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The JLC/NLC Baseline Design [1]

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The JLC/NLC is a normal conducting linear collider based on X-band RF technology. The collider is designed to cover the center-of-mass energy range from 90 GeV to 1.3 TeV with a luminosity of 2 to 3 $\times 10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$ between 500 GeV and 1 TeV. The X-band RF system, which is based on the operating NLC Test Accelerator X-band RF system, was recently modified in a way that will ensure a less expensive and faster demonstration of a full RF sub-unit. In this paper, the baseline beam parameters and RF system design for the JLC/NLC will be described, along with the demonstration schedule.

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The JLC/NLC Baseline Design

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1 THE JLC/NLC PROJECT

The concept of a linear collider for TeV-scale particle physics research is now well-established in the high energy physics community. The broad outlines of such a facility – initial operation at 0.5 TeV in the center-of-mass, ultimate energy reach of at least 1.0 TeV, and luminosity in excess of $10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ over this range – have been endorsed by Asian, European, and U.S. advisory panels [1, 2, 3].

Over the last 10 years, a number of design proposals for linear colliders have been presented. The primary variable in the proposals is the design of the main linear accelerators, which in turn drives design variations in other systems (damping rings, etc.). At this time, two main linac technologies are in competition for use in the next generation linear collider: a low-frequency, long-pulse, superconducting RF system [4], and a high-frequency, short-pulse, normal conducting RF system. The latter is the basis for the Japan Linear Collider/Next Linear Collider (JLC/NLC), which is being advanced by Japan and the United States in concert.

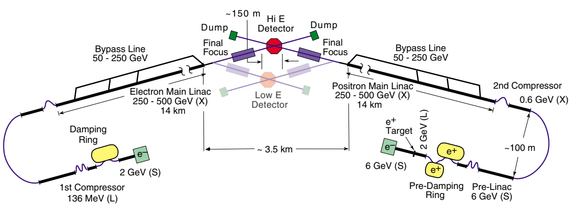

Figure 1: Schematic of the JLC/NLC design.

Figure 1 shows a schematic of the JLC/NLC design. Features of interest include:

- Conventional electron source (polarized DC gun) and positron source (thick production target with electron drive beam), based on SLC designs with appropriate improvements.
- Damping rings similar in design and parameters to third generation synchrotron light sources and the KEK-ATF prototype damping ring.
- Bypass lines parallel to each linac to transport lower-energy beams to the final focus without unwanted emittance dilution in unused portions of the linac.
- Two interaction regions capable of operation from 90 GeV to 1.3 TeV CM.

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Figure 2 shows the layout of the JLC/NLC main linac: the accelerator and its support systems (klystrons, etc.) are in separate tunnels, so that the latter may be maintained without human access to the accelerator tunnel.

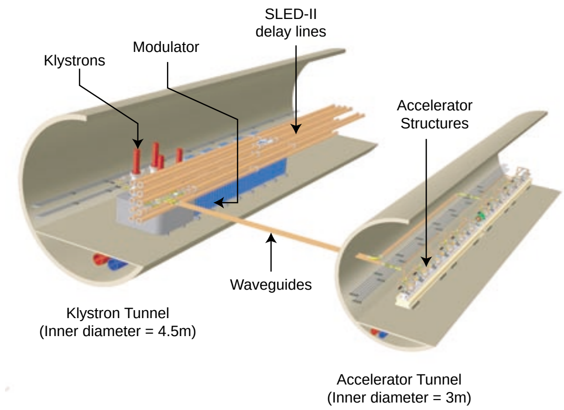

Figure 2: Two-tunnel layout of the JLC/NLC design.

2 ADVANTAGES OF X-BAND

Any proposed technology for a future linear collider must satisfy a number of competing demands: it must achieve an acceptably high gradient and an acceptably high efficiency of conversion from AC power to beam power to minimize construction and operating costs; it must achieve a high reliability; it must transport the beam with minimal dilution of the emittance, especially the very small vertical emittance; and it must be amenable to engineering and mass production, and may not place unacceptable demands upon the design or performance of any other subsystem.

The principal advantages of today's superconducting RF technology are very efficient acceleration, low input power (which eases the design of the RF power sources), and, because of the low frequency and weak wakefields of such structures, loose alignment tolerances for emittance preservation. The most obvious advantage of higher-frequency, normal conducting RF structures is its relatively high accelerating gradient, which permits a high-frequency linac to be built on a smaller site than a comparable superconducting linac. In addition, there are a number of other, more subtle, advantages to the high-frequency system:

- High frequency structures are amenable to much shorter filling times than superconducting ones (on the order of 100 *nanoseconds* compared to 1 *millisecond*.
- Since the filling time of a high-frequency structure is so short, it can be pulsed many more times per second than a superconducting linac, which makes beam-based feedback on a linac-pulse to linac-pulse timescale more effective.
- Normal conducting structures have cleanliness requirements which are more compatible with industrial mass production than those of superconducting structures.
- Because normal conducting structures are not sealed up in a cryostat, optical and contact alignment techniques can be used and thus the tighter tolerances of such structures are not much harder to achieve than the tolerances on superconducting structures.
- As a result of the shorter fill time, high frequency structures are compatible with relatively short bunch trains, thus the beam sources and damping rings for such a complex are much more like existing systems than what would be needed for a superconducting linac.

The short bunch trains and small damping rings required for an X-band linear collider have also permitted test facilities for these portions of the complex to be constructed in a reasonable manner, although full testing of the emittance preservation and luminosity generation remains beyond the capability of any conceivable test facility.

3 OPERATING RANGE AND PARAMETERS

The JLC/NLC accelerating gradient is based on the requirements of cost optimization: higher gradients imply lower civil construction and accelerator costs but incur a penalty in RF power source costs. For X-band RF technology a shallow minimum in capital costs is found at an unloaded gradient of about 70 MeV/meter [5]; the JLC/NLC baseline has been chosen at 65 MeV/meter for this reason.

The physics mission of the linear collider requires operational capability at center-of-mass energies from 90 GeV to 1 TeV, and a luminosity in excess of $10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ from 0.5 TeV to 1 TeV CM. The JLC/NLC parameters have been selected to achieve luminosity of 2 to 3 $\times 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ over the 0.5 to 1.0 TeV CM range. The relevant parameters are shown in Table 1. At lower CM energies the luminosity will be somewhat reduced due to the larger geometric emittance of the beam in the final focus and the increased impact of collimator wakefields at lower energies.

Table 1: JLC/NLC Parameters for 120 Hz repetition rate at a site with 60 Hz AC power. If constructed at a 50 Hz site, repetition rate becomes 150 Hz at 0.5 TeV CM and 100 Hz at 1.0 TeV CM, yielding 2.5×10^{34} luminosity for both energies.

Parameter	0.5 TeV CM	1.0 TeV CM
Luminosity (10^{34})	20	30
Bunch Charge (10^{10})	0.75	
Bunches/Train	192	
Bunch Spacing (nsec)	1.4	
σ_z (μm)	110	
$\gamma\epsilon_{x,y}$ at DR exit (μm)	3×0.02	
$\gamma\epsilon_{x,y}$ at IP (μm)	3.6×0.04	
$\beta^*_{x,y}$ (mm)	8×0.11	13×0.11
$\sigma^*_{x,y}$ (nm)	243×3.0	219×2.3
Pinch Enhancement	1.51	1.47

In order to achieve maximum luminosity, the JLC/NLC design assumes a substantial beam current (0.86 amperes), which results in a reduction of the accelerating gradient from 65 MeV/meter to 50 MeV/meter. Since the JLC/NLC accelerating structures are conditioned up to the full unloaded gradient of 65 MeV/meter, operation at higher CM energy is possible if the beam current is reduced, thus trading off luminosity for CM energy. At negligible loading, 1.3 TeV CM can be achieved in the baseline design at a luminosity of about $0.5 \times 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$.

4 RF SYSTEM

Figure 3 shows the evolution of the JLC and NLC RF systems from 1996 to the present, unified JLC/NLC configuration. In 1999, the baseline RF system for the JLC/NLC consisted of the following: One solid-state modulator driving eight klystrons, each of which produced 75 MW peak power over a 1.5 μsec pulse length; the power from the klystrons was combined and distributed in a dual-mode Delay Line Distribution System (DLDS) pulse compression system; the resulting 375 nsec, 600 MW RF pulses were distributed to four RF girders, each of which included three 1.8 m X-band structures. The unloaded gradient reached 70 MeV/meter [10].

The principal disadvantage of the 1999 baseline system is that a minimum of 600 MW of klystron peak power is required for any system-level demonstration. In addition, high-power tests of accelerating structures have indicated that a 60 cm structure has superior performance to the longer structures favored in earlier configurations.

In order to demonstrate a “JLC/NLC-ready” RF system in a timely manner, the baseline design of the system

Figure 3: Evolution of the JLC and NLC main linac designs, from 1996 to the present.

was substantially modified. In the present baseline, one solid state modulator drives two klystrons, with 75 MW peak power and 1.6 μsec pulse length; the power from the klystrons is combined and compressed in one dual-moded SLED-II unit, with a pair of 31 meter long cylindrical waveguides; the resulting 400 nsec RF pulse is sent to one RF girder, which contains eight 0.6 m X-band structures; the latter reach 65 MeV/meter unloaded gradient.

The efficiency of the 2003 baseline is mildly reduced from that of the 1999 design because SLED-II is inherently less efficient than DLDS. As a result the unloaded gradient is lower, as noted above, and thus the linac length has been increased to compensate.

5 ACCELERATING STRUCTURE

The invariant requirements of the JLC/NLC structures are the frequency of the fundamental mode (11.424 GHz), and the attenuation parameter τ (0.55-0.60). The combination of these requirements in turn fixes the structure fill time at about 110 nanoseconds.

The 1999 baseline design envisioned use of structures with a 1.8 meter length, implying an average group velocity of about $0.06c$. During high-power RF testing, it was shown that such structures have unacceptable gradient limitations due to frequent, high-energy breakdown events damaging the upstream (high group-velocity) end of the structure [6]. Extensive testing has shown that structures with lower group velocity are less susceptible to damage.

The present JLC/NLC structure baseline design is 60 cm in length, implying an average group velocity of $0.02c$, tapering from $0.03c$ at the input coupler to $0.01c$ at the output coupler. The ratio of the average iris radius to the RF wavelength, a/λ, has been reduced from 0.18 to 0.17, which increases the shunt impedance of the structure at the expense of a moderate increase in the severity of the wakefields. In order to achieve the low group velocity while maintaining a large iris radius, the phase advance per cell has been increased to 150°, and in addition the thickness of the irises has been increased [7]. As in previous designs, a combination of dipole-mode detuning and weak damping will be used to control the long-range transverse wakefield; in the present design, use of "four-fold interleaving" (4 families of 60 cm structures with slight variations in dipole-mode frequencies between families) will reduce the long-range wakefield to negligible levels [8].

6 RF SYSTEM DEVELOPMENT AND TESTING

A prototype of the JLC/NLC baseline RF system is under construction at SLAC. The system will ultimately provide the design RF power level and pulse length to a baseline girder of eight (8) 0.6 meter RF structures. Testing milestones include:

- Demonstration of 450 MW power, 400 nsec pulse length out of a dual-moded SLED-II system with all associated support hardware and software (TRC R1 goal) [9] – Summer 2003.
- Acceptance testing of 0.6 meter RF structure with $a/\lambda = 0.17$ (TRC R1 goal) – Autumn 2003.
- Integrated system test: 1 modulator, 2 klystrons, 1 SLED-II system, eight (8) "JLC/NLC Ready" RF structures, and beam (TRC R2 goal) – mid-2004.

The first two milestones in the list above will be achieved using 50 MW, solenoid-focused klystrons. The "JLC/NLC-ready" klystron requires 75 MW peak power, 1.6 microsecond pulse length, 120 or 150 Hz repetition rate, and permanent magnet focusing. This klystron is being developed in a separate U.S./Japan program; a number of prototypes are already in testing, and additional units will become available over the next few months. It is expected, therefore, that all TRC R1 and R2 goals related to beam acceleration will be achieved within 1 year of this writing.

7 ACKNOWLEDGEMENTS

The JLC/NLC design is the result of the tireless efforts of collaboration members in the United States and Japan. Their excellent work is gratefully acknowledged.

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