Two Experimental Regions

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1 Two Experimental Regions (Section 5.1)

The physics program of the NLC will be dictated by the scenario that Nature has afforded us. As discussed in section 4, this implies that NLC must have the flexibility to operate over a wide range of energies. Moreover, in many scenarios, the salient physics measurements will require significant integrated luminosities at center-of-mass energies differing as much as a factor of five. Luminosity in a linear collider facility falls linearly with decreasing energy. Optimization of luminosity over a wide range of energies is not possible in a single focussing system, and to cover a wide range, more than one optical system is a preferred solution. To provide high luminosity at low energies, a final focus system dedicated to the low energy regime, combined with bypass transport sections for portions of the linear accelerating components is required. In the NLC, this requirement leads to an asymmetric layout of two IR regions, one dedicated to the lower energy physics program, while the second is dedicated to higher energies and is expandable to the multi-TeV regime for future upgrades of the NLC. In the following sections, we discuss the two IR regions for the NLC.

1.1 Dual Energy IR Design

In an attempt to optimize the collider design for the desired physics program which extends from the Z-pole to many TeV, we have introduced a dual energy IR design. There are two reasons for this choice. First, by having one of the two IRs in a direct line with the main linacs that accelerate the beams, the dual energy layout allows us to support the possibility of operating with beam energies of many TeV once the appropriate rf technology is developed; this layout eliminates the bending where incoherent synchrotron radiation will dilute the beam emittances. Second, the final focus beamlines are naturally optimized to operate over roughly a factor of four to five in beam energy; synchrotron radiation and magnet strength limits the higher energy end of this range while vacuum apertures limit the low energy end. By designing one IR to operate from 90 GeV to 350 GeV (or perhaps 500 GeV) and the other to operate between 250 GeV and 1 TeV, we provide overlapping coverage of the energy range that is thought to be initially of interest.

Because the straight-ahead IR could support multi-TeV beam collisions, we refer to this as the "high-energy" IR (HEIR). The second IR is then reached by bending the beam from this direct line. This bending will limit the maximum energy attainable in this second IR and thus this IR is refered to as the "low-energy" IR (LEIR). Of course, depending on the design optimization, the two IRs would perform similarly up to the maximum energy of the LEIR.

With this starting point, the collider layout is then determined by the length of the beam delivery systems, the required transverse separation of the IRs, and the desired crossing angle in the interaction regions. Given the new final focus optics design which utilizes local chromatic correction, the final focus can be relatively short. The present NLC design is 700 meters long for a nominal cms energy of 1 TeV. However, this same length is sufficient to focus multi-TeV beams for 5 TeV in the center-of mass. In addition to the final focus optics itself, there are diagnostic regions and beam collimation regions upstream of the IP. Depending on the operating mode, these regions could likely be shared. In the present NLC design, these regions are roughly 1300 meters long for a total beam delivery system length of 2 km per side. This length could be reduced; however it is relatively inexpensive and provides a conservative solution to the beam optics and the beam collimation problems.

To attain reasonable transfer efficiency of the rf to the beam in a normal conducting linear collider, the bunches must be spaced very close together. In this case, both IRs must have a non-zero crossing angle. Typical values for the crossing angle could range from 6 mrad to 40 mrad. The larger angles result in easier beam extraction and the IR integration but lead to more difficult tolerances. The minimum crossing angle is set by the 'multi-bunch kink' instability. At cms energies below 1.5 TeV the minimum angle is roughly 2 mrad. However, studies of the CLIC 3 TeV IR, suggest a minimum crossing angle of 15 mrad is necessary at multi-TeV energies. For these reasons, we suggest a crossing angle of 20 mrad at the HEIR and between 20–40 mrad at the LEIR.

The Interaction Halls have been sized assuming that one would house the NLC "Large" Detector and that one would house the "Small" Detector. See the table below for the list of hall parameters. The hall length (transverse to the beam) is large enough to allow assembly of the detector while a concrete wall shields the interaction point. The wall would also serve as radiation shielding if the detector is not deemed to be "self-shielded." If the detector were built in place, on the beam line, and could be self shielded, the length could be reduced by roughly a factor of three. The hall width (length parallel to the beamline) is set by the constraint that the doors open just enough to allow servicing of the inner detectors.

The baseline design assumes that the two IR halls are physically separated so that activities and mechanical equipment operating in one hall are seismically isolated from the other hall. For example, the LIGO experiment has used 100m as a minimum separation for rotating machinery and sensitive detectors. While the means to actively detect and compensate for culturally induced ground vibration is a key element of the NLC R&D program, passive compliance with vibration criteria is the ideal. In principle each of the IR halls could be designed to accommodate two detectors that share the beamline in a push-pull manner, thus increasing experimental opportunities, or the overall NLC layout could be changed to support one push-pull IR only at a considerable cost savings. In any push-pull scheme, major installation activities might need to be curtailed if they introduced uncompensated vibration of the final magnets producing data for the detector currently on the beam line.

Table 5.1.1 The Baseline Interaction Region Parameters

Parameter	Small Detector	Large Detector
Detector footprint	12 X 11 m	20 X 20 m
Pit Length	40m	62m
Pit Width	20m	30m
Pit depth below beamline	5m	7m
Max hook height above apron	11m	14m
Crane overlap of apron	14m	14m
Door height	10m	13m
Door width	10m	13m
Barrel weight	2000 MT	7300 MT
Door weight	500 MT	1900 MT
Total weight	3100 MT	11100 MT

These features are illustrated in the NLC schematic and the IR Region schematic shown in Figures 5.1.1 and 5.1.2. The main linacs are aligned to provide the 20 mrad crossing angle at the HEIR and the LEIR beamline is bent from the straight-ahead beams. The transverse separation between the two IR collision points is presently set at 25 meters. However we are also providing roughly 500 meters longitudinal separation of the two IR halls for increased vibration isolation. In addition, by-pass lines are installed along the side of the linac so that lower energy beams can be transported to the final focus without passing through the unnecessary accelerator structures.

1.2 The Low Energy IR Region

The experimental program in the LEIR region is a function of the range of accessible center-of-mass energies and the available luminosity. The amount of luminosity dedicated to a particular $\sqrt{s}$ will depend on the physics that is revealed by the Tevatron and the LHC. This need for flexibility imposes the requirement that the LEIR have high performance over the range $m_{\rm Z} \lesssim \sqrt{s} \lesssim m_{t\bar{t}}$. Table 5.1.1 gives the basic parameters of the low energy IR region at key center-of-mass energies. In the following, we outline the basic LEIR physics program as a function of increasing beam energy.

The lowest operating energy of the LEIR is determined by the requirement that high statistics studies at the Z-pole be possible. The goal of a next generation Z-pole experiment would be the significant reduction in the experimental errors in key Electroweak parameters. The success of this program relies on the availability of longitudinally polarized beams. It is anticipated that polarized electron beams would be initially available; however, it is highly desirable to eventually have positron polarization as well. One feature pertaining to beam polarization in the LEIR is the need to account for the spin precession in the 25 mrad bend in the beam transport system.

Precise determination of the Electroweak parameters could be particularly valuable in understanding the Standard Model and physics beyond, particularly at a time when the Higgs boson mass is experimentally determined. In the event that only a single Higgs boson is observed with no other direct evidence of new physics from the LHC programs, then a crucial aspect of the NLC program will be the precision Electroweak measurements. A benchmark of such program would be to accumulate a sample of 10^9 Z° decays over a 3 year period. Given the nominal 10^7 seconds per year imposes the instantaneous luminosity requirement of 1×10^{33} cm^{-2}s^{-1}.

Table 5.1.1 Low Energy Experimental Parameters

Energy	Luminosity (cm^{-2}s^{-1})
92 GeV	3.4×10^{33}
250 GeV	9.4×10^{33}??
500 GeV	17×10^{33}??

The W-pair threshold occurs near $\sqrt{s} = 160$ GeV with the maximum production cross-section at $\sqrt{s} \sim 200$ GeV. The region around the W pair threshold has been extensively explored by LEP and is of limited interest. However, in the event that a significantly improved measurement of the W mass is required it will be necessary to have dedicated running at W-pair threshold. Studies have shown that an error on the W mass of 6 MeV would be obtainable with 100 fb^{-1} [?]. Given the otherwise very limited physics program in this energy range, the need for high instaneous luminosity is evident.[1]

Beyond the W-pair threshold, it is highly likely that next benchmark center-of-mass energy will be the production threshold for a light Higgs boson. Precise measurements of the Higgs mass, width, spin-parity, and its branching modes are essential to help understand the role this object would play in electroweak symmetry breaking. The associated production process $e^+e^- \to$ Z°H° with Z° $\to \ell^+\ell^-$ $(\ell = e, \mu)$ provides

[1] Although investigation of W-boson properties will be an important goal of any NLC program, many of these studies, *e.g.* the Triple Gauge Boson couplings, are best performed at the highest achievable center-of-mass energy.

a model independent tag of Higgs production; a Higgs signal is easily indentifiable in the dilepton recoil mass distribution. The maximum cross-section for associated production occurs at roughly $m_{\rm Z} + \sqrt{2} m_{\rm h}$. In minimal SUSY, the mass of the lightest CP even scalar is required to satisfy $m_{\rm h} \lesssim 135$ GeV. The minimal Standard Model Higgs boson is constrained to lie in the mass range $\sim 130 < m_{\rm H} < 180$ GeV. Both of these ranges are consistent with the current fits for the Higgs mass using the precision Electroweak data. Is is therefore essential that the LEIR design be capabale of delivering high luminosity in the range $220 \lesssim \sqrt{s} \lesssim 340$ GeV. The study of a light Higgs boson will also benefit from control of the beam polarization; for example, for the measurement of the HWW coupling, one can exploit the large difference in the $\nu\overline{\nu}{\rm H}^{\circ}$ production cross-section for e^-_L and e^-_R beams. For some processes, positron polarization is also desirable. In the event that such a light Higgs boson exists, it is foreseen that the focus of the LEIR program will be precision Higgs studies.

The $t\overline{t}$ threshold occurs near 350 GeV. The low energy IR region would be the natural facility to focus on this important topic. The threshold onset is a difficult process to study experimentally because of the resolution smearing caused by the natural energy spread from bremsstrahlung in the initial state, and from energy spread in the linear collider. The amount of dedicated running at the $t\overline{t}$ threshold will be dictated by the Higgs physics program. If a light Higgs is present, $m_{\rm H} \lesssim 180$ GeV, it may be desirable to run below the $t\overline{t}$ threshold to control physics backgrounds and to optimize the Higgs production rate. For the case where the physics of Electroweak symmetry breaking has conspired to produce a heavy Higgs boson that somehow satisfies the precision constraints, study of the top quark properties will assume a central importance. The integrated luminosity requirements for the LEIR at or above the $t\overline{t}$ threshold in such a scenario will be the order of 100 fb^{-1} necessitating instaneous luminosities of at least 5×10^{33} cm^{-2}s^{-1}.

Other physics options for the low energy IR have been considered extensively. The region would serve well as the location for a "second generation" detector for $\gamma - \gamma$ collisions should the technologies warrant developing such a facility. Similarly, an e^-e^- option might fit well in the LEIR, should the physics motivations lead in this direction.

In summary, a low energy IR region has many uses and advantages in an NLC program. It would provide considerable flexibility in the physics program, and would preserve many physics opportunities in scenarios in which the NLC is upgraded to multi-TeV operations for high energy studies in the other IR region.

1.3 The High Energy IR Region

The design of the NLC allows for an IR region capable of upgrading to multi-TeV operations in an energy-upgraded NLC. To assure this possibility, the beam delivery systems are aligned in a straight-ahead configuration relative to their respective linacs, with very little bending of the incoming beams between the linear accelerator structure and the IR region. As discussed in section 5.1.1, to preserve the non-zero crossing angle at the point of collisions, the two halves of the collider structure are not collinear, but cross at an angle at the collision point in the high energy IR region. Table 5.1.2 gives the basic parameters of the HEIR region.

The HEIR physics program is intimately related to the realized EWSB scenario. In the event of a Supersymmetric universe, the focus of the HEIR program will be measurement of sparticle properties. It is highly unlikely that the full SUSY spectrum will be accessible at $\sqrt{s} = 500$ GeV; therefore,the energy reach of the HEIR region should be upgradable to the multi-TeV region. EWSB arising from some new strong dynamics is also likely to put a premium on the energy reach. It is clear that in comparison to the LEIR, the physics requirements for the HEIR are, to first order, straightforward: the highest possible luminosity at the highest possible energy.

The energy span of the HEIR runs from 250 GeV to 500 GeV in the initial phase. Therefore the physics program can in principle include everything from 250 GeV on up, which overlaps in energy with the LEIR. Studies of W-pairs, low lying SUSY states and the $t\bar{t}$ threshold could occur in the HEIR. For a light Higgs boson consistent with the current thoretical and experimental constraints, the maximum cross section for rare process $e^+e^- \rightarrow \mathrm{Z^\circ H^\circ H^\circ}$ occurs at $\sqrt{s} \sim 500$ GeV. This process is of great interest as it enables measurement of the Higgs self-coupling which in turn can be related to the shape of the Higgs potential. The W-fusion process, $e^+e^- \rightarrow \nu\bar{\nu}\mathrm{H^\circ}$, which is sensitive the HWW vertex has a cross-section that increases with center-of-mass energy. Although, the bulk of of the precision Higgs physics is likely to be performed at the LEIR, there is Higgs physics unique to the HEIR. The measurement of the Higgs self-coupling defines a accelerator benchmark, depending on the exact mass, a measurement requires integrated luminosites the order of 1000 fb^{-1} which corresponds to approximately 3-4 years at design luminosity.

Supersymmetry remains for many reasons at the front as a candidate for physics beyond the Standard Model. Almost all scenarios or versions of SUSY models result in low lying states that would appear in e^+e^- annihilations below 500 GeV. Although the discovery phase for SUSY is likely to occur at the Tevatron or LHC, the NLC will play a key role in the detailed study of the sparticle spectrum and subsequant delineation of the soft SUSY-breaking Lagrangian.

To fully exploit the physics potential of the NLC, a number of special operating conditions may be necessary for the HEIR. For example, in EWSB models with extended Higgs sectors, of which SUSY is the most widely studied, a $\gamma - \gamma$ mode of operation for the HEIR may be crucial. For example, the $\gamma - \gamma$ mode enables production of a single Higgs boson; for the case of a nominal 500 GeV center-of-mass, this would effectively increase the mass reach from 250 GeV to 400 GeV for production of heavy CP even scalars and CP odd psuedo-scalars. Control of the electron and positron beam polarization will also be extremely useful. For Higgs physics it can be used to increase the nominal production cross section for the self-coupling measurement. Beam polarization will also be useful in unravelling gaugino and slepton mixing. The need for an e^-e^- operating mode may be necessary to decipher selectron production.

Is is likely and perhaps desirable that there be a staged evolution of the HEIR center-of-mass energy. Although the goal of the initial phase of the NLC is 500 GeV for HEIR, it may not make it feasible to turn on at this energy. An intermediate commisioning stage with $\sqrt{s} \sim 250$ GeV and modest luminosity could potentially be very relevant and exciting, especially if direct evidence from the LHC indicated production of a light Higgs boson and/or Supersymmetric states would be possible. The next obvious commissioning stage could be the $t\bar{t}$ threshold at 350 GeV. Even at 10% of design luminosity, the physics program promises to be rich. For example, dedicating 10 fb^{-1} to a scan of the $t\bar{t}$ threshold would lead to 200 MeV error on the top quark mass [**?**].

Table 5.1.1 High Energy Experimental Parameters

Energy	Luminosity (cm^{-2}s^{-1})
250 GeV	8×10^{33}
500 GeV	20×10^{33}??
1000 GeV	34×10^{33}??

1.4 Alternative IR Scenarios

The baseline scenario that we have assumed considers two interaction regions; a high energy region limited only by the available accelerating structures and a low energy region that is limited to roughly 500 GeV center-of-mass energy. It is appropriate to discuss alternative scenarios and the interplay between the physics programs of the high and low energy interaction regions. The issue is compounded by the physics scenarios that may arise. An additional consideration is the possible staging of the maximum center-of-mass energy which may be necessary from a funding perspective. The possibilities can be broadly classified as one of four types:

a) Single interaction region with one detector;

b) Single interaction region with two detectors;

c) Two interaction regions, high energy and low energy;

d) Two high energy interaction regions.

For scenario a), there is an obvious cost advantage, however, the NLC physics program could be unduly compromised. The physics program would be tightly coupled to the available center-of-mass energy. Depending on the details of the realized physics scenario, it may not be possible to simultaneously satisfy the needs of diverse user

community. The question of how one reconciles mutually exclusive requirements for luminosity and choice for the center-of-mass energy may not be straightforward. For instance, in the event of a light higgs boson, a 300-500 fb^{-1} data sample at the maximum of the associated production cross-section becomes a priority. It may be difficult to meet this goal and provide high luminosity running at the Z° or W-pair threshold.
It is difficult to identify the merits of scenario b), given the limitations of having single IR outlined above for scenario a). Given that the total luminosity accumulated by both experiments will be comparable to that for a single experiment; this scenario would only be of interest if the two detectors were of sufficient different capabilities or there were very strong sociological arguments for a second collaboration. One possible scenario where differences between detectors could arise is if there arose the need to have a dedicated $\gamma - \gamma$ collider program. In such a scenario, it would be more natural to consider push-pull capability for one of the IRs in a two IR facility (see below).
The scenario that we have chosen as the baseline is c); there are a number of considerations in its favour. It makes it possible to have parallel physics programs running simulataneously; a clearly desirable feature. The upgrade path for the HEIR is less complex. It provides for a lower energy IR that can be dedicated to precision studies of the Higgs boson, Z-pole or $t\bar{t}$ system. Moreover, in this scenario both the HEIR and LEIR will cover the preferred energy range for the study of a light Higgs. The two IR design adds a degree of flexibility that enables the NLC to address essentially any physics scenario that could arise.
It affords a natural energy staging scenario. As discussed in section 5.1.3, staging the HEIR energy at the beginning of the NLC program would make it possible to perform an initial investigation of the region above 250 GeV. Commissioning of the LEIR program would likely follow the completion of the full complement of accelerating structures required to reach 500 GeV. Many of the high luminosity measurements foreseen for the LEIR would benefit from longitudinally polarized positron beams which are not likely to be available at the initial stages of running.
Given the need to have minimal bending in the beam delivery system in order to preserve beam emittances, scenario d), which has two high energy IRs of similar performance becomes techically challenging if not cost prohibative. Given the interest exhibited by many members of the physics community in the low energy potential of NLC, and the need to perform high statistics studies of the Z-pole in a number of physics scenarios that could arise, it would seem prudent to have at least one IR capable of delivering that physics.

1.5 Push-Pull Option

As the physics program of the NLC evolves, new ideas for physics may arise and/or new technologies for collider detectors may emerge. Flexibility to respond to such a situation is desirable in a large facility like the NLC. The two IR regions allow for a push-pull configuration in a least one of the two regions. Preserving a push-pull configuration in one IR hall would be useful and could serve to optimize the capability of the NLC to respond to new or different physics when the situation arises. An example of such a physics need would be a detector which might be designed and optimized for $\gamma - \gamma$ physics. The $\gamma - \gamma$ option has received considerable interest and discussion, but might not be ready technically at the beginning of the NLC program. A push-pull configuration in one IR would keep the option alive without permanently taking away access to the NLC beams from another detector.

The footprint of the push-pull IR hall must not impede on the beamline of the adjacent region. In addition, access to the detector captured between the two beamlines must be possible, and adequate shielding must be provided to permit work in the IR hall when beams are alive in the machine. Scenarios for staging a third detector would have to be considered and understood. These are complicated issues and involve assumptions which may not be appropriate at a future date. Nevertheless, provision for staging a third detector in a push-pull configuration would be a low cost and effective means for keeping open future possibilities for a unique and special purpose detector.

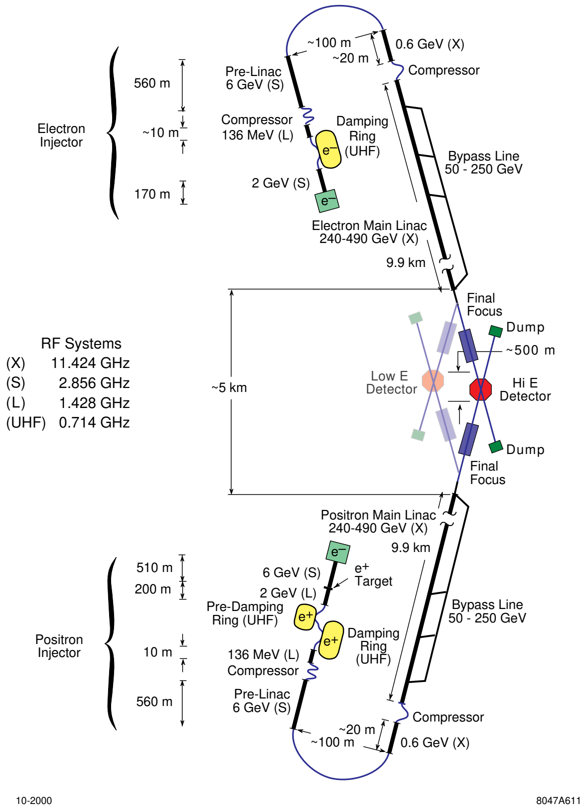

Figure 1: Schematic of the non-zero crossing angle of the two linacs and the Dual Energy IR layout.

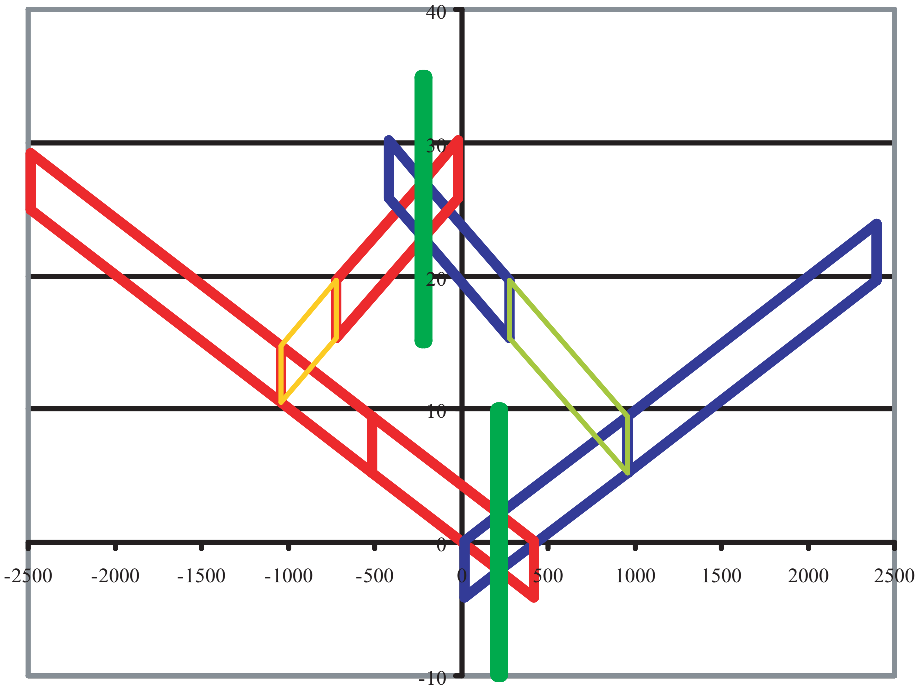

Figure 2: Schematic of the Two IR region, showing a lateral separation of 25 meters, a longitudinal separation of 500 meters.