RE-OPTIMIZATION OF THE FINAL FOCUS SYSTEM OPTICS WITH VERTICAL CHROMATICITY CORRECTION*

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Abstract

The purpose of the final focus system (FFS) of the future linear colliders (ILC and CLIC) is to demagnify the beam to the required size at the interaction point (IP). This can be done in a compact way based on a local chromaticity correction [1]. For an enlarged horizontal beta function at the IP βx*, chromaticity on horizontal plane will be smaller. We get a smaller vertical beam size, at the expense of a larger horizontal beam size, with chromaticity correction mainly in the vertical plane using fewer sextupoles: 2 or 3 instead of 5. For a new FFS design with this scheme, we'll also not need the first peak of β, which will reduce overall vertical chromaticity. This can lead to a shorter and easier to tune FFS. Another benefit is that the beamstrahlung at the IP will be reduced.

INTRODUCTION

The Principles of the Present FFS Design

The purpose of the final focus system (FFS) of the future linear colliders (ILC and CLIC) is to demagnify the beam to the required size at the interaction point (IP). This can be done in a compact way based on a local chromaticity correction [1]. The general layout is shown in Figure 1.

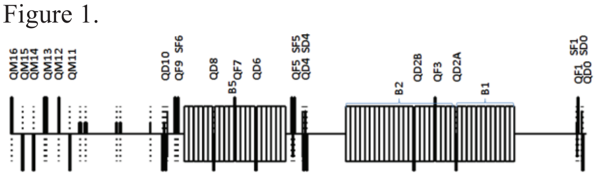

Figure 1: The layout of the ILC FFS with local chromaticity correction.

For the present ILC FFS design [2] [3]:

- A Final Doublet of strong quadrupoles (QD0, QF1) provides the focusing.
- The FD generates chromaticity which will significantly dilute the beam size. Two sextupoles (SD0, SF1) next to the FD and a bend upstream to generate dispersion across the FD will locally cancel the chromaticity.
- The FD generates second-order dispersion as well. Half of the entire horizontal chromaticity of the FFS is generated upstream of the bend (Thus one more intermediate focus in a non-dispersion region is needed. See Figure 2) for the sextupoles to cancel the chromaticity and the second-order dispersion at the same time.
- The sextupoles generate geometric aberrations. So two more sextupoles (SD4, SF5) upstream of the bend are required for cancel these aberrations and higher order ones.
- One more sextupole (SF6) upstream also helps to cancel higher order aberrations.
- The residual higher order aberrations can if needed be minimized further with octupoles and decapoles.
- Six more quadrupoles (QM11-16) are needed upstream to match the incoming beta function.

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The Idea of a New FFS Design

For an enlarged horizontal beta function at the IP βx*, chromaticity on horizontal plane will be smaller. It may be possible to get a smaller vertical beam size, at the expense of a larger horizontal beam size, with chromaticity correction mainly in the vertical plane using fewer sextupoles: 2 or 3 instead of 5. If it works, we'll also not need the intermediate focus for full compensation of second-order dispersion, which will reduce overall vertical chromaticity. This can lead to a shorter and easier to tune FFS. Another benefit is that the beamstrahlung at the IP will be reduced.

This idea was first tried with the present 500GeV ILC FFS design [2]. The beam parameters of this original design and the linear lattice functions are shown in Table1 and Figure 2.

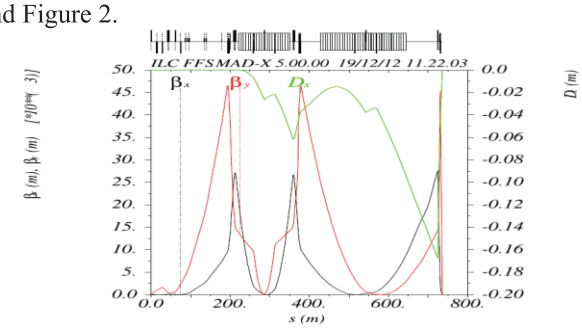


Figure 2: The linear lattice functions of ILC FFS with βx*/βy*=15mm/0.4mm.

It's quite simple to examine this idea. For the present energy spread 0.06% and an enlarged βx*, we will try to get a smaller vertical beam size σy* by studying σy* as a function of βy* with chromaticity correction mainly in the vertical plane. Before doing this, it's worthy to check the optimum βx* and βy* with chromaticity correction in the both planes. This will supply us the estimated βy* and σy* for chromaticity correction mainly in the vertical plane.

To obtain and study the variable optics, the MADX [4] tracking code is used. In the following all the beam sizes are defined as rms values of the particle distributions and without considering radiation effect. For the linear beam size, it's calculated with $\sigma^* = \sqrt{\beta^* \varepsilon^*}$.

Table 1: Beam Parameters of ILC FFS with βx*/βy*=15mm/0.4mm

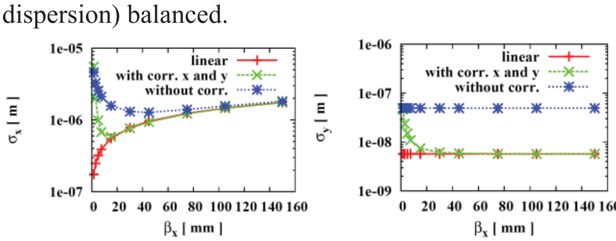
Parameters	Value
Beam energy E (GeV)	250
Normalized emittance $\gamma\varepsilon^*_{x/y}$ (um)	10/0.04
Energy spread σ_E/E (%)	0.06
Beta functions at IP $\beta^*_{x/y}$ (mm)	15/0.4
Angular dispersion at IP D'^*_x	0.008
Beam sizes at IP $\sigma^*_{x/y}$ (nm)	590/7.4
Beam divergence at IP $\theta^*_{x/y}$ (urad)	37/14

CHROMATICITY CORRECTION IN BOTH PLANES

The beta functions in the both planes are changed at the IP by successively applying the following procedures:

- Fit matching quadrupoles QMs to get wanted βx* and βy* and maintain αx*=αy*=0.
- Fit sextupoles SD0, SF1, SD4, SF5 and SF6 to cancel T122, T126, T166, T324 and T346 [5].
- Track with MADX to get the beam size.

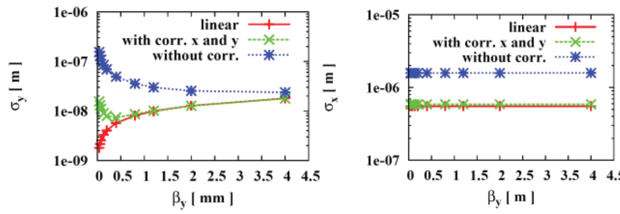
Firstly, we study σx* as a function of βx* with nominal βy*=0.4mm.With chromaticity correction in both planes, σx* was minimized when βx*=15mm. See Figure 3(a). We show the impact of variable βx* on σy* with Figure 3(b). Third order coupling aberrations enhance the vertical beam size σy* for small βx*. We also track without chromaticity correction. Without chromaticity correction, the horizontal beam size σx* was minimized when βx*=45mm as the linear beam size and second order aberrations (chromaticity and second order dispersion) balanced.



(a) (b)

Figure 3: (a) The horizontal beam size σx* as a function of βx* when βy*=0.4mm. (b) The impact of the variable βx* on σy* when βy*=0.4mm.

Then, we study σy* as a function of βy* with nominal βx*=15mm. With chromaticity correction in both planes, σy* minimized when βy*=0.4mm. See Figure 4(a). In Figure 4(b), we find that σx* is independent of βy*. Without chromaticity correction, the vertical beam size σy* was minimized when βy*=4mm as the linear beam size and chromaticity balanced.



(a) (b)

Figure 4: (a) The vertical beam size σy* as a function of βy* when βx*=15mm. (b) The impact of the variable βy* on σx* when βx*=15mm.

CHROMATICITY CORRECTION MAINLY IN THE VERTICAL PLANE

We turn off sextupoles SF1, SF5 and SF6; Refit sextupoles SD0 and SD4 to cancel T324 and T346 which are the largest vertical second order terms.

Firstly, we study σx* as a function of βx* with nominal βy*=0.4mm. With chromaticity correction in vertical plane, σx* minimized when βx*=75mm. See figure 5.

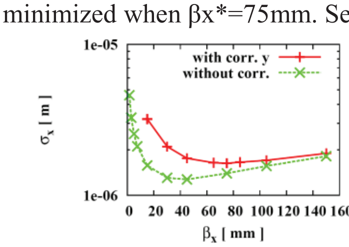
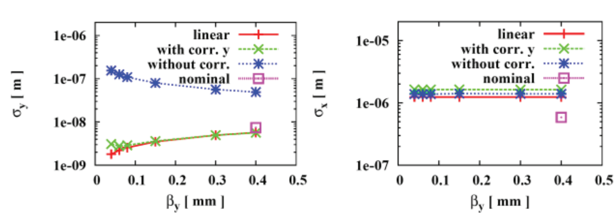


Figure 5: The horizontal beam size σx* as a function of βx* when βy*=0.4mm.



(a) (b)

Figure 6: (a) The vertical beam size as a function of βy* when βx*=75mm. (b) The impact of the variable βy* on σx* when βx*=75mm.

Then, we study σy* as a function of βy* with enlarged βx*=75mm. With chromaticity correction mainly in the vertical plane, σy* minimized when βy*= 0.06mm. See Figure 6(a). We get a smaller vertical beam size as expected comparing with nominal case. The vertical beam size was decrease with a factor 0.375 while horizontal one

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2.80. See table 2 and figure 7. It seems possible to get a smaller σy* and not decrease the luminosity much with chromaticity correction mainly in the vertical plane. There's room for optimization.

Table 2: Beam Parameters of ILC FFS

	Corr. x and y	Corr. y
sextupoles used	SD0, SF1, SD4, SF5, SF6	SD0, SD4
$\beta^*_{x/y}$ (mm)	15/0.4	75/0.06
$\sigma^*_{x/y}$ (um/nm)	0.586/7.41	1.64/2.78

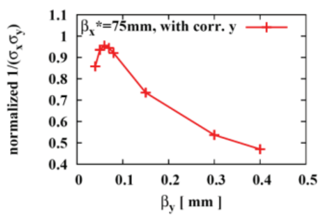

Figure 7: The geometric luminosity normalized by the original one (βx*/βy*=15mm/0.4mm, correction in both plane) as a function of βy* when βx*=75mm.

Optimization

We try to optimise the sextupole fitting with MAPCLASS [6] for the following case:

- Minimise all the aberration for σy* with SD0 and SD4.
- Minimise the product σx*·σy* with SD0 and SD4.
- Minimise the product σx*·σy* with SD0, SD4 and SF1.

The results for these cases are almost the same with the one which cancel T324 and T346 with SD0 and SD4.

We're trying the redesign of the linear optics to remove the upstream intermediate focus which is no longer needed in this design, thereby reducing the vertical chromaticity. This would also include an optimization of the bending magnet strength, taking into account that with the larger horizontal beam size, radiation effects will no longer be so important.

ADVANTAGES AND LIMITATIONS

This new proposed scheme of chromaticity correction has some advantages and limitations:

- 2 sextupoles instead of 5 leads to a shorter and easier to tune FFS.
- The energy loss due to beamstrahlung $\delta_E \propto 1/(\sigma_x^2\sigma_z)$. Thus larger horizontal beam size will lead to less beamstrahlung.
- On the other hand, a smaller vertical beam size will enhance the luminosity reduction from the hour glass effect. See Figure 8. A shorter bunch length is needed for mitigation.

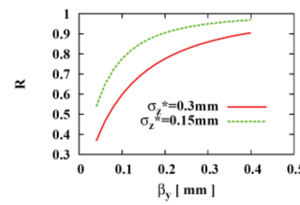

Figure 8: Analytic luminosity reduction due to hour-glass effect.

CONCLUSIONS AND FURTHER WORK

For an enlarged βx*, chromaticity on horizontal plane will be smaller. We get a smaller vertical beam size, at the expense of a larger horizontal beam size, with chromaticity correction mainly in the vertical plane using fewer sextupoles: 2 or 3 instead of 5.

We check the optimum βx* and βy* with chromaticity correction in the both planes. The minimum beam sizes σx*=0.586um and σy*=7.41nm are found when βx*=15mm and βy*=0.4mm.

With chromaticity correction mainly in the vertical plane, the minimum beam sizes σx*=1.64um and σy*=2.78nm are found when βx*=75mm and βy*=0.06mm. The geometric luminosity is almost recovered with a factor 0.95.

This new proposed scheme of chromaticity correction would leads to a shorter and easier to tune FFS. The beamstralung will be reduced due to larger horizontal beam size. However, a shorter bunch length would be needed to mitigate the luminosity reduction from the hour glass effect..

We're trying the redesign of the linear optics to remove the upstream intermediate focus which is no longer needed in this design, thereby reducing the vertical chromaticity. This would also include an optimization of the bending magnet strength, taking into account that with the larger horizontal beam size, radiation effects will no longer be so important.

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