BACKGROUND AND ENERGY DEPOSITION STUDIES FOR THE CLIC POST-COLLISION LINE *

R. B. Appleby, M. Salt, University of Manchester and the Cockroft Institute, England
L. C. Deacon†, E. Gschwendtner, CERN, Geneva, Switzerland

Abstract

After the interaction point, the 1.5 TeV, 14 MW CLIC electron/positron beams must be transported safely to the main beam dump. In designing the CLIC post-collision line detailed simulations must be carried out in order to ensure that losses are kept within reasonable limits. Results for back-scattered photon flux arriving at the detector are recalculated after updates and enhancements to the geometry description used in the study presented in [1]. Initial results of neutron fluxes are presented. Additionally, energy deposition calculations are carried out, showing that, when the full electromagnetic showers are included, in the current design the standard magnet coils would have a short lifetime due to radiation damage to conventional insulation material. Changing the magnet mask material from graphite to iron and lengthening the intermediate dump by 2 m of iron are shown to substantially lessen the energy deposition in the magnet coils and thereby extend magnet lifetimes.

INTRODUCTION

As described in [2], the multi-TeV, nanometre beam size collisions at CLIC lead to beam-beam effects such as disruption of the main beam, production of beamstrahlung photons and coherent pair production. A conceptual design for a post-collision line [2] [3] was designed to transport the spent beam and associated particles to the dump, minimising losses where required, and minimising the back-scatter of particles to the detector.

From the IP, the spent beam passes through 27.5 m of drift space before encountering five vertically bending magnets to provide separation between electrons/positrons of opposite charge and beamstrahlung photons. To protect these magnets, carbon-based protection absorbers scrape the beam.

The magnets are numbered in the following way: magnets 1a, 1b and 2-4 are the window shaped magnets upstream of the intermediate dump. Magnets 5-8 are the C-shaped magnets downstream of the intermediate dump.

Intermediate Dump

At 67 m from the IP, the beams are directed onto the intermediate dump. For the purpose of simulations, the dump is assumed to consist of a carbon-based absorber with water-cooled aluminium plates and an iron jacket. The asymmetric aperture design is intended to absorb all the coherently produced electrons/positrons of the opposite charge to the main beam, as indicated in [1]. The minimum vertical half-aperture is 5 cm for the upper aperture and 49 cm for the lower aperture, centred on the beamstrahlung photon axis. Beamstrahlung photons pass through the intermediate dump aperture, as well as electrons/positrons of the same charge as the main beam and possessing at least 14% of the nominal beam energy. Electrons/ positrons below this energy threshold should be lost in the lower half of the intermediate dump, which is necessary to avoid losses in the following four C-type magnets.

Main Dump

Electrons/positrons and photons that pass through the aperture of the intermediate dump are directed through four vertically bending C-type magnets, designed to reduce the derivative of the dispersion to zero for the charged beam. From the end of the final C-type magnet onwards, both the electrons/positrons and beamstrahlung photons are transported in parallel towards the main dump at 315 m from the IP. The main dump is a water based dump, similar in design to that of the ILC [4].

Detector Background

The bunch train length at CLIC is 156 ns, during which time a photon travels 46.8 m. The CLIC SiD detector ends 6.2 m downstream of the IP. Therefore, photons scattered from less than 26.5 m from the IP will hit the end of the detector within the same bunch train, but photons scattered from further away than this can be ignored. In [5] the authors calculated $0.727 \pm 0.048\,\mathrm{cm}^{-2}$ photons per bunch crossing back-scattered from the first magnet and mask only. The photon flux scattered back to the detector within the same bunch train is likely to be considerably less. From an electronics radiation exposure point of view, the back scattered particle flux from the post-collision line and dump is required to be small.

SIMULATION TOOLS

The Monte Carlo code GEANT4 [6] was used, with collision data generated using GUINEA PIG [7]. GEANT4 was interfaced using BDSIM [8], which was updated to allow the construction of the accelerator tunnel and floor, and the earth surrounding the tunnel. Also, a new beam

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† l.deacon@cern.ch

line component was added to BDSIM in order to build the asymmetric beam pipe shape designed to accommodate the spent beam particles and photons from the intermediate dump to the main dump. Electromagnetic leading particle biasing was not used, so the full showers were tracked. However, the low energy kinetic energy cuts were, again, set to 10 keV in order to capture the low energy information. Energy losses were recorded by volume in order to allow more detailed analysis, in contrast to the previous method of comparing energy flux through sampling planes of finite extent perpendicular to the beam line.

Water was added to the main dump. The outer dimension of the beam pipes between magnets one to four have been changed to the correct thickness.

The concrete tunnel, and the earth around it, were added, along with the beam pipe connecting the intermediate dump to the main dump, which has an asymmetric shape, and the window at the end of the vacuum pipe, just before the main dump.

The detector is not included in the simulation.

LOCATIONS OF PARTICLE LOSS

All components in the post-collision line up to and including the main dump were included in the simulation. Figure 1 shows the power loss per metre in Watts along the post-collision line. As a cross check the input and output energies and energy of losses of all the particles were added together and energy was found to be conserved in the simulation.

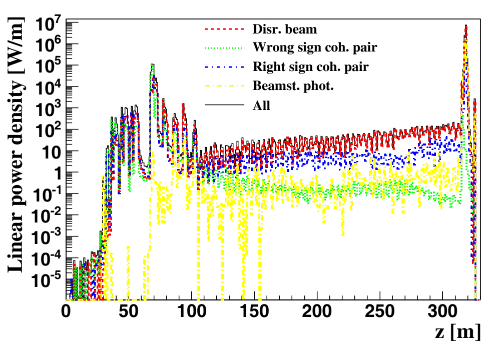

Figure 1: Energy deposition by primary and shower particles in accelerator components, dumps and beam pipes.

The rates of energy loss in individual components can be obtained by integrating the histogram in Figure 1 along their length.

ENERGY LOSS AND MAGNET LIFETIME

For magnet 5, which suffers from the highest rate of energy deposition at ~ 6 kW an estimate of the magnet lifetime is obtained. The magnet lifetime is limited by radiation damage to the coil insulation [9]. A conservative estimate for the dose limit for radiation damage to a standard magnet coil is estimated to be 10^7Gy. The mass of magnet 5 is 6.9×10^7 kg, therefore it's dose rate is 8.7×10^2 Gy/s. Assuming a homogeneous magnet and uniform particle distribution, it's lifetime would therefore be ~ 4 years, assuming continuous 365 days running. In order to improve this some changes to the post-collision line were tested in the simulation.

Alternatively, more radiation resistant magnets could withstand up to about 10^{10} Gy [9].

Table 1: Preliminary results for calculated magnet lifetimes in the post-collision line before (**v1**) and after (**v2**) making the described changes to the masks and intermediate dump.

Magnet coil	Lifetime [year] - v1	Lifetime [year] - v2
1a + 1b	2500	200
2	5.7	36
3	1.2	7.6
4	1.2	8.4
5	11	26
6	13	20
7	19	33
8	170	230

SIMULATION TEST OF CHANGES TO MAGNET SHIELDING

The following changes were proposed and tested:

- The linear power density in the magnets was similar to that in the masks. Therefore, the mask density was increased by changing their material from graphite to iron.
- Particles penetrating the intermediate dump lead to losses in the four C-shape magnets downstream (magnets 5 to 8). Therefore the intermediate dump was lengthened by 2 m of iron.

To save computing time, components downstream of the final magnet were not included and the simulation code was changed so that energy loss in individual volumes could be registered. By only considering the energy deposited in the coils, and assuming that the coils are homogeneous copper and that the energy is deposited uniformly within a coil, and that the coil insulation could withstand a dose of 10^7 Gy, the magnet lifetimes were estimated. These simulations are ongoing but preliminary results are shown in Table 1. Only radiation in the coils is considered. The simulations do not include components downstream of magnet 8, and therefore back-scatter from the final drift and main dump are not included, which is assumed to be the reason why the lifetime obtained for magnet 5 in this simulation is 11 years instead of the 4 years quoted above. Further studies are ongoing. The preliminary results presented in Table 1 suggest improvements by up to a factor 7 in magnet lifetimes following making the changes described above.

Table 2: Photon flux arriving at the detector averaged over a 12 m by 12 m plane 3.5 m downstream of the IP.

Input particles	Flux [cm^{-2}]	$<$ E $>$ [keV]
Disrupted beam	7.5 ± 1.1	360
Beamstrahlung photons	<0.5	
Coh. pairs - other sign	8.4 ± 0.9	230
Coh. pairs - same sign	6.1 ± 0.6	300
All	$22^{+3.1}_{-2.6}$	

BACK SCATTERED PHOTON FLUX

The back scattered particles were recorded at a 12 m by 12 m plane 3.5 m upstream of the IP (the detector was not included in the simulation) in order to give an estimate of the back scattered photon flux arriving at the detector. Figure 2 shows the photon flux per bunch crossing per cm^2 across this plane. The back scattered energy flux was also plotted, and showed an energy flux of between 0.01 GeV/cm^2 and 0.05 GeV/cm^2 across the tunnel opening, except for a 1 m^2 area centred on (-0.5 m, 2.5 m) which had an energy flux of 0.22 GeV/cm^2. The results are summarised in Table 2.

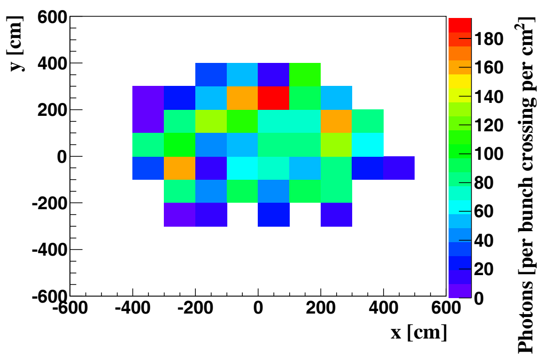

Figure 2: Back scattered photon flux arriving at a plane 3.5 m downstream of the IP. The shape is consistent with the tunnel walls and floor.

NEUTRONS

Neutrons will be produced predominantly in the main beam dump. The neutron flux within a 12 m by 12 m square plane 3.5 m upstream of the IP (the detector is not included in the simulation) is shown in Table 3.

Table 3: Neutron flux arriving at the detector averaged over a 12 m by 12 m plane 3.5 m downstream of the IP. In column 3 is the average *kinetic* energy.

Input particles	Flux [cm^{-2}]	$<$ E$_k$ $>$ [keV]
Disrupted beam	1.6 ± 0.5	950
Beamstrahlung photons	<0.5	
Coh. pairs - other sign	1.6 ± 0.4	350
Coh. pairs - same sign	0.7 ± 0.2	390
All	$3.9^{+1.6}_{-1.1}$	

SUMMARY

The geometry of the BDSIM/Geant4 simulation of the post-collision line has been updated and enhanced. The model has been used to study electromagnetic and photon backgrounds in the post-collision line of CLIC and to study magnet energy deposition and lifetime. Back scattered photons to the detector from the first magnet in the post-collision line onwards do not affect the experiment because they would reach the detector outside of the time span of a bunch train. However, particle flux to the detector could be important from an electronics exposure point of view. Photon flux to the detector has been presented. Also, initial results on the neutron flux reaching the CLIC detector are presented. Preliminary results show that the energy deposition and therefore lifetime of the magnet coils would be improved by changing the mask material from graphite to iron and lengthening the intermediate dump by 2 m of iron. Further improvements are possible - space is available to add more shielding. An alternative method would be to use more radiation resistant magnets.

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