Update to the NLC Injector System Design*

S. D. Anderson, Y. Batygin, V. Bharadwaj, J. E. Clendenin, P. Emma, K. S. Fant, Z. Li, B. McKee, M. H. Munro, C. D. Nantista, C. E. Rago, T. O. Raubenheimer, M. C. Ross, N. Phinney, D. C. Schultz, J. C. Sheppard†, C. M. Spencer, M. D. Woodley, SLAC, Stanford, California 94309, USA
D. Atkinson, J. N. Corlett, A. Wolski, LBNL, Berkeley, California 94720, USA
A.Sunwoo, K. van Bibber, W. Stein, LLNL, Livermore, California 94550 , USA

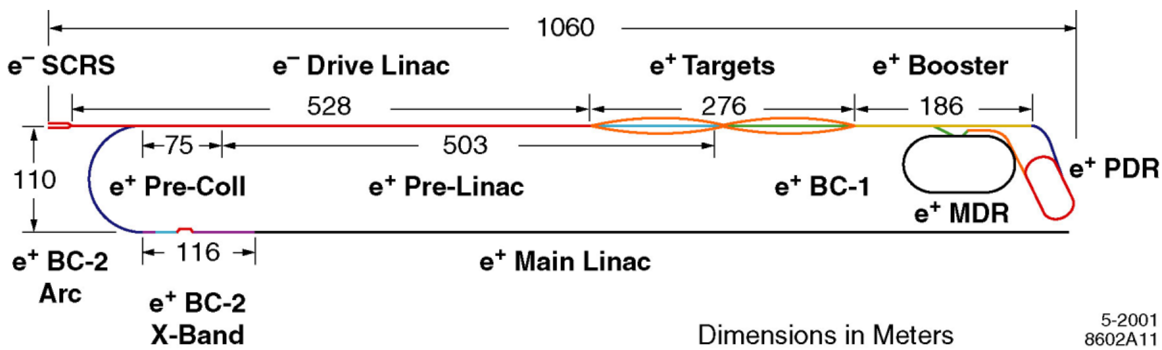

Figure 1: Layout of the NLC Positron Injector System for the cut-and-cover configuration (see section 2).

Abstract

The Next Linear Collider (NLC) Injector System is designed to produce low emittance 8 GeV electron and positron beams at 120 hertz for injection into the NLC main linacs. Each beam consists of a 265 ns train of bunches (190 bunches spaced by 1.4 ns or 95 bunches spaced by 2.8 ns); each bunch has a population of up to 1.6×10^{10} particles for 2.8 ns (or 0.8×10^{10} particles for 1.4 ns). Horizontal and vertical emittances are specified to be $\gamma\varepsilon_x = 3\times10^{-6}$ m-rad and $\gamma\varepsilon_y = 2\times10^{-8}$ m-rad; bunch length at injection is variable from 90-140 μm. Electron polarization of greater than 80% is required. Electron and positron beams are generated in separate accelerator complexes each of which contains the source, damping ring systems, linacs, bunch length compressors, and collimation regions. Investigation into the feasibility of polarized positrons for the NLC has begun; operations at 180 Hz and the centralization of the injector complex have been studied. The need for affordable, low technical risk, reliable injector subsystems is a major consideration in the design effort. This paper presents an overview of the NLC injector systems with an emphasis on changes in the design since 1999 [1] and discusses the planned R&D.

1 INTRODUCTION

The Next Linear Collider Injector System is designed to produce low emittance electron and positron beams for injection into the NLC main linacs. Table 1 lists the design beam parameters for the NLC Injector System.

The need for low technical risk, reliable injector subsystems has been a major consideration in the design effort. Technologies chosen for the design of the NLC injector systems are based on experience with previously built and operated high energy colliders and with third generation synchrotron light sources. Polarized electrons are produced using a dc photocathode gun that is very similar to the SLC polarized source [2]. Unpolarized positrons are generated using multiplexed target systems that will be run in parallel; the peak energy deposition in each target assembly is designed to be the same as in the SLC positron system which ran for more than 5 years without trouble [3,4]. The parameters of the two main damping rings are similar to the present generation of synchrotron light sources and the B-Factory colliders in that they must store high-current beams (~1 A) while attaining small normalized emittances. The acceleration gradient in the injector S-band linacs [4] is only modestly higher than the gradient in the SLC linac and the S-band klystrons are based on the 65 MW SLAC 5045 klystrons. Injector L-band linacs [5] have been designed with low gradients to avoid problems associated with high fields in the structures and ancillary rf distribution systems. The X-

Table 1: NLC Injector System Beam Parameters

Energy	E	8 GeV
Energy Spread	$\Delta E/E$	1%
Single Bunch σ_E	σ_E/E	1.5%
Horizontal Emittance	$\gamma\varepsilon_x$	3×10^{-6} m-rad
Vertical Emittance	$\gamma\varepsilon_y$	2×10^{-8} m-rad
Bunch Length	σ_z	90-140 μm
Electron Polarization	P_e	>80%
Positron Polarization	P_p	No
Particles/Bunch	n_b	$0.8\times10^{10}(1.6\times10^{10})$
Number of Bunches	N_b	190 (95)
Bunch Spacing	T_b	1.4 ns (2.8 ns)
Repetition Rate	f	120 Hz

*Work supported by the U.S. Department of Energy under Contract Nos. DE-AC03-76SF00515 (SLAC), DE-AC03-76SF00098 (LBNL), and W-7405-ENG-48 (LLNL).
† jcs@SLAC.Stanford.edu

band rf for the bunch length compressors is adapted from the NLC main linac rf system.

Descriptions of the choice of injector layouts, the polarized electron source, the positron system, damping ring systems, and bunch length compression systems follow. The possibility of polarized positrons is followed by a discussion of present and future injector system activities. An explicit description of the 6 GeV injector prelinacs has not been included. While key to the functioning of the injector systems, the prelinacs are not seen to be fundamentally difficult. The designs of the prelinacs are based on proven S-band technologies for which performance is well demonstrated and understood in the operating range of the NLC injector design.

2 LAYOUT CONSIDERATIONS

The present NLC configuration includes two injector system layouts: a remote, near surface cut and cover design and a centralized deep bored tunnel design. A design requirement for both is that technical components are not shared between the electron and positron generation, damping, and initial acceleration systems.

In the near surface cut and cover configuration, the electron and positron systems are located in separate complexes at the upstream ends of the respective main linacs, separated by about 25 km. Whereas it is reasonable to consider combining the two injector complexes at a central location, such a layout requires the addition of lengthy and costly low emittance-preserving transport lines. Wherever possible, cost savings are taken through the sharing of accelerator housings and klystron galleries among injector subsystems (e.g. in Fig. 1, the e- drive linac, e+ targets and e+ booster linac share a common accelerator tunnel and equipment support housing with the e+ prelinac).

The layout for the deep bored tunnel design is quite similar, except that the separate electron and positron injector complexes are placed closer to the center for the purpose of placing them on the Fermilab site and utilizing its existing facilities. The two injectors are separated by about 5 km and are located at or near grade level, with separate housings for each complex. Beamlines are required to drop the damped, injector beams down to the long haul transport lines placed in the main linac tunnel. Each injector has approximately 10 km of low emittance preserving transport lines and turnout beamlines at their ends for the purpose of connecting into the 180° bunch compressor arcs at the entrances to the main linacs.

A fully centralized injector is under consideration for the Fermilab site. This compact layout is located on or near the surface. The accelerator components for both electron and positron injectors are located in a common housing with shared equipment galleries and facility infrastructure.

3 POLARIZED ELECTRON SOURCE

The NLC injector electron source system creates polarized electron beams of the required energy and emittance for injection into the electron damping ring system. Polarized electron beams are produced with a III-V semiconductor photocathode dc electron gun, bunched with a 714 MHz sub-harmonic RF system and accelerated in an S-band linac to the energy of the damping ring, 1.98 GeV. Gun high voltage is in the range of 150-200 kV, up from the 120 kV of the SLAC system.

Improvement of the SLC photocathodes is required for NLC operation due to the higher pulse charge requirements. Efforts at SLAC [6] and at Nagoya University [7] are concentrating on developing cathodes with a highly doped surface layer to permit rapid dissipation of surface charge that builds up as beam is extracted.

4 CONVENTIONAL POSITRON SOURCE

The injector positron source system [8] creates positron beams of the required energy and emittance for injection into the positron damping rings. The positrons have an edge emittance of 0.3 m-rad as required by the pre-damping ring acceptance. Positrons are produced by colliding 6.2 GeV electrons into three separate high Z material targets, capturing the resulting positrons, and accelerating them to the 1.98 GeV energy of the pre-damping ring system. Utilization of three targets keeps the peak shock stress in the individual targets to the same peak stress incurred in SLC operations [9]. The present design of the positron generation system is based on limiting the peak energy deposition and integrated fluence in the targets to the level of the SLC positron target. Ongoing research is aimed at developing better target material [10] and at improving the understanding of fatigue and radiation damage in a positron target.

5 DAMPING RINGS

The NLC damping rings [11] are designed to damp the incoming electron and positron beams to the small emittances needed for collisions. The rings have three purposes: (1) damping the incoming emittances in all three planes, (2) damping incoming transients and providing a stable platform for the downstream portion of the accelerator, and (3) delaying the bunches so that feedforward systems can be used to compensate for charge fluctuations. To meet these goals, three damping rings have been designed: two identical main damping rings, one for the electrons and one for the positrons, and a pre-damping ring for the positrons. The pre-damping ring is needed because the emittance of the incoming positrons is much larger than that of the electrons. Each damping ring will store multiple trains of bunches at once. At every machine cycle, a single fully damped bunch train is extracted from the ring while a new bunch train is injected. In this manner, each bunch train can be damped for several machine cycles.

The parameters of the two main damping rings are similar to the present generation of synchrotron light sources and the B-Factory colliders in that they must store high-current beams (~1A) while attaining small normalized emittances. Table 2 compares the NLC ring parameters with those of the SLAC B-Factory Low-

Energy Ring (PEP-II LER), the Advanced Light Source (ALS) at Lawrence Berkeley National Laboratory, and the Accelerator Test Facility (ATF) damping ring at KEK in Japan, which was built to verify many of the damping ring design concepts. In particular, the stored beam currents are less than half of what the PEP-II LER has achieved, while the emittance, energy, and size of the NLC rings are similar to those of the ALS and the ATF. These other rings have been largely successful in meeting their design parameters, and have been able to test and verify many of the accelerator physics and technology issues that will arise in the NLC damping rings.

Table 2: Comparison of NLC main damping rings with design parameters of other rings.

	NLC MDR	PEP-II LER	LBNL ALS	KEK ATF
Energy (GeV)	1.98	3.1	1.5	1.54
Circumference(m)	300	2200	197	139
Current (A)	0.8	2.16	0.4	0.6
$\gamma\varepsilon_{x,\ equilib.}$ (10^{-6} m-rad)	2.17	400	12	4.3
$\gamma\varepsilon_{y,\ equilib.}$ (10^{-6} m-rad)	0.014	12	0.12	0.03

Additional experiments and theoretical studies are planned to further understand and predict behavior in the damping rings and through the extraction system. Investigations are focused on intra-beam scattering, electron cloud and ion driven instabilities, dynamic aperture limitations, extraction system stability, and vacuum systems technologies.

6 BUNCH LENGTH COMPRESSION

The NLC bunch length compressors must reduce the ~4 mm rms length of the bunches extracted from the damping rings to the 90-140 μm bunch length required for the main linacs and final focus systems. A two-stage compressor system has been designed where the first stage follows the damping ring and the second stage is at the exit of the S-band prelinac. Table 3 lists the beam parameters of the two compressor stages, Bunch Compressor 1 and Bunch Compressor 2 . The entries in Table 3 are a single bunch values.

Table 3: Beam parameters in the two compressor stages.

Bunch Compressor 1				
Energy	E	1.98	1.98	GeV
Energy Spread	σ_E/E	0.2	2	% FW
Bunch Length	σ_Z	5	0.5	mm, rms
Bunch Compressor 2				
Energy	E	8	8	GeV
Energy Spread	σ_E/E	0.5	3	% FW
Bunch Length	σ_Z	500	90-140	μm, rms

Electron and positron bunch compression systems are identical. A cost and performance optimization study has been conducted for the bunch compression system [12]. This study has resulted in the reduction in the energy of the S-band prelinac to 6 GeV (final injector beam energy of 8 GeV) and the utilization of 600 MeV of X-band rf in the second compressor sections.

7 POLARIZED POSITRONS

The JLC [13] and TESLA [14] polarized positron design studies are being examined in regards to NLC requirements. Initial NLC effort is concentrated on the understanding of conversion and collection processes with the goal of estimating the photon-to-polarized positron yield captured in a predamping ring. Yield estimates drive the requirements on the methods of photon production and on the positron collection systems. One possibility for an NLC polarized positron system is based on a helical undulator [15]. A dedicated electron beam for photon generation is produced by doubling the repetition rate of the first part of the electron main linac and sent through the undulator. Alternatives include using the colliding electron beam extracted from the main linac at an energy of about 150 GeV, transported through an undulator and reinjected into the main linac for further acceleration and transmission to the IP's.

8 FUTURE PLANS

The thrust of the present R&D and design activities fall into three broad categories: (1) improving the technical foundation of the NLC injectors systems design through feasibility demonstrations, technology reviews, and augmented system simulations; (2) developing alternate schemes to assure the realizability of the designs; (3) and investigating the feasibility of novel options which improve either the operability or capability of the overall design

Although not presently included in the injector design, considerable thought and effort are going into the studies on the feasibility and efficacy of polarized rf guns and sources of polarized positrons. Because of the considerable work to be done in the development of these systems, neither are presently included as part of the present design configuration. The current design does not preclude the adoption of either or both systems into the NLC complex at a later time

9 REFERENCES

[1] V. Bharadwaj, *et al.*, Proc. 1999 PAC,3447, NY 1999.
[2] R. Alley, *et al*.,, Nucl. Instr. and Meth**. A365**,1995.
[3] P. Krejcik, et al., Proc. 3rd EPAC, Berlin, 1992.
[4] V. Bharadwaj, *et al.* ,this Conference.
[5] K. Bane and Z. Li, LCC-0043, July 2000.
[6] G.A. Mulhollan, *et al*, Phys. Lett. **A282**, 2001.
[7] K. Togawa, *et al*, Nucl .Instr. and Meth. **A455**, 2000.
[8] Y. K. Batygin, *et al.*, this Conference.
[9] W. Stein, *et al.*, this Conference.
[10] A.Sunwoo, UCRL-PRES-143841, April, 2001.
[11] D. Atkinson, *et al.*, this Conference.
[12] P. Emma, LCC-0021, August 1999.
[13] T. Omori, KEK 99-188 (2000).
[14] W. Bialowons *et al.*, DESY 1997-048, May 1997.
[15] A. A. Mikhailichenko, SLAC Report 502 (1997).