CHAPTER 8

Collimation, Final Focus and Interaction Region

Contents

8.1 Introduction

8.1.1 Description of Beam Delivery System and Interaction Region

The Beam Delivery System is a sequence of beam lines which prepare the beam produced by the main linac for collision at the Interaction Point (IP). While the acceleration technologies adopted by different linear collider designs for their main linacs vary considerably, all designs have beam delivery systems which contain approximately the same subsystems in the same order:

- A collimation system which removes particles at large amplitudes in position, angle, or energy; such particles would otherwise generate backgrounds and/or radiation; either by synchrotron emission in magnets or by impacting the vacuum chamber of the accelerator and producing an electromagnetic shower
- An achromatic arc which permits the beams to collide with a small horizontal angle, and which provides additional protection against muons for the detector
- A final focus system which performs the demagnification of the beams down to the small sizes required for luminosity production, and which uses sextupoles in a dispersive region to cancel the large chromaticity of the demagnifying final lenses
- An extraction line which transports the spent beams and collision debris (pairs and beamstrahlung photons) to high-power dumps some distance from the detector.

8.1.2 Performance Requirements

At the end of the linac, the high energy beam has transverse dimensions of 10-μm by 1-μm in x and y, respectively. The energy density of the compact beam can destroy most materials in a single pulse. The Gaussian core of the beam may be accompanied by a distribution of particles, commonly referred to as the beam halo, which are at large amplitudes compared to the beam core. The halo particles can cause backgrounds in the particle detector as they hit nearby apertures or radiate synchrotron photons in the strong fields of the final focusing magnets. The focusing properties of the beam delivery system are a strong function of energy, and, therefore, particles which are different in energy from the design by more than a few percent also pose a risk of backgrounds.

The collimation section of the accelerator must remove all particles which are likely to generate backgrounds, either by virtue of their amplitudes or their energies. Typically this is done by inserting a metallic scraping element close to the beam, although non-linear magnetic elements are also being considered. The interaction of the halo with the collimator material produces muons; the overall system must be designed so that these particles do not themselves form an important background for the detector. At the linear collider, building a collimation system is made difficult because of the energy density of the beam and because the collimator may induce wakefields that can amplify beam jitter, increase emittance, and enlarge the final beam spot size.

In addition to protecting the detector from backgrounds caused by particles which are far from the design orbit or energy, the collimation system protects the detector and the final focus from being damaged by full bunch trains which are outside the collimation envelope. Klystron misfires and other hardware failures may make this a relatively frequent occurrence.

In order to maximize efficiency, each pulse of the linac accelerates a train of approximately 90 bunches which are separated by 2.8 nanoseconds (84 centimeters). Maximum luminosity and stable operation are achieved if each bunch collides with one and only one bunch of the opposing beam. This is accomplished by colliding the beams at a shallow horizontal crossing angle (anywhere from 4 to 30 milliradians). The crossing angle is provided by achromatic arcs which are just downstream of the collimation systems on either side. The crossing angle also separates the disrupted (large-emittance) outgoing beam from the low-emittance incoming beam, allowing the outgoing beam to be transported in a beamline with a larger aperture. The arcs also provide additional protection for the detector from muons which are generated in the collimation system, since the detector is not on the flight path of most of the muons.

The clean beam must then be demagnified by about a factor of 40 (250) in x (y) to a transverse size of 235-nm (3.9-nm) at the interaction point (IP). Important design issues in the final focus include energy upgradability, tuning schemes, sensitivity to varying incoming beam conditions, and tolerances on alignment, vibrations, and magnetic field changes.

The interaction region (IR) design must be compatible with the detector and provide adequate masking against backgrounds. In addition, it must include a support platform for the final magnetic lenses, which must be stable with respect to each other to the nm level, and incorporate adequate instrumentation for measuring and maintaining the machine's luminosity. Detector backgrounds can arise from either the IP itself, through the fundamental electromagnetic and hadronic processes resulting from the beam-beam interaction, or from the accelerator elements. Questions of collimation depth, assumptions of beam halo production mechanisms, energy bandwidth of the extraction line, and magnet apertures and field gradients can determine the intensity and energy spectrum of charged particles, photon, and neutrons impacting near the IP.

8.1.3 Historical Background

Before the ISG was organized, both KEK[1, 3] and SLAC[2] published design reports on a future linear collider. These reports included detailed designs of final focus and collimation systems.

These designs were influenced to a great extent by the experience of running the SLC from 1989 through June 1998 to produce high luminosity interactions with sufficiently low machine backgrounds that the SLD physics detector could efficiently trigger and take data. At the SLC high luminosity was usually coupled to low backgrounds. When incoming beam jitter, energy tails, or beam halo were large, luminosity was low and the detector's HV wire imaging systems could not stay on. The sense that a design must be stable, robust, and tunable permeated the thinking when designs for future linear colliders were considered.

In addition, an international collaboration, the Final Focus Test Beam at SLAC[4], was formed to prototype a final focus system with the same demagnification required for future linear colliders. This international effort was co-led by a Japanese - American team. SLAC was responsible for the assembly of the beamline while KEK provided, among other items, the optics and the laser interferometer which was used to measure the final beam spot size. The outstanding accomplishment of the FFTB was a demonstration of a 60 nm beam size at the Interaction Point. It is worth mentioning that the final result was realized only after several earlier runs of the experiment. The collaboration found and corrected the weak points in the setup, built additional instrumentation to monitor the beam, and ultimately achieved its goal.

8.1.4 Summary of ISG Activities on Interaction Region Issues

A working group was formed at the second ISG meeting in July, 1998 to study R&D issues for the beam delivery areas of a linear collider. As knowledgeable people who could work on the accelerator physics aspects of the collimation and final focus lattices were otherwise occupied, it was decided to initially limit the scope of the working group to items of importance in the area of the interaction region.

The general goals were as follows;

- Set a guideline for IR performance.
- Identify necessary hardware elements and their specifications.
- Identify and evaluate scientific tools available for designs of individual parts.
- Set efficient procedures for overall design.
- Identify R&D items.

The following sections describe some of the issues addressed by the working group and gives some summary of the results. Items which are still under discussion and future plans are described in the last sections.

8.2 Interaction Region Layout

Fig. 8.1 and Fig. 8.2 show the current concepts of the IR layout for the JLC and the NLC designs. In the JLC design the beams cross at 8 mrad and exit through the coil pocket of a conventional iron

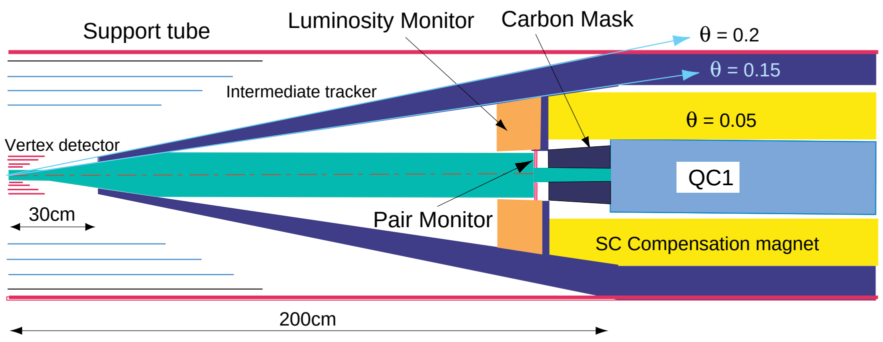

Figure 8.1: *Plan view of the currently proposed interaction region for the JLC detector.*

magnet that is shielded from the detector's solenoid field by a superconducting coil. In the NLC design the beams cross at 20 mrad, exit past the outer radius of a permanent magnet final focusing element, and are accepted by an extraction line that begins 6 m from the IP.

A critical issue is how to stabilize the beams against vertical jitter to keep them in collision. All IR designs must incorporate means to keep the relative vertical motion of the final focusing quadrupole magnets on either side of the IP to less than the design y beam spot size of 3 nm. The nanometer-scale vertical motion could be driven by naturally occurring seismic activity or by cultural sources. Cultural sources could be either self-induced (e.g. motors, compressors, or flowing cooling water) or independent of the project (e.g. nearby road traffic). Low frequency drift and jitter can be corrected for by the use of a slow feedback system that monitors the beam-beam deflection with precision Beam Position Monitors (BPMs) and controls FFTB-style movable magnet supports. Here "low frequency" and "slow feedback" refer to the maximum frequency for which the 120 Hz accelerator repetition rate can drive a correction signal; ∼3-5 Hz is typically taken as the frequency below which this feedback would operate effectively.

For higher frequencies, other means must be taken to protect against potential jitter. The JLC design is based on the assumption that a support tube that spans the IP and ties the focusing magnets together will suffice to lock the quadrupole magnets together. The NLC design assumes that a support tube is insufficient and that compact low mass magnets free of cooling water can be tied together by "attaching" each magnet independently to the local bedrock with active sensors that drive piezoelectric actuators. To this end, a significant amount of R&D has been done on developing a so-called "optical anchor" interferometer as a candidate for the active sensor.

There are many open questions of mutual interest that should be answered before finalizing any IR design.

- **Passive compliance and definition of vibration standards**
  What criteria (as measured by a well defined procedure using specified hardware) should be applied to site selection, equipment purchased, mounting devices and the like? How often may these criteria be violated and what is the cost in luminosity lost and what recovery procedure

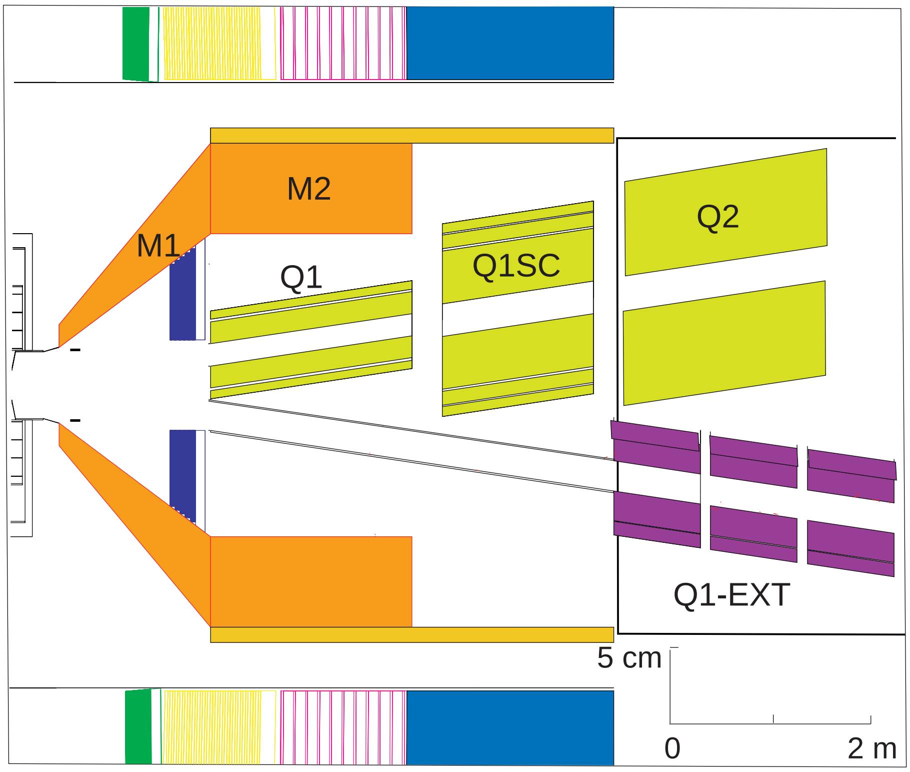

Figure 8.2: *Plan view of the currently proposed interaction region for the NLC small detector.*

is required?

- **Effectiveness of vibration suppression schemes**
  What reduction in amplitude can be expected from any proposed scheme which hopes to suppress relative jitter? How should one measure the amplitude and frequency response of these methods? What vibration suppression will beam-based feedback supply? What R&D is required to develop very low latency feedback that could correct the trailing bunches in a train after the behavior of the early bunches has been measured?

- **Utility of a support tube**
  The assumptions made in the ANSYS analysis of the JLC support tube are being independently evaluated by the SLAC engineering staff. This is occurring with the full cooperation of all parties, and with the relevant exchange of all documentation and information. We hope to have, by the next meeting of the ISG group, a more detailed understanding of what realistic suppression the tube might provide. We would like to understand the sensitivity of the result to assumptions on how the tube is supported in the detector, its construction, the size and weight of the final quadrupole magnets, and the input spectrum of ground vibration.

- **Measurement of final quadrupole vertical motion**
  Over the next few years, we plan to construct and instrument different test apparatus that will

serve to demonstrate that we can achieve the vibrational tolerances required by any design. Ideally, at the end of this effort, we will test a full mechanical mockup of the interaction region, using mechanics for the masses of the final quad magnet technology chosen within the constraints of the detector chosen. For now, the simpler set ups will tell us how easy or difficult it may be to stabilize the optical elements as a function of their size, shape, and weight. It would be useful to use a joint facility for this purpose so that the various suggestions being considered can be equally evaluated.

8.3 Detector Backgrounds

From the point of view of the experimental detector, the issue of most concern is detector backgrounds. Detector backgrounds are expected to come from the following sources:

Machine Backgrounds	IP Backgrounds
Direct beam loss	Disrupted primary beam
beam-gas scattering	Beamstrahlung photons
collimator edge scattering	e^+e^- pairs from beam-beam interactions
Synchrotron radiation	Radiative Bhabhas
Muon Production	Hadrons from $\gamma\gamma$ interactions
Neutron back-shine from Dump	
Extraction Line Loss	

Machine backgrounds

The beams must be collimated to limit the profile of synchrotron radiation through the IR. Since the beams may have long tails at 1 - 0.1% of the total intensity, a large number of $\mu^\pm$ pairs can be created at the collimators. If one wishes to limit the rate to less than one muon/pulse, these muons have to be prevented from reaching the detector by muon attenuators or spoilers. The collimation depth required is set by ℓ^* and the aperture of the final quadrupole magnets.

IP backgrounds

The $e^\pm$ pairs cause two major backgrounds in the detector.

The first is from the primary electrons and positrons. Although most of them are produced in very forward angles $\propto m_e/E_e$, they are significantly deflected by the strong magnetic field of the beam and acquire relatively large transverse momenta. They may then hit parts of the detector, in particular the vertex detector which is closest to beam line. The hit rate depends on the radial location of the vertex detector, whose minimal radius is typically 1 to 2 cm and on the strength of the detector-solenoidal magnetic field, 2 (JLC) to 6 (NLC) Tesla. Generally, physics requires the smallest radius with the strongest magnetic field for better tagging efficiency of bottom/charm quarks. However, there may be a limitation on the maximum field strength coming from the optics of the final focus system, in particular if there is a large horizontal crossing angle as for the NLC.

The second background is due to the secondary photons and neutrons back-scattered from the beam pipe, the quadrupole magnets or the beam dump. The detectors are shielded from the photons by conical and cylindrical masks of tungsten around the final quadrupole magnets. However, soft photons with a few hundred KeV are easily produced in an electromagnetic interaction, so it is very important to have the "minimum" material near the IR. Even with this masking system, several thousand photons/pulse can be scattered into the central tracking region at $r > 30$cm. To absorb the neutrons, additional masks, e.g. made of boronated polyethylene, are necessary in front of the quadrupole magnets and the beam dump. The present estimation is $10^8 - 10^9$ neutrons/cm^2/year at the vertex detector which is well below the tolerable level for a Charge Coupled Device (CCD).

8.3.1 Background Calculations

Since the potentially most serious background is produced by e$^\pm$ pairs generated by the beam-beam interaction, we have devoted much effort to calculating this background. First, e$^\pm$ pairs are generated by a simulation of the beam-beam interaction. Then these pairs are tracked in the realistic three-dimensional detector geometry while simulating high energy interactions with the detector materials. Any particle hitting a detector component is counted as detector background. We have developed software tools to carry out the calculation, and come to a reasonable understanding of the background and the masking scheme. However, due to the differences between JLC and NLC in the machine, IR and detector designs, it is not straightforward to compare the background calculations. The process of understanding and resolving the differences has nonetheless been valuable for attaining a deeper understanding of the background issues.

To simulate the beam-beam interaction, the JLC group uses ABEL and CAIN, and the NLC group ABEL and Guinea-pig. We have compared these three programs, and found a good agreement between CAIN and Guinea-pig, although ABEL predicted 20% less e$^\pm$ pairs than the other programs. This was found to be due to a different treatment of the beam-size effect and after revision, ABEL is now consistent with CAIN and Guinea-pig.

To simulate high energy interactions, both the JLC and NLC groups use GEANT 3 which is a standard tool for high energy detector simulation. Both photons and e$^\pm$ are tracked to 10 KeV. While GEANT 3 is a reliable simulation program for photons and e$^\pm$, it does not simulate neutron production. Since GEANT 3 has a neutron transport package based on MICAP, we have written a program to simulate the giant-dipole-resonance (GDR) process which is the dominant process for low energy ($<$ 20 MeV) neutron production. However, since other processes to produce higher energy neutrons are not simulated, we may underestimate the neutron background. Because of this GEANT limitation, both the JLC and NLC groups use FLUKA 98 to calculate the neutron background.

The e$^\pm$ hit density in the CCD vertex detector appears to be different for JLC and NLC. However, when the differences in the solenoid field strength and the machine energy are taken into account, the two numbers are consistent. We have a consensus that the e$^\pm$ hit density can be reduced to an acceptable level for the vertex detector either by using a strong solenoidal field (6 Tesla vs. 2 Tesla) or by increasing the vertex detector radius (2.5 cm vs. 1.2 cm).

There is at least a factor of five difference in the number of photons hitting the central tracking chamber for the two designs. Since the NLC detector uses either a Silicon tracker (Small detector) or TPC (Large detector), the low energy photons are not a problem. The JLC detector, on the other hand, plans to use a drift chamber and the photon background becomes very important. We have spent a significant effort to understand the difference between the two calculations. The complete history of those background photons is followed to identify which part of the detector has produced the photons. The background photons reaching the tracking chamber at large radius come from low energy secondary $e^{\pm}$ that are produced in the final doublet and then come back to the IP following the solenoid field lines to interact with the beam-pipe and vertex detector materials. The detailed differences in the magnet geometries and beamline setups produce the different estimates of photon backgrounds.

Some difference is also seen in the neutron background calculations. While both groups use FLUKA 98 to calculate the neutron background, the neutron hit density in the vertex detector is estimated to be $7 \times 10^7/\mathrm{cm}^2/\mathrm{year}$ for JLC, and $2 \times 10^9/\mathrm{cm}^2/\mathrm{year}$ for NLC. The geometry difference and machine energy difference (500 GeV in JLC and 1 TeV in NLC) seem to explain this difference. However, there is a difference in the source of neutron background. QC1 is identified as a dominant contributor for JLC, while the majority of neutrons are produced in M1 for NLC. Further investigation is required.

8.3.2 Machine Backgrounds

Machine backgrounds not discussed in the previous section include muon production, synchrotron radiation, and lost particles arising from beam gas scattering. Discussions on how to estimate the level and distribution of halo outside the beam core have only just begun. The beam halo controls the depth to which the beam must be collimated to limit synchrotron radiation and the number of muons produced in the collimation system. Beam vacuum requirements have not been discussed at all. The sensitivity of the detectors to beam loss as a function of position should be calculated for each of the final focus and collimation designs currently being considered.

Muon Backgrounds

To suppress the muon background the JLC design incorporates two concentric oppositely magnetized steel toroids around some length of the beamline downstream of the collimation region. The NLC design includes some number of 9 m long tunnel filling dipole magnets. We are still discussing the effectiveness of each of these two approaches.

8.3.3 Future Work on Background Calculations

We have found that the calculations can be highly sensitive to the assumptions used in the calculational model. There will continue to be an ongoing effort to reconcile any discrepancies between calculations as they arise, such as the current differences in muon and neutron background estimates.

8.4 Collimation, Final Focus, and Extraction Line Lattices

The current versions of the JLC and the NLC incorporate different schemes for the collimation system, the final focus, and the extraction line. While work on a common lattice was not explicitly a goal for the ISG, for completeness of this report we briefly describe below the designs being considered.

As was stated in the introduction, only time and available manpower have kept us from comparing the pros and cons of each other's designs. The lattices currently being used should be considered as working prototypes, good for engineering studies and cost estimates. The parameter space of potential solutions is vast and certainly best explored in a collaborative manner. We expect the time scale of this work to be set by design deadlines imposed by the relevant international or national organizations.

8.4.1 The JLC Beam Delivery System

The JLC Beam Delivery System [3] design contains:

- An energy collimation system, 400 m in length, which eliminates particles which differ from the design energy by more than 2%
- A betatron collimation system, 800 m in length, which performs combined collimation in x, x', y, and y', two collimation iterations per degree of freedom, and uses nonlinear elements to enlarge the beam halo at the collimators relative to the core; the collimation amplitudes are $\pm 6\sigma_x$ and $\pm 40\sigma_y$
- An 7.5 mrad arc composed of combined-function bending/focusing magnets, 200 m in length; in order to allow 2 interaction regions, each side of the Beam Delivery System contains 2 such arcs in sequence, and one or the other arc is deactivated to deliver beam to each IP
- A final focus system which provides the final demagnification required to achieve the design luminosity, 1600 m in length; the final focus uses an "asymmetric dispersion" chromatic correction scheme [12] and incorporates a 3.5 mrad reverse-bend arc, to provide a final total crossing-angle of 8 mrad.

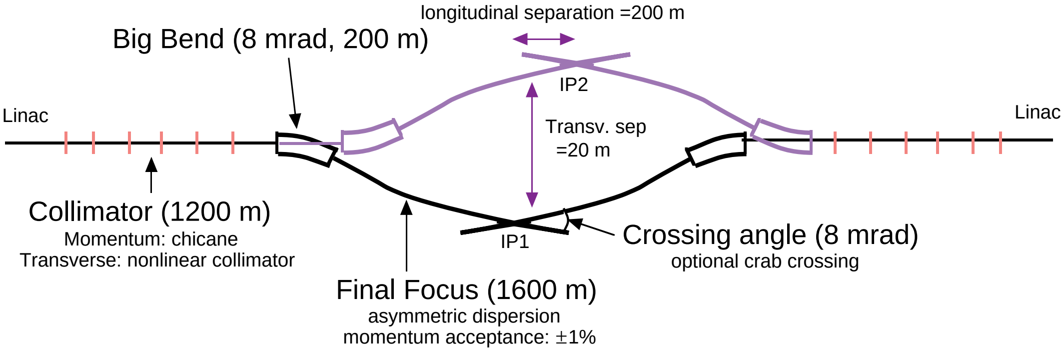

Figure 8.3: *Schematic layout of the beam delivery system at JLC (JLC Design Study, April 1997).*

8.4.2 The NLC Beam Delivery System

The NLC Beam Delivery System described in the ZDR contains:

- A combined energy/betatron collimation system, 2500 m in length, which collimates x/x' at $\pm 5\sigma$, y/y' at $\pm 35\sigma$, and δ at $\pm 4\%$, two collimation iterations per degree of freedom, and provides passive protection against large energy or betatron errors arising in the main linac; only linear elements are used to enlarge the beam and halo
- A 10 mrad arc of separated-function magnets, 400 m in length, which is subdivided into a 1 mrad "IP Switch" followed by a pair of side-by-side 9 mrad arcs which bend in opposite directions; by reversing the bend polarity of the switch, the beam may be directed into either of 2 interaction regions
- An optical module for correction of xy coupling followed by a 4-dimensional emittance diagnostic module, with a combined length of 350 m
- A final focus system, 1800 m in length, which uses the conventional chromatic correction optics of the Final Focus Test Beam [13] to achieve the demagnification and chromatic correction required; the total crossing angle is 20 mrad.

Present thinking on the NLC Beam Delivery System incorporates a number of changes from the design described in the ZDR. The collimation system will be divided into an energy collimation lattice which incorporates passive protection against large single-pulse energy errors, followed by a betatron collimation lattice which does not provide passive protection of collimators but instead incorporates "consumable" or "renewable" collimators; the total collimation system lattice will be on the order of 1.2 km in length. The lattice of the 10 mrad arc will be converted to combined-function magnets to

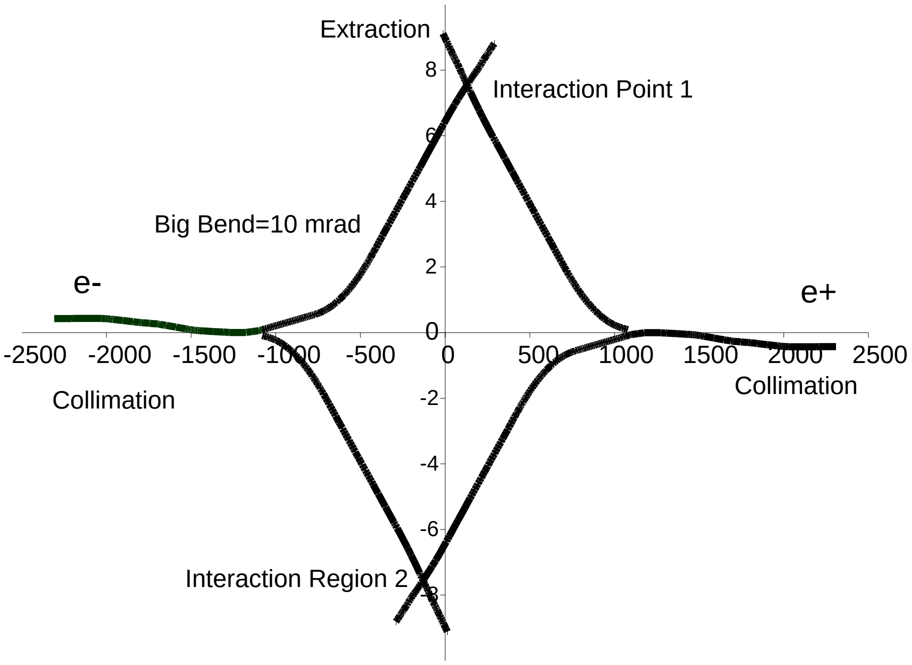

Figure 8.4: *Schematic layout of the beam delivery system at the NLC.*

permit a reduced length (200 m instead of 400 m) and reduced SR emittance dilution (12% at 1.5 TeV CM). The optical module for coupling correction and emittance diagnostics will be reduced in length to 240 m by increasing the strength of the quadrupole magnets in the system. Finally the final focus length will be reduced to approximately 850 meters by reoptimizing the bend magnets for 1 TeV CM instead of 1.5 TeV CM; the performance at 1.5 TeV CM will still be acceptable for the shorter system, although some small modifications in the magnet positioning will be required.

8.4.3 Technology Choices

Complementing the lattice design effort is an R&D program on various accelerator components that are common to any machine design. This program includes work in the following areas.

- **Collimators:** There is an active program to design and prototype collimators that would not need to be replaced if they were to be damaged by the beam. A damaged collimator surface would cause a wakefield that could increase the beam emittance to unacceptable levels. One line of engineering develops collimators based on rotating wheels or moving metal tapes that may be moved to a fresh position if damaged. Another R&D effort investigates the feasibility of using a continuously regenerated metal surface by refreezing a liquid metal on a drum of an appropriate material. The tolerances that can be achieved by such systems will influence the collimation lattice design.

- **Permanent Magnets:** Improvements in cost, reliability, tolerances, or complexity may be achieved by replacing appropriate electromagnets in the beam delivery lattice with permanent magnets. The field quality, strength, variability, temperature sensitivity, radiation resistance, and magnetic rigidity in an external field are being investigated for a variety of permanent magnet designs.

- **Instrumentation:** Simulations and engineering prototypes are beginning on the beam position monitors, kicker, and associated electronics that would use the variation of beam-beam deflection angle to correct the offset of the colliding beams after only a small fraction of a bunch train has gone by. If successful, the tolerances for the vibration stability of the final quadrupole magnet mounts would be relaxed.

  It has been suggested that the energy distribution of the beam-beam pairs be used as a luminosity monitor. R&D on an appropriate pixelated device is beginning.

8.5 Summary and Conclusions

IR issues are listed together with JLC and NLC status, tools and planned R&D in Table 8.1,8.2.

In formulating the designs for the beam delivery, we have tried to learn from the experience of SLC and FFTB. While reaching design beam energy was never a problem at the SLC, the luminosity achievable was often limited by problems with high backgrounds and unstable operation. It is important not to underestimate the difficulty of reliably delivering good beam as we enter a new regime of beam size, roughly 1000 times smaller than ever attempted. The JLC/NLC will also have to deal with very high beam intensity, where new physical processes begin to become important sources of background particles which could be very detrimental to the physics program. Both JLC and NLC have emphasized conservative designs which can accommodate larger backgrounds than expected and which have flexibility to respond to unforseen optics limitations.

As outlined in this chapter, there remains a considerable amount of work to do in the final focus, collimation, and interaction region areas to solidify our understanding. The different approaches to each issue currently advocated by the JLC and NLC groups should be considered more as possible points in the space of all solutions than as well studied optimal solutions. The most efficient way to attack these challenging problems will be to continue to collaborate in a coherent manner in the allocation of new resources and in the frank examination of all conclusions reached.

Item	JLC	NLC	tools and R&D etc.
collimation	nonlinear, ellipse 1.2km/1.5TeV $6\sigma_x \times 40\sigma_y$	linear, rectangular 2.4km/1.5TeV $7\sigma_x \times 35\sigma_y$	SAD,EGS wakefield meaurement detail tunnel geometry shorter collimation exotics: laser,liquid metal ?
muon-background	6 iron cylinders $0.6\phi \times 120$m	4 spoilers $3 \times 3 \times 9$m^3	MUCARLO radio-activation in tunnel optimization with two schemes
crossing angle	8 mrad or smaller SR backgrounds option (L 40% up) higher luminosity w/o crab cavity	20 mrad or larger "6 Tesla" must easier extraction of disrupted beam	ABEL,CAIN,Guinea-Pig tolerance for crab cavity requires 0.2^o phase stability needs prototype cavity
FF Q magnet	warm magnet (2.2m) inner r=6.85mm $\ell^* = 2$m	2 permanet mag. (1m)+Q1SC(0.5m) inner r= 7, 8mm outer r= 2, 2.5cm PEP-II experinece $\ell^* = 2$m	warm magnet: water cooling w/0 vibration permanent magnet: no beam-based alignment SC magnet: how to extract beam?
SC shielding mag.	must	no at least for small detector	thinner cryostat for smaller dead cone
detector solenoid	2 Tesla	6 Tesla	GEANT optimization with calorimeter performance
support of FF-Q	support tube with active alignment	optical anchor no support tube	ANSYS analysis with measured ground motion
feedback	slow ($<$ 10Hz) O(nm) ground motion at $>$ 10Hz causes 5% L loss.	slow ($<$ 10Hz) fast feedbak(2.8ns, $<$ 200Hz)	SAD, TURTLE, MERLIN CAIN BPM:10-100nm resolution

Table 8.1: *IR issues.*

Item	JLC	NLC	tools and R&D etc.
SR background	no problem with collimation/mask	same as JLC	SQRAD,MQRAD,GEANT SLD experiences; large fluctuation of SR background in CDC.
$e^{\pm}$ pairs	1 hit/mm^2/train at r=2.4cm(B=2T) 10,000γ in CDC for $\sqrt{s}$ =500GeV	10 hits/mm^2/train at 1.2cm(B=6T) 120,000γ in CDC for $\sqrt{s}$ =1 TeV	ABEL,CAIN,Guinea-Pig GEANT detailed geometry at IP tolerable hit rates ?
neutrons	10^7 n/cm^2/year giant resonances	2×10^9 n/cm^2/year with high energy n	GEANT,FLUKA98 depend on detailed geometry CCD/VTX:<10^{10}n/cm^2/year
pair monitor	double discs of CCD		ABEL,CAIN,Guinea-Pig GEANT, dE/dX measurement
Shintake mon.			laser optics close to IP?
IP-BPM			O(10nm) resolution
L measurement	acollinearity angle of Bhabha scattering		L within a 1% beam energy spread ?
beam dump line		a chicane to separate electrons and photons with a commom dump	ABEL,CAIN,Guinea-Pig SAD,GEANT,FLUKA98 to measure E, ΔE, P etc.

Table 8.2: *IR issues (continued).*

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