Chapter 3

A Zeroth-Order Design for the Next Linear Collider

The Next Linear Collider consists of a set of subsystems—injectors, linacs, beam delivery lines, and interaction regions. These are responsible for creating intense and highly condensed beams of positrons and polarized electrons, accelerating them to high energy, focusing them to small spots, and colliding them in an environment that allows sensitive particle detectors to operate for physics. We introduce these various parts of the collider in this section, and then provide a more detailed discussion of each. A comprehensive design study of the NLC is given in Ref [1].

3.1 Overview of Collider Systems

A schematic of the NLC is shown in Fig. 3.1. The physical footprint of the collider complex is approximately 30 km in length and less than 1 km wide. This includes all beam transport lines in the injectors and linacs necessary to obtain 1 TeV cms energy, and all space needed in the beam delivery sections to accomodate 1.5 TeV cms energy. To reach 1.5 TeV, however, it may be necessary to extend the "trombones" in the layout of the collider to provide additional length for the main linacs. Rather simple beam-transport lines can be used to do this without moving the injectors or damping rings.

3.1.1 Injectors and Damping Rings

The electron injector system for the collider is copied from the system presently operating reliably at the SLC. This includes a polarized photocathode electron gun, and a bunching system that operates at a subharmonic of the main linac rf frequency. The new challenge for the NLC injector is that it must produce trains of 90 bunches spaced by 1.4 ns at the machine pulse repetition rate of 120–180 Hz. The bunched beam is accelerated in an S-band linac to 2 GeV, then injected into a damping ring designed to condense the transverse phase space of

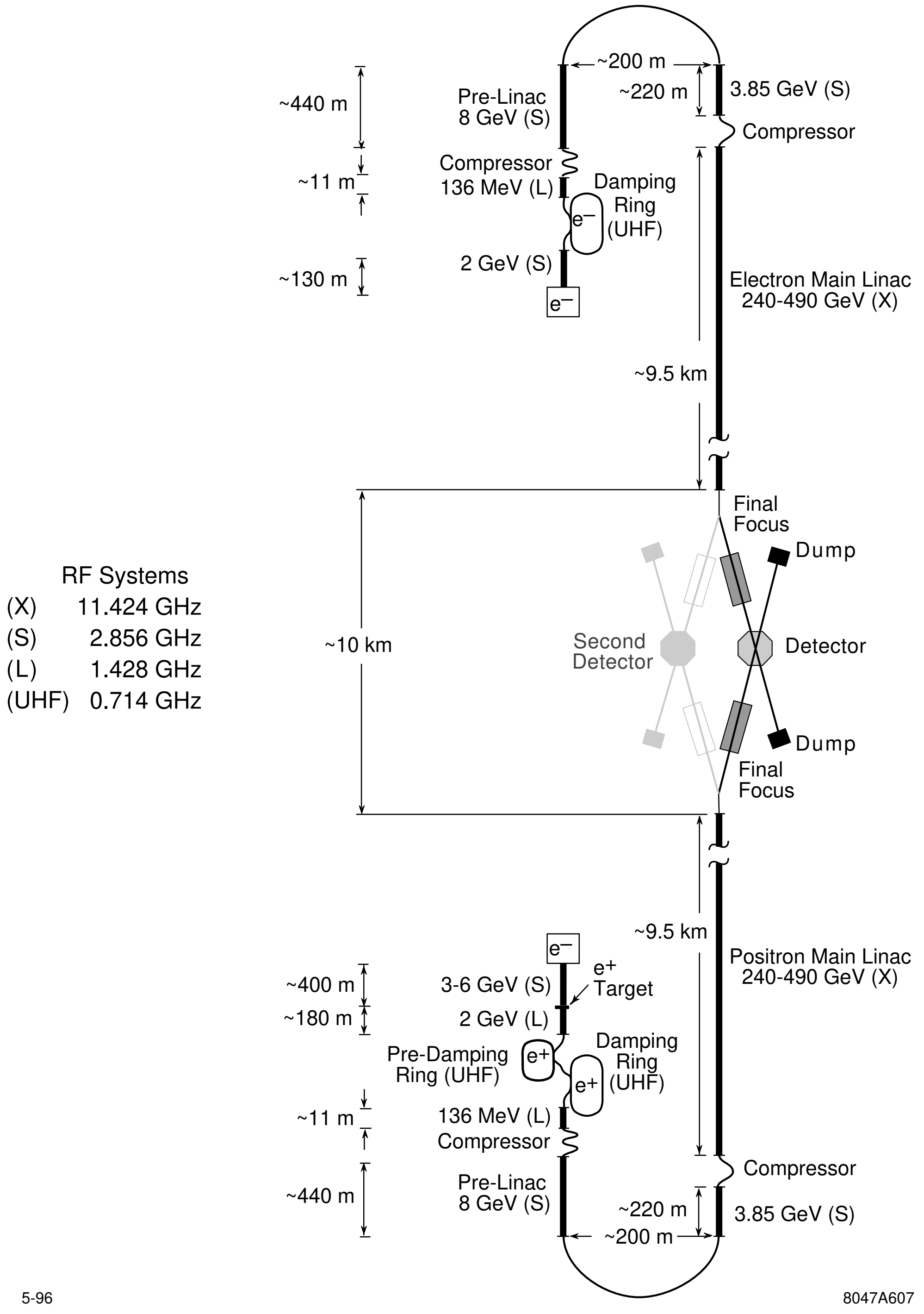

Figure 3.1: Schematic layout of NLC systems (not to scale).

the beam through radiation damping. The required vertical emittance, $\gamma\varepsilon_y = 3\times10^{-8}$m-rad, is two orders of magnitude smaller than achieved in the SLC damping rings. This places tight constraints on the alignment of ring magnets, but many lessons have been learned from operation of the SLC damping rings, and several modern synchrotron light sources also provide valuable experience. Wiggler magnets, similar to that used in the SSRL ring at SLAC, are included in the NLC design to reduce damping times, and the vacuum and rf systems required for the NLC ring are similar in size and complexity to those of the Advanced Light Source at Lawrence Berkeley National Laboratory.

The techniques for positron production planned for the NLC are also largely copied from those in use at the SLC. Positrons are created in electromagnetic showers produced by targeting 3–6 GeV electrons onto a rapidly rotating metallic disk. The high-emittance positron beam is focused in an extended solenoid, and accelerated to 2 GeV in a large-aperture L-band linac. This leads to a good capture efficiency. To further improve efficiency and ease operational tuning tolerances, the beam is cycled through a large-aperture pre-damping ring prior to injection into a main damping ring identical to that used for the electron beam. The overall layout also includes transport lines that will allow the drive electron beam to bypass the positron-production target and pre-damping ring (Fig. 3.2). This will allow the study of e^-e^- collisions (with both beams polarized).

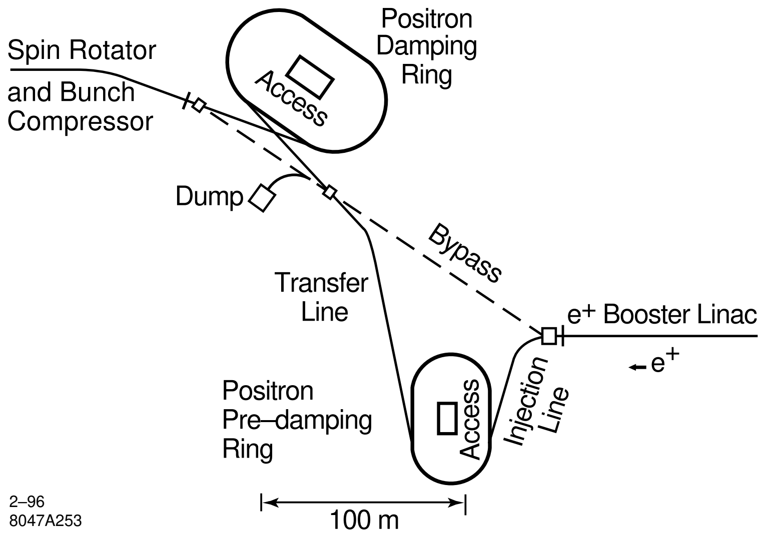

Figure 3.2: Layout of the positron target area and damping rings.

3.1.2 Bunch Length Compressors

The lengths of the electron and positron bunches become too great in the damping rings for the beams to be successfully accelerated in the main X-band linacs, so they must be reduced. This is done in stages (Fig. 3.1). A first compressor, located immediately after the damping rings, reduces the bunch length from 4 mm to 0.5 mm to optimize injection into an S-band linac that accelerates the beams to 10 GeV. The bunch lengths are then further compressed to 100–150 μm in a two-stage compressor that also bends through a 180° arc, reversing the direction of travel; this arc allows for future upgrades of the main linac length and permits feedforward of measurements of the bunch charge and trajectory made in the damping rings and compressors. This ability to preset the energy gain and injection orbit to the main linac is an important feature of the design.

3.1.3 Main Linacs

The main linacs of the NLC will use normal-conducting traveling-wave copper structures powered with 11.424 GHz microwaves. The required power is generated by klystrons in 1.2-μs pulses which are then compressed into shorter 0.24-μs pulses of higher peak power in a passive rf transformer (SLED-II). A train of 90 electron (or positron) bunches is accelerated in the main linac by each rf pulse. While the number of particles in each of these bunches is less than that in the SLC, the total charge accelerated by each rf pulse is more than an order of magnitude greater. This multibunch design and the correspondingly larger fraction of energy transferred from the power sources to the beam is one of the important differences between the SLC and the NLC. The linac focusing lattice is designed to allow the center-of-mass energy to be increased from 300 GeV to 1 TeV; further upgrade to 1.5 TeV will require modifications. Diagnostic stations, located at five positions along each of the two main linacs, will include laser wire scanners to measure the transverse phase space, beam-based feedbacks to correct for centroid shifts of the bunch train, multibunch BPMs and high-frequency kickers to measure and correct bunch-to-bunch position errors, and magnetic chicanes to provide noninvasive energy and energy spread measurements. These feedbacks must maintain bunch trajectories to within a few microns of a tuned reference orbit in order to prevent unacceptable emittance growth.

3.1.4 The Beam Delivery System

The beam delivery system consists of a collimation section, a switchyard, the final focus, the interaction region, and the beam extraction and dump. These are shown schematically in Figure 3.3.

After acceleration in the main linac, the beams enter collimation sections where particles at the extremes of the energy and transverse phase space are eliminated by collimators. Collimation is performed for both the horizontal and vertical planes at two betatron phases that differ by 90° to effectively cut the beam in both position and angle. This primary collimation is then followed by secondary collimation in both planes and both phases to remove particles that are scattered by the edges of the primary collimators. These collimation sections are rather extensive, but our experiences at the SLC and FFTB have proven the need to perform this function well.

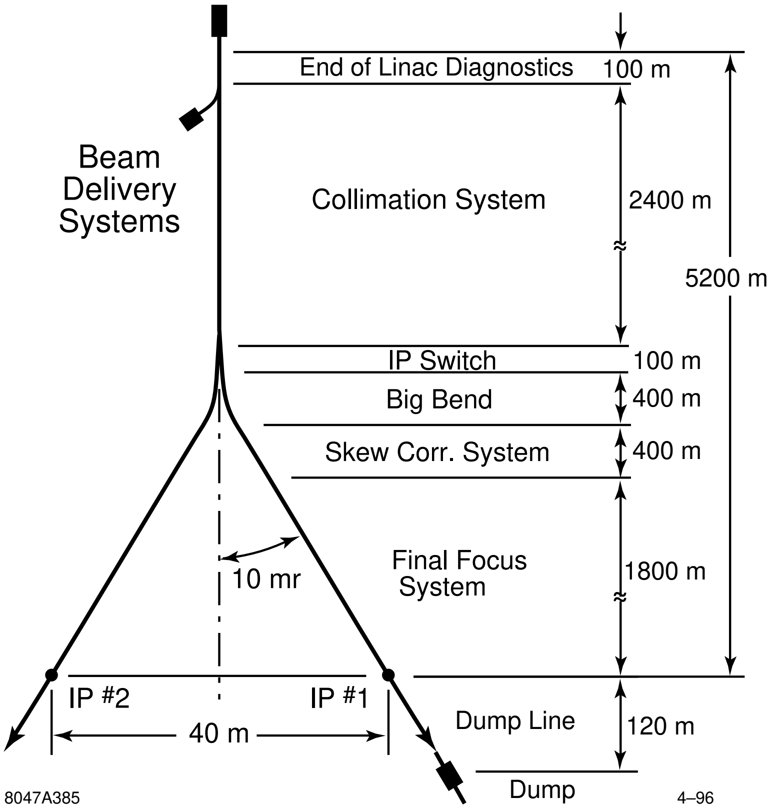

Figure 3.3: Schematic layout of the beam delivery system.

A passive switching section is used to direct the beams to one of two possible interaction points (IPs). The beam is deflected in the switchyard by 10 mrad to produce a 20-mrad crossing angle between the two beams at each IP. This deflection introduces little emittance growth, but greatly reduces detector backgrounds and provides the IP crossing angle required to collide the closely spaced bunches in each train.

The NLC final focus follows the design of the Final Focus Test Beam (FFTB) at SLAC. The optics consist of a matching section with appropriate instrumentation to measure the incoming beam phase space, horizontal and vertical chromatic correction sections, a final transformer, a final doublet, and a diagnostic dump line for the exiting beam. The final doublets require active stabilization to maintain beam collisions. Measurement of the final spot size is a particular challenge, but can be performed with an advanced laser fringe monitor similar to that used in the FFTB. In-situ tuning of the spot sizes and luminosity can also be done using measurements of the beam-beam deflections and other techniques developed at the SLC.

3.1.5 Interaction Region

Two interaction regions are included in the layout of the NLC. These, of course, must share the available luminosity, but it will be possible to install two complementary experiments. As with all colliders, the interaction region will be a very crowded location. The final quadrupole magnets of the machine optics must be positioned as closely as possible to the collision point, and high-Z masking must be installed to protect elements of the experimental detector. The detector itself will require clear access to as much of the volume around the interaction point as possible. The design presented in this document includes quadrupoles 2 m from the interaction point, and complete access for detector elements at polar angles greater than 150 mrad. Calorimetric measurement of Bhabha scattering at smaller polar angles should also be possible, and is expected to provide a precise determination of the luminosity-weighted center-of-mass energy spectrum.

The NLC is designed to collide electrons and positrons at a 20-mrad crossing angle. This prevents the tightly spaced bunches of one beam from being disturbed, as they approach the interaction point, by bunches in the opposing beam that are leaving the interaction point. To avoid loss of luminosity due to this crossing angle, it is necessary to use a pair of deflection rf cavities to "crab" the beams so that the bunches collide head on. This is a new task not encountered at the SLC, but a system with reasonable specifications has been designed.