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Simulations of Beam Halo in the CLIC BDS

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Abstract

The passage of the core bunch through collimators generates wake-fields due to the change in beam-pipe geometry and the resistivity of the collimator material. Simulations of the CLIC beam delivery system (BDS) are performed in order to take into account the effect of these wake-fields on the beam halo. In addition, full simulation of the interaction of the halo particles with the collimator material and other beam-line elements is performed to study the effect of shower generation and multiple scattering on halo re-population, and we discuss how these effects alter the collimation depth of the beam delivery system.

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1 Introduction

The CLIC beam delivery system uses a series of spoilers and absorbers to reduce the extent of the beam halo. Using BDSIM [1], we are able to simulate the effect of multiple scattering and electromagnetic showers from the interaction of the halo with the collimator material. The effect of wake-fields arising from the collimation are simulated using Placet [2]. An interface of the two codes can then account for the effect of the wake-fields on the beam halo and secondary particles.
This study uses the 2005 lattice with $L^* = 4.31$ m with the exception that the thickness of the off-momentum particle spoiler has been lengthened to 90 mm and the aperture of the vertical spoilers has been reduced to 80 μm [3].

2 Main bunch tracking

2.1 Placet

Placet is a programmable tracking code for the simulation of beam dynamics in future linear colliders. It handles macro-particle or bunch slice tracking, and calculates the effects of wake-fields in collimators and accelerating structures. However, Placet is not designed to incorporate the physics processes that occur when beam halo interacts with the beam-line collimators.

2.2 BDSIM

BDSIM is an extension to the Geant4 toolkit [4]. By combining accelerator-style tracking within the beam-line with traditional Geant-style tracking for particles in matter, it allows for a fast simulation of the secondary particle backgrounds from collimation. However, BDSIM is a single-particle tracking code, and as such cannot perform wake-field calculations.
The parameters for the initial bunch distribution used in this section are shown in Table 1. The same particle distribution is used for both the Placet and BDSIM simulation

Table 1: Beam parameters used for the main bunch, and as the baseline for the beam halo. These are based on the old (2005) CLIC parameter set. [5]

Parameter	Symbol	Value	Unit
Horizontal emittance	$\gamma\epsilon_x$	0.68	μm
Vertical emittance	$\gamma\epsilon_y$	0.01	μm
Horizontal β-function	β_x	64.171	m
Vertical β-function	β_y	18.244	m
Horizontal twiss α	α_x	-1.951	
Vertical twiss α	α_y	0.606	
Bunch length	z	30.8	μm

2.3 Wakefield effects

BDSIM has been interfaced to Placet in order to provide these calculations [6]. We assume that halo particles will not contribute significantly to the wake-fields. In this case, BDSIM handles tracking of the beam halo while Placet tracks the main beam and performs the wake-field calculations. The kicks from the collimator wake-fields are communicated from Placet to BDSIM and applied before tracking continues.

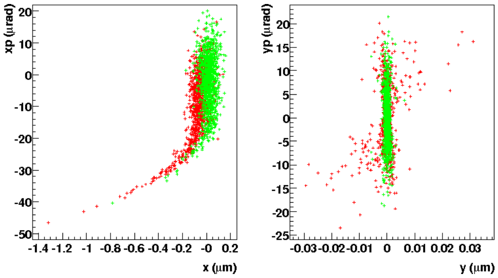

Figure 1: Particle distributions in x-xp and y-yp phase-space at the IP, with wake-field effects included. Simulations from Placet (red) and BDSIM (green).

Figure 1 shows a comparison of the phase-spaces for the main beam as tracked in BDSIM using this technique with the same beam tracked in Placet. We can see that there is reasonable agreement in the shape of the bunch in both x- and y- phase-space. The RMS width and the width from a Gaussian fit to the distributions is shown in Table 2. The values for the beam sizes are close to the design configuration for these CLIC parameters, $\sigma_x^* = 60$ nm, and $\sigma_y^* = 0.7$ nm.

Table 2: Beam sizes at the IP in BDSIM and Placet, RMS (top) and Gaussian fit (bottom).

σ_x^* / σ_y^* (nm)	Placet	BDSIM
without wake-fields	96.7 / 3.15	59.24 / 0.78
with wake-fields	110.2 / 4.16	59.21 / 0.83
without wake-fields	52.2 / 1.04	44.43 / 0.64
with wake-fields	54.2 / 0.97	44.37 / 0.68

3 Halo tracking

We now apply this method to the tracking of beam halo. The halo used for these simulations is comprised of concentric rings in transverse phase-space. Each ring has a width of 5σ in x and 10σ in y and contains 10000 particles. This generates an approximate $1/r$ density distribution in transverse phase-space, which we allow to extends from 0–40 σ in x and from 0–190 σ in y, giving a total halo population of 1520000. For the parameter set used, this is approximately 0.06% of the charge of the main bunch. This is roughly

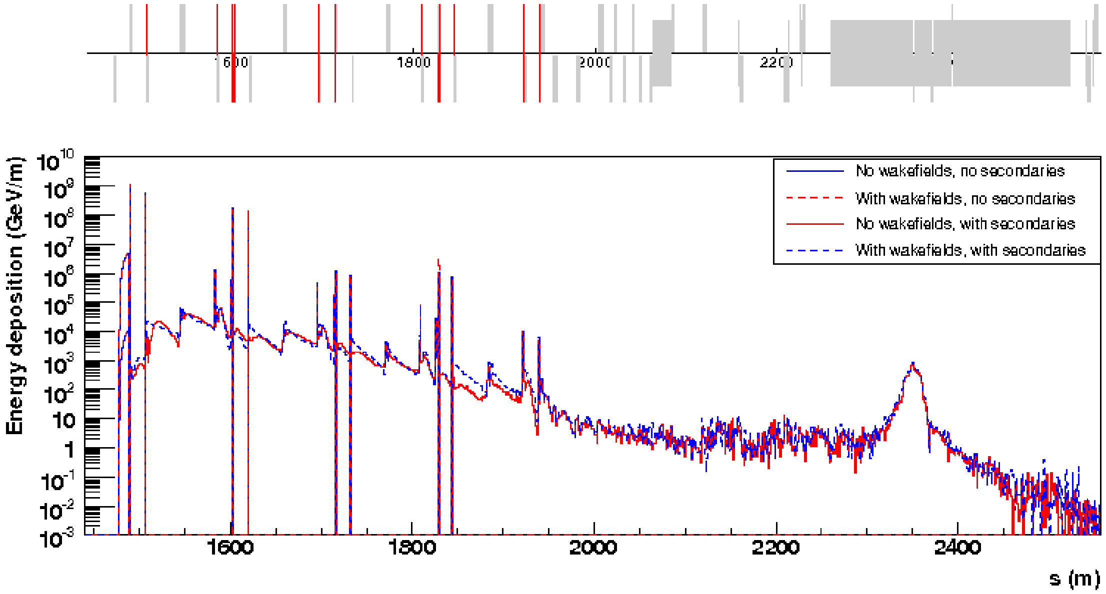

Figure 2: Energy deposition profiles in the CLIC collimation system with and without wake-fields and secondary particles. Without secondary particles, all losses are on the collimators.

half the "worst case" value of 10^{-3}. The longitudinal phase-space is identical to that of the main beam: a Gaussian of width 30.8μm in z, and a flat distribution with full width 1% of the nominal beam energy in E.

3.1 Energy loss profiles

We perform simulations for four cases: with and without wake-field effects, and each of these with and without secondary particles. In the case of both of these effects being switched off, we would expect to produce a traditional style loss-map as would be generated by, e.g. MAD, where any particle interacting with the aperture of the beam-line is considered to be lost.

From Figure 2, we see that without the production of secondary particles the loss distribution is as we would expect – particles are lost almost exclusively on the collimators, barring some small losses immediately prior to the first betatron spoiler. This configuration also persists when wake-fields are introduced, the only significant change being an increase in the losses on ysp4 by a factor of 3, from 10^6 GeV/m to $3 \cdot 10^6$ GeV/m.

The same figure also shows the effect of secondary particle production. In this case we see that that losses are no longer confined to the collimators. Losses from secondary particles extend throughout the BDS from the location of the first betatron spoiler all the way to the interaction point (IP). This distribution of the losses serves to decrease the maximum load at any one location from 10^9 GeV/m to 10^6 GeV/m. Including the wake-field effects, we see that the secondary particle losses increase by up to a factor of 5 immediately after each collimator for tens of metres, but that far from the point of impact losses remain similar to the non-wake-field case. It may be surmised that the near losses are from charged particles with a lower energy than the beam nominal energy, which are swept aside by the magnetic fields. These charged particles will also be kicked by the wake-fields, increasing their divergence and so leading to earlier losses, while the losses further down the beam-line are photons, which are not affected by either the magnets or the wake-fields.

3.2 Collimation depth

We now look at the distribution of particles in the beam halo at the entrance to the final focussing quadrupole, QD0. The constraints on the particle distribution are set such that the fan of synchrotron radiation from the bending of the halo particle trajectories in the final magnet will pass cleanly through the interaction region (IR) without impinging on the face of the exit magnets or masks. Looking at the same four cases as above, we can determine the location of the particles in transverse phase-space and count the particles which are outside the collimation depth.

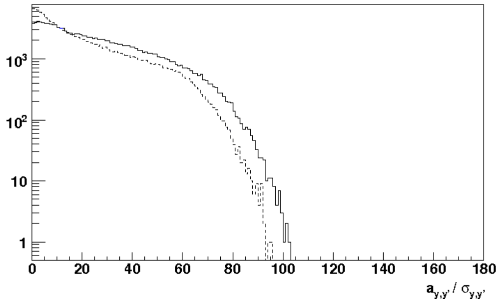

Figure 3: Number of particles in each ellipse in *y*-*yp* phase-space with (dashed lines) and without (solid lines) wake-fields. Secondaries turned off.

Figs. 3 and 4 show the number of particles at each σ in *y*-*yp* phase-space, with and without secondary particles respectively. The requirement is to have as few particles as possible outside the collimation depth. For this lattice and parameter set the collimation depth is $14\,\sigma_X$ and $83\,\sigma_y$ [7]. We notice that in the cases where wake-field effects are present, there is an increase in the number of particles at low σ, and a decrease in mid-to-high σ.

The number of particles outside the collimation depth is shown in Table 3. We see that wake-fields effects tend to suppress the number of particles outside the collimation depth in the vertical plane, while secondary particle production increases the number. We would expect secondary particle production to lead to an increase in the number of uncollimated halo particles as showering generates a large number of particles. The suppressing effect of wake-fields is still sufficient to reduce this number below the case where neither effect is included. Overall the effect is a suppression of the total number from 562 to 526 – this number will be even lower when we account for the double-counted particles which are outside the collimation depth in both x and y.

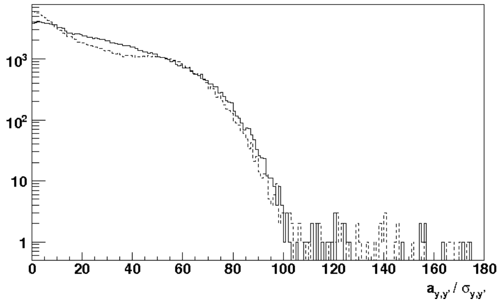

Figure 4: Number of particles in each ellipse in *y*-*yp* phase-space with (dashed lines) and without (solid lines) wake-fields. Secondaries turned on.

Table 3: Number of particles outside the collimation depths of 14/83 $\sigma_{x/y}$. This total does not include particles outside the beam-pipe radius.

Wake-fields/secondaries?	N/N	Y/N	N/Y	Y/Y
# of particles (x)	0	0	75	98
# of particles (y)	562	113	600	428
Total # at QD0 ($\times 10^5$)	1.37	1.29	1.37	1.29

These numbers do not include particles outside the beam-pipe radius, as these will not be affected by the quadrupole field, and hence will not contribute to the synchrotron radiation background. However, these particles may impact directly on the detector, and so must be included in any future work which examines the background in the IR.

4 Conclusions

Wake-fields clearly have a significant effect on the residual beam halo at the entrance to the final quadrupole. The effect of the wake-fields to reduce the number of particles near the edge of the collimation depth is of potential benefit, however the inclusion of secondary particles into the simulation reduces this effect. The full effect of the extraneous particles on detector backgrounds needs further study – we intend to apply synchrotron radiation to the next round of simulations, and to investigate full detector simulations.

It will also be necessary to perform this analysis for the updated lattice and parameter set.

Acknowledgement

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