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Overview of the CLIC Collimation Design

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Abstract

The collimation system of the Compact Linear Collider (CLIC) should simultaneously fulfill three different functions. It must (1) provide adequate halo collimation to render the detector background acceptable, (2) ensure collimator survival and machine protection against mis-steered beams, and (3) not significantly amplify incoming trajectory fluctuations via the collimator wake fields. We describe the present layout of CLIC post-linac collimation and characterize its potential performance.

1 INTRODUCTION

Two different final-focus optics have been designed for CLIC at 3 TeV [1]. The shorter system provides a larger free length from the IP, l^*, and generates no tails in the final-doublet region. Although, in principle, collimation could be integrated into the final focus proper [2], the short system does not easily allow for collimation of all types of incoming beam tails or for machine protection, *e.g.*, in case of a mis-steered beam or large energy error. Therefore, a dedicated collimation system upstream appears necessary, in particular for more frequent energy errors [3].

As a preliminary baseline design we have scaled the collimation optics adopted for NLC in Ref. [4] to the 3-TeV CLIC requirements. The optics consists of two parts, devoted to energy and betatron collimation, respectively. Compared to the original NLC design, the length of the energy collimation section was increased by a factor of 8, which enlarges the spot size at the collimators to a value where they can withstand the impact of a full bunch train of nominal emittance, and we have reduced the dipole bending angles by a factor 32, so as to keep the emittance growth from synchrotron radiation at a tolerable level. We have not modified the optics of the betatron collimation section, since large betatron oscillations with small emittance-beams are not thought to occur frequently, and since the collimators here are supposed to be replacable or renewable as they are in the NLC scheme.

The optical functions of a 3-TeV CLIC beam delivery system based on a short final focus are displayed in Fig. 1. The first 5.6 km accommodate the collimation system, the last 550 m the final focus.

The horizontal emittance growth from synchrotron radiation is given by the formula [6] $\Delta\gamma\epsilon_x \approx (4 \times 10^{-18}\ \mathrm{m}^2\mathrm{GeV}^{-6})\ E^6 \sum_i L_i < \mathcal{H}_i > /|\rho_i|^3$, where the sum is over all bending magnets, ρ_i the bending radius, E the beam energy, L the magnet length, and $\mathcal{H}$ the 'curly H' function defined by Sands [7] (see also Ref. [8] for a more precise estimate of emittance growth due to synchrotron radiation). Evaluating this expression for the baseline optics of Fig. 1 we obtain $\Delta\gamma\epsilon_x \approx 0.042\ \mu$m for the collimation section, and $\Delta\gamma\epsilon_x \approx 0.163\ \mu$m for the final focus, to be compared with a design normalized emittance of $\gamma\epsilon_x \approx 0.68\ \mu$m. The contribution from the collimation section is reasonably smaller than the other two numbers.

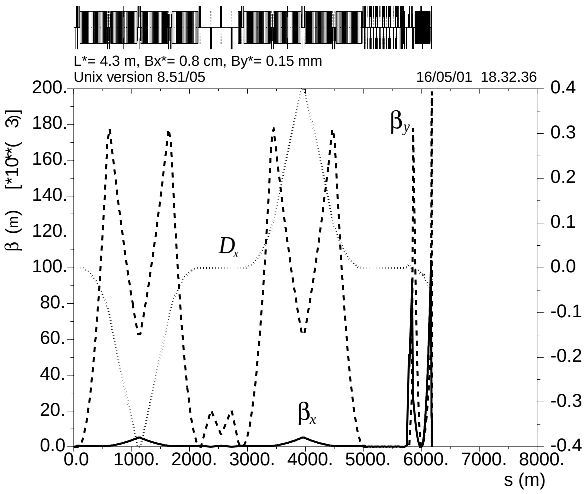

Figure 1: Optics of a 3-TeV beam delivery system (BDS) consisting of a 5.6-km long collimation section, scaled from the NLC design [4], and a 550-m final focus as proposed by Raimondi [5].

2 BACKGROUND

The collimation system is designed to remove off-momentum particles and large amplitude halo particles. We studied the background in the detector, due to secondary muons, produced in the collimation of high energy beam particles. Using the program MUBKG developed for TESLA [9], we simulated the production of muons on 1 radiation length carbon spoilers and the path of these muons through the CLIC tunnel geometry. The results for the baseline final-focus optics are illustrated in Fig.2, in terms of the ratio of beam particles removed by the collimation to the number of muons reaching the detector. For the last pair of spoilers (SPX4, SPY4), at about 500 m distance from the IP, this ratio reaches about 10^{-4}. Lowering the c.m. energy to 500 GeV increases the number of beam particles that can be collimated for a given muon flux in the detector by about an order of magnitude. The dependence on the distance is weak, and we expect to obtain similar numbers for the shorter final focus and the dedicated collimation system. We also studied the reduction of the muon flux by a system of three massive, oppositely magnetized (2 Tesla)

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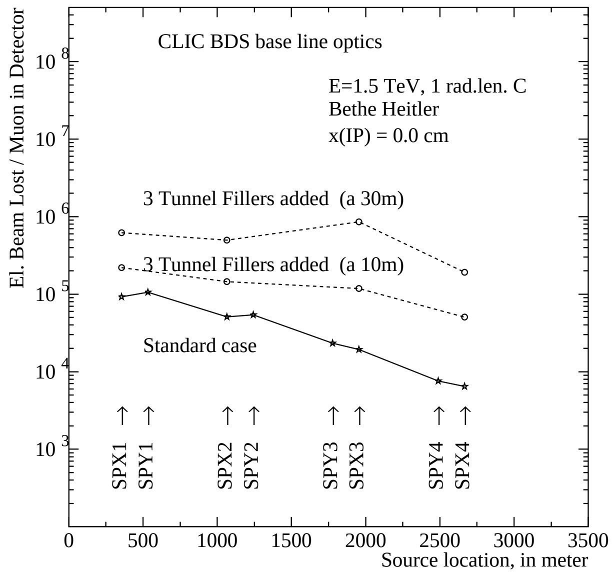

Figure 2: Number of lost electrons per muon passing through a detector with 7.5-m radius as a function of position along the baseline final focus. Potential collimator locations are indicated. The IP is at 3282 m.

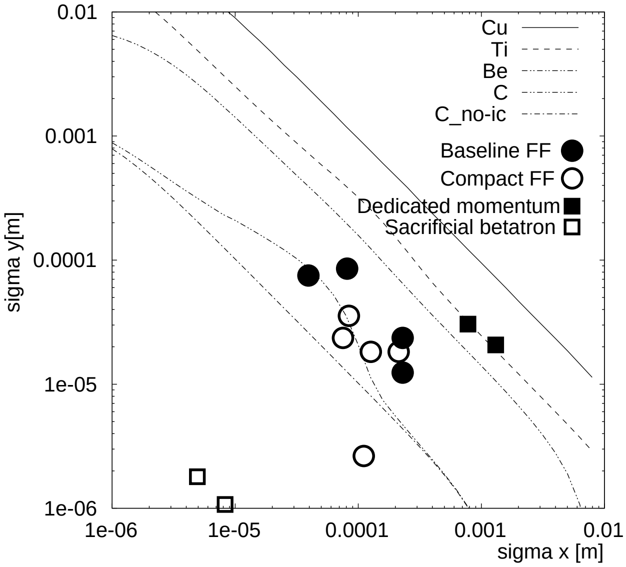

Figure 3: Vertical vs. horizontal beam sizes required for spoiler survival [11] and typical values at prospective spoiler locations in the CLIC beam delivery system, as computed from the design emittance and energy spread. The lowest curve refers to carbon without image current (diamond).

"Iron Tunnel Fillers" [10] placed downstream of the last pair of spoilers. The results for 10 m and 30 m tunnel fillers are also shown in Fig.2. The reduction is more pronounced for muons produced in the last spoilers.

3 COLLIMATOR SURVIVAL

Passive survival of the collimators is a concern. In Fig. 3, the design beam sizes at spoiler locations in the energy and betatron collimation sections, the compact final focus and the alternative baseline final focus are superimposed on spoiler survival curves for various materials, which take into account the energy deposition by both ionization and by image current ohmic heating [11]. In the energy collimation section, the rms radial beam size $\sigma_r = \sqrt{\sigma_x \sigma_y}$ is $147\ \mu$m and 1.862 mm at the spoilers and the absorbers, respectively, assuming nominal emittances. Figure 3 illustrates that this should be sufficient to guarantee survival of the energy-collimation spoilers for beam impact, provided that the spoilers are made from beryllium, carbon, or possibly titanium [11]. We also note that beam sizes in the baseline final focus are slightly more forgiving than those in the compact final focus, and that the spoilers in the betatron collimation section are 'sacrificial' and will certainly be destroyed by beam impact.

4 WAKE-FIELD EFFECTS

The deflection of the beam centroid by a tapered circular collimator is [12, 13]

$$\Delta y' = \frac{2N_b r_e}{\gamma \sigma_z} \left[\frac{(4\lambda\sigma_z)^{1/4}}{g^{3/2}} + \frac{L_F (\lambda\sigma_z)^{1/2}}{2\sqrt{\pi} g^3} \right] y \qquad (1)$$

where y is the offset from the center of the chamber, $\lambda[\mathrm{m}] = \rho[\Omega\mathrm{m}]\ /(120\pi)$, L_F the length of the collimator flat part, and g the half gap. The taper angle is assumed to be optimally chosen as $\theta_{\rm opt} \approx 1.1(\lambda\sigma_z/g^2)^{1/4}$ [12]. Equation (1) is correct for $\sqrt{\sigma_z\lambda} \ll g \ll \sqrt{\sigma_z\lambda}\sigma_z\ /\lambda$ [12], which, *e.g.*, for $\rho \approx 4 \times 10^{-8}\ \Omega$m gives 60 nm $\ll g \ll$ 16 mm.

If the trajectory of the incoming beam changes, this change may be amplified by the collimator wake fields, possibly resulting in an enhanced displacement at the interaction point (IP). We have computed the combined effect of 4 vertical spoilers and 4 absorbers located in the betatron collimation section of Fig. 1. We assume that the spoilers are made from beryllium and extend over 0.5 radiation lengths (r.l.), or 177 mm, and that the copper-coated titanium absorbers are 712 mm long (20 r.l.). Note that solid copper would not be an adequate absorber material, since, even with protective spoilers upstream, copper could not withstand the stress induced by the impact of a bunch train [14].

The collimation depth is set to $80\sigma_y$, leaving a few σ margin [1] to ensure that all beamline elements downstream are shadowed by the collimators. If needed, octupole magnets upstream of the final doublet, which 'fold in' the beam tails [15], could be employed to further increase the required collimation depth.

Figure 4 shows the IP displacements at the IP for sine-like and cosine-like trajectories with a 1σ initial amplitude. For the nominal charge, the IP displacements never exceed 1σ, *i.e.*, 'enhancement' of the initial 1σ position change essentially is absent. The IP displacement significantly increases only for bunch populations larger than 2×10^{10}, or 5 times the nominal. It is clear that the IP displacement depends on the betatron phase of the incoming oscillation. Selecting always the betatron phase with maximum displacement, Figs. 5 and 6 display the dependence on the bunch population and the collimator beta function (maintaining a constant collimation depth). From these figures we conclude that the jitter enhancement due to collimator wake fields is not a severe limitation in CLIC, and that the beta function is close to optimum. It is interesting that for certain values of beam current the centroid-beam jitter at the IP is strongly reduced. A collimator wake acts on the coherent beam motion like an additional quadrupole, and for certain wake-field strengths the 'coherent' beta function at the IP becomes smaller. In these cases, the displacement of the bunch tail at the IP is opposite to that of the head.

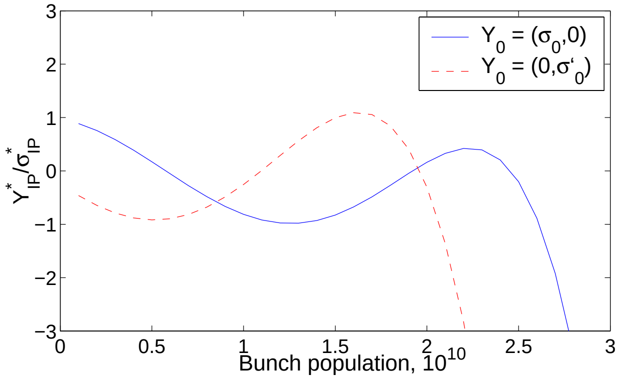

Figure 4: IP orbit displacement for a 1σ change in incoming beam position or slope (the two curves) as a function of bunch population. The nominal value is $N_b = 4 \times 10^9$.

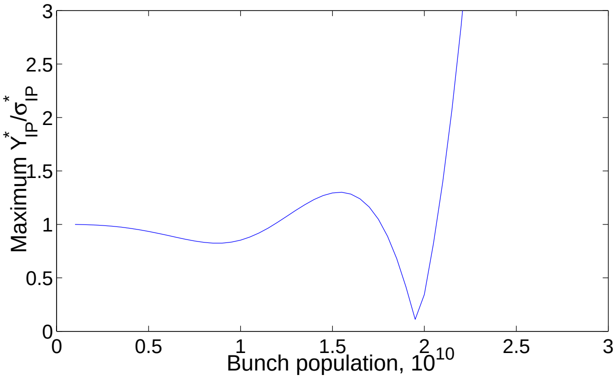

Figure 5: Maximum IP orbit displacement for a 1σ change in incoming beam trajectory as a function of bunch population N_b. The nominal value is $N_b = 4 \times 10^9$.

5 CONCLUSIONS

We have presented the first design of a CLIC collimation system for 3 TeV. The system guarantees spoiler survival in the energy collimation section and it exhibits surprisingly benign wake field effects. Suppression of muon background at 1.5 TeV is more difficult than at lower energies. A drawback of the proposed system is its substantial length of about 6 km. It could be shortened by about 30%, if we relax the requirements on emittance growth due to synchrotron radiation and omit the betatron collimation section, which does not appear to be essential [3].

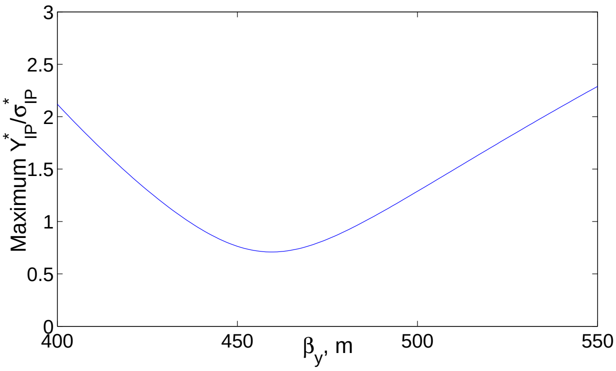

Figure 6: Maximum IP orbit displacement for a 1σ change in incoming beam trajectory as a function of beta function at the collimator. The nominal beta function is 483 m.

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