1. Requirements

The electron and positron pre-linacs accelerate the beams received from their respective first bunch compressor systems from 1.98 to 8.0 GeV, while maintaining the low emittance produced in the damping rings. Each pre-linac uses 4-meter S-band (2856 Mhz) structures for acceleration, each with a loaded energy gradient of 17 MV/m (21 MV/m unloaded). Transverse focusing is accomplished using quadrupoles on movers between every or every other accelerator structure.

In addition, the positron system must be able to deliver electrons to the downstream systems for commissioning. Polarized electrons are required for $\gamma-\gamma$ or $e^-e^-$ running.

2. Technical Description

2.1 Beam Parameter Table

<table>
<thead>
<tr>
<th>Parameter Name</th>
<th>Symbol</th>
<th>Input</th>
<th>Output</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bunch Spacing</td>
<td>$T_b$</td>
<td>1.4/2.8</td>
<td>1.4/2.8</td>
<td>ns</td>
</tr>
<tr>
<td>Energy</td>
<td>$E$</td>
<td>1.98</td>
<td>8</td>
<td>GeV</td>
</tr>
<tr>
<td>Bunch Energy Variation</td>
<td>$\delta_{E/E}$</td>
<td>1</td>
<td>1</td>
<td>% Full Width</td>
</tr>
<tr>
<td>Single Bunch Energy Spread</td>
<td>$\sigma_{E/E}$</td>
<td>2</td>
<td>0.25</td>
<td>% Full Width</td>
</tr>
<tr>
<td>Horizontal Emittance</td>
<td>$\varepsilon_x$</td>
<td>3.0</td>
<td>3.0</td>
<td>$10^6$ m-rad</td>
</tr>
<tr>
<td>Vertical Emittance</td>
<td>$\varepsilon_y$</td>
<td>0.02</td>
<td>0.02</td>
<td>$10^6$ m-rad</td>
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<tr>
<td>Bunch Length</td>
<td>$\sigma_z$</td>
<td>500</td>
<td>500</td>
<td>microns</td>
</tr>
<tr>
<td>Particles/Bunch</td>
<td>$n_B$</td>
<td>0.76/1.52</td>
<td>0.76/1.52</td>
<td>$10^{10}$ particles</td>
</tr>
<tr>
<td>Train Population Uniformity</td>
<td>$\Delta n_T/n_T$</td>
<td>1</td>
<td>1</td>
<td>% Full Width</td>
</tr>
<tr>
<td>Bunch-to-Bunch Pop. Uniformity</td>
<td>$\Delta n_B/n_B$</td>
<td>2</td>
<td>2</td>
<td>% rms</td>
</tr>
<tr>
<td>Number of Bunches</td>
<td>$N_b$</td>
<td>192/96</td>
<td>192/96</td>
<td>#</td>
</tr>
<tr>
<td>Repetition Rate</td>
<td>$f$</td>
<td>120</td>
<td>120</td>
<td>Hz</td>
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<tr>
<td>Horizontal Beam Jitter</td>
<td>$\Delta_\gamma J_x$</td>
<td>0.015</td>
<td>0.015</td>
<td>$10^6$m-rad</td>
</tr>
<tr>
<td>Vertical Beam Jitter</td>
<td>$\Delta_\gamma J_y$</td>
<td>0.0004/0.0006</td>
<td>0.0008/0.0012</td>
<td>$10^6$m-rad</td>
</tr>
<tr>
<td>Polarization</td>
<td>$P_e$</td>
<td>80</td>
<td>80</td>
<td>%</td>
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<tr>
<td>Beam Power</td>
<td>$P_b$</td>
<td>58</td>
<td>233</td>
<td>KW</td>
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</tbody>
</table>
2.2 Layout and Function Description

The pre-linacs are part of the second bunch compression scheme, which requires a pseudo $2\pi$ longitudinal phase space rotation for stability, which can only be achieved by two RF systems (pre-linac, post arc RF) and two magnetic compressors (180° turnaround arc, chicane magnet). The pre-linacs are the first RF system and accelerate the beams from 1.98 to 8 GeV, while maintaining the low emittances from the damping rings.

Each pre-linac consists of 18 S-band RF modules, each consisting of a modulator powering two klystrons, that feed two SLED assemblies which together power six 4-meter accelerator structures. The 18 RF modules include two spare RF modules of overhead. The loaded gradient of the structures is 17 MV/m (21 MV/m unloaded).

Beam focusing is accomplished using tunable, permanent magnet quadrupoles between each structure for the first 5 modules and between every second structure for the remainder. The end of pre-linac is a matching section with electromagnet quadrupoles and steering feedbacks. Each quadrupole has a BPM.

The pre-linac diagnostics include a bunch length measuring cavity, three RF BPM output couplers in each accelerator structure and PLIC to detect beam loss.

The Pre-Linacs must have two enclosures, one for the beamline components and local electronics, which cannot be accessed while beams are running, and another for the modulator/klystron pairs and other accelerator utilities that need to be accessed while beams are running.

2.3 System Drawings

Pre-Linac Beamline View
Pre-Linac Plan View

2.4 Technical Issues

The two-SLED high power combined RF system, which is used in all of the injector linacs, needs to be modeled and then tested, because it is crucial for stable injector operation. Low level control of two-SLED power combiner permits fine control of the high power RF for the purpose of beam loading compensation for beams of different intensities and provides a convenient method to control total power delivered to the accelerator when beam is not present.

The permanent magnet quadrupoles need to meet the center shift and long term stability requirements of the pre-linac system.

2.5 System Optics Decks

Injector Optics Decks
2.6 System Boundaries
The pre-linac system is preceded by the Bunch Compressor 1 (BC-1) system and followed by either the pre-collimation system or the long transport line system depending on if the injectors are near the beginning of the main linacs or are located and near the ends of the main linacs.

2.7 Sub-Systems
The list of beamline sub-systems:

2.7.1 RF system
There are 18 RF modules in a pre-linac and a RF module is: one Solid State Modulator, two S-Band Klystrons, two SLED I cavities, rectangular Waveguide and six 4-meter accelerator structures. RF generation begins with two klystrons that are driven by a solid-state modulator. The SLED output of the two klystrons are combined and distributed to 6 accelerator structures. The combination of two the SLEDs cavities permits vernier control of the RF waveform for beam loading compensation, while allowing for constant power delivery to the structures during a machine protection system fault and recovery. Each RF accelerator structure has three output couplers along its length, each sampled by an RF BPM module. All structures have independent x, y and roll movers.

2.7.2 Magnet system
Most quadrupoles are tunable permanent magnets, except in the matching section where they are electromagnets. The tunable permanent quadrupoles have a tunable range of +/- 20%. Each quadrupole contains a BPM. Beam steering is accomplished independent x, y and roll movers. The polarities of the magnets in the positron are reversible to allow e⁻ operation.

2.7.3 Vacuum System
The accelerator vacuum module system is a manifold ion pump scheme, with a hot filament gauge. The operating vacuum pressure is < 10⁻⁸ torr.

2.7.4 Instrument System
Pre-Linac beam loss is detected by PLIC, which runs its entire length. All quadrupoles are on independent x, y and roll movers and each quadrupole contains a BPM. Each RF accelerator structure has three output couplers along its length, sampled by an RF BPM module. All structures have independent x, y and roll movers. The beam line instrumentation must function equally well for either positron or electron beams.

3. Configuration Choice
The NLC2003 Pre-Linac configuration has a S-band (2856 MHz) RF system for acceleration and tunable permanent magnets for focusing. S-band has been chosen over C-Band (double the frequency of S-band) because C-Band alignment tolerances are 10 times tighter than S-band and development costs for C-band are large compared to those of S-band. Permanent magnets have been chosen over electromagnets to lower the costs of the magnet systems and its associated conventional facilities, such as cable trays, cooling water etc.