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Tolerance to offsets for a plasma lens in NLC

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A plasma lens at or near the interaction point of a linear collider is a possible way to boost the luminosity and or ease the requirements of the conventional final focus system. However the luminosity with a plasma lens is more sensitive to the effects of jitter. In this note we report on the results of simulations of luminosity as a function of vertical offset in an NLC design.

I.

Recent successful demonstrations of focusing by a plasma lens[1] raise the possibility of using such a lens in future linear colliders. The purpose of this note is to simulate what the effect of beam jitter on luminosity would be if a plasma lens were used at the NLC interaction point. Since the beams are quite flat, we only concern ourselves with the vertical jitter.

A plasma lens could either be located right at the interaction point, or a few millimeters upstream. In either case the expected amount of vertical beam-to-beam jitter is comparable to the beam size σ_{y_0} at the entrance to the plasma lens.

The parameters used [2] for the nominal NLC designs near 1/2 TeV and 1 TeV center of mass energy are given in Table I. We shall focus on the NLC-B-500 design. The GUINEAPIG beam-beam program[**?**] is used to simulate the beam-beam interaction and resulting luminosity.

We assume that the demagnification by the plasma lens will be about a factor of three in both the x and y directions, for the nominal case. Thus if the final vertical beam size is the nominal value for the NLC-B-500 design, namely $\sigma_y = 4.88$ nm, then the beam size before demagnification by the plasma lens is assumed to be about $\sigma_{y_0} = 14.6$ nm. Incoming jitter, however, is not demagnified by the plasma lens, unlike in a conventional final focus where the jitter is demagnified by the same factor as the beam size.

To obtain an estimate of the luminosity with jitter taken into account, we calculated the luminosity as a function of offset dy of the two beams. This was done for a range of demagnifications by the plasma lens, corresponding to vertical beam sizes between 2.88 and 5.88 nm. The beam size before demagnification is kept fixed at $\sigma_{y_0} = 14.6$ nm. We show the results of scans in the beam-to-beam vertical offset (in units of the vertical beam size) in Figure 1. In this figure, the horizontal beam size is kept at its nominal value $\sigma_x = 327$ nm. Each curve in this figure corresponds to a particular value of the final vertical beam size. [The fact that the luminosity for $dy = 0$ decreases dramatically for the red curve is due to the hour-glass effect. In other words, in attempting to get a very small spot size assuming constant incoming emittance, the vertical beta function has been made significantly smaller than the bunch length.]

The points marked on each curve show where the value of the vertical offset in nm is equal to 7.3 nm (diamonds), 10.3 nm (squares), 14.6 ($'s), 20.7 nm (X's), or 29.2 nm (+'s). From the standpoint of maximizing luminosity with these amounts of jitter taken into account, we see that the optimum vertical beam size is close to the nominal value of 4.88 nm and not extremely sensitive to it.

If the beam-to-beam jitter coming into the plasma lens is equal to the assumed incoming beam size $\sigma_{y_0} =$ 14.6 nm (corresponding to the $ symbols in Figure 1), the luminosity loss is about 30% compared to the case of no jitter. This amount of incoming jitter is at the optimistic end of the range of values presently anticipated in the NLC design. For comparison, the luminosity loss due to jitter assuming a conventional focusing system is about 10%, assuming the same amount of jitter coming into the focusing system. The difference of course comes from the fact that in the conventional system, the jitter is demagnified by the same factor as the beam size. Table II shows the luminosity loss in the conventional and plasma lens systems for varying amounts of jitter coming into the focusing system. Obviously, to take maximum advantage of the benefits offered by a plasma lens, it is desirable to keep the vertical jitter as small as possible.

We may also reduce the final horizontal beam size to regain some or all of the luminosity lost due to jitter. (This can also be done in the conventional designs without plasma lens; in either scenario, higher luminosity comes at the expense of higher beamstrahlung, as will be discussed further in a moment.) In Figure 2 we show

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TABLE I: 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]	276/3.4	327/4.88	364/7.57	198/2.71	234/3.90	261/5.41
$\mathcal{L}_0$ [10^{33} m^{-2}]	4.78	4.50	3.49	8.37	7.87	6.83
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
Υ_{avg}	0.14	0.11	0.09	0.39	0.30	0.25
$\mathcal{L}_D$ [10^{33} m^{-2}]	6.51	5.84	5.21	12.57	11.36	10.24
$H_D \equiv \mathcal{L}_D/\mathcal{L}_0$	1.36	1.30	1.49	1.50	1.44	1.50
n_γ	1.08	1.18	1.24	1.39	1.53	1.62
δ_B	4.3%	3.9%	3.7%	9.5%	9.2%	8.7%
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

TABLE II: Luminosity loss due to jitter in conventional and plasma lens systems. We assume $\sigma_y = 4.88$ nm and that the beam size coming into the focusing system is three times larger, i.e. $\sigma_{y_0} = 14.6$ nm.

Beam-to-beam offset entering focusing system	Luminosity loss for conventional system	Luminosity loss for plasma-lens
$\sigma_{y_0}/2 = 7.3$ nm	3%	14%
$\sigma_{y_0}/\sqrt{2} = 10.3$ nm	5%	21%
$\sigma_{y_0} = 14.6$ nm	10%	32%
$\sqrt{2} \cdot \sigma_{y_0} = 20.7$ nm	14%	46%
$2 \cdot \sigma_{y_0} = 20.7$ nm	23%	65%

scans of the vertical offset with the horizontal beam size reduced to $\sigma_x = 270$ nm. These reductions in the horizontal beam size can increase the luminosity to values comparable with the original nominal luminosity, but only if the jitter is kept quite small (squares and diamonds in Figure 2. The optimum vertical beam size (for the assumed beam-to-beam jitter of 10.3 nm) is still close to the nominal value of 4.88 nm.

Of course, reducing the beam size drives up the number n_γ of beamstrahlung photons emitted per electron, as well as the average fractional beamstrahlung energy loss δ_B. For the nominal horizontal beam size $\sigma_x = 327$ nm and with $\sigma_y = 4.88$ nm, we have $n_\gamma = 1.3$ and δ_B=4.6%. For $\sigma_x = 270$ nm and $\sigma_y = 4.88$ nm, we have n_γ=1.6 and δ_B=6.3%. These values are with a beam-to-beam offset of 10.3 nm taken into account – they are larger than the values for head-on collisions. This is because with an offset of this size, each beam has greater overlap with regions of higher field from the other beam than it does for head-on collisions. The horizontal beam size probably should not be reduced too much further, since the n_γ values become substantially larger than the nominal design values.

In conclusion, since the luminosity obtained using a plasma lens can be significantly more sensitive to vertical incoming jitter than a conventional system, control of vertical jitter is even more important than in the conventional system. This must be weighed against the reduced requirements on the conventional final focus system upstream of the plasma lens. Some of the luminosity lost due to vertical jitter can be regained by decreasing the horizontal beam size. Issues associated with the crab crossing, backgrounds, and stability of operation must of course be addressed as well.

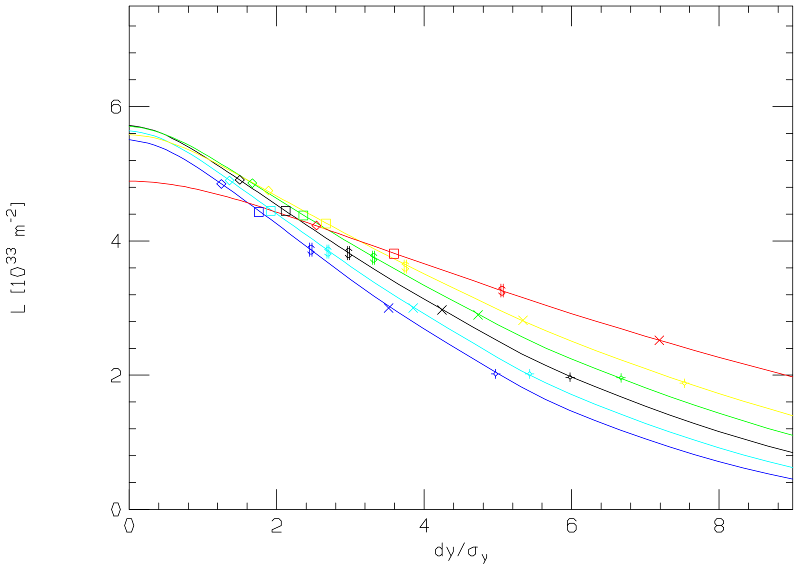

FIG. 1: Luminosity (per bunch) for y-scans, shown versus dy/σ_y, for several vertical beam sizes, with horizontal beam size kept at its nominal value of $\sigma_x = 327$ nm. Curves are shown for $\sigma_y = 2.88$ nm (red), $\sigma_y = 3.88$ nm (yellow), $\sigma_y = 4.38$ nm (green), $\sigma_y = 4.88$ nm (black), $\sigma_y = 5.38$ nm (cyan), $\sigma_y = 5.88$ nm (blue). The diamonds are the points (one on each curve) for which the beam-to-beam offset is about $\frac{\sigma_{y0}}{2} = 7.3$ nm. The squares are the points for which the beam-to-beam offset is about $\sqrt{2} \cdot \frac{\sigma_{y0}}{2} = 10.3$ nm. The \$'s are the points for which the beam-to-beam offset is about $\sigma_{y0} = 14.6$ nm. The X's are the points for which the beam-to-beam offset is about $\sqrt{2} \cdot \sigma_{y0} = 20.7$ nm. The +'s are the points for which the beam-to-beam offset is about $2 \cdot \sigma_{y0} = 29.2$ nm.

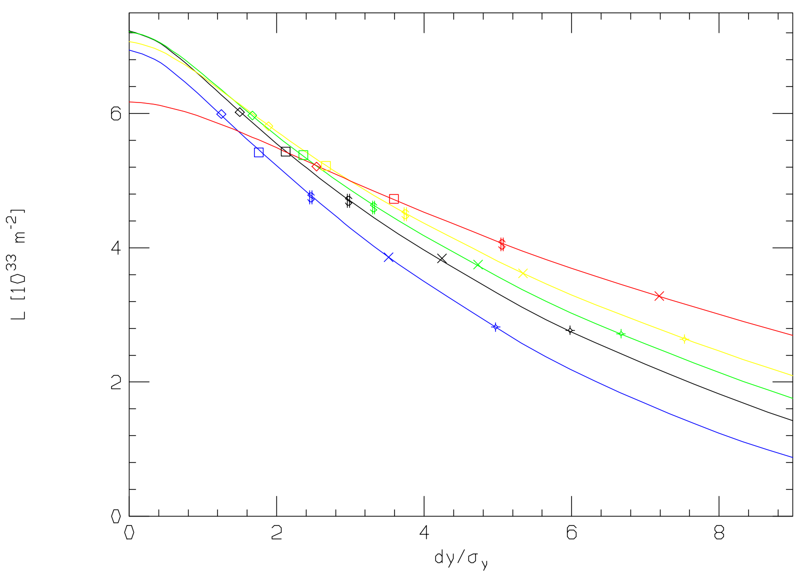

FIG. 2: Luminosity (per bunch) for y-scans, shown versus dy/σ_y, for several vertical beam sizes, with horizontal beam size reduced to $\sigma_x = 270$ nm. Symbols and colors are as in the previous figure.

Acknowledgments

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[1] See J.Ng, et.al., these proceedings
[2] Parameters as of 1998 (differences from current parameters are not significant for the present study).