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Optimization of NLC Luminosity for e-e- Running*

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Abstract

We examine the optimization of the NLC for e^-e^- running. The dependence of luminosity on the interaction point beta functions β_x, β_y, emittances ϵ_x, ϵ_y, bunch charge N, and bunch length σ_z are very different for e^+e^- and e^-e^- because disruption reduces the luminosity in e^-e^- rather than increasing it as in e^+e^-. We examine how much luminosity may be regained in e^-e^- by varying these parameters away from optimized flat beam e^+e^- values. The results are compared with round beam e^-e^- designs considered in an earlier paper.†

† F.Zimmermann, K.A.Thompson, and R.H.Helm, Second International Workshop on Electron-Electron Interactions at TeV Energies, Santa Cruz, CA, 22-24 September 1997; Int.J.Mod.Phys A13:2443 (1998).

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OPTIMIZATION OF NLC LUMINOSITY FOR e^-e^- RUNNING *

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1. Introduction

In this paper we study the optimization of IP parameters for e^-e^- luminosity in the NLC. Simulation results are obtained using the Guineapig[2] beam-beam program. We begin from the nominal NLC e^+e^- interaction point parameters and then examine how to optimize these parameters for e^-e^- running. We focus on the 1 TeV center of mass case, but the general trends would be similar at 1/2 TeV. A previous study (Ref. 1) examined some possible round beam designs for e^-e^- running. Here we focus on the case of flat beams.

2. Basic Parameters and Results for NLC Baseline Designs

Interaction point parameters for the NLC baseline designs[3] at 1 TeV center of mass energy are shown in Table 1 for both the e^+e^- and e^-e^- modes of running. We use the following definitions: geometric luminosity per bunch (disruption and hour-glass effects not included) $\mathcal{L}_0 \equiv N^2/4\pi\sigma_x\sigma_y$; hour-glass parameters $A_{x,y} \equiv \sigma_z/\beta^*_{x,y}$; disruption parameters $D_{x,y} \equiv 2r_e\sigma_z N/\gamma\sigma_{x,y}(\sigma_x + \sigma_y)$; $\mathcal{L}_D \equiv$ actual luminosity per bunch with disruption and hour-glass effect taken into account; the disruption (de-)enhancement $H_D \equiv \mathcal{L}_D/\mathcal{L}_0$. For e^-e^-, the effect of disruption is of course a reduction in luminosity compared to the geometric luminosity, i.e. $H_D < 1$. L_D is the luminosity per second taking the number of bunches per train and the repetition rate into account. The average number of beamstrahlung photons produced per incoming beam particle is denoted by n_γ, and the average fractional beamstrahlung energy loss per particle by δ_E. The horizontal and vertical rms angular divergences (in μrad) of the outgoing disrupted beam are denoted by θ_x^{rms} and θ_y^{rms}.

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Table 1. NLC IP parameters for baseline designs at 1 TeV

	NLC-A-1000	NLC-B-1000	NLC-C-1000
E_{beam} [GeV]	523.	504.	489.
N [10^{10}]	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
β_x/β_y [mm]	10/0.125	12/0.15	13/0.2
σ_z [μm]	90.	120.	145.
σ_x/σ_y [nm]	197.69/2.71	233.99/3.90	260.62/5.41
$R \equiv \sigma_x/\sigma_y$	73	60	48
$\mathcal{L}_0$ [10^{33} m^{-2}]	8.365	7.870	6.830
A_x/A_y	0.009/0.72	0.01/0.8	0.011/0.725
D_x/D_y	0.094/6.85	0.103/7.03	0.136/6.53
Num. bunches per train	95	95	95
Repetition rate	120	120	120
e+e- results:			
$\mathcal{L}_D$ [10^{33} m^{-2}]	12.57	11.36	10.24
$H_D \equiv \mathcal{L}_D/\mathcal{L}_0$	1.50	1.44	1.50
n_γ	1.39	1.53	1.62
δ_E	9.5%	9.2%	8.7%
L_D [cm^{-2}sec^{-1}]	14.33	12.95	11.67
θ_x^{rms} [μrad]	126	140	149
θ_y^{rms} [μrad]	33	37	41
H_D^{anlyt}	1.51	1.46	1.50
e-e- results:			
$\mathcal{L}_D$ [10^{33} m^{-2}]	4.09	3.77	3.39
$H_D \equiv \mathcal{L}_D/\mathcal{L}_0$	0.49	0.48	0.50
n_γ	1.25	1.37	1.44
δ_E	8.7%	8.2%	7.8%
L_D [cm^{-2}sec^{-1}]	4.66	4.30	3.86
θ_x^{rms} [μrad]	114	124	132
θ_y^{rms} [μrad]	110	119	128
H_D^{anlyt}	0.45	0.44	0.46

We have elsewhere given[4] the following analytic approximation for the disruption de-enhancement H_D in e^-e^- collisions:

$$H_D = \left[1 - 0.15 f(R) \left(\frac{A_y}{1+0.4D_y}\right)^{f(R)}\right] \times$$
$$\exp\left(-\frac{f(R)D_y}{3\sqrt{\pi}}\right) I_0\left(\frac{f(R)D_y}{3\sqrt{\pi}}\right) \min(1, 1+0.1\ln D_y) \quad . \qquad (1)$$

Here $R \equiv \sigma_x/\sigma_y$ is the aspect ratio of the beam, and

$$f(R) \equiv 1 + \frac{1}{R^2} \quad . \qquad (2)$$

The modified Bessel function I_0 may be approximated by

$$I_0(x) = \begin{cases} 1 + \frac{x^2}{4} + \frac{x^4}{64} + \frac{x^6}{2304} & (x < 1) \\ \frac{e^x}{\sqrt{2\pi x}}\left[1 + \frac{1}{8x} + \frac{9}{128x^2}\right] & (x > 1) \quad . \end{cases} \qquad (3)$$

There also exists an analytic approximation to H_D for e^+e^- collisions.[5] The results of these analytic approximations to the disruption (de-)enhancement are denoted in Table 1 by H_D^{anlyt}.

The fractional luminosities with initial state radiation (ISR) included are shown in Table 2 for both e^+e^- and e^-e^-. 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-1000.

3. Scaling of Luminosity with Individual Parameters

We show in Figures 1 through 6 the results of varying the parameters β_x, β_y, ϵ_x, ϵ_y, N, and σ_z. In each of these figures, the vertical line shows the nominal e^+e^- value

Table 2. Fractional luminosities for baseline designs at 1 TeV c.m., with effects of beamstrahlung and initial state radiation included.

	e^+e^-	e^-e^-
$L_{99.5\%}$	27%	35%
$L_{99\%}$	33%	42%
$L_{98\%}$	41%	50%
$L_{95\%}$	56%	64%
$L_{90\%}$	70%	77%
$L_{80\%}$	84%	88%
$L_{50\%}$	97%	98%

of the parameter that is being varied. The solid curves (from top to bottom) denote the amount of luminosity above 99.5%, 99%, 98%, 95%, 90%, 80%, 50%, and 0% of the nominal energy. The dashed curve in each plot shows n_γ and the dotted curve shows δ_E.

Changing the emittances or the beta functions does not have much effect on the e^-e^- luminosity. This is because the effects on the undisrupted spot size and on H_D tend to cancel each other out. Decreasing horizontal or vertical spot size using any of these four parameters does give a slight improvement in the total luminosity. If the horizontal spot size is decreased, n_γ rises sharply and there is little improvement in the luminosity near the nominal energy. If the vertical spot size is decreased, there is almost no effect on n_γ and δ_E, and there is some improvement in the luminosity near the nominal energy.

Decreasing σ_z produces significant improvement in both the fractional and total luminosities. The main reason for the luminosity increase is the smaller disruption D_y. (Decreasing σ_z also helps by reducing the hour-glass parameters, but D_y is sufficiently large that this makes little contribution – see Eq. (1) above and Figure 2 of Ref. 4.) There is, however, a significant increase in the fractional energy loss δ_E due to beamstrahlung when σ_z is decreased.

Increasing the bunch charge N also significantly increases fractional and total luminosities, but at the cost of significantly increasing δ_E and n_γ. Increasing N hurts by increasing the disruption $D_y \propto N$, and H_D decreases significantly as a function of D_y in the range of D_y being considered here. However, increasing N helps by increasing the geometric luminosity $\mathcal{L}_0 \propto N^2$, and the latter is the dominant effect.

4. Optimizing e^-e^- Luminosity

Clearly to improve the luminosity of these flat beam designs, one would like to decrease σ_z and/or increase N. Obviously we cannot change N and σ_z arbitrarily. Not only are there constraints on how high an n_γ can be tolerated, but there are also constraints due to upstream systems, e.g., the linacs and damping rings. One of these constraints is the energy spread in the linac which scales approximately as N/σ_z. Increasing N/σ_z by 50% or maybe 100% is probably as far as it is reasonable to go. Tables 3 and 4 show the results of doing so by increasing N alone, decreasing σ_z alone, or by a combination of the two. Maintaining the emittance also becomes much more difficult as the bunch charge N is pushed up, so it may not be feasible to double N and keep all the other parameters at their nominal values. A factor of two increase in total luminosity is probably the most optimistic that one could hope for by increasing N/σ_z. The luminosity increase near the peak energy is much less, due to increased beamstrahlung losses. The round beam designs of Ref. 1 can obtain comparable luminosities even without putting a plasma at the IP to reduce disruption, but such designs have the disadvantage of much higher beamstrahlung losses and increased backgrounds.

5. Conclusions

It appears that getting to even 2/3 the nominal e^+e^- luminosity in e^-e^- flat beam running mode would make the operation of the linacs significantly more challenging. This may be a strong motivation for pushing the more radical option of round beams with a plasma lens at the IP as discussed in Ref. 1.

References

1. F.Zimmermann, K.A.Thompson, and R.H.Helm, Second International Workshop on Electron-Electron Interactions at TeV Energies, Santa Cruz, CA, 22-24 September 1997; Int.J.Mod.Phys A13:2443 (1998).
2. D.Schulte, Ph.D. thesis, University of Hamburg 1996; TESLA-97-08.
3. e^+e^- parameters as of 8/8/98 obtained from Tor Raubenheimer.
4. K.A.Thompson and P.Chen, 4th International Workshop on Linear Colliders (LCWS 99), Sitges, Barcelona, Spain, 28 Apr - 5 May 1999; SLAC-PUB-8230.
5. K.Yokoya and P.Chen, in M.Dienes, et al. (ed.), Frontiers of Particle Beams: Intensity Limitations, (Springer-Verlag, 1992), p.415.

Table 3. Increase N/σ_z by factor ~ 1.5

	nominal NLC-B-1000	increase N only	decrease σ_z only	increase N decrease σ_z
N $[10^{10}]$	0.95	1.425	0.95	1.1
σ_z $[\mu\text{m}]$	120.	120	80	90
$\mathcal{L}_0$ $[10^{33}\ \text{m}^{-2}]$	7.87	17.7	7.87	10.55
A_y	0.8	0.8	0.53	0.6
D_y	7.03	10.5	4.69	6.1
$\mathcal{L}_D$ $[10^{33}\ \text{m}^{-2}]$	3.77	7.16	4.50	5.44
$\mathcal{L}_{99.5\%}$	1.36	2.14	1.55	1.78
$\mathcal{L}_{99\%}$	1.61	2.58	1.84	2.12
$\mathcal{L}_{98\%}$	1.93	3.15	2.20	2.55
$\mathcal{L}_{95\%}$	2.46	4.16	2.80	3.30
$\mathcal{L}_{90\%}$	2.92	5.11	3.35	3.99
$\mathcal{L}_{80\%}$	3.35	6.10	3.90	4.69
$\mathcal{L}_{50\%}$	3.69	6.97	4.38	5.30
$H_D \equiv \mathcal{L}_D/\mathcal{L}_0$	0.48	0.40	0.57	0.52
n_γ	1.37	1.95	1.36	1.57
δ_E	8.2%	13.7%	9.8%	11.3%
θ_x^{rms} $[\mu\text{rad}]$	124	190	130	150
θ_y^{rms} $[\mu\text{rad}]$	119	195	135	155

Table 4. Increase N/σ_z by factor ~ 2

	nominal NLC-B-1000	increase N only	decrease σ_z only	increase N decrease σ_z
N [10^{10}]	0.95	1.9	0.95	1.3
σ_z [μm]	120.	120	60	80
$\mathcal{L}_0$ [10^{33} m^{-2}]	7.87	31.5	7.87	14.7
A_y	0.8	0.8	0.40	0.53
D_y	7.03	14.1	3.52	6.4
$\mathcal{L}_D$ [10^{33} m^{-2}]	3.77	11.1	4.97	7.48
$\mathcal{L}_{99.5\%}$	1.36	2.88	1.70	2.25
$\mathcal{L}_{99\%}$	1.61	3.50	2.00	2.68
$\mathcal{L}_{98\%}$	1.93	4.33	2.37	3.25
$\mathcal{L}_{95\%}$	2.46	5.86	3.02	4.25
$\mathcal{L}_{90\%}$	2.92	7.40	3.62	5.22
$\mathcal{L}_{80\%}$	3.35	9.10	4.24	6.26
$\mathcal{L}_{50\%}$	3.69	10.76	4.84	7.27
$H_D \equiv \mathcal{L}_D/\mathcal{L}_0$	0.48	0.35	0.63	0.51
n_γ	1.37	2.4	1.33	1.78
δ_E	8.2%	18.5%	10.8%	14.2%
θ_x^{rms} [μrad]	124	260	135	185
θ_y^{rms} [μrad]	119	265	140	195

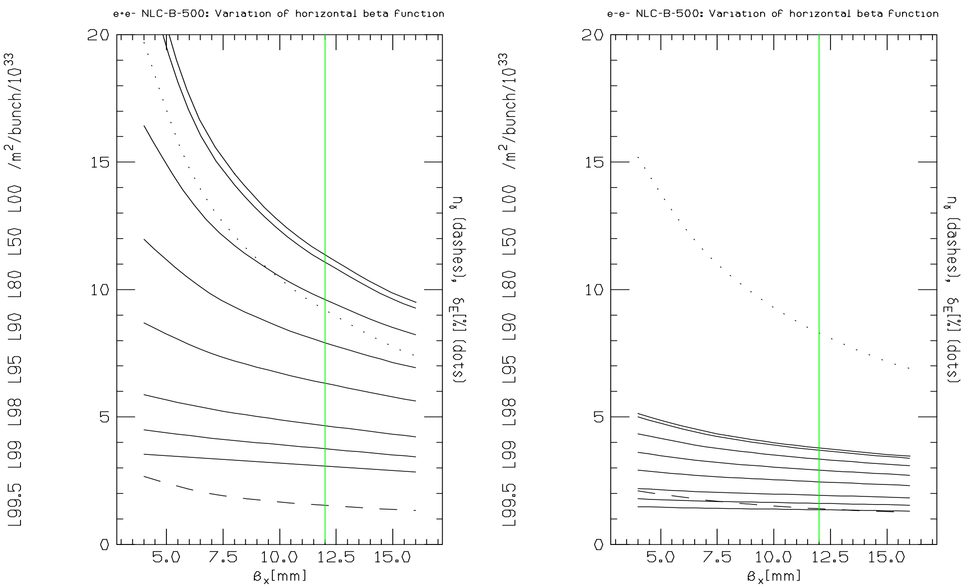

Fig. 1. e^+e^- and e^-e^- designs at 1 TeV c.m. with variation of horizontal beta function. Here and in the following figures, the vertical line shows the nominal e^+e^- design value of the parameter that is being varied. The solid curves (from top to bottom) denote the amount of luminosity above 99.5%, 99%, 98%, 95%, 90%, 80%, 50%, and 0% of the nominal energy. The dashed curve shows n_γ and the dotted curve shows δ_E.

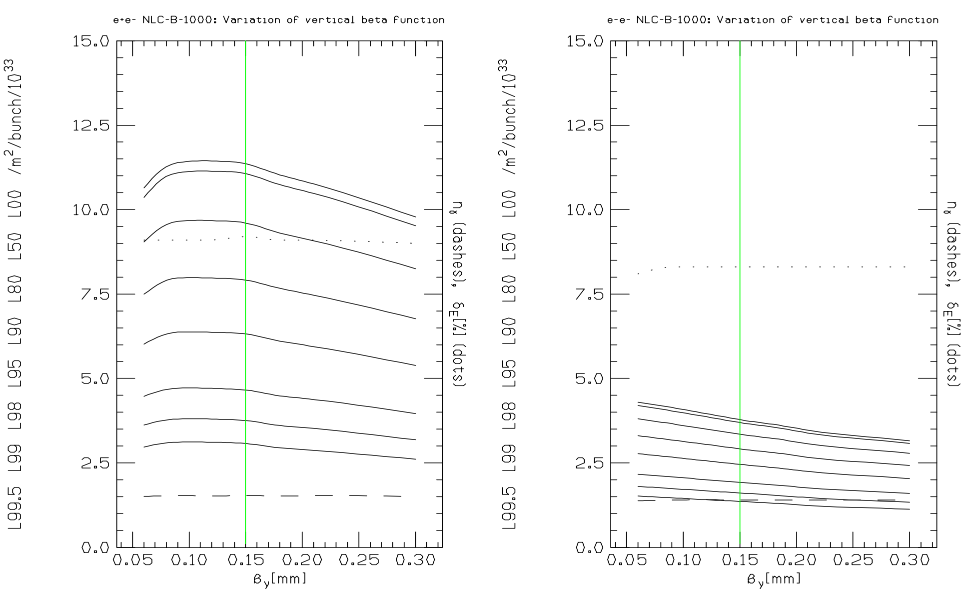

Fig. 2. e^+e^- and e^-e^- designs at 1 TeV c.m. with variation of vertical beta function.

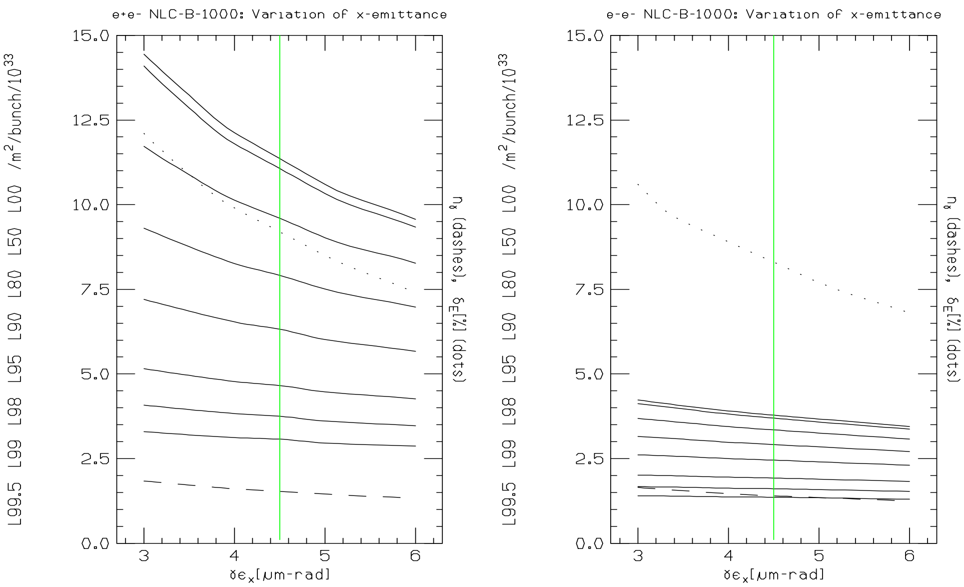

Fig. 3. e^+e^- and e^-e^- designs at 1 TeV c.m. with variation of x-emittance.

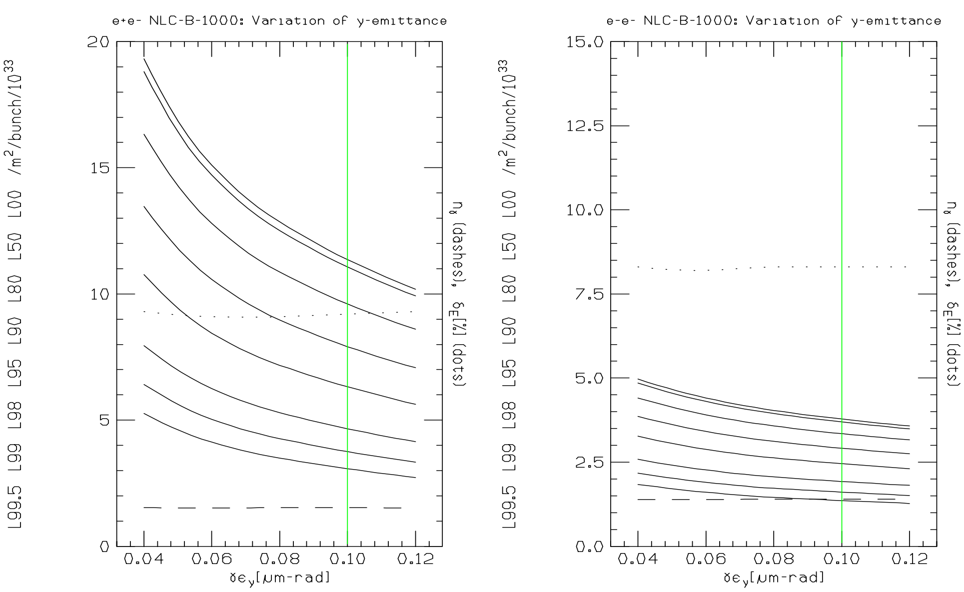

Fig. 4. e^+e^- and e^-e^- designs at 1 TeV c.m. with variation of y-emittance. Note the different vertical scales.

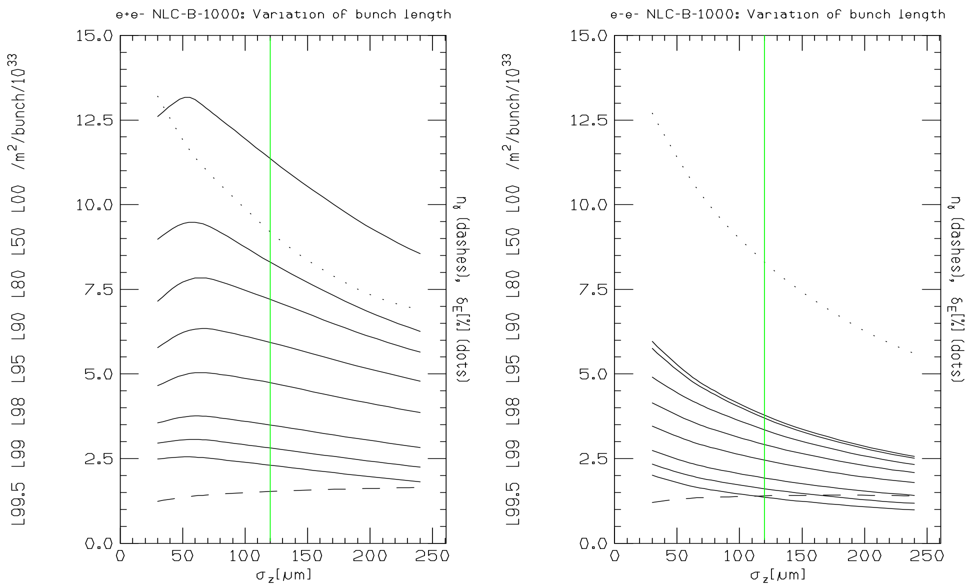

Fig. 5. e^+e^- and e^-e^- designs at 1 TeV c.m. with variation of bunch length.

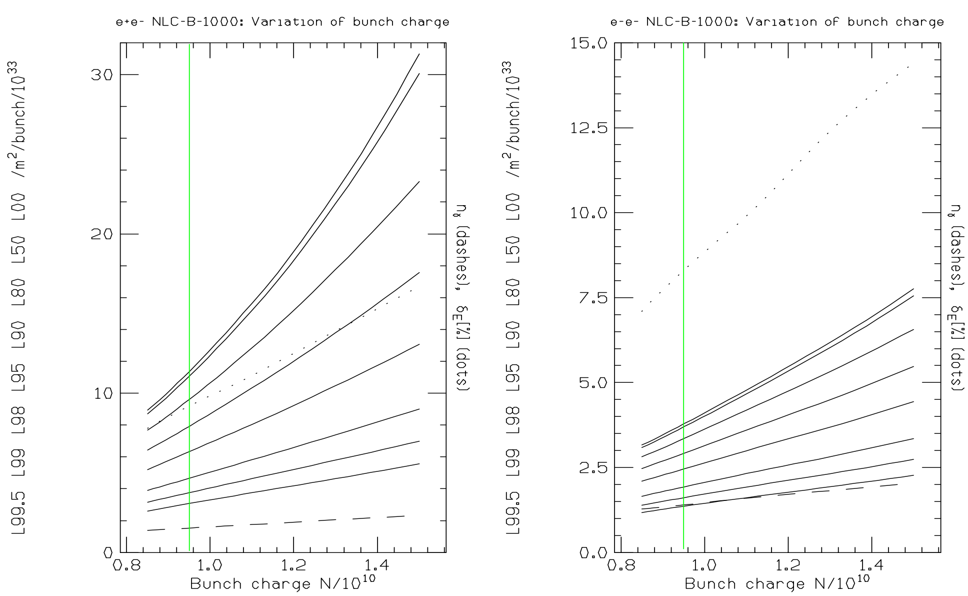

Fig. 6. e^+e^- and e^-e^- designs at 1 TeV c.m. with variation of bunch charge. Note the different vertical scales.