SIMULATION OF BEAM HALO IN CLIC COLLIMATION SYSTEMS*

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Abstract

Simulations of the CLIC collimation systems are performed to take account of collimator wake-field effects from the core beam on the halo. In addition full simulation of the interaction of the halo with the collimator material is performed to study the effect of multiple scattering.

INTRODUCTION

Halo particles are those particles which are at a large offset or angle to the main bunch, or those with a large energy deviation from the nominal. Left unchecked these particles may cause damage to machine elements, or produce backgrounds in the detector region. In particular, charged halo particles at the final quadrupoles can emit synchrotron radiation which may hit the vertex detector [1].

The current design of the CLIC collimation system uses a spoiler/absorber scheme [2]. The angular divergence of the halo is increased by intercepting the particles with a thin spoiler. The affected particles – and any secondary particles that may be generated by the interaction – are then collected by a thick absorber. Loss maps can be generated by assuming that any particle intercepted by the aperture is lost. Using BDSIM [3], we are able to simulate the effects of multiple scattering and electromagnetic showers on the loss map. The change in beampipe geometry and impedance at the collimators can give rise to wake-fields. This effect is modelled in PLACET [4].

COMPUTER CODES

BDSIM

BDSIM is a Geant4 [5] extension toolkit for simulation of particle transport in accelerator beamlines. It provides a a MAD-style interface that builds a collection of classes representing typical accelerator components and utilises a collection of physics processes for fast tracking together with procedures geometry construction and interfacing to ROOT [6] analysis. BDSIM combines accelerator-style particle tracking with traditional Geant-style tracking based on Runge-Kutta techniques. This approach means that particle beams can be tracked efficiently when inside the beampipe, while also enabling full Geant4 processes when beam-particles interact with beamline apertures. Tracking of the resulting secondary particles is automatic. The code is described further in [3, 7] and is available for download at [8].

PLACET

PLACET is a programmable tracking code for the simulation of beam dynamics in future linear colliders. It can simulate a linear collider from the damping rings to the interaction point (IP), taking into account single- and multi-bunch effects, such as synchrotron radiation emission (coherent and incoherent), short- and long-range wake-fields in the accelerating cavities, resistive and geometric wakes in the collimators. PLACET can simulate normal RF cavities with relatively low group velocities, as well as the transfer structures specific to CLIC. Recent improvements include the possibility to simulate bunch compressors and ground motion. PLACET is available for download at [9].

COLLIMATOR WAKE-FIELDS

Short-range wake-fields arise from the interaction of the electromagnetic field of the bunch particles with the wall of the beampipe, either from a resistive response to the image charge of the bunch, or as the geometry of the beampipe changes. Fields from the particles at the front of the bunch can affect those particles which follow behind. Long-range wake-fields arise from the same effects, but affect particles in following bunches in the train rather than those within the same bunch. In this paper we focus on the effects of short-range wake-fields.

BDSIM/PLACET Interface

BDSIM is a single-particle tracking code — each particle is tracked from start to end before the next begins tracking. This makes calculating wake-field effects impossible, as this requires a description of the entire bunch at the same time. Equally, it is necessary to track the main bunch simultaneously with the halo, as the kicks experienced by the halo are dependent on the halo particles' positions relative to the main bunch when the kick is calculated.

To overcome this, BDSIM has been interfaced to PLACET. The beam halo is tracked up to the first collimator in BDSIM. Simultaneously, the main bunch is tracked to the same location in PLACET. BDSIM then passes the halo description in Guinea-Pig [10] format through a fifo to PLACET. PLACET tracks both the halo and the main bunch through the collimator, calculating the wake-field kicks of the main bunch on the halo. This kicked halo description is then passed back through the fifo to BDSIM, which applies the kicks to the initial bunch distribution and then continues tracking to either the next collimator, when this process

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is repeated, or to the end of the beamline if no more collimators are found.

TRACKING RESULTS

PLACET tracking of core bunch with wake-fields

Wake-field effects on the core bunch act to increase the emittance. By performing tracking with and without the wake-field effects we see that the RMS beam size at the IP is increased by 10%. The effect is less pronounced when using a Gaussian fit to determine the beam size, suggesting that the large offset particles are most strongly kicked. As halo particles are at much more extreme offsets, the effect of the wake-fields on the beam halo must be taken into account.

Table 1: Beam sizes at IP in PLACET: RMS (top) and Gaussian fit (bottom)

	σ_x (nm)	σ_y (nm)
without wake-fields	96.7	3.15
with wake-fields	105.4	3.51
without wake-fields	52.2	1.04
with wake-fields	54.4	1.05

BDSIM tracking of secondaries

By including Geant4 physics processes, BDSIM is able to more properly determine the energy load on the beamline elements. Fig. 1 shows the energy deposition using a typical loss map, where any particle interacting with the aperture is assumed to be completely absorbed. Here it is clear that the losses are mainly on the collimators.

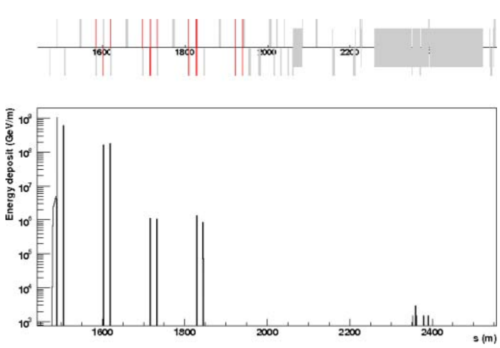

Figure 1: Halo-related energy depositions as a function of distance from entrance to the BDS, assuming "black" collimators.

Fig. 2 shows the energy deposition when the physics processes are turned on, allowing multiple scattering and electromagnetic showers. It is clear that losses are now not restricted to the collimators, although the energy load on the spoilers and absorbers is greatly decreased. Charged particles below 10 GeV and photons below 1 GeV were excluded from the tracking in order to speed up computation. This simulation does not yet include energy deposits from synchrotron radiation.

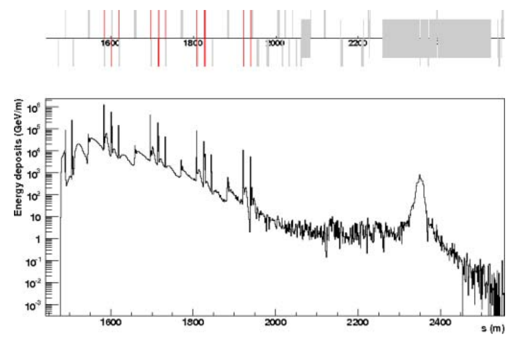

Figure 2: Halo-related energy depositions as a function of distance from entrance to the BDS, assuming collimators made from beryllium (spoilers) and titanium (absorbers).

HALO TRACKING

In this analysis, the halo distribution is generated from a number of annuli in the x-x' and y-y' phase-spaces. Each ring is of equal width (5σ in x, 10σ in y, where $\sigma_i = \sqrt{\epsilon_i \beta_i}$ and $\sigma_{i'} = \sqrt{\epsilon_i / \beta_i}$ and β_i is the beta function at the entrance to the beam delivery system (BDS)) and contains 10000 particles. This builds up to a "$1/r$" density distribution in phase-space. The particles are distributed along a Gaussian in z, and have a flat energy distribution with a 1% full width about the nominal beam energy. These values are the same as used in [2].

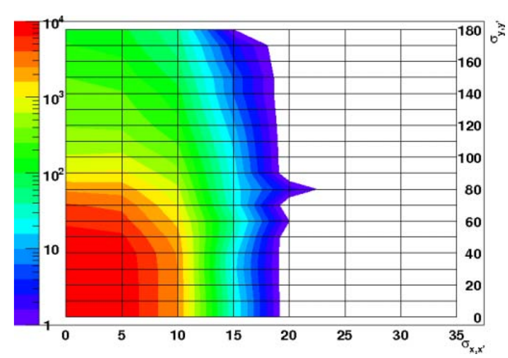

Figure 3: Number of halo particles that reach the CLIC IP as a function of initial position in phase-space, assuming "black" collimators. Tracking was performed in BDSIM.

BDSIM/PLACET tracking of Halo

The halo was tracked in four cases: with and without both wake-field effects and secondary particle generation. As a baseline, with both options switched off, the number of particles reaching the IP as a function of the initial phase-space ring is shown in Fig. 3. The collimation depths for the CLIC BDS are set to $10\ \sigma$ in x and $80\ \sigma$ in y. From this plot, it can be seen that the number of particles at the IP is reduced by an order of magnitude or more for phase-space rings whose inner radius is equal to or greater than the collimation depth.

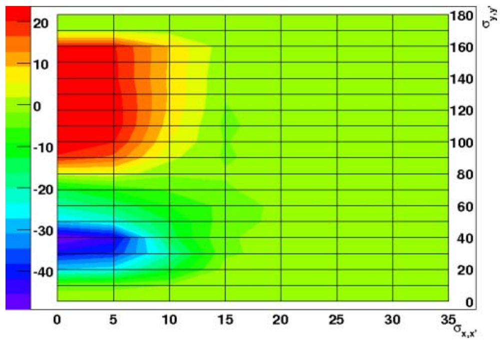

Figure 4: Significance of the difference in number of halo particles at the IP vs the inner radii of the phase-space rings from which the particles originated, in units of $\sigma_{i,i'}$. The ring in x, x' phase space has a width of 5 σ, and that of the y, y' phase-space has a width of 10 σ.

Comparing the cases where we have secondary particle generation turned on, we can determine the significance of the difference in the number of particles that reach the IP from each phase-space ring. Taking our significance indicator as $S = (N_1 - N_2)/\sqrt{(N_1 + N_2)}$, we can see from Fig. 4 that there are deviations up to $S = 20$ and $S = -50$ in the low x region but minimal deviation above the collimation depth in x. Focussing on the $0 < x, x' < 5\ \sigma$ rings, we can plot the number of particles reaching the IP from each of the rings in y, y' phase-space. This is shown in Fig. 5. Here we clearly see a large deficit in particle numbers from the rings below collimation depth in y when wake-fields are turned on, but an increase in numbers above the collimation depth.

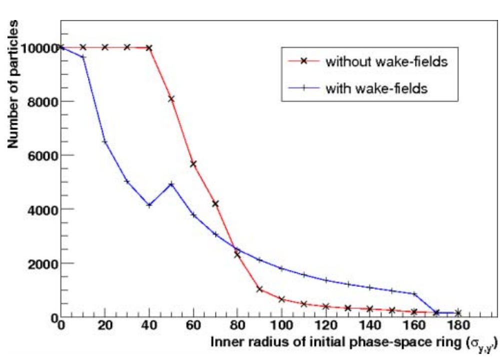

Figure 5: Number of halo particles at the IP vs inner radius of the intial phase-space ring in y, y'. Particles have an initial position within a ring of 0–5 σ in x, x', and each y, y' ring has a width of 10 σ

Finally, we can compare the total number of particles arriving at the IP from all phase-space rings in each of the four cases. As can be seen from Table 2, the total number of particles at the IP actually decreases by 25% when wake-field effects are applied. When secondary particle generation is included, this decrease becomes only 17%, however the number of particles in the troublesome larger offset region increases by approximately a factor of four (Fig. 5). There is no change in the number of particles when secondary particle generation is included but wake-fields are not. Note that secondary particle production does not include synchrotron radiation in any of the cases studied.

Table 2: Total number of halo particles at the IP with and without wake-field effects and secondary particle generation. The initial halo population in each case was 1520000

# of particles at IP	wake-fields off	wake-fields on
secondaries off	160663	119707
secondaries on	160770	133583

SUMMARY

Simulations of the CLIC BDS have been performed to evaluate the effect of wake-fields and multiple-scattering on halo population at the IP. On its own, secondary particle generation does not increase halo population, although energy losses are no longer confined to the collimators. The addition of wake-fields decreases overall halo population by up to 25%, but this reduction comes mostly in the low x, x', low y, y' region; this is from previously uncollimated particles which are lost down-stream due to wake-field kicks. The decrease in collimation efficiency for large offsets requires further study to determine the impact at the IP.

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