Design Status of the NLC Beam-Delivery System and Possible Future Studies*

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We outline some highlights in the present design of the beam-delivery and removal system for the Next Linear Collider (NLC), and present a long list of possible or desirable future studies. On several of the listed items work has already been started since the Snowmass workshop. Other studies could be conducted, for example, in the framework of a conceptual design report (CDR).

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ABSTRACT

We outline some highlights in the present design of the beam-delivery and removal system for the Next Linear Collider (NLC), and present a long list of possible or desirable future studies. On several of the listed items work has already been started since the Snowmass workshop. Other studies could be conducted, for example, in the framework of a conceptual design report (CDR).

I. Introduction

The present design of the NLC beam delivery system is described at length in the Zeroth Order Design Report [1]. The beam delivery system covers the region between the two main X-band linacs. From the end of the linac, both electron and positron beams are transported through a short diagnostic section, a collimation section, an interaction-point (IP) switch, a big bend, and a final-focus system, until they reach the interaction region, where the two beams collide. Afterwards, exit beamlines guide the spent beams to the final beam dumps. A schematic view of half the system is depicted in Fig. 1. With a total length of about 10 km, the beam delivery system occupies more than one third of the total NLC length.

Throughout the design of the beam-delivery system, we tried to incorporate the lessons learned at the Stanford Linear Collider (SLC) and at the Final-Focus Test Beam (FFTB). The presently proposed system fulfills all specified requirements. For example, the system is designed to operate in the center-of-mass energy range from 350 GeV to 1.5 TeV; for each energy the system is capable of producing the design spot sizes at the interaction point; its momentum bandwidth is satisfactory; optical aberrations and emittance growth are tolerable; the expected background in the detector is a non-issue, thanks to collimation, muon spoilers and efficient masking; numerous tuning schemes and diagnostics elements, which are modeled after SLC and FFTB, constitute an integral part of the design; and the system also foresees a second interaction point, *e.g.*, devoted to γ-γ collisions. The present design represents an existence proof for an NLC beam-delivery system which promises excellent performance.

Regardless, there are still unresolved questions which need experimental clarification before the system could be built with full confidence. In addition, there is a long list of possible future
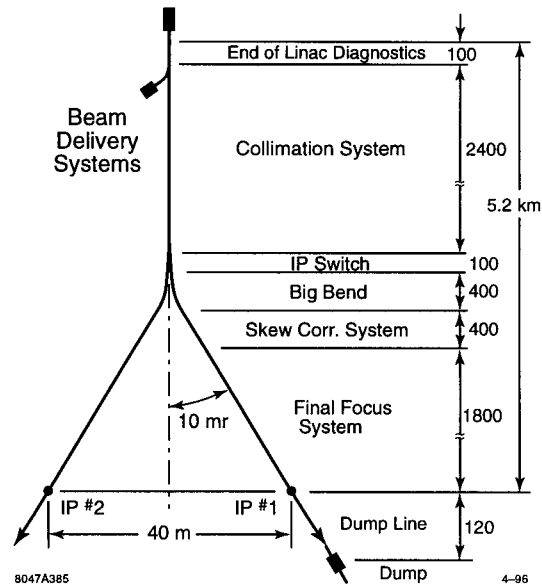
Figure 1: Schematic of the NLC beam delivery and removal system.

design optimizations or modifications. Some of these modifications could reduce the system length or its cost, improve the performance, or loosen certain tolerances.

In the remainder of this paper, we will give an extensive list of possible future experiments and studies, which are aimed partly at resolving some last uncertainties, but primarily at optimizing and fine-tuning the design, and confirming the design choices already made. Several of the following questions were raised by the external review committee, which assessed the status of the NLC design in March 1996 [2].

II. Collimation System, IP Switch, Big Bend, and Skew Correction

SLC experience has demonstrated that efficient collimation is essential for the performance of a linear collider. Thus, during the NLC design much effort has been devoted to understanding the collimator wakefields as well as the resultant beam losses and steering effects [1]. Specific items concerning the collimation system that deserve more careful studies are:

- A re-evaluation of the nonlinear collimation scheme, discussed in [3], and a quantitative comparison with the

present linear collimation system. At first sight, the non-linear system did not seem to offer much of an advantage for the NLC.

- Understanding a factor of 4 discrepancy between measured and predicted wakefields for small collimator gaps, observed in the SLAC linac [4].

- A re-thinking of the machine-protection philosophy. If we abandon the requirement that the collimators have to survive the impact of a full bunch train, and would instead rely on active protection schemes, the collimation system could be enormously simplified and considerably shortened. The risks, benefits and disadvantages of such a sacrificial-collimator strategy should be quantified. This study has to be coordinated with the machine-protection design.

- Improvement of large-amplitude transmission by adding more octupoles to the collimation system.

- Chromatic correction of big bend and skew correction system (SCS) using sextupoles in the big bend.

- Chromatic correction of the IP switch by using the sextupoles in the final IP phase collimation section and adjusting the phase relationships between them and the switch.

- Design of a three-stage collimation system (replacing the original four-stage system) with increased beta functions for improved collimator survival.

- Investigation of non-invasive tuning schemes which do not (or not seriously) affect the IP spot size, such as waist sweep and coupling scans in the skew correction section, which during a scan are corrected downstream.

- Unifying the magnet designs for all NLC subsystems and reducing the number of different magnet types as much as possible.

III. Final Focus

The final-focus system could be further optimized by addressing the following questions:

- What is the impact of the free length from the last quadrupole to the IP, $l^\star$, on the length of the final-focus system? We note that the length of the present final-focus design also offers convenient leeway for later energy upgrades.

- Is it possible to design a system with identical geometry for all beam energies between 170 and 750 GeV? Presently, at two beam energies horizontal magnet displacements, by up to about 20 cm each, are necessary during the 'adiabatic' energy upgrade. A single geometry, though not strictly necessary, would have operational advantages.

- Re-evaluation of the odd-dispersion final-focus optics put forward by Oide [5].

- Optimization of final-doublet parameters, in particular specification of field and aperture of the permanent and the superconducting magnet for different beam energies. Continued work on final-doublet magnet design.

- Should we design a final focus for lower emittance? While the present system adapts well to larger-than-design emittances, it does not make optimum use of beams with smaller emittances.

- Reduction of the remaining design aberrations in the final-focus system, especially the 10% spot-size increase from synchrotron radiation. Investigate optics with a smaller horizontal IP beta function, to compensate horizontal dilutions.

- Refine estimates of the Oide effect for off-axis beams.

- Determine the optimum location of the crab cavity; compare crab-cavity designs based on X-band and C-band rf.

- A review of the machine-protection philosophy. In most parts of the NLC the turn-on operation, after a down period, will be conducted with single bunches, whose emittance is intentionally increased by about a factor of 100. This is not possible in the final-focus system, because of the very large beta functions. Therefore, the first bunches to pass through the final focus after an interruption will be single bunches at nominal emittance. It should be verified that no conceivable magnet failure in the final focus can result in a beam loss at a position where the impact of a single nominal-emittance bunch would cause serious damage and material destruction.

In addition, the proposed installation of one spoiler upstream of each beam-delivery magnet for machine-protection purposes [1] does not appear practical for the region between the sextupoles in the chromatic-correction system and the final doublet. Recent studies [6] indicate that the beam-energy spread induced by geometric wake fields from these collimators would considerably degrade the chromatic correction of the final focus. Thus a different protection strategy may need to be developed for this part of the beam-delivery system.

IV. Interplay with the Detector

The designs of the beam-delivery system and the NLC detector (NLD) are heavily interrelated. This is most obvious for the final doublet, the final transformer, and the collimation section. Several questions involving both accelerator and detector could be studied in more detail, for example:

- The optimum free length $l^\star$ as determined by background considerations and by engineering considerations on the integration of final doublet and detector.

- The limit on the beam divergence at the interaction point. The present SLC luminosity is sometimes divergence-limited, *i.e.*, a further raise of the divergence and a possible

reduction of the IP spot size are precluded by an increase of the detector background with increasing divergence. The background mainly arises from synchrotron radiation in the final triplet, and is a problem, if the masking-system design angular divergence is exceeded, or if the relative alignment of the masks within the detector to the beam is not optimized. At the NLC, the synchrotron-radiation induced background is expected to be considerably smaller. The NLC IP region is, not only in this regard, much more similar to the proposed SLC-2000 upgrade [7] than to the present SLC system. The conclusions of a comprehensive SLC/SLD-2000 background study [8] are consistent with the NLC background study [9], when differences in IP parameters are taken into account.

- Optimum location, apertures and wakefield effects of the synchrotron-radiation masks in the final transformer.

- How soft must the 'soft bend' (the last 64-m long bending section before the IP) be? The field strength in the present design is 12 Gauss, corresponding to a critical energy of 200 keV for the 1-TeV NLC.

- Improvements to the interaction-region simulations and background generators [9].

- Impact of the detector solenoidal field on the IP beam optics.

- Design of the RF shield around the IP.

- Optimum principal cone angle for detector.

V. Muon Studies

Muons created during collimation are one of the main potential background sources. To render their effect unimportant, four muon spoilers will be placed at strategic locations in the final focus and beam-delivery section, similar to (but more voluminous than) the muon spoilers in the SLC. Extensive studies of muon transport through the system have been performed ($\geq 10^{14}$ lost electrons were considered). The studies predict that less than one muon can hit the detector per bunch train. Nevertheless, further studies and optimizations could be performed, for instance:

- Muon tracking for a beam energy of 750 GeV.

- The effect of penetrations through the muon spoilers (e.g. for cable trays etc.)

- Exploring the multiple-scattering parameter space in the Monte-Carlo simulation; test robustness of calculation results.

- Finding the optimum number of muon spoilers.

- Studying the parametric dependence of muon-induced background on tunnel size, number of spoilers, tunnel alcoves, big bend, magnet supports, distance of beam pipe to ground, etc.

VI. Beam Disposal Line

Different from the SLC, where incoming and spent beams share the same beamline, the NLC design comprises a dedicated beam disposal line, which is possible due to a 20-mrad IP crossing angle. Major differences in IP diagnostic and beam disposal between the NLC and the SLC arise from the much higher beam power and its distribution over several particle types in the NLC. Although the NLC disposal line is quite compact (the distance from the IP to the dump is less than 110 m), it separates neutral and charged particles, and allows for abundant diagnostics, monitoring, feedback stabilization, production of secondary (and even tertiary) beams, and for parasitic experiments, before the primary neutral and charged beams are recombined into a common dump. Because more space is always useful for as yet unanticipated experiments or monitors as well as for undesigned hardware, the following issues and areas of further study are listed:

- Higher-order optics; especially chromatic correction, to accommodate the energy spread of the spent beam.

- More Monte-Carlo simulation studies for detectors, beam and luminosity monitors. For example, a study of using particles produced by pair production and beamstrahlung to monitor the beam-beam overlap and interaction characteristics.

- Optics changes for detecting low-angle particles in a high-rate luminosity monitor.

- RF pick-ups or other post-IP devices to monitor the incoming and outgoing beams for feedback stabilization of the IP collision.

- Design of magnets that are better matched to operation in a strong solenoid with crossing angles; especially determining the optimum magnet apertures.

- Other schemes to recover the beam energy and/or to use the spent positrons and electrons or beamstrahlung photons, *e.g.*, storing low-energetic positrons in a recycler ring, or using the electrons to produce polarized positrons, or generating secondary beams, such as polarized-neutron or photon beams.

VII. Experiments

Experimental verification of a few as yet unproven technologies and of theoretically uncertain predictions is indispensable. The following experiments are planned or currently in progress:

- Building and testing of a protoype optical anchor for a model of the final doublet to demonstrate that the doublet quadrupoles can be tied to the bedrock with nanometer precision by means of laser interferometry.

- Demonstration that the phase difference of the two crab cavities can be stabilized to 0.2° X-band. This test is inexpensive and straightforward.

- There is some uncertainty concerning the wakefield of a flat tapered collimator (a theoretical result is derived in Ref. [10]). This is not really a problem, since we could always use circular collimators, the wakefield for which is well known. However, we think that flat collimators facilitate beamline design and operation. Therefore, an experiment is planned to measure the wake of a prototype tapered collimator in the SLAC linac.

- The parameter choices for the collimator system depend critically on material-destruction parameters. These will be verified by impacting the 50-GeV beam from the SLAC linac on target materials of interest.

- A non-intercepting IP beam-size monitor, which is based on the principle of the pin-hole camera and which, in the NLC, will utilize the beamstrahlung generated by the beam-beam interaction, is being tested on the FFTB [11]. Lacking a second particle beam, in our experiment bremsstrahlung from foils and wires as well as Compton-backscattering from a laser beam are used to supply the highly energetic photons. The expected resolution of the pin-hole method would be sufficient for measuring the beam sizes at the NLC IP. The method provides a possibility for real-time feedback to optimize the NLC luminosity. It could also be demonstrated at the SLC using the recently commissioned IP laser wire [12].

- As part of the E-144 experiment on the FFTB line, tests are being conducted on certain secondary-beam possibilities, including polarized photons, positrons and neutrons.

VIII. Conclusion

The design of the NLC beam delivery and removal system is mature and complete. A few critical questions—the first four items in Section VII.—will be resolved by experiments within the next year. Of course, the beam-delivery system can be further optimized and it can also be compared with a variety of design alternatives. Possible directions of further studies are illustrated by the long list of future study items compiled in this paper.

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