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Update of the Status of Machine Detector Interface Studies for CLIC

D. Schulte

Abstract

The Compact Linear Collider (CLIC) study team at CERN is working on the design of an electron-positron linear collider, with the main focus on a machine with a centre-of-mass energy of $E_{cm} = 3\,\mathrm{TeV}$ and a luminosity of $10^{35}\,\mathrm{m}^{-2}\mathrm{s}^{-1}$ [1]. Because of the high energy and high luminosity, the background in this machine is expected to be higher than in low-energy linear colliders. These backgrounds need to be carefully investigated in order to verify that the experimental conditions are acceptable. For the same reason the luminsoity spectrum needs careful consideration. This paper gives a brief update on the status of the necessary machine/detector interface studies for CLIC.

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Update of the Status of Machine Detector Interface Studies for CLIC

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The Compact Linear Collider (CLIC) study team at CERN is working on the design of an electron-positron linear collider, with the main focus on a machine with a centre-of-mass energy of $E_{cm} = 3\,\text{TeV}$ and a luminosity of $10^{35}\,\text{m}^{-2}\text{s}^{-1}$ [1]. Because of the high energy and high luminosity, the background in this machine is expected to be higher than in low-energy linear colliders. These backgrounds need to be carefully investigated in order to verify that the experimental conditions are acceptable. For the same reason the luminsoity spectrum needs careful consideration. This paper gives a brief update on the status of the necessary machine/detector interface studies for CLIC.

I. INTRODUCTION

A short summary of the background in the detector due to beam-beam interaction can be found in references [2][3] and in the references therein. The latter paper also describes the masks used to reduce the background. This paper will concentrate on the new developments.

II. BEAM DELIVERY SYSTEM AND MUON BACKGROUND

The last quadrupoles of the final focus system will be positioned inside of the detector. Depending on which of the two options for the final focus system is used, the distance of the final quadrupole to the interaction point (IP) will be $l^\star = 2\,\text{m}$ or $l^\star = 4.3\,\text{m}$. The available space for the final quadrupoles is very limited, especially in the case of $l^\star = 2\,\text{m}$, where the outer radius must stay below $20\,\text{mm}$ [4]. Several different designs for the final quadrupole were considered [5]. A design that is based on permanent magnets is very promising. It should be possible to achieve the required small outer radius with this approach.

In the collimation system, the tails of the beams are scraped off to avoid background in the detector. It also serves to protect both the final focus system and the detector in case of machine failures. A first design of this system has been developed [6]. It is based on a design for the Next Linear Collider (NLC) [7] which was scaled to achieve the required performance. The total length is $5.6\,\text{km}$. The first part of the system collimates the beam in energy, the second part performs collimation of transverse tails. It is anticipated that energy errors from one pulse to the next are common, while large transverse errors are rare. Therefore the beam size at the energy collimators must be large enough so that they are not damaged, while the transverse collimators are sacrificial [6]. Possible failures that can lead to large energy or position errors of the beam have been investigated [8] [9]. This work needs to continue.

When beam particles hit the collimators, they induce electro-magnetic showers in which muons are produced. Since muons can easily penetrate material, they have a significant probability to reach the detector and cause background. The study of the potential muon flux is continuing. A modified version of the GEANT based program MUBKG, which was used for the TESLA study [10], has been developed [6]. This allows to study the muon rate in the detector. First results show that it is much more difficult to reduce the background flux in CLIC with iron absorbers than in lower energy machines. One of the goals of the study is to implement the different muon production processes into GEANT4.

In CLIC the beams collide with a crossing angle of $\theta_c = 20\,\text{mradian}$ at the IP. This is the smallest angle which is compatible with the necessity to provide enough space for the outgoing coherent pairs which are created in the interaction point [11]. Also the multi-bunch kink instability [12] sets a lower limit [13]. This instability is due to parasitic crossings of bunches in the detector. A more complete treatment of the multi-bunch kink instability, which includes the non-negligible effect of the coherent pairs, has been performed [3]. It also showed that $\theta_c = 20\,\text{mradian}$ is acceptable. When the beams have a crossing angle at the IP, they are deflected by the longitudinal magnetic field in the detector. This leads to the emission of synchrotron radiation, which modifies the particle trajectories and leads to an increase of the spot size in the IP. For a solenoid field of $B_z = 4\,\text{T}$ the spot size growth is acceptable if the crossing angle is $\theta_c \leq 20\,\text{mradian}$ [14].

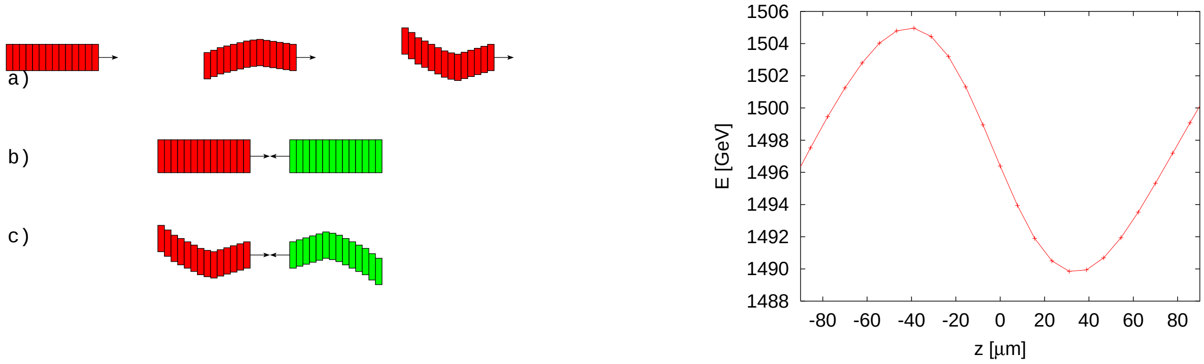

FIG. 1: The left side schematically shows the modification of the bunch shape in the linac (a). Usually, for further calculations the final bunches are modeled by broader ones which are straight (b), while realistic calculations need to take into account the correlation of the transverse and longitudinal position within the bunch. The right side shows the correlation of the final beam energy to the longitudinal position within the bunch. The head of the bunch is at $z < 0$.

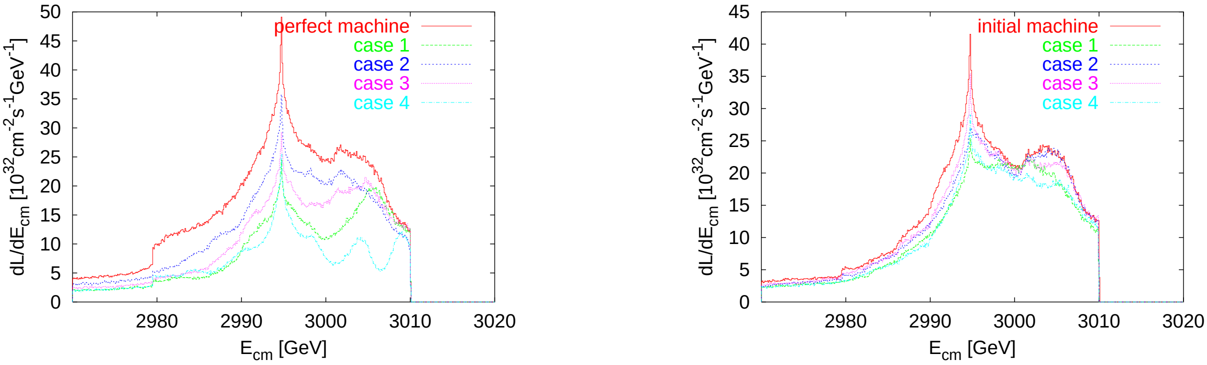

FIG. 2: The luminosity spectrum in the peak. On the left side four examples of the spectrum are shown for different initial misalignments. For comparison the case of a perfectly aligned machine is also displayed. On the right side a single machine is shown together with four examples of how the spectrum could look like 10 minutes later, when the machine is moving together with the ground.

III. WAKEFIELD EFFECTS AND THE LUMINOSITY SPECTRUM

In the main linac the shape of the bunches will be distorted due to transverse wakefields. The energy spread within the bunch also leads to a distortion due to dispersion, since particles at different energies are focused differently by the same quadrupole. The left side of Fig 1 schematically shows how the bunches are deformed while passing through the linac (a). Conventionally these bunch deformations have been described by the growth of the projected emittance, i.e. the overall transverse size of the bunch. In the simulation of the following part of the machine, the correlation of transverse and longitudinal position was therefore neglected. In the figure this is shown for the example of beam-beam interaction (b). Simulation of the real situation, shown in (c), may however lead to very different results, as has been shown in recent quantitative investigations for TESLA [15] and CLIC [16]. The actual luminosity loss due to bunch deformations can be more than an order of magnitude larger than calculated without the correlation. The impact this has on the different tolerances needs to be investigated in detail.

In normal-conducting accelerators, the final beam has a correlated energy spread along the bunch, see Fig. 1 (right). Since the different slices of the beam also have different offsets, the luminosity spectrum will be affected by the bunch shape. This has been simulated using the following procedure. The beam has been tracked through the main linac using PLACET [17] and a simplified beam delivery system has been used to transport it to the IP. The beam-beam interaction has then been simulated using Guinea-Pig [18]. A realistic beam delivery system, which adds to the bunch deformations due to non-linear and energy dependent effects, will be included in the simulations in the near future.

When the elements of the linac are put into the tunnel they have small misalignments with respect to the nominal position. The resulting effect this has on the beam is largely corrected using beam-based alignment.

While the average amplitude of these initial misalignments is approximately known, their actual distribution is not. Several different misalignments have been simulated and some examples of resulting luminosity spectra are shown on the left side of Fig. 2. Obviously they can significantly depend on the initial misalignments of the linac.

When the linac has been installed it will move continuously due to the motion of the ground. A single machine has been simulated with given misalignments. Then 10 minutes of ground motion and the appropriate reaction by the feedbacks were simulated. As the right side of Fig. 2 shows, the luminosity spectrum can change quite significantly in this time.

IV. CONCLUSION

Calculation of the beam delivery system of CLIC is progressing. A first design of the complete beam line exists. However, further evaluation of the performance of this system is necessary. The availability of the program to simulate the muon background is a major step towards this goal. Also the search for possible improvements of the system is continuing. The final quadrupoles are however posing a challenge. A design has been developed that can meet this challenge. It has been verified that the chosen crossing angle between the two beams is compatible with a solenoid field of $B_z = 4\,\mathrm{T}$.

It has been shown that the actual bunch shapes need to be taken into account in simulations of the beam-beam interaction. They not only modify the luminosity loss significantly, but they also affect the luminosity spectrum. These effects need further study.

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