BEAM DELIVERY SYSTEM OPTIMIZATION FOR CLIC 380 GEV

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Abstract

The CLIC Beam Delivery System (BDS) has been re-optimized for its initial stage at 380 GeV and two design options with $L^* = 4.3$ meters and $L^* = 6$ meters are proposed here. Mitigation of beamline imperfections for beam size preservation is a critical task for the CLIC Final Focus System (FFS) in order to prove its feasibility. In this study the FFS optimization for both L^* options has been performed by adding as figure of merit the tuning efficiency. The effectiveness of the tuning techniques applied to these different lattices will be decisive for the final layout of the BDS.

INTRODUCTION

The nominal BDS layout was based on the $\sqrt{s} = 500$ GeV design planned in the old energy staging strategy [1, 2]. The nominal FFS design has an L^* of 4.3 meters, forcing the last quadrupole QD0 to be integrated inside the experiment and protected by an anti-solenoid, to avoid interplay between the quadrupole and the solenoid fields. A longer L^* option of 6 meters is proposed in order to ease the Machine Detector Interface (MDI) [3] but one has to expect an increase in chromaticity propagated to the Interaction Point (IP) (see Table 1). The length of the FFS for $L^* = 6$ m is scaled according to the increase of L^* from the nominal design. A scan of the bending magnet angles of the FFS has been performed in both L^* cases in order to find the optimal dispersion level by considering the total and peak luminosities of an error-free system [4]. The total luminosity (L_{total}) takes into account all the collisions at the IP while the peak luminosity ($L_{1\%}$) refers to the collisions with energy larger than 99% of the maximum energy. The same scan is performed here by looking at the tuning efficiency of lattices with magnetic elements transversely misaligned by $\sigma_{RMS} = 10$ μm. The tuning procedure consists in applying the Beam Based Alignment (BBA) technique [5] and scans of linear knobs using pre-computed combination of sextupole displacements [6] in order to correct for a chosen set of linear aberrations at the IP.

Table 1: CLIC 380 GeV Parameters for Both L^* Options

L^* [m]	4.3	6
Final focus system length [m]	553	770
$\gamma\epsilon_x/\gamma\epsilon_y$ [nm]	950/20	950/20
β^*_x/β^*_y [mm]	8.2/0.1	8.2/0.1
$\sigma^*_{x,\text{design}}$ [nm]	145	145
$\sigma^*_{y,\text{design}}$ [nm]	2.3	2.3
$L_{\text{total, design}}$ [10^{34} cm^{-2}s^{-1}]	1.5	1.5
$L_{1\%,\text{ design}}$ [10^{34} cm^{-2}s^{-1}]	0.9	0.9
Chromaticity ξ_y ($\approx L^*/\beta^*_y$)	43000	60000

The sextupoles are coupled with dispersion η_x for chromaticity correction [7] and their strengths k_2 can be reduced by increasing the dispersion level in the FFS. Reduced k_2 leads to a reduction of the impact of optics transverse misalignments on $\sigma^*_{x,y}$. When the sextupoles are displaced horizontally, feed-down to normal quadrupole kicks are generated [8] and the corresponding changes in the IP spot size are evaluated by:

$$\Delta\sigma^*_x = k_2\Delta_x\beta_{x,s}\sigma^*_{x0} \quad (1)$$

$$\Delta\sigma^*_y = k_2\Delta_x\beta_{y,s}\sigma^*_{y0} \quad (2)$$

where $\beta_{x,s}$ and $\beta_{y,s}$ are the β-functions at the sextupole location. Vertical sextupole displacements generate skew quadrupole kicks that increase the spot size by

$$\Delta\sigma^*_y = k_2\Delta_y\sigma_{x,s}\left|R^{s\to *}_{34}\right| \quad (3)$$

where $\sigma_{x,s}$ is the horizontal beam size at the sextupole location and $R^{s\to *}_{34}$ is the matrix element from the sextupole to the IP. At $\sqrt{s} = 380$ GeV the synchrotron radiation generated in the bending magnets of the FFS is minor. Thereby, increasing the dispersion level along the FFS up to a factor 2 has a small impact on the luminosity at the CLIC initial stage. Above this level, the impact of synchrotron radiation becomes important on the horizontal beam size at the IP. A set of lattices has been optimized for both L^* options in which the dispersion is increased up to a factor 2 in steps of 10% as shown in Fig. 1. A tuning simulation campaign, comparing both L^* options for different dispersion profiles, has been performed to optimize the tuning.

IMPACT OF DISPERSION ON TUNING PERFORMANCES

For this comparative study, each lattice has been tuned by applying one tuning iteration consisting in a 1-to-1 correction and Dispersion Free Steering [9] (BBA) and 2 scans of sextupole knobs for linear aberration correction at the IP. This corresponds to approximately 500 luminosity measurements for one iteration. The 100 machines have been randomly misaligned and tuned for each lattice.

Figure 2 shows the average vertical beam size σ^*_y and average total luminosity over 100 machines after tuning. One can observe the strong impact of the dispersion level in the FFS on beam size, as expected from Eqs. (2)–(3). By increasing the dispersion level by a factor 2 the average σ^*_y is reduced for both L^* designs from approximately 7 nm to 3 nm. The optimal designs for both L^* were chosen according to the maximum average luminosity recovered after one iteration of BBA and linear knobs and the maximum number of machines that recover the design total luminosity.

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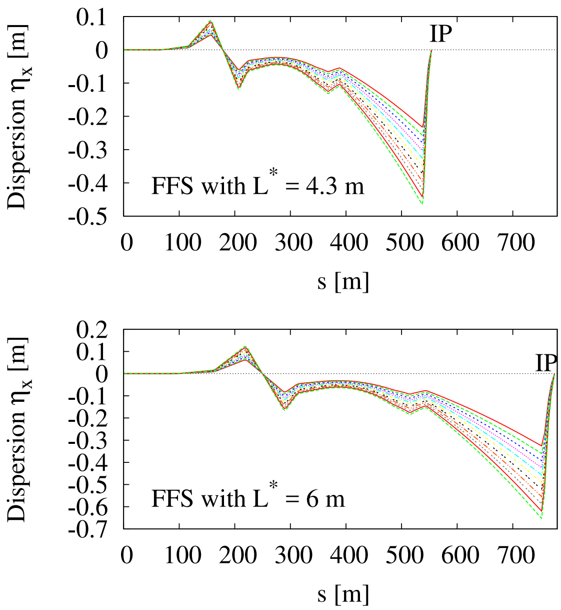

Figure 1: Dispersion profile along the FFS with bending magnet angles increased up to a factor 2. Top: L^* = 4.3 m design; Bottom: L^* = 6 m.

For L^* = 4.3 m the average luminosity has been increased from 82% of the design total luminosity L_0 (see Table 1) to 110% of L_0 if the dispersion is increased by 60%. For L^* = 6 m, the optimal design was found by increasing the dispersion level by 90% leading to an increase of the average luminosity from 72% of L_0 to 106% of L_0. The gain in tuning efficiency by choosing the optimal FFS design is very clear in Fig. 3. For the nominal L^* design, without dispersion increase, 34% of the machines simulated reach L_0 while 88% of the machines reach the design luminosity with the optimal design. For the long L^* case the number of machines that reach L_0 has been increased from 15% to 99%. The benefit of increasing dispersion on tuning effectiveness was demonstrated when considering only transverse misalignments as error conditions. The luminosity loss of the new tuning-based optimized designs compared to the old one is approximately 7% for L^* = 4.3 m and almost no loss for the long L^* option. The luminosity performances for the error-free lattices of the new optimized FFS are summarized in Table 2 as well as the tuning efficiency.

Table 2: CLIC 380 GeV Performances for Both L^* Options

L^* **[m]**	**4.3**	**6**
L_{total} / $L_{1\%}$ [10^{34} cm^{-2}s^{-1}]	1.95 / 1.1	1.75 / 1.05
σ_x^* / σ_y^* [nm]	147 / 2.4	150 / 2.7
Tuning success ratio		
(90%L_0 with x, y misaligned)	95%	99%
# of Lumi. measurement	≈500	≈500

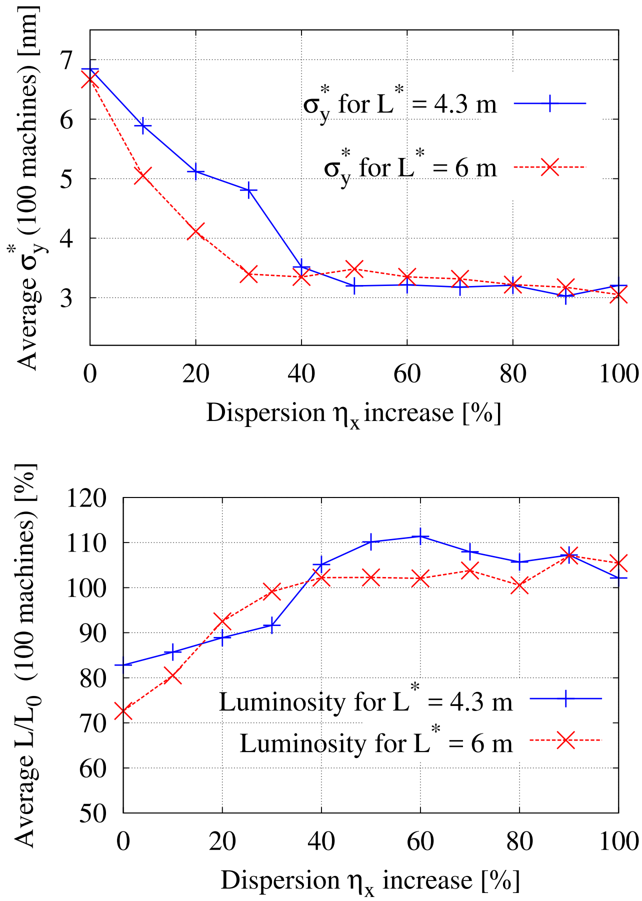

Figure 2: Average vertical beam size at the IP (top) and total luminosity, normalized to the design luminosity L_0, (bottom) of 100 machines simulated after 1 iteration of BBA and linear knobs tuning of the FFS with increased dispersion level.

PERFORMANCE COMPARISON OF THE OPTIMAL DESIGNS

Considering a tuning performance goal for the CLIC FFS of 90% of the machines reaching L_0, the tuning-based optimization for both L^* lattices has allowed to achieve the tuning goal with only 500 luminosity measurements if only transverse optics misalignment are implemented in the simulation. However, in order to ultimately prove the feasibility of these new designs, one has to add roll and strength errors into the beamline. In the following study, the tuning procedure has been applied to the nominal optimized design with L^* = 4.3 m, considering as beamline imperfections x and y misalignment of $\sigma_{x,y,RMS}$ = 10 μm, roll of $\sigma_{roll,RMS}$ = 300 μrad and relative strength error of $\sigma_{strength,RMS}$ = 10^{-4}. These realistic imperfections have been applied to all quadrupoles, sextupoles and BPMs of the FFS.

Tuning Under Realistic Error Conditions

When the strength of the normal sextupole magnets are changed by Δk_2, this gives rise to 2nd order optics com-

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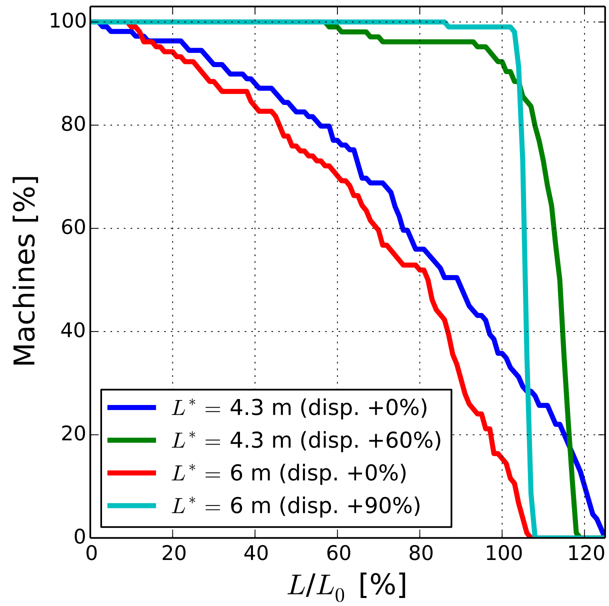

Figure 3: Tuning performance comparison of the $L^* = 4.3$ m and $L^* = 6$ m FFS designs without dispersion increase and with optimal dispersion level after 1 iteration of BBA and linear knobs. Only transverse misalignments are considered as beamline imperfections.

ponents. In our study these aberrations are not yet target by 2nd order knobs. According to the coefficient map formalism described in [10], strength errors introduce $T_{xx'x'}$, $T_{xx'\delta}$, $T_{x\delta\delta}$and $T_{xy'y'}$ 2nd order aberrations that impact the horizontal beam size. $T_{yx'y'}$ and $T_{yy'\delta}$ aberrations impact the vertical beam size. The chromatic aberrations are enhanced by the increase of dispersion and should be corrected by dedicated nonlinear knobs.

In Fig. 4 one can observe the impact of the additional imperfections on the tuning efficiency. After one iteration, 42% of the machines reach L_0 for $L^* = 4.3$ m. Under realistic error conditions more knobs scans will be needed to achieve the required tuning performance. It is worth noticing that in the tuning procedure simulated here, only linear knobs are applied. The 2nd order knobs, consisting in precomputed combination of strength variations of the 5 normal sextupoles present in the FFS, will be constructed and added to the tuning procedure. These new knobs will be used to specifically correct for the nonlinear aberrations described above and should reduce the tuning time needed to reach the goal. Investigations on both L^* options are ongoing to check the impact of dispersion increase on tuning performance under roll and strength errors of the optics in addition of the transverse misalignments considereded previously. The choice of the final layout of the FFS will be based on the tuning performance with all imperfections.

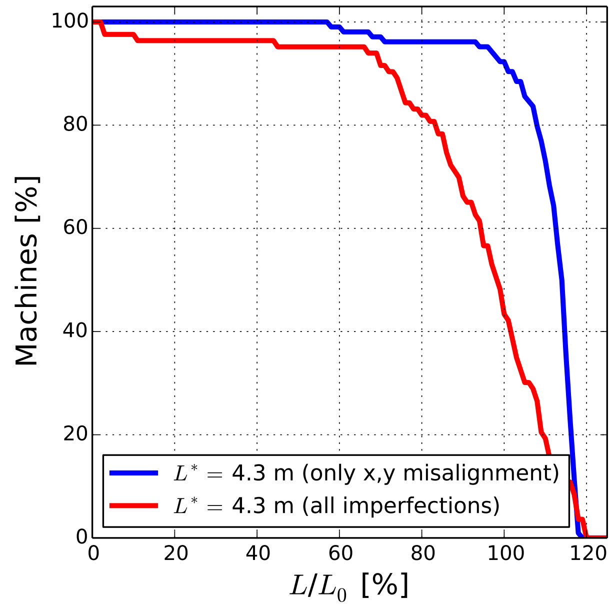

Figure 4: Tuning performances of the FFS with $L^* = 4.3$ m under realistic error conditions.

CONCLUSION

An alternative way of optimizing the FFS has been explored by applying changes in the lattice in order to improve the tuning efficiency while keeping the luminosity within the design requirements. Increasing the dispersion level in the FFS allowed to weakening the sextupoles and thus making the beamline more tolerant to optics transverse misalignments. The benefit on the tuning performance is significant for the two L^* options studied here. The optimal dispersion increase was chosen to maximize the probability to recover the design luminosity. Increasing the dispersion level by 60% for $L^* = 4.3$ m and by 90% for $L^* = 6$ m, increase the probability to recover L_0 by a factor 2.6 and 6.6 respectively after one iteration of BBA and linear knobs. With roll and strength errors added into the beamline, the tuning efficiency is deteriorated and additional knobs and scans are needed to achieve the desired performance. Dedicated investigations are ongoing to verify the impact of the dispersion increase on tuning under realistic error conditions and nonlinear knobs will be added into the tuning procedure in order to correct the residual 2nd order aberrations.

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