DESIGN OF THE CLIC PRE-MAIN LINAC COLLIMATION SYSTEM

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Abstract

A main beam collimation system, upstream of the main linac, is essential to protect the linac from particles in the beam halo. The proposed system consists of an energy collimation (EC) system just after the booster linac near the start of the Ring To Main Linac (RTML) transfer line and an EC and betatron collimation (BC) system at the end of the RTML, just before the main linac. The design requirements are presented and the cleaning efficiency of the proposed systems is analysed depending on different design choices.

INTRODUCTION

The Compact Linear Collider (CLIC) is a proposed electron-positron collider with a centre of mass energy of 3 TeV. CLIC relies on very low emittance beams to achieve the design luminosity of 5.9×10^{34} $cm^{-2}s^{-1}$ [1]. The resulting transverse energy density of the main beams will be of the order of GJ/mm^2; this poses a significant risk of damage to components of the machine in the event of uncontrolled beam losses [2].

The RTML transports the electron and positron bunch trains from the damping rings to the entrance of the main linacs (Fig. 1). Along the RTML, bunches are accelerated from 2.86 GeV to 9 GeV and the bunch length is reduced from 1.8 mm to 44 µm.

Collimation systems will be used to protect the machine from errant particles or bunches. A post-main linac collimation system has been designed to protect the detector from dangerous particles [3]. The RTML collimation systems outlined in this paper are designed to prevent potentially dangerous particles entering the main linacs, leading to breakdowns or damage of the RF structures.

RTML COLLIMATION

Dilution by Spoiler

The collimation in the RTML consists of three systems, two EC systems to protect against beam energy errors and a BC system to remove particles in the beam halo and to protect against miss-steered bunches. All three collimation systems will employ a spoiler-absorber based design. The spoiler consists of a 20 cm long block of beryllium, while the absorber consists of a 70 cm long block of titanium; the BC spoilers and absorbers may be coated with copper to reduce the resistive wakefields induced by the passing beam. The absorbers are situated further from the passing beam than the spoilers, hence their induced wake kicks are significantly smaller. The spoilers and absorbers will have tapered edges to reduce the geometric wakefields (Fig. 2). A smaller taper angle, θ_T, results in a smaller geometric contribution to the impedance but a larger resistive contribution and longer spoilers; thus the taper angle is chosen as a compromise. The induced wakefields interact with the passing beam, leading to emittance growth and jitter amplification; thus the wakefield amplitude must be minimised.

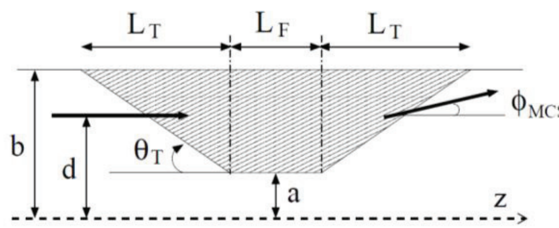

Figure 2: Longitudinal sketch of a spoiler or absorber.

The primary purpose of a spoiler is to increase the volume of phase space occupied by the collimated particles via multiple Coulomb scattering (MCS). In the event of a full CLIC bunch train colliding with the absorber the beam must have been diluted sufficiently by the spoiler to prevent damage to the absorber by melting or thermal fractures [3]. Figure 3 shows a plot of beam size at the absorber versus spoiler length, L, normalised in terms of radiation length, X_0, which is 0.353 m for beryllium. The horizontal, σ_x, vertical, σ_y and radial, σ_r, beam sizes are shown, σ_r is the geometric mean of σ_x and σ_y. The criterion for survival of the absorber is given by Eq. (1) [3]; this is for the nominal CLIC bunch charge of 3.72×10^9 electrons [1].

$$\sigma_r = \sqrt{\sigma_x \sigma_y} \geq 600\mu m \qquad (1)$$

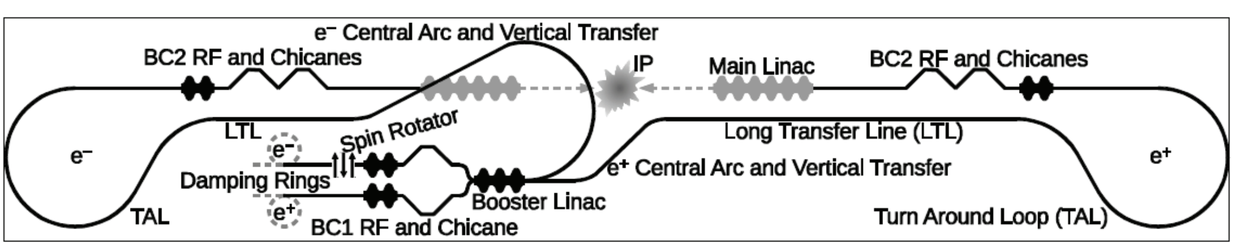

Figure 1: Sketch of the CLIC RTML [1].

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The RMS horizontal and vertical beam sizes are given by Eqs. (2) and (3); $R_{i,j}$ is the (i,j) element of the transfer matrix between the spoiler and the absorber, ϕ_{MCS} is the increase in angular spread due to the spoiler and $\sigma_{x,0}$ is the unspoiled beam size.

$$\sigma_x \approx \sqrt{R_{1,2}^2 \phi_{MCS}^2 + \sigma_{x,0}^2} \approx \sigma_{x,0} \quad (2)$$

$$\sigma_y \approx R_{3,4}\phi_{MCS} \quad (3)$$

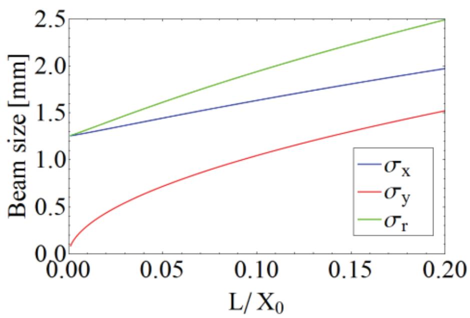

Figure 3: Beam size at absorber vs. spoiler length for EC1.

Energy Collimation

Energy collimation is achieved by situating a spoiler-absorber pair within a region of large horizontal dispersion. The first energy collimator (EC1) is situated after the booster linac, at the start of the central arc. The second system (EC2) is situated in the first chicane for the second bunch compressor, where the horizontal dispersion is suitably large. Both EC1 and EC2 will cut at energy deviations of $\pm 4\sigma_E$.

Beam jitter is dependent on the betatronic component of the beam size, σ_β; thus to minimise coupling between energy and betatron collimation, β_x must be minimised in the EC systems.

The emittance growth through a collimator is dependent on the aperture of the spoiler [4]; this is particularly true for the EC systems (Fig. 4). A minimum spoiler aperture of ±5 mm has been chosen for the EC systems because the emittance growth will be < 1pm and less sensitive to the spoiler aperture.

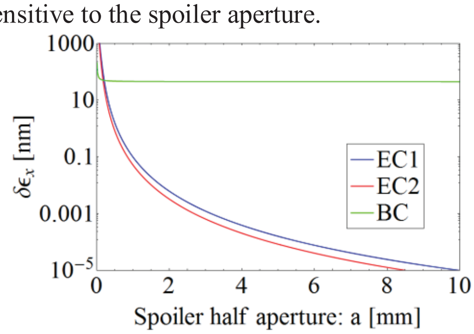

Figure 4: Emittance growth vs. spoiler half aperture for $1\sigma_\beta$ beam jitter.

For the baseline designs of EC1 and EC2, the same spoiler and absorber parameters are used as for the post-linac EC system [3]. The optics at EC1 has been fully optimised and matched to the existing optics of the RTML. However EC2 still requires further investigation to determine whether it is suitable. Limited space in the current design of the bunch compressor chicane does not allow for an upstream spoiler. Unfortunately the radial beam size at the absorber is very small: ~260 µm; therefore it is likely that the absorber would suffer damage in the event of a collision with a full CLIC bunch train. For the current EC2 design it has been assumed that the drift length in the chicane can be increased from 1 m to 2 m to allow sufficient space for a spoiler.

Betatron Collimation

The design of the BC system is notably more challenging than the designs of the EC systems. The positional displacement of the beam is dependent on $\sqrt{\beta}$ and thus the betatronic beam size, σ_β. For the EC systems the spoiler aperture, $a \gg \sigma_\beta$, this however is not true for the BC system. This results in larger amplitude wakefields and thus significant emittance growth (Fig. 4).

Simulation studies were undertaken to investigate the impact of induced wakefields in the BC system on the beam emittance; thus allowing the BC design parameters to be optimised. The emittance growth through the collimator is dominated by the spoiler design; the absorber is situated significantly further from the beam envelope [3]. Hence the critical design parameters to optimise are the spoiler aperture and the taper angle, θ_T. Figure 5 shows how the emittance growth varies with these parameters. Nominal values a = 0.5 mm and θ_T = 88 mrad were chosen to keep the emittance growth within 5% of the theoretical minimum. This however is not sufficient to keep emittance growth within tolerable limits; Table 1 shows the emittance growth budget for the RTML [1].

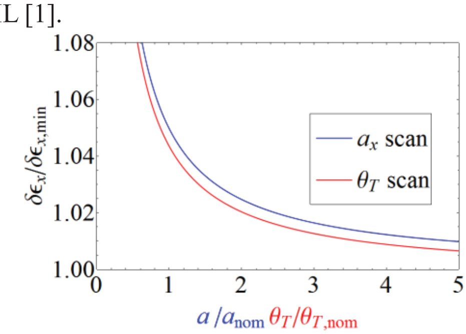

Figure 5: Emittance growth vs. spoiler design parameters.

Table 1: RTML Emittance Growth Budget

	Design	Static	Dynamic
$\Delta\varepsilon_x$	60 nm	20 nm	20 nm
$\Delta\varepsilon_y$	1 nm	2 nm	2 nm

The emittance growth is also dependent on the beam jitter at the entrance of the BC system. The dynamic budget is reserved for emittance growth due to stochastic processes such as beam jitter; a maximum of 25% of the dynamic budget in each transverse plane has been allocated for the BC system. The static budget allows for emittance growth due to static mis-alignment of components in the RTML. Tracking simulations in

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PLACET have shown that the RTML uses less than 50 nm of the horizontal design budget; the remaining 10 nm have also been allocated to the BC emittance growth budget.

Table 2 summarises the results of the wakefield simulations and particle tracking in PLACET. This table shows the emittance growth budgets and the corresponding limits on position jitter at the entrance of the BC system and at injection into the RTML (Inj).

Table 3 summarises the important design parameters of the three collimation systems. BCH and BCV refer to the horizontal and vertical BC systems respectively.

Table 2: Beam Stability Requirements for the BC System

	$\Delta\varepsilon$	σ_{jitt} @ BC	σ_{jitt} @ Inj
Horizontal	15 nm	$0.21\sigma_x$	$0.10\sigma_x$
Vertical	0.5 nm	$0.13\sigma_y$	$0.27\sigma_y$

Table 3: Design Parameters for EC1, EC2 and BC

Parameter	EC1	EC2	BCH	BCV
RMS energy spread	±0.33%	±1.7%	±1.7%	±1.7%
Collimator cut	$\pm 4\sigma_E$	$\pm 4\sigma_E$	$\pm 8\sigma_x$	$\pm 50\sigma_y$
Spoiler aperture	±5 mm	±20 mm	±0.6 mm	±1 mm
β at spoiler	50.6 m	35.5 m	118 m	595 m
Horizontal dispersion	0.38 m	0.29 m	0.00 m	0.00 m
$R_{3,4}$	2.4 m	1.1 m	84 m	421 m
Number of spoilers	1	1	4	4
Phase advance between spoilers	N/A	N/A	0.75π	0.25π
Total insertion length	38.7 m	2.0 m	110 m	110 m

Collimation Efficiency

The collimation efficiency of the BC system depends on the number of spoiler-absorber pairs, n. Assuming each spoiler-absorber pair is separated by a phase advance $(2m+1)\pi/n$, the uncollimated region in normalised phase space will form a regular 2n-sided polygon, where m is an integer ≥ 0 and $(2m+1)$ and n are mutually prime. The acceptance region of the beam in normalised phase space will form a circle. The collimation efficiency is defined as the ratio of areas in phase space between the acceptance region and the uncollimated region and is given by Eq. (4).

$$\eta_{coll}=\frac{\pi}{4n}\cot\left(\frac{\pi}{4n}\right) \quad (4)$$

As $n\to\infty$, $\eta_{coll}\to 1$; however, the emittance growth scales approximately linearly with n. Efficiency in terms of emittance growth is defined in Eq. (5).

$$\eta_{emit}=\frac{\delta\varepsilon_{nom}}{\delta\varepsilon_{nom}+n\delta\varepsilon_{coll}} \quad (5)$$

The total efficiency is defined as $\eta_{tot}=\eta_{coll}\eta_{emit}$; Fig. 6 shows all three efficiency curves. The maximum for the total efficiency occurs for n = 4.4; hence n = 4 is chosen as the optimum number of spoiler-absorber pairs. These curves were calculated for the nominal parameters of the BC system.

At present, it seems unlikely that the extraction kicker and septa for the damping rings can be designed with sufficient stability to meet the stringent jitter requirements stated in Table 2. Proposed feed forward systems located across the central arc and turn-around loop of the RTML are currently being investigated as a solution; this would significantly relax the requirements of the damping ring extraction system. Furthermore, this can significantly reduce the emittance growth through the RTML.

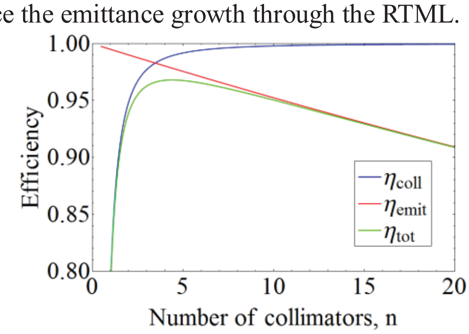

Figure 6: Collimation efficiency vs. the number of spoiler-absorber pairs in the BC system.

CONCLUSIONS

Baseline designs of CLIC pre-linac collimation systems, located in the RTML, have been presented. They consist of two energy collimation systems (EC1, EC2) and one betatron collimation system (BC) consisting of 4 spoiler-absorber pairs in each plane. Further investigation is needed to confirm the feasibility of EC2.

Further wakefield studies are needed for the BC system to investigate the effect of long range wakefields on later bunches. In addition, development of the proposed RTML feed forward systems is needed and further studies of the damping ring extraction stability.

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