SLAC–PUB–8691
October, 2000
(A)

PROGRESS WITH THE JLC/NLC X-BAND LINEAR COLLIDER*

T.O. Raubenheimer
Stanford Linear Accelerator Center, Stanford University, Stanford, CA 94309

Abstract

An electron/positron linear collider with a center-of-mass energy between 0.5 and 1 TeV would be an important complement to the physics program of the LHC in the next decade. The Next Linear Collider (NLC) is being designed by a US collaboration (FNAL, LBNL, LLNL, and SLAC) which is working closely with the Japanese collaboration that is designing the Japanese Linear Collider (JLC). This paper will discuss the technical difficulties encountered as well as the changes that have been made to the NLC design over the last year. These changes include improvements to the X-band rf system as well as modifications to the beam delivery system. The net effect has been to reduce the length of the collider from about 32 km to 25 km and to reduce the number of klystrons and modulators by a factor of two. Together these lead to significant cost savings.

Invited paper presented at the APS Meeting of the Division of Particles and Fields (DPF2000)
9-12 August 2000, Columbus, Ohio

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

PROGRESS WITH THE JLC/NLC X-BAND LINEAR COLLIDER DESIGN*

T.O. Raubenheimer
Stanford Linear Accelerator Center, Stanford University
P.O. Box 4349, Stanford, California, 94309, USA

An electron/positron linear collider with a center-of-mass energy between 0.5 and 1 TeV would be an important complement to the physics program of the LHC in the next decade. The Next Linear Collider (NLC) is being designed by a US collaboration (FNAL, LBNL, LLNL, and SLAC) which is working closely with the Japanese collaboration that is designing the Japanese Linear Collider (JLC). This paper will discuss the technical difficulties encountered as well as the changes that have been made to the NLC design over the last year. These changes include improvements to the X-band rf system as well as modifications to the beam delivery system. The net effect has been to reduce the length of the collider from about 32 km to 25 km and to reduce the number of klystrons and modulators by a factor of two. Together these lead to significant cost savings.

1. Introduction

The Next Linear Collider (NLC) is a future electron/positron collider that is based on copper accelerator structures powered with 11.4 GHz X-band rf.[1,2,3] It is designed to begin operation with a center-of-mass energy of 500 GeV and to be adiabatically upgraded to 1 TeV cms with a luminosity in excess of $1\times10^{34}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$. A schematic of the NLC, which is not to scale, is shown in Fig. 1. The collider consists of electron and positron sources, two X-band main linacs, and a beam delivery system to focus the beams to the desired small spot sizes. The facility is roughly 26 km in length and supports two independent interaction regions (IRs).

The NLC proposal was started by SLAC and later joined by LBNL, LLNL, and FNAL. Work at Fermilab is just starting and will focus on the main linac beam line while the efforts at LBNL and LLNL are focused on the damping ring complex, the modulator systems and the gamma-gamma interaction region. In addition, there has been a close collaboration with KEK for several years concentrated primarily on X-band rf development. The JLC linear collider and the NLC have developed a set of common parameters with very similar rf systems;[4] a status report on the progress of this collaboration was published earlier this year.[5]

In May 1999 for a major DOE review, the NLC project presented both the technical design and a conservative cost estimate for the project. The reviewers concluded that the technical design was in very good shape but questioned the viability of the project with the estimated total project cost. Over the last year, the NLC collaboration has concentrated on cost reduction and has been able to

*Work supported by the U.S. Department of Energy, Contact Number DE-AC03-76SF00515.

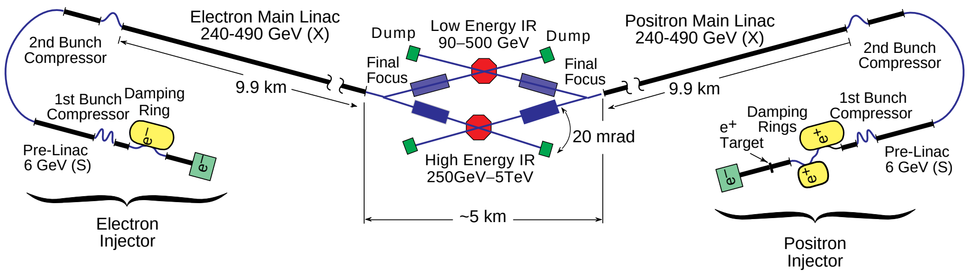

Figure 1: Schematic of the NLC.

lower the estimate by $\sim 30\%$. In the following, we will summarize the status of the NLC rf system and then discuss modifications to the optical design. A more detailed status report can be found in Ref. 3 while the current IP and beam parameters can be found at Ref. 2.

2. RF Design

The rf system for the NLC design operates at a frequency of 11.424 GHz to support the higher acceleration gradients needed for TeV-scale colliders. Currently, the NLC rf system is in its third design iteration. The evolution of the rf system has been driven by costing models that have been developed for the collider and by the results from the ongoing R&D programs. The present cost estimate for the rf system has decreased by roughly 50% from that in the 1996 ZDR cost model!

The first iteration of the rf system was based on conventional thyratron-switched modulators, 50 MW Periodic Permanent Magnet (PPM) focused klystrons, the SLED-II pulse compression system and a Damped-Detuned (DDS) accelerator structure. This configuration was described in the NLC ZDR and is the technology used in the NLC Test Accelerator (NLCTA) which began operation in 1997.[1,6]

The next iteration of the rf design was based on the conventional modulators, a 75 MW PPM X-band klystron, the Rounded DDS (RDDS) accelerator structure which has 12% higher shunt impedance and the Delay Line Distribution System (DLDS) pulse compression scheme which has significantly higher efficiency than the SLED-II system. This design was presented at the 1999 NLC DOE review.

The most recent iteration of the rf design is based on solid-state modulators with an rf pulse length of $3\,\mu$s instead of $1.5\,\mu$s from the klystrons. These parameters reduce the number of klystrons and modulators by a factor of two. In addition, the rf system uses an enhancement of the DLDS scheme where the rf power is propagated in multiple modes to reduce the amount of waveguide. The recent status of these components was described at the *20th International Linac Conference*, Monterey, California, August, 2000.[7,8,9,10,11]

Although all these results are very positive, we have also uncovered a major problem in the structure design. The NLC design calls for a gradient of 70 MV/m to attain a center-of-mass energy of 1 TeV with a reasonable length linac. In the past, we have tested short X-band structures at gradients of over 100 MV/m but it is only recently that we have had sufficient rf power to test the full structures at their design gradient. During these recent tests, damage has been observed after 500 hours of operation with an onset between 40 and 50 MV/m.[12]

Recently, a workshop was held at SLAC to discuss the breakdown phenomena and the world-wide R&D on high gradient acceleration.[13] The two primary differences between the present structures and those tested at much higher gradients is the structure length and the group velocity of the rf power in the structure. To study this, SLAC and KEK are constructing 12 structures with different group velocities and lengths; we expect to have results by the spring of 2001.

3. Beam Delivery Optics

Another significant change to the design is in the beam delivery system (BDS). This region includes the beam collimation section and the final focus, both of which have been completely redesigned over the last year. This has resulted in a design that is more robust and is half the length of that presented in 1999.

The beam collimation system has two purposes: it must collimate the beam tails to prevent backgrounds at the IP and it must protect the downstream components against errant beams. In the previous design, the beam collimation section was designed to survive any mis-steered or off-energy incoming beam. This is a difficult constraint because the beam density is normally so high that the beam will damage any material intercepted.[14] In a pulsed linac, the beam energy can change significantly from pulse-to-pulse, but fortunately, large changes to the beam trajectory which are not due to energy errors are much less frequent. We have taken advantage of this fact and redesigned the collimation system to passively survive any off-energy beam but to allow on-energy beams with large betatron errors to damage the collimators. The betatron collimators will be 'consumable' collimators which can be rotated to a new position after being damaged.[15] The net effect is that we now have a design that is roughly half as long with much better performance.[16]

The previous final focus system (FFS) was based on the lattice of the Final Focus Test Beam (FFTB) at SLAC which was constructed from separate modules for the chromatic correction and made full use of symmetry. Although this makes the design of the FFS conceptually simpler, it has the disadvantage of making the FFS quite long—1.8 km for 750 GeV beams. A new design has been adopted where the chromaticity of the strong final magnets is corrected locally near these magnets.[17] This results in a compact design with many fewer elements which has better performance than the conventional FFS. In particular, the new FFS has a larger energy bandpass with comparable alignment tolerances and a more linear transport which should reduce the backgrounds due to beam tails. Because of the better performance, it is possible to increase $L^\star$, the free space from the final magnet to the IP, from 2-m to 4.3-m; this simplifies the design of the interaction region and the interface with the high-energy physics detector.

In addition, the increase in the length of the FFS with beam energy in the new design is much slower than for the earlier design. The present FFS is only 700 m in length but can focus 2.5 TeV beams while an equivalent conventional design would have to be roughly 10 km in length. This change makes it much more reasonable to consider a multi-TeV collider using an advanced high-gradient rf system such as the CLIC two-beam design.[18] We have taken advantage of this possibility in the NLC design by eliminating the bending between the main linacs and one of the two interaction regions to limit the emittance dilution due to synchrotron radiation for very high energy beams as illustrated in Fig. 1. In this case, once a high gradient rf system is developed, the NLC could be upgraded to a multi-TeV facility in a cost effective manner, reusing much of the infrastructure and beam line components.

4. Summary

Over the last year, the NLC collaboration has focused on new technology developments and design changes to reduce the facility cost. We are making extensive changes to our baseline rf system and to the beam line optics, reducing the collider footprint from 32 km to 26 km while maintaining the energy reach of the facility. We have also uncovered a high gradient limitation in our accelerator structure design and are vigorously investigating solutions—although earlier structure designs have operated at gradients well over 100MV/m, the present structures are limited to gradients between 40 and 50MV/m. Finally, we have also modified the collider layout so that it does not preclude upgrading the facility to a multi-TeV collider once an appropriate rf system has been developed.

1. NLC ZDR Design Group, SLAC Report-474 (1996).
2. http://www-project.slac.stanford.edu/lc/NLC-tech.html .
3. T.O. Raubenheimer, "Progress in the Next Linear Collider Design," *physics/0010077*.
4. N. Toge, "JLC Progress," *physics/0008172*.
5. International Study Group, N. Toge, ed., KEK 2000–7, SLAC–R–559 (2000).
6. R.D. Ruth *et al.*, "Results from the SLAC NLC test accelerator," *Proc. of the 1997 IEEE Part. Acc. Conf.*, Vancouver, Canada (1997).
7. E. Cook, "Review of Solid-State Modulators," *physics/0008189*.
8. R.L. Cassel, *et al.,* "Solid-State Induction Modulator Replacement for the Conventional SLAC 5045-Klystron Modulators," *Proc. of the 20th Int. Linear Acc. Conf.*, Monterey, CA (2000).
9. E. Jongewaard, *et al.,* "Next Linear Collider Klystron Development Program," *hep-ex/0008038*.
10. S. Tantawi, "New Development in RF Pulse Compression," *physics/0008204* .
11. J. Wang, *et al.*, "Design, Fabrication and Measurement of the First Rounded Damped Detuned Accelerator Structure (RDDS1)," *physics/0009025*.
12. C. Adolphsen, *et al.,* "RF Processing of X-band Accelerator Structures at the NLCTA," *physics/0008197*.
13. *Structure Breakdown Workshop*, SLAC, August 28–30, 2000, http://www-project.-slac.stanford.edu/lc/wkshp/RFBreakdwn/struct_breakdown_wrkshp.htm .
14. M.C. Ross, *et al.,* "Single Pulse Damage in Copper," *Proc. of the 20th Int. Linear Acc. Conf.*, Monterey, CA (2000).
15. J. Frisch, E. Doyle, K. Skarpas, "Advanced Collimator Systems for the NLC," *Proc. of the 20th Int. Linear Acc. Conf.*, Monterey, CA (2000).
16. P. Tenenbaum, *et al.,* "Studies of Beam Optics and Scattering in the Next Linear Collider Post-Linac Collimation System," *physics/0010078*.
17. P. Raimondi, "New Developments in Linear Collider Final Focus Systems," *physics/0008072*.
18. J.P. Delahaye, "CLIC, a Two-Beam e^+e^- Linear Collider in the TeV Range," *physics/0008064*.