SLAC-PUB-7118
February 1996
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COMMENTS ON THE POSSIBLE USE OF THE SLC AS AN e^-e^- COLLIDER

R. ERICKSON
Stanford Linear Accelerator Center
Stanford, CA 94309

In this letter, we discuss practical issues that must be addressed to reconfigure the SLAC Linear Collider as the first multi-GeV e^-e^- collider.

It has been suggested[1] that the SLAC Linear Collider, which was designed to collide electrons with positrons, could be modified to collide electrons with electrons. A cursory examination of this suggestion leads us to conclude that such a modification is technically feasible, but by no means trivial. In this letter we outline the issues that must be addressed to realize this possibility.

The normal SLC operating cycle starts with the production and acceleration of two bunches of polarized electrons which are stored in the north damping ring for one interpulse period (approximately 8.3 msec). During this time, the emittances of the two bunches shrink by roughly a factor of ten. Both bunches are extracted from the north damping ring and reinjected into the linac, following one positron bunch from the south damping ring. The positron bunch and the first of the two electron bunches are accelerated to the full SLC energy (approximately 47 GeV) and transported around the arcs to the interaction point: the positrons around the south arc and the electrons around the north. The polarization of the electron bunch can be manipulated with magnetic elements to nearly any desired orientation at the interaction point.

During acceleration in the linac, the positron bunch precedes the first electron bunch by 17.69 meters, corresponding to 168.5 S-band wavelengths, or 59.00 nsec. This spacing equals the difference in path lengths of the two arcs, arranged so that the two bunches meet at the interaction point in the center of the collider hall. Note that this spacing also equals approximately half the circumference of each damping ring. During each machine pulse, a new bunch of positrons is prepared for use in a subsequent machine pulse. This is done by kicking the second electron bunch out of the linac at the two-thirds point and directing it into a target. Positrons produced in the target are transported back to the injector area, accelerated to 1.2 GeV, and stored in the south damping ring. This cycle repeats 120 times per second.

As the preceding description implies, the existing SLC hardware is capable of producing one pair of polarized electron bunches on each machine pulse and storing them in the north damping ring, while extracting a second pair and accelerating them to the end of the linac. This can be achieved simply by turning off the kicker

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

magnet at the two-thirds point in the linac. The various systems associated with positron production, including the south damping ring, are not needed.

The first technical challenge in using the SLC to collide particles of the same charge will be to develop a method for separating the two bunches at the entrances to the arcs. The large dc magnet that symmetrically deflects the electrons and positrons apart in normal SLC operation (approximately 1 degree of deflection from straight ahead for each beam) will have to be replaced with a more sophisticated system, consisting perhaps of a fast bipolar kicker magnet or an rf separator, followed by a current-sheet septum magnet. A set of devices of this kind could not easily be made to fit in the space now occupied by the dc magnet and may require that the pulsed device be placed some tens of meters upstream. Space for new devices (approximately 25 m) exists along the beam line between the end of the linac and an appropriate septum position, although the 50Q2 and 50Q3 quadrupoles are located in this region. Quadrupole 50Q2, which is horizontally focusing, would partially cancel any horizontal deflection introduced near the end of the linac. 50Q3, which is horizontally defocusing, would assist in the deflection process, but would have to be replaced with a larger-aperture magnet to pass the separated beams. The kicker magnet or rf separator would be a formidable device, because it must be capable of deflecting two high-energy bunches by equal but opposite amounts when they are separated by just 59 nsec, and the deflections must be stable on an angular scale comparable to the angular divergence of the beams.

A cursory inspection of the magnet layout in this region suggests that new complications arise from the modified geometry. If the center of curvature of the first bend is moved upstream, then both the north and south beamlines, from the septum magnet to the second bend magnet in each line (51B2 and 52B2), will have to be repositioned outward slightly from their existing positions, and the second bends must be increased in strength slightly to deflect the beams back onto the SLC design trajectories. This modification to the geometry would spoil the optical match into the arcs (the linear dispersion, in particular, must be carefully matched in this region), and so will require changes to the quadrupole strengths or positions to restore the required optical properties. When an acceptable match to the arcs is achieved, electrons can be transported the rest of the way to the interaction point simply by reversing the polarities of all the magnets in the south arc and south final focus system.

The SLC final focus system has an "S-bend" geometry, meaning that both the incoming electron beam and the incoming positron beam bend to the right through the last set of bend magnets on the north and south sides, respectively, as they approach the interaction point. After passing through the collision point, the outgoing beams follow the same trajectories through which the incoming beams approach the I.P. Kicker magnets located some 350 feet from the I.P. on each side kick the outgoing beams off this path and into an array of septum magnets which further deflect the outgoing beams down special dump lines (equipped with spectrometer magnets and associated detector apparatus) and into massive, water-cooled, aluminum dumps in heavily shielded alcoves.

Reversing the polarities of all the magnets in the south final focus system to transport an incoming electron beam will fundamentally change the way the outgoing beams are handled. Specifically, the outgoing electron beam from the north, upon reaching the first bend magnet in the south tunnel (dipole B1, approximately 127 feet from the I.P.), will be deflected to the west, away from the trajectory of the incoming beam, and into the aisle, rather than to the east along the incoming beam path. Similarly, the outgoing beam from the south, upon reaching the first bend magnet in the north tunnel, will be deflected to the east, toward the wall. The bend angle of each of these magnets is nominally one degree.

With the existing hardware in place, the outgoing beam on each side would exit the vacuum chamber near the thin window at the beamstrahlung detector and collide with the copper coils of quadrupole Q7 approximately three inches off center. The next obstacle beyond Q7 would be sextupole SX7, where the outgoing beam would be about four inches off center (Q7 and SX7 each have a pole-tip to pole-tip aperture of 1.625 inches). To provide a clear path for the outgoing beams, these magnets will have to be replaced with special designs, possibly involving mirror plates and asymmetric coil arrangements, that provide a passage for a new dump-line vacuum chamber. The short drift section between dipole B1 and quadrupole Q7 on each side is now densely packed with diagnostic equipment related to beamstrahlung detection, small-angle Bhabhas, and polarimetry. A careful study of these systems is needed to fully understand the implications of changing the vacuum chamber geometry in this area. The beamstrahlung monitors, in particular, may have to be rebuilt to accommodate the new dump-line geometry.

Assuming the e^-e^- mode is to be used with a substantial beam current for more than a few days, a safe and well-shielded beam dump will be needed on each side. There are two possible approaches to this issue. A conceptually simple approach is to build new dumps similar to the existing dumps, but on the new outgoing beam trajectories. This would entail excavation of new alcoves and construction of new concrete walls, as well as the fabrication and installation of the dumps themselves and their associated cooling systems, diagnostic equipment, and PPS safety barriers.

A possible alternate approach would be to build new transport lines (approximately 250 feet of new transport line on each side) to direct the outgoing beams to the existing dumps. On the south side, this beamline would transport the outgoing beam up and over the incoming beamline equipment and back down to match a trajectory into the existing dump lines. In the north tunnel, the dump line would snake through the tunnel between the incoming beamline and the east wall. This approach avoids the need to excavate new alcoves and would not introduce any new radiation safety issues. The disadvantages are that new magnets and beam steering equipment would be needed in an already-crowded tunnel area, and that these dump lines would interfere with other existing equipment (such as the muon toroids). Some excavation would likely be needed in the north tunnel (where the incoming beamline is already close to the east wall) to provide space for new magnets.

The SLC has delivered an integrated luminosity of about 50 nbarn^{-1}/day while colliding electrons with positrons at the center of mass energy of the Z^0. The modifications described above could be expected to yield similar luminosity with e^-e^- collisions. In normal e^+e^- operation, the SLC performance becomes limited by various emittance growth effects as the charge per bunch is increased. The same limitations would effect e^-e^- operation. Other issues that need to be examined are the changes to control system functions, including the steering and feedback algorithms for those parts of the machine that normally see both positrons and electrons, and the spin manipulation procedures needed to provide the desired polarization orientation of both bunches at the collision point.

It is interesting to consider the possibility of doubling the luminosity by using the south damping ring to process a second pair of electron bunches. The linac could then be used to accelerate four bunches of electrons, two of which would be deflected into each arc. Using both damping rings for same-charge bunches would require that the dc magnets now used to deflect the beams from the linac into the LTR transport lines (and from the RTL transport lines back into the linac) be replaced by pulsed bipolar devices ("DRIP kickers"). In addition, a spin-rotator solenoid is needed in the south LTR if spin polarization is to be preserved in the south damping ring. The spin orientations of the first bunches from each of the two damping rings must be identical after they are reinjected into the linac, because both will be subjected to the same spin precession effects as they are transported through the south arc. Similarly, the second bunches from the two rings must have identical orientations in the linac, since they will both be transported through the north arc.

Two timing arrangements for four bunch operation could be considered. In one arrangement, the second pair (from the south damping ring) follows the first pair, such that the four bunches are equally spaced in the linac, with the last bunch following approximately 177 nsec after the first. The DRIP kickers would be designed to kick two bunches one way, change sign, and kick two more the other way. The high-energy kicker at the end of the linac would deflect alternately right-left-right-left. A complication arises because the rf accelerating gradient changes significantly over the 177 nsec duration of the bunch quadruplet. This is due to the time structure of the rf pulse and to beam loading effects, and could result in energy variations among the bunches that would preclude optimal focusing if left uncorrected. Manipulations of the rf time structure in a few sectors could be developed to balance the energies of the four bunches. Another timing arrangement could interleave the two pairs of bunches such that the first bunch from the south ring falls midway between the two bunches from the north ring, resulting in four equally spaced bunches in about 88 nsec. This would relieve the energy profile problem somewhat, but would impose more severe demands on the kicker magnets. Note that in either timing arrangement, collisions are achieved only between the first bunch from a damping ring and the second bunch from the same ring.

In normal SLC operation, opposite-sign bunches must be spaced by a half-odd-integer number of S-band wavelengths in order to be accelerated. If two bunches with the same charge are to be accelerated, they must be spaced by an integer number of wavelengths. As a result, the point in space where the opposing bunches collide will necessarily be shifted along the beam path by a quarter of an S-band wavelength, or about 2.62 cm. This is of no consequence for the collider itself, but may be of concern if an existing high-precision vertex detector were to be used at the interaction point.

Acknowledgments

The idea of running the SLC in an e^-e^- mode has been around since the days when the SLC was first proposed. The issues outlined here have arisen from informal discussions among a number of people, stimulated mainly by the recent interest stirred up by C. Heusch. I would like to thank him, along with D. Whittum and J. Sheppard, who provided valuable suggestions and encouraged me to write this letter as a record of our discussions. D. Whittum suggested that a four-bunch mode should be feasible, and offered a variety of other provocative ideas to trigger further studies. This work was supported by Department of Energy contract DE-AC03-76SF00515.

References

1. C. Heusch, Expression of Interest, submitted to the Stanford Linear Accelerator Center, 1995.