CLIC FINAL FOCUS STUDIES[*]

R. Tomás, H. Braun ,D. Schulte and F. Zimmermann
CERN, Geneva, Switzerland

Abstract

The CLIC final focus system has been designed based on the local compensation scheme proposed by P. Raimondi and A. Seryi. However, there exist important chromatic aberrations that deteriorate the performance of the system. This paper studies the optimization of the final focus based on the computation of the higher orders of the map using MAD-X and PTC. The use of octupole tail folding to reduce the size of the halo in the locations with aperture limitations is also discussed.

INTRODUCTION

The transfer map between two locations of a beam line is expressed in the form

$$\vec{x}_f = \sum_{jklmn} \vec{X}_{jklmn} \, x_0^j \, p_{x0}^k \, y_0^l \, p_{y0}^m \, \delta_0^n \tag{1}$$

where $\vec{x}_f$ represents the final coordinates (x_f, p_{xf}, y_f, p_{yf}), the initial coordinates are represented with the zero subindex and $\vec{X}_{jklm}$ are the map coefficients of the corresponding final coordinate. The MAD-X version including PTC can provide $\vec{X}_{jklm}$ up to the desired order.

The quadratic standard deviation of the final density distribution, $\sigma_x^2 = <x_f^2>$, is derived in [1] as function of the coefficients on the transfer map and the CLIC beam density. The following sections discuss how to extract the nature of the aberrations.

The order-by-order approach

By truncating the map at order q we only consider the coefficients X_{jklmn} such that $j+k+l+m+n \leq q$. The resulting beam size is represented by σ_q. Thus defined, σ_1 corresponds to rms size given by the linear Twiss functions, σ_2 takes into account the effect of chromatic aberrations and sextupoles, σ_3 incorporates octupolar fields, etc. The final finite size of the bunch is given by σ_q when q tends to infinite. However there must be a finite order p that gives a satisfactory approximation. The evaluation of $\sigma_q - \sigma_{q-1}$ gives the contribution of the order q to the final rms beam size. From this contribution the order of the most relevant aberrations is inferred and subsequently the appropriate multipolar correctors are chosen. However the optimum location of the correctors still needs to be identified.
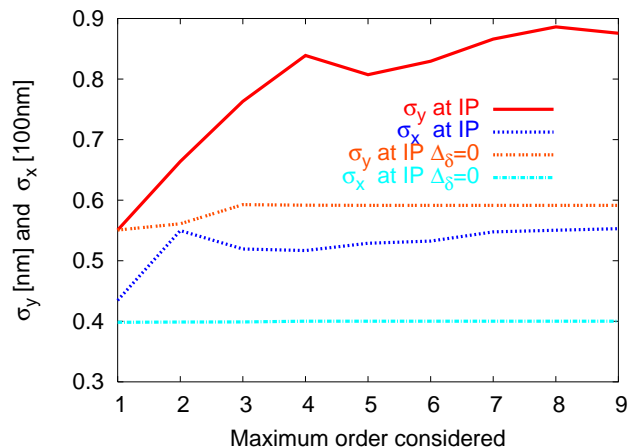
Figure 1: Horizontal and vertical rms beam sizes at CLIC Interaction Point as function of the maximum order considered in the transfer map. Both the nominal and monochromatic beams are considered.

Chromatic versus achromatic correctors

The recipe to decide if the correctors should be placed in locations with or without dispersion is as follows. $\sigma_{q,\Delta_\delta=0}$ is defined as the rms size of an monochromatic beam, $\Delta_\delta = 0$. If the contribution from the most relevant order q, $\sigma_q - \sigma_{q-1}$, is much larger than its corresponding monochromatic contribution, the correctors should be placed in dispersive locations possibly together with achromatic correctors to cancel the arising geometric aberrations. In the opposite case only achromatic correctors should be placed.

OPTIMIZATION OF THE CLIC BDS

The CLIC BDS consists of a collimation section and a Final Focus System (FFS). The collimation section has a length of about 2 km. The horizontal and vertical normalized beam emittances are $\epsilon_x = 68 \times 10^{-8}$ m and $\epsilon_y = 1 \times 10^{-8}$ m, with a relativistic gamma of $\gamma = 3 \times 10^6$. The full energy width of the beam is $\Delta_\delta = 0.01$. The rms beam sizes at the IP are computed as described in [1] and plotted up to the 9th order in Fig. 1. The nominal beam as well as the achromatic beam ($\Delta_\delta = 0$) are shown leading to the conclusion that most of the aberrations are chromatic. Only octupolar geometric aberrations appear in the vertical plane. The most relevant horizontal aberrations are the first order dispersion and the chromaticity (of sextupolar order). The total number of non-zero coefficients of the 9th order transverse map is 4002, of which 2070 are horizontal and 1932 are vertical. These large numbers make the evaluation of the rms beam size very slow. A better approach for
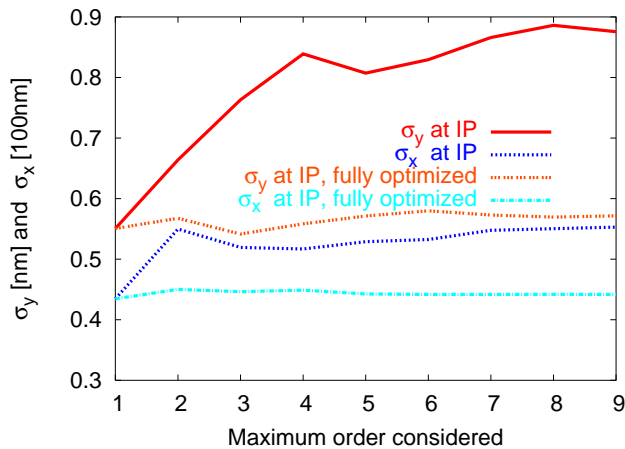
Figure 2: Horizontal and vertical rms beam sizes at the CLIC IP for the nominal BDS and the one fully optimized.

Figure 3: Horizontal and vertical rms beam sizes at the CLIC IP for the nominal BDS and the one linearly and non-linearly optimized.

an optimization of the beam sizes is to consider the collimation section and the final focus separately.

The collimation section only needs a small adjustment of the chromaticity sextupoles. In this context this is efficiently achieved by matching the rms beam sigmas of order 2 to those of order 1 by varying the strengths of the chromaticity sextupoles. The code MAPCLASS [3] was written with the purpose to minimise nonlinear aberrations. MAPCLASS uses an implementation of the Simplex method.

The remaining aberrations originate entirely in the FFS. The CLIC FFS has been designed based on the local chromaticity correction scheme proposed in [2]. This scheme basically consists of two pairs of sextupoles, one pair for the horizontal plane and the other for the vertical. We assume that the pairs of sextupoles are combined magnets including octupolar and decapolar magnetic components. Using all these non-linear elements (sextupoles, octupoles and decapoles) in the FFS the rms beam sizes at the IP are minimized with the Simplex method. The optimization needs the map up to order 6th. The result of the optimization of the FFS is shown in Fig. 2 together with the initial configuration. This confirms the compensation of the aberrations up to the higher orders.

Exactly the same algorithm can be used to optimize the linear parameters. The rms beam sizes up to order 5 are minimized again using the Simplex method as before but only varying the strengths of the quadrupoles. The result is shown in Fig. 3 together with the initial configuration. Both the horizontal and vertical beta functions have been reduced at the IP as can be seen at the first order of the plot. The horizontal non-linear aberrations stay well compensated while in the vertical plane small aberrations have arisen as a consequence of the focusing. This implies that for further reduction of the beam sizes more iterations correcting non-linear and linear orders are required.

The real benefit of reducing the rms size at the IP is luminosity and therefore it has been computed for all the former stages of the optimization. Bunches of 10000 macro-
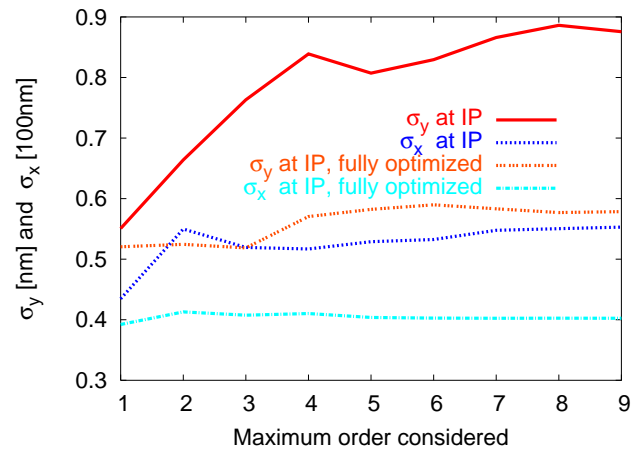
particles have been tracked trough the CLIC BDS using PLACET [4]. The same beam parameters as mentioned above have been used and the effect of synchrotron radiation has been included, which is not taken into account by the described optimization procedure. The luminosity has been computed using the code GUINEA-PIG [5], see table 1 for the nominal values. The relative reduction of the beam sizes with and without radiation together with the relative luminosity increase is shown in table 2. The total luminosity (L_{tot}), the luminosity coming from the collisions with energy larger than 99% of the maximum energy ($L_{1\%}$) and their ratio ($L_{1\%}/L_{tot}$) are shown in the table. Both the total luminosity and the luminosity in the energy peak increase as the rms beam sizes get smaller.

OPTIMIZING DISPERSION IN THE FFS

In order to use the bending angles as variables in the minimization procedure it would be mandatory to introduce analytical penalty functions that account for the effect of radiation in the final beam sizes. Instead another approach for the optimization of bending angles in the FFS has been used. The starting point is the above FFS configuration with the best performance. It is well known that the lower the dispersion is the less radiation is produced and the stronger the sextupoles need to be powered. There must be an optimum dispersion for which the combined effects of radiation and sextupoles are minimum The FFS is optimized using MAPCLASS for different levels of dispersion reduction and the luminosities are computed for the different cases as done above. Fig. 4 shows the resulting total and peak luminosities together with the required increase of sextupolar strength for the different levels of dispersion reduction. A table containing the numerical values of the relative variation of the rms beam sizes and luminosities can be found in [1]. The figure shows a peak in the luminosities at about a 20 The sextupole strength is not

Table 1: CLIC nominal rms beam sizes and luminosities.

Case	$\sigma_x^{rms}[nm]$ (no rad)	$\sigma_x^{rms}[nm]$ (rad)	$\sigma_y^{rms}[nm]$ (no rad)	$\sigma_y^{rms}[nm]$ (rad)	$L_{tot}[cm^{-2}/s]$	$L_{1\%}[cm^{-2}/s]$
Nominal	55	88	0.87	5.3	$6.15\ 10^{34}$	$2.65\ 10^{34}$

Table 2: CLIC relative differences of beam sizes and luminosities for the different optimizations stages. All numbers are in percent units.

Case	$-\frac{\Delta\sigma_x}{\sigma_x^{rms}}$ (no rad)	$-\frac{\Delta\sigma_x}{\sigma_x^{rms}}$ (rad)	$-\frac{\Delta\sigma_y}{\sigma_y^{rms}}$ (no rad)	$-\frac{\Delta\sigma_y}{\sigma_y^{rms}}$ (rad)	$\frac{\Delta L_{tot}}{L_{tot}}$	$\frac{\Delta L_{1\%}}{L_{1\%}}$	$\frac{L_{1\%}}{L_{tot}}$
Nominal	0	0	0	0	0	0	43
Corrected collimation section	12	30	14	58	9	6	42
Corrected FFS non-linearities	20	35	35	69	31	19	39
Lower β_x and β_y at IP	27	37	34	64	45	29	38
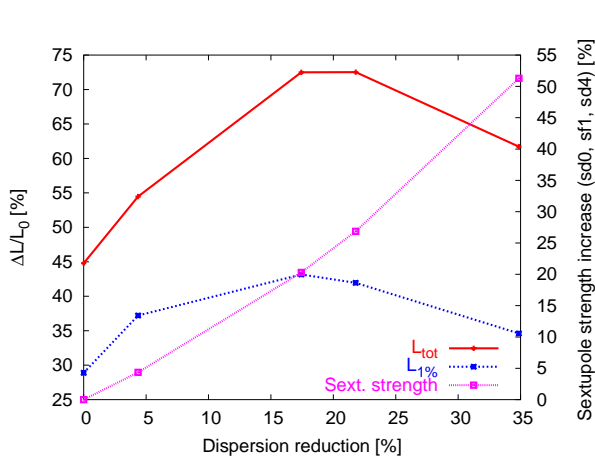
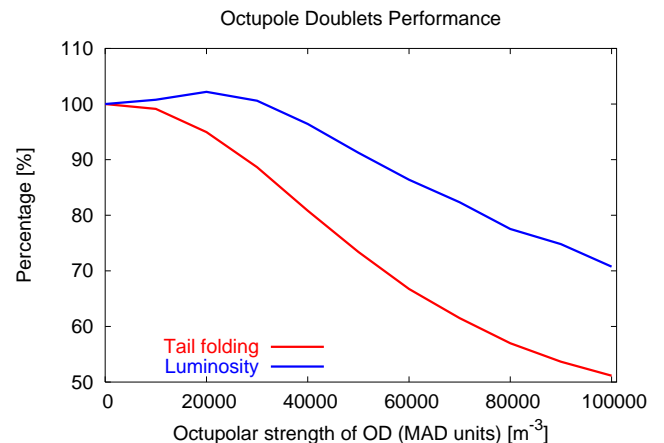Figure 4: Relative luminosity versus dispersion reduction through the FFS.

Figure 5: Performance of octupole doublets in terms of octupole tail folding and luminosity. The tail folding curve corresponds to the ratio between the halo size with ODs and without ODs at the quadrupoles.

linear with the dispersion reduction, as could be predicted in a first approximation. The ratio $L_{1\%}/L_{tot}$ is reduced to 0.36 at the luminosity peak. The maximum gain of 72% in total luminosity confirms the usefulness of the presented algorithm for the optimization of beam lines.

OCTUPOLE TAIL FOLDING IN CLIC

The concept of octupole tail folding was introduced in [6]. By placing octupole doublets before the quadrupoles of the FFS the tail of the halo can be folded in leading to a larger required collimation aperture. This is of interest to reduce the effect of the wake fields in the collimators. In this section we briefly assess the possibility of applying the octupole tail folding to CLIC. The Twiss functions before the FFS quadrupoles in CLIC are not well suited for octupole tail folding for two reasons: 1. The ratio β_y/β_x has a maximum of 4 when optimum values would be about 20 due to the shape of the halo. 2. The divergence of the beam is not low enough for the best performance of the octupole doublets. Two octupole doublets have been placed in front of the FFS quadrupoles. Its parameters have been optimized to give as best a tail folding and luminosity as possible. The performance of the ODs is shown in Fig. 5.

The tail folding curve corresponds to the relative change of the halo size at the quadrupoles with and without ODs. The halo reduction by a factor of two implies a luminosity loss of 30%. Also the size of the halo in the low beta region increases by a factor 2. The use of ODs in CLIC would require a new optics (and probably a longer FFS) for an acceptable tail folding performance without luminosity loss.

ACKNOWLEDGMENTS

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