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CLIC SIMULATIONS FROM THE START OF THE LINAC TO THE INTERACTION POINT

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Simulations for linear colliders are traditionally performed separately for the different sub-systems, like damping ring, bunch compressor, linac, and beam delivery. The beam properties are usually passed from one sub-system to the other via bunch charge, RMS transverse emittances, RMS bunch length, average energy and RMS energy spread. It is implicitly assumed that the detailed 6D correlations in the beam distribution are not relevant for the achievable luminosity. However, it has recently been shown that those correlations can have a strong effect on the beam-beam interaction. We present first results on CLIC simulations that integrate linac, beam delivery, and beam-beam interaction. These integrated simulations also allow a better simulation of time-dependent effects, like ground perturbations and interference between several beam-based feedbacks.

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Simulations for linear colliders are traditionally performed separately for the different sub-systems, like damping ring, bunch compressor, linac, and beam delivery. The beam properties are usually passed from one subsystem to the other via bunch charge, RMS transverse emittances, RMS bunch length, average energy and RMS energy spread. It is implicitly assumed that the detailed 6D correlations in the beam distribution are not relevant for the achievable luminosity. However, it has recently been shown that those correlations can have a strong effect on the beam-beam interaction. We present first results on CLIC [1] simulations that integrate linac, beam delivery, and beam-beam interaction. These integrated simulations also allow a better simulation of time-dependent effects, like ground perturbations and interference between several beam-based feedbacks.

1 INTRODUCTION

To design a linear collider and to investigate its potential performance, numerous simulations have to be performed. Four of the main areas of research are the main linac, the collimation system, the final focus system and the beam-beam interaction. Each of these necessitates quite complex investigations which are usually performed by experts with specialised simulation codes. The result of one simulation is fed into the next one in the form of simple values, e.g. bunch charge, RMS emittances and energy spread.

This approach, to split the problem into sub-problems, allowed for very efficient development of solutions for each part. However, as the designs mature, it becomes necessary to improve the simulations by also taking correlation effects into account. An early attempt studied the implications longitudinal effects in in the damping ring, bunch compressor and main linac had on the beam-beam effects [2]. Combined simulations of the TESLA linac and of the interaction of the colliding beams have been performed [3]. They showed that the luminosity reduction as calculated from the emittance growth strongly underestimated the real effect.

Simulations of the integrated systems are therefore important. Two basic approaches are possible. One can try to simulate all the systems with a single program or one can define interfaces which allow to use different programs for the different sub-systems. The first approach may simplify the simulation of the whole machine by a single person. The second approach seems simpler if the subsystems are simulated by different persons with different preferred codes. It also allows one to easily include specialised simulation codes which are relevant for only one sub-system.

We followed both approaches. The first, by extending PLACET [4] to also cover the beam delivery system; a similar extension has been made at SLAC by combining [5] LIAR [6] and DIMAD [7] and at DESY by extending MERLIN [8] to include the simulation of accelerating structures. The second approach led to defining a simple file format which can be used to transfer beams from one code to another one. This interface has been implemented for the beam dynamics codes MAD [9], DIMAD [7], MERLIN and PLACET, for the collimation system simulation BDSIM [10] and for the beam-beam simulation program GUINEA-PIG [11].

Comparison between the results of different codes for the tracking through the final focus system has been performed, and the results are reported elsewhere [12]. Currently, a comparison of the results of tracking through the whole machine including the main linac using MERLIN, LIAR/DIMAD and PLACET is ongoing [13].

2 THE PERFECT MACHINE

We first consider a machine without any imperfections. The main linac lattice is taken from [14] and the beam-delivery system (BDS) from [15]. The tracking in the linac and BDS is performed with PLACET; the beam-beam interaction is simulated with GUINEA-PIG. The initial normalised emittances used are $\epsilon_x = 680\,\mathrm{nm}$ and $\epsilon_y = 5\,\mathrm{nm}$,

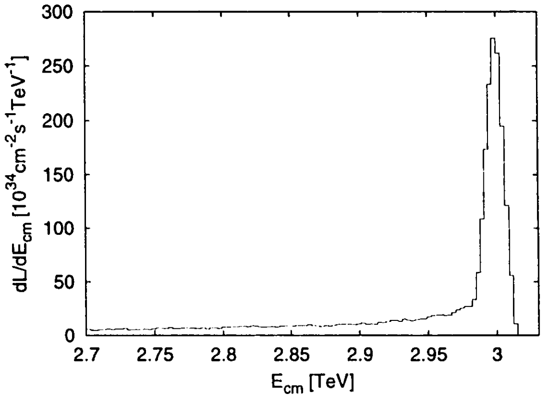

Figure 1: The luminosity spectrum for the perfect machine.

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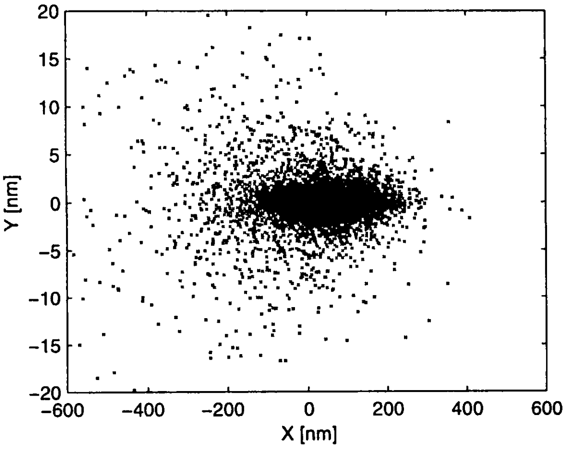

Figure 2: Particle distribution in the x-y plane at the IP.

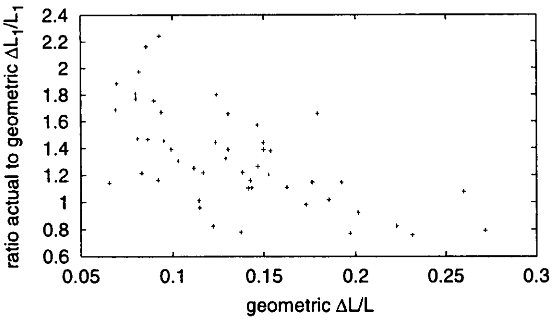

Figure 3: The loss of luminosity in the peak, $\mathcal{L}_1$, due to the static imperfection in the main linac of CLIC. The effect of the BDS and the beam-beam forces have also been included, but for them no imperfections were taken into account.

and the beam is accelerated from 9 GeV to 1.5 TeV. The beta-functions at the interaction point (IP) are $\beta_x = 6\,\mathrm{mm}$ and $\beta_y = 70\,\mu\mathrm{m}$. In the main linac the emittance is perfectly preserved, while it grows in the beam delivery system. At the IP we find RMS beam sizes of $\sigma_x \approx 100\,\mathrm{nm}$ and $\sigma_y \approx 2.2\,\mathrm{nm}$ and emittances $\epsilon_x \approx 3\,\mu\mathrm{m}$ and $\epsilon_y \approx 33\,\mathrm{nm}$. The luminosity is $\mathcal{L} \approx 12 \times 10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$; the luminosity spectrum is shown in Fig. 1.

More important than the total luminosity is the fraction that is useful for the physics experiments. This part varies, depending on the actual investigation; we use $\mathcal{L}_1$ as a figure of merit, which is the fraction of the luminosity with $E_{cm} > 0.99E_{cm,0}$. For the perfect machine we find $\mathcal{L}_1 \approx 4.9 \times 10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$.

The simulation was also performed using MAD for the beam delivery system. The x-y distribution of the particles at the IP is shown in Fig. 2.

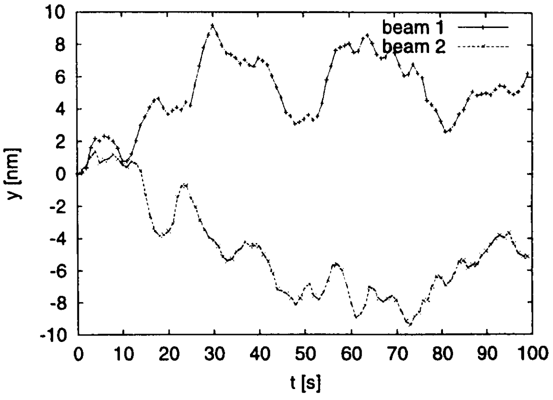

Figure 4: The relative offsets of the two beams at the IP due to ground motion in the main linacs and the beam delivery systems of CLIC. No feedbacks are included.

3 MAIN LINAC ALIGNMENT

The beam-based correction of static imperfections has been simulated [14, 16]. In [16] the beam-beam interaction has also been included. But in these simulations the effect of the beam delivery system has been ignored, the whole system being replaced by a simple transfer matrix. As indicated above, the BDS strongly changes the beam distribution. We have therefore repeated the simulations including full tracking through the BDS. For the linac and the BDS, PLACET is used; for the beam-beam, GUINEA-PIG. In Figure 3 the relative luminosity reduction is shown for 50 different cases, compared to a perfect machine, if beam-beam forces are neglected. The ratio of actual reduction with beam-beam forces to the geometric is also shown. Obviously the beam-beam effect increases the loss. In these simulations the centres-of-charge of the beams were colliding. Introducing small angles in the bunches may potentially lead to an improved luminosity [3], but this needs to be studied.

4 GROUND MOTION

To simulate the effect of ground motion, a model developed by A. Seryi [17] has been implemented in PLACET. The model takes into account correlations of the ground motion in space and time. It has been used to fit data obtained by measurements at CERN [18]. Figure 4 shows the motion of the two beams at the interaction point in the absence of feedbacks.

5 PLACET/BDSIM INTEGRATION

The definition of a common interface describing the bunch structure enabled the interfacing of PLACET to a GEANT4-based program BDSIM. Geant simulation [19] has traditionally been used in the modelling of particle detectors and, for this purpose, it includes a wide range of physics processes describing the interaction of elementary particles with materials. BDSIM combines this Geant functionality with accelerator-style particle tracking and is thereby well suited to simulating in detail the interactions of beam particles with materials in the beam delivery system, and subsequent tracking of secondaries.

A prime example is the interaction of off-momentum particles with spoilers and collimators, where the details of edge-scattering will affect the collimation efficiency, as indeed will the tails of phase-space distributions of bunches exiting the linac. For this reason, interfacing the codes so that the detailed bunch structure is mapped to full simulation of downstream beam element geometries, may be important to the final design of the beam delivery system. These effects may be particularly important for the detailed treatment of halo collimation, where the shapes of tails in the distributions will be the dominant factors determining the global collimation requirements. In this case, small regions of phase-space may match holes in the collimation efficiency, and predicting the occupancy of these holes could be the key to designing an effective collimation system. The need for exploring integrated simulations in this case is thus apparent.

As a first step in this direction, this idea was applied to off-momentum particles in the CLIC baseline beam delivery system [20] where a bunch leaving the linac with an energy 2% lower than nominal was generated with PLACET and interfaced to BDSIM. The results are presented in Fig. 5 and show the energy deposition in the beamline elements after the spoiler, which for this simulation was taken as one radiation length of graphite. The absorber, taken as 1 m of iron, clearly absorbs a large fraction of the total energy. However, studies of this nature allow subsequent optimisation of relative positions of spoilers and absorbers in the collimation system. The energy deposition before the spoiler is due to synchrotron radiation.

6 CONCLUSION

For the design of future linear colliders it is very important to be able to simulate the whole machine in a consistent way. This requires that full advantage be taken of the information obtained from the simulation of the different sub-systems. Therefore integrated simulations are vital. Within the CLIC study, we started this integration process by defining and implementing interfaces and by extending the capabilities of programs. First results demonstrate the usefulness of this approach.

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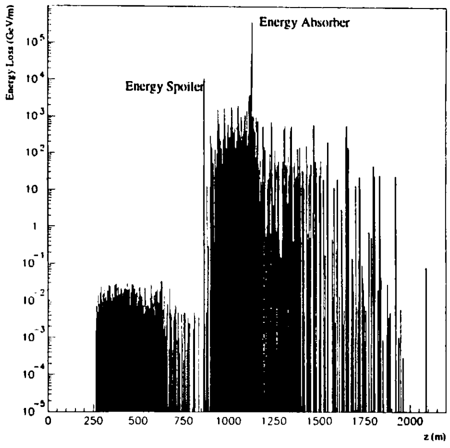

Figure 5: Energy loss in the BDS determined using BDSIM as a function of distance from the linac for a CLIC bunch generated in PLACET with energy 2% lower than nominal. The energy loss before the spoiler is due to synchrotron radiation. 1000 1.5 TeV electrons plus secondaries have been tracked for this plot. Only the first part of the collimation system is shown, since little energy is lost further downstream. Simulation with better statistics needs to be performed to obtain meaningful results for this region.

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