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TUNING-BASED DESIGN OPTIMIZATION OF CLIC FINAL FOCUS SYSTEM AT 3 TEV

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Abstract

The tuning aims to mitigate static imperfections of the Final Focus System (FFS) for emittance preservation at the Interaction Point (IP). A simulation campaign on the nominal CLIC FFS at 3 TeV has shown the need of rethinking the design in order to ease the tuning of the machine. The goal is to optimize the lattice in order to make the FFS more tolerant to misalignments by reducing the strength of the sextupoles. The tuning efficiency is promoted as figure of merit to find the optimal layout of the FFS.Acomparative study of the tuning performances has been carried out for different FFS lengths and for an alternative L^* option.

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The tuning aims to mitigate static imperfections of the Final Focus System (FFS) for emittance preservation at the Interaction Point (IP). A simulation campaign on the nominal CLIC FFS at 3 TeV has shown the need of rethinking the design in order to ease the tuning of the machine. The goal is to optimize the lattice in order to make the FFS more tolerant to misalignments by reducing the strength of the sextupoles. The tuning efficiency is promoted as figure of merit to find the optimal layout of the FFS. A comparative study of the tuning performances has been carried out for different FFS lengths and for an alternative L^* option.

INTRODUCTION

The design of the FFS for the final stage of CLIC has been optimized in the past for the nominal design with $L^* = 3.5$ m [1–7] and the parameters for this lattice are shown in Table 1. The total luminosity (L_{total}) and the peak luminosity coming from the collisions with energy larger than 99% of the maximum energy ($L_{1\%}$) are shown in the table. Under transverse misalignments of the magnetic elements, the nominal design is relatively challenging to tune [8]. Alternative designs are proposed here to ease the tuning of the FFS by reducing the impact of transverse misalignments on $\sigma^*_{x,y}$. The solution explored here is to reduce the strength of the FFS sextupoles in order to make the beamline more tolerant to these imperfections. Indeed, when the sextupoles are displaced horizontally and vertically, feed-down to normal and skew quadrupole kicks respectively are generated [9] and the corresponding changes in the IP vertical spot size are evaluated by:

$$\Delta\sigma^*_y = k_2 \Delta_x \beta_{y,s} \sigma^*_{y0} \quad (1)$$

$$\Delta\sigma^*_y = k_2 \Delta_y \sigma_{x,s} \left| R_{34}^{s\rightarrow *} \right| \quad (2)$$

where $\beta_{x,s}$ and $\beta_{y,s}$ are the β-functions at the sextupole location, $\sigma_{x,s}$ is the horizontal beam size at the sextupole location and $R_{34}^{s\rightarrow *}$ is the matrix element from the sextupole to the IP. Sextupoles are placed in dispersive region to correct chromaticity and their strengths (k_2) can be reduced by increasing the level of dispersion at their locations. Increasing the angle of the bending magnets in the FFS is an option, but for CLIC 3 TeV, synchrotron radiation strongly limits the angle increase. The window to increase dispersion is too small to significantly reduce k_2 without drastically reducing the luminosity. The alternative solution studied here to reduce k_2 was to increase the length of the FFS and therefore increase the dispersion.

Table 1: CLIC 3 TeV Design Parameters for Both L^* Options

L^* **[m]**	**3.5**	**6**
FFS length [m]	450	770
$\gamma\epsilon_x/\gamma\epsilon_y$ [nm]	660 / 20	660 / 20
β^*_x/β^*_y [mm]	7 / 0.068	7 / 0.1
σ^*_x/σ^*_y [nm]	40 / 0.7	40 / 1
σ_z [μm]	44	44
δ_p [%]	0.3	0.3
p/bunch N [$\times 10^9$]	3.72	3.72
Nbr of bunches n_b	312	312
f_{rep} [Hz]	50	50
L_{total} [10^{34}cm^{-2}s^{-1}]	5.9	5.9
$L_{1\%}$ [10^{34}cm^{-2}s^{-1}]	2	2
Chromaticity ξ_y (L^*/β^*_y)	51500	60000

LONGER FFS DESIGN OPTIMIZATION

The FFS length and the Final Doublet (QF1 and QD0) distance to the IP are optimized accordingly in order to cancel chromaticity and residual nonlinear terms. For the longer systems, the distance between QF1 and QD0 has been changed for each lattice in order to cancel the residual second order dispersion term that affects the horizontal beam size at the IP. The strength of the quadrupoles and sextupoles are first approximated according to the FFS length ratio and the square of the length ratio respectively. Bending magnet angles are then optimized in order to compromise between synchrotron radiation generated and geometric aberrations generated by the sextupoles. In order to observe the impact of longer FFS on tuning performance, 7 new FFS lattices have been re-optimized with length increased up to 829 meters. All designs fulfill the luminosity requirements (see Table 2) and the dispersion profiles for each lattice are shown in Fig. 1. One can see on Fig. 2 that when the length of the system is increased, the dispersion at sextupole locations increases accordingly, leading to weaker sextupoles.

IMPACT OF FFS LENGTH ON TUNING PERFORMANCES

The tuning simulation applied to these lattices consists in a 1-to-1 correction and Dispersion Free Steering [10, 11] (Beam Based Alignment) and 2 scans of sextupole knobs for linear aberration correction at the IP. This correspond to approximately 500 luminosity measurements for one iteration. The quadrupoles, sextupoles and BPMs of the 100 machines simulated for each lattice have been randomly misaligned by $\sigma_{x,y,RMS} = 10$ μm. Fig. 3 compares the tuning efficiency of each lattice after one tuning iteration of BBA and linear

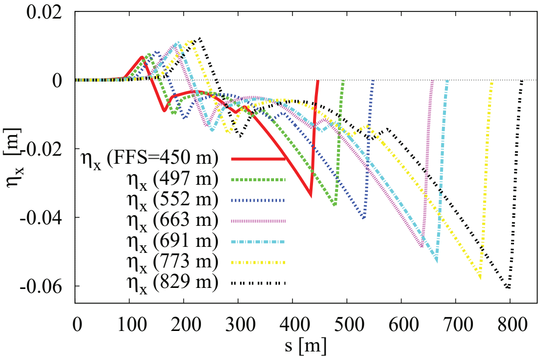

Figure 1: Dispersion profile for increased FFS length.

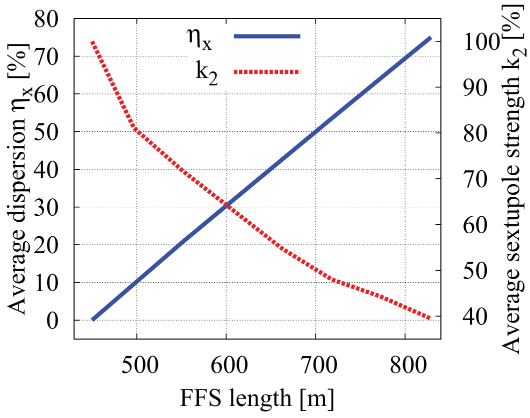

Figure 2: Average dispersion at sextupole locations and average sextupole strength as function of the FFS length.

knobs. The nominal design with a length of 450 meters is the least performant compared to longer systems. The tuning efficiency increases with length up to a certain length between 691 meters and 773 meters. The average luminosity, over the 100 machines, after one tuning iteration is summarized in Table 2. The best performance in this study was found for a FFS length of 691 meters. The average luminosity, normalized to the design luminosity L_0, was increased from 33% for the nominal design to 61% for the best FFS length. Further iterations with the linear knobs have been applied on this new design and the tuning performance is shown in Fig. 4. After 10 iterations, which corresponds to approximately 4000 luminosity measurements, there is 83% of the machines that reach 110% of L_0. That falls slightly short of the conceptual design report (CDR) [12] target for CLIC 3 TeV FFS which aims for 90% of the machines reaching 110% of L_0 with $\sigma_{x,y,RMS} = 10\ \mu$m of optics transverse misalignment. The CDR tuning goal aims to recover 110% of L_0 to provide a budget for the luminosity loss due to dynamic effects in the BDS.

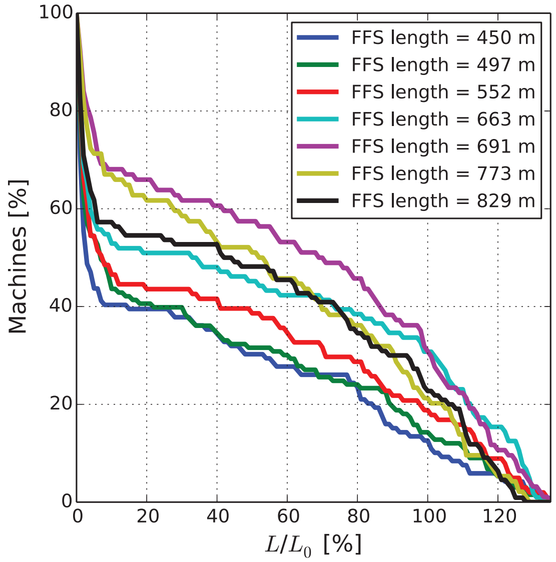

Figure 3: FFS length tuning performance comparison.

Table 2: FFS Length Luminosity and Tuning Effectiveness Comparison

FFS length [m]	L_{total} / $L_{1\%}$ [10^{34}cm^{-2}s^{-1}] (error-free lattice)	Average (L / L_0) [%] (1 tuning iteration)
450	7.04 / 2.3	33
497	7.1 / 2.33	36
552	7.2 / 2.34	42
663	7.2 / 2.38	51
691	7.06 / 2.38	61
773	7.02 / 2.34	53
829	6.95 / 2.34	50

TUNING PERFORMANCE OF LONG L^* FFS DESIGN

In order to ease the Machine detector interface (MDI) and avoid interplay between the last quadrupole QD0 and the solenoid fields, a longer L^* option has been proposed [2] for CLIC FFS. A new detector model has been designed allowing QD0 to be located outside the experiment with an L^* of 6 meters. The new lattice with $L^* = 6$ m has been optimized and fulfills the design requirements [13]. However, the long L^* option has to prove its tuning feasibility. The β_y^* has been changed to 0.10 mm [12] in order to optimize the luminosity for an error-free lattice. In the present study β_y^* is increased to improve the tuning performance while keeping the maximum luminosity achievable within the requirements.

Tuning-based Optimization of β_y^*

According to Eqs. (1), the impact of transverse misalignment of sextupoles on the beam size can be reduced by

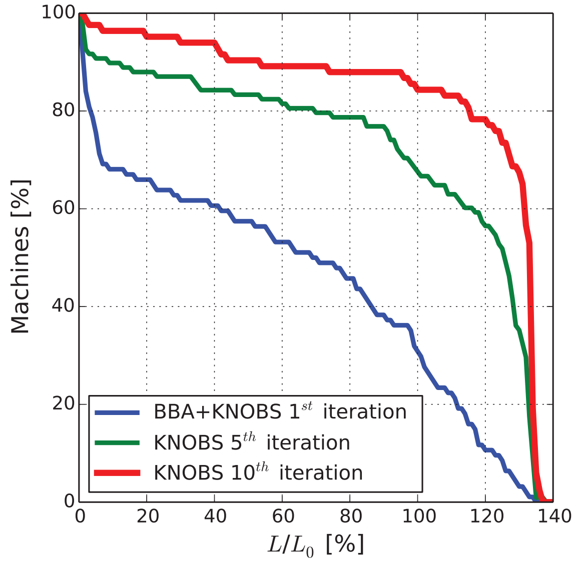

Figure 4: Tuning performance after ≈4000 luminosity measurements for the optimized FFS with a length of 691 meters and $L^* = 3.5$ m.

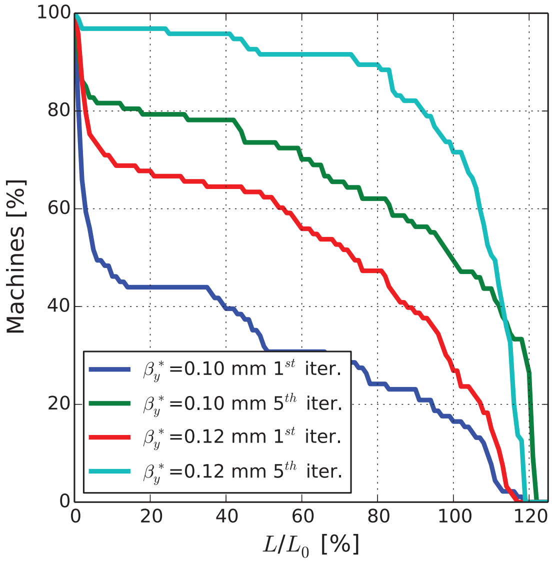

Figure 5: $\beta_y^* = 0.10$ mm versus $\beta_y^* = 0.12$ mm tuning performance comparison of the FFS with $L^* = 6$ m.

reducing the β-function at the sextupole locations by increasing β_y^*. In order to keep the total and peak luminosities within the design requirements, β_y^* was increased to 0.12 mm. The total and peak luminosities for these optics are $L_{\text{tot}} = 6.4 \times 10^{34}\text{cm}^{-2}\text{s}^{-1}$ and $L_{1\%} = 2.1 \times 10^{34}\text{cm}^{-2}\text{s}^{-1}$ respectively. The impact on tuning efficiency is shown in Fig. 5 where both β_y^* options are compared. After one tuning iteration 17% of the machines reach L_0 for $\beta_y^* = 0.10$ mm while 48% of the machines reach L_0 for $\beta_y^* = 0.12$ mm. After several linear knobs iterations the gain in tuning performance is also very clear for the larger β_y^* option.

There is approximately 4400 luminosity measurements needed to have 90% of the machines that reach the design luminosity and 82% of the machines that reach 110% of L_0, as shown in Fig. 6. Further studies are ongoing to prove the tuning feasibility under more realistic error conditions, adding roll and strength errors on the optics, which may require new knobs to correct nonlinear aberrations generated by these imperfections.

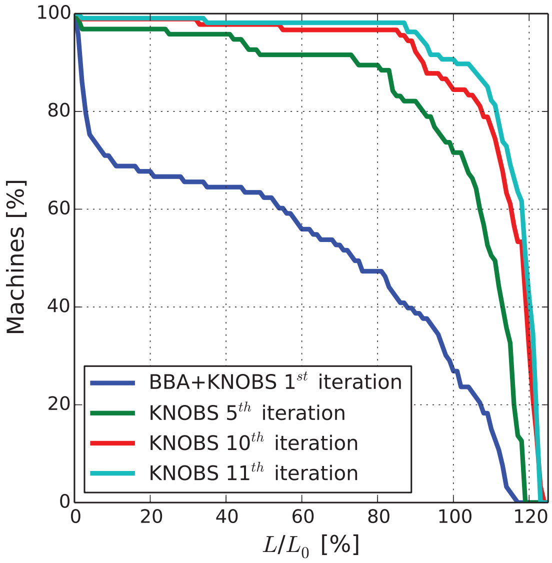

Figure 6: Tuning performance after ≈4400 luminosity measurements for the optimized FFS with $L^* = 6$ m.

CONCLUSION

The benefit on tuning of mitigating the impact of optics transverse misalignments on beam size by either reducing the FFS sextupole strengths (k_2) or increasing the β^* has been demonstrated. Increasing the length of the FFS is a satisfying way to weaken the strength of the sextupoles and ease the tuning while keeping the luminosity within the required performance. By lengthening the FFS from 450 meters to 691 meters, the average luminosity recovered after one scan of linear knobs has been increased from 33% to 61% of L_0. Further scans of the linear knobs have shown the tunability of this longer system. The tuning study carried out on the $L^* = 6$ m design has demonstrated its feasibility when the IP parameters are optimized to maximize luminosity along with tuning efficiency. With 90% and 81% of the machines that reach L_0 and 110% of L_0 respectively, in approximately 4400 luminosity measurements, the $L^* = 6$ m lattice is a robust candidate for the future CLIC FFS at 3 TeV.

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