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OPTIMIZATION OF THE CLIC BASELINE COLLIMATION SYSTEM

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Abstract

Important efforts have recently been dedicated to the improvement of the design of the baseline collimation system of the Compact Linear Collider (CLIC). Different aspects of the design have been optimized: the transverse collimation depths have been recalculated in order to reduce the collimatorwakefield effects while maintaining a good efficiency in cleaning the undesired beam halo; the geometric design of the spoilers have also been reviewed to minimize wakefields; in addition, the optics design have been polished to improve the collimation efficiency. This paper describes the current status of the CLIC collimation system after this optimization.

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Abstract

Important efforts have recently been dedicated to the improvement of the design of the baseline collimation system of the Compact Linear Collider (CLIC). Different aspects of the design have been optimised: the transverse collimation depths have been recalculated in order to reduce the collimator wakefield effects while maintaining a good efficiency in cleaning the undesired beam halo; the geometric design of the spoilers have also been reviewed to minimise wakefields; in addition, the optics design have been polished to improve the collimation efficiency. This paper describes the current status of the CLIC collimation system after this optimisation.

INTRODUCTION

The postlinac collimation systems of the future linear colliders will play an essential role in reducing the detector background at the interaction point (IP), and protecting the machine by minimising the activation and damage of sensitive accelerator components. The CLIC collimation system has been described in [1] and [2]. It consists of two sections: a first section dedicated to passive machine protection against mis-steered or errant beams with energy deviation larger than about 1.3% of the nominal beam energy; and one dispersion-free section, containing eight spoilers made of Be and eight Cu-coated Ti absorbers, dedicated to the cleaning of the transverse halo of the beam, thereby reducing the experimental background at the IP.

The collimator wakefield effects are an important issue of concern, since they can degrade the luminosity performance of the system. The collimation system must provide a good collimation efficiency without compromising the luminosity stability. In principle, the spoiler material has been selected to get high robustness and to reduce the wakefield effects. Be seemed to be a good candidate (see [3, 4]).

In order to further mitigate the wakefield effects on the luminosity performance we have optimised the following aspects of the CLIC collimation system design:

- The collimator aperture: the aim is to optimise the collimation depths, increasing the collimator aperture, while keeping a good collimation efficiency.
- The spoiler geometric design.

In addition, the optics characteristics of the betatron collimation section have been revisited and optimised in order to improve the collimation efficiency.

COLLIMATOR APERTURE

The necessary betatron collimation depths have been determined from the following conditions: (I) the synchrotron radiation photons emitted in the first final quadrupole magnet (QF1) should not hit the second final quadrupole (QD0); (II) no beam particles should hit either QF1 or QD0; and (III) the collimation apertures should be enough to provide an acceptable cleaning efficiency of the undesired beam halo. The final quadrupoles impose limiting apertures of 4.96 mm (QF1) and 3.83 mm (QD0).

In order to optimise the collimation depths according to the above criteria, macroparticles travelling at high transverse amplitudes have been tracked using the code PLACET [5]. The particles positions and angles have been checked at the entrance, in the middle and at the exit of QF1 and QD0. Ray-tracing calculations of radiation photons, emitted in the final quadrupoles, have been also performed through the interaction region. These studies have determined the following optimum transverse collimation depths: 15 σ_x (horizontal) and 55 σ_y (vertical) [6].

Fig. 1 compares the luminosity performance considering 0.2 σ_y beam position jitter and wakefield effects for the new (15 σ_x, 55 σ_y) and old (10 σ_x, 44 σ_y) collimation depths. A slight improvement is obtained if the new apertures are used: 1.8% compared to 2.3% RMS luminosity loss for the new and old apertures, respectively.

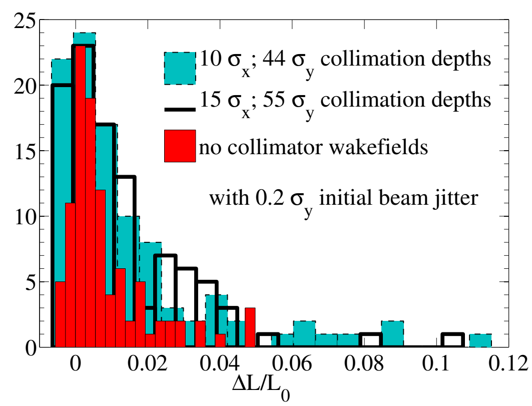

Figure 1: Luminosity loss distribution for 100 simulated machines considering an initial position jitter of 0.2 σ_y, for the following cases: without collimator wakefield effects; with wakefield effects for the new collimation depths (15 σ_x, 55 σ_y); and with wakefield effects for the old depths (10 σ_x, 44 σ_y).

Table 2 summarises the CLIC collimator parameters after optimisation.

Table 1: 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	8
E–AB	3213.03	39271.5	0.416	5.41	8
β_y–SP	114.054	483.253	0	8	0.1
β_y–AB	114.054	483.184	0	1	1
β_x–SP	270.003	101.347	0	0.12	8
β_x–AB	270.102	80.9043	0	1	1

SPOILER DESIGN

This section is devoted to the optimisation of the geometric dimensions of the collimation spoilers, considering the spoiler geometry of Fig. 2. The main contribution to the collimator wakefields arises from the betatron spoilers, whose jaws are much closer to the beam than those of the energy spoiler. In principle, we can try to obtain a shallower taper angle to reduce the geometric components of the wakefield effects, without increasing the resistive component. In this optimisation process we have also to take into account the following requirements:

- The spoiler must provide enough beam angular divergence by multiple Coulomb scattering (MCS) to decrease the transverse density of an incident beam reducing thus the damage probability of the downstream absorber and/or another downstream component.
- Spoiler protection: minimise the heating (by ionization) of the spoiler material due to the impact of the beam. The aim is to increase the spoiler survivability.

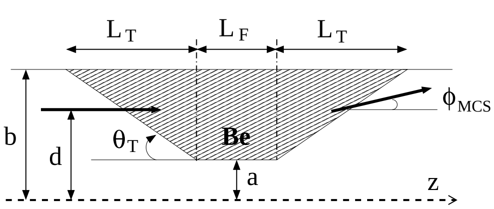

Figure 2: Spoiler jaw longitudinal view.

For the protection of the CLIC absorbers (made of Ti-Cu coated), the RMS radial beam size $\sigma_r = \sqrt{\sigma_x \sigma_y}$ must be larger than about 600 μm at the absorber position [7]. We can rewrite this condition in terms of the angular divergence $\phi_{\rm MCS}$ given by MCS in the spoilers and the transfer matrix elements $R_{34}^{sp\to ab}$ and $R_{12}^{sp\to ab}$ from the spoiler to the absorber: $\sigma_r \simeq (|R_{34}^{sp\to ab}||R_{12}^{sp\to ab}|)^{1/2}\phi_{\rm MCS} \gtrsim$ 600 μm. Knowing that $R_{34}^{sp\to ab} = -483.22$ m and $R_{12}^{sp\to ab} = 114.03$ m between the vertical betatron spoilers and absorbers, then $\phi_{\rm MCS} \gtrsim 3 \times 10^{-6}$ rad ensures the absorber survival. This condition is fulfilled if the Be spoiler (Fig. 2) is designed with a centre flat section of length $L_{\rm F} \gtrsim 0.1$ radiation length. For instance, selecting $L_{\rm F} = 0.2$ radiation length guarantees a safe margin of angle divergence by MCS for absorber survival for all taper angle $\theta_{\rm T}$.

In the case of the energy spoiler-absorber, we have to take into account the dispersive component of the beam size ($D_x\sigma_E$, with D_x the horizontal dispersion and σ_E the RMS beam energy spread). In this case, the absorber survival condition can be approximated by $(|R_{34}^{sp\to ab}|D_x\sigma_E\phi_{\rm MCS})^{1/2} \gtrsim 600$ μm. Considering $\sigma_E = 0.5\%$, and $R_{34}^{sp\to ab} \simeq 160$ m, then $\phi_{\rm MCS} \gtrsim 10^{-6}$ rad. This condition is fulfilled if $L_{\rm F} \gtrsim 0.02$ radiation length for the Be energy spoiler.

Regarding the energy spoiler, another issue of concern is the thermo-mechanical survival limits of the spoiler. The heating of the spoiler should not surpass the material melting limit and the mechanical fracture limit. This imposes an important constraint to the permitted spoiler taper length (taper angle) of the energy spoiler, which is aimed to survive in case of a direct impact of an entire bunch train. It is worth mentioning that while the above survival condition is very important for the energy spoiler, it is not very restrictive for the betatron spoilers, which are planned to be consumable. A detailed evaluation of thermo-mechanical properties of the CLIC spoilers is given in Ref. [9]

Beam tracking simulation studies, using the code PLACET [5], have been performed to find an optimum betatron spoiler taper angle to reduce the wakefield effects and, in consequence, to improve the luminosity performance. Fig. 3 shows the relative luminosity loss due to beam-beam offset errors (generated at the beam delivery system entrance) and including the wakefield effect contribution from all the CLIC spoilers. Different spoiler taper angle cases are compared. Reducing the taper angle from 88 mrad (a 25 cm long betatron spoiler) to a new taper angle of about 8 mrad (a 2 m long spoiler) about 9% beam offset tolerance increase is observed. In view of this very modest advantage of reducing the taper angle, one may simply decide to maintain the original 88 mrad taper angle.

The optimised parameters for the CLIC spoilers are summarised in Table 2.

Table 2: Geometrical parameters of the CLIC spoilers.

Parameter	β_y–SP (β_x–SP)	E–SP
Vert. half-gap a_y [mm]	0.1 (8.0)	8.0
Hor. half-gap a_x [mm]	8.0 (0.12)	3.51
Tapered part radius b [mm]	8.0	8.0
Tapered part length L_T [mm]	90.0	90.0
Taper angle θ_T [mrad]	88.0	50.0
Flat part length L_F [radiation length]	0.2	0.05

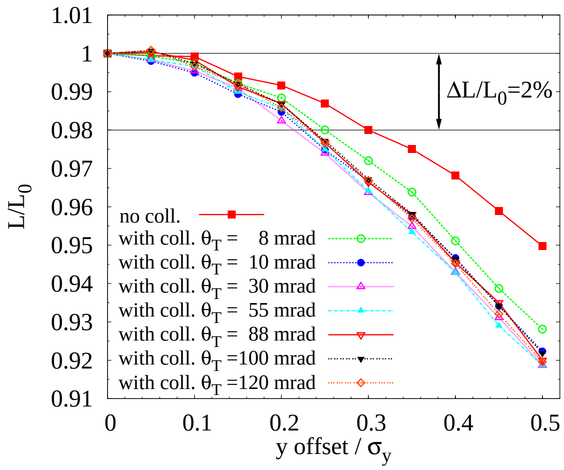

Figure 3: Relative luminosity versus y beam-beam offset with collimator wakefield effects for different taper angle cases, compared with the case without collimator wakefield effects (square points and red solid line).

OPTICS OPTIMISATION

By design the phase advance of the betatron spoilers respect to the FD and the IP has to be matched to allow an efficient collimation of the transverse halo. Fig. 4 shows the design transverse phase advances of the CLIC betatron spoilers. However, in the lattice version 2008 the phase advances between the fourth spoilers (YSP4 and XSP4) and the FD were not an exact multiple of $\pi/2$: $\Delta\mu_{x,y}^{SP4\rightarrow FD} = 9.7\pi/2, 10.6\pi/2$. Therefore, following a similar phase optimisation procedure as it was used for the ILC [10], and using some matching quadrupoles at the end of the betatron collimation section (Fig. 5), we have polished the collimation optics in order to further improve the collimation efficiency. A phase-matched solution has been found at $\Delta\mu_{x,y}^{SP4\rightarrow FD} = 10\pi/2, 11\pi/2$, which improves the collimation efficiency by 20%. Fig. 6 compares the halo profile at the FD entrance for the original and the new matched lattices from tracking studies through the beam delivery system using the code MERLIN [11].

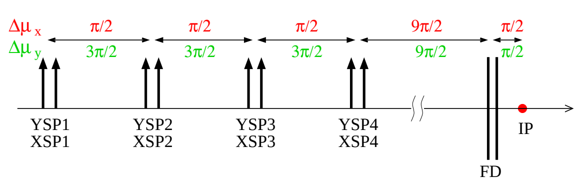

Figure 4: Schematic showing the approximate values of the phase advance between the CLIC betatron spoilers, FD and IP.

SUMMARY AND OUTLOOK

We have presented the results of the optimisation of the CLIC baseline collimation system. This optimisation has covered aspects of the physical design of the collimators with the aim of mitigating collimator wakefield effects, improving thus the luminosity performance of the collider, while still keeping a good beam halo collimation efficiency. In addition, an optimisation of the optics of the betatron collimation section has led to about 20% improvement of the cleaning efficiency of the system.

We plan to evaluate the performance of this system, considering the optimised optics and the new collimator parameters, using specialised codes for beam tracking studies in collimation systems, such as for example BDSIM [2, 12].

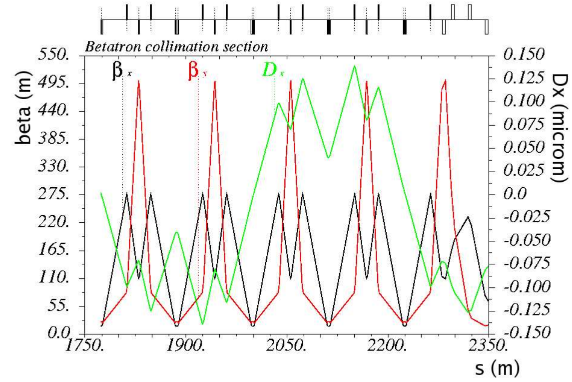

Figure 5: CLIC betatron collimation optics section.

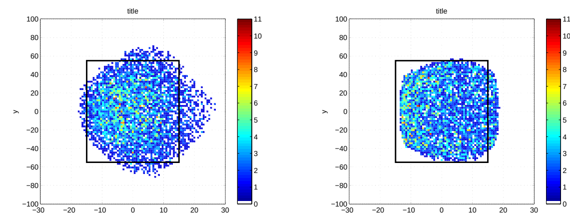

Figure 6: Beam halo x-y profile at the entrance of the FD before (Left) and after (Right) optimisation. In this example no beam energy spread has been considered. The black square contour represents the collimation window.

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