PERFORMANCE EVALUATION OF THE CLIC BASELINE COLLIMATION SYSTEM*

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Abstract

We review the current status of the collimation system of the Compact Linear Collider (CLIC). Calculations are done to study the survivability of the CLIC energy spoiler in case of impact of a full bunch train considering the most recent beam parameters. The impact of the collimator wakefields on the luminosity is also studied using the updated collimator apertures, and we evaluate the beam position jitter tolerance that is required to preserve the nominal luminosity. Moreover, assuming the new collimation depths, we evaluate the collimation efficiency.

INTRODUCTION

The CLIC Beam Delivery System (BDS), downstream of the main linac, consists of a 370 m long diagnostics section, an almost 2000 m long collimation system, and a 460 m long final focus system (FFS) [1]. Figure 1 shows the betatron and dispersion functions along the CLIC BDS. Some relevant CLIC design parameters are shown in Table 1.

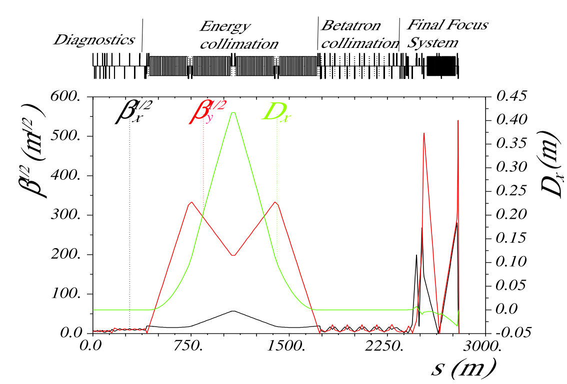

Figure 1: Horizontal dispersion and square root of the betatron functions for the CLIC BDS.

We can distinguish between two collimation sections:

The first postlinac collimation section is dedicated to energy collimation. The energy collimation depth is determined by failure modes in the linac [2]. A spoiler/absorber scheme, located in a region with non-zero horizontal dispersion, is used for intercepting mis-steered or errant beams with energy deviation larger than about 1.3% of the nominal beam energy.

Downstream of the energy collimation section, a dispersion-free section, containing eight spoilers made of beryllium (Be) and eight copper (Cu)-coated Titanium (Ti) absorbers, is dedicated to the cleaning of the transverse halo of the beam, thereby reducing the experimental background at the Interaction Point (IP).

The CLIC betatron collimation depths have been determined from the following conditions: (I) synchrotron radiation photons emitted in the first final quadrupole magnet, so-called QF1, should not hit the second final quadrupole, so-called QD0; (II) no beam particles should hit QF1 or QD0. Adopting these criteria the CLIC betatron collimation depths have been set at 10 σ_x in the horizontal plane and 44 σ_y in the vertical plane (set as of beginning 2008 [1]).

Table 2 summarises the CLIC post-linac collimator parameters.

Table 1: CLIC Parameters for 3 TeV Centre-of-Mass Energy

Centre-of-mass energy (TeV)	3
Design luminosity (10^{34} cm^{-2}s^{-1})	5.9
Energy spread (%)	1
Linac repetition rate (Hz)	50
Particles/bunch at IP ($\times 10^9$)	3.72
Bunches/pulse	312
Bunch length (μm)	45
Bunch separation (ns)	0.5
Bunch train length (μs)	0.156
Emittances $\gamma\epsilon_x/\gamma\epsilon_y$ (10^{-8} rad·m)	66/2
Transverse beam sizes at IP σ_x^*/σ_y^* (nm)	45/0.9

Table 2: CLIC post-linac optics and collimator parameters. Horizontal and vertical β-functions, horizontal dispersion, horizontal and vertical half gaps. Notation: E-SP (energy spoiler), E-AB (energy absorber), $\beta_{x,y}$–SP (horizontal and vertical betatron spoilers respectively), and $\beta_{x,y}$–AB (horizontal and vertical betatron absorbers respectively).

Collimator	β_x[m]	β_y[m]	D_x[m]	a_x[mm]	a_y[mm]
E-SP	1406.33	70681.9	0.27	3.51	25.4
E-AB	3213.03	39271.5	1.231	5.41	25.4
β_y–SP	114.054	483.253	0.	10.	0.08
β_y–AB	114.054	483.184	0.	1.	1.
β_x–SP	270.003	101.347	0.	0.08	10.
β_x–AB	270.102	80.9043	0.	1.	1.

SPOILER SURVIVABILITY

The energy spoiler has been designed with the condition of surviving in case of a deep impact of an entire bunch train or, at least, withstanding the impact of as many

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bunches as possible.

The principal mechanism for spoiler damage is the instantaneous heat deposition . The main sources for such a heating are the energy deposition by direct beam-spoiler impact, the image current heat deposition (ohmic heating) and electric field breakdown. Assuming a thin spoiler ($\approx 0.5\ X_0$, with X_0 the radiation length of the material), in case of a deep beam-spoiler impact the energy deposition is basically done by ionization.

We have calculated the instantaneous temperature rise in the energy spoiler by the deep impact of a full train using the code FLUKA [3], considering a spoiler made of Be with the geometry of Fig. 2 and the new CLIC parameters (Table 1). The input is a train with 312 bunches, 3.72×10^9 particles per bunch, 1.5 TeV beam energy, with $\sigma_x = 796\ \mu$m and $\sigma_y = 21.9\ \mu$m horizontal and vertical beam sizes at spoiler, respectively. No energy spread has been assumed. We have obtained a maximum increment of temperature of about 280 K, which is below of the melting limit (1267 K), and even below the thermal fracture limit (370 K).

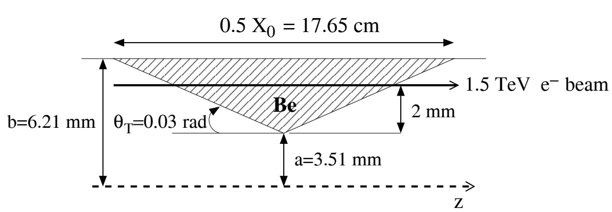

Figure 2: Schematic of a Be based energy spoiler for CLIC. The figure is not to scale.

Other spoiler design options with different geometry and/or combining Titanium alloy (Ti6Al4V) and Be are extensively studied elsewhere [4].

Unlike the energy spoiler, the betatron spoilers have been designed to be sacrificial, i.e. they would be destroyed if they suffer the direct impact of a bunch train. A possible alternative is the use of rotating consumable collimators [5] as betatron spoilers for CLIC.

COLLIMATOR WAKEFIELD EFFECTS

Collimator wakefields in the BDS can be an important source of emittance growth and beam jitter amplification, consequently degrading the luminosity. CLIC collimator wakefields have previously been studied using the tracking code PLACET [6] with collimation depths 10 σ_x and 83 σ_y. Since the new vertical collimation depth was reduced to 44 σ_y (80 μm collimator half gap), we have recalculated the effects of the collimator wakefields on the luminosity. The value of the luminosity has been computed using the code GUINEA-PIG [7].

Figure 3 compares the relative luminosity versus initial vertical beam position offset, generated at the entrance of the BDS, with collimator wakefields and without collimator wakefields. The joint effect of all the BDS collimators has been considered. For instance, with 1 σ_y beam position offset, we obtain about 15% luminosity loss without wakefield effects and 35% luminosity loss with wakefields.

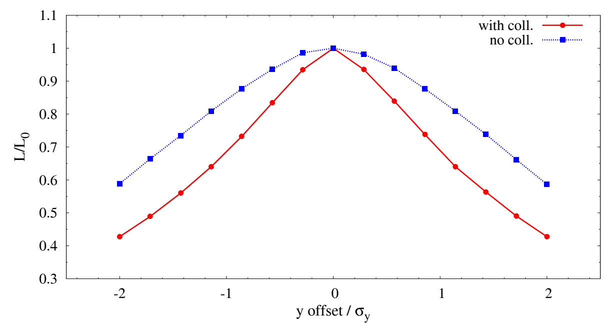

Figure 3: Luminosity loss versus initial vertical position offset at the entrance of the BDS with collimator wakefield effects (solid red line and circle points) and without collimator wakefield effects (dotted blue line and square points).

Monte Carlo simulations of luminosity distribution for 100 machines (Fig. 4) show about 5% rms luminosity loss and about 18% maximum luminosity loss due to wakefield effects and 0.2 σ_y beam position jitter. Therefore, the collimator wakefields impose a very tight initial beam jitter tolerance $< 0.2\ \sigma_y$.

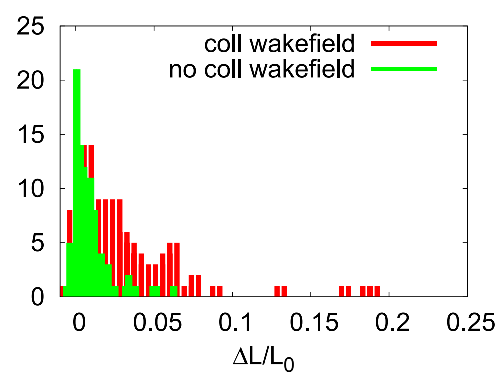

Figure 4: Luminosity loss distribution for 100 machines considering an initial position jitter of 0.2 σ_y, with (red) and without (blue) collimator wakefield effects.

New studies have recently determined the following optimum CLIC collimation depths: 15 σ_x and 55 σ_y [8]. These new values can help to reduce the wakefield effects.

COLLIMATION EFFICIENCY

Energy Collimation

The energy collimation system fulfils a machine protection function against mis-steered beams coming from the linac with large momentum error $\gtrsim 1.3\%$.

We have studied the efficiency of this system by means of beam tracking simulations using the code PLACET. Gaussian distributions of 10^5 off-energy macroparticles are tracked through the BDS lattice. In these simulations the spoiler is treated as a "black" collimator, i.e. any macroparticle interacting with the aperture is assumed to be completely absorbed without secondary particle production. Figure 5 shows the relative number of lost particles versus the average beam energy offset. We have compared three cases with different energy spread (assuming a Gaussian energy spectrum): $\sigma_E = 0\%$ (monochromatic beam), $\sigma_E = 0.25\%$ and $\sigma_E = 0.5\%$. The system seems to work as expected. For average energy offsets $\gtrsim 1.3\%$ practically 100% of the particles of the beam are removed by the energy spoiler.

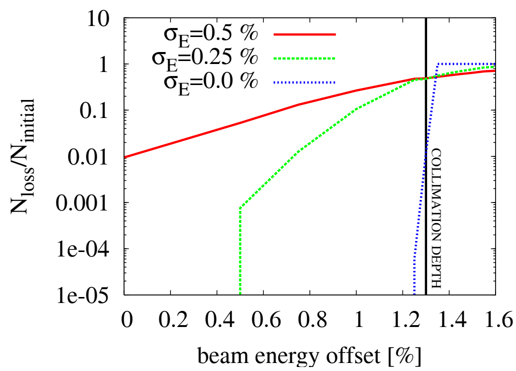

Figure 5: Relative beam particle loss at the energy spoiler versus the average energy offset of the beam. The curves correspond to the cases with beam energy spread 0%, 0.25% and 0.5%. The vertical solid black line indicates the limit of the energy collimation depth.

Betatron Collimation

The function of the betatron collimators is to clean the transverse beam halo to reduce the particle background at the IP. Here we use the following collimation depths: $\pm 10\ \sigma_x$ and $\pm 44\ \sigma_y$ in the phase spaces x-x' and y-y', respectively. To evaluate the cleaning efficiency of this system particles travelling at high transverse amplitude have been tracked using the code PLACET. We have used a simple halo model, which consists of a Gaussian distribution of 50000 macroparticles with $10^{3/2}\sigma_{x,y}$ rms, 1.5 TeV nominal beam energy and no energy spread. Figure 6 (Left) shows the transverse profile of the particle distribution at the entrance of the BDS.

Considering "black" spoilers, approximately 96% of the initial particle distribution is cleaned by the betatron collimation system. About 84% particle loss are localised at the two first betatron spoilers.

Figure 6 (Right) shows the remaining halo transverse profile at QF1 after collimation. Approximately 10% of the non-collimated particles, which corresponds to $\approx 0.44\%$ of the initial halo, remain outside the collimation window.

These results show a good cleaning performance of the system. Optimisation of the phase advance between spoilers and final doublet might further improve the cleaning efficiency.

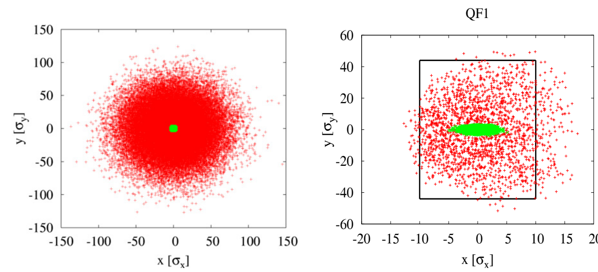

Figure 6: Left: transverse profile of the input halo at the BDS entrance. Right: halo profile at QF1 after collimation. The green ellipse represents the nominal beam core. The collimation window is also represented.

CONCLUSIONS

We have studied the performance of the current CLIC collimation system design with the most recent CLIC beam parameters.

Currently different momentum spoiler designs are being studied [4]. Be based spoilers might be a suitable solution in terms of high robustness and acceptable wakefields.

Collimator wakefields can cause severe single and multi-bunch effects leading to significant luminosity loss. To reduce the collimator wakefield effects we need to study the possibility of increasing the final quadrupole doublet aperture, thereby increasing the collimation depths.

BDS multiparticle tracking simulations show that the collimation system works as expected. The momentum collimation section protects the machine, totally intercepting beams coming from the linac with average energy offsets $\gtrsim 1.3\%$. Using simple transverse beam halo models, simulations show a good cleaning efficiency of the betatron collimation section. However, future studies with more realistic simulations should also include the energy deposition in spoilers and absorbers with secondary particle production and the collimator wakefield effects on the halo. In addition more realistic halo models would be useful as an input for the cleaning efficiency studies.

Finally, the author would like to thank the CLIC study group for many helpful discussions.

REFERENCES

[1] F. Tecker, *et al.*, CLIC-Note-764 (2008).

[2] D. Schulte and F. Zimmermann, CLIC Note 492 (2001); CERN-SL-2001-034 (AP) (2001).

[3] A. Fasso, *et al.*, CERN-2005-10 (2005).

[4] J. L. Fernández-Hernando and J. Resta-López, these proceedings.

[5] J. Frisch, E. Doyle, K. Skarpaas, SLAC-PUB-8463 (2000).

[6] G. Rumolo, A. Latina and D. Schulte, EUROTeV-Report-2006-026 (2006).

[7] D. Schulte, Ph.D. Thesis, TESLA-97-08 (AP).

[8] R. Tomás, *et al.*, these proceedings.