EFFICIENT COLLIMATION AND MACHINE PROTECTION FOR THE COMPACT LINEAR COLLIDER

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Abstract

We present a new approach to machine protection and collimation in CLIC, separating these two functions: If emergency dumps in the linac protect the downstream beam line against drive-beam failures, the energy collimation only needs to clean the beam tails and can be compact. Overall, the length of the beam-delivery system (BDS) is significantly reduced.

INTRODUCTION

Presently the CLIC design allocates a length of 2 km per beam to collimation on each side of the collision point. This does not only represent about 10–20% of the total collider length, but in addition, emittance growth due to synchrotron radiation in this region reduces the luminosity by about 15%.

The main reason for the substantial length of the collimation system is that the beam sizes need to be blown up, at least for the off-momentum collimator, so as to guarantee collimator survival in case of beam impact due to an upstream failure [1] (see Fig. 1). Indeed, mis-phased or unstable off-energy drive beams are likely failure modes in CLIC [2].

If the only function of the collimation system were removing the beam tails and improving the physics-detector background, it could be substantially shortened. In this case smaller spot sizes are accepted at the momentum collimators, accepting occasional damage on them and relying on the concept of ”renewable” or ”sacrificial” collimators, as also used in the CLIC betatron collimation. Such collimators have been investigated for the NLC project and are presently further developed for the LHC phase 2 of collimation. It can therefore be considered reasonable to profit in the CLIC design from such advanced collimators.

Advanced “sacrificial” collimators are conceived so as to accept a number of damages from disturbed beam. For example, rotatable collimators might survive several dozens of destructive beam impacts, recovering by rotating the jaw such that an undamaged surface is again presented to the beam. The frequency of damaging events is a crucial parameter for evaluating the feasibility of a non-robust momentum collimation for CLIC. Energy errors can be frequent in a linear collider and an alternative protection against these errors must be ensured, if the momentum collimation should be non-robust. In the following we describe such a novel handling of energy errors.

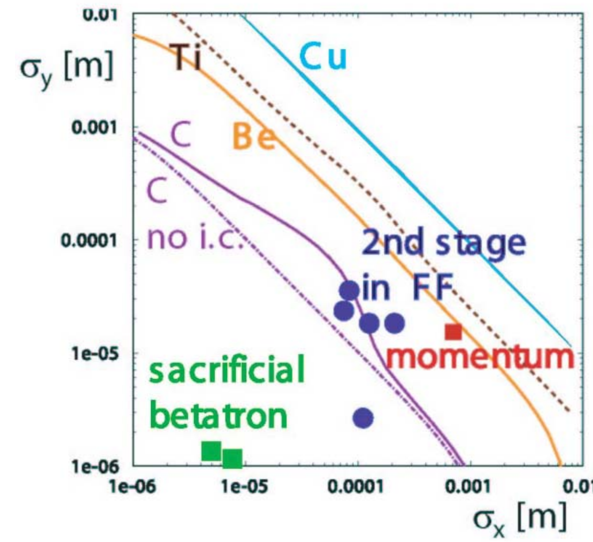

Figure 1: CLIC damage threshold diagram: minimum horizontal and vertical rms spot sizes in case of beam impact on various materials (for carbon calculations with and without the effect of image currents are shown) [1]. The nominal beam sizes at various collimator positions in the present CLIC collimation system and final focus are also indicated by the plotting symbols [3].

ACTIVE PROTECTION

Basic concept and layout

We propose that energy errors will be handled in the linac itself. The present passive machine protection is abandoned and instead an active protection system is adopted, relying on unique features of the CLIC design:

1. The CLIC accelerating fields are generated by the CLIC drive beams, each feeding 669 m long drive beam sectors. Any problems in the drive beam will translate into energy errors of the main beam. It is a unique feature of the CLIC design that the drive beams are supplied against the direction of the main beam. Drive-beam monitors can therefore record the quality of the drive beam and trigger a beam abort for the main beam in due time.

2. Additional beam quality monitors are used for the main beam, providing an additional possibility for beam abort before a disturbed beam can damage accelerator equipment.

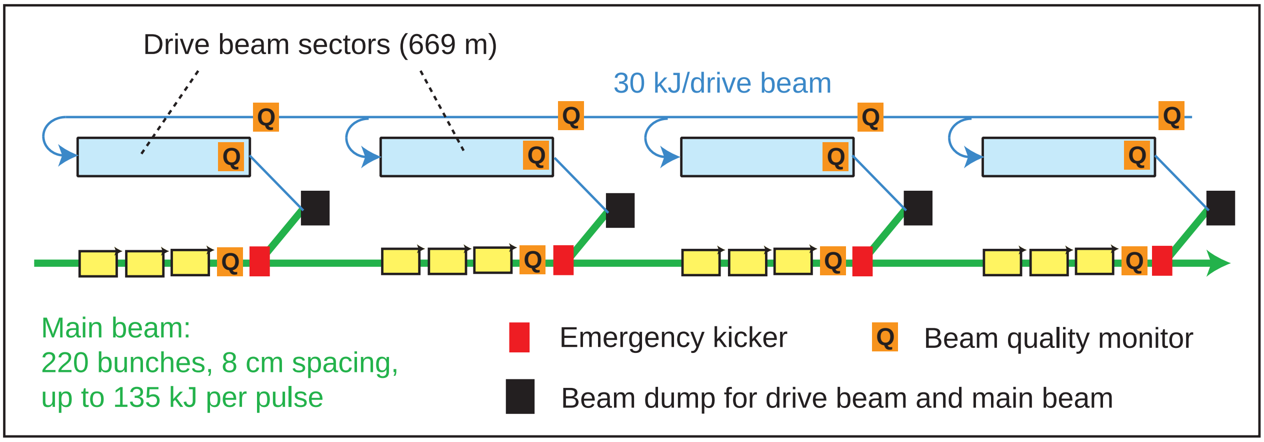

Figure 2: Emergency kickers for active machine protection and shared beam dumps along the CLIC main linac.

3. Emergency kickers are distributed along the main linac. Based on information from the beam-quality monitors for both main and drive beams, the emergency kickers extract the main-beam bunches onto a dump whenever a problem is detected with either the preceding bunches of the main beam or with one of the two neighboring drive beams. These kickers must always be fired before a full bunch train can impact on the collimators, allowing for smaller beta functions or lower dispersion at the collimators.

The overall layout of the active emergency-dump system is illustrated in Fig. 2. Emergency dumps are foreseen at the start or end of each drive beam sector (21 per side). The beam quality is monitored in the main linac just upstream of the emergency kickers, in the adjacent drive-beam turnaround loops, and at the end of the last drive-beam decelerator of the preceding drive beam. The beam quality signals travel in beam direction towards the kicker. The solution is economical in that the anyway required drive-beam dumps can also be used for disposing the main beam in case of emergency, as is shown in Fig. 2.

Parameters for emergency kickers

To deflect a 1.5-TeV beam at the end of the linac by 1 cm over 50 m, an integrated kick strength of 1 Tm or 300 MV is needed. Primary requirements for the CLIC emergency kicker are summarized in Table 1. It is noted that the quoted rise time refers to the main beam dump in case that the incoming drive beam is missing or of bad quality. This provides a maximum reaction time of about twice the length of the drive beam segment (669 m). For more ambitious protection goals (beam dump triggered by quality of main beam or exiting drive beam) much shorter kicker rise times must be considered (in the range of several ns).

Table 1: Parameters of proposed emergency kicker system for active machine protection in the CLIC main linac.

Parameter	Value
Kick strength	$\leq$1 Tm or $\leq$300 MV
Pulse length	60 ns
Repetition rate	up to 150 Hz
Rise time	$< 4\ \mu$s

EXPECTED GAINS

The proposed new concept for collimation results in several important gains for the CLIC design:

1. **Gain in luminosity:** For the present baseline beam-delivery system with the 2005 CLIC parameters, the geometric luminosity obtained by particle tracking is 3.6×10^{34} cm^{-2}s^{-1}. Without the long collimation system, the luminosity in the tracking is 4.8×10^{34} cm^{-2}s^{-1} which is 25% larger than that for the full system [4]. Tracking confirms our expectation that by shortening the collimation system and lowering the dispersion function, both aberrations and synchrotron-radiation effects are reduced. Ultimately, we expect that after further optimization the 25% higher luminosity of the bare final focus can be recovered. We note that this luminosity gain would come on top of an additional 70% luminosity improvement achieved by correcting aberrations in the final focus alone [5].

2. **Reduced length of the CLIC BDS:** Figures 3 and 4 show the optics for the present and the proposed shorter beam-delivery system. The beam-delivery length is substantially reduced from 2.6 km (per side) to 1.2 km. The total CLIC footprint can be reduced by 2.8 km, q significant reduction in overall length.

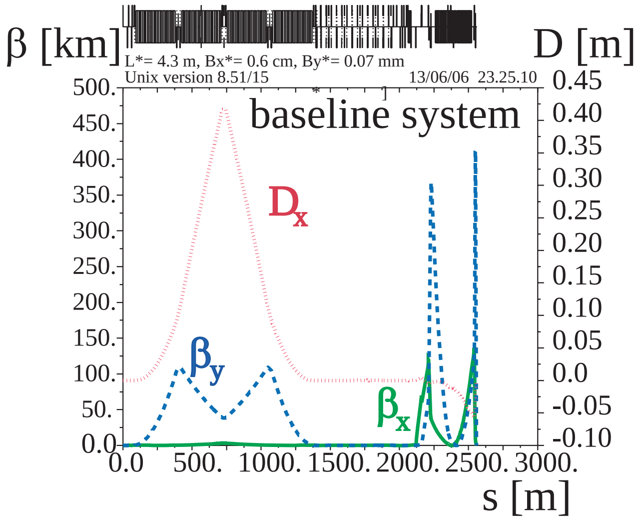

Figure 3: Optics of the CLIC baseline 3-TeV beam-delivery system with 2-km long collimation section, for $\beta_x^* = 6$ mm, $\beta_y^* = 70$ μm.

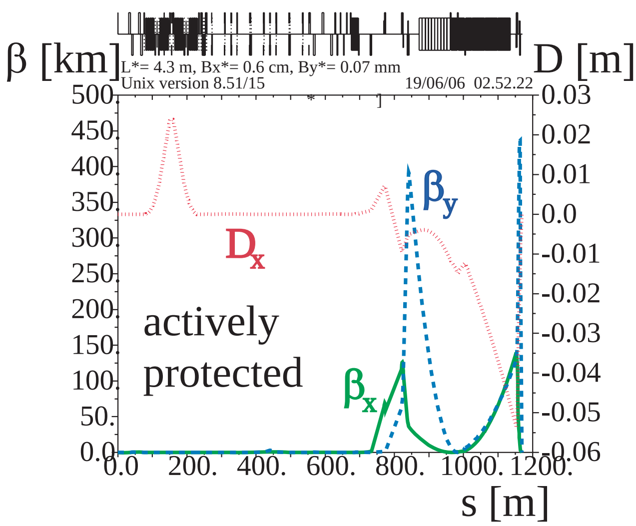

Figure 4: Optics of the proposed shorter 3-TeV beam-delivery system with 0.5-km long collimation section, for $\beta_x^* = 6$ mm, $\beta_y^* = 70$ μm.

3. **Improved local protection:** The use of emergency kickers along the CLIC linac improves the overall protection of the CLIC linac. One needs no further to rely on the transport of the main beam through the complete linac in case of energy errors.

4. **Economical usage of equipment:** The use of the already existing drive beam dumps also for the main beam makes optimal use of the CLIC investment.

The parameters of the present and the proposed alternative beam delivery system are summarized in Table 2.

Table 2: Parameters of present and proposed alternative 3-TeV BDS, consisting of Final Focus (FF) and Collimation System (CS). Spot sizes at the interaction point (IP) and luminosity are computed without pinch but including synchrotron radiation, for IP beta functions $\beta_x^* = 6$ mm, $\beta_y^* = 70$ μm. All values quoted were obtained without linear and nonlinear optimization by the MAPCLASS code [5]. This optimization is known [5], or expected, to further improve the luminosity by 70%–100%.

parameter	Baseline	Proposed
FF length [km]	0.5	0.5
CS length [km]	2.1	0.7
BDS length [km]	2.6	1.2
hor. rms spot σ_x^* [nm]	67.64	61.58
vert. rms spot σ_y^* [nm]	2.32	1.79
Luminosity w/o pinch $[10^{34}$ cm^{-2}s$^{-1}]$	3.56	3.68

CONCLUSION

An alternative solution for the CLIC beam delivery system has been investigated. The machine protection function is removed from the momentum collimation and is instead performed in the linac. Active machine protection in the CLIC linac relies on monitoring the quality of the drive and main beams and triggering a beam dump in case of abnormalities. The beam dumps for the 21 drive beam sections per beam are also used as emergency dumps for the main beam. The proposed solution requires the addition of fast kickers along the main linac.

Removing the machine protection functionality from the momentum collimation allows reducing its length. The length of the CLIC beam delivery system is reduced by more than a factor of two. The overall CLIC footprint is shortened by 2.8 km, a significant gain in length and cost. The luminosity potential is also improved with a shorter beam delivery. It is noted that CLIC momentum collimators would adopt a sacrificial design, as already foreseen for the CLIC betatron collimation.

Further studies should investigate the detailed performance and requirements for the proposed system.

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