Linear Collider Collaboration Tech Notes

High-luminosity NLC Designs with Near-equal Horizontal and Vertical Beta Functions

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Abstract:
Modifications are studied of the NLC designs with aspect ratio close to or equal to 1, so that higher luminosity and/or much-relaxed vertical tolerances are obtained.

High-luminosity NLC designs with near-equal horizontal and vertical beta functions

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In this note we consider some modifications of the NLC for high luminosity running. One way to get very high total luminosity is to change the beta functions to make the aspect ratio σ_x/σ_y smaller. Such designs have the additional advantage that, due to the larger vertical beam size, tolerances in the final focus are significantly loosened. Due to higher disruption, n_γ and Υ are driven up, and the effects of the resulting higher backgrounds still need to be addressed in more detail. However it is also possible to reduce the charge per bunch, which yields comparable luminosity and backgrounds to the nominal designs, but with relaxed vertical tolerances.

The NLC-B-1000 standard design has $\beta_x^\star = 12$ mm, $\beta_y^\star = 0.12$ mm, $\sigma_x = 330$ nm, and $\sigma_y = 5$ nm (see Table 1). Simply reversing the polarity of the final doublet allows one to obtain $\beta_x^\star = 1$ to 2.5 mm, $\beta_y^\star = 1$ to 1.3 mm, $\sigma_x = 60$ to 100 nm, and

TABLE 1. IP parameters for three ~1 TeV c.m. NLC designs

	A-1000	B-1000	C-1000
E_{beam} [GeV]	523.	504.	489.
N [10^{10}]	0.75	0.95	1.1
$\gamma\epsilon_x/\gamma\epsilon_y$ [μm-r]	4.0/0.06	4.5/0.1	5.0/0.14
$\beta_x^\star/\beta_y^\star$ [mm]	10/0.125	12/0.15	13/0.2
σ_z [μm]	90.	120.	145.
σ_x/σ_y [nm]	198/2.7	234/3.9	261/5.4
$\mathcal{L}_0$ [10^{33} m^{-2}]	8.37	7.87	6.83
A_x/A_y	0.009/0.72	0.01/0.80	0.011/0.725
D_x/D_y	0.094/6.9	0.103/7.0	0.136/6.5
Υ_{eff}	0.39	0.30	0.25
$\mathcal{L}_D$ [10^{33} m^{-2}]	12.4	11.4	10.2
H_D	1.50	1.44	1.50
n_γ	1.4	1.5	1.6
δ_B	9.5%	9.2%	8.7%
Bunches/train	95	95	95
Rep. rate	120	120	120
L_D [10^{33}cm^{-2}sec^{-1}]	14.3	12.9	11.7

$\sigma_y = 8$ to 12 nm.

A final triplet solution which can produce $\beta_x^\star = \beta_y^\star = 1$ mm has also been found. The quadrupoles are in a DFFD configuration; they have aperture radii of 1 cm and pole-tip fields of 12.5 kG. The horizontally-focusing quadrupoles are 2.4 meters long, and the vertically- focusing quadrupoles are 2.6 meters long. The beam sizes without Oide effect are $\sigma_x = 63$ nm and $\sigma_y = 8.0$ nm; including the Oide effect raises these to $\sigma_x = 70$ nm and $\sigma_y = 8.3$ nm. The triplet chromaticities are $\xi_x = 12,900$ and $\xi_y = 26,000$, while those for the NLC's standard doublet design are $\xi_x = 4,350$ and $\xi_y = 35,600$. The quadrupoles for the triplet configuration are more conventional than the present doublet design, but the increased horizontal chromaticity will require a redesigned chromatic correction system to achieve correction with the limited magnetic fields attainable in warm iron sextupole magnets. The increased chromaticity will also intensify higher-order chromatic aberrations and reduce the system bandwidth, though neither of these issues has been studied.

We used the beam-beam code Guineapig [1] to simulate several designs with parameters similar to those in the "standard" NLC designs [2], except that the beta functions at the IP are modified. Three such modified designs are shown in Table 2. The first is the same as NLC-A-1000 except that $\beta_x^\star = \beta_y^\star = 1.0$ mm. The second is the same as NLC-B-1000 except that $\beta_x^\star = \beta_y^\star = 1.3$ mm. The third is a less extreme modification of NLC-A-1000, in which $\beta_x^\star = 2.5$ mm and $\beta_y^\star = 1.0$ mm. In all three cases, the horizontal beam size σ_x is smaller but the vertical beam size σ_y is several times larger than in the baseline designs.

Although these designs have high total luminosity, they also have much higher beamstrahlung, so the fraction of luminosity at the highest energy end of the spectrum is reduced, as may be seen from Table 3 and Figure 2. The number of beamstrahlung photons per particle, n_γ, is very high, particularly in the equal-beta cases, and the resulting backgrounds will need to be evaluated.

It is also worth noting that in these cases, since the disruption is so high, we must use the effective beam sizes [3] rather than the nominal undisrupted beam sizes σ_x, σ_y when calculating the effective beamstrahlung parameter Υ_{eff}. This has been done in calculating the values of Υ_{eff} in Table 2. The number of coherent e^+e^- pairs (for Υ_{eff} of order 1 or less) is given by [4]

$$n_{coh} = \frac{7}{128} \exp\left(- \frac{16}{3\Upsilon_{eff}} \right) \quad . \tag{1}$$

This yields about a hundred times as many coherent pairs as the standard NLC designs.

We also consider variations of the NLC-B-1000 design in which $\beta_x^\star = \beta_y^\star = 1.3$ mm and we reduce the charge from its nominal value $N = 0.95 \times 10^{10}$. The results are shown in Table 4. For the cases with $N = 0.4 \times 10^{10}$ and $N = 0.55 \times 10^{10}$, note that we also decreased the bunch spacing from 2.8 to 1.4 nsec and doubled the number of bunches, to obtain luminosities comparable to the nominal NLC designs. The luminosity spectra are shown in Figure 3.

TABLE 2. IP parameters for ∼1.0 TeV c.m. NLC designs, with equal or near-equal beta functions

	A-1000-bx1by1	B-1000-bx1.3by1.3	A-1000-bx2.5by1.0
E_{beam} [GeV]	523	504	523
N [10^{10}]	0.75	0.95	0.75
$\gamma\epsilon_x/\gamma\epsilon_y$ [μm-r]	4.0/0.06	4.5/0.1	4.0/0.06
$\beta_x^\star/\beta_y^\star$ [mm]	1.0/1.0	1.3/1.3	2.5/1.0
σ_z [μm]	90.	120.	90.
σ_x/σ_y [nm]	62.5/7.65	77.0/11.5	98.8/7.65
$\mathcal{L}_0$ [10^{33} m^{-2}]	9.36	8.11	5.92
A_x/A_y	0.090/0.090	0.092/0.092	0.036/0.090
D_x/D_y	0.85/6.9	0.96/6.4	0.35/4.6
Υ_{eff}	1.9	1.5	0.83
$\mathcal{L}_D$ [10^{33} m^{-2}]	35.1	31.3	13.7
H_D	3.7	3.9	2.3
n_γ	4.7	5.1	2.6
δ_B	41%	40%	22%
Bunches/train	95	95	95
Rep. rate	120	120	120
L_D [10^{33}cm^{-2}sec^{-1}]	40.0	35.7	15.6

TABLE 3. Fractional luminosities for ∼1.0 TeV c.m. NLC designs, with equal or near-equal beta functions (beamstrahlung and ISR both included).

	A-1000-bx1by1	B-1000-bx1.3by1.3	A-1000-bx2.5by1.0
beamst.+ISR:			
$L_{99.5\%}$	5.4%	5.0%	14%
$L_{99\%}$	7.0%	6.5%	18%
$L_{98\%}$	9.4%	8.9%	23%
$L_{95\%}$	15%	14%	34%
$L_{90\%}$	22%	22%	47%
$L_{80\%}$	35%	35%	65%
$L_{50\%}$	70%	72%	93%

TABLE 4. IP parameters for modified NLC-B-1000 design, with $\beta_x^\star = \beta_y^\star = 1.3$ mm and reduced charge

N [10^{10}]	0.7	0.55	0.4
E_{beam} [GeV]		504	
$\gamma\epsilon_x/\gamma\epsilon_y$ [μm-r]		4.5/0.1	
$\beta_x^\star/\beta_y^\star$ [mm]		1.3/1.3	
σ_z [μm]		120.	
σ_x/σ_y [nm]		77.0/11.5	
A_x/A_y		0.092/0.092	
$\mathcal{L}_0$ [10^{33} m^{-2}]	4.40	2.72	1.44
D_x/D_y	0.71/4.7	0.56/3.7	0.40/2.7
Υ_{eff}	0.91	0.63	0.40
$\mathcal{L}_D$ [10^{33} m^{-2}]	13.2	6.81	3.10
H_D	3.0	2.5	2.2
n_γ	3.5	2.7	1.9
δ_B	28%	20%	12%
Bunches/train	95	190	190
Rep. rate	120	120	120
L_D [10^{33}cm^{-2}sec^{-1}]	15.0	15.6	7.0

The backgrounds are of course larger in these designs and must be dealt with. In particular, the dump-line, which is already a challenge for the nominal NLC designs, must be able to handle an even more severely disrupted beam in the high luminosity designs. This issue is still under study. However, by reducing the charge, one has a design option in which the luminosity is similar to that in the nominal designs but the vertical beam size is larger, while n_γ and Υ are within reasonable limits.

REFERENCES

1. D.Schulte, Ph.D. thesis, 1996.
2. See http://www-project.slac.stanford.edu/lc/nlc-tech.html under Accelerator Physics parameters.
3. P.Chen, IEEE Particle Accelerator Conference (PAC 93), Washington, DC, 17-20 May 1993.
4. Yokoya,K. and Chen,P., in M.Dienes,et.al. (ed.), Frontiers of Particle Beams: Intensity Limitations, (Springer-Verlag, 1992), p.415.

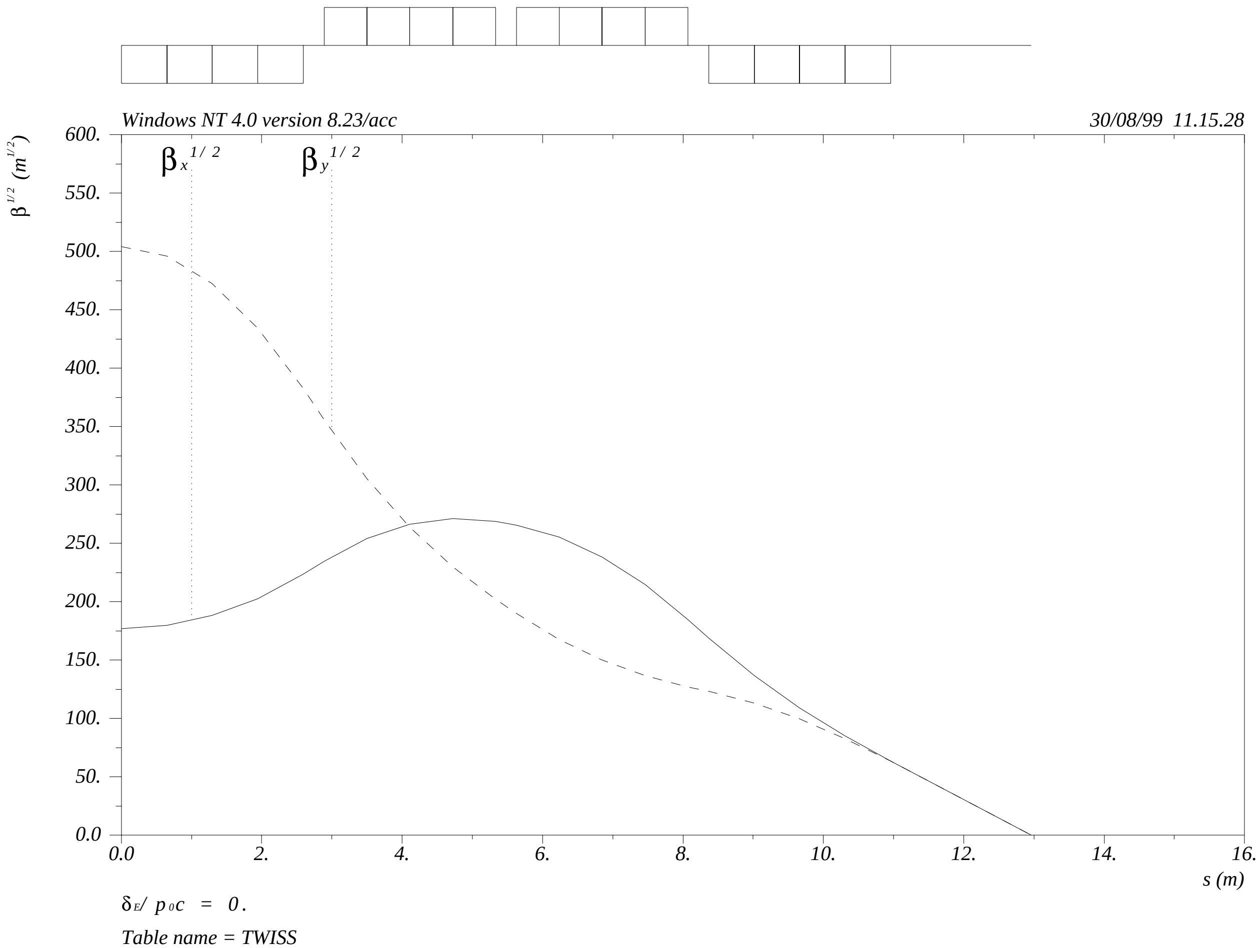

FIGURE 1. Beta functions for final triplet solution with $\beta_x^\star = \beta_y^\star = 1$ mm

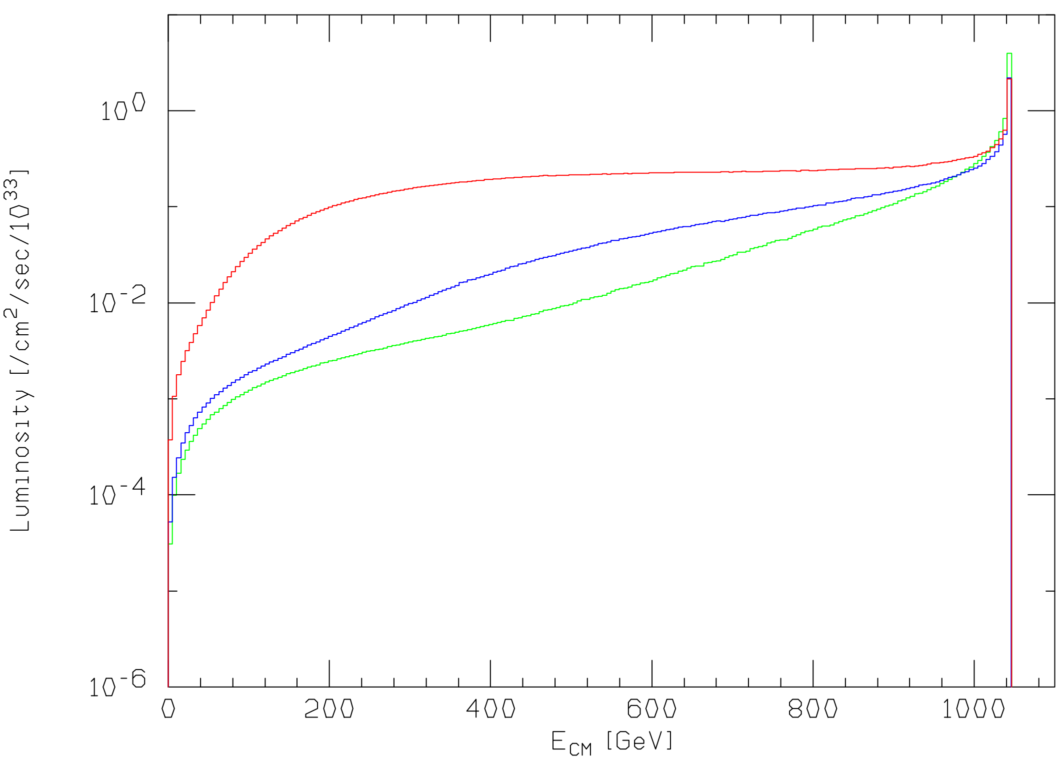

FIGURE 2. Luminosity spectra (taking number of bunches and repetition rate into account, and with beamstrahlung and ISR included) for NLC-A-1000 (green curve), for NLC-A-1000bx1by1 (red curve), and NLC-A-1000bx2.5by1 (blue curve).

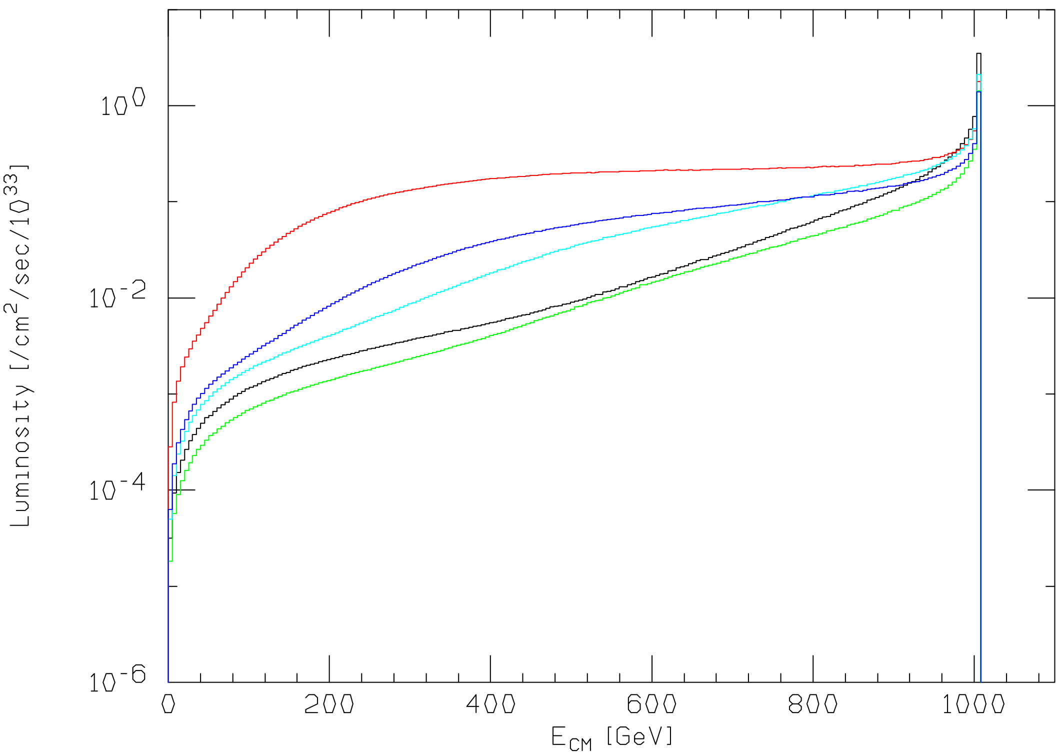

FIGURE 3. Luminosity spectra (taking number of bunches and repetition rate into account, and with beamstrahlung and ISR included) for NLC-B-1000 (black curve), and for NLC-B-1000 with $\beta_x^\star = \beta_y^\star = 1.3$ mm and $N = 0.95 \times 10^{10}$ (red curve), $N = 0.7 \times 10^{10}$ (blue curve), $N = 0.55 \times 10^{10}$ (cyan curve), $N = 0.4 \times 10^{10}$ (green curve). Note that the number of bunches is assumed to be doubled in the $N = 0.55 \times 10^{10}$ and $N = 0.4 \times 10^{10}$ designs (see text).