MUON BACKGROUNDS IN CLIC*

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Abstract

We report on a study of muon backgrounds in CLIC. Halo and tail particles are generated by HTGEN and tracked through the CLIC lattice using PLACET. For particles that hit aperture limits, we use BDSIM for the detailed simulation of interactions and the tracking of the secondaries towards the detector.

INTRODUCTION

Halo particles in linear colliders can result in significant losses and serious background that may reduce the overall performance. Even if most of the halo is stopped by collimators, the secondary muon background may still be significant. It is therefore important to include in collimation studies halo generation and tracking. In the following we employ advanced simulation tools to estimate the number of the generated muons in the collimation section of the CLIC beam delivery system (BDS) and track them to the interaction point (IP) where they can be used as input to the CLIC detector simulations.

SIMULATION PROCEDURE

The halo generation is performed by HTGEN [1], which produces a set of four-vectors of halo particles impacting on the spoilers in the CLIC BDS. These four-vectors are then passed to BDSIM [2], which performs the secondary generation and tracking. These codes are now briefly discussed in turn.

Halo Generation and Tracking

Halo particles can be produced anywhere in the system. Here we assume that beams are cleaned before they are accelerated in the CLIC linac so that we only need to consider the extra halo production in the linac and the BDS. There are many possible processes which can contribute to the production of halo particles. A rather comprehensive list of potential halo production processes can be found in [3]. A basic class of halo production processes that will always be present is beam gas scattering. We use the HTGEN code to generate halo by beam-gas scattering (Mott scattering) and inelastic scattering (Bremsstrahlung). It is fully interfaced and integrated in PLACET [2], which allows the tracking of the halo together with the beam core. More information can found in [4]. The halo component will be further enhanced in a real machine by any deviations from the ideal machine as caused by misalignment and magnet tolerances. These unwanted effects could in principle be simulated in PLACET if we would know the actual parameters of the real machine including all tolerances. The simulations presented here based on generation by beam gas scattering alone have been done for the nominal lattice without tolerances, and can therefore be expected to only account for part of the halo component present in a real machine.

BDSIM

BDSIM is a toolkit based on Geant4 [5], thus giving access to many electromagnetic and hadronic interaction models as well as a powerful geometry description framework. On top of this, fast particle tracking routines and some additional physics processes are introduced, and a high level geometry description language is added. An interface to PLACET has also been developed in order to combine PLACETs wake-field effects on the beam halo, with BDSIMs capability for secondary generation and tracking [6].

MUON ESTIMATES

The flux of halo particles that will impact on the collimators will depend on the collimator settings and details of the lattice parameters including imperfections and misalignment. Based on preliminary collimation studies and simulations under rather idealistic assumptions, previous studies [7] have found for 10 nTorr CO both in the CLIC linac and BDS, that a fraction of about 2×10^{-4} of all particles will have large amplitudes and hit the spoilers in the BDS section. With 1.24×10^{12} particles per train, this was found to translate into a flux of 2.4×10^{8} particles per train impacting on the spoilers. At 1.5 TeV, a fraction of about 9×10^{-4} of these particles were expected to produce secondary muons, resulting in a flux of about 2×10^{6} muons per train, many of which would be seen as background in the detector in the interaction region. Reducing the muon flux would require rather massive, magnetized shielding to be effective; a detailed study of this issue is therefore important. In the following these studies are updated by employing modern simulation tools and the latest CLIC lattices. The effect of swapping the betatron and energy collimation sections is estimated to result only in a modest (40)% reduction in the muon flux reaching the detector.

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Spoiler Geometry

The halo was tracked from the first (vertical) spoiler to the interaction point using BDSIM. The spoiler geometry is based upon option 1 in [8]. The spoiler is tapered at the ends towards the centre from a 10 mm aperture when the spoiler is fully closed down to zero at the centre of the spoiler. The tapered part of the spoiler is made of Beryllium. In the middle of the spoiler is a flat titanium block 21mm long. The total length of the spoiler is 400 mm.

Magnet, Beam Pipe and Tunnel Geometry

Material included in the simulation were all magnets, spoilers, absorbers, the beam pipe and the concrete tunnel walls at a radius of 2.25 m. The magnets were modelled using solid iron cylinders 25 cm in radius. The beam pipe material was stainless steel. All the correct magnet apertures were included. The beam pipe's radius was 8.21 mm, except where magnet apertures dictate, and its thickness 2 mm, and the beam pipe was tapered such that it changed linearly between successive beam line components. The tunnel was filled with air at standard temperature and pressure.

A concrete floor was added to the tunnel along with a beam line offset to match the baseline design in the CLIC linac, which is assumed at this stage to be approximately the same as the tunnel cross section in the linac for the CLIC conceptual design report [9]. Included in the floor are the cooling water pipes.

Physics Processes and Cross Section Biasing

The following physics processes were turned on: electron/muon multiple scattering, electron/muon ionisation, electron/muon bremsstrahlung, e+/e- annihilation, photoelectric effect, Compton scattering, gamma to e+/e- pair production, gamma to $\mu^+\mu^-$ pair production and the interaction of muons with nuclei.

Since muon production processes have a relatively low cross section, cross section biasing is used to reduce required computing time. The muon production cross section is enhanced by some factor F_e. To preserve the shape of the electromagnetic cascade the parent particle has some probability of being kept alive and the daughter and parent particles are then re-weighted as follows:

$$w_s = w'_p / F_e \tag{1}$$

$$w_p = w'_p - w_s \tag{2}$$

where w means weight, p and s subscripts denote parent and daughter and $'$ indicates the original weight. A uniform random number is generated between 0 and 1 and if this number is less than w_p then the parent particle is kept alive.

Tests were carried out to determine how muon cross section biasing affects the shape of electromagnetic cascades. 250 GeV electrons were fired into iron and energy loss was plotted in a histogram for different levels of muon cross section enhancement. The results are shown in Fig. 1. The shower shape remains the same for the cross section enhancements shown. A sufficient number of muons are generated by setting F_e to 10^4, so this enhancement factor was used in the main simulations.

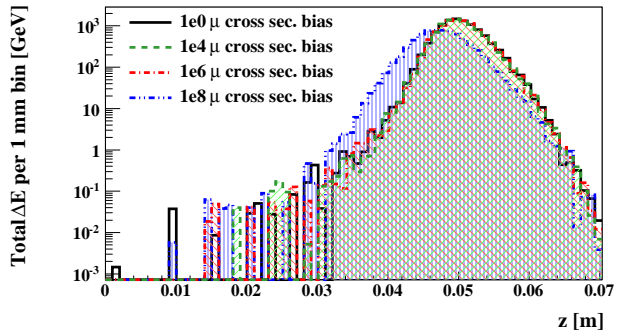

Figure 1: Energy loss profiles for different levels of muon production cross section enhancement.

At 1500 GeV incident particle energy the $\gamma \rightarrow \mu^+\mu^-$ process dominates, and therefore the muon flux from the e^- and e^+ beam will be similar (Fig. 2). At 250 GeV the muon flux from $\gamma - > \mu^+\mu^-$ and $e^+e^- \rightarrow \mu^+\mu^-$ will of a similar magnitude, so the differences between the two colliding beams will have to be taken into account when simulating the 250 GeV machine.

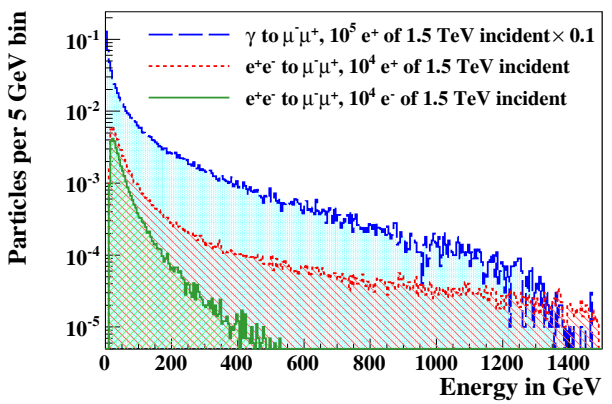

Figure 2: Muon spectra for various muon production processes.

A low energy cutoff must be set for photon electron and muon production. We assume a 25 cm iron wall upstream of the detector. According to a Geant4 simulation [10] muons with energies greater than ~ 0.5 GeV have a range in iron greater than this. Therefore the low energy particle production cutoff was set to 0.5 GeV.

Table 1: Muon flux at the entrance to quadrupole QD0, ~ 3 m upstream of the IP per halo particle and per electron bunch. For the order of collimation: energy then β or β then energy.

Coll. ord.	N_μ per halo particle	N_μ per bunch
E then β	$(5.56 \pm 0.01) \times 10^{-5}$	207 ± 2
β then E	$(2.27 \pm 0.09) \times 10^{-5}$	84.6 ± 2

Results

In the original collimation system layout, the energy collimation section comes first. A modified beam line was developed using MAD [11] and translated to BDSIM in which the betatron and energy collimation sections are swapped around, increasing the distance from the first betratron spoiler YSP1 to the IP by $\sim$ 1 km. The resulting muon flux estimates are shown in Tab. 1. When calculating the total muon flux per bunch we assume that the halo particles make up 1×10^{-3} of a bunch, which using the parameters from [12] gives 3.72×10^6 halo particles per bunch.

The results show a modest decrease of 40% in the muon flux after changing the order of the collimation sections. Example plots Figs. 3 and 4 show the spectrum and distribution of the muons for the "swapped" beam line.

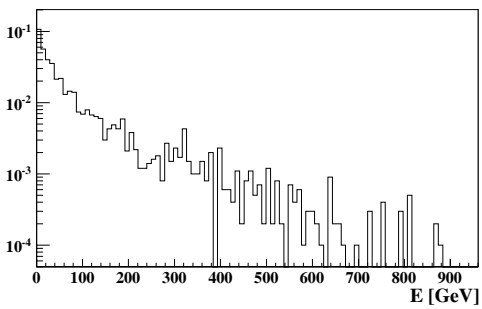

Figure 3: Muon energies at the entrance to QD0 for the $beta$ then E collimation beam line.

SUMMARY

Detailed halo and muon production simulations have been carried out. Prediction of energy spectra and spatial distributions are expected to be rather realistic. However, the absolute flux is hard to predict. Beam gas estimates given here should be considered as a lower limit. Conservative estimates should allow for a good safety factor which could be provided by allowing for magnetized muons shields. Data files containing the four momenta, weights and origin of the muons are available online at https://www.pp.rhul.ac.uk/twiki/bin/view/JAI/ClicMuon for machine detector interface and detector simulation.

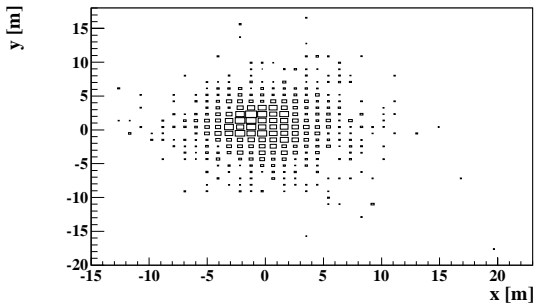

Figure 4: Muon x:y distribution at the entrance to QD0 for the $beta$ then E collimation beam line.

More results and details of this work will be presented in a future paper. Further tests will be carried out, including magnetised muon shields.

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