# BACKGROUND SIMULATION FOR THE CLIC BEAM DELIVERY SYSTEM WITH GEANT

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*Abstract*

Background simulation with particle interactions in the materials of an accelerator environment and their follow up towards the detector are described. The studies include muon production and follow up using the Geant3 program and the development of a general simulation environment suited to accelerator optics descriptions based on Geant4.

## 1 INTRODUCTION

Ideally, a realistic background simulation should be able to both

- track primary beam and secondary particles through the lattice as well as
- simulate the interaction of particles in materials (collimators, beam pipe walls).

In practice however, these two aspects are mostly taken care of by very different specialized programs.

For the study of beam particles in the magnet lattice of the machine there is for example the program MAD [1]. For the simulation of the interaction of particles in matter, there is the Geant program [2], which is much used for the simulation of particle detectors. Interfacing these two different "worlds", as in principle required to treat both primary (beam) and secondary particles correctly, can be a rather non-trivial task.

We will report here on background studies for the very high energy linear collider project CLIC[3], and in particular on the muon background. First estimates based on electromagnetic muon-production from primary Bremsstrahlung photons and the follow up of the muons with Geant3, already indicated rather high background levels, of the order of thousands of muons reaching the detector for each bunch train crossing. This strongly motivated a more complete, combined approach to background simulations, which can easily be adapted to new geometries, to guide both the beam delivery and CLIC detector design.

## 2 MUON BACKGROUND, GEANT3

The simulation started from the existing MUBKG code developed for TESLA [4]. For the geometry, we used the base line design for the CLIC beam delivery system (BDS) [5]. We simulated 1.5 TeV electrons, impacting on 1 radiation length thick carbon spoilers.

The program simulates the Bethe-Heitler process in the following way. For a given photon energy the differential cross section for muon pair production is evaluated as a function of the muon momentum and its production angle by using the expressions given by Tsai [6] (on p. 815). The total number of events in each momentum-angle bin is then given by the product of the differential cross section and the photon path length, summed over all possible photon energies. The follow up of the muons through the BDS geometry and the simulation of the energy loss of the muons is done using GEANT3 [2].

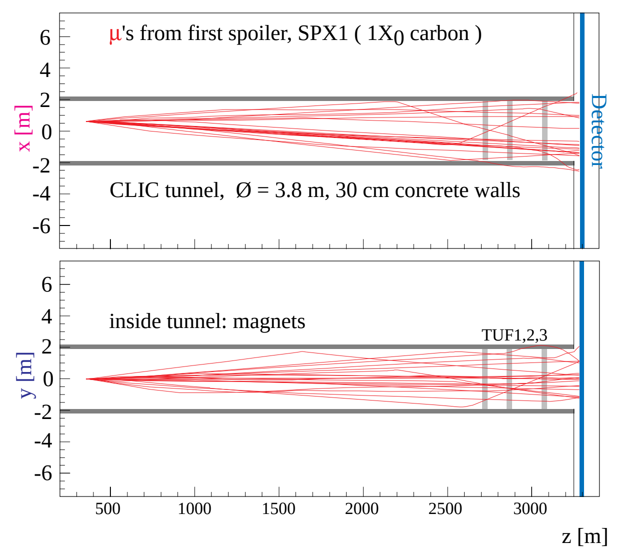


Figure 1: Tracking of muons, produced at the first spoiler, through the beam delivery system up to the detector region. Top is the horizontal and bottom the vertical plane.

Fig. 1 shows tracks of muons, which were produced at the first, horizontal spoiler (SPX1) and which were able to reach the detector after about 3 km. The figure also shows the position of three optional, each 10 or 30 m thick, magnetized (2 T) iron "tunnel fillers" (TUF). They should be considered as a first trial of implementing a dedicated muon protection system and have not yet been optimized in properties and positioning.

The tracks that reached the detector region were further used as input for a Geant3 detector-simulation. Fig. 2 shows how a physics event with muon background may look like in a detector at CLIC[1].

Quantitative results of the beam delivery simulation are illustrated in Fig. 3. The results are given in terms of the ratio of beam particles removed by the collimation system with respect to the number of muons reaching the detector. For the last pair of spoilers (SPX4, SPY4) at about 500 m from the IP, the ratio reaches about $10^{-4}$. Lowering the c.m. energy to 500 GeV increases the number of beam particles that can be collimated for a given muon flux in the detector by an order of magnitude. The dependence

[1] Fig. 2 and the CLIC detector simulation were done by M. Battaglia, CERN.

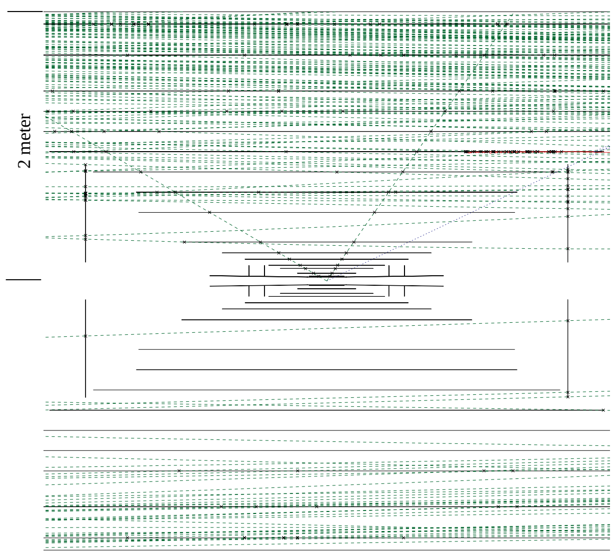


Figure 2: Physics event ($e^+e^- \rightarrow \tilde{\mu}\tilde{\mu} \rightarrow \chi_0\mu\chi_0\mu$) and muon background (in this case 1650 $\mu$ tracks) as seen in the detector simulation.

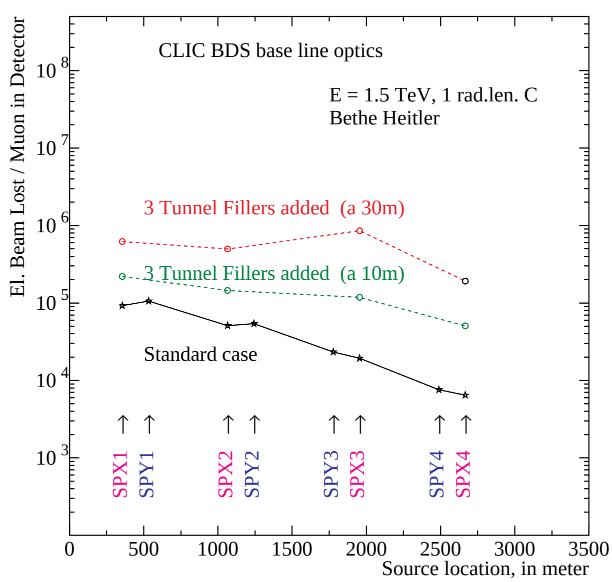


Figure 3: Number of lost electrons per muon passing through a detector with 7.5 m radius as a function of position along the baseline final focus. Potential collimator locations are indicated. The IP is at 3282 m.

on the distance is weak, and we expect similar numbers for other collimation and final focus designs considered for CLIC [7].

For an estimate of the muon flux in the detector, assumptions have to be made about the fraction of halo electrons in the beam that will hit collimators. Here we assume a fraction of $f_{\mathrm{tail}} = 10^{-3}$, all hitting the first spoiler. With the parameters listed in Table 1, and for the two ($e^+$ and $e^-$) beams in CLIC we estimate that $2\,N_e\,N_b\,f_{\mathrm{tail}} c_\mu / r_{e\mu} \approx 2.7 \times 10^4$ muons reach the detector per bunch train crossing. With a muon protection system of three tunnel fillers (TUF), this would be reduced to 4000 muons per train (26 per bunch crossing).

The factor of $c_\mu = 2$ is based on more complete simulations for TESLA at 250 GeV and accounts for other muon production processes (mainly from secondary photons in the cascade and hadronic muon production) [4].

Table 1: Parameters to estimate the muon flux at the detector

| Parameter | symbol | value |
|---|---|---|
| Beam energy | $E$ | 1.5 TeV |
| Number of $e^+$, $e^-$ per bunch | $N_e$ | $4 \times 10^9$ |
| Bunches per train | $N_b$ | 154 |
| Fraction of tail particles | $f_{\mathrm{tail}}$ | $10^{-3}$ |
| Secondaries and other processes | $c_\mu$ | 2 |
| $e/\mu$ ratio without TUF | $r_{e\mu}$ | $9.2 \times 10^4$ |
| $e/\mu$ ratio with TUF | $r_{e\mu}$ | $6.2 \times 10^5$ |

## 3 GEANT4 STUDIES

The techniques and structures of Geant3 have now been upgraded into Geant4 [8] which is an object-oriented package, written in C++. The Geant4 code will exist into the foreseeable future, forming the simulation framework for most of the LHC experiments in addition to some currently running ones.

More recently, the efficient methods of accelerator particle tracking based on transfer matrices have been included within the Geant4 framework into a program, `BDSIM` [9], that combines both the speed of accelerator-style particle tracking for particles in the accelerator beam pipe, with traditional Geant-style tracking when the particles pass through matter. In this way detailed studies of collimation efficiency are possible, including edge effects at element boundaries and particle interactions such as production and subsequent tracking of secondary particles in spoilers and collimators. Production of synchrotron radiation is another such process which, together with tracking of the synchrotron photons, enables accurate energy accounting for absorption in the beam pipe and accelerator elements.

The beam delivery systems of candidate linear colliders are currently undergoing frequent changes and optimizations and so `BDSIM` is set up to interface easily to already existing descriptions of beam lines. In this way a simple input file builds the entire beam line in Geant4 and this will allow comparative studies of collimation efficiency across the range of candidate machines, as well as optimisation of a given collimation system. An example of the use of `BDSIM` in studies of collimation efficiency have been demonstrated in [10]. In addition, a common bunch format has been incorporated [11] so that detailed descriptions of halo distributions can be utilised to explore any phase-space holes in the collimation efficiency.

The pair-production of muons by gamma conversion in the presence of nuclear fields has recently been added as

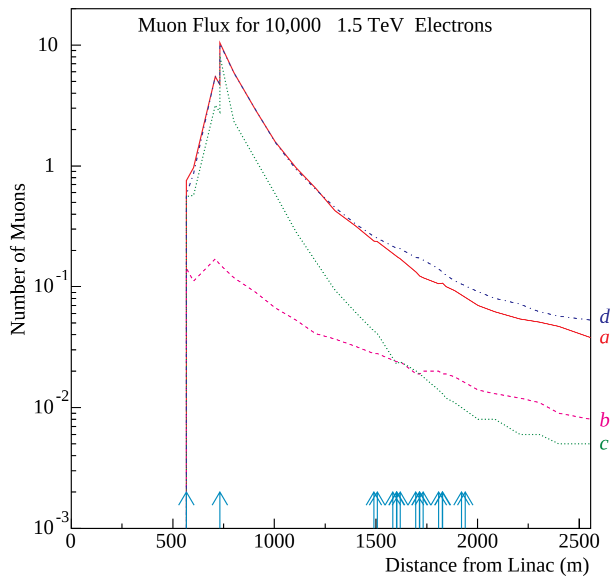


Figure 4: Muon flux determination from Geant4 for a 1.5 TeV beam with a -2% offset in energy. The positions of the spoilers and collimators are shown by arrows. Case *a* corresponds to magnet elements consisting of unmagnetised (and case *d* magnetised) cylinders of iron of diameter 20 cm with fully simulated showers, case *b* for the case with only the first photon of a shower contributing. Case *c* is the same as case *a* except that magnet elements have diameter 50 cm.

standard electromagnetic process in Geant4. Details are described in [12]. Together with the already existing electromagnetic cascade and energy loss code, this now allows for accurate modelling of electromagnetic cascades including muons in Geant4. The full simulation can be rather time consuming. The speed was increased significantly by cutting low energy (below some GeV) particles. The simulation of 10 000 1.5 TeV electron cascades and their tracking through the beam-delivery requires some hours of CPU on a current desktop computer.

First, preliminary results are shown in Fig.4, where the muon production from a 1.5 TeV electron beam, which impinges completely on the energy spoiler, is shown for a variety of cases. The default is the full simulation, where muons are produced anywhere in the cascade. For comparison purposes with Geant3 based simulations, secondary production can optionally be disabled (case *b*).

Our first Geant4 results already indicate, that the thickness and magnetisation of the magnet elements have significant effects on the total muon rate at the detector, as does the effect of production of muons by secondaries in showers. The fact that the final muon rate can vary by more than an order of magnitude depending on the details of these effects, stresses the need for full simulations for the eventual reliable determination of background rates at the linear collider.

# 4 SUMMARY

We performed background studies using Geant for the CLIC beam delivery system. The rate of muons, produced as secondary particles in the collimation of high energy (1.5 TeV) electrons can be substantial and requires a good simulation.

In addition to dedicated muon production and follow up of secondaries with Geant3 for a single fixed geometry, we have extended Geant4 such, that tracking through the machine lattice and materials is done in a combined, flexible way. The simulation can be built from an existing (MAD-like) machine description. This allows for background optimisation during machine design.

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