was almost entirely due to changes in operating procedures and to reconfiguration of existing hardware, as opposed to costly upgrades. The luminosity increased steadily throughout the run reaching a peak of over 250 Z^0/hour with over 5000 Z^0s delivered in the last 24 hours. This demonstrates that the SLC remains on a steep learning curve and continues to provide valuable experience on the physics and operation of linear colliders. Based on the knowledge gained in the last run, we believe that the luminosity can be increased by another factor of three to four with modest hardware changes. These include moving the final triplets closer to the interaction point (IP) in order to reduce backgrounds and allow higher angular divergence, a feedforward system from the linac to the IP to correct transverse jitter, and a number of smaller improvements to further reduce the beam emittance. Current research on higher polarization photocathodes could also potentially provide polarization in excess of 85%. The higher polarization together with an average luminosity of 25-50,000 Z^0s per week would support a significant physics program for SLD. These improvements would also allow the SLC to finally reach or surpass design luminosity.

Final Focus Modifications

With the installation of octupoles in the final focus in early 1998, the minimum beam size achievable at the IP is no longer limited by higher order aberrations. The operational performance is determined by the maximum angular divergence that can be sustained without causing excessive backgrounds in the detector. The primary source of background is synchrotron radiation emitted by the beam in the final triplets which scatters into the detector. This can be greatly reduced by moving the triplets closer to the IP and increasing the field of the first quadrupole of each triplet. In this configuration, the clearance across the triplet would be increased by 20-30% in both planes. In addition, the synchrotron radiation swath would have a much shorter lever arm and exit more cleanly. This would allow operation with more optimal angular divergences of 600 by 280 microradians, an increase of 25% in the horizontal and 20% in the vertical. Taking into account the additional disruption enhancement, the expected increase in luminosity is about 70%.

The mechanical modifications required to move the triplets 71 cm closer to the IP have been investigated and appear to be straightforward. One radiation shielding mask (M2) and the beam position monitor between the triplet and the IP need to be removed, and the monitor reinstalled upstream. Turtle ray traces indicate that in the new configuration, the M2 mask is no longer critical and, if desireable, additional masking could be installed inside the triplets. The superconducting cables powering the triplets would be lengthened with a splice and a structural spool piece inserted. This would decrease the maximum retraction of the SLD doors requiring some modification to the earthquake bracing and scaffolding. The choice of 71 cm allows the SLD luminosity monitors to remain without modification although their electronics would need to be relocated. Spare power supplies are available for increasing the field of the final quadrupoles.

To take full advantage of the increased angular divergence and produce the smallest possible beams at the IP, it would also be desirable to reduce the residual aberrations due to synchrotron radiation from the bends in the chromatic correction section (CCS) of the final focus (FF). A softened bend configuration was partially implemented at the end of 1997 using offset quadrupoles and steering dipoles. The radius of curvature can be further increased by adding more bend magnets in the CCS. Suitable existing magnets have been located and extra power supply channels are available so the only costs of this project are supports, installation and cabling. The expected luminosity increase from both final focus upgrades is 120%.

Linac to IP FeedForward

During present operation, transverse beam jitter is typically 20-40% of the beam size in the linac which causes a significant increase in the effective emittance. This can be reduced by developing a system to measure the beam trajectory at the end of the linac and correct it with fast kickers near the IP. It is possible to make a correction on the same pulse by taking advantage of the shorter communication path directly to the collider hall rather than the longer path followed by the beams around the arcs. Such a system was considered for the SLC several years ago and a similar system is under study for the NLC. Either a simple microwave or optical link would be used to send a fast signal to the collider hall. A digital signal processor would calculate the necessary corrections from position monitor data in the linac. Since the deflecting field needed is small, existing position monitors can be used as simple stripline kickers, driven by solid-state electronic pulsers.

An added benefit of reducing the sensitivity to jitter is the possibility of using a better linac lattice. The present lattice is a compromise between jitter control and chromatic emittance dilution. Reduced transverse jitter would also improve the resolution of the final optimization of the beams at the IP. The proposed feedforward system could increase the luminosity by about 30%, assuming a 60-80% reduction in the present jitter.

Emittance Reduction

Several smaller upgrades could reduce the emittance of the beams at the end of the linac by 15-20% in X and Y for both electrons and positrons. These include an RF frequency shift to reduce the emittance from the damping rings, bellows shields in the ring to linac transfer lines (RTL) and additional independent supplies for a few RTL magnets. Improved feedback and steering methods would allow better optimization and stabilization of the linac orbits. Together these could increase the luminosity by 50-75% taking into account the additional disruption enhancement.

In the damping rings, the horizontal damping time and equilibrium emittance can be reduced by increasing the horizontal partition number. This can be accomplished by modifying the closed orbit to go off-axis through the quadrupoles in dispersive regions. To shift the orbit, one can either physically displace the magnets or change the accelerating frequency. A mid-store frequency shift allows full aperture for injection while reducing the emittance. This has been tested in the both damping rings and a 15% decrease in the horizontal emittance was measured for e^+ and a 10% decrease for e^-. More work is needed on the RF controls for a final production installation.

Two modifications are planned for the RTLs. A new optics was installed in 1997 to reduce the beam size in tight apertures where there were losses. Independent power supplies for a few quadrupoles near the end of the RTL would allow the flexibility to further improve the optics. Wakefields from the bellows were identified as a source of emittance growth and some of the RTL bellows were shielded during the 1997-8 run. This reduced the positron vertical emittance by almost 50%. Shields should be installed for the rest of the RTL bellows. With these improvements one can expect a 10% decrease in the horizontal emittance of both beams, a 20% decrease in the electron vertical emittance, and about 5% increase in throughput.

Higher Polarization

SLAC has an active research program on photocathode materials for future linear colliders. Two promising ideas will be tested in 1998 and could provide higher polarization for a future SLC run. The two approaches under study are thinner epilayer cathodes or gradient doping. The GaAs/GaAsP strained layer cathodes should in principle have 100% polarization but only 80% has been achieved. SLAC presently uses 100 nm layer photocathodes but less depolarization is expected if a 50 or 75 nm cathode can be found which is capable of delivering full SLC beam currents. Another possibility is gradient doping where high dopant density is used on the surface of the cathode to provide high quantum efficiency with a lower concentration in the bulk of the material to reduce depolarization. Some combination of these techniques has the potential to increase the polarization to a value of over 85%.

Compatibility with PEP-II

During the 1997-8 run, the SLC operated concurrently with PEP-II commissioning for periods of a few weeks. Based on this successful experience, the projected interference between the two programs has been greatly reduced. In particular, almost all SLC tuning and machine studies are compatible with PEP injection. One critical problem was matching of the linac lattice to the lower energy of the PEP extraction lines. A modified lattice was developed for the High Energy Ring commissioning and proved completely adequate for both programs. A similar lattice has been developed for the Low Energy Ring which provides a reasonable match in simulations. We are confident that the problem can be solved without the need for additional hardware such as pulsed quadrupoles. An updated estimate of the impact of running the two programs concurrently is 10% inefficiency for PEP-II and 15% for SLD. These numbers are sensitive to the exact strategy for PEP fills and could be improved even further, particularly if fast kickers were used for PEP injection.

Reliability Issues

Hardware failures have had a severe impact on the deliverable integrated luminosity for SLD and will continue to be an issue for PEP-II. Refurbishment of the damping ring complex magnets and of the positron source girders is already planned for PEP-II. However, SLC operation requires higher performance from these systems and the higher current and duty cycle causes additional stress on many components. For PEP operation alone, the damping rings might be reconfigured somewhat to improve reliability. For SLC the damping ring kicker magnets must be replaced more frequently due to radiation damage. SLC also requires a rotating positron target, while for PEP-II, future spares could be less expensive stationary targets.

In addition, the polarized source and SLC beam delivery systems would require upgrades for a future SLD run. In particular, the Ti:Sapphire laser system is not required for other scheduled programs and effort would be needed on development of some components such as pulsers and Yag cavities for which replacements are no longer available. Manpower is also required to support operation of the polarized source beyond the presently scheduled End Station A experiments. Several arc and final focus systems have caused frequent problems and need refurbishing. These include the arc tunnels and vacuum systems, final focus plug doors, septum magnets and CCS quadrupoles, as well as radiation damaged components in the beam switchyard. The total cost for SLC-related reliability projects, excluding polarized source manpower, has been roughly estimated to be 500K$. Some investment may be required for electrical and utility work to support both programs.

Appendix A - Luminosity Improvements

	1998 parameters	Final Focus improvements only	Emittance improvements only	2000 parameters (All upgrades)
I	$4.0\ 10^{10}$	$4.0\ 10^{10}$	$4.0\ 10^{10}$	$4.0\ 10^{10}$
ε_x^{FF} (10^{-5} m-rad)	5.5	5.5	4.5	4.5
ε_y^{FF} (10^{-5} m-rad)	0.9	0.9	0.7	0.7
θ^*_x (μrad)	470	600	470	560
θ^*_y (μrad)	240	280	240	260
σ_x^{IP} (μm)	1.5	1.1	1.3	1.0
σ_y^{IP} (μm)	0.65	0.50	0.55	0.40
Z_n (Z/hr)	10	18	15	26
H_d	1.9	2.2	2.3	2.4
Luminosity (Z/hr)	300	630	550	1000
($cm^{-2}sec^{-1}$)	$2.8\ 10^{30}$	$5.8\ 10^{30}$	$5.1\ 10^{30}$	$9.3\ 10^{30}$

Appendix B - Luminosity Upgrades

(preliminary, detailed costs estimates not available)

Decreased L* - move triplets closer to IP	~$50K
Fast feedforward Linac -> IP	~100K
Additional CCS bends to soften bend radius	50K
Additional power supplies for RTLs, SLTR tuning	40K
DR RF frequency ramp to lower emittance	20K
Higher polarization cathodes (also NLC)	20K
Feedback system upgrades	20K
Total	<$500K

Appendix C - Reliability Upgrades

(preliminary, detailed costs estimates not available)

Source Laser	$150K
Arc vacuum chambers, pumps, valves	90K
Arc tunnel maintenance	20K
FF Plug doors, controls and mechanical	40K
FF Septum coils and CCS quad refurbishment + spares	90K
FF kicker power supply redesign	50K
Misc. maintenance due to SLC requirements	35K
Total	~$500K