UPDATES TO THE CLIC POST COLLISION LINE

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Abstract

The 1.5 TeV Compact Linear Collider (CLIC) beams, with a total power of 14 MW per beam, are disrupted at the interaction point due to the very strong beam-beam effect. The disrupted beam has a power of 10 MW. Some 3.5 MW reaches the main dump in the form of beamstrahlung photons, and about 0.5 MW of e^+ and e^- coherent pair particles with a very broad energy spectrum as well as the lower energy disrupted beam particles need to be disposed of along the post collision line. Calculations for the energy deposition in the magnet coils and the resulting magnet lifetimes for various shielding configurations are presented.

INTRODUCTION

As described in [1], 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 [1] [2] was proposed to transport the spent beam and associated particles to the dump, minimising losses where required, and minimising the backscatter of particles to the detector.

From the interaction point (IP), the spent beam passes through 27.5 m of drift space before encountering five vertically bending dipole magnets to provide separation between electrons/positrons of opposite charge and beamstrahlung photons. To protect these magnets, carbon-based protection absorbers scrape the beam. In [3] it was reported that changing the material of the masks of the first four magnets from carbon to iron would improve their shielding, extending their lifetime by up to 7 times. It was reported that extending the intermediate dump by 2m improved the lifetimes of the C-shaped magnets after the dump by about a factor of 2. In this paper improved magnet lifetime calculations are presented, in which the peak energy deposit in the coil insulation is considered, and more detailed and accurate models of the magnet coils and the intermediate dump are used. Various shielding configurations are then evaluated based on this model.

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

RADIATION DAMAGE

The radiation hardnesses of various magnet coil insulation materials have been verified both experimentally and operationally in magnets at various CERN accelerators [4]. One of the most commonly used materials is fibreglass reinforced epoxy resin. The material selection is based on mechanical properties, radiation resistance and optimal properties for vacuum impregnation. Using a typical fibreglass impregnated epoxy resin [4], and assuming a low instantaneous dose [5], we assume that the maximum dose that the magnet coils can withstand is 10^7 Gy.

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UPDATES TO SIMULATION

The Monte Carlo code GEANT4 [6] was used, with collision data generated using GUINEA-PIG [7]. GEANT4 was interfaced using BDSIM [8]. Improvements to the simulation model of the post collision line are outlined in the following sections.

Geometry

The main dump is encased in a concrete cylinder with 1 m thick walls in order to shield from back scattering from within the main dump. A hole is left at the front for the incoming beam line.

Previously, in the C-shaped magnets we assumed a uniform field. This field only existed within the vacuum pipe. In order to better simulate the trajectories of particles both inside and outside the beam pipe (the latter could be important for calculating the energy deposition in the magnet coils), a realistic field map was generated from the magnet design covering the entire magnet, including fringe fields.

The magnet coils were modelled as shown in Figure 1, based upon [9], as blocks of epoxy resin with cylinders of copper inside, representing the insulation and the cables. The cables are 16 mm in diameter and 30 mm apart. The material properties of the epoxy resin are given in [4].

A picture of magnet 5 is shown in Fig. 1. The magnet is made of a large iron yoke (red) with coils winding around the pole ends (orange).

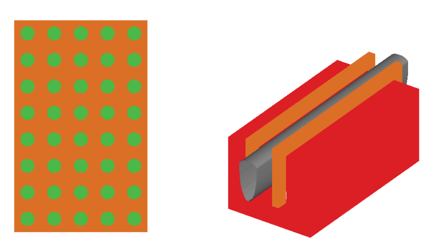

Figure 1: C-shaped magnet simulation with detailed coil geometry. Left: a section of the coil. The copper cables are shown in green, and the insulation is in orange. Right: The magnet yoke (red), coils (orange) and beam pipe (grey).

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The field map used in the simulation was generated using Opera 2D finite element simulation software. The magnetic field maps indicate that horizontal focusing will occur between the two uppermost coils for positively charged particles, deflecting these particles away from the coils.

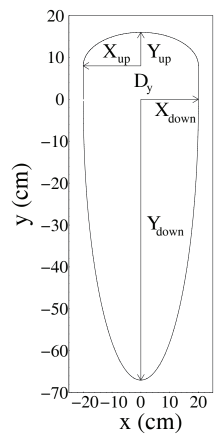


Figure 2: Shape of the intermediate dump aperture. D_y is the vertical distance between the two half-ellipses. From [1].

The aperture of the intermediate dump is of the shape shown in Figure 2, with the variables except D_y narrowing over the first 2 metres. D_y increases throughout, to follow the beam dispersion. The shape is designed to allow the disrupted beam with greater than 14% of the maximum energy to pass though, and to intercept both positively and negativly charged coherent pair particles.

Physics Processes

The low energy cut-off of the electromagnetic processes was changed from an energy based cut-off to a distance in material based one. This improved the speed of the simulation through different materials without sacrificing accuracy. Two regions were defined: the default region and the precision region. The magnets were included in the sensitive region with a cut-off range of 1 mm in order to be able to resolve the peak energy deposition. In the default region, the range was set to 10 cm in order to speed up tracking through the intermediate dump, which in the baseline design is 6 m long. A modified version of the GEANT4 physics list QGSP BERT HP was used, with the gamma conversion to muons and e^+e^- to muons cross sections enhanced by a factor of 10^4, re-weighting the resulting muons accordingly, in order to be able to study muon signal/background for post-dump luminosity monitoring. Processes important for hadrons, not present in the previous simulation [3], but now included, are hadron bremsstrahlung, coulomb scattering, elastic scattering and pair production. Elastic scattering is particularly important when considering, for example the scattering of neutrons from the walls of the tunnel.

Materials

The neutron scattering cross sections can vary widely for different isotopes. Therefore, the materials used in the dumps, C-shaped magnets and tunnel walls were read from the National Institute of Standards and Technology (NIST) materials database, which is built in to GEANT4, using the naturally occurring isotope concentrations.

RESULTS

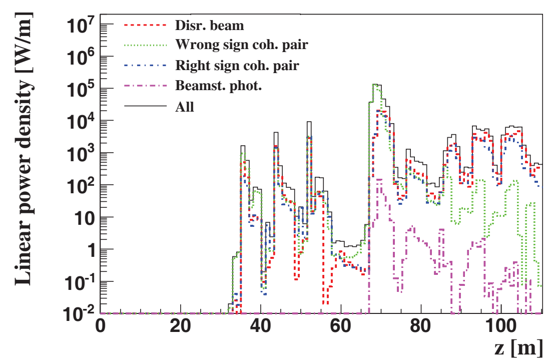
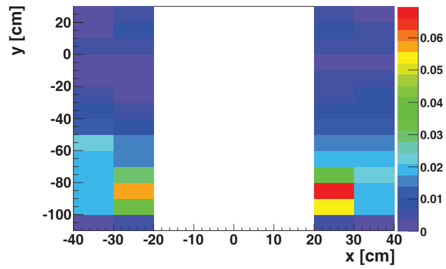


Figure 3: Energy loss along the post collision line. The first three groups of peaks correspond to window frame magnets 2 to 4 and their protection absorbers. The largest peak corresponds to the intermediate dump. Downstream of this, the peaks correspond to the C-shape magnets 5 to 8.

For the baseline design, in which the intermediate dump is 6 m long and the absorber material is carbon, the energy deposition histogram as a function of longitudinal in Figure 3 shows that while the energy deposited in the window shape magnets 1-4 is around 100 W/m, the energy deposited in the C-shaped magnets is around 1 to several kW/m. This is partly due to the fact that secondary particles from the intermediate dump are scattered to large angles and hit magnets 5-8 downstream. Also, relatively low energy particles not hitting the dump aperture can hit the beam pipe further downstream, shower near the C-shaped magnets. As can be seen in Figure 4 the energy deposition is localised. In the case of magnet 5, the dominant contribution comes from the disrupted beam.

We quote the the highest rate of energy deposition averaged over cubes of 1 cm^3 and 1000 cm^3 due to opposite sign (e. g. positive for the electron beam line) coherent pair particles in table 1, and the resulting estimated magnet lifetime assuming the magnet coil insulation material can withstand 10^7 Gy. The different shielding configurations are:

- **c1:** The baseline configuration.
- **c2:** The intermediate dump is extended by 4 metres. The positions of all the components remain constant.



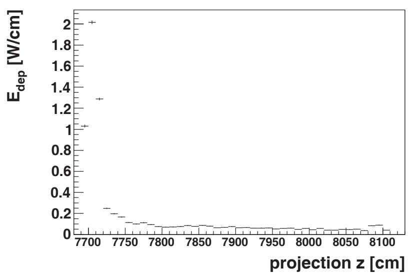


Figure 4: Top: 2D histogram in 10 cm sided bins showing the rate of energy deposit per volume in watts per cm^3 simulated in the insulation material in the coils of magnet 5 due to the disrupted beam. Bottom: rate of energy deposition per length in the same volume as a function of longitudinal position along the beam line.

- **c3:** As **c2**, but the absorbing material in the dump is changed to lead (tungsten is probably a better choice due its higher melting point).
- **c4:** As **c3**, with the addition of a 3 cm layer of lead on the exposed surfaces of the coils, 10 cm at the upstream and downstream faces.
- **c5:** 0.5 m long iron masks in front of the C-shaped magnets are added to **c1**. The mask dimensions are 0.8 m × 1.25 m. The dimensions of the aperture are 0.1 m × 1.2 m.

Table 1: Magnet lifetimes of magnet 5 due to the disrupted beam calculated from the peak energy deposition rate according to two different volume resolutions.

Config.	Lifetime [years]
c1, 1 cm^3 res.	$(1.22 \pm 0.56) \times 10^{-2}$
c1, 1000 cm^3 res.	0.350 ± 0.014
c2, 1 cm^3 res.	$(2.6 \pm 1.1) \times 10^{-2}$
c2, 1000 cm^3 res.	1.81 ± 0.15
c3, 1 cm^3 res.	$(3.3 \pm 1.4) \times 10^{-2}$
c3, 1000 cm^3 res.	2.16 ± 0.14
c4, 1 cm^3 res.	$(3.5 \pm 1.6) \times 10^{-2}$
c4, 1000 cm^3 res.	0.949 ± 0.034
c5, 1 cm^3 res.	$(8.9 \pm 6.3) \times 10^{-2}$
c5, 1000 cm^3 res.	7.94 ± 0.97

SUMMARY

Several configurations for shielding the C-shaped magnets have been tested in a simulation and the best results were achieved using the masks as described in **c5**. The results indicate that further improvements may be required if the magnets are to survive in the CLIC post-collision line radiation environment for a sufficient length of time. Further optimisation is planned in the future, and radiation hardened magnets such as those described in [10] may improve the magnet lifetime by a factor of 100, and could be used if necessary. Improvements to the collimation scheme will be considered, such as modifying the shape of the intermediate dump aperture.

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