

NLC Pulsed Extraction for 250 GeV Beams

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Abstract

We present an architecture which permits extraction of bunch trains from the NLC main linac at the 250 GeV point while preserving the quality of the beam.

1 Introduction

In recent months, the NLC collaboration has been considering a significant reconfiguration of the collider to permit simultaneous operation of the principal interaction region at high energies (in excess of 500 GeV CM) and a second interaction region at lower energies (below 500 GeV CM) [1]. The principal changes to earlier NLC site configurations are as follows:

- The injectors, damping rings, and first 50% of the main linac are to operate at 180 bunch trains per second rather than 120
- The main linacs are not set collinear, but incorporate a crossing angle of 20 milliradians total, such that the principal IR beam delivery systems require no net bending angle
- A second interaction region, with a potentially large crossing angle and a “big bend” of up to 50 milliradians, is added
- The geometry of the site is adjusted to provide the horizontal separation desired between IR halls (presently 100 meters) and no longitudinal separation
- A “bypass beamline” is added to the main linac tunnel, which permits extraction of the beam from the main linac at energies of approximately 50, 180, and 250 GeV; the bypass beamline transports the beam to the end of the main linac where it is either transported to the low-energy IR (LEIR), or reinjected back into the high-energy IR (HEIR) beam delivery system.

The last item – extraction of the beam into a non-accelerating “bypass” beamline parallel to the main linac – is desirable because it eliminates the requirement that magnets downstream of the 50 GeV point be capable of operation at 50 GeV strengths, which would not be possible if those magnets are all hybrid permanent magnets with limited strength adjustability; also, it eliminates the requirement that low-energy beams pass through almost 10 km of X-band accelerator structures, which would guarantee miserable beam quality for the LEIR. Figure 1 shows a schematic of the presently-proposed layout.

In this Note, we describe a proposed configuration for the extraction beamline which transports 250 GeV beams from the main linac to the parallel bypass line. The design is, at least in principle, compatible with extraction of 60 bunch trains per second for LEIR use while retaining 120 trains per second of unextracted beam for HEIR use. While the design requires at least two additional extraction beamlines, in this Note we describe only the extraction line which must operate at highest energy, with the assumption that lower-energy extraction will typically be easier to accomplish.

2 Requirements of the Extraction Beamline

The principal requirement of the extraction beamline is that it must successfully transport 250 GeV beams from the main linac to the parallel bypass line while limiting the impact on beam quality. Our specification is that the extraction line cannot increase the normalized horizontal emittance by more than 1.5×10^{-7} m.rad (5% of damping-ring extraction emittance).

The second requirement is that the extraction line (and, in fact, the bypass line) should accommodate the radial space requirements of the main linac with a minimum of heroics: because the deflection angles permitted are limited by synchrotron radiation, the two beamlines are going to be extremely close together in x for a substantial distance in z .

The third requirement, related to the requirement above, is that the number of acceleration girders which are displaced to make room for the extraction line should be minimized; this is equivalent to requiring that the increase in main linac footprint required for the extraction line be minimized.

3 Optics Description

The optics design is based on the FODO lattice which is present at the 250 GeV point in the main linac (end of sector 11 in the CD 0.4 optics or sector 22 in the CD1 optics). It is assumed that a short nonaccelerating FODO section is inserted at this location to accommodate extraction.

The optical functions of the extraction line are shown in Figure 2. The magnet spacing is the same as in the downstream portion of the main linac (17.672 meters from downstream face of one quad to upstream face of the next quad). The first quad in the line is the F quad at the end of Sector 11 of the main linac. This quad is followed by a set of 5 bend magnets, each 3 meters long and providing a bending field of 0.72 kilogauss. At the end of these magnets the bent beam is offset by 1.1 cm from the unbent one, with an angle of 1.295 milliradians. The next quad, horizontally-defocusing (D polarity) is twice as long as the standard main linac quad (76.5 inches or 194.3 cm), with an aperture radius of at least 2 cm and a pole-tip field of 6.19 kG; this combination gives the QD a focal length equal to the main linac QD which is in the original main linac deck, but with a greater length and aperture. For the straight-ahead beam this quad is a pure quad, and its strength is matched to the FODO optics at this point; for the bent beam the quad is a combined-function bend/quad, providing a bending field of 3.6 kG or an integrated bend of 7 kG (1/3 of the total bending). At the downstream face of this magnet the bent beam is 1.45 cm from the main linac centerline, and has a relative angle of 0.1227 degrees or 2.142 milliradians.

The next 7 quads are based on main linac standard quads, 38.25 inches in length with 0.5 inch full bore. The strengths are adjusted to provide a 90° per cell phase advance in x and y (slightly different from the linac lattice at this location), and some of the quads may need to be extremely skinny in x (as may some of the corresponding quads in the main linac at this z location). At the fourth quad ($z = 56.44$ meters), the distance between the beam centerlines is 9.32 cm, which is sufficient to accommodate linac structures; thus, Sector 12 can begin with a quad next to the fourth quad of the extraction beamline.

Following the ninth quadrupole in the lattice are a set of 5 bends and one combined bend/quad which are identical to the equivalent magnets in the start of the beamline but with opposite bending polarities. These magnets eliminate the horizontal dispersion functions and deflect the extracted beam to a trajectory parallel to the main linac. The separation of the centerlines of the two beampipes is 31.9 cm, and the total length of the extraction line is 168.8 meters.

4 Emittance Dilution

The principal emittance dilution factor of concern in bending beamlines for electrons is synchrotron radiation. The emittance dilution from this source is given by [2]

$$\Delta\gamma\epsilon_x = 4 \times 10^{-8} \text{ m.rad} E^6 [\text{GeV}] I_{5x}, \quad (1)$$

where I_{5x} is the fifth synchrotron integral in the horizontal plane [3]. At 250 GeV, the equation above indicates that the dilution of the normalized emittance is approximately 1.2×10^{-7} m.rad, while tracking studies indicate that emittance dilution from other sources (high-order dispersions and chromaticity) add another 3×10^{-8} m.rad, for a total of 1.5×10^{-7} m.rad (coincidentally equal to our dilution budget).

An additional source of emittance dilution is power supply jitter in the bend magnets. Because the deflection at the first QD is so large (1.1 cm) compared to the RMS horizontal beam size (8.8 micrometers), the tolerance on bend magnet power supply stability is severe. If we assume that the five bend magnets at one end are powered in series, and that a train-to-train jitter of $0.1 \sigma_x$ is tolerable, then typical power supply stability tolerances will be 80 parts per million, although powering all 5 magnets at one location with separate supplies will relax this by a factor of 2. If all 10 bend magnets are powered in series, the tolerance becomes looser – the variation in the first five magnets is cancelled by the equal and opposite variation in the last five for small changes in magnet strength.

If the magnets are operated as pulsed bends, such that 60 trains per second are directed to the LEIR and 120 to the HEIR (for example), then an additional tolerance appears: the flatness of the bend magnet field over the bunch train. In order to avoid large intra-train offsets of the bunches, the pulsed bending field must be constant at the same 80 parts per million over the 300 nanoseconds of the bunch train. In this case it is not clear that powering matched bend magnets from a common supply would work, since the frequency characteristics of the power line from the supply to the two magnets would come into the equation, and these may be hard to match to the required precision. At this time, we know of no pulsed magnet and power supply which can meet this requirement, nor do we know of satisfactory alternatives (electrostatic kickers, crab cavities, etc). On the other hand, we know of no other user that has requested such a device in the past, and achieving such tolerances may be possible once the requirement is communicated to engineers: “ask and ye shall receive.”

5 Conclusions

We have designed an “existence proof” of an extraction beamline which allows trains of 250 GeV bunches to be removed from the main linac and transported to a parallel, nonaccelerating beamline, with minimal emittance dilution. A cursory examination indicates that in general the two beamlines can be made to coexist without heroics, and that for DC extraction of the beam the magnet tolerances appear to be manageable. This would permit the NLC to operate with beams to the HEIR for some period and then to switch quickly to delivering beams to the LEIR.

It is not clear yet that the beamline as designed can be used for extraction on a train-by-train basis due to the tight tolerances on the bending field stability over the period of one bunch train. These tolerances can probably be met if the magnets are DC, but may be hard to manage if a pulsed supply is used. However, the size, field strength, repetition rate, and rise/fall times required for pulsed operation all appear to be achievable with conventional technology, as the SLAC linac contains one pulsed bend magnet (the 2-9 dump) which is capable of pulsing to several kilogauss at 120 Hz, and has rise/fall times short enough to dump or transmit consecutive beam pulses [4].

6 Acknowledgements

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References

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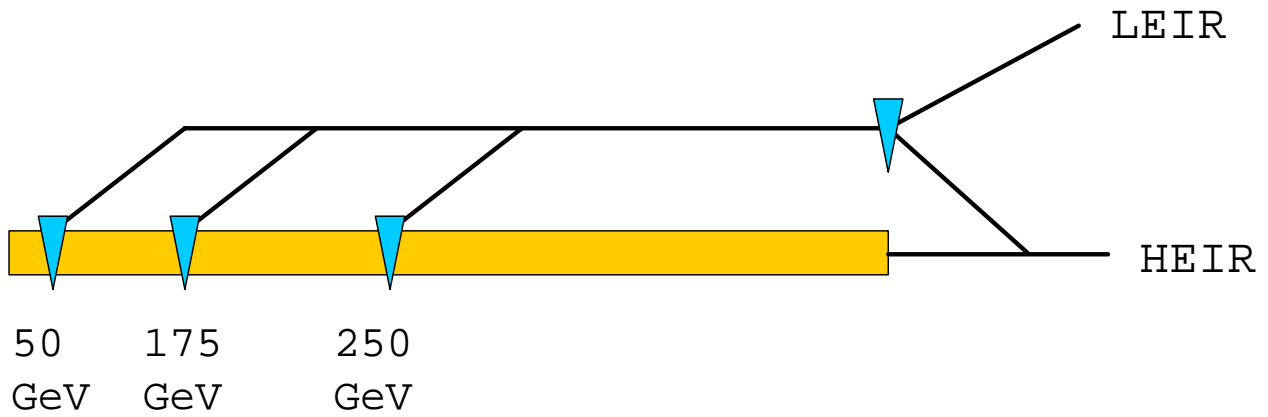


Figure 1: Schematic of one side of the NLC footprint. The main linac (gold bar) contains several extraction points (blue triangles) which permit beams to be removed at relatively low energies to a collinear bypass line; from the bypass line the beams can go to either the HEIR or LEIR.

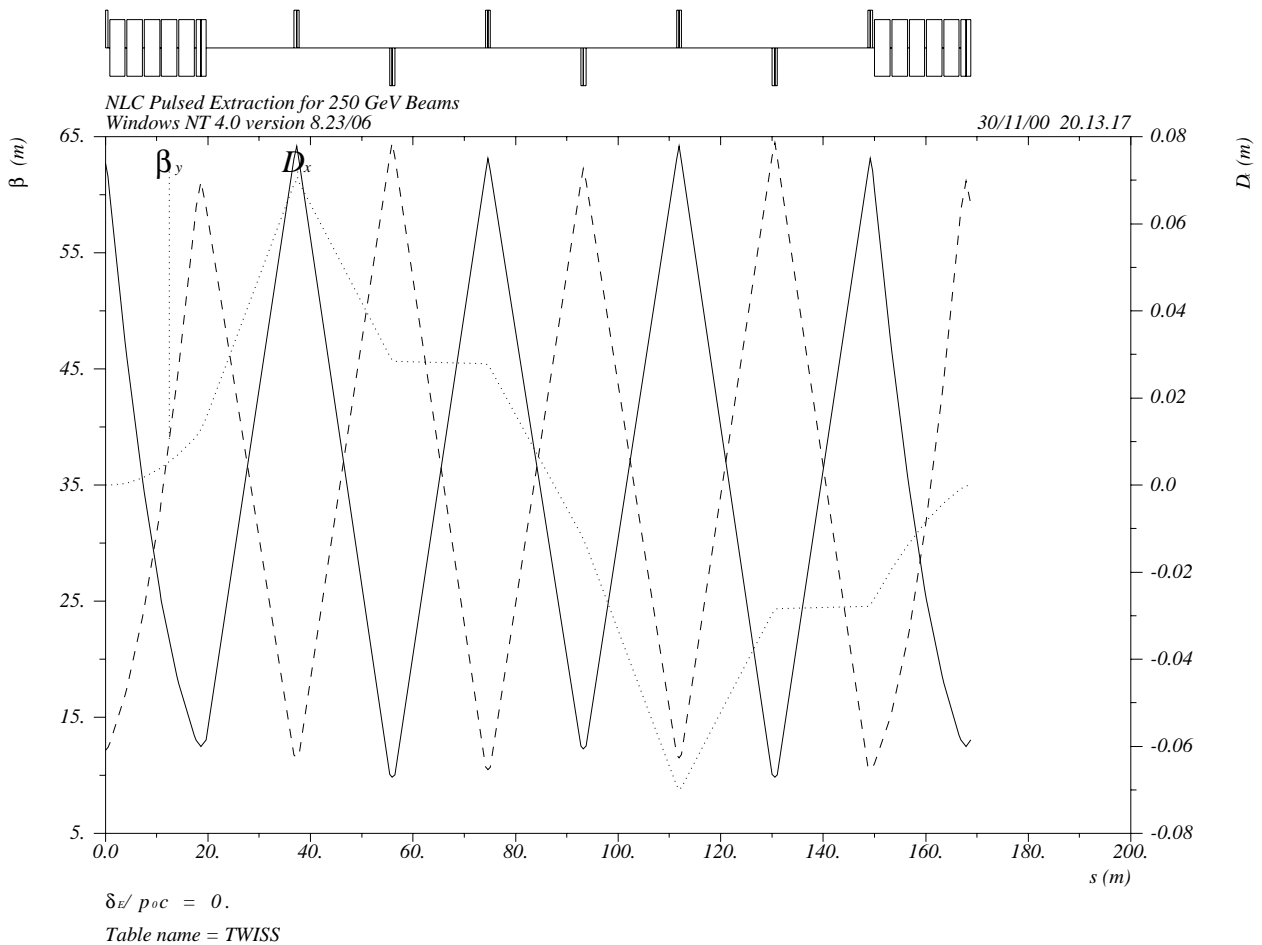


Figure 2: Twiss parameters for 250 GeV extraction line from NLC main linac to bypass beamline.