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Linear Collider Collaboration Tech Notes

Luminosity for NLC Design Variations

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Abstract:

In this note we give Guineapig simulation results for the luminosity and luminosity spectrum of three baseline NLC designs at 0.5~TeV and 1.0~TeV and compare the simulation results with analytic approximations. We examine the effects of varying several design parameters away from the NLC-B-500 and NLC-B-1000 designs, in order to study possible trade-offs of parameters that could ease tolerances, increase luminosity, or help to optimize machine operation for specific physics processes.

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INTRODUCTION

In this note we give Guineapig [1] simulation results for the luminosity and luminosity spectrum of three baseline NLC designs at 0.5 TeV (NLC-A-500, NLC-B-500, and NLC-C-500) and 1.0 TeV (NLC-A-1000, NLC-B-1000, and NLC-C-1000) [2]. we examine the effects of variations of several design parameters away from the NLC-B-500 and NLC-B-1000 designs. One of our purposes is to study possible trade-offs of parameters to ease tolerances or increase luminosity. Another (future) application will be to examine how the basic designs might be modified in special cases where one wants to optimize the luminosity for particular physics channels.

BASIC PARAMETERS AND RESULTS FOR SIX BASELINE DESIGNS

We start by giving the definitions of the luminosity-related parameters shown in Table 1. The geometric luminosity per bunch, not taking account of disruption or hourglass effect, is given by

$$\mathcal{L}_0 \equiv \frac{N^2}{4\pi\sigma_x\sigma_y} \quad . \tag{1}$$

The hour-glass effect reduces the undisrupted luminosity when one of the parameters

$$A_{x,y} \equiv \frac{\sigma_z}{\beta^*_{x,y}} \tag{2}$$

is significantly less than 1. The luminosity with hour-glass effect but without disruption, calculated by turning off the electromagnetic interaction in the Guineapig simulation, is denoted by $\mathcal{L}_{0A}$ in the table.

The disruption parameters are

$$D_{x,y} = \frac{2r_e\sigma_z N}{\gamma\sigma_{x,y}(\sigma_x+\sigma_y)} \tag{3}$$

We denote the actual luminosity with disruption and hour-glass effect taken into account by $\mathcal{L}_D$.

Let us define $H_D \equiv \mathcal{L}_D/\mathcal{L}_0$. An analytic approximation for H_D obtained by fitting simulation results for flat beams has been given by Yokoya and Chen [3]:

$$H_D^{anlyt} = \left[1 + D_y^{1/4}\left(\frac{D_y^3}{1 + D_y^3}\right)\left(\ln(\sqrt{D_y} + 1) + 2\ln\frac{0.8}{A_y}\right)\right]^{1/3} \quad . \tag{4}$$

We also show in the table the enhancement of the luminosity over the luminosity with hour-glass effect, $H_{DA} \equiv \mathcal{L}_D/\mathcal{L}_{0A}$.

For reference we include the values of the average beamstrahlung parameter Υ, as calculated from the analytic approximation given by Yokoya and Chen [3]:

$$\Upsilon_{avg}^{anlyl} = \frac{5}{12}\Upsilon_{max}^{anlyt} = \frac{5Nr_e^2\gamma}{6\alpha\sigma_z(\sigma_x + \sigma_y)} \quad . \tag{5}$$

Yokoya and Chen also give analytic approximations for n_γ, the average number of beamstrahlung photons produced per incoming beam particle:

$$n_\gamma \approx 2.12\frac{\alpha N r_e}{\sigma_x + \sigma_y}\frac{1}{(1 + \Upsilon_{avg}^{2/3})^{1/2}} \quad , \tag{6}$$

and δ_B, the average beamstrahlung energy loss per particle:

$$\delta_B \approx 0.864\frac{r_3^3 N^2\gamma}{\sigma_z(\sigma_x + \sigma_y)^2}\frac{1}{[1 + (1.5\Upsilon_{avg})^{2/3}]^2} \quad . \tag{7}$$

These are shown in the table as n_γ^{anlyt} and δ_B^{anlyt}. Also shown in the table are the simulation results for n_γ and δ_B. The agreement between the analytic approximations and the simulation results for H_D, n_γ and δ_B is quite good for these parameter sets, generally within a few percent.

We examine the luminosity spectra with and without initial state radiation (ISR). The luminosity spectra for NLC-B-500 and NLC-B-1000 are shown in Figures 1 and 2 respectively. The fractional luminosities with and without ISR are shown in the table. For example, $L_{99\%}$ denotes the percentage of the luminosity with center of mass energy greater than or equal to 99% of the nominal center of mass energy. These numbers are not significantly different for the A, B, and C variations of the designs, so are shown only for NLC-B-500 and NLC-B-1000.

Finally, we show the number of bunches per train, the repetition rate, and the luminosity per second, L_D, that takes these factors into account.

EFFECTS OF VARIATIONS OF SOME MACHINE PARAMETERS

In this section we show the results of varying the bunch charge N, bunch length σ_z, horizontal beta function β_x, vertical beta function β_y, horizontal emittance $\gamma\epsilon_y$,

TABLE 1. NLC IP parameters for baseline designs

	NLC-A-500	NLC-B-500	NLC-C-500	NLC-A-1000	NLC-B-1000	NLC-C-1000
E_{beam} [GeV]	267.5	257.5	250.	523.	504.	489.
N [10^{10}]	0.75	0.95	1.1	0.75	0.95	1.1
$\gamma\epsilon_x/\gamma\epsilon_y$ [10^{-6} m-rad]	4.0/0.06	4.5/0.1	5.0/0.14	4.0/0.06	4.5/0.1	5.0/0.14
β_x/β_y [mm]	10/0.1	12/0.12	13/0.2	10/0.125	12/0.15	13/0.2
σ_z [μm]	90.	120.	145.	90.	120.	145.
σ_x/σ_y [nm]	276.43/3.39	327.35/4.88	364.50/7.57	197.69/2.71	233.99/3.90	260.62/5.41
$\mathcal{L}_0$ [10^{33} m^{-2}]	4.777	4.496	3.490	8.365	7.870	6.830
A_x/A_y	0.009/0.9	0.010/1.00	0.011/0.725	0.009/0.72	0.01/0.8	0.011/0.725
D_x/D_y	0.094/7.67	0.117/7.87	0.136/6.53	0.094/6.85	0.103/7.03	0.136/6.53
H_D^{anlyt}	1.41	1.36	1.49	1.51	1.46	1.50
$\mathcal{L}_D^{anlyt} \equiv H_D^{anlyt} \cdot \mathcal{L}_0$ [10^{33} m^{-2}]	6.74	6.11	5.20	12.63	11.33	10.25
n_γ^{anlyt}	1.04	1.13	1.18	1.32	1.45	1.53
δ_B^{anlyt}	4.4%	3.9%	3.6%	10.7%	10.1%	9.5%
Υ_{avg}^{anlyt}	0.14	0.11	0.09	0.39	0.30	0.25
$\mathcal{L}_{0A}$ [10^{33} m^{-2}] (sim)	4.10	3.78	3.13	7.49	6.92	6.10
$\mathcal{L}_D$ [10^{33} m^{-2}] (sim)	6.51	5.84	5.21	12.57	11.36	10.24
$H_D \equiv \mathcal{L}_D/\mathcal{L}_0$ (sim)	1.36	1.30	1.49	1.50	1.44	1.50
$H_{DA} \equiv \mathcal{L}_D/\mathcal{L}_{0A}$ (sim)	1.59	1.55	1.67	1.68	1.64	1.68
n_γ (sim)	1.08	1.18	1.24	1.39	1.53	1.62
δ_B (sim)	4.3%	3.9%	3.7%	9.5%	9.2%	8.7%
Fractional luminosities (beamstrahlung only):						
$L_{99.5\%}$ (sim)		61%			46%	
$L_{99\%}$ (sim)		67%			52%	
$L_{98\%}$ (sim)		75%			59%	
$L_{95\%}$ (sim)		86%			72%	
$L_{90\%}$ (sim)		94%			83%	
$L_{80\%}$ (sim)		99%			94%	
$L_{50\%}$ (sim)		$\sim$100%			$\sim$100%	
Fractional luminosities (beamstrahlung + ISR):						
$L_{99.5\%}$ (sim)		37%			27%	
$L_{99\%}$ (sim)		44%			33%	
$L_{98\%}$ (sim)		54%			41%	
$L_{95\%}$ (sim)		69%			56%	
$L_{90\%}$ (sim)		81%			70%	
$L_{80\%}$ (sim)		91%			84%	
$L_{50\%}$ (sim)		98%			97%	
Num. bunches per train	95	95	95	95	95	95
Repetition rate	120	120	120	120	120	120
L_D [cm^{-2}sec^{-1}]	7.42	6.66	5.94	14.33	12.95	11.67

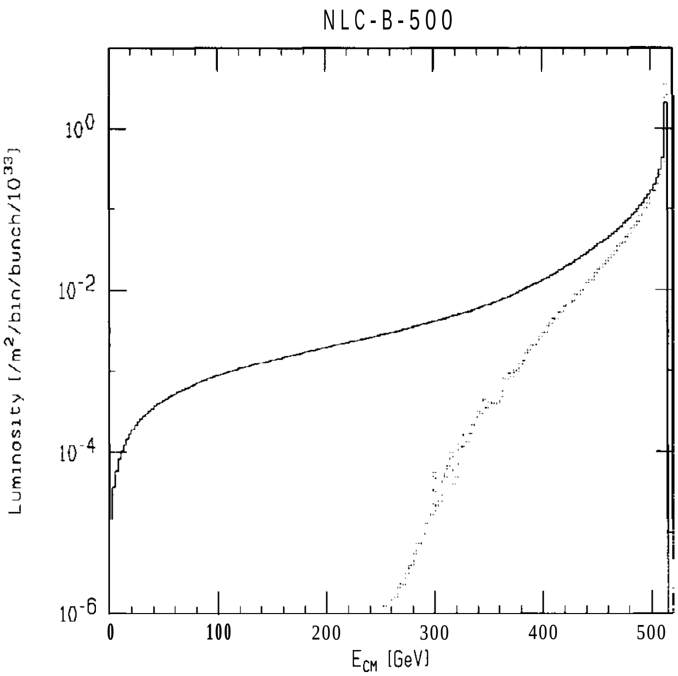

FIGURE 1. NLC-B-500 luminosity spectra with beamstrahlung and ISR included (solid histogram) and with beamstrahlung only (dotted histogram).

and vertical emittance $\gamma\epsilon_x$. The dependences of $\mathcal{L}_D, n_\gamma$, and δ_B on these parameters are shown in Figures 3 through 8 for variations away from the NLC-B-500 design and in Figures 9 through 14 for variations away from the NLC-B-1000 design. The luminosity curves shown have both beamstrahlung and ISR included. In each of these figures, the vertical line shows the nominal value of the parameter that is being varied.

DISCUSSION AND CONCLUSIONS

From the standpoint of parameter optimization, a very interesting result of this study is that the total and fractional luminosity is quite insensitive to variations in the vertical beta function (see Figures 6 and 12). The geometric luminosity without hourglass effect, $\mathcal{L}_0$, scales as $\beta_y^{-1/2}$. Also, $D_y \sim \beta_y^{-1/2}$ and $A_y \sim \beta_y^{-1}$. Although $H_D^{anlyt}(D_y, A_y)$ decreases when D_y decreases, it increases when A_y decreases, and it is the latter effect which dominates as one increases the beta function from its nominal NLC-B-1000 design value of 0.15 mm. Furthermore, although the simulation result agrees fairly well with the analytic result for increasing β_y, it is even flatter, as one sees from Figure 15. In this figure, the solid curve is the simulation result for the total luminosity, the upper dotted curve is $\mathcal{L}_0$, the lower dotted curve is H_D^{anlyt}, and the dashed curve (product of the two dotted curves) is $\mathcal{L}_D^{anlyt}$, the analytic result for the total luminosity. (We also see from this plot that the simulation and analytic results don't agree very well when the hour-glass effect becomes very strong.) The upshot is that it appears one could increase β_y with very little reduction in the luminosity. This would significantly loosen the tolerances in the final focus, which scale roughly between $\sqrt{\beta_y}$ and β_y.

REFERENCES

1. D.Schulte, Ph.D. thesis, 1996.
2. Parameters as of 8/8/98 obtained from Tor Raubenheimer.
3. Yokoya,K. and Chen,P., in M.Dienes,et.al. (ed.), Frontiers of Particle Beams: Intensity Limitations, (Springer-Verlag, 1992), p.415.

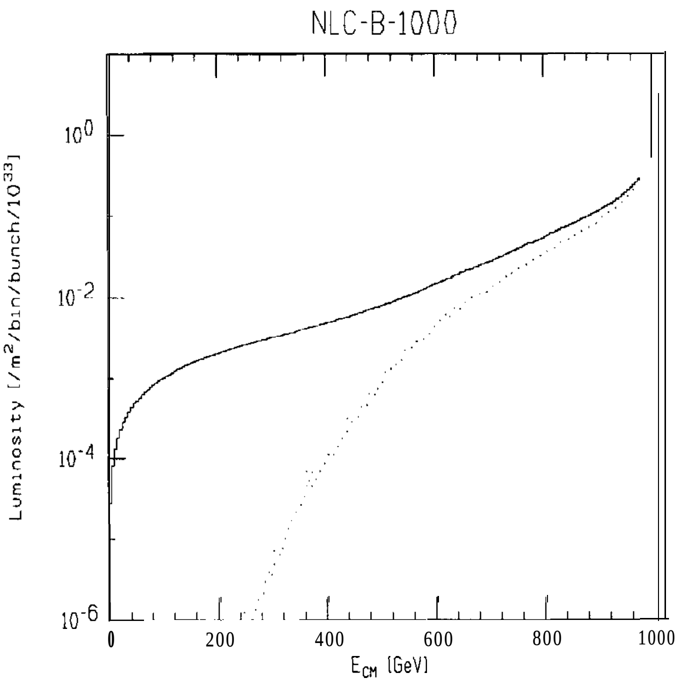

FIGURE 2. NLC-B-1000 luminosity spectra with beamstrahlung and ISR included (solid histogram) and with beamstrahlung only (dotted histogram).

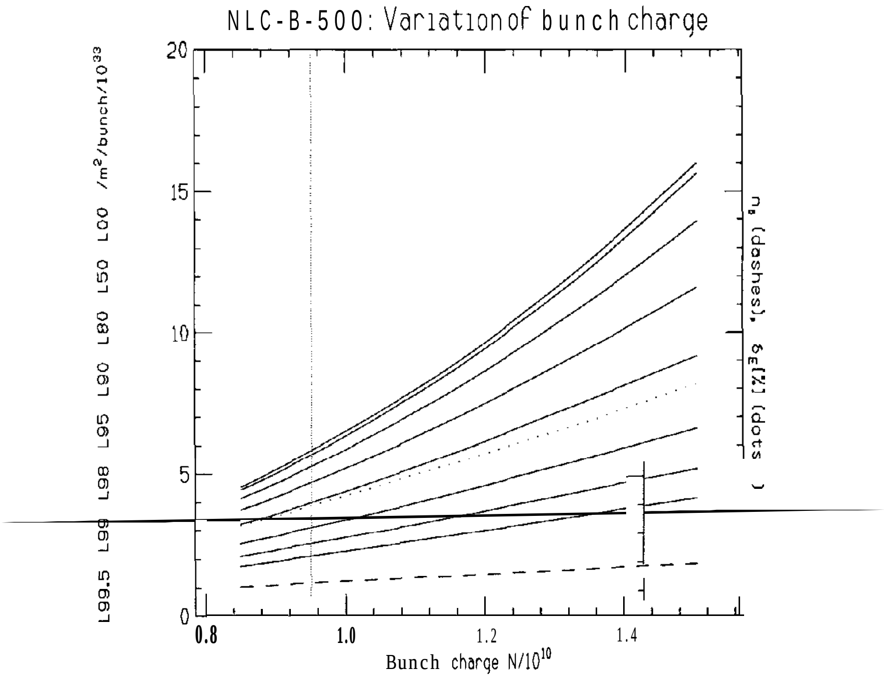

FIGURE 3. NLC-B-500 design with variation of bunch charge

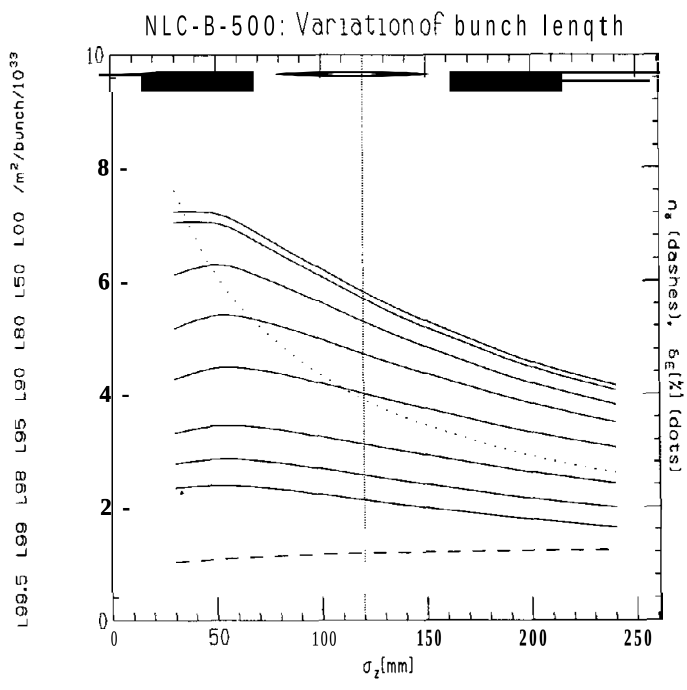

FIGURE 4. NLC-B-500 design with variation of bunch length

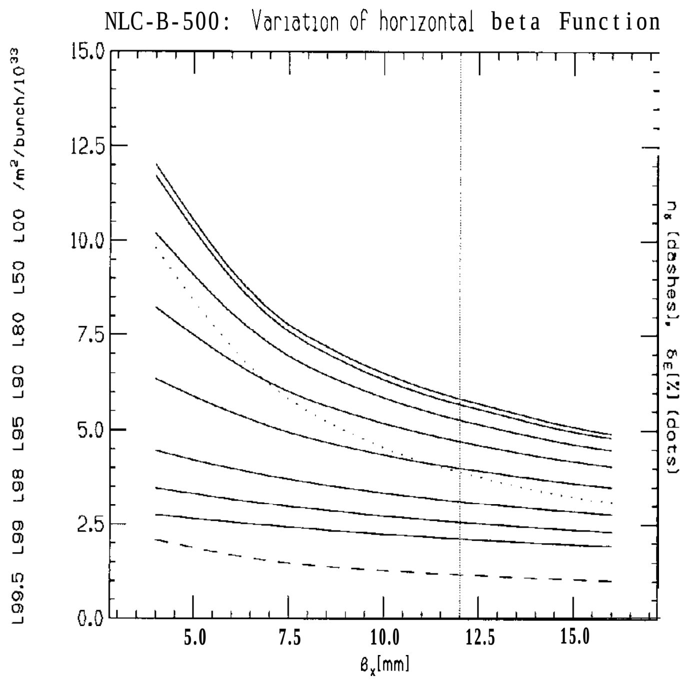

FIGURE 5. NLC-B-500 design with variation of horizontal beta function

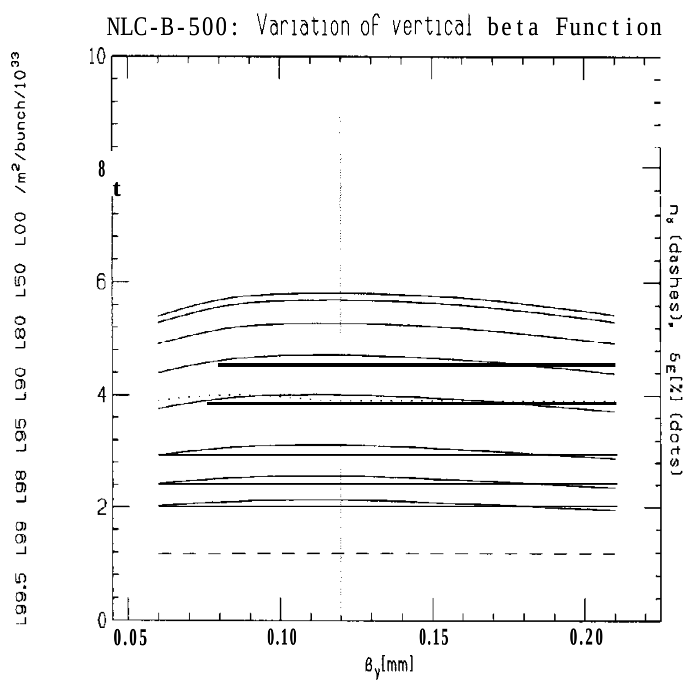

FIGURE 6. NLC-B-500 design with variation of vertical beta function

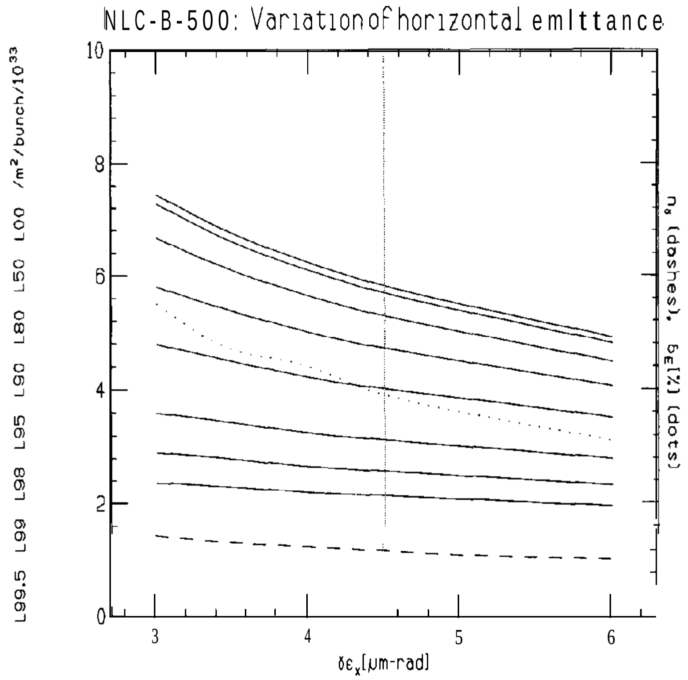

FIGURE 7. NLC-B-500 design with variation of x-emittance

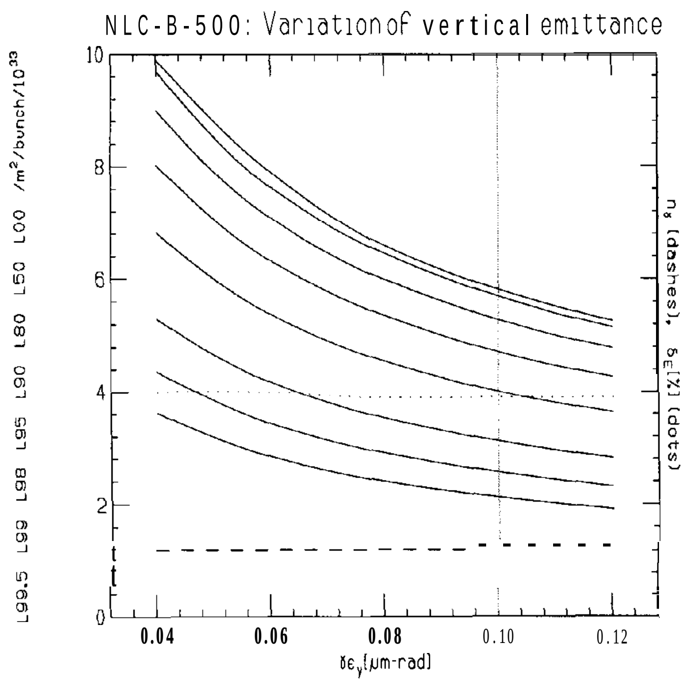

FIGURE 8. NLC-B-500 design with variation of y-emittance

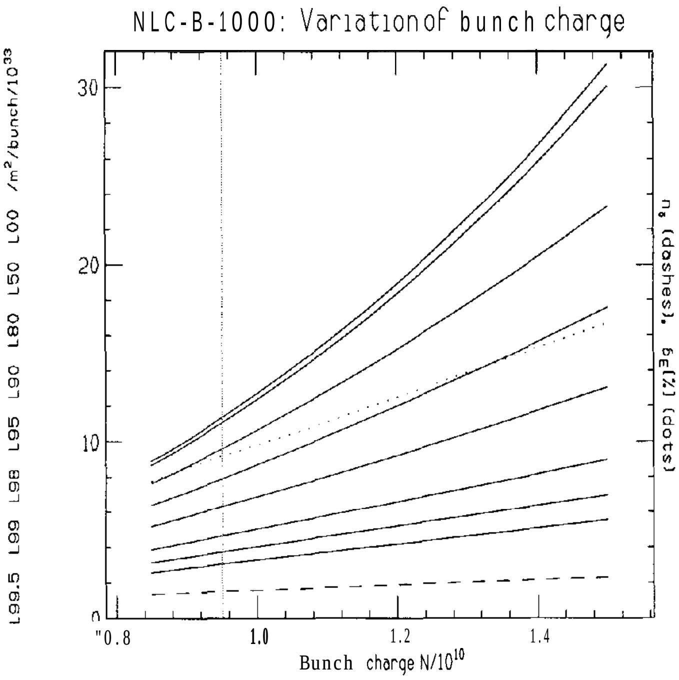

FIGURE 9. NLC-B-1000 design with variation of bunch charge

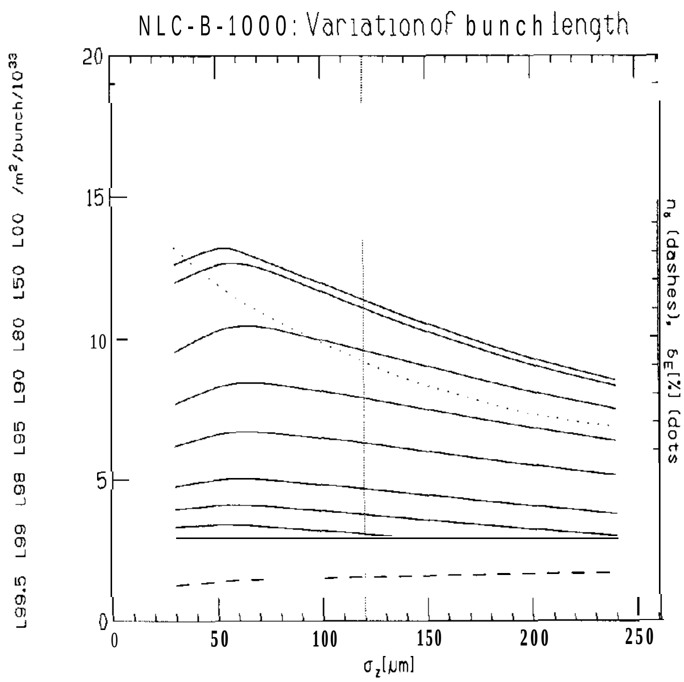

FIGURE 10. NLC-B-1000 design with variation of bunch length

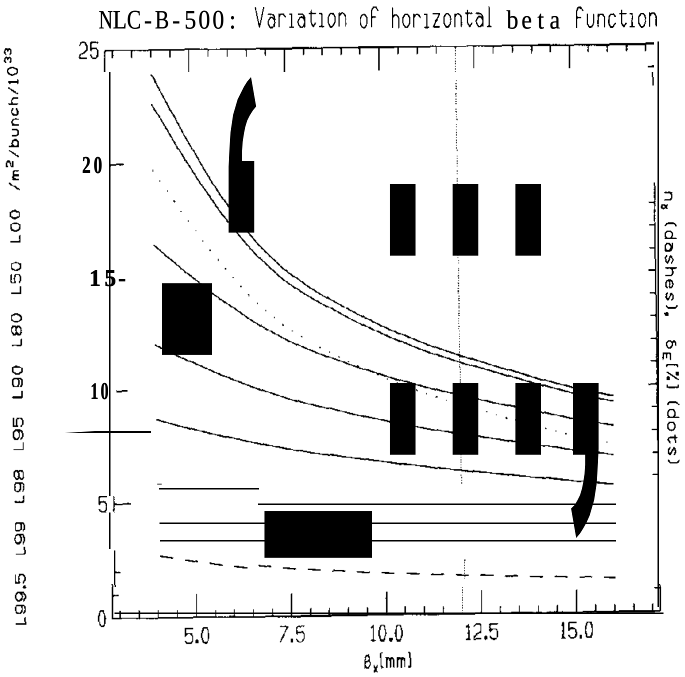

FIGURE 11. NLC-B-1000 design with variation of horizontal beta function

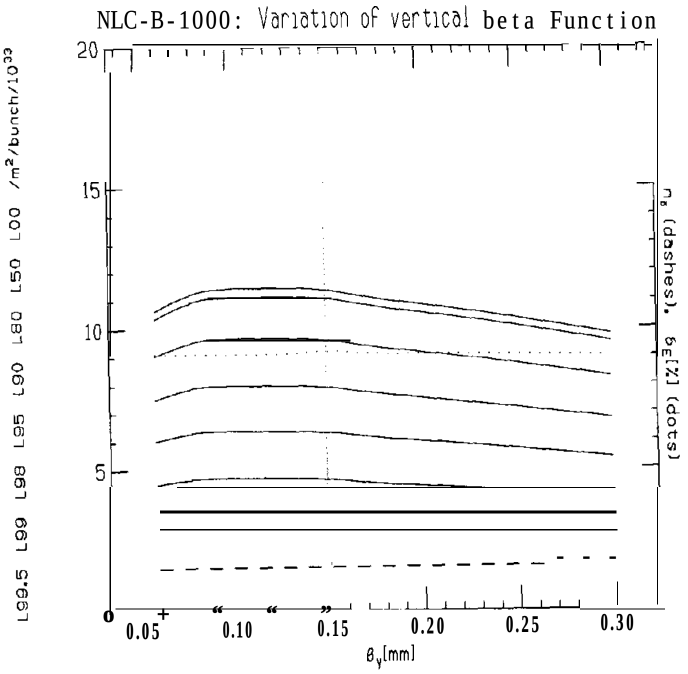

FIGURE 12. NLC-B-1000 design with variation of vertical beta function

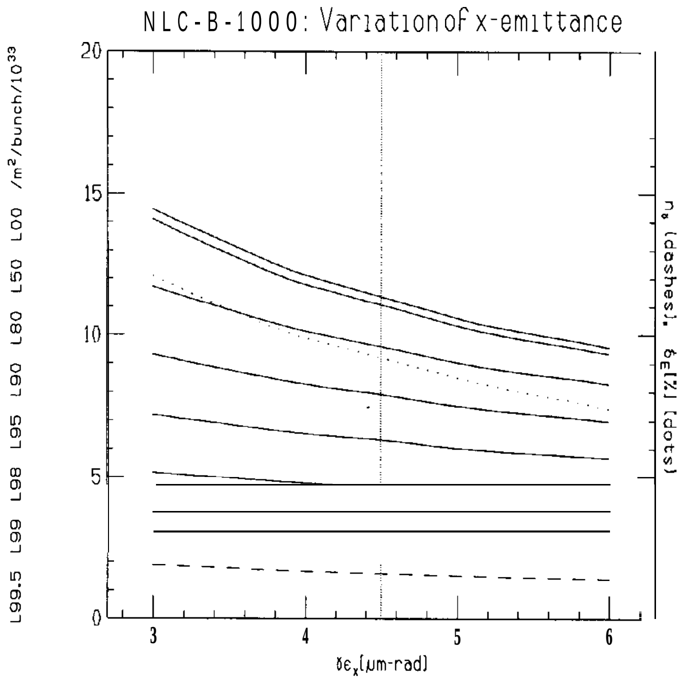

FIGURE 13. NLC-B-1000 design with variation of x-emittance

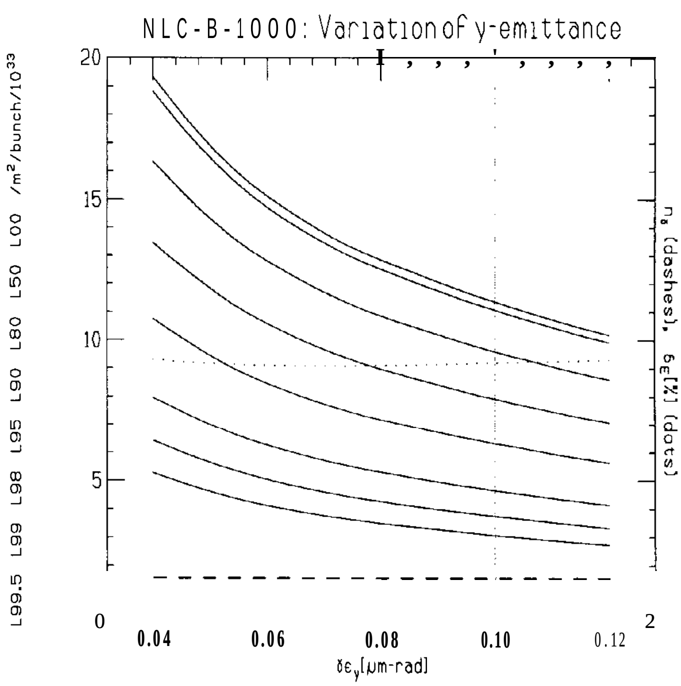

FIGURE 14. NLC-B-1000 design with variation of y-emittance

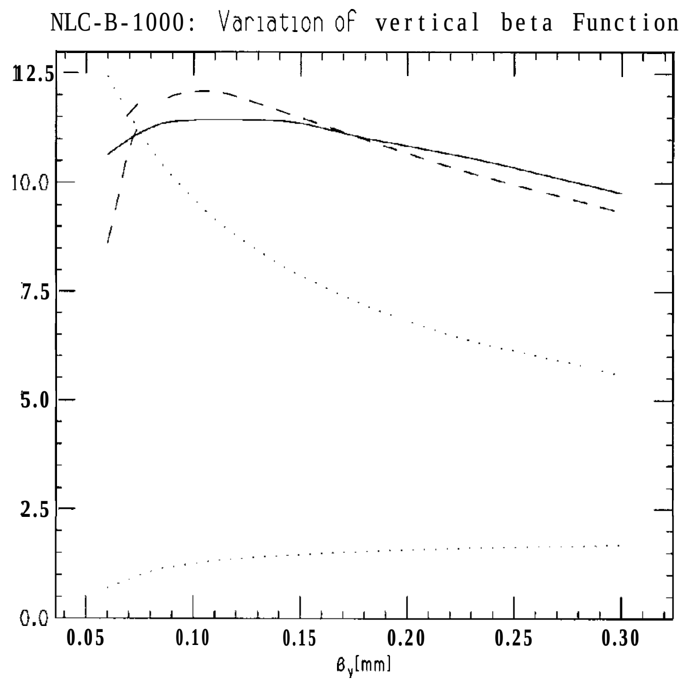

FIGURE 15. Detailed luminosity information for NLC-B-1000 design with variation of vertical beta function. The solid curve is the simulation result for $\mathcal{L}_D$, the upper dotted curve is $\mathcal{L}_0$, the lower dotted curve is H_D^{anlyt}, and the dashed curve (product of the two dotted curves) is $\mathcal{L}_D^{anlyt}$.