CLIC BEAM DELIVERY SYSTEM REBASELINING AND LONG L^* LATTICE OPTIMIZATION

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Abstract

In the framework of the CLIC rebaselining, the Beam Delivery System (BDS) have been re-optimized for its initial stage at 380 GeV c.o.m with respect to its energy upgrade to 3 TeV c.o.m. Both stages were optimized for a short (nominal) and a long L^* (6 meters) allowing the last quadrupole (QD0) to be located outward of the detector solenoid field influence. Final Focus System (FFS) optics designs based on the Local chromaticity correction [1] and performance comparisons for both L^* options are shown.

INTRODUCTION

The CLIC operation strategy is to initially collide beams at 380 GeV c.o.m energy, with staged upgrades up to 3 TeV. The nominal BDS lattices for the first and final stages are designed with $L^* = 4.3$ m and $L^* = 3.5$ m respectively for optimal luminosity performance, leading to the integration of the last quadrupole QD0 inside the detector. However this configuration is challenging for the machine detector interface (MDI), QD0 stabilization, access during maintenance and shielding against the solenoid magnetic field, with an anti-solenoid reducing forward acceptance. An L^* of 6 meters allows to take away these challenges of QD0 integration while inevitably loosing luminosity due to the increase of chromaticity generated at the Final Doublet (FD), which scales as $\xi_y \propto L^*/\beta_y^*$. We describe here the optimization process applied for all lattices in order to achieve the design performance that are reported on Table 1.

Table 1: CLIC Design Parameters for Both Energy Stages and Both L^* Options

CLIC energy	**380 GeV**	**380 GeV**	**3 TeV**	**3TeV**
L^* [m]	4.3	6	3.5	6
FFS length [m]	553	770	450	770
$\gamma\epsilon_x/\gamma\epsilon_y$ [nm]	950 / 20	950 / 20	660 / 20	660 / 20
β_x^*/β_y^* [mm]	8.2 / 0.1	8.2 / 0.1	7 / 0.068	7 / 0.1
σ_x^*/σ_y^* [nm]	145 / 2.3	145 / 2.3	40 / 0.7	40 / 1
σ_z [μm]	70	70	44	44
δ_p [%]	0.3	0.3	0.3	0.3
p/bunch N [$\times 10^9$]	5.2	5.2	3.72	3.72
Nbr of bunches n_b	352	352	312	312
f_{rep} [Hz]	50	50	50	50
L_{tot} [10^{34}cm^{-2}s^{-1}]	1.5	1.5	5.9	5.9
$L_{1\%}$ [10^{34}cm^{-2}s^{-1}]	0.9	0.9	2	2
Chrom. ξ_y (L^*/β_y^*)	43000	60000	51500	60000

OPTIMIZATION OF THE 380 GeV LATTICES

The nominal BDS design for the first energy stage at 380 GeV is based on the optimized 500 GeV BDS [2] [3] using the Local FFS scheme and 6 sextupoles for chromaticity correction. In the case of the $L^* = 6$ m lattice, the FFS length has been scaled according to the increase of L^* (40%) as shown in Figure 1. In both cases the size of the dispersion has been scanned. Increasing the dispersion implies more synchrotron radiation while it requires weaker sextupoles to cancel the chromatic aberrations and one has to balance between these two effects in order to find the optimal design. Various optics have been optimized for different dispersion levels and the luminosities are computed to select the best. For the nominal $L^* = 4.3$ m the scan has shown that no change in dispersion level was needed to meet the design requirements while for the $L^* = 6$ m lattice at least 25% of increase is needed and the optimal design was found by increasing the dispersion by 70%. This leads to increase the total and peak luminosity by 10% and 8% respectively, as shown in Figure 2. For this last case, the average strength of the sextupoles has been reduced by 40%, which should improve tuning performance.

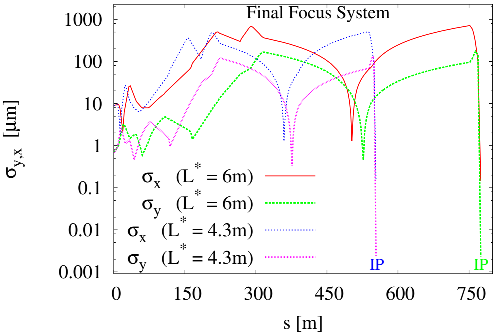

Figure 1: Horizontal and vertical rms beam sizes along the FFS for $L^* = 4.3$ m and $L^* = 6$ m at 380 GeV c.o.m energy.

Figure 3 shows a comparison of the non-linear optimization of the rms horizontal and vertical beam sizes at the IP $\sigma^*_{x,y}$ performed with MADX [4] and MAPCLASS [5] for both short and long L^* lattices with dispersion optimized. One can directly observe the impact of the last drift L^* on the transverse beam size due to the rise of chromaticity originated at the Final Doublet (FD). The higher order chromatic aberrations contributes to 3.5% and 22% of the horizontal and vertical beam size growth respectively for the $L^* = 4.3$ m lattice compare to 9% and 57% of the hor-

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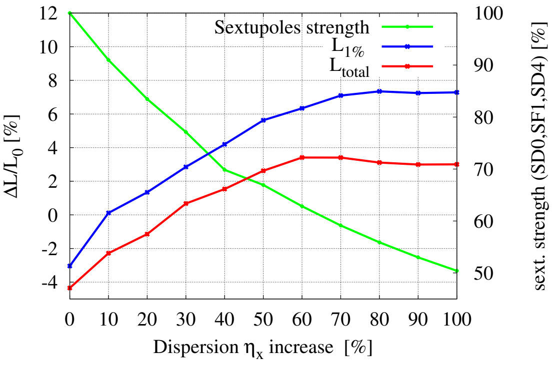

Figure 2: Relative luminosity versus dispersion increase through the FFS for L^*= 6 m at 380 GeV c.o.m energy.

izontal and vertical beam size growth respectively for the $L^* = 6$ m lattice. The luminosities, computed using PLACET and GUINEA-PIG codes [6], are $L_{\text{tot}} = 1.52 \times 10^{34}\text{cm}^{-2}\text{s}^{-1}$ and $L_{1\%} = 0.94 \times 10^{34}\text{cm}^{-2}\text{s}^{-1}$ for the long L^* and $L_{\text{tot}} = 1.86 \times 10^{34}\text{cm}^{-2}\text{s}^{-1}$ and $L_{1\%} = 1.09 \times 10^{34}\text{cm}^{-2}\text{s}^{-1}$ for the nominal L^*. In Figure 4, L_{tot} and $L_{1\%}$ computed versus beam energy deviation shows the comparison in bandwidths.

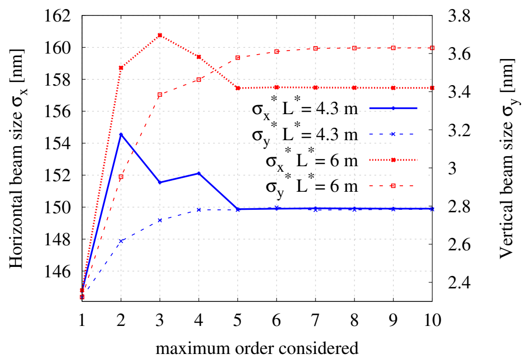

Figure 3: Horizontal and vertical rms beam sizes at the CLIC 380 GeV IP for both L^* options.

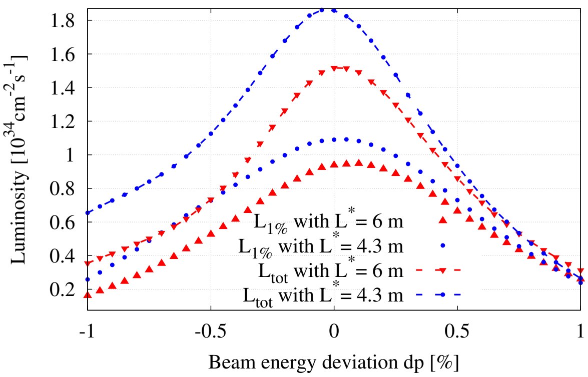

Figure 4: Total and peak luminosities versus beam energy deviation showing the bandwidths for both L^* options at 380 GeV c.o.m.

In order to face possible emittance dilution due to static and dynamic imperfections along the beamline, a budget of 50% of the nominal vertical emittance at the exit of the Linac has been proposed. Thus, both designs have been re-optimized considering a vertical normalized emittance of $\gamma\epsilon_y = 30$ nm at the entrance of the BDS. The vertical emittance has been increased by a factor 1.5, so using the same optimized lattices previously presented the new luminosity is multiplied by a factor $1/\sqrt{1.5}$ (around 20% of luminosity loss). The simulations have shown that for the $L^* = 4.3$ m design the luminosity requirements are met ($L_{\text{tot}} = 1.5 \times 10^{34}\text{cm}^{-2}\text{s}^{-1}$ and $L_{1\%} = 0.9 \times 10^{34}\text{cm}^{-2}\text{s}^{-1}$) without any changes in the linear optics. However, for the long L^* option, further optics optimization are needed. Reducing $\beta^*_{x,y}$ does not sufficiently reduce the beam size to meet the design performance. The introduction of a pair of octupoles in the dispersive region of the FFS separated by a π-phase advance ($-I$ transformation) allows to cancel the remaining octupole terms arising from the interaction of the interleaved sextupole pairs [7]. With $\beta^*_x = 7$ mm and a pair of octupoles, the beam sizes are reduced to $\sigma^*_x = 151$ nm and $\sigma^*_y = 3.1$ nm and the luminosity goal is achieved.

OPTIMIZATION OF THE 3 TeV LATTICE

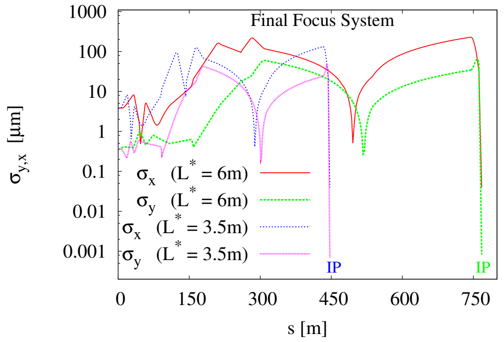

Figure 5: Horizontal and vertical beam sizes along the FFS for $L^* = 3.5$ m and $L^* = 6$ m at 3 TeV c.o.m energy.

At top energy the CLIC BDS has been fully optimized in the past for the nominal design with $L^* = 3.5$ m [8] [9] [10]. Here we focus on the optimization of the $L^* = 6$ m BDS. The FFS length has been increased by 70% to scale with the new L^* as shown in Figure 5. A scan of the $\beta^*_{x,y}$ has been made showing that increasing β^*_y from 0.068 mm to 0.1 mm (see Table 1) gives better performances, in addition with lower ξ_y at the IP and lower β_y along the FFS. However, the total luminosity remained below the design one. A dispersion optimization has been performed as for the first stage, but at 3 TeV synchrotron radiation dominates the contribution to the beam size growth at the IP and thus reducing dispersion level in the FFS allows to increase luminosity as shown in Figure 6. In Figure 7 one can see the large impact of synchrotron radiation on the performance of the system. When the dispersion decreases, the horizontal beam size without synchrotron radiation slightly increases, while when the synchrotron radiation is taken into account σ_x^* significantly decreases. The optimal performances were found by decreasing the dispersion level by 15% . This leads to increase L_{tot} and $L_{1\%}$ by 11% and 3% respectively and finally the average strength of the sextupoles has been increased by 18%.

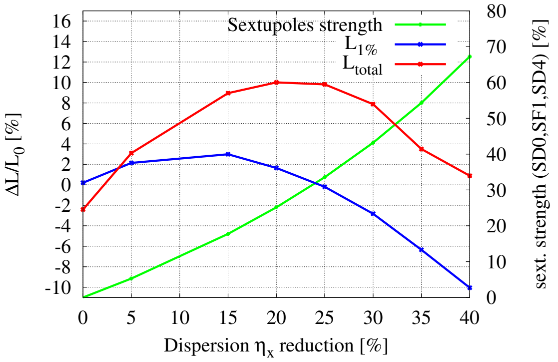

Figure 6: Relative luminosity versus dispersion reduction through the FFS for L^*= 6 m at 3 TeV c.o.m energy.

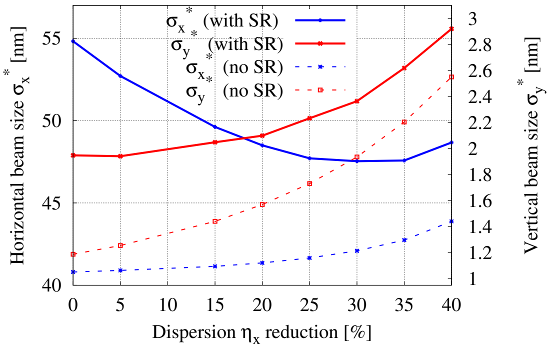

Figure 7: Horizontal and vertical rms beam sizes at IP with and without synchrotron radiation versus dispersion reduction through the FFS for L^*= 6 m at 3 TeV c.o.m energy.

In comparison with the nominal design (see Figure 8), the optimized lattice with L^* = 6 m leads to 17% and 10% of total and peak luminosity loss respectively, with $L_{\text{tot}} = 6.43 \times 10^{34}\text{cm}^{-2}\text{s}^{-1}$ and $L_{1\%} = 2.1 \times 10^{34}\text{cm}^{-2}\text{s}^{-1}$. No higher order multipoles have been inserted in the beamline for the long L^* lattice so one can expect further improvements by introducing octupoles or decapoles.

BDS LAYOUTS FOR ENERGY UPGRADE

The BDS for the 380 GeV up to 3 TeV will be hosted inside the 4.5 diameter CLIC tunnel [11]. In order to avoid modifications in the tunnel during the energy upgrade, the BDS entry must be aligned with the Main Linac. The 380 GeV BDS with L^* = 4.3 m is based the 500 GeV BDS where modifications in the crossing angle (18.27 mrad) and in the bending angle in the dipoles of the collimation section have been applied already to make the alignment with the nominal 3 TeV BDS (L^* = 3.5 m) [12]. The large increase of the bending angle in the dipoles of the FFS with L^* = 6 m at 380 GeV have lead to reduce the crossing angle from 20 mrad to 16.2 mrad and increase the bending angle in the dipoles of the collimation section by 15% in order to align with the long L^* 3 TeV BDS as shown in Figure 9. The BDS performances presented were performed after alignment.

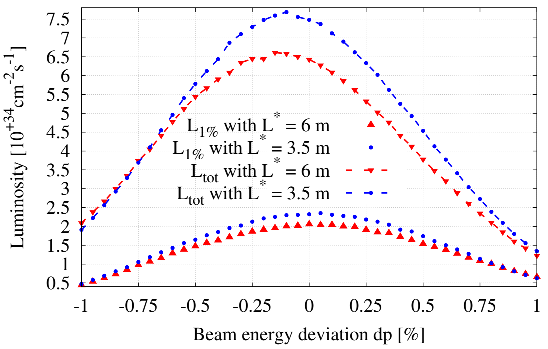

Figure 8: Total and peak luminosities versus beam energy deviation showing the bandwidths for both L^* options at 3 TeV c.o.m.

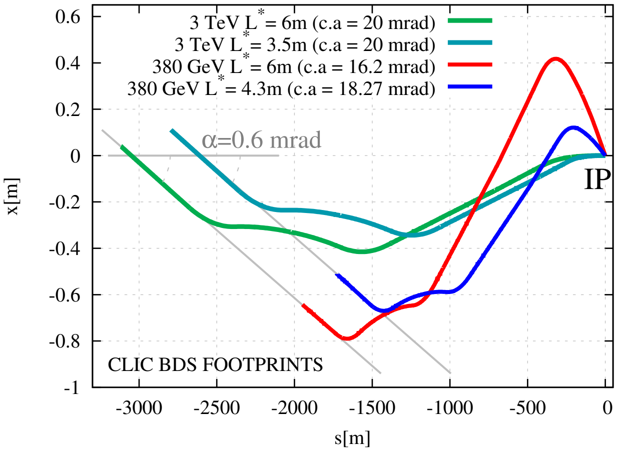

Figure 9: 3 TeV BDS & 380 GeV BDS footprints for nominal and long L^* configurations. For each L^* lattice, both 3 TeV and 380 GeV BDS are now aligned with the LINAC.

CONCLUSIONS AND OUTLOOK

Two long L^* designs have been optimized and proposed for the CLIC BDS at low and top energies taking into account the energy upgrade. While the short L^* options achieve optimum luminosity with a good margin above the requirements, the long L^* takes away many challenges of QD0 integration and possible integrated luminosity loss by moving the quadrupole outward of the detector region. The new long L^* lattices meet the performance requirements. A fair comparison between these two options must include tuning of the FFS and impact of the detector solenoid on luminosity.

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