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LOWERING THE CLIC IP HORIZONTAL BETA FUNCTION

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Abstract

In order to alleviate the beamstrahlung photon emission, the beams at the CLIC Interaction Point (IP) must be flat. We propose to explore this limit reducing the horizontal IP beta function for CLIC at 500 GeV c.o.m. energy to half of its nominal value. This increases the photon emission during collision but it also increases luminosity and might allow to reduce the bunch charge keeping the same luminosity. This configuration can also be considered for lower energies where beamstrahlung is less critical.

INTRODUCTION

The Compact Linear Collider (CLIC) [1] needs to focalize the beam to very small sizes to achieve a luminosity of the order of $10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$. This strong focalization is driven by the Final Doublet (FD) within the Final Focus System (FFS) that demagnifies the beam coming from the linac from a few micrometers to the nanometer level. Since the beam is not completely monochromatic, particles with different energies are focalized at different points. The FFS must carry also the important task to compensate this effect by means of sextupoles and other higher order multipoles. The strong fields present during collision at the Interaction Point (IP) lead to the emission of photons, the so called beamstrahlung, which can cause a luminosity loss. It also increases the background in the detector due to creation of electron-positrons pairs and soft hadronic events and influences experiment by smearing the luminosity spectrum. In order to reduce this radiation, flat beams are required. In the next sections this limit is explored.

FINAL FOCUS OPTIMIZATION

A novel Final Focus System (FFS) scheme was proposed in [2] with the aim of reducing the total length of the system compared with previous schemes, correcting the chromaticity locally, placing a pair of sextupoles interleaved with the FD. Upstream of the FD a bending section is needed to create the required dispersion at the sextupoles for the chromaticity compensation. The geometric aberrations also introduced by the sextupoles are canceled adding two more sextupoles placed in phase with them and also upstream of the bending section. One more sextupole is used to correct higher order aberrations.

The system optimization is carried out using MADX [3] and MAPCLASS [4]. The system is designed to have the β-functions at the IP given in Table 1. MADX allows to

Table 1: CLIC Design Parameters at 500 GeV Center of Mass Energy [1]. The Energy Spread σ_δ Represents the Full Width of a Fat Distribution

Parameter [Units]	**Value**
Center of mass energy E_{CM}, [GeV]	500
Repetition rate f_{rep}, [Hz]	50
Bunch population N_e $[10^9]$	6.8
Number of bunches n_b	354
Bunch length σ_z, [μm]	72
IP beam size σ_x^*/σ_y^*, [nm]	200/2.26
Beta function (IP) β_x^*/β_y^*, [mm]	8/0.1
Norm. emittance (IP) ϵ_x/ϵ_y, [nm]	2400/25
Energy spread σ_δ, [%]	1.0
Luminosity $\mathcal{L}_{\mathrm{T}}$ $[10^{34}\mathrm{cm}^{-2}s^{-1}]$	2.3

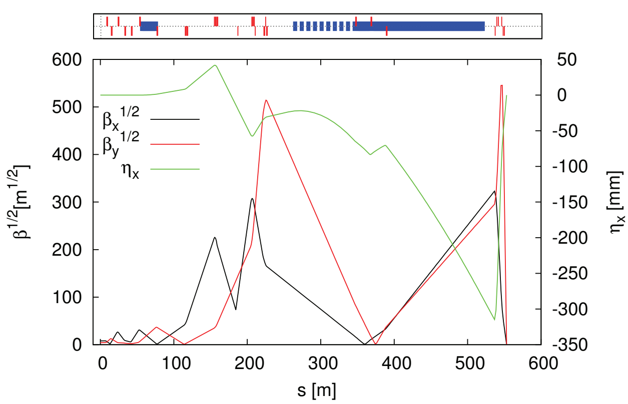

Figure 1: Optics of the CLIC 500 GeV local correction scheme final focus system showing horizontal and vertical β-functions and dispersion function.

set the magnet configuration and match optical functions from the entrance of the FFS to the required β-functions at the IP to reach nanometer beam sizes. MAPCLASS is a Python based code for linear and nonlinear optimization of the beam size.

Ideal Distributions

First of all we consider ideal beam distributions at the IP i.e. beam distributions generated at the IP with the parameters present in Table 1 without passing through the FFS. Therefore the beam distributions do not suffer from beam dilution due to nonlinear aberrations or synchrotron radia-

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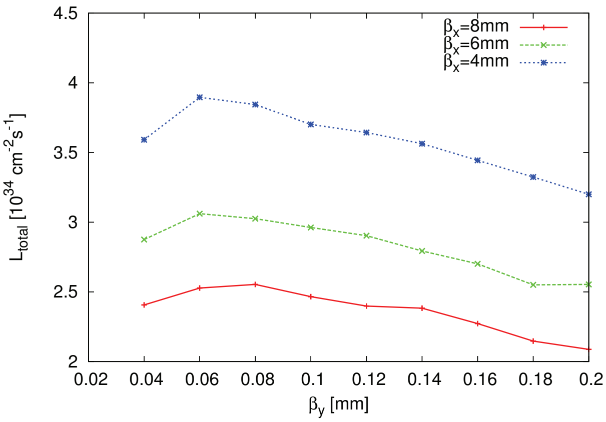

Figure 2: Total luminosity for different values of β_x^* asuming ideal distributions at the IP.

tion effects. In Fig. 2 the total luminosity for ideal distributions for three different values of β_x^* is shown as a function of the vertical beta function β_y^*. We observe that luminosity is higher for lower β_x^*. Also the reduction of β_y^* implies an increase of the luminosity until when the vertical beta function is comparable to the longitudinal beam size, where due to the hourglass effect luminosity starts to decrease. Therefore the optimal value for β_y^* is close to 0.065 mm.

Realistic Distributions

Simulations using ideal distributions give an overall idea of how the system will perform. The vertical β-function at the IP is set to the optimal value found in the using ideal distributions, i.e. $\beta_y^* \approx 0.065$ mm. This change in β_y^* will not affect considerably the value of the luminosity. The horizontal β-function is chosen to have three different values: 8, 6 and 4 mm.

The beam is now affected by the strong focusing by the FD and chromatic effects must be taken into account. The chromatic compensation is carried out by means of sextupoles. In all cases we use five sextupoles for chromaticity correction, In Fig. 3 the beam size is sequentially optimized order by order until higher order contributions are negligible. One can see that beyond order 6 the beam size does not change substantially. Although the horizontal beam size decreases due to the change in the β-function, the nonlinear aberrations do not present more impact for smaller values of β_x^*. Nevertheless, the reduction of the horizontal β-function has an important impact on the vertical plane, where one can see that the beam size dilution becomes important for $\beta_x^* = 4$ mm. The impact of nonlinearities in the later case represents a 25% beam size increase. For that reason and regarding that the terms of the map that mainly contribute to the beam size dilution are decapolar terms, we decided to add two decapole magnets in the FD region to correct this aberration. Also the bending angle was increased in order to better compensate the aberrations although increasing the synchrotron radiation effects. The

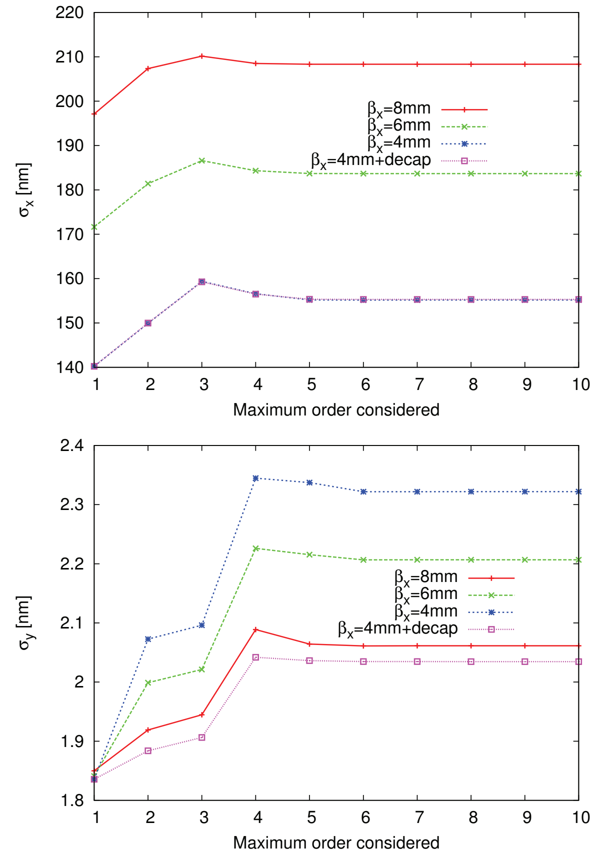

Figure 3: High order optimization using MAPCLASS for CLIC FFS for horizontal plane (top) and vertical plane (bottom).

Table 2: Beam Size for Different Configurations at the IP Taking into Account Synchrotron Radiation Effects

β_x^* [mm]	σ_x^* [nm]	σ_y^* [nm]
8	210.1	2.51
8	213.3	2.20
6	189.2	2.36
4	163.6	2.84
4+decap	162.8	2.56
4+decap+high disp.	166.6	2.31

result after reoptimization is shown in Fig. 3 and one can see the big improvement that decapoles and higher dispersion represent reducing the total impact of the aberrations to less than 10%. In Table 2 the RMS beam sizes are summarized taking into account synchrotron radiation effects in bending magnets and the Oide effect in quadrupoles. It is observed that the dispersion increase is translated into a horizontal beam size dilution because of synchrotron radiation but the vertical beam size reduction is larger and this implies a net luminosity increase as it is shown in Table 3.

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Table 3: Luminosity in Units $[10^{34}\text{cm}^{-2}\text{s}^{-1}]$ and Emitted Photons per Particle During Collision

β_x^* [mm]	$\mathcal{L}_T$	$\mathcal{L}_{1\%}$	$\mathcal{L}_{1\%}/\mathcal{L}_T$	n_γ
8^*	2.31	1.40	0.61	1.32
8	2.34	1.45	0.62	1.30
6	2.70	1.56	0.58	1.47
4	3.12	1.61	0.52	1.74
4+decap	3.20	1.65	0.52	1.74
4+decap+h.disp.	3.28	1.71	0.52	1.71

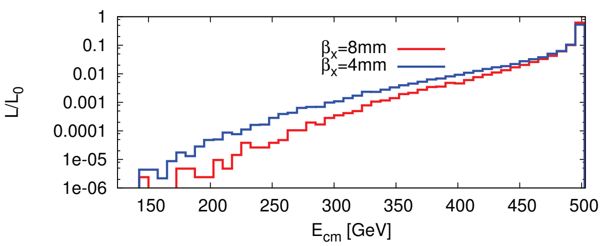

Figure 4: Luminosity spectrum for $\beta_x^* = 8$ and $\beta_x^* = 4$ mm with high dispersion and decapoles.

LUMINOSITY PERFORMANCE

Luminosity in a linear e^+e^- collider is given by the approximated expression,

$$\mathcal{L} = \frac{N^2 f_{\text{rep}} n_b}{4\pi\sigma_x^*\sigma_y^*} H_D \quad (1)$$

where N is the number of particles per bunch, f_{rep} the repetition frequency, n_b the number of bunches per train, $\sigma_{x,y}^*$ the transverse beam size at the IP and H_D the enhancement factor due to pinch effect.

In Table 3 the total luminosity and peak luminosity (luminosity delivered by particles with energies $\geq 0.99E_0$) values are shown. A luminosity increase is seen when β_x^* is reduced. If we compare the initial value for luminosity given by the CDR configuration with the best luminosity value when we consider $\beta_x^* = 4$ mm, higher dispersions and the decapoles, it represents a gain above 40% in total luminosity and a 22% gain in peak luminosity.

The reduction of the horizontal beam size increases beamstrahlung photon emission during the beam collision that might create undesirable background. The photon emission also induces a decrease of the quality of the luminosity spectrum since more particles are colliding with a different energy from the nominal value. This effect can be observed comparing the ratio of the peak and total luminosity. The smaller the β_x function, the smaller the ratio as can be observed in Table 3. The luminosity spectrum is shown in Fig. 4. The peak luminosity (bin centered at 500 GeV) is lower for $\beta_x^* = 4$ mm as it is shown in Table 3. The rest of the luminosity is spread in the long tail representing luminosity of particles with lower energies.

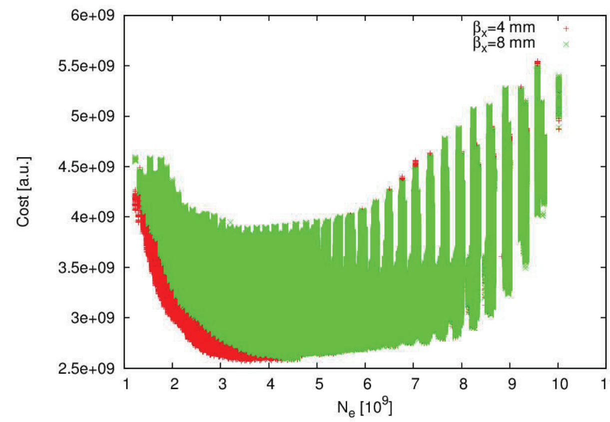

Figure 5: Cost of the accelerator (without injectors) in arbitrary units as a function of the number of particles per bunch.

CHARGE SCALING AND COST OPTIMIZATION

The reduction of β_x^* can be used as an option to reduce the bunch charge while keeping luminosity constant. It can be seen that, since $\sigma_x^* = \sqrt{\beta_x^*\epsilon_x}$, a reduction of a factor 2 in β_x^* could correspond to a reduction of a factor $\sqrt{2}$ in bunch charge while keeping approximately the same luminosity. Nevertheless, the luminosity spectrum gets worse since the beam size is less flat and the photon emission increases as it has been explained in previous sections. The bunch charge reduction could yield a reduction of the cost of the accelerating structures. In Fig. 5 the cost estimation of the whole accelerator as a function of the bunch charge is shown for two different values of β_x^*: 8 and 4 mm. Only a few configurations at low bunch charges are cheaper for the case at $\beta_x^* = 4$ mm with respect to $\beta_x^* = 8$ mm. Note the wide cost range due to the large set of design parameters. In any case, there is a save in power consumption due to the lower charge.

CONCLUSIONS

We have obtained a lattice with a factor 2 reduction in β_x^* at the IP. Although this cannot redefine the design parameters, it shows that the design has some flexibility. We have explored to use this new lattice to increase luminosity.

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