THE OPTICS DESIGN FOR THE FINAL FOCUS SYSTEM OF CLIC 380 GeV

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Abstract

The first stage of the Compact Linear Collider (CLIC) is planned to be at the center-of-mass energy of 380 GeV. The final focus system (FFS) was re-optimized for this energy and for L* of 6 m (distance between the Interaction Point (IP) and the last quadrupole, QD0). Furthermore, the FFS optics was optimized for the vertical beta-function of 70 microns to approach the Hourglass effect limit. This paper reports the exploration of shortening the Final Doublet (FD) within the FFS to reduce the chromaticity. In addition, an alternative optics design is investigated with a different dispersion profile along the FFS, which outperforms the previous optics with the same β^*, increasing luminosity by 5 %.

INTRODUCTION

The FFS design at the initial stage of CLIC [1] with the center-of-mass of 380 GeV [2] is foreseen to have L^* of 6 m. The optics had been scaled from the old version with $L^* = 4.3$ m [3, 4]. This led to the increase of the FD chromaticity, and to the total and peak luminosities reduction of around 4%. The total luminosity ($\mathscr{L}_{total}$) considers all the collisions at the IP, while peak luminosity ($\mathscr{L}_{peak}$) ignores the collisions with an energy offset greater than 1%. In addition, due to the strong 3rd order chromatic aberrations, a pair of octupoles had been introduced to the lattice. To compensate for the luminosity loss and to approach the limit of the Hourglass effect, the vertical beta-function has been reduced to 70 µm [5]. Table 1 gives the key parameters for this design.

This paper reports the results of new optics optimizations. First, the FD chromaticity is reduced by shortening both QF1 and QD0. Then a new dispersion profile is adopted. At both stages, the lattice has been numerically optimized to reduce the aberrations at the IP. The optimization consists of several steps. First, the IP Twiss parameters are matched to the target values. Second, the 2nd order horizontal beam size is scanned for a set of upstream horizontal chromaticities. For the optimal value, which should be similar to FD chromaticity, both chromaticity and 2nd order dispersion are corrected simultaneously. Then the IP 5th order beam size is optimized with the sextupoles. Finally, the bending angles are scanned to find the optimal dispersion level. It consists in maximizing the total and peak luminosities.

Throughout this study, MAD-X [6] is used to perform the optics calculations, and Mapclass [7–9] is used for the IP beam size evaluation. Furthermore, for comparison and to estimate the IP luminosity, Placet [10] and Guinea-Pig [11] are utilized.

Table 1: Key Parameters of the FFS for CLIC 380 GeV

FFS length [m]	770
Normalized emittance (IP) $\epsilon_{n,x}/\epsilon_{n,y}$ [nm]	950/30
Beta function (IP) β_x^*/β_y^* [mm]/[mm]	8/0.07
IP beam size σ_x^*/σ_y^* [nm]	143.0/2.7
Bunch length σ_z [µm]	70
RMS energy spread δ_p [%]	0.3
Total luminosity $\mathscr{L}$ [10^{34}cm^{-2}s^{-1}]	1.66
Peak luminosity $\mathscr{L}_{peak}$ [10^{34}cm^{-2}s^{-1}]	0.96
Vertical chromaticity $\xi_y^* \approx L^*/\beta_y^*$	85000

OPTICS WITH SHORT FD

The chromaticity generated by the FD can be minimized by decreasing the length of both QF1 and QD0. The central longitudinal location of the magnets is not modified to simplify the optics optimization. The condition $L^* = 6$ m is also preserved. Based on the aperture feasibility estimated in [5], we set the shortening factor to approximately 2 for both magnets.

To modify the upstream chromaticity, the distance between the dipoles Dip2 and the FD is changed (refer to Fig. 1). It allows changing the beta-function level upstream while preserving the FD chromaticity the same. It has been estimated that introducing an additional drift of 4.75 m between the FD and Dip2 is required to match the horizontal chromaticity generated by the FD and upstream of the FD, see Fig. 2. The 5th order beam size is optimized by means of adjusting the strengths of the sextupoles in the FFS and is evaluated to $\sigma_x^* = 143.02$ nm and $\sigma_x^* = 2.59$ nm. In this case, the octupoles are not needed to reach a small beam size. The bending angles scan showed that dispersion level is already optimal.

ALTERNATIVE DISPERSION PROFILE

This optics is based on the optics with a short FD but has a different dispersion profile in the FFS, see Fig. 3. It is performed by inverting the polarity of the QD6B quadrupole

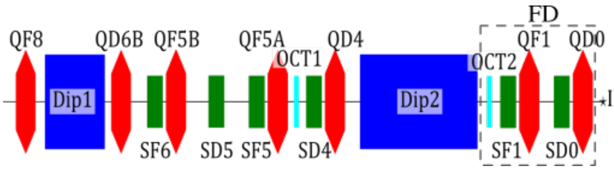

Figure 1: Schematic layout of the FFS of CLIC. Quadrupoles are indicated in red, sextupoles in green, dipoles in blue, and octupoles in cyan.

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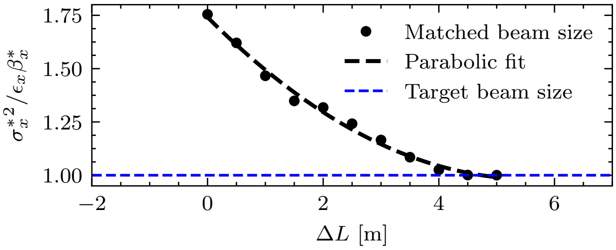

Figure 2: The normalized 2nd order beam size at the IP as the function of the distance change between the FD and Dip2.

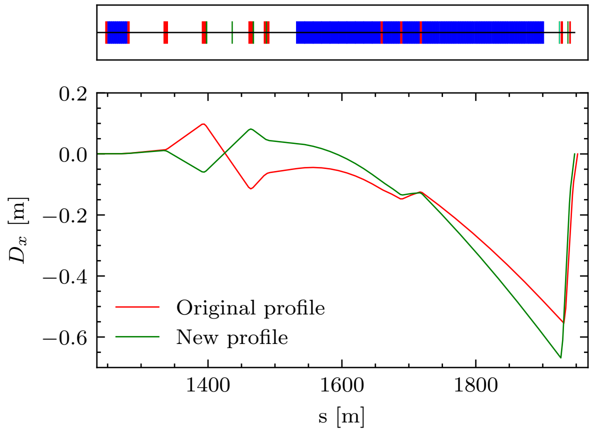

Figure 3: Comparison of the dispersion profiles in the FFS.

magnet. Such a scheme offers a larger dispersion at the FD location, which, potentially, can reduce the aberrations from the sextupoles. Adjustment of the upstream horizontal chromaticity has been performed numerically, simultaneously matching the Twiss parameters at the IP and the chromaticity, see Fig. 4. For the calculations, the thin-lens approximation for the quadrupole chromaticity has been used:

$$\xi_{x,y} \approx \pm k_L \beta_{x,y}, \tag{1}$$

where k_L is the integrated strength of the quadrupole and $\beta_{x,y}$ is the beta-function at quadrupole location. A new FFS dispersion also led to the need for readjustment of the sextupoles location, in particular SD5. The best position for SD5 has been found to be 6 m closer to the IP, see Fig. 5. It allowed to reduce the minimum 5th order beam size achievable with sextupoles by around 0.4 nm in both planes to $\sigma_x^* = 143.02$ nm and $\sigma_x^* = 2.49$ nm. In addition, a pair of interleaved decapoles, named DEC1 and DEC2, has been introduced to the lattice to cancel the 4th order aberrations to the horizontal and vertical beam size. They are placed in the FD region, next to SF1 and SD0 sextupoles, respectively.

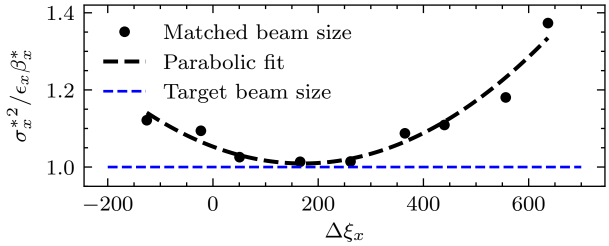

Figure 4: Normalized 2nd order beam size at the IP as a function of the difference between the FD and upstream chromaticities.

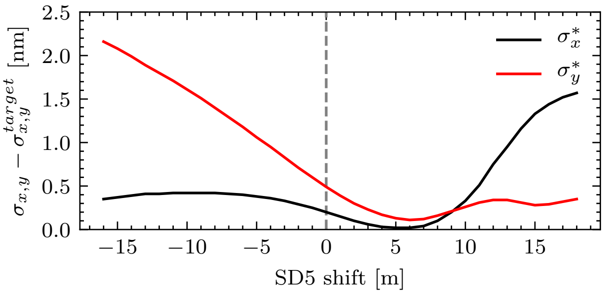

Figure 5: Beam size at the IP evaluated for the transfer map of 5th order as a function of SD5 sextupole location.

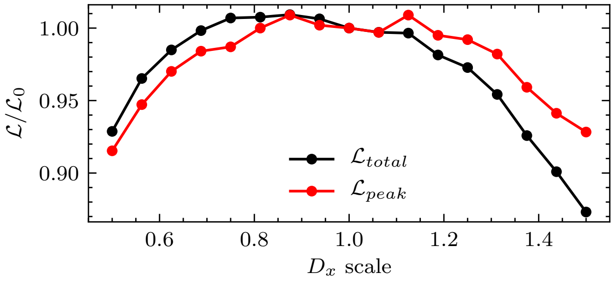

Figure 6: Relative luminosity as the function of the dispersion scale along the FFS.

The scan of the bending angles of the FFS showed that 12.5% reduction of the dispersion is the optimal level to maximize both total and peak luminosities by about an extra 0.5%, see Fig. 6.

PERFORMANCE COMPARISON OF THE OPTICS

Beam Size and Luminosity

The beam size is evaluated with Mapclass for up to the 8th order, see Fig. 7. For the comparison, the previous designs with $\beta_x^* = 70\,\mu$m and $\beta_x^* = 100\,\mu$m are also included. We see that the optics with short FD provides a similar aberration control as with the initial FD, although with the advantage that it does not need octupoles. The optics with a new dispersion profile provides the best aberration cancelling, yielding almost linear σ_y^*. Beam size evaluated with PLACET tracking, and luminosity estimated with Guinea-Pig are shown in Table 2. One can see that the optics with a new dispersion profile increases the luminosity by 5% compared to the other designs with $\beta_y^* = 70\,\mu$m and outperforms the optics with $L^* = 4.3$ m.

Table 2: Beam size at the IP evaluated with PLACET including synchrotron radiation and with Mapclass for the transfer map of 8th order. Luminosity is calculated with Guinea-Pig

	MAPCLASS		**PLACET + Guinea-Pig**				
Optics	σ_x^* **[nm]**	σ_y^* **[nm]**	σ_x^* **[nm]**	σ_y^* **[nm]**	**Energy bandwidth [%]**	$\mathscr{L}_{total}$	$\mathscr{L}_{peak}$
$\beta_y^* = 100\,\mu\text{m}$, ($L^* = 4.3$ m)[a]	144.00	3.07	-	-	-	1.70	0.96
$\beta_y^* = 100\,\mu\text{m}$	141.90	3.14	144.22	3.14	0.52	1.63	0.93
$\beta_y^* = 70\,\mu\text{m}$	143.48	2.72	145.78	2.74	0.35	1.66	0.96
$\beta_y^* = 70\,\mu\text{m}$, Short FD	142.74	2.63	144.72	2.71	0.42	1.66	0.96
$\beta_y^* = 70\,\mu\text{m}$, Short FD + altern. D_x	142.43	2.45	143.82	2.67	0.3	1.74	1.01

[a] Refer to [3].

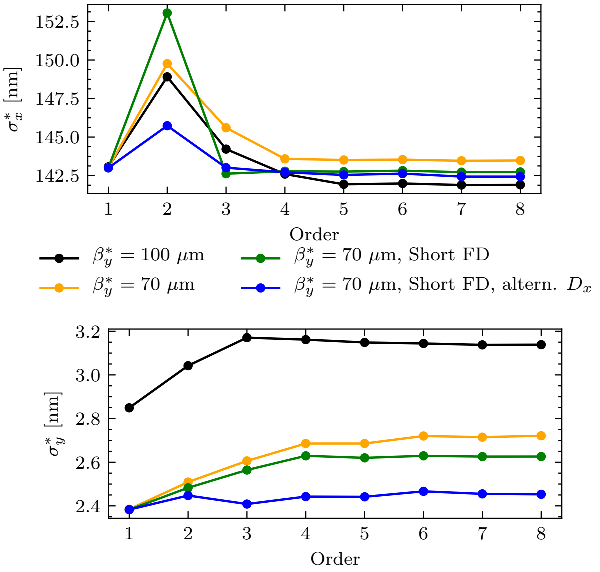

Figure 7: Horizontal (top) and vertical (bottom) beam size at the IP as a function of the transfer map order.

Energy Bandwidth

We define the energy bandwidth as the width of the energy region around the reference energy, where both horizontal and vertical beam sizes stay below a 10% growth, compared to the on-momentum beam values. In Table 2 the values of the energy bandwidth are given, estimated for the different optics.

The luminosities versus relative energy offset are given in Fig. 8. For reference, the design target values of total $1.5{\times}10^{34}\text{cm}^{-2}\text{s}^{-1}$ and peak $0.9{\times}10^{34}\text{cm}^{-2}\text{s}^{-1}$ luminosities are shown. The width of the region in energy where the peak luminosity is larger than the target is comparable for all designs. In the case of the total luminosity, the optics with $\beta_y^* = 100\,\mu\text{m}$ has a larger width than the others due to the specific shape of the horizontal beam size for a negative energy offset.

CONCLUSION

The optics of the CLIC Final Focus System has been optimized to maximize the IP luminosity for a longer L^* design.

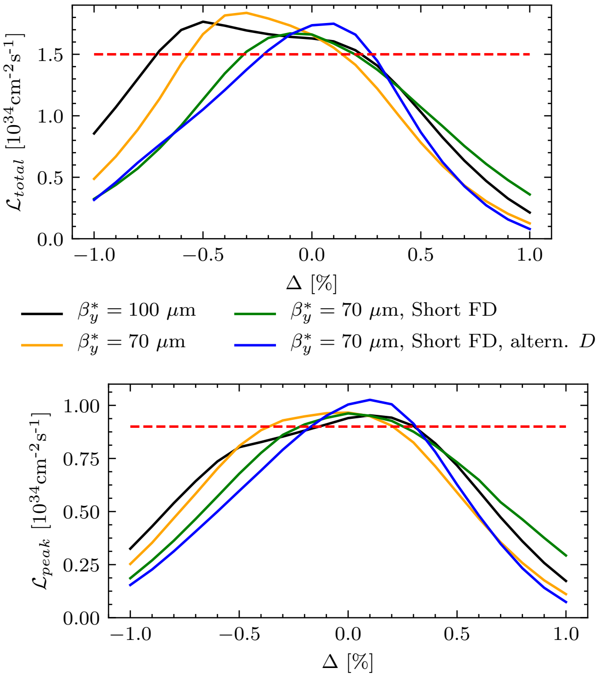

Figure 8: Total luminosity (top) and peak luminosity (bottom) with the presence of the energy offset. Red dashed line corresponds to the target design.

The Final Doublet has been shortened to decrease the chromaticity. This allows to increase the energy bandwidth and to remove the octupoles from the lattice. Furthermore, a new optics design featuring a new dispersion profile has been explored. Such a design provides the best transport aberrations correction. It yields the highest luminosity among the optics designs for the FFS of CLIC at 380 GeV. This design recovers the luminosity reduction experienced when the L^* was increased from 4.3 m to 6 m with an excess of 2%, which makes it the best candidate for the FFS of CLIC at 380 GeV.

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