SLAC-PUB-9634
June 2002

The NLC IR and e+e-/e– e– Compatibility Issues*

T.W. Markiewicz

Stanford Linear Accelerator Center
Stanford University, Stanford CA 94309

Abstract

This paper collects and summarizes information presented at previous e-e- workshops. Firstly, the various options for reconfiguring magnets and power sources to convert the NLC to e- e- operation are discussed. Secondly, the expected backgrounds from pair creation at the interaction point are presented. Lastly, beam loss in the extraction line is discussed.

Submitted to the Proceedings of the
4th International Workshop on Electron-Electron Interactions at TeV Energies (e- e- 01)
University of California at Santa Cruz, CA
7-9 December 2001

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

The NLC IR and e+e-/e– e– Compatibility Issues

T.W. Markiewicz[1]

Stanford Linear Accelerator Center
Stanford University, Stanford CA 94309

This paper collects and summarizes information presented at previous e-e- workshops. First, the various options for reconfiguring magnets and power sources to convert the NLC to e- e- operation are discussed. Second, the expected backgrounds from pair creation at the interaction point are presented. Lastly, beam loss in the extraction line is discussed.

1. e– e– Switchover In The NLC Linac

At the 1997 e-e- workshop Erickson discussed the e– e– option in the light of SLAC Linear Collider (SLC) experience.[2] At the time of construction, it was assumed that the impact of retrofitting the SLC for the e-e- mode of operation would be minor and that nothing need be done at the time of initial construction to allow for the mode. This convenient way of not thinking about the problem proved to be wildly optimistic. Subsequent analysis showed that major alterations would be needed to the accelerator and that operations would be affected for numerous shifts while magnets were re-standardized and stable beams recovered.

In 1999, R. Larsen analyzed the goals and requirements of an engineered switchover from e+e- operations to e-e- operations at the NLC and presented three models for how the injector area could be designed[3].

A practical conversion would:
- Add only modest initial capital cost
- Be accomplished quickly
- Reconfigure quickly back to normal operation.

The basic technical requirements are:
- Add a new polarized e– source
- Bypass the positron target
- Reverse all magnets where e– will travel through e⇐ sections *in the same direction*
- Fully automate or semi-automate electromagnetic polarity reversal
- Re-match phase at injection to the e⇐ main linac.

As most of the magnets requiring polarity reversal lie in the Positron Injection area, Larsen concentrated his efforts there.

---

[1] This work supported by U.S. Department of Energy Contract DE-AC03-76SF00515.

[2] *e- e- Collisions in a TeV Collider Built for e+ e- Operation*, R. Erickson, 2nd International Workshop on Electron-Electron Interactions at TEV Energies, Santa Cruz, Ca, 22-24 September 1997.

[3] *e– e– SWITCHOVER IN THE NLC LINAC*, R.L. Larsen, 3rd International Workshop on Electron-Electron Interactions at TEV Energies, Santa Cruz, Ca, 10-12 December 1999.

The Injection area can be implemented in the following ways:

- *Reverse polarities* of all magnets in the path of the polarized e– beam
- *Reverse the direction* of the new polarized e– beam so that ideally no polarity reversals are required
- *Design an independent system* for polarized e– injection that can operate alternately or in tandem with the e⇐ system.

The three models are shown in Figures 1-3. A brief description and summary of the merits and costs of each accompanies the figures. The models are not offered as solutions but as general concepts to illustrate the problems to be investigated.

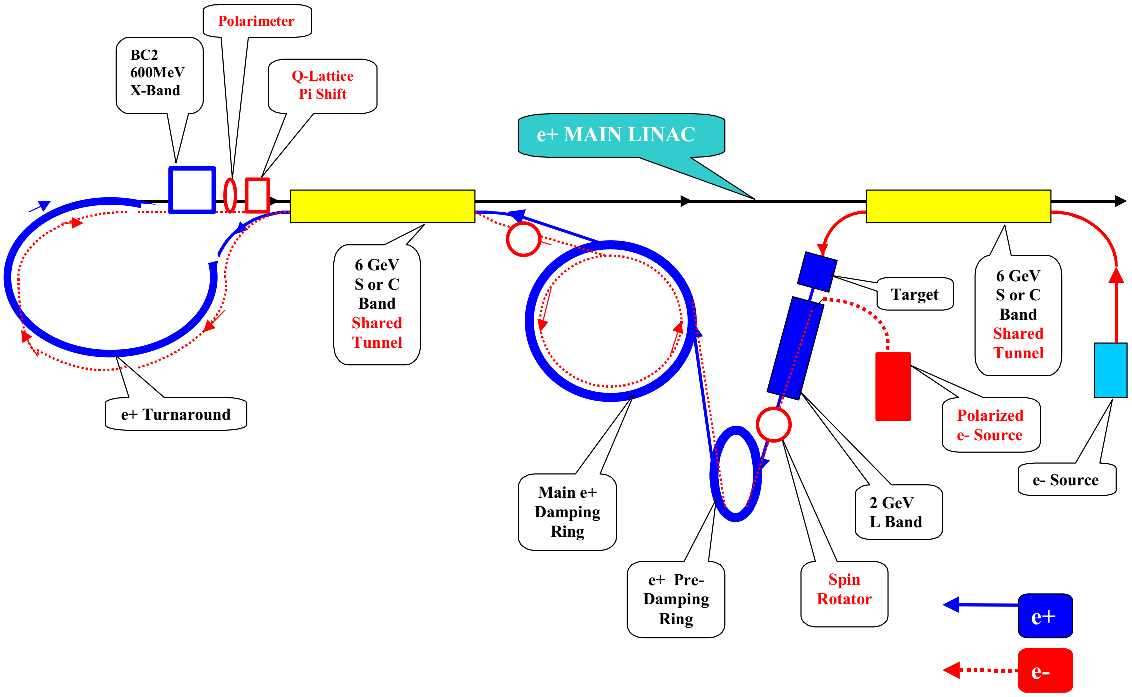

Fig. 1 Polarity Reversal Model

Description:

- New e– Source installed near e⇐ vault bypasses target.
- Injects into 2 GeV pre-accelerator.
- New Spin Rotator and Polarimeter are added.
- Magnets reversed in ½ the PDR, the Main DR, Turnaround and all injection and extraction lines.
- New Q Lattice π Shift after Turnaround.

Advantages:

Only tunneling required is for Polarized e– Source vault and transport line.
Re-uses all e⇐ beamline components.

Disadvantages:

Requires automated reversing switches for all electromagnets.

Requires complicated magnet design and mechanics to rapidly reverse permanent magnets. Wrenches may be only solution in some cases. Must reverse without breaking vacuum.

Re-standardization of magnets and subsequent tuning will be time-consuming.

Re-start could take several shifts.

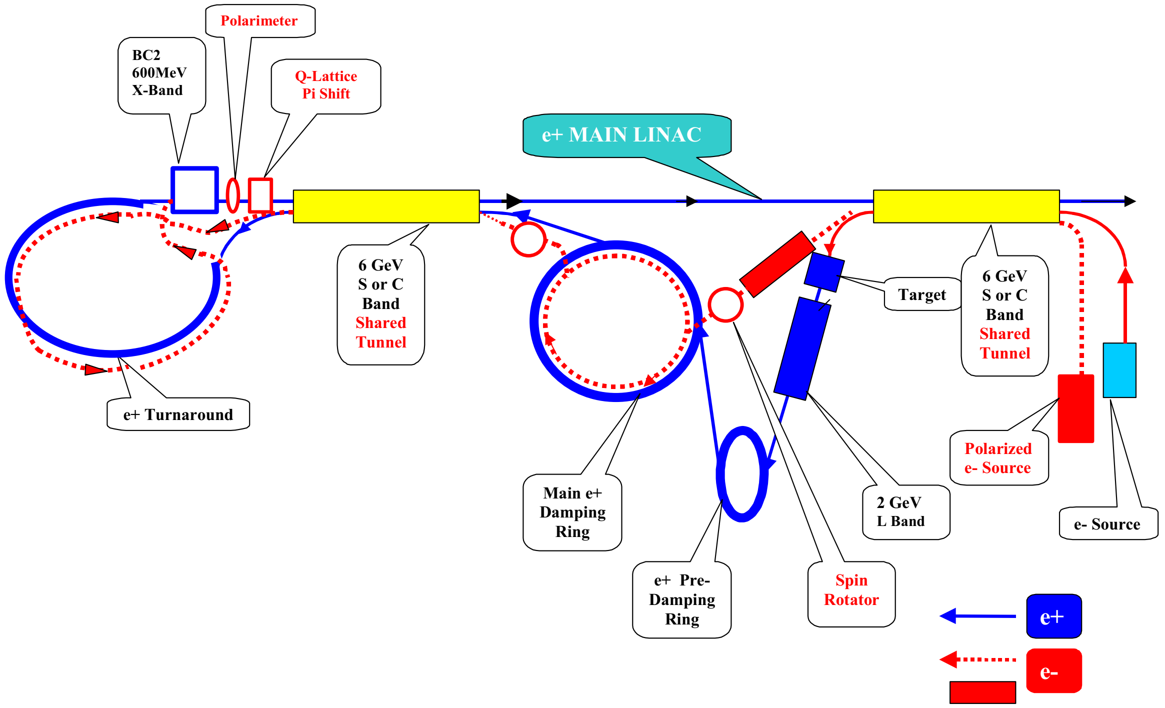

Fig. 2 Direction Reversal Model

Description:

A new Polarized e– Source is located near the e⇐ Source.

Beam is extracted from the first linac at 2 GeV.

A new tunnel and transport line injects beam into the Main DR in reverse direction.

A new Spin Rotator and Polarimeter are added.

A new extraction line is added for the reversed beam out of the MDR.

Beam is injected into the Turnaround in the reverse direction.

Reverse Polarity fast Kickers are added (not shown).

Launch into Q Lattice π Shift after Turnaround.

Advantages:

Avoids polarity reversals of all magnets in MDR and Turnaround.

Avoids PDR bypass entirely.

Avoids problems associated with juxtaposition of electromagnets and permanent magnets.

Switchover essentially automated and quick.

Disadvantages:

Requires additional tunneling.

Requires additional components for injection, extraction, kickers.

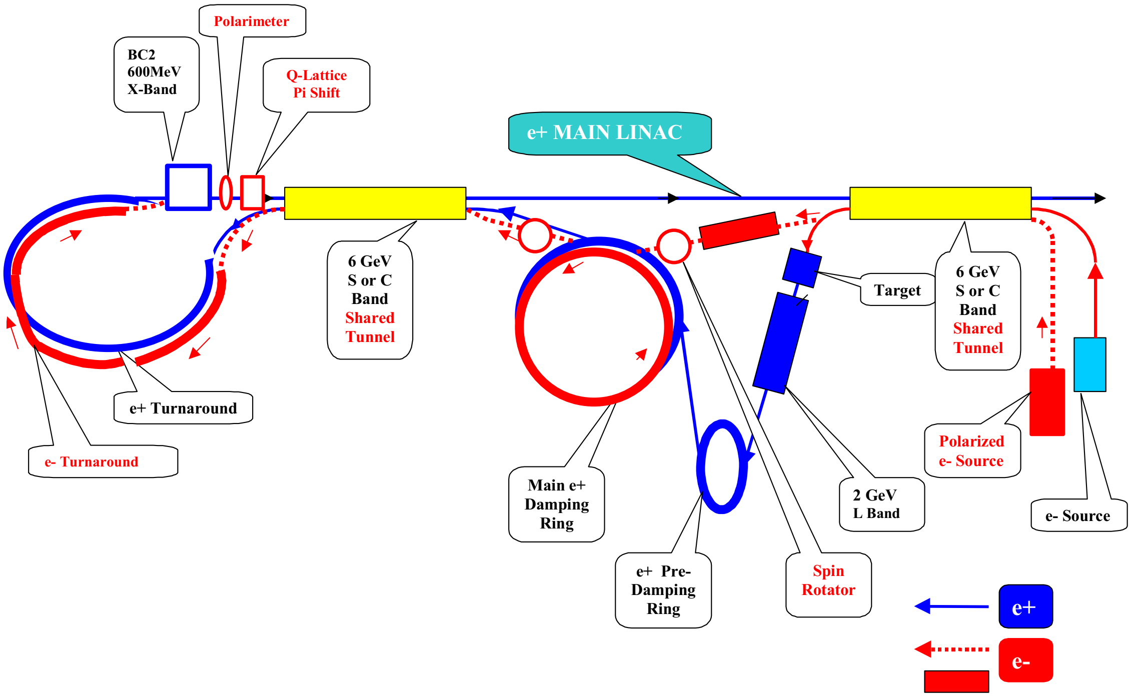

Fig. 3 Independent Systems Model

Description:

Design Polarized e– Injection to be completely independent up to Main Linac.

Add Spin Rotator, Polarimeter and Q Lattice π Shift

Diagram shows shared or parallel housings but could be completely separated to eliminate interference during construction of second complex.

Linacs are shared to reduce cost.

Could couple upgrade with 2nd IR Detector.

Advantages:

Systems switchover requires zero down time.

Systems are always tuned.

True parasitic running possible.

Interleaved ML operation possible.

More physics options available in one or both IR’s.

Initial civil work if on same side would be less costly.

Construction at later date could be completely non-interfering.

Flexibility of programming and operational non-interference is optimized.

Disadvantages:

Additional capital cost would be significantly higher than other models.

Larsen concluded that the Polarity Reversal model is impractical, because of the time required to make switchovers, or in the case of permanent magnets, rotations or physical reversals, followed by re-standardization and then bringing up the beams with new optics parameters. With a higher capital construction cost, the Direction Reversal model fared better and should provide smooth operation once an either-or decision is made as to which mode to run. While the Independent System model is the ideal solution in the long run, it is not clear if its higher initial cost can be recovered through significantly less downtime of the total physics program. As an implementation strategy one might build the Direction Reversal model early and then depending on how the discovery physics program and operational experience play out over time, decide later whether building an independent injector is justified.

In any event, the clear message is that if we are to be serious about e-e- operation, the appropriate beam transport must be engineered in at the beginning of the project.

2. IP Backgrounds

The incoherent production of e+e- pairs at the IP from the beam-beam interaction through $\gamma\gamma \rightarrow$ e+e- (Breit-Wheeler), $e\gamma \rightarrow$ ee+e- (Bethe-Heitler), and ee $\rightarrow$eee+e- (Landau-Lifshitz) processes is the most important background source for the inner tracking detectors at the next linear collider. While over the course of time both the beam spot parameters at the IP and the IR design have evolved, the ratio of e-e- to e+e- backgrounds is fixed by the nature of the beam-beam interaction. In the 1997 e-e- conference, Maruyama showed[4] the data in Figure 4, comparing the e+e- and e-e- pair-induced hit density in the vertex detector as a function of longitudinal position z for due layers at r = 1 cm and r = 2 cm for two different values of the detector's solenoid field. As there is an anti-pinch effect for e-e- interactions, the absolute number of pairs for the e-e- case is reduced by roughly a factor of three, the ratio of the e-e- luminosity to the e+e- luminosity. The shapes of the distributions are similar.

	# particles per bunch		Mean Energy (GeV)	
	e+e-	e-e-	e+e-	e-e-
Disrupted Primary Beam	2 x10^{10}	2 x10^{10}	460	460
Beamstrahlung Photons	3 x10^{10}	3 x10^{10}	30	30
e+/e- Pairs	88K	26K	10.5	10.5

Table I: The number of disrupted beam particles, beamstrahlung photons, e+e- pairs and radiative bhabhas from Guinea Pig simulations of e+e- and e-e- interactions at 1 TeV center of mass energy.

---

[4] *Backgrounds at an e− e− Linear Collider*, T.W. Markiewicz, T. Maruyama, 2nd International Workshop on Electron-Electron Interactions at TEV Energies, Santa Cruz, Ca, 10-12 December 1997.

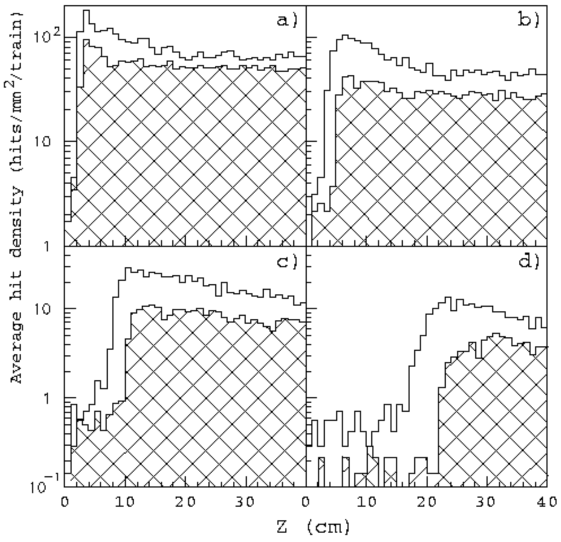

Fig. 4 Electron pair hit density per mm^2 per train of 90 bunches, for the interaction of similar e+e- (open histogram) and e-e- (hashed histogram) colliders. As the pairs leave the IP, hits are scored at different radii as a function of their longitudinal position z. Part (a) and (c) refer to r=1 cm and r=2 cm at B=2 Tesla, while part (b) and (d) refer to r=1 cm and r=2 cm at B=4 Tesla.

At the 1999 e-e- conference Gronberg updated the 1997 results[5] somewhat. Table I compares the numbers of beamstrahlung photons and pairs for the two cases at 1 TeV center of mass while Figure 5 shows the angular distributions of the disrupted beam and the beamstrahlung photons for the e+e- and e-e- cases. Additionally, the neutron radiation dose to the detector scales as the number of pairs, as pairs lost near the IP are the dominant source of neutrons in the vertex detector. Table II lists the relevant neutron background numbers. Recall that only the relative number of e+e- versus e-e- neutrons is of interest here; the absolute dose has changed as the IP parameters and the IR design have changed.

Neutron Backgrounds at the IP x10^9 hits/cm^2/year	e+e-	e-e-
e+e- pairs	1.7	0.6
Radiative Bhabhas	0.02	0.02
Disrupted Beam		
Lost in the Extraction Line	0.01	0.10
Back-shine from the beam dump	0.2	0.2
Beamstrahlung		
Back-shine from the beam dump	0.05	0.05

Table II: The number of neutrons per cm^2 per year seen by the inner layer of the vertex detector. The beam-beam pair component scales as expected while the remaining contributions are constant.

---

[5] *Charged Particle and Neutron Backgrounds in an e− e− Interaction Region at the NLC,* J. Gronberg, 3rd International Workshop on Electron-Electron Interactions at TEV Energies, Santa Cruz, Ca, 10-12 December 1999.

3. Beam Loss in the Extraction Line

Table III lists, for the 500 GeV and 1 TeV “A” IP parameter sets, some features of the e-e- beam at the interaction point. In the first four rows, the widths of the x, x′, y and y′ distributions are listed along with the corresponding widths for e+e-. In addition to the roughly factor of two spot size increase in *y* for e-e collisions relative to e+e- collisions, there is also a factor of three increase in the width of the angular distribution of the beam in y coming out of the IP. This additional angular spread, coupled with the disruption-induced low energy tail on the beam, can in principle cause unacceptable beam loss in the extraction line that transports the disrupted beam to the dumps. The following two rows of Table III provide some measure of the amount of e-e- beam in the lowest part of the beam energy distribution. Y. Nosochkov has designed[6] the extraction line for the NLC and compared its performance for e-e- transport to that of e+e-. When the e-e- beams are transported with the nominal e+e- lattice, which uses bend magnets with 50mm vertical apertures, the beam loss is about 10 times as large as for the e+e- case. If the vertical magnet aperture is increased the loss can be lessened somewhat. Nosochkov then designed a devoted e-e- extraction line lattice where the chicane dipoles have very large 108mm apertures. In this case, the beam losses are about the same as those for e+e- in the nominal design.

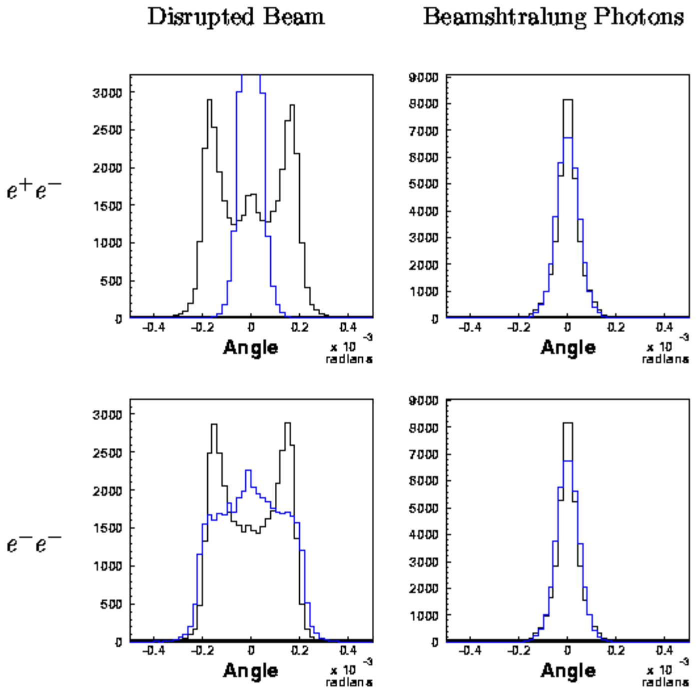

Figure 5: The angular distributions of the disrupted beam and the beamstrahlung photons. The solid black line is the x distribution while the dashed blue line is the y distribution.

---

[6] NLC Extraction Line Studies, Y. Nosochkov and T. Raubenheimer, LCC Note#0034, SLAC-PUB-8313, Aug.12, 1999.

	A535	A1046
x (nm) e-e- (e+e-)	276 (274)	199 (198)
x' (μr) e-e- (e+e-)	152 (167)	114 (125)
y (nm) e-e- (e+e-)	7.5 (4.5)	5.8 (3.2)
y' (μr) e-e- (e+e-)	142 (45)	110 (33)
%beam w/ $\Delta E/E < -0.6$	0.03%	1.03%
%beam w/ $\Delta E/E < -0.7$	0%	0.28%
%beam loss w/ e+e- lattice w/50 mm ap. magnets	0.95%	3.20%
%beam loss w/ e+e- lattice w/80 mm ap. magnets	0.62%	2.39%
%beam loss w/ e-e- lattice w/108 mm ap. magnets	0.002%	0.22%

Table III: Features of the disrupted beam affecting extraction line design and performance of the extraction line.

4. Conclusions

While there does not appear to be anything fundamental that would keep e-e- operation from being realized at the NLC, it is nonetheless not yet incorporated as part of the baseline design. It is good to remember that the $\gamma\gamma$ option is being preserved for all linear collider designs presently being discussed and that the $\gamma\gamma$ collisions require highly polarized electron beams to produce highly polarized photons. If the same level of thought and design that has made $\gamma\gamma$ appear to be a viable option is applied to the e-e- case, it too could become an interesting addition to the collider's physics programs. It must not be considered only as an afterthought.

Acknowledgement

R. Larsen (SLAC), T. Maruyama (SLAC), Y. Nosochkov (SLAC) and J. Gronberg (LLNL) have provided all the original analysis summarized in this contribution to the proceedings.